Belle II Silicon Vertex Detector (SVD)

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- Belle II at SuperKEKB
- Belle II Vertex Detector
- Belle II SVD
- Origami Concept
- Performance Tests
- Summary

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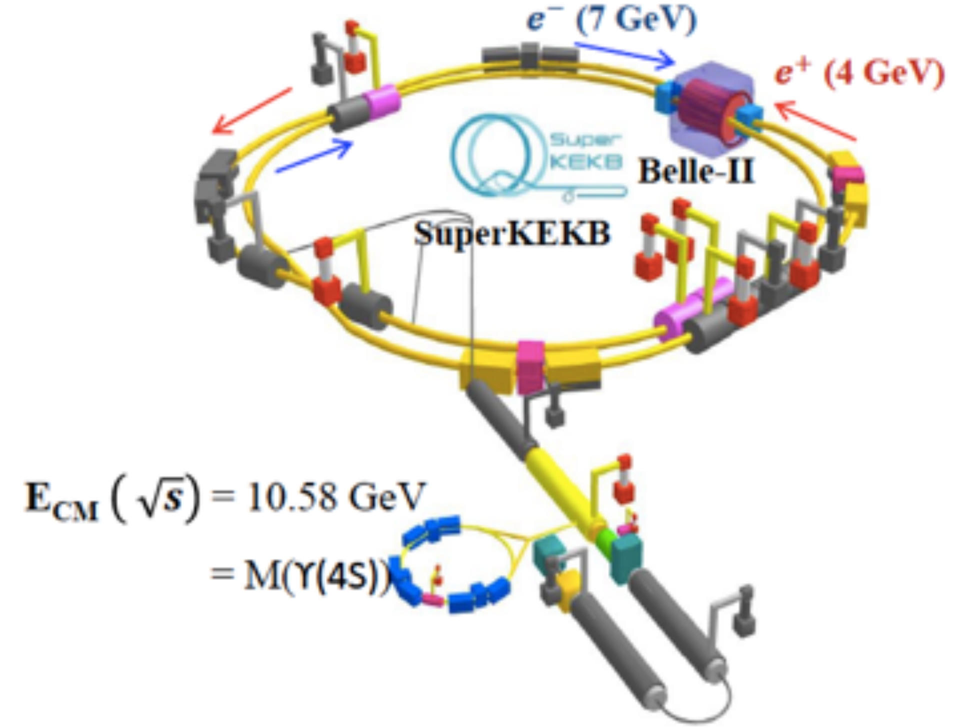
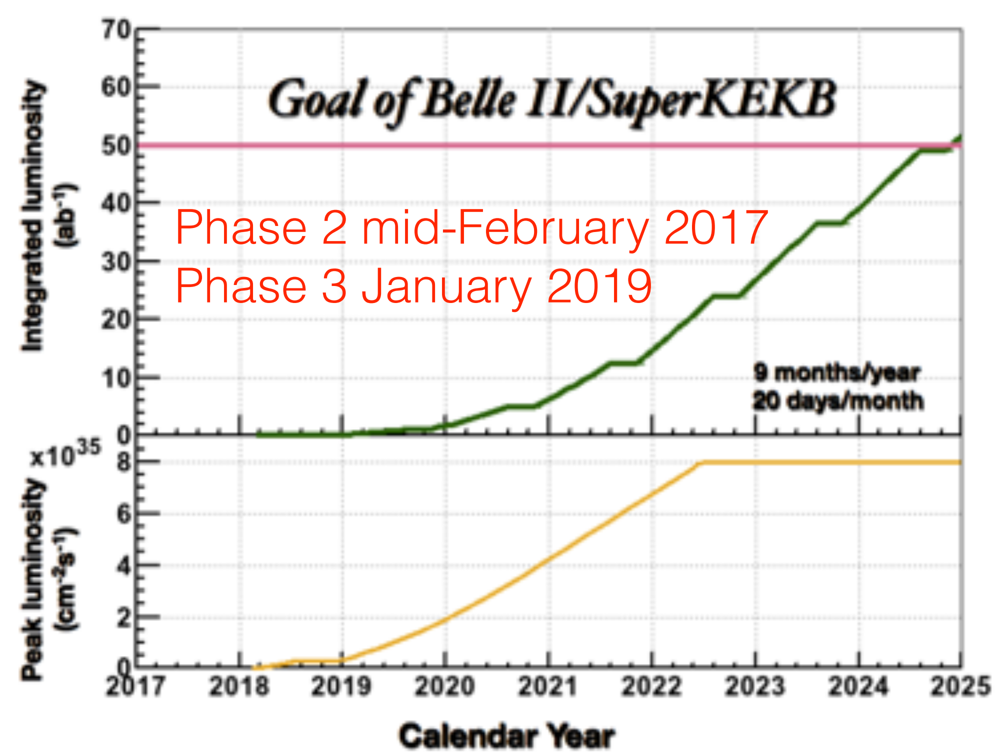
Belle II at SuperKEKB

- Boost (βγ) = 0.28 [0.67 x KEKB]
- E_{CM} = 10.58 GeV [Similar as KEKB]
- Peak luminosity = 8.0 x 10^{35} cm^{-2} sec^{-1}[40 x KEKB]
- Integrated luminosity = 50 ab^{-1} (by 2025) [50 x KEKB]



SuperKEKB luminosity projection



- KEKB: 3 μm (vertical) x 100 μm (horizontal)
  Super KEKB: 60 nm (vertical) x 10 μm (horizontal)
  - Increased current (×2 KEKB)
  - Several other upgrades: RF magnet, vacuum

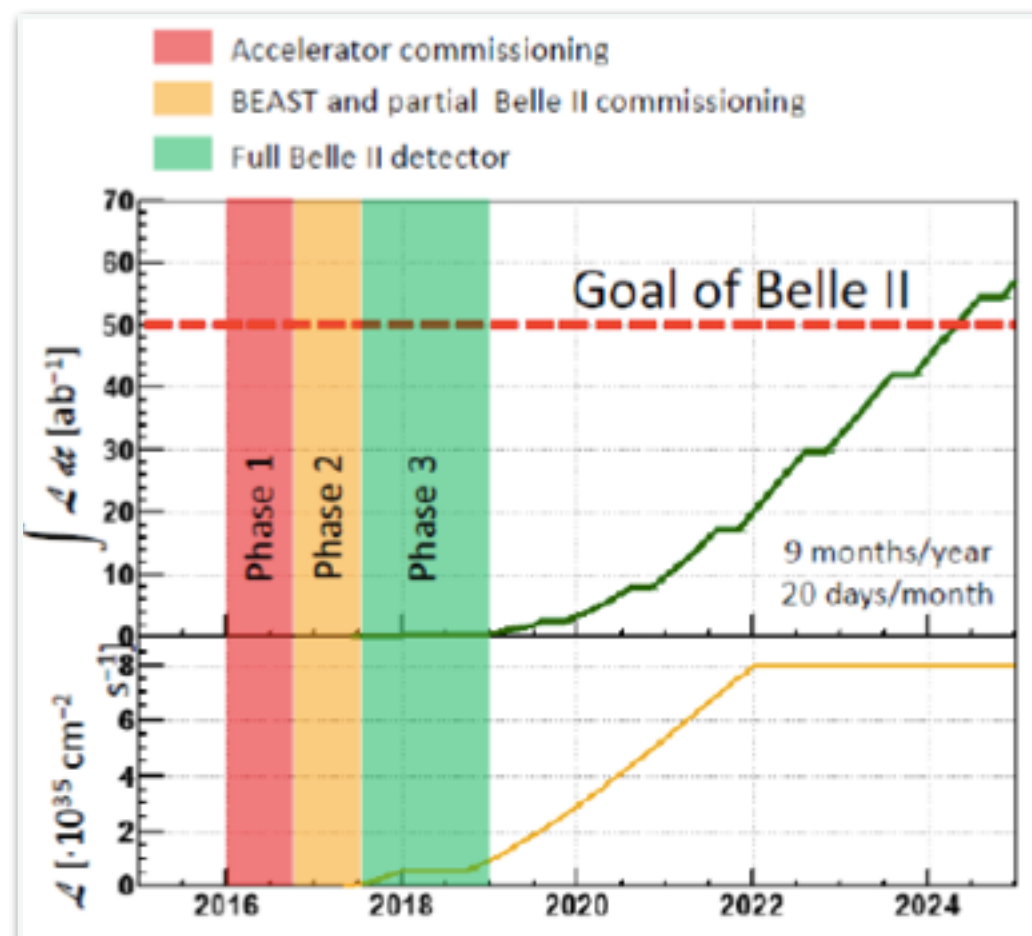
Goal of Belle II

- CP violation studies: precise determination of decay vertices of B mesons and tagging of D meson by the charge of low-momentum pion in $D^{*+/-} \rightarrow D^0\pi^{+/-}$

