Laboratory and beam-test performance study of 55 μm pitch iLGAD sensors bonded to Timepix3 readout chips

Peter Švihra[1]
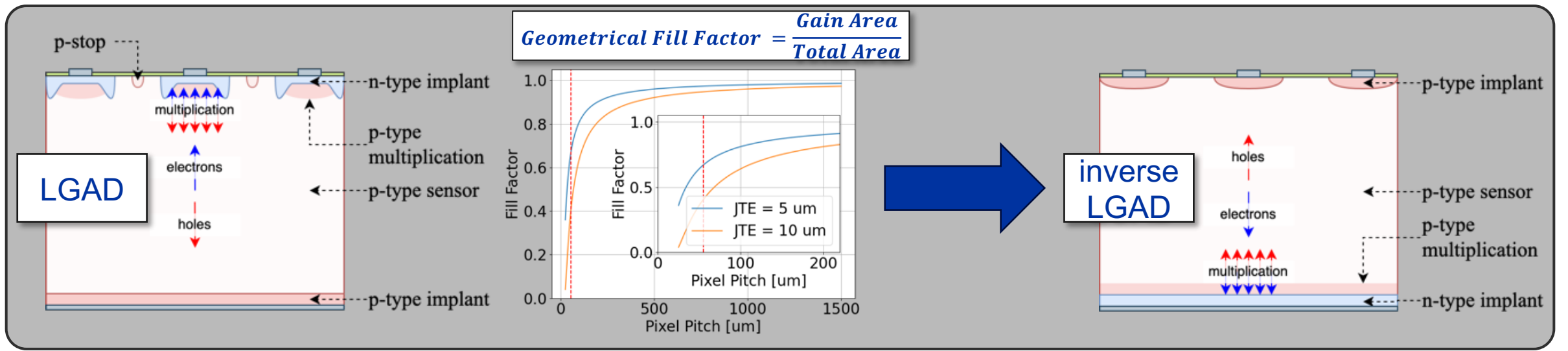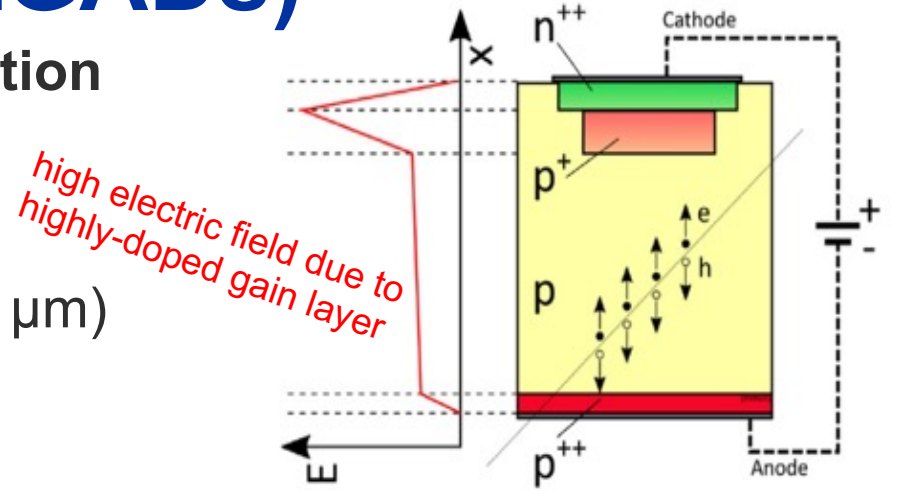
D. Maneuski[2], D. Dannheim[1], E. Buschmann[1,3], J. Braach[1], R. Bates[2], Y. Otarid[1]

1: CERN, CH
2: University of Glasgow, UK
3: BNL, USA

Low Gain Avalanche Detectors (LGADs)

Semiconductor detectors with intrinsic charge multiplication

- Improved Signal-to-Noise Ratio

- Excellent timing capabilities (< 30 ps) for thin LGADs (~ 50 μm)

- Low energy X-rays detection (< 5 keV)

