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INTERACTION REGION DESIGN FOR A SUPER-B FACTORY*

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Abstract

We present a preliminary design of an interaction region for a Super-B Factory with luminosity of 1×10^{36} cm^{-2} sec^{-1}. The collision has a ±17 mrad crossing angle and the first magnetic element starts 0.3 m from the collision point. We show that synchrotron radiation backgrounds are controlled and are at least as good as the backgrounds calculated for the PEP-II accelerator. How the beams get into and out of a shared beam pipe is illustrated along with the control of relatively high synchrotron radiation power from the outgoing beams. The high luminosity makes radiative bhabha backgrounds significantly higher than that of the present B-Factories and this must be addressed as the design is further improved.

INTRODUCTION

Work toward an asymmetric-energy B factory design with a luminosity of at least 1×10^{36} $cm^{-2}s^{-1}$ has been going on for a couple of years now. Initially, designs looked at ways of increasing the number of bunches, increasing the beam currents (up to 10-20 A) and lowering the β_y^* to achieve the large increase in luminosity [1]. Recently however, a new idea has come forward where one has a "crabbed waist" at the interaction point through the use of a fairly large horizontal crossing angle, very low emittance beams and extremely small β_y^* values in conjunction with modest beam currents (similar to present day B factories) and typical bunch lengths (~10 mm) [2]. The low emittance beams and the modest beam currents are a help in the design of an interaction region (IR) with a small radius detector beam pipe that has acceptable detector backgrounds.

FINAL FOCUS OPTICS

The final focus of the Super-B design calls for a small β_x^* (20 mm) and a very small β_y^* (0.2 mm). These small beta functions require the final focus magnets to be as close to the interaction point (IP) as possible in order to keep the maximum beta values as low as possible and minimize the chromaticity generated in the final focus. Table 1 lists the accelerator parameters that are important for the IR design.

We have adopted a beam-stay-clear (BSC) envelope that is similar to the one used in the PEP-II design [3]. The X value is defined as 15 uncoupled beam sigmas +1 mm for closed orbit distortion (COD). The Y value is defined as 15 fully coupled beam sigmas +1 mm COD.

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Table 1: Accelerator parameters for a Super-B Factory design with L = 1×10^{36} cm^{-2} s^{-1} that influence the IR

	LER		HER
Energy (GeV)	4.0		7.0
Current (A)	3.95		2.7
No. bunches		3466	
Spacing (m)		0.63	
β_x^* (mm)	20		20
β_y^* (mm)	0.2		0.2
Emittance X (nm-rad)	1.6		1.6
Emittance Y (pm-rad)	4		4
Crossing angle (mrad)		34	

QD0

With the above parameters in mind we have positioned the first quadrupole magnet (QD0) to start 0.3 m away from the IP. A collision crossing angle of ±17 mrad separates the beam centers by only 5.1 mm and the two BSC envelopes by only 1.8 mm at 0.3 m away from the IP so the QD0 is a magnet shared by both beams. In order to produce similar final focus beta functions for the different energy beams, we have set the gradient of QD0 to be that required for the high-energy beam (HEB) for a magnet length of 0.75 m. This magnet is then too strong for the low-energy beam (LEB) so we shorten the length of this magnet to 0.46 m to get the correct integrated strength for the LEB. The beams therefore need to be separate enough at 0.76 m from the IP to be able to place a magnet that continues the vertical focusing for the HEB while making a field free region for the LEB. We label this 0.29 m long magnet QD0H. This also means the two beams enter separate beam pipes at this location (0.76 m).

QD0H and QF1

The beam separation at 0.76 m is 31.9 mm for the incoming LEB side and 36.4 mm for the incoming HEB side. The difference is due to the fact that the LEB is easier to bend than the HEB and that the QD0 magnetic axis is parallel to a line bisecting the beam trajectories but is offset so that the incoming beam (either LEB or HEB) is minimally bent by the QD0 field. The BSC envelopes at 0.76 m are about 3 mm for each beam, well inside a beam pipe of 10 mm radius, the same size as the detector beam pipe. We therefore select a beam pipe radius of 10 mm for each separate beam at 0.76 m. We then have 11.9 (31.9-20) and 16.4 (36.4-20) mm of space for two beam pipe walls and a magnet. Using permanent magnet (PM) material with a remnant field of 1.4 T, we can construct a cylinder with an inner radius of 12 mm and an outer radius of 20 mm (8 mm thick) that has enough strength to satisfy the HEB gradient requirements. The PM blocks have a very low residual field beyond the outer radius of

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the material and hence make a good field-free region for the LEB. This leaves enough room for a 2 mm thick beam pipe for each beam at this narrow location. Beyond 0.76 m from the IP the distance between the beams grows rapidly and it is relatively easy to accommodate separate beam pipes and magnets for the two beams.

The next quadrupole magnet (QF1) from the IP is an x focusing magnet that is 0.4 m long and is located between 1.45 m and 1.85 m from the IP. There are two separate magnets at this location, one for each beam and beyond QF1 the beam lines for both beams have the same layout with counterpart magnets at each z location. Figs. 1 and 2 show this IR layout.

