SVD

The Belle II Silicon Vertex Detector Upgrade

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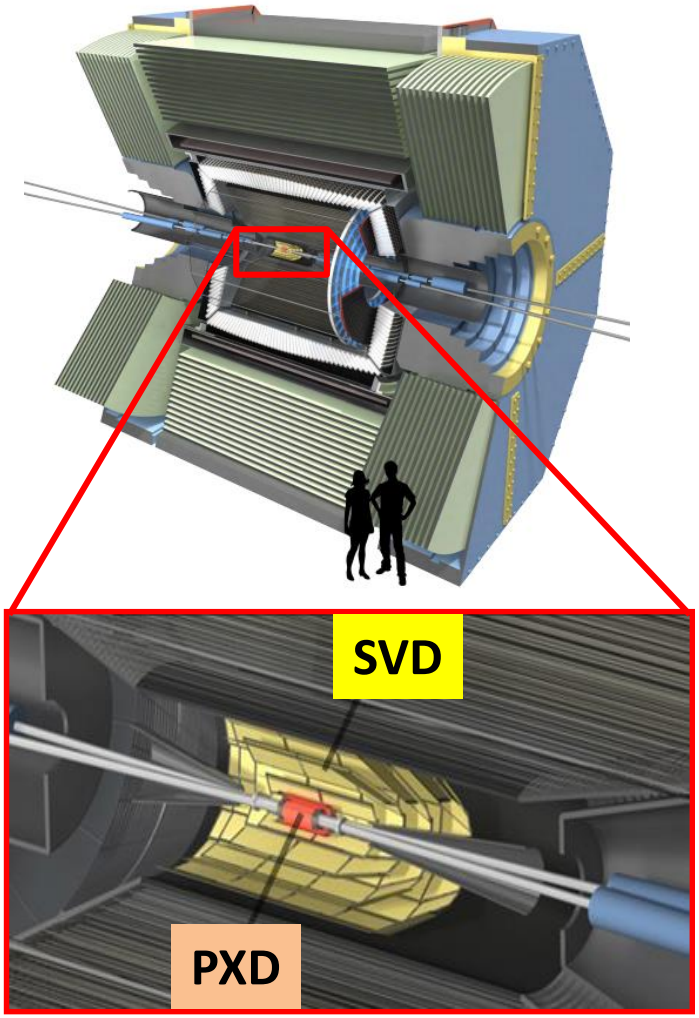
Belle II Vertex Detectors



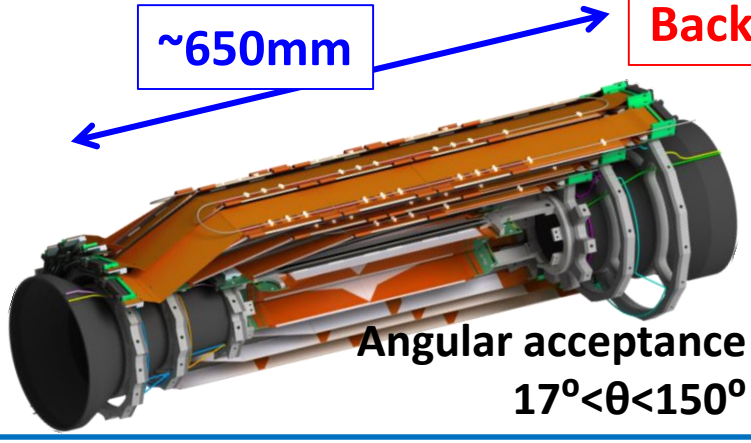
- PiXel Detector (PXD)
  - Based on DEPFET pixels – see previous talk
- Silicon Vertex Detector (SVD)
  - Double-sided silicon strip detectors (DSSDs)

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

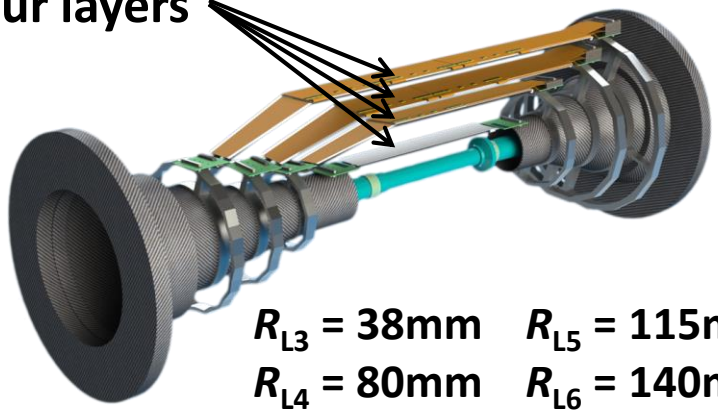
SVD Structure Overview

SVD cut model

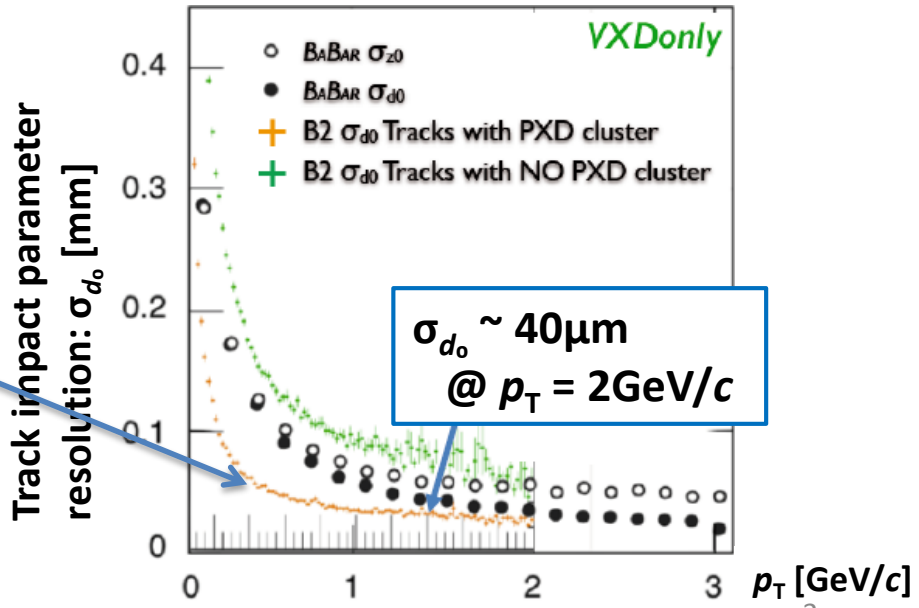


Forward

Layer structure

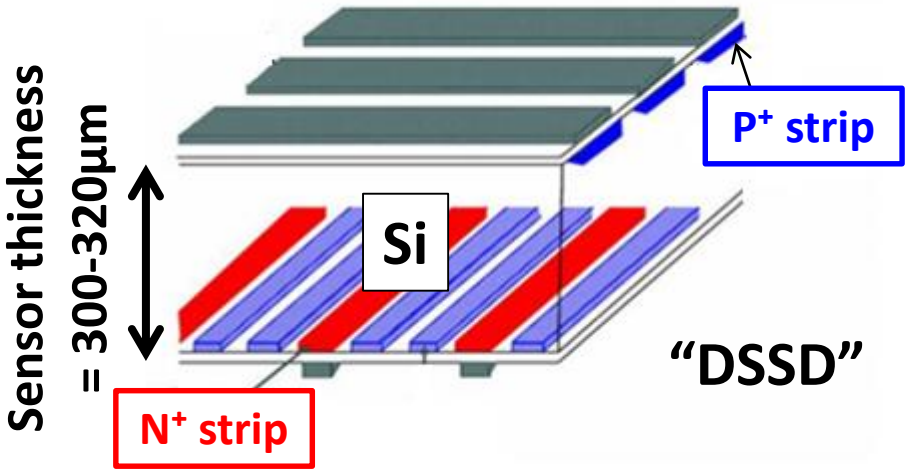


- 4 SVD layers (L3 to L6) composed of ladders arranged in a windmill structure
- Improved resolution at IP wrt. to Belle I
- Very lightweight – only 0.58%X_0 per layer



SVD Sensors and Readout ASIC

Double-sided Si strip detector

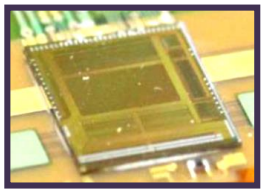


	Rectangular	Trapezoidal
# of *p*-strips	768	768
p-strip pitch	75μm	50…75μm
# of *n*-strips	512	512
n-strip pitch	240μm	240μm
Active area	57.72x122.9 mm²	5890 mm²

Readout ASIC (APV25)

- Since a high hit rate is anticipated in Belle II, a readout chip should have a short signal shaping time for low noise and a good radiation hardness.

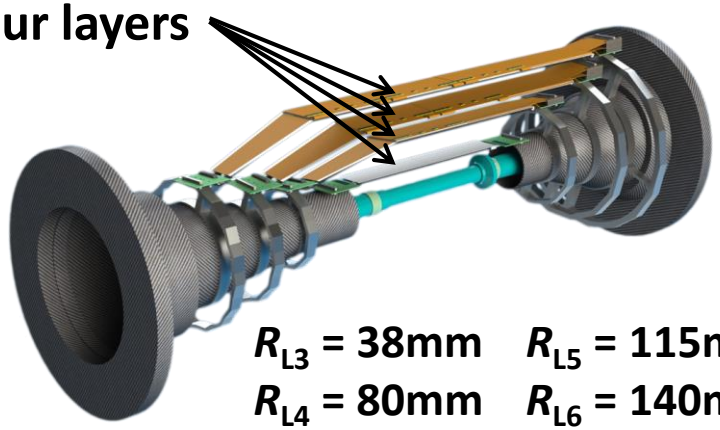
We adopted the APV25



- The APV25 was originally developed for the CMS.
  - Shaping time = 50ns.
  - Radiation hardness > 1MGy.
- Other characteristics
  - # of input channels = 128 / chip.
  - 192-deep analog pipeline for the dead-time reduction.
  - Thinned to 100μm for the material budget reduction.

