New results from PXD standalone test beams

Ringberg 30 May 2017

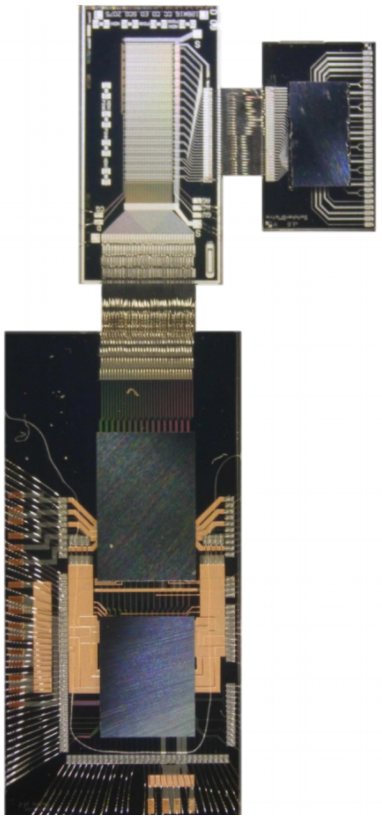
B. Schwenker

University of Göttingen

Idea of the talk

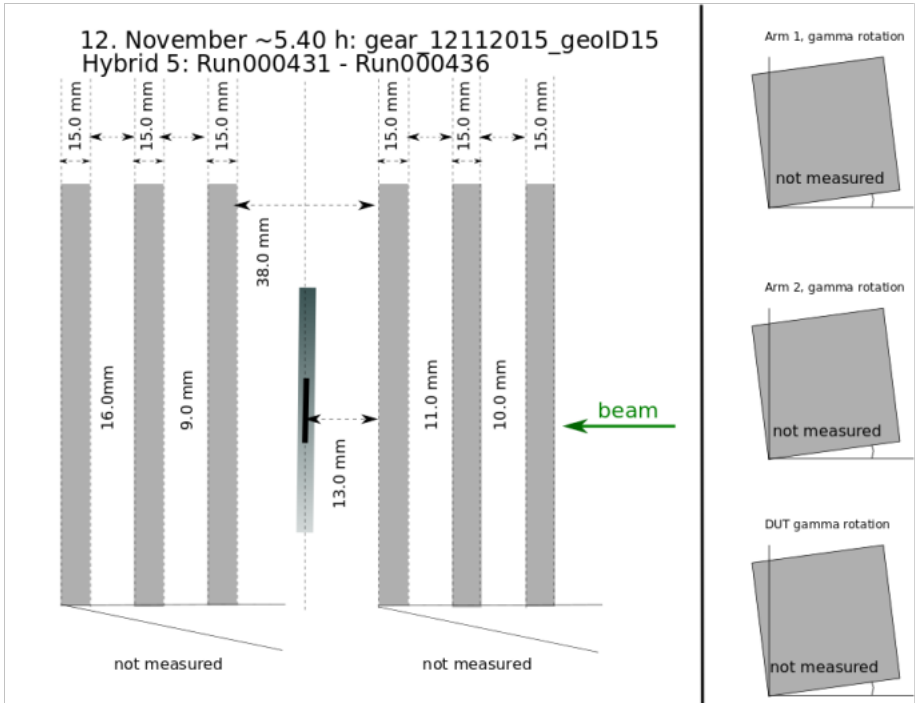
- Reminder how the PXD detector simulation was tuned against test beam data
  - Where are the tuning knobs?
  - What data is needed to adjust them
- Update measurements on spatial resolution from PXD standalone test beams
  - Combined test beams do not really help much in understanding spatial resolution
  - “Extrapolation” from SVD to PXD has much larger errors then “interpolation” in EUDET telescope
  - For Belle II case, errors on cluster positions will likely be based on PXD digitizer “tuned” against track data.
    - See Peter’s talk

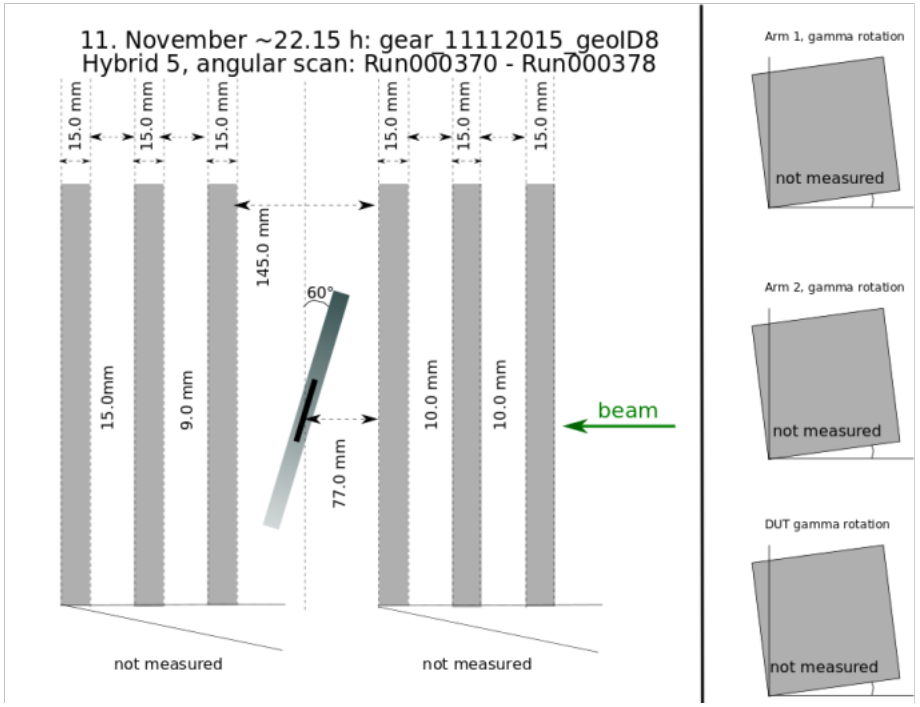
Small PXD9 @ DESY (Nov. 2015)



- First Belle II type matrix in a test beam with EUDET telescope
- PXD9 small Belle II type matrix
  - Pixel pitch: 50x55 μm^2 (→ layer 1 PXD)
  - Gate length: 5µm (→ like PXD)
  - thin gate oxide (→ like PXD)
- Still a very valuable data set
  - High resolution telescope (in-pixel study)
  - High statistics: Millions of (precise) tracks matched to PXD cluster
  - Angular scan: Tilt of PXD sensor against beam (up to 60 degree)

Telescope geometries





:- small distances to keep tel. interpolation error small.

