Digitizer Improvements & Validation

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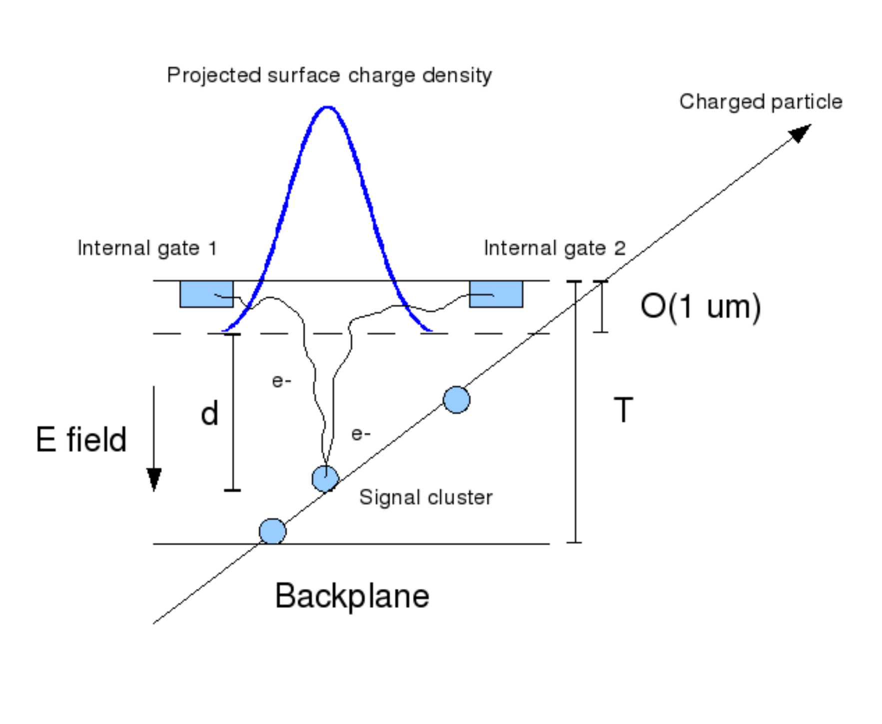
Outline

- Implementation of a physics motivated model for drift and diffusion of signal charge.
- Extrapolation of Digitizer performance from PXD 5 to PXD 6 sensors.
- Validation of Digitizer algorithm with DEPFET testbeam data.
- Open issues for further testbeam studies.

Signal Charge Collection

B = 0, for simplicity



Digitizer view on charge collection:

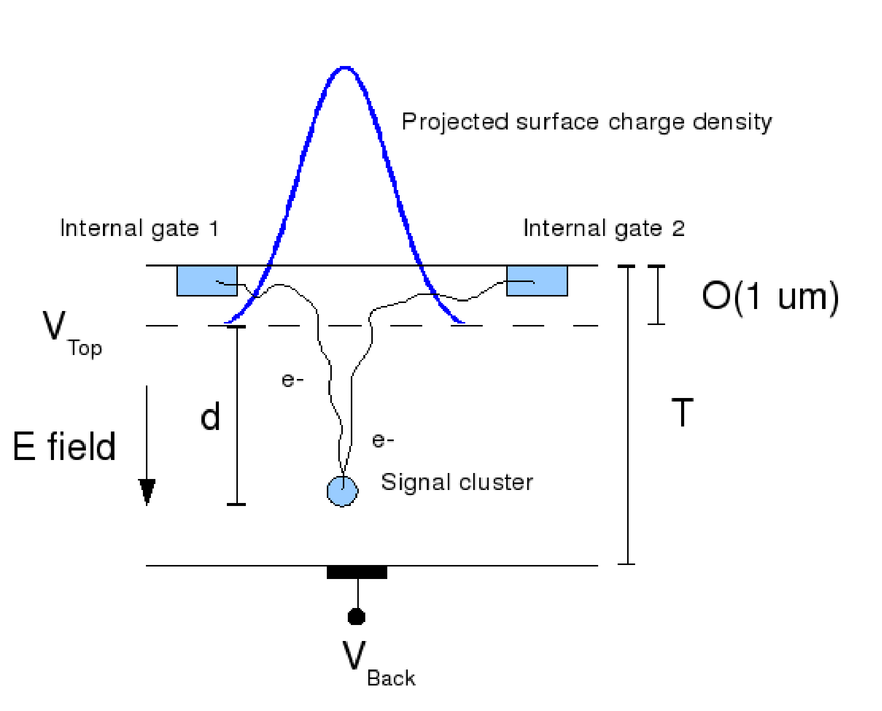
1) Primary particle impinging on sensor produces signal charge cluster (-> Geant4 input)
2) Signal electrons are projected to top surface in homgeneous electric field.
3) Lateral drift fields collect signal charge into internal gate.
4) Current parametrization:

$$\sigma_{Diffus} = \sqrt{Kd}$$

5) Pixel signal obtained from integration of surface charge over pixel area.

