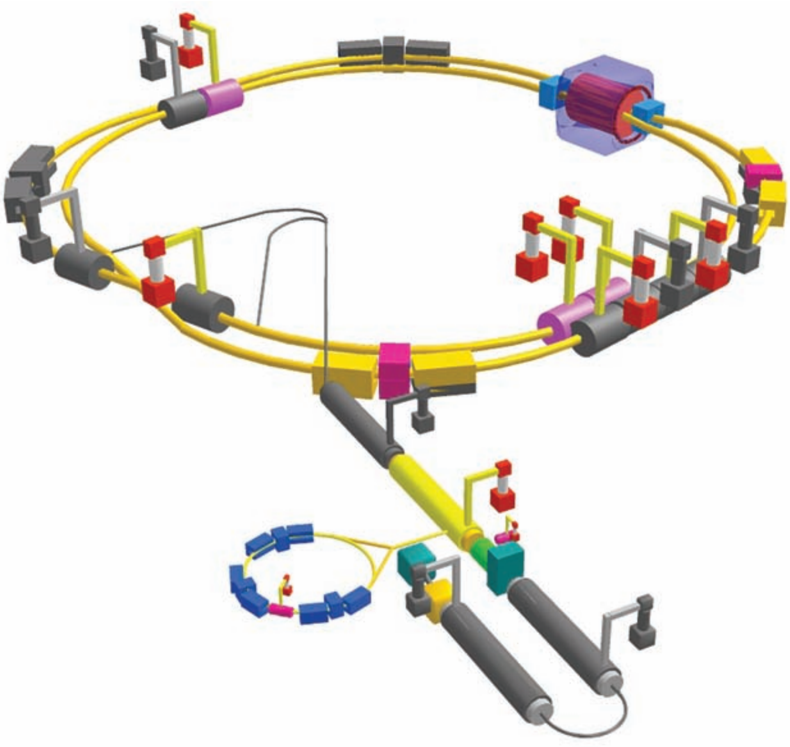
SuperKEKB goes in hunt of flavour at the terascale

KEK is upgrading its B factory to provide a 40-fold increase in luminosity by using a large crossing-angle and squeezing the beams down to nanometres. The Belle experiment will also see a second incarnation.



A schematic view of SuperKEKB. (Image credit: KEK.)

What is dark matter? Why is there more matter than antimatter in the universe? These are some of the most fundamental puzzles in modern particle physics. The clues to the answers might reside in the physics of the symmetry breaking of electroweak forces at tera-electron-volt scale. Projects at the energy frontier, such as CERN's LHC, are complementary to the approach of flavour physics, where measurements of rare processes at lower energies can be sensitive to new types of interaction. SuperKEKB will provide a promising path to such new physics by enabling detailed studies of the decay processes of heavy quarks and leptons.

From 1998 to 2010, KEK, the Japanese High-Energy Accelerator Research Organization, operated its B factory, KEKB – an asymmetric electron–positron collider, 3 km in circumference – and achieved the world's highest luminosity of $2.11 \times 10^{34}\,cm^{-2}\,s^{-1}$, more than double the design value. There, the Belle experiment precisely analysed the characteristics of pairs of B and $\overline{B}$ mesons produced in the collisions and confirmed the effect of CP-violation as indicated by the theory of Makoto Kobayashi and Toshihide Maskawa, who both received the Nobel prize in physics in 2008.

