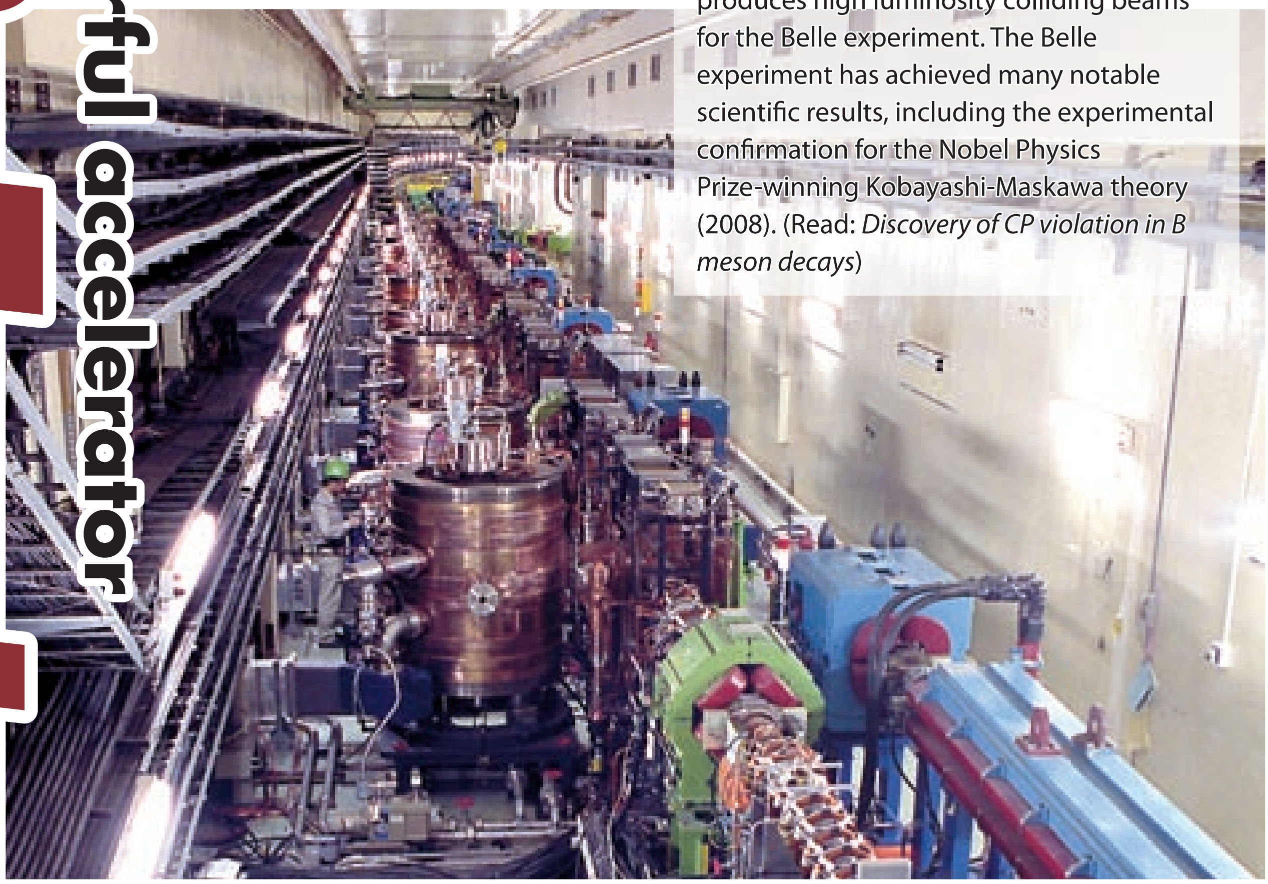
KEKB B-Factory

The world's most powerful accelerator



KEKB, the B-Factory accelerator at KEK, produces high luminosity colliding beams for the Belle experiment. The Belle experiment has achieved many notable scientific results, including the experimental confirmation for the Nobel Physics Prize-winning Kobayashi-Maskawa theory (2008). (Read: *Discovery of CP violation in B meson decays*)

KEKB Quest for CPV
kekb.jp

KEKB Accelerator

High Energy Accelerator Research Organization (KEK)
Accelerator Laboratory

The KEKB B-Factory

A Double-Ring Collider Delivering the World's Highest Luminosity

The world's most advanced collider.

