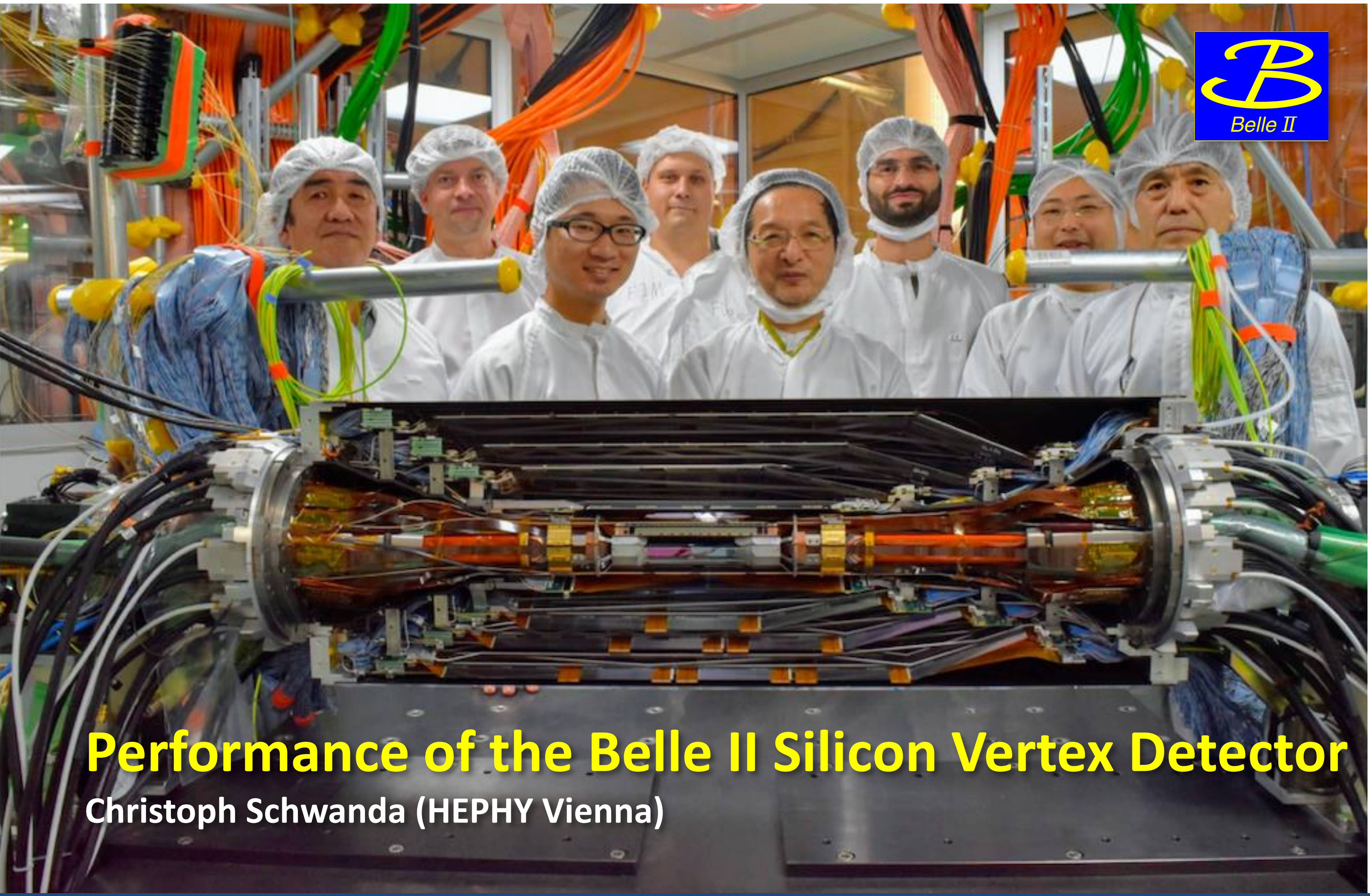


Performance of the Belle II Silicon Vertex Detector

Christoph Schwanda (HEPHY Vienna)

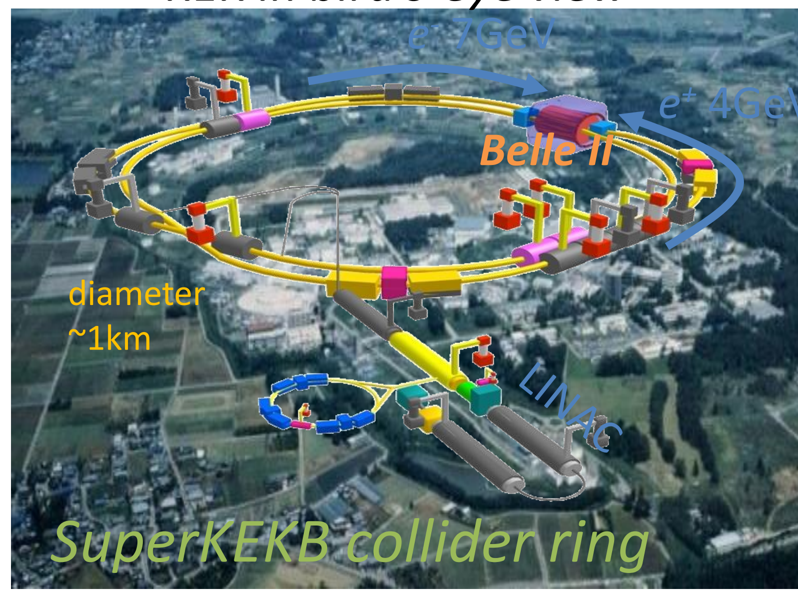
Joint Annual Meeting of the Swiss and Austrian Physical Societies
August 26-30, 2019, Zurich University, Switzerland

HARDWARE OVERVIEW

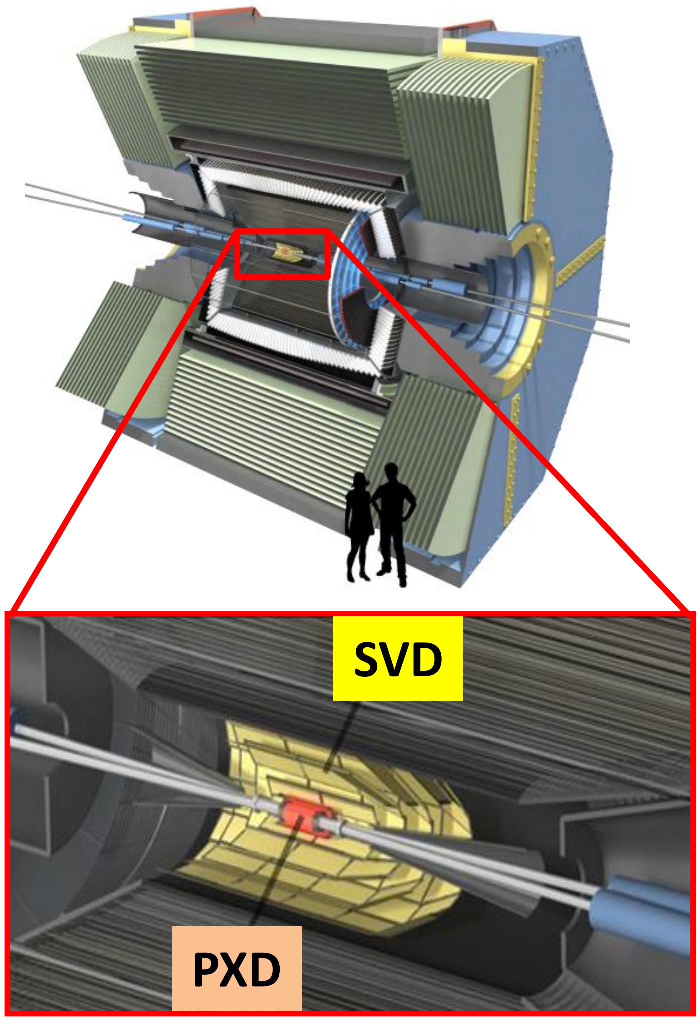
SuperKEKB and Belle II Experiment

- 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 designed luminosity: $L = 8.0 \times 10^{35}$ cm^{-2}s^{-1}
- Belle II experiment
  - Intensity frontier experiment at SuperKEKB to discover and understand physics beyond the SM (BSM).
  - Precise determination of the decay vertices and low-momentum tracking are essential to perform the BSM search.

