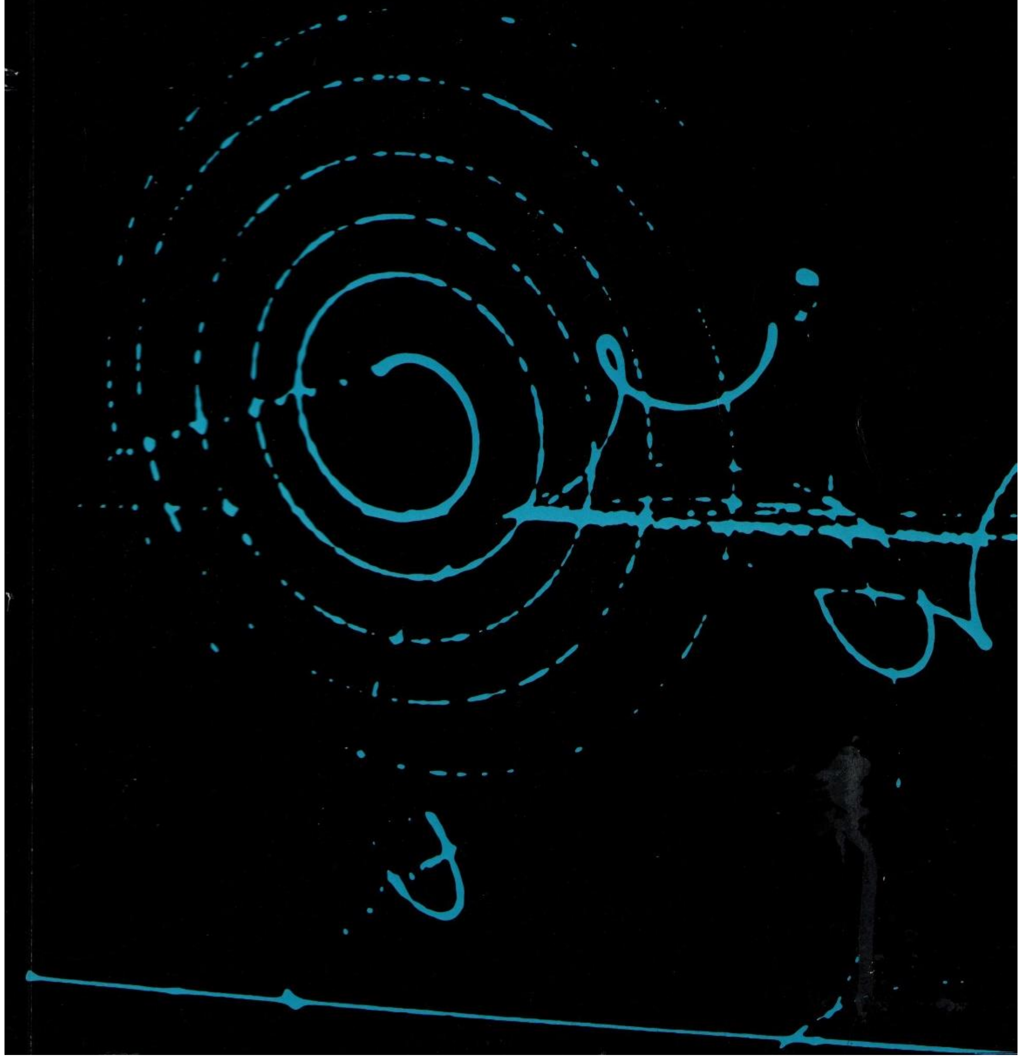
RUTHERFORD

The work of the Rutherford Laboratory 1976



The front cover shows a detail from a Rutherford Laboratory computer simulation of an elementary particle scattering process.

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The Work of the Rutherford Laboratory 1976

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Director's Introduction

Many of the changes in the Laboratory's programme mentioned in the Introduction to the 1975 Annual Report have now come to fruition and if those projects which are still under consideration are approved the shape of our future programme will be firmly established.

We reported last year that Council had decided to build a high-power laser facility at the Laboratory. This project has gone very well. The laser is operational and the experimental programme has been started. We were fortunate in securing the services of Professor Alan Gibson of the University of Essex to run the Centre.

Last year we reported the merger of the Atlas Computer Laboratory with the Rutherford Laboratory. This year the Laboratory's computer resources have been expanded by the installation of a second large IBM 360/195 machine, making the Chilton campus the site of one of the most powerful research-oriented computer complexes in Europe. We are also providing a home for the joint Computer Board-SRC Networks Unit under Mr W Williams and for the Secretariat of the National Committee on Computer Networks under Mr D Audsley.

Unlike the other SRC Boards, the Engineering Board has not had a tradition of funding research at any of the Council's laboratories on a significant scale. However, it has long been recognised that the experience of the Rutherford Laboratory in developing, constructing and operating sophisticated equipment may be of value to the Engineering Board's programme. In October 1975, a Panel was set up under the chairmanship of Professor G Allen of Imperial College, London, to study this possibility. The Panel has recommended that a small number of projects should be undertaken to establish the future role of the Rutherford Laboratory in this area.

The Engineering Board is supporting the Laboratory's superconducting magnet development programme and work on filamentary superconductors. We are also responsible for the management of the Engineering Board's new Interactive Computing Facility. Based on multi-user minicomputers, this service will soon become operational, although requirements to reduce SRC expenditure have meant that the initial service will be less ambitious than originally planned.

Council also agreed in November 1976 to the formation in the Laboratory of an Energy Research Support Unit whose job it will be to assist university workers in an area of research crucial to the future well-being of our country.

Last year mention was made of an outline design for a high intensity 800 MeV proton synchrotron which would be used to generate intense fluxes of slow neutrons. The Neutron Beam Research Committee asked us to develop these ideas and in December 1976 a proposal to build a Spallation Neutron Source (SNS) was put to the Science Research Council and approved in principle by them. The project would require no new buildings and would make use of a lot of the Nimrod equipment when it is phased out of operation in 1978. Full project approval is expected in 1977.

Despite the growing commitment to multi-disciplinary research, a large proportion of the Laboratory's resources is still devoted to high energy physics. On a domestic level the research programme has had its problems as a result of financial cutbacks but the Laboratory has a big job to do in furthering the UK involvement in high energy physics research at the international level. As well as CERN in Geneva and the Fermi National Accelerator Laboratory in the USA, the UK programme of high energy physics will now make use of the new electron-positron colliding beam machine PETRA at the DESY Laboratory in Hamburg.

The year 1976 was a difficult one for the Laboratory but in retrospect it was a very exciting year of change.

G H Stafford
Director

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Section 4 Technology and Instrumentation

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Laboratory Organisation

Director:
G. H. Stafford

Deputy Director:
G. Manning

Administration Division
General and administrative services for the Laboratory as a whole, for visiting scientists and for the UK participation in the CERN research programme.
Division Head and Laboratory Secretary: J. M. Valentine.

Atlas Computing Division
Computer applications: interactive computing.
Division Head: G. Manning.

Computing and Automation Division
Operation of the Laboratory's central computers together with all the services and peripheral equipment involved in the processing of experimental data, including the provision and maintenance of telecommunications links between universities and other research centres and the Laboratory. Research and development work in computing and related techniques.
Division Head: W. Walkinshaw.

Engineering Division
Provision of electrical, mechanical, safety, building and environmental services. The Division includes the Council Works Unit which caters for other SRC establishments as well as the Laboratory.
Division Head and Chief Engineer: P. J. Bowles.

High Energy Physics Division
Experiments in particle physics and nuclear physics in collaboration with university groups. Co-ordination of work on the Laboratory's Nimrod accelerator: support for teams of scientists from the UK and abroad. Supervision of UK involvement in the CERN research programme.
Division Head: J. J. Thresher.

Instrumentation Division
Investigation and design of new particle accelerator systems. Design and manufacture of special nuclear physics apparatus and nuclear electronics for use by experimental teams. Radiobiological research. Support for energy research.
Division Head: D. A. Gray.

Laser Division
Provision of beams and instrumentation for scientists using laser radiation in experiments. Development of high-power laser techniques.
Division Head: A. F. Gibson.

Neutron Beam Research Unit
Support for research by universities using UK reactors and the reactor at the Institut Laue-Langevin, Grenoble. Development of new instruments and techniques; investigation and design of new neutron sources; participation in experiments.
Head of Unit: L. C. W. Hobbis.

Nimrod Division
Operation and development of Nimrod 8 GeV proton synchrotron accelerator. Accelerator design; experimental area management; development of beam line components and cryogenic targets.
Division Head: R. G. Russell.

Technology Division
Design, development and construction of major items of experimental apparatus. Exploitation and application of new techniques, especially superconductivity. Chemical Technology.
Division Head: D. B. Thomas.

Theory Division
Research in the theory of elementary particles — their scattering, decay and reaction mechanisms — with special emphasis on phenomenological analysis of experimental data.
Division Head: R. J. N. Phillips.

1 Particle Physics

The announcement in November 1974 of the discovery of a massive long-lived particle called J or Ψ opened a new chapter in High Energy Physics. So dramatic have been the subsequent discoveries that the present era is frequently referred to as the "New Physics" in contrast to all that went before. The significance of the present time parallels the momentous advances around 1930 and Rutherford's description of those as "the heroic days of physics" has been justifiably applied again today. 1976 saw the award of the Nobel Prize for Physics go to the co-discoverers of the J/Ψ meson which was the start of the new era. To appreciate the discoveries of 1976 and their place in the recent expansion of our understanding of Nature it is worthwhile to recall the developments of the years immediately preceding 1976.

A primary aim in physics is to unify Nature's phenomena. Maxwell unified electricity and magnetism in the 19th century and in the past few years there has been an increasing belief among physicists that this familiar electromagnetic interaction might be unified with the weak interaction. If such an idea can be shown to work then it would signify a major advance in understanding and hence much effort has been directed towards investigating it. The original idea of Glashow, and of Salam and Weinberg was attractive but appeared to suffer from the difficulty that at high energies certain processes had infinite probability. In the past few years there has been an upsurge of interest in this model as the result of three major discoveries.

In 1971 G. 't Hooft of Utrecht showed that the theory was renormalisable, that is to say the infinities are no different from those one is used to meeting in quantum electrodynamics and can be removed by traditional and well proven methods. This meant that for the first time one had a viable theory of weak interactions which did not violate any general principle such as relativity, causality or unitarity and which, further, suggested an intimate link between weak and electromagnetic interactions.

The first experimental support for this theory came in 1973 with the discovery of "neutral current" interactions in which neutrinos interact with matter without transfer of electrical charge. These phenomena were predicted by the Weinberg-Salam model and contrast with the previously well known "charged current" interactions where the neutrino turns into a charged lepton with associated transfer of electrical charge to the target. The discovery of neutral currents raised a problem; namely why is strangeness conserved in the neutral current interactions in contrast to the charged case?

The theoretical answer was to postulate that a new family of particles should exist with a property called charm and with rather distinctive production and decay characteristics which had the effect of cancelling the unwanted strangeness changing neutral currents.

The J/Ψ discovery was like a pointer which showed the direction to go in search of charmed particles and in 1976 experimentalists showed that such particles indeed exist. In May the first charmed mesons were found in the debris produced in the electron positron annihilations at SPEAR in California with precisely the predicted properties. What appeared to be the first charmed baryons were then reported from the Fermilab near Chicago. Both of these separate experiments observed the decay products of the charmed particles. In the autumn it was announced that a collaboration involving a team from University College London have made what appears to be the first positive identification of a charmed particle track in an emulsion exposure.

The identification of this new charmed property of Nature compares at first sight with the discovery of the strange particles in 1947. What makes the discovery of charm potentially *more* significant is its relation with the unified theories of weak and electromagnetic interactions. In the immediate future it will be necessary to verify that charm has all of the required properties to fulfil this dream. Experiments at the new SPS at CERN will be instrumental in investigating the properties and spectroscopy of the charmed particles. The discovery of charm confirms that the three quarks, out of which all hadronic matter was previously thought to be made, are supplemented by a fourth (charmed) quark.

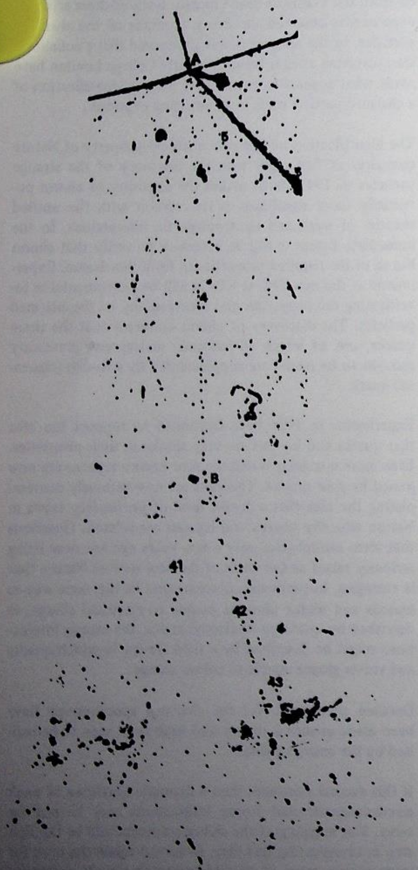
Experiments in 1976 have continued to support the idea that quarks and leptons are very similar in their properties. Even more intriguing is that the *four* known leptons are now joined by *four* quarks. Theorists are now seriously contemplating the idea that a deeper level of profundity exists in Nature whereby quarks and leptons are related. Questions that were metaphysics only a few years ago are now being seriously raised as the result of the new view of Nature that is emerging. In particular, it seems that in the same way as leptons and vector photons couple to electrical charge, as described by quantum electrodynamics, the strong interactions might be described by a field theory in which quarks and vector gluons couple to colour charge.

Detailed predictions for the charmed spectroscopy have been made in such a theory and have been seen to be realised by the emerging data.

If this success continues then a dramatic syntheses of weak electromagnetic and strong interactions may be not far away. The mapping of the charm continent will be the first step in investigating this idea. In turn it raises the need for more precise maps of the old spectroscopies, in particular that of the strange particles which are in many respects lighter brothers of the newly emerging charmed particles. The Rutherford Laboratory has long specialised in this lower-energy domain.

Another aspect of Particle Physics actively pursued is that having close associations with the field of Nuclear Physics. This work is concerned with the interactions of high energy elementary particles with complex nuclei and with the low energy properties and behaviour of these particles. As well as using the facilities available at the high energy accelerators, this work also uses the intense neutron beams available from the reactor at the Institut Laue-Langevin in Grenoble, France.

In addition to research into the fundamental aspects of Particle Physics, the practical application of particle beams to the field of radiobiology is being studied. The use of particle beams in radiobiology is mainly directed towards the treatment of cancer. Compared to γ- or X-rays, beams of charged particles are more easily controlled and have a greater potential for destroying a tumour and leaving healthy tissue viable.



Observation of 'charm' at Fermilab (Experiment 46)

Particle Physics Experiments

Section	Experiment Number	Title	Collaboration	Accelerator or Location	Technique
1.1		**High Energy Physics**			
1.1.1		**Meson Spectroscopy**			
	1	Study of Neutral Boson using a Time of Flight Trigger (Proposal 88)	Birmingham University Tel Aviv University Westfield College, London Rutherford Laboratory	CERN PS	Counter
	2	Polarisation Measurements for $\bar{p}p$ Annihilations into $\pi^-\pi^+$ and K^-K^+ (Proposal 103)	Queen Mary College, London Daresbury Laboratory Rutherford Laboratory	CERN PS	Counter
	3	Production Threshold Effects in Pion-Proton Elastic Scattering (Proposal 128)	Imperial College, London	Nimrod	Counter
	4	Study of Exclusive Reactions in πp and Kp Interactions (Proposal 145)	Amsterdam University CERN Cracow University Max Planck Institute, Munich Oxford University Rutherford Laboratory	CERN SPS	Counter
	5	Study of Meson Resonances decaying into Strange Particles in the Omega Spectrometer at the SPS (Proposal 158)	Birmingham University	CERN SPS	Counter
	6	$\bar{p}p$ Interactions at 4·1 GeV cm Energy in Omega (Proposal 177)	CERN Glasgow University Liverpool University	CERN SPS	Counter
1.1.2		**Baryon Spectroscopy**			
	7	Study of $\pi^+p \rightarrow \pi\pi N$ Interactions in the 1 GeV/c Region (Proposals 39, 86)	Cambridge University Imperial College, London Westfield College, London	Nimrod	1·5m and 80cm bubble chambers
	8	Differential Cross-Section, Polarisation and Spin Rotation Measurements in the Reaction $\pi^-p \rightarrow K^\circ\Lambda^\circ$ (Proposals 87, 114, 166)	Bristol University Cambridge University Rutherford Laboratory	Nimrod	Counter
	9	A Study of the K_1° Interactions in the Range 300-800 MeV/c (Proposal 89)	Bologna University Edinburgh University Glasgow University Pisa University Rutherford Laboratory	CERN PS	2m bubble chamber
	10	Coherent production of I = ½ Baryon States on Helium (Proposal 95)	CERN University College, London Uppsala University	CERN PS	Counter
	11	Measurement of the Differential Cross-Section and Polarisation in the Reactions $\pi^-p \rightarrow \pi^\circ n$ and $\pi^-p \rightarrow \eta^\circ n$ (Proposal 101)	Rutherford Laboratory	Nimrod	Counter
	12	Interactions of Slow and Stopped K^- Mesons (Proposal 117)	Birmingham University Durham University Brussels University University College, London Warsaw University	Nimrod	1·5m bubble chamber
	13	S = −2 Baryon Resonances using a Rapid Cycling Vertex Detector (Proposal 119)	CEN Saclay College de France, Paris Oxford University Rome University Rutherford Laboratory	Nimrod	Hybrid
	14	π^+p, K^-p Elastic Differential Cross-Sections (Proposal 120)	Bristol University Southampton University Rutherford Laboratory	Nimrod	Counter
	15	Polarisation Measurements in K^+N Interactions (Proposal 136)	Queen Mary College, London Rutherford Laboratory	Nimrod	Counter

Section	Experiment Number	Title	Collaboration	Accelerator or Location	Technique
	16	Study of K^-p Interactions in the 1 GeV/c Region (Proposal 159)	Imperial College, London Rutherford Laboratory	CERN PS	2m bubble chamber
	17	Search for Exotic Δ^* States in $\pi^+p \rightarrow K^+\Sigma^+$ using RMS (Proposal 193)	Edinburgh University Rutherford Laboratory Westfield College, London	Nimrod	Counter

1.1.3 Intermediate Energy Reactions

Section	Experiment Number	Title	Collaboration	Accelerator or Location	Technique
	18	Study of 4 GeV/c π^+p Interactions in a Track Sensitive Target (Proposal 91)	CERN Lawrence Berkeley Laboratory Rutherford Laboratory Turin University	Nimrod	Bubble Chamber TST
	19	Differential Cross Sections and Polarisations in Hypercharge Exchange Reactions (Proposal 100)	Birmingham University CERN Genova University Stockholm University Rutherford Laboratory	CERN PS	Counter
	20	Study of $\bar{p}p$ annihilations at 2·0 GeV/c in a Track Sensitive Target (Proposal 115)	Tata Institute, Bombay Melbourne University	Nimrod	1·5m Bubble Chamber TST
	21	Helicity Amplitudes in π^-p (↑) $\rightarrow K^\circ\Lambda^\circ$ at 5 GeV/c (Proposal 124)	CERN ETH, Zurich Helsinki University Imperial College, London Southampton University	CERN PS	Counter
	22	π^-p Interactions at 22 GeV/c (Proposal 134)	Oxford University Pisa University Pavia University Rutherford Laboratory	CERN PS	BEBC
	23	Y^* Production in 7 GeV/c π^+p and K^-p Interactions (Proposal 147)	Imperial College, London	SLAC	Hybrid
	24	A Study of the Antiproton Annihilation Mechanism in 4π and 6π Final States (Proposal 183)	Liverpool University	CERN SPS	Counter
	25	Spin Dependence of Elastic Proton-Proton and Neutron-Proton Scattering (Proposal 186)	CERN Oxford University Paris-Sud University	CERN PS	Counter

1.1.4 Higher Energy Experiments

Section	Experiment Number	Title	Collaboration	Accelerator or Location	Technique
	26	K^-p Interactions at 70 GeV/c (Proposal 161)	Glasgow University CEN Saclay Rutherford Laboratory	CERN SPS	BEBC
	27	Direct Lepton Production in 70 GeV/c π^-p Interactions using BEBC equipped with a TST (Proposal 176)	Bologna University Glasgow University Rutherford Laboratory Saclay Turino University	CERN SPS	BEBC TST
	28	$\bar{p}p$ Interactions at 100 GeV/c	Cambridge University Michigan State University FNAL	FNAL	30″ Bubble Chamber
	29	Internal Target Experiments at the Fermi Laboratory (Proposal 143)	Imperial College, London Rochester University Rutgers University	FNAL	Counter
	30	Exclusive Hadronic Processes at Large p_T (Proposal 151)	CERN Genoa University LAPP, Annecy NBI, Copenhagen Oslo University University College, London	CERN SPS	Counter
	31	SPS Beam Dump Experiment in the Omega Spectrometer (Proposal 184)	Birmingham University CERN Ecole Polytechnique, Paris MPI, Munich Neuchâtel University	CERN SPS	Counter

Section	Experiment Number	Title	Collaboration	Accelerator or Location	Technique
	32	Inclusive Particle Production at Low Transverse Momenta and Large Angles at the ISR (Proposal 131)	CERN University College, London Bristol University MIT NBI, Copenhagen Lund University	CERN ISR	Counter
	33	High Transverse Momentum Behaviour at the ISR (Proposal 129)	Liverpool University Daresbury Laboratory Rutherford Laboratory	CERN ISR	Counter
	34	Search for Narrow Resonances and Correlation Measurements at the ISR	CERN Daresbury Laboratory FOM, the Netherlands Lancaster University Liverpool University Lund University Manchester University Rutherford Laboratory Utrecht University	CERN ISR	Counter
	35	Study of High Transverse Momentum Phenomena in the Split Field Magnet (Proposal 130)	Liverpool University Orsay Laboratory Scandinavian Universities Rutherford Laboratory	CERN ISR	Counter
	36	Study of High Transverse Momentum Phenomena (Proposal 146)	CERN Columbia University Oxford University Rockefeller University	CERN ISR	Counter

1.1.5 Weak and Electromagnetic Interactions

Section	Experiment Number	Title	Collaboration	Accelerator or Location	Technique
	37	CP in a High Magnetic Field (Proposal 168)	Imperial College, London Rutherford Laboratory	Nimrod	Counter
	38	Muon-Nucleon Scattering (Proposal 96)	University of Chicago Harvard University Oxford University University of Illinois	FNAL	Counter
	39	Experiments with High Energy Charged Hyperons (Proposal 140)	Bristol University Geneva University Orsay Laboratory (LAL) CRN Strasbourg-Cronenbourg Rutherford Laboratory	CERN SPS	Counter
	40	Muon Physics at the CERN SPS (Proposal 179)	LAPP, Annecy CERN DESY Freiburg University Kiel University Lancaster University Liverpool University Oxford University Sheffield University RMC Shrivenham Turin University Wuppertal University Rutherford Laboratory	CERN SPS	Counter
	41	Photon and Electron Physics in the Omega Spectrometer Facility (Proposal 180)	Bonn University CERN Daresbury Laboratory Ecole Polytechnique, Paris Glasgow University Lancaster University Manchester University LAL Orsay Paris 6 University Sheffield University	CERN SPS	Counter
	42	Study of Neutrino and Antineutrino Interactions at High Energy	Bari University Birmingham University Brussels University Ecole Polytechnique, Paris Rutherford Laboratory Saclay University College, London	CERN SPS	BEBC TST

Section	Experiment Number	Title	Collaboration	Accelerator or Location	Technique
	43	Electron Position Collisions at Petra (Proposal 190)	Aachen University Bonn University DESY Hamburg University Imperial College, London Maine University Oxford University Rutherford Laboratory Weizmann Institute	PETRA	Counter
	44	A Compact Magnetic Detector for Petra (Proposal 191)	Daresbury Laboratory DESY Hamburg University Heidelberg University Lancaster University Manchester University Tokyo University	PETRA	Counter
1.1.6	**Searches for New Particles**				
	45	Heavy Particle Search (Proposal 144)	Rutherford Laboratory University College, London AWRE Aldermaston	Cosmic Rays	Mass Spectrometer and Counters
	46	Search for Short Lived Particles Produced in Neutrino Interactions at Fermilab (Proposal 163)	Brussels University University College, Dublin FNAL CERN Imperial College, London Open University Mulhouse Institute Rome University Strasbourg University	FNAL	Emulsion and Counter
	47	Search for Short Lived Particles Produced in Neutrino Interactions at CERN (Proposal 189)	Ankara University Brussels University University College, Dublin CERN University College, London Open University Pisa University Rome University Strasbourg University Turin University	CERN SPS	Hybrid and Emulsion
	48	Charm Search in Omega (Proposal 164)	Bari University Birmingham University Bonn University CERN Daresbury Laboratory DESY Ecole Polytechnique, Paris ETH, Zurich Freiburg Universities Glasgow University Liverpool University Milan University Orsay Laboratory Rutherford Laboratory CEN Saclay Westfield College, London	CERN PS	Counter
	49	Search for New Particles Produced in Association with Ψ (3.1) (Proposal 175)	Saclay Imperial College, London Indiana University	CERN SPS	Counter
	50	Search for Charmed Particles (Proposal 185)	Harvard University Oxford University Illinois University	FNAL	Counter

Section	Experiment Number	Title	Collaboration	Accelerator or Location	Technique
1.2	**Nuclear Physics**				
	51	Search for Time-Reversal Violation Effects in Nuclei	Sussex University ISN Grenoble	Reactor, ILL	
	52	Search for Parity Violating Effects in Radiative Neutron-Proton Capture	Sussex University Harvard University ILL	Reactor ILL	
	53	A Measurement of the Neutron Lifetime	Sussex University Rutherford Laboratory	Reactor, ILL	
	54	Search for an Electric Dipole Moment of the Neutron	Sussex University Oxford University Harvard University Oak Ridge National Laboratory Technical University, Munich Centre D'Etudes Nucleaire Grenoble ILL Rutherford Laboratory	Reactor, ILL	
	55	Experiments with Exotic Atoms	Birmingham University Surrey University Rutherford Laboratory	Nimrod	
	56	Measurement of Triple Scattering and Polarisation Parameters in Nucleon-Nucleon Scattering between 200 and 520 MeV	BASQUE Collaboration Bedford College, London AERE Harwell Surrey University Queen Mary College, London University of British Columbia University of Victoria	TRIUMF	
	57	Measurements of π^-–Nucleus Backward Scattering and of the Decay Rate $\pi^0 \to e^+e^-$ with the Omicron Spectrometer	Birmingham University Oxford University Daresbury Laboratory University College, London Amsterdam CERN Ljubljana Turin	CERN SC	
	58	Coulomb-Nuclear Interference in Alpha Particle Scattering	King's College, London	AERE Tandem	
	59	Microscopic Helium 3 Optical Potentials	King's College, London	AERE VEC	
	60	Analysing Power Studies using Polarised ^{3}He Beams	King's College, London Birmingham University	Birmingham Cyclotron	
1.4	**Radiological Experiments**				
	61	Some Long-Term Effects of Negative Pions in Mice	Medical College of St. Bartholomew's Hospital, London	Nimrod	
	62	Chromosome Aberrations in White Blood Cells	National Radiological Protection Board; Rutherford Laboratory	Nimrod	
	63	Irradiation of Frozen Cancer Cells	Glasgow Institute of Radiotherapeutics and Oncology; Rutherford Laboratory	Nimrod	
	64	Study of the Physical Nature of Pion Induced Radiation	Medical College of St. Bartholomew's Hospital, London; Leeds University Surrey University Rutherford Laboratory	Nimrod, AERE VEC	

1.1 High Energy Physics

From the physicists's point of view, the material Universe consists of elementary particles which interact through fields of force. Four apparently distinct force-fields are known, namely gravity, electromagnetism, the weak force of radioactive decay and the strong force. It is hoped that one day the relationships between these forces will be understood, perhaps to the extent of them being different manifestations of a common "universal force". Important steps towards such a unification of the weak and electromagnetic interactions have been made in the last few years.

Stable matter consists essentially of three different elementary particles: protons and neutrons tightly bound together by the strong force form the nuclei of all atoms, and the nuclei are surrounded by a cloud of orbiting electrons which determine the chemical properties of the atoms. Many other kinds of elementary particle have been found, most of them being highly unstable. They fall into two families known as *leptons* and *hadrons*. The leptons, or "light" particles, do not feel the strong nuclear binding force, and appear to be truly elementary and without internal structure. This family consists of the electron, the muon, which is just a heavier electron, and two neutrinos which are electrically uncharged and apparently massless. To each of the four leptons there corresponds an anti-particle, making eight distinct objects.

The hadrons, or "heavy" particles, interact among themselves with the strong force, and appear to have a complex internal structure. A very large number of different hadron states have been discovered with differing masses, spins, charges and so on. A very great deal of effort has been devoted to searching for these states and measuring their properties as a step in the process of bringing order to chaos. The theoretical scheme which does this most successfully and economically is the quark model. The hypothetical quarks, like the leptons, are assumed to be truly elementary and without internal structure. Given a set of four different quarks named *up*, *down*, *strange* and *charmed* and four corresponding antiquarks it appears to be possible to construct all the known hadrons. Three quarks can bind together to form a baryon (e.g. proton = up + up + down), or three antiquarks to form an antibaryon, or a quark and an antiquark can bind to form a meson (e.g. π^+ = up + antidown). All of the known hadrons states fit into this scheme which is therefore highly economical. It is also intriguing that four quarks are required, hinting at a deeper relationship with the four known leptons. This has only become clear during the last two years with the discovery of new hadrons requiring charmed quarks for their interpretation.

Thus, the business of High Energy Physics is to understand the nature of the elementary particles and of the forces between them. The experimental study of these particles requires a means for producing particles and apparatus for observing them. They are created by concentrating a large amount of energy into a sufficiently small volume of space. The energy then transforms itself into massive particles, following Einstein's energy-mass equivalence relationship $E = mc^2$. The method used for concentrating sufficient energy is to accelerate a beam of stable particles (protons or electrons) and allow these beam particles to collide with either a stationary target nucleus or, in some cases, with an oppositely directed beam. The produced particles can be observed with a variety of different techniques. *Bubble Chambers* make visible, as discernable tracks, the paths of all the charged particles produced in a collision. The tracks are then measured with automatic machines which is a relatively slow process. *Counter* experiments sample the particle trajectories at several points using electronic devices called scintillation counters, spark chambers, multiwire proportional chambers and so on. The information is less complete but adequate for most experiments, and can be handled directly by computers at high speed. These two extreme techniques are brought together in *hybrid* detectors, in which a bubble chamber is surrounded by an electronic apparatus (Experiments 13, 23, 47).

During 1976 a total of 50 High Energy Physics experiments were supported by the Rutherford Laboratory. Most of these experiments are carried out by teams of physicists from British universities working in collaboration with groups from overseas universities and research institutes, and approximately half of the experiments also directly involve physicists from the Rutherford Laboratory.

The majority of the experiments are carried out at the European Centre for Nuclear Research (CERN) in Geneva. The CERN experiments are grouped around three main machines: the 28 GeV Proton Synchrotron (PS), the 400 GeV Super-Proton Synchrotron (SPS) and the Intersecting Storage Rings (ISR). The PS has the dual role of providing secondary beams of particles of up to about 20 GeV for experiments and of injecting proton beams into the other two machines. The approved British experiments using the PS as a source of particles completed data-taking during 1976 and the emphasis has shifted to the higher energy machines. A major step forward for European High Energy Physics occurred in 1976 with the successful completion and first operation of the 400 GeV SPS accelerator. Fourteen experiments at the SPS are supported by the Rutherford Laboratory and a great deal of effort has gone into preparing equipment in order to be able to take data as soon as the machine comes into routine operation. In many cases these experiments are far more sophisticated than one usually finds at a new machine, much of the "preliminary exploration" having been carried out at the Fermilab 400 GeV accelerator. Thus it is expected that already in 1977 the SPS experiments will be highly competitive with experiments at Fermilab.

The Intersecting Storage Rings at CERN, in operation since 1971, provide a unique facility in that proton-proton collisions can be studied at a still higher energy than available at the SPS and Fermilab. Two stored proton beams of up to 31 GeV each are brought into head-on collision giving a collision energy equivalent to that of a 2000 GeV beam on a stationary target. The limitation to proton-proton (or deuteron) collisions is however a severe one, hence the comparative richness of the SPS programme. Storage rings for electron-positron collisions have proved extremely fruitful over the past two years, opening up the new "charmed" spectroscopy. Higher energy (15 GeV) electron-positron colliding beam machines are now under construction at Hamburg (PETRA) and Stanford in Califormia (PEP),and two major experiments (Experiments 42 and 43) at PETRA involve UK physicists supported by the Laboratory.

The Rutherford Laboratory itself houses the 8 GeV Nimrod proton synchrotron which also has a very active experimental programme with 12 current experiments. Despite the obvious interest of the very high energy experiments, particle physics is complex already at Nimrod energies, with a large variety of particles and resonances which are produced and whose interactions can be studied. The basic goals of particle physics being to understand the structure of the particles and of the forces between them, it is clear that the detailed information obtained in these lower energy experiments forms a vital part of the 'jigsaw puzzle'.

The Rutherford Laboratory has also been involved in experiments at the Stanford Linear Accelerator Laboratory (SLAC) and the Fermi National Accelerator Laboratory (FNAL) in the United States during 1976.

A short review of each of the experiments supported by the Rutherford Laboratory during 1976 is given in the following pages. The division into section is rather artificial fo various reasons. Some of the experiments are powerful (and complex!) enough that they can simultaneously work in several fields – for example meson and baryon spectroscopy, searches for new particles and reaction mechanisms. Furthermore, happily, many of the barriers between weak, electromagnetic and strong interactions are crumbling.

Close relationships are being discovered between, for example, lepton production in hadronic interactions (Experiments 27 and 36) and hadron production in leptonic interactions (Experiments 38, 40-44). Even the once clear distinction that existed between different experimental techniques is disappearing as bubble chambers become surrounded by electronic particle detectors and as some socalled "counter experiments" begin to look like electronic bubble chambers. A most interesting development is the use of photographic emulsion stacks in conjunction with electronic detectors (Experiment 46) and with a bubble chamber (Experiment 47). Emulsion stacks have been used in cosmic ray physics for some time; with the advent of high energy neutrino beams they have an important new role. The probable observation of a charmed particle track in Experiment 46 deserves a special mention.

An interesting experiment which could in principle show a direct connection between the weak and electromagnetic interactions is (Experiment 37) an attempt to modify a weak decay process $K^0_L \rightarrow \pi^+\pi^-$ with a very strong magnetic field. It is by no means clear whether fields generated in the laboratory can be high enough to cause this predicted phenomenon, so this experiment is something of a "shot in the dark", but a positive result would be of major importance.

Most of the experiments in Sections 1.1.1 and 1.1.2 are aimed at searching for resonant states or unstable hadrons and systematically measuring their properties. In the now-standard quark model this information allows the quark-quark forces at relatively large spatial separations (low relative momenta) to be inferred. Experiments studying large transverse momentum production (for example Experiments 30, 33, 35, 36) may provide complementary information on the strong quark-quark forces at small spatial separations (high relative momenta). Many of the experiments in Section 1.1.5 are concerned not only with the weak and electromagnetic interactions but also with the quark-proton structure of hadrons. The influence of the so-called "New Physics", i.e. J/Ψ and charm, on the experimental programme is particularly evident in Section 1.1.6.

1.1.1 Meson Spectroscopy

EXPERIMENT 1

A Study of Neutral Bosons using a Neutron Time of Flight Trigger

Birmingham University; Tel Aviv University; Westfield College, London; Rutherford Laboratory

This experiment is studying the reactions

$$\pi^- p \rightarrow \pi^+\pi^- n \qquad 1$$

$$\pi^- p \rightarrow \pi^+\pi^-\pi^0 n \qquad 2$$

$$\pi^- p \rightarrow \pi^+\pi^-\pi^+\pi^- n \qquad 3$$

$$\pi^- p \rightarrow \pi^+\pi^-\pi^+\pi^-\pi^0 n \qquad 4$$

using the OMEGA spectrometer at CERN. Neutrons, in the energy range 10-400 MeV are detected in an array of scintillation counters, and the charged particles from the recoil in the OMEGA spark chamber system. Data has been taken at 12 and 15 GeV/c incident π^- momentum corresponding to recoil masses in the range 0·6-2·3 and 0·6-2·6 GeV/c^2 respectively.

At small momentum transfers reaction 1 is dominated by pion exchange. This enables a partial wave analysis to be performed on the $\pi\pi$ system. Such an analysis on the 12 and 15 GeV/c data is nearing completion. The leading resonances ρ, f° and g are clearly seen and there is evidence for the new spin 4 meson called the h(2040).

Although the quark model has had considerable success there are several meson resonances awaiting confirmation. For example, the A1 and A3 spin parity $J^P = 1^+, 2^-$ respectively are observed in 3π partial wave analyses as non-resonating diffractive threshold enhancements. Reaction 2 proceeds via charge exchange and should therefore be a good place to look for these resonances. Preliminary results of an Illinois 3π partial wave analysis show strong production of the ω(780), A2(1310) and ω(1675) $J^P = 1^-, 2^+, 3^-$ resonances though information on the unnatural parity states $J^P = 0^-, 1^+, 2^+$ awaits the complete analysis

The analysis of reactions 3 and 4 is at an earlier stage though preliminary results look encouraging. Reaction 3 is found to be dominated by $\rho^\circ\pi\pi$ production. Looking for higher mass mesons cascading into $\rho^\circ\pi\pi$ has revealed a strong signal for the following reaction chain:

$$\pi^- p \rightarrow g^\circ(1700)n \rightarrow A2(1310)\pi n \rightarrow \rho^\circ\pi\pi n$$

The analysis of reaction 4 is complicated by the combinatorial background. Fig 1.1 shows the $\pi^+\pi^-\pi^\circ$ mass combinations from approximately 1/3 of the total data sample. Strong production of η(548) and ω(780) are observed, the background under the η(548) being relatively small. Plotting the $\eta\pi\pi$ effective mass in Fig 1.2 shows clear signals for the η'(958) and D(1285) meson resonances.

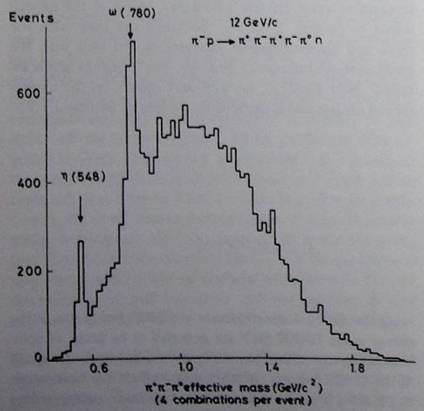


Fig 1.1. 3π Mass spectra from Experiment 1

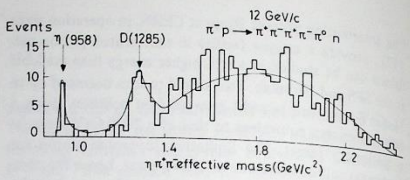


Fig 1.2. $\eta\pi\pi$ Mass spectra from Experiment 1

EXPERIMENT 2

Polarisation Measurements for $\bar{p}p$ Annihilations into $\pi^-\pi^+$ and K^-K^+

Queen Mary College, London; Daresbury Laboratory Rutherford Laboratory

This experiment measured the angular distribution of the polarisation asymmetry parameter P in the reactions

$$\bar{p}p \rightarrow \pi^-\pi^+$$

and $$\bar{p}p \rightarrow K^-K^+$$

using a polarised target. Several thousand $\pi^-\pi^+$ and several hundred K^-K^+ events were recorded at each of 11 momenta in the range 1·0 to 2·2 GeV/c.

Data analysis was completed early in the year. The polarisation asymmetry in both reactions is extremely striking, being very large and positive over most of the angular range. Moreover, it is very similar for the two reactions, although their differential cross section behaviour is quite different. As a stringent test of the experiment, differential cross sections for $\bar{p}p \rightarrow \pi^-\pi^+$ were generated and compared with previous hydrogen target measurement; the agreement, both in shape and overall normalisation, is remarkably good.

An amplitude analysis of the $\pi^-\pi^+$ data, using new polarisations and earlier cross sections, has been carried out by members of the group. This indicates the existence of three new meson resonances, whose properties are summarised below.

JP	IG	M(GeV/c²)	Γ(GeV/c²)
3⁻	1⁺	2·15 ± 0·03	0·20 ± 0·02
4⁺	0⁺	2·31 ± 0·03	0·21 ± 0·03
5⁻	1⁺	2·48 ± 0·03	0·28 ± 0·04

Fig 1.3 indicates how these new states relate to existing meson resonances.

Work on this experiment is now almost complete. Some data on the polarisation in $\bar{p}p$ elastic scattering, at a few momenta and covering a limited angular range, will soon be available.

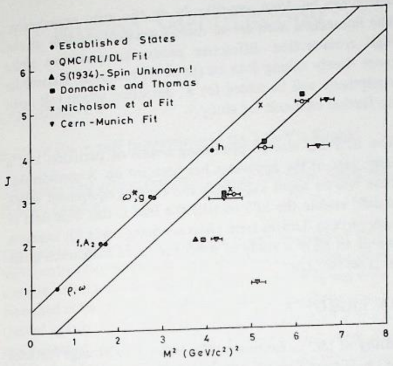


Fig 1.3. Meson resonances (Experiment 2)

EXPERIMENT 3

Production Threshold Effects in Pion Proton Elastic Scattering

Imperial College, London

Generally, interactions of particles at high energies result in several alternative final states. Although these states are physically distinct, the individual processes cannot be considered in isolation. The sum of the probabilities over all the possible final states must be unity and this simple requirement leads one to expect quite a complex reaction of one state back on the other. The complexity arises essentially because not only the amplitudes but also the relative phases of the various waves have to be considered. Conversely, if the reaction can be measured, then direct information on the phases may be available.

It had been recognised for many years that the best conditions under which to observe such effects would be found close to the threshold for the production of two quasi-stable particles. This is because the abrupt change in cross section from zero right at threshold propagates as an equally abrupt change, or cusp, in the other channels. Several attempts have been made to see such cusps, particularly at the threshold $\pi^- + p \rightarrow K + \Sigma$, and the mechanism has been successfully invoked in explaining certain rapid variations in cross sections in other channels. However hitherto the effect has not been isolated, and an unambiguous, quantitative study has not been possible. Experimentally the difficulty lies mainly in the simultaneous need for both very high momentum resolution and high statistical accuracy.

Earlier measurements of meson production cross sections suggested the search for a cusp near the threshold for a production in the reaction $\pi^- + p \rightarrow \eta + n$. For this reaction the cross section rises rapidly from a sharp threshold, also the zero spin and the isotopic spin of the η simplifies the analysis, and finally the relatively low energy at threshold limits the important final states to just three; elastic scattering, charge exchange scattering and η production.

In the present experiment the differential cross section in the elastic channel was measured at intervals of 1 MeV/c in incident momentum. The data were subdivided into 15 regions of cos θ*, where θ* is the c.m. scattering angle. Fig 1.4 shows typical results for two values of cos θ*. From the shapes of the cross sections just below and above threshold both the amplitude and phase of f, the non spin-flip scattering amplitude, can be extracted. The result is shown in Fig 1.5, which however should still be regarded as preliminary. An interesting point is that the method determines the absolute phase of f away from the forward direction.

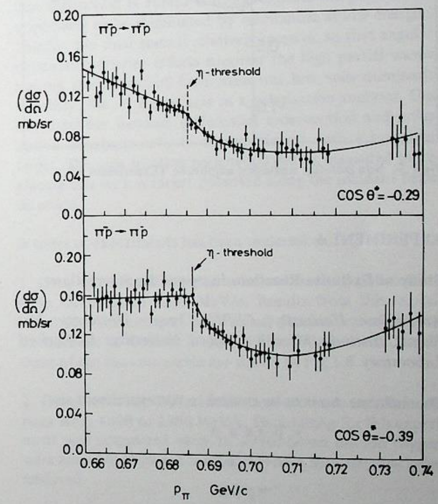


Fig 1.4. Threshold effects in π^-p scattering (Experiment 3)

Data, both in the production cross section and in the elastic channel, have been collected near other meson thresholds and analysis, which is more complicated, is still in progress.

Analysis is also in progress on an experiment which is attempting to measure directly the width of the η' meson by means of a missing mass technique. The experimental resolution function has a full width at half maximum of somewhat under 1 MeV.

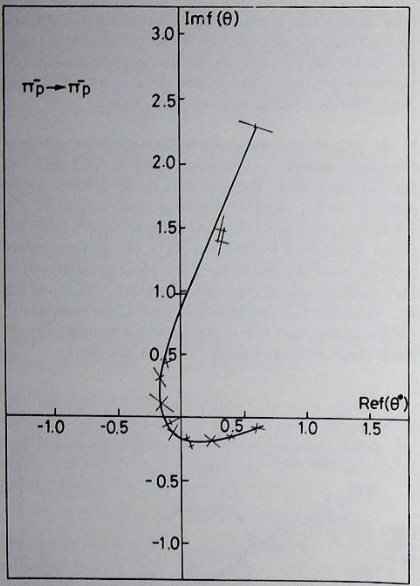


Fig 1.5. Non spin-flip scattering amplitude (Experiment 3)

EXPERIMENT 4

Study of Exclusive Reactions in πp and Kp Interactions

Amsterdam University; CERN; Cracow University; Max Planck Institute Munich; Oxford University; Rutherford Laboratory

The main reactions to be studied in this experiment are

$$\pi^-p \rightarrow \pi^+\pi^-n$$
$$\rightarrow K^+K^-n$$
$$\rightarrow p\bar{p}n$$
$$\pi^\pm p \rightarrow K^\pm K^0_S p$$
$$K^-p \rightarrow K^-\pi^+n$$
$$\rightarrow K^0_S \pi^-n$$

over a momentum range up to 100 GeV/c in order to study new massive resonances. For this purpose a sophisticated multiparticle spectrometer has been constructed with two spectrometer magnets for tracking charged particles over a wide momentum range, and with extremely efficient π° rejection.

The equipment will handle high multiplicity events, and one can envisage an extended range of experiments some of which can be done parasitically on the main experiment. The immediate aims are to rapidly accumulate data on the high cross-section diffractive production processes while more slowly taking data on the above reactions. Meanwhile equipment will be added for π° detection which will open up further channels for study.

The SPS has started producing beams of particles, and a large part of the apparatus has been set up. A considerable time will be spent exploiting the existing equipment which should enable the SPS to take the lead in this wide field of new physics. Longer term plans are being made for improvements to allow a study of states produced with much smaller cross-sections.

EXPERIMENT 5

Study of Meson Resonances Decaying into Strange Particles in the Omega Spectrometer at the SPS

Birmingham University

Mesons made of strange quark-antiquark pairs are produced much more copiously by incident kaons than by pions since the kaon itself contains a strange quark. Apart from the ϕ-meson, only one other, the f′(1514), is known to be in this class. Several more are expected and will be searched for using the Omega spectrometer and the RF separated beam at the SPS.

EXPERIMENT 6

$\bar{p}p$ Interactions at 4·1 GeV c.m. Energy in OMEGA

CERN; Glasgow University; Liverpool University

The OMEGA magnetic spectrometer at CERN will be used to study the characteristics of the $\bar{p}p$ interaction in the centre of mass energy region around 4 GeV in order to search for evidence of new bosons or charmed particles. A complicated structure has been revealed in this energy region in e^+e^- experiments.

A trigger on a forward proton or K^+ is chosen in order to reduce the background of non-resonant processes.

The advent of the long pulse superconducting R.F. separated beam into OMEGA will provide CERN with a facility available nowhere else in the world. This will give the experiment a high sensitivity coupled with high acceptance for multiparticle processes. Valuable backward scattering data for $\bar{p}p \rightarrow \bar{p}p$ or K^+K^- will also be obtained.

The experiment has been accepted for a test run of 5 days which should allow an evaluation of the signal and background levels. Hopefully the experiment will run as soon as the R.F. beam becomes available. Construction of hardware and preparation of on-line and off-line programs is in progress.

1.1.2 Baryon Spectroscopy

EXPERIMENT 7

Study of $\pi^+p \rightarrow \pi\pi N$ Interactions in the 1 GeV/c Region

Cambridge University; Imperial College, London; Westfield College, London

The results obtained at 9 momenta from threshold to 1700 MeV centre-of-mass energy with the Imperial College four-variable, maximum likelihood, isobar model program were presented at the Topical Conference on Baryon Resonances, Oxford in July 1976. The higher statistics permitted a much more detailed study of the decay properties and hence the SU(6) classifications of the $I = \frac{3}{2}$ resonances in this region than had been possible in the previous analyses of the Berkeley-SLAC and Saclay groups. Among the results obtained was the observation of the sign of the ρ_1 N decay of the $S_{31}(1650)$ about which there was uncertainty in the previous analyses. The value of this sign is a non-trivial test for the current theoretical models based on Melosh transformations which appear to be the only ones even to approximate to a description of the confused state of ρN decays. In addition the first evidence was presented for the decay of the P_{33} wave to $P_{11}(1470)\pi$ around 1690 MeV. This tends to confirm the assignment of the P_{33} state in this region to a $(56,0^+)$ radial excitation. This may help to clear up the very confused situation which exists with regard to the P_{33} wave.

One of the refinements introduced into the analysis has been the addition of an incoherent I = 2, one-pion-exchange term. It was found that this contribution made little difference to the magnitudes and phases of the major partial waves. However, evidence that this I = 2 $\pi\pi$ scattering term was necessary, and had been introduced in a consistent way, was provided by the similarity of the I = 2, S-wave scattering lengths obtained from independent fits at different energies.

It seems likely that this analysis could make a significant contribution to the determination of this important $\pi\pi$ scattering parameter about which there is considerable experimental confusion.

In the course of the analysis the importance of unitarity corrections to the isobar model has been investigated by looking for a Dalitz plot dependence to the isobar couplings. It is now found, as reported at the Oxford Conference, that with the extra partial waves introduced in the recent refitting, consistent results are obtained on each half of the Dalitz plot. This is an important result which previous analyses had insufficient statistics to check. It gives greater confidence in the many results already obtained by different analyses using the isobar model assumptions.

EXPERIMENT 8

Differential Cross-section, Polarisation and Spin-rotation measurements in the reaction $\pi^-p \rightarrow K^\circ\Lambda^\circ$

Bristol University; Cambridge University; Rutherford Laboratory

This team has been conducting a series of experiments at Nimrod to study nucleon resonances and their couplings to inelastic channels. The intention is to measure the masses, widths and channel coupling constants of resonances of isotopic spin 1/2. The $K^\circ\Lambda^\circ$ channel has a number of advantages in this respect. First, it is pure I-spin 1/2. (The only other nucleon channel of pure I=1/2 accessible to experiment is η°n). Secondly, there is no Pomeron exchange, so that diffraction is absent and one expects the partial-wave amplitudes to be dominated by resonances at low energies. Thirdly, the final state is relatively massive, so that angular-momentum barrier effects suppress the high partial waves, making resonances of high mass but low spin dominant. Fourthly, the Λ° decay acts as a polarisation analyser. One can therefore measure differential cross-section and polarisation simultaneously in an experiment with a hydrogen target. The spin rotation parameters can be measured by replacing this with a target polarised along the incident beam direction.

A series of experiments has been undertaken:

1. (Proposal 87) **Differential cross-sections and polarisation from threshold to 1333 MeV/c.** Results from this experiment were presented at the Topical Conference on Baryon Resonances at Oxford in July 1976. Polarisation Data at three of the nine momenta are shown in Fig 1.6.

2. (Proposal 114) **Differential cross-sections and Polarisations from 1400 to 2380 MeV/c.** Data taking for this experiment was completed early in 1976. Seven million triggers were recorded at eleven momenta. These data are now being analysed.

3. (Proposal 166) **Measurement of the spin-rotation parameters A and R from 1·1 to 2·0 GeV/c.** The detection system for this experiment is a modification of that used for proposal 114. The major change is the replacement of the hydrogen target with a target polarised along the incident beam direction. To achieve this polarisation and permit the large angular aperture required for the outgoing particles, a superconducting magnet (PT55) was designed and constructed (Section 4.1.1). A system of low-mass magnetostrictive spark chambers with remote readout has been developed.

A partial-wave analysis was made of the world data on this reaction by R. D. Baker and was presented at the Topical

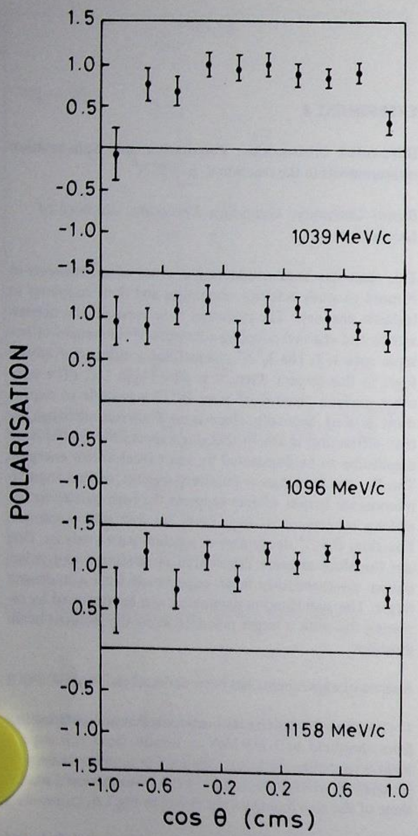


Fig 1.6. Polarisation data from $\pi^- p \to K^\circ \Lambda^\circ$ (Experiment 8)

Conference on Baryon Resonances at Oxford in July 1976. He made both a conventional energy-dependent fit and, independently, an analysis using the Barrelet zero technique. It is a general problem of amplitude analysis that cross-section and polarisation data do not determine the reaction amplitudes uniquely. One obtains solutions containing well-established resonances, but these fits are ambiguous with other, less elegant, ones. The advantage of the Barrelet zero analysis is that it exposes the ambiguities explicitly.

The spin-rotation parameter measurements will provide the additional information required to select the correct solution and reject the others. This experiment (Proposal 166) is unique in that it is the first measurement of spin-rotation parameters in the resonance region in any reaction. It is intended to take data with high statistics, at four or five momenta, as the Nimrod schedule permits.

EXPERIMENT 9

A Study of the K°_L Interactions in the Range 300 – 800 MeV/c

Bologna University; Edinburgh University; Glasgow University; Pisa University; Rutherford Laboratory

The experiment is based on two separate exposures of the CERN 2 metre hydrogen bubble chamber to a beam of K°_L particles of well defined momenta. A total of over 1 million photographs were obtained and have been analysed and the final event sample is available on data summary tape.

Papers have been published on the data available from the first exposure in the channels of primary interest:–

$K^\circ_L p \to K^\circ_S p$	1
$\Lambda^\circ \pi^+$	2
$\Sigma^\circ \pi^+$	3
$\Lambda^\circ \pi^+ \pi^\circ$	4

The complete data sample will yield about 600 events per 10 MeV centre of mass energy in the range 1550 – 1700 MeV in channels 1 and 2 and about 400 events per 10 MeV in channel 3. These data allow the phase shift solutions in this range to be well determined. Also, with this level of accuracy, narrow structures such as the reported Σ(1580) can be investigated.

Other channels currently being measured are:–

$K^\circ_L p \to \Sigma^+ \pi^\circ$	5
$\Sigma^\pm \pi^\mp \pi^+$	6

the first to complement and verify the data from reaction 3 and the second to look for a cross-section bump at 1580 MeV reported in another experiment.

An analysis of the Dalitz plot in the decay $K^\circ_L \to \pi^+\pi^-\pi^\circ$ ($K^\circ 3\pi$) has been performed using 4700 events. The knowledge of the K°_L momentum allows these events to be separated from the more numerous semi-leptonic decays on the basis of a constrained kinematic fit, which means that the final data are free from background.

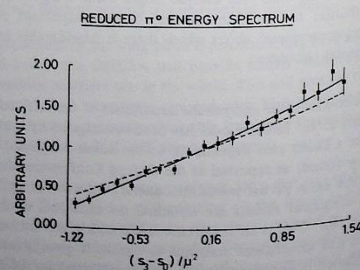


Fig 1.7. Results from Experiment 9

The data are well described by a spectrum linear in the π° energy with a slope parameter g = 0·610 ± 0·022 (Fig 1.7). This result taken together with those from the $K^+ 3\pi$ decay indicate substantial violation of the non-leptonic $\Delta I = \frac{1}{2}$ rule.

EXPERIMENT 10

Coherent Production of I=½ Baryon States on Helium

University College, London; CERN; Uppsala University

Data collection for this experiment ended in 1974 and the data analysis has been completed.

A beam of 18·3 GeV/c protons from the CERN PS was incident upon a cylindrical, thin-walled target containing helium gas at high pressure. Fast forward charged particles from an interaction in the target were detected in a conventional spark chamber spectrometer, which contained two modular, atmospheric-pressure Cerenkov counters for particle identification. Recoiling alpha particles were detected in scintillation counters surrounding the target. Both pulse height and time-of-flight were recorded to aid in separating alpha particles from recoiling ^{3}He, tritons, protons and pions. The direction of the recoil was obtained from two cylindrical spark chambers operating at low pressure.

The principal reactions observed are single pion production,

$p\,^4He \to p\,\pi^\circ\,^4He$	1
$p\,^4He \to n\,\pi^+\,^4He$	2

and double pion production,

$p\,^4He \to p\,\pi^+\pi^-\,^4He$	3

The data are particularly interesting because the observation of a helium nucleus recoiling intact in the final state implies that the Nπ or Nππ system produced by the coherent dissociation of the incident proton is in a pure I=½ state. A simple consequence of this constraint is that the cross section for reaction 1 should be one half of that for reaction 2. The experimental data are consistent with this expectation.

The final data consist of mass distributions for the three reactions, and, for each 100 MeV mass interval below 2 GeV/c^2, four-momentum transfer distributions to the helium nucleus and decay angular distributions. Spherical harmonic moments of decay distributions have been evaluated in both s- and t-channel helicity frames, using the direction of the outgoing pion as analyser for reactions 1 and 2, and the normal to the $p\,\pi^+\pi^-$ decay plane for reaction 3. In addition, the moments of the $(p\,\pi^+)$ direction in the $p\,\pi^+\pi^-$ rest frame have been evaluated for reaction 3.

The mass distributions show the expected twin enhancements at 1·5 and 1·7 GeV/c^2 superimposed upon a smooth background (Fig 1.8). The 1·7 GeV/c^2 peak is more prominent in the $p\,\pi^+\pi^-$ data, because Deck effect background is relatively smaller than in the single pion channels. In fact, the distribution of $p\,\pi^+\pi^-$ masses, with the $p\,\pi^+$ sub-mass selected to be in the Δ^{++} mass band, can be fitted rather better with two non-interfering Breit-Wigner resonances than with a $\Delta^{++}\pi^-$ Deck distribution and a single resonance, so the evidence for significant $\Delta^{++}\pi^-$ Deck background in reaction 3 is by no means strong.

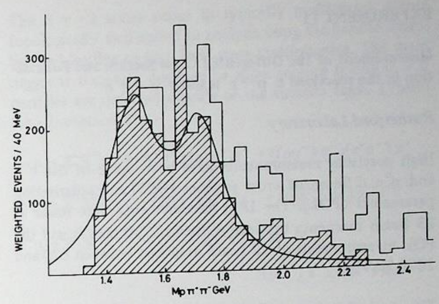


Fig 1.8. $p\pi^+\pi^-$ effective mass distribution. Shaded events have the $p\pi^+$ sub-mass within the Δ^{++} mass region. The smooth curve is the result of fitting two non-interfering Breit-Wigner resonances to the shaded distribution. The masses and widths of the two peaks are M_1=1·50 GeV/c^2, Γ_1=0·20 GeV/c^2, and M_2=1·72 GeV/c^2, Γ_2= 0·20 GeV/c^2, respectively (Experiment 10)

The four-momentum transfer distributions have the characteristic narrow forward peak expected for coherent production from ^{4}He. Fitting the $p\,\pi^+\pi^-$ t-distribution to the form Ae^{Bt}, with t in the range $0{\cdot}07 \leqslant -t \leqslant 0{\cdot}15$ (GeV/c)^2, the coefficient B is found to decrease slowly from (70·9±8·2) (GeV/c)$^{-2}$ at $M_{p\,\pi^+\pi^-}$ = 1·4 GeV/c^2 to (37·0±7·4) (GeV/c)$^{-2}$ at 2·0 GeV/c^2. The slopes for single pion production show a similar trend, but are 10-15 (GeV/c)$^{-2}$ smaller. By comparison, the elastic scattering slope in the same t region is measured to be (43·4±0·1) (GeV/c)$^{-2}$.

The spherical harmonic moments vary smoothly as a function of the mass of the produced system. In single pion production only the coefficients A_1, A_2 and A_3 are significant below 2 GeV/c^2. The moments of the distribution of the decay plane normal in reaction 3 show a rather similar overall behaviour.

The azimuthal angular distributions are not flat in either s- or t-channel helicity frames, for any of the reactions, with the possible exception of the decay plane normal for reaction 3 in the t-channel. Apart from this single instance, neither s- nor t-channel helicity appears to be conserved in these reactions.