:- Hybrid 5 mechanics a bit bulky → larger distances to PXD

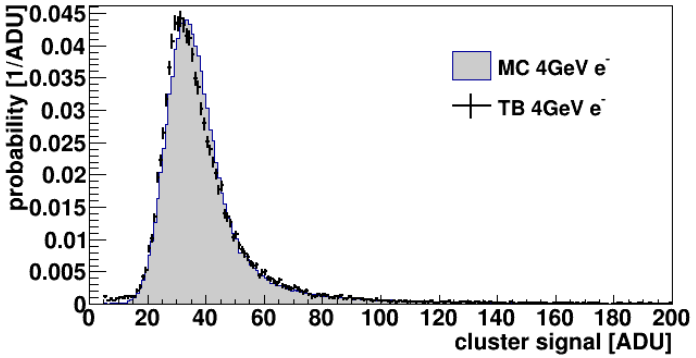
:- Rotating Hybrid 5 implies moving arms away and increases material.

:- Different distances for all angles, still interpolation errors @ PXD grows

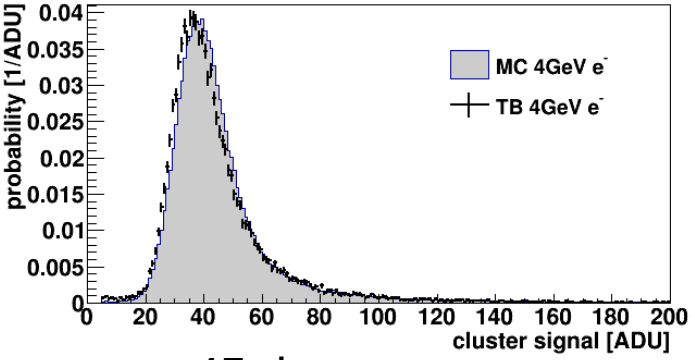
Landau spectra for different tilts

MC: Energy losses from Geant4 + Charge sharing etc. from ‘tuned’ PXD Digitizer

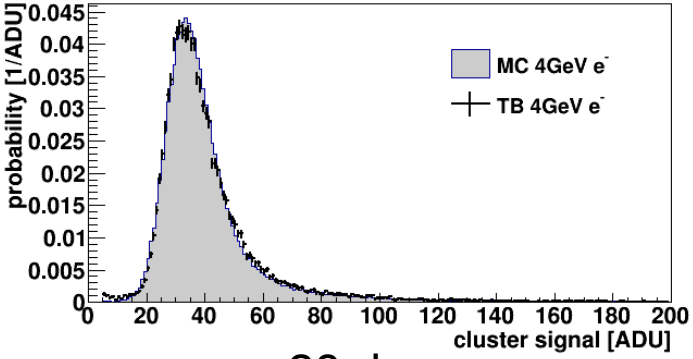
0 degree



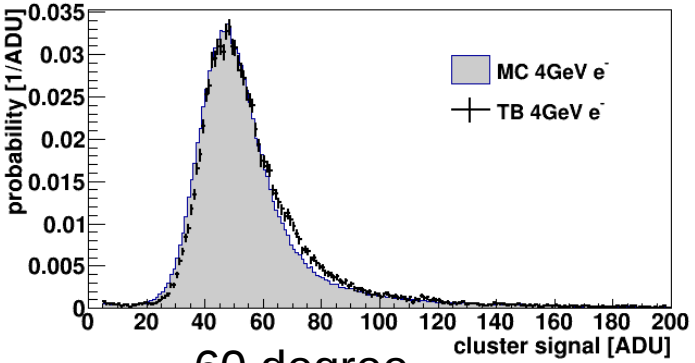
30 degree

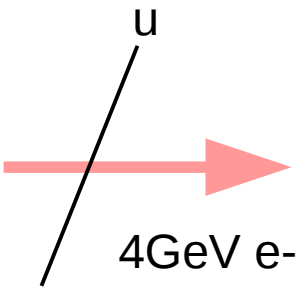


10 degree

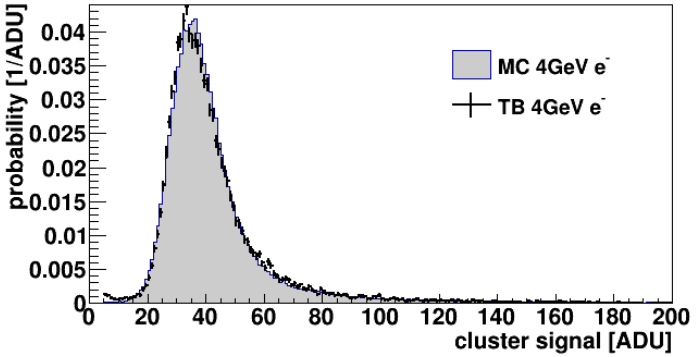


