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AN e-p FACILITY IN THE CERN SPS

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A 25 GeV electron (or positron) storage ring installed in the SPS tunnel above the proton synchrotron would provide e-p collisions with a luminosity in the range of 10^{31} to 10^{32} cm^{-2} s^{-1}. The collisions would normally take place at an intermediate plateau of the SPS-cycle up to 270 GeV, and could be followed by acceleration and extraction of the proton beam for fixed target experiments. The feasibility of such a facility is demonstrated and the essential features presented.

Introduction

Collision of e-p will provide new insights for high energy physics. To this end, such facilities have been considered by nearly all High Energy Physics laboratories.

The scheme advanced here proposes to house an e-ring in the SPS-tunnel above the synchrotron,[1] thus permitting a relatively high energy at modest RF-power owing to the large radius of the SPS. It is proposed to collide the electron beam with the proton beam during an intermediate plateau at 270 GeV where the synchrotron can run in a d.c. mode.

This yields a centre-of-mass energy of 165 GeV^2 equivalent to a maximum momentum transfer squared of 27000 GeV^2, about a factor of 50 above the value which can be reached with the SPS. The addition of an e-ring would therefore permit the SPS programme on electromagnetic and weak interactions to be extended into a new unexplored energy range where a pointlike weak interaction would be stronger than the electromagnetic interaction.

Fig. 1 shows a cross-section of the SPS tunnel with the small electron storage ring positioned 75 cm above the median plane of the synchrotron.

The collisions take place in one or two of the long straight sections of the synchrotron where the electrons are brought down into the plane of the protons to cross them horizontally with a very small angle. Near the interaction point, the tunnel has normal cross-section, which limits the transverse dimensions of the detector system. However, with the moving centre-of-mass, a large fraction of the interesting physics lies within fairly small angles with respect to the proton beam, and could be studied with detectors of relatively small lateral extension.[2]

The proton ring does not need any modification except for a few elements in the interaction region. The synchrotron cycle has to be extended somewhat to accommodate a plateau at 270 GeV where the two bunched beams will be brought together.

Fig. 2 shows an example of a synchrotron cycle which provides a 50% duty factor for e-p experiments. Fixed target experiments using the extracted beams will still get, on average, 30% of the protons of normal operation; in this comparison, it was assumed that normal operation will provide them with 2×10^{13} protons in ∿ 6.8 s. Thus, this colliding-beam facility does not exclude fixed target physics.

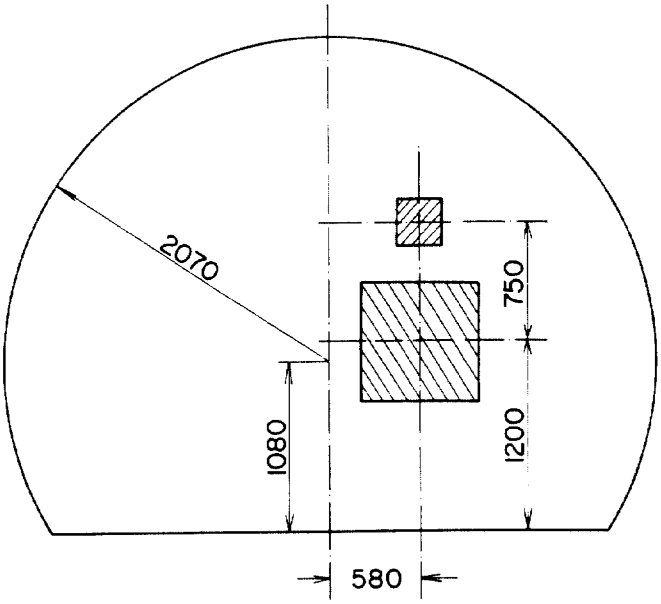

Fig. 1 - Cross-section of the SPS-tunnel at the quadrupoles with the electron ring installed above the proton synchrotron.