Signal Charge Collection II

B = 0, for simplicity



- Define a 'collection' plane a few microns below top surface.
- Assume a constant potential V_{Top} on the 'collection' plane.
- Solve 1D Poisson equation between top plane and 'collection' plane for potential.
- Use potential to calculate drift time for a signal cluster to collection plane.
- Calculate width of surface charge cloud:

$$\sigma_{Diffus} = \sqrt{2D_{n,Si}t_C}$$

Some Details

Solve 1D Poisson equation for potential from collection plane to backplane:

$\partial_x^2 \psi = -qN_d/\epsilon$

$\psi(0) = V_{top}$

$\psi(T) = V_{back}$

Parabolic potential is given as:

$\psi(x) = \frac{qN_d}{2\epsilon} x(T-x) + \frac{x}{T}(V_{back} - V_{top}) + V_{top}$

Electron drift time t_c for charge cluster created in depth d below top surface:

$\frac{dx_e}{dt} = -\mu_n E, \qquad E = -\partial\psi$

$x_e(0) = d$

Solution for $x(t_c) = 0$ is:

$t_c = \frac{\epsilon}{\mu_n q N_d} \log\left[1-y\right], \quad y = \frac{\frac{qN_d}{\epsilon} d}{\frac{qN_d}{2\epsilon} T + \frac{V_{back} - V_{top}}{T}}$

The width of charge cloud at collection plane is:

$\sigma = \sqrt{2 D_n t_c}$

The lateral fields drifting the electron cloud into the internal gate is not taken into account. A magnetic field parallel to sensor surface shifts the center of the charge cloud according to electron Lorentz drift.

Signal Charge Collection III

PXD 5 sensors:

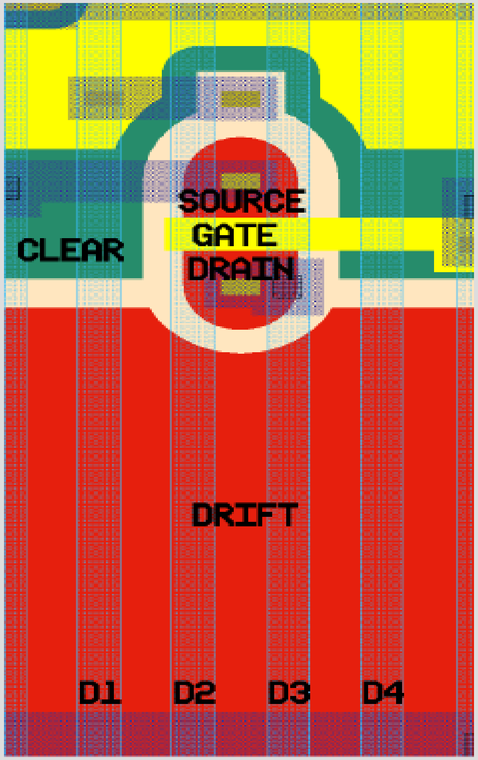
- ILC prototype sensors with small pitches ~20x20 um^2 and sensor thickness of 450 um.
- Available for validation studies; Parameters:
  - V_{Back} = -207V, relative to source.
  - Bulk doping concentration: $N_D = 10^{12}$ cm^{-3}
  - V_{top} ~ -20V, relative to source.
- V_{top} is fitted from TB data and needs some tuning.
- In principal V_{top} should come as input from device simulations.

PXD 6 sensors:

- Belle II prototype sensors with larger pitches ~50x50 um^2 and thickness of 50 um.
- PXD 6 not finished, expected parameters:
  - V_{Back} ~ -20V
  - $N_D = 10^{13}$ cm^{-3}
  - V_{top} ??
- Issue: Drift time from charge collection plane is ~ 20 us due to large pitch and small E fields.
- This simple model may not work, at least needs validation!!!

Future Plans

Integrate electrostatic potentials from full 3d device simulation (MPI HLL) into Digitizer.



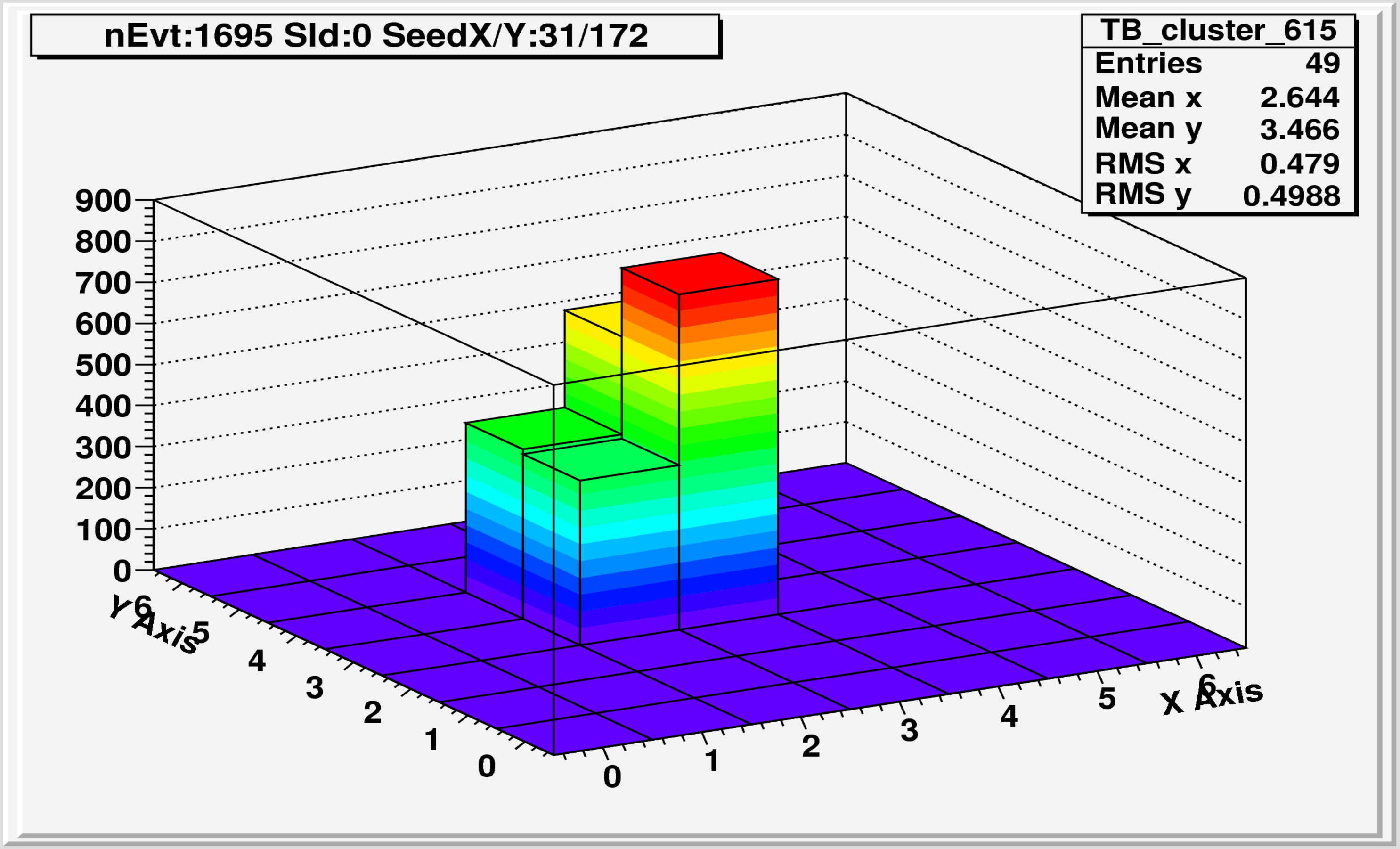
PXD 6 baseline design, single pixel.