45 degree

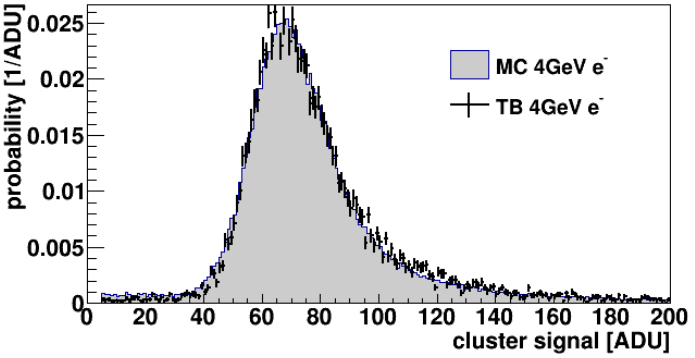




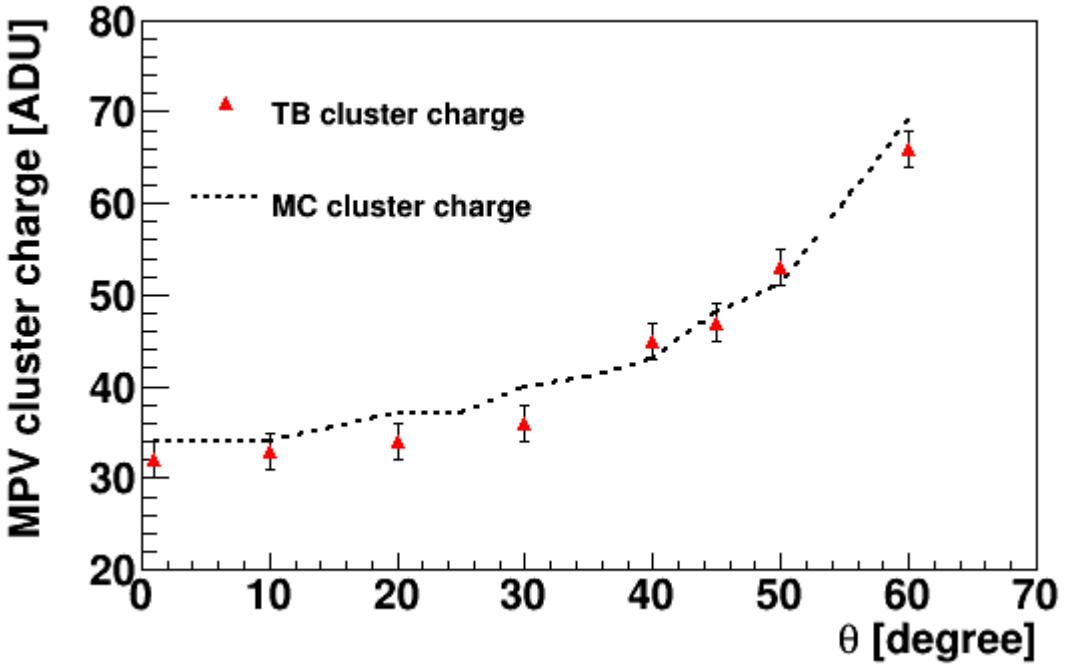
20 degree



60 degree



Calibration of the gq from Landaus



:- We have two charge conversions factors:

$g_t = g_q \times g_{ADC}$

g_q takes charge to current

:-need charged particles

g_{ADC} takes current to codes

:- Take g_{ADC} from ADC curves

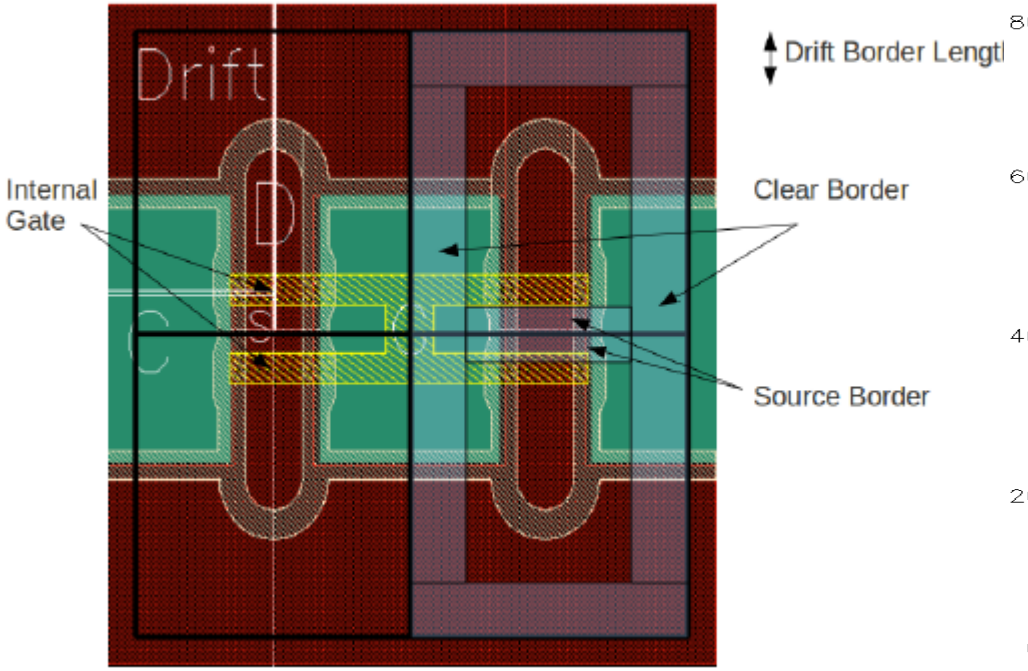
g_{ADC} = 1/120 ADU/nA

:- Final result:

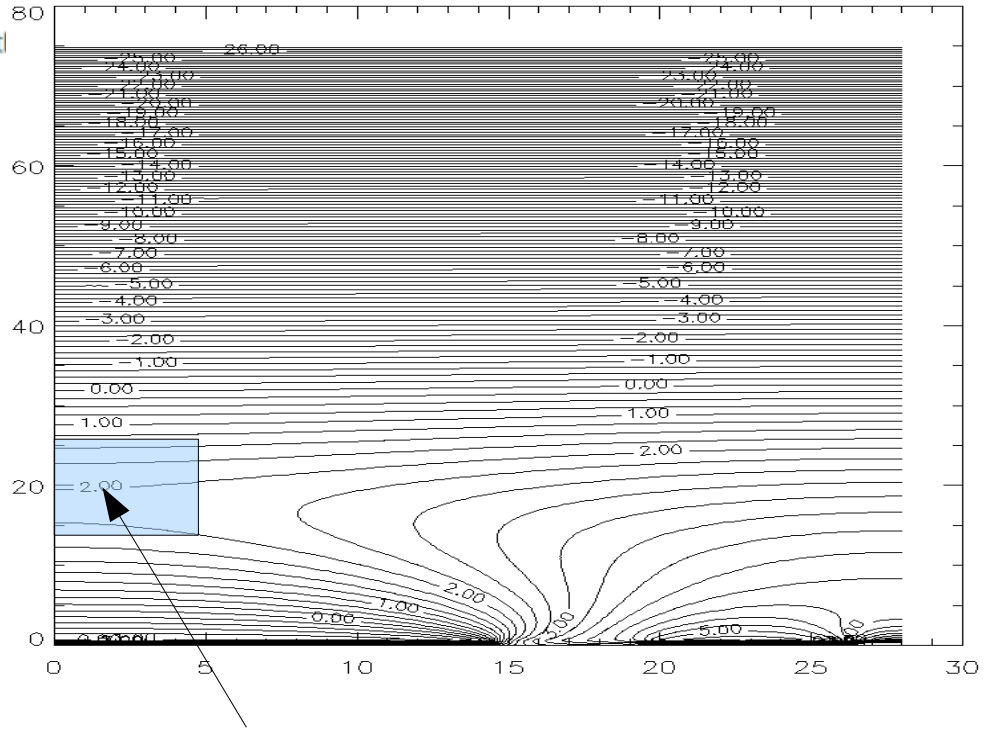
$g_q = g_t / g_{ADC}$ = 740 +/- 50 pA/e

Charge sharing model in digitizer (short reminder)

DEPFET unit cell (2x2 pixels)

