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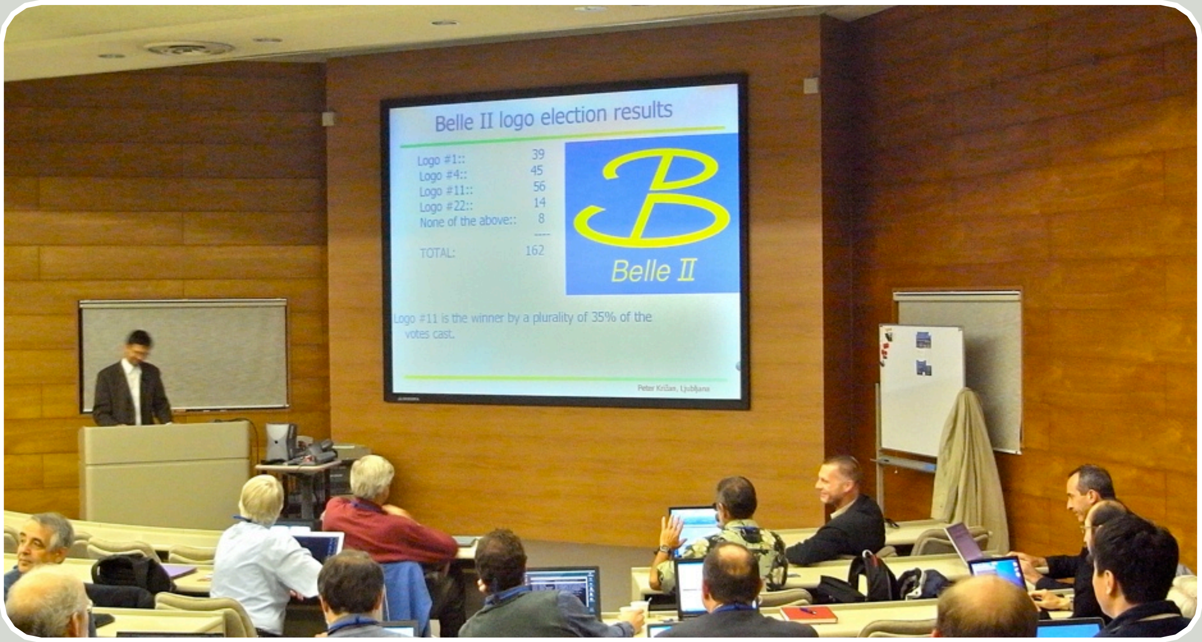
FEATURE STORY



The first spokesperson of the Belle II collaboration, Prof. Peter Krizan of the University of Ljubljana, presents the Belle II logo election result. Look for two ‘e’s in the ‘B’.

Belle II’s new logo and new beginning

[SuperKEKB-Belle II Experiment, Nano Beam Design]

The 4th open meeting of the Belle II collaboration was held on November 18-20, 2009. The meeting saw intense discussions, sometimes going late into the night, by the Belle II collaborators. The final design is due this month and the experiment is in good shape.

Beams of electrons (e^-) and positrons (e^+) collide head-on and produce B mesons. That’s the gist of the KEK B Factory experiment. When you know this, you’d notice how clever the design of the Belle collaboration logo is: two ‘e’s colliding head-on and producing the letter ‘B’.

There were 37 proposed logos for the new SuperKEKB-Belle II experiment, the proposed upgrade of the KEK B Factory experiment. When the first spokesperson of the Belle II collaboration Prof. Peter Krizan of the University of Ljubljana introduced the new logo in his opening remarks at the 4th open meeting of the Belle II collaboration, the logo was greeted with applause. The many elaborate designs which were proposed reflect the team’s enthusiasm, but the final choice could not be simpler: a mere addition of ‘II’ at the end of ‘Belle’ in the Belle experiment original logo.

“I guess people couldn’t let go of the design of the original Belle logo,” says Belle’s co-spokesperson Prof. Yoshihide Sakai of KEK.

The winning logo was submitted by Marc Rosen of the University of Hawaii.