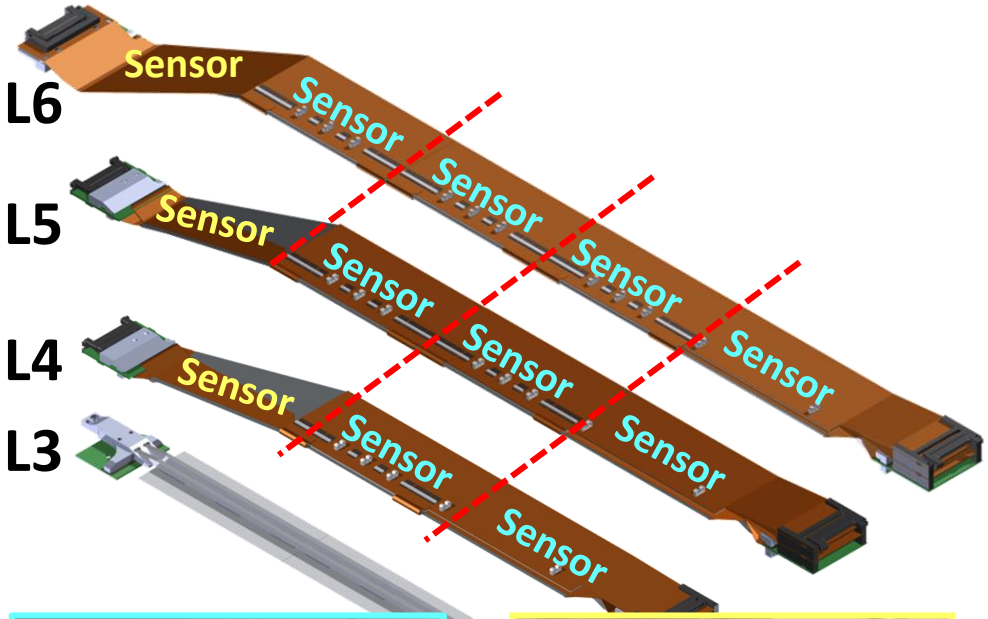
SVD Ladder Layout

Four layers

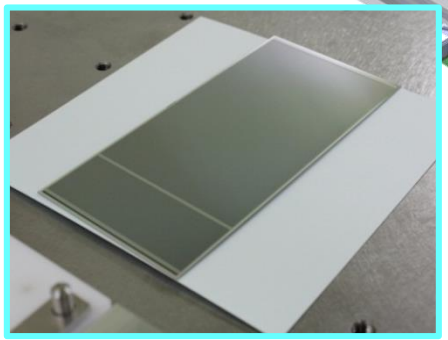


R_{L3} = 38mm R_{L5} = 115mm

R_{L4} = 80mm R_{L6} = 140mm



Layer	Ladders	Sensors / Ladder	APVs
6	16	5	800
5	12	4	480
4	10	3	300
3	7	2	55

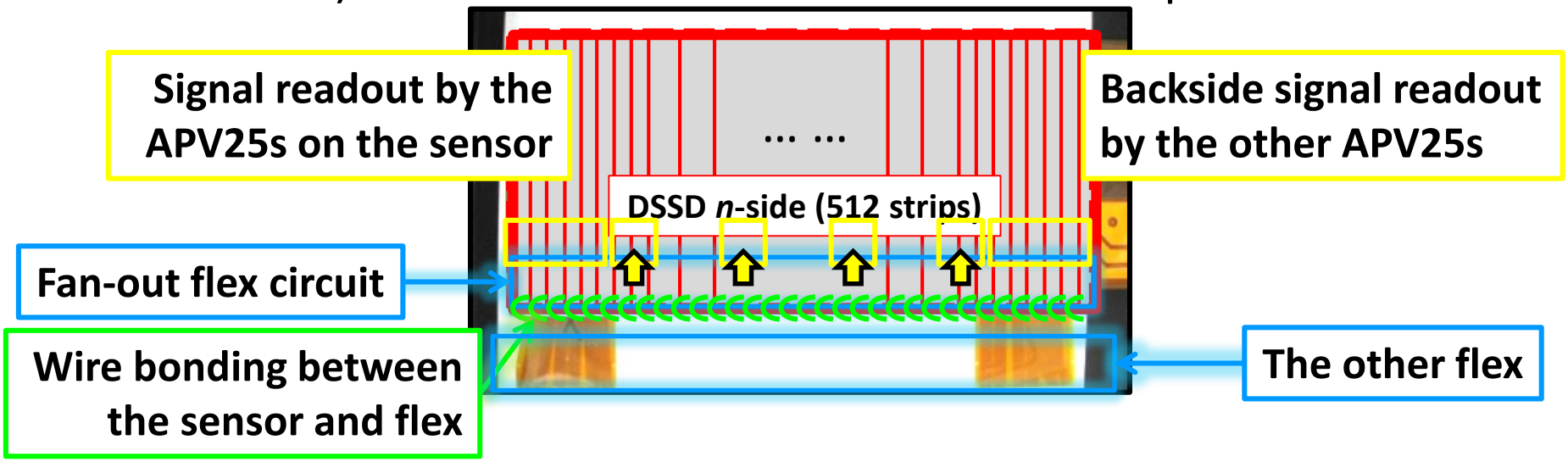


Rectangular sensor

Trapezoidal sensor

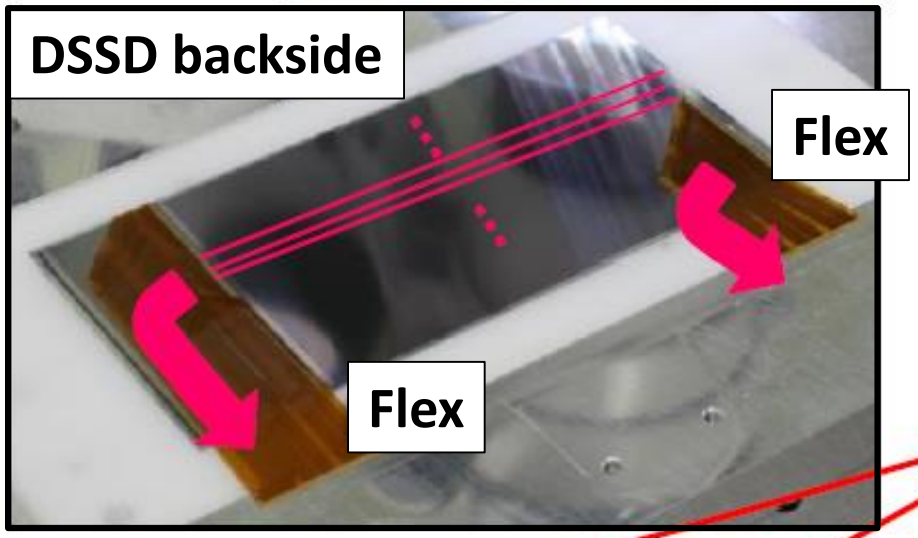
Chip-on-Sensor and "Origami" Concepts

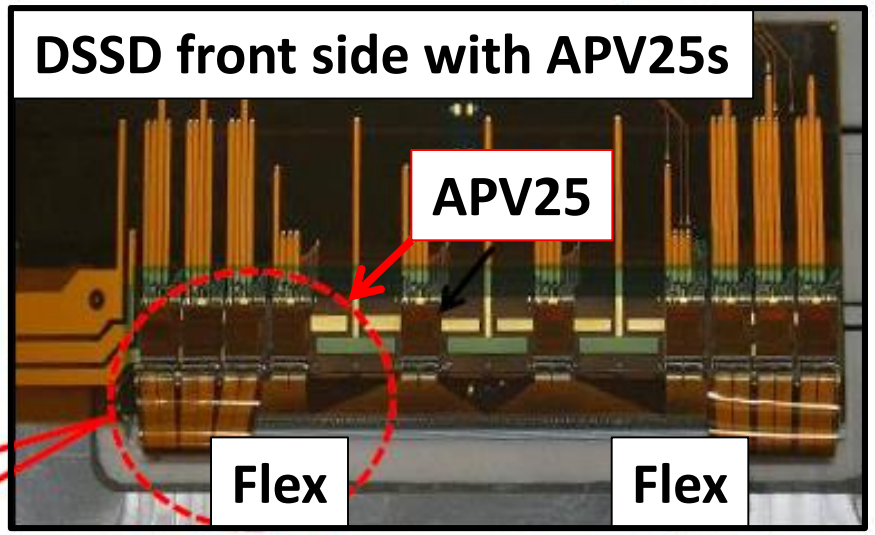
- APV25 on sensor
  - The APVs for the inner sensors are placed directly on the DSSDs to minimize the analog path length (capacitive noise)
- P-side readout
  - Signals on the sensor backside are brought to the upper side by other flex circuits and readout by APV25 chips mounted on the top

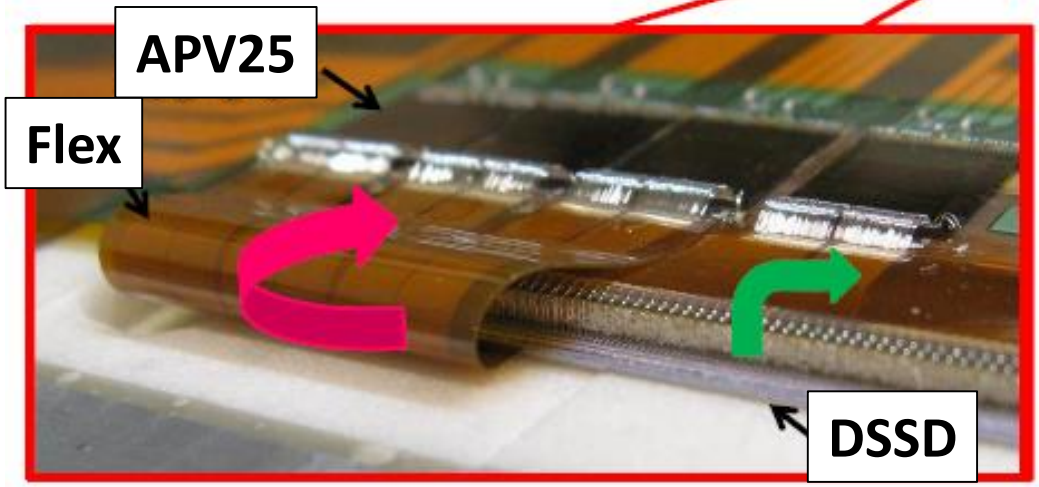


Readout ASICs on the same side & same line → easier chilling by a single cooling pipe.

Snapshot – the "Origami" Concept







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

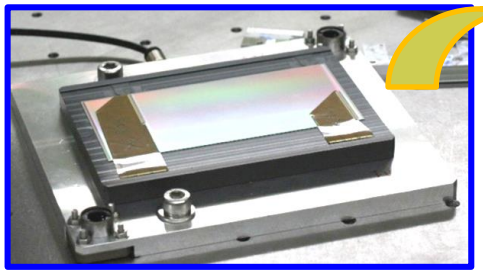
SVD Ladder Assembly

APV25

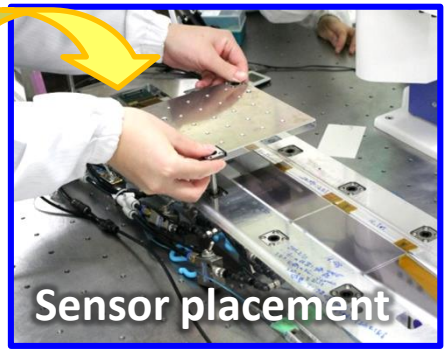
Layer	Institute
3	Melbourne (AUS)
4	TIFR India @ IPMU
5	HEPHY Vienna
6	IPMU Tokyo U
FW & BW	INFN Pisa

Precision DSSD alignment

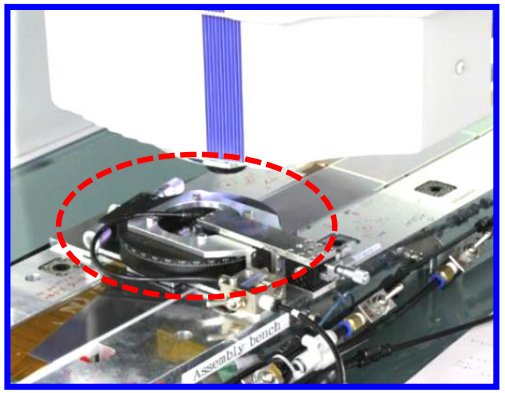
DSSDs are handled with precision assembly jigs (*O*(50μm)), on which the sensors are fixed by vacuum chucking.



Sensor fixed on a jig



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

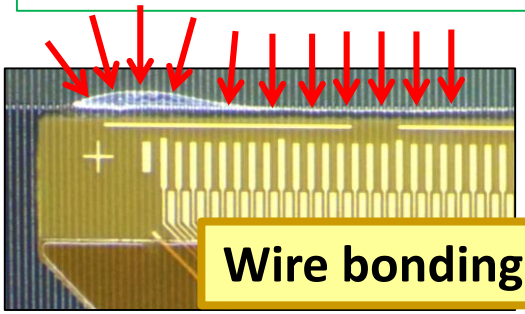


SVD Ladder Assembly

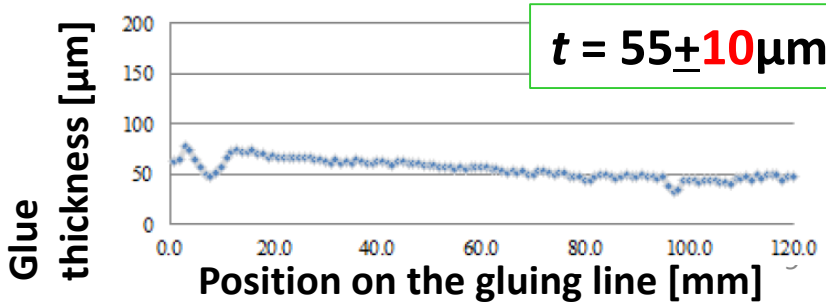
Ladder fabrication: gluing

Ladders are fabricated by gluing the components by Araldite®2011.

