Summary of DEPFET characteristics measured at test beams

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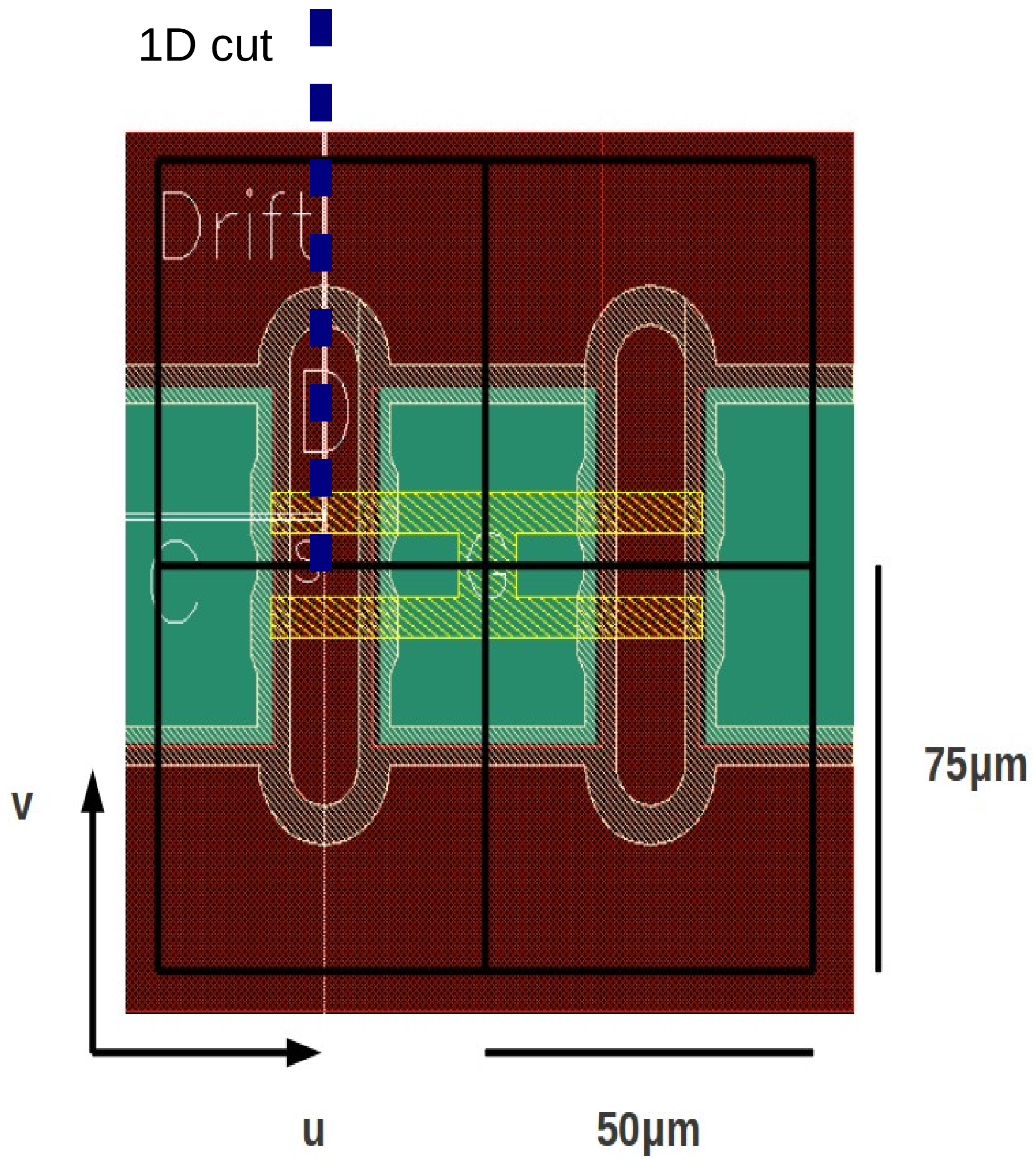
Outline

- Brief review of digitizer model and parametrization developed for Belle II PXD.
  - Which parameters are there? How to set their values?
- Brief review of data pre- processing for test beams with Hybrid H4.1.XX systems.
  - Pedestals, common mode, noise and signal calibration.
- Summary of test beam measurements relevant for validation of PXD digitizer.
  - Focus on test beams with well understood, smoothly running (small) PXD6 sensors.

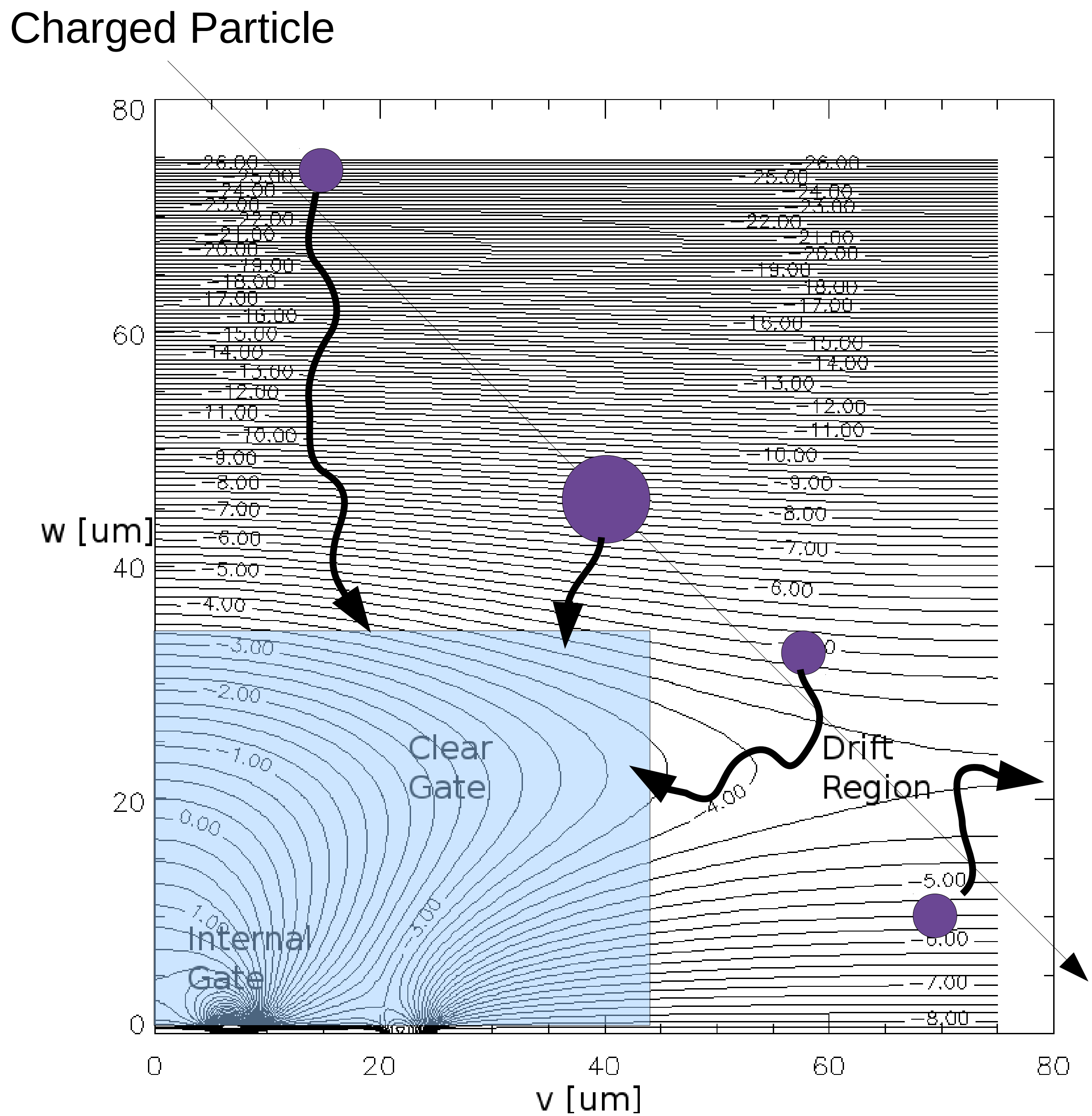
Sensor layout tested



Standard sensor (PXD6):

- 50µm thick sensor
- 50x75µm² pixels
- Double pixels
- Surrounded clear gate
- Gate length 5µm

Charge Collection Model



:- Equipotenial lines for fully depleted sensor (R. Richter)

:- Potential along w axis well described by parabola.

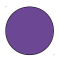
→ good: fast analytical model for Drift and diffusion :)

:- Potential near IG (blue box) is rather complex; but not relevant for charge sharing.

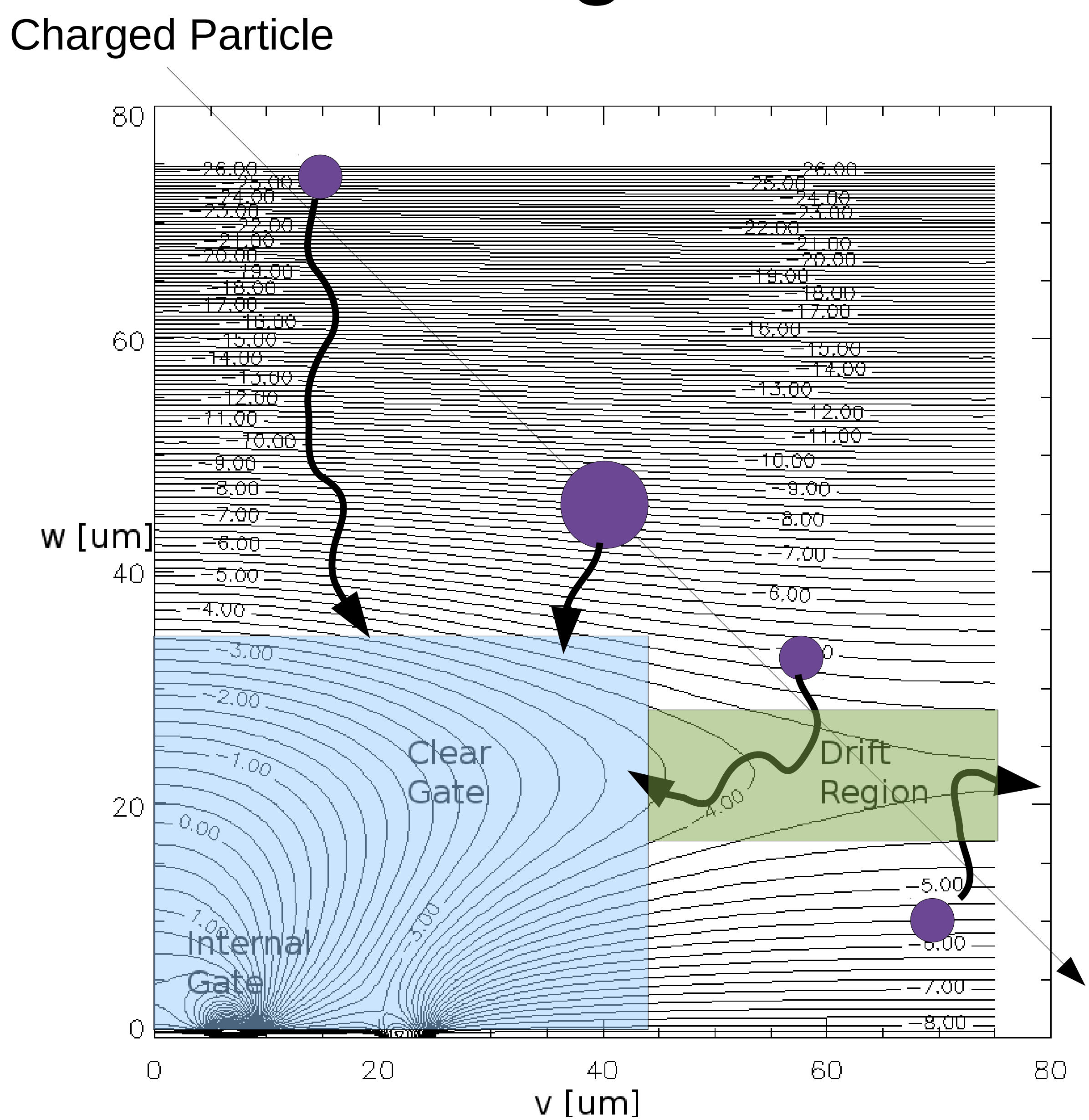
→ Assume: e^- reaching blue box always reach IG.

