SUPER-B FACTORY USING LOW EMITTANCE STORAGE RINGS AND LARGE CROSSING ANGLE*

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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 of over 10^{36}/cm^2/s. This collider, called a Super-B Factory, would use a novel combination of linear collider and storage ring techniques. In this scheme an electron beam and a positron beam are stored in low-emittance damping rings similar to those designed for a Linear Collider (LC). A LC style interaction region is included in the ring to produce sub-millimeter vertical beta functions at the collision point. A large crossing angle (+/- 17 mrad) is used at the collision point to allow beam separation and reduce the hourglass effects. Beam currents of about 2.3 A x 1.3 A at 4 x 7 GeV in 1733 bunches can produce a luminosity of 10^{36}/cm^2/s. Such a collider would produce an integrated luminosity of about 10,000 fb^{-1} (10 ab^{-1}) in a running year (10^7 sec) at the Y(4S) resonance.

DESIGN FROM PAST SUCCESSES

The construction and operation of modern multi-bunch e^+e^- colliders [1,2] 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 (~90%):

1) Colliders with asymmetric energies can work.
2) Beam-beam energy transparency conditions are weak.
3) Interaction regions with two energies can work.
4) IR backgrounds can be handled successfully.
5) High current RF systems can be operated (3 A x 1.9 A).
6) Beam-beam vertical parameters can reach 0.06 to 0.09.
7) Continuous injection is done during data production.
8) The electron cloud effect (ECI) can be managed.
9) Bunch-by-bunch feedbacks at 4 nsec spacing work.

Lessons learned from the SLC and subsequent linear collider studies and experiments (FFTB, ATF) [3,4] are:

A) Small horizontal and vertical emittances can be produced in a damping ring with a short damping time.
B) Very small beam spot sizes and beta functions can be achieved at the interaction region.
C) Interaction regions can have very small vertical betas.

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LUMINOSITY AND CROSSING ANGLE

The design of a 10^{36} cm^{-2}s^{-1} e^+e^- collider combines extensions of the design of the present *B* Factories and linear collider concepts to allow improved beam parameters to be achieved. The luminosity L and beam-beam parameters, ξ_y, ξ_x, in an e^+e^- collider are given by the expressions:

$$\mathcal{L} = \frac{\gamma^+ \xi_y N^+ f_c}{2\, r_e\, \beta_y}\left(1+\frac{\sigma_y}{\sigma_x}\right) \propto \frac{N^+\,\xi_y}{\beta_y}$$

$$\xi_y = \frac{r_e N^-}{2\pi\gamma^+}\frac{\beta_y}{\sigma_y\left(\sigma_x\sqrt{1+\varphi^2}+\sigma_y\right)} \propto \frac{N^-\sqrt{\beta_y}}{\sigma_y\sigma_z\theta}$$

$$\xi_x = \frac{r_e N^-}{2\pi\gamma^+}\frac{\beta_x}{\sigma_x^2\left[(1+\varphi^2)+\frac{\sigma_y}{\sigma_x}\sqrt{1+\varphi^2}\right]} \propto \frac{N^-\beta_x}{(\sigma_z\theta)^2}$$

where f_c is the frequency of collision of each bunch, N is the number of particles in the positron (+) and electron (-) bunches, σ is the beam size in the horizontal (x) and vertical (y) directions, γ is the normalized beam energy, ε is the beam emittance, β is the beta function (cm) at the collision point for each plane and θ is the crossing angle. The Piwinski angle is ϕ.

SUPER-B FACTORY PARAMETERS

A schematic drawing of the Super-B Factory is shown in Figure 1. There are two rings each with six arcs and six small straight sections. Two of the straights are for injection, two for possible interaction regions and two for damping wigglers. There are RF stations in three straights per ring. The crossing angle at the interaction point is shown in Figure 2 where the long-thin-flat bunches are made to collide. Sextupoles near the interaction region in a dispersive section are used to create a longitudinal waist shift over the width of the beam to correct the beam-beam hour-glass effects, dubbed crab waist correction [5-9]. An arc lattice cell is shown in Figure 4 to produce low emittances.

The parameters of the Super-B Factory are listed in Table 1. Note the beam currents are lower than present B-Factories at 2.3 A x 1.3 A for e- and e+ at 4 x 7 GeV.

