The Belle II Pixel Detector

DEPFET Collaboration

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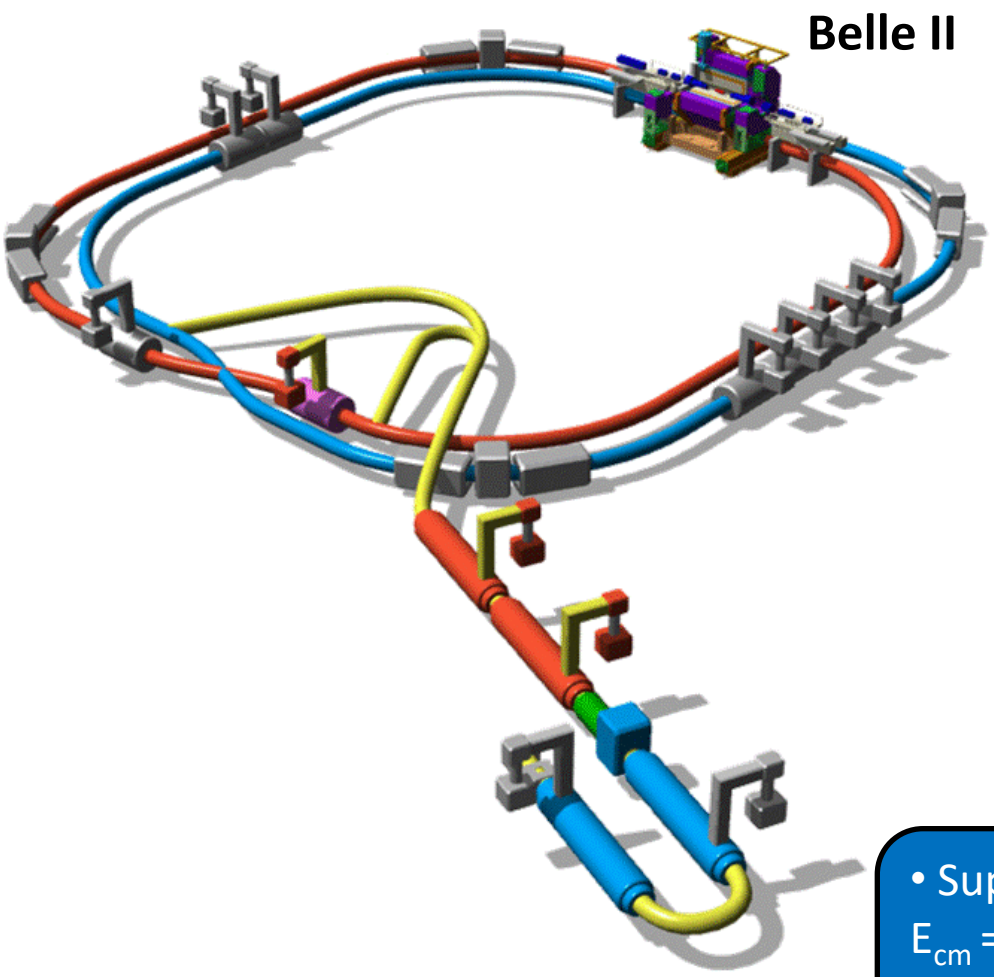
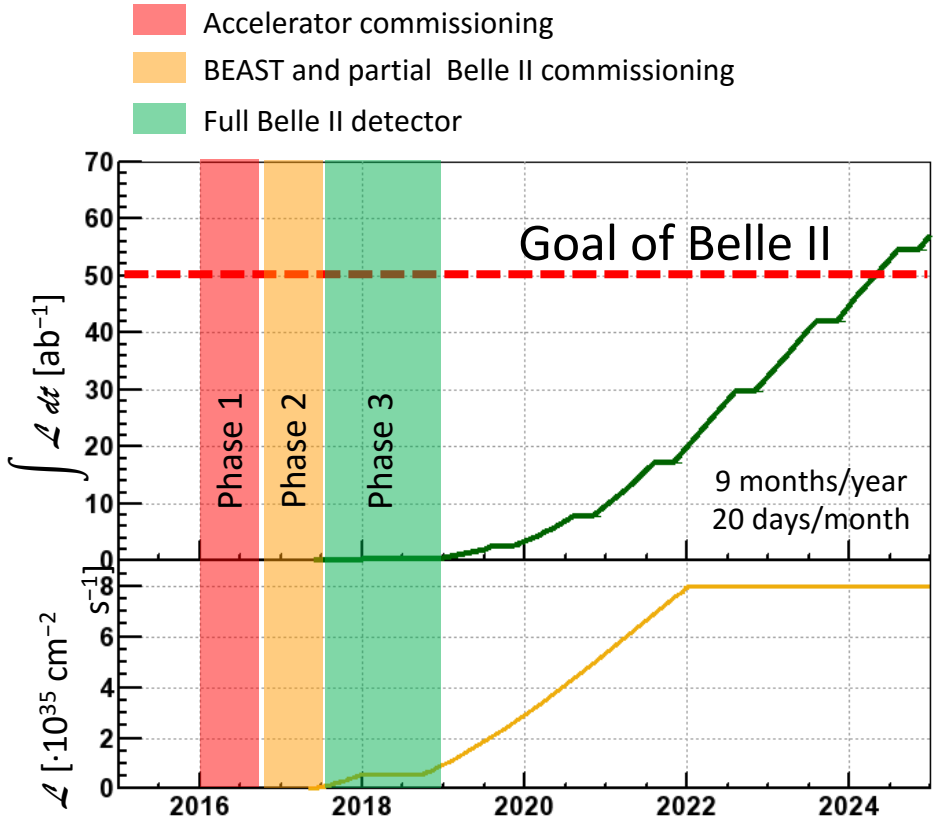
The SuperKEKB Accelerator





- SuperKEKB: Asymmetric energy e^+e^- collider
  E_{cm} = m(ϒ(4S)) = 10.58 GeV
- Peak luminosity: $\mathcal{L} = 8 \cdot 10^{35}$ cm^{-2} s^{-1} (x40 than KEKB)
  Beam size reduction. Higher current.

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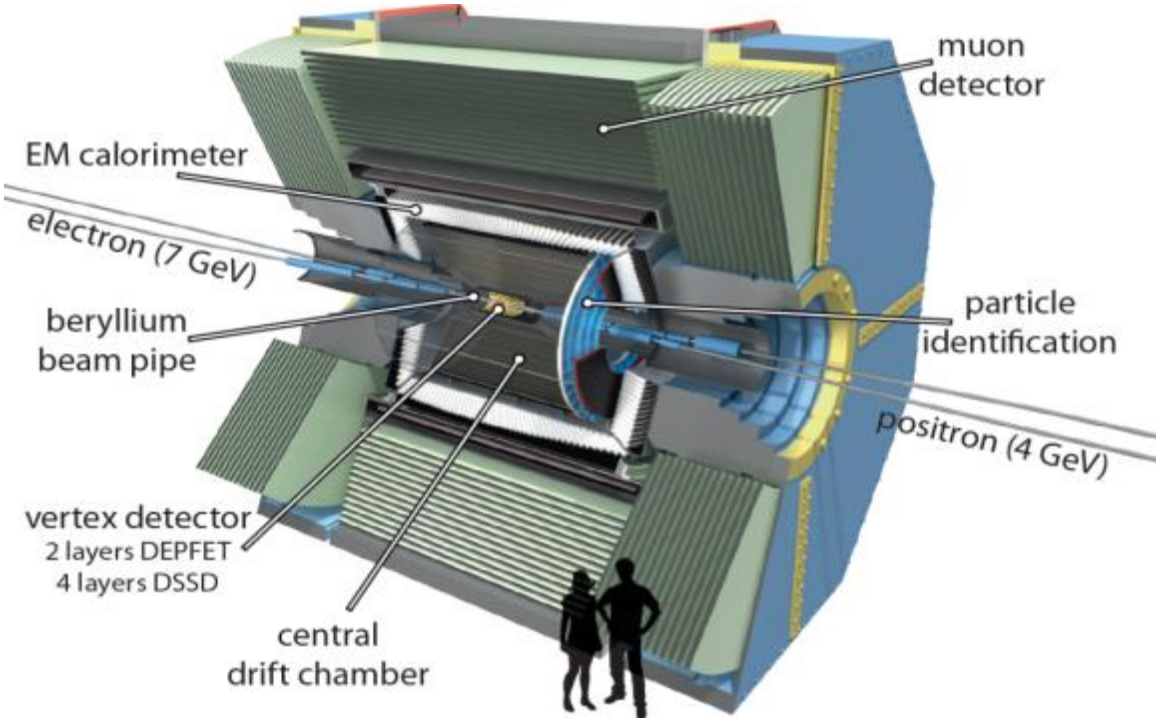
The Belle II Detector

- Detector requirements
  - Light material
  - **Vertexing capability**
  - Particle identification
  - E.M. calorimetry
  - K^0_L and muon ID
  - Data handling capabilities



→ New detector: **Belle II**

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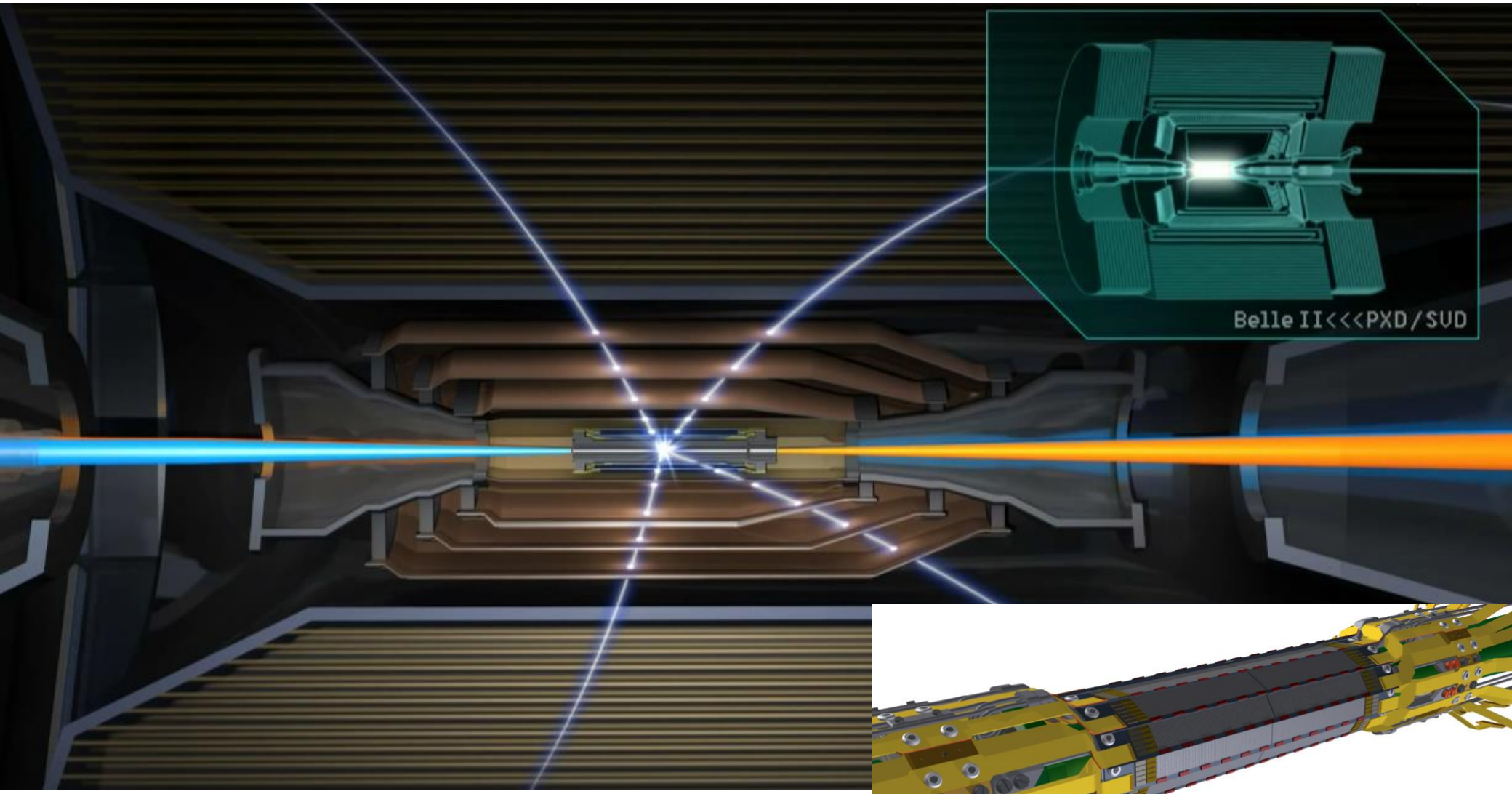
The Belle II Pixel Detector



