Belle-II Silicon Vertex Detector

Outline

- Belle-II Experiment at SuperKEKB
- Belle-II Vertex Detector
  - Belle-II Pixel Detector
  - Belle-II Silicon Vertex Detector
- SVD Key Features
- Ladder Assembly Procedure
- Mechanical and Electrical Quality Tests
- Status and Summary

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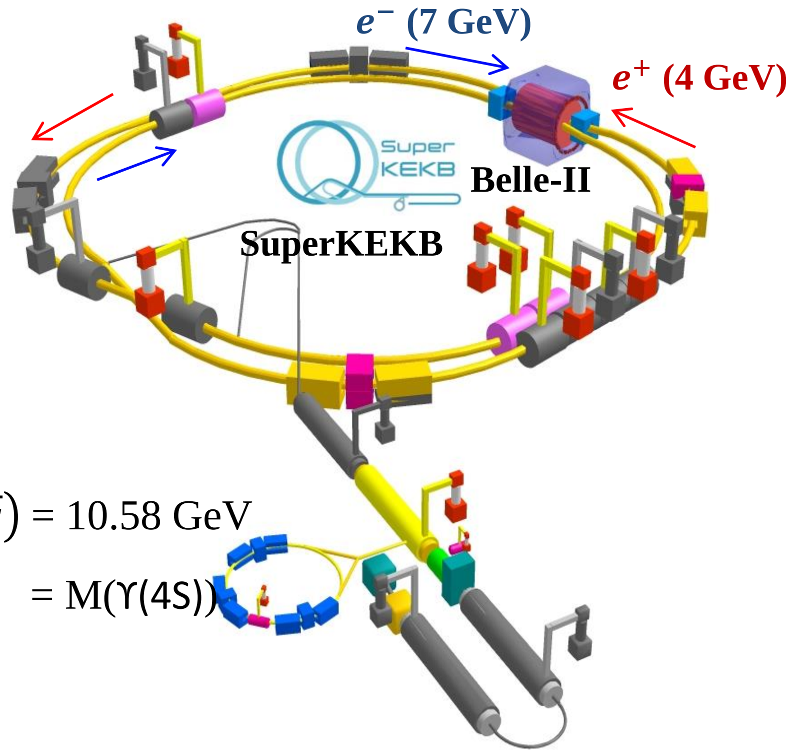
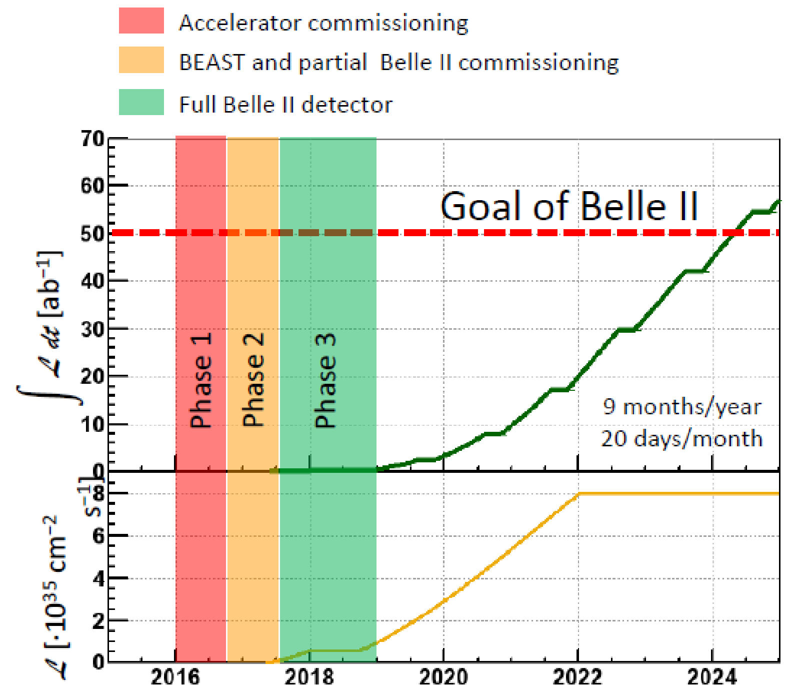
Belle-II Experiment at SuperKEKB





$E_{CM}\ (\sqrt{s}) = 10.58$ GeV

$= M(\Upsilon(4S))$

Boost ($\beta\gamma$) = 0.28 (2/3rd of KEKB) -- (Improved vertexing required)

Peak Luminosity = 8.0×10^{35} cm^{-2}sec^{-1} (× 40 KEKB). **(World's Highest)**

Reduced beam size (Vertical beam size 48/56 nm for LER/HER) (0.94 for LER/HER at KEKB).

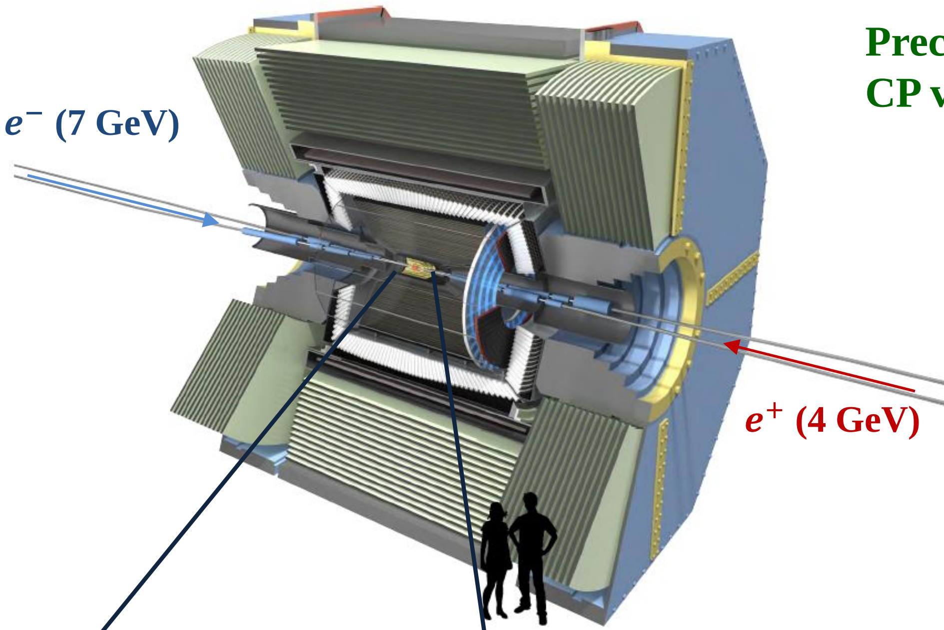
Increased Current (×2 KEKB), Upgrades to RF magnet, vacuum, etc

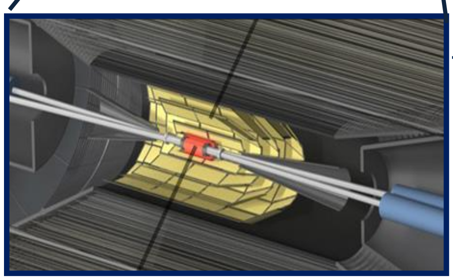
Integrated Luminosity = 50 ab^{-1} (by 2025) (× 50 KEKB)

Motivations : Search for NP signatures (charged Higgs, etc) in FCNC processes, in lepton flavor violating decays & in missing energy modes of B decays. Search for new sources of CP violations, etc.

Belle-II Vertex Detector

Precise measurement of decay vertex is necessary for CP violation measurements & for new physics search





Vertex Detector

Pixel Detector

2 layers of DEPFET pixels
(Innermost 2 layers)

Silicon Vertex Detector

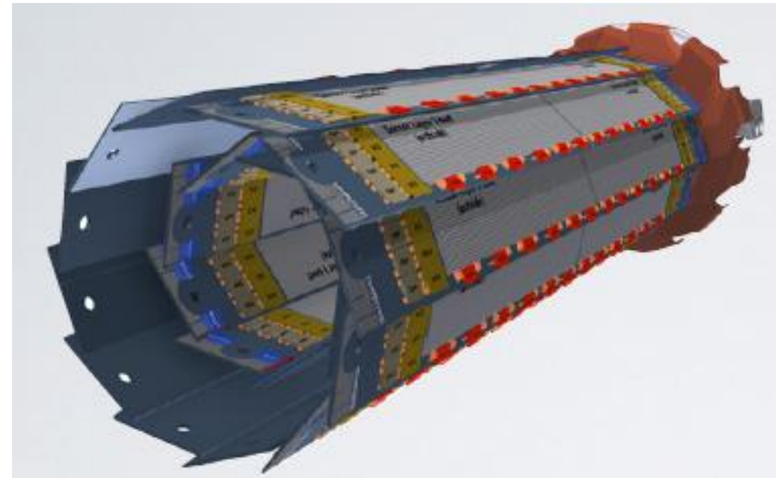
4 layers of DSSDs

VXD Requirements :

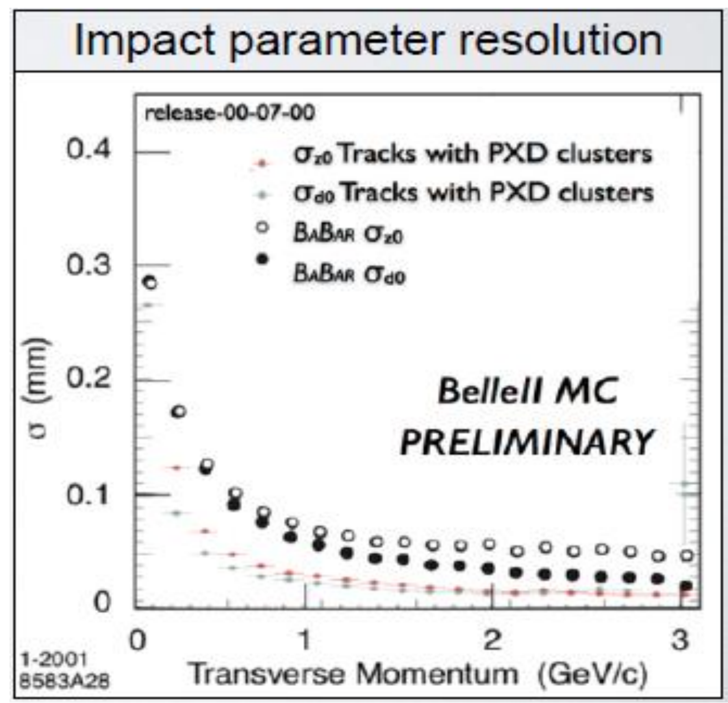
- Excellent spatial resolution and tracking.
- Fast readout electronics.
- Radiation tolerant (upto 100 kGy)
- Immune to background hits.
- Low material budget.
- Long term mechanical stability

Belle-II Pixel Detector

- 2 layers of DEPFET pixels.
- Low material budget
- Angular acceptance : $17^o < \theta < 150^o$
- Thickness = 75 μm
- Pixel Size = $50 \times 55\ \mu m^2$
- Low Noise and low power consumption
- Excellent spatial resolution ($\sigma < 15\ \mu$m)



