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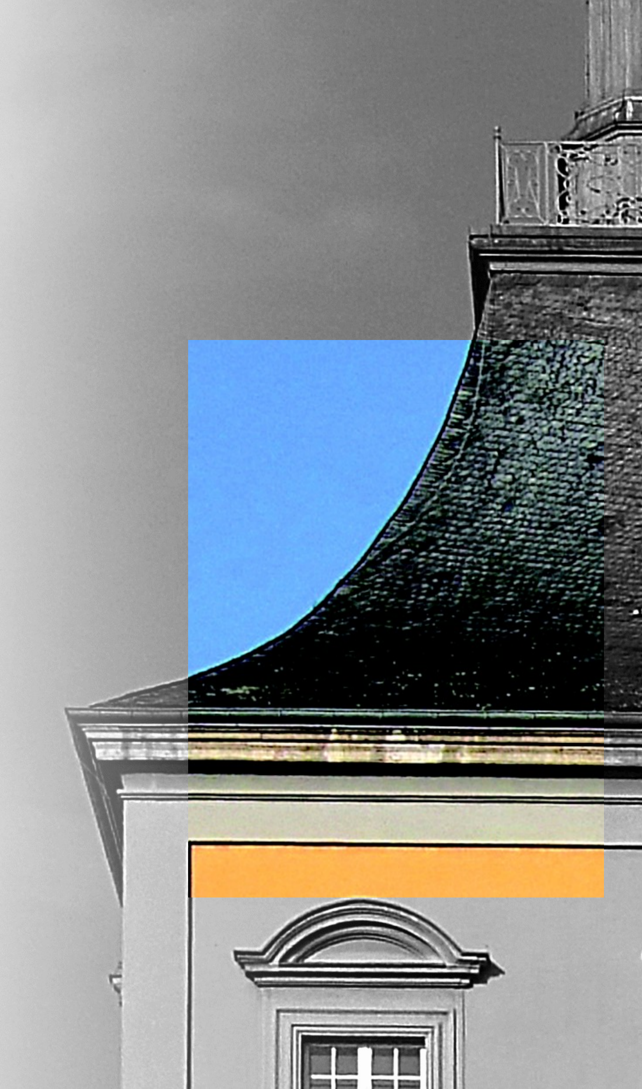
THE BELLE II PIXEL DETECTOR (PXD)

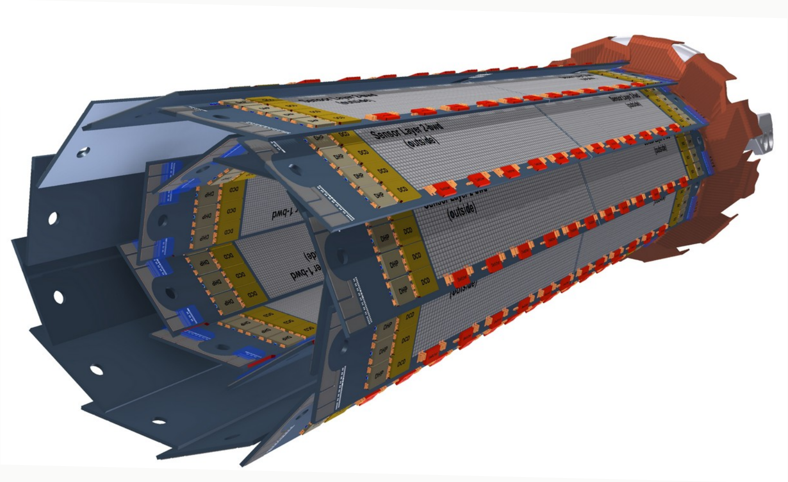


5^{th} Belle II Starterkit Workshop, KEK

31.01.2020

PXD BASICS – AT A GLANCE

- Silicon detector based on DEPFET technology
- Full configuration: 2 layers of 8 and 12 ladders with 40 sensors in total (7.68 Mpx) at 1.4 cm and 2.2 cm
  - Currently: full L1 (8 ladders), partial L2 (2 ladders), 20 sensors in total (3.84 Mpx) installed
- 20 µs integration time (rolling shutter readout)
- Maximum of 3% occupancy acceptable
- Very thin: active region only 75 µm thick, 500 µm frames for self-supporting structure
  - Just 0.2% X_0 per layer



