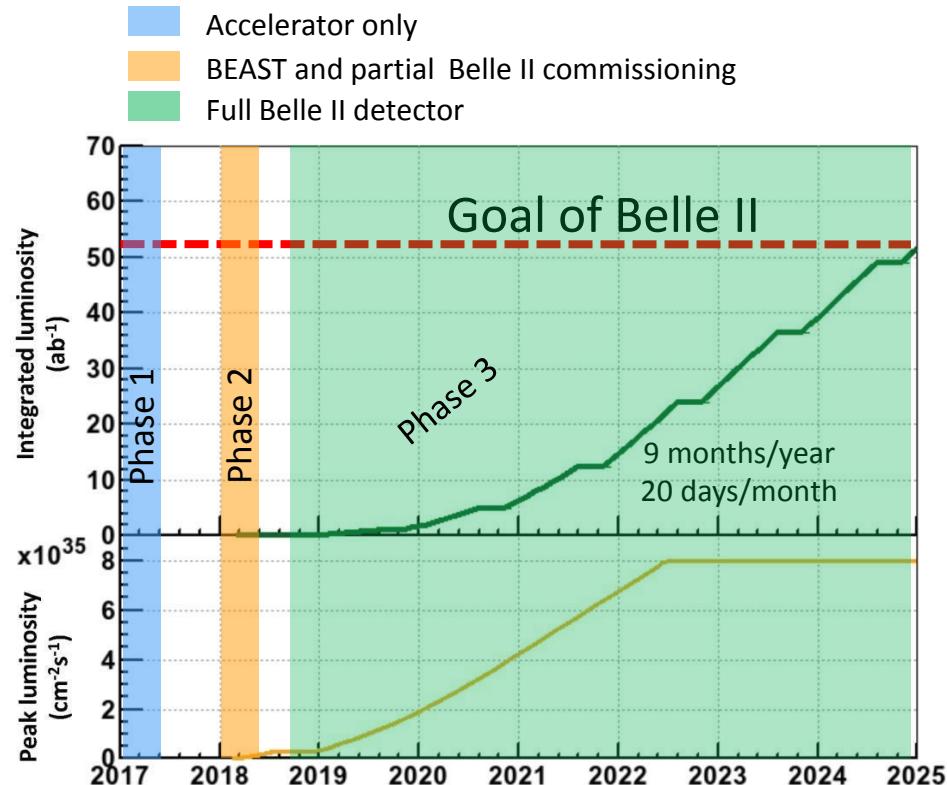


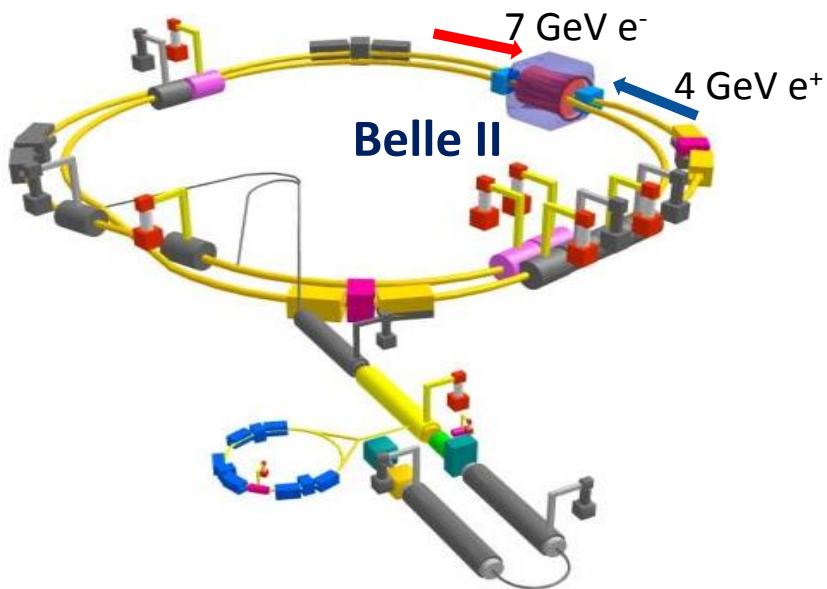
THE BELLE II PIXEL DETECTOR STATUS AND PERFORMANCE

FLORIAN LÜTTICKE ON BEHALF OF THE BELLE II PXD/DEPFET COLLABORATION
Universität Bonn, Physikalisches Institut, Nussallee 12

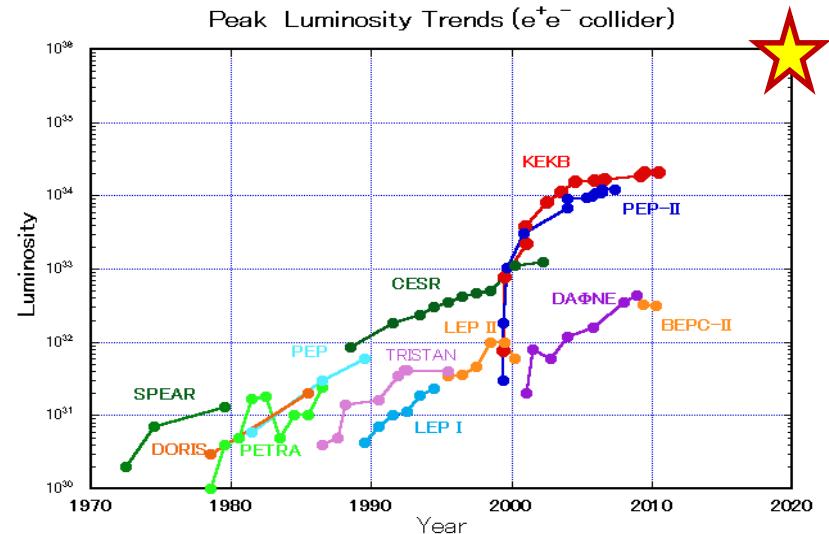
BELLE II COMMISSIONING

- Phase 1
 - Accelerator commissioning. No Belle II detector, no final focus system, no collisions.
- Phase 2
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- Asymmetric energy (4 GeV, 7 GeV) e^+e^- collider at the $E_{cm}=m(Y(4S))$
- Final luminosity $8 \cdot 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$, 40 times higher than KEKB

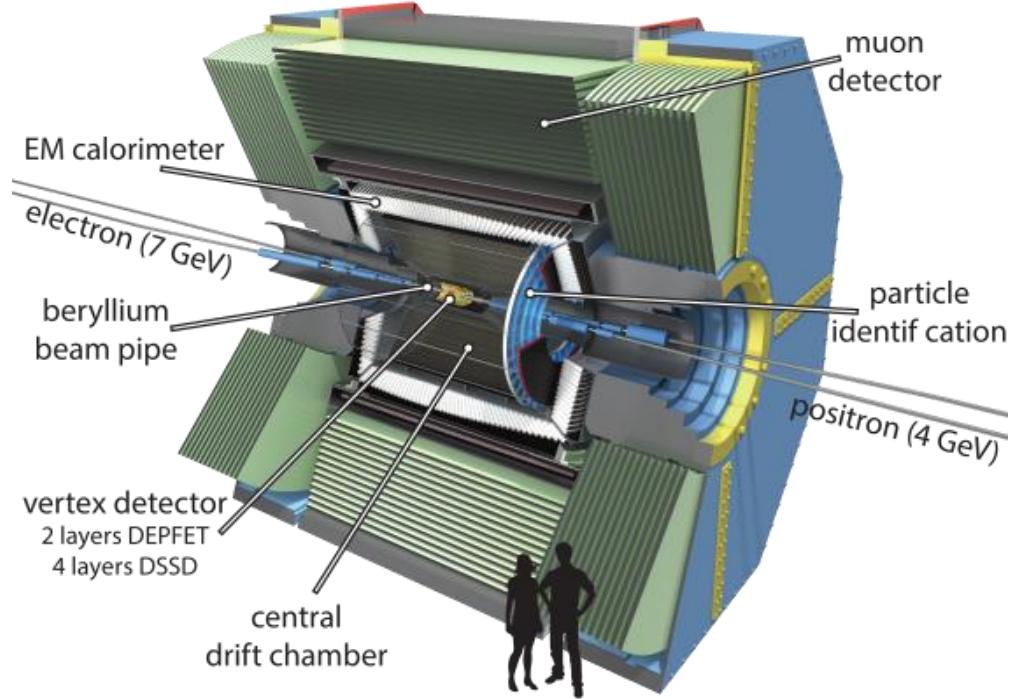


Precision measurements using B Mesons (+ Charm, + Tau)

- CKM parameters
- Search for rare decays
- Search for physics beyond the standard model
- CP Violation

THE BELLE II DETECTOR

- 30 kHz event rate
- 50 MeV - 4 GeV momentum range
- Acceptance between 17° - 155°



Silicon Vertex Detector (SVD)

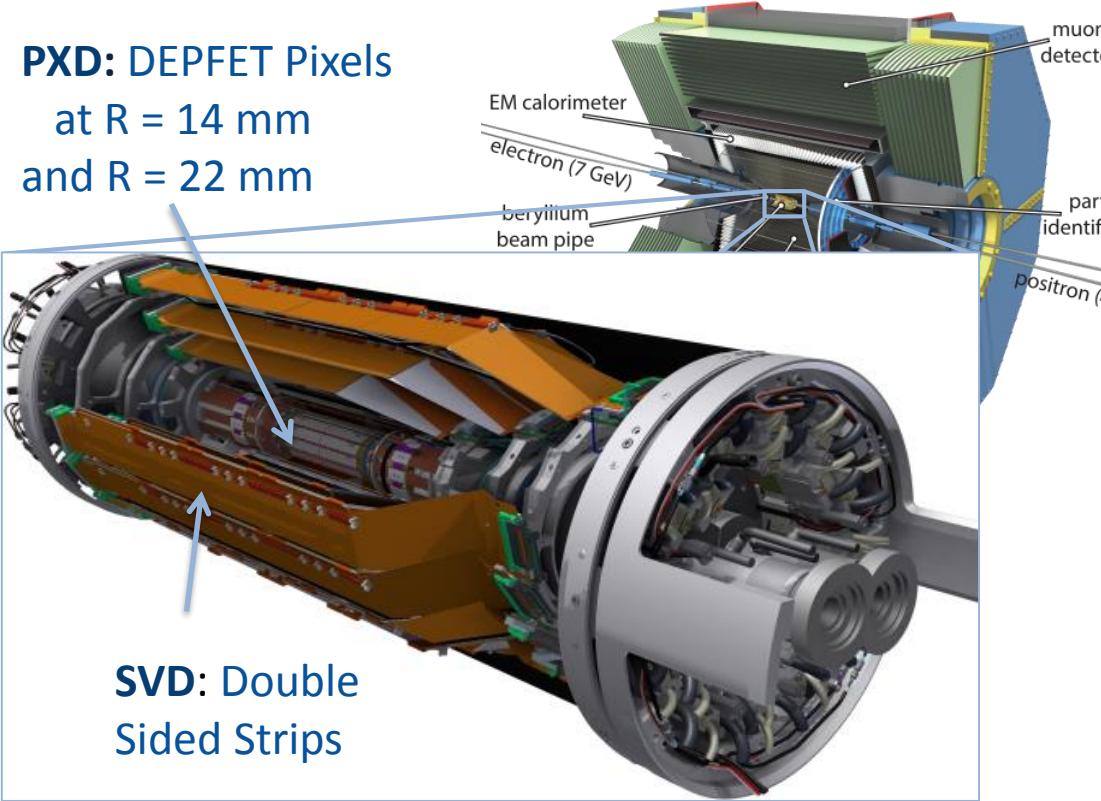
- 4 layer double sided Strips

DEPFET PiXel Detector (PXD)