KEK in bird's-eye view



Belle II Vertex Detectors

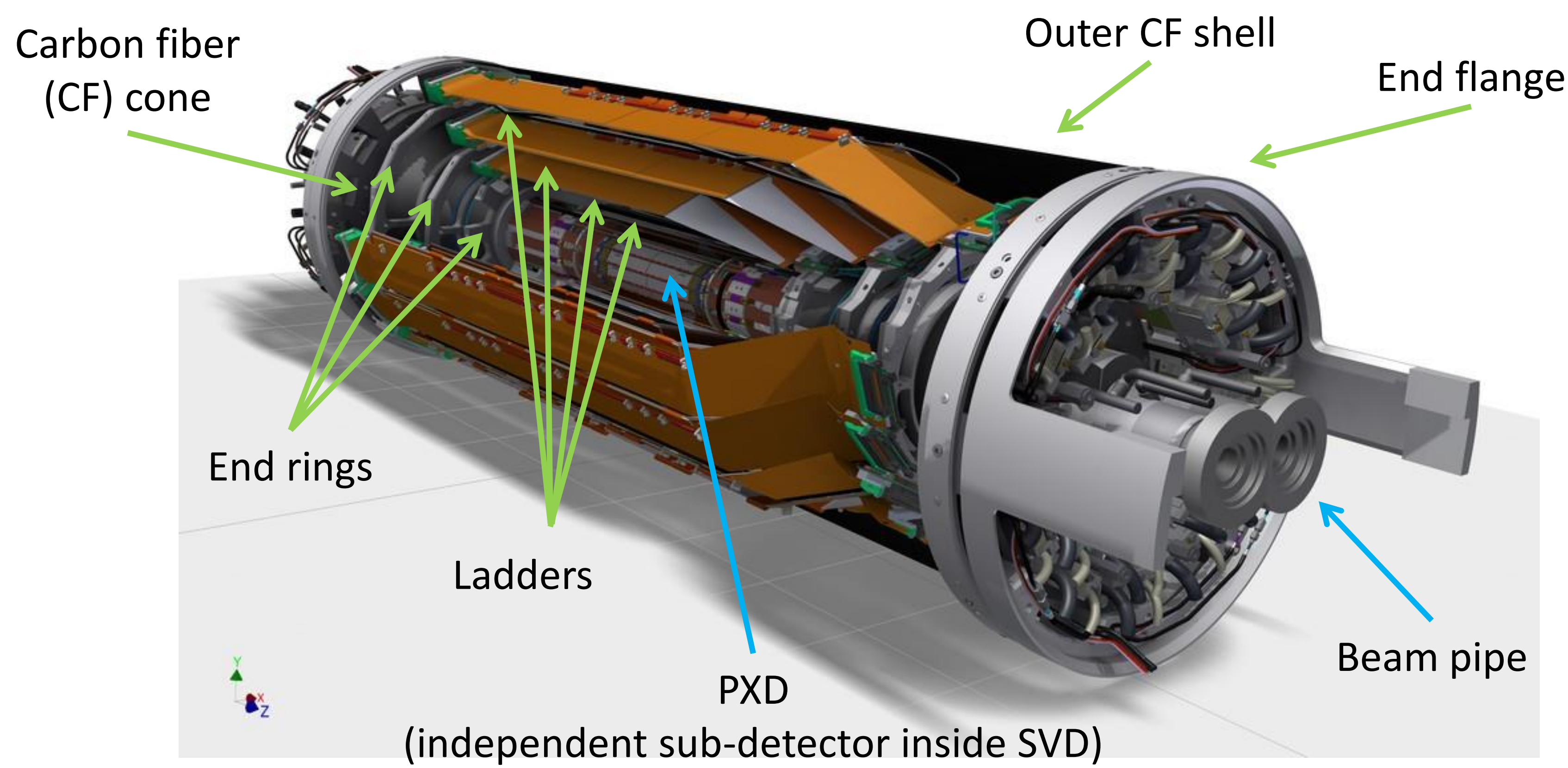


- PiXel Detector (PXD)
  - Based on DEPFET pixels – see previous talk
- Silicon Vertex Detector (SVD)
  - Double-sided silicon strip detectors (DSSDs)

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

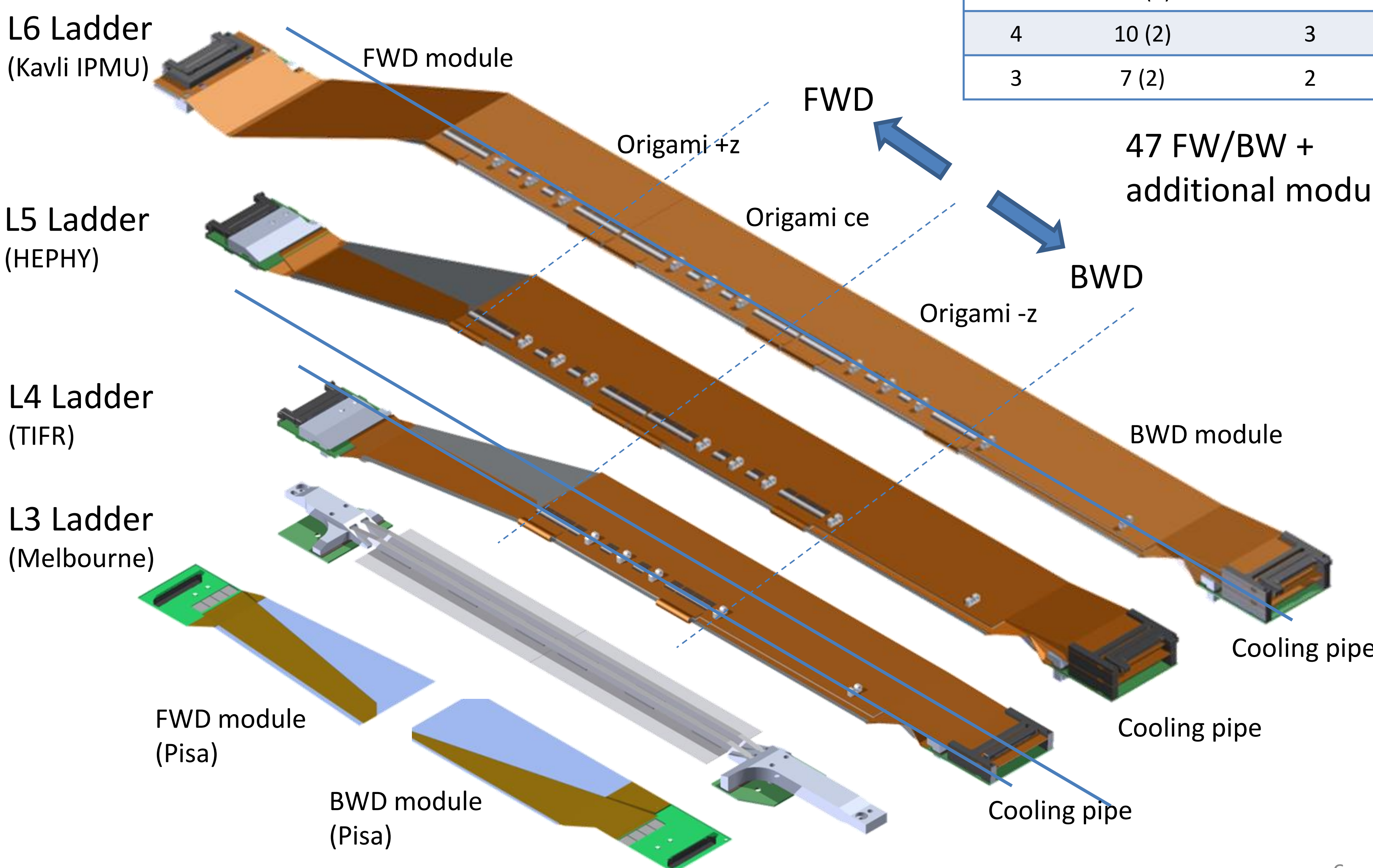
Components of the Belle II SVD



SVD ladders

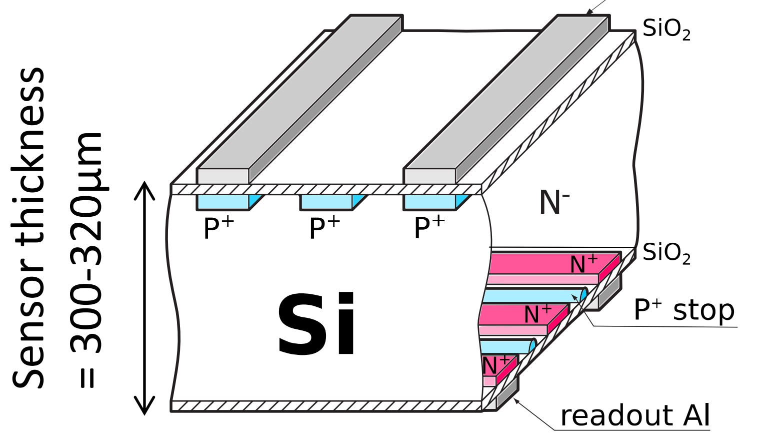
Layer	Ladders (spares)	DSSDs / ladder
6	16 (4)	5
5	12 (3)	4
4	10 (2)	3
3	7 (2)	2

47 FW/BW + additional modules

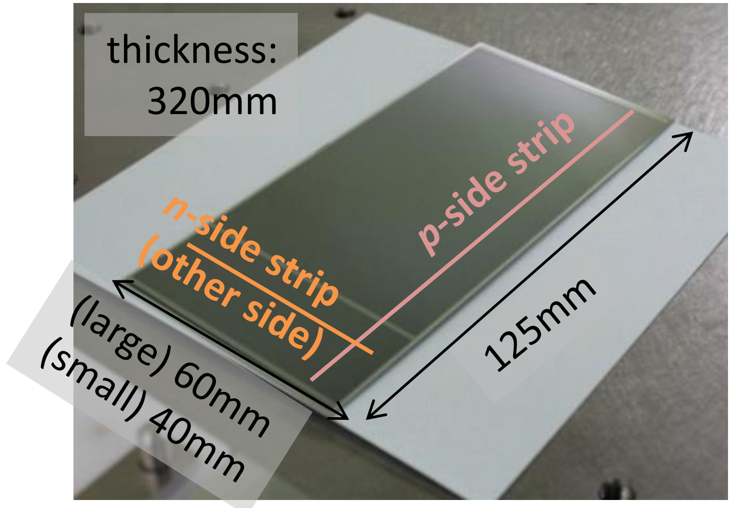


SVD Silicon Sensor

DSSD (Double-sided Si strip detector)



Rectangular sensor (HPK)

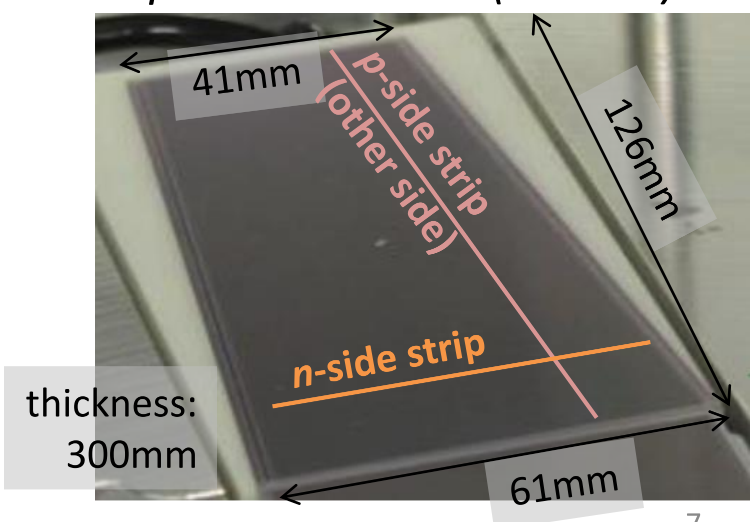


Strip numbers and pitches

- 3 types of DSSD sensors

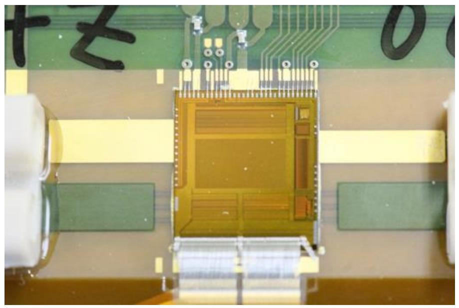
Sensors	Rectangular (Large)	Rectangular (Small)	Trapezoidal
# of *p*-strips	768	768	768
***p*-strip pitch**	75µm	50µm	50…75µm
# of *n*-strips	512	768	512
***n*-strip pitch**	240µm	160µm	240µm

Trapezoidal sensor (Micron)

