STATUS OF KEKB AND ITS FIRST RESULT

Shin-ichi Kurokawa
KEK, High Energy Accelerator Research Organization

Abstract

KEK B-Factory, KEKB, is a high-luminosity, two-ring, asymmetric-energy, electron-positron collider for B-physics. It consists of an 8-GeV electron ring and a 3.5-GeV positron ring housed in a 3-km tunnel. The performance of KEKB has been steadily improved during these two years from the start of physics experiment in mid 1999. Especially the improvement of performance in 2001 was remarkable, and the peak luminosity was almost doubled from 2.26 × $10^{33}cm^{-2}s^{-1}$ at the end of 2000 to 4.49 × $10^{33}cm^{-2}s^{-1}$ in July. The maximum integrated luminosities per day, per 7 days, and per month are 232/pb, 1492/pb, and 4760/pb, respectively. The experiment at KEKB, BELLE, has logged 33.1/fb from the start of the experiment by July 2001. This high performance of KEKB is attributed to successful fine tuning of the machine, and also to the suppression of beam blow-up due to electron cloud instabilities by solenoid field imposed on the positron ring vacuum chambers. By analyzing data accumulated by early July, BELLE has detected a clear signal of CP-violation at the bottom quark sector. We reasonably expect that by the end of 2002, BELLE will have logged 100/fb. A study on super KEKB with a luminosity of $10^{35}cm^{-2}s^{-1}$ has started.

1. HIGHLIGHTS

Figure 1 summarizes the increase of peak and integrated luminosity per day, stored currents in the rings and the accumulated luminosity by BELLE from the start of the physics experiment in June 1999 up to the July, 2001.

We witnessed a rapid improvement of the performance of KEKB[1] in 2000 and 2001. The peak luminosity of KEKB was only a little higher than 1.0 × $10^{33}cm^{-2}s^{-1}$ in April 2000, reached 2.0 × $10^{33}cm^{-2}s^{-1}$ in July, and surpassed 3.0 × $10^{33}cm^{-2}s^{-1}$ in March 2001, and 4.0 × $10^{33}cm^{-2}s^{-1}$ in June. The luminosity of KEKB finally reached 4.49 × $10^{33}cm^{-2}s^{-1}$ in July 03, 2001.