KEKB is a particle accelerator that produces a great number of pairs of B mesons and anti-B mesons by colliding electrons and positrons -- thus the name, "B-Factory." An electron ring and a positron ring are installed inside KEKB's circular tunnel, which is 3 kilometers in circumference and 11 meters underground. In these rings, electrons and positrons circulate at near the speed-of-light in opposite direction at energies of 8 billion electron-Volts and 3.5 billion electron-Volts, respectively. The two beams collide at the interaction point, where the Belle detector is installed to observe the particle interactions.

One measure of the performance of a collider is a quantity called luminosity. The rate of particle interactions, such as the production of B-mesons and anti-B mesons, is proportional to the luminosity. Thus, in order to study rare events, scientists need to produce high luminosity collisions.

On May 9, 2003, KEKB's luminosity reached the world's highest record luminosity at $10^{34}cm^{-2}s^{-1}$. This luminosity was thought beyond the reach of accelerators ten years before; in accelerator science, this remarkable accomplishment is comparable to the great achievement witnessed by the world when runners broke 10 seconds in the 100-meter sprint for the first time.

One of the keys to higher luminosity is to store high current beams in both rings. For this purpose, KEKB utilizes superconducting cavities, and a special type of normal-conducting radio-frequency cavities called ARES (Accelerator Resonantly coupled with Energy Storage). Another key to higher luminosity is to focus the beams as tightly as possible. KEKB utilizes superconducting magnets to compress the beam size down to 110 micrometers in width, and 2 micrometers in height at the collision point.

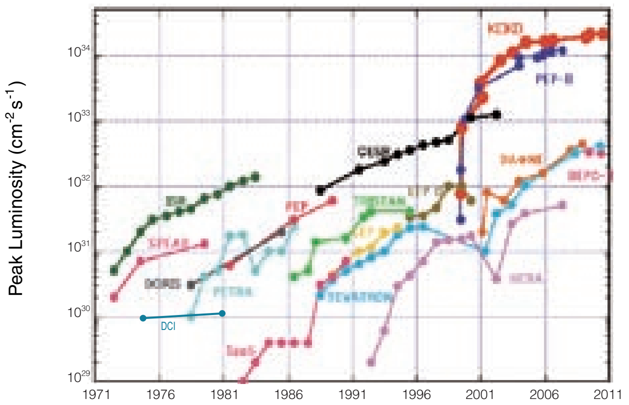
KEKB was upgraded by installing the world's first crab cavities in February 2007, and skew sextupole magnets in March 2009. As the result, KEKB achieved a luminosity of $2.11\times10^{34}cm^{-2}s^{-1}$ in June 2009, breaking its own world record again.

The high luminosity generated a large amount of collision data. The Belle group found evidence for the violation of charge-parity symmetry (CP violation) in B meson decays, providing experimental confirmation for the Kobayashi-Maskawa Theory of CP violation. This led to the Nobel Physics Prize in 2008, half of which was shared by Kobayashi and Maskawa.

As of July 30, 2010, the operation of the KEKB accelerator has been temporarily suspended in order to carry out upgrades for higher performance.

