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DEPFET

Active Pixel Detector

Characterization and performance of large thin DEPFET detectors

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DEPFET Collaboration

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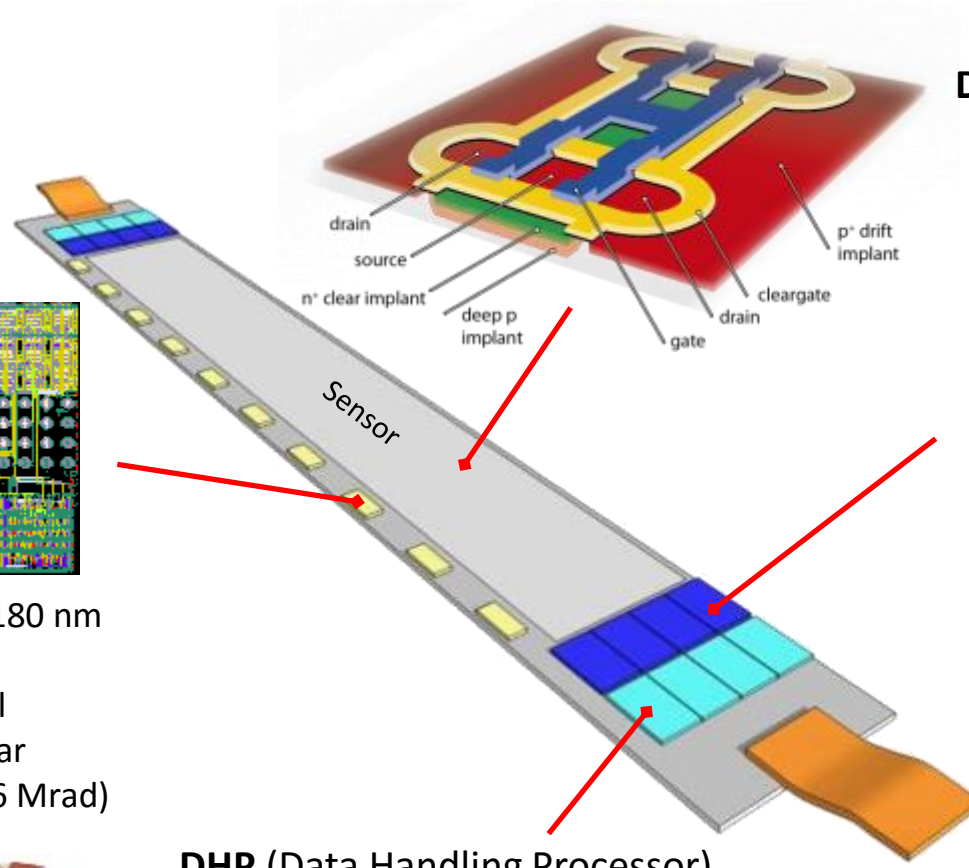
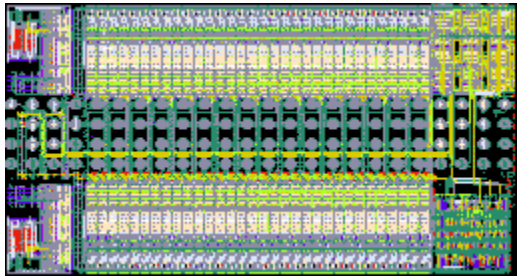
The DEPFET Module



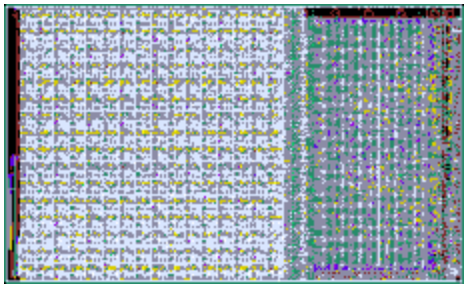
SwitcherB

Row control



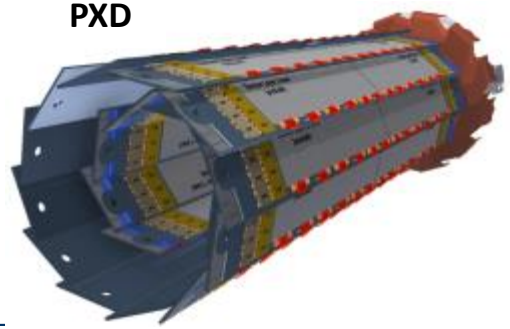
AMS/IBM HVCMOS 180 nm
Size 3.6 × 1.5 mm^2
Gate and Clear signal
Fast HV ramp for Clear
Rad. Hard proved (36 Mrad)

DCDB (Drain Current Digitizer)
Analog frontend

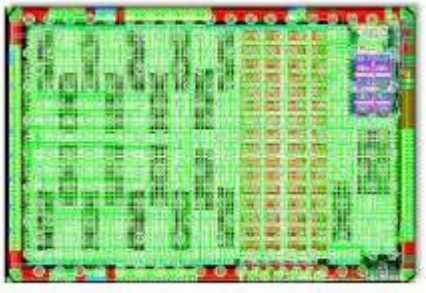


UMC 180 nm
Size 5.0 × 3.2 mm^2
TIA and ADC
Pedestal compensation
Rad. Hard proved (20 Mrad)

PXD



DHP (Data Handling Processor)
First data compression



TSMC 65 nm
Size 4.0 × 3.2 mm^2
Stores raw data and pedestals
Common mode and pedestal correction
Data reduction (zero suppression)
Timing signal generation
Rad. Hard proved (100 Mrad)

PXD9 DEPFET Sensors

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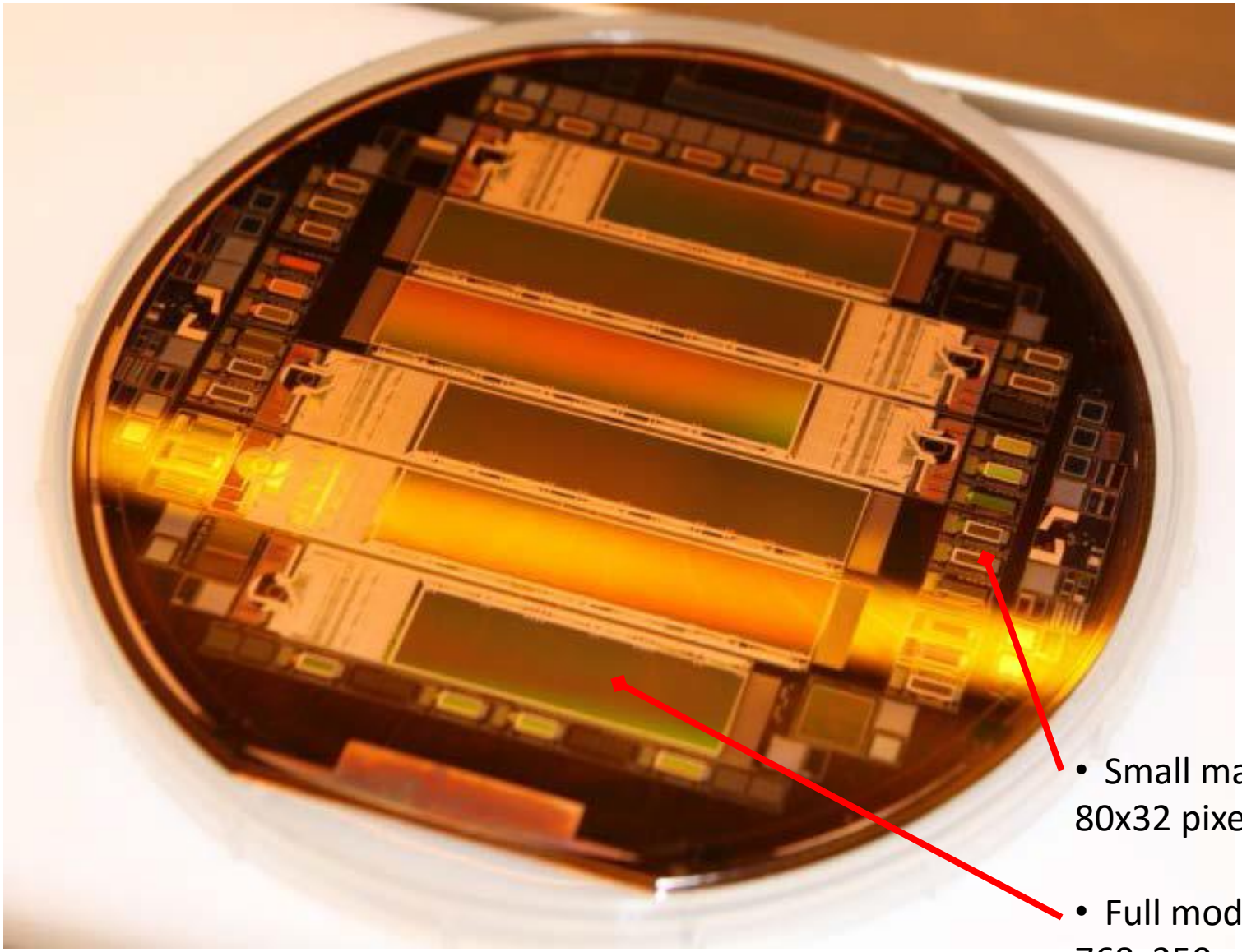


- Small matrices
80x32 pixels

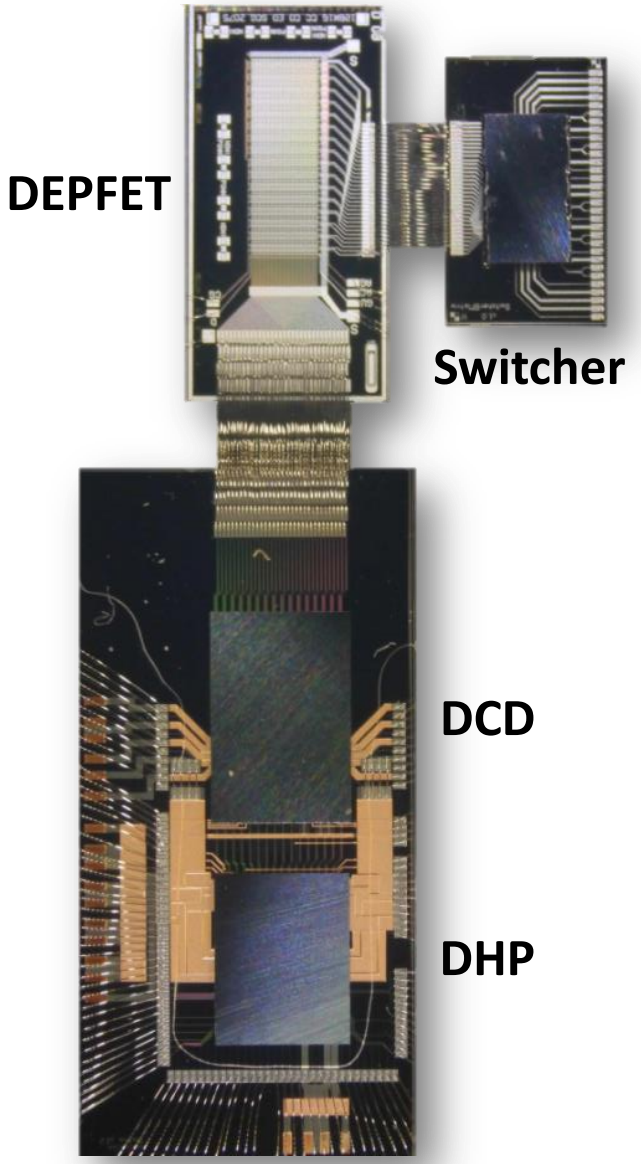
- Full modules with large matrices
768x250 pixels

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
  - DHPT → DHH

- DESY Nov 2015:

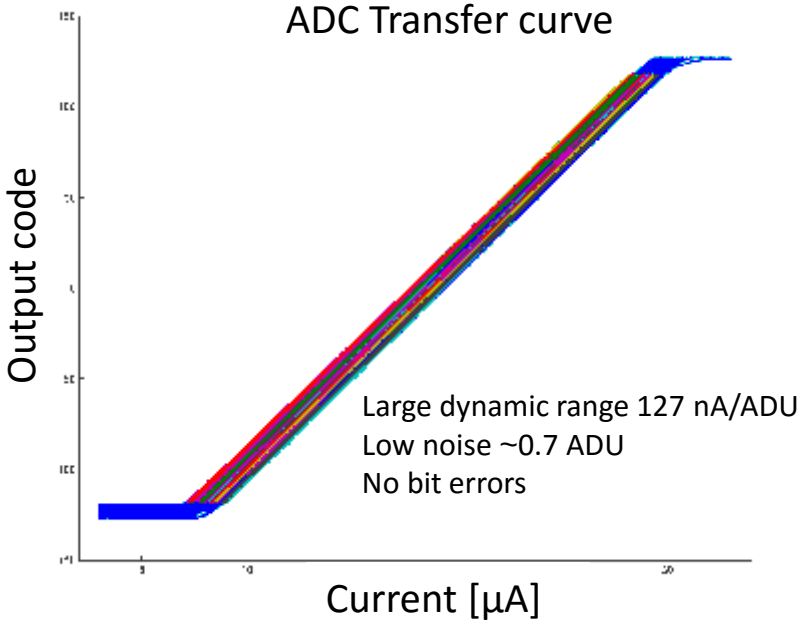
First Belle II type matrix in a test beam



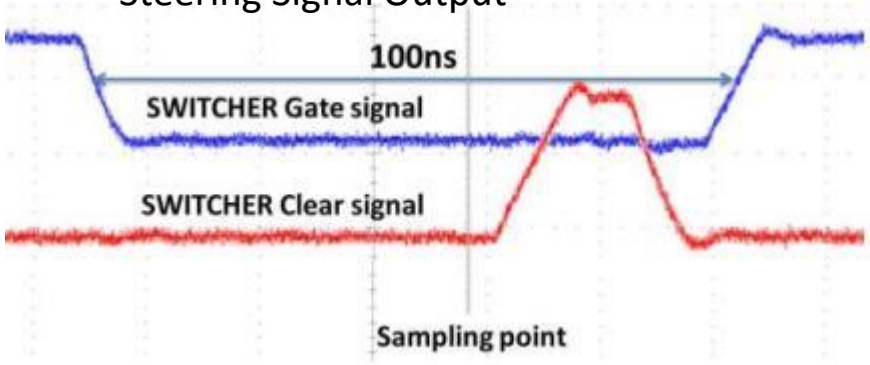
Hybrid 5 – ASIC Optimization

- Drain Current Digitizer (DCD):
  - Uniformity and linearity of ADCs
- Data Handling Processor (DHP):
  - High speed link settings
  - Steering sequences
  - Signal timing
- Interchip communication