:- Very weak drift fields along v axis between pixels → diffusion!!

:- Landau fluctuations (Geant4) impact spatial resolution.

 Electron group

Charge Collection cont'd



In drift region, electric field along v is roughly linear:

$E_v = \kappa^*(v\text{-}vd)$

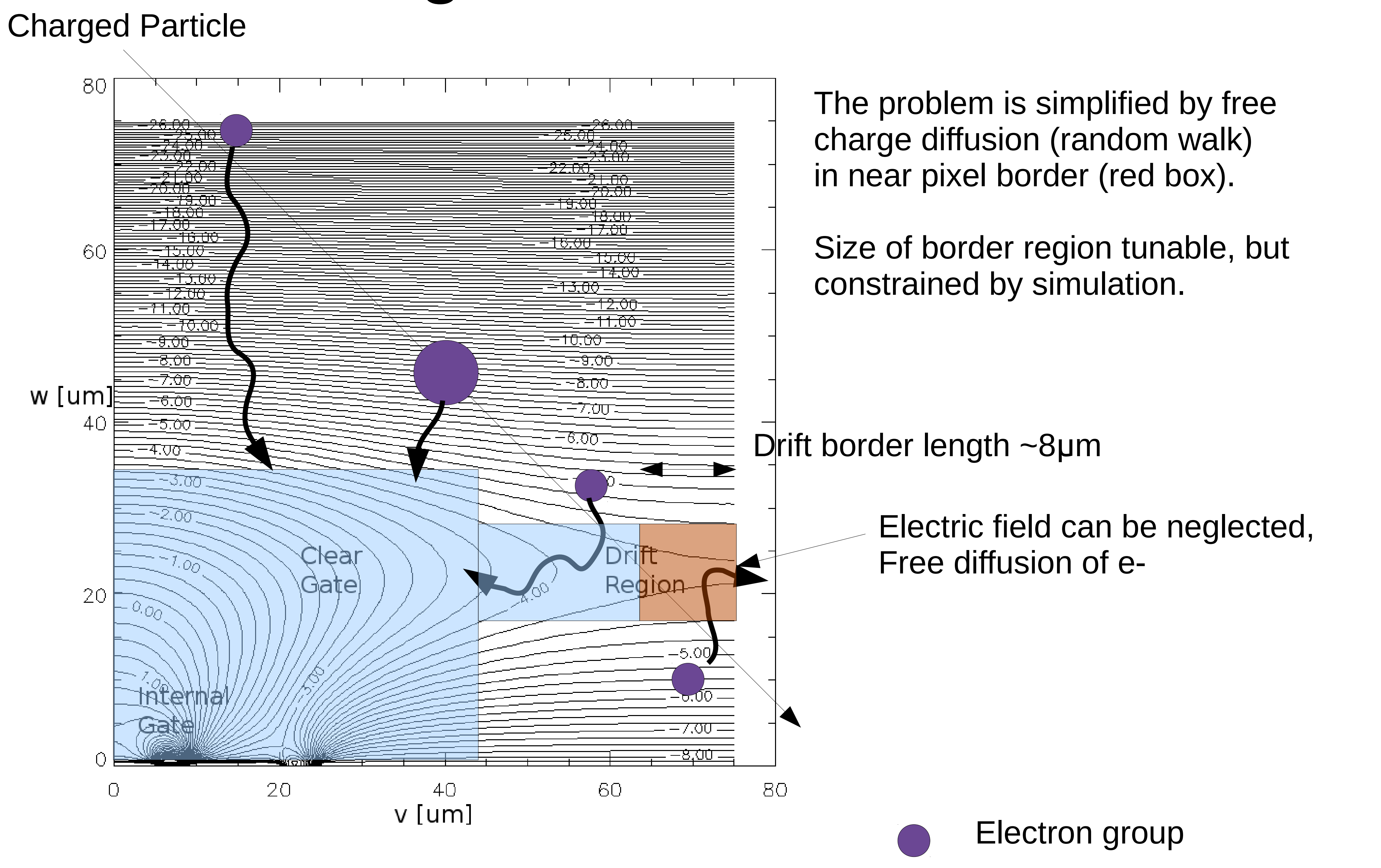
Field slope can be estimated from device simulations.

We want the probability that particle goes ultimately left (-v) or right (+v).

→ Simulate drift diffusion process (simple in 1D, but slow in 3D)

Electron group

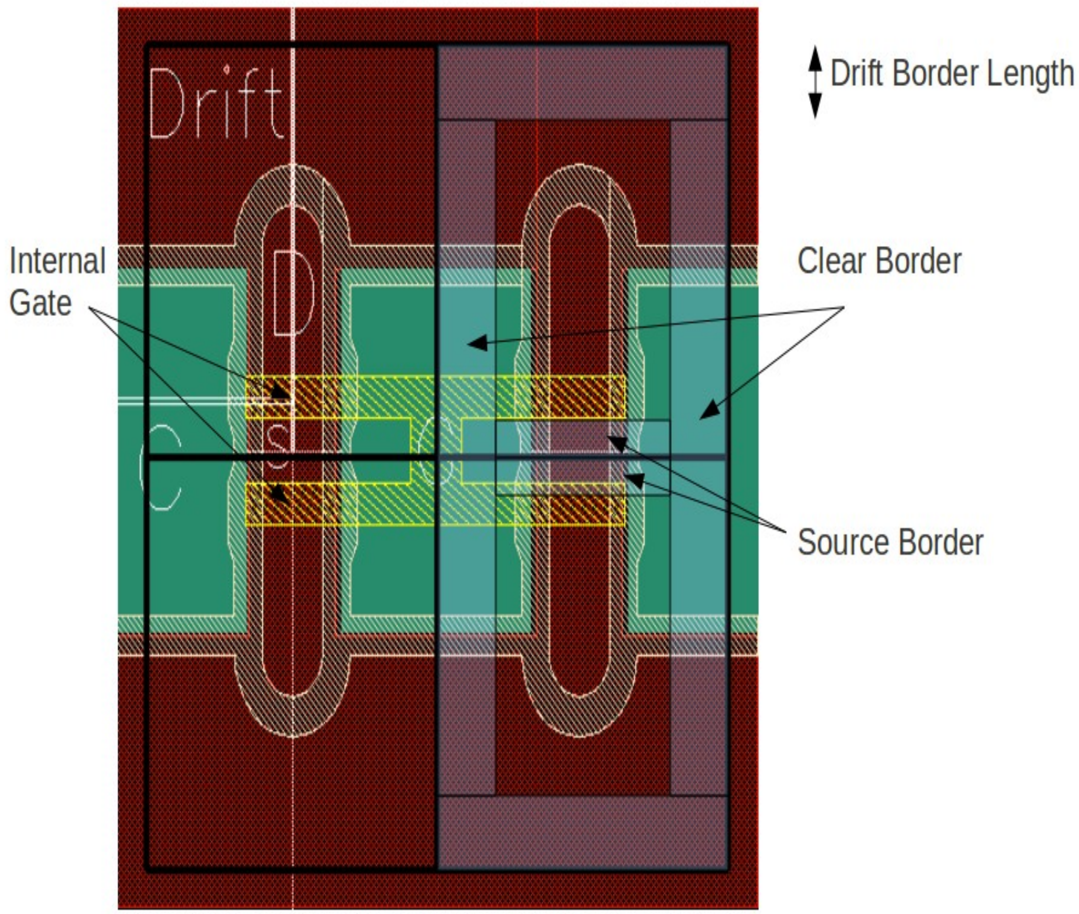
Charge Collection cont'd



The problem is simplified by free charge diffusion (random walk) in near pixel border (red box).

Size of border region tunable, but constrained by simulation.

Charge collection cont'd



:- Model is mostly analytical, random walks in small volumes near Single pixel borders.

:- Parabolic potential fixed by bulk doping and bias voltages

:- Size of border regions estimated from device simulations.

:- Size of border sligthly tuned by +/-2μm to measured cluster data.

:- Lorentz shift in magnetic field is simulated; but test beams discussed here w/o B field.

Parameter Summary

Used for TB simulation

	Belle II PXD	PXD6
Sensor Thickness (in μm)	75	50
Pixel Pitch (in μm^2)	50×75	50×75
Pixel Noise (ENC)	$100 - 200$	120
ZS Threshold (N_{zs})	5	5
Bulk Doping (in 10^{12}cm^{-3})	10	10
Back plane Voltage (in V)	-26	-13.5
Drift Border Length (in μm)	9	9
Clear Border Length (in μm)	10	10
Source Border Length (in μm)	7	7

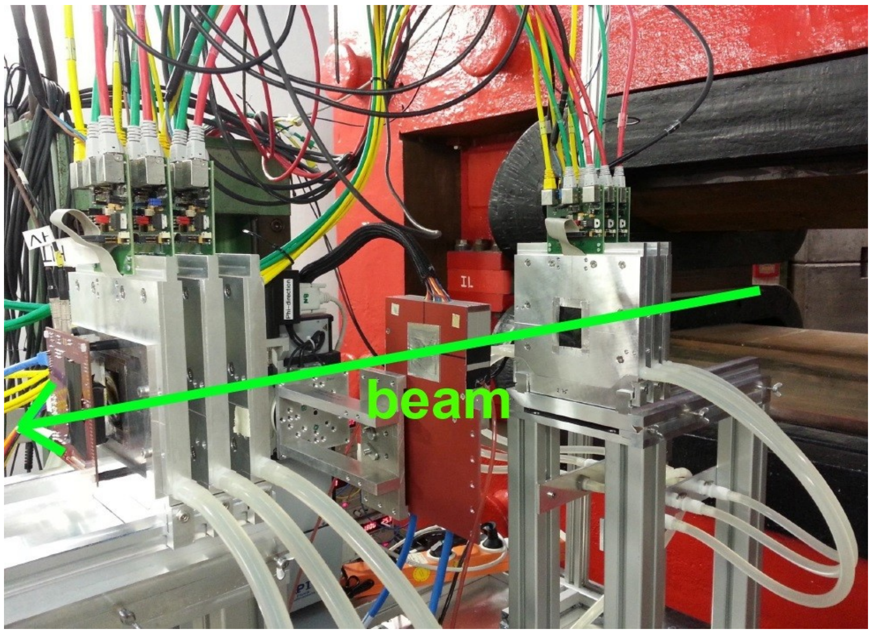
Table 3.1.: Overview of DEPFET simulation parameters: The first column specifies parameter settings for Belle II PXD modules. The second column specifies parameter settings for the simulation of the most recent DEPFET prototype modules available for test beams.