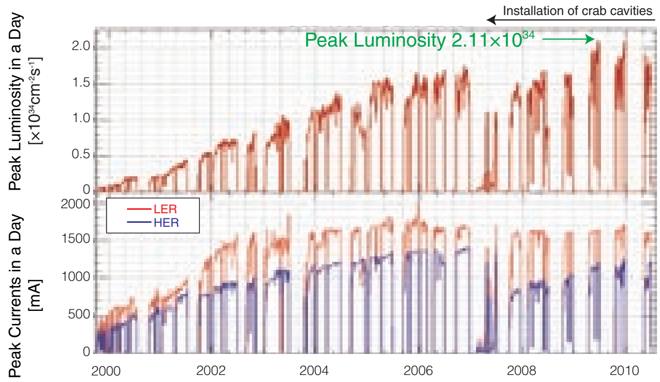
"As late as 2001, the two particle detectors BaBar at Stanford, USA and Belle at Tsukuba, Japan, both detected broken symmetries independently of each other. The results were exactly as Kobayashi and Maskawa had predicted almost three decades earlier." (Excerpt from the press release issued by the Royal Swedish Academy of Sciences)

Accelerator world history



KEKB's luminosity surpassed that of its rival B-Factory PEP-II in the U.S. in April 2001, and has been recording new world records ever since.

Improvements in the power of KEKB



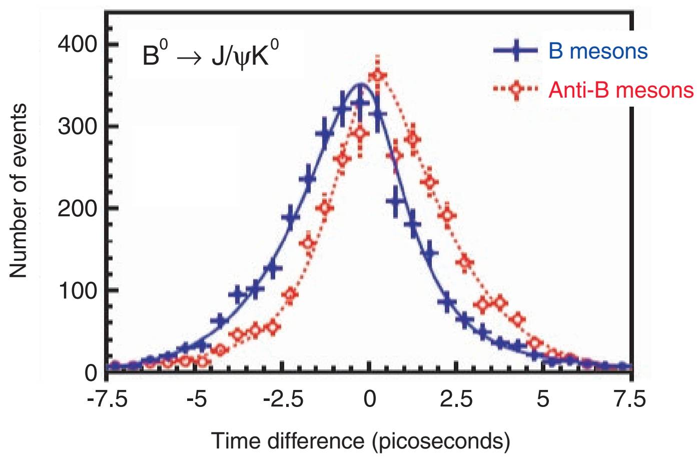
The graph shows peak luminosity (top) and integrated luminosity (bottom) from the start of the experiment in 1999 until June 2010. All luminosity world records are held by KEKB.

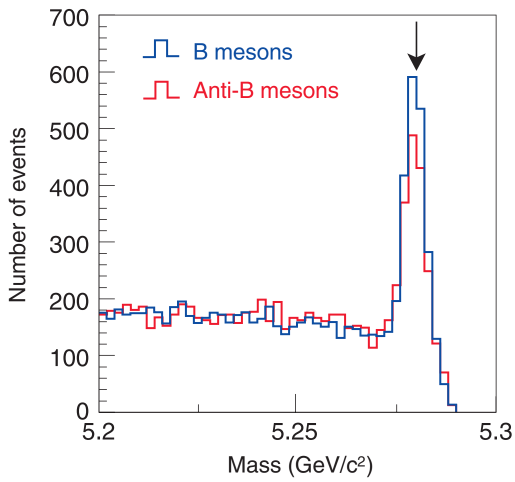
Discovery of CP Violation in B Meson Decays

In 2001, the Belle experiment at KEKB discovered a violation of the charge-parity symmetry (CP violation) in B meson decays.

B mesons decay via various decay modes. In one mode (for example, B → J/psi and Ks mesons), when a B meson decays physicists can measure the decay times of the B meson and anti-B meson that were created as a pair. The difference in the decay times is then plotted for many B meson decays (the left figure: blue). The distribution changes when the decay time differences are plotted for anti-B meson decays, versus for B meson decays (the left figure: red). This is called CP violation, and the degree of the CP violation agrees with the prediction made by the Kobayashi-Maskawa Theory.

In other B meson decay modes, physicists are conducting measurement to look for "direct CP violation." In the mode in which a B meson decays into a pair of charged kaon and charged pion, the numbers of B meson decay events and anti-B meson decays event differ. (In the right figure, the peaks show the numbers of decay events in this particular decay mode.) This provides evidence for a new type of CP violation independent of the CP violation found in the left figure.