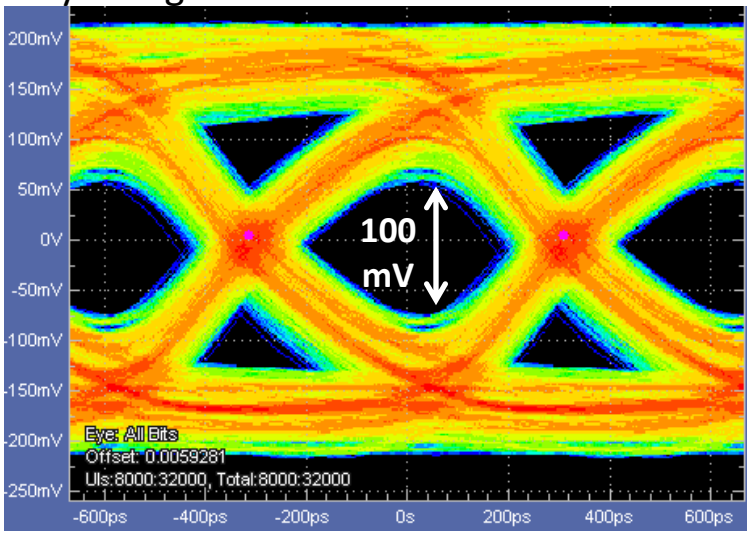
ADC Transfer curve



Steering Signal Output

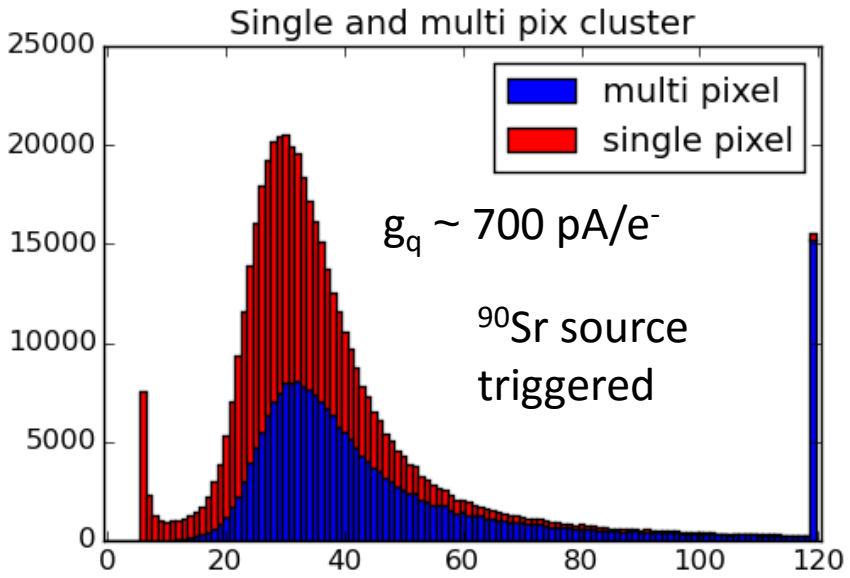


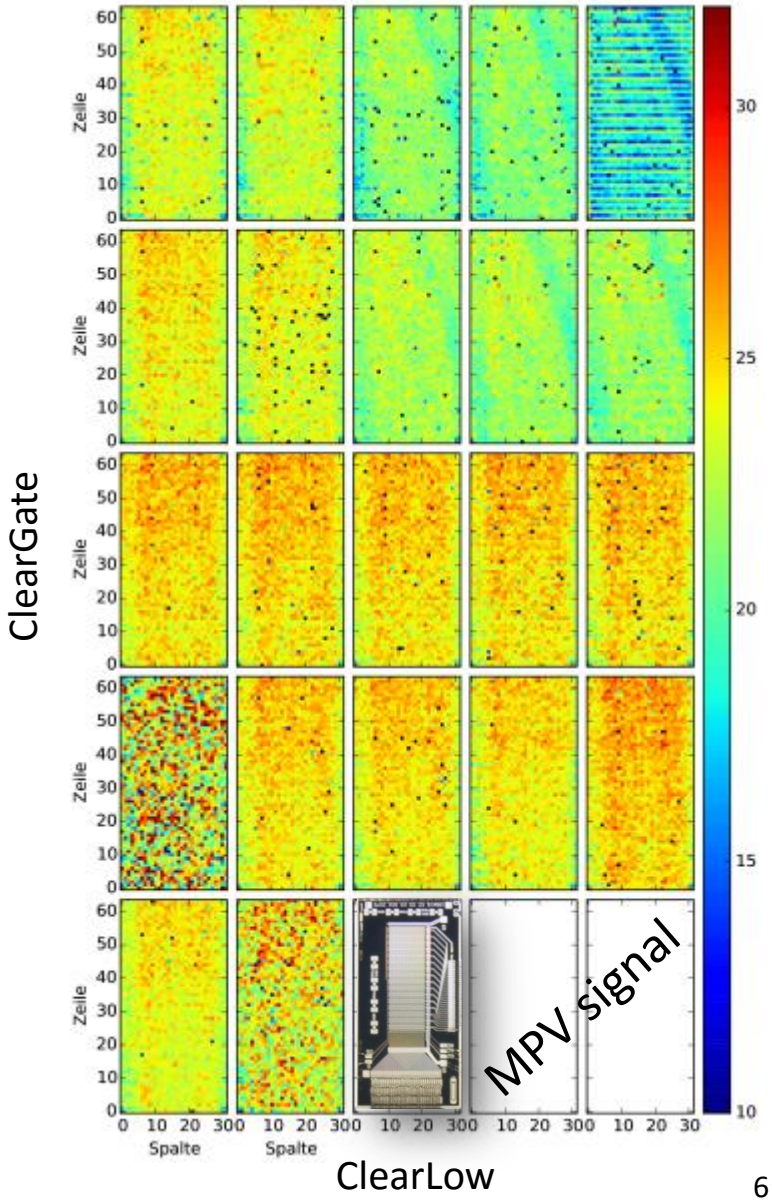
Eye Diagram after 15m cable Cable



Hybrid 5 – Sensor Optimization

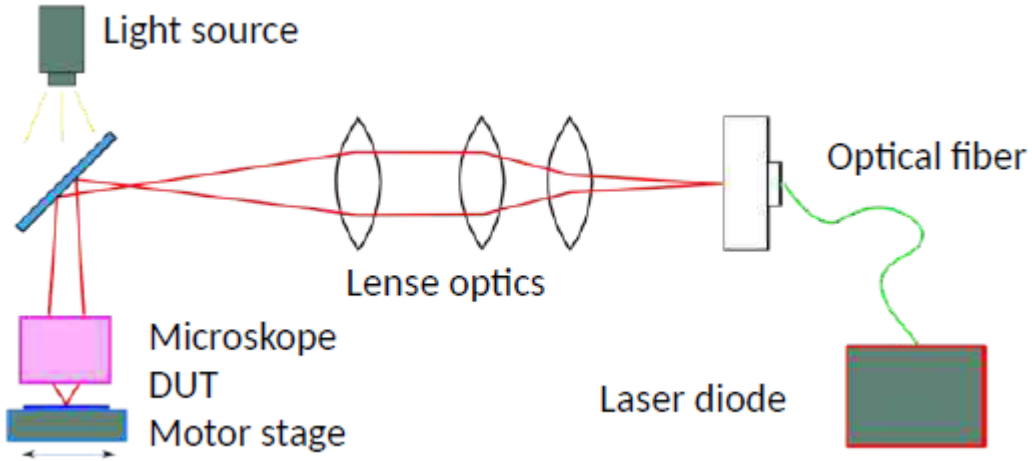
- Optimization of DEPFET voltages
  - Source measurements

