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THE STATUS OF CHEER

presented for the CHEER group by

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The Canadian High Energy Electron Ring (CHEER) was conceived as a Canadian contribution toward building an electron-proton colliding beam facility. It was assumed that the electron ring would be built tangent to one of the high energy proton machines in the United States, notably the Tevatron or Isabelle. The Tevatron was chosen as the proton machine for the design study(1) because it is expected to have available protons of the highest energy in the world within the forseeable future. The Fermilab project, at the time of the design study, also appeared to be closer to realization than Isabelle. The CHEER project, right from the outset was considered to be international in scope, and physicists from the United States as well as Europe participated in many phases of the design. At present, the National Science and Engineering Research Council (NSERC) is considering a request for 2.2 million dollars for a more detailed design and engineering study.

The choice of the Tevatron as the proton machine leads to constraints being placed on the maximum permissible electron energy in CHEER as well as the maximum luminosity that can be expected. The choice of the Tevatron also implies limited running time for an e-p experiment at Fermilab, for within the present design framework it is not possible to run the external target program and the e-p program simultaneously. All these difficulties are offset by the consideration that it would be possible to have an e-p collider operational at Fermilab by 1985 at the highest possible proton energies, three to five years earlier than anywhere else.

The goal of the CHEER group was to produce a design of an electron storage ring tangent to the Tevatron at DO that would store electrons or positrons that could be longitudinally polarized at the interaction point with both helicities either for e^+ or e^- being available. Of course one also desires a high electron energy and a large luminosity.

Of particular interest are the interaction region and the polarization scheme. The Tevatron superconducting magnet DC heat load limit require that the electron energy be less than or equal to 10 GeV

The Interaction Region

One of the fundamental constraints on the interaction region is that the Tevatron long straight sections allow a maximum of 50 metres free space in which to install the detector and bring the electron beam onto a colliding orbit. Luminosity considerations further constrain the orbit to a zero degree crossing angle. The necessary bending of the electron beam in the interaction region results in moderately high levels of synchrotron radiation in the interaction region. Another major consideration is the lifetime of the circulating electron beam. In order not to limit the lifetime by the size of the beam pipe, we have used an aperture criterion of $\pm 15\sigma$ throughout the interaction region (recent CESR data suggest that $\pm 12\sigma$ may not be sufficient).

The use of the Tevatron in a colliding e-p facility requires the introduction of a low-beta long straight section in order to achieve the necessary luminosity. Several proposals for low-beta insertions are outlined in the 1979 Tevatron design report in the context of the $\bar{p}$-p colliding beam proposals. Values of β^* as small as 1 metre are considered in that report(2). Unfortunately, all of these type II designs require extra quadrupoles in the long straight section reducing the available free space to less than 16 m. The demands of e-p differ from $\bar{p}$-p in the major respect that it is imperative to minimize the electron synchrotron radiation. This means that only soft bends can be used to separate the two beams. Thus, we have chosen the type I low-beta insertion, which allows 50 metres between the cold to warm transitions at either end of the long straight section. This insertion has the added advantage of requiring minimal modifications to the Tevatron. The major drawback is that β^* as low as 1 m cannot be achieved.

The changes required in the Tevatron lattice consist of replacing existing quadrupoles with stronger, independently powered, 3-shell quadrupoles, each 4 m in length. With this arrangement a β^* of 10 m can be reached with a β_{max} of 250 m. Lower β^*s can be achieved, but β_{max} increases correspondingly. The critical factor which determines the minimum β^* achievable is the largest β_{max} tolerable (located in the 3-shell quadrupoles). As β_{max} (and therefore beam size) increases, the beam becomes more sensitive to the higher order field harmonics in the superconducting dipoles. This could result in instabilities. We assume 500 m for β_{max} (β^* = 5 m) at 1000 GeV as a reasonable working value on which to base luminosity calculations. A value nearer 1000 m (β^* = 2.5 m) may be achievable, but it is difficult to provide a more accurate estimate of β^* without experience of the Tevatron in view of the possible operational complexity of this machine.

Injection into the Tevatron at 150 GeV may prove difficult with β_{max} in the 500-1000 m range due to the increased size of the beam at lower energy. An operational scenario may require the beam to be injected, accelerated and stored with β^* = 10 m. This value would then be adiabatically reduced to the lowest possible stable value by ramping quadrupoles 1 to 8.

To achieve the required low value for β_e^*, two sets of opposite polarity quadrupoles are located at each end of the detector. The circulating proton beam passes through these quadrupoles. We have not yet calculated their detailed effect on the Tevatron lattice, but given the high momentum of the proton and the large changes already introduced to provide low β_e^*, no difficulty is anticipated.

A possible electron insertion is displayed in Figure 1. The insertion is symmetric about the intersection point and only the downstream electron side is shown.

The main feature of this insertion is a series of progressively softer bends as the intersection is approached. This is dictated by the necessity to minimize the synchrotron radiation near the interaction region in order to reduce to manageable levels both the heat load in the Tevatron super-conducting magnets and the background in the detector.