KEKB B-Factory

KEKB accelerator

http://kekb.jp

Inter-University Research Institute Corporation
High Energy Accelerator Research Organization
Accelerator Laboratory

September 2010

http://www.kek.jp

Components o

Radio Frequency Acceleration Equipment

The cavities which accelerate the particles using high frequency electromagnetic fields, the klystrons which supply the high frequency electromagnetic waves to the cavities, and so on.

Magnets

The electromagnets which make the magnetic fields keeping the particles in their orbits, their power sources, and so on.

Beam Diagnostics System

The collection of systems which, during operation, check the state of the beam in the accelerator to see if it is traveling according to design.

Vacuum System

The containers which maintain the vacuum state along the beam's path. There are various types of component around the accelerator.

Beam Transport System

The system which transports the beam from the injection accelerator into the ring.

Control System

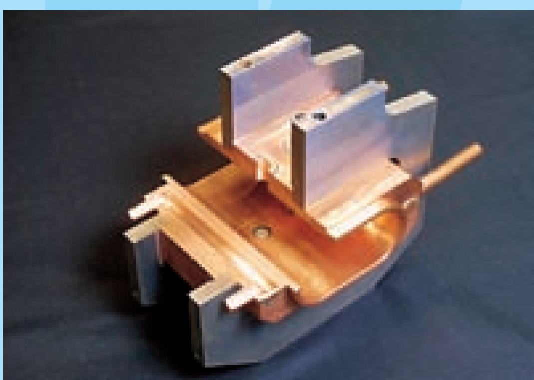
The system which remotely controls all the components of the accelerator.

Injector

This is a large and complex accelerator, which supplies the KEKB rings with positrons and electrons.

Electromagnets in the arc region:
Electromagnets guide beams in a circle, and are one of the critical accelerator components. More than 2,000 electromagnets of various types are employed.

Steerable mask:
Masks installed inside beam ducts preve
particles from hitting the detector, reduci
noise. The ducts themselves are mov
control over the distance between beam a
are installed in various locations in the rin



A beam position monitor block:
A button-shaped electrode monitors the beam positi
by detecting the electrical signals from the beam. T
monitor blocks are integrated into the beam ducts. Ea
ring employs more than 400 beam position moni
blocks.

