Conceptual Design of a High Luminosity 510 MeV Collider *

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Abstract

We discuss the magnetic lattice design of a high luminosity 510 MeV electron-positron collider, based on high field superconduction bending dipoles. The design criteria are flexibility in the choice of the tune and beta functions at the interaction point, horizontal emittance larger than 1 *mm mrad* to produce a luminosity larger than $10^{32}cm^{-2}s^{-1}$, large synchrotron radiation damping rate, and large momentum compaction. The RF system parameter are chosen to provide a short bunch length also when the beam energy spread is determined by the microwave instability. A satisfactory ring dynamic aperture, and a simultaneous small value of the horizontal and vertical beta function at the interaction point, we expect will be achieved by using Cornacchia-Halbach modified sextupoles.

Introduction

In order to study CP violation in the Φ-meson system it is necessary to have a machine with a large luminosity. The luminosity in a collider is given by the expression

$$\mathcal{L} = \frac{fN^2}{4\pi\sigma_x\sigma_y} \tag{1}$$

where f is the frequency of collisions, N is the number of particles in each bunch, σ_x and σ_y are the horizontal and vertical dimensions of the bunch respectively. Presently the largest luminosities which have been obtained in electron-positron machines is $10^{32}cm^{-2}s^{-1}$. In order to make interesting tests of the standard model it would be desirable to have luminosities in the range of $10^{33}cm^{-2}s^{-1}$ to $10^{34}cm^{-2}s^{-1}$. This is a very challenging accelerator problem.

At UCLA we are proposing to build an electron-positron storage ring at $510MeV$ per beam to be used as a Φ-factory. The name we have assigned to it is the Superconducting Mini Collider Φ-factory or the SMC/Φ-factory. In order to achieve large luminosities in a ring we have adopted a certain strategy. First we will build a storage ring whose luminosity is about $10^{32}cm^{-2}s^{-1}$. We will then employ new methods to increase the luminosity to the range of several times $10^{33}cm^{-2}s^{-1}$.

The collider will evolve in three phases. In phase one we will use conventional technology and methods which we expect will achieve an average luminosity greater than $2 \times 10^{32}cm^{-2}s^{-1}$. In phase two we would like to increase the luminosity to $10^{33}cm^{-2}s^{-1}$. To achieve this high luminosity we will have to use new ideas. One of our favorite ideas to go to this high luminosity is to run the machine in a quasi-isochronous mode [1]. The momentum compaction in the ring would be decreased by changing the strength of the quadrupoles. The bunch length would then decrease allowing for a more strongly focused beam at the interaction point. In phase three we plan to use a quasi-linear configuration where the bunches would be colliding outside the ring in a bypass. In this paper we will discuss only our phase one design.

Design Goals of Phase 1

As was mentioned in the previous section, the objective in phase one is to build a machine whose luminosity is $2 \times 10^{32}cm^{-2}s^{-1}$. We have several design goals in phase one and we list them here. The first goal is to design our ring with a small circumference. There are several reasons for doing this. First of all if one looks at the expression for the luminosity of a collider given in equation 1, the luminosity is proportional to the frequency of collisions, f. One can increase the frequency of collisions by either increasing the number bunches in the ring or making the ring smaller. The second reason is that if one has a small ring one then needs a large field in the dipoles to bend the beam, increasing the energy loss due to synchrotron radiation. This is an advantage. It will increase the damping time which will help to damp collective instabilities. Also the radiation which the dipole produces in dispersive regions will increase the transverse emittance of the beam allowing us to put more current in the beam. The current is also limited by the beam-beam interaction. In our ring we have assumed a linear beam-beam tune shift of 0.05. The third reason for choosing a compact ring design is that a compact ring has a naturally large momentum compaction. The threshold peak current, I_p, for the longitudinal microwave instability which is the dominant coherent effect for small rings increases as the momentum

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compaction goes up.

$$I_p \propto \alpha \qquad (2)$$

where α is the momentum compaction of the ring. This is an approximate relation valid when the bunch length is on the order of the beam pipe radius.

There are two other reasons why we chose to build a small ring and they are practical reasons. The first of these two reasons is we are trying to make the machine as affordable as possible. By limiting the number of magnetic elements, we have decreased the cost. In particular if we did not have such strong bending dipoles, we might have to increase the emittance and reduce the damping time with wigglers as has been proposed in the Frascati machine [2]. The second of these practical reasons is that the building which is to be built to house this ring is not so large that it will be able to fit within its walls a machine of the size of that which is to be built in Frascati.

