# Luminosity Tuning and Operation Statistics at KEKB


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*Abstract*

The KEKB B-Factory (KEKB) started a collision experiment in 1999 and achieved the design luminosity of 10 $nb^{-1}s^{-1}$ in May, 2003. We achieved 21.1 $nb^{-1}s^{-1}$ in 2009 (more than the double of the design luminosity). The integrated luminosity surpassed 1000 $fb^{-1}$ in 2009. We routinely make tuning on machine parameters related to beam collision even during the physics experiment. The purpose of this adjustment (called "knob tuning") is to maintain the high luminosity by optimizing the collision parameters and to obtain an even higher luminosity. We installed crab cavities in February, 2007. The method of luminosity tuning changed to some extent and some new tuning methods were introduced. We installed skew sextupole magnets in March, 2009 and the e+/e- simultaneous injection scheme was realized. After those, the peak and integrated luminosity improved drastically. We also describe the operation statistics.


## 1. Introduction

The KEKB B-Factory (KEKB) [1] [2] started a collision experiment in 1999 and achieved the design luminosity of 10 $nb^{-1}s^{-1}$ in May, 2003. We introduced the continuous injection scheme which enables us to do data acquisition during the beam injection in 2004. We installed crab cavities in February, 2007. The crab cavities are used in a usual physics operation and it was proven that they operate very stably under the condition of the high current beams. We installed skew sextupole magnets in March, 2009 and the e+/e- simultaneous injection scheme was realized. After those, the peak and integrated luminosity improved drastically. Figure 1 shows the history of the KEKB operation.

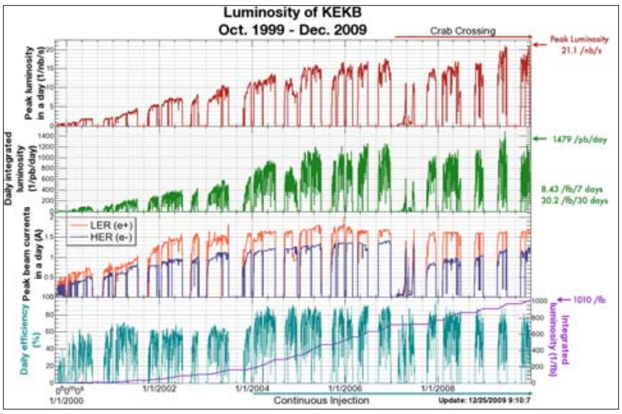


Fig 1: History of the KEKB operation.

## 2. Injection method

When the beam was injected, data acquisition had been temporarily stopped until 2003. Electrons (HER) and positrons (LER) were injected after a physical experiment had been done for about one hour, and data acquisition was resumed afterwards. We introduced a continuous injection mode (CIM) that enables the beam injection during the data acquisition in 2004. In the CIM method the injections of HER and LER had been switched every about ten minutes. Afterwards, we succeeded in shortening the switch interval greatly. We could switch at intervals of about five minutes in 2008. Afterwards, an injection method was improved further. An HER and LER simultaneous injection (which means pulse-to-pulse switching for linac pulse) was realized in April, 2009. Beam injection schemes are shown in Figures 2 and 3 before and after introducing the CIM method.

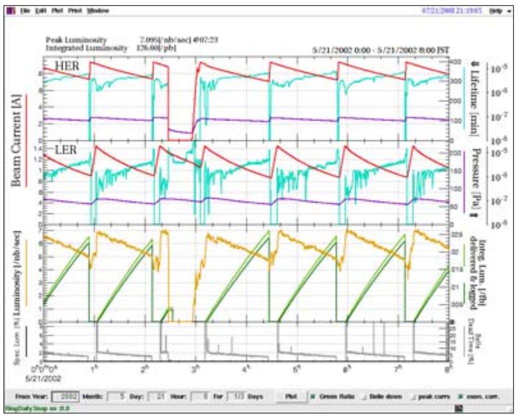


Fig 2: Before introducing the CIM method.