EXPERIMENT 11

Measurement of the Differential Cross Section and Polarisation in the reactions $\pi^- p \rightarrow \pi^\circ n$ and $\pi^- p \rightarrow \eta^\circ n$

Rutherford Laboratory

High precision measurements have been made of the $\pi^\circ n$ and $\eta^\circ n$ differential cross sections (DCS) and polarisation parameters (POL). The DCS measurements were made at 23 beam momenta between 620 and 2730 MeV/c and the POL measurements at 22 beam momenta between 620 and 2270 MeV/c.

The analysis of the $\pi^\circ n$ differential cross section data is now complete and results have already been published. The ηn differential cross section analysis is well advanced; some preliminary results are shown in Fig 1.9. Production of data summary tapes at all momenta is now in progress. A study of systematic effects and a careful check of the analysis procedure is also being carried out.

The $\pi^\circ n$ polarisation analysis is now almost complete and preliminary results have been published. The ηn polarisation analysis is at a preliminary stage and work is continuing to understand the background from other processes. A preliminary raw asymmetry distribution is shown in Fig 1.9.

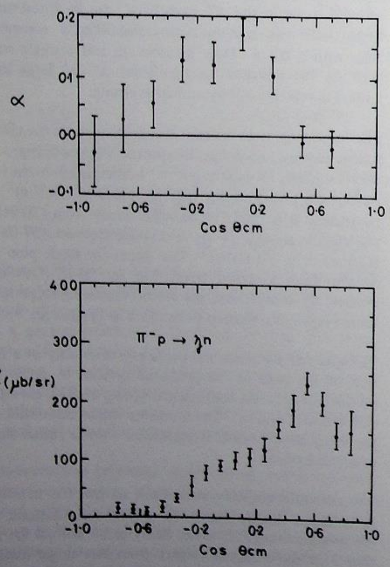


Fig 1.9. Raw asymmetry parameter and differential cross-section for $\pi^- p \rightarrow \eta n$ at 1274 MeV (Experiment 11)

These data represent the best and most complete set of measurements in the charge exchange channel and will provide powerful constraints to partial wave analyses of the πN system.

EXPERIMENT 12

Interaction of Slow and Stopped K^- Mesons

Birmingham University; Durham University; Free University of Brussels; University College, London; Warsaw University

This was the last experiment in the British 1·5m Bubble Chamber. 900,000 pictures were taken, with K^- mesons interacting in a sensitive hydrogen target (TST), surrounded by a neon-hydrogen mixture in which γ-rays could be detected. A considerable effort is still being spent on scanning and measuring the film, concentrating on the region of K^- momenta from 420 MeV/c down to rest.

The analysis is split into a number of parts, each in a different state of completeness. The most advanced part is a measurement of the ratio of Σ^+ to Σ^- production at rest. The result (to be published) disagrees by about five standard deviations with an earlier bubble chamber experiment, but is in good agreement with a result from an emulsion experiment. This is especially interesting since a recent analysis of the real parts of KN and $\overline{K}N$ forward scattering amplitudes, using higher energy data and dispersion-relations, was in severe disagreement with the results of multichannel analyses only in one region; at rest and close to rest in the $\overline{K}N$ channel. The multi-channel analyses all depend very heavily on the data from the same earlier bubble chamber experiment, and preliminary calculations have shown that inserting the charged value for the Σ^+ to Σ^- ratio into a multi-channel analysis does reduce the discrepancy with the dispersion calculations. The collaboration is therefore changing its priorities in the continued analysis of the experiment. As well as completing the planned programme of work on the Λ° to Σ° ratio at rest, and up to 420 MeV/c, it is intended to collect data in all channels over the same momentum region. This will provide a totally new set of numbers for the multi-channel analysis both close to rest, where the earlier data disagree with the dispersion relations, and above 250 MeV/c where there has never been very much data available.

This experiment has benefitted, at a number of the collaborating laboratories, from the cancellation or delay of planned bubble chamber runs at CERN and on NIMROD. Scanning and measuring effort which would have been used on these other experiments has been made available to the collaboration, so emphasis on the low momentum multichannel problem has been changed in a way which could not have been planned when the pictures were first taken.

EXPERIMENT 13

S = -2 Baryon Resonance Studies using the Rapid Cycling Vertex Detector (RCVD)

CEN Saclay; College de France, Paris; Oxford University; Rome University; Rutherford Laboratory

This experiment uses the RCVD – a small fast cycling bubble chamber specifically designed to work in conjunction with external electronic detectors which provide a trigger for picture taking on selected events. The physics of the experiment makes use of the detailed vertex information available from the bubble chamber and its relatively high sensitivity to small cross section processes to study the S = -2 states produced by incident K^- at 2·8 GeV/c. The anticipated sensitivity is 3–500 events/μb for a run of 90–100 days of data taking.

The experimental set up is shown in Fig 1.10. The bubble chamber is 30 cms in diameter, 20 cms deep and is designed to cycle at 60 Hertz. The relatively thin walls allow particles to emerge over a large solid angle with the minimum of interaction or scattering. The optics and the expansion system are both at the base of the chamber, the piston also being the main window. The chamber and trigger system are mounted in a 20 Kgauss magnetic field.

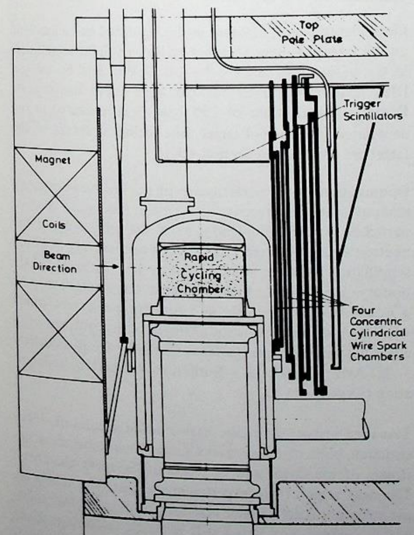


Fig 1.10 Experimental Set-up with RCVD (Experiment 13)

The S = -2 states occur in typically multivertex events topologically well suited to analysis using the bubble chamber and leading to high final state multiplicities. The main trigger is therefore designed to allow picture taking if ⩾ 5 particles are detected outside of the vacuum tank. Typical S = -2 reactions are:–

$$K^- p \rightarrow \Xi^- K^\circ \pi^+ \rightarrow (\Lambda^\circ \pi^-)(\pi^+\pi^-)\pi^+ \rightarrow ((p\pi^-)\pi^-)(\pi^+\pi^-)\pi^+$$

$$K^- p \rightarrow \Xi^- K^+ \pi^+ \pi^- \rightarrow (\Lambda^\circ \pi^-) K^+ \pi^+ \pi^- \rightarrow ((p\pi^-)\pi^-) K^+ \pi^+ \pi^-$$

$$K^- p \rightarrow \Xi^\circ K^\circ \pi^+ \pi^- \rightarrow (\Lambda^\circ \pi^\circ)(\pi^+\pi^-)\pi^+\pi^- \rightarrow ((p\pi^-)\pi^\circ)(\pi^+\pi^-)\pi^+\pi^-$$

$$K^- p \rightarrow \Lambda^\circ K^\circ \overline{K}^\circ \rightarrow (p\pi^-)(\pi^+\pi^-)(\pi^+\pi^-)$$

Background triggers are expected from the five or more body direct channels having S = -1, and from primary and secondary interactions occurring in the walls of the bubble chamber or vacuum tank.

The trigger system consists of four concentric wire spark chambers which surround the vacuum tank of the bubble chamber, which are in turn surrounded by a set of large pre-trigger scintillators.

The sequence of events is as follows:–
The bubble chamber sends a beam demand pulse to the accelerator about 4 msec before sensitivity. The fast spill thus requested lasts less than 500 μsec and occurs just before the liquid pressure minimum. The beam defining counters require that a K^- particle enters the chamber and the pre-trigger scintillators give a candidate event pulse if more than three secondary particles are detected in coincidence. This pulse starts the timing of the bubble growth, triggers the high tension on the spark chambers and stops the fast spill to minimise background in the pictures. The long memory of the bubble chamber during bubble growth (1 - 2 msec) is used to read out the spark chambers, clean up the spark spectrum and obtain by comparison between the four chambers and the counters a multiplicity for the event. If the condition n ⩾ 5 is satisfied a flash trigger pulse is generated and the picture is taken.

The overall status of the experiment is that the complete system of bubble chamber, trigger and pre-trigger plus beam line has been constructed and is in the process of commissioning. The bubble chamber performance however is not yet satisfactory for data taking although the pictures shown were at a frequency of 28 Hertz with 15 pulses in a burst matched to a flat top from Nimrod of 600 Msec.

The beam line is rather critical because of the bubble chamber's need for purity and the intensity requirement to give about 40 fast spills per Nimrod flat top. The beam line has been tuned and yields about 500 K^- on a background of about 400 $(\pi^- + \mu^-)$ in fast spill operation.

The pre-trigger counters and the associated fast electronics have been contributed by the Saclay, College de France part of the collaboration. The system has been set up and pre-trigger rates measured for K^- incident particles with magnetic field off and on. The results are consistent with the Monte Carlo predictions.

The wire spark chambers were constructed by Rutherford in collaboration with the University of Rome. The chambers were completed and have been extensively studied during the year and it is clear that they now provide the basis for the required main trigger. The special purpose CAMAC units to read out the four chambers in parallel, to clean the wire spectra and construct cluster multiplicities were built in Rome who also helped to provide the PDP 11/40 computer system which is used to make the final decisions in software.

A detailed analysis of large batches of spark chamber and pre-trigger data written on tape using the PDP 11/40 is in progress together with a scan of some 14,000 triggered pictures (using the $n \geqslant 3$ pre-trigger condition only – all spark chamber data on tape for off line selection) and the associated spark chamber data.

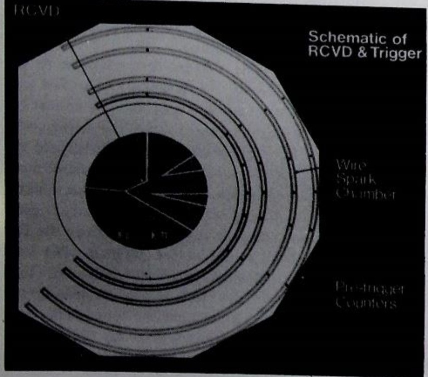


Fig 1.11. Schematic view of RCVD and trigger (Experiment 13)

EXPERIMENT 14

$\pi^{\pm}$p, K^-p Elastic Differential Cross-Sections

Bristol University; Southampton University; Rutherford Laboratory

This collaboration has in the past made extensive measurements of $K^{\pm}$p and $\pi^{\pm}$p elastic differential cross-sections using particle beams from Nimrod. During the last year a comprehensive set of $\pi^{\pm}$p data has been published and the latest experiment to measure K^-p cross-sections has taken data.

The analysis of the $\pi^{\pm}$p data is almost complete, and the results of this experiment were published at the Oxford Baryon Conference in July. The complete data set taken at 51 momenta in the range 0·4–2·15 GeV/c contains more than 1·6 million elastic scattering events.

The setting up of the experiment to study K^-p elastic scattering is completed. Data has been taken at 13 K^- momenta, and in all more than 7 million triggers have been written onto magnetic data tapes. Data analysis is proceeding well, and it is hoped to complete this experiment with a further 3 months of data taking during 1977.

EXPERIMENT 15

Polarisation Measurements in K^+N Interactions

Queen Mary College, London; Rutherford Laboratory

1976 saw the installation and commissioning of apparatus for this experiment which is designed to measure the polarisation parameter in the reactions $K^+n \rightarrow K^+n$ and $K^+n \rightarrow K^\circ p$, where the target neutrons are polarised. In the momentum range 0·7–1·4 GeV/c.

Clean identification of kaons in the separated beam incident on the target has been achieved by time-of-flight techniques in the momentum range 0·7 - 1·0 GeV/c, and by using a DISC Cerenkov counter for momenta above this region. Deuteron polarisations of 28% have been measured in the deuterated propanediol target. The technical details of the target are described in Section 4.1.1.

Optimisation of the performance of the low mass, capacity readout spark chambers, which detect final state charged particles, is near completion, as is the setting up of the neutron counters. These latter consist of one array of liquid scintillation counters, used previously in a Rutherford Laboratory experiment which measured the reaction $\pi^-p \rightarrow \pi^\circ n$, and two arrays of plastic scintillation counters, which were used in the slow neutron trigger experiment, performed on the Omega spectrometer at CERN by the Birmingham – Tel Aviv – Westfield – Rutherford Laboratory collaboration (Experiment 1).

Test data written onto tape have enabled successful reconstruction both of beam tracks in multiwire chambers upstream of the target and of tracks in the spark chambers. The next stage of the experiment includes data taking on the experimentally simpler reactions to measure the polarisation parameter in π^-p and K^-p elastic scattering, along with the collection of preliminary data on the K^+n reactions.

EXPERIMENT 16

Study of K^-p Interactions in the 1 GeV/c Region

Imperial College, London; Rutherford Laboratory

The high statistics data of K^-p interactions in the momentum range of 0·960 to 1·400 GeV/c obtained from 415,000 pictures of the CERN 2m hydrogen bubble chamber, together with a carefully selected set of the most recent $\bar{K}N$ data were used to find an energy dependent partial wave solutions to the reactions:–

$$\bar{K}N \rightarrow \bar{K}N \qquad \bar{K}N \rightarrow \Sigma\pi \qquad \bar{K}N \rightarrow \Lambda\pi$$

These partial waves parametrised as a sum of resonances and simple backgrounds fit the data well over the wide cm energy range 1480 to 2170 MeV. The solutions provide a better determination of the parameters of the established resonant states, confirming several other states and providing evidence for some new states. At present, certain class of ambiguities associated with the solution are being investigated using the method of Barrelet zeros.

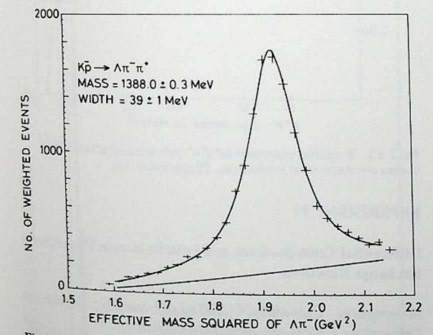


Fig 1.12. Results from Experiment 16

The analysis of 3 body channels i.e.:–

$K^-p \rightarrow K^-p\pi^\circ$ (15,000 events)

$K^-p \rightarrow \bar{K}^\circ p\pi^-$ (20,000 events)

$K^-p \rightarrow K^-N\pi^+$ (20,000 events)

$K^-p \rightarrow \Lambda^\circ\pi^+\pi^-$ (25,000 events)

has been progressing throughout the year, This consisted of the extraction of the quasi-two body final states such as $\Lambda(1520)\pi$, $K^*(890)N$ and $\Sigma(1385)\pi$. The standard isolar model philosophy has been adopted for this extraction and several variations of this model have been tried. Partial wave analysis of the pure I = 1 channel $\Lambda(1520)\pi$ is in progress including data from earlier experiments covering the cm energy range 1700 – 2170 MeV. The more complicated channel $K^*(890)N$ is being analysed over the same energy range. This is believed to be the first attempt of this type of analysis for this channel.

Using data from this and previous experiments, an energy dependent partial wave analysis of $\Sigma(1385)\pi$ channel was carried out in the cm energy range 1775 – 2170 MeV. An interesting feature of this channel is that the subsequent decay of Λ° from $\Sigma(1385)$ enables one to measure the full polarisation matrix of the $\Sigma(1385)$ which provides an extra useful constraint on the partial wave solution. The results of these partial wave analyses should provide further tests of the quark model and $SU(6)_W$ predictions. As an example of the quality of the 3 body data, Fig 1.12 shows the effective mass^2 distribution of $\Lambda^\circ\pi^-$ in the $\Lambda^\circ\pi^+\pi^-$ showing clearly the $\Sigma^-(1385)$ resonance. This has led to the most precise determination of the masses and widths of $\Sigma^{\pm}(1385)$.

There are two data extensions to the experiment. The first is from 310,000 2m hydrogen bubble chamber pictures at 4 incident K^- momenta between 0·92 and 1·04 GeV/c. The second is from 480,000 81 cm hydrogen bubble chamber pictures covering the K^- momenta range between 0·675 – 0·850 GeV/c, which were obtained from the Heidelberg-Munich Collaboration. Final data summary tapes are now being produced.

EXPERIMENT 17

Search for Exotic Δ^* States in $\pi^+p \rightarrow K^+\Sigma^+$ using RMS

Edinburgh University; Westfield College, London; Rutherford Laboratory

The Rutherford Multiparticle Spectrometer (RMS) group have had a new proposal approved to study the Δ^* spectrum between 1900 and 2400 MeV by measuring $d\sigma/d\cos\Omega$, P. A and R in the reaction $\pi^+p \rightarrow K^+\Sigma^+$. The measurements will involve data taken from a liquid hydrogen target and a new frozen spin polarised target being constructed at the Laboratory (Section 4.1.1). Using these measurements an independent partial wave analysis free of discret energy independent partial wave analysis free of discrete ambiguities can be performed. The resonance amplitudes in this channel have the property of providing an explicit signal for Δ^* states in a (27) multiplet of SU(3), i.e. exotic Δ^* states. In addition, of course, the analysis will provide important new information for the classification of conventional Δ^* states in SU(6) x 0(3) multiplets.

RMS itself is now approaching completion and data taking is expected in summer 1977. Approximately 2/3 of the detector system has been satisfactorily tested. The π13 beam has been tuned (see Section 6) and fluxes of π^+ measured.

1.1.3 Intermediate Energy Reactions

EXPERIMENT 18

Study of 4 GeV/c π^+p Interactions in a Track Sensitive Target

CERN; Lawrence Berkeley Laboratory; Rutherford Laboratory; Turin University

This is the first experiment using the Track Sensitive Target (TST) technique developed at the Rutherford Laboratory. The experiment involved the operation of a neon-hydrogen bubble chamber surrounding a perspex walled target containing liquid hydrogen. The liquid neon-hydrogen and the hydrogen in the target are simultaneously track sensitive so that production vertices can be seen inside the hydrogen, whilst gamma rays from the decay of π° mesons penetrate the perspex and are converted into electron positron pairs in the neon-hydrogen.

Events involving more than one neutral particle can be analysed with a TST. These are difficult to study in other experiments. In particular the reaction $\pi^+p \rightarrow \pi^+p\pi^\circ\pi^\circ$ can be kinematically reconstructed using the converted gamma rays from the π° decays. Such a multineutral final state cannot be studied in a chamber filled entirely with hydrogen, while other techniques such as heavy liquid bubble chambers and spark chamber arrangements have been unable to provide good information on the $\pi^\circ\pi^\circ$.

This successful TST experiment is a major development of the bubble chamber technique and has led to several proposals for high energy experiments at CERN. The new problems of optical reconstruction, kinematical fitting and event selection have all been solved and this groundwork will benefit all the future experiments.

The status of the analysis is that over 500,000 pictures have been scanned, while about 80,000 events have been measured and fully reconstructed. These events include over 2,500 examples of the reaction $\pi^+p \rightarrow \pi^+p\pi^\circ\pi^\circ$. A study of the $\Delta^{++}\pi^\circ\pi^\circ$ channel is in progress and should yield results in the new year.

In the meantime, experiments with other techniques have studied direct lepton production in hadron collisions. Although this phenomenon had been observed at high energy and high p_T some time ago, recent experiments indicated that the leptons might also be present at lower energies. The hydrogen-neon surrounding our TST is a good gamma ray converter, and it also allows one to identify electron tracks through their characteristic behaviour, such as curling and producing bremsstrahlung. Some of the film has been scanned for examples of direct electron production. Although one example of ω° or $\rho^\circ \rightarrow e^+e^-$ has been found the remaining electrons are all compatible with π°, η° and ω° decays as shown in Fig 1.13. The absence of any extra electrons leads to useful upper limits at 4 GeV/c, on both the production of direct single electrons and positrons and massive pairs.

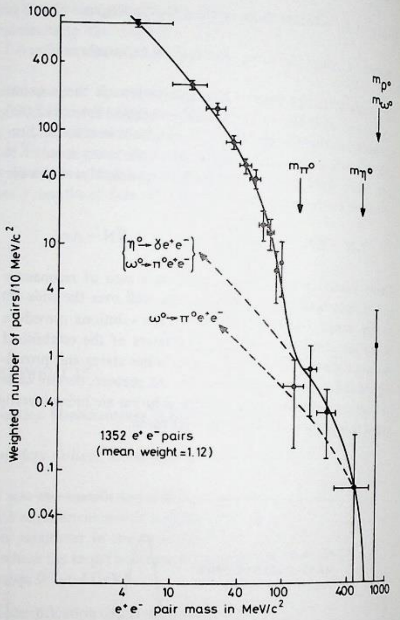


Fig 1.13. Weighted experimental e^+e^- pair mass spectrum. The curves are theoretical predictions (Experiment 18)

EXPERIMENT 19

Differential Cross-Sections and Polarisations in Hypercharge Exchange Reactions

Birmingham University; Genova University; Stockholm University: CERN; Rutherford Laboratory

This experiment has measured differential cross-sections and polarisations for the pairs of line reversed hypercharge exchange reactions

$$\pi^+p \rightarrow K^+\Sigma^+$$

$$K^-p \rightarrow \pi^-\Sigma^+$$

and

$$\pi^+p \rightarrow K^+\Sigma^+(1385)$$

$$K^-p \rightarrow \pi^-\Sigma^+(1385)$$

Measurements were made at 7 and 10 GeV/c incident momentum, and cover a range of (four-momentum transfer)^2, t, from 0 to about -4 (GeV/c)^2. The running of the experiment was completed at CERN in August 1974, and some

results on the scattering cross-sections were presented in the 1975 Annual Report. They show only modest breaking of the exchange degeneracy prediction of equal differential cross-sections. The analysis is expected to be completed in the near future.

EXPERIMENT 20

Study of $\bar{p}p$ Annihilations at 2·0 GeV/c in a Track-Sensitive Target

Tata Institute, Bombay; Melbourne University

The main aim of this experiment, using the Track Sensitive Target (TST) in the 1·5 m Bubble Chamber at the Rutherford Laboratory, has been the study of $\bar{p}p$ annihilations involving two or more neutral pions. About 40,000 events with two or more associated γ-rays have been scanned and measured. The final results on these reactions are expected in the coming year.

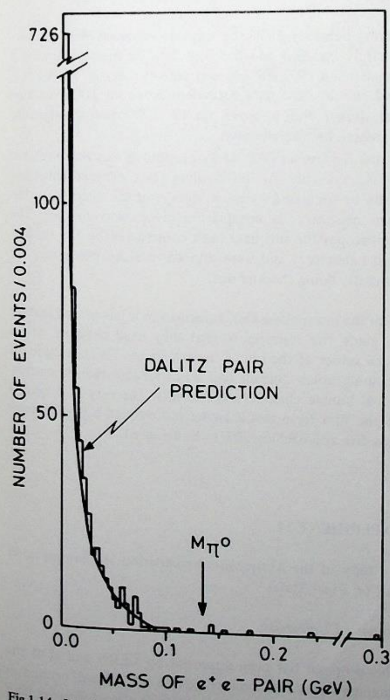


Fig 1.14. Invariant mass of all e^+e^- pairs compared with the distribution expected from Dalitz pairs (Experiment 20)

Over the last year considerable interest has been focussed on the anomalously high rate of direct lepton (electrons and muons) production reported in many counter experiments in hadron-hadron collisions. The ratio of inclusive lepton to pion production has been reported to be about 10^{-4} at various incident energies and at transverse momenta down to about 200 MeV/c. A search for these leptonic events could throw light on the mechanism involved in causing this relatively high level of lepton production. In 120,000 pictures, around 10^5 interactions have been examined with a total of $1{\cdot}3 \times 10^5$ π°s involved. Preliminary results based on momentum measurement on the scan table indicate that almost all the direct electron candidates are consistent with Dalitz pairs ($\pi^\circ \rightarrow \gamma e^+e^-$) (Fig 1.14). Correcting for detection efficiency a value of $1{\cdot}21 \pm 0{\cdot}04 \times 10^{-2}$ is obtained for the ratio of Dalitz pairs to π°s produced, to be compared with a reported value of $1{\cdot}17 \pm 0{\cdot}05 \times 10^{-}2$.

There are, however, 10 unexplained candidates that may be examples of e^+e^- decays of a vector meson V° with $m_{\pi^\circ} < m_{V^\circ} \lesssim 2m_\pi$. While investigations are still in progress, the ratio of direct electron production to π° production in $\bar{p}p$ collisions at 2·0 GeV/c is found to be about 10^{-4}, but definitely smaller than the value $6{\cdot}0 \times 10^{-4}$ reported at ISR energies for p_T around 200 MeV/c. The measurement is consistent with the results obtained from 22,500 annihilations at 1·6 GeV/c in the Gargamelle heavy liquid bubble chamber.

EXPERIMENT 21

Helicity Amplitudes in $\pi^-p\uparrow \rightarrow K^\circ\Lambda$ at 5 GeV/c

CERN; ETH Zürich; Helsinki University; Imperial College, London; Southampton University

Data taking for this experiment was completed in December 1975. 7×10^6 triggers for the reaction $\pi^-p \rightarrow K^\circ\Lambda$ were recorded on magnetic tape. These include 6×10^6 triggers from the propanediol frozen spin polarised target – average polarisation greater than 90%: the remainder were taken using a pure carbon target and a liquid hydrogen target.

The data reduction programs for V° finding and kinematic hypothesis testing are now processing data on the Rutherford Laboratory 360/195 computer.

In 40% of the triggers a $K^\circ_S \rightarrow \pi^+\pi^-$ decay is identified with mass precision $\Delta m = 15$ MeV fwhm.

10% of the triggers are considered as candidates for $\pi^-p \rightarrow K^\circ\Lambda$ and will be submitted for further analysis in order to determine the helicity amplitudes. Final results are expected in about 18 months.

In addition a further 5×10^6 triggers were recorded with a relaxed trigger condition. A hard wired processor is being developed at Imperial College in order to perform the equivalent tasks now being done on the 360/195. These data should allow analysis of the process $\pi^-p\uparrow \rightarrow K^\circ\Sigma^\circ$.

EXPERIMENT 22

π^-p Interactions at 22 GeV/c

Oxford University; Pisa University; Pavia University; Rutherford Laboratory

The experiment was carried out using the Big European Bubble Chamber (BEBC) filled with hydrogen and exposed to a beam of 22 GeV/c π^--mesons.

The fraction of the exposure allocated to the Rutherford Laboratory contained some 11K pictures suitable for analysis. The film has been triple scanned and all events containing a strange neutral particle decay have been measured on an HPD and processed through geometry and kinematics. An event recovery chain (PATCHUP) working off-line on the HPD measurement information has been found very effective in increasing pass rates through the analysis chain and is being used on all current measurements. Data from all laboratories will be combined and a study of inclusive K°, Λ°, γ and π° physics will be carried out.

The experiment has admirably served its purpose as a pilot project in having shown up innumerable problems thus facilitating a rapid and efficient analysis of future BEBC experiments. The measuring accuracy obtained using the HPD on a sample of BEBC events containing strange neutral particle decays is given in Fig 1.15.

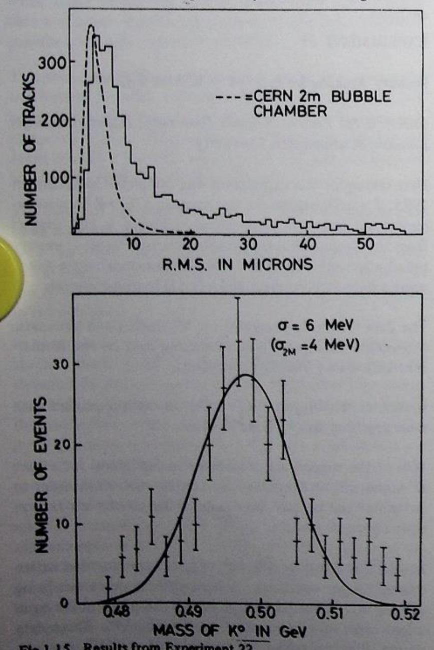


Fig 1.15. Results from Experiment 22

EXPERIMENT 23

Y* Production in 7 GeV/c π^+p and K^-p Interaction

Imperial College, London

The experiment uses the SLAC Hybrid Facility (SHF) to investigate Y* production in the reactions:

$$\pi^+p \rightarrow \pi^+ Y^{*+} \qquad 1$$

$$K^-p \rightarrow \pi^- Y^{*+} \qquad 2$$

The SHF consists of the 40″ SLAC rapid cycling chamber which is capable of being triggered by means of data from proportional wire planes (PWC) and a large multicell Cerenkov counter downstream and other proportional wire planes upstream of the chamber. Detection of a fast outgoing K for reaction 1 or π for reaction 2 triggers a picture.

During February 1976 the third downstream PWC was successfully installed and the first data for reaction 1 with 3 downstream PWC stations was taken in March. After a second run in June data equivalent to about 100 events/μb was chosen. Full approval for the 300 event/μb originally requested has been granted.

At the September PAC Meeting, approval was also given for the K^- exposure. As this involves a fast π trigger which can easily be simulated by muon decays of the beam Ks it has been necessary to construct a muon veto counter. The hodoscopes for this have been constructed by the Rutherford Laboratory and were shipped to SLAC where they are currently being checked out.

With the beam plane PWC information it has proved feasible to guide the scanners so that they need examine only a small subset of the tracks on each frame. This has made the scanning much quicker and more reliable than in conventional bubble chamber experiments. The very high quality of the film from this chamber has enabled a first measure pass rate approaching 90% to be achieved.

EXPERIMENT 24

A Study of the Antiproton Annihilation Mechanism in 4π and 6π Final States

Liverpool University

This proposal has been approved by CERN and is at the planning stage. It is expected that a test run will occur during the Spring of 1977, with the main data following later in the year.

Low statistics studies using bubble chamber data at incident momenta of up to 9 GeV/c indicate that the annihilation process is significantly different from other processes, the two major features being high values of the average transverse momentum, and the absence of strong leading particle effects. The main aim of this experiment is to study these features in the exclusive multibody reactions $\bar{p}p \rightarrow 2\pi^+2\pi^-$ and $\bar{p}p \rightarrow 3\pi^+3\pi^-$ at 8, 15 and 30 GeV/c, and hence gain some insight into the development of the annihilation mechanism with energy and multiplicity.

Since the annihilation channel cross sections decrease very rapidly with energy relative to the total cross section, a selective trigger is necessary to obtain reasonably sized data samples. Not enough is yet known about the dynamics of antiproton annihilation at these energies to design an unbiased trigger, and so an enrichment trigger will be implemented on the CERN Omega Spectrometer to remove those commonly occurring events which are clearly *not* the desired annihilation channels. Thus a counter system around the target will demand at least three charged particles, while a large Cerenkov counter downstream will veto the majority of events containing an antiproton, and a lead-scintillator γ-veto system will reject a large proportion of π° containing final states. The major feature of this enrichment trigger is that inefficiences in the veto system will not result in any loss of, or bias to, the sample of required events.

Various studies have been performed to simulate real Omega operating conditions, and a method developed to correct for the (very small) loss of events due to geometrical factors. In addition the group has been working in conjunction with members of the CERN-Glasgow-Liverpool collaboration (Experiment 6), using Monte Carlo methods in the design of the γ-veto system being built by them for the use of both experiments.

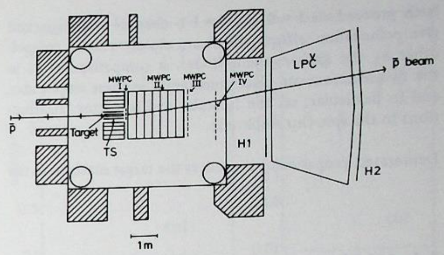


Fig 1.16. Omega layout for Experiment 24

EXPERIMENT 25

Spin Dependence of Elastic Proton-Proton and Neutron-Proton Scattering

Oxford University; CERN; Paris-Sud University

In 1976 the CERN, IPN Orsay, Oxford collaboration completed an experiment to measure the polarisation parameter, P_o, in the elastic scattering of 24 GeV protons by a polarised proton target in the C9 beam at the CERN proton synchrotron.

At energies above 7 GeV, there is diffractive structure in the differential cross section for elastic proton-proton scattering at a four-momentum transfer squared of t = −1·5 $(GeV/c)^2$, and in such a region, strong spin dependent effects are seen. The present study has measured the polarisation parameter P_o throughout this region, out to t = −5 $(GeV/c)^2$.

Protons scattered out of a high intensity proton beam by a propanediol polarised target, were detected by scintillation counter hodoscopes. Up to t = −0·9 $(GeV/c)^2$, the angular correlation between the two outgoing protons, and time of flight, were sufficient to distinguish the elastic events. But at larger scattering angles, where the differential cross section becomes very small, the velocity of the forward particle measured with a Cerenkov Counter, and the momentum of the recoil proton measured by a spectrometer magnet were also required.

Preliminary results (Fig 1.17), which have been presented at the Argonne Conference, show a peak with small positive value at |t| = 0·3 $(GeV/c)^2$, dipping to zero around |t| = 0·8 $(GeV/c)^2$. The peak value at |t| = 1·7 $(GeV/c)^2$, which is dominant in lower energy measurements, is still present. After falling to zero or becoming negative around |t| = 2·0 $(GeV/c)^2$, the polarisation is consistent with zero. Around |t| = 1 $(GeV/c)^2$, there is evidence for a sharp negative dip.

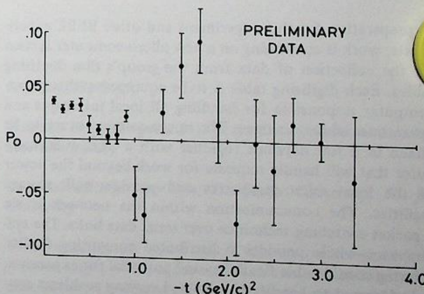


Fig 1.17. Polarisation parameter for pp elastic scattering at 24 GeV/c (Experiment 25)

In the latter part of the year, the apparatus was modified to measure the polarisation parameter, P_o, for neutron-proton scattering at 24 GeV/c in order to complement the proton-proton data. The two processes

$$p + p \rightarrow p + p$$

and

$$p + n \rightarrow p + n$$

both proceed via I = 0 and I = 1 t- channel exchange, and give polarisation effects which are closely related to each other by the exchange amplitudes. A comparison of P_o in the two reactions can place constraints on these amplitudes, and in particular, on the isoscalar and isovector contributions to the spin-flip amplitude.

Deuterated propanediol is used as the target material in the standard CERN polarised target. The forward scattered proton is detected by multiwire proportional chambers, and its momentum measured by a small aperture spectrometer magnet. The recoiling neutron is detected by an array of plastic scintillators. Elastic events are distinguished both by the velocity of the recoil neutron as measured by its time of flight, and by the momentum of the forward proton.

1.1.4 Higher Energy Experiments

EXPERIMENT 26

K^-p Interactions at 70 GeV/c

Glasgow University; CEN Saclay; Rutherford Laboratory

This experiment, designed to be run at the CERN SPS using the Big European Bubble Chamber (BEBC), has been fully approved and is scheduled to run in 1977.

The main aim of this experiment is to perform a general exploration of K^-p interactions in a new energy range with greater precision and detail than carried out so far. The interaction of high energy negative kaons with protons is a particularly rich source of different kinds of particles and processes and is ideally suited to an exploratory experiment.

In preparation for this experiment and other BEBC experiments, work is continuing on a new micro-computer system for the collection of data from the group's film digitising tables. Each digitising table is to be equipped with a micro-computer responsible for handling all local interrupts and operator-machine dialogue. The micro-computers are to be linked in a star network together with a GEC 4080 computer that will handle requests for work beyond the power of the local micro-computers and provide bulk storage facilities. The communication within the network is via a packet switching technique over serial data links. The system as a whole provides a distributed computing facility offering considerable flexibility and potential for expansion. It is designed to handle the new and varying problems concerned with the measurement of film from the large European Bubble Chamber (BEBC) and from the new Rapid Cycling Chambers.

Each micro-computer in the system has 16K bytes of semi-conductor memory, sixteen prioritised and vectored interrupting I/0 channels and eleven non-interrupting I/0 channels. The hardware is fully developed and operational in a prototype model. Four production units are in an advanced stage of construction. The basic software for communication within the network is operational and work is proceeding on application programmes both in the micro-processors and in the GEC 4080 computer.

EXPERIMENT 27

Direct Lepton Production in 70 GeV/c π^-p Interactions using BEBC Equipped with TST

Bologna University; Glasgow University; Rutherford Laboratory; Saclay; Torino University

The aim of this experiment is to determine in detail the cause of the large e/π ratio (about 10^{-4}) obtained in many counter experiments.

This experiment is due to start after the May - June SPS shutdown. The preparatory work for the experiment is now well advanced and computer generated events have been produced on film which has been scanned and measured in order to understand the scanning and measuring problems associated with this experiment.

The possibility of producing such film is only possible now that the extremely high resolution microfilm recorder FR80 (see Section 5) is available on site to produce images on 35 mm film.

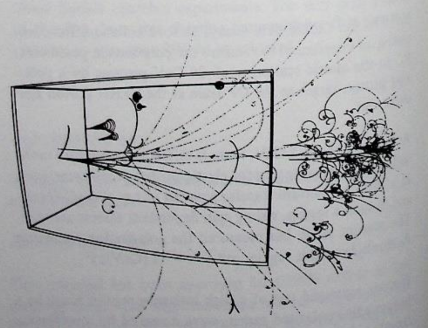


Fig 1.18. Computer-generated events (Experiment 27)

Events were generated in space by following all particles through the chamber, allowing them to interact or decay by strong, electromagnetic and weak processes. Charged particles left 'bubbles' which were projected into any of the five cameras where the distorted image position was recorded on magnetic tape for plotting on the FR80. An example of such an image is shown in Fig 1.18 where the incident beam is 70 GeV/c π^- and inside the chamber, filled with a Ne/H_2 mixture, there is a track sensitive target (TST) of pure hydrogen. The imposed camera distortions cause the flat walls of the TST to appear curved. Besides this experiment, the method has been used to study the problems of neutrino interactions both with and without the TST.

EXPERIMENT 28

$\bar{p}p$ Interactions at 100 GeV/c

Cambridge University; Michigan State University and Fermi National Accelerator Laboratory

Measurement of the film from this 100,000 picture exposure at FNAL is now complete, yielding about 10,000 $\bar{p}p$ interactions, and a similar number of π^-p interactions. Interest so far has centred on the $\bar{p}p$ interactions, and especially on comparing them with pp interactions at the same energy, since differences between $\bar{p}p$ and pp interactions may be expected to yield information about annihilations in the high energy $\bar{p}p$ system. The work on topological cross-sections has indicated that difference distributions do indeed have properties similar to lower energy data on annihilations, in particular a larger average charged multiplicity than non-annihilations, and a lower value for the correlation moment f_2^-.

Many aspects of inclusive particle production have now been examined. Fig 1.19 shows $d\sigma/dy^*$ for production of γ, K_s^o and $\Lambda/\bar{\Lambda}$ in 100 GeV/c $\bar{p}p$ and pp collisions. The $\bar{p}p$ data are consistently higher than pp, most strikingly in the central region for γ and Λ/Λ. Much work has also been carried out on two particle correlation effects, the inclusive production of ρ^o and Δ^{++} resonances, and on exclusive processes, which should be published in the near future. This experiment is seen as the first of a series investigating the $\bar{p}p$ annihilation process at high energies, involving work at FNAL, CERN (BEBC and EHS) and SLAC.

The π^-p data on this film has been augmented by a further 1,000,000 pictures from an earlier experiment at FNAL, on which neutral particle production is being studied with substantially better statistics than previous experiments at this energy.

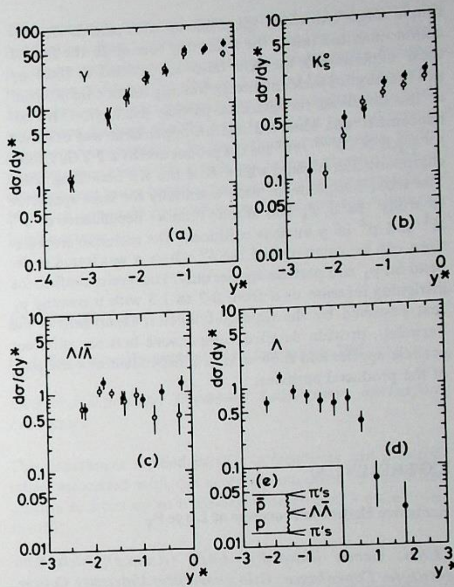


Fig 1.19. Results from Experiment 28

EXPERIMENT 29

Internal Target Experiments at the Fermi National Accelerator Laboratory

Imperial College, London; Rochester University; Rutgers University

These experiments make use of the unique feature of the internal target which is the very wide range of incident energies, between injection at 8 GeV and extraction at 400 GeV, over which reactions of interest can be studied. The subject of the current research is the study of pp and pd elastic and inelastic reactions by means of a high resolution recoil spectrometer, in conjunction with forward particle and polar and azimuthal hodoscopes.

The new internal target experimental hall was completed in May 1975 and following this the superconducting recoil spectrometer was installed and tested along with a new gas jet target. Preliminary runs in February 1976 were followed by the first data runs in June 1976 which are now being analysed. In parallel with the above activities the group performed two short experiments using nuclear targets and a simple single arm recoil spectrometer with particle identification mounted inside the main ring tunnel. In the first of these experiments the K/π ratio was studied at fixed $p_\perp$ as a function of incident energy looking for an enhancement at the threshold for charmed particle production. No enhancement was observed and an upper limit was obtained for $\sigma_T.B$ of 10^{-30} cm² for the production of a 2·2 GeV mass charm-anticharm pair, where B is the Kπ branching ratio. The second experiment used essentially the same apparatus to study the S, $P_\perp$ and atomic number dependence of $\pi^\pm$, $K^\pm$ and $p^\pm$ in p nucleus collisions. The inclusive cross-sections can be parametrised by A^α where α was found to depend on $p_\perp$ and particle species only. The results confirm the intriguing increase of α from 0·7 to 1·3 with increasing $p_\perp$ first observed by the Chicago-Princeton experiment at the Fermilab, provide detailed comparisons between different particle species and show α to be independent of s and p_{CM} of the produced particles.

EXPERIMENT 30

Exclusive Hadronic Processes at Large P_T

CERN; Genoa University; LAPP (Annecy); Niels Bohr Institute, Copenhagen; Oslo University; University College, London

This experiment is currently being set up in the West Area unseparated hadron beam, H1B, at the CERN SPS. The aim is to measure elastic scattering of pions, kaons protons and antiprotons on protons, and antiproton annihilation into $\pi^+\pi^-$ and K^+K^-, at incident momenta between 20 and 80 GeV/c and four-momentum transfers greater than 2 $(GeV/c)^2$. Since the elastic differential cross section is expected to be very small in much of this region of energy and four-momentum transfer, the experiment has been designed to measure values of $\frac{d\sigma}{dt}$ down to 10^{-37} cm² $(GeV/c)^{-2}$. A very intense beam, of the order of 10^8 ppb, will be used, together with a 1 m-long hydrogen target. In addition, the spectrometer arms for secondary particles have large aperture and are designed to operate at high counting rates.

EXPERIMENT 31

SPS Beam Dump Experiment in the Omega Spectrometer

Birmingham University; CERN; Ecole Polytechnique; MPI Munich; Neuchâtel University

The mechanisms by which J/Ψ particles are produced in hadronic collisions are not yet understood. The available evidence suggests that they are not predominantly produced in association with charmed particles and it is also known that π-mesons produce them more easily than protons. If this is due to the presence of an antiquark in the pion which annihilates with a quark in the target nucleon to form the J/Ψ then even more copious production should be expected from antiprotons because they contain three antiquarks. Moreover the direct comparison of the production of J/Ψ particles by $\bar{p}$ and p should help to clarify the mechanism. The experiment will detect the two-muon decay of J/Ψs produced by p, $\bar{p}$, π^+, π^-, K^+ and K^- using the 40 GeV/c S1 beam in the West area at CERN. A copper absorber (beam dump) immediately after a heavy target serves to identify muons and allows high incident fluxes to be used (~10^7 per pulse) which combined with the large acceptance of Omega will yield several hundred J/Ψ particles per day from pions. No data exist for $\bar{p}$, K^+ or K^- at the present time.

EXPERIMENT 32

Inclusive Particle Production at Low Transverse Momenta and Large Angles at the CERN Intersecting Storage Rings

CERN; University College, London; Bristol University; Massachusetts Institute of Technology; Niels Bohr Institute; Lund University

The ISR experiment 131 was proposed in Autumn 1973, the data acquisition was completed at the end of 1974 and the final data has now been published. The experiment measured single-particle inclusive cross-sections for pions, kaons and protons at very low transverse momenta. A single-arm spectrometer was used to detect particles emerging at 90° in the CMS, and a very good data normalization was achieved by using the hodoscopes of the Pisa-Stony Brook total cross-section experiment as an ISR luminosity monitor. Data taken by the two experiments were combined in a study of multiplicity distributions associated with a charged particle identified in the spectrometer.

The results on the low p_T inclusive cross-sections have been published and some data taken with a deuteron trigger are still being analysed. The study of the energy dependence of the inclusive pion spectra in the central region, where pions constitute 90% of the particle yield, is of particular interest in the light of the observed rise of the total inelastic pp cross-section at very high energies. Previously published data omit a significant fraction of the production spectra at very low p_T and are given with typical normalization uncertainties of about 5 - 10%. Over the transverse momentum range 40 to 400 MeV/c and the ISR energy range $\sqrt{s}$ = 23 to 63 GeV, the inclusive cross-sections for π^+ and π^- were found to increase by 36 ± 2% and 41 ± 2%, respectively (Fig 1.20). Over the same energy range, the average increase in the invariant cross-section is 52 ± 8% for K^+, 69 ± 8% for K^-, 8 ± 5% for p and 84 ± 6% for $\bar{p}$. For kaons and protons the range covered in p_T is 100 MeV/c to 300 and 500 MeV/c, respectively.

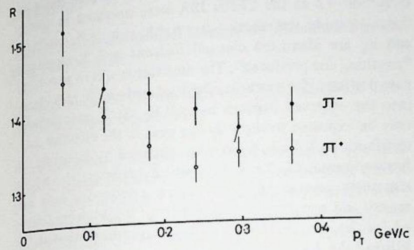


Fig 1.20. P_T dependence of π^+ and π^- invariant differential cross-sections (Experiment 32)

The energy dependence of the pion spectra in the central region indicates that Feynman Scaling, i.e. energy independent cross-sections, does not hold at ISR energies. The observed s-dependence is in agreement with the quantum field theoretical model of Cheng and Wu. The energy and p_T dependence is also well described by the Landau hydrodynamical model. In many models the approach to scaling for pions is expected to be of the form $A + B\,s^{-\alpha}$ with α being either 0·5 or 0·25. Fits to the new data give very small values of α in the range 0·03 - 0·05.

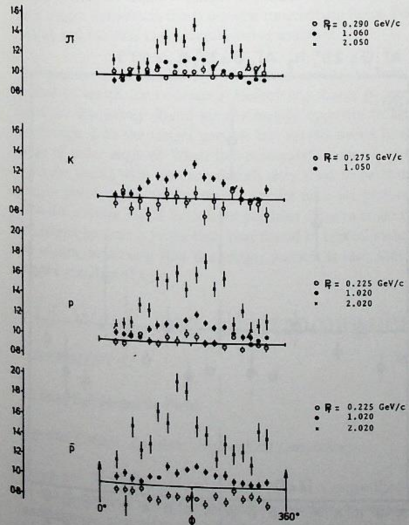


Fig 1.21. Normalized azimuthal distributions of associated particles for given values of p_T of the trigger particle at θ = 90°, φ = 0°, and at $\sqrt{s}$ = 45 GeV (Experiment 32)

The correlation data have been analysed and submitted for publication. Event topologies were studied for low and high p_T trigger particles and the associated multiplicity distributions show evidence for distinct low and high p_T domains. For a low p_T trigger particle the multiplicities associated with pions decrease slightly with increasing p_T and remain momentum-independent for the other particle types. Multiplicities associated with a high p_T particle show a marked enhancement over a broad cone opposite the trigger particle. Increased same-side correlations are observed for a high p_T baryon trigger.

EXPERIMENT 33

High Transverse Momentum Behaviour at the ISR

Liverpool University; Daresbury Laboratory; Rutherford Laboratory

This experiment studied particle correlations and multiplicities, associated with the central production of identified charged hadrons up to transverse momenta of 3·5 GeV/c at the ISR.

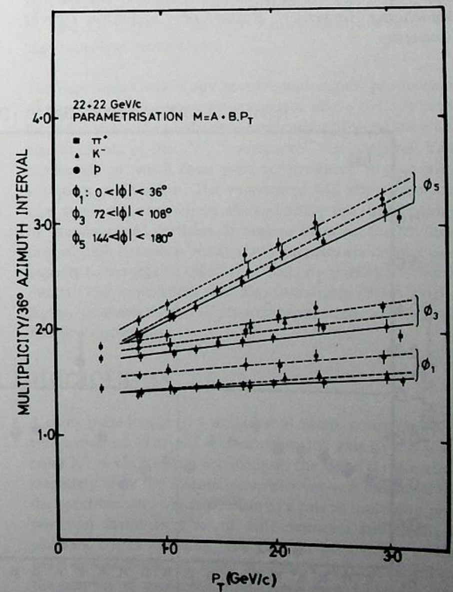


Fig 1.22. The p_T dependence of the associated multiplicity (M) for π^+, K^- and p in 3 φ regions. Linear fits are superimposed. (Experiment 33)

The apparatus consisted of a spectrometer (the Wide Angle Spectrometer WAS) to detect and identify the high p_T charged hadron, and arrays of scintillator hodoscopes covering nearly the entire 4π solid angle to measure the associated charged particle multiplicity distributions.

Of particular interest is the dependence of the associated multiplicity on the quantum numbers of the trigger particle.

No strong variation in multiplicity with particle type was observed. The π^+, π^- and K^+ mesons were found to be produced with very similar associated multiplicities, agreeing well with naive quark-parton models. A slight excess was observed associated with K^- production but protons are produced with about a 10% excess of particles when compared to pions. This excess is clearly seen in Fig 1.22 for 3 azimuthal regions: towards the trigger particle (ϕ_1), perpendicular to the trigger (ϕ_3) and away from the trigger (ϕ_5). A linear increase in multiplicity with p_T is observed for all particle types.

EXPERIMENT 34

Search for Narrow Resonances and Correlation Measurements at the ISR

CERN; Daresbury Laboratory; FOM, the Netherlands; Lancaster University; Liverpool University; Lund University; Manchester University; Rutherford Laboratory; Utrecht University

In this experiment two single particle spectrometers in intersection 12 at the CERN ISR were operated in coincidence to study the reaction $p + p \rightarrow h_1 + h_2 + X$, where h_1 and h_2 are identified charged hadrons and X represents "anything else produced". The motivation was to search for new particles, for example, charmed hadrons, which decay into the observed hadrons h_1 and h_2. Such new particles may be expected to show up as a peak in the effective mass distribution of the h_1h_2 system, obtained by summing the four-momenta of the two observed particles. No strong structures corresponding to narrow resonances were observed, and upper limits of the order of 0·1 mb were deduced for the product of the production cross-section at the ISR and the decay probability into the hadrons h_1h_2.

Values were obtained for the correlation R between the two hadrons in the phase space region covered by the experiment, and are shown in Fig 1.23. The largest correlations observed are for $\bar{p}p$ and K^-K^+, indicating that baryon-number-conserving and strangeness-conserving effects extend up to rapidity differences of at least 1·4 and 2 units respectively. Some effects of charge conservation can be observed in that neutral pairs generally have a higher value of R than double-charged pairs of otherwise similar nature. The fact that rare combinations, e.g. $\bar{p}\bar{p}$ and K^-K^-, do not have especially small values of R implies that the production of a pair of baryons or strange particles does not significantly inhibit the production of a further pair. The analysis of this experiment is now final.

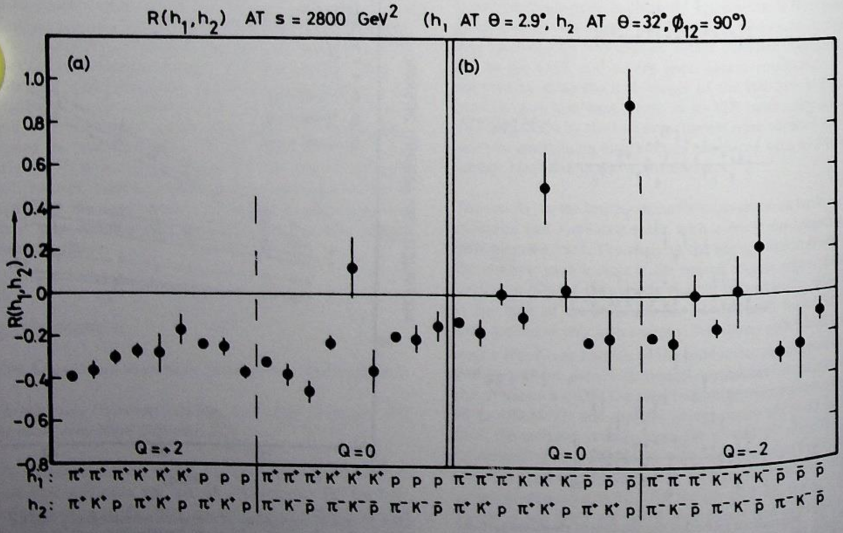


Fig 1.23. Correlation (R) between hadrons (Experiment 34)

EXPERIMENT 35

Study of High Transverse Momentum Phenomena in the Split Field Magnet

Liverpool University; Orsay Laboratory; Scandinavian Universities; Rutherford Laboratory

This experiment is designed to study the structure of events containing high transverse momentum hadrons at the CERN ISR. The experiment is a continuation of previous investigations using the Wide Angle Spectrometer, in which the unexpectedly high cross-section for single charged hadron production at high transverse momentum p_T was established and in which the angular distribution of the associated charged particles was measured. Theoretical explanations for the observed phenomena usually invoke a large angle scattering between point-like hadron constituents, or partons. The scattered partons are then expected to materialise into "jets", or clusters of high transverse momentum particles with similar direction.

The magnetic spectrometer used in the earlier ISR experiments was used to provide a trigger for the Split Field Magnet detectors. The momenta and charges of most of the other particles produced in the same event can then be measured. In addition, some of these associated particles can be identified using a system of hodoscope counters with time-of-flight measurements. The experiment completed data taking in July 1976, having recorded about 8 x 10^6 events with trigger particles in the transverse momentum range 1-5 GeV/c, and the data are currently being analysed.

The particle distributions in momentum space are being studied to search for evidence of hadron jets. Large p_T particles are frequently found approximately opposite in azimuth angle ϕ to the trigger particle but spread over a large range of polar angle Θ. When two moderately large p_T particles are found with similar azimuth they tend to be close also in polar angle, as one would expect on a jet picture. Also the average p_T of associated particles close in angle to the trigger particle is larger than that found in typical inelastic events, indicating that the trigger particle is also sometimes a member of a jet.

Invariant mass distributions are being studied to investigate the role played by resonances in high p_T particle production. For example the invariant mass distribution of a high p_T $\pi(K)$ with an associated particle shows a significant $\rho(K^*)$ peak. Finally, it is expected that measurements of correlations between pairs of identified hadrons will provide more direct information on the internal dynamical processes for p_T particle production.

EXPERIMENT 36

Study of High Transverse Momentum Phenomena

CERN; Columbia University; Oxford University; Rockefeller University

This experiment is at present being installed and set-up at the CERN ISR. It consists of a superconducting solenoidal magnet of radius 70cm and length 1·5m with a 1·5 Tesla field. All charged particles produced with polar angles $\Theta \gtrsim 45°$ will be detected in a set of four double-module cylindrical drift chambers inside the magnet. Two arrays of lead glass Cerenkov counters, each consisting of 168 blocks, will be used for triggering the apparatus on electrons or π° of high transverse momentum.

The experiment will study massive lepton pair production to search for new narrow meson states above the J/Ψ and Ψ' and to study the production mechanism of these mesons. Measurements of the e^+e^- "continuum" test the Drell-Yan mechanism in which these pairs are produced from quark-antiquark annihilation. The experiment will also trigger on high transverse momentum π°s and study the distributions of the associated particles. If present ideas on the production of high transverse momentum particles are correct one expects to see jet-like clusters of high p_T particles in these events. The experiment will also investigate direct single-lepton production, direct photon production, and lepton-hadron correlations.

1.1.5 Weak and Electromagnetic Interactions

EXPERIMENT 37

CP in a High Magnetic Field

Imperial College, London; Rutherford Laboratory

Salam and Strathdee have suggested that in a gauge theory of the weak interactions, it would be possible to suppress spontaneous symmetry violations. In particular, the presence of a high enough magnetic field could turn off the CP violating decay $K^\circ_L \rightarrow \pi^+\pi^-$. The speculation will be tested in this experiment.

A short pulse-length (0·5 ms) neutral beam, containing K°_L and unwanted neutrons, passes down the axis of the solenoid. $K^\circ \rightarrow \pi^+\pi^-$ events occurring in the fiducial region immediately after the solenoid are detected and measured by the spectrometer, which consists of a pair of multiwire proportional chambers, a set of drift chambers and finally a plane of trigger counters. The amount of material in the beam has been made as small as possible, in order to reduce the number of unwanted interactions from neutrons. The solenoid will be pulsed coincidentally with the fast spill, and events occurring when the field is high (30-40 Tesla) will be recorded.

'Background' data without the high field will be taken on alternate pulses. If the field is high enough, suppression of CP violation will show as a regeneration of K_S°, and consequent interference in the fiducial region between the decays $K_S^\circ \to \pi^+\pi^-$ and $K_L^\circ \to \pi^+\pi^-$. The distribution of these events should therefore show a difference between 'field-on' and 'field-off' pulses.

The power supply and solenoid have already been tested (see Section 4.10.7) and are now installed in the beam-line, as is the rest of the equipment. 'No field' data have been taken under normal slow spill conditions, and work has started on operating with the fast spill and the magnet pulsing. Data taking will take place during 1977, and a result is expected towards the end of the year.

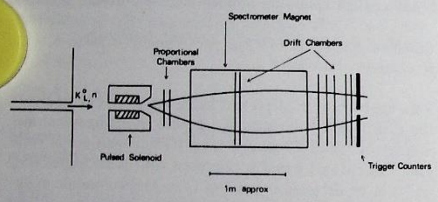


Fig 1.24. Layout of Experiment 37

EXPERIMENT 38

Muon-Nucleon Scattering

Chicago University; Harvard University; Oxford University; Illinois University

The purpose of this experiment is to probe the internal structure of the nucleon by measuring the inelastic scattering of high-energy muons by protons and neutrons. The experiment has the feature that not only the scattered muon is detected, but forward produced hadrons are measured as well.

The analysis of data taken in 1975 with 100 GeV and 150 GeV muons is now virtually complete. Extensive running at 225 GeV has taken place in 1976. The measurements extend knowledge of the nucleon structure functions by more than a factor of ten in energy.

The main physics results of the data analysed so far are as follows:–

The Bjorken scale invariance is broken in a systematic way. Fig 1.25 shows the average nucleon structure function $\nu W_2(Q^2,\omega)$ for a deuteron target plotted as a function of Q^2 for various ω bins. Here ν is the muon energy loss, Q^2 is the square of the four-momentum transfer and $\omega \equiv 1/x = \frac{2M\nu}{Q^2}$, where M is the nucleon mass. At low ω νW_2 decreases

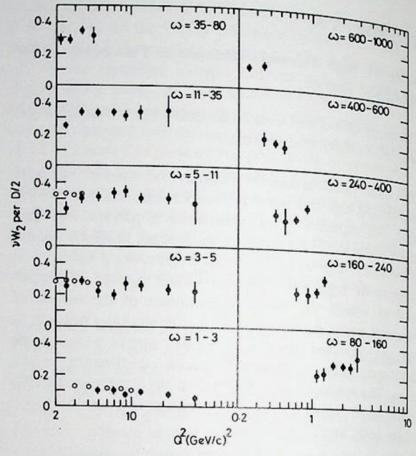


Fig 1.25. The nucleon structure function νW_2 per nucleon of deuterium as a function of Q^2 and $\omega = 2M\nu/Q^2$. The open circles are results from SLAC (Experiment 38)

with increasing Q^2, while at large ω it tends to increase. This form of scale-breaking is inconsistent with the parton form-factor as the sole source of scaling breakdown, but is consistent with field-theoretical models based on asymptotic freedom.

Fig 1.26 shows νW_2 as a function of ω, averaged at each ω over the range of Q^2 accessible in the experiment. The decrease at large ω for which the average Q^2 is small has two possible explanations: scaling turns on more slowly as a function of Q^2 at large ω, or νW_2 decreases at large ω indicating little excitation of the sea of parton-antiparton pairs. To achieve higher Q^2 at large ω one needs higher energy and the data at 225 GeV will throw additional light on this.

The area under $\nu W_2(Q^2,x)$ is approximately independent of Q^2. This is related to the form of the scaling violation: an increase at small x (large ω) and a decrease at large x with increasing Q^2. There is no evidence above the 10% level for the excitation of new quarks or new degrees of freedom.

Several important results come from studies of the forward-produced hadrons:–

(a) Feynman scaling of the hadron structure functions holds rather well. That is, integrating over other kinematical variables of the hadrons, the distribution in $x_\parallel = \frac{P_{11}}{P_{11}\,max}$ is independent of Q^2 and of s, the square of the energy in the centre of mass system of target nucleon and virtual photon.

