FUTURE EUROPEAN PROTON STORAGE RING FACILITIES

B.W. Montague

CERN
1211 Geneva 23, Switzerland

Abstract: The status of the CERN studies on future proton colliding-beam facilities is presented. Proton-proton Large Storage Rings of 400 × 400 GeV^2, using superconducting magnets, are being designed for a luminosity of 10^{33} cm^{-2} s^{-1}. A 20 GeV electron ring is incorporated into the design to permit e-p collisions at 20 × 400 GeV^2 with a luminosity of 10^{32} cm^{-2} s^{-1}, using one of the coasting proton beams. Antiproton-proton collisions are feasible, both in the existing 30 GeV ISR and in the future 400 GeV LSR. The performance of these $\bar{p}$-p facilities would be enhanced by the use of the stochastic cooling principle under active study at the ISR.

Résumé: Nous presentons l'état des études au CERN sur les installations futures pour collisions de faisceaux de protons. De grands anneaux de stockage de protons-protons à 400 × 400 GeV^2 utilisant des aimants supraconducteurs sont à l'étude, devant atteindre une luminosité de 10^{33} cm^{-2} s^{-1}. Un anneau d'électrons à 20 GeV a été incorporé au projet, permettant des collisions d'e-p à 20 × 400 GeV^2 avec une luminosité de 10^{32} cm^{-2} s^{-1}, utilisant un des faisceaux de protons dégroupés. Il est possible de réaliser des collisions d'antiprotons-protons à la fois dans les ISR actuels à 30 GeV et dans les futures LSR à 400 GeV. Les performances de ces installations de $\bar{p}$-p seraient augmentées en utilisant le principe de refroidissement stochastique à l'étude actuellement aux ISR.

1. INTRODUCTION

Studies on possible future European colliding-beam facilities have been in progress at CERN for some time under the heading of Long-Term Development (LTD). This talk presents the main results of that part of the work involving at least one beam of protons, i.e. facilities for: p-p, e-p and $\bar{p}$-p collisions.

The contributors to these studies are listed in the Appendix; for many of them this has been an additional part-time activity over and above their normal responsibilities. In the interest of brevity only the more recent references are cited here; these contain a fairly extensive bibiliography of earlier work.

The scope of the LTD work can broadly be divided into two parts, namely new machines and major extensions of the existing ISR. The main topics are outlined here and most of them developed in subsequent sections.

1.1 New Machines

(i) Large Storage Rings (LSR) for p-p collisions of 400 × 400 GeV^2, and a luminosity $\mathcal{L} = 10^{33}$ cm^{-2} s^{-1} formed the starting point of these studies. In the first phase, a design using normal magnets was considered (Autin et al. $^{1)}$); this machine turned out to have an uncomfortably large power consumption and physical size.

The present studies concentrate on a similar machine but using superconducting magnets. This should result in lower power consumption, smaller ring size, a higher performance potential and possibly a lower cost, though this is still uncertain.

(ii) An e-p facility of 20 × 400 GeV^2 with a luminosity $\mathcal{L} = 10^{32}$ cm^{-2} s^{-1} is being closely integrated into the design of the superconducting p-p machine. In contrast to other e-p proposals we assume at present the use of a coasting proton beam, rather than one tightly bunched, partly to complement other studies and partly because of misgivings about the behaviour of intense proton bunches, resulting from a certain amount of ISR experience at relatively low bunch currents.

(iii) A $\bar{p}$-p option of 400 × 400 GeV^2 with a luminosity $\mathcal{L} = 10^{29}$ cm^{-2} s^{-1} is a possible addition to these facilities which is being kept under review.

1.2 Extended ISR Development

(i) Superconducting quadrupoles are being designed for a low-β insertion which should bring the ISR luminosity to above 10^{32} cm^{-2} s^{-1}. The experience with s.c. magnet technology will be valuable for the design and costing of the LSR.

(ii) $\bar{p}$-p in the ISR appears to be feasible with a luminosity of ∿ 5 × 10^{24} cm^{-2} s^{-1}, which could possibly be increased to ∿ 10^{26} cm^{-2} s^{-1} by the use of stochastic cooling of the antiprotons.

