JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

CLICTD TEST-BEAM RESULTS

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CLICdp Collaboration Meeting

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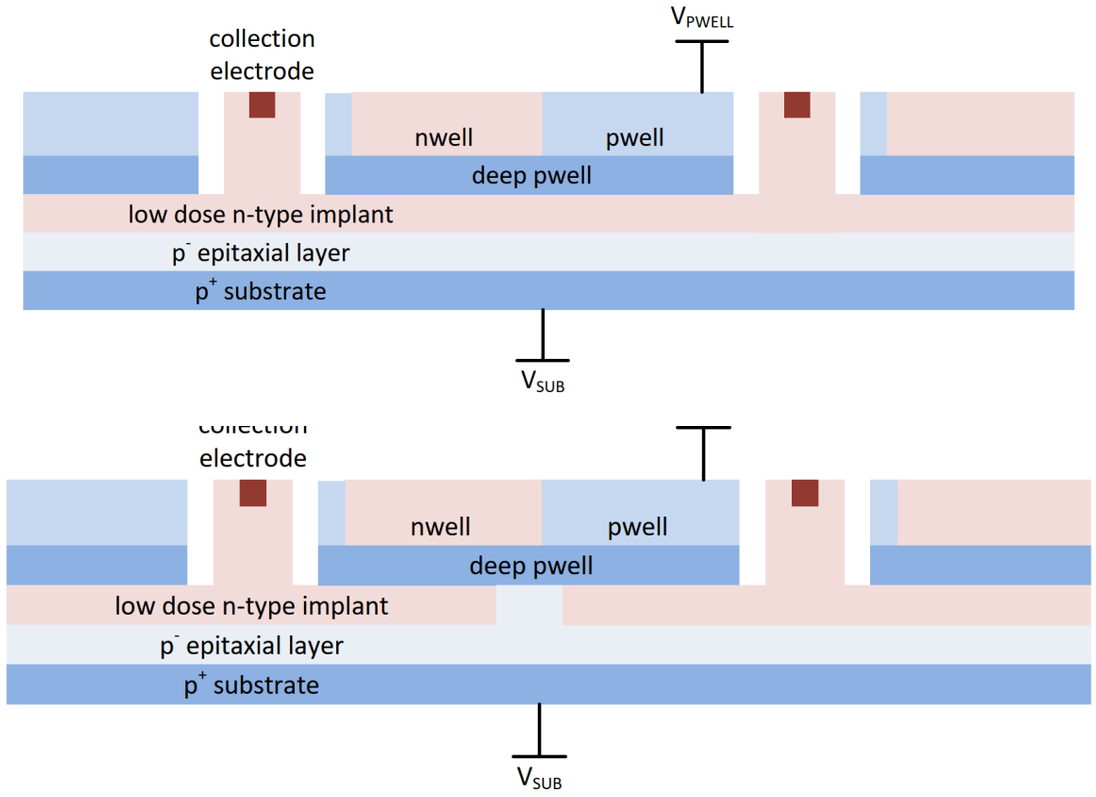
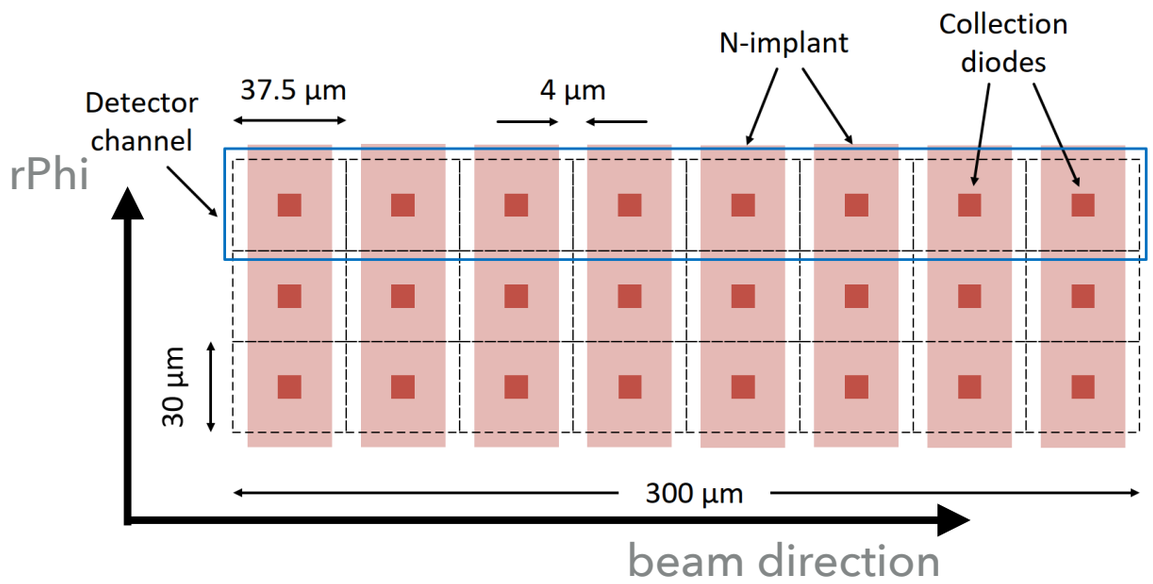
CLICTD TRACKER CHIP

- CLICTD (180 nm CMOS imaging process) was designed in two process variants
- Gap in the n-type implant was introduced in one spatial dimension to speed up charge collection
- Epitaxial layer: 30 um
- Bias voltage applied to substrate and p-wells, best performance expected at -6V/-6V

- Channel pitch: 300 µm x 30 µm (16x128 channels)
- Sub-pixel pitch: 37.5 µm x 30.0 µm
- Analogue front-end of 8 sub-pixels are grouped together in one digital front-end (= detector channel)
- Frame-based readout with 40 MHz
- 8-bit ToA (10 ns ToA bins) + 5-bit ToT (combined ToA/ ToT for every 8 sub-pixels in 300µm dimension)





CLICTD TEST-BEAM MEASUREMENTS JULY/AUGUST 2020

Very successful test-beam periods where we tested various assemblies (different thicknesses, different processes) at different bias voltages, different thresholds and different rotation angles –> **huge parameter space**

Effect of different bias voltages

- Sensor at -3V/-3V and minimum threshold
- Threshold scans for -3V / -3V

Comparison of process variants

- Nominal data for an assembly with and without gap in the n-layer at the same threshold
- Threshold scans for both process variants

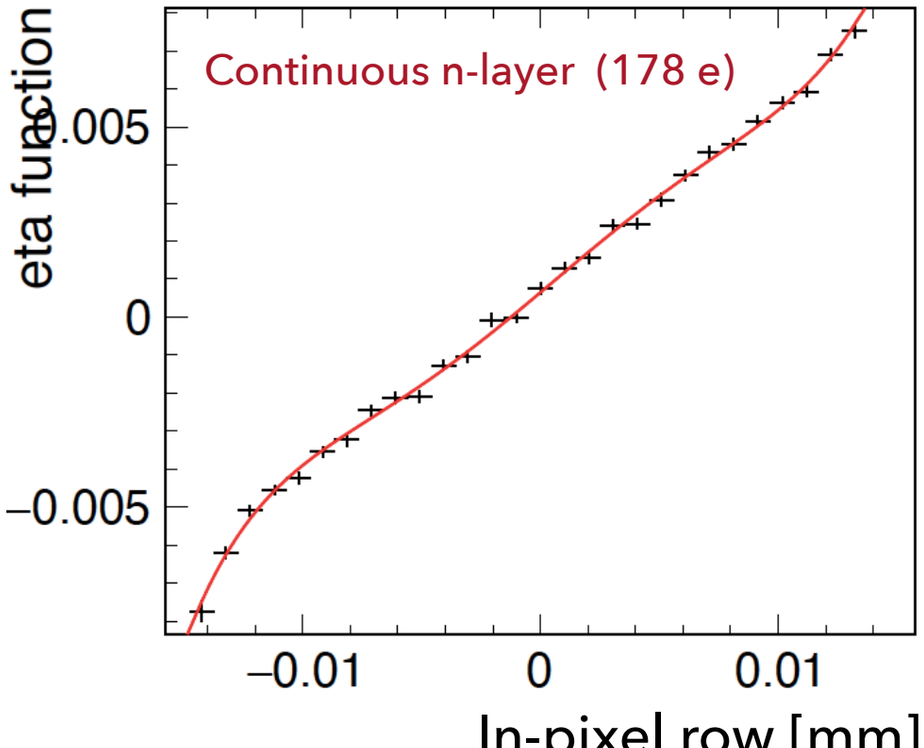
Thinned assemblies

- Nominal data and threshold scans for assemblies thinned down to 50 um and 100 um of both processes variants