The unique feature is the final softbend. M1 is an air-core dipole running the entire 13 metre length of the detector. A uniform 51 qauss field is provided by four anodized aluminum 1-turn coils sandwiched between two tubes, the inner one stainless steel, the outer one

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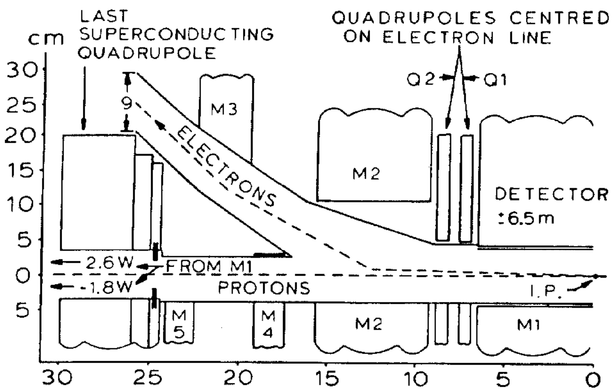

Fig.1 The electron insertion

aluminum. The 8 cm bore is large enough to achieve a vacuum of 10^{-11} torr and also provide $\pm 15\sigma$ aperture for the electron beam at either end of the detector. Adequate cooling for the resistive power loss in the coils ($\sim$3 KW) is provided by water flowing in the 3 mm gap between the tubes. The mean raduation length of this assembly is about 5%.

Immediately following the detector is a free space of 35 cm for vacuum pumping, beam pipe flange, plumbing, etc. before the first two quadrupoles, Q1 and Q2 of the electron lattice. The proton beam passes through these quadrupoles 0.5 mm off axis. Space permitting, it would be better to have another bend before Q1 and Q2 so that the electron and proton lattices are decoupled. A gradual bend for low synchrotron radiation into the Tevatron and detector necessitates a long drift to separate the beams far enough to fit in even half-quadrupoles. This would put them too far from the intersection point for a reasonable electron lattice.

The long bend M2 deflects the electron beam into its own beam pipe. The C-magnet M3 bends the electrons out past the last superconducting quadrupole. A dogleg, M4 and M5, in the Tevatron beam line compensates the bending of the protons in M1, M2 and the off-centre quadrupoles, Q1 and Q2. The only critical magnet in this group is the septum M4: the pole tips may have to be shaped to prevent stray field from disturbing the electron beam. Some variation in the M2-M5 scheme may be possible by making M2 an even softer bend. This would move M4 closer to M5. Both M3 and M4 would have correspondingly larger fields.

In Figure 1 the beam pipe is shown only schematically. Connecting flanges are necessary before and after M2, after M4 and after M5. Downstream of M3 the electron pipe can become the standard pipe in the rest of the electron ring. There is room inside M2 and M3 for distributed vacuum pumping and ample space between for extra pumping. Cooling the beam pipe from the synchrotron radiation head load of M2 and M3 presents no serious problems.

Synchrotron radiation from the electron beam reaching the Tevatron appears to the superconducting magnets as a DC heat load. At present, there is no detailed information on the ability of the magnets to absorb heat in the DC mode while maintaining their superconducting state. The available experience with AC power dissipation suggests that to prevent the creation of bubbles in the helium, a heat load of greater than 5 watts on the dipoles should be avoided (this does not imply that the magnets would turn normal, but it seems prudent to use this as the criterion). The quadrupoles, being somewhat smaller, are more sensitive and a value of 3 watts should be used. These power levels assume a uniform distribution of the load along the length of the magnet, which is the case in our insertion design. The levels are probably quite conservative since the critical energy of the radiation is so low that it is essentially all photo-absorbed very near the surface of the magnet and never reaches the helium.

From Figure 1 it can be seen that the only sources of radiation impinging on the superconducting aperture are M1, Q1 and Q2. A pair of remotely adjustable collimators set to ±2 cm protects the superconducting quadrupoles from almost all of this radiation and blocks the radiation from the beginning of the bend in M2. The ±2 cm aperture limitation imposed is similar to that of the extraction Lambertsons and should impose no operational restrictions.

About 4 watts from M1 passes through the collimators and is distributed along almost the whole length of the last two superconducting dipoles. Q1 and Q2 radiate about 10 watts and half of this is intercepted by the collimators. Most of the rest hits in the last two dipoles; only a small fraction illuminates the superconducting quadrupoles. We are therefore somewhat below 5 watts per dipole and well below 3 watts per quadrupole. A detailed calculation of the Q1 and Q2 radiation will allow an optimization of the M1 bend angle to minimize the total heat load on the superconducting magnets from M1, Q1 and Q2.