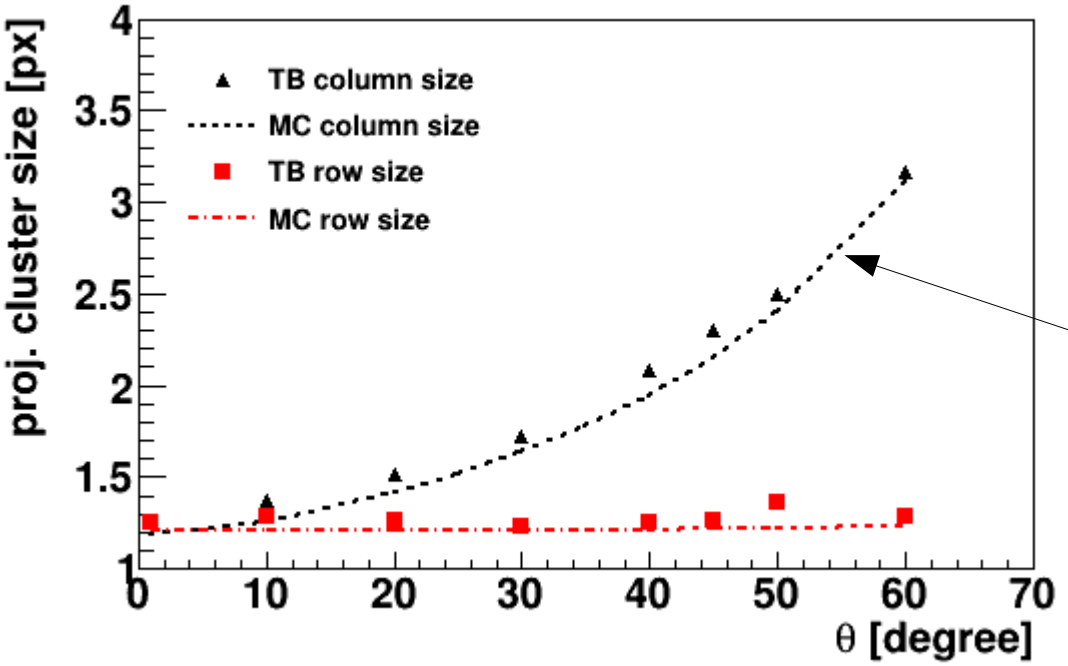


Cut in r-φ (clear – cleargate-internal gate)



Charge transport dominated by diffusion
→ size of this are key to model cluster size
→ estimate possible from device simulations
→ need to be tuned +/- few microns

Calibration of sharing areas



Depends on size of charge sharing region between columns

:- Module tilted against the beam axis up to 60° around v-axis

:- Elongated clusters along u axis (multi-column clusters)

:- Telescope tracks used to select pure signal cluster sample

:- **Digitizer model matches cluster shapes for all tilts :)**

PXD Digitizer calibration for Belle 2

:- Main parameters for PXD Digitizer (so far) are size of charge sharing regions, gq and slope of ADC transfer curve (ADC gain) and Lorentz angle.

→ need to measure this for small/large pitch and inner/outer layer
→ variations on samemodule or between modules?
→ System related: select nominal ADC gain(DCD), select hit threshold (DHP),..

:- Calibration needs clean samples of PXD clusters for different charged track incidence angles (~50k per angle):

→ Can select these samples using SVD (or SVD + CDC) tracks extrapolated to PXD.
→ Track only tags a PXD signal cluster; no need for very precise intersects (position errors of <50um should be fine)

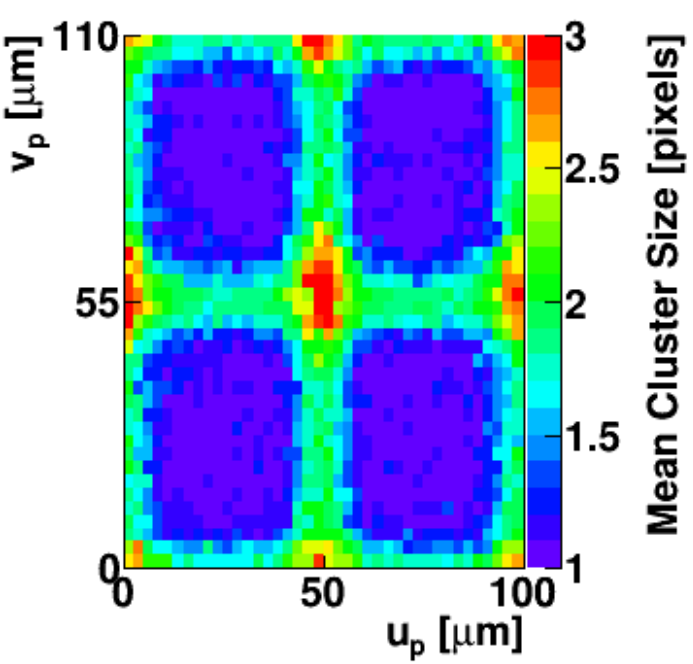
:- Calibration (tuning) of PXD digitizer should be integrated into the basf2 calibration Framework (→automation)

→ Important for good simulation, estimation of cluster position errors

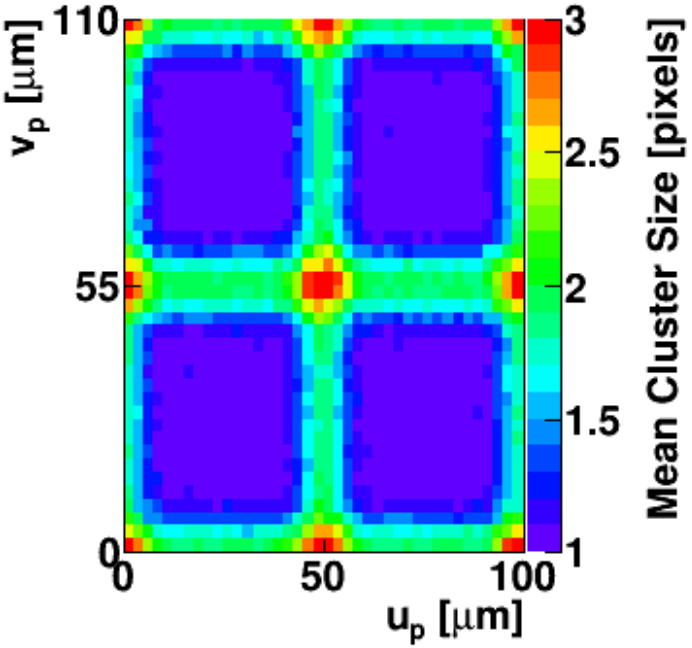
:- Need to understand (measure) how digitizer vs. data agreement evolves after irradiation.

