KEKB AND SUPERKEKB

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Abstract

The KEKB B-factory continues to improve the luminosity after having achieved the design value of 10/nb/s. Since Jan. 2004, KEKB is being operated in the Continuous Injection Mode (CIM) which significantly boosts the integrated luminosity. This paper presents recent progress of KEKB and future plans one of which is introduction of crab crossing.

OVERVIEW

The KEKB B-factory is an electron-positron energy-asymmetric double-ring collider for B physics[1, 2]. It consists of an 8-GeV electron ring (HER) and a 3.5-GeV positron ring (LER) and an injector (J-Linac), as shown in Fig. 1. Both rings are placed side-by-side with 1.1 m distance in the tunnel constructed for TRISTAN. Collision is observed by the Belle detector located at the single interaction point (IP).

The construction of KEKB started in 1994 and the first event was observed by Belle in June 1999. After four-years operation, the peak luminosity exceeded its design value of 10/nb/s ($= 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$) in May 2003. The status of KEKB before 2003 summer is summarized in Ref. 3. The peak record is still continuously being improved and reaches to 13.92/nb/s so far. Not only the peak but the integrated luminosities are well improved by introducing the continuous injection mode (CIM) this year.

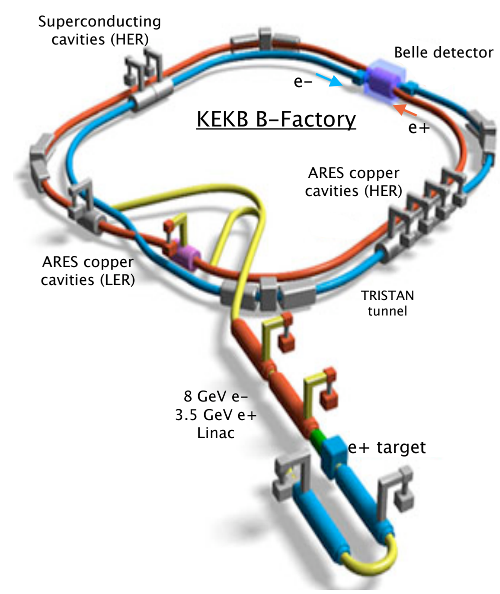

Figure 1: Schematic layout of KEKB.

BEAM PARAMETERS

Current, Beam-beam parameter, and β_y^*

The luminosity is given as

$$L \approx \frac{\gamma_\pm}{2er_e}\frac{I_\pm \xi_{y\pm}}{\beta_y^*}\frac{R_L}{R_y} \quad (1)$$

Higher currents $I_\pm$, larger vertical beam-beam parameter ξ_y, and smaller β_y^* are necessary to obtain higher luminosity. R_L, and R_y are reduction factors of the luminosity and ξ_y, respectively, due to the hour-glass effect and the finite crossing angle (22 mrad at KEKB). The ratio R_L/R_y