2 Layers of DEPFET-based silicon pixels

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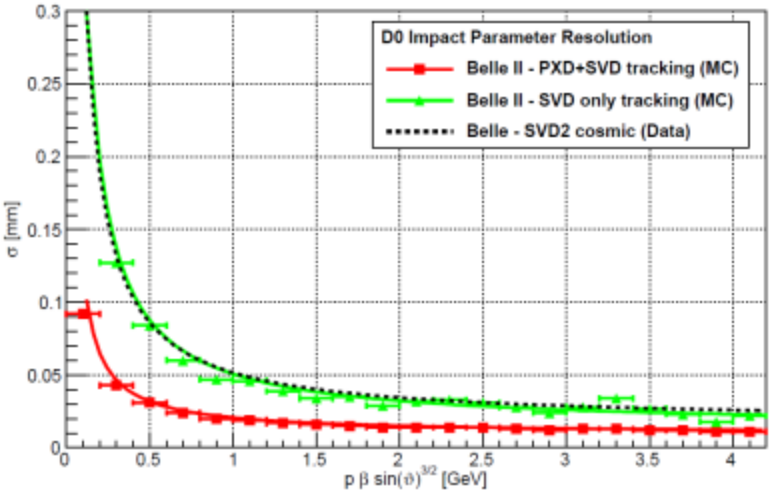
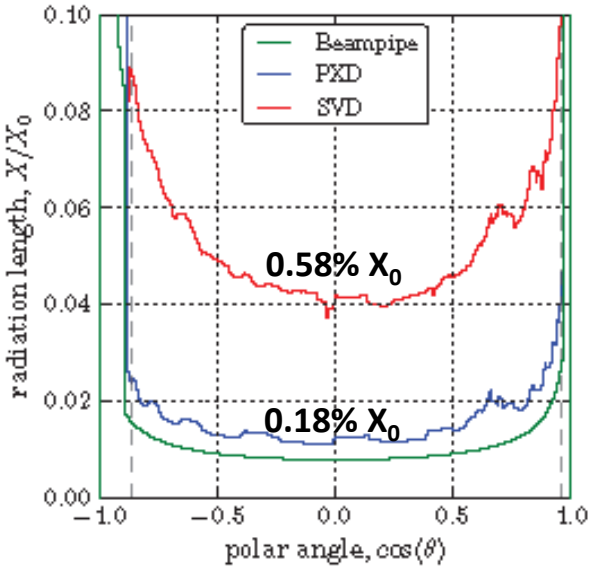
Belle II Vertex Detector Requirements

	Belle II PXD
Occupancy	0.4 hits/μm²/s
Radiation	2 Mrad/year
	$2 \cdot 10^{12}$ 1 MeV n_{eq} per year
Duty cycle	1
Frame time	20 μs
Momentum range	Low momentum (< 1 GeV)
Acceptance	17º-155º
Material budget	0.21% X_0 per layer
Resolution	15 μm (50x75 μm²)





- Modest resolution (15 μm), dominated by multiple scattering → Pixel size (50 x 75 μm²)
- Lowest possible material budget (0.2% X_0/layer)
  - Ultra-transparent detectors
  - Lightweight mechanics and minimal services

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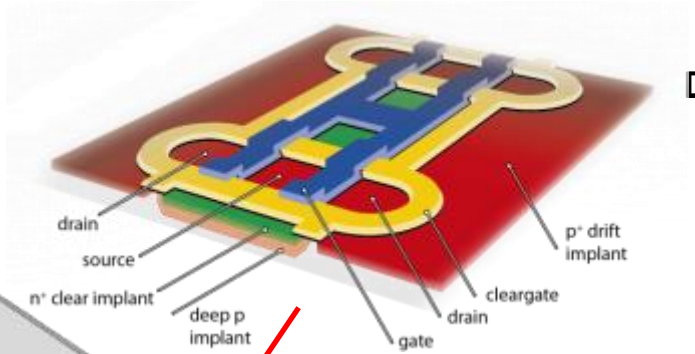
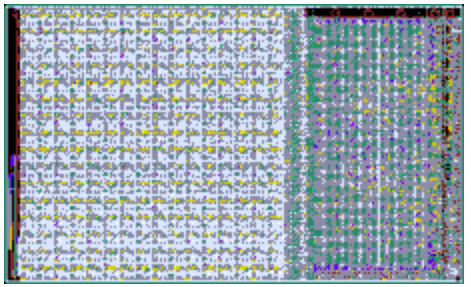
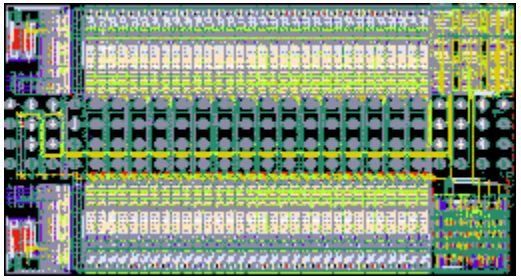
The DEPFET Ladder



DCDB (Drain Current Digitizer)
Analog frontend



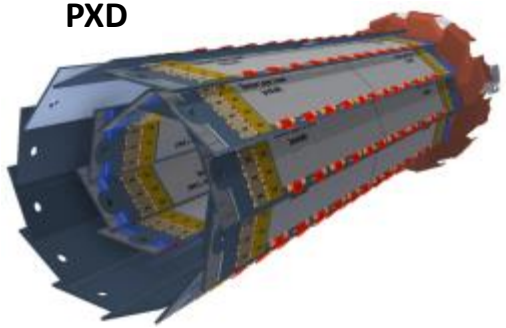
SwitcherB
Row control



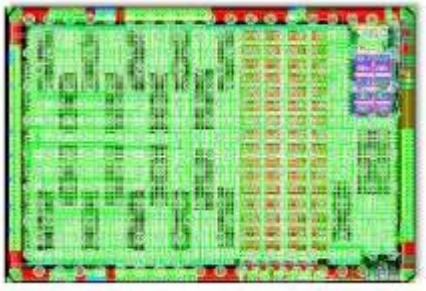
AMS/IBM HVCMOS 180 nm
Size 3.6 × 1.5 mm^2
Gate and Clear signal
Fast HV ramp for Clear
Rad. Hard proved (36 Mrad)

UMC 180 nm
Size 5.0 × 3.2 mm^2
TIA and ADC
Pedestal compensation
Rad. Hard proved (20 Mrad)

PXD



DHP (Data Handling Processor)
First data compression



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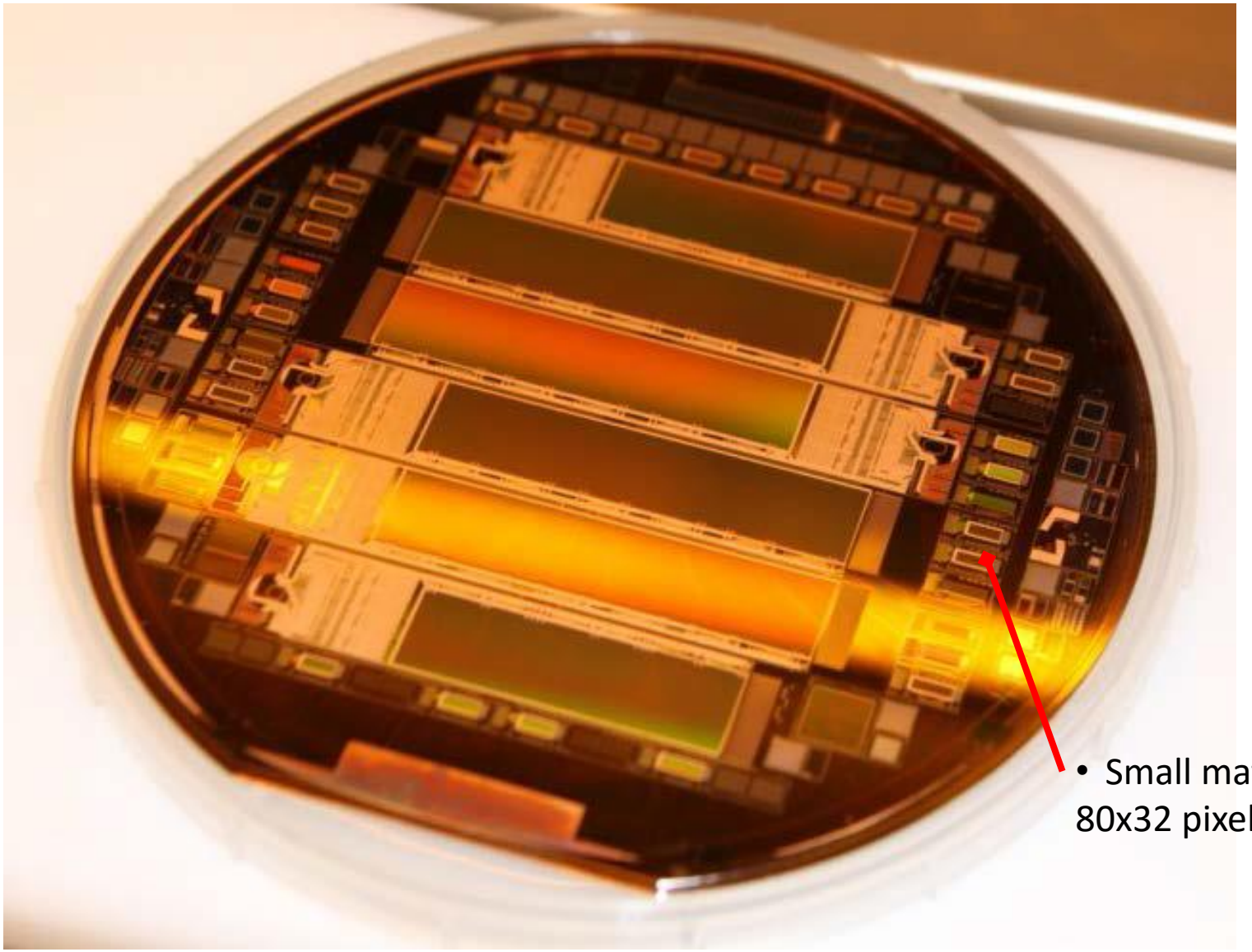
PXD9: Belle II DEPFET Sensors



