SUPER B-FACTORIES

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Abstract

Energy-asymmetric e^+e^- B-factories at Υ(4S), PEP-II and KEKB, have been operating at the luminosity frontier. For investigations on particle physics beyond the Standard Model, a higher luminosity B-factory has been strongly required[1]. This paper will review major upgrade plans of both machines toward Super B-factories.

INTRODUCTION

After successful beam operation and fruitful results in elementary particle physics at the B-factories, PEP-II (SLAC) and KEKB (KEK), Super-B-factories with higher luminosities are being planed earnestly. Their target luminosities aim at 4 - 7 $\times$ $10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, several ten times higher than the present records as shown in Fig. 1. The Super-B-factories reviewed in this paper are e^+e^- energy-asymmetric double-ring colliders which are expected to be realized by upgrading the existing machines in the very near future with minimum interruption on the on-going experiments[1, 2]. The layout of one of the plans, SuperKEKB, is shown in Fig. 2.

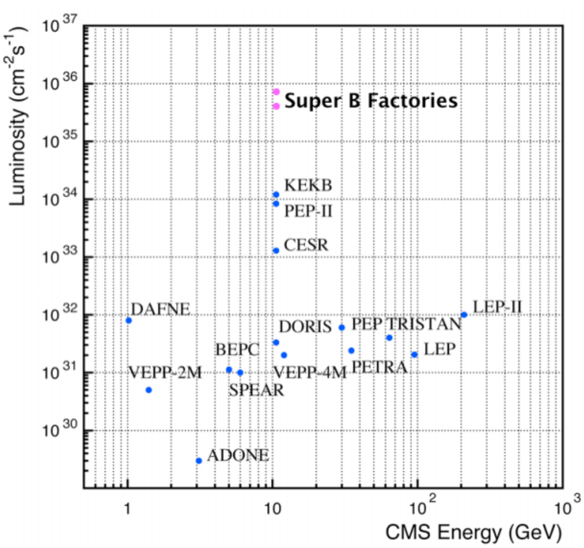

Figure 1: Luminosities of e^+e^- colliders.

BEAM PARAMETERS

The basic design concept of the Super-B-Factories is based on a well-known formulae of the luminosity of a

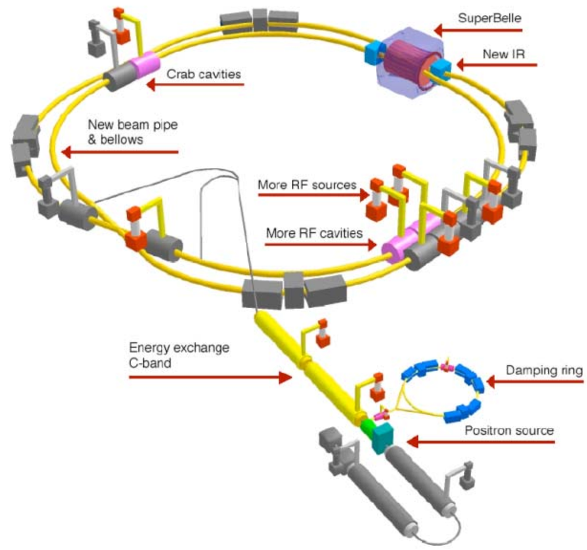

Figure 2: Schematic layout of SuperKEKB.

e^+e^- ring collider:

$$\mathcal{L} = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \xi_{y\pm}}{\beta_y^*}\frac{R_\mathcal{L}}{R_y} \qquad (1)$$

where $\gamma_\pm$ is the Lorenz factor, r_e the classical electron radius, $\sigma^*_{x(y)}$ the horizontal(vertical) beam size at the interaction point (IP), $I_\pm$ the stored beam current, $\xi_{y\pm}$ the vertical beam-beam parameter, β_y^* the vertical β function at the IP. We have assumed β_y^* and the beam sizes of the both beams are equal to each other. The subscript $\pm$ denotes the parameters of the flavors of the beam.

The parameters $R_\mathcal{L}$ and R_y are the geometrical reduction factor of the luminosity and that of the vertical beam-beam parameter due to the crossing angle and the hour-glass effect. The ratio $R_\mathcal{L}/R_y$ is not far from unity when the bunch length σ_z is smaller than β_y^*.

To achieve higher luminosity, higher currents ($I_\pm$), higher beam-beam parameters ($\xi_{y\pm}$), and smaller β functions (β_y^*) are required to the utmost limits. A consistent set of the machine parameters including I, ξ_y and β_y^* should be selected with careful consideration because almost all of the parameters have complicated interferences each other.