Occupancy (L1)	0.4 hits/ $\mu\text{m}^2/\text{s}$
Radiation (L1)	20kGy/year
	$2 \cdot 10^{12}$ 1 MeV n_{eq} per year
Frame time	20 μs
Material budget	0.2% X_0 per layer
Resolution (σ_{Z_0})	15 μm (50x75 μm^2)

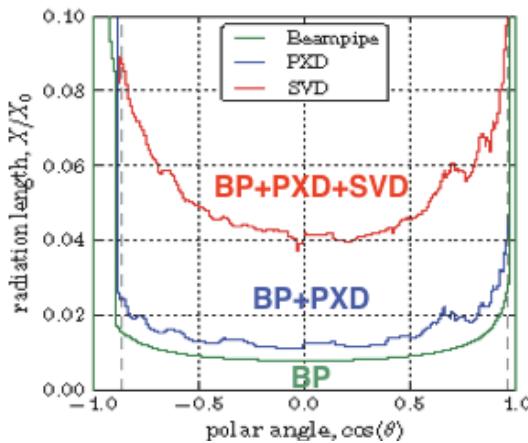
BELLE II VERTEX DETECTOR

PXD: DEPFET Pixels
at R = 14 mm
and R = 22 mm



BELLE II VERTEX DETECTOR IMPACT PARAMETER

Material budget

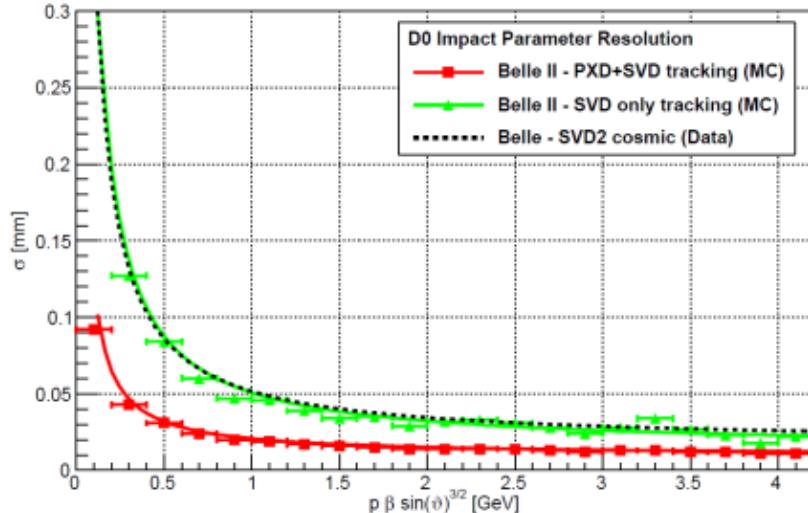


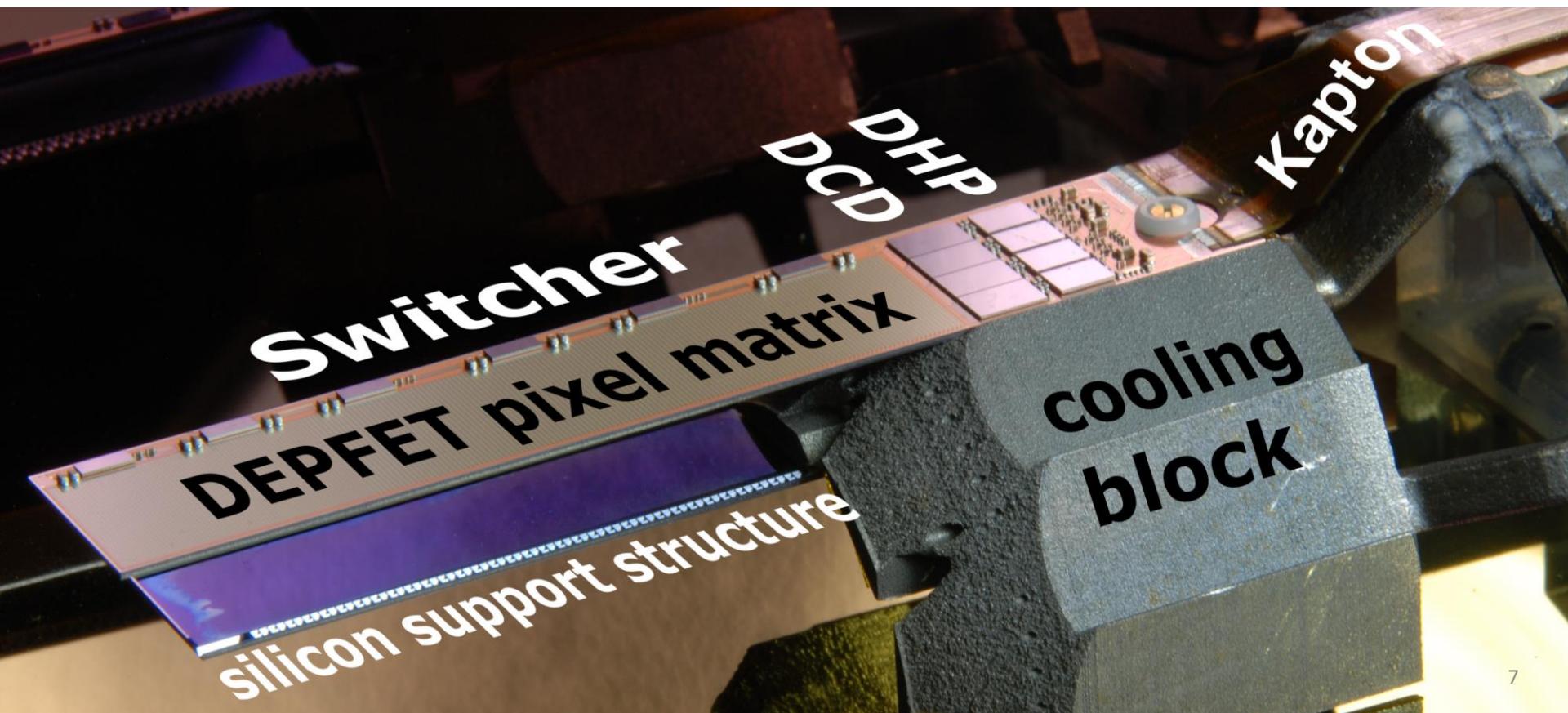
$$\sigma_{d0} \approx a \oplus \frac{b}{p \sin^{\frac{3}{2}} \theta}$$

a: Geometry, governs at high momentum

b: Multiple Scattering, dominates at low momentum

- Modest resolution (15 μm), dominated by multiple scattering (Pixel size $50 \times 75 \mu\text{m}^2$)
- Lowest possible material budget (0.2% X_0/layer)





DEPFET – DEPLETED P-CHANNEL FIELD EFFECT TRANSISTOR

- FET in saturation: $V_{GS} > V_{th}$ and $V_{DS} \geq (V_{GS} - V_{th})$

$$I_d = \kappa \left(W_{ass} + \sqrt{\frac{a q}{t h C}} \right)^2 - V_{th}$$

- Charge modulates drain current

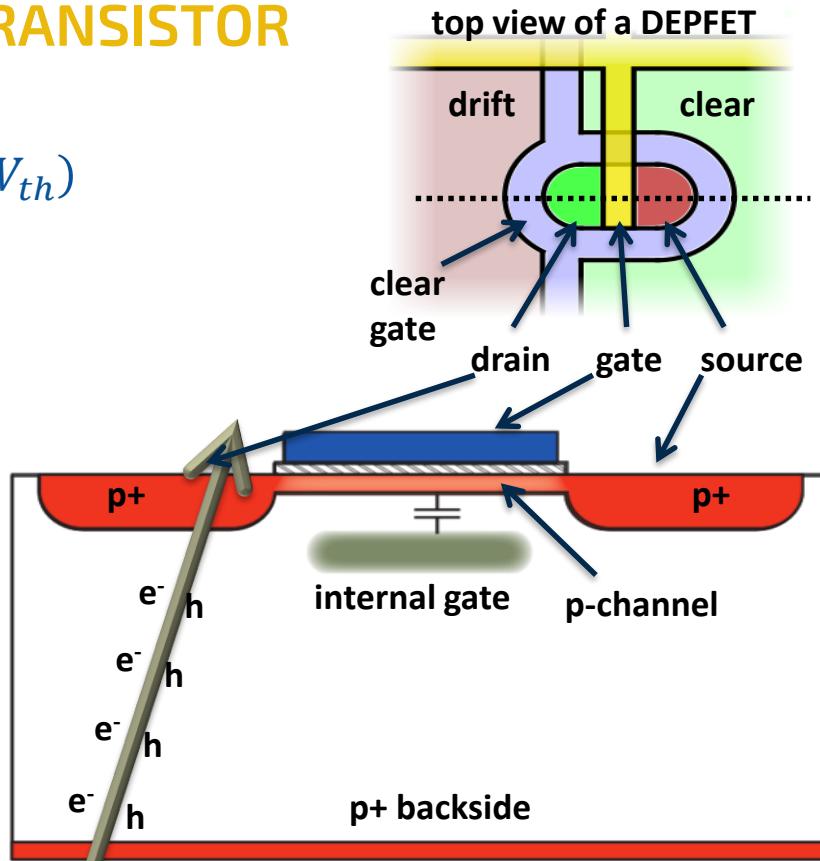
- Conversion factor:

$$g_q = \frac{dI_d}{dq} = \alpha \frac{g_m}{C}$$

- Internal amplification

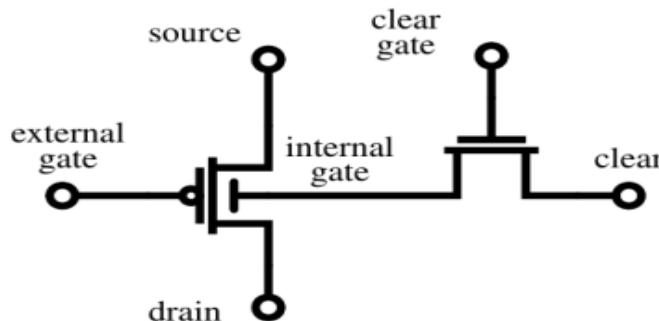
$$g_q \approx 700 \frac{pA}{e^-}$$

I_d : source-drain current
 C : gate capacitance
 κ : device constant
 V_{GS} : gate voltage
 V_{th} : threshold voltage
 g_m : transistor gain