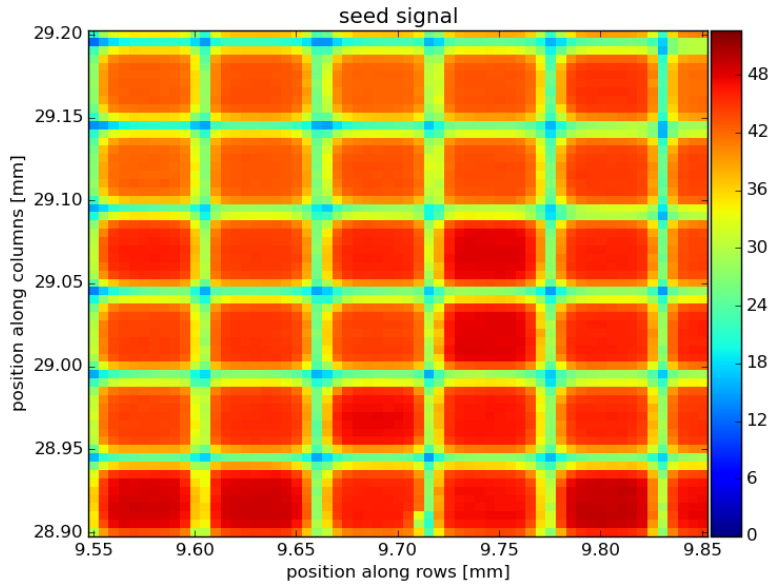


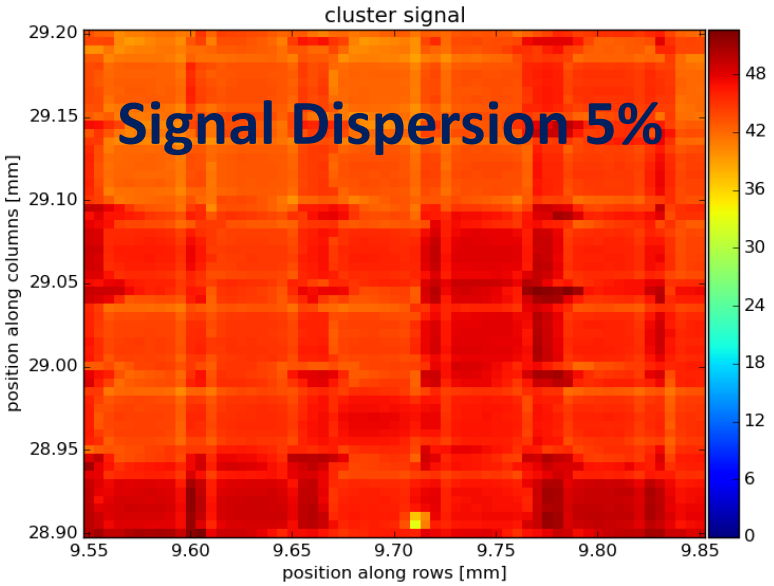


Hybrid 5 – Sensor Optimization

- Optimization of DEPFET voltages
  - Source measurements
  - Laser measurements

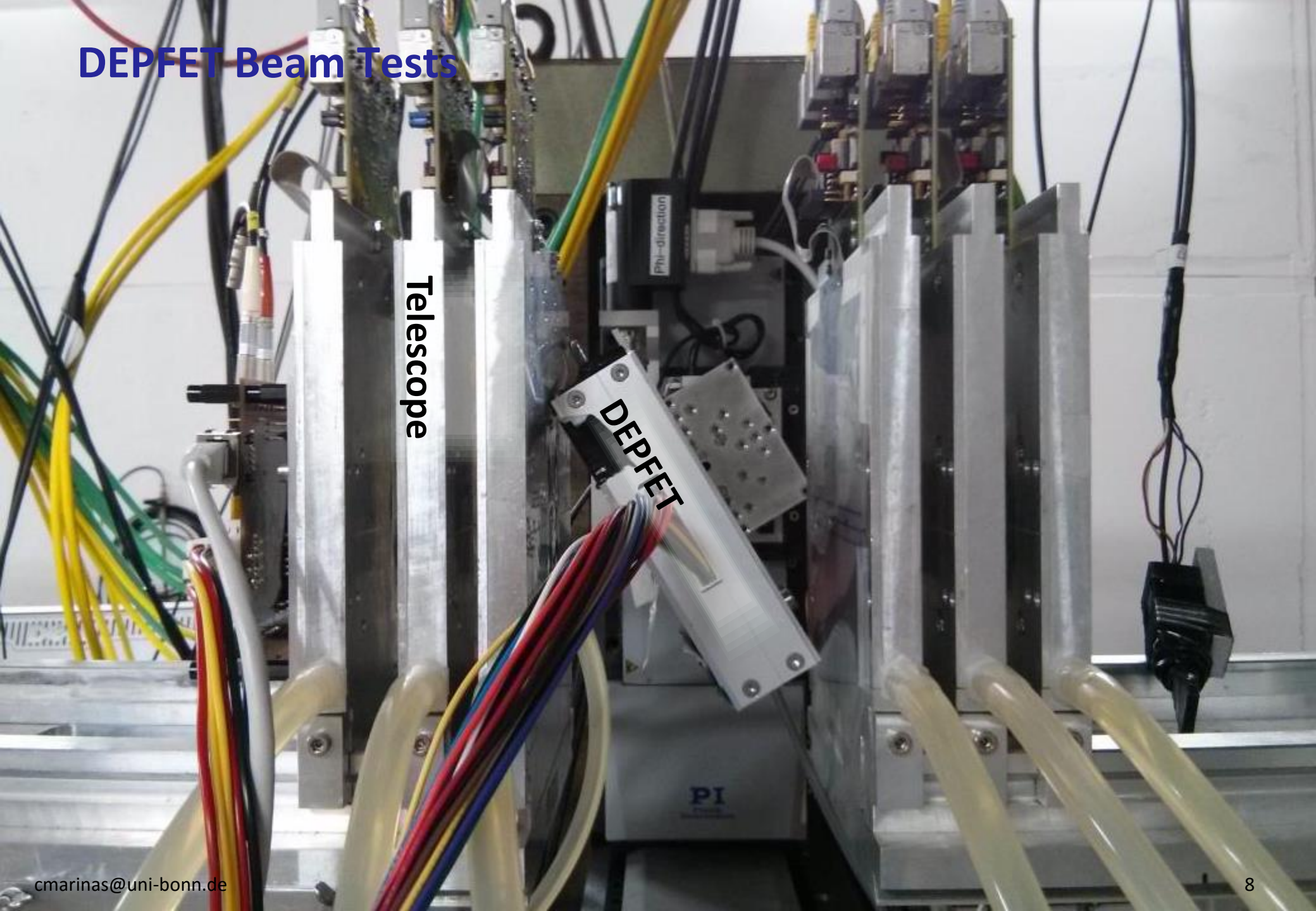




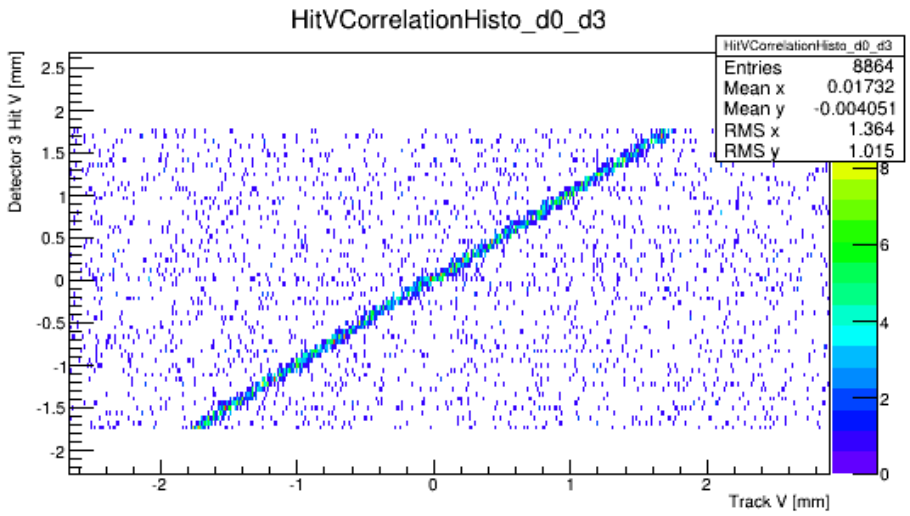


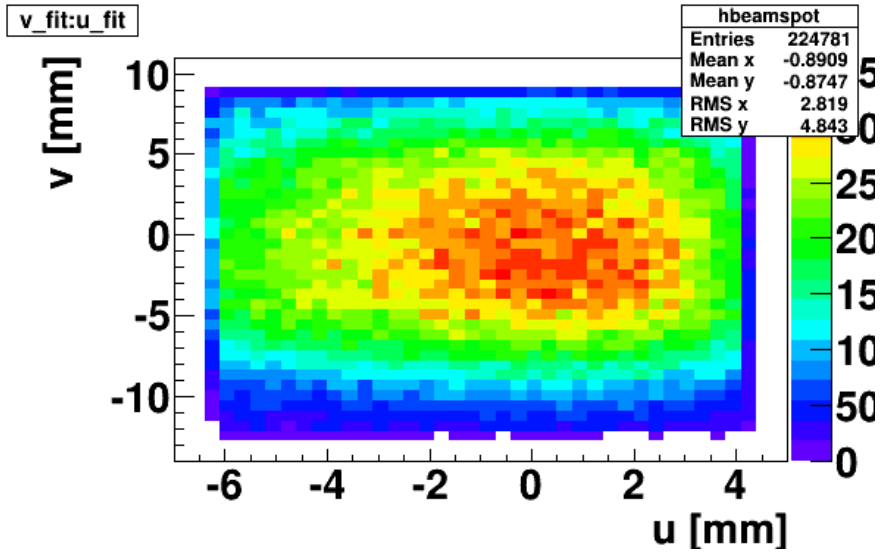
- Laser focused through microscope
- ~3 µm spot size
- Laser moves over matrix – position resolution

DEPFET Beam Tests



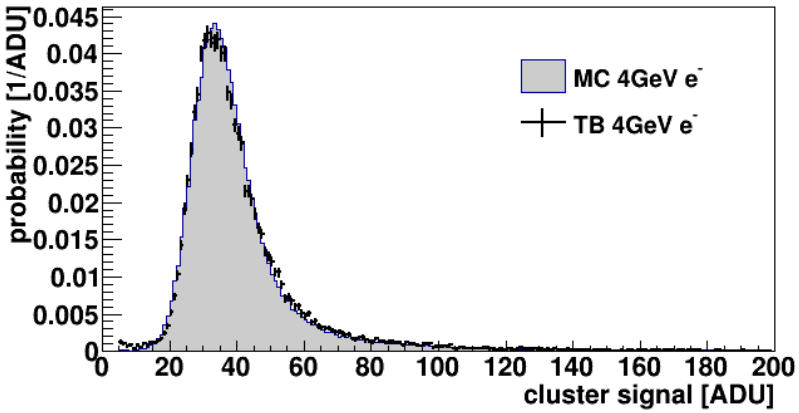
First Sanity Checks





- Correlations with the telescope
- Beam spot with 4 GeV electrons
- Landau peak

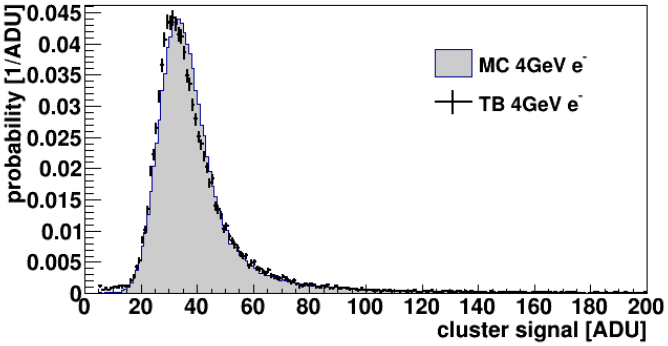
→ Successful integration within few hours time



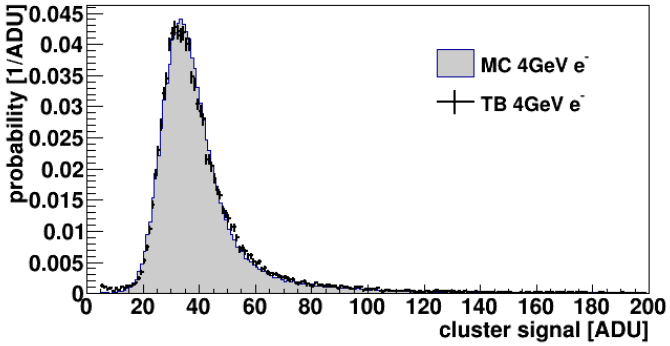
Belle II PXD Signal

- Measured 4 GeV electrons at different incidence angles
- Checked against Geant4 simulation with DEPFET Clusterizer
- $g_q = 740 \pm 50$ pA/e$^-$ measured

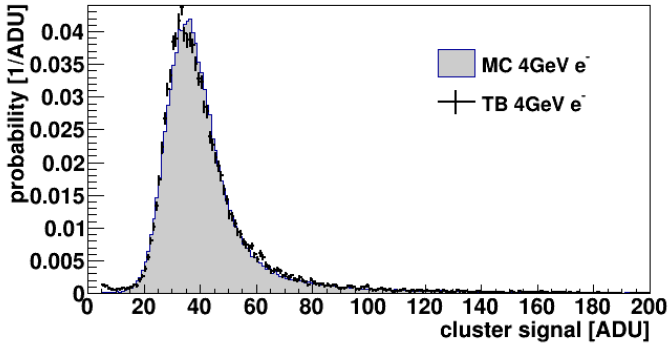
0 degree



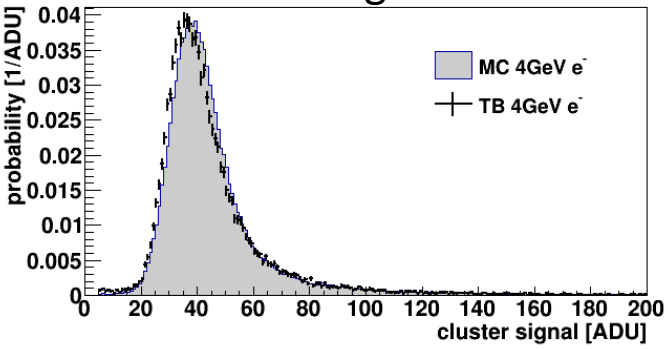
10 degree



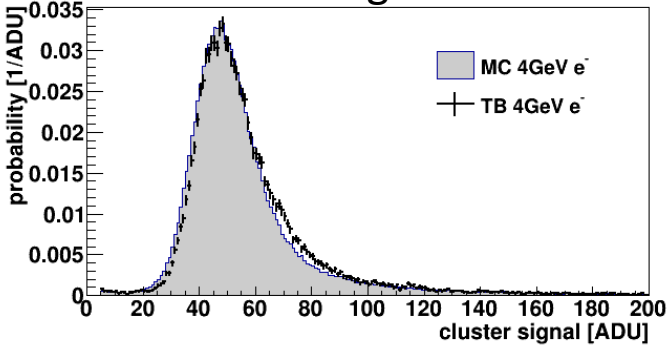
20 degree



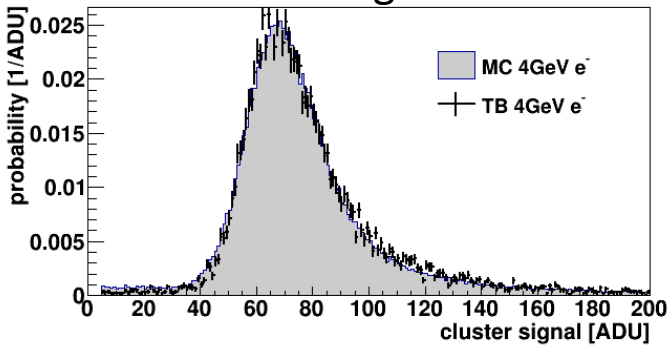
30 degree



45 degree



60 degree



Belle II PXD Signal

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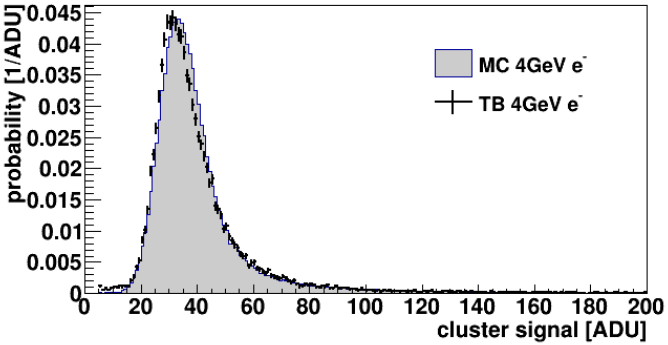
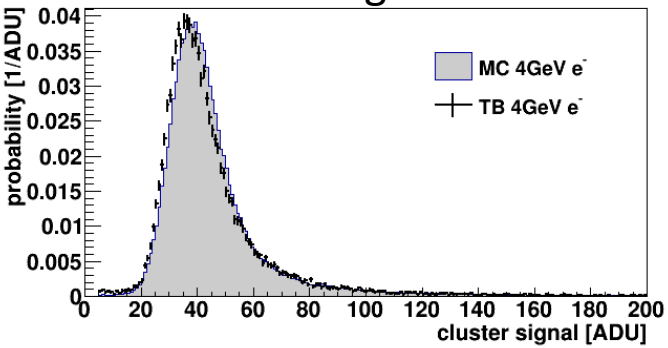
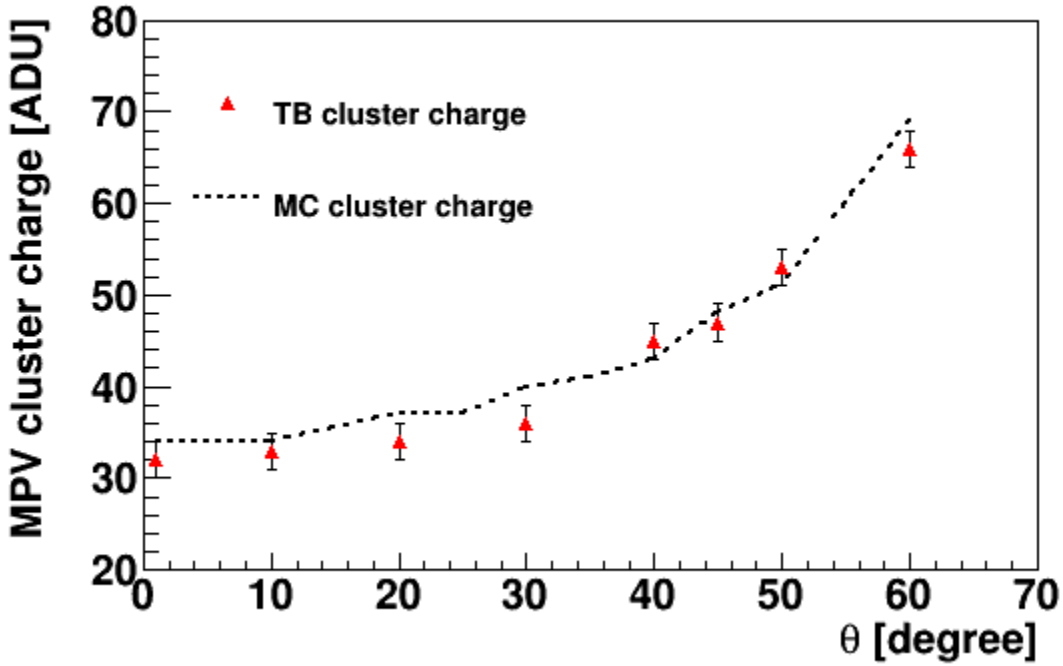
- $g_q = 740 \pm 50$ pA/e$^-$ measured