The main beam parameters chosen for the Super B-factories together with those of the present B-factories[3, 4] are summarized in Table 1. Both machines have several characteristics in common :

- The beam energies and the charges are switched from the existing machines: Exchanging electrons

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Table 1: Machine parameters of Super PEP at SLAC and SuperKEKB at KEK.

	PEP-II		**Super PEP**		**KEKB**		**SuperKEKB**		
	LER	**HER**	**LER**	**HER**	**LER**	**HER**	**LER**	**HER**	
Energy	3.1	9.0	3.5	8.0	3.5	8.0	3.5	8.0	GeV
Particle	e^+	e^-	e^-	e^+	e^+	e^-	e^-	e^+	
Circumference	2200		2200		3016		3016		m
Current	2.45	1.55	15.5	6.8	1.73	1.26	9.4	4.1	A
Bunches	1588		6900		1388		5000		
Curr./bunch	1.54	0.98	2.25	0.99	1.25	0.91	1.88	0.82	mA
Spacing	1.26		0.31		1.77 or 2.36		0.59		m
Cross. Angle	0		30		22		30		mrad
Emittance ε_x	27	51	28	28	19	24	24	24	nm
β_x^*	50	32	15	15	59	56	20	20	cm
β_y^*	1.05	1.05	0.15	0.15	0.65	0.62	0.30	0.30	cm
Hor. Size @IP	170 (Σ)		65	65	103	116	69	69	μm
Ver. Size @IP	7.2 (Σ)		.6	.6	2.1	2.1	.73	.73	μm
Bunch Length	11	11	1.75	1.75	~ 7	~ 7	3.0	3.0	mm
RF Voltage	3.8	16.5	43	33	8	15	15	20	MV
RF Freq.	476		952		509		509		MHz
ξ_x	0.053	0.055	0.105	0.105	0.110	0.073	0.152	0.152	
$\xi_{x,\text{dynamical effects}}$							0.041	0.041	
ξ_y	0.064	0.046	0.107	0.107	0.092	0.056	0.215	0.215	
$\xi_{y,\text{dynamical effects}}$							0.187	0.187	
Luminosity	0.921		70		1.562		40		$10^{34}/\text{cm}^2$/s

and positrons, the low energy ring (LER) stores 3.5 GeV electrons and the high energy ring (HER) 8 GeV positrons to reduce the electron-cloud instability (ECI).

- The ratio of beam currents is set so as to satisfy the energy-transparency condition, $I_+/I_- = \gamma_-/\gamma_+$. For the LER of Super PEP, the current is decreased by increasing the energy to 3.5 GeV. Although the HER currents are relatively higher at the present B-factories, which is probably chosen to compensate the luminosity degradation due to the ECI, this condition will be valid for Super B-factories with sufficient measures against the ECI.
- Every rf-bucket filling to maximize the number of bunches.
- Finite crossing angle (30 mrad) to make a lattice of the interaction region (IR) feasible at collision with short bunch spacing, to avoid luminosity-dependent detector background, etc., as shown in Fig. 3[5].
- Crab crossing[6] is necessary to ensure the high beam-beam parameter.

Concrete choices of the parameters including the target luminosity itself are different between both machines as: higher currents and smaller β_y^* at Super PEP and higher $\xi_{y\pm}$ at SuperKEKB. In the following sections, upgrade strategies concerning these key parameters are reviewed.

HIGHER CURRENT

In the Super-B-factories, required beam currents are 3 - 6 times higher than present. Both RF and vacuum systems must be upgraded for beam operation at higher currents. Beam instrumentation such as position monitors, bunch-by-bunch feedback systems, and synchrotron radiation monitors also need to be improved so as to overcome heating due to beam-induced currents and the higher-oder modes (HOM) in various components.

RF system

For the RF system, there are two different approaches toward the Super B-factories. A new RF system with higher RF frequency is being considered for Super PEP mainly to increase the number of bunches, which is one of the biggest changes for the upgrade.

On the other hand, the existing RF system will be used as much as possible for SuperKEKB. Longitudinal coupled-bunch instabilities due to the accelerating mode of cavities with a large detuning frequency and phase modulations by transient beam loading at a gap of bunch train are main difficulties to be overcome for stable operation at high currents. To reduce the detuning frequency, normal-conducting Accelerator Resonantly-coupled with Energy-Storage cavities (ARES)[7] and single-cell superconducting cavities[8], which have been operated at KEKB, will be still usable at SuperKEKB with minimum modifications.