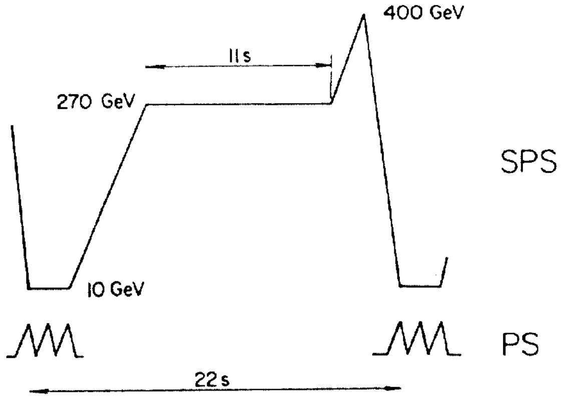

Fig. 2 - Example of an SPS-cycle with sin ϕ_s = 0.4 including a flat top at 270 GeV.

An attractive feature of this scheme is that these high-intensity proton bunches only need to live over one, somewhat extended, synchrotron cycle and not over many hours, thus relaxing long-term stability requirements for intense, bunched proton beams.

This report deals mainly with operation at 25 × 270 GeV^2. However, without any changes in the installation, the facility will operate at reduced average luminosity up to 28 × 400 GeV^2, yielding a maximum centre-of-mass energy of 210 GeV. A more detailed description of this proposal is given elsewhere.[3]

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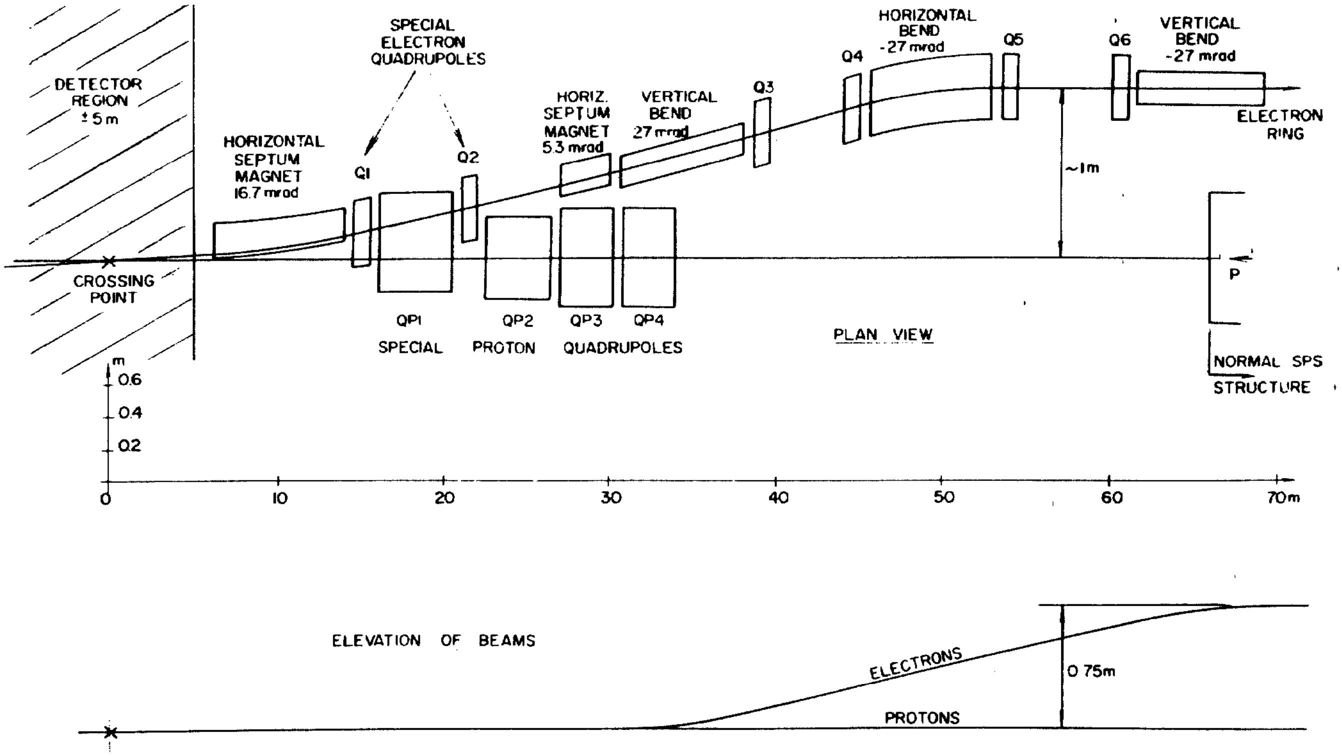

Fig. 3 - Geometry of interaction region

The interaction region

Since it is important not to exclude the possibility of working with either electrons or positrons, elements common to electron and proton beam must be avoided. This excludes zero crossing angle. On the other hand, the finite crossing angle should be very small to get maximum luminosity. It is determined by the septum which bends the electrons away from the protons to get enough separation at the first focusing elements. Since the horizontal emittance is larger than the vertical one, horizontal crossing was chosen. Fig. 3 shows a possible layout for a crossing angle of 5 mrad.

