21st November, 1960. NI/PC/60/5

NATIONAL INSTITUTE FOR RESEARCH IN NUCLEAR SCIENCE

PHYSICS COMMITTEE

ELECTRON ACCELERATOR IN GeV ENERGY RANGE

Report of the Working Party

ABSTRACT

We have examined the fields of physics open to an electron accelerator with an energy of a few GeV, and the types of accelerator which are available for this work. We unanimously agree that there is a very strong case for the immediate construction of a 4 GeV electron synchrotron with a mean intensity of 5 µA.

This machine would make available for experiment the important fields of electron-nucleon scattering and the photo- and electro-production of strange particles in the threshold and resonance region. This is a wide and important field which can, and should, be studied in the U.K. in parallel with the efforts being made in the U.S.A., Germany and the USSR.

We have given a great deal of attention to the possibilities of other types of accelerator aimed at the same objective, but have concluded that the synchrotron we propose is the simplest, cheapest, and most effective machine.

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Electron Accelerator in GeV Energy Range

I. Introduction

The Working Party was set up at the meeting of the National Institute Physics Committee on 9th May, 1960 with terms of reference as follows:-

(1) to review the fields of experiment accessible to an electron accelerator with peak energy limited to 4 GeV, making some assessment of the interest and importance of the various fields.

(2) to obtain a clear definition of the performance and beam qualities that might be expected if the proposed electron accelerator were either (a) a linear accelerator or (b) a synchrotron.

(3) to make an assessment of the relative efficiency with which the two accelerators would permit experiment in the relevant fields of experiment. In making this assessment it is inevitable that some regard should be paid to the cost and complexity of the project set by each accelerator, not to mention the time of construction before the accelerator can be expected to come into operation.

The membership of the Working Party was as follows:

D. M. Binnie,	P. T. Matthews,
A. B. Clegg,	A. W. Merrison,
J. C. Gunn (Convener),	J. G. Rutherglen.

At our last two meetings we were assisted by J. M. Cassels, who had been asked to collaborate in our considerations, and by T. G. Pickavance, L. B. Mullett and W. Walkinshaw.

During the progress of our enquiries, detailed reports on various matters of importance have been presented to us either by members of the Working Party or by other interested parties. A copy of each of these reports has been deposited with the Secretary. For reference a list is given in Appendix 1.

II. Interesting Fields of Experiment

It is proposed that the electron accelerator under consideration should have a peak energy below 4 GeV. Qualitatively then we shall have available photon, electron (and possibly positron) beams of energy up to 4 GeV. This choice of energy was largely influenced by considerations of the overall scale and cost of the project. It does however have some real physical significance as marking a division between two fields of experiment. In Tables I and II are present respectively the centre of mass energies*

Table I. Available energy (in excess of proton mass) in C.M. system

Photon Energy Lab. System (MeV)	500	1000	1500	2000	3000	4000
Centre of mass available energy (MeV)	410	722	984	1214	1614	1957

* continued overleaf

Table II. Photoproduction threshold energies (lab. system)

$\gamma + p \rightarrow$	$\pi^+ + p$ $\pi^+ + n$	$\Lambda + K^+$	$\Sigma^0 + K^+$ $\Sigma^+ + K^0$	$p + K^+ + K^-$ $p + K^0 + \bar{K}^0$	$\Sigma^- + K^+ + K^+$ $\Sigma^0 + K^+ + K^0$	$p + p + \bar{p}$ $p + n + \bar{n}$
Photon Energy (GeV)	0.15	0.91	1.04	1.51	2.37	3.75

available for particle creation in the interaction of a photon with a proton as a function of the laboratory photon (or electron) energy and the threshold laboratory photon energies for various processes of interest. We see that the highest elementary threshold in the field of photon-kaon-hyperon physics is at 2.37 GeV with the production of the hyperon. By comparison the nucleon pair production threshold is at 3.75 GeV. The proposed limit of 4 GeV therefore means that we are concerned with an accelerator which can cover the whole range of photo-kaon physics, allowing adequate energy above threshold to investigate the kaon-hyperon interaction and any consequent resonances of the type found in photo-pion experiments. However no effort is made to compete in the field of nucleon or hyperon pair production.

We now comment briefly on the available fields of experiment.