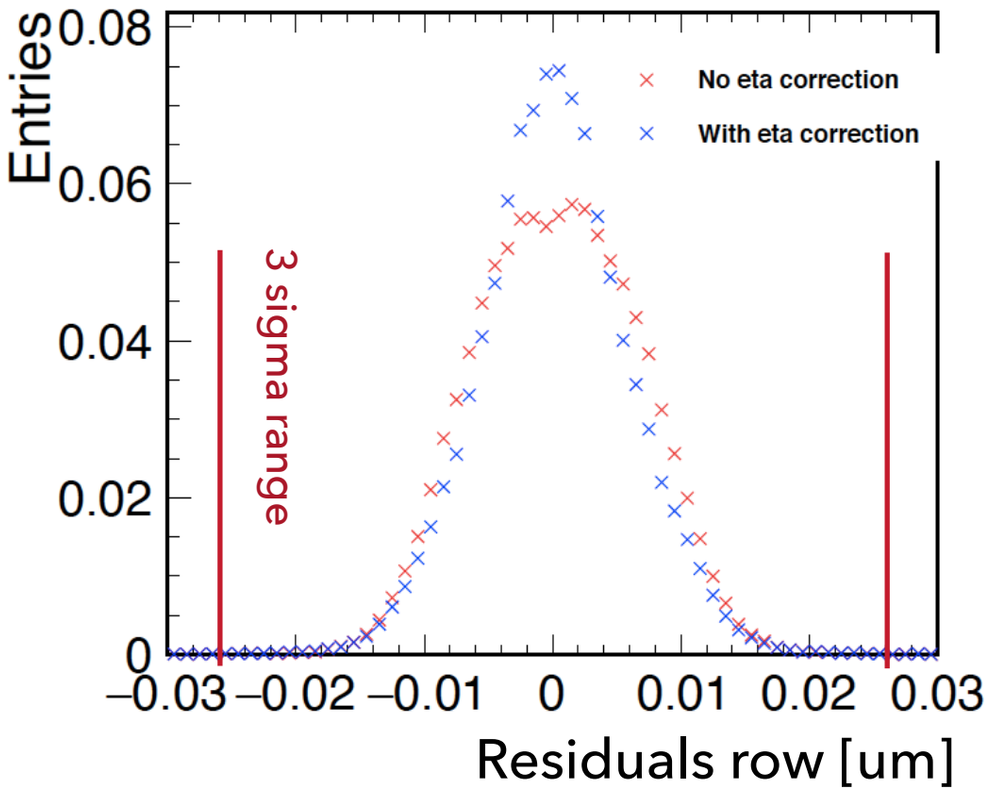
Rotation scans

- Rotation data (0 deg up to 90 deg) for various assemblies, including thinned assemblies around both rotation axes

SPATIAL RESOLUTION WITH ETA CORRECTION



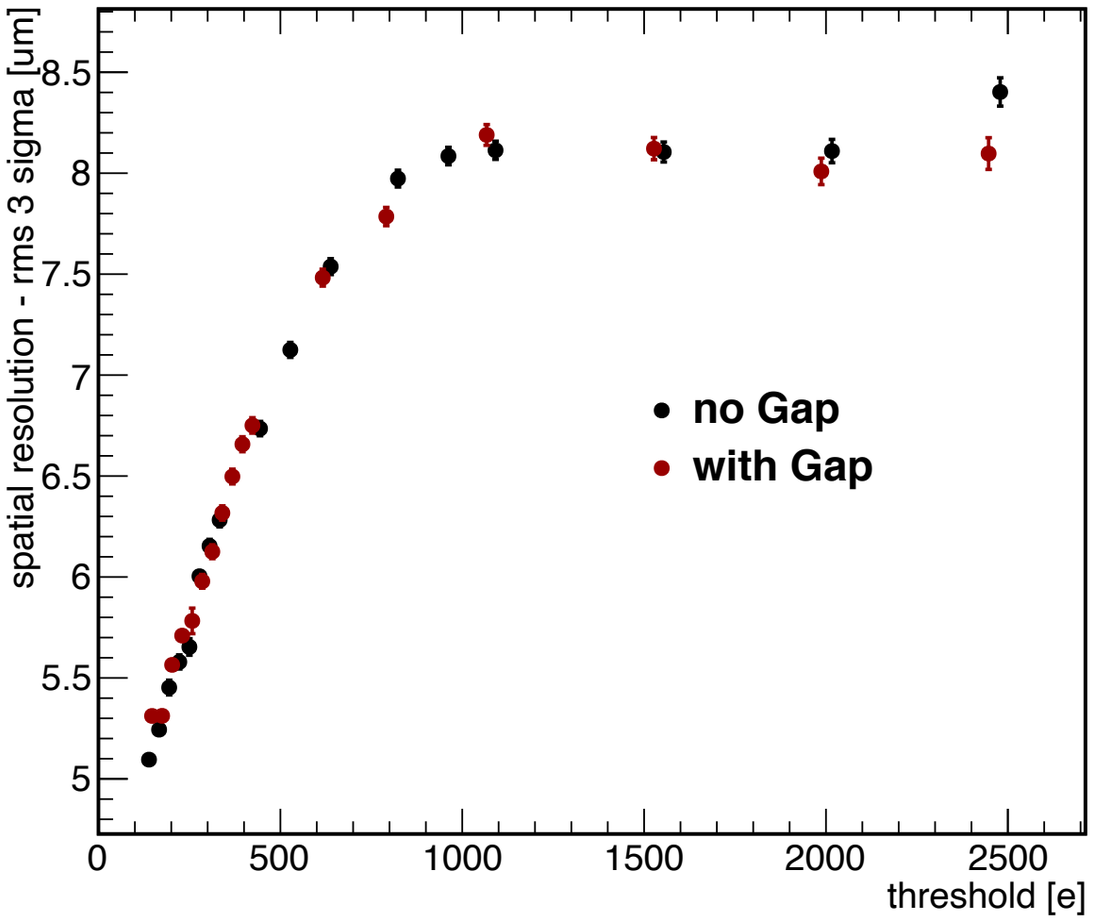
- Cluster position for multi-pixel clusters first determined with charge-weighted centre-of-gravity algorithm (assumes linear charge sharing)
- The eta correction is a data-driven method to take contributions from non-linear charge sharing into account
- Eta distribution is defined as in-pixel track position as a function of in-pixel cluster position

