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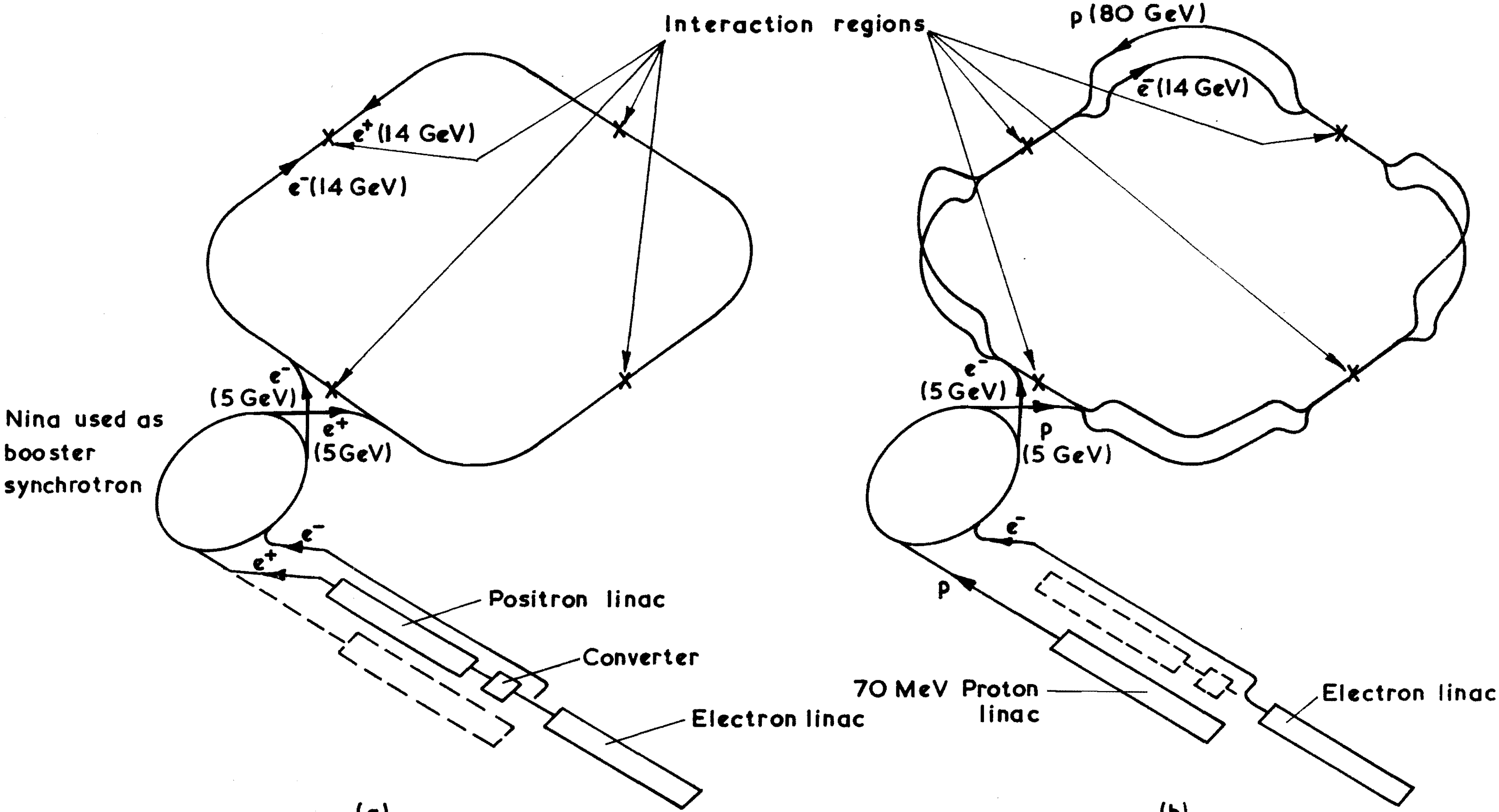


(a)
EPIC (Stage 1)

(b)
EPIC (Stage 2)

Fig. 1.1 SCHEMATIC DIAGRAM OF EPIC (STAGE 1) FOR $e^+ e^-$ COLLISIONS AND EPIC (STAGE 2) FOR ep COLLISIONS.

1. INTRODUCTION

In the 1973/4 five year forward look (NP1(73)Rev) the Board presented to Council a programme in which it was recommended that the two existing domestic accelerators, NIMROD and NINA, be phased out in the period 1977-1980 and be replaced by a storage ring complex - EPIC.

The proposed complex has great potential and could be built in stages, with each stage being capable of first class physics.

> Stage 1 would be a single accelerator ring in which 14 GeV electrons collide with 14 GeV positrons counter-rotating within the same ring.
>
> Stage 2 could add within the same tunnel an additional magnet ring for protons. This would be sited above the electron ring and the two beams would be deflected to give ep collisions in four regions shown in figure 1.

EPIC would provide facilities complementary to those of CERN and would enable physicists to undertake a wide range of exciting experiments. Many of the fundamental questions of high energy physics, that currently puzzle physicists, could be investigated. Examples are:

(a) What is the nature of the recently discovered sub-structure of protons and neutrons?

(b) What are the properties of these nucleon constituents (partons)?

(c) Are the quarks which were invented to explain the properties of the multitudinous "elementary" particles, the same as partons?

(d) Does the weak interaction have a non-zero range and if so what is the mediating particle?

(e) Are the new theories that unify the weak and electromagnetic interactions on the right lines and, if so, which version provides the best description of nature?

(f) Why are there two sorts of neutrinos; why, indeed, does the muon exist at all; are there heavier leptons?

(g) Why does nature distinguish between right and left and what is the significance of the observed violation of time reversal?

The Nuclear Physics Board requested a feasibility study to assess the physics interest and practical possibilities of EPIC. Nine working parties involving 35 university staff and 32 Daresbury and Rutherford Laboratory staff have worked during the past year and have written over 100 reports. The appendix gives details. A full feasibility report has been written giving the conclusions of this and other studies, and the present report summarizes the case.

High energy physicists conventionally use beams of energetic particles incident upon stationary targets. A consequence of conservation of momentum and special relativity is that the major part of the momentum of the beam particles is wasted projecting the products of the collision forward in the laboratory. As an example, if a 400 GeV proton hits a stationary proton, 373 GeV appears as forward motion in the laboratory and only 27 GeV of useful energy is available in the centre of mass system. On the other hand, in a head on collision between two particles of equal and opposite momentum, all the energy of the primary particles is available for the interaction. Hence, a 13.5 GeV proton beam colliding head-on with another 13.5 GeV proton beam can be used to study the same physical processes as with a 400 GeV proton beam incident upon stationary protons. This principle is the basis of all colliding beam systems; it greatly enhances the effective energy of the incident particles. To be useful, these must be stable particles as they must be stored in a magnet ring system for periods of hours.

The proposed Stage 1 of EPIC is such a system for e^+e^- interactions. The full energy of 28 GeV would be available for the collisions. If a stationary e^- target were used, the e^+ beam would have to have an energy of 800,000 GeV to reach an equivalent collision energy. The highest energy electron accelerator currently available is the Stanford 2 mile long linear accelerator giving 25 GeV.

EPIC (Stage 2) would enable protons (or deuterons) to be stored at an energy of 80 GeV in a conventional magnet ring, or at 200 GeV in a superconducting magnet ring. In collision with 14 GeV electrons, this would give centre of mass energies of 67 and 106 GeV respectively.

Chapter 2 of this report summarizes the present state of knowledge in high energy physics; Chapter 3 outlines the role that EPIC could play and Chapter 4 describes the status of the EPIC machine design. Chapter 5 gives the conclusions of the feasibility study. Briefly these are:

1. The participants in the feasibility study strongly urge the Nuclear Physics Board of the Science Research Council to seek approval for the early construction of a 14 + 14 GeV e^+e^- system as a first stage of EPIC.

2. This would provide a world class machine that can be built with known machine technology. The physics studies that can be foreseen are of fundamental importance and can be undertaken with currently available techniques.

3. The long term objective should be the addition of a second accelerator ring to enable ep physics to be studied.

2. THE NATURE OF PARTICLE PHYSICS, PROGRESS MADE AND THE OUTSTANDING PROBLEMS

To put in perspective the physics that can be studied with EPIC, we first review briefly the state of particle physics, discuss the progress made and identify some of the outstanding problems.

Among the greatest advances of the last hundred years were the formulation of Maxwell's equations, relativity and quantum mechanics, which together have led to a very good basic understanding of phenomena on an atomic and molecular level.

The interaction which governs this domain is the electromagnetic force between charged particles which takes place even when the particles are separated. The force between the particles is due to the exchange of photons - the quanta of the electromagnetic field. The relevant theory is quantum electrodynamics (or QED). It enables us to calculate and predict purely electromagnetic effects with great accuracy. So far all predictions when confronted with experimental data have been verified.

High energy physics is concerned with the sub-atomic domain. A general consequence of quantum mechanics (the Heisenberg uncertainty principle) is that one cannot know both the position and momentum of a particle with unlimited precision at the same time. It follows that as one probes structures at smaller and smaller distances higher and higher energies are required. Hence exploration of sub-atomic phenomena requires high energy particles. Study of the nature of the electromagnetic interaction at very small distances is one of the aims of high energy physics, but it is only a part of the whole,

Examination of the behaviour of compound structures of protons and neutrons in nuclei showed the existence of new types of short range forces. The study of these forces, the structure of neutrons and protons and related sub-nuclear questions are in the domain of particle (or high energy) physics. This field of research has seen its main growth in the last thirty years. Even after extensive investigations new phenomena are still being found which suggest new physical concepts and mechanisms, which in turn suggest further experimental tests. A final synthesis has not yet evolved but there are ideas and partial theories that quantify and correlate many features of the sub-nuclear scene.

A striking feature that has emerged is the great abundance of discovered particles that appear to be as elementary as the proton and neutron. There are several hundred now known. The existence of this glut of particles was difficult to reconcile with the concept that they were elementary. A major advance was a classification of all known states in terms of three basic building blocks - called quarks - and their antiparticles. This can be thought of as analogous to the classification of elements within the periodic table and it may be as important for physics as that concept proved for chemistry. The basic force between the quarks may be explained in terms of a new super-strong interaction. The resulting states formed by combinations of these quarks bound by this super-strong interaction are then slightly modified by the normal strong interaction and the electromagnetic interaction, resulting in the observed physical states.

