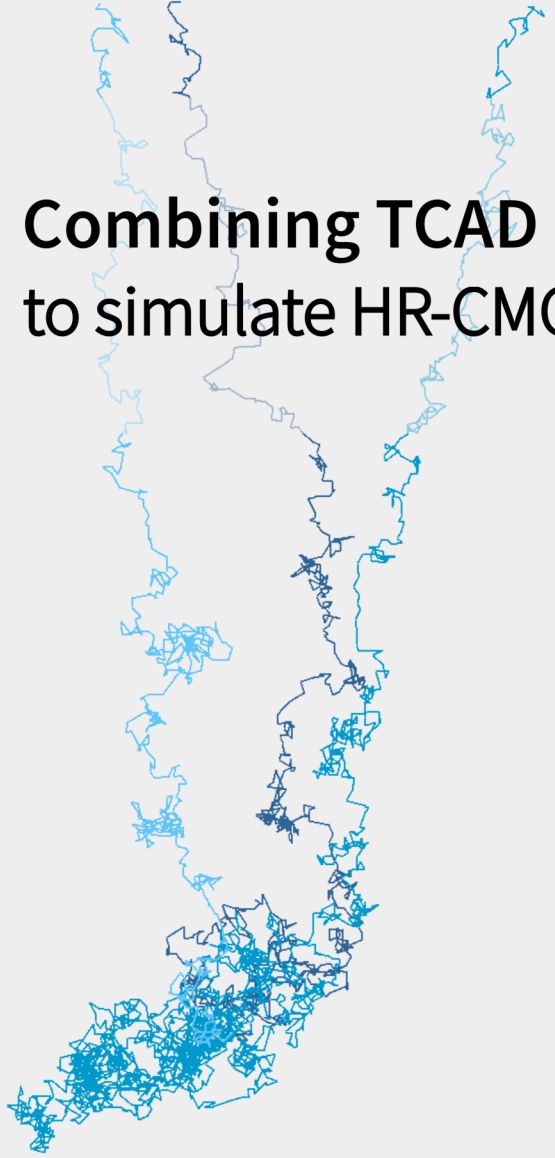
http://clicdp.cern.ch



Combining TCAD and Monte Carlo methods
to simulate HR-CMOS pixel detectors using the Allpix^2 framework

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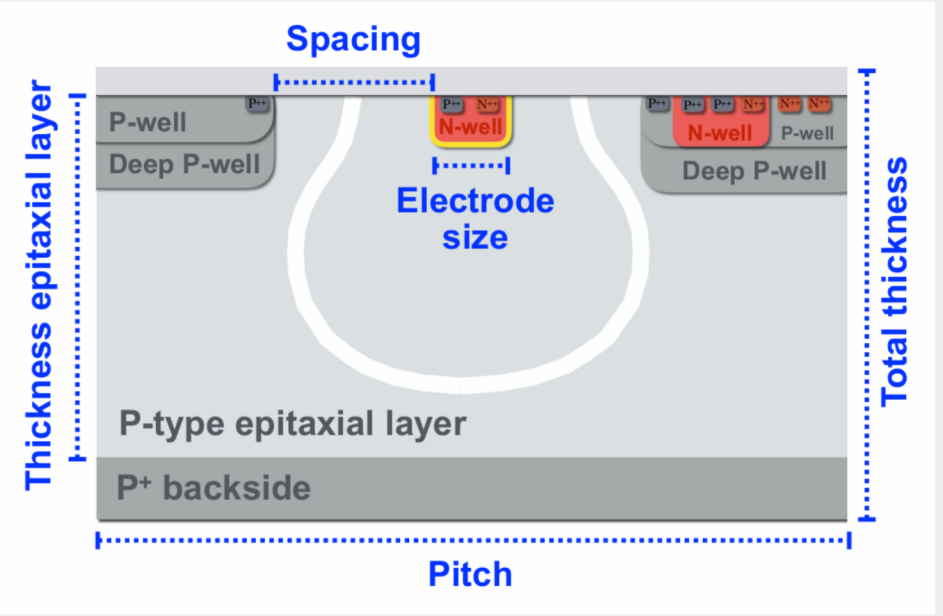
Magdalena Munker, CERN
Simon Spannagel, CERN

1st Allpix Squared User Workshop
CERN, 27 November 2018

CMOS Sensor with High-Resistivity Epitaxial Layer

- Monolithic Silicon CMOS sensor
  - 180nm process
  - 25um epitaxial high-resisitivity Si on
  - 75um standard-Si substrate

- Small collection electrode for good SNR
  - Partial depletion of the epitaxial layer
  - Substrate undepleted
  - Highly non-uniform electric fields

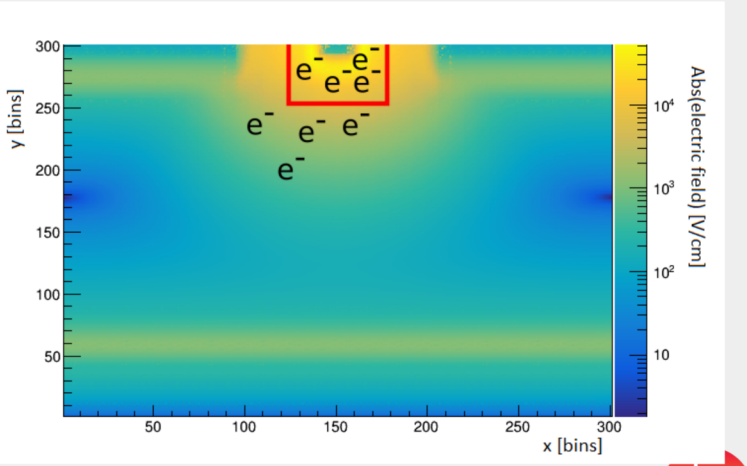


Simulation - Concept

- Use **TCAD for electrostatic simulation** of the field with bias voltage applied
  - See talk by Magdalena

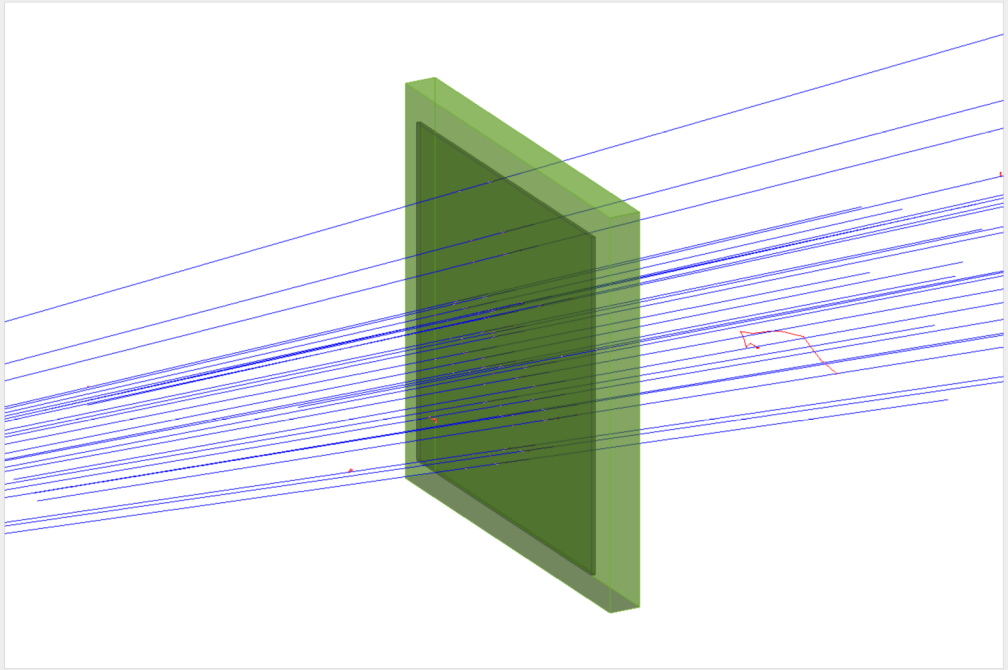
- Use Allpix Squared **to simulate particle passage**

- Simulation model based on “collected charges”
  - With small collection diode, impact from induction during drift should be small
  - Define region of collection implant for collection of charges