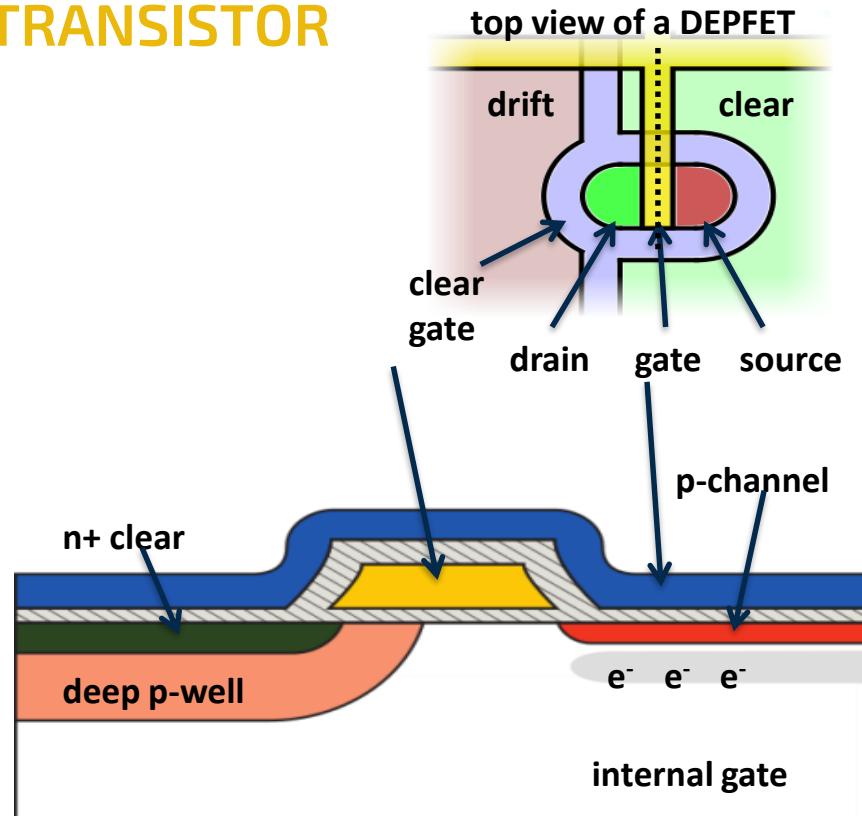


DEPFET – DEPLETED P-CHANNEL FIELD EFFECT TRANSISTOR

- Nondestructive readout
- Charge needs to be cleared
- Clear contact attractive for electrons

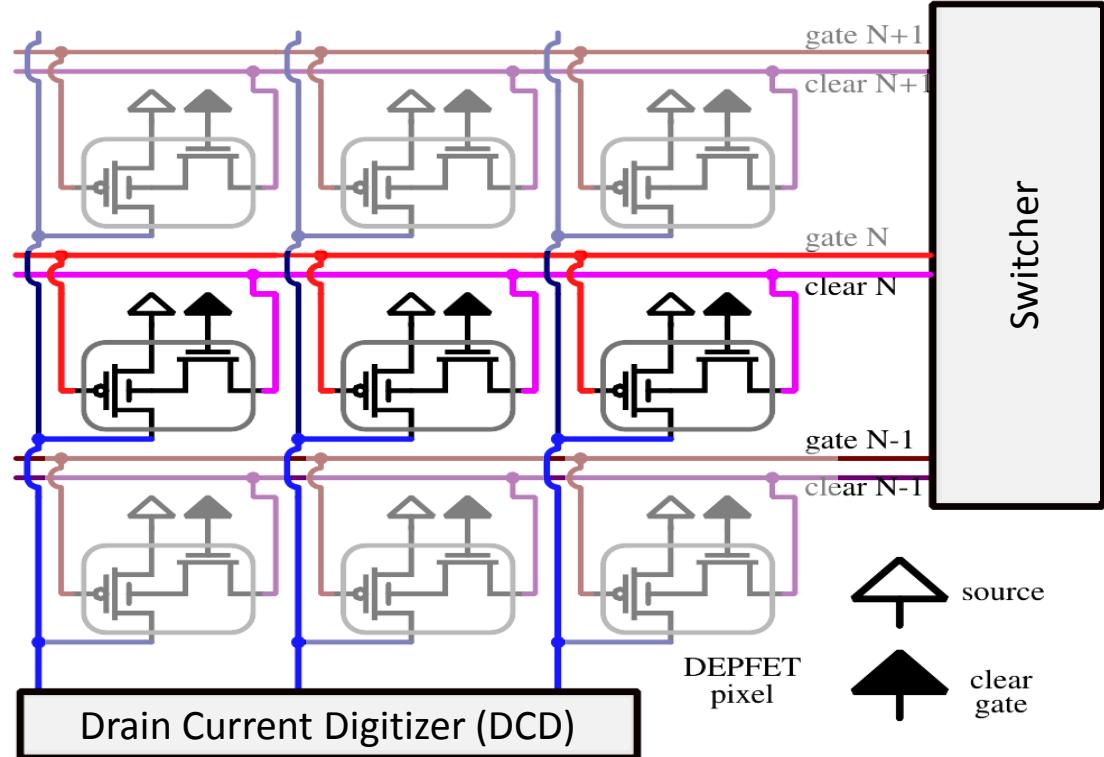


- Collect charge: low clear potential
- Remove charge: high clear potential



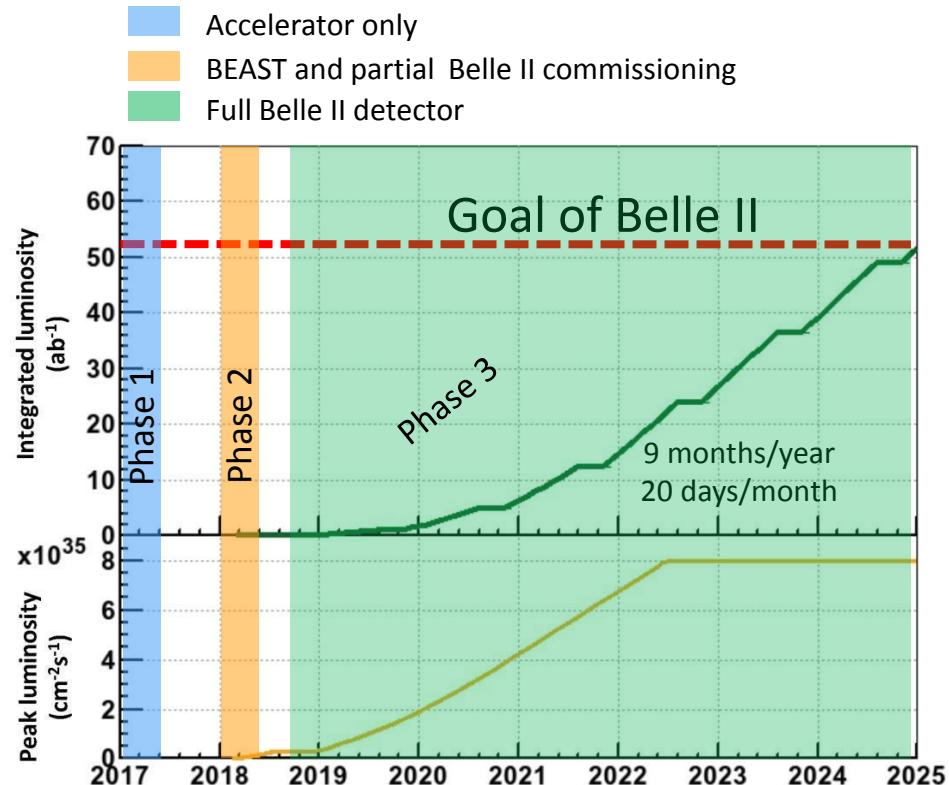
DEPFET READOUT

- Single transistor
- Transistor array
- Steering connected row wise
- Drain connected column wise
- Reading one row
- Clearing one row

