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DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH
and
NATIONAL INSTITUTE FOR RESEARCH IN NUCLEAR SCIENCE
JOINT CONSULTATIVE PANEL FOR NUCLEAR RESEARCH

THE FUTURE HIGH ENERGY PHYSICS PROGRAMME OF EUROPE

The Working Party set up by the Panel on 6th March, 1963 have drafted their report, a copy of which is enclosed.

Because of the shortness of the time available, it has unfortunately proved to be impossible to circulate the draft to members of the Panel before submitting it to the Advisory Council for Scientific Policy. Copies of the report are in fact being sent to the A.C.S.P. today. However, consideration of proposals of this magnitude will clearly take a considerable time, and there will be opportunities to make any corrections and amendments in the light of the observations of members of the Panel.

Will members who have observations to make or who consider that there should be a further meeting of the Panel to consider the report, kindly communicate with one of the secretaries?

I. A. Learmouth
D.S.I.R. State House, London

J. A. V. Willis
NIRNS, Rutherford Laboratory
Chilton, Didcot, Berks.

Joint secretaries

25th April, 1963.

THE FUTURE HIGH ENERGY PHYSICS PROGRAMME OF EUROPE

Report of a Working Party appointed by the

DSIR/NIRNS JOINT CONSULTATIVE PANEL FOR NUCLEAR RESEARCH,

at its meeting of 6th March, 1963.

ABSTRACT

Recent developments in high energy physics are reviewed, and it is shown that an early decision is required on a programme of future European high energy accelerator construction, and of expanding support for existing facilities, if significant contributions to the subject are to come from Europe from 1970 onwards. Such a programme should specifically include the construction of a new proton accelerator whose energy should be as high as possible within the range 150-300 GeV, and the provision of a pair of storage rings in association with the existing C.E.R.N. proton synchrotron. Rough estimates are given of man power and cost in relation to the whole nuclear research programme. It is strongly urged that the United Kingdom should play a full part in this European programme and that, if possible, the new accelerator should be built upon a site in the United Kingdom.

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INTRODUCTION

The primary objective of physics is to provide an understanding of the fundamental laws of nature and of the ultimate structure of matter. In terms of distance the two present frontiers of physics lie at 10^{-14} cm on the one hand and at 10^{+27} cm on the other. At intermediate distances the laws of physics are known, they carry the power of prediction, they may be applied to situations of ever increasing complexity and practical significance.

At distances beyond 10^{27} cm, at which lie the furthest detected galaxies, we know nothing of the laws of physics or of the nature of the universe. Only at such great distances, it would seem, can we hope to learn in what manner and at what rate matter is created. For these studies we require large optical and radio telescopes. Our largest particle accelerators, on the other hand, enable us to investigate the interactions between the elementary forms of matter down to distances of 10^{-14} cm. Within such distances we again know nothing of the laws of physics or of the structure of matter.

High energy physics over the last 15 years has revealed the astonishing and unexpected richness of nature in the form of some 50 recognisably different states of elementary matter, most of them only semi-stable. To understand their properties - that is, to unravel the laws which govern the behaviour of matter at such exceedingly small distances - we have soon to go to still higher energies. Our present knowledge tells us that the increase in energy, if it is to be significant, must be substantial.

Progress in high energy physics has been such that we shall need the new facilities to be operative in the early 1970's. They will take at least 7 years to build and must therefore be begun within a year or two. Before describing the proposed facilities, however, we wish briefly to review the progress that has already been made in trying to understand the nature of matter and its fundamental interactions.

A BRIEF REVIEW OF PROGRESS

We may distinguish four stages in the gradual elucidation of the nature of matter during the last 100 years or so. There was first the recognition of the atomic constitution of matter; second, the study of the electron shell surrounding the atomic nucleus; third, the problems raised by the structure of the nucleus considered as an assemblage of neutrons and protons; and fourth, the study of the structure of the elementary particles themselves, and of the forces between them, which constitutes high energy physics. The first two stages of this process are already part of our scientific and cultural heritage, fundamental to all our science. The third, thanks to the peculiar accident of the fission process, has already given rise to a nuclear power industry: it remains a field for pure research which continues to attract deep interest and in which many basic problems remain unsolved. But more important than that, from the present point of view, the study of nuclear structure has shown that the interactions which matter undergoes are far more diverse than we had thought in the days when the inverse square laws of electromagnetism and gravitation could account for most of what we knew. For the recognition in the early 1930's that the mere existence of nuclei demanded an entirely novel kind of force between nuclear particles, enormously strong but extending no further than about 10^{-13} cm; the prediction by Yukawa that such forces might be mediated by the rapid exchange between neutrons and protons of an entirely new kind of particle of mass intermediate between proton and electron, and the discovery of this particle (the pi-meson, or pion) in the cosmic radiation by Powell in 1947: these were the beginnings of elementary particle physics whose secrets can be uncovered only at increasingly higher energies and with the aid of increasingly complex and costly equipment.

A first glimpse of what was in store for us was already provided by Powell's original work which showed that there were in fact two kinds of particle of similar mass, the strongly interacting one required by Yukawa to account for the binding of atomic nuclei, and a weakly interacting one (the mu-meson, or muon) whose existence was quite unexpected and whose function we still do not understand. A second glimpse was provided at about the same time by Rochester and Butler's studies of the cosmic radiation whose extremely energetic particles were found to give rise, through interactions with ordinary matter, to still further particles, the so-called K-mesons and hyperons.

All these new forms of matter we have found to be ephemeral in the extreme, most of them having lifetimes of 10^{-10} sec. or less. However, on the natural nuclear time scale of 10^{-23} sec (a distance of 10^{-13} cm divided by the velocity of light) such lifetimes are very long indeed, so that the interactions responsible for them must be very weak. In fact, the decay processes now appear to be very similar to the well-known beta-decay process of radioactivity which is also, on the nuclear time scale, an exceedingly slow process. It seems likely that all these decay processes involve a universal weak interaction. Like the strong interaction which binds nuclei together and is responsible for the production of elementary particles in high energy collisions, the weak interaction is of very short range, not more than 10^{-13} cm. An important step forward was taken in 1957 when it was found, following a suggestion by Lee and Yang, that the weak interaction violates parity conservation, seemingly one of the most natural conservation laws of quantum physics.

Some of these decay processes involve the emission of the neutrino, the uncharged and mass-less particle proposed by Pauli in 1931 to account for the properties of beta-radioactivity. This particle eluded positive experimental detection until 1959: it plays a central role in our picture of the weak interactions and its detection therefore opens up in principle a fruitful new field of experimental investigation.

Thus, to the long-range electromagnetic and gravitational interactions of classical physics we have now to add the short-range strong and weak interactions. The relative strengths of these four fundamental interactions may be described by their "coupling constants" which are of the order of 1 for the strong interaction, 1/137 for the electromagnetic interaction, 10^{-12} for the weak interaction, and 10^{-38} for gravitation. It is often conjectured that there may be an underlying unity behind all four interaction types, for instance that each of them may be mediated by further particles whose properties are closely related.