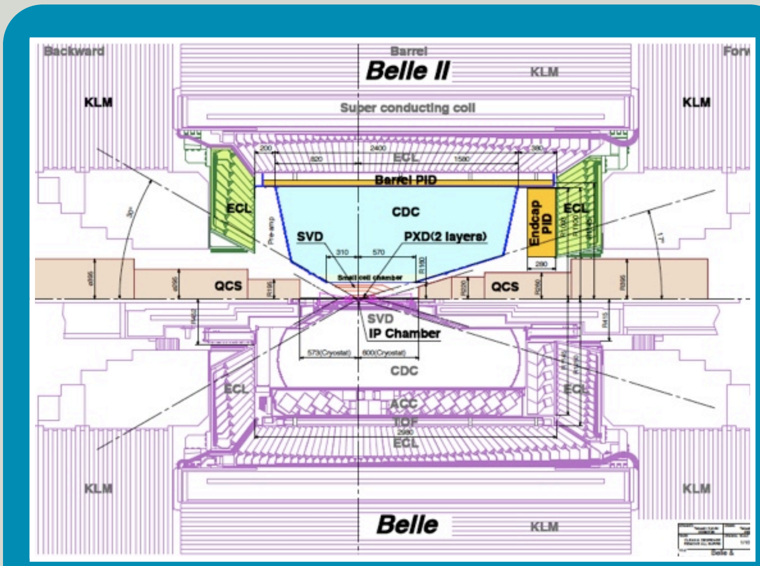
106 participants from 38 institutions in 16 countries attended the 4th open meeting of the Belle II collaboration held on November 18-20, 2009, on KEK campus. The Belle II is a collaboration of around 300 physicists from 13 countries/regions. The technical coordinator for the Belle II collaboration, Dr. Yutaka Ushiroda, says that this was the last meeting before the final detector design due this month. “Each sub-detector group was expected to come to an agreement on the basic direction to take concerning their design.”

SuperKEKB’s new nano beam design

The goal of the SuperKEKB, the proposed upgrade of the current KEKB accelerator, is to bring the luminosity—the measure of how efficiently an accelerator produces particle collision events—up to 8 x 10^{35} cm^{-2} s^{-1}. This is 40 times greater than the KEKB’s current luminosity. This increased luminosity will make it possible to explore physics beyond the Standard Model. It will provide the means to evaluate different models of new physics in detail, which the Large Hadron Collider (LHC) at CERN is not designed to do.

Achieving the luminosity goal is far from a straightforward process. Accelerator scientists have been working hard for over years trying to optimize the accelerator design to reach the target luminosity. In October, the new SuperKEKB design was officially approved, changing the accelerator design a hundred and eighty degrees.

“This was the first meeting since the official accelerator design change from the high current scheme to the nano beam scheme. We needed to develop a shared understanding of design changes on detector side,” says Sakai. “On top of that, especially for those components that still have several technology choices, it was important to bring all open issues to the table to discuss them face-to-face.”



The future (top) and current (bottom) Belle detector configuration. Barrel PID will reduce its material size dramatically.

Higher luminosity means more signals and stronger radiation. The key for the Belle II upgraded detector is the fast tracking and radiation hardening. The detector itself will not undergo drastic changes in its overall design, but many of the smaller components will.

Belle II detector design

The most important new component of the Belle II is the innermost detector. The center of this detector contains pixelated detectors (PXD), which are located inside the four layers of the silicon vertex detector (SVD). These components are carefully arranged to improve the detector's vertex—the collision point—resolution. Outside the SVD are the central drift chamber (CDC) for charged particle tracking, the particle identification device (PID) for particle identification, and an electromagnetic calorimeter (ECL) to measure the energy of particles. The outermost detector is the K_L meson and muon detector (KLM). Both the PID and ECL are designed as barrel shapes. PID also has an endcap to catch particles going in forward direction with respect to the beams' directions, while ECL has two endocaps in forward and backward directions.

When electrons and positrons collide head-on, the collisions produce B mesons. These B mesons quickly decay into D and then K mesons or various other particles, such as tau leptons and pions, in which physicists look for signs of physics beyond the Standard Model. The particles traverse each of the detector components, which gather the information necessary for physicists to calculate the charge, energy, momentum, and path of the particles.