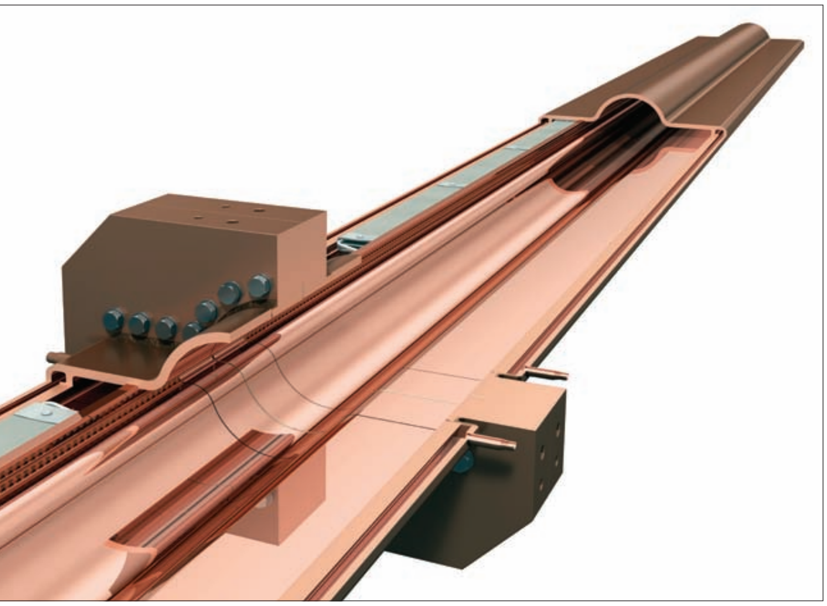
KEK has played a central role in flavour physics not only with the record-breaking KEKB but also with the world's first long-baseline neutrino oscillation experiment, KEK-to-Kamioka (K2K). Now, because large facilities are increasingly required for experiments in particle physics, a new style of international competition and co-operation has become necessary between institutes around the world. Together with the Japan Proton Accelerator Complex, which is a high-intensity proton facility built jointly with the Japan Atomic Energy Agency, KEK is continuing to play a leading role as one of the international focal points in flavour physics. As an international collaboration, SuperKEKB is open to the world and currently more than 400 physicists from 60 institutions from 17 countries and regions are working together to upgrade the Belle experiment to Belle II.

SuperKEKB will provide a promising path to new physics via detailed studies of the decay processes of heavy quarks and leptons.

Forty times more collisions

SuperKEKB is essentially an upgrade project to increase the luminosity to $8 \times 10^{35}\,cm^{-2}\,s^{-1}$, or 40 times greater than at KEKB. Engineering a higher luminosity in a collider involves both increasing the beam current and reducing the beam size at the interaction point. The original approach for the upgrade was to increase the beam current and the beam–beam parameter – the "high current option".

In March 2009 the SuperKEKB design changed course based on ideas from SuperB, using a large crossing-angle at the interaction point and beams squeezed to nanometre-scale to increase ▷



The antechamber reduces the effect of electron cloud in the positron beam pipe. (Image credit: Rey Hori.)

Ground-breaking ceremony

Ground-breaking ceremony participants joined together in opening one eye of the Daruma doll, a Japanese tradition for starting a new project. (Image credit: Sonja Blaschke.)

More than 200 physicists, government officials and national representatives from around the world gathered at KEK on 18 November to celebrate the official ground-breaking ceremony of SuperKEKB, held in the Kobayashi Hall.

KEK's director-general, Atsuto Suzuki, addressed the assembled guests, describing the project as an important milestone towards the understanding of new physics at the high-intensity frontier, in a complementary role to the LHC at the high-energy frontier.

His speech was followed by words from: Peter Krizan, professor at the University of Ljubljana and Jozef Stefan Institute and Belle II spokesperson; Hiroaki Aihara, professor at the University of Tokyo and chair of the Belle II executive board; Takao Kuramochi, director-general of the Research Promotion Bureau, MEXT; Michael Procario, director of the Facilities Divisions, Office of High Energy Physics, of the US Department of Energy; and Takashi Tachibana, a prominent Japanese journalist. Video messages followed from Rolf Heuer, director-general of CERN, and Piermaria Oddone and Young-Kee Kim, director and deputy-director of Fermilab, respectively.

The ceremony concluded with remarks by Katsunobu Oide, director of the Accelerator Laboratory, KEK, and a Daruma doll ceremony. This is a traditional Japanese ritual in which one eye is drawn on the doll, to wish for the ultimate achievement of a big project, when the second eye will be completed.

luminosity – the "nano-beam option". The scheme has the advantage of reaching 8×10^{35} cm^{-2} s^{-1} with only the double the current, but that is not to say that there are no other challenges.

The high current (3.6 A in the 4 GeV positron ring, 2.6 A for the 7 GeV electron ring) will lead to "electron cloud" effects in the positron ring when synchrotron radiation hits the walls of the beam pipe. To counteract such phenomena, SuperKEKB will use a special vacuum chamber for the positron ring with two small "antechambers", one on the outside of the main beam pipe and one on the inner side. One suppresses the formation of electron clouds and the other contains vacuum pumps. In addition, the chambers between magnets will be wrapped with solenoid coils to reduce the effect of secondary electrons. Test antechambers developed at KEK from a prototype produced in collaboration with a team at the Budker Institute of Nuclear Physics have already been tried out in sections of the KEKB ring.