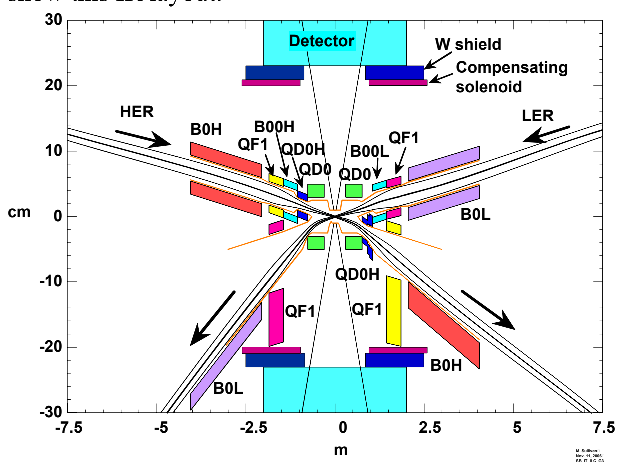

Figure 1: Layout of the Super B interaction region. Note the expanded vertical scale.

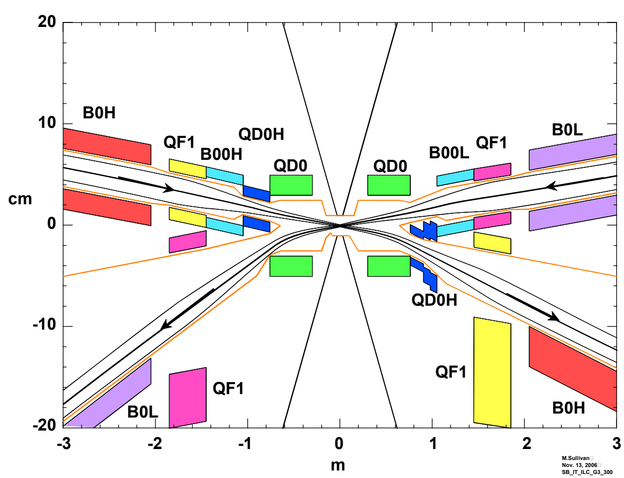

Figure 2: Closer view of the final focus magnets. The dark blue blocks are the QD0H permanent magnets. The design is different on each side of the IP. The incoming side has a narrow beam aperture and hence can be designed as a cylinder. The outgoing beam line for the HER has to accommodate the outgoing synchrotron radiation fan as well as the outgoing HER beam.

SYNCHROTRON RADIATION BACKGROUNDS

The detector beam pipe for the Super-B design has a 10 mm radius. This small radius means that the detector is more susceptible to synchrotron radiation (SR) photons from the incoming beams. This is especially true if the magnetic axis of the shared QD0 magnet is centered between the beam trajectories. In this case, the incoming beams are bent by the QD0 magnetic field and generate photons that cannot be shielded from the detector beam pipe unless the beam pipe radius is increased. Increasing the radius of the beam pipe effectively decreases the luminosity since the detector efficiency is decreased.

As mentioned above, we have moved the axes of the QD0 magnets so that they are much closer to the incoming beam trajectories thereby eliminating the QD0 magnet as a source of SR background for the detector.

The next most important background source after the QD0 is the focusing radiation coming from the incoming beams as they travel through the QF1 magnets. This radiation comes from the horizontal over-focusing of the beam and because of this over-focusing the angles of the photon trajectories are steeper making it more difficult to shield the detector beam pipe from this source. In order to control this background rate we introduce a small bending magnet between the QD0 and QF1 magnets on the incoming beam lines only. These bending magnets redirect the focusing radiation from the QF1 magnets away from the central Be beam pipe.

In summary, there are no photons coming from the incoming beams that are directly incident on the detector beam pipe. The remaining incoming photons that are incident on the surfaces near the detector beam pipe have been simulated with a program that uses EGS [4] to model the backscattering rate from these surfaces. An estimate of the solid angle acceptance for the detector beam pipe from these surfaces indicates that the rate of photons incident on the detector beam pipe from these secondary surfaces is comparable to the calculated background rate for the PEP-II interaction region. Figure 3 shows the photon-rate/beam-crossing on the nearby surfaces for photons over 10 keV.

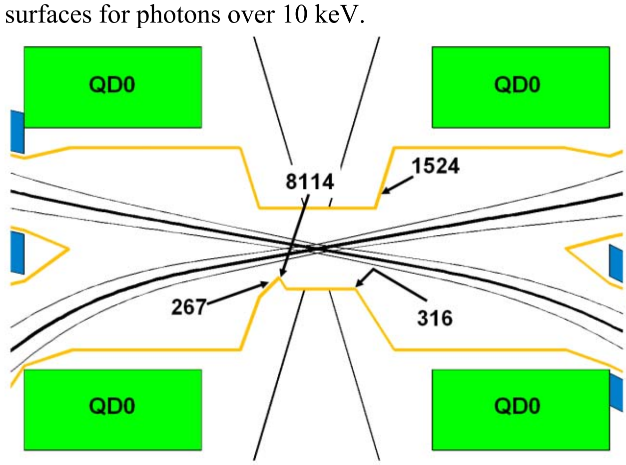

Figure 3: The mask tip is 3 mm in from the 10 mm radius pipe. This is the only surface that is inside the detector beam pipe so the overall masking design is quite open and has no obvious cavities for trapping higher-order-mode (HOM) power.