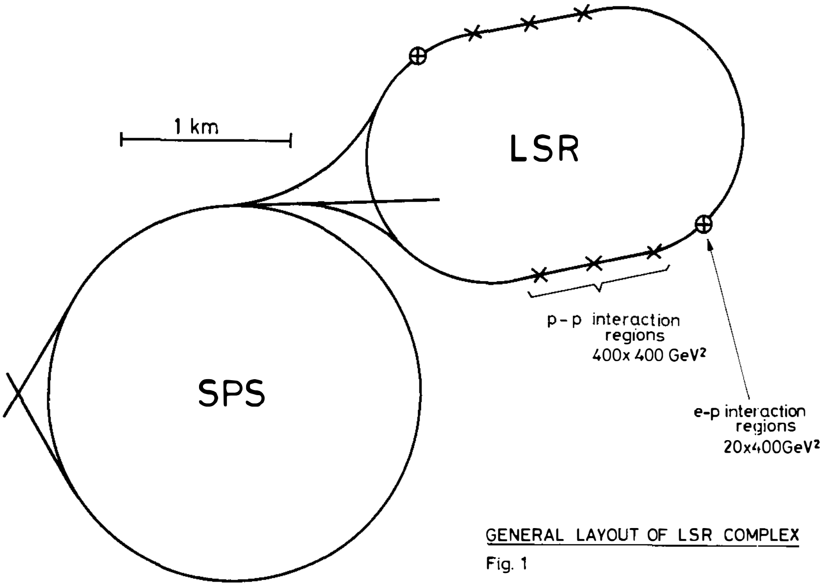
(iii) Conversion of ISR to s.c. magnets has often been discussed as a means of obtaining p-p collisions of 100 × 100 GeV^2 or more in the existing ISR tunnel. However, the constraints of this tunnel on the geometry and superperiodicity of such a machine are such that a nominal bending field of at least 5 Tesla would probably be required to achieve sufficient luminosity, interaction-region space and experimental flexibility for this energy range.

We believe that such a conversion would be more appropriate to the use of niobium-tin superconductor, the technology for which is, however, less advanced than for that of niobium-titanium. We therefore concentrate our effort at present on the larger machine, for which practical engineering solutions are nearer to hand, keeping a superconducting-magnet ISR as a reserve project for which the 400 GeV storage-ring studies would also be largely relevant.

2. THE LSR COMPLEX

The general layout of a facility for 400 × 400 GeV^2 p-p and 20 × 400 GeV^2 e-p physics is shown in Fig. 1. The two proton rings and the electron ring are in the same tunnel of a racetrack shape imposed by site considerations. The six p-p interaction regions are in two groups of three in the straight arms of the racetrack, whilst the two e-p regions are near the ends of the bending arcs. The aim is to enable p-p and e-p experiments to run simultaneously and independently, without adding too much to the machine circumference.

Because of the geometrical problems arising from colliding three separate beams, the detailed layout design of the proton and electron lattices is closely integrated. This makes it possible, if necessary, to add the electron ring for the e-p facility after the proton rings are in operation, with the minimum disturbance to the experimental programme.



GENERAL LAYOUT OF LSR COMPLEX

Fig. 1

2.1 The p-p Interaction Regions

Three types of interaction region are foreseen; a low-beta region for large-angle experiments requiring the highest luminosity, a general-purpose region with plenty of unobstructed space and a high-beta crossing with special optics to permit measurement of very small scattering angles well into the coulomb region. These interaction regions are not yet designed in detail, but are expected to be rather similar to those described in Ref. 1 for the normal-magnet machine. Approximate parameters are given in Table I.

Table I: Main Parameters of p-p Interaction Regions

	Low-Beta	General-Purpose	High-Beta
Luminosity (cm^{-2} s^{-1})	10^{33}	10^{31} - 10^{32}	10^{30} - 10^{31}
β_v^* (m)	$\sim$ 1	$\sim$ 14	$\sim$ 400
Crossing angle (mrad)	2 - 3	10 - 15	10 - 15
Free space rear I.R. (m)	± 5 - 7	± 60 - 80	± 15 - 20

2.2 The Proton Rings

The main lattice of the proton rings is of the separated-function FODO type with superconducting dipoles and quadrupoles. The basic parameters are shown in Table II. With the need to accommodate a third ring for electrons in the same tunnel, the ring layout requires careful consideration. At present we favour an arrangement with the two proton rings in the same horizontal plane on opposite sides of the tunnel, with an access passage in the middle. The electron ring would be either above or below the plane of the protons and to one side. With such an arrangement it should be possible to accommodate the three rings in a tunnel very little larger in cross-section than that of the SPS.

