A High Luminosity Superconducting Mini Collider for Phi Meson Production and Particle Beam Physics

C.Pellegrini, D. Robin, D. Cline, J. Kolonko
University of California at Los Angeles, Department of Physics
405 Hilgard Avenue, Los Angeles, California 90024

C. Anderson, W. Barletta, A. Chargin
Lawrence Livermore National Laboratory
Livermore, California 94550

M. Cornacchia
Stanford Synchrotron Radiation Laboratory
P.O. Box 4349, Stanford, California 94309

G. Dalbacka
Maxwell Laboratories, Inc.
4905 Central Av., Richmond, California 94804

K. Halbach
Lawrence Berkeley Laboratory
1 Cyclotron Road, Berkeley, California 94720

E. Lueng, F. Kimball, D. Madura, L. Patterson
General Dynamics, Space Systems Division
P.O. Box 85990, San Diego, California 92186

Abstract

A 510 MeV electron-positron collider has been proposed at UCLA to study particle beam physics and Phi-Meson physics, at luminosities larger than 10^{32} cm^{-2} s^{-1}. The collider consists of a single compact superconducting storage ring (SMC), with bending field of 4 T and a current larger than 1 A. We discuss the main characteristics of this system and its major technical components: superconducting dipoles, RF, vacuum, injection.

Introduction

A high luminosity, low energy (510 MeV per beam), electron-positron collider is being proposed for construction at UCLA. The goals of this program are:
1. particle beam physics research;
2. phi meson physics, CP and CPT violation studies;
3. graduate student training.

The collider energy has been chosen to coincide with the phi resonance energy. To obtain the large luminosity and to keep the system cost and size to a level where it can be accomodated on a University campus, we have chosen a compact design, using superconducting magnets, shown in Fig. 1.

The choice of a compact design, about 17m circumference, maximizes the collision frequency, and the synchrotron radiation damping rates. Injection is done with a linac-positron accumulator complex, to keep the filling time at about one minute. The beam lifetime is about one hour and is dominated by the beam-beam bremstrahlung. The vacuum system requires the use of low desorption materials, and an antechamber design. The use of specially modified sextupoles is needed to provide a large enough dynamic aperture.

Designs for large luminosity Phi-Factories have been developed also at Novosibirsk, Frascati and KEK, and are described in other contributions to these Conference. The Novosibirsk design is also based on superconducting magnets, while the Frascati design uses room temperature magnets and high field wiggler to reduce the damping time. All these designs share some features, like large non linear beam dynamics effects,

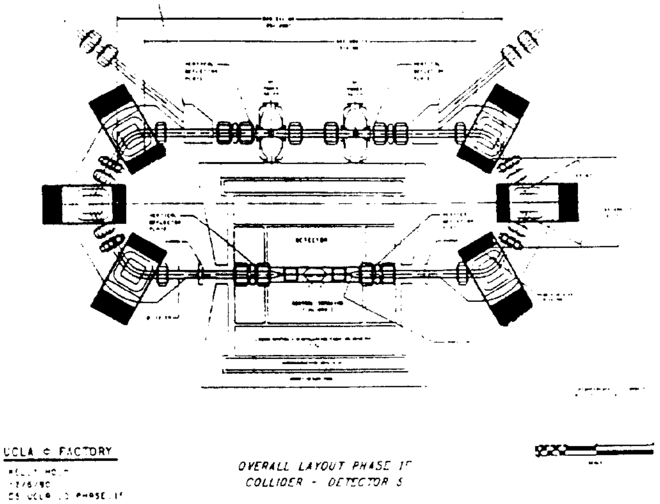

Figure 1: Conceptual Drawing of the UCLA SMC/Φ-Factory

Work supported by DOE contract DE-FG03--90ER40565

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large currents and short bunches, and the need to increase the damping rate, given the low beam energy, and the potential damage from intrabeam scattering. The SMC is the first step in a program to develop colliders of increasing luminosities and flexibility in the choice of the energy of the beams. Some of the future upgrades to increase the luminosity to the 10^{33} level are also discussed.

Storage Ring

A list of the main parameters of SMC is given in Table 1. The main advantages of the choice of superconducting dipoles and a compact ring are:

1. the high revolution frequency increases the luminosity for a given number of electrons and positrons and simplifies the positron injection system;
2. the large bending field and small radius of curvature maximizes the synchrotron radiation damping rates and produces a large momentum compaction, thus incresing the threshold fro the microwave instability;
3. the small circumference makes the system compact and reduces the cost.

The disadvantages are limited space for injection and instrumentation, larger non linear effects due to the small bending radius, and the large synchrotron radiation power density on the vacuum chamber walls.

The magnetic lattice design is discussed in another paper presented at this Conference [1]; this design was based on the requirements of flexibility in the choice of operating point and beam emittance, in addition to a dispersion free interaction region. The large non linearities present in the ring, because of the low beta and the small bending radius, tend to reduce the useful dynamic aperture. As shown in [1] we intend to solve this problem using the modified sextupoles proposed by Cornacchia and Halbach [2].