Glue spread below bonding pads affects to the bonding yield and pull strength → glue amount and glue lining are controlled by a gluing robot.

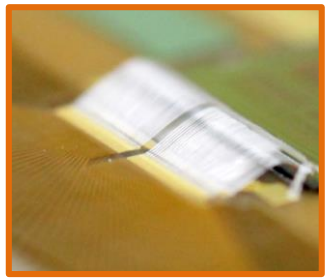


Appropriate spread of glue to the flex edge



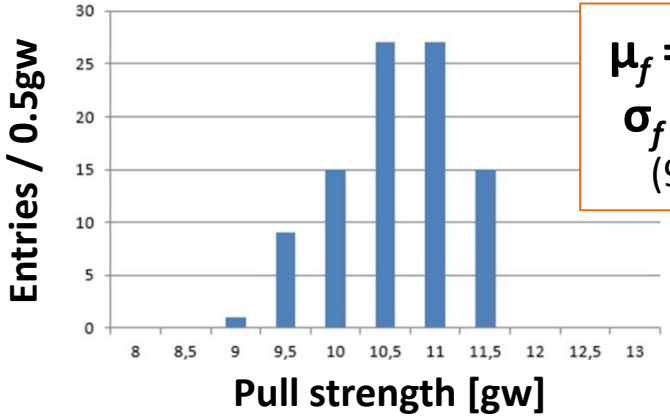
t = 55±10μm

Electrical connection: wire bonding



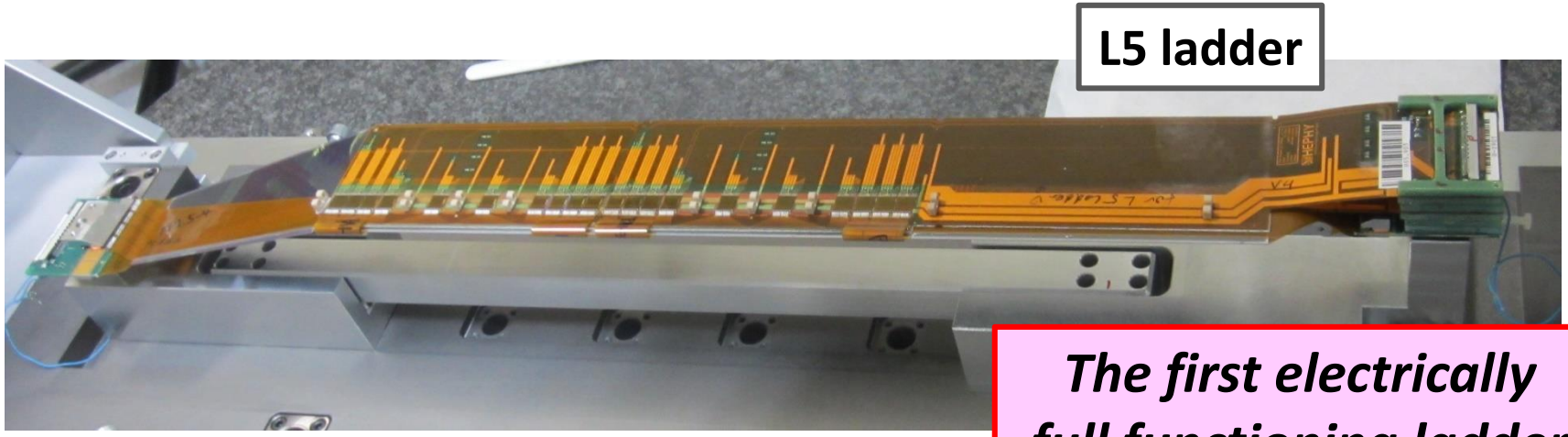
The flex↔DSSD strips and flex↔APV25s are electrically connected by the wire bonding with Aℓ(99%) wire(ϕ=25μm). Number of total bonds = 450k.

Bonding machine parameters are so tuned to realize yield>99% and pull strength f: μ_f>5gw, σ_f/f<20%.



μ_f = 10.7gw
σ_f = 0.6gw
(97 samples)

Electrically Full Functioning Ladder



The first electrically full functioning ladder completed in Apr. 2015

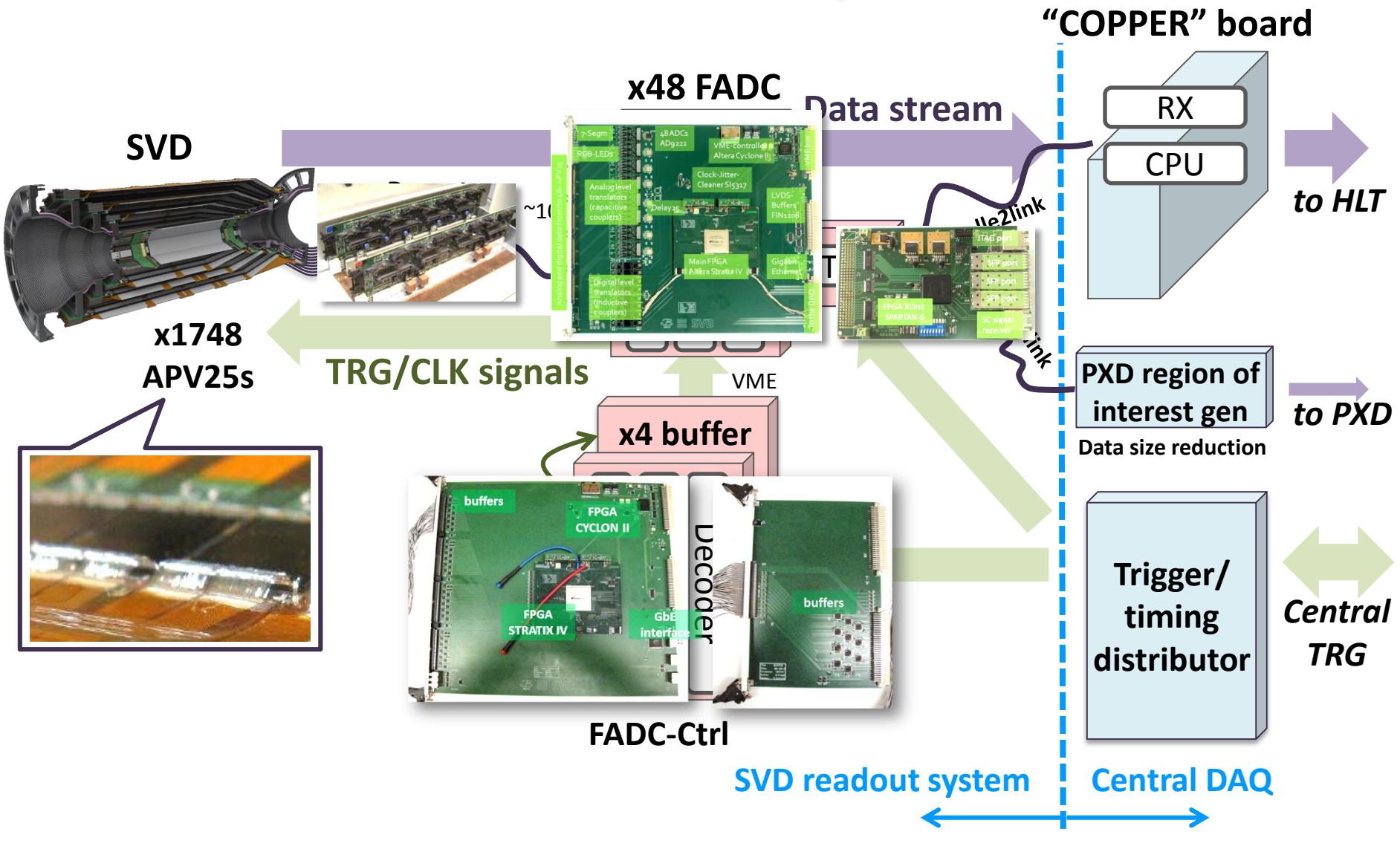
Sensor displacement is measured by the CMM.

- Sensors displacements found to be **<160μm** from the design.

CO_2 Cooling

The total SVD (Origami) power dissipation 688(328) W
Edge hybrids: APV25 chips cooled by end rings
A pre-bent cooling pipe (OD=1.6mm) will be clipped onto the ladders on top of the Origami APVs

FADC Readout System

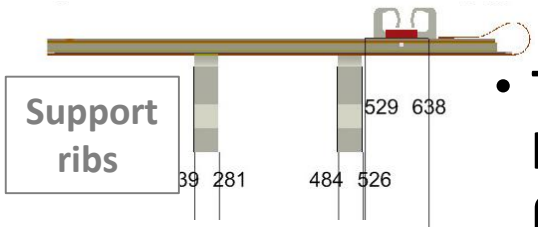


Prototypes of all components have been developed.

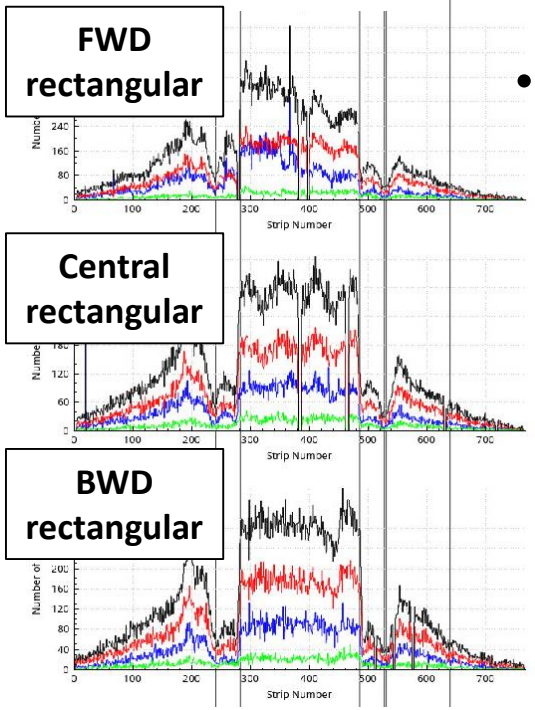
Electrical Performance Studies

Study on the full functioning ladder

Ladder cross-section



Hit maps

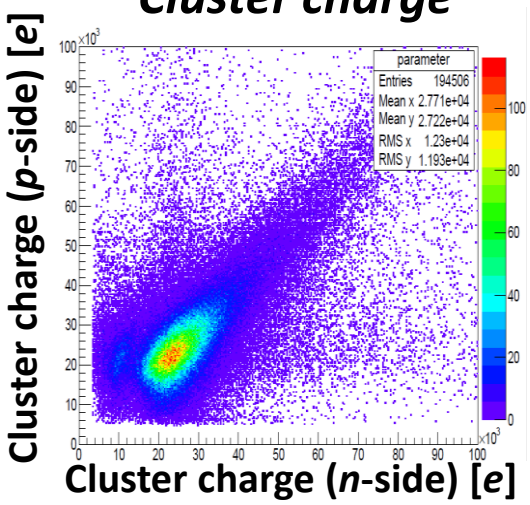


- The ladder is bombarded by β-rays from ^{90}Sr (12.3MBq).
- Shades by the support ribs are clearly observed in the hit maps.

Simultaneous operation of origami sensors worked as expected.