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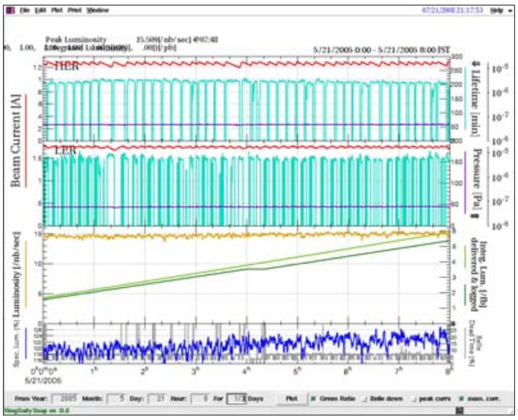


Fig 3: After introducing the CIM method.

Figure 4 shows the appearance of the present simultaneous injection. The beam currents of HER and LER can be kept at almost constant values at any time by the simultaneous injection. The temperature changes of the vacuum chambers that receive the influence of the synchrotron radiation from the beam have become small. The luminosity change has also become small. They are advantageous for the luminosity tuning.

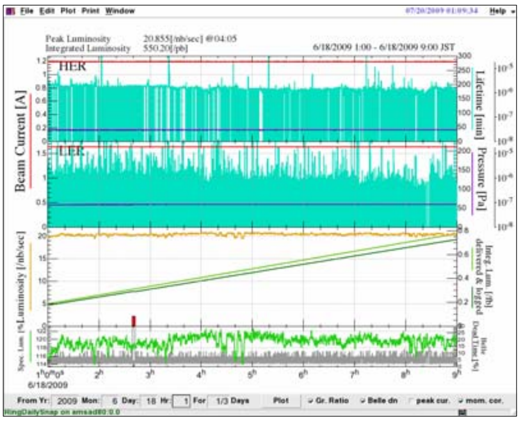


Fig 4: Appearance of the present simultaneous injection.

## 3. Orbit correction at collision point

We make a bump near the interaction point (IP) of HER with steering magnets. The HER beam is made to collide with that of LER in the best condition. This system is called “iBump feedback”[3]. It is the best to adjust the difference of the position（offset） and the difference of the angle （crossing angle）at the IP to 0. The offset and crossing angle in the vertical direction were adjusted to 0 as much as possible. We do not use a feedback for the horizontal crossing angle, because the angle is comparatively a big value (22mrad). We have used two kinds of feedbacks for the horizontal offset.（Easy feedback: Feedback to keep the ratio between the read value of a kick angle of a horizontal steering magnet and the height of horizontal bump at some target value that is empirically determined. Beam-size feedback : Keep the vertical beam size of LER at some target value）. The feedbacks (Easy feedback, Beam-size feedback) for the horizontal offset are not used with the crab cavity, since behavior of the beams to the horizontal offset has changed. Now, we use the same method for the horizontal offset as the feedback for the vertical offset based on the beam-beam deflection method, which keep the beam-beam kick at some target value.

## 4. Knob tuning

The orbit corrections of the rings are done every about ten seconds. This system is called “Continuous Closed-orbit Correction” (CCC). As for the orbit correction around the IP, neither the correction accuracy nor the rates of the correction are enough by CCC. Therefore, we need the iBump system, which manipulates the orbits around the IP at a rate of about 1Hz. In the knob tuning, the x-y couplings and the vertical dispersion at the IP are also tuned by making orbit bumps at the positions of sextupole magnets. When we changed these knobs, the orbits around the rings are distorted. Then we halt the data acquisition for the luminosity tuning until the orbits become stable. In the usual tuning, several setting values are tried for each knob looking for a better performance. Usually, we set each knob at the value which gives the highest luminosity. The best value is determined by fitting the knob set vs. luminosity curve with a parabolic function as shown in Figure 5. Sometimes, we use another method for the knob search called the Downhill Simplex Method which is explained in section 4.2.

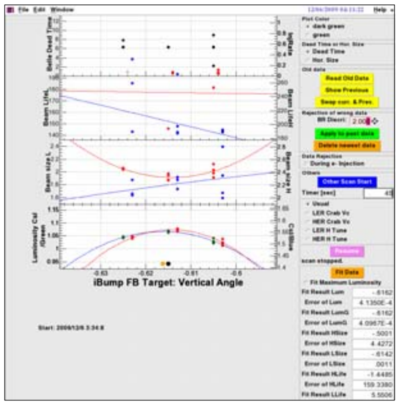


Fig 5: Appearance of the knob scanning.