In the simplest form of this model two of the quarks are given charges of one third of the elementary charge e and the remaining one is given a charge of two thirds e. The proton, neutron and other similar states called baryons are constructed from combinations of three quarks (qqq). Meson states such as pions, kaons, etc are made from quark-antiquark pairs ($q\bar{q}$). Free quarks have not yet been found and this may mean that they are very massive and tightly bound. Perhaps they are only a mathematical abstraction. Be that as it may, the quark model has had remarkable success in predicting and correlating the lower-mass meson and baryon states, in predicting their masses, quantum numbers, magnetic moments and transition rates. The elegance and economy of the quark model has great aesthetic appeal.

The fact that we have a good theory for the electromagnetic interaction makes the electron and the photon very useful probes of the strong interaction. A photon can be absorbed by any particle with a charge or magnetic moment. If this particle is also one that experiences the strong interaction the outcome can be a final state containing strongly interacting particles only. Electroproduction is also very similar. When a beam of electrons strike a target, their purely electromagnetic interactions are mediated by "virtual" photons, which are absorbed by the target. The resulting reaction can be looked upon as photoproduction by photons of non-zero mass, as their momentum and energy can be varied independently. Electrons and photons are therefore valuable probes for studying details of the strong interaction.

A striking and significant phenomenon has recently been discovered in electron proton scattering experiments. The cross section for elastic scattering of electrons by protons can be expressed as a product of the cross section that one would get if the proton were a point multiplied by a term that is a measure of the proton size and structure - this latter term is called the proton "form-factor". This form-factor is unity when the scattering angle for the electron is small, resulting in a small momentum transfer to the proton. As the scattering angle is increased the momentum transfer increases and the mass squared (Q^2) of the virtual photon exchanged between electron and proton also increases. It is found that at large Q^2 the cross section falls very rapidly and the form-factor is proportional to $\frac{1}{Q^4}$. This experimental fact is consistent with the idea, that the proton is a diffuse object that tends to break up when hit hard.

In apparent contradiction to these observations, if one studies inelastic electron scattering in which the proton is transformed into other states and sums over all possible inelastic states by merely looking at the scattered electron and measuring its angle and energy, then one finds a behaviour that is initially surprising and contradictory - the inelastic form factor does not fall rapidly with Q^2. One would expect that the inelastic form-factor would depend upon both the energy, ν, of the virtual photon, and upon Q^2; but experimentally it depends only upon the ratio Q^2/ν and for very large ν the cross section varies only slowly with Q^2. This is precisely what one would expect if the proton were a point. The apparent contradiction between this result and the elastic scattering is resolved if the proton is made up of constituent point parts called partons. The form factor for elastic ep scattering is small at large Q^2 because the extended cloud of constituents must recoil as a whole. Inelastic scattering from the proton results from the interaction of the exchanged photon with a single point-like constituent, followed by the break up of the proton.

This indication of a sub-structure to the proton (and the neutron), and the related "scaling" property that "deep-inelastic electron scattering" depends not upon ν and Q^2 independently but upon the "scaled" ratio Q^2/ν is of fundamental significance. It is a major objective for the future to study the sub-structure further and to see if scaling persists at higher energies. If scaling breaks down as the energy ν increases it could indicate that a new scale of energy or length had been met (these could correspond to the free production of the constituent partons or to a non-zero size for the partons). Experiments can be made to measure the properties of the partons - their spin, their charge, how many exist within the nucleon and whether they are accompanied by antipartons. It is an exciting possibility, suggested by existing data, that the partons are to be identified with the quarks that are a natural explanation of the observed properties of the hadrons. Electron and muon beams from the new accelerators at NAL and CERN will provide higher energy virtual photons ($\sim$ 200 GeV) to probe the nucleon structure in more detail. To probe still deeper, with higher energies, both e^+e^- and ep colliding beams could offer unique possibilities in providing virtual photons with up to an order of magnitude more energy.

Beside strong and electromagnetic interactions, there is the weak interaction, characterized by a very small coupling constant which is responsible for the decay of strongly interacting particles and for processes such as radioactive β-decay. Weak interactions do not obey the same symmetry rules as strong and electromagnetic interactions; for example, it was discovered in 1956 that they are not invariant under the operations of space reflection (or parity, P) and particle-antiparticle reflection (or charge conjugation, C). In 1964, it was also discovered that the decay of neutral K mesons violates time reversal and the combined CP symmetry. This violation does not fit into the existing theory of the weak interaction and the current belief is that it is due to a new super-weak interaction.

The conventional theory of the weak interaction (Fermi theory) has serious shortcomings. The theory assumes a point interaction, a consequence of which is that the cross section for scattering processes mediated by the weak interaction increases indefinitely with energy. This prediction is confirmed by experiments with neutrinos having energies up to about 70 GeV, but must clearly break down at some energy well before the cross section rises to such a value that conservation of probability (unitarity) is violated. An attractive way out is that the weak interactions may in fact be mediated by an intermediate meson W, just as the photon mediates the electromagnetic interaction. The analogy with the electromagnetic force turns out to be very close; the W is required to have spin 1, just like the photon, and to interact with currents that are closely related to the electromagnetic current. This idea has been developed into a theory which holds the promise of unifying the electromagnetic and weak interactions. If successful this could be a synthesis as important to our understanding as the unification of electric and magnetic phenomena through Maxwell's equations.

A possible way of studying the weak interaction is to investigate either of the reactions, $e^+ + e^- \rightarrow \mu^+ + \mu^-$ or $e + p \rightarrow \nu$ + anything. Use of EPIC will enable much higher centre of mass energies to be reached than are possible even with beams from the new CERN proton synchrotron (SPS).

An important theoretical prediction is that weak interaction cross sections become as large as those of the electromagnetic interaction, when the momentum transfer becomes very large. This is because the former interaction depends little on momentum transfer, whereas the latter decreases rapidly. Should we reach an energy regime in which the strength of the two interactions which have such widely differing properties becomes equal, new discoveries of a fundamental nature would be almost bound to be made.

As the energy of the particle accelerators has increased, so have the discoveries multiplied; indeed many of the most important discoveries were not anticipated when the machines at which they occurred were being planned. Experiments at the new particle accelerators now being built may answer some of the fundamental questions listed above and new and unexpected discoveries will be made. There are strong indications that as the energy is increased a greater simplicity is found. The highest energies yet attained from an accelerator system have been achieved with the pp intersecting storage rings at CERN; there is a clear need for equally high energies for e^+e^- and ep systems.

3. THE ROLE OF EPIC

Before outlining the role that EPIC can play in studying high energy physics we indicate what other electron and proton colliding beam facilities exist or are planned.

e^+e^- colliding beam facilities already exist and have worked at energies up to 2.5 + 2.5 GeV. Both SPEAR (at SLAC, USA) and DORIS (at DESY, Germany) have development programmes that will enable them to work ultimately at 4.5 + 4.5 GeV.

No ep colliding beam system has yet been constructed. Germany has approved a development of the e^+e^- system DORIS to enable protons to be stored and machine physics studies to be made using a 3.5 GeV electron beam colliding with a 3.5 GeV proton beam.

There are no approved projects for energies greater than those mentioned above although Germany, Italy, Japan and USA all have paper studies in progress considering new e^+e^- and ep systems.

In section 3.1 below we present a general case for EPIC and in the following sections further details are given on the studies that can be made with an e^+e^- system and an ep system.

3.1 General Case for EPIC

The major advantage of a colliding beam system is the greatly increased centre of mass energy. The 30 + 30 GeV pp ISR system at CERN is working and has already produced unexpected and important results. Why is it necessary to build additional systems involving electrons?

The interaction between protons is complex. Because protons are charged one force acting between them is electromagnetic; but the proton is also strongly interacting and can exchange pions, kaons and other mesons and we have no complete theoretical understanding of these much stronger effects. In addition the proton is itself a complex object - probably with a complex substructure, and it is doubly difficult to probe this inner structure using another proton.

On the other hand we have excellent theoretical understanding of quantum

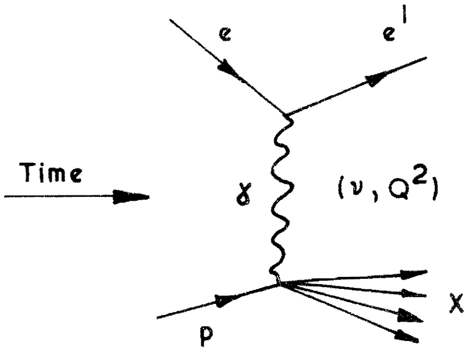


Fig 3.1 SINGLE PHOTON EXCHANGE CONTRIBUTION TO INELASTIC ELECTRON SCATTERING $e^{+}+p \longrightarrow e' +$ ANYTHING

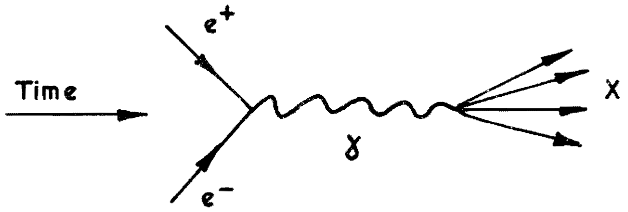


Fig 3.2 SINGLE INTERMEDIATE PHOTON CONTRIBUTION TO ELECTRON POSITRON ANNIHILATION $e^{+}+e^{-} \longrightarrow$ ANYTHING

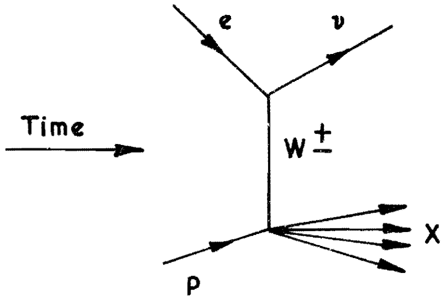


Fig 3.3 SINGLE INTERMEDIATE VECTOR BOSON EXCHANGE CONTRIBUTION TO THE WEAK INTERACTION $e+p \longrightarrow \nu +$ ANYTHING

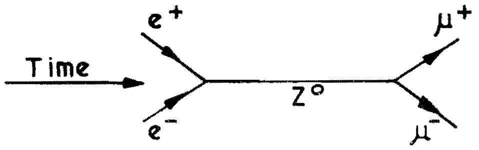


Fig. 3.4. A POSSIBLE WEAK INTERACTION CONTRIBUTION TO THE REACTION $e^{+}+e^{-} \longrightarrow \mu^{+}+\mu^{-}$

electrodynamics (QED). Fig. 3.1 shows diagrammatically the major contribution to the ep interaction - the exchange of a single virtual photon. The incoming electron is inelastically scattered and a final state X is formed from the interaction between the virtual photon and the proton. The upper part of the diagram is well described by QED and the proton structure is probed by the well understood virtual photon of energy ν and mass squared Q^2, (where Q is the four-momentum carried by the photon).

