Belle II Silicon Vertex Detector

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on behalf of the Belle II SVD group

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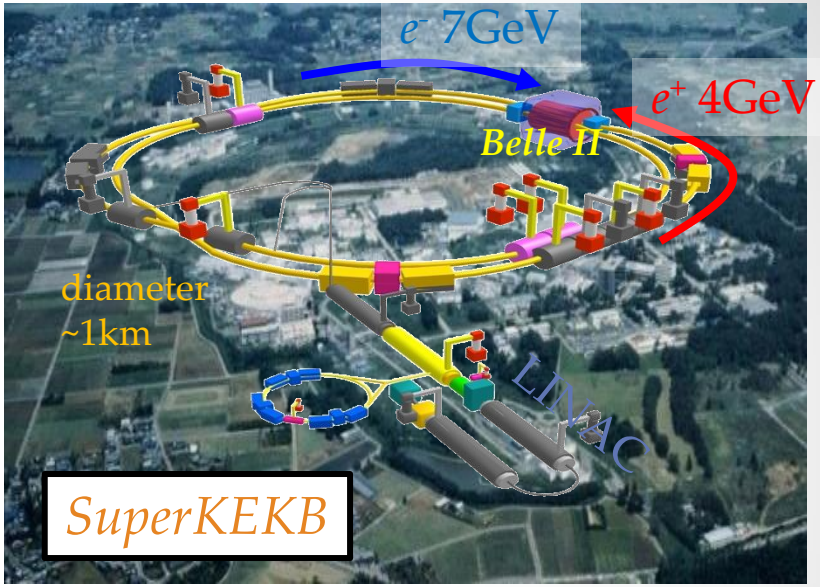
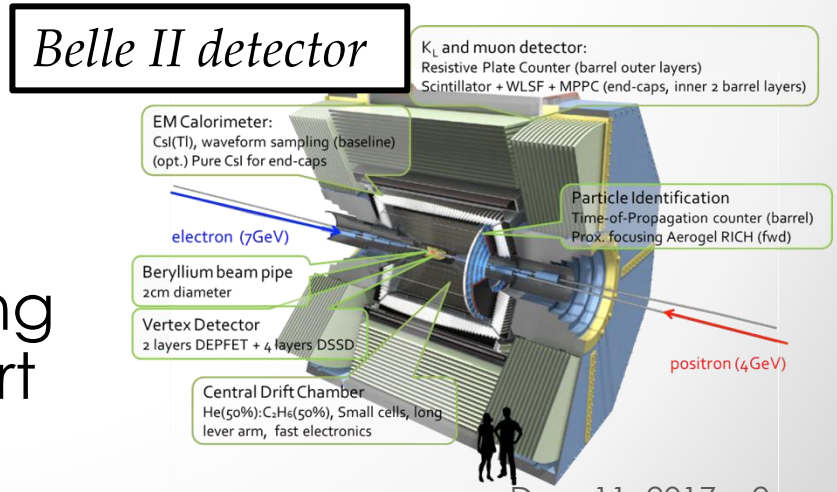
HSTD11@OIST

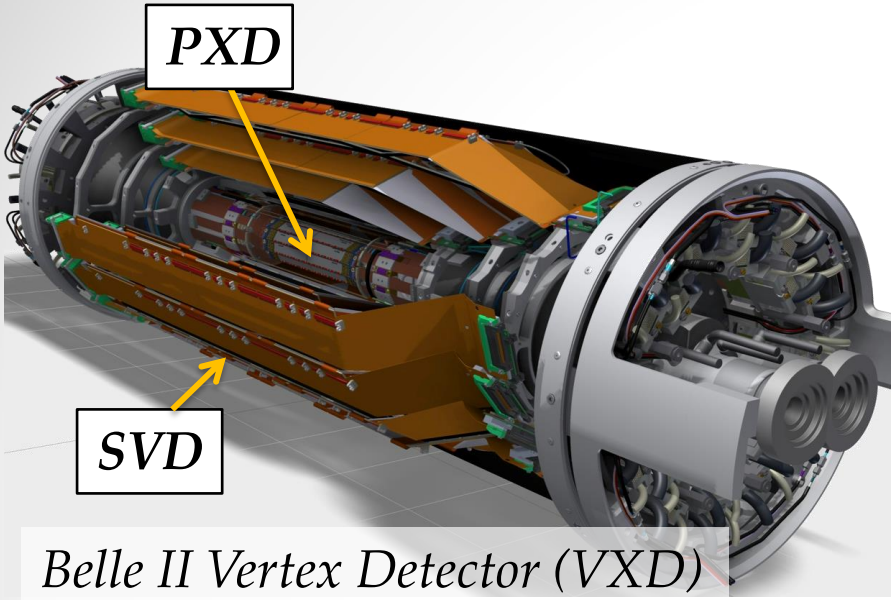
SuperKEKB and Belle II

- 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
    - ← 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 π 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

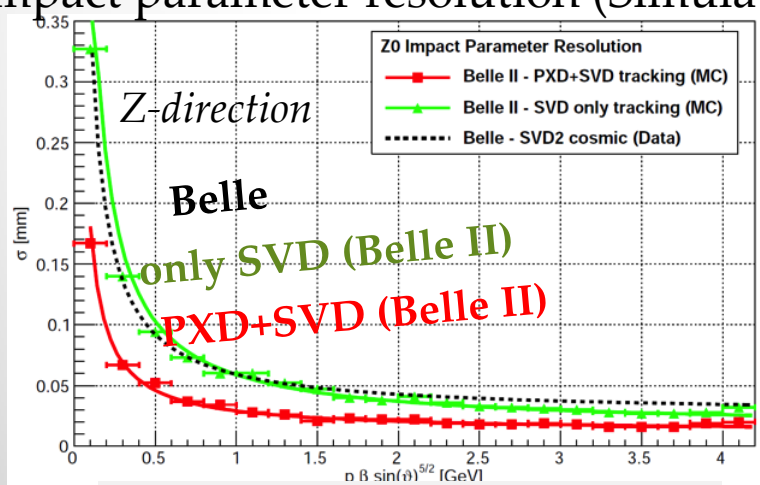


Belle II Vertex Detector (VXD)

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 kGy
- Self-tracking capable – to track particles down to 50 MeV in p_T

Impact parameter resolution (Simulation)



Significantly improved resolution compared to Belle (20μm at 2 GeV)

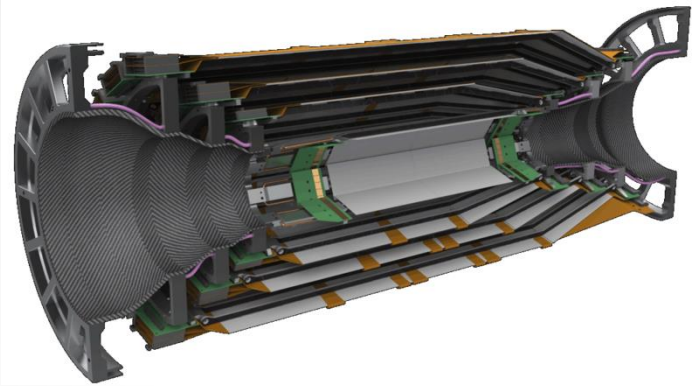
VXD consists of two detectors:

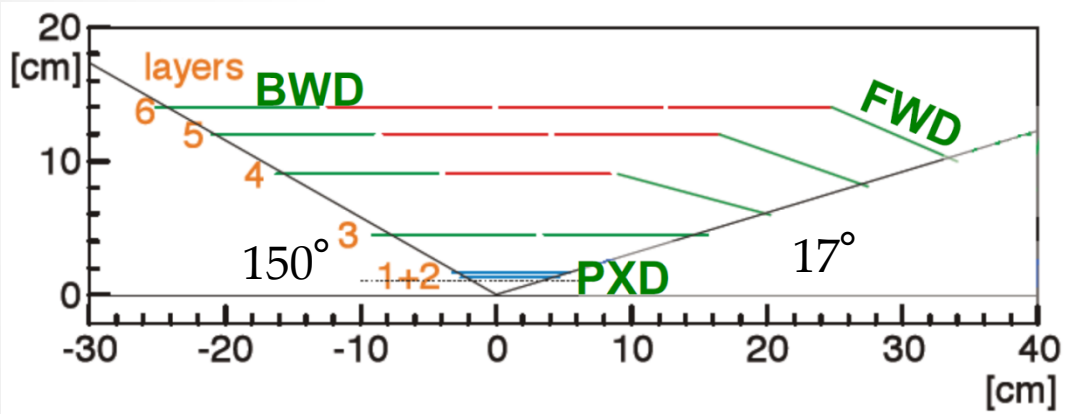
- PiXel Detector (PXD)
  - Innermost 2 layers (r=1.4, 2.2 cm)
  - Based on DEPFET pixels
    - Thickness 75 μm
    - Pixel size 50x55μm