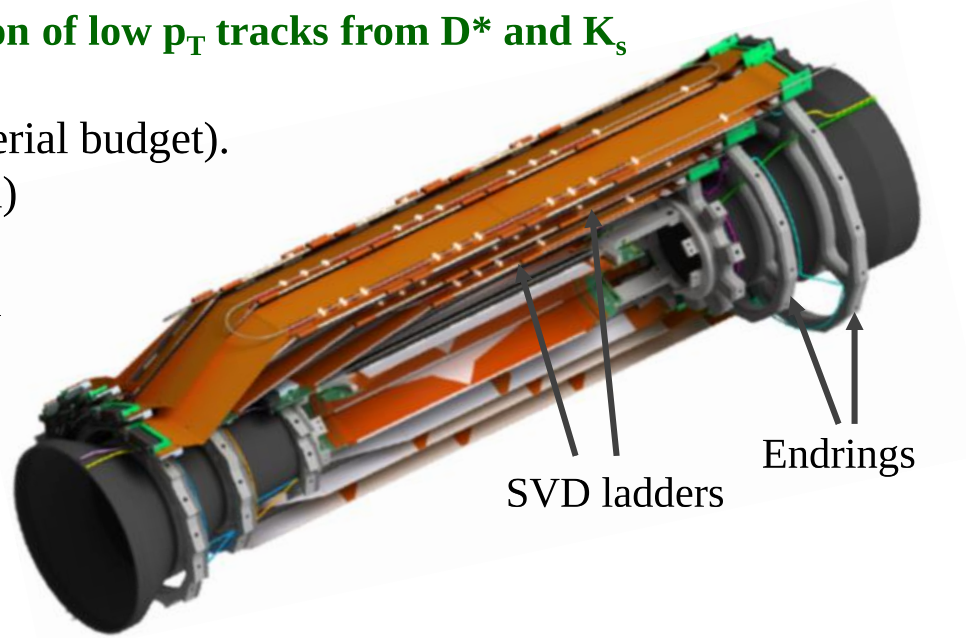
Layer	No. of Ladders	Radius
L1	8	14 mm
L2	12	22 mm



Large backgrounds, high occupancy (6.7%)

Belle-II Silicon Vertex Detector

- **Information from Belle-II SVD will be useful in eliminating background hits in PXD.**
- **SVD is important for efficient reconstruction of low p_T tracks from D* and K_s**

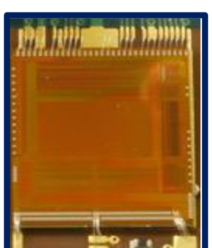


- 4 layers of DSSD sensors (DSSD: low material budget).
- Slant FW region (material budget reduction)
- Angular acceptance : $17^o < \theta < 150^o$
- Radii : 38 mm, 80 mm, 115 mm & 140 mm
- SVD length : ~ 650 mm
- Excellent time resolution (σ ~ 2-3 ns), impact parameter (~20 μm)

Electronics requirements :

The readout chip should have :

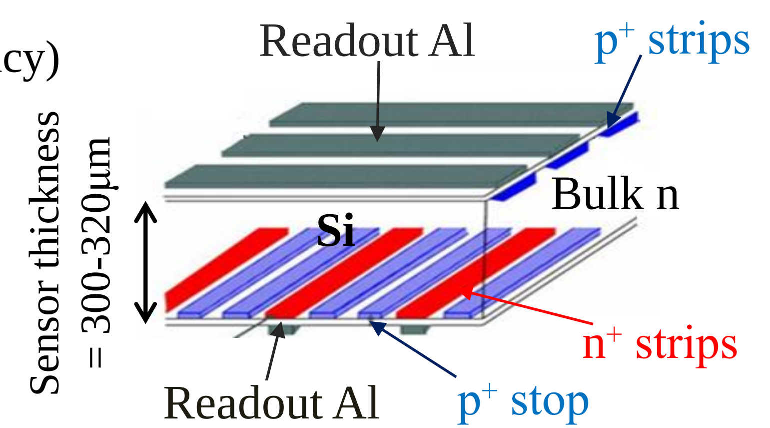
- Short shaping time (to prevent pileup & high occupancy)
- Radiation hardness
- Low material budget



APV25 Chip

APV25 characteristics

- Shaping time = 50 ns
- Radiation hardness > 300 kGy
- Reads 128 channels/chip

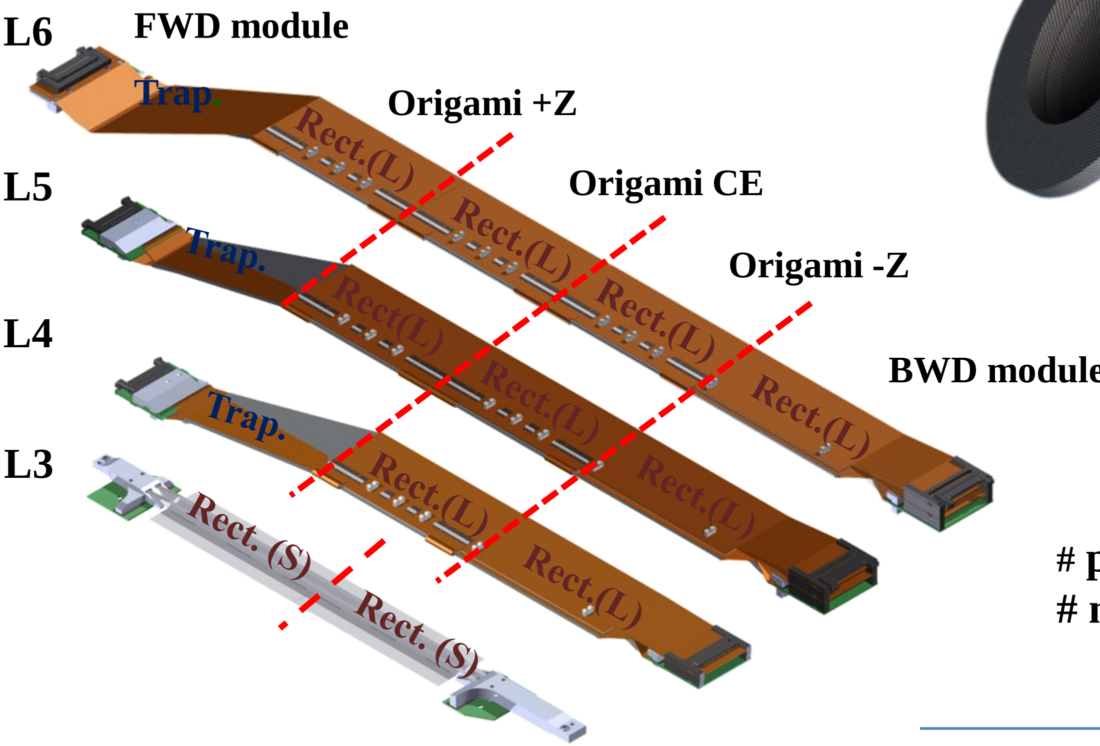


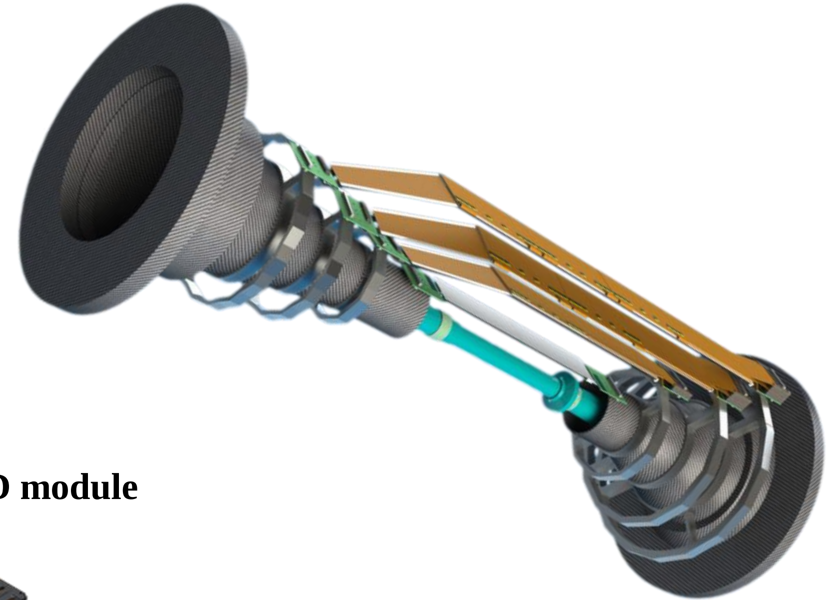
DSSD (Double Sided Si strip Detector)

Contd....

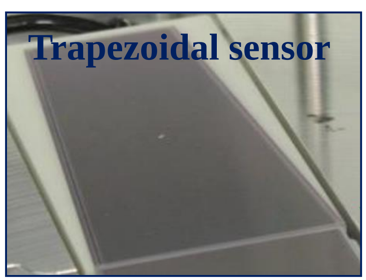
Belle-II SVD (in Details)

The SVD Ladders





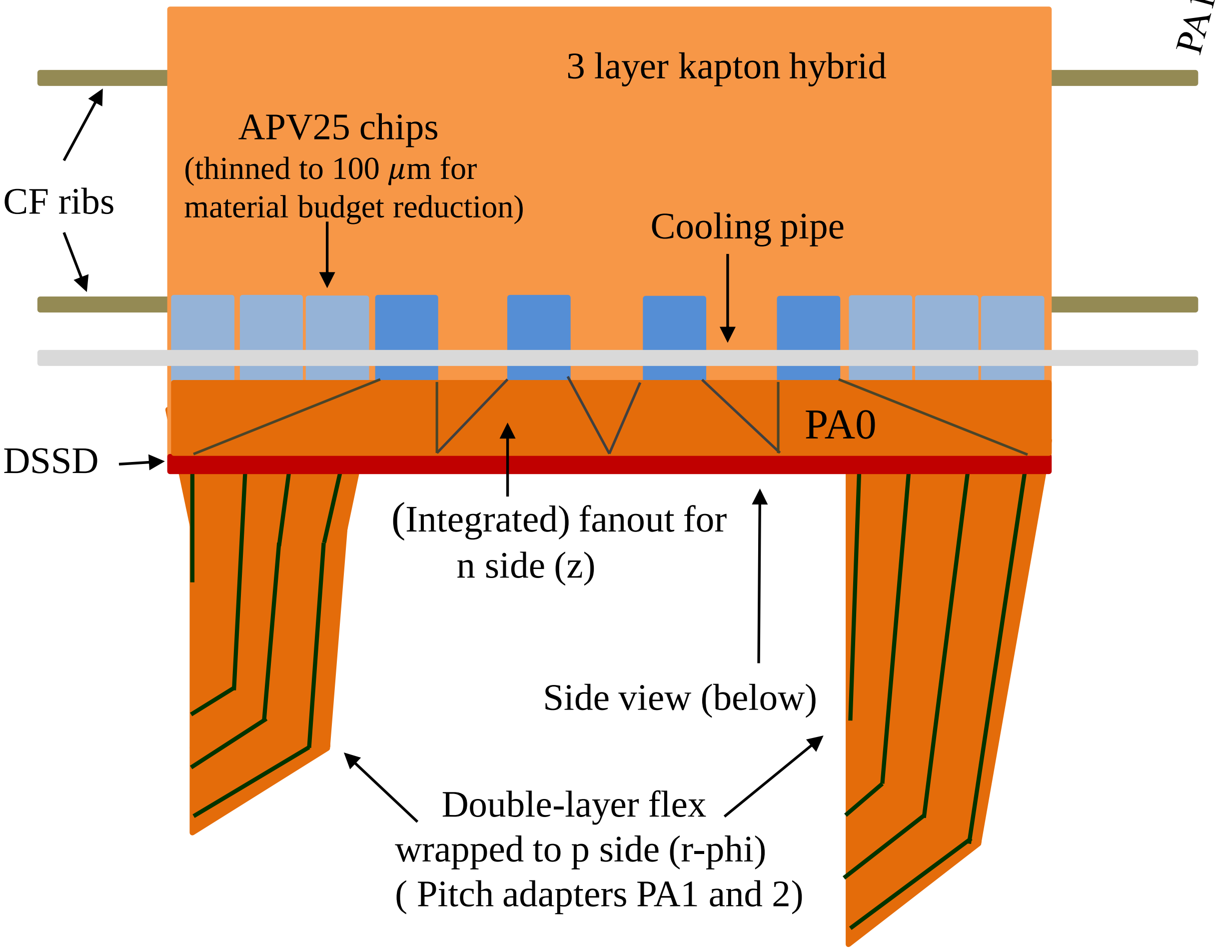
 # p-strips : 768 in each sensor.
 # n-strips : 768 in Rect.(S) sensor and 512 in Trap. & Rect.(L) sensors.

