Belle II Silicon Vertex Detector

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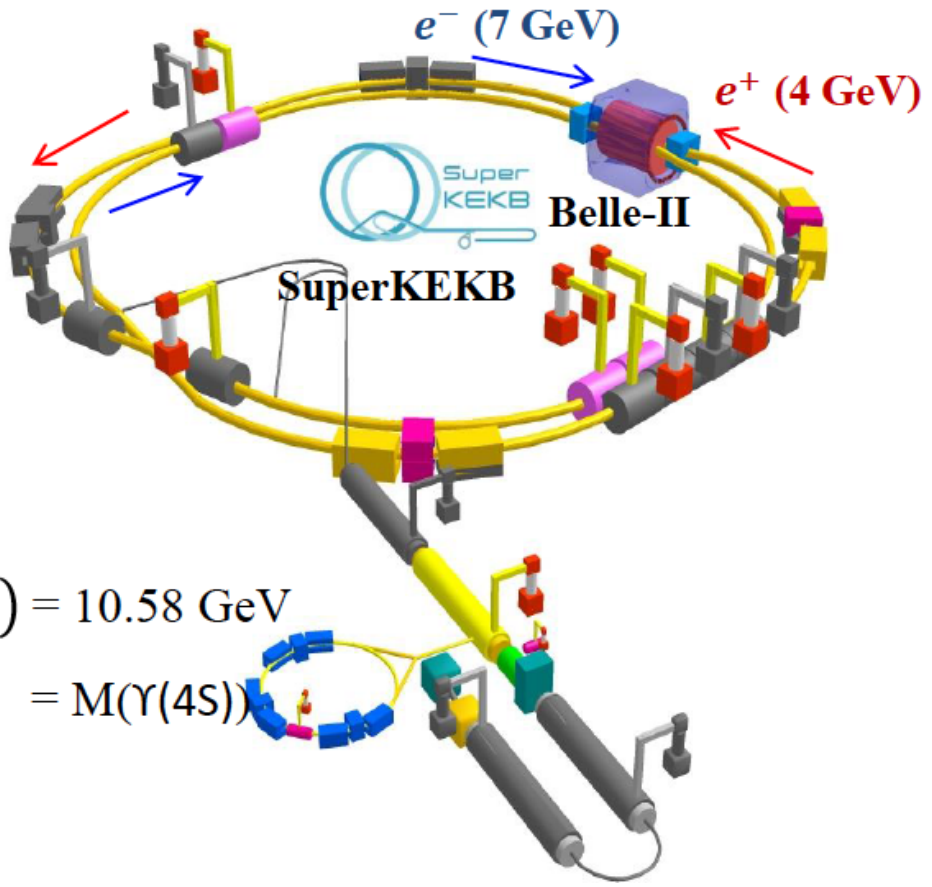
On behalf of the Belle-II SVD Group

Outline

- Introduction
  - SuperKEKB & Belle II
  - Belle II vertex detector
- Overview of SVD
- Sensor and readout ASIC
- Novel ‘Origami’ concept
- CO_2 cooling system
- Assembly procedure
- Quality assurance
- Test beam performances
- Schedule and milestones
- Conclusions

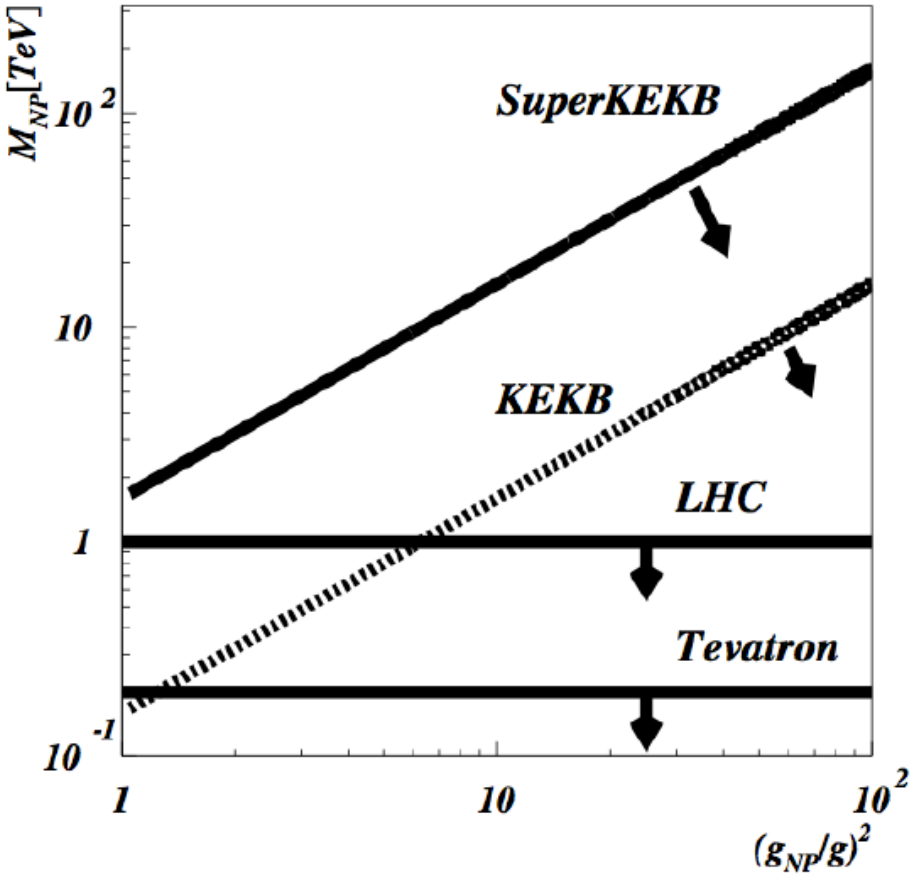
SuperKEKB & Belle II



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

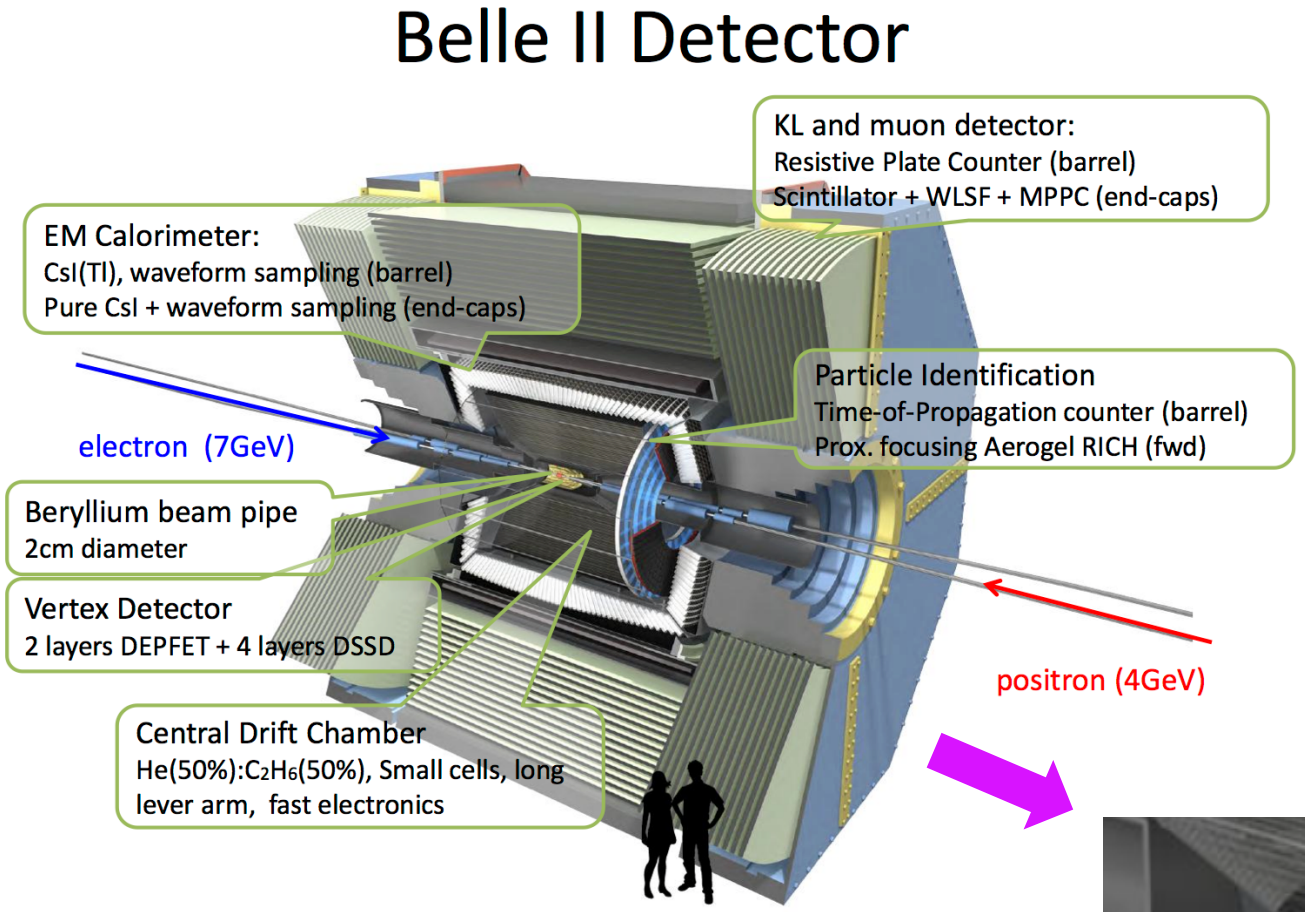
= M(ϒ(4S))

- Next-generation flavor factory with peak luminosity = 8.0×10^{35} $cm^{-2}s^{-1}$ World's highest
- Beam current (×2) and beam size (1/20) compared to KEKB



- Goal: studies of new source of CP violation and rare decays of beauty, charm mesons and tau leptons ➠ indirect probe for new physics
- Complementary to energy-frontier expts
- Experiment with the full detector (Phase-3) will start towards end of 2018