- Challenging performance uniformity with small pixels

high electric field due to highly-doped gain layer

$$\text{Geometrical Fill Factor} = \frac{\text{Gain Area}}{\text{Total Area}}$$

LGAD → inverse LGAD

Sensor bonded to Timepix3 ASIC

- **Production of iLGAD sensors**
  - Produced at Micron Semiconductor
  - Double sided -> backside sensitive to scratches
  - **Needs to be fully depleted**
  - **Designed multiplication factor ~5**
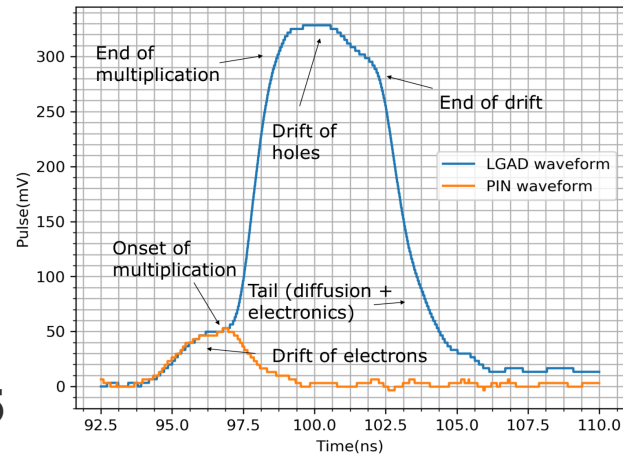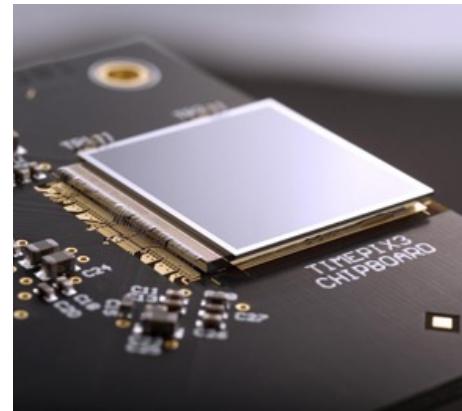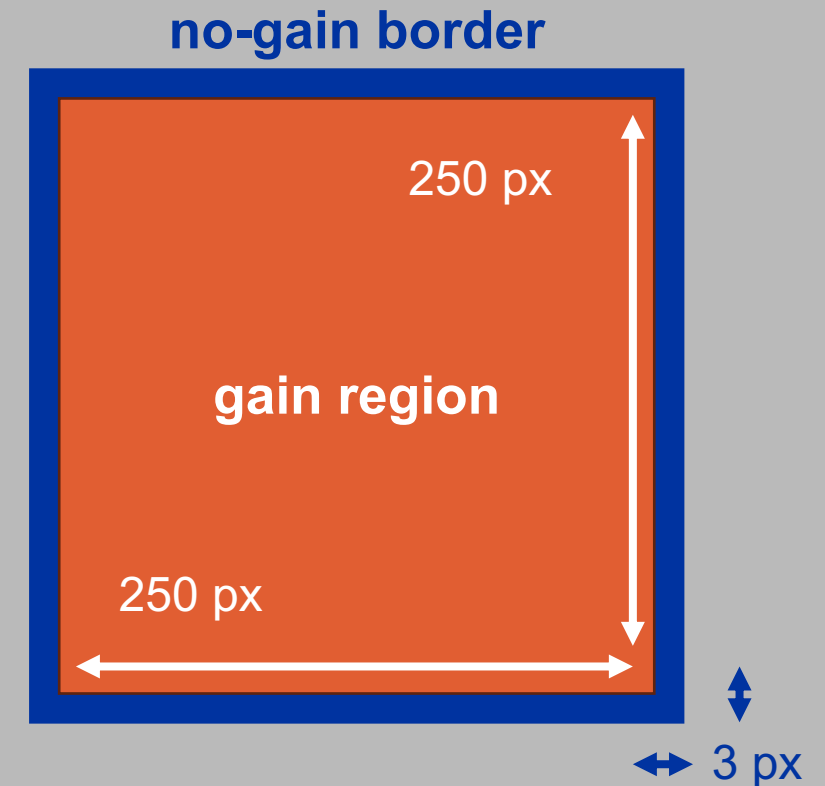 - Produced as **300 μm thick**