Inter pixel charge sharing

Small PXD9 in test beam



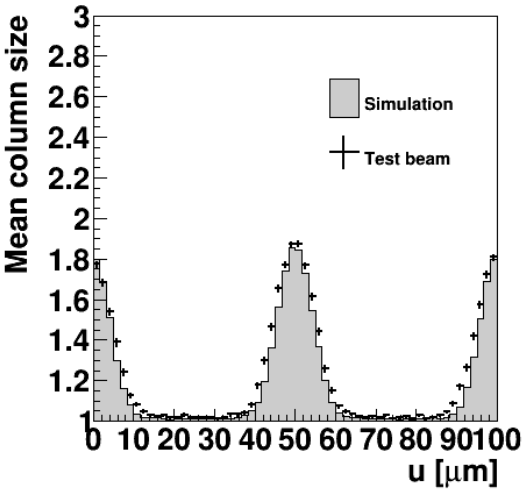
"Tuned" PXD9 Digitizer



Summary of "tuned" digitizer parameters PXD9 50x55:

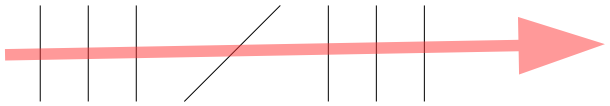
:- Charge sharing region between rows: ~12um
:- Charge sharing region between columns: ~12um

Expected resolution for two row cluster ~3.5um



Spatial resolution of EUDET telescope

:- Depends on many factors: Beam energy, M26 hit threshold, distance between sensors along beam line (z axis), X/X0 of DUT(s)

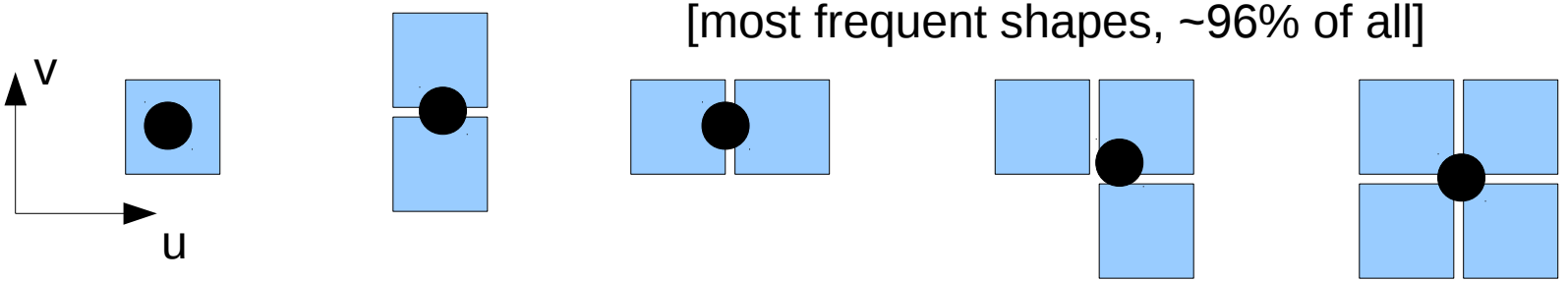


:- M26 sensors are digital (detect signal over threshold) and have pitch 18.4um. What is their spatial resolution?

→ Pitch/Sqrt(12) is wrong (charge sharing between small size pixels)

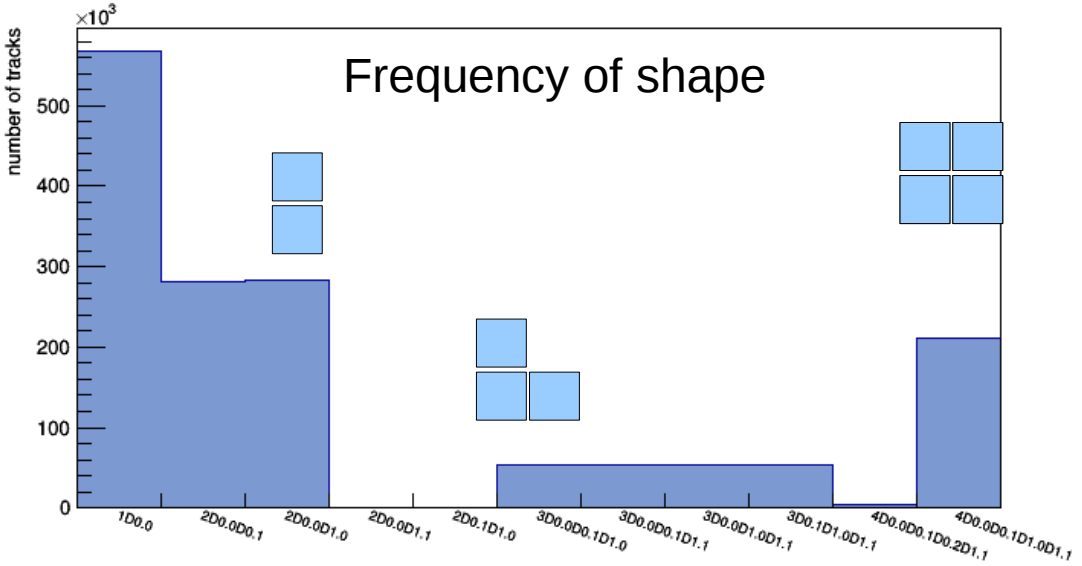
→ Also the shape of the (digital) cluster matters (L shape clusters etc)

[most frequent shapes, ~96% of all]



:- There is “some” intuition where the measured position is, covariance matrix is less clear … Developed a data driven method to estimate positions and cov. matrix for all cluster shapes.