Table II: <u>Main Parameters of Superconducting LSR</u>

Nominal momentum	400	GeV/c	(injection from SPS)
Bending field	3.93	Tesla	
Betatron wave numbers	$\sim$ 24		(main lattice)
	33 - 37		(with insertions)
Number of lattice periods	96		
Period length	40.4	m	
Bending radius	340	m	
Arc radius	617.3	m	
Total circumference	$\sim$ 6	km	
Aperture radius	25	mm	(vacuum pipe)
Stacked current	$\sim$ 7	A	
Beam-beam linear tune shift	$\lesssim$ 0.005		

2.3 <u>The e-p Facility</u>

We have concentrated so far on an e-p design using a coasting proton beam for reasons outlined in the introduction. As a result of this assumption the choice of parameters for the electron storage ring is quite different from that for an e^+-e^- ring, in particular, favouring operation in a many-bunch mode.

With 400 GeV protons and 20 GeV electrons the c.m. energy $\sqrt{s}$ = 178 GeV. The design luminosity of 10^{32} cm^{-2} s^{-1} requires a near-zero crossing angle between electron and proton beams at the interaction region and therefore some means of separating the beams within a reasonable distance. This separation is produced (in the vertical plane) by means of an iron-free coincidence magnet consisting of four longitudinal conductors in a Helmholz arrangement, extending about 5 m either side of the interaction point.

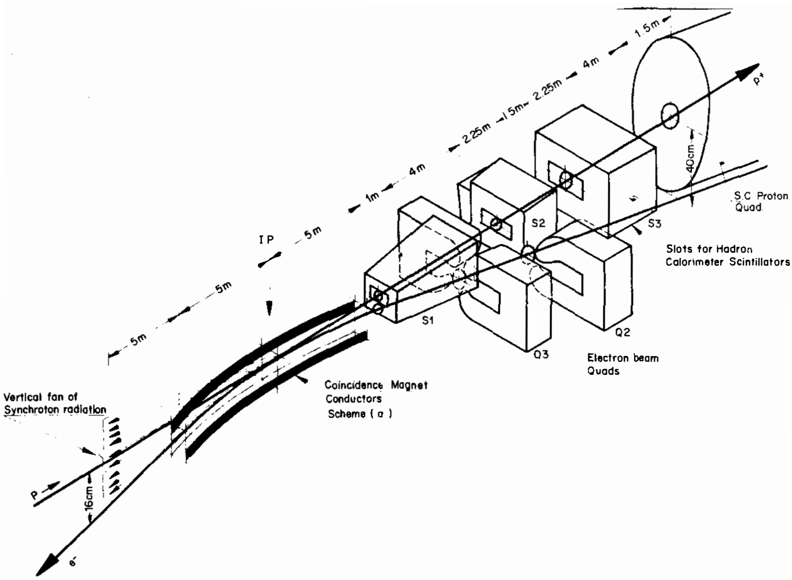
Such a magnet around the interaction point introduces, however, two main complications. Firstly, the detector arrangement and the machine components in this region have to be closely integrated, in order that the physics can benefit fully from the available luminosity; secondly, the synchrotron radiation from the electrons not only gives rise to important technological problems of heating and vacuum, but is also a potentially serious source of background from γ-p interactions, with a luminosity of $\sim 2 \times 10^{32}$ cm^{-2} s^{-1}!

These problems have been examined by a CERN e-p Working Group [2]. A trial detector arrangement was studied in order to quantify the problems arising in this type of interaction region (Figs. 2 and 3). The synchrotron radiation background has been further examined by Hoffmann [3], leading to some small changes in the magnetic field distribution in order to soften the synchrotron radiation from the interaction point. Our preliminary conclusions are that the known problems are most likely tractable but that more detailed work will be required to produce a convincing design.