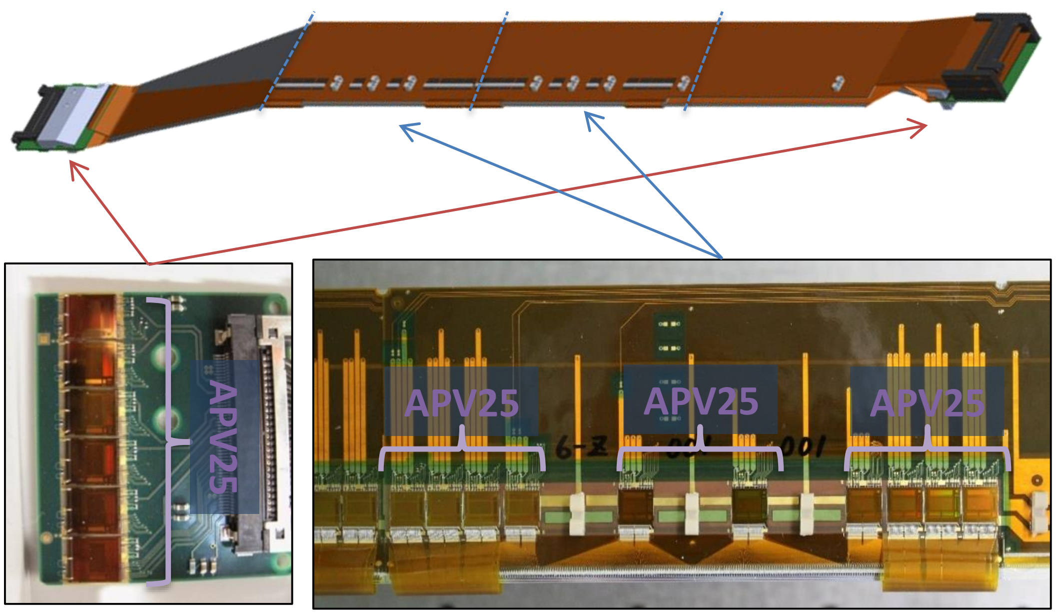


Front-End Readout ASIC

APV25 chip



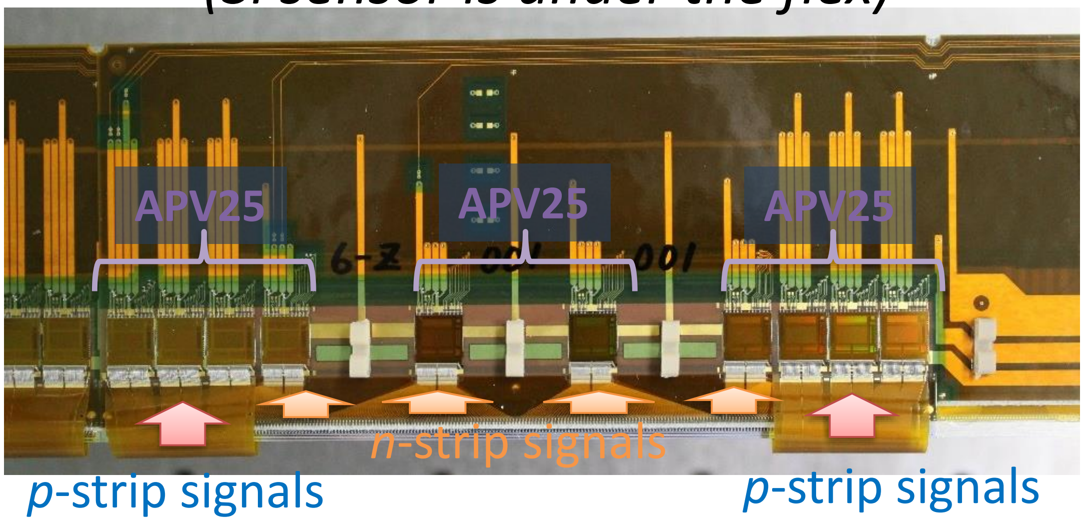
APV25 chips in ladder



- 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
- Chip-on-Sensor (see next slide)
  - Thinned to 100μm thickness for the material budget reduction.
  - Max. heat dissipation: 0.4W
    - → Necessity of cooling

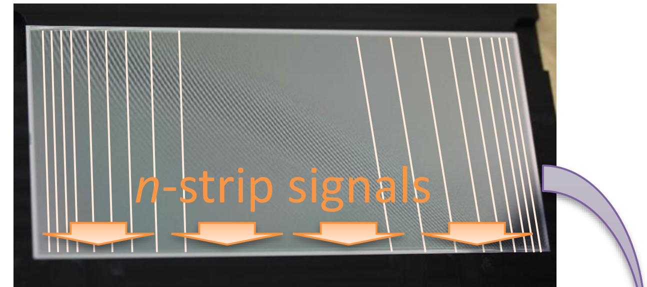
Chip-On-Sensor Concept

ORIGAMI flex
(Si sensor is under the flex)

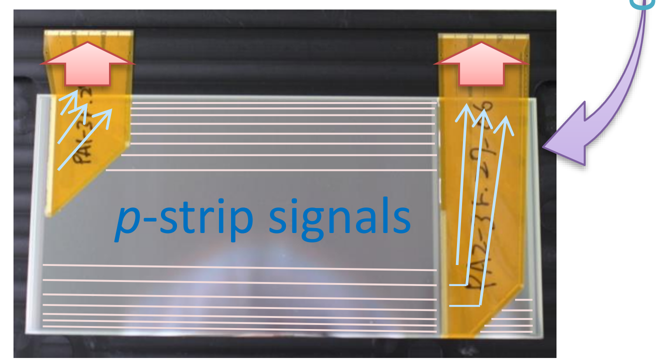


- **Flex circuit (ORIGAMI flex) is glued on sensor *n*-strip surface with an electrical/thermal-isolation foam.**
- **APV25 are placed on the ORIGAMI flex to minimize the analog path length (capacitive noise).**
  - Sensor strips and ORIGAMI flex are connected with Al wire-bonding (ϕ25μm).

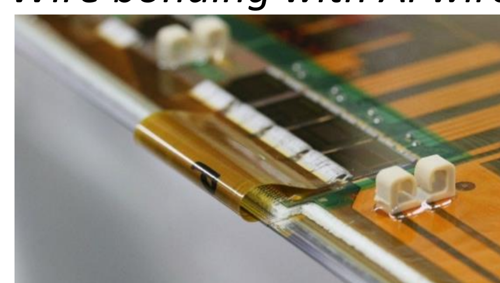
Sensor under ORIGAMI (n-strips)



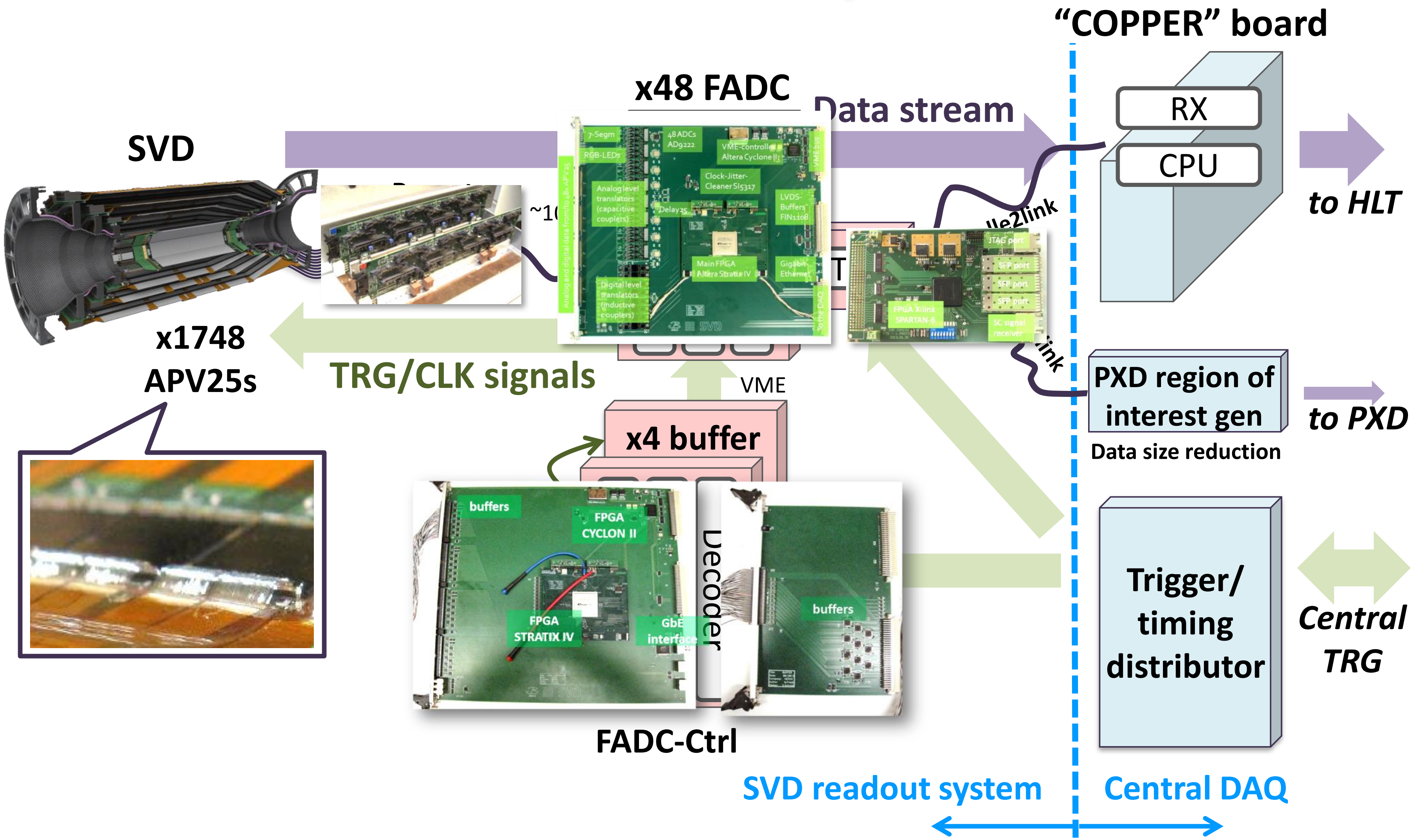
Sensor from other side (p-strips)



Wire bonding with Al wires.