The existing high energy accelerators have enabled us to produce the pions and K-mesons and the hyperons (particles heavier than the neutron and proton) in the laboratory, copiously enough to study their production mechanisms, their decay processes, and to elucidate some of their basic properties such as mass, electric charge, spin and parity. In particular, it has been found that the particles occur in groups, called charge multiplets, within which they differ essentially only in their electric charges. Thus there are three pions (π^+, π^0, π^-) of identical spin and almost identical mass, but of positive, zero, and negative charge (in units of the electronic charge), there are two nucleons (p^+, n^0), three Σ-hyperons ($\Sigma^+, \Sigma^0, \Sigma^-$), and so on. Still further groups of "particles" have shown themselves as resonances in high energy collisions produced with the aid of accelerated particles. Their lifetimes, deduced from the resonance widths, are still relatively long. The present picture of the hyperon states of matter is shown in figure 1 which may be thought of as displaying the excited states of the basic nucleon system. Except for the proton all are unstable. There is no reason to suppose that further states will not be added to this spectrum as time goes on: most of them have been found in the last 5 years.

The existence of the charge multiplets - sets of almost degenerate states of matter - points to a new conservation law, that of the conservation of isotopic spin, which in turn tells us that the strong interactions, whatever their detailed description, must possess a certain symmetry property, that of invariance under rotation of the isotopic spin variables used to describe the degeneracy. The same symmetry property shows itself in the form of there being simple relationships between the cross-sections for production of different members of the same charge multiplets. Further analysis of the strong interactions has suggested that isotopic invariance is only a part of the full symmetry displayed by nature: there is evidence that the strong interactions may display the so-called unitary symmetry. On the basis of this more complete symmetry a number of new states of matter have been predicted by Salam and others, and some of them have already been discovered as resonances in high energy collisions. Still other conservation laws reveal themselves as selection rules governing the production and decay mechanisms. The new conservation laws represent our first attempts to describe the laws of nature which hold at very short distances.

One interesting way to describe the structure of matter is to work in terms of the electric charge and current distributions associated with each particle. The electromagnetic "form factors" of the proton and neutron may be measured using accelerators which give finely collimated beams of high energy electrons. Pioneer work of this kind has been done during the past 10 years, in particular by Hofstadter at Stanford and by Wilson at Cornell. The interpretation of the form factors is not a simple matter: for the effect of the strong interaction between nucleons and pions is to produce a pion cloud around the nucleon and the pion cloud itself contributes to the charge and current distribution. In this way we are able to use the relatively well-understood electromagnetic interaction of electrons as a powerful tool to learn more about strong interaction phenomena: electron accelerator and proton accelerator can be used to complement each other. This was the main reason for the NIRNS decision to build the 4 GeV electron accelerator NINA at Daresbury in addition to the 7 GeV proton accelerator NIMROD at Chilton.

But in addition to the electromagnetic form factors we may also discuss, and hope eventually to measure, the strong and weak form factors. If there indeed exists a unity among the fundamental interactions it may be expected to manifest itself in closely related form factors. But the weak form factor cannot be measured adequately with any existing machine: for this we shall need intense beams of neutrinos obtainable only from the radioactive decay in flight of pions produced by proton accelerators of much higher energy than is available today.

The present generation of accelerators has thus provided us with a tantalising picture of the world of elementary particles. It seems that we stand at a point in time similar to that of the 1920's when a whole range of quantum phenomena had been recognised and when many of them had yielded to the first crude attempts at classification and interpretation, but when the Schrödinger Equation had yet to be proposed. Over the next 8 to 10 years the present accelerators will certainly enable us to learn a great deal more of the strong interactions whereby most of the particles are produced, and of the weak interactions whereby most of them decay. Not only shall we possess a list of the elementary states of the spectrum of matter, but we shall have set them down firmly in a "periodic table" whose outlines in terms of the new conservation laws are already clear to us. There will remain, however, the problems connected with the existence of so many distinct states of matter, the quantitative nature of their interactions, and the relationship between the fundamental types of interaction. Whether or not the new Schrödinger Equation has been discovered by that time, we shall need to extend the energy range, intensity, and quality of the particle beams available to us 10 years hence if the present state of knowledge of the fundamental structure of matter is to be carried forward a further significant step.

THE PROPOSED EUROPEAN PROGRAMME

We shall not attempt to give a detailed theoretical justification for any particular advance in energy. Each substantial advance in accelerator physics in the past has been amply justified in the event and has enabled us to learn much more than we had supposed would be possible beforehand. At the frontiers of physics the unexpected becomes commonplace. The physics that is being accomplished with the 25 GeV proton synchrotron at CERN has turned out to be far more significant than was predicted even in the most imaginative attempts to justify the construction of the machine. But even though that machine will continue to be an indispensable tool for European physicists for at least a decade to come, the list of profoundly interesting problems that can be elucidated only at much higher energies continues to grow. There is, for example, the suspicion that at sufficiently high energies the weak interaction itself becomes strong. By the early 1970's we must therefore expect a tremendous interest in higher energies.

The distance down to which we may explore the nature of matter varies less rapidly than inversely with the energy of the accelerated particles. Furthermore, there are certain important high energy phenomena whose properties appear to vary only logarithmically with energy. At sufficiently high energies, it would seem, the present complex situation may acquire a new simplicity, an example of which is the prediction that certain nuclear cross sections are expected to approach each other asymptotically. Thus, to break through the present frontier at 10^{-14} cm we shall require a very substantial increase in particle energies.

However, there are two rather distinct physical requirements. One is to provide secondary beams of pions, K-mesons, hyperons and neutrinos of much higher energies and intensities than are available at the present time. This requires high primary intensity as well as high energy. The other is to increase the energy of the primary accelerated particles to the highest value possible without for the time being necessarily requiring a very high intensity. Both requirements have been under close study by a panel of European physicists meeting at CERN, and we are in complete accord with their conclusions, a brief summary of which now follows.

The first requirement of intense energetic secondary beams can be met only by constructing a proton synchrotron in the energy range 150 to 300 GeV and with a circulating current of 10^{13} protons per second. This would go some way towards meeting the second requirement also since it would provide a primary proton energy some 6 to 10 times greater than the 25 GeV available at CERN or the 30 GeV available at Brookhaven. The new accelerator would incidentally require more than a mere scaling up of the existing CERN machine: it would be economically very favourable to inject into the machine at an energy of several GeV with the aid of a preliminary synchrotron. A 150 GeV machine would be about 1.2 km in diameter and would require a total site of about 10 square kilometres, while a 300 GeV machine would have twice the diameter but would require only twice the total site area. Apart from the obvious difficulties connected with the enormous size of such a machine, the project would be able to rely upon known technologies. A sketch of a possible 300 GeV machine is shown in figure 2 in which the present CERN machine is also drawn to scale.