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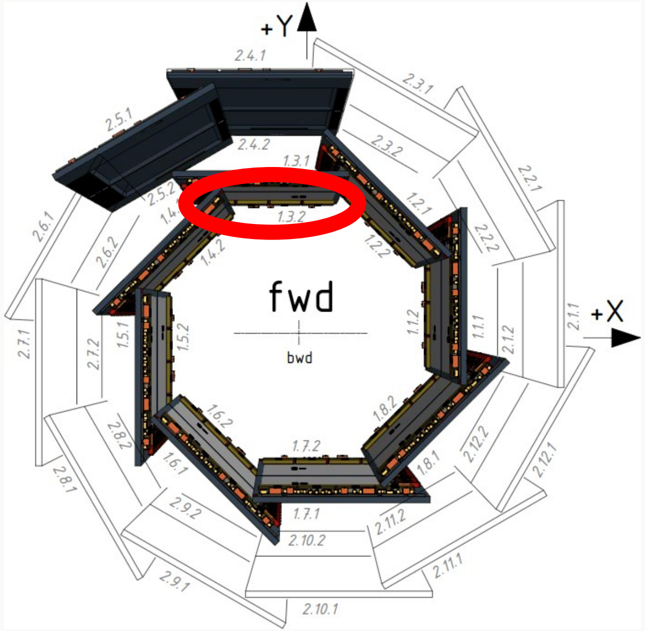
  - But 1 module in L1 switched-off (1.3.2), so 19 sensors (3.65 Mpx)
  - Issues were known before, so it‘s backed-up with the two ladders in L2



DEPFET – WHAT IS THAT? (SIMPLIFIED)

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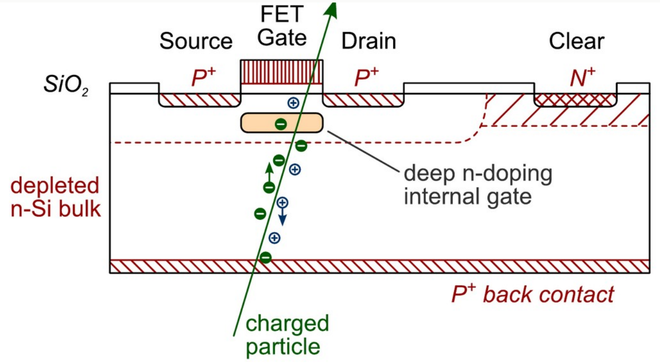
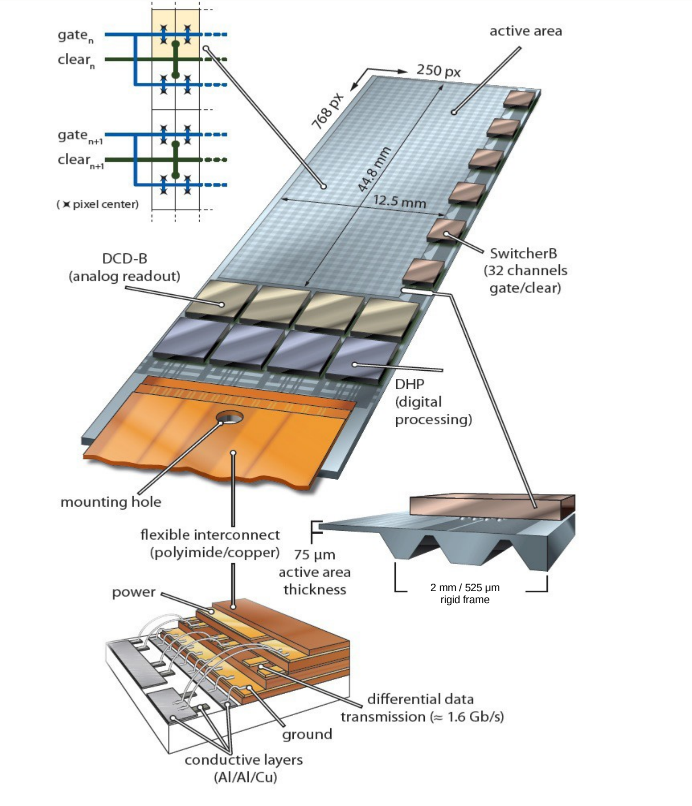
- DEPFET: Depleted P-channel Field Effect Transistor
- Particle passes through depleted region (depleted = no free space charges) and creates electron-hole (e-h) pairs
- Electrons drift into internal gate, holes to p-doped backside
- During readout charge in internal gate is measured non-destructively, electrons stay in internal gate (measurement can be repeated)
- Charge signal is amplified by transistor
- Amplified signal is digitized and sent out to DAQ system
- Clear pulse clears internal gate, pixel ready for next measurement