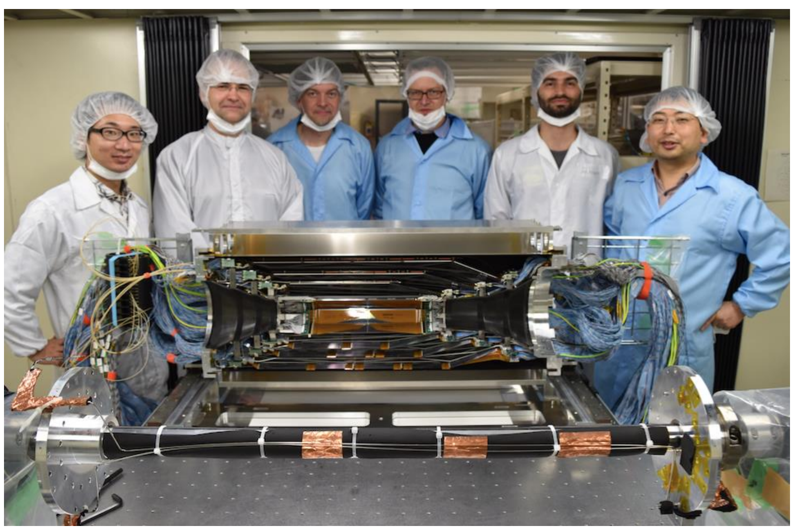
FADC Readout System



SVD COMMISSIONING

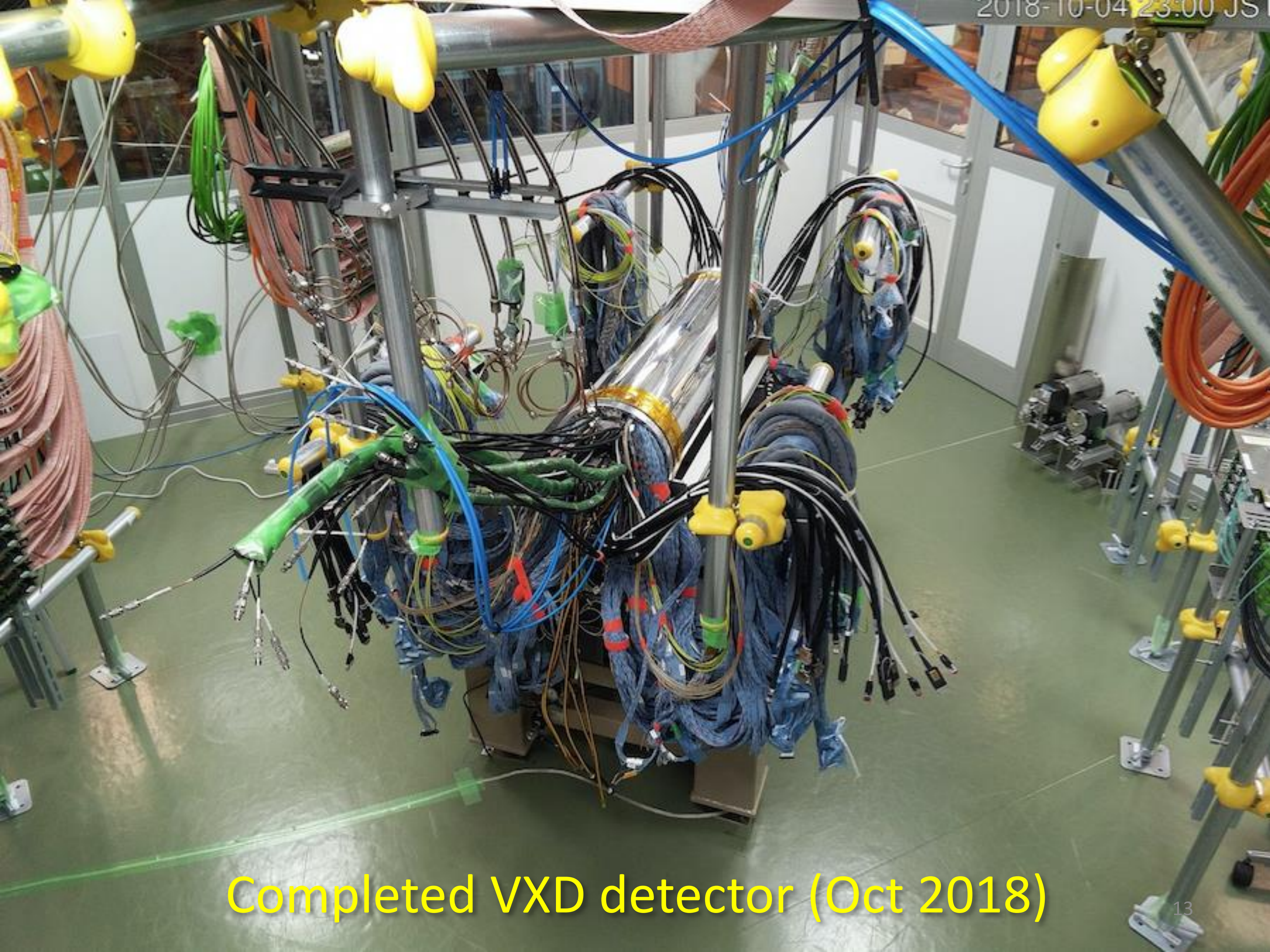
SVD assembly and commissioning

- +X half mount was completed in Feb 2018
- -X half mount finished in Jul 2018
- From Jul to Sep 2018 the two half shells were operated in a dry box in Tsukuba experimental hall (SVD commissioning)
- End of Sep/beginning of Oct 2018 the SVD was moved into the VXD clean room, mounted on the PXD



SVD +X completion (Feb 2018)

SVD -X completion (Jul 2018)

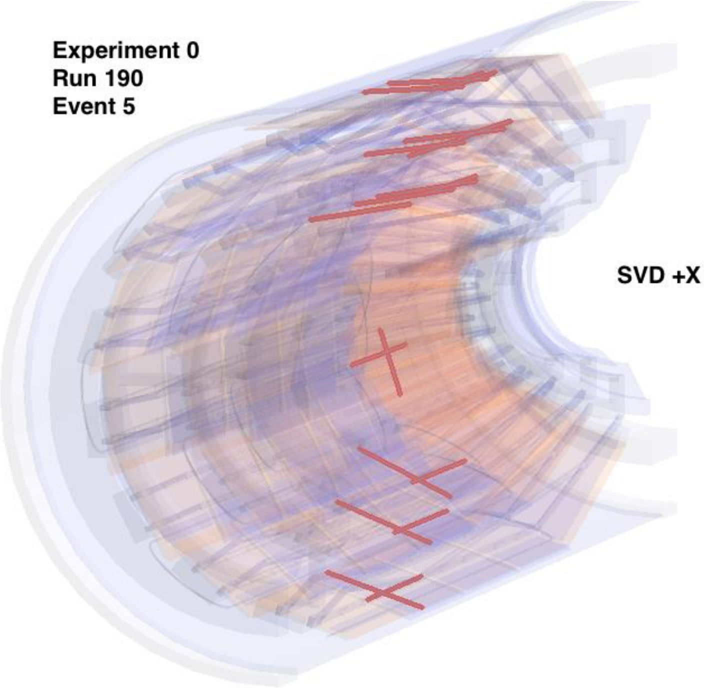


Completed VXD detector (Oct 2018)

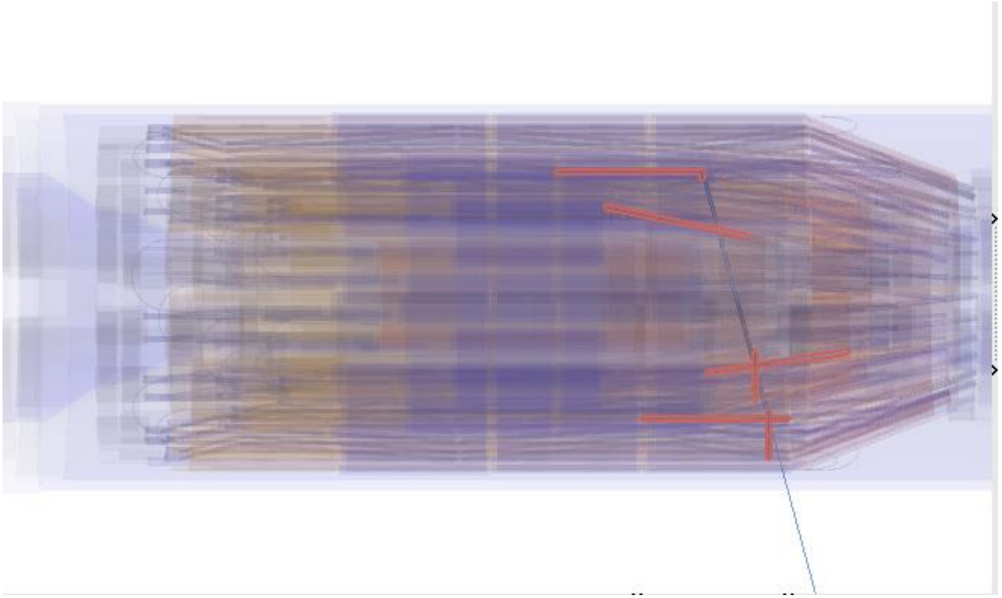
SVD commissioning (Jul-Sep 2018)

- The two SVD halves were operated from Jul to Sep in Tsukuba B4
- Cosmic data and special background runs have been taken to understand the system prior to the start of data taking

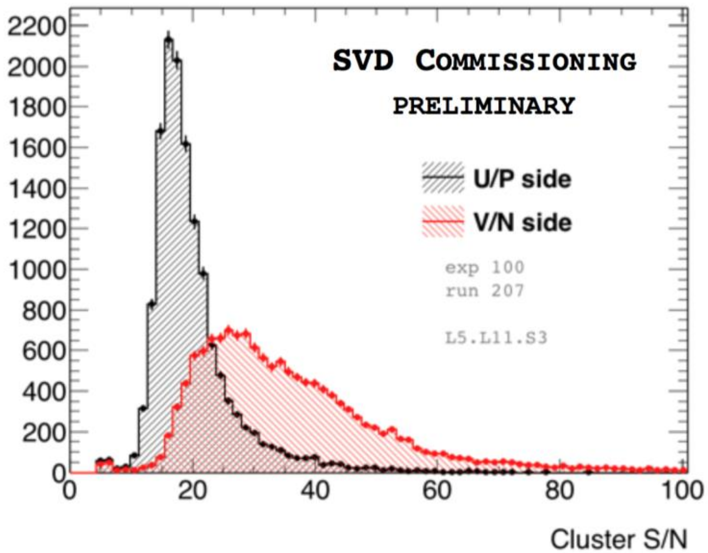
First cosmic event in SVD +X (Jul 10, 2018)



First cosmic event in full SVD (Aug 17, 2018)