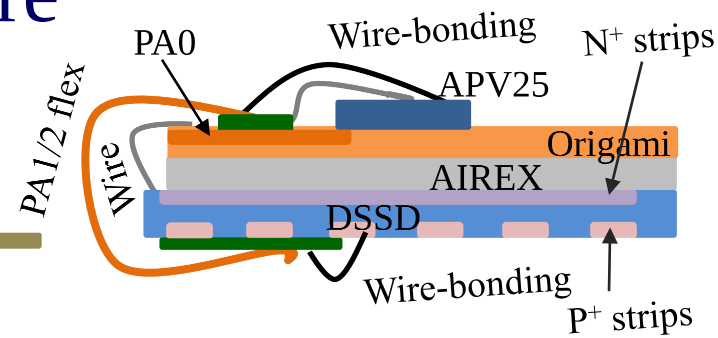


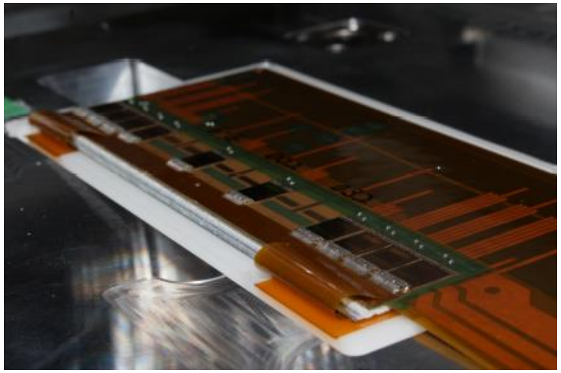
Layer	# of Ladders	Sensors/Ladder	APVs
L3	7	2	168
L4	10	3	300
L5	12	4	480
L6	16	5	800

SVD Key Feature

The "Origami Concept" (APV25 Chip-On-Sensor)





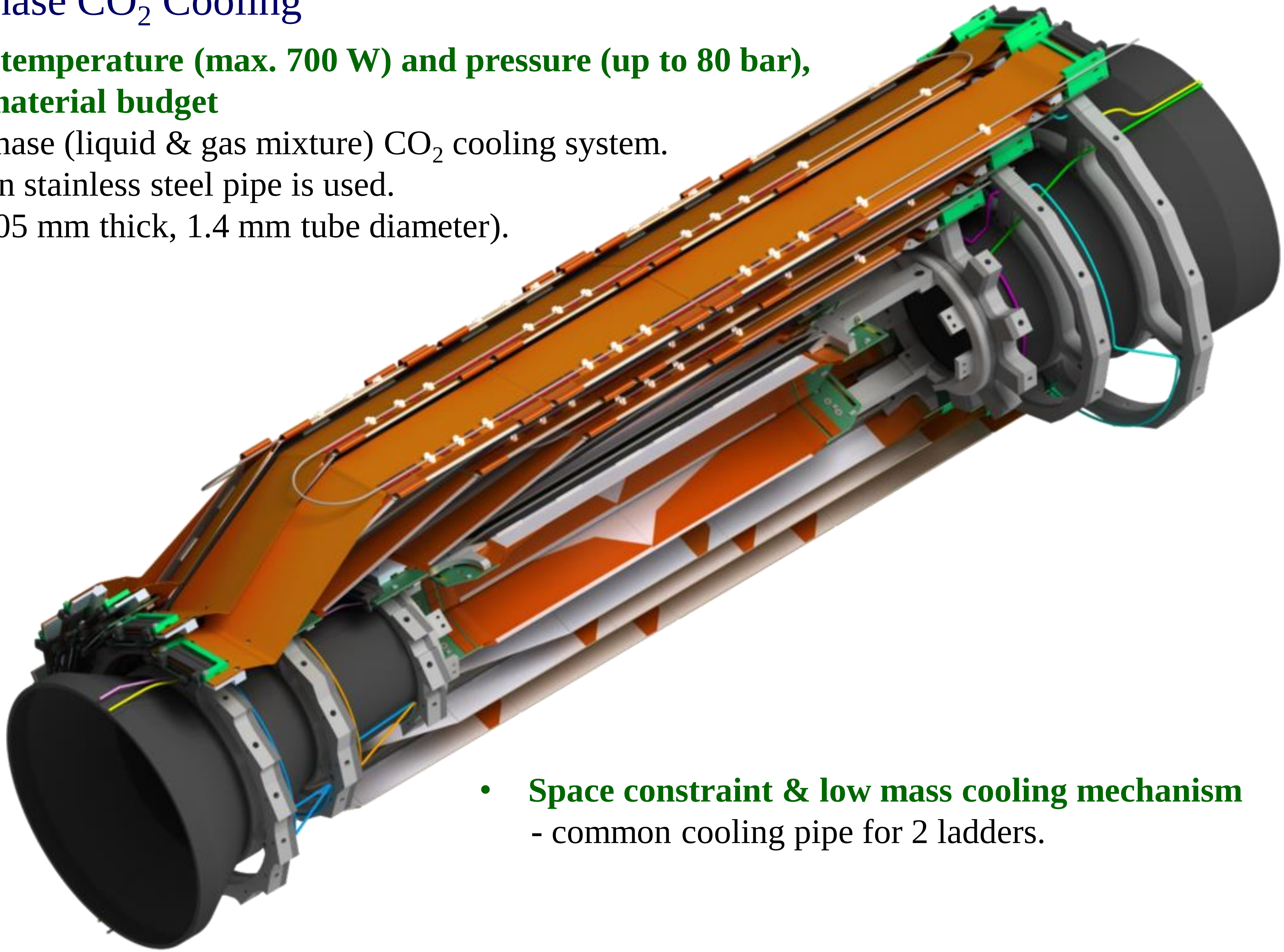


- For the inner sensors, Origami-flexible circuit is glued over the n-side of the DSSD with an electrical/ thermal isolation. The APVs are placed over the Origami-flex to minimize the **analog path length for capacitive noise reduction & fast readout.**

SVD Key Feature

Dual Phase CO_2 Cooling

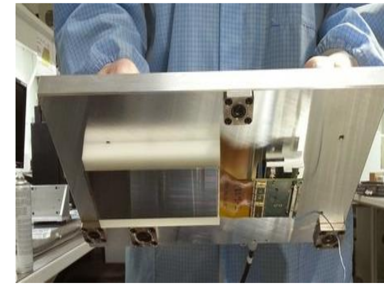
- **High temperature (max. 700 W) and pressure (up to 80 bar), low material budget**
  - 2 phase (liquid & gas mixture) CO_2 cooling system.
  - Thin stainless steel pipe is used. (0.05 mm thick, 1.4 mm tube diameter).



- **Space constraint & low mass cooling mechanism**
  - common cooling pipe for 2 ladders.

Ladder Assembly Procedure

Ladder assembly procedure for L4, L5 and L6



DSSD jig holding DSSD sensor

❑ BW and FW subassemblies (at Pisa)

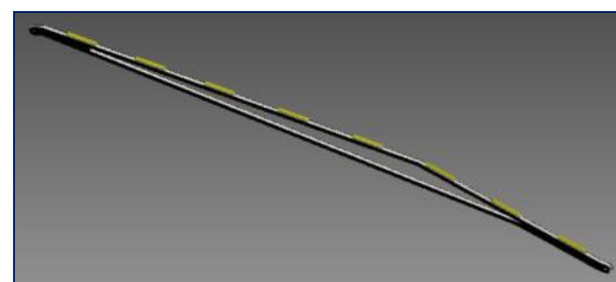
- Electrical test of DSSD sensors (Parts level EQA).
- Alignment of the detector and hybrid boards on the gluing jig.
- Gluing of the p-side DSSD with PA.
- n-side gluing.
- Wirebonding.
- Electrical test and laser scan.

FW and BW sensor sub-assemblies

- Subassemblies having sensor and hybrid board are fixed in multipurpose chuck.
- Shipping to the three assembly sites (TIFR, HEPHY and IPMU).
- Electrical inspection on arrival (Sub-assembly level EQA).

❑ Rib sub-assembly

- Gluing of ribs with the forward and backward endmounts.



Carbon Fibre Ribs : Support

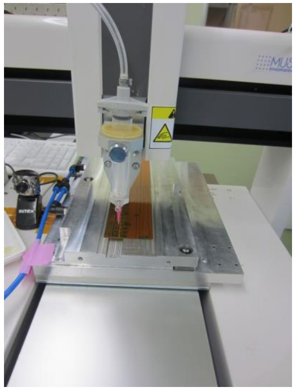
Ladder Assembly Procedure

Contd….

- Inner Sensor Subassemblies & Subassembly alignment (at the assembly sites)

✓ Sensor + PA subassemblies (at each site) (part 1)

- Electrical test of the DSSD sensor and Origami (Parts level EQA).
- Gluing of the PAs (PA1 and PA2) with p-side of the rect. DSSD.
- Wirebonding of the PA1 and 2 with p-side DSSD.



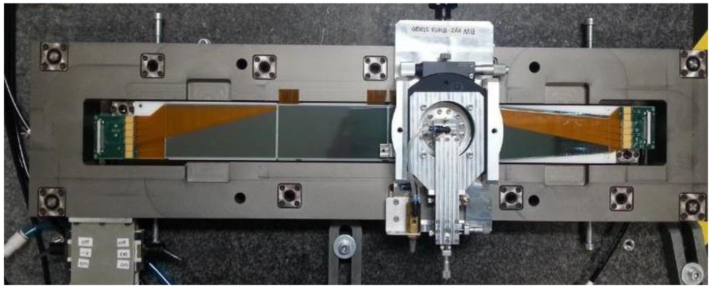
Gluing

✓ Sensor + Subassembly alignment on the assembly bench

- Placing inner DSSDs on the assembly bench.
- Placing FW/BW subassembly on the assembly bench from the FW/BW multipurpose chucks.
- Aligning each sensor using XY-Ɵ position tuning jig under coordinate measuring machine (CMM).

✓ Sensor + PA subassemblies (at each site) (part 2)

- Gluing AIREX (thermal/electrical insulator) on the sensors.
- Gluing Origami to the inner sensor.



DSSD alignment with XY-θ jig.

Contd....

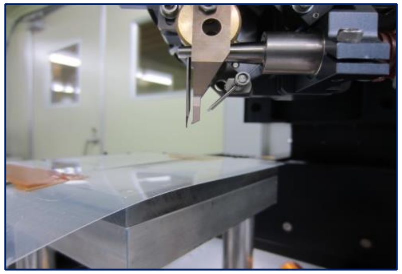
Ladder Assembly Procedure

- Wirebonding between PA0 and n-side of DSSD and PA0 to n-side APVs
- Wrapping the pitch adapters PA1/2 with PA-bend jig and gluing.
- Wirebonding of PA1/2 with p-side APVs.
- Electrical inspection (Sub-assembly level EQA)

Origami (with PA0)

❑ Full ladder assembly

- Gluing the FW/BW sub-assembly onto the ribs.
- Placing APV guards on the subassemblies.
- Gluing the origami subassemblies onto the ribs.



