Commissioning of the Belle II Pixel Vertex Detector

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On behalf of PXD-DEPFET Collaboration

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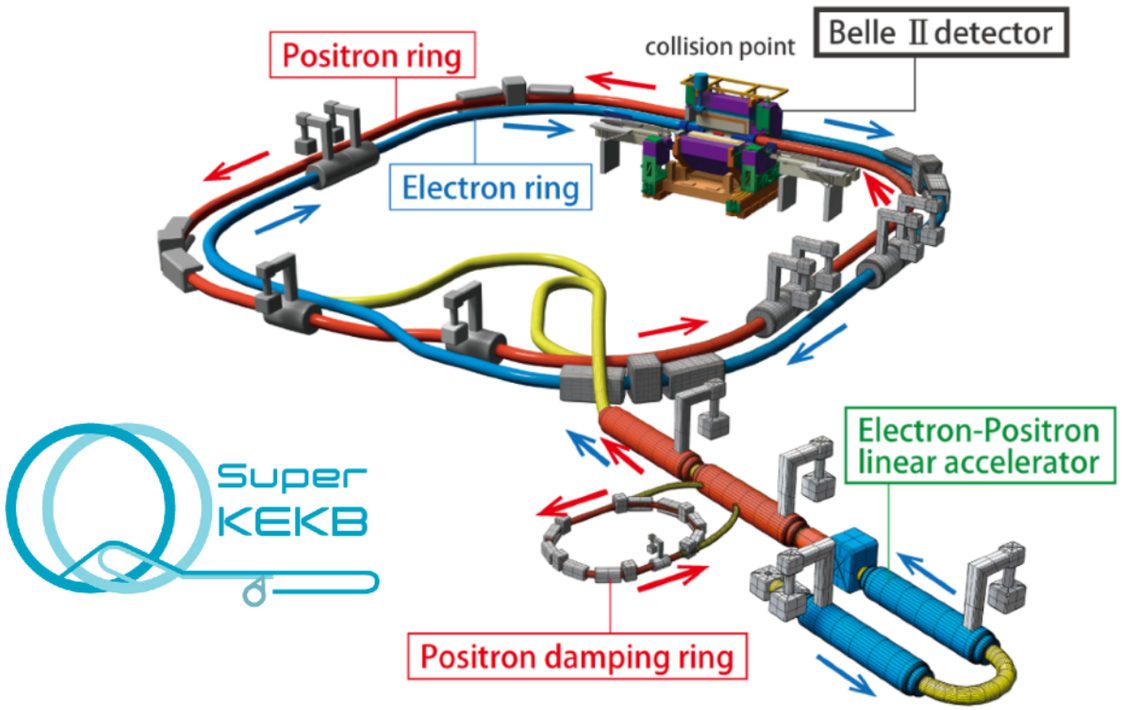
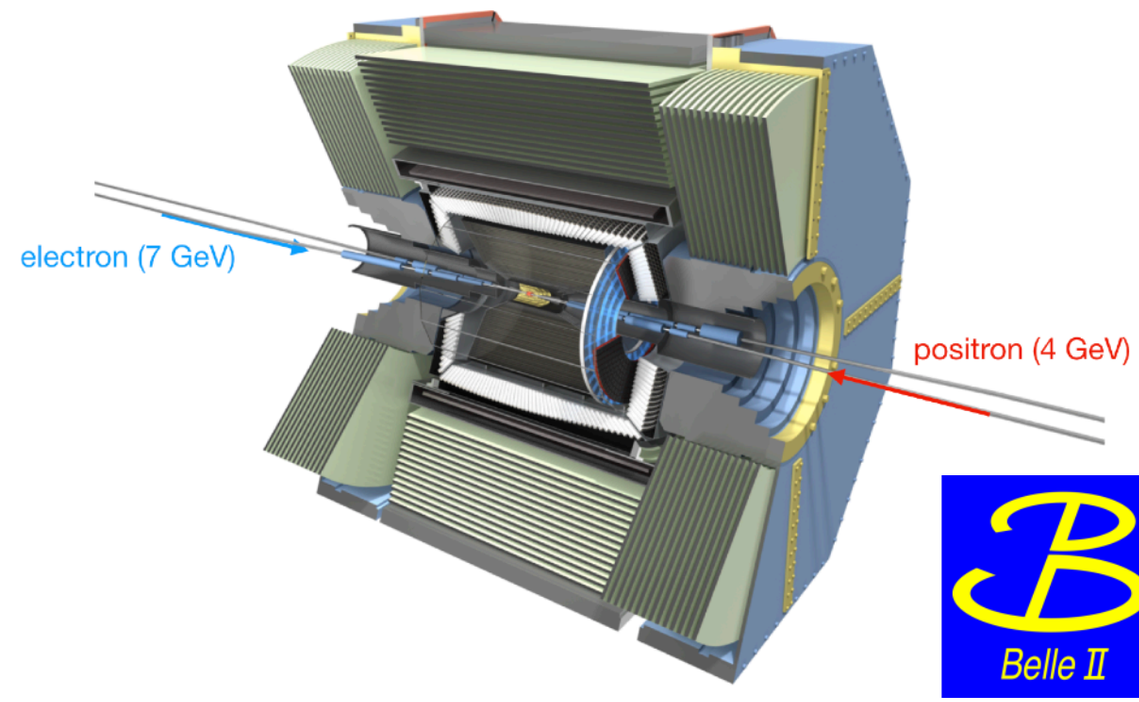
HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

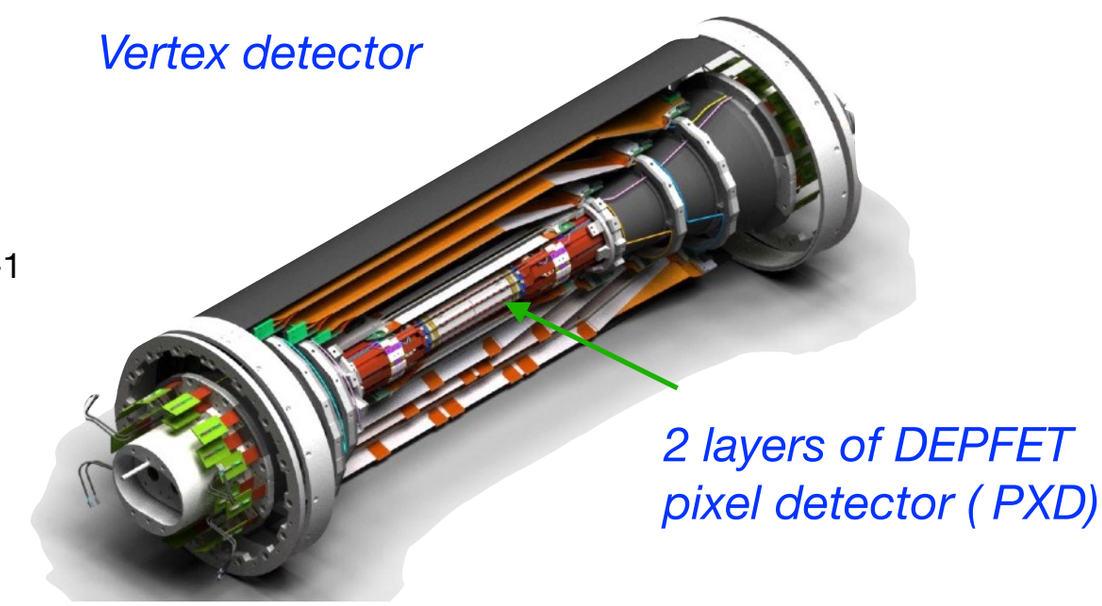
SuperKEKB and Belle II

The new generation of B-factory





- SuperKEKB: Asymmetric energy e^+e^- collider
  - E_{cm} = m(Υ(4S)) = 10.58 GeV
- Design instantaneous luminosity: 8×10^{35} $cm^{-2}s^{-1}$
  - x40 than KEKB
- Physics data taking started in Mar.2019, expected to accumulate $50ab^{-1}$ by 2027.