2.4 Polarised Electrons for e-p

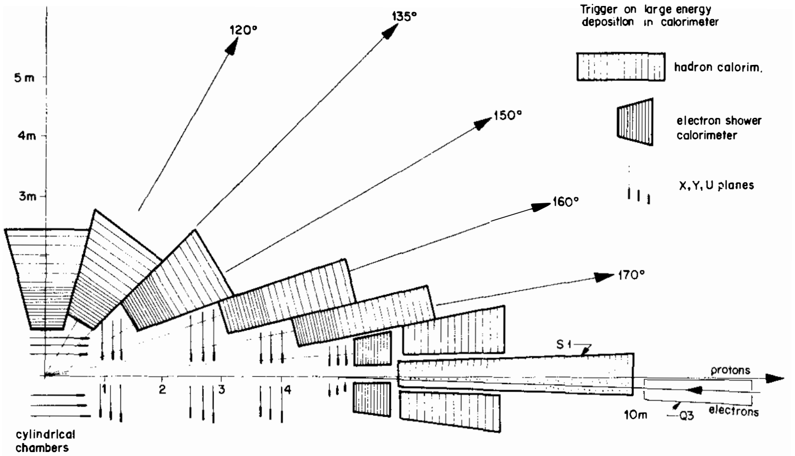
The now well-established natural polarisation of electrons in a storage ring could provide a useful means of studying weak interactions in e-p collisions. This requires that the polarisation vector be rotated from its natural transverse direction into the longitudinal direction at the interaction point. Various methods of achieving this have been described in the literature, using either transverse or longitudinal magnetic fields, or a combination of both. For high-energy electrons the longitudinal fields required are excessively strong. Methods using purely transverse fields usually result in an interaction region substantially tilted with respect to the horizontal plane, which, for e-p collisions at small crossing angles, means considerable vertical bending of the proton beam.

We have avoided these difficulties by using an alternating sequence of vertical and horizontal bending of the electron beam (Montague [4]) which adapts quite well to the e-p layout of Ref. 2. An example of such a layout in Fig. 4 shows the evolution of the polarisation vector through the bending magnets.



e - p Interaction Region **Beam Line Components** Fig 2

(Vertical scale enlarged)



