DUAL APERTURE HIGH LUMINOSITY COLLIDER AT CORNELL

D.Rubin, G.Dugan, A.Mikhailichenko, J.Rogers*
Laboratory of Nuclear Studies, Cornell University, Ithaca,NY 14853

Abstract

We describe a very high luminosity electron-positron collider that operates in the Υ_{4s} energy range. Trajectories intersect with a small horizontal crossing angle so that closely spaced bunches collide only at the interaction point. An electrostatic deflector steers the counter-rotating beams into side-by-side vacuum chambers that share a common dipole guide field. The beams also share superconducting RF accelerating cavities. Independent focusing and chromaticity correction is provided by dual aperture superconducting quadrupoles and sextupoles. The machine is installed above the synchrotron injector in the CESR tunnel. The existing storage ring can remain for service as an accumulator or dedicated synchrotron light source. With 3A/beam in 180 bunches, $\beta_v^* = 7mm$, beam-beam tune shift parameter $\xi = 0.06$ and beam energy of 5.3GeV, we anticipate luminosity of $3 \times 10^{34} cm^{-2}s^{-1}$.

1 INTRODUCTION

Luminosity projections for the dual aperture machine are based on straightforward extrapolation of CESR parameters. At present we store trains of bunches in a single ring that collide at a small horizontal crossing angle[1]. We propose to increase the number of bunches, spacing them uniformly rather than in trains, to increase the current in each bunch, decrease β_v^*, and to increase the beam-beam tuneshift parameter. The parameters of the dual aperture machine, and CESR parameters as it operates today, are shown in Table I.

Table I. Dual Aperture Machine

Parameter	CESR	New Machine
Number of SC cavities		10
E[GeV](beam energy)	5.3	5.3
I_{tot}[A](current/beam)	0.16	3.06
n_b(number of bunches)	18	180
I_{bunch}[mA](current/bunch)	9	17
S_b[ns](bunch spacing)	42	14
θ^*[mrad]	± 2.1	± 2.3
β_v^*[mm]	18	7
β_h^*[m]	1	1
σ_l[mm](bunch length)	19	7
$\epsilon_h[10^{-7}m]$	2.2	2
P_{SR}[MW](per beam)	0.176	3.4
V_c[MV](cavity voltage)	6	24
ξ_v	0.04	0.06
$L[10^{33}cm^{-2}s^{-1}]$	0.41	30.2

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2 OPTICS AND ORBITS

The trajectories of the beams as they extend from the interaction point to the first dual aperture magnet are shown in Fig. 1. The quadrupole magnets Q1 and Q2 are the same magnets that are being assembled for installation as part of the Phase III upgrade[2]. The 4 meter long separator kicks the beams onto the axes of a dual aperture quadrupole (Q4) 20m from the interaction point, where the beam to beam separation is 81mm. The separator voltage is comparable to that of the horizontal separators now in service in CESR. Note that at distances greater than 2.1m from the IP the separation of the beams is always at least $10\sigma_x$. Bunches can be uniformly spaced every 14ns.

Throughout the rest of the machine the beam trajectories are on the respective axes of the dual aperture quadrupoles. In contrast to present day operation of CESR, where multibunch beams share a common aperture, there are very few parasitic long range interactions in the dual aperture machine. The tunes, orbits, chromaticities, coupling etc., of the beams can be independently manipulated. And nowhere do the trajectories explore the fringe fields of sextupoles, skew quads, or dipole correctors. We expect that this qualitative improvement in the optics will translate to enhanced beam-beam performance.

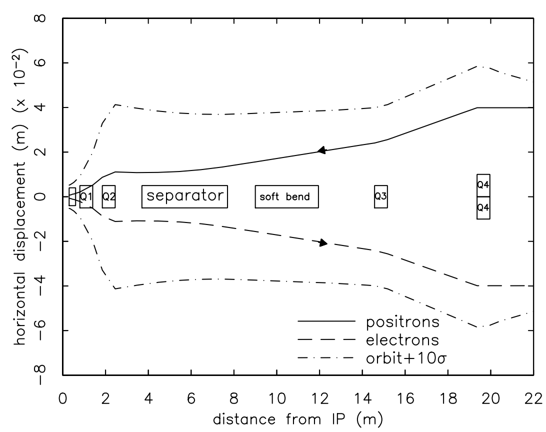

Figure 1: The crossing half angle is $2.3mrad$. The separator kicks the beams $\pm 1.9mrad$. The beams are 81mm apart at the dual aperture quadrupole 20m from the IP.