Belle II vertex detector

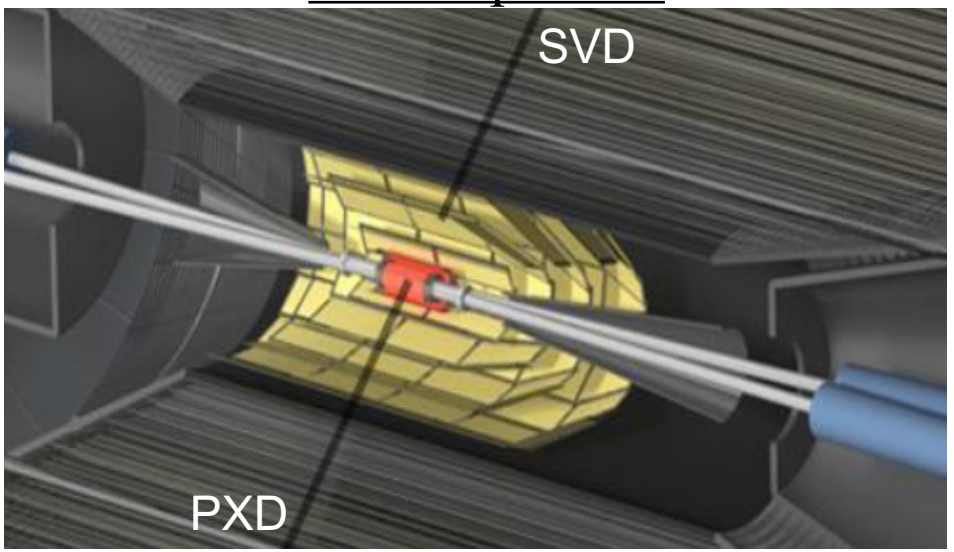


- Inner tracking element: two layers of DEPFET based pixel (PXD) and four-layer double-sided Si microstrip detector (SVD)

☞ SVD in physics harvesting

1) Excellent vertex resolution
2) Good low-p_T tracking
3) Good K_S coverage

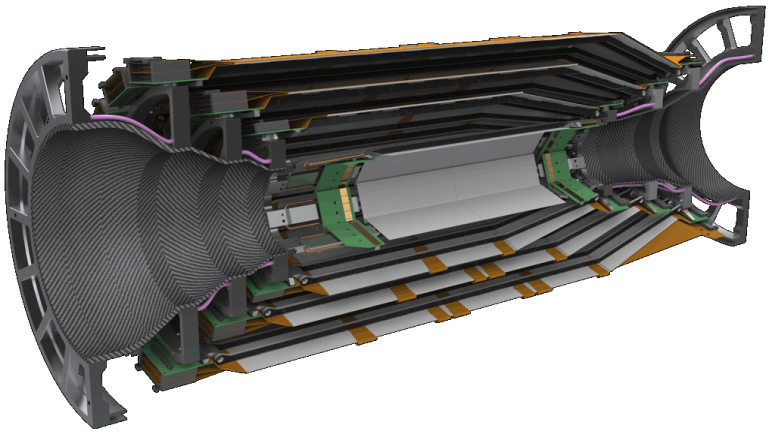
Close-up view:



☞ SVD system requirements

- Fast readout electronics
- Radiation tolerant, up to 0.1 MGy
- Immune to background hits
- Low material budget
- Long-term mechanical stability

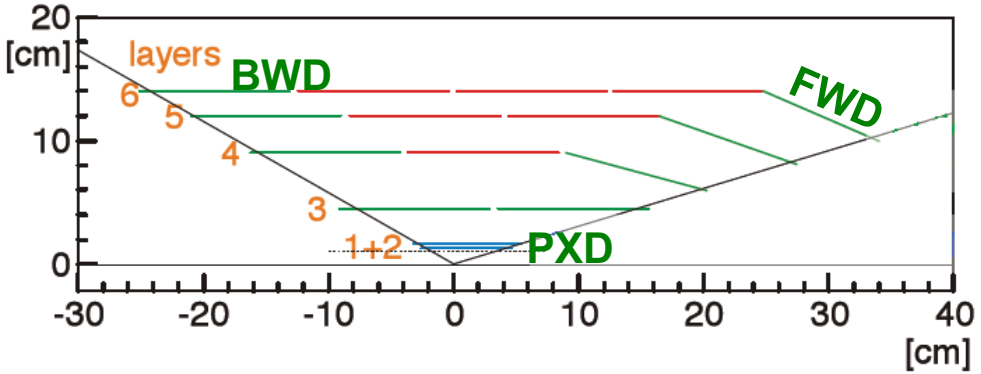
SVD overview



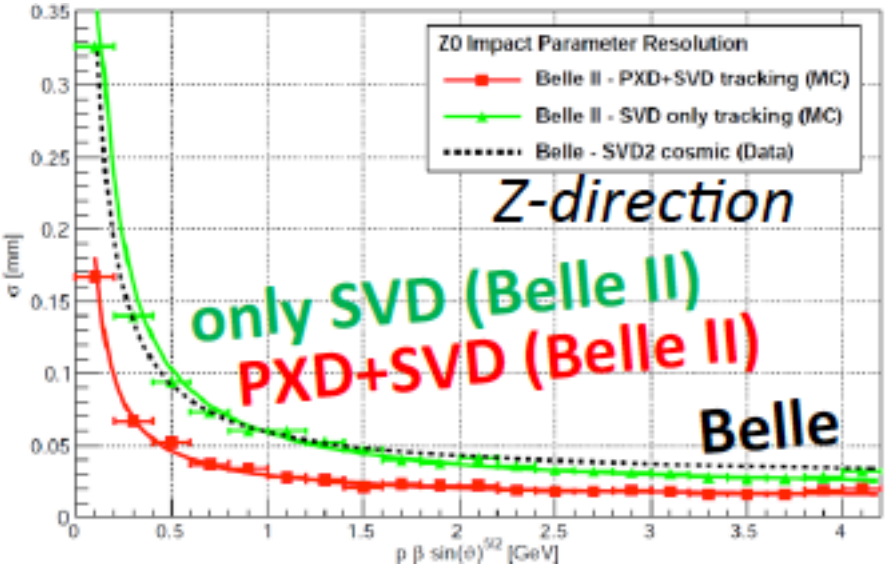
- Global enterprise involving groups from Australia, Asia and Europe

Layer	Ladder	Institute
3	7(+1)	Melbourne
4	10(+2)	TIFR Mumbai
5	12(+3)	HEPHY Vienna
6	16(+4)	Kavli IPMU

INFN Pisa: Layer 4-6 forward (FWD) and backward (BWD) modules



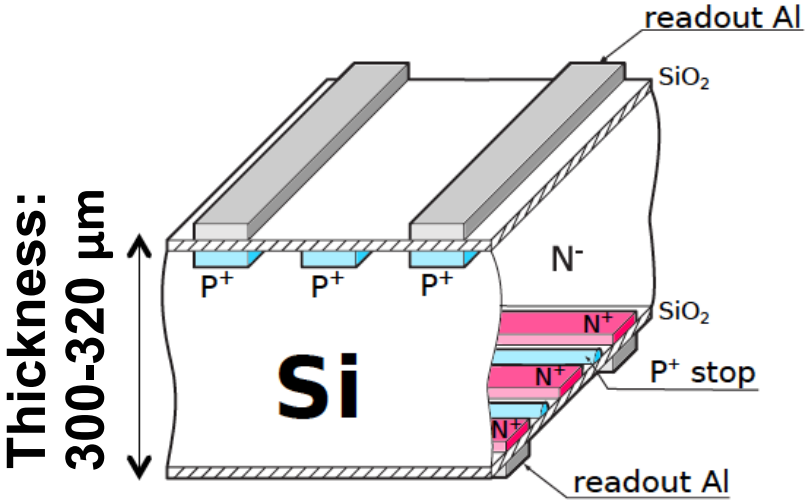
Layer	Sensor/ ladder	Origami	Length	Radius	Slant angle
3	2	0	262 mm	39 mm	0°
4	3	1	390 mm	80 mm	11.9°
5	4	2	515 mm	104 mm	17.2°
6	5	3	645 mm	135 mm	21.1°



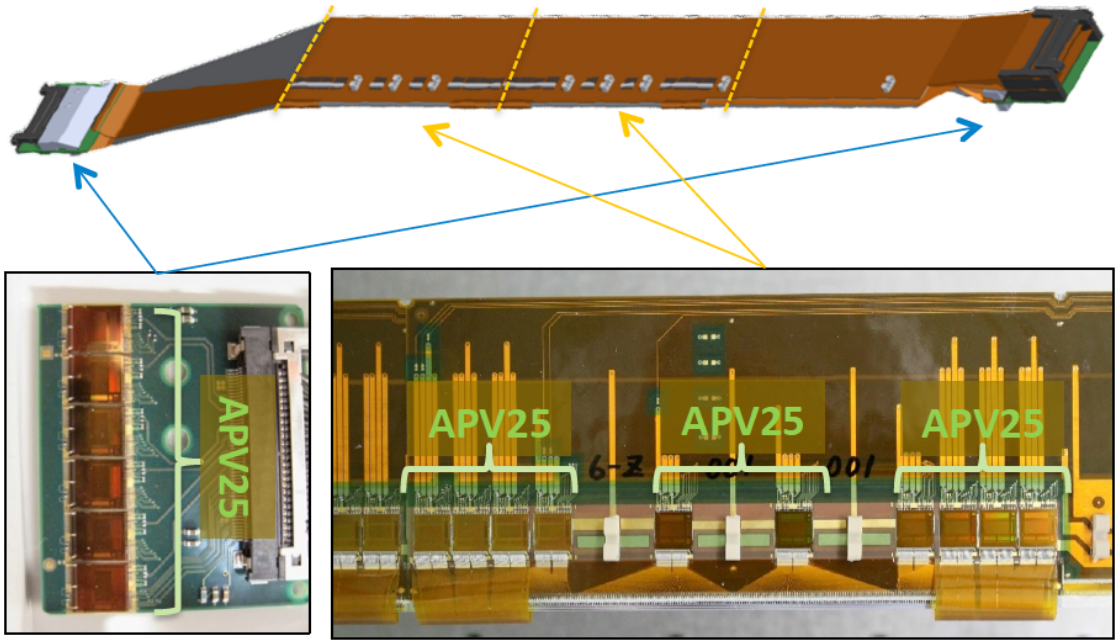
- Significantly improved resolution compared to Belle (20μm at 2 GeV)