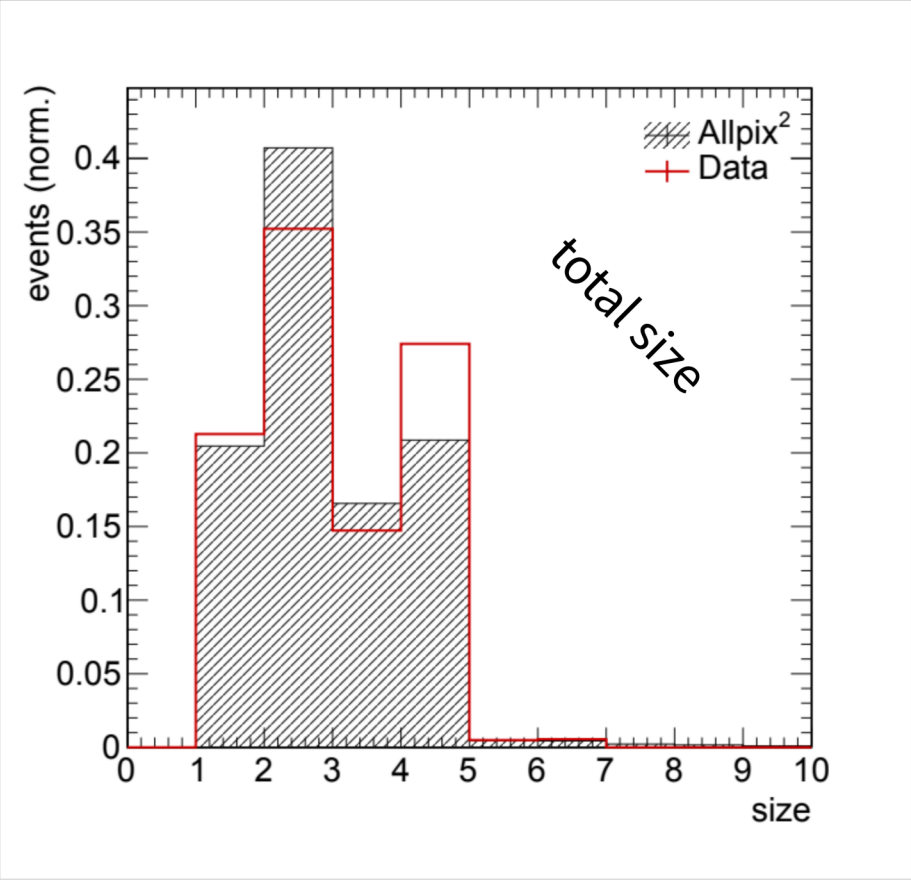
Simulation - Detector

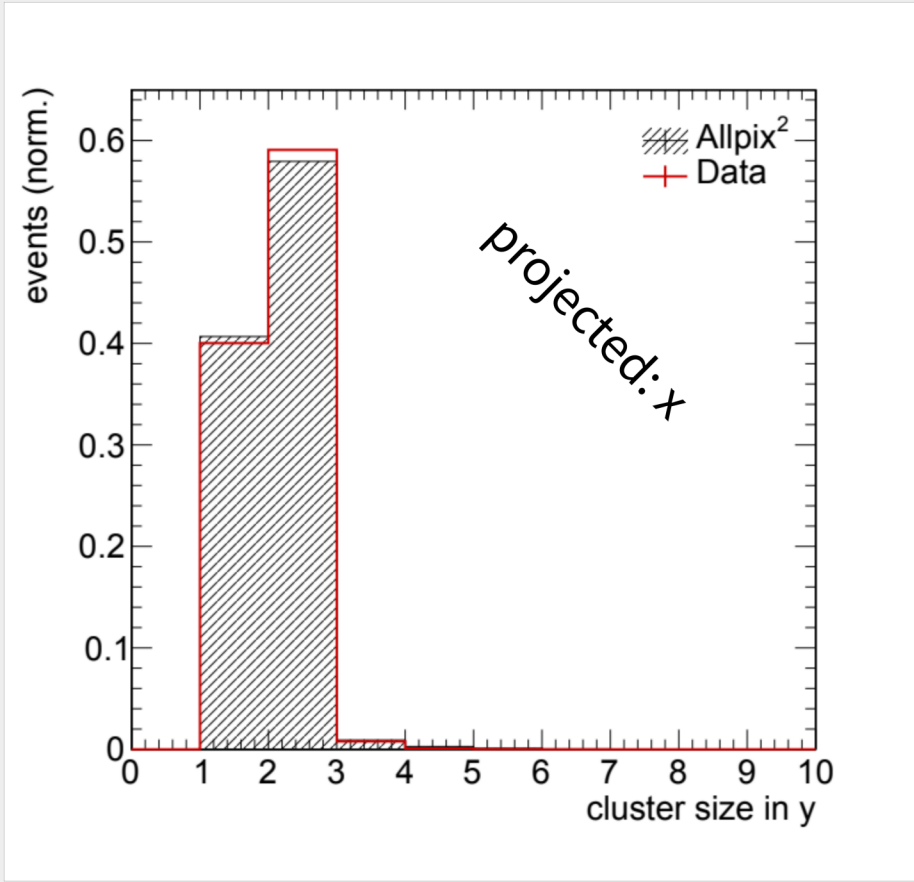
- ALICE Investigator-like detector
  - 28x28 um pixel pitch
  - 2x2 um charge collection implant
- SPS Beam: 120 GeV Pions
- Simulate detector only, no telescope
  - Monte Carlo truth used for reference track information



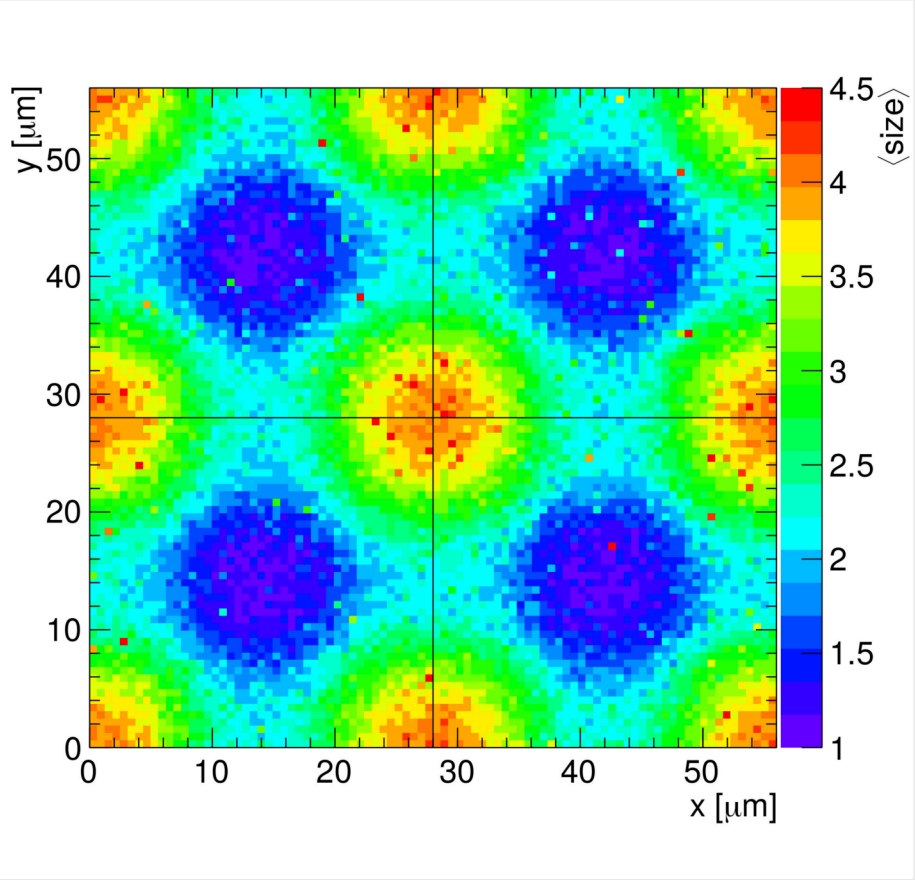
- Comparison with test beam data from Magdalena's PhD thesis
- Using CLICdp Timepix3 telescope, ca 25k events recorded