Discard signals <600e-
→ from TB calibration

Border Sizes:
→ depend on pixel pitch
→ smaller for ILC ($20\text{x}20\text{um}^2$)

So far, test beams with Hybrid 4.1 test systems are our best (only) choice to validate the Digitizer.

Hybrid 4.1 test beams

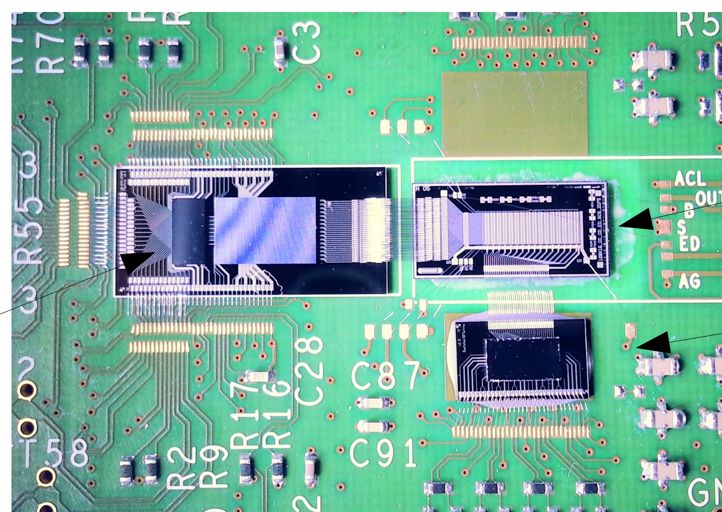


:- Test beams with EUDET telescope at DESY and CERN SPS.

:- EUDET gives triggers and track parameters at DEPFET sensor

:- Resolution depends on geometry and beam energy

u,v intersection ~2μm (CERN)
du/dw, dv/dw slopes ~30μrad (CERN)



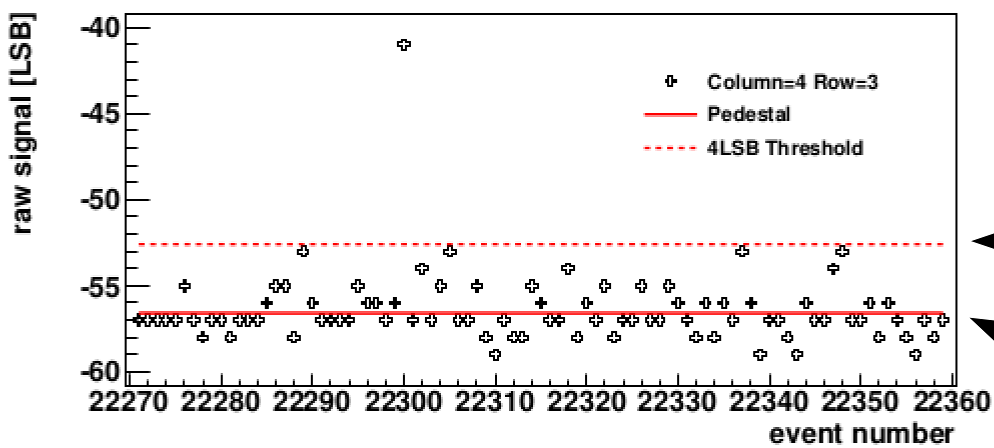
Small PXD6 sensor (32x64 pixels)

SwitcherB

DCDBv2 and DCD-RO

Raw data processing (offline)

(Data from H4.1.11 in 3GeV e- beam)



Uncalibrated data from a Single pixel (100 triggers)

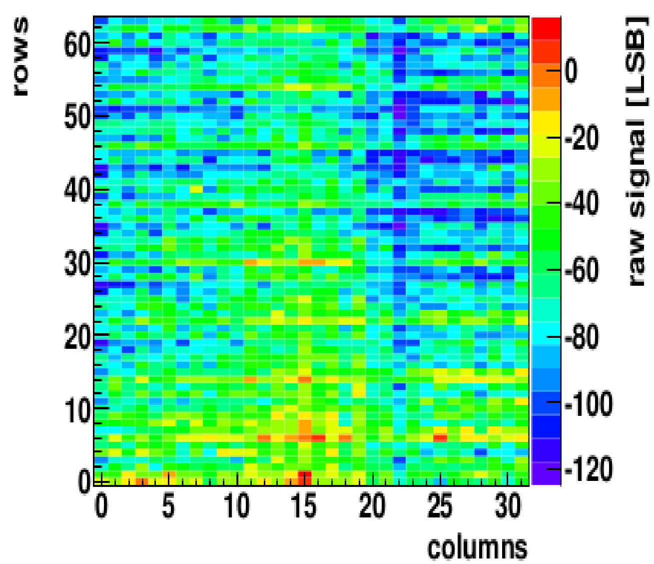
Zero suppression ~3-4LSB

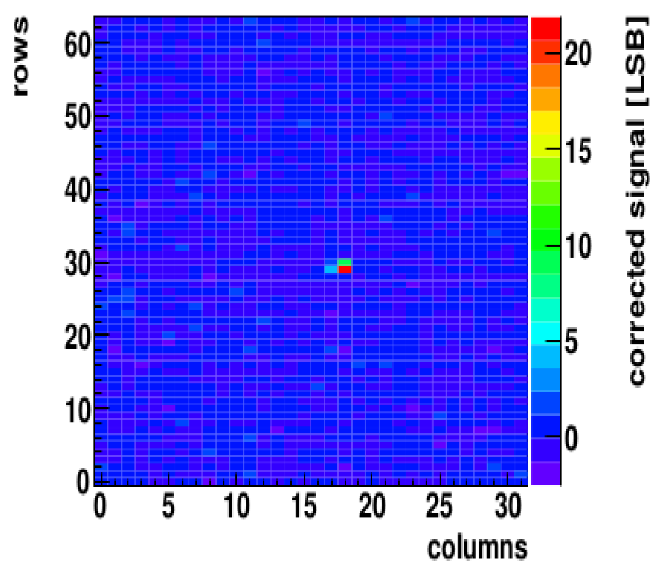
Pedestal in LSB

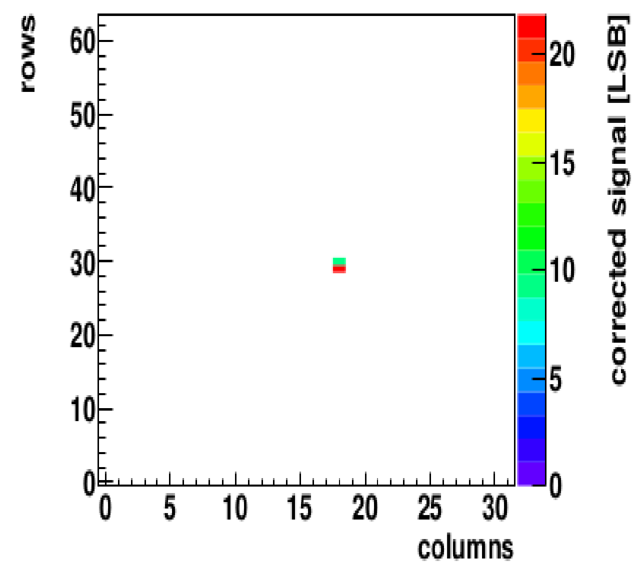
Raw Event

Pedestal Sub.

Zero Suppression

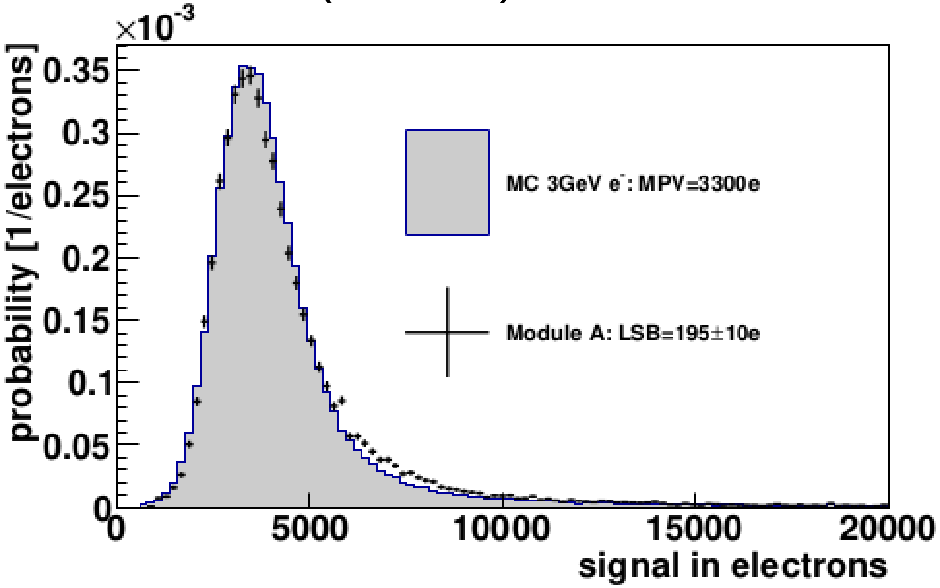




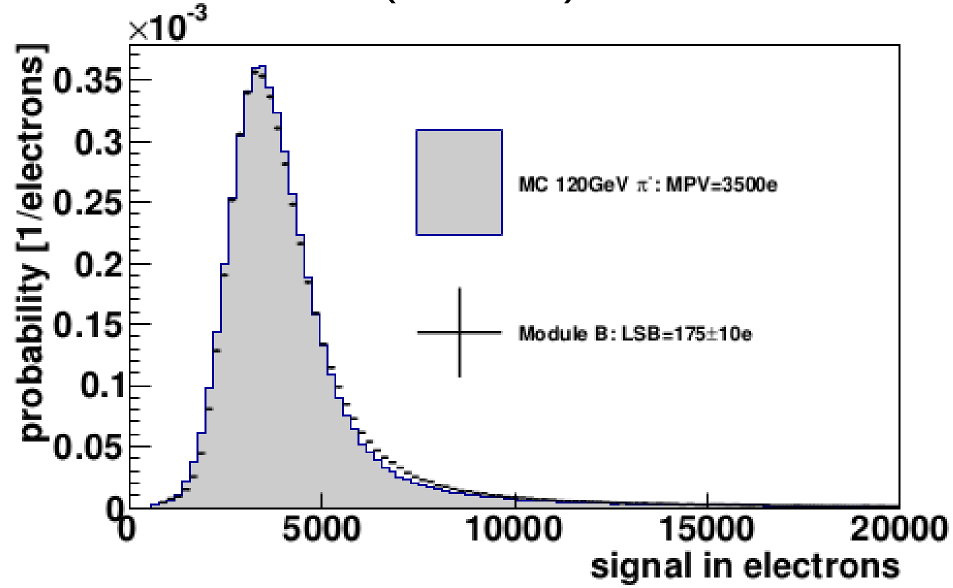


Signal Calibration

(H4.1.11)



(H4.1.15)



(Calibrated cluster charge, clusters matched to telescope track)