0 degree



30 degree

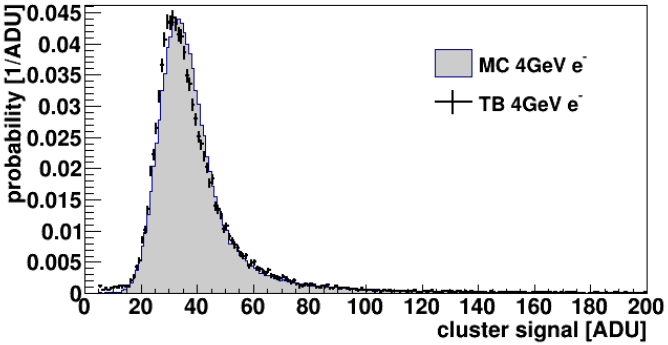




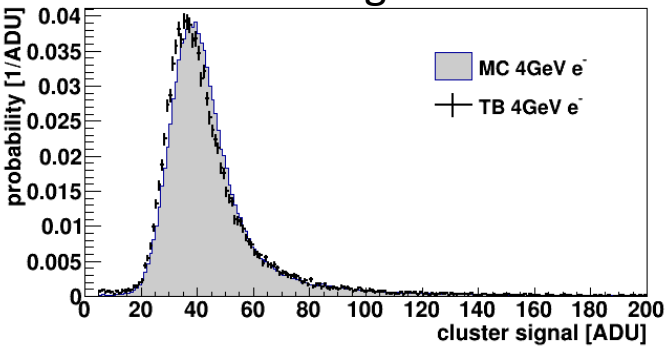
Belle II PXD Cluster Size

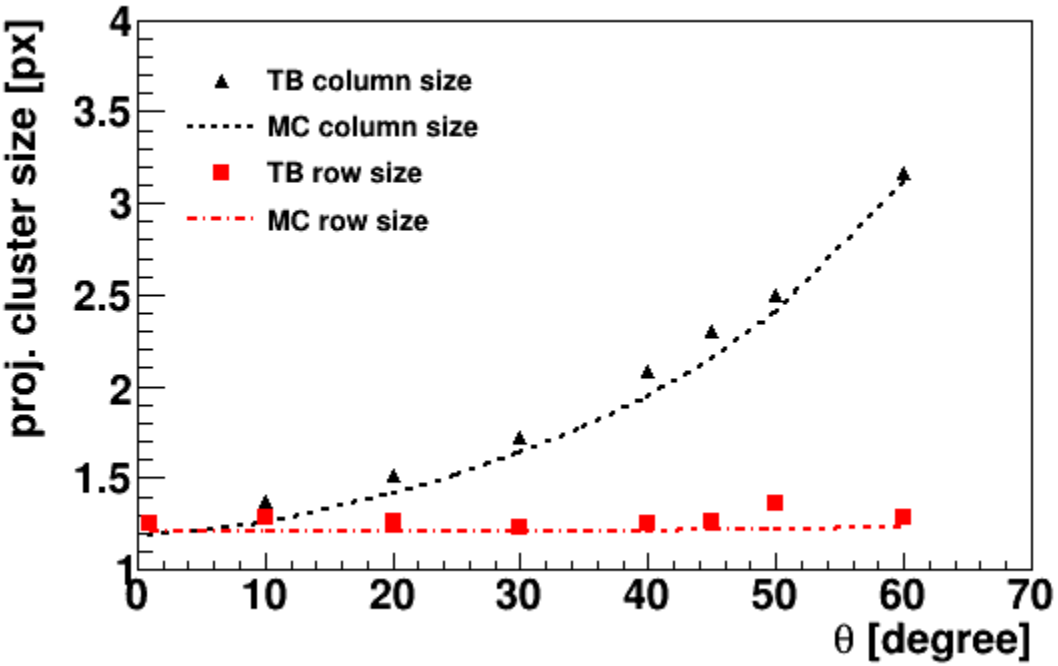
- Measured 4 GeV electrons at different incidence angles
- Checked against Geant4 simulation with DEPFET Clusterizer
- $g_q = 740 \pm 50$ pA/e$^-$ measured

0 degree



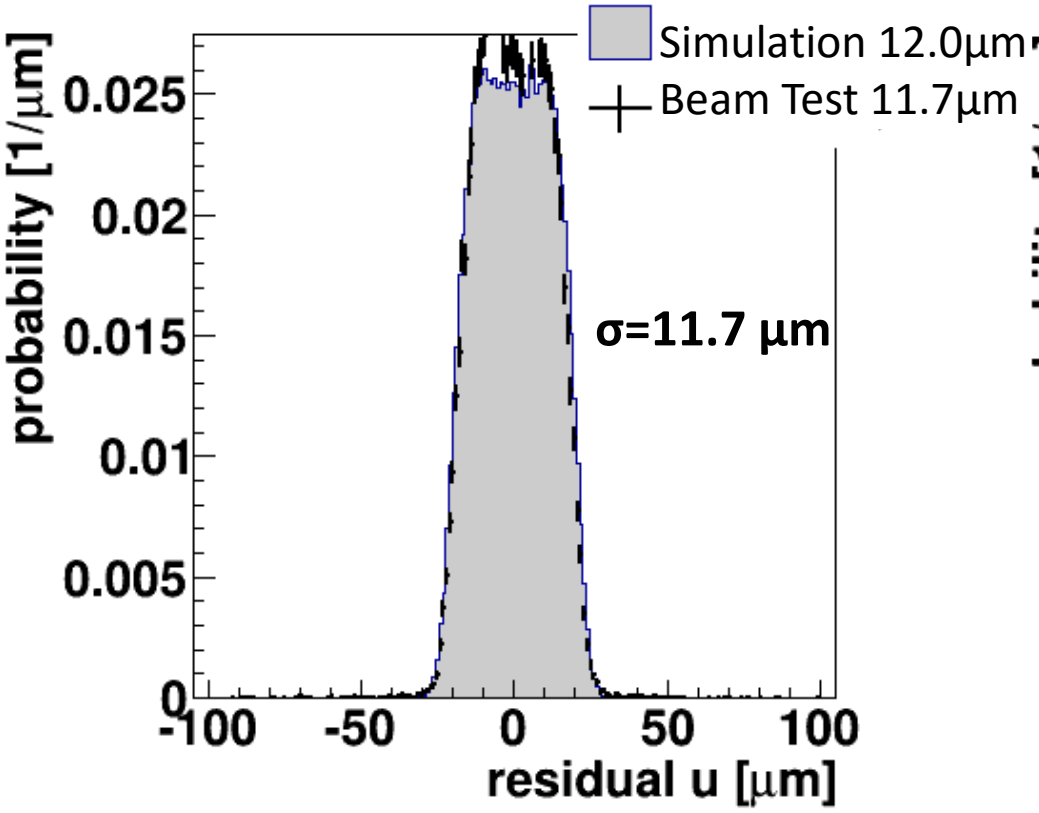
30 degree



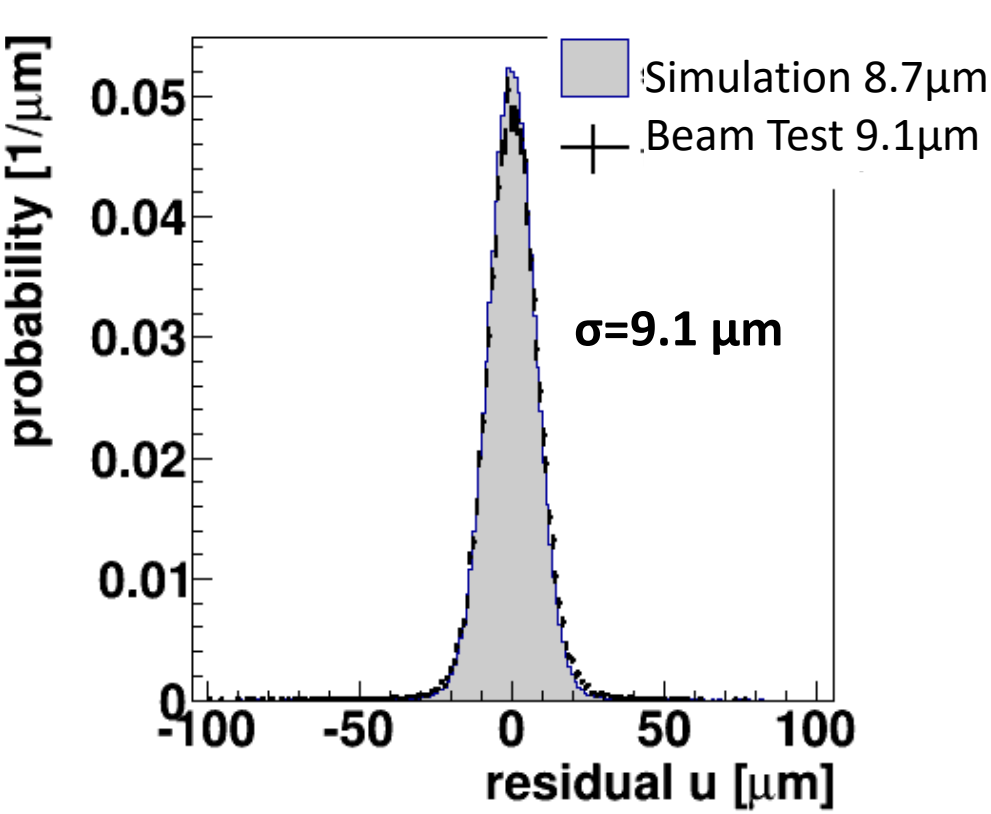


Belle II PXD Residuals

0° tilt: perp. incidence



30° tilt: many 2 pixel clusters

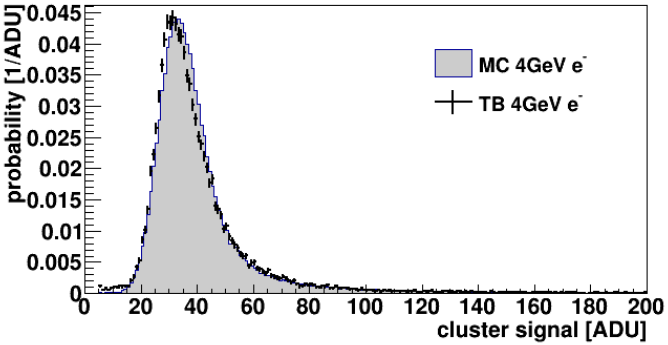


- Matrix tilted along column: multi-column clusters
- Expectation for single pixel readout: $\mathrm{RMS} = 50\,\mu\mathrm{m}/\sqrt{12} \approx 14.5\mu\mathrm{m}$

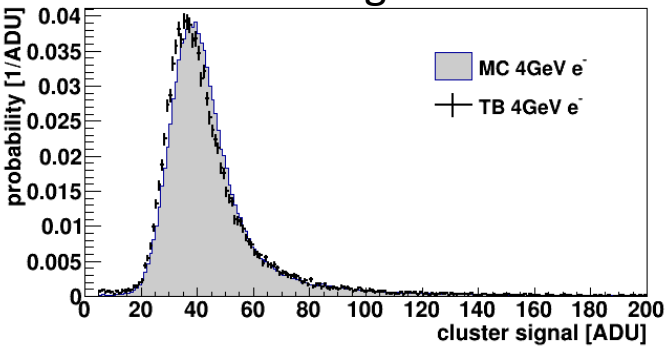
Belle II PXD Residuals

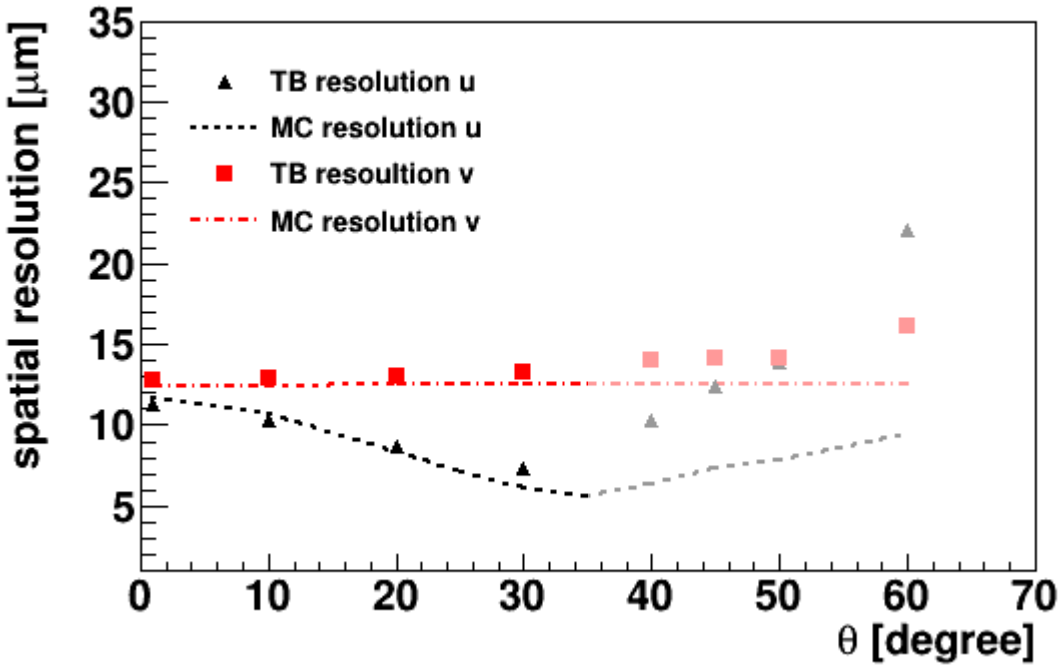
- Measured 4 GeV electrons at different incidence angles
- Checked against Geant4 simulation with DEPFET Clusterizer
- $g_q = 740 \pm 50$ pA/e$^-$ measured