DEPFET PXD for Belle II

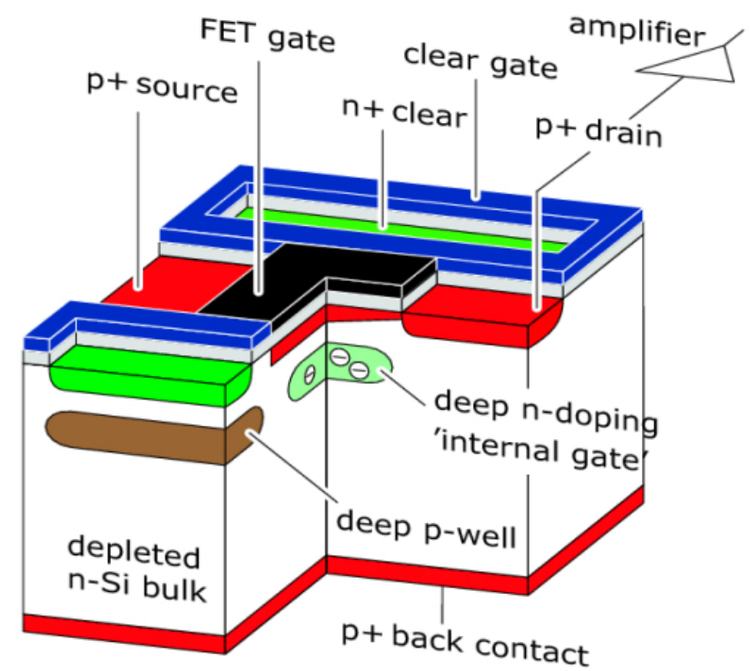
Depleted P-channel Field-Effect Transistor (DEPFET) combines detection and amplification within one device.

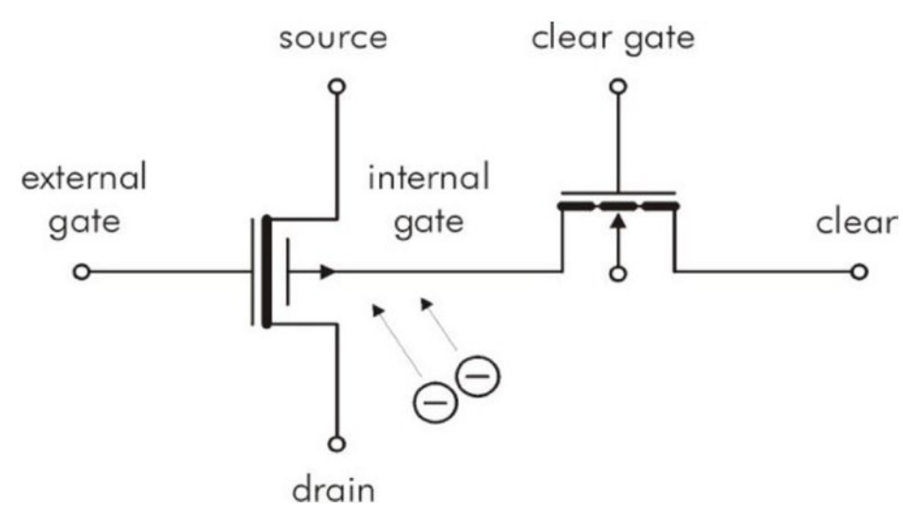
Each pixel is a p-channel FET on top of fully depleted silicon bulk

- Fast charge collection (~ns)
- Charges collected in the “internal gate”
- Readout of modulated drain current
  - ➡ internal amplification

$$g_q = \frac{\partial I}{\partial q} \approx 500 \frac{pA}{e^-}$$

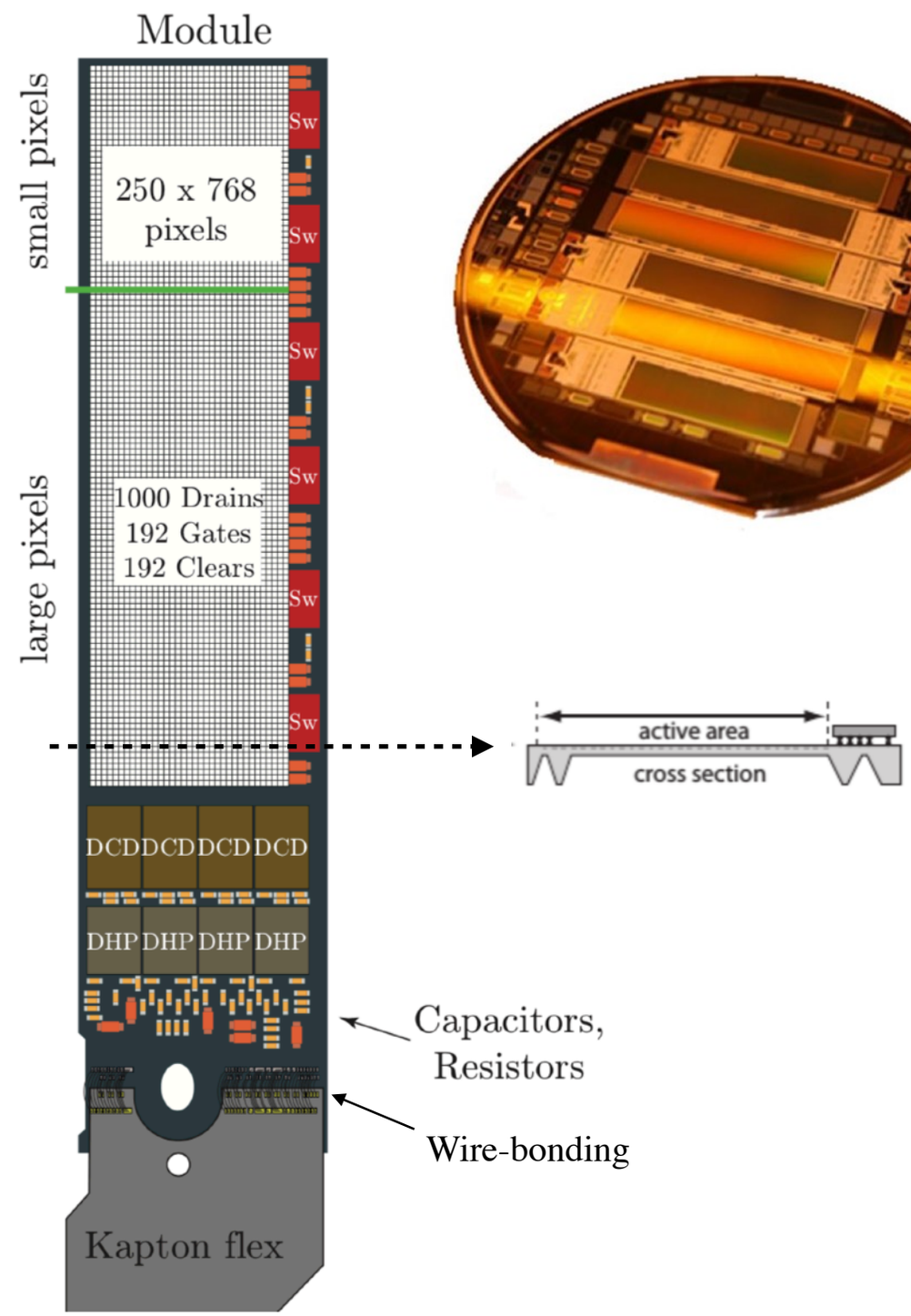
- High Signal to Noise Ratio (SNR)
- Periodical clearing of “internal gate” required to reset the pixel





