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Abstract

A Super B Factory, an asymmetric e^+e^- collider with a luminosity of 10^{36} cm^{-2}s^{-1}, can provide a sensitive probe of new physics in the flavor sector of the Standard Model. The success of PEP-II and KEKB in producing unprecented luminosity with unprecedently short commissioning time has taught us about the accelerator physics of asymmetric e^+e^- colliders in a new parameter regime. It appears to be possible to build on this success to advance the state of the accelerator art by building a collider at a luminosity approaching 10^{36} cm^{-2}s^{-1}. Such a collider would produce an integrated luminosity of 10,000 fb^{-1} (10 ab^{-1}) in a running year. Design studies are underway to arrive at a complete parameter set based on a collider in the PEP-II tunnel but with an upgraded RF system (perhaps a higher frequency) and an upgraded interaction region [1-6].

2.11.1 Design Constraints

The construction and operation of modern multi-bunch e^+e^- colliders have brought about many advances in accelerator physics in the area of high currents, complex interaction regions, high beam-beam tune shifts, high power RF systems, controlled beam instabilities, rapid injection rates, and reliable uptimes (~95%).

The present successful B-Factories have proven that several design concepts are valid. 1) Colliders with asymmetric energies can work. 2) Beam-beam energy tranparency conditions are weak. 3) Interaction regions with two energies can work. 4) IR backgrounds can be handled. 5) High current RF systems can be operated (2 amps x 1 amp). 6) Beam-beam parameters can reach 0.06 to 0.9. 7) Injection rates can be good and continuous injection is feasible. 8) The electron cloud effect (ECI) can be managed to a small effect. 9) Bunch-by-bunch feedbacks at the 4 nsec spacing work well.

In addition to the above lessons learned, new techniques can be employed [1,3]. A) The beam lifetimes will be low so continuous injection will be needed. B) Continuous injection will be used to push the beam-beam parameter to higher values than can be tolerated when long lifetimes are required. C) Much higher currents are needed and the vacuum chamber and feedbacks must be made to match. D) Bunch-by-bunch feedbacks will need to operate at the 1 nsec scale, down from the present 4 nsec time. E) Much shorter bunches will be needed; on the order of 2 mm. F) Higher-power vacuum chambers and HOM tolerant chambers will be needed. The use of expansion bellows will need to be minimized or a high-power design developed. G) Very low vertical beta functions at the interaction of about 1.5 to 2.5 mm will be needed. H) Special chromaticity corrections will be needed. I) Every technique to reduce the wall plug power will need to be used. For example, reducing the energy asymmetry to reduce synchrotron

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radiation, increase the vacuum chamber bores to reduce resistive wall effects,, and increasing the RF cavity bores to reduce HOM losses.

2.11.2 Parameters

The design of a 10^{36} $cm^{-2}s^{-1}$ e^+e^- collider combines a natural extension of the design of the present *B* Factories with a few new ideas and special circumstances to allow improved beam parameters to be achieved. The luminosity L in an e^+e^- collider that has a limited vertical tune shift ξ_y with flat beams (r=0.02) is given by the standard expression

$$L = 2.17 \times 10^{34}(1+r)n\xi_y\left(\frac{EI_b}{\beta_y^*}\right)\ \text{cm}^{-2}\text{sec}^{-1} \qquad (1)$$

where I_b is the bunch current (amperes), n is the number of bunches, *E* is the beam energy (GeV), and β_y* is the vertical beta function (cm) at the collision point. The luminosity gain of the Super *B* Factory comes from the increase of the beam currents by about a factor of eight, lowering β_y* about a factor of five, and increasing the beam-beam tune shifts about 25%. The resulting gain is about a factor of 50 over that of the present *B* Factories when they are upgraded to about $2\text{x}10^{34}$ $cm^{-2}s^{-1}$ over the next few years. In addition, due to continuous injection with the luminosity always near the maximum, the integrated luminosity per unit time of the Super *B* Factory is expected to increase another 20 to 30% over the present machines. The parameters of a representative 10^{36} $cm^{-2}s^{-1}$ e^+e^- collider are listed in Tables 1 and 2 for different RF frequencies. These parameters were chosen after balancing beam dynamics effects, technology limits, luminosity performance, and SLAC site AC power issues. The PEP-II tunnel is an excellent site for this collider. The SLAC power substation can provide 140 MW if needed.

The beam energies are 8 GeV for the high-energy ring and 3.5 GeV for the low-energy ring. Lowering the high-energy ring energy from 9 GeV reduces the synchrotron radiation load on the RF system. The e^+ and e^- may be exchanged if need be as either particle can be stored in either ring using the versatile SLAC injector. The linac can provide low emittance beams with 80 Hz of electrons and 20 Hz of positrons. The remaining 20 Hz will be used to generate positrons at the production target.