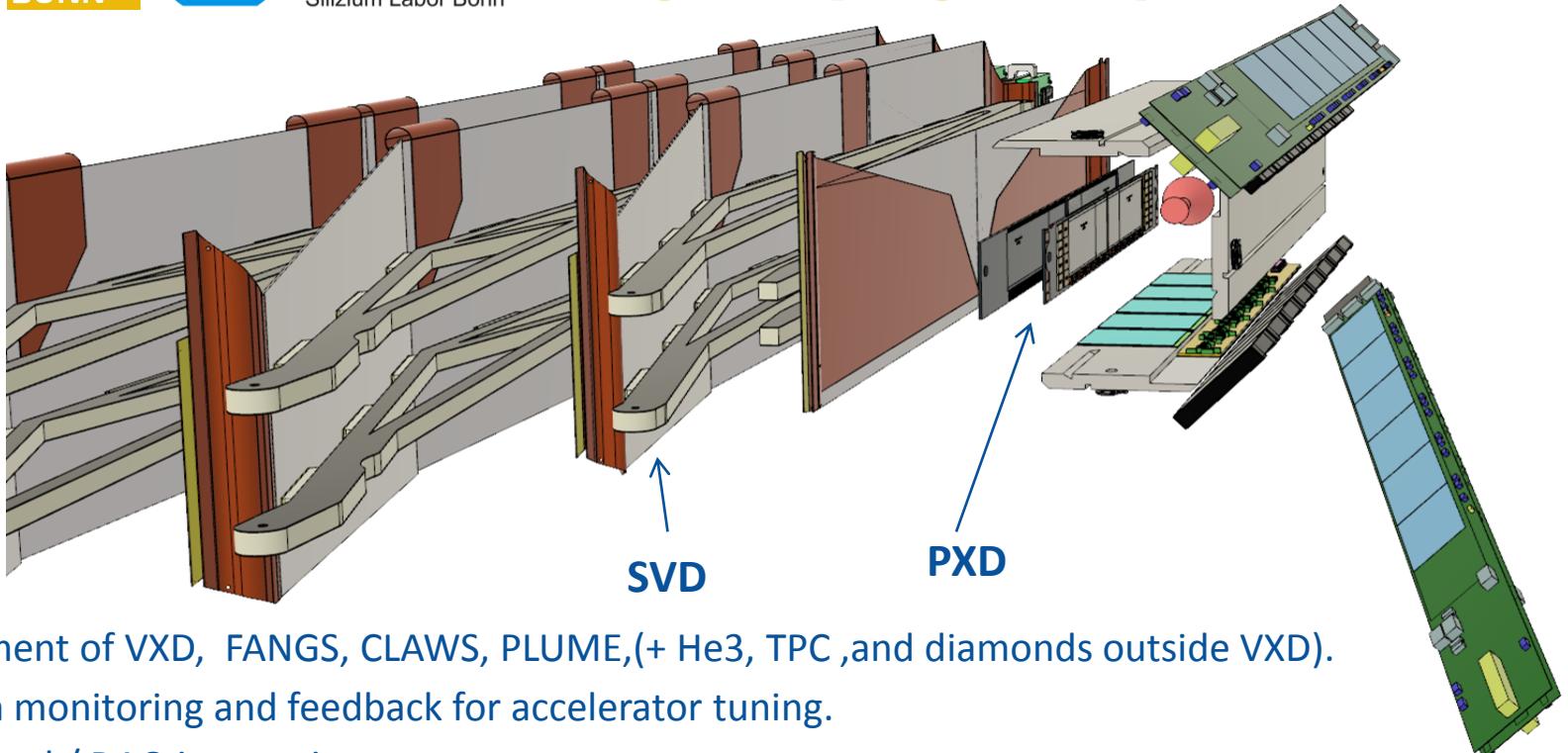


BELLE II COMMISSIONING

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PHASE 2 – BEAST II VXD

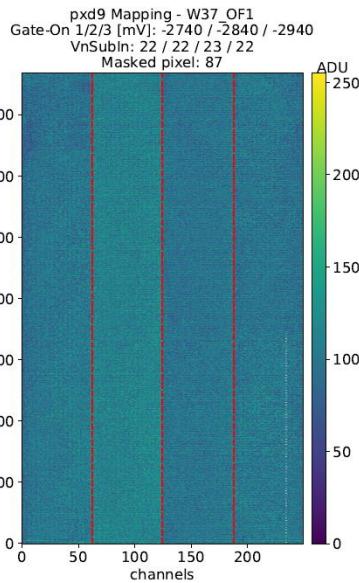
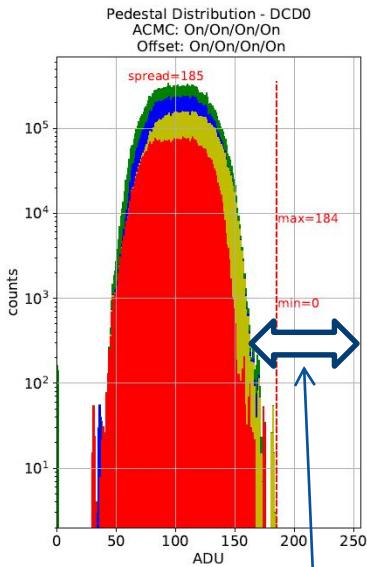


- One segment of VXD, FANGS, CLAWS, PLUME,(+ He3, TPC ,and diamonds outside VXD).
- Radiation monitoring and feedback for accelerator tuning.
- Slow control / DAQ integration

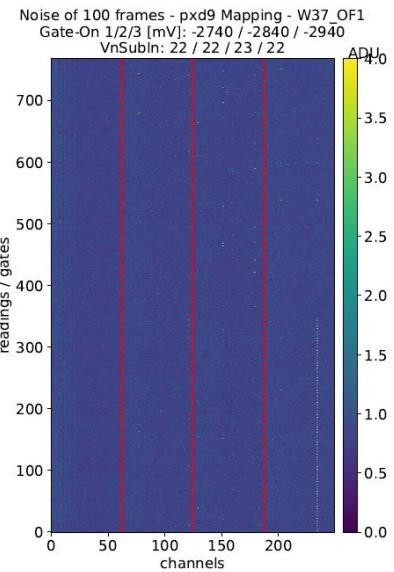
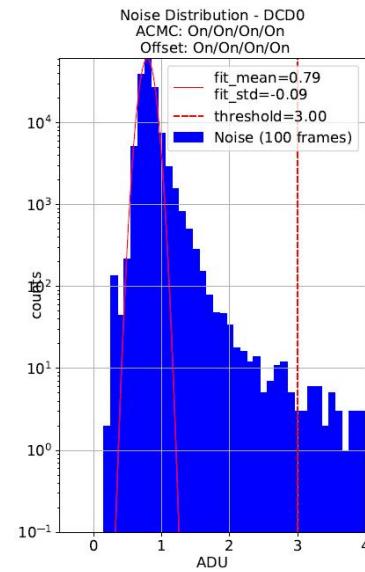
See talk of J. Baudot, Tuesday, Session 8

PHASE 2 PXD PERFORMANCE

- Narrow Pedestal current distribution
Stable over time

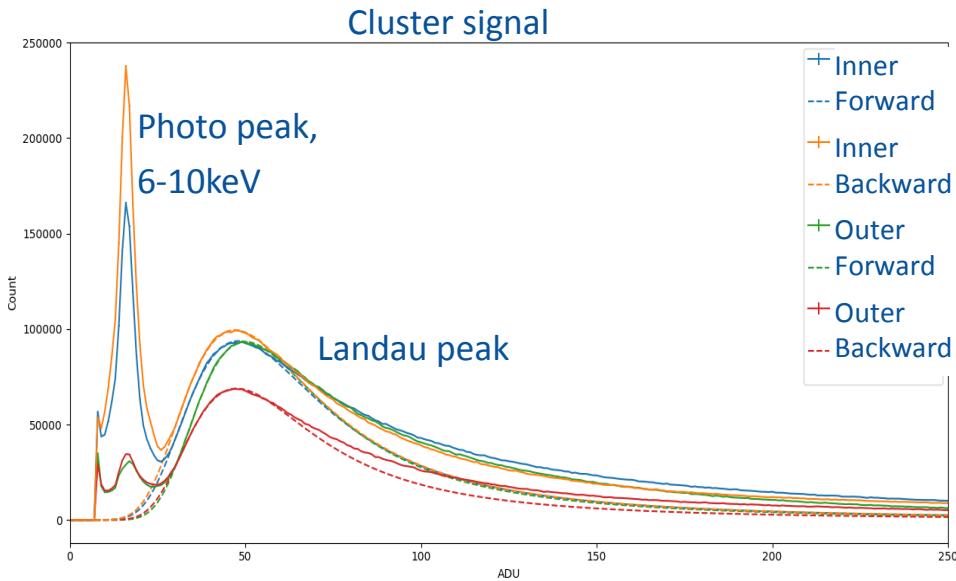


- Noise ~0.8 LSB (100e ENC)

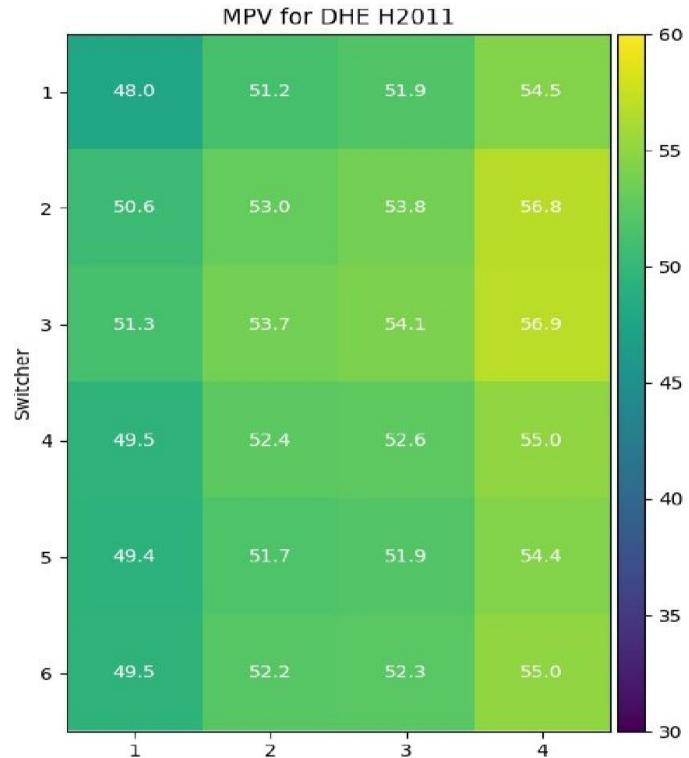


Signal Headroom

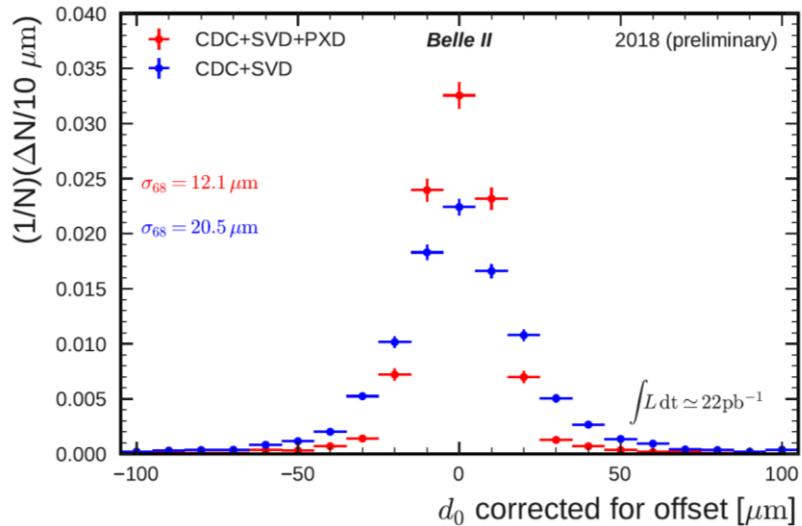
PHASE 2 PXD PERFORMANCE II



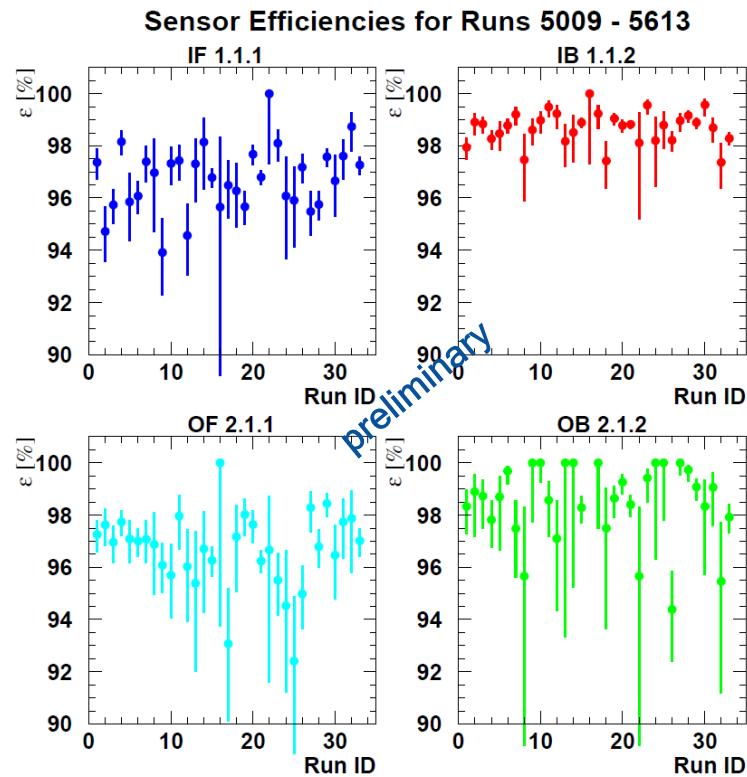
- SNR > 50 for all sensors, 10% spread
- Sensitivity to low keV Photons
- Threshold ~900e⁻
- Inner layer absorbs most photons