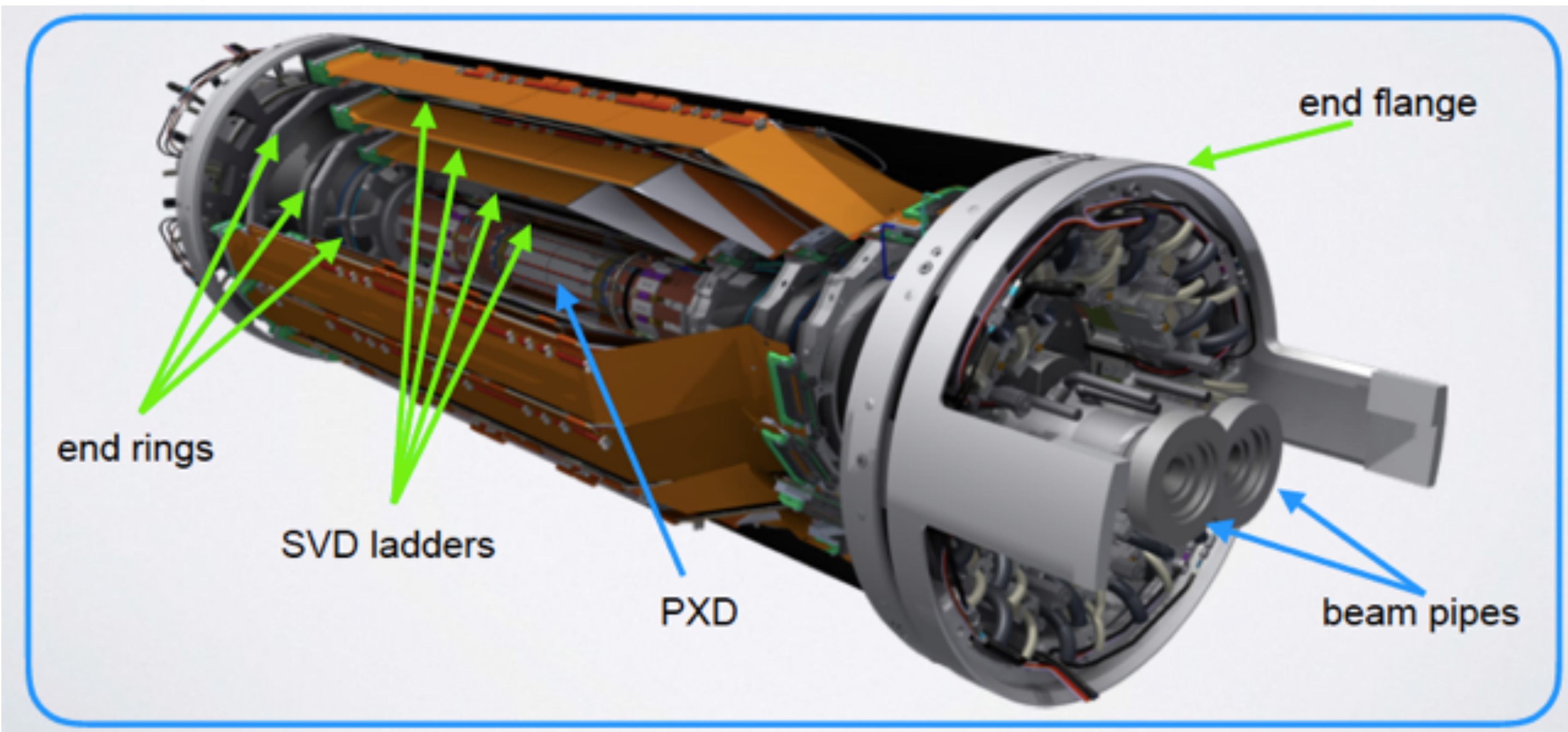
- Indirect search for new physics by studying super-rare decays: reconstruction and identification (dE/dx) of low-momentum tracks as well as decay vertex information for suppressing continuum $e^+e^- \rightarrow$ qq-bar (q = u,d,s,c) background

- 1st physics run with full detector: Fall 2018

Belle II collaboration:
101 institutions spanning over 23 countries



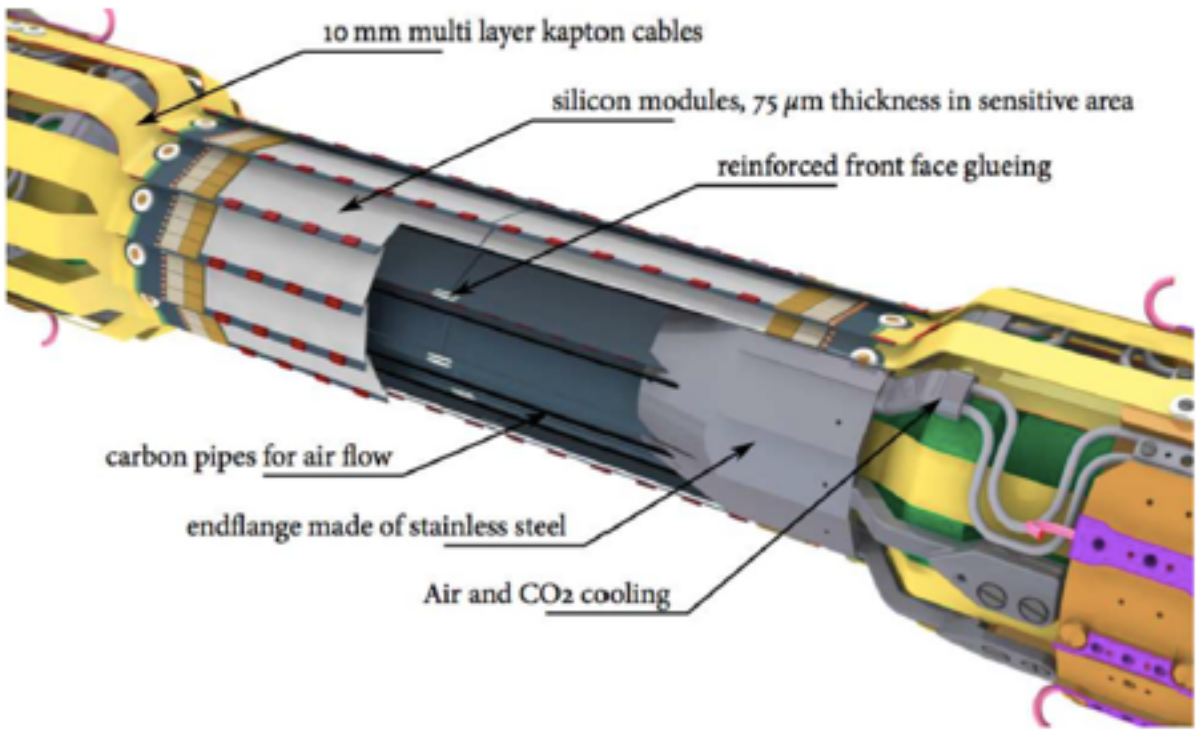
Belle II Vertex Detector (VXD)



- PiXel Detector (PXD): Two layers of Depleted p-channel FET (DEPFET) pixels
- Silicon Vertex Detector (SVD): Four layers of Double sided Silicon Strip Detectors (DSSDs)

- Design optimized for precise vertex reconstruction of short-lived meson decays
  - reduced boost ($\beta\gamma$ = 0.28) & high luminosity/background: thin pixel detector at small radius & silicon strip detector with fast readout electronics
  - bigger radius and acceptance extended in the forward region (polar angle coverage up to 17 deg.)

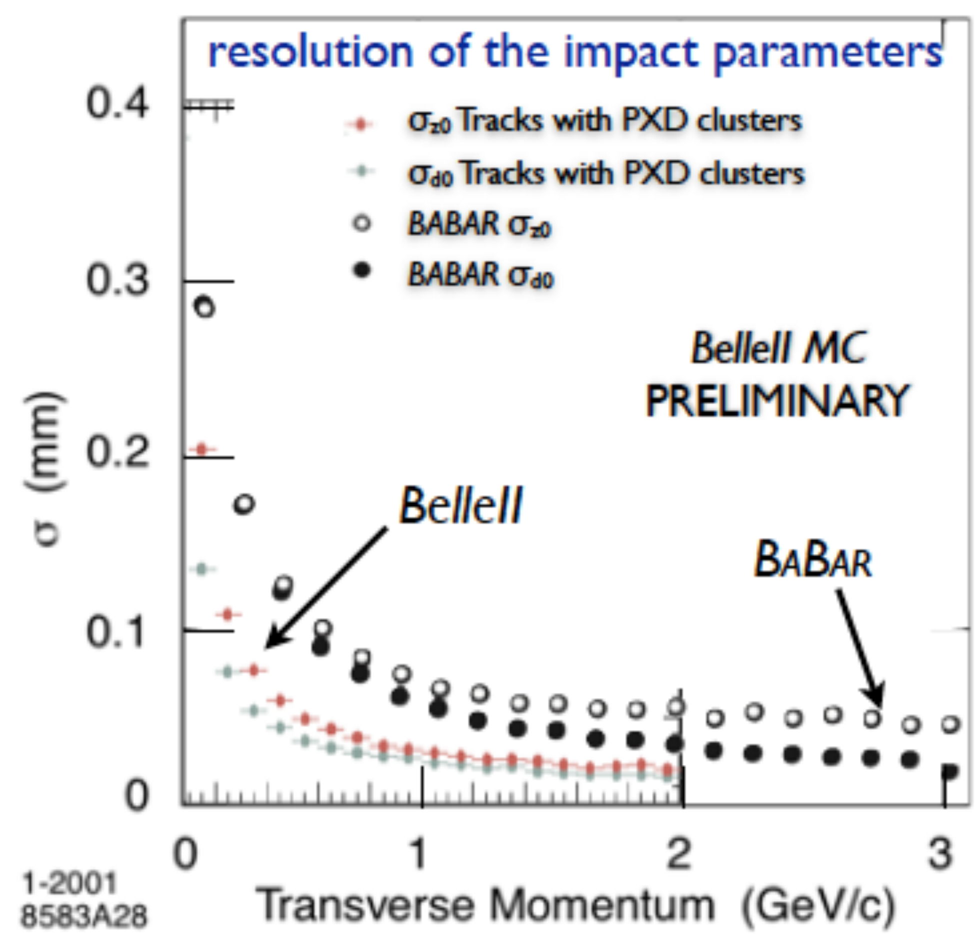
Belle II PXD



Two layers of DEPFET pixels:

- Thickness: 75 μm
- Pixel size: 50 x 55(60) μm^2 [L1]
  50 x 70(85) μm^2 [L2]
- Low power usage
- Low noise

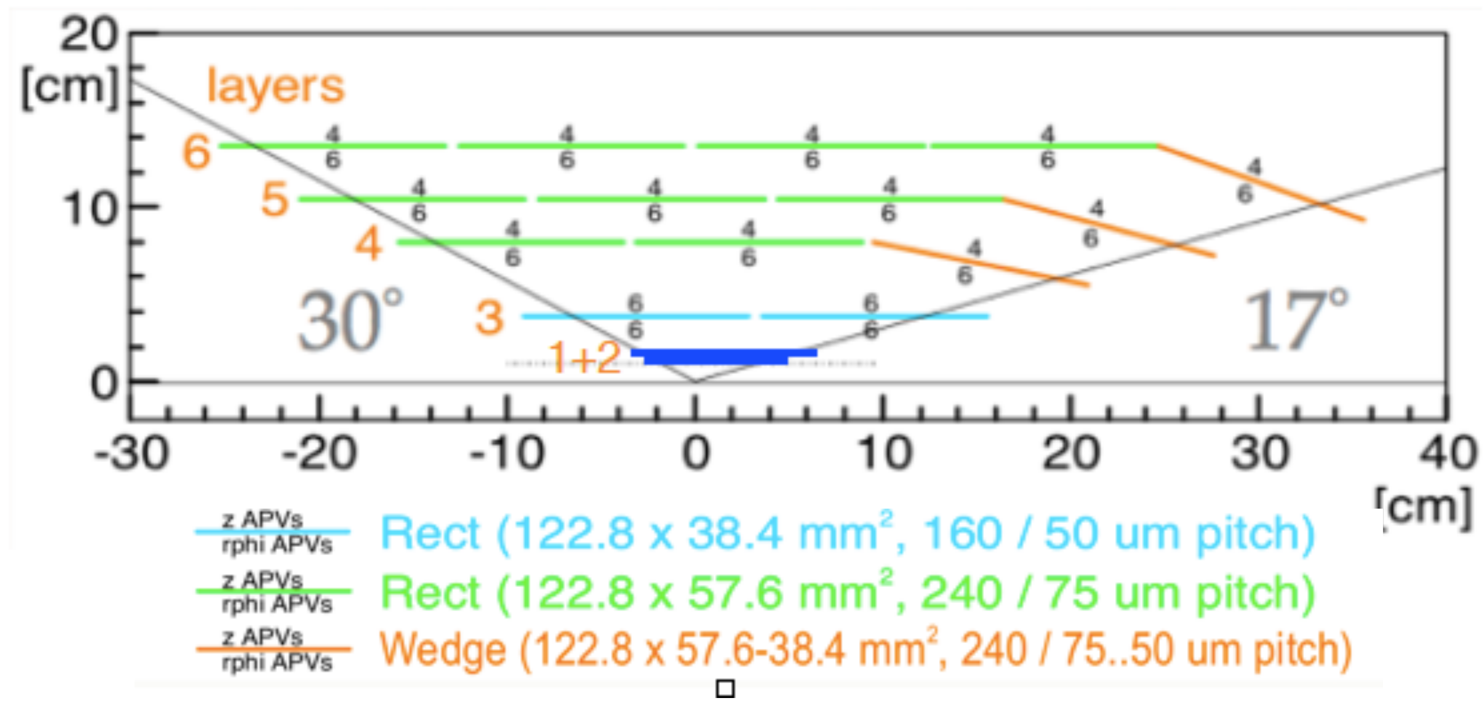
Layer	# of ladders	Radius (in mm)
L1	8	14
L2	12	22



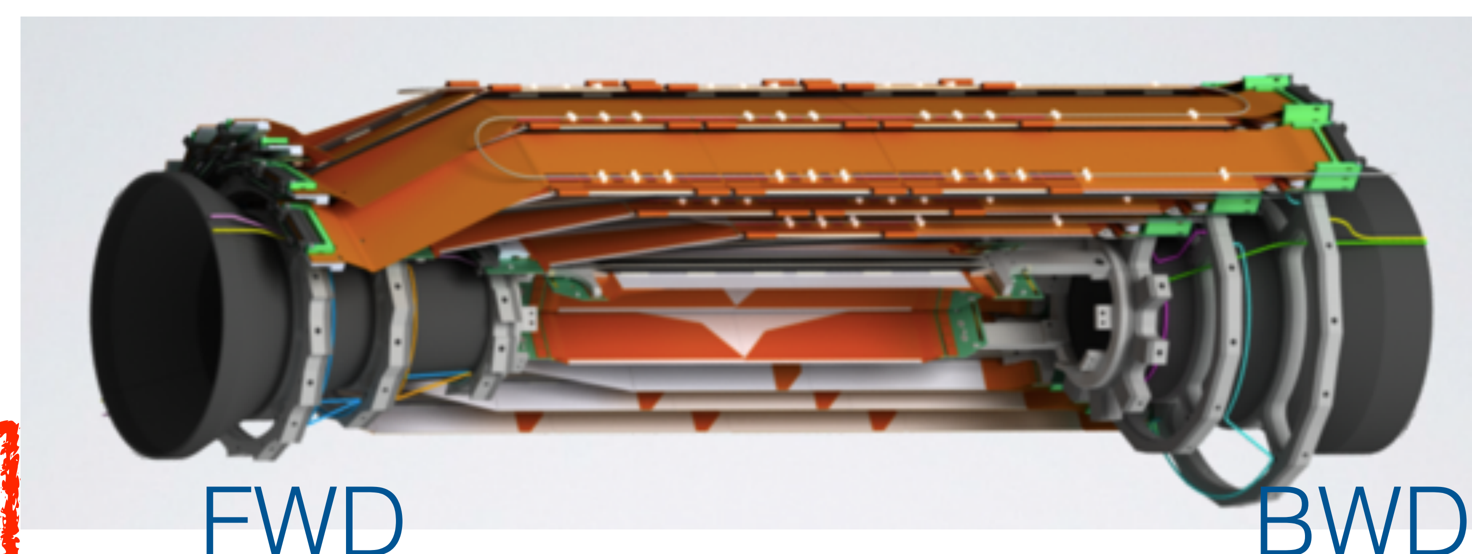
Belle II SVD

- Lantern-shaped design
- Need: occupancy reduction, minimal capacitive load on electronics
- Opt for: Single sensor readout, electronics in active volume

- APV25, designed for CMS silicon tracker, was chosen
  - Radiation hard above 100 kGy
  - Fast shaping time - Occupancy < 3 % even in the innermost layer at full luminosity
  - Pipeline readout - Matches the Belle II high rate data acquisition with minimum dead time