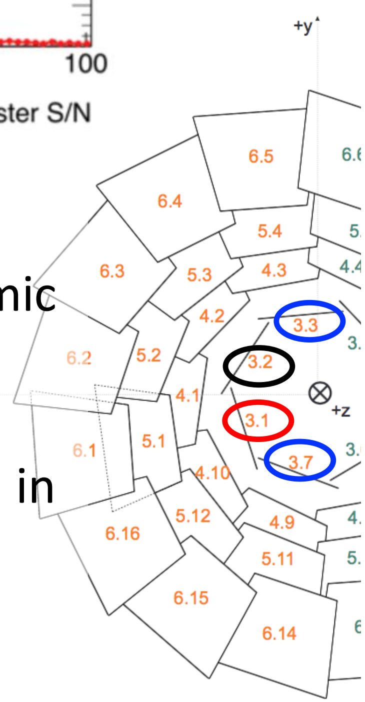


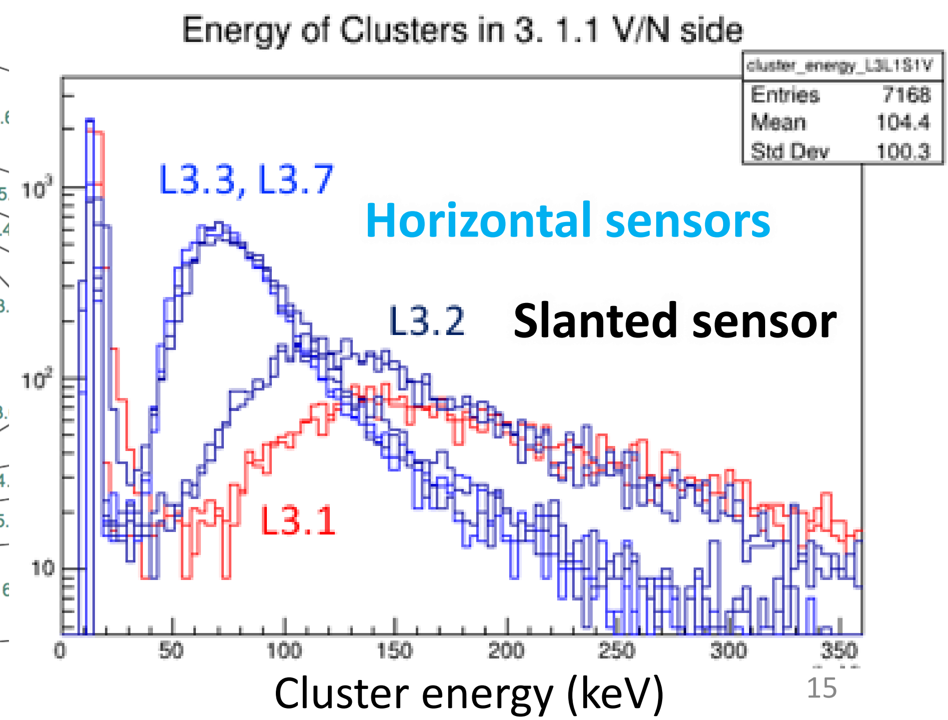
SVD commissioning – SNR, cluster energy



- We have collected about 30 x 10^6 cosmic events with both SVD halves
- The SNR is larger than 25 for N side, slightly lower on P side due to the longer strips and larger capacitance load to the preamplifier

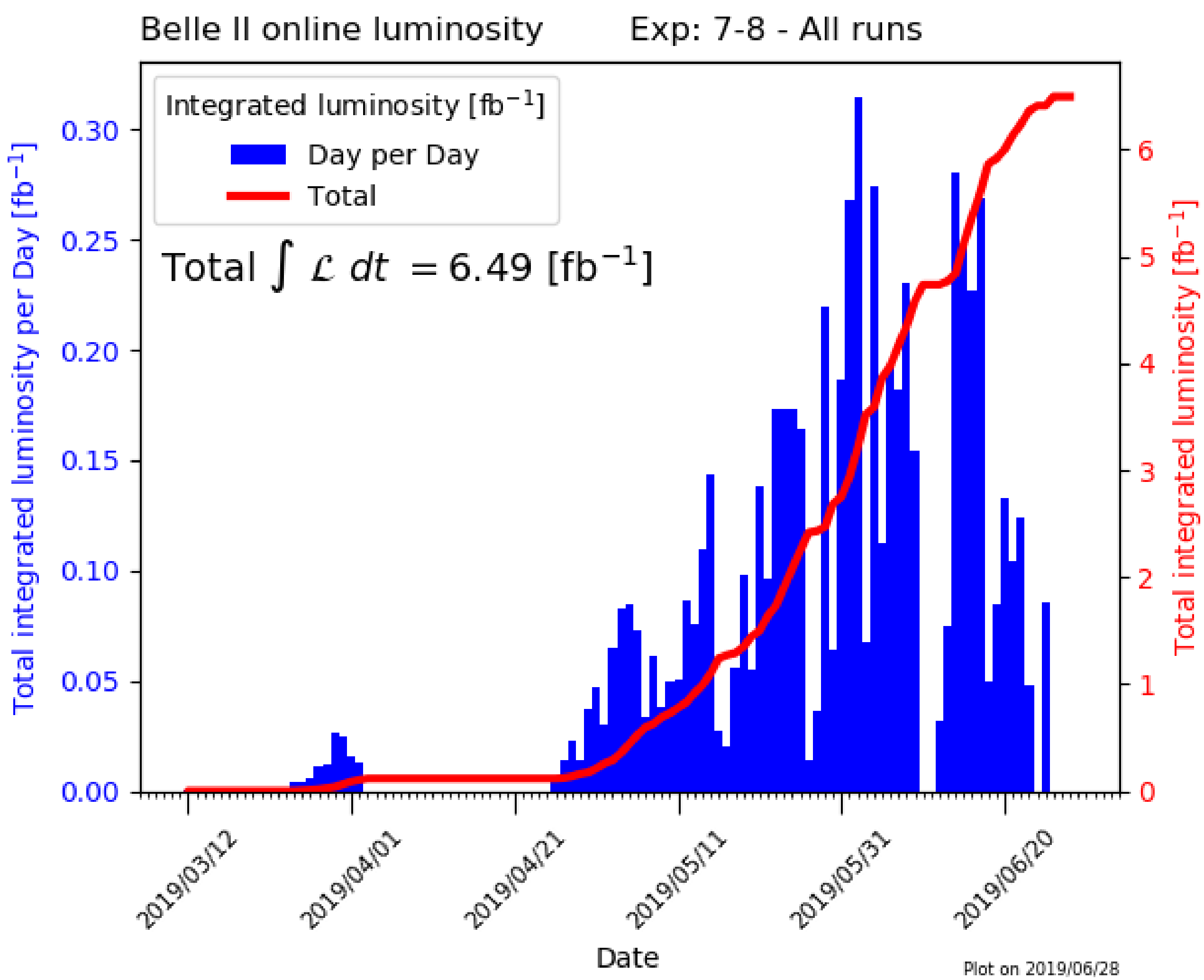
- Cluster energy in horizontal silicon sensor (300 μm thick) by a cosmic ray (MIP) is peaking at 80 keV
- Larger energy deposited in slanted and vertical sensors, as expected
- Low energy peak due to noise cluster





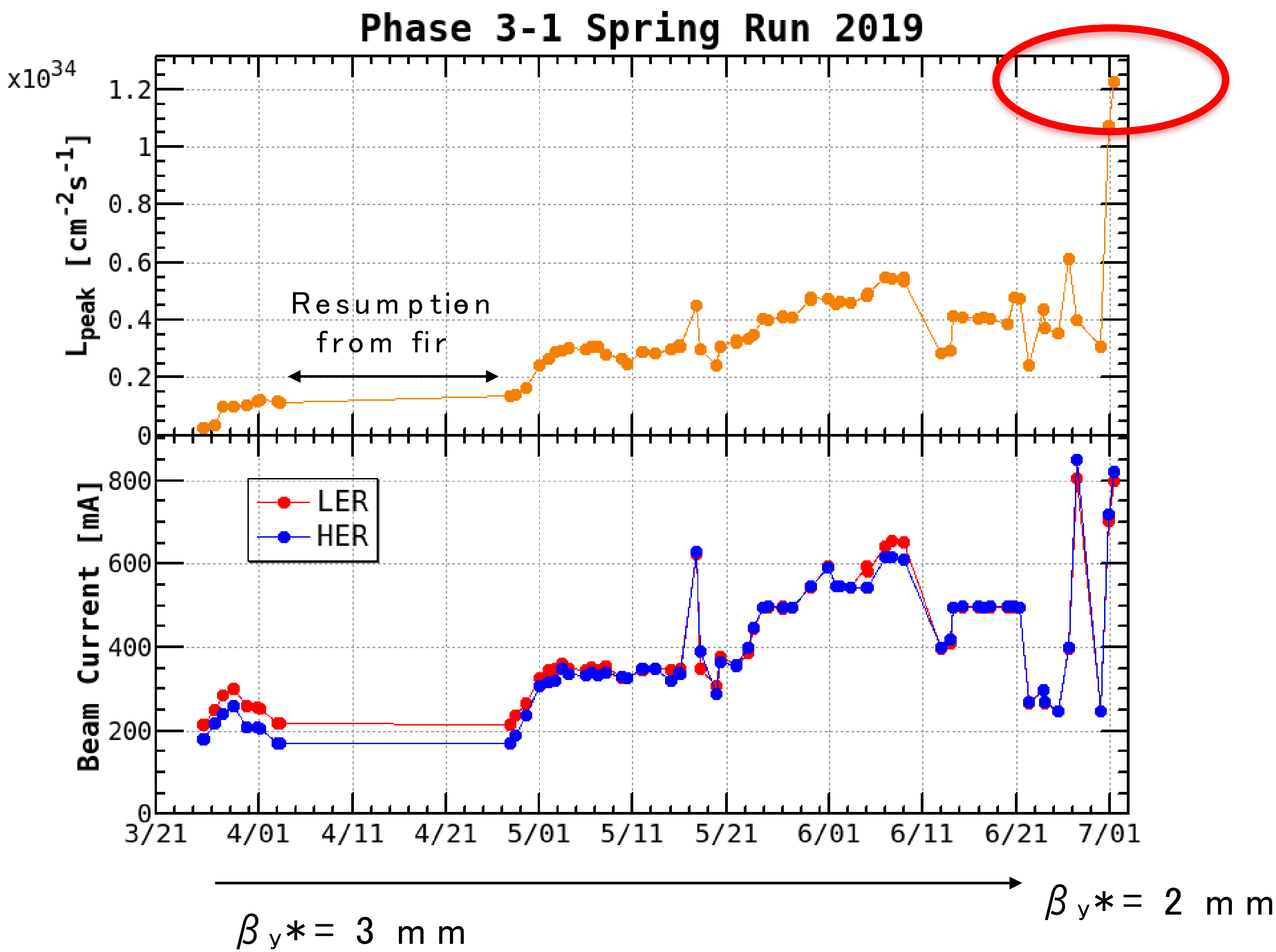
SPRING 2019 RUN ("PHASE 3", EXP. 7/8)

Integrated luminosity by the end of the first run (March to June 2019)



