Physikalisches Institut, Heidelberg University

Impact of the incidence angle on HV-MAPS performance

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12th edition of the Beam Telescopes and Test Beams Workshop

On behalf of Heidelberg HV-MAPS collaboration

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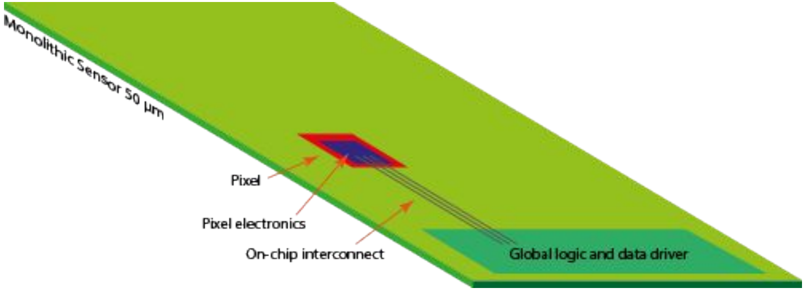
High Voltage Monolithic Active Pixel Sensor

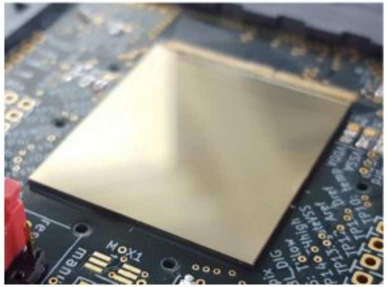
- **Monolithic**:
  → Integrated readout and sensor in a single chip
- **Active**:
  → in-pixel amplifier
- **High Voltage**:
  → Fast charge collection via drift
  → Depletion area ~15 μm at −60V for 20 Ωcm



In this study, **MuPix10**, one of the HV-MAPS prototypes developed for the Mu3e pixel tracker is used to conduct the rotation studies

MuPix10 key feature

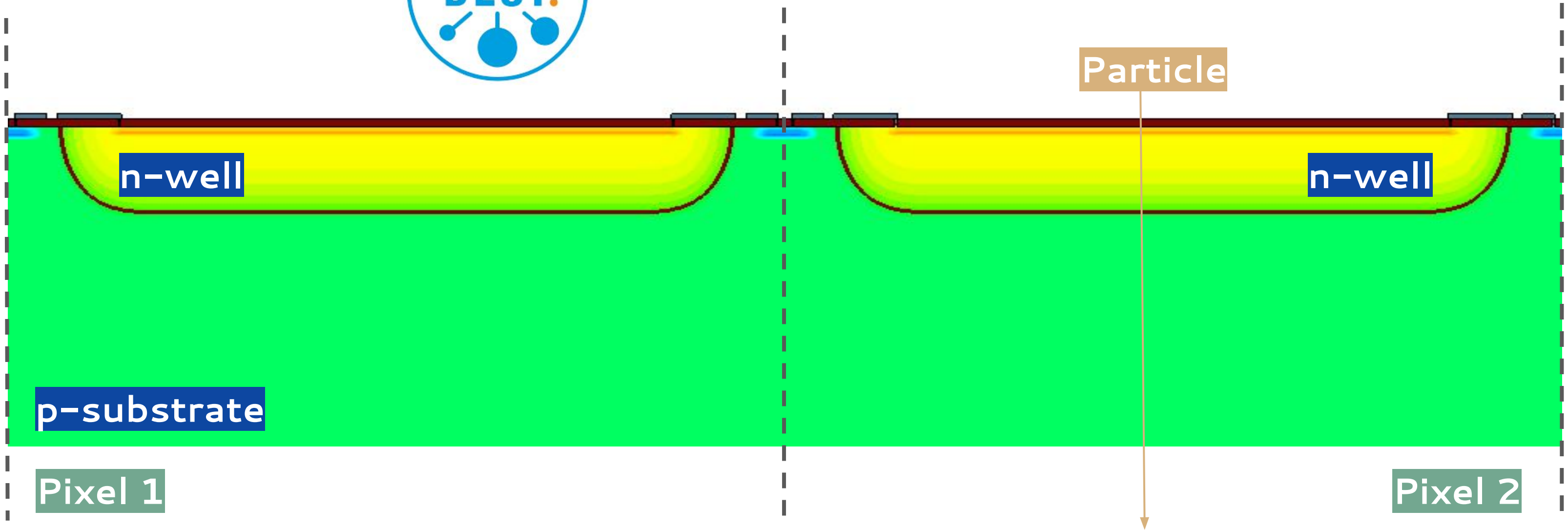
Pixel size [μm^2]	80x80
Sensor Thickness [μm]	50,60,70,80,**100**
Substrate resistivity [Ωcm]	10-20, **200-400**



Why to study different incidence angles?

- **HV-MAPS applications:**
  → Mu3e Pixel Tracker
  → LHCb Mighty Track
  → DESY TelePix

In this application, particles might not enter the detector perpendicularly to its surface



MuPix10 TCAD SDE simulation

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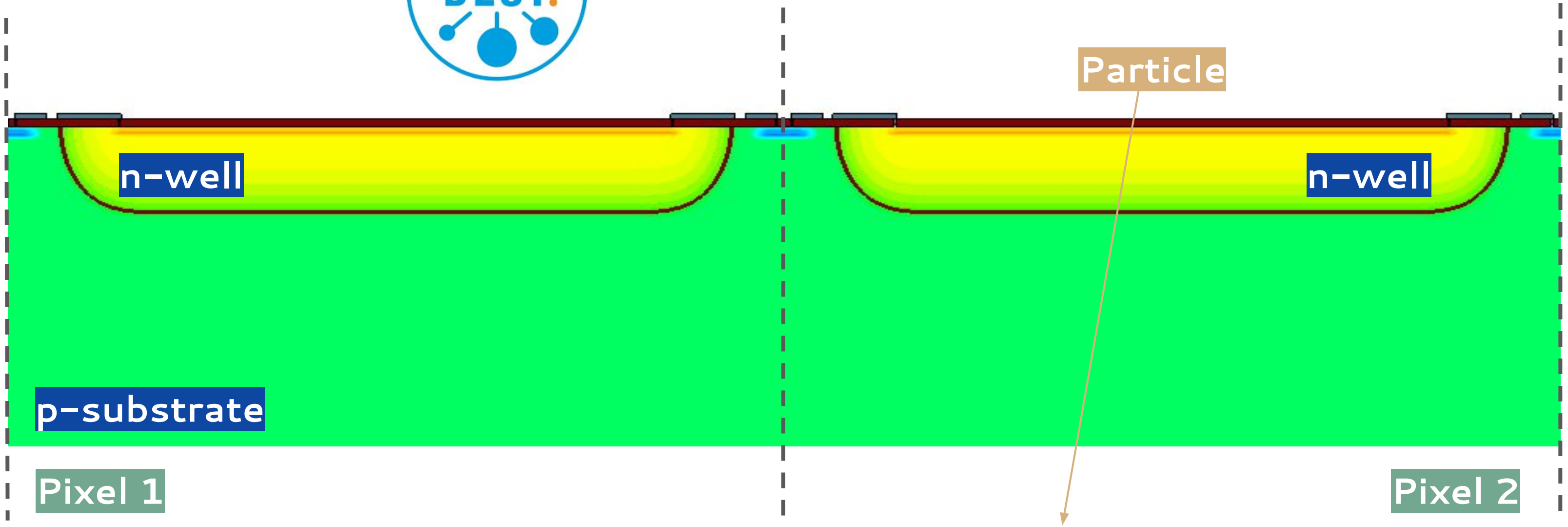

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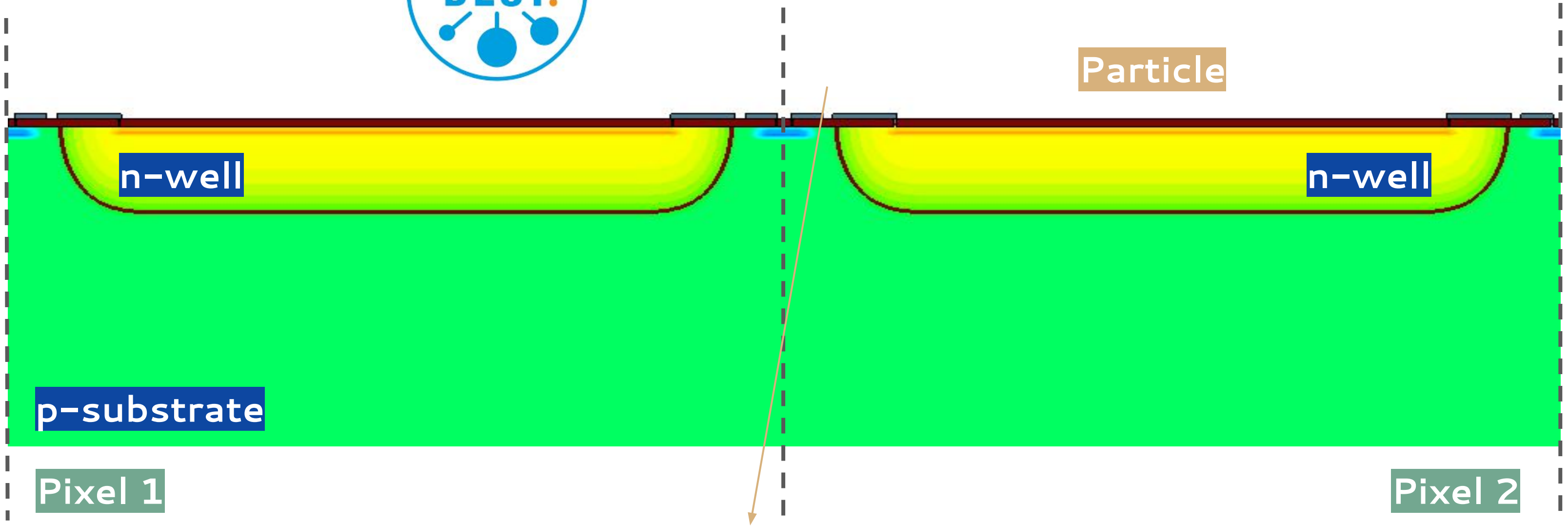
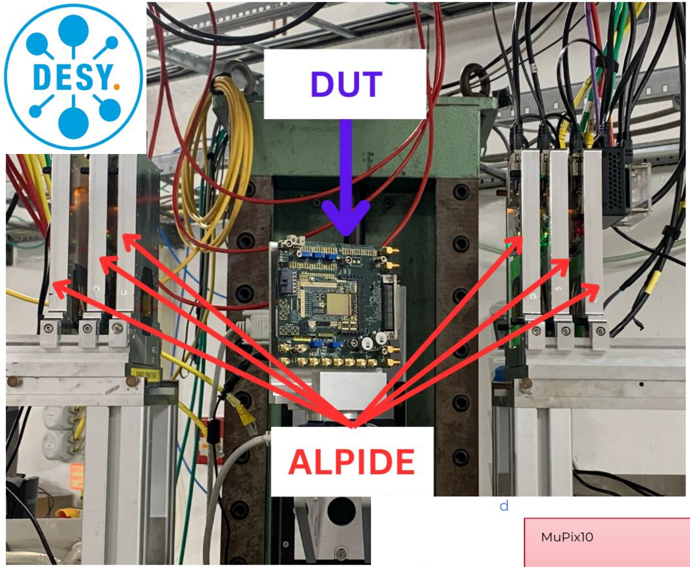
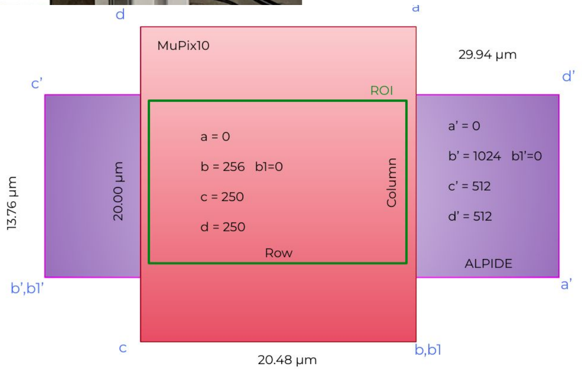