In addition to the strongly interacting particle beams, a machine in this energy range would produce high energy neutrino beams for the study of the weak interactions. The neutrino beams would have an intensity 2 or 3 orders of magnitude greater than is available today, so that the radically new field of neutrino physics could at last be fully exploited.

We have to fix the actual energy by further considerations. In the first place the <u>annual</u> cost of any machine in this energy range will be independent of the energy for the first eight years of construction (see Appendix 2 and Figure 4), so that a lower energy machine would merely be finished sooner. However, the higher the energy the more useful and versatile the machine. To this extent the energy becomes a matter of how long we are prepared to wait before the machine becomes operational. On the other hand, we should take into account high energy facilities being planned elsewhere in order to avoid unnecessary duplication. A machine of 60 to 70 GeV is already under construction in the U.S.S.R., while one in the range 150 to 300 GeV is being actively considered in the U.S.A. It is possible that in the interests of rapid completion the U.S.A. may choose to build a 150 GeV machine to be finished in 1970, and that they may simultaneously make provision for a machine in the 600 to 1000 GeV range for completion in 1980. In that case the best European contribution might well be judged by a 300 GeV machine. Be that as it may, it is clear that the actual choice of energy, bearing in mind a proper phasing of accelerator construction over the world as a whole and the degree to which international co-operation in research can be made effective, is a matter that would have to be left to the European body as a whole.

There remains, however, the second physical requirement which is to increase the primary energy to the greatest possible extent. This requirement may be met by a device which would at the same time greatly improve the general facilities and flexibility of the existing CERN machine for operation at 25 GeV. For the proton beam of the 25 GeV synchrotron could be injected over many pulses into a pair of concentric, intersecting storage rings, and the two beams so formed could be made to collide with each other with an energy of relative motion of 50 GeV. Due to relativistic effects this energy is the same in the centre of mass system as that obtained by allowing 1400 GeV protons to strike a stationary target. The addition of storage rings adjacent to the CERN machine (figure 3) would not be equivalent to the building of a 1400 GeV accelerator because it would provide so few events of 50 GeV energy in the centre of mass: the range of experiments made possible by the clashing beam technique is very restricted due to the absence of secondary beams. Nevertheless, this device would provide a window into the very high energy region unattainable by any other means within the immediate future and at a very low relative cost. This proposal, too, is under active consideration by the panel of European physicists.

It must be emphasized that the two proposals - the building of a new accelerator and the provision of storage rings for the CERN machine - are not alternatives, but two complementary aspects of the same programme of high energy physics, each in itself desirable. It would make no sense to proceed with storage rings as a cheap alternative to building the new accelerator owing to the limited range of experiments which can be done with storage rings.

FINANCE AND MANPOWER

We shall assume that the proposed facilities are to be provided within the CERN, or some similar, European framework in which the financial commitment of the UK will continue to amount to about one quarter. Expenditure on European projects is worthwhile, however, only if it forms part of a properly integrated national programme of high energy physics research. This is already apparent at CERN where those countries with adequate home-based high energy facilities are the ones which derive the greatest benefit. The big international facilities act not as a drain upon the home-based research groups but as a stimulus to them, the best use being made of both when regular exchanges of staff take place.

In trying to formulate an overall nuclear physics programme we have to bear in mind not only the new proposals of accelerator and storage rings, but also the support and normal development of existing facilities at CERN and NIRNS, the support for home-based high energy physics programmes financed through DSIR and NIRNS, and the support of a fairly massive programme of nuclear structure research. As the ACSP itself has emphasized, the UK will derive maximum benefit from international projects only if our contribution to these projects is considered as the apex of a large home-based programme of integrated high energy studies. It takes many years, in general, before a young physicist is fit to make use of very large and costly machines of the kind we are discussing. Merely in order that these facilities should be properly used we therefore have to insist that the first consideration must be the support of university departments and of the national facilities of NIRNS and D.S.I.R.

During most of the next decade at least, the existing generation of accelerators readily available to UK physicists (NIMROD, NINA and the CERN machine) will continue to provide vital and fundamental information provided that they are properly supported and developed. It would be very wasteful - and, in the case of CERN, damaging to European goodwill - if we were not to continue to gain maximum benefit from these machines.

The fact remains that if we are to envisage the continuation of a vigorous high energy programme beyond the early 1970's, work must begin within the next year or two upon the new European accelerator since it will take at least 7 years to build.

We have tried to estimate the likely numbers of UK research workers wishing to work in the high energy field by that time. Our detailed arguments are given in Appendix 1. We may summarize the situation here by saying that the facilities already provided or under construction (including those of CERN) should be sufficient to absorb all our high energy physicists by

1967. However if we examine the present size of the physics community and project into the future on the conservative assumption that the fraction of research workers wishing to work in high energy physics remains no more than it is now, we must conclude that by 1972 there is likely to be a substantial surplus of at least 100 high energy physicists who will have to be accommodated elsewhere. On present estimates this would be considerably more than the UK quarter-share of the proposed European programme. It therefore seems quite sure that there will be no lack of scientific manpower: on the contrary, there would even be a sizeable balance for a possible new national project from 1972 onwards. Nor is the provision of an adequate number of professional engineers and technicians considered to be a serious problem although we are concerned at the shortage of really outstanding engineers required for design and development work on accelerator projects of this kind.

It is hardly possible at the present time to give firm estimates of expenditure on the proposed high energy physics programme. For reasons we have already given, the long term scale of expenditure is a matter subject to considerable variation and dependent upon the results of diplomatic as well as scientific negotiation with other nations, not only those of Europe. Nevertheless in Appendix 2 we have tried to give as detailed a financial picture as we can of the maximum likely UK expenditure on high energy physics and on the rest of nuclear physics, and our estimates are based upon our experience of the total expenditure of CERN and other large research organisations.

The Appendix shows the relative annual amounts which we consider necessary (a) to provide the new accelerator, (b) to make full use of the existing CERN machine, including the provision of storage rings, (c) to support and develop home based high energy facilities financed through NIRNS and DSIR, and (d) to continue an active programme of nuclear structure physics. This last is included only because it is customary in the UK to consider high energy physics and nuclear structure physics together for financial purposes: we do not consider it our task, nor were we properly constituted, to attempt to evaluate the needs of the nuclear structure programme, and indeed this is being done independently by a specially appointed DSIR panel under the chairmanship of Dr. J. B. Adams. In any case nuclear structure research is likely to form a rather small fraction of the total nuclear physics budget by the end of the present decade.

