PARAMETERS OF A SUPER-B-FACTORY DESIGN*

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Abstract

Parameters are being studied for a high luminosity e^+e^- collider operating at the Upsilon 4S that would deliver a luminosity in the range of 7 to 10 x 10^{35}/cm^2/s. Particle physics studies dictate that a much higher luminosity collider than the present B-Factory accelerators will be needed to answer future new key physics questions. 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. Such a collider could produce an integrated luminosity of 10,000 fb^{-1} (10 ab^{-1}) in a running year. A Super-B-Factory [1-8] with 30 to 50 times the performance of the present PEP-II accelerator would incorporate a higher frequency RF system, lower impedance vacuum chambers, higher power synchrotron radiation absorbers, and stronger bunch-by-bunch feedback systems. The present injector based on the SLAC linac needs no improvements and is ready for the Super-B-Factory.

PARAMETERS

The design of a 7 to 10 x10^{35} cm^{-2}s^{-1} e^+e^- collider combines an 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

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

where I_b is the bunch current (amperes), n is the number of bunches, E is the beam energy (GeV), r is the vertical to horizontal emittance ratio (~0.01) 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 five, lowering β_y* about a factor of four, and increasing the beam-beam tune shifts about 80%. The resulting gain is about a factor of 30 to 50 over that of the present *B* Factories. 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 be 10 ab^{-1} per year with a peak luminosity of 7x10^{35} cm^{-2}s^{-1}. The parameters of a representative e^+e^- colliders at SLAC at 7 x10^{35} cm^{-2}s^{-1} are listed in Table 1. The PEP-II tunnel at SLAC is an excellent site for this collider.

The beam energies are 8 GeV for the high-energy ring (HER) and 3.5 GeV for the low-energy ring (LER). Lowering the high-energy ring energy from the present 9 GeV reduces the overall synchrotron radiation load on the RF system and raises the instability thresholds for the low energy beam. 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+.

Table 1: Parameters for a Super B Factory at 952 MHz

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
RF klystron/cavity	24/24	18/18
RF volts (MV)	30	23
β_y* (mm)	1.7	1.7
β_x* (cm)	14	14
Emittance (x/y) (nm)	24/0.28	24/0.28
σ_z (mm)	1.8	1.8
Hourglass-X-angle factor	0.81	0.81
Crossing angle(mrad)	14	14
IP Horiz. size (μm)	58	58
IP Vert. size (μm)	0.7	0.7
Horizontal ξ_x	0.12	0.12
Vertical ξ_y	0.12	0.12
Lumin. (x10^{34}/cm^2/s)	70	70

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RF FREQUENCY SELECTION

An RF frequency of 952 MHz is the leading design choice for the Super B-Factory. 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. SLAC in association with industry has the ability to design and manufacture CW 952 MHz klystrons producing 1 MW. RF cavities at 952 MHz can be made with a similar design to either the Cornell CESR or KEKB style superconducting RF cavities. The bore of the cavities will be enlarged to reduce the R/Q for beam stability reasons. (See Figures 1, 5 and 6.)

In the Super *B* Factory, the single bunch currents are only about a factor of two higher than those of PEP-II although 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%. [6] 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 dimensions.

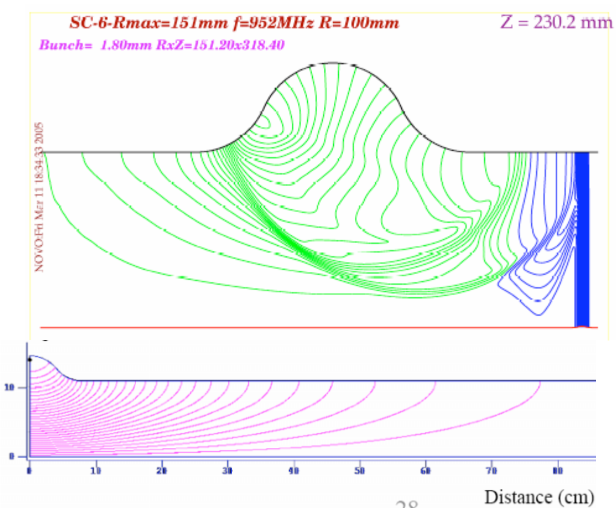

Figure 1: HOM calculation for a 952 MHz SC RF cavity with a 100 mm bore and RF fields along the beam line.

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 Figures 3 and 4. 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 [7].

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. New magnets of this style for the BEPC-II collider are under construction [8]. A minor redesign of these magnets will work well for a Super *B* Factory.

The beams must have a crossing angle about ±14 mrad at the collision point to avoid parasitic crossing effects. 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 as shown in Figure 2.

The increases in the beam-beam parameters from the present 0.08 range to 0.12 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. Both techniques have been successfully demonstrated at the present *B* Factories.

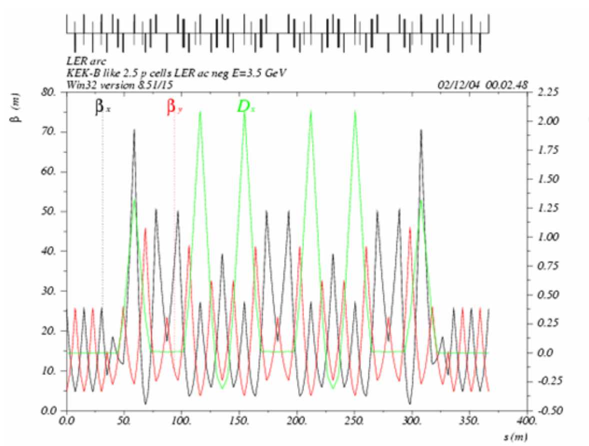

Figure 2: LER lattice with 2.5 π phase advance/cell.