DEPFET – WHAT IS THAT? (SIMPLIFIED)

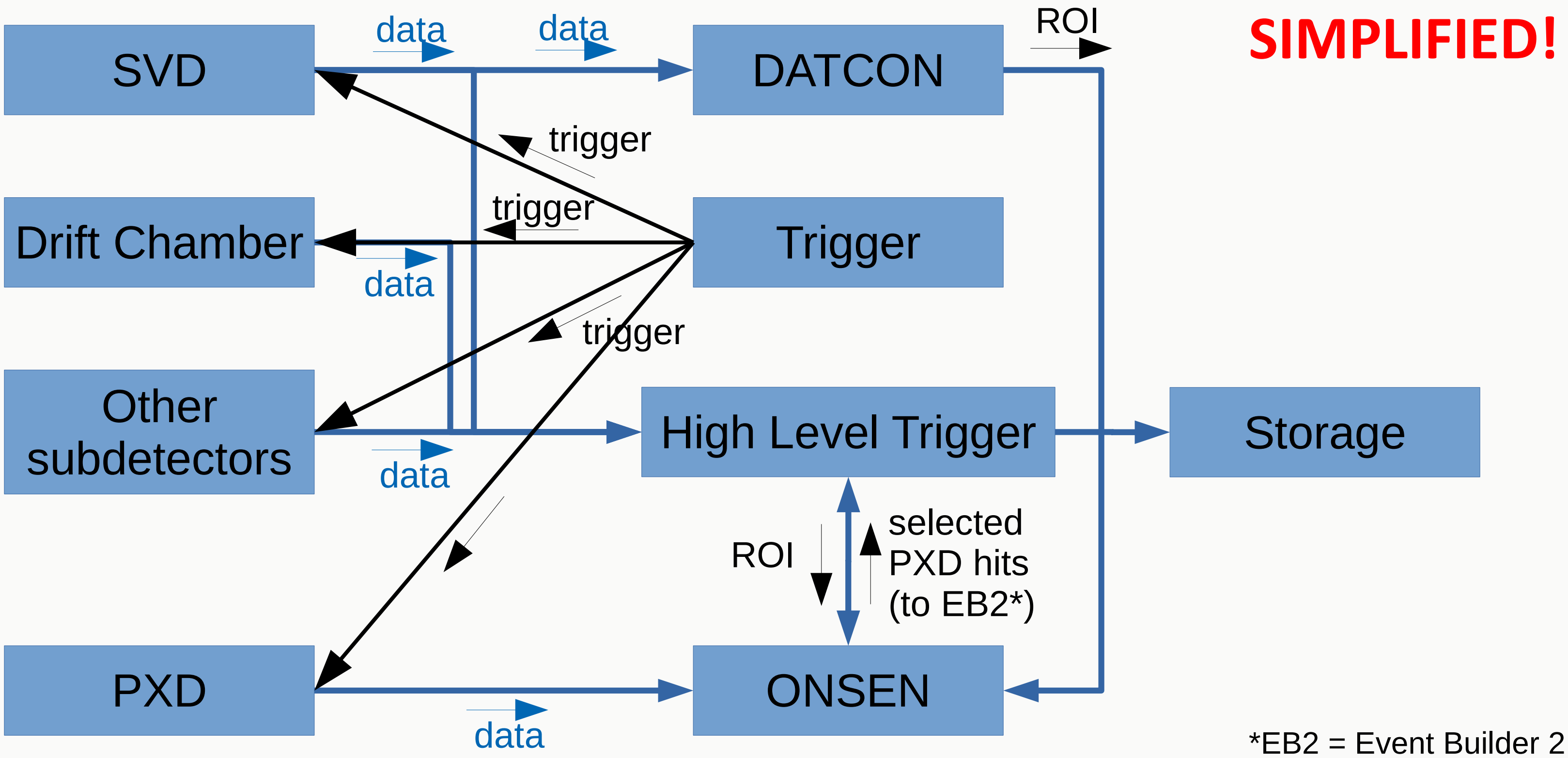
- Active area of modules has a length of 44.8 (61.44) mm and a width of 12.5 mm for L1 (L2)
- 250 x (256+512) pixels (50 µm x (55-85) µm)
- 3 different ASICs (Application Specific Integrated Circuit):
  - 6 switchers on the long edge – switch between rows
  - 4 Drain Current Digitizers (DCD) – digitize signal
  - 4 Data Handling Processors (DHP) – stores data for short time and removes noise (and more...)
- Highly integrated and complex detector