(1) Elastic Scattering of Electrons

The reactions of greatest interest are the elastic scattering of electrons at protons and at deuterium. The latter reaction enables an estimate to be made of electron-neutron scattering. Up to an energy certainly in excess of 1 GeV electron-proton and electron-neutron scattering can be interpreted in terms of four form factors, $F(q^2)$, where q^2 denotes the square of the 4-momentum transfer in the scattering. These form factors describe the internal structure of the nucleons and theoretical techniques are now being established which enable significant estimates to be made for them. The present experimental evidence, in particular as it has been derived for electron-neutron scattering, is not sufficiently precise. Moreover there is a need to extend the experiments to higher energies. Eventually, possibly at an electron energy around 2 GeV, the interpretation of elastic scattering in terms of four form-factors will become inadequate. Above this energy the phenomenon will certainly be more difficult of interpretation. Up to this energy, however, there is a very important and fundamental field in which further experiment is required.

(2) Photoproduction of K-mesons

The simplest reactions here are the two body reactions leading to the production of K^+ mesons

$$\gamma + p \rightarrow K^+ + \Lambda^0$$
$$K^+ + \Sigma^0$$

Study of these reactions has already started on the synchrotrons at Cal. Tech. and Cornell. So far it has only been possible to study the reactions fairly near to threshold with errors that cannot be estimated as better than $\pm$ 10%. In analogy with the photopion case it will clearly be important both to make the lower energy measurements more precise, and to extend them to higher energies (say to allow up to 1 GeV interaction energy between the photo-produced hyperon and kaon). It will be remembered that the resonances in the pion-nucleon system, of which 4 have so far been established, were discovered through work on photo-meson production.

The general significance of photo-production reactions for K-meson physics is obvious by analogy with the pion case. We should mention here at least two respects in which photo-production experiments go beyond what can be learned by compounding information on known electromagnetic interactions with that on meson scattering

(i) the direct photo-production diagram.

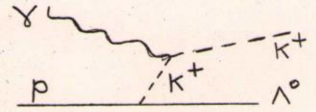


Fig. 1 illustrates the 'retardation' diagram which gives rise to a 'pole' term, proportional to $(1-v\cos\theta)^{-1}$ in the photoproduction amplitude (v = outgoing K-meson velocity). The residue at the pole is proportional to the K-meson coupling constant and its sign determines the K-meson parity. There are other terms present in the photo-production amplitude which make it hard to disentangle this pole-term, so that quite refined experiments, not at present available, are required before this method of extrapolation to the pole can be usefully employed.

(ii) a knowledge of the hyperon magnetic moments is involved in the magnetic dipole photo-production amplitude. This may well be one of the most effective methods of obtaining information on those moments.

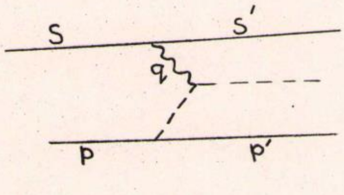
There are many photo-production reactions beyond the two considered above. Still of fundamental interest are reactions such as

$$\gamma + p \longrightarrow K^o + \Sigma^+ .$$

At higher energies, however, the situation is likely to become confused by reactions in which a single K is accompanied by one or more pions. These complex reactions are possibly not of great interest in themselves. It will be important however that they can be eliminated in the study of the basic two-body interactions. This sets a considerable experimental problem, accentuated by the bremsstrahlung character of the available photon beams, which is not likely to be quickly solved.

(3) Inelastic Electron Scattering - Electro-Production of Mesons

Processes of outstanding interest are the electro-production at a nucleon of either π- or K-mesons. Rough experiments of this type are not likely to supply results of significance, as the bulk of electro-production will be described in terms of the effective Weizsacker-Williams photon spectrum. Moreover there are certain important effects, which require for their study experiments of an order of magnitude more precise than have yet been performed. Typically we refer to the study of the electro-magnetic form factor of the pion (similar considerations clearly apply with K-mesons).