MuPix10 TCAD SDE simulation

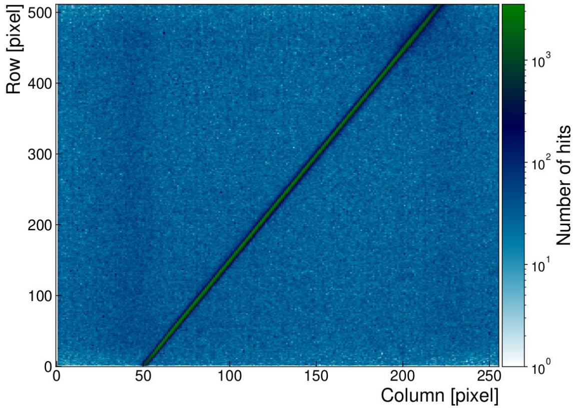
DESY Testbeam

- 4 GeV electron beam
- ADENIUM Telescope
    - 6 ALPIDE reference layers
- MUPix10 DUT on rotation station
    - Resistivity: 200-400 Ωcm
    - Thickness: 100 µm
    - Rotations: 0°, 25°, 43°, 62°

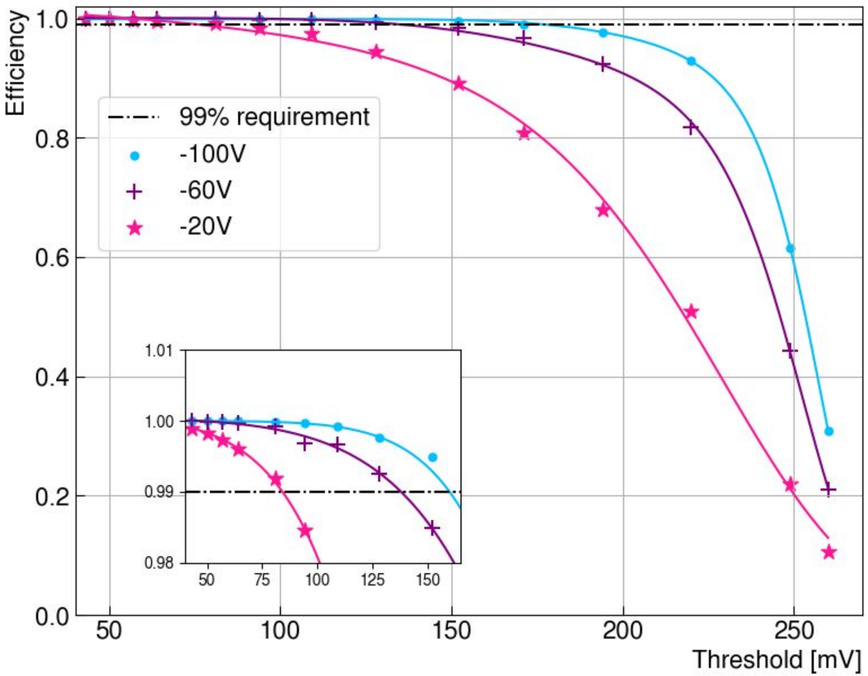




Testbeam reconstruction using Corryvreckan

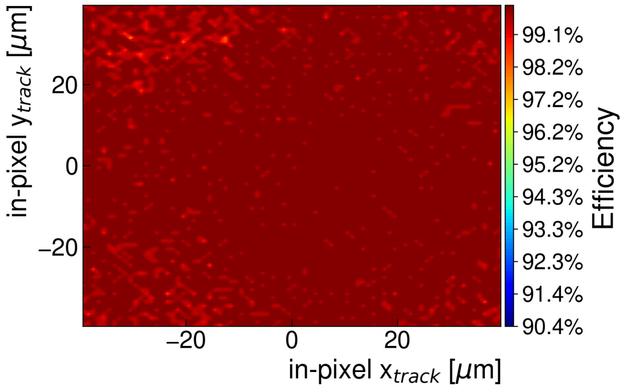


Efficiency (non-rotated)

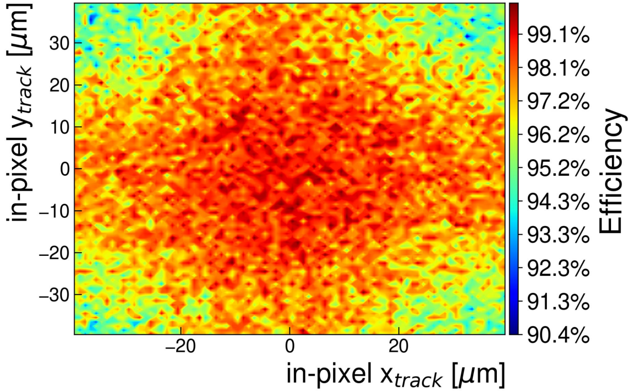


Efficiency increases for higher voltages and decreases for higher thresholds

In-pixel efficiency at 109 mV threshold

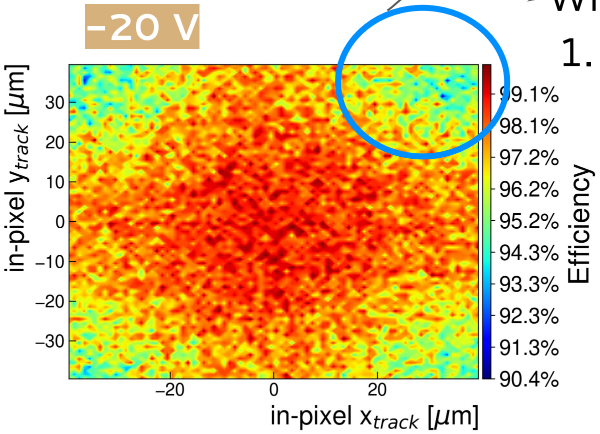


-100 V



-20 V

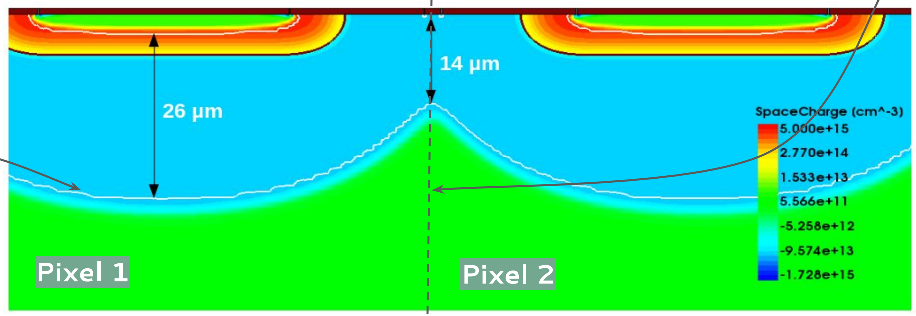
Efficiency (non-rotated)



Why the lower efficiency areas?

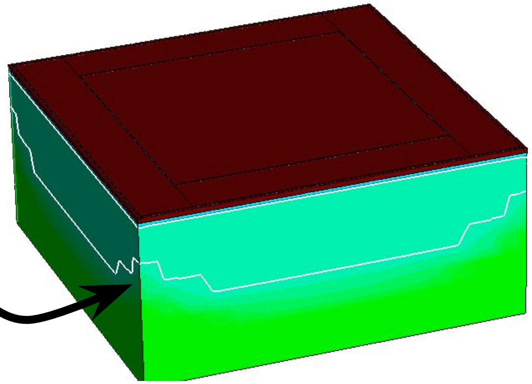
1. Low charge collection due to small or no **depletion** in the **pixel edge**

White line represents the extension of the depletion zone



TCAD simulation example of depletion depth in the pixel center and edge

Smaller depletion at corners



Efficiency (non-rotated)

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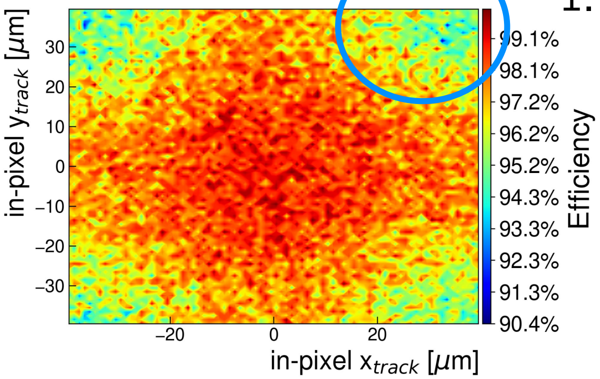

