Readiness of PXD software for phase 2 & Preparation status for phase 3

BPAC focused review on VXD, 15.10.17

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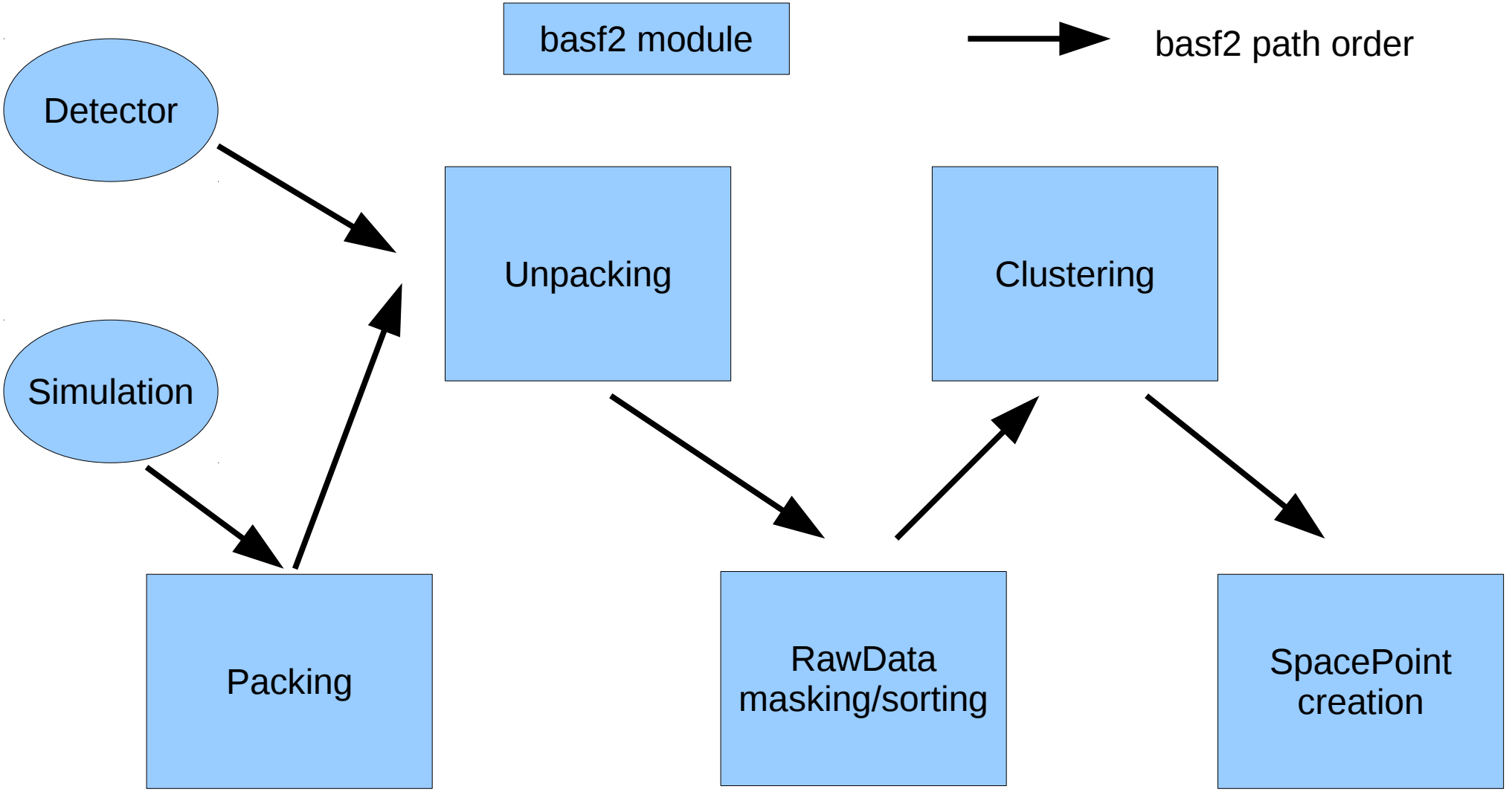
Overview of PXD software



All basf2 modules and data objects for this flow-diagram exist & working

Packing/unpacking of raw data

:- based on documentation: PXD DAQ Data Formats (Belle II technical note)

:- RawPXD object: Exact copy of data received on event builder from one Onsen selector node (Phase 3 setup: 8 RawPXD objects per event)

:- PXDUnpacker: basf2 module which decodes RawPXD objects and unpacks data into new dataobjects.

:- PXDRawHit: data object for single hit after zero suppression (sensorID, ucell, vcell, signal, startrow, …)

:- PXDRawROIs: data objects for ROIs sent from HLT and ONSEN to to event builder

:- objects for non zero suppressed data (→pedestals) or hardware clusters.