The process concerned is illustrated by the diagram Fig. 2. The electron initial and final states s,s' radiates a virtual photon q. We are interested in final electron states, say, such that $q^2 > \mu^2$. For the diagram shown the meson-production amplitude is proportional to the electro-magnetic form factor of the pion $F_\pi(q^2)$. This amplitude has, like that considered in the previous section a 'pole' term $1/(\Delta^2 + \mu^2)$, $\Delta = p'-p, \mu$ = meson mass. The pole at $\Delta^2 = -\mu^2$ lies outside the physical region, but extrapolation to it should be possible, if for given q^2 the experiment can be carried out for a suitable range of values of Δ^2.

It must be stressed that, notwithstanding their potential interest, these electro-production experiments are of great difficulty. They have been of obvious importance in our consideration of the potentialities of the proposed accelerators.

(4) Photo-Production of Meson and Hyperon Beams

It is generally believed that an electron accelerator is unlikely to be very efficient as compared with a proton accelerator in the production of secondary meson or hyperon beams. Photo-production cross-sections are probably reduced as compared with corresponding nucleon-nucleon cross-sections by a factor between 100 and 1000. Very intense electron beams may regain this factor (c.f. the linear accelerator specification quoted below). However the question of duty cycle may then become important. Probably a reasonable attitude is neither to ascribe too much importance to the possibility of secondary meson beams in assessing the case for an electron accelerator, not to neglect the possibility that they may in certain cases be a useful extra feature.

Recently, in particular, a suggestion has been made by Drell that high energy photons may even prove superior to protons in the production of meson beams near the peak of the energy spectrum. The process considered by Drell is due to another of the 'pole' terms, characteristic of the various photo-processes.

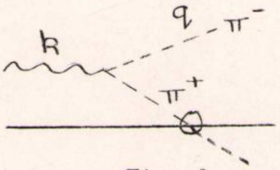


Fig. 3

It is illustrated in Fig. 3. We consider the π^- (or π^+) mesons produced with energy ω not much less than k. These are concentrated in a forward cone of angle $\theta \sim K/\omega$ and the differential cross-section within this cone is approximately

$$\frac{d^2\sigma}{d.\Omega d\omega} = \frac{e^2}{8\pi^2 \hbar c} \frac{\omega^3(k-\omega)}{\mu^2 k^3} \sigma_+ (k-\omega)$$

where $\sigma_+ (k-\omega)$ is the total interaction cross-section at the target of π^+ mesons of energy $(k-\omega)$.

For example for the production of 3 GeV π^- with incident 4 GeV photons we find a cross-section of 0.4 mb/sterad/GeV. The resulting predicted meson beam with 5% momentum resolution and solid angle 10^{-3} sterad. calculated for a bremsstrahlung beam with $Q = 10^{14}$/sec. and a 15 cm. Be target is around 10^7/sec.

Though at 4 GeV the Drell process may be of some importance for pions, one would certainly have to go to considerably higher energy before it became of importance for K-production. In this case also the simple diagram, Fig. 3., ceases to be of unique significance.

(5) Other Processes

There are a variety of other experiments the importance of which in the programme of a 4 GeV electron accelerator it would be hard to assess. We mention briefly a few examples.

(i) Production of pairs of mesons

The experiment, $\gamma + p \longrightarrow \pi^- + \pi^+ + p$, if carried out in sufficient detail gives information on the π-π interaction.

(ii) Elastic scattering of photons

This is a difficult field of experiment, perhaps not of particular importance at very high energies. A recent aspect of possible interest is its relationship to π^o-decay. Such a relationship can also be shown in the forward photo-production of π^o mesons (Primakoff effect).

(iii) Electrodynamics

The key experiments in electrodynamics (e^-e^-), (e^-e^+) collisions require storage rings. We have not considered them as part of the programme for the National Institute electron accelerator. There are, of course, other subsidiary experiments in electrodynamics e.g. large angle e^-e^+ pair production where the presence of a proton is used to facilitate the large momentum transfers necessary to form a test of electrodynamics.

(iv) Experiments using polarised photons

Coherent photon production from electron bombardment of single crystals has recently been shown to yield partially plane polarized photons of energy up to about 1/3 of the initial electron energy. With the availability of 4 GeV electrons this should enable interesting studies to be made of azimuthal asymmetries associated with the pion-nucleon resonances, and any such effects for the $K\Lambda$ system.