- Slightly below 7/fb, about half of the original projection

Instantenous luminosity history



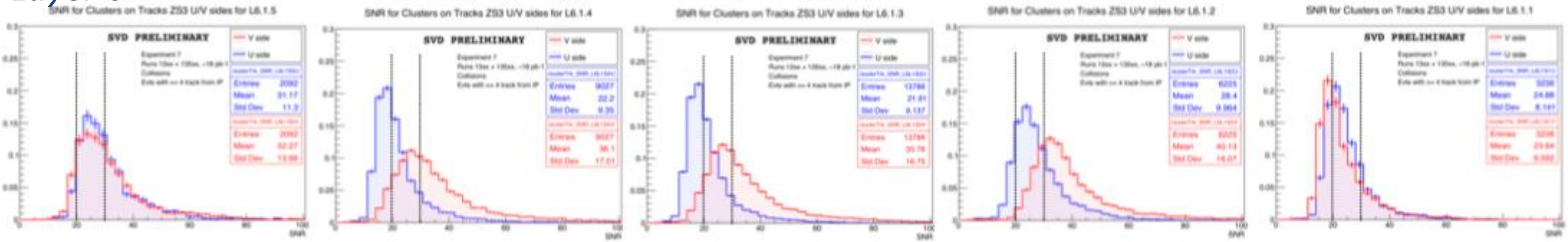
- > $10^{34}/cm^2/s$ was achieved in the very last days

SVD operation in spring 2019

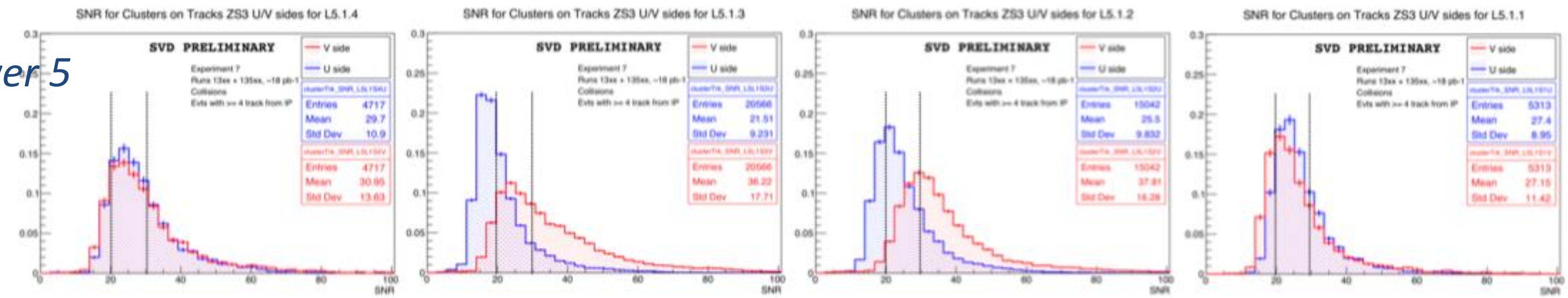
- SVD operation has been smooth and stable throughout the spring run, no major issue has been encountered
- Excellent performance
  - Cluster efficiency above 99% in L3-L6 and on both n- and p-sides (see following slides)
- SVD background situation
  - Currently the occupancy is ~<0.3% in physics runs
  - Limit for good tracking performance is 2-3%

Signal-to-noise ratio for SVD clusters included in tracks (exp. 7)

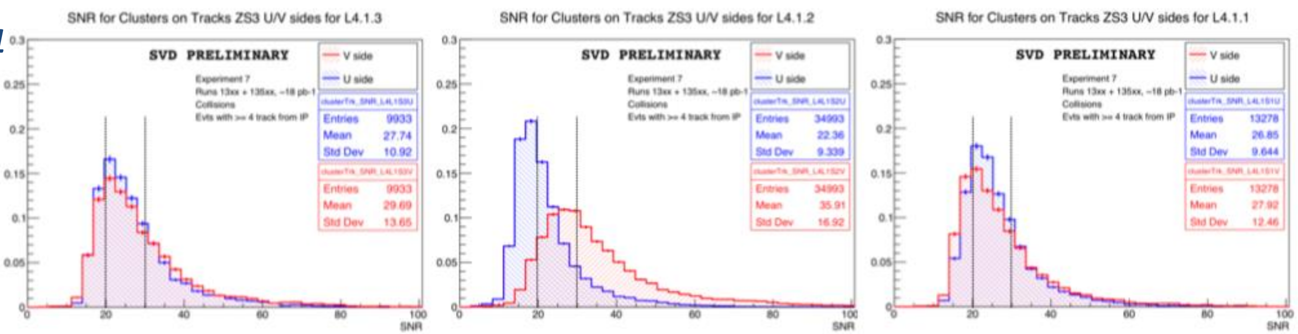
Layer 6



Layer 5



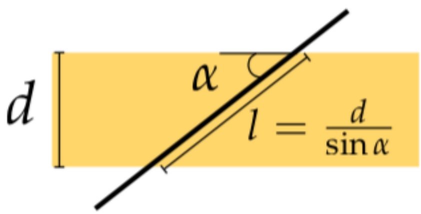
Layer 4



- SNR > 15 in every SVD sensor
- Higher SNR for forward and backward sensors

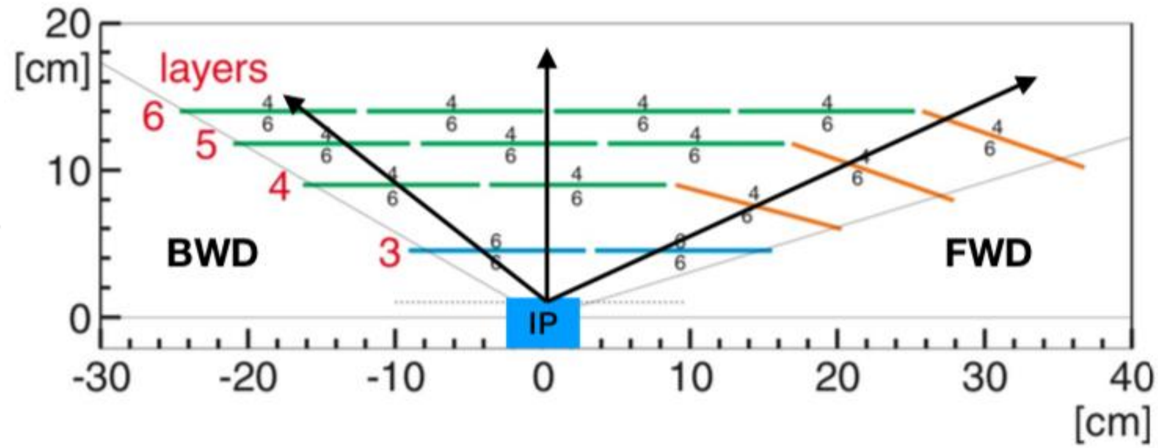
$$SNR_{cls} = \frac{\sum_{strips} S_i}{\sqrt{\sum_{strips} N_i^2}}$$

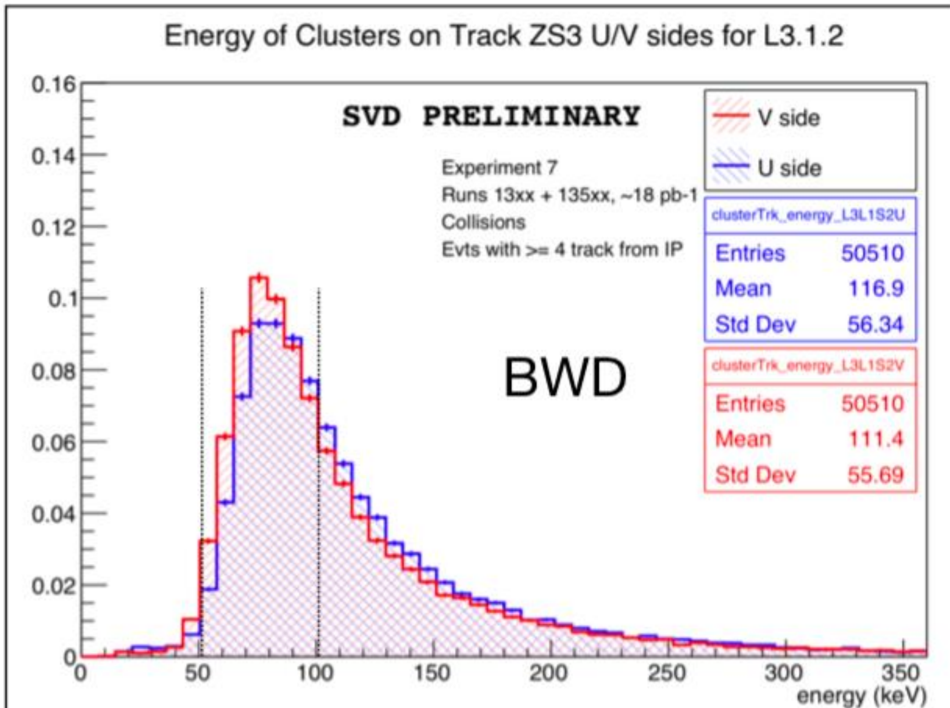
Energies of SVD clusters included in tracks (exp. 7)