Superconducting Magnets

Several option are available in the construction of the superconducting dipoles. Configurations with and without enhancing permeable materials are possible. Because the storage ring will be operated essentially at fixed energy, the effects of highly non linear materials in the magnets are acceptable. For this reason a superferric (iron enhanced) design has been selected that utilizes superconducting coils in a racetrack dipole configuration with a room temperature iron yoke. This configuration has the advantage of reducing the criticality of the conductor placements, reducing the required amount of superconductor, and reducing structural material needed.

Table 1: SMC Parameters List

Beam Energy, MeV	510
Luminosity, $cm^{-2}\,s^{-1}$	$2\ 10^{32}$
Circumference, m	17.4
Bending Radius, m	0.425
Momentum Compaction	0.11
Horizontal tune	2.1
Vertical Tune	3.85
Energy loss/turn, KeV	14.1
Damping time, horizontal, ms	4.6
Damping time, vertical, ms	4.2
Damping time, energy, ms	2.0
Emittance, mm mrad	3.2
Vertical/Horizontal coupling	0.2
Particles/bunch	$4\ 10^{11}$
Number of bunches/beam	1
Collision frequency, MHz	17.2
β_x at IP, cm	19
β_y at IP, cm	3.9
$\delta\nu_x$	0.05
$\delta\nu_y$	0.05
RF frequency, MHz	499
RF voltage, KV	400
Synchrotron tune	0.02
Bunch length, cm	3
Average current, A	1.2
Peak current, A	270
Z/n, Ω	3
Lifetime, beam-beam, hrs	2.5
Lifetime, Touschek, hrs	2.5
Lifetime, gas (10 nT), hrs	1.8

An additional design consideration is the cooling method and conductor to be employed. To minimize cost, a state of the art pool boiling conductor has been selected. Magnets built by this method simply immerse the conductor pack in liquid helium. Designed correctly, this a simple and reliable method.

There are six magnets in the ring, each bending the beam by 60^0. By designing magnets with a relatively large good field region, it is intended to produce magnets that require no curvature. The beam enters the dipole at an angle to the magnet centerline, and exits at a similar, although oposite, angle. By eliminating the magnet curvature, the manufacturing of these dipoles is simplified and cost is reduced.

Convential copper coils to produce the same field would require a power consumption of about 3 MW. Thus superconducting magnets (even with refrigeration power considered) are less expensive than conventional magnets when operation costs are included.

Beam Parameters and RF system

We assume as a design goal a peak luminosity of $3\ 10^{32}$ $cm^{-2}\ s^{-1}$. To achieve this luminosity requires a beam current of 2A per beam, in a single bunch, with a bunch length not larger than 3 cm, and an energy spread not larger than 0.1%. The RF, vacuum and injection system are designed for these beam characteristics. The bunch length and energy spread is determined by the microwave instability and the RF system. To evaluate the RF voltage needed we estimate a longitudinal broad band impedance of 3 Ω, with contribution coming from the RF cavities, other ring elements, and the vacuum impedance. This last term is unusually large and is responsible for the emission of coherent synchrotron radiation. The threshold for the fast head-tail is larger than that of the microwave instability and has no effect on the design. Intrabeam scattering has been evaluated and is not important, because of the short damping times.

Table 2: RF Parameters	
Frequency, MHz	499
Voltage, KV	400
Shunt Impedance, MOhm	5
Synchrotron radiation losses (4 A), KW	56
HOM+BB losses (4A), KW	56
Cavity losses, KW	32
Total Power, KW	144

For the RF system we choose a 500 MHz cavity, based on the Daresbury design, for the avalaibility of the power sources, and to reduce the voltage needed to produce the short bunch length. We can use one or two cavities. A list of parameters is given in Table 2 for the one cavity case.

Vacuum and injection systems

These systems are discussed in more detail in other papers presented at this Conference [3], [4]. We only want to mention here that this design produces a very large synchrotron radiation load, up to 10 KW/m. It is shown in [3] that this can be controlled with an antechamber design.

The injection system is required to provide $6\ 10^{11}$ positrons, with an injection time shorter than 1 minute. We used a solution, [4], with electron positron conversion at 200 MeV, full injection energy of 510 MeV, and a positron accumulator ring. In this system we can reach our goal with a safety margin, usin an electron gun like the SLC gun built at SLAC.

Conclusions

We have established the feasibility of a 510 MeV electron-positron collider with luminosity larger than 10^{32} $cm^{-2}\ s^{-1}$, and the capability of testing the accelerator physics and technology relevant for large peak and average current operation. Further studies will be needed to optimize the system design and have a more detailed understanding of some of these effects. More work wiil also be needed to fully develop the design of the superconducting dipoles, the RF, and the vacuum systems.

We also intend to continue our work for the design of a higher luminosity collider, and the next step in our program is to study a system based on the Quasi Isochronous Ring concept [5,6].

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