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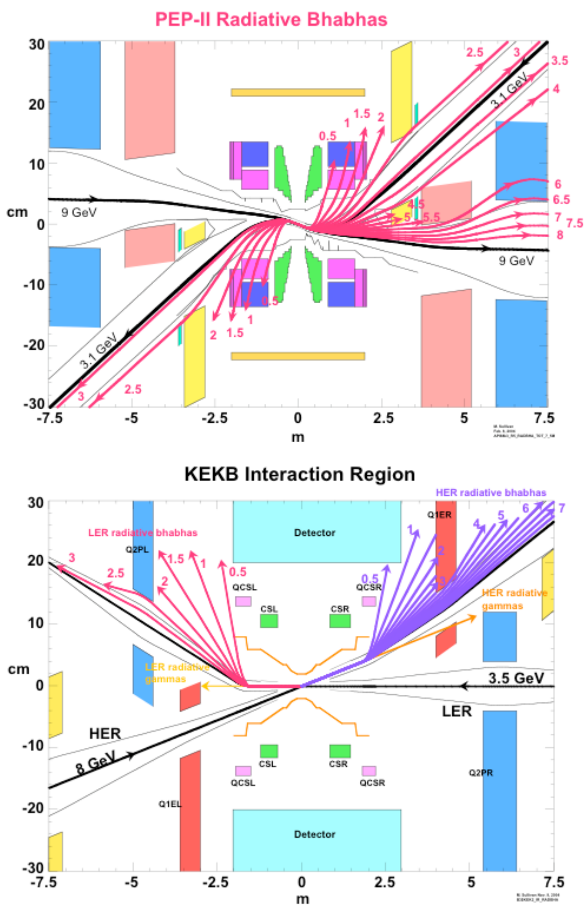

Figure 3: Comparison of the luminosity-dependent detector background due to radiative Bhabha events (by M. Sullivan). Without the crossing angle (upper), this effect is significant.

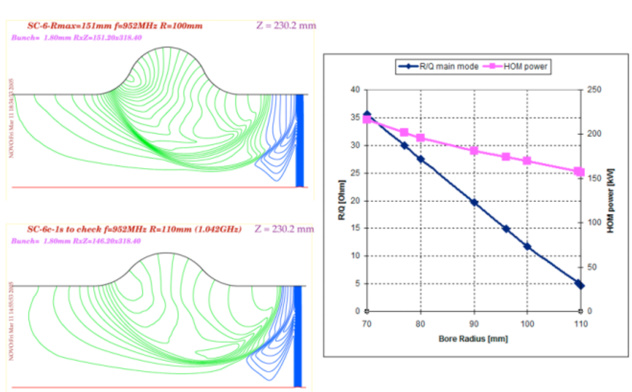

Figure 4: Superconducting cavity of 952 MHz for Super PEP (by S. Novokhatski[9]).

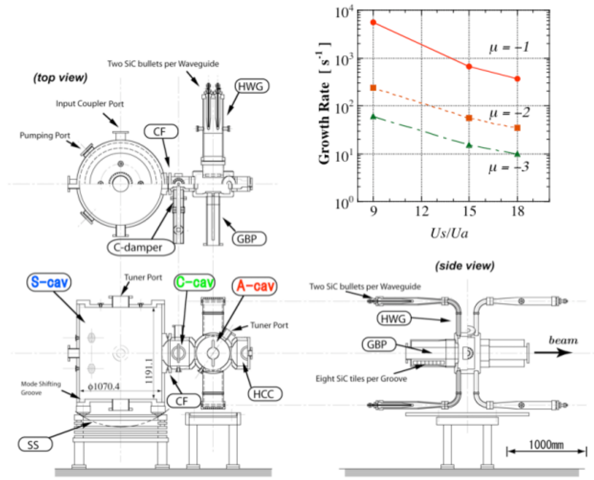

Figure 5: ARES cavities (by T. Kageyama et al.).

High frequency RF system A new RF system of 952 MHz is proposed to double the number of bunches. Compared with normal-conducting energy storage cavities, superconducting cavities are preferable because of smaller wall loss and the higher RF voltage. In order to decrease R/Q to a reasonable level, the radius of the beam pipes connected to the superconducting cavities is increased. The growth rate is estimated to be acceptable in the LER when R/Q is 5 or 12 Ω. (The growth time τ of -1 mode is 2.3 msec[10].) High power klystrons also look to be achievable.