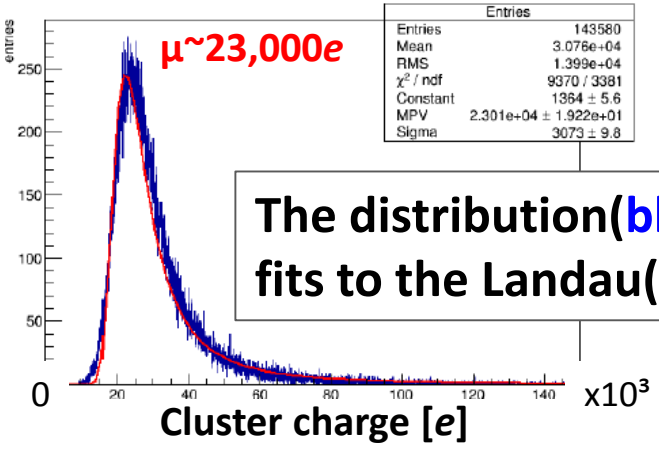
Study on a single sensor

Cluster charge



Correlation between *p*- and *n*-side clusters

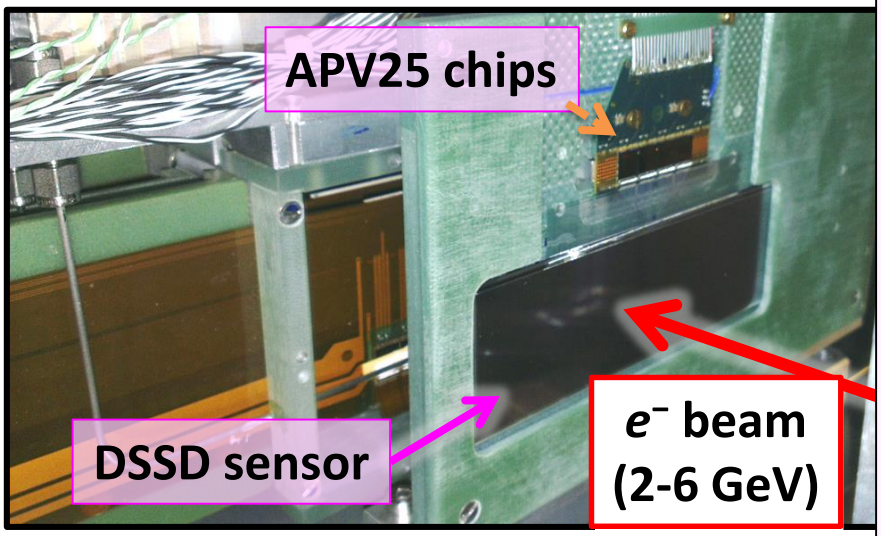
P-side cluster charge (#strip≥2)



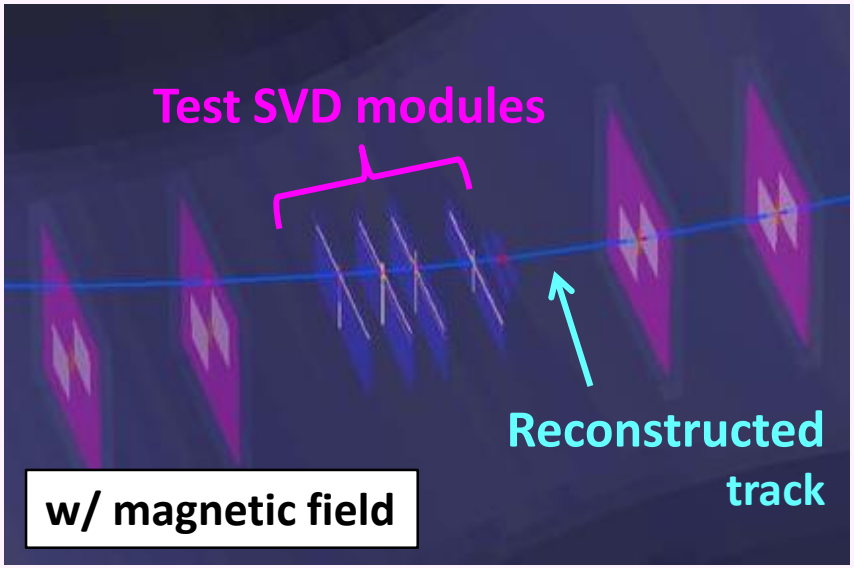
The distribution(blue) well fits to the Landau(red).

