Storage Ring Colliders for e^+e^-

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Abstract

The cost-performance relation for e^+e^- storage ring colliders is discussed. Costs as a function of luminosity, energy and electric power are given for current technology. Possible improvements to technology are listed and their influence on cost and performance is given. Taking into account improvements in superconducting rf technology that we can reasonably hope for in the next decade and incorporating ideas about conventional construction technology discussed at this DPF Summer Study, it is shown that a 500 MeV (cm) e^+e^- storage ring collider with capital cost about \$500 million may be feasible.

Introduction

Based upon the extensive experience with e^+e^- storage rings which the community now has, it is possible to relate cost and performance with some reliability. The cost of the collider can be written approximately as the sum of circumference related costs such as tunnel, magnets, vacuum, controls, etc. and power related costs such as rf power generating equipment, cavities, etc. One form of the relation is[1]

$$(C-C_f) = g_\rho \cdot \rho + (g_{cav} + L_0\, g_{lum})\, \frac{E^4}{\rho}$$

C_f are the "fixed" costs such as lab and office space, injector, etc. which do not necessarily scale with the primary accelerator parameters. E and ρ are the beam energy and bending radius and L_0 is "scaling" luminosity, L/E. The g's, defined in detail in the reference, are unit costs. These coefficients contain hardware costs and basic relations of storage ring physics. For example, g_{cav} involves the cost of cavities, cavity services and rf power sources necessary to produce unit voltage at a fixed gradient and g_{lum} contains the relation between luminosity, beam power and other basic physics parameters. In particular, the "cost of luminosity" can be written

$$C_{lum} = \text{const.} \times P_b(L) \times \tilde{c}$$

where $$P_b(L) = \text{const.} \times \frac{\beta^*}{\Delta Q} \times L_0 \times \frac{E^4}{\rho} = H\, L_0\, \frac{E^4}{\rho}$$

= rf power to the beams and $\tilde{c}$ is the unit capital cost for supplying rf power plus the operating cost in terms of electric power costs for a certain number of hours of operation and contains the ac to rf conversion efficienty as well as cost per kwh of electricity.

Once the unit costs, or g's, are known, one can find the radius, ρ, of the machine which minimizes capital plus 5 year operating costs.

Current Technology

With current technology we have

$$(C-C_f)_{capital} = [\ 185\rho + (233+86\ L_0)\ \frac{E^4}{\rho}]\ [M\$(1982)]$$

$$\rho_{optimum} = \frac{233 + 401\ L_0}{185}\ E^2 \quad ;(0.50 \le E \le 4.0)$$

where E is the beam energy in 100's of GeV, ρ the magnetic radius in km and L_0 is the scaling luminosity, L/E in units of $[\ 10^{32}cm^{-2}sec^{-1}/100\text{'s GeV}]$, i.e. $L_0 = 1$ for $10^{32}cm^{-2}sec^{-1}$ at 100 GeV beam energy (200 GeV cm).

In obtaining the numerical coefficients several assumptions have been made. These are:

a) Circumferential costs can be scaled from PEP/PETRA;
b) $\beta^* = 3$ cm and $\Delta Q = .05$ for $E < 0.5$;
c) Superconducting cavities of 3MV/m, $Q_0 = 2\text{x}10^9$ can be used*;
d) The optimization is done for five years @ 4,400 hours of full energy operation per year with a power cost of 7.5¢/kwh and a net ac-rf conversion efficiency of 60%.

For energies above $E_{beam} \sim 400$ GeV the coefficients take on new and higher values as "beamstrahlung" comes into play and β^* can probably no longer be held at 3 cm but must rise. We do not discuss this in detail as, at the current state of the technology, a storage ring collider for e^+e^- in that energy range is impractically expensive.

One way of presenting this relation is to plot $(C-C_f)_{capital}$ v.s. E_{cm} for a given luminosity. Such a graph is given in Figure 1. A most illuminating way of presenting the relations, suggested by Wiedemann, includes the electric power usage directly. This is most important because power usage is indeed a primary parameter and consumption is excess of about 100 Mw would probably be socially intolerable. In Figure 2 this Wiedemann method of displaying the relation is used. Luminosity is plotted v.s. E_{cm} at constant rf power (50 Mw rf) with $(C-C_f)_{capital}$ as a parameter. At the lower energies one can put a good part of the cost into luminosity. As the energy rises, more and more of the cost goes into simply establishing the energy.