Cluster Size Distributions



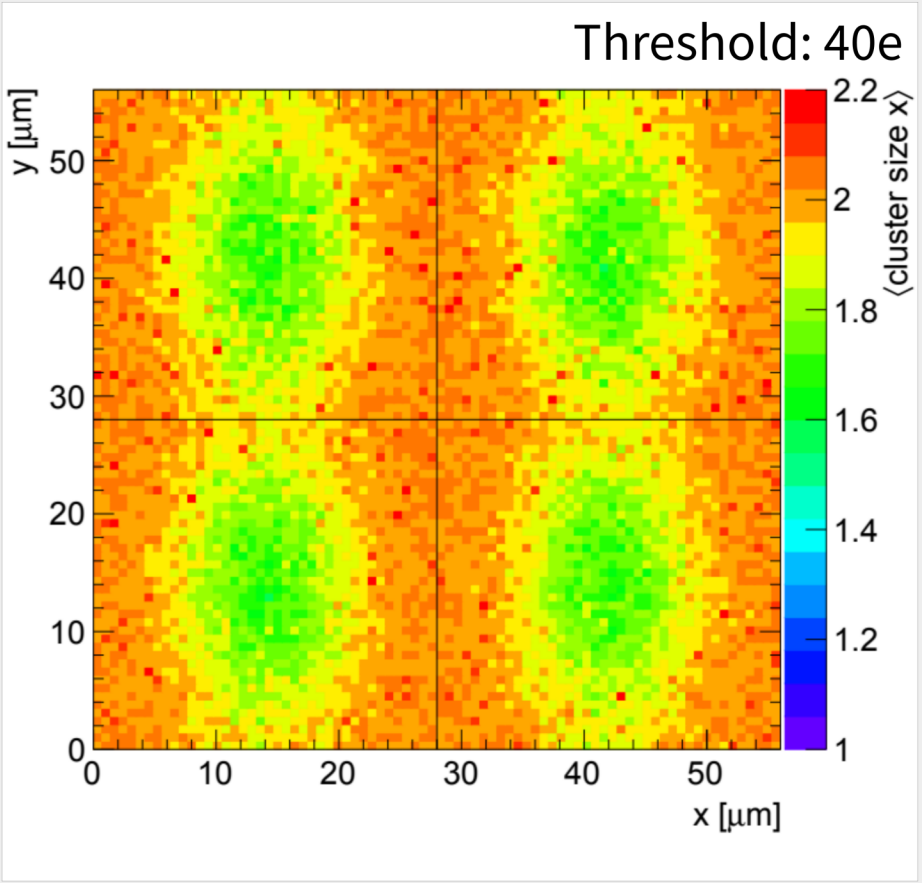


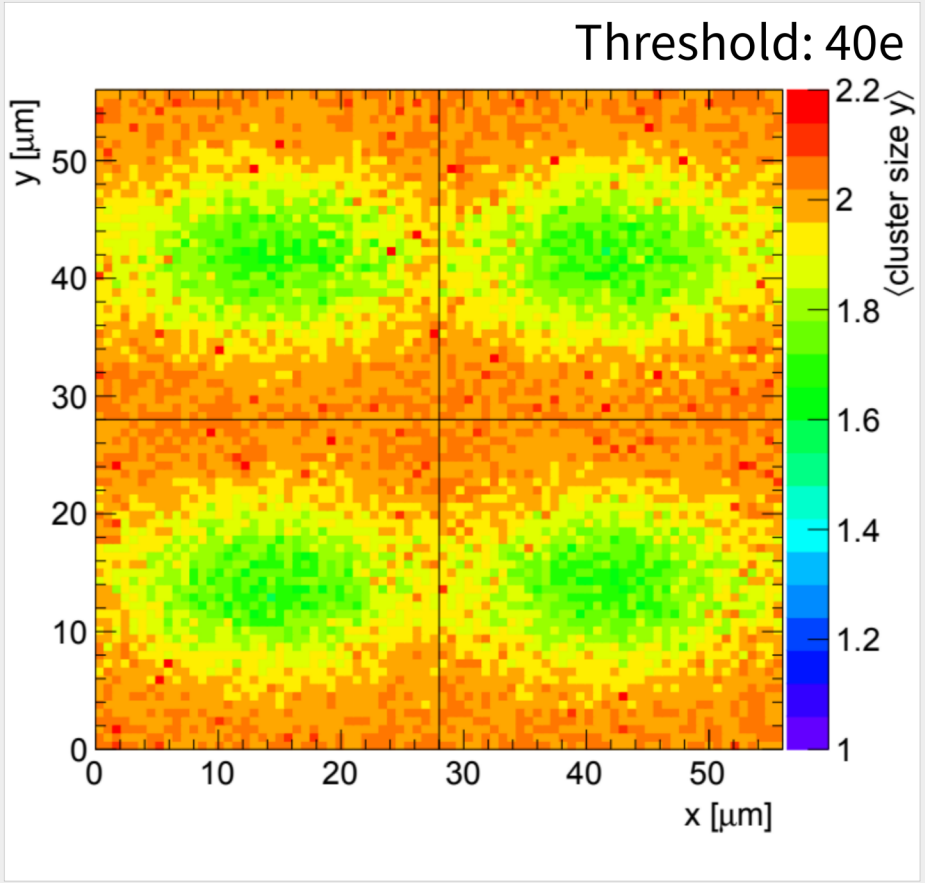
In-Pixel Distribution of Cluster Size



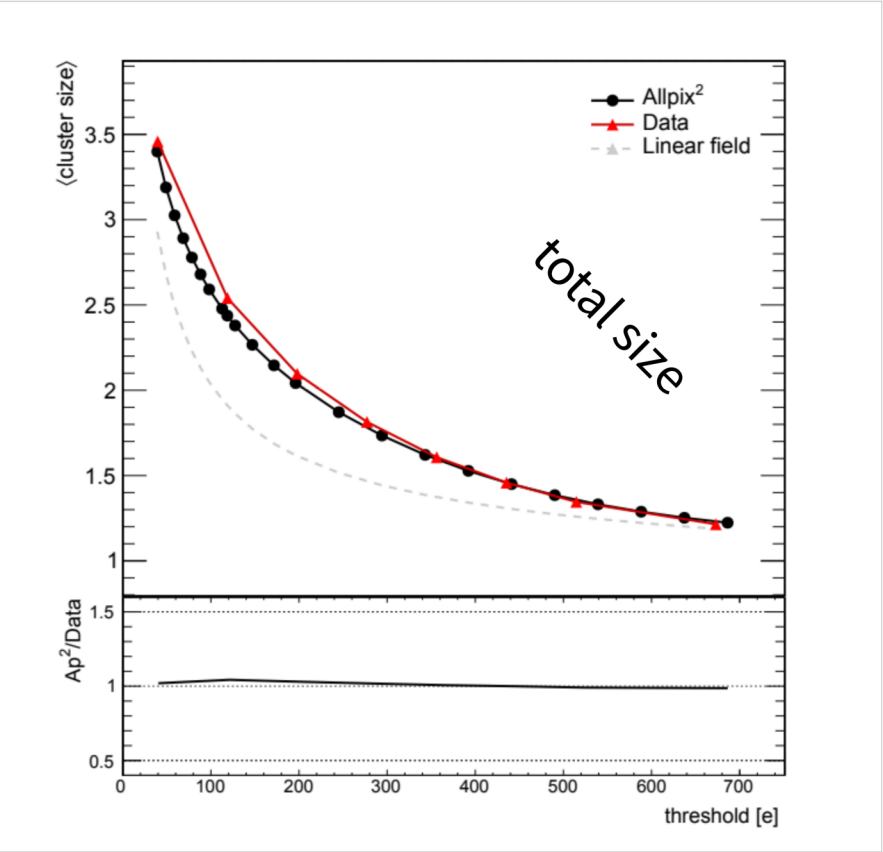
- Using Monte Carlo truth to calculate position within pixel
- Fold statistics from full sensor into four pixel cells
- Mean size behaves as expected:
  - 1-px cluster in pixel center,
  - Charge sharing towards neighbors
    - In edges
    - In corners

