SLAC-PUB-14656

DESIGN OF A $10^{36}CM^{-2}S^{-1}$ SUPER-B FACTORY *

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Abstract

Parameters have been studied for a high luminosity e+e- collider operating at the Upsilon 4S that would deliver a luminosity of 1 to 4 x $10^{36}/cm^2/s$. This collider, called a Super-B Factory, would use a 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) or the next generation light source. 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 (+/- 24 mrad) is used at the collision point to allow beam separation. A crab-waist scheme is used to reduce the hourglass effect and restore peak luminosity. Beam currents of 1.8 A at 4 x 7 GeV in 1251 bunches can produce a luminosity of $10^{36}/cm^2/s$ with upgrade possibilities. 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 Υ(4S) resonance. Further possibilities include having longitudinally polarized e- at the IR and operating at the J/Psi and Psi' beam energies.

DESIGN STRATEGY

The construction and operation of modern multi-bunch e^+e^- colliders [1,2,3] 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%). A Conceptual Design Report (CDR) [4] was issued in May 2007, with about 200 pages dedicated to the accelerator design. This report discusses site requirements, crab waist compensation, parameters optimization in order to save power, IP quadrupole design, Touschek backgrounds, spin rotator scheme, and project costs. A possible layout at Tor Vergata University near Rome is shown in Figure 1. The ring lattices have been modified to produce very small horizontal (a few nm-rad) and vertical emittances (a few pm-rad). Crab waist sextupoles near the interaction region introduce a left-right longitudinal waist position variation in each beam allowing a vertical beta function which is much smaller than the bunch lengths.

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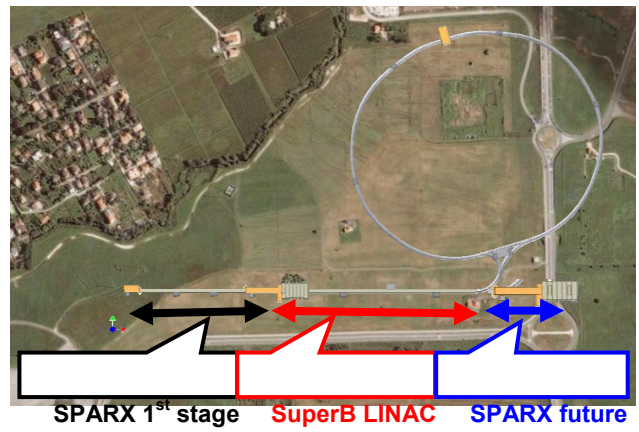

Figure 1: Possible SuperB location at Tor Vergata University with a ring circumference of 1800 m and an injector located adjacent to the future SPARX FEL.

LUMINOSITY AND CROSSING ANGLE

The luminosity L and beam-beam parameters, ξ_y, ξ_x, in an e^+e^- collider with a horizontal crossing angle are given by

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

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

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

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 $\phi = \theta\sigma_z/\sigma_x$.

The Super-B accelerator consists of two asymmetric energy rings, colliding in one Interaction Region (IR) at a large horizontal angle, with a spin rotator section in the HER to provide longitudinal polarization of the electron beam at the IP. In order to have equal tune shifts for the two beams, asymmetric B-Factories operate at unbalanced

beam currents, with a current ratio inverse to the energy ratio. For SuperB, with an energy ratio of 7/4 and a large crossing angle, new conditions for having equal tune shifts are possible. LER (+) and HER (-) beams can have different emittances and β* but equal currents:

$$\xi^+ = \xi^- \Leftrightarrow \frac{\beta_y^+}{\beta_y^-} = \frac{E^+}{E^-} \qquad (1)$$

Then, in order to have equal vertical beam sizes at IP, the LER and HER vertical and horizontal emittances must be:

$$\varepsilon_y^+ = \frac{E^-}{E^+}\varepsilon_y^-, \quad \varepsilon_x^+ = \frac{E^-}{E^+}\varepsilon_x^- \qquad (2)$$

with the horizontal beam sizes in the inverse ratio with the beam energies. Thus, the LER beam sees a shorter interaction region, in a ratio 4/7, with respect to the HER beam. This allows for further β_y* reduction, a larger emittance, increased Touschek lifetime, and reduced injection rates. Table 1 summarizes Super-B beam parameters for three operational scenarios. Figure 2 shows the left-right crab waist compensation at the IP. Figure 3 shows the beam cross sections at the IP with unequal emittances but equal beam-beam tune shifts.