For the detectors to work properly, triggers (TRG) need to be in place to distinguish particle signals from various background noises. Another necessary component is the data acquisition system (DAQ) that integrates different sub-detectors. The meeting offered parallel sessions on each of these detector components that continued even after dinner.

Among the many open issues to be discussed at the meeting, there were three outstanding issues that will greatly influence the final design of the Belle II detector: the barrel PID, the endcaps of the ECL, and the structure of the detector itself (the accelerator design might require a slight rotation of the entire detector). At the meeting, the review committee for the endcap ECL design was officially established.

One-bar and two-bar options for barrel PID

The barrel PID is a cylindrical structure around the beam pipes. It is designed to identify the type of a charged particle by determining the particle mass from measured momentum and velocity. Particle identification, especially of K mesons and pions, is crucial for future B factory experiments.

Of all the detector components, the barrel PID component will undergo most changes from the original design. In the current Belle detector, the barrel PID consists of two parts. First, there is an array of 960 counters called threshold čerenkov counters which detect čerenkov light emitted by charged particles passing through. Second, there are arrays of plastic scintillation counters that measure the time-of-flight of particles from the interaction point to the PID. Combining the information from the PID with the ionization energy loss measured in the CDC, physicists can identify charged particles passing through the PID.

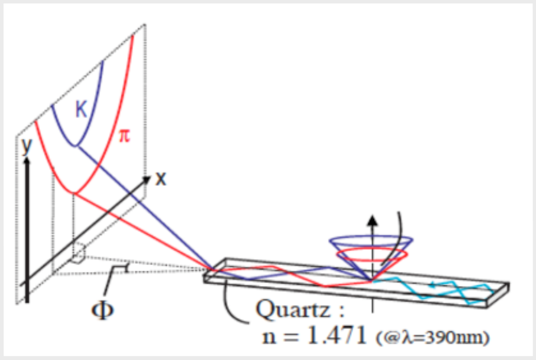
There are three problems with this design for Belle II. First, the scintillation counters will become useless in noisy background at Belle II. Second, the threshold čerenkov counters are not expected to provide good enough resolution for K meson and pion separation. This is a problem, as distinguishing the two particles is important for exploring new physics. Third, the large mass of materials used in the current design negatively affects the performance of the ECL, which is just outside the PID. Particles can get easily disturbed by materials in the PID, and this disturbance results in inefficient ECL measurements.

Belle's co-spokesperson Prof. Yoshihide Sakai of KEK says a feasible and viable final design of Belle II design is now very close.

The chosen solution to all three problems is called a time of propagation (TOP) counter. This uses a technology called ring imaging čerenkov, in which propagation time of čerenkov photons and position information of particles can be inferred from the čerenkov light produced by those particles. The čerenkov light is a light emitted by charged particles traversing through an insulator faster than the speed of light in the medium. Because of the speed, a charged particle can create a cone of čerenkov light, like the sonic shock front of supersonic aircraft. The čerenkov light then undergoes total internal reflection inside the quartz bar to reach the photo detectors at the ends. The TOP counter provides a clear

The Belle II collaborators gather around in front of the meeting venue for a group photo.

Dr. Toru Iijima of Nagoya University works on the barrel PID.



The ring imaging čerenkov counter can separate K meson signals and pion signals more efficiently, and in a smaller space, than other technologies.

separation of K meson and pion signals. Additionally, at just a few centimeters in thickness, the TOP counter would reduce the disturbance effect of PID material on ECL measurements.

Proposed and developed by Nagoya University, the TOP counter is an alternative to the DIRC technology utilized at the BaBar experiment at SLAC and the proposed SuperB Factory experiment (SuperB in Italy). While a TOP counter measures time and one dimensional position, a DIRC counter measures two dimensional positions but with no time information.

“We decided on the TOP counters because DIRC requires a big space that Belle II cannot afford,” says Belle’s co-spokesperson Dr. Toru Iijima of Nagoya University. With 20 photons detected for each particle path, the performance of TOP is equivalent to a time-of-flight with a time resolution of just 4 picoseconds. Even for light, that’s only a 1.2 millimeters of traveling.

For design of the TOP counters, the PID experts have proposed various configurations. The two remaining candidates for the final design are the ‘one-bar’ and ‘two-bar’ options.