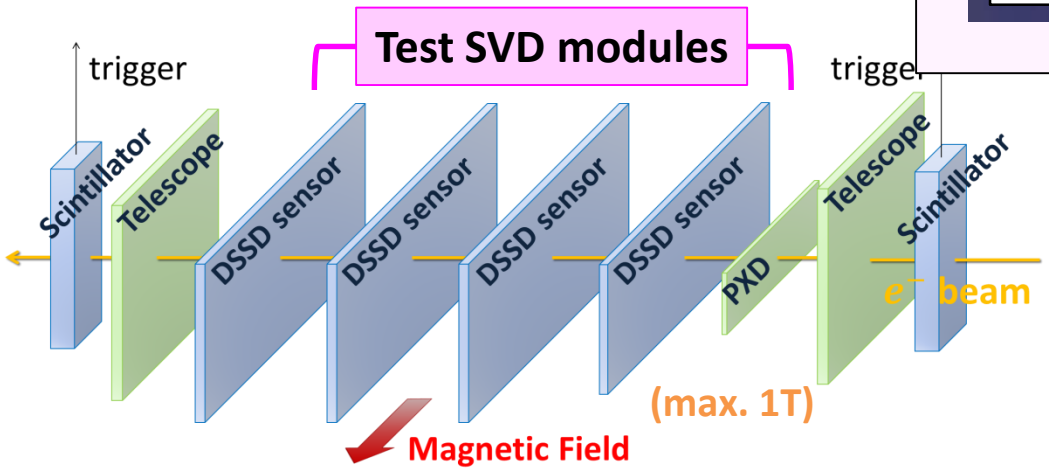
SVD+PXD DAQ Test @ DESY Beam Line

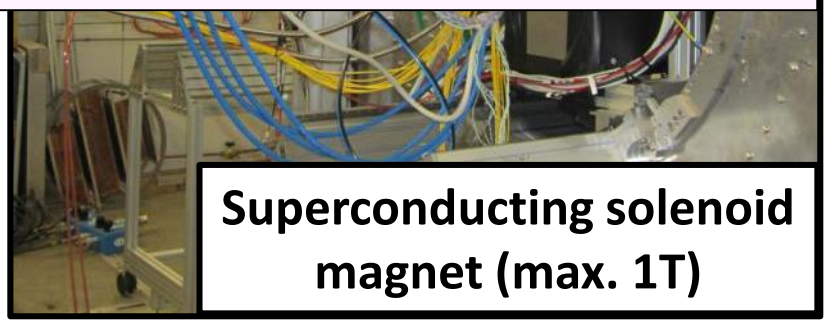
4-layers test SVD modules



Event display

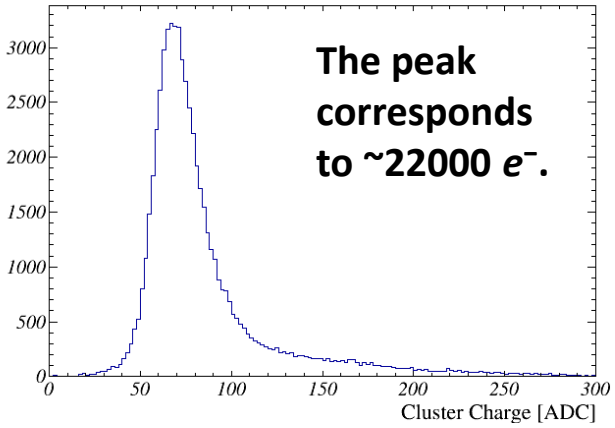




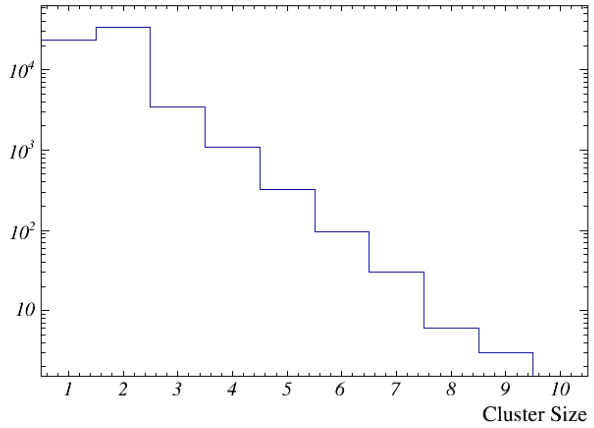


SVD+PXD DAQ Test @ DESY Beam Line

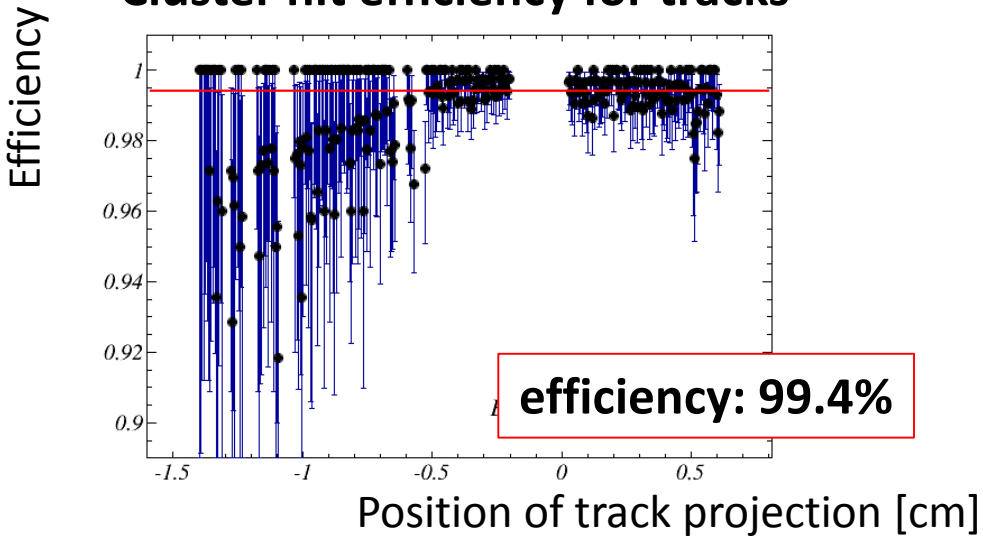
Cluster charge distribution



Cluster size distribution

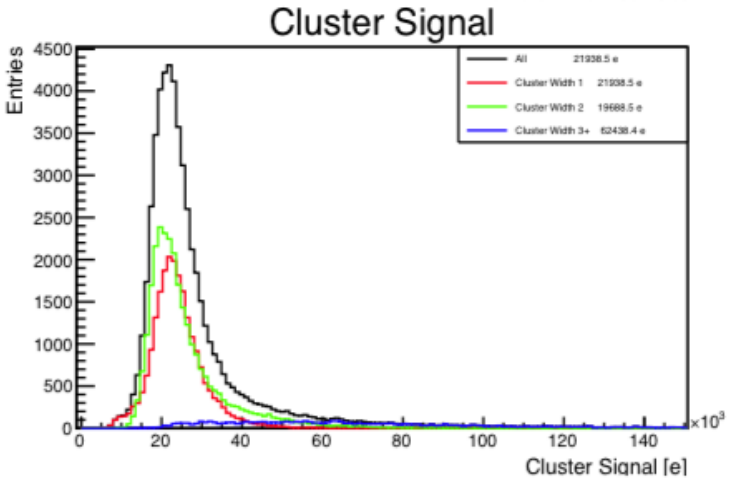


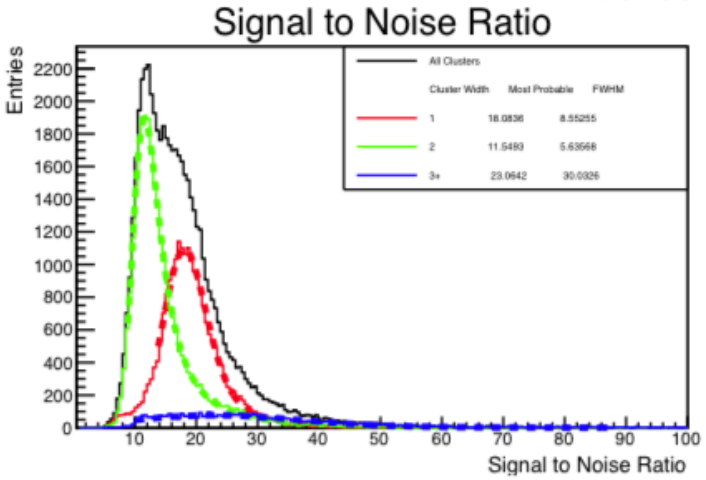
Cluster hit efficiency for tracks



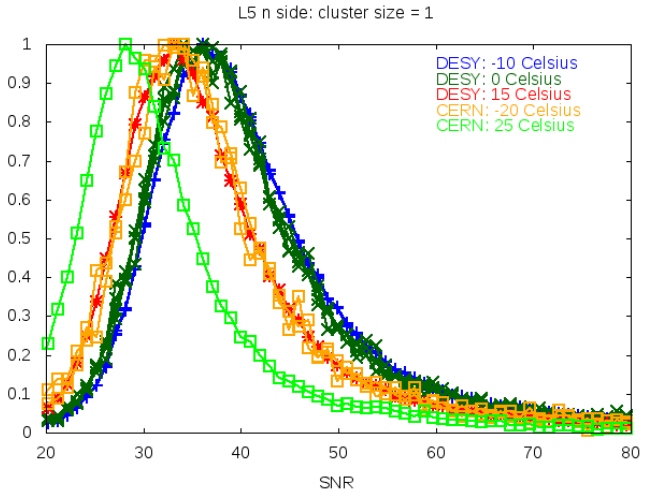
SVD TEST @ CERN BEAM

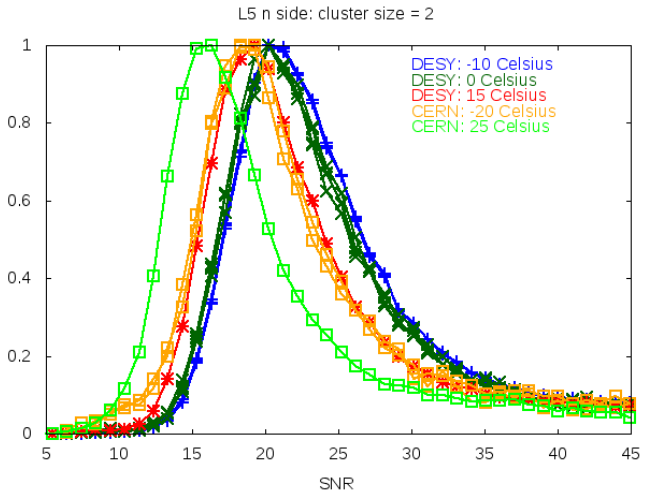
FWD/BWD module, no cooling





L5 module, with/without cooling





VXD (PXD + SVD) Schedule

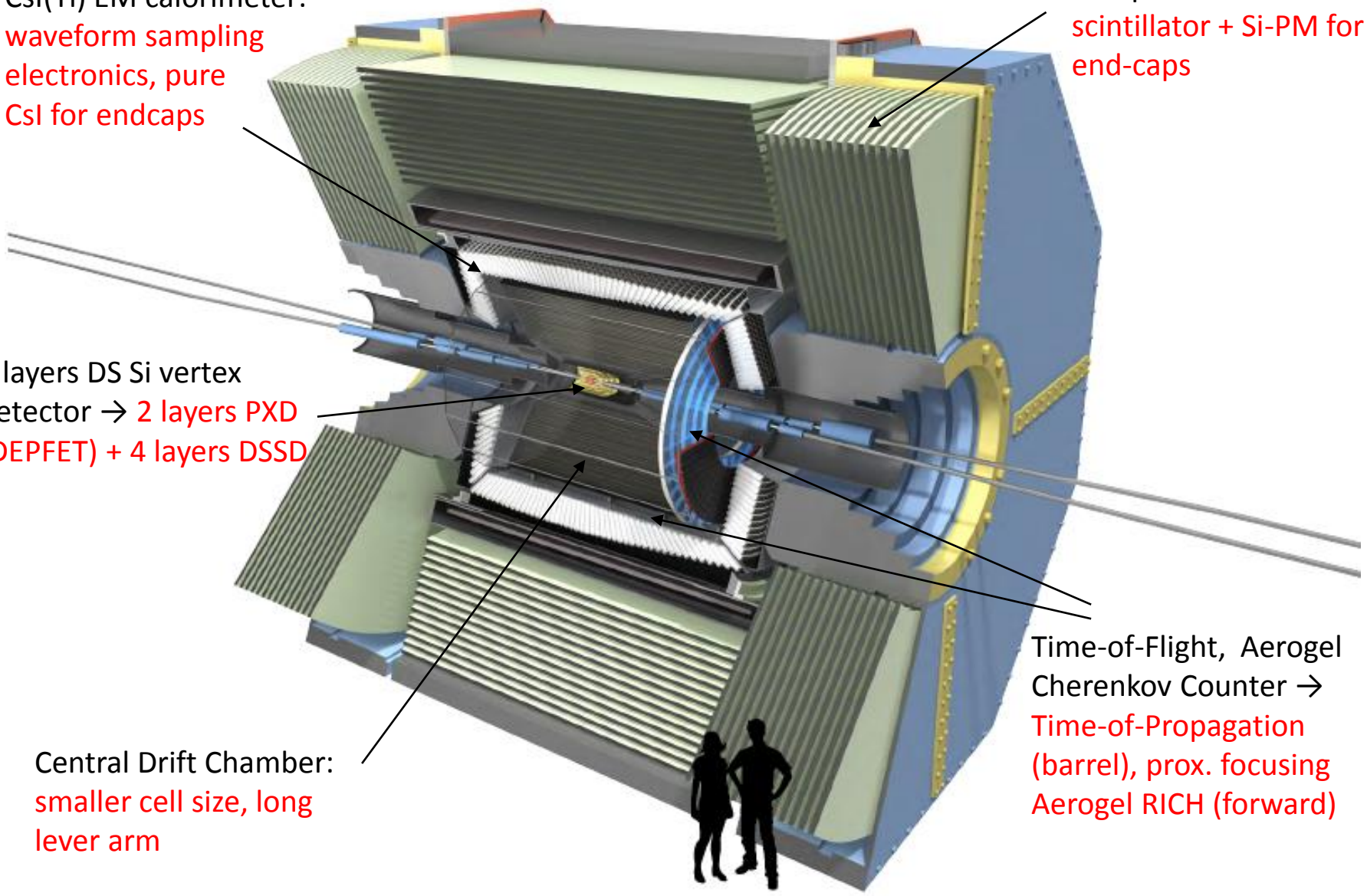
High level milestones	
First mass production ladder (L4-L6)	Oct. 2015
2nd beam test	Jan.-Feb. 2016
Start of ladder mount to support structure	Apr. 2016
SVD readiness in KEK	Feb. 2017
PXD readiness in KEK	Apr. 2017
PXD+SVD integration	Jun. 2017
PXD+SVD combined cosmic ray test	Jun. 2017
PXD+SVD installation	Apr. 2018
Start of physics run	4Q 2018

Summary

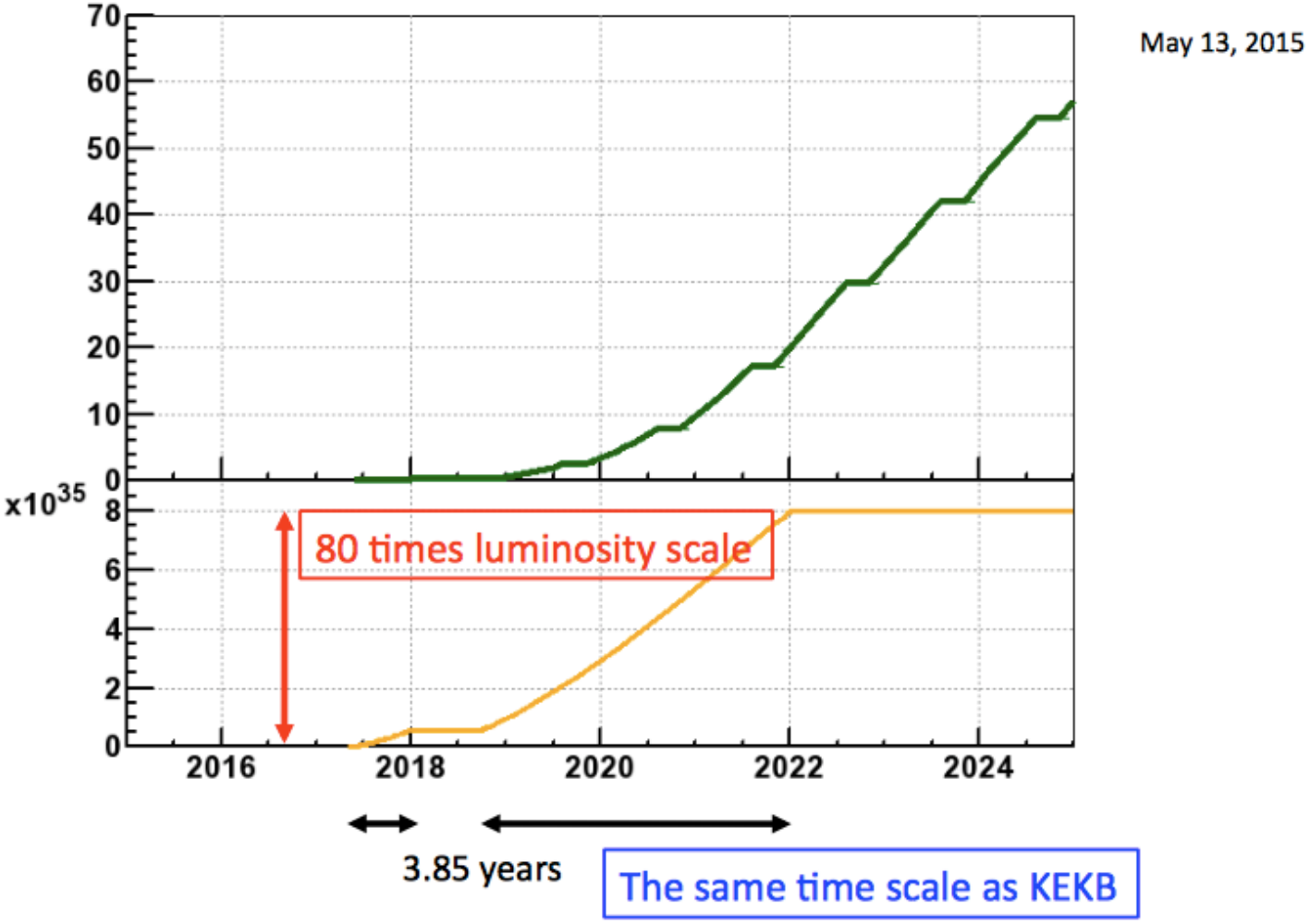
- SVD is a 4 layer silicon strip detector for the Belle II experiment
  - Together with the PXD it provides inner tracking
  - Improved track resolution at the IP and better low momentum tracking w.r.t. to the Belle I SVD
- SVD ladders
  - Assembly challenging because of the use of the ‘origami chip on sensor’ concept
  - The prototype phase is now coming to an end, the SVD ladder mass production will start in autumn 2015
- FADC readout
  - Prototypes of the system exist and the full readout chain has been confirmed