Poster by L. Andricek

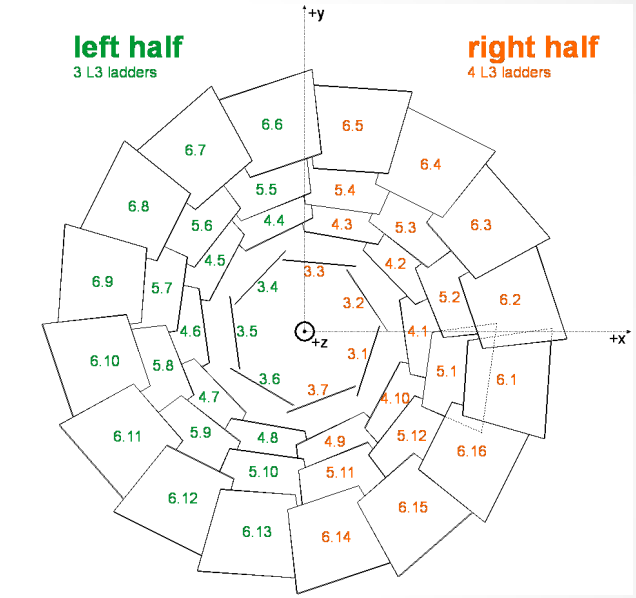
- Silicon Vertex Detector (SVD)
  - Outer 4 layers (r=3.9 ~ 13.5 cm)
  - Double-sided Si strip detectors (DSSDs)

Belle II SVD Overview





Viewed from Forward

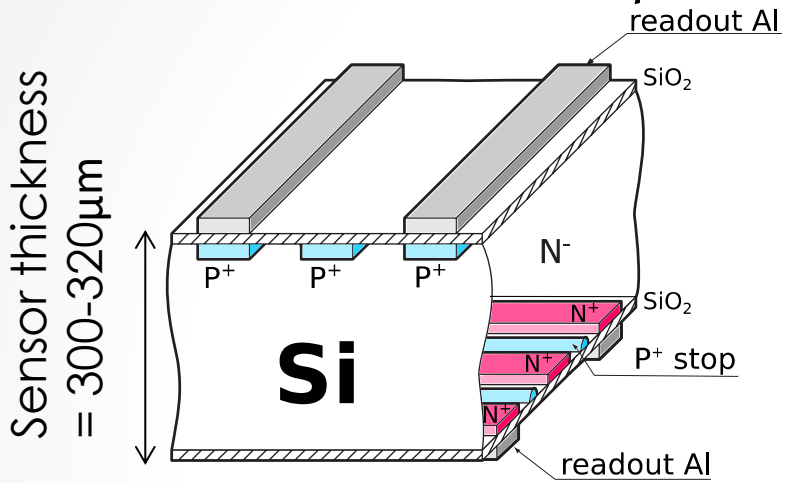


Layer	Ladder /Layer	Sensor/ladder	Origami	Length	Radius	Slant angle
3	**7**	2	0	262 mm	39 mm	0°
4	**10**	3	1	390 mm	80 mm	11.9°
5	**12**	4	2	515 mm	104 mm	17.2°
6	**16**	5	3	645 mm	135 mm	21.1°

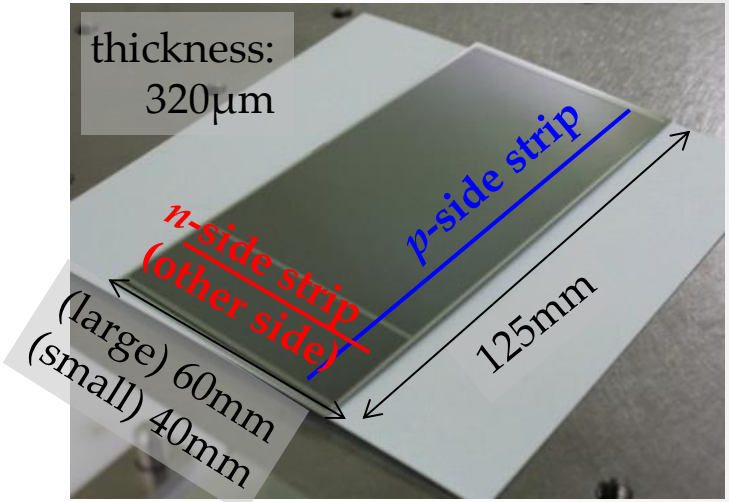
- 4 layers consists of ladders
- Large outer radius for vertexing with Ks decaying in VXD volume
- Arranged in windmill shape with overlaps for alignment
- Slant shapes in FWD region for the material budget reduction.
- Average material budget: 0.7%X_0 per layer

SVD Silicon Sensor

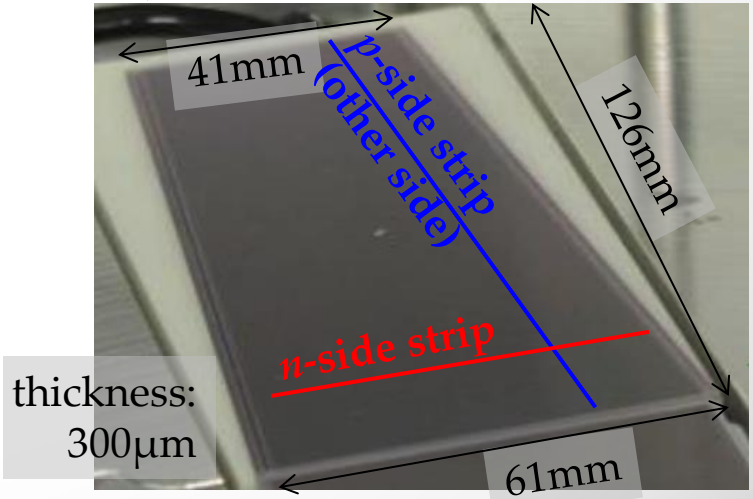
DSSD (Double-sided Si strip detector)



Rectangular sensor (HPK)



Trapezoidal sensor (Micron)



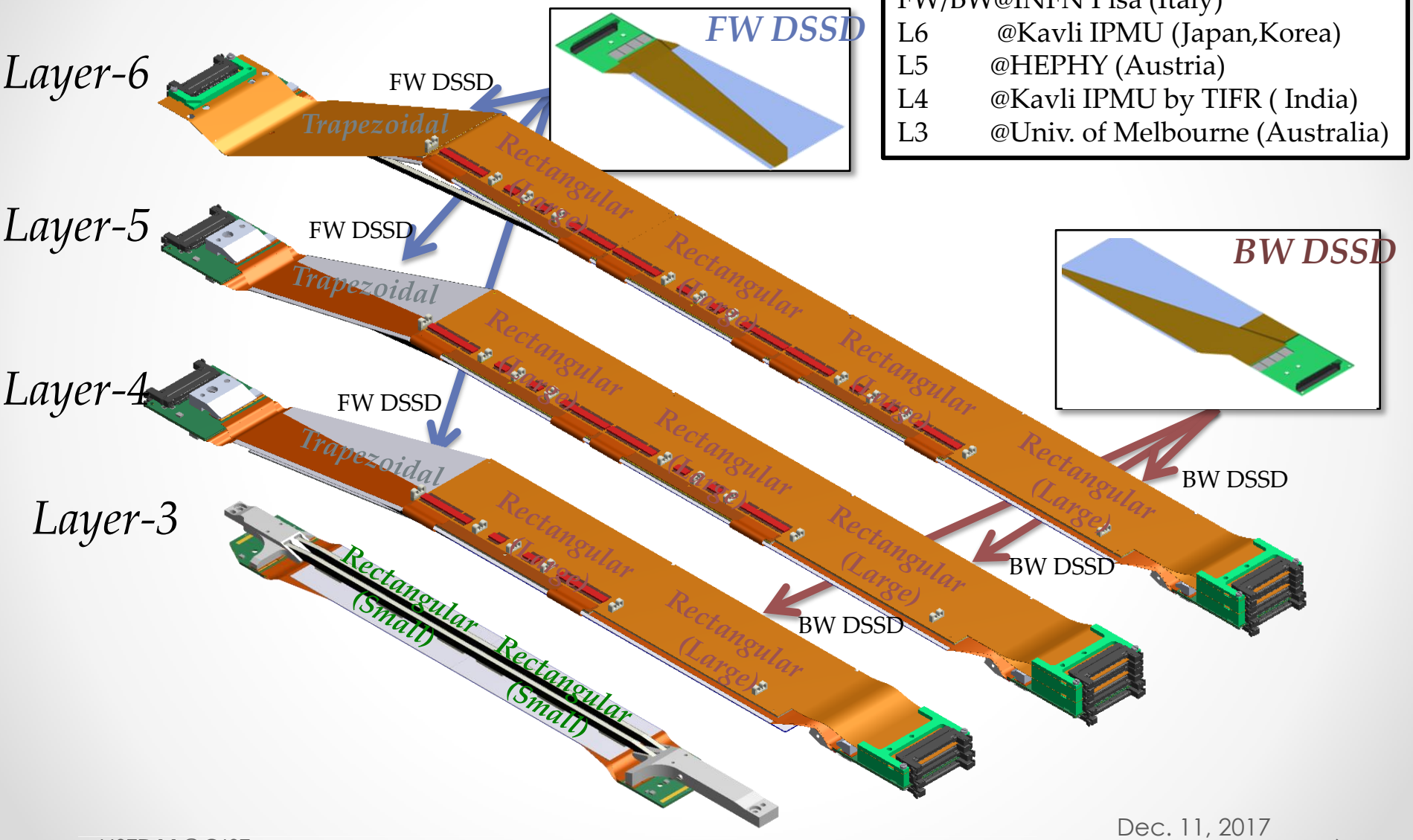
Strip numbers and pitches

- 3 types of DSSD sensors

Sensors	Rectangular (Large)	Rectangular (Small)	Trapezoidal
# of *p*-strips	768	768	768
p-strip pitch	75μm	50μm	50…75μm
# of *n*-strips	512	768	512
n-strip pitch	240μm	160μm	240μm