III. Specification of the Proposed Electron Accelerators

Here we quote only a brief summary of the properties that might be expected from the two types of accelerator. For further detail on the synchrotron and linac possibilities we refer to the papers by Mullett and Gunn & Moorhouse.

Synchrotron

Peak Energy:	4 GeV
Intensity:	up to $5 \times 10^{11} e^-$ per pulse (possibly even 10^{12}).
Pulse Rate:	50 pulses/sec
Mean electron intensity:	2.5×10^{13} e^-/sec
Pulse Duration:	1 m.sec. at peak energy; possibly longer at lower energies
Duty Cycle:	5% or better, up to 10%
Bremsstrahlung Beam:	at least 2% conversion efficiency.

The bremsstrahlung beam in the usual approximate form Qdk/k would then have a Q value, say between 5×10^{11} and 10^{12}/sec.

The synshtroton will include straight sections (length ~ 1.7m) to permit electron beam experiments with internal targets. The design of the magnetic lattice will be particularly aimed at easing such experiments.

It has been estimated that the plant cost of such an accelerator will be around £1M, with an approximately equal sum for buildings and equipment. It has also been (very provisionally) estimated that the accelerator might be complete and ready to commence operation 4 years after the decision to proceed with its construction.

Linear Accelerator

Peak Energy:	2 GeV at 200 ma. pulse current or 4 GeV at 10 ma. pulse current
Pulse Duration:	3μ sec.
Pulse Rate:	500 pulses/sec.
Duty Cycle:	1.25×10^{-3}

Mean Electron Intensity: $1.5 \times 10^{15} e^-$/sec. for 200 ma. pulse current
Primary Beam Energy Spread: approximately 3%

Various secondary beams would also be available with the linac.

Resolved electron beam: e.g. $10^{14} e^-$/sec. at 1 GeV $\pm$ 1.5 MeV.
Resolved bremsstrahlung beam $Q = 2 \times 10^{12}$/sec.
Unresolved e^+ beam: about $10^{12} e^+$/sec.
Annihilation photon beam: 10^8 photons/sec. in 10 MeV band.

The positron beam would best be achieved by the acceleration of positrons created at relatively low energies c.f. Gunn and Moorhouse. In this way the background problem at the high energy end of the accelerator would be greatly diminished. The pulse current in the positron accelerator stage is then only of the order of 1/10 ma.

Experimental difficulties associated with the relatively short duty cycle of the linac have been much in our minds, and are discussed below. They are sufficiently serious for us to have considered the possibility that a simple single turn injection storage ring should be associated with the linac c.f. Rutherglen. It is estimated that in such a storage ring the mean electron current might be of the order of 1 μa with a duty cycle of 50%.

It will be appreciated that the linac set-up we have been led to contemplate is rather elaborate as compared with the synchrotron, involving as it does not only the linac, but also the complication of positron focussing arrangements and possibly a storage ring. We have not obtained detailed costs for all these items, but it is our opinion that the plant and building costs associated with the complete linac project could not be less than £5M, as compared with £2M for the synchrotron. Also it seems highly probable that the linac project would require for its completion a time appreciably longer than the four years estimated for the synchrotron.

IV. Comparison of the Accelerators

In the previous section together with a brief specification of the accelerators we have already given some very provisional comparison of their cost and complexity. We now turn to an assessment of their probable efficiency in the carrying out of the experiments defined in Section II. First in a general way the main features of the two accelerators may be contrasted.

Electron Beams

(a) Accessibility The electron beam of the synchrotron is internal, and is in this respect at a disadvantage relative to the accessible linear accelerator beam.

(b) Intensity The mean current of the synchrotron beam is expected to lie between 4 and 10 μa. The corresponding mean current of the linear accelerator might be as high as 200 μa at lower energies. However beyond 2 GeV we have not contemplated a mean current much in excess of 10 μa. Moreover for most electron beam experiments the linac beam would have to be resolved, and with a width of 3 MeV at 1 GeV our estimate is for a mean beam of around 15 μa. The only obvious case in which the larger linac intensity might be of immediate use is in the production of secondary meson beams. Otherwise there is little difference between the intensity of electron beams offered by the two accelerators.

