Belle II Experiment

Takeo Higuchi
Kavli IPMU Associate Professor

It is known that there are four fundamental interactions between particles: electromagnetic, weak, strong, and gravitational interactions. All particle interactions but gravity can be precisely formulated by the Standard Model of particle physics (SM). The SM is a powerful theory that can explain most known particle behaviors. Only a few exceptional behaviors are seen experimentally.

However, it is also known that the SM is not the ultimate theory of Nature. For example, while the existence of dark matter is widely accepted, its properties do not match any SM particles. For these reasons, new physics Beyond the SM (BSM) is believed to exist as an extension of the SM.

Belle II Experiment

Kavli IPMU has been a member of the Belle II experiment, a high-energy physics experiment searching for BSM physics. In the experiment, we produce B-meson pairs and tau-lepton pairs from collisions of electrons and positrons accelerated by the SuperKEKB accelerator. Since B mesons and tau leptons are unstable particles, they decay into other particles immediately after production. If there is BSM physics and it contributes to a certain decay process, there should be a discrepancy between the experimental observation of that process and the corresponding theoretical prediction by the SM. We will investigate BSM physics in the Belle II experiment by precisely measuring B-meson and tau-lepton decay processes to search for such discrepancies.*

*See page 24.

Furthermore, if we are successful in finding evidence for BSM physics, we will try to build a theoretical model for it.

Because the discrepancies we are looking for are very small, we need to produce an enormous number of B mesons and tau leptons to unambiguously find evidence for BSM physics. The event production rate by the predecessor of the SuperKEKB accelerator (the KEKB accelerator, which provided data for the Belle experiment and contributed to proving the Kobayashi-Maskawa theory) was the highest in the world at that time. The SuperKEKB accelerator is designed to be capable of 40 times the event production rate of the KEKB accelerator.

The Belle II detector, the particle detector of the Belle II experiment, is located at the interaction point of electrons and positrons, and has a cylindrical structure with respect to the beam axis. There are four parameters that characterize particle decay: decay position (vertex) of the particle, energy and momentum of daughter particles from the decay, and the species of the daughter particles. The Belle II detector is designed to be capable of measuring these parameters. While the detector design of Belle II is based on the Belle detector, it has many upgrades. For example, due to the increase of the accelerator luminosity, signals in the detector from adjacent events can overlap. In order to solve this problem, we have increased the speed of detector response to particles by employing new sensors and that of signal collection by employing new readout electronics. We also renewed the entire data acquisition system from signal digitization to data storage in order to cope with the higher event rate and larger data size. Furthermore, we introduced a virtual organization of multiple computer resources across the Belle II collaborating universities and institutes in order to mitigate resource shortages that can potentially happen in data analysis. With these upgrades in the Belle II detector and peripheral systems, we aim to obtain 50 times more data than the Belle experiment had accumulated.

Belle II SVD

Information of decay vertices of the B meson and other particles is an essential input to quantitatively discuss the existence of BSM physics. The Belle II vertex detector (VXD) is located at the innermost position of the Belle II detector structure, and has a six-layer cylindrical shape (Fig. 1). The two innermost layers are pixel detectors (PXD), and the other four layers are silicon vertex detectors (SVD). Kavli IPMU is contributing to the R&D of the SVD and production of the SVD fourth layer.

The dimensions of an SVD sensor (Fig. 2, left) are about 125 mm×60 mm. Each sensor has electrodes (strips) with a pitch of 50μm at the minimum (Fig. 2, right). Each strip is connected to a readout application specific integrated circuit (ASIC). When a charged particle passes through a sensor, an electrical signal is induced on the strips around the passing position. We detect a particle position by measuring signals on the strips. Because the topside strips and backside strips are running orthogonally to each other, a two-dimensional measurement of the particle position can be obtained.

Each SVD layer consists of ladders. A ladder is an array of sensors in a ladder shape. It is comprised of the following components: sensors, sensor supports, readout ASICs of strip signals (APV25), flex circuits connecting strips and ASICs, etc. These components are fabricated using glue (Fig. 3). A fourth-layer ladder, for which Kavli IPMU is responsible for the