The second design goal is to have a machine which was flexible and that the control of the tune, the bending and the final focus system were decoupled. In other words we wanted the arc regions which are to bend the beam around 180 degrees to be unaffected by what was happening in the interaction region. We wanted to have the ability to adjust the tune without affecting the dispersion in the bends or the focussing in the interaction region. In other words we wanted to decouple all three of these functions so that we could adjust one parameter while minimizing the effects on the other parameters.

The third design goal is to build a machine whose dynamic aperture was large enough to give a good lifetime. This is somewhat difficult for machines like this because we have a large chromaticity in the ring which is a result of the large quadrupole strengths necessary to produce the small beam size at the interaction point. There will then have to be strong chromaticity correcting sextupoles in the ring in order to make the chromaticity zero. Also nonlinearities in the field are enhanced as a result of the small bending radius of the dipoles. We expect the Halbach-Cornacchia sextupoles to increase the dynamic aperture and they will be discussed later.

The fourth design goal is to build a ring which had the capability of decreasing the momentum compaction by several orders of magnitude with out significantly changing the configuration of the ring. What we mean by significantly is that we did not want to change the overall circumference of the ring. In addition we do not want to change the dipoles because they are the most complicated and expensive magnets in the ring and we want to build them so as to keep them at fixed strength.

Linear Lattice Design

As one can see from the artists conceptual design in Figure 1, the lattice consists of two straight sections and two 180 degree bending sections or arcs. In each of the 180 degree bends there are three dipoles which bend the beam 60 degrees each. Between the dipoles there is a quadrupole and a sextupole. In one of the two straight sections the

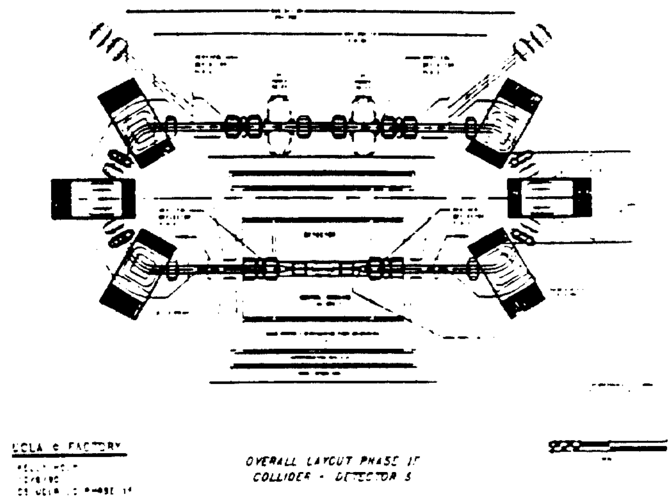

Figure 1: Conceptual Drawing of the UCLA SMC/Φ-Factory

detector will be placed In the interaction region a triplet is placed to provide a small beam size. In the other straight section the beam will be injected.

Arcs

The arcs consist of three dipoles and two quadrupoles and two sextupoles. Since we have zero dispersion in the straight sections the quadrupoles function is to bend the off energy particles back to the on energy ones when they reach the straight sections. They are thus both horizontally focussing.

The dipoles have a bending field of four tesla. They are parallel faced magnets to take advantage of the fact that edge focussing provides focussing in the vertical plane and helps to compensate for the defocussing in that plane due to the quadrupoles. Each dipole has small field gradient (n= 0.23) which also provides some vertical focussing. The magnets are H-type shaped for stability and have been designed by General Dynamics.

Straight Section

The interaction region consists of a triplet and controls the beta function at the interaction point. We can have $\beta_x = 19cm$ and $\beta_y = 3.9cm$. consistent with a bunch length of $3cm$. The quadrupole closest to the interaction point is $30cm$ away.

The fourth quadrupole farthest from the interaction region is used to vary the tune of the ring. It does not effect the dispersion and changes the final beta very little.

The reference parameters for the ring are given in Table 1. The current in the ring is $1.16A$ which is rather large. We have calculated with the help of ZAP[3] the lifetimes of the beam due to such things as Touschek scattering, intrabeam scattering, gas scattering and beam-beam lifetime. We have found that the limiting factor at this current is the gas scattering which for a pressure of $10^{8} torr$ is $1.8 hours$.