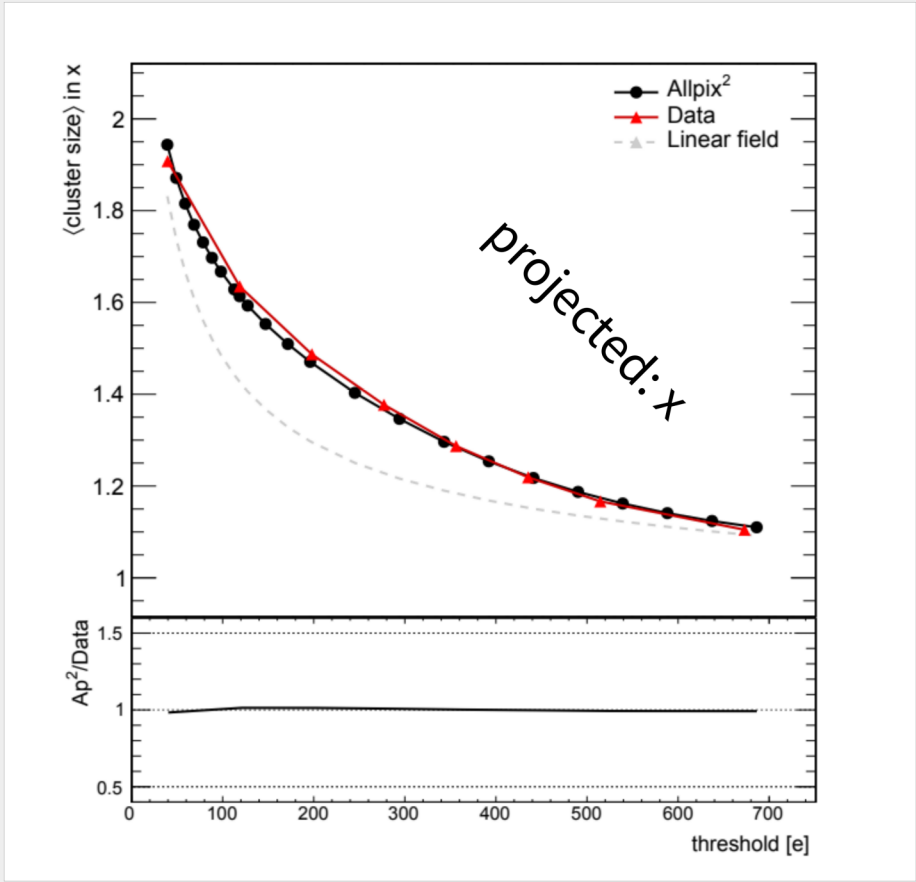
Projected Cluster Sizes – Correlation





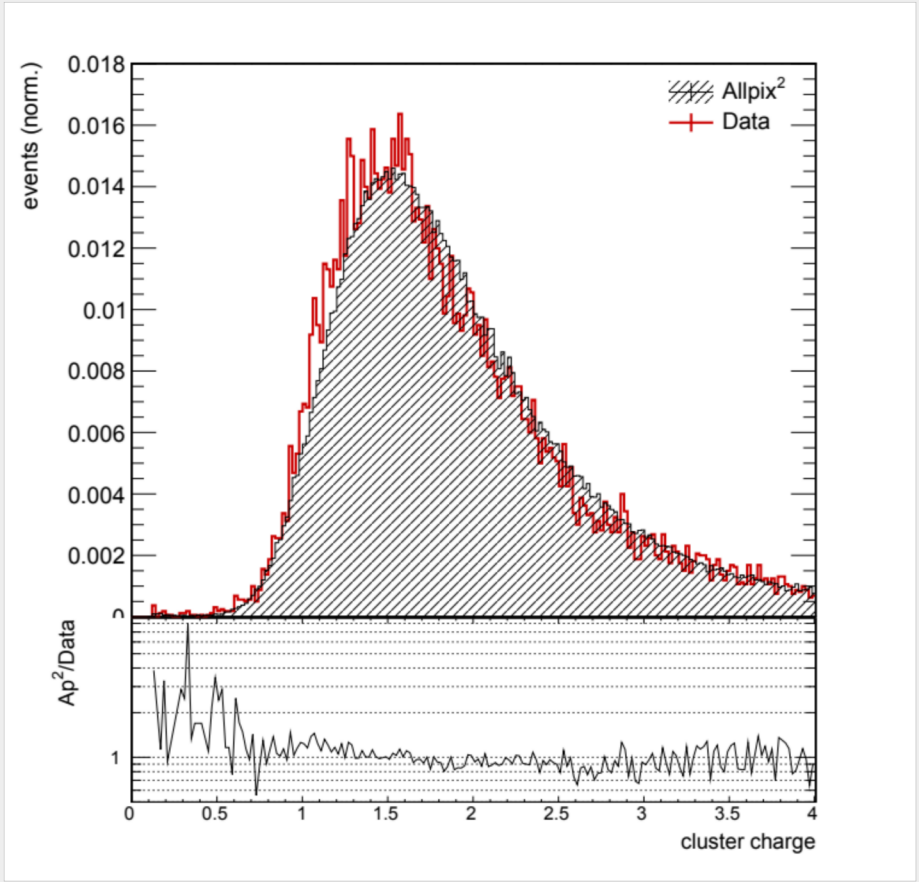
Mean Cluster Size





Cluster Charge Distribution

- Charge distribution matches well
- Simulation includes
  - Landau fluctuations,
  - Delta rays, …
- Using Geant4's photoabsorption Ionization model (PAI)
  - Improve description of energy deposition
  - Relevant since charge is collected from upper ~40um only



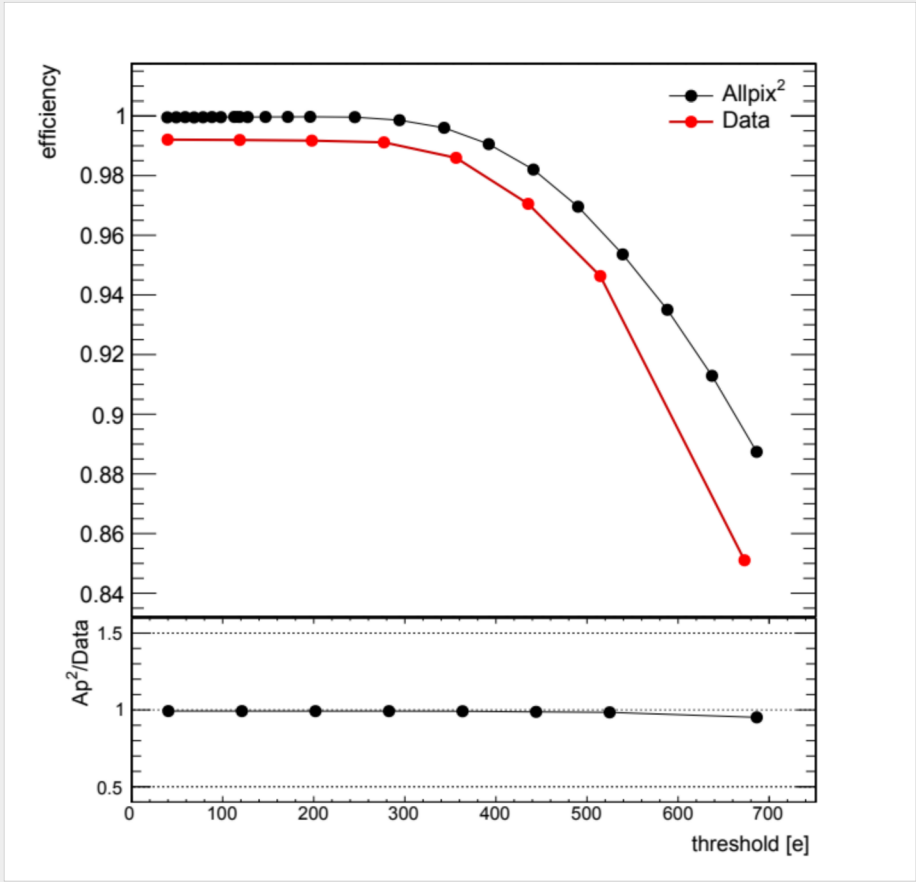
Uncertainties / Sensitivity

- Several parameters found with strong influence on simulation:
  - Electric field – small changes yield strong changes
  - Integration time – approximation of carrier life time and readout peaking time, tuned for “equivalent” cluster sizes
  - Known parameters from data: threshold , track resolution
- These parameters are strongly correlated

