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COLLIMATION ISSUES FOR THE PEP-II B-FACTORY*

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Abstract

This note describes how beam collimation affects detector backgrounds at the collision point for the PEP-II B-factory, a joint effort of three laboratories: LBNL, LLNL, and SLAC. Beam collimation controls the transverse size as well as the maximum allowed energy spread of the beam. The location of synchrotron radiation masks is determined by the transverse size of the beam in that the masks must prevent radiation generated by beam particles located at large transverse beam positions from directly striking the detector beam pipe. Collimation of the energy spread of the beam is important in the control of backgrounds produced by beam particles that strike a gas molecule (lost beam particles).

I describe some preliminary information from background studies during the first months of commissioning the high energy ring of the PEP-II B-factory and present some model predictions for synchrotron radiation backgrounds when collimators are not present.

1 INTRODUCTION

PEP-II, a high-luminosity B-factory located at the Stanford Linear Accelerator Center (SLAC) is a high current (1-2 A) asymmetric-energy e^+e^- storage ring accelerator that operates at a center-of-mass energy equal to the mass of the Upsilon (4S) resonance (10.58 GeV).[1,2] The high beam currents are achieved by storing a large number of bunches (about 1600) into each beam. The energy asymmetry imparts a boost to the nearly stationary B mesons formed from the decay of the 4S resonance and allows precision vertex tracking detectors to look for a difference between the decay profiles of the matter and antimatter B mesons, thereby observing a violation of CP.

The PEP-II design has a low-energy beam (LEB) of 3.1 GeV and a high-energy beam (HEB) of 9 GeV. The beams collide head-on and are separated by a horizontal bending magnet located between 0.2 m and 0.7 m on either side of the interaction point (IP). The separation of the beams continues as they travel through QD1, a vertically focusing quadrupole. The QD1 magnets are essentially centered on the HEB orbit which places the LEB off-axis in these magnets. The large offset of the LEB orbit in QD1 bends the LEB further away from the HEB producing enough separation to allow QF2, a horizontally focusing magnet located between 2.8 m and 3.4 m from the IP, to be a septum quadrupole. QF2 is the second half of the final focus doublet for the LEB (QD1 is the other half). The HEB travels through a field free region in QF2; QD4 and QF5 (centered at 4.45 m and 6.2 m and 1.5 m long) are the main final focusing magnets for this beam. Figure 1 shows a layout of the interaction region of PEP-II. The B1 magnets and the QD1 magnets are made from permanent magnet material; both of these magnets are inside the solenoidal field of the detector.[3]

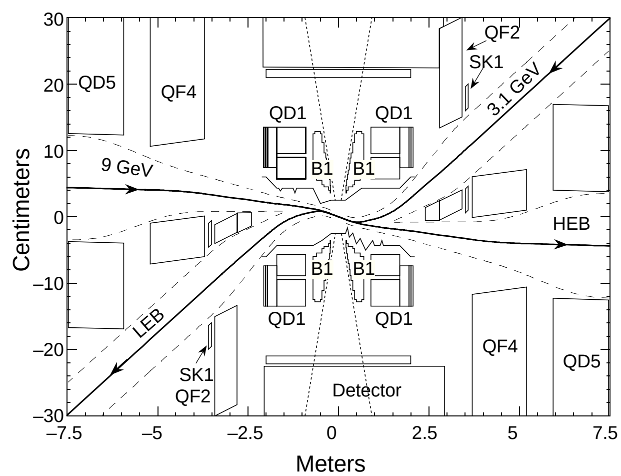

Figure 1. Layout of the interaction region of the PEP-II B-factory. The vertical scale is highly exaggerated. The detector for PEP-II is offset in z by 37 cm in the direction of the HEB.

2 DETECTOR BACKGROUNDS

The detector in a B-factory must be protected from two main beam-related backgrounds, synchrotron radiation and beam-gas bremsstrahlung. These backgrounds are controlled through the use of masks located near the detector or just upstream of the detector. I make a distinction between masks and collimators as follows. Masks are beam aperture limiting devices that are generally used near or just upstream of the collision point to block or absorb specific backgrounds. Collimators are aperture limiting devices that are designed to limit the overall range of the beam particles. They limit the maximum transverse size of the beam and the maximum energy spread of the beam particles. Usually, collimators are located farther from the collision point since they concentrate on screening out particles that can travel several times around a ring before escaping and striking the beam pipe.