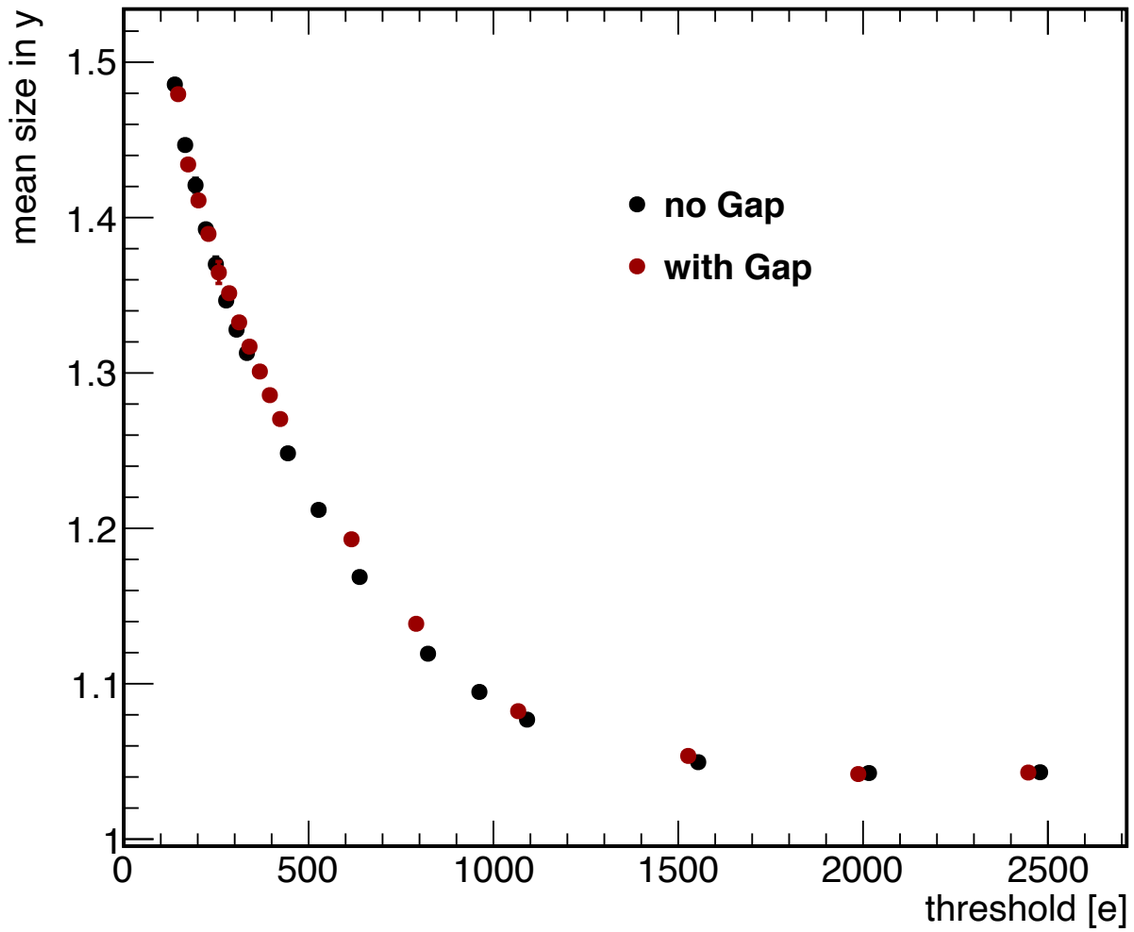


- Only cluster position in row direction is corrected with eta algorithm (in column direction sub-pixel scheme requires modified correction method)
- RMS of 3 sigma (= 99.7%) of entire residual distribution (also 1 pixel cluster): 5.1 um (before correction: 5.7 um)

