SuperKEKB and Belle II

- SuperKEKB collider at KEK
  - $e^+e^-$ collider with $\sqrt{s}$ of 10.58 GeV = $M_{\Upsilon(4S)}$
    - Asymmetric beam: $e^+ 4$ GeV, $e^- 7$ GeV
  - World-highest design luminosity: $L = 8.0 \times 10^{35}$ cm$^{-2}$s$^{-1}$
    - x40 larger lum. than KEKB
    - $\leftarrow$ x20 by beam size, x2 by beam current

- Belle II experiment
  - Intensity frontier experiment to discover and understand physics beyond the SM
  - Belle II detector
    - General purpose 4 $\pi$ spectrometer
    - Tolerable to high beam background
    - Improved particle identification
    - Excellent vertex resolution

- SuperKEKB and Belle II are being constructed for physics run start in 2018.
Belle II Vertex Detectors

VXD consists of two detectors:

- **PiXel Detector (PXD)**
  - Innermost 2 layers ($r = 1.4, 2.2$ cm)
  - Based on DEPFET pixels
  - Thickness $75\, \mu$m
  - Pixel size $50 \times 55\, \mu$m

- **Silicon Vertex Detector (SVD)**
  - Outer 4 layers ($r = 3.9 \sim 13.5$ cm)
  - Double-sided Si strip detectors (DSSDs)

**VXD requirements**
- Fast – to operate in high background environment
- Better resolution at IP – to compensate reduction of boost wrt. Belle I
- Radiation hard up to $100\, \text{kGy}$
- Self-tracking capable – to track particles down to $50\, \text{MeV}$ in $p_T$

**Impact parameter resolution (Simulation)**

- Significantly improved resolution compared to Belle ($20\, \mu$m at 2 GeV)

**Poster by L. Andricek**

Dec. 11, 2017
Belle II SVD Overview

- 4 layers consists of ladders
- Large outer radius for vertexing with Ks decaying in VXD volume
- Arranged in windmill shape with overlaps for alignment
- Slant shapes in FWD region for the material budget reduction.
- Average material budget: 0.7%$X_0$ per layer

<table>
<thead>
<tr>
<th>Layer</th>
<th>Ladder /Layer</th>
<th>Sensor/ladder</th>
<th>Origami</th>
<th>Length</th>
<th>Radius</th>
<th>Slant angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>7</td>
<td>2</td>
<td>0</td>
<td>262 mm</td>
<td>39 mm</td>
<td>0°</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>3</td>
<td>1</td>
<td>390 mm</td>
<td>80 mm</td>
<td>11.9°</td>
</tr>
<tr>
<td>5</td>
<td>12</td>
<td>4</td>
<td>2</td>
<td>515 mm</td>
<td>104 mm</td>
<td>17.2°</td>
</tr>
<tr>
<td>6</td>
<td>16</td>
<td>5</td>
<td>3</td>
<td>645 mm</td>
<td>135 mm</td>
<td>21.1°</td>
</tr>
</tbody>
</table>
SVD Silicon Sensor

DSSD (Double-sided Si strip detector)

- Strip numbers and pitches
  - 3 types of DSSD sensors

<table>
<thead>
<tr>
<th>Sensors</th>
<th>Rectangular (Large)</th>
<th>Rectangular (Small)</th>
<th>Trapezoidal</th>
</tr>
</thead>
<tbody>
<tr>
<td># of p-strips</td>
<td>768</td>
<td>768</td>
<td>768</td>
</tr>
<tr>
<td>p-strip pitch</td>
<td>75μm</td>
<td>50μm</td>
<td>50…75μm</td>
</tr>
<tr>
<td># of n-strips</td>
<td>512</td>
<td>768</td>
<td>512</td>
</tr>
<tr>
<td>n-strip pitch</td>
<td>240μm</td>
<td>160μm</td>
<td>240μm</td>
</tr>
</tbody>
</table>

Rectangular sensor (HPK)

- Thickness: 320μm
- p-side strip:
  - (large) 60mm
  - (small) 40mm

Trapezoidal sensor (Micron)

- Thickness: 300μm
- n-side strip:
  - 41mm
  - 61mm

Sensor thickness = 300-320μm
Assembly sites:
FW/BW@INFN Pisa (Italy)
L6 @Kavli IPMU (Japan,Korea)
L5 @HEPHY (Austria)
L4 @Kavli IPMU by TIFR (India)
L3 @Univ. of Melbourne (Australia)
Readout ASIC

APV25 chip

- APV25 chip
  - A high background in Belle II requires short signal shaping time and a good radiation hardness.
  - APV25 chip is a suitable solution for SVD.
    - Originally developed for CMS.

- APV25 Specification
  - # of input channels: 128 ch.
  - Shaping time: 50nsec
  - Radiation hardness: > 1MGy
  - Max. heat dissipation: 0.4W
To minimize the noise by the capacitance of the signal line, Readout chip is mounted on the Origami flex circuit glued on sensor.

Signal from p-side is readout via the pitch adapter flex wrapped at the sensor edge.

To reduce the material budget, APV chips is thinned down to 100 μm.
CO2 Cooling for Ladders

- Max. heat dissipation ~ 0.4 W/APV → 700W in total
- 2-phase (liquid and gas mixture) CO2 cooling system
  - Efficient and low mass cooling
  - Simple control of coolant temperature (only with pressure)
  - Small pressure loss in tubes
- Thin stainless tube (OD:1.6mm, thickness:0.1mm) is employed.
  - Less material budget
SVD Ladder Parts

- **Origami flex**
  - Flexible circuit to transmit detector signals to the ladder ends.