Refined parametrization:

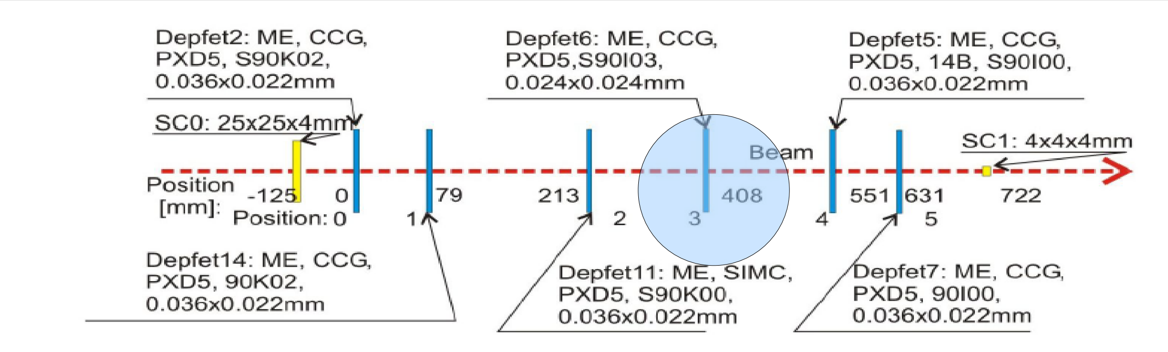
1) Define regions with well known potentials on collection plane.
2) Regions: Source, Drain, Gate and Drift regions.
3) Interpolate potentials between regions.
4) Calculate drift and diffusion into internal gate for all signal cluster.

Needs device simualtion input from MPI HLL (R. Richter).

Digitizer Cluster Output



DEPFET Testbeam Campaigns



DEPFET Teleskop (2008)

- Data from DEPFET testbeams with 120 GeV pions at Cern SPS collected 2008/2009.
- All DEPFET sensors (2008/2009) from PXD 5 production: sensor thickness 450 um, small array of 64x128 or 64x256 pixels.
- Non zero suppressed analog readout at rate of ~2 μs per frame with S3B readout board.
- Systematic studies carried out with central sensors (DUT's):

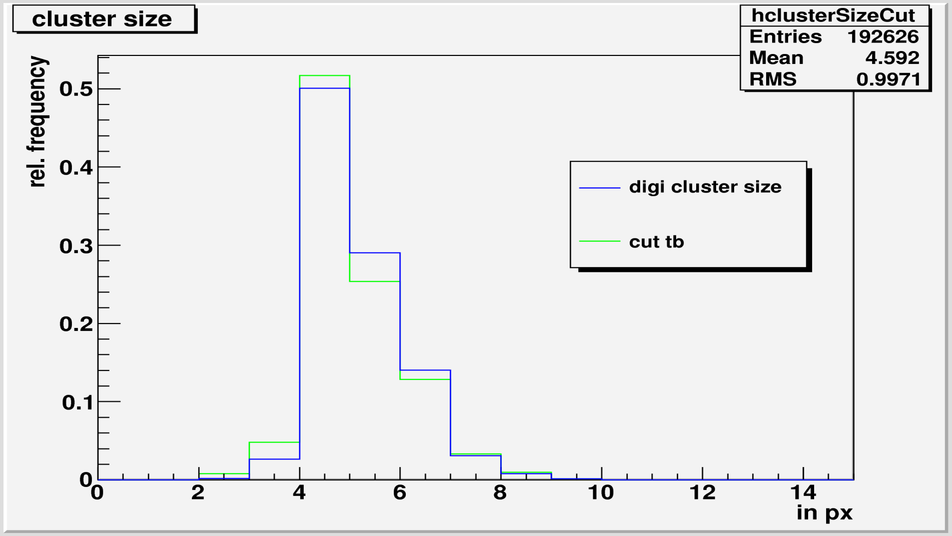
Sensor	Pitch	Noise	gain g_q
DUT 2008	$24x24um^2$	284 ENC	360 pA/e^- (gate: 5um)
DUT 2009	$20x20um^2$	174 ENC	655 pA/e^- (gate: 4um)