The rearrangement of the cost equations which displays the information in this fashion is

$$\rho\,[km] = \frac{C[M\$] - \frac{g_{lum} P_b [MW]}{H} + \sqrt{\left(C - \frac{g_{lum} P_b}{H}\right)^2 - 4 g_\rho\, g_{cav}\, E^4 (100\,GeV)^4}}{2 g_\rho}$$

$$L = \frac{P_b}{H} \frac{\rho}{E^3}\ [10^{32}cm^{-2}sec^{-1}] \qquad H = 48.8$$

R/D Needed for Capability Upgrade

Examination of the cost relation shows that there are three primary areas where significant cost savings might be achieved. These are: 1) reduction of circumferential costs such as housing, magnets, vacuum, controls, services, etc., 2) reduction of cavity costs; and 3) improvement in efficiency of rf generation and reduction in capital cost of rf generating equipment.

One approach to reduction of standard component and housing costs has been studied by the group dealing with very large, multipurpose facilities.[2] Their approach is to employ true mass production methods for the components and to bring their reliability to the point where human access to them need be had only very infrequently. In this picture the arcs of the machine can be encased in a relatively small pipe and laid much as a large pipeline is laid. Sensitive components are restricted to a few places on the ring where easy access can be provided in the usual manner.

Cavity costs can, in principle, be much reduced through R/D by improvement in superconducting cavity performance. The figures given above are based on an operating gradient of 3MV/m with a Q_0 of 2×10^9. Small cavity arrays, working at frequencies of interest for storage ring service have operated at gradients of 9 MV/m and $Q_0 = 2 \times 10^{10}$. This achievement of E_{acc} = 9MV/m and $Q_0 = 2 \times 10^{10}$ does not seem out of the question for real operating systems. Under these latter conditions the cost of the cavity system would be reduced to 1/3 since one would need only 1/3 of the length to produce a given voltage and the operating power per unit length would remain the same since $P_{op} \alpha E^2/Q_0$.

Potential gains in cost and efficiency of rf power sources in the appropriate frequency range are hard to gauge. Efficiencies for cw generation are already in the 50 to 70% range and manufacturing costs are tied to demand. While one may hope for gains in these areas, their potential influence on overall costs are not likely to be major.

Future Capabilities Based on Reasonable Expecations for R/D Results

To illustrate the potential influence of improved cost effectiveness for standard components and for superconducting rf cavities, Figures 3 and 4 are plotted. Figure 3 shows the influence of achievement of 9 MV/m and $Q_0 = 2 \times 10^{10}$ g_{cm} = 86. In Figure 4 we have added to this improvement, a sharp drop in standard component and housing costs i.e. g_ρ = 24, g_{cav} = 78, g_{lum}= 86. The achievable figure for g_e is hard to estimate. If we adopt ring costs projected by the group studying big proton machines, including housing, magnets, installation, controls, etc., we have g_ρ = ring cost/ρ $\frac{754\text{M\$}}{31\text{ km}}$ = 24M$/km, or about 4k$ per running meter. The potential benefits of such an achievement are clearly very great and should be pursued vigorously for the benefit of all types of accelerators.

Evidentialy, if these R/D goals can be met, the particle physics community could contemplate an e^+e^- storage ring collider of cm energy 500 GeV at a reasonable cost.