OUTGOING SR FANS

The exiting beams are strongly bent as they travel through the QD0 magnets. This is because the outgoing beams exit the shared QD0 magnet far off-axis. The outgoing LEB generates 88 kW of SR power in QD0 and the outgoing HEB generates 141 kW. The beam pipe for the outgoing beams is designed so that these high power fans do not strike any nearby surfaces and are absorbed on beam pipe surfaces that are meters away from the collision point. Figure 4 show the SR fans generated by the HEB and the LEB.

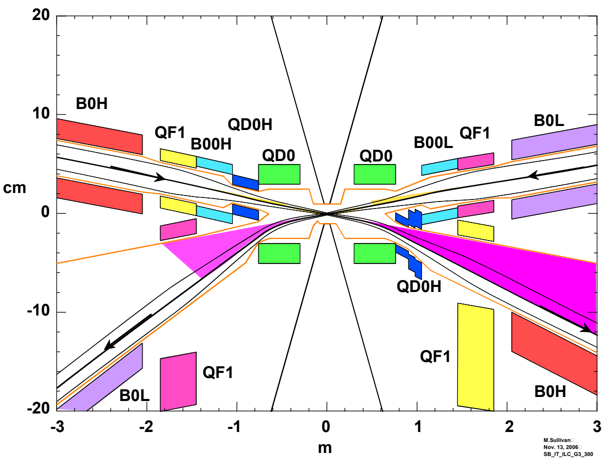

Figure 4: Interaction region layout with the outgoing high-power synchrotron radiation fans displayed. The outgoing beam pipes are shaped so that the radiation does not hit the pipe in the first few meters from the IP.

The larger beam pipes on the outgoing beam lines mean that the magnets on these lines must have large apertures. One possible design for the outgoing QF1 magnet is one similar to the horizontally split quadrupole magnets used in SPEAR 3 [5]. These magnets have no material in the horizontal plane and this allows the horizontal fan to pass through the magnet without striking the beam pipe. The outgoing B0 magnets can be C-shaped bend magnets. The two designs suggested above imply iron core magnets which would need to be shielded from the detector magnetic field. We would accomplish this by inserting a compensating super-conducting solenoid around both beam lines and into the detector far enough so that at least the QF1 and B0 magnets can be iron core magnets. Figure 1 shows a suggested layout of the compensating solenoid.

RADIATIVE BHABHAS

The strong bending of the outgoing beams also produces backgrounds for the detector by over-bending the beam particles that have undergone a radiative bhabha interaction at the IP. The gamma produced by this reaction and the reduced energy beam particle both can generate backgrounds in the detector if these particles strike beam pipes close enough to the detector. The gammas are generally produced in the direction of the beam and hence exit the IP along the crossing angle trajectories. In the case here the outgoing gammas are along the edge of the strong outgoing SR fans and hence do not intersect the beam pipe until the fans are several meters away from the collision point as mentioned above. However, the outgoing off-energy beam particles can be a source of background for the detector. Figure 5 shows a drawing of the trajectories of some of the radiative bhabha beam particles from the LEB and the HEB.

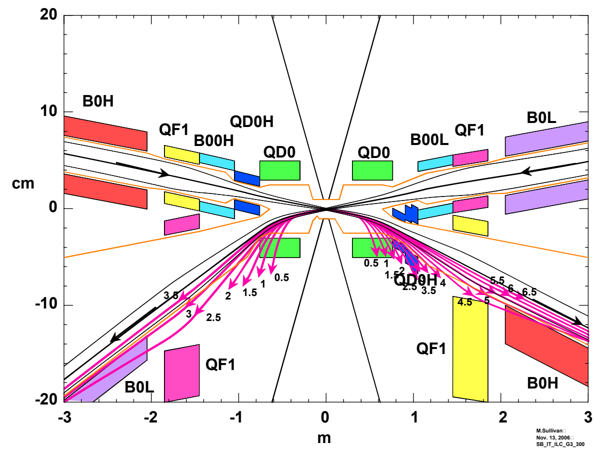

Figure 5: Trajectories of selected energies for beam particles from radiative bhabha interactions. The small number near the trajectory is the energy in GeV.

SUMMARY

We have constructed an interaction region for a Super-B factory design. The design incorporates the "crab waist" scheme for making high luminosity collisions and demonstrates that synchrotron radiation backgrounds can be controlled and are comparable to the present PEP-II accelerator. The design has strong bending of the outgoing beams through the shared QD0 magnet and this could benefit from further optimization. The strong bending makes powerful SR fans and locally bends out the beam particles from radiative bhabha interactions making backgrounds in the detector. Although the bending is comparable to that of the PEP-II IR design the Super-B design calls for much lower emittance beams and this bending might contribute to emittance growth.

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