Vertical Midplane Section of LSR e-p Detector Fig. 3

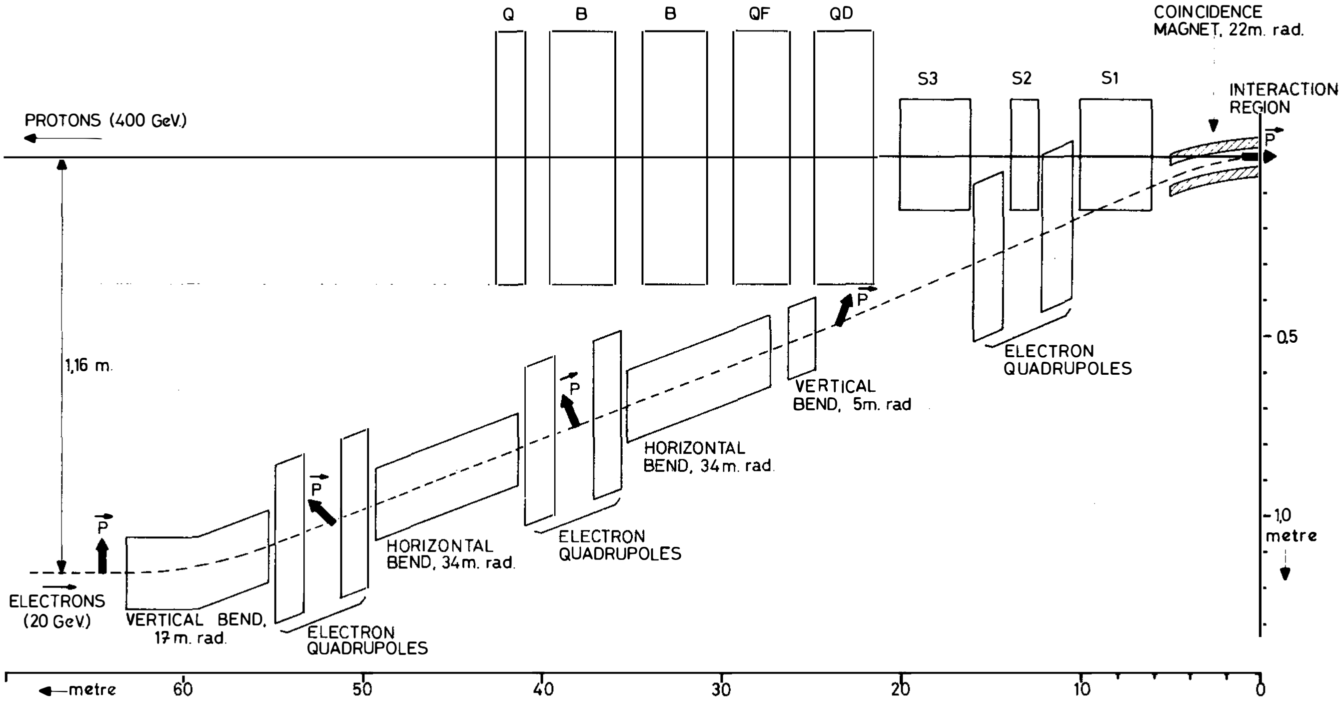


Fig.4 VERTICAL PROJECTION OF e-p INTERACTION REGION.

2.5 Electron Ring

The electron storage ring has a similar racetrack shape to the proton rings and, at least in the main bending arcs, is installed in the same tunnel. Since the two e-p interaction regions are located near the ends of these arcs, the electron beam can pass along the straight arms of the racetrack sufficiently far from the p-p interaction regions as not to interfere with their detector arrangements. At the same time this provides plenty of length for the RF accelerating cavities of the electrons, permitting a possible increase in electron energy at a later stage.

Preliminary parameters for the electron ring are given in Table III. Currently, a comparison is in progress between separated function and combined function lattices, together with a study of various wiggler-magnet schemes to control radiation damping and polarisation times as functions of energy. These parameters are therefore constantly under review.

3. Antiproton-Proton Collisions

The possibility of $\bar{p}$-p collisions has been considered since the early days of ISR studies about 15 years ago. Recent evaluations of these possibilities have been made for the ISR by Hübner et al. [5] and for the LSR by Koshkarev [6]. Their results are outlined below.

Table III: Parameters of the Electron Ring

Nominal energy	20 GeV
Radiation loss per turn	27.5 MeV
RF voltage per turn	37 MV
Beam current	0.25 A
No. of bunches	4100 or 2050
RF frequency	200 MHz
Radiated power	6.9 MW
Total RF power	10 MW
β_x^*, β_y^* (electrons)	1 m, 0.3 m
β_x^*, β_y^* (protons)	5 m, 1 m
Quantum lifetime	10 hours
Radiation damping time	30 m sec.
Polarisation time	2 hours
Beam-beam linear tune shifts	0.025 (electrons) 2×10^{-4} (protons)

3.1 $\bar{p}$-p in the ISR

The proton beam would be extracted from the PS in three turns, injected into the SPS to fill 3/11 of the circumference and accelerated to 400 GeV. The proton beam extracted from the SPS is focused on to an external target, from which the secondary beam of antiprotons is collected and transported to the ISR, where it is injected and stacked over many such cycles, following the normal ISR stacking procedure. The final circulating $\bar{p}$ current in the ISR is then proportional to three factors; the maximum proton line density in the SPS, the $\bar{p}$ conversion factor in the target, and the 6-dimensional phase-space acceptance of the ISR. Putting in our present best estimates of the various factors involved we would expect to obtain a final circulating antiproton current of about 24 μA which with 30 A of protons in the other ring would give a $\bar{p}$-p luminosity of

$$\mathcal{L}_{\bar{p}\text{-}p} \approx 5.5 \times 10^{24}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$$

Under these conditions the filling time of the ISR with antiprotons would be around 2 hours.

3.2 $\bar{p}$-p in the LSR

With two high-energy storage rings available, a more efficient procedure is possible. One first makes a full stack (∿ 7 A) of 400 GeV protons in one of the LSR rings and then ejects it on to an external target. Antiprotons are collected at ∿ 30 GeV (or possibly less), accelerated in the SPS and stacked in the other LSR ring. The cycle is repeated until the second LSR ring is full of $\bar{p}$, and the final stack of protons is left in the first ring.

The $\bar{p}$-p luminosity obtainable is then:

$$\mathcal{L}_{\bar{p}\text{-}p} \approx 2 \times 10^{29}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$$

A filling time of about a day is required for this luminosity, and proportionally less for lower values.