- Negligible influence from variations of
  - Threshold dispersion, input noise, additional noise hits
  - Stepping size of the charge deposition and transport algorithms
  - Number of charge carriers propagated together (5 → 1)

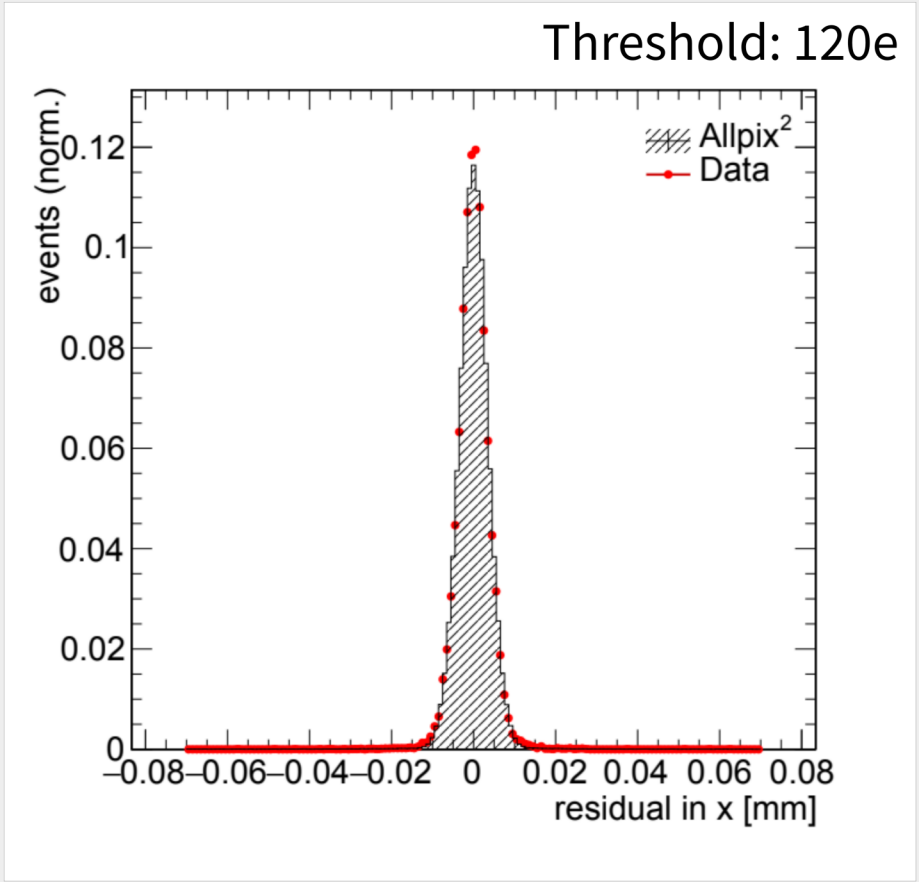
Efficiency

- Detection efficiency as function of charge threshold
- Good reproduction of shape
- Absolute value of data expected to be lower
  - Complex test beam setup
  - Effects of readout system
- ALPIDE chip in same technology reaches similar efficiencies as simulation



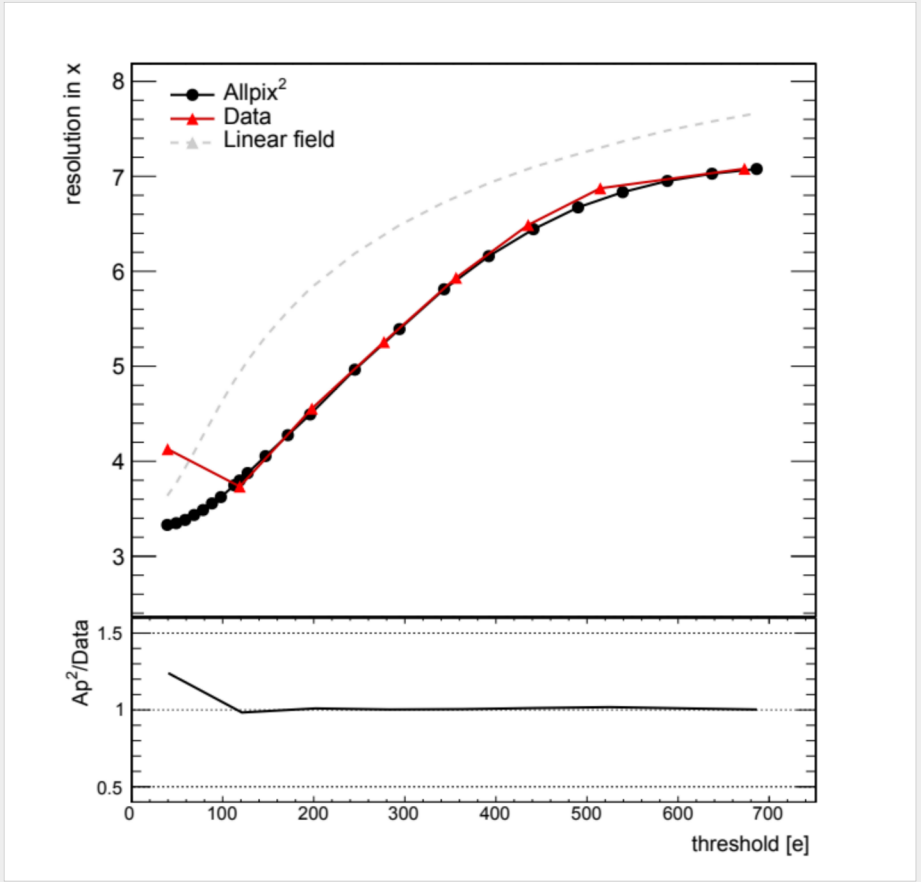
Detector Resolution

- Compare particle impact with reconstructed cluster position
- Using Monte Carlo truth information
  - Smeared with measured telescope resolution: ~2um
- Residual width (distribution RMS):
  - Data: 3.7um
  - Simulation: 3.6um



Detector Resolution

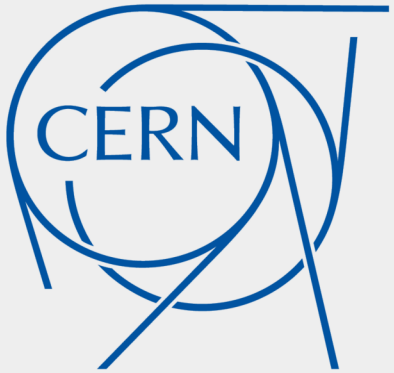
- Threshold scan 40 – 700e
  - No telescope resolution subtracted
- Very good agreement
- Deviations only at lowest threshold
  - Chip designers: “to be expected”
  - Cross-talk/effects in test chip
  - Various, only partially understood noise sources (non-gaussian)
- Relevant range for future chips:
  - 150 – 300e



Summary & Outlook

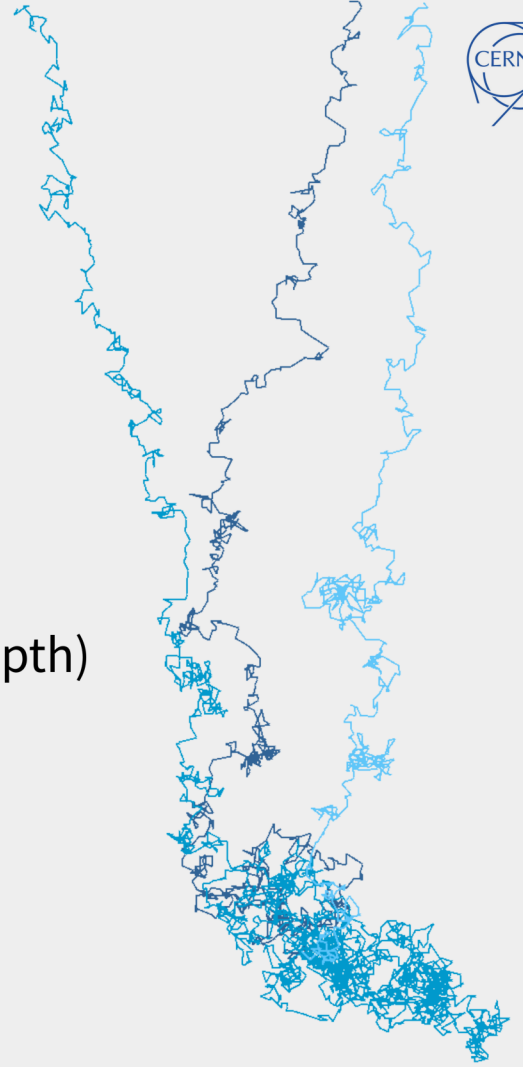
- **Simulation of HR-CMOS process** combining TCAD & Monte Carlo methods
  - Direct access to performance parameters
  - Allows to gauge HR-CMOS sensor designs
- Simulations **validated with test beam measurements** of ALICE Investigator
  - Very good agreement in most control observables and performance parameters
- Validated simulation can be used to simulate
  - CLICTD chip performance (different geometry, different doping profiles)
  - Behavior under different conditions such as magnetic fields