### 4.1 Tuning knobs

・iBump feedback

The target value of the horizontal offset, the vertical offset, and the vertical crossing angle are adjusted to the best value by the knob scanning. The scans for these knobs are done at the beginning of the luminosity tuning. After other tunings, the target scans are tried again.

・Coupling, vertical dispersion at the IP

The x-y couplings and the vertical dispersion are also important tuning knobs.

・Waist

The minimum position of the vertical beta function at the IP of each beam is adjusted.

・Betatron tune

The horizontal and vertical tunes are important tuning items in the daily operation. An optimum set of the tunes shifts slightly day by day. The luminosity tends to increase with horizontal tunes closer to the half integer. In case of LER, the lifetime of the head part of the bunch train, where the amount of the electron clouds smaller, decrease when the horizontal tune is lowered toward the half integer. To prevent this problem, we introduced a pulsed quadrupole magnet in 2007, which can raise the horizontal tune only of the head part of the bunch train.

・Crab tilt

The x-y coupling parameters around the crab cavities are tuned so that the vertical crab angle at the IP is corrected.

・Horizontal dispersion

The horizontal dispersion at the IP is adjusted by making bump orbits at sextupole magnets of eight pairs.

・Vertex point

The RF phase of LER is adjusted so that collision point is kept at the nominal position. We can know the collision point from the data on the vertex position sent from the Belle detector every about 5 minutes.

・Chromaticity

The chromaticities of the betatron tunes and the Twiss parameters at the IP are tuned by using the sextupole magnets. The main purpose of the tuning is to extend the beam lifetime. In addition, the luminosity is also changed by the sextupole setting. The sextupole tuning is also used to increase the luminosity.

Figure 6 shows the betatron tune plot chart. Figure 7 shows the coupling and vertical dispersion adjustment panel.

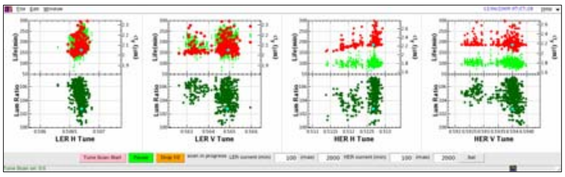

Fig 6: The betatron tune plot.

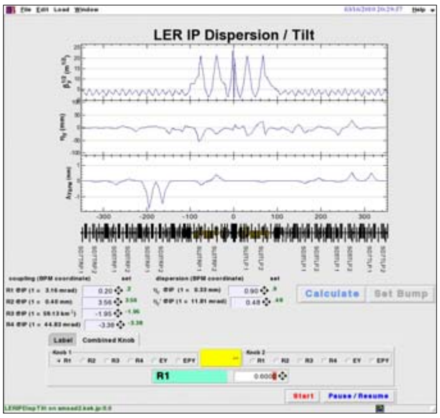


Fig 7: The coupling and vertical dispersion adjustment panel.

## 4.2 Downhill Simplex Method

The scanning by Downhill Simplex Method (DSM) was introduced in October, 2007. In this method, the 12 knobs of the x-y coupling and vertical dispersion at the IP for both beams are searched simultaneously according to the DSM algorism. Usually this search is continued until the search converges. At KEKB, we use both the DSM search and the single knob scan. It turned out that the DSM search improves the luminosity more quickly than the single knob scans when the knobs are far from the optimum values in such a case as just after the optics correction. However, the luminosity eventually achieved by the DSM search is not so different from that by the single knob scans. Usually we use the DSM search after the optics correction. In every day's operation we use the single knob scan. Sometimes, we try to do the DSM search to minimize the vertical beam size of either beam. The e+/e- simultaneous injection has contributed to the speed-up of the knob search, since the beam currents become more constant and so we can start the data taking for the search anytime during the operation. Figure 8 shows the appearance of the knob search by DSM. Figure 9 shows a history of the knobs with DSM.