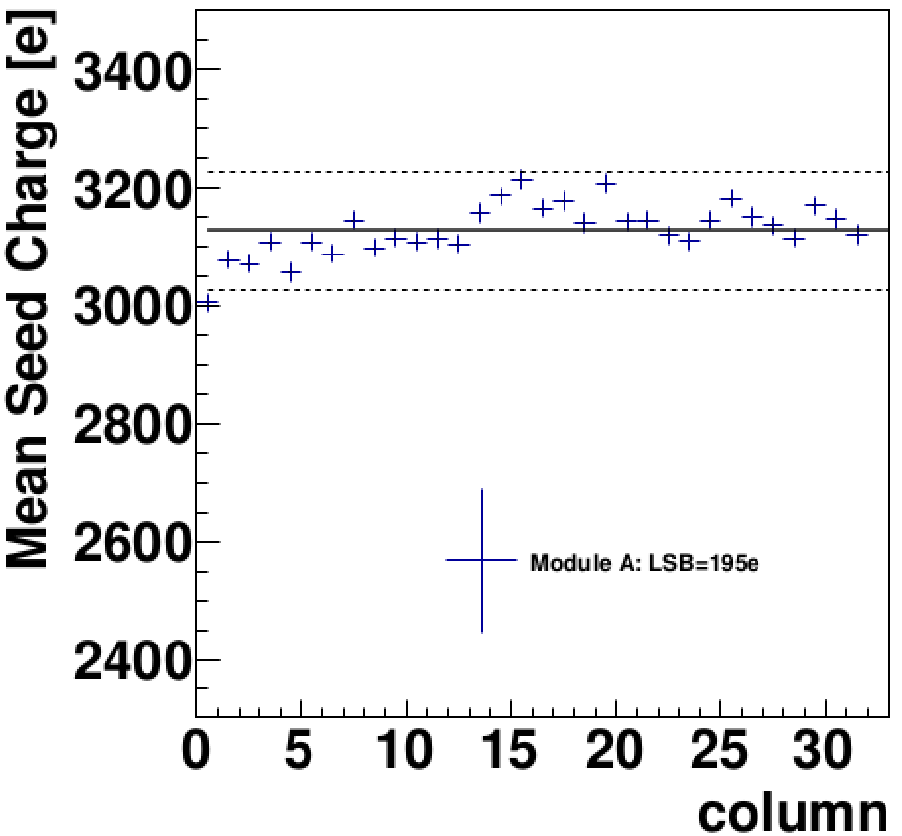
:- Using most probable signal charge from Digitizer as reference for calibration

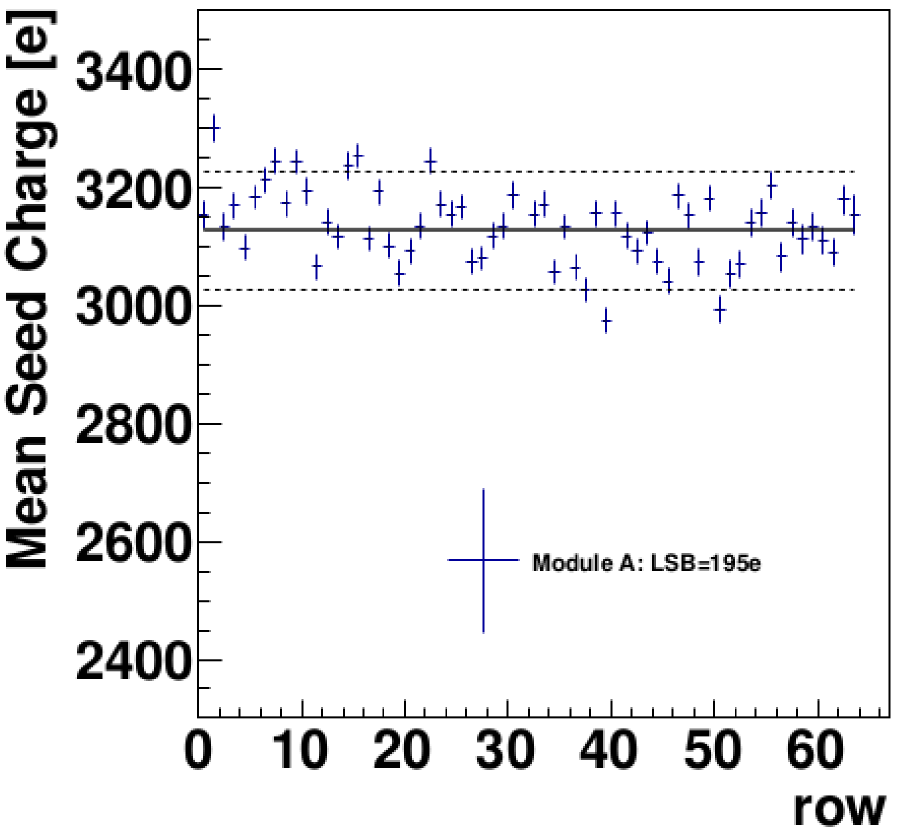
:- For 50um thin sensors: signal from 3GeV e- or 120GeV pions basically the same

:- For H4.1.11: LSB=175+/-10e- → Pixel noise 0.6LSB=120e- (Input for Digitizer)

:- Assuming LSB=100nA at DCD the DEPFET amplification is 510pA/e-

Uniformity of response

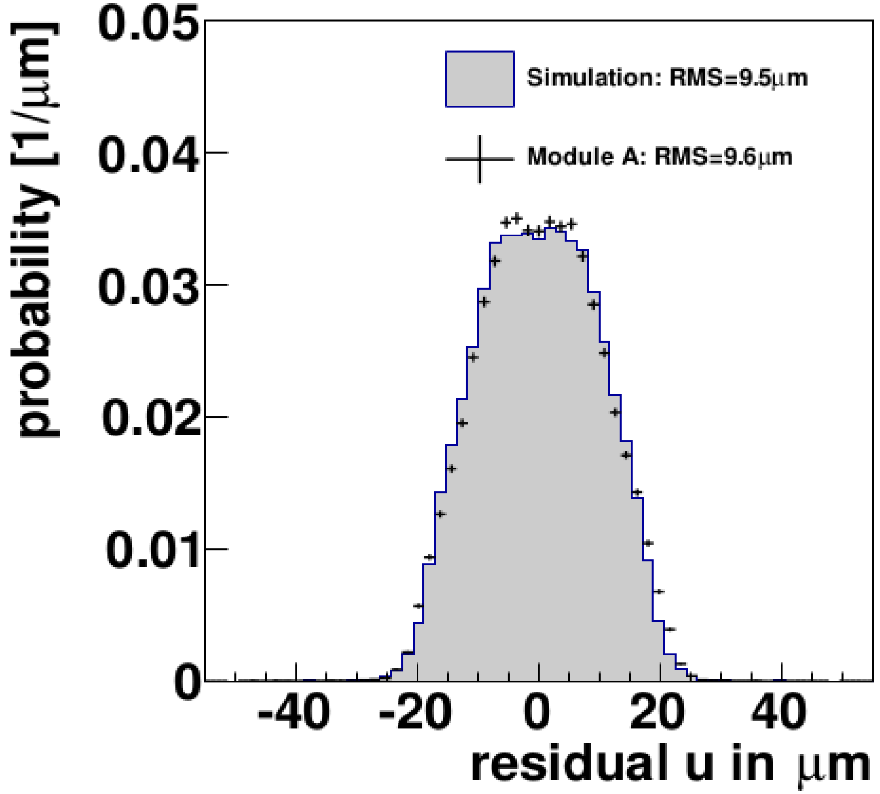


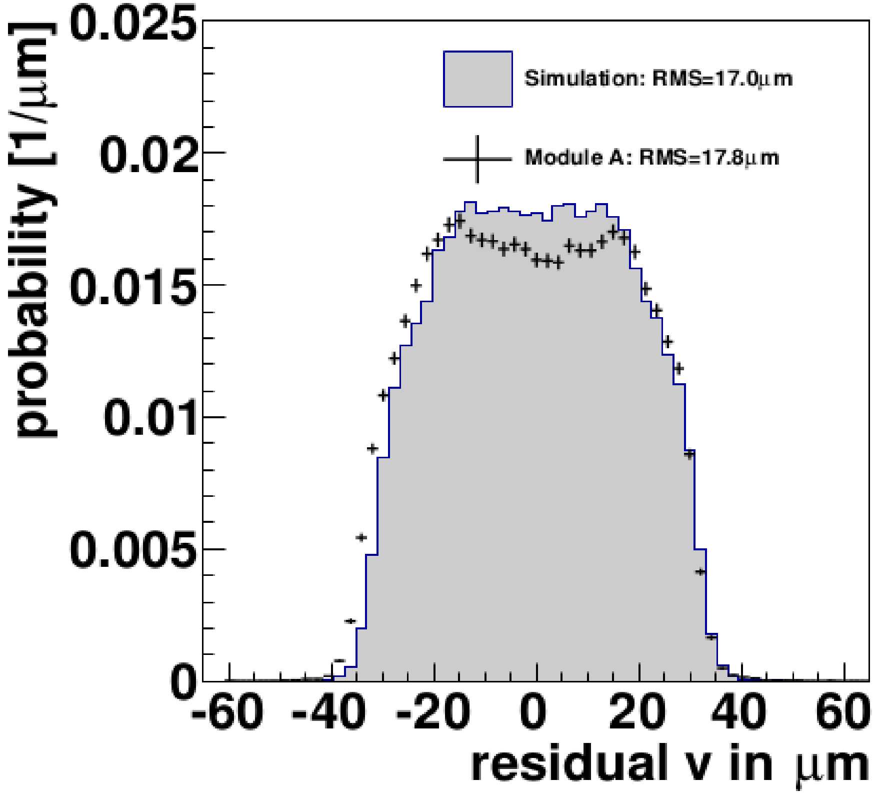


:- Mean seed charge per pixel column (row) as proxy for overall signal amplification

:- Mean seed charge uniform to better than +/-100e-

Center of Gravity residuals (Perp. incidence)





:- residuals are sum of two independent errors:

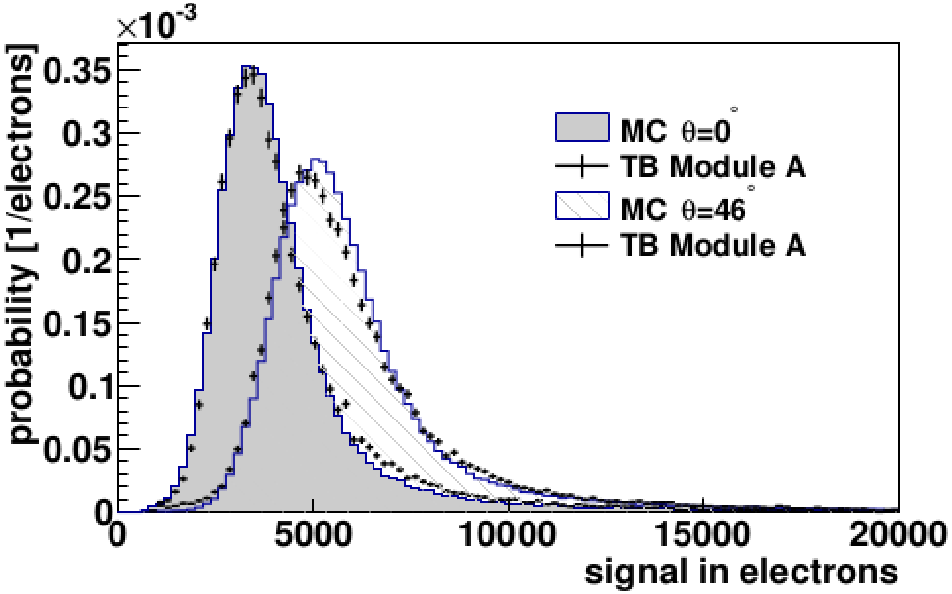
a) telescope error (M26 hits and tracking)