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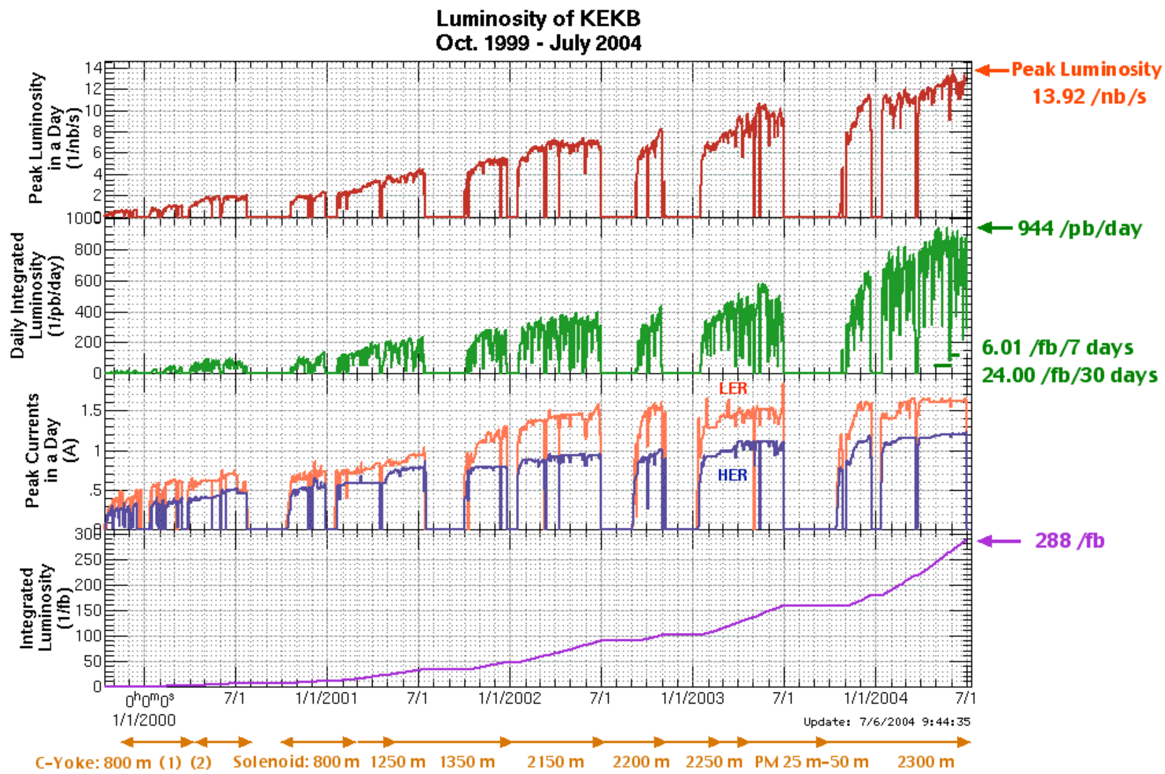

Figure 2: History of KEKB performance. 1) Peak luminosity in a day (1/nb/s) , 2) daily integrated luminosity (1/pb), 3) peak currents in a day, and 4) total integrated luminosity. Arrows and numbers at bottom show the total length covered with magnetic field of solenoid and permanent magnets.

is close to unity when the bunch length σ_z is well smaller than β^*_y.

The beam parameters are summarized in Table 1. In actual parameters of HER, I_- and ξ_{y-} are a little larger, and β^*_{y-} is much smaller than design values. Because σ_z (7 mm) is longer than β^*_{y-} (6.5 mm), R_L/R_y is decreased to 0.8. Consequently, the luminosity reaches to 1.39 times higher than the design value.

Bunch spacing

Now the average bunch spacing is selected to be 3.77 rf buckets which is much longer than the design value (1 rf bucket spacing). The specific luminosity was degraded by $\sim 10\%$ when the average spacing was decreased from 3.77 to 3.5. The bunch fill pattern of the 3.5 spacing was composed by mixing 4-, 3-, 2-bucket spacings. The vertical blowup of LER beam size was observed at bunches after 2-bucket spacing. We suspect that the blowup may caused by electron clouds or interference of electron cloud and the beam-beam effect. In this condition, the LER current I_+ is limited to ~1.65 A, and the luminosity is compensated by larger ξ_{y+} (144%) and smaller β^*_{y+} (5.2 mm) even with smaller I_+(61%).

Longer spacing means larger bunch currents which are 2.4 and 4.2 times in LER and in HER, respectively. The HOM heating powers are estimated to be 1.4(LER) and 2.4(HER) times larger even with the bunch length longer than the design value. The beam operation must be very careful for heating, discharge, vacuum leak, etc.

Betatron tune

The horizontal betatron tune ν_x is one of the most important parameters to achieve high luminosity at KEKB. When ν_x is coming closer to a half-integer resonance, the luminosity is being significantly improved. The present values of the fractional part of ν_x are 0.506(LER) and 0.511(HER). The merit of ν_x closer to the half-integer is larger dynamic emittance which should decrease effective beam-beam parameter and then should improve the luminosity. Recent beam-beam simulations reproduce well this tune dependence. As shown in Fig. 3, the access to the half-integer (from 0.511 to 0.506 in LER) improved the specific luminosity by 25%.