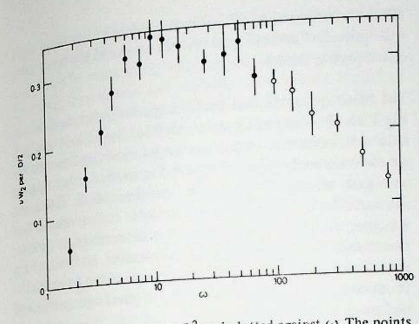


Fig 1.26. νW_2 averaged over Q^2 and plotted against ω. The points with open circles have $Q^2 < 2$ (GeV/c)^2 (Experiment 38)

(b) Other distributions, such as transverse momentum, show very little dependence upon Q^2 or s. The main differences between photoproduction and electro- or muo-production occur between Q^2 = 0 and Q^2 = 1 (GeV/c)^2.

(c) There is a considerable degree of universality of the produced hadrons in muon scattering, neutrino scattering, and e^+e^- annihilation.

(d) Vector mesons such as the ρ° are diffractively produced at the higher energy with the same Q^2 and t dependence as at lower energies.

EXPERIMENT 39

Experiments with High Energy Charged Hyperons

Bristol, Geneva, Heidelberg Universities; Lab. de l'Acc. Lin. Orsay; CNR Strasbourg-Cronenbourg; Rutherford Labortory.

This experiment in the West Area of the SPS at CERN is designed to study the weak decays of charged hyperons. The emphasis is on decays which have an electron in the final state and the list of processes to be investigated includes; $\Xi^- \to \Lambda e^-\bar{\nu}$, $\Xi^- \to \Sigma^\circ e^-\bar{\nu}$, $\Sigma^- \to \Lambda e^-\bar{\nu}$, $\Lambda \to p e^-\bar{\nu}$, $\Omega^- \to \Lambda K^-$ and possibly $\Sigma^- \to n e^-\bar{\nu}$ and $\Sigma^+ \to n e^+\nu$.

These decays are believed to arise from the conversion from one type to another of a single quark inside the baryon. Thus a comparison of the different hyperon semileptonic decays gives an insight into the underlying quark structure of the baryons. In addition detailed information will be obtained concerning the symmetry properties of the weak interaction itself.

The hyperons are produced in a beryllium oxide target by a 200 GeV attenuated proton beam from the SPS. They are transported to the apparatus along a very short beam line consisting of three iron yoke bending magnets and two superconducting quadrupoles. The overall length of the beam line, including a high resolution DISC Cerenkov counter which identifies the hyperons, is 12·5 metres. The maximum momentum at which the hyperon beam will operate is 150 GeV/c but the decay experiment will use 100 GeV/c particles. At rest the lifetimes of the charged hyperons are of the order of 10^{-10} seconds, but because of relativistic time dilation a few percent of them survive to the end of the beam line. A flux of the order of 10^4 Σ^- per burst is expected at the apparatus.

The apparatus consists of a large magnetic spectrometer with drift chambers to analyse the charged decay products. It is augmented by an array of lead glass counters, a lead-scintillator hodoscope and a lead-proportional chamber hodoscope to measure gamma-rays. One of the principal problems in the experiment is to identify electrons from leptonic decays against the background of pions coming from the non-leptonic decays of the hyperons which occur several thousand times more frequently. A threshold gas Cerenkov counter, the lead glass array, lead-scintillator shower counters and two lithium foil-xenon proportional chamber transition radiation detectors will all be used to suppress the pion background to a negligible level.

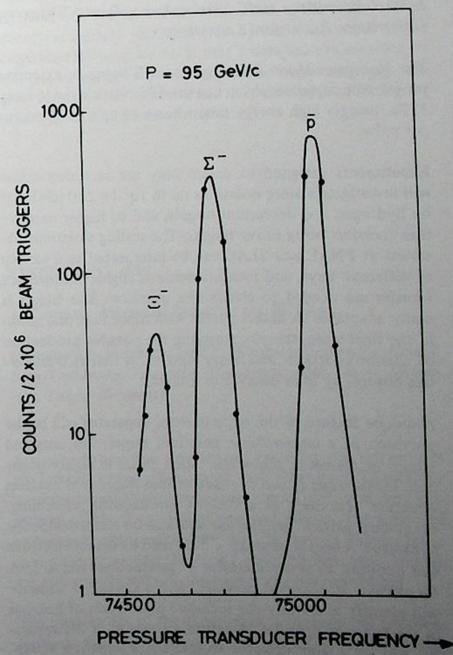


Fig 1.27. Preliminary flux measurements made in the charged hyperon beam at the CERN SPS (Experiment 39)

The Rutherford Laboratory and Bristol University have supplied the gamma-ray hodoscope, one of the two on-line computers, much of the fast trigger electronics and all the electron detectors except the transition radiation detector. This equipment arrived on schedule in the West Area during the spring and summer of 1976 and by November commissioning was well under way using stray muons from the West Area production targets.

Tuning of the charged hyperon beam started in December 1976. Fig 1.27 shows preliminary measurements of the particle fluxes made using the DISC Cerenkov counter; the particle types are clearly separated. Studies of the properties of the beam will include a measurement of hyperon yields and a search for new, heavy, short-lived particles using additional Cerenkov counters temporarily installed in the beam.

EXPERIMENT 40

Muon Physics at the CERN SPS

European Muon Collaboration: LAPP Annecy; CERN; DESY; Freiburg, Kiel, Lancaster, Liverpool, Oxford, Sheffield Universities; RMC Shrivenham; Turin, Wuppertal Universities; Rutherford Laboratory

The European Muon Collaboration will begin an extensive programme of muon physics in the SPS North Area in early 1978, using a high energy muon beam of up to 10^8 muons per pulse.

Experiments designed to detect only the scattered muon will investigate scaling violations up to $|q^2| = 250\ (GeV/c)^2$ on hydrogen and deuterium targets, and to higher momentum transfers using heavy targets. The scaling violations observed at FNAL and SLAC can be interpreted in a variety of different ways, and measurements at higher momentum transfer are needed to clarify the question. The trigger is easily adaptable to detect events with more than one muon in the final state, thereby studying the possible production of charmed particles and heavy leptons, as well as ψ and ψ-like bosons, by their decay into muons.

A unique feature of the experimental apparatus will be the provision of a large-volume polarised target, 1m long and 50mm in diameter. Since the muon beam is highly polarised, measurements can be made of spin-dependent nucleon structure functions as a further investigation of scaling. Secondary particle production will also be studied with the apparatus. A lead-glass array will be used to detect electrons and photons, to study inclusive π^0 production, and to look for decays of charmed particles, and a Cerenkov detector will identify and study the inclusive production of hadrons in the forward direction. A natural extension of the apparatus will be a large detector around the interaction vertex, which will allow the study of particle multiplicities, and inclusive hadron production over the whole angular range.

These measurements of hadron production at large $|q^2|$ will provide further tests of the remarkably successful quark-parton model.

The basic apparatus, the forward spectrometer, is shown in Fig 1.28. The incoming muon, defined by hodoscopes and halo veto counters, strikes the target. Scattered muons are momentum analysed in a large 4 Tm spectrometer magnet, and pass through a thick iron absorber which filters out produced hadrons. Scintillation counter hodoscopes define a trigger, and the muon trajectory is determined by proportional and drift chambers. The calorimeter, in front of the iron absorber, measures the energy loss of the muon to the produced hadrons and will separate electromagnetic and hadron-induced showers.

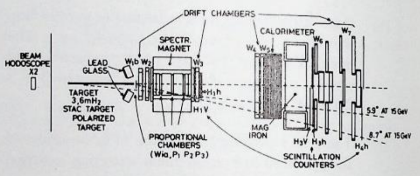


Fig 1.28. Forward spectrometer for Experiment 40

As a result of the recent SRC re-organisation, responsibility for the UK part of the muon programme was transferred from Daresbury Laboratory to the Rutherford Laboratory this year. The Rutherford Laboratory are responsible for the construction of the proportional chambers P1, P2, P3 within the spectrometer magnet, the large area drift chambers W6 and W7, and, in conjunction with Lancaster University, the calorimeter. The polarised target is a joint Liverpool, Rutherford, CERN project, with Rutherford responsible for the superconducting solenoid, and Liverpool for the cryostat.

EXPERIMENT 41

Photon and Electron Physics in the Omega Spectrometer Facility

Bonn University; CERN; Daresbury Laboratory; Ecole Polytechnique; Glasgow University; Lancaster University; Manchester University; LAL Orsay; Paris 6 University; Sheffield University

In 1974, this British-French-German Collaboration proposed a programme of photon and electron physics using the Omega Spectrometer at the CERN SPS; initially photoproduction would be studied using a tagged photon beam produced from an 80 GeV/c electron beam, and electroproduction physics would be done at a later stage.

Since the original proposal, an exciting new field of high-energy physics has been opened by the discovery of the ψ particles. The most likely explanation of their properties is the charm hypothesis and recently some decay modes of charmed particles have been identified. Because of the importance and urgency of understanding more about these new discoveries, the initial programme has been amended to put the highest priority on studying photoproduced charm states. The experimental equipment is essentially the same, but the electronics trigger requires a high multiplicity of 5 or more charged tracks in the final state, and the luminosity is increased by a factor of 10. Initially the intention is to select a final state electron (or positron) from charm semi-leptonic decays using a fast offline procedure. However, at the trigger level the data are essentially unbiassed, and it will be possible to study charm in several other ways. The run will also produce valuable data on the photoproduction of other channels requiring high luminosity.

The Collaboration has provided equipment which will complement the existing detectors of the CERN Omega Facility. The British team has built a spectrometer to measure the energy of the incident electron beam, a precision photon tagging system and the associated readout electronics. The German team has provided the experiment trigger electronics, a large scintillation counter hodoscope and four arrays of shower counters. The French team has constructed a photon (or π^0) detector $6m^2$ in area, consisting of a 700-element scintillator hodoscope to measure the position of each photon and a 340-cell arrangement of lead glass counters to measure the photon energy.

There has been intense activity at CERN during 1976 installing this equipment and preparing the online and offline computer programs. During November 1976 the first electron beam from the SPS passed along the beamline and interactions were clearly seen in the Omega detectors. The plan is to perform a first-order tune of the electron beam, and to record some high-energy interactions on magnetic tape before embarking on the main data-taking run.

EXPERIMENT 42

Study of Neutrino and Anti-Neutrino Reactions

Universita di Bari; Birmingham University; ULB-VUB Brussels; Ecole Polytechnique, Paris; CEN Saclay; University College, London; Rutherford Laboratory

This experiment scheduled for the CERN SPS is designed to use the track sensitive target (TST) technique to study previously unanalysable reactions with neutral pions in the final state, including dilepton events and charmed particle production.

EXPERIMENT 43

Electron Positron Collisions at PETRA

Aachen, Bonn Universities; DESY; Hamburg University; Imperial College, London; Maine, Oxford Universities; Rutherford Laboratory; Weitzmann Institute

This experiment is planned at the electron-positron colliding beam facility (PETRA) now under construction at the Deutsches Elektronen Synchrotron DESY at Hamburg. Data collection should commence in 1979 when the accelerator has been commissioned.

Secondary charged particles from e^+e^- collisions will be observed in cylindrical proportional chambers and drift chambers situated in an axial field at 0·5 Tesla. The field will be produced by a conventional solenoid of length 4·5m and diameter 2·9m. High energy photons will be detected in a modular system of lead plates immersed in liquid Argon, and penetrating μ mesons will be identified by drift chambers immediately beyond the iron return yoke of the solenoid. A very important feature of the experiment will be the provision for the identification of fast charged particles by means of two arrays of threshold Cerenkov counters. The apparatus will therefore have a comprehensive capability, and will be particularly well suited to the study of high energy secondary particles. One of the main hopes of the experimental programme is that a detailed examination of the jets of particles anticipated at the highest energies will give fundamental information on what appear to be the point-like constituents of matter.

EXPERIMENT 44

A Compact Magnetic Detector for PETRA

Daresbury Laboratory; DESY; Hamburg University; Heidelberg University; Lancaster University; Manchester University; Tokyo University

A new collaboration was formed involving the Universities of Lancaster and Manchester and Daresbury Laboratory working together with colleagues from DESY and the Universities of Hamburg, Heidelberg and Tokyo. The proposed experiment was accepted by the UK Particle Physics Selection Committee and the DESY Program Research Committee and construction of the equipment has now begun.

The physics aim of the experiment is to study the hadronic, leptonic and electromagnetic final states which result from collisions between electrons and positrons in the PETRA storage ring.

An early important measurement will be that of the parameter

$$R = \frac{\sigma(e^+e^- \to \text{hadrons})}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

which can then be related theoretically to the number of degrees of hadronic freedom (or number of quarks). The proposed experimental program also includes a search for new particles, particularly in the direct channel $e^+e^- \to V$, searches for new heavy leptons $e^+e^- \to L^+L^-$, a measurement of the interference between the weak and electromagnetic contribution to the process $e^+e^- \to \mu^+\mu^-$ and a study of the two-photon process $e^+e^- \to e^+e^-$ + hadrons. The major items of equipment, which are planned for installation in the interaction region towards the end of 1978, are a cylindrical array of high-resolution drift chambers, a warm coil solenoid magnet, a 3000-element lead-glass array and an iron-concrete muon filter containing 500 single-wire 4m long drift chambers. In addition, there will be a double tagging system for studying two-photon processes. A general view of the proposed detector is shown in Fig 1.29. The box-shaped muon filter has been withdrawn to show the iron return yoke of the solenoid.

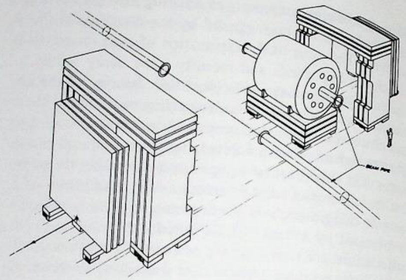


Fig 1.29. Proposed detector for Experiment 44

1.1.6 Searches for New Particles

EXPERIMENT 45

Heavy Particle Search

Rutherford Laboratory; University College, London; AWRE Aldermaston

This experiment is a search for stable or very long lived charged particles in the mass range 5 to 300 times the proton mass. Any such particles would be continuously produced by cosmic ray interactions (for example by pair production) at a rate too small for direct observation, but during the lifetime of the earth would accumulate as a small concentration (typically 10^{-28} to 10^{-20}) in ordinary matter. In particular particles of charge +1 would form heavy hydrogen-like atoms and (like cosmic ray produced tritium) become a constituent of terrestrial water.

The object of the experiment is to increase this hypothetical concentration by a very large factor ($\sim 10^{12}$) using isotopic enrichment techniques, and study the resulting samples using sensitive detection techniques.

The samples are being produced by multi-stage electrolysis of heavy water; 6000 litres D_2O (originally obtained by enrichment of 120,000 litres of natural water) are being progressively reduced to produce sample volumes in the region 1 to 10^{-3}ml which are subsequently converted to D_2 gas. In this way any heavy particle concentration will be increased to the region 10^{-8} to 10^{-14}. Part of this region, down to 10^{-10} - 10^{-11} is accessible by sensitive mass spectrometry techniques; to detect concentrations down to 10^{-14} or lower, a time of flight spectrometer is being constructed, in which the particle velocities will be measured before and after passage through a thin foil, enabling any new heavy particles to be distinguished from high-Z heavy ion impurities.

By the end of 1976, the D_2O enrichment work had reached the final stages of its 2½ year programme, and the construction of the time of flight system was in progress. Mass spectrometer runs carried out so far correspond to a concentration limit (in natural H_2O) of about 10^{-18}, and it is planned to reach the target sensitivities of $< 10^{-26}$ by the end of 1977.

EXPERIMENT 46

Search for Short-Lived Particles Produced in Neutrino Interactions

Brussels University; University College Dublin; Fermi National Accelerator Laboratory; CERN; Imperial College, London; University College, London; Open University; Institute of Exact and Applied Sciences Mulhouse; Rome University; Strasbourg University

In this experiment, neutrino interactions are located in a block of nuclear photographic emulsion from the observation of secondary particles from the interactions, in wide gap spark chambers placed downstream. The position of the interaction in the emulsion block can then be predicted to within a volume of some hundreds of mm^3 from a reconstruction of the spark chamber pictures of the event. The high spatial resolution characteristic of emulsion should enable the paths of single short-lived particles with lifetimes down to a few times 10^{-14} sec. to be observed.

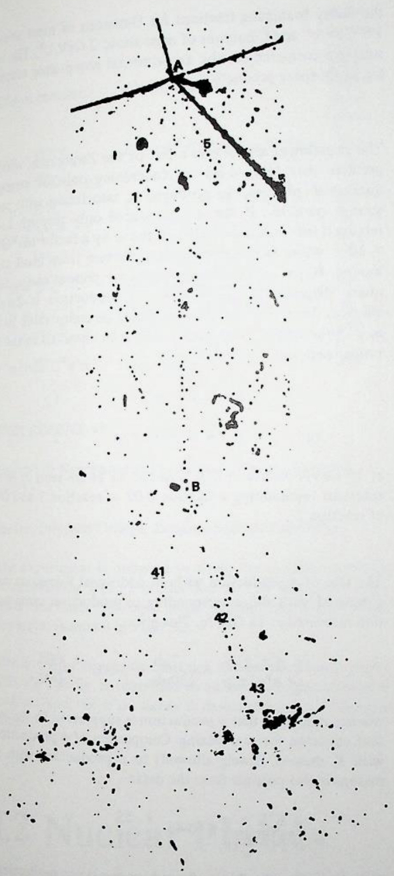


Fig 1.30. The likely formation of a charmed particle in emulsion at FNAL. Momentum conservation at B demands the emission of an uncharged particle, and the decay of this particle was detected in the associated spark chamber system. This event has all the characteristics of a charm process (Experiment 46)

The exposure of 20 litres of emulsion to the neutrino beam at the Fermi National Accelerator Laboratory has now been completed, the emulsion processed at CERN and a search for neutrino interactions is under way. Owing to a breakdown of the neutrino beam at a critical stage only about one third of the anticipated exposure was obtained, but this should have produced about 150 neutrino interactions in the emulsion. So far about one third of the expected interactions have been scanned for in the emulsion and 20 have been located. Steps are under way in an attempt to improve the success rate but already an event has been seen which is almost certainly an example of the decay of a particle after a time of $\sim 5 \times 10^{-13}$ sec. Fig 1.30 is a microphotograph of the event. The unstable particle emitted from the neutrino interaction at A produces the track 4 which has a length of 182 μm. The particle appears to break up into three charged particles at B, which produce the tracks labelled 41, 42, 43. Momentum conservation at B requires the emission of at least one more particle, which must be uncharged. A V^0 decay which can be interpreted as a Λ^0 or K^0, and in the correct position to enable a momentum balance at B to be achieved, was observed in the associated spark chamber system. This event has the characteristics to be expected for the decay of a charmed particle and represents the first time such a decay has been seen directly.

EXPERIMENT 47

Search for Short-Lived Particles Produced in Neutrino Interaction at CERN

Ankara University; Brussels University; University College, Dublin; CERN; University College, London; Open University; Pisa University; Rome University; Strasbourg University; Turin University

This experiment will employ a similar technique to Experiment 46 to observe neutrino interactions in a block of emulsion but it will be carried out using the neutrino beam at the CERN SPS. The stack consisting of 30 litres of nuclear photographic emulsion will be placed upstream and just outside the window of the bubble chamber, BEBC. The location of secondary tracks from neutrino interactions in the emulsion will be carried out using BEBC in conjunction with a multiwire chamber between the emulsion block and the window of BEBC. The tracks of the secondary particles in BEBC with its high magnetic field and associated external muon identifier will provide a much more powerful analysis system than was available at the Fermilab. It is expected that $2{\cdot}5 \times 10^5$ photographs with liquid hydrogen filling will yield several thousand neutrino interactions in the emulsion block and these will be scanned, looking for the emission of short-lived charged or neutral particles.

EXPERIMENT 48

Charm Search at Omega

Bari University; Birmingham University; Bonn University; CERN; Daresbury; DESY; Ecole Polytechnique; ETH (Zurich); Freiburg University; Glasgow University; Liverpool University; Milan University; Orsay; Rutherford Laboratory; CEN Saclay; Westfield College, London

The charm search experiment was proposed in January 1975 shortly after the discovery of the J/ψ and ψ' mesons to look for the production of hadrons containing explicit charm using the CERN Omega Spectrometer. The experiment was designed to make a rapid search in the most favourable exclusive channels to a sensitivity of 100 nanobarns using the highest available π^- beam momentum, then 19 GeV/c. According to the charm hypothesis, charmed particles are produced in pairs in strong interactions and then decay weakly. A typical reaction to expect would be $\pi^-p \to D^0D^-p$ with $D^0 \to K^-\pi^+$ and $D^- \to K^+\pi^-\pi^-$. These states would give 6-prong events satisfying a 4-constraint kinematic hypothesis.

$$\pi^-p \to K^-K^+\pi^+\pi^-\pi^-p$$

The first run in March 1975 recorded 3 million interactions triggering on a forward K^- (or $\bar{p}$) having a horizontal transverse momentum greater than 0·5 GeV/c. In the second run in June 1975 a further 2 million triggers with a forward K^+ (or p) were recorded. Multiplicity requirements were also incorporated into the triggers. The first run (28 events/nb) was primarily aimed at pair production of charmed mesons, and the second run (5 events/nb) at associated production of a charmed meson and baryon.

Fig 1.31 shows the arrangement of the Omega apparatus for the first experiment. The 60cm H_2 target was exposed to a 19 GeV π^- beam. Forward are 80 gaps of optical spark chambers and on either side a further 32 gaps. A superconducting magnet provides a field up to 1·8T. Television cameras, developed at the Rutherford Laboratory, view the chambers and record the spark co-ordinates on magnetic tape. Multiwire proportional chambers III and IV were used to provide the trigger and the downstream Cerenkov counters distinguish π's from K's and protons.

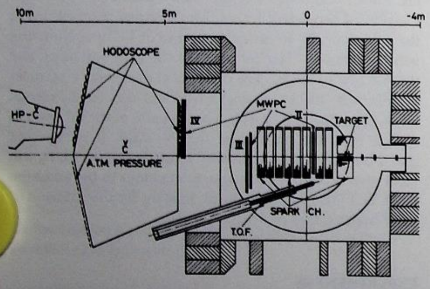


Fig 1.31. Arrangement of apparatus for charm search at Omega (Experiment 48)

The data was processed through pattern recognition, geometrical reconstruction (ROMEO) and kinematic fitting programs. The total number of 4-constraint fits was 4454 for the hypothesis $\pi^-p \to K^+K^-\pi^-p$ and 8484 for the hypothesis $\pi^-p \to K^+K^-\pi^+\pi^-\pi^-p$. Searches were performed for accumulations of events in 2-dimensional effective mass plots. No statistically significant evidence was found for the production of pairs of charmed hadrons. Upper limits are shown in the table for the production cross-section times the decay branching fractions for D-mesons of mass above 1·5 GeV/c² and C-baryons of mass above 2 GeV/c². The results are corrected for the experimental acceptance assuming phase-space production.

The experiment also allows a test of the Zweig rule, which predicts that ideal ϕ-mesons (consisting only of strange quarks) should only be produced in association with two strange particles. If the ϕ is produced only through ω-ϕ mixing it is suppressed relative to the ω by a factor $\tan^2\Theta m = 10^{-2}$ where Θm measures the departure from ideal ω-ϕ mixing. When extra strange particles are present connected quark diagrams are possible and ϕ production is Zweig allowed. Then the ϕ production should be comparable to ω or ρ^0 production. ϕ production has been observed in the 6-prong reactions

$$\pi^-p \to K^+K^-\pi^+\pi^-\pi^-p \qquad 1$$

$$\text{and} \qquad \pi^-p \to K^+K^-K^+K^-\pi^-p \qquad 2$$

at 19 GeV/c with $\phi \to K^+K^-$. About 45 ϕs are seen in both reactions representing a fraction 0·02 of reaction 1 and 0·6 of reaction 2.

The rate of ϕ production without additional K-mesons was compared with the corresponding ω production cross-section measured at 16 GeV/c. This gives

$$\frac{\phi\ \pi^+\pi^-\pi^-p}{\omega\ \pi^+\pi^-\pi^-p} = \frac{\cdot7\mu b}{130\mu b} = 0\cdot005 \begin{array}{l}+\cdot005\\-\cdot002\end{array}$$

whence it appears that ϕ production is suppressed to the extent expected for ω-ϕ mixing. Comparison of ϕ production with K mesons (Zweig allowed) to ρ production with K mesons is also possible from the data:

$$\frac{\phi^-K^+K^-\pi^-p}{\rho^0K^+K^-\pi^-p} = 0\cdot45 \begin{array}{l}+\cdot25\\-\cdot15\end{array}$$

This shows that the Zweig allowed process is not suppressed. However the ratio of the Zweig forbidden ϕ production process to the Zweig allowed ϕ production process is unexpectedly large:

$$\frac{\phi\pi^+\pi^-\pi^-p}{\phi K^+K^-\pi^-p} = 1\cdot7 \begin{array}{l}+\cdot9\\-\cdot5\end{array}$$

The result is understood as a consequence of the difficulty of producing extra K mesons at our modest energy and not as a violation of the Zweig Rule.

Upper limits (95% confidence level) for charm production cross sections times decay branching fraction for $M_D > 1\cdot5$ GeV and $M_C > 2\cdot0$ GeV:

Charm reaction	Charm decays	Cross Section upper limits (nb) phase space
$\pi^-p \to D^-D^0p$	$D^- \to K^+\pi^-\pi^-$; $D^0 \to K^-\pi^+$	75
$\pi^-p \to \bar{D}^0D^0\pi^-p$	$\bar{D}^0 \to K^+\pi^-$; $D^0 \to K^-\pi^+$	80
$\pi^-p \to D^-C^+$	$D^- \to K^+\pi^-\pi^-$; $C^+ \to K^-p\pi^+$	65
$\pi^-p \to \bar{D}^0C^0$	$\bar{D}^0 \to K^+\pi^+\pi^-\pi^-$; $C^0 \to K^-p$	75
$\pi^-p \to \bar{D}^0C^0$	$\bar{D}^0 \to K^+\pi^-$; $C^0 \to K^-p\pi^+\pi^-$	65
$\pi^-p \to \bar{D}^0C^0$	$\bar{D}^0 \to K^+\pi^-$; $C^0 \to K^-p$	40
$\pi^-p \to D^-C^0\pi^+$	$D^0 \to K^+\pi^-\pi^-$; $C^0 \to K^-p$	45
$\pi^-p \to \bar{D}^0C^+\pi^-$	$\bar{D}^0 \to K^+\pi^-$; $C^+ \to K^-p\pi^+$	55
$\pi^-p \to \bar{D}^0C^0\pi^+\pi^-$	$\bar{D}^0 \to K^+\pi^-$; $C^0 \to K^-p$	50

EXPERIMENT 49

Search for New Particles Produced in Association with ψ(3.1)

Saclay; Imperial College, London; Indiana University

The experiment is designed to study the reaction products accompanying ψ(3.1) production in 150 GeV/c π^- collisions on a liquid hydrogen target. A schematic layout of the apparatus is shown in Fig 1.32.

The ψ trigger is provided through its leptonic decay modes. The e^+e^- decay is identified in an electromagnetic shower counter and the $\mu^+\mu^-$ decay is detected using a 2·5m iron filter.

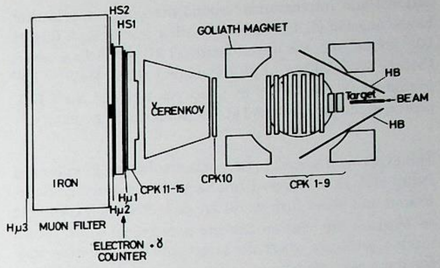


Fig 1.32. Layout of apparatus for Experiment 49

An array of multi-wire proportional chambers, situated inside the Saclay GOLIATH magnet is used to measure the momenta of the charged reaction products. This detector combines good time resolution, high acceptance and a capability to handle many tracks. Hadrons are identified using a downstream Cerenkov counter. In addition to providing the ψ trigger the shower counter can identify electrons and measure the energy and position of photon showers.

EXPERIMENT 50

Search for Charmed Particles

Harvard University; Oxford University; Illinois University

The purpose of this experiment is to search for charmed particles produced by interaction of 220 GeV/c pions with protons. The experiment will be carried out at Fermilab using the muon scattering apparatus from another experiment.

1.2 Nuclear Physics

The momentous events which have occurred during the last two years in High Energy Physics are now being felt in the lower energy range of Particle Physics. The collective name of Nuclear Physics is used to encompass a wide range of such investigations. High energy discoveries of additional quantum numbers have given credence to recent gauge theories which have beautifully resolved the apparent abnormalities of past theories of weak interactions (β decay). These theories, through the postulate of a fourth quark state of matter (charm), predicted the now observed weak interactions with strangeness conserving neutral currents. This has led to unified theories of weak and electromagnetic interactions where the mass of the intermediate particle concerned, the zero mass photon in the case of electromagnetism and the high mass (tens of GeV) intermediate vector boson in the weak interactions, characterise the two types of the one basic interaction. Further extrapolation of this 4-quark model to a 6-quark or a multiquark model in general, as is suggested by the high energy e^+e^- annihilation experiments at SPEAR, leads naturally to the possibility of incorporating a CP violating interaction into these gauge theories of the weak interactions.

The Nuclear Physics experiments described in this Section endeavour to make precision measurements on particle properties and interactions in such a way as to test theories of the type indicated above. These experiments are in regions where the theories are expected to hold but which are very different from the energy region where the qualitative features of the interactions have been established. The high intensities of these particles necessary for such precision measurements are obtained from several laboratories, both national and international, around the world: the Institut Laue-Langevin (ILL), Grenoble with a reactor core flux of 10^{15} n/cm^2/sec; the meson factory TRIUMF at Vancouver, Canada, with 100μA of proton current at 500 MeV ($\sim 10^{15}$ protons/sec), the CERN Synchrocyclotron and the 8 GeV proton accelerator Nimrod at the Rutherford Laboratory.

The experiments at ILL, Grenoble involve precision tests of Parity and Time Reversal Invariance in neutron capture reactions and some first results are presented. An experiment to measure the neutron half life is described which should reach a precision where the effects of the finite mass scale for the weak interactions are important and which will enable the gauge models to be tested in β decay processes unencumbered by the presence of other nucleons. The experiment to search for a possible electric dipole moment (e.d.m) of the neutron has grown in importance with the development of the gauge theories mentioned earlier where the CP violating amplitude is included naturally in the theory. The magnitude of the predicted e.d.m. for the neutron covers many orders of magnitude depending on the exact form of the theory and whether the CP violation is carried by the Higgs mesons themselves or as a phase in the multi-quark transition amplitudes. This experiment, using ultra cold neutrons from a newly established source at ILL, should considerably constrain the type of gauge theory describing the weak interactions.

The programme of experiments using stopping pions and kaons from Nimrod is now well established and measurements have continued throughout the major part of 1976. With the beam line situated at the last target station in the X3 beam complex in Hall 3 (see Fig 6.1) the experiment can run at almost any time when the extracted proton beam is available and at the same time as other Hall 3 users. The study of exotic atoms, involving as it does aspects of elementary particle, nuclear structure and atomic physics is a particularly fruitful field and a wealth of experiments can be carried out. The group this year reports the first observation of strong interaction effects on the X-ray line-shape and position in sigma-atoms. These measurements are difficult as the observation of the X-rays involves a three-stage process; production of the kaon by a proton in the initial target, production of the sigma hyperon by capture of the kaon in the second target and finally atomic capture of the sigma and production of the observed X-ray in this same target. As a result the yield of X-rays is low and long counting times are involved.

The group has also continued with its studies of kaonic atoms in nuclei, including the very light nuclei Lithium and Beryllium. As a very natural extension of this work, a measurement the yield of X-rays from kaonic hydrogen is planned. Again the yields of X-rays are expected to be low; in this case due to the presence of large "Stark effects" which give rise to premature capture of the kaons by the proton before they reach atomic states of low principal quantum number.

Studies of nucleon-nucleon scattering continue to be of fundamental importance in efforts to understand the basic nucleon-nucleon force. At energies below about 300 MeV the features of the scattering process, which are usually analysed in terms of phase shifts are now relatively well determined. However the extension of these studies to higher energies poses several problems. Many more phase-shifts are required to describe the scattering whilst the onset of pion production at energies above 300 MeV means that the phase-shifts are complex quantities. The lack of suitable neutron and proton beams has also severely hampered this work.

With the advent of the "pion-factories" the situation has now changed. The 550 MeV H$^-$ cyclotron at the TRIUMF facility in Vancouver with its variable energy intense polarised and unpolarised proton beams is particularly suitable. After the installation and calibration of a large quantity of complex apparatus by a British-Canadian collaboration to measure the triple-scattering parameters in nucleon-nucleon interactions around 500 MeV, during 1976 both the accelerator and equipment gave excellent performance and four different spin rotation parameters were each measured at 3 or 4 angles at 5 different energies between 200 and 520 MeV. Unique and well determined sets of scattering phase-shifts are now available at all five energies. The experiment will now be continued to measure similar quantities for the neutron-proton system.

Work on the large volume magnetic spectrometer system at the CERN Synchrocyclotron has continued and the group hopes to start taking data during 1977. The large detector volume and efficiency will not only be used to observe the rare decay mode $\pi^0 \to e^+e^-$ but will also be used to measure the small cross-sections expected for the backward scattering of pions by protons and deuterons. This latter experiment will be used as a test of the apparatus.

The experiments by the King's College, London group represent work and progress over the past year in studies of ^{3}He and alpha-particle scattering by nuclei using the accelerators at AERE Harwell and at Birmingham University. This long programme of low energy nuclear structure investigations is still supported at the Rutherford Laboratory for historical reasons. The recent availability of polarised ^{3}He beams has given a considerable stimulus to this work.

EXPERIMENT 51

Search for Time-Reversal Violation Effects in Nuclei

University of Sussex; ISN Grenoble

This experiment, designed to measure $\gamma\gamma$-correlation following the decay of a polarised nucleus, was installed in March 1976 and its initial runs have been successful. An ensemble of polarised nuclei is created following the capture of polarised neutrons and the measurement is sensitive to the presence of the T-violating P-conserving term J $(k_1 \times k_2)(k_1 \cdot k_2)$ where k_1 and k_2 are the momenta of the correlation γ-rays and J is the nuclear spin. The latter can be regularly reversed by reversing the neutron spin direction. The γ-ray correlations are measured in an array of 6 detectors.

A major effort has been made to examine in great detail the influence of systematic effects. Particular care was taken in the mounting of the experiment to minimise background sources of radiation in the vicinity of the experiment; final beam collimation was carried out 1·5 metres away from the target and the neutron dump was 2 metres downstream. In each case ^{6}Li (as lithium fluoride, 95% ^{6}Li) was used and the target holder was also lined with ^{6}Li so that the γ-background was minimal and the number of neutrons scattered out of the beam negligible. The polarisation of the neutrons was reversed about 4 metres from the target and there was no detectable influence of this changing magnetic field on the detectors. Thermal stability of the complete detector system was obtained by enclosing them in a thermally insulated container.

These experimental features, which are believed to be necessary, were not common in previous measurements where one was led to believe that systematic variations were the most serious limitation to achieving a high precision result. Extensive tests of the system have been made using cascades from radioactive sources and following n capture. The apparatus and method appear capable of measuring an asymmetry of 1 part in 10^6.

The experiment used a titanium (^{48}Ti) target and measured the well resolved

$$\tfrac{1}{2}^- \xrightarrow{(341\ \text{keV})} \tfrac{3}{2}^- \xrightarrow{(1378\ \text{keV})} \tfrac{7}{2}^- \text{ cascade in } {}^{49}\text{Ti}.$$

This nucleus is one of the few that are known to be suitable for a T-violation test; the neutron capture cross section and available polarised neutron flux provide the maximum count rate that the 3" x 3" Sodium Iodide detectors can accept without serious loss of resolution. Also the many factors which enter the correlation function and relate the value of the asymmetry to sin η, although small, do not limit the measurements greatly.

The preliminary test measurements and the first few weeks of data have been fully analysed. The distribution of the asymmetry measurements appears very satisfactory indicating the absence of systematic effects and the preliminary result for the asymmetry is $A = (4 \pm 61) \times 10^{-6}$, which corresponds to sin $\eta = (0.07 \pm 1.0) \times 10^{-2}$, where η is the phase difference in the mixed E2 + M1 341 keV transition.

Further measurements have been made and the data being analysed should substantially reduce the errors in the values given above. It is also intended to examine other cases which have a more favourable relationship between the measured asymmetry A and the value of sin η which can be deduced from it.

EXPERIMENT 52

Search for Parity Violating Effects in Radiative Neutron-Proton Capture

Sussex University; Harvard University; ILL

A measurement of the circular polarisation of the 2·2 MeV γ-ray following the reaction $n + p \to d + \gamma$ is indicative of parity violation. A previous measurement by Lobashov et al in 1972 obtained $P_\gamma = -(1{\cdot}3 \pm 0{\cdot}4) \times 10^{-6}$ while theoretical predictions range between $P_\gamma = +2{\cdot}2 \times 10^{-7}$ and $P_\gamma = +3{\cdot}1 \times 10^{-9}$. It is thus important to establish clearly the validity or otherwise of the previous measurement and during the past years the feasibility of mounting an inpile experiment at the ILL reactor has been examined.

An inpile experiment allows a sufficiently large neutron flux at the target and by using a through tube two sets of analysing-measuring equipment may be placed on each side of the target. In this manner an inherently symmetric experimental system may be constructed and the short term instability of the reactor does not limit the final accuracy which is possible.

A preliminary study has been made of the technical aspects of mounting the experiment. A considerable amount of lead shielding is required to remove bremsstrahlung originating from the β-decay of fission products. This radiation may either be scattered by the target and related equipment into the analysing magnets or it may enter the magnets directly from the core. Such radiation is a very serious limitation to the confidence which may be placed on any result since bremsstrahlung from high energy electrons is almost 100% circularly polarised. It is thus possible that any measured small asymmetry could be due to this source of radiation.

Extensive calculations have been carried out by Robert and Ageron at ILL to estimate this effect. They have considered internal bremsstrahlung and limited their computations to single scattering of the photon. It is apparent that only by substantially increasing the amount of shielding beyond that at present possible can an acceptable 'signal to background' ratio be obtained. This requires that the through tube diameter to be increased from 10 cm to 16 cm and while the heavy water vessel has been designed to allow such a modification it is a substantial and expensive effort to make such a change. It is hoped that a decision will be taken in the near future.

EXPERIMENT 53

A Measurement of the Neutron Lifetime

Sussex University; Rutherford Laboratory

The half life of the neutron, for which the currently accepted value is 10·61 ± 0·16 min, is one of the least accurately determined of particle parameters, and successive measurements, although consistently showing a reduction in value with each increase in precision, have not always been in agreement. The prospect of obtaining a reliable value for this parameter is critical to the theory of the weak interaction in nuclei, since it plays a central role in establishing values of the weak coupling constants whose precision is not limited by uncertainties associated with nuclear structure. It seems important therefore to subject this problem to continuing investigation and by as many different techniques as may be devised.

The present experiment has developed from a technique first employed at the low flux reactor LIDO at AERE Harwell and uses a modified version of the apparatus designed and built at that laboratory. In this scheme protons of energy <1 keV, emitted in the β-decay of the neutron, are stored in an ultra high vacuum electromagnetic trap, formed by superposing an electrostatic potential well on the axial magnetic field of a superconducting magnet. The stored protons are periodically released from the trap, accelerated and detected, the whole device behaving somewhat as a 4 π-counter with signal/background enhancement in the ratio of storage time to counting time.

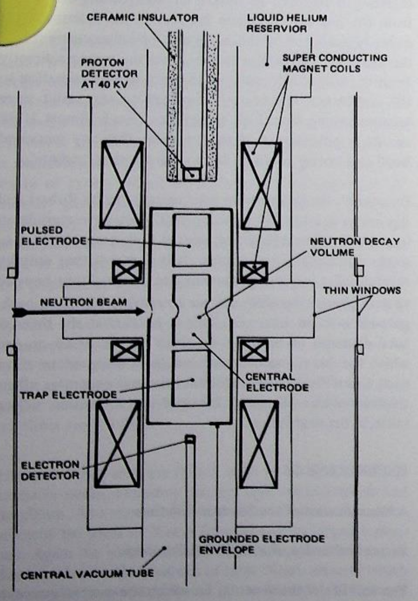


Fig 1.33. Apparatus for Experiment 53

In the earlier measurements decay rates of the order of 0·2 cps were observed in an effective source volume of neutron beam of about 10cm^3. The new version utilizes a capture flux of about 4·5 x 10^8 neutrons cm^{-2} sec^{-1} at a mean neutron wavelength of 29 A°, i.e. a temperature <1°K. This represents a beam density of about 2 x 10^3 neutrons cm^{-3} and count-rates of about 2 per second per cm^3 of beam are expected. Thus a much higher counting rate is available for a smaller source volume and this is achieved in an environment of low γ-ray background and zero flux of fast and epithermal neutrons. The sensitive volume of beam can therefore be restricted to a region of near uniform magnetic field with a proportionate improvement in the reliability of the source volume determination.

To establish a precise definition of the volume of beam sampled by the proton detector the proton trajectories from source to detector must be known accurately and this poses a severe problem of alignment. This has been studied by recording the collection efficiency as a function of magnetic field for electrons from a point source of ^{147}Pm which is systematically moved to selected positions within the source volume.

In the unmodified apparatus the system of three co-axial trapping electrodes was maintained at a potential of 40 KV and protons released from the trap traced out cyclotron orbits whose guiding centres were accelerated along the magnetic field lines eventually reaching a detector fixed at earth potential. Experience gained with this arrangement showed it to be unsatisfactory in that, in order to inhibit electrical breakdown in the annulus between the electrodes and the cryostat wall, where electric and magnetic fields are crossed rather than parallel, it was necessary to contain the trapping electrodes within a hollow cylindrical insulator which was placed directly in the path of the neutron beam. In the current arrangement the trap potential is set near earth whilst the detector, protected by a single ceramic insulator, is fixed at a negative potential of −40 KV; analogue and digital signals are then transmitted down to earth through a high-voltage capacitor. The only material in the path of the neutron beam comes from the thin aluminium windows of the cryostat and the thin beryllium central electrode.

With this arrangement protons released from the trap are accelerated to energies of about 40 keV and are detected in a silicon surface barrier detector with a collecting area of 50 mm^2. This contrasts with a collecting area of 300 mm^2 used in the earlier experiment with a corresponding reduction in detector noise. In addition, a small plastic scintillator is placed on the axis just outside the fixed potential trapping electrode, which detects the 0·78 MeV β-particles from neutron-decay. This affords the possibility of using a coincidence technique to determine the precise shape of the proton spectrum in the low energy region where detector noise is significant.

To eject protons from the trap, one of the trapping electrodes is fed with 2·5 KV negative pulses supplied by a double pulse generator in alternate periods of 1 m sec and 5 m sec. The proton spectra are sampled for a finite period (~ 0·1 - 1·0μsec) after successive release pulses and are stored in separate memory blocks of a multichannel analyser. Assuming that the correlation time for fluctuations in the background and in the beam is much larger than the time delay between successive sampling operations, the difference between the spectra stored after 1 m sec and after 5 m sec represents the spectrum of protons stored for 4 m sec, the background having been removed in the subtraction.

Of equal overall weight with the problem of determining the number of neutron decays per second in a known volume of neutron beam is the question of determining the density of neutrons in that volume. To transport the neutrons from the exit of the main guide tube to the cryostat a selection of nickel plated boron-glass guide tubes is used, each of length about 1 metre and variable in diameter over the range 0·3 to 1·0 cm. This permits the accumulation of data for various values of the source volume. Upon leaving the cryostat the beam traverses an assayed boron foil and the neutron density is determined by counting α-particles from the reaction $^{10}B(n,\alpha)^7Li$. These are recorded in four surface-barrier detectors set to view the boron foil from different angles and positions. The effective solid angles for α-particle collection are calculated from the geometry and the relative intensity across the beam determined by scanning the boron foil with a boron carbide aperture variable in vertical and horizontal directions. This system has also been developed from the earlier version which successfully employed activation of boron foils and a single α-particle counter to determine the neutron density.

The re-built apparatus has now virtually reached its final form and is currently undergoing testing for correct alignment and high voltage stability. The experiment is to be set up on the cold neutron beam H18 at the High Flux Beam Reactor at ILL Grenoble.

EXPERIMENT 54

Search for the Electric Dipole Moment of the Neutron

Sussex University; Oxford University; Harvard University; Oak Ridge National Laboratory; Technical University Munich; Centre d'Etudes Nucleaire Grenoble; ILL; Rutherford Laboratory

The observation of a finite electric dipole moment (EDM) in the neutron or any other elementary particle would be evidence for simultaneous P and T violation in fundamental interactions. Theoretical papers containing a discussion of T violation continue to appear at the rate of several per year and interest seems to have grown during the past year. The realisation that gauge theories with more than four quarks may embrace T violating left handed weak currents, for example, reveals a model for T violation which has the attraction of being prompted by the growing belief, based on the results of high energy experiments, that there are an increasingly large number of quarks. In contrast, the search for the electric dipole moment of the neutron requires the detection of energy changes as small as 10^{-20} eV.

Development of the apparatus is continuing. Construction of the guide tube installation for the ILL high flux reactor, which will allow ultra-cold neutrons with velocities of the order 5 metres per second to be extracted from the reactor core, is well advanced. The out of pile guide has been delivered and its transmission has been measured to be about 75%. The 6 metre lengths of stainless steel guide for the in-pile section have been honed and electro-polished ready for testing. Installation and commissioning of the source should take place in the spring of 1977. Fig 1.34 shows how the ultra-cold neutron source will increase the availability of very long wavelength neutrons and the way the output spectrum is expected to relate to outputs from the existing H15 and H18 guides from the cold source. The spectrum which might be obtained from a suitable guide to a new cold source is also given.

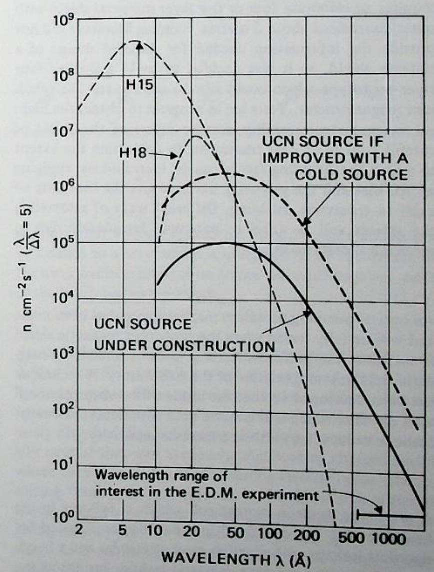


Fig 1.34. The neutron flux available after velocity selection with a resolution of λ/Δλ of 5 from the ultra-cold neutron (UCN) source under construction and indication of the way it would be improved if the converter were cooled. The flux from existing H15 and H18 guides at ILL is given for comparison (Experiment 54)

Thin polarising foils which will work in both reflection and transmission are needed for the EDM experiment. Foils produced by the Neutron Beam Research Unit at the Rutherford Laboratory have been tested using ultra cold neutrons from the FRM reactor at Garching, near Munich. Using similar foils for the polariser and analyser, a change of count rate greater than a factor of five was obtained after spin flip between the foils, but the accuracy of the measurement was limited by the very low count rate. More precise measurements will be made when the source at ILL is available. The transmission loss was about 30% which may be reduced to 10% or less by using a thin vanadium foil as a substrate.

A slow neutron proportional counter containing He^3 in a suitable geometry has been developed and tested with slow neutrons. Stable operation over a period of months and a satisfactory pulse height spectrum have been established and work is in progress to add a thin window which will transmit ultra-cold neutrons. An overall detection efficiency of 70% is expected.

The ultra-cold neutrons will be stored in a beryllia bottle for a time of the order 30 s in a magnetic field of 10^{-2} gauss which has to be stable to 10^{-8} gauss for this period. This requires an elaborate four or five layer mumetal shield with outer dimensions about 2 metres. Existing literature did not provide the information needed for detailed design of a suitable shield, so it was decided to build a smaller four layer prototype which could also be used to test the rubidium magnetometer. Tests are in progress to obtain the highest magnetic permeability for the layers of the shield of careful control of heat treatment; to determine the extent to which the shielding factor can be increased by applying an AC bias and the geometry likely to give the best ratio of axial to transverse shielding. Different ways of assembling the shields will be tried to minimise degradation due to mechanical deformation.

An optical pumping rubidium magnetometer has been made and will be fully tested when the prototype magnetic shield is available; the performance is at present limited by magnetic field inhomogeneities in the Laboratory. A technique has been developed to coat the inside of the absorption cell with eicosane which will later be used with deuterated polythene to reduce linewidth and increase sensitivity.

A prototype neutron storage cell which is full size in the field direction but one third in radius has been tested for electrical leakage with stainless steel electrodes and a beryllia insulator. The sparking rate and leakage current at the design electric field and applied voltage are compatible with the requirements of the experiment. The experiments are now about to be repeated with beryllium electrodes which are likely to be more effective neutron reflectors.

EXPERIMENT 55

Experiments with Exotic Atoms

Birmingham University ; Surrey University; Rutherford Laboratory

An exotic atom is one in which an orbital electron has been replaced by a heavier negatively charged particle. These experiments aim to make measurements of the X-ray spectra emitted from exotic atoms formed by stopping hadrons (kaons or pions) and to study the γ-ray spectra from the residual nucleus following the final interaction of the hadron with the target nucleus.

An exotic atom is formed when a slow negatively charged hadron travelling through matter is captured so as to move in an atomic orbit around the target nucleus. In the capturing process the hadron expels an electron from the target atom by the Auger effect and then occupies an atomic orbit which corresponds to a highly excited atomic state of the hadronic or exotic atom. The hadron initially cascades through the atomic energy levels by Auger transitions and then by radiative transitions in which X-rays are emitted. Finally the strong interaction between the hadron and the nucleus becomes important and the hadron is absorbed. As a result of this interaction the final observable X-ray transition is frequently broadened and shifted in energy as well as being attenuated.

Measurements of the strong interaction shift, broadening and attenuation of this last X-ray transition give information about the very low-energy kaon-nucleus interaction and the possibility of learning about nuclear properties in the surface region. Some measurements were discussed in last year's report. These have now been extended to the very light nuclei Lithium and Beryllium. The earlier measurements for Silver and Cadmium, which gave results apparently in disagreement with theoretical predictions, have been repeated and the neighbouring nuclei Indium and Tin also studied. As these experiments involve very precise measurements (a few parts in 10^4) of X-ray energy, considerable effort has been spent on checking the apparatus and calibration techniques. Possible contamination of the X-ray spectra by nuclear γ-rays has been investigated. Preliminary analysis indicates that the new results do seem to be more in accord with theoretical predictions. A summary of the presently available measurements of shifts and widths for kaonic atoms, made both at the Rutherford Laboratory and elsewhere is shown in Fig 1.35.

When kaons are stopped in a nuclear target, in about 8% of the captures sigma hyperons will be emitted. These hyperons can then be stopped in the same target to form sigma atoms. Experiments are difficult due to the relatively low numbers of X-rays produced but in the present work measurements of the width, shift and yield of the n = 5 → 4 sigma X-ray transition in Magnesium, Aluminium and Silicon have been made. Analysis of the data is complicated by the need to include the fine structure splitting of the X-ray lines due to the magnetic moment of the sigma hyperon and the presence of a nearby pionic X-ray transition. These will be the first measurements ever made of strong interaction shifts and widths of sigma-atoms.

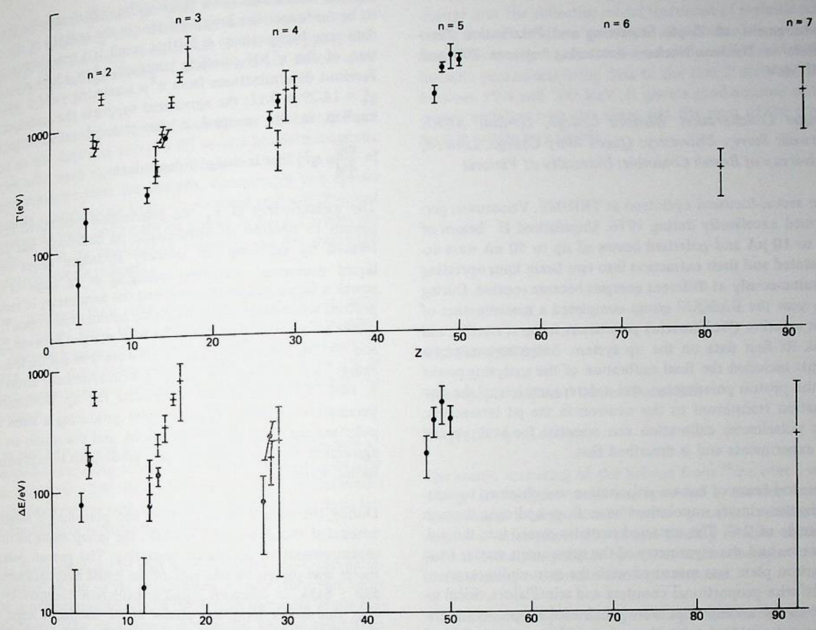


Fig 1.35. Measurements of strong interaction shifts (ΔE) and widths (Γ) for kaonic atoms made at the Rutherford Laboratory (•) and elsewhere (+) (Experiment 55)

The X-ray spectra of pionic and kaonic atoms in these three nuclei have also been measured together with the spectra of γ-rays emitted by the residual nucleus following the capture of the pion or kaon. This great wealth of data is now being analysed in the hope of building up a rather complete picture of the final capture process.

The case where a kaon is bound by a proton to form an exotic hydrogen atom is of particular interest as X-ray measurements give information on the very low-energy kaon-nucleon interaction which it is difficult to obtain by other means. In particular in hydrogen the energy shift and width of the 1s level caused by the strong interaction can be related in a way which is independent of the details of the kaon-nucleon interaction to the real and imaginary parts of the K^-p scattering length.

An experiment to try to detect and measure the 2p – 1s X-rays from K^-p atoms is now being prepared using a liquid hydrogen target. There are two particular problems. The expected X-ray energy of 6·5 keV is low and the X-rays are easily absorbed. Secondly since the K^-p atoms are electrically neutral they can approach neighbouring charged nuclei where they will be exposed to strong electric fields. The resulting "Stark-mixing" can lead to the direct absorption of kaons from states of high principal quantum number n so giving only a very low relative yield for the 2p – 1s transition. As a result the expected number of X-rays is very small and the reduction of unwanted background is essential. Very detailed studies of background effects have been made using mock-ups of various proposed target arrangements and these have proved particularly valuable in arriving at the final design.

EXPERIMENT 56

Measurement of Triple Scattering and Polarisation Parameters in Nucleon-Nucleon Scattering between 200 and 520 MeV

Basque Collaboration; Bedford College, London; AERE Harwell; Surrey University; Queen Mary College, London; University of British Columbia; University of Victoria

The sector-focussed cyclotron at TRIUMF, Vancouver, performed excellently during 1976. Unpolarised H^- beams of up to 10 μA and polarised beams of up to 50 nA were accelerated and their extraction into two beam lines operating simultaneously at different energies became routine. During the year the BASQUE group completed a measurement of spin rotation (Wolfenstein) parameters in pp scattering and took its first data on the np system. Subsidiary measurements included the final calibration of the analysing power of the proton polarimeter, and a determination of the polarisation transferred to the neutron in the pd interaction. The polarimeter calibration was essential for both pp and np experiments and is described first.

A proton beam of known polarisation was obtained by scattering the primary unpolarised beam from hydrogen through an angle of 24°. The scattered particles passed into the polarimeter and the asymmetry of the subsequent scatter from a carbon plate was measured with the surrounding array of multi-wire proportional counters and scintillators. Small instrumental asymmetries were eliminated by precessing the scattered protons' spins through ± 90° by means of the 6 Tm superconducting solenoid. The calibration was performed at nine energies between 209 and 518 MeV with a typical precision of ± 2% at each energy. An interpolation formula has been fitted to these data for use in the subsequent experiments. The overall normalisation remains to be fixed by precise determination, by double scattering, of the polarisation in pp scattering at 24°.

Following this calibration the pp Wolfenstein parameters D, R and R′ and the polarisation parameter P were measured at four angles and five energies between 209 and 515 MeV. The polarised (∼ 75% primary beam was directed onto the liquid hydrogen target. The spins of protons scattered through 6°, 9°, 15° and 24° were measured by the scattering asymmetry produced in the polarimeter array. The solenoid, now returned to the primary beam, was used to direct the incident spin vector horizontally or vertically so as to determine R or D respectively. To measure R′ a dipole magnet was used to precess the longitudinal component of the spins of scattered protons to the transverse direction. The values of P were obtained in several ways, for example by averaging the D data over up and down primary spin directions. The measured values of the parameters have been incorporated into the existing sets of data for p-p scattering and partial wave analyses have been performed at each energy. The conclusion is that unique and well-determined solutions now exist at all five energies. The data have thus refined the isotriplet NN phase shifts sufficiently for them to be no longer the limiting factor in the analysis of the np data now being taken. A further result is a new determination of the π^0NN coupling constant, g_0^2 = 13·84 ± 0·65. Previous determinations from $\pi^{\pm}$p scattering yield a value g_+^2 = 14·29 ± 0·18; the agreement supports the assumption implicit in the comparison that it is g^2 rather than f^2 $(= \frac{m_\pi^2}{4M^2}\, g^2)$ that is charge independent.

The measurement of R_t, the polarisation transferred from proton to neutron in quasi-elastic pd collisions, was performed by replacing the primary hydrogen target with liquid deuterium. Neutrons emerging at an angle of 9° struck a liquid hydrogen target and the asymmetry of recoil protons was measured in scintillator counter telescopes. The values of neutron polarisation at four energies between 220 and 495 MeV were found to be between 0·94 (at the lowest energy) and 0·49 (at the highest), with systematic errors of ± 14%. The experiment to measure the np Wolfenstein parameters depends critically upon producing a beam of polarised neutrons by this technique, and the results are in agreement with phenomenological predictions of high polarisation transfer.

During the second half of 1976, and preceding a lengthy scheduled shutdown of TRIUMF, the group made its first measurements of np elastic scattering. The proton polarimeter was placed on one side of the liquid hydrogen target and a bank of fourteen liquid scintillation counters, each over one metre long, was placed at the conjugate angle to detect elastically scattered neutrons. By modifying the trigger requirements it is possible to detect and spin-analyse simultaneously those events in which the neutron scatters in the polarimeter and the proton is detected in the scintillator bank. By using two dipole magnets with crossed fields to re-orient the spin vector of the secondary neutron beam, measurements have been made of D and D_t in np elastic scattering at 325 MeV. Analysis is in progress at the Rutherford Laboratory, and further data at 220, 425 and 495 MeV, including A, A_t, R and R_t will be taken.

EXPERIMENT 57

Measurements of π^--Nucleus Backward Scattering and of the Decay Rate $\pi^0 \rightarrow e^+e^-$ with the Omicron Spectrometer

Birmingham University; Oxford University; Daresbury Laboratory; University College, London; Amsterdam; CERN; Ljubljana; Turin

The former heavy liquid bubble chamber magnet at the Rutherford Laboratory has now been rebuilt as a large volume multi-particle spectrometer to exploit the good duty cycle of the CERN Synchrocyclotron. New magnet poles and major changes in yoke and coil configurations have been designed with the Rutherford Laboratory's G-FUN 3-D magnet design program (Section 4.6). Particle positions will be determined with drift and proportional chambers contained in a Helium gas box so as to reduce multiple Coulomb scattering and which can be withdrawn on air bearings onto a dummy magnet pole for surveying purposes. Construction and assembly of these items are almost complete.

Unwanted events in a typical experiment of this type can add to the data rate so as to fill several hundred magnetic tapes, with each tape requiring of the order of one hour of large computer time for analysis. Accordingly two special purpose processors are being constructed; one will filter out unwanted events before the dedicated computer whilst the other, online via the CAMAC highway, will determine initial, approximate momenta.

The chambers, their electronics and the online computer are at present being tested with an experiment to measure π^- backward scattering off H_2O and D_2O. Results from the latter target should also provide a severe test of the use of Fadeev equations and the effects of nucleon isobars in the deuteron.

The first experiment with the spectrometer will measure π^- backward scattering from Carbon at various energies over the range 50 - 200 MeV. There are several optical-model potentials agreeing with the existing forward angle data, but giving different predictions at 180°.

The main emphasis of this work however, is on the determination of the so far unmeasured $\pi^0 \rightarrow e^+e^-$ rate, this being the specific responsibility of the British members of the collaboration. The experiment is designed to give more than 100 events at the, so called, unitary lower bound of 5 x 10^{-8} for the branching ratio of the π^0 decay to this final state; a lower value would test invariance principles. A branching ratio greater than 4 x 10^{-7} would be significant for unified models whilst intermediate values are a test of meson vector dominance.

EXPERIMENT 58

Coulomb/Nuclear Interference in Alpha Particle Scattering

King's College, London

The analysis of the 19 MeV alpha elastic and inelastic scattering data obtained from ^{52}Cr, ^{56}Fe, ^{66}Ni and ^{64}Zn to investigate the interference of Coulomb and Nuclear contributions has been completed and is being prepared for publication. Optical model parameters have been extracted from the elastic data and a systematic DWBA study has been performed to check a number of assumptions made in the conventional collective model treatment of inelastic scattering. The deep forward angle minima produced by the Coulomb-Nuclear interference provided a very sensitive test of this theory. The main conclusions are that the Coulomb and Nuclear deformations need to be different but that the real and imaginary nuclear components of the form factor have equal deformations and that their shapes are correctly predicted by the usual derivative model.

