6 January 1976 PPC6 (76)

PARTICLE PHYSICS COMMITTEE

THE FUTURE HIGH ENERGY PHYSICS PROGRAMME AT NIMROD

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The attached paper discusses the future programme of physics at Nimrod. In the time available it has not been possible to present a detailed breakdown of the cost of each experiment, but this will be provided in due course.

THE FUTURE HEP PROGRAMME AT NIMROD

Introduction

In 1972 it was decided by Council to approve the construction of a new 70 MeV injector for Nimrod which, along with other minor modifications to the accelerator would increase the intensity of the extracted proton beam delivered to the experimental halls to 10^{13} protons per pulse. Underlying this decision was the firm belief that by upgrading Nimrod in this way the particle physics community would have at its disposal a competitive domestic facility with a useful life extending well into the next decade.

The construction of the injector is now complete and commissioning has started, with Nimrod continuing to run with the existing 15 MeV injector until a reliable 70 MeV beam is achieved. The first attempt to inject 70 MeV protons into Nimrod is planned for July 1976.

By this time Nimrod will be serving seven large scale experiments, each with its own beam line, as well as a test beam and a low energy pion beam for radiobiological work. The arrangement of the experiments in the two main experimental halls is shown in Figure 1 and details of the beams are given in Table 1. The three beams in Hall 1 make up a totally new complex in which the radiation shielding and the detailed arrangements for providing beams of secondary particles have been specially designed to make maximum use of the high intensity extracted beam when it becomes available.

The Experimental Programme

The present programme of experiments at Nimrod and the plans for future work are directed very largely towards studying the properties of resonances produced in hadron-hadron interactions. These resonances are very naturally interpreted in terms of the quark model and theories developed within the framework of SU(3) and higher symmetries. The recent discovery of the new ψparticles and the explanation of their properties in terms of bound states of a new type of quark has at once strengthened the interest in the quark model of the older particles and provided a stimulus to obtain a deeper understanding of it. There remains therefore a pressing need for experimentation at Nimrod energies despite the great importance now of moving to the higher energies that the new accelerators offer. If quarks should turn out to be permanently bound, either in fact or in practice because sufficiently high energy accelerators cannot be built to release them, then one of the major sources of information on their properties and interactions must be the resonance spectrum of hadrons.

In its simplest form the quark model sets out to explain the entire spectrum of hadron states currently known, excepting the recently discovered ψ particles, in terms of just three basic constituents known as the n, p and λ quarks. Each quark carries spin $\frac{1}{2}$ and fractional electric charge. The baryons, e.g. the proton, the pion-nucleon and kaon-nucleon resonances, and the Λ, Ξ and Ω particles, are regarded as bound states of three quarks and the mesons, e.g. π, K, ρ, etc as quark-anti-quark pairs.

The λ quark carries the quantum number of strangeness with the value - 1; its anti-particle has a strangeness of + 1. Thus within this framework baryons may exist with strangeness 0, - 1, - 2, or - 3, and mesons with strangeness 0 and ± 1. There is no place in the model for baryons with positive strangeness or mesons with strangeness greater than 1. Indeed it has become as important to determine whether or not these states, which have come to be called exotic states, exist, as to investigate the systems where resonances can readily be produced.

An experiment which will have a direct bearing on the possible existence of exotic baryon resonances is about to start on Nimrod. The aim of the experiment is to study the interaction of positively charged kaons with polarized neutrons and to use the results with those of other related experiments in a detailed analysis to search for resonant state or, if none is found, to place upper limits on the probability of their being produced. A polarized deuterium target will be used to provide the polarized neutrons.