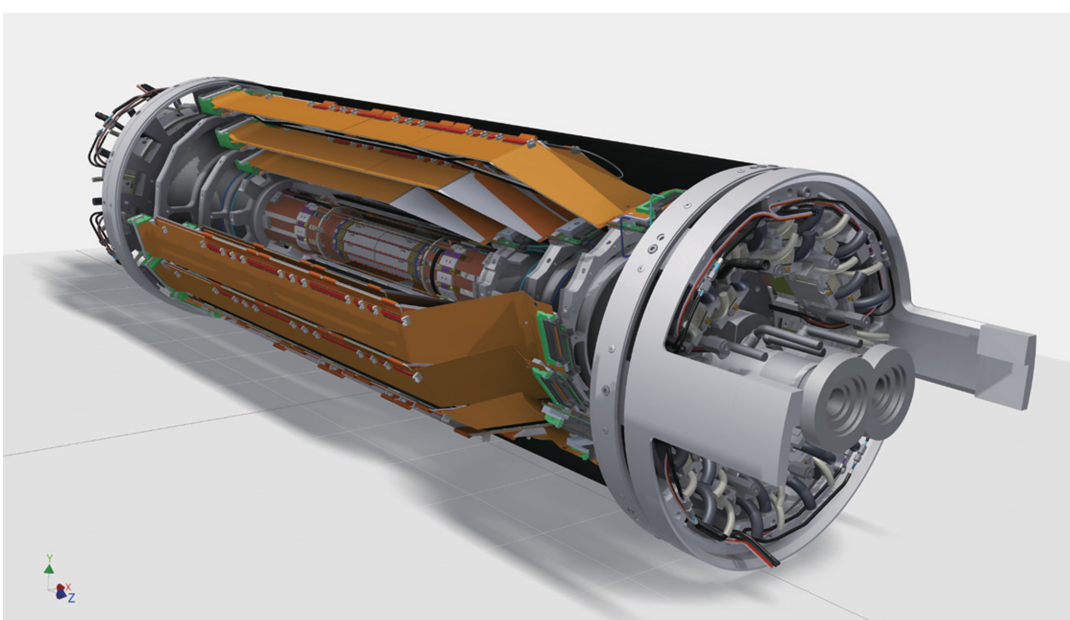
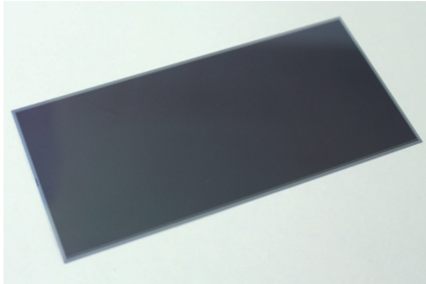


Figure 1. The Belle II vertex detector (VXD). The VXD has a six-layer cylindrical shape surrounding the electron-positron collision point. Its full length is 935 mm and diameter is 310 mm.



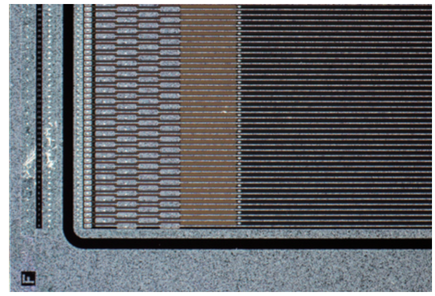


Figure 2. Picture of an SVD sensor is shown on the left. Strips are seen in the magnified picture on the right.

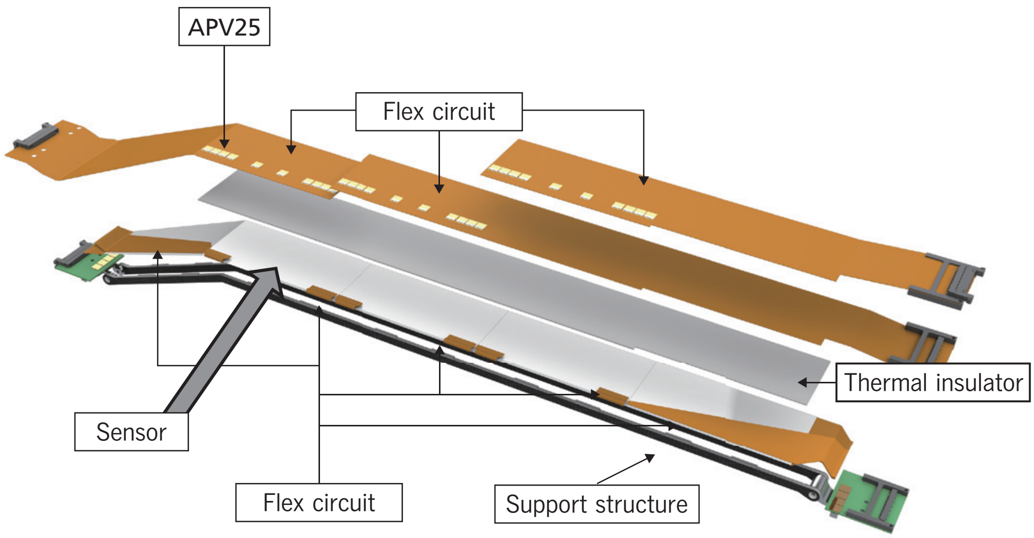


Figure 3. Exploded view of an SVD ladder of the fourth layer. The black parts at the bottom are ladder supports. Five sensors are arrayed on the supports. The brown parts on the sensors are readout flex circuits.

production, has five sensors, and it is 749 mm in full length. Each sensor in a ladder must be aligned at a precision of less than 200μm to avoid conflicts of sensors within a ladder and across ladders. A strip and flex circuit, and a flex circuit and APV25, are connected by aluminum wires with a 25μm diameter, and the total number of wires in a fourth-layer ladder is more than 12,000. The price of a ladder is comparable to that of a small bus.