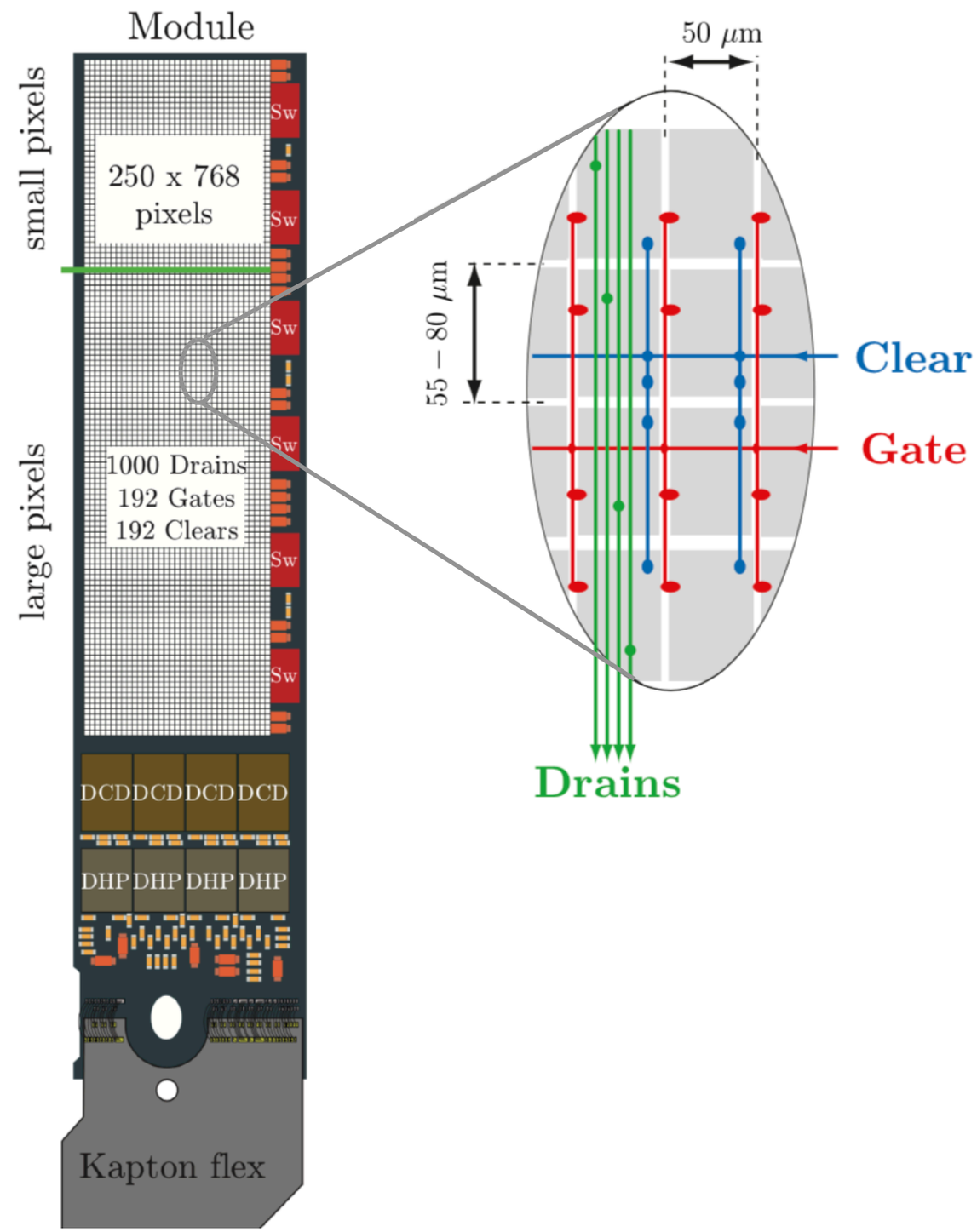
PXD Module Concept

- Pixel size: varies in z direction, 50 x 55-85 μm²
  - optimized to have the best resolution in forward direction around 45° incident angle
- 250 x 768 pixels per module
- By thinning the active sensor thickness can be reduced to as little as 50 μm.
- For optimal position resolution (COG) 75μm were chosen for PXD
- 3 Metal layers for circuitry
  - 2Al + 1Cu
- Mechanically self-supporting device



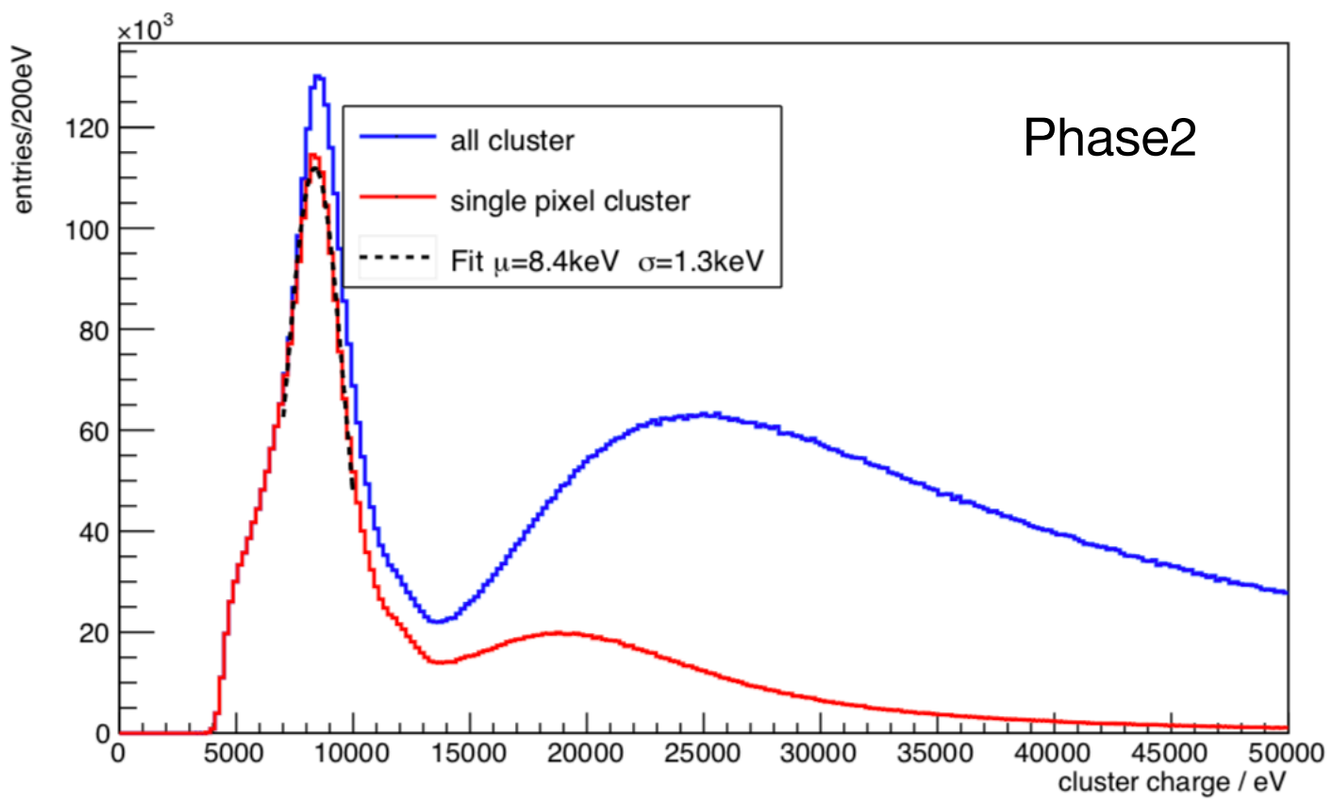
PXD Module Concept

- 3 types of ASICs are bump-bonded to the module
  - Switcher: controls the gate and clear lines of the matrix.
  - DCD: consists of 256 current mode pipeline 8-bit ADCs digitalize the inputs for drain lines.
  - DHP: digital processor chips, 0- suppression & triggered readout.
- Rolling shutter mode
  - Read signals row-by-row
  - 4 rows in parallel
  - Read-Clear cycle in ~100ns
    - Full integration time is 20μs (twice the revolution time of SuperKEKB)
  - Only 'activated' rows consume power
    - Low sensor power consumption
- Max. Acceptable average occupancy <3%.