PXD DAQ SYSTEM

- High data rate due to high granularity
  - At 3% occupancy 20 GB/s = ~1 MB / event
  - Mostly background hits, neither neccessary nor possible to store all data
- PXD has an online data reduction system
  - Extrapolate found tracks onto PXD sensors to calculate Region of Interest (ROI) and only store active pixels within these, selection is made in ONSEN (ONline SElector Node)
  - Two systems for this: HLT (using full tracking or SVD tracking only) and DATCON (Data Acquisition Tracking Concentrator Online Node) run on FPGAs (Field Programmable Gate Arrays)
  - Has to be fast and reliable – pixel hits outside RoI are not be stored and lost forever
- Data reduction by a factor of ~10 required to about 100 kB / event

PXD DAQ SYSTEM



*EB2 = Event Builder 2

LOW MOMENTUM CLUSTER RESCUE

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- As seen in the talk on particle detectors, low momentum (and thus low energy) particles lose more energy in the same amount of material
- In Belle II we are interested in the decay $D^* \rightarrow D\,\pi_s$ where the index s indicates a slow or soft pion
- This means the pion has low energy (up to a few 100 MeV) and thus tends to leave high energy clusters in the PXD but maybe don‘t even traverse the full SVD
- The cluster rescue algorithm should take care of these clusters to be stored even if they are not inside an RoI
- But: this algorithm is not net implemented, only planned so far
- Would be a nice feature for future studies to better reconstruct the above decay in future