The theoretical work being done on the inclusion of exchange into the collective model treatment of inelastic scattering is now complete and has been submitted for publication. The theory has been used to analyse all the available inelastic proton scattering data to the first 2^+ state of ^{24}Mg between 17·5 and 100 MeV. It gives a good account of the energy variation over this range and fits most of the cross-section results very closely.

EXPERIMENT 59

Microscopic Helium 3 Optical Potentials

King's College, London

The elastic scattering of the helions from ^{56}Fe over a wide energy and angular range has provided a valuable test of microscopic folding models for the optical potentials. It is now well established that simple folding models used for proton and alpha particle potentials are inadequate for helion scattering and double folding is essential.

The model developed at King's College involves double folding of an effective nucleon-nucleon interaction into the density distributions of both target and projectile densities. Using the Green density dependent effective interaction allows the inclusion of saturation effects due to the target and projectile densities to be included. The model includes exchange terms and can, in its complete form, also produce the imaginary potential using the forward scattering approximation. Using the model on the ^{144}Sm and ^{40}Ca data at 53 and 33 MeV respectively proved to be fairly successful, however some difficulties were observed in fitting backward angle measurements. Applying the model to the ^{56}Fe elastic scattering measured at 30 MeV, 50 MeV and 80 MeV emphasised the difficulty. The oscillations in the angular distributions become smoothed out as the energy increases and this feature was not reproduced by the model. This problem has been traced to the shape of the potential at a radius of ≃ 4 fm – a radius that became more important at the higher energies. By including an approximate treatment of second order terms in the potential this difficulty has been alleviated. This development has emphasised the value of measurements over a wide range of energies.

The model is now being applied to the 53 MeV data on the Calcium isotopes. There is every indication that the second order terms described above not only produce a fit to the elastic scattering but also allow the (h,α) reaction, which has given trouble under momentum mismatch conditions, to be fitted with conventional DWBA.

EXPERIMENT 60

Analysing Power Studies using Polarised ^{3}He Beams

King's College, London; Birmingham University

Using the 33·4 MeV polarised helion beam at the Birmingham Radial Ridge Cyclotron, a set of experiments has provided differential analysing powers for ^{26}Mg and ^{27}Al targets. The analysis of these measurements, which included the analysing powers for inelastic scattering and the (h,α) reaction, in addition to the elastic polarisations, have proved to be very interesting.

The elastic polarisations, in conjunction with previously measured differential cross-sections covering a wide angular range, were analysed using a phenomenological Optical Model. The resultant fits to the data were sensitive to the spin-orbit potential and required an unambiguous spin-orbit geometry of r_{so} = 0·9 fm and a_{so} = 0·2 fm. The small diffuseness implies a sharp localisation of the interaction, and agrees with previous work on lighter nuclei. The small radius parameter (compared with that of the real potential r_R = 1·14 fm) shows that the interaction takes place predominantly inside the nuclear surface. The resultant fits for ^{26}Mg are shown in Fig 1.36. Prior to these measurements it has been conventional to use $r_{so} = r_R$ and $a_{so} = a_R$. In addition, an analysis using simple folding models, which calculate the spin-orbit potential by folding a suitable interaction into a nuclear density distribution, has been shown to be inadequate, indicating that a more sophisticated microscopic approach is necessary. The latter is being investigated.

The inelastic data were analysed with the DWBA using the Collective Model. Although the cross-sections were fairly insensitive to the form factor used, the analysing powers were fitted better by a form factor with a real radius 20% smaller than that of the real optical potentials. In addition this gave deformation parameters closer to those obtained by other methods. This result is in agreement with recent theoretical calculations for proton inelastic scattering.

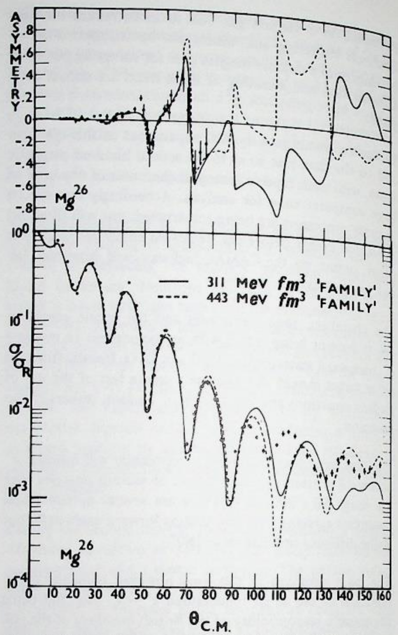


Fig 1.36. Polarisation asymmetry and elastic differential cross-sections for ^{26}Mg (^{3}He, ^{3}He) at 33·4 MeV. The full lines are for J_R/A_1A_T = 311 and 443 MeV.fm^3 potentials respectively (Experiment 60)

The analysing powers for the (h,α) reaction showed great sensitivity to the form of finite range corrections used in the DWBA. This indicates the necessity for exact finite range calculations, and provides a stringent test of the applicability of the DWBA in reactions with such deformed nuclei. A coupled channels analysis of the inelastic data, and two-step stripping analysis of the reaction data, is still in progress.

1.3 Theoretical High Energy Physics

The work of Theory Division has been directed largely to charmed particles and to dual unitarisation. The study of charm has been dominated by experiment, by the discovery of new particle families and the need to understand them. A topical meeting on the new particles was convened at the Rutherford Laboratory in February 1976, with speakers from SLAC, Fermilab, DESY and CERN describing the latest experiments and their implications. As the year progressed, charmed particles began at last to be clearly identified experimentally, so that quantitative studies could proceed on firmer ground.

In nice contrast to charm, the subject of dual unitarisation is dominated by theory, by the need to extend incomplete dual models of strong interactions into a complete scheme including unitarity. A small specialist meeting on this topic was held at the Cosener's House with leading workers from Europe and the U.S.A. It is encouraging that the dual unitarisation program, although highly constrained mathematically, gives many rather realistic predictions.

Each year about Christmas time the Theory Division organizes a large but informal meeting at the Rutherford Laboratory, mainly for theorists from British university groups. Because of a timing fluctuation there were two such meetings in 1976, during January 5-7 and December 15-17. In each case nine principal speakers were invited to survey progress in different areas. About 200 people attended, of whom 120 were accommodated in St. Hugh's College and St. Hilda's College, respectively. During the summer an active visitor program attracted physicists from Europe, Israel, Canada and U.S.A. to spend time working at the Laboratory.

Charmed Particle Production in e^+e^- Collisions

The discovery in the Spring of new particles in e^+e^- annihilation created a lot of theoretical excitement in view of the expectation that charmed particles should be produced in these experiments. Some detailed investigations into the production characteristics of charmed particles in e^+e^- annihilation were made and compared with the data. These investigations suggested that pseudoscalar (D) and vector (D*) charmed mesons have been produced; subsequent data seem to confirm this. A test has been proposed whereby a $^3D_1$ component in the D* can be investigated and the possibility of $D^o\bar{D}^o$ mixing (analogous to $K^o\bar{K}^o$ mixing) has been looked into. A calculation of the rates for producing axial vector charmed mesons has been made and the results suggest that it may be copiously produced in current e^+e^- experiments. The characteristic properties of charmed baryon production in these experiments have also been investigated with a view to aiding their experimental discovery.

Semileptonic Charm Decays

It is important to find simple ways to recognize charmed particles when they have been produced. One promising way is to pick out decay leptons (μ or e), since among the ordinary particles only π and K mesons decay readily into leptons, and their characteristics are quite different from expected charm decays. In this way, the celebrated dilepton events in neutrino scattering and the electron plus multi-hadron events in e^+e^- collisions have been identified as charm production, where the extra final lepton comes from charmed particle decay.

To establish this identification more firmly, and to learn more about the charm decay mechanisms, realistic calculations of the whole charm production and decay chain are made for the experiments mentioned. Charmed meson production is calculated by methods that work for ordinary mesons, and various semileptonic decay modes are tried out. The results agree well with available data, provided that semileptonic decays are predominantly multibody (e.g. $D \rightarrow K^*\ell\nu$) and frequent.

Charm Production by Weak Neutral Currents

Neutrino scattering is a good way to learn about weak interactions, since neutrinos have no strong or electromagnetic interactions to confuse the picture. There are two kinds of weak interactions, the more familiar "charged current" kind where a unit of charge is transferred and "neutral current" interactions with no charge transfer. Charged-current production of charmed particles has been identified via semileptonic charm decays, and it will be interesting if neutral-current charm production can be similarly identified, since it will provide important extra information about weak interaction systematics. Neutral currents are expected to have a charm-conserving component, leading to events where charm and anticharm are produced together; however, the expected rate for these processes turns out to be rather low, and the fraction that can be identified is lower still, of order 10^{-3} of the total interaction rate. It will not be easy to establish and measure them experimentally. There may also be a charm-changing component (it is forbidden in some theories): this would give an enhanced production of charm – not anticharm – and has some other characteristics to distinguish it. The identifiable fraction is at most of order 4 x 10^{-3} for neutrino beams, 4 x 10^{-2} for antineutrinos.

Weak Interaction Models

The model of Weinberg and Salam for unifying weak and electromagnetic interactions has been very successful phenomenologically both in the analysis of neutral current neutrino scattering data and in the requirement of charm to aid the incorporation of hadrons. At the same time it is a very crude scheme for understanding the fundamental structure of weak interactions and attempts are currently being made to derive it as part of a larger structure, perhaps ultimately incorporating the strong interactions into a single scheme with the weak and electromagnetic interactions. Most of these models require more than the known four (including charm) types of quark. The extra quarks which are presumably associated with very heavy particles, enrich the algebraic structure of the weak interactions. Ways can be found to make this algebraic structure include the parity operator, so that the large variation of masses typical of these models can be related to the maximal violation of parity observed in weak interactions.

Mass Scales and Charm Production

A comparison of deep inelastic processes, where different kinds of quark are excited, can give a clue to the role of different mass scales in symmetry and scale breaking. Charmed particle production adds a great deal to leverage in such a systematic study, because the mass scale involved is large.

Complementary descriptions of deep inelastic processes involving photons are provided by the parton model, which has no mass scales, and generalised vector meson dominance, which has explicit scale dependence. By matching up these two descriptions, results about symmetry and scale breaking in $e^+e^- \to X$, leptoproduction, $\gamma^*\gamma^* \to X$ and $pp \to \mu^+\mu^-X$ are obtained. In particular, charm production cross section estimates can be made. One interesting result is a prediction for the size and q^2-dependence of the charm-anticharm quark sea in $\mu p \to \mu X$ which is in encouraging agreement with recent Fermilab data.

Duality Predictions for Charmed Meson Masses

When finite energy sum rules are saturated by the leading resonances and Regge poles, they give constraints between the masses and couplings of the intermediate particles. The ratios of sum rules for $PP \to PV$ scattering, cut off successively after the vector and tensor meson contributions, can be used to determine some of the resonance masses. Applied to $\pi K \to \pi K^*$ scattering, this method gives a satisfactory mass prediction for the intermediate K^{**} meson that is well known experimentally. Applied to various πD, KF and KD scattering channels, the method gives mass predictions for D^{**}, F, F^* and F^{**} charmed mesons, that have yet to be identified experimentally.

Dual Unitarisation : The Planar Bootstrap

Strong interactions show marked regularities such as exchange degeneracy, ideal mixing and the Zweig-rule. Dual unitarisation starts with a system that has these regularities and also includes some unitarity corrections. The set of dual amplitudes which already have all planar loops included is chosen as this first approximation, with the assumption that such amplitudes are unchanged by further planar insertions. This self-consistency requirement constitutes the "planar bootstrap" and allows the calculation of the triple-reggeon coupling which in turn sets the scale of the strong interactions.

In general the solution of the reggeon propagator is complicated, but in a one-dimensional approximation the solution is obtained analytically and its physical properties easily examined. The constraints of the bootstrap equations may be used to probe symmetry breaking between Regge trajectories. Although the couplings may themselves satisfy SU(3) symmetry, the non-linearity of the equations allows certain non-symmetric solutions for the trajectories – in particular solutions with small SU(3) breaking but badly broken SU(4) symmetry. A well-known problem in the planar bootstrap is that the insertion of the planar loop introduces, in addition to the leading pole contribution, an apparent undesirable Regge cut. Investigations have been made whether this cut may be cancelled in the dual unitarisation scheme, but it appears that substantial modifications to the reggeon bootstrap may be required for this.

Diffraction and the Pomeron

By including non-planar insertions in the dual amplitudes the dual unitarisation scheme generates a vacuum trajectory which can be identified with the Pomeron and therefore can describe diffraction scattering. More precisely, this Pomeron is an f-trajectory which is "renormalised" upwards by the non-planar insertions. The single non-planar loop turns out to become more important as the momentum-transfer t becomes more negative, and less important for positive t. Consequently the Pomeron-f trajectory passes through the physical f-meson, has an intercept close to 1 and then becomes very flat for negative t. This gives interesting symmetry properties for the Pomeron as a function of t which can be tested against elastic scattering data. We expect a significant SU(3) octet component at t = 0, decreasing to leave the Pomeron a pure SU(3) singlet at large negative t. This tendency appears to be shown by the data on πp and Kp elastic scattering at Fermilab and explains the slopes of the cross-sections for photo-producing the ρ, ϕ, ψ vector mesons. Interesting predictions follow for hyperon beam diffractive excitations.

Breaking of Planar Regularities

In the dual unitarisation scheme, the introduction of non-planar insertions violates certain regularities such as exchange degeneracy (EXD) between the Regge trajectories, ideal mixing of states (purity of quark states) and the Zweig rule for decay and scattering amplitudes. The single non-planar loop breaks EXD between I = 0 and I = 1 trajectories but a higher-order diagram is needed to break EXD between the ρ and A_2 trajectories. Using the one-dimensional approximation the magnitude of the splitting can be quickly estimated. The sign of the breaking is a more complicated matter. However when all discontinuities of the graph are considered the sign as well as the magnitude is in accordance with the trajectories extracted from experimental data. Calculations of Zweig-rule breaking effects can be tested against the now considerable data on ψ and ψ' decays. These decays may be described by three classes of non-planar graphs, whose behaviours differ as the mass of the decaying particle is varied.

Many of the unexpected features of these decays can be qualitatively understood in terms of these three graphs and even with crude approximations many of the quantitative estimates for the branching ratios are good. An interesting prediction is that if any further states, similar to ψ and ψ', are discovered at higher masses then their hadronic widths will be of the order of their leptonic widths. The asymptotic behaviour of non-planar graphs has been somewhat clarified. Some of these graphs have a similar energy dependence to planar graphs, refuting the concept of 'asymptotic planarity'. However, none of these non-planar graphs violate purity of quark states or exchange degeneracy and so these regularities are preserved asymptotically.

Miscellaneous Aspects of Dual Unitarisation

The non-planar insertions, which boost the f-trajectory up to the Pomeron, also tend to depress the ω-trajectory unrealistically – at least when baryon exchange is neglected. Including baryon exchange in the loops has several significant effects. Firstly, the ω-trajectory is restored to a realistic value. Also the Pomeron trajectory is boosted even further; above baryon-antibaryon thresholds, the intercept is greater than 1, giving rising total cross-sections. In addition the ω coupling to baryons is enhanced, which is supported by experimental data. The dual unitarisation scheme makes a novel prediction, that multiplicities in different production processes depend on whether reggeon-exchange, Pomeron-exchange or annihilation is the dominant mechanism. A simple relation between the multiplicities, which is a critical test of the scheme, agrees quite well with data.

Although it was originally constructed for calculating hadronic amplitudes, the dual unitarisation scheme can be extended to lepton-hadron and current-hadron amplitudes. A tentative step in this direction gives a model for e^+e^- annihilation in which the conversion of quarks into the final hadrons is quite specific. From this model corrections to the value of R given by parton models can be estimated.

Leptons in Strong Potentials

Studies have continued of unusual phenomena which could occur in the presence of strong short range potentials, in particular at the critical potential at which electron or muon bound states would be drawn into the negative energy continuum. In this area of quantum electrodynamics normal perturbation theory cannot be used, and most of the results are obtained by direct computer summation of the perturbed vacuum levels, subtracting the divergent contributions.

This work investigates

(a) the close analogy between weak and electromagnetic currents (for example the formal similarity between the production of an electron plus neutrino and the creation of an electron positron pair).

(b) the apparent symmetry between the weak interactions of leptons and those of the hadronic (quark) constituents. It has been demonstrated, for example, that a short range critical potential can produce lepton bound states of sub-hadronic size, suggesting that localised lepton states of this type could participate in hadronic weak interactions.

Work this year has concentrated on pair production in short range potentials; a computer programme has been developed which will expand the complete set of bound and continuum levels at any potential V_1 in terms of the complete set of another potential V_2 (or zero); this enables momentum spectra to be computed for the electron and positron wave-packets created by these strong potentials. Preliminary results show a remarkable asymmetry in the pair production spectrum of a critical potential; one lepton is created with quite sharply defined momentum, but its antiparticle is produced as a wavepacket with very large momentum spread (governed by the reciprocal of the potential range). The observational interpretation of this new result is not yet clear.

1.4 Radiological Experiments

During the past year the experimental programme has continued to evaluate the radiation field of negative pions as a possible radiotherapeutic agent for combating cancer.

Negative pions offer advantages over the usual γ-ray treatment because being heavy charged particles they can penetrate deep to a target volume and deposit much of their kinetic energy in a stopping region. They are absorbed there – causing further local ionization to be deposited by fragments of atomic nuclei shattered by the liberation of the pions' rest mass.

The result is a variation of dose with depth such that an initial flat region, 'the plateau', is followed by a high dose region, 'the peak'. Beyond the peak the dose falls rapidly to a low value. The biological damage is further enhanced at the peak because the nuclei fragments are densely ionizing and more efficient than fast particles. The energy deposited per unit length of an ionizing track is called the Linear Energy Transfer or LET.

The inverse ratio of the required doses of two specified radiations at the same dose rate, one of which is a reference radiation, usually γ-rays, to produce equal damage is known as their Relative Biological Effectiveness (RBE). Further, the absence of oxygen, as occurs in tumours with a poor blood supply, produces less radioresistance to the fragments than to γ-rays. The ratio of doses required to produce the same level of damage without and with oxygen is known as the Oxygen Enhancement Ratio (OER).

These RBE and OER parameters have been measured in bean roots and on very sensitive *in vivo* systems of normal tissues in mice, on single cells, namely chromosome aberrations in white blood cells (lymphocytes) and on the reproductive capacity of cancer cells in culture. A review of the work from 1971-76 can be found in the Rutherford Laboratory Report RL-76-092.

Plans to extend measurements to skin and gut, and to solid tumours, have had to be shelved when it was decided not to connect the new 70 MeV injector to Nimrod. Biological studies are proceeding however with cancer cells and blood cells, as is the programme to measure the physical properties of the pion induced radiation.

EXPERIMENT 61

Some Longterm Effects of Negative Pions in Mice

Medical College of St. Bartholomew's Hospital, London

The longterm effects of partial body exposure of 1 day old SAS/4 mice from either ^{60}Co gamma rays or negative pions have been studied. The mice were originally irradiated to induce cataracts, but they have now all died and have been systematically studied to determine both their lifespan and the main causes of death. The experiment including controls involves 400 mice given pion doses between 40 and 200 rad and 384 mice given ^{60}Co gamma rays between 40 and 300 rad, both radiations given at the same dose rate (about 60 rad h^{-1}) and to the heads and upper parts of the thorax of the day old mice.

Both radiations produced considerable lifeshortening – and from the slopes of regression lines it can be calculated that for pions (Fig 1.37) 6·83 ± 1·5% of life is lost per 100 rad and for ^{60}Co the value is 5·67 ± 0·46%. So the relative biological efficiency of pions for 10 weeks lifeshortening is about 1·3 compared with ^{60}Co gamma rays. The dotted line through the pion points suggests an even higher RBE for pions at low doses, a conclusion that might be expected for the high LET pion radiation, but the small number of points probably makes this an unwarranted conclusion.

The analysis of the causes of death was difficult because of the rather small number of animals involved, but by combining mice dying from all tumours it was possible to analuse the incidence rates of tumours. Such an analysis showed that the incidence rate of tumours at any particular age was greater than in the controls for peak pion doses (60 and 200 rad) but not for plateau doses (40 and 136 rad), while the incidence rate of tumours at any age was only greater for ^{60}Co doses of 200 and 300 rad and not for doses less than 200 rad.

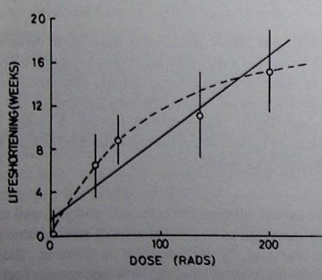


Fig 1.37. Life-shortening of mice irradiated by pions (Experiment 61)

EXPERIMENT 62

Chromosome Aberrations in White Blood Cells

National Radiological Protection Board; Rutherford Laboratory

The objective of this work is to investigate the profile of biological damage in a beam with a broad peak dose region of a size suitable for the irradiation of solid tumours. Blood samples were placed at varying depths in the water phantom and exposed to a pion beam in which three different momenta, 128, 146 and 166 MeV/c, were superimposed. Earlier work by this group at 160 MeV/c showed a peak to plateau biological effect ratio of 1·7 times the dose ratio. In the present experiment it was assumed that this value was appropriate for all three momenta. They were therefore combined in a ratio, 0·27 : 0·46 : 1·0, of the monitored incident beam which resulted in an expanded ionisation peak of about 10 cm and a predicted flat-topped biological effect. 150 rads were given to a sample 12·4 cm deep approximately in the middle of the expanded peak. This dose was chosen as being representative of a likely daily dose in a fractionated therapy regime. Fig 1.38 gives the dose profile (curve C), the predicted (curve A) and the observed biological effects (data points) for dicentric chromosome aberrations. It can be seen that there is a reasonable agreement between the two biological profiles. There is, however, a rapid fall-off in the observed data at a depth which corresponds to the peak of the highest momentum. Hence the dashed line (B) is drawn to indicate that for 166 MeV/c a biological enhancement factor of 1·2 would have been more appropriate. For comparison with conventional low LET therapy, curve D shows the profile of dicentric abberations which would be obtained for cobalt-60 γ radiation depositing 150 rads at 12·4 cm.

This experiment has demonstrated that the combination of several pion momenta can provide a beam in which the peak is enlarged to a size suitable for radiotherapy. However, before further attempts at peak widening are made, it is necessary to examine separately a series of likely momenta to determine the relationship between dose and biological effect at varying depths, especially across the peaks.

In the first part of the experiment described above, the first blood sample, 1 cm deep into the plateau, gave a higher aberration yield than was observed in the succeeding five samples. This phenomenon has also been described by two other Rutherford research groups studying the inhibition of bean root growth and the survival of frozen Hela cells. If this is a real effect it will have important consequences in the skin sparing techniques to be employed in pion radiotherapy.

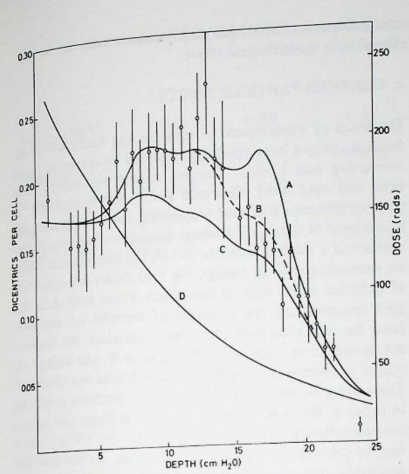


Fig 1.38. Observed yield of dicentric aberrations. Absolute prediction using a 1·7 enhancement for each momentum (A), using a 1·2 for 166 MeV/c (B), and the pion dose profile (C). Also shown is a damage profile for 150 rad ^{60}Co radiation at 12·4cm depth (D) (Experiment 62)

Irradiations have been successfully completed in which 150 and 360 peak rads at 160 MeV/c were given to blood samples held in a water phantom in the front and middle of the plateau, in the peak and in the tail. Over the first 3 cm of the plateau, ten samples were arranged along the axis of the beam, each occupying 3 mm and separated by very thin Mylar film. The results of the microscope analysis for chromosome aberrations will soon be available and the data will be compared with measurements made with a small parallel plate ionisation chamber.

EXPERIMENT 63

Irradiation of Frozen Cancer Cells

Glasgow Institute of Radiotherapeutics and Oncology; Rutherford Laboratory

The cells were frozen at liquid nitrogen temperatures to reduce biological and chemical activity, for in such a state there is little dose rate dependence. Following earlier work which determined the RBE for the pion beam at the peak position and for 14 MeV neutrons, further experiments have investigated the response of frozen HeLa cells at other absorber depths at a number of beam positions. A specially designed cell holder of much smaller volume was used to improve the resolution of this 'biological dosimetry' technique.

Preliminary results suggest RBE values which are not significantly different from unity for two positions in the "plateau" region of the beam just before the ionisation peak, and two in the "tail" region just after it. At the first plateau position in the irradiation set-up, however, the RBE value is more similar to that found at the three positions closest to the peak; namely 1·9. The current aim is to derive complete survival curves for frozen cells irradiated at these various positions, particularly the first (or "entrance") position. The next step will be the determination of values for OER along the depth dose profile.

EXPERIMENT 64

Study of the Physical Nature of Pion Induced Radiation

Medical College of St. Bartholomew's Hospital, London; Leeds University; Surrey University; Rutherford Laboratory

The structure of the radiation field induced by pions is very complex because they produce many different particles according to their reaction with the object irradiated. In order to attempt to interpret biological results as well as to understand the field for its own sake the deposited energy distribution (dose) is measured using ion chambers, the distribution of sizes of events and Linear Energy Transfer (LET) contributing to the dose using proportional counters and nuclear emulsions, and the specific nature of the events using counter telescopes. A new program has begun to measure the neutron component due to the incident flux as well as products of pion interactions, by observing induced radioactivity.

1. DOSE MEASUREMENTS

A small parallel plate ion chamber 1·7mm thick, 12mm nominal diameter has been constructed with 0·95mg/cm^2 aluminized melinex windows extending well away from the sensitive volume. A depth scan is shown in Fig 1.39. It is seen that any build up or falloff at the surface of a phantom irradiated with a pion beam is not greater than 10%. The peak position so measured agrees with the depth in a phantom determined with the central point of a standard 0·2 cm^3 cylindrical air equivalent Farmer type ion chamber, as opposed to say the inside front face, to within a millimeter. Both these preliminary results are being checked in detail.

2. DETERMINATION OF EVENT SIZES AND LET SPECTRA USING PROPORTIONAL COUNTERS

Ionization event size spectra have been measured at various positions of interest over the pion depth dose profile and in both water and perspex phantoms. These measurements,

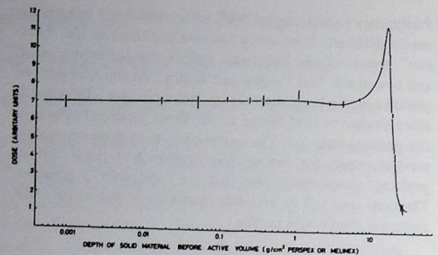


Fig 1.39. Depth-dose curve using a thin parallel plate ionization chamber (Experiment 64)

made with a 1·27 cm diameter, 1 μ effective diameter spherical Rossi proportional counter, are now being used to derive LET spectra from a Monte Carlo simulation technique.

Similar measurements have been made of neutron event size spectra at the Harwell Variable Energy Cyclotron (VEC) in collaboration with the MRC. The neutrons are produced in the VEC from the bombardment of a Beryllium target with 40 MeV deuterons from the VEC and give a spectrum of neutron energies with a modal energy of about 20 MeV.

More recently, attention has been given to the possibility of measuring ionization event size spectra in much smaller physical volumes. For this purpose two parallel plate chambers, based on an original design by Rossi, have been constructed. These chambers have electrodes composed of tissue and bone equivalent conducting plastic, and present a sensitive volume of 0·015 cc. with cylindrical geometry to the radiation field. When operated in the proportional mode with a tissue equivalent gas supply at constant pressure (about 760 mm of Hg), the chambers produce sufficient gas gain to allow events of $>$ 10 keV/μ to be measured. Calibration is achieved with a low activity alpha source, vacuum deposited on to a small area of the negative electrode. In the near future it is hoped that these chambers will be used to measure ionization event size spectra in a perspex phantom, at positions in the peak and plateau regions of the depth dose profile.

3. DETERMINATION OF EVENT SIZES AND LET SPECTRA USING NUCLEAR EMULSIONS

Work has continued on the exposure of insensitive emulsions in attempts to quantify the LET distributions in the peak region and at the surface of the stopping material. For this purpose 10 μm thicknesses of K0 and K2 emulsions mounted on a thin melinex base have been exposed in specially designed holders. Results are presently being analysed. Measurements will also be made in conjunction with the new parallel plate ionization chamber to relate the total dose to the detailed track measurements. If this becomes possible it might then enable the emulsions to be exposed simultaneously with a radiobiological sample and give a precise indication of the LET distribution which can be correlated with the biological effect.

4. CHARGED PARTICLE SPECTRA

The series of experiments to measure the spectrum of individual charged heavy particles liberated by stopping pions interacting with Carbon, Oxygen, muscle equivalent solution, and rigid bone substitute have been completed. A counter telescope was used comprising one of several totally depleted Si specific ionization detectors of various thicknesses and a thick Si detector or CsI(Th) scintillation counter measuring residual energy. Fig 1.40 shows the spectrum of particles which exist in soft tissue. From such data the LET spectrum and the spectrum of particles on emission from the spallating nuclei have been obtained. An important parameter in determining the dose is W, the energy required to liberate an ion pair as observed in an ion chamber. The average W value in Nitrogen gas for particles produced in tissue at the peak allowing for pions in flight and lepton contamination is calculated to be 35·8 ± 0·4 eV/ip, which may be compared to 34 eV/ip for electrons. As the dose has invariably been measured with a detector with a greater Carbon/Oxygen ratio than tissue, another important parameter is the ratio of energy liberated. This may be deduced from the Table.

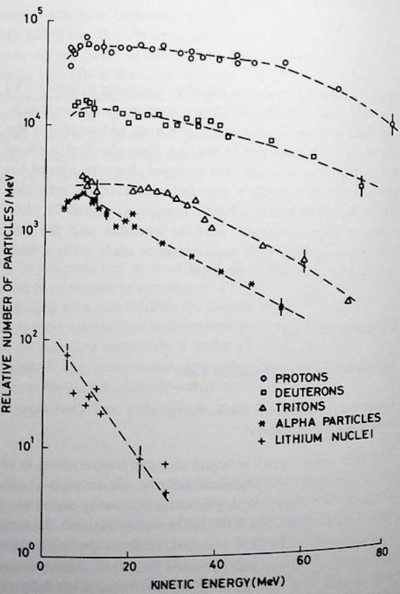


Fig 1.40. Energy spectra of charged particles observed from a thick target of muscle equivalent solution at the pion peak (Experiment 64)

Relative dose deposited in soft tissue as observed originating from the materials listed due to various particles of the energy intervals specified

	p	d	t	He	Li	Be	Sum
Energy (MeV)	1–80	1–80	1–80	1–80	6·3–38	10–38	
Graphite (C)	1·17 ± ·18	·64 ± ·12	·38 ± ·08	·54 ± ·04	·025 ± ·005	·015 ± ·003	2·78 ± ·23
Water (O)	1·56 ± ·40	·52 ± ·10	·17 ± ·04	·39 ± ·03	·016 ± ·003	–	2·66 ± ·41
Muscle Soln.	1·67 ± ·40	·72 ± ·14	·20 ± ·04	·39 ± ·04	·017 ± ·003	–	3·00 ± ·43
Bone Subst.	1·70 ± ·42	·71 ± ·14	·25 ± ·05	·45 ± ·04	·017 ± ·003	–	3·13 ± ·45

2 Neutron Beam Research

In addition to its continuing programme of neutron beam research and development, the Neutron Beam Research Unit (NBRU) at the Rutherford Laboratory has for some years been carrying out studies of future neutron sources, culminating this year in a proposal by the SRC's Neutron Beam Research Committee for a new high intensity pulsed source based on a proton synchrotron spallation source at the Rutherford Laboratory. A substantial portion of this work has also fallen on other groups in the Laboratory, most notably the Instrumentation Division, which has been responsible for the design of the proposed accelerator. An outline description of the spallation neutron facility is given in Section 2.1.1. The NBRU has continued its support of the University neutron beam community which uses facilities at AERE Harwell, the Institut Laue-Langevin (ILL), Grenoble, and elsewhere. NBRU members have participated in a variety of scientific programmes using neutron beams, frequently in collaboration with University groups; a selection of current work is described.

2.1 Future Source Studies

2.1.1 Spallation Neutron Facility

Towards the end of 1976 a proposal was submitted to the Science Research Council for the construction of a high intensity neutron facility at the Rutherford Laboratory. The proposal has been prepared by a coordinating group under the auspices of the Neutron Beam Research Committee of the SRC, with the scientific case evaluated by four separate working groups of the neutron beam community and the source design undertaken by Rutherford Laboratory staff. The facility is specifically designed for the study of condensed matter by thermal neutron scattering and the source is based on a high-performance 800 MeV proton synchrotron with an external neutron-spallation target station and associated moderators.

No new buildings are required for the proposed facility as full use is made of the services and buildings that form the Nimrod complex. Use is also made of the existing 70 MeV proton linac injector and of the magnet power supply system from the NINA accelerator at Daresbury. The proton synchrotron is designed to provide $2{\cdot}5 \times 10^{13}$ protons per pulse, at an energy of 800 MeV, with a pulse duration of approximately 200 ns and a pulse repetition frequency of nominally 53 Hz. The source is estimated to yield 4×10^{16} spallation and fission neutrons per second from a uranium (^{238}U) target. The neutrons are brought to thermal and epithermal energies in two moderator assemblies, one cold moderator directly above the target and one ambient temperature moderator below. Special openings are made in the target shield wall to provide for the external neutron beam lines.

Existing Nimrod services, such as water cooling, air conditioning and electricity distribution, are more than adequate for the proposed source and can be used with little modification. Also, most of the shielding for the target station is available on site. Steel shield thicknesses of 4-5 m are required plus additional layers of concrete and special linings for the beam openings.

The 800 MeV synchrotron is designed to fit into the Nimrod magnet hall and to be compatible with a modified NINA magnet power supply. The mean radius is 26 m and the synchrotron components are arranged in 5 superperiods. Of the 5 long straight sections, 1 is for injection, 1 for extraction, 2 for RF cavities and 1 is free for diagnostics and developments. Charge exchange injection of negative hydrogen ions is employed, using a foil system for H^- stripping. The 70 MeV linac injector requires modifications for the rapid-cycling mode of operation and for the use of H^- ions in place of protons.

The 800 MeV protons in the synchrotron are extracted as a single turn 200 ns pulse and transported to the target station in Experimental Hall 3 using Nimrod beam line elements within a well-shielded enclosure. The proposed target material is depleted uranium 238. This material has been chosen since it gives a neutron yield twice that of non-fissile heavy metals. The mean power dissipated in the target is 350 KW and the 300 mm long target is segmented to allow adequate cooling. Narrow water cooling channels pass between the individual uranium plates which are clad with Zircaloy-2 which has a high corrosion resistance to water. The maximum temperature in the uranium is 600°C and the cooling is by nucleate boiling of the water. Targets will need to be replaced at intervals of 3-6 months. There is a gradual build up of radio-isotopes in the target and precautions are adopted to prevent the accidental release of these isotopes. Irradiated targets are handled entirely by remote methods, the total activity one day after shutdown being of the order of 100 kilocuries.

Target and moderator design are still under study and a prototype low power target is being installed in a 1 GeV external beam line at Nimrod. Moderator geometries and reflector materials will be evaluated on this prototype and the results compared with those obtained from detailed computer simulation programs.

It is planned to locate the main control room for the facility in the building that presently houses the Nimrod 15 MeV linac. Control of the 70 MeV linac, 800 MeV synchrotron and the target station will be undertaken by a central computer system, together with separate computers for the individual subsystems. The control system is considered an important feature for the successful operation of the high intensity source. The source could be completed and the first experiments under way by the end of 1982.

2.1.2 New Linac of AERE Harwell

The new electron linac at AERE, Harwell, is scheduled to commence operating in 1978, and a joint SRC/AERE programme of condensed matter research with neutrons is envisaged, following the successful exploitation of the previous machine which was closed down in November 1976. Rutherford Laboratory staff have been closely involved with the various working parties considering the design and applications of the new linac. A target cell group has considered the general user requirements of the experimental facilities, the arrangement of beam tubes around the target, the shielding of the target cells and the specification of the instrument hall. A target design team is studying the detailed design of the electron beam target, which will be water-cooled clad uranium. Measurements of heat transfer have been carried out at Rutherford Laboratory on an experimental rig to confirm the design parameters.

A moderator design team is considering the detailed design of the moderator assembly. To obtain acceptably narrow pulse widths for neutrons of energy less than about 0·2 eV, poisoned or cold moderators are required; for the latter, relatively few materials have the desired properties, and the optimum solution is not obvious. The use of reflectors to increase the slow neutron flux is also being considered. Computer codes are being adapted to simulate various moderator-reflector configurations. All this work is closely coupled to analogous studies for the Spallation Neutron Source.

2.1.3 Nimrod Spallation Measurements

Experiments on the production of neutrons by proton spallation reactions are being performed using Nimrod. A beam hole has been acquired at the X3 target station on one of the Nimrod 7 GeV extracted proton beams (Section 6.2). A small concrete block house has been built, and equipment installed to investigate neutron flux intensities and distributions for various target-moderator configurations. These measurements have provided valuable background experience for a full scale Spallation Neutron Source mock-up experiment.

2.2 Neutron Beam Instrumentation

2.2.1 Polarised Beam Techniques

Polarisation Analysis in the Thermal Neutron Region

A ^3He-^4He dilution refrigerator, which is to be used to cool the ^{149}Sm polarising filter, has been commissioned and thoroughly tested at the Rutherford Laboratory. The base temperature, as measured by ^{60}Co nuclear orientation thermometry has consistently reached 16 mK; this is achieved about 24 hours after ^4He is first introduced into the cryostat. The refrigerator and its associated control panel can be moved to different scattering angles by means of a motorised drive.

The complete system operated in the Badger I instrument area at the DIDO reactor at AERE, Harwell during tests on the metallic polarising filter material $Sm_{0{\cdot}025}\ La_{0{\cdot}975}\ Ag$. The refrigerator ran stably at 16 mK for the duration of the polarising efficiency measurements (~14 days). The polarising efficiency of the filter was estimated to be +6% by using the shim method with both Heusler Alloy and Co:Fe crystal polarisers. The shim ratio was greater than unity for the Heusler polariser and less than unity for Co:Fe, thus confirming that the filter polarising efficiency is positive, as predicted in earlier feasibility studies.

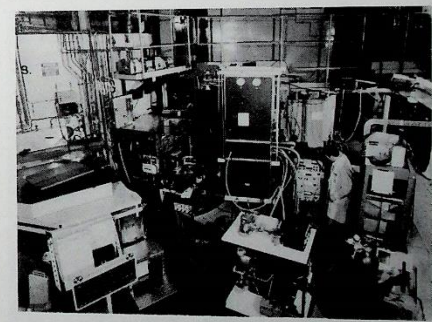


Fig 2.1 ^3He-^4He dilution refrigerator containing the polarising filter at DIDO

The metallic filter was cooled in the ^3He dilute phase of the dilution unit mixing chamber, and the measured transmission loss due to ^3He absorption was encouragingly low (~7%). It is believed that the low polarising efficiency is due to the majority of the Sm^{3+} ions in the sample being antiferromagnetically coupled, or at least having a zero net magnetisation, and tests on other materials with greater minimum Sm-Sm separations including the double nitrate CSMN are planned when the equipment is re-installed in DIDO (Fig 2.1).

Polarising Methods for Cold Neutrons

Steady progress has been made towards the construction of long wavelength ($\lambda > 5$ Å) polarising Soller guide, and a prototype, with beam area 3 cm x 0·5 cm, has been successfully tested at ILL. Following a series of measurements on single reflections from thin films of alloys of different cobalt:iron composition deposited on to different plastic substrates, an alloy with composition Co_{75} Fe_{25} deposited on to polymethylpentene (TPX) was selected as the best polarising surface for the guide channels. A by-product of these measurements was the observation, for the first time, of the interference of neutrons reflected from thin metallic films.

The prototype curved polarising guide (length $\sim$ 0·16 m) (Fig 2.2) gave a polarising efficiency of about 95% with a transmittance of about 40% for the neutrons of the required spin state near its critical cut-off wavelength $\lambda^* = 7$ Å. The measurements have been compared with a computer model of the neutron transport through the channels; the comparison suggests that there was some non-uniformity in quality between different reflecting films in the prototype. It is believed that this problem will be remedied when the metallic films are deposited using a new electron beam source in a vacuum deposition facility since the effect is almost certainly due to excessive heating of the plastic substrate with the resistive heating method which has been used hitherto. Two polarising Soller guides (polariser and analyser) for the IN 11 spin-echo spectrometer at the ILL are now being constructed.

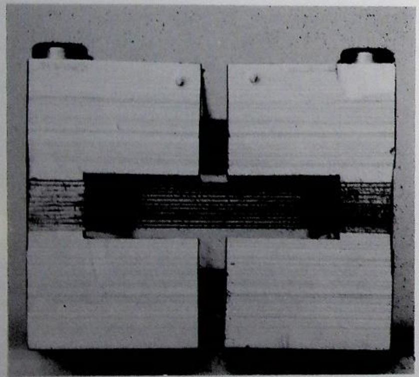


Fig 2.2 Prototype curved polarising guide

In order to obtain an absolute calibration of the efficiencies of long wavelength polarisers, a Stern-Gerlach polarimeter has been constructed (Fig 2.3) which can be used to spin-analyse beam areas of about 0·2 x 3 mm² for wavelengths $\lambda > 3{\cdot}5$ Å. The apparatus, which is basically a 1m long water-cooled electromagnet, has been successfully tested at the Herald reactor at AWRE. The Stern-Gerlach system allows the polarisation of polychromatic beams to be measured directly, and it is planned to use it to obtain a full characterisation of the wavelength dependence of the polarising Soller guides; it may also be used for the calibration of any long wavelength polarised beam instrument.

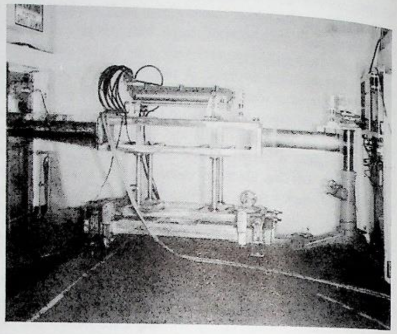


Fig 2.3 Stern-Gerlach polarimeter at the Herald Reactor

Neutron Spin Flippers

There are four types of spin-flipper which may be used to reverse the neutron spin polarisation with high efficiency ($\sim$ 99%); these are a) the r.f. spin flipper, b) Mezei spin flippers, c) the Drabkin two-coil flipper and d) the Dabbs foil or current sheet flipper. The principle of operation of spin flippers a) and b) depends on the neutron spin undergoing a well-defined number of Larmor precessions in a fixed magnetic field and over a well-defined distance; their flipping efficiencies therefore depend on the neutron velocity (or wavelength) and the magnetic field homogeneity over the flipper. In spin flippers c) and d) the neutron spin experiences a fast magnetic field reversal which it cannot follow adiabatically, and the neutron polarisation is reversed by an action which is not critically neutron velocity-dependent. Spin flippers c) and d) can therefore be used with white beams and they are potentially suitable for pulsed source instruments.

The efficiencies (with 1 Å neutrons) of a Drabkin two-coil flipper and a Dabbs foil flipper have been measured. A 100% flipping efficiency was measured along the coil axes of the Drabkin flipper, and the decrease in the off-axis efficiency was attributed to a magnetic guide field mismatch at the ends of the flipper, rather than to the problem of achieving a sufficiently sudden field-reversal region between the foils, as had been previously postulated by other workers. The Dabbs foil also gave high flipping efficiencies (> 99%) in an optimized arrangement of the magnetic guide fields; however its performance was even more critically dependent on the interaction between the guide and flipper fields than was the case for the two-coil flipper.

2.2.2 Guide Tubes

Further measurements of the transmission of the experimental 5° "bender" were carried out on the 4H5 beam hole at the DIDO reactor at AERE, Harwell. By careful optimisation of the alignment of the bender, the transmission efficiency was increased from 0·4 to 0·5 at a wavelength of 12 Å. The variation of efficiency with wavelength was also measured and good agreement with computed values was obtained. A new bender with the same geometry but having 50 films, ie a more practical device capable of accepting a 1 cm wide beam, was completed. The larger number of films made construction more difficult and the alignment of the films was less satisfactory than in the smaller device. However, measurements of transmission gave values of over 0·4, only marginally lower than those obtained with the earlier bender.

Alternative methods of manufacture based on the Melinex collimator ideas are being examined with the objective of making rather larger benders, with apertures of several tens of square cm and radii of curvature of a few metres. A vacuum coating facility was commissioned and used to deposit copper and iron-cobalt alloy on Melinex films for use in both benders and polarisers (Section 2.2.1). This facility was improved towards the end of the session with addition of a larger, stainless steel vacuum tank and an electron beam evaporation source.

2.2.3 Fine Slit Collimators

Soller collimators with stretched Melinex film blades, as described in the 1975 Report, have proved very successful. 31 collimators have been delivered to laboratories in various countries and another 10 are on order. The total value of collimators supplied and on order is approximately £25,000. Two local firms are now able to manufacture these devices. Some simple experiments have been done on the susceptibility of the collimator blades to radiation damage by placing some close to the target of the Harwell linac, ie in an intense γ and fast neutron flux. Embrittlement of the Melinex films is noticeable after an accumulated dose of 1 megarad, though the gadolinium oxide loaded paint showed no visible degradation. A blade made from stretched aluminium foil was unaffected by several megarads and a complete collimator with these blades is being constructed for evaluation as a device suitable for use as a "first collimator" in the main beam where the radiation levels may be high.

A "reflecting collimator" has been constructed ie a device having blades with reflecting, rather than absorbing, coatings. The coating material is chosen so that the critical angle for reflection equals the required angle of collimation at the wavelength of interest. Thus, neutrons incident at angles less than the critical angle, which would have been lost on an absorbing surface, are transmitted while those incident at angles above the critical angle enter the Melinex film and are scattered out of the beam. The transmitted beam intensity should be double that of an absorbing collimator. The device will be evaluated on the G1 hole at AWRE.

2.2.4 Position Sensitive Detectors

The use of coincidence techniques to reduce electronic noise has been applied to a new Position Sensitive Detector (PSD) system. In this system the neutron convertor is an array of separate pieces of scintillator each of which is coupled by flexible glass fibre optics to three photo-multipliers (PMs) out of a set of N. By accepting only output pulses which are coincident in time on three PMs, each combination of 3 out of N codes one channel of positional information, ie the number of channels which can be coded by N PMs is N!/(3!(N-3)!). Thus 20 PMs could code 1140 channels. A prototype detector module using 9 PMs and having 84 channels in a linear array has been constructed. The elements are 50 mm high and 3 mm wide (ie a spatial resolution of 3 mm). These particular dimensions were chosen to suit the D4 liquids instrument at ILL where it is intended to test the module. Since the resolution of the detector is set by the mechanical construction, it is very stable and accurately known. Also, the only active components in the detector itself are the PMs which are standard commercial tubes with good reliability. In the event of a fault on a PM, the system is "self-diagnosing" ie the particular combination of channels which are affected identifies the faulty tube. Replacement is easy and inexpensive.

Preliminary evaluation of the prototype has been carried out using a hard wired decoder giving 84 separate output channels, each one being used to set one of 84 latches which are then interrogated by a PDP11/05 computer every time an output pulse is detected, the accumulated count on the particular channel being increased by one each time ie the system operates in a pulse counting, digital mode. Visual display of the count on each channel is available together with teletype printed output. Excellent results have been obtained with respect to the uniformity of response from channel to channel and also over each resolution element. The electronic noise (the count rate with no sources present) is exceptionally low (eg < 6 counts per hour per channel). The detection efficiency using lithium loaded, zinc sulphide scintillator, is moderate, a value of 40% at 1 Å being measured by direct comparison with a gas counter. Methods of improving this by the use of multilayer sandwiches of neutron converter and plastic scintillator are being investigated.

2.2.5 Instrument Control and Data Acquisition

Software development

A Digital Equipment Corporation 32K PDP 11/40 computer has been installed and commissioned. It will be used to develop specific program packages for use in data acquisition, to study the application of on-line graphical techniques as aids to neutron scattering experiments and to produce more flexible instrument control systems. Systems software development has included the installation of a number of real-time operating systems, the writing of software to drive a Tektronix 4010 graphics display and a start has been made on linking the PDP 11/40 to the Laboratory's IBM 360/195 for its program archival and line printer facilities. An applications program to derive an improved orientation matrix for a crystal, from which a limited number of reflection angles (ω and ν) have been measured, has been implemented on the PDP 11/40 and is now available for use on instruments at the ILL.

Microprocessor System for the Control of Mechanisms

A study has been made of the possible use of a microprocessor system to automatically control the positioning of up to 8 mechanical movements of a neutron beam scattering apparatus. Sixteen bit microprocessor systems that were readily available on the market were examined in detail to assess their software and hardware capabilities. The programme and data store requirements, the ease of interfacing external devices to the system and comparative costs were investigated. The selected microprocessor system has now been purchased and an interface to control the positioning of one shaft has been designed and manufactured. A shaft simulator has also been designed and will shortly be tested. The system is now being commissioned using paper tape-based software.

2.2.6 Pulsed Source Instrumentation

A liquid nitrogen cooled polyethylene moderator built at the Rutherford Laboratory was successfully mounted on the Harwell linac during 1976. The function of the moderator is two-fold, first to give sharper and clearer pulses in the thermal range, and secondly to obtain more cold neutrons. The flux distributions from a thick ambient polyethylene moderator are shown in Fig 2.4. The 0·001 inch foil was present also for pulse length reasons, preventing the build up of a large Maxwellian distribution having long pulse times. The cold moderator is seen to shift the Maxwellian from the 1 Å region to the 2 Å region, and so preserve good pulse shapes in the 1 Å region. The 77K moderator gives a Maxwellian with a peak at 1·93 Å corresponding to an effective temperature of 102K. It is seen that there is a residual thermal Maxwellian of low intensity. Its cause is not known, but it appears stable in intensity and should give no ill-effects. The gain factor of the new moderator over the Gd foil moderator is also shown in Fig 2.4. Gains of 7 or so occur at 3 Å, and the loss at 1 Å of about 0·6 is compensated in figure of merit terms by the 30% decrease in pulse width.

A notable feature has been the low nitrogen consumption, corresponding to a nuclear heating in the moderator of less than 50 watts. The system was designed and tested for a 400 watt heat load and it may prove possible to use the present moderator on the new linac. The improvement over earlier estimates of heating is partly from a lead wedge between target and moderator which severely attenuates gamma heating without noticeable effect on the neutron spectrum.

Close collaboration continued between NBRU and AERE staff on a number of instrument projects on the Harwell linac prior to its close-down in November. The chopper experiment described in the 1975 Report was successfully commissioned, and the apparatus has been scheduled for routine use as an inelastic spectrometer. This work has been supplemented by tests with a beryllium filter device encouraging the implementation of a full scale filter instrument on the new linac.

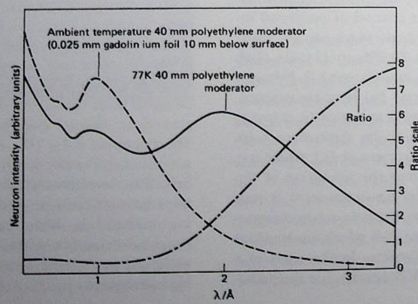


Fig 2.4. Neutron flux distributiona from two moderators in the AERE linac

2.2.7 Equipment for ILL

The NBRU is collaborating with ILL in the design and manufacture of an ultracold neutron (UCN) facility to be installed on an inclined beam hole at the ILL reactor. The in-pile part of the facility, together with an oil-free vacuum pumping unit, is being supplied by the Rutherford Laboratory. The former consists of a cylindrical stainless steel guide tube, 6 m long and 70 mm diameter with the internal surface honed and electropolished to achieve the best possible surface quality. Sample tubes, 2 m long and finished in this way were tested for transmission of cold neutrons (velocity about 20 ms^{-1}) at ILL with encouraging results. The inner end of the guide tube is sealed by a rounded Zircaloy window which transmits UCNs from the cooling water surrounding the tube, which acts as a room temperature converter. The Zircaloy window is joined to the stainless tube by electron beam welding to a special Zircaloy-aluminium-stainless steel transition piece formed by friction welding. The intermediate aluminium section is exceptionally thin (a fraction of a millimetre) to minimise losses of UCNs.

An aluminium outer casing is used with a very thin concentric stainless tube between it and the guide tube to separate the inlet and outlet cooling water flows. The standard ILL beam hole shielding components are used with some internal parts remade to suit the UCN assembly. Test rigs have been built for checks of water flow, leakage across the thin intermediate tube and pressure testing of the whole assembly. Measurements of the coefficient of heat transfer across the intermediate tube have been made. The mechanical design is complete and delivery of components is proceeding.

The mechanical and electronic components for a fourth shaft on D3 have been delivered to ILL and brought into service to allow the use of a superconducting magnet on this instrument. A shaft encoder/motor simulator was developed at Rutherford Laboratory for checking shaft drive systems. A duplicate of this device has been supplied to ILL. A duplicate of the D3 flipper control unit was also supplied for use on the D7 instrument.

2.3 Current Programme Support

Throughout the year, the NBRU has continued to be actively involved in the SRC support of UK university teams engaged in neutron beam scattering programmes. The UK university community and the programme of work associated with this field is still growing. Nearly 280 university staff, research associates and research-students are now involved in the current SRC-supported programme on reactors in the UK and abroad. Proposals for SRC-supported experiments on reactors at home or abroad are made twice a year through the NBRU. A total of 379 proposals was submitted during the year, compared with 298 in 1975. 137 of these were for experiments on UK reactors, 237 for ILL, Grenoble, 2 for Jülich, Germany, 2 for Risø, Denmark and 1 for Saclay, France.

The NBRU is responsible for funding approved experiments by university teams, ie for travel, subsistence, materials and equipment. Nearly 570 claims for travel and subsistence were processed during the year and 10 new Rutherford Laboratory/university agreements were set up. Some of the early agreements have now expired and currently there is a total of 25 agreements in operation for this type of funding. The Unit is also able to purchase directly items of equipment of general use for loan to university teams, for example a Perkin-Elmer infra-red spectrophotometer – currently at ILL – and supplies of separated isotopes. UK university teams have continued to expand their use of facilities at ILL Grenoble. Part of the NBRU's service to users is to provide close contact with ILL staff and a liaison service for UK users. Over 230 visits to the Institut were arranged during the year, compared with 170 in 1975, most of these being for experiments on the reactor. Transport of equipment and samples for these experiments has been provided on over 90 occasions.

The NBRU has provided computing support for university users of both the AERE, Harwell, and ILL neutron beam facilities. 14 university groups have been individually helped with data-handling or programming problems, mostly connected with work at the ILL. In addition, the changeover to the FR80 graphics device has involved the unit in considerable rewriting of the AERE data reduction programs which produce graphical output. Completely new data reduction programs have been written for the graphical display of data originating from the D11 small-angle scattering apparatus, the CURRAN powder diffractometer and time-of-flight instruments.

A joint NBRU–SRC London Office Secretariat has been set up for the Science Board's Neutron Beam Research Committee with effect from 1 October 1976 as part of the SRC's new arrangements for central facilities.

A one day meeting on profile analysis techniques in neutron powder diffractometry was held at the Rutherford Laboratory on 4 March 1976. Some 60 participants from the Universities, AERE, AWRE and the Rutherford Laboratory attended. Work is now in hand, in collaboration with Oxford University and the ILL, to include the necessary profile refinement and least squares modules in the Cambridge University Crystallographic Subroutine Library. This Library and a number of the more frequently used main programs are now available on the Rutherford Laboratory's IBM 360/195.

2.4 Participation in Neutron Beam Science

Standard Calibration Samples for Long Wavelength Studies

The use of calibration samples falls into two categories:

1) The normalisation of instrument geometry ie, normalising detector solid angle and efficiency.

2) The placing of the measured scattered intensity onto an absolute basis to give differential cross-sections.

To date vanadium has been used almost exclusively and for shorter wavelengths ($< \sim 4$ Å) it is an ideal material with an incoherent cross-section of ~ 5 barns atom^{-1}. For thin samples at shorter wavelengths the scattering is strong and corrections for multiple scattering, absorption and self shielding are relatively easy. Under these conditions the scattering is fairly isotropic (ie, the corrections mentioned are small). At longer wavelengths ($\lambda > \sim 4$ Å), however, the absorption plays an increasingly important part so that at 10 Å for instance the absorption is five times the scattering. This leads to a very large angular dependence of the resulting scattering as absorption path lengths vary as a function of angle for both planar and cylindrical samples. As a calibration sample this is clearly unsatisfactory. Furthermore, the diffuse scattering spectrometer D11B at the ILL will be able to operate to wavelengths of 20 Å and there is clearly a need for good calibration samples at these wavelengths. As the wavelengths considered are beyond the Bragg cut-off, diffraction and multiple diffraction are no problem. A consideration of elements with published incoherent and absorption cross-sections shows that hydrogen and deuterium are good contenders as both have very high ratios of incoherent to absorption cross-sections. Another contender is zirconium which has a published $\sigma_{inc}/\sigma_{abs}$ of 14 at 1·08 Å, just over seven times that of vanadium. Test experiments on the Harwell 'Glopper' with a cylindrical sample of zirconium have been made and these were very encouraging as far as scattered intensity is concerned. However, further materials, namely polyethylene and copper, are also under consideration and experiments on these are scheduled.

Use of Standards in Polarisation Analysis Experiments and Measurements of Multiple Scattering in Vanadium

The determination of spin-flip and non-spin-flip scattering cross-sections by the polarisation analysis technique provides a powerful method for separating incoherent (nuclear spin and/or paramagnetic) and coherent scattering. It has been shown that for samples which do not give well-defined Bragg peaks, and where either the incoherent or coherent cross-sections dominate, the precision achieved in this separation depends strongly on the errors involved in the calibration of the polarisers and spin-flipper of the polarisation analysis instrument, and particularly when large scattering samples are used, on a proper evaluation of the multiple scattering in the sample. A series of experiments was carried out (in collaboration with University of Kent) to measure these effects on the D5 spectrometer at the ILL, and tests made on possible standard scatterers for future experiments.

Profiles of the incident beam polarisation and spin flipper efficiency over the beam area at the scatterer position were obtained by measuring direct beam flipping ratios with both Heusler and Co:Fe crystal analysers. This enabled a beam area to be selected for the scattering experiments over which these parameters were constant to ± 0·5%. With a pyrolytic graphite monochromating crystal as the scatterer, the flipping ratios measured for the (0,0,6), (0,0,8) and (0,0,10) reflections with the Co:Fe analyser were equal, within the measurement error, to the direct beam flipping ratio. It was concluded therefore that pyrolytic graphite is a suitable scatterer to check the calibration of polarisation analysis instruments, and that, in particular, it can be usefully employed to reveal instrumental depolarisation effects. An attempt was made to use the amorphous non-spin-flip scatterer perfluoro polyethylene to cross check the instrument calibration; this gave flipping ratios significantly different to those for the direct beam, and it was concluded that this was due to a small hydrogen impurity in the specimen.

The use of vanadium as a standard relies on understanding the multiple scattering. Using a vanadium sample of area 9·5 cm x 4 cm and thickness 2 cm the flipping ratio at various scattering angles was measured with the Co:Fe analyser and Heusler crystal polariser; in this mode of operation the calculated flipping ratio is insensitive to the value used for the spin flipper efficiency. The calculated flipping ratios (using the instrument calibration parameters together with a Monte-Carlo evaluation of the multiple scattering in the sample) at three angles of scatter (30°, 50° and 70°) were found to disagree significantly from those determined experimentally. A thorough examination of the experimental arrangement led to the conclusion that the disagreement was due to a geometrical effect where all the primary scattering, but only 72% of the multiple scattering, entered the detector. Experimental tests of this hypothesis are shortly to take place.

Local Atomic Arrangements in Titanium-Zirconium

The α–β isomorphous titanium-zirconium system is particularly attractive to study by neutrons, as null-matrix alloys may be made. Measurements (in collaboration with ILL) have previously been made over a wavevector transfer $|Q|$ of 1·5 Å^{-1} to 17 Å^{-1} at various temperatures between 450°C and 700°C. Recently low $|Q|$ data have been taken on the 'Glopper' to determine the sign of the first short range order parameter (indicating clustering or short range order). Although not fully processed, data taken from 0·1 Å^{-1} $< |Q| <$ 2·5 Å^{-1} indicates that clustering takes place over the phase regions 450°C and 700°C. Detailed analysis will enable short range order parameters to be extracted.

Magnetic Studies

There have been several neutron diffraction investigations of the magnetic properties of materials which crystallise with the orthorhombic MnP type structure. All investigators agree that the observed magnetic satellite intensities correspond to a "double spiral", but there are at least two differing descriptions of the details of the moment distribution. In MnP all Mn atoms are thought to have the same moment, but the envelope of the spiral is elliptical with the longer axis parallel to b̲. In FeP, the two spirals are said to have different Fe atom moments, but a circular envelope. The magnetic structures of MnP and FeP are now being re-examined in collaboration with Queen Elizabeth College, London at the ILL. Polarisation analysis measurements have been made on (hoℓ) satellite reflections from a single crystal of MnP at 4·2K. In no case did the observed flipping ratio differ from unity by more than 10%. For the instrumental geometry used, these observations indicate that the components of magnetisation perpendicular to c* of the orthorhombic unit cell are at most 5% different in magnitude. This result does not agree in detail with the magnetic structure proposed by Forsyth, Pickart and Brown, who deduced from unpolarised beam measurements that the components of magnetisation perpendicular to c* differed by some 18%. The new analysis does, however, agree that the component parallel to b* is the greater. The observations are also inconsistent with a two-moment, cylindrical-envelope model of the type proposed for FeP by Felcher et al. A similar experiment will be carried out on FeP.