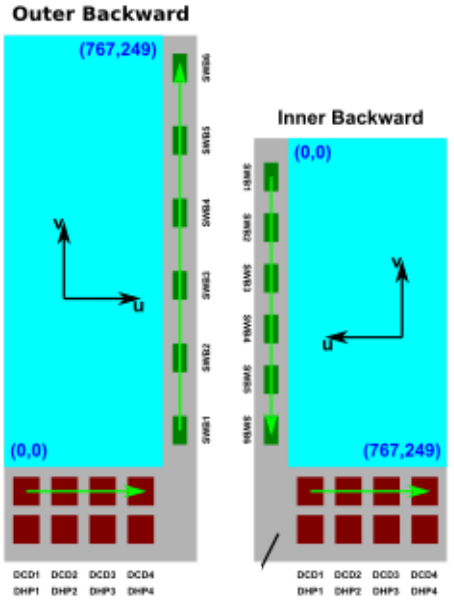
:- PXDPacker: basf2 module which encodes simulated PXD hits (PXDDigits) into RawPXD objects

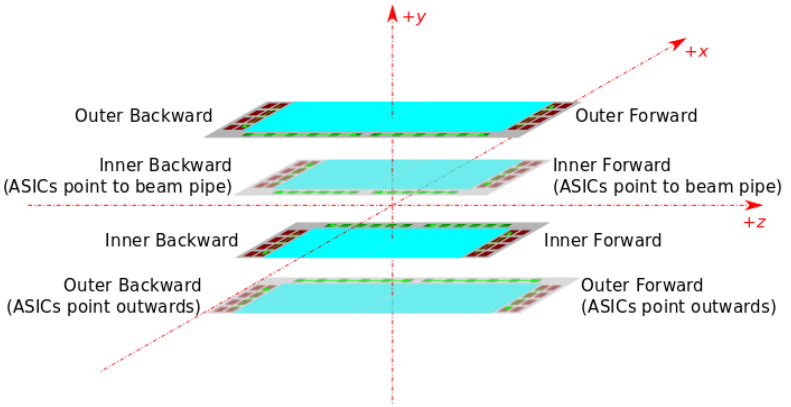
Dedicated basf2 test available to check unpacking ‘inverts’ packing.

Packing/unpacking of raw data (cont.)

:- Error checking and checksumming is done during unpacking.
  :- currently errors are logged
  :- missing: dedicated data object to hold found problems for DQM (critical for Phase2)

:- PXD will start with hit-based data format in phase2:
  → requires mapping of zero suppressed hits: row/col → vcell/ucell
  → in firmware on ONSEN for ROI filtering and offline in unpacker (→ checked in TB17)





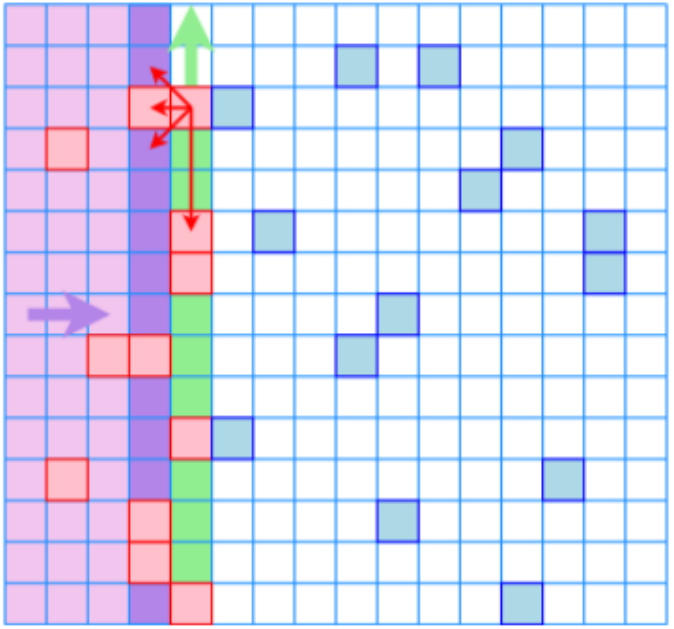
[Belle II Note 10: The vertex detector numbering scheme]

Masking and clustering

:- PXDRawHitSorter: basf2 module which reads PXDRawHits and creates PXDDigits sorted (for each sensor) by frameNr, vcell and ucell.

:- applies a bad pixel mask to filter crap data
:- currently read from a XML file
:- will be read from a dbobject soon

:- PXDClusterizer: basf2 module for clustering and hit reconstruction.



Fast2D clustering: (M. Ritter)
:- running buffer for digits in a single row (blue)
:- generic case: look at three positions in buffer and nearest pixel downstream in current row.

Missing:
:- clustering not ‘aware’ of ignored pixels
:- ‘global’ signal thresholds for accepting cluster

→ ConditionsDB interface under work

Hit reconstruction for different cluster sizes

*Turchetta, R. : Spatial resolution of silicon microstrip detectors. NIM A335 (1993) 44-58

:- PXDCluster contains:

- 2d position on sensor
- 2x2 covariance mat.