Sensor and ASIC

- Double-sided silicon micro-strip detector (DSSD): p-in-n 6′ wafer



- APV25 chip: originally developed for CMS



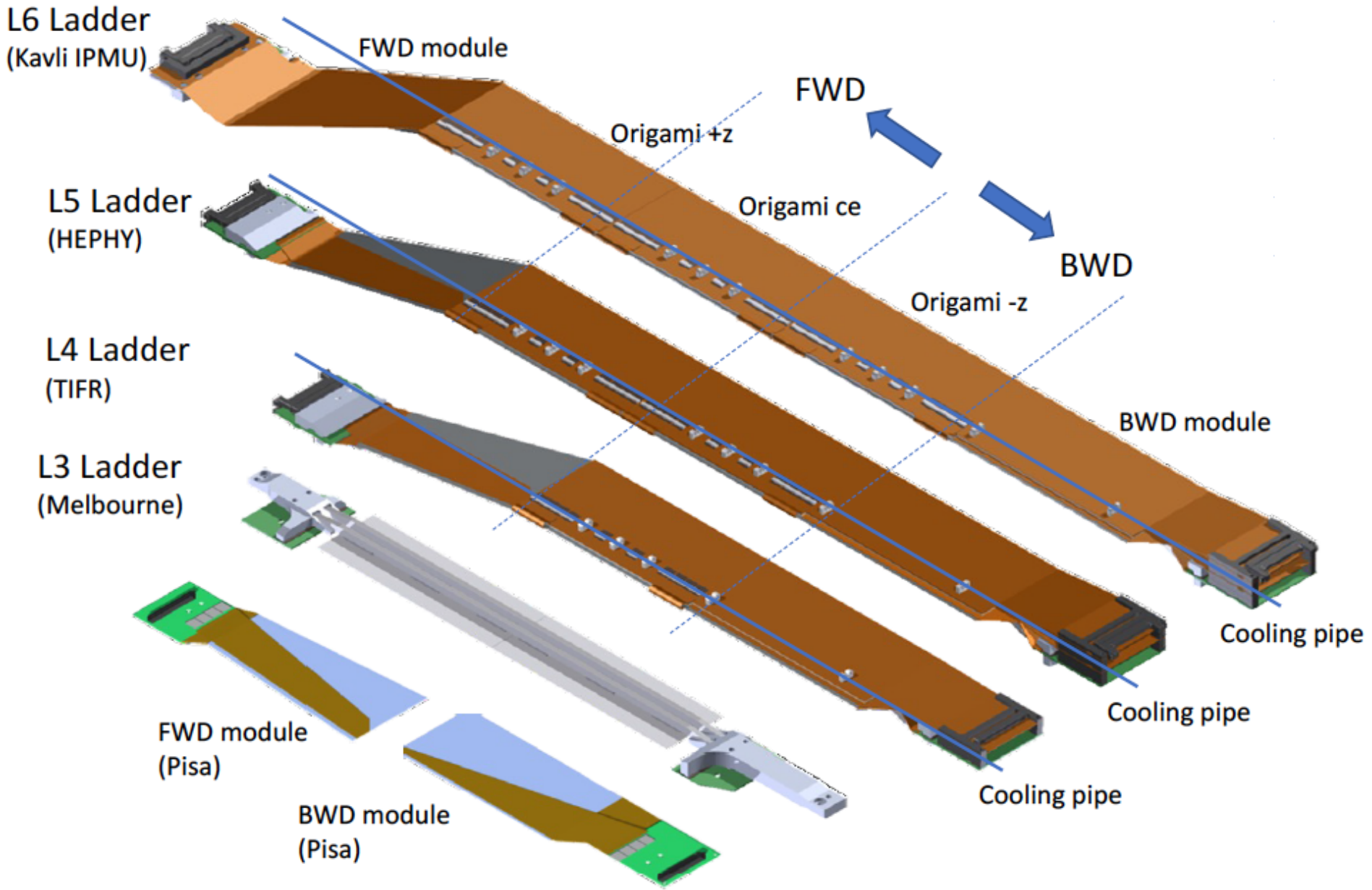
Sensors	Rectangular (Large)	Rectangular (Small)	Trapezoidal
# of *p*-strips	768	768	768
p-strip pitch	75µm	50µm	50...75µm
# of *n*-strips	512	768	512
n-strip pitch	240µm	160µm	240µm

HPK Micron

Requirement: short shaping time to cope with Belle-II high rate as well as high S/N

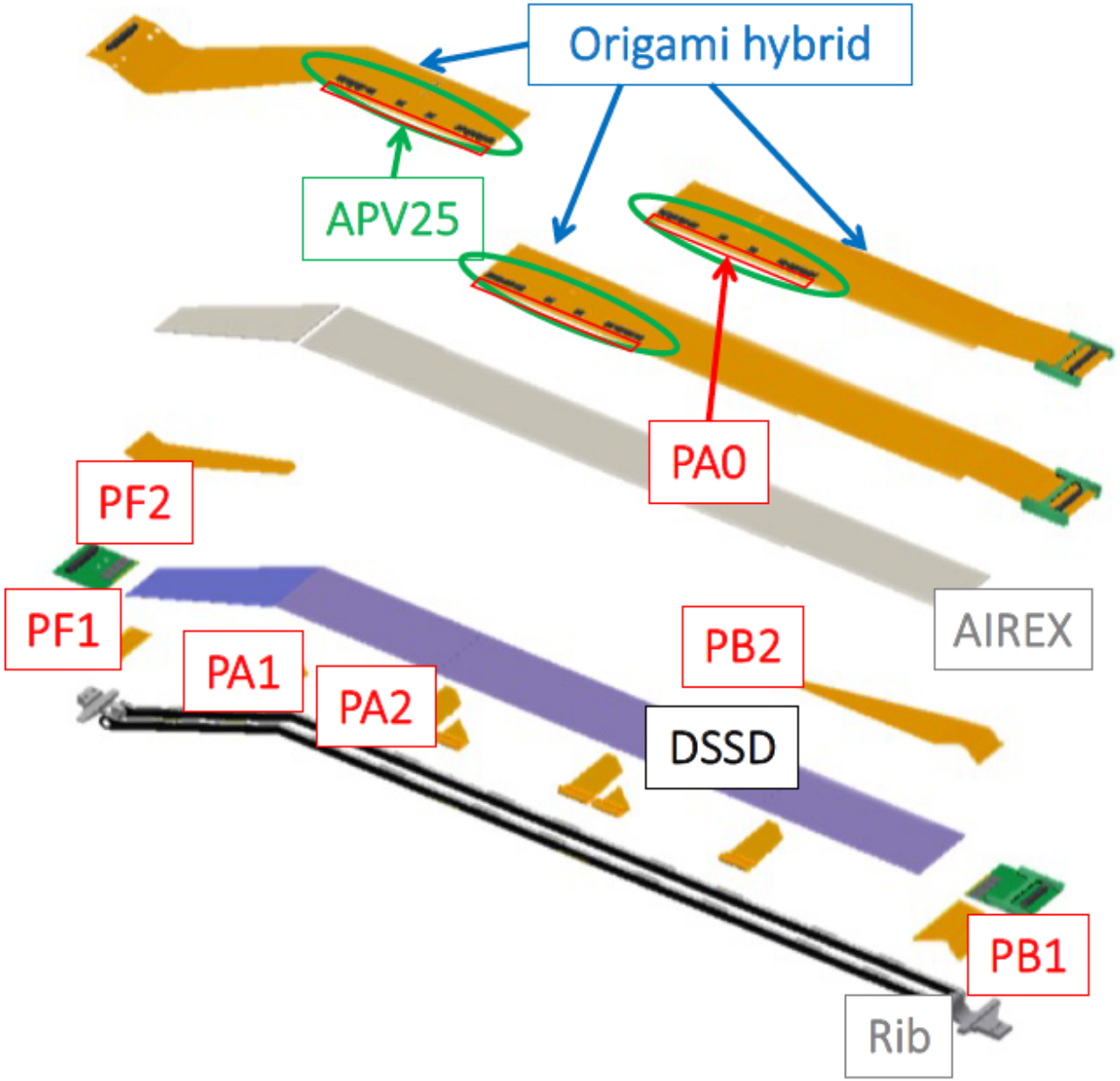
- Shaping time: 50 ns
- Radiation hardness: > 1 MGy
- # input channels: 128 per chip
- 192 cells deep-analog pipeline for dead-time reduction
- Thinned down to 100µm to reduce material budget

DSSD location in ladders



Ladder: basic unit

☞ Below we show the anatomy of a typical SVD ladder



DSSDs
- 2 small rectangular (L3)
- 2-4 large rectangular (L4-6)
- 1 trapezoidal (L4-6)

Origami hybrid
Flexible circuit to transmit detector signals to the ladder ends

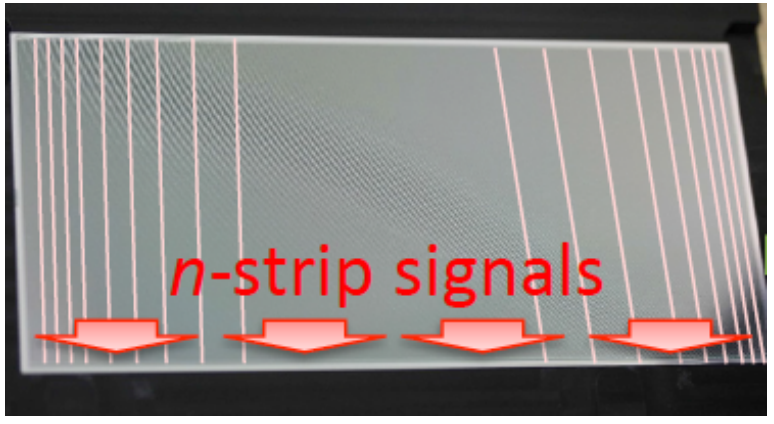
APV25
Readout ASIC of the strips

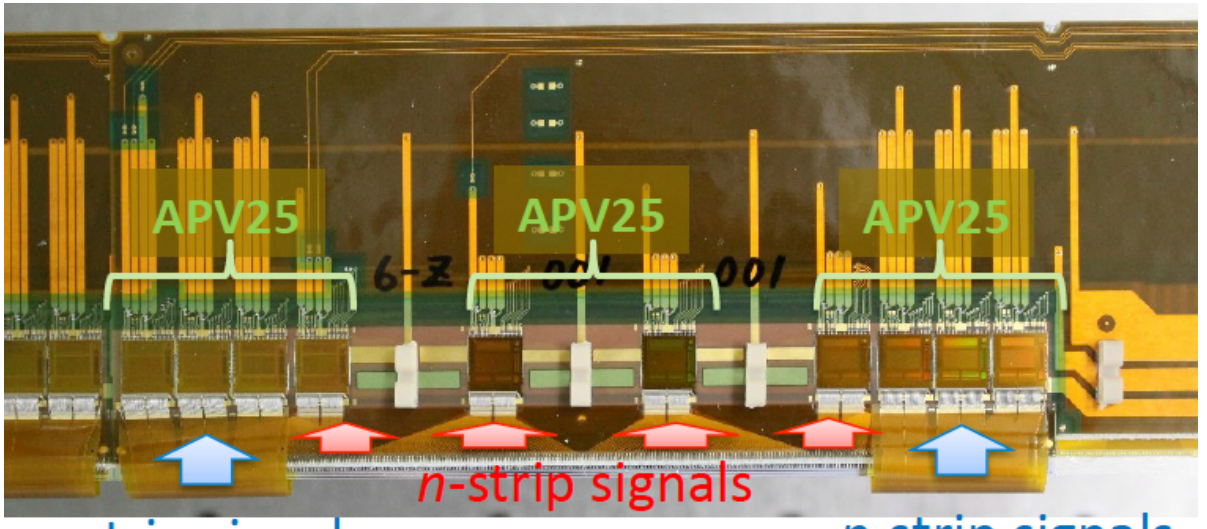
FlexPA (PA/PF/PB)
Flexible circuit to transmit detector signals to the APV25