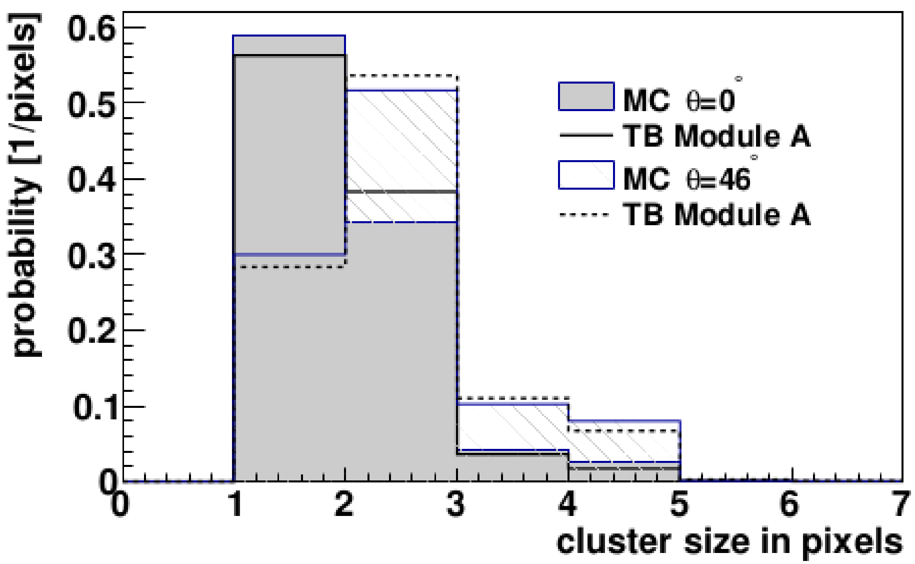
b) Sensor position error

:- however: telescope errors are very small here ~2um

→ residuals = position error for homogeneous illumination

Response for tilted sensor





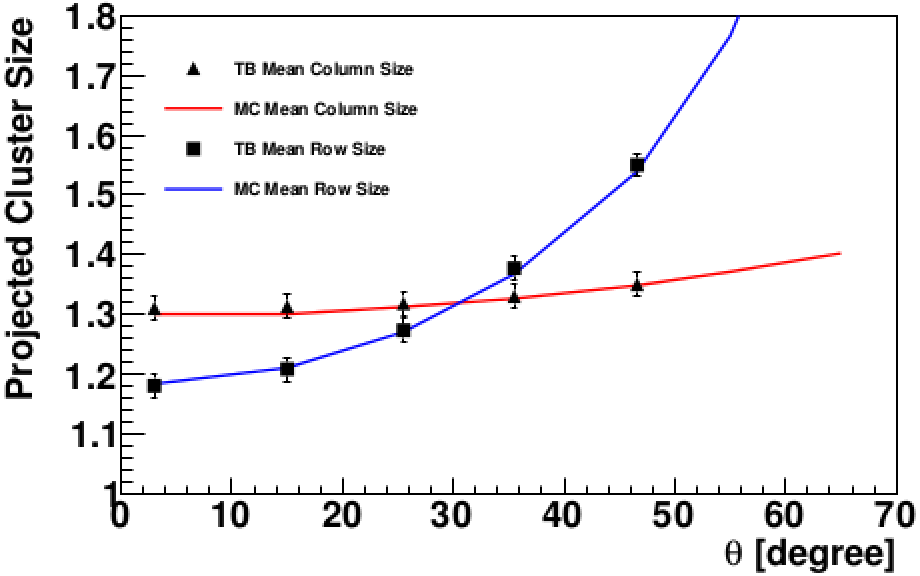
:- Tilt scan up to θ=46° at DESY test beam in 3GeV e- beam (H4.1.11)

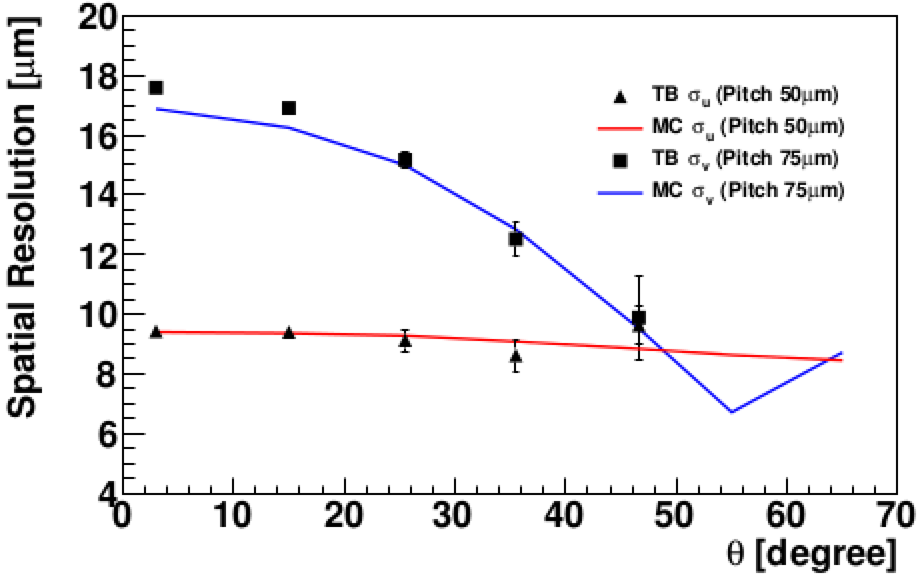
:- Long clusters in Z (75um pitch)

:- du/dw ~ 0rad (due to small beam divergence)

:- dv/dw = tanθ (due to rotation of sensor to beam axis)

Tilt scan residuals





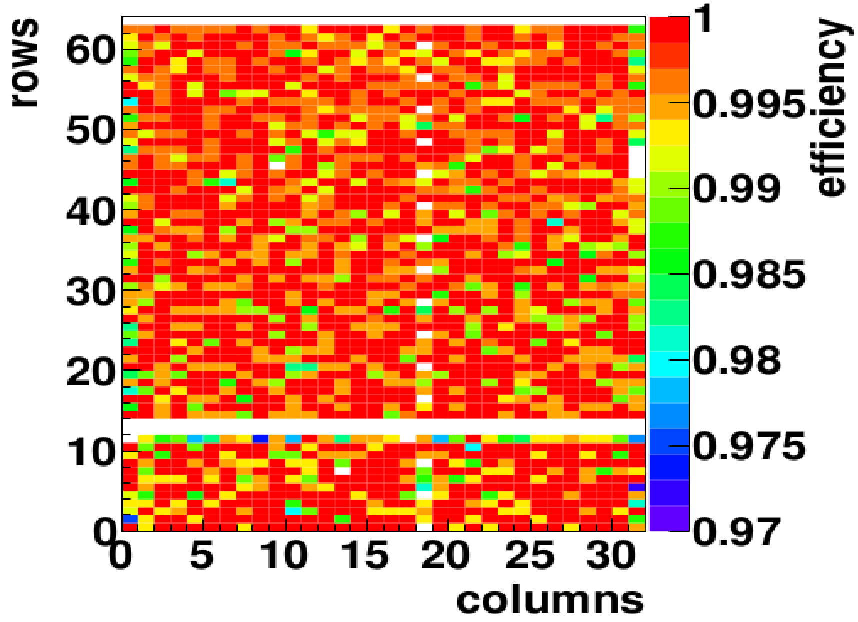
:- Spatial resolution is obtained after subtration of tel. error from residuals

:- For 75um pitch & 50um thick sensor: best resolution of ~6.7um at 55°

→ hardly measurable at DESY (large tilt → large spacings → large tel. Error)

→ Should be repeated and completed at CERN

Hit Efficiency Measurements

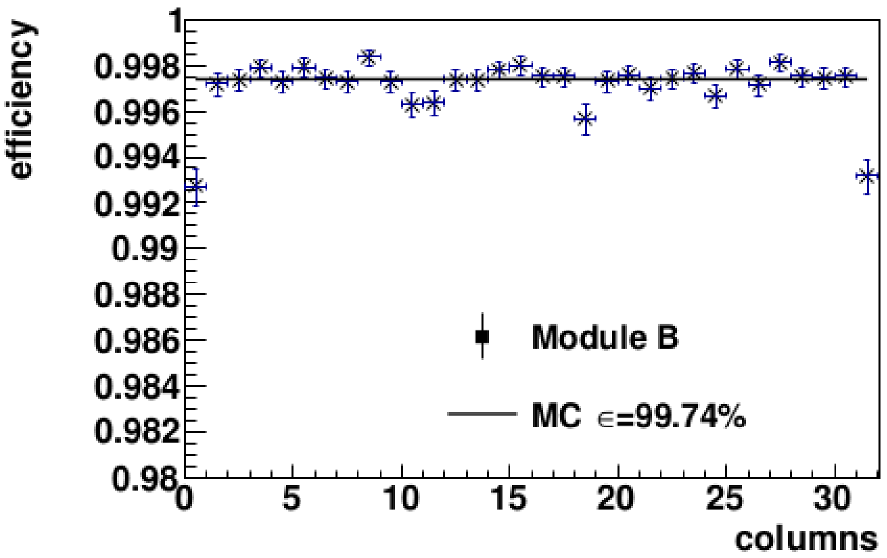


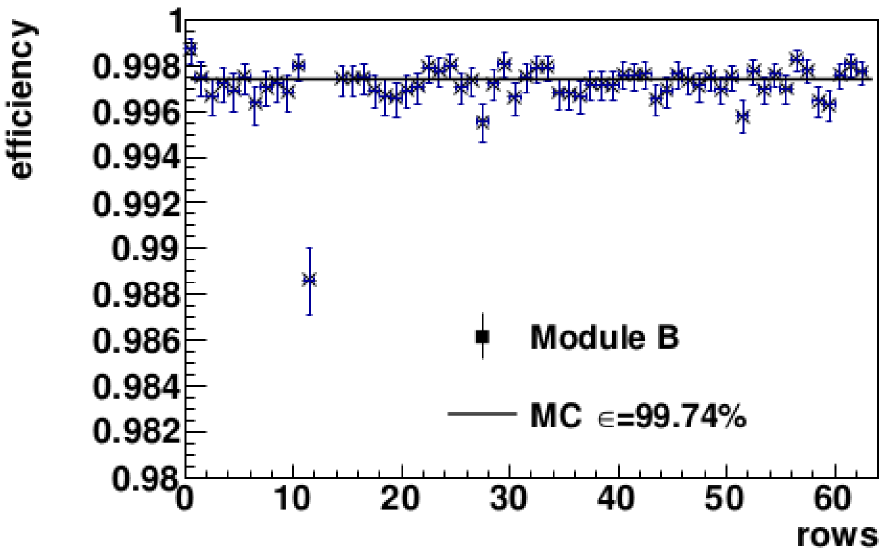
:- Hit efficiency measurment during CERN TB 2012 using EUDET tracks.

