Analysis of test-beam data from Timepix3 assembly with active-edge sensor

Niloufar Alipour Tehrani (CERN & ETH Zürich)

CERN
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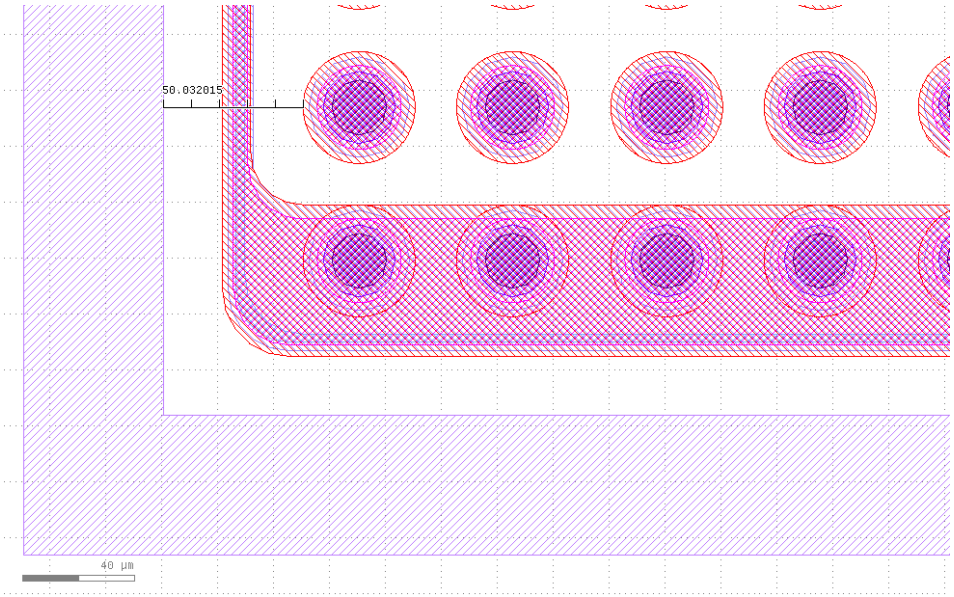
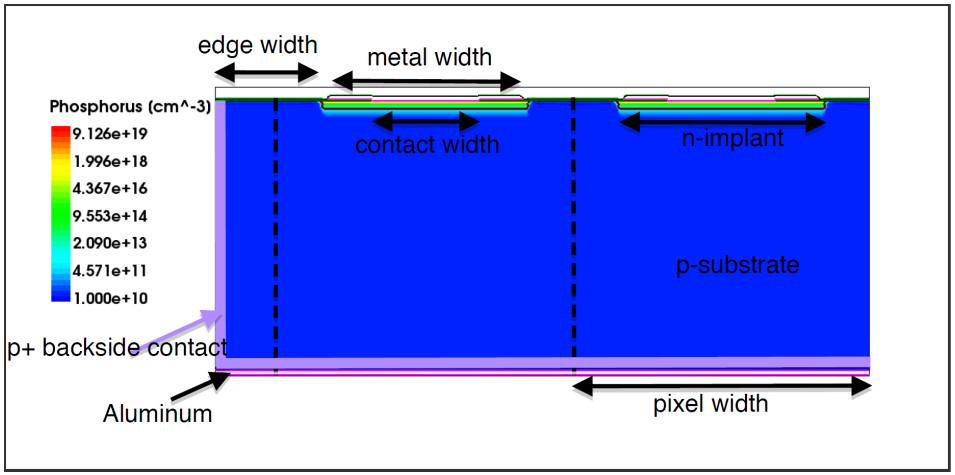
Introduction

- Analysis of the data from August 2015 SPS test-beam
  - Telescope: EUDET Telescope
  - DUT: W5_E2 (100 µm n-in-p sensor+Timepix3 readout, 50 µm active edge with grounded guard-ring).

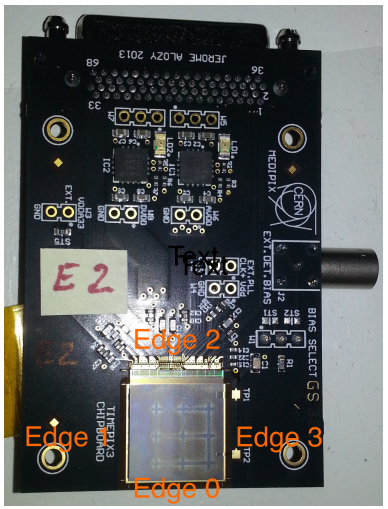


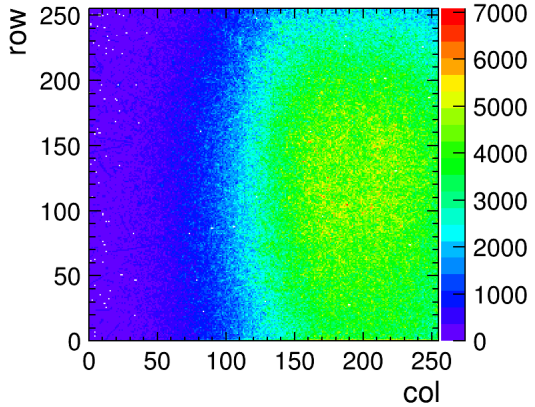


- Active-edge sensor:
  - To control the voltage at the edge, an implantation is done on the sidewall ⇒ creates an extension of the backside electrode on the edge.
  - Guard rings are used to establish a smooth voltage drop between the edge and the last pixel.

Timepix3: settings and equalisation

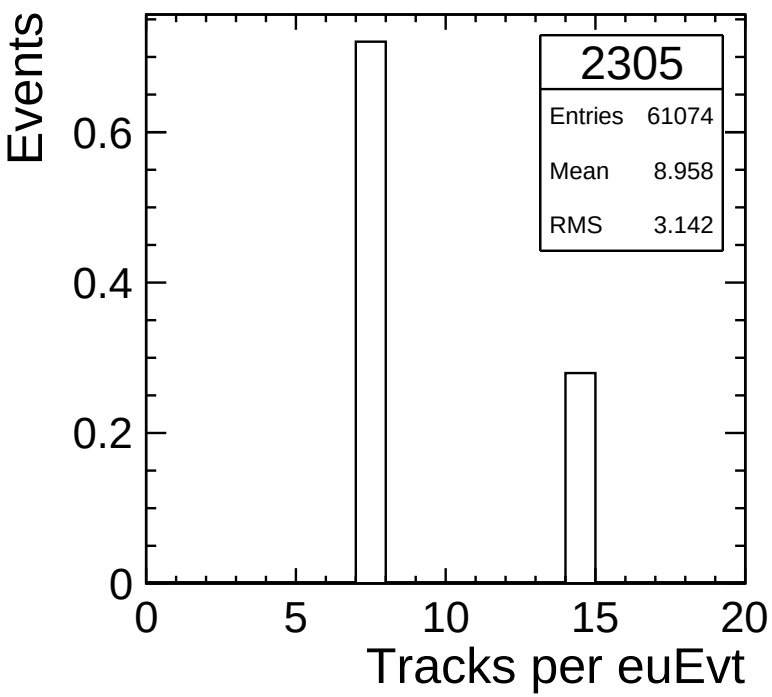
- Ikrum: 10
- VFBK: 150
- Clk: 40 MHz
- 40 pixels masked after equalisation and 5 extra pixels masked as they tended to be noisy.
- After equalisation: mean=1128.01 and σ=3.63.
- Gain: -10.42e-/LSB
- Center of noise: 1106.9.
- The baseline is at: 1114.34 ± 17.43
- The chip can be operated at 6σ away from the noise: THL=1156 (508 e-)



