EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

NP Internal Report 75-16
4 December, 1975

A POSSIBLE SCHEME TO OBTAIN e^-e^- AND e^+e^- COLLISIONS

AT ENERGIES OF HUNDREDS OF GeV

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GENEVA

1975

1. INTRODUCTION

The construction of a very large electron-positron storage ring has been recently approved in Western Germany and a similar project is under consideration in the United States. For these machines the maximum value of the centre-of-mass energy, about 50 GeV, is fixed mainly by the large power that must be supplied to the beams to compensate for the synchrotron radiation losses. Because of these losses, the storage ring scheme is today considered unrealistic for energies an order of magnitude larger than 50 GeV. It is therefore worth discussing alternative solutions, even if they cannot become practical in less than ten or fifteen years.

For the sake of our argument, we consider a centre-of-mass energy of 300 GeV, that corresponds to the so-called unitarity limit of weak interactions. At these energies, weak interactions dominate the cross-section and electron-electron collisions are almost as interesting as electron-positron collisions. We thus start by considering the simpler case of an electron-electron colliding beam machine.

2. ELECTRON-ELECTRON COLLISIONS

The working principle of a conventional, very high energy, electron storage ring can be characterized as follows: "use" the same electron many times, by keeping it on a circular orbit, and accept to throw away energy through incoherent synchrotron radiation. The opposite possibility is considered here: "use" each electron only once, by having it moving on a straight path without radiation losses, and, after the interaction point, recover coherently a large fraction of its energy.

For e^-e^- collisions this can be achieved with the scheme shown in Fig. 1. Two collinear, superconducting standing-wave linacs accelerate two continuous beams of electrons up to, say 150 GeV, and magnetic lenses focus them to very small transverse dimensions in one, or more, low β interaction regions. After crossing, the electron bunches give back their energy to the electromagnetic field of the opposite linac, since there the electric field will be given the opposite phase to decelerate them.

Stationary conditions are thus achieved and in each linac the energy given back to the electromagnetic field by the decelerated electrons is used to accelerate the beam which moves in opposite direction. If the currents of the two beams are equal, the only lost energy is the small natural dissipation in the superconducting cavities and that still retained by the decelerated bunches at the end of the "uphill" path. This latter energy can be smaller than 1 GeV, i.e. less than 1% of the electron energy at the interaction points. The largest power consumption would then be due to cavity losses and the thermodynamic inefficiency of the low-temperature cryogenic systems.

We suppose that the beams are separated along the whole length of the linacs so that beam-beam collisions happen practically only in one crossing region. In this crossing region the luminosity has the form

$$L = \frac{f}{2\pi} \frac{N_1 N_2}{r_1^2 + r_2^2}, \quad (1)$$

where f is the frequency of the bunches (which cannot be larger than the linac frequency), $N_{1,2}$ are the number of electrons per bunch and $r_{1,2}$ are the r.m.s. transverse radii of each of the beams, supposed to be gaussian and circular. We define the normalized invariant emittance, measured at two standard deviations of a gaussian and at a point where the local β -function has a minimum, as:

$$\epsilon = \pi (2r) \frac{2\Delta p}{m_e c}, \quad (2)$$

where Δp is the r.m.s. transverse momentum of the electrons in a bunch. If the β -function minimum is β^* and the electron energy E , one has

$$\frac{c\Delta p}{E} = \frac{r}{\beta^*}$$

and

$$\epsilon = 4\pi \frac{r^2}{\beta^*} \frac{E}{m_e c^2} = \frac{4\pi r^2 \gamma}{\beta^*}. \quad (3)$$

Introducing the average currents $I_{1,2}$ of the beams, Eq.(1) takes then the form

$$L = \frac{I_1 I_2}{e^2 f} \frac{\gamma}{\beta^*} \frac{2}{\epsilon_1 + \epsilon_2} \quad (4)$$

Note that, for a given power in the beams, the luminosity can be increased by filling a smaller fraction of the buckets, thus reducing f in Eq.(4).

For an L-band linac with one quarter of the buckets filled ($f \approx 250$ MHz), $I_1 = I_2 = 10$ mA and $\beta^* = 0.2$ m (the value assumed for PEP and PETRA) at $E = 150$ GeV, one has $L = 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$ for $\epsilon_1 = \epsilon_2 \approx 7.3 \cdot 10^{-6} \pi \text{ m}$. This emittance is obtained in low energy commercial linacs which accelerate ~ 150 mA up to 20 MeV⁽¹⁾. At present, SLAC emittances are larger by a factor ~ 250 because the beam break-up effect limits the current to 50-80 mA at 20 GeV. However, at 10 mA the emittance can certainly be reduced considerably and it should be possible to avoid undue emittance growth of low-current beams during acceleration.