2.11.3 RF Frequency Selection

Two RF frequencies for the Super *B* Factory have been studied: 476 MHz as in the present PEP-II and 952 MHz. At the higher frequency, more bunches (about 6900) can be stored, thereby reducing single bunch effects and higher order mode losses at the high total current. Industry has the ability to make cw 952 MHz klystrons at the MW level needed for this accelerator. RF cavities at 952 MHz can be made with a similar design to the PEP-II style copper cavities, using improved HOM dampers and with additional storage cavities to help reduce longitudinal multi-bunch instabilities.

In the Super *B* Factory, the single bunch currents are a factor of two higher than those of PEP-II or KEKB; the total current is increased by a factor of eight, but there are four to eight times as many bunches. Furthermore, the bunch lengths are about five times shorter. These short high-charge bunches lead to increased single bunch effects; Higher-Order-Mode (HOM) losses and resistive wall losses that have to be minimized in each ring, see Figure 1. HOM losses in the RF cavities will be reduced by opening the beam channel through the RF cavities about 50%. The resistive wall losses of the short bunches in the vacuum chambers will be reduced by a factor of two by increasing the vacuum chamber radius.

Table 1 Super B Factory Parameters with 476 MHz RF.

Parameter	**LER**	**HER**
Energy (GeV)	3.5	8
RF frequency (MHz)	476	476
Vertical tune	72.64	56.57
Horizontal tune	74.52	58.52
Current (A)	11.0	4.8
Number of bunches	3450	3450
Ion gap (%)	1.2	1.2
HER RF klystron/cav	22/44	18/36
HER RF volts (MV)	29	24
β_y* (mm)	2.2	2.2
β_x* (cm)	15	15
Emittance (x/y) (nm)	27.5/0.4	27.5/0.4
σ_z (mm)	2.5	2.5
Lum hourglass factor	0.82	0.82
Crossing angle(mrad)	15	15
IP Horiz. size (μm)	64	64
IP Vert. size (μm)	0.9	0.9
Horizontal ξ_x	0.15	0.15
Vertical ξ_y	0.15	0.15
Lumin. (x10^{34}/cm^2/s)	50	50

2.11.4 Interaction Region

The interaction region is being designed to leave the same longitudinal free space as that presently used by *BABAR* but with superconducting quadrupole doublets as close to the interaction region as possible, as shown in Figure 2. A crossing angle is used to separate the two beams as they enter and leave the interaction point. The overall interaction region is shorter than for PEP-II, allowing a shorter detector if that is advantageous [6].

Recent work at Brookhaven National Laboratory on precision conductor placement of superconductors in large-bore low-field magnets has led to quadrupoles in successful use in the interaction regions for the HERA collider in Germany [7]. A minor redesign of these magnets will work well for the Super *B* Factory.

The beams must have a crossing angle at the collision point to avoid parasitic crossing effects; the anticipated crossing angle is +/- 12 to 17 mrad. Short bunches are also needed to avoid the geometrical hour-glass effects that could reduce the luminosity during collisions. The short Super *B* Factory bunches are made by providing extra over-voltage in the RF system and by a high phase-advance quadrupole lattice in each ring.

The low beta functions at the collision point will make the ring chromaticity high. Correcting the chromaticity is the task of sextupole magnets, but sextupoles reduce the dynamic aperture of the storage ring. Due to the naturally reduced lifetimes of the beams, the dynamic aperture and the resulting vacuum system do not have to be designed for lifetimes of hours, only for one hour, thus, reducing costs.

The increases in the beam-beam parameters from the present 0.06 to 0.09 range to 0.15 will be achieved by operating just above but very close to the half-integer horizontal tune where standard, but strong, dynamic beta effects occur. Also, pushing the transverse tunes closer to specific resonances allows a higher tune shift and more luminosity but with shorter beam lifetimes. Both techniques have been successfully demonstrated at the present *B* Factories.