The intermetallic compounds FeGe and MnSi are isostructural (B20) and ferromagnetic. Their bulk magnetisation behaviour is similar and surprising, showing no zero field remanence or hysterisis. These observations suggest that the materials may be antiferromagnetic in zero external field, and Beckman et al postulate the existence of a conical spin system in cubic FeGe which collapses to ferromagnetism when an external applied field is increased to 0·2T. Neutron diffraction experiments in zero field have indicated a ferromagnetic moment of 1·0 μB/Fe atom in FeGe and 0·4 μB/Mn atom in MnSi. The neutron small angle scattering from powder samples of both materials at temperatures between 4K and ambient has now been examined in collaboration with QEC London and the ILL. In both cases a strong, low-angle diffraction ring was observed below the magnetic ordering temperature. The corresponding real space repeat distances were found to be 19 ± 1 nm and 70 ± 1 nm in MnSi and FeGe respectively. The application of a magnetic field perpendicular to the neutron beam direction causes these rings to collapse into sharp diffraction spots with scattering vectors in the direction of the field. No changes in the repeat distances are apparent.

Removal of the field leads to a partial recovery of the original patterns but, in addition, there is appreciable intensity in a position corresponding to a 35 nm repeat in FeGe. A similar effect is observed in MnSi, but the second order component is much less intense. These observations are consistent with the rotation of the propagation vector of a helical spin structure toward the direction of the magnetic field. Simultaneously, the field-induced ferromagnetic moment is increased, which results in a reduction of the magnitude of the observed helical component. The effects are produced by lower fields at temperatures near the transition temperature.

The spin wave dispersion in Fe_3Si has been measured in collaboration with the ILL. Fe_3Si is a ferromagnet with two crystallographically inequivalent iron sites, Fe_I and Fe_{II}, which have moments of 2·23 μB and 1·07 μB respectively. The primitive unit cell contains three magnetic atoms, two of Fe_{II} and one of Fe_I. There are thus one acoustic and two optic branches to the dispersion curve. The acoustic branches have been measured out to the zone boundary in the [00ξ], [0$\xi\xi$] and [$\xi\xi\xi$] directions. Some further measurements are necessary at low momentum transfer to separate the magnon and phonon excitations in this region. The results show that the spin wave stiffness constant, D, is higher than predicted by Leoni and Natole.

The spatial distribution of the aligned susceptibility in K_2ReCl_6 has been studied in collaboration with AERE at the ILL. Polarised beam measurements were made on reflections lying in the zero, first and second layers for specimens with <110> vertical. Flipping ratios for twenty five independent reflections, together with at least one equivalent, were measured at 0·989 Å. The sin θ/λ limit of these data is 0·5 Å^{-1} and the largest residual flipping ratio, (R–1), was 17 x 10^{-3}. The radial form factor calculated for neutral rhenium from Hartree-Dirac-Slater wave functions by Cromer and Waber becomes negative at about 0·36 Å^{-1}, and the data show very marked departures from this theoretical curve. A preliminary analysis shows that, although some part of these deviations is due to a departure from spherically symmetric magnetisation density on the Re ions which is due to the cubic crystalline field, there are still major differences which must be attributed to the covalent bonding to the Cl octahedra.

Liquid Metals

In the study of simple liquids it has become clear that a greater understanding may be achieved if both the coherent and incoherent dynamical structure factors $S(k,\omega)$ and $S_s(k,\omega)$ are known for the same liquid. These functions have been measured for liquid nickel in collaboration with Imperial College, London and AERE. A lengthy data treatment procedure to correct for multiple scattering and resolution effects has been completed, and the resulting functions compared with several theoretical models. These measurements provide the first values of $S_s(k,\omega)$ and the first dual measurements of $S_s(k,\omega)$ and $S(k,\omega)$ for a liquid metal.

Crystalline Electric Field Effects in Rare Earth Hydrides

Investigations into the effect of the hydrogen concentration in non-stoichiometric praesodymium hydrides/deuterides on its crystalline electric field levels have been carried out on IN4 and IN5 at ILL, in collaboration with Birmingham

University. Previous measurements by other investigators on $PrD_{2.0}$ and $PrD_{2.5}$ have led to the belief that the hydrogen/deuterium is present in a negatively charged form. Observations on IN5 of low-lying energy levels cast doubt on this interpretation and it may be that the hydrogen/deuterium is present in a protonic form.

Neutron Scattering from Palladium Hydride

High resolution measurements of the quasi-elastic broadening due to scattering from the diffusing hydrogen in the β-phase of palladium hydride have been carried out (in collaboration with Birmingham University) on the IN5 spectrometer using a sample of palladium black. Previous uncertainties in the data from reflection and transmission geometry have now been accounted for. In the low momentum transfer |Q| region the data fit well to the Chudley-Elliott jump diffusion model but deviations from this theory occur at higher values of Q. It is thought that those deviations are due to positional correlations of the hydrogens at low temperatures and, in order to predict the measured shape of the data, the diffusion mechanism of the hydrogens must be represented as a series of jumps which are correlated to each other. In order to investigate the Q behaviour of the jumping process more accurately measurements have recently been carried out on a single crystal of β-phase palladium hydride when the broadening can be represented by a single Lorentzian rather than as an average of many Lorentzians as is the case for a powder. In this way the deviations from the Chudley-Elliott model should be more easily observed and accounted for.

3 Laser Research

During 1976 the work of the Rutherford Laboratory's Laser Division steadily increased. In the early weeks of 1976 the orders for the Laser and some major pieces of experimental and diagnostic equipment were placed. The strength of the Division grew from six at the beginning of the year to twenty at the close of the year. Four specialists in Lasers and Laser-plasma interaction physics were recruited and two university scientists were seconded to work full time at the Laboratory.

3.1 Laser Equipment

The Laser installed at the Rutherford Laboratory is designed to deposit approximately 800GW of beam power in sub-nanosecond pulses onto targets less than 100 μm in size. Based on Nd:glass as the active medium, the laser consists of an oscillator pulse generator followed by a sequence of amplifiers and beam control elements (see Fig 3.1). It is conveniently divided into a single beam 'driver' stage and a double beam 'booster' stage. The driver stage became fully operational in November 1976 and is able to deliver 100GW onto targets in pulses from 25 ps to 200 ps in duration. Acceptance tests, based on 100 full power shots and measuring parameters such as energy, pulse duration, beam quality and the shot-to-shot repeatability of these quantities are satisfactorily completed. These showed that target intensities as high as 10^{16} W/cm^2 are currently possible. This puts the Rutherford Laser amongst the top six in the world for highest irradiance coupled to high reliability. In addition to providing pulses for target experiments measurements have been made on the driver Laser to fully analyse its performance. Measurement facilities allow full characterisation of the pulses to be made and the Laser is monitored to provide a rapid diagnosis of any departures from optimum operation.

The final booster stages of amplification in the high power Laser system are provided by the 108 mm aperture disc amplifiers. Acceptance testing of this equipment was carried out in September 1976 at the contractors plant in California during which the amplifiers were shown to perform up to specification from an optical and electrical point of view. The two amplifiers and their associated power conditioning equipment were delivered to the Rutherford Laboratory in early November 1976 and installation started soon afterwards. At that time, following the installation of the two supplementary rod amplifiers (see Fig 3.1), the Laser will be able to provide 800GW pulses (400GW per beam) for compression experiments.

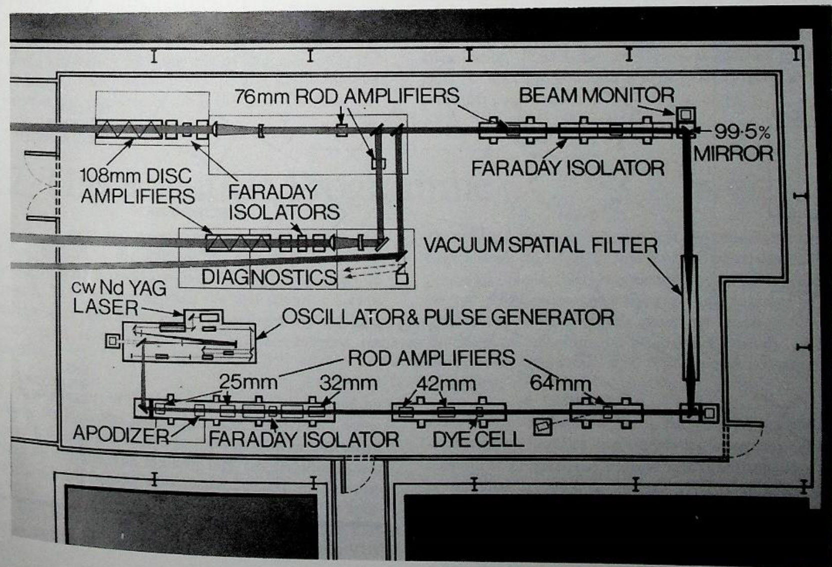


Fig 3.1. Configuration of equipment

To match the delivery and installation time scales offered by the suppliers of the Laser components it was necessary to modify and use existing buildings in the Laboratory. High power Lasers demand a very clean environment to prevent contamination of surfaces in the high power beam and they demand very high mechanical stability to maintain alignment. 10 μm specks on a surface can be burnt into and damage that surface at high power densities. The necessary environmental conditions were specified to the Council Works Unit who carried out the necessary work to provide:

(a) The Laser Area clean room to house the 100GW driver, Supplementary Amplifiers and disc amplifiers (see Fig 3.1). This is a class 100,000 area held to 20°C ±1°C and 45%±10% R.H.

(b) An adjoining experimental area panelled to give a nominally stable and isolated environment (see Fig 3.2).

(c) A Laser and experimental control room fitted with power distribution switches and protection systems.

(d) An energy storage room, to house the capacitors, charging units and ignition switches required by the disc amplifiers.

(e) A clean assembly area in which to assemble the disc amplifiers, consisting of a class 100 vertical laminar flow area 17 feet by 12 feet and surrounding area of the same size at class 10,000 containing the cleaning equipment.

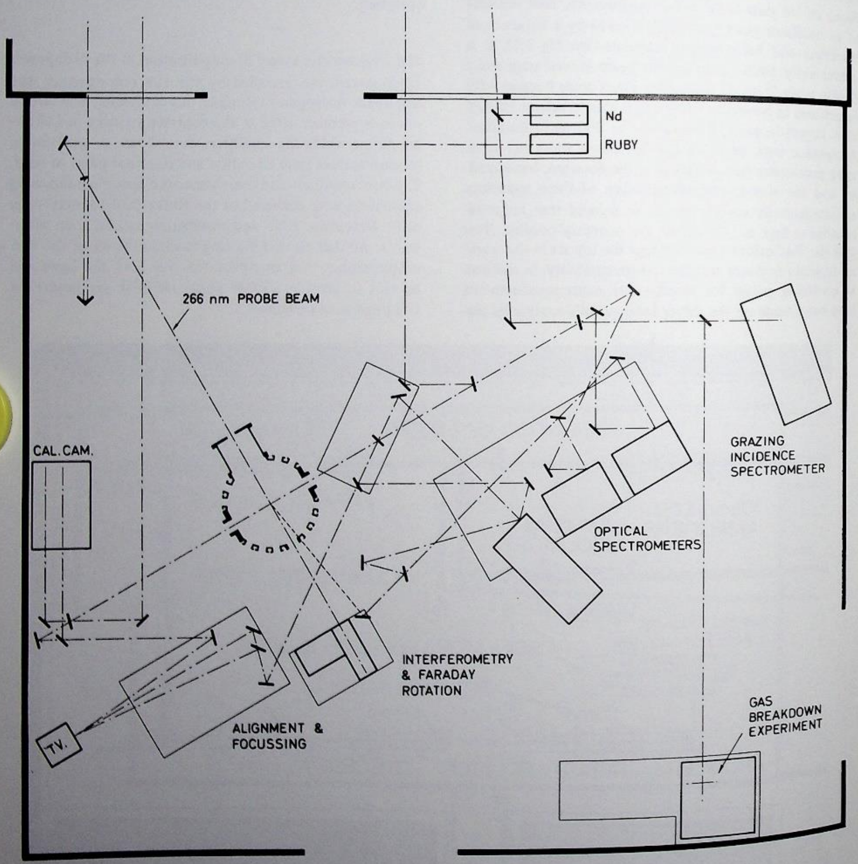


Fig 3.2. Layout of target area

A programme of topics in plasma physics and non-linear optics, using single beam-plane target interactions, was agreed upon. Resulting from the requirements to house the necessary diagnostic devices around the plasma, a Target Vessel has been designed and constructed (see Fig 3.3). Its geometry is based on a sphere approximately 1 metre diameter, the shell having some 38 flanged ports for laser beam entry and diagnostic devices. The shell is fitted with an automatic vacuum system, and houses an optical bench mounted through the vacuum shell onto the concrete floor. On the bench is the target mount which can be translated in x, y and z directions, and two lens mounts which can also be adjusted in x, y and z directions, and tilted on horizontal and vertical axes. Some of the controls for these movements are brought outside the vacuum and can be adjusted to ±10 μm.

It was decided early in the project to provide on-line computing facilities for the High Power Laser. The computer chosen was a GEC 4080 which will be used for surveillance, data acquisition and analysis and fault diagnosis. CAMAC was chosen for the computer interface and experimenters will be encouraged to make maximum use of the facilities this offers, using commercially available modules whenever possible. A transient digitizer with CAMAC interface is available which gives the capability to analyse fast waveforms. It is planned to interface the streak cameras to the computer using Optical Multichannel Analysers (OMA) so that phenomena requiring pico-second time resolution can be handled. The GEC 4080 is connected, via a data-link, to the main Laboratory computers thus allowing very extensive data analysis.

The 100GW driver and the 800GW main amplifiers of the Laser having been supplied by different manufacturers leaves the Laboratory with the task of interconnecting the two sections. The manufacturers of the Driver System emphasised the interference from the Disc Amplifier discharge circuits could adversely affect the performance of their circuitry. To obviate any problems that may arise, optical isolation has been used for interconnection between the systems. Timing delays have been provided for synchronisation. Flash lamp check circuits and fast gating circuits for laser protection in case of Faraday isolator misfire are under construction.

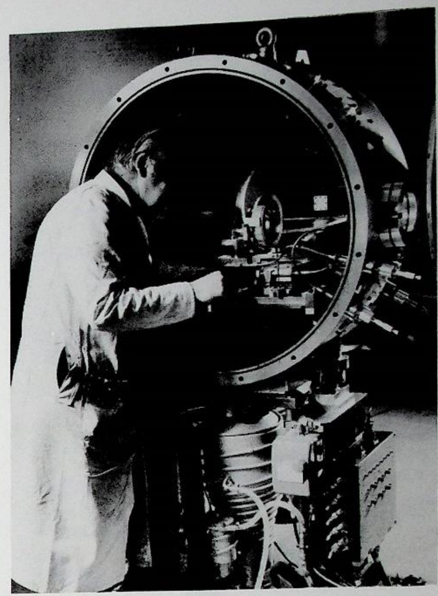


Fig 3.3. Target Vessel

3.2 The Scientific Programme

In 1976, the scientific programme progressed from broad outlines, defined at the stage of the project proposal and approval, to specific plans and development of experimental apparatus. The year also brought the first scientific data in December with preliminary experiments in grazing incidence vacuum ultra violet spectroscopy and laser-induced gas breakdown.

Fig 3.4 shows part of the emission spectrum generated by focusing 50 gigawatts power from the single beam driver stage of the laser to a 40 micron focal spot on an iron target surface in vacuum. The resulting high temperature plasma emitted radiation in the VUV region from ion species ranging from Lithium like Fe^{23+} to Neon like Fe^{16+}. The spectrum was recorded with apparatus from SRC Appleton Laboratory as part of their study of solar and laboratory VUV spectra.

The start of data acquisition is just the observable tip of a large iceberg of effort on the part of university and SRC personnel. Some thirty university physicists representing ten university research teams have come together in committees and working parties under the broad headings of 'Single beam experimental programme', 'Study of Laser compression of matter', and 'Theory and computational modelling'.

Plans have been made for Phase I activity during which the experimental facilities and supporting computer programmes will be progressively brought into operation. This phase is expected to continue through 1977. University groups have also undertaken to develop both apparatus and computer programmes using their own facilities supported in part by eight University agreements. Fabrication of targets is being undertaken at the Rutherford Laboratory and it has

Laser produced spectra of iron produced with 100 GW laser of Central Laser Facility and Naval Research Laboratory operated at 50 GW 56 GW respectively

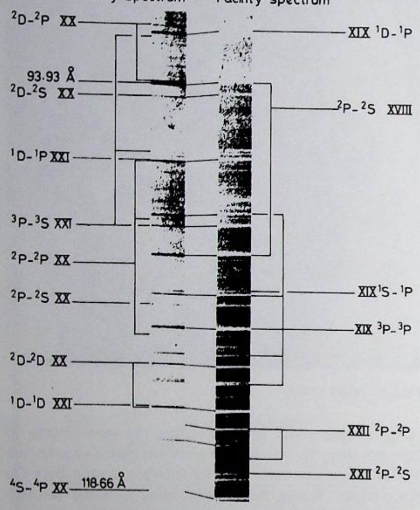


Fig 3.4.

already been possible to select and mount microsphere targets for implosion experiments as shown in Fig 3.5.

Computer work has included development of codes for optical design, and design work on aspheric clamshell reflectors for focusing 11 cm diameter Laser beams at 160° cone angle. Hydrodynamic computer codes for spherically symmetrical implosion simulation and for two-dimensional plane target interactions have been established at Rutherford Laboratory from sources elsewhere and will be further developed and used to support the experimental programme.

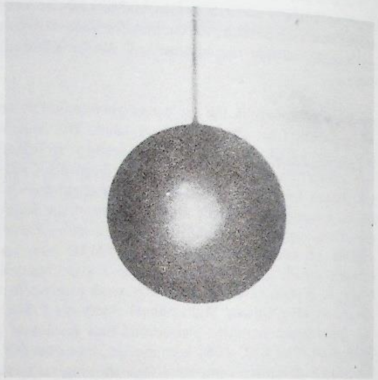


Fig 3.5. Microsphere target for implosion experiments

4 Technology and Instrumentation

Front-line research in physics requires sophisticated technical and engineering support. A substantial proportion of the Rutherford Laboratory's effort in technology and instrumentation is therefore directed towards the design, development and manufacture of complex experimental systems. At the same time, longer-term research is also undertaken in areas of potential importance in applied science and engineering.

Specific projects which involve a high degree of complexity stimulate continued technological development through the involvement of multi-disciplined project teams. Systems such as the Rapid-Cycling Vertex Detector and polarised target assemblies require ongoing research in areas such as cryogenics, mechanical engineering, optics and superconductivity for their advancement and for their efficient operation. The technical expertise acquired on such complex projects can find application outside the field of particle physics.

This expertise is now beginning to find use in the support of SRC Engineering Board programmes by the Laboratory, examples being the work done on quality control in the production of niobium-tin conductors in collaboration with AERE, Harwell, and IMI Ltd, and on an assessment for Euratom of superconductors for fusion reactor applications. Another illustration is the increased industrial use of Rutherford Laboratory computer programs for the calculation of magnetic fields.

An important part of the Laboratory's support work is the provision of a pool of trained manpower and tested project control methods to deal with continual requirements for individual items of apparatus as and when they occur. These requirements can range from tiny pieces of microcircuitry to huge electromagnets and vast arrays of particle detection equipment.

In particular, the trend towards larger equipment and more sophisticated instrumentation systems for particle physics research experiments continues, as does the demand for finer spatial and time resolution capabilities. Much work is being done to investigate ways of meeting these demands without incurring corresponding increases in cost.

4.1 Polarised Targets

4.1.1 Polarised Targets for High Energy Physics

A necessary requirement for the full understanding of a large class of particle scattering processes is a study of the spin dependence of the reactions. One way to accomplish this is by providing proton or neutron targets whose spin axes are preferentially aligned along a given direction. This can be effectively achieved by a process known as "dynamic polarisation" for which the necessary requirements are: the target material (usually an organic compound containing free protons), a high magnetic field, a very cold environment (0·5K) and microwave power.

Two targets have now been installed in beam lines in the experimental areas and a third is under construction. Although the targets are very different in their characteristics they have many components in common which allows efficient operation, maintenance and spares coverage.

Axially-Polarised Proton Target, PT–55 (Experiment 8)

The complete target system was assembled in the test area, early in the year (Fig 4.1). During tests, positive and negative proton polarisations close to 60% were obtained with propanediol. Since higher values had been expected, the various sub-systems were investigated thoroughly. Some deficiency in the cavity venting was detected resulting in a shortage of liquid helium-3 in the cavity. This was improved substantially by changes to the cavity design. The complete system has subsequently been installed in the beam line in Experimental Hall 1 in place of the liquid hydrogen target used for the first part of the experiment.

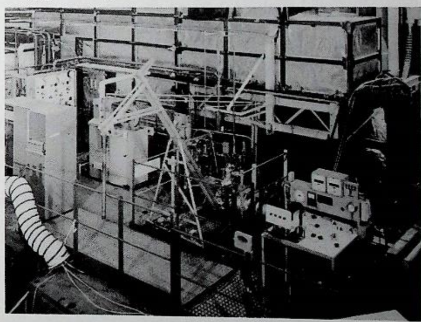


Fig 4.1. Installed axially-polarised proton target, showing the He-4 refrigerator and He-3 services.

Since September 1976, the superconducting magnet has been operated to allow a thorough investigation of the performance of the various particle detectors in the high magnetic field.

Now that these tests have been largely completed the system is being prepared for re-testing including polarisation before the experimental particle physics programme starts.

Polarised Deuteron Target

Summer 1976 saw the successful commissioning of the polarised deuteron target, in position in the K20 beam line (Fig 4.2), and this autumn saw it providing test data for the setting up of HEP counter equipment (Experiment 15). The collaborating groups from Queen Mary College, London, and the Rutherford Laboratory can now begin their extensive data-taking programme to study the interaction of K mesons with polarised neutrons. Details of this important interaction are to be inferred by scattering the K meson beam from deuterium nuclei – proton-neutron pairs – in the target material. In the final tests a deuteron polarisation of 28% was achieved – comfortably above the design figure of 25%. The performance as a normal polarised proton target, which is important since frequent background measurements from undeuterated material will be required in this study, is likewise extremely good for a ^{3}Helium-cooled target of this size.

The large volume of the new target – 45 cc – raises questions as to the homogeneity of polarisation. Measurements in four zones of the target gave the same polarisation to within 5%. This indicates that both the refrigeration and the density of the polarising microwave power are well distributed in the target cavity. More sophisticated magnetic resonance experiments performed in the laboratory have likewise demonstrated that there are no significant polarisation gradients on a microscopic scale around the paramagnetic chromium complexes which are introduced into the target material for the purposes of dynamic polarisation.

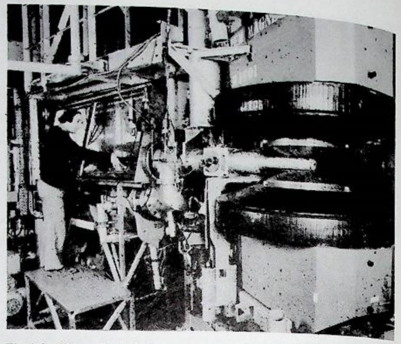


Fig 4.2. The polarised deuteron target (before installation of the counter arrays), showing the cryostat between the poles of the electromagnet, and the large He-3 pumping line. The cryostat insert can be seen withdrawn into a glove box, which for cold loading and changing of the target material is sealed and purged.

Frozen Spin Polarised Target for RMS (Experiment 17)

The cryogenic microwave and nuclear magnetic resonance systems for the frozen spin target for RMS have been designed and much of He-3 and He-4 systems has been assembled (Fig 4.3).

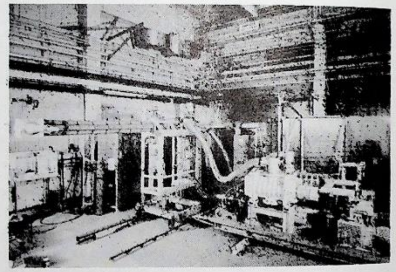


Fig 4.3. The frozen spin polarised target for RMS during the construction of the cryostat and the gas handling systems.

Although based on a dilution cryostat designed at CERN a number of changes have been made in order to enhance the high temperature refrigeration to allow a more rapid polarisation.

4.1.2 Polarised Target Research and Development

Material (CrV doped propanediol) has been provided for existing targets: giving over 90% polarisation for protons and 28% for deuterons for K20 beam line experiments.

An electrostatic sphere-making machine has been developed to produce target material beads at high speed and of selected diameter.

In the laboratory, the study continued of the thermodynamics of the nuclear spins and paramagnetic centres in typical target materials. In particular, the magnetic resonance techniques which probe the field gradients around each paramagnetic centre were developed. From results such as those shown in Fig 4.4, important conclusions can be drawn as to how the various components of the nuclear spin energy in these gradients should be assigned to different thermodynamic reservoirs, and precisely how these reservoirs exchange energy with the vibrating lattice. These techniques found an immediate application in a feasibility study for a proposed neutron diffraction experiment to study the microscopic diffusion of dynamic polarisation. The resonance methods would totally complement an angle scattering experiment.

The dilution refrigerator has been modified to incorporate the requirements for polarised target research. A high homogeneity 5 Tesla solenoid has been installed, as well as a microwave system and NMR coaxial leads with adequate heat-sinking.

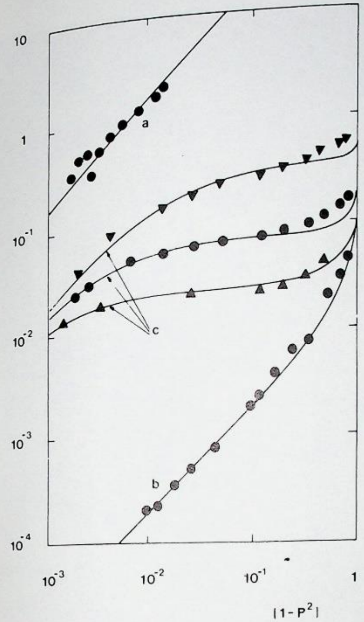


Fig 4.4. Results of the magnetic resonance experiments on the propanediol target material showing the rate of (a) dipolar relaxation, (b) Zeeman relaxation and (c) the polarisation decay during selective irradiation of protons near the chromium complexes. The drawn curves represent their theoretical variation with chromium polarisation, P.

4.1.3 Polarised Targets for Neutron Beam Research

Recently, the advantages of polarised targets in some areas of neutron beams research have also been recognized. This year the Group undertook work in collaboration with the Neutron Beam Research Unit for various projects at the Institut Laue Langevin (ILL), Grenoble, and this promises to be only the beginning of a fruitful involvement in this field.

The application of polarised targets to neutron work divides broadly into two categories. One is the fundamental study of the spin-dependent strong interaction between neutrons and nuclei; the other is in the exploitation of this interaction to provide useful research techniques and devices. It is this second category for which the two projects described below are primarily though not uniquely, intended.

An Oxford University Group, working at the ILL, is at present studying the application of dynamic polarisation with neutron diffraction. Neutron, unlike X-ray, diffraction can pin-point the positions of hydrogen nuclei in a crystal lattice so that this work is potentially important to biological cryostallography.

In order to extend the temperature range accessible to these experiments down to 0·4K, a ^{3}Helium evaporation insert is being built for the existing cryomagnet. This will be a compact and powerful refrigerator with a number of special features. The liquid ^{3}Helium, which is itself opaque to neutrons, must be excluded from the path of the beam, and a suitable rotating seal in the large helium pumping line must allow the cryostat to tilt and rotate on the spectrometer platform.

By using components recuperated from previous targets, a complete pumping and purifying system for the recirculating ^{3}Helium gas has already been built (see Fig 4.5), at great saving in time and cost. Full scale polarisation tests of the complete apparatus will be undertaken next year before shipment to Grenoble.

The very large spin dependence of the scattering amplitude for neutrons on hydrogen makes a polarised proton target, used in transmission an effective polariser of an unpolarised neutron beam or, equivalently, an analyser of a polarised beam. Such a device, the IN9 filter, is presently being commissioned at the ILL, and the Rutherford Laboratory work described below has contributed significantly to the performance which this filter now achieves.

A polarisation measurement system of high accuracy has been installed and is able to measure polarisation to ± 1%. Significant improvements in magnetic field stability of the target were attained using a control system developed at the Rutherford Laboratory. The IN9 filter requires a proton polarisation stability and order of magnitude better than that of polarised targets used in High Energy Physics experiments. A system has been developed which has reduced proton polarisation variations to less than ± 0·5% over a 40-hour interval.

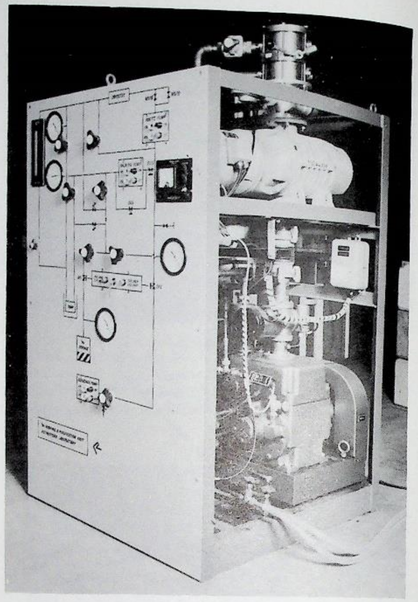


Fig 4.5. Helium-3 pumping and purification unit for dynamic polarisation experiments on the D3 and D5 spectrometers of the Institut Laue-Langevin, Grenoble.

4.2 Low Temperature Research Facility

Dilution refrigerator experiments have been carried out, providing temperatures down to 30mK for collaborations with university visitors.

The work with Bristol University on the superconductor, polysulphur nitride, has been extended. The object of the experiments so far has been to study the effect of crystal growth conditions on the resistive properties. The superconducting transition temperatures are rather lower than in the best materials reported elsewhere, and there is a strong dependence of resistance on current density, as well as a finite resistance below the transition temperature in some cases: these effects are probably due to structural imperfections and they may have significant implications for the type II behaviour of this material.

Some experiments on magneto resistance have been carried out by Bedford College workers, in which dilution refrigerator temperatures and fields up to 5 Tesla have been provided.

4.3 Rapid Cycling Vertex Detector (RCVD)

The Rapid Cycling Vertex Detector (RCVD) is a small rapid cycling bubble chamber designed specifically to operate with external counter systems. This hybrid philosophy retains the merits of the bubble chamber of the interaction vertex in combination with the merits of counter techniques to analyse the particles leaving the chamber. To draw maximum advantage from the fast data-taking abilities of the associated counters the chamber is designed to operate at 60Hz. Experience with this chamber is likely to prove invaluable in the design of future, more sophisticated experimental systems. Along these lines design work has been undertaken on a rapid cycling bubble chamber for the European Hybrid Spectrometer which will operate on the 400 GeV SPS at CERN.

The year has seen significant advances in RCVD development. In February 1976, the system was tested for 10 million expansion cycles with liquid nitrogen. This was followed in July by the first commissioning tests with liquid hydrogen. The chamber was cycled at 25Hz and achieved sensitivity for the first time. During the summer, modifications to the chamber were made to improve picture quality and in November the device was commissioned with its external trigger system and data taken at 28Hz.

Early commissioning tests revealed a problem at the top of the chamber where the optical mirror system also acted as the main heat exchanger. This resulted in local turbulence and consequently poor contrast for particle tracks. Modifications have been made to reduce the turbulence but condensation on the outside of the chamber window has remained a problem. This is believed to originate as moisture outgassing from the glass reinforced plastic components in the optics cartridge, as it can be pumped away when the system is warm.

Good quality pictures were obtained during trigger tests with the chamber operating in the single shot mode. Work is now proceeding to correlate tracks observed in the chamber with events recorded in the surrounding detector systems (scintillation counters and wire spark chambers). A maximum cycling rate of 28Hz with 15 expansions per burst and 1 burst every other Nimrod flat top was achieved. The chamber was sensitive on all but the first two expansions in each burst and it is confidently expected that data can be taken at this rate (Experiment 13).

During the later commissioning tests the electromagnetic vibrator which expands the chamber has performed well and camera operation has been reliable at the modest trigger rates attempted. Valuable experience was gained on the electronic synchronisation units. This system can now demand beam in synchronism with the rapid cycling mode of operation and trigger the flash tubes and camera when useful events are recorded in the external detector system. The refrigeration system is capable of sustaining a faster rate especially when known sources of spurious nucleation have been eliminated. Therefore a concentrated effort is being made to reach the design cycling rate of 60Hz in 1977.

4.4 Superconducting Magnets and General Superconductor Research

In the past decade, the Laboratory has played a leading role in research and development work for the applications of superconductivity. The initial impetus arose from the requirements of particle physics research for magnetic fields larger in magnitude and volume than were possible using conventional iron-cored magnets; significant advances in this field have already been made possible by the availability of much larger bubble chamber and spectrometer magnets, as well as many other special purpose high-field devices. Pulsed superconducting magnets for accelerators have now been developed so that their feasibility is established. The continuing support at the Laboratory for particle and neutron-beam research is represented by several magnets under construction, while an extensive programme of ongoing research into new conductors and into constructional techniques is under way.

Progress in superconducting magnets in connection with particle physics has made it possible to pursue new applications for superconductors, and as a major research group in this field, advice and assistance has been sought from the Laboratory on these new uses. Examples are magnetic levitation for high speed transport applications, AC generators and toroidal magnets (Tokamaks) for fusion research, the latter relying for their next advance on the use of superconducting magnets.

DC Dipoles

The Mk 1 superconducting dipole has been completed and is now in operation. It has an operating field of 5 Tesla at 700 Amperes and is a model of the type of magnet which would be used to transport charged particle beams from proton synchrotrons operating at energies in excess of 200 GeV. Its first utilisation was in an experiment outside the particle physics area, in an experiment conducted by Appleton Laboratory researchers on molecular absorption in the 2mm wavelength region as part of an experiment into atmospheric propagation (Fig 4.6). It has now been shipped to the Argonne National Laboratory, USA for use by an Imperial College Group in ultra-violet spectroscopy work on the diamagnetic Zeeman effect.

A Mk 2 superconducting dipole is now under construction, designed to operate at a slightly higher field, 6 Tesla at 800A, and to have a higher field homogeneity than its predecessor.

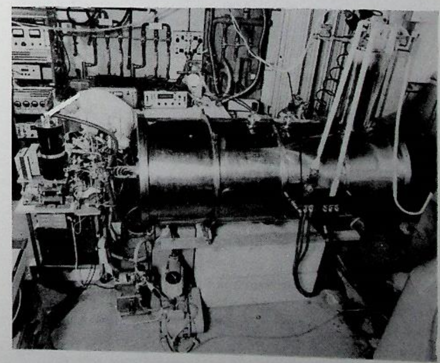


Fig 4.6. Mk 7 Superconducting Dipole Magnet in horizontal cryostat for an experiment on molecular absorption by Appleton Laboratory.

Hexapole Magnets

Hexapole magnets are required for focussing and polarising slow neutron beams by interaction with the magnetic moment of the neutron. Superconducting windings are essential to achieve the high current density required. Two hexapole magnets are at present nearing completion; the niobium-titanium version shown in section in Fig 4.7 is for experimental use by the Neutron Beam Research Unit. The coil is approximately one metre long with iron pole and yoke pieces designed to enhance useful magnetic field and decrease field peak. The set of windings for this prototype magnet are almost complete and ready for potting in epoxy resin. The remaining R & D work to establish the assembly structure was finished and the whole magnet is scheduled for testing vertically in a conventional cryostat in the Spring of 1977. It is also hoped that this assembly of 6 identical windings will shed some light on the general problem of factors affecting training. If successful, it is planned to re-test the magnet in a custom-built horizontal cryostat as for use on a neutron beam line.

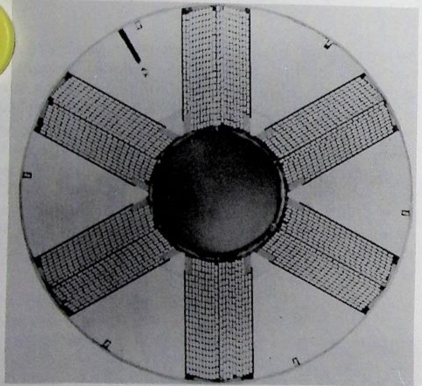


Fig 4.7. Niobium-Titanium Hexapole – sectional view of test coil showing iron poles with pole tips of filled epoxy resin. Bore is 50mm.

The second hexapole is a prototype magnet to assess the performance of the new filamentary niobium-tin superconductor. While the coil geometry is very similar, the poles are copper and the iron yoke is omitted. The magnet length is approximately 0·3M. Coil research and development work was completed early in the year and subsequent effort has been concentrated on coil manufacture. At an early stage problems were encountered with the conductor; short sample tests showed that the critical current density was below the original specification. An extensive series of tests with variations in heat treatment period and temperature failed to produce an improvement in conductor performance. In the light of these tests magnet performance was re-assessed and it was concluded that the coil could still make an important contribution to niobium-tin technology from the construction and operational stability aspects.

A number of important construction techniques were evaluated in the development programme, in particular conductor insulation, coil winding feasibility and epoxy resin impregnation. Winding of the six poles is now complete and these are in various phases of processing (Fig 4.8). It is estimated that six poles will be ready for assembly in the force support structure and full test by mid-February 1977. Two poles have been fully processed and tested with encouraging results. The coils reached short sample performance after a small number of "training" quenches from the 80% current level. If this performance is achieved in the six pole assembly the magnet will produce a sextupole field of 4 Tesla at a radius of 25mm.

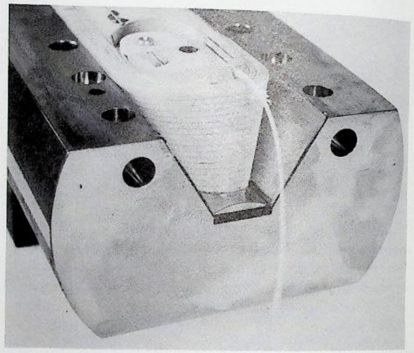


Fig 4.8. Niobium-Tin Hexapole – single pole in mould assembly prior to heat treatment phase

Niobium-Tin Magnets

The size and complexity of magnets made from filamentary niobium tin composites have increased steadily as better material has become available. Fig 4.9 illustrates the largest solenoid made so far at the Laboratory. It has a field of 10 Tesla in a bore of 85mm, and is now used in conjunction with another niobium tin magnet to provide 12 Tesla for the superconductor testing service. A small racetrack magnet has been made as a first step towards the straight sided magnets required for applications such as beam handling magnets and superconducting generators. This prototype has performed well, reaching critical current after some initial training quenches.

High-Field Insert for NMR Magnet

At the request of the SRC Science Board, the Laboratory is supervising the development of a high-field niobium-tin insert magnet by the Oxford Instrument Company. The insert will form part of the high-resolution NMR system being developed for use by a biochemistry group at Oxford University.

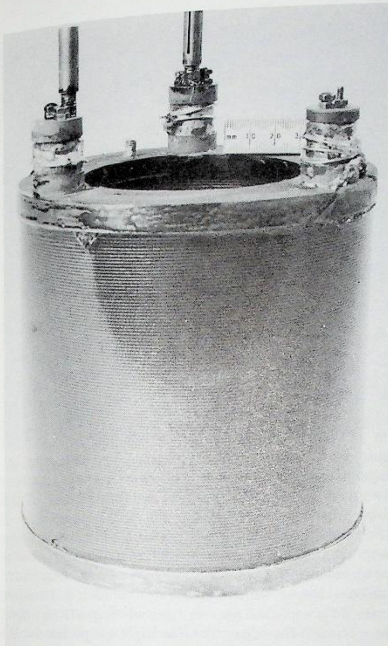


Fig 4.9. 10 Tesla Niobium-Tin Solenoid currently in operation in the Superconductor Testing Facility

During the year it has become apparent that the most serious problem with this magnet is that of forming a good persistent current joint in the filamentary niobium-tin conductor. A joint resistance of about 5 x 10^{-12} ohm is required if the complete magnet is to achieve a decay rate of less than 1 part in 10^7 per hour. Several schemes have now been investigated and most have been found to be inadequate. Recently, however, a new technique has produced a few joints with resistances less than 10^{-10} ohm. At this level the resistance can no longer be measured by direct methods and it is necessary to infer the joint resistance from the decay of current in a circuit containing the joint. A suitable circuit (a small magnet) has been constructed and tests are in progress to determine the actual joint resistance. Early problems with releasing the impregnated magnet from its former have been circumvented by manufacturing the former from specially selected low permeability stainless steel. The field perturbation from the former is then low enough to be within the normal compensating range of the trim coils.

Superconducting Thin Wall Solenoid

Particle physics experiments proposed for the PETRA storage ring complex at DESY, Hamburg, will employ large solenoidal magnetic detector systems. The magnet will surround the beam intersection region with a multiplicity of particle detectors arranged inside and outside the magnet windings. To give a maximum detection efficiency the magnet wall must be "thin", typically half a radiation length of electrons in the GeV energy range. Since half a radiation length is 45μm for aluminium and as low as 7mm for copper it is essential to use aluminium or other suitable materials in the structural components. A design study and costing has been carried out for "thin" solenoids ranging in diameter from 1·2-6m, length 2·0-5·0m and central field 1·0-1·5 T.

The problems which present most difficulty in this type of coil are force restraint and coil protection during quench. In such an open magnet geometry a normal resistive region (quench front) will propagate through the coil at a relatively slow rate. Consequently during quench the magnet stored energy (∿20MJ) may be dissipated in a relatively small part of the magnet volume, possibly leading to coil burn-out. The proposed protection scheme is therefore based on rapidly quenching the entire coil as soon as a resistive region develops, thereby safely dissipating stored energy over a larger volume. The decreasing magnetic field associated with the development of a quench induces a current in an aluminium cylinder which is closely coupled to the coil both electromagnetically and thermally. The resultant heating is sufficient to initiate quench conditions throughout the coil. Good thermal contact between the coil and aluminium cylinder must be maintained during cooldown and magnet excitation. It is proposed that this is best achieved by locating the cylinder on the outside of the coil where it could also act as a force restraint. The possibility of winding the coil on the inside of the cylinder has been investigated with encouraging results. The use of aluminium honeycomb material for cryostat construction has been considered in an attempt to achieve a "thin" magnet wall.

Solenoid for Large Polarised Target

This magnet is being constructed for a polarised target experiment which is part of the European Muon Collaboration programme scheduled for the CERN SPS. The scale of magnet and target volume required is shown in Fig 4.10. Coil design work has been completed and subsequent effort directed towards the practical aspects of achieving the specified fields.

In order to meet the stringent field homogeneity requirements special coil winding techniques were developed to ensure a perturbation free winding. The main coil must be wound as a single unit 1·6M long and this makes coil protection difficult. The protection technique discussed in the previous section is to be employed with the solenoid wound

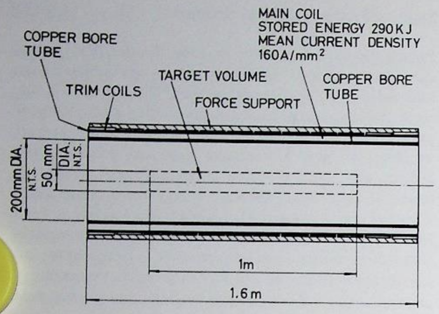


Fig 4.10 Section through large polarised target Solenoid

on a copper tube for energy coupling. Thermal contact between coil and tube will be maintained by conductor winding tension compressing the bore tube and a 10mm thick force restraint of copper wire.

A 300mm-long model coil was built to assess winding techniques and has proved the structural integrity of the system under repeated thermal cycling. Manufacture of the main solenoid coil is now in progress.

Large Aperture Superconducting Bending Magnet

A preliminary design study was carried out for a proposed bending magnet to be operated in a beam line at the Fermi National Accelerator Laboratory.

The specification called for a magnet strength of 4·88 Tm over a room temperature bore of 0·76m wide by 0·3m high. A strict limit of 1·68m was placed on the overall length of the magnet and the total liquid helium consumption was limited to 4 litres/hour. This required a special coil design with ends taking up minimal length and yet of sufficient cross section to be fully cryogenically stabilised.

The GFUN 3D program was used to compute the field. The warm iron shield was taken into consideration and was found to contribute 15% to the central field.

Magnet Training Research

The premature quenching of superconducting magnets impregnated with epoxy resin continues to be a severe problem. Two hypotheses have been advanced regarding the origin of the localised release of heat within the coil: (a) cracking of the impregnant or (b) sudden yielding within the conductor itself. Results consistent with possibility (a) have been obtained using a small racetrack coil in which the impregnant is a thermosetting resin which can be restored to an uncracked state by reheating. The maximum field, however, was less than 4T, and the possibility still exists of both processes being significant in high field coils.

Work on possibility (b) has consisted of theoretical studies of the microstresses in the metallic and non-metallic constituents of superconducting magnets which occur during cooldown and during excitation. The studies indicate that the conductor matrix can be introduced into the plastic state by differential thermal contraction and that a possible explanation of observed training behaviour resides in the inelastic processes which occur in the conductor matrix during excitation of the coil.

Whatever mechanism is responsible for training, the use of higher heat capacity materials in the coil should lead to less training. It has been reported that gadolinium oxide has a very large specific heat near 4·2K and some experiments using small coils have clearly shown that adding this material to the resin impregnant does increase the amount of energy required to quench the superconductor, and its use in larger coils should therefore be investigated.

Superconducting Niobium-Tin Composites

As part of a national effort to maintain the UK's advanced position in the supply of superconducting composites, the Laboratory has formed a collaboration with Imperial Metal Industries (IMI) and AERE Harwell. The objective of this joint programme is to develop niobium-tin composites to the point where they are readily available in standard forms with reproducible properties. The intention is to produce composites suitable for all the likely uses of niobium-tin in magnets, but as a first step the collaboration will concentrate on composites suitable for small magnets (ie round wire about 0·5mm diameter). The larger composites needed for high energy physics and for fusion experiments can be made by restacking the smaller composites.

The design for the small magnet composite is based on the existing copper ring type shown in Fig 4.11. The attractive features of this design are that the diffusion barrier has a simple shape and that the proportion of pure copper in the composite can be altered at a very late stage in the production process. The immediate objectives of the development programme are to lower the cost of this composite by scaling up the billet weight and to improve the current carrying capacity at fields greater than 10 Tesla. Further problems to be investigated include the replacement of the present fragile insulation based on glass fibres by a more robust, thinner coating and the improvement of the mechanical strength of the composite. Recent experiments suggest that strains as high as 0·4% can be tolerated without damage to the superconducting properties of the niobium tin.

Superconductor Testing Facilities

The test services have been operated successfully for the past twelve months. Various improvements have been made, notably the maximum field which is now 12T in 50mm bore. Techniques have become well-established but concerted efforts are being made to increase efficiency, thereby

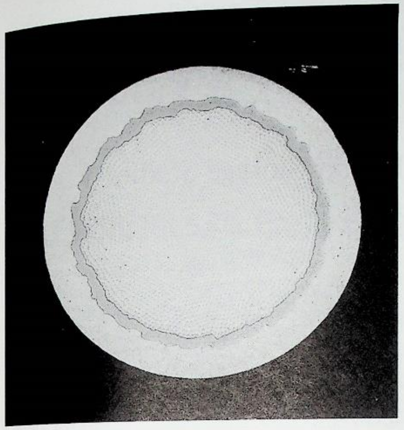


Fig 4.11. Filamentary Niobium-Tin Composite with 2,500 niobium filaments in a bronze matrix surrounded by a tantalum diffusion barrier and an outer shell of pure copper (Photo IMI Ltd.)

reducing charges to customers, while maintaining the present high level of accuracy. Refinements have also been made to the AC loss measurement technique, enabling accurate data to be provided for work at Warwick University on engineering applications of superconductors.

Tokamak Conductor

The Laboratory is participating in the Euratom thermonuclear fusion programme by developing, in collaboration with Culham Laboratory and IMI, a large conductor suitable for a tokamak fusion reactor. Some demonstration conductors based on niobium-titanium have been produced, and a detailed first assessment of the problem has been completed. Possible alternative conductor designs based on the higher field potential of niobium-tin are now being studied.

Magnetic Levitation

Studies are being made on possible applications of the principle of stable electromagnetic levitation, for example in connection with a future high speed ground transport system. Computer studies have suggested realistic configurations of superconductor and iron to give large lift forces yet maintain low magnetic field strength in the region above the magnet system, and so be suitable for a passenger compartment. It has been estimated that a useful lift to passive weight ratio exceeding 3:1 might be achieved within existing technology.

In addition to experiments demonstrating stable levitation in novel topological arrangements, measurements have been made of the restoring forces produced by displacements from equilibrium. These measurements verify that large forces can be produced in practice using existing superconducting materials. With the arrangement used, shown in Fig 4.12, lift forces of nearly 100kg weight were demonstrated.

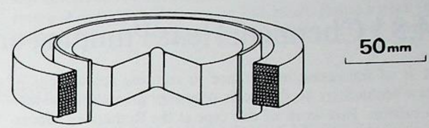


Fig 4.12. Experimental arrangement used to demonstrate stable levitation and verify computed lift forces.

University Work

Liaison work with universities for the Engineering Board of the SRC has been carried out especially in the co-ordination of the programme of R&D work towards a superconducting alternator. In addition to discussing and assessing progress of the work, opportunities have arisen to offer help in areas where the Laboratory has experience, especially in the fields of computation (eg magnetic fields) and cryogenics (use of superconductors). As an example involving both of these a preliminary design was drawn up in response to a proposal from Southampton for a superconducting dipole winding capable of rotation at 3,000 rpm. With an auxiliary stator, problems in rotor damping and eddy current losses/heating can be studied in a rotating field system where the anisotropic iron is driven well beyond saturation.

Another area where the Laboratory can help universities is by allowing use of existing large facilities to extend the scale of their university work; for example, a group from Warwick are availing themselves of the higher fields and currents available at the Rutherford Test Facility in their study of losses in superconductors exposed to additional but small fluctuating magnetic fields which often arise in engineering applications of superconductors.

Following a request from the Nuclear Structures Committee of the Nuclear Physics Board some preliminary work has been done on the design for a split pole double focussing high resolution spectrometer magnet for use at Oxford.

Work for Industry

The Laboratory is sometimes approached by Industry for help in these areas where new technologies are involved and help has been given in a similar way to such firms as Oxford Instrument, Thor Cryogenics, IMI, and CERL.

4.5 General Technology

As well as its traditional involvement in cryogenics and superconductivity, the Laboratory is also active in a number of more general technological areas. Some of this activity is the direct result of the SRC's requirement to offer increased support to engineering work in higher education.

4.5.1 Chemical Heat Pumping and Energy Storage Studies

It is of increasing importance to consider applications of new technology to the fields of energy generation and conservation. Past work of this type at the Rutherford Laboratory has included studies of the use of superconducting magnets for the large scale storage and transfer of electrical energy. The Laboratory is also collaborating in work directed towards eventual fusion power reactors.

Preliminary studies have been made of a possible new area of work, involving the development of heat pumping and/or energy storage systems based on two-component chemical systems. The principle involves the use of a concentrated chemical solution to draw, for example, water or ammonia vapour from a cool reservoir, and recondense it at a higher temperature, thus converting low grade heat to higher grade heat by chemical action. A well-known example of this is the absorption refrigerator cycle; by choosing chemical systems with suitable operating temperatures the principle could be used as the basis of space heating systems for buildings, using solar collectors or air heat exchangers as the source of low grade heat.

Although proposed many years ago, and already in use for air conditioning of buildings, relatively little work has been done to study and develop the principle for the more ambitious objective of space heating. The feasibility study initiated this year involved both theoretical assessments of possible chemical systems and cycles, and practical work on test rigs simulating heat pumping cycles.

As a result of this preliminary work, it is believed that it should be possible to develop cost-effective practical systems, and a proposal for the construction of a larger operational prototype is being prepared.

4.5.2 Chemical Technology

The Chemical Technology Group provides general services in the fields of plastics technology, chemistry and materials testing for the various activities of the Laboratory.

Plastics Technology

This has included materials selection and their application to a wide variety of projects, examples being the manufacture of precision high-strength castings in unfilled, filled or reinforced epoxy resins, impregnation of coils and other assemblies, and the use of structural adhesives. These techniques were employed on such projects as bubble chambers and the experimental work in connection with the Millimetre Wavelength Radio Telescope (Section 4.7.2). In support of this work, fundamental investigations into the properties affecting performance of these materials was undertaken, such as radiation damage testing and studies of cure parameters and cure shrinkage.

General Chemistry

A wide ranging Chemical Service has been provided at the Laboratory including chemical analyses for quality control and specification purposes, chemical aspects of water treatment and corrosion control, waste disposal and safety matters. Many other matters of a chemical nature were routinely referred to the group, from boiler feed water analysis to electroplating and chemical cleaning. The provision of a range of carefully prepared solutions for laser work and analysis for atmospheric ozone are other examples of routine tasks.

Of a less routine nature is the contribution currently being made to alternative energy sources based on the storage of chemical energy (Section 4.5.1).

Materials Testing

This work is complementary to plastics technology and to many other projects at the Laboratory. Tests on materials and components have been made over a range of temperature from 600K to 4·2K. Custom-built apparatus is available for thermal contraction and thermal conductivity measurements in liquid helium together with instruments for performing a wide range of mechanical tests at temperatures down to that of liquid helium. This equipment was used in support of the Laboratory work on superconductivity and Bubble Chamber development and specimens have ranged from sections of prepared components to small diameter superconductive wires.

Thermomechanical properties of polymeric materials, physical characteristics of liquids and the mechanical properties of solids, have given much useful design information to engineers.

A specimen preparation and metallurgical polishing service is also available and this is closely linked to the superconductivity programme. Additionally, many other specimen types have been prepared, for example resin impregnation studies and welding tests.

Radiation Dosimetry of Nimrod

The Nimrod vacuum vessels, being of epoxy-glass laminate construction are susceptible to radiation damage, and monitoring of the radiation dose to two octants has continued throughout the year. Hydrogen pressure dosimeters specifically developed for this purpose were used and the maximum recorded dose for the year was 142 Mrad, giving a peak integrated radiation dose since machine start up of 945 Mrad.

4.5.3 Work for SRC Engineering Board

The recent increased emphasis by the Science Research Council in supporting engineering research in universities has been reflected by increased involvement by the Rutherford Laboratory in the support of such research. This has manifested itself in a number of ways. Firstly, as an experiment, the Laboratory has been asked to provide technical support to two of the major committees of the Engineering Board; the Aeronautical and Mechanical Engineering Committee, and the Electrical and Systems Engineering Committee. Although this arrangement has been in operation for only a few months a number of matters have already been referred by these committees for detailed technical evaluation by engineers with the appropriate skills at Rutherford Laboratory. The Laboratory has for example been asked to assess the practical feasibility and cost of establishing an electron beam lithographic facility to provide University researchers with prototype solid state electronic components of novel and advanced types which would otherwise not be available.

A second activity being undertaken is the provision of help to university engineers in the preparation of grant applications which if approved would require the use of existing Rutherford Laboratory facilities or the construction of specialist apparatus of a scale beyond that appropriate to a single university department. There is, for example, interest in using a pair of large motor-alternator sets which presently power the Nimrod accelerator, as a test bed for studying the transient performance of this type of machine. A further preliminary proposal under evaluation calls for the use of these machines after some modification to the associated large flywheels for testing full-scale linear motors for possible train propulsion.

A third activity being supported by the Engineering Board at Rutherford Laboratory is the superconducting magnet development programme, particularly the development of niobium-tin filamentary superconductors. This programme is seen as of future importance in a number of Engineering Board programmes, for example that on superconducting ac generators. The skills of the Laboratory in this technology have already proved of value in the design of a superconducting dipole coil in a rotating cryostat undertaken for Southampton University as part of the programme on superconducting ac generators.

Considerable help has also been given to a number of university engineering departments with the problems of computation of magnetic field distribution in magnets and electrical machines, a subject in which the Laboratory has established a significant world reputation.

4.6 Computing Applications

The Laboratory has considerable expertise in the area of computing applications in which the computer is used as a design tool to help solve technological and engineering problems. In addition to the demands of internal projects associated with apparatus for high energy physics and superconductivity research, the computing applications techniques developed at the Laboratory have been widely used by industry and universities.

A highlight of 1976 was the COMPUMAG Conference on the Computation of Electromagnetic Fields organised by the Laboratory and held at St Catherine's College, Oxford, in April. Over 200 delegates attended this meeting drawn from many countries and from a wide range of disciplines. The Conference was successful notably as a forum for the interchange of ideas but also emphasised the increasing importance of the Rutherford Laboratory in engineering computing.

Magnet Design Computer Programs

Over the last six years a unique code (GFUN3D) for the solution of three-dimensional non-linear magnetostatics fields has been developed. A major activity during 1976 has been the further exploitation of this code in the design of magnets – approximately 450 configurations have been analysed. The magnets analysed have ranged from the large JET Tokamak, through medium sized high energy physics magnets to the small magnets used in the electronics industry. Also increasing use of the program has been made by engineers in the electrical machines field. One of the most encouraging developments has been that magnets designed using GFUN have been built and the results of measurements have been available for comparison with the computer fields. As an example of the accuracy the program can achieve the results for the model dipole for EPIC are shown in Fig 4.13.

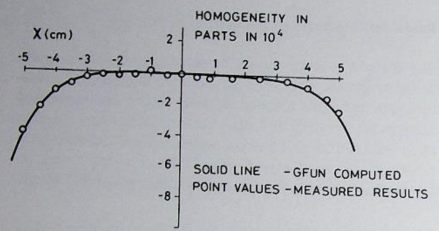


Fig 4.13. Comparison of measurements with computed valves for the EPIC C-Magnet.

The use of GFUN under contract by external organisations has continued, for example, the design of the JET and RFX11 fusion machine magnet cases on behalf of Culham Laboratory, the design of superconducting ac devices for International Research and Development Corporation and electronic components for Plessey Ltd. Also there have been contracts to implement the code at various overseas laboratories, including Oak Ridge National Laboratory, Tennessee, and Lawrence Berkeley and Livermore Laboratories in California.

The algorithm used in GFUN is based on a volume integral equation involving iron function sources. This algorithm is now almost six years old and whilst it is still the only viable general 3D code available at present, it could be improved. To this end alternative methods have been examined based on solving boundary integral equations derived from Green's Theorems. It is hoped to see the original GFUN algorithm replaced by a new algorithm which will be capable of higher accuracy for lower cost.

The range of applications of computer programs has been extended to include time-dependent electromagnetic problems. For example algorithms (EDDY) to compute eddy current effects have been studied and a program of work initiated, in co-operation with Imperial College, to extend the existing techniques to treat full three-dimensional time dependent problems. Fig 4.14 illustrates the use of the eddy current program for currents enclosed in a rectangular box.

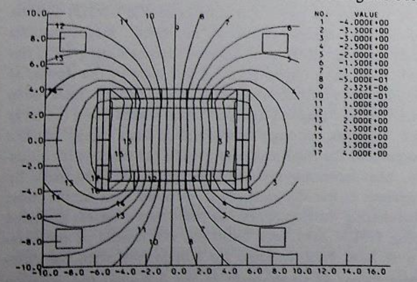


Fig 4.14. Field contours for a copper box driven by two pairs of bars.

Interactive Graphics

Programs such as GFUN and EDDY have been using interactive graphics for data checking and displaying results on the central computer for many years. The project aimed at using a GEC4080 computer for all interactive graphics work is now well advanced.

GEC 4080 Computer

Magnetic analysis of solenoid systems without iron can now be done with a program which operates in the GEC4080 alone. Data input, analysis and display of results are all done in the 4080.

The use of the 4080 for data input to the GFUN program in the 360 is expected to begin in an experimental fashion early in 1977. Most of the code necessary for this has now been developed and tested. Fig 4.15 shows a computer-generated picture of the magnet system used in the polarised deuteron target experiment (Section 4.1.1).

Interest has been shown in using this system as a user interface to other analysis programs. The system which will be used initially for GFUN is in fact much more general than this. With only a small amount of additional work it could be used to prepare data for any similar program and to display results.

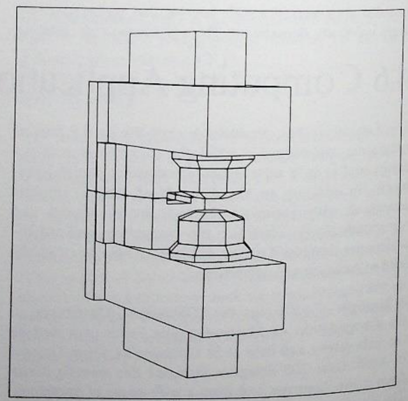


Fig 4.15. Computer-generated picture of the magnet pole and yoke used in the polarised deuteron target experiment (see Fig 4.2)

4.7 Atmospheric Physics and Space Research

Rutherford Laboratory participation in Space activities began in early 1969 when the Laboratory was asked to provide support for two experiments approved by ESRO and NASA respectively which had run into problems. One was a joint Edinburgh-Liege experiment, where the Laboratory provided the Project Scientist and Project management, with a full support team for the production of test gear, interface documentation and investigational analysis. This culminated in a highly successful experiment. The other was the Selected Chopper Radiometer (SCR) experiment to fly on Nimbus 'E' (5), a joint Oxford University and Reading University project, where the Laboratory provided the project management and complete project engineering service including design, manufacture, testing of the engineering model with all interfacing, test gear and simulation of spacecraft services. This was an extremely successful venture and the experiment has completed four years operation in orbit and is now in its fifth year, which is a record for such complex mechanisms operating in synchronism every second in space. This experiment provides the temperature profile of the earth's atmosphere up to 45 Km in height with supporting observations of water vapour distribution and cloud conditions, etc.