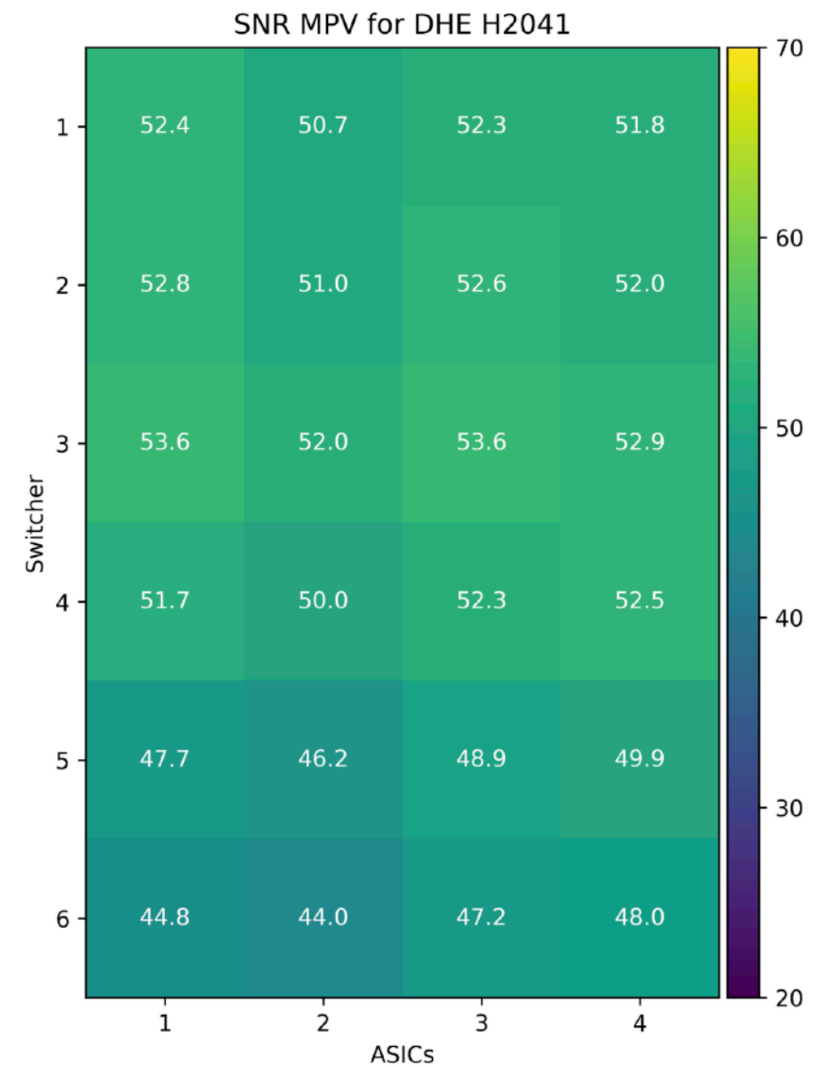


DEPFET Module Performance

- Soft components (<10keV) on calibrated cluster energy spectra.
  - hint for synchrotron radiation

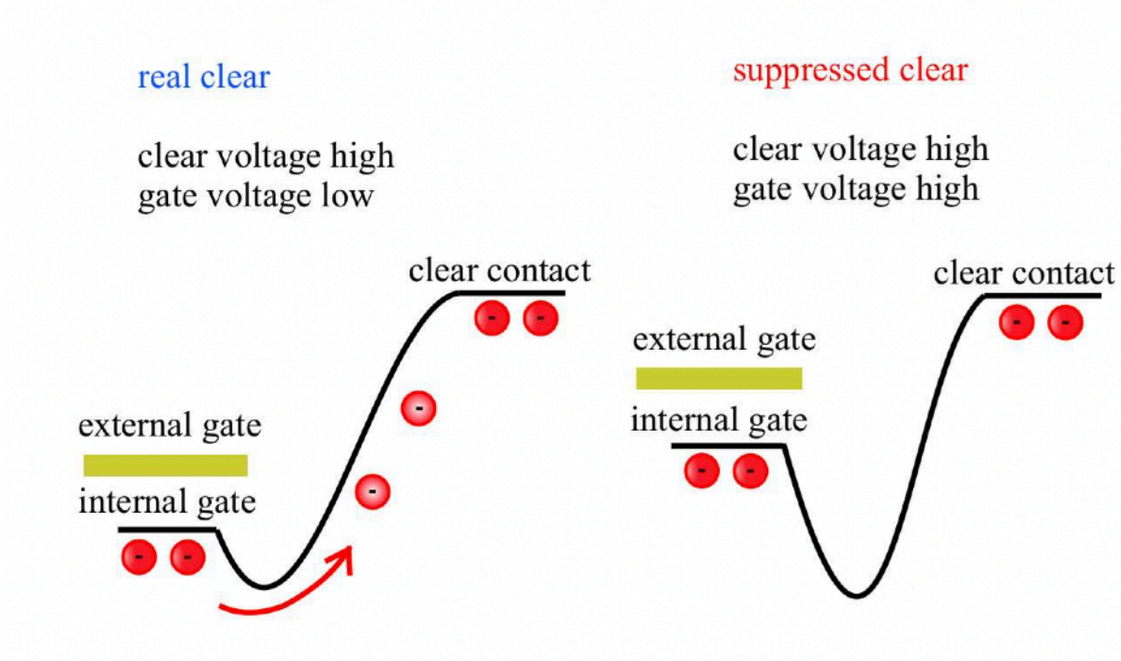


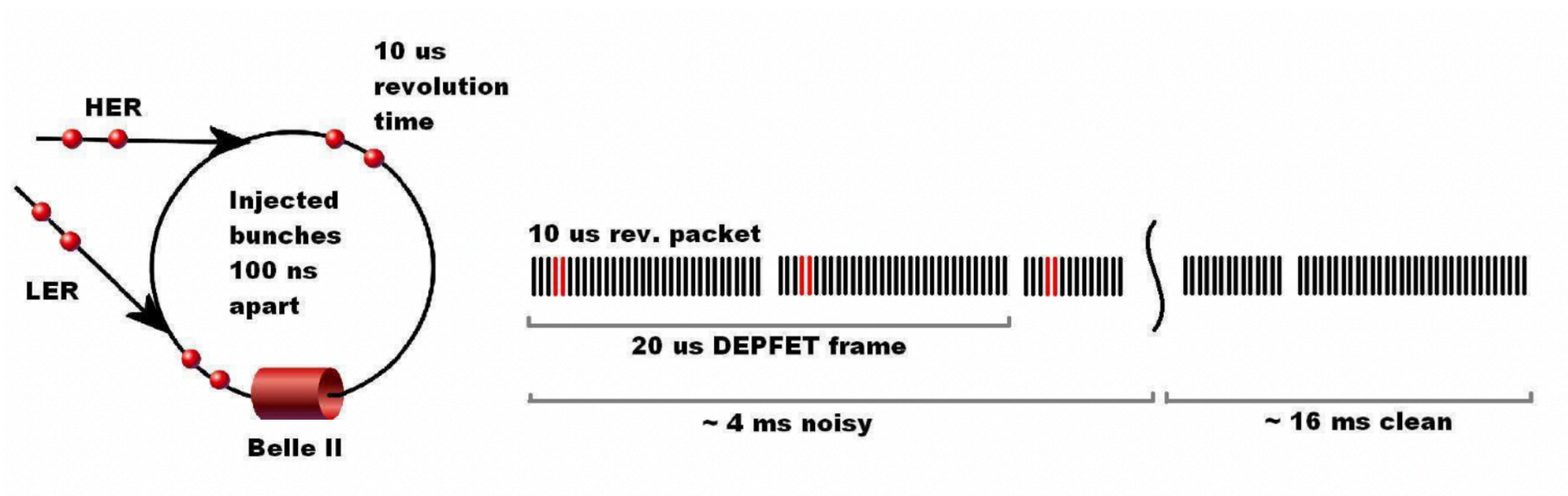
- SNR ≳ 50 has been achieved
  - from PXD Phase3 module