Similarly e^+e^- annihilation reactions are dominated by one photon intermediate states and fig. 3.2 represents $e^+ + e^- \rightarrow X$. When the final state X contains no strongly interacting particles (e.g. $e^+ + e^- \rightarrow \mu^+ + \mu^-$) QED can be used to calculate the expected cross section and angular distribution. Small corrections are expected from strong interaction and weak interaction effects but these can be estimated, identified and separated. Hence experiments can be made to check QED to less than 10^{-15}cm, that is a distance smaller than $\frac{1}{100}$ the radius of the proton.

If the final state X contains protons or other hadrons, one can investigate their sub-structure and determine some of the properties of their constituent parts - the partons.

Electrons, muons and protons all experience the weak interaction. Our theoretical understanding requires that a messenger, or mediator, act between the interacting particles, but no suitable particle has been discovered in spite of many attempts to find it - it has been named the intermediate vector boson (or W). Fig. 3.3 represents $e + p \rightarrow \nu + X$. A similar but neutral particle can contribute to $e^+ + e^- \rightarrow \mu^+ + \mu^-$ through the weak interaction. Fig. 3.4 represents this.

At energies which are currently available the weak interaction effects are completely negligible compared with the electromagnetic effects. As the centre of mass energy increases the electromagnetic effects become smaller and the weak interaction effects larger. In the EPIC energy range one can hope to look for effects from both interactions and can even reach a sufficiently high centre of mass energy in the ep case that the weak effects should dominate. The experimentally observed weak interaction cross sections seen in ν interactions increase as the square of the centre of mass energy. This increase would result in

TABLE 3.1

Accelerator	Reason Built	Achievements
Bevatron/Nimrod (8 GeV protons)	Search for anti nucleons. Study of πp and pp interactions.	Detailed study of resonance physics leading to quark model, and to the concept of duality for strong interactions. Study of weak decays including investigation of basic symmetries.
PS/AGS (30 GeV protons)	Study of particle reactions at higher energy.	Discovery of: two neutrinos, Ω^- particle, CP violation in K decay, neutral currents in weak interaction. Measurements of muon anomalous magnetic moment to an accuracy of order one part per million.
ISR ((30 + 30) GeV protons)	Study of pp reaction at very high energy. Searches for new particles.	Increase in pp total cross section. Unexpected yield of particles with large transverse momentum.
SLAC (25 GeV electrons)	Tests of QED. Measurement of form factors of nucleons.	Deep inelastic electron scattering indicating a sub-structure to the nucleon. Use of hadron beams.

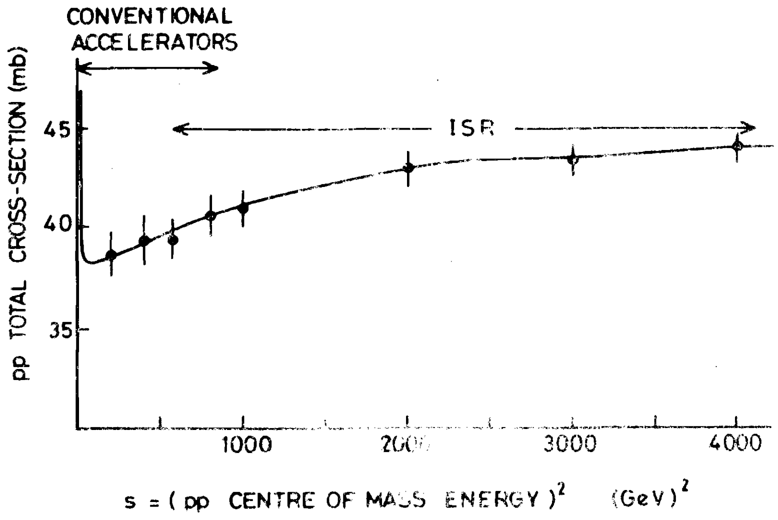


FIG 3·5 TOTAL CROSS SECTION FOR pp REACTION AGAINST s, SHOWING THE INCREASE OBSERVED IN THE ISR ENERGY REGION.

violation of probability conservation (i.e. more comes out than goes in) if it continues to energies well beyond the EPIC range. One expects to see deviations well before this catastrophe is reached and hence fundamental discoveries are almost certain in the EPIC energy range.

High Energy Physics is at the moment predominantly an experimentally led subject. Theoretical advances are dependent upon the provision of a large body of experimental data from which can be extracted certain patterns suggesting theoretical models - these models are then modified and refined by confronting them with experimental results testing their predictions. The provision of data such as momentum spectra, angular distributions, correlations, particle composition etc is the backbone of the subject. EPIC will certainly make rich contributions of this kind.

At the energies reached at the CERN pp storage rings unexpected and important discoveries have already been made - such as the increase in pp total cross-section at energies greater than those available at conventional accelerators (see figure 3.5). This result should be checked and complemented by studies with other particles in the same energy region. Similarly other detailed measurements at the ISR would be of much greater significance if they could be supplemented by measurement of other reactions in the same energy region. EPIC would give such possibilities; for example the γp total cross-section for hadron production is predicted to rise from 120 to 160 μbarns in the EPIC energy region if it follows the observed pp cross-sections.

The detailed arguments presented above and in the rest of this report are a minimal case for EPIC. It is that which can be made now with our current knowledge of physics, our current understanding of accelerator physics and of experimental technique. The exploitation could start in about 1981 and although all relevant subjects may have made advances by that time, experience leads us to expect these to make the significance of EPIC much greater than our presented case.

Indeed, in retrospect the best justification for building accelerators has been the discovery of the unknown and the unexpected. This is illustrated in table 3.1, where, for four classes of existing accelerators, the

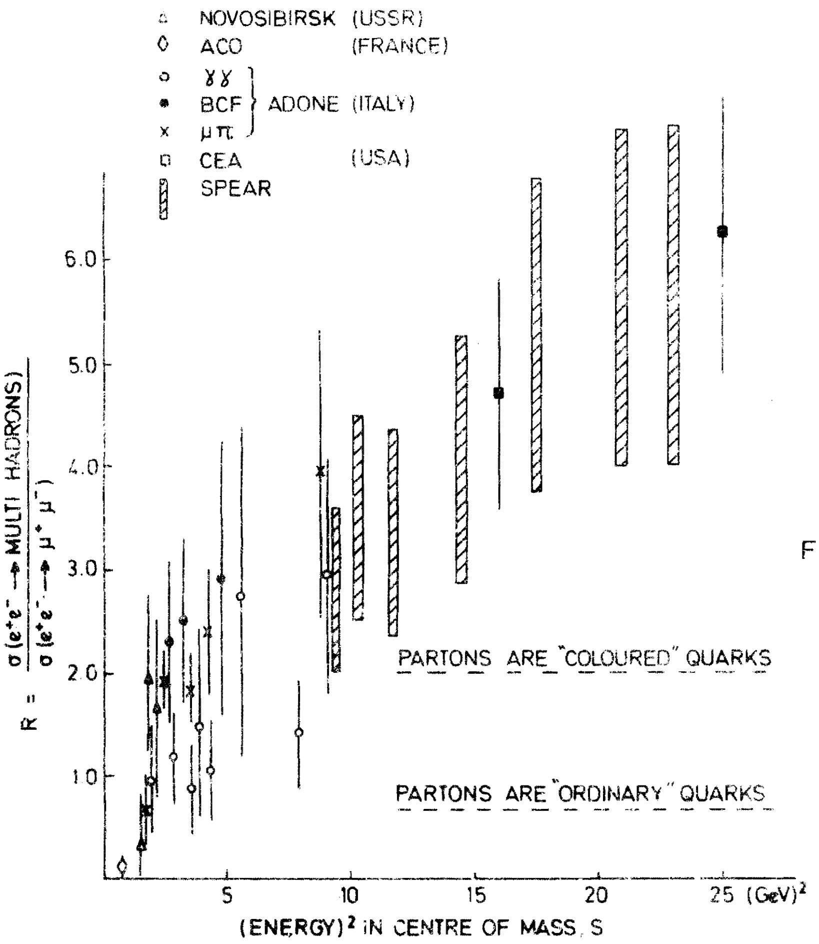


FIG.3.7. EXPERIMENTAL RESULTS e^+e^- ANNIHILATION INTO MORE THAN TWO HADRONS
(NOTE: EPIC CAN REACH UP TO S=784 (GeV²))

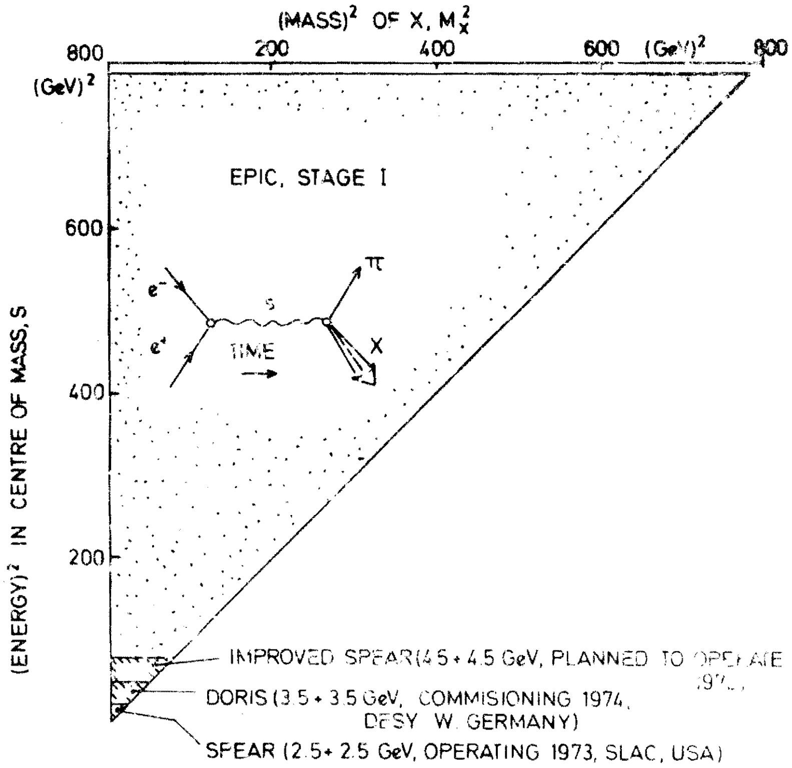


FIG.3.6: COMPARISON OF EPIC, STAGE I, WITH EXISTING AND APPROVED e^+e^- STORAGE RINGS. THE BOUNDARIES OF THE KINEMATIC WHICH CAN BE EXPLORED ARE SHOWN.

original case is compared with the actual achievements. In all cases it clearly substantiates the claim that the case presented for accelerators when they are proposed is a minimal one.