- **Timepix3 readout chip**
  - Developed by the Medipix collaboration
  - **256x256 pixels**
  - **55 μm pitch**
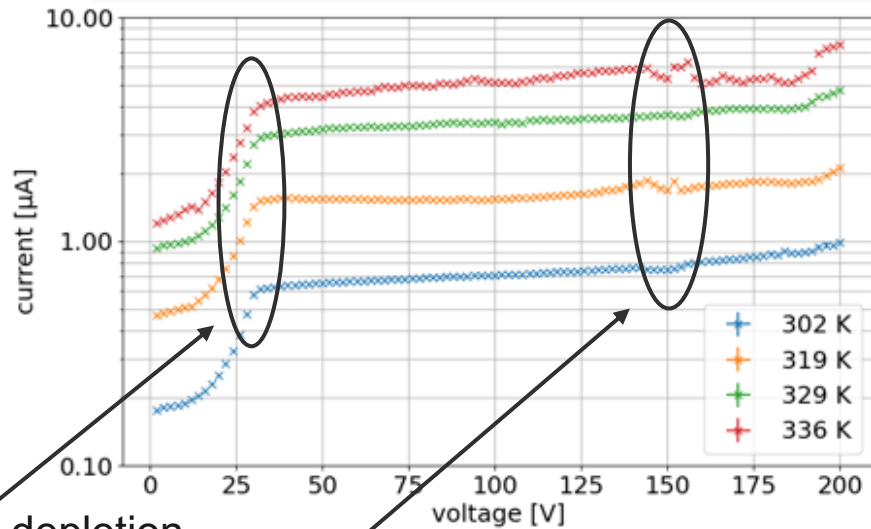 - **1.5625 ns time binning**
  - Device ID W0068_I11

Figure courtesy N. Moffat, (2020), PhD thesis

Sensor layout

no-gain border

250 px

gain region

250 px

3 px

Laboratory tests – preparation

- **Per-pixel electronic calibration**

  - Automatic equalisation based on noise

  - Done only for operational threshold 1000 DAC
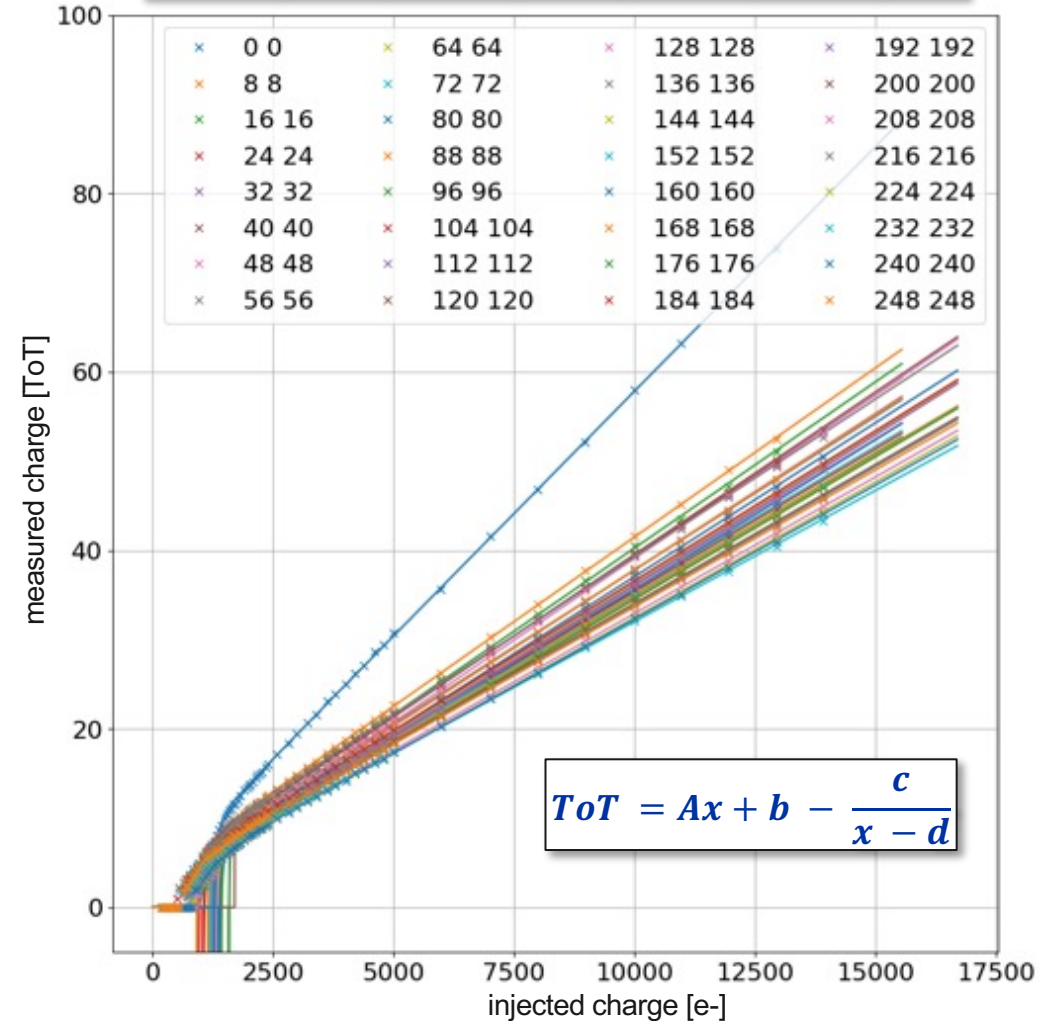
- **Operating point establishment**