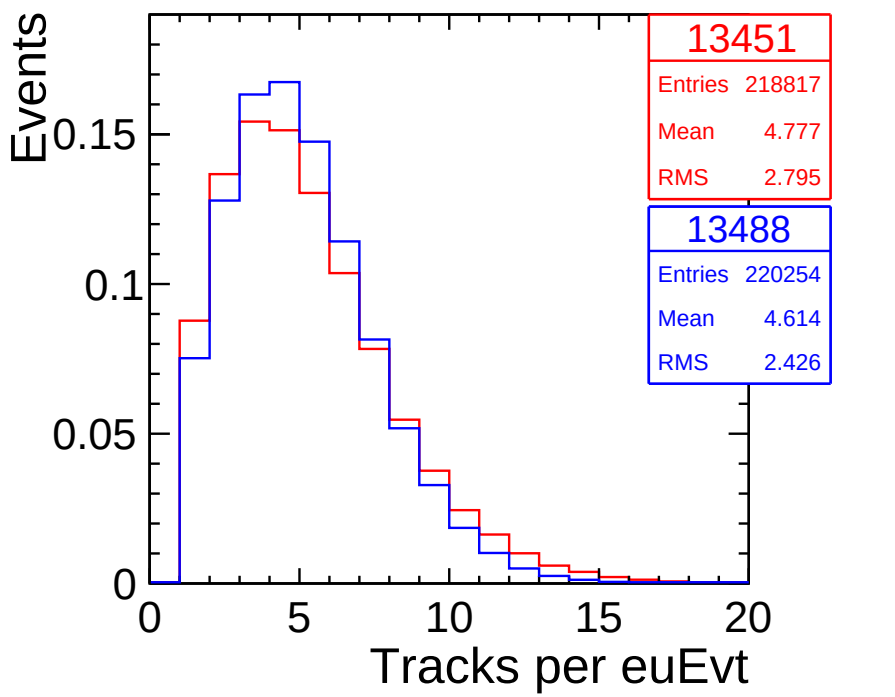


Number of tracks per event

Timepix1: run 2305



Timepix3: runs 13451 and 13488

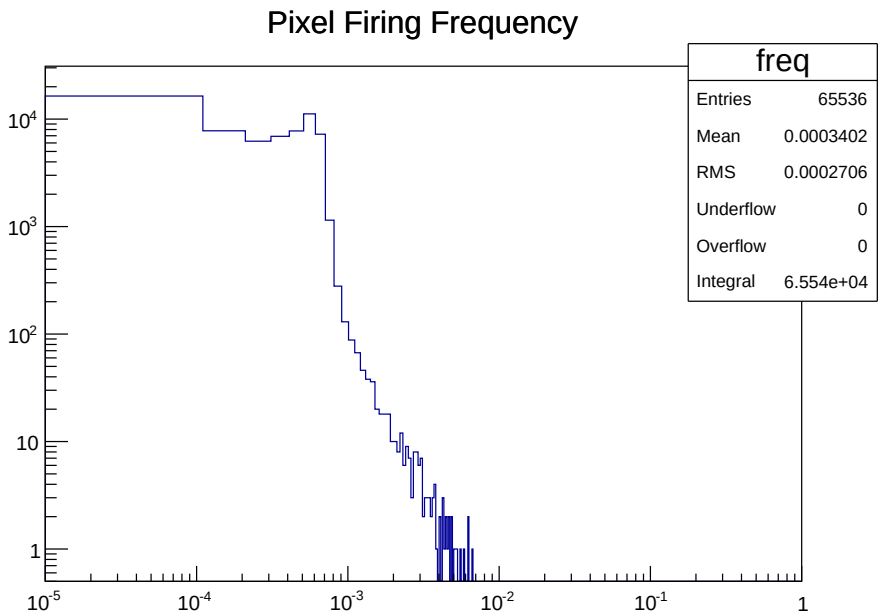


- For Timepix1, due to the slow readout using the Fitpix, the MiMTLU was accumulating 15 tracks and writing them in the file ⇒ 15 tracks per euEvt were expected.
- These plots also depend on the beam position and also conditions (DESY, SPS).

Hot pixels

- All the hot pixels were masked after the equalisation.
- A pixel is considered hot if its firing frequency is higher than 0.01.
- Even with a very low threshold (THL=1160 ($\sim 510e-$), no hot pixel is observed in data.

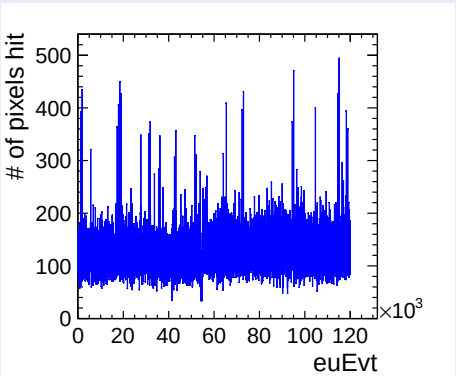
- Run 13451

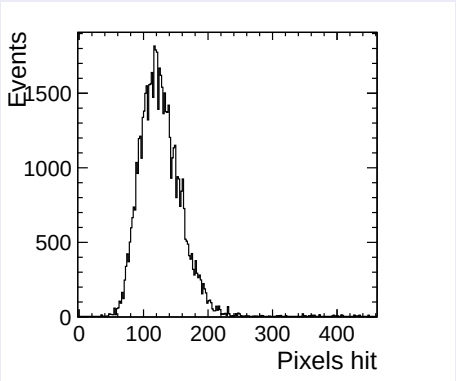


Hits per event

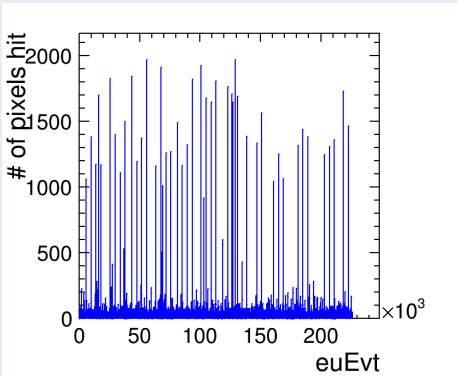
- The number of pixels hit depends on the beam, sensor thickness, threshold, bias voltage, ...
- For some events, a large number of hits in Timepix1 and Timepix3 data is seen.