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2.1 Synchrotron radiation masking

The beam separation scheme of the PEP-II design generates strong bending radiation just upstream of the collision point. This radiation must be blocked from striking the detector beam pipe. The radiation generated by the beams as they go through the powerful B1 magnets does not strike any of the upstream masks or beam pipes. However, the radiation produced by the LEB as it travels through the QD1 magnet must be intercepted by masks before the radiation can strike the detector beam pipe.

The QD4 magnet is placed about 14 mm off-axis from the HEB orbit. The bending of the HEB by the off-axis QD4 redirects the radiation produced by beam particles at large transverse orbits (many beam sigmas) as they go through QF5 from striking the inside surfaces of the masks near the IP. The beam pipe of the detector is a thin tube of beryllium and is very transparent to x-rays. Just outside of the Be beam tube is a silicon vertex detector that is sensitive to x-rays; the vertex detector is concerned about occupancy as well as radiation damage. Figures 2 and 3 show the bend radiation fans for the LEB and the HEB near the collision point.

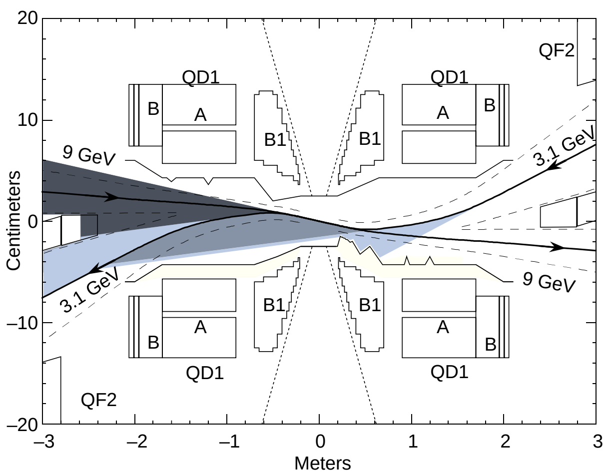

Figure 2. The bend radiation fans generated by the LEB as it travels through the interaction region. The shading of the fans is a measure of the intensity of the radiation. The darker the shading the more intense the radiation.

In addition to blocking the upstream bend radiation, the masks also prevent the radiation produced by beam particles out at large transverse distances from striking the beam pipe. The primary source of synchrotron radiation background for PEP-II is from photons that strike close enough to the tip of the masks to scatter through the tip and strike the detector beam pipe. Nevertheless, the photon rate from large transverse beam particles (out in the beam tails) can be quite high if the particle density is high enough. There is a great deal of uncertainty about the particle density in these beam tails. The density depends on several not fully understood mechanisms that can push particles out into the tails. The beam-beam

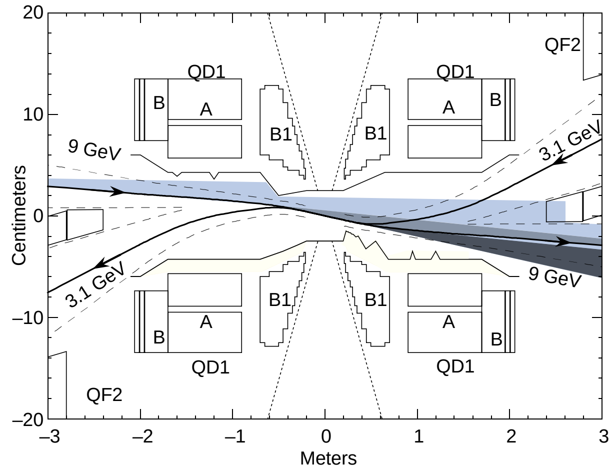

Figure 3. The bend radiation fans generated by the HEB as it travels through the interaction region. The more intense radiation fans have a darker shading. The very intense radiation fans produced in the B1 magnets does not strike any nearby surfaces and is absorbed in a dump that is about 15 m away.

collision is one such mechanism and another is gas-scattered beam particles that are still inside the energy and/or dynamic aperture of the accelerator. The exact parameters that determine the distribution of the beam tails are very accelerator specific. A study of the beam tails in the CERN LEP accelerator has been made and the results are in rough agreement with the tail distributions used in the B-factory design.[4] For synchrotron radiation background studies, the PEP-II design models the beam-tail distribution as another, lower amplitude, gaussian with a larger beam sigma than the nominal beam gaussian distribution. This second gaussian has a particle density at the 10σ limit that determines a beam life-time of about one hour assuming there is a physical aperture at the 10σ limit.[5] Figure 4 shows the beam tail distributions used in the calculation of detector backgrounds from synchrotron radiation. The backgrounds are calculated using the maximum emittance allowed by the accelerator design for each beam. This emittance is also used to calculate the beam-stay-clear (BSC) for each beam. The maximum total emittance used for the LEB is 100 nm-rad and for the HEB is 50 nm-rad.