0 degree



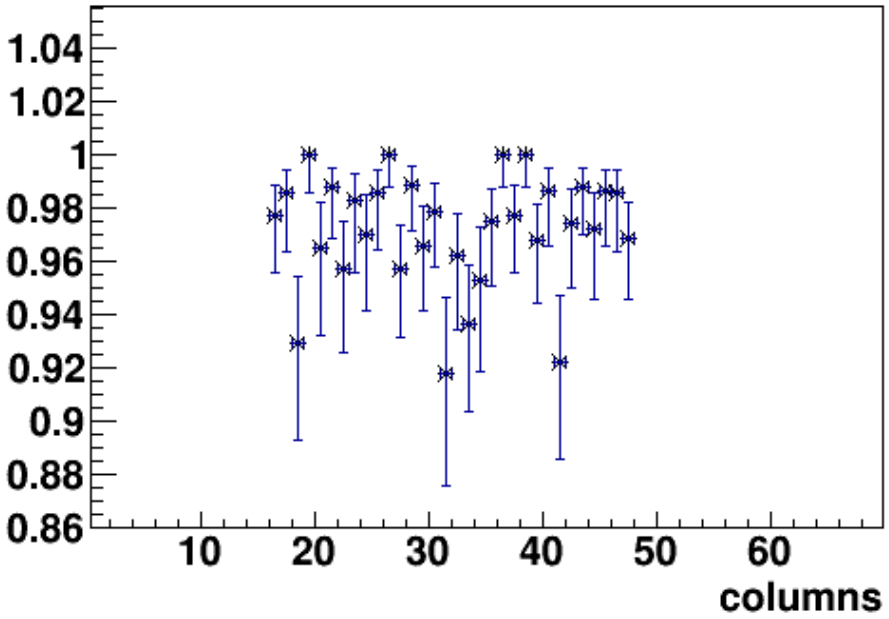
30 degree

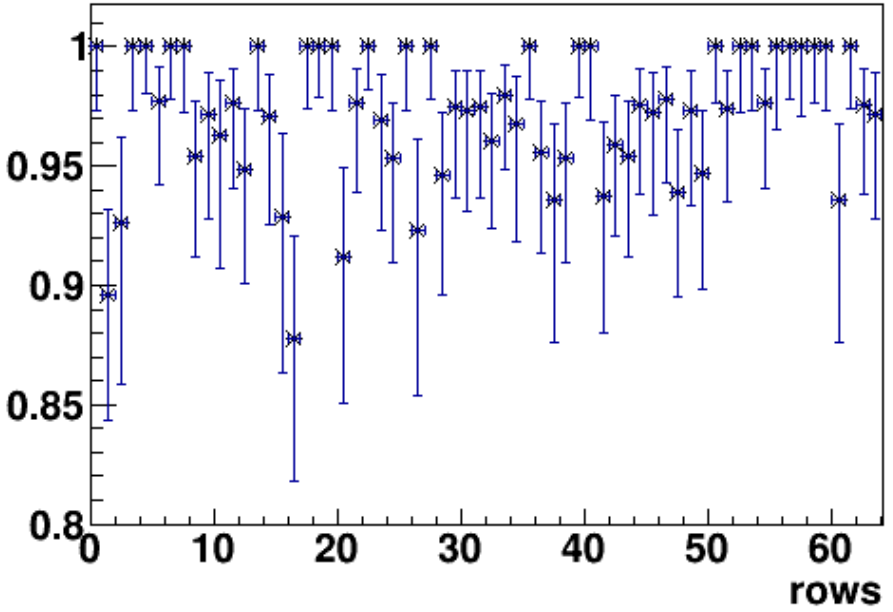




Belle II PXD Efficiency

- Zero Suppression Cut = 5 ADU (~1000 e^-)
- 2 noisy (masked) pixels
- Noise occupancy on level ~10^{-5}





Belle II PXD on Hybrid 5 - Summary

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November 2015 test beam:

- First time to see MIPs with PXD9 Belle II thin sensors
- Well trained team: systematic studies and obtain huge statistics
- Results are satisfactory, as expected by design and also according to simulations:
  - Charge collection
  - Cluster size
  - Residuals
  - Efficiency

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

Belle II Vertex Detector

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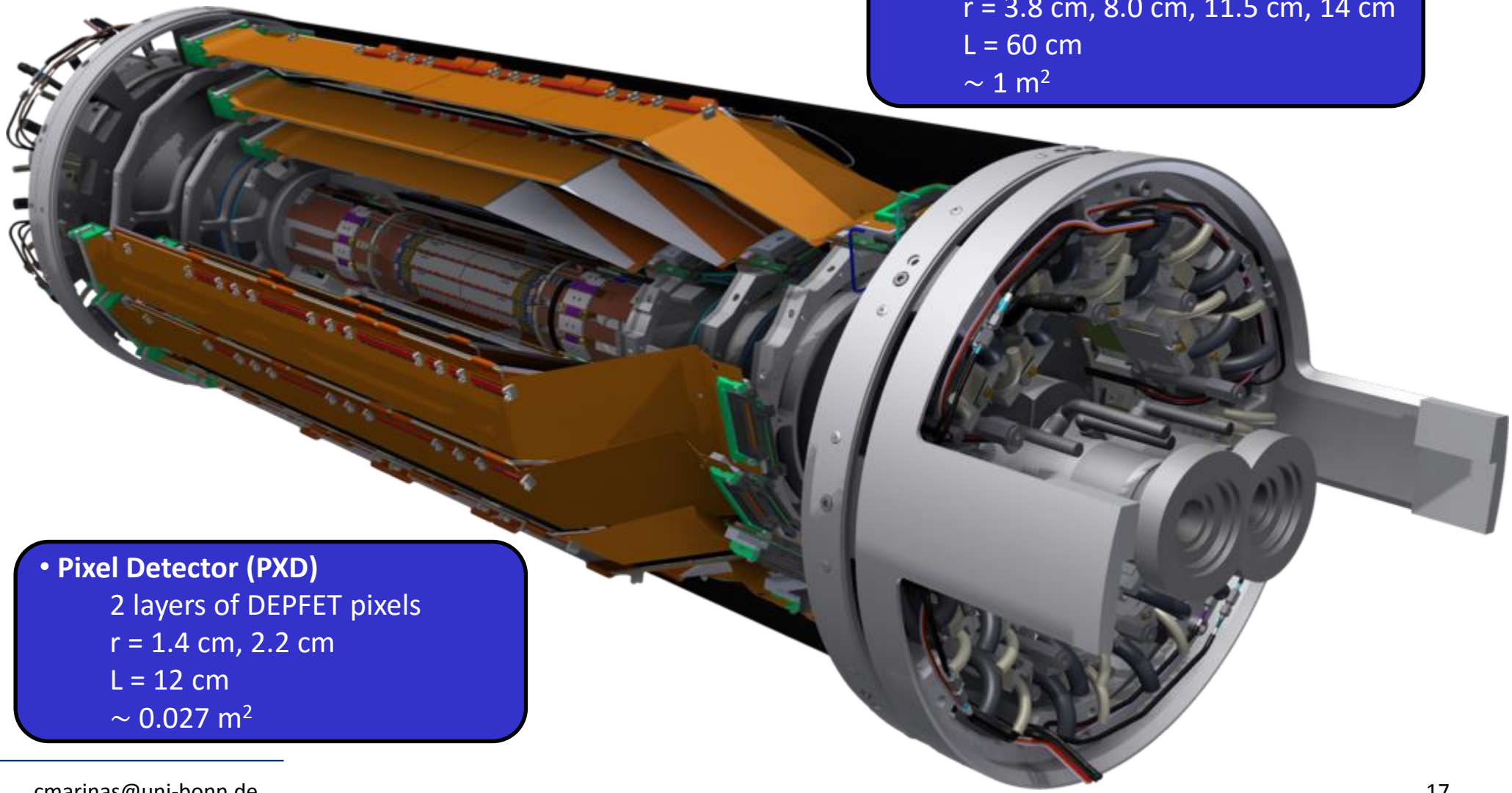
- **Silicon Vertex Detector (SVD)**
  - 4 layers of DSSD
  - r = 3.8 cm, 8.0 cm, 11.5 cm, 14 cm
  - L = 60 cm
  - ~ 1 m^2



- **Pixel Detector (PXD)**
  - 2 layers of DEPFET pixels
  - r = 1.4 cm, 2.2 cm
  - L = 12 cm
  - ~ 0.027 m^2

Belle II Tracker – Combined Test Beam

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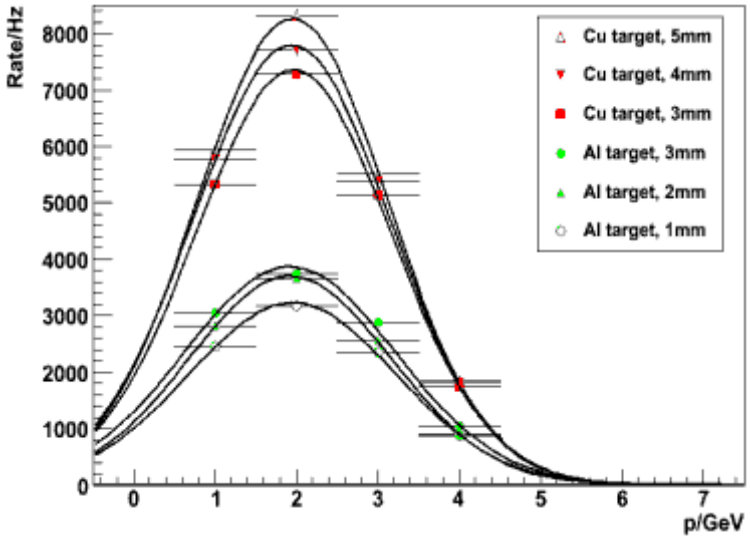
- VXD common test beam in April 2016 (4 weeks)
- Small sector of the final sensors and ASICs*
  2 PXD + 4 SVD layers
- Complete DAQ readout chain: HLT, event building
- CO_2 cooling, slow control, monitoring, environmental sensors
- Illumination with (up to) 6 GeV e^- under 1T solenoid magnetic field (PCMAG)
- Alignment, tracking algorithms, ROI



- **<u>Goal</u>: System integration and Phase 2 Commissioning**

Test Beam Set Up

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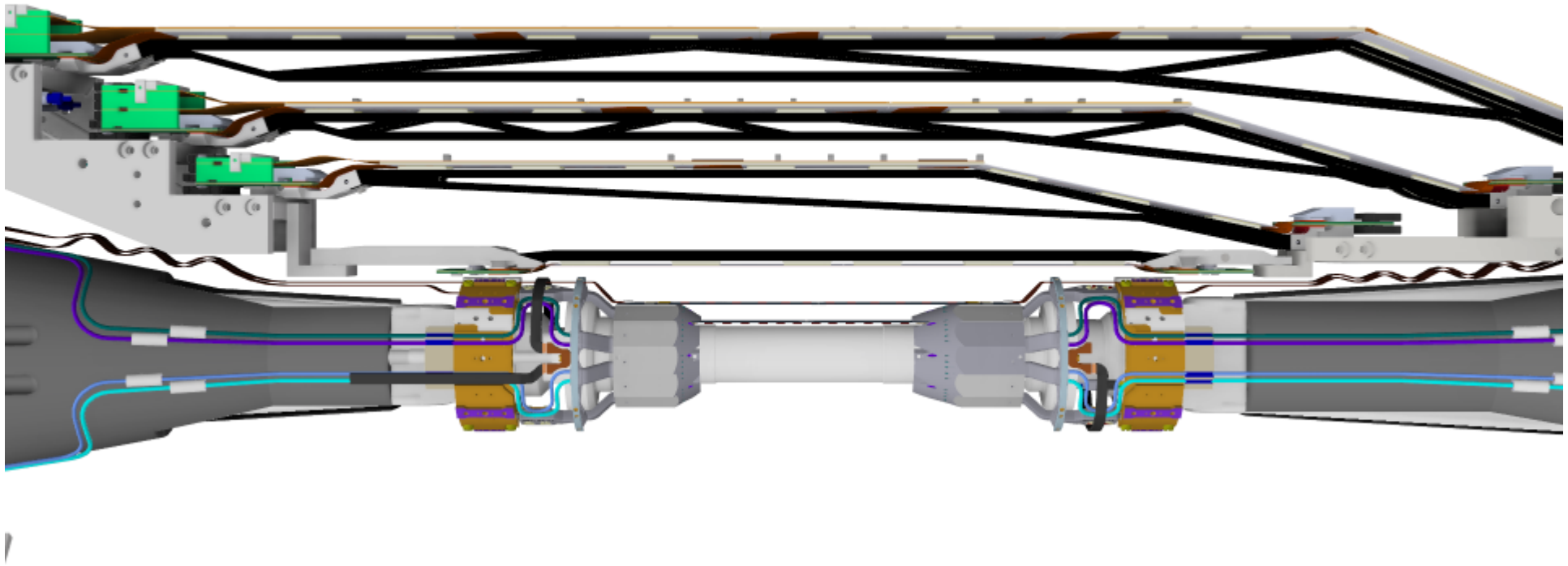
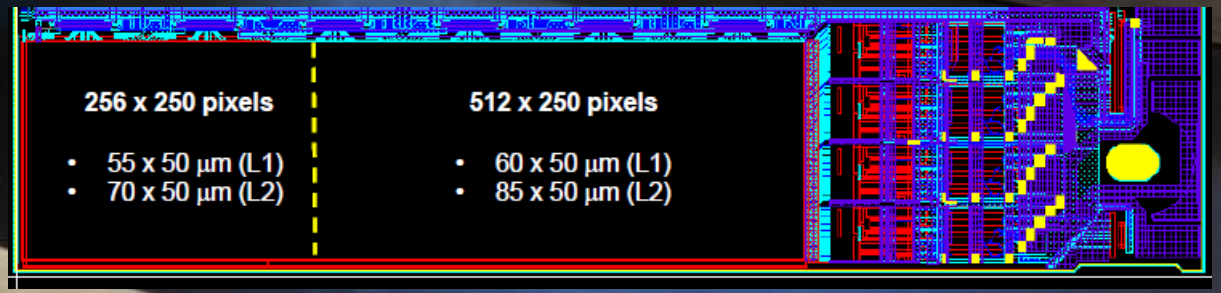
- Two PXD and four SVD layers
- Horizontal plane (highest background sensitivity)