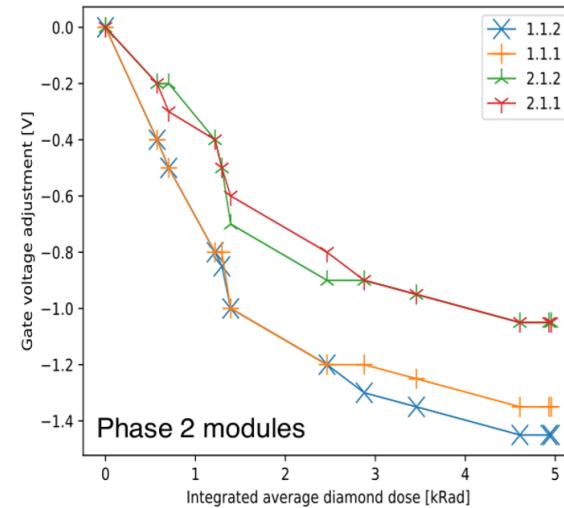
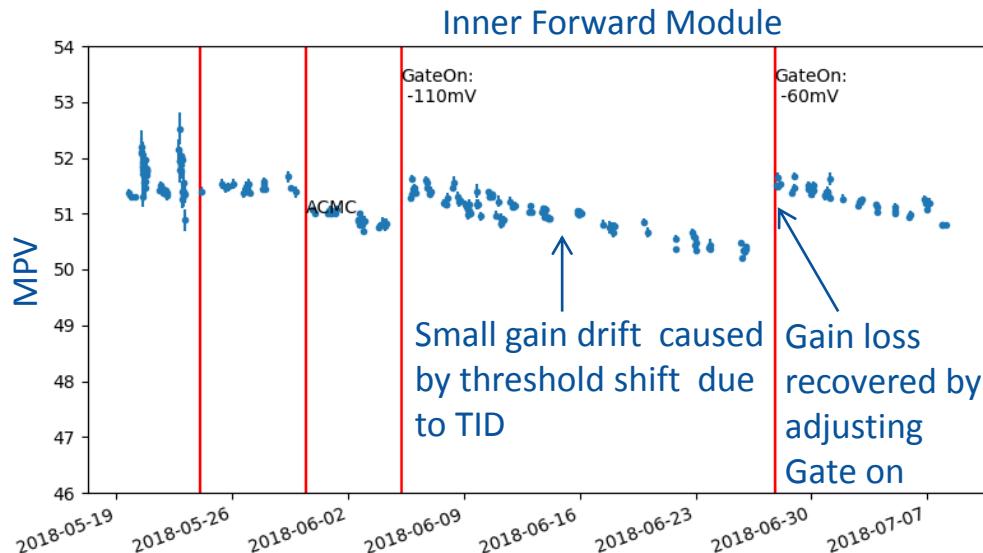
PHASE 2 PXD PERFORMANCE III



- PXD successfully integrated in Belle II DAQ
- $\sigma_{68}^{meas} = 12.1 \mu\text{m} \pm 0.2 \mu\text{m}(\text{stat}) \pm 0.1 \mu\text{m} (\text{sys})$
- $\sigma_{68}^{exp} = 9.9 \mu\text{m} \pm 0.2 \mu\text{m}(\text{stat})$



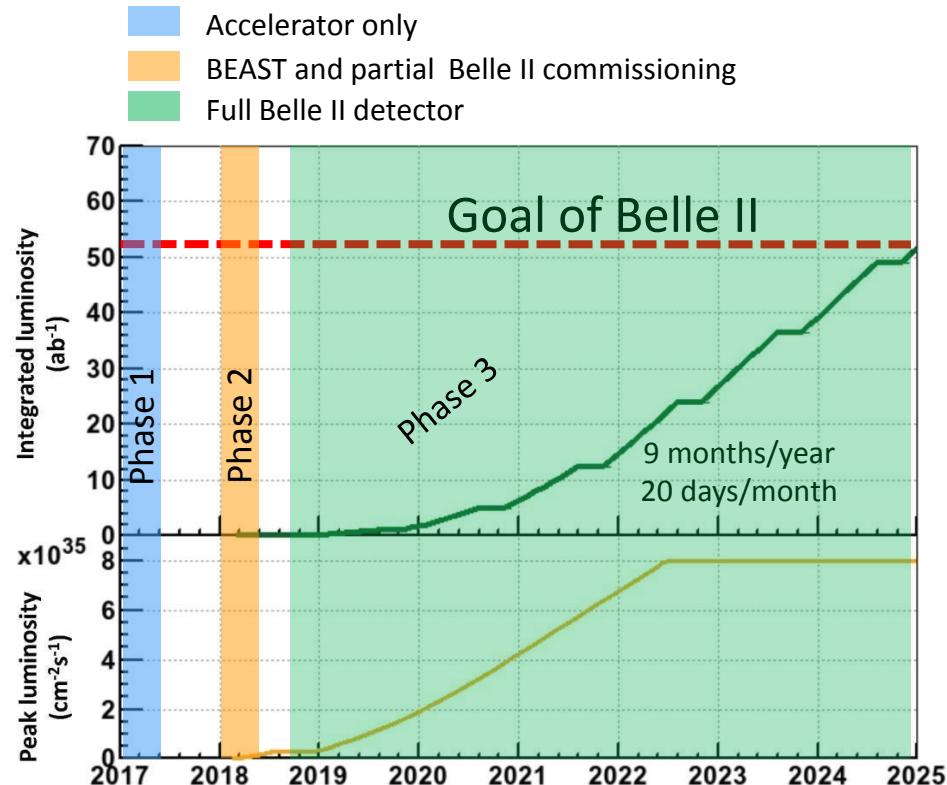
PHASE 2 PXD TID



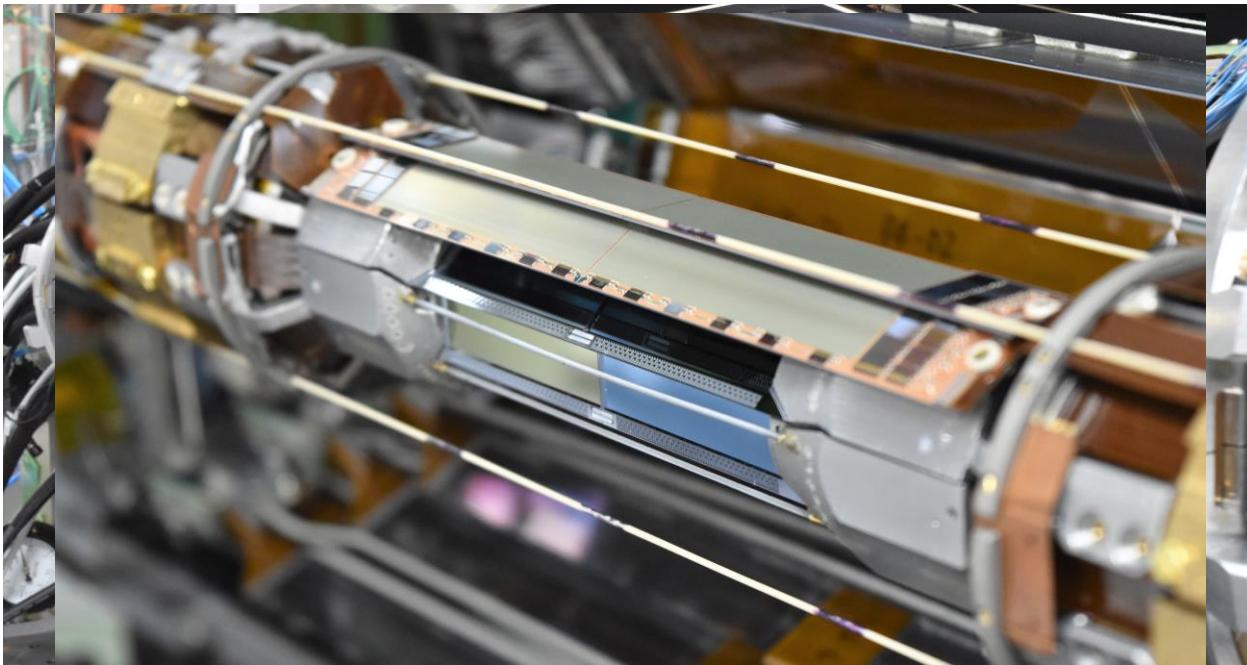
- TID changes transistor threshold
- $MPV \sim g_q \sim \sqrt{I_D} \sim U_{GS} - U_{th}$
- Higher Background than simulated
- Discrepancy between diamond and radiochromic foil
- PXD at different position than diamond

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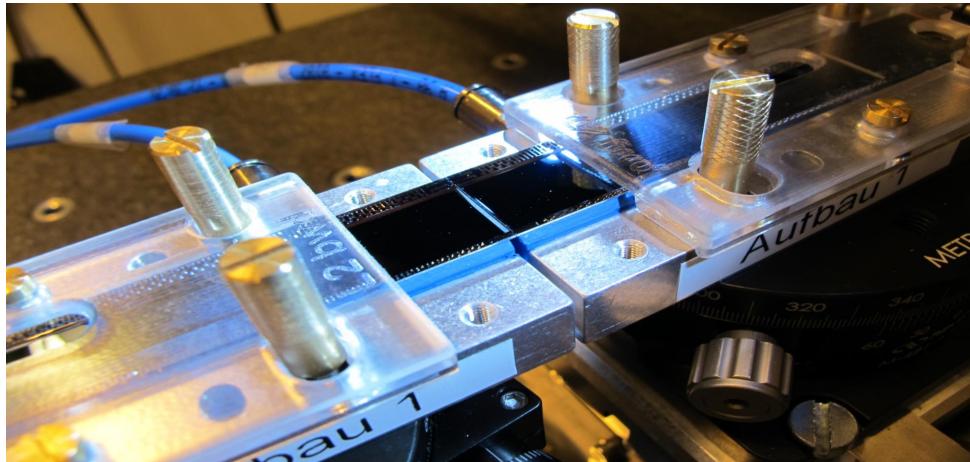