2.2 Lost beam particles

Beam particles can scatter off of gas molecules in the vacuum chamber in two ways: beam-gas-bremsstrahlung (BGB) and coulomb scattering. In BGB, the beam particle loses energy and emits a photon with the photon energy and the scattered beam particle energy nearly adding up to the original beam energy. In coulomb scattering, the beam particle scatters elastically off of the gas molecule changing the trajectory of the particle but leaving the particle energy intact. In BGB, the photon energy spectrum falls off as 1/k so the scattering rate is highest

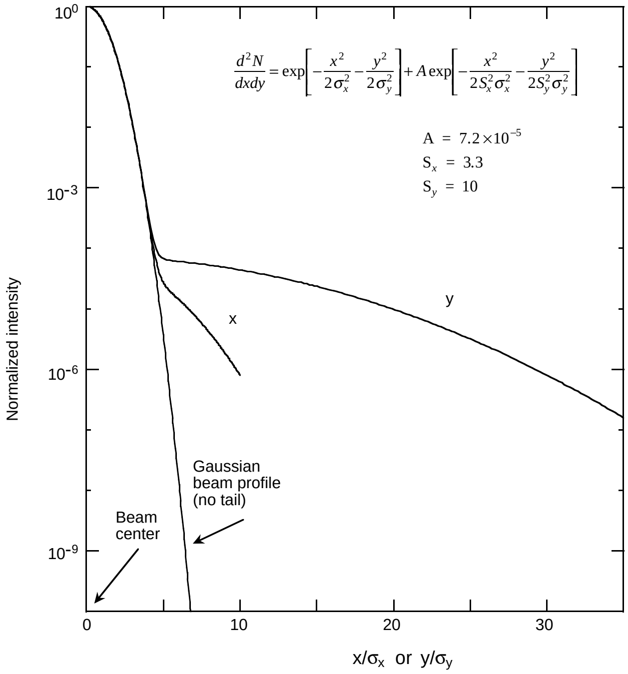

Figure 4. The beam tail distribution used in the calculation of the synchrotron radiation backgrounds for the BaBar detector in PEP-II. The model assumes the tails are cut off at 10σ in x and 35σ in y.

for the lowest energy photons. Since photons travel in straight lines, only those interactions sufficiently close to the detector have a photon as part of the background source. The off-energy beam particles can travel through some portion of the magnetic lattice of the machine before striking the beam pipe near the detector and generating electromagnetic showers that produce backgrounds in the detector. In the PEP-II design, an energy loss of at least 2% is needed before the lost particle will strike the beam pipe near the detector. For coulomb scattered lost particles a minimum scattering angle of 0.33 mrad is needed before the particle has a chance of striking near the detector beam pipe.

Masks are installed upstream of the detector (from 10 m to 60 m) to clip off lost particles before they can strike the beam pipe near the detector. These masks are placed as close to the beam as possible (right up to the BSC) and hence the effectiveness of these masks is determined by the transverse size of the beam.

3 BEAM COLLIMATION

The background studies for the PEP-II B-factory assume that there are no particles beyond the 10σ limit in transverse dimensions as well as in energy. In the vertical dimension, the 10σ value is computed when the beam is fully coupled (half of the total emittance is in the vertical dimension). With the nominal coupling of 3%, this corresponds to about 35σ. This extra room accounts for the ring dynamic aperture needed for the injected beam since the vertically injected pulse enters the ring at about 8 fully coupled beam sigmas or 28 nominal beam sigmas.

3.1 Beam particles beyond 10σ

If there is no beam collimation then the particles in the beam tails extend out either to the limits of the dynamic aperture or until a physical aperture is encountered. The physical aperture of the beam pipe near the IP in the PEP-II B-factory is designed with a BSC of 15σ plus an additional 2 mm for closed orbit distortion. However, the beam lines in the rest of the two-ring accelerator have a fairly large physical aperture (generally > 35σ_x uncoupled and 30σ_y fully coupled except in the injection region). Therefore, without collimation, the interaction region is one of the few tight spots in the accelerator. In addition, the beta functions are larger in the interaction region than anywhere else in the ring for both beams. This makes it much more likely for off-energy particles to escape in this region and strike a local beam pipe thereby generating backgrounds in the detector.