The total presented in Appendix 2 amounts to a doubling in annual UK expenditure on nuclear physics over a period of about 5 years, reaching about £20 million per annum in 1968, and probably continuing at a somewhat lower rate of rise thereafter as far as this presently envisaged programme is concerned. By far the largest item would, of course, be the new accelerator: it would require a total establishment of about 4,000 persons.

SITING OF THE NEW ACCELERATOR

The proposed new accelerator is so large that the problem of finding a suitable site for it will have to be taken largely on geological grounds. The foundations must be stable over long periods of time to about a millimetre over the 1 to 2½ kilometre diameter of the machine. Experience at CERN has shown that we shall be able to make adequate use of a new large scale facility wherever it may be built (within reason) in Western Europe. However, it seems that there are two or three possible sites in the United Kingdom which would meet our stringent geological requirements (for example, in Lincolnshire) and the question naturally arises as to whether the accelerator could be built in this country.

Of the various international projects being undertaken in Europe at the present time only the Dragon reactor is on British soil. To site the new project in this country would be an immensely encouraging step forward from our point of view, and there can be no doubt that we should derive benefit in excess of our allotted share merely by its being so readily accessible to us and by having a large international scientific community in our midst. We consider that these advantages would be such that they would obviate the need for further national requirements in high energy physics for some considerable time. Quite apart from the purely scientific aspects, however, a project of this magnitude, calling for the most exacting standards of design and construction, would provide a considerable stimulus to British industry. As a matter of fact, the consumer spending of some 4,000 staff, many of them foreign, would alone amount to about a third of the total expenditure on the subject.

We therefore consider that if it is technically feasible, a site in the United Kingdom should be offered for European consideration at the earliest opportunity.

SUMMARY AND CONCLUSIONS

Physics is today on the threshold of far-reacting developments which will come to fruition with a new theory of the nature of matter and of its fundamental interactions. Either at this stage or the one beyond, gravitation, matter creation, and the problems of cosmology are likely to be unified with high energy physics. Quite apart from the intellectual challenge of taking part in this great synthesis of physical thought, the new picture we shall have of the nature of matter is sure to produce resounding effects upon the whole of physical science. With complete justice we may point to the developments of the 1920's and early 1930's which saw the birth of the new quantum mechanics and the incorporation within its framework of the theory of relativity. The concepts which were then introduced seemed strange and esoteric and of no practical importance: they have now pervaded the whole of science. It may well be that the discoveries of high energy physics will never in themselves be of practical significance; but the grandchildren of these discoveries, if not the children, will one day form the new foundation of everything that we do.

It seems inconceivable that a country whose scientists from Newton onwards have been in the forefront of physical discovery should not continue to take part in this most exciting of intellectual activities. So far we have been well supported. At the present time we have, or shall shortly have, national facilities for high energy physics which are bettered only by those of the U.S.A., while our share in CERN gives us opportunities which are second to none. Already the effects of CERN and NIRNS are being felt: physicists are beginning to return from the U.S.A. to make use of what has been provided at home, many of them of the highest ability. But we shall be ready for the next big step in the early 1970's and the other European nations are determined to go forward. The international development of science would be struck a most serious blow if we were not to remain with them, and in this country we should undoubtedly face a new wave of emigration.

It is sometimes feared that high energy physics, developing at the present rate, might absorb too large a fraction of the country's scientific and technological skill. However we have shown that more than enough research physicists will wish to make use of the proposed facilities if the present ratio is merely maintained. Moreover, a large fraction of research workers in this subject leave it after a few years. They have received a training on the use of large scale equipment of the most exacting nature. It would be difficult to find a better training ground for people who wish to acquaint themselves with the most advanced techniques of vacuum engineering, high power electronics, and automatic data processing. It is simply not true that high energy physics makes no contribution towards the training of useful physicists and engineers.

It is also sometimes stated that high energy physics bleeds off too large a fraction of the highest quality research workers who would otherwise devote themselves to less expensive and more immediately rewarding research. It may indeed be true that the pace of high energy research is too great. Although the pace is mainly set by the intrinsic interest of the subject, it may well be possible to moderate it somewhat by increased international co-operation in research of which these proposals form an important part. But if adequate facilities are not provided at least on the European scale, the inevitable result will be that our high energy physicists will seek appointments in the U.S.A. where adequate facilities will certainly exist. We do not believe that a greater proportion of these physicists would be content to work in other fields: they would merely work in other countries. It should surely be the aim of United Kingdom Government policy to avoid this situation by playing a full part in future European collaboration in science.

We must also consider the educational effect of a decision not to participate further in this most fundamental and challenging field of research. It is one of the most important functions of an advanced research worker in any academic discipline to educate 50 to 100 undergraduates in following generations, only a small minority of whom, of course, will take up specialised research. The removal from the university scene of research workers who have dedicated themselves to high energy physics would thus be a most serious blow to the morale and intellectual spirit of the whole scientific community of the country.

We therefore recommend that the United Kingdom should continue to play a full part in European collaboration in high energy physics, and that it should be prepared to agree to a substantial enlargement of the existing programme in order to achieve significantly higher energies along the general lines discussed in this report. In particular we endorse the specific proposals of a panel of European physicists which call for the construction of a new proton accelerator whose energy is yet to be determined within the range 150 to 300 GeV, and the provision of storage rings for the existing CERN machine at Geneva. Finally we wish again to stress the advantages of placing the new accelerator on a site in the United Kingdom.

Members of the Joint Panel who attended
meetings of the Working Party were:

Professor B. H. Flowers, F.R.S. (Chairman)
Dr. J. B. Adams, F.R.S.
Professor C. C. Butler, F.R.S.
Professor J. M. Cassels, F.R.S.
Sir Harrie Massey, F.R.S.
Professor P. T. Matthews, F.R.S.
Professor A. W. Merrison
Dr. T. G. Pickavance
Professor C. F. Powell, F.R.S.
Mr. J. Hubbard
Dr. J. A. V. Willis (Joint Secretaries)

Appendix 1

MANPOWER FOR NUCLEAR AND HIGH ENERGY PHYSICS

It is necessary for clarity to distinguish between low energy and high energy nuclear physics, although the two fields are considered together for financial and planning purposes in this country. The proposed big expansion is in high energy physics. The dividing line, in terms of accelerator energy, is usually taken to be the threshold for production of pions - about 200 MeV. The whole CERN programme and the proposed new international programme are in the high energy field. N.I.R.N.S. are active in both fields (the smaller accelerator at the Rutherford Laboratory is a low energy machine), and D.S.I.R. finance work in both fields on recommendations by their Nuclear Physics Sub-Committee.

The number of post-Ph.D. experimental physicists in Britain, using high energy machines, is at present about 120. A number of others make little use of machines, but study cosmic radiation. The following 6 machines are involved:

CERN	25 GeV	protons
CERN	600 MeV	protons
NIMROD	7-8 GeV	protons (experiments in active preparation)
Birmingham	1 GeV	protons
Liverpool	400 MeV	protons
Glasgow	450 MeV	electrons

The number working in fundamental research with low energy machines is roughly 90; there are 5 university machines (two more under construction), one at N.I.R.N.S. and one at A.E.R.E.