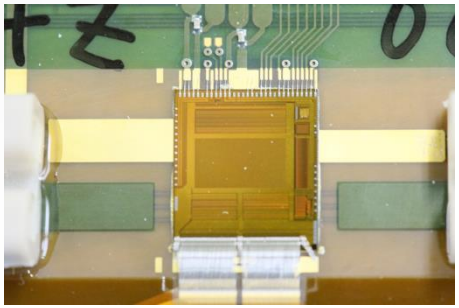
DSSD Locations in Ladders

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)

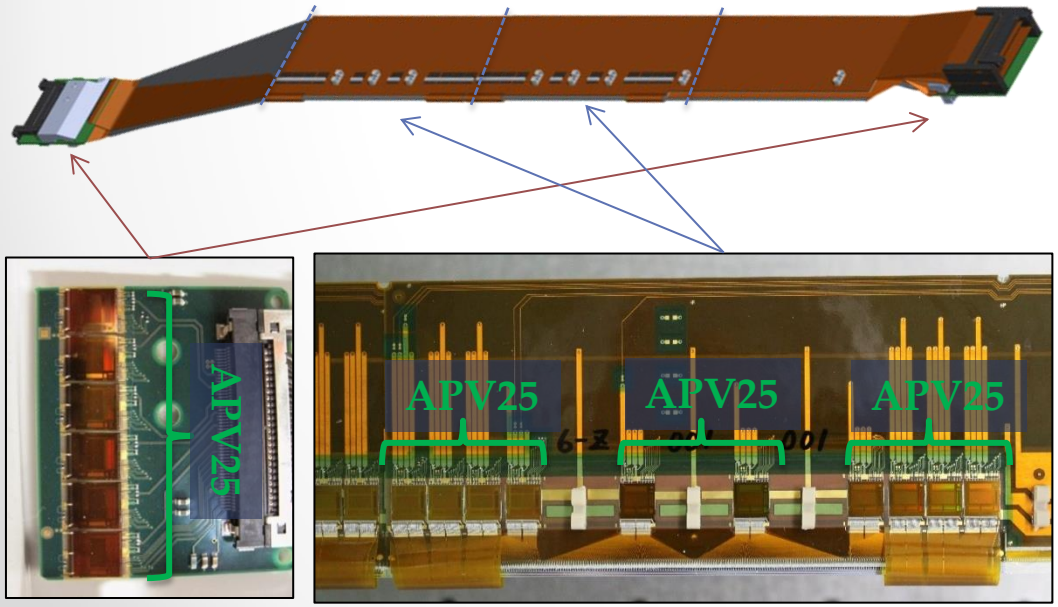


Readout ASIC

APV25 chip



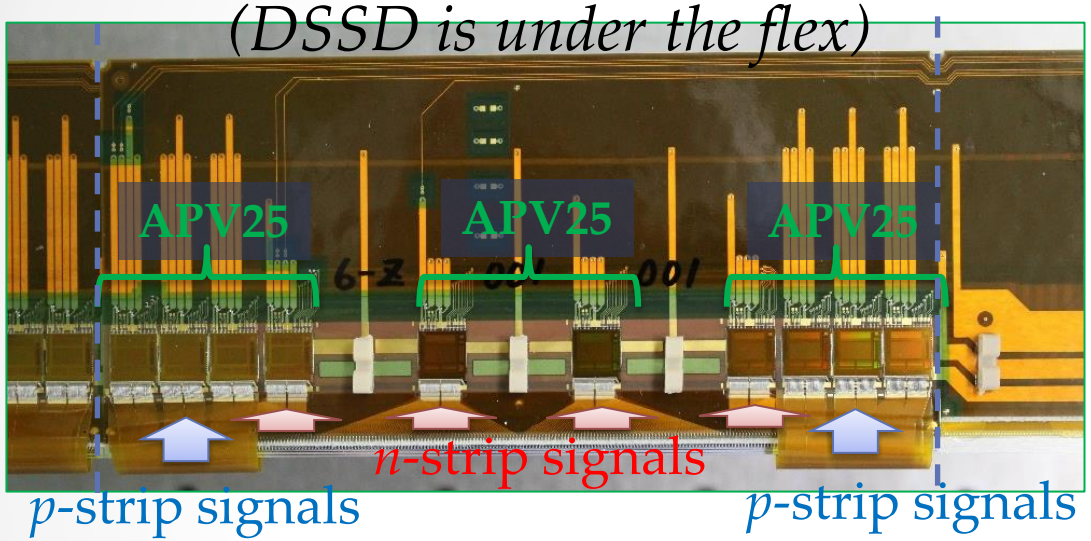
APV25 chips in ladder

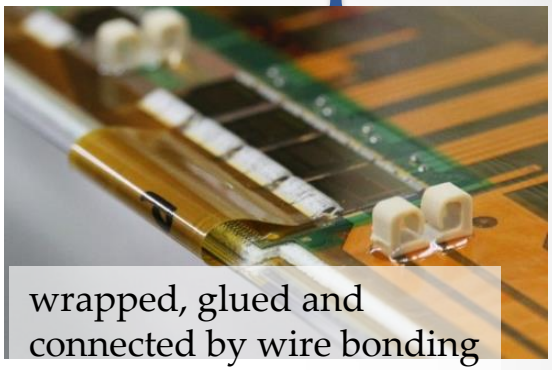


- APV25 chip
  - A high background in Belle II requires short signal shaping time and a good radiation hardness.
  - APV25 chip is a suitable solution for SVD.
    - Originally developed for CMS.
- APV25 Specification
  - # of input channels: 128 ch.
  - Shaping time: 50nsec
  - Radiation hardness: > 1MGy
  - Max. heat dissipation: 0.4W

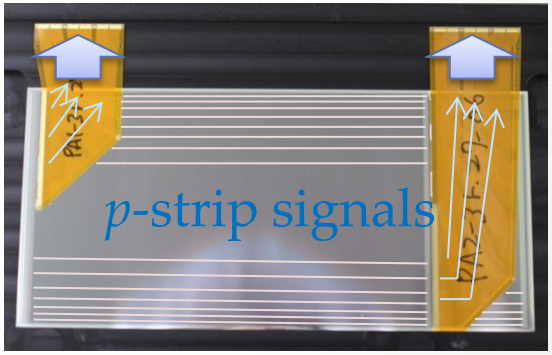
Origami Chip-On-Sensor Concept

Origami Flex
(DSSD is under the flex)





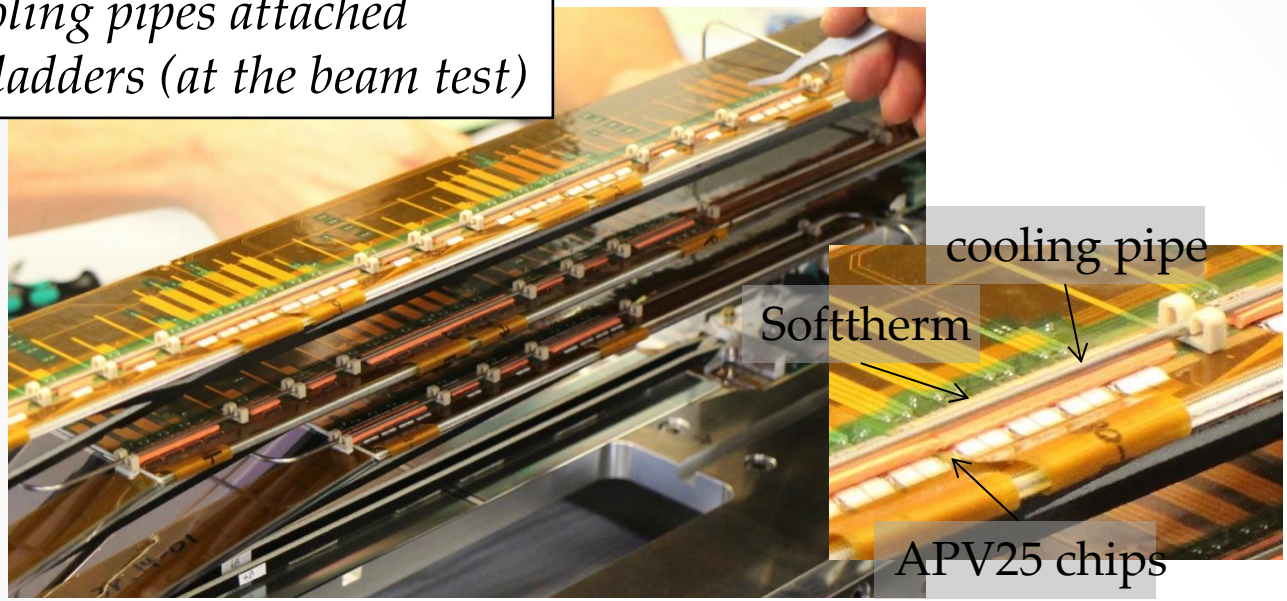
Signal from other side (p-strips)



- 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

Cooling pipes attached on ladders (at the beam test)