  telescope resolution (= 1.78 um) unfolded
- Requirements for CLIC tracker: 7 um

SPATIAL RESOLUTION ROW



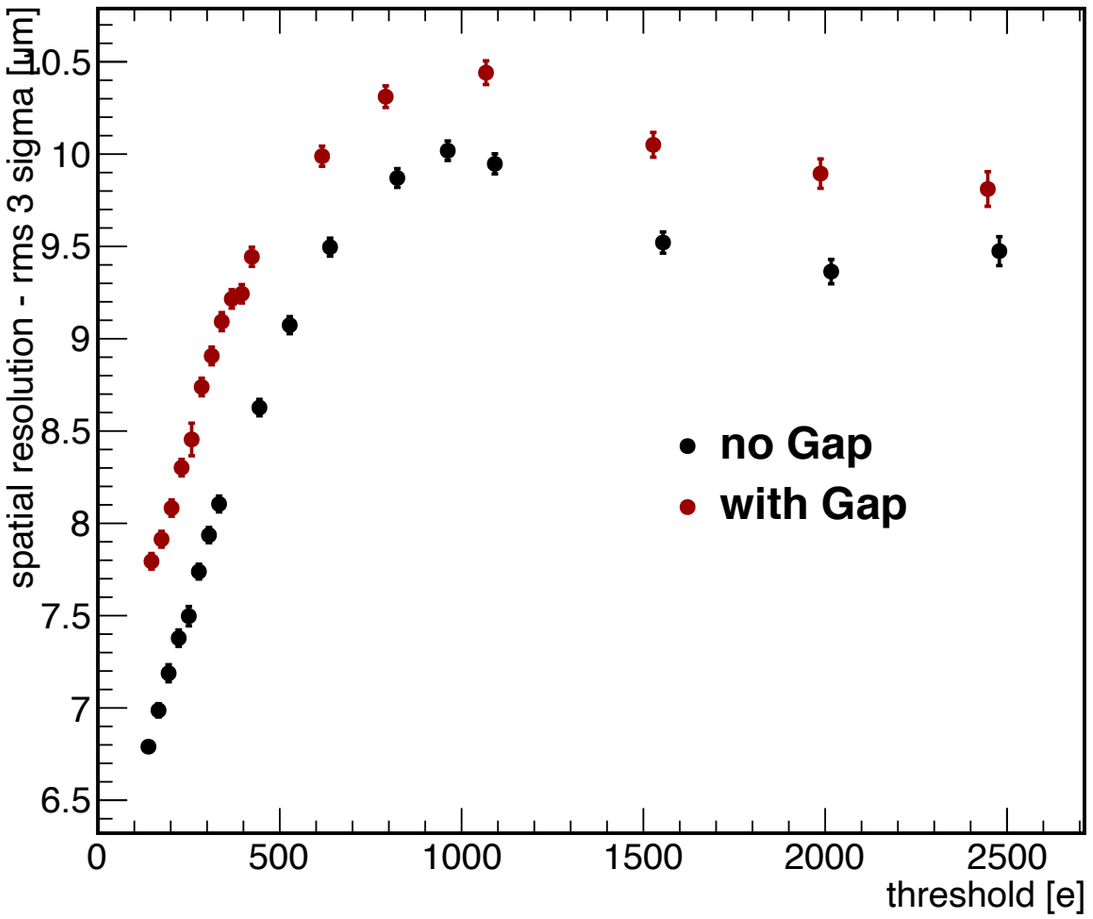


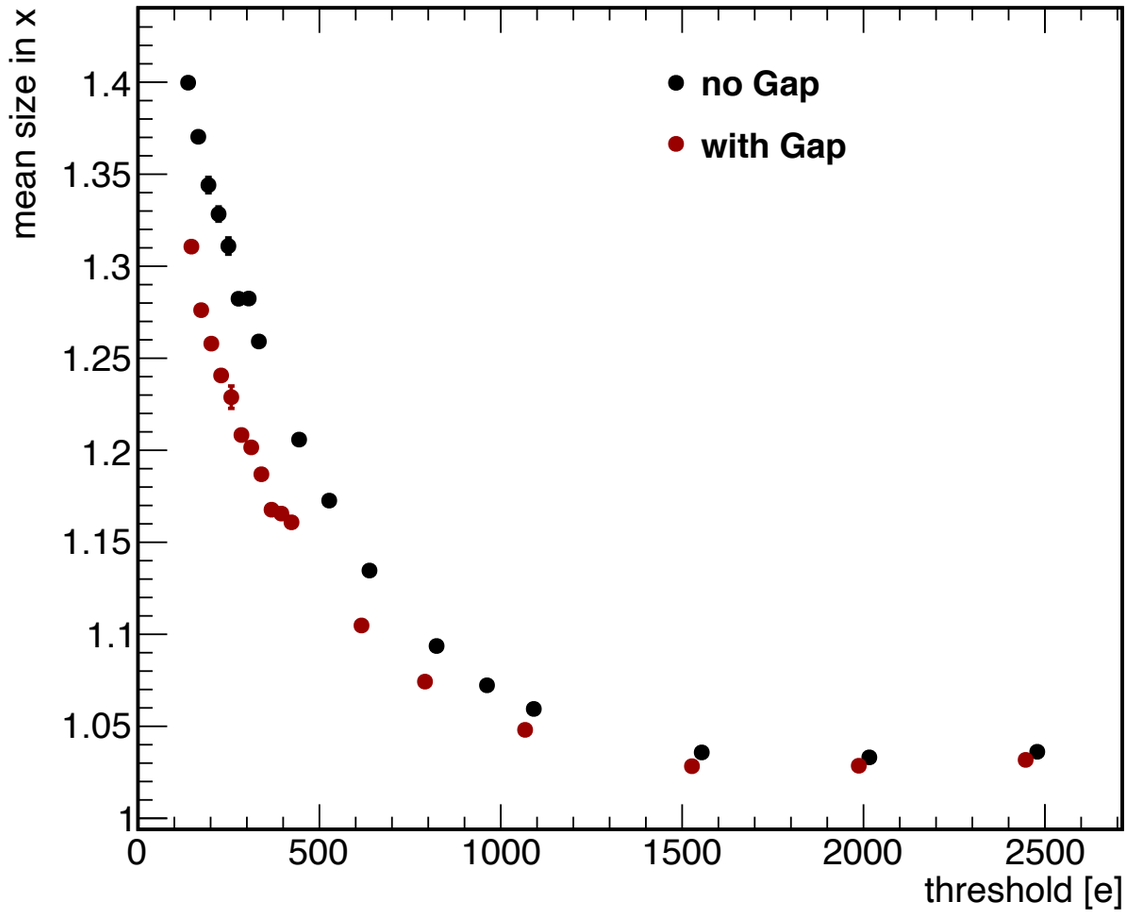
- Spatial resolution worsens with increasing threshold due to decreasing cluster size
- No difference between process variants because the gap is only introduced in column direction
- Also for high thresholds, resolution better than binary resolution of 8.7 um

  Binary resolution: $30\mu m/\sqrt{12} = 8.7\mu m$

SPATIAL RESOLUTION COLUMN

No stringent requirements for CLIC tracker in this spatial dimension



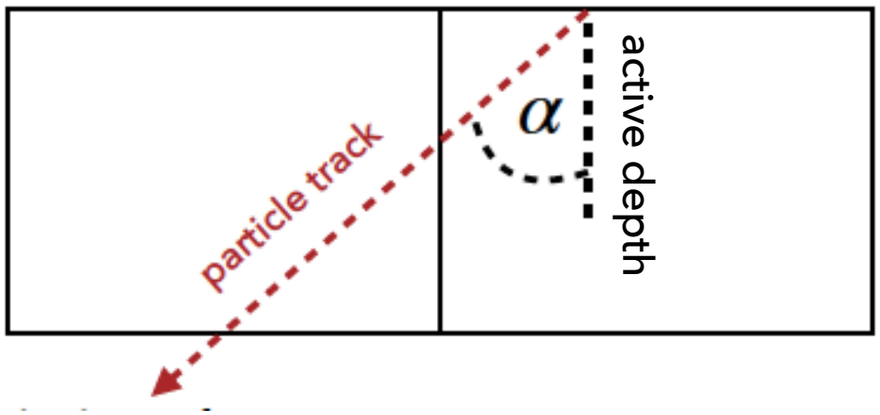


- No eta correction applied
- Less charge sharing due to gap in the n-implant leads to a smaller cluster size and worse spatial resolution
- Resolution gets slightly better at very high thresholds due to shrinking effective pixel size (decreasing efficiency at pixel edges)
- Also for high thresholds, resolution better than binary resolution of 10.8 um

  Binary resolution: $37.5\mu m/\sqrt{12} = 10.8\mu m$

ACTIVE DEPTH FROM ROTATION SCANS

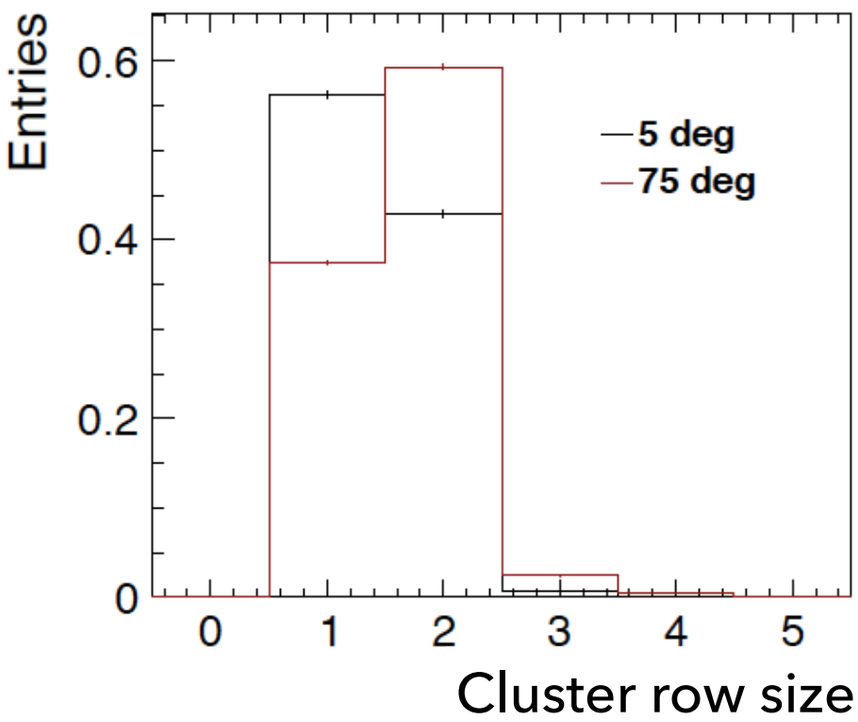
Geometrical model:

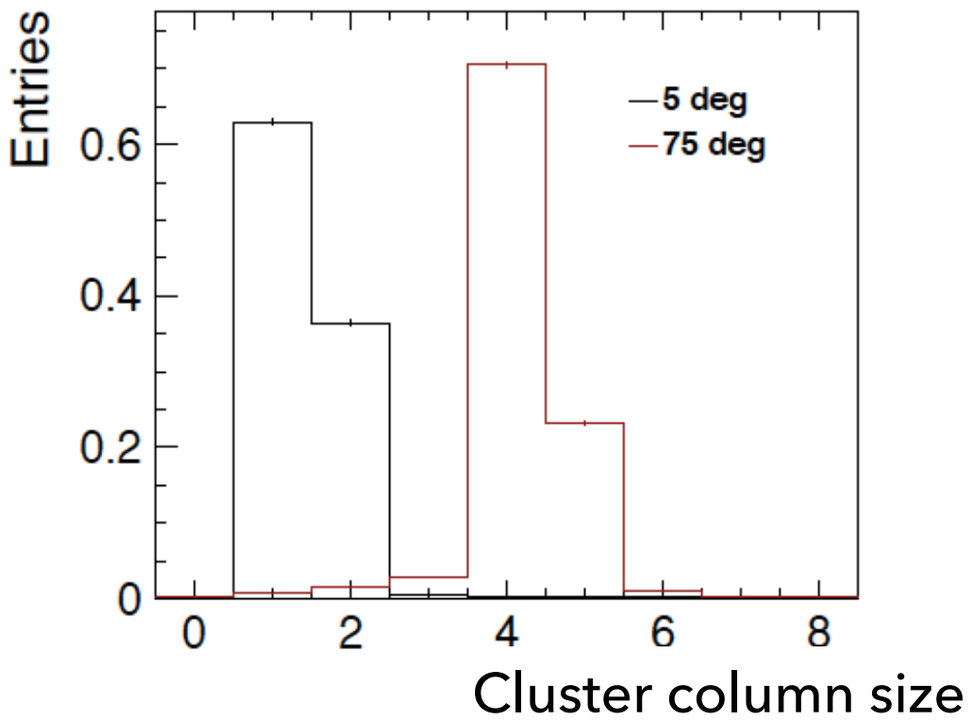


$$\text{size}_x = \frac{d_{\text{depth}} \cdot \tan(\alpha)}{\text{pitch}_x}$$

- Cluster size increases for inclined particle tracks since energy is deposited in several adjacent pixel cells
- Active depth can be estimated by analysis of rotation-dependent cluster size
- This model neglects contributions from diffusion and sub-threshold effects