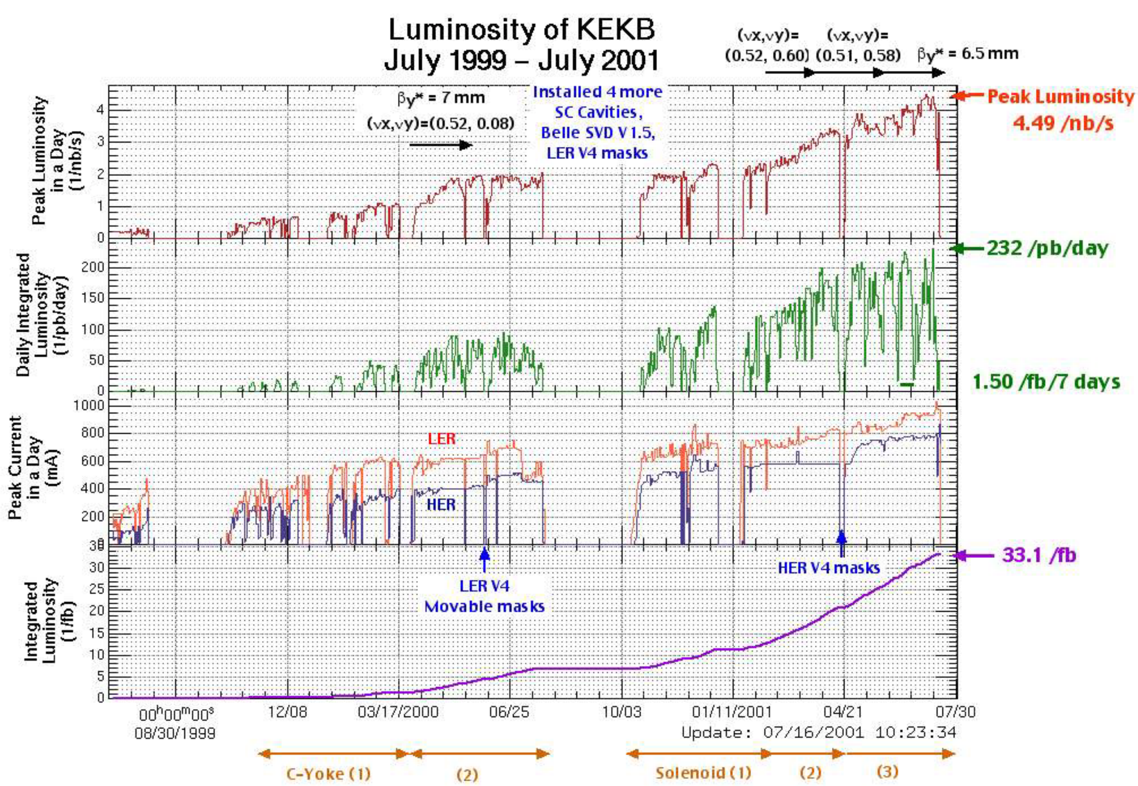

Fig. 1 The increase of peak and integrated luminosity per day, stored and currents in the rings and the accumulated luminosity by BELLE from the start of the physics experiment in June 1999 up to the July, 2001.

Along with the improvement of the peak luminosity, the integrated luminosity per day and per month were also increased up to 232/pb/day and 4760/pb/month. This means that KEKB has indeed entered into a new realm of collider machines together with PEP-II[2] (a B-factory at Stanford Linear Accelerator Center; the experiment at PEP-II is called BaBar) and showed that it could work as a machine that can produce real physics. In February the BELLE and BaBar experiment groups published the first result of CP-violation in Physical Review Letter[3,4], and In July 2001, they announced at the Lepton-Photon Conference held in Rome that CP was violated at B-mesons.

2. FEATURES OF KEKB

KEKB is a two-ring, asymmetric-energy, electron-positron collider and is aimed at producing copious B and anti-B mesons (B meson is composed of anti-bottom quark and a light quark) like a factory. The design luminosity of KEKB is $10^{34}cm^{-2}s^{-1}$, which is more than one-order of the magnitude higher than the maximum luminosity ever achieved by electron-positron colliders before the advent of the B-factories ($8.2 \times 10^{32}cm^{-2}s^{-1}$ by CESR of Cornell University was the highest). The two 3016-m long rings, the 8-GeV electron ring (HER) and the 3.5-GeV positron ring (LER), are housed in a tunnel 11 m below the ground level. They are installed side-by-side and cross at one point called the interaction point, IP, where electrons and positrons collide. The BELLE detector surrounds the IP. Electrons and positrons are directly injected from a linac at full energy. Figure 2 shows a schematic layout of KEKB.

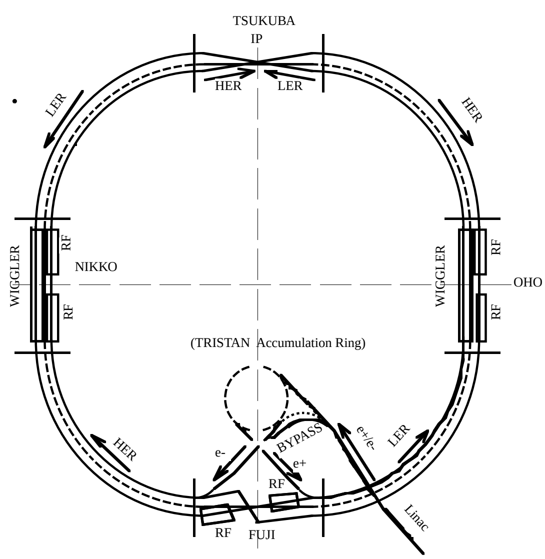

Figure 2: Schematic layout of KEKB

In order to obtain a high luminosity, we should increase the beam currents in the rings and squeeze the beams at IP as much as possible. At KEKB, the design currents in the rings are 1.1 A in HER and 2.6 A in LER and the design beam size at the IP is 90 μm in horizontal direction and 1.9 μm in vertical direction. The main issue is, therefore, how to store such large currents in the rings and at the same time maintain stable collisions between electron and positron beams.

In an electron or positron ring, the beam circulates in the ring as a train of bunches: each bunch consists of a large number of particles (a few billion at KEKB). At KEKB, the beam can be distributed to 5000 bunches with a bunch spacing of 59 cm. Table 1 summarizes the main design parameters of KEKB.

Table 1 Main parameters of KEKB

Luminosity($10^{33}cm^{-2}s^{-1}$)	10
Number of rings	2
Number of interaction points	1
Circumference(m)	3016
Beam energy(GeV)	8.0(e^-)/3.5(e^+)
Total current per beam(A)	1.1(e^-)/2.6(e^+)
Number of bunches	5120 × 0.9 (10% bunch gap)
Bunch spacing(m)	0.59
Crossing angle(mr)	±11
Beam-beam tuneshift ξ_x/ξ_y	0.039/0.052
Beta-function at IP β_x*/β_y*(cm)	33/1
RF frequency(MHz)	508.887
Type of cavities	NCC* and SCC* for e^-; NCC for e^+
Detector	BELLE

*NCC and SCC stand for normal conducting cavity and superconducting cavity.