- **APV25**
  - Readout ASIC of the strips.

- **DSSD sensor**
  - HPK rectangular large L4,5,6, small L3
  - Micron trapezoidal FW in L4,5,6

- **PA0 and FlexPA (PA/PF/PB)**
  - Flexible circuit to transmit detector signals to the APV25.

- **Mechanical parts**
  - AIREX, Rib, Endmounts
Challenges in Origami Flex Production

- Origami flex production was not trivial because of:
  - Large flex size, APV thinning to 100 μm, pitch conversion 480 μm → 88 μm in small length (~6mm) on PA0, etc.

→ Several problems occurred in studies of production

- **All problems have been solved** by cooperation with companies and introducing intensive quality checks
  - More than one e-tests such as connectivity checks of all signal lines are inserted
  - Selection of thinning method and inspection of each APV after thinning
  - Hand soldering of all passive parts, not reflow
  - Improved flex design
  - etc.

→ In the end, we produced excellent quality Origamis **without any dead-ch**
Precision DSSD alignment

DSSDs are handled with precision assembly jigs ($O(50\mu m)$), on which the sensors are fixed by vacuum chucking.

Sensor fixed on a jig

Sensor placement

Sensors are aligned in $O(10\mu m)$ by a position tuning jig with monitoring through a CMM.

Gluing Quality Control

- Various parts are glued together with Araldite® 2011 → glue spread affect the wire bonding yield and pull strength
- Robotic control of glue amount and lining

Wire bonding

Bonding parameters tuned to realize $>99\%$ yield and pull strength $>>5gw$

\[
\mu_f = 10.7gw \\
\sigma_f = 0.6gw \\
(97 \text{ samples})
\]
Ladder Quality Assurance

1. Geometrical precision measured with an optical CMM
   → typical value <150μm in the xy plane and 200μm along the z axis

2. I-V curve measurement
   → Confirm the sensor functionality for biasing.

3. Electrical qualification with laser/b-source (Sr^{90})
   → check defects in the strips and particle response
Ladder Production Status

[Status As of Oct. 2017]

• FW/BW DSSD
  o BW: 100% completed
  o FW: 100% completed

• Layer-3 Ladder
  o 100% completed

• Layer-4 Ladder
  o 8 out of 10+2 ladders (75%) completed

• Layer-5 Ladder
  o 100% completed

• Layer-6 Ladder
  o 13 out of 16+4 ladders (65%) completed

• All ladder production will complete by Mar. 2018
Beam Test of SVD Ladders

- **e⁻ beam (2-5 GeV/c)** at DESY in Apr. 2016
  - Test for ladders in all 4 layers (1 ladder/layer)
  - SVD + PXD combined setup

**Beam test setup**
(@ DESY T24/1 hall)
Performance in Beam Test

- Very good spatial resolution: consistent with expectations
  - Layer-5 p strips: \( \sigma = 13\mu m \)
  - Layer-5 n strips: \( \sigma = 36\mu m \)
- Strip hit efficiency: > 99%

Excellent performance of ladders confirmed by the beam data
• Ladders are mounted on the structure and assembled in two halves at KEK
  o Then combined with the beam pipe and PXD
• Dedicated mount/measurement tools have been developed
• Now the first half is being assembled
  o Completed Layer 4 with cooling pipe so far
Mounted the first layer 3 ladder (Sep. 2017)

Completed layer 4 (first half) with cooling pipe (Oct. 2017)

Now mounting layer 5 ladders

**SVD Schedule**

Completion of 1st half shell  Jan, 2018  
Completion of SVD       Apr, 2018  
Start of VXD installation 3Q 2018  
Start of physics run  4Q 2018
Partial SVD Installed in Belle II

- One sector of SVD (4 ladders) and PXD (2 ladders) has been installed in Belle II for SuperKEKB phase II operation
  - Included in the global Belle II DAQ
  - First beam collisions expected in Apr. 2018
- Full SVD and PXD will be installed in 3Q 2018, after establishing the good background condition in beam collisions in Phase II operation
Radiation Monitoring for Beam Abort

- Single Crystal Diamonds, scCVD 4.5x4.5x0.5 mm³
  - High radiation tolerance
  - Small temperature dep.
  - Simple and compact detector structure

- Current measurement with long high-quality cabling

**Installation locations**
- 6 + 6 diamond sensors
- SVD Layer-3 and -4
- 4 + 4 diamond sensors
- PXD-beam pipe

Prototype sensors are produced. They were tested in SuperKEKB beams.

**Hit counts vs. Beam size**

- $I_{HER}=540 mA$
- $I_{HER}=360 mA$
- $I_{HER}=160 mA$

BG enhancement due to Touschek effect was detected. Dec. 11, 2017
Conclusions

• SVD plays essential role in the physics program in Belle II

• All R&D needed for the SVD production have been completed and final SVD assembly is now on going.

• The good quality of assembled ladders and SVD is verified by checks of quality performed in each step of ladder parts production, ladder production, and SVD assembly.

• Phase II VXD with one SVD sector has been installed and ready for the first collision planned in Apr. 2018

• Final SVD will be installed in 3Q 2018 and physics run with full Belle II detector will start in 4Q 2018
• Old PA0 design

• Improved PA0 design
  • Thicker neck
  • Covered by coverlay
  • Laser cutting
Belle II Collaboration

784 colleagues, 106 institutions, 25 countries/regions  (Nov. 30, 2017)