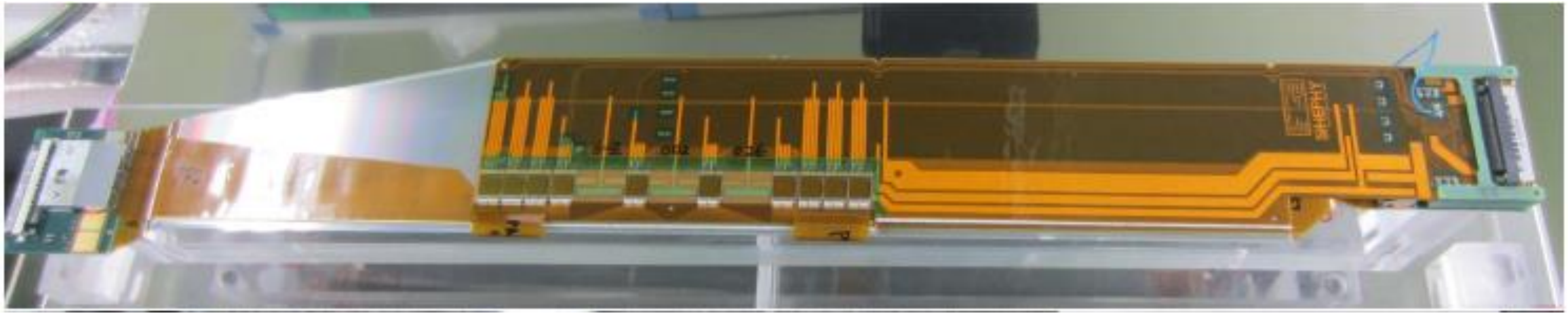
Wirebonding

❑ Glue CO_2 clips.

❑ Connect the ground wires to the endmounts.

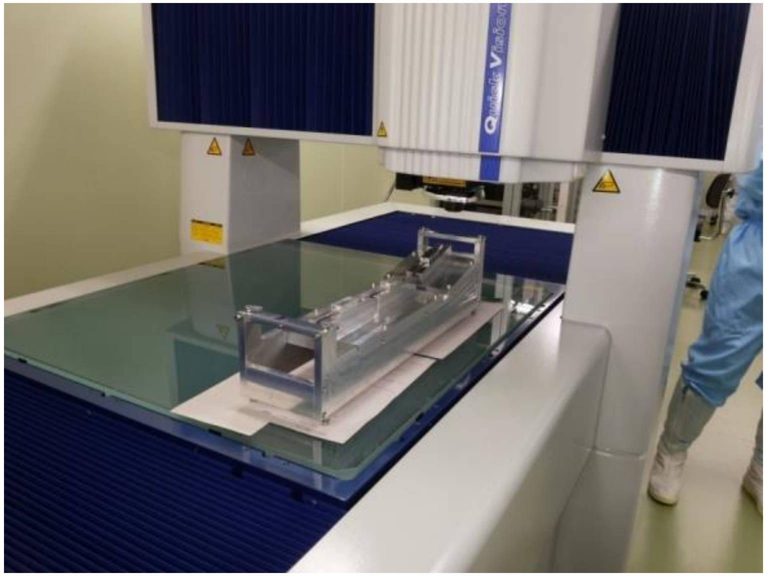
Challenges : All the components have to be properly aligned and positioned (i.e., glued) on the support ribs (CF ribs), matching exact geometrical tolerances.

Mechanical Precision Measurement with CMM



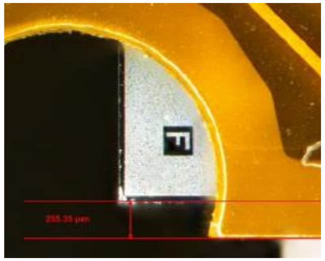
Fully assembled L4 ladder

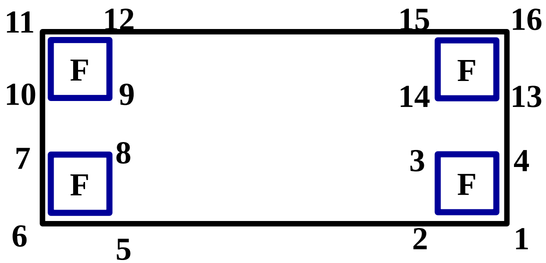
We do mechanical testing under CMM to make sure that the spacing between the sensors, tilt, slant and rotation angles are within desired precision.



CMM bench

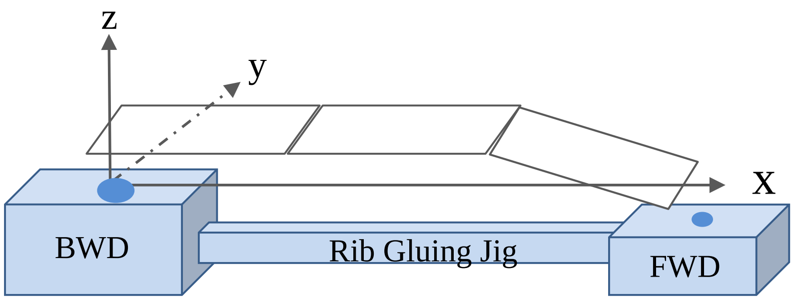
F marks are present at the DSSD corners for alignment during assembly and final measurement on the ladder.



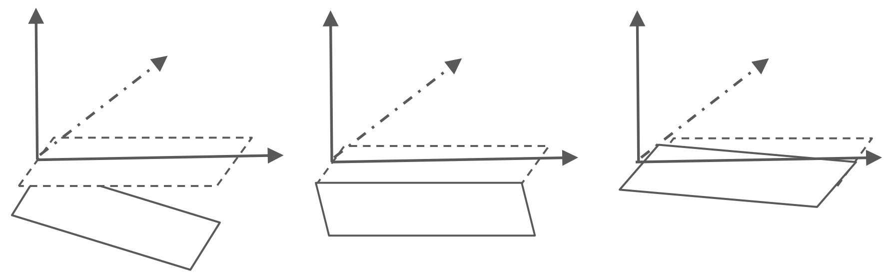


DSSD sensor

Mechanical Precision Measurement with CMM



Ladder Coordinate Frame (L4)



Slant, tilt and rotation angles

Survey Results : Translational and Rotation parameters

Displacement of the DSSD sensors in XYZ directions w.r.t. nominal position : Should be less than 200 μm.
Slant angle : Design requirement is 11.9 degrees for FW sensor and 0 degrees for CE and BW sensors.
Tilt and slant angle : Design requirement is 0 degrees for all sensors.

Sensor	Δx (μm)	Δy (μm)	Δz (μm)	Slant angle	Tilt angle	Rotation angle
L4 Forward	-72.3972	-10.1284	79.7179	-11.9384 ± 0.0051	-0.0280 ± 0.0118	-0.0229 +- 0.01
L4 Origami-Z	12.5750	-39.0695	-26.2813	-0.0544 ± 0.0008	0.0639 ± 0.0017	-0.0279 +- 0.01
L4 Backward	- 63.8592	-36.3776	1.09204	-0.0042 ± 0.0025	-0.0007 ± 0.0053	-0.0863 +- 0.01

Results of a final grade L4 ladder.

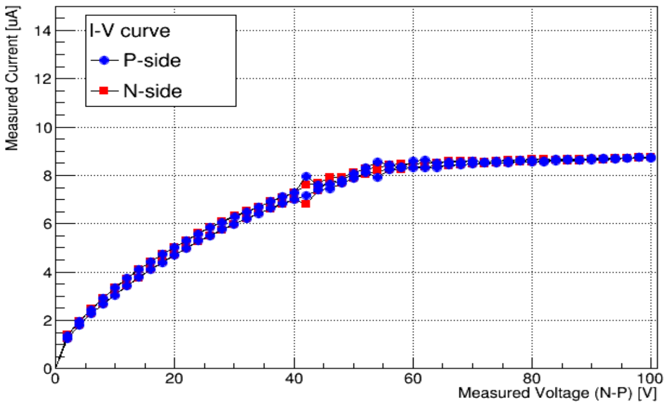
Results are within desired precision. Similar results are observed in all assembled ladders of all layers.

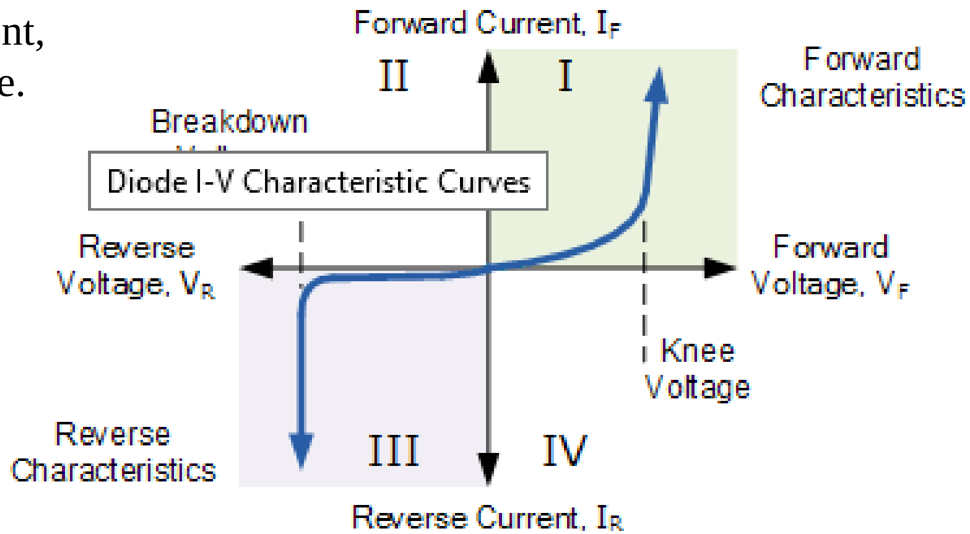
Electrical Quality Assurance

I-V Characteristics Curve :

To check the quality of the DSSD sensor

IV tests are needed to determine the dark current, breakthrough voltage and full depletion voltage.