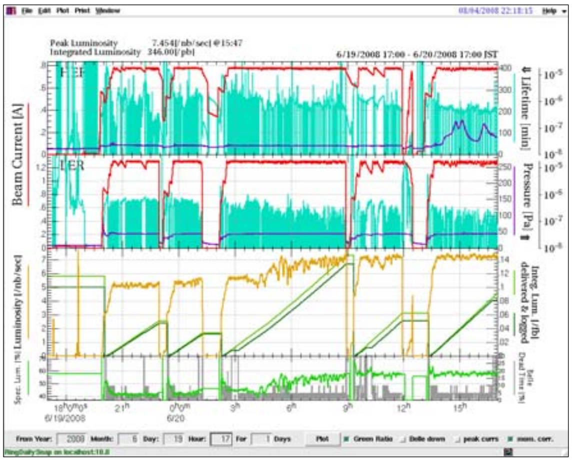


Fig 8: The appearance of the knob scanning by DSM.

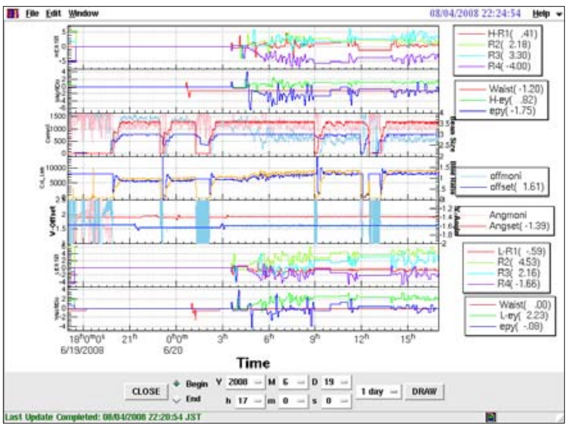


Fig 9: A history of the knobs with DSM.

## 5. Crab cavities

The crab cavities were installed in February, 2007. The purpose is to realize virtually the head-on collision. Before the crab cavities were installed, the peak luminosity 17.60/nb/s had been recorded with the HER/LER beam currents of 1340/1662mA. After the crab cavities were installed, the peak luminosity 16.10/nb/s had been recorded with the HER/LER beam currents of 934/1605mA. In May 2009, the peak luminosity 21.08/nb/s was recorded with the HER/LER beam currents of 1188/1637mA. The improvement of the luminosity was chiefly brought by the installed of skew sextupole magnets. In addition, the increase of the HER beam currents contributed to this. There are two reasons why HER beam current was able to be increased. First, the aperture was extended near the LER crab cavity by the optics change. Second, the $\beta_x$ at the IP was loosened.

## 6. Skew sextupole magnets

It has been shown by the beam-beam simulations that the momentum dependence of the x-y coupling at the IP would degrade the luminosity if remaining values are larger.[4] To correct these chromaticities of the x-y coupling at the IP, 14 pairs of skew sextupole magnets (10 pairs for HER and 4 pairs for LER ) were installed in March 2009. The effects of the newly installed magnets were remarkable. The peak luminosity was increased by 15 or 17% by these magnets. The Fig.10 shows the luminosity and other related parameters on May 2nd 2009, when the sextupole magnets were used in the beam operation for the first time. In the single day, the peak luminosity was increased from 16.3 $nb^{-1}s^{-1}$ to 18.5 $nb^{-1}s^{-1}$ owing to the tuning using the magnets.

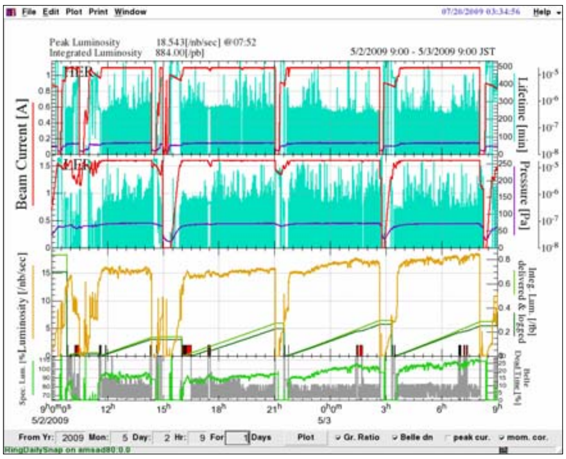


Fig 10: The luminosity change on May 2nd 2009 when skew sextupole magnets were firstly used.