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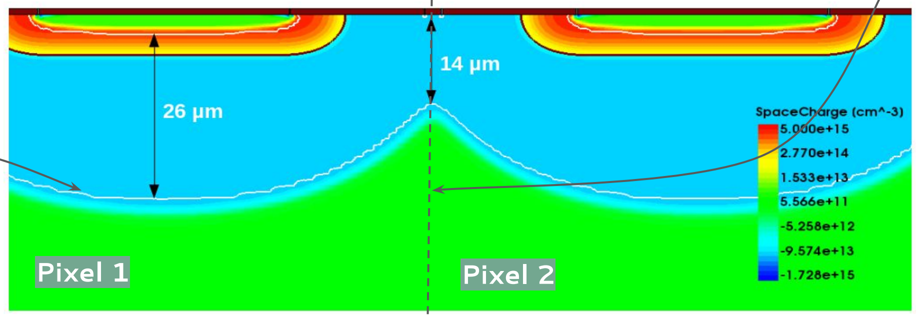
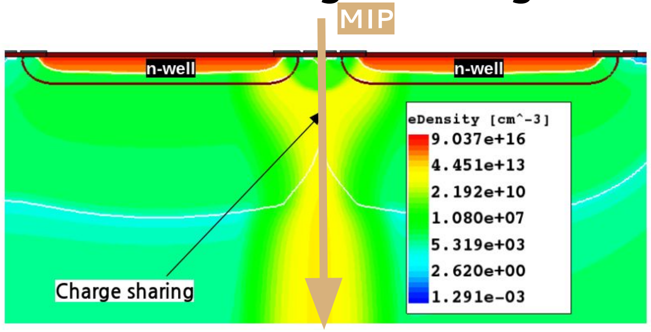


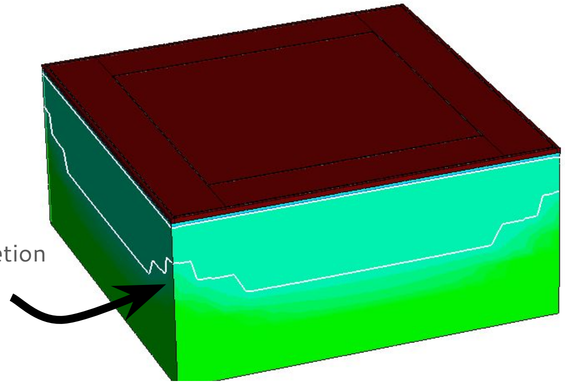
TCAD simulation example of depletion depth in the pixel center and edge

2. Increase **charge sharing** at the edge

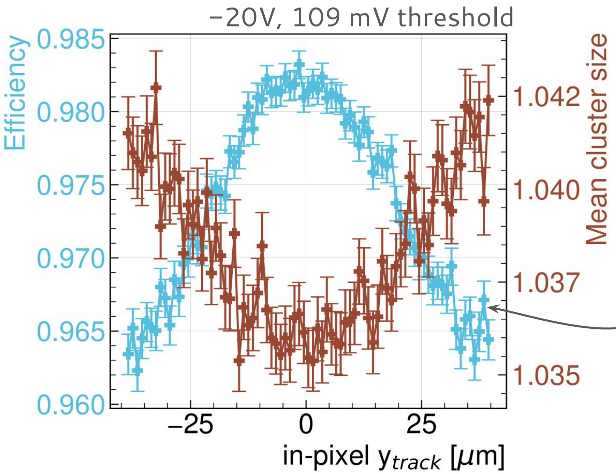


eDensisty TCAD simulation for a MIP passing for the pixel edge

Smaller depletion at corners

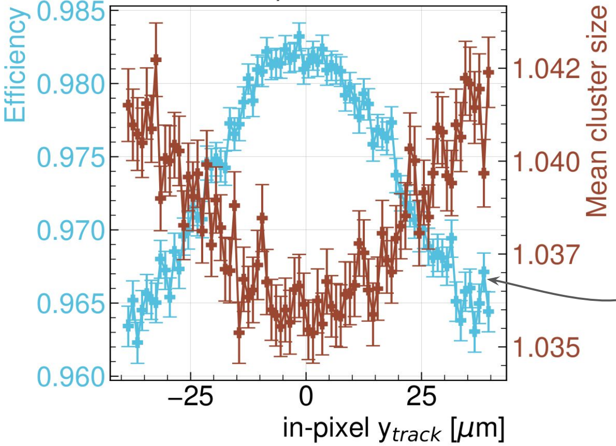


Cluster size (non-rotated)



Efficiency decreases in the areas of higher cluster sizes

Cluster size (non-rotated)



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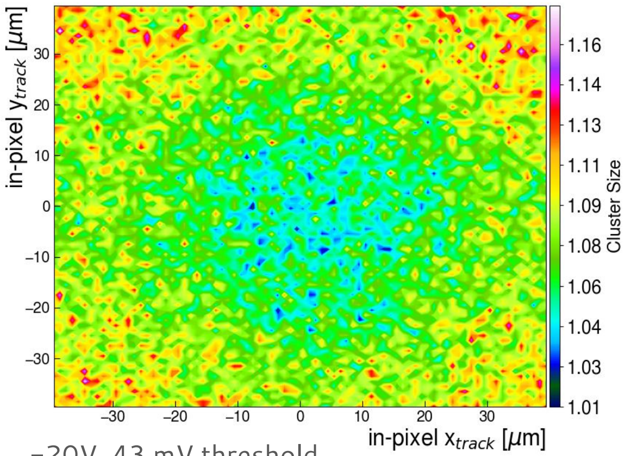
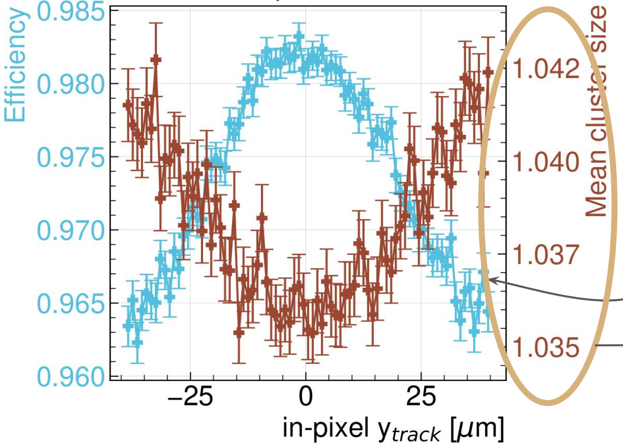


−20V, 43 mV threshold

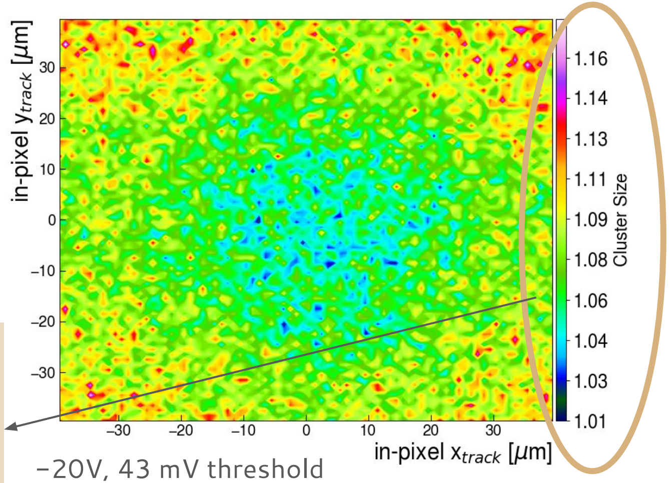
Cluster size (non-rotated)

−20V, 109 mV threshold



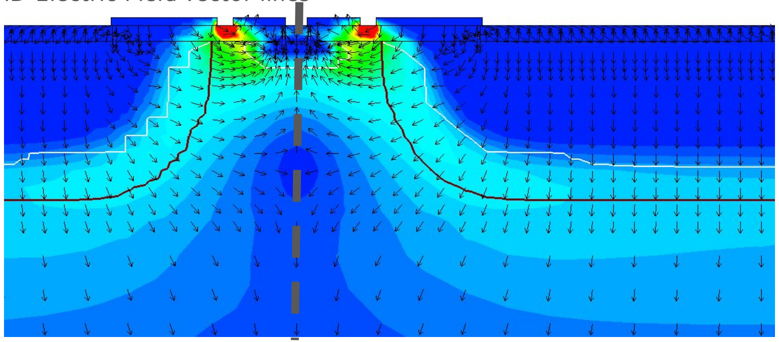
Efficiency decreases in the areas of higher cluster sizes

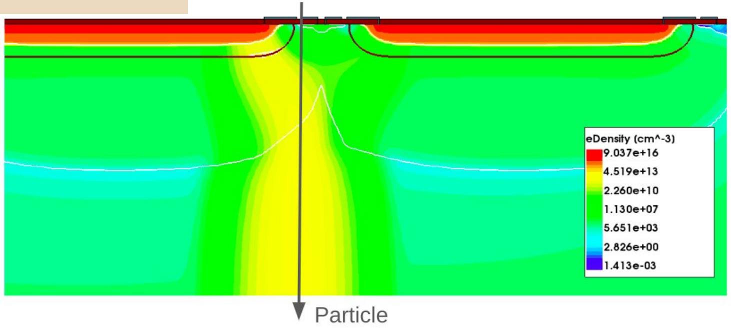
Electrons close to the pixel edge are drift to the hit pixel due to the electric field distribution in HV-MAPS