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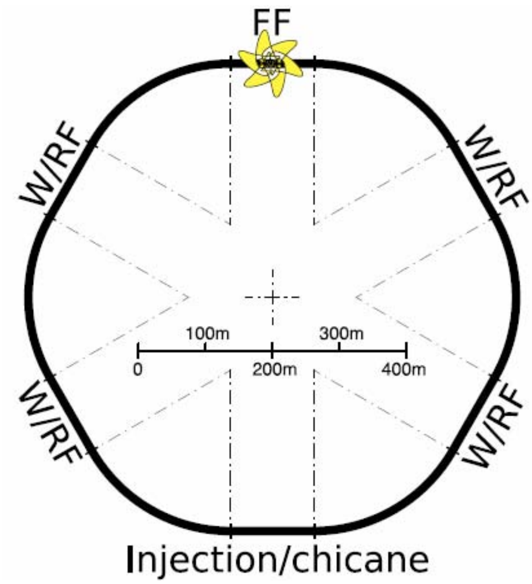

Figure 1: Super-B Factory with circumference = 2250 m.

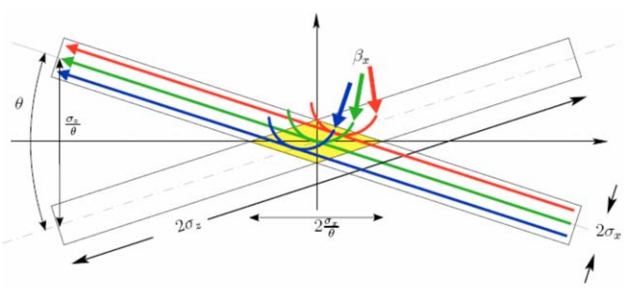

Figure 2: Interaction region showing two thin beams crossing at a large angle with crab waist to improve the beam-beam interaction.

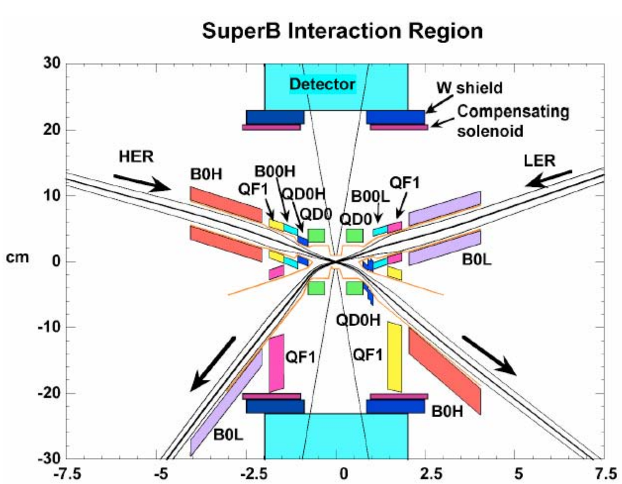

Figure 3: Interaction region for two asymmetric beams.

Table 1: Super-B Factory accelerator/collision parameters

	Low Energy Ring	High Energy Ring
σ_x* (μm)	5.7	5.7
η_x (mm)	0.0	0.0
σ_y* (nm)	35	35
β_x* (mm)	20	20
β_y* (mm)	0.3	0.3
σ_z* (mm)	6.0	6.0
σ_E*/E	0.84×10^{-3}	0.9×10^{-3}
RF voltage	6	18
ε_x (nm)	1.6	1.6
ε_y (nm)	0.004	0.004
RF freq	476	476
θ_x (mrad)	2x17	2*17
Num wigglers	4	2
Lifetime (min)	3.6	5.1
N_{part} (10^{10})	6.2	3.5
$N_{bunches}$	1733	1733
I (A)	2.28	1.30
Circ (m)	2250	2250
$\tau_{x,y}$ (ms)	32	32
τ_z (ms)	16	16
f_{coll} (MHz)	238	238
y/x Tune Shift	0.17/0.004	0.17/0.004
L_{umi} (10^{36})	1.0	1.0

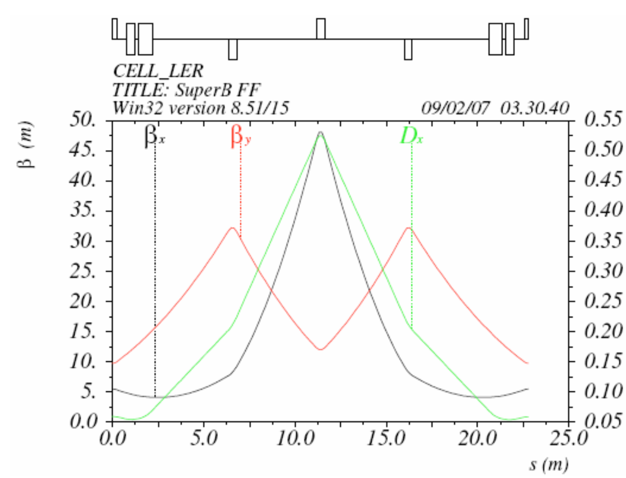

Figure 4: LER arc lattice cell.