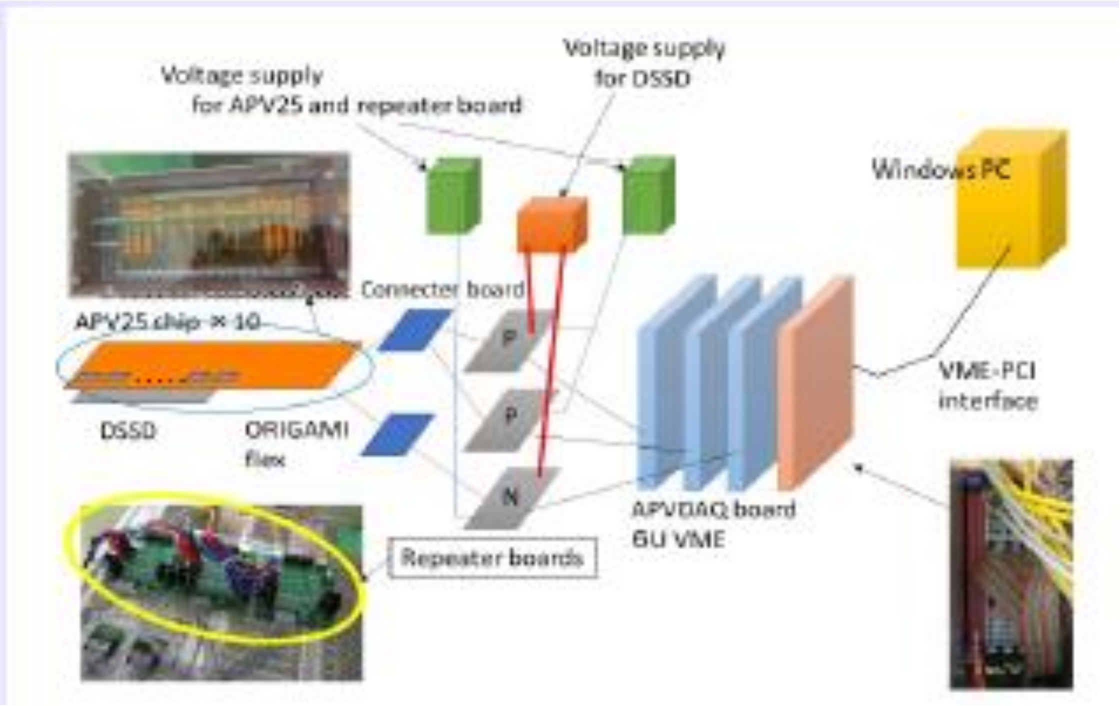


Reverse voltage vs reverse (leakage) current

Electrical Test and Source Scan:

Electrical or radioactive signals are passed through the DSSD modules (with APVs) to check the APV response. Based on the APV response curves we identify some of the strips as defective.

Electrical Quality Assurance



Cabling of the APVDAQ

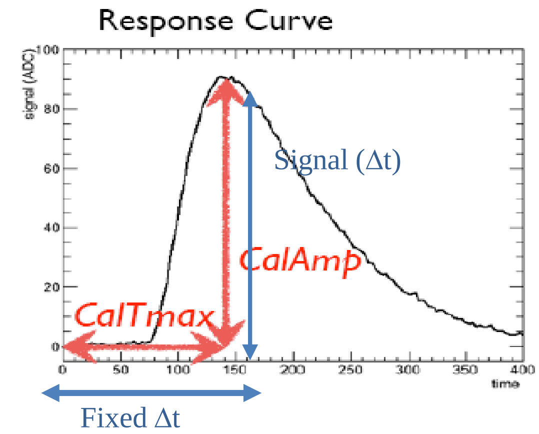
APVDAQ Run modes

- ADC delay scan
- FIR calculation
- Software/Pedestal run
- Internal calibration scan
- Intcal vs vsep scan

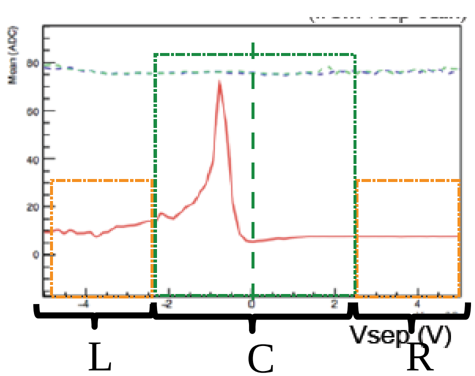
Electrical Quality Assurance

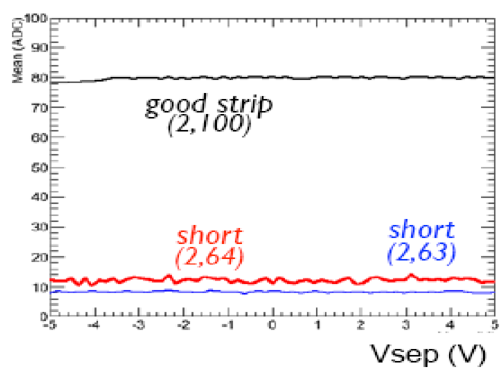
APV response evaluated at a fixed for different values of Vsep.

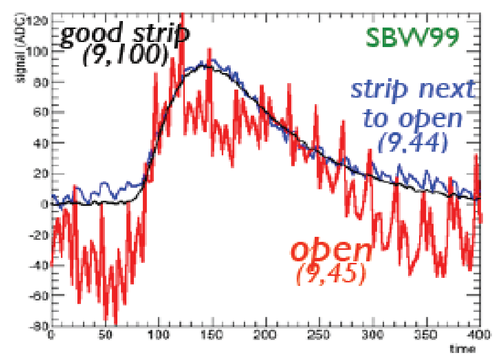
$$\text{Mean} = \frac{\Sigma_i^N Signal_i(\Delta t)}{N} \qquad \text{RMS} = \sqrt{\frac{\Sigma_i^N (Signal_i(\Delta t) - Mean)^2}{N-1}}$$

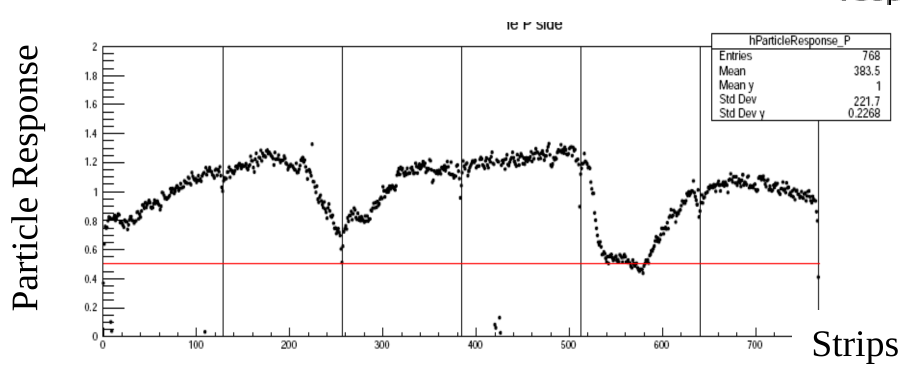


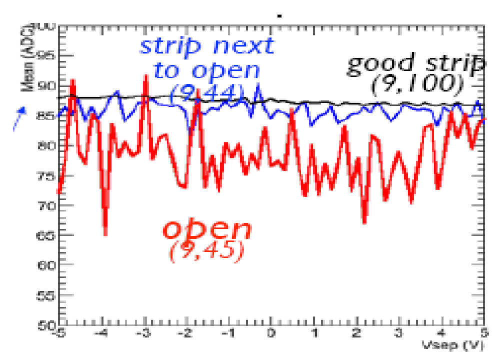
- | average $_{LR/L/R}$ (Mean) – max $_C$ (Mean) | > 20.0 → **Pinhole**
- Gain or Average (Mean) < 50 ADC → **Short**
- Very large noise (Noise > 50 ADC) → **Open**
- Noise > 8 ADC → **Noisy**
- Particle response < 0.5 → **Particle response defect**











Very few defects (< 2%) are observed in all assembled ladders. The defective strips are noted.

Status and Summary

FW and BW subassemblies of Layers 4, 5 and 6 are produced at INFN, Pisa. **Layer 3** ladder assembly is done by University of Melbourne, **Layer 4** by TIFR India, **Layer 5** by HEPHY Vienna and **Layer 6** by Kavli-IPMU, Tokyo.

- All sites have assembled electrically functional SVD ladders having desired mechanical precision.
- Mass production of final SVD ladders is ongoing at different sites.

As of mid Sept., 2016.

FW/BW Subassembly : BW : 100% completed.
FW : 94 % completed.

Layer 3: 5 out of 7+2 ladders completed (56%).

Layer 4: 3 out of 10+2 ladders completed (25%).

Layer 5: 4 out of 12+3 ladders completed (27%).

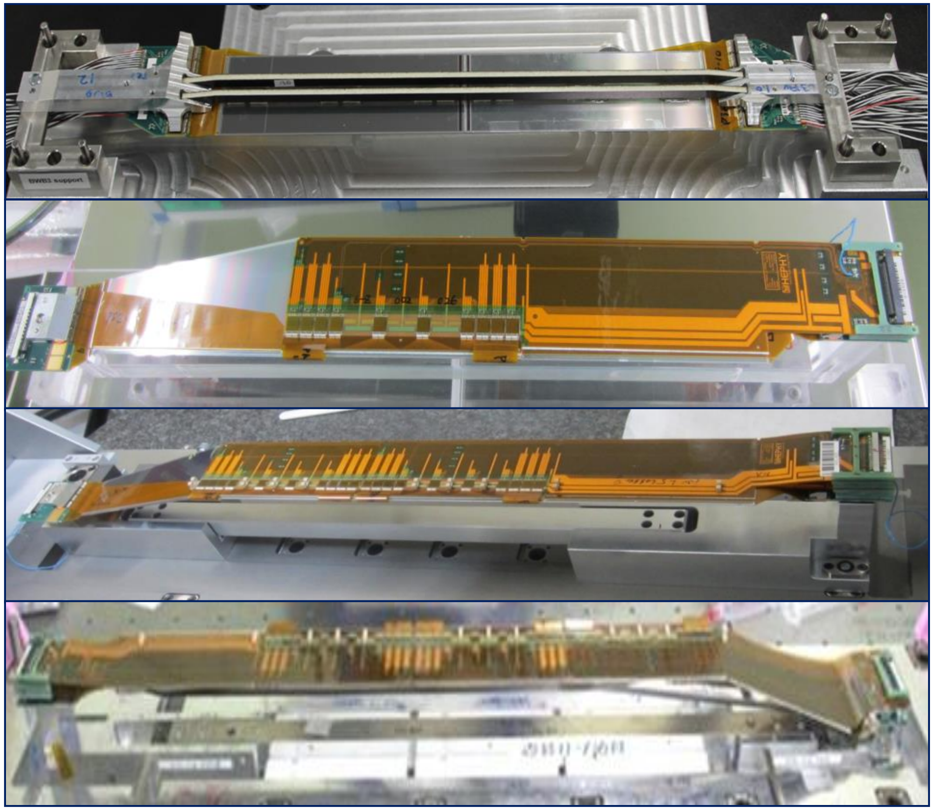
Layer 6: 3 out of 16+4 ladders completed (15%).

- Ladder production is expected to complete by Nov 2017.

Contd....

Status and Summary

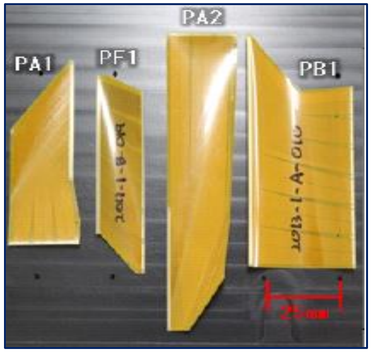
- SVD ladder mount (at KEK) is scheduled to start on Feb 2017. (– SVD assembly procedure is being developed and checked with prototypes of necessary assembly tools. Procedure is well checked by review committee.)
- SVD readiness at KEK by Dec 2017.
- Start of PXD + SVD integration planned on Dec 2017.
- VXD commissioning on June 2018.
- Belle II physics run forseen on Fall 2018.

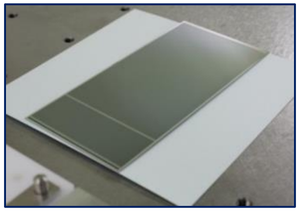


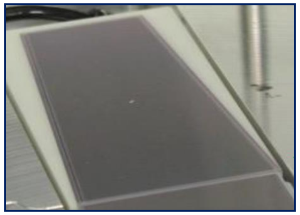
Thanks....

Backup Slides....