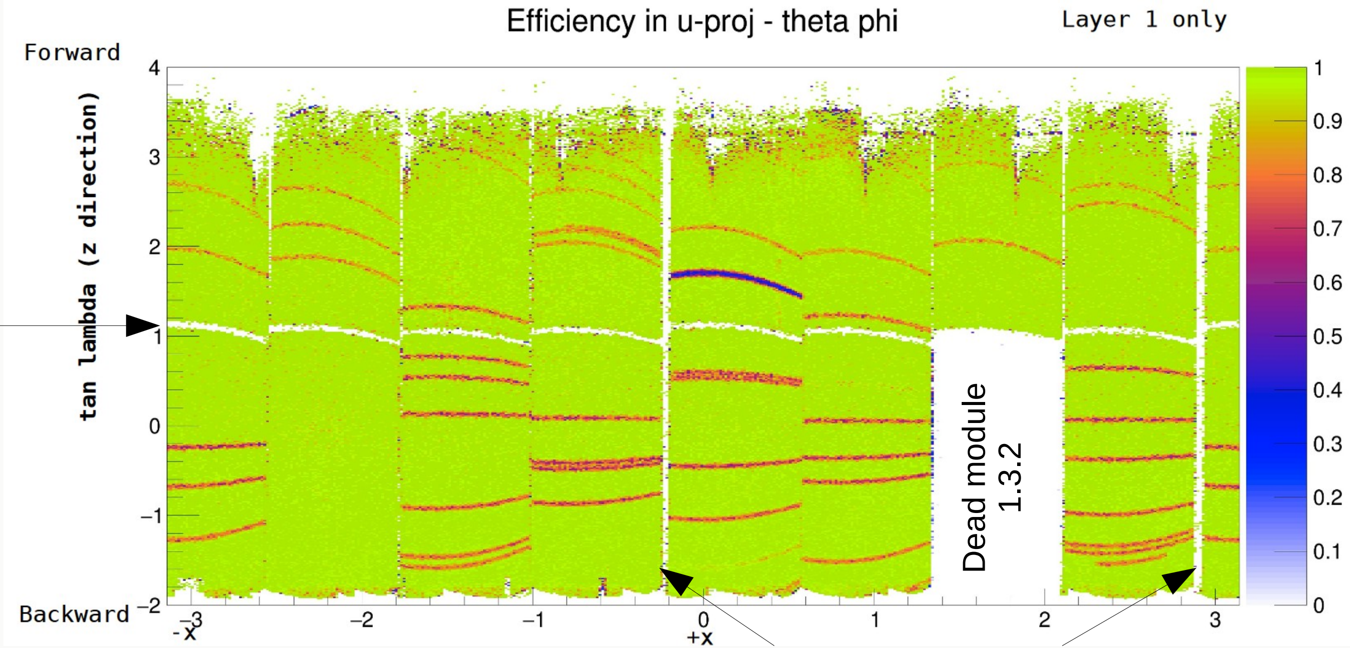
PXD DATA

- Because of online data reduction, PXD heavily relies on the CDC and SVD to work really well, as well as tracking
- If the correct hit belonging to a track is not inside a RoI, the wrong one might be attached to the track, or none at all
- Both has negative influence on track parameter estimation (see tracking lecture), vertexing performance (see vertexing lecture), and possibly life time measurements for e.g. time dependent CPV measurements
- Even with data reduction, the true PXD hit still drowns in background hits
  - At 3% occupancy and with about 3 pixels per hit: 76.8k hits in PXD (rather more)
  - Reduction by factor 10: >7000 hits in RoI
  - Only about 25 hits of tracks among these

PXD PERFORMANCE

- Measuring PXD performance is a bit tricky
- After applying RoI selection, it‘s a convolution of
  - Track reconstruction – no track → no RoI
  - RoI calculation – RoI too small → correct hit might be outside RoI (but usually there is at least some hit inside the RoI that might be attached to a track)
  - Actual PXD sensor efficiency
- Results shown on following slides resemble this

PXD HIT EFFICIENCY – LAYER 1 ONLY



Glued area between modules*

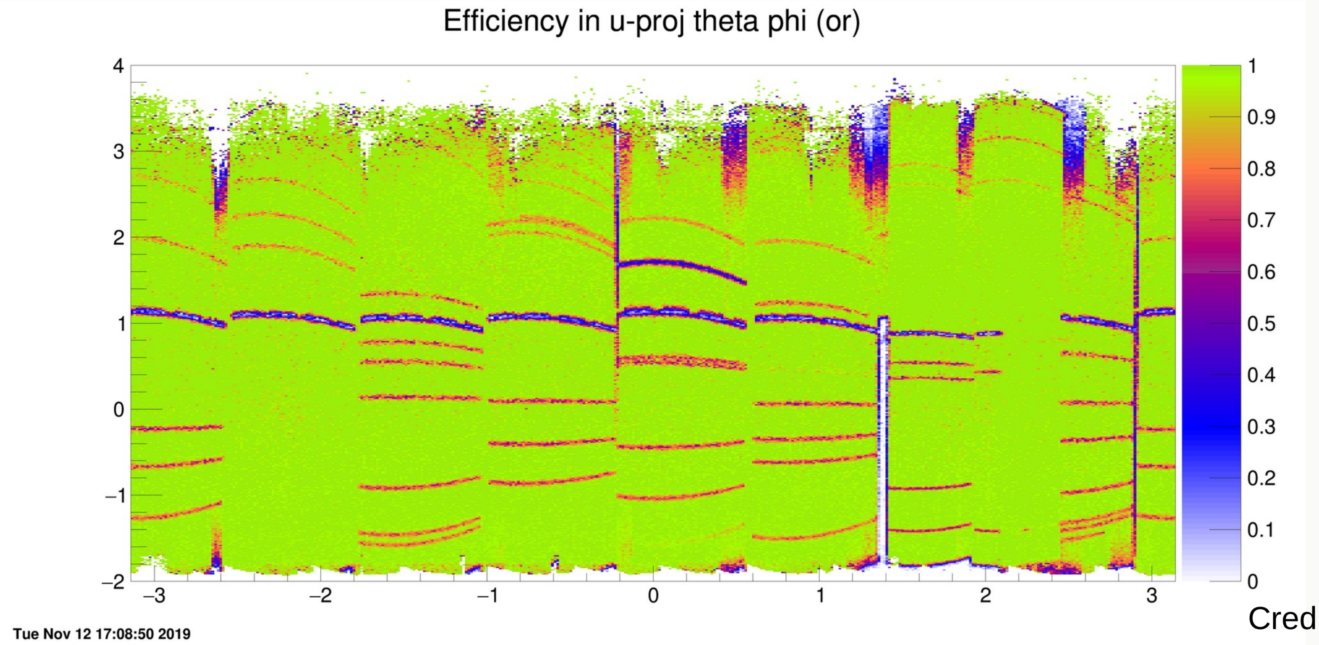
*Artificial gaps between all modules because 10 pixel closest to boarders are not used for analysis (in all cases)