References

1. D. Ritson, M. Tigner CLNS-406 (1978).
2. R.F. Huson et al., - These proceedings.

e^+e^- STORAGE RING CURRENT TECHNOLOGY
CAPITAL COST VS E_{CM}

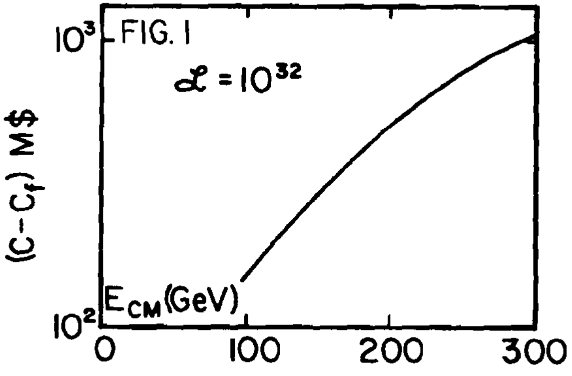

FIG. 1

e^+e^- STORAGE RING COLLIDER
$\mathscr{L}$ VS E_{CM}

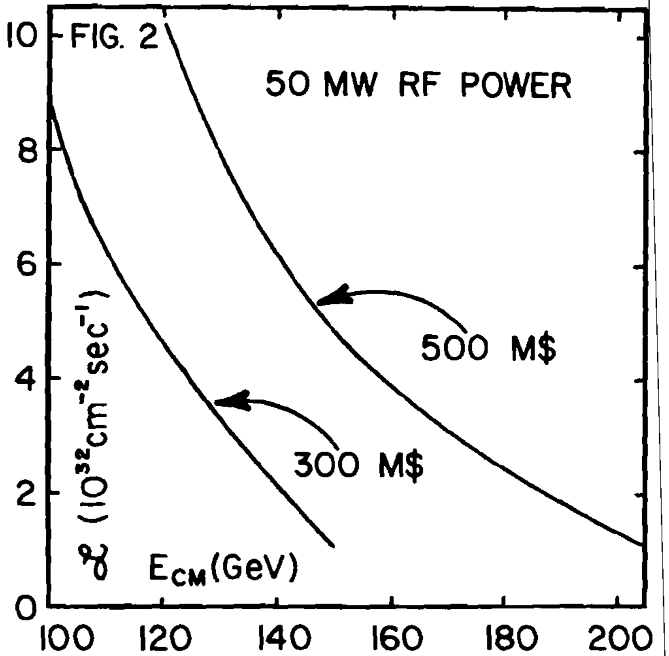

FIG. 2

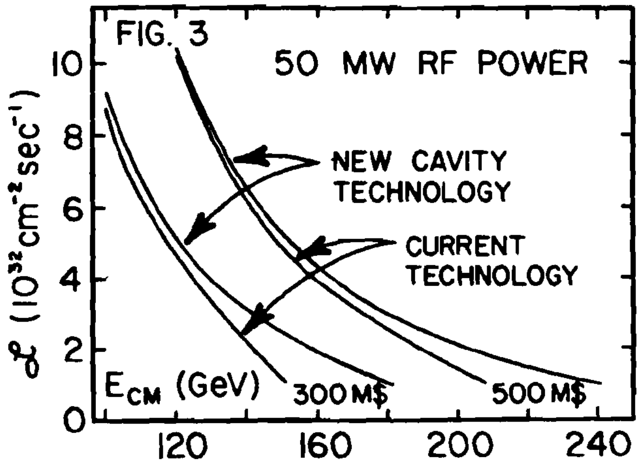

FIG. 3

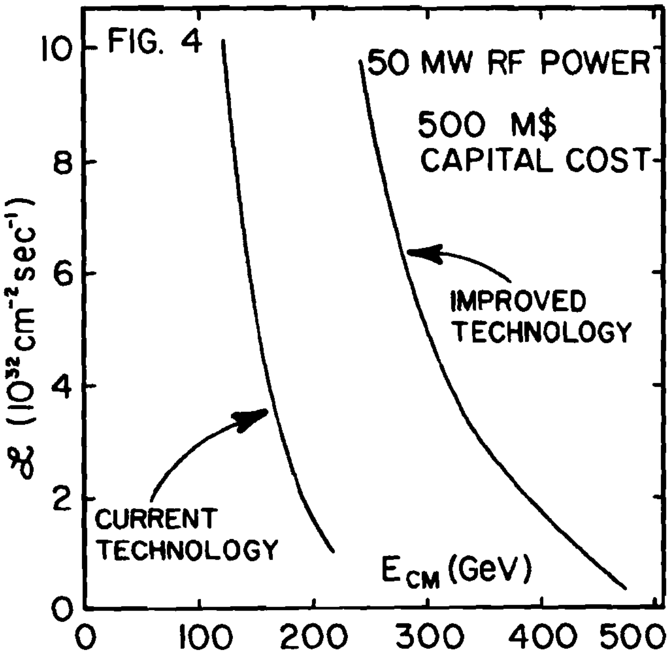

FIG. 4