(c) Duty Cycle The synchrotron duty cycle of 5% is 40 times longer than that of the linac. Some improvement might be found for both accelerators but the ratio of 40 is not likely to be very far out. This difference in duty cycle becomes important in particular for coincidence experiments, where conditions of background may fix a maximum instantaneous beam intensity, I say, beyond which random coincidences become too numerous in relation to real events. The intensity I, may be less than the instantaneous intensity, I_o say, available with the accelerator. The efficiency of the accelerator for this type of experiment is then given by $I\tau$ instead of by the mean current $I_o\tau$ (here τ denotes duty cycle). In this way the possibility arises that the linear accelerator without storage ring may, for certain experiments, be as much as a factor 40 inferior to the synchrotron. Such a condition is probably rarely, if ever reached, in electron beam experiments of interest. We shall see that it can arise with the bremsstrahlung beam.

In conclusion then for electron beam experiments we must balance the accessibility of the linac beam, able to be resolved and transported, and permitting the use of external targets, in particular of liquid hydrogen or deuterium, against the benefit the synchrotron duty cycle may offer in coincidence experiments.

2. Photon Beams

(a) Intensity and Duty Cycle

The mean intensity of the synchrotron bremsstrahlung beam might be as high as a Q of 10^{12}/sec. which is comparable with the linac resolved bremsstrahlung beam Q = 2 x 10^{12}/sec. In photo-production experiments of the type considered below a Q as high as this could not be tolerated on account of background difficulties. Here the difference in duty cycle comes in, and while the synchrotron intensity need be reduced by a factor of only 20, that for the linac must be reduced by about 1000.

It is for this reason that we believe that a form of storage ring would have to be included in a linear accelerator project, if photoproduction experiments were to be attempted. It has been estimated that, for 10 ma. pulse current in the linac, a mean storage ring current of 0.5 μa could be achieved with a duty cycle of say 50%. A high conversion efficiency to bremsstrahlung could be achieved and the estimated Q is 5 x 10^{11}/sec.

(b) Positron Annihilation Beam

This feature can only be effectively provided with the linac. We have estimated a positron beam of $10^{12}e^+$/sec. with energy spread, say, 30 MeV at 1 GeV. The effectiveness of the photon beam, combining annihilation photons concentrated around 1 GeV with a bremsstrahlung background, produced when the resolved positrons are incident on a liquid H_2 (or LiH) target, is hard to assess. One estimate predicts 10^8 annihilation photons/sec. in a 10 MeV band. On the whole the annihilation beam appears to be too weak, as compared, say with the synchrotron bremsstrahlung radiation in a similar energy band, to be of general value. In special circumstances, however, it offers the possibility of overcoming the duty cycle difficulties of the linac.

V. Comments on particular experimental fields

1. Elastic scattering of electrons

It seems certain that both the synchrotron and the linear accelerator proposed would, together with suitable detection systems, make possible very effective study of electron elastic scattering. The beam intensities are comparable, so that a decision between the accelerators depends on whether more importance attaches to the accessibility of the linac beam or to the better duty cycle of the synchrotron. For electron-proton scattering duty cycle considerations are not important since only the scattered electron need be detected. The linac has then the advantage of external targets, including targets of hydrogen or deuterium. Although we would judge that the linac may thus be superior for such experiments it has been shown at Cornell that very satisfactory scattering measurements can be made with a synchrotron using a difference method with internal C, CH_2 targets.

For electron-neutron scattering (inferred from electron deuterium scattering) duty cycle considerations might become important if it were decided to detect the recoil proton in coincidence. Such coincidence measurements may ultimately be important for the measurement of the neutron form factors, so in this case a marginal advantage may rest with the synchrotron. On the whole however we feel that elastic scattering experiments give no grounds for discrimination between the two accelerators.