Rotation performed around row axis





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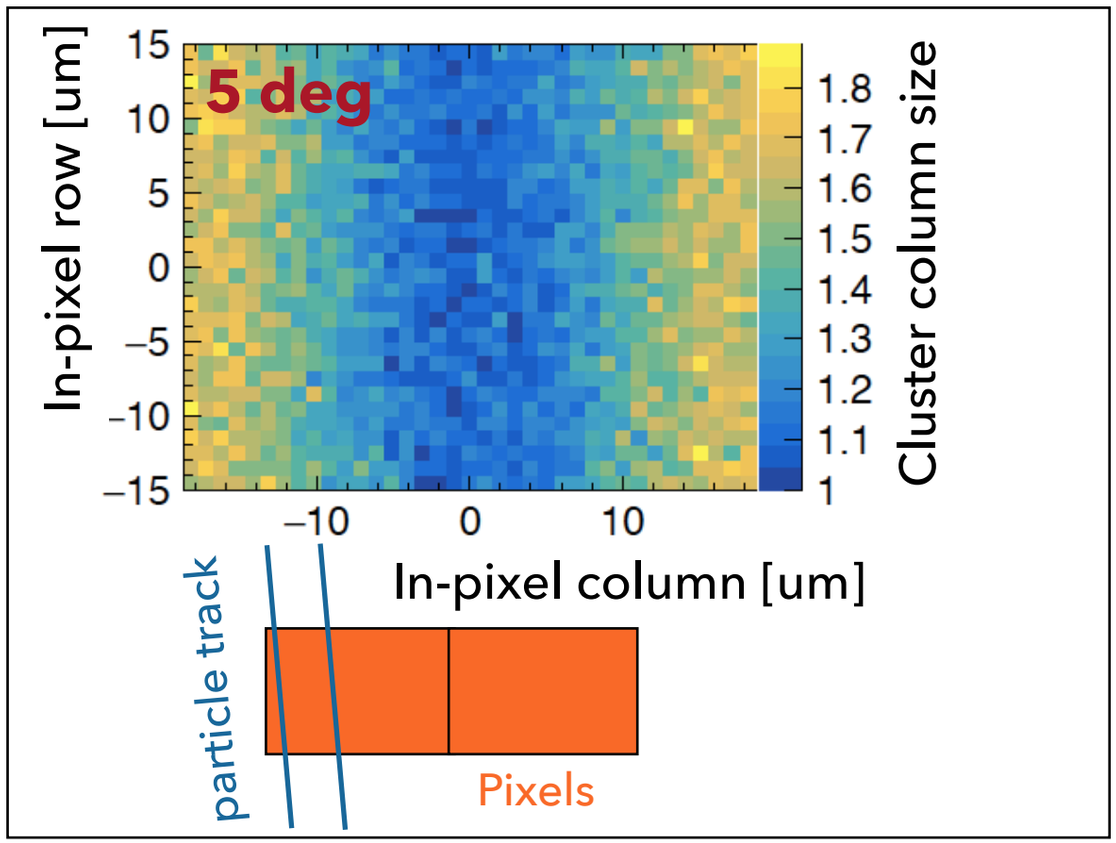
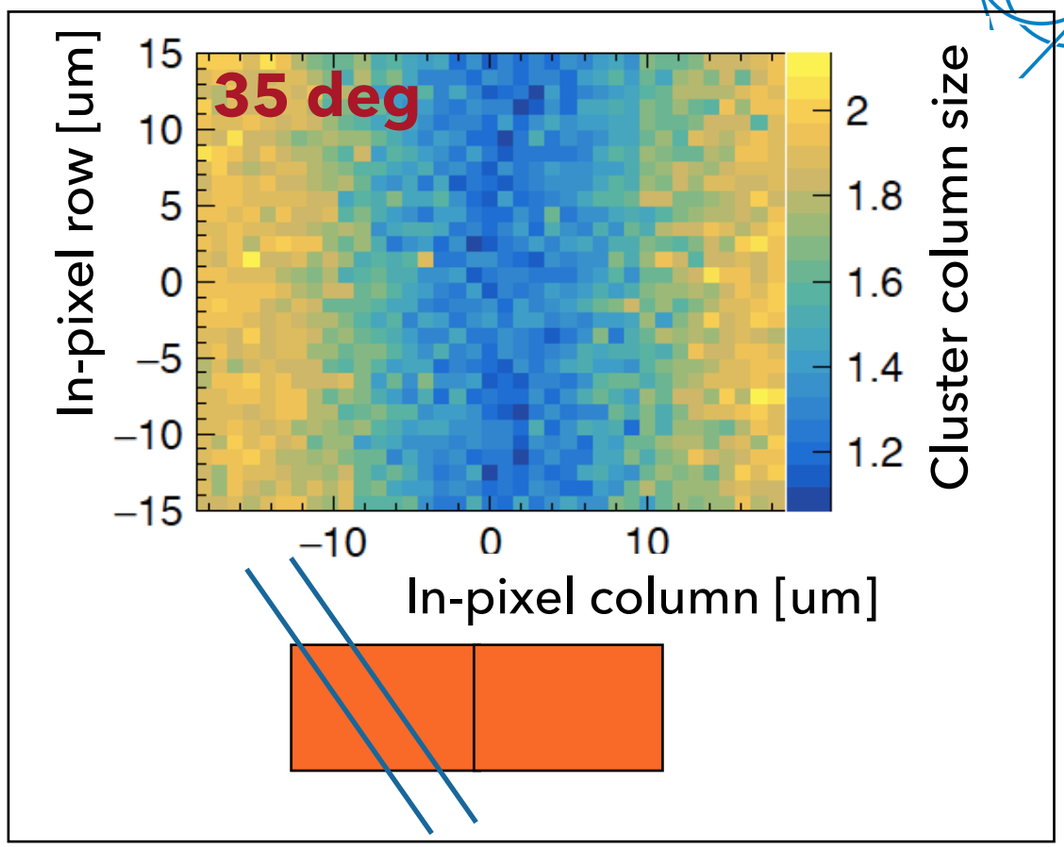
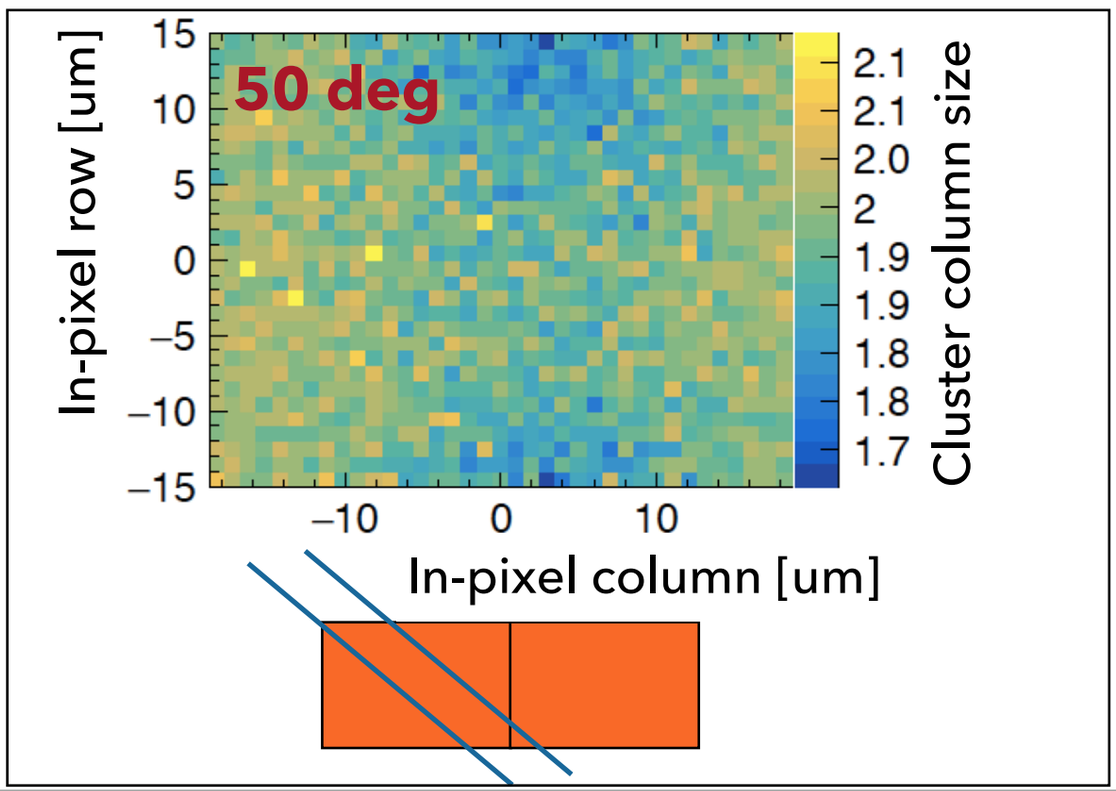
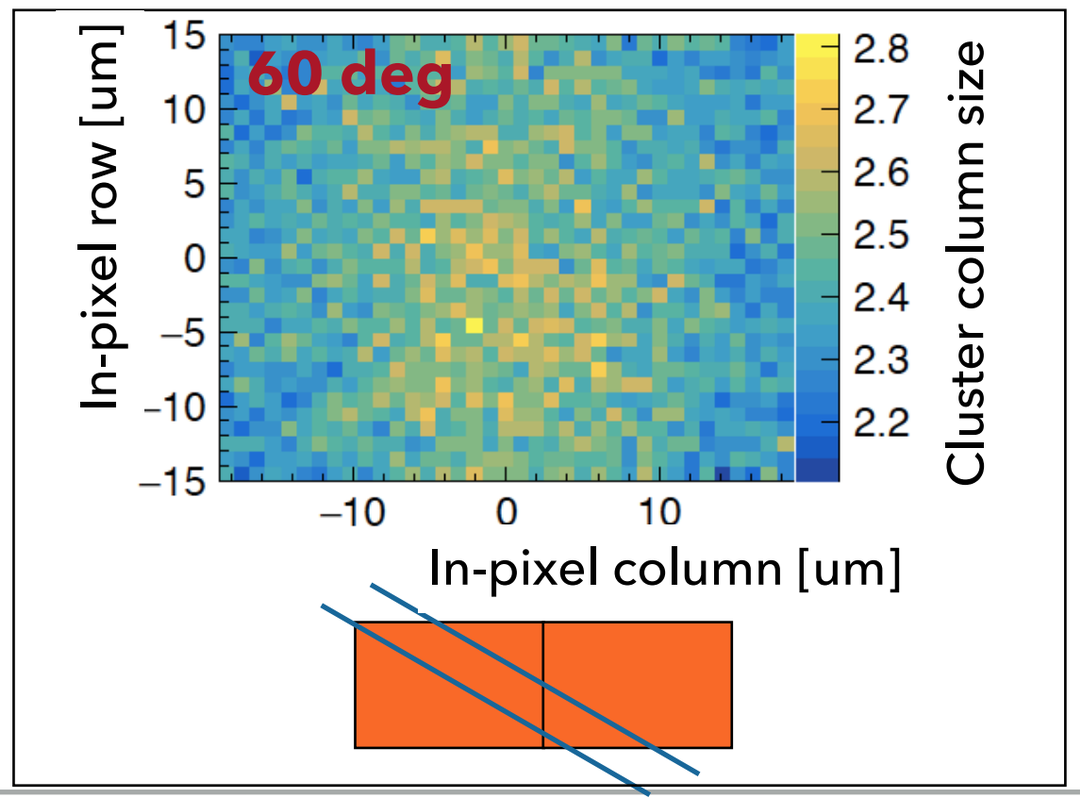
IN-PIXEL CLUSTER SIZE IN X