- Small matrices 80x32 pixels

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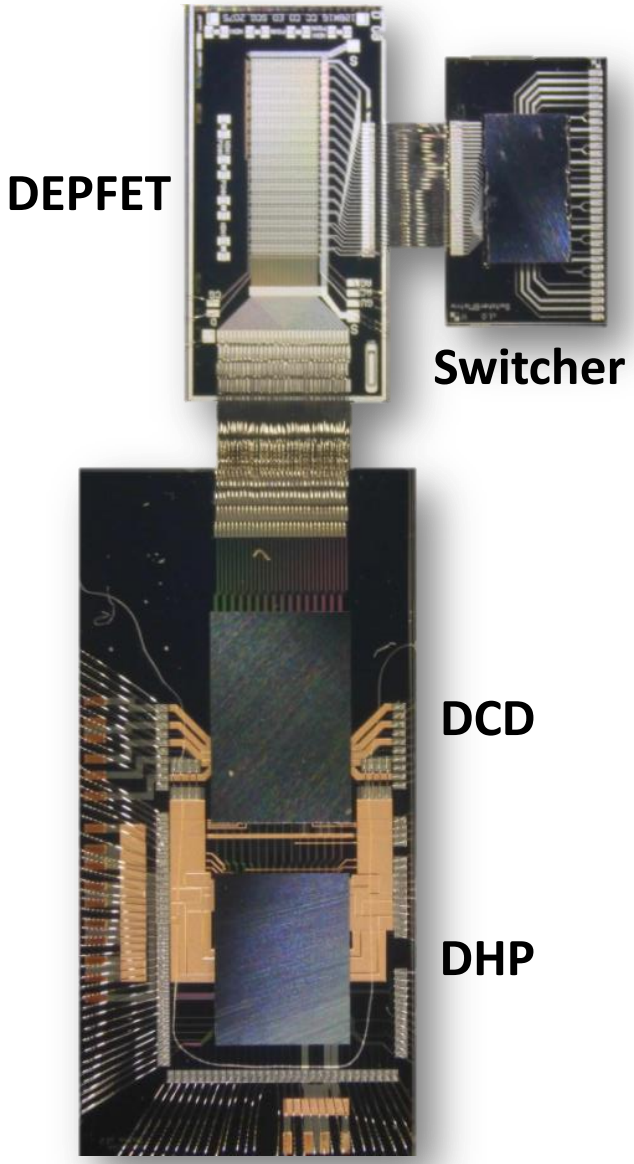
Hybrid 5 – Full System Demonstrator

- PXD9 small Belle II type matrix
  - Pixel pitch: 50x55 μm^2
  - Thinned to 75 µm
  - Gate length: 5 µm
  - Thin gate oxide
  - 32x64 pixels readout
- Final readout chain
  - SwitcherB
  - DCDB
  - DHPT
  - DHH



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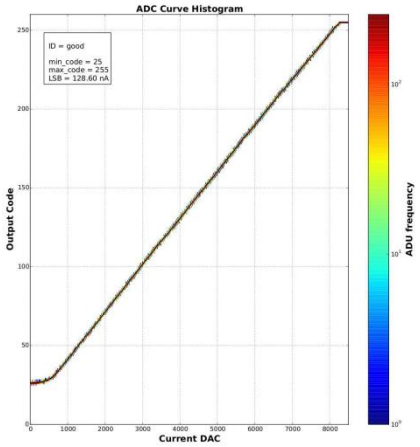
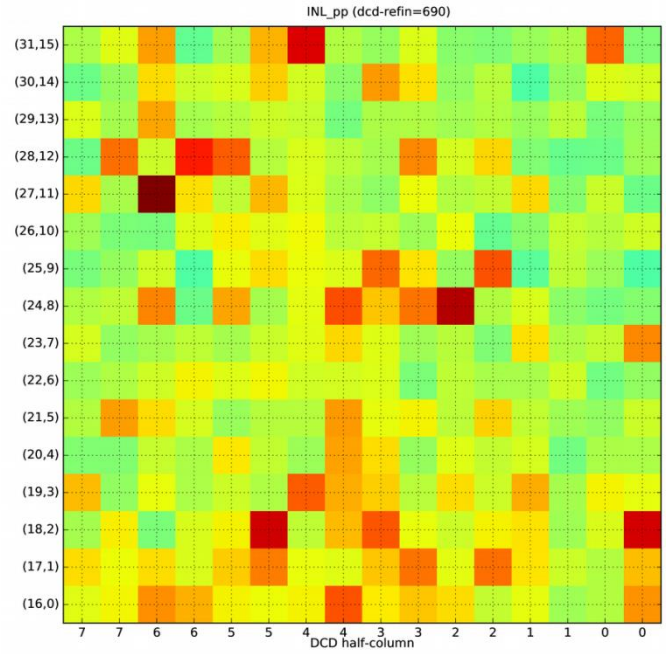
ASICs Performance

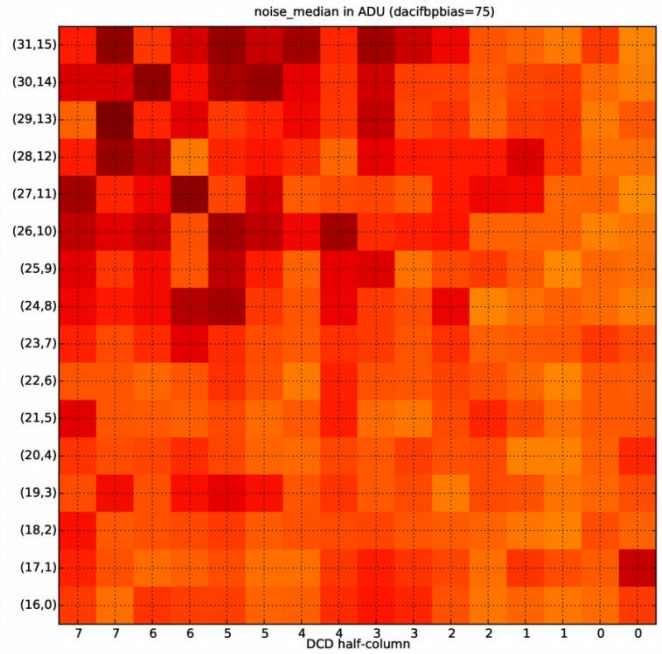
- DCDB4.2

All channels show good linearity (INLpp < 8 ADU)
All channels show low noise < 0.55 ADU
Homogeneous gain map

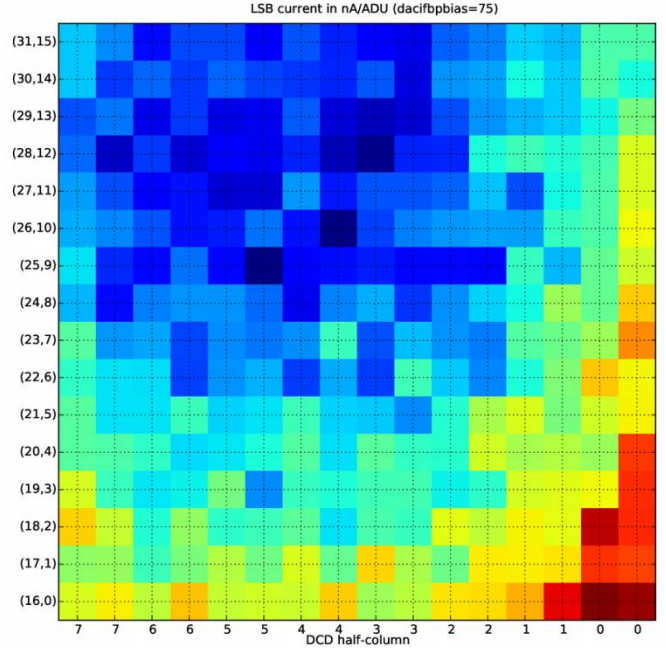




INLpp < 8 ADU
Median = 4.5



Noise < 0.55 ADU
Spread < 0.08 ADU



Homogeneous gain
Min to max variation ~10%

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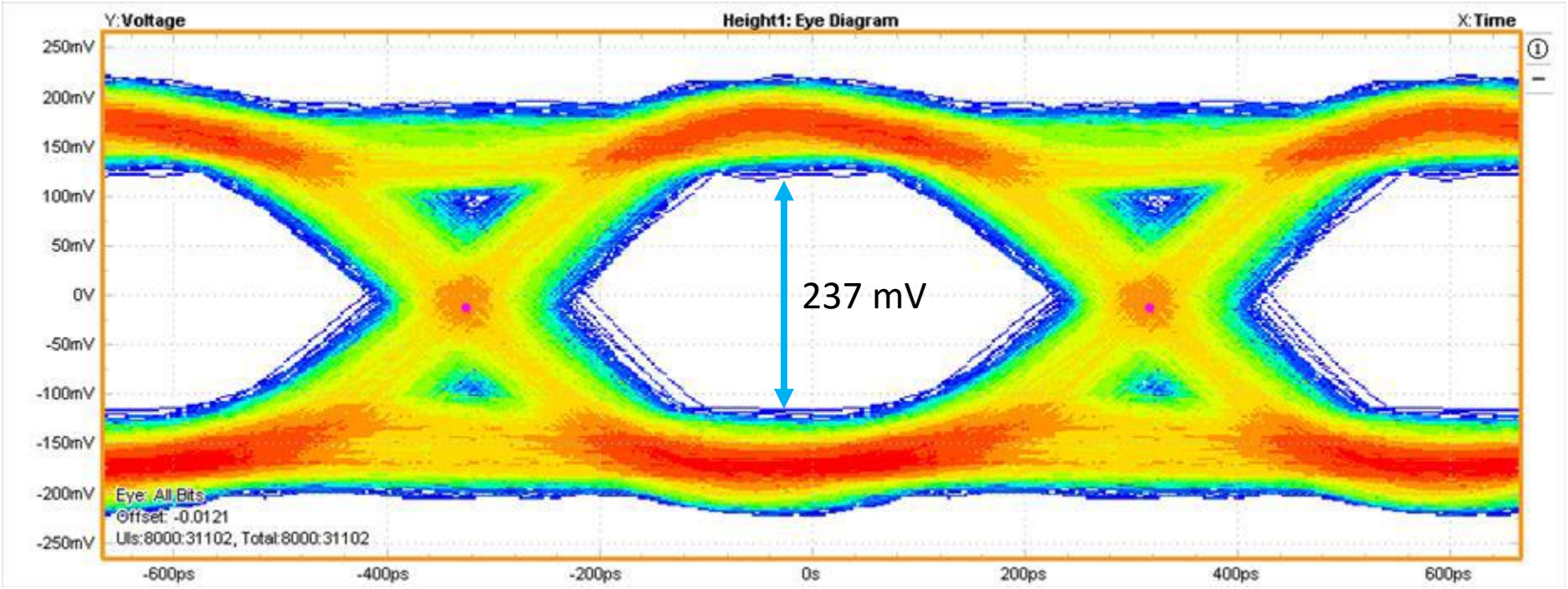
ASICs Performance