Data Processing

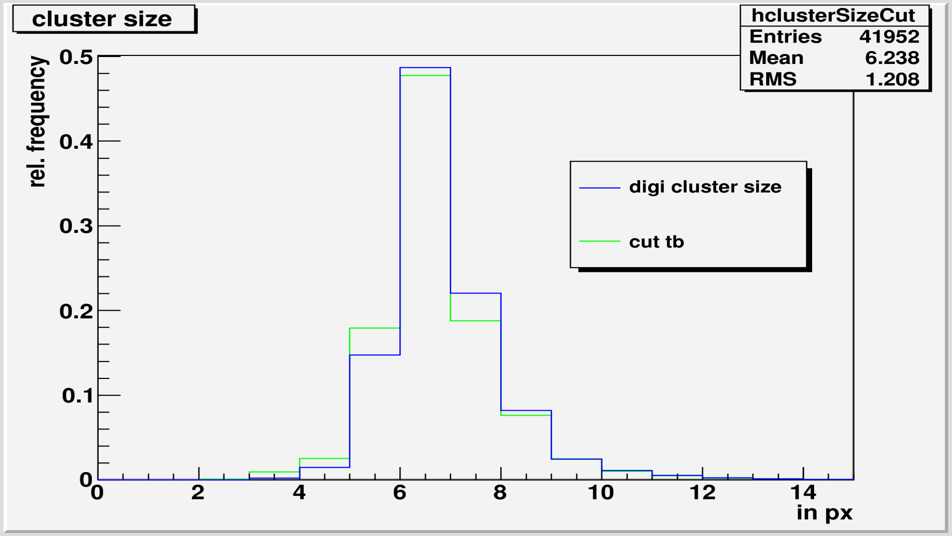
- Digitizer pixel signals should be compared with testbeam signals after pedestal and common mode correction.
- Common analysis chain (clustering/reconstruction) for testbeam and Digitizer data.
- Cluster are extracted from an NxM field around an seed pixel using the following thresholds:
  - Seed Signal Cut: $7xN_{el,pixel}$
  - Neighbour Signal Cut: $2.6xN_{e,pixell}$
  - Cluster Signal Cut: $7xN_{el,cluster}$
- Additional testbeam cuts: low occupancy (< 3 Seeds per frame), pixel on sensor boundary excluded.