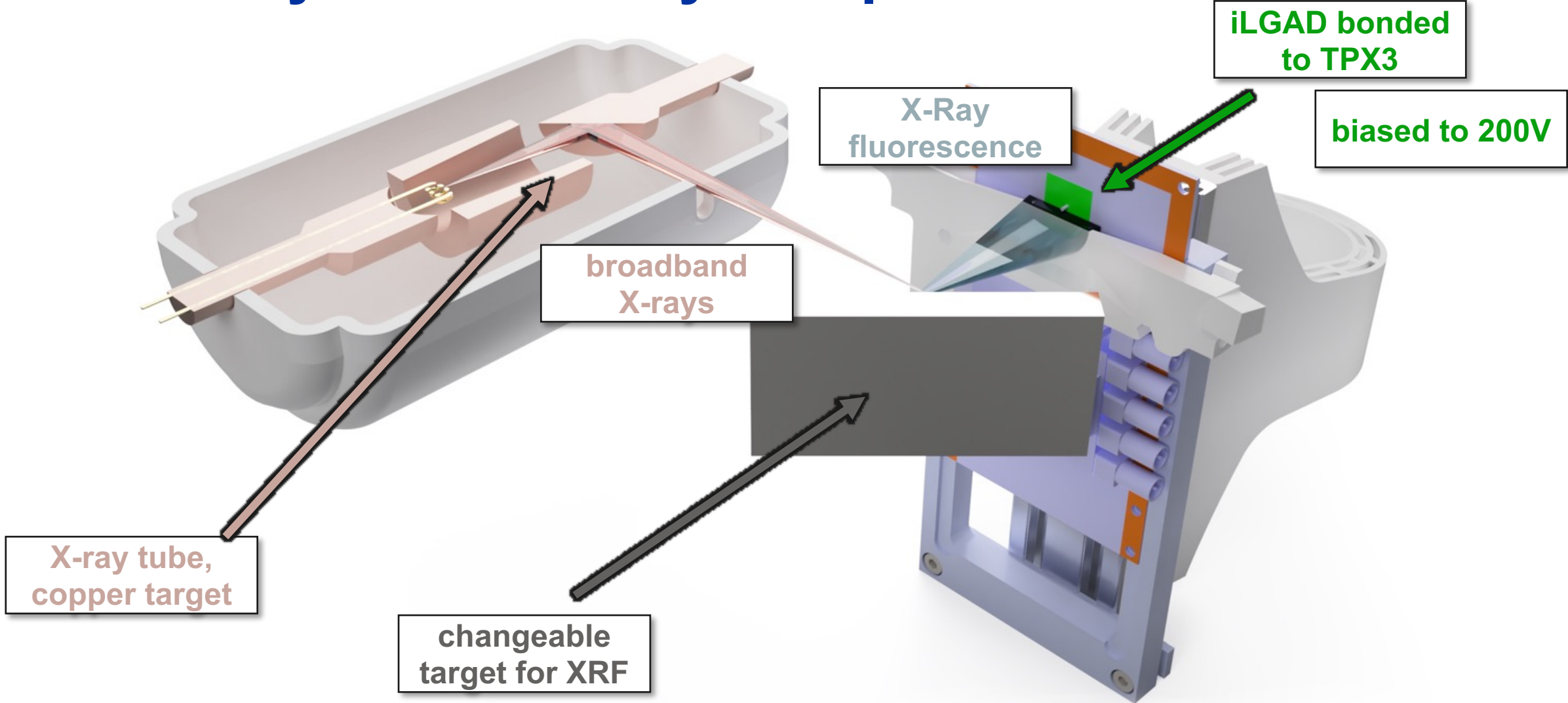IV curves at different temperatures
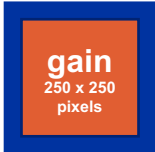
Gain layer depletion