Table 1: SuperB main parameters

Parameter (LER/HER)	Nominal	Upgrade	Ultimate
Energy (GeV)	4/7	4/7	4/7
Luminosity ($cm^{-2}s^{-1}$)	$1x10^{36}$	$2x10^{36}$	$4x10^{36}$
C (m)	1800	1800	1800
N. of bunches	1251	1251	2502
F_{RF} (MHz)	476	476	476
N. part/bunch	$5.5x10^{10}$	$5.5x10^{10}$	$5.5x10^{10}$
I_{beam} (A)	1.85/1.85	1.85/1.85	3.7/3.7
β_x* (mm)	35/20	35/20	35/20
β_y* (mm)	0.22/0.39	0.16/0.27	0.16/0.27
ε_x* (nm rad)	2.8/1.6	1.4/0.8	1.4/0.8
ε_y* (pm rad)	7/4	3.5/2	3.5/2
σ_x* (μm)	10/5.7	7/4	7/4
σ_y* (μm)	0.039	0.023	0.023
σ_z (mm)	6.	6.	6.
θ_{cross}(mr)	48	48	48
α_c ($x10^{-4}$)	3.2/3.8	3.2/3.8	3.2/3.8
$\tau_{x,y}/\tau_s$ (ms)	40/20	28/14	28/14
x-tune shift	0.004/0.003	0.006/0.003	0.006/0.003
y-tune shift	0.15	0.20	0.20
RF AC power (MW)	26	54	64

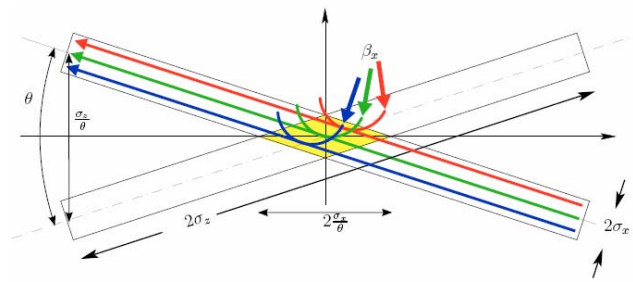

Figure 2: Interaction region showing two beams crossing at a large angle with the crab waist to improve the beam-beam interaction.

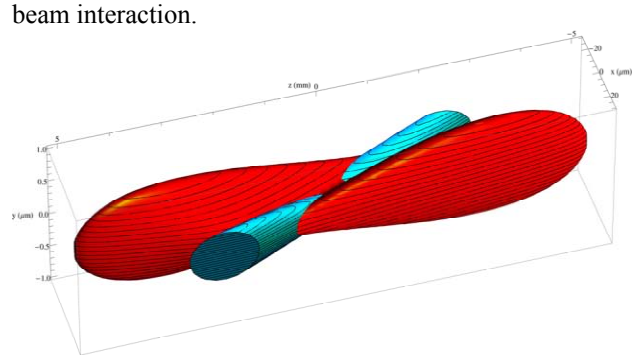

Figure 3: Beam cross sections at the IP with parameters from Table 1 and crab waists.

SUPER-B FACTORY LAYOUT

The two rings each have two arcs and two long straight sections. One straight is for the interaction region. The other is for diagnostics, RF, damping wigglers and injection. Sextupoles near the interaction region in a dispersive section are used to create a longitudinal waist shift over the width of the beam. The crab waist concept is being tested at the DAFNE collider at INFN, Frascati, Italy, with good results [5,6]. Dynamic apertures have been studied with the crab waist sextupoles [6], shown in Figure 4, with more work continuing.