- DHPT1.2: Proper data transmission after 10 m Infiniband cable



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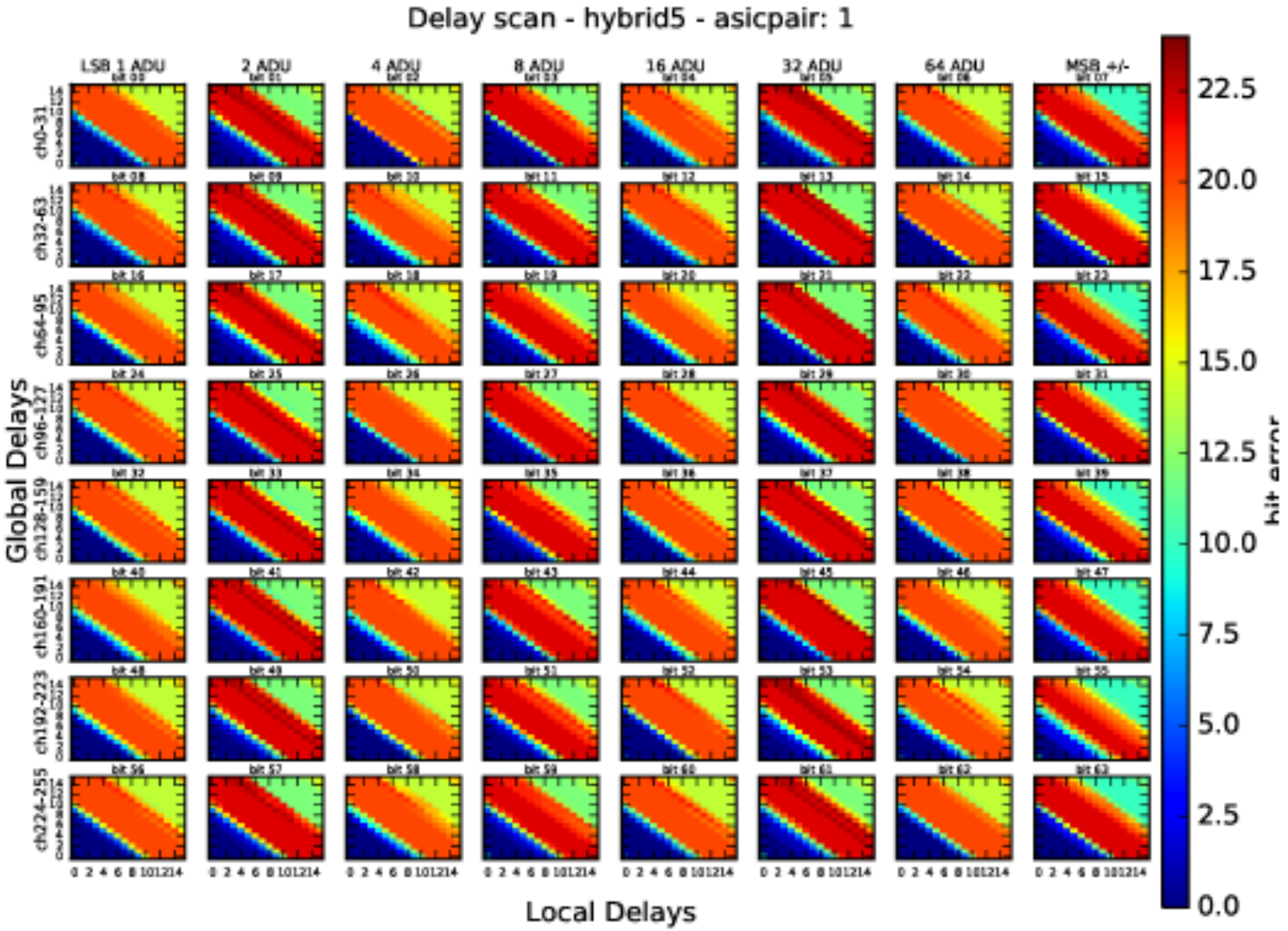
ASICs Performance

- Error free DCDB4.2-DHPT1.1 communication



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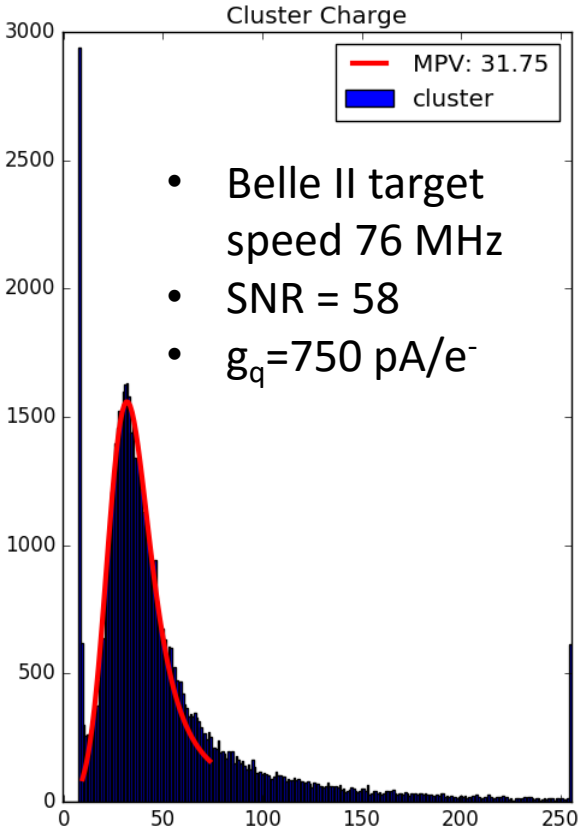
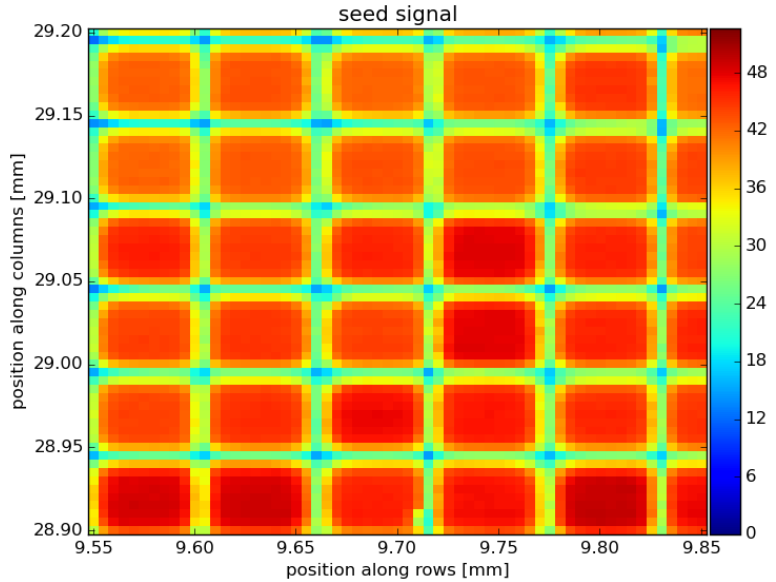
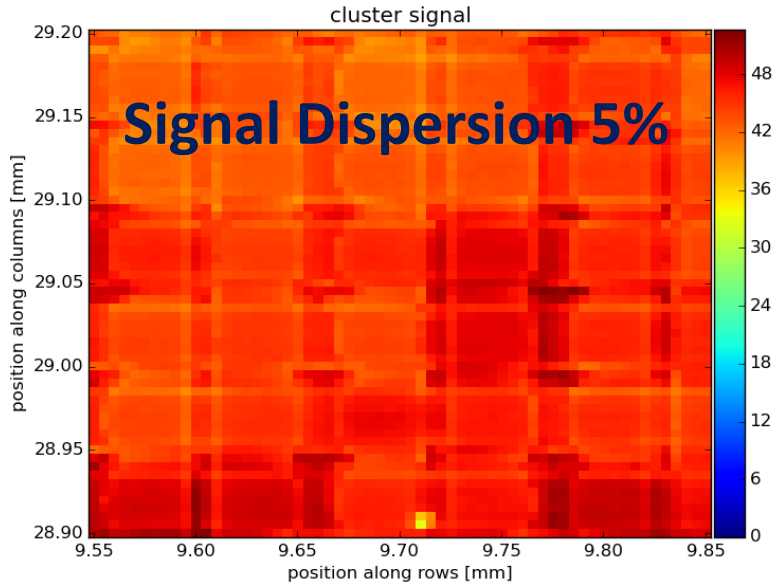
Belle II DEPFET Sensors

- Optimization of DEPFET voltages
  - Source measurements
  - Laser measurements



- Belle II target speed 76 MHz
- SNR = 58
- g_q=750 pA/e^-





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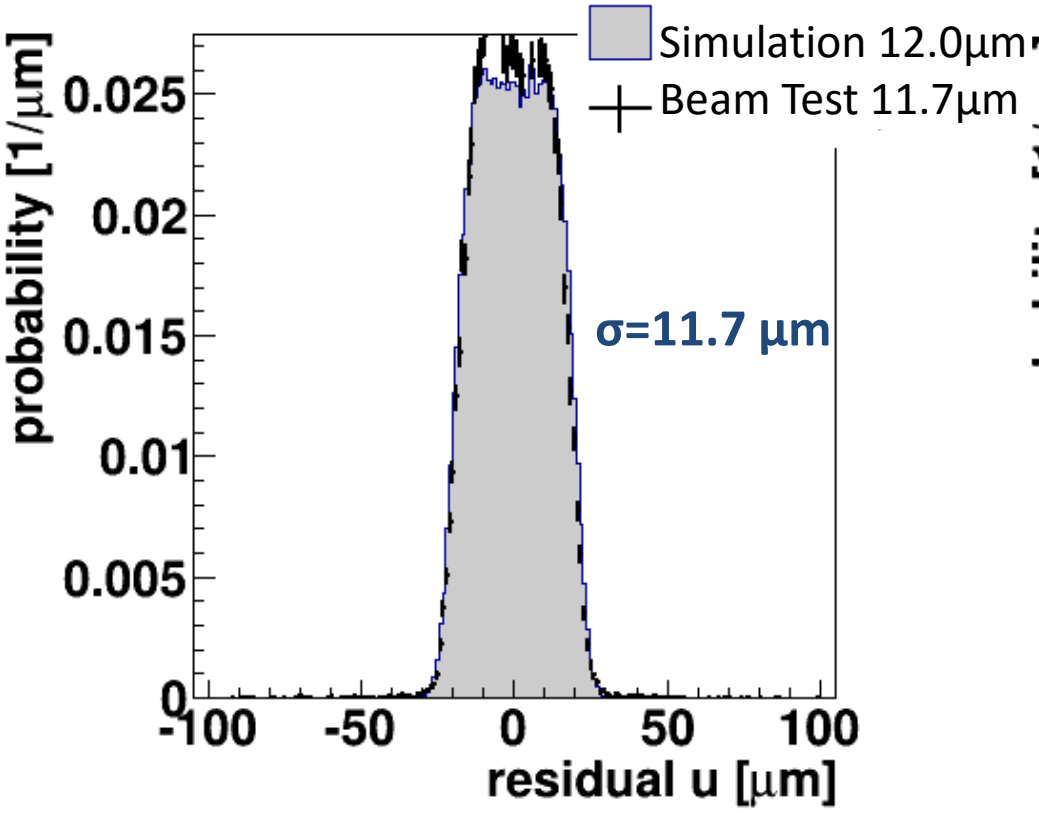
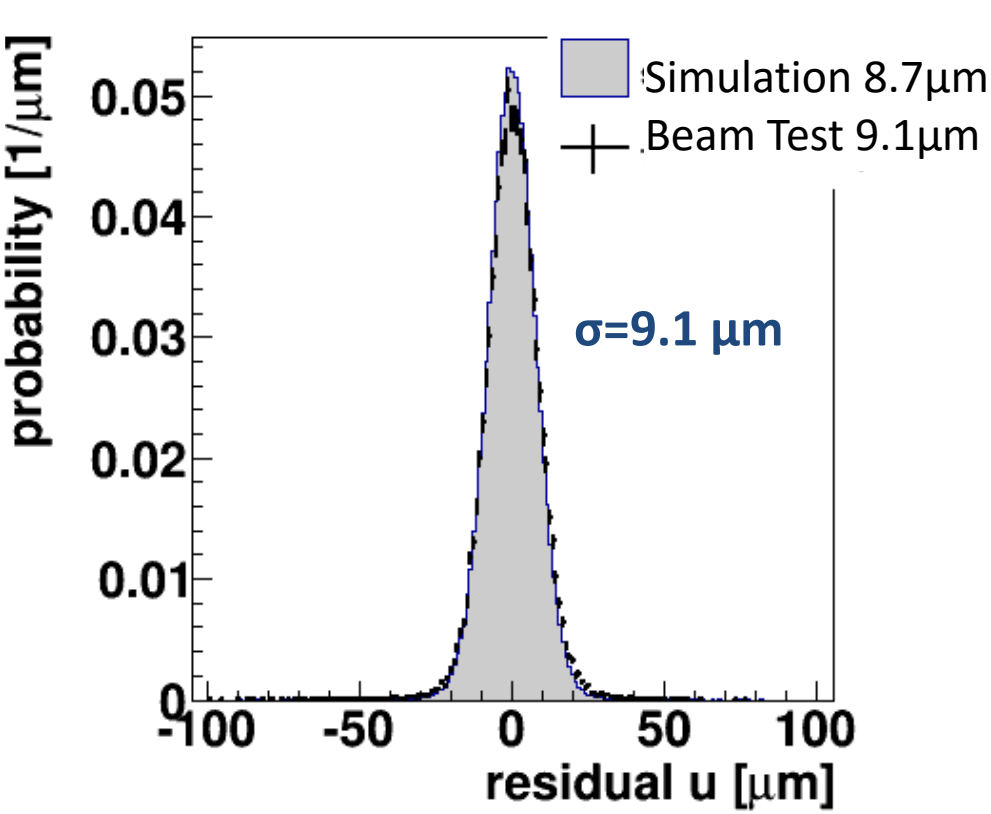
Belle II PXD Residuals