Because of the size of the ring and the amount of synchrotron radiation, the vacuum system will be difficult.

Table 1

SMC Parameter List

Beam Energy, MeV	510
Luminosity, $cm^{-2}s^{-1}$	2×10^{32}
Circumference, m	17.4
Dipole bending radius, m	0.425
Horizontal betatron tune, m	2.1
Vertical betatron tune, m	3.85
Momentum compaction	0.11
Energy loss/turn, KeV	14.1
Horizontal damping time, ms	4.6
Vertical damping time, ms	4.2
Longitudinal damping time, ms	2.0
Natural emittance, $mm\ mrad$	3.2
Vertical/horizontal coupling	0.2
Number of 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
σ_x at IP, cm	0.78
σ_y at IP, cm	0.071
$\delta\nu_x$,	0.05
$\delta\nu_y$,	0.05
RF frequency, MHz	500
Harmonic number,	29
RF voltage, kV	400
Synchrotron tune,	0.02
bunch length, cm	3
Average current, A	1.16
Peak current, A	269
Z/n, Ω	3
Lifetime: Beam-beam, $hours$	2.8
Lifetime: Touschek, $hours$	2.5
Lifetime: Gas, $10^{-8}Torr$	1.8

Dynamic Aperture

The ring's small bending radius enhances nonlinearities in the fields. This fact and also the fact that the large natural chromaticity in the ring is quite large and has to be corrected for by strong chromaticity correcting sextupoles tends to leave the ring with a small dynamic aperture. In order to avoid a short lifetime due to quantum fluctuations, it is desirable to have a dynamic aperture which is at least ten times the rms bunch size in both planes.

A possible way to increase the dynamic aperture would be to use modified sextupoles whose strength is not a pure sextupole in place of a normal sextupole. This possibility has been proposed by M. Cornacchia and K. Halbach[4]. They have demonstrated that the dynamic aperture can be increased. In particular for a ring such as ours, Cornacchia did some calculations of the dynamic aperture for a sextupole whose fields expressed in complex notation are

$$B^* = -iz^2 e^{kz^2} \tag{3}$$

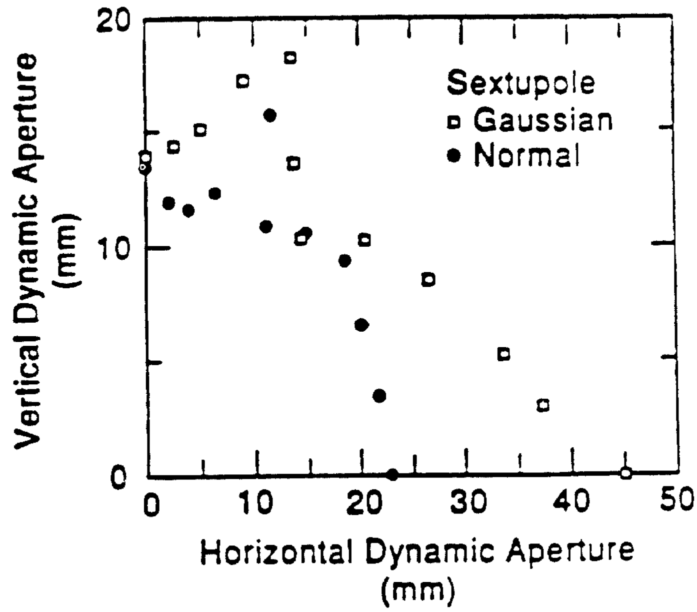

Figure 2: Dynamic aperture due to modified and normal sextupoles

where $B_x = \mathcal{R}e(B^*)$ and $B_y = -\mathcal{I}m(B^*)$. z is the coordinate in complex notation were $z = x + iy$. The results of his calculation can be seen in Figure 2.

These results are preliminary because the model in the computer code that was used does not provide the proper Hamiltonian for rings having a small bending radius. We think that the qualitative behavior is correct. The sextupoles do help increase the dynamic aperture.

We are now adapting a code Krakpot[5] in collaboration with E. Forest which was used to study the dynamic aperture of the SXLS ring at Brookhaven National Laboratory. This program has the ability of implementing these modified sextupoles in the lattice and also has the proper Hamiltonian.

References

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[5] KRAKPOT was developed by E. Forest, J. Murray and M. Reusch to track particles in Brookhaven's SXLS ring