The simulations also say that the luminosity will be improved by 20% by getting ν_x close to the half-integer in HER same as in LER. In HER, however, the synchro-betatron resonance $2\nu_x + \nu_s$ = integer is much stronger than in LER as shown in Fig. 4, so stable operation at lower ν_x is difficult. Optimization of beam parameters is planed to avoid the synchro-betatron resonance in some ways: 1) better chromaticity correction to weaken effects of the resonance and 2) changing the synchrotron tune by adjusting

Table 1: Machine parameters of KEKB. The peak luminosity improved by 32%, and integrated luminosities by 53-87% in a year.

	2004 June		**2003 May**		**Design**		
	LER	**HER**	**LER**	**HER**	**LER**	**HER**	
Energy	3.5	8.0					GeV
Circumference	3016						m
Current	1.58	1.19	1.38	1.05	2.6	1.1	A
Bunches	1289		1256		5000		
Curr./bunch	1.23	0.93	1.09	0.83	0.52	0.22	mA
Spacing	1.8 or 2.4		1.8 or 2.4		0.6		m
Emittance ε_x	18	24	18	24	18	18	nm
β_x^*	59	56	59	58	33	33	cm
β_y^*	0.52	0.65	0.62	0.7	1.0	1.0	cm
Hor. Size @IP	103	116	103	118	77	77	μm
Ver. Size @IP	2.1	2.1	2.2	2.2	1.9	1.9	μm
ξ_x	.107	.075	.093	.068	039	.039	
ξ_y	.070	.057	.067	.053	.052	.052	
Lifetime	152	178	133	259			min.
Luminosity	13.92		10.57		10		/nb/s
$\int$Lum/24 hrs	944		597		$\sim$ 600		/pb
$\int$Lum/7 days	6007		3876				/pb
$\int$Lum/30 days	23998		12809				/pb

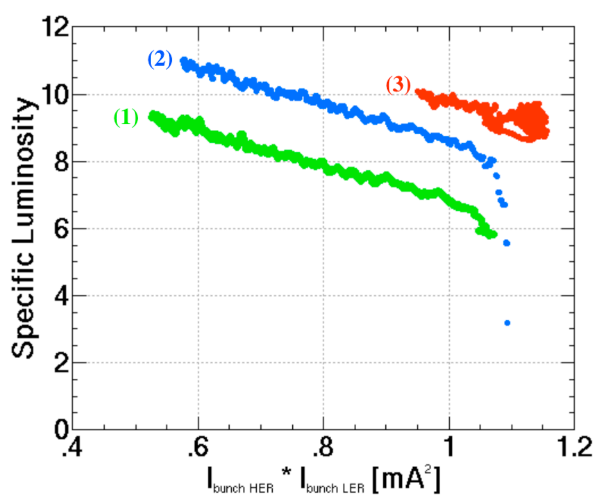

Figure 3: Specific luminosity. (1) October 2002, (2) December 2003, (3) June 2004 (CIM).

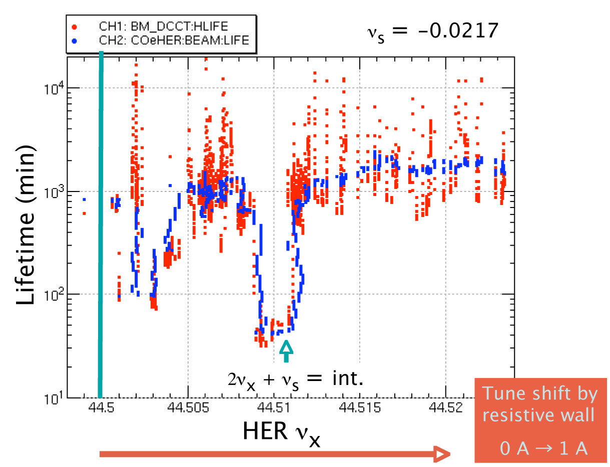

Figure 4: Synchro-betatron resonances in HER. The beam lifetime significantly shortened at the resonance $2\nu_x + \nu_s =$ integer.

the momentum compaction factor.