The Polarization Scheme

The natural transverse polarization must be rotated into a longitudinal orientation just prior to collision with the proton bunch. On emerging from this region an equivalent operation must restore the polarization to its original transverse direction. The rotation of the polarization can be accomplished by a sequence of vertical and horizontal bends. Only one sense of longitudinal polarization is possible within a fixed geometry and provision of the other sign demands a rearrangement of the bends. The insertion region in the machine includes all these magnets and the straight section in which collisions take place. A conceptual scheme for spin rotation is illustrated in Figure 2. The bends are designed for $\pi/2$ rotation and a sequence of two vertical and two horizontal bends brings the polarization into the longitudinal state or returns it to its original orientation. The path shown by a dashed line would result in right-handed electron and positrons, while the other sign of polarization is achieved in the solid path. To effect a change in helicity requires a displacement of magnets on either side of the interaction region.

The design of the polarization insertion must be integrated with the lattice design and with a concurrent study of depolarization in the machine. The theoretical work on depolarization provides a basis for cautious optimism that such a design effort will be successful.

Depolarization in electron storage rings is caused by various mechanisms, such as integer resonance depolarization, stochastic depolarization, vertical closed orbit distortion depolarization and several others[3]. All of these phenomena are under investigation, the machine parameters being optimized to limit these effects.

The Injection Scheme and RF

An injection scheme that will fill the CHEER ring with either electrons in 2 second or with positrons within 10 minutes has been designed.

In our proposal, a 300 MeV Linac in conjunction with a 300 MeV accumulator ring creates a single bunch containing 10^{11} electrons or positrons. When this bunch has been formed and suitably damped, it is injected into a booster synchrotron and accelerated to 2 GeV before being transferred to CHEER. A total of 42 bunches are needed to completely fill CHEER, leading to a circulating beam current of 120 milli-amperes. An RF system, operating at a frequency of 804MHZ continuously replaces the 1 Megawatt of synchrotron radiation produced at 10 GeV.

The Luminosity

We have assumed that the Tevatron protons would be rebunched by a factor of 7 from 1113 bunches to 159 bunches. It is estimated that the rebunching process would be 50% efficient leading to bunches containing 6×10^{10} protons of 2 m in length. Because of the finite proton bunch length only zero degree crossing will lead to reasonable luminosities, so as shown in the interaction region discussion, we have designed for head-on collisions. Also because of the finite proton bunch length we must use integral values for the beam size and betatron functions rather than the ones encountered at the geometrical interaction point.

If we assume a uniform longitudinal distribution of protons, and neglect the electron bunch length as well as the transverse variation of the proton bunch size with length we obtain

$$\Delta\nu_e = k_e \cdot \left(\frac{n_p}{\sigma_p^2}\right) \left(\beta_e^* + \frac{\ell_p^2}{48\beta_e^*}\right) \tag{1}$$

$$\Delta\nu_p = k_p \cdot \frac{n_e \, \beta_p^*}{\sigma_e^{*2}\left(1 + \frac{\ell_p^2}{48\beta_e^{*2}}\right)} \tag{2}$$

Since M_p, G_p, ℓ_p are all determined by the Tevatron design or existing knowledge of the proton machine at Fermilab, β_e^* is determined by a choice of $\Delta\nu_e$. In fact we can choose β_e^* so that $\Delta\nu_e$ is a minimum. If we choose $N_e = 10^{11}$, choose the minimum β_p^* consistent with good Tevatron operation, then the maximum permissible proton turn shift $\Delta\nu_p$ determines the minimum electron emittance. For $\beta_p^* = 5$ m, $\beta_e^* = 0.3$ m, $\Delta\nu_e = 0.025$, $\Delta\nu_p = 0.005$ we obtain a luminosity of 3×10^{31} cm^{-2} sec^{-1}.

Because the Tevatron proton bunches are of equal geometric size in both transverse directions, to maximize the luminosity, we have to introduce a coupling of 1 in the electron beam between the vertical and horizontal directions. This in turn depolarizes the beam. Adequate polarization may be achieved with a coupling of K = 0.2, and a corresponding loss in luminosity of a factor of 2.

Future Developments

The polarization scheme will undergo extensive study to understand the effect of all known depolarizing mechanisms including the effects of the spin rotation magnets and the superconducting solenoid in the detector. The Tevatron rebunching procedure will also be reviewed in an attempt to minimize the proton bunch length.

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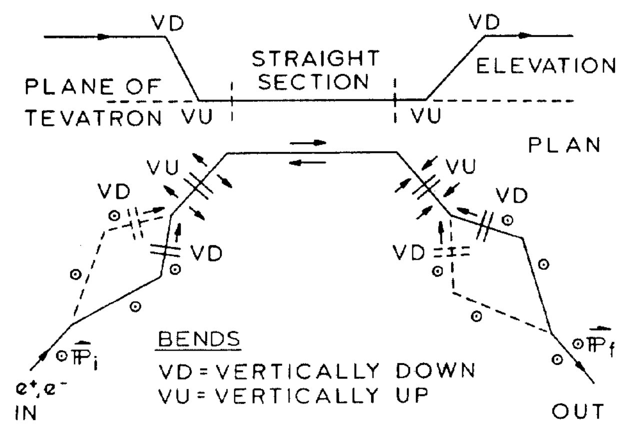

Fig.2 Scheme for spin rotation