## 7. Operation statistics

KEKB has been operated for about nine months every year. Figure 11 shows the operation days and hours of each fiscal year. The operation time was 275 days (6552 hours) in FY 2004, 162 days (3849 hours) in FY 2008 and 150 days (3551 hours) in FY 2009.

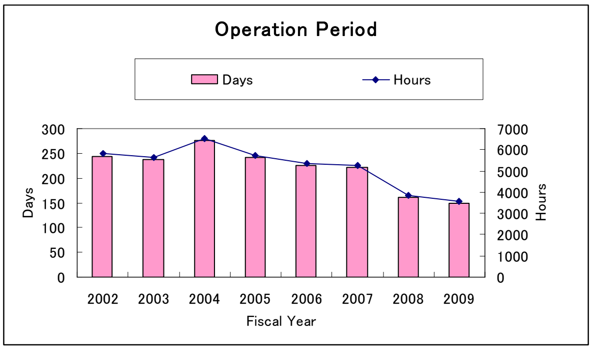


Fig 11: Operation period.

The main purpose of the KEKB operation is the physical experiment. The study for the accelerator performance improvement has been also done (Beam tuning, Machine tuning, and Machine study). Figure 12 and 13 show the breakdown of use of KEKB operation time in each fiscal year. In FY 2006 and 2007, a long time was devoted to the study of crab crossing and the portion of the physics experiment was decreased down to 50%.

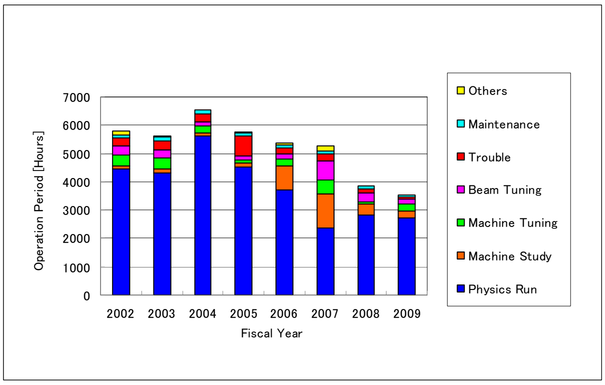


Fig 12: The use of available time for KEKB in hours.

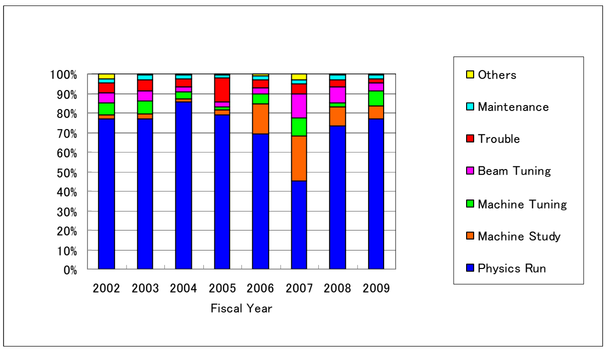


Fig 13: The use of available time for KEKB in percentage.

Figure 14 shows the breakdown of the operation statistics in FY 2008 and 2009. In these fiscal years, almost no dedicated machine time was used for crab crossing. However, the machine study for SuperKEKB, which is the upgrade project of present KEKB, increased and so the portion of the machine study is larger compared with before the installation of the crab cavities. We have a plan to stop the KEKB operation in the middle of 2010 and to start the work for the upgrade.

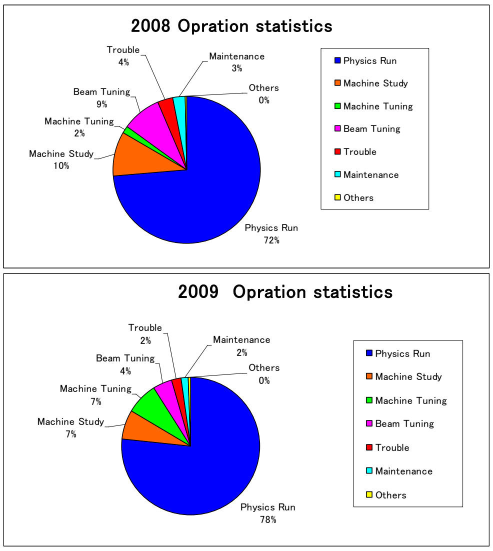


Fig 14: Detailed content of operation in fiscal year 2008 and fiscal year 2009.