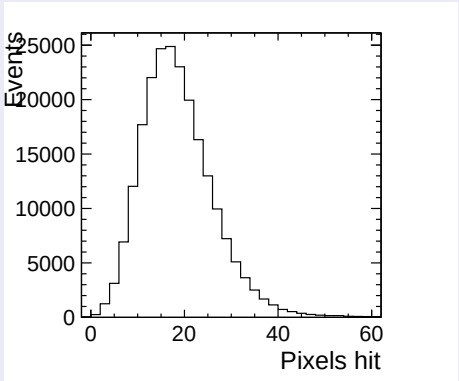
Timepix1: run 2305





Timepix3: run 13488





Analysis strategy

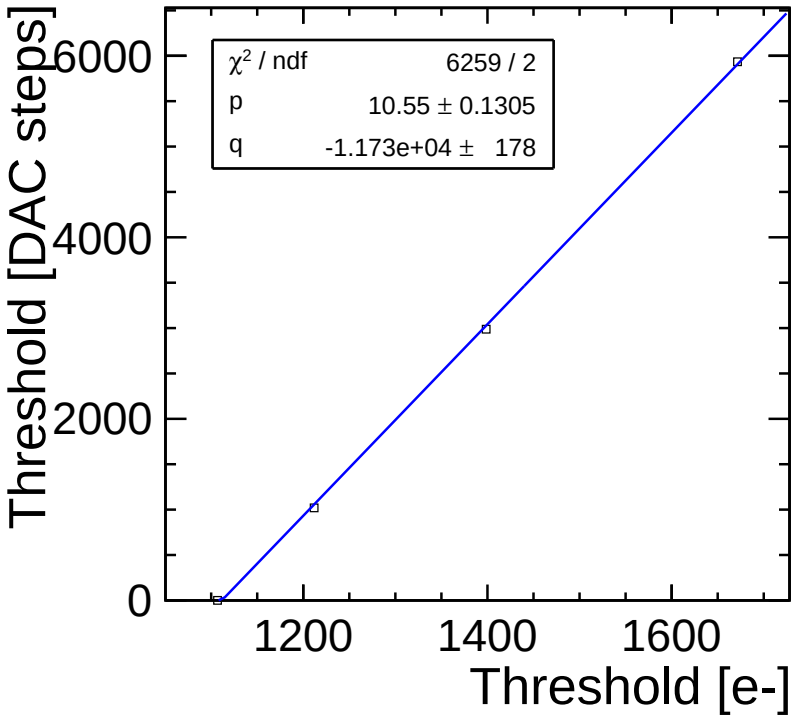
- The tracks are reconstructed using the Eutelescope framework.
- The pyEudetAnalysis framework is used for the anaylsis of the DUT data (alignement and track extrapolation).
- Each run contains $\sim$ 200k events $\Rightarrow$ split into subruns of $\sim$ 10k events.
- Some pixels in Timepix3 are hit more than once at the same Eutelescope event (probably have different TOA values). These hits are discarded at the moment since the TOA is not considered.
- Runs analysed:
  - Threshold scan: runs 13451-13479.
  - Bias scan: runs 13487-13513. Runs 13495-13513 are un-usable since the Timepix3 producer crashed and its data is not recorded (only the EUTelescope data is recorded).
  - Nominal runs: 13597-13609.

THL calibration for W5_E2

- The threshold calibration: s-curve measurement using test-pulses.
- -10.42 e- per THL DAC step.

$$THL[e-] = pTHL[DAC] + q \qquad (1)$$

THL [DAC]	THL [e-]
1160	510.30
1190	826.80
1300	1987.30

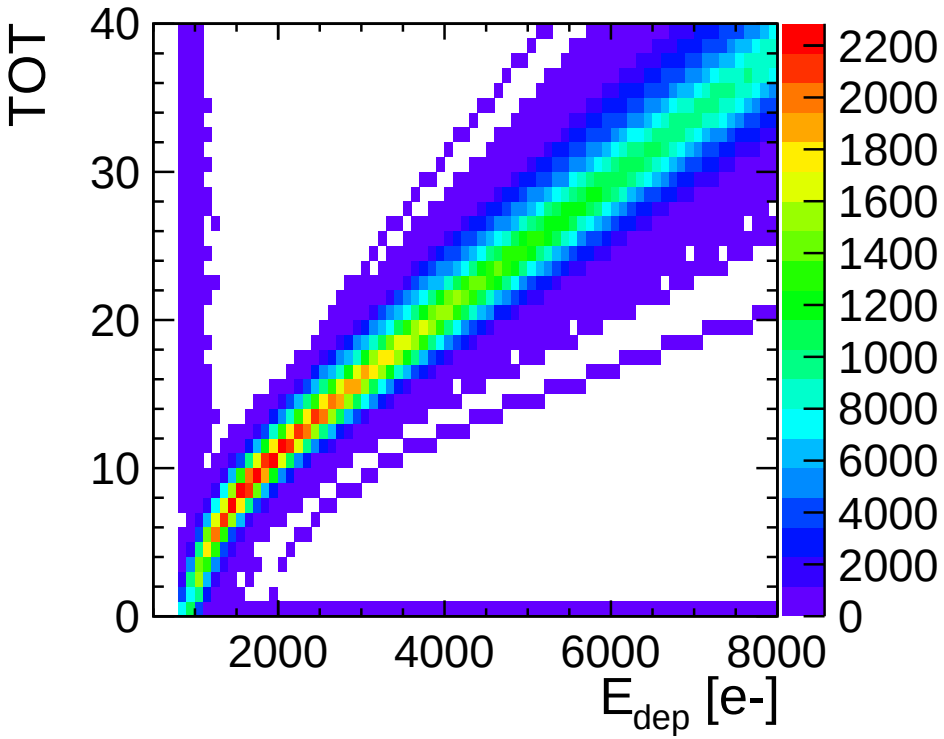


TOT calibration for W5_E2

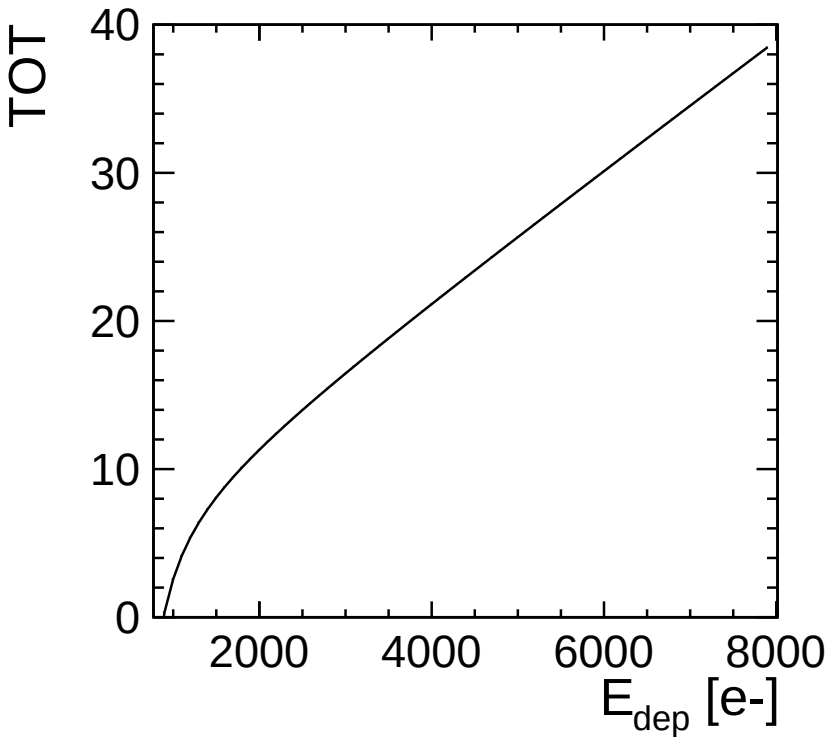
- The TOT/TOA calibration is done using test-pulses charges between 200e- and 14000e-.

$$\mathrm{TOT} = a\,E + b - \frac{c}{E - t}\ , \tag{2}$$

- Pixel-by-pixel calibration

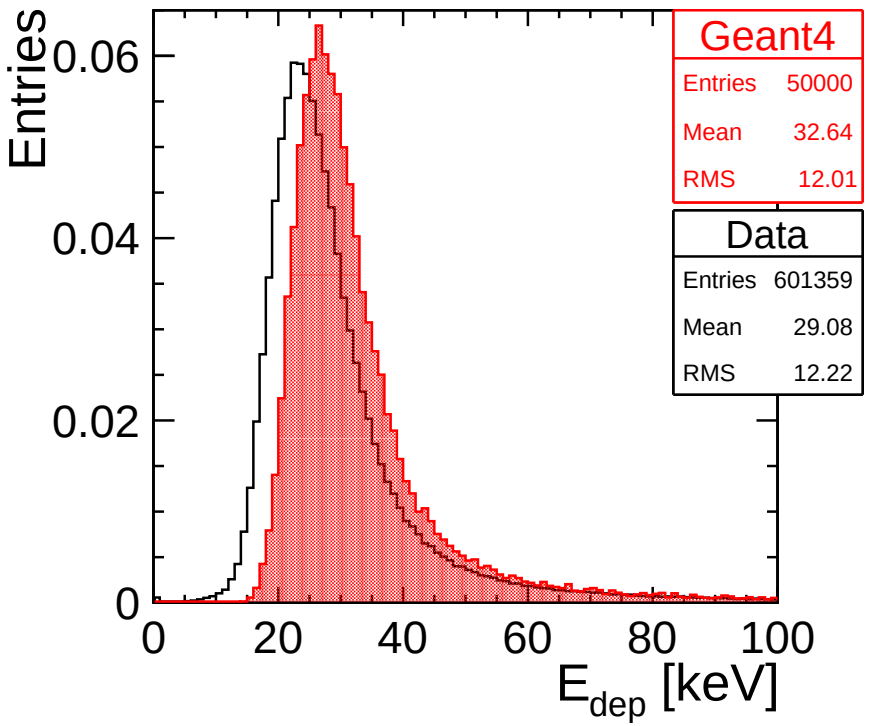


- Global calibration: average of the calibrations for each pixel.