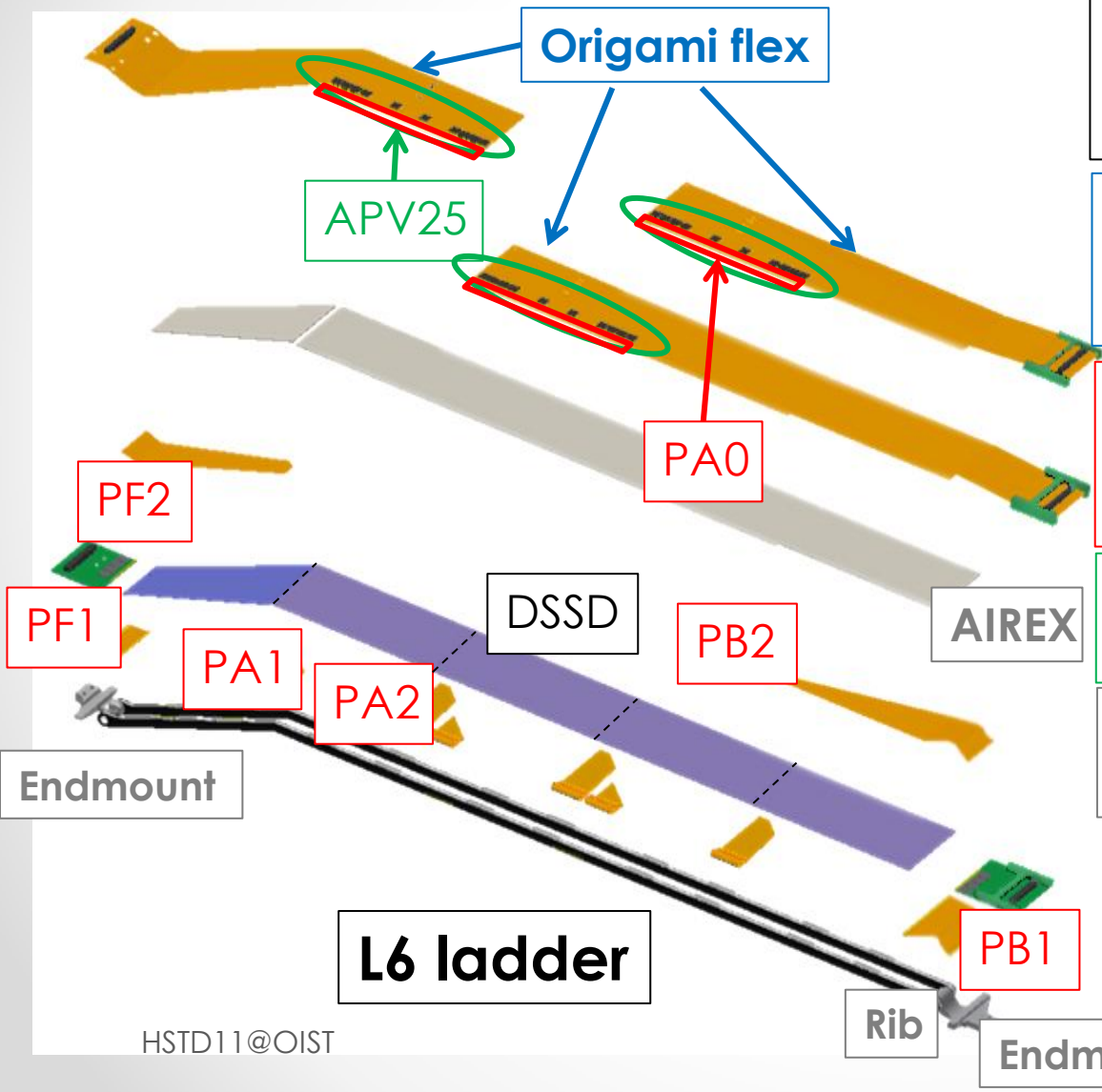


Softtherm 86/125

thermal-conductive dielectric pad.

- 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



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

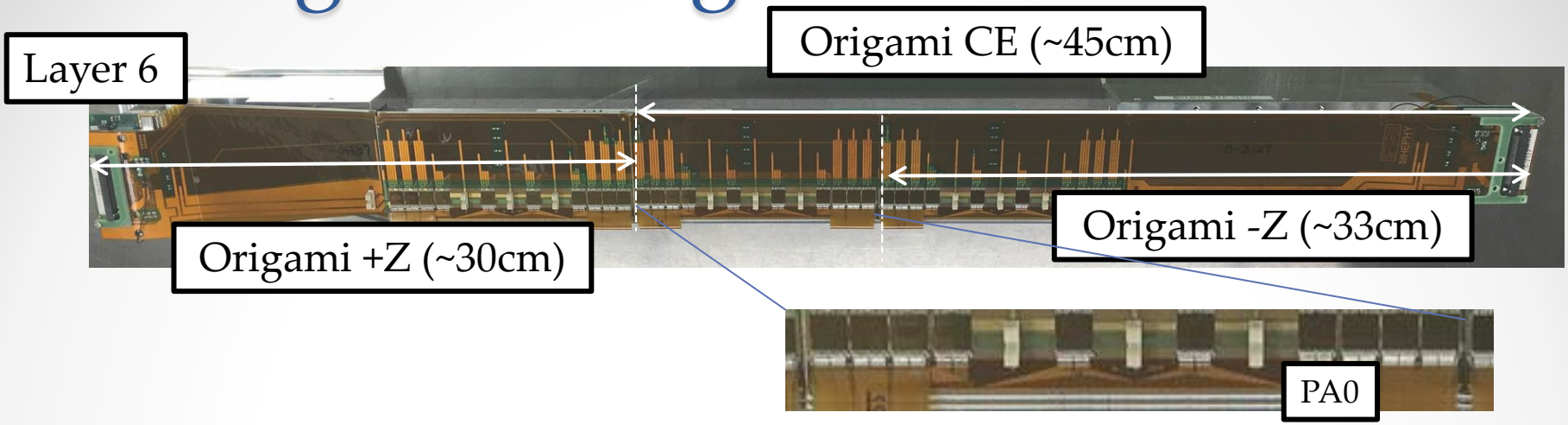
Origami flex
Flexible circuit to transmit detector signals to the ladder ends.

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

APV25
Readout ASIC of the strips.

Mechanical parts
AIREX, Rib, Endmounts

Challenges in Origami Flex Production

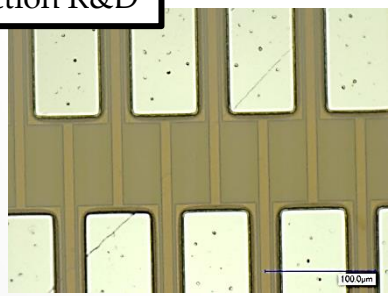


- Origami flex production was not trivial because of
  - Large flex size, APV thinning to 100 μm, pitch conversion 480 μm → 88 μm in small length (~6mm) on PA0, etc.

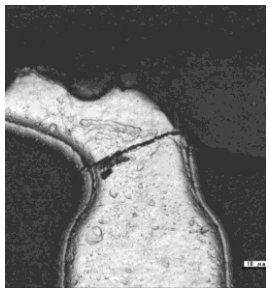
→ Several problems occurred in studies of production

Problems in the production R&D

Blister in reflow soldering



Micro crack on APV



Crack on PA0

- **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.

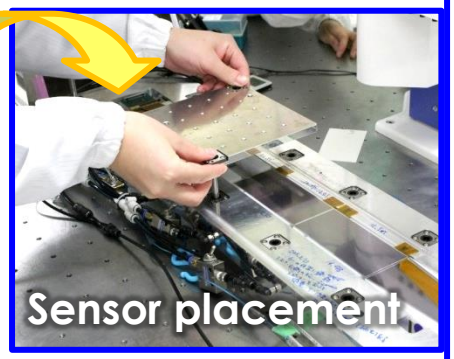
→ In the end, we produced excellent quality Origamis **without any dead-ch**

Ladder Assembly Procedure

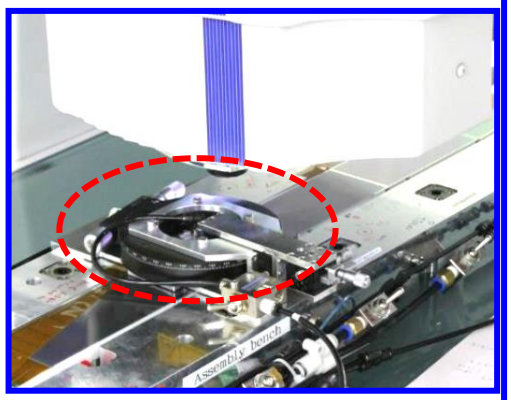
Precision DSSD alignment

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

Sensor fixed on a jig

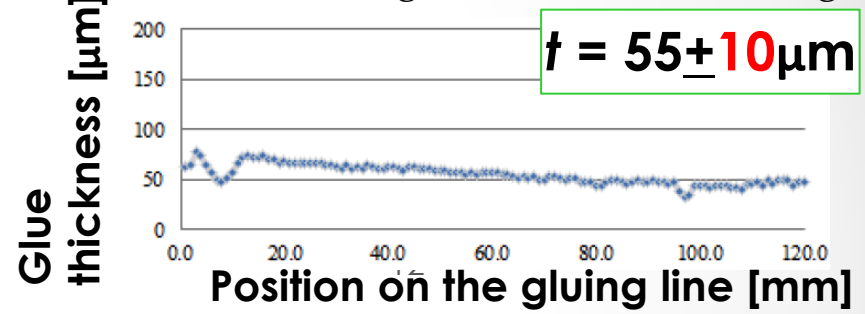


Sensors are aligned in O(10μm) by a position tuning jig with monitoring through a CMM.