STATUS OF PHASE 3



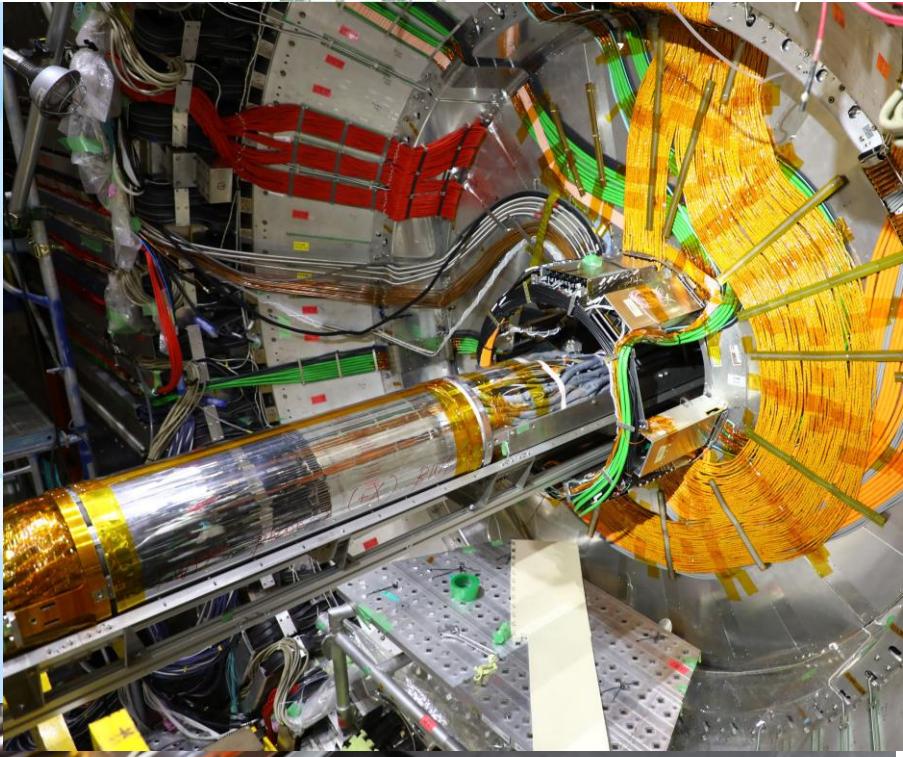
Full layer 1 and 2 layer 2 ladders installed

- Largest Problem: Gluing modules to a ladder
 - Stopped due to low yield
- PXD2020:
 - Replace current PXD in 2020 with completely new PXD
 - New gluing approach
 - More tooling
 - Modules face up
 - Keep working steps
 - Extensive test program



PHASE 3 - TIMELINE

- 21.08. & 04.09 Half shells arrived at KEK
- 05.09 Combining half shells with beam pipe
- 12.09. Module operation of two half shells.
All Modules working.
- 03.10. Mating with SVD half shells
- End of October: Cosmic ray test.
All Modules working.
- 21.11. Installation into Belle II
- 07.12. Digital parts working, analog tests pending



CONCLUSION

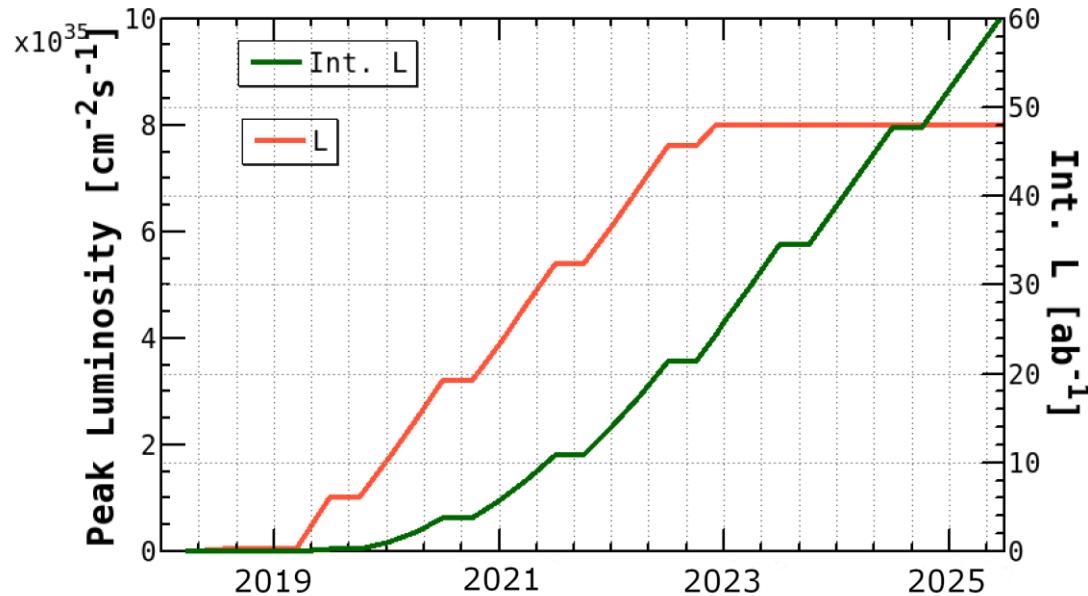
- Phase 2:
 - Good PXD performance
 - Successful integration into global Belle II DAQ and global slow control
 - Background more than 10x higher than expected
- Phase 3:
 - Full layer 1 and partial layer 2 installed
 - VXD inserted into Belle II
 - Digital tests successful, analog tests this week.

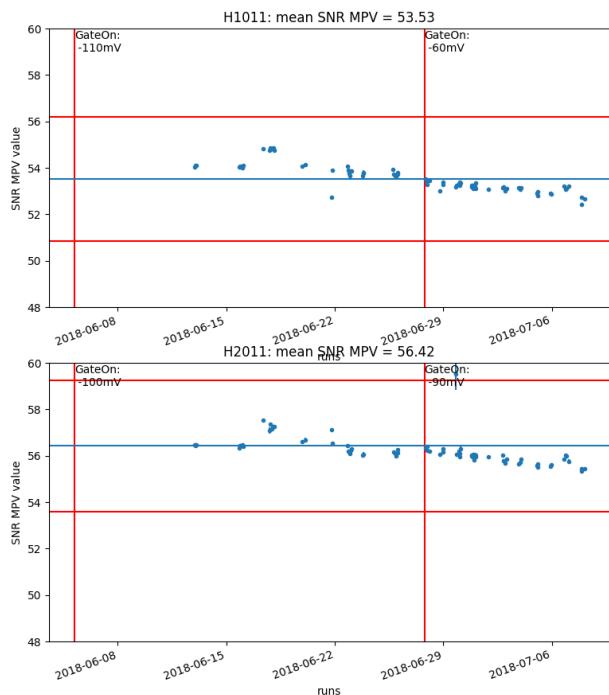
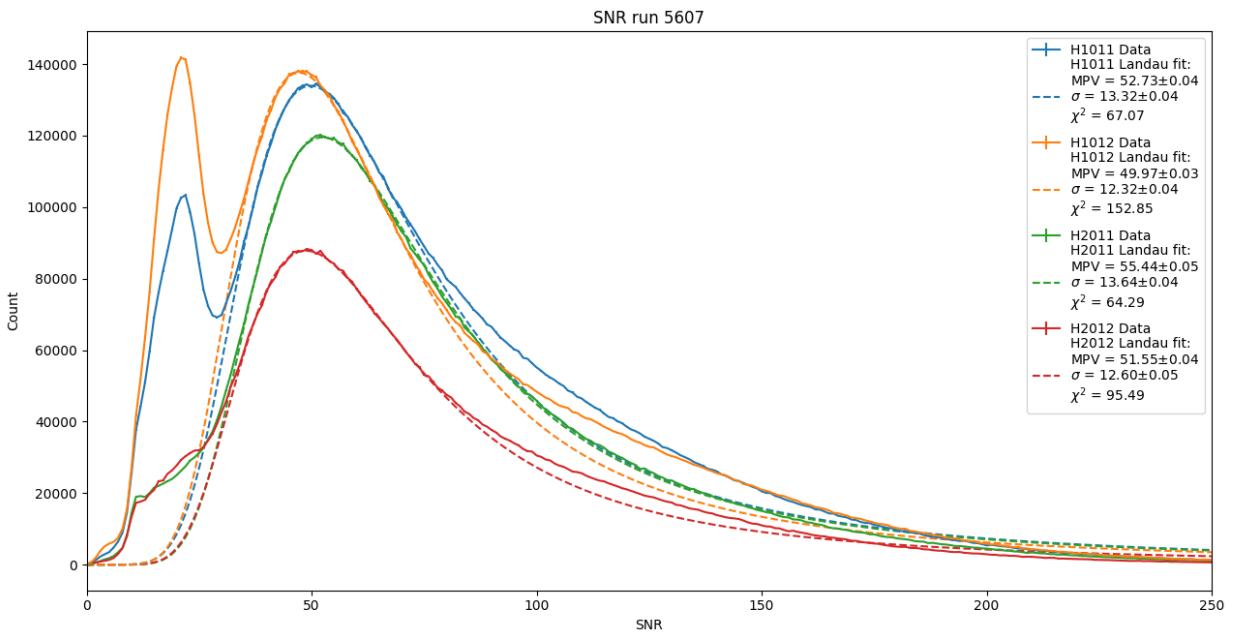
Thank you for listening.
Questions?