−20V, 43 mV threshold

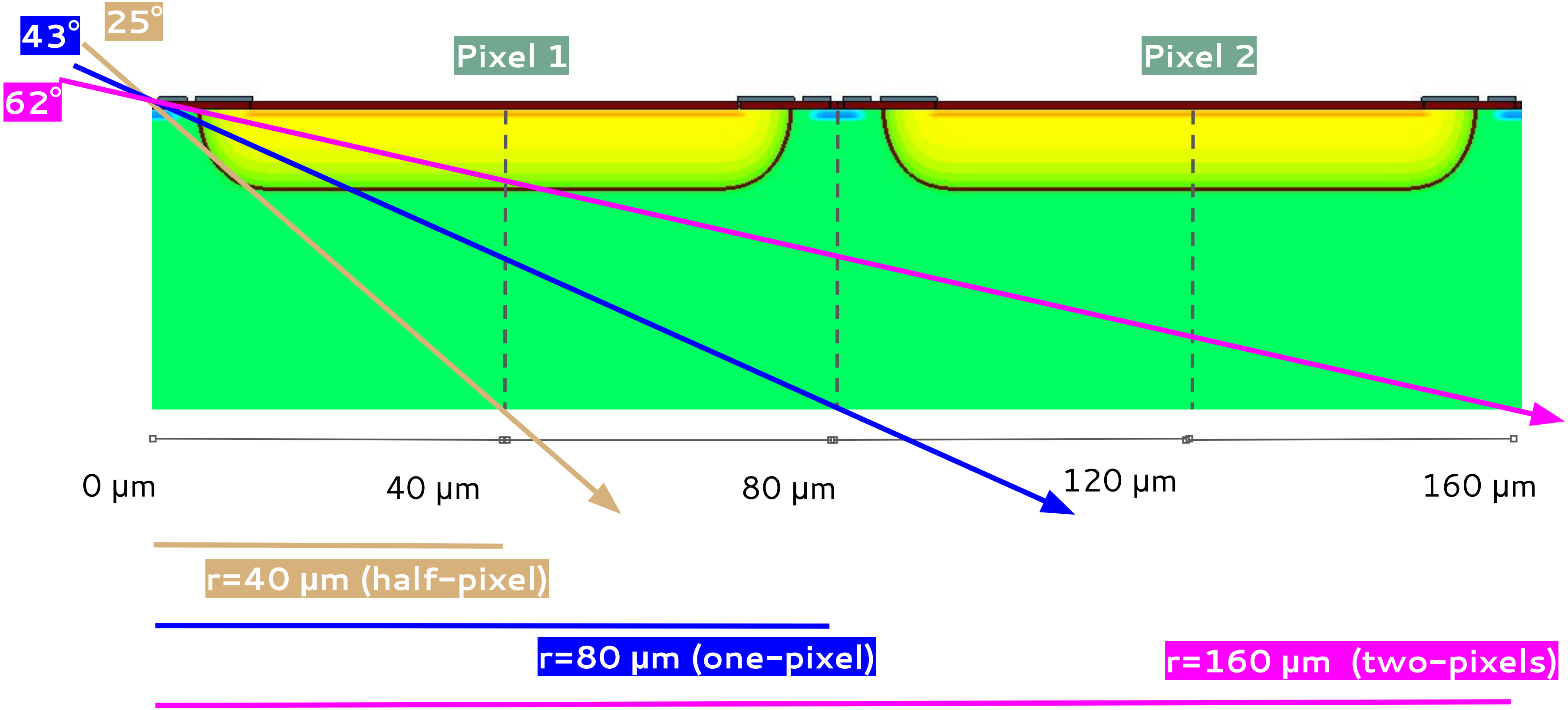
TCAD Electric Field vector lines





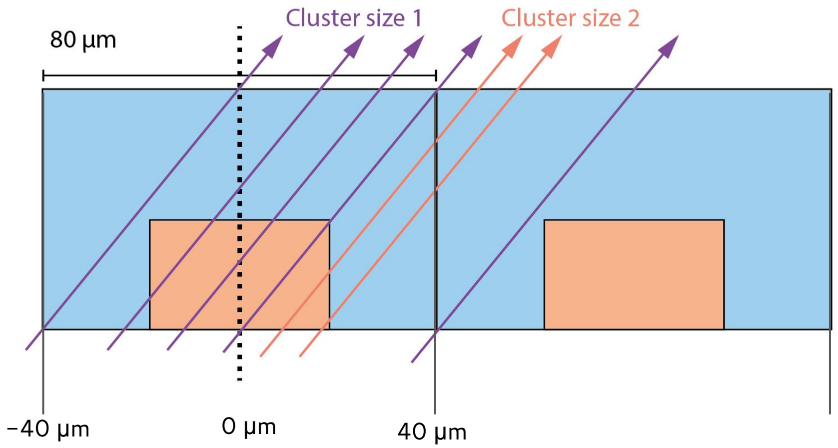
TCAD simulation electron density created from a particle passing 5 μm from the pixel edge

Why this rotations?



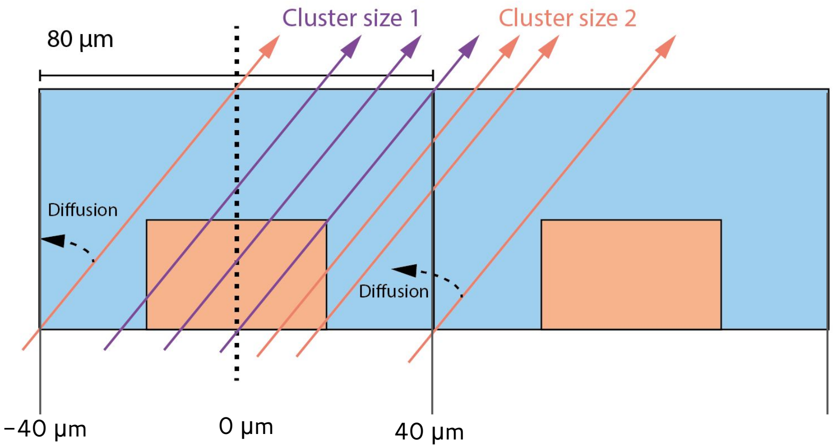
Cluster size (25° rotation)

Ideal cluster size case



Cluster size (25° rotation)

Considering lateral diffusion



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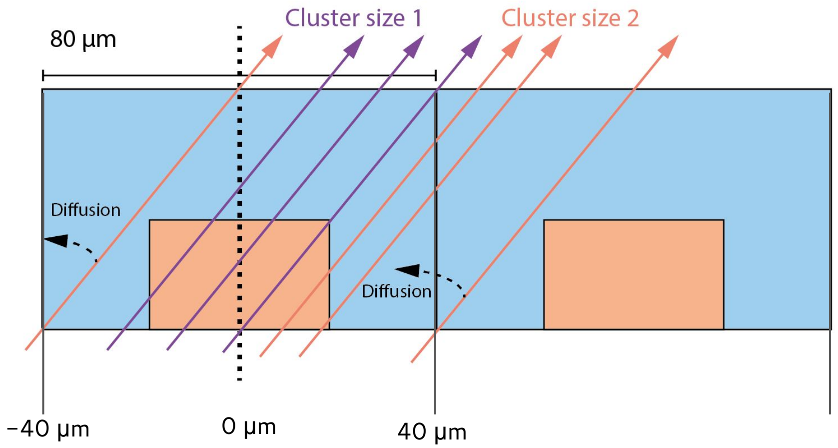

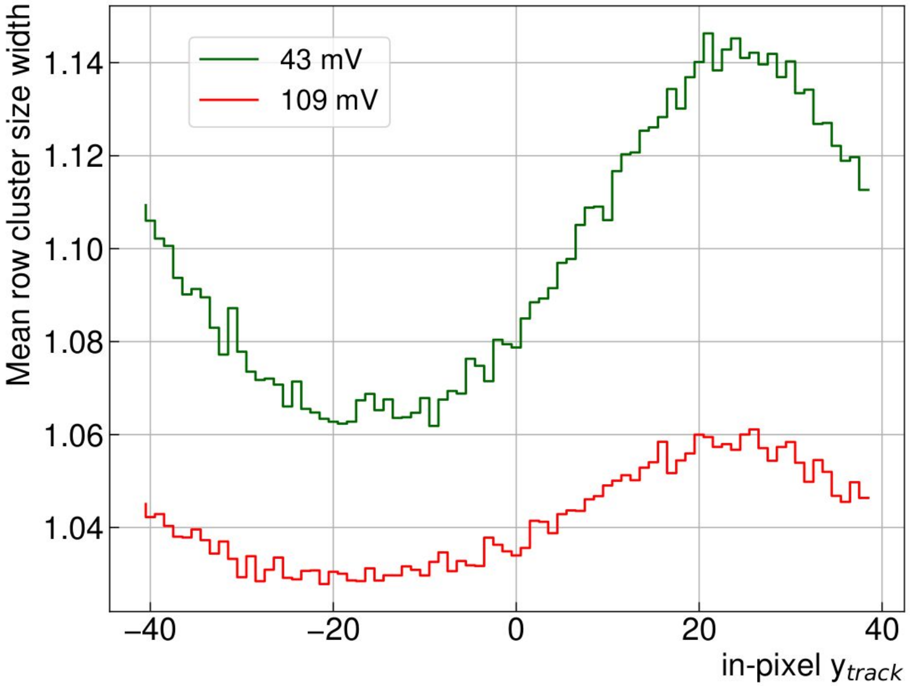

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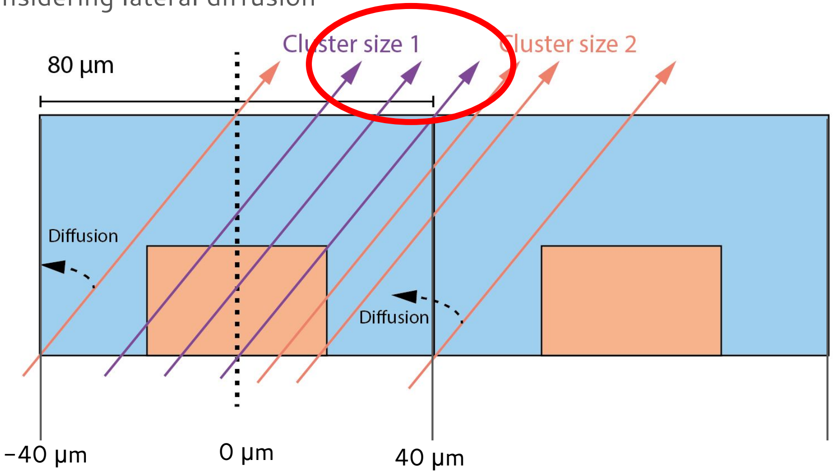

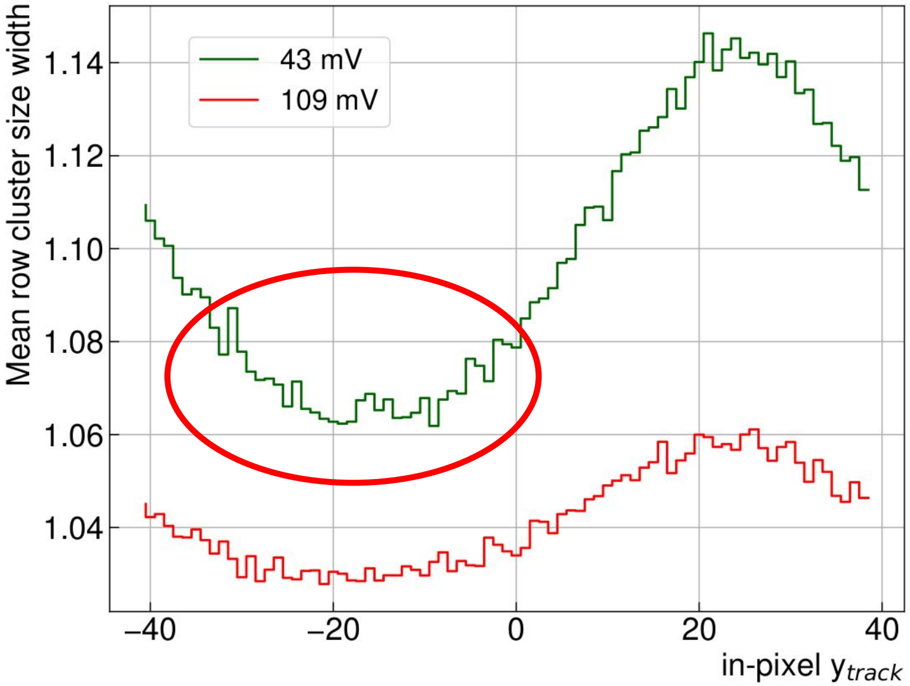

−Left side of the pixel has mostly cluster size 1 since path of the particle is inside the hit pixel.

