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ISSUES FOR BACKGROUND CALCULATIONS IN E^+E^- FACTORIES*

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ABSTRACT
There are several interdependent and often conflicting background issues that drive any design of the interaction region (IR) in an e^+e^- factory. Synchrotron radiation must be kept away from the detector beam pipe and lost beam particles must be absorbed in masks to protect the detector from unwanted occupancy and radiation damage. This note discusses some of these issues and looks at various e^+e^- factories to see how certain decisions have influenced a particular IR design.

1 Introduction

The machine design of an interaction region must do several things in the same physical space. In the case of e^+e^- factories, the two high-current beams are brought into collision while being tightly focused in order to attain the highest possible luminosity. At the same time, a detector with a large solenoidal magnetic field that affects the colliding beams, must have the lowest possible background from the beam and yet needs the thinnest possible beam pipe as well as the largest possible solid angle for detecting particles produced from the collision. On top of all this, backgrounds from lost beam particles must be kept to a minimum by maintaining the lowest possible vacuum in the beam pipes just upstream of the detector for each beam.

2 Accelerator parameters related to the IR design

The accelerator design must select values for several parameters that have a strong influence on the IR design. Some of these parameters, for instance the beam energies, are decided by the physics requirements while other parameters like the ring circumference, are decided by already existing structures or construction limits. Table 1 lists some of the accelerator parameters for five factories: the Frascati Phi Factory (DAΦNE)[1,2], the

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Beijing Tau-Charm Factory (BTCF)[3,4], the Cornell B-Factory (CESR-III)[5,6], the KEK B-factory (KEKB)[7,8], and the SLAC, LBNL, LLNL B-factory (PEP-II)[9,10].

Table 1. Some parameters of five e^+e^- factories.

	DAΦNE		BTCF		CESR-III		KEKB		PEP-II	
	e^+	e^-	e^+	e^-	e^+	e^-	e^+	e^-	e^+	e^-
E_{beam} (GeV)	0.51	0.51	1.5-3.0		5.3	5.3	3.5	8.0	3.1	9.0
I (A)	5.3	5.3	0.57	0.57	0.5	0.5	2.6	1.1	2.14	0.99
β_y^* (cm)	4.5	4.5	1.0	1.0	1.0	1.0	1.0	1.0	1.5	2.0
ε_x (nm-rad)	1000	1000	153	153	251	251	18	18	66	49
$\sigma_{(x,y)}$ (μm)	212, 21.2		315, 4.8		388, 11.7		77, 1.9		181, 5.4	
r	0.01		0.015		0.03		0.02		0.03	
ξ	0.04		0.04		0.03		0.05		0.03	
S_b (m)	0.81		3.78		4.2		0.59		1.26	
# of bunches	120		86		nine 5-bunch trains		5027		1654	
θ_c (mrad)	±12.5		±2.6		±2.1		±11		head-on	
L ($cm^{-2}sec^{-1}$)	1×10^{33}		1×10^{33}		1.75×10^{33}		1×10^{34}		3×10^{33}	

Let us see how some of the accelerator parameter selections affect the design of an IR.

2.1 Beam energies

The energy of the beams clearly control many aspects of the IR. For symmetric energy designs, (DAΦNE, BTCF, CESR-III), beam trajectories are inherently symmetric which tends to simplify the beam orbit design near the IP. Symmetric energy beams also means that the synchrotron radiation (SR) backgrounds and the lost particle backgrounds are the same for each beam. The two asymmetric energy designs, (KEKB, PEP-II) have to decide how much energy asymmetry to employ. The greater the asymmetry, the easier it is to separate the beams, however, the SR from the high energy beam (HEB) becomes more difficult to manage as the beam energy increases.

2.2 Beam aspect ratio

The value of the horizontal to vertical ratio of the beam plays an important role in the design of the IR. Beams with a ratio of near one can increase the luminosity of an accelerator by as much as a factor of two[11], however, it is much more difficult to shield detectors from the SR generated by the final focusing quadrupoles because the beta functions in these magnets are significantly larger than they are in designs for flat beams. In general, e^+e^- factories have chosen a flat beam design; a notable exception is the Novosibirsk phi-factory design which uses round beams[12)].