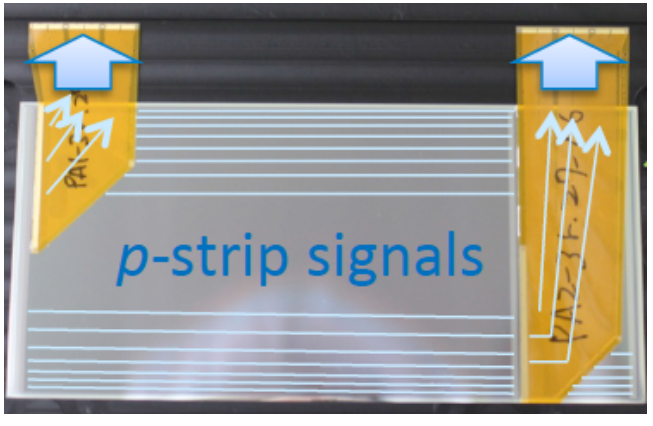
PA0
Flexible circuit glued on the Origami hybrid to transmit *n*-side detector signals to the APV25

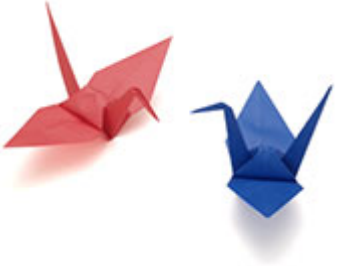
AIREX
Thermal insulator between the DSSD and APV25

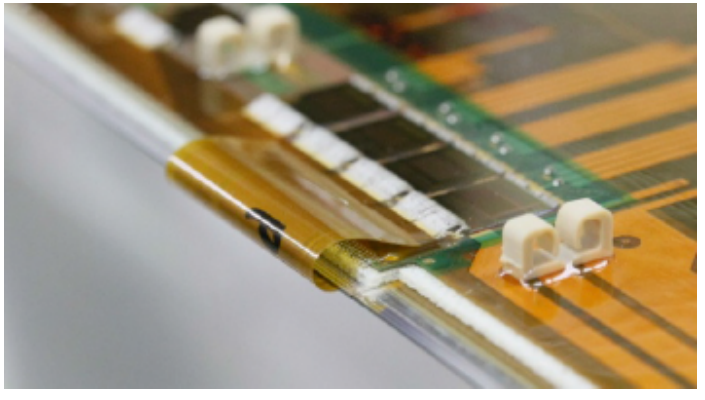
Novel Origami concept





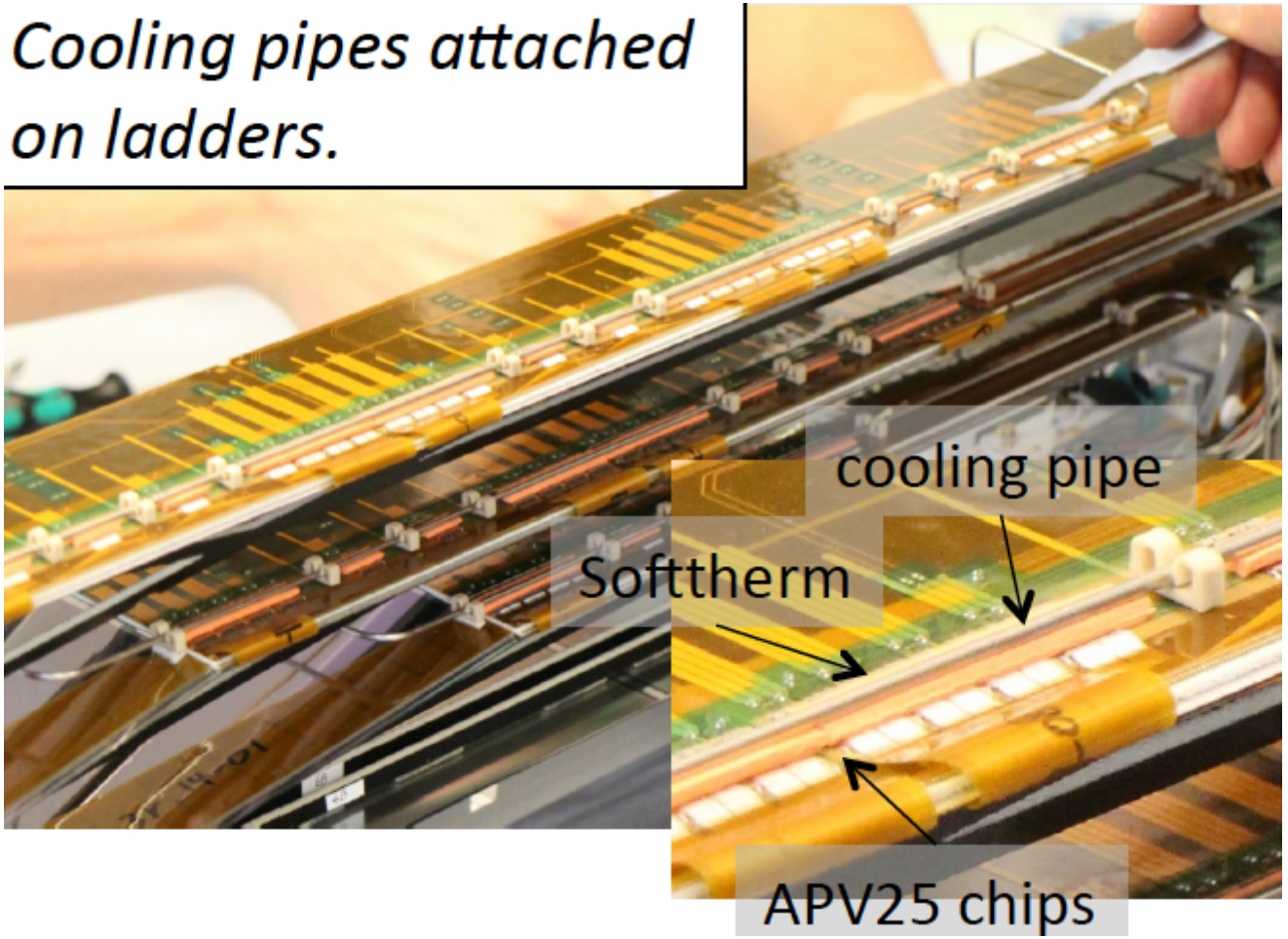


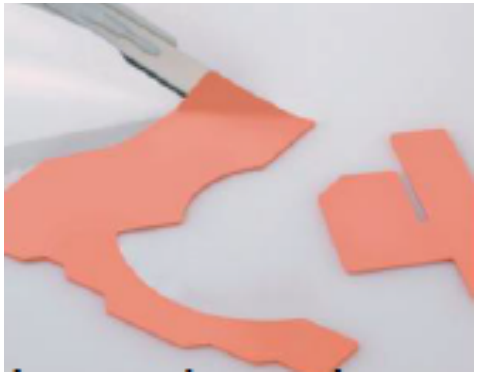




- Origami flex is glued on sensor n-strip surface with an electrical/thermal-isolation foam
- APVs are placed on the flex to minimize the analog path length ➠ reduce capacitive noise

CO_2 cooling system





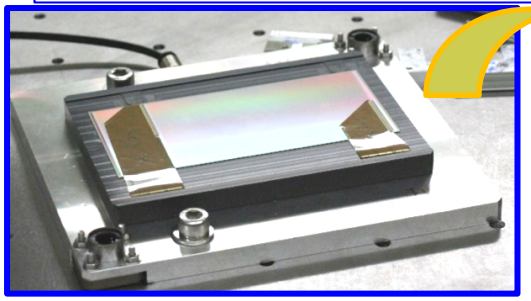
Softtherm 86/125: thermal-conducting dielectric pads

- Total heat dissipation from all APV25 chips can go up to 700 W ➠ need cooling
- Employed dual-phase CO_2 cooling system, which provides an efficient and low-mass solution with simple control of coolant temp (only with pressure)
- Thin stainless tube: 1.6-mm outer diameter and 0.1-mm thick ➠ reduced material budget

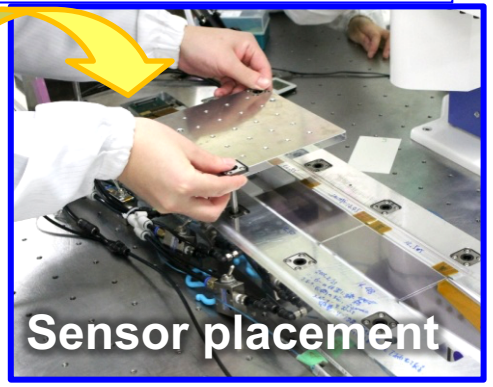
Assembly procedure

Precision DSSD alignment

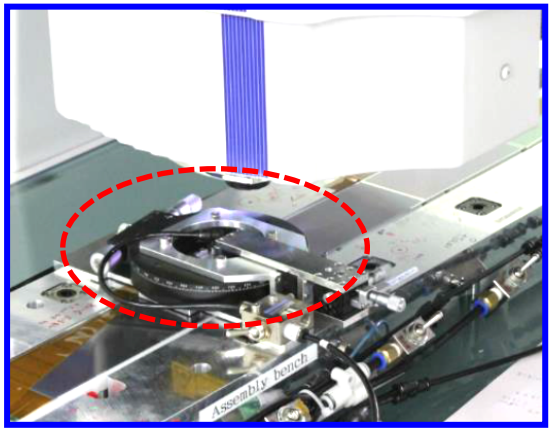
DSSDs are handled with precise assembly jigs [*O*(50μm)], on which the sensors are fixed by vacuum chucking



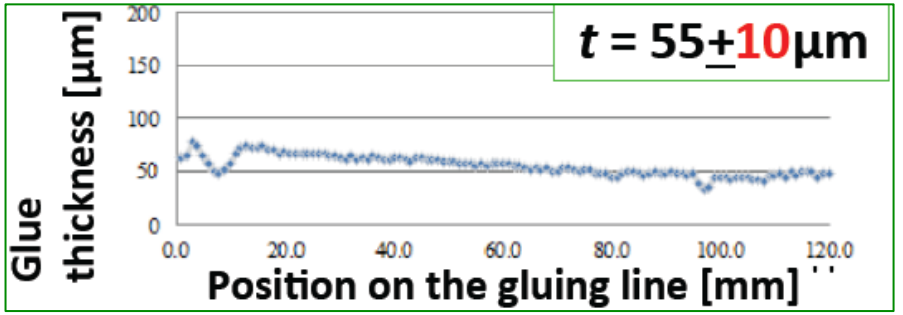
Sensor fixed on a jig



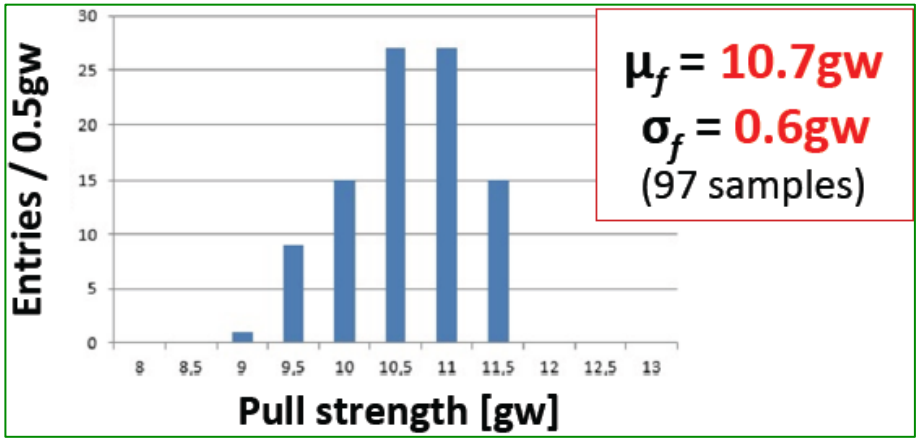
Sensors are aligned with precision of 10μm by a position tuning jig with monitoring via an optical CMM