A study of the output of Ph.D.'s in experimental physics over the last 5 or 6 years reveals the following:

1. A third of the theses have been written on high and low energy nuclear physics and cosmic rays.
2. About 30 per cent of the physicists have stayed in the subject of their theses in British universities or at N.I.R.N.S. or CERN.
3. The number of students accepted for postgraduate research has kept pace with the increase in undergraduate numbers and, judging by the classes of degrees obtained by applicants to D.S.I.R. for grants, the quality has been well maintained.

The future output of Ph.D.'s can, therefore, be fairly confidently predicted from the planned growth of student numbers. Allowing for wastage and for transfers (which are already taking place) from low energy and cosmic ray physics to high energy machines, there would be a total of 180 Ph.D. experimentalists in high energy physics by 1967/8, and about 300 by 1972/3.

This growth is calculated on the assumption that a third of physics research students will wish to work in nuclear research as in the past and that substantially over a half of them will take up other work after obtaining their Ph.D.'s

The existing programme, to which the 4 GeV N.I.R.N.S. machine Nina will be added, will be able to absorb most of the 180 by 1967/8 and, with proper exploitation of the machines, will be able to train the newcomers among them. But there would be a surplus of at least 120 by 1972/3 if no new facilities had been built by then. The 120 would, on present estimates, be considerably more than the U.K. share of the new European programme and would leave an adequate balance for the projects envisaged in the N.I.R.N.S. long range forecasts.

A similar survey of the low energy field shows that there would, on the same assumptions, be more than enough Ph.D. research workers to exploit the existing and planned machines and the major nuclear structure machine proposed in the N.I.R.N.S. forecasts. By 1972/3 a number of the older machines will have been scrapped; at least two of the high energy machines and three of the low energy machines.

It seems certain, then, that the proposed programme can be manned with experimental physicists without diverting students from other fields, and with more than half the output of Ph.D. physicists exported to other activities as at present. By comparison, it has been estimated in the U.S.A. that if the whole of the American programme now under discussion goes ahead 3,000 Ph.D. research workers will be involved. No difficulty is anticipated in training this number.

There remains the important question of supporting staff. High energy physics needs a higher proportion of support to research staff than any other field of fundamental study at the present time. The needs of low energy research in this connection are much less and can be ignored by comparison. The present high energy programme engages about as many honours graduate applied physicists and professional engineers as nuclear physicists, and considerably more technicians. Experience in this country and abroad has shown that there is little difficulty in recruiting the applied physicists, who work on accelerator design and development, the development of research apparatus, and on data reduction. They come from the same source as the nuclear physicists, but most of them are trained "on the job", having been recruited with bachelor's degrees. They are not, therefore, a heavy load on post-graduate University teaching and their numbers are not great in relation to the output of first graduates. The number of these physicists required from the U.K. by the proposed national and international programme would be not more than 150, in addition to those now engaged, by 1972.

Similarly, there would be no difficulty in obtaining the roughly equal numbers of professional engineers required. But here there is a difficulty of quality. Both in the U.S.A. and in this country it has proved to be very difficult to obtain enough really outstanding engineers for design and development work on accelerator projects. This is the most serious manpower problem, and appears to be connected with a deficiency in the basic training of engineers which is of broader national significance than the high energy research programme.

The technical staff are recruited at lower academic levels ranging from pass degrees down to G.C.E. at "A" level, H.N.C., or O.N.C. No difficulty has been experienced in obtaining suitable staff in the present U.K. programme.

The table shows the estimated staff build-up required for the proposed CERN storage rings and for the 300 GeV accelerator on the most rapid programme (completion by 1972). It may be assumed that about a quarter of the staff would be graduate scientists and professional engineers, and that the U.K. might be expected to contribute about a quarter of these key people.

Estimated staff build-up for proposed European Programme

(all grades of staff)

	1964	1965	1966	1967	1968	1969	1970	1971	1972
Storage rings for C.P.S.	25	90	170	250	360	456	not estimated		
New 300 GeV accelerator	35	150	330	505	790	1075	1390	1615	1860

FINANCE

A strong CERN working party set up in 1962 has provided estimates of the cost of both a 150 GeV machine and a 300 GeV machine. The former could be completed in 6 years; the latter would take about 2 years longer. The CERN working party's estimates have been used in this appendix.

Figure 4 shows the annual total estimated cost of both the 150 GeV machine and the 300 GeV machine. The U.K. contribution would, on the basis of the formula at present applied to CERN, amount to 24% of the total. It is estimated that in the first 8 years from the start of construction (1964) there would be no significant difference in cost between the two machines.

Figure 5 shows the estimated annual expenditure on the total nuclear research programme, if the proposal for the 300 GeV machine were adopted.

The details shown are:

(a) U.K. contribution to the cost of the new European machine.

(b) U.K. contribution to the existing CERN laboratory on the assumption that storage rings will be added to the 25 GeV proton synchrotron.

(c) the cost of the national high energy physics programme financed directly from government funds (NIRNS and DSIR);

(d) the cost of the national programme for nuclear structure research (NIRNS and DSIR);

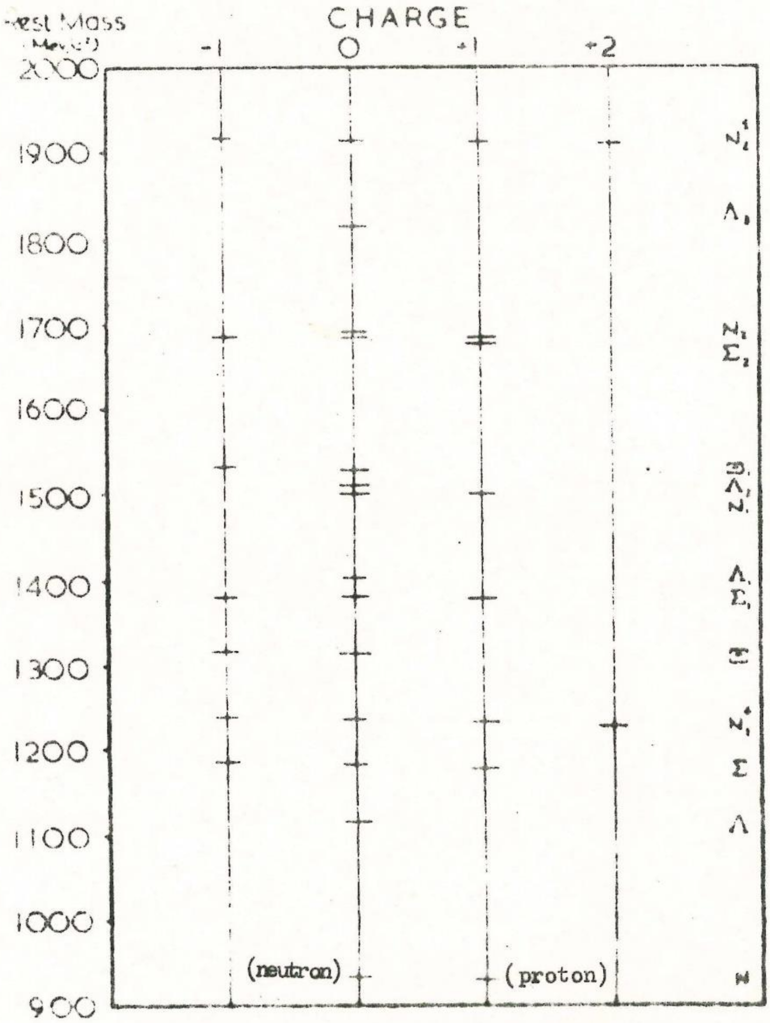
(e) the total cost of all these programmes.