- **Ongoing investigation**: use carrier lifetime in substrate


CERN

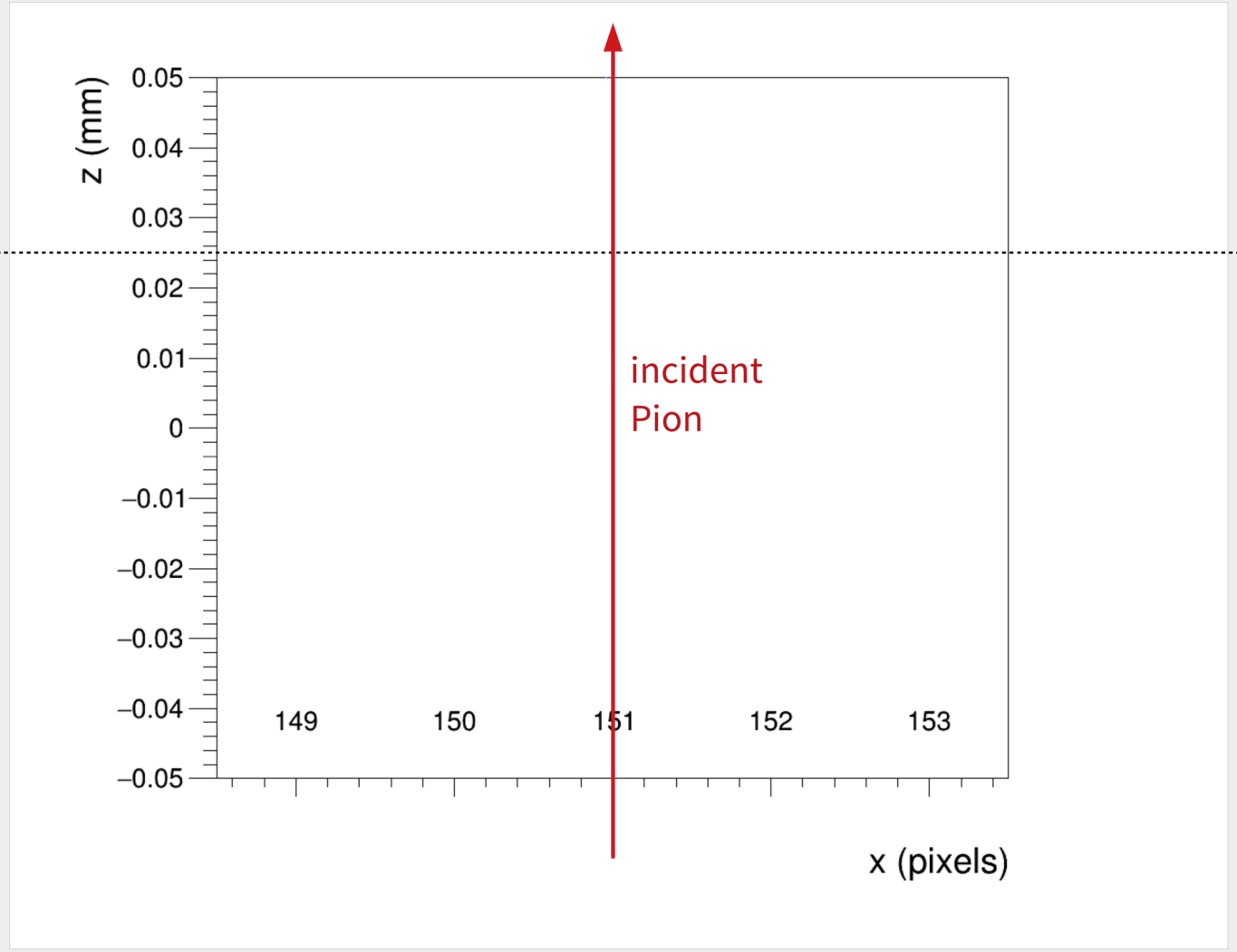
Allpix² Drift Visualization

- Allpix² allows to record drift/diffusion path of individual charge carriers
  - See talk by Koen
- On the following pages:
  - One particle, perpendicular incidence in pixel center
  - Projection of drift paths onto X-Z plane (pitch vs. sensor depth)
  - Only draw charges which have reached the sensor implant
- Stop the propagation after different integration times
  - Allows to see where charge carriers are collected from
  - And how they reach the implant