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

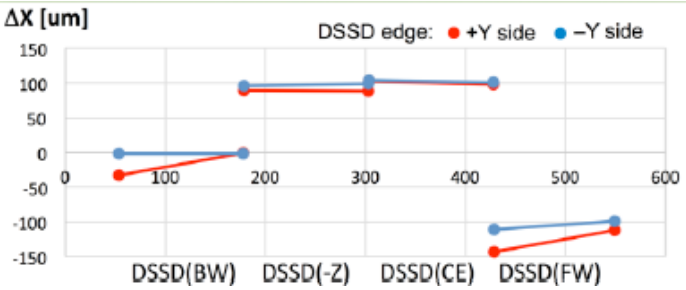


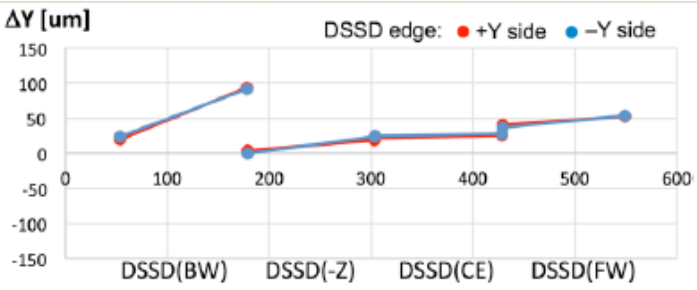
- Bonding parameters tuned to realize >99% yield and pull strength >5gw with 20% spread

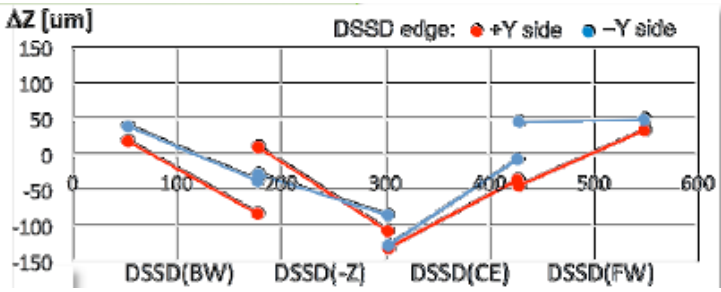


Quality assurance

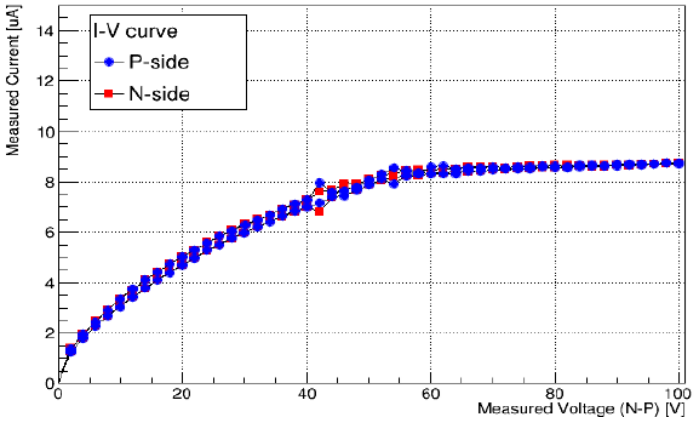
- Geometrical precision measured with an optical CMM ➠ typical value <150µm in the xy plane and 200µm along the z axis



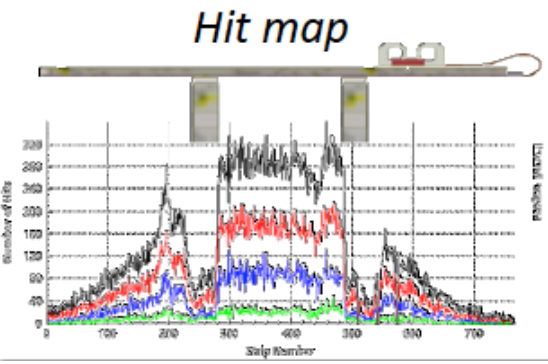


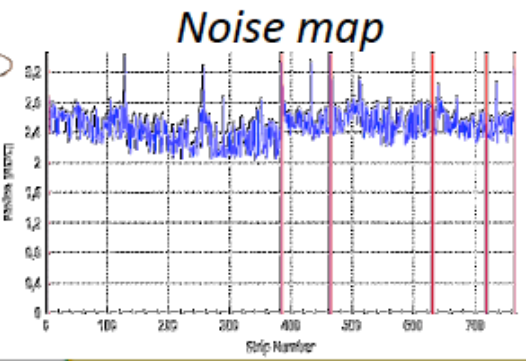


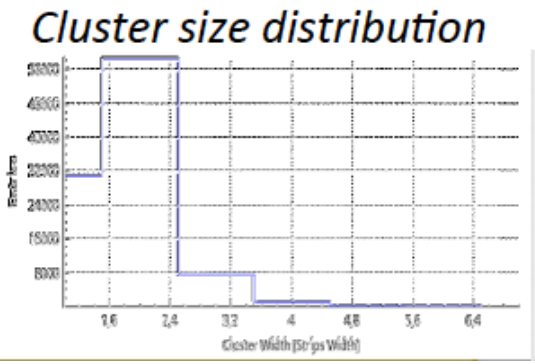
- Measure I~V curve (right) ➠ confirm the sensor functionality for biasing

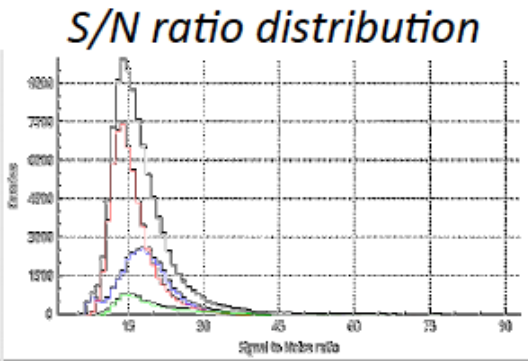


- Electrical qualification with external laser or Sr^{90} beta source (below) ➠ check defects in the strips and particle response





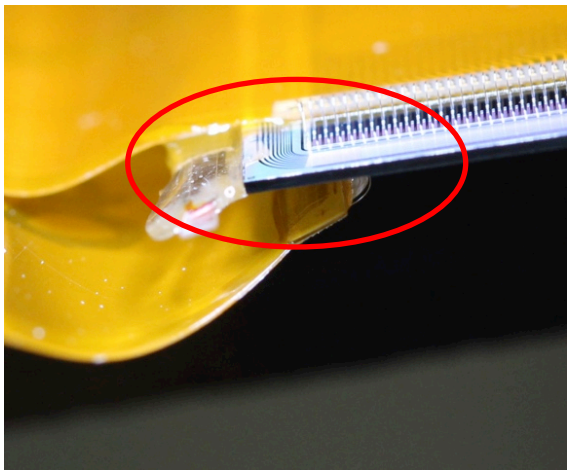




- And, lots of optical inspection...

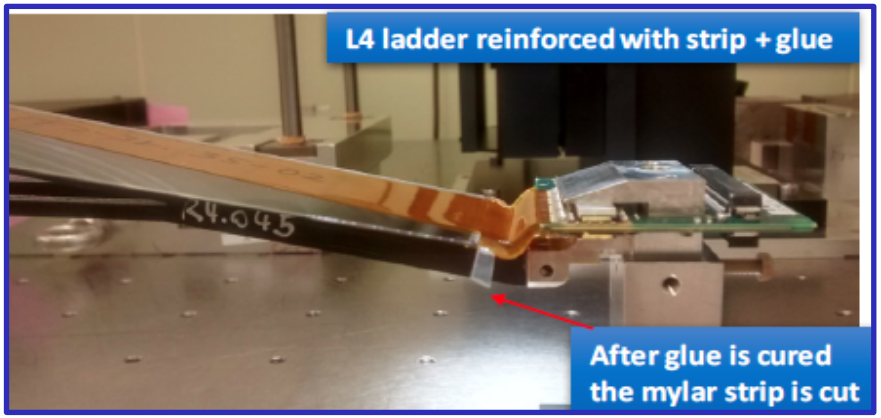
Key challenge: peel-off

- Glue joint between the PF1 pitch adapter and FW sensor found to be lifted off on some L4 and L6 ladders



- Main cause:
  - Only 1.3mm overlap between the sensor and PF1
  - Stress on PF1 due to bending angle, critical for L4 followed by L6 while L5 is somewhat relaxed