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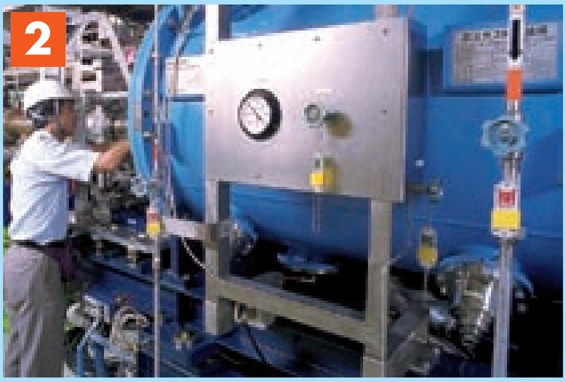
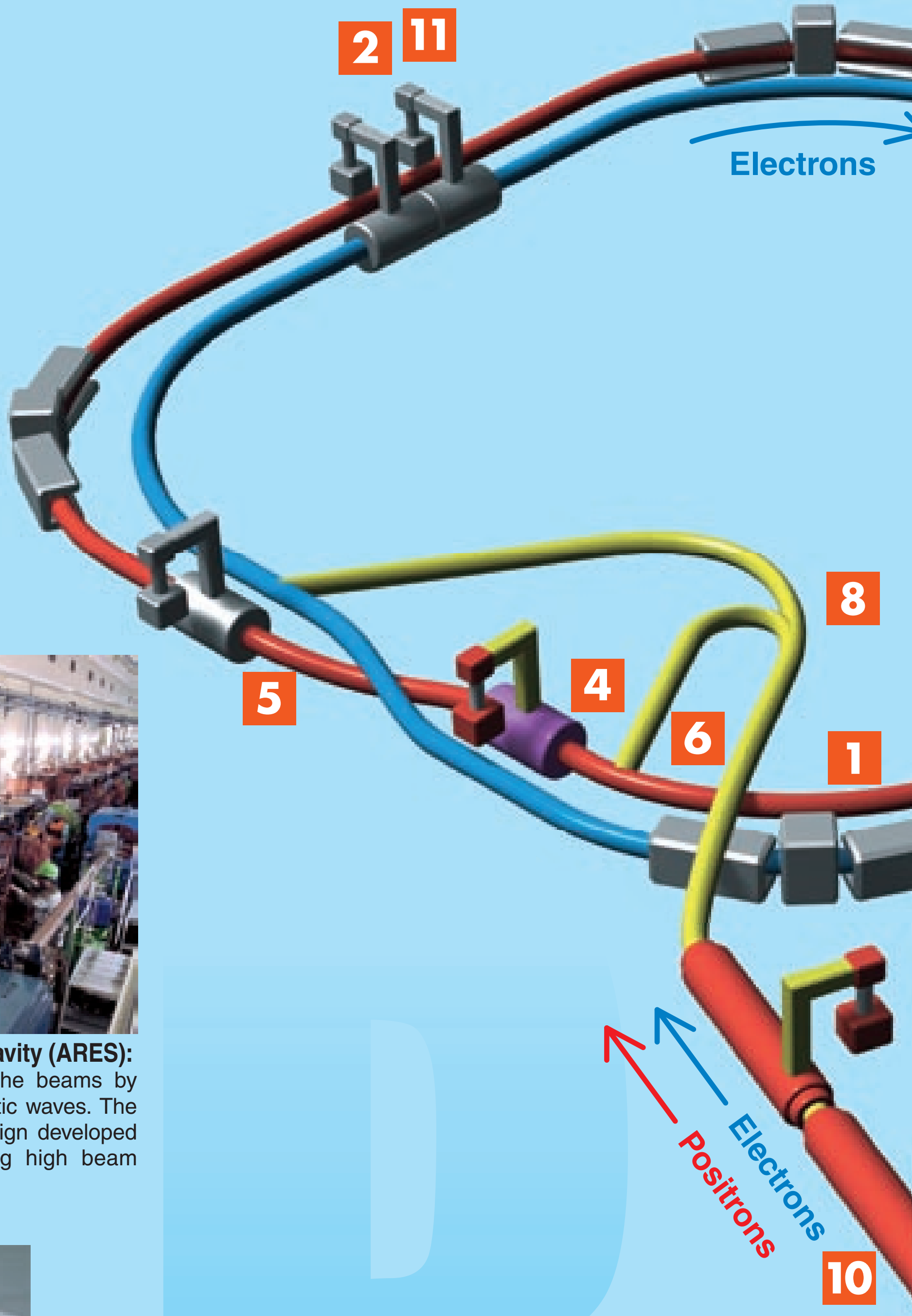


Superconducting cavity:
The superconducting cavity installed in the electron ring. The cavity is made of superconducting materials, which create a high acceleration voltage. KEK's superconducting technology is among the most advanced in the world.



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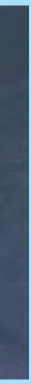
Normal-conducting radio-frequency cavity (ARES):
The ARES cavities provide energy to the beams by accelerating them with the electromagnetic waves. The three-cavity combination is a unique design developed specifically for the purpose of handling high beam currents.