Cluster Size Distributions

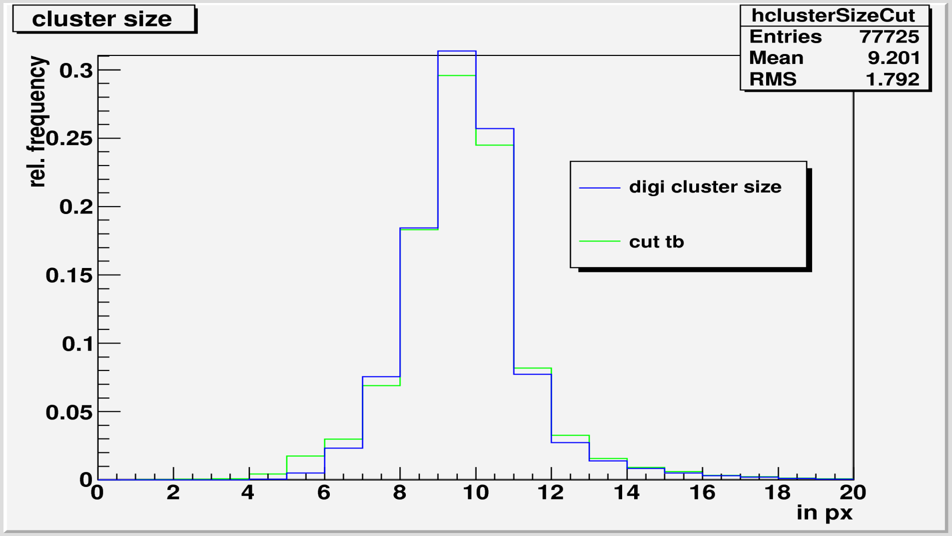
ϴ = 0°



ϴ = 6°



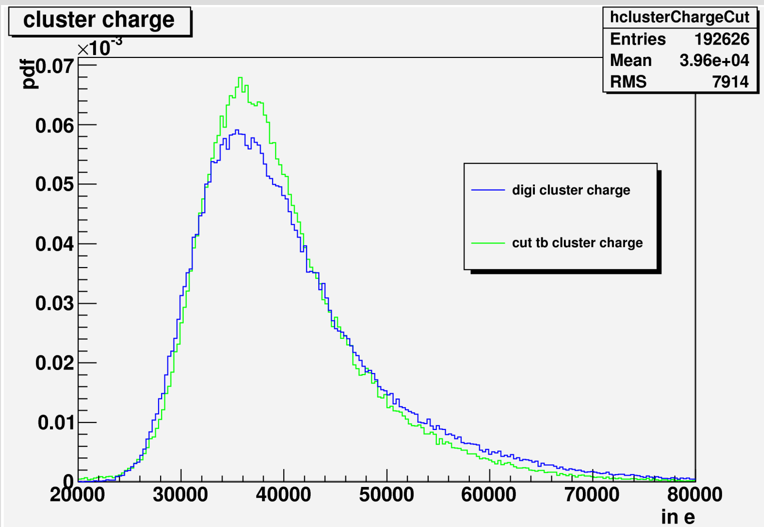
ϴ = 12°



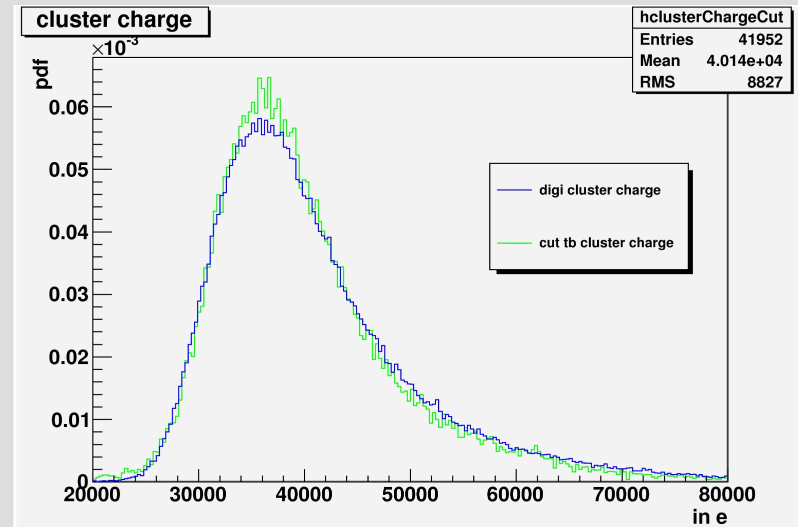
- Data taken from 24x24 um^2 DEPFET sensor.
- Good agreement between TB and Digitizer.
- Systematics deviations ~ 5 % in each channel.

Cluster Signal Distribution

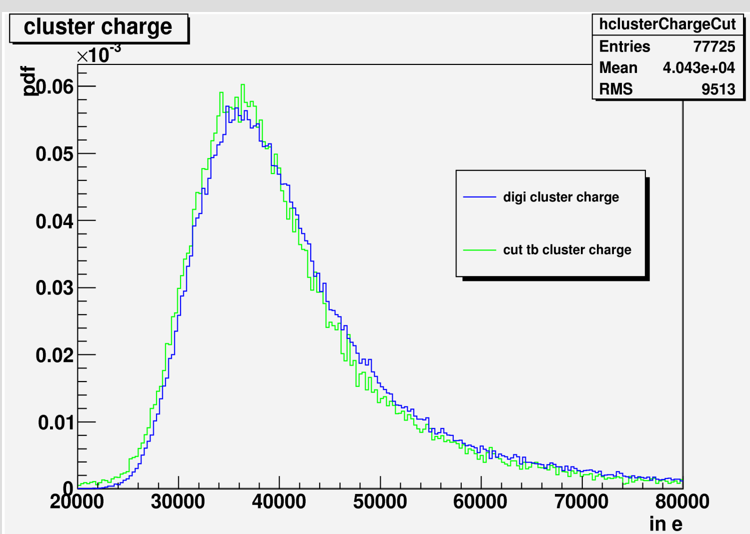
Θ = 0°



Θ = 6°



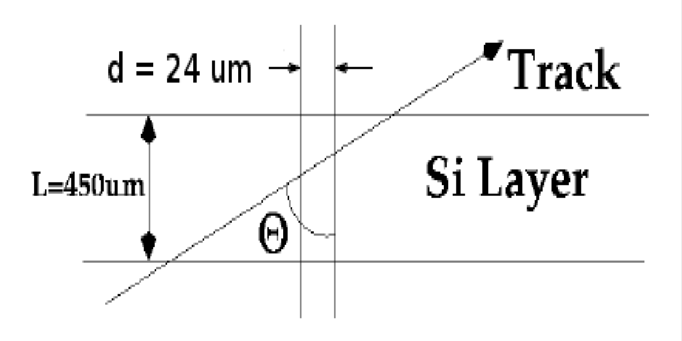
Θ = 12°



- Agreement improves with increasing incidence angle.
- Possible explanation is internal gate saturation:
  - Normal incidence: most signal charge deposited in seed pixel.
  - Internal gate no longer attractive for electrons if signal charge > 60.000e-

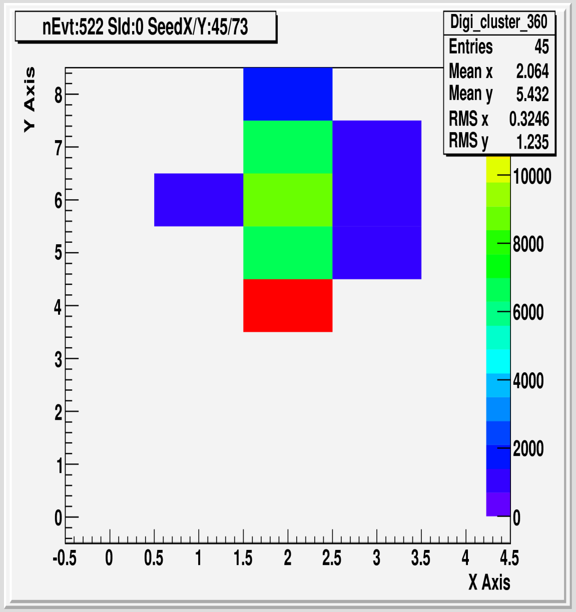
Thin Sensors

Testbeam clusters at inclined angles can be used to probe energy loss in thin silicon slices.