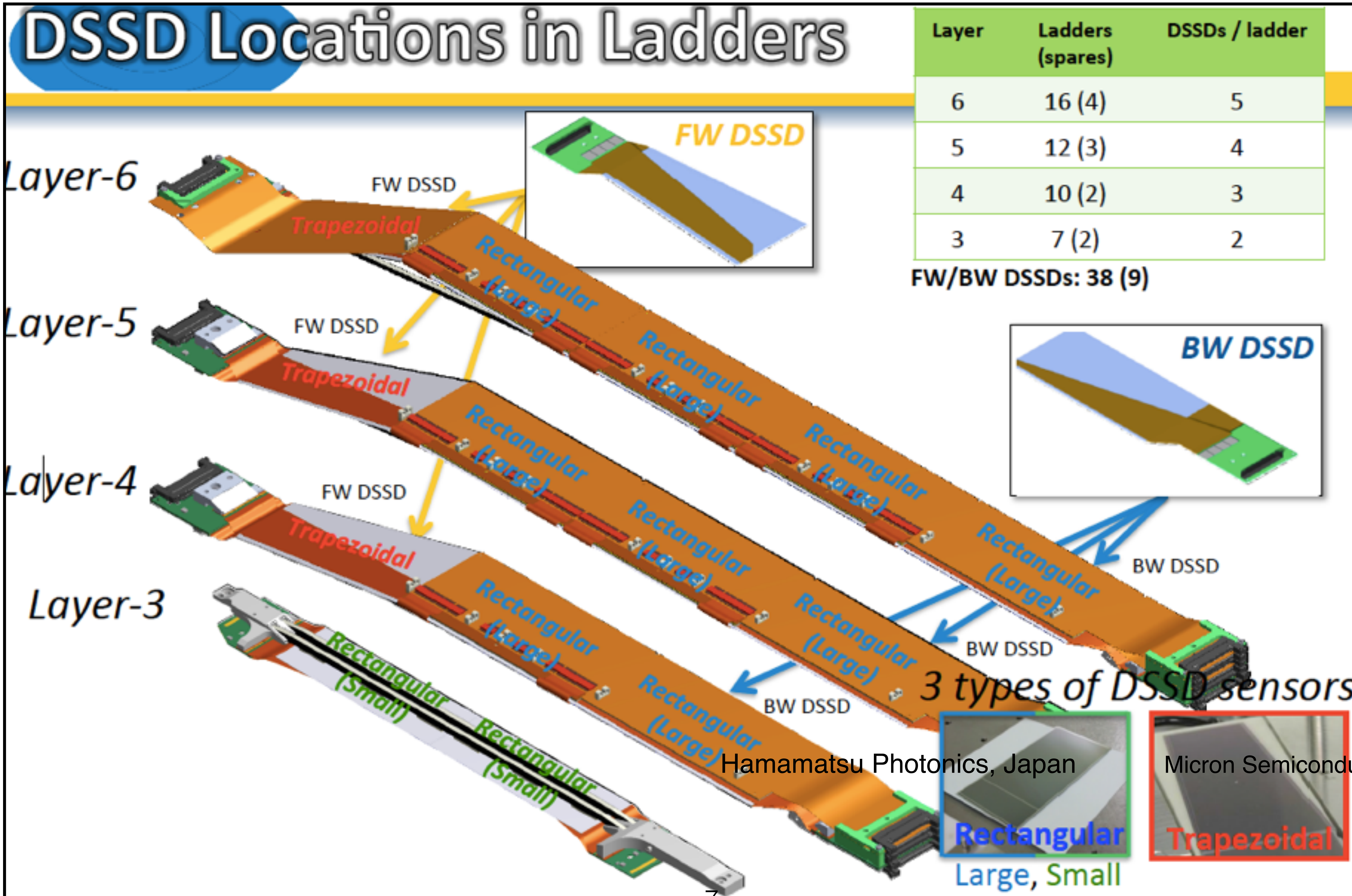


Sensors fabricated from 6 inch silicon wafers with n-type substrate of about 300μm



Peripheral sensors on FWD, BWD regions
Inner sensors in other regions

SVD Layers

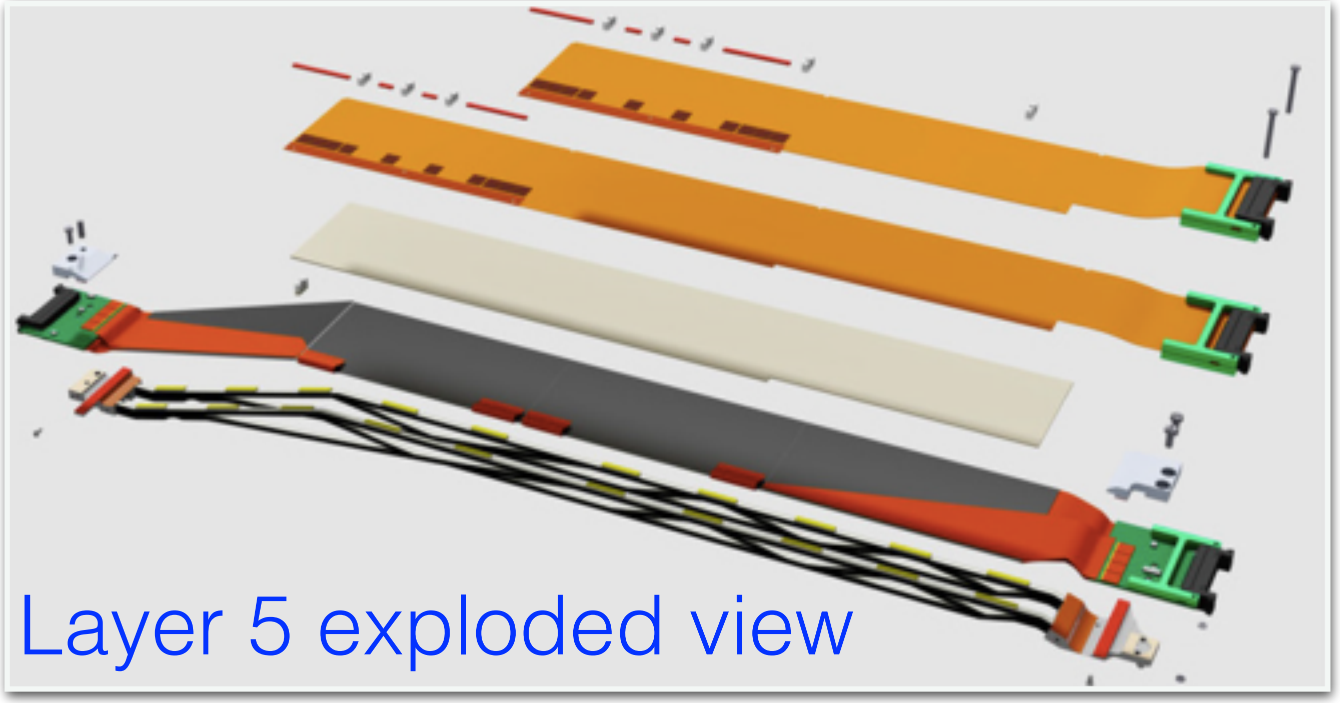


Layer	Ladders (spares)	DSSDs / ladder
6	16 (4)	5
5	12 (3)	4
4	10 (2)	3
3	7 (2)	2

Production of SVD Layers

FW and BW sub-assemblies of L4, L5 and L6: INFN, Pisa

Layer	# of ladders	Radius (in mm)	Institute
L3	7	39	Melbourne, Australia
L4	10	80	TIFR, India
L5	12	115	HEPHY, Vienna
L6	16	140	Kavli-IPMU, Japan

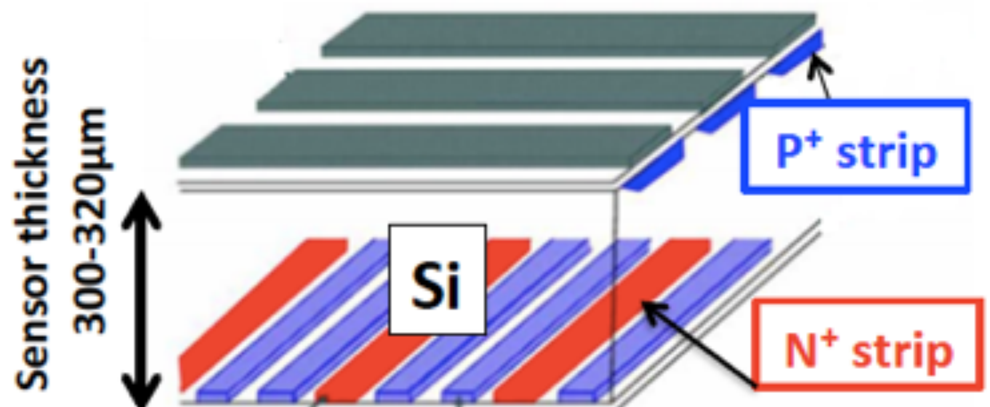


Bottom to top: carbon fiber ribs (black), four sensors (grey), APV25 and flex circuits (red), hybrids (green), Airex foam (white), two Origami flexes (orange) with thinned APV25 (brown) and clips for the cooling pipes (grey)

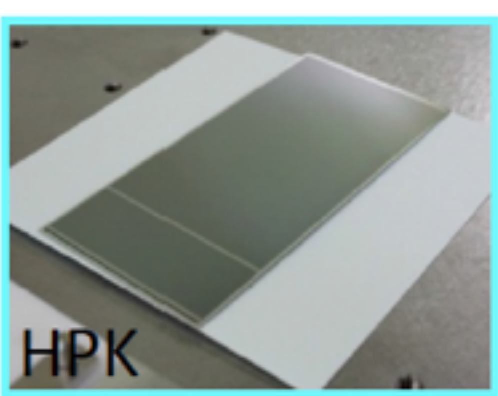
- Origami PCB: chip-on-sensor (glued onto top-side or n-side of sensor, separated by 1 mm layer of Airex
- Ladders are supported by two carbon fibre ribs reinforced with Airex from bottom side and an Al end-mount structure on each side

