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# COMMENTS ON THE DESIRABILITY AND FEASIBILITY STUDY FOR $e^+e^-$ COLLIDING RINGS WITH $L \sim 10^{32}$ $sec^{-1}$ $cm^{-2}$ AND $E_{cm} = 120$ GeV

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## 1. PHYSICS MOTIVATIONS

The recent observation of the neutral currents$^{1)}$ and the remarkable agreement of the result with the Weinberg-Salam model$^{2)}$ suggests that both charged and neutral intermediate vector mesons could exist in the relatively near-by mass range 30-100 GeV/c$^2$. Within the framework of the Weinberg-Salam (W-S) model, masses are determined by the only free parameter of the theory, the Weinberg angle $\theta_V$.

Although for the moment these are simple speculations, in the not too distant future, neutrino experiments now under way at Fermilab$^{3)}$ and later at the CERN SPS, will reach a potential sensitivity capable of detecting propagator effects in the range predicted by the W-S model. We believe it likely that these experiments would verify such a prediction, giving model-independent evidence for a finite value of propagator mass. The present sensitivity of the neutrino experiments already sets a limit > 15 GeV/c$^2$ and puts the direct production of eventual quanta of the weak field outside the range of machines at present proposed, such as PEP, PETRA, and EPIC. However, the machines will test the existence of propagator effects due to a neutral vector boson Z$^0$ in the mass range of the W-S model.

It is expected that in the forthcoming years we shall find a substantial amount of *indirect* evidence either in favour of or against the W-S model and the existence of a new mass scale of weak interactions. In either case the study of weak interactions, up to centre-of-mass energies of 120 GeV, is of the most fundamental interest. For instance, even in the extreme case of a weak interaction cut-off at the unitarity limit (∿ 300 GeV), we expect a reduction of cross-sections at $E_{cm}$ = 120 GeV of the order of

$$\frac{\Delta\sigma}{\sigma} = \frac{1}{\left[1 + \left(\frac{120}{300}\right)^2\right]^2} = 0.74 \; .$$

In this case the cross-section will be dominated by weak interactions, the original photon propagator surviving only as a "correction" term of order $(37/120)^2 \simeq 10\%$.

It has been pointed out that proton-proton colliding beams could also probe weak interactions at very high energies$^{4)}$, and more specifically that the production of intermediate bosons by the Drell-Yan mechanism of parton-antiparton annihilation is expected to be relatively large (∿ $10^{-33}$ cm$^2$). The estimates are however theoretically uncertain and so is the validity of scaling for this domain. Furthermore, intermediate bosons will be produced with a high ($\gtrsim$ 20) associated hadron multiplicity, which makes the experimental observation more difficult. Instead, in the reaction initiated by $e^+e^-$ colliding beams the process can be calculated exactly and the production is elastic, i.e.

$$e^+ + e^- \rightarrow W^+ + W^- \qquad e^+ + e^- \rightarrow Z^0$$

with a two-body kinematics which is well defined. It is evident that in the study of purely leptonic particles, lepton-lepton collisions are vastly superior.

Finally, $e^+e^-$ colliding beams are a powerful tool for the search for new particles. In a special class are the neutral vector mesons with the same quantum numbers as those of the photon which are directly produced in production-type processes (such as the ψ-J). Another class is that of point-like, charged particles: they can be produced in pairs with known and large cross-section. Examples of these particles are (besides the $W^\pm$) heavy leptons, quarks, charged gluons, and so on. In general, one can say that at very high energy, $e^+e^-$ collisions liberate everything which exists and is charged, provided form factors do not depress the cross-section too much.

An important choice for the design of the machine is the desired value of the luminosity. The reference reaction has been taken to be $e^+ + e^- \rightarrow \mu^+ + \mu^-$, which at high energy has the cross-section $\sim (\pi/3)\alpha^2\lambda\!\!\!^{-2}$. Taking E = 120 GeV, the pure e.m. cross-section is $\sigma(\mu^+\mu^-) \leq 10^{-35}$ cm$^2$. Note that this will by now be a small fraction of the cross-sections since weak interactions are perhaps a factor of 10 larger, and also note that many channels are occurring at the same time. For instance, the production of the $Z^0$ at the resonance will be

$$\sigma(Z^0) = \sigma(\mu^+\mu^-) \cdot \frac{9}{2}\, \pi B_i B_f \left(\frac{\Gamma}{2\Delta E}\right) \frac{1}{\alpha^2} ,$$

where $B_i$ and $B_f$ are the branching ratios of $Z^0$ into the initial and final states. Taking $\Gamma = 1$ GeV, $B_i = B_f = 1/10$, and $2\Delta E = 1$ GeV, one finds

$$\sigma(Z^0) \cong 2500\, \sigma(\mu^+\mu^-) ,$$

and the $Z^0$ cross-section will indeed be very large. On the other hand, the cross-section for production of a pair of $W^\pm$'s is of the order of the one for $\mu^+\mu^-$.

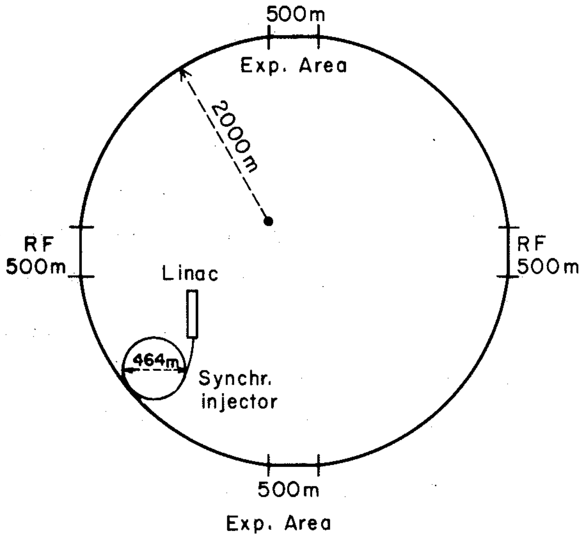
It appears reasonable to suggest a design luminosity of $10^{32}$ sec$^{-1}$ cm$^{-2}$, which would still give 1 ev/hour from e.m. production of $\mu^+\mu^-$ pairs for a reasonable solid angle of detection. A larger luminosity, although useful, requires a prohibitive amount of RF power.