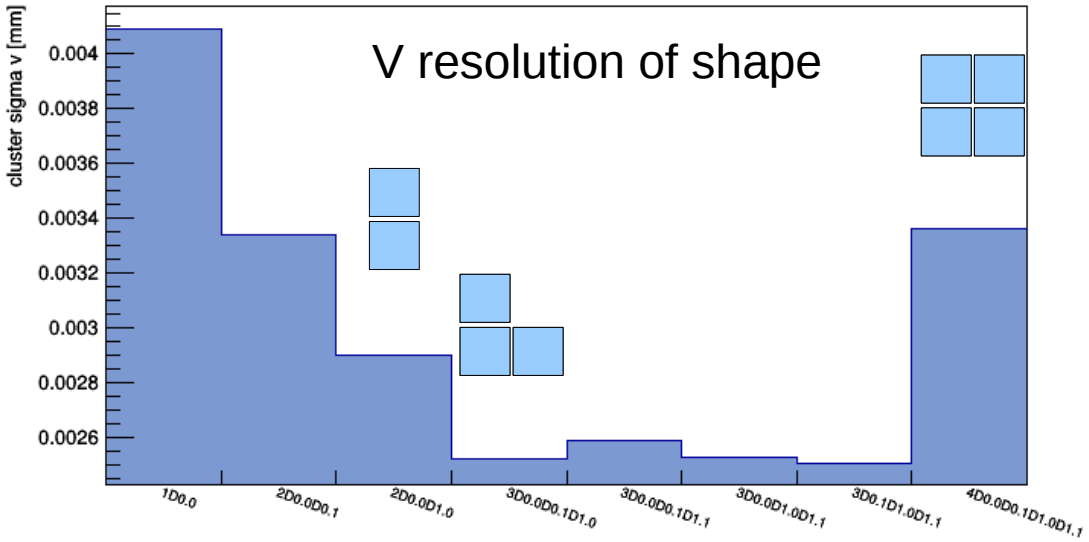
Calibration of M26 clusters



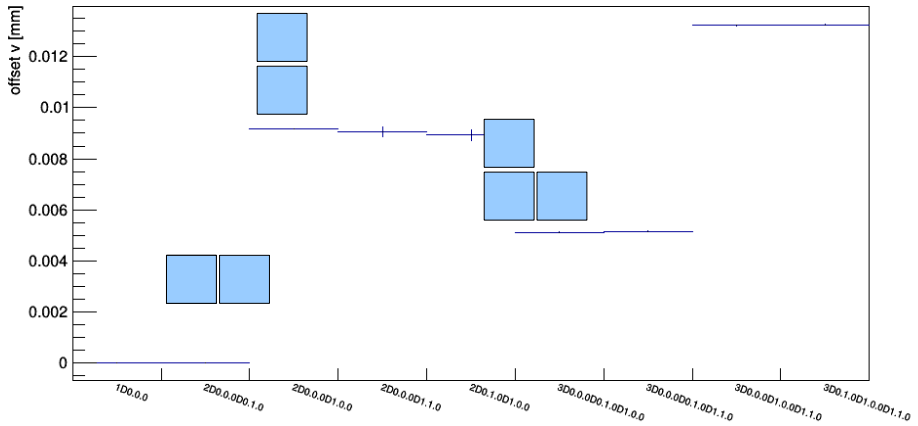
:- 1.6 Mio tracks used for calibration
:- results for v position of M26 cluster

:- averaged cluster sigma: 3.5um

:- track fit should use shape dependent offsets/sigmas

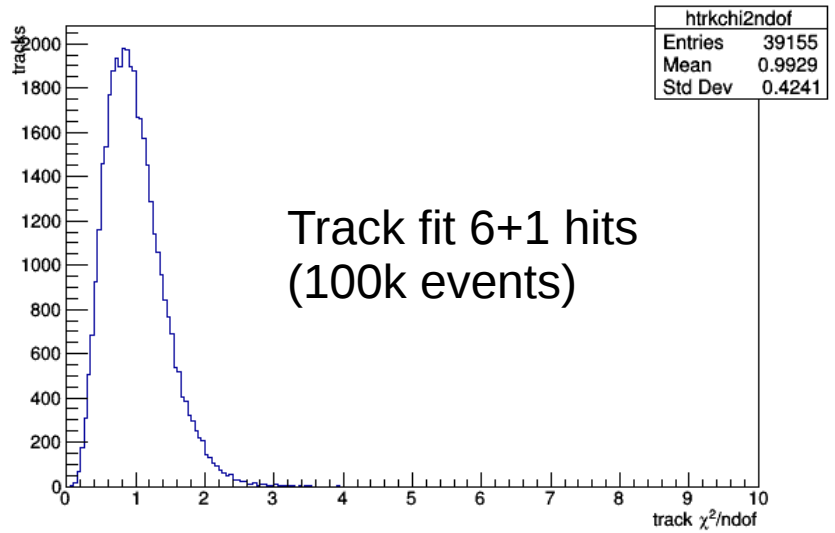


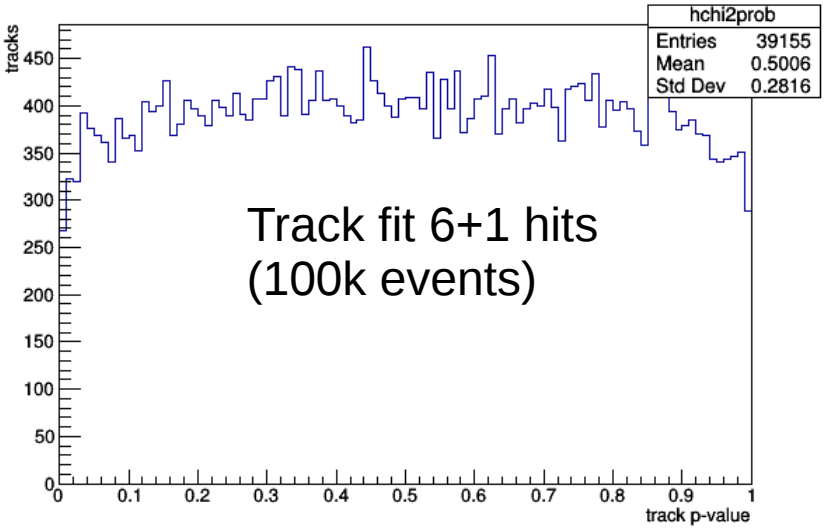
Position offset
(rel. to center of lower left pixel)



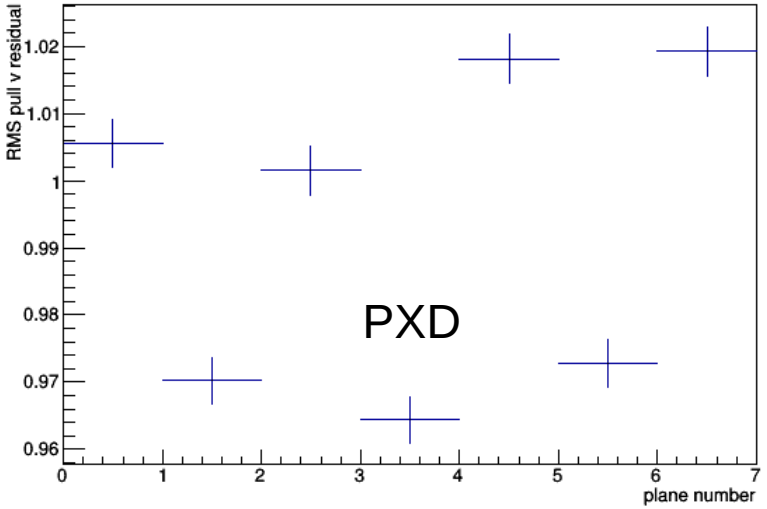
[you can ask me about the algorithm after the talk]

How well does track fitting work using these corrections?