2. Photoproduction of K-mesons

In order to establish orders of magnitude we consider a specific experiment, $\gamma + p \rightarrow K^+ + \Lambda^0$. We shall assume the target to be $\frac{1}{2}$ gm/cm^2 of H_2, and that, after momentum analysis the K^+ mesons arising from a 50 MeV bite at the top of the bremsstrahlung beam are being counted by a telescope subtending $\frac{1}{100}$ steradian at the target. This telescope counts also a certain number of π^+ mesons and protons - in a typical arrangement despite preliminary selection these are 5 times the K^+ rate. A coincidence arrangement may then be used to identify the K^+ events, consisting of a side counter to detect the K^+ decay. The resolving time determined by the K-meson lifetime will be of the order of 2×10^{-8} sec. Unfortunately the side counter will have very high counting rate, and the condition when real and random events are equal in number is found in practice to arise when the instantaneous flux of K^+ into the telescope is of the order of 9/sec. (or a mean rate of 27/min. with the synchrotron duty cycle). Assuming a cross-section for the process of 10^{-31} cm^2/sterad. we find that the instantaneous Q must not exceed 6×10^{11}/sec. The corresponding instantaneous beam current is 5 μa. This is very small compared with the instantaneous current (perhaps 100 μa) available with the synchrotron and, of course still smaller in relation to the linac intensity. In this sort of experiment one is thus in a regime where the efficiency of the accelerator is directly proportional to its duty cycle.

We have made some effort to assess whether by improved counting techniques it might be possible to increase the instantaneous electron beam that can be tolerated in the production of bremsstrahlung for K-photoproduction. However an instantaneous beam of about 50 μa is the highest we can predict for 'reals' equal to 'randoms', so that the maximum useful instantaneous intensity is around 15 μa.

There is no doubt then that for photo-production experiments the linac bremsstrahlung beam is much inferior to that of the synchrotron. It is for this reason that a storage ring, or annihilation photon beam have been considered in conjunction with the linac. The storage ring certainly restores the balance - its 'instantaneous' current of 1 μa could even be increased with profit.

The figure already given for the Q of the storage ring bremsstrahlung beam is 5×10^{11}/sec. By comparison the synchrotron with 15 μa peak beam current will have a Q of 10^{11}/sec., so that the balance is in fact in favour of linac plus storage ring. However against the linac-storage ring combination we must remember its complexity and indeed the doubt whether variable energy of injection would be guaranteed, so as to facilitate the bremsstrahlung subtraction method.

Consideration of the annihilation photon beam has clearly shown that it is not sufficiently intense to enable photoproduction reactions to be satisfactorily studied in competition with the bremsstrahlung difference method using the synchrotron. The most interesting possibility suggested for the annihilation beam, indeed, is that due to Binnie, that a very weak beam from well resolved positrons should be used within a well defined angle, so that the annihilation beam is in a defined energy range. By choice of angle the bremsstrahlung background can be reduced, and it is estimated that a liquid hydrogen bubble chamber could be profitably employed in an annihilation beam of this sort. This would have the advantage of enabling the more complex photoproduction events to be sorted out. The idea is interesting, but we are agreed that it could not wisely be made the basis of a large experimental programme.

Our conclusion is that for photoproduction experiments the synchrotron is the wisest choice of accelerator, being matched only by the costly, complex and not necessarily technically feasible project of a linac with a variable energy storage ring.

3. Electro-Production of Mesons

Some form of coincidence counting is likely to be called for in these experiments, which mostly also have rather small cross-sections. The dictum has been quoted to us that "they need the intensity of a linac together with the duty cycle of a synchrotron". The synchrotron we are considering has indeed a "linac intensity". Thus apart from the question of beam accessibility it may prove to be the most suitable accelerator. We should not however wish to put this view quantitatively. No doubt in some possible arrangements the high intensity linac might in fact be superior. The truth is that the experiments are hard with either accelerator, but on the whole are likely to prove at least as successful with the less elaborate synchrotron.

4. Other Experiments

We shall not give detailed consideration to other experiments, such as the production of secondary meson beams, as we feel that at 4 GeV these should not condition the choice of accelerator.

Conclusions and Recommendations

The evidence presented in Sections II & IV show that there is a rich field of experimental interest open to an electron accelerator in the energy region up to 4 GeV. Our studies have convinced us that there is roughly comparable interest in the electron beam and in the photon beam experiments possible in this region. Thus it is highly desirable that any accelerator to be constructed should be efficient at both these types of experiment. As a historical fact, until recently, electron accelerators have been successful at either one or the other type of experiment. The two accelerators we have considered represent the attempt to modify the linac, so as to permit photon beam experiments, and to modify the synchrotron to permit electron beam experiments.