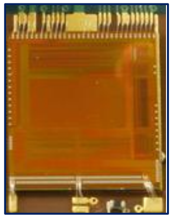
Ladder Anatomy: Components of an SVD ladder



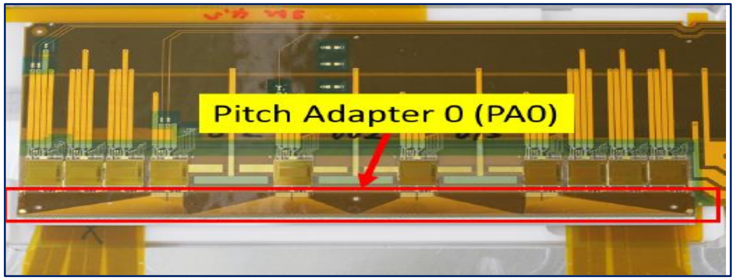




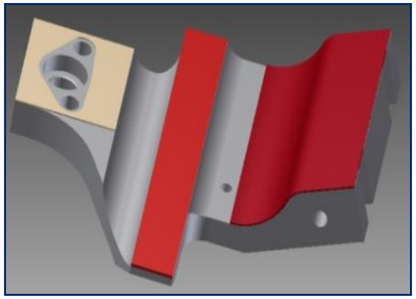
Rectangular & trapezoidal DSSD sensors



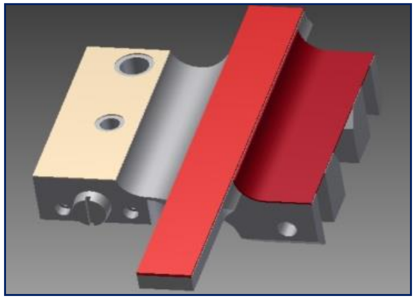
APV25 chip



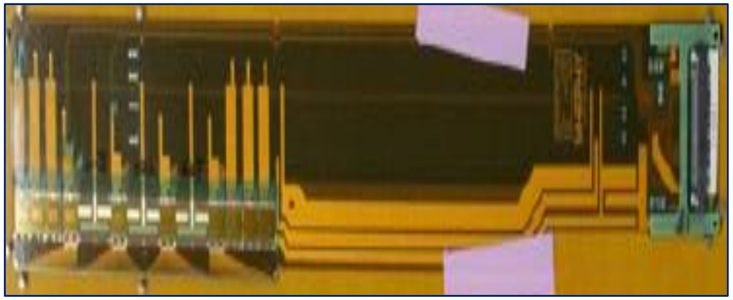
Pitch adapters PA1,2, PF1,2, PB1,2 & PA0 :
Flex circuits to transmit detector signals to APVs



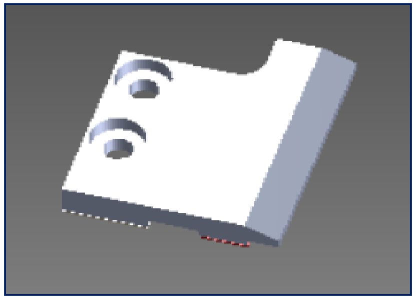
Backward end mount



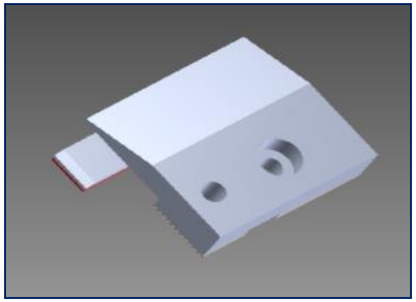
Forward end mount



Origami : Flexible circuits to transmit detector signals to ladder ends.

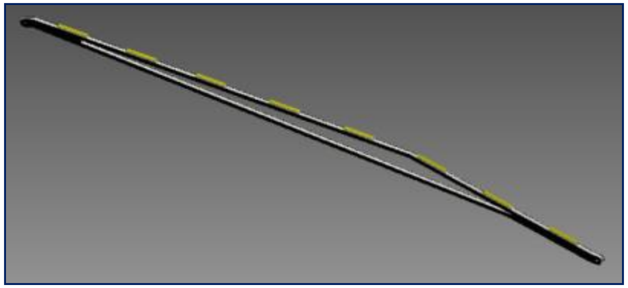


Backward APV guard

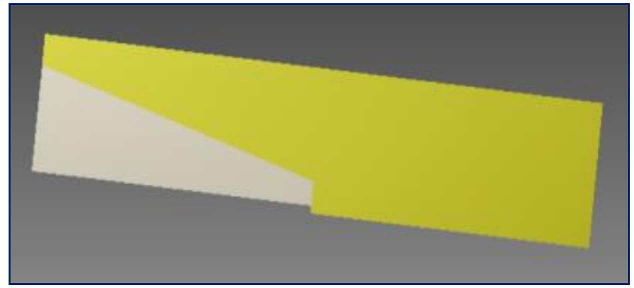


Forward APV guard

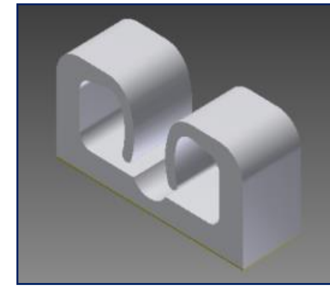
Ladder Anatomy: Components of an SVD ladder



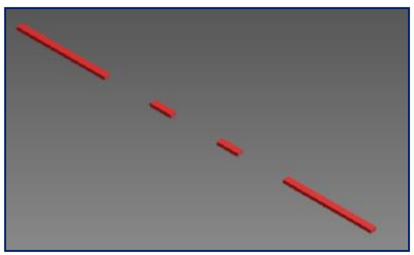
Carbon Fibre Ribs : Support



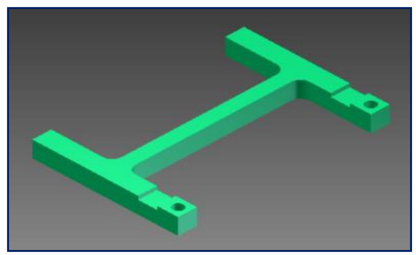
Airex : Thermal and electrical insulator between DSSDs and APV25 chips



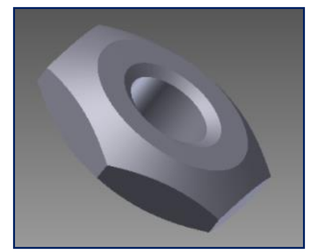
CO_2 clamps



Keratherm

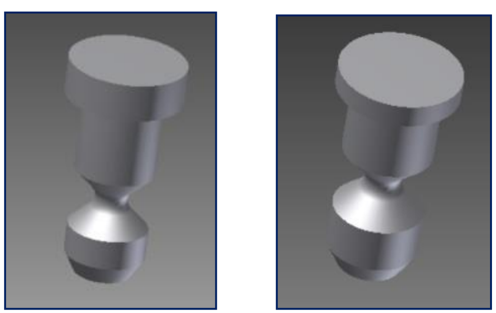


H shape

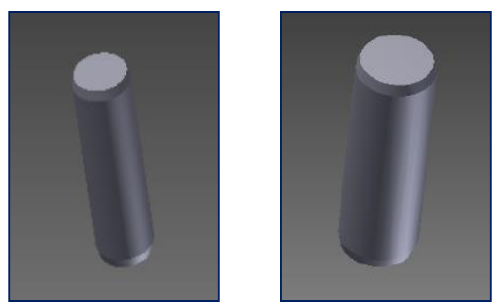


DIN 439 (M2 x 0.4)

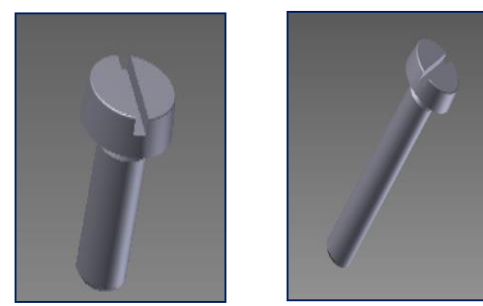
Prism rail



FW and BW kokeshi pins

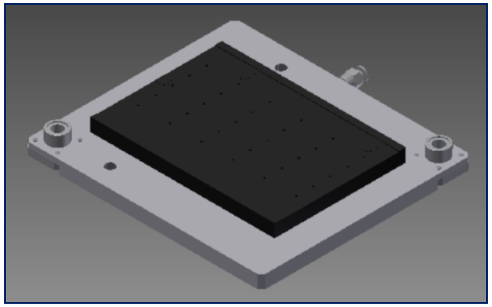


DIN 84 (M2 x 8 and M2 x 12)

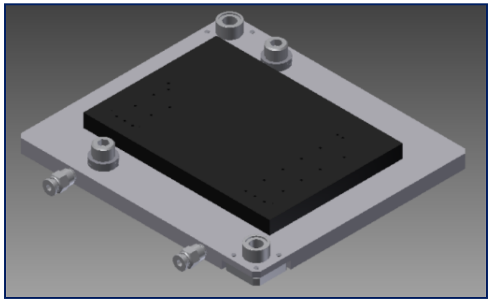


ISO 8734 Pins
(φ1 x 10 mm & φ3 x 10 mm)