-3LSB zero suppression (~600e-)
-no cuts on cluster signal

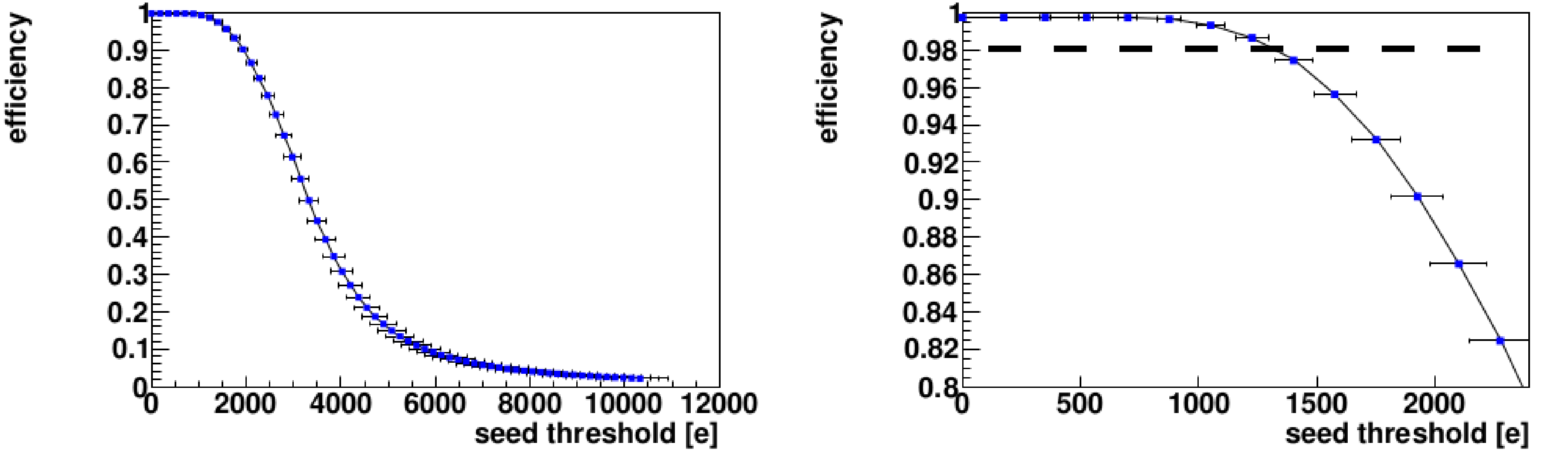
:- Measured both effi pixel by pixel and averaged over cols and rows.

:- Good agreement with simulation





Hit Efficiency and Seed Signal Cut

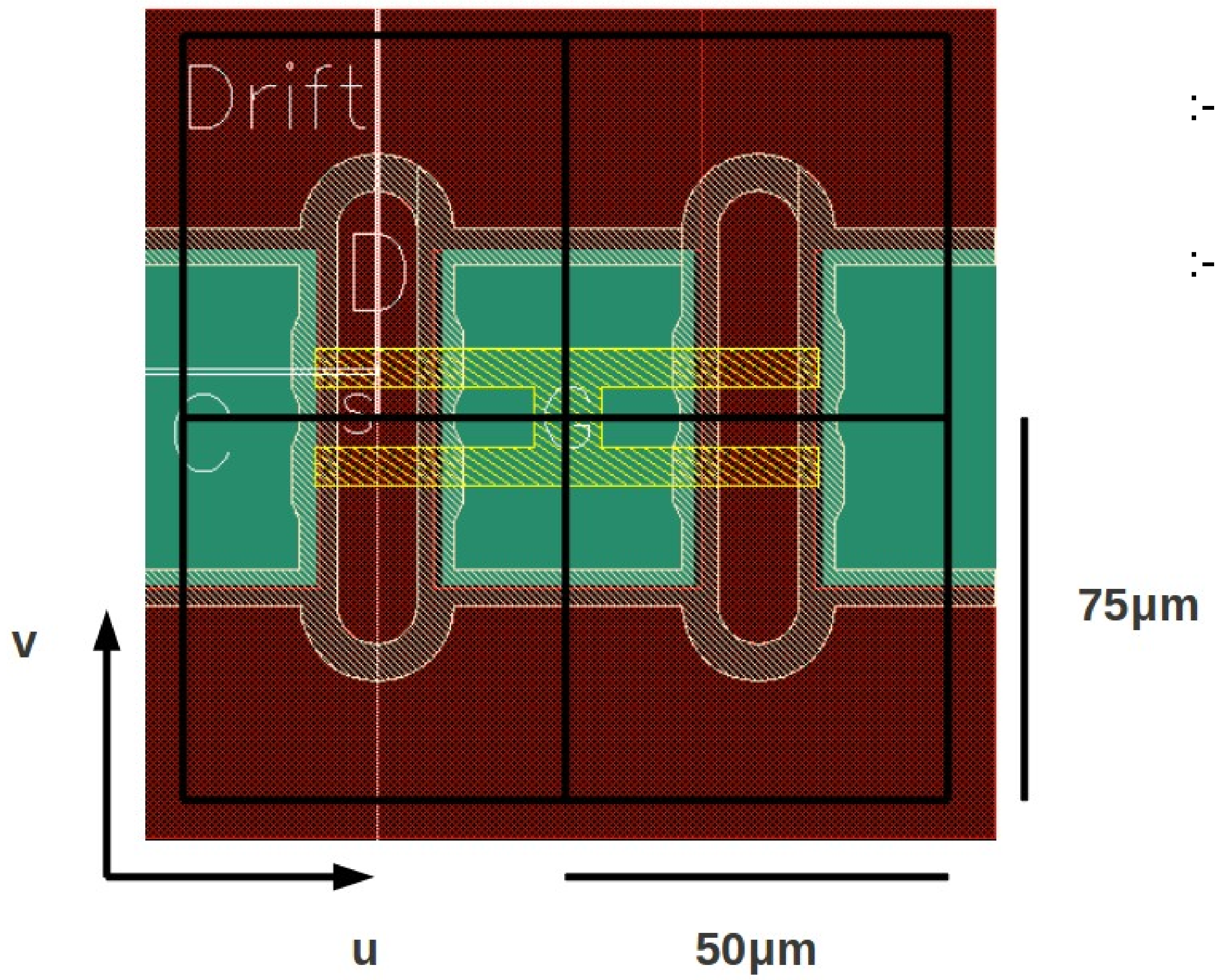


:-Zero suppression kept at 3LB (600e), But requirement on seed signal is increased in range 600-12,000e-

:- Overall efficiency drops below 98% at around 1200e. This will be relaxed when going to 75um thick sensors.

In pixel measurements

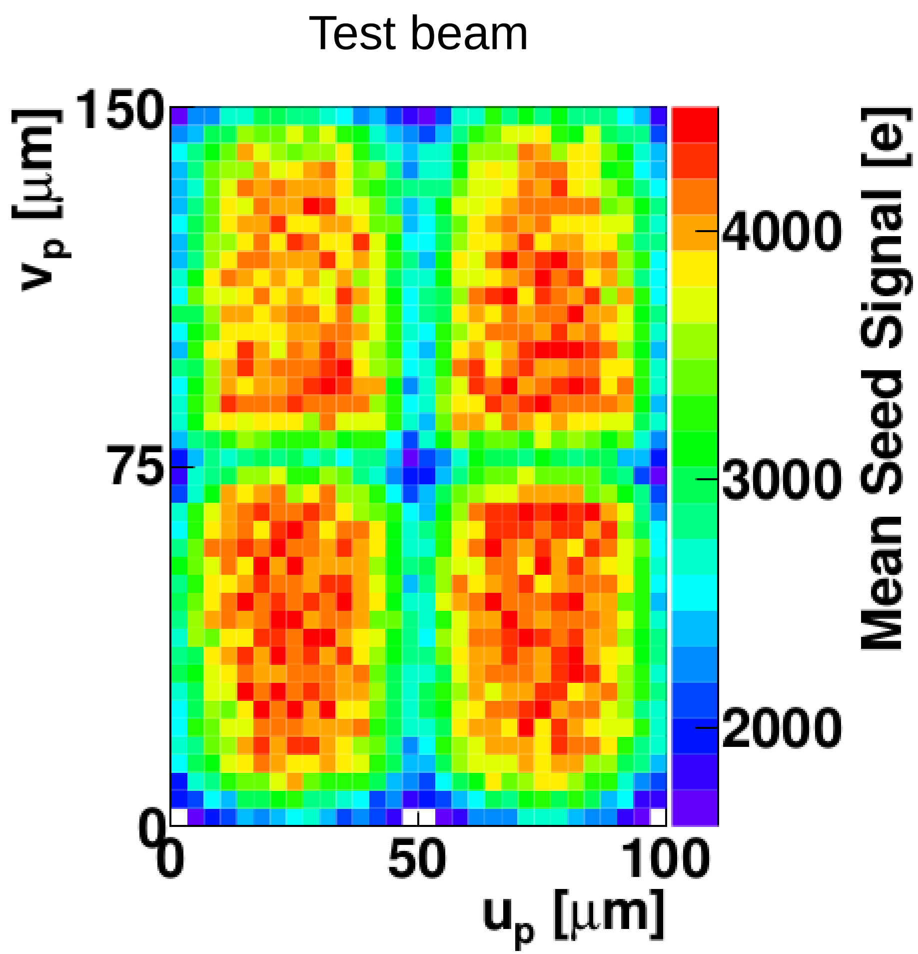
:- Exploit high telescope resolution of 2um and large data sets to measure response inside the a 4fold pixel cell.

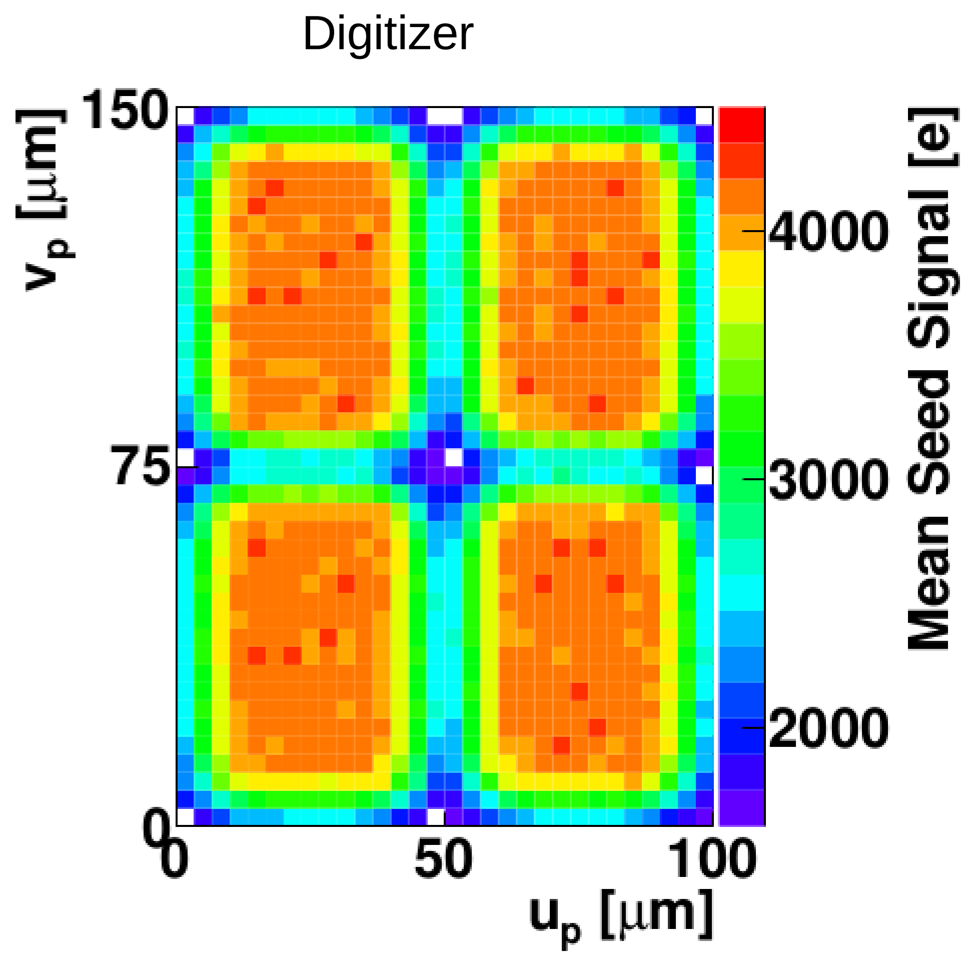


:- all tracks at perp. Incidence into sensor.