Our present understanding of the spectrum of resonant states produced in the pion-nucleon system stems very largely from precise experiments on elastic scattering which have provided data from which more than 20 resonant states have been established. In this field the contribution of Nimrod based experiments stands unchallenged. Well over half of all the available data on elastic scattering has come from these experiments to which must now be added recent work of comparable quality on the $\pi^- p$ charge exchange reaction and an experiment currently in progress to study the important inelastic process, $\pi^- p \rightarrow \Lambda K^0$. The latter may itself show up resonant states as yet unseen in elastic scattering but, probably of greater significance, it will provide information on the probability for the decay of resonances into the ΛK^0 channel for which theory makes very clear predictions. It is interesting to note that this experiment will measure for the first time for any reaction studied in the resonance region the effect of the strong interaction on the direction of the baryon spin. The results of these measurements, when taken with the results of the cross-section and polarization measurements already made, will provide data on the complete set of physically measurable quantities for this reaction. A full analysis of the data is then possible with no discrete ambiguities and with the minimum of theoretical assumptions.

A special polarized proton target in which the direction of the proton spin can be oriented along the direction of the incoming pion beam has been built for this experiment and will be ready for use early in 1976. When the experiment is complete the target and the bulk of the detection system will be used to make similar measurements on pion-nucleon scattering and other reactions.

Experiments which study the interaction of negatively charged kaons with protons are also of great importance in baryon spectroscopy. At Nimrod the number of such experiments was initially rather limited because of the relatively low intensities achieved in secondary kaon beams. However, with the steady increase in the intensity of the primary proton beam in recent years and with the prospect of still greater intensities in the future, experiments with kaons now dominate the Nimrod programme. Experiments which measure differential cross sections and polarizations for elastic scattering are already in progress or being commissioned. They aim to reach much the same level of precision as the earlier pion-nucleon experiments have achieved so that equally incisive information about the resonant states with strangeness - 1 can be provided.

Negatively charged kaons are also used to produce baryon states with strangeness - 2. Very few of these Ξ^* states have been observed, although many are expected to exist, and little is known about their basic properties. The reactions in which they are produced have complex topologies which call for the use of bubble chamber techniques. However, they also have small cross-sectionswhich seriously limits the statistical accuracy that can be obtained by conventional means. To solve these problems a rapid cycling vertex detector has been constructed at the Rutherford Laboratory and is being installed for use in a 2.8 GeV/c kaon beam at Nimrod. The device is a small hydrogen bubble chamber capable of cycling at 60 Hz which is placed inside the old helium bubble chamber magnet. Picture taking is controlled by an external trigger system consisting of scintillation counters and wire spark chambers used in conjunction with a small on-line computer. The information reaching the computer is analysed during the bubble growth time of the chamber and if an event with the appropriate topology has occurred a picture is taken.

Construction of the bubble chamber is now complete and the first cool-down is about to commence. Commissioning of the beam and the trigger system has already started.

Another important facility that is being constructed for use on Nimrod is the Rutherford Multiparticle Spectrometer. It has much in common with the OMEGA spectrometer at CERN and its construction was proposed by a group of physicists who were among the first to use OMEGA and to recognise the potential of such an instrument. The old 1.5 m bubble chamber magnet is being modified for use as the spectrometer magnet and it will be filled with cylindrical spark chambers and other detectors. Assembly will be complete by June 1976, all detectors having been fully tested prior to installation. Initially, a liquid hydrogen target will be used with the device but this will be replaced in 1977 by a frozen spin polarized target to enable spin dependent effects to be investigated. The first experiment to be carried out is a study of π^+ induced reactions at 4 and 6 GeV/c. The aim is to obtain information on the interaction mechanisms at these energies particularly those leading to a meson and a baryon resonance in the final state.

The spectrometer with its frozen spin polarized target will be a powerful device capable of being used for a wide range of experiments. The first round of experiments is expected to be complete by the end of 1978. An extension to embrace kaon induced reactions will then follow.

Another interesting experiment, this time concerned with weak interactions, is being prepared for operation late in 1976. In the most recent developments of the theory of weak interactions, an important part has been played by gauge theories with spontaneously broken symmetries. Salam and Strathdee have suggested that under some conditions, the underlying symmetry of the theory could be restored. In particular the well-known CP violation, which permits the occurence of the decay $K^o_L \rightarrow \pi^+\pi^-$, could be 'turned off' if the K^o sample were placed in a high magnetic field. The experiment is intended to test this notion. A K^o beam, extracted from Nimrod in a fast spill mode (pulse length $\lesssim$ 1 ms) will pass down the axis of a pulsed solenoid, whose peak field will reach 350-400 kg. If this field value is above the critical value at which CP symmetry is restored, then there will be a change in the decay distribution of the $K^o_L \rightarrow \pi^+\pi^-$ events downstream of the solenoid. These events will be recorded by a simple spectrometer comprising a magnet, drift chambers and multiwire proportional chambers.