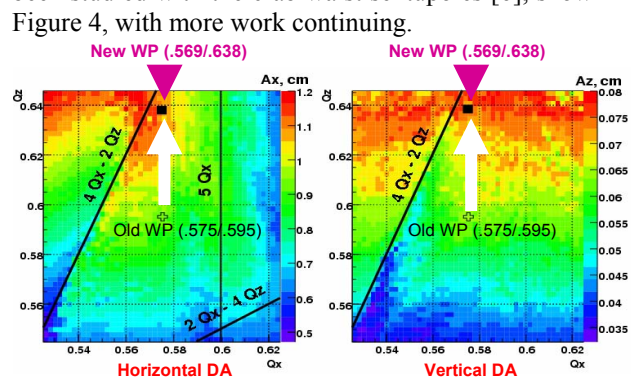

Figure 4: Dynamic aperture with crab waist for the HER versus horizontal and vertical tune used to find the optimum tune plane locations. Red is better and blue is worse.

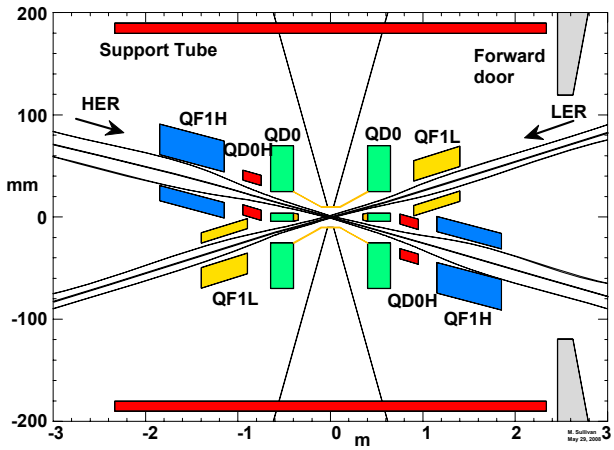

Figure 5: Interaction region for two asymmetric beams.

INTERACTION REGION PARAMETERS

The interaction region (Figure 5) is designed to be similar to that of the ILC and 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 [7,8]. 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 6. The choice for a finite crossing angle at the IP greatly simplifies the IR design, naturally separating the beams at the parasitic collisions. The resulting vertical beta is about 0.2-0.3 mm and the horizontal 35 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.

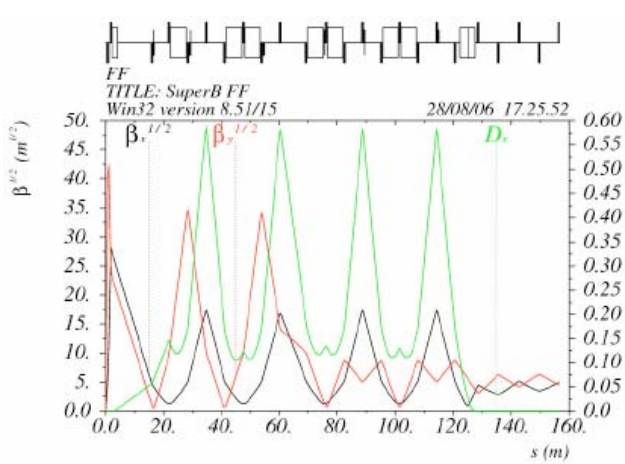

Figure 6: IR optical parameters for a Super-B-Factory.

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 26 MW is needed for the nominal case. 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 4 times the design luminosity that will require more power [9]. Due to the advantages of the very low emittances and the crab waist with this design, the power requirements are significantly lower than those of the present B-Factory colliders.

INJECTION REQUIREMENTS

The injection system needed for the Super-B is similar to that for PEP-II, shown in Figure 7. Table 2 shows the basic injector parameters. Since the beam lifetimes are of the order of 10-30 minutes, continuous injection is needed. The injector will operate at 100 Hz and inject about 2 bunches per pulse. The values shown here are for the upgraded collider at higher luminosity.

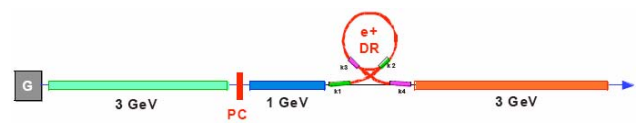

Figure 7: Schematic of the Super-B injector.

Table 2: 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
Polarization	%	0	89

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