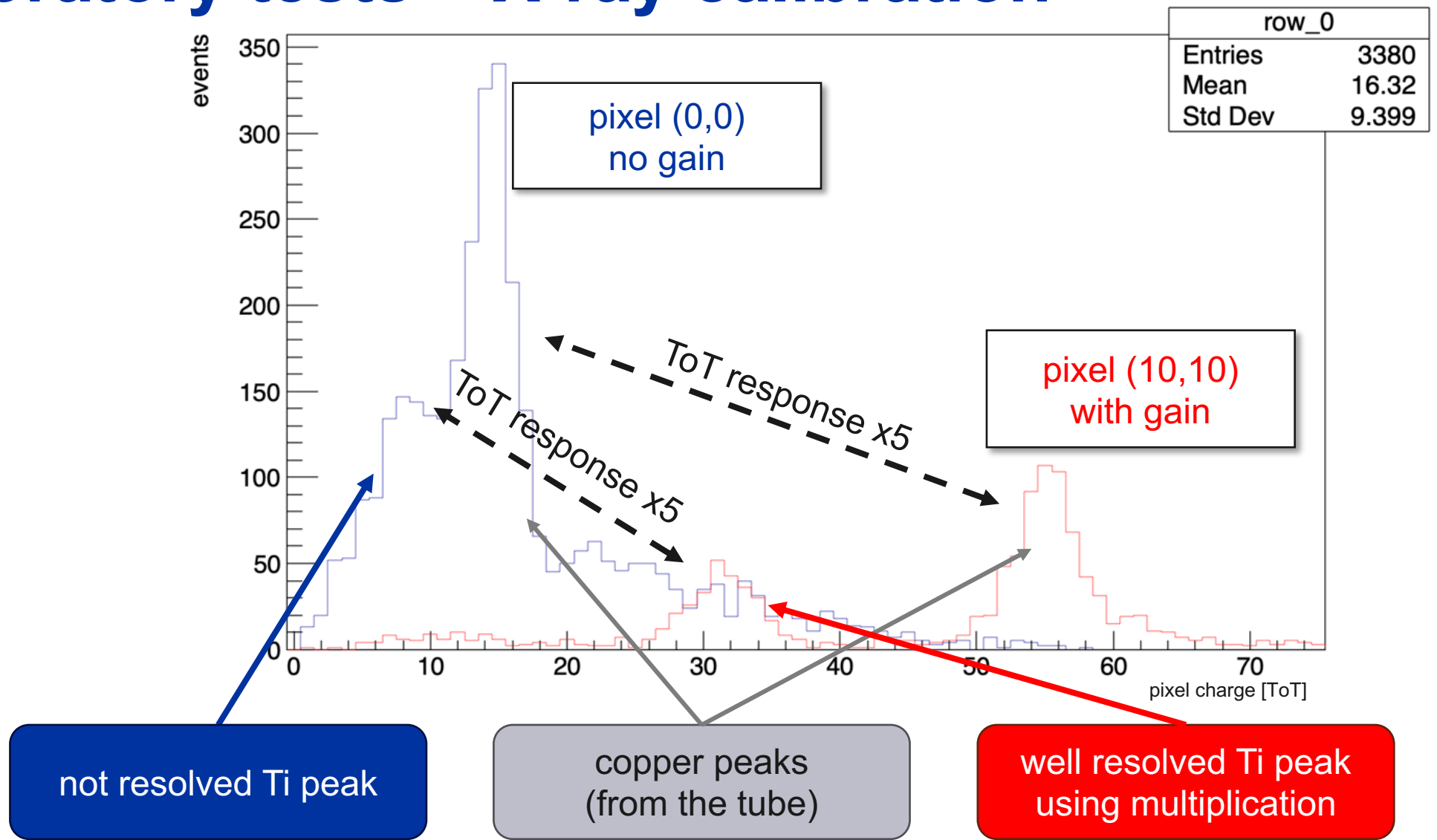Full sensor depletion

per-pixel energy calibration

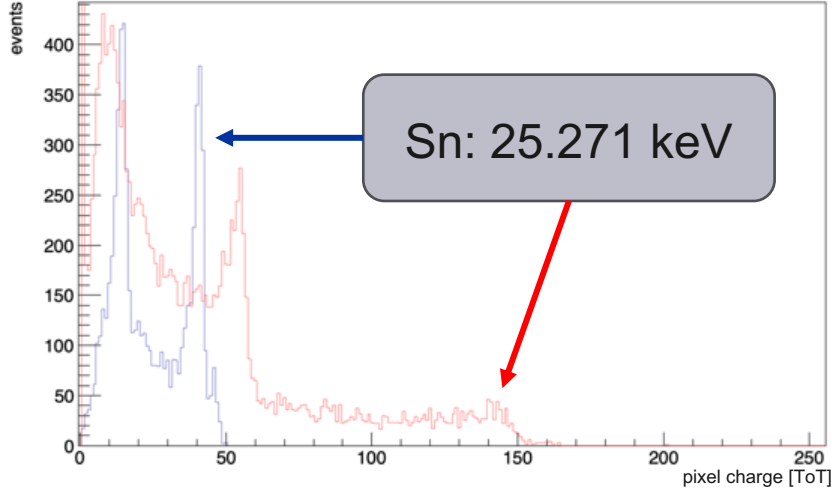$$ToT = Ax + b - \frac{c}{x - d}$$