The ‘one-bar’ option, proposed by the University of Hawaii and University of Cincinnati, has a quartz wedge attached at one end of the quartz bar to expand the width of the čerenkov signals so that two arrays of photon detectors can fit on the end of the bar. This increases the time resolution, but takes up an extra 2.5 centimeters in the vertical direction because of the wedge size.

Nagoya University has been pursuing more compact and simpler configurations. The ‘two-bar’ option proposed by Nagoya University splits the single quartz bar into two pieces: one 1.5 meters and the other 0.5 meters. Each end has photon detectors 2.5 centimeters in thickness. The idea is to split the signals at the section where resolution become worse, and detect them with only one end. (The asymmetry of the dimension is introduced because of the energy difference of the electron and positron beams.)

“Both configurations have similar capabilities with different pros and cons, which is why it has been difficult to make a choice,” says Iijima. The one-bar option introduces space between the barrel PID and ECL sitting just outside, possibly decreasing the efficiency of gamma ray measurement in the ECL. When electron-positron pair creation from gamma ray occurs inside the barrel PID, the electron and positron may be identified as different event by the ECL sitting a few centimeters farther apart. On the other hand, the ‘one-bar’ option provides robustness to an inherent small (few tens-of-picoseconds) jitter in measurement of the time of collision. The robustness is thought to come from the wedge of the ‘one-bar’ design, adding vertical resolution.

“There are still some simulation studies required before we decide on the final configuration,” says Iijima. The team will meet again on December 12, 2009 to come to consensus and define the future responsibility of each group (Nagoya University, University of Hawaii, University of Cincinnati, Jozef Stefan Institute, KEK, Tokyo Metropolitan University, Chiba University, and Toho University).

The ECL endcaps

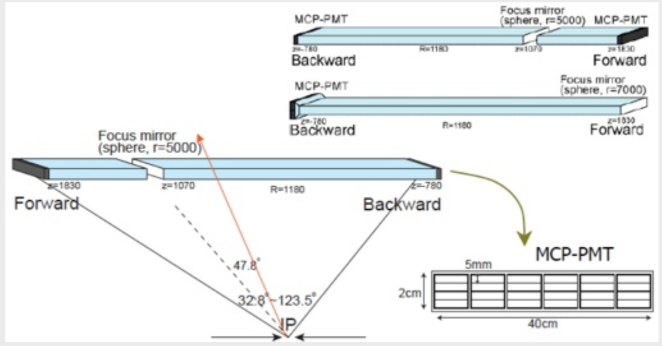
Located immediately outside of the PID, the ECL measures the electromagnetic energy of particles through the amount of light deposited in the crystals. It has barrel and endcap components.

“The barrel ECL will be left as it is for economic reasons,” explains Prof. Gary Varner of the University of Hawaii, the chair of endcap ECL review committee, an internal advisory committee to make the final recommendation for endcap ECL upgrade. Since electrons and positrons collide head-on, the detector sees higher radiation rate in forward and backward directions than the sides. “The concern is that the rate would be high enough to start to degrade the physics the endcap ECL detector can do.”

To cope with the higher radiation rate and higher occupancy, the electronics will be entirely replaced. An open question is whether the photon detectors and crystal scintillator components should be replaced as well. Higher radiation also damages the photo detectors and increases their leakage current. “Increased leakage current may make the noise, and therefore the recorded background energy level fluctuations, too large and the photo detectors may need to be replaced. If the physics warrants it, the crystals may need to be replaced, which is difficult and expensive process,” says Varner.

There are currently two types of photo detectors and three types of crystals being considered, each having different advantages and disadvantages. The two proposed types of photo detectors, the photo pentode (PP) and the avalanche photo diode (APD), are both photo-electron multiplier devices. These have lower gains (10^2) than those used for the barrel PID (10^6), but provide sufficient gain for replacement the present Thallium-doped cesium iodide (CsI(Tl)) crystal which produces a number of photons per deposited energy.

For the crystal, the collaborators are studying pure cesium iodide (Pure CsI), lead tungstate (PWO), and bismuth silicon oxide (BSO). These have been proposed by the Budker Institute of Nuclear Physics (BINP), Korea, and Nara



The proposed one-bar and two-bar configurations for the barrel PID design.