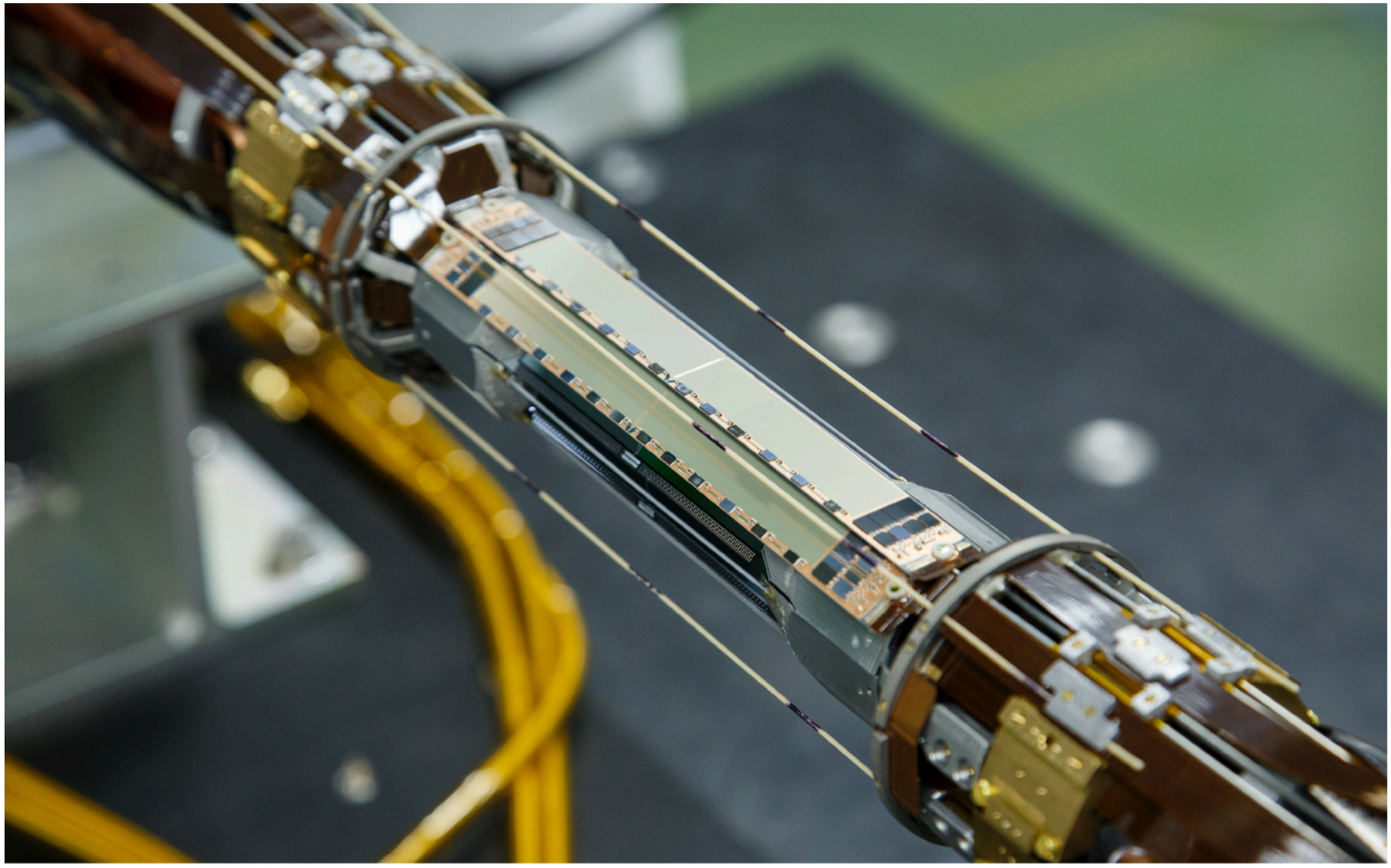
Gated Mode Operation

- At design luminosity we have to inject at 2x25Hz (=> 20ms)
- Sensor can be periodically blinded with Gated Mode (GM)
  - Newly created charges are not collected
  - Charges in internal gate are preserved
- The principle was tested extensively in the lab
  - Pedestal fluctuation for several gates observed after returning to normal mode.