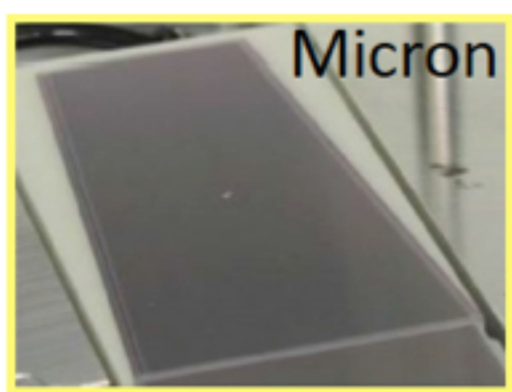
SVD Sensors

Double-sided Si strip detector



	Rectangular	Trapezoidal
# of *p*-strips	768	768
p-strip pitch[µm]	75 (L3:50)	50→75
# of *n*-strips	512 (L3:768)	512
n-strip pitch[µm]	240 (L3:160)	240
Active area[mm²]	7030 (L3:4738)	5890

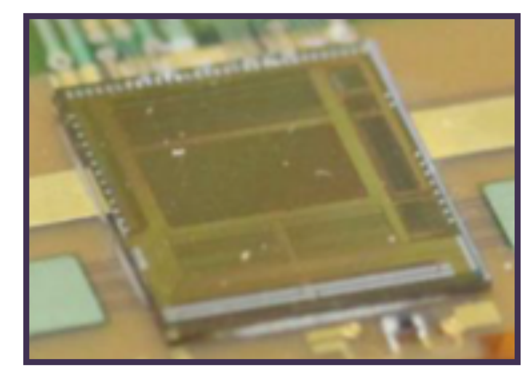




 # p-strips : 768 in each sensor.
 # n-strips : 768 in Rect.(S) sensor and
512 in Trap. & Rect.(L) sensors

Requirement: Short shaping time and low noise

To cope with the Belle II high hit rate, readout chip should have a short signal shaping time though short shaping usually causes higher sensitivity to noise



Readout ASIC: APV25

Originally developed for CMS

- Shaping time = 50 ns
- Radiation hardness > 1 MGy
- # of input channels = 128 / chip
- 192 cells deep analog pipeline for the dead-time reduction
- Thinned to 100 µm for material budget reduction

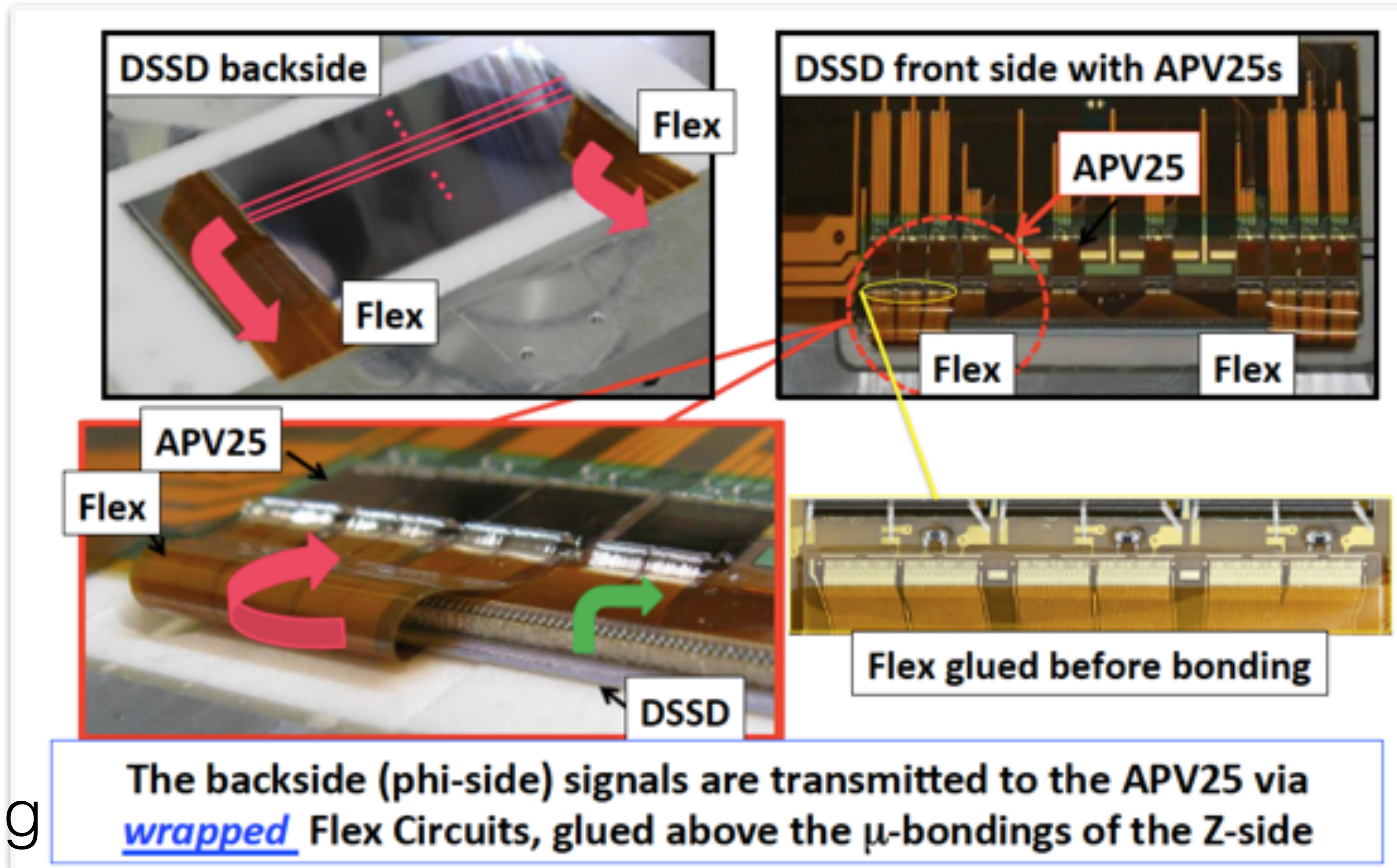
‘Origami’ Concept in Action

Signals on the phi-side of inner sensors transferred to the z-side by flex circuits → all APV25 chips can be mounted on the z-side

- Most important advantage of this novel concept is the reduction of capacitive noise

- Placing read-out chips on the same line line allows the same cooling channel to be used, keeping the material budget low

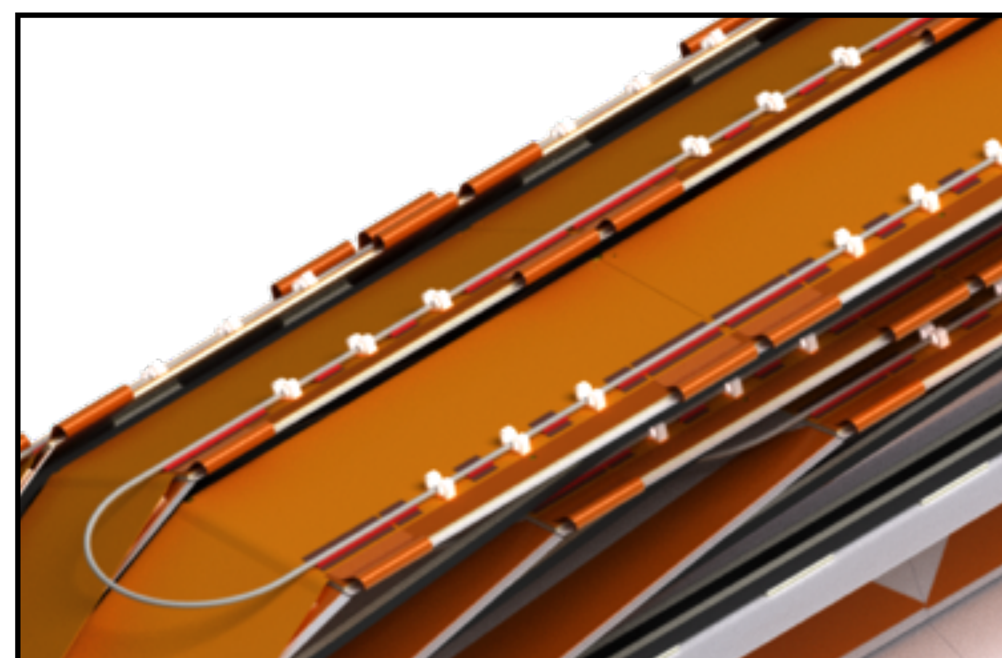
- Average material budget for a ladder: $x/X_0 = 0.6\%$



Dual Phase CO_2 Cooling

- Our detector dissipates ~700W, which requires efficient cooling
  Advantage of CO_2 cooling: Low cooling temperature (20 to -30 deg. C)
  - 2 phase (liquid & gas mixture) CO_2 cooling system
    Efficient and low mass cooling
    Simple control of coolant temperature (only with pressure)
    Small pressure loss in tubes
  - Thin stainless steel pipe is used – Less material budget
- Owing to space constraint & low mass cooling mechanism
-common cooling pipe for 2 ladders