Test Beam set up to mimic commissioning detector arrangement



Pixel Detector



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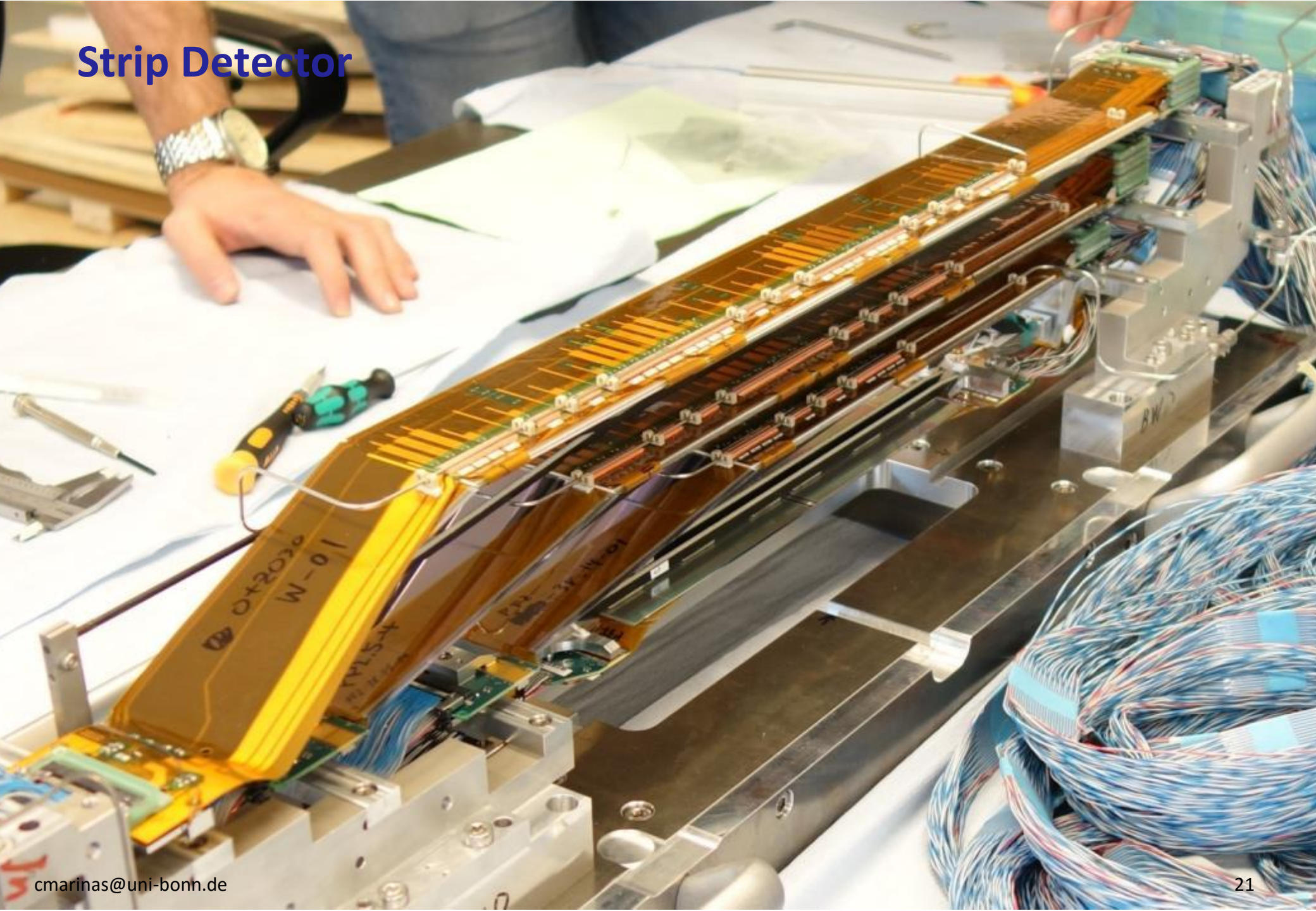
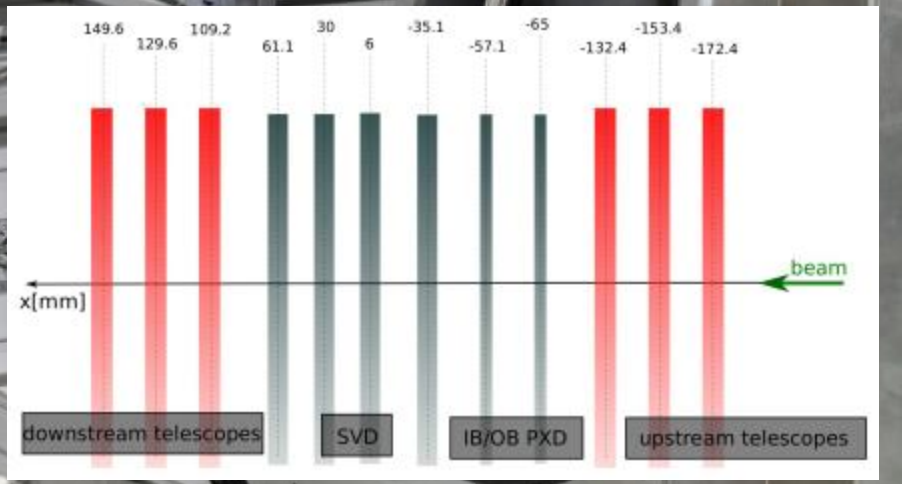
Strip Detector



Belle II Vertex Detector

Integration Into PCMAG



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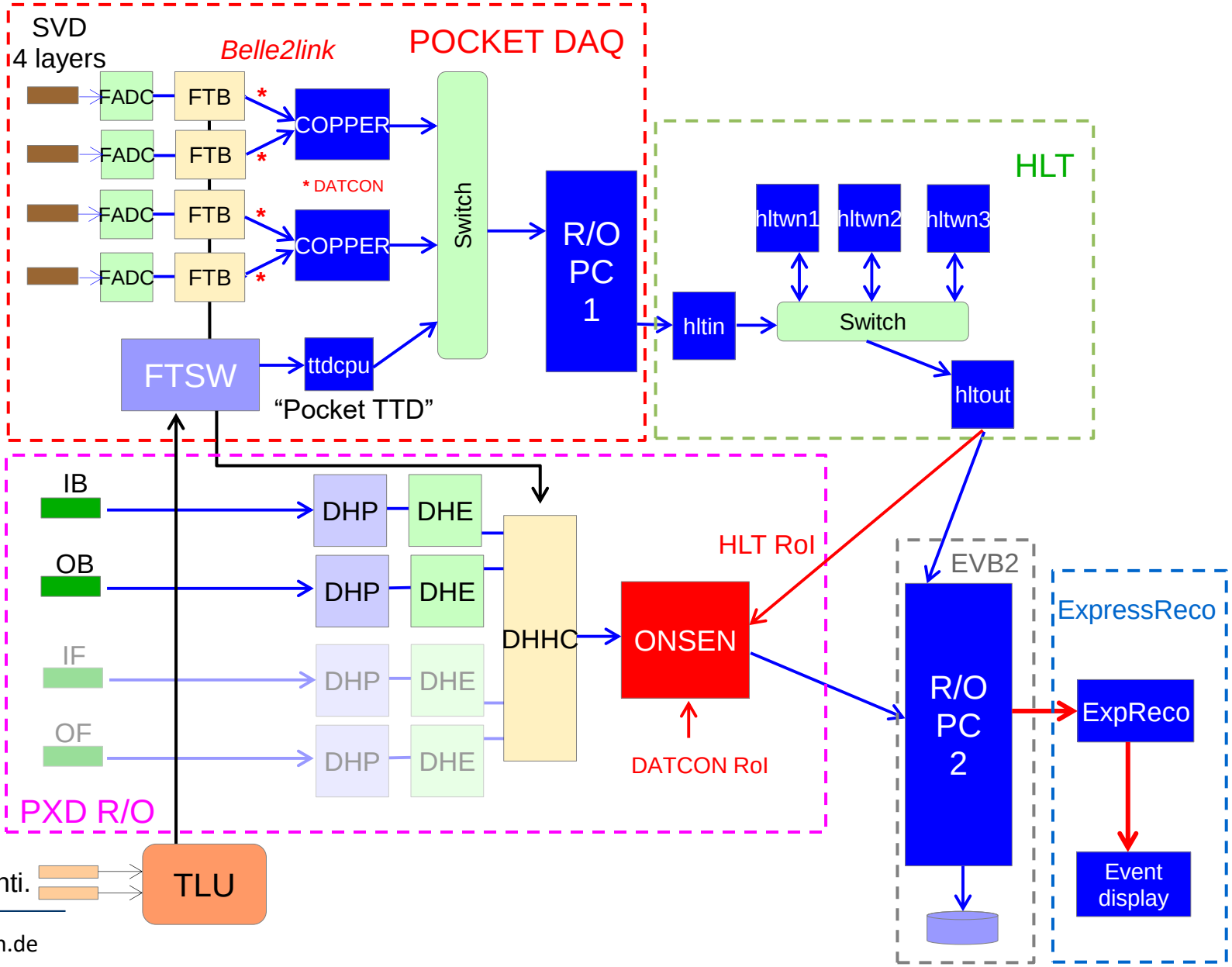
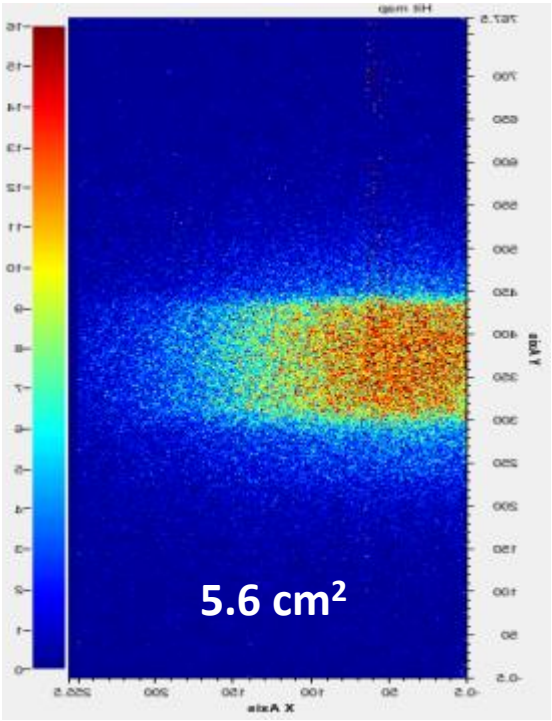
DAQ Structure

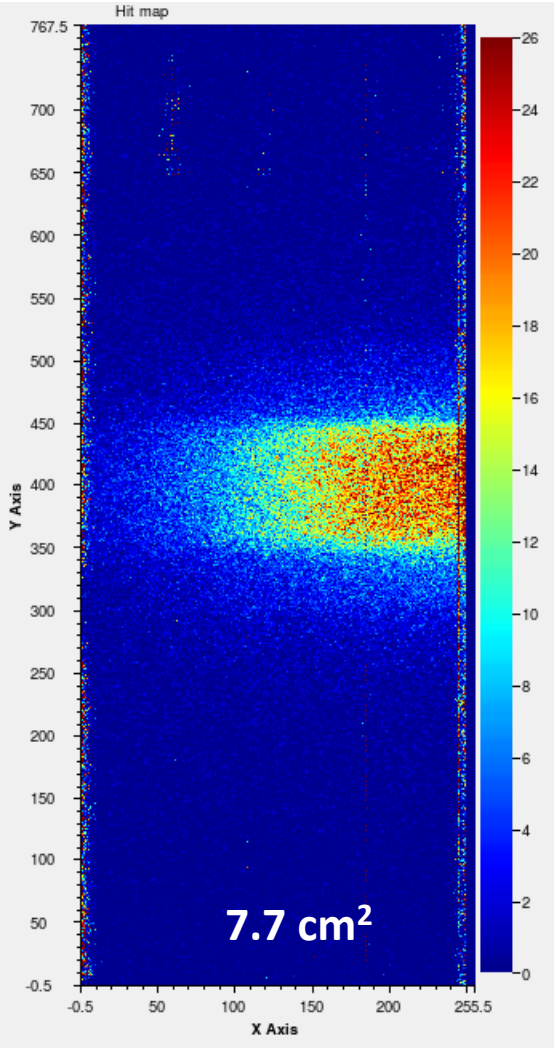


PXD Hit Maps

Threshold = 5 (~ 1200 electrons)