Nimrod also provides facilities for a team of nuclear structure physicists to do experiments with stopping kaons. An intense stopping kaon beam has been in operation since 1974 and is being used for measurements of energy shifts, widths and intensities of X-rays from kaonic atoms formed in a variety of targets. The results provide a means of studying nuclear properties in the surface region of nuclei and give information about the very low energy kaon-nucleus interaction and capture process. In some elements the ground state spin and quadrupole moment cause a hyperfine splitting of the X-ray transitions observed which gives information about both charge and matter quadrupole distributions.

Cost of Programme

In attempting to forecast the cost of the programme it is assumed that Nimrod will operate for a total of 5500 hours for high energy physics experiments in each financial year from 1977/78 onwards and that seven experiments will be running throughout the five year period. This will provide each experiment with approximately 1800 hours per year of operation at high intensity as well as a substantial amount of parasitic operation with low intensities.

About 90 physicists and research students, 15 of whom are from France and Italy, are participating in the present approved programme which is summarized in Table 2. Table 3 gives a list of new experiments currently under consideration. If they are approved this level of participation will remain much the same throughout the five year period. In addition many physicists are expecting to use the test beam for commissioning new equipment for CERN experiments.

The major cost of this programme is in operating the accelerator itself which for 5500 hours of operation is estimated to be £4.0M per year including all staff costs and overheads. The cost of running and maintenance of the Nimrod experiments is estimated to add a further £1.5M to this figure, again including staff costs and overheads, By operating Nimrod for only 2700 hours in 1976/77 a saving of approximately £0.6M will be achieved.

In the time available it has not been possible to prepare more than this global estimate of costs. The Particle Physics Committee is invited to make recommendations on the detailed information required and the form of presentation. A suggested format is given in Table 4.