Two of the most characteristic designs in a ladder are the chip-on-sensor concept and the Origami concept (Fig. 4). In order to minimize the length from a strip to the APV25, and to prevent capacitive noise coupling, we designed the APV25 chips to be placed immediately above the sensor. With this configuration, however, there is no straightforward way to read the backside strips of the sensor. Therefore, we led the backside signals to the topside APV25 by putting a flex circuit on the backside of the sensor, folding and gluing it to the topside, and connecting the flex circuit and APV25 by wires.

We are currently assembling fourth-layer ladders of the SVD in a clean room at the Kavli IPMU. Twenty ladders including four spare ladders are being produced. We started this activity in 2012 with the establishment of the assembly procedure of ladders from a very complicated combination of very expensive parts. Since it was impossible to manually assemble the ladder with such precision, we designed dedicated assembly jigs. We currently employ more

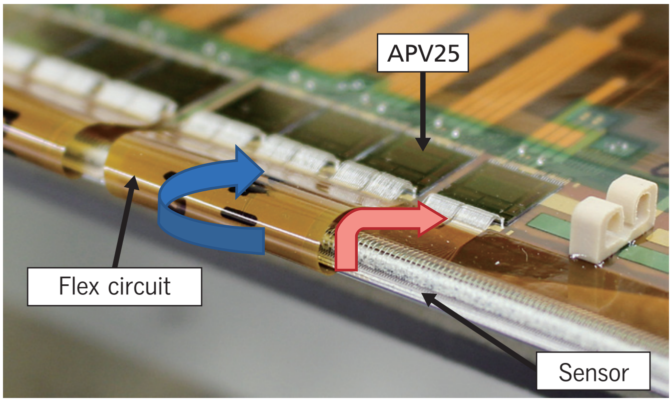


Figure 4. Photo showing the chip-on-sensor concept and Origami concept. Signals from the backside of the sensor are read out by putting a flex circuit on the sensor backside, folding it to the sensor topside, and leading the signals to the APV25.

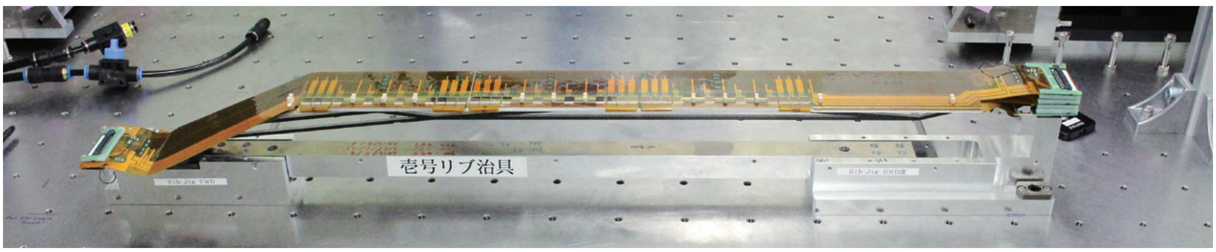


Figure 5. Photo of a completed ladder.

than 20 different jigs to assemble the ladder. In addition to the development and debugging of the assembly procedure, we also developed a gluing procedure of the ladder components and a wire bonding procedure for the electrical connection of parts. Through assemblies of more than ten mockup ladders, we established the assembly procedure of the ladder in 2015. In parallel with these activities, we also developed a test stand to evaluate the electrical quality of the assembled ladder. The test stand is equipped with a PC, and it analyzes readout signals from strips of the ladder that are irradiated by beta rays. We finally succeeded in assembling the first ladder with full electrical functionality in 2016. We tested this ladder together with ladders for other layers in an experiment using electron beams, and confirmed that our ladder had good particle-detection performance as expected.

Our next challenge was to stabilize the ladder quality for all the ladders we were going to fabricate. We employed an idea of stringent quality control into our ladder assembly line. We note the special implementation of the following items to the assembly line: mechanization and manualization of assembly operations to minimize operator-dependent instabilities, securing traceability of all ladder parts through incoming inspections, installments of multiple checkpoints to the assembly line to detect an error as early as possible in the assembly process, and quality assurance of the completed ladder through a visual check, mechanical precision check, and electrical test.

We are currently assembling ladders in our clean room, and have produced five working ladders to date (Fig. 5). We estimate we will finish the full ladder assembly by early 2018.

The assembled ladders will begin to be mounted onto the VXD structure from the summer of 2017. The PXD and SVD will be combined to form the VXD by the summer of 2018, and a combined performance test of the VXD will be carried out using cosmic rays. The VXD will be installed into the Belle II detector structure in the autumn, and the real data-taking of particle interactions will start around the end of 2018.