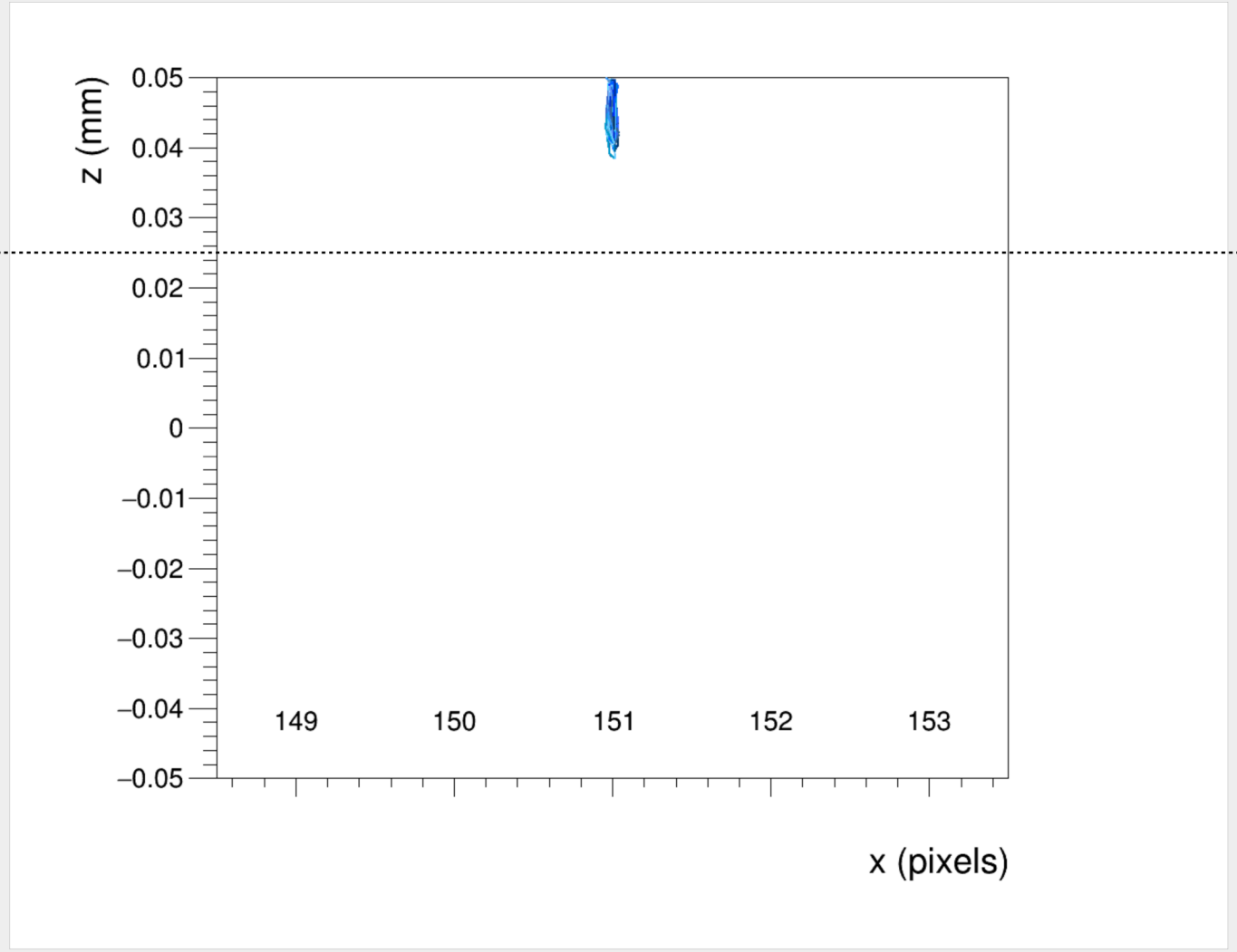
epitaxial

substrate



epitaxial

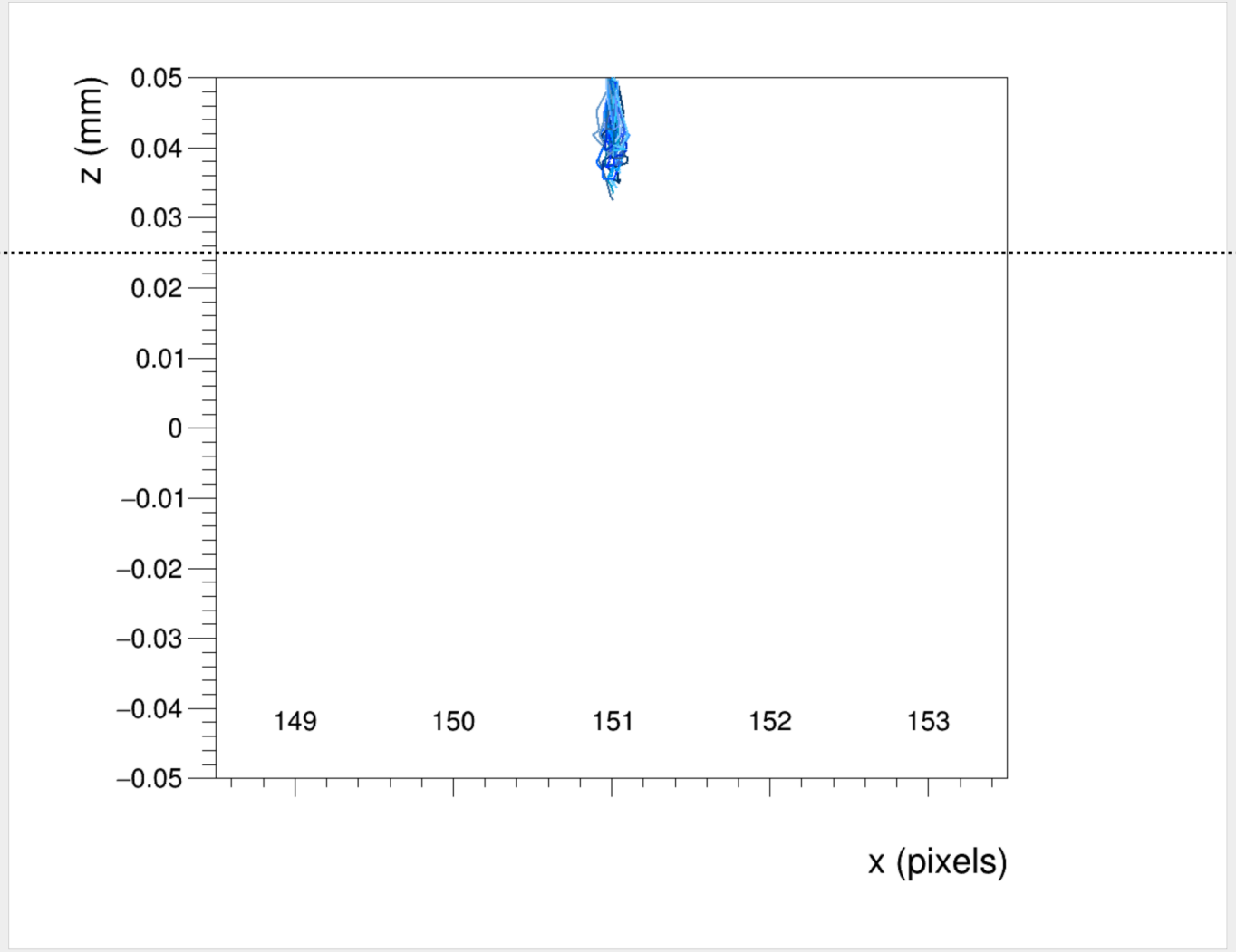
substrate



0.5ns

epitaxial

substrate

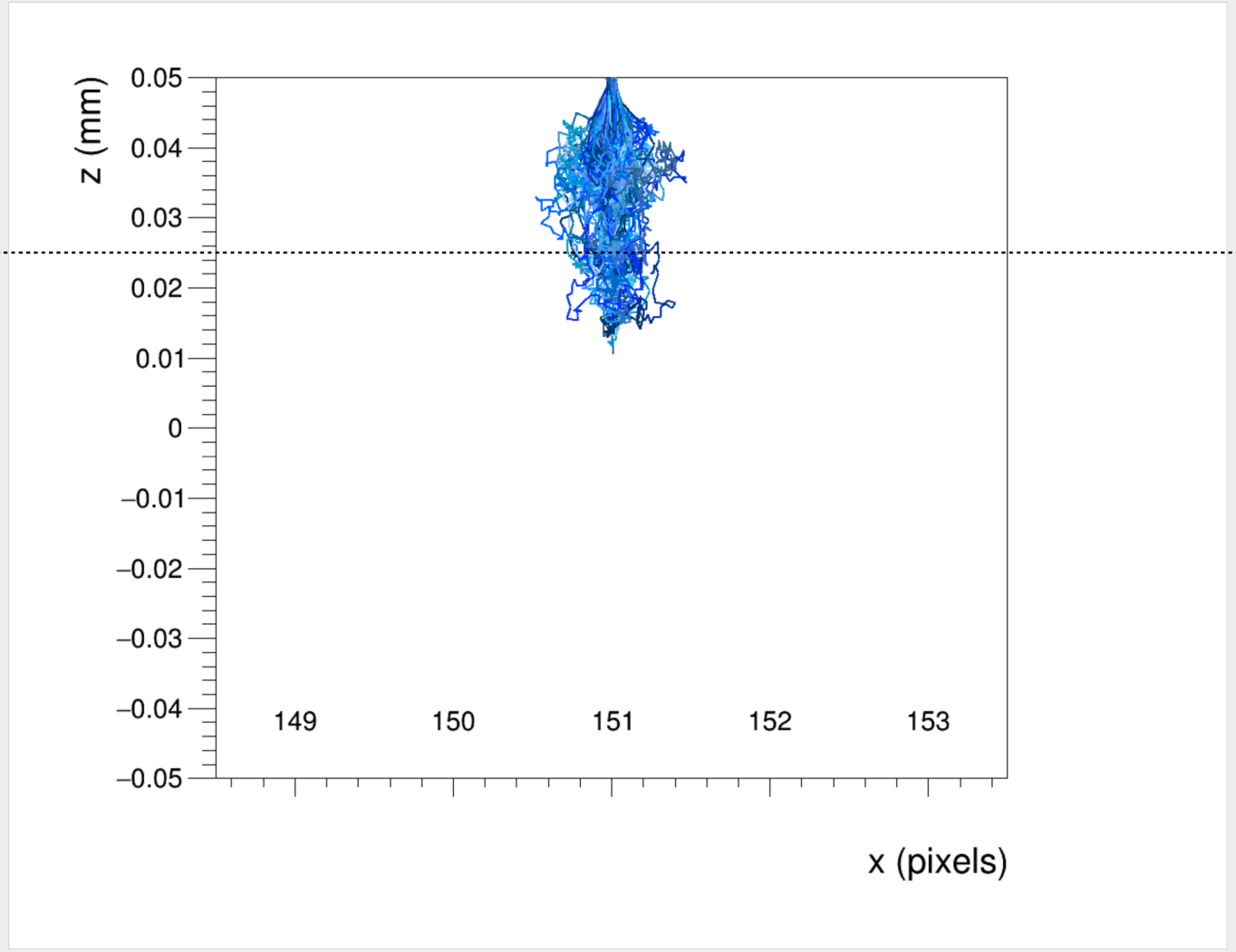