- Estimation for finding/resolution

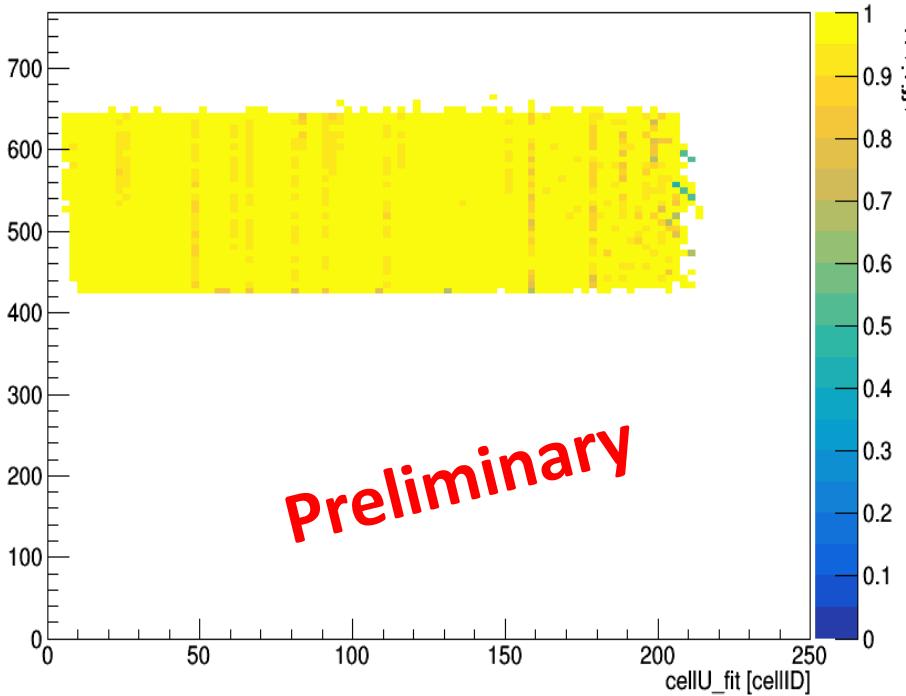
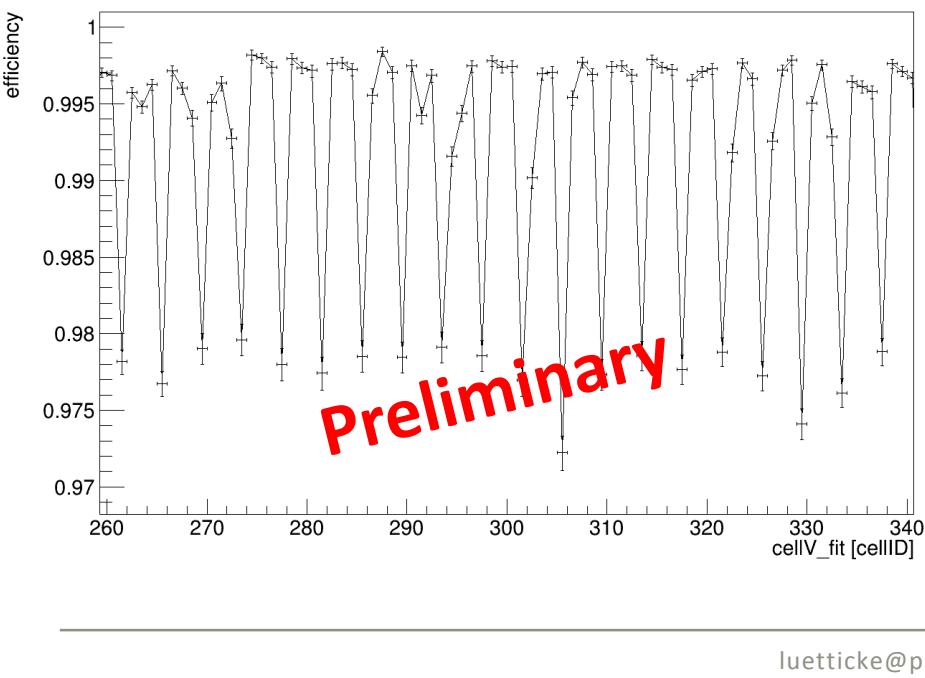


UPDATED LUMINOSITY PROFILE

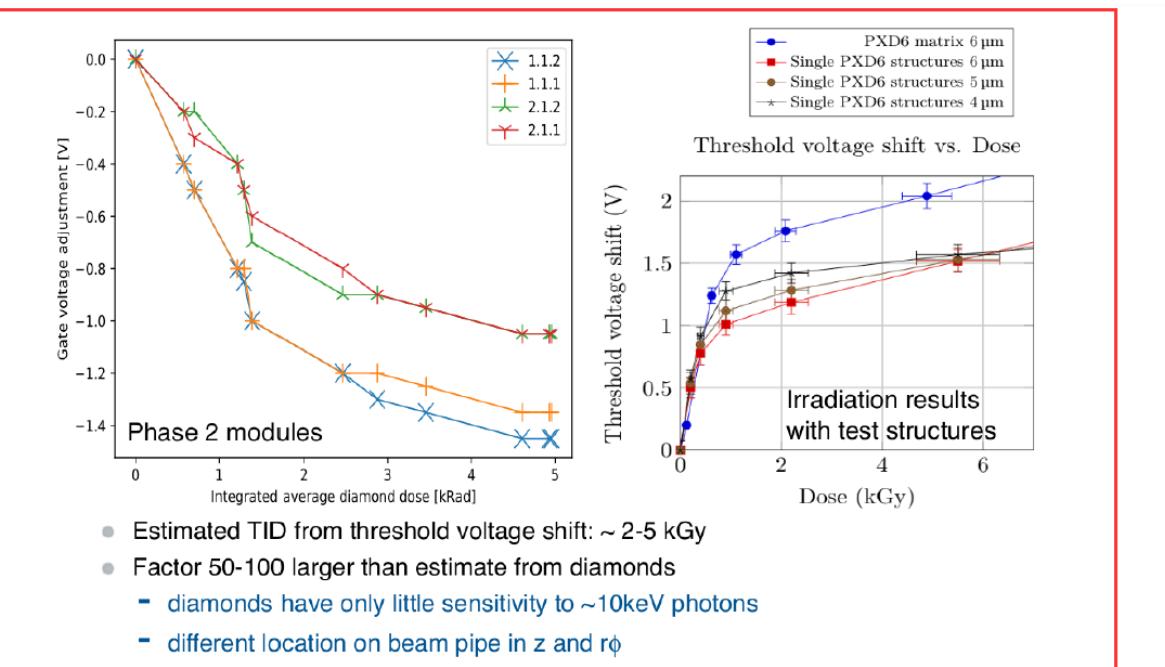




EFFICIENCY DURING BEAM TEST



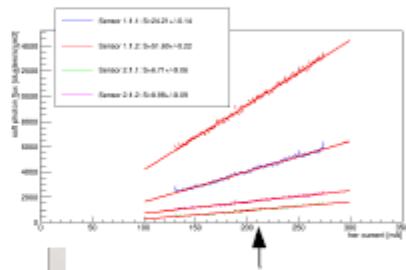
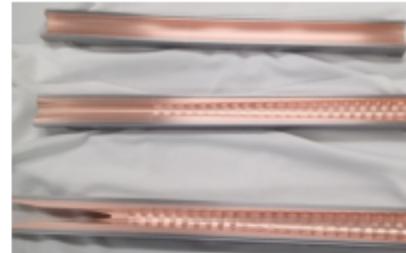
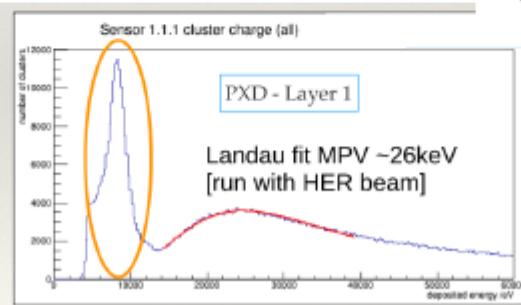
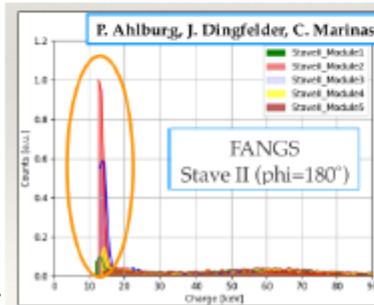
TOTAL IONIZING DOSE FOR PXD



- Radio-chromic foils @ diamonds see factor 5-10 higher dose than diamonds and a soft radiation component (<100keV)
- Ratio of PXD dose rate (sens. Si volume) to diamond dose rate gives factor 10-100 depending on run condition

SR RADIATION BACKGROUND IN PHASE 2

- $R_{sr} = E^2 B^2 \rightarrow$ dominant contribution expected from HER
- Energy of SR photons expected to be from few keV to tens of keV
- Inner surface of beryllium beam pipe coated with Au layer to absorb SR photons
- Ridge structures of incoming pipes to avoid hits from forward reflected SR photons in beam pipe
- Direct hits stopped by tapered shape of incoming beam pipes
- PXD (+X) and FANGS (-X) observed soft photon peaks for both beam around 6-10keV
- "Postdicted" in new MC simulations with more precise Geant4 physics list

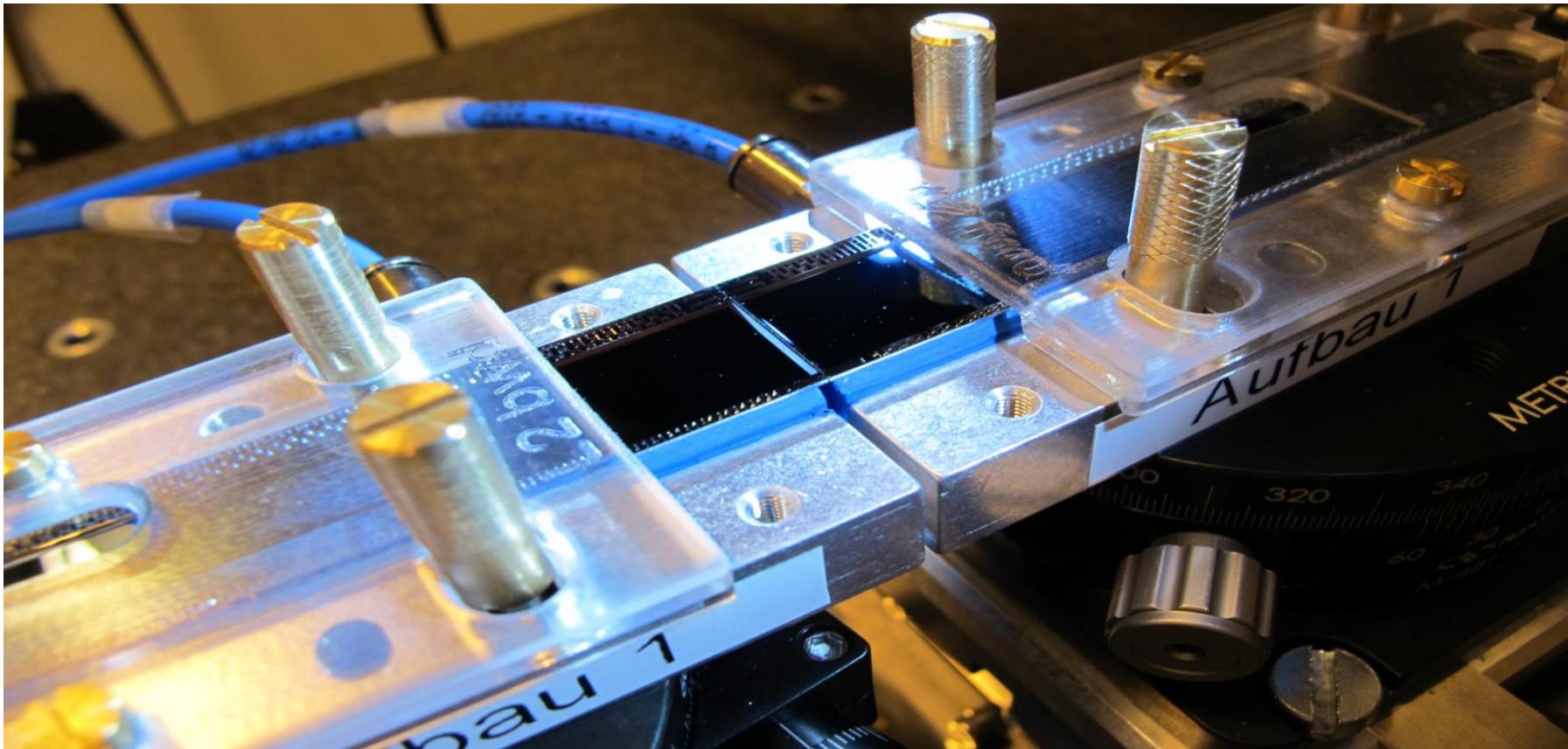


B. Schwenker,
Vertex 2018

PARTIAL PXD IMPLICATIONS

- Layer 1 important for physics parameters
- Layer 2 important to extrapolate the SVD track to the correct layer 1 PXD hit.
 - No Background: Negligible performance difference with full PXD.
 - Design Background: 2% Efficiency loss, slightly degraded time resolution
 - Higher Background: Much worse performance