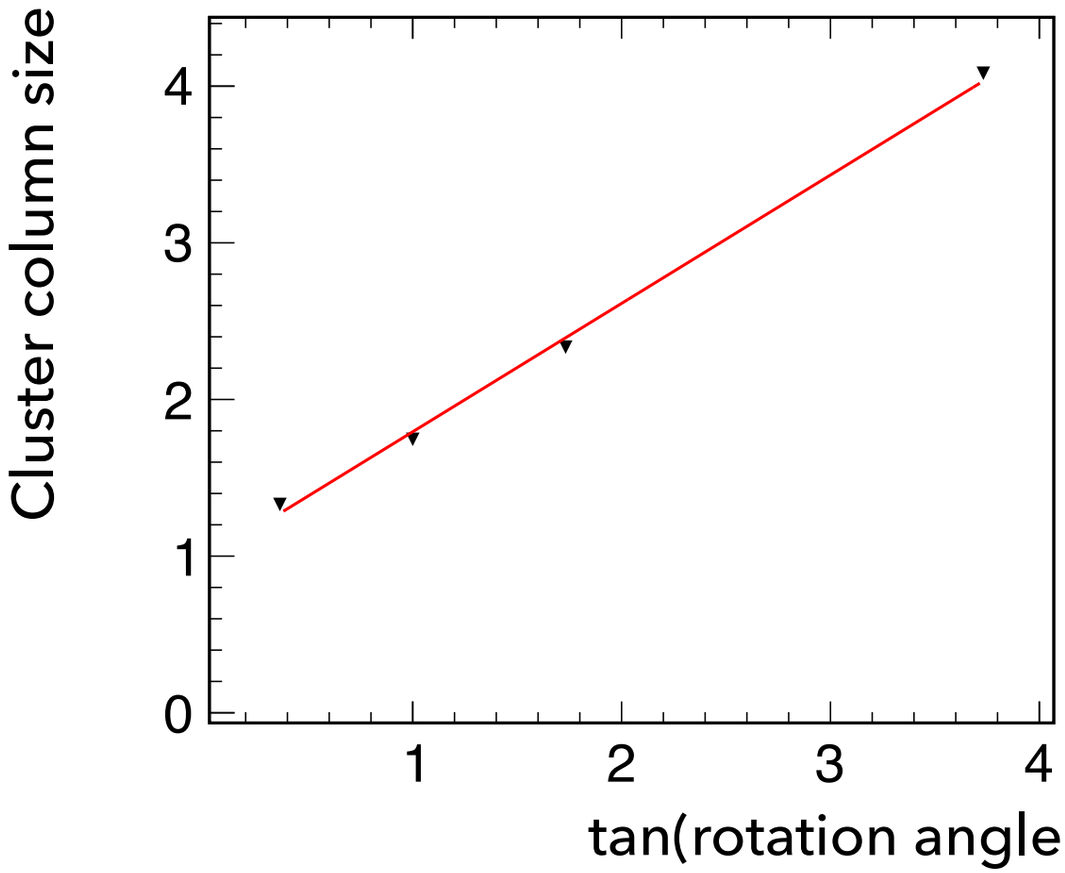
In-pixel plots illustrate that cluster size at low angles is still dominated by charge sharing via diffusion