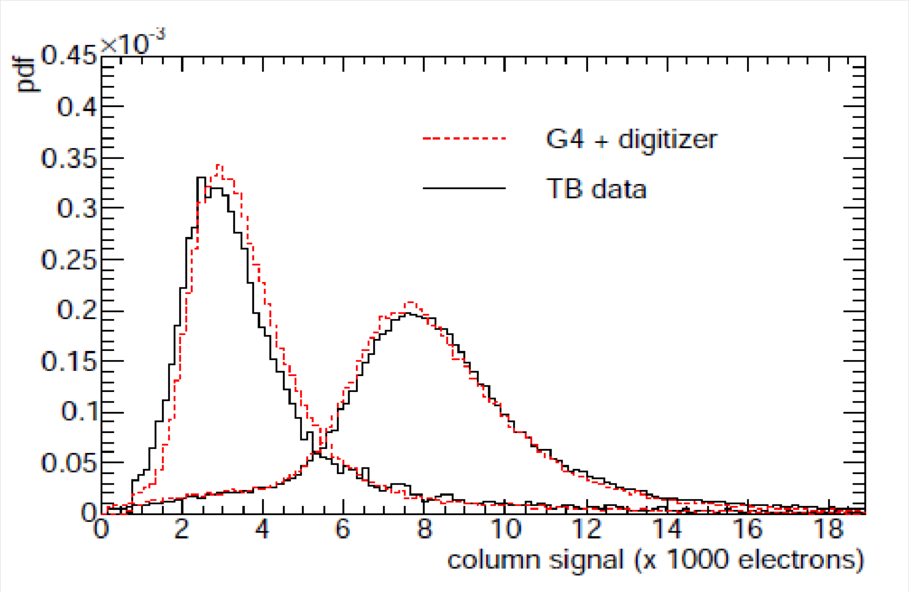


Track length per pixel: l = d/sin(Θ)

Track length per pixel is 40 um (112 um) for 36° (12°) incidence.



Teststrahl Cluster unter 12°

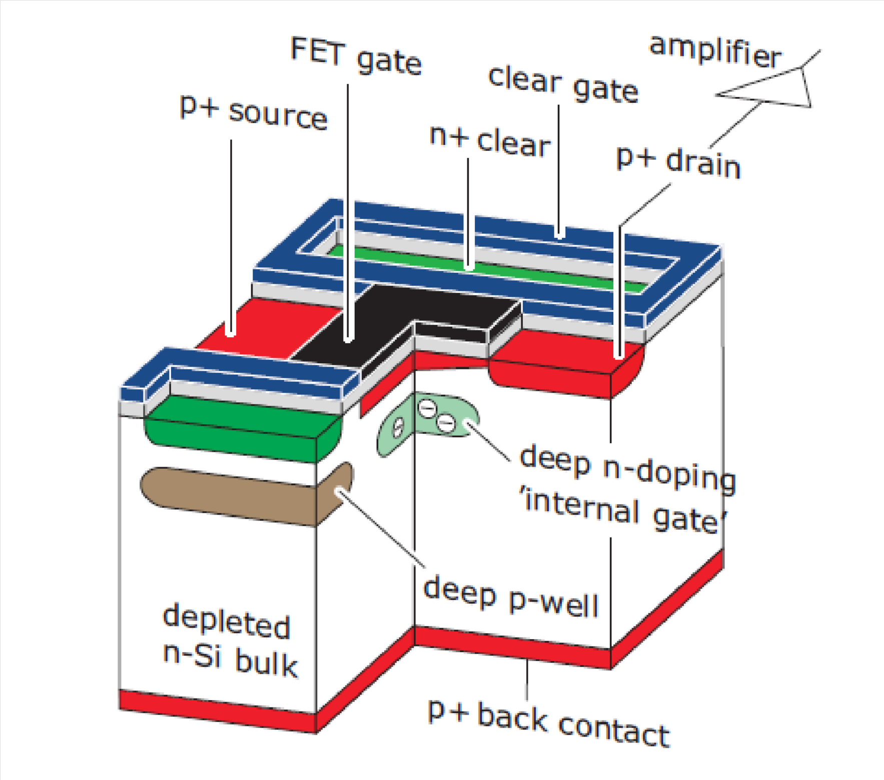


Summary and Outlook

- Reasonable agreement between Digitizer and testbeam data for ILC prototype sensors (PXD 5).
- Feed data (potentials) from device simulations into Digitizer code !!
- Testbeam data with PXD 6 sensor is urgently needed to validate Digitizer for Belle II prototype.
- Estimate for PXD 6 electronic effects is needed:
  - Noise level for final readout chain?
  - Cross talk (for example between long drain lines)?
- Impact of irradiation damage on signal collection is not studied yet.
- We should try to have a testbeam end of 2010 with PXD 6 sensors using the EUDET telescope and S3B system.