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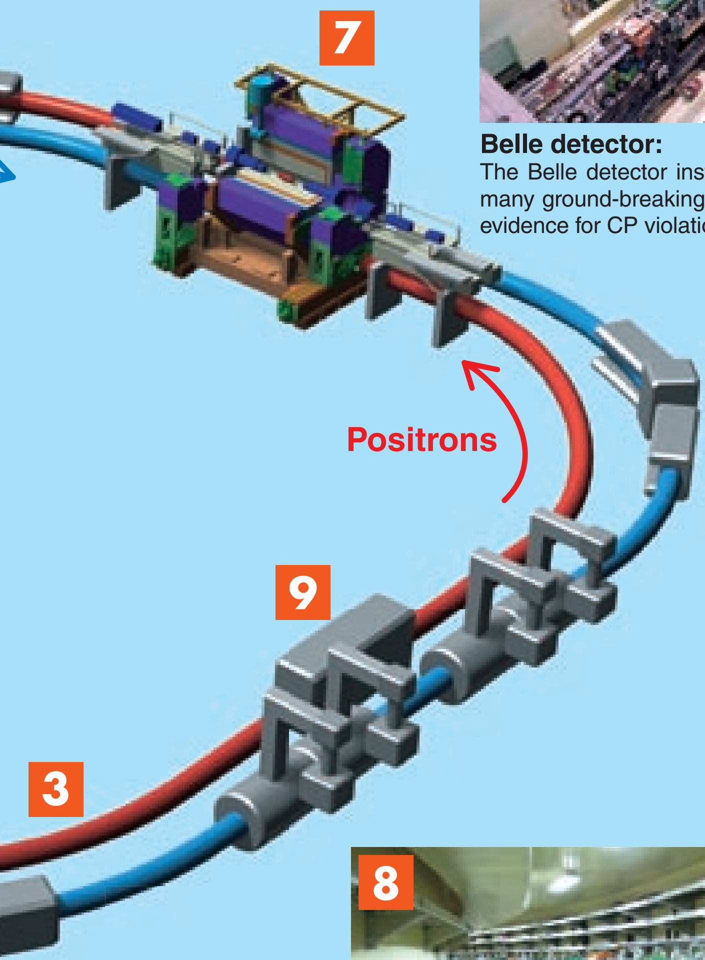
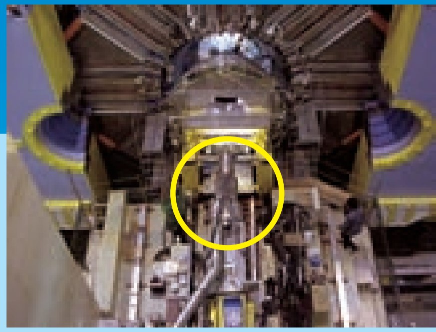
Horizontal kicker:
The horizontal kicker suppresses unwanted beam oscillation in the horizontal direction while running the accelerator. The horizontal kicks are provided by radio-frequency electromagnetic waves which are transmitted via thick cables.

Injection point:
This is the entry point of the beams delivered from the injector into the storage ring. An electromagnet installed at this point pulses the magnetic field inside at high frequency in order to efficiently feed new beams into the circulating beams in the storage ring.



Belle detector:
The Belle detector installed at KEKB has made many ground-breaking discoveries, including the evidence for CP violation.

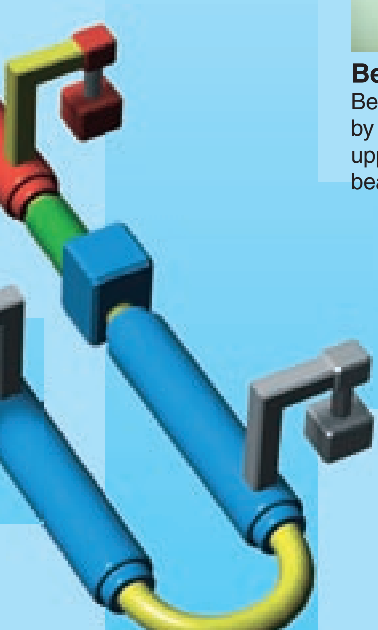


Superconducting quadrupole magnets at the interaction point:
These focusing magnets compress the beams to achieve a higher rate of electron-positron collisions.

Control room:
Accelerator scientists control KEKB's many pieces of equipment from the central control room. Many monitors are lined up to display the current status of the accelerator. The central control room also controls equipment at sub-control rooms located around the ring.

Beam transport line:
Beams are delivered from the injector to the storage ring by the beam transport line. The delivery line consists of upper and lower lines for delivering positron and electron beams, respectively.