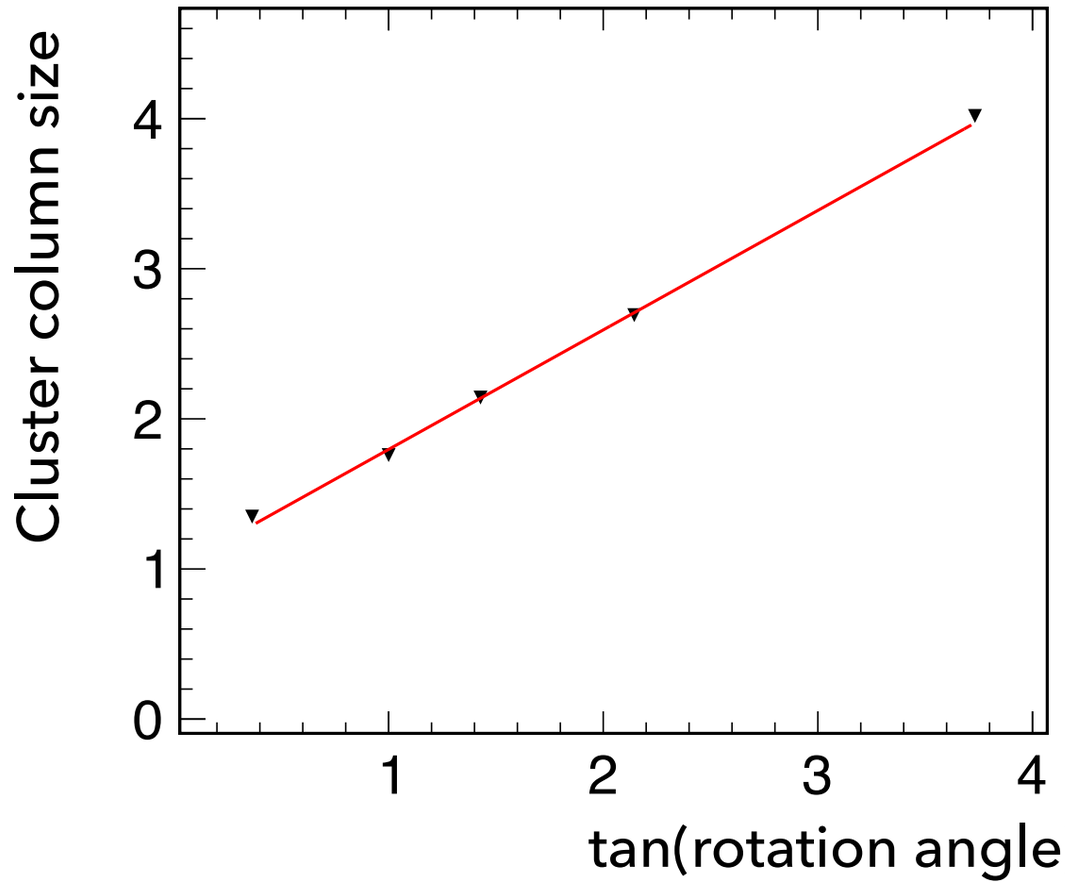
ESTIMATION OF ACTIVE DEPTH

Nominal thickness (300 um)