3.2 Synchrotron radiation from particles beyond 10σ

The synchrotron radiation masking design has been optimized with the assumption that there are no beam particles beyond 10σ in x and 35σ in y. Table 1 summarizes the change in background rate in the detector for cases in which there are beam particles beyond the design limits.

Table 1. Summary of the effect on backgrounds from synchrotron radiation when beam particles exist beyond the design values of 10σ_x and 35σ_y.

Case	Photons/collision > 4 keV that strike the detector beam pipe	Ratio to nominal	Primary source
Design	10	1	mask tips
11σ_x, 39σ_y	10	1	mask tips
12σ_x, 42σ_y	10	1	mask tips
13σ_x, 46σ_y	370	37	HEB direct
14σ_x, 49σ_y	4200	420	HEB direct
15σ_x, 53σ_y	15400	1540	HEB direct

The photon rates shown in Table 1 depend exclusively on the assumed particle density in the high sigma regions. For this study, I take a conservative approach and assume that the beam life-time is determined by the particle density at the edge of the distribution. Therefore the beam-tail particle density remains constant at the beam edge. This is done by broadening the beam-tail sigma while holding the beam-tail amplitude constant.

3.3 Lost beam particles beyond 10σ

Lost particle simulations used to study backgrounds in electron storage rings have not studied lost beam particles that survive for more than one turn and, in most cases, only lost beam particles produced just upstream of the detector have been analyzed. The PEP-II design included lost particle production as far upstream as one sixth the circumference of the ring (about 370 m). As stated earlier, lost particle background studies found that a beam particle had to lose at least 2% of the beam energy before the particle would be able to strike the beam pipe near the detector. The 10σ energy aperture for PEP-II is 0.6%. If no beam particles are allowed to be outside the 10σ energy cut either through the use of collimators or because of the dynamic aperture of the accelerator, then only those lost particles produced just upstream of the detector can contribute to background calculations. However, if the dynamic aperture is large enough to include particles with a large energy deviation and no collimation has been installed, then beam particles can have a significantly increased energy distribution. Particles out at the high sigma energy values may be stable enough to go around the accelerator several times before getting lost. If this is the case, the interaction region is one of the more likely places for these particles to finally strike a beam pipe.

The PEP-II HEB was first commissioned last June 1997 and was further commissioned last September and October. Lost particle backgrounds were measured in the interaction region and the rates were significantly higher than expected. Some preliminary tests were made to discover the source of this background by turning off sections of pumping around the ring. It was found that the entire ring was contributing at some level to the observed background. The ring dynamic aperture was found to be reasonable (the accelerator matches the model quite well) and no collimators were as yet installed. The lack of energy collimation allows beam particles to populate the energy space out to the edge of the dynamic aperture. It can take several turns for these particles to be finally lost with the odds being high the particle will be lost in the interaction region. This coming January 1998 an energy collimator will be installed and it is hoped that this will make a significant difference in the background level measured in the interaction region.

4 SUMMARY

Collimation of the PEP-II B-factory stored beams is an important aspect of the overall design of the control of detector backgrounds. The masking of the detector beam pipe from upstream synchrotron radiation sources depends on the maximum transverse size of the beam. The masks are positioned so as to shield the detector beam pipe from radiation generated both by upstream bend magnets and by large transverse beam particles as they travel through the final focusing quadrupoles. Beam particles that are beyond the design cutoff can increase backgrounds in the detector by as much as a factor of a thousand.

Lost beam particles (especially beam-gas bremsstrahlung) produce a tail of off-energy particles that will go out to the limit of the dynamic aperture of the accelerator in energy space. This limit can be much larger than the 10σ limit assumed in background models. The off-energy particles near the aperture limit are not necessarily accounted for in background models since these particles can travel around the ring several times before they are lost. The class of particles that do get lost this way are likely to leave the machine in the places where physical apertures are close to the beam orbit. This is usually in one of two places: the injection region where physical apertures are close to the beam and in the interaction region where the large beta functions push the beam out to near the physical aperture.

Beam collimation helps control detector backgrounds by cutting off the long non-gaussian beam tails in energy and in the transverse beam dimensions. Good collimation produces a better understood beam profile in transverse space and in energy space which, in turn, makes the accelerator more amenable to modeling and computer simulations leading to a more accurate understanding of the dynamics of the accelerator.

5 ACKNOWLEDGMENTS

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