1.5ns

10ns

epitaxial

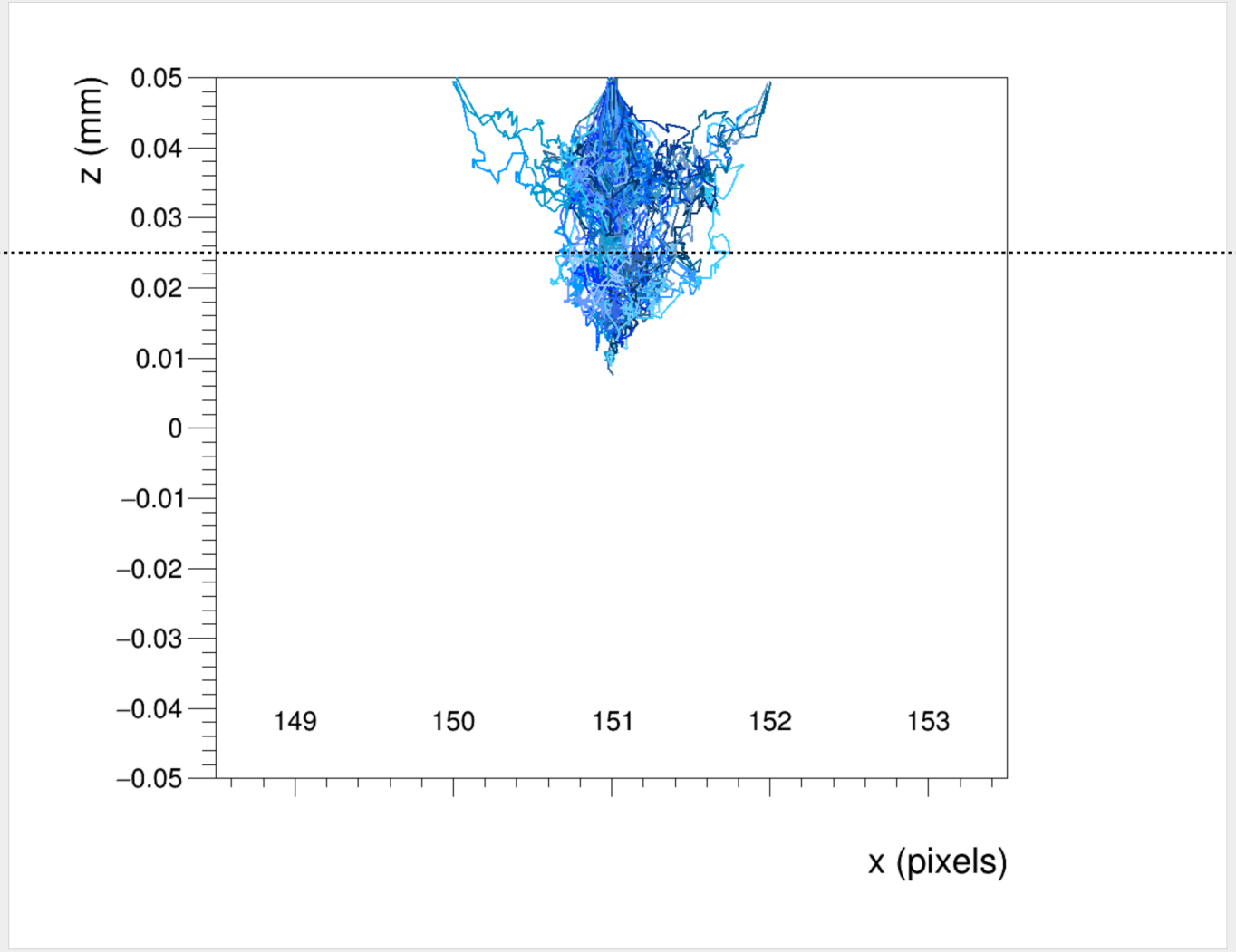
substrate



15ns

epitaxial

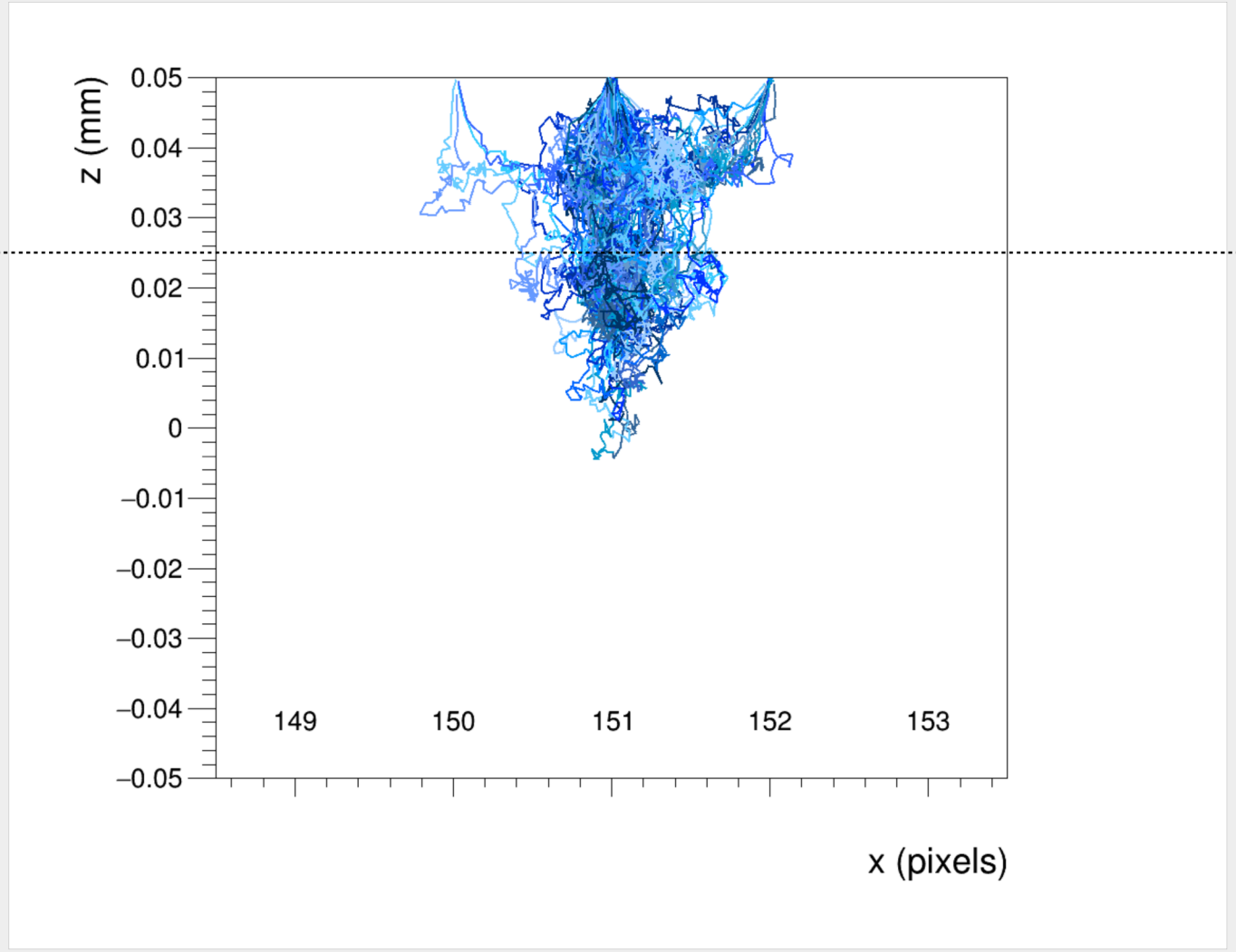
substrate



20ns

epitaxial

substrate



25ns

epitaxial

substrate