0° tilt: perp. incidence



30° tilt: many 2 pixel clusters



- Matrix tilted along column: multi-column clusters
- Expectation for single pixel readout: $\mathrm{RMS} = 50\,\mu\mathrm{m}/\sqrt{12} \approx 14.5\mu\mathrm{m}$

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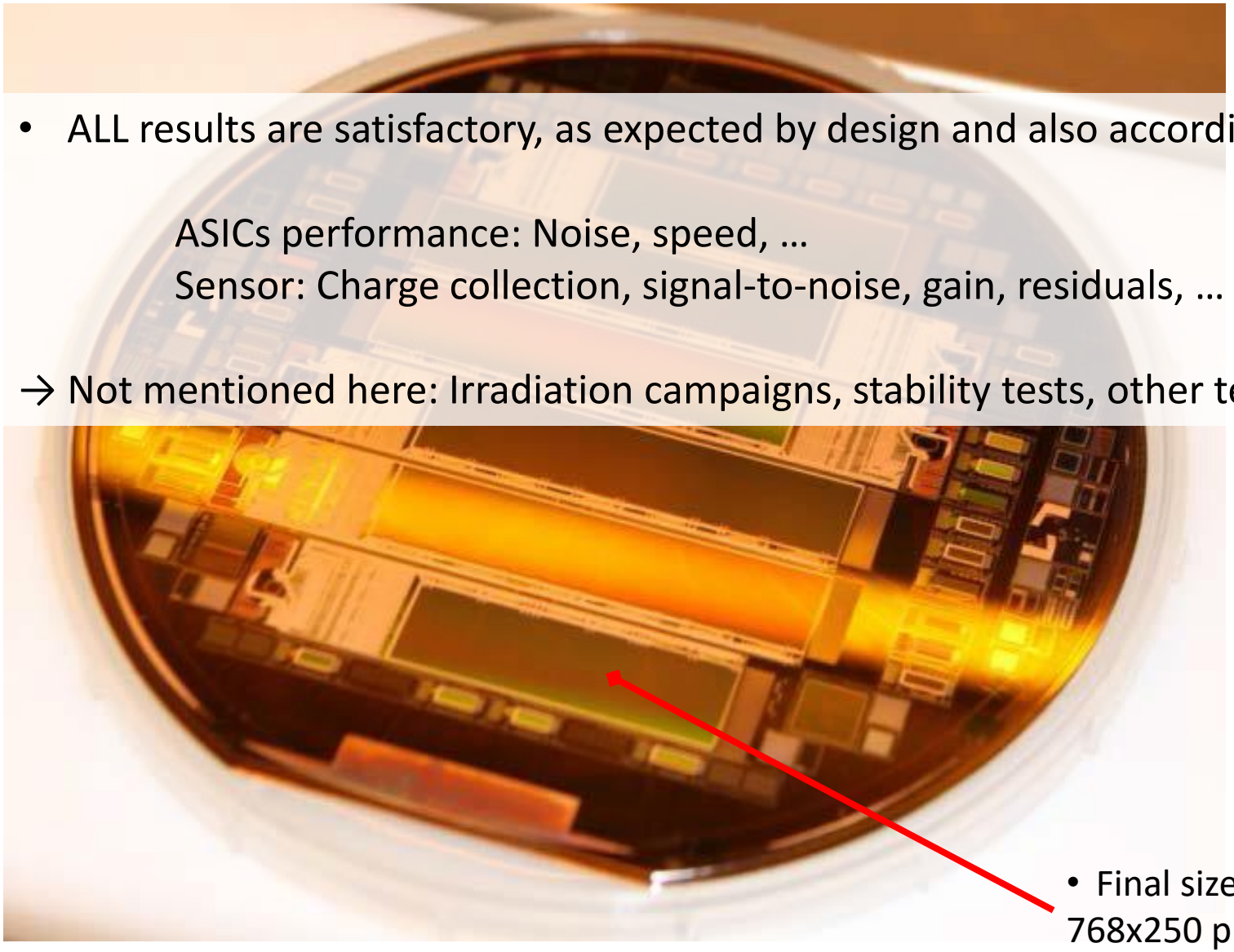
PXD9: Belle II DEPFET Sensors



- ALL results are satisfactory, as expected by design and also according to simulations:

  ASICs performance: Noise, speed, …
  Sensor: Charge collection, signal-to-noise, gain, residuals, …

→ Not mentioned here: Irradiation campaigns, stability tests, other test vehicles…

- Final size modules 768x250 pixels

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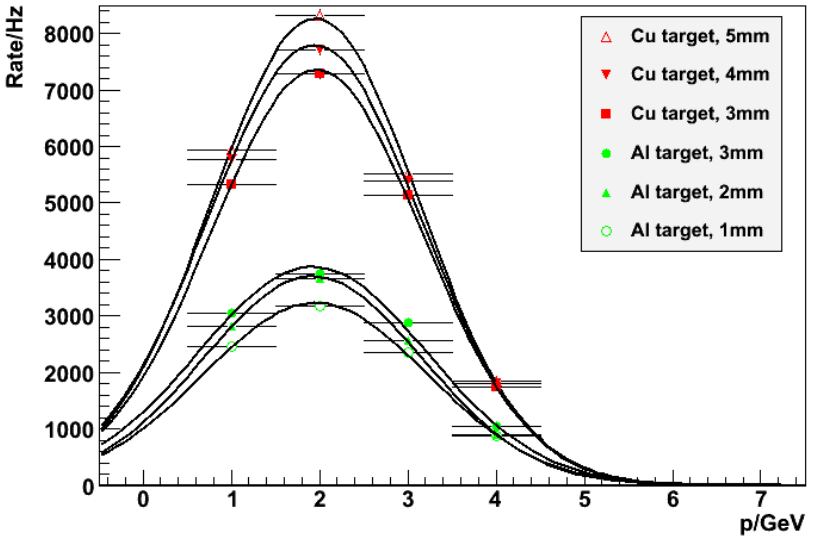
DESY TB

- VXD common test beam in April 2016
- Small sector of the final sensors and ASICs*
  2 PXD + 4 SVD layers
- Complete VXD readout chain: HLT, monitoring, event building, PocketDAQ
- CO_2 cooling, slow control, environmental sensors
- Illumination with (up to) 6 GeV e^- under solenoid magnetic field (PCMAG)
- Alignment, tracking algorithms, ROI



- **Goal**: **System integration and Phase 2 Commissioning**

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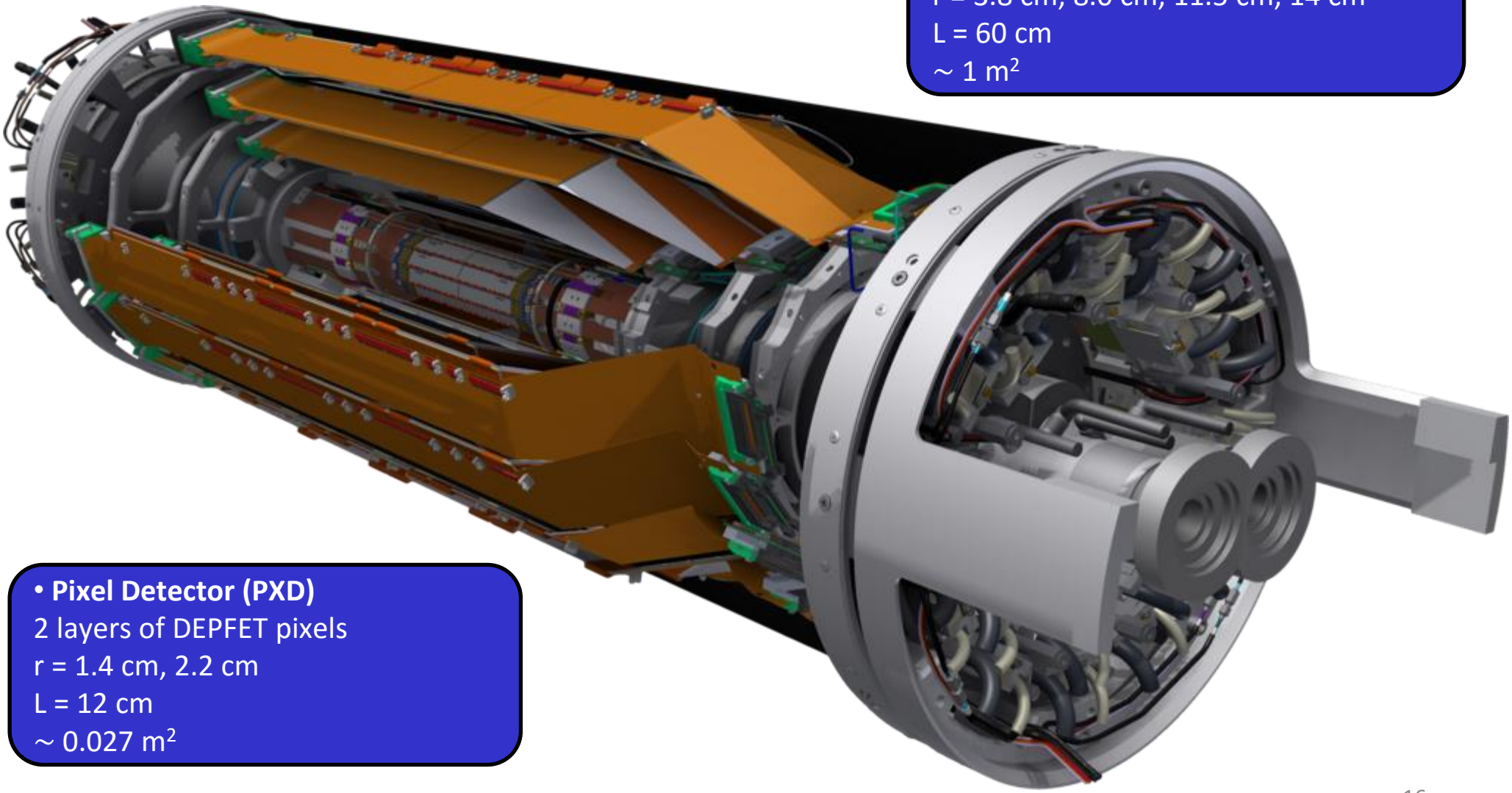
Belle II Vertex Detector