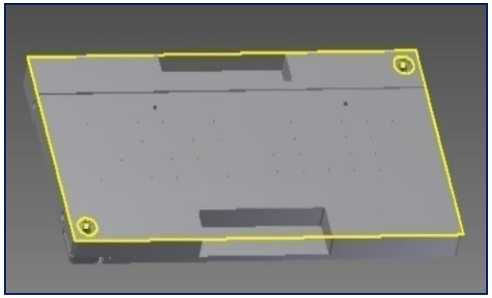
Jigs Used for Ladder Assembly



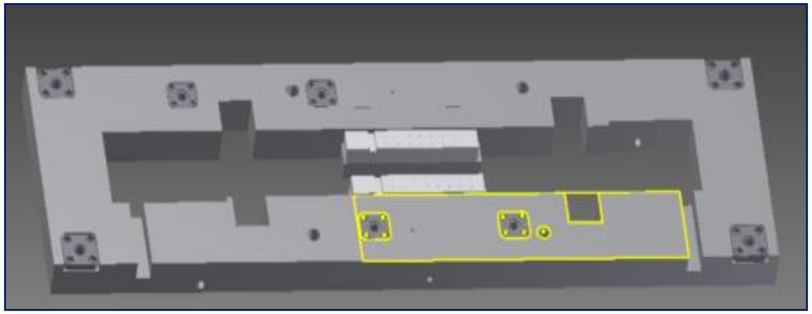
DSSD jig



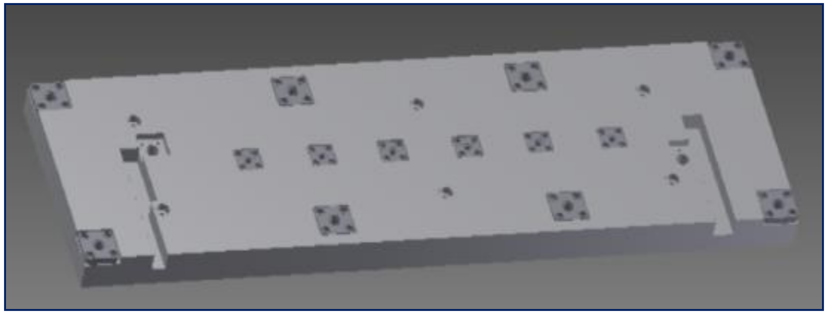
PA1 and PA2 jig



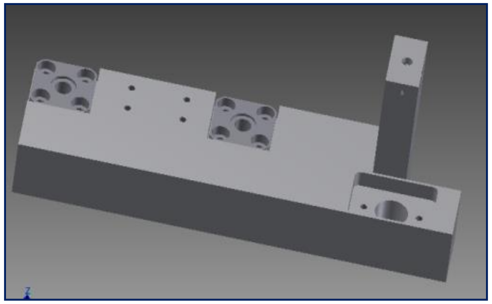
Airex jig



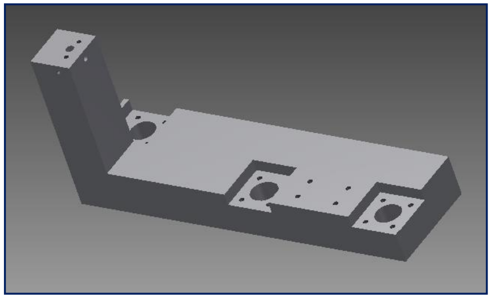
Assembly bench



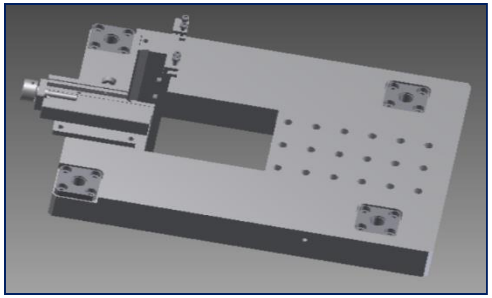
Assembly base



BW mount block



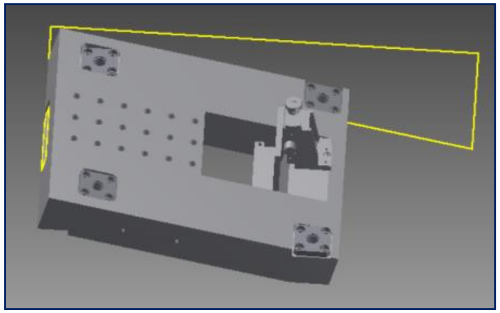
FW mount block



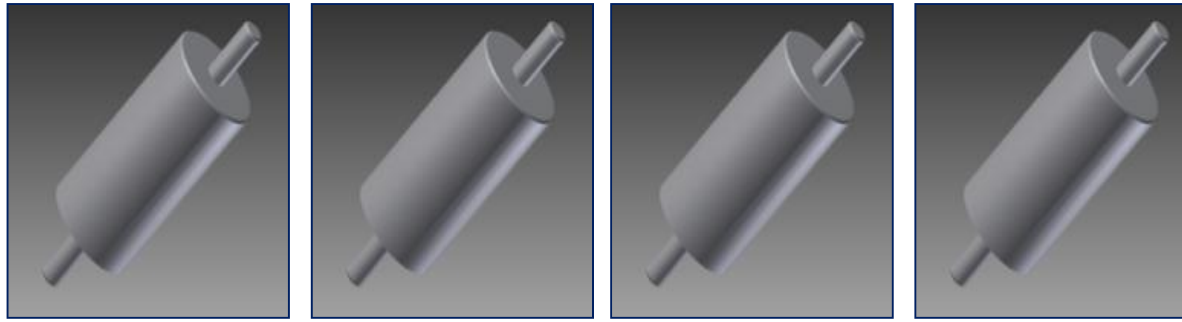
BW jig

Jigs Used for Ladder Assembly

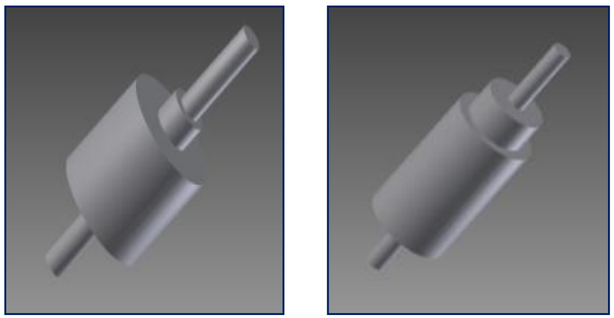
Backup Slides....



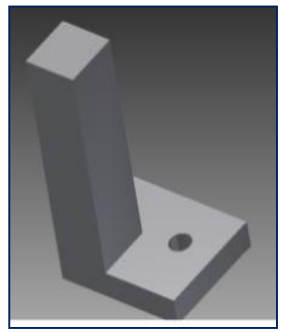
FW (slanted) jig



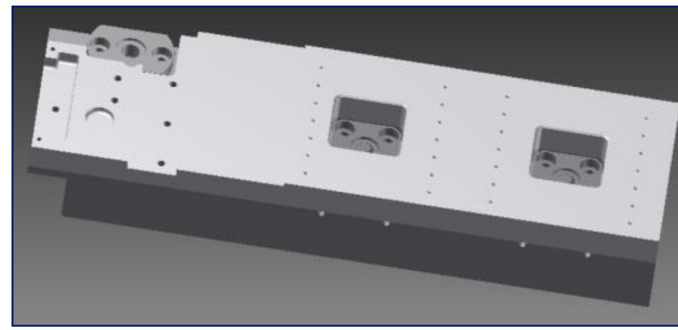
BW supporting rods for assembly bench



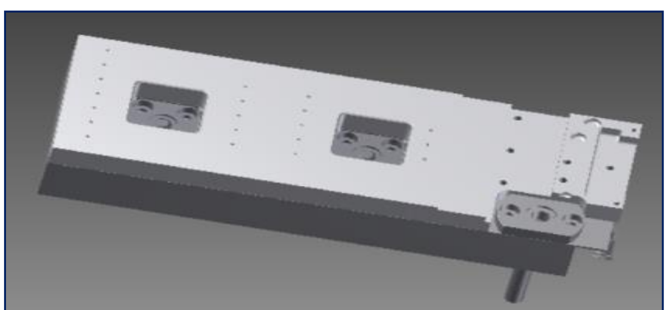
FW supporting rods



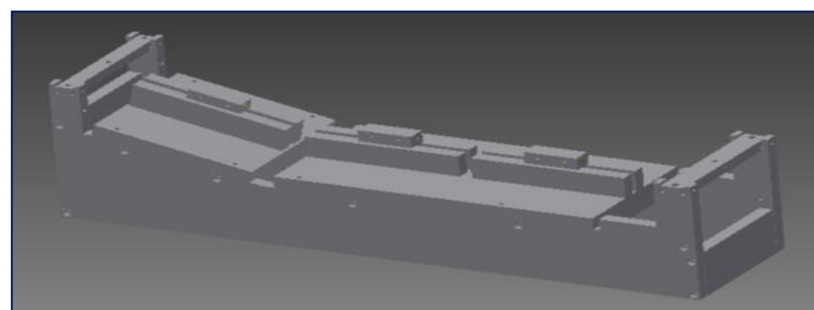
Slant support



BW inlet 2 jig



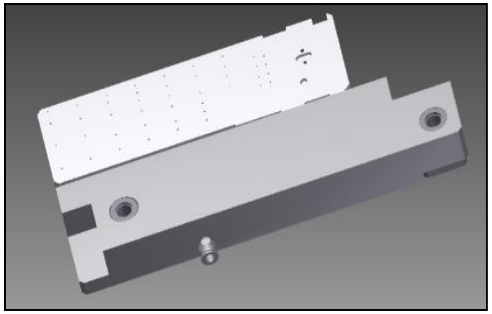
FW inlet 2 jig

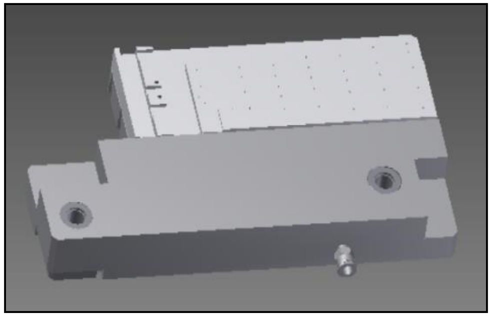


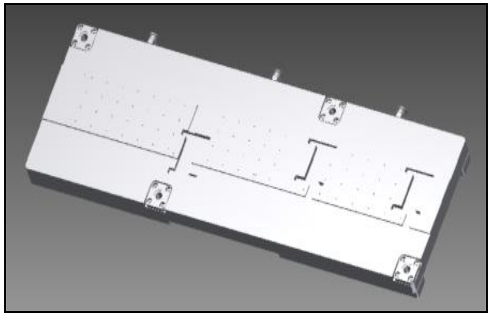
Rib gluing jig

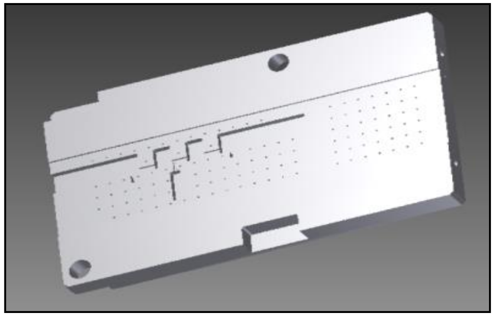
Jigs Used for Ladder Assembly

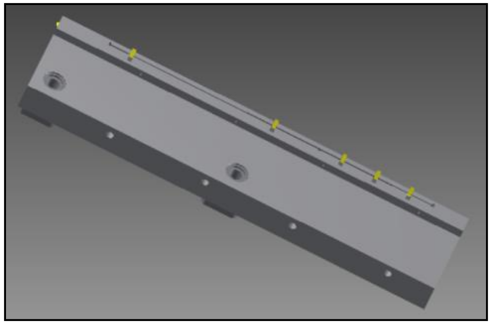
Backup Slides....

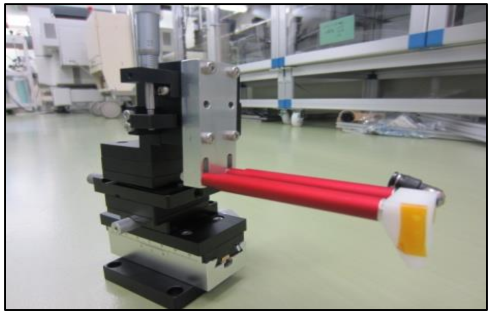

PB2 jig

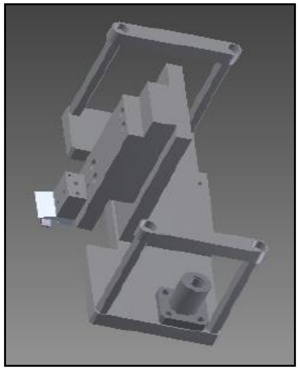
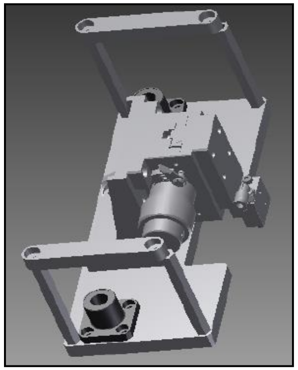