FIGURE I

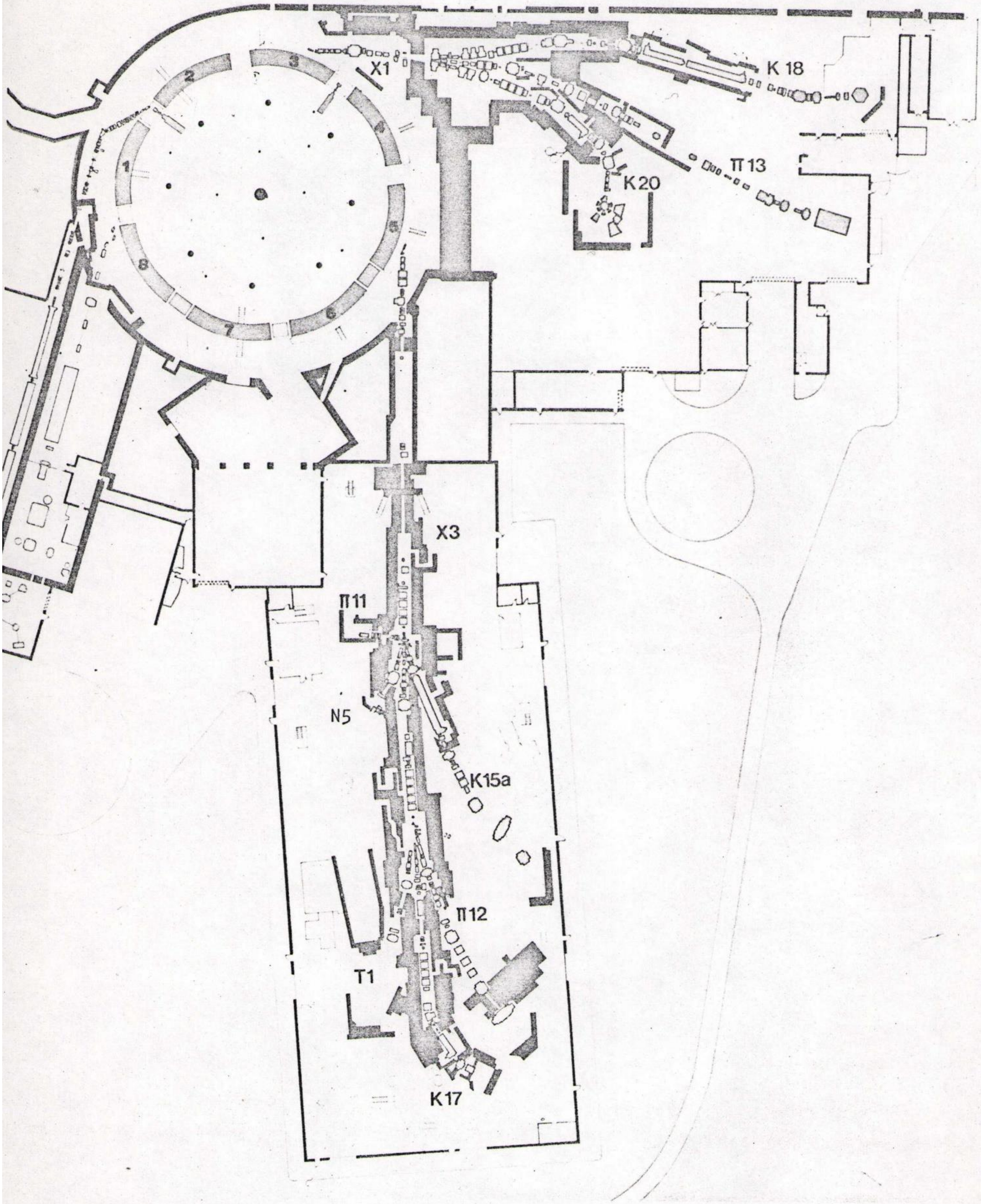

TABLE 1 SECONDARY BEAMS AT NIMROD

	DESCRIPTION	
K20	Low Energy Separated Kaon Beam	Momentum Range: 0.700 - 1.4 GeV/c Beam Intensity per 10^{12} protons: $K^+ \sim 10^4$, $K^- \sim 5 \times 10^3$ } at 1.0 GeV/c Momentum Bite: $\sim \pm 2\%$
π13	High Energy Pion Beam	Momentum Range: 3 - 6 GeV/c Beam Intensity per 10^{12} protons: $\pi^+ \sim 2 \times 10^6 - 10^5$ $\pi^- \sim 10^6 - 0.5 \times 10^5$ Momentum Bite: ± 1% Provision has been made to install a separator at a later stage for work with kaons
K18	Separated Kaon Beam for the RCVD	MomentumRange: 2.4 - 3.0 GeV/c Beam Intensity per 10^{12} protons: $K^- \sim 10^3$ at 2.8 GeV/c Momentum Bite: ± 2%
K15	Separated kaon beam	Momentum Range: 1.2 - 2.5 GeV/c Intensity per 10^{12} protons: $K^+ \sim 1.5 \times 10^4$ $K^- \sim 0.8 - 1.1 \times 10^3$ ($K/_\pi \approx \frac{1}{20}$) Momentum Bite : ± 2%
π12	Medium Energy Pion Beam	Momentum Range: 1.4 - 2.4 GeV/c Intensity per 10^{12} protons: $\pi^- \sim 10^5$ Momentum Bite: ± 0.8%
K17	Stopping Kaon Beam	Momentum: 0.6 GeV/c Intensity per 10^{12} protons: $K^- \sim 7 \times 10^3$ (10^3 stopped) Momentum Bite: ± 2%

TABLE 1 (CONT.) SECONDARY BEAMS AT NIMROD

	DESCRIPTION	
T1	Test Beam	Momentum Range: 0. - 2.5 GeV/c Intensity per 10^{12} protons: $\sim 10^5$
N5	Neutral Beam for K^o studies	Momentum: $\sim$ 1 GeV/c Mean. Intensity per 10^{12} protons: $\sim 1.9 \times 10^4$ K^o_L $\sim 7 \times 10^5$ neutrons
π 11	Low Energy Pion Beam for Radiobiological Studies	Momentum: o.16 GeV/c Intensity per 10^{12} protons: $\pi^- \sim 10^7$. Momentum Bite: $\pm$ 7%