One of salient features of KEKB is the adoption of a finite-angle crossing at IP, where the electron and positron bunches collide at an finite angle of ±11 mr. This scheme does not require any separation dipole magnets and makes the interaction region much simpler. Another advantage of the scheme is that bunches are separated quickly after the collision and allows the shortest bunch spacing of 59 cm.

KEKB fully exploits superconducting equipment. First, a pair of superconducting final-focus quads are used to squeeze the beams at the IP. These quads are fully immersed within a high magnetic field of a detector solenoid of 1.5 T. They have been stably running with only a few quenches due to beam halos in unusual conditions of the beams.

Second type of superconducting equipment at KEKB is single-cell, single-mode, superconducting accelerating cavities. Superconducting cavities installed in HER have been operated very stably from the start of the commissioning up to now. Typical breakdown rate of the cavities was less than once per month per cavity.

Although simulation does not show any degradation of luminosity at the finite-angle crossing of KEKB, we plan to adopt crab crossing as a fall-back option. For this purpose superconducting crab cavities are being developed.

3. MAIN RECENT IMPROVEMENTS

After the summer shutdown in 1999, the operation of KEKB was resumed on October 12, 1999, and continued until July 23, 2000, with a short break around the New Year Holidays. By July 23, 2000, the peak luminosity was increased up to $2.04 \times 10^{33} cm^{-2}s^{-1}$.

During the summer shutdown of 2000, we made a few modifications to the machine. First, in addition to four superconducting cavities, four superconducting cavities were added to HER in order to increase the current limit of HER up to 900 mA. Second, we replaced movable masks of LER with much robust ones. In the operation before the summer shutdown of 2000, movable masks of LER suffered from archings, which caused a few cases of vacuum leak. In this new movable mask system, we use a vacuum chamber of approximately constant cross section, and displace it gradually along the beam direction to move the beam from the center to a location near one edge of the chamber and back. This shape of masks greatly reduces amount of HOM power generated by the beam. Figure 3 illustrates the idea of the masks and Fig. 4 shows the photo of the masks installed in the ring. This replacement of moveable masks removed current limitation in LER. Thirdly, we suffered from heating of bellows near the IP; these bellows were replaced with ones with better cooling. Last of main modifications was the solenoid winding over LER vacuum ducts. Before the summer shutdown of year 2000, most of LER vacuum ducts in the arc sections were equipped with permanent magnets quads (called C-yoke magnets). During the shutdown of year 2000, we removed the permanent magnets and installed solenoids over 800 m of LER vacuum ducts (see Fig. 5).

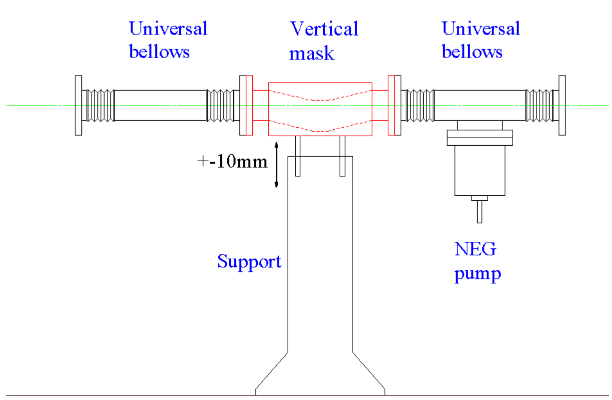

Fig. 3 Scheme of the new movable mask

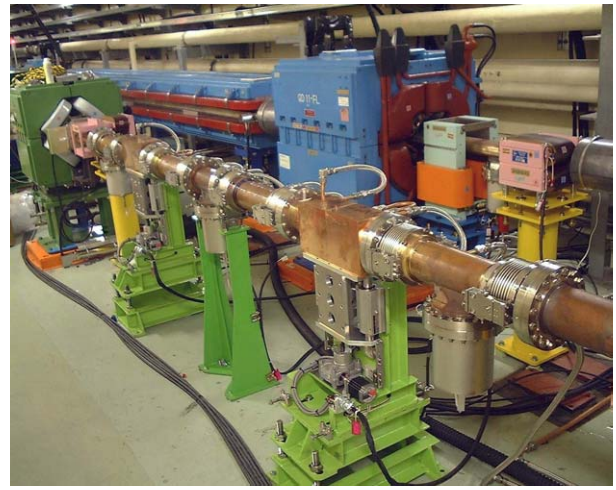

Fig. 4 Movable mask installed in the tunnel.