BACKUP

The Belle II detector



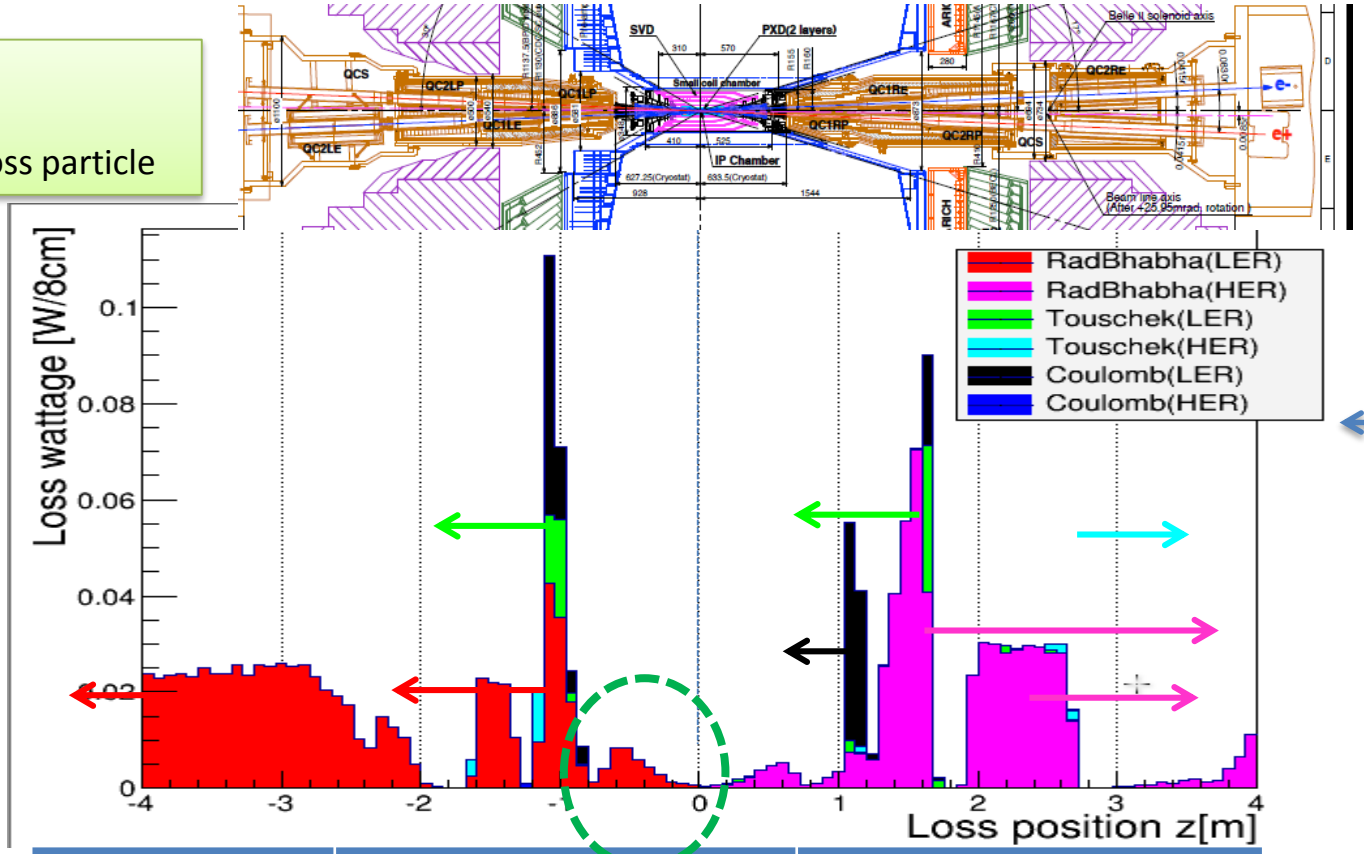
A target luminosity profile of SuperKEKB/Belle II



Ver. 2014.6.18
(9th campaign)

BG loss distribution

Loss wattage
= loss rate
  * energy of loss particle



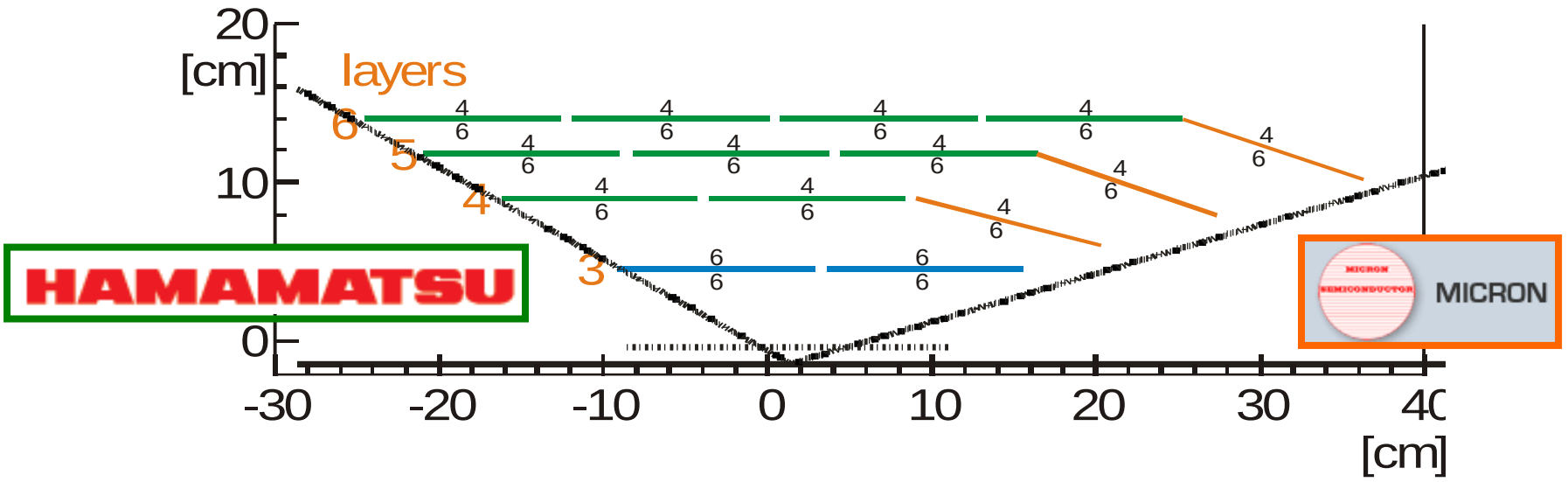
HER
(e-)

LER
(e+)

1GeV ,1GHz
= 0.16W

	LER (4GeV e+)	HER (7GeV e-)
Rad. Bhabha	0.74 W (eff. 1.2GHz)	0.59W (eff. 0.52GHz)
Touschek	0.078W (0.12GHz)	0.02 W (0.02 GHz)
Coulomb	0.18 W (0.28GHz)	0.001W (0.001GHz)

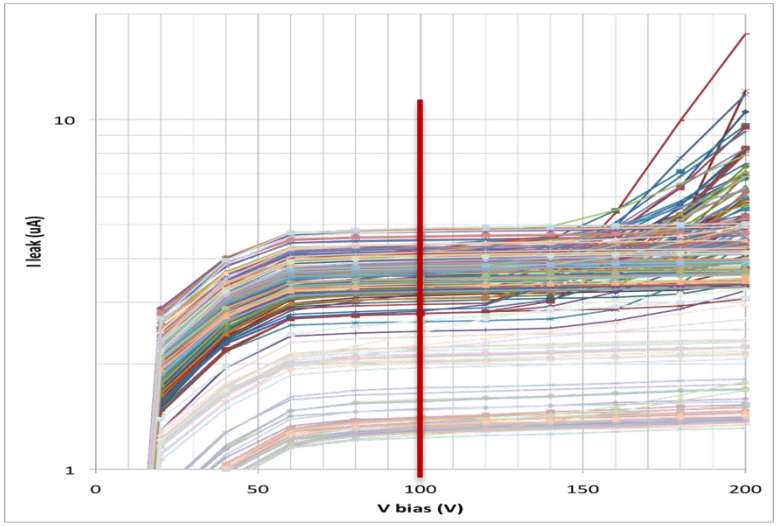
Sensors: Types and Vendors

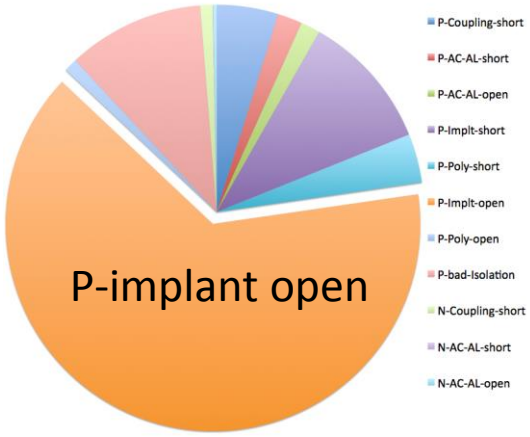


Layer	# of Ladders	Rect. Sensors [narrow]	Rect. Sensors [wide]	Wedge Sensors	APVs
6	16	0	64	16	800
5	12	0	36	12	480
4	10	0	20	10	300
3	7	14	0	0	168
Sum:	45	14	120	38	1748

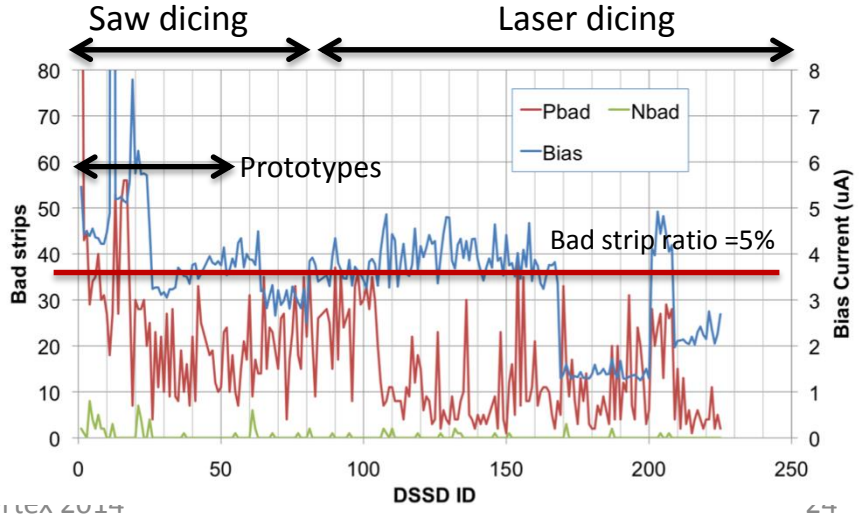
Rectangular sensors (HPK)

- Small DSSDs
  - Delivery of 24 pcs. scheduled for end of September
  - Two mechanical samples available
- Large DSSDs:
  - Production finished
  - 150 pcs in hand

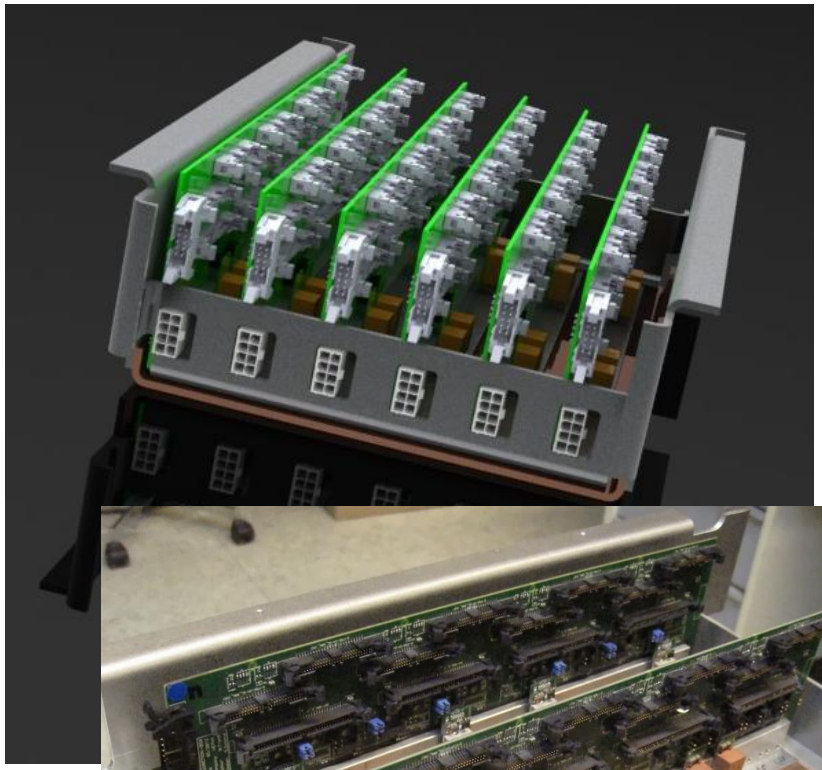


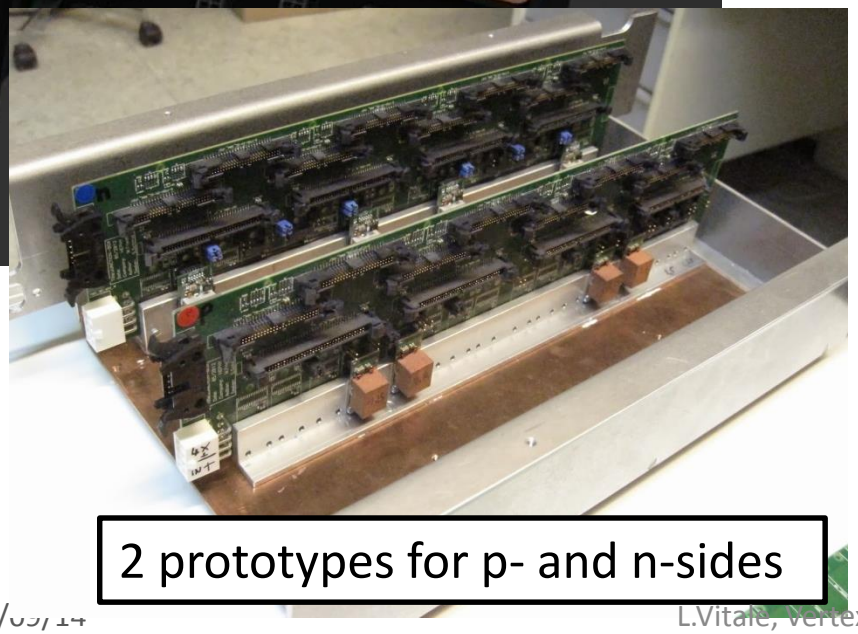


Classification of bad strips (ID>26)