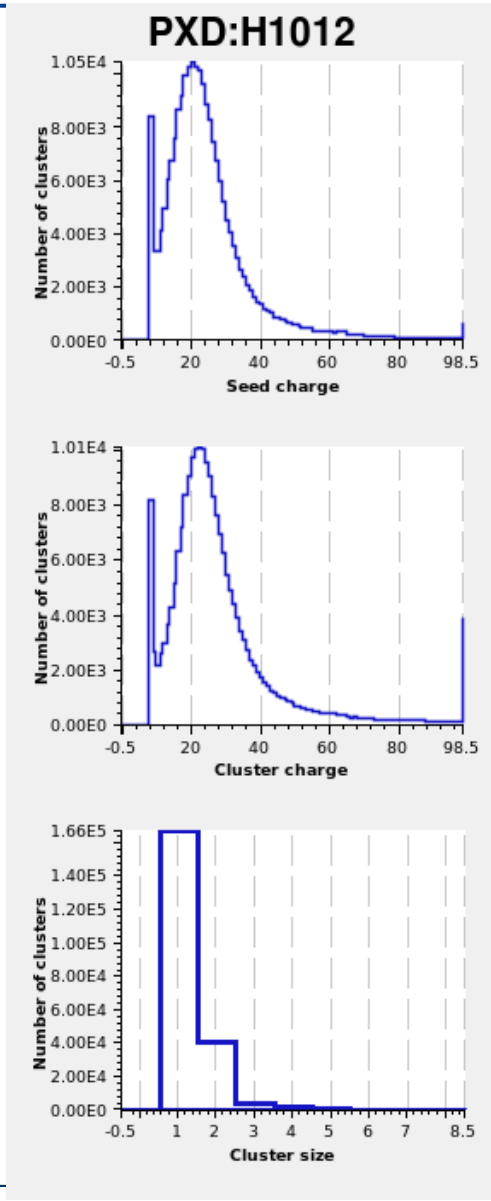
Inner Backward



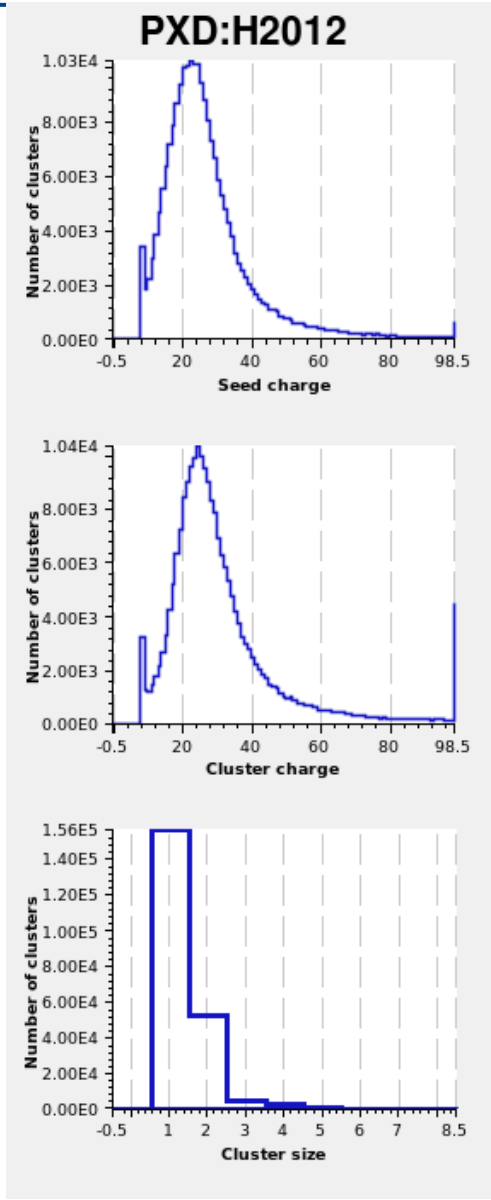
Outer Backward

Trigger on 4 scintillators
Collimated beam
No magnetic field

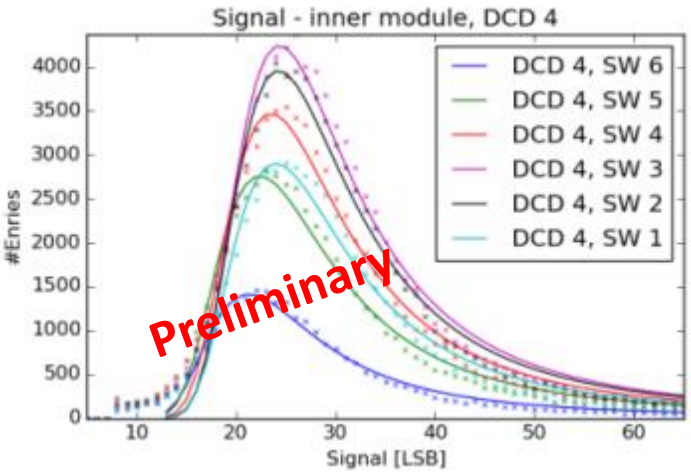
PXD Signals

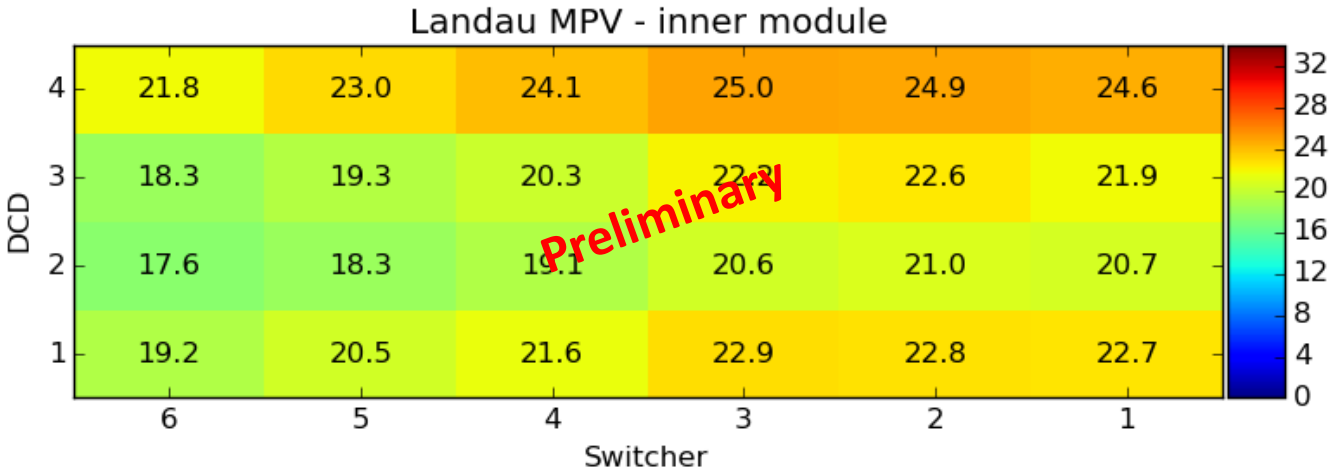


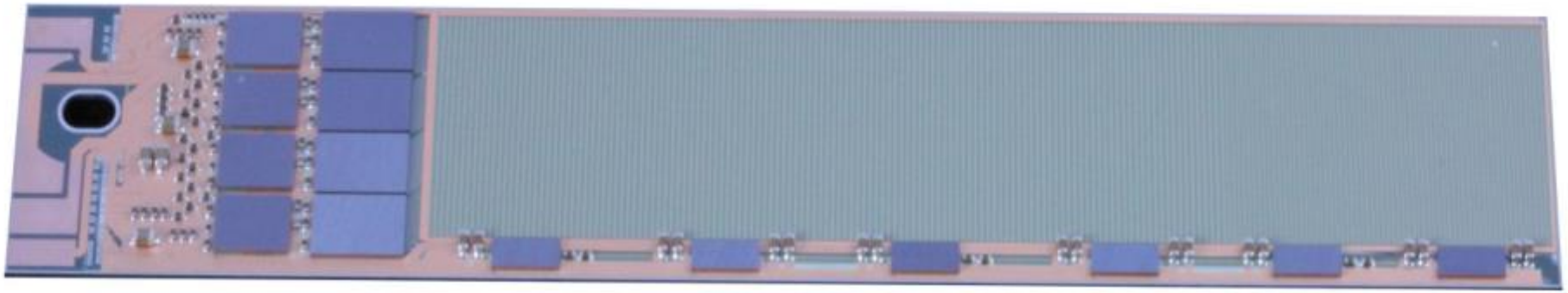
SNR ~ 32 for perpendicular incident MIPs



Landau MPV

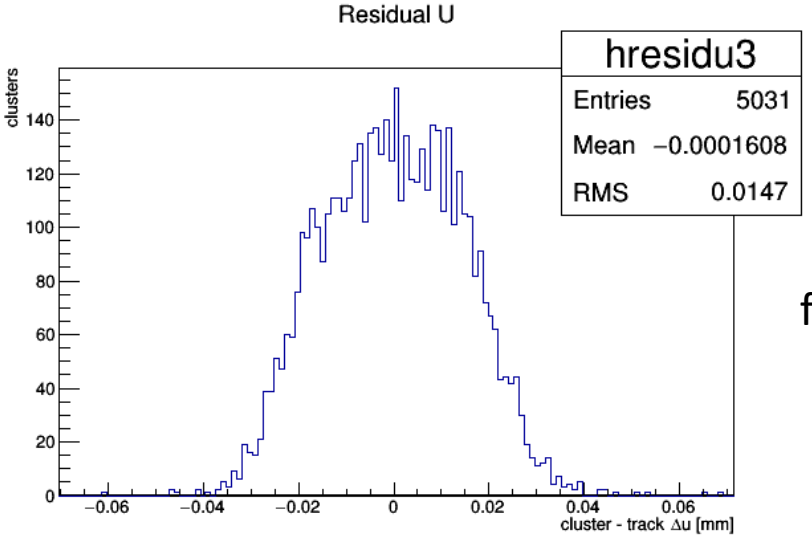




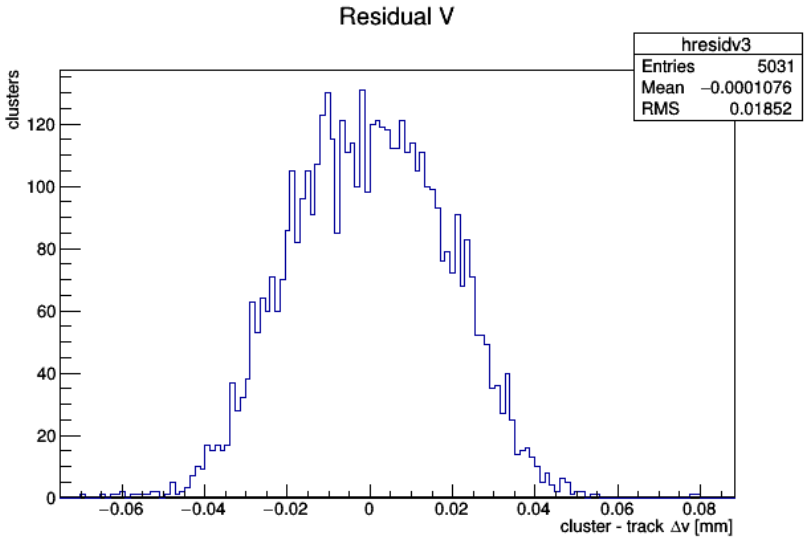


- The response from the matrix is rather uniform even without tuning. Modules just worked using operating parameters from Hybrid 5
- There is lot of room for improvements with better optimization of voltages and ASICs

PXD Residuals



15 µm (18 µm) for perpendicular incident MIPs



Online Data Reduction

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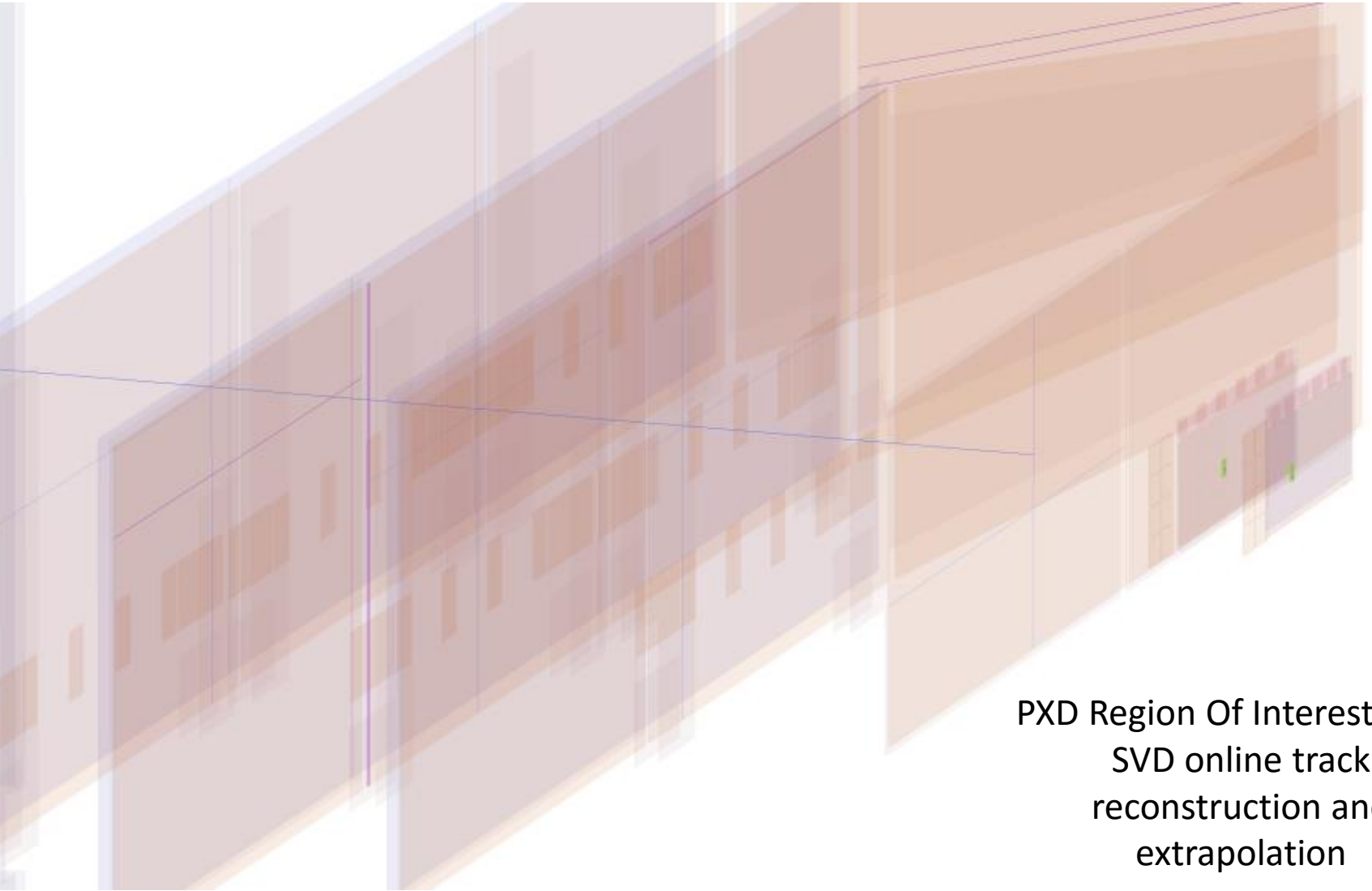
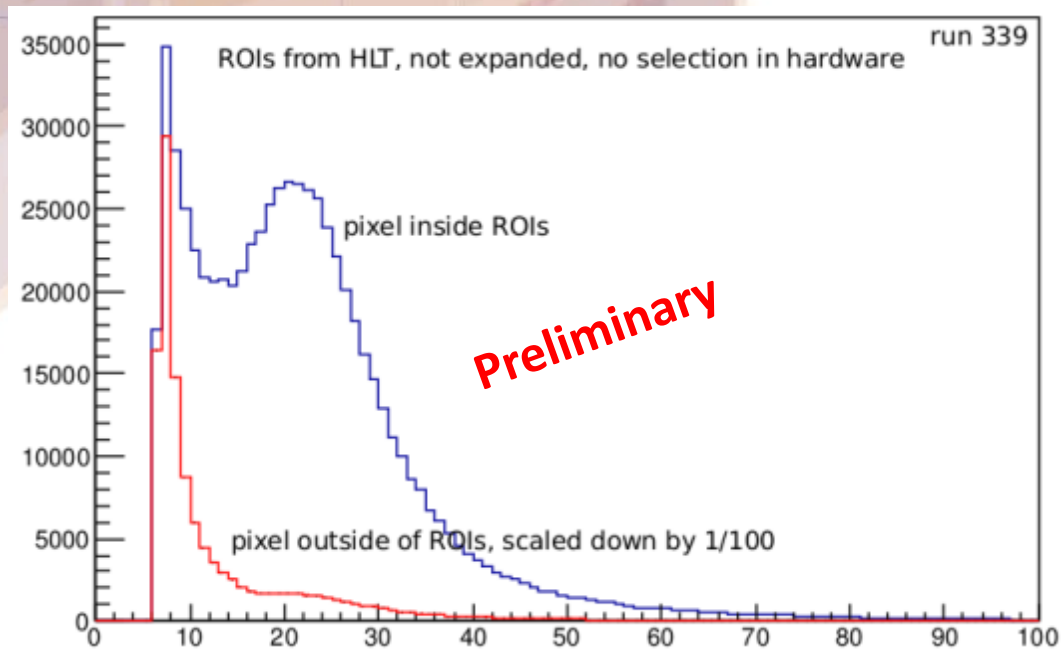