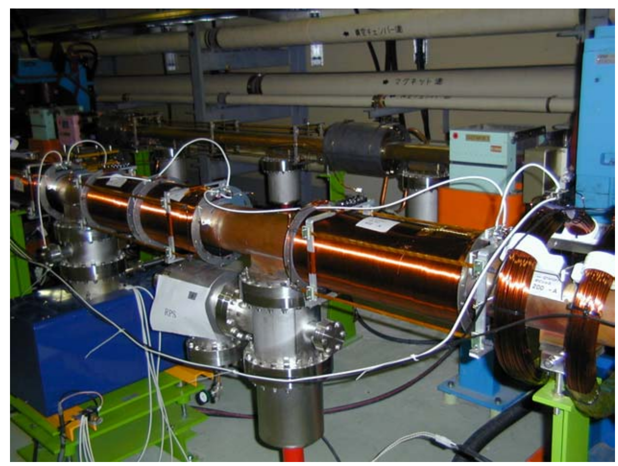

Fig. 5 Solenoids wound over LER vacuum ducts

Operation was resumed on October 10, 2000. The increase of the peak luminosity was not prominent in this autumn run; however, the integrated luminosity per day and per 7 days increased considerably due mainly to stable operation of KEKB.

During short winter shutdown around the New Year Holidays, we wound another 430 m of solenoids over LER vacuum ducts. The operation was resumed on January 2001, and from that on, the performance of KEKB has been steadily improved. In mid February vertical tunes of LER and HER were changed from above integer(0.08) to above half integer(0.60). This tune change made the machine much stabler. Also in mid March, the horizontal tunes of both rings were made much closer to half integer from 0.52 to 0.51, which helped increase the peak luminosity. On March 22, 2001, the peak luminosity surpassed $3.0 \times 10^{33} cm^{-2}s^{-1}$, and on June 11, 2001, and reached $4.0 \times 10^{33} cm^{-2}s^{-1}$. Finally on July 3, 2001, KEKB has achieved a peak luminosity of $4.49 \times 10^{33} cm^{-2}s^{-1}$. Table 2 shows a parameter list of KEKB when we achieved the highest luminosity.

Table 2 Performances at the maximum luminosity

Energy e^+/e^- (GeV)	3.5/8.0
Peak luminosity ($10^{33}cm^{-2}s^{-1}$)	4.49
Current e^+/e^- (A)	0.85/0.72
Number of bunches	1153
Beta function at IP β_x^*/β_y^*(cm)	59(e^+),63 (e^-)/0.65
Beam sizes at IP σ_x^*/σ_y^*(μm)	103(e^+),123 (e^-)/2.3
Beam-beam tuneshift e^+ ξ_x/ξ_y e^- ξ_x/ξ_y	 0.064/0.049 0.050/0.030
Max int. luminosity/day (1/pb)	232
Max int. luminosity/7 days (1/pb)	1492
Max int. luminosity/month (1/fb)	4.76

4. ELECTRON CLOUD INSTABILITIES

Electron cloud instability (ECI) is the most serious instability at KEKB and it limits its performances[5]. Synchrotron light from the positron beam hits the inner wall of vacuum chambers and produces photoelectrons. These photoelectrons are attracted by the beam to form clouds around it. Also electrons created by multipacting form cloud around the beam. The clouds then excite head-tail type oscillation within a bunch and the beam blows up. If we apply solenoid field parallel to the beam, electrons that come out from the inner surface of the vacuum ducts are confined close to the wall.

Figure 6 shows the result of beam study on the effect of solenoid field done in October 2000, when we had 800 m long solenoids. Two trains of 60 bunches were stored and beam-size measured by the double-slit interferometer and normalized at the IP with respect to the stored current in LER with (1) all solenoids were excited at 5 A, (2) all solenoids were excited at 3 A, (3) half of the solenoids were excited at 5 A, and (4) all solenoids were switched off. Excitation current of 5 A corresponded to 50 gauss of maximum solenoid field. From the figure, we can see that (1) solenoids effectively suppressed the photoelectron instabilities, and increased the threshold, (2) 30 gauss was sufficiently strong to suppress the instabilities, and (3) the increase of threshold current was proportional to the length of applied solenoids. The solenoid effect to the luminosity was measured at KEKB at collision mode. Figure 7 shows the result of study done at KEKB in May, 2001. It shows that (1) when the 430-m long solenoids (NEG-bellows section) wound in January 2001 were turned off, the luminosity decreased by 25% at high current and the reduction of the luminosity became small when the current decreased, and (2) if all solenoids were turned off the reduction of the luminosity was much larger.