PF2 jig

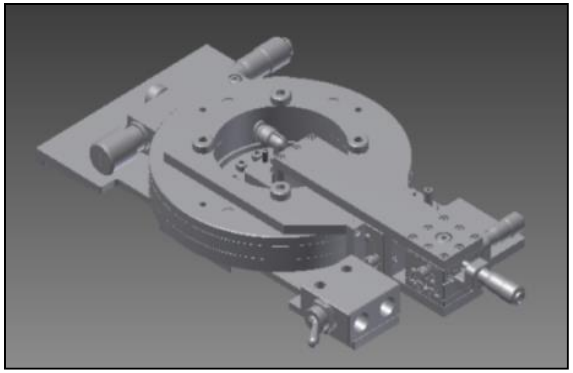

Origami alignment jig


Origami-Z jig


CO_2 clamp jig


PA bend jig



FW and BW APV guard jigs

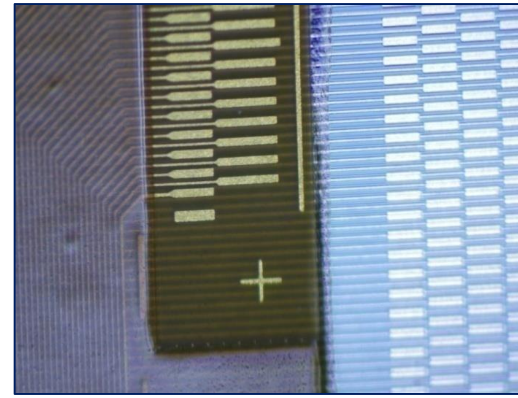

XY theta stage

Gluing

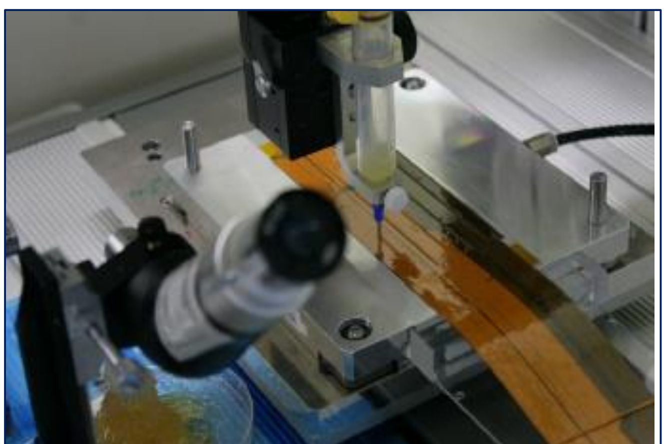
The components are attached using Glue Aryldite

Short master 3 gluing robot

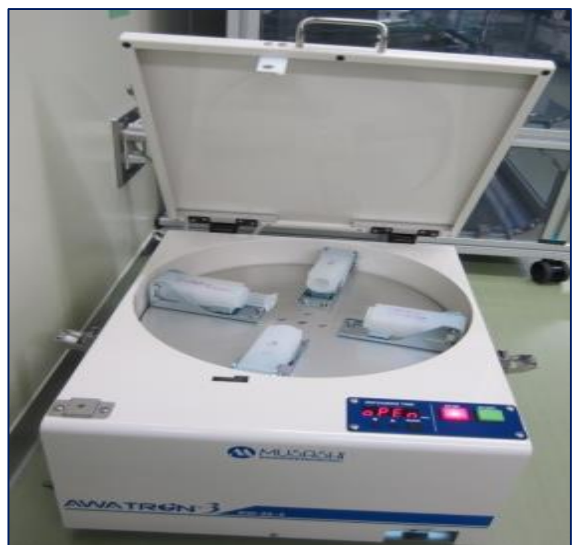
Glue Dispenser



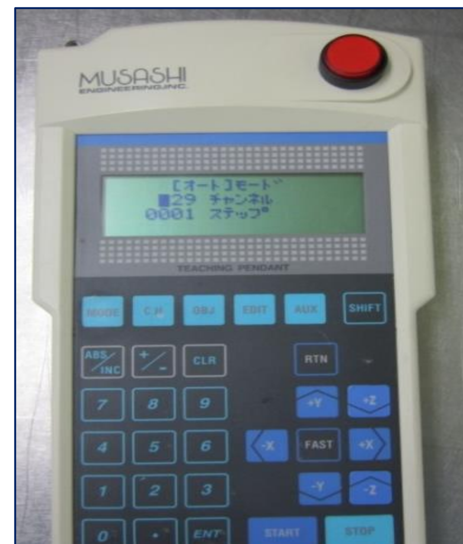
Microscopic Pictures



Gluing on Origami flex



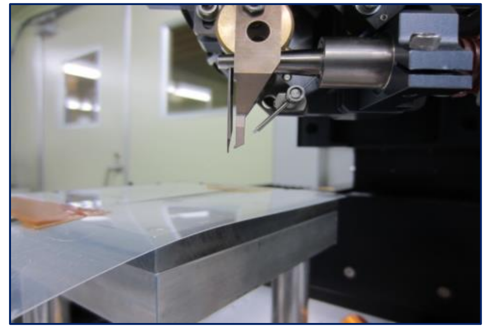
Centrifuge

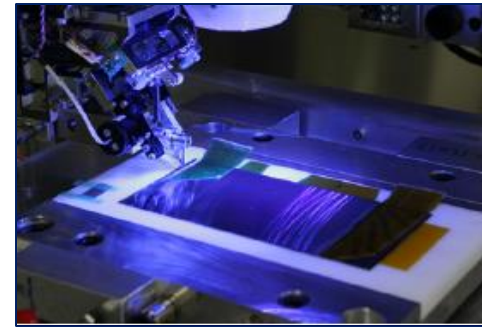


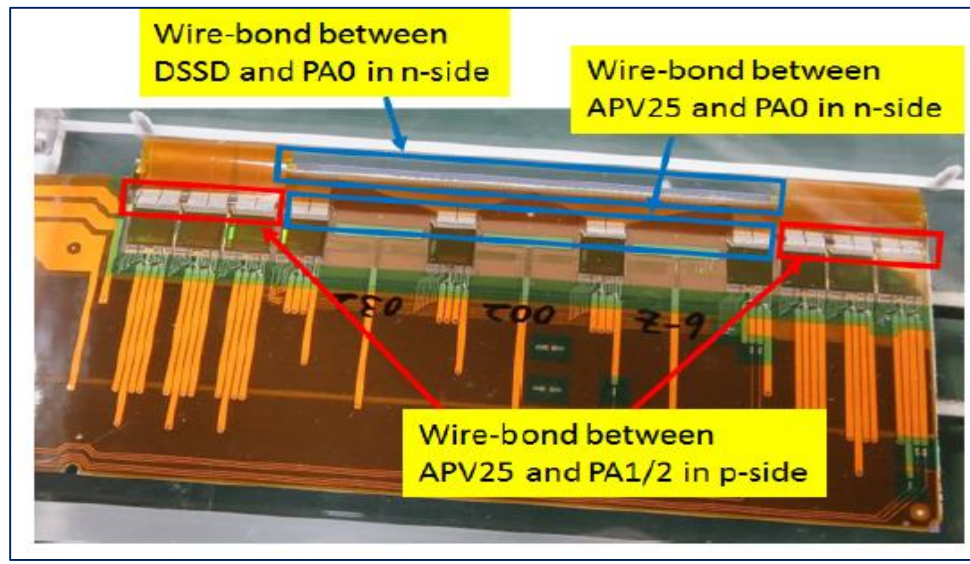
Teaching pendant

Wirebonding

The components are electrically connected using the wire-bonding. Quality of the wirebonding is determined by visual inspection and using pull force (in gf) with pull tester.



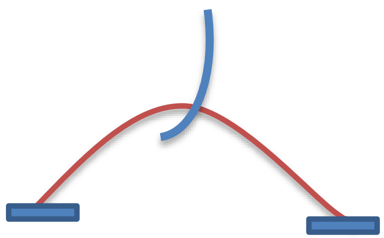




Pull Testing of Strength of Wire Bonds

Force is applied on the wire bonds (by the pull tester) to check the strength of the wire bonds.
Quality Factors : Bonding yield, Pull strength

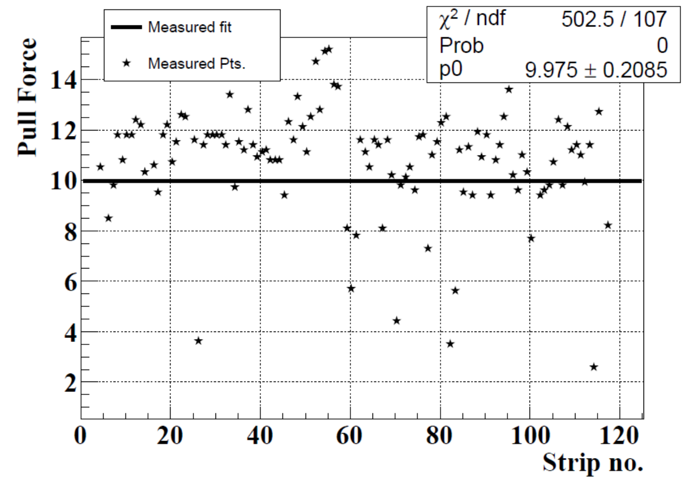
Pull Force



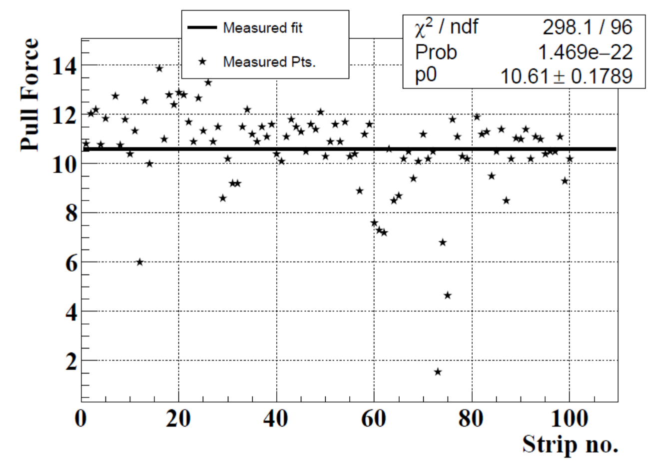
Loop dist. = 1510 μm

Loop Height = 533 μm

Pull tester



PA0 inner loop (Class B L4)



PA0 outer loop (Class B L4)

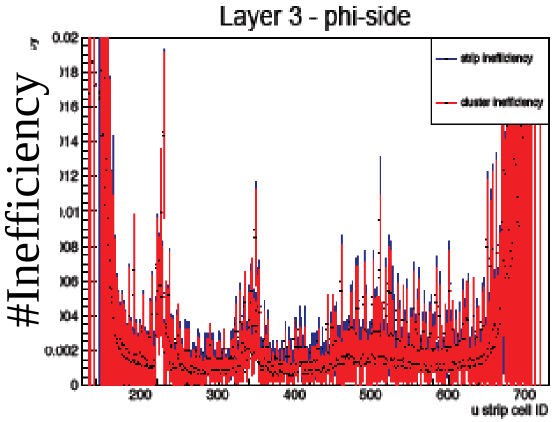
Average pull strength = 11.0 gmf

Beam Test

In Apr. 2016, a beam test was done at DESY (Hamburg, Germany) for about a period of 4 weeks with a combined module of (PXD +SVD). The module was assembled and tested under realistic conditions with electron beam energies ranging from 2 - 5 GeV and B field ranging from 0 - 1T.

Beam test main motivations:

- PXD + SVD integration.
- Software and hardware verification.
- SVD efficiency and resolution studies.



Efficiency of each SVD layer was evaluated by:

Track extrapolation using hits on 3 SVD layers.

Prediction of the extrapolated track position on the 4^{th} SVD layer.

Counting the number of hits/clusters on 300 μm wide region around the predicted track position.

Calculation of the efficiency of the layer as: ϵ = #hits/#tracks.

Inefficiency defined by $\eta = 1 - \epsilon$

Results : Inefficiency is observed to be less than 1%