2.3 Collision angle and bunch spacing

These two parameters, to a large extent, control how the beams are separated after the collision. The closer the bunch spacing the more rapidly the beams must be separated in order minimize beam disruptions from parasitic crossings on either side of the interaction point (IP). Introducing a nonzero crossing angle at the IP makes it much easier to separate the beams at the expense of possibly introducing synchro-betatron coupling resonances at the collision point. The Cornell machine (CESR) has demonstrated that a crossing angle that is small with respect to the beam spot size (about 10% of σ_x/σ_z) does not significantly affect the performance of the accelerator.

2.4 A small β_y^* at the IP

In order to maximize the luminosity all designs have small beta functions and hence small spot sizes at the collision point. Small beam spots at the IP mean large beams in the final focus quadrupoles which leads to large beam chromaticity and limited beam dynamic aperture. This places stringent requirements on field quality for these magnets and has led all e^+e^- factory designs to place these final quadrupoles as close to the IP as possible. In all designs, these magnets are now inside the detector. This in turn has limited the type of magnets to be either superconducting or permanent magnet because of the detector solenoidal field.

2.5 The beam emittance and beam-stay-clear definition

The beam emittance is generally determined by other accelerator parameters (i.e. beam energy, ring circumference, ring lattice design...) but the beam emittance has a strong influence on the IR design. The larger the emittance the larger the transverse beam dimensions and the more room that is needed in magnets near the IP. In addition, large beams mean that it is more difficult to separate the beams and avoid parasitic crossing effects. Folded in with the effect the beam emittance has on the IR design is the definition of the beam-stay-clear (BSC). Generally, in order to minimize detector background due to lost beam particles, the BSC is defined to be largest in the IR when compared to the rest of the accelerator. These dimensions are again controlled by the beam emittance together with the beta function values chosen in the IR.

2.6 Beam tails

The non-gaussian beam tails generated mainly by the beam disruption during collision can influence the SR backgrounds and when taken into account usually alter the design of the masking for SR. Beam scattering from gas molecules and, for low energy beams, Touschek scattering are other sources of beam tail production. One has to be careful that particles out at large beam sigma values (in the beam tails) do not introduce large detector backgrounds because they can produce radiation at angles that can get around mask tips that work quite well for the majority of the beam particles. It is difficult to estimate the particle density in the beam tails and hence it is difficult to estimate the contribution to background rates from these beam tail particles. The PEP-II design has chosen a somewhat conservative approach in that the beam tail population is assumed to determine the colliding beam lifetime, estimated at a couple of hours. In addition, the beam tails are assumed to be cut off at 10 beam sigmas. The designed masking can shield the detector from beam tail particles out to about 12 beam sigmas before background rates start climbing due to particles out at high beam sigma generating SR that gets around the mask tips.

2.7 Beam pipe heating from higher-order-mode power and SR

The large beam currents of all e^+e^- factories mean that significant amounts of power from higher-order-mode (HOM) heating and SR must be controlled near the IP. The space around this region is very precious; the detector takes up a lot of the available space and other machine elements take up most of the rest of the space. In designs where the two beams go into separate rings (all designs but CESR-III) the joined beam pipes make a local cavity that traps HOM power. All designs have large beams in the final focusing magnets which usually means the beam pipe is large in order to accommodate these large beams again creating a local cavity. Space must be allocated for properly absorbing this power generated by the high-current beams.

3 Detector requirements related to the IR design

The detector, aside from its presence, also places demands on the IR design. The strong solenoidal field (0.5 to 1.5 T) does more than limit the type of accelerator magnets for the final focusing elements: it also introduces coupling and steers the two beams. A nonzero crossing angle together with the need to quickly separate the beams means that both beams cannot be parallel to the detector field. Consequently, at least one and in most cases both beams are steered by the detector magnet. The detector also wants as much unobstructed solid angle view of the collision point as possible (this also maximizes the effective luminosity of the accelerator plus detector) which pushes the final focus magnets into as little space as possible. All e^+e^- detectors want a beam pipe that is as thin (or as transparent to particles from the collision) as possible around the collision point and in nearly all cases this pipe should be as small as possible. The beam pipe for the DAϕNE design is an exception. The DAϕNE physics requirements call for a beam pipe with a radius of about 11 cm; most other designs have a pipe radius of less than 3 cm. The small radius requirement makes shielding the beam pipe from SR difficult and ultimately the need to protect the beam pipe from too much SR determines the minimum radius of the pipe. A smaller pipe is also much harder to shield from lost particle backgrounds. The transparency of the pipe is ultimately set by engineering constraints and by the estimated SR background rates that penetrate through the pipe. Lost particle backgrounds are kept to a minimum by lowering the vacuum in the upstream beam pipes as much as possible.