It is highly probable that the rapid improvement of the performance of KEKB observed in year 2001 was due to suppression of beam blow-up by solenoids.

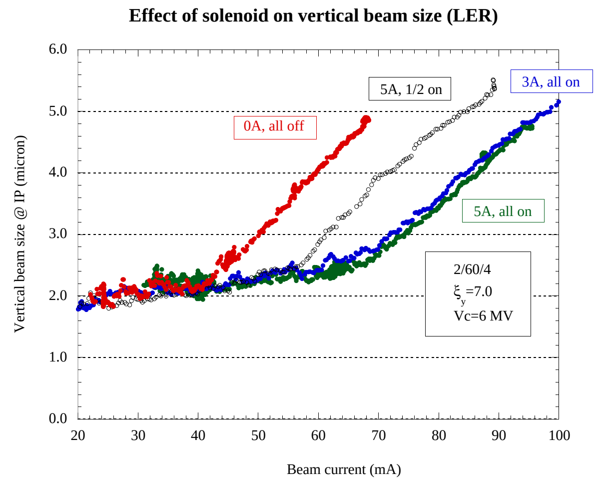

Fig. 6 Effect of solenoid field for short bunch train

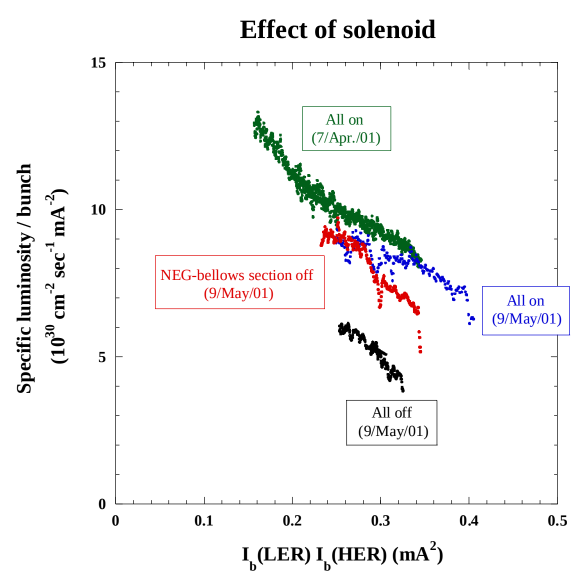

Fig. 7 Effect of solenoid field to KEKB luminosity.

5. OBSERVATION OF CP-VIOLATION

Both BELLE and BaBar experiments observed a violation of CP-violation in the decays of B mesons in July. This is the first matter-antimatter asymmetries observed for particles other than K mesons and marks a major experimental breakthrough in a search that has been going on almost 40 years since the discovery of CP-violation in K mesons in 1964. These results are published in the August 27, 2001, issue of Physical Review Letters.

The observed asymmetries by BELLE[6] and BaBar[7] are:

A_{cp}=0.99 ± 0.14 ± 0.06 (BELLE)
A_{cp}=0.59 ± 0.14 ± 0.05 (BaBar)

The first numbers after ± are statistical errors and the second ones systematic errors. The statistical significance of the BELLE measurement corresponds to the possibility of no CP violation is smaller than one part in 10 million, whereas that of BaBar smaller that one part in 30,000.

6. FUTURE PROSPECTS AND CONCLUSION

Both B-Factories have a capability of delivering 5-6/fb/month; therefore, it is reasonably expected that by the end of 2002, both BELLE and BaBar will have accumulated 100/fb and in 4 to 5 years the accumulated luminosity will be increased up to or higher than 300/fb. At KEKB discussion has started on super KEKB with a luminosity of $10^{35}cm^{-2}s^{-1}$.

ACKNOWLEDGEMENTS

This talk is made on the basis of hard works of KEKB staff members. I thank all of my colleagues and many visiting scientists who have devoted themselves to construction and commissioning of KEKB.

REFERENCES

[1] KEKB B-Factory Design Report, KEK Report 95-7, August 1995.
[2] PEP-II Conceptual Design Report, SLAC Report 418, LBL-PUB-5379, June 1993.
[3] A. Abashian, et al., Phys. Rev. Lett. 86 (2001) 2509.
[4] B. Aubert, et al., Phys. Rev. Lett. 86 (2001) 2515.
[5] K. Ohmi and F. Zimmermann, Phys. Rev. Lett. 85 3812 (2000).
[6] K Abe, et al., Phys. Rev. Lett. 87 (2001) 091802
[7] B. Aubert, et al., Phys. Rev. Lett. 87 (2001) 091802