It will be evident that the modification of the linac has been the less successful. The difficulty lies essentially in the duty cycle, which can be appreciably prolonged beyond the figure here considered only at unacceptable cost. The annihilation beam is not sufficiently important to be a decisive element in the GeV energy range and we believe that this idea should be discarded. We are thus forced to the consideration of a linac-storage ring combination, technically difficult and certainly with a capital cost several times that of the synchrotron. Such a combination could only be recommended if its potential performance far outclassed that of the synchrotron, and only then after a full appraisal of the technical problems.

By contrast the synchrotron has been found to be directly well adapted to high energy electron beam experiments, in addition to its normal application to photon experiments. Its success is, of course, dependent on effective use of the straight sections, to permit both internal targets and the analysis of the particles produced in them. It is important that in a synchrotron design great attention should be paid to these matters.

The final decision then rests between the synchrotron and the linac-storage ring combination. Purely on theoretical performance we might find it hard to judge between these accelerators. The advantage is probably a slight one either way. However when all the other factors of cost, technical difficulty and reliability are included we are in no doubt that the synchrotron is much the wisest choice.

We think it is not without profit that our decision in favour of the perhaps somewhat conventional synchrotron should come at the end of considerable efforts to find a more 'interesting' or 'original' accelerator. This serves to strengthen our unanimous recommendation, in the energy region up to 4 GeV, in favour of the electron synchrotron.

Finally we hold the view that the existence of the higher energy Hamburg and Cambridge accelerators should be no deterrent to the building of a British 4 GeV synchrotron. The field of interest is certainly big enough to contain all these accelerators. It is always possible, indeed, that the higher energy machines may follow the normal tendency of concentrating activity near their peak available energy. Whether they do so or not, the experiments of meson photoproduction and electro-production are of such interest, and of such difficulty, that they will provide important work for many years to come. The existence of competition merely makes it desirable that no time be wasted in the initiation of a project that, at moderate cost, will enable the National Institute to enter an interesting and important field.

Our recommendations are as follows:

1) The interest of photon and electron beam experiments in the region below 4 GeV is fully such as to justify the construction of a British electron accelerator of this peak energy.

2) This accelerator should be an electron synchrotron, in the design of which particular attention should be given to the feasibility of electron beam experiments.

3) To secure full value from this project it should be initiated at as early a date as possible.

Copies of the following detailed studies and notes, prepared during the working party's deliberations, have been deposited with the Secretary NIRNS at the Rutherford High Energy Laboratory, and may be consulted on request:-

1. Production and Use of Annihilation Beams - D. M. Binnie.

2. Electroproduction of K^+ Mesons - W. S. C. Williams.

3. Note on Storage Rings - J. G. Rutherglen.

4. Coincidence Ratio in Photoproduction Experiments - A.B.Clegg.

5. Electron Synchrotron Design - L. B. Mullett

6. Notes on Physics Research with 4 GeV Synchrotron or 2 GeV Linac - J. M. Cassels

7. Electron and Positron Linear Accelerators - J. C. Gunn and R. G. Moorhouse.

8. Miscellaneous Correspondence and Minutes of Working Party Meetings.

No 5 has been circulated to the Physics Committee as NI/PC/60/4: No. 7 was one of the papers considered by the Sub-Committee on new high-energy accelerators - see NI/PC/60/3 (page2)

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1st March, 1961. NI/61/2 Addendum

NATIONAL INSTITUTE FOR RESEARCH IN NUCLEAR SCIENCE

GOVERNING BOARD

4 GeV Electron Synchrotron Siting

Note by the Chairman

If the Board adopt the recommendations of the Physics Committee on this proposal, the siting of the proposed electron synchrotron will need urgent study. There are very strong arguments in favour of a site in the north, both because of the Board's expressed intention not to concentrate all their facilities at the Rutherford Laboratory, and because of the special interest of the Universities of Glasgow, Liverpool and Manchester in this project.

The practical choice lies between looking for a site

(a) Near Liverpool and Manchester

(b) Near Glasgow

or (c) Half way between

I suggest that alternative (c) should be discarded, as it would make the site convenient to nobody.

If it is not possible to reach an agreed choice between (a) and (b) at our meeting on March 9th I would like to set up a small working party to study the question and report back to the Board at our next meeting.

Rutherford High Energy Laboratory,
Harwell.