- **Silicon Vertex Detector (SVD)**

4 layers of DSSD
r = 3.8 cm, 8.0 cm, 11.5 cm, 14 cm
L = 60 cm
$\sim 1\ m^2$



- **Pixel Detector (PXD)**

2 layers of DEPFET pixels
r = 1.4 cm, 2.2 cm
L = 12 cm
$\sim 0.027\ m^2$

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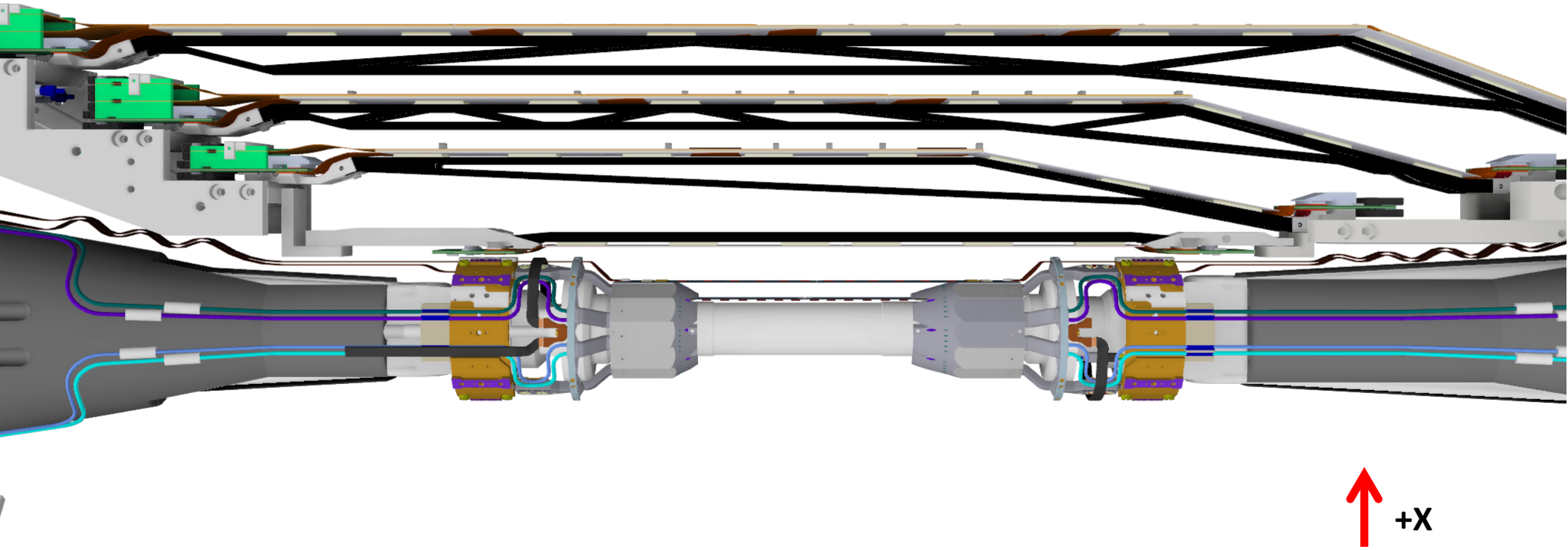
VXD Phase 2 Hardware

- Two PXD and four SVD layers
- +X direction, horizontal plane (highest background sensitivity)

Test Beam set up to mimic Phase 2 arrangement



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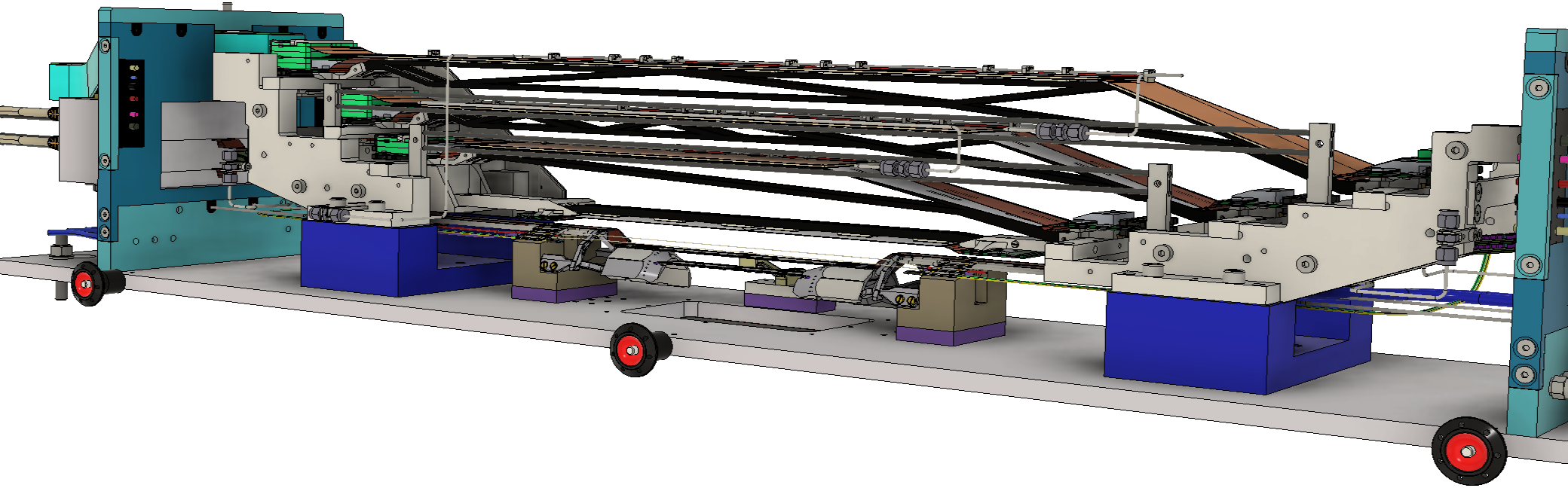
Test Beam Set Up



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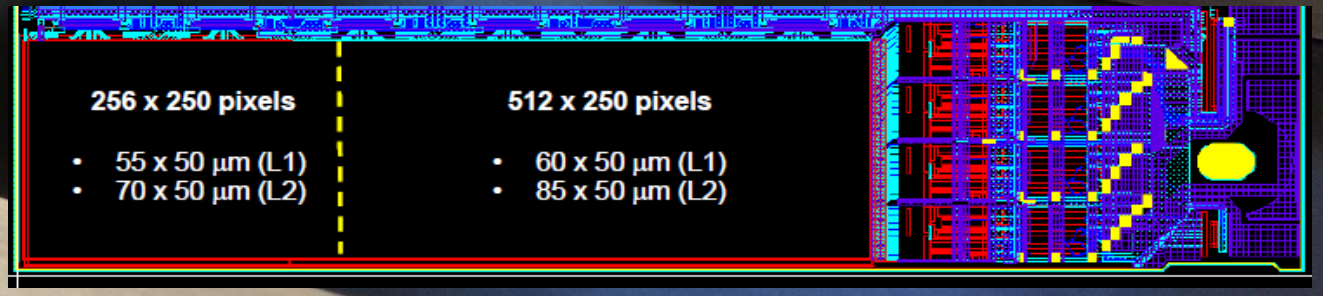
PXD on the SCB



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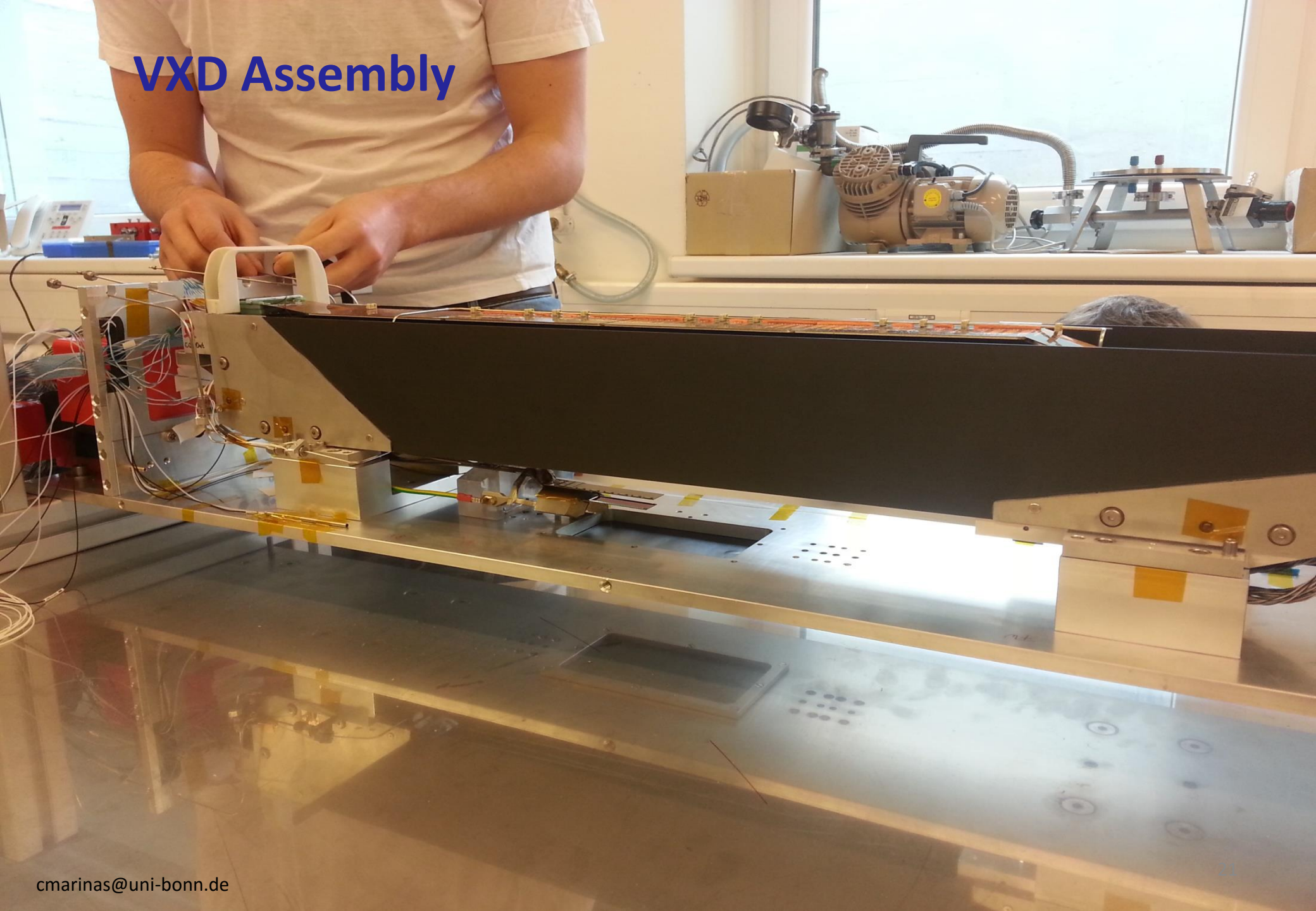
SVD Cartridge