Laboratory tests – X-ray setup

iLGAD bonded to TPX3

biased to 200V

X-Ray fluorescence
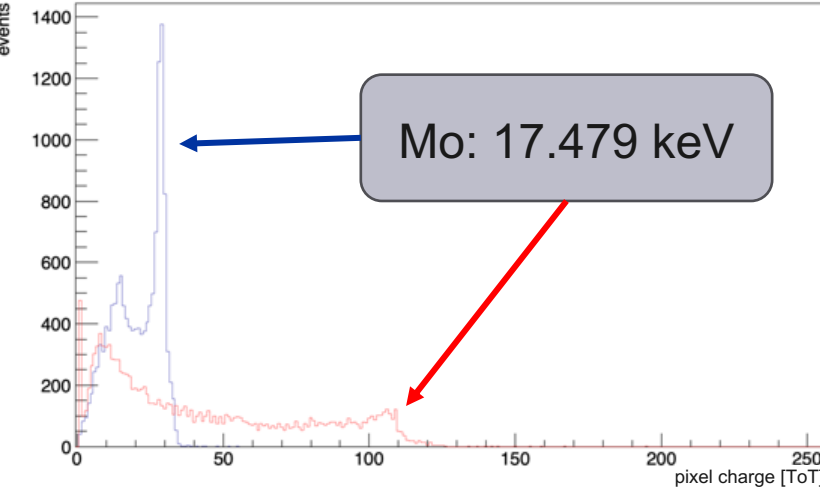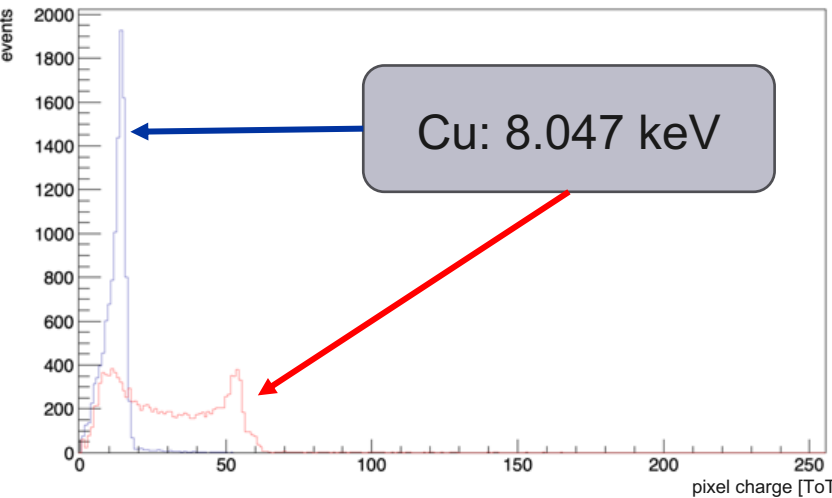
broadband X-rays