Cluster size (25° rotation)

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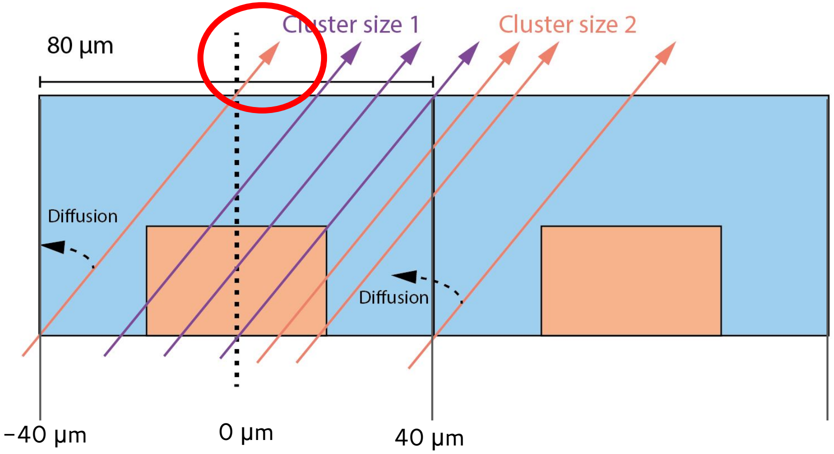
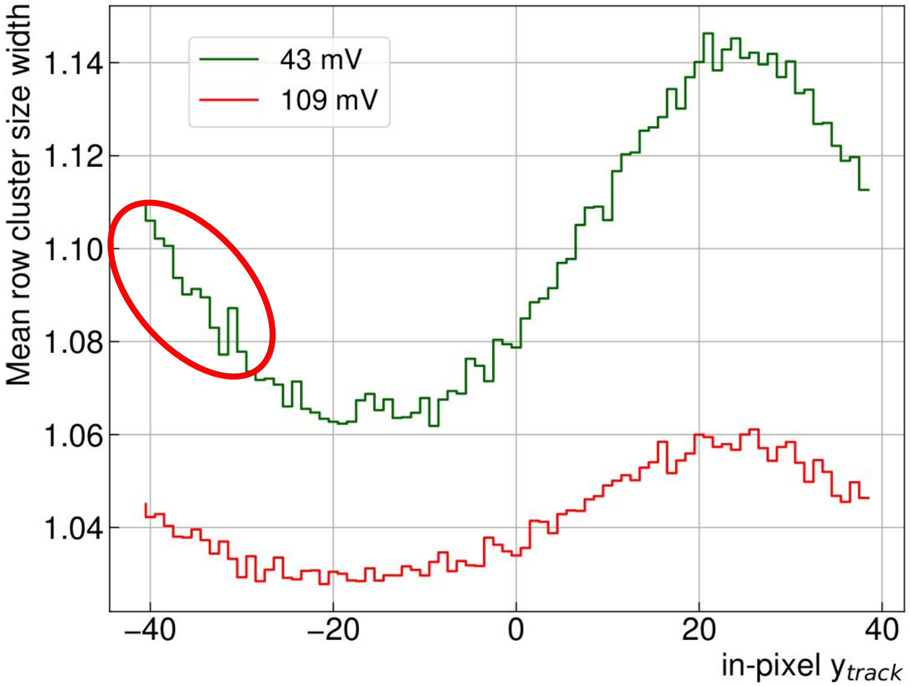
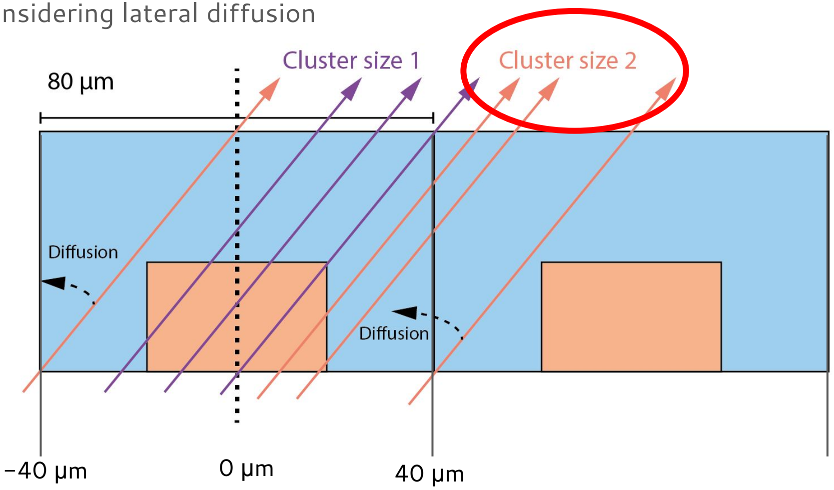


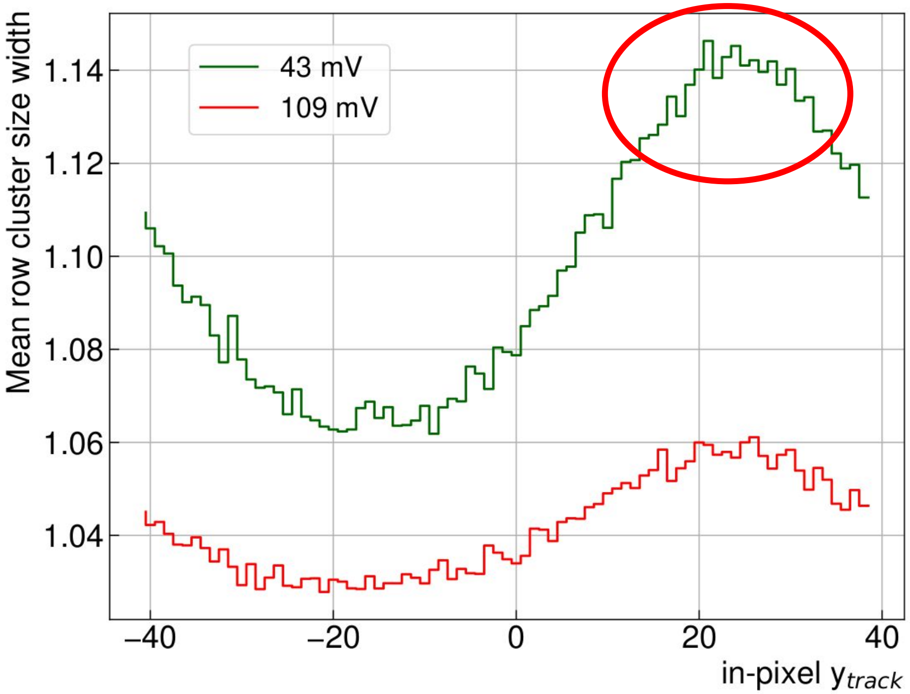


- Left side of the pixel has mostly cluster size 1 since path of the particle is inside the hit pixel.
- Particles close to the pixel edge have an increasing mean cluster size due to a higher charge sharing probability.

Cluster size (25° rotation)

Considering lateral diffusion

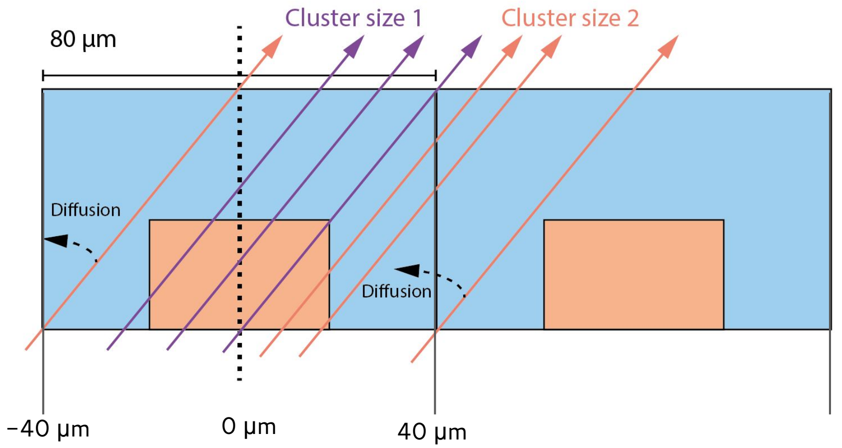


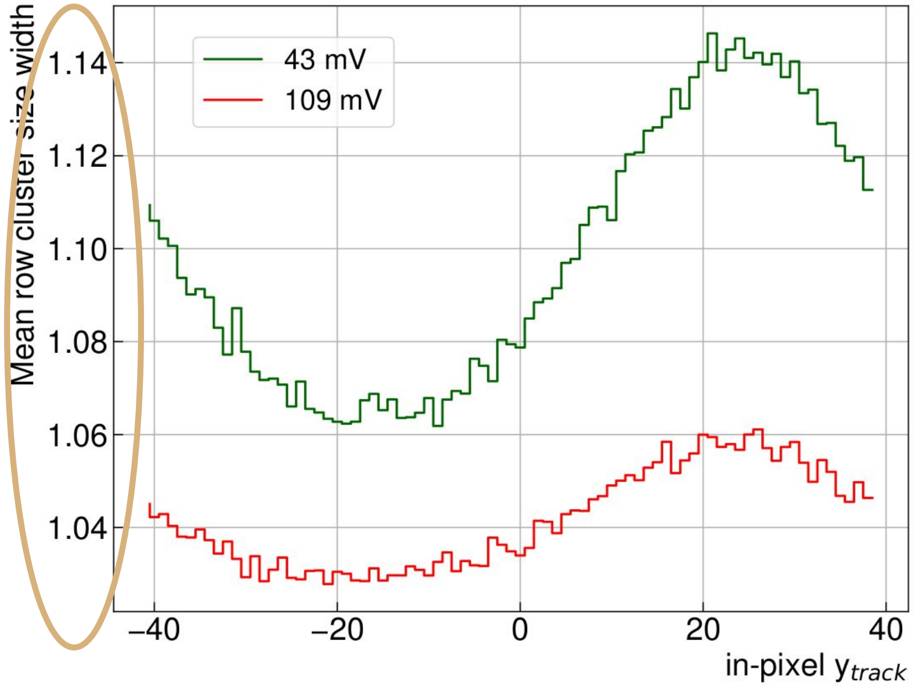


−Left side of the pixel has mostly cluster size 1 since path of the particle is inside the hit pixel.
−Particles close to the pixel edge have an increasing mean cluster size due to a higher charge sharing probability.
−Right side of the pixel has an increased probability of cluster size 2.