- Total SVD (Origami) power dissipation 688 (328) W
- Edge hybrids: APV25 chips cooled by end rings
- A pre-bent cooling pipe (wall thickness 0.1mm) is clipped onto the ladders on top of the Origami APV25 chips

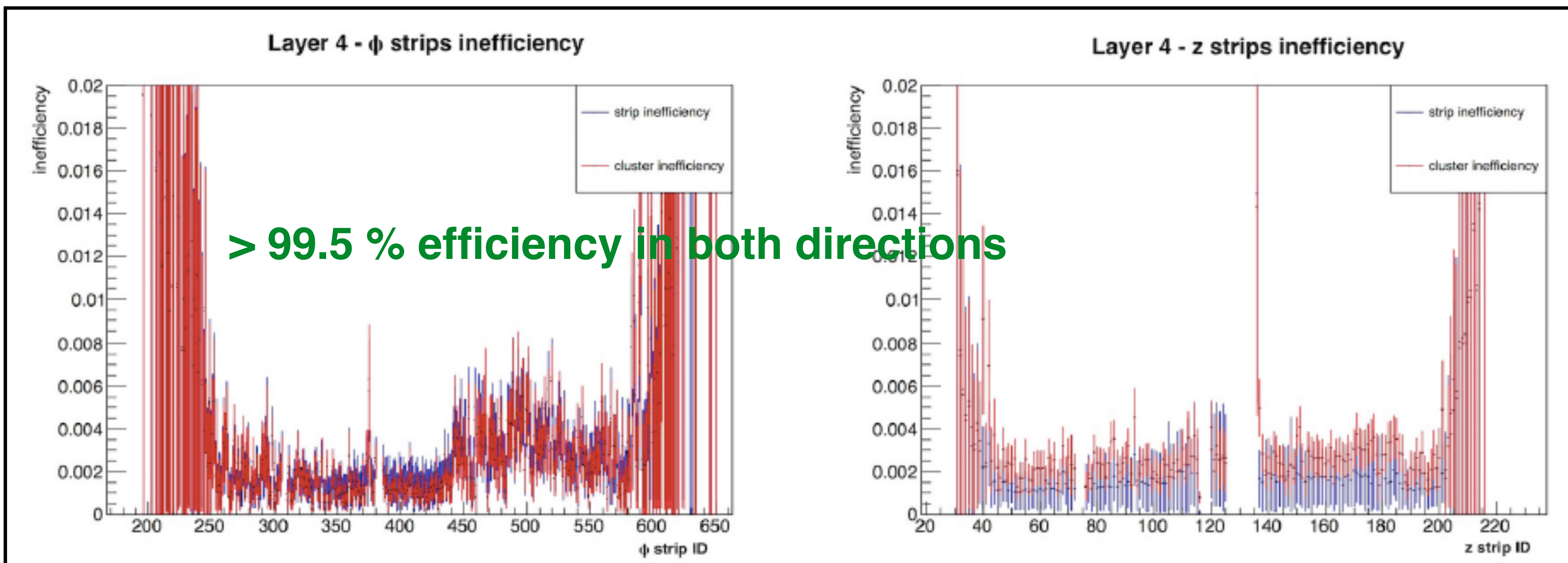


Sensor Performance

- e^- beam energy: 5 GeV (1 T magnetic field)
- 4 SVD layer data used [1 layer studied using other 3 layers as reference]
- One hit per layer and fitting a track passing through 3 reference layers
- Estimate hit point on 4th layer

$$\varepsilon = \frac{\#hits}{\#tracks} \qquad \eta = 1 - \varepsilon$$

[# of hits within 300 μm from estimated hit point]
Tracks: $2 < p_{fit} < 4$ GeV



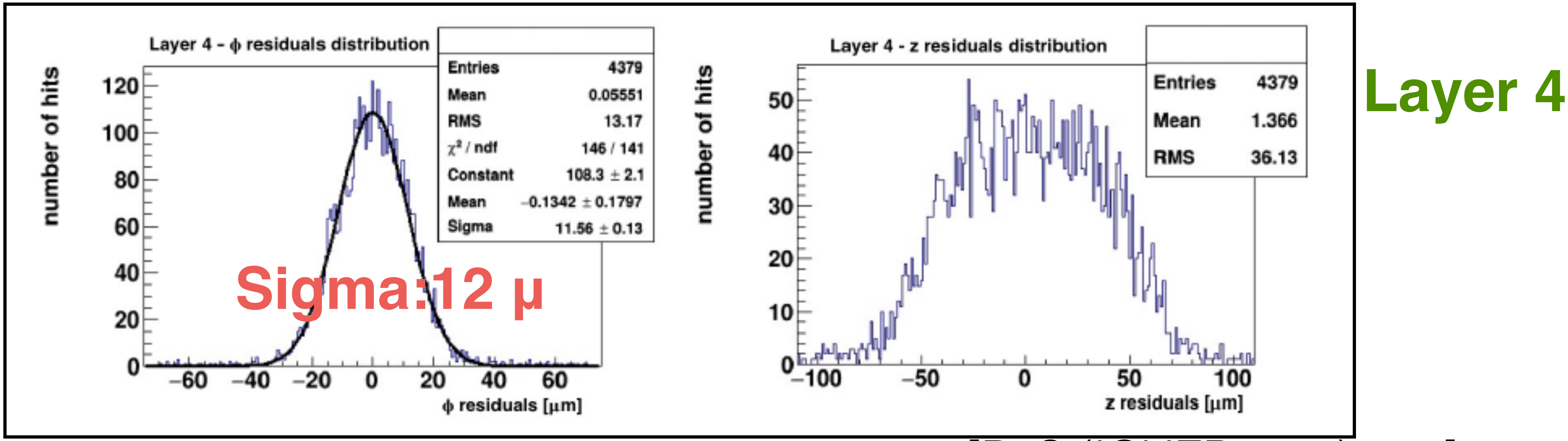
> 99.5 % efficiency in both directions

[PoS (ICHEP2016) 248]

Sensor Efficiency

- 4 SVD, 2 PXD and 6 layers of the EUDET telescope used: total 12 layers
- Require to have at least 10 hits in 11 layers used as a reference

$$R_{dig} = pitch/2\sqrt{12}$$



[PoS (ICHEP2016) 248]

Ladder Assembly

- Complex process:
Requires precision assembly jig (O(50μm)), on which the sensors are fixed by vacuum chucking followed by gluing and wire-bonding
- FW and BW subassemblies for L4, L5 and L6 produced at INFN, Pisa

FW and BW sensor sub-assemblies

Layer	Institute
L3	Melbourne, Australia
L4	TIFR, India
L5	HEPHY, Vienna
L6	Kavli-IPMU, Japan

As of May, 2017
FW/BW subassembly: BW : 100% completed
FW : 94 % completed
Layer 3: Finished production
Layer 4: 6 out of 10+2 ladders, 50% completed
Layer 5: 12 out of 12+3, 80% completed
Layer 6: 7 out of 16+4 ladders completed, 35% completed

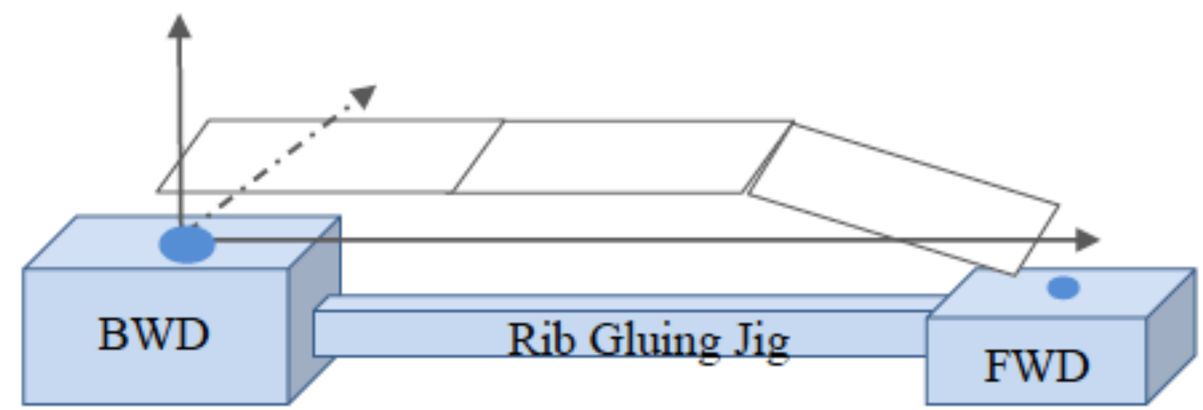
Mechanical Precision Measurement

- Measurements performed using an optical coordinate measuring machine
- Displacement < 150 μm (nominal value) in all directions (L4)

Sensor	Δx (μm)	Δy(μm)	Δz(μm)
Forward	-122	-11	120
Origami-Z	23	-10	4
Backward	-48	-40	33