For EPIC the physics exploitation envisaged now is much greater and more significant that that presented for any previous accelerator and if this is in reality a small fraction of what it actually achieves - its future will be indeed dramatic.

3.2 e^+e^- physics with EPIC (Stage 1)

A. Hadron production in e^+e^- annihilation

The kinematic region available at EPIC for the study of the fundamental and important area of e^+e^- annihilation into hadrons is "terra incognita" and this is one of the major attractions of the proposed device. In figure 3.6 we show an aspect of the new physical domain opened up by EPIC, and compare this with that appropriate to facilities presently operating, and planned to operate in the near future. The energy available will permit searches for hadron sub-structure of length less than 10^{-15}cm, equivalent to one part in a million of the volume of the nucleon.

An illustration that experimental results in new domains yield important surprises is given by the recent results from SPEAR on the annihilation of e^+e^- into hadrons. Figure 3.7 plots these results as a ratio R(s) for different s = (centre of mass energy)^2, where

$$R(s) = \frac{\text{rate for } e^+ + e^- \to \text{all purely hadronic state}}{\text{rate for } e^+ + e^- \to \mu^+ + \mu^-}$$

The experimental results increase linearly with s, in contradiction with a wide class of theories that predicted that the cross-section should exhibit "scaling", that is that R(s) should approach a constant value as s increases.

Much of the conventional wisdom concerning high energy e^+e^- interactions stems from the parton model, discussed in section 2. Figure 3.7 gives value of R(s) predicted assuming a single intermediate photon and different quantum number assignments for the partons. The parton picture assumes that an intermediate photon from the annihilation of the e^+e^- pair materialises into a parton-antiparton pair which further decays into

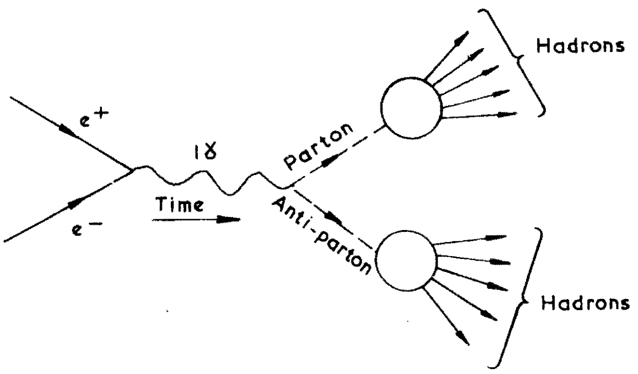


FIG. 3·8 a) THE PARTON PICTURE OF e^+e^- ANNIHILATION INTO HADRONS

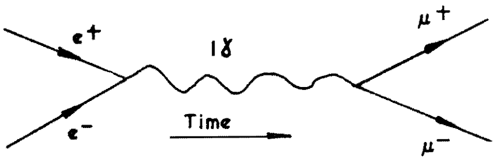


FIG. 3·8 b) e^+e^- ANNIHILATION INTO $\mu^+\mu^-$

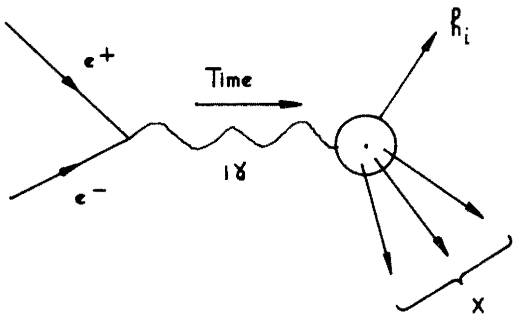


FIG 3·9 a) ANNIHILATION INTO A GIVEN HADRON (h_i) AND ANYTHING (X)

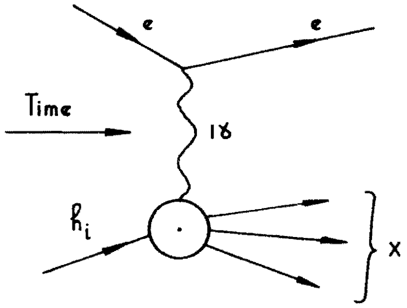


FIG 3·9 b) SCATTERING e^- ON A GIVEN HADRON (h_i) TO GIVE e^- PLUS ANYTHING (X) hadrons as illustrated in figure 3.8(a). The process is similar to $e^+e^- \to \mu^+ + \mu^-$ illustrated in figure 3.8(b). The theory assumes that the partons and muons are point charges of spin $\frac{1}{2}$, and predicts that the constant value for R(s) should be given by

$$R(s) = \sum_{\text{all partons}} q_i^2$$

where q_i is the charge of partons of type i. The simplest scheme of fractionally charged quarks with conventional statistics gives R = 2/3. An attractive elaboration gives R = 2. We emphasize that R has reached 6 at s = 25(GeV)^2. Does this value persist at higher values of s, indicating that we shall have to change radically our ideas of nature's underlying symmetry, or does it decrease to the expected values?

The study of single hadrons (h_i) from $e^+ + e^- \to \gamma \to h_i$ + anything is also of great interest. There are theoretical hints that a strong and direct relation should exist between the annihilation $e^+ + e^- \to \gamma \to h_i$ + anything, and the scattering $e^- + h_i \to e^-$ + anything (see figure 3.9). If this turns out to be true then the substructure of <u>all</u> hadrons (h_i) can be investigated via e^+e^- collisions. This is in contrast to the colliding electron-nucleon systems which can only directly explore the constituents of protons and neutrons.

The parton model demands the creation of a parton-antiparton pair by the photon. The manner in which possible fundamental constituents may materialize into familiar hadrons (see figure 3.8) is intrinsically of great interest, and could also be a crucial input to theories of the production of high transverse momentum particles from hadron-hadron collisions at high energies. This is because the substructure of hadrons should be manifest at short distances - which correspond, via Heisenberg's uncertainty principle, to high transverse momenta.

<u>Measurements of hadron production in e^+e^- annihilation at EPIC energies should illuminate a whole range of apparently quite different purely hadronic processes.</u>

B. Muon production in e^+e^- annihilation

As has been explained in section 3.1 the study of $e^+ + e^- \to \mu^+ + \mu^-$

is of interest both as a test of QED and because of possible weak interaction effects. The rate expected for the QED contribution to the reaction is close to 20 events/hour in each interaction region, which is adequate for precise experiments. We have remarked that recent results from SPEAR indicate an increase in the ratios R(s) as s increases (see figure 3.6). This increase is consistent with the reaction $e^+ + e^- \rightarrow$ hadrons simply being independent of energy. If this were to persist it would require a catastrophic breakdown of QED for $s \lesssim 2500$ GeV^2. EPIC could reach $s \simeq 1000$ GeV^2 and we would therefore expect to see a change in the behaviour of the annihilation cross-section to hadrons, or a breakdown of QED in the EPIC energy range.

Figure 3.4 represents a weak interaction contribution to $e^+ + e^- \rightarrow \mu^+ + \mu^-$ mediated by a possible intermediate heavy neutral particle Z^o. This would be a neutral current contribution to the weak interaction. The question of the existence of such neutral weak currents is perennial, and only recently there has been evidence that such currents may indeed exist. They are required by some of the theories attempting to unify the weak and electromagnetic reactions. At EPIC energies the cross section for $e^+ + e^- \rightarrow \mu^+ + \mu^-$ is expected to have a contribution from the electromagnetic interaction, a small contribution from the weak interaction, and a contribution from interference between the weak and electromagnetic effects. This latter effect is expected to be about ten percent and will also give rise to a forward backward asymmetry in the muon angular distribution.

The EPIC design may allow the use of polarised beams. This would make possible experiments to detect parity violating effects which would reflect directly the character of the weak interaction and could not be mimicked by higher order electromagnetic corrections. The expected magnitude of these effects is about ten percent. The relative strength of weak and electromagnetic effects in $e^+ + e^- \rightarrow \mu^+ + \mu^-$ increases as s^2, or as the fourth power of the primary machine energy. Hence weak interaction contributions cannot be seen at SPEAR or DORIS and the increased energy available with EPIC is crucial for such experiments.

The study of $e^+ + e^- \rightarrow \mu^+ + \mu^-$ at EPIC energies will increase our basic understanding of the weak and electromagnetic interactions.

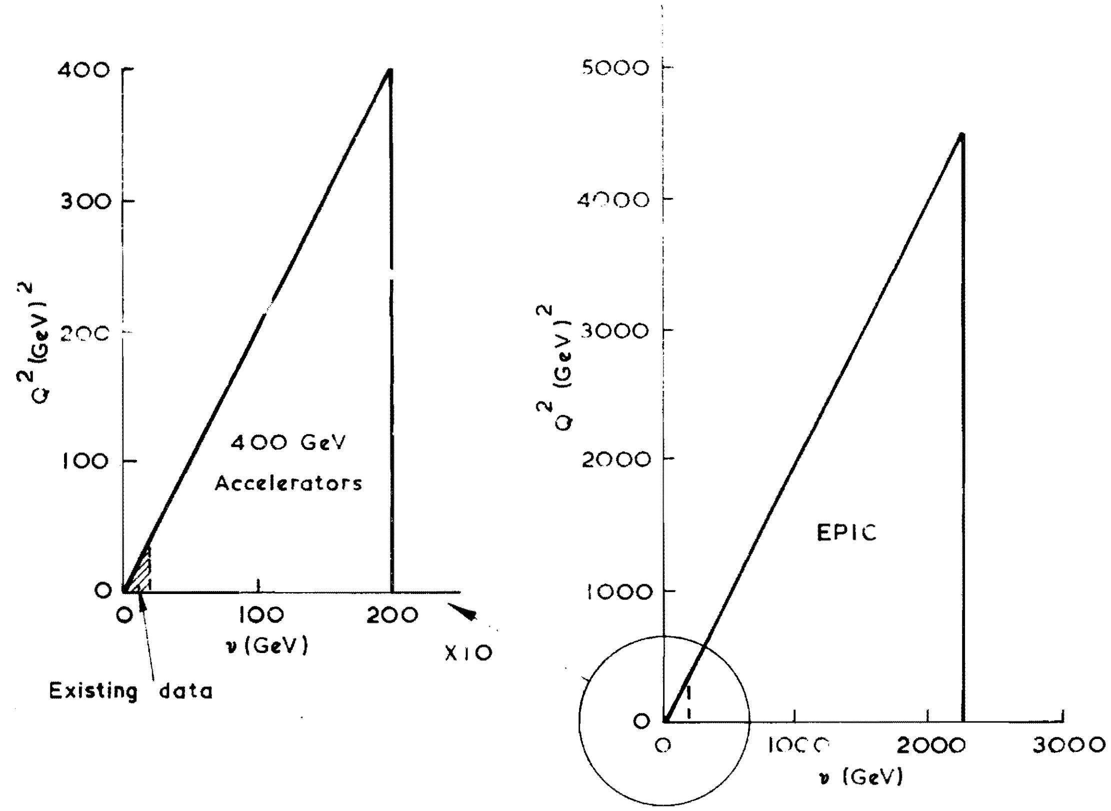


Fig. 3.10. Q^2, ν REGION COVERED BY EPIC COMPARED WITH THAT ACCESSIBLE TO ELECTRON AND MUON BEAMS FROM 400 GeV PROTON ACCELERATORS. THE SHADED AREA REPRESENTS THE VERY SMALL REGION SO FAR INVESTIGATED.