Gap between half shells*

Credit: B. Spruck

- Efficiency of PXD on L1
- Red lines are low efficiency regions due to dead gates (switcher ASICs)

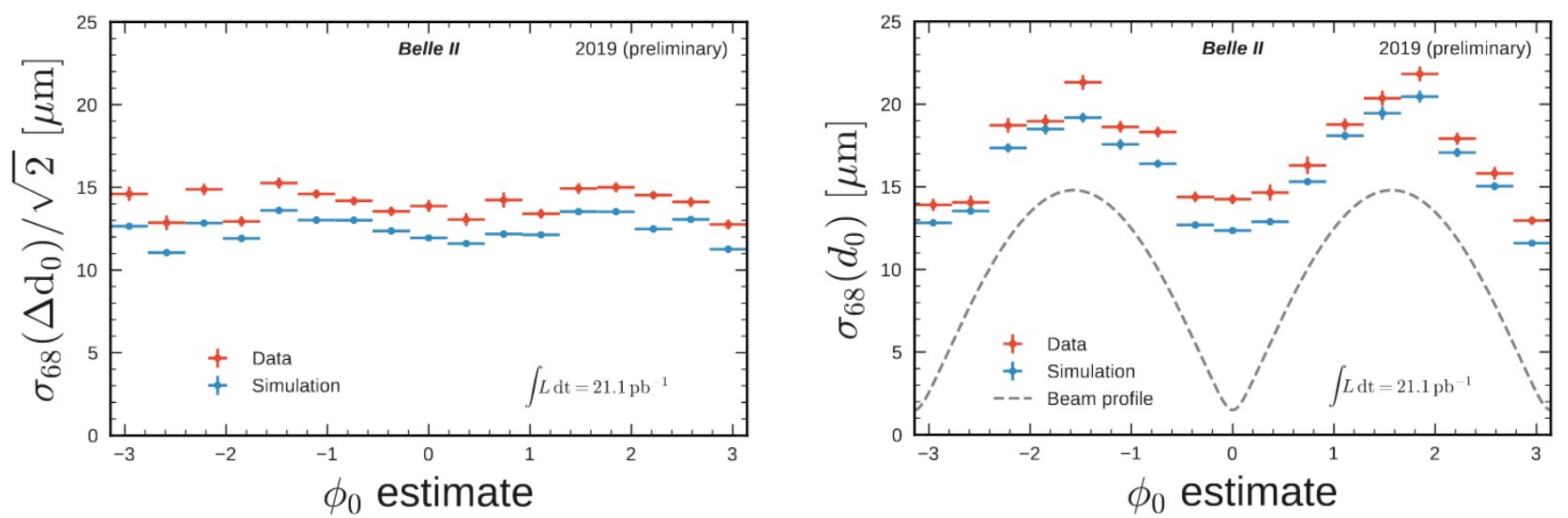
PXD HIT EFFICIENCY – BOTH LAYERS



Credit: B. Spruck

- Efficiency when requiring a hit in L1 **or** L2
- Inefficient regions have same reasons as explained on previous slide

PXD VERTEX RESOLUTION



- Vertex resolution using PXD data, left distribution of the impact parameter resolution error, right the impact parameter resolution
- In both cases, data are close to simulation values

SUMMARY

- PXD works well but already suffers from radiation damage
- High efficiency in most of the detector
- Good primary vertex resolution
- Background worse than expected
- Depending on analysis, you should use a cut on the number of PXD hits in your analysis to be sure the tracks you‘re dealing with contain PXD hits (more details in tracking lecture)
- Full new PXD will be installed in 2021 or 2022 (depends on many other things)

THANK YOU FOR YOUR ATTENTION!