Similar results for other layers

Final grade L4 ladder



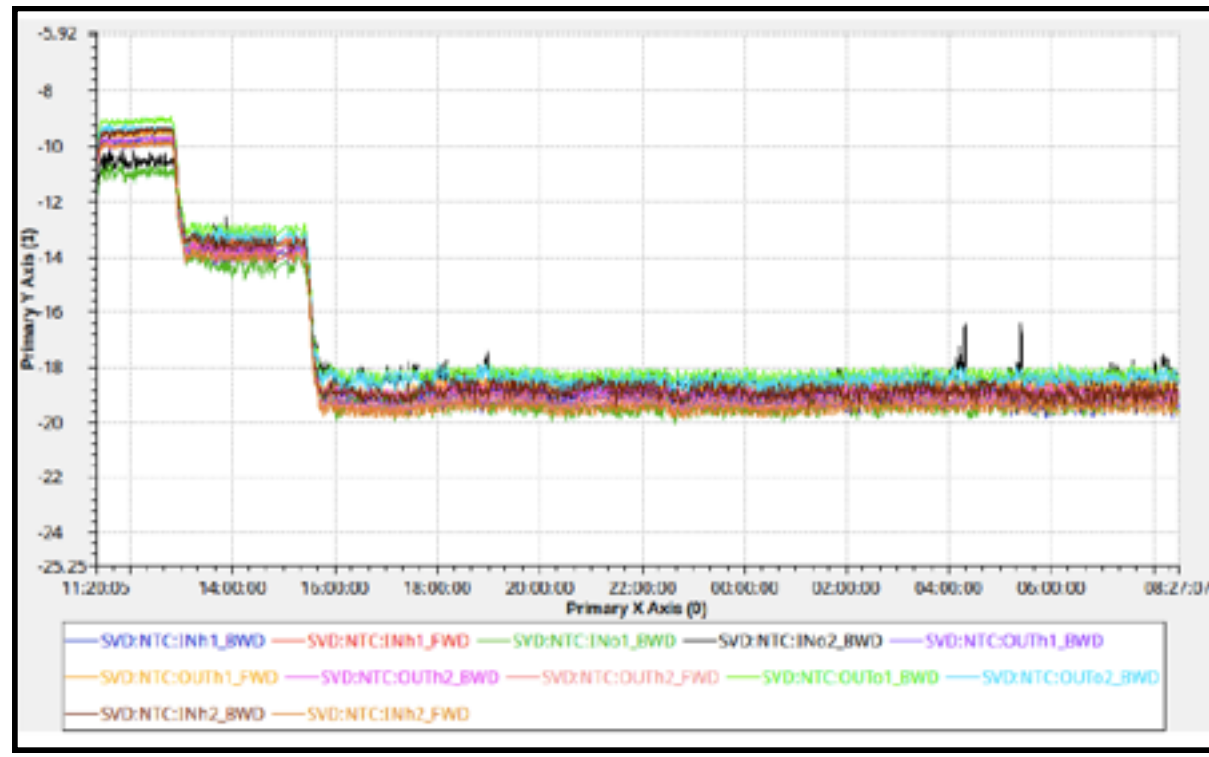
Ladder Coordinate Frame (L4)

[D. Dutta, IPRD, 2016]

Humidity and Temperature Monitoring

- To avoid humidity condensation on the cooling pipes, the whole volume of PXD/SVD will be kept dry by a flux of nitrogen
- 4 sniffing pipes, steadily sampling the dew point with external sensors will be used: Two in the “cold” VXD volume, two in the “warm” VXD volume, both for PXD and SVD
- Thermalization is promptly reached by all the sensors and with a consistent offset between circulating fluid and NTC sensors of about 8 deg. C, as expected by previous tests. (DESY, April 2016)

Beam Test at DESY, April 2016



Temperature measured by 12 NTC thermistors attached at the CO_2 in/out lines when the CO_2 cooling system was decreased gradually in steps down to -27 deg C

[PoS (Vertex2014) 017, PoS (Vertex2016) 051]

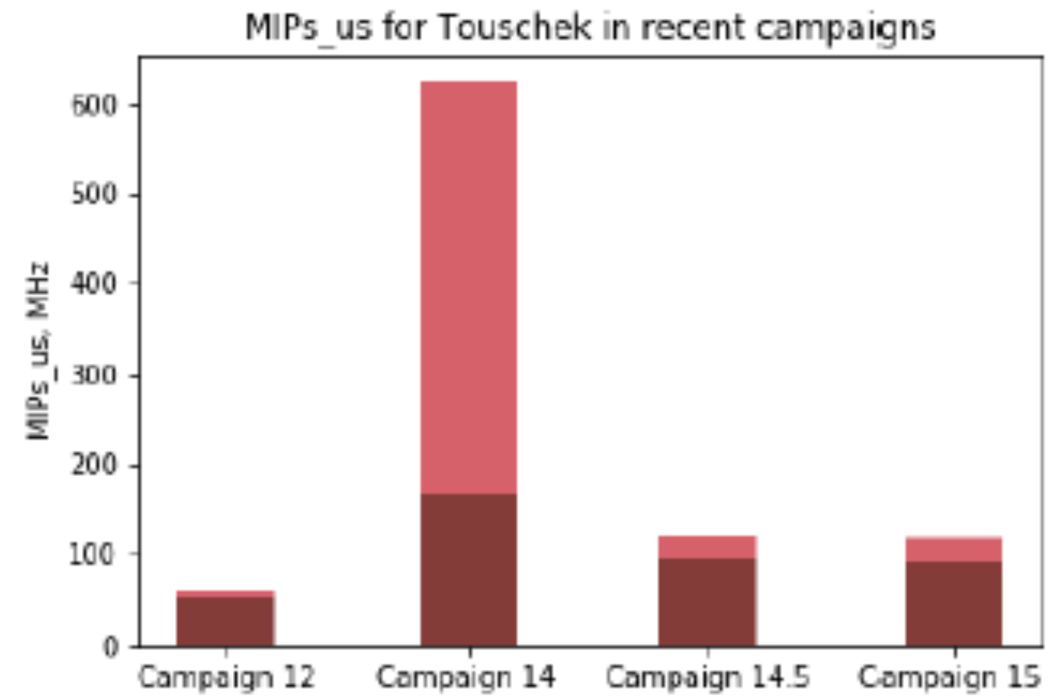
Background Monitoring

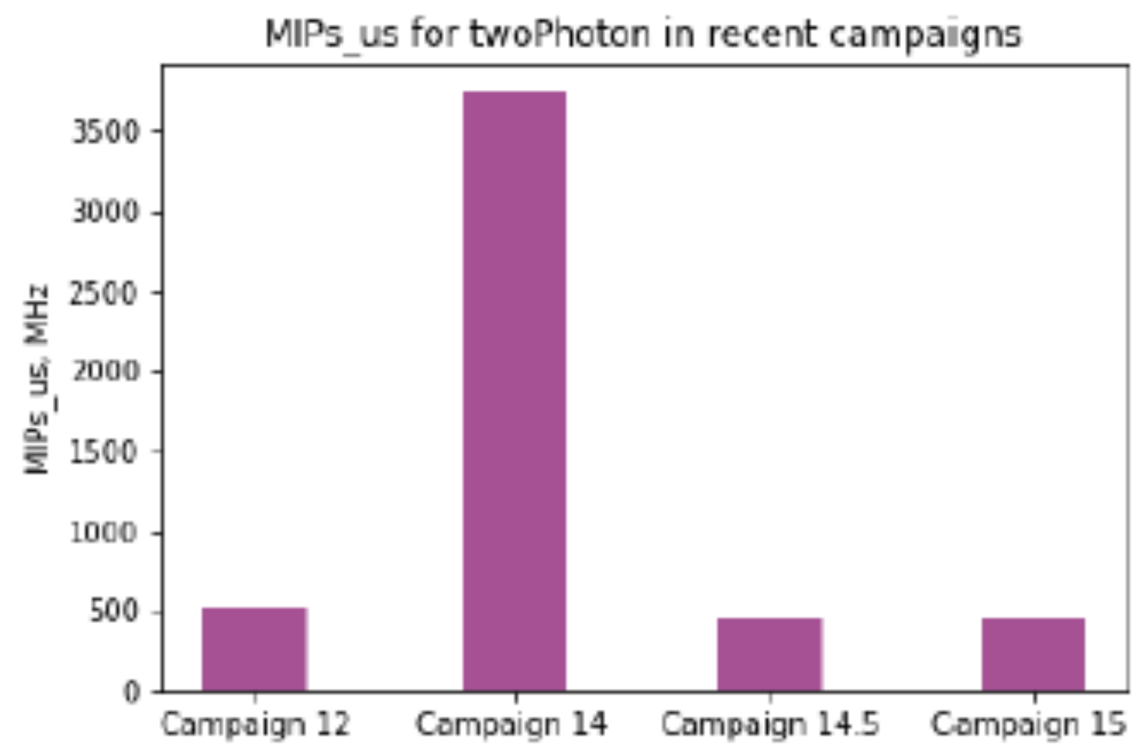
- Main background sources: Touscheck scattering, radiative Bhabha scattering, e^+e^- pair production in two photon scattering, and off-momentum particles from beam-gas interactions

- Synchrotron-radiation induced backgrounds are expected to be smaller and will be kept under control by an appropriate shielding

15th beam background simulation campaign:
Geant4 magnetic field tracking for two-photon samples:
- Results consistent with that of the last "stable" campaign
- SVD stays within safe limits

- New version of SVD simulation/reconstruction settings being prepared (strip capacitances, noises etc.)