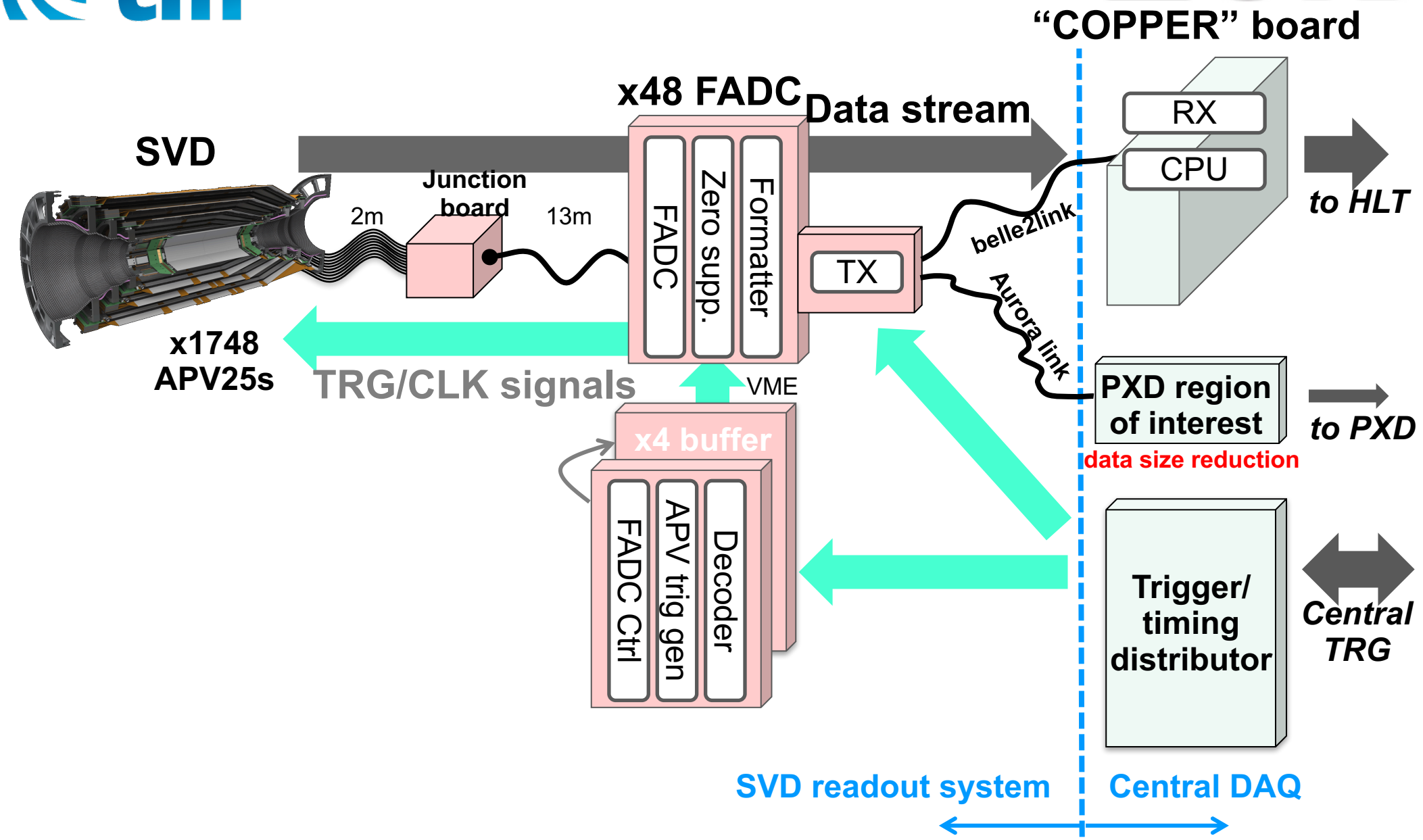
- Exercised a glue reinforcement strategy:
  - Insert a thin mylar strip between PF1 and PF2 to glue them close to the sensor edge
  - Add drops of glue near the sensor corners



- Developed a staggering assembly procedure to arrest the infant mortality

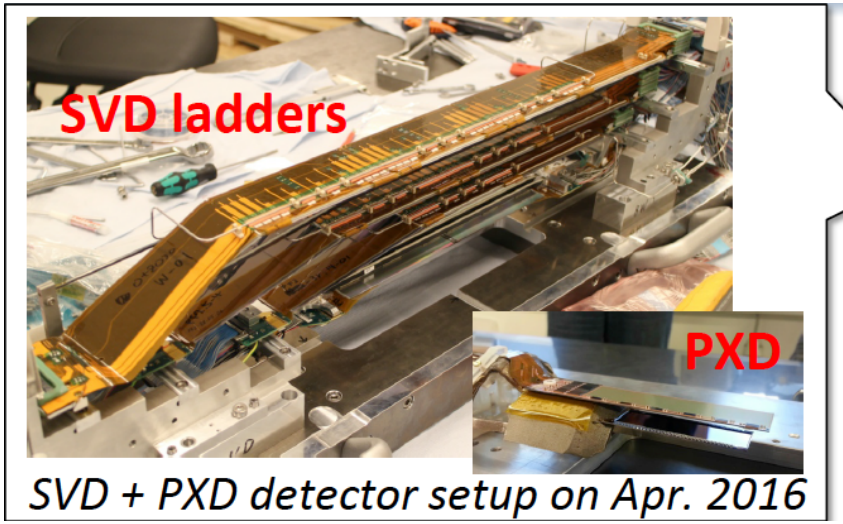
☞ No more peel-off encountered after above countermeasures

Backend electronics

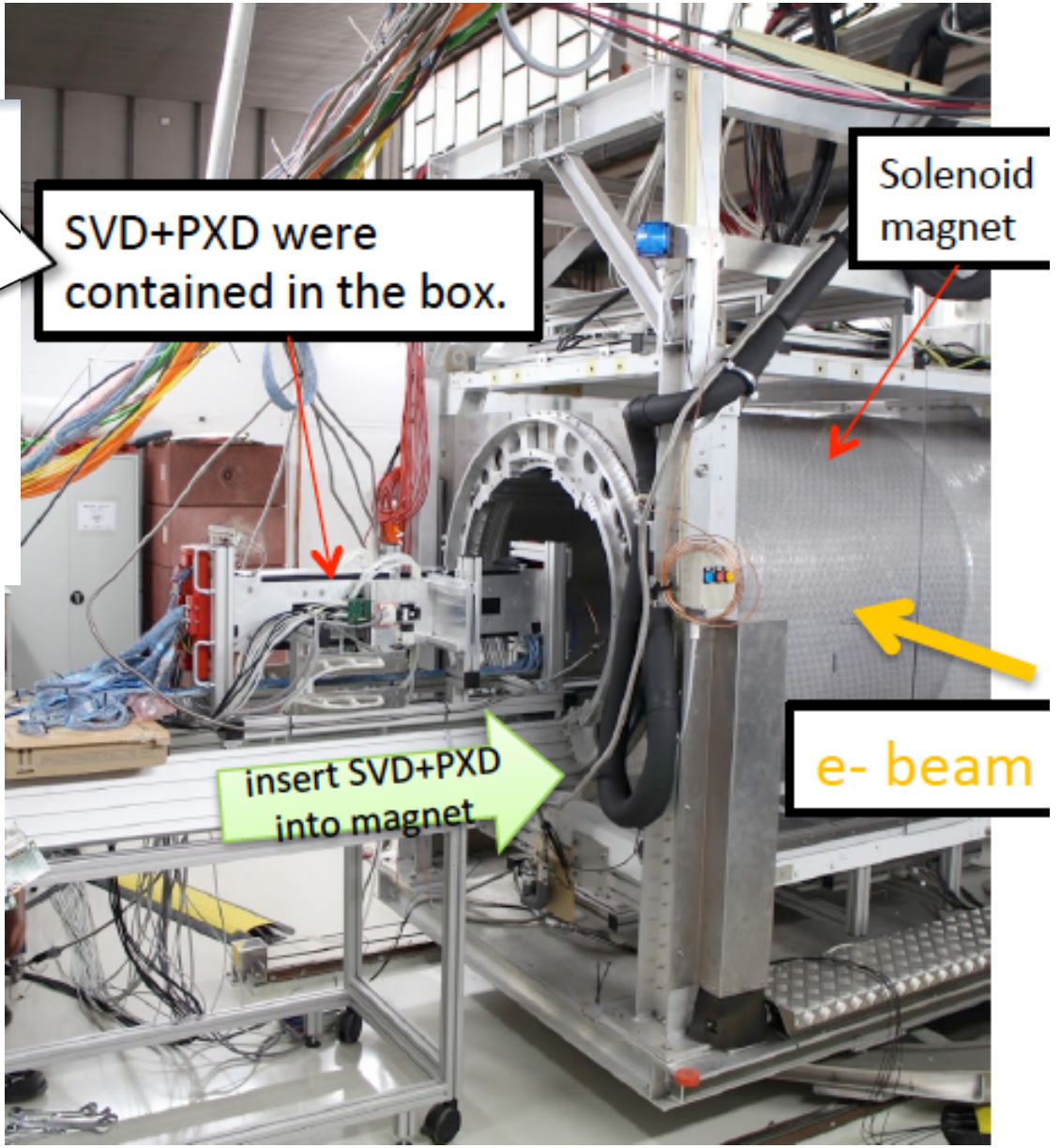


☞ Prototypes of all components are developed and tested

System under test-beam



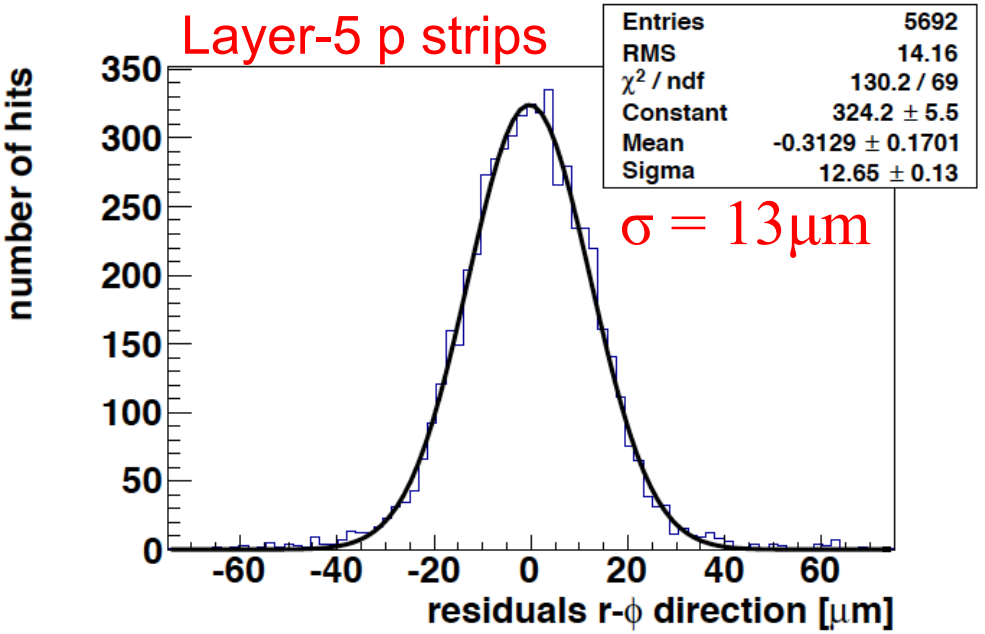
SVD + PXD detector setup on Apr. 2016

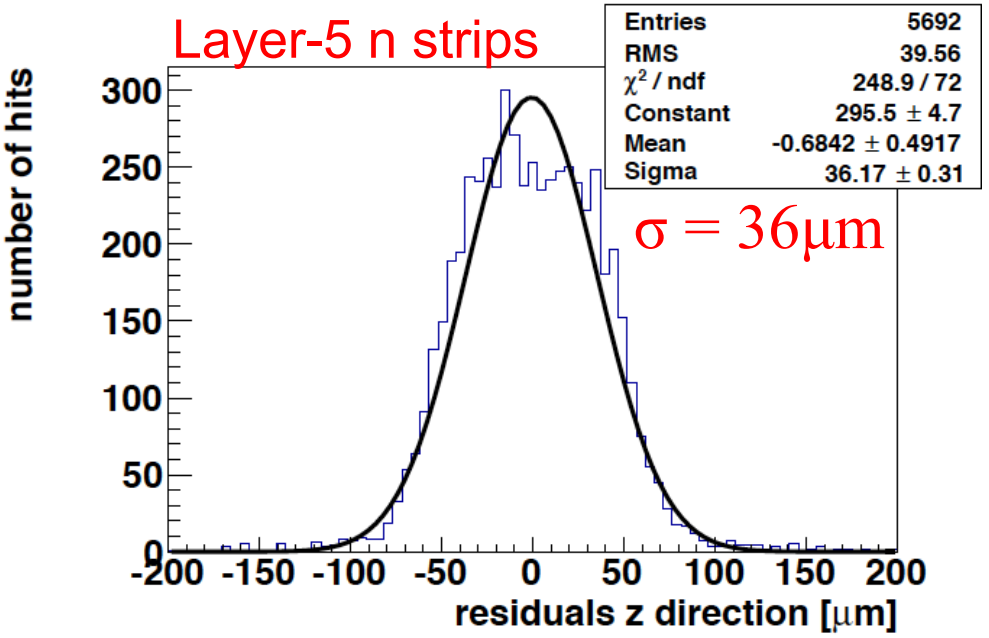


- e^- beam (2-5 GeV) at DESY in Apr 2016
  - All L3-6 SVD ladders
  - + combined with PXD
- In the past, an L5 ladder was also tested at CERN-SPS ➠ Origami concept