Others; β_x^*, ε_x, α_p

Beam parameters in the horizontal plane, β_x^* and ε_x also influence the luminosity. According to simulations, smaller β_x^* and ε_x will improve the luminosity. The lattices of KEKB rings have a wide range of tunability based on 2.5π cell structure as $10 \le \varepsilon_x \le 36$ nm and $-4 \times 10^{-4} \le \alpha_p \le 4 \times 10^{-4}$. Flexible optimization will be possible from now on.

CONTINUOUS INJECTION MODE

The Continuous Injection Mode (CIM) is, in other words, continuous data taking by the Belle detector during injection. After trials several times since Dec. 2001, CIM was finally realized in both rings at the end of 2003. As shown in Fig. 5, the merit of CIM is remarkable. Before introduction of CIM, the downtime for injection amounted to 3 hours a day and the average luminosity during running time was limited to 82% of the peak value. After CIM, the vetoed time at usual injection of 10 Hz is only about 3% (40

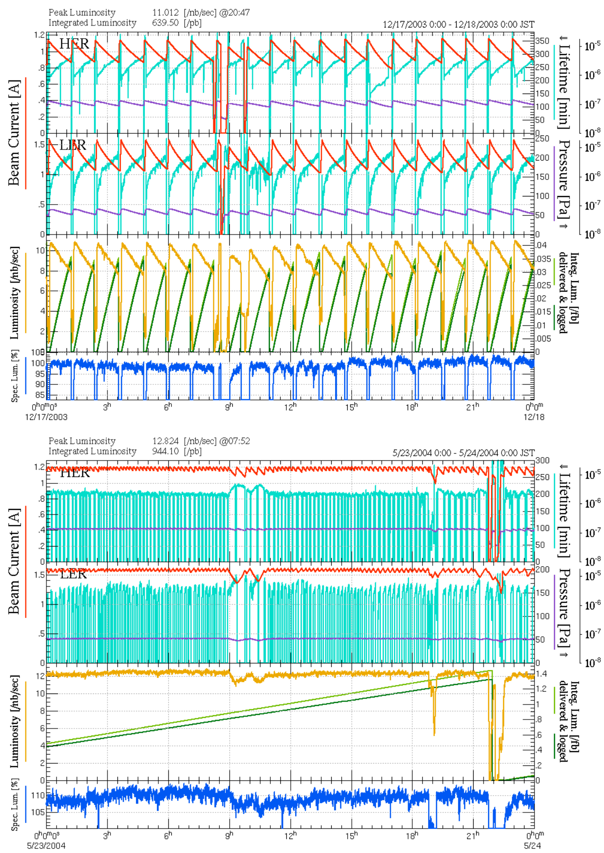

Figure 5: Effect of CIM. The best days before CIM (656/pb/day, upper) and after CIM (944/pb/day, lower).

minutes a day). Besides this, the luminosity stays near its peak value by keeping beam currents constant in alternate injection of positrons and electrons with periodicity of 10 minutes. CIM provides stable machine conditions such as temperatures, orbits, tunes etc., which is better for collision tuning, resulting higher luminosity as shown in Fig. 3.

CRAB CAVITY

The finite crossing angle of 22 mrad gives various merits such as optimization of the lattice near IP and reduction of beam background to the Belle detector at KEKB. Introduction of the crab-crossing scheme shown in Fig. 6 is also prepared against luminosity degradation due to the crossing angle. Although no serious problem has been caused by the crossing angle, recent simulations[6, 7] predict that head-on collision may bring about larger beam-beam parameter $\xi_y \sim 0.1$ which means that the luminosity may be doubled. In order to install superconducting crab cavities early 2006, the design of hardware components such as cryostat, input couplers, tuners etc. is being finalized.

On the contrary of the original plan, 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. More precise estimations are under way.