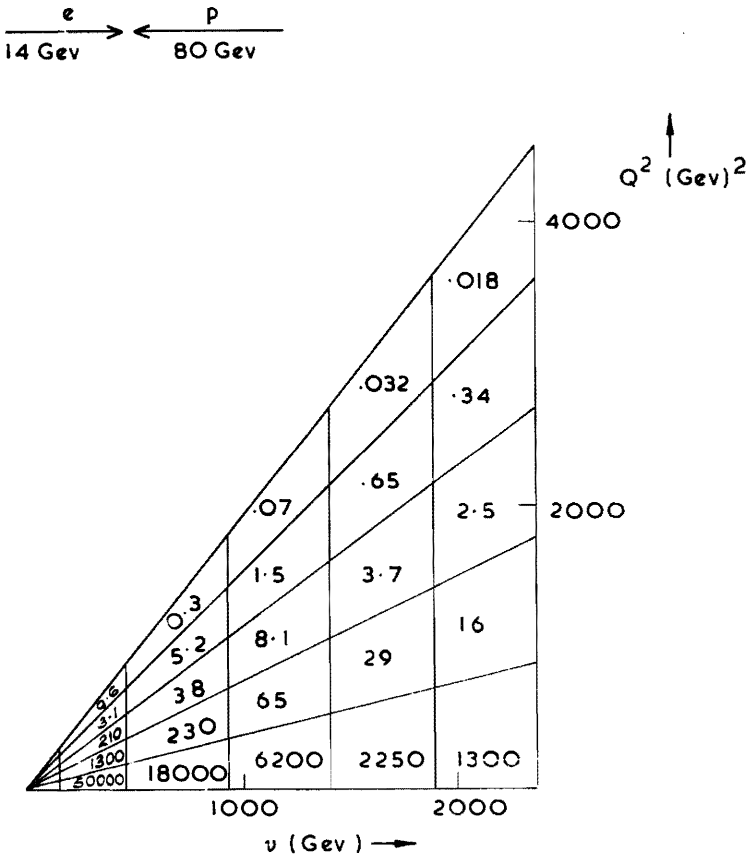


Fig. 3.11. NUMBERS SHOWN ARE EVENTS/DAY FOR INELASTIC ELECTRON SCATTERING. (VERY SMALL VALUES OF Q^2 ARE EXCLUDED)

C. Other e^+e^- reactions

There is another class of e^+e^- reactions in which an e^+e^- pair remains in the final state. The general reaction of this type is $e^+ + e^- \rightarrow e^+ + e^- + X$. The cross sections expected exceed the annihilation cross section by more than a factor of a hundred at EPIC energies. The reactions can be recognised by detecting the e^+ and e^- in the final state. A large range of physics can be studied depending upon the nature of the final state e^+e^-X. Further tests of QED can be made when X contains no hadrons. If X includes hadrons one may consider them as produced by the collision of two photons, $\gamma + \gamma \rightarrow X$.

The experiments probe the structure of the photon itself.

3.3 ep physics with EPIC (stage 2)

The physics that can be covered with an ep colliding beam system can be summarised under the following headings:-

a) Deep inelastic scattering - investigation of the nucleon sub-structure.

b) Weak interaction studies - of a fundamental interest in their own right but also yield information on hadron structure.

c) Photoproduction - γp reactions yield information that broadly complements and enhances the pp studies at the ISR.

A. Deep inelastic scattering ($e + p \rightarrow e' +$ anything)

As discussed in section 2 the results of electron proton scattering experiments may be interpreted by assuming that the proton has a sub-structure of point-like particles called partons. This behaviour was predicted theoretically by Bjorken and is one of the most significant discoveries in elementary particle physics. Its continued study is perhaps the foremost aim for the future. Existing data has been obtained for Q^2 and $2M_P\nu \lesssim 25$ GeV^2. Further measurements will be made using electron and muon beams at the 400 GeV proton accelerators for Q^2 and $2M_p\nu \lesssim 200$ GeV^2. EPIC will allow a further factor of 10 increase in Q^2 and ν. Figure 3.10

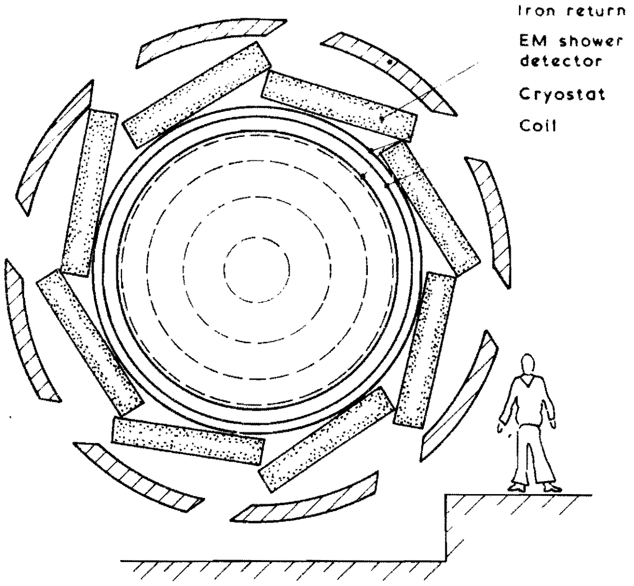


FIG. 3.12 SCHEMATIC DRAWING OF A POSSIBLE SOLENOID DETECTOR FOR EPIC.

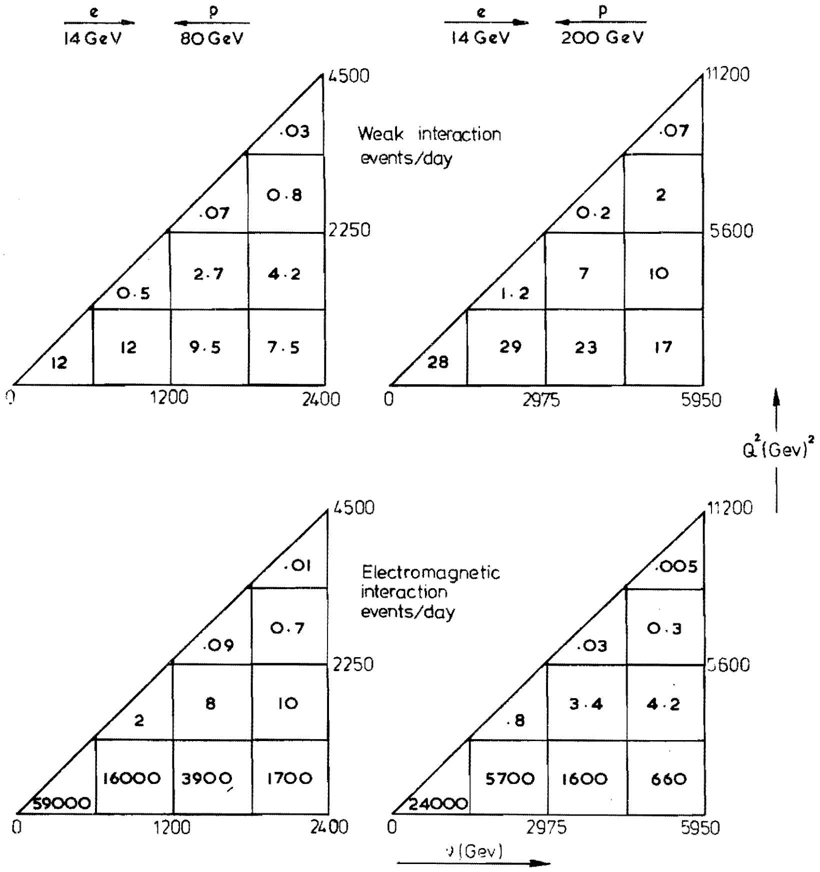


FIG. 3.13 COMPARISON OF WEAK AND ELECTROMAGNETIC RATES AT TWO EPIC ENERGIES.

shows clearly the new kinematic region that EPIC will make available - the increase is dramatic.

Scaling can be used to extrapolate the existing data to this new energy region resulting in a predicted counting rate shown in figure 3.11. Such rates could be observed and the scaling assumption tested for a range of Q^2 and ν 100 times greater than that currently covered. A breakdown of scaling would occur if a new length or energy scale existed - corresponding for example to a non-zero size for the partons or to the production of free partons.

Detailed measurements of the cross sections, particle compositions, momentum distributions, multiplicities and correlations in the final states will enable the nature of the sub-structure to be probed carefully. One can expect to determine the spin and charges of the partons, their momentum distributions and their basic interactions.