VXD Assembly



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Integration into PCMAG

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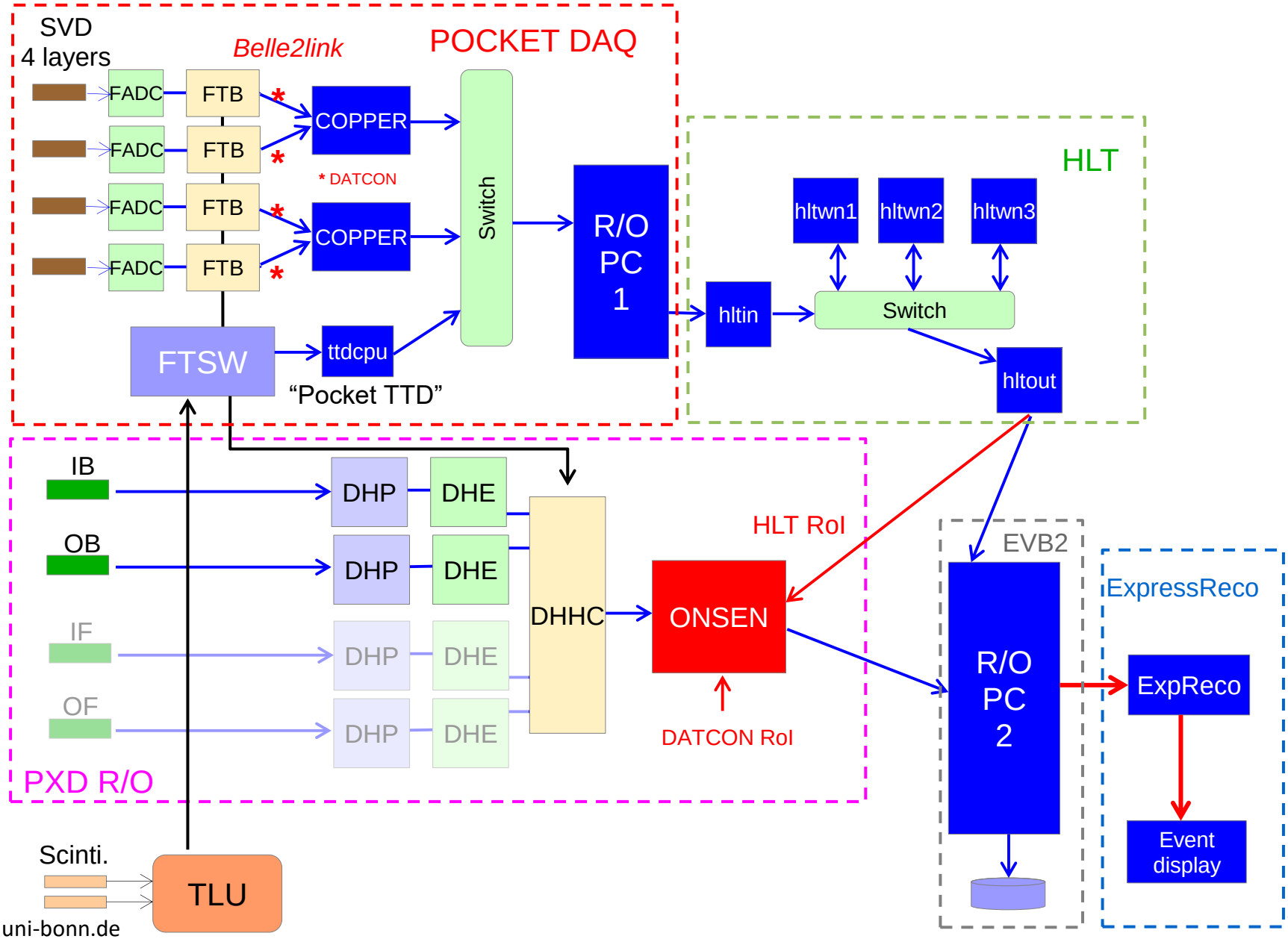
VXD-Test Beam DAQ Structure



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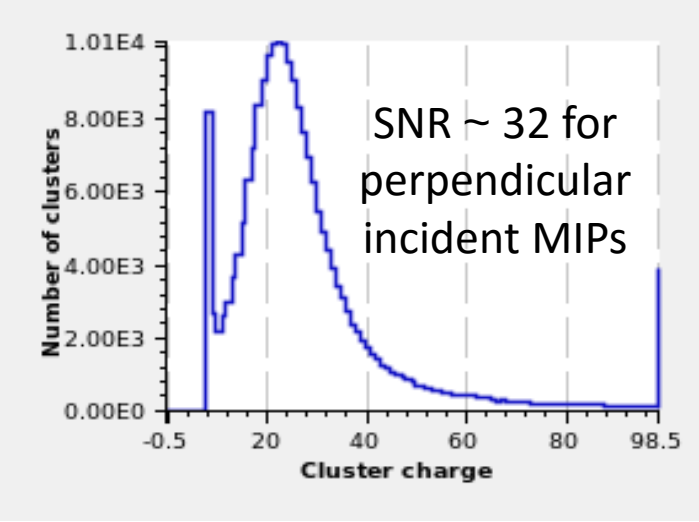
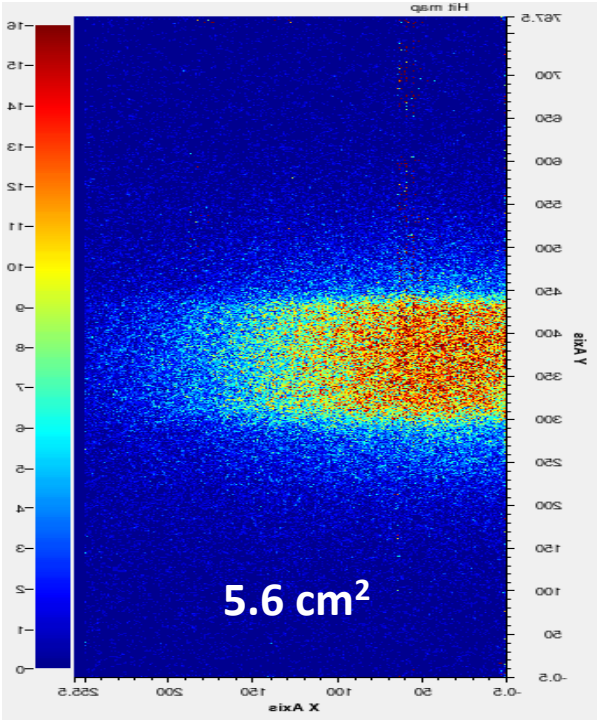
PXD Hit Maps

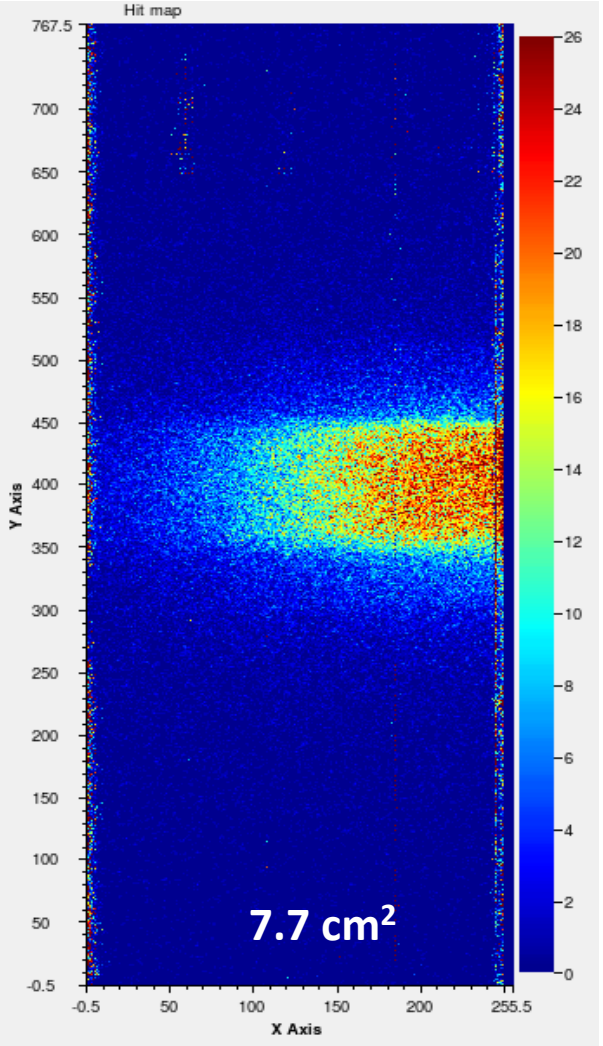
- Threshold = 5 (~ 1200 electrons)
- MIP ~ 6000 electrons