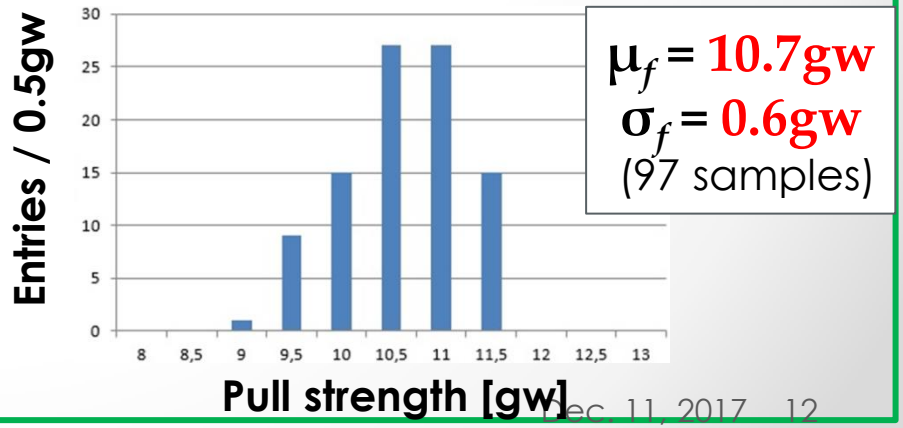
Gluing Quality Control

- 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

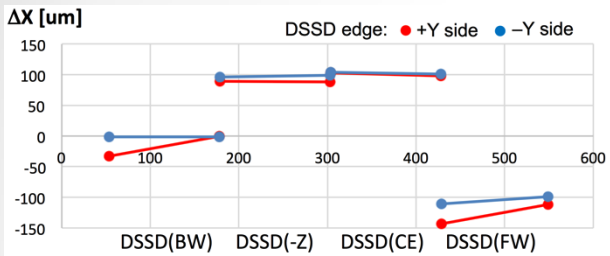
Bonding parameters tuned to realize >99% yield and pull strength >> 5gw

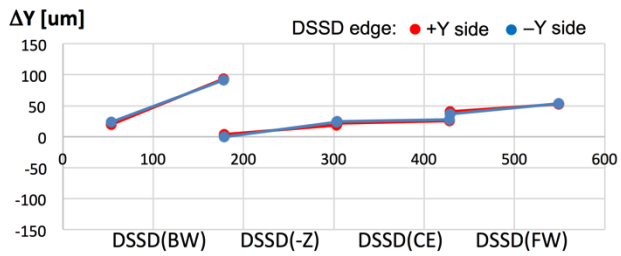


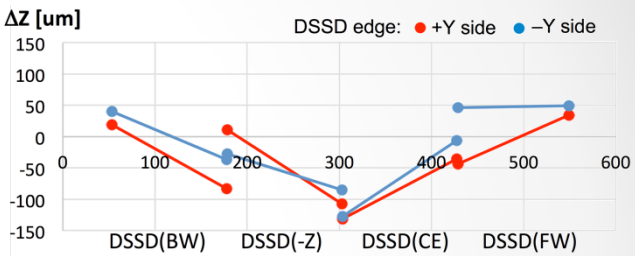
Ladder Quality Assurance

1. Geometrical precision measured with an optical CMM

→ typical value <150μm in the xy plane and 200μm along the z axis

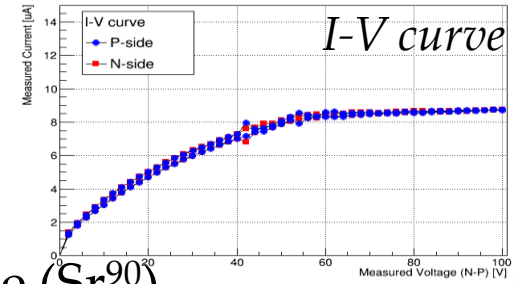






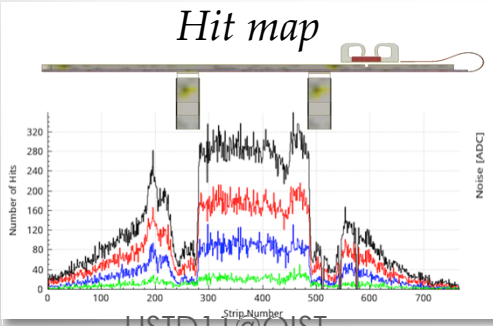
2. I-V curve measurement

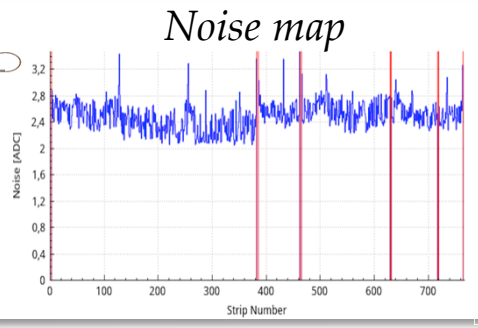
→ Confirm the sensor functionality for biasing.

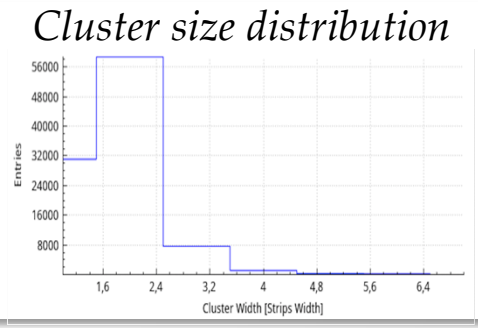


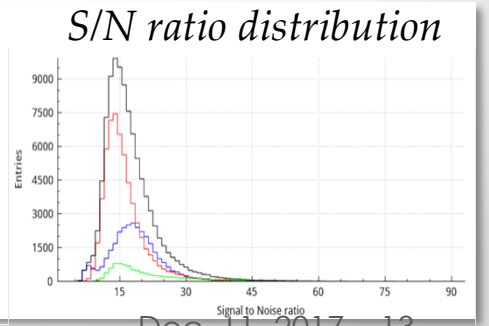
3. Electrical qualification with laser/b-source (Sr^{90})

→ check defects in the strips and particle response





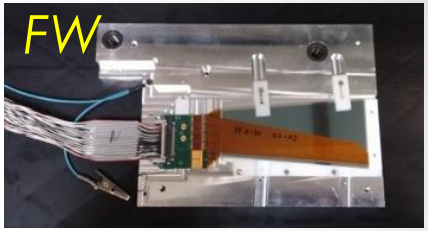


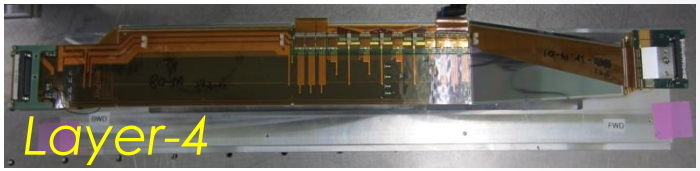


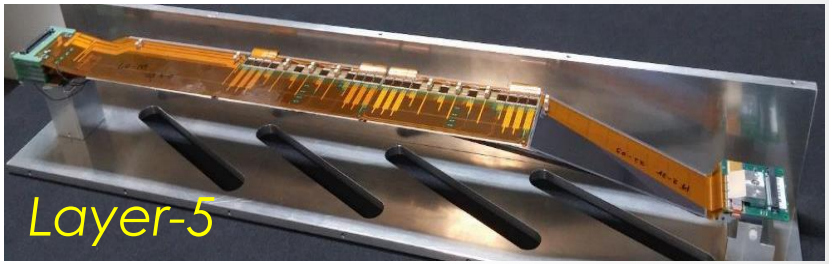
Ladder Production Status

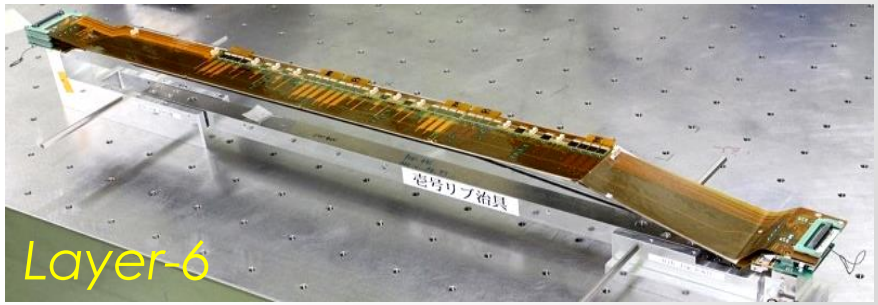
[Status As of Oct. 2017]

- FW/BW DSSD
  - **BW: 100% completed**
  - **FW: 100% completed**
- Layer-3 Ladder
  - **100% completed**
- Layer-4 Ladder
  - **8 out of 10+2 ladders (75%) completed**
- Layer-5 Ladder
  - **100% completed**
- Layer-6 Ladder
  - **13 out of 16+4 ladders (65%) completed**
- All ladder production will complete by Mar. 2018