B. Weak interaction studies

As was mentioned in section 3.1 EPIC will enable a collision energy and values of Q^2 to be reached at which weak interaction rates have become as high as electromagnetic rates. It will therefore be of great interest to choose a reaction that necessarily proceeds via the weak interaction and compare the cross-sections with those for deep inelastic electron scattering. Such a reaction is:-

$$e + p \rightarrow \nu + \text{anything}$$

It is not practicable to detect the ν directly, but one can detect all other particles, note the absence of an electron in the final state, and deduce that a neutrino was produced by a large imbalance in momentum at right angles to the beam direction. The feasibility report includes a careful study of such an experiment and concludes that the measurements can be made. Figure 3.12 is a sketch of the large solenoid detector required. The electromagnetic reaction, $e + p \rightarrow e' +$ anything, is readily identified by observing the inelastically scattered electron. Figure 3.13 compares the weak and electromagnetic interaction rates for two different values of the proton energy in EPIC. It demonstrates that, as Q^2 is increased at fixed energy, the weak rate increases relative to the

TABLE 3.2

Effect of finite values of the intermediate vector boson mass on the total weak interaction rate at EPIC

M_W GeV/c^2	Events/day	
	$P_e = 14$ $p_p = 80$ GeV/c	$p_e = 14$ $p_p = 200$ GeV/c
∞	28	96
80	22	60
40	10	26

The rates shown are calculated for that part of the Q^2-ν plane where the ratio of the weak to electromagnetic cross-section is predicted to exceed 0.01.

TABLE 3.3

Rates for some photoproduction reactions that can be studied at EPIC

Experiment	Cross Section	Rate	Physics Interest
Total Cross Section	1) $\sigma_T \sim (120 + 70/\sqrt{2M\nu})\ \mu b$ 2) $\frac{\sigma_T\ (\gamma p)}{\sigma_T\ (pp)} = \text{const}$	60 s^{-1} "	Does γp total cross-section follow an extrapolation of present trends or does it increase like p - p cross section?
Diffractive Scattering $\gamma p \to \rho p$ ωp ϕp	 $\sim 12 \mu b$ $\sim 2 \mu b$ $\sim 1 \mu b$	 6 s^{-1} 1 s^{-1} 0.5 s^{-1}	Momentum transfer distributions at small Q^2. $(0 < Q^2 < 1$ GeV/c$)^2)$
Inclusive reaction $\gamma p \to h$ + anything, where h is an observed hadron or photon	$\sim 100 \mu b$	60 s^{-1}	Comparison with $p + p \to h$ + anything at ISR energies.
Compton Scattering $\gamma p \to \gamma p$	$0.1 \mu b$	3 per minute	Tests of dispersion relations

electromagnetic rate, and also that the total weak rate rises as the machine energy is increased, whereas the total electromagnetic rate falls.

The calculations are made assuming that the "structure functions" describing the interaction of the weak current with the proton are the same as that for the electromagnetic interaction - which is itself extrapolated from energies one hundred times below the EPIC regime. We make no apology for these gross and probably unjustified assumptions - the purpose of EPIC is to find the true situation and only guesses can be used at this stage.

A further assumption has been that the intermediate vector boson, which may mediate the weak interaction, has infinite mass. Table 3.2 shows the effect of other values of the mass (M_W) on the expected counting rate - thus demonstrating that one will be able to "measure" M_W.

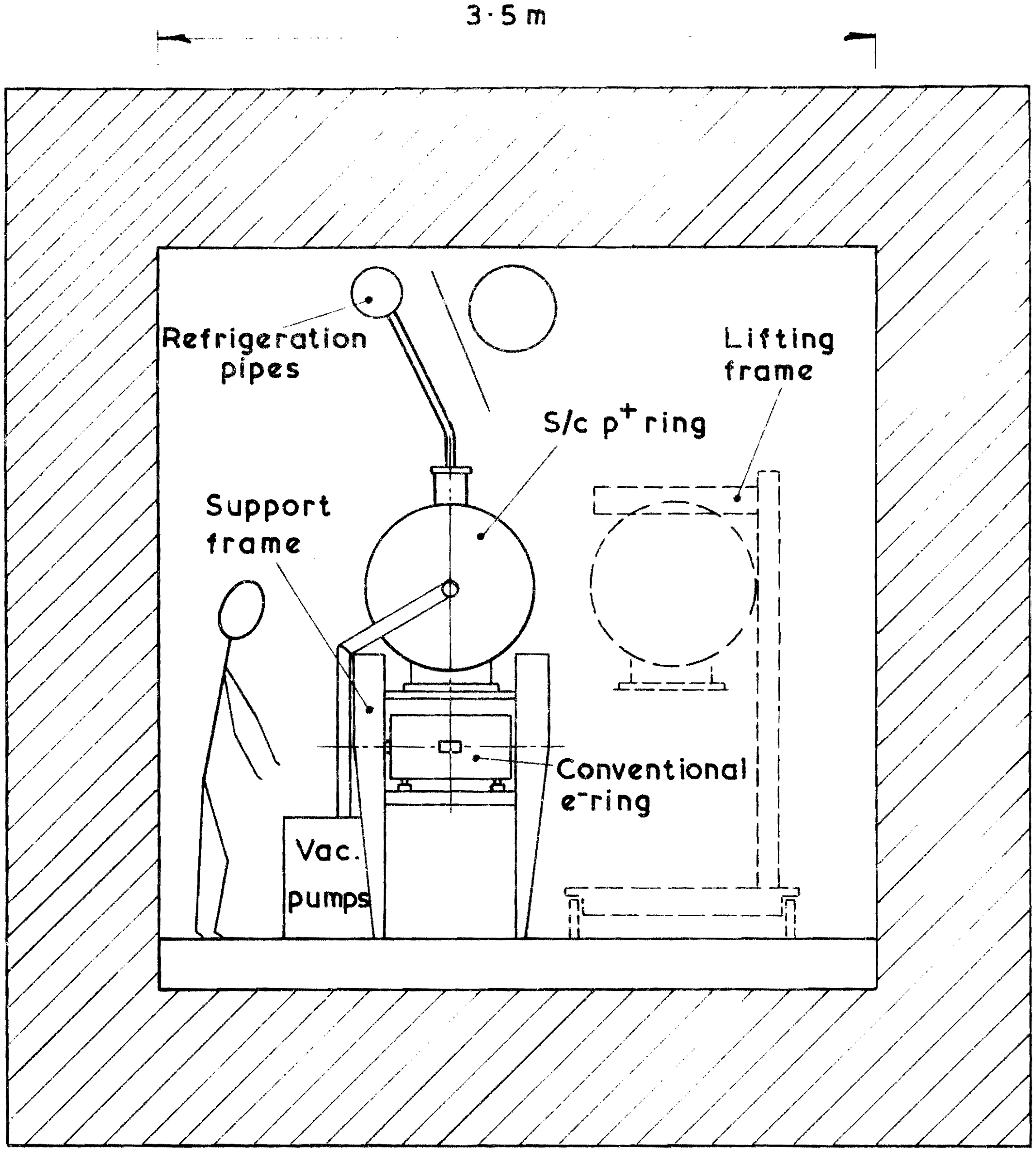
As one has to detect all particles in the final state additional detailed information on the structure of the proton and even on possible structure of the W itself may be obtained.

These experiments are difficult, the counting rate is low, but even with existing techniques they are possible and fundamental discoveries are almost certain.

C. Photoproduction

If the process $e + p \rightarrow e' + X$ is measured for small values of Q^2 and extrapolated to $Q^2=0$ the cross section obtained is the same as that for real photons for $\gamma + p \rightarrow X$. Small values of Q^2 correspond to small scattering angles for the electron and one can place detectors to select low Q^2 events and measure "photoproduction" cross sections.

For energies reached in colliding beam systems γp studies are the only ones that can complement pp studies. The effective luminosity of EPIC for γp reactions is about 5×10^{29} cm^{-2} sec^{-1} which gives counting rates that are quite high. Table 3.3 lists some of the reactions which have adequate rates. It is important that most of the physics programme at the CERN ISR be repeated using γp rather than pp. The two sets of measurements are complementary and together are of much greater use than either independently.



Epic tunnel cross section

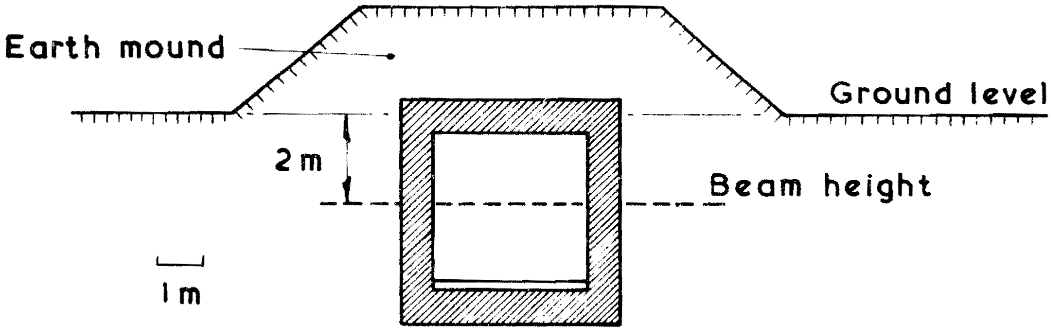


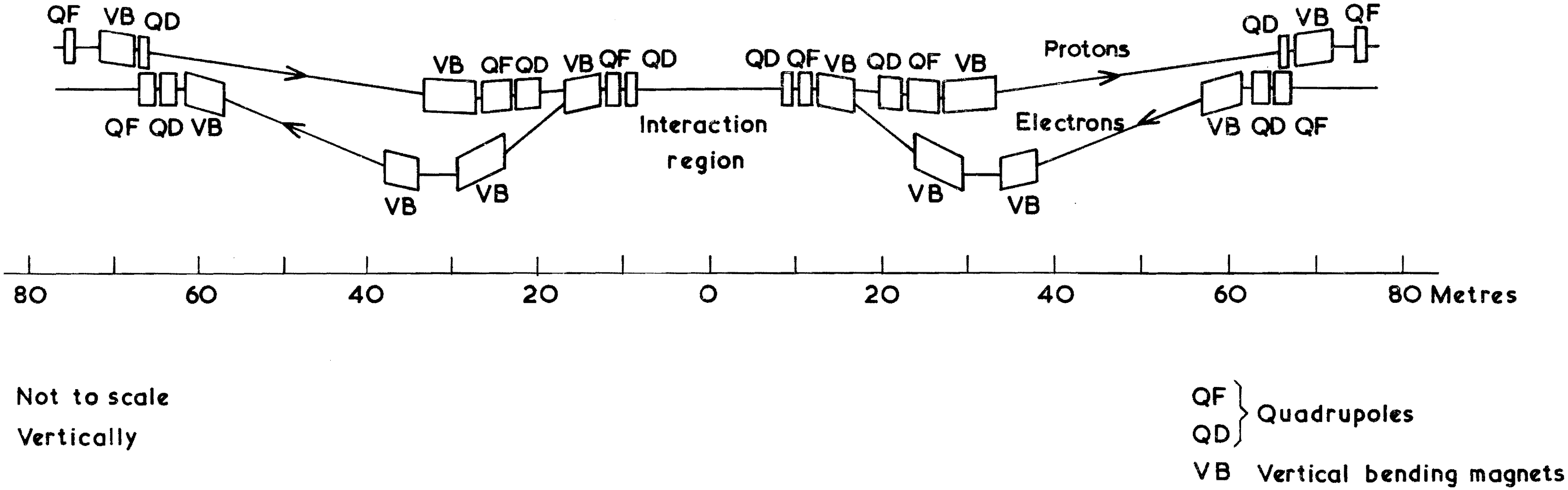
Fig. 4·1 SCHEMATIC DIAGRAM OF CROSS SECTION OF EPIC TUNNEL