- Active depth from fit: (30.7 + 0.3 - 3.4) um

Thickness : 50 um

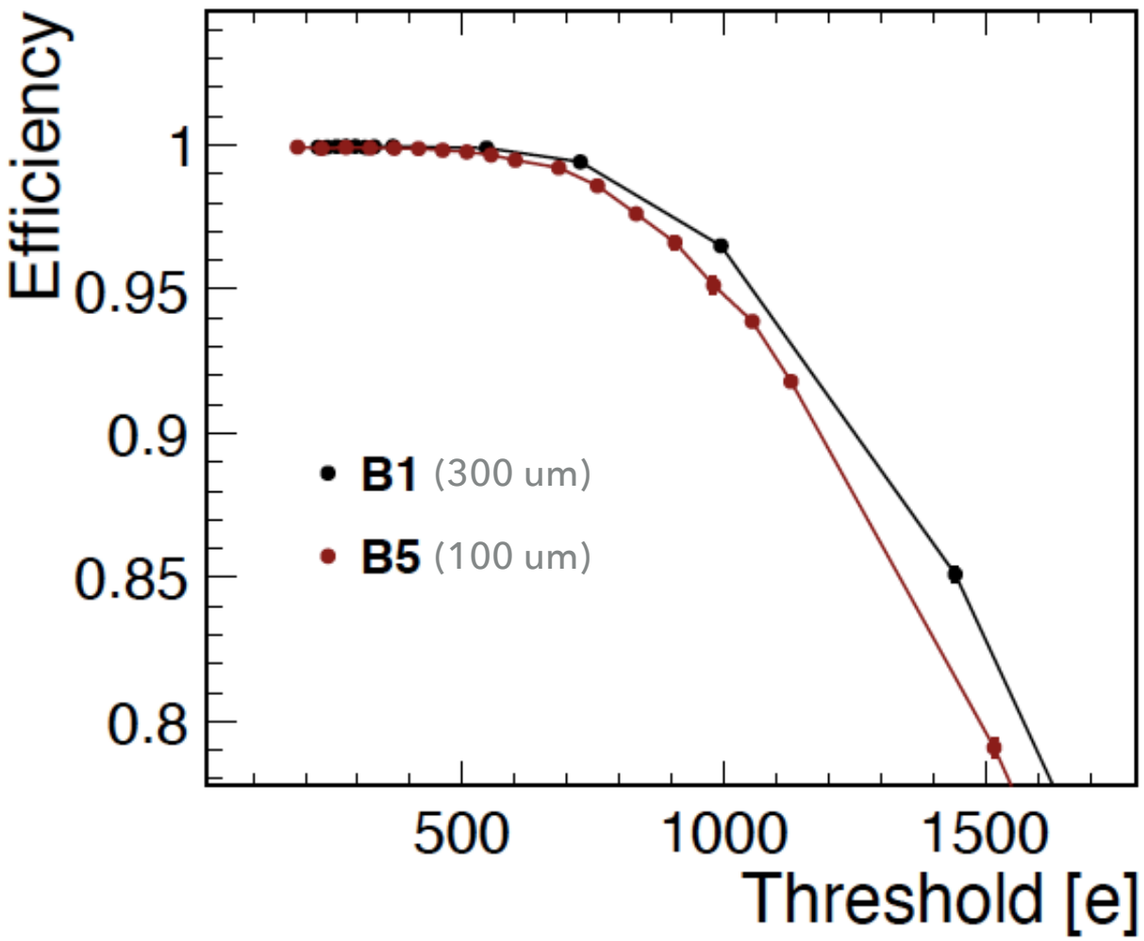


- Active depth from fit: (29.8 + 0.9 - 1.0) um

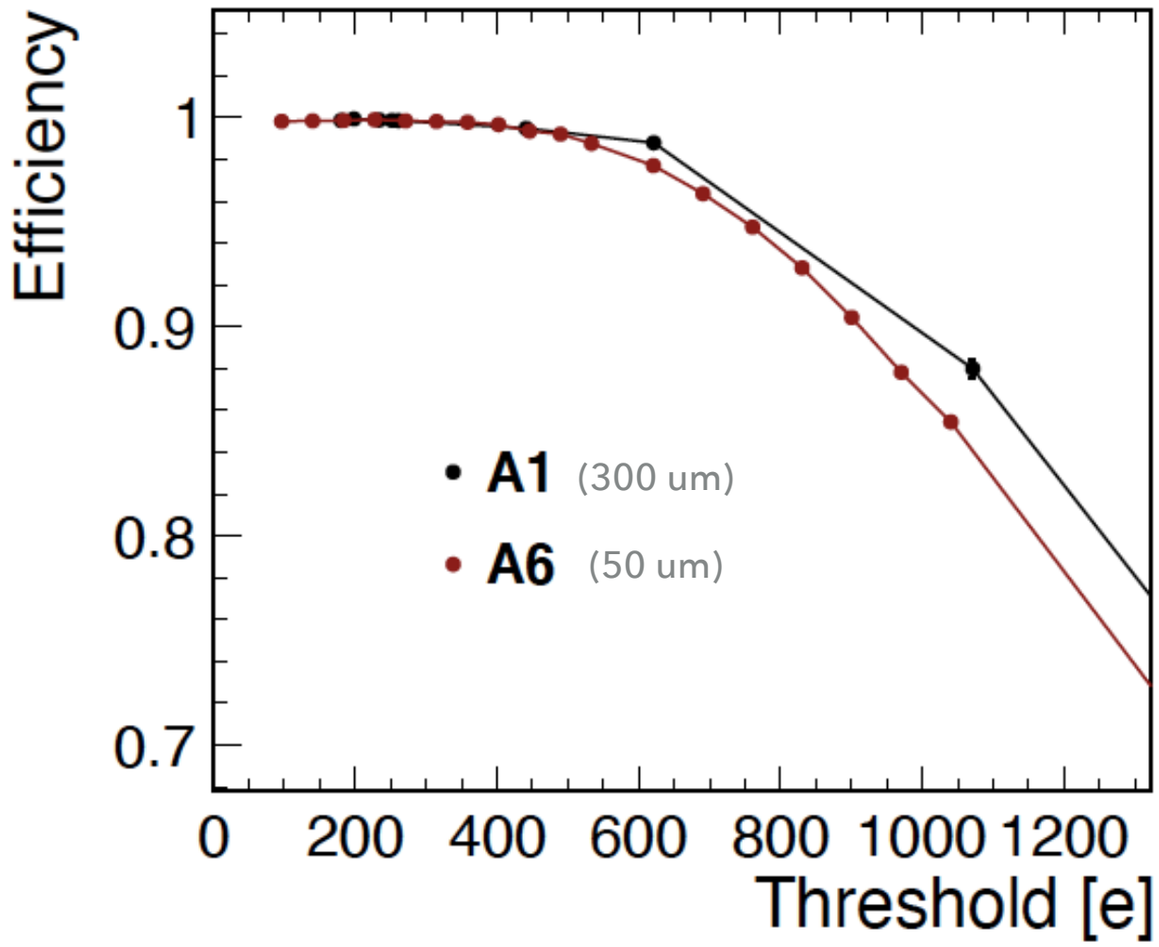
- For now, uncertainties estimated by removing first/last point and fitting again
- Thickness of epitaxial layer: 30 um, depletion depth (TCAD): 23 um
- As expected, no difference in active depth for assemblies with nominal thickness and thinned ones
- Contribution of charge sharing via diffusion and sub-threshold effects will be investigated in simulation

EFFICIENCY STUDIES: THINNED SENSORS

With gap



No gap



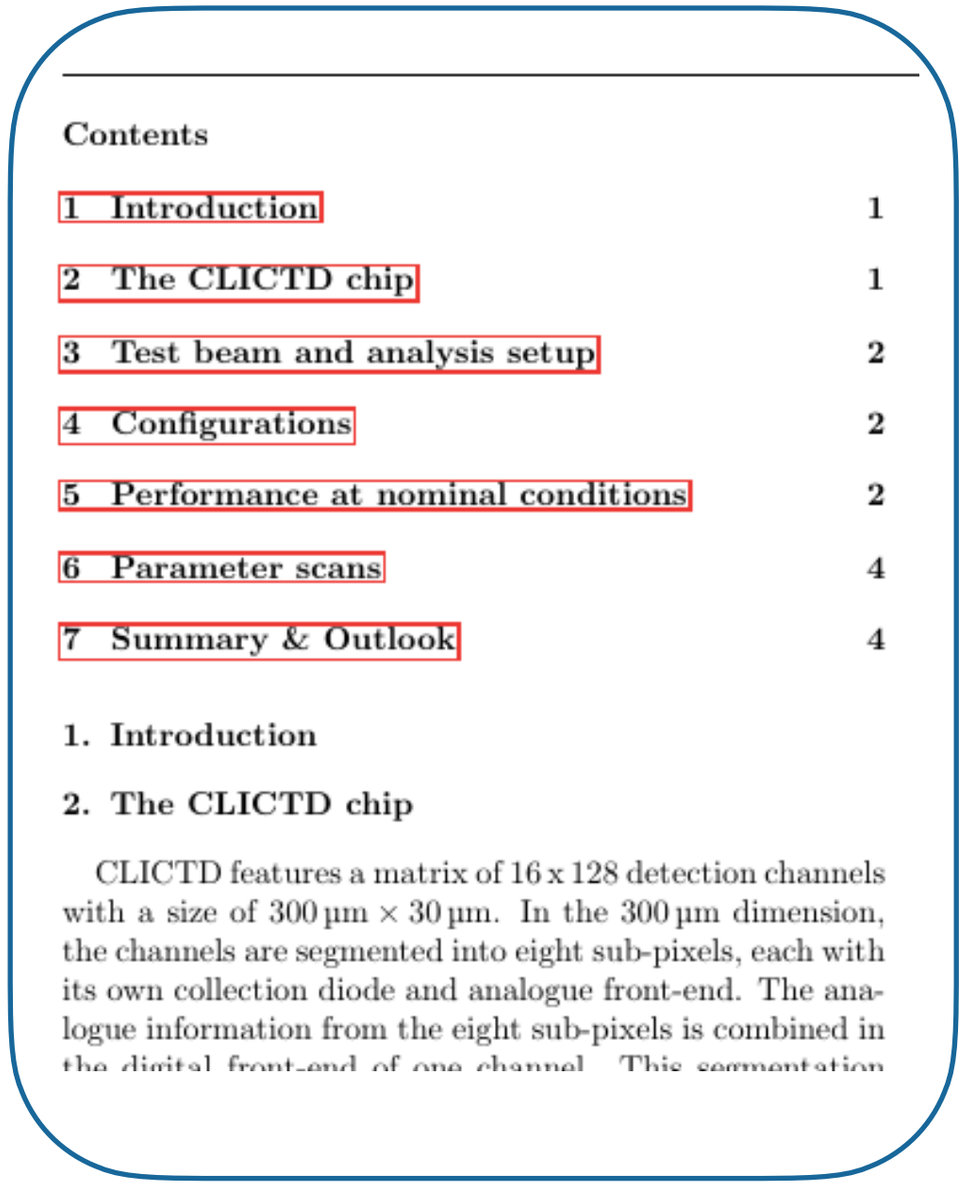
- Similar efficient operation window for thinned assemblies supports the notion that the thinning does not alter the active depth

OUTLOOK

- Paper about initial CLICTD test-beam results is in preparation

- Analysis of parameter scans turned out to be a very time-consuming task since we took data at many different thresholds

- Currently working on the correct treatment of the ToT calibration



Contents

1. Introduction

2. The CLICTD chip

CLICTD features a matrix of 16 x 128 detection channels with a size of 300 µm × 30 µm. In the 300 µm dimension, the channels are segmented into eight sub-pixels, each with its own collection diode and analogue front-end. The analogue information from the eight sub-pixels is combined in

SUMMARY / OUTLOOK

- CLICTD spatial resolution was found to be 5.1 um after eta correction (Fulfils CLIC tracker requirements of < 7 um)
- Estimation of active depth from simple geometrical model yields ~30 um for nominal thickness (300 um) and thinned assemblies (down to 50 um)
    - In agreement with expectations from sensor layout and 3D TCAD simulations
- CLICTD test-beam paper in preparation

Thank you very much!

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Part of the measurements leading to these results have been performed at the Test Beam Facility at DESY Hamburg (Germany)