4.7.1 Infra-Red Radiometers

This atmospheric physics research is a collaboration between the Rutherford Laboratory and the Department of Atmospheric Physics, Oxford University.

Radiometers in Orbit

The pressure modulated radiometer (PMR) launched in July 1975 on Nimbus 'F' spacecraft is continuing to provide synoptic data of the atmosphere's temperature profile to a height of 90 Km on a twice-daily basis. It is still being assisted in these measurements up to 45 Km in height by the Selected Chopper Radiometer (SCR) experiment launched on Nimbus 'E' in July 1972 which is creating a record in space for such complex mechanisms operating every second in synchronism.

Stratospheric and Mesospheric Sounder (SAMS) Nimbus 'G'

This complex radiometer for temperature and composition atmospheric sounding is to be launched in 1978. This complex radiometer will measure temperature using CO_2 channels as in Nimbus 'F' but is able to cover greater heights and will also detect small quantities of a number of different gases. The greater sensitivity is obtained by viewing the limb of the atmosphere instead of vertically downwards. However this produces problems in the precision and stability of the scanning mirror mechanism.

Work is well advanced at the Laboratory on components for the flight model with the pressure modulator cells being filled and its scanning mirror, secondary optics and black body mechanism being assembled ready for testing. The engineering model of this radiometer (Fig 4.16) with its electronic module was assembled by Hawker Siddeley Dynamics Ltd. Stevenage and is now at Oxford University completing its test programme before being shipped to U.S.A. for integration and testing with the spacecraft.

A second experiment for the Department of Atmospheric Physics, Oxford University, is a smaller radiometer of novel design, using two pressure modulators, and was launched in Nimbus 'F' (6) in July 1975. This is operating successfully after 18 months in orbit, providing synoptic temperature measurements of the earth's atmosphere to a height of 90 Km, covering the earth twice daily. Development models were designed, tested and built at Rutherford Laboratory, together with test gear and simulation of spacecraft services, etc.

The third experiment for Oxford University is SAMS to fly on Nimbus 'G'. This is a more complex experiment and used 7 pressure modulators. The Rutherford Laboratory is again providing the project management and project engineering with all the development models and test gear plus all the pressure modulators, mechanisms, scanning mirrors etc. being provided to the contractor, Hawker Siddeley Dynamics Ltd., for incorporation in the engineering and flight model sensor-housing.

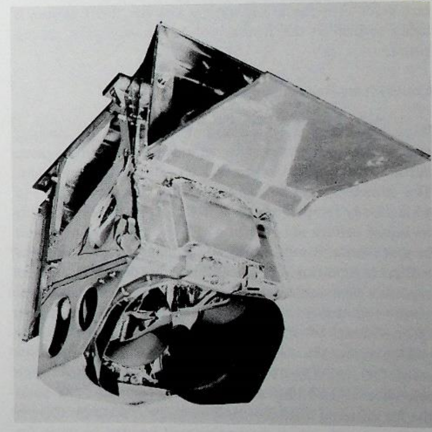


Fig 4.16. Engineering model of SAMS radiometer

During the year the engineering radiometer cells were vacuum processed and calibrated and a standard procedure for this processing developed. Problems due to subsequent leakage of the cells were resolved as were those related to the electronic drive circuitry. Test gear for the model is now in use and comprises a thermal vacuum tank with liquid nitrogen (LN_2) cold walls enclosing the instrument and its passive radiant cooler together with separate targets which can be varied in temperature using LN_2 and heaters.
The automatic test equipment comprises a PDP8M computer which is interfaced with the radiometer and will operate other units to simulate the spacecraft command and telemetry signals. This also provides print-outs of measured values from the detectors, thermistors and other transducers including mirror position etc on to a teletype console. Two of these units have been made, one for the USA. A further test tank is being constructed to house an infra-red source and slit, adjustable in position together with a large telescope using a spare 11" off-axis paraboloidal mirror and a 10" flat reference mirror. This will be used with the flight model to accurately measure the instrument's field of view.

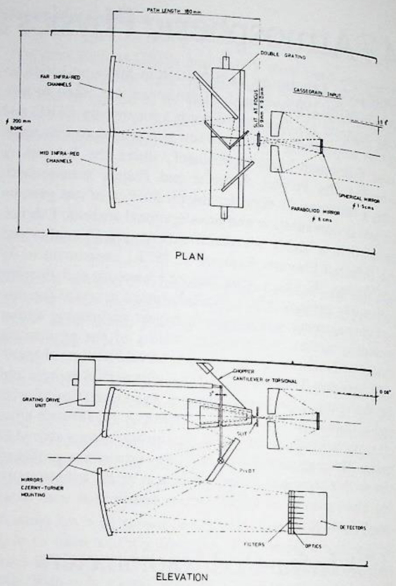


Fig 4.17. Optics for Cooled Infra-Red Radiometer

Pressure Modulated Radiometer for Venus Orbiter – Pioneer Spacecraft

The flight model pressure modulator cells are now being integrated with the rest of the Vortex experiment at Caltech's Jet Propulsion Laboratory and the flight backup is being refilled at the Rutherford Laboratory prior to despatch.

Cooled Infra-Red Radiometer

Work is in progress on a design and cost study for a cooled radiometer to measure very small quantities of various gases, particularly atomic oxygen and aerosol in the atmosphere. The detectors must be able to measure radiances to 10^{-6} of a blackbody temperature at 200°K and this requires cooling to liquid helium temperatures. The management of liquids in space under conditions of weightlessness is possible if the helium is superfluid i.e. at less than 2°K (40 torr) inside the cryostat. The radiometer will use a 6cm cassegrain input mirror followed by a dichoric beam splitter and two grating spectrometers of the Czerny-Turner form, Fig 4.17. One grating covers the mid infra-red band of 8·3 to 20·3μm (for aerosol, O_3, HNO_3, CF_2Cl_2 and $CFCl_3$ with a temperature reference at 14-15μm using the CO_2 signal) and the other the far infra-red band (for H_2O at 48μm and atomic oxygen at 63 and 147μm). A mechanism will be used to pivot the gratings through a small angle which must be accurately measured and the signal must be chopped at around 100Hz by a vibrating or torsional system.

A second cryostat is to be used for the calibration of the radiometer and is shown with the complete radiometer in Fig 4.18. This cryostat contains a sublimation cooler using solid argon at 84°K. It retracts and pivots out of the field of view for the periods of observation.

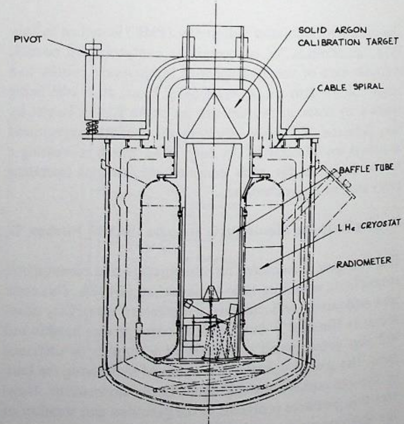


Fig 4.18. Cooled Infra-Red Radiometer. The calibration target retracts and pivots, leaving the radiometer viewing the limb of the atmosphere.

The radiometer is expected to fly on Spacelab together with a version of SAMS (the updated engineering/flight backup model with Joule-Thompson coolers or solid cryogens replacing the passive radiant cooler). It will be mounted on the large microwave antenna of Caltech's Jet Propulsion Lab's Microwave Limb Sounder (MLS) so that all three experiments view the same part of the atmospheric limb simultaneously. The combined experiment is called MIMSE (Microwave Infrared Mesospheric Stratospheric Experiment).

4.7.2 Millimetre Wavelength Radio Telescope

The Laboratory has assisted the Appleton Laboratory in a design study and proposal for a Millimetre Wavelength Radio Telescope. The main dish would be 15 metres diameter and capable of operating to the wavelength limit imposed by the atmosphere at about 0·8mm, which requires the surface error, with respect to a paraboloid of revolution, to be less than 0·05mm rms.

Since the changes in shape are so large a dish structure must inevitably be larger than this value, the dish has been designed using the 'homologous principle', whereby it deforms from one paraboloid of revolution to another as the elevation angle of the dish is changed. Finite element computer programs written at the laboratory have been used to analyse the distortions of the multi-rod structure which supports the dish surface, and the deformations of the telescope mount. NASTRAN has been used at the National Engineering Laboratory, East Kilbride, to confirm these calculations and to analyse the dynamic performance of the telescope.

A method of making aluminium surface panels, stiffened with aluminium honeycomb, is being developed, and shows much promise. The fundamental design for the telescope drive and control system has been completed. The costs involved in completing the design and constructing the telescope have been estimated. The proposal is being considered by the ASR Board.

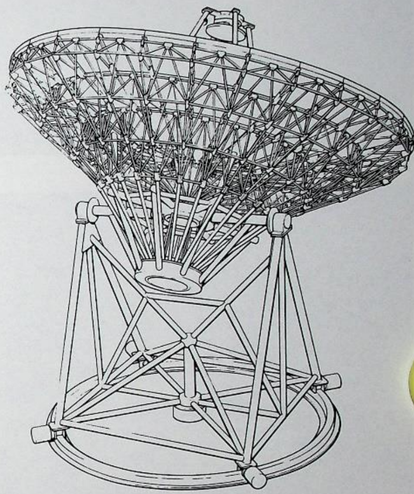


Fig 4.19. The U.K. Millimetre Wavelength Telescope. Its diameter would be 15 metres, with the surface of the dish constructed to an accuracy of 0·05 millimetres.

4.8 Detector Development

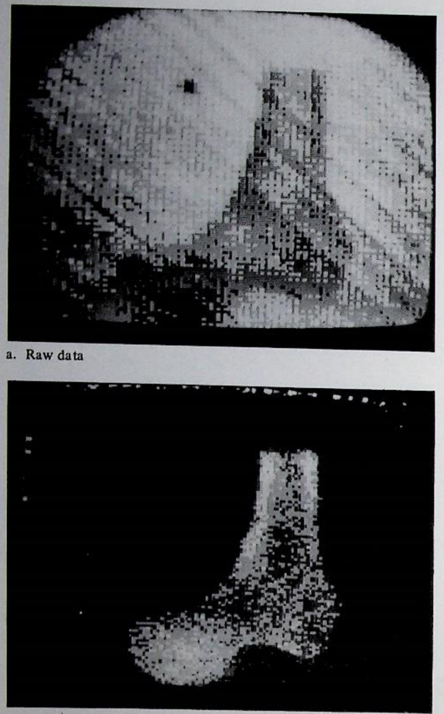
As well as satisfying the widely varying requirements of particle physics experiments, the Laboratory's detector development programme also investigates the potential usefulness of detectors and detector techniques for applications in other areas.

MWPC X-Ray Imaging Detector

The Detector Development Group has contributed to the development of the Rutherford multi-wire proportional chamber (MWPC) X-ray imaging system by making theoretical and practical studies of those device parameters which are relevant to the biomedical field. Development work on this detector system has been mainly concentrated on the evaluation of the system as a detector in the measurement of bone mass by means of photon absorptiometry techniques. This work was carried out in collaboration with staff from the MRC Mineral Metabolism Unit at Leeds General Infirmary (See Fig 4.20).

The detector system used for these investigations was a Xenon-filled 20 x 20 cm MWPC operating at ambient pressure. The inherent spatial resolution of the detector was 2 mm and the data produced by the detector was processed by means of a PDP 11 computer. Initial investigations have been carried out using aluminium object samples and dry bone samples of radius, humerus and femur bones. Measurements were carried out on these samples in both air and with the samples submerged in a water bath.

The theoretical work showed the importance of the spatial resolution of the MWPC for the accuracy and reliability of bone mineral measurements, which is the currently proposed application of the device. The practical work verified the predictions of a previous theoretical study by showing the dramatic improvement in spatial resolution obtainable by means of pulse height selection in the MWPC output pulses.



a. Raw data

b. Processed data, showing extent of scan

Fig 4.20. Output from MWPC X-Ray Imaging Detector

CPEM X-Ray Imaging Detector

Work recently completed at the Laboratory has shown that X-rays in the more generally used region of the spectrum (10–140 keV) can be detected and thus imaged in a detector consisting of two cascaded channel plate electron multipliers (CPEM). The observed efficiencies range from 1-10% and the calculated spatial resolution is better than 10ℓp/mm over the whole range. Modelling of the detection process indicates that the detection efficiency can be at least doubled by suitable modifications.

This discovery could have a wide range of applications in which a spatial distribution of X-rays is to be detected, for example medical and industrial X-ray intensifiers.

CPEM Photomultiplier Tube

A development programme extending over the past three years has culminated in the production of a new type of photomultiplier aimed principally at High Energy Physics Research applications but with good potential in other fields. The tube uses two channel plate electron multipliers (CPEM) as the gain producing elements instead of the usual metal dynodes. This results in a high gain (2×10^7), a short transit time (∼ins) and a fast anode pulse (rise time 1ns, fwhm 2·5ns). The device is extremely compact as the photograph shows and has the great advantage of being able to operate in magnetic fields of up to 1 Tesla, without magnetic screening of any sort. The problems of gain stability, device lifetime and counting rate effects have been thoroughly explored.

Secondary Emission Detectors

It has recently been shown in the Laboratory that minimum ionising particles can be detected by the secondary emitting surfaces of a Channel Plate Electron Multiplier with an efficiency of 60%, a spatial resolution of ∼10μm, and a response time of ∼10ns. Developments are in hand to raise the efficiency to 99·5% leaving the other parameters unchanged and so produce a new generation of ultra precise x-y recording detectors for use with CERN SPS beams. The mass and physical dimensions of these detectors are low in the beam direction and hopefully some reduction in the scale of SPS layouts would be facilitated by the introduction of devices having such high spatial precision.

Fig 4.21. CPEM Photomultiplier

Gas Proportional Scintillation Counter

The potential uses of this technique in High Energy Physics Research are being investigated. The attraction of having track imaging devices that run at high repetition rates with proportionality stimulates the attempt to deal with the main difficulty of the technique, namely that the emission is in the ultra-violet region of the spectrum. Calorimetry of hadronic cascades is one particularly promising application of gas proportional scintillation and a joint project with Leeds University Physics Department is currently being negotiated for a cosmic ray calorimeter.

4.9 Electronic Design and Development

Electronic instrumentation work at the Rutherford Laboratory continues to cater for the demands of particle physics experiments, but important applications have been realised in other areas, especially physiology and biomedicine.

MWPC Read-Out Electronics

During the first half of 1976 the MWPC read-out electronics for the Rutherford Multiparticle Spectrometer (Experiment 17) and the K15 and K20 beam lines at Nimrod were completed and installed. Instrumentation of a total of 6,500 wires was effected. An improved version of the Rutherford Laboratory MWPC read-out electronics has been developed and is currently being assembled here for the European Muon Collaboration experiment at CERN (Experiment 40). Data from 6,800 wires will be processed.

The basic element is a hybrid amplifier/discriminator which produces standardised digital pulse outputs. This has a maximum sensitivity of 2 microamps with an input impedance of 100 ohms. These elements are usually mounted near the chambers and the digital signals fed to multiplexer units each of which accommodates 32 channels. Up to 32 chassis, each containing 16 multiplexers, feed into a double width CAMAC control module.

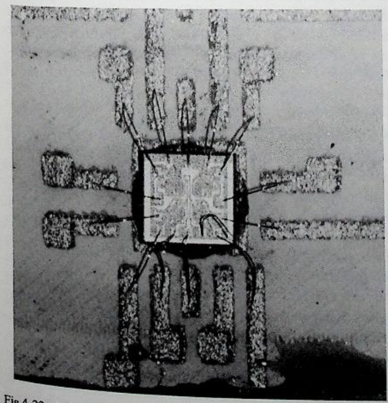


Fig 4.22. Integrated circuit on a thick-film hybrid for use with MWPCs.

Drift Chamber Electronics

A modular read-out system which can handle up to 96 wires was provided during 1976 for an Imperial College/Rutherford Laboratory experiment (Section 1.1.5, Experiment 37). The basic module, which is essentially a time-to-digital converter (TDC), accepts up to 16 events, in any combination, on 8 wires. Using this system a time resolution of 2·5 nanoseconds, equivalent to a spatial resolution of 125 microns can be realised.

In drift chambers, events can occur in such rapid succession that some would be lost if the read-out was direct to the computer with its relatively long access time. For this reason the TCD outputs are stored in a fast 512-word memory buffer for subsequent transfer to the computer. The system is constructed so that up to 16 TCD units (128 wires) and a buffer module occupy one 19 inch chassis.

Special-Purpose Data Processor

A special purpose data processor is being designed and built by the Electronics Group for the WA7 collaboration at CERN, and is scheduled to start data-taking on the SPS in the spring of 1977. In this experiment the ratio of 'good' events to 'bad' events is likely to be so low that considerable pre-processing of this data is essential before it is written onto magnetic tape. The hardware must do this with sufficient speed to keep pace with the incoming data.

The processor consists of an assembly of function units, each of which is tailored to perform efficiently some particular aspect of the track analysis problem. These units have access to a common data store and are activated by a variable length instruction word from a separate instruction store.

The processor has its user programs assembled and loaded by the data acquisition computer to which it is a slave.

CAMAC for Rutherford Multiparticle Spectrometer (RMS)

The data-taking system for the Rutherford Multi-particle Spectrometer (RMS) (Experiment 17) was completed during the year. It is more sophisticated than those previously supplied, not only in the degree of interlacing of data transfers, but also in the proportion of the total system implemented in CAMAC.

The high speed tape decks, the visual display units and the data-collecting modules all communicate with the RMS computer, an IBM 1130, via a single CAMAC system on one direct memory access channel. Many of the data transfers between the CAMAC system, the computer and tape decks are effected by autonomous controllers (Fast Channel Units). The computer central processing unit is only used in an organisational role, thus making a faster overall system than would otherwise have been obtained.

High Voltage Power Supplies

A system of modular high voltage power supplies has been developed specifically for use with MWPC and Drift Chamber Detector systems. These EHT units are externally powered from a common low voltage power module which also provides interlocking facilities for gas alarms, safety lock off, etc. Both EHT and low voltage supply units are housed in double-width NIM modules. Two types of EHT supply have been produced to date, a dual unregulated supply for Drift Chamber applications and a fully regulated supply for use with MWPCs. Both types are provided with adjustable overcurrent trips, the settings of which are indicated on selection by means of a front panel meter. Monitoring facilities for EHT output voltage and current are available both as analogue signals on the rear panel for data logging and on a front panel meter display. EHT output voltages are controlled to ramp up after switch on, the rate of rise being limited to 10% per second to the set value. At switch off or after an overcurrent trip the output voltage also reduces slowly and the load is thus protected from fast switching transients.

The Drift Chamber EHT unit provides both cathode (0 to -5kV) and anode (0 to +3kV) high voltage supplies in one unit and is intended for applications involving low beam currents ($< 10\mu A$). In such applications the load regulation on the anode supply is negligible and since the cathode load is a potential dividing chain of high stability resistors, a fully regulated supply is not necessary and it is sufficient to ensure stability against variations in mains supply voltage etc, and this protection is provided by the low voltage supply module.

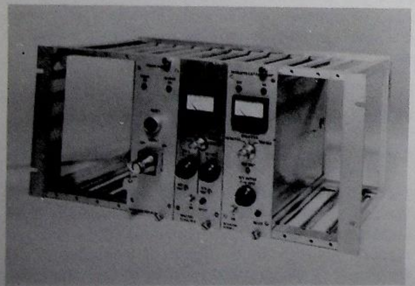


Fig 4.23. High voltage power supply

For MWPC applications however, especially where high beam currents are involved, a fully regulated supply with high stability is required. The EHT unit for use with MWPC has been developed specifically to meet these requirements and will operate over the range 0 – 10kV with a maximum current loading of $250\mu A$. The temperature stability of the output voltage is better than ± 200 ppm per °C and regulation against changes in load such that a change in load current of $250\mu A$ will produce less than 5 volt variation in output voltage. Transient response is such that the output voltage will be within 1 volt of its final value within 5 milliseconds and the peak excursion during the recovery period will never exceed 20 V. Variations due to fluctuations in mains supply voltage are negligible since as for the Drift Chamber EHT supply full protection is provided by the low voltage supply module.

The increased pulse repetition rate and duty cycle required from the RMS (Experiment 17) and RCVD (Section 4.3) spark chamber systems has necessitated an uprating of the performance of the HV power supplies which are used to charge the capacitors in the HV pulsing systems. Modifications to the invertor circuits of the existing capacitor charging supplies have increased the constant current rating of the existing units such that these can now charge loads of up to 10 nF to 10kV in less than 10 milliseconds on a duty cycle of 25%. Stability of the charging voltage is better than 200 volts.

Accurate Spatial Measurements Using a TV Camera

This year two more very high definition vidicon camera systems for reading out optical spark chambers were made for a Bristol University/Rutherford Laboratory experiment (Experiment 8). Continuing development of the camera is taking place with the aim of increasing sensitivity by reducing head amplifier noise and by changing the camera tube from the lead oxide vidicon to the more sensitive silicon diode array type.

A similar camera system has been made and supplied by the Laboratory to Oxford University for a physiological investigation. The requirement was to measure dynamically and with negligible mechanical loading the relative movement of two points on a sliver of muscle 2-5mm long. The specimen, which is immersed in a clear fluid, is subjected to a force varying at a frequency of up to 500Hz. To measure the extension, two $25\mu m$ diameter wires are inserted into the muscle and these are illuminated periodically by a pulsed light source. The instantaneous images of the wires are stored on the vidicon face and, as with optical spark chambers, the time taken by the vidicon's electron beam to scan the distance between the two images is proportional to the separation of the wires. Further electronic instrumentation enables the motion of the wires to be reconstructed from the pulsed samples.

X-Ray Detector Electronics

Further development has taken place in the electronics associated with an MWPC X-ray detector for use in bone mineralisation measurements at Leeds Infirmary.

Detailed improvements have been made in signal detection and in the digital read-out circuitry, but the major change has been the provision, in the CAMAC part of the system, of a semi-conductor memory. This acts both as a data acquisition buffer and as a display buffer, relieving the computer of many of its duties and enabling a much higher data rate to be achieved. The corresponding reduction in patient exposure time is an important clinical advantage.

This application demonstrates an advanced method of using CAMAC. Whereas the basic CAMAC system has one dedicated crate controller, which is usually on-line to a computer, in this case any one of several modules can become a source of CAMAC commands, only one of which is the computer and its interface. This means that a very flexible interlacing of data and commands exists between source modules and normal 'user' modules.

4.10 Physics Apparatus

Physics experiments require a continual supply of specially-built apparatus and detection equipment. The range of detectors built for experiments during 1976 covered scintillation counters, Cerenkov counters, spark chambers, multi-wire proportional chambers and drift chambers.

4.10.1 Scintillation Counters

The largest unit built in 1976 was a hodoscope for use in the Omega Spectrometer at the SPS as part of an experiment to study meson resonances (Experiment 5). It has an active area approximately six metres wide by four metres high consisting of two horizontal rows of thirty scintillation counters per row, each counter having a scintillator area 205 mm wide x 1900 mm long. Individual counter assemblies are supported by thin aluminium alloy sheet folded to form a rigid low mass "stiffback", or spine, the scintillator active area being taped in position while light guide and photo-tube housing are clamped to mountings on the spine. A simple but rigid low mass frame supports the hodoscope counters. It is made from large diameter thin wall aluminium alloy tube, and standard extruded aluminium alloy channel mounted on four wheels to permit lateral alignment, and fitted with four jacks for raising to beam height.

A veto scintillation counter for polarised target P55 (Section 4.1.1) has been designed and installed in the experiment. It consists of a hemispherical cup of scintillation material NE110 approximately 45 mm outside radius x 6 mm thick, joined to three equally pitched four branch light guides about 600 mm tip radius which are roughly perpendicular to the beam, target and scintillator cup axis. Since the target magnet fringe field is large, it is necessary to mount the photo-tube bases over two metres from the target, and to use extension light guides. The space surrounding the target is congested, containing the upstream counters, target support structures and services to both magnet and cryostat, and this extension system has therefore allowed much easier installation of this extremely fragile detector.

A gamma ray hodoscope using scintillation strips has been completed for the SPS Hyperon experiment (Experiment 39). The detector consists of 122 pieces of 40 mm wide scintillator with associated light guides, photomultipliers, bases and shielding, and has an active area of 1040 mm x 1040 mm with a 40 mm x 40 mm hole in the centre. These are closely packed in three layers, angled at 0°, 45° and 90° to the vertical, and held behind a 15 mm layer of lead. To avoid the need for complicated and expensive clamping devices, a system was devised whereby the layers were interleaved with foam rubber and the resulting sandwich clamped together.

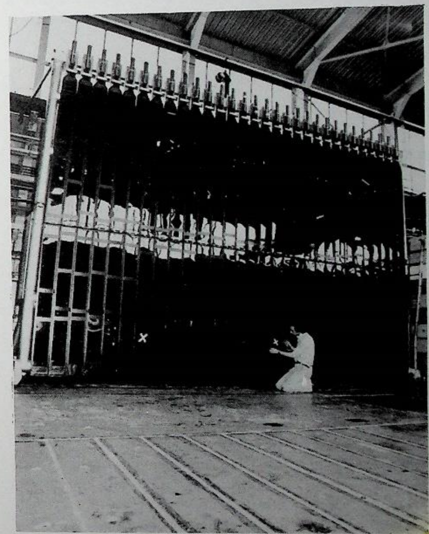


Fig 4.24. Hodoscope for Omega spectrometer

4.10.2 Cerenkov Mirrors

Two high pressure gas Cerenkov counters have been installed in SPS experiments in the West Hall at CERN. The light output due to the Cerenkov effect is low and considerable attention has to be paid to the efficient collection of the light by the photomultiplier tubes. This requirement has led to development of several techniques in mirrors for Cerenkov counters.

The mirrors for the RMS Cerenkov counter were made by preforming a sheet of polyester material on a mould of the required shape and adhering a stiff backing of pre-formed glass fibre laminate to it. After curing, the polyester surface was aluminised and protected with a layer of magnesium fluoride.

Using techniques developed at CERN and the Rutherford Laboratory, thirty-four Cerenkov mirrors to be used in a CERN experiment have been produced. Each mirror is 1·95 metres long by 0·41 metres wide, has a spherical radius of 6·2 metres, average mass is 1 gm/cm^2 and a reflectivity better than 75% at 250 mm. The mirror installation covers an area approximately 6 metres wide and 4 metres high with the mirrors being supported from the edge of the Cerenkov counter "window" by a low mass frame designed and made by the Laboratory. The units are of a laminated construction approximately 50 mm thick, consisting of a reflective surface of electro-chemically polished aluminium sheet, two layers of a pre-formed polyurethane foam (each 25 mm thick) and a sheet of soft aluminium as the backing plate.

Each layer is bonded to the next with epoxy resin, the assembly being held in place by vacuum over a spherically contoured former during the curing cycle, trimming and assembly being done after curing as the final operation. The method has proved to be simple in production with high repeatability and relatively low cost, tests on finished mirrors with visible light and pinhole source set up in the operating geometry produced images up to 30 mm diameter.

4.10.3 Proportional and Drift Chambers

Production of proportional chambers for experiments at Nimrod and CERN has continued. Large chambers of dimensions 2 m x 1 m are being manufactured for the European Muon Collaboration. Smaller chambers, with 1 mm wire spacing have been built for the measurement of beam particle positions.

A system of drift chambers has been produced for use on the Nimrod CP experiment comprising two units having active areas of 62 x 16 cm^2 designed for operation in a magnet aperture where the field strength is 1 Tesla and five larger units having active areas 62 x 40 cm for operation in a field free region. The right left ambiguities are solved by offsetting the appropriate chambers by half the cell pitch. Drift distances employed are ± 24 mm giving 12 cells on the horizontal (x) measuring units and 7 cells on the vertical (y) measuring units.

Experience gained during the commissioning of these chambers has indicated a need for a system to monitor gas gain and drift characteristics. A unit has been tested under Laboratory conditions and is undergoing operational tests.

A prototype drift chamber has been built to evaluate the use of film wire – fine wires bonded closely together on a backing sheet – as a suitable material for composite cathode planes for application in large area drift chamber detector systems.

The prototype chamber has an active area of 160 x 300 mm with two drift sections of ± 40 mm. The cathode planes are constructed using film wire pasted onto a low mass backing material. Cathode spacing is 16 mm and the wires on the film wire are 75 μm diameter beryllium-copper wire wound on a 2 mm pitch. The anode and field wires are supported on a rigid frame, the anode wires being 20 μm diameter gold plated tungsten and the field wires 75 μm diameter beryllium copper.

Initial tests have been carried out under laboratory conditions and the chamber characteristics obtained to date are as expected from the chamber geometry and indicate a satisfactory performance.

4.10.4 Spark Chambers

The production of spark chambers using film wire bonded to low mass expanded polystyrene has continued. Spark chambers have been installed in a large number of experiments, notably RMS (Section 4.10.5) and the PT55 polarised target (Section 4.1.1).

In the modified geometry of the PT55 experiment, additional particle detection is required in the now larger space between the target and the first detector of the spectrometer, to allow installation of polarised target magnet. This has been achieved by using a group of eight low mass magnetostrictive spark chambers mounted in the conical volume of the magnet cryostat between target and spark chamber.

Each chamber consists of a simple earth plane of aluminium foil, facing a high voltage plane made from aluminium "film wire", each plane being supported by a foam polystyrene/Melinex low mass laminate and separated by a simple Perspex ring. The chambers, of varying diameters, are bonded together to form a truncated cone 600 mm diameter at its base to 150 mm diameter at the crown by 120 mm high. The problem of monitoring the chambers has been resolved by extending the "film wire", of each high voltage plane outside the fringe field of the magnet, approximately five metres per plane being required. Magnetostrictive "wands" are then attached to each tail which is then supported from the experiment structure. HT is supplied to the plane from a busbar feed at the wand station, power and readout amplifiers are mounted on the wand base so as to provide easy access for setting up and maintenance.

4.10.5 Rutherford Multiparticle Spectrometer

During the year, work has continued on the manufacture of equipment for the Rutherford Multiparticle Spectrometer (RMS) to satisfy new physics requirements. The Spectrometer enables a range of particles to be observed over a forward angular coverage of ±140°. This is achieved by using eight concentric cylindrical capacitive readout wire spark chambers, backed up by a large multiwire proportional chamber and a series of large flat wire spark chambers situated in the forward direction. The demanding construction of the cylindrical wire chambers has been achieved by utilising a combination of low mass and film wire technology. Also installed to one side of the cylindrical chambers are two large flat capacitive readout wire spark chambers. All this equipment is installed around a hydrogen target in the throat of a large electro magnet.

The flat chambers have been built using established stretched wire technology attached to metal frames. Immediately behind the large flat chambers on the exit side of the magnet has been installed large time of flight hodoscopes. At the exit of the magnet there will be a large high pressure Cerenkov counter into which will be installed eighteen spherically curved mirrors. Beam particles are detected by a series of small multiwire proportional chambers.

4.10.6 European Muon Collaboration Experiment

In collaboration with Germany and France, the UK is designing, building and testing components for the muon experiment to be mounted in the North experimental hall of the 300 GeV accelerator at CERN.

The design of the calorimeter light guides and photomultiplier housings is complete. The manufacture of over 600 light guides made from Plexipop material (a new low cost scintillator developed at CERN) approximately 3·5 metres x 0·28 metres x 10 mm thick and formed into units of 6 and 9 forks has commenced. The detector fork systems will be used to detect electrons and hadrons when assembled at CERN between plates of lead and steel, this forming a calorimeter unit (designed by CERN) weighing approximately 128 tons.

The design of the light guide unit is such that Plexipop material is used throughout. This avoids joints except where it is connected to the photomultiplier where an optical quality silicone rubber transition piece containing an ultra violet filter is used.

The production, bending and annealing of large light guides to these dimensions requires large ovens and the design of special tooling to avoid marking the material whilst bending.

Six drift chamber units 3·65 metres x 4·51 metres and six drift chamber units 3·0 metres x 3·65 metres have been designed. The final detail drawings are being prepared and will give a 38 operational gap system covering an area approximately 12 metres x 4 metres. Between 25 mm thick glass fibre skin Nomex honeycomb panels are stretched 20 micron gold tungsten sense wires and 100 micron beryllium-copper potential wires. The wires require to be accurately positioned at 6 cm pitch and tensioned to minimise catenary effects. The wires are fixed using solder and epoxy resin to printed circuit boards around the edge of the panels.

On to each face of the glass fibre Nomex honeycomb panels is wallpapered a 0·38 mm glass-fibre-backed 35 micron thick copper etched circuit. The etched circuit consists of 3 mm copper strips which are positioned to within a tolerance of ± 0·5 mm. In order to produce lines of equal potential across the gap a voltage gradient is applied at approximately 1 KV/cm to the copper etched wallpaper. 6 KV is applied to the potential wires and 1·7 KV to the sense wires and functions in a gas mixture of 75% Argon 25% Isobutane plus a small quantity of Methylal.

The schedule for producing these drift chambers is such that it is necessary to have two production lines running in parallel. It is expected that all items will be delivered to CERN during the year 1977 and to achieve this, one production line is being set up in building R12 for making the W6 chambers and the other production line has been prepared in building R8 for the W7 chambers.

The design is complete for three proportional chambers each 2 metres x 1 metre. Each chamber is of multiple construction and consists of two stainless steel frames and eight thin glass fibre epoxy resin frames. The glass fibre resin frames are accurately machined in thickness with printed circuit boards glued to their faces. Attached to the printed circuit boards are three sets of sense wires stretched between four sets of high voltage wires.

In each gap the 20 micron gold tungsten sense wire planes are wound with a 2 mm pitch between wires and accurately positioned using a printed circuit comb to within ± 0·05 mm and tensioned to 50 ± 5 grammes. The high voltage planes of 100 micron beryllium copper wires of 1 mm pitch are stretched across the glass fibre epoxy resin frames in a horizontal direction and tensioned to 225 ± 25 grammes.

The frames are bolted together with O ring gas seals between each adjacent support frame with a Melinex gas envelope supported from the stainless steel frames. The chamber operates in a gas atmosphere of Argon, Isobutane and Methylal.

A feature of this design of chamber is the small gap of 16 mm between each set of sense wires thus permitting precise tracking of curving particles. The three chambers are mounted inside a large spectrometer magnet, and manufacture of these chambers has begun.

4.10.7 30-40 Tesla Pulsed Solenoid

During tests to date, the second prototype solenoid in the N5 beamline at Nimrod has reliably operated at 30 T during 2-3 msec pulses once every 5 seconds. The first coil failed at 32 T after reliable performance at 25 T, and improvements in materials used for the present coil suggest a working field of 35 T or more for tens of thousands of shots.

Originally designed at the Rutherford Laboratory based on experience gained in Nimrod Division building high field pulsed magnets, the design has been improved by computer studies at Imperial College, where construction of three coils and one magnet assembly has been assisted by Laboratory staff who have also prepared the large energising installation, first for test purposes remote from experimental hall 3 and lately in situ at N5.

To avoid early mechanical failure due to radial coil-bursting forces of 400 tons (at 40 T) on the 150 mm long, 50 mm diameter bore, the solenoid is machined as a 30-turn helix from a solid billet of beryllium copper, with an insulating, interleaved helix built up from glass mat sectors impregnated with polyamide resin. A heavy non-magnetic steel yoke encloses the 120 mm outside diameter of the coil to contain it in the event of a catastrophic failure. Fatigue, due to coil-bounce attending the 300 ton (at 40 T) axial magnetic forces, is minimised by prestressing axially to 100 tons via massive stainless steel bolts and end plates one of steel and the other of beryllium copper with a conically-profiled central aperture to attenuate the field rapidly away from the coil. By water cooling close to the current-carrying inner skin of the coil, the magnet may be operated every other Nimrod pulse, leaving the 'quiet' beam bursts for a control experiment.

Energising currents of up to 200,000 Amperes are derived by discharging through the 15 μH coil a 150,000 μF capacitor bank charged at up to 8 kV; current reversal is prevented by a crowbar arrangement. The system is similar to those used for previous pulsed beamline magnets at the Laboratory. Estimates of material strengths and fatigue properties based on the latest computer analyses indicate that it is not too unreasonable to expect eventually to operate at 40 T with the present design of magnet.

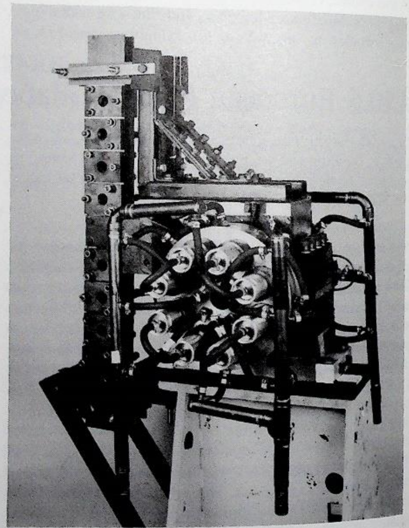


Fig. 4.25. 30-40 Tesla pulsed solenoid

4.11 Energy Research Support Unit

The Energy Research Support Unit was set up by Council at its meeting in November 1976. During the previous year, a number of universities working in the energy field had enquired into the possibility of receiving assistance in their energy research from Rutherford Laboratory. A small working group was set up to investigate ways in which the Laboratory could meet the requirements of university workers. It was concluded that direct assistance could be given in the design and use of instrumentation, manufacture of prototype equipment, computing problems, the organisation of meetings and conferences and, in general, the type of support that the Laboratory already gives in other fields including high energy physics and research using neutron beams and lasers.

Proposals for Unit involvement in the following university research projects are in various stages of preparation:

i) A total energy system involving a high speed heavy vapour turbine and generator system.

ii) Research on energy systems with Stirling engines.

iii) An aerogenerator for the Cambridge Architectural Division.

iv) Research on energy utilisation in buildings.

v) Research and development on heat pumps.

For its first year of operation the Unit has been given a provision of 18 man-years of effort, 6 of these being for the central role of general support, coordination and "pump-priming", and the remaining 12 for direct support to specific projects, when these receive approval by the SRC committees.

5 Computing

The experimental facilities available to users of the Rutherford Laboratory for scientific studies are capable of generating very considerable quantities of data. To allow the analysis of such data, some of the most powerful computing facilities in Great Britain are installed at the Laboratory. These are used not only for the analysis of the very large volumes of data, which are collected in Particle Physics experiments and aboard space satellites, but also in computations employing complex mathematical models developed for the theoretical study of physical and chemical phenomena.

The use of the computing facilities is implicit in much of the work reported in other sections. The work reported in the following sub-sections, however, has taken place mainly in the two Divisions of the Laboratory responsible for the development of the computing facilities. During the year the work and structure of the two Divisions was rationalised. Broadly, the Computing and Automation Division assumed the responsibility for running the existing IBM 360/195 and ICL 1906A computers and the FR80 microfilm recorder, for the provision of computing services based on this equipment to a widely distributed community of users, and for the development of the systems and applications software and the telecommunications facilities necessary to sustain a high level of service. The Atlas Computing Division, again broadly, was assigned responsibility for the detailed implementation of the outline proposals on the SRC's Interactive Computing Facility and for continuing work on applications programming in such specialised fields as Quantum Chemistry, Crystallography, and Databases.

5.1 Atlas Computing Division

The Atlas Computing Division has two major roles to play in support of computing within the Science Research Council.

(a) To co-ordinate and manage the provision of interactive computing facilities by the SRC, whether sited in the universities or at Chilton. This task has been assigned to the division as a result of a decision taken by Council, who accepted the proposals of a technical group set up by the SRC Engineering Board, and chaired by Professor H Rosenbrock (UMIST). Although the impetus for providing an 'Interactive Computing Facility' has stemmed from the engineering community, the facilities will be available to workers funded by other SRC boards, subject to approval through the normal subject committee structure of the SRC.

(b) To provide and support applications software for university scientists and engineers, and occasionally for other establishments within the SRC. In this respect, the division may be regarded as a specialist form of 'software house'. This work is largely oriented towards providing software for the large IBM 360/195 and ICL 1906A computers on site, with some effort being devoted to a very sophisticated microfilm recorder, the III FR80, and to an Optronics P1000 microdensitometer. In the future, applications work is planned on the equipment provided for the Interactive Computing Facility.

The Interactive Computing Facility

The implementation of the recommendations of the Technical Group Report on Engineering Computing Requirements (April 1976) has been pursued vigorously during the year. In the early phase of the project, considerable effort was put into the tender exercise for the large central interactive computer to be installed at Chilton. After full discussion with six manufacturers, a comprehensive tender document was prepared containing both batch and interactive benchmarks. Unfortunately, due to lack of funds generally within the SRC, the decision was taken in September 1976 not to buy a large central machine, but instead, to proceed more quickly with a programme for developing multi-user minicomputer systems as the main method for providing interactive facilities within SRC in future.

After a tender exercise involving thirty manufacturers, orders were placed for a Prime 400 and GEC 4070. The Prime 400 has been installed, and is intended to provide interactive facilities for up to 100 new users after appropriate software development. It is intended that the Prime 400 remain at Chilton and give the Laboratory local experience of managing an interactive system. The GEC 4070 will be placed in a university department once the assessment and development of the system is complete. Both machines have 192K bytes of memory, card reader, lineprinter and communications lines for about 8 users. The Prime 400 has two 70M byte discs, while the GEC 4070 has two 35M byte discs. Initially, these systems will be assessed by mounting and running existing interactive software packages at present used in university engineering departments. This assessment programme will be a joint exercise between the Laboratory and the universities of Cambridge, Glasgow and Leeds.

The proposed enhancements of the PDP10 systems at Edinburgh and UMIST have been completed, and an extended service at both sites is planned. The programme of enhancements of these PDP10 machines has been co-ordinated by the Division. Interactive services are to be operated by the two universities under contract with SRC, to operate from December 1976. Arrangements have been made to connect the three main sites; Edinburgh, UMIST and Chilton, by 9·6K bytes Post Office communications lines, and further connections to the individual star networks are planned as well as a connection between the Interactive Computing Facility network and the IBM 360/195 processors at the Laboratory, thus providing access to powerful batch computing facilities.

In addition to the general meeting held on 26 April 1976 to inform the user population in the universities and polytechnics of the plans for the Interactive Facility, the Laboratory has organised five meetings with special subject groups, including finite element techniques, artificial intelligence, electromagnetic studies, and circuit design (digital and continuous). Those who attended these special meetings have assisted us greatly in defining suitable software and associated development programme which the Interactive Computing Facility can usefully support.

Quantum Chemistry and the 'Meeting House'

The past year has marked the introduction of a new version of the Laboratory's quantum chemistry program package, ATMOL3. This new version provides a wider range of Hartree-Fock methods, more powerful molecular integral evaluation codes, and can handle larger cases than the previous version, ATMOL2. The new version is now well documented, and in production use by numerous university groups.

To provide facilities for more accurate computation of molecular wavefunctions, a general purpose configuration interaction program constructed in Munich in a collaboration between workers at the University of York and the Max Planck Institut, Munich, has been obtained as part of the 'Meeting House' project, and in collaboration with the originators, numerous corrections and extensions have been incorporated; particularly new procedures for configuration selection have been coded, and new procedures for the diagonalization of large sparse matrices have been incorporated, to provide powerful facilities for the extraction of excited state wavefunctions. The system is interfaced to ATMOL3, and now referred to by the acronym SPLICE. SPLICE is now in production, thus providing the first easily available large scale general purpose configuration interaction program for UK workers.

Microdensitometer Operations

The SRC microdensitometer service to university and polytechnic crystallographers, based on an Optronics P-1000 photoscan interfaced to a Computer Automation Alpha-16 minicomputer, has continued to run successfully and has served approximately thirty university groups. The intensity data for some 75 structures have been collected during the year, an increase of 50% on last year. There are now some 30 publications in the crystallographic literature which describe crystal structure analyses based on data obtained from this service. Accuracy remains excellent; the R-factor, which is a measure of the overall accuracy of the densitometric and film taking operations and the theoretical model, for about 60 fully refined structure analyses averages 7·0%, which compares well with factors of 10% and 4·5% obtainable using the human eye or a diffractometer respectively.

A minor, though not unimportant application of the microdensitometer continued to be in the routine digitization of film negatives to magnetic tape. Such jobs were performed for 15 different groups, and for a total of over 200 films. The range of disciplines covered included pneumoconiosis studies of lung X-ray photographs for the Medical Research Council, X-ray fibre diffraction patterns for Exeter University and proton beam pictures of metal edges for UKAEA, Harwell.

Crystal Structure Information Retrieval

An important project was the implementation on the Interactive Computing Facility's PDP10 computer at Edinburgh of an on-line interactive program for the retrieval of crystal structure information compiled by Dr O Kennard's group at Cambridge. The work was performed at the request of the SRC Data Compilation Committee, and will provide a country-wide service to crystallographers and chemists from early in 1977. The system allows the rapid retrieval and display of bibliographic and structural information from the complete organic and organometallic crystallographic literature of over 14,000 compounds.

The work for this project has been logically divided into two components:

(a) the implementation of codes for processing the sequential data sets of crystallographic information received from Cambridge, to produce 'inverted files', the latter facilitating the rapid interrogation of the data base. This phase of the work has been performed on the RL IBM 360/195 computer, the 'inverted files' being produced in a PDP10-compatible magnetic tape format.

(b) The implementation of codes on the Edinburgh PDP-10 for the on-line interrogation of the above-mentioned 'inverted files'.

All code for this project was received from the originator, R J Feldmann of the National Institutes of Health, Bethesda, USA, but considerable work has since been put into correcting and enhancing the original code.

Microfilm Recording

The Information International Inc FR80 microfilm recorder has run for the past year using the basic software supplied by the manufacturer, and an accounting system developed by Atlas Computing Division. Modifications of the manufacturer's software have resulted in some 10,000 lines of code being added to the standard software. These additions have had to be installed as 'binary patches' because the original source code has not been made available by the manufacturer, and these 'patches' have to be re-applied with each release of the manufacturer's software. In consequence, it has become increasingly difficult to maintain and develop the existing software, and therefore a totally new system called FR80 DRIVER is under construction.

FR80 DRIVER will provide all the facilities of the existing software and additionally includes a number of features to improve the performance of the FR80 and extend its facilities in an upwards compatible mode. These new capabilities include performance measurement, powerful text processing orders and a sophisticated colour selection mechanism. FR80 DRIVER has been specifically designed to provide a flexible, maintainable basis for future developments. The prototype was completed in April 1976, and the initial production version is due for release in February 1977

Automated Production of Specialised Publications

Since the arrival of the FR80 microfilm recorder, interest has grown steadily in computerised text processing, to improve the quality and economics of certain publications. Particularly suitable candidates for this work are large collections of text and/or numeric data which are already in machine-readable form (on tape or disc). Much of the time consuming activity involved in manual typesetting of tables and indexes followed by the necessary proof reading can be eliminated by using suitable programs on a large computer (IBM 360/195 or ICL 1906A) and the FR80 to handle the layout. Additionally, the FR80 allows one to mix text and numeric tables with diagrams, and to vary the output medium (eg microfiche, 35 mm film or hardcopy).

One example of such work at the Laboratory has been a project to produce the print masters for the indexes to publications to the field of X-ray crystallography. This has been undertaken in collaboration with staff from the Cambridge Crystallographic Data Centre and members of the Data Bases, Information Retrieval and Text Processing Section of the Atlas Computing Division under the sponsorship of the SRC Data Compilation Committee. The preparation and validation of the data is performed at Cambridge and the data is then sent to Chilton on magnetic tape. The tape is subsequently processed by programs developed by the Laboratory, to control the choice of font, tabulation, line-splitting, justification (vertical and horizontal), pagination etc, before generating the appropriate orders to the FR80 to output the result at high speed. An example of the output is shown in Fig 5.1. In addition to the yearly indexes, a 20-year cumulative index of about 14,000 compounds is in the course of preparation.

It is anticipated that the experience gained from this project will enable more complex programs to be developed. A further publication that the Cambridge group hope to produce

ALIPHATIC CARBOXYLIC ACID SALTS

(AMMONIUM, IA, IIA METALS)

2.1 **Potassium hydrogen bis(trichloroacetate)**
$C_2Cl_3O_2^-$, $C_2HCl_3O_2$, K^+
L.Golic, F.Lazarini Cryst. Struct. Commun., 3, 645,1974
Residue 2 also classified in 1

2.C **Oxotremorine sesquioxalate**
1-(4-(2-Oxopyrrolidin-1-yl)but-2-ynyl)pyrrolidinium sesquioxalate
$C_2HO_4^-$, $C_{12}H_{19}N_2O^+$, $0.5C_2H_2O_4$
For complete entry see 32.22

2.2 **Sodium fluoroacetate**
$C_2H_2FO_2^-$, Na^+
K.Vijayan, A.Mani, B.M.Vedavathi, S.Ramaseshan
Acta Crystallogr., Sect. A, 31, S58,1975

2.3 **Strontium acetate thioacetate tetrahydrate**
$C_2H_3O_2^-$, $C_2H_3OS^-$, Sr^{2+}, $4H_2O$
M.M.Borel, M.Ledesert Acta Crystallogr., Sect. B, 31, 725,1975
Residue 2 also classified in 11

2.4 **Sodium hydrogen diacetate (neutron study)**
$C_2H_3O_2^-$, $C_2H_4O_2$, Na^+
M.J.Barrow, M.Currie, K.W.Muir, J.C.Speakman, D.N.J.White
J. Chem. Soc., Perkin Trans. 2, 15,1975
Residue 2 also classified in 1

2.C **bis(N-Methylethylenediamine) copper(II) malonate dihydrate**
$C_3H_2O_4^{2-}$, $C_6H_{20}CuN_4^{2+}$, $2H_2O$
For complete entry see 76.30

2.5 **Lithium hydrogen maleate dihydrate**
$C_4H_3O_4^-$, Li^+, $2H_2O$
M.P.Gupta, S.M.Prasad, T.N.P.Gupta Acta Crystallogr., Sect. B, 31, 37,1975
Residue 1 also classified in 1

Fig 5.1. Example of FR 80 text output

by this method requires the economical formatting of text mixed with tables of various sizes and accurately drawn stereoscopic pictures for about 1700 molecular structures.

'Finite Elements' Film

This twelve-minute 16mm computer-produced colour film, complete with optical sound-track, was the award winning Great Britain entry in the International Technical Films Competition held in Moscow, October 1976. Produced by the Division in collaboration with the Royal College of Art, 'Finite Elements' introduces the theory behind this engineering computational technique, and presents a selection of real engineering problems which have been solved by the finite elements method.

Although intended for an audience of practising engineers, the film is eminently suitable, because of its visually attractive computer-animated screenplay, for a non-scientific audience. The computer-generated title music adds the finishing touch to what must be counted the first entirely computer-produced engineering film to be made in the UK. It is now being marketed by Compeda Ltd., a subsidiary of the National Research Development Corporation, London.

S2/68 Ultra-Violet Sky Survey

The data collected by the S2/68 ultra-violet sky survey telescope aboard the TD1-A satellite is still the subject of much activity. Workers at University College, London and the Royal Observatory, Edinburgh supported by staff of the

Atlas Computing Division have used the data banks extracted by the first scan of the raw data tapes; the main topics of interest have been the distribution and properties of interstellar dust and ultra-violet objects. The FR80 has been used extensively to plot the spectra.

The second scan of the raw data is almost complete. It is building up a new data-bank containing all the useful spectra detected by the experiment – about 200,000 spectra of 30,000 stars, many of them very faint. A star catalogue is to be published on microfiche, using the FR80 microfilm recorder, to achieve a suitable level of data compression, containing a summary of the mean spectra based on this data-bank.

5.2 Computing and Automation Division

On 1st April 1976 the Atlas Computing Division's responsibility for activities on the ICL 1906A and its share of the IBM 360/195 was transferred to the Computing and Automation Division, which then became responsible for all computing activity on both machines, with the associated network of workstations, and for the FR80 recorder service.

Under a long term Science Research Council plan for computing facilities a second IBM 360/195 central processor, with 1 Mbyte core and channels, was ordered in June. It was decided to house the major computers in the Atlas building, which was promptly modified so that installation of the new machine began on schedule in November. Core memory and peripheral devices will be transferred from the first 360/195 (195/1) to the new processor, and the central computing service will be based on 195/2. A major factor in the schedule has been to reduce to an absolute minimum the time with no service available. After the service has been re-established, 195/1 will be moved to the Atlas building and a coupled two-processor system will be created. Software development has naturally been concentrated this year on preparations for the new system.

Funding arrangements have also changed under the Council plan. The 195/1 was funded by the Nuclear Physics Board and the ICL 1906A and FR80 by the Science Board, but in October responsibility for funding and overall planning was transferred to the new Facilities Committee for Computing. Some of the operations statistics which follow were prepared on a different basis for the final quarter of the year because of this change, but the effects are small in most instances.

The central computer (195/1) operated throughout the year under saturation conditions and achieved record figures. Nearly 8300 hours of good machine time were available to users, and provided 6108 hours of accountable job processing time after deducting overheads. Turnround and time allocations, decided by committees of users, were effectively controlled by the COPPER priority system. Peripheral equipment was augmented by 8 200 Mbyte Memorex type 3675 disc drives and another block multiplexor, plus upgrading of all remaining 9 track tape decks for 6250 bpi recording.

The established 'star' network of over 30 remote workstations changed slightly during the year. Connections were made for several more workstations by private or public Post Office lines, and re-arrangements enabled some stations to access either the 360/195 or 1906A. As the Atlas-Daresbury-Rutherford private network came into use further workstations were able to access Laboratory computers, although of course jobs can only be run by authorised users.

Except during the disruption of the last quarter caused by building work, over 1000 hours of CPU time per quarter were available to users of the ICL 1906A, with an average of 76 hours/week job processing time after overheads. The machine is not under intense pressure and normally operates on a five-day week, but seven-day cover was provided for the UK5 space satellite project. Over 240,000 jobs were processed during the year.

A GEC 4080 computer was bought in 1974, initially to liberate the large section of core in the central computer required by certain interactive graphics programs. Software has been developed which already allows the computer to be accessed by up to six users simultaneously from terminals attached to 360/195 workstations. During the year this subsidiary computer complex became an Operations Group responsibility. An attached interactive system ('ASPECT', which is still being developed) allows rotation of a displayed picture in three dimensions and zooming, etc. by hardware.

5.2.1 Services

Central Computer Operations

Although average machine availability, (1 – down time/scheduled time), was slightly above last year at a record 98·1% the IBM 360/195 was invariably saturated, with a backlog of 20 - 60 hours of low priority work on Monday mornings. CPU utilisation, CPU time/(scheduled - down time), was also a record at 89·7%, with CPU time at 7431 hours for the year (7310 in 1975). These excellent figures were achieved with over 30 remote workstations attached, from which jobs taking 3786 hours of CPU time were submitted. Machine statistics appear in Tables 5.1 and 5.2.

Table 5.1

IBM 360/195 Machine Utilisation (all times in hours)

	First Quarter	Second Quarter	Third Quarter	Fourth Quarter	Total for Year	Weekly Averages 1976	Weekly Averages 1975
Job Processing	2010	2113	2010	2044	8177	157·3	155·6
Software Development	27	26	33	25	111	2·1	2·2
Total Available	2037	2139	2043	2069	8288	159·4	157·8
Lost Time							
Hardware	34	16	61	38	149	2·9	3·1
Software	4	3	2	3	12	·2	·4
Total Scheduled	2075	2158	2106	2110	8449	162·5	161·3
Hardware Maintenance	13	20	14	13	60	1·1	1·1
Hardware Development	12	5	–	4	21	·4	1·3
Total Machine Time	2100	2183	2120	2127	8530	164·0	163·7
Switched Off	83	1	64	58	206	4·0	4·3
Total Time	2183	2184	2184	2185	8736	168·0	168·0

Table 5.2

IBM 360/195 Distribution of CPU Time and Jobs by Funding Authority

	First Quarter CPU (Hrs)	First Quarter (Jobs)	Second Quarter CPU (Hrs)	Second Quarter (Jobs)	Third Quarter CPU (Hrs)	Third Quarter (Jobs)	Fourth Quarter CPU (hrs)	Fourth Quarter (Jobs)	Total for Year CPU (Hrs)	Total for Year (Jobs)	Weekly Average CPU (Hrs)	Weekly Average (Jobs)
Astronomy Space & Radio Board.	59	(12478)	72	(11845)	71	(13136)	97	(21533)	299	(58992)	5·8	(1135)
Engineering Board	65	(3891)	59	(5365)	57	(4558)	59	(5109)	240	(18923)	4·6	(364)
Nuclear Physics Board	1118	(88111)	1210	(102774)	1009	(88874)	990	(92926)	4327	(372685)	83·2	(7167)
Science Board	220	(17058)	209	(17750)	259	(16181)	169	(16454)	857	(67443)	16·5	(1297)
Other Research Councils	19	(7882)	15	(6646)	19	(8323)	31	(10150)	84	(33001)	1·6	(635)
Miscellaneous	70	(30660)	73	(27628)	74	(29028)	84	(36573)	301	(123889)	5·8	(2382)
User Totals	1551	(160080)	1638	(172008)	1489	(160100)	1430	(182745)	6108	(674933)	117·5	(12980)
System Control and General Overheads	276	(709)	328	(666)	338	(729)	381	(675)	1323	(2779)	25·4	(53)
Totals for 1976	1827	(160789)	1966	(172674)	1827	(160829)	1811	(183420)	7431	(677712)	142·9	(13033)
Totals for 1975	1685	(145562)	1872	(153482)	1883	(149660)	1870	(159626)	7310	(608330)	140·6	(11697)
(a) Nuclear Physics Board												
HEP Counters	599	(38962)	480	(40965)	365	(32915)	405	(34899)	1849	(147741)	35·6	(2841)
RL - Film Analysis	54	(6154)	120	(11124)	77	(7507)	90	(9696)	341	(34481)	6·6	(663)
RL - Others	25	(8867)	28	(8911)	24	(8308)	80	(8896)	157	(34982)	3·0	(673)
Theory	64	(4452)	74	(6237)	59	(7294)	39	(6756)	236	(24739)	4·5	(476)
Universities												
Nuclear Structure	55	(6736)	64	(7967)	103	(7194)	103	(7176)	325	(29073)	6·2	(559)
Film Analysis	321	(22940)	444	(27570)	381	(25656)	273	(25503)	1419	(101669)	27·3	(1955)
Totals	1118	(88111)	1210	(102774)	1009	(88874)	990	(92926)	4327	(372685)	83·2	(7167)
(b) Science Board												
Chemistry	112	(6026)	96	(6792)	94	(4844)	86	(5651)	388	(23313)	7·5	(448)
Physics	68	(7985)	92	(8115)	147	(8574)	42	(4709)	349	(29383)	6·7	(565)
Miscellaneous	40	(3047)	21	(2843)	18	(2763)	41	(6094)	120	(14747)	2·3	(284)
Totals	220	(17058)	209	(17750)	259	(16181)	169	(16454)	857	(67443)	16·5	(1297)

Table 5.3

ICL 1906A Machine Utilisation (all times in hours)

	First Quarter	Second Quarter	Third Quarter	Fourth Quarter	Total for Year	Weekly Average
Job Processing	1429	1438	1424	919	5210	100·2
Software	24	44	54	0	122	2·3
Total Available	1453	1482	1478	919	5332	102·5
Lost Time						
Hardware	45	43	35	17	140	2·7
Software	26	9	5	1	41	0·8
Miscellaneous	27	7	12	17	63	1·2
Total Scheduled	1551	1541	1530	954	5576	107·2
Hardware Maintenance	104	104	104	64	376	7·2
Total Machine Time	1655	1645	1634	1018	5952	114·4
Switched Off	529	539	550	1166	2784	53·6
Total Time	2184	2184	2184	2184	8736	168·0

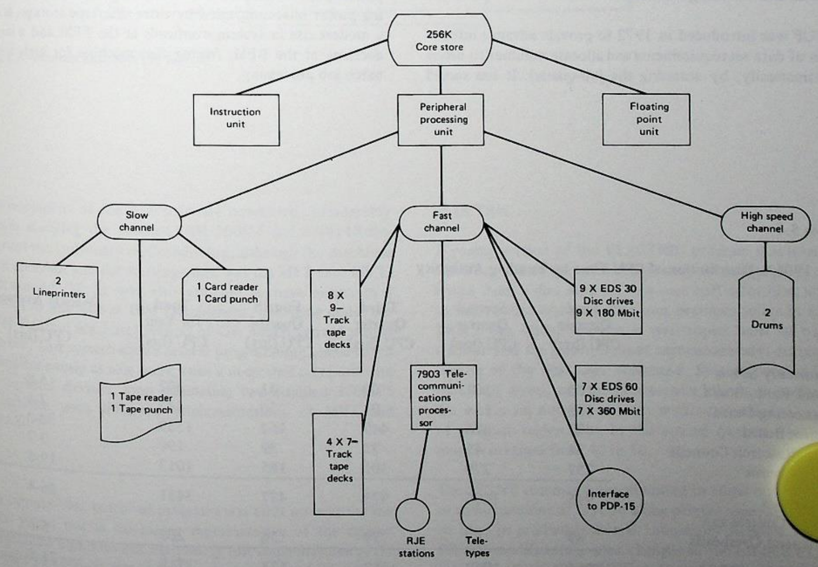


Fig 5.2. ICL 1906A hardware configuration

Growth in use of the ELECTRIC remote job entry and file handling system has continued, with a rise in the weekly average from 350 users to 450 and from 1750 hours logged – in to 2350 over the year. By the end of the year jobs loaded via ELECTRIC took some 75% of CPU time used.