## 8. Integrated and peak luminosity

The luminosity is the important parameter in the colliding-beam accelerator. It is important to increase integrated luminosity for the success of the physical experiment. For this purpose, in addition to increasing the peak luminosity, it is important to decrease the frequency of the beam abort, to decrease the failure rate of the machine, and to decrease the dead time of the detector by the beam noise. Figure 15 shows the history of the annual integrated luminosity and the daily averaged luminosity.

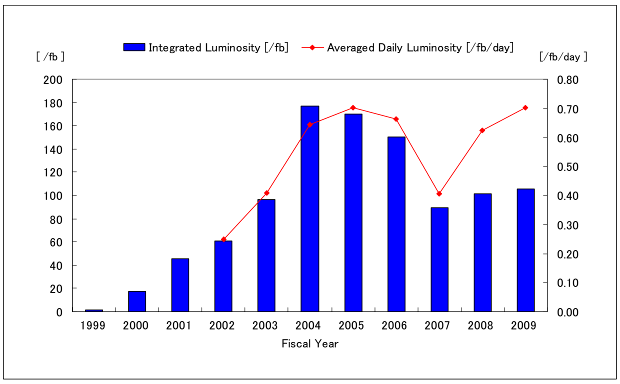


Fig 15: The history of the annual integrated luminosity and the daily averaged luminosity.

The operation time of FY 2008 was about six months. The integrated luminosity was 101.06 $fb^{-1}$ and the maximum peak luminosity was 16.381 $nb^{-1}s^{-1}$. The averaged daily luminosity of 0.6 $fb^{-1}day^{-1}$ is lower than 0.68 $fb^{-1}day^{-1}$ in FY 2005. However, it increased rapidly after the crab cavities were installed.

The operation time of FY 2009 was about six months. The annual integrated luminosity was 105.43 $fb^{-1}$ and the maximum peak luminosity was 21.083 $nb^{-1}s^{-1}$. The averaged daily luminosity was 0.7 $fb^{-1}day^{-1}$.

## 9. Beam abort

We have a beam abort system that protects accelerator devices from damages due to the beams. When a malfunction of accelerator device or beam loss is detected, the beam is aborted within 100~160μs. Figure 16 shows the frequency of the beam aborts from October, 2004 to December, 2008.

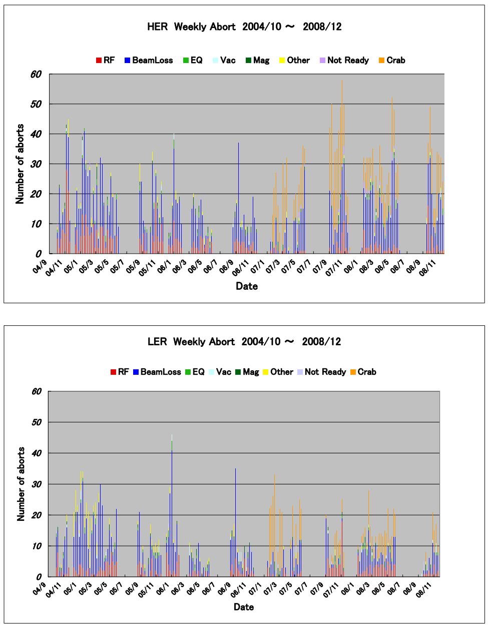


Fig 16: Details of abort from October, 2004 to December, 2008.

In the period from November 2004 to December 2006, 60% of HER beam aborts were caused by the beam losses and 30% were caused by RF trips. These two kinds of aborts account for 90% of beam aborts. In the case of LER, 64% of aborts were caused by the beam losses and 18% were caused by RF trips. These two kinds of aborts account for more than 80% of beam aborts.

After having installed the crab cavities, beam aborts caused by crab cavity trips became serious. In case of HER, 45% of beam aborts were due to the crab cavity trips, 41% were due to the beam losses and 7% were due to the RF trips. In case of LER, 43% of beam aborts were due to the crab cavity trips, 30% of aborts were due to the beam losses and 18% were due to the RF trips.