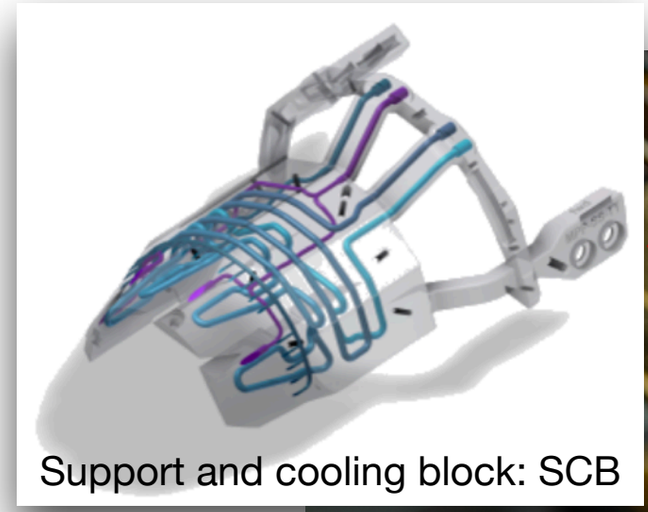


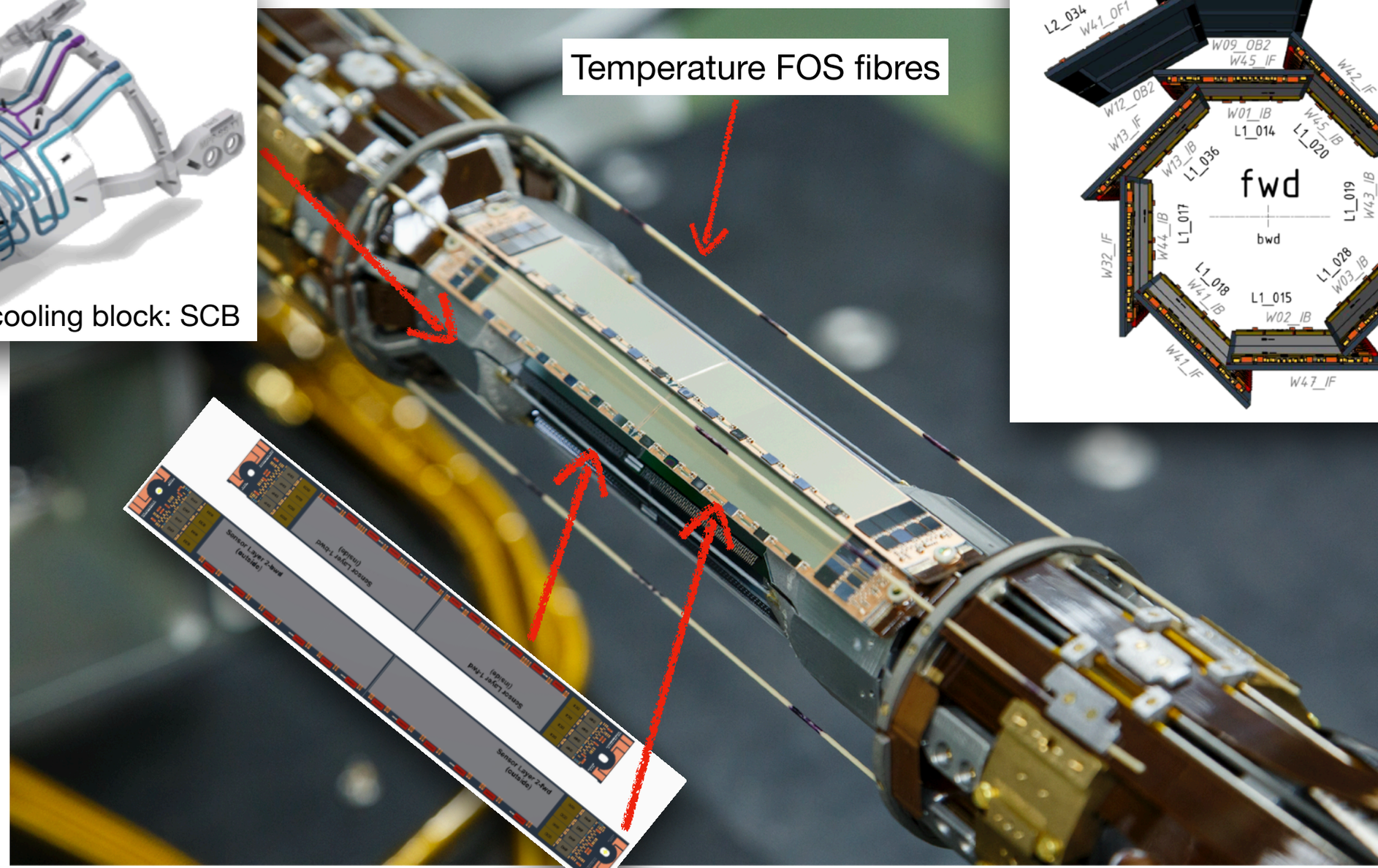
Belle II PXD for early Phase 3

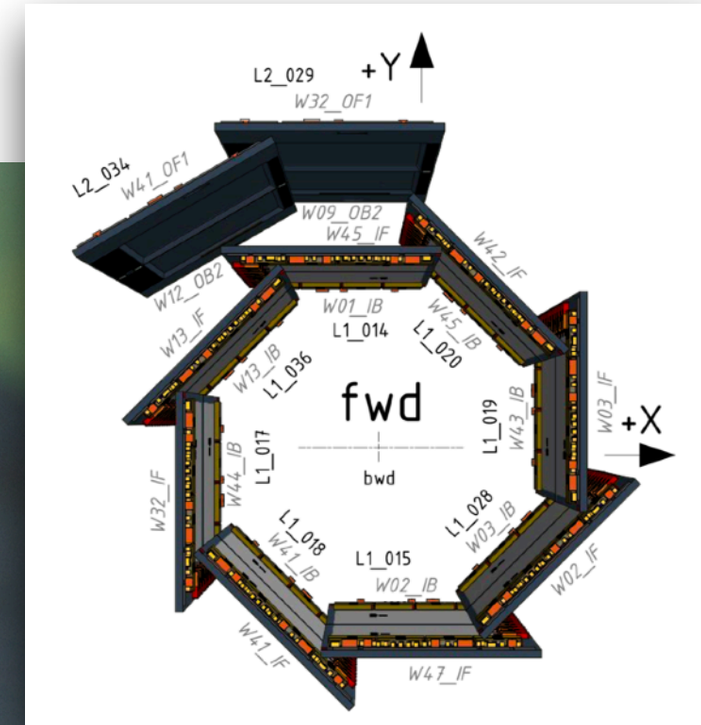


- 2 layers of DEPFET sensors @ r = 14(22) mm
- Sensitive area per module: L1: 12.5mm x 44.8mm, L2: 12.5mm x 61.44mm
- Sensor thickness: 75 μm, 0.21% X_0 per layer

Belle II PXD for early Phase 3





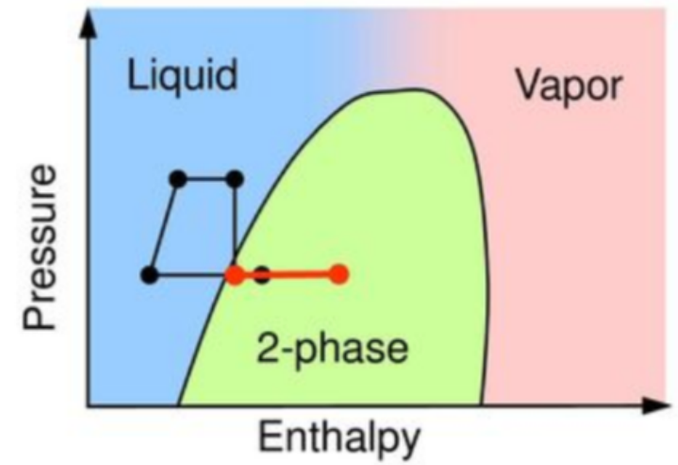


- Each ladder is formed by a pair of mirrored DEPFET sensors
- Due to problems in ladder gluing, only half of designed PXD (full L1+2 L2 ladders) was installed in 2018/2019, will be finalized in 2021.

Thermal Management

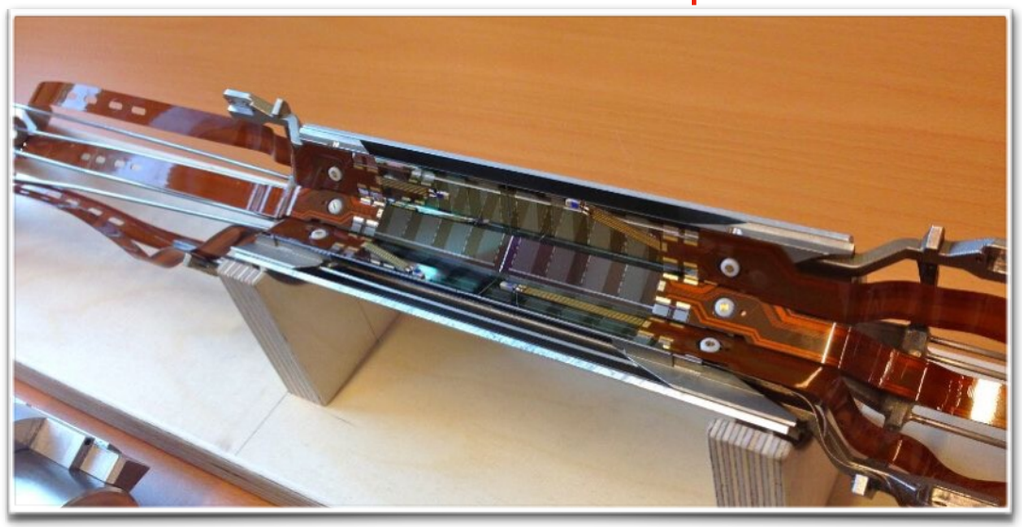
- The power consumption of full PXD is 420W,
  - 360W are contributed from DCD/DHP, where locate in the end of stave.
    - ➡ Active 2 phase CO2 cooling is required there.
  - Little power from matrix (0.5W per module) and Switchers (1W per module)
    - ➡ Air cooling is sufficient in the sensitive area.