- sum of charges
- highest charge

:- mostly based on Turchetta* classical paper.

Hit position: (u_c, v_c)	Hit position error $\begin{pmatrix} \sigma_u^2 & \rho\sigma_u\sigma_v \\ \rho\sigma_u\sigma_v & \sigma_v^2 \end{pmatrix}$
Positions and their errors are calculated separately from cluster projections to each direction. The correlation coefficient is calculated as $\rho = \frac{\sum_{pixels} S_i (u_i - u_c)(v_i - v_c)}{\left(\sum_{pixels} S_i [(u_i - u_c)^2 + \epsilon_u^2]\right)^{1/2} \left(\sum_{pixels} S_i [(v_i - v_c)^2 + \epsilon_v^2]\right)^{1/2}}$	(u_i, v_i) pixel positions S_i pixel signals $\epsilon_u = \frac{p_u}{\sqrt{12}}$ in-pixel spread $\epsilon_v = \frac{p_v}{\sqrt{12}}$ in-pixel spread
size in u = 1 Center of pixel	$\sigma_u = p_u \frac{(n_v+2)S_{thr}}{S+(n_v+3)S_{thr}}$ n_v cluster size in v S_{thr} 0-supp. threshold
size in u = 2 $u_c = \frac{S_1 u_1 + S_2 u_2}{S}$	$\sigma_u = p_u \frac{(n_v+2)S_{thr}}{S+(n_v+3)S_{thr}}$ n_v cluster size in v S_{thr} 0-supp. threshold
size in u > 2 $u_c = \frac{u_h+u_t}{2} + p_u \frac{S_h - S_t}{2S_0}$, $S_0 = \sum S_i$	$\sigma_u = \frac{p_u}{2}\left[2\left(\frac{S_{thr}}{S_0}\right)^2 + \frac{1}{2}\left(\frac{S_h}{S_0}\right)^2 + \frac{1}{2}\left(\frac{S_t}{S_0}\right)^2\right]^{1/2}$

The same formulas are used for v

Track dependent hit reconstruction

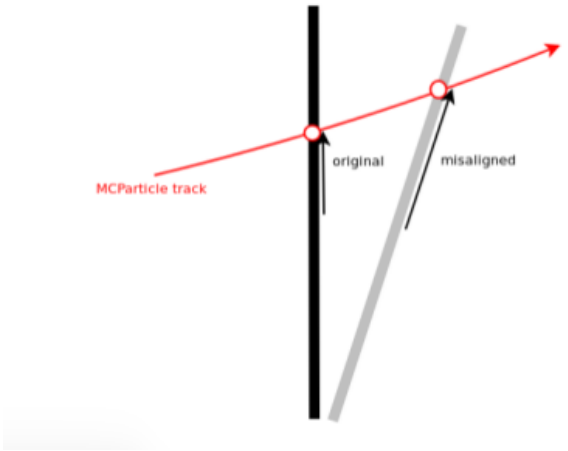
:- PXDRecoHits pass reconstructed hit data to tracking.

:- Tracking software asks for hit position and covariance mat. through RecoHit and passes current track state with query.

:- RecoHit provides access to lookup table for hit positions / 2x2 covariance mat from conditionsDB. If not available, use classical formulas for hit positions.

→ PXDRecoHit interface tested and working

:- Handling of misalignment uses logically similar mechanism (P. Kvasnicka/ T. Bilka)



Black: Position of planar sensor in Geant4 model.

Grey: Position of misaligned sensor; only trafo is stored.

Displace planar hit using state of MCParticle.