Horizontal and vertical ring separation can be accommodated within the normal cross-section of the SPS tunnel. The first of the septa has a stepped field increasing from ∿ 0.1 T to 0.2 T to soften the synchrotron radiation directed towards detector and counter-rotating protons. The first focusing elements are special septum quadrupoles which fit between the two beams. The p- and the e-insertions are fully matched to the lattice for particles on central orbit.

Radiative polarization of the electron beam is expected. The polarization vector will be rotated into the longitudinal direction by a combination of vertical and horizontal bends.[4] The intersection layout shown in Fig. 3 is compatible with this requirement.

Performance

Given the energy, the lattices and the proton injector, one obtains the parameters given in Table I.

The permissible tune shift of the protons is increased to 0.01 in view of the fact that the protons have to sustain it for only ∿ 10 s and not for hours as in a storage ring. During acceleration, the two beams will be separated vertically by a local closed orbit bump to avoid excessive proton tune shifts at low energies. The electron tune shifts would tolerate an increase in proton current by a factor 2 once one has learned to handle such an intensity. The luminosity would increase by the same factor.

In order to synchronize the electron bunches with the proton bunches, the average radius of the electron ring is about 13 mm larger than the SPS radius and the protons must be displaced inwards by 10 mm at 145 GeV and 10 mm outwards at 400 GeV. The electron beam must remain centred to maintain radiation damping for all oscillation modes.

Table I - Performance

		Protons	Electrons
Peak luminosity	L cm^{-2} s^{-1}	0.5×10^{32}	
Energy	E GeV	270	25
Total number of particles		2×10^{13}	1.5×10^{13}
Number of equidistant bunches k_b		60	
Crossing angle	α mrad	5	
Beta-functions at crossing ($\alpha_p^* = 0$)	β_x^* m	6.5	1.5
	β_y^* m	0.6	0.3
Circumference	2πR m	2π 1100	2π 1100.013
Beam size at crossing	σ_x^* mm	0.35	0.35
	σ_y^* mm	0.07	0.03
Bunch length	σ_s mm	300	30
Energy spread	σ_E/E	0.8×10^{-3}	0.8×10^{-3}
Beam-beam tune shifts	$\Delta Q_x/\Delta Q_y$	0.01/0.01	0.006/0.014

Electron ring

The electron ring has virtually the same geometry and lattice as the synchrotron except that the elements are much smaller, need less power and cooling. The transverse dimensions (w × h) of the dipoles are about 28 × 14 cm^2, and of the quadrupoles 30 × 30 cm^2. The weight of each element is $\sim$ 2 t. The power dissipation is less than 1 MW at 25 GeV. Since these elements are conventional, one could build them rather quickly. Much of the installation could take place during normal shut-downs of the SPS, thus minimizing interference with SPS operation.

Parasitic loss into higher modes and bunch lengthening will be minimized by employing the same vacuum pipe wherever possible. Its dimensions are $w = \pm 45$ mm and $h = \pm 30$ mm allowing for a 10 mm peak-to-peak closed orbit distortion.

The RF system is assumed to operate at a frequency of 200 MHz. However, other frequencies will be considered if valid reasons are found. The shunt impedance was obtained by scaling from PEP and SPEAR.

Table II - Parameters of the e-ring at 25 GeV (30 GeV)

Bending radius	ρ = 740 m
Tune	Q = 28
Energy loss into synchr. rad.	eU_0 = 47 (97) MeV/turn
RF frequency	f = 200 MHz
Power loss { synchr. rad.	P_s = 4.9 (10) MW
cavity fund.	P_c = 2.5 (10) MW
Cavity shunt impedance	Z_c = 15 MΩ/m
Polarization time	τ_p = 100 (40) min

Injection into the e-ring is at 5 GeV and a fast cycling synchrotron is needed. If an injector like NINA is used in combination with a wiggler magnet it takes 7 min to fill all 60 electron bunches. More elaborate schemes are required to get an acceptable positron filling time.