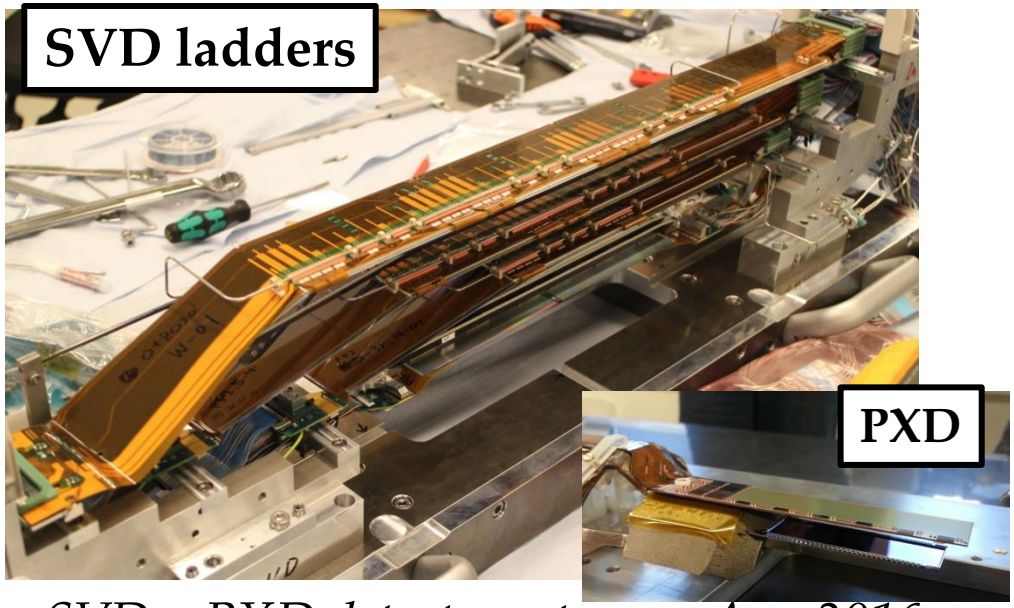




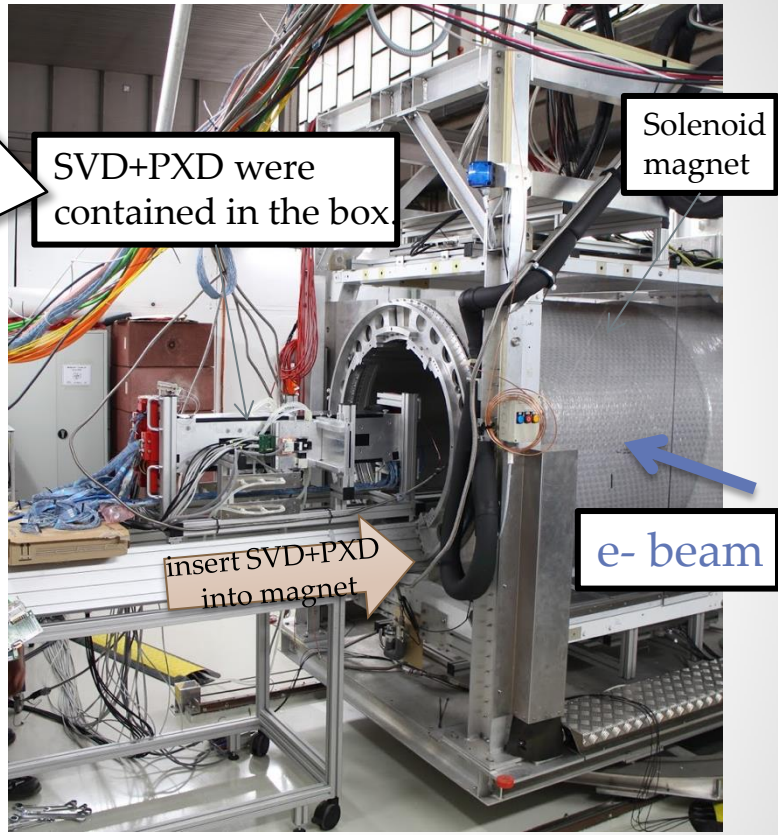




Beam Test of SVD Ladders



SVD + PXD detector setup on Apr. 2016

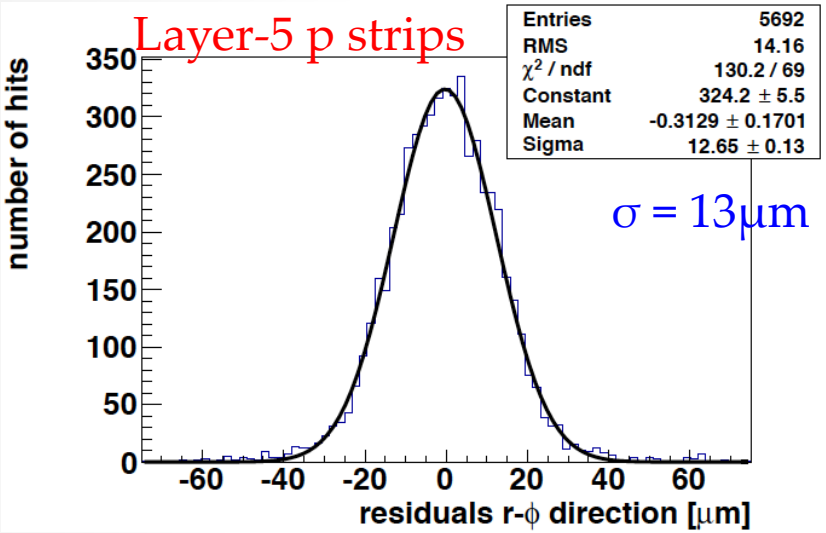


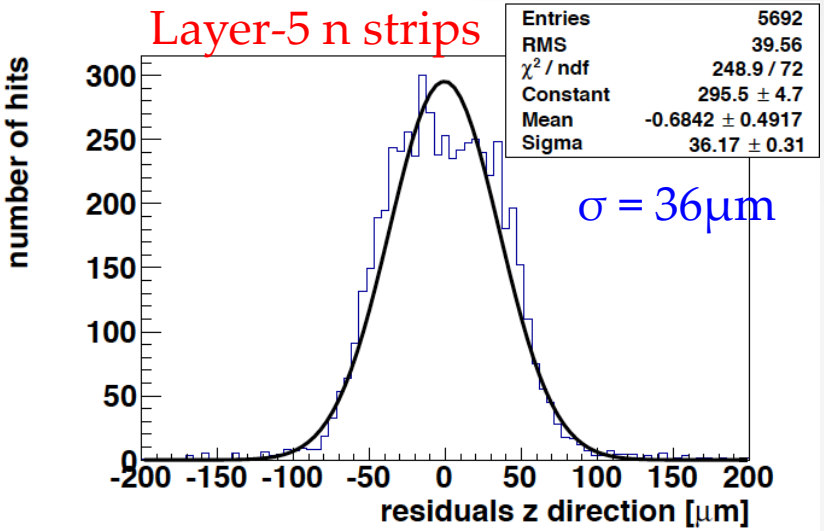
Beam test setup (@ DESY T24/1 hall)