Cluster size (25° rotation)

Considering lateral diffusion





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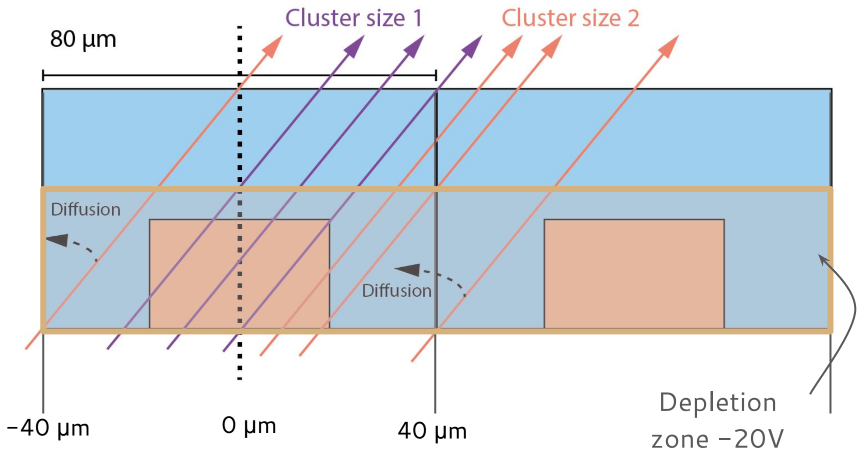
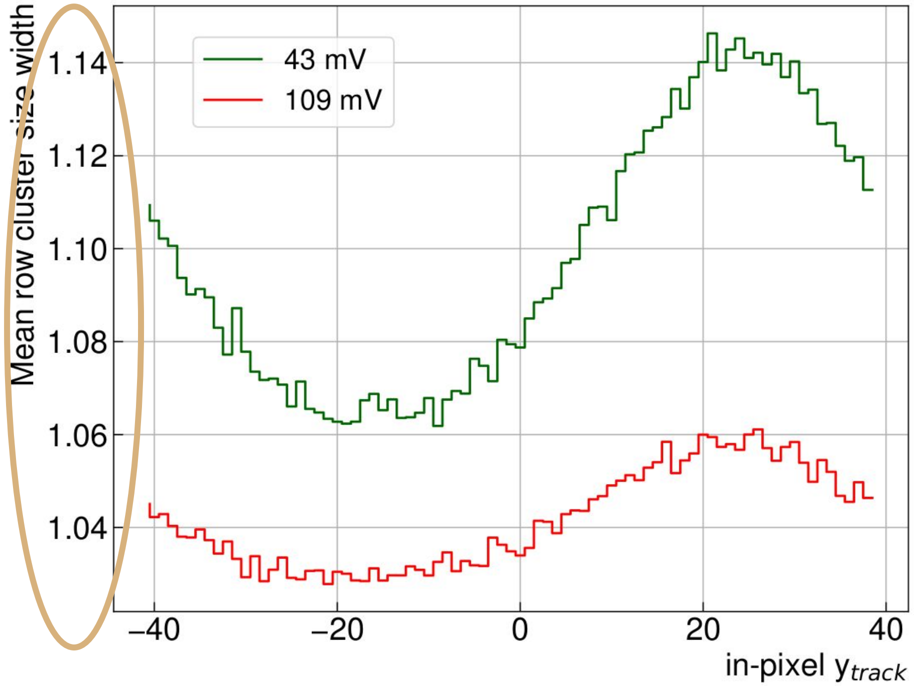


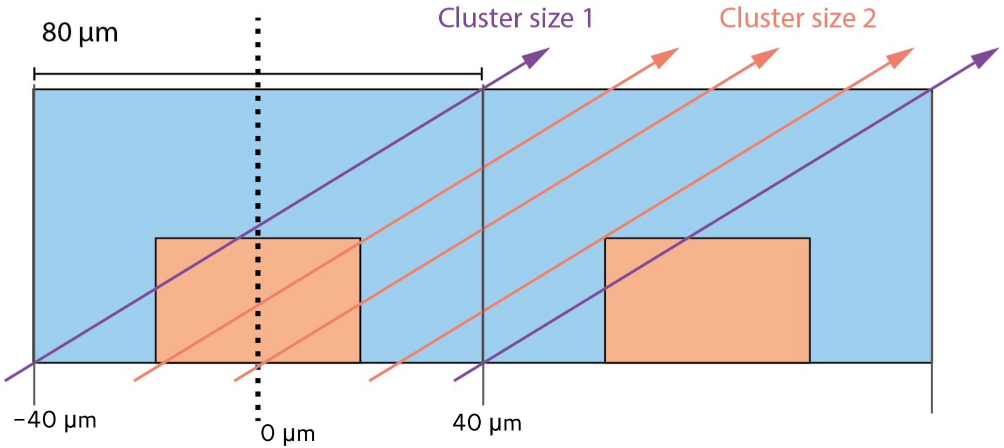


- Left side of the pixel has mostly cluster size 1 since path of the particle is inside the hit pixel.
- Particles close to the pixel edge have an increasing mean cluster size due to a higher charge sharing probability.
- Right side of the pixel has an increased probability of cluster size 2.

- Depletion zone at −20 V: ˜45 µm. Path of the particle outside of the depletion zone in neighbor pixel.

Cluster size (43° rotation)

Ideal cluster size case



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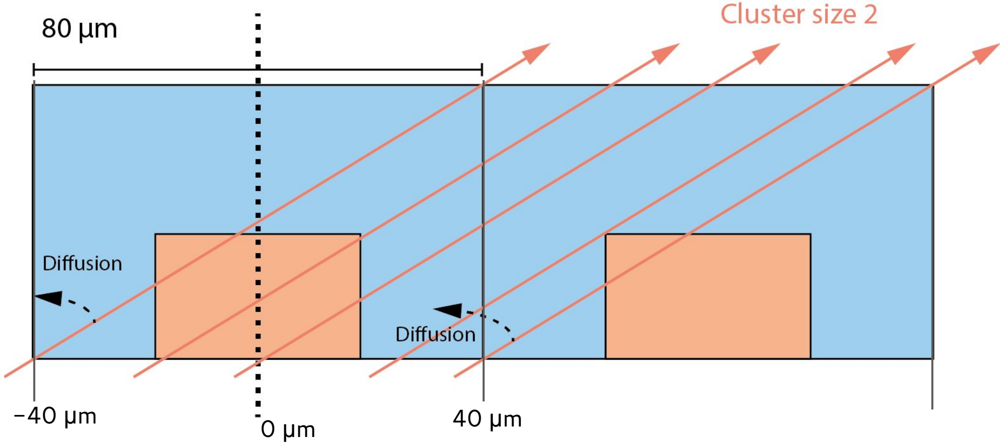
Considering lateral diffusion



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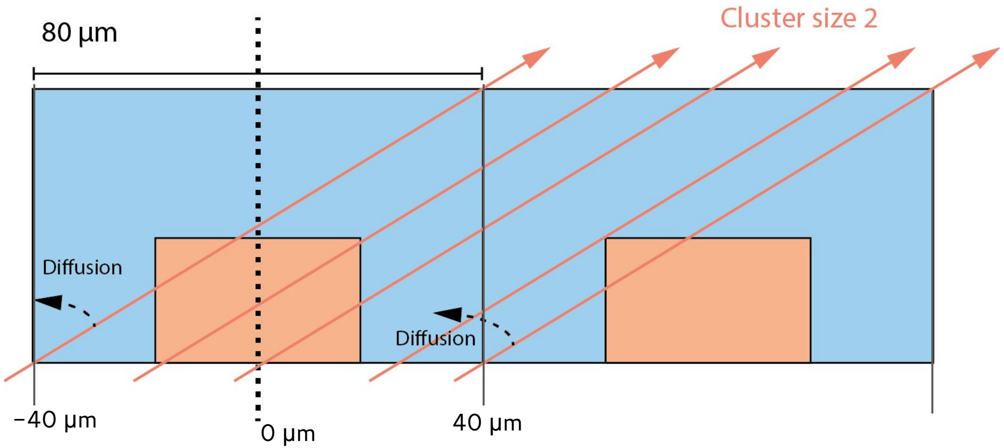
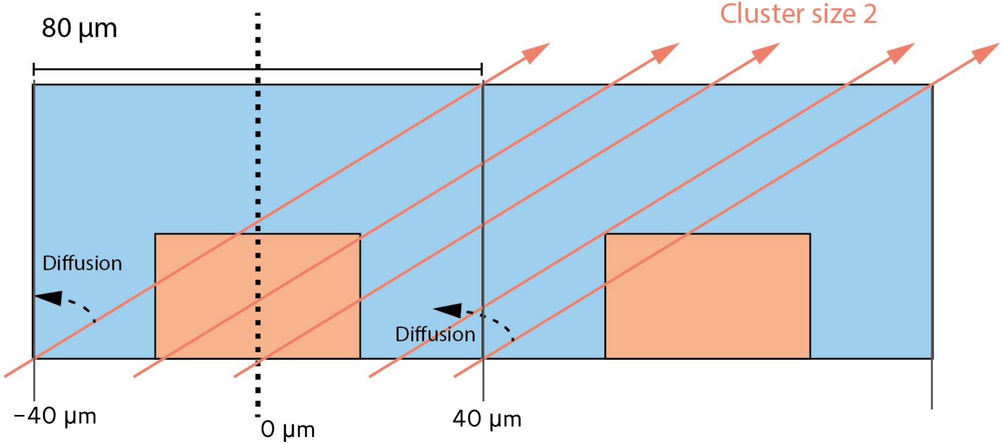
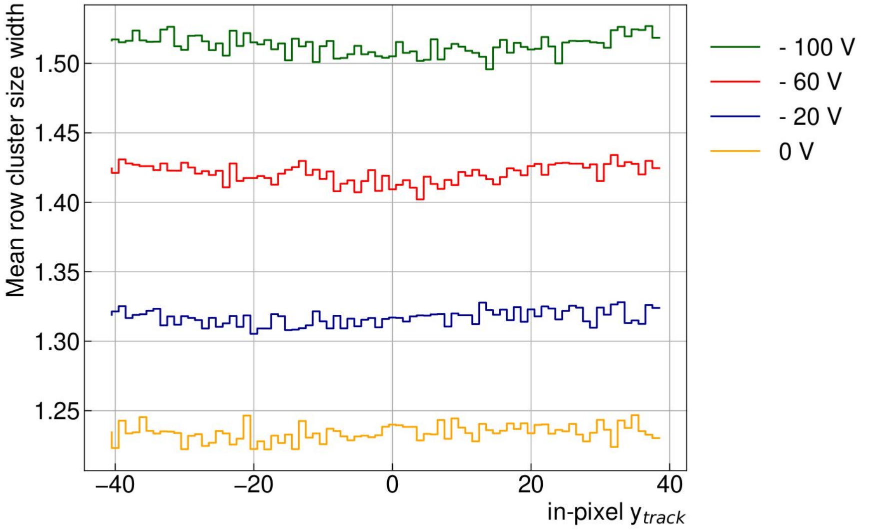