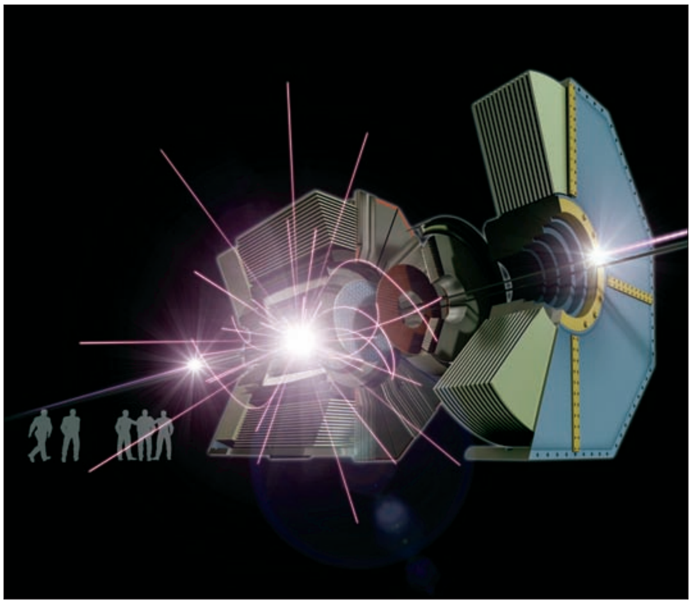
Further changes

The new design will be based on a larger crossing-angle (4.8°), requiring a redesign of the final-focus with eight higher-gradient quadrupole magnets placed nearer the interaction region to squeeze the beam to nanometre scale. These are unusually small superconducting quadrupole magnets, whose inner diameters are only 4–8 cm, or one-sixth the diameter of the KEKB quadrupoles. These magnets require current controls to protect them from quenches because the current density in the superconductor can go beyond 2000 A/mm^2 and on quenching the temperature will rise to more than 1000 K within around 50 ms. In addition, the accelerator design demands much smaller fabrication errors to ensure a quadrupole field quality of a few 10^{-4}.

Therefore, while SuperKEKB will be based on KEKB, various parts of the accelerator will be replacements. Others will be new. A new positron source and a flux concentrator will help in generating a high-current positron beam and a new damping ring (135 m in circumference) will be added to reduce the emittance of the positron beam. Moreover, as well as changing the beam pipe in the main positron ring for one with "antechambers" as described above, the dipole magnets in this ring will be replaced. A new RF system will also help in accelerating high-current beam.

Because the SuperKEKB accelerator will produce electron–positron collisions at a much higher rate, the detector will also need to be upgraded. The aim is to accumulate an integrated luminosity

B factories



Artistic impression of Belle II. (Image credit: Rey Hori.)

of 50 ab^{-1} by 2021, which is 50 times more data than the previous Belle detector acquired. Thus the Belle II detector will also be an upgrade. The data-acquisition system will be redesigned with a network of optical fibres. Trigger electronics will be replaced with a new system. A pixel detector will be added for better resolution of particle tracking and a silicon vertex detector will cover a larger solid angle. A central tracking chamber, a time-of-propagation chamber and an aerogel ring-imaging Cherenkov detector are also being newly built.

The first beam of SuperKEKB is expected in 2014 and the physics run will start in 2015. Ultimately, Belle II should collect 40 times more B-meson samples per second than its predecessor – roughly 800 $B\bar{B}$ pairs per second. This will allow the Belle II collaboration to examine the effects of unknown particles in a higher energy region in the search for clues to new physics. Belle II at SuperKEKB will form one of the international focal points for particle physics in the coming decade.

Résumé

Le SuperKEKB part en chasse à l'échelle du téra

Le KEK procède actuellement à une amélioration de son usine à B, afin d'arriver à une luminosité 40 fois plus élevée. La nouvelle configuration prévoit un grand angle de croisement et des faisceaux comprimés à l'échelle du nanomètre (option « nano-faisceau »). La machine atteindra une luminosité de 8.10^{35} cm^{-2} s^{-1}, pour une intensité double seulement. L'angle de croisement plus grand (4,8°) a nécessité une nouvelle conception de la focalisation finale, avec huit aimants quadripoles supraconducteurs à gradient plus élevé. L'intensité plus élevée nécessite une chambre à vide spéciale pour l'anneau à positons, ainsi qu'une nouvelle source positons et un nouveau système RF. L'expérience Belle connaîtra également une deuxième incarnation.

Youhei Morita, KEK.