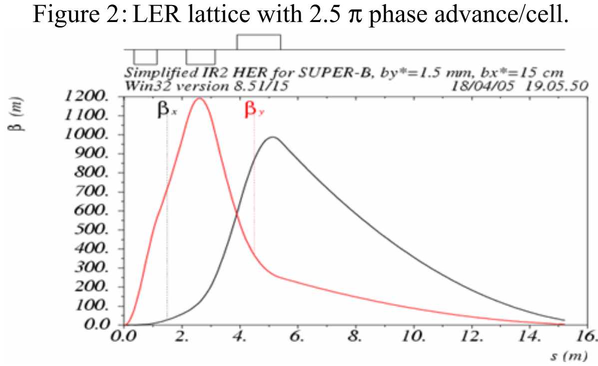

Figure 3: Beta functions in the HER interaction region.

POWER SCALING

The power required by a collider is the sum of a site base plus RF sources and magnets. A summary is shown in Table 2. 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 (~10MW), 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), cryogenic losses and AC distribution inefficiencies. The AC transformers and high voltage power supplies are about 90% efficient. The RF klystrons are about 65% efficient. 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

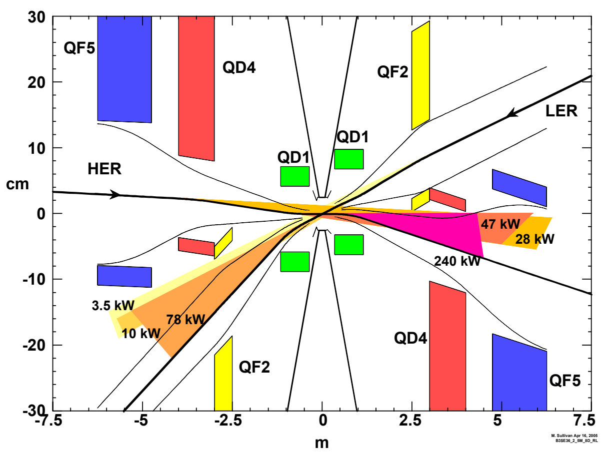

Figure 4: Interaction region for a Super B-Factory. The first quadrupole is at 35 cm from the interaction point.

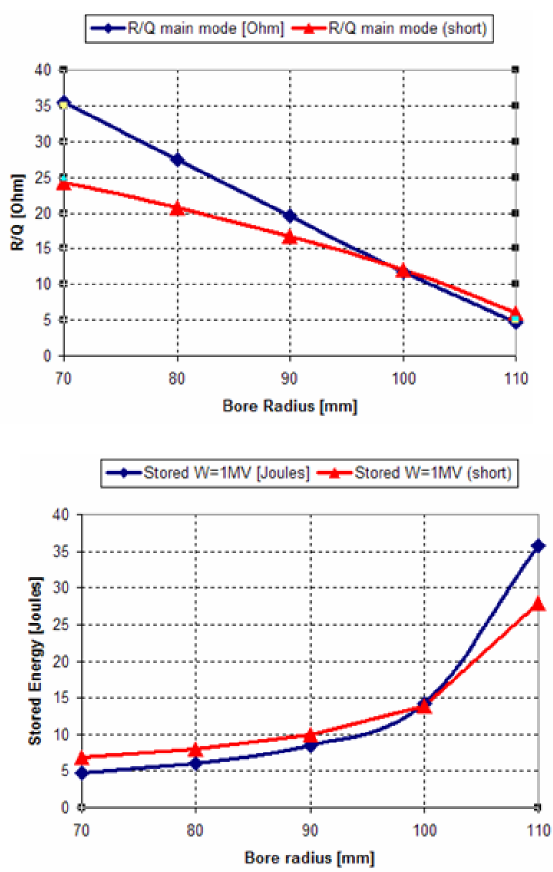

Figure 5: R/Q and stored field energy versus cavity bore.

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 the same total current. The total power needed is about 128 MW. The SLAC power substation and transmission lines can easily provide up to 140 MW.

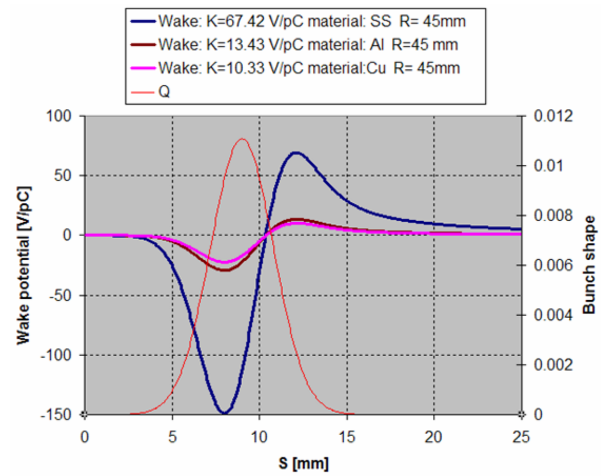

Figure 6: Resistive wall wakes for a 1.8 mm long bunch.

Table 2: AC Power needed for a SLAC Super B-Factory

Power use	LER (MW)	HER (MW)	Sum (MW)
AC HOM Losses	13	3	16
AC synch. rad. losses	30	30	60
AC magnet losses	5	5	10
AC cryogenics	1	1	2
AC other lab projects	--	--	40
Total SLAC site power	--	--	128

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