The average availability of the ICL 1906A advanced to 95·6% and the CPU utilisation, after a relatively slack final quarter, averaged 69·7%. The total CPU time used was depressed by building alterations in the autumn to 3718 hours (3851 hours in 1975), of which over 30% was taken by jobs loaded from remote workstations. Statistics are given in Tables 5.3 and 5.4 and the ICL 1906A configuration is shown in Fig 5.2.

Central Computer System Developments

The main developments for the existing central computer lay in providing increased disc and tape storage capacity, extending the SETUP subsystem, and in detailed changes to improve efficiency and limit system overheads. Software for the dual IBM 360/195 array took high priority after the new machine was ordered.

Early in 1976 eight 200 Mbyte Memorex 3675 disc drives were installed, and the remaining 1600 bpi tape decks were upgraded to 6250 bpi. Congestion of disc traffic was significantly reduced by installation of a third block multiplexor channel and matching software.

SETUP was introduced in 1972 to provide advance information of data set requirements and allocate volumes to drives (automatically, by scanning the job-queue). It has served well, but disc packs and tapes are now handled on such a scale in the computer room that further automatic assistance is needed, particularly to take advantage of the dual machines. The new version will indicate volumes currently rarely called, which can therefore be relegated to a more remote store-room, and will also assist the librarian with the system formalities for introducing new tapes.

Various modifications were made to HASP to improve servicing of the numerous RJE (Remote Job Entry) workstations, and MAST was streamlined, with much of its data-handling time now properly accounted to users (instead of appearing as an overhead).

Fig 5.3 shows in outline the planned dual machine layout. The machines will be run asymmetrically, with a front-end machine (FEM) handling telecommunications, line printers, card readers and punch via HASP, MAST and ELECTRIC. The majority of batch-stream jobs will be fed from the single job-queue to the back-end machine (BEM), but residual resources of the FEM will also be utilised for such jobs. Both machines will access all external storage devices but a user may, if he wishes, direct that a job be run on a particular machine. If the FEM fails it will be possible for the BEM to take over its role, continuing the ELECTRIC service in combination with reduced batch processing. The design philosophy, based on the available large increase in processing power unaccompanied by extra disc/tape storage, is for a modest rise in system overheads at the FEM and a larger decrease at the BEM, freeing that machine for high speed batch job processing.

Table 5.4

ICL 1906A Distribution of CPU Time by Funding Authority

	First Quarter CPU (hrs)	Second Quarter CPU (hrs)	Third Quarter CPU (hrs)	Fourth Quarter CPU (hrs)	Total for Year CPU (hrs)	Weekly Average CPU (hrs)
Astronomy Space and Radio Board	100	101	60	41	302	5·8
Engineering Board	132	114	91	50	387	7·4
Science Board	472	476	449	162	1559	30·0
Other Research Councils	34	45	72	39	190	3·7
Miscellaneous	257	270	301	185	1013	19·5
User Totals	995	1006	973	477	3451	66·4
System Control and General Overheads	69	63	79	56	267	5·1
Totals for 1976	1064	1069	1052	533	3718	71·5
Totals for 1975	867	1007	992	985	3851	74·1

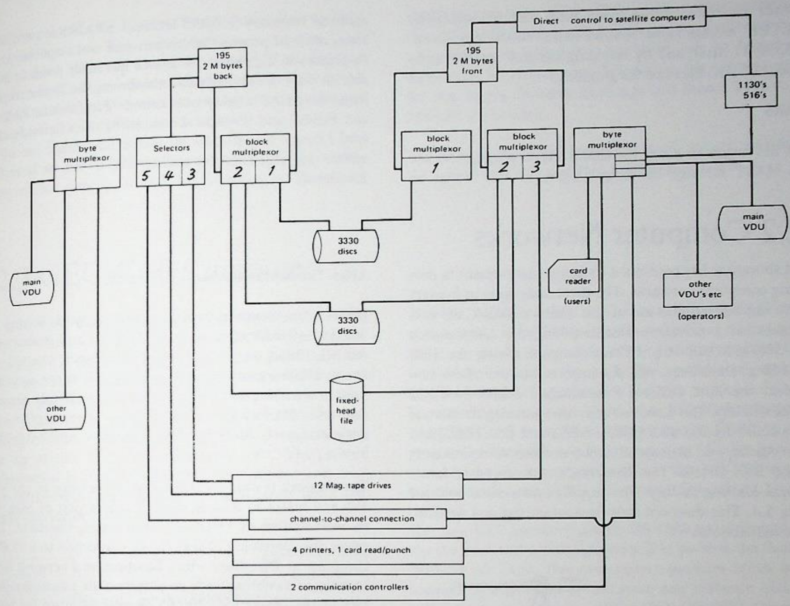


Fig 5.3. Planned dual 360/195 layout

Development of the new software benefitted considerably from studying the coupled IBM 360/65 and 370/145 system at the University of Gothenburg, although the machines are different and the starting-point was the MFT (not MVT) version of OS. It was also valuable to have access to a 370/158 machine at IBM Birmingham, operating under the VM (Virtual Machine) version of OS, which proved simple to use. This system allows several programming teams to act simultaneously as sole users, with a dedicated computer and peripheral devices, even simulating two coupled 360/195 machines with different implementations of MVT and HASP.

A sample 'test batch' of programs was built up over the last six years, but is no longer representative of the current workload and does not adequately test some features of the 360/195 CPU. It was therefore thoroughly revised, and run extensively on the existing machine, prior to tests with the coupled machine configuration.

ELECTRIC

A paging version of the ELECTRIC program was introduced. When a user becomes active, a work area (page) is transferred from a disc data set to a core buffer for him, and returned to disc when another user becomes active in ELECTRIC. The initial transfer is overlapped with an overlay transfer and the return is made asynchronously, during processing of the next user command. System overheads are thus kept down, and the new version allows an increase in the maximum number of users without significant increase of program region size. In the second quarter, this maximum was raised from 40 to 50.

The PRINT command was modified to allow output of two or more columns of text on a line-printer page, and has been so used in producing several Laboratory Reports. Another PRINT modification, plus changes to the off-line ELMUG program, allows ELECTRIC and graphics files to be output to the FR80 plotter, for reproduction there in hardcopy, microfiche or film of standard types.

Demands for more filing space were met by increasing ELECTRIC storage from 108000 to 137700 blocks (an entire 3330/11 disc), and by doubling the data sets for archived ELECTRIC files and for graphics.

STAIRS

Work has begun to adapt the IBM STAIRS program for the local MAST message handling system, so that it can be accessed from any 360/195 terminal. STAIRS is an information retrieval program which can pick out required words or phrases in a database. A service was made publicly available in June 1976 from two databases, the first compiled from the SLAC weekly publication "Preprints in Particles and Fields" and the second comprising titles in the Rutherford Library. So far some 40 people have made use of the service, together taking on average 25% of the 1½ hours/day scheduled.

5.2.2 Computer Networks

The Laboratory has continued its active involvement in developing computer networks. The three main areas of interest remain the operational use of the ARPA network, the development of a private network linking the Laboratory's IBM 360/195 and ICL 1906A computers with the IBM 370/165 at Daresbury, and the implementation of connections to the Post Office's Experimental Packet-Switched Service (EPSS). The Laboratory is also pursuing its interest in the collaboration with CERN, DESY and ESA (European Space Agency) on high speed data transmission experiments via the ESA Orbital Test Satellite, and arranged an international Meeting in July. The proposed network is outlined in Fig 5.4. This does not show temporary test and development connections.

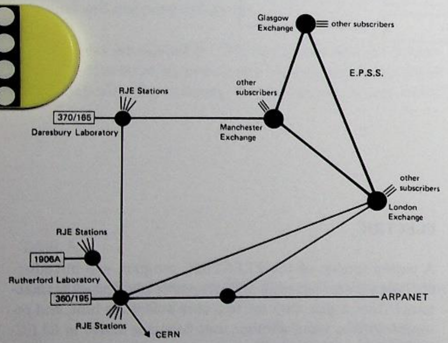


Fig 5.4. Main network connections to the Rutherford Laboratory computers

ARPA

The U.S. Advanced Research Projects Agency (ARPA) has established a computer network linking over 60 sites in the USA, mostly university and Government research laboratories. The network is linked to the Department of Statistics and Computer Science at University College, London, and thence to the Laboratory's 360/195. Some 1000 jobs were submitted to the Laboratory via this network during the year, using about 3 hours CPU time, and there was also some traffic in the reverse direction.

Atlas–Daresbury–Rutherford Network

Progress has continued on a private network linking the 360/195 at Rutherford with the 370/165 at Daresbury and the ICL 1906A on the Atlas site. This network was designed to use EPSS-compatible protocols, so that it can use EPSS itself (or its successor) at some later date, if this becomes desirable. Meanwhile it permits the Laboratory to offer network-type facilities to users in advance of the full EPSS service.

The network is now operational via Daresbury to the 360/195 and offers an RJE service for a large part of each day to workstations at Liverpool, Manchester, Sheffield, Lancaster and Daresbury. These are all connected to a PDP-11 computer at Daresbury which functions as a network node, capable of switching each workstation to either the 360/195 or the Daresbury 370/165. Similar facilities for workstations connected to the GEC 4080 node on the Atlas site, with switching between the 360/195 and 1906A, should soon be available.

Work is in progress on further developments including a File Transfer Protocol permitting users' files to be moved from one computer to another, and an Interactive Terminal Protocol allowing users anywhere on the network to use the various interactive facilities available at the different sites. Both will be compatible with the protocols defined for EPSS.

EPSS

This experimental Post Office network, which is scheduled to run for two years in the first instance, has now become available for a few hours each day. It will not be officially opened as a service until it can operate reliably for at least eight hours daily.

The network comprises three packet-switching exchanges (at London, Manchester and Glasgow) linked by wide-band 48 kbaud lines. The Laboratory has a 48 kbaud line to the London Exchange, a 2·4 kbaud line to Manchester and a 4·8 kbaud line to Glasgow. A GEC 2050 minicomputer is used as a front-end to the 360/195 for communicating with the line to London, its function being to resolve the major differences between EPSS network protocol and the protocol used by IBM.

The connection to the London Exchange was first made in June, and has since been successfully used in a variety of test situations, including the driving of a HASP workstation at University College, London. The Manchester connection was also established and used for testing interactive access to the Laboratory's 1906A via the network.

Work is at an advanced stage to enable GEC 2050 computers connected directly to an EPSS Exchange to function as HASP workstations. This involves networking software in the 2050 itself, thus avoiding the need for front-end machines. When this software is ready, it can be tested very thoroughly by driving a workstation at the Laboratory via the line to the Glasgow Exchange and thence back to the 360/195 via London.

The experience gained from this work should provide for the Laboratory's future data transmission needs.

5.2.3 GEC 4080 Computer

The GEC 4080 is a medium size computer with processing power of about one 'Atlas Unit' for FORTRAN programs. One installed at the Laboratory in 1974 now provides workstation and interactive computing facilities (particularly interactive graphics) for some local and remote users. The central Operations Group became responsible for normal running of the 4080 system during the year, including clean-up of disc space, taking back-ups, etc. The present configuration is shown in Fig 5.5, and there are now over 20 registered users from 360/195 terminals, including a few outside the Laboratory.

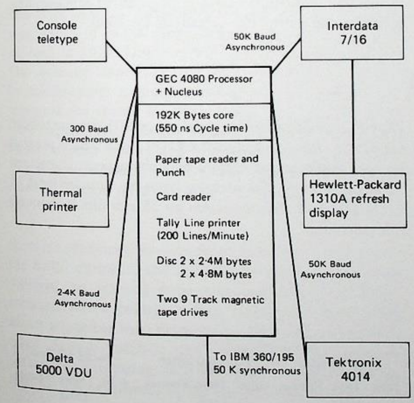


Fig 5.5. GEC 4080 configuration

Operating System

The production system is DOS 2·2 supplied by GEC, but considerably modified to provide a full multi-user system. Warwick University supplied modifications for multi-access and a scheduler, and locally-written extensions include two-way links to the IBM 360/195, multi-shell facilities at terminals and spooling for line printers.

The GEC 4080 can thus be used as a standard HASP workstation, with ELECTRIC facilities available at all its terminals. It can also be accessed from any terminal attached to an IBM 360/195 workstation or to the central computer, but a limit of six simultaneous users has been imposed. Files can be transferred between 4080 and 360 disks, including ELECTRIC, for example enabling a user in CERN to run a program on the 4080 creating a temporary file for line printer output and then submit a job to the 360/195 to print the contents on the CERN workstation line printer.

The new GEC operating system OS 4000 was delivered during the year and is being developed to provide the facilities available to DOS. The new system provides much better accounting and security, and some new software packages will only be provided by GEC within OS 4000. Currently work on HASP multileaving and terminal access has been completed, enabling the 4080 to act as a standard 360/195 workstation and to be accessed from any ELECTRIC terminal. The remaining major development for file transfer is scheduled for early completion.

ASPECT Display

This interactive facility comprises a Hewlett-Packard 1310A electrostatic display head refreshed by an Interdata 7/16 minicomputer, connected to the GEC 4080 by a 50 Kbaud line. Two alternative 1310A heads are available. The first allows only light-pen interaction and is used for Patch-up. The second, using special hardware which is still under development, allows interaction by keyboard and tracker balls as well as light-pen, and offers windowing, zooming, and translations and rotations of the displayed picture in two or three dimensions. It is intended to add hardware characters and broken lines to the display facilities, and variable intensity levels.

ASPECT software comprises a package of routines in the GEC 4080 called by the user's program and communicating with a program in the Interdata 7/16. This graphics package was written locally, partly in BABBAGE and partly in FORTRAN, but the GINO-F graphics package (from the Computer Aided Design Centre) is being adapted to support the ASPECT system and will in due course replace the present package. There are two versions of the Interdata 7/16 program for handling light-pen, tracker ball and keyboard interactions, refreshing the display, and responding to instructions from the GEC 4080. The first and simpler (1·0) is used in production for Patch-up while the second (2·2) is the development system containing more extensive facilities. Version 2·2 is being adapted to suit Patch-up and the modified GINO package in the 4080, and made more robust.

Applications

Rescue of bubble chamber track failures ('Patch-up'). The Patch-up system based on GEC 4080, Interdata 7/16 and Hewlett-Packard 1310A has been in regular use for more than a year. It has generally worked well, being faster than the previous very similar system and more convenient to use. In all nearly 24,000 faulty events have been displayed, of which over 10,000 were 'rescued' successfully and passed quality criteria in the GEOMETRY program.

Magnet Design. The magnet design program GFUN (see Section 4.6) proved considerably too big for the present 4080 FORTRAN compiler and linkage editor and had to be split into several (currently four) processes. This necessitated much program reorganisation, of which advantage was taken to rewrite the input section in a much more general form suitable for design of any three dimensional object, not necessarily a magnet. Engineers have shown a lot of interest in this package, which uses GINO and strict ANSI FORTRAN and can therefore be easily transferred to other computers. When rewriting is completed next year, the user will be able to design an object on the GEC 4080, run an IBM 360/195 analysis program and display the results on the 4080.

To run the whole GFUN program the user must load four processes, which necessitated that access be provided from a terminal to several 'shells' in the GEC 4080. As mentioned previously, the DOS 2·2 operating system was adapted locally to meet this need, but no similar modification exists for the new OS 4000 system and if written locally may conflict with future development of OS 4000 by GEC. However, a new virtual FORTRAN compiler to be offered by GEC next year should handle large programs without splitting.

COMPUMAG Conference. An international conference on computing magnetic fields was held at Oxford in April. A 4080 with two graphics terminals, installed there temporarily and linked by a Post Office line driven at 4·8 Kbaud to the Laboratory's IBM 360/195, was used for demonstration purposes. The GFUN program running in the 360/195 was demonstrated at one terminal (Computek 400), using the 4080 as a workstation, and simultaneously the part of GFUN then available in the 4080 was demonstrated at the other (Tektronix 4014). The ASPECT system was also attached to the 4080 and some of its potential demonstrated by displaying picture files created on the 4080.

5.2.4 Visible Record Production

An III (Information International Incorporated) type FR80 recorder was installed in the Atlas Laboratory in 1975. The FR80 comprises an III 15 computer (similar to a PDP 15) with magnetic tape deck for data input on 7 or 9 track tapes, a precision cathode ray tube and cameras. From data supplied on tape it produces high quality graphical output on colour or black and white film (16 or 35 mm), on hardcopy (12" width sensitive paper) or on 105 mm microfiche (at 42x or 48x demagnification). The input data is processed and displayed, as vectors or alphanumeric characters, within a range of 256 intensity levels on a square mesh of $2^{14} \times 2^{14}$ units. The resolution on 35 mm film is about 80 line-pairs/mm.

Table 5.5

FR80 Utilisation

	First Quarter			Second Quarter			Third Quarter			Fourth Quarter			Totals for Year		
	Jobs	Time (hrs)	Frames	Jobs	Time (hrs)	Frames	Jobs	Time (hrs)	Frames	Jobs	Time (hrs)	Frames	Jobs	Time (hrs)	Frames
ardcopy															
Single Image Format	1889	56	24800	2186	45	30500	1920	43	24900	2352	58	32600	8347	202	112800
Multiple Image Format	784	13	4300	927	15	6100	651	11	4500	632	16	5100	2994	55	20000
(Number of Images)	–	–	(14300)	–	–	(21800)	–	–	(18500)	–	–	(20500)	–	–	(75100)
35 mm Monochrome	310	28	7100	558	22	9100	262	19	8700	323	22	8600	1453	91	33500
Colour	82	13	1900	212	30	5900	104	27	2400	132	39	3600	530	109	13800
16 mm Monochrome	16	1	1900	4	1	500	6	1	3900	46	12	29700	72	15	36000
Colour	36	10	16000	45	26	17600	27	20	16200	22	30	22700	130	86	72500
16 mm Precision Monochrome	61	18	53200	51	7	29700	90	23	105400	43	7	33200	245	55	221500
Microfiche	1076	100	2700	1615	106	4500	1047	120	2700	1153	198	4500	4891	524	14400
Totals	4254	239	111900	5598	252	103900	4107	264	168700	4703	382	140000	18662	1137	524500

The Laboratory machine includes more varied facilities than usually provided at FR80 installations and some time has been lost to development and breakdowns, including replacement of a CRT. But except for colour work (which is processed at least once per week) each day's input has usually been processed by the following morning. In Table 5.5 the output for each quarter is shown, including repeats of faulty runs (some 10% of the total). Users often require several related diagrams, etc, on hardcopy frames. The table shows these separately as Multiple Image Format, and also separates frames taken by the 16 mm precision camera (the universal 16/35 mm camera is used for others).

Software developments for the FR80 are described in Section 5.1 (Microfilm Recording).

5.2.5 Film Measuring & Data Analysis

HPD (Hough-Powell Device) Operations

Production measurements were made for three bubble chamber experiments during the year. Including remeasures of GEOMETRY/KINEMATICS failures, the numbers of three-view events were

$K^o p$ (< 1 GeV/c) (Experiment 9)	2m chamber	14,000
$K^- p$ (~ 1 GeV/c) (Experiment 16)	2m chamber	40,000
	81cm chamber	65,000
$K^- p$ (8·25 GeV/c) (a CERN Experiment)	2m chamber	9,000
		128,000

This stage of the $K^o p$ experiment was completed during the year, a total of 54,000 events having been measured on film exposed in 1974. Low energy $K^- p$ events on 2m chamber film included 1000 (making a total of 75000) pre-digitised by collaborators at Imperial College, and completed measurements for them. The high energy $K^- p$ measurements were requested by Glasgow University, initially to provide bubble density information not otherwise easily available. The film was taken in 1974, and measurements already made at Glasgow were adapted to provide pre-digitisings for HPD.

Some measurements were made on 22 GeV/c $\pi^- p$ film from the BEBC chamber. The standard pre-digitising rules were followed, to generate three points per track (including a common vertex point) on three views only. About 1000 events altogether were measured on HPD, and a sub-sample taken through 'patch-up' and GEOMETRY for kinematic fitting. The processing chain had reached a pre-production level for this experiment by the end of the year.

HPD Development

A detailed study of the HPD optics was begun, with the aim of improving digitising of BEBC film. It revealed some mechanical weaknesses (which do not affect normal operations on film from the 2m or similar chambers) and investigation is continuing.

The two DDP 516/Memorex 1270 serial interfaces were commissioned early in the year and the HPD control program in the 360/195 modified so that it now communicates directly with the DDP 516 satellite computer, independent of the MAST message-handling system previously used. The change has improved efficiency and allows this part of the CPU time used to be properly accounted (instead of appearing as an overhead). The system was subsequently developed for operation of the HPD1/HPD2 tandem complex, and the new version is in full operational use.

The HPD1 machine has been operated satisfactorily, but comparisons with HPD2 show a lesser quality of output. This problem is being studied.

Track Analysis Software

Most of the developments in track analysis software for bubble chambers have been associated with BEBC (Big European Bubble Chamber). Several modifications have made the Geometry program (adapted from the CERN LBCG program) more robust, and various quality criteria have been introduced. Some of the elements in the chain of processing programs have already been altered to handle more than the three camera views always used in the past, because four views will be necessary in some BEBC experiments, and a modified version of the Patch-up system has been tested on the 22 GeV/c $\pi^- p$ experiment in BEBC. Encouraging results have been obtained on a small sample of the 700 V^o events measured, and further investigations are proceeding. A larger group of 3500 events with at least one gamma has been pre-digitised and awaits HPD measurements and subsequent analysis.

In a future BEBC experiment a track-sensitive target will be used (a transparent box of liquid hydrogen in a chamber otherwise filled with a neon/hydrogen mixture). The arrangement causes optical problems in track reconstruction and problems in fitting trajectories of particles travelling through more than one medium. A version of the LBCG program, adapted for the new situation, has been tested with some success on simulated events but final testing awaits measurements from real film.

In optical spark chamber experiments plumbicon cameras or other electronic systems have largely superseded film cameras, for example in Omega experiments at CERN and in the π12 beamline at Rutherford. Plumbicon cameras yield digital information on spark position and intensity, but the apparent position depends somewhat on the intensity in a way which is characteristic of each camera. The effect on measuring precision is significant, so either calibration is necessary or the spark parameters should be over-determined and their true values deduced with the aid of redundant information. Programs have been written for both methods.

In the e-γ collaboration experiment at Omega (Experiment 41) straight wires were painted with 'Scotchlite' reflective coatings, illuminated with flashes of different intensities and scanned by the plumbicon cameras. The calibration program analysed the results and gave intensity corrections across the whole camera tube face. In the π12 experiment four cameras were arranged at 0°, 10°, 80°, and 90° in a plane normal to the incident beam. The position of a spark inferred from each close pair was correlated with an orthogonal view and found to show a systematic error depending on intensity. By analysing a large sample of sparks a correction table for each camera was established. This experiment requires positional accuracy of about ½mm, so it is essential to remove the systematic errors of up to 2½mm due to intensity variations.

6 Accelerator Operations and Development

Accelerator operations at the Rutherford Laboratory are centred on Nimrod, the 8 GeV proton synchrotron, which is still a focal point for research by many collaborations of scientists at both national and international level.

The scientists make use of the different available extracted beams from Nimrod, which are accessed through semi-permanent beamlines. The configuration of these various beamlines is indicated in Fig 6.1.

6.1 Operation of Nimrod

This year, running time on Nimrod was restricted to 8 cycles, due to financial limitations on the amount of electricity that could be used. To make optimum use of the time available, the High Energy Physics schedule was arranged on the principle that an accelerator cycle was run only when at least one experimental team could take data.

Most of the beam went to Hall 3, where a total of seven experiments could run simultaneously, with Hall 1 taking approximately 10% of the beam by the "peeling off" technique described in the 1975 report. The three Hall 1 users were able to share this beam on a pulse by pulse basis using the M14 switching magnets for setting up their experiments, and two of them, π13 and K20, have found it possible to use the peeled beam for data-taking.

Towards the end of the year the full extracted beam of 2 x 10^{12} protons per pulse was supplied alternately to Hall 1, in the form of a synchronised multiple fast spill for the Rapid Cycling Vertex Detector (see Section 4.3), and to Hall 3 as a composite spill. The Hall 3 spill consisted of a fast spill for N5, followed by a slow spill for the other users, from which part was "peeled off" for the K20 and π13 users in Hall 1.

The operations record for High Energy Physics Research is:-

Scheduled time	3736 hours
Realised beam time	3151 hours

i.e. "beam on" for 84·4% of scheduled physics research time

The remainder of the year is accounted for as follows:–

Machine Physics	973 hours
Shutdown periods	3876 hours

Total number of protons accelerated to full energy was about 14·3 x 10^{18}

Machine pulses with beam totalled 3·96 x 10^6.

Circulating beams in excess of 4 x 10^{12} protons per pulse and extracted beams of 2 x 10^{12} protons per pulse were normal. Machine repetition rates varied between 8 and 20 pulses per minute with flat tops of 300-900 milliseconds, according to user requirements.

Operating statistics for the magnet power supply for the year are:–

Machine running time	4465 hours
Machine pulsing time	4180 hours
Total pulses	4,739,447

Nimrod has now completed over 83 x 10^6 pulses.

6.2 Nimrod Development

Improvements to the Field Correction System

A new field correction system has been installed on Nimrod. Independent amplitude and phase control of the zero and first harmonic components of field gradient and median plane around the ring are available, and control of the amplitude and sign of the second harmonic components. The system can provide sixteen sets of corrections through the acceleration cycle, and has been used to accelerate the beam without radial steering. Eight bi-polar solid state current sources are used to power sixteen pole face windings in octant pairs.

Beam Spill for the Rapid Cycling Vertex Detector (RCVD)

A series of 0·5 ms extracted proton beam pulses is required, synchronised to the 60 Hz rate of the RCVD in beamline K18. These pulses are produced by means of RF beam steering, using a servo-system. Satisfactory beam spill has been produced for use by the RCVD during its commissioning phase and further optimisation of the spill duty cycle is under investigation, including the adjustment of the fast spill duration as a shutter to terminate the spill to the bubble chamber.

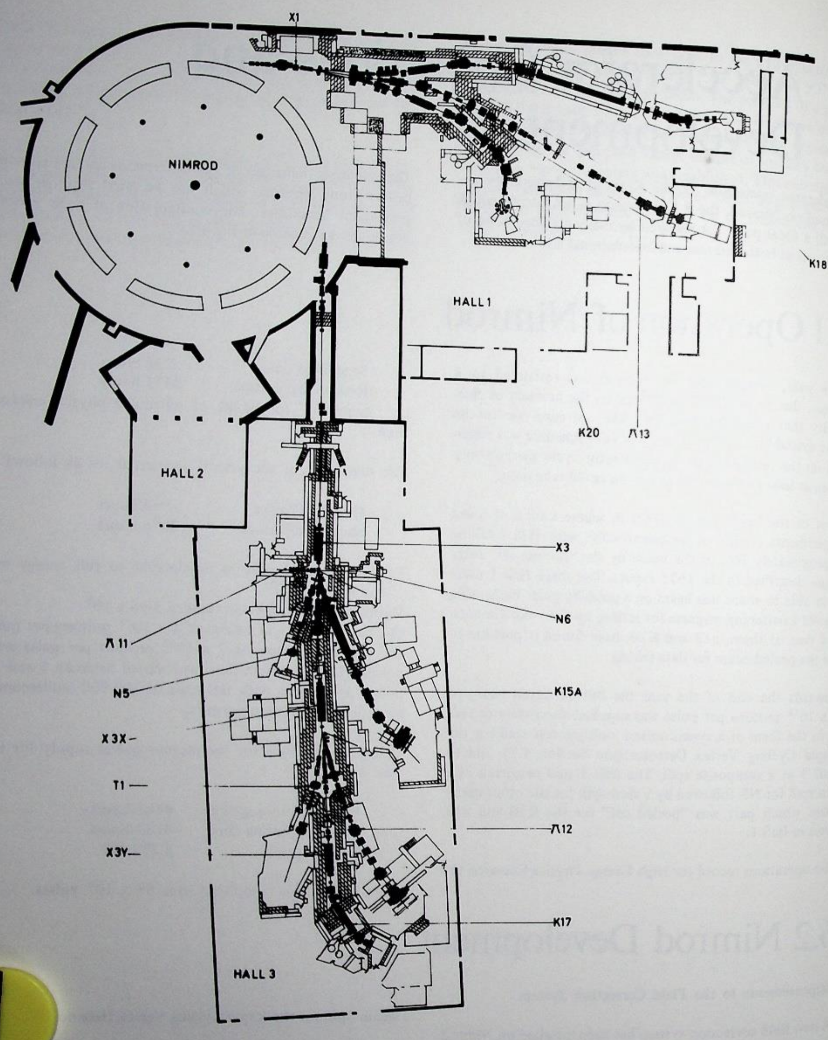


Fig 6.1. Nimrod experimental areas and beamlines

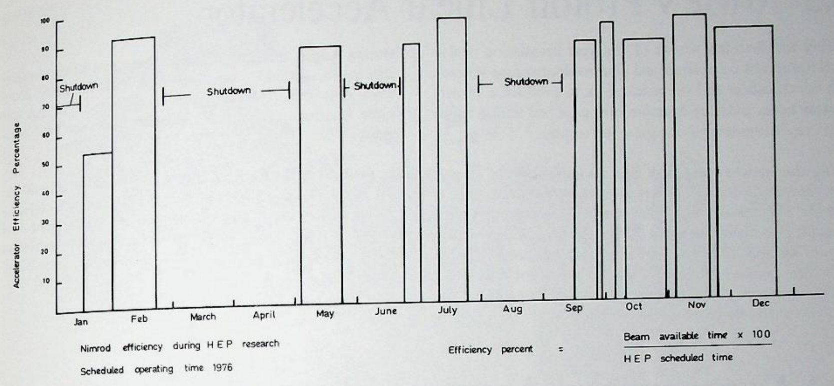


Fig 6.2. Nimrod operation record, 1976

Extracted Beam for Neutron Spallation Studies

Extracted beams at energies down to 1 GeV have been produced as part of a programme to study a spallation neutron source target. A 5 μsec pulse containing at least 2×10^{10} protons is required at the target. To achieve this a 200 μsec pulse containing 5×10^{11} protons is extracted from Nimrod. A 5 μsec slice of this pulse is deflected on to the target using a fast ferrite kicker magnet which is being developed for the purpose. The kicker magnet is a one metre-long single-turn window frame design, with an aperture of 10 cm x 10 cm, designed to operate at up to 600 gauss. Both the magnet and its pulsed power supply make extensive use of existing materials and equipment. A quarter length model has been tested at up to 4500 A and gives rise and fall times of 1 μsec and 2 μsec respectively.

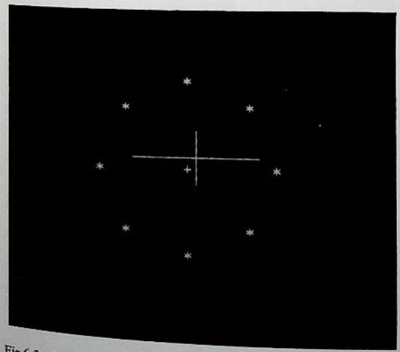


Fig 6.3. Display generated from the Nimrod computer using data from the extracted beam profile monitoring system. The large cross indicates the horizontal and vertical spread of the beam and its position relative to the axis of the flight tube (small cross). Any of the monitors can be selected for display, and the picture can be refreshed on each Nimrod pulse

Beam Monitoring in Hall 3 Extraction System

A beam profile measurement system has been installed in the Hall 3 beamline, as an aid to setting it up at various energies. It consists of a number of Strip Secondary Emission chambers (SECs) similar to the system in use on the Hall 1 extracted beamline, with which beam intensity, vertical and horizontal profiles, beam position and time structure can be monitored. For both Hall 1 and Hall 3 extraction systems, the beam profile monitoring has been extended back to the extraction magnet input. Here the strip SEC is raised during the 0·5 sec dwell time of the plunged extraction magnet in a manner similar to an internal target.

Control, data reduction and display in the monitoring system are through the main control room computer, using programs written by the Nimrod Operating Staff in the interpretive language RTI-75. A variety of graphical and printed data is available, the graphics displays being renewed at each beam pulse. An example of an output display is shown in Fig 6.3.

6.3 70 MeV Proton Linear Accelerator

During the first few weeks of the year installation of the accelerator was completed and commissioning runs started. The specification for the machine is to produce a 75 mA proton beam pulse of duration 500 μsec and with a maximum repetition rate of one pulse per second.

Using the buncher and tank 1, a 10 MeV beam of 80 mA was measured at a temporary beam stop between tanks 2 and 3. The remainder of the machine was progressively brought into operation and a 70 MeV beam was first achieved during May 1976. A period of machine study followed in which detailed knowledge of the characteristics of the accelerator was gained, and some standard operating conditions for the equipment was established.

During August shielding was added over part of the accelerator in preparation for running at high mean intensity, since when runs with 70 MeV output beams of over 70 mA and pulse lengths up to the maximum of 500 μsec have been made.

In the light of the financial situation now prevailing, and the probable closure of Nimrod during 1978, plans to inject a 70 MeV beam into the synchrotron have been dropped. It is hoped that the linear accelerator will see future service as the injector for the neutron spallation facility now being proposed.

6.4 Experimental Areas and External Beams

Installation of Beamlines

Hall 1

During the early part of the year the beamlines K18, K20 and π13 external to the new Hall 1 blockhouse were completed. The former 1·5 m hydrogen bubble chamber magnet was modified to become the Rutherford Multiparticle Spectrometer (RMS) magnet for π13. The reassembled magnet, weighing 400 tons was positioned in π13 beamline in March.

Hall 3

The π8A beamline was removed and replaced with the N5 beamline, including a 30-40 T pulsed solenoid and its power supply. Part of the shield wall of Hall 3 blockhouse was upgraded to reduce the background radiation in N5 to an acceptable level, and further modifications made to allow an outlet for the NBRU experimental beamline, N6.

Hall 1 – Phase II Beam Sharing Scheme

Two types of septum magnet, M17 and M18, have been manufactured for this scheme.

The M17 magnet (Fig 6.4) has an eight stack septum with a laminated yoke and is pulsed with a maximum current of 12,000 A giving a field of 1·0 T. The septum thickness is 10 mm and the length of the magnet 23 cm.

The M18 magnet (Fig 6.5) has a two-turn edge cooled winding with a total septum thickness of 1·5 mm. The maximum pulsed current of 7000 A gives a field of 0·35 T.

A special programmable system, using series and shunt regulators, has been built at the Laboratory to power the magnets. The regulators are identical in design and use some 3000 and 1500 power transistors respectively. The system is digitally controlled and is designed to give a flat top current stability better than 0·02%.

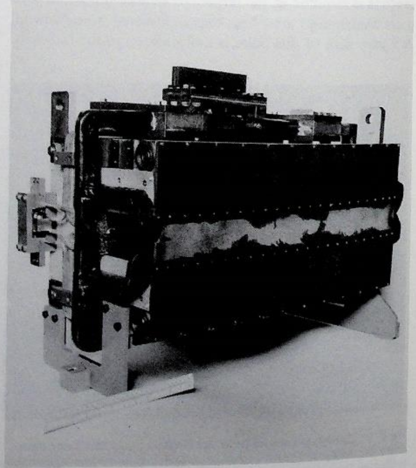


Fig 6.4. The M 17 septum magnet constructed at the Laboratory for the Hall 1 beam sharing scheme

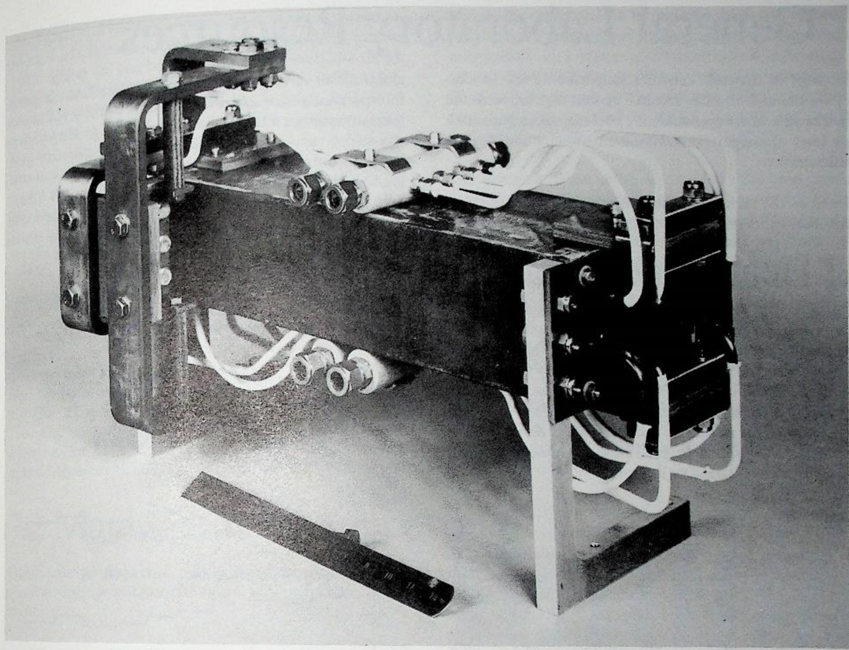


Fig 6.5. The M 18 septum magnet

6.5 Design Studies

Several members of the Laboratory have contributed to a study sponsored by the European Committee for Future Accelerators for the design of a 100 GeV e^+e^- storage ring – LEP. The main contribution has been to the design of an injection system consisting of 400 MeV e^+ and e^- linacs injecting into a fast cycling A.G. synchrotron. To achieve a short main ring filling time, positron bunch trains will be injected sequentially to occupy the whole circumference of the main ring, the process continuing until the total required charge has been accumulated. These bunches are then regrouped into 32 containing the same total charge by repeated back transfer into the synchrotron and re-injection after a suitable time delay.

To minimise the synchrotron radiation losses a combined function lattice is used with zero gradient dipoles between F and D magnets. This last feature enables straight sections, for RF, injection and ejection components, to be provided simply by omitting the dipoles in some of the cells. To ensure a small output beam emittance the lattice F and D magnets are powered at different equilibrium field levels. The table below summarises some of the main injector parameters.

Injection Energy	400 MeV
Peak Energy	20 GeV
Circumference	1·391 km
Qx, Qz	12·85, 15·35
Radial Damping Partition No.	0·084
Peak Synchrotron Radiation Loss/Turn	88·9 MeV
RF Frequency	358·7 MHz
Peak RF Power	4·7 MW

7 General Laboratory Resources

The range of scientific activities supported by the Laboratory on-site and at other research centres together with the requirements of its ever-widening circle of users demands a high level of support services and an efficient and flexible administration.

As well as the services and functions described in this Section, the Laboratory provides comprehensive backup in many other areas, including communications, housing, transport and office services and library, printing and photographic facilities, all having a direct bearing on the efficient day-to-day running of the Laboratory's activities, the quality of its output and the well-being of employees and visiting scientists, and which are none the less important for not being explicity described in an annual summary of the Laboratory's work.

7.1 Health and Safety Group

In April, 1975, the Health and Safety at Work Act 1974 became law. During 1976, the first full year under the Act, considerable effort has been expended by all those involved in the workings of the newly established Safety Policy Committee and Divisional Safety Committees. Aspects of Health and Safety affecting the Laboratory have been reviewed by these committees and where necessary sub-committees have been formed to obtain expert advice to ensure that safety standards are maintained or improved.

General Safety

The Group carried out its executive responsibilities for the statutory examination and certification of registered plant and installations. The advice of the Group has been sought on many occasions and its members have been involved throughout with staff from the Laser, Rapid Cycling Vertex Detector and Spallation Neutron Source projects.

Each Divisional Safety Committee has toured its own areas on a regular basis, and a member of the Health and Safety Group is always present on these tours. Hazards which are noticed during a tour are then immediately reported to those concerned and appropriate remedial actions taken.

The Group has been in continual contact with the Health and Safety Executive's Nuclear Installations Inspectorate and has been involved in a number of tours and in discussions with the inspectors. Any points made by the Inspector during these tours have also been dealt with immediately.

Training forms an increasingly important role for the Group in the Laboratory. Safety induction courses have continued for new staff and safety courses have recently been introduced for re-training. All members of staff are being encouraged to take 'Save-a-Life' (immediate first aid) training which is being given by Safety Group members and by Medical Division, AERE, Harwell.

A course for Safety Representatives was held at the Laboratory in October. The lectures were given by tutors from RoSPA and Aston University. Other, similar, courses are planned in the early part of 1977. Separate safety courses have also been organised to meet the particular needs of small numbers of staff.

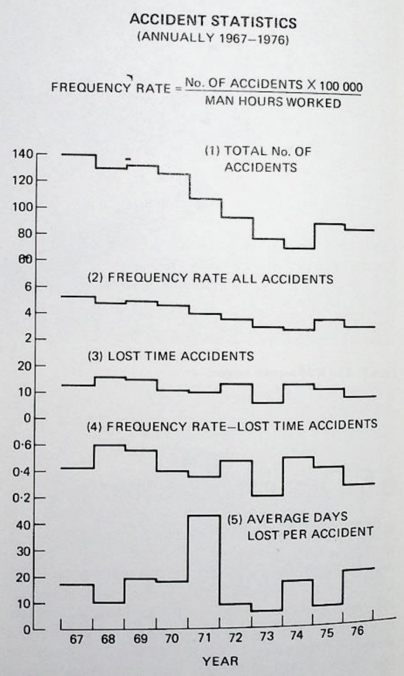


Fig 7.1. Accumulation of accident statistics

The Group has endeavoured to maintain safety awareness in the Laboratory by several means, in particular by the Issue of 'Safety News' and Health and Safety Notices, by safety displays and by showing a series of safety films in the Lecture Theatre.

Group staff and insurance inspectors carried out regular inspection of registered items of equipment. They include (1975 figures in 'brackets):– lifting machines 357 (351), lifting tackle 2521 (2542), pressure vessels 922 (908), safety valves 363 (335), permanent fire fighting installations 21 (21), breathing apparatus etc. 145 (145), and experimental high voltage apparatus 403 (400).

During the year, 86 accidents were reported, 8 of which resulted in lost time. The statistics for the past ten years are shown in Fig 7.1.

Radiation Protection

The number of personal dosimeters issued to Laboratory employees, visitors and contractors has remained nearly constant over the past few years. This year the average monthly issue of neutron track films and $\beta\gamma$ films was 390 and the six monthly issue of TLD dosimeters was about 350. The analysis of these dosimeters and the results of other routine monitoring work shows that no one working at the Laboratory exceeded the permitted level of exposure to ionising radiation. As in previous years, the highest exposures were accumulated by the personnel engaged in the maintenance and repair of Nimrod; a few individuals received about half the permitted dose. The neutron track films were processed by the National Radiological Protection Board, the $\beta\gamma$ films by AERE, Harwell, and the TLD dosimeters by Rutherford Laboratory staff.

The shielding of the new beams in Hall 1 has been carefully monitored during commissioning and has proved to be satisfactory at the present levels of beam used. No special restrictions on the use of experimental area have had to be imposed. Measurements of the radiation from the new 70 MeV injector during its commissioning have shown that the shielding of the machine is adequate for the designed beam intensities.

The Radiation Protection Section continued to collaborate with the π 11 beamline team and with members of Instrumentation Division who are studying the design of the proposed Spallation Neutron Source, and with the Neutron Beam Research Unit irradiation service at the Herald reactor at AWRE, Aldermaston.

7.2 Manufacturing Supporting

Manufacturing support is provided by mechanical and electrical workshops with estimating and outside manufacturing sections.

A very wide range of equipment is manufactured in the workshops often with only sketchy instructions and information. During the year, over 1,000 separate jobs were undertaken. Assistance was also given outside the workshop to other divisions including changing pump and fan controls for the Computer & Automation Division and the installation of power supplies for Laser Division. Approximately 500 jobs were placed by the Outside Manufacturing Section ranging from small bushes to a pair of pole pieces, each weighing approximately 20 tonnes for the Omicron Magnet at CERN.

Stern - Gerlach Magnet

This magnet was manufactured completely by the workshops for the Neutron Beam Research Unit. It is designed for the measurement of the degree of polarisation of beams and neutrons.

An interesting feature of the magnet is the 90° dihedral pole tips, set on swivels so that the gap between the knife edges can be tapered and widened by varying degrees. The pole tips were manufactured in a high cobalt/iron alloy. They were approximately 1 metre long, and the cross section 40 mm x 35 mm, with flatness tolerances of ·025 mm and straightness of ·05 mm. Cobalt iron is difficult to machine and these tolerances aggravated the problem. Tooling for the coils was designed and manufactured by the workshops. This magnet has already been used with very satisfactory results.

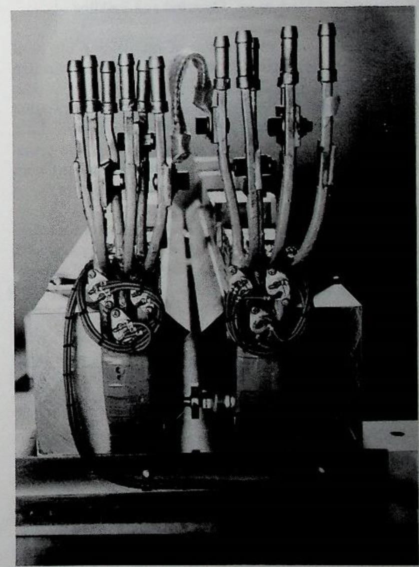


Fig 7.2. Stern Gerlach magnet manufactured for the Neutron Beam Research Unit

Rutherford Multiparticle Spectrometer (RMS)

The equipment for the RMS experiment (Experiment 17) is designed to position either a hydrogen target or a polarised target between the poles of a large magnet previously used in bubble chamber experiments.

This involved the manufacture of a trolley which supports a beam comprising a cluster of stainless steel tubes approximately 75 mm diameter by 4 metres long, which in turn carries the cryostat. The trolley is designed to move on rails in two directions at 90° to each other. Problems caused by distortion from welding had to be overcome in order to achieve the specified tolerances. Because of the accuracy required, the outer jacket of the cryostat was machined from solid material rather than fabricated in sheet metal. The bending of stainless steel tubes with walls 0·1 mm thick necessitated preliminary development work.

The outer radiation shield assembly for the target and cryostat is very complex and includes sheet metal fabrications manufactured from 0·1 mm thick stainless steel. The welding of this thin material to form cylinders posed problems as the welds had to be vacuum tight. These cylinders also had to fit one inside the other with very small clearances involving accuracies which are three times greater than is usual for sheet metal work.

Ion Source Development

The following ion sources were manufactured:

(a) a spare source for the 70 MeV injector
(b) an ion source for the 'heavy particle search' equipment
(c) a negative ion source

Although these items are small in size, they provided interesting problems, e.g. producing discs with very small holes of ·05 mm diameter in tungsten sheet, 4 mm thick. Spark erosion and vacuum brazing equipment were used in the manufacture of components and final assembly.

7.3 Laboratory Maintenance and Supplies

Maintenance – Mechanical, Electrical and Building

In addition to its normal duties of maintaining site plant and services, the Mechanical and Electrical Services Section also had a major involvement in the modification work at the former Atlas Laboratory in preparation for the two IBM 360/195 computers. A great deal of work was carried out while the existing ICL 1906A computer was still in operation and this necessitated very strict control over the work and the provision of a number of temporary facilities.

The Electrical Services Section provided a service for closed circuit television, still and cine projection and tape recording at various Rutherford Laboratory and SRC courses, conferences and lectures. In addition to those held at Rutherford Laboratory, events at Oxford, Stratford-upon-Avon, Swindon, Newbury and Abingdon have been covered.

Extensive maintenance and minor modification work has been carried out by the Building and Civil Engineering Group, ranging from major repairs to flat roofs to the salting and gritting of icy roads in winter.

Electricity Supplies

With Nimrod operational for a considerable part of the year, electricity consumption has remained at a relatively high level. Economies in consumption have been made by switching off as much equipment as possible when not in use. Fig 7.3 shows the pattern of consumption over the last few years. The higher maximum demand is due to additional scientific equipment in use. Advantage is taken of an agreement with the Southern Electricity Board to give the Laboratory a rebate if demand is reduced at designated 'Potential Peak Warning Periods' during the months of November, December, January and February. Special arrangements are made for this and a rebate for this of approximately £140,000 is anticipated for the current financial year.

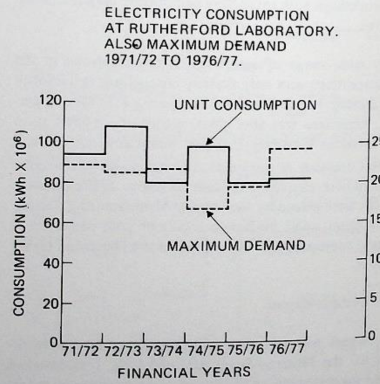


Fig 7.3. Use of electricity over the last five years

Steam Consumption

Further progress has been made in reducing steam consumption at the Laboratory. Particular emphasis has been placed on cutting down still further the steam mains left in service during the Summer months, hence reducing the Summer mains losses. The effect of this can be seen clearly on the graph of steam consumption for the last three years (Fig 7.4). Apart from the need for energy saving as such, the price of steam has increased considerably over the last two years. The savings made have resulted in a significant reduction in the Laboratory's budget. For example, the reduction in steam usage from the 1974/75 level gives an initial saving of at least £40,000.

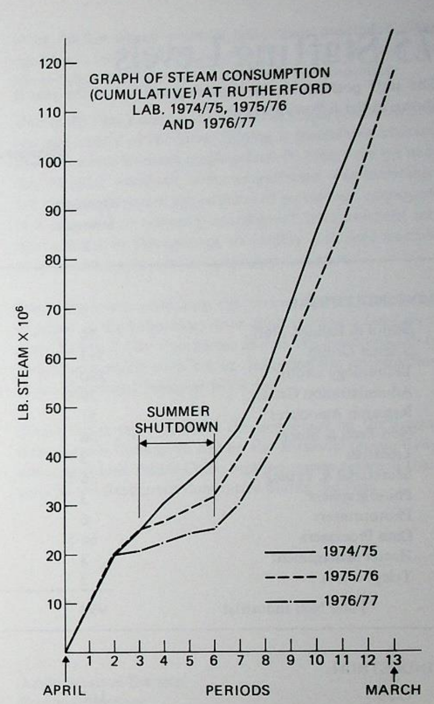


Fig 7.4. Steam usage

7.4 Electronics Services and Production

Much effort was expended on the acceptance-testing of 1,600 new units, predominantly those designed at the Laboratory and manufactured either by sub-contractors or the internal manufacturing section. Consequently, highly-specialised test equipment has been built and test programs written to enable semi-automatic testing to be carried out under computer control. In some notable instances, commercial items have been shown to be outside their published specifications, necessitating re-design by the manufacturer.

Some 2,500 commercial instruments – oscilloscopes, pulse/signal generators, power supply units etc – were accepted for repair. Of these, about 40% were sent to specialist firms after initial diagnosis. In the more specialised electronic instrumentation field a much smaller number of units, about 250, were repaired. Nearly half of these were commercial designs.

Some 6,500 man-hours were spent servicing physical instruments such as chart recorders, graph plotters etc., about 5% being sent to outside firms. 35% of the work involved repair or calibration in situ, for example on beam lines.

The major commitment in electronics production during 1976 was to high energy physics experiments, particularly in the production of electronics instrumentation for multi-wire proportional chambers.

55 new printed circuit designs were completed, involving 190 drawings (7000 man-hours). 70% of the work was done in-house. 400 electronic assembly jobs were completed at a cost of 34,000 man-hours, 85% of the work being done internally. Printed circuit boards to the value of £35,000 were produced to our designs by specialist firms during the year.

7.5 Staffing Levels

The staff position at the beginning and end of the year is shown in the following table:–

	Opening Strength 1.1.76	Changes during 1976 Gains	Changes during 1976 Losses	Closing Strength 31.12.76
NON-INDUSTRIAL				
Senior & Banded Staff	34	4	4	34
Science Group	343	18	39·5	321·5
Technology Group	330·5	3·5	32	302
Administration Group	79·5	5·5	10	75
Research Associates	51	17	21	47
Non-Tech & Stores	36		10	26
Librarian	2			2
Secretarial & Typing	36·5	14	8·5	42
Photographers	3			3
Photoprinters	6	1		7
Data Processers	66·5	6·5		60
Hostel Management	3	1	1	3
Telephonists	2			2
Total Non Industrial	993	64	132·5	924·5
INDUSTRIAL				
Craft	168	6	15	159
Non-Craft	132	16·5	24	124·5
Apprentices	27	3	6	24
Total Industrial	327	25·5	45	307·5
GRAND TOTALS	1320	89·5	177·5	1232

The figures listed under "changes" include new entrants, resignations and promotions. Staff on sandwich courses, and those working part-time are counted as half.

7.6 Staff Relations

Formal discussions have continued between the local Staff Side and Management at the quarterly Whitley Committee meetings, but numerous informal talks have also taken place in a year during which staff numbers reduced appreciably and the work of the Laboratory has diversified. A voluntary premature retirement scheme introduced early in the year played a significant part in achieving the necessary staff reductions. Local discussions between Staff Side and Management eased the inevitable problems of implementing this scheme. A number of staff commenced retraining for work in new fields, on moving to the Laser Project, the Energy Research Support Unit, to computing work and on work for the Council's Engineering Board. In addition the installation of another major computer led to a shortage of well-qualified staff in this specialised area of work. This shortage was eased by the rationalisation of operational schedules and staffing but the need for volunteers able and willing to transfer to this field of work is still evident.

As staff have been reorganised into different working groups a certain amount of relocation within the laboratory proved necessary. This caused staff some problems but the situation has now been ameliorated by an agreement reached on the Laboratory Whitley Committee for the prior discussion of accommodation moves with the local Staff Side.

The new Health and Safety at Work Act led to the setting up of a Safety Policy Committee at the Laboratory with Staff Side representation. In addition, Staff Side also supplied one representative on each of the divisional safety committees. Individual members of staff have wider responsibilities under this Act and these have been actively discussed in the above committees.

In the past it has often proved difficult to establish a suitable forum for dealing with problems experienced jointly by staff using common facilities provided by AERE Harwell. During 1976 a combined Staff Sides' Liaison Committee was set up to meet this need. It is currently chaired by the Rutherford Laboratory Staff Side Chairman and meets quarterly.

Management and Trades Union Side representatives met regularly at the quarterly meetings of the Local Joint Consultative Committee, including the annual meeting chaired by the Director. Industrial relations continued at a normal level throughout the year.

The phased reduction in the numbers of contract employees continued and following local discussions, a new agreement for the use of contract labour was concluded. This agreement facilitated the construction work necessary for the installation of the second IBM 360/195 computer.

During the year a number of industrial employees retired or resigned, many of the latter finding it possible to improve their prospects in other employment. In order to cope with the essential workload, some recruitment was inevitable, but so as to safeguard the position of permanent employees in a situation of reducing complement, an agreement was concluded with Management to employ a limited number of industrial employees on temporary contracts.

Shop stewards representing the various Trades Unions recognised at the Laboratory took their places on the Laboratory Safety Policy Committee and on the divisional safety committees which were set up following the introduction of the Health and Safety at Work Act.

Trades Union representatives also continued on the Suggestions Awards Committee and on the divisional productivity sub-committees. Trades Union representatives resumed their seats on the Restaurant Committee during the year.

7.7 Finance

The Laboratory's expenditure for the financial year 1976/77 was £16·35 million, of which £2·68 million was capital expenditure and £13·67 million was recurrent. Corresponding figures for 1975/76 were £14·83 million, £1·45 million and £13·38 million. The capital expenditure of £2·68 million included £0·85 million on the second IBM 360/195 computer, £0·55 million on the Interactive Computing Facility and £0·45 million on the Laser Facility.

A brief analysis of the net expenditure is:

	£ million
Staff expenditure (salaries and wages, insurance, superannuation, etc)	7·06
Research and development	6·60
Plant and equipment	2·37
Building works	0·32
Total	16·35

The research and development expenditure can be broken down as follows:

Administration Division	9·6%
Common Services	5·8%
Technology Division	4·8%
Computing and Automation Division	3·2%
Computer maintenance and rental	4·4%
Engineering Division	7·0%
Electricity	14·0%
High Energy Physics Division	19·4%
Nimrod Division	3·8%
Instrumentation Division	2·0%
University Agreements	2·2%
Neutron Beam Research Unit	2·5%
Laser Division	2·3%
Atlas Computing Division	11·7%
SRC Works Unit	2·3%
Interactive Computing	2·6%
Other activities: Engineering Board, Astronomy, Space and Radio Board, Energy Research, etc	2·4%

8 The Council Works Unit

During 1976, the Science Research Council Works Unit has been engaged on a wide range of design and construction work. Many of the requirements have been rather unusual, for example, the 1 mm wavelength Astronomy Telescope housing (Section 4.7) and the Clean Room for the 700 giga-watt Neodymium-glass laser (Section 3). A very recent request has been to investigate deficiencies in the air conditioning systems at the NASA Tracking Station at Winkfield.

The Appleton Laboratory (and Outstations)

The construction of the new computer building at the Appleton Laboratory was completed in the early part of the year, and the ICL 1904A computer was transferred into the new area. In addition to the provision of a fully air-conditioned building for the computer and its support facilities, computer electrical supplies with new generators and a standby diesel generator were also installed. A second diesel generator was installed and commissioned as a standby electrical supply to the site as a whole in case of total electrical supply failure and work on reinforcing the 11kv mains to the site was completed.

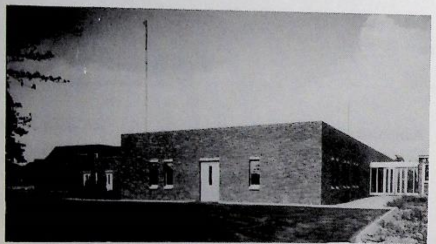


Fig 8.1. Computer building at Appleton Laboratory

The area vacated by the 1904A computer has been converted into laboratory, office and conference room accommodation. An air-conditioning unit was also transferred from the old 1904A area to the Chilbolton Observatory where it was re-installed in the control room. This gave increased cooling capacity to deal with heat load of additional computing equipment.

A new security gatehouse with automatic road barriers was designed and constructed during the year. Outline schemes were prepared and costed for extensions to the Balloon Payload Integration Area and the Workshop.

Preliminary work has been carried out in conjunction with the Astrophysics Division of Appleton Laboratory regarding the design and costs of various types of housing for the 1 mm wavelength Astronomy Telescope. The proposed structure is approximately 26 m high with a 22 m square base and must be capable of surviving winds up to 200 Km/hr on a mountain site (see Section 4.7.2).

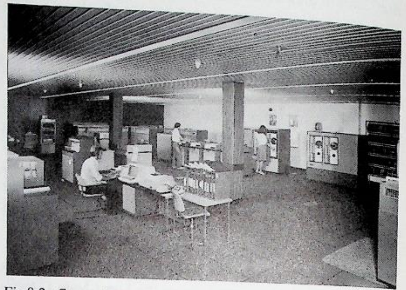


Fig 8.2. Computer room at Appleton Laboratory

The Royal Observatory, Edinburgh

Two new temporary buildings were constructed in the grounds of the Observatory.

Schemes were prepared for new workshop buildings and the modernising of the Management Building heating system. A design was prepared and cost estimates provided for improvements to the existing visitors' facilities. A new staircase and entrance to the West Dome were included in the proposals to improve safety and the means of escape from areas open to the public in case of fire.

The Royal Greenwich Observatory

The conversion of offices of the West Building Archive Store was completed. This provided accommodation for the staff engaged on the Northern Hemisphere Observatory project.

The installation of emergency lighting and additional fire alarms, together with various detailed building modifications were completed in the Castle. These were carried out to the requirements of the East Sussex Fire Authority. The work presented quite novel problems in preserving the appearance of the fabric; the building work was carried out with great skill by the Observatory's own craftsmen.

Design work was completed on the conversion of part of the ground floor of the Castle into a visitors' exhibition area. This involves the specialised problems of the effective display of historic and educational exhibits for the public.

SRC Swindon Office

The main building contractor and the two major sub-contractors for the electrical and mechanical services were appointed early in the year to construct the new office building at Swindon. This will be occupied jointly by the Science Research Council and the Natural Environment Research Council during 1978.

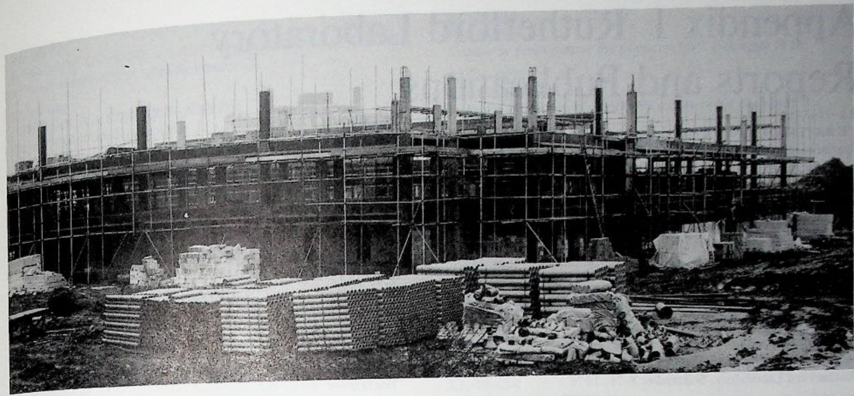


Fig 8.3. Building new offices at Swindon

Construction commenced as planned on May 3rd 1976. The programme of work has been arranged to give staggered dates for occupation, namely: (a) SRC Block on January 31st 1978, (b) NERC and Conference Blocks on April 30th 1978 and (c) overall completion on July 31st 1978. Fig 8.3, taken in late October 1976, illustrates the progress at that time, and the more advanced state of the SRC Block.