Upgrade of ARES and superconducting cavities For SuperKEKB, in the HER, ARES cavities of current version running at KEKB for 6 years are expected to be used without major upgrade. The superconducting cavities will also be used for SuperKEKB with modest upgrades in the HOM dampers and the input couplers. In the SuperKEKB LER, by increasing the stored energy ratio U_s/U_a from 9 to 15 for the ARES cavities, the coupled-bunch instabilities due to the π/2 accelerating mode can be reduced to a manageable level. (τ = 1.5 msec for -1 mode.) A longitudinal bunch-by-bunch feedback system will be necessary. High power tests for the input coupler and the HOM damper are in progress[11].

Vacuum system

Vacuum chambers must be replaced in both rings for higher currents and shorter bunch length. It is necessary to manage intense synchrotron radiation (SR) power (28 kW/m at SuperKEKB), dense photoelectrons, high gas load, intense HOM power and high wall current. Beam pipes with ante-chamber and with TiN or NEG coating will be adopted to reduce SR density and secondary electron yields, which are similar concept to the present PEP-II. R&D works on vacuum components such as a prototype ante-chamber made of copper and bellows with comb-type

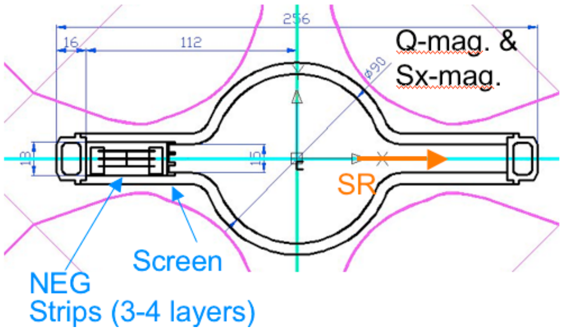

Figure 6: Beam pipe with ante-chamber for SuperKEKB (by Y. Suetsugu et al.).

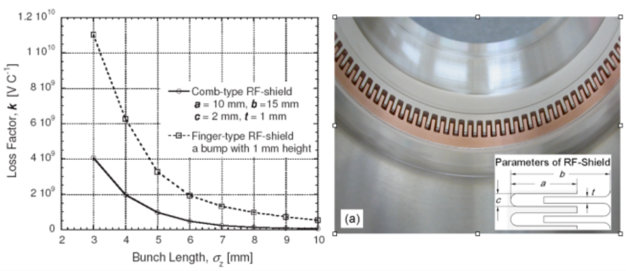

Figure 7: Bellows chamber with comb-type RF shield for SuperKEKB (by Y. Suetsugu et al.). Prototype bellows chambers were installed in the LER at KEKB and showed good performance.

RF shield to reduce impedance are in progress[12]. New bellows design with HOM absorber is proposed for Super PEP.

Injector

To keep higher currents effectively against shorter beam lifetime and reduce beam background at injection, upgrading injector is required. In particular, to inject 8 GeV positrons at SuperKEKB, energy upgrade with C-band RF system is necessary. C-band components are steadily being developed[13].

HIGHER BEAM-BEAM PARAMETER

A collision with a finite crossing angle gives various merits such as large beam separation near the IP, optimization of the IR lattice, and reduction of the detector background. The crossing angle collision is working well at KEKB up to $\xi_y \sim 0.06$.

To pursue higher luminosity, however, recent beam-beam simulations[14] suggest that a head-on collision may bring about larger beam-beam parameter as shown in Fig. 8. According to a further study with strong-strong simulations, ξ_y can reach ~ 0.2 at a good working point of the tunes, (ν_x, ν_y) = (.503, 550) which is very close to the half-integer[15].

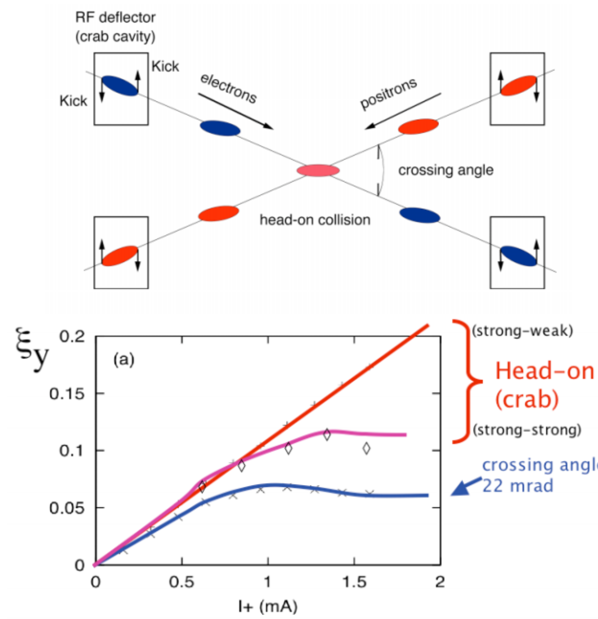

Figure 8: Schematic view of the crab-crossing scheme[6]. On the contrary of the original plan at KEKB, one cavity will be installed in each ring. Though the crabbing orbit propagates over the rings, any problem has not yet been pointed out so far.

