DESIGN FOR A 10^{36} SUPER-B-FACTORY AT PEP-II*

J. Seeman[†], Y. Cai, F.-J. Decker, S. Ecklund, A. Fisher, J. Fox,
S. Heifets, A. Novokhatski, M. Sullivan, D. Teytelman, U. Wienands
SLAC, Menlo Park, CA 94025, USA
M. Biagini, INFN, Frascati, Italy

Abstract

A Super B-Factory, an asymmetric e^+e^- collider with a luminosity of 2.5 to 7 x10^{35} cm^{-2}s^{-1}, can provide a sensitive probe of new physics in the flavor sector of the Standard Model. The success of the present B-Factories, PEP-II and KEKB, in producing unprecedented luminosity with very short commissioning times has taught us about the accelerator physics of asymmetric e^+e^- colliders in a new parameter regime. From this experience, it is possible to build on this success to advance the state of the accelerator art by constructing a collider with 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 at SLAC but with an upgraded RF system, vacuum system, magnet system, and interaction region [1-7]. The present injection system based on the SLAC linac needs no improvements and is ready for the Super-B-Factory.

DESIGN CONSTRAINTS

The present successful B-Factories have proven many advances in accelerator physics. 1) Colliders with asymmetric energies can work. 2) Beam-beam energy transparency conditions are weak. 3) Interaction regions with two energies can work. 4) Interaction region backgrounds can be handled. 5) High current RF systems can be operated (2.5 amps x 1.5 amp). 6) Vertical beam-beam parameters can reach 0.08. 7) Injection rates can be good and continuous injection improves the average efficiency by 40%. 8) The electron cloud effect (ECI) can be managed. 9) Bunch-by-bunch feedbacks at the 4 nsec spacing work well.

In addition to the above lessons learned, new techniques can be employed. A) In the new collider the beam lifetimes will be naturally low so continuous injection must be used. B) Continuous injection and strong tune management will be used to push the beam-beam parameter to higher values than can be tolerated when long beam lifetimes are required. C) Bunch-by-bunch feedbacks will need to operate at the 1 nsec scale, down from the present 4 nsec time. These faster feedbacks are under construction. D) Much shorter bunches will be needed; on the order of 2 mm. E) Higher-power vacuum chambers and HOM tolerant designs will be needed. F) Very low vertical beta functions at the interaction of about 1.5 to 2.5 mm will be needed. G) Many techniques to reduce the wall plug power will be used; for example, reducing the energy asymmetry to reduce synchrotron radiation, increasing the chamber bores to reduce resistive wall effects, and increasing the RF cavity bores to reduce HOM losses.

*Supported by US DOE contract DE-AC03-76SF00515.
†seeman@slac.stanford.edu

PARAMETERS

The design of a 2.5 to 7 x10^{35} 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 is given by the standard expression

$$L = 2.17\times10^{34}(1+r)n\xi_y\left(\frac{EI_b}{\beta_y^*}\right)\ \mathrm{cm^{-2}sec^{-1}} \qquad (1)$$

where I_b is the bunch current (amperes), n is the number of bunches, E is the beam energy (GeV), r is the vertical to horizontal emittance ratio (~0.02) 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 six, lowering β_y* about a factor of four, and increasing the beam-beam tune shifts about 25%. The resulting gain is about a factor of 35 over that of the present *B* Factories when they are upgraded to about 2x10^{34} cm^{-2}s^{-1} over the next few years. In addition, due to continuous injection with the luminosity always near the maximum as shown successfully in the present B-Factories, the overall integrated luminosity per unit time of the Super *B* Factory is expected to produce 10 ab^{-1} per year with a peak luminosity of 7x10^{35} cm^{-2}s^{-1}. The parameters of two representative e^+e^- colliders at SLAC at 2.5 and 7 x10^{35} cm^{-2}s^{-1} are listed in Tables 1 and 2. The 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 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 the present 9 GeV reduces the overall 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 e- and 20 Hz of e+.

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. The initial (phased) operation of this new Super-B-Factory will likely have both the present RF frequency 476 MHz with a 952 MHz RF system added. The final configuration of the new B-Factory will likely only have 952 MHz RF.

In the Super *B* Factory, the single bunch currents are only about a factor of two higher than those of PEP-II; the total current is increased by a factor of five. Furthermore, the bunch lengths are about four times shorter. These short, high-charge bunches lead to increased single bunch effects. Higher-Order-Mode (HOM) losses and resistive wall losses have to be minimized in each ring. HOM losses in the RF cavities will be reduced by opening the beam channel through the RF cavities by 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 and magnet radii.

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 [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 [7]. New magnets of this style for the BEPC-II collider are under construction. A minor redesign of these magnets will work well for a Super *B* Factory.

Table 1. Initial (early project) parameters for a Super B Factory at 2.5 x 10^{35} with combined 476 MHz and 952 MHz RF.