4 Some general issues concerning backgrounds

4.1 Synchrotron radiation rates and beam energy.

The critical energy of SR has an E^3 beam energy dependence so a relatively small change in beam energy can dramatically change the SR photon rate. In addition, photon penetration through SR mask tips and through thin beam pipes can increase rapidly with an increase in photon energy. Combining all of these factors means that background rates from SR can rapidly change with changes in beam energy. IR designs should always try to estimate backgrounds from the highest beam energy settings of the factory.

4.2 Lost beam particle backgrounds.

Most of this background comes from the beam pipe just upstream of the detector. The vacuum in this pipe must be as low as possible. Designs should try to make the apertures in the IR as large as possible so that beam particles that are about to be lost have a better chance of getting through the IR before colliding with the beam pipe.

4.3 Upstream bend magnets.

There is always an upstream bend magnet that sprays SR photons into the IR. Whenever possible, designs try to place this magnet as far from the IP as possible and make it as weak as possible in order to minimize this source of background.

4.4 The transverse size of the beam.

High luminosity generally pushes the beam size to large values in the final focusing elements near the IP. Large beams in these magnets make it more difficult to protect the detector beam pipe from direct SR that comes from the beam particles out at large sigma. In order to shield the detector beam pipe SR masks have to come in to a smaller

a) b)

Figure 1a. *Layout of the DAϕNE Accelerator. The design has the lowest energy beams. The symmetric, low beam energies mean that SR is not a major design issue. The beams are separated by a ±12.5 mrad horizontal crossing angle. The large emittance of the beams (see Table 1) is compensated for by the small beta functions in the final focus quadrupoles. The permanent magnet quads are placed as close as possible to the IP. With the large crossing angle, both beams are steered by the detector solenoid and by the final focus quads. Compensation solenoids on either side of the IP help correct effects on the beam from this field. The primary background is lost particles, hence the vacuum in the pipe just before the detector is as low as possible.* Figure 1b. *Vertical view of the BTCF accelerator. This symmetric energy design has the largest beam energy range. A small horizontal crossing angle of ±2.6 mrads starts the beam separation and vertical electrostatic plates complete the separation. The moderate beam energies and the large energy range mean that SR must be carefully masked out. The superconducting final focus quads are placed as close as possible to the IP in order to keep the beam size in these quads reasonable. The small crossing angle keeps detector solenoid steering to a minimum. Backgrounds from lost beam particles are kept to a minimum by keeping the vacuum in the beam pipes upstream of the detector as low as possible.*

Figure 3. *Layout of the PEP-II asymmetric energy B-factory. PEP-II has the largest energy asymmetry of the three B-factories. The beams collide head-on and powerful horizontal bending magnets are used to initiate beam separation which continues through the next shared element QD1. The strong bending generates significant SR; most of it passes through the IP but some must be masked from the detector beam pipe. The lost particle backgrounds are minimized by lowering the upstream vacuum as much as possible. The detector field steers both beams necessitating local orbit correction.*

6 Summary

High luminosity e^+e^- factories bring several challenges to any interaction region design. The large beam currents of the factories make the old problem of detector backgrounds more difficult and also raise the relatively new problem of beam pipe heating. Interaction region designs must cope with heating due to I^2R wall losses as well as HOM heating from the cavity-like structure inherent in interaction region beam pipes. The tight focusing of the beams means that machine elements must be close to the collision point and hence are deeply imbedded inside the detector. Many accelerator design decisions (i.e. crossing angle, beam energies, emittances,...) strongly affect the accompanying interaction region design. In the end, all designs must overcome the same set of challenges; the differences are in the details of specific accelerator and detector choices.

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