Beam handling in the PS and the SPS

The SPS is supposed to be filled by three PS-pulses each consisting of 20 bunches having the right length to fit into one SPS-bucket at the injection energy of 10 GeV. Each PS-pulse will consist of $\sim 0.7 \times 10^{13}$ protons, which is comfortably within the present performance of the PS. The bunches will be shortened in the PS before transfer by bunch shaping on the unstable fixed point of the RF buckets as proposed by D. Boussard. Kickers with fast response times will be required in the PS and the SPS to place the bunches correctly in orbit.

The expanded RF system of the SPS will provide enough acceptance for these high intensity bunches although the beam loading will be noticeable due to the low stored energy of the accelerating tanks. Longitudinal stability requires a controlled blow-up of the bunch area by a substantial factor yielding a bunch 60 cm long at 270 GeV. For the same reason, the acceleration rate has to be decreased somewhat, which is taken into account in Fig. 2.

Performance at other energies

The machine is conceived as a missing-RF machine. Thus in the first stage, the number of electrons will be limited by the available RF power (7.4 MW) above 25 GeV. All other machine components would be capable of operation to 30 GeV.

It is proposed to use a wiggler system [5] or variable tune [6] to control the beam size for optimum performance at all energies. Fig. 4 shows the luminosity variation if the electron energy is held constant. Considering also the luminosity variation for constant proton energy indicates that to reach centre-of-mass energies below the nominal value, it is better to reduce the electron energy, while to increase the centre-of-mass energy, it is better to increase the proton energy. However, luminosity is not the only consideration relevant for this choice. The kinematic of the collisions may impose more dominant constraints.

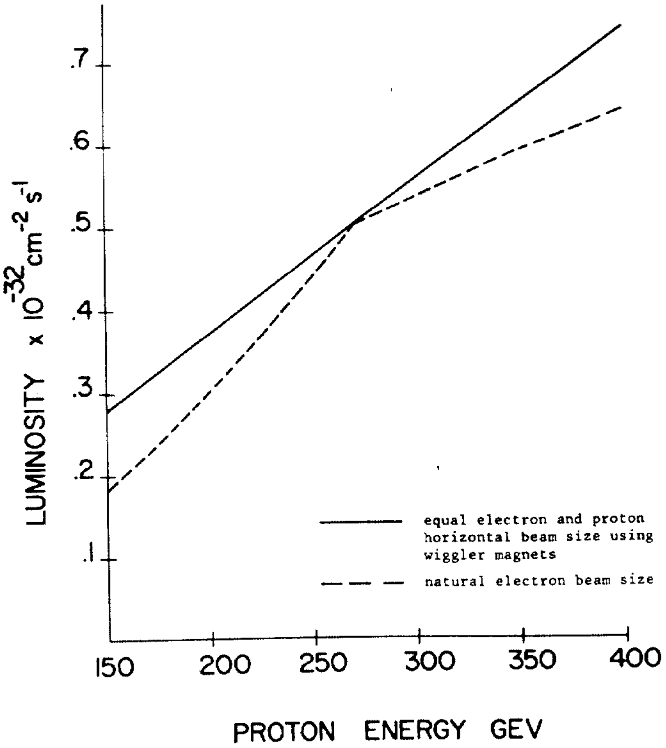

Fig. 4 - Luminosity variation for 25 GeV electrons against protons of different energies.

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References

1. "The 300 GeV Programme"; CERN/1050 (1972)
2. "e-p Working Group"; CERN Report 76-12 edited by L. Camilleri (1976) 161
3. R. Billinge et al.; CERN Int. rep. ISR/76-50 (1976)
4. B.W. Montague; CERN Int. rep. ISR/76-2 (1976)
5. J.M. Paterson, J.R. Rees and H. Wiedemann; Report PEP-125 (1975)
   A. Hutton; Part. Acc. 7 (1976) 177
6. J. Rees and B. Richter; Report PEP-69 (1973)