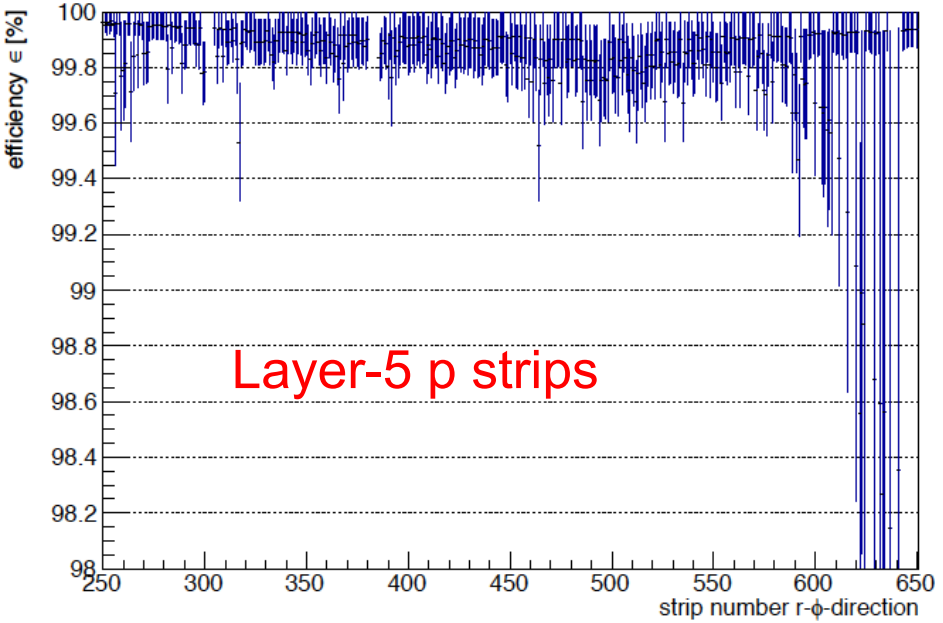
A sample of results

- Very good spatial resolution: consistent with expectations



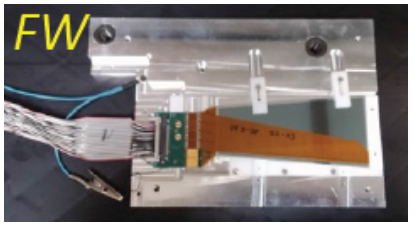


- Excellent strip hit efficiency: > 99%



Status of assembly

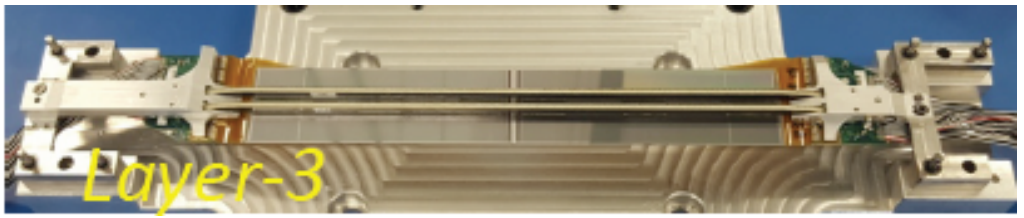
All sites into mass production for a while

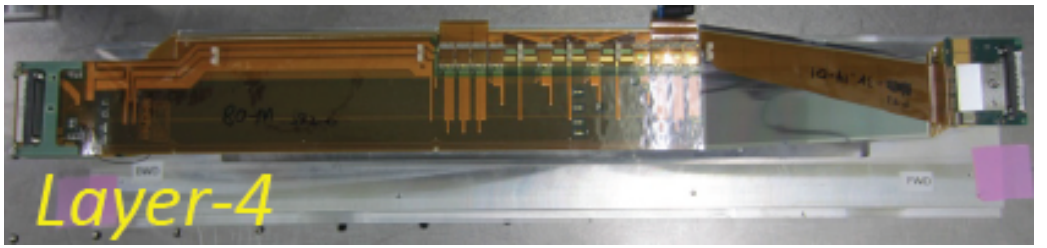


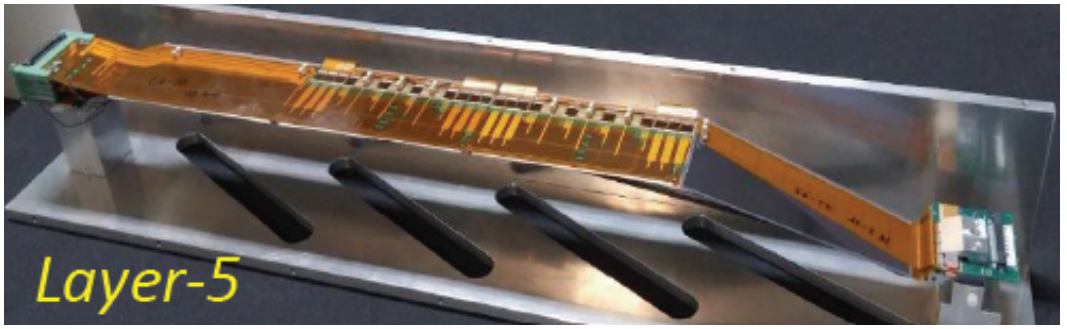
As of Sep 12, 2017:

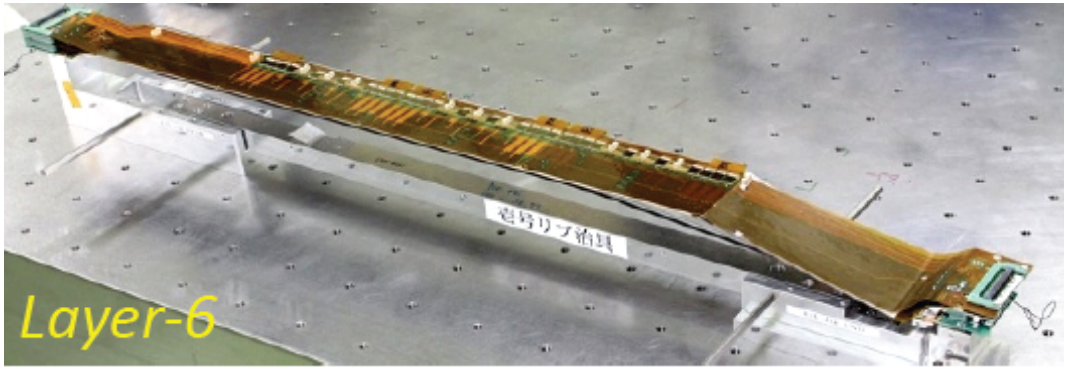
- L3: 100% completed
- L4: 7 out of 12 done (60%)
- L5: Just finished
- L6: 12 out of 20 done (60%)
- FW/BW modules: close to finish