E_{dep} distribution (preliminary)

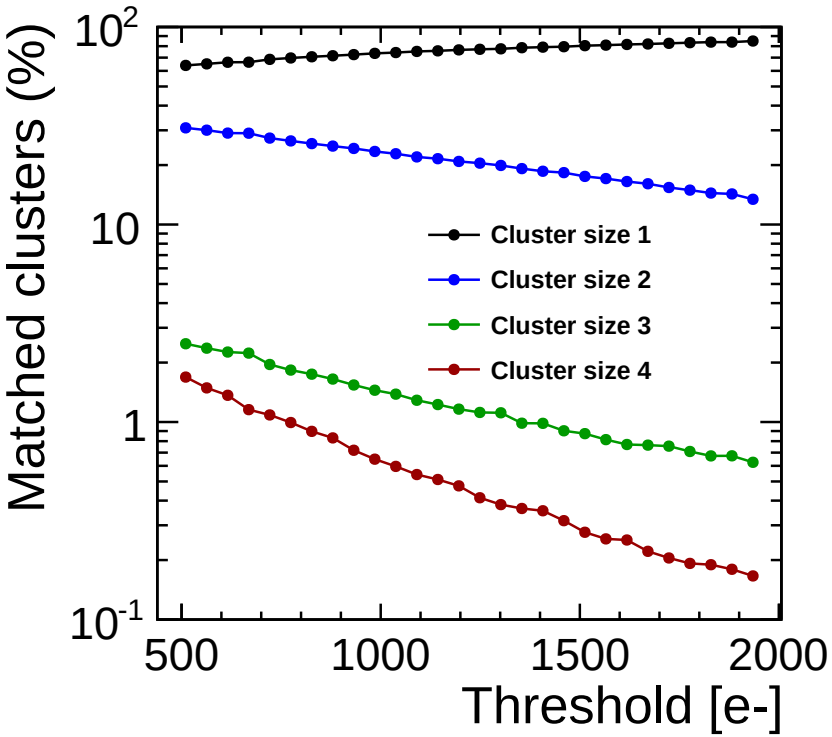
- Apply the pixel-by-pixel calibration to the run 13457 $\Rightarrow$ THL=1190.
- The calibration was done in the lab in the in the tracking mode with (VFBK-THL=50mV) which corresponds to THL=$\sim$1192-1194.
- The width of the distribution is in good agreement with GEANT4 but more work is needed to understand the shift of the peak.



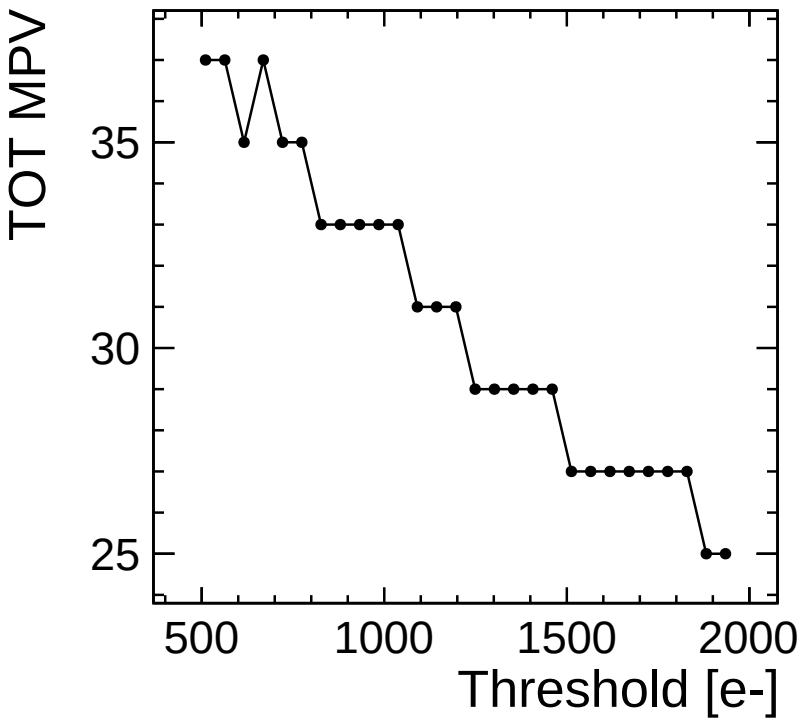
THL scan for W5_E2

- The threshold is scanned from THL=1160 (510 e-) to THL=1300 (2000 e-).

- Fraction of 1, 2, 3, 4-hit clusters.
- More charge sharing for lower threshold.

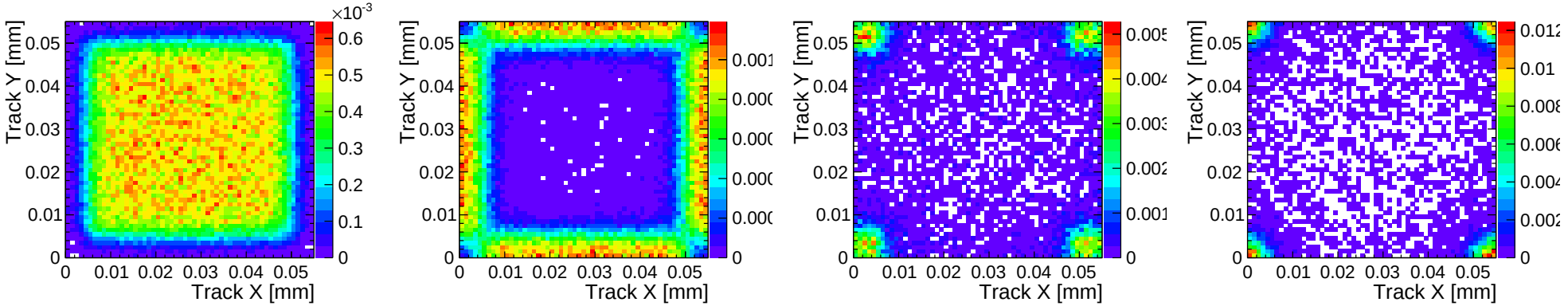


- The TOT MPV is obtained by taking the bin corresponding to the maximum of the histogram (no fitting).