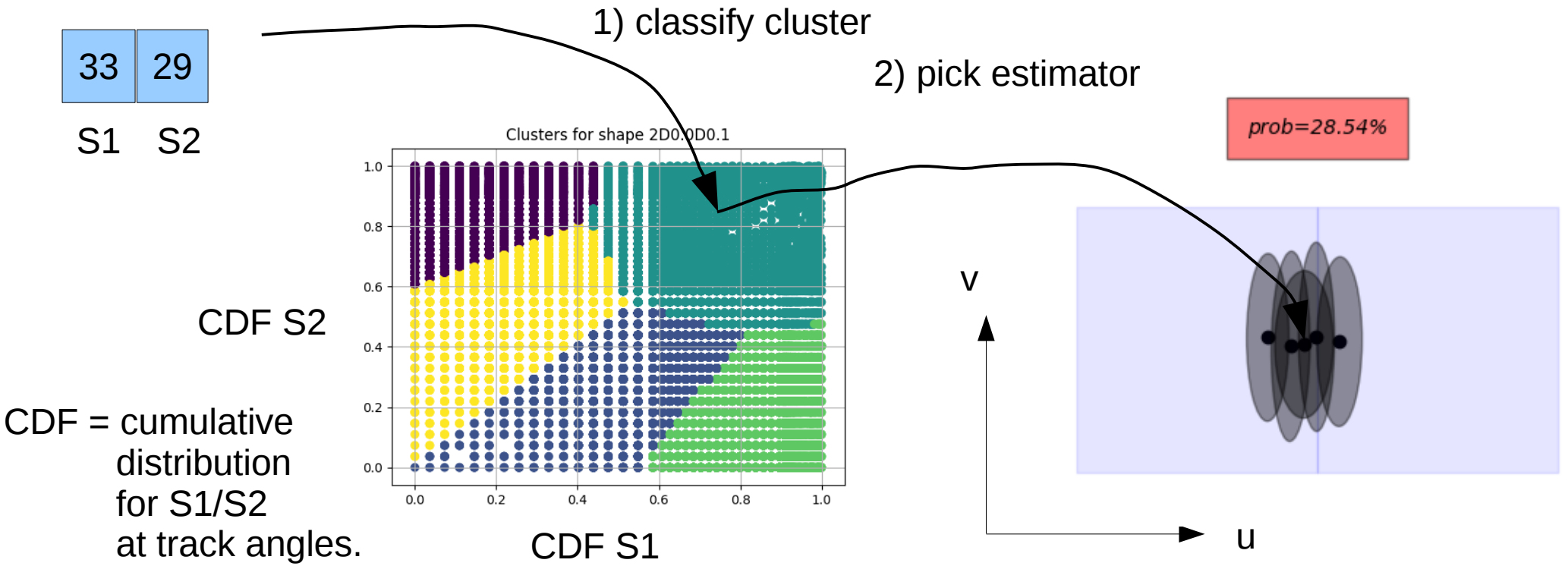
Track dependent hit reconstruction

:- Classify the clusters into shapes (shapeID) depending on angles (2D grid) and pixelkind.

:- Create lookup tables for positions and position covariance mat. for most frequent shapeIDs (either from test beam data or simulations).

:- Lookup tables also store probability that track of certain incidence angles creates shapeID

Example: '2u' cluster 'added' to track with θ_u =-25°, θ_v =0° (pixel kind 50x55µm^2)

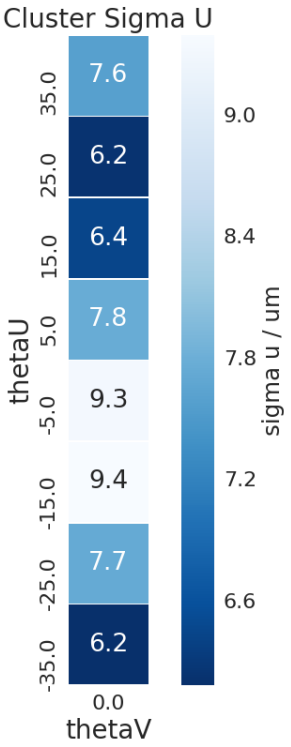


Intrinsic position resolution of PXD

:- Results for 50x55μm^2 pixels in Belle II magnetic field

:- Digitizer parameters fitted against data from test beam

Average cluster sigma

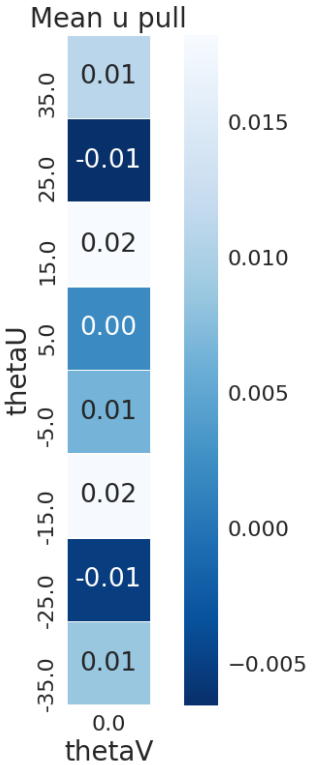


Reco Truth

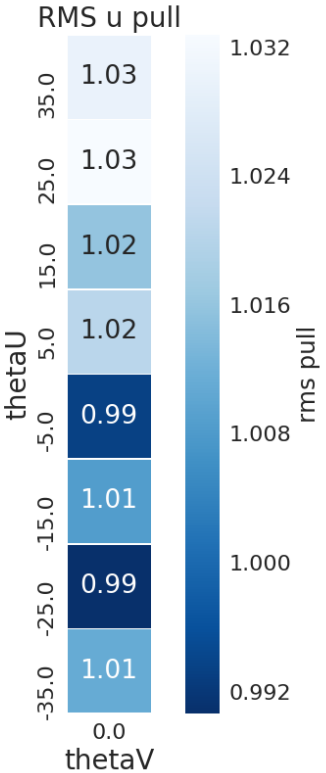
$$\mathbf{pull}_u = \frac{u_k^m - u_k^x}{\sqrt{V_{k,uu}}}$$

This is under active development
Plan to finish for phase 2.