INTERACTION REGION PARAMETERS

The interaction region (Figure 3) is being designed to leave about the same longitudinal free space for the detector as that presently used by *BABAR* or *BELLE* but with superconducting quadrupole doublets QD0/QF1 as close to the interaction region as possible [10].

A preliminary design of the Final Focus, similar to those of the NLC/ILC, has been performed for the IP parameters in Table 1. The total FF length is about 160 m and the final doublet is at 0.5m from the IP. A plot of the optical functions in the incoming half of the FF region is presented in Figure 5. The choice for a finite crossing angle at the IP greatly simplifies the IR design (Figure 3), since the two beams are now naturally separated at the parasitic collisions. The resulting vertical beta is 0.3 mm and the horizontal 20 mm. These beta values are much closer to a linear collider design than a traditional circular collider. The beams enter the interaction point nearly straight to minimize synchrotron radiation and lost particle backgrounds. The beams are bent more while exiting the IR to avoid parasitic collisions and the resulting beam-beam effects.

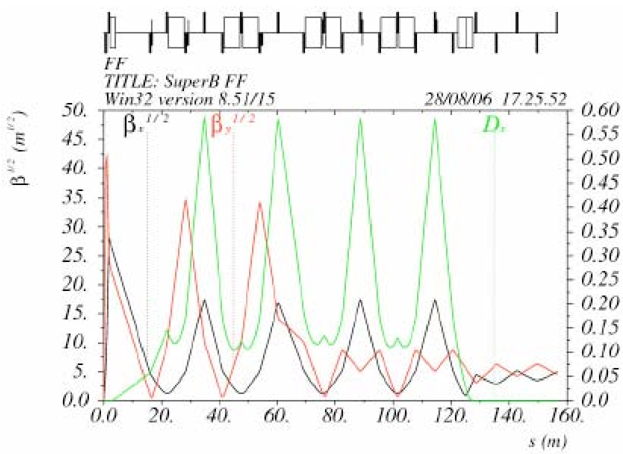

Figure 5: IR optical parameters for a Super-B-Factory.

Table 2: Super-B factory AC power requirements

Parameter	Units	Value
Beam energy (HER/LER)	GeV	7.0/4.0
Beam current (HER/LER)	Amp	1.3/2.3
HER RF power	MW	8.6
LER RF power	MW	8.6
HER magnet power	MW	4.0
LER magnet power	MW	3.0
Cooling system power	MW	2.4
Control power	MW	0.5
Injection system power	MW	4.0
Lights and HVAC	MW	3.0
Total site power for accelerator	MW	34.1

POWER REQUIREMENTS

The power required for this collider is the sum of power for the magnets, RF system, cooling water, controls, and the accelerator operation. The present estimates indicate about 34 MW total as shown in Table 2. These values do not include the campus power requirements or that of the particle physics detector. There are upgrade possibilities for this collider to 2 to 3 times the design luminosity that will require more power [8]. Due to the advantages of the very low emittances and the crab waist with this design, the power requirements here are lower than at present B-Factory colliders.

INJECTION REQUIREMENTS

The injection system needed for the Super-B is similar to that for PEP-II or a scaled-up version of the DAPHNE injector. Table 3 shows the basis injector parameters. Since the beam lifetimes are below 10 minutes, continuous injection is needed. The injector will operate at about 100 Hz and inject about 2 bunches per pulse. The numbers shown here are for the upgraded collider to a higher luminosity. The injector could be shared with other projects as needed.

Table 3: Super-B Injection Parameters

Parameter	Unit	e+	e-
Linac energy	GeV	4	7
Damping ring energy	GeV	1	1
Linac frequency	MHz	2856	2856
Bunches per pulse		2	2
Injection efficiency	%	67	85
Pulse rate per beam	Hz	75	25
Injected particles/pulse	10^{10}	4	5.1
Injection rate total	10^{12}/sec	2.0	2.6

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