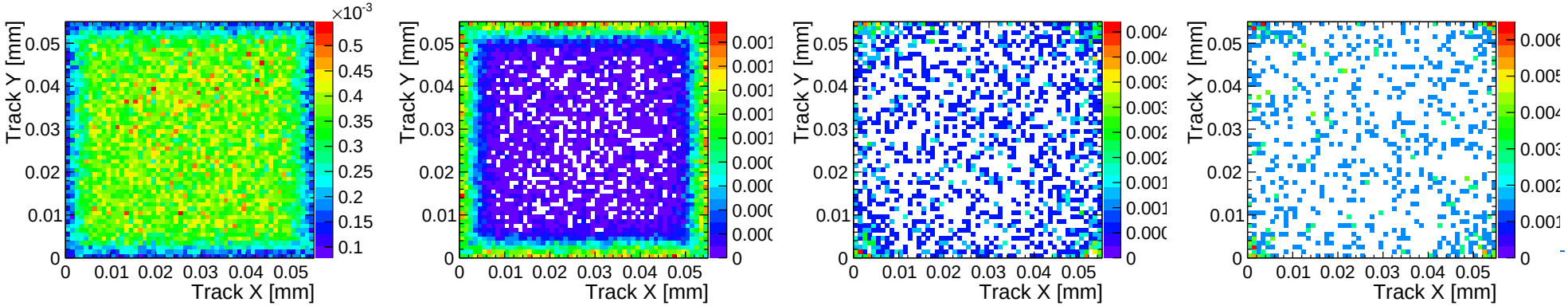


Charge sharing and THL

- Track position within pixels for 1, 2, 3 and 4-hit clusters.
- Run 13451, THL=1160 (510 e-)

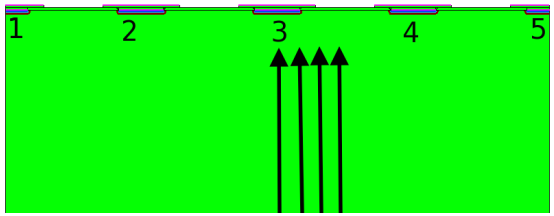


- Run 13479, THL=1300 (1987 e-)

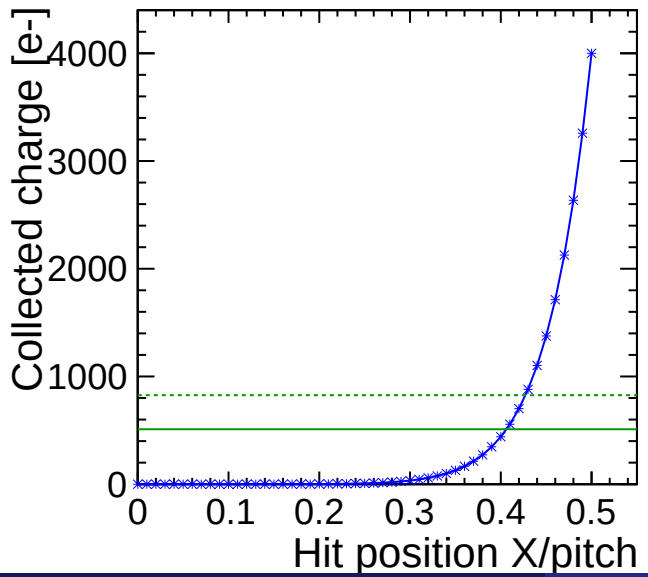


Validation of the simulation

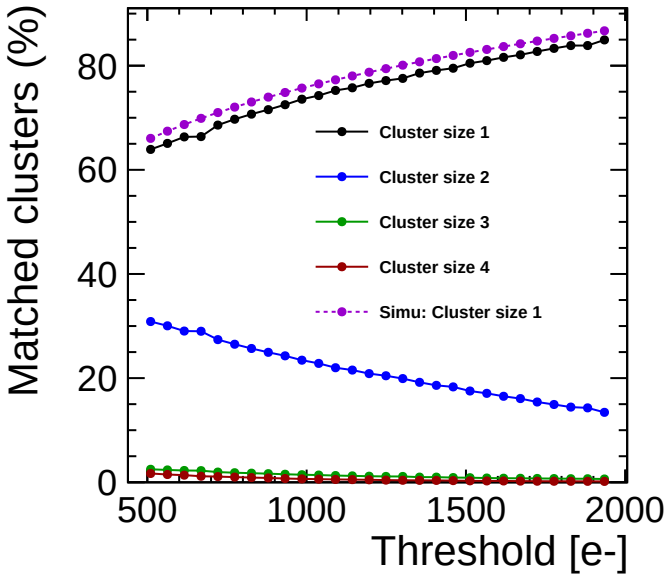
- For simulation: $V_{depletion} = -16\ V$ (given by the CV-curve) and $V_{bias} = -20\ V$.
- We assume a constant energy deposition of $80e-$ per μm.
- No noise is considered in the simulation.



- The charge deposited by diffusion in a neighbouring pixel vs. primary hit-position (Andreas and Magdalena's approach).

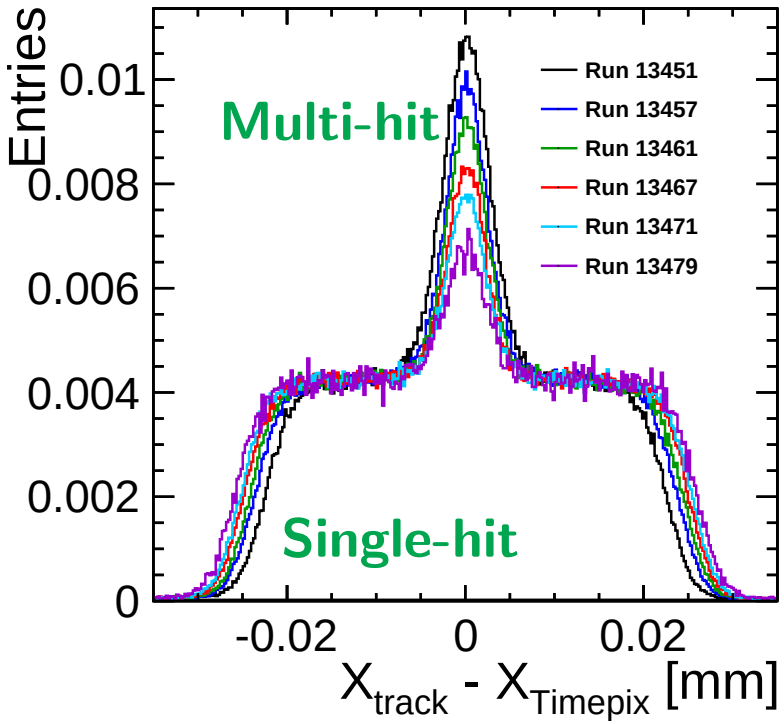


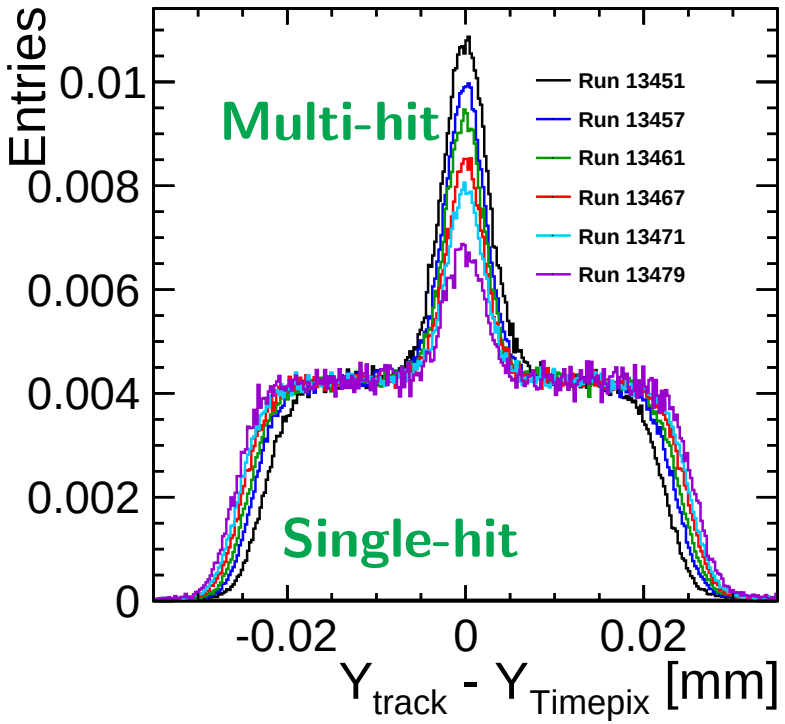
- Good agreement of the 1-hit cluster distribution ($\sim 2\%$ discrepancy).