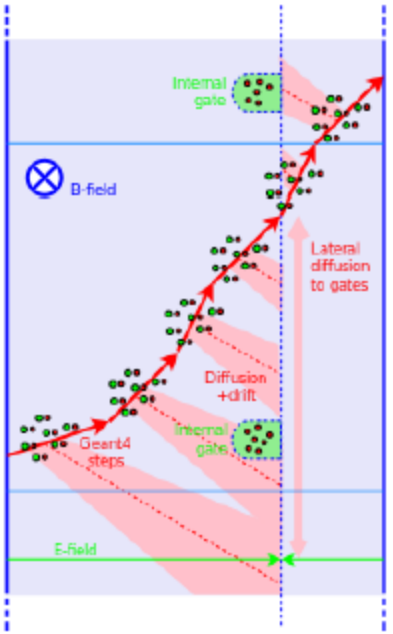
unbiased

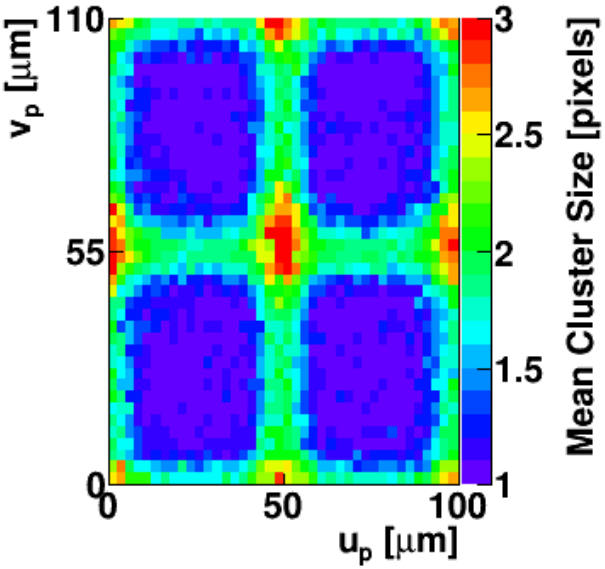


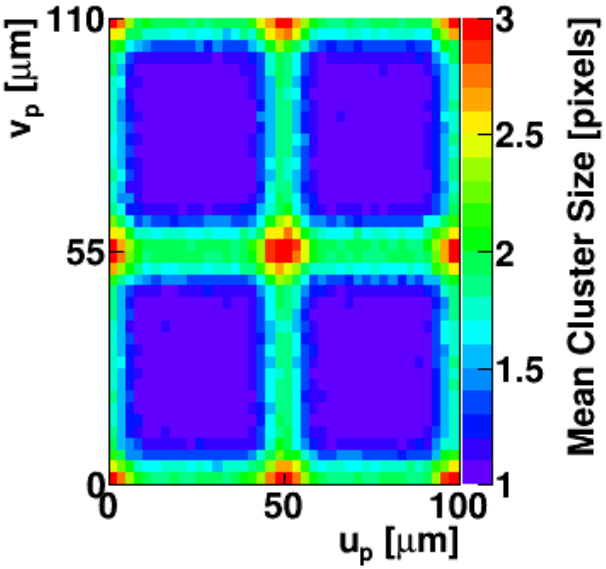
consistent



Validation of PXD detector simulation



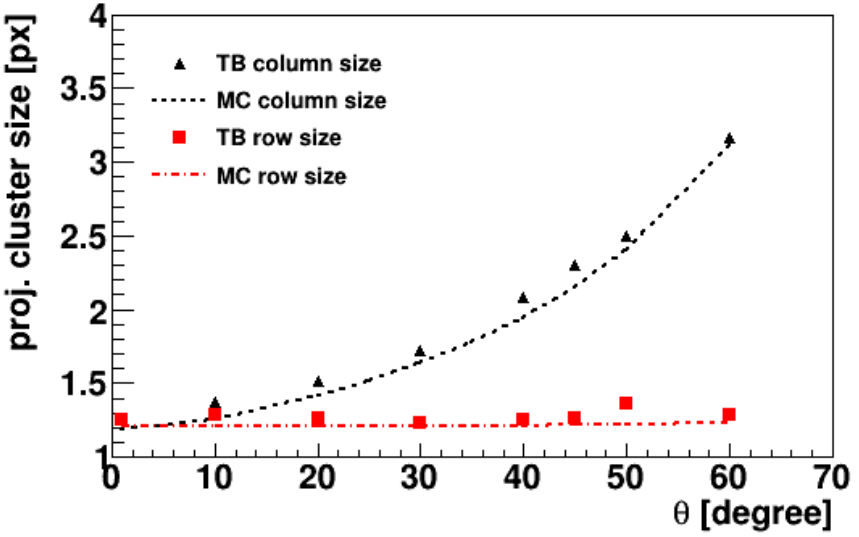




[PXD test beams at DESY with EUDET telescope]

:- Follow particle with small Geant4 steps (5um)
:- Velocity, diffusion and Lorentz shift intgrated into zero pot. plane.
:- Lateral diffusion into internal gate simulated as Brownian walk.