Table 2 Super B Factory Parameters with 952 MHz RF

Parameter	**LER**	**HER**
Energy (GeV)	3.5	8
RF frequency (MHz)	952	952
Vertical tune	72.64	56.57
Horizontal tune	74.52	58.52
Current (A)	15.5	6.8
Number of bunches	6900	6900
Ion gap (%)	1.2	1.2
HER RF klystron/cav	32/64	25/50
HER RF volts (MV)	43	33
β_y* (mm)	1.5	1.5
β_x* (cm)	15	15
Emittance (x/y) (nm)	19.5/0.19	19.5/0.19
σ_z (mm)	1.75	1.75
Lum hourglass factor	0.8	0.8
Crossing angle(mrad)	15	15
IP Horiz. size (μm)	54	54
IP Vert. size (μm)	0.5	0.5
Horizontal ξ_x	0.15	0.15
Vertical ξ_y	0.15	0.15
Lumin. (x10^{34}/cm^2/s)	100	100

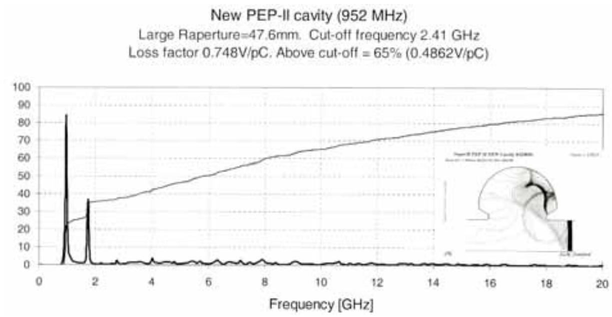

Figure 1 HOM calculation for a 952 MHz PEP-II style RF cavity with an increased bore.

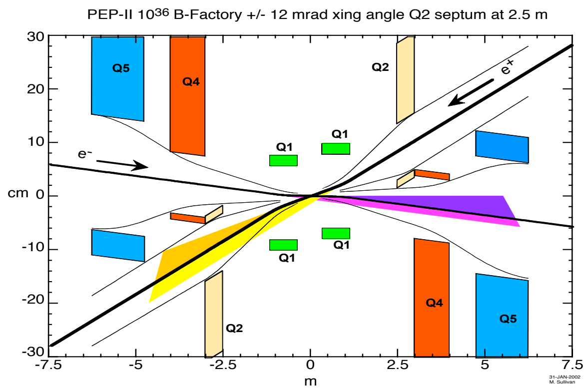

Figure 2 Interaction region for a Super B-Factory. Note the first quadrupole is at 30 cm from the interaction point. This first quadrupole will have a quadrupole, x and y dipole, solenoidal, and skew quadrupole windings.

2.11.5 Power Scaling

The power required by a collider is the sum of a site base plus RF sources. With a Super B-Factory, there will be an overall base level due to the SLAC campus (~15 MW), the linac running for PEP-II at 30 Hz (~8MW), The PEP-II magnets (~7 MW), the linac running for LCLS (~10 MW), and SPEAR (~5 MW) for a total of about 40 MW.

The total RF power is the sum of the cavity wall losses, beam synchrotron radiation, beam resistive wall losses, beam higher order mode losses (HOM), and AC distribution inefficiencies. The AC transformers and high voltage power supplies are about 90% efficient. The RF klystrons are about 65% efficient. For beam stability control, the klystrons do not run at full power which reduces their efficiency to about 50%. The RF power losses to the cavity walls are 70 to 100 kW depending on the voltage. The synchrotron radiation losses are minimized by reducing the energy asymmetry of the B-Factory to 3.5 x 8 GeV and by adding dipoles to the low-energy ring to reduce the effective bending radius. The vacuum chamber bores are enlarged to reduce the resistive wall losses that go inversely with the chamber size. The HOM losses are reduced by going to a higher RF frequency with more bunches but same total current.

The total power of a Super-B Factory at the SLAC site as a function of luminosity is shown in Figure 3. If the site power is limited to 120 MW that is within the range of the incoming power lines, then a luminosity of about $5x10^{35}$ luminosity is possible at 476 MHz and 1×10^{36} at 952 MHz.

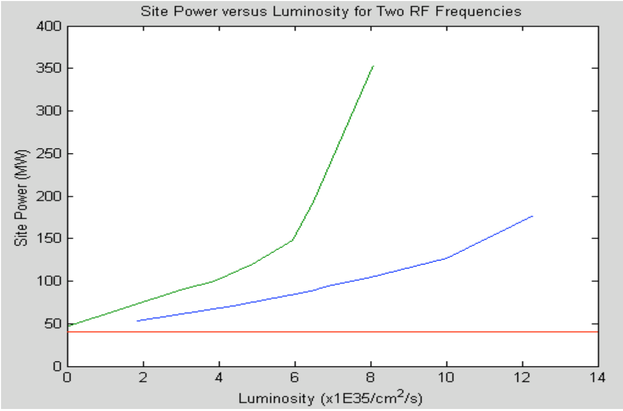

Figure 3 Site power scaling for two RF frequencies The upper curve is for 476 MHz and the lower curve 952 MHz. The power above the 40 MW horizontal line is from the overall PEP-II RF system. The currents increase with the luminosity and, thus, increase the power usage.

2.11.6 References

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