Inner Backward

Trigger on 4 scintillators
Collimated beam
No magnetic field



Outer Backward

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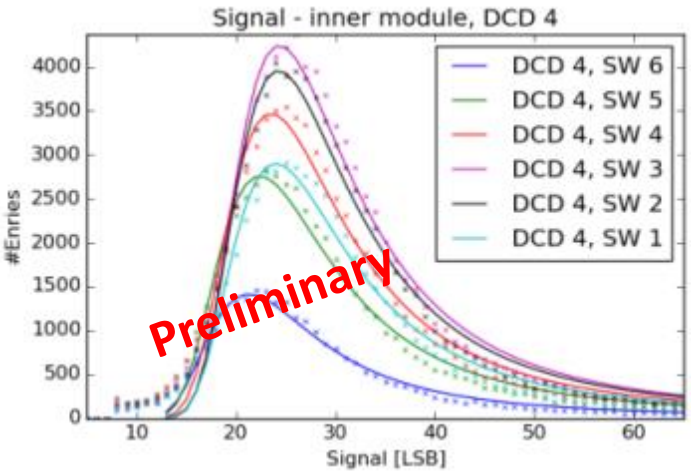
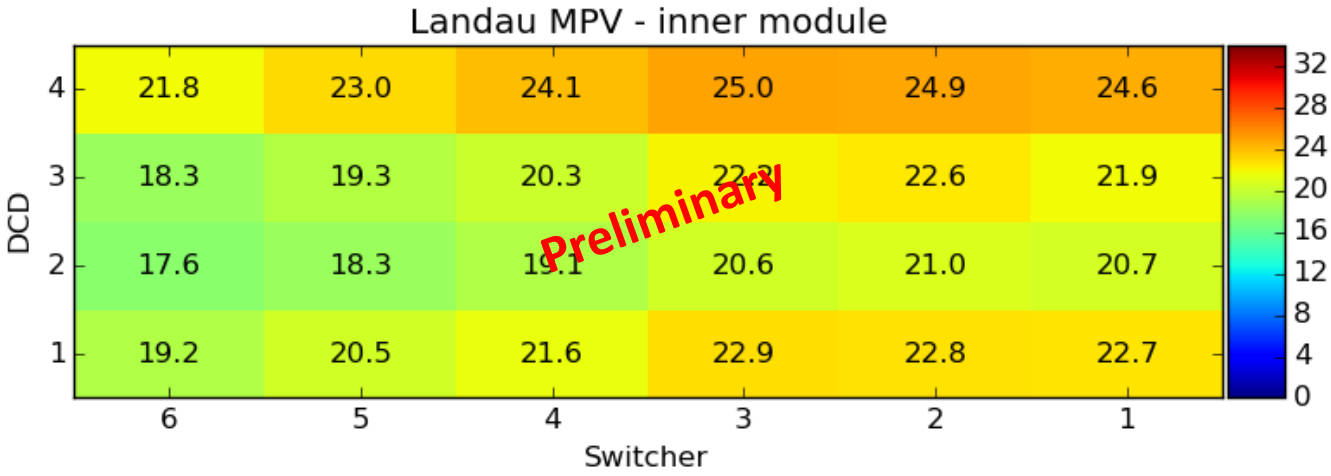
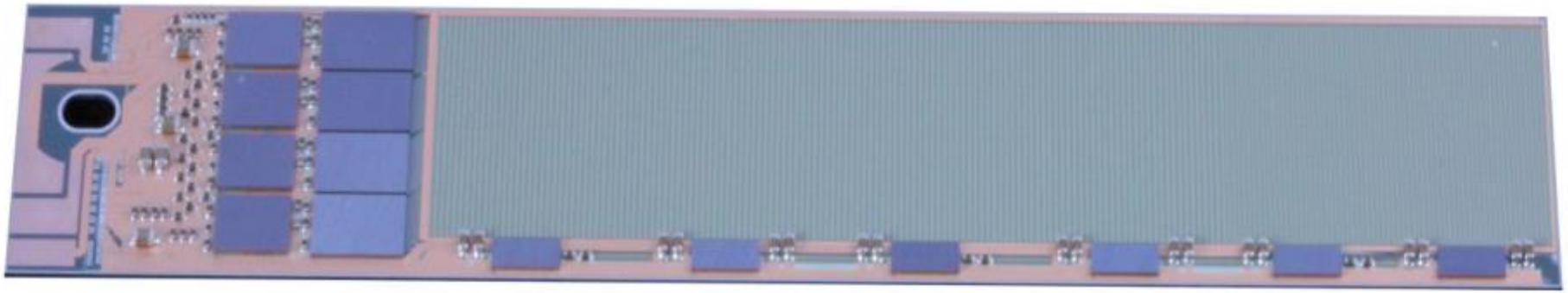
PXD Signals







- The response from the matrix is rather uniform even without tuning. Modules just worked using operating parameters from Hybrid 5
- There is lot of room for improvements with better optimization of voltages and ASICs

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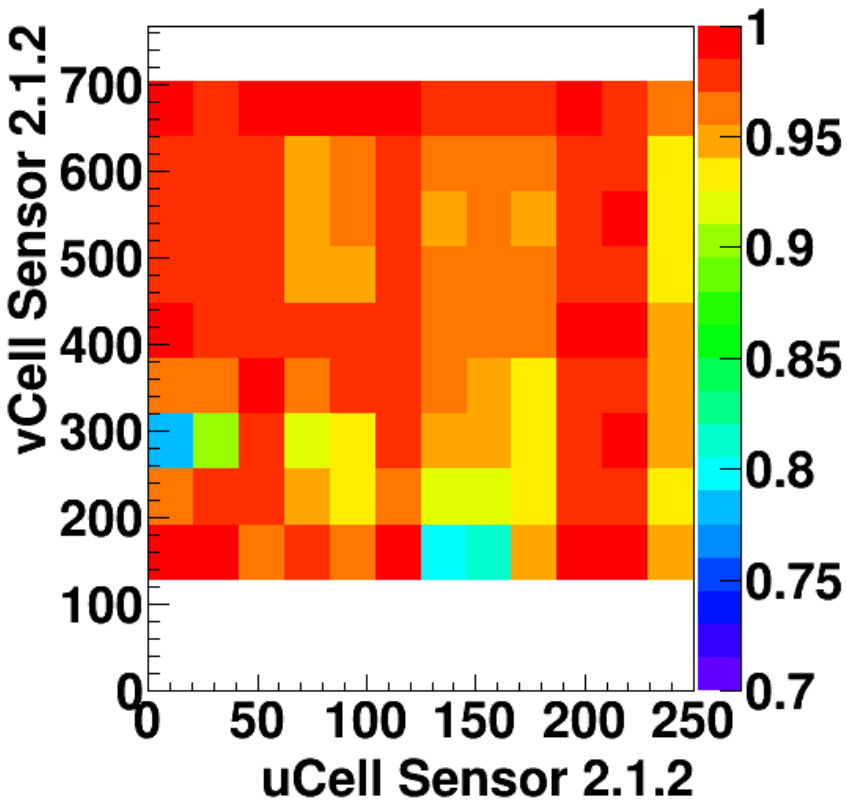
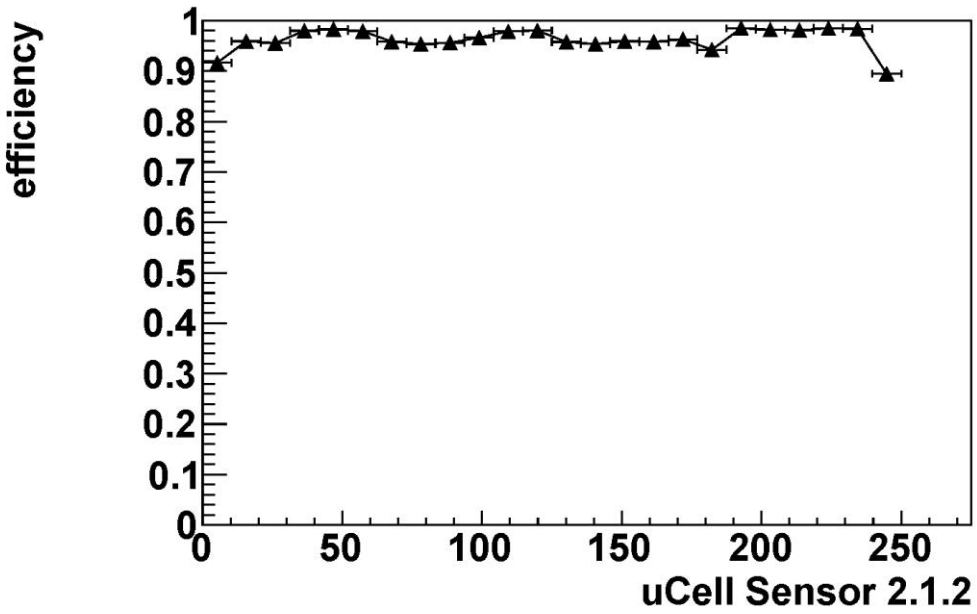
PXD Efficiency





Efficiency >95%

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Conclusion

- Full scale detector demonstrator: Sensor and ASICs OK
- 2 PXD layers fully operational with SVD: ‘Final’ Phase 2 hardware
  - High SNR and efficiency, residuals according to specs
  - Only possible with an operational DAQ system
  - Slow control and monitoring system ready
- Preparations for the BEAST commissioning phase started
- Mass detector production will follow

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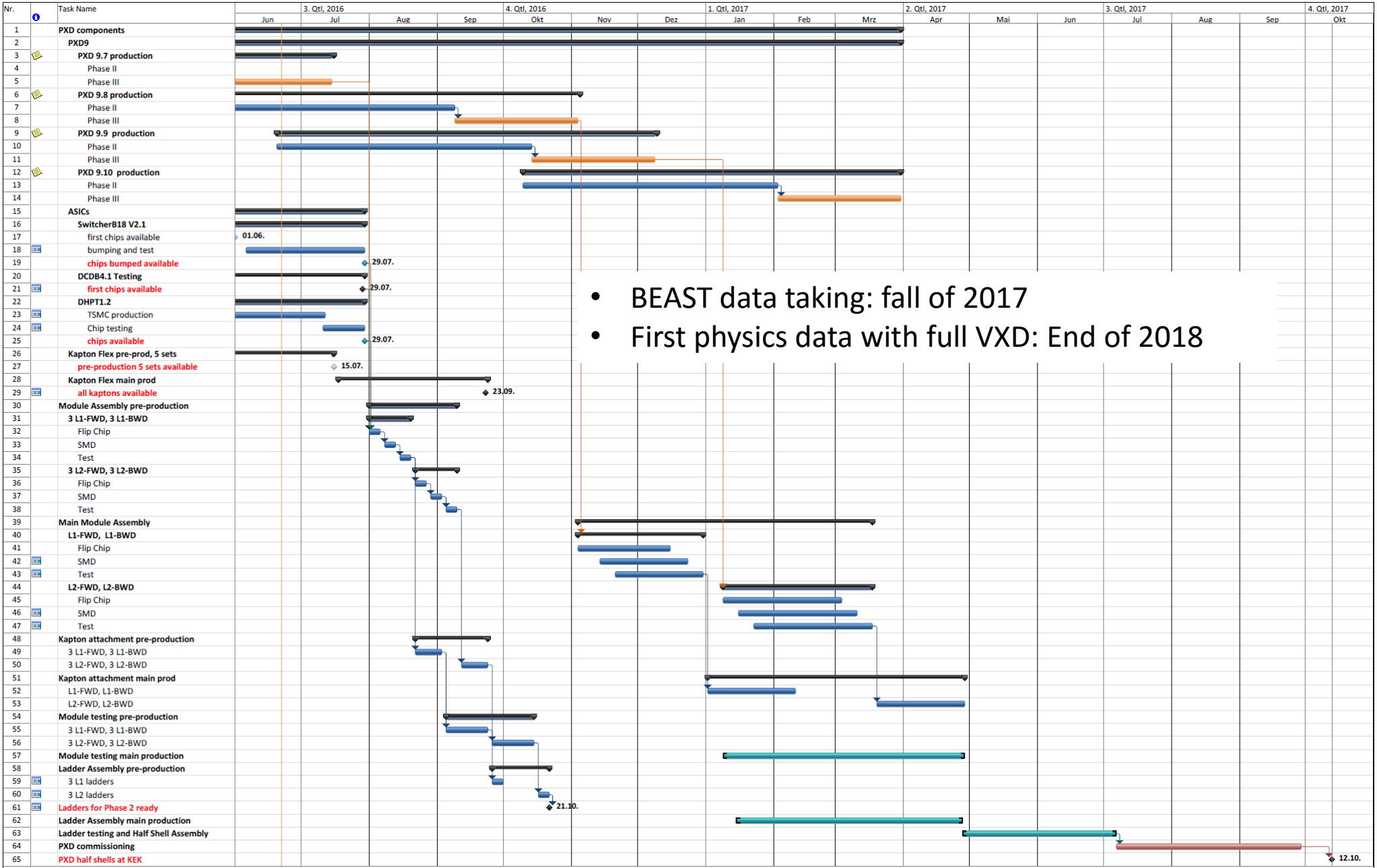
Schedule



- BEAST data taking: fall of 2017
- First physics data with full VXD: End of 2018

Thanks