→ Stable code:

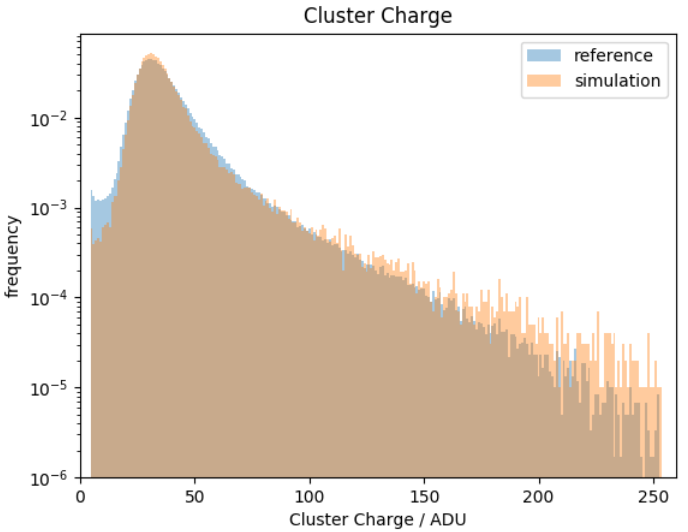


PXD detector simulation

:- PXDDigitizer:
  :- stable code, well tested on many test beams including TB17/TB17
  :- new: simulation of pedestals
    → ADC channel digitizes drain current + signal.
    → large variations of drain currents over matrix
    → left over range for signal varies from pixel to pixel
  :- missing feature: dead pixels & noisy (bad) pixels
  :- missing feature: simulation of gated mode

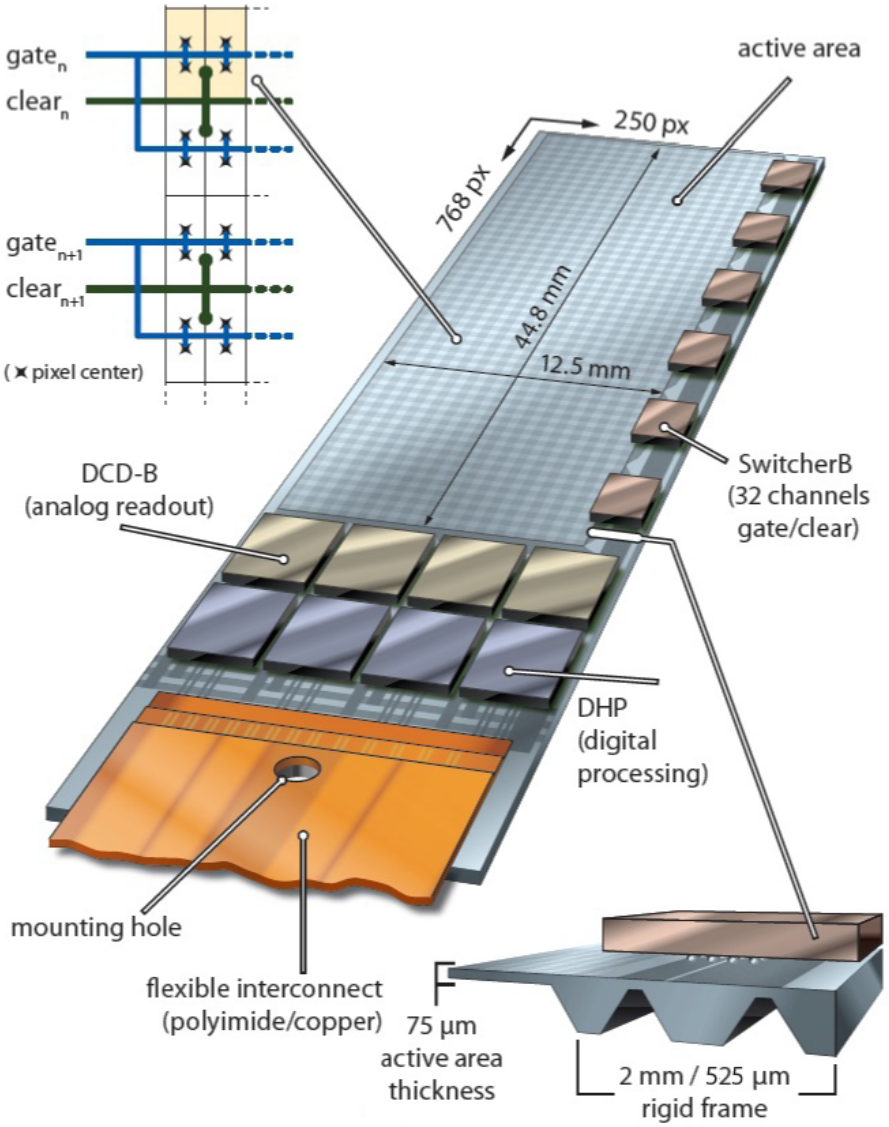
Pedestal mean=40ADU / rms=10ADU

Pedestal mean=150ADU / rms=40ADU



Data: DESY test beam Nov. 2015 (run 436)