Residuals

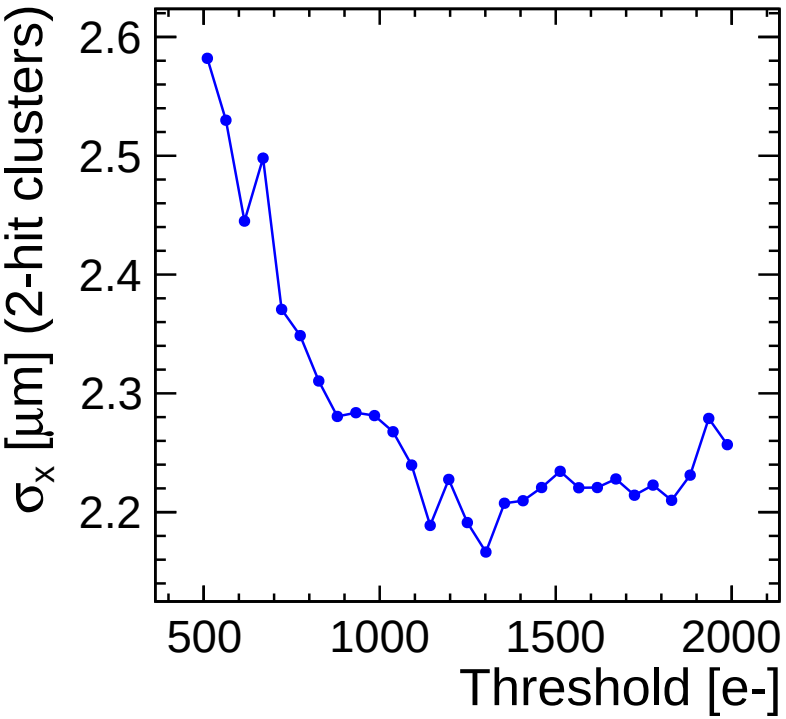
- Residuals (track position - hit position) in x and y-directions for different thresholds.
- The Eta-correction method is used to determine the hit position.

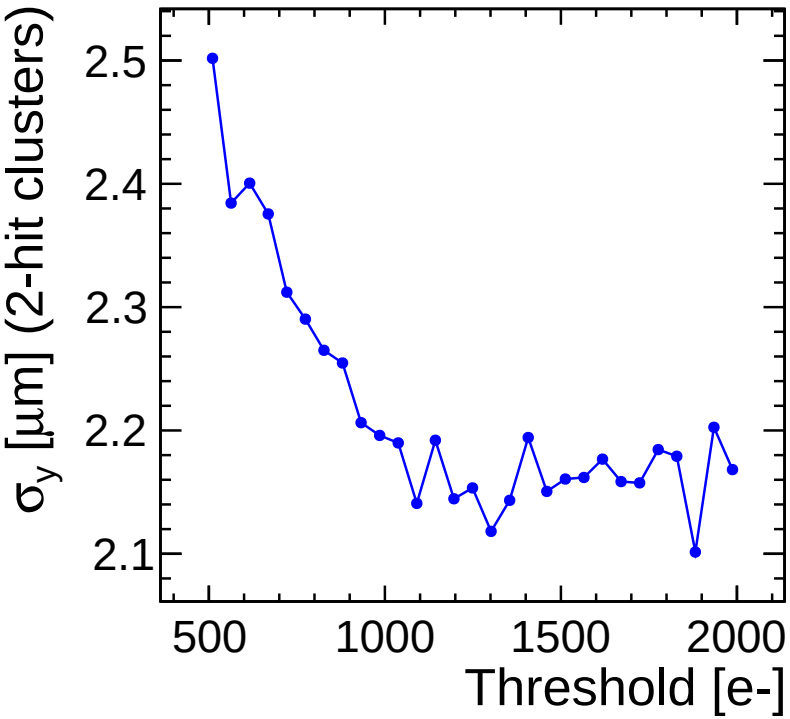




Resolutions for 2-hit clusters

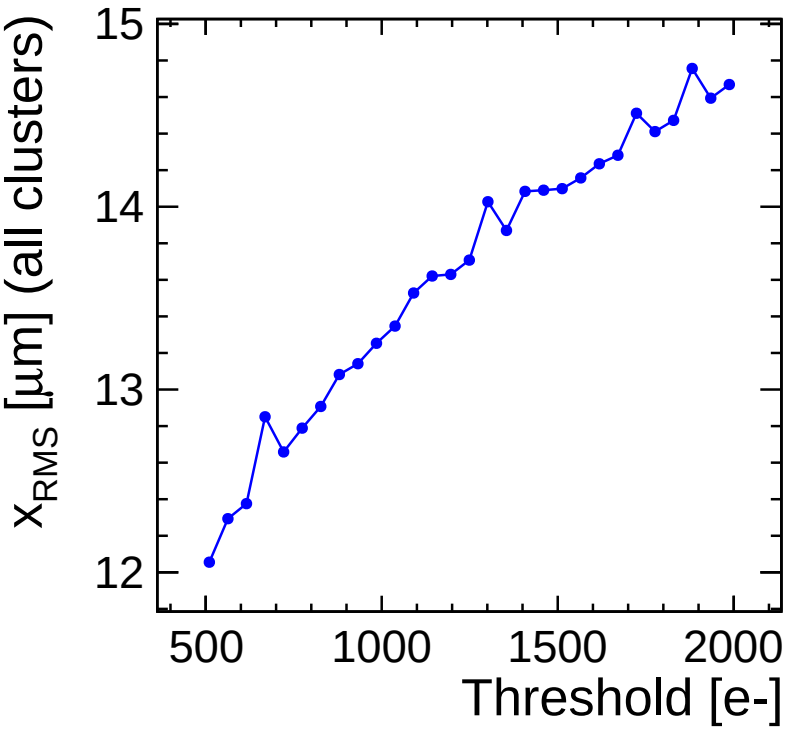
- Better resolution for 2-hit clusters at higher thresholds
  $\Rightarrow$ less charge sharing, more precise reconstruction of the hit-positions for 2-hit clusters.