Figure 6 shows in tabular form the cost estimates represented graphically in figures 4 and 5 and the sources of the estimates.

No clear prediction is available for a national high energy research programme going beyond 1967. It has been assumed for the purpose of this appendix that this expenditure will continue to increase at about the same rate for the period 1967-72 as in the prediction for the period immediately before 1967. But if the new European machine were not built, a more rapidly increasing national programme might be required in order to keep the subject in a healthy state.

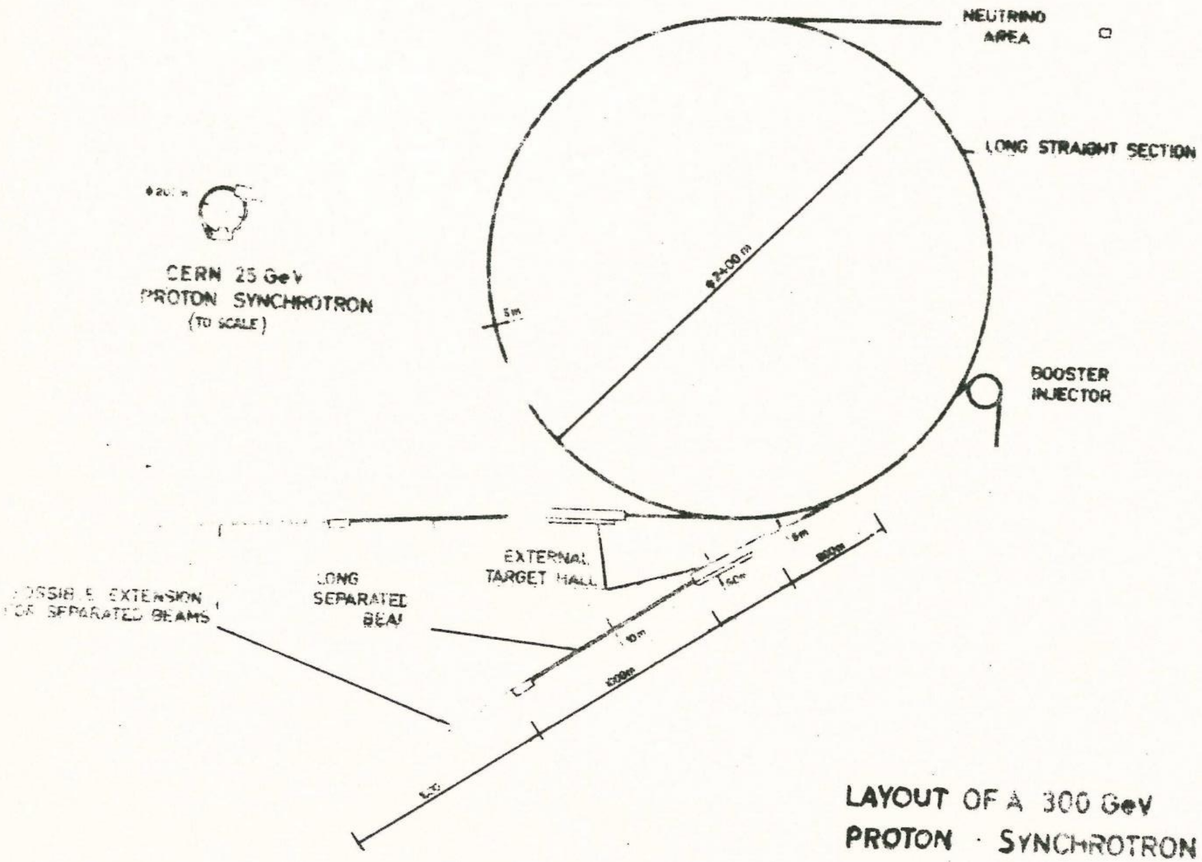
The adoption of the proposal for the new European machine would involve a conscious decision that the U.K. expenditure on international programmes, which is at present about one third of the total U.K. expenditure on high energy physics, would rise to about half of the total in 5 years.