2-phase CO_2 cooling

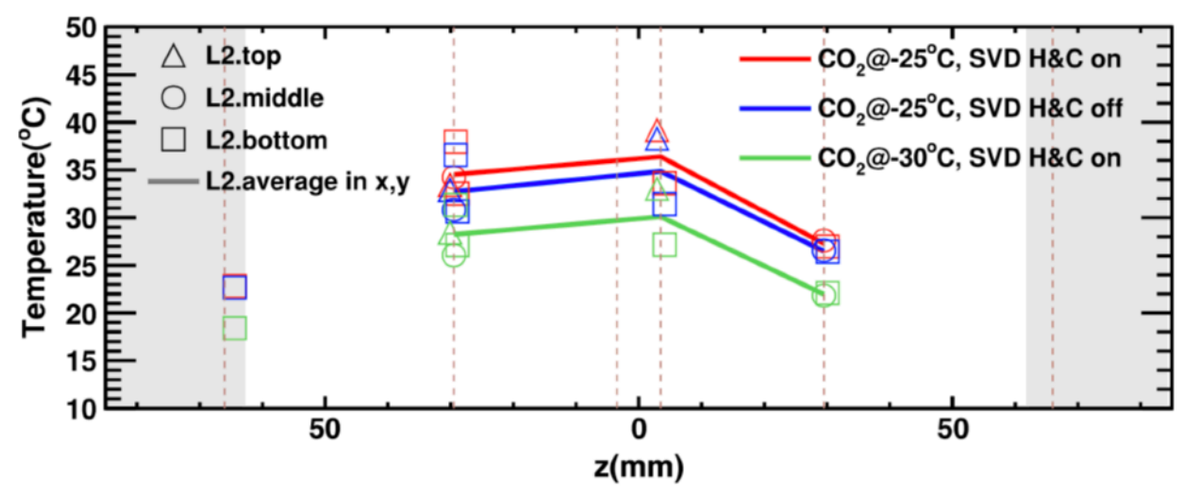


2PACL: 2-Phase Accumulator Controlled Loop

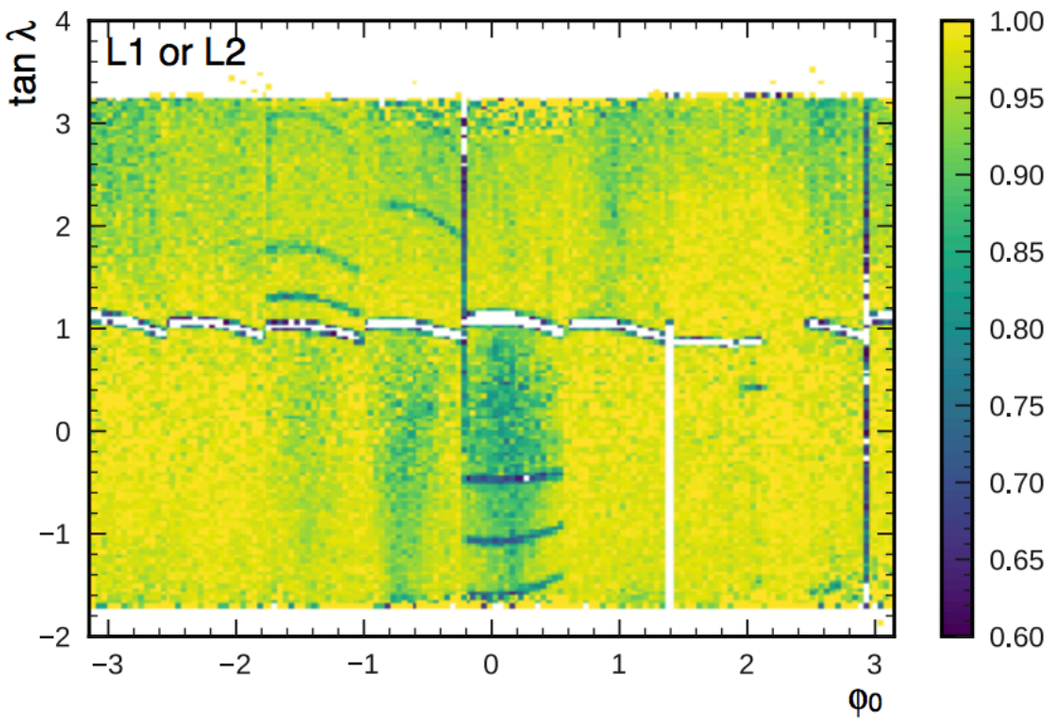
Thermal mock-up



Temperature along the PXD ladder

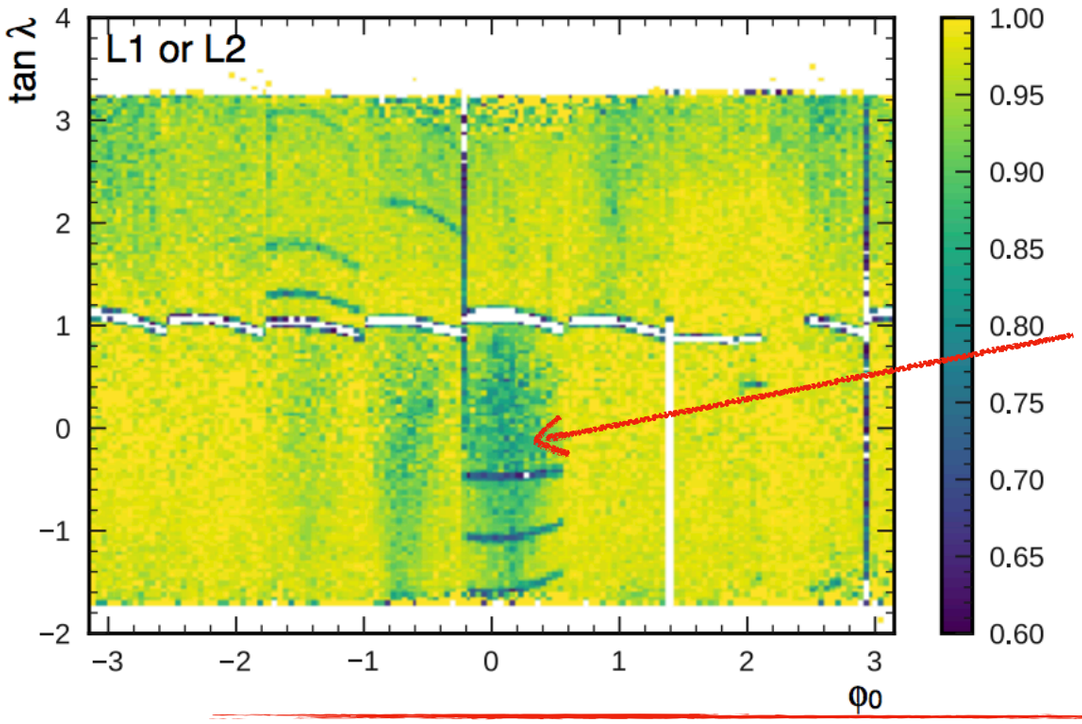


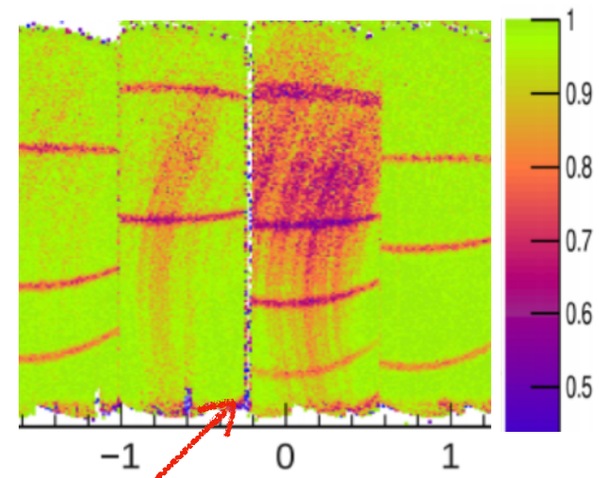
PXD Performance: Efficiency

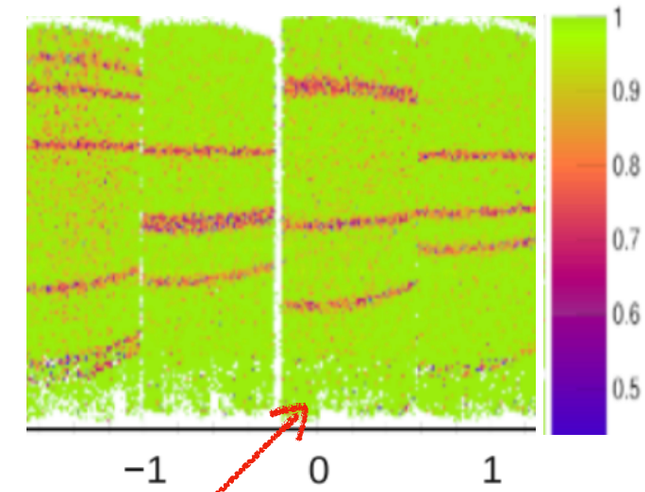


- Projection on the ϕ_0-tan(λ) plane.
- $\lambda \equiv \pi/2 - \theta$, : angle between a track and the plane ⊥ to the beam.
- Gaps between fwd & bwd modules and between half shells
- Few modules not yet at optimal working point

PXD Performance: Efficiency







Ring structures indicate shift of working point

- The rings due to small scale variations in the bulk doping.
- Almost completely invisible if properly biased.