- 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

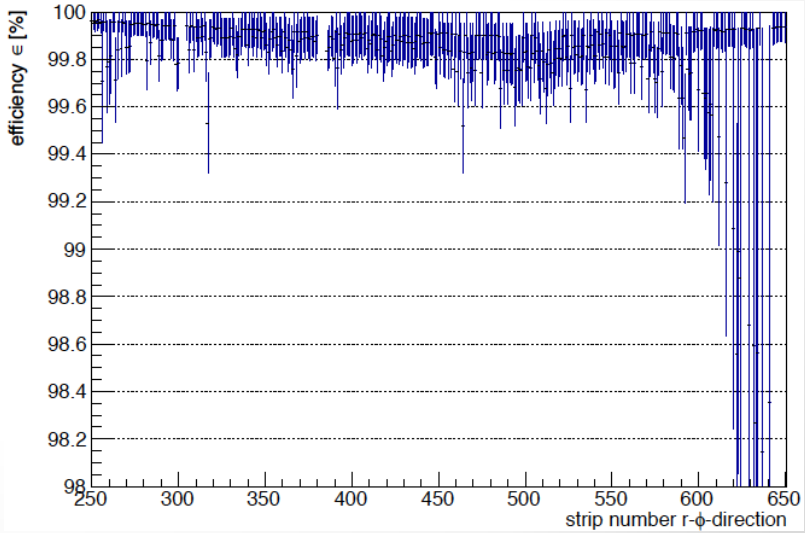
Performance in Beam Test

- Very good spatial resolution: consistent with expectations





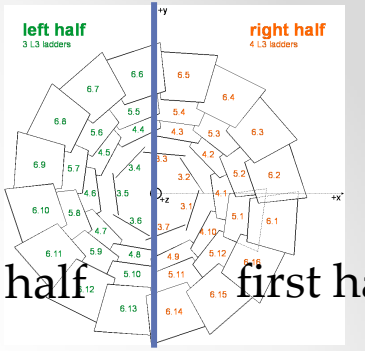
- Strip hit efficiency: > 99%

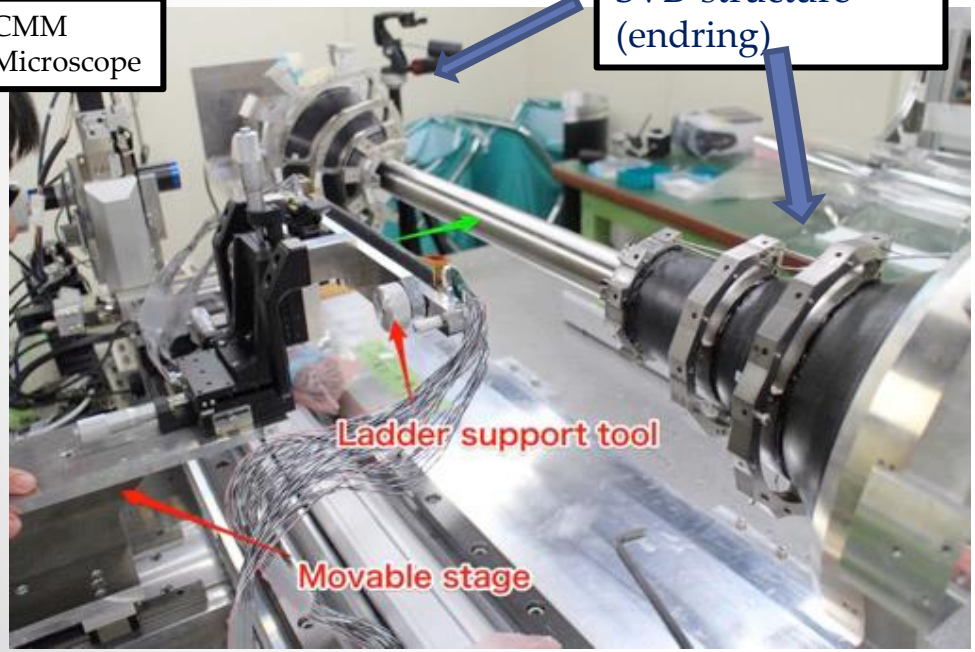


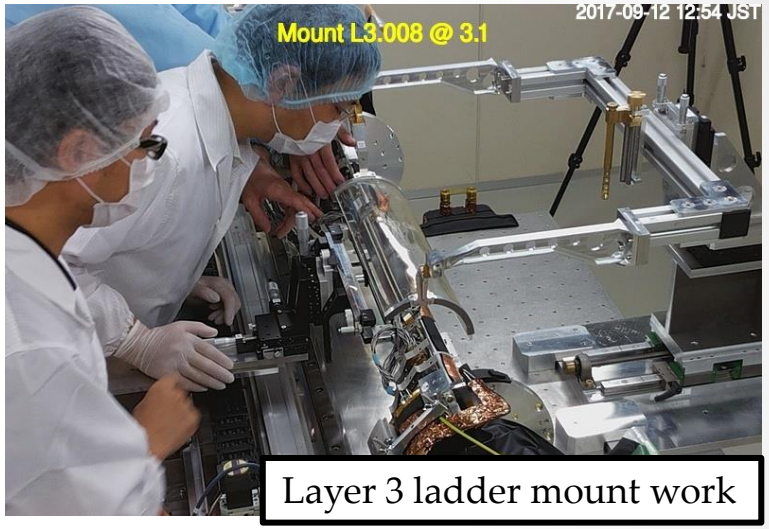
Excellent performance of ladders confirmed by the beam data

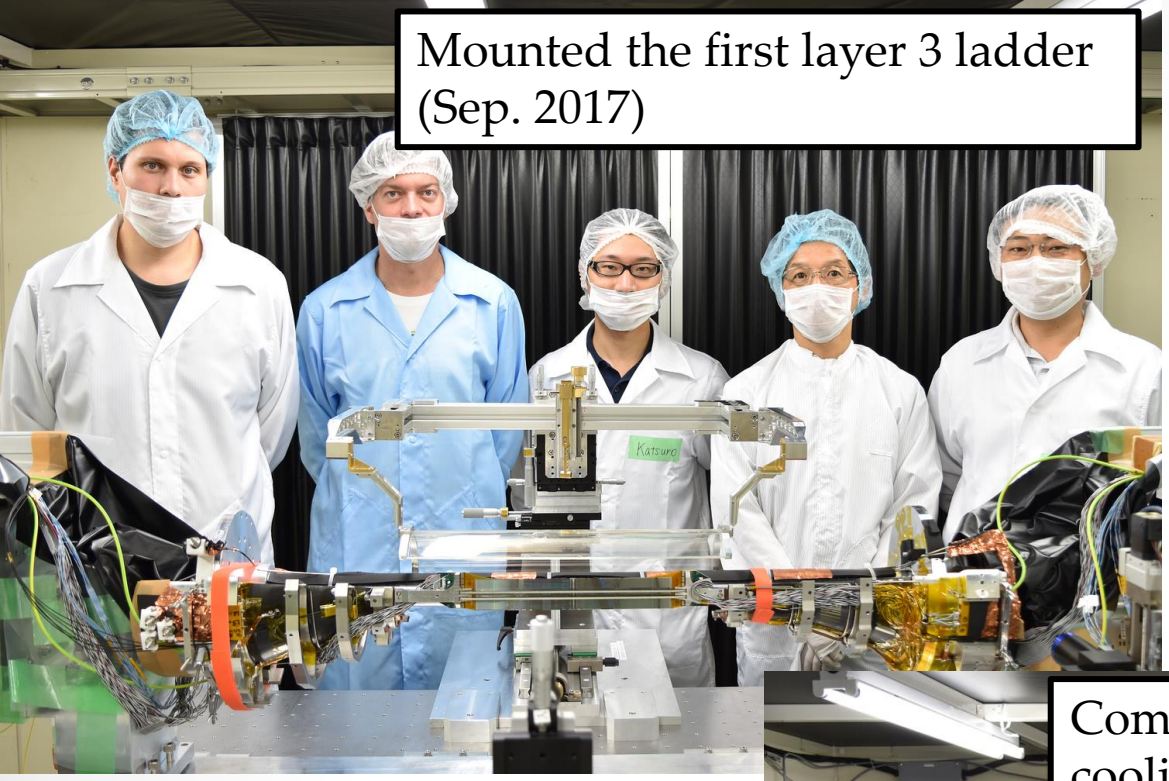
SVD Assembly

- Ladders are mounted on the structure and assembled in two halves at KEK
  - Then combined with the beam pipe and PXD
- Dedicated mount/measurement tools have been developed
- Now the first half is being assembled
  - Completed Layer 4 with cooling pipe so far

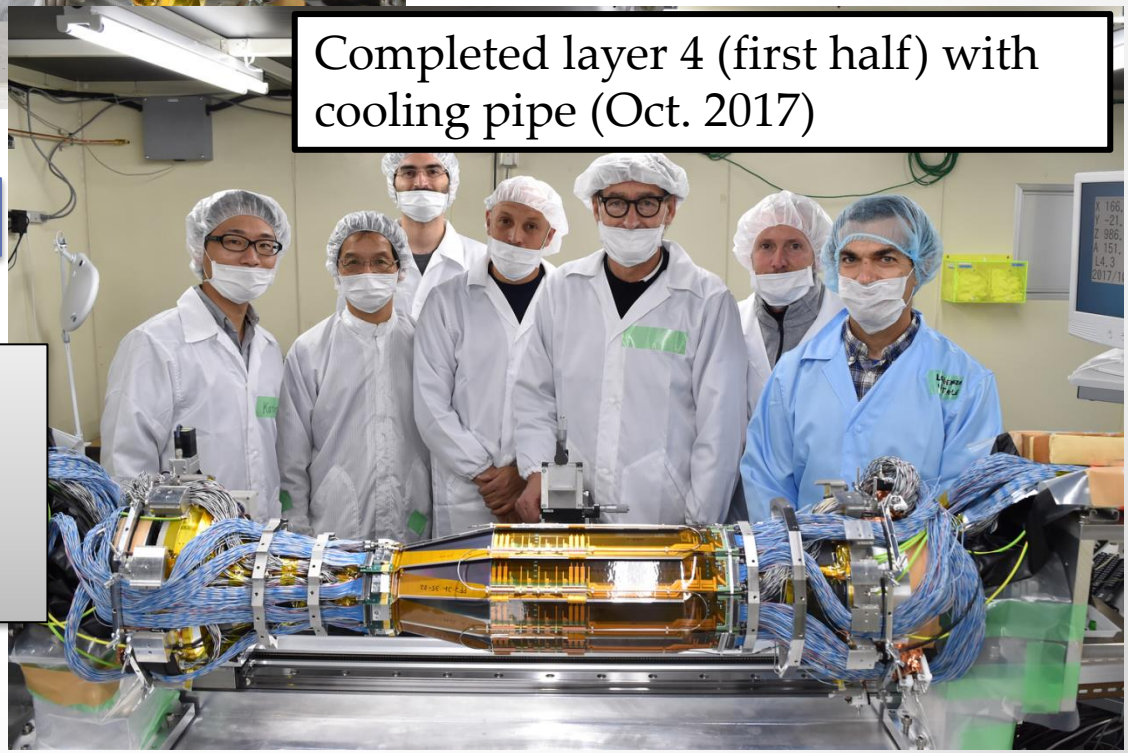








Mounted the first layer 3 ladder (Sep. 2017)



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

Now mounting layer 5 ladders

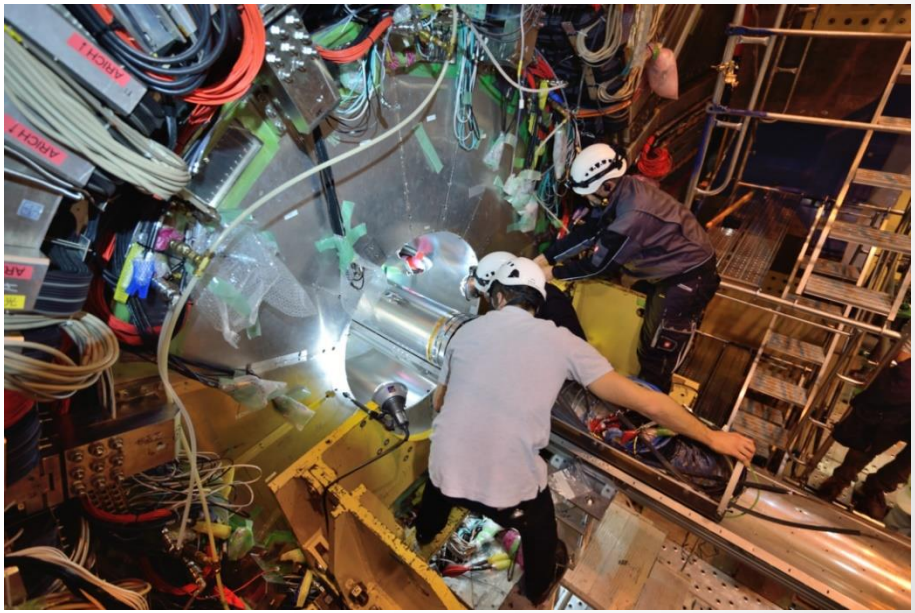
SVD Schedule

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

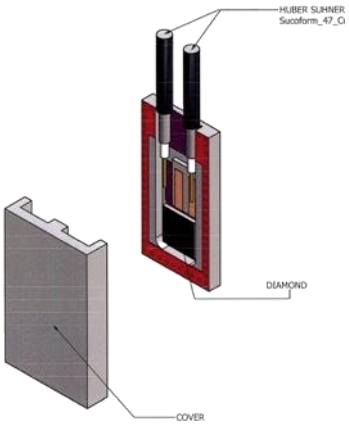
Partial SVD assembled with the beam pipe