TABLE 2

APPROVED NIMROD EXPERIMENTS

Group	Proposal	Experiment	Estimated Completion Date	No. of Physicists
RL/Surrey/Birmingham	113	Experiment with stopping kaons	December 1977	B'ham 3 Surrey 2 Res St 2 RL 5
RL/Rome/Oxford/ Paris	119	A proposal to study the S= -2 baryon resonances using a Rapid Cycling Hydrogen Bubble Chamber	September 1977	Oxford 2 Res St 1 Rome 6 Res St 1 Paris 7 Res St 1 RL 3
Bristol/S'oton/RL	120	A proposal to measure differential cross-sections for K^-p elastic scattering in the momentum range 1200-1900 MeV/c	March 1977	Bristol 4 Res St 4 S'oton 2 Res St 1
QMC/RL	136	A proposal to measure polarization in $K^{\pm}$ n elastic and charge exchange scattering	July 1978	QMC 6 Res St 3 RL 4
RL/W'field/Ed'burgh	150	A study of exchange mechanisms in quasi 2-body final states using the RMS facility	December 1978	Ed'burgh 2 Res St 2 RL 5 W'field 4 Res St 2
Bristol/RL	166	Measurement of the A and R parameters in the reaction π^-p and Λ^0K^0 between 1.0 and 2.1 GeV/c	December 1977	Bristol Res St 1 RL 6
Imperial College/RL	168	An experiment on CP in a high magnetic field	December 1977	Imp Coll 6 Res St 2 RL 2

TABLE 3

NEW NIMROD EXPERIMENTS NOT YET APPROVED

Group	Experiment	Prob Starting Date	Comments
RL/Birmingham/Surrey	Nuclear Structure Experiments with stopping kaons	Early 1978	The group is proposing to extend the range of its present work
Durham/Warsaw	Study of low energy Λp interactions	End 1977	The experiment will be done with the Rapid Cycling Vertex Detector now being used for Proposal 119
RL/Rome/Oxford/ Paris	Study of S -2 baryon resonance production in deuterium.	End 1977	This also uses the Rapid Cycling Vertex Detector and will be in competition with the experiment above
Bristol/S'oton/RL	Study of inelastic two-body K^-p interactions	Mid 1978	This experiment will follow Proposal 120 and will use the same equipment
QMC/RL	Measurement of the polarization in the reactions $K^-n \to K^-n$ and $K^-p \to K^0n$	Early 1979	This experiment will follow Proposal 136 and will use the same equipment.
RL/W'field/Edinburgh	A study of Kaon induced interactions using the RMS facility and a polarized proton target	Early 1979	This experiment will follow proposal 150
Bristol/RL	Measurement of the spin rotation parameters in $\pi^{\pm}p$ elastic scattering	Mid 1978	This experimentwill follow Proposal 166 and will require only minor additions to the equipment now in use
Imperial College/RL	(i) Follow up of present CP experiment (ii) Mass of ν associated with the muon (iii)Threshold effects in RMS	Mid 1978	The group will decide which of these experiments to pursue when the results of proposal 168 are known

TABLE 4 FORMAT FOR PRESENTATION OF COSTS

COSTS IN FY 1976/77

Experiments

Proposal	Experiment	MY Total	Salaries and O/H's £K	R & D £K	Total Cost £K
113	Experiment with Stopping Kaons				
119	A proposal to study the S = -2 baryon resonances using a Rapid Cycling Hydrogen bubble chamber.				
	etc for all other experiments mentioned in tables 2 and 3.				

Operation of Nimrod

Item	MY Total	Salaries and O/H's £K	R & D £K	Total Cost £K
Operation and Maintenance				
Electricity (2700 hrs/year)				

Computing

	MY Total	Salaries and O/H's £K	R & D £K	Total Cost £K

Similarly for subsequent financial years.