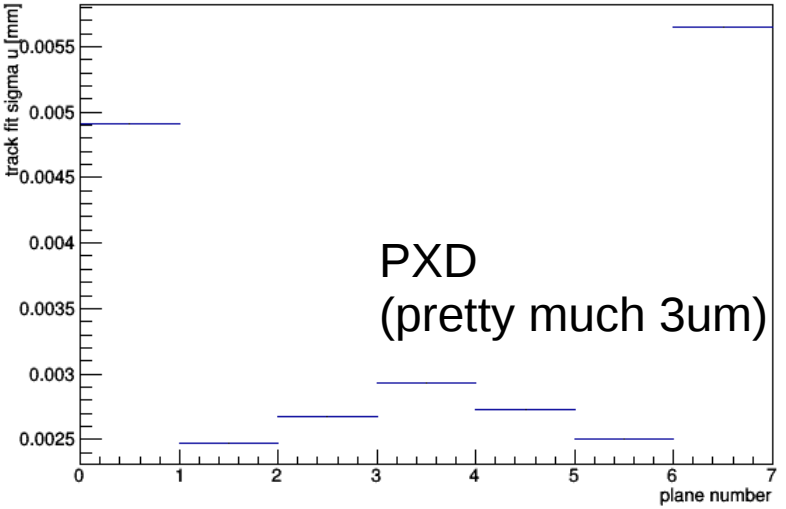




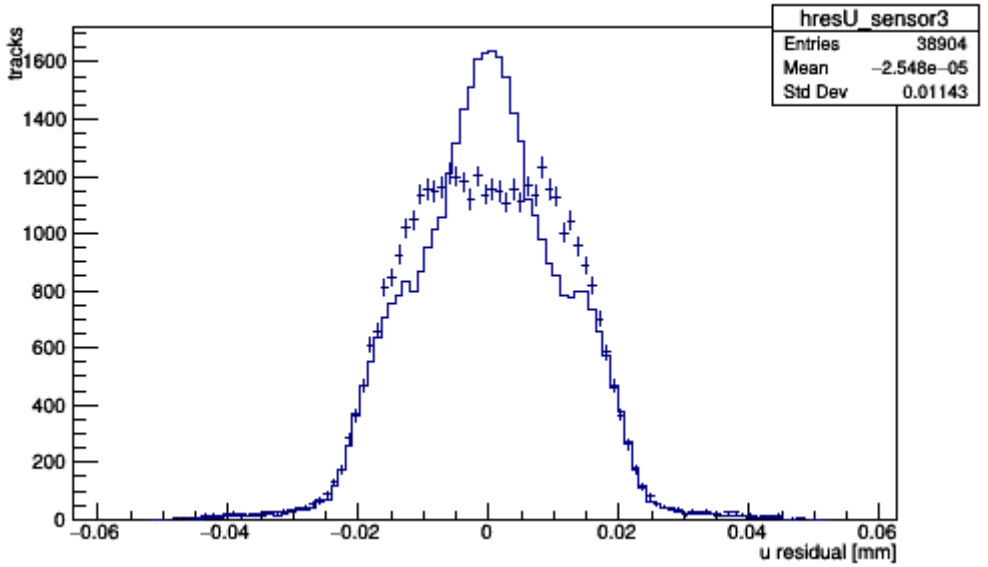
RMS of standard. residuals (all planes)



Average error (sigma) of tel. interpolation



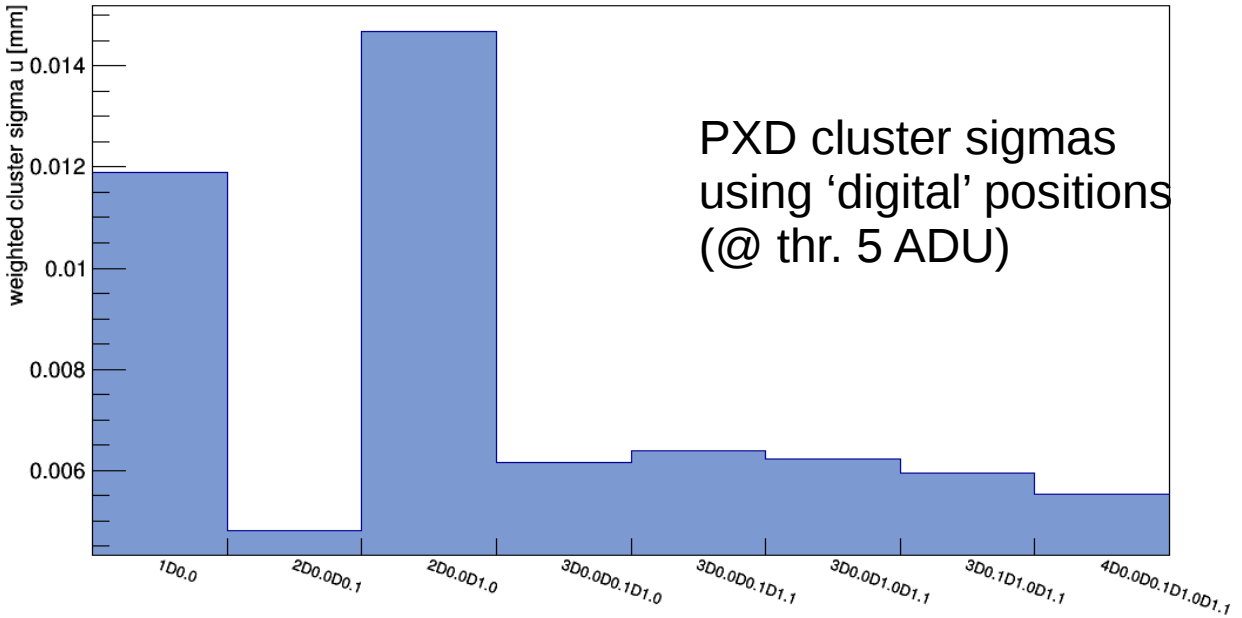
Residuals at perp. incidence



:- compare u residuals using different position reconstructions (PXD)
- → center-of-gravity (crosses)
- → digital (solid line)

:- ‘Digital’: using same method as for M26 sensors (hit thr. 5ADU)

:- Cog performs worse than digital
- → charge sharing restricted to ~10um region between pixels
- → true for close to perp. incidence



PXD cluster sigmas using ‘digital’ positions (@ thr. 5 ADU)

:- Cluster sigmas obtained after subtracting tel. Interpolation error

:- double column cluster have sigma ~5um.