3.3 Stochastic Cooling

For both the ISR and the LSR, $\bar{p}$-p luminosities could be improved by stochastic cooling of the antiprotons to obtain a higher phase-space density. The feasibility of this has already been demonstrated at the ISR (Bramham et al. 7)); the reduction of effective beam height during cooling is shown in Fig. 5. The techniques of stochastic cooling are discussed by Thorndahl 8); one notes that the time scale of cooling at

28 GeV is measured in hours and depends in an important way on the performance of the feedback electronics.

If one were to use a special small cooling ring in the 2 - 4 GeV range, the scale of cooling times could be reduced to minutes, though for a smaller number of particles at a time. The choice of parameters then becomes a complicated balance between cooling energy, bandwidth and power of the electronic feedback system, required $\bar{p}$-p luminosity, acceptable accumulation times and various other considerations. The studies of stochastic cooling in progress at the ISR will give valuable information for determining the performance limits of $\bar{p}$-p collisions.

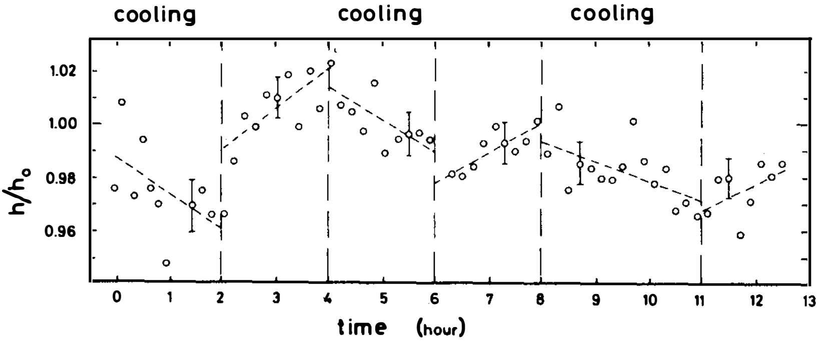


Fig.5. RELATIVE EFFECTIVE HEIGHT VERSUS TIME.

REFERENCES

1) B. Autin, D. Blechschmidt, A.A. Garren, K. Johnsen, E. Keil, B.W. Montague, J.-C. Schnuriger, C. Zettler, B.W. Zotter; 400 GeV Large Storage Rings with Conventional Magnets, report CERN/ISR-LTD/75-46 (1975).

2) The e-p Working Group; Some Remarks about LSR e-p Interaction Regions, report CERN/ISR-GS/75-33 (1975).

3) H.F. Hoffmann; Interactions of the Synchrotron Radiation with the Proton Beam in the LSR e-p Interaction Regions, report CERN-ISR-LTD/75-53 (1975).

4) B.W. Montague; Longitudinal Polarisation of High-Energy Electrons in Colliding-Beam Storage Rings, report CERN/ISR-LTD/76-2 (1976).

5) K. Hübner, K. Johnsen, G. Kantardjian; The Feasibility of Antiprotons in the ISR, report CERN/ISR-LTD/75-45 (1975).

6) D.G. Koshkarev; The Possibility of $p\bar{p}$ Colliding Beam Experiments in the LSR, report CERN/ISR-DI/75-2 (1975).

7) P. Bramham, G. Carron, H.G. Hereward, K. Hübner, W. Schnell, L. Thorndahl; Stochastic Cooling of a Stored Proton Beam, Nucl. Inst. and Meth. 125 201 (1975).

8) L. Thorndahl; Stochastic Cooling of Momentum Spread and Betatron Oscillation for Low-Intensity Stacks, report CERN-ISR-RF/75-55 (1975).

APPENDIX

Contributors to the Proton Storage Ring Studies

Autin B.	
Blechschmidt D	
Fischer G.E.	(SLAC)
Garren A.A.	(LBL)
Gourber J.-P.	
Hoffmann H.F.	
Hofmann A	
Hübner K.	
Hutton A.M.	
Johnsen K.	
Kantardjian G.	
Koshkarev D.G.	(ITEP)
Keil E.	
Montague B.W.	
Resegotti L.	
Schnuriger J.-C.	
Van Steenbergen A.	(BNL)
Zotter B.W.	