To accumulate the integrated luminosity effectively, it is important to decrease the frequency of the beam aborts. We have been paying a close attention to the causes of the beam aborts and trying to decrease the frequency. As for the aborts due to the crab cavity trips, the frequency has been decreasing as aging of the cavities by the beams advances.

## 10. Breakdown time

Figure 17 shows the history of the troubles in each fiscal year. Figure 18 shows details in FY 2008. Figure 19 shows details in FY 2009.

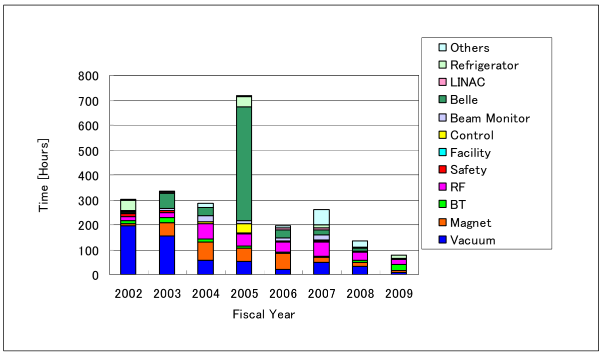


Fig 17 : The history of the troubles in each fiscal year.

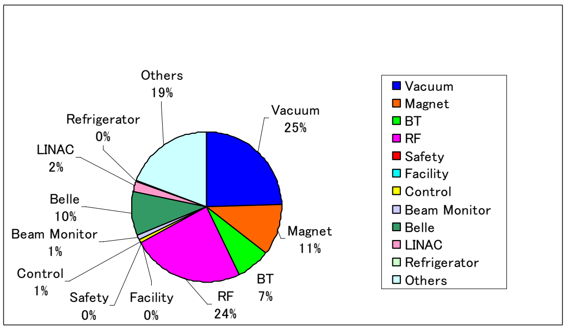


Fig 18 : Trouble details in fiscal year 2008.

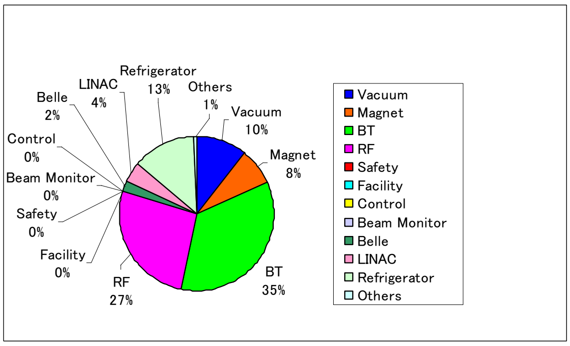


Fig 19 : Trouble details in fiscal year 2009.

The breakdown time due to the troubles has been decreasing, even if we take the decrease of the operation time in to account. FY 2005 was an exceptional year, when the trouble of Belle detector accounted for a large portion. In the figure 18 and 19, the details of the troubles in FY 2008 and FY 2009 respectively. In FY 2009, the trouble rate of BT was exceptionally high, since several troubles accidentally coincided in this fiscal year.

## 11. Summary

The luminosity has improved greatly by introducing skew sextupole magnets. In addition, the simultaneous injection of HER and LER was put to practical use. The beam currents became more constant, and the knob tuning was speeded up. The operation by using the crab cavities was established. The total integrated luminosity is 1018 $fb^{-1}$ and the maximum peak luminosity is 21.08 $nb^{-1}s^{-1}$.

## 12. Acknowledgements

Our heartfelt appreciation goes to the members of KEKB Commissioning Group who provided carefully considered feedback and valuable comments.

## 13. References

[1] KEKB B-Factory Design Report, KEK Report 95-7 (1995).
[2] http://kekb.jp.
[3] Y. Funakoshi, et.al., "Orbit feedback system for maintaining an optimum beam collision" , Phys. Rev. ST Accel. Beams 10, 101001 (2007).
[4] Y. Funakoshi, et.al.," RECENT PROGRESS OF KEKB", Proceedings of PAC07, Albuquerque, New Mexico, USA.