PXD geometry & materials

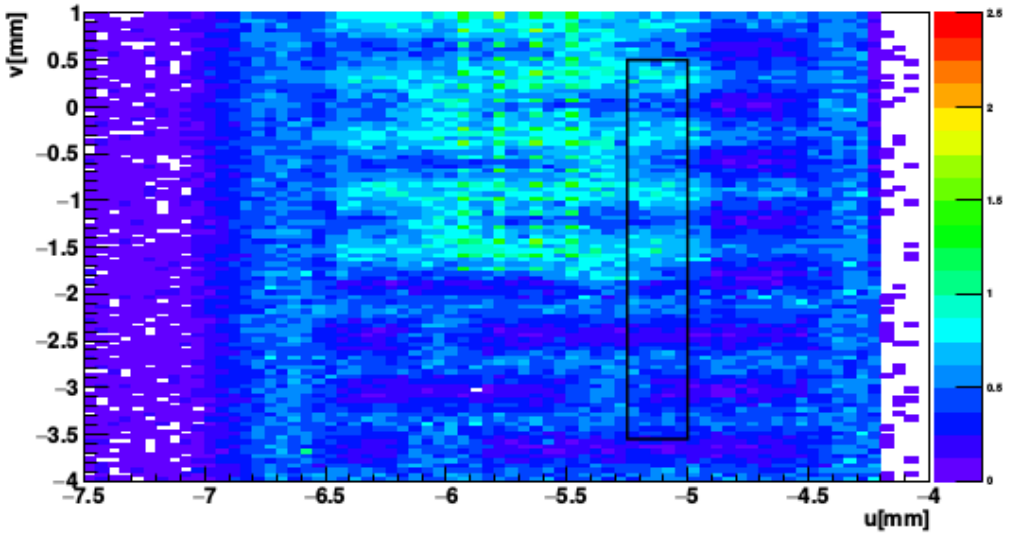


:- PXD ladder designed for low mass support.

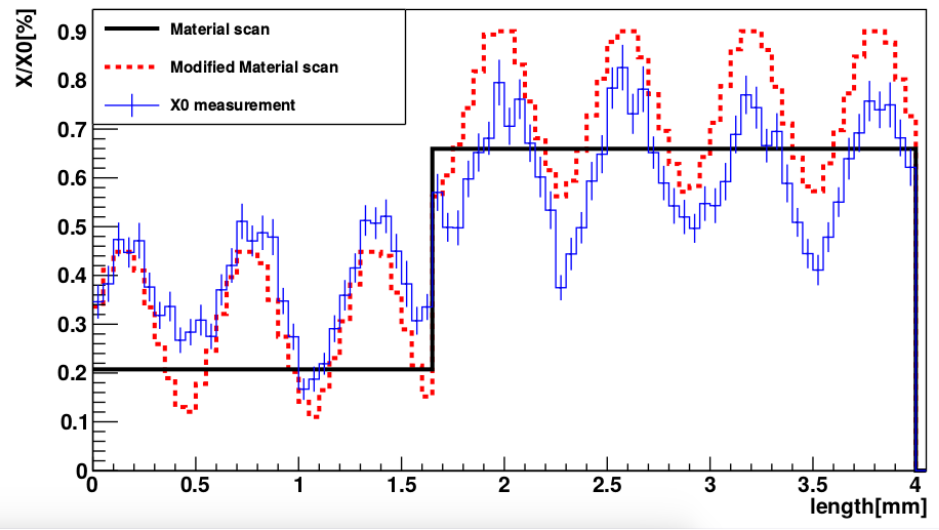
:- Still geometry not trivial to implement in Geant4 (ASICs, Caps, Si etchings)