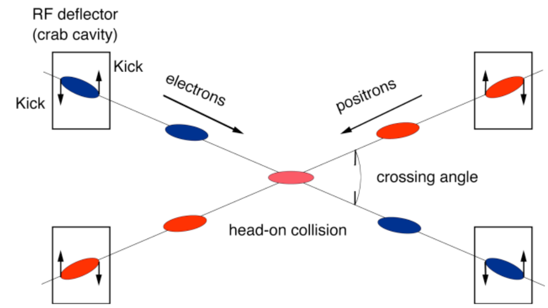

Figure 6: Schematic view of the crab-crossing scheme[5]. In the original design, we planed to install two crab cavities in each ring. Free spaces are reserved in the interaction region.

Table 2: Machine parameters of SuperKEKB. The value of ξ_y was estimated with strong-strong beam-beam simulations.

	Design		
	LER	HER	
Energy	3.5	8.0	GeV
Circumference	3016		m
Current	9.4	4.1	A
Bunches	5018		
Curr./bunch	1.87	0.82	mA
Spacing	0.6		m
Emittance ε_x	24	24	nm
β_x^*	20	20	cm
β_y^*	0.3	0.3	cm
Bunch length	0.3	0.3	cm
ξ_y	0.14	0.14	
Luminosity	250		/nb/s

SUPERKEKB

In order to achieve 20 times higher luminosity (250/nb/s), the SuperKEKB project is being planed[8]. Existing resources such as tunnel, facilities, magnets, power supplies will be reused as much as possible. Main parameters of SuperKEKB are summarized in Table 2. Smaller β_y^* (3 mm), larger ξ_y ($\sim$0.14) and higher currents (9.4 A in LER and 4.1 A in HER) are pursued. Items to be upgraded are: 1) new IR with redesigned final quadrupoles and compensation solenoids, 2) new beam pipes and bellows, 3) reinforced cooling system, 4) more rf systems with improved ARES cavities, couplers, and HOM absorbers of superconducting cavities, 5) upgraded Linac with C-band rf system and a damping ring, etc. R&D efforts are being carried out on antechambers, couplers for ARES cavities, and C-band system in Linac.

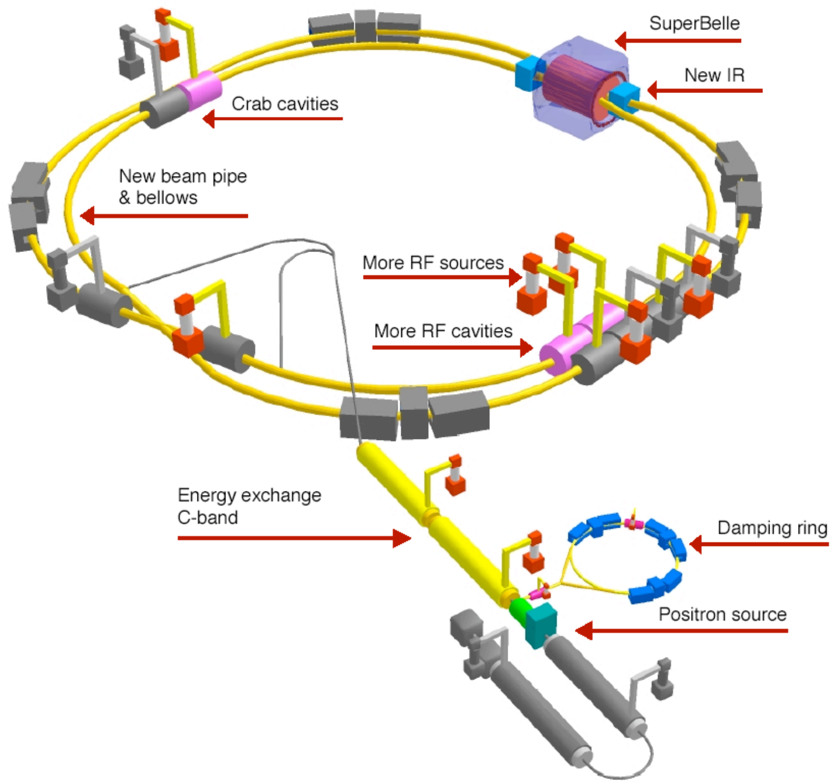

Figure 7: Schematic layout of SuperKEKB.

ACKNOWLEDGMENT

The authors thank all people who have supported KEKB during design, construction, and operation.

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