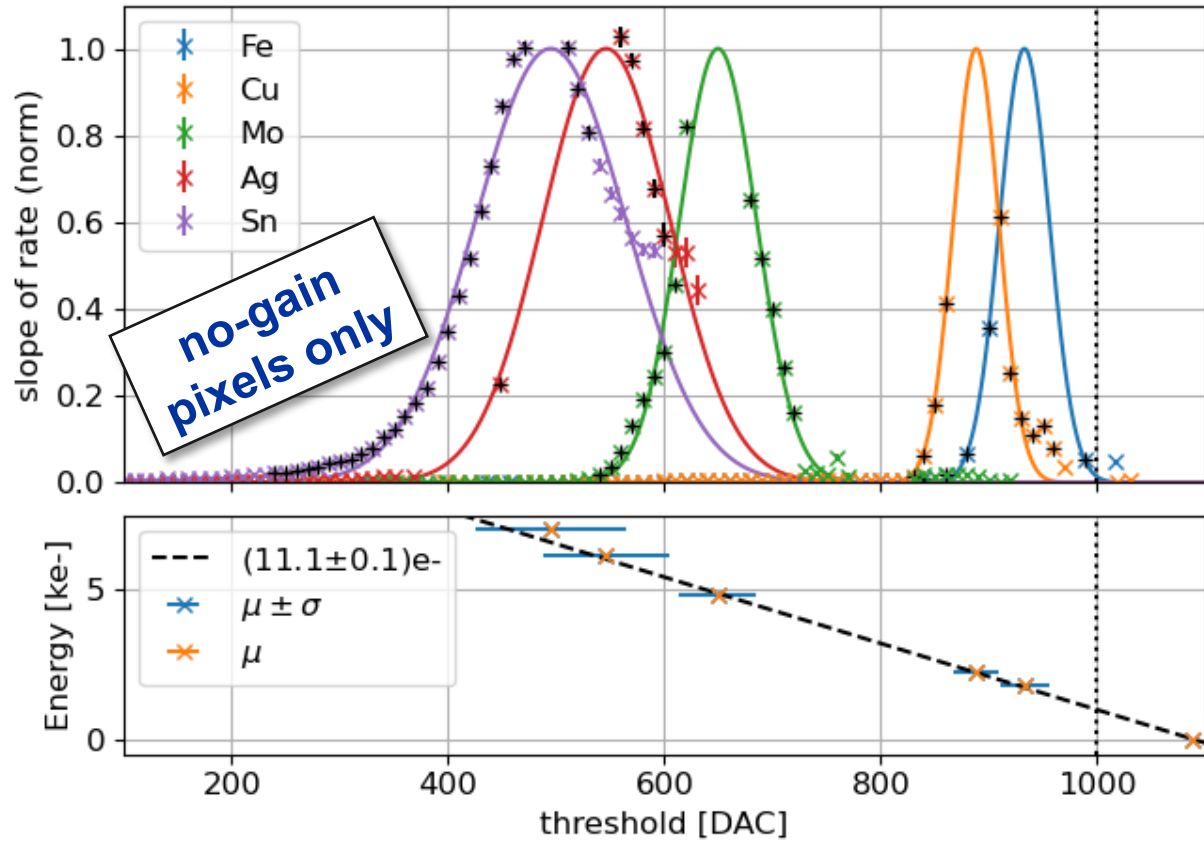X-ray tube, copper target

changeable target for XRF

Laboratory tests – X-ray calibration

no-gain border

gain
250 x 250
pixels

row_0	
Entries	3380
Mean	16.32
Std Dev	9.399

pixel (0,0)
no gain

pixel (10,10)
with gain

ToT response x5

ToT response x5

events

pixel charge [ToT]

not resolved Ti peak

copper peaks
(from the tube)