4. THE EPIC MACHINE DESIGN

The recommendation stemming from the feasibility study is that EPIC should be built in two stages. Stage 1 should consist of a single storage ring containing electrons and counter-rotating positrons (figure 1.1(a)). After some years spent in the investigation of e^+e^- physics an additional ring could be added, thus making possible the study of e-p reactions (figure 1.1(b)). To leave space for the extra ring, the storage ring tunnel will be made slightly larger than would be necessary for the e^+-e^- ring alone. However, the premium to be paid for this will only be a few per cent of the total cost of the project. Extra RF cavities could be added to raise the e^+e^- collision energy to at least 34 GeV centre of mass energy and possibly to 40 GeV.

The average radius of the tunnel, which will be only a metre or two below ground (figure 4.1) is nearly 350 metres. The construction of the experimental areas and ring tunnel on the site of the Rutherford Laboratory presents no problem. It is planned to make use of NINA, in a modified form, as a booster injector of electrons, positrons and (later) protons. It will be housed partly in what is now Experimental Hall 1. Besides the many existing buildings, beam-line elements and power supplies of which the project will take advantage, the new 70 MeV linac from NIMROD will serve as an excellent injector of protons for NINA,and the existing NINA electron linac, somewhat improved, will be used to inject electrons and positrons. The current cost for provision of this existing equipment would be about £7M.

For storage rings the event rate can be calculated by multiplying the cross section for a particular process by a factor called the luminosity, which is proportional to the product of the numbers of particles in the colliding beams; obviously, the more particles there are circulating the greater the chances of a collision occurring. In addition, the event rate can be increased if the beams can be reduced in cross sectional area at the collision point. This is brought about by incorporating strong magnetic lenses at each interaction region. In the first stage of EPIC, the electron and positron stored beams will each consist of two bunches, there being about 5×10^{11} particles per bunch. Like bunches will be separated by 180° of machine azimuth; there will be four interaction regions, at which the beam size will be about 0.02 cm high and 0.06 cm wide. At each collision point the expected luminosity is about 0.4×10^{32} cm^{-2} sec^{-1}, which is an order of magnitude greater than that at the CERN ISR.



Not to scale
Vertically

FIG 4.2 VERTICAL ARRANGEMENT OF LATTICE ELEMENTS IN e-p INSERTION

The electrons and positrons will emit copious amounts of synchrotron radiation because of the transverse acceleration in the bending magnets. A very powerful RF accelerating system will be needed to replace the 1-2 megawatts that will be lost through synchrotron radiation.

There are no machine physics uncertainties in the design of such an e^+e^- system. It can be costed accurately,and built with existing technology.

It is not essential for the protons of Stage 2 to be bunched. An example of an unbunched system is the ISR at CERN, where well over 10^{14} protons are stored in each ring. EPIC would require at least as many for the unbunched case (together with the beams crossing at an angle, instead of being collinear), but in opting for a bunched system we are able to reduce this figure by two orders of magnitude without loss of luminosity. Not only will the machine costs be less, but radiation shielding will also be much less expensive, and the consequences of accidental loss of the beam to the vacuum chamber wall and magnets not nearly so damaging.

The major undertaking of Stage 2 would be the installation of a second magnet ring above the e^+e^- ring (figures 1.1 and 4.2). This proton storage ring could have either conventional or superconducting magnets, resulting in proton energies of 80 or 200 GeV respectively. Vertical bending magnets bring the paths of the beams into coincidence at the four interaction regions (figure 4.2). With four bunches of each type of particle circulating, the theoretical luminosity is $\approx 0.5 \times 10^{32}$ cm^{-2} sec^{-1} at the lower proton energy.

Major problems are presented by the fact that protons do not undergo radiation damping; furthermore, the difference in path length required to equalise circulation time of the protons and electrons changes as the centre of mass energy is varied. To achieve the quoted luminosity for an e-p ring, the design has had to allow for the following factors:

(a) Very large and carefully controlled RF voltages required to minimise the proton bunch-length and diffusion rate.

(b) The creation of a variable path-length difference between the electron and proton rings in order to allow centre of mass energy changes.

(c) The synchronisation of the two beams in the collision mode.

TABLE 4.1 Basic Capital Costs for EPIC (£M) (excluding staff costs)

	Stage 1 (e^+e^-)		Additional cost of Stage 2 (e-p)			
			Either 14-80 GeV		Or 14-200 GeV	
Linacs	0.22					
Transfer	0.05					
Booster	1.00					
Total Injection		1.27		0.1		0.1
Magnets	2.4		4.75		14.7	
Vacuum	1.55		2.1		3.6	
RF	2.2		1.5		1.5	
Miscellaneous	0.57		.5		2.2	
Total Main Ring A		6.72				
Total Main Ring B				8.85		22.00
Power Supplies and controls		2.95		2.25		3.25
Refrigerator						3.05
Buildings, services etc		6.25		0.59		1.91
		17.2		11.8		30.31
Design 10%		1.7		1.2		3.0
Installation 10% of equip.		1.0		1.0		3.0
TOTALS		£19.9M		£14.0M		£36.3M

(d) Acceleration of the protons without degrading the beam size and angular divergence.

(e) The defocussing effect of the electron beam on the protons.

Only (d) and (e) represent major uncertainties which have yet to be clarified.

Much theoretical work is being done on these problems in Europe and the USA, and together with experiments to be made at DESY and the ISR, this should provide adequate understanding of the important problems within the next few years.

The feasibility study has provided initial cost estimates for the different components of EPIC (see Table 4.1) and has shown that the scheme is technically viable. A short list of parameters is given in Table 4.2 below, and a more detailed technical description of the project will be found in the full feasibility report.

TABLE 4.2

Mean radius (metres)	348.8	
No. of interaction regions	4	
Length of each int. region (metres)	17	
	e-ring	p-ring
Maximum momentum $\hat{p}$ (GeV/c)	14	80
Q-value	19.2	19.3
Peak R.F. volts (MV)	42.8	3.0
Natural bunch length* (cm)	3.5	35.0
Enhanced H-amp* at X (cm) at $\hat{p}$	0.06	0.102
Enhanced V-amp* at X (cm)	0.016	0.031
For e^--p collisions:		
No. of bunches/beam	4	4
No. of particles/bunch	5×10^{11}	7.5×10^{11}
Luminosity/int. region (cm^{-2} sec^{-1})	$\sim 0.5 \times 10^{32}$	
For e^--e^+ collisions:		
No. of bunches/beam	2	
No. of particles/bunch	5×10^{11}	
Luminosity/int. region (cm^{-2} sec^{-1})	$\sim 0.5 \times 10^{32}$	

* Amplitudes marked amp* are 2 times RMS values. X is Interaction Region

5. CONCLUSIONS OF THE EPIC FEASIBILITY STUDY

The feasibility study involved 78 physicists who produced 120 reports. The subjects covered included not only the machine physics, e^+e^- physics and ep physics outlined in this brief report, but also experimental utilisation, the possibility of the use of polarised beams, storage and use of deuterons, pp physics and provision of test beams from the booster accelerator. Further information may be found in the reports listed in the appendix.

The conclusions of the study are:-

a) A 14 + 14 GeV electron positron colliding beam system can be constructed with known technology for approximately £20M, excluding staff costs. Its luminosity at 14 + 14 GeV would be 4×10^{31} cm^{-2} sec^{-1} and its energy could be raised to about 17 + 17 GeV at somewhat reduced luminosity.

b) The physics programme that can be undertaken with this machine, using known experimental techniques, is of world class and fundamental discoveries are almost certain.

c) Provided that early approval for construction could be obtained we could be better placed than other European nations to build the accelerator. Such opportunities are extremely rare and the participants in the feasibility study strongly press the Nuclear Physics Board of the Science Research Council to seek approval for the early construction of a 14 + 14 GeV e^+e^- system as a first stage of EPIC.

d) The long-term objective should be the addition of a second accelerator ring to enable ep physics to be studied. The existing machine physics uncertainties should be resolved in the next few years. The physics that can be studied is complementary to that investigated with an e^+e^- system and also to that studied using the CERN pp ISR system.