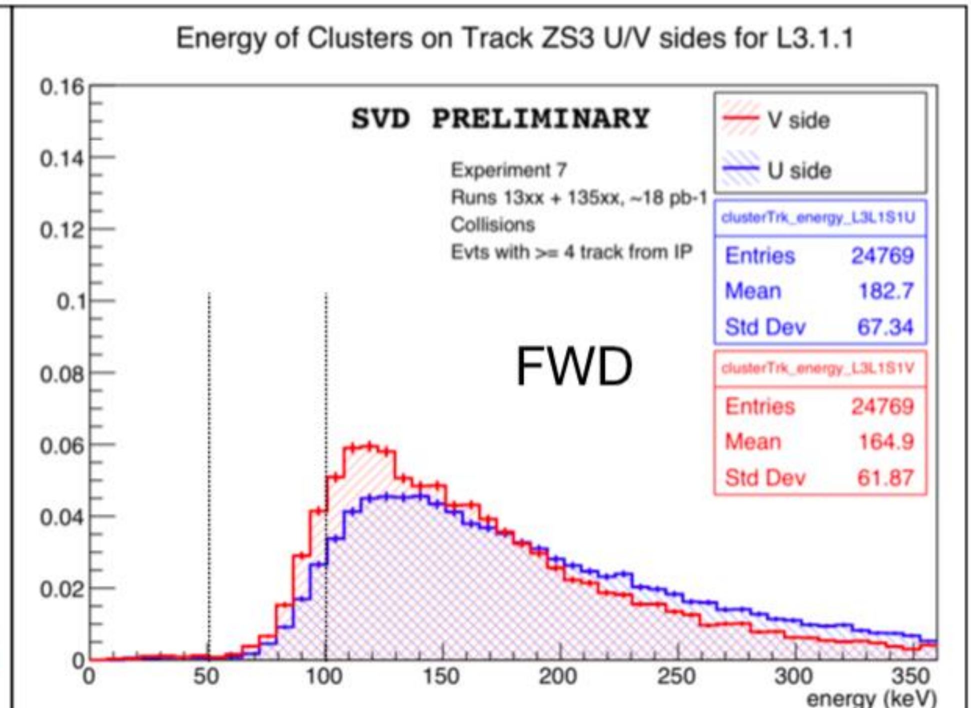


$$d = 300\mu m$$

$$E \simeq \frac{d}{\sin\alpha} \cdot 80 \frac{e^-}{\mu m}$$

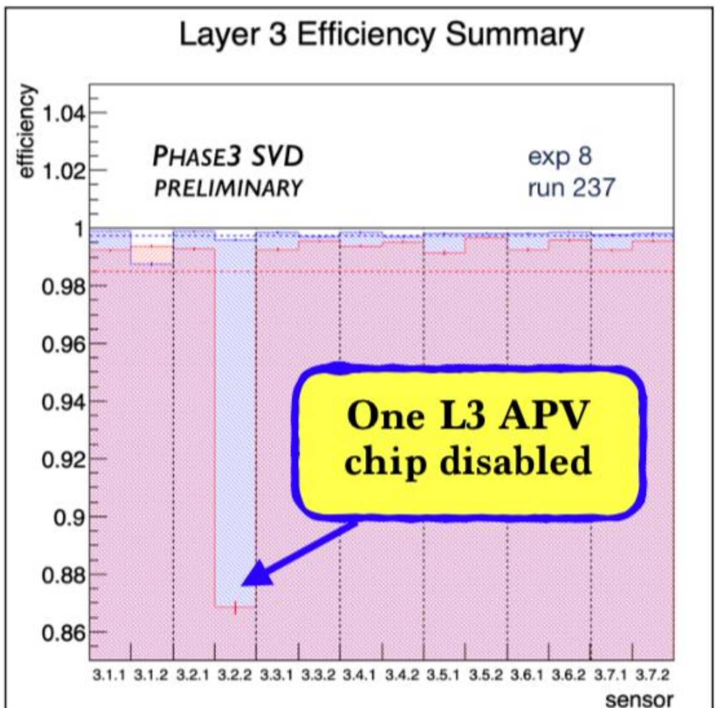






SVD sensor efficiency (exp. 8)

- Sensor efficiency is calculated as the fraction of times a cluster is found within ±0.5 mm from the extrapolated position of tracks on the sensor.
- Forward and Backward sensors have efficiency slightly higher than barrel sensors.
- On average, efficiency is above 99% for most of the sensors, with the exception of a L3 sensor that had a read-out chip masked.



efficiency	r-φ	z
Layer 3	(99.75±0.02)%	(98.46±0.05)%
Layer 4	(99.66±0.04)%	(99.37±0.06)%
Layer5	(99.62±0.06)%	(99.43±0.08)%
Layer 6	(99.30±0.10)%	(99.30±0.10)%

Summary

- SVD construction and commissioning
  - After years of construction and preparation, SVD assembly was completed in Feb 2018 (+X half shell) and Jul 2018 (-X half shell)
  - From Jul to Sep 2018, the entire SVD was operated for the first time outside of Belle II (SVD commissioning)
  - Finally, the detector was successfully combined and installed in Belle II in Oct to Dec 2018
- Spring 2019 run ("phase 3")
  - SVD operated successfully throughout Belle II's first physics run from Mar to Jul 2019
  - All sensors worked as expected, with efficiencies above 99% and Signal-to-Noise Ratios above 15
  - No major issues were observed in SVD during the first period of data taking

BACKUP

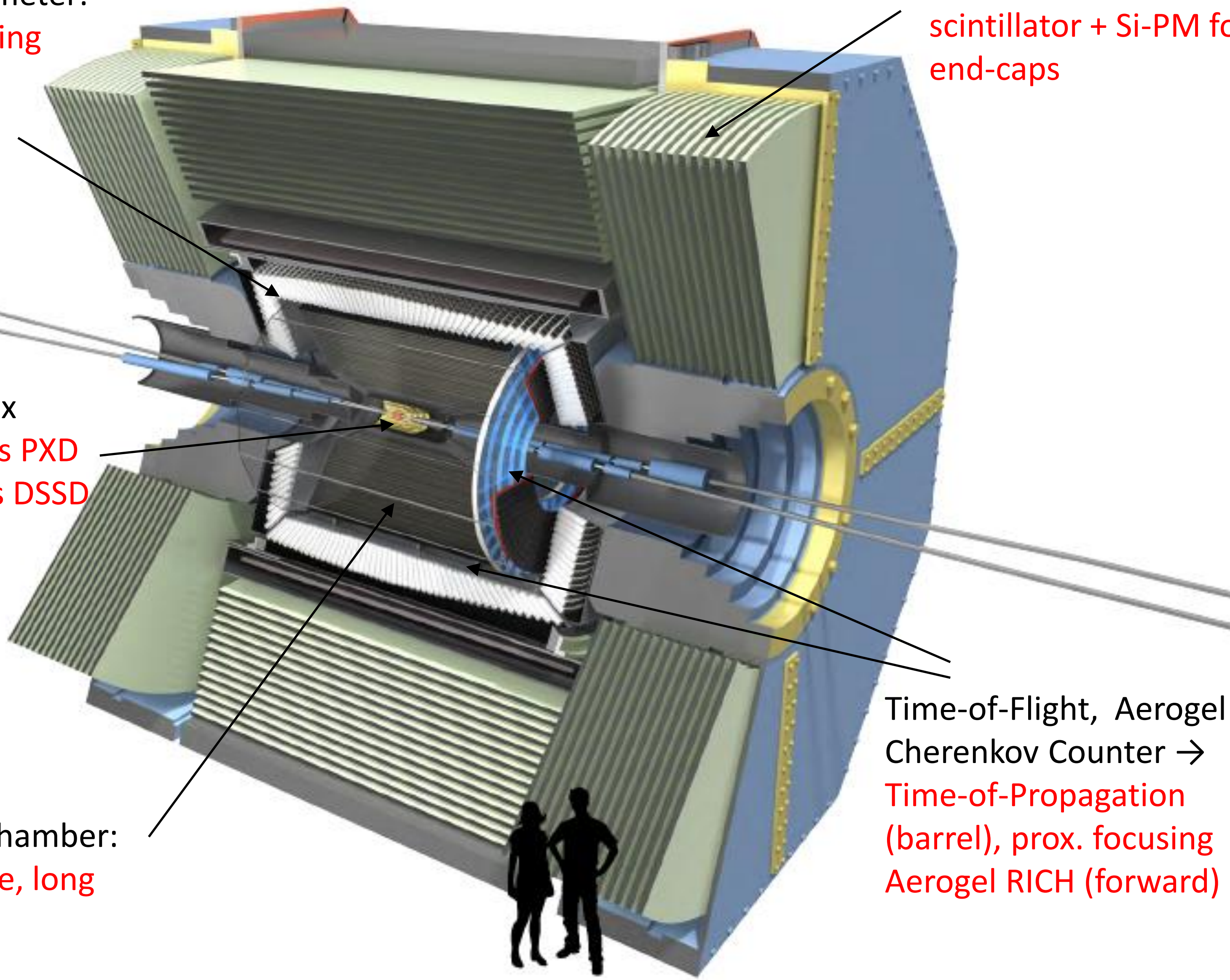
SKB parameters

	July 1 08:58	June 26 14:09	June 20 19:10
β_x*(mm)	80	80	100
β_y*(mm)	2	2	3
I_{LER} / I_{HER} (mA)	799.7 / 821.5	396 / 398	494.7 / 496.1
n_b	1576	789	1576
$I_{b\,LER}$ / $I_{b\,HER}$ (mA)	0.507 / 0.521	0.502 / 0.504	0.314 / 0.317
$\xi_{y\,LER}$ / $\xi_{y\,HER}$	0.0355 / 0.0197	0.0389 / 0.0220	0.0335 / 0.0189
L_{sp} x10^{30}	29.5	30.7	21.5
L x10^{32}	122.94	61.25	47.85