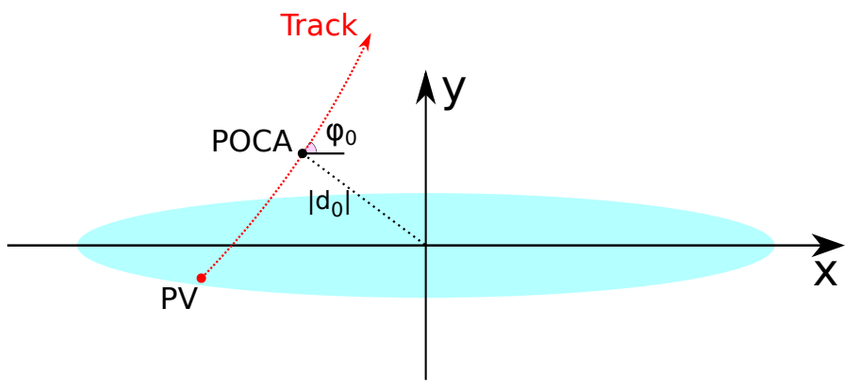
Voltages were adjusted to cure the rings

- Projection on the ϕ_0-tan(λ) plane.
- $\lambda \equiv \pi/2 - \theta$, : angle between a track and the plane ⊥ to the beam.
- Gaps between fwd & bwd modules and between half shells

Transverse Impact Parameter (d_0) Resolution

- After correcting for the beam spot position, the ϕ-dependent $\sigma(d_0)$ depends on the intrinsic VXD resolution and transverse size of the luminous region:

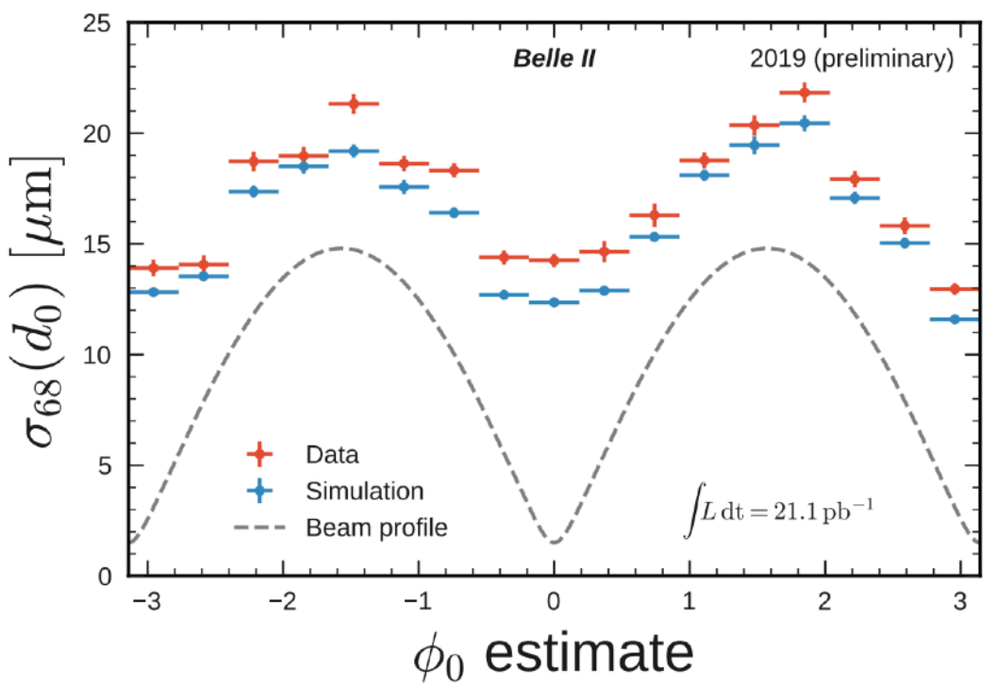
$$\sigma_{d_0} = \sqrt{\sigma_i^2 + (\sigma_x \sin\phi_0)^2 + (\sigma_y \cos\phi_0)^2}$$

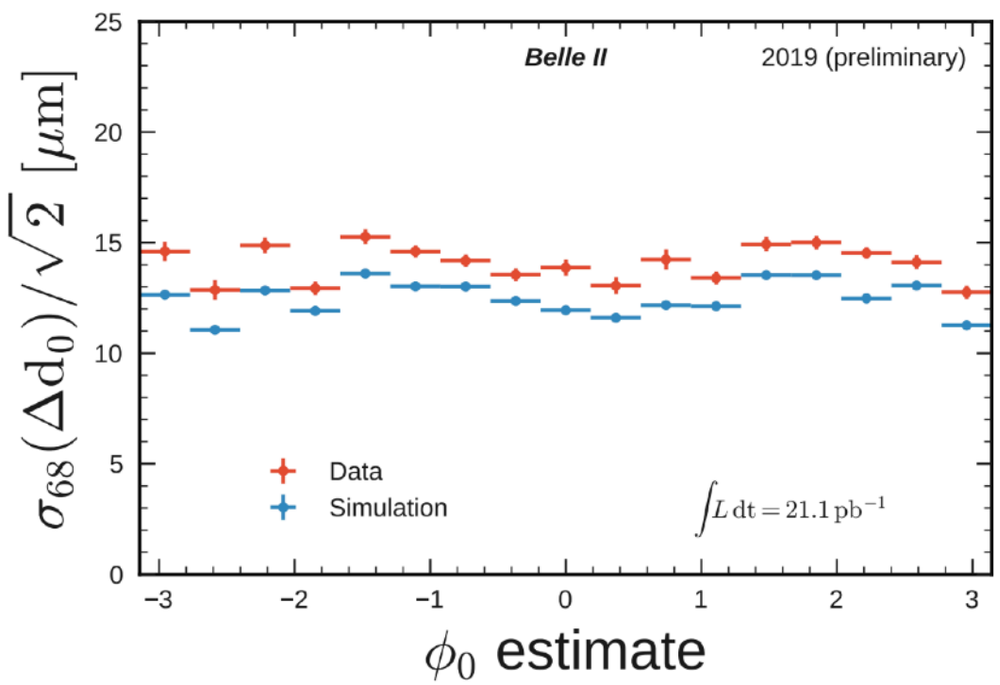


- In early phase 3, σ_x = 14.8μm and σ_y = 1.5μm
- The intrinsic resolution is estimated by

  $\Delta d_0 \equiv d_0(t_-) + d_0(t_+)$,

  from 2-track (t_- and t_+) events, which are produced back-to-back.





- Good agreement observed between data and MC expectation

Summary

- The first real beam experience with a completely new detector type (DEPFET) and half of the full scale has been achieved.
  - Challenging operating conditions close to the IP at a very ambitious machine like SuperKEKB
- PXD system is continuously being improved and optimized in the 2019 spring runs.
- Good PXD performance is demonstrated
  - Efficiency -> further module optimisation possible
  - Impact parameter resolution very close to MC expectation