MEMBERSHIP OF THE EPIC WORKING PARTIES

1. e^+e^- Chairman: R H Dalitz (Oxford University)

G Conforto	Rutherford Laboratory
W N Cottingham	Bristol
N Dombey	Sussex
E Gabathuler	Daresbury Laboratory
D Lyth	Lancaster
D Morgan	Rutherford Laboratory
A Segar	Oxford
W Toner	Rutherford Laboratory
R V Budny	Oxford
A McDonald	Oxford

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(photo production)

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P Dickenson	Manchester
W Galbraith	Sheffield
G Ringland	Rutherford Laboratory
D G Sutherland	Glasgow
R Worden	Rutherford Laboratory
W H Range	Liverpool
G Brookes	Sheffield
R Marshall	Daresbury Laboratory

3. ep → e at large angle Chairman: F Foster (Lancaster University)

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K Bowler	Edinburgh
A Clegg	Lancaster
W N Cottingham	Bristol
D Evans	Durham
G Hughes	Lancaster
P Landshoff	Cambridge
G Ringland	Rutherford Laboratory
D G Sutherland	Glasgow
T Tso	Rutherford Laboratory
R Worden	Rutherford Laboratory
H Montgomery	Daresbury Laboratory
F Close	Daresbury Laboratory
J Thompson	Daresbury Laboratory
P Norton	Daresbury Laboratory

4. Weak interactions

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A McFarlane	Cambridge
G Myatt	Oxford
H Osborn	Cambridge
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K Barnham	Imperial College
P D B Collins	Durham
R Ott	Rutherford Laboratory
G Ross	Rutherford Laboratory
R Sekulin	Rutherford Laboratory
W Toner	Rutherford Laboratory
D Williams	Daresbury Laboratory

6. Use of e and p beams

Chairman: P I P Kalmus (Queen Mary College)

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G Rees	Rutherford Laboratory
V Suller	Daresbury Laboratory
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D Perry	Rutherford Laboratory

7. pp

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P V Landshoff	Cambridge
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A D Martin	Durham
R J N Phillips	Rutherford Laboratory

8. Other fields

Chairman: C J Damerell (Rutherford Laboratory)

(acceleration of d beams, polarised e, p and d beams synchrotron radiation)

P Duke	Daresbury Laboratory
F Farley	Shrivenham
J D Lawson	Rutherford Laboratory
V Suller	Daresbury Laboratory
T Tso	Rutherford Laboratory
G Marr	Reading
F Wickens	Rutherford Laboratory
B Ratcliff	Rutherford Laboratory

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M Donald	Rutherford Laboratory
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C Planner	Rutherford Laboratory
N M King	Rutherford Laboratory
B Loach	Rutherford Laboratory
W A Smith	Rutherford Laboratory
J R Bennett	Rutherford Laboratory

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G Saxon	Daresbury Laboratory
N Marks	Daresbury Laboratory
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M W Poole	Daresbury Laboratory
D E Poole	Daresbury Laboratory
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PAPERS AND MINUTES PRODUCED BY THE EPIC WORKING PARTIES

EPIC WORKING PARTY NO 1

EPIC/WP1/P1	$e\bar{e}$ $e\bar{e}$+ Hadrons at EPIC energies	C J Brown D H Lyth
2	EPIC ways of studying weak bosons	R Budny
3	Bibliography on e^+e^- reactions leading to final state of leptons and photons only	N Dombey
4	Photon photon collisions in electron colliding beams at EPIC energies	W N Cottingham
5	$e\bar{e} \to e\bar{e}$+ hadrons at EPIC energies (II)	C J Brown D H Lyth
6	Bibliography for $e\bar{e} \to e\bar{e}$+ hadrons via 2-photon annihilation	D Lyth
7	W^o effects in inclusive experiments at EPIC energies	R Budny
8	Effects of neutral weak currents in annihilation	R Budny
9	Beam-beam bremsstrahlung: the ultimate limit	W T Toner
10	Interim Report	R H Dalitz
11	Colliding electron beams at EPIC energies (III)	C Brown D Lyth
12	Colliding electron beams at EPIC energies (IV)	C Brown D Lyth
13	Preliminary design characteristics of the e^+e^- Italian storage ring Superadone	G Conforto
14	Multiplicities in $e^+e^- \to$ hadrons via the one photon graph	A McDonald
15	Muon helicity measurements	W T Toner
16	One photon-two photon, I and II	W T Toner
17	On the inclusive distribution of pions from electron colliding beams at EPIC energies	W N Cottingham
18	W^o effects in Bhabha scattering	R Budny A McDonald

EPIC WORKING PARTY NO 2

EPIC/WP2/P1	Compton Scattering	W Range
2	Total γ-hadronic cross sections	G R Brookes
3	Feasibility of measuring the total photoabsorption cross section with ep colliding beams	N E Booth

EPIC WORKING PARTY NO. 3

EPIC/WP3/P1	Electroproduction kinematics conventions	M Ibbotson F Foster
2	Rates for electroproduction inclusives $(e + p \rightarrow e + k)$	F Close J Thompson
3	Some physics questions about deep inelastic ep	P V Landshoff
4	Separation of σ_T and σ_L on EPIC	P Norton
5	Photon physics for EPIC	F E Close
6	Notes taken at the meeting of EPIC Working Party Chairmen, June 11 at RHEL	G Hughes
7	Preliminary design of an electron detector for EPIC	G Hughes
8	$\gamma\pi$ scattering experiments at EPIC	R P Worden
9	The physics interest of deep inelastic eN scattering at EPIC	P V Landshoff G Ringland
10	ep or e^+e^-: The question of priority.	P V Landshoff G Ringland
11	The kinematics of the parton fragmentation region	G Ringland
12	Summary of activities of EPIC Working Party 3.	F Foster
13	EPIC Notes	P R Norton H E Montgomery
14	Hole fragmentation and parton fragmentation - an experimental view.	F Foster
15	Exploitation of a double arm transverse field spectrometer at EPIC.	F Foster

EPIC WORKING PARTY NO 4

EPIC/WP4/P1	Weak interaction rates in e-p collisions (EPIC) (Oxford Report 11/73).	D H Perkins
2	Production of intermediate weak bosons by weak interactions in EPIC.	G Myatt
3	Observations of weak interaction events in EPIC.	P J Dornan
4	Notes on experimental problems: II	W Venus
5	Interim short report of Working Group No 4	

EPIC WORKING PARTY NO 5

EPIC/WP5/P1	Equivalent radiator for EPIC	W T Toner
2	Some estimated cross sections for EPIC	P D B Collins
3	EPIC experiments	W T Toner
4	Two-body kinematics for EPIC	R J Ott
5	Kinematically allowed regions (in the Laboratory system) for reactions ep-ep (n), etc.	R L Sekulin R J Ott
6	Calculation of total EM and weak rates	R L Sekulin
7	Kinematics of total EM and weak rates	K Barnham
8	Some considerations in the design of a solenoid for use with EPIC	G Kalmus
9	Study of the possibility of filling specific interaction channels and ep elastic scattering in particular	T C Bacon
10	Errors in Q^2 due to unobserved final states along the initial beam direction	G G Ross
11	Effects of scaling breakdown	G G Ross
12	Polarization at EPIC	G G Ross
13	Report of activities of working party 5	G E Kalmus
14	Detection of small-angle particles at EPIC, using a superconducting shield	W T Toner
15		
16	Controlled lepton polarisation in EPIC?	W T Toner
17	A toroidal magnetic field configuration for an EPIC detector.	C M Fisher
18	EPIC Study Week: Solenoid Group Report.	Kalmus etc.

EPIC WORKING PARTY NO 6

EPIC/WP6/P1	Table - comparison of intensities in EPIC and conventional machines	P I P Kalmus
2	Extracted beams from EPIC?	P I P Kalmus
3	Provision of test beams from the booster	T G Walker

EPIC WORKING PARTY NO 7

EPIC/WP7/P1	Possible scheme for pp working party	B Duff
2	Papers for meeting No 2	B Duff
3	Visit of EPIC WP7 to RHEL 14 May	D P Barber
4	Physics interest of pp at EPIC	
5	The generalisation of the van der Meer method to include the case of bunched collinear beams	D P Barber
6	Report from Working Party 7	
7	Bunched or DC proton beam for EPIC?	B G Duff P I P Kalmus G H Rees

EPIC WORKING PARTY NO 8

EPIC/WP8/P1	Polarised $e^{\pm}$ beams	C J S Damerell
2	Electron polarization in EPIC	F J M Farley
3	The problem of accelerating polarized protons in EPIC	F Wickens
4	Status Report	C J S Damerell
5	Status on polarized proton source	T Tso
6	Determination of the transverse polarization of particles in EPIC	

PAPERS PRODUCED BY THE MACHINE STUDY GROUP

EPIC/MC/1	Initial design aspects of storage rings for a possible future UK facility.	G Rees
2	Literature search - Storage rings.	D A Gray
3	Useful formulae for luminosity estimates of colliding beams.	G H Rees
4	Suggested initial list of storage ring machine topics for detailed study.	G H Rees
5	The effect of noise on bunch compression in an e-p storage ring.	G H Rees
6	Notes on beam instabilities.	J R Maidment C W Planner
7	ESR I: Sensitivity to closed orbit errors.	J R Maidment
8	ESR I: Non-linear resonances and the working point.	J R Maidment
9	Conversion of magnet power supplies for NINA when used as a booster for EPIC.	N Marks
10	ESR I: Momentum dependent Q-shifts.	J R Maidment
11	ESR I: Magnet apertures, and injection at 2.1 GeV/c.	M R Harold
12	Some EPIC parameters of interest to experimentalists.	M R Harold
13	A first magnet-lattice design for EPIC II/III.	G Rees
14	Closed orbit distortion due to energy loss by synchrotron radiation in ESR I.	J Maidment
15	Injection into the PR at 5 GeV/c	M R Harold
16	Positron production and accumulation for the EPIC positron/electron ring.	G Saxon
17	High current and beam-beam effects in EPIC	J D Lawson
18	Energy variation for e-p collisions in EPIC II.	G H Rees
19	Preliminary accelerating structure and beam loading considerations for the EPIC 11/111 electron ring.	T Swain
20	Initial studies of longitudinal space charge forces in e-p beam-beam interactions for bunched and unbunched p beams.	G H Rees
21	Further consideration of the EPIC electron injection problem.	G Saxon
22	Path length adjustment for energy variations in EPIC.	D Lewin
23	Good field requirements in the electron ring of EPIC 11/111.	J R Maidment
24	Deuterons in EPIC?	J D Lawson
25	Beam separation in the EPIC 11 e^+-e^- option.	J R Maidment
26	Proposed reference numbering system for EPIC lattice components.	B G Loach

EPIC/MC/27	Reflections on ERICE.	J D Lawson M Donald
28	Good field requirements in the proton ring of EPIC 11/111.	J Maidment
29	Q-shifts and Q-spreads associated with the head-on collision of bunches of unequal size.	J D Lawson
30	Beam separation in the EPIC II e-p option.	J R Maidment
31	Shielding for EPIC. First estimates.	D R Perry
32	A preliminary analysis of process control requirements of EPIC.	J C Hopkins
33	Eddy current effects in a rectangular vacuum vessel.	S A Armitage
34	Synchrotron radiation spectra from the EPIC electron ring.	V P Suller
35	Multi-mode excitation of a lossy line by a pulsed beam.	J D Lawson
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38	A modified magnet lattice for the EPIC booster.	M Donald G Rees
39	EPIC up-dated: variable damping and tunes in the e± ring.	G Rees
40	Particle scattering in EPIC: some preliminary comments.	J D Lawson
41	Injection schemes for EPIC.	G Saxon
42	Hot or cold bore for a superconducting EPIC ring?	J R J Bennett
43	Vacuum requirements for the proton ringof EPIC.	J R J Bennett
44	Eddy currents in the vacuum chamber of the EPIC electron ring.	J R J Bennett