PXD Region Of Interest using SVD online track reconstruction and extrapolation

Online Data Reduction



Online Data Reduction

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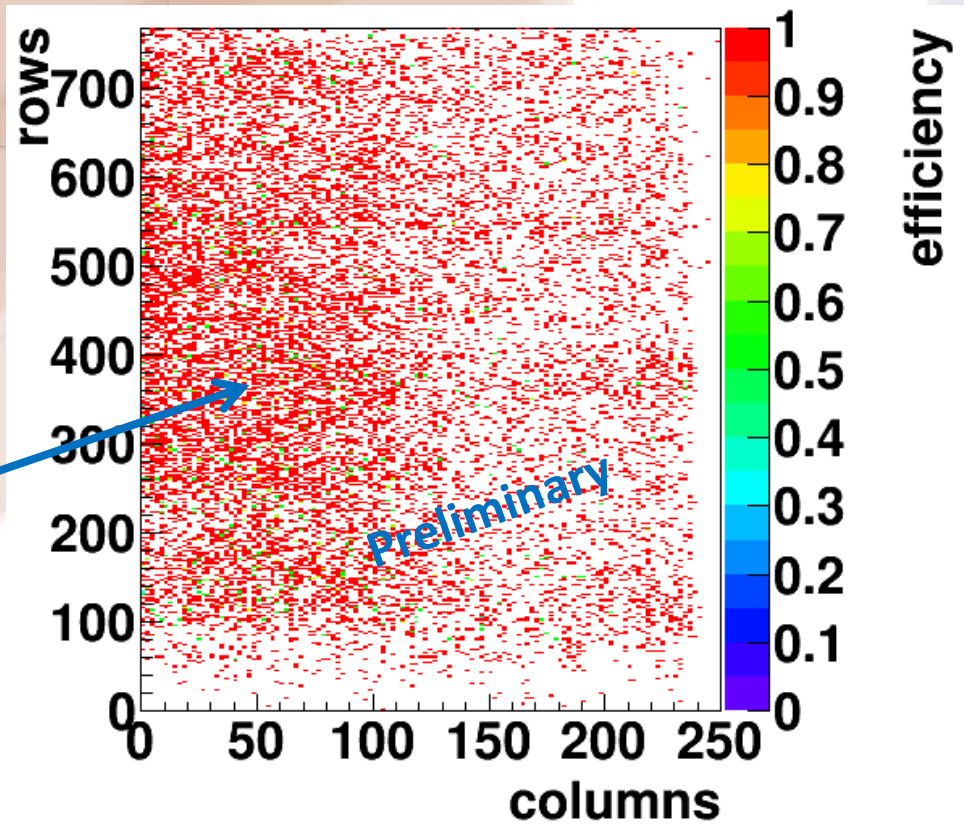
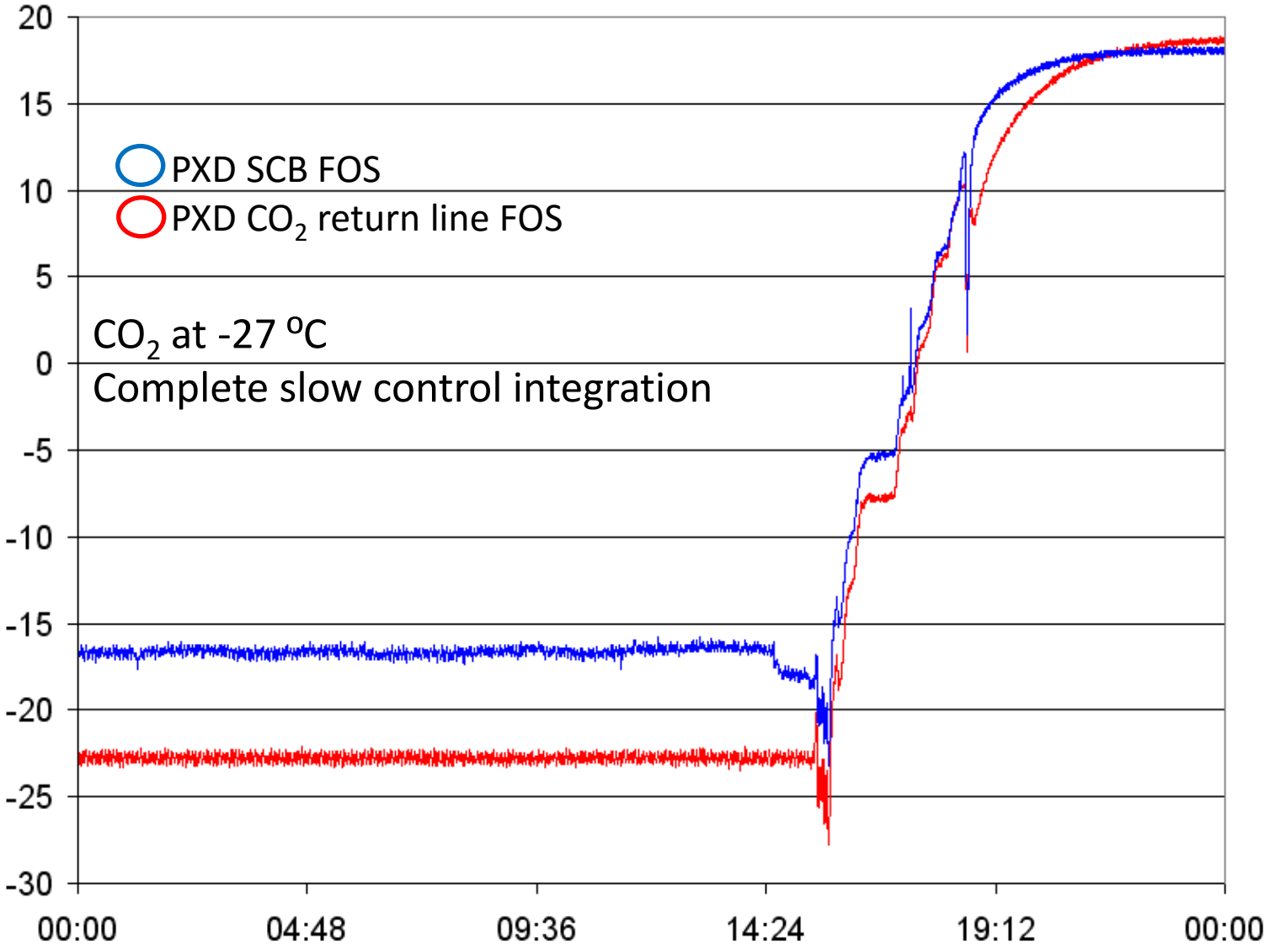
Product of: ROI selection efficiency
and detector efficiency



cmarinas@uni-bonn.de

PXD Environmental Monitoring



Main Achievements

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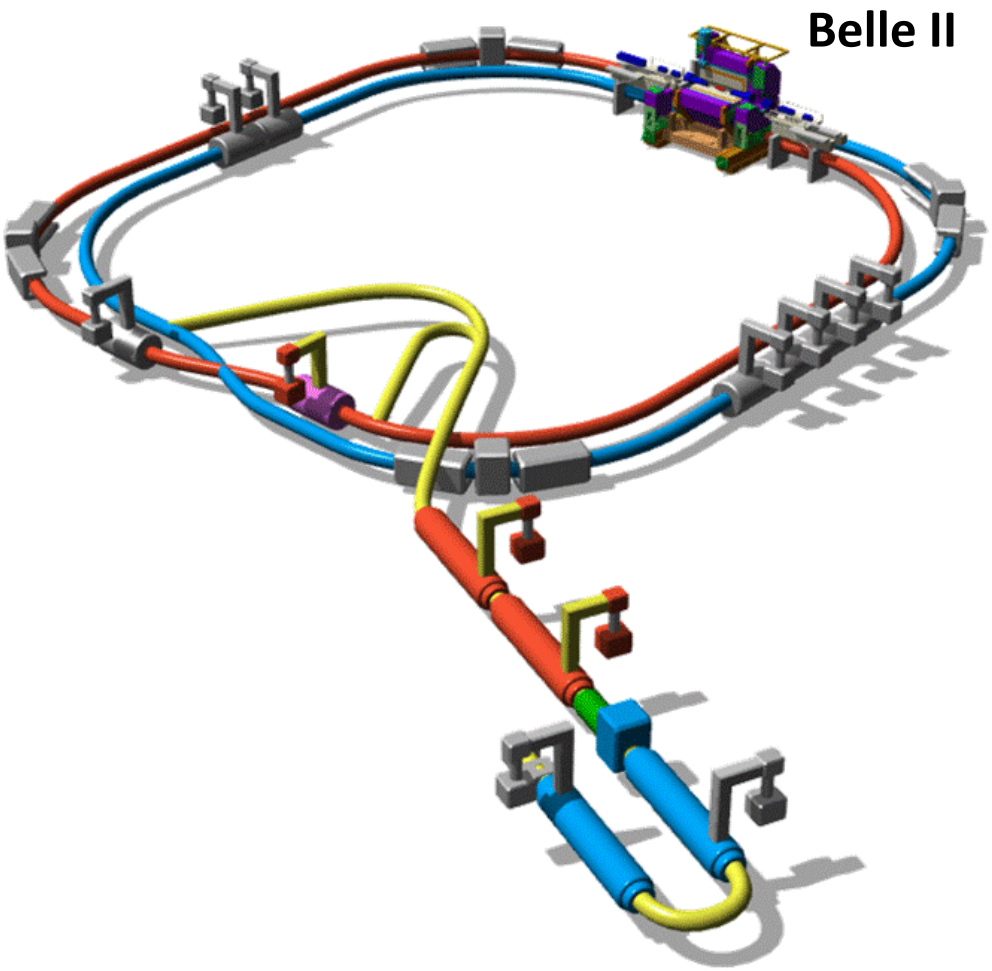
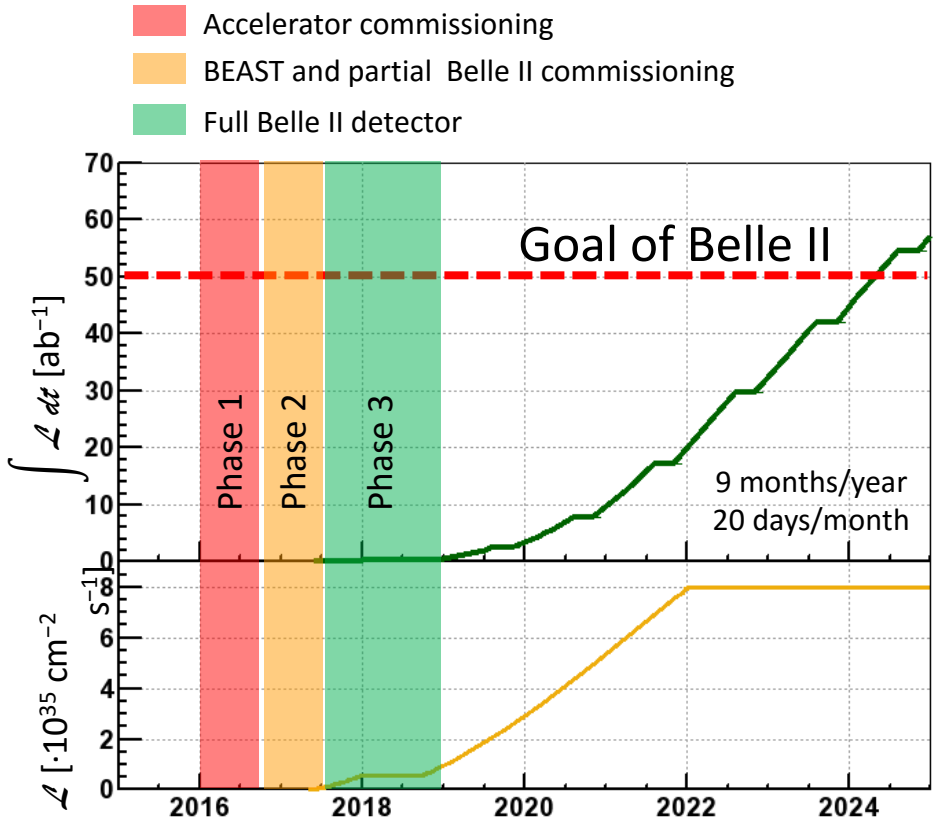
- Detectors fully operational: ‘Final’ Phase 2 hardware
- Hitmaps as expected in all layers. SNR OK
- PXD residuals according to specs
- Interdetector correlations (mapping and timing)
- Online data reduction
- 7 kHz ‘artificial’ trigger rate for 1 hour
- Few hours 2 kHz steady data acquisition
- Alignment
- Noise immunity studies → No interference observed
- Start/Stop fully controlled by master Run Control
- Environmental monitoring mostly integrated into EPICS
- Operation under realistic environmental conditions (CO_2 @ -27 ºC)

The SuperKEKB Accelerator





→ The fun is about to start!

Thanks