:- single pixel cluster ~12um

Summary

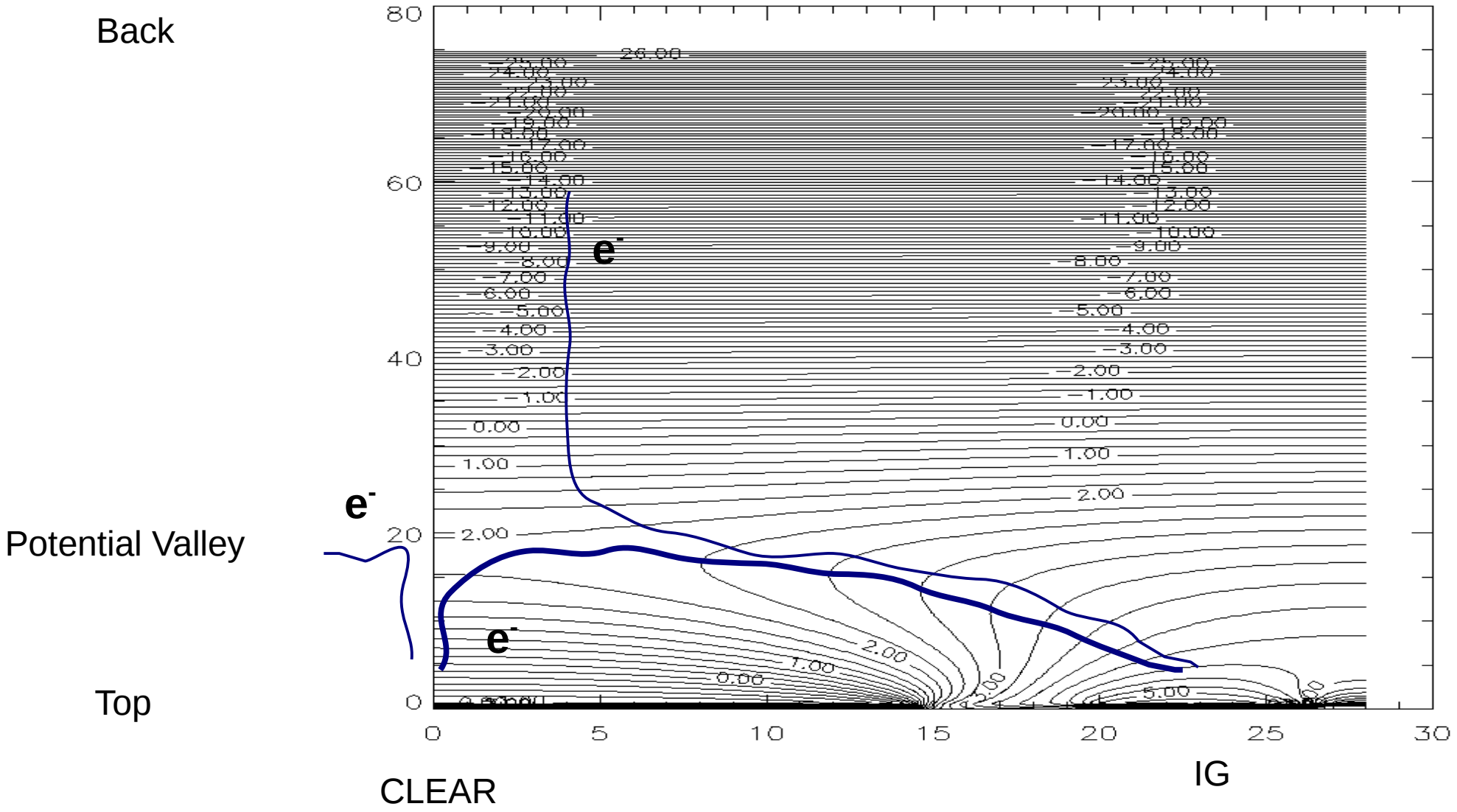
- So far, the PXD digitizer could always be “tuned” to test beam data
  - Many tests for small sensors (Hybrid 4/5) in PXD standalone test beams with EUDET tel.
  - Some tests for large PXD9 (April 16) show agreement for cluster charges and size.
  - “Tuned” parameters are in the right ball park; Similar but not identical parameters for different test beams (small/big PXD9)
- How global are these tuned parameters?
  - Variations on same modules / variation between modules
  - How do parameters evolve with irradiation?
    - Never measured irradiated large PXD9 sensors
    - Only very few sensors went to test beams
    - For Belle 2: need for automated tuning of parameters

Backup slides

H5 voltages during TB

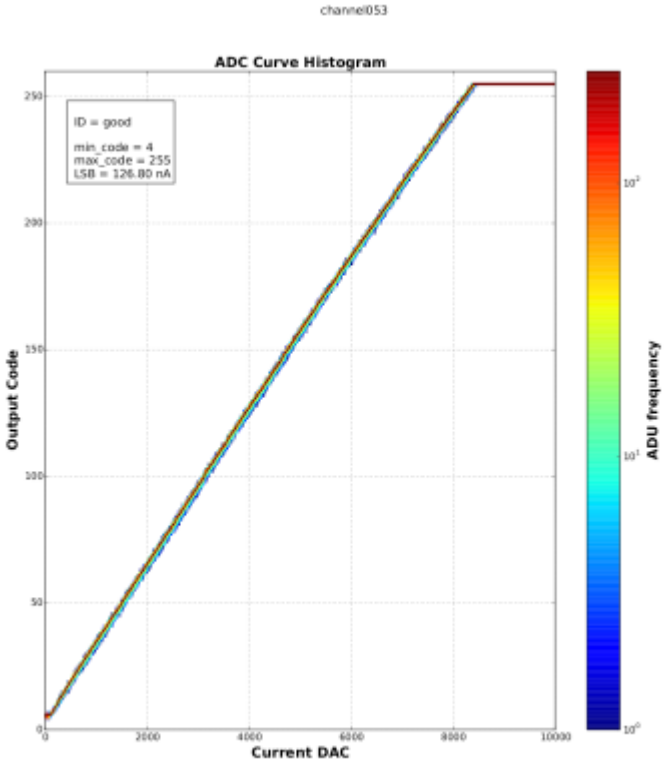
- CCG: -1V
- Clear-low: 5V
- Clear-high: 20V
- Gate-on: -2.5V
- Gate-off: 3V
- HV: scanned from -60V to -80V
- Drift: scanned from -1V to -5V

2D Potential Map in R-Φ Cut: Clear – Clear Gate – IG



Testing results Hybrid 5

All testing results EMCM/Hybrid5 collected here:
http://twiki.hll.mpg.de/bin/view/DepfetInternal/Emcmresults



:- ADC curve with DHE current source after optimization

:- large dynanic range: 127nA per ADU

:- low noise noise: ~0.7ADU

:- no missing code / no bit errors