Prof. Gary Varner of the University of Hawaii (center) is the chair of the endcap ECL selection committee.

Heated discussions went on during the banquet on the second day. Krizan (center) believes it is much better to discuss open issues face-to-face than via video-conference.

Womans University, respectively. Varner says that pure CsI and PWO are well studied, though Pure CsI is less dense and not as capable of separating tight showers, while PWO needs to be cooled (to as much as minus 25 degrees Celsius) for high light yield. BSO is a dense crystal, needs no cooling, and has good performance and radiation hardness, but is not yet well studied, and is supported by only very limited data.

“Good ECL performance is essential for good physics. We need to know how much benefit we can get by replacing the photon detectors and crystals, and that’s being studied right now,” says Varner. A recommendation will be made before the end of this year.

Rotate the Belle detector?

The accelerator design team has recently requested the Belle II collaborator to consider if the Belle detector can be rotated. To achieve the target performance, SuperKEKB scientists have been running many simulations. They recently found out that it might be necessary to make the crossing angle of electrons and positrons much wider at the interaction point.

“The accelerator components need to come well deep inside the Belle detector, which makes the crossing angle larger,” explains Prof. Junji Haba of KEK, the leader of the Belle II structure group. “The cryostats that keep the superconducting components cool near the interaction region also become more voluminous to cover the wide angle, which will affect the detector geometry.”

The beam quality at the interaction region also depends on the angles of the two beams relative to the axis of the Belle II spectrometer solenoid magnets. The current solenoid axis coincides with the axis of the positron ring. When the beams are not in line with the axis of the magnet, electrons and positrons experience transverse forces from the magnet, affecting the beam quality. These effects are now under intense study.

The Belle II collaborators also need to study the effect of changing the angle of the beams on the detector performance, taking into account such parameters as the acceptance of detector components and background noises.

The most serious issue, however, is not one of physics, but one of mechanics. No one can tell exactly what will happen if when actually rotating the 1,400-ton Belle detector. “Close to 9,000 of the crystal bars of the ECL calorimeter are supported by very thin aluminum, because we want as little material as possible in the region, and the structure is extremely fragile,” says Haba. “The slightest shock could cause disastrous results.” They are currently examining safe ways to rotate the detector, closely collaborating with several companies to either replace the 16 assemblies of rollers beneath the detector or to implement new system.

“If rotation is what it takes to achieve the target performance of the SuperKEKB accelerator, then we will do it,” says Haba. The final decision again will be made before the end of this year. Meanwhile, the teams are working on various simulations and analyses from both detector and accelerator sides.

The viable final design is within reach

On top of these three outstanding issues, there were detailed studies for each sub-detector and subsystem. The meeting provided parallel sessions for each of them, some going well into the night. Attended by scientists of diverse interests, the plenary sessions included talks by accelerator scientists and physicists from the SuperB in Italy and theorists.

“The meeting was a big step forward,” says Krizan. “The most exciting feature of this meeting was the enormous progress that was made by the collaborators of Belle II since our previous meeting in July.”

The meeting also saw new members to the collaborations. Dr. Shuji Tanaka of KEK, a new member of the pixelated detector group, says “This is the most exciting time for Belle II, as we are discussing different technology options and designing the detector.” He has worked at LEP and ATLAS at CERN and will bring new insights into the collaboration.

A new institution, Bonn University, joined the collaboration, bringing 9 experts and students to work on the pixelated detectors. The collaboration also saw the addition of three graduate students, one each from the US, Germany, and Austria. “It was nice to see so many international collaborators and young researchers at the meeting,” says Sakai. “There was a great sense that a feasible and viable final design is now very close.”

“We now have a very good idea of what the final design will look like, although there still remain some choices we have to make in certain sub-detectors,” says Ushiroda. “I am pleased to see the collaboration is now beginning to move towards the technical design report due in March of next year.”

Prof. Junji Haba of KEK, the leader of the Belle II structure group, presents Belle II structure summary.

The technical coordinator for the Belle II collaboration Dr. Yutaka Ushiroda of KEK (right) discusses the Belle II detector design with new member Dr. Shuji Tanaka of KEK.

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