:- All results from H4.1.11

Mean Seed Charge

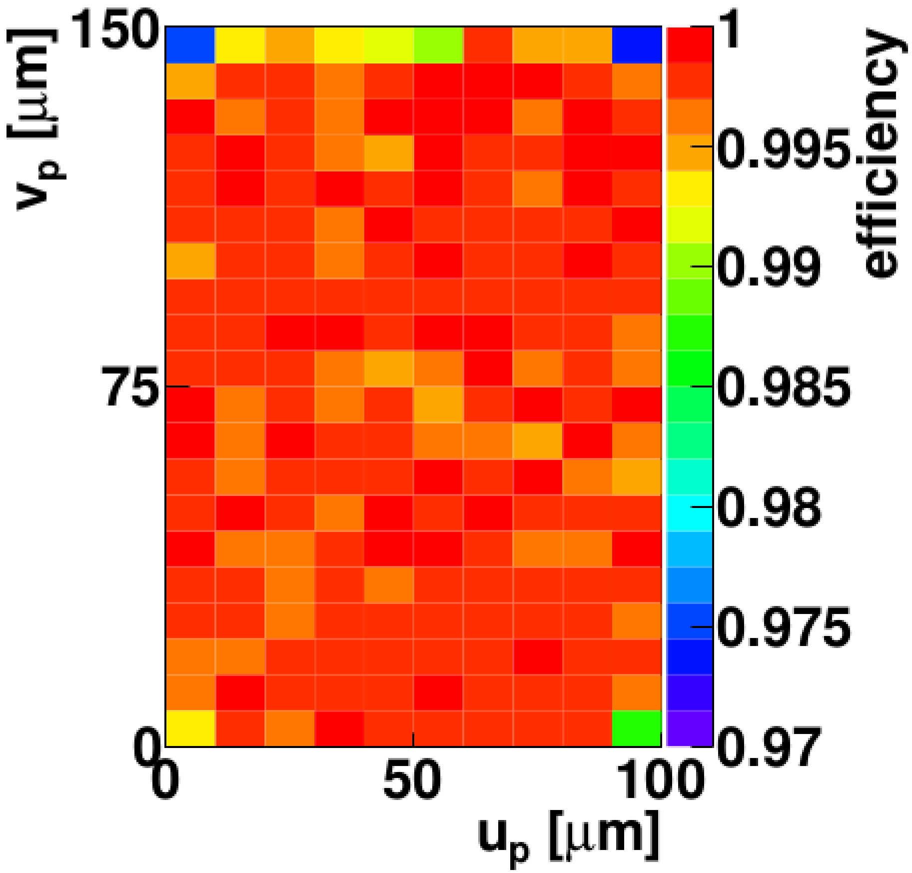




:- Mean seed signal drops below 2000e- due to charge sharing
:- Of course, can have less due to landau fluctuations

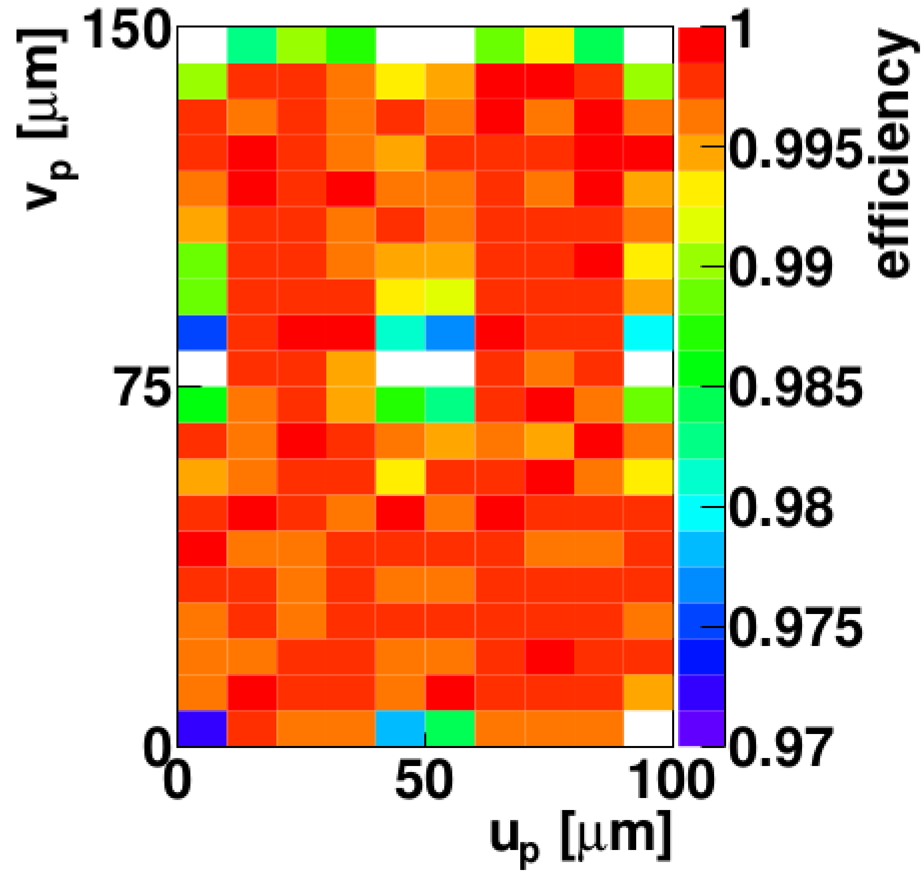
In pixel efficiency measurments

600e seed threshold (TB)



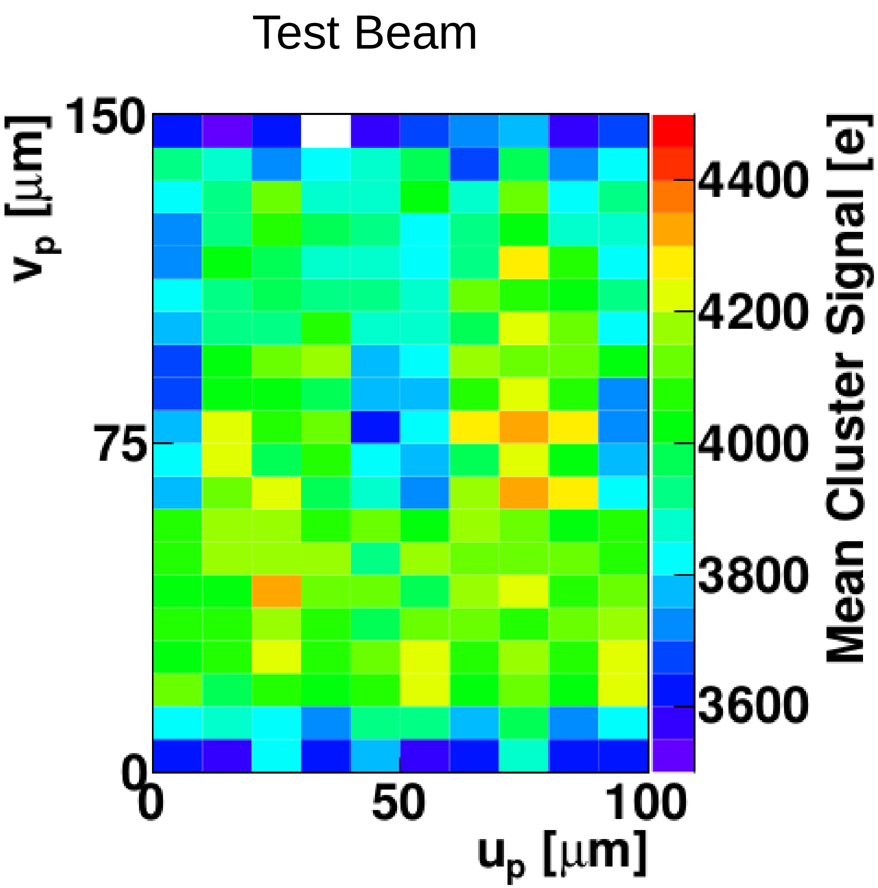
:- Near uniform effi in 4fold pixel

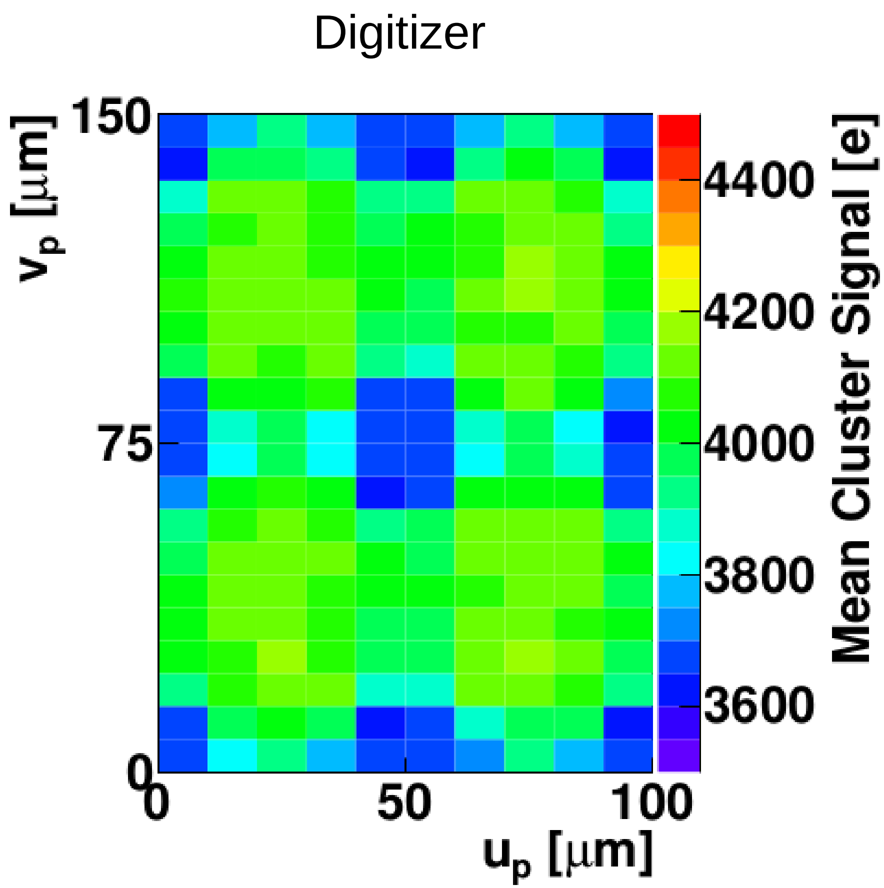
1200e seed threshold (TB)



:- Inefficiency grows from pixel corners.