From Belle to Belle II

CsI(Tl) EM calorimeter:
waveform sampling electronics, pure CsI for endcaps

RPC μ & K_L counter:
scintillator + Si-PM for end-caps

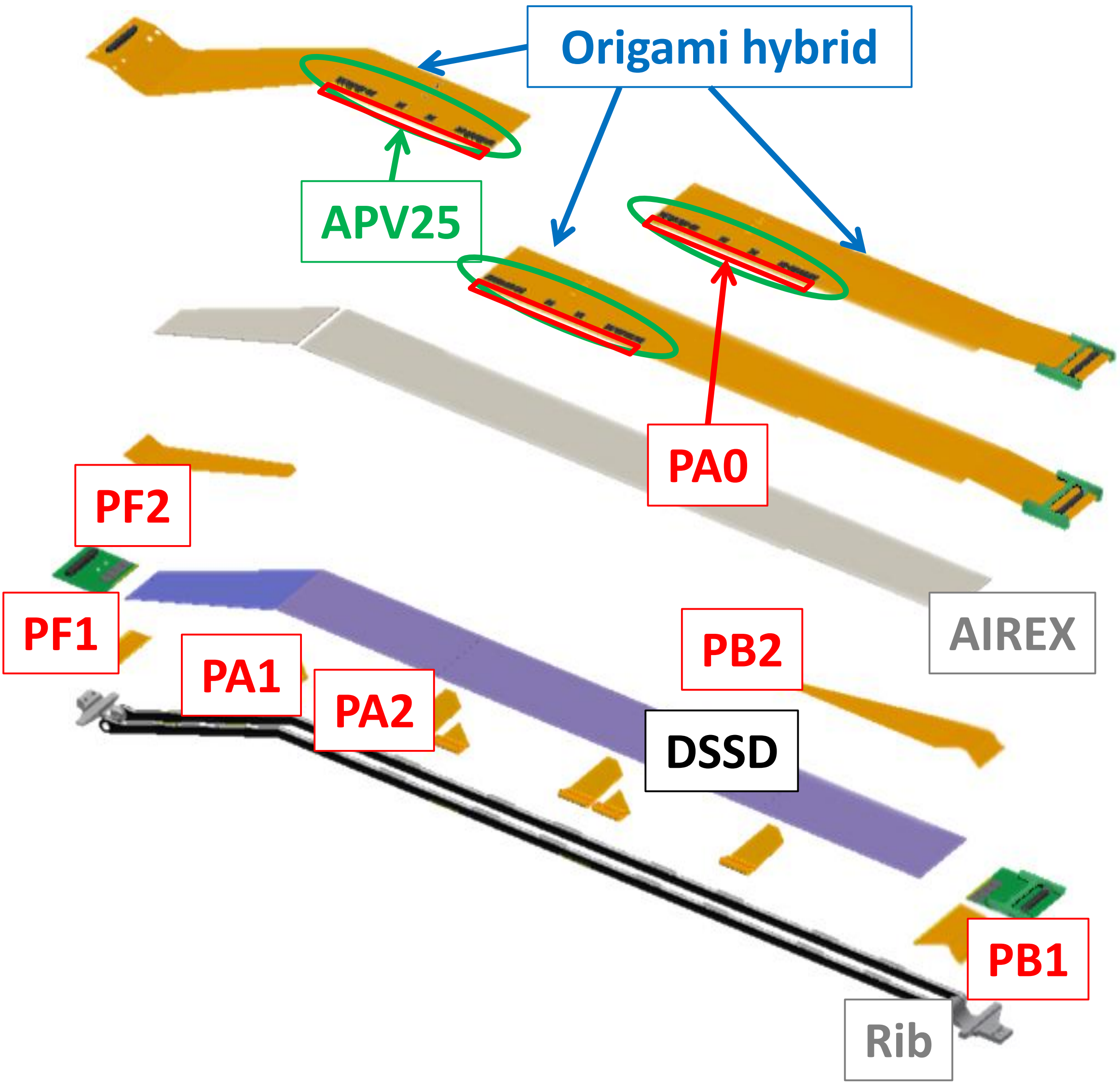


4 layers DS Si vertex detector → 2 layers PXD (DEPFET) + 4 layers DSSD

Time-of-Flight, Aerogel Cherenkov Counter →
Time-of-Propagation (barrel), prox. focusing Aerogel RICH (forward)

Central Drift Chamber:
smaller cell size, long lever arm

Ladder Anatomy (L6 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

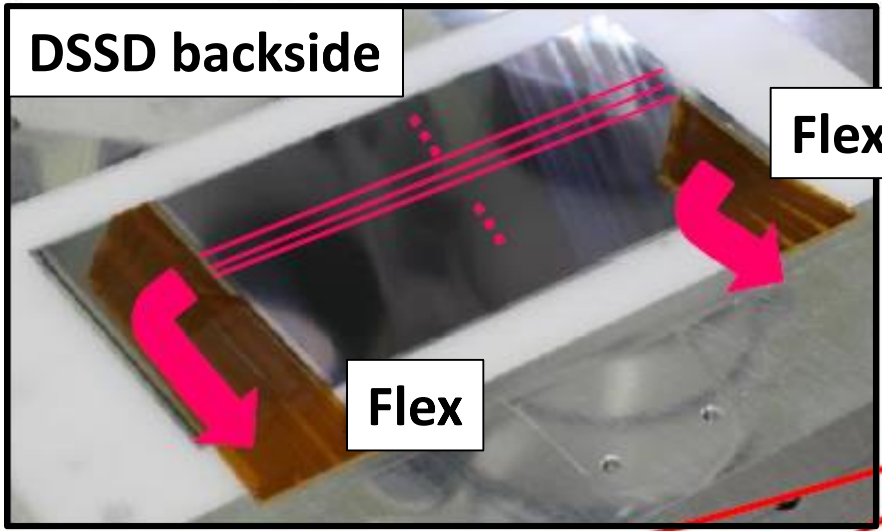
APV25
Readout ASIC of the strips

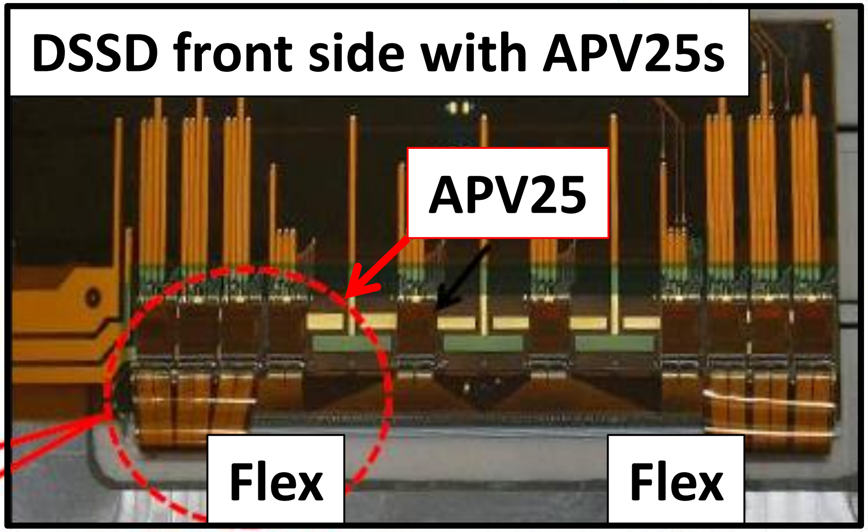
FlexPA (PA/PF/PB)
Flexible circuit to transmit detector signals to the APV25

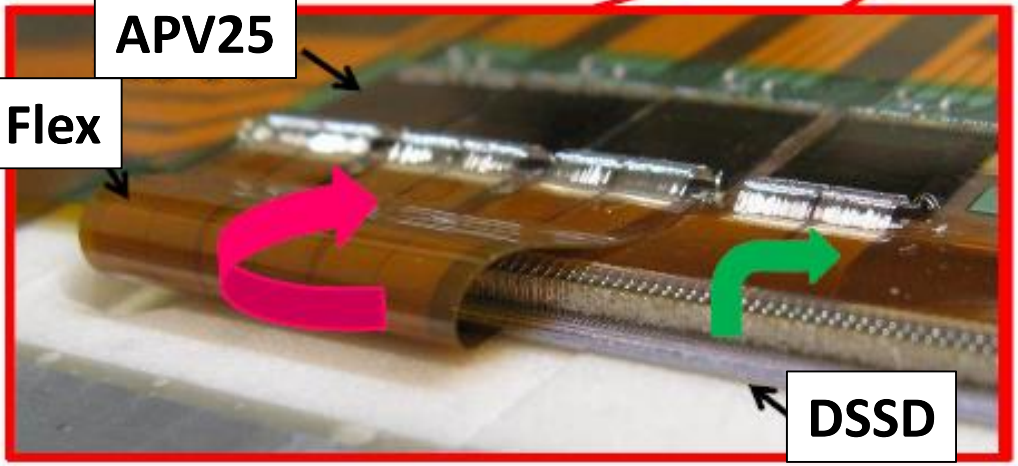
PA0
Flexible circuit glued on the Origami hybrid to transmit *n*-side detector signals to the APV25

AIREX
Thermal insulator between the DSSD and APV25

Snapshot – the “Origami” Concept



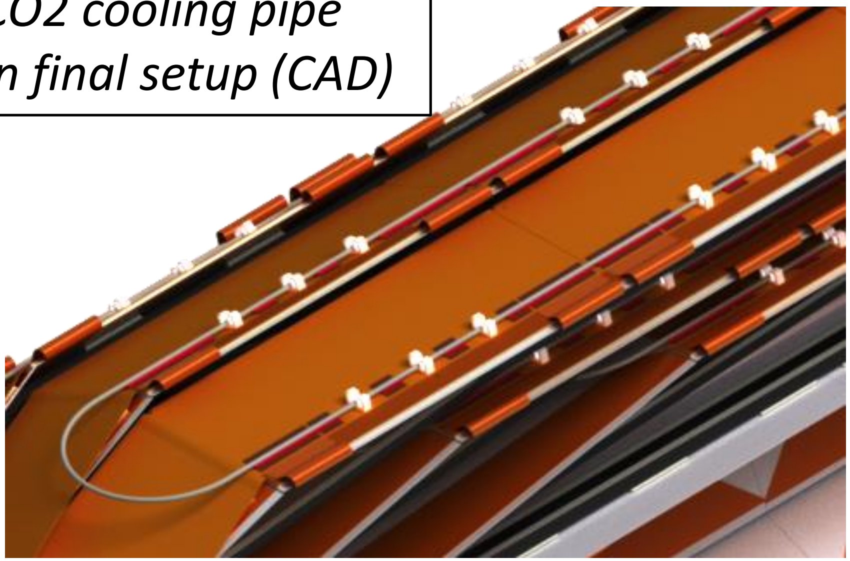




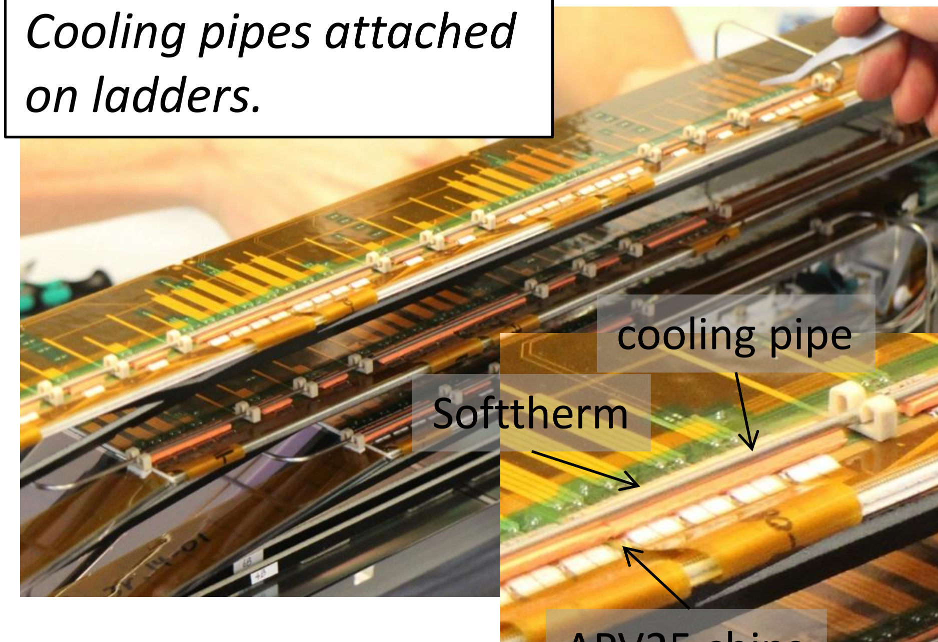
The backside signals are transmitted to the APV25 via *bent* (and glued) flex circuits.

CO2 Cooling for Ladders

CO2 cooling pipe in final setup (CAD)



Cooling pipes attached on ladders.



- Necessity of cooling
  - SVD total heat dissipation from all APV25 chips can be 700W in max.
- 2-phase (liquid and 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 tube (OD:1.6mm, thickness:0.1mm) is employed.
  - Less material budget

Softtherm 86/125

thermal-conductive dielectric pad.