Junction box

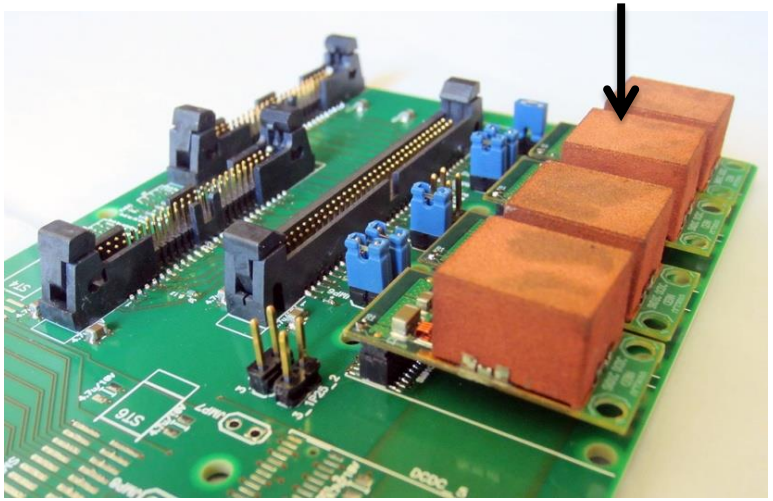




2 prototypes for p- and n-sides

- Supply HV and LV to DSSD and APV25.
  - DC/DC converter
- Joint signals between APV25 and FADC board.

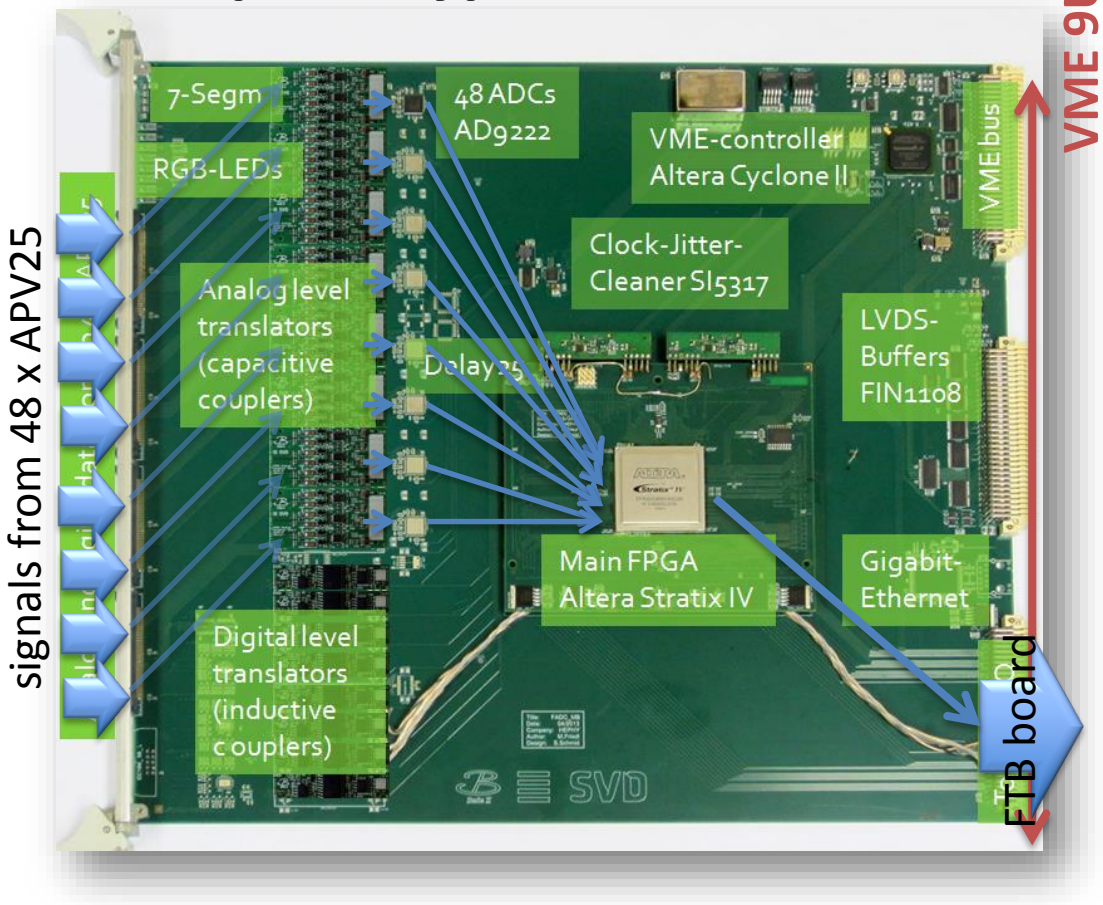
DC/DC converters



Development of Prototype FADC Board

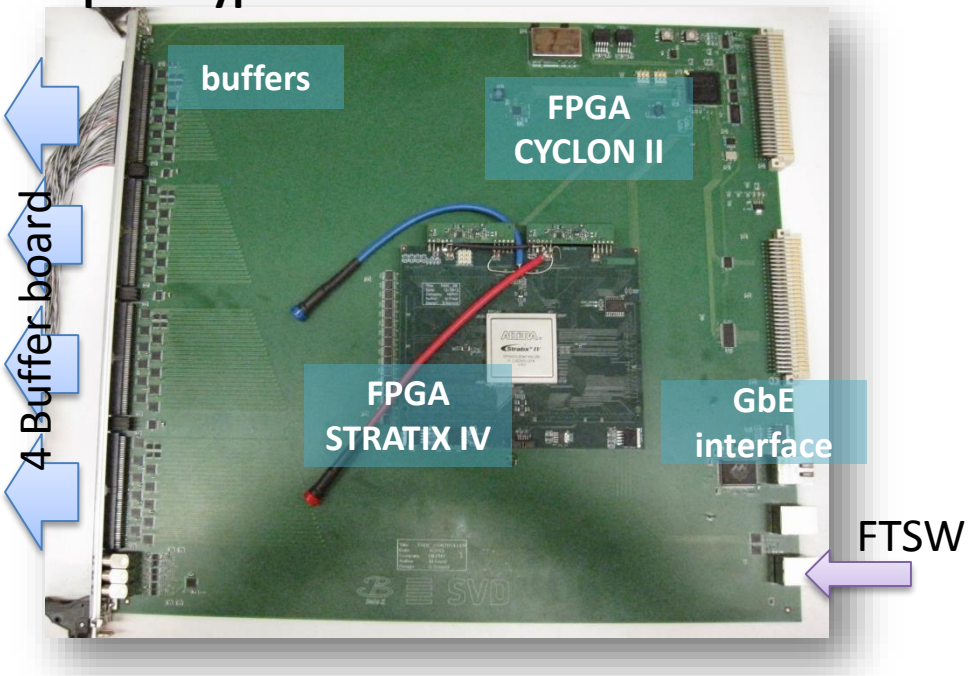
- High signal density
  - readout 48 APV25 outputs
- APV25 signal processing on FADC
  - analog level conversion (AC coupling)
  - 10-bit ADC
  - FPGA (Stratix IV) data processing
    - FIR filter
    - Common-Mode Correction
    - Zero-Suppression
  - data transmission to FTB

prototype FADC board

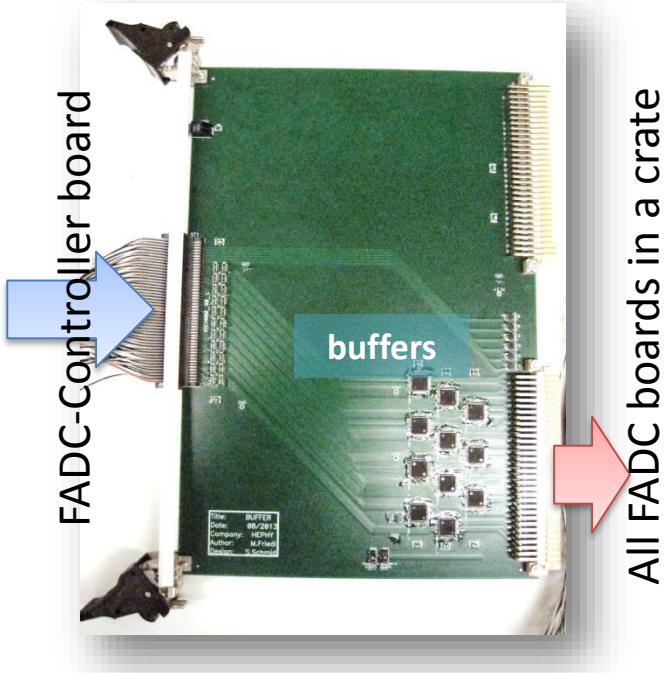


FADC-Controller and Buffer boards

1st prototype of FADC-Controller board



Buffer board



- We will have 4 crates with FADC modules
- One has single FADC-Controller
  - Receives FTSW signals
  - Distributes clock, trigger and other controls to all Buffer
- Each crate has single Buffer module
  - Receives FADC-Controller signals
  - Distributes signals to FADCs through backplane bus

Ribs

- L3 produced and delivered
- New truss rib design for L4-L6
- Improved stiffness at knee, while material budget kept low
- New ribs for L4, L5 and L6 ordered
- All produced now

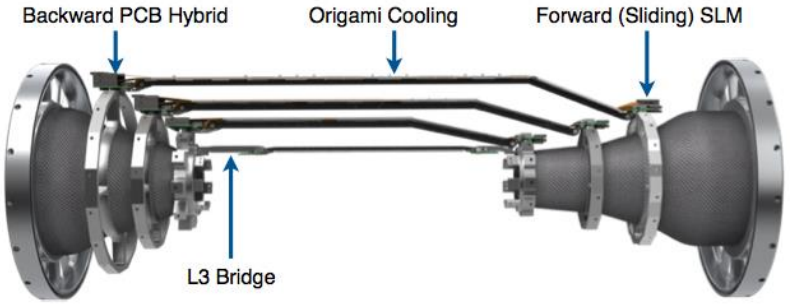
Thermal mock-up (DESY)

Belle II strips and pixels share the same volume
PXD+SVD power dissipation: 360+700 W
CO_2 cooling pipes (-20°C); dry air / nitrogen flow (20°C)

A PXD+SVD thermal mock-up is in preparation at DESY (Oct. 2014)
It will be crucial for understanding several aspects and setting the exact location for the ambient sensors