Eq.(3) gives for the r.m.s. radius of the bunches at the interaction point $r \approx 2 \cdot 10^{-3}$ mm, a very small size indeed, the practical implications of which need further study.

3. ELECTRON-POSITRON COLLISIONS

We now consider an electron-positron colliding beam machine. The net flow of current in the system is zero if at both far ends of the superconducting linacs electron and positron bunches are injected in opposite phases. Since positron sources yield much lower phase space densities than electron sources⁽²⁾, using the simple collinear scheme it would be difficult to achieve e^+e^- luminosities in excess of $10^{30} \text{ cm}^{-2} \text{ s}^{-1}$. To reduce the positron transverse emittance one could consider the following scheme. At each end of the system, positrons are produced in a converter either from the main decelerated electron beam or, possibly, from a dedicated electron linac. The positrons are accelerated and injected continuously

into a damping ring with fast damping properties, stored for a large number of revolutions and ejected continuously into the main linac with the required small transverse emittance. In this scheme the luminosity would be given by Eq.(4), where the positron current would be much smaller than the electron current. Since the electron and positron bunches would be used only once, there would be no problem with the beam-beam Q-shift and the slow instabilities typical of storage rings. We have not yet, however, found a plausible method of continuously injecting and extracting positrons from the damping rings, so that the idea of throwing away positrons after a single traversal of the system does not seem, at present, very good.

An alternative solution could be based on the idea of recirculating the positron bunches after most of their energy has been recuperated and at the same time using radiation damping at low energy to reduce the beam emittance. This is shown schematically in Fig.2. The two recirculators work at ~ 1 GeV and have the main function of bending the positron path by $\sim \pi$ at an energy much smaller than the collision energy, so that radiation losses are small and can easily be compensated. These rings can then act as damping rings to reduce the positron emittance to a value comparable to that of the electrons. The system is now rather similar to a normal circular storage ring and the luminosity may be limited by the beam-beam Q-shift according to the usual equation ($I = I_1 = I_2$):

$$L = \frac{I \Delta Q \gamma}{2e r_e \beta^*} \quad , \quad (5)$$

where r_e is the electron classical radius. With $E = 150$ GeV, $I = 10$ mA, $\Delta Q = 0.06$, $\beta^* = 0.2$ m, one obtains $L \approx 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$ per crossing point. To reduce the contribution of the incoherent beam-beam interaction along the linacs it will be necessary to separate the beams transversely. It will also be necessary to stabilise any coherent beam-beam effects. This recirculation arrangement has clear advantages for obtaining high e^+e^- luminosities, but is subject to the usual instabilities of normal storage rings and may require careful damping of the large number of excitation modes connected with the large number of bunches.

4. CONCLUSIONS

In our opinion the above simple considerations show that the proposed schemes are worth more thoughts and investigations. It is clear that there are formidable, and maybe even fundamental, problems to solve, and that, at the present level, the technology of superconducting cavities is very far from satisfying the requirements, and certainly too costly. We note that, if this kind of machine can be built, its cost, being a linear function of the energy, will become increasingly competitive and then advantageous in comparison with that of conventional storage rings. However, at present it is not possible to exclude that the cross-over point in cost between storage rings and this machine is so high that our scheme will never be of practical use, even for a worldwide collaboration.

Being aware of all these shortcomings, we think that this hypothetical colliding beam accelerator deserves the greek name "péloron", which means "object of enormous dimensions, prodigious being, monster". Only if it will be built shall we read in the letters of this ancient name its description: Positron and Electron Linear Oscillator Radiating Only Negligibly.

After this work was completed, I have been informed by Albert Hofmann that he had considered the application of the same principle to a colliding beam facility.

I am very grateful to Bryan Montague and Kjell Johnsen for devoting much of their time to discuss the possibilities of this scheme, to estimate parameters and to invent solutions.

I warmly thank Giuseppe Cocconi for many stimulating discussions and for continuous advice, and Hugh Hereward for reading the manuscript and suggesting various improvements.

REFERENCES

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2. F. Amman, Ibid. p. 535.

Fig. 1 Schematic drawing of the collinear electron-electron colliding beam machine.
 If accelerating fields of ~ 10 MV/m can be achieved, the length of the superconducting linacs has to be ~ 15 km to obtain $(150 + 150)$ GeV collisions.

Fig. 2 In this scheme the electron bunches are dumped after a single traversal while, to save positron current, the positrons are recirculated in a low energy ring.