Figure 1



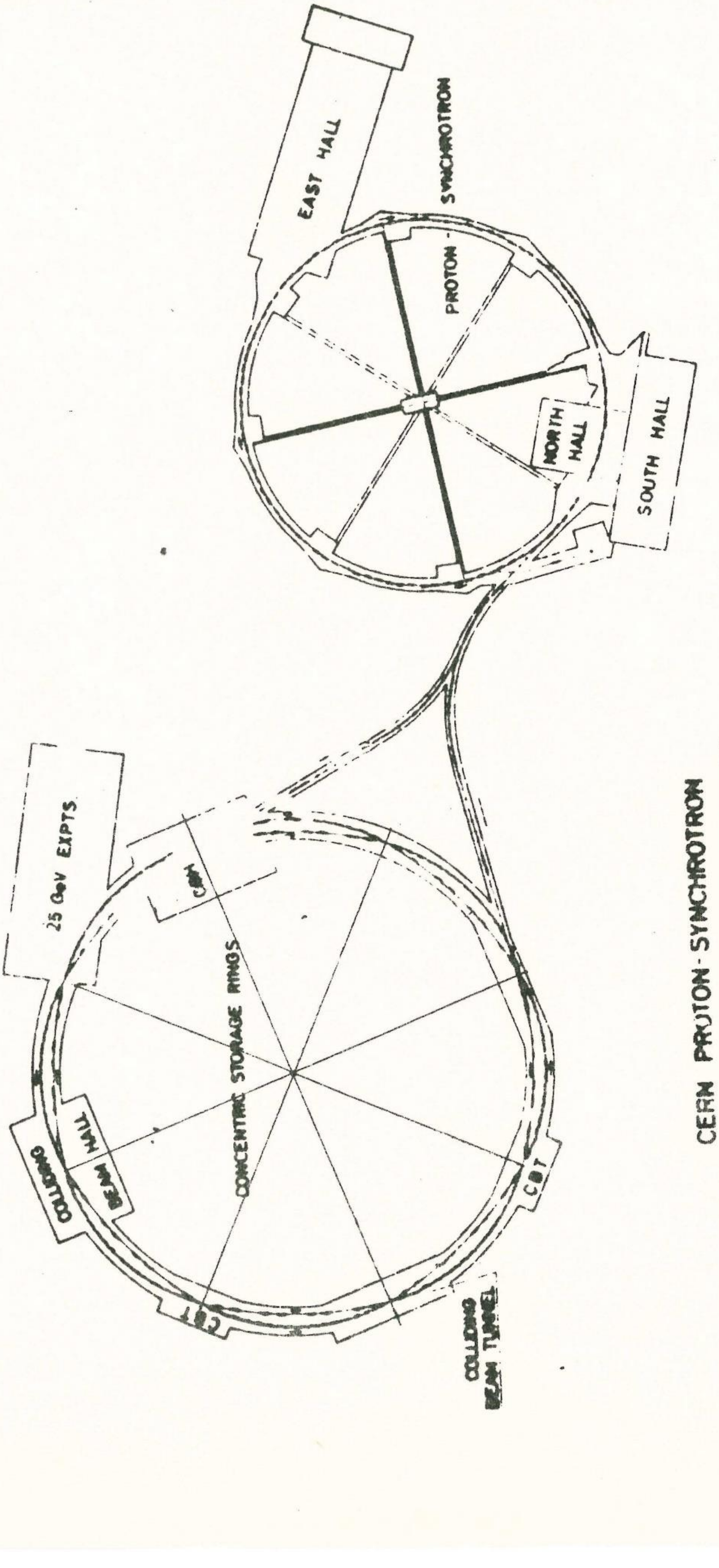
The known hyperon states, indicating their mass and charge (November. 1962). It should be stressed that this diagram may rapidly become out of date.

Figure 2



LAYOUT OF A 300 GeV
PROTON · SYNCHROTRON

Figure 3



CERN PROTON-SYNCHROTRON
WITH CONCENTRIC STORAGE RINGS

Figure 4

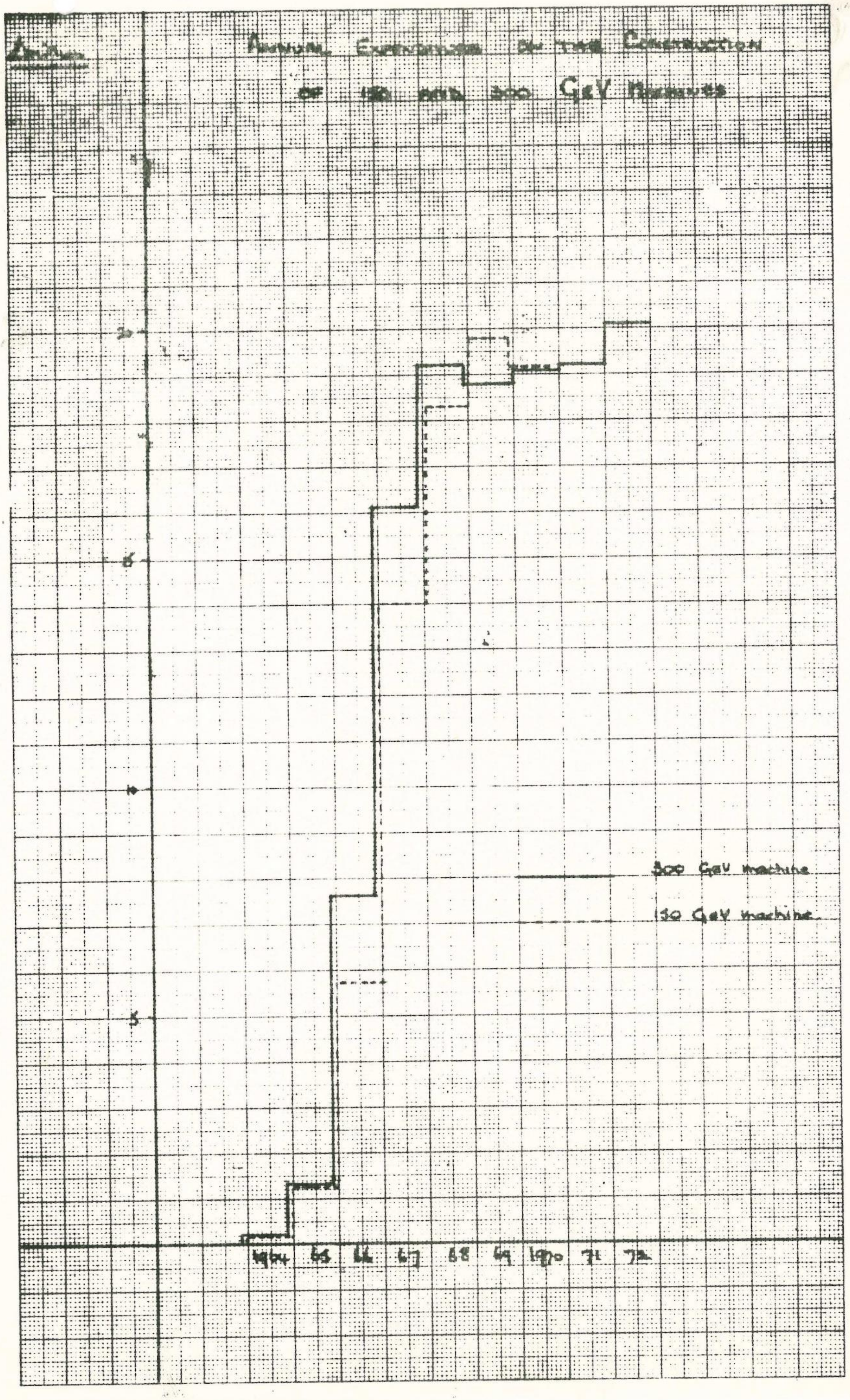

Annual Expenditure on the Construction
of 150 and 300 GeV Machines
20
15
10
5
1964
65
66
67
68
69
1970
71
72
300 GeV machine
150 GeV machine