Cluster size (43° rotation)

Considering lateral diffusion



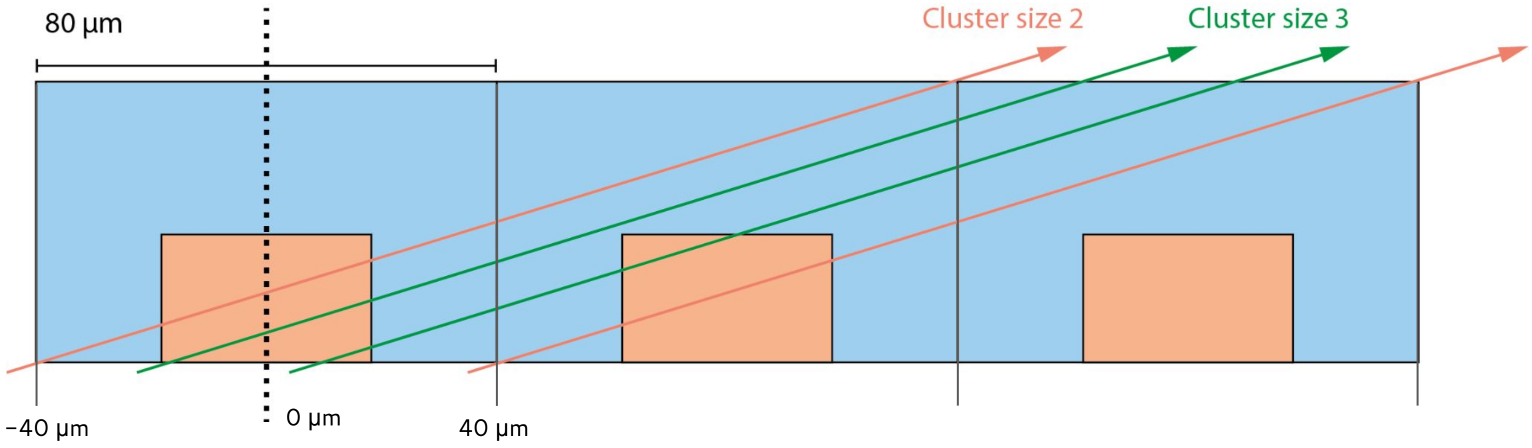


-All the in-pixel positions of the particle can result in cluster size 2.

-Depletion zone increases with the voltage, and so does the path of the particle inside the depletion zone in the neighbor pixel.

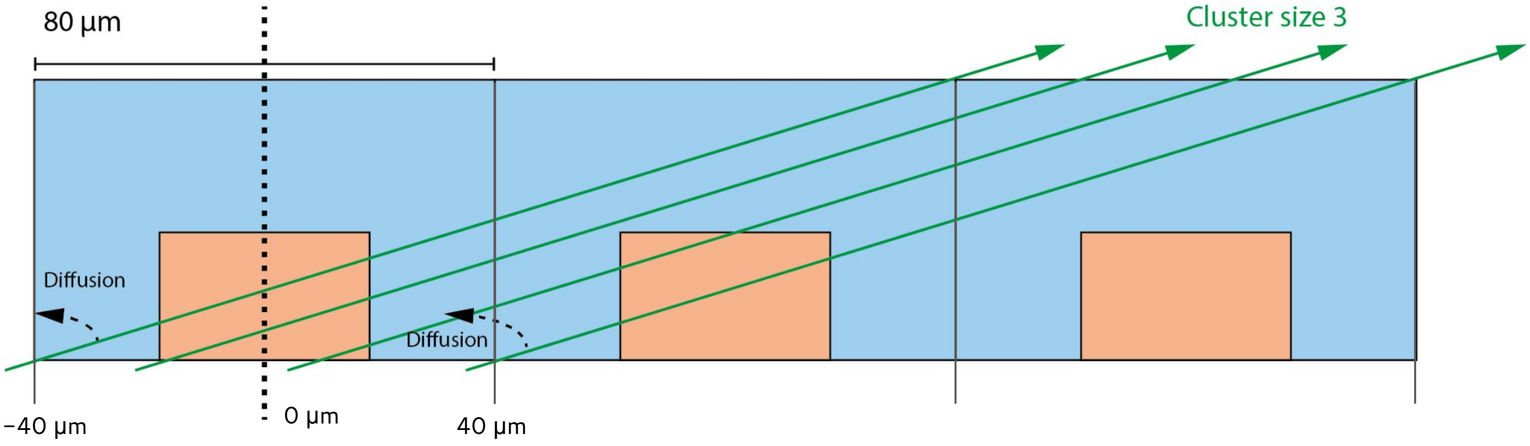
Cluster size (62° rotation)

Ideal cluster size case



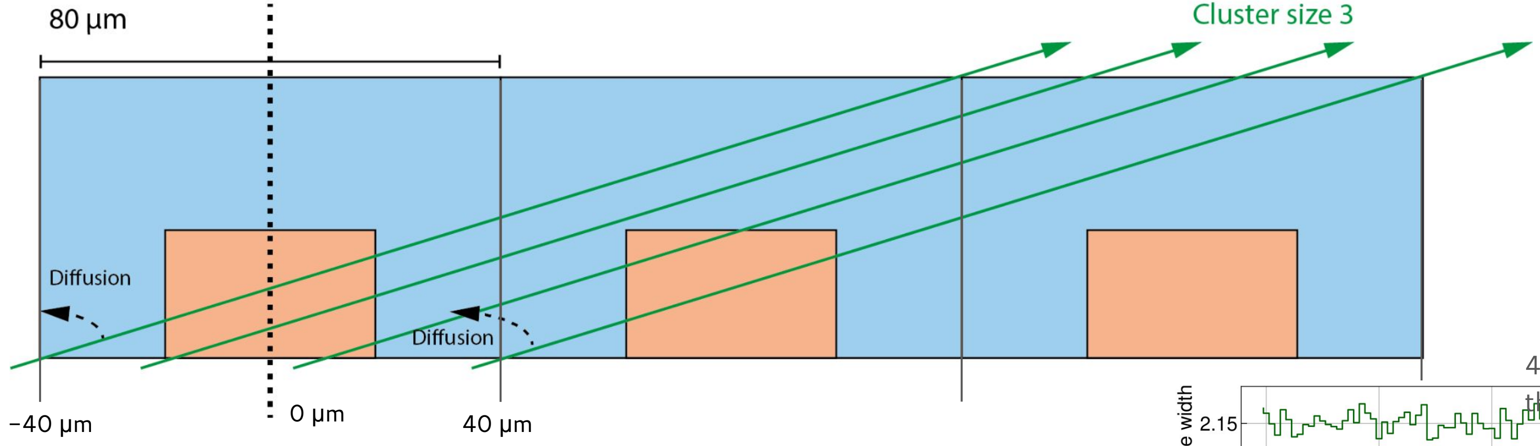
Cluster size (62° rotation)

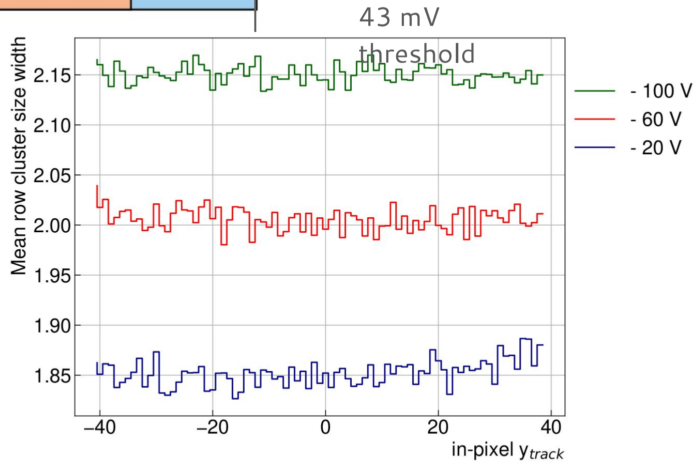
Considering lateral diffusion



Cluster size (62° rotation)