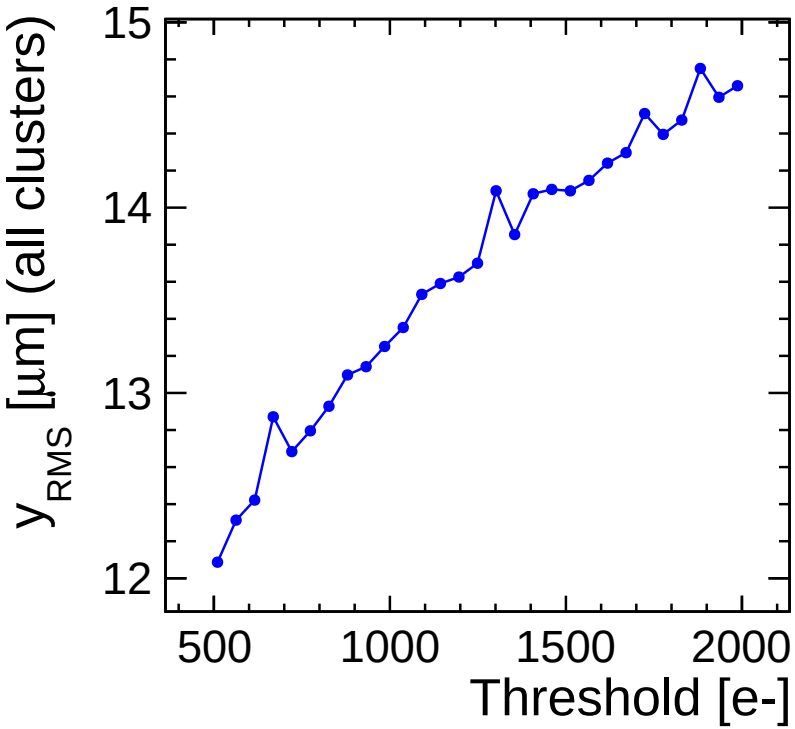




RMS of the residuals for all cluster sizes

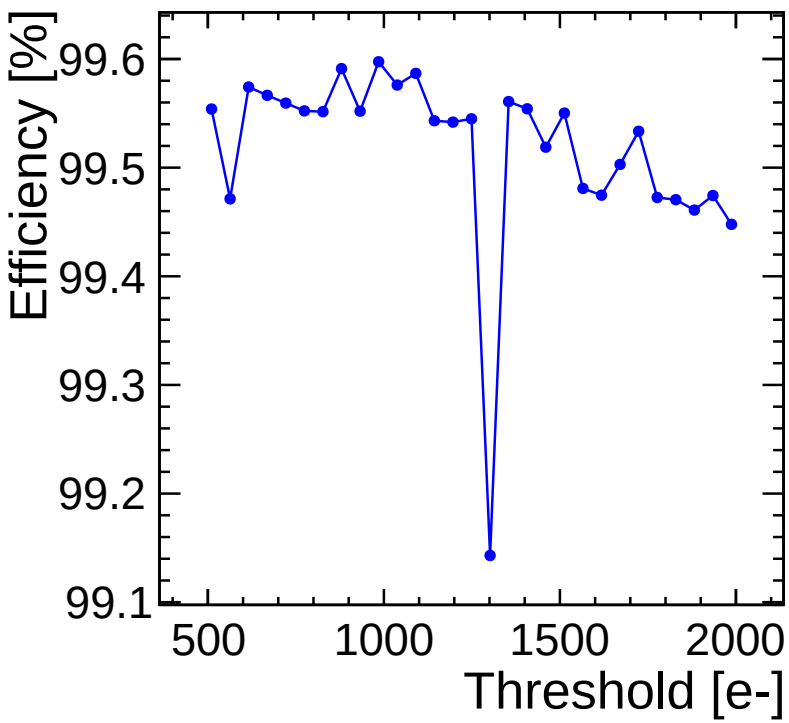
- For lower thresholds, the fraction of multi-hit clusters increases and the overall resolution gets better.





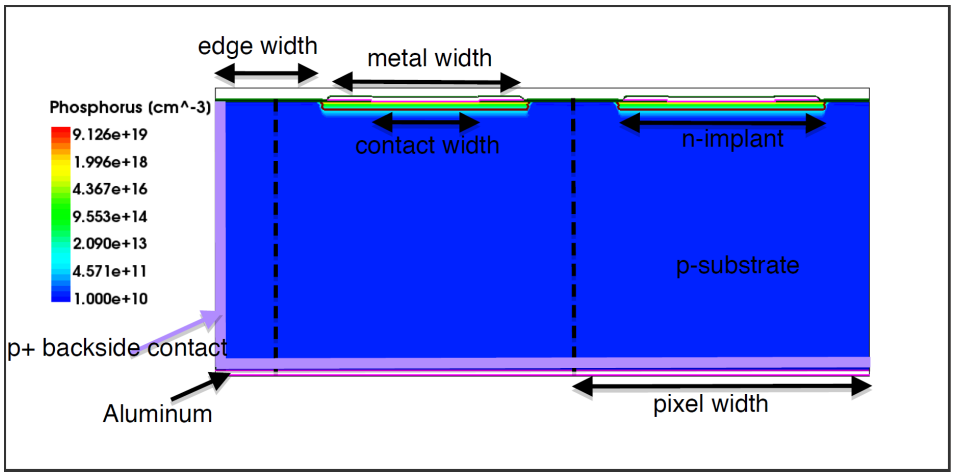
Efficiency for threshold scan (preliminary)

- For some runs (or part of them), the DUT data and telescope data seem to be un-synchronised (maybe due to some timing issues) $\Rightarrow$ more investigation is needed.
- For the efficiency calculations, considered only sub-runs of the data where efficiency was higher than 99%.
- The tendency of decreasing efficiency with increasing threshold can be seen.

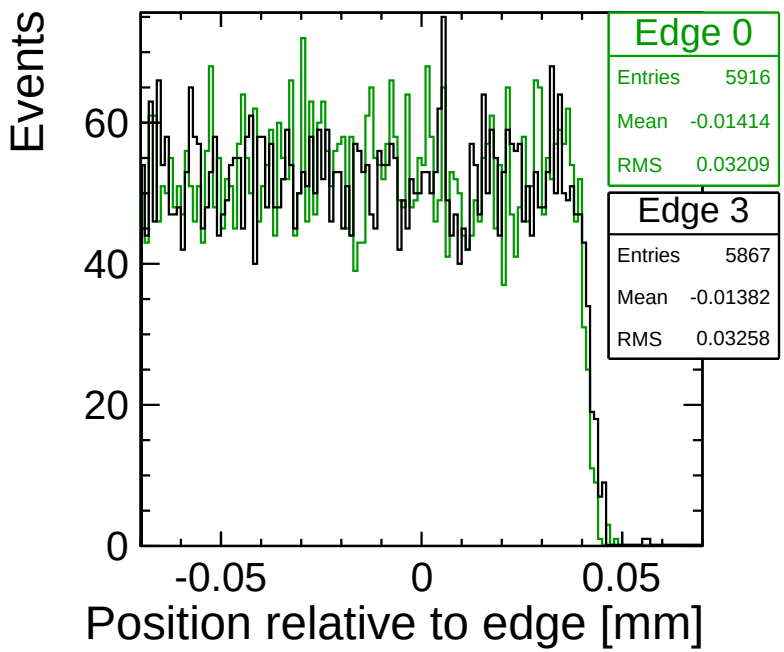


Sensor edge

- W5_E2 has an edge of 50 µm.
- The edge width is the distance between the doping concentration of the last pixel and the edge of the sensor.
- The distance between the last pixel and the edge of the sensor is expected to be 42 µm.



- Run 13451

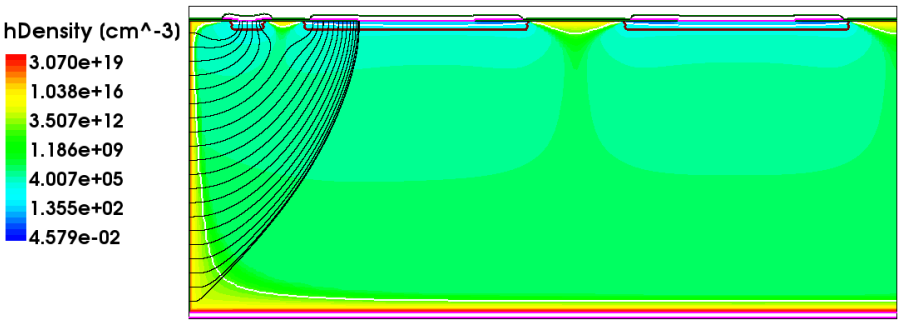


- Tracks are detected at the physical edge of the sensors.
- More investigation needed on the efficiencies.