3 ACCELERATING CAVITIES

The beam current and reduced bunch length are supported by increased RF power and accelerating voltage. With the development a high power, 500Mhz waveguide window, each of the single cell superconducting cavities can deliver 800 kW to the beam at a peak voltage of 3MV. Four superconducting RF cavities will be installed in CESR during the next year for the Phase III upgrade/citepadamsee. Ten cells are required to store 180, 17mA bunches in each beam with bunch length of 7mm.

In order to obtain the highest accelerating voltage in each beam with the fewest number of cells, both beams circulate through the same set of cavities along parallel orbits that are displaced $\pm 40.5mm$ from the cavity axis. The beam tube radius of the cavities is 120mm. The impedance of the superconducting RF system is very low. Each cell has a large aperture. The R/Q of the higher order modes is low and there is excellent damping. Finally, very few cells are required. It appears that deflecting modes excited by the off axis beams will be tolerable.

4 VACUUM AND IMPEDANCE

The vacuum chamber must be capable of handling large synchrotron radiation heat load, maintaining a long beam-gas lifetime, and must minimize the coupling impedance to avoid beam instability.

4.1 Vacuum system

Synchrotron radiation parameters derived from the overall machine parameters are listed in Table II. The linear and surface power densitites are sufficiently low to allow the use of an extruded aluminum chamber. However, we are considering the use of a formed copper chamber for improved synchrotron radiaton shielding. To withstand the power density in the higher field "hard bend" magnets near the interaction point copper chambers are required. The gas load in the vacuum chamber comes almost entirely from the photodesorption from the chamber walls. If we require a beam-gas lifetime of 3 hours at an ultimate photodesorption coefficient of 2×10^{-6}, the average linear pumping speed in the storage ring arcs must be $230l - s^{-1} - m^{-1}$, as summarized in Table III.

Table II: Synchrotron radiation parameters in arc magnets

Parameter	Value
Beam energy(GeV)	5.3
Current per beam (A)	3.06
Normal bend radius (m)	88
Vertical beam divergence(μrad)	30
Radiation divergence(μrad)	54mm
Total divergence(μrad)	62
Beam chamber radius (mm)	27
Minimum radiation stripe width (mm)	0.135
Maximum linear power density (kW/m)	4.39
Maximum surface power density (W/mm^2)	13.0

Table III: Vacuum parameters in arc magnets

Parameter	Value
Photon emission rate ($s^{-1}m^{-1}$)	2.4×10^{19}
Photodesorption coefficient	2×10^{-6}
Outgassing rate ($s^{-1}m^{-1}$)	4.7×10^{13}
Required beam-gas lifetime (hours)	3
Average pressure (CO_2 equivalent)(Torr)	6.4×10^{-9}
Average linear pumping speed ($ls^{-1}m^{-1}$)	230

The two vacuum chambers must be separate and have circular cross sections where they pass through the dual bore quadrupole magnets. This circular cross section must be maintained through the dipole magnets as well to minimize the coupling impedance. A Ti sublimation pump supplements the distributed ion pumps in the chamber to improve the pumping speed at low pressures. The conductance of the pump slots is well in excess of that needed to maintain the necessary linear pumping speed. The chambers in the quadrupole magnet packages however, must be pumped through their ends with lumped ion pumps. The conductance of the pipe requires that the unpumped region be no longer than 1.3 m. Recent experience with synchrotron light sources [4] indicates that it may be possible to install the chamber without an $insitu$ bake, reducing the need for sliding joints, and the associated the coupling impedance.

4.2 Impedance and Stability

The loss factors for critical vacuum chamber components for a bunch length of 7mm are substantial. Total higher order mode power disspated in separators, RF cavities, crotches, scrapers and beam position monitors for a 3A beam is estimated to be nearly 1MW. The beam is predicted to be stable against all single- bunch instabilities and longitudinal coupled bunch instabilities because of the use of very low impedance superconducting RF cavities. The beam will be transversely unstable due to the resistive wall impedance, and will require active feedback of the type currently in use in CESR. The beam is predicted to be stable against the fast ion instability. The photoelectron instability is expected to be weak because of the relatively large bunch spacing.