Considering lateral diffusion

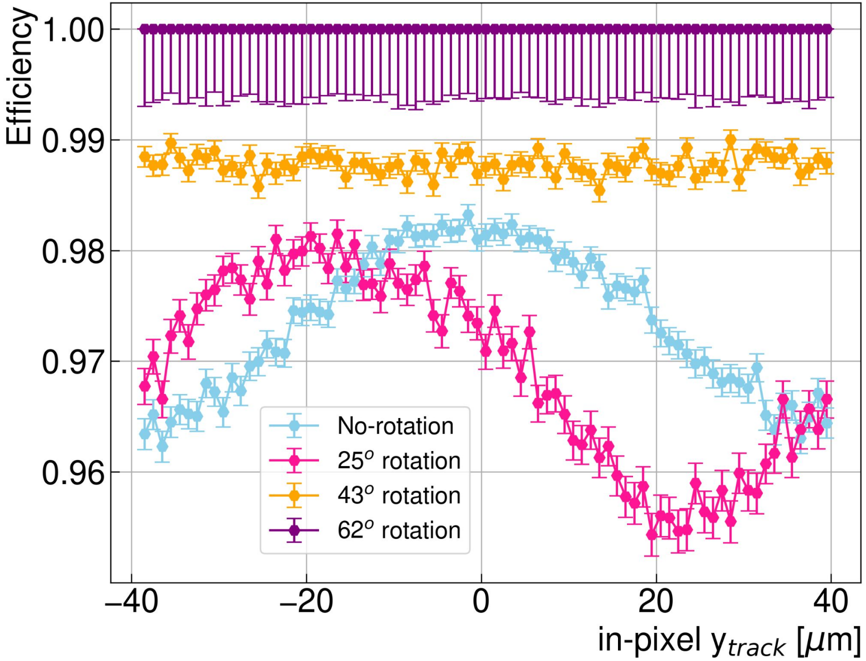


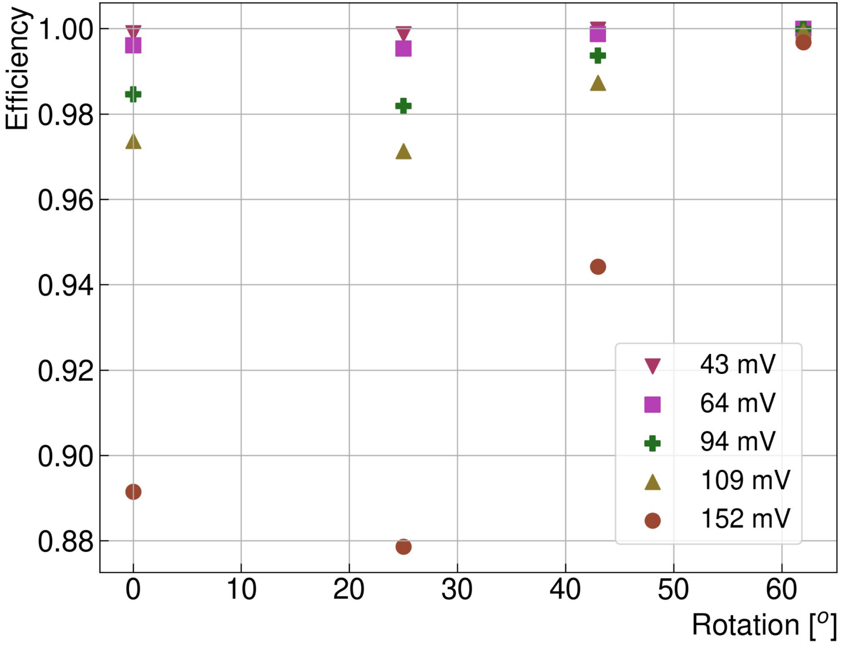


−All the in−pixel positions of the particle can result in cluster size 3.

−Increase of the particle path inside the depletion zone in the neighbor pixel.

Efficiency (-20 V, 43 mv threshold)

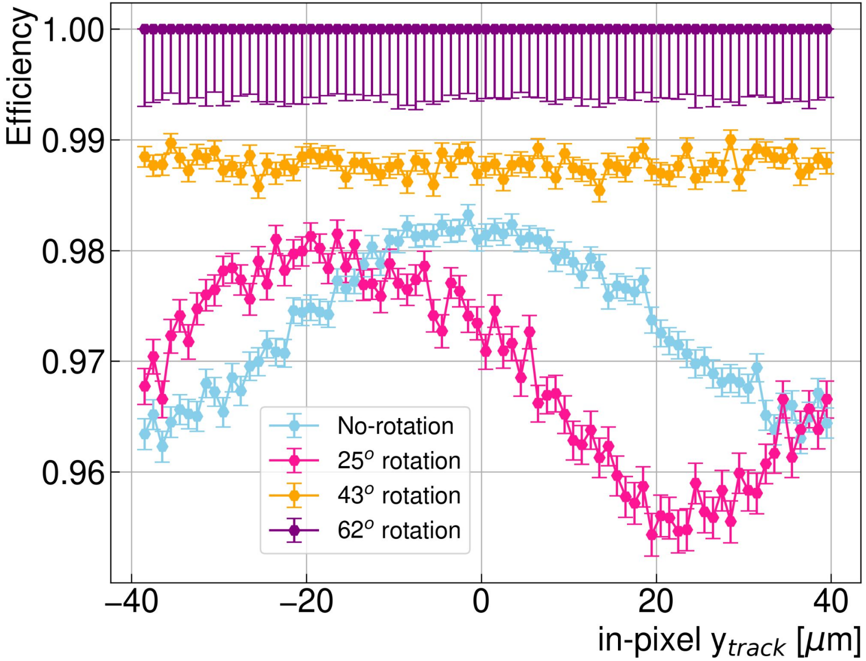


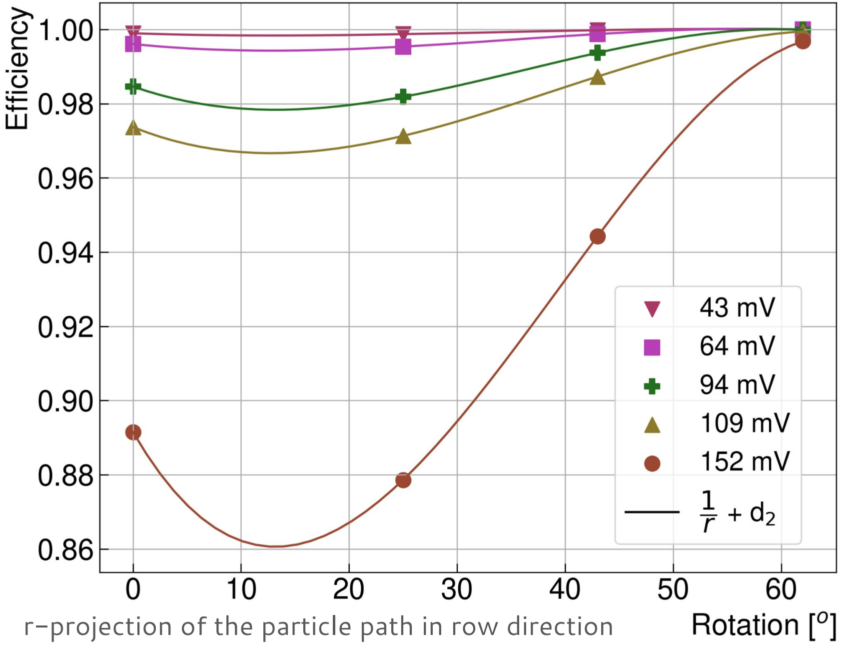


-Efficiency decreases for small rotations due to an increased charge sharing.

-For large rotations, the increased path of the particle in the depletion zone increases the efficiency despite the increased cluster size.

Efficiency (-20 V, 43 mv threshold)



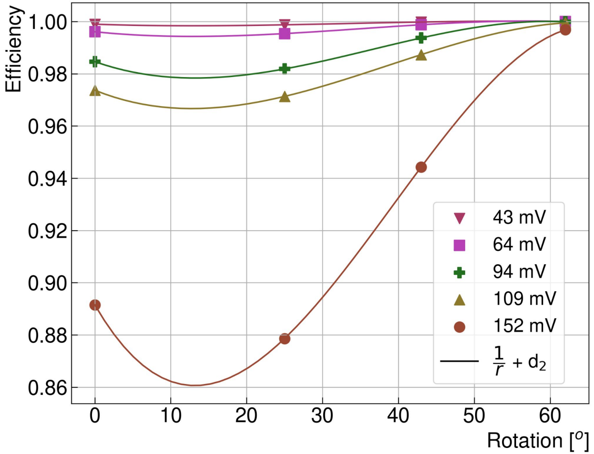


r-projection of the particle path in row direction
d_2-path of the particle inside the depletion zone

-Efficiency decreases for small rotations due to an increased charge sharing.
-For large rotations, the increased path of the particle in the depletion zone increases the efficiency despite the increased cluster size.

Summary and Outlook

- Performance of MuPix10 was studied for different incidence angles.
- Efficiency increases with the incidence angle, except for low rotations (< 13° according to the fit for a 100 μm sensor biased to −20 V).
- These results can be well described by a function that considers the individual contributions of cluster size and the path inside the depletion zone.
- Data for different sensor thicknesses was taken and preliminary results show a shift in the minimum of the efficiency curves.
  → Diffusion has a significant contribution to the signal and can also be considered in the efficiency fit.

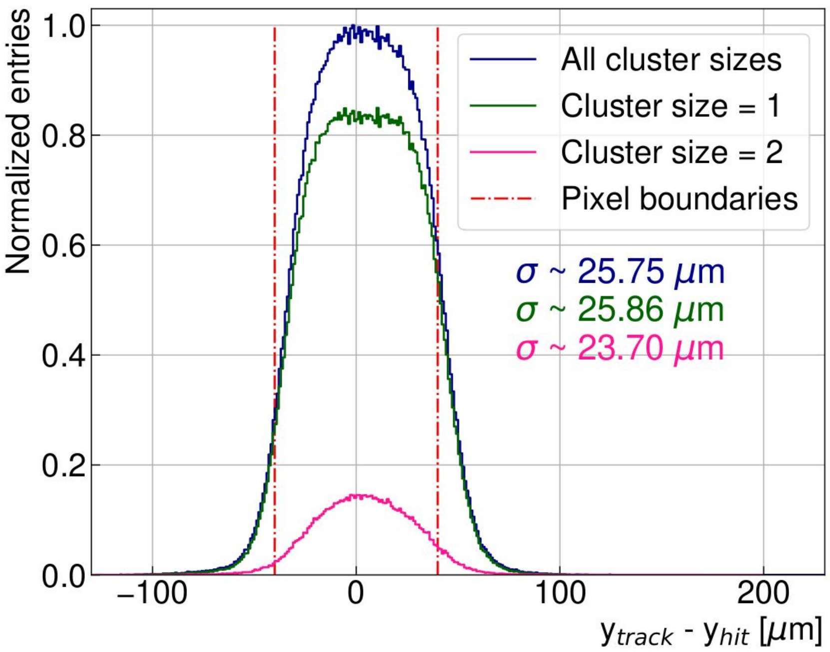


Annie Meneses Gonzalez, TCAD Simulations and Characterization of High-Voltage Monolithic Active Pixel Sensors. DOI: 10.11588/heidok.00033792

Backup

Position resolution

25°



43°