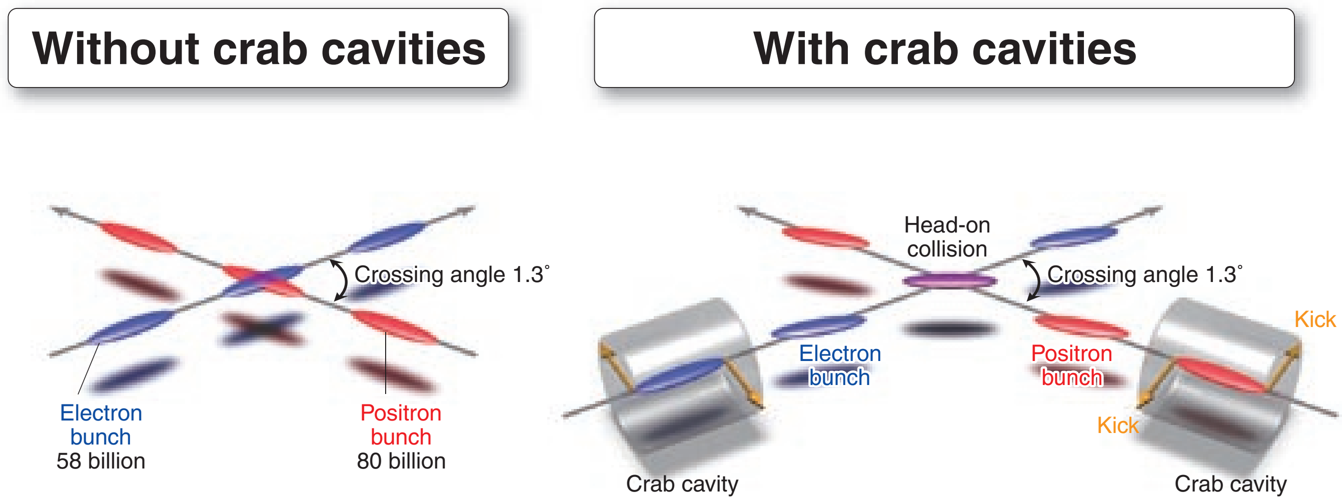
Wiggler magnet:
This special magnet suppresses beam oscillations by taking advantage of, and strengthening the effect of, the beam's own damping mechanism called "radiative damping."



Injector:
The powerful linear accelerator provides KEKB's double rings with 8 billion electron-Volt electron beams and 3.5 billion electron-Volt positron beams. The injector is a multi-purpose accelerator, also feeding beams to other electron accelerators located at KEK.

Solenoid magnets for positron ring:
Solenoid magnets are installed over the entire positron ring to suppress the harmful build-up of electron clouds. KEKB showed a dramatic increase in luminosity after their installation.

Bunches of electrons and positrons colliding



Each bunch makes a bunch crossing 100 thousand times every second. Around 1,400 bunches circulate in each ring.

The above shows schematic views of electron-positron collisions. Electrons and positrons travel forming bunches inside the accelerator rings. Each ring circulates around 1,400 bunches, making a bunch crossing every 6 or 8 nanoseconds at the center of the Belle detector (A nanosecond is a billionth of a second). At KEKB, each bunch is only 110 micrometers in width, 2 micrometers in height, and 7 millimeters in length, the smallest size realized by a ring collider. Any slight deviation of the beam trajectory can result in severe luminosity loss. Many state-of-the-art hardware and software components are employed at KEKB to make sure that the bunch crossing always occur at the centers of the bunches.

11 Crab cavity:

Aiming for still higher luminosity, KEKB developed the world's first crab cavities, which were installed in both the electron and positron rings in February 2007. Without crab cavities, the electron and positiron bunches do not collide head-on at the interaction point, but instead cross at an angle, because the electron and positron beam trajectories themselves cross at an angle. However, recent simulations showed that head-on collisions would bring about higher luminosity.

Crab cavities produce radio-frequency electromagnetic fields, which kick the head and tail of each bunch in opposite directions so that, in effect, the bunches make head-on collisions.