Figure 5

ANNUAL EXPENDITURE OF THE TOTAL NUCLEAR RESEARCH PROGRAMME

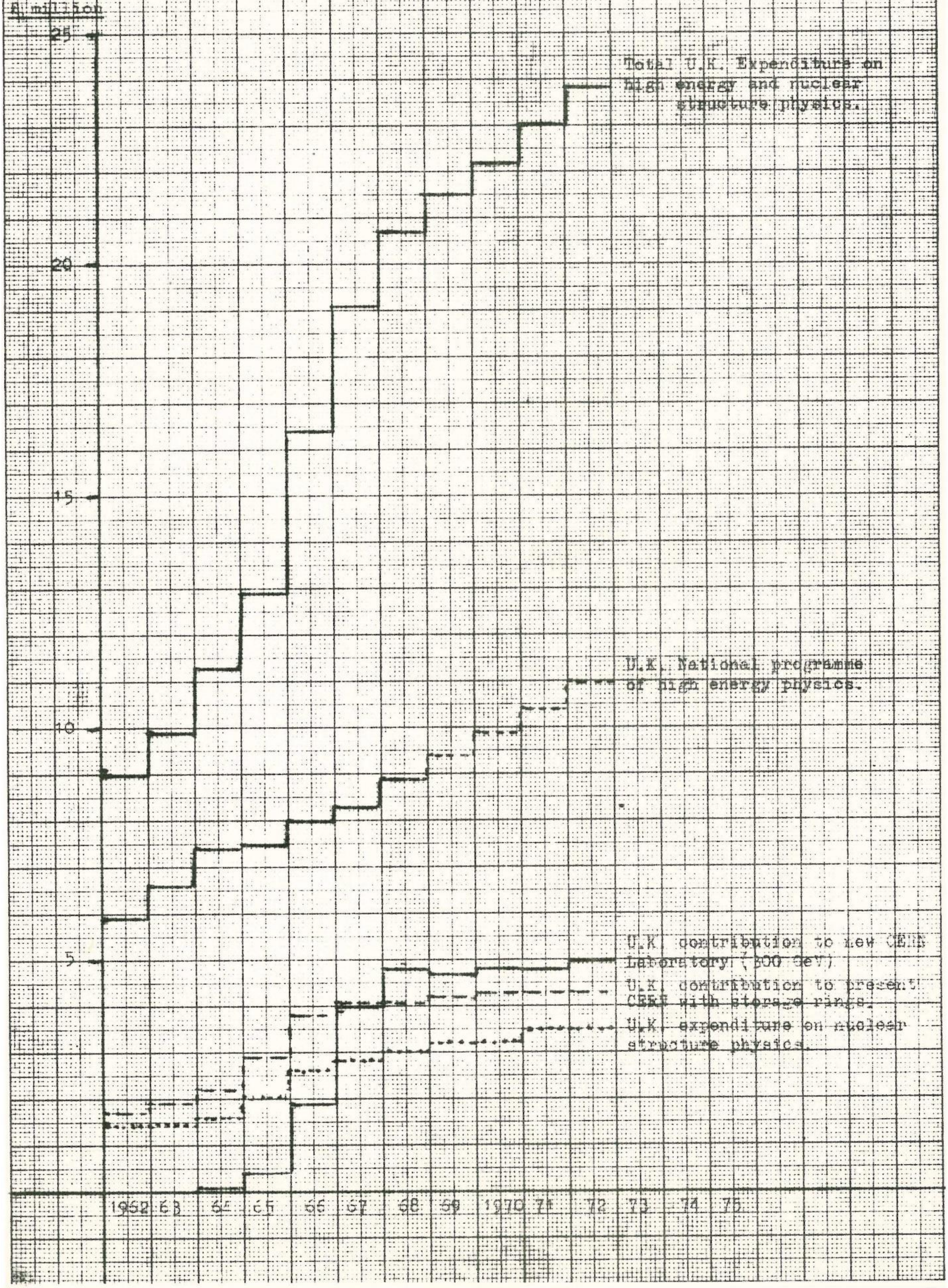


Table of Estimated Costs represented in Figures 4 and 5 **Figure 6**

(£million)

Calendar year or financial year ~~ending~~ beginning in:	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
1. New CERN											
(a) Full estimated cost 150 GeV machine (1)			0.2	1.3	5.7	14.0	18.3	19.8	19.1		
(b) " " " 300 GeV machine (1)			0.2	1.3	7.6	16.1	19.2	18.8	19.1	19.2	20.1
(c) U.K. contribution 300 GeV machine (2)			0.1	0.4	1.9	4.0	4.8	4.7	4.8	4.8	5.0
2. Existing CERN plus storage rings											
(a) Full cost (3)	6.7	7.6	8.8	11.7	15.2	15.8	16.2	16.8	17.0	17.0	17.0
(b) U.K. contribution (2)	1.7	1.9	2.2	2.9	3.8	4.0	4.0	4.2	4.3	4.3	4.3
3. U.K. expenditure on nuclear structure physics											
(a) D.S.I.R. (4)	0.5	0.4	0.6	0.6	0.7	0.8					
(b) N.I.R.N.S. (5)	1.0	1.0	1.0	1.5	2.0	2.0					
Total	1.5	1.4	1.6	2.1	2.7	2.8	(3.0)	(3.0)	(3.5)	(3.5)	(3.5)
4. U.K. expenditure on high energy physics											
(a) D.S.I.R. (4)	0.6	0.4	0.6	0.7	0.8	0.9	(1.0)				
(b) N.I.R.N.S. (6)	5.3	6.2	6.8	6.8	7.2	7.4	7.9				
Total (6)	5.9	6.6	7.4	7.5	8.0	8.3	8.9	(9.4)	(9.9)	(10.4)	(11.0)
5. Total U.K. expenditure on high energy and nuclear structure physics											
(a) U.K. contribution to new CERN			0.1	0.4	1.9	4.0	4.8	4.7	4.8	4.8	5.0
(b) U.K. contribution to existing CERN	1.7	1.9	2.2	2.9	3.8	4.0	4.0	4.2	4.3	4.3	4.3
(c) U.K. expenditure on nuclear structure physics	1.5	1.4	1.6	2.1	2.7	2.8	(3.0)	(3.2)	(3.2)	(3.5)	(3.5)
(d) U.K. expenditure on high energy physics	5.9	6.6	7.4	7.5	8.0	8.3	8.9	(9.4)	(9.9)	(10.4)	(11.0)
Total	9.1	9.9	11.3	12.9	16.4	19.1	20.7	21.5	22.2	23.0	23.8

FOOTNOTES

(1) Based on CERN working party estimates (CERN papers AR/Int.63-4 and 5).
(2) It is assumed that the present rate of contribution to present CERN (24%) will apply.
(3) Based on information provided by Dr. Adams and including estimates for the addition of storage rings contained in CERN paper AR/Int.SG/63-11
(4) Rough estimate. It is assumed that rather less than half total DSIR expenditure on nuclear physics is for nuclear structure physics. Total figures were taken from "Cockcroft Committee" report, April, 1962.
(5) NIRNS expenditure on Proton Linear Accelerator and proposed new facilities.
(6) Based on draft 5-year expenditure forecast 1964-65 to 1968-69.

NOTE: In compiling these figures no account has been taken of expenditure from university funds on nuclear physics research. This may be of the same order as that of DSIR shown in 3(a) and 4(a) above.