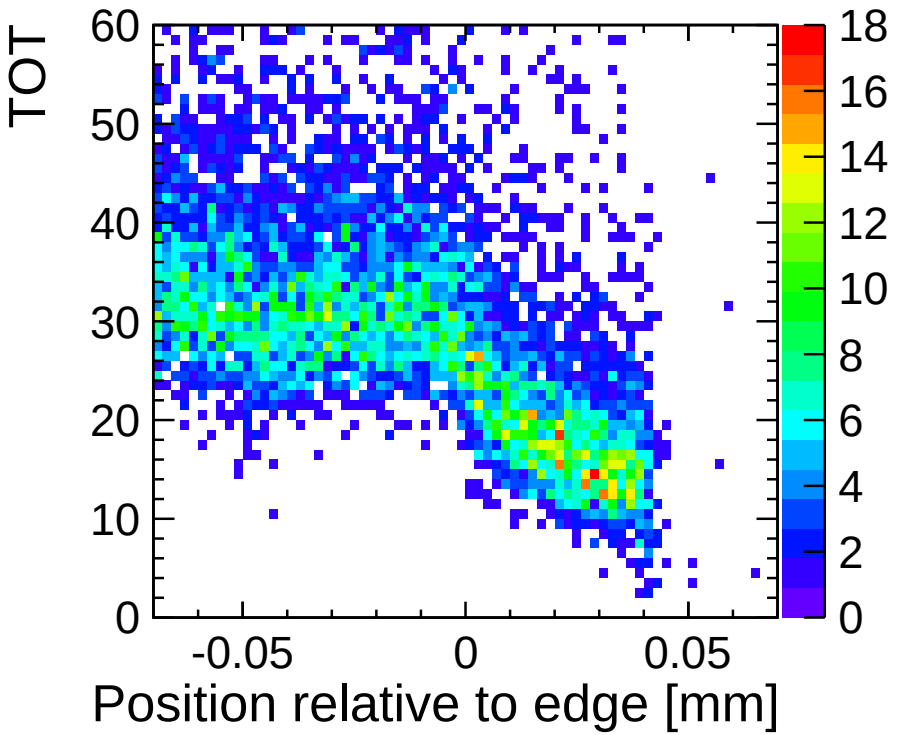
TOT distribution at the edge

- TOT distribution at the edge 0 for run 13457

- The drop in the signal is expected at the edge since a part of the signal is lost in the guard-ring.

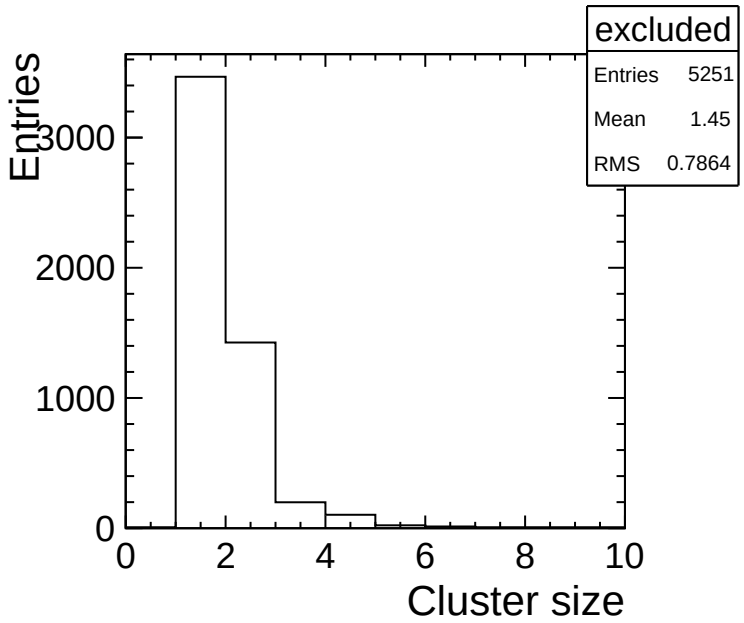


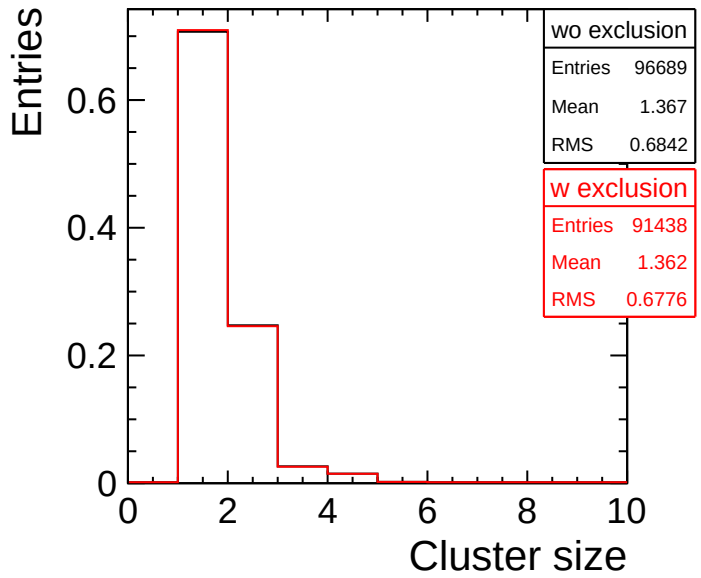
- The signal loss at the edge is expected to be smaller for a floating guard-ring.



Timepix1: exclusion of hot/dead/masked pixels

- Study the impact of excluding clusters containing or neighbouring a hot/dead/masked pixel on the cluster-size distribution.
- Run 1189 (L04-W0125, 100 µm sensor).
- 29 masked/dead pixels
- 207 hot pixels





- Their impact is very small on the cluster-size distribution for a non-rotated assembly.
- See backup for other assemblies.

Conclusions

- A successful test-beam thanks to many people :)
- It is possible to operate Timepix3 at very low threshold (∼500 e-) and benefit for more charge sharing and higher resolutions.
- The active-edge sensor is efficient to the very edge and behaves as expected.
- Simulations are in agreement with data.

Future work

- Consider TOA in the analysis.
- Comparison between Timepix1 and Timepix3 data.
- GEANT4 simulation of the test-beam set-up.
- Integration of the Advacam active-edge assemblies into the Timepix3 telescope.

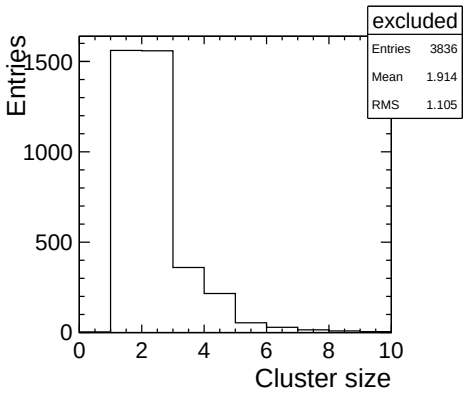
Plans for the test-beams in SPS, October 2015

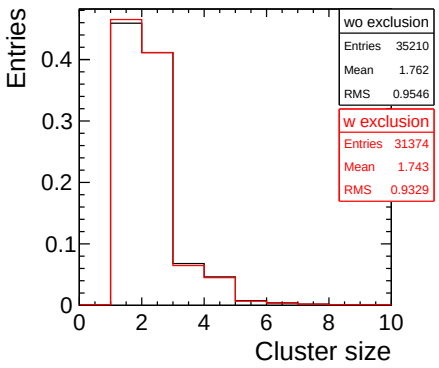
Assembly	Thickness	$V_{depletion}$ (specs.)	V_{bias}	THL: 6σ >noise center
W5_E2 (E1)	100 µm	-16 V	-20 V	1156
W5_J2 (E2)	100 µm	-16 V	-20 V	1126
W5_F1 (E3)	150 µm	-25 V	-30 V	1148

- Bias scan (-50 V to 0 V)
- Threshold scan:
  - W5_E2: THL=[1160 (∼510 e-), 1560 (∼4600 e-)] (or higher)
  - W5_J2: THL=[1130, 1530 (4600e-)]
  - W5_F1: THL=[1150, 1650 (5600e-)]
- Power pulsing

Backup: Timepix1, exclusion of hot/dead/masked pixels

- Run 2312 (B06-W0125, 200 µm)
- 198 masked/dead pixels
- 8 hot pixels





- Run 127 (A06-W0110, 50 µm)
- 0 masked/dead pixels
- 5 hot pixels