A crab-crossing collision, which is equivalent to a head-on collision in the center-of-mass frame, is expected to recover luminosity degradation due to a crossing angle. In order to study the effects of the crab crossing, superconducting crab cavities[16] will be installed in both rings at KEKB early 2006. A new crab cavity which can be used for higher current of 10 A has also been designed[17].

SMALLER BETA FUNCTION AT IP

Short bunch length

The smallest attainable β_y^* depends on the bunch length because the condition $\beta_y^* \leq \sigma_z$ is required to avoid the hour-glass effect. In the LER of Super B-factories, the coherent synchrotron radiation (CSR) may limit the minimum bunch length because of large bunch current and short bending radius. A simulation predicts that the CSR instability will be induced on the conditions σ_z = 3 mm and 2 mA/bunch at SuperKEKB[18]. The radius of the beam pipe may have to be decreased to stabilize the CSR effect. More realistic simulations with other kinds of impedances need to be done. The HOM losses at high currents are also limit the minimum bunch length.

Lattice design

The lattice in the IR must be replaced to realize smaller β_y^*. The smallest attainable value of β_y^* also depends on whether a practical design of IR is possible or not. A baseline design including a reasonable layout of final-

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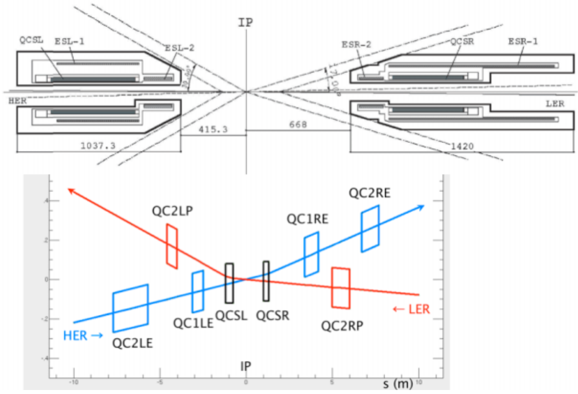

Figure 9: Final quadrupole magnet and compensation solenoids for SuperKEKB (by N. Ohuchi).

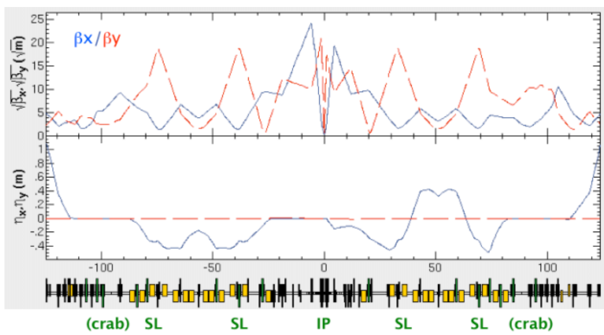

Figure 10: IR lattice of the LER for SuperKEKB.

focusing system, practical design of IR special magnets, and consistent lattices of whole rings are prepared for SuperKEKB (β_y^* = 3 mm). Final quadrupoles and compensation solenoids are superconducting magnets, and the second vertical-focusing quadrupoles only for the HER are being considered on both normal and superconducting versions[19]. Design works on the IR for Super PEP are also in progress[20]. Detector background issues are intensively being studied for both Super B-factories[20, 21].

The lattices of KEKB rings have a wide range of tunability based on 2.5π cell structure. The horizontal emittance ε_x and the momentum compaction factor α_p are independently adjustable. Without major changes in the arcs, the beam-optical parameters can be adjusted to the required values, then most of the ring magnets are usable for SuperKEKB.

Efforts on improving lattices to achieve small α_p for the bunch length of 1.75 mm are also going on for Super PEP.

SUMMARY

The baseline design of a Super B-factory with the luminosity of $\sim 4 \times 10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ based on the present RF frequency is now available. Steady progress is being made with R&D works on hardware components. Construction of the Super B-factory is expected to start in the near future, around the year 2010.

ACKNOWLEDGMENT

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