Backup Slides

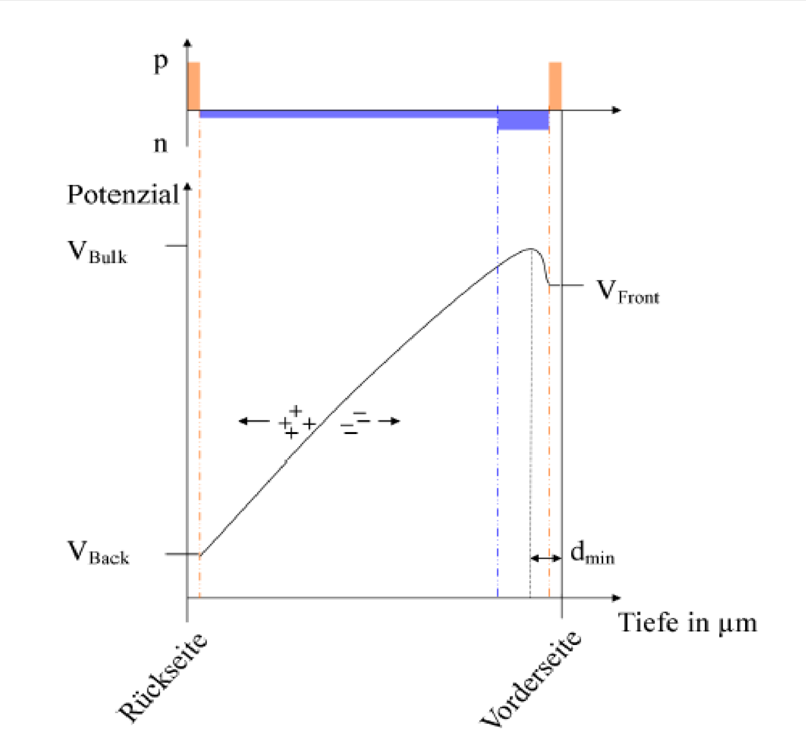
DEPFET Pixel Sensor



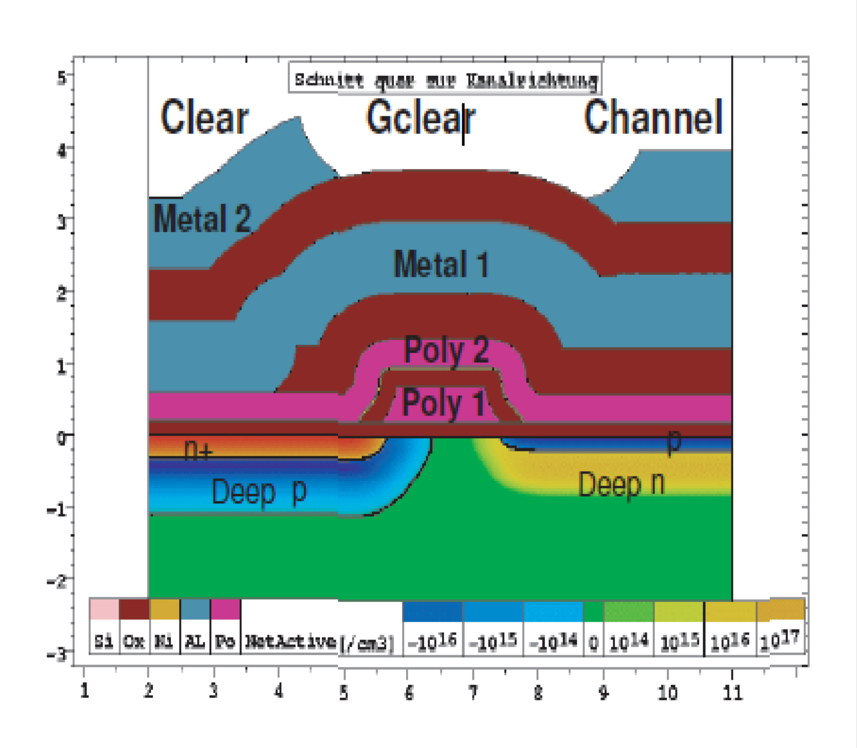
- Homogenously doped n-type silicon substrat
- P-MOSFET array on sensor surface.
- Fully depleted substrate by: V_{back}, $V_{source} < V_{bulk}$
- Potential maximum (PM) under PMOS channel by deep n doping and $V_{back} << V_{source}$
- FET „OFF": signal electrons are collected in PM.
- FET „ON": signal charge in PM increases drain current.
- Additional clear structure to struktur remove signal charge from PM.

Elektrostatisches Potential im Si Substrat

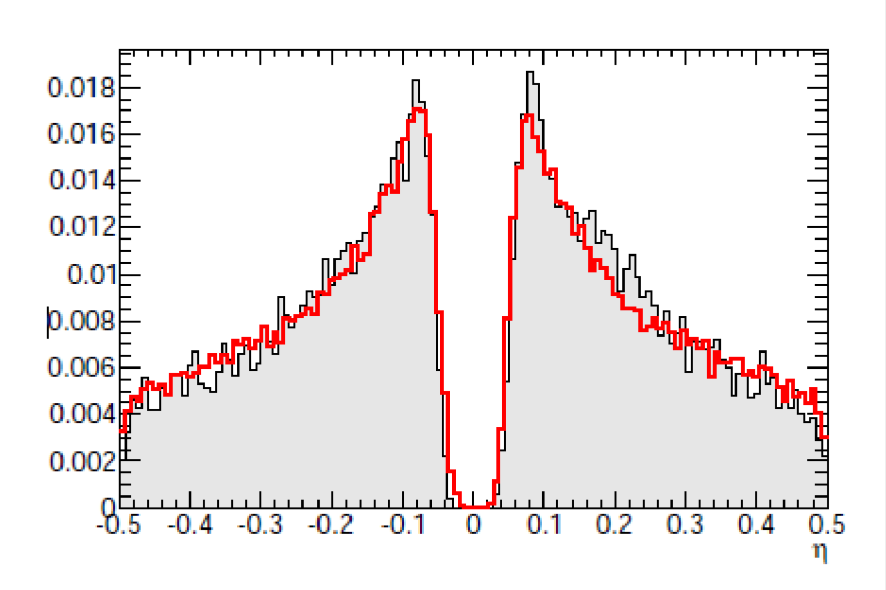
Vereinfachtes 1D Bild für die Simulation der Driftzeit:



Querschnitt durch das FET Gate mit Oberflächen Implantationen:



Eta Verteilung (DUT 2008)

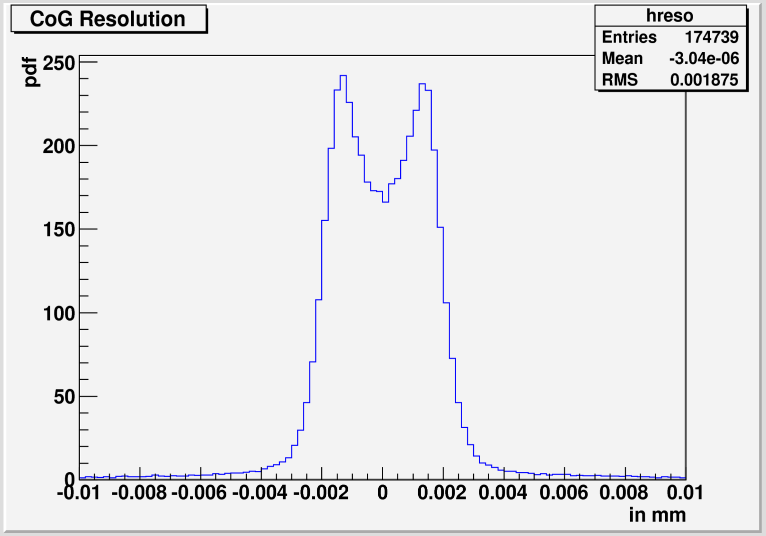


$$\eta = \frac{S_{left}}{S_{rigth} + S_{left}}$$

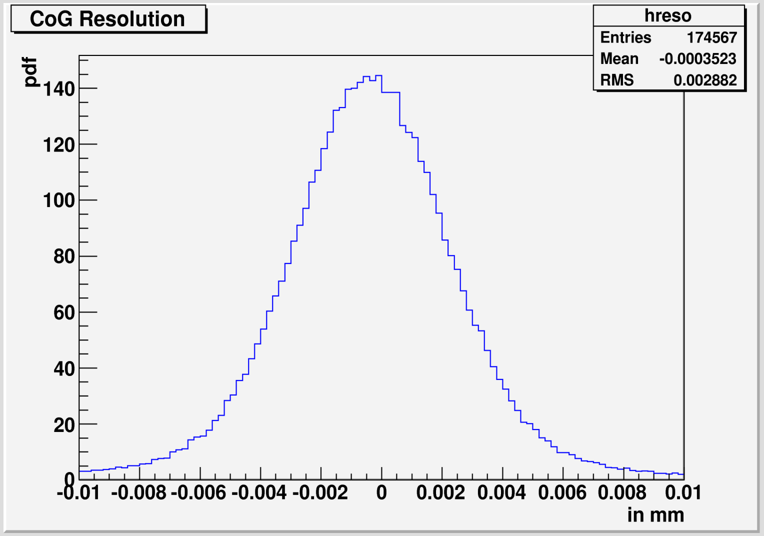
$$Z(\eta) = Z_{left} + pitch \star \int_0^{\eta} \rho(\eta')d\eta'$$

Digitizer CoG Punktauflösung

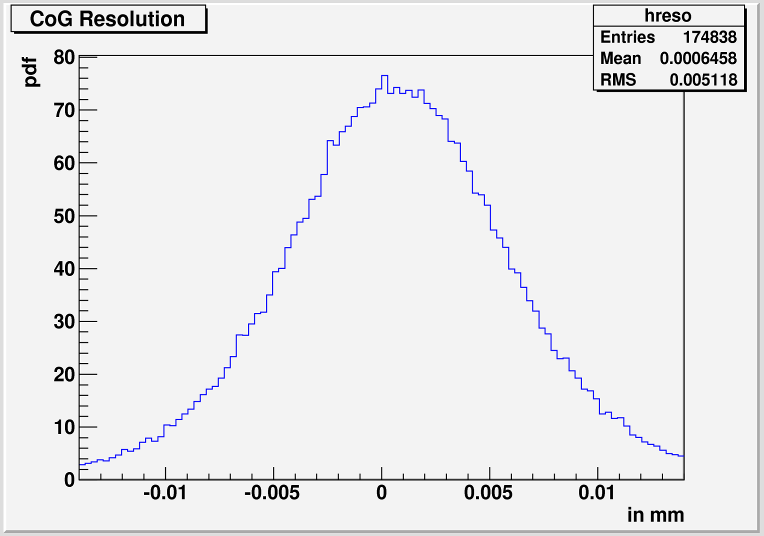
Θ = 0°



Θ = 6°



Θ = 12°



- Resolution = MC hit – CoG hit
- RMS values:
  - 0°: 1.8 um
  - 6°: 2.9 um
  - 12°: 5.1 um
- Double peak for normal incidence CoG.