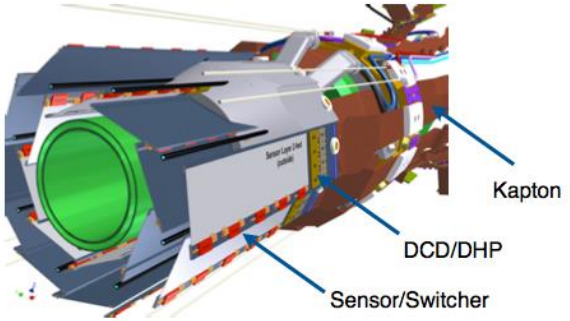
SVD

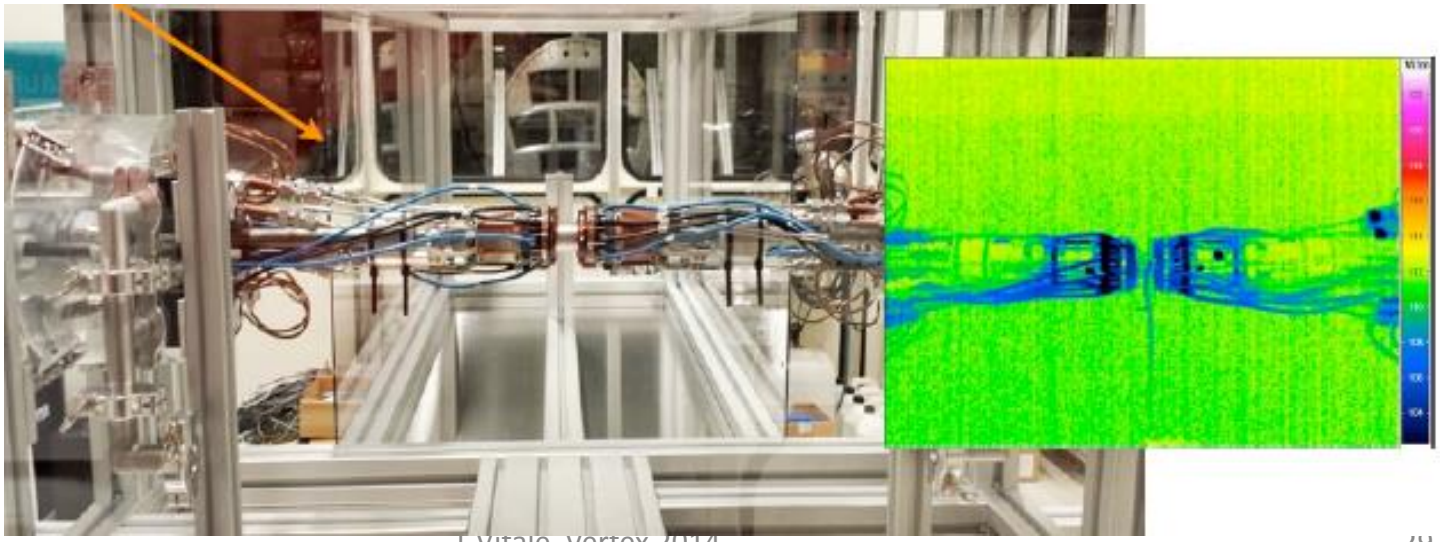
1748 APV25 chips
~ 0.4W / chip
~ 700W in total



PXD

18W per ladder
~ 360 W in total

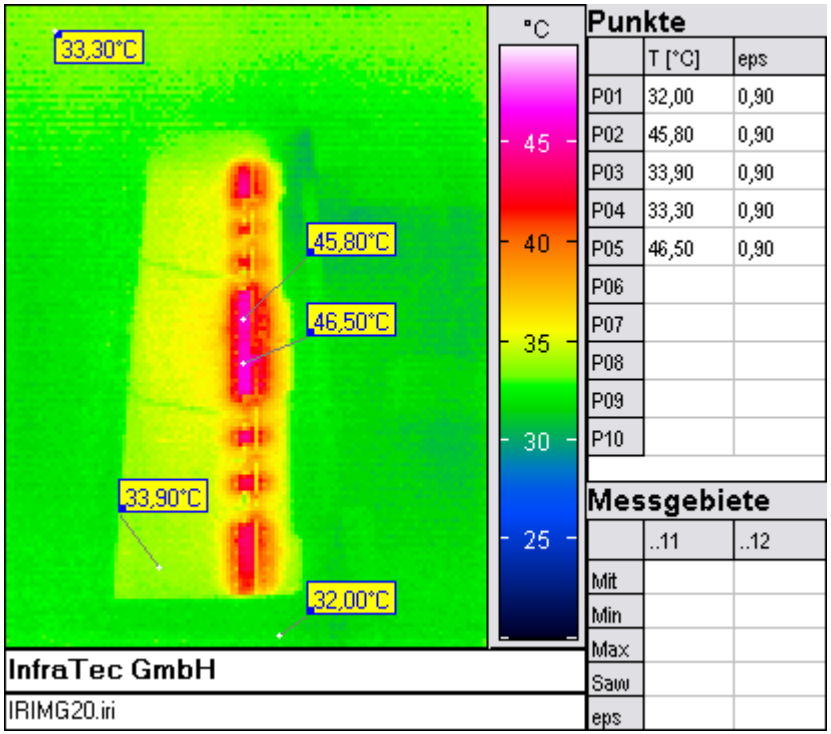




1. Origami Cooling (3/3)

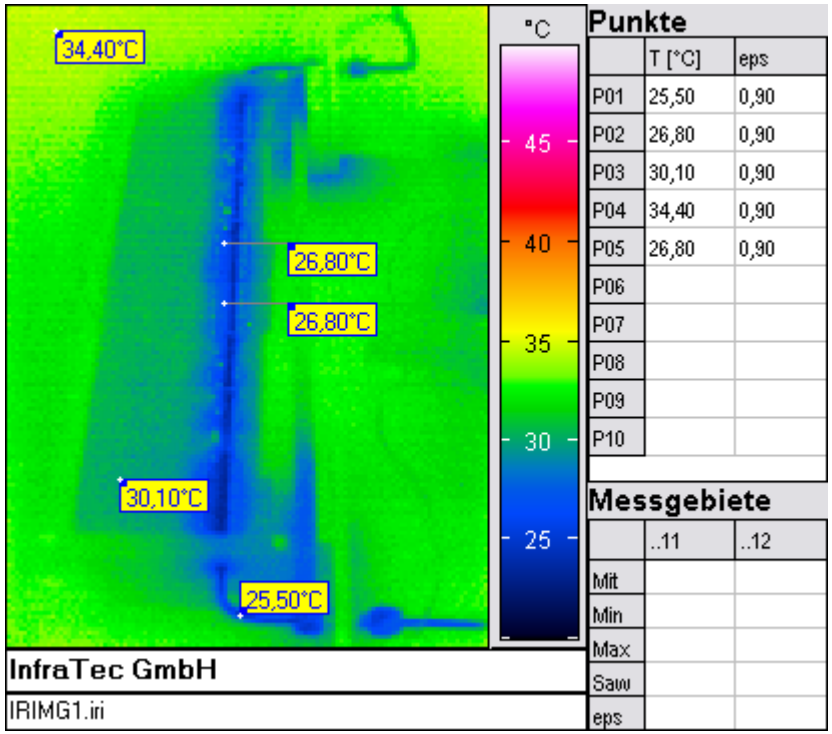
Camera does not provide correct absolute values!

APVs on without cooling



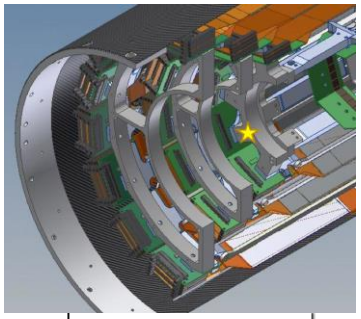
- Pipe @ room temperature
- APV chips much hotter

APVs on with cooling



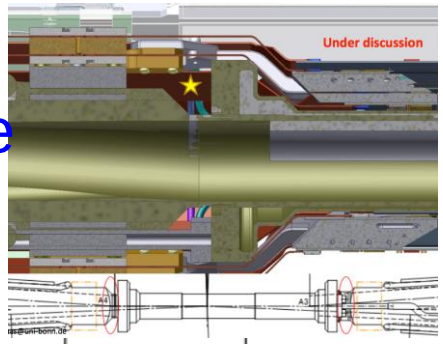
Pipe has -16°C (thermocouple)
APV chips have similar temp.

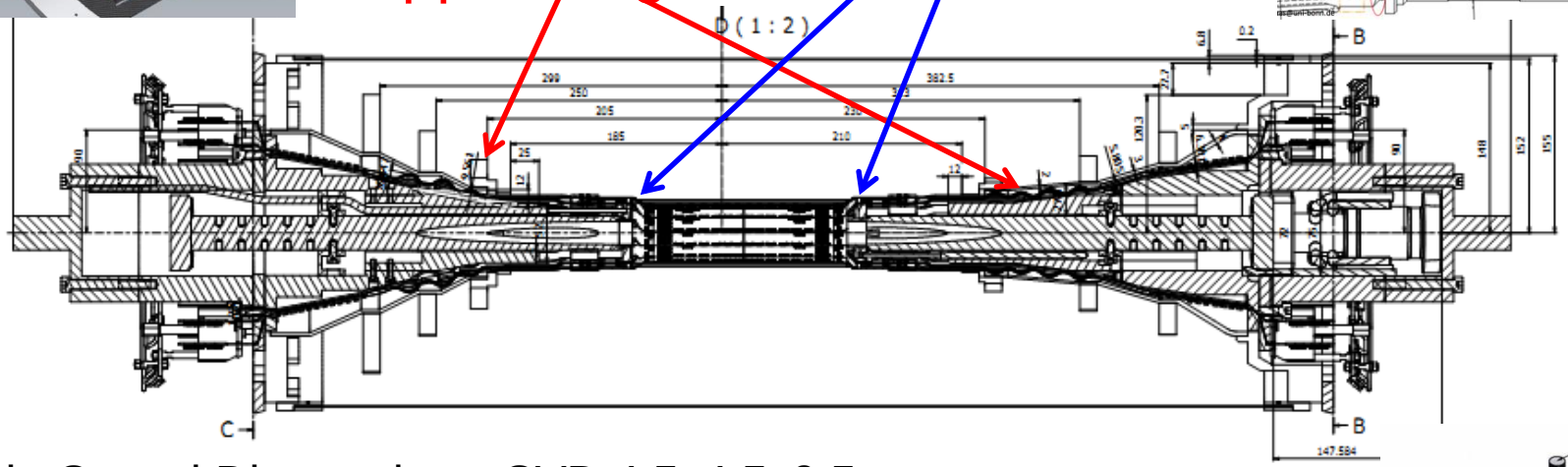
Radiation monitoring & Beam Abort



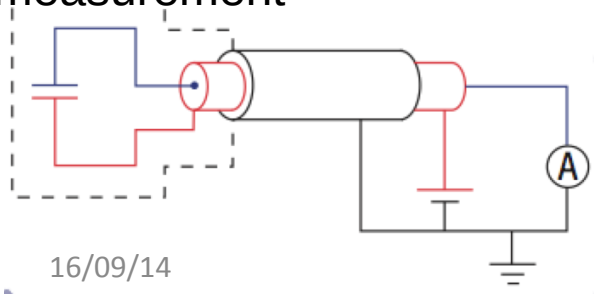
6 + 6 sensors
Close to SVD
L3
support rings

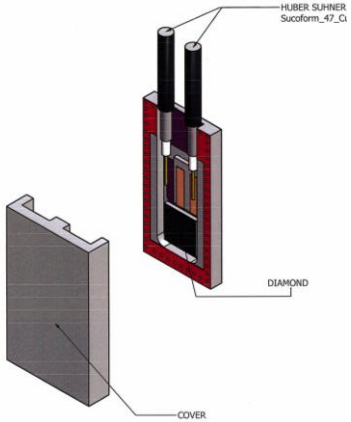
4 + 4 sensors
PXD-beam pipe





Single Crystal Diamonds, scCVD 4.5x4.5x0.5 mm^3, Long high quality cabling and current measurement



Voltage sources
(150÷500 V)
picoAmmeters

Small sensors and
Compact Mechanics
12 x 20 x 3.1 mm^3
multi-layer package,
Rogers laminate