Timeline

Completion L4 production (10+2)	Oct 2017 (May 2017)
Completion L5 production (12+3)	Sep 2017 (Mar 2017)
Completion L6 – just enough (16)	Dec 2017
Completion L6 production (16+4)	Mar 2018 (Sep 2017)
Start of ladder mount (1st half shell)	Jul 2017 (Feb 2017)
Start of ladder mount (2nd half shell)	Nov 2017 (Jul 2017)
SVD ready for integration	Mar 2018 (Dec 2017)

Summary

- Belle II SVD has partially slanted geometry to reduce material budget and optimize the track incidence angle
- Novel “Origami chip-on-sensor” concept has been successfully tested and now in production
- Ladder production is expected to be completed by the end of 2017
- Ladder mount for first half-shell on July 2017
- SVD commissioning foreseen in October 2018
- Belle II physics run data taking is foreseen in Fall 2018

BACK-UP

Electronics and Read-out Systems

- In January 2014, complete system test for the Belle II VXD performed: Beam test of a significant VXD subset was performed with 2-6 GeV e^- at DESY and inside a 1 T magnetic field in a direction perpendicular to the beam line

- Setup included two DEPFET modules, fully equipped ladders of each layer (with one large rectangular DSSD each), FADC and FTB boards, CO_2 cooling, slow control and environmental sensors based on Fiber Optical Sensors (FOS)

[PoS (Vertex2014) 017]

Electrical Quality Assurance

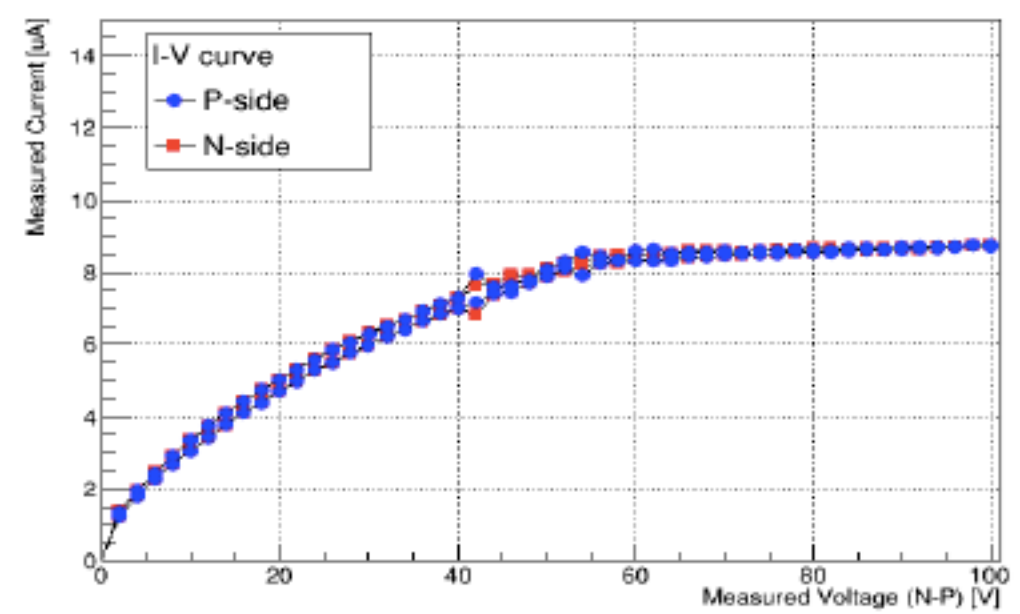
- Check the quality of the Origami flexible circuits, BW & FW subassemblies and fully assembled ladder

- List defects and classify them

- Introduced a common electrical quality assurance system and procedure for all sites

I-V Characteristics Curve

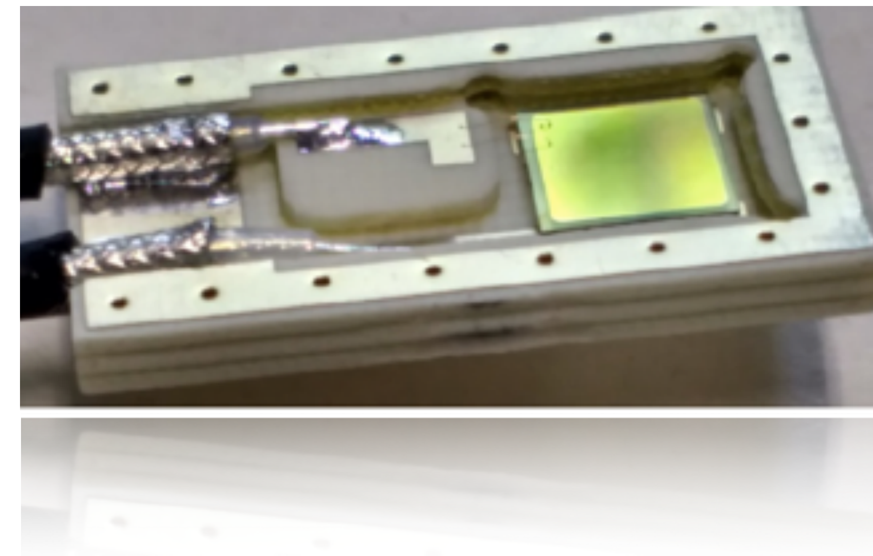
To check the quality of the DSSD sensor

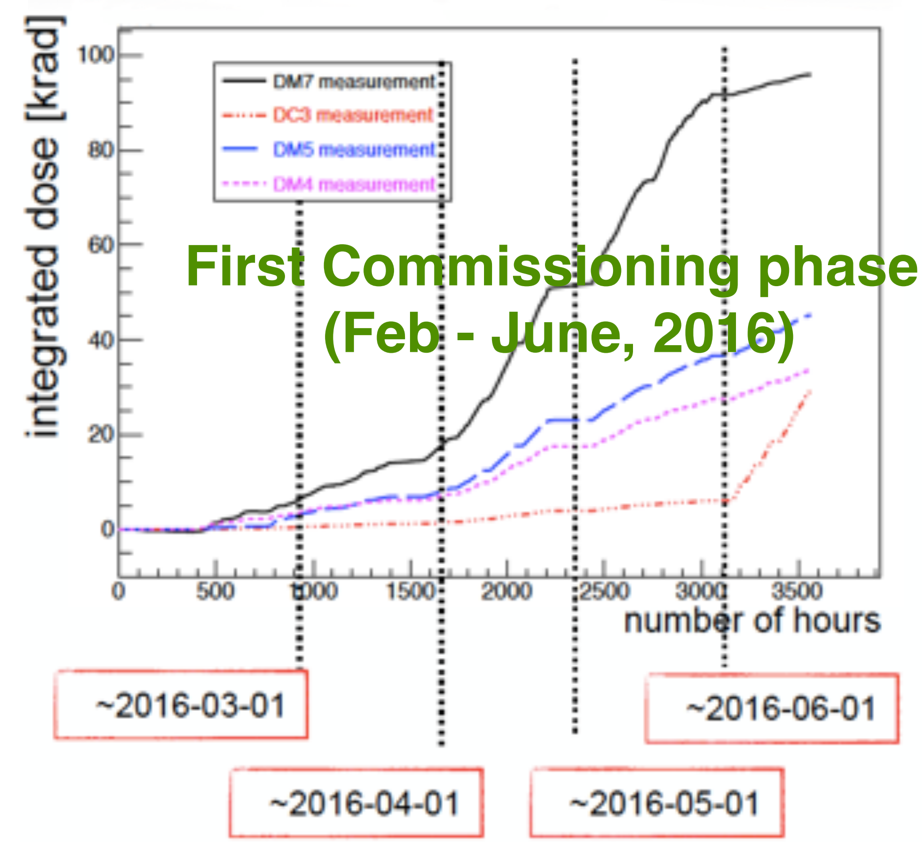


[D. Dutta, IPRD, 2016]

Radiation Monitoring

- Radiation-hard diamond sensors using Chemical Vapour Deposition technique to provide the dose rate measurements
- Small sensors 4.5 x 4.5 x 0.5 mm³ with (Au/Pt/Ti deposition with thicknesses 250/120/100 nm respectively)
- Set of 8 sensors on an empty groove behind the beam pipe cooling manifold, 4 upstream and 4 downstream of the PXD; 12 sensors close to the support rings of the inner SVD layers
- First commissioning phase: The integrated doses shown are in agreement with the integrated beam currents.





Integrated doses are in agreement with the integrated beam currents

[PoS (Vertex2016) 051]