All expected to finish by March 2018









Radiation monitoring

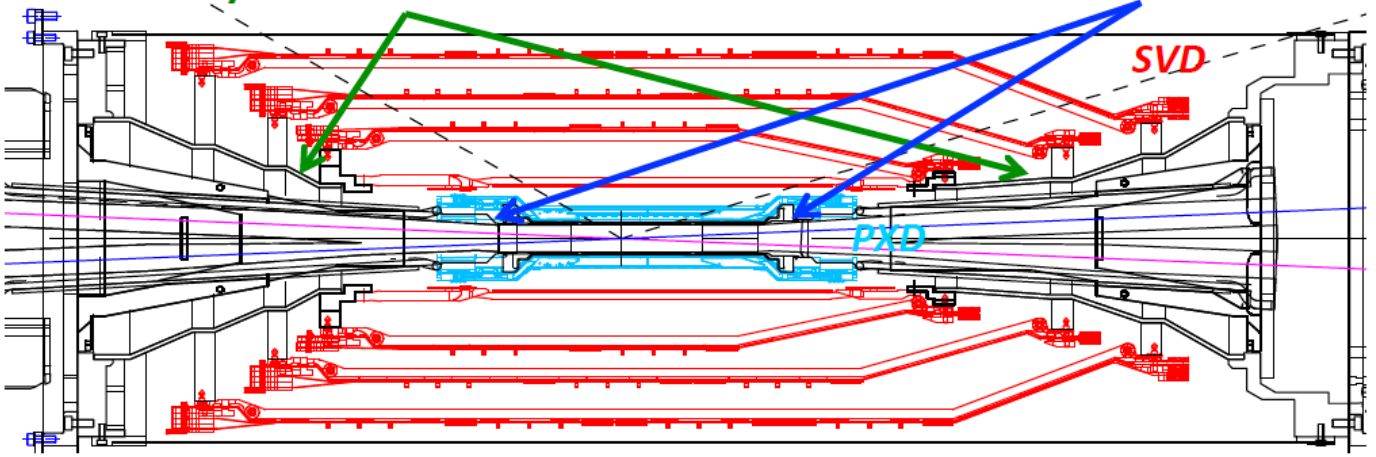
Installation locations

6 + 6 diamond sensors

SVD Layer-3 and -4

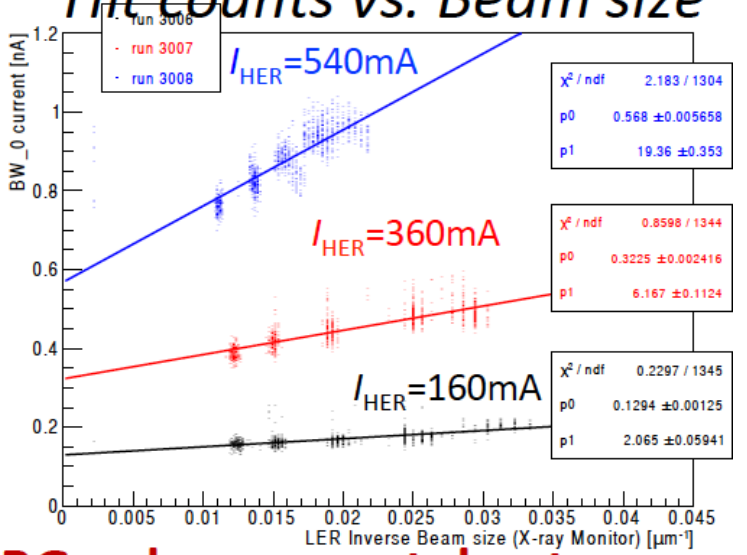
4 + 4 diamond sensors

PXD-beam pipe

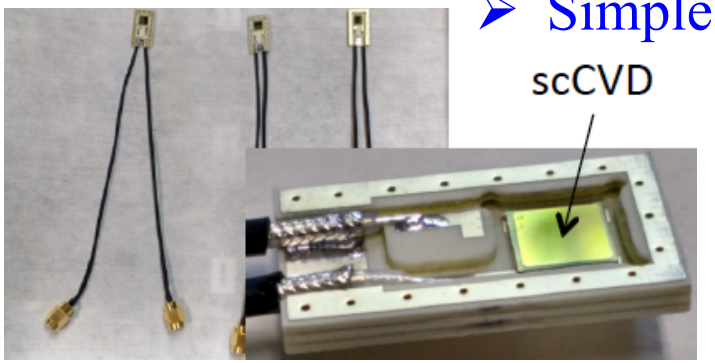


☞ Demonstration below

Hit counts vs. Beam size

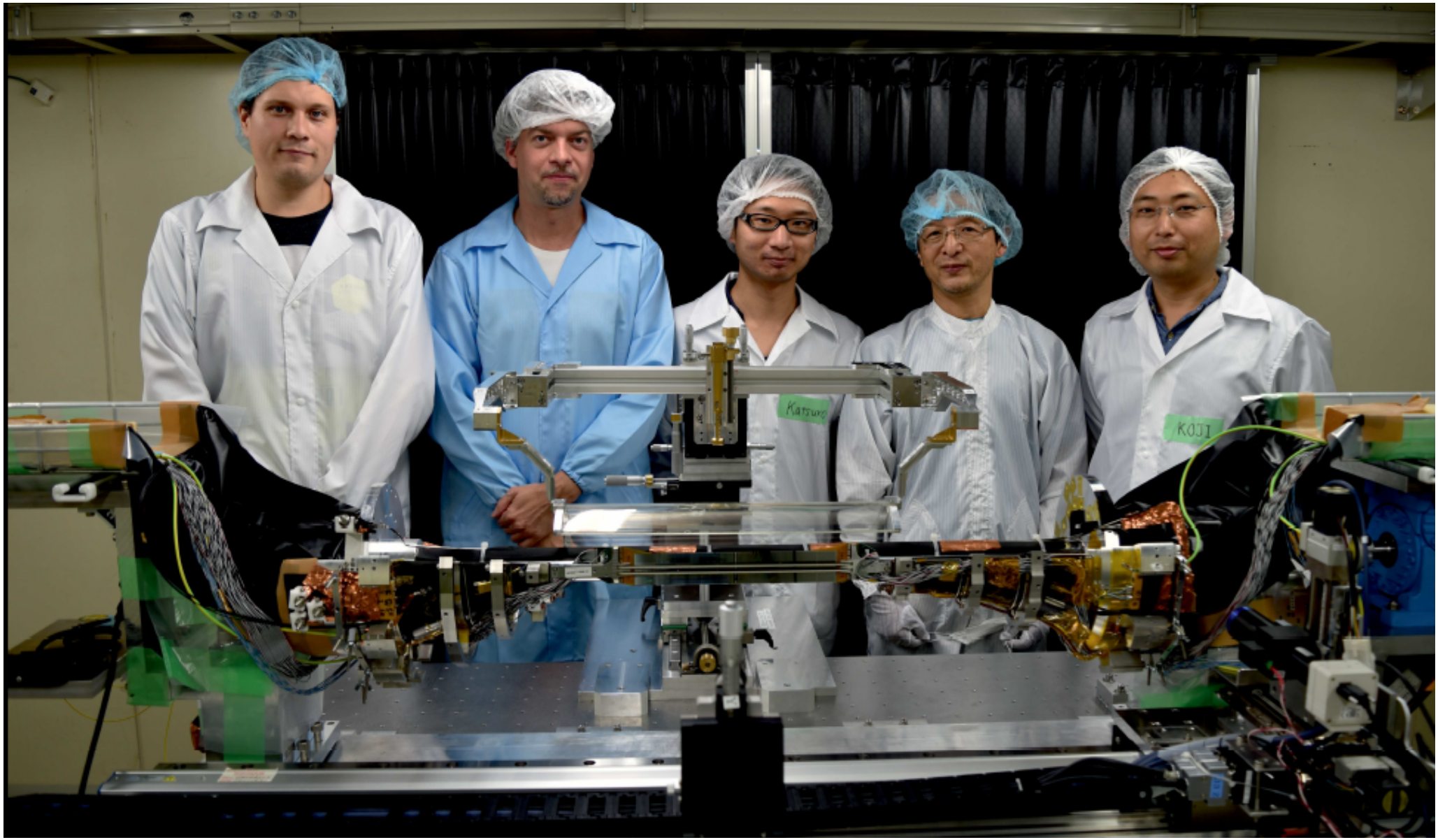


- Single crystal diamond (scCVD): 4.5×4.5×0.5 mm^3
  - ➢ High radiation tolerance
  - ➢ Small temperature dependence
  - ➢ Simple and compact structure



BG enhancement due to Touschek effect was detected

A recent milestone



☞ First L3 ladder is successfully mounted just yesterday

Overall schedule

High-level milestone	Date
SVD ladders for half-shell	Ready
SVD ladder mount at KEK	Sep 2017
SVD ladder production finish	Mar 2018
SVD ready at KEK	Apr 2018
Start of VXD installation	3Q 2018
Start of physics run with VXD	4Q 2018

Conclusions

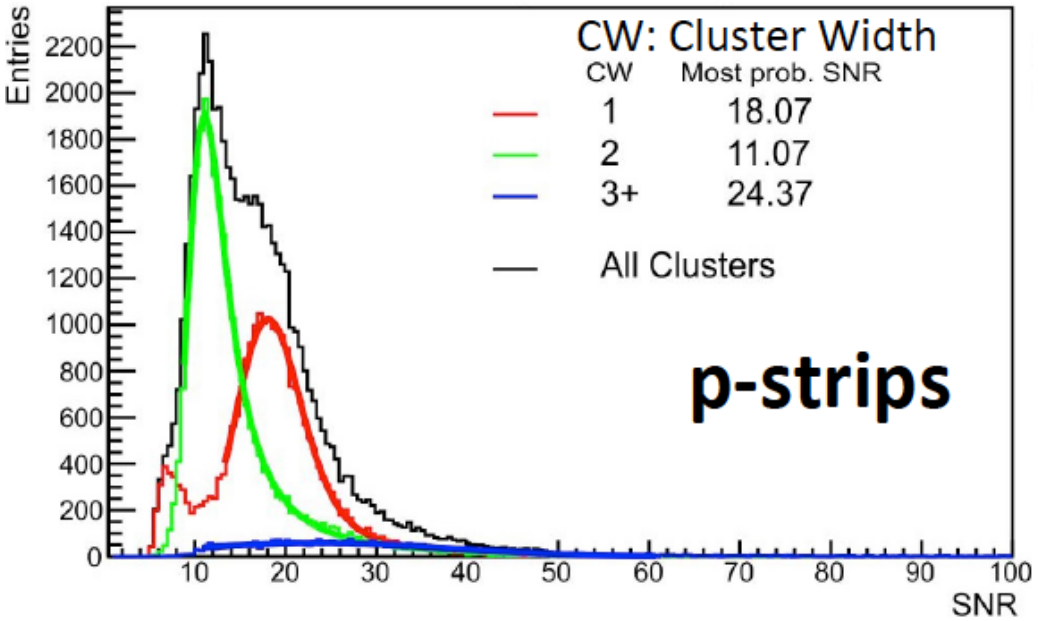
- SVD will play a key role in the physics program of Belle II
- After successful R&D and prototyping phase, we are now into production in full swing
- All sites are at the last leg of production; expect to finish by Mar 2018
- Ladders are individually qualified as well as their performances tested with beams
- Integration of the ladders into half-shell has already begun

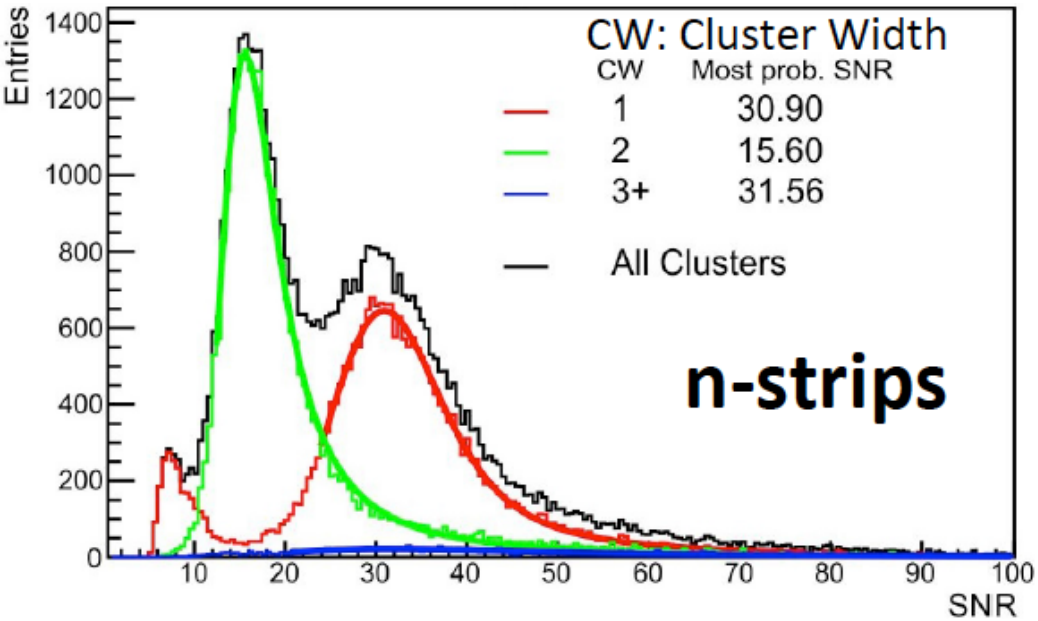
☞ Eagerly looking forward to the physics harvesting phase of Belle II

Supplementary information

A sample of results (old)

- Signal-to-noise ratio (SNR) for an Origami module





☞ SNR improves with CO_2 cooling

CW = 1	w/o cooling	w/ cooling
p-strips	18.1	21.1
n-strips	30.9	35.1