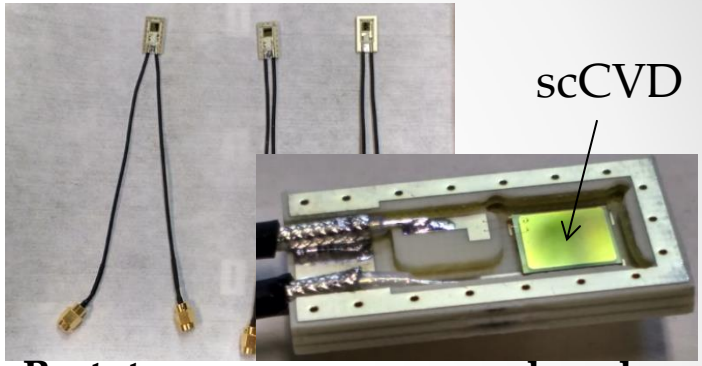


Phase II VXD installation on Nov. 18

Radiation Monitoring for Beam Abort

- Single Crystal Diamonds, scCVD 4.5x4.5x0.5 mm^3
  - High radiation tolerance
  - Small temperature dep.
  - Simple and compact detector structure
- Current measurement with long high-quality cabling





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

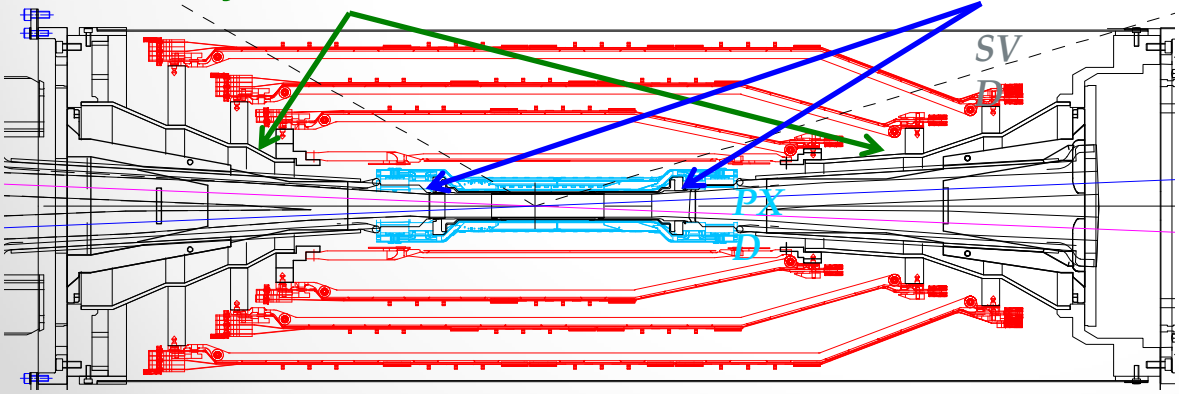
Installation locations

6 + 6 diamond sensors

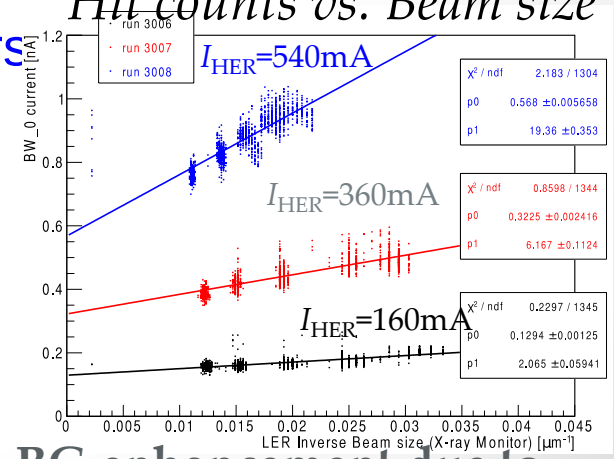
SVD Layer-3 and -4

4 + 4 diamond sensors

PXD-beam pipe



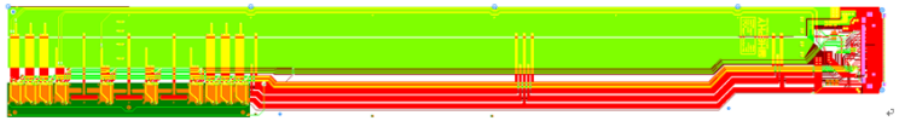
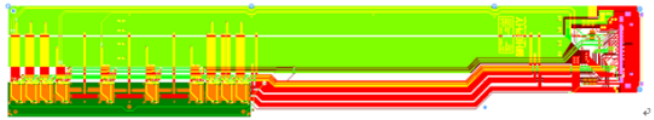
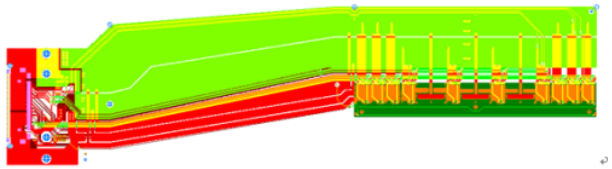
Hit counts vs. Beam size



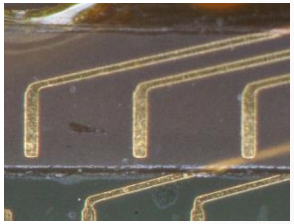
BG enhancement due to Touschek effect was detected.

Conclusions

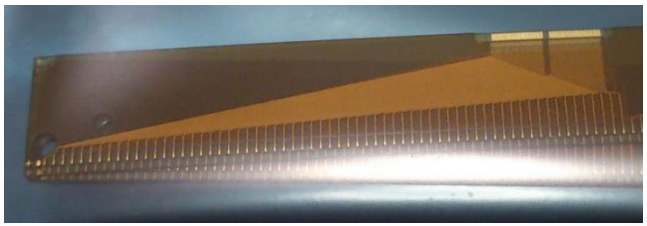
- SVD plays essential role in the physics program in Belle II
- All R&D needed for the SVD production have been completed and final SVD assembly is now on going.
- The good quality of assembled ladders and SVD is verified by checks of quality performed in each step of ladder parts production, ladder 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

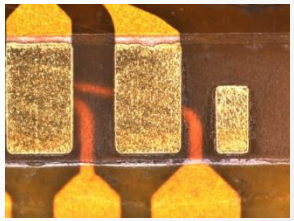
Name	Size (mm^2)	Layout
Origami CE	450.71 x 57.39	
Origami -Z	326.12 x 57.39	
Origami +Z	303.62 x 82.00	
PA0	124.9 x 7.2	

- Old PA0 design

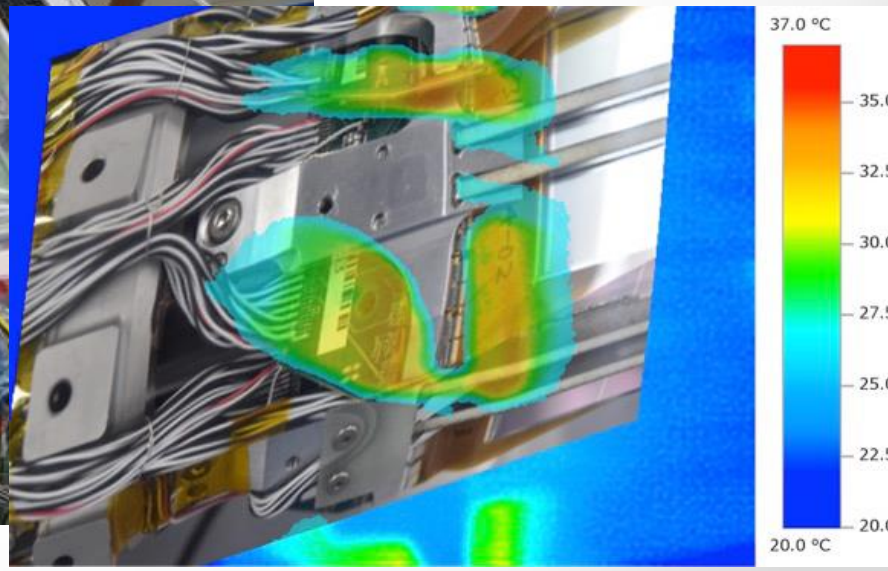


- Improved PA0 design
  - Thicker neck
  - Covered by coverlay
  - Laser cutting






Cooling Test of L3 ladders
2017-09


37.0 °C
35.0
32.5
30.0
27.5
25.0
22.5
20.0
20.0 °C

Belle II Collaboration

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