5 ARC MAGNETS

The arc dipoles will be conventional resistive magnets. The width of the dipoles is sufficient to accomodate both beams, with a beam-to-beam separation of 81mm. Parameters of the magnets are given in Table IV.

Table IV: Dipole magnet parameters

Parameter	Requirements
Number of magnets	140
Magnetic length	3200mm
Field	0.24T
Pole width	300 mm
Gap	65 mm
Good field aperture(0.05%)	135mm X 54 mm
Ampere-turns/pole	6000 A
Current	600 A
Power	10.9 kW

5.1 Quadrupoles, Sextupoles and Correctors

The requirement for closely-spaced dual bore quadrupoles in the two ring symmetric collider arises from the desire to minimize, as much as possible, the separation of the beams in the two rings. Minimizing this separation allows not only the quadrupoles but also the dipoles to be smaller. This results in less costly and simpler magnets. The limited space available in the existing tunnel for the new rings provides an additional motivation to keep overall dipole and quadrupole cross section small. Furthermore, the difficulties of beam separation as the beams emerge from the interaction region is minimized with a small beam separation. The goal for the beam-to-beam separation in the current design, 81mm, requires a sufficiently high current density that a normal conducting solution for the quadrupoles would have prohibitively large operating costs. Thus a superconducting coil design is the only practical and affordable choice. Table V presents the parameters of the superconducting quadrupoles.

Table V: Quadrupole magnet parameters

Parameter	Requirements
Number of magnets	90
Magnetic length	380mm
Field gradient	10T/m
Pole tip diameter	70 mm
Gap	65 mm
Good field aperture(0.05%)	54
Ampere-turns/pole	6750 A
Current	150 A
Heat leak($4.6^\circ K$ to $300^\circ K$)Power	2W

The quadrupole is shown in Fig. 2. A prototype has been fabricated and tested[5]. The warm bore tube is water cooled. The coil was fabricated from NbTi operating at $4.6^\circ K$. The cryostat contains inner and outer LN_2 shields, and multilayer insulation. The combination of a rectangular coil cross section, and a hyperbolic shape for the iron, assures excellent field quality over the 54 mm diamter aperture. The required field quality has been measured in the prototype.

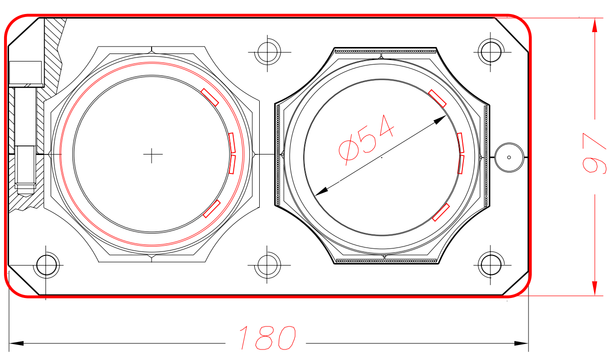

Figure 2: Dual aperture superconducting quadrupole magnet.

Adjacent to each quadrupole will be a sextupole and a dipole corrector. These magnets will also be superconducting, and will be packaged in the same cryostat with the quadrupole. Each quadrupole, sextupole, and dipole corrector in the ring will be separately powered. To reduce the heat leak due to the multiplicity of leads, high temperature superconductor will be used for the current lead transition to room temperature.

An alternative high temperature superconductor (HTS) design is being explored[6].

6 INJECTION

Table VI summarizes the requirements on the injector system. The current performance of the Cornell Linac/synchrotron complex is adequate to satisy the requirements indicated in Table VI, on a charge-per-bunch basis. However, the Linac/synchrotron now accelerates only 14 bunches, not 180, per cycle; so the total current must be increased by a factor of more than 10. There may be some multibunch stability issues which will need to be solved in this mode of operation.

Table VI: Injector requirements (per species)

Parameter	Requirements
Bunches per synchrotron cycle	180
Particles per bunch	2×10^7
Total particles per synchrotron cycle	3.6×10^9
Transfer efficiency	90%
Fill time (minutes) at 60Hz	5
Total particles in storage ring	6×10^{13}

The existing transfer lines from the synchrotron to CESR need to be modified by the insertion of a switching dipole in each line. New transfer lines, starting from this dipole, then bring the beams up to an injection system into the two-ring collider. In this scheme, positron beams can also be transferred from CESR into the two-ring collider.

7 REFERENCES

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