Parameter	LER	HER
Energy (GeV)	3.5	8
RF frequency (MHz)	476+952	476+952
Vertical tune	72.64	56.57
Horizontal tune	74.51	58.51
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)	3	3
β_x* (cm)	25	25
Emittance (x/y) (nm)	40/0.5	40/0.5
σ_z (mm)	3.4	3.4
Hourglass/X-angle factor	0.80	0.80
Crossing angle(mrad)	15	15
IP Horiz. size (μm)	98	98
IP Vert. size (μm)	1.2	1.2
Horizontal ξ_x	0.107	0.107
Vertical ξ_y	0.107	0.107
Lumin. (x10^{34}/cm^2/s)	25	25

Table 2. Goal parameters for a Super B Factory 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	74.51	58.51
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)	28/0.3	28/0.3
σ_z (mm)	1.75	1.75
Hourglass-X-angle factor	0.80	0.80
Crossing angle(mrad)	15	15
IP Horiz. size (μm)	65	65
IP Vert. size (μm)	0.6	0.6
Horizontal ξ_x	0.105	0.105
Vertical ξ_y	0.107	0.107
Lumin. (x10^{34}/cm^2/s)	70	70

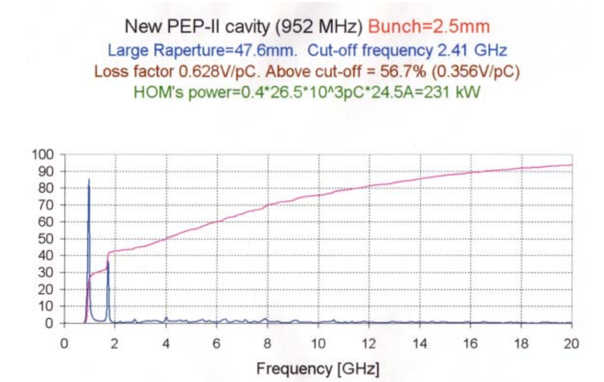

Figure 1. HOM calculation for a 952 MHz PEP-II style RF cavity with an increased bore.

The beams must have a crossing angle at the collision point to avoid parasitic crossing effects; the anticipated crossing angle is about ±15 mrad. The short Super *B* Factory bunches are made by providing extra over-voltage in the RF system and by a high phase-advance and low momentum compaction magnetic lattices.

The increases in the beam-beam parameters from the present 0.08 range to 0.107 will be achieved by operating just above but very close to the half-integer horizontal tune where predictable, 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. This will increase the injection rate but the injector can handle this increase. Both techniques have been successfully demonstrated at the present *B* Factories.

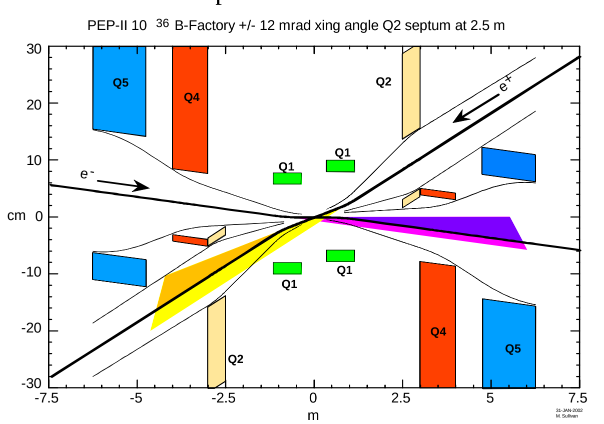

Figure 2. Interaction region for a Super B-Factory. Note the first quadrupole is at 30 cm from the interaction point. This first quadrupole will have fields with quadrupole, x and y dipole, solenoidal, and skew quadrupole windings.

POWER SCALING

The power required by a collider is the sum of a site base plus RF sources and magnets. 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 Super-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 Super-B-Factory 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 power of a Super-B Factory at SLAC as a function of luminosity is shown in Figure 3. If the site power is limited to 120 MW, then a luminosity of about $5x10^{35}$ is possible at an RF frequency of 476 MHz and near $1x10^{36}$ at 952 MHz. The SLAC power substation and transmission lines can provide up to 140 MW.

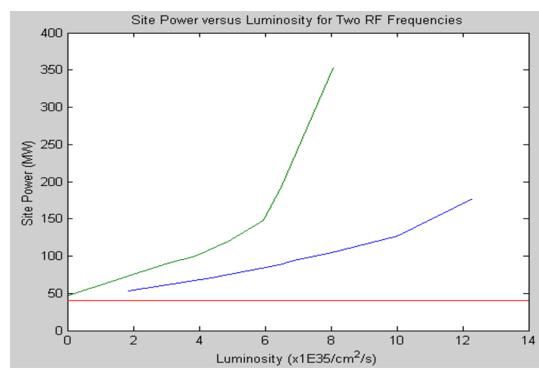

Figure 3. Site power scaling for two RF frequencies. The upper curve is for 476 MHz and the lower curve 952 MHz. The power above the 40 MW horizontal line is from the overall PEP-II RF system and beam effects.

REFERENCES

[1] J. Seeman, "Initial Parameters for a 10^{36}/cm^2/s e^+e^- B-Factory," SLAC-PUB-8787, March 2001.

[2] J. Seeman, "Prospects on Future Higher Luminosity e+e- Colliders," ICFA e+e- Factories Workshop, Ithaca, New York, October 2001.

[3] P. Burchat *et al*, "Physics at a 10^{36} e+e- B-Factory," Snowmass, July 2001.

[4] S. Henderson *et al.*, "Lepton Colliders Working Group Report," Snowmass, July 2001.

[5] J. Seeman *et al.*, "Design Studies for a 10^{36} Super-B-Factories," PAC2003, Portland, OR, May 2003.

[6] M. Sullivan, "Interaction Region Upgrades of e+e- B-Factories," PAC2003, Portland, May 2003.

[7] B. Parker *et al.*, "Superconducting Magnets for use inside the HERA ep Interaction Regions," PAC 1999, New York, p. 308.