:- Measured radiation length profile for PXD modules at test beam at DESY

X0 imaging: Reconstruct material profile from scattering kinks



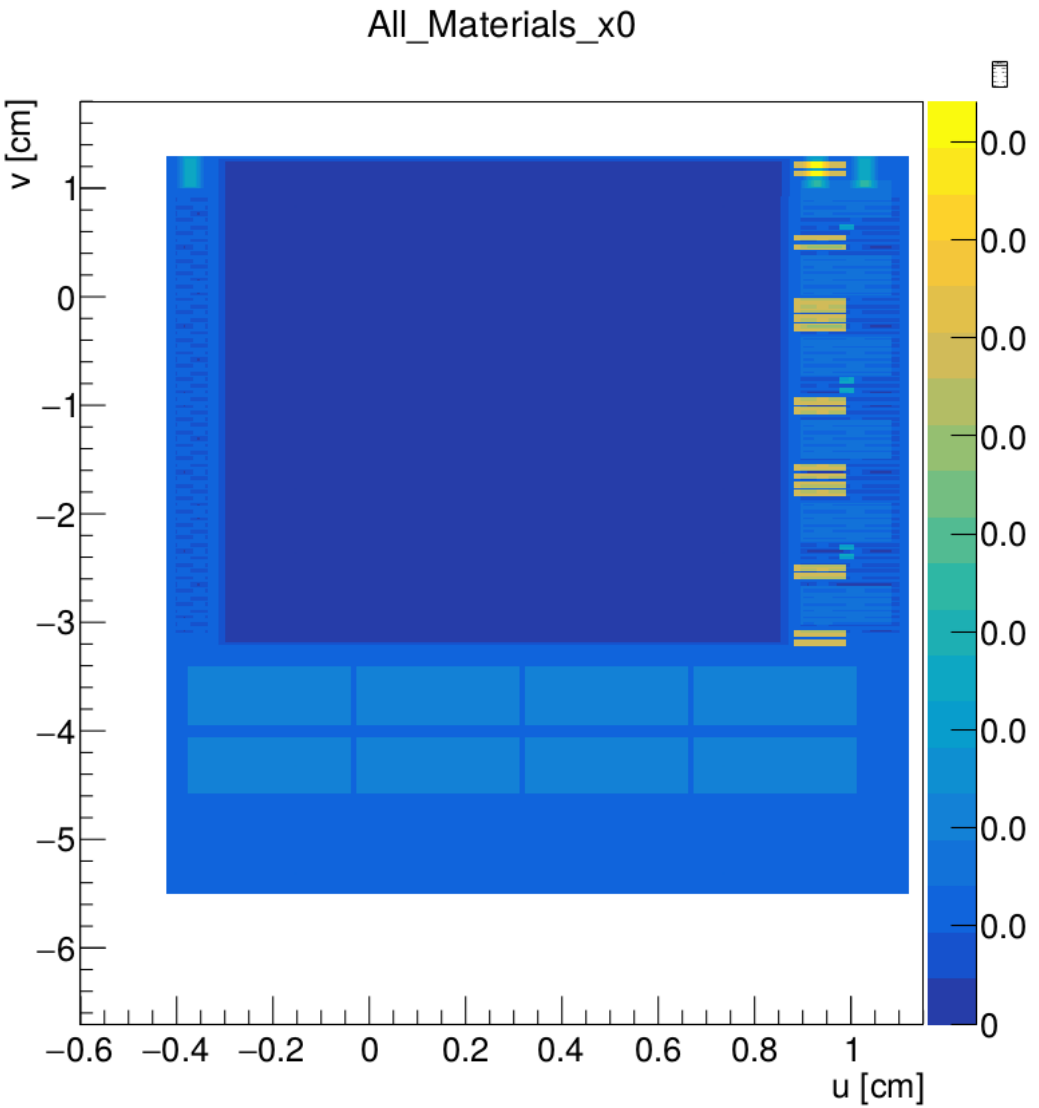
X/X0 [%]



:- Mechanical PXD prototype installed in EUDET telescope (Nov. 2015)
:- Exposed to 4GeV beam for several hours (~30mio tracks)
:- Quantitative X0 profile for comparison with simulations
:- more details: https://doi.org/10.1016/j.nima.2016.06.086

:- Based on measurements/most recent CAD: Refinement of PXD geometry in PXD (done)

Current version of PXD half-ladder



Summary: Readiness for phase 2

:- All critical (core) parts of pxd reco software stress tested in test beams

  :- VXD test beams in 2014 / 2016 / 2017 studied with basf2 sw.
  :- See talk on PXD performance on monday

:- Some lessons from TB17 for PXD sw:

  :- need more (strict) error checks in unpacker → DAQ firmware not finished
  :- store error mask in data object → flag if PXD data can be used
  :- flag errors in the PXD DQM → for the shifter

:- Work on DB interface is underway, but not yet finished

  :- interface to DB to get dead/bad pixels, pedestals, clustering thresholds
  :- currently calibration constants in online configDB, not in conditionsDB
  :- need mechanism to import constants to offline conditionsDB

Preparation status for phase 3

:- Some things missing for phase 2, but can be done in remaining time

:- In many cases, we will have to learn from phase 2 experience (as we learned from TBs)

:- Some topics are pretty clear:

  :- Simulation of PXD operation in gated mode (event wise flag for PXD gating)

  :- Transition from hit based to cluster based data format (code prepared, waiting for FW)

  :- Learn about calibration of multi-module PXD during phase2

    → in test beams modules were rather stable and uniform after online calibration
    → only needed to upload new pedestals from time to time before a new run

    → see talk on PXD performance tomorrow.