LADDER ASSEMBLY



T Ackermann, E Töpper, H.G. Moser:

1) Module on transport & test jig

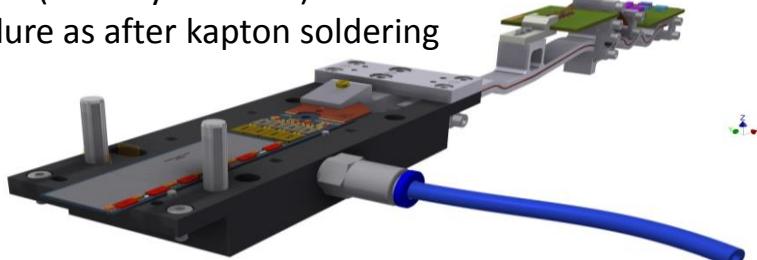


2) Take off and put on glue jig

Glue jig almost identical with test jig, just shorter

Held by vacuum (balcony and EOS)

Similar procedure as after kapton soldering



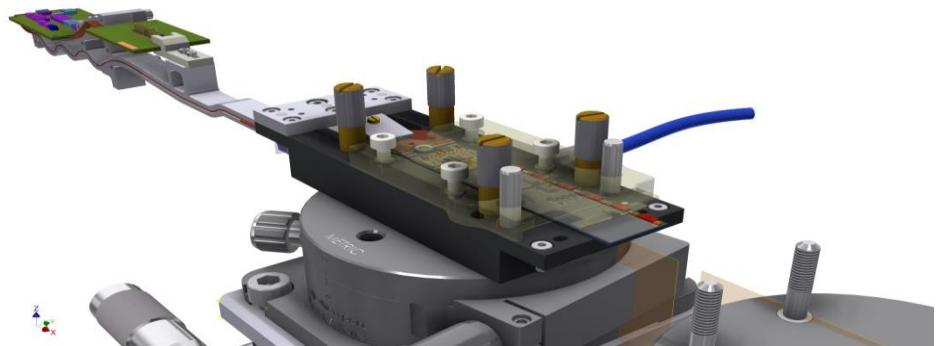
3) Cover with protective cover & clamp



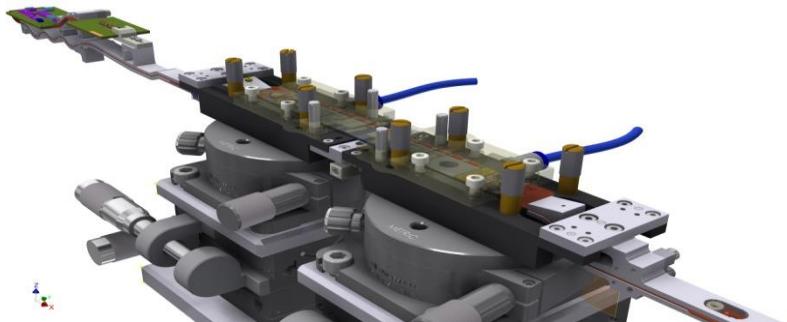
4) Dispense glue (modules & stiffeners)

NEW METHOD (CONT.)

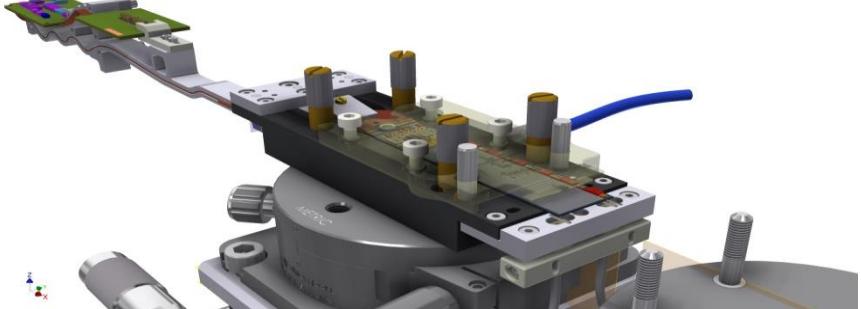
5) Place on alignment stage



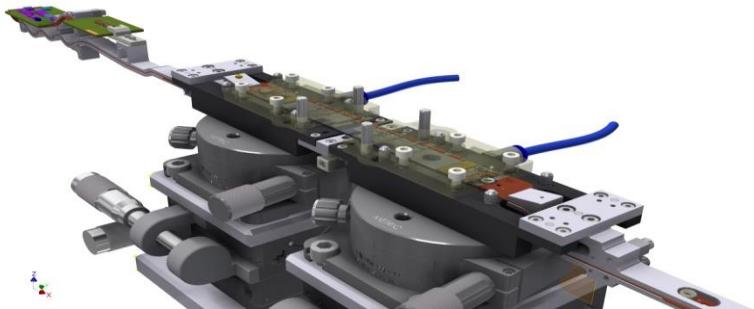
7) Place 2nd module on stag



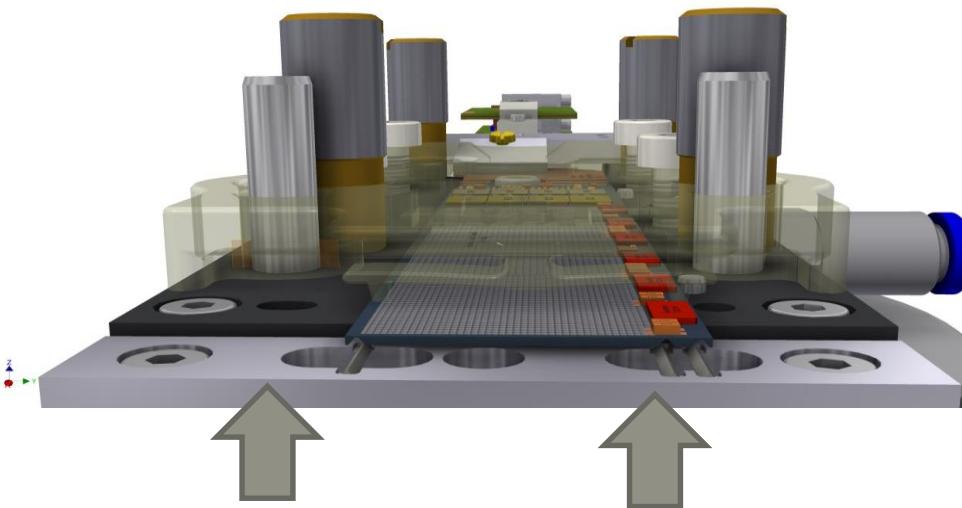
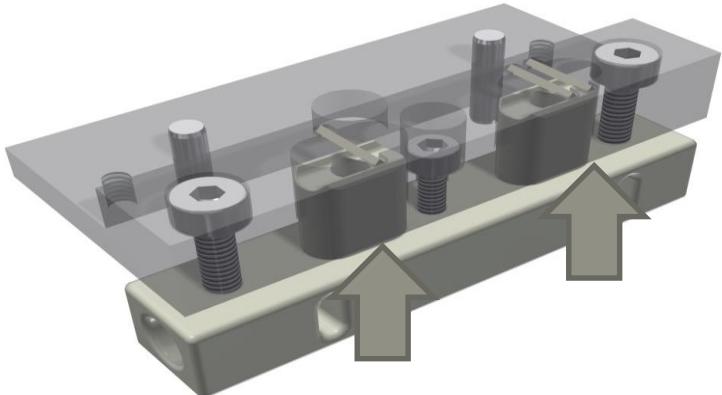
6) Add table with ceramic stiffeners



8) Align and join together

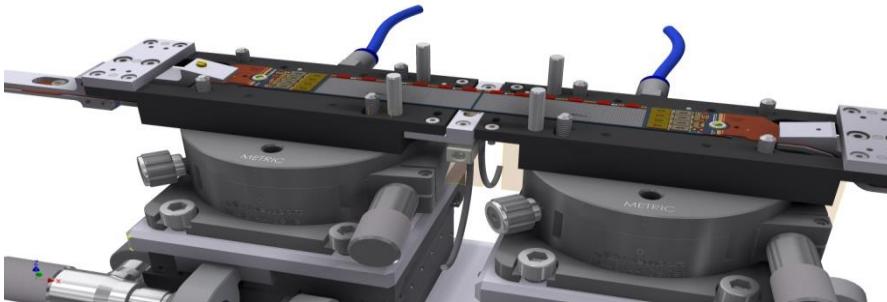


NEW METHOD (CONT.)

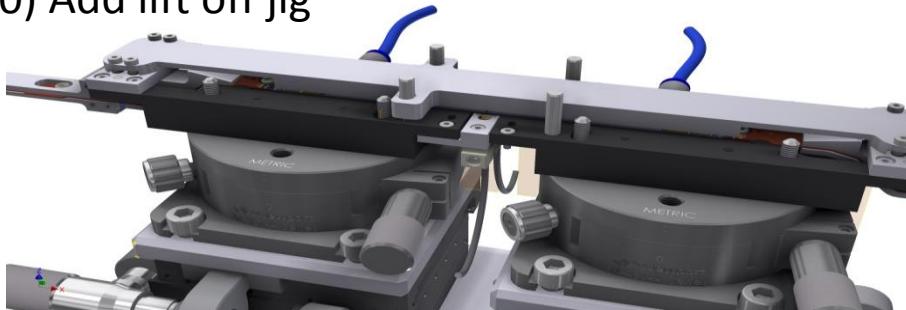


Ceramic stiffeners placed in slots in a table exactly under the grooves.
Pushed inside grooves by lifting guided lifters.
Stops to prevent over-travel.
Self alignment due to triangular geometry (to be checked).

9) Place stiffeners, cure for 48h



10) Add lift off jig



11) Lift off and place on ladder jig
Same procedure as for ladder mounting



12) Remove lift off jig