Mean Cluster Charge

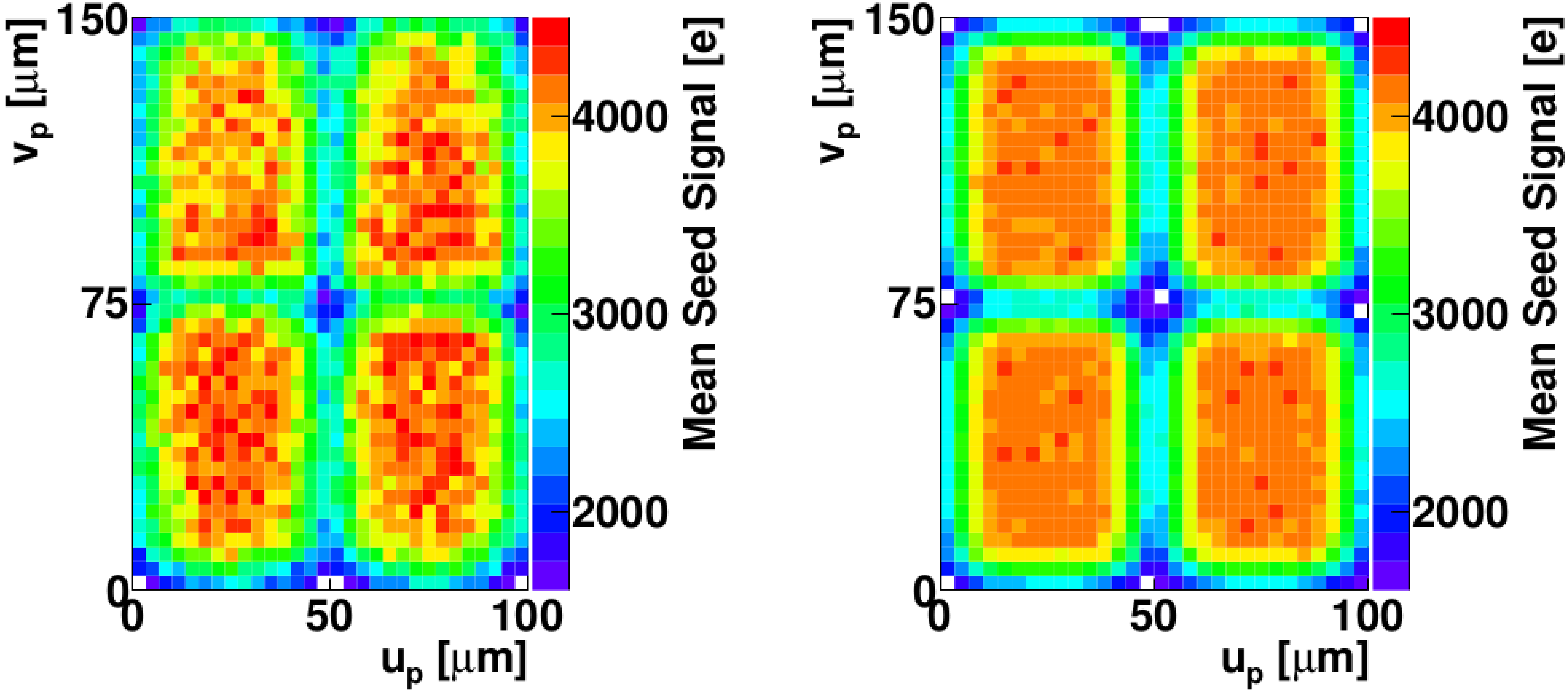




:- Charge loss in Digitizer is entirely due to zero suppression cut of 600e-. Digitizer assumes a complete charge collection.

:- Test beam charge loss is qualitatively similar, but the statistical errors are large.

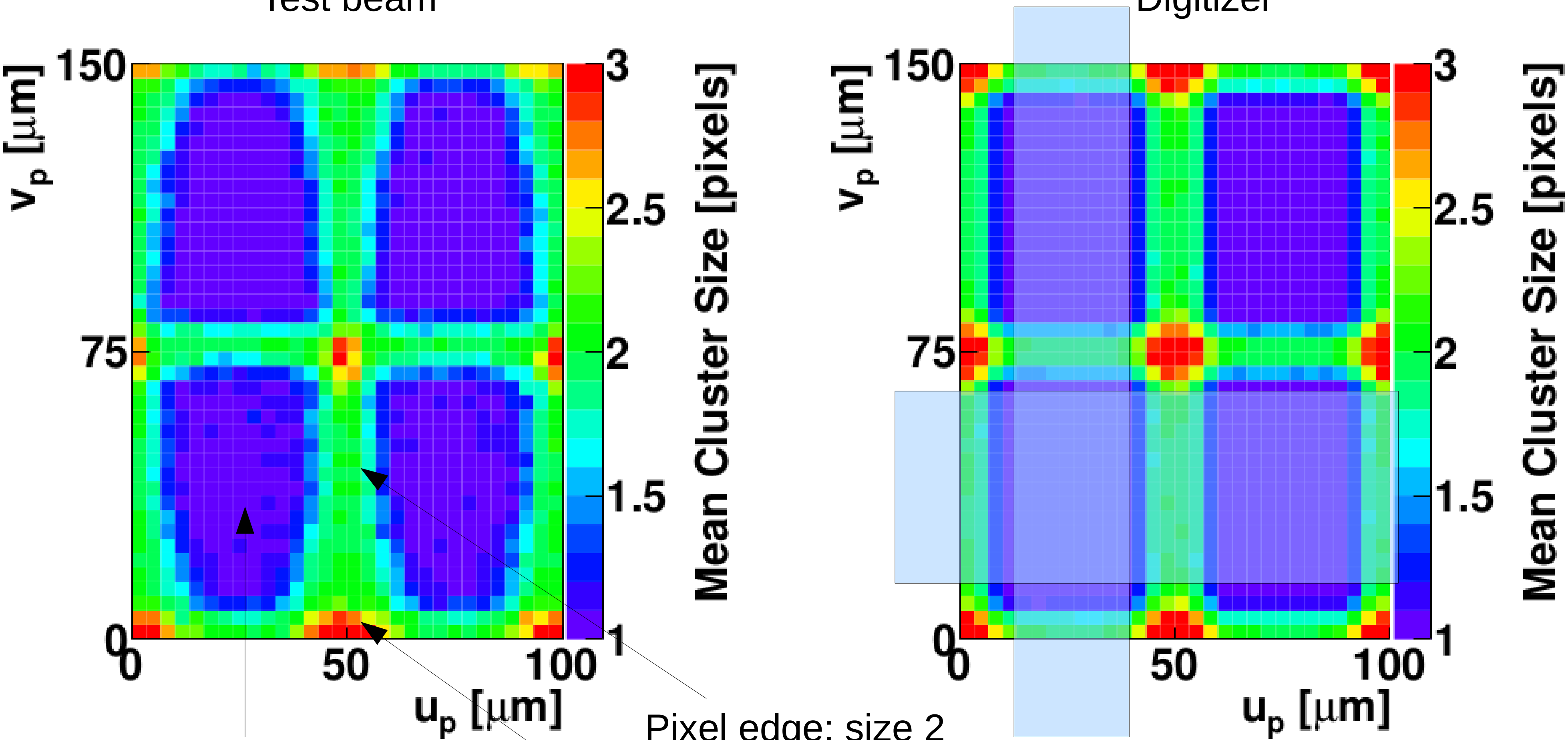
Mean Seed Signal



Mean Cluster Size (Charge Sharing)

Test beam

Digitizer



Pixel edge: size 2

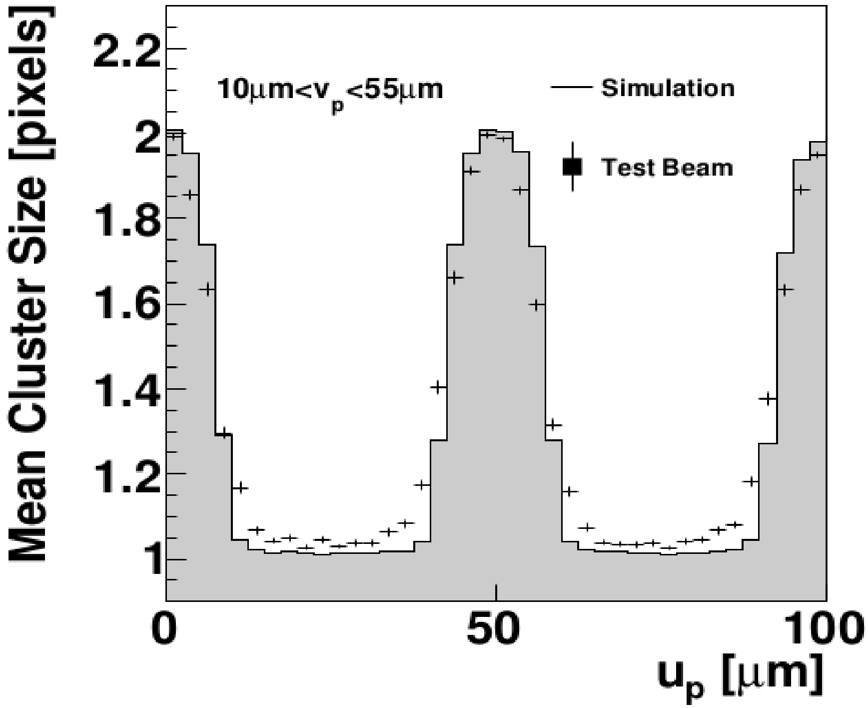
Pixel center: size 1

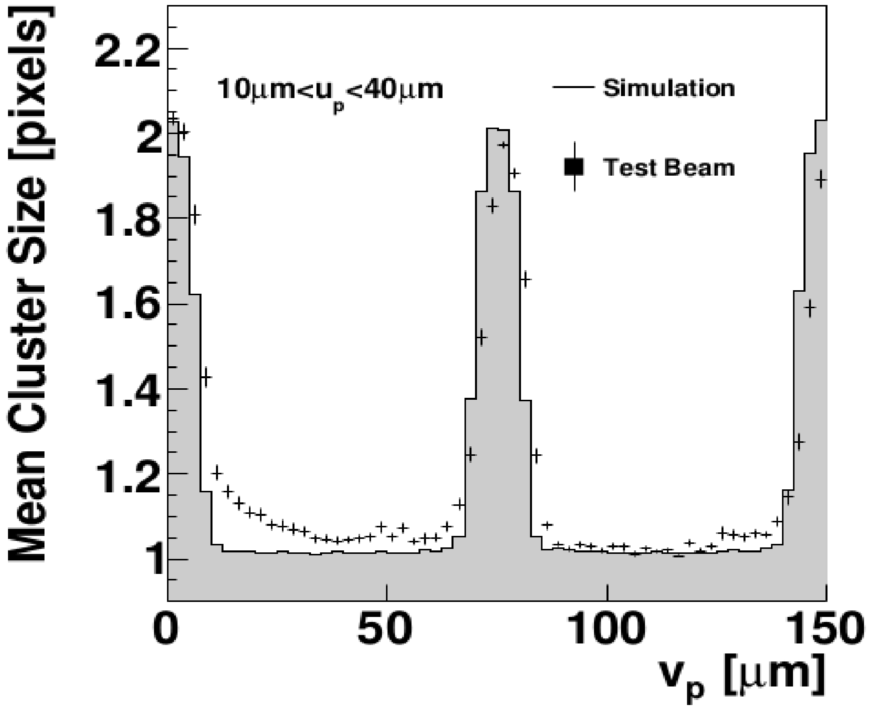
Corner: size 3

Can also look at projections

:- Charge sharing in clear regions
well described.

:-Charge sharing in drift regions
shows deviations (3D field effects).
:- Effect depends on drift voltage used
(can be mitigated)





Conclusion

- Digitizer model is reasonably simple and fast, all parameters related to measurable objects.
- Test beams with well understood small PXD6 sensors in 2012/2013 used for validation.
- Small PXD6 with standard design sensor show good performance (noise/landau/resolution/effi)
  - Of course, this must be achieved for large sensors at full speed.
  - Simplictic Digitizer works well: simulations agree well with test beam data. Even when looking very closely.
  - Test data in magnetic field is needed to look at Lorentz shift modeling. January 2014 TB probably too noisy.