## 2. GENERAL DESCRIPTION: SIZE

Because of the high energy and the large amount of synchrotron radiation, a large magnetic ring is obviously required. Nevertheless, the top value of the magnetic field is determined by the values of the field and the energy at injection. We shall consider here an injection energy of 20 GeV, high enough to supply an appreciable damping time, and an injection field of 400 gauss. A lower value of the field does not seem to us technically practical. Also a fast cycling injector at 20 GeV seems to us relatively easy to design and not exceptionally expensive.

By scaling, then, the top field value at 60 GeV would be of 1.2 kG with a bending radius of $\rho = 1667$ m. The total bending circumference is $2\pi\rho = 10{,}472$ m. We increase the regular bending part of the machine by 20% to make space for quadrupoles and drift sections, and in addition we add straight sections for a total amount of 2000 m, which we believe would be adequate for the RF system and the experimental insertions. The total circumference would then be $2\pi R = 2\pi \times 2{,}318 \text{ m} = 14{,}566$ m.

Thus, the shape that one would give to the machine could be the one shown in Fig. 1, which has symmetry 4 with four straight sections, each 500 m long, and four 90° circular arcs with a radius of exactly 2 km.



The energy loss per particle per turn would be of 8.5 MeV at 20 GeV and of 688 MeV at 60 GeV. The revolution frequency is $f = 20.6$ kHz; namely, the revolution time is $T = 48.6$ μsec. From this we derive the energy damping time which is $\tau = 113$ msec at 20 GeV and $\tau = 4.2$ msec at 60 GeV. This time is reasonably small, also at low energy, so that one can consider an injection rate of 10 pulses/sec, and this should also be the repetition cycle of the injector synchrotron.

Positrons can be produced by sending the electrons from a high intensity linear accelerator at several hundred MeV energy on a target in front of the injector synchrotron. Either electrons or positrons are then accelerated in the

The last number in turns would give a size to the injector synchrotron. Since this should supply the stack in 10 pulses, it can eject four bunches at a time. By taking the same RF frequency, the size of the injector can be 1/10 of the storage ring size; namely, it can have a radius of 231.8 m, which is an adequate size for a 20 GeV electron beam (see Fig. 1). The RF power required to run the injector should not exceed 5 MW, so that the total RF power required for the entire system is around 60 MW.

The RF peak voltage can be set to 1,000 MV/turn, which corresponds to a synchronous phase

$$\phi_s = \arcsin \frac{688}{1{,}000} = 43.5^\circ \ ,$$

a very reasonable number.

Finally, if the entire RF system has to be accommodated within a total length of 1 km, one requires about 1 MV/m, which should not be difficult to obtain at the frequency of 476 MHz. Also the radiation loss spread all over the vacuum chamber is of about 3 keV/m, certainly a large quantity but not difficult to cope with (PEP has the same amount of loss per unit of length).

## 6. BUNCH LENGTH, QUANTUM LIFETIME

The r.m.s. bunch length (in unit of time) is calculated according to the formula

$$\sigma_\tau^2 = \frac{C_q}{c} \frac{R}{J_E \rho} \frac{\alpha \gamma^2}{f_{RF}} \frac{E}{\hat{v}} \ ,$$

where

$C_q = 3.84 \times 10^{-13}$ m

$c = 3 \times 10^8$ m/sec

$f_{RF} = 476$ MHz

$\hat{v} = 1$ GeV .

At 60 GeV one obtains $\sigma_\tau = 0.02$ nsec, to be compared to $\sigma_\tau = 0.004$ nsec at 20 GeV. At the same time the bucket length is $\tau_B \sim 1$ nsec. From these numbers we can calculate the quantum lifetime which is given by

$$\tau_q = \frac{\tau_E}{2} \frac{e^\xi}{\xi} \ ; \qquad \xi = \frac{J_E E}{\alpha h E_1} F(q) \ ,$$

where $\tau_E = 4.2$ msec, $E_1 = 1.08 \times 10^8$ eV, and in our case $F(q) \sim 0.6$. We obtain ($\xi \simeq 100$):

$$\tau_q \approx 1.6 \times 10^{35} \text{ hours} \ ,$$

which is a very long time.

We would like to call attention to the fact that the beam peak current is close to 1000 A, a very large number indeed, and one could expect collective effects that would endanger the beam stability. On the other hand, it is possible, in our case, to increase the number of bunches by a factor of 10. In this way the beam-beam tune-shift would be reduced by the same factor and the peak current would be of a more reasonable amount of 100 A.

## 7. CONCLUDING REMARKS

An $e^+e^-$ colliding beam facility with centre-of-mass energy of 120 GeV appears entirely feasible with present-day technology and a reasonable amount of RF power, provided a very large machine radius and low magnetic fields are chosen. The very large tunnel could be made unconventionally cheap, since magnets are very light. The total power consumption of the machine is close to 50 MW, and it could fit on the largest existing machine sites such as FNAL or BNL.

The interest in such a machine is immense, since it will provide an entirely new way of studying weak interactions at very high energies and eventually produce $W^\pm$ and Z particles (if their mass is in the kinematic range).

We suggest that the scientific community considers this amongst the possible future options for new projects.

## REFERENCES

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