The dry summer gave an excellent start to the building work and by the end of summer, the progress was ahead of schedule. The estimated final cost, which is updated each month, is well within the approved sum. Every effort is being made to ensure that this initial success is maintained.

The Rutherford Laboratory

A large amount of design and installation work was carried out in the modification to the former Atlas Laboratory buildings to accommodate two IBM 360/195 computers. This involved extensive modifications to the air-conditioning plants, chilled water plant, electrical distribution and power supplies and the building fabric within an extremely short time-scale. Very detailed programming was necessary with close liaison between client, equipment manufacturers and the CWU project team. The project was completed within the cost allocation, and a little ahead of the scheduled target date.

Detailed planning was also necessary for the construction of a Laser Clean Room within an existing laboratory. An associated control room and a clean preparation facility were also provided. The operation of the high-power laser called for relatively dust-free and constant temperature conditions. A very clean laminar-flow facility is necessary for the assembly and preparation of laser components. Both installations were completed to programme and more than met the design requirements. Outline schemes for possible extensions to the laser target area, which involve a new addition to the building, have been produced.

A number of other schemes were designed and constructed, including improvements to the reception facilities in the main entrance and the main staircase plus associated enclosures. Modifications were also made to the enclosure of the R1 East staircase.

Appendix 1 Rutherford Laboratory Reports and Publications

RL-75-140
J E BATEMAN, M W WATERS, R E JONES
Spatial resolution in a xenon filled MWPC x-ray imaging detector – a computing physics approach

RL-75-155
J T MORGAN, G B STAPLETON
The use of molecular sieves for controlling gas pressures in the nimbus G radiometers

RL-75-161
J D LEWIN
Renormalized vacuum polarization for finite range potentials

RL-75-168
P G MURPHY, ed.
Proceedings of the School for Young High Energy Physicists, Rutherford Laboratory, September 8–26, 1975

RL-75-175
HEP ELECTRONIC GROUP
GEC 4080 RUFUS Manual

RL-75-178
C W PLANNER
The r f system for the 70 MeV linac injector

RL-75-181
J D DOWELL, J GARVEY, M JOBES, I R KENTON, J MAWSON, T MCMAHON, I F CORBETT, S DAGAN, R J ESTERLING, M R JANE, N H LIPMAN, P J LITCHFIELD, KCTO SUMOROK, G ALEXANDER, I BAR-NIR, Y GHAT, J GRUNHAUS, E H BELLAMY, M G GREEN, J B LISTER, J R LISTER, P V MARCH, A R ROBERTSON, B J STACEY, J A STRONG, D H THOMAS : L V MARCH
Birmingham-Rutherford-Tel Aviv-Westfield College Collaboration
Omega production in the section $\pi^- p \to \pi^+\pi^-\pi^\circ n$ at 8 and 12 GeV/c

RL-75-184
P MANSFIELD
Magnetic fields of curved conductors

RL-75-189
J R J BENNETT, A CARNE, D A GRAY, M R HAROLD, J T HYMAN, A R MORTIMER, G H REES, A G WHELDON
A high intensity 53 Hz. 800 MeV proton synchrotron

RL-75-193
W WALKINSHAW, A T LEA
Computing and Automation Division quarterly report 28 September – 28 December 1975

RL-75-195
A J MIDDLETON
Creep of aluminium vacuum chamber extrusions during bake-out: a theoretical estimate

RL-76-002
F J SWALES
70 MeV injector: 10 MeV beam stop

RL-76-003
G V DASS
Angular distributions of neutrino and antineutrino scatterings by electrons and gauge models

RL-76-004
J R J BENNETT
Gas evolution in epoxy under irradiation and maximum allowable beam loss in the proposed 800 MeV proton synchrotron

RL-76-005
R G FOWLER
Screens for high voltage equipment

RL-76-007
D R PERRY
Physical aspects of a radiobiological pion beam

RL-76-008
K PALER, T P SHAH, S N TOVEY
The Illinois partial wave analysis programme at the Rutherford Laboratory, a user's guide

RL-76-010
G EGERT, H DACHS
The use of curved ideal crystals as monochromators for neutrons. An un-edited translation of a paper from Journal of Applied Crystallography

RL-76-011
H DACHS
The Guinier system using a neutron guide-tube. An un-edited translation of a paper from Journal of Applied Crystallography

RL-76-012
C HONG-MO, J KWIECINSKI, T S TSUN
Almost stable particles with masses above 5 GeV

RL-76-013
R D BAKER
Barrelet zeros in partial wave analysis

RL-76-15
A BIGI, W CAMERON, P CAPILUPPI, R CASALI, P CROFT, E FLAMINIO, G GIACOMELLI, R JENNINGS, G KALMUS, P LUGARESI-SERRA, G MANDRIOLI, A MINGUZZI-RANZI, V MOGGI, W MORTON, A NAPPI, K J PEACH, A M ROSSI, W VENUS
Bologna-Edinburgh-Glasgow-Pisa-Rutherford Laboratory Collaboration
Study of the reaction $K^\circ_L p \to K^\circ_S p$ in the c.m. energy

RL-76-017
P J HEMMINGS, H HURST
Access to the Rutherford Laboratory 360/195 computing system via the switched public network

RL-76-018
N J NEWMAN
A Fortran package for solving linear algebraic equations with a large dense matrix using direct access disk storage

RL-76-019
M H R DONALD, J R M MAIDMENT
Closed orbit in the presence of synchrotron radiation loss

RL-76-020
P I P KALMUS, R B JONES
Particle accelerators and the fundamental constants

RL-76-021
F E CLOSE, R L KINGSLEY, G A RINGLAND, D SIVERS
Evidence for the appearance of more than one new quark from data e^+e^- and νN collisions

RL-76-022
R W TUCKER
Extended particles and the exterior calculus

RL-76-023
T KAWAGUCHI, K KONISHI, H NAKKAGAWA
Deep inelastic processes and SU(4) symmetry

RL-76-025
F E CLOSE
Theoretical aspects of electron-positron annihilation below 3 GeV

RL-76-027
M J NEWMAN
Application of interactive graphics techniques to magnet design

RL-76-028
H BALDOCK, R P HAND, J S HUTTON, D MADEN, R A ROSNER
A 7-track magnetic tape labelling scheme

RL-76-030
J T HYMAN, R A ROSNER, W A SMITH
The selection of small computers

RL-76-031
B ALPER, D ASTON, A G CLARK, P J DUKE, W M EVANS, C N P GEE, R J GRAY, E S GROVES, L E HOLLOWAY, J N JACKSON, J V MORRIS, R J OTT, S E ROCK, T P SHAH, A J SHAVE, J J THRESHER, W A WENZEL
Multiplicities associated with the production of pions, kaons or protons of high transverse momentum, at the ISR

RL-76-032
A T LEA
The role of Nuclear Physics 195 Computer Representative

RL-76-033
F E CLOSE, D M SCOTT, D SIVERS
Mass scales and asymptotic symmetry in deep inelastic scattering

RL-76-034
D E GRAY, ed.
Nimrod operation and development. Quarterly Report, October 1 to December 31 1975

RL-76-035
R G FOWLER
The production of filaments for the ion source of the preinjector of the 70 MeV injector

RL-76-036
K KONISHI
Symmetry breaking and planar bootstrap equations

RL-76-037
C J COLLIE
Magnetic fields and potentials of linearly varying current or magnetisation in a plane-bounded region

RL-76-038
M N WILSON, C R WALTERS
Development of superconductors for fusion technology

RL-76-039
R M BROWN, A G CLARK, P J DUKE, W M EVANS, E S GROVES, R J OTT, H R RENSHALL, J J THRESHER, M W TYRRELL, T B WILLARD
A measurement of the efficiency for the detection of neutrons in the momentum range 200 to 3200 MeV/c in large volume liquid scintillation counters

RL-76-040
R SIDLOW
Ion source changeover and assembly procedure (70 MeV injector)

RL-76-041
J SIMKIN, C W TROWBRIDGE
Magnetostatic fields computed using an integral equation derived from Green's theorems

RL-76-042
R G FOWLER
New injector for Nimrod: assembly of preinjector column

RL-76-043
C S BIDDLECOMBE, C J COLLIE, J SIMKIN, C W TROWBRIDGE
The integral equation method applied to eddy currents

RL-76-044
W WALKINSHAW, A T LEA
Computing and Automation Division quarterly report 29 December 1975 to March 1976

RL-76-045
C J BATTY, S D HOATH, R L ROBERTS
Measurement of Lorentzian linewidths: numerical evaluation of the Voigt integral

RL-76-046
R G ROBERTS
Symmetry properties of the pomeron for T not equal to 0

RL-76-047
D H READING
Medical applications of multi-wire proportional chambers

RL-76-048
D C LARBALESTIER, D EVANS
High strength austenitic stainless steels for cryogenic use

RL-76-051
K G POTTER
Improved bearing material for service in irradiated and vacuum conditions

RL-76-052
M H R DONALD
User's guide to HARMON

RL-76-053
R L KELLY, R J N PHILLIPS
Further discussion of 1934 MeV resonance

RL-76-054
C HONG-MO, T S TSUN
Baryon exchange effects in dual unitarisation

RL-76-055
J E BATEMAN, R J APSIMON
A new photomultiplier tube utilising channel plate electron multipliers as the gain producing elements - further results

RL-76-056
C HONG-MO, K-I KONISHI, J KWIECINSKI, R G ROBERTS
The breaking of exchange degeneracy in dual unitarisation

RL-76-057
D F R MILDNER, G C STIRLING
Condensed matter research using pulsed neutron sources: a bibliography. 2nd edn.

RL-76-058
P P STARLING, J JENKINS
Administration Division use of the Rutherford Laboratory IBM 360 Computer. Part 2

RL-76-059
I LISNEY
A simple introductory guide to the NIMROD GEC 4080 computer

RL-76-060
R D BAKER, K W ABBOTT, J A BLISSETT, I J BLOODWORTH, T A BROOME, G CONFORTO, J C HART, C M HUGHES, R W KRAEMER, M L MALLARY, R MAYBURY, N MIDDLEMAS, A G PARHAM, B T PAYNE, T W L SANFORD, D H SAXON, P E STRICKLAND, T G WALKER
A study of the reaction $\pi^- p \to K^\circ \Lambda^\circ$ in the resonance region

RL-76-061
G V DASS
Testing time-reversal-invariance in inclusive single- and di-lepton production by neutrinos

RL-76-062
R BELL, P HOUZEGO, B MEARDON, A WILLIAMS
Operating instructions for a cryosample changer

RL-76-063
E EISENHANDLER, W R GIBSON, C HOJVAT, P I P KALMUS, L C Y LEE, T W PRITCHARD, E C USHER, D T WILLIAMS, M HARRISON, W H RANGE, M A R KEMP, A D RUSH, J N WOULDS, G T J ARNISON, A ASTBURY, D P JONES, A S L PARSONS
Differential cross sections for anti-proton-proton elastic scattering between 0·69 and 2·43 GeV/c

RL-76-064
L R F EMPEIGNE
The software for the Nimrod strip SEC beam profile monitors

RL-76-065
R L KINGSLEY
On effects of D(o) - D(-o) mixing at Spear

RL-76-066
A CARNE
Extraction from the 800 MeV 53 Hz SNS synchrotron

RL-76-067
J E BATEMAN, M W WATERS
An investigation of the possible application of a bidimensional MWPC to x-ray absorptimetry

RL-76-068
K-I KONISHI, J KWEICINSKI
S channel discontinuities of Reggeon diagrams with planar vertices

RL-76-071
C W TROWBRIDGE
Applications of integral equation methods for the numerical solution of magnetostatic and eddy current problems

RL-76-072
D J MILLER
A consumer's guide to particle-detectors

RL-76-076/B
J C KERR
Application software for multi-wire beam profile monitors

RL-76-077
D J CRENNELL
A study of the possibility of using BEBC to detect prompt electrons

RL-76-078
A E STORMER
Automatic management of partitioned datasets

RL-76-079
A E STORMER
HASP performance improvement modifications

RL-76-081
R C ARNOLD
Multi-eikonal theory for high energy hadron production

RL-76-082
S WOLFRAM
Neutral weak interactions and particle decays

RL-76-083
J DIAS DE DEUS
Reggeon pomeron and annihilation processes in the dual unitarization scheme

RL-76-084
F E CLOSE, D M SCOTT, D SIVERS
Charm production and mass scales in deep inelastic processes

RL-76-085
S F J COX, S F J READ, W Th WENCKEBACH
The behaviour of nuclear spins near highly polarized paramagnetic centres

RL-76-087
W WALKINSHAW, A T LEA
Computing and Automation Division Quarterly Report. April - June 1976

RL-76-089
A S DUNN, A G WATERS, J M COLLINS
A guide to the Rutherford Laboratory C & A Division GEC 4080 computing system

RL-76-090
C HONG-MO, K-I KONISHI, J KWIECINSKI, R G ROBERTS
Non-planar effects in Regge trajectories at large t greater than 0.

RL-76-091
M K CRADDOCK, C J REASON, R A J RIDDLE
The K17 beamline for stopping kaons at Nimrod

RL-76-092
R E ELLIS, P J LINDOP, J E COGGLE, G FRASER
Radiobiological work using a negative pion beam at the Rutherford Laboratory 1971-76

RL-76-093
R M BROWN, A G CLARK, J K DAVIES, J de PAGTER, P J DUKE, W M EVANS, R J GRAY, E S GROVES, R J OTT, H R RENSHALL, T P SHAH, A J SHAVE, J J THRESHER, M W TYRRELL
Differential cross section and polarisation measurements in π^-p charge exchange scattering from 618 to 2724 MeV/c

RL-76-094
V W EDWARDS, C A SCOTT, M N WILSON
Training behaviour of pressure-impregnated superconducting racetrack magnets

RL-76-095
K-I KONISHI
New approach to strong interaction physics based on dual unitarization

RL-76-097
G V DASS, H FRAAS
Can phi-photoproduction easily reveal the pole-cut nature of the pomeron?

RL-76-099
V R SAUNDERS
Atmol 3, part 2 – Card input conventions

RL-76-100
V R SAUNDERS
Atmol 3, part 3 – Disk and tape file handling

RL-76-101
V R SAUNDERS
Atmol 3, part 4 – Molecular integrals for contracted Cartesian Gaussian Orbitals-energy integrals

RL-76-102
V R SAUNDERS
Atmol 3, part 5 – Library of Gaussian functions, maintenance program

RL-76-104
V R SAUNDERS
Atmol 3, part 7 – Molecular integrals for Slater type orbitals - energy integrals

RL-76-106
V R SAUNDERS, M F GUEST
Atmol 3, part 9 – The SCF program

RL-76-107
V R SAUNDERS
Atmol 3, part 10 – The service program

RL-76-108
M F GUEST
Atmol 3, part 11 – The Mulliken analysis program

RL-76-111
P J LITCHFIELD, R J CASHMORE, A J G HEY
SU(6)(W) and decays of baryon resonances

RL-76-112
F E CLOSE
Comments on charm production in electron positron annihilation

RL-76-113
R L KINGSLEY
Weak interactions, quark masses and spontaneous violation of parity

RL-76-114
C J BATTY, S F BIAGI, M BLECHER, R A J RIDDLE, B L ROBERTS
J D DAVIES, G J PYLE, G T A SQUIER, D M ASBURY
Measurement of kaonic x-rays from Li, Li H and Be

RL-76-116
J KWIECINSKI, N SAKAI
On the Regge-cut cancellation in planar amplitudes of the dual unitarisation scheme

RL-76-117
A A CARTER
The complex zeros of differential cross-sections

RL-76-118
C HONG-MO
e^+e^- annihilation into hadrons from dual unitarisation

RL-76-119
G NELSON, I WATERS, M JACQUES, N H LIPMAN, J D MILNE
A draft report on the investigation of energy saving by thermal insulation to a classroom at Gosford Hill School, Kidlington

RL-76-122/B
JWE LEWIS, S W LOVESEY
Short wavelength collective density excitations in monatomic liquid

RL-76-123/B
R H C MORGAN
Possible applications of the NIMROD 70 MeV linear accelerator to proton radiography

RL-76-124/A
G KARL
Pseudoscalar meson masses in a quark model

RL-76-125/A
R C ARNOLD
Calculation of the fine structure constant alpha in a model for spontaneous breakdown of strong interaction symmetry

RL-76-126/A
J DIAS DE DEUS, T SHIMADA
Geometrical scaling at inelastic threshold

RL-76-127/B
J B MARSH, K H SOUTEN, B O'HAGEN
A method of testing multiwire proportional chambers by glow discharge/photographic techniques

RL-76-129/A
J DIAS DE DEUS, S JADACH
Quark diagram structure of particle production

RL-76-130/B
A L LINTERN
Problems with spare chamber gas recirculator/purifier systems in use at Rutherford Laboratory and recommendations on commissioning procedures

RL-76-131/B
R D BAKER
A & R parameters in $\pi^-p \rightarrow K^o\Lambda^o$ or $K^o\Sigma^o$

RL-76-132/A
R W WITTY
Dimensional flowcharting

RL-76-134/A
S MATSUDA
Contribution of d-wave charmed quark pair in e^+e^- charm production

RL-76-138
K W BELL
Improved gas mixtures for use in multiwire proportional chambers and magnetostrictive spark chambers

Appendix 2 Publications and Other Accounts of Laboratory Work

Publications and accounts of Laboratory work, including Rutherford Laboratory Reports (Appendix 1) are listed here under the Section of the Annual Report to which they correspond.

Section 1 Particle Physics

1.1.1 Meson Spectroscopy

J D Dowell et al
ω^o production in the reaction $\pi^-p \rightarrow \pi^+\pi^-\pi^o$ at 8 and 12 GeV/c
Nuclear Physics B108 (1976) 30

J R Arch
An energy independent dipion partial wave analysis using 12 GeV/c data from the OMEGA spectrometer
Thesis, Westfield College, HEP/T/60

Birmingham, Rutherford, Tel Aviv, Westfield College Collaboration
A study of the D(1285) meson produced in the reaction $\pi^-p \rightarrow \pi^+\pi^-\pi^-\pi^on$ at 12 GeV/c beam momentum
International Conference on High Energy Physics, Tbilisi 1976

E Eisenhandler et al
Differential cross sections for antiproton proton elastic scattering between 0·69 and 2·34 GeV/c
Nuclear Physics B113 (1976) 1.

A A Carter et al
Measurement of the polarisation parameter for antiproton-proton annihilation into charged pion and kaon pairs between 1·0 and 2·2 GeV/c
3rd European Symposium on $\bar{N}N$ Interactions, Stockholm, July, 1976

E Eisenhandler
Antiproton formation experiments
3rd European Symposium on $\bar{N}N$ Interactions, Stockholm, July, 1976

A A Carter et al
Measurement of the polarisation parameter for antiproton-proton annihilation into charged pion and kaon pairs between 1·0 and 2·2 GeV/c
Symposium on High Energy Physics with Polarized Beams and Targets, Argonne National Laboratory, August, 1976

A A Carter et al
Measurement of the polarization parameter for annihilation into charged pion and kaon pairs between 1·0 and 2·GeV/c
International Conference on High Energy Physics, Tbilisi 1976

N C Debenham et al
Backward π^-p reactions between 0·6 and 1·0 GeV/c
Physical Review D 12, 2545 1975

J Keyne et al
Study of ω production near threshold in the reaction $\pi^- + p \to \omega + n$
Physical Review **D 14**, 28 1976

H N Sarma
A cusp in pion proton elastic scattering
Thesis, University of London 1976

M J Emms et al
A partial wave analysis of the $(3\pi)^\circ$ system from the charge exchange reaction $\pi^+ n \to \pi^+\pi^-\pi^\circ p$ at 4GeV/c
Physics Letters 60B (1976) 109

B Conforto, G Conforto
The Q region in non-K-induced reactions
International Conference of High Energy Physics, Tbilisi, 1976

A C Borg et al
Inclusive production of Δ^{++} and Δ° in K^-p interactions at 14·4 GeV/c
Nuovo Cimento **34A** (1976) 21

B Drevillon et al
Partial Wave analysis of the low mass $\bar{K}^\circ \pi^+\pi^-$ system produced in the reaction $K^-p \to \bar{K}^\circ\pi^+\pi^-n$ at 3·95 and 14·3 GeV/c
Nuovo Cimento **32A** (1976) 276

H Abramowicz et al
Lamda polarisation in the reaction $K^-p \to \Lambda$ + anything at 14·3 GeV/c
Nuclear Physics **B105** (1976) 222

M Spiro et al
New Evidence for K* (1780) production
Physics Letters **60B** (1976) 389

A C Borg et al
Inclusive pion and eta production in K^-p interactions at 14·3 GeV/c
Nuclear Physics **B106**(1976) 430

G Otter et al
Evidence for structure in the 1^+ state of the Q region
Nuclear Physics **B106** (1976) 77

D Denegri et al
Comparison of $N \to N\pi$, $N\pi\pi$ and ΛK diffractive excitation systems at 14·3 GeV/c and 500 – 1500 GeV/c
Nuclear Physics **B114** (1976) 413

Ecole Polytechnique – Rutherford – Saclay Collaboration
Some two-body reactions $K^-p \to 0^\circ \frac{1}{2}^+$ and $K^-p \to 0^- \frac{3}{2}^+$ at 14·3 GeV/c
International High Energy Physics Conference, Tbilisi, 1976

Saclay – Rutherford – Ecole Polytechnique Collaboration
Reactions $K^-p \to K^-\omega p$, $K^-p \to K^-\psi p$ and the Zweig rule
International High Energy Physics Conference, Tbilisi, 1976

Saclay – Rutherford – Ecole Polytechnique Conference
Evidence for a narrow K* (1900) resonance decaying into K* (890)ω and K* (890) ρ
International High Energy Physics Conference, Tbilisi, 1976

Ecole Polytechnique – Rutherford – Saclay Collabotation
Ξ^* production in K^-p interactions at 14·3 GeV/c
International High Energy Physics Conference, Tbilisi, 1976

Saclay – Ecole Polytechnique – Rutherford Collaboration
Comparison of $N \to N\pi$, $N\pi\pi$ and ΛK diffractive excitation systems at 14·3 GeV/c and 500 - 1500 GeV/c
International High Energy Physics Conference, Tbilisi, 1976

Saclay – Ecole Polytechnique – Rutherford Collaboration
Momentum transfer distributions of some diffractive enhancements in K^-p interactions at 14·3 GeV/c
International High Energy Physics Conference, Tbilisi, 1976

Ecole Polytechnique – Rutherford – Saclay Collaboration
Ξ^* production in K^-p interactions at 14·3 GeV/c
Topical Conference on Baryon Resonances, Oxford, 1976

1.1.2 Baryon Spectroscopy

K W J Barnham
$\pi N \to \pi\pi N$, a review of the experimental situation
Topical Conference on Baryon Resonances, Oxford, 1976

K W Abbott et al
A study of the reaction $\pi^-p \to K^\circ\Lambda^\circ$ in the resonance region
Topical Conference on Baryon Resonances, Oxford 1976

K W Abbott et al
A study of the reaction $\pi^-p \to K^\circ\Lambda^\circ$ in the resonance region
International Conference of High Energy Physics, Tbilisi 1976

L Bertanza et al
A study of $K^\circ_L p$ reactions in the c.m. energy range 1490-1700 MeV
International Conference on High Energy Physics, Tbilisi, 1976

L Bertanza et al
A study of the reactions $K^\circ_L p \to \Lambda\pi^+_,\Lambda\pi^+\pi^\circ$ and $\Sigma^\circ\pi^+$ in the c.m. energy range 1490-1700 MeV
Nuclear Physics **B110** (1976) 1

A Bigi et al
Study of the reaction $K^\circ_L p \to K^\circ_S p$ in the c.m. energy range 1490 - 1700 MeV
Nuclear Physics **B110** (1976) 25

A Bigi et al
Study of the reaction $K^\circ_L p \to K^\circ_S p$ in the c.m. energy range 1490 - 1700 MeV
Topical Conference on Baryon Resonances, Oxford, 1976

Bologna, Edinburgh, Glasgow, Pisa, Rutherford Laboratory Collaboration
Results from a $K^\circ_L p \to \Lambda\pi^+$ experiment in the region of the narrow (1580) (D13) resonance
Topical Conference on Baryon Resonances, Oxford, 1976

L Bertanza et al
A study of the reactions $K^\circ_L p \to \Lambda\pi^+_,\Lambda\pi^+\pi^\circ$ and $\Sigma^\circ\pi^\pi$ in the c.m. energy range 1490 -1700 MeV
Topical Conference on Baryon Resonances, Oxford, 1976

R M Brown et al
Measurements of the polarisation parameter P and the differential cross section for the reactions $\pi^-p \to \pi^\circ n$ and $\pi^-p \to \eta^\circ n$ in the resonance region
Topical Conferance on Baryon Resonances, Oxford, 1976

D J Bardsley et al
Measurements of π^+p and π^-p elastic differential cross-sections from 0·4 to 2·15 GeV/c
Topical Conference on Baryon Resonances, Oxford, 1976

Rutherford Laboratory – Imperial College Collaboration
A formation study of the reaction $K^-p \to \Sigma(1385)\pi$
Topical Conference on Baryon Resonances, Oxford, 1976

Rutherford Laboratory – Imperial College Collaboration
A formation study of the reaction $K^-p \to K^*N$
Topical Conference on Baryon Resonances, Oxford, 1976

G P Gopal et al
Partial wave analysis of $\bar{K}N$ two body reactions between 1480 and 2170 MeV
Topical Conference on Baryon Resonances, Oxford, 1976

1.1.3 Intermediate Energy Reactions

C M Fisher, J Guy and W Venus
Observation of the relativistic rise in bubble density in a neon-hydrogen bubble chamber
Nuclear Instruments and Methods 133 (1976) 29-34

C J S Damerell et al
SU_3 Comparison of line reversed charge exchange and hypercharge exchange reactions
Physics Letters 60B (1976) 121

A Berglund et al
A study of the line reversed hypercharge exchange reactions $\pi^+p \to K^+\Sigma^+(1385)$ and $K^-p \to \pi^-\Sigma^+(1385)$ at 10 GeV/c
Physics Letters 60B (1976) 117

1.1.4 Higher Energy Experiments

R E Ansorge et al
Charged particle multiplicities in 100 GeV/c $\bar{p}p$ interactions
Physics Letters **59B**, 299 (1975)

J R Carter et al
Measurement of the inclusive forward γ, Λ° and K°_Sspectra produced in proton-copper interactions at 24 GeV/c
Nuclear Physics **B103**, 52 (1976)

J G Rusbrooke et al
On the difference between $\bar{p}p$ and pp topological cross-section up to 100 GeV/c
Physics Letters **59B**, 303 (1975)

J G Rushbrooke et al
Spin-parity analysis of diffractive $np \to (p\pi^-)p$ and the question of a parity-change rule
Physics Rev. **D13**, 1835 (1976)

D R Ward et al
Search for charmed particle production in neutron-proton interactions
Nuclear Physics **B101**, 29 (1975)

R E Ansorge et al
Strange particle production in neutron-proton interactions at 10–24 GeV/c
Nuclear Physics **B103**, 509 (1976)

D R Ward et al
Comparison of neutral particle production in 100 GeV/c $\bar{p}p$ and pp interactions
Physics Letters **62B**, 237 (1976)

J G Rushbrooke
High-energy antinucleon-nucleon annihilation interactions
Third European Symposium on $\bar{N}N$ Interactions, Stockholm, 1976

G A Smith et al
Two particle correlations in 100 GeV/c $\bar{p}p$ interactions
New York Meeting of American Physical Society, 1976

J Whitmore et al
Properties of inclusive $\pi^\pm$ production in 100 GeV/c antiproton-proton interactions
To be submitted to Physics Rev. Letters

J Whitmore et al
$\bar{p}p$ elastic scattering and two-prong inelastic scattering at 100 GeV/c
To be submitted to Nucl. Physics B.

R Raja et al
Neutral particle production in 100 GeV/c $\bar{p}p$ interactions
Submitted to Nucl. Physics D.

J Whitmore et al
Study of multiparticle production in 100 GeV/c antiproton-proton interactions
International Conference on High Energy Physics, Tbilisi, 1976

J Whitmore et al
The elastic and inelastic two-prong reaction in $\bar{p}p$ interactions at 100 GeV/c
International Conference on High Energy Physics, Tbilisi, 1976

D R Ward et al
Comparison of neutral particle production in 100 GeV/c $\bar{p}p$ and pp interactions
International Conference on High Energy Physics, Tbilisi, 1976

CERN, London, Bristol, MIT, Copenhagen, Lund Collaboration
Data from inclusive particle production at low transverse momenta and large angles at the CERN ISR
Scandinavian Conference on High Energy Physics, Spatind
New York Meeting of the American Physical Society
International Colloquium on Multiparticle Reactions, Munich

K Guettler et al
Inclusive production of low-momentum charged pions at x = 0 at the CERN Intersecting Storage Rings
International Conference on High Energy Physics, Tbilisi
Physics Letters **64B** (1976) 111

K Guettler et al
Inclusive production of low-momentum charged pions, kaons and protons at x = 0 at the CERN Intersecting Storage Rings
International Conference on High Energy Physics, Tbilisi

G Bellettini et al
Correlation studies of events with a charged hadron at x = 0 in proton-proton collisions at the CERN ISR
International Conference on High Energy Physics, Tbilisi
Submitted to Nuovo Cimento

K Guettler
The spectra of single particles produced with low transverse momenta in very high energy proton-proton collisions
Ph.D. Thesis, University College London

B Alper et al
Multiplicities associated with the production of pions, kaons or protons of high transverse momentum at the ISR
Nuclear Physics **B114** (1976) 1

M G Albrow et al
A search for narrow resonances in proton-proton collisions at 53 GeV centre of mass energy
Nuclear Physics **B114** (1976) 365

M G Albrow et al
Correlations between two identified charged hadrons at the CERN ISR
Physics Letters **65B** (1976) 295

B Alper et al
Production spectra of $\pi^\pm K^\pm p^\pm$ at large angles in proton-proton collisions at the CERN ISR
Nuclear Physics **B100** (1976) 237

M G Albrow
Inelastic Diffractive Scattering at the CERN ISR
International Conference on High Energy Physics, Tbilisi 1976

1.1.5 Weak and Electromagnetic Interactions

W S C Williams
Deep inelastic muon scattering; hadron production in inelastic muon scattering at 147 GeV
XI Rencontre de Moriond, Flaine, France 1976

N E Booth
Muon Physics
Canadian Institute of Particle Physics International Summer School, McGill University, Montreal, Canada, 1976

T W Quirk
Measurements of the nucleon structure function in muon deep inelastic scattering at 100 and 150 GeV/c
International Conference on High Energy Physics, Tbilisi 1976

G I Kirkbride
Muon-nucleon inclusive interactions at 150 GeV
D.Phil. Thesis, University of Oxford 1976

W A Loomis et al
Inclusive hadron production in inelastic muon-proton scattering at 150 GeV
Physics Rev. Letters 35 1483 (1975)

H L Anderson et al
Measurement of nucleon structure function in muon scattering at 147 GeV/c
Physics Rev. Letters 37 4 (1975)

H L Anderson et al
Properties of inclusive hadron spectra in muon-nucleon scattering at 150 GeV/c
Physics Rev. Letters 36 1422 (1976)

Bologna – Edinburgh – Glasgow – Pisa – Rutherford Collaboration
A study of the Dalitz plot in the decay $K_L^o \to \pi^+\pi^-\pi^o$
International Conference on High Energy Physics, Tbilisi 1976

1.1.6 Searches for New Particles

E H S Burhop et al
Observation of a likely example of the decay of a charmed particle produced in a high energy neutrino interaction
Physics Letters **65B** (1976) 299

The Omega Groups
Charm search in 19 GeV/c π^-p exclusive reactions
Nuclear Physics **B11** (1976) 189

The Omega Groups
Test of the Zweig Rule in π^-p interactions at 19 GeV/c
Physics Letters **65B** (1976) 89

1.2 Nuclear Physics

C J Batty, S F Biagi, R A J Riddle, B L Roberts, G J Pyle, G T A Squier
Strong interaction in kaonic atoms
Phys. Lett. **60B**, 355, 1976

C J Batty, S Hoath, B L Roberts
Measurement of Lorentzian linewidths: Numerical evaluation of the Voigt Integral
Nucl. Inst. Meth. **137**, 179, 1976

C J Batty, S F Biagi, M Blecher, R A J Riddle, B L Roberts, J D Davies, G J Pyle, G T A Squier, D M Asbury
Measurement of kaonic X-rays from Li, Li H and Be
Nucl. Phys. (Submitted for publication)

N M Clarke, C B Fulmer, J F Hafele
^{3}He elastic scattering from ^{208}Pb and ^{209}Bi at 71 MeV
Physics Review **12**, (1975) 87

B C Sinha, P J Siemens
Damping of shape oscillations and relative motion in heavy ion reactions
Physics Letters **65B**, (1976) 5

N M Clarke
Phonon admixtures in states of ^{56}Fe excited by ^{3}He scattering
Journal of Physics G (Nuclear Physics) **1**, (1975) 895

B C Sinha
The optical potential and nuclear structure
Physics Report **20C**, (1975) 1

S A Weisrose
The importance of low partial waves in helion inelastic scattering
Journal of Physics G (Nuclear Physics) **1**, (1975) 653

M D Cohler, N M Clarke, C J Webb, R J Griffiths, S Roman, O Karban
The shape of the helion spin orbit potential
Journal of Physics G (Nuclear Physics) 2, (1976) L151

M D Cohler, B C Sinha, R J Griffiths, N M Clarke
Pauli exchange effects in ^{3}He and ^{4}He interaction potentials
Physics Letters **63B**, (1976) 377

R J Griffiths, B C Sinha, N M Clarke
Details of the nuclear surface from ^{3}He scattering over a wide energy range
Journal of Physics G (Nuclear Physics 2, (1976) L1

1.3 Theoretical High Energy Physics

V Barger, R J N Phillips, T Weiler
Dimuon production by neutrinos; tests of weak current models
Phys. Rev. **D13**, 2511

V Barger, T Weiler, R J N Phillips
Problem with parton-model descriptions of neutrino data
Phys. Rev. **D14**, 1276

V Barger, T Weiler, R J N Phillips
Parton distributions from neutrino data
Nucl. Phys. **B102**, 439

V Barger, T Weiler, R J N Phillips
Charge-symmetry tests in neutrino scattering
Nucl. Phys. **B105**, 108

V Barger, T Weiler, R J N Phillips
Charm production by partons in neutrino scattering
Nucl. Phys. **B107**, 422

V Barger, R J N Phillips, T Weiler
Dimuon data test weak current models
Phys. Letters **62B**, 227

V Barger, R J N Phillips
Signature of hadrolepton production by neutrinos
Nucl. Phys. **B110**, 461

V Barger, R J N Phillips
Geometrical aspects of high energy elastic scattering
Phys. Letters **60B**, 358

V Barger, R J N Phillips
Weak semileptonic decay distributions of new particles
Phys. Rev. **D14**, 80

V Barger, R J N Phillips
New particle decays and μeK events
Phys. Rev. Letters **36**, 1226

V Barger, R J N Phillips
Dimuons from inelastic μN scattering
Phys. Letters **65B**, 167

V Barger, T Gottschalk, R J N Phillips
Multiple kaon semilepton decays of the new particles
Phys. Letters **64B**, 333

V Barger, T Gottschalk, R J N Phillips
Effects of multiplicity on charm semileptonic decay distributions
University of Wisconsin preprint C00-569

V Barger, R L Kingsley, R J N Phillips, D M Scott
Charm production by weak neutral currents
Wisconsin preprint C00-574

H M Chan, K Konishi, J Kwiecinski, R G Roberts
Non-planar effects in Regge Trajectories at large $t > 0$
Phys. Letters **64B**, 301

H M Chan, J Kwiecinski, R G Roberts
Zweig-rule and violations as consequences of dual unitarisation
Phys. Letters **60B**, 367

H M Chan, K Konishi, J Kwiecinski, R G Roberts
J/ψ, ψ' and related decays from dual unitarisation
Phys. Letters **60B**, 469

H M Chan, K Konishi, J Kwiecinski, R G Roberts
The breaking of exchange degeneracy in dual unitarization
Phys. Letters **63B**, 441

H M Chan, J Kwiecinski, S T Tsou
Almost stable particles with masses above 5 GeV
Letters at Nuovo Cim. **16**, 219

H M Chan, S T Tsou
Dual unitarisation – a new approach to hadronic reactions
Phys. Reports (to be published)

F E Close, D Sivers, D M Scott
Mass scales and asymptotic symmetry in deep inelastic scattering
Phys. Letters **62B**, 213

F E Close, D Sivers, D M Scott
Charm production and mass scales in deep inelastic scattering
Nucl. Phys. in the press

F E Close
Comments on charm production in electron positron annihilation
Phys. Letters **65B**, 55

G V Dass
Angular distributions of neutrino and antineutrino scatterings by electrons and gauge models
Phys. Letters **62B**, 86

G V Dass
General relations between neutrino and antineutrino scattering
Phys. Letters **60B**, 461

G V Dass
Non-diagonal neutral currents and the scattering of neutrinos and antineutrinos by electrons
Nucl. Phys. **N101**, 125

J Dias de Deus
A simple geometrical approach to particle production in collisions with nuclei
Nucl. Phys. **B107**, 146

J Dias de Deus, T Shimada
Geometrical scaling at inelastic threshold
Phys. Letters **65B**, 475

R L Kingsley
On effects of $D^o - \bar{D}^o$mixing at SPEAR
Phys. Letters **63B**, 329

K Konishi
Symmetry breaking and planar bootstrap equations
Nucl. Phys. **B116**, 356

K Konishi, J Kwiecinski
S-channel discontinuities of Reggeon Diagrams with planar vertices
Nucl. Phys. **B**, to be published

J Kwiecinski, R G Roberts, D P Roy
Duality for the reggeon-reggeon amplitude. A study through quasi three-body reactions
Nucl. Phys. **B102**, 353

J Kwiecinski, N Sakai
The reggeon bootstrap of the dual unitary model in the one-dimensional approximation
Nucl. Phys. **B106**, 44

B R Martin, D Morgan, G Shaw
"Pion-pion interactions in particle physics"
Academic Press Inc. (London) 1976

R O Raitio, G A Ringland
Phenomenological analysis of high p_T spectra and angular multiplicity correlations in pp collisions
Phys. Rev. **D14**, 2291

R G Roberts
Symmetry properties of the pomeron for t = 0
Nucl. Phys. **B116**, 334

D Sivers
Estimating cross sections for the production of new particles
Nucl. Phys. **B106**, 95

Rutherford Laboratory Reports (See Appendix 1)
RL–76–003, 012, 021, 022, 023, 025, 026, 033, 036, 046, 053, 054, 056, 061, 065, 068, 080, 081, 082, 083, 084, 090, 095, 097, 112, 113, 116, 118, 124/A, 125/A, 126/A, 129/A, 134/A, 141/A 144/A, 151/A, 155/A

1.4 Radiological Experiments

R J Purrott
Chromosome aberration yields in human lymphocytes exposed to fractionated doses of negative π mesons
International Journal of Radiation Biology Vol 28, No 6, 559-602, 1975

A J Mill, J D Lewis, W S Hall
Response of HeLa cells to irradiation with π^- mesons
British Journal of Radiology, **49**, 166-171, 1976

A J Mill, J D Lewis, W S Hall
Recovery in mammalian cells irradiated with a beam of π^- mesons
British Journal of Radiology, **49**, 357-359, 1976

J E Coggle, M Y Gordon, P J Lindop, J Shewell, A J Mill
Some *in vivo* effects of π^- mesons in mice
British Journal of Radiology, **49**, 161-165, 1976

D R Perry
Physical aspects of a Radiobiological pion beam
PhD thesis, Surrey University, 1976

A G Perris
Energy spectra of charged particles emitted at the capture of negative pions in elements and materials of relevance to radiobiology and radiotherapy
PhD thesis, London University, 1976

R E Ellis, C A Lewis, D H Reading
LET distributions in the π^- beam at the Rutherford Laboratory, UK
Physics in Medicine and Biology, **22**, 153, 1977

Section 2 Neutron Beam Research

J B Hayter, J Penfold, W G Williams
Observation of the interference of neutrons reflected from thin films
Nature **262** 569

M W Johnson, N H March, B McCoy, D I Page, R L Perrin, S K Mitra
Structure and effective pair interaction in liquid nickel
Phil. Mag. **33** 203

A J Leadbetter, R M Richardson, C J Carlile
The nature of Smectic-E phase
J de Physique Colloques **37**, C3 - 65

C Wilkinson, J B Forsyth
Spiral magnetic properties in MnP-type structures
International Conference on Solid Compounds of Transition Elements, Uppsala, Sweden, 1976

C Wilkinson, F Sinclair, J B Forsyth
Magnetic structures in cubic FeGe and MnSi
International Conference on Solid Compounds of Transition Elements, Uppsala, Sweden, 1976

J B Forsyth
Recent progress in the experimental determination of magnetisation density distributions
Sagamore Conference on Charge, spin and momentum density, Kiljava, Finland, 1976

M W Johnson, N H March, B McCoy, D I Page
Neutron diffraction and atomic dynamics in liquid nickel
International Conference on Liquid Metals, Bristol, 1976

J Jacobe, B H Meardon, R J Stewart
Dead time limitations for thermal neutron detector systems
ILL preprint

B H Meardon
Soller collimators
Conference on Developments in Neutron Scattering Instrumentation, Rutherford Laboratory, 1976

W G Williams
Polarising curved Sollers
Conference on Developments in Neutron Scattering Instrumentation, Rutherford Laboratory, 1976

C J Carlile
High pressures, a progress report
Conference on Developments in Neutron Scattering Instrumentation, Rutherford Laboratory, 1976

Section 4 Technology and Instrumentation

S F J Cox, S F J Read, W T Wenckebach
Nuclear dipole relaxation in highly polarised dilute paramagnets
19th Congress Ampere, Heidelberg, September, 1976

D Evans, J T Morgan
The use of ultrasonics to monitor the cure of epoxide resins
N.D.T. for Plastics & Rubbers, London, 1976

D C Larbalestier, D Evans
High strength austenitic stainless steels for cryogenic use
J.C.E.C., Grenoble, 1976

D Evans, B F Colyer
Sources of instability in superconducting magnets and possible explanations of the training problem
I.C.E.C., Grenoble, 1976

R W Barnard, J F Hastings, P J Hunter
An optical system for measuring length changes in isolated cardiac muscle
Journal of Physiology, Vol. 260, No 2, September, 1976

J E Bateman, M W Waters, R E Jones
Spatial resolution in a xenon-filled MWPC X-ray imaging detector – a computing physics approach
Nuclear Institute & Meth. 135 (1976) 235

J E Bateman, R J Apsimon
A new photomultiplier tube utilising channel plate electron multipliers as the gain producing elements
Nucl. Inst. & Meth. 137 (1976) 61

J E Bateman
The improvement of the spatial resolution of a xenon-filled X-ray imaging MWPC by means of pulse height selection
Nucl. Inst. & Meth. 140 (1977) 211

A Horsman, D H Reading, J Connolly, W Glasgow, M S F McLachlan
Bone imaging using a gadolinium-153 source and a xenon-filled multiwire proportional counter as detector
American Journal of Roentgenology, 126, (6), 1273-75, 1976
(Extended abstract, Proceedings of the International Conference on Bone Mineral Measurements – New Orleans, January 1976)

D H Reading
Multi-wire proportional chambers
Medical Images: Formation, Perception and Measurement, pp 39-50
London, Institute of Physics and John Wiley and Sons.
(Proceedings of the 7th L H Gray Memorial Conference – Leeds, April 1976)

M J O'Connell
Computing a Laplacian field component from boundary observations only
Computer Physics Communications 11 (1976) 221-236

G H Rees
Beam-beam interactions in e-p storage rings
International School on the Theoretical Design of Particle Accelerators, Erice, November 1976

W A Smith, J T Hyman
An economical and effective method of networking PDP-8s
DECUS (UK) Conference, Nottingham April 1976

J B Marsh, J E Boon, E W G Wallis
Flexible film cable incorporating soldering flux
Patent, filed April 1976

5.1 Atlas Computing Division

P A Machin, M Elder
SRC microdensitometer service – Report for the year ending 31 March, 1976

M Elder, P B Hitchcock, R Mason, G C Shipley
A refinement analysis of the crystallography of the phospholipid 1,2 dilauroyl-DL-phosphatidylethanolamine and some remarks on lipid-lipid and lipid protein interactions.
To be published in Proc. Roy.Soc.A.

P A Machin, J Woodhead-Galloway
Compressibility and direct correlation function for water
Molecular Physics, 31, 233

J Woodhead-Galloway, P A Machin
X-ray scattering from a gas of uniform hard discs using the Percus-Yevick approximation: an application to a 'planar liquid'
Molecular Physics, 32, 41

J Woodhead-Galloway, P A Machin
Modern theories of liquid and the diffuse equatorial X-ray scattering from collagen
Acta Cryst., A32, 368

P Kent, J A Birmingham
Tree searching and tree pruning techniques
Advances in Computer Chess (ed. M R B Clarke), Edinburgh University Press, 1

L G Kuo-Petravic, M Petravic
Comment on 'Self-consistent solution for an axisymmetric pulsar model'
Phys. Rev. Letters, 36, 12

L G Kuo-Petravic, M Petravic, K V Roberts
Tranal – a program for the translation of symbolic Algol I into symbolic Algol II
Comp. Phys. Communications, 11, 5

K M Crennell
Uses of a microfilm recorder for linguistic research
Proceedings of 41 International Symposium, Oxford. Use of the computer in linguistic and literary research

K M Crennell
Software Review – FAMULUS
Computers and the Humanities, 10, 233

G W Robinson
The 1906A TASK system (Revised edition)

T R Peart, A H Francis
The CASS (Computer Aided Sound Synthesis) manual

P A Dewar
The SMOG system manual

D C Sutcliffe
An algorithm for drawing the curve f (x,y)=0
Computer Journal, 19, 246

D C Sutcliffe
A remark on a contouring algorithm
Computer Journal, 19, 333

F R A Hopgood
Computer animation used as a tool in teaching computer science
'1975 best computer papers' edited by I Auerbach

R W Witty
The switching reverse polish algorithm
To be published in SIGPLAN

R W Witty, F Louzani
Dimensional flowchart generators
FR80 Technical Paper 25

V R Saunders
An introduction to molecular integral evaluation in 'Computational Techniques in Quantum Chemistry and Molecular Physics'
eds G H F Diercksen, B T Sutcliffe and A Veillard (Reidel), 347

M F Guest, V R Saunders
Configuration interaction studies of electron deficient molecules
APSG calculations of the boron hydrides B_2H_6, B_4H_4, B_4H_{10}, B_5H_9 and B_6H_{10}
Submitted for publication in Molecular Physics

M F Lappert, J B Pedley, G Sharp, M F Guest
Bonding studies of compounds of boron and group 3-5 elements
Ab initio SCF MO calculations and He(I) photoelectron spectra of halogen bridged dimeric species of group III halides and methyl halides
J. Chem. Soc (Faraday II), 72, 539

L M R Derrick, I H Hillier, M F Guest, D R Lloyd
The electronic structure of transition metal complexes containing organic ligands. IV low and high energy photoelectron spectra and ab initio SCF MO calculations of iron tricarbonyl trimethylene methane
Molecular Physics, 31, 23

J N Murrell, A J C Varandas, M F Guest
The potential energy surface for the lowest quartet state of H_3
Molecular Physics, 31, 1129

M F Guest, W R Rodwell
Ab initio study of the ground and excited states of hydrogen sulphide using SCF and CI calculations.
Molecular Physics, 32, 1075

C D Garner, I H Hillier, M F Guest
The nature of the metal-metal interaction in tetra-μ-carboxylato-chromium (II) systems
Chem. Phys. Letters, 41, 91

W R Rodwell, M F Guest, D T Clark, D Shuttleworth
Theoretical assignments of the electronic states of the π-radical cation of ethylene
To be published in Chem. Phys. Letters

C D Garner, I H Hillier, F E Mabbs, C Taylor, M F Guest
Electron spin resonance spectrum of tetraphenylarsonium oxotetrachlorchromium (IV), $[Ph_4As]$ $[CrO1_4]$
J. Chem. Soc (Dalton), 2258

M A Gittens, D M Hirst, M F Guest
An ab initio potential surface for the reaction $N^+ + H_2 \rightarrow NH^+ NH^+$
Symposium Faraday Society 62

M F Guest, W R Rodwell, T Darko, I H Hillier, J Kendrick
Configuration interaction calculations of the satellite peaks associated with C_{1s} ionization of carbon monoxide
Accepted for publication in J. Chem. Phys.

W R Rodwell, M F Guest, T Darko, I H Hillier, J Kendrick
Correlation effects and the ls hole satellite spectrum of N_2
Submitted for publication in Chemical Physics

R W Barnard, J F Hastings, P J Hunter
An optical system for measuring length changes in isolated cardiac muscle
J. Physiology, 260, 14

Rutherford Laboratory Reports
RL–76–99, 100, 101, 102, 104, 106, 107, 108, 110, 122/B, 132/A

Appendix 3 Lectures, Seminars and Meetings

Nimrod Lecture Series

G Ringland (RL, 19th January)
Direct Lepton Production.

M Davier (Orsay, 26th January)
High Statistics Study of Particle and Antiparticle Elastic Scattering and C = – 1 Exchange.

Chan Hong-Mo (RL, 2nd February)
μ-Ψ Physics from Old Ideas.

R Hemingway (CERN, 9th February)
Status of Ξ^* Search and Other Aspects of Hadron Spectroscopy in K^-p Reactions at 4·2 GeV/c.

R W Tucker (Lancaster University, 12th/13th February)
Some Techniques in the Theory of Extended Particles.

J C Polkinghorne (DAMPT, Cambridge, 16th February)
A review of Large p_T Processes.

S M Flatté (CERN, 23rd February)
Internal Density Waves in the Ocean.

E Derman (Oxford, 1st March)
Dimuon Epidemiology.

P D Grannis (Stonybrook and UCL, 8th March)
Measurement of Associated Multiplicities in High p_T Interactions at the ISR.

A Irving (Liverpool, 15th March)
Regge Poles: Requiem or Rhapsody?

P Jenni (CERN, 22nd March)
Coulomb - Nuclear Interference Scattering Experiments Between 1 and 10 GeVc.

M Cresti (CERN, 29th March)
An Investigation of the S-Region's Antiproton Interactions at 600 GeV/c.

J Charap (QMC, 5th April)
Spin and Torsion, a Neglected Aspect of General Relativity.

R L Kelly (Carnegie-Mellon, 12th April)
Partial Wave Analysis of K^+p Elastic Scattering from 800-2500 MeV/c.

J J Sakuri (UCLA and CERN, 26th April)
Properties of Neutral Current.

C Wilin (UCL, 10th May)
Alignment Effects in Pion-Deuteron and Proton-Proton Total Cross Sections.

R H Dalitz (Oxford, 17th May)
A New Baryon Spectroscopy.

David Aschman (Princeton, 26th May)
Measurement of γ-Rays of ψ and ψ' at SPEAR.

L Wolfenstein (Carnegie-Mellon University, 3rd June)
The phenomenology of Neutral Currents.

D Morrison (CERN, 14th June)
Pathological Science.

A R Martin (Daresbury, 21st June)
The Search for Mesons.

T Applequist (Yale, 28th June)
Infra-red Aspects of Gauge Theories.

W G Scott (Fermilab, 2nd July)
Review of Bubble Chamber Neutrino Results from E45 and E180.

J Gunion (California, 5th July)
Universality of Hadron Multiplicities in Color Gauge Models.

Dr Rosenzweig (Pittsburgh, 12th July 1976)
Diquarks and the Structure of Exotic Mesons and Baryons.

E Wilson (CERN, 19th July)
The Commissioning of the SPS.

G E Kalmus, F Close, T G Walker (RL, 28th July)
Reports on the Tbilisi Conference.

R Arnold (ANL, 2nd August)
Multi-Eikonal Production Theory.

I Gaines (Fermilab, 13th September)
Data on Production of Charmed Baryons from Fermilab.

D Treille (CERN, 20th September)
Omega Past and Future.

A Donnachie (Manchester, 27th September)
J/Ψ Production in Hadron Collisions

G Lutz (CERN, 18th October)
Results from the CERN-Munich Polarised Target Experiment.

J Pati (IC and Maryland, 25th October)
Lepton Quark Symmetries.

D H Davis (UCL, 1st November) -
Searches with Photographic Emulsions for Charmed Particle Production Neutrinos and 300 GeV Protons.

M Abolins (Michigan State and CERN, 5th November)
Charm Production in Hadronic Interactions.

G Karl (RL and Guelph, Canada, 8th November)
Coherent Parity Violation.

P K Kabir (CERN, 22nd November)
Weak Interaction Review, Charm and CP Violation.

R Barlontaud (Saclay, 29th November)
Recent Results on 32 GeV/c $K^{\pm}p$ and $\bar{p}p$ Interactions at Serpukhov in the Mirabelle Bubble Chamber.

Seminars in High Energy Physics

I Halliday (Imperial College, 14th January)
Large p 'Phenomena and Vector Mesons.

R Orr (CERN, 21st January)
Results from the HPWF ν Experiment.

R Horgan (Oxford, 28th January)
Asymptotic Behaviour of Chiral Non-Symmetric Structure Functions in non-Abelian Gauge Theories.

A de Belleton (College de France, 4th February)
$K^-p \rightarrow \Lambda\pi$ in the Formation Region using Barrelet Zeros.

U Sukhatme (DAMTP Cambridge, 11th February)
Derivative Analyticity Relations for Amplitude Analysis.

K Sumorok (RL, 25th February)
Study of the Reaction $\pi^-p \rightarrow \omega n$ in the Omega Spectrometer.

E Corrigan (Durham, 10th March)
Monopoles in Gauge Theories.

J Bartels (Hamburg, 17th March)
Reggeon Field Theory in Production Processes.

T Quirk (Oxford, 24th March)
Results from the FNAL Muon Experiment.

M Green (Cavendish, Cambridge, 31st March)
Novel Applications of the Renormalization Group.

G G Ross (CERN, 7th April)
Weak Decays and Asymptotic Freedom.

J Cleymans (Bielefeld, 13th April)
Particle Classification with the MIT Bag Model.

S Sharrock (UCL, 28th April)
Particle Production at Low Transverse Momentum at the ISR.

R M Brown (RL, 4th May)
Future Counter Experiments with Charged Hyperon Beams.

W L Turner (RL, 12th May)
The Frascati Meeting and Preparation for Experiment at PETRA.

M J Couniham (CERN, 18th May)
Inclusive Production of Resonances.

B Combridge (DAMPT, Cambridge, 19th May)
Inclusive Processes at Large Transverse Momemtum.

C E Vayonakis (Sussex, 25th May)
Properties of Scattering Amplitudes in Non-Abelian Gauge Theories.

P Sanders (Oxford, 16th June)
Experiments on Weak Neutral Currents in Atomic Physics

D P Roy (Wisconsin, 18th June)
Systematics of Zweig Rule Violation.

J Rushbrooke (Cambridge, 30th June)
$\bar{p}p$ Annihilation Physics at 100 GeV/c

M Coupland (QMC, 21st July)
Measurement of Polarisation in $\bar{p}p \rightarrow \pi^-\pi^+$ and $\bar{p}p \rightarrow K^-K^+$.

N Rornqvist (Helsinki, 21st July)
Sister Trajectories in the Dual Model.

M Gronai (Technion, Haifa, 26th July)
Searching for Heavy Leptons with Longitudinally Polarised e^+e^- beams.

G Fisk (Fermilab, 29th July)
Test of Charged Symmetry in High Energy Neutrino Interactions.

W Bishari (Weizmann Institute, 4th August)
Exchange Degeneracy Breaking and the Pomeron in Scattering and Particle Domains.

J Albright (Florida State, 29th September)
Looking for Long Lived Charm.

R L Thews (RL, 6th October)
Constraints on Meson Radiative Decays from Duality.

J Litt (CERN, 13th October)
Results from the Single Arm Spectrometer Experiment at Fermilab.

A A Carter (QMC, 20th October)
New Evidence for Resonances in $\bar{p}p \rightarrow \pi^-\pi^+$.

S P Kruglov (INPI, 27th October)
Particle Physics at Leningrad Nuclear Physics Institute.

M G Albrow (RL, 28th October)
Report on the ISR Workshop.

J L Cardy (CERN, 3rd November)
Reggeon Field Theory $\alpha(o) > 1$.

C Bradasohia (Pisa, 10th November)
Vector Meson Search at DESY.

E Corrigan (Durham, 17th November)
Some Interesting Classical Solutions to Gauge Theories.

F K Loebinger (Manchester, 24th November)
Single Diffractive Excitation at the CERN ISR.

U Sukhatme (DAMPT, Cambridge, 30th November)
The Size and Shape of Inelastic Diffractive Dissociation.

B Martin (UCL, 1st December)
$\bar{K}N$ Interactions in the Resonance Region.

B Schrempp (Geneva, 7th December)
Surface Waves as Carriers of Hadronic Diffraction.

J Guy (RL, 21st December)
Electron Production in 4 GeV Interactions in Track Sensitive Target Experiment.

High Energy Physics Data Handling Section Seminar

P P Haskell (RL, 21st January)
Formal Languages.

C Osland (RL, 28th January)
Languages I have known.

P P Haskell (RL, 11th February)
Use of Formal Languages in Compiler Writing.

J Scott (IC, 17th March)
New Ideas in Machine Architecture.

I Croall (Harwell, 24th March)
The Status 11 Information Retrieval System.

A Lewis (Harwell, 31st March)
Real-Time Basic for CAMAC.

M Curtis (RL, 7th April)
The Role of MAST in the Rutherford Central Computing System.

R A Rosner (RL, 28th April)
The INFOL Information Retrieval System.

K Jeffrey (Institute of Geological Studies, 5th May)
'G EXEC' Generalised Data Handling System.

D H Reading (RL, 19th May)
Multi-Wire Proportional Chambers in Medical Applications.

P Wilde (RL, 19th May)
The Reconstruction of Pictures from Their Projections.

P Clout (Daresbury, 26th May)
Data Acquisition at Daresbury.

A Peatfield (Daresbury, 16th June)
Serial CAMAC.

B Forsyth (RL, 23rd June)
Data Acquisition and Assessment at ILL.

H Davies (CERN, 30th June)
The Design of the CERN Network.

M J B Duff (UCL, 7th July)
New Methods for Image Processing Using LSI Arrays.

D J Howarth (IC, 14th July)
Do-it-Yourself Operating Systems.

D Machen (Los Alamos, 27th October)
The LAMPS Control System.

G Frank (Manchester, 17th November)
The Manchester University Operating System.

D Ould (RL, 24th November)
A Computer Approach to the Wire-wrapping Problem.

Rutherford Laboratory Lectures

Sir Denys Wilkinson (Oxford, 15th January)
What is the Nucleus Made of?

G Perry MBE (Kettering Grammar School, 26th February)
Kettering Observations of Chinese and Russian Space Missions.

R Dwek (Oxford, 18th March)
Antibodies: The Body's Defence at a Molecular Level.

D Sciama (Oxford, 22nd April)
Particle Creation by Black Holes.

R Eden (Cavendish Laboratory, Cambridge, 20th May)
Aspects of Energy Research in the Cavendish Laboratory.

J K Dawson (ETSU, AERE, 17th June)
The Work of the Energy Technology Support Unit.

E C Zeeman (Warwick, 30th September)
Applications of Catastrophe Theory to Physics.

R Arnold (Argonne, 14th October)
Ion-Beam Fusion.

A F Gibson (University of Essex, 25th November)
Lasers.

A Gibson (Culham, 8th December)
The Jet Project.

Seminars in Computing

D Parkinson (ICL, 23rd January)
The ICL Distributed Array Processor (DAP).

J Cable (IBM, 6th February)
IBM's New Time Sharing System – VSPC.

M J Holmes, D Dent (RL, 20th February)
Hardware for Computer Graphics.

I J Bloodworth (RL, 5th March)
Graphics at Rutherford: ENPLOT and FASUMX.

R W Hockney (Reading, 19th March)
Parallel Computers.

R Candlin (Edinburgh, 2nd April)
An Economical Solution to the CPU Time Problem.

A T Lea (RL, 21st May)
An Overview of the 360/195.

E B Fossey (RL, 18th June)
The Rutherford ICL 1906A Computer – its Facilities and Usage.

Dr Richards (LBL, 16th July)
The Berkeley Data Management System (BDMS) – an Introduction.

P Preuss (San Diego, 20th July)
"DISPLA – An Interactive Graphics Package".

Meetings and Special Events

Theoretical Physics Meeting (5-9 January)

Atlas Computer Division Meeting (29-30 January)

Laser Meeting (6-7 February)

'New Physics' Meeting (18-20 February)

Conference of the Computation of Magnetic Fields (Compumag)
St Catherine's College, Oxford (31 March-2 April)

Topical Conference on Baryon Resonances
St Catherine's College, Oxford (5-9 July)

6th British Vacation School in Elementary Particle Physics
Southampton University (9-22 September)

Summer School for Experimentalists (6-24 September)

Theoretical Physics Meeting (15-17 December)