well resolved Ti peak
using multiplication

Laboratory tests – X-ray calibration per pixel

Ti: 4.510 keV

Fe: 6.403 keV

Cu: 8.047 keV

Mo: 17.479 keV

Ag: 22.162 keV

Sn: 25.271 keV
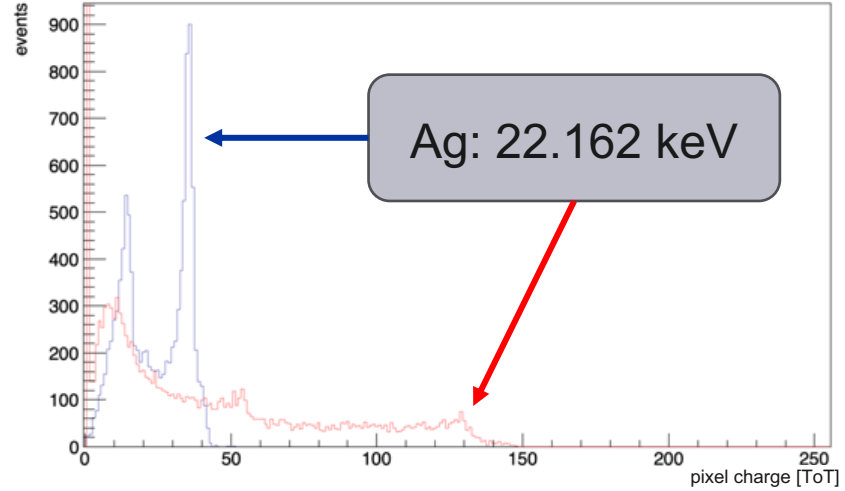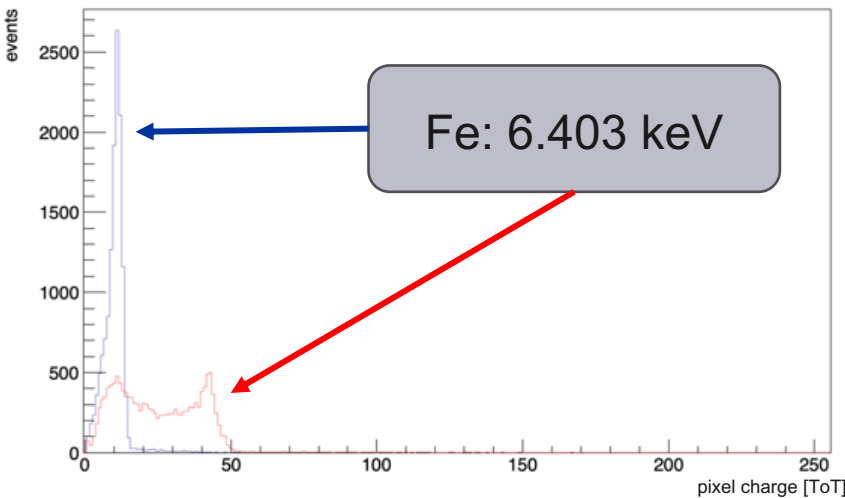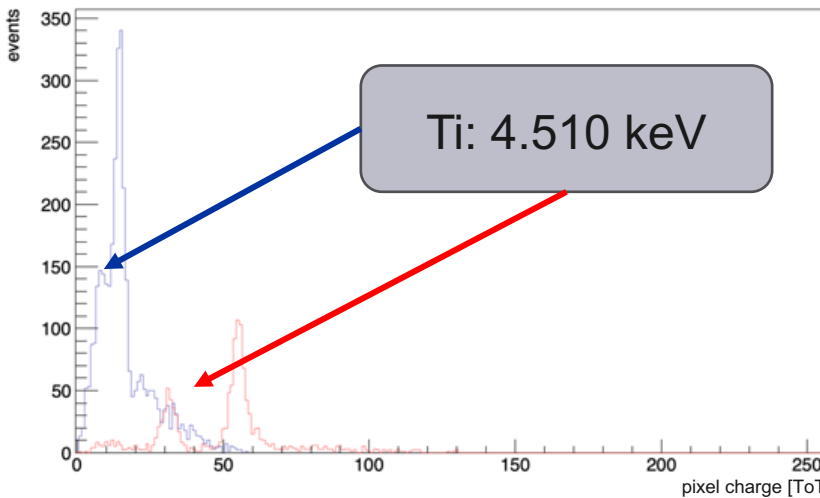
Laboratory tests – calibration results

W0068_I11 baseline = 1088 DAC, 1000 DAC = 983.1 e-

no-gain pixels only

1 DAC = 11.1 e-

Laboratory tests – calibration results

gain
250 x 250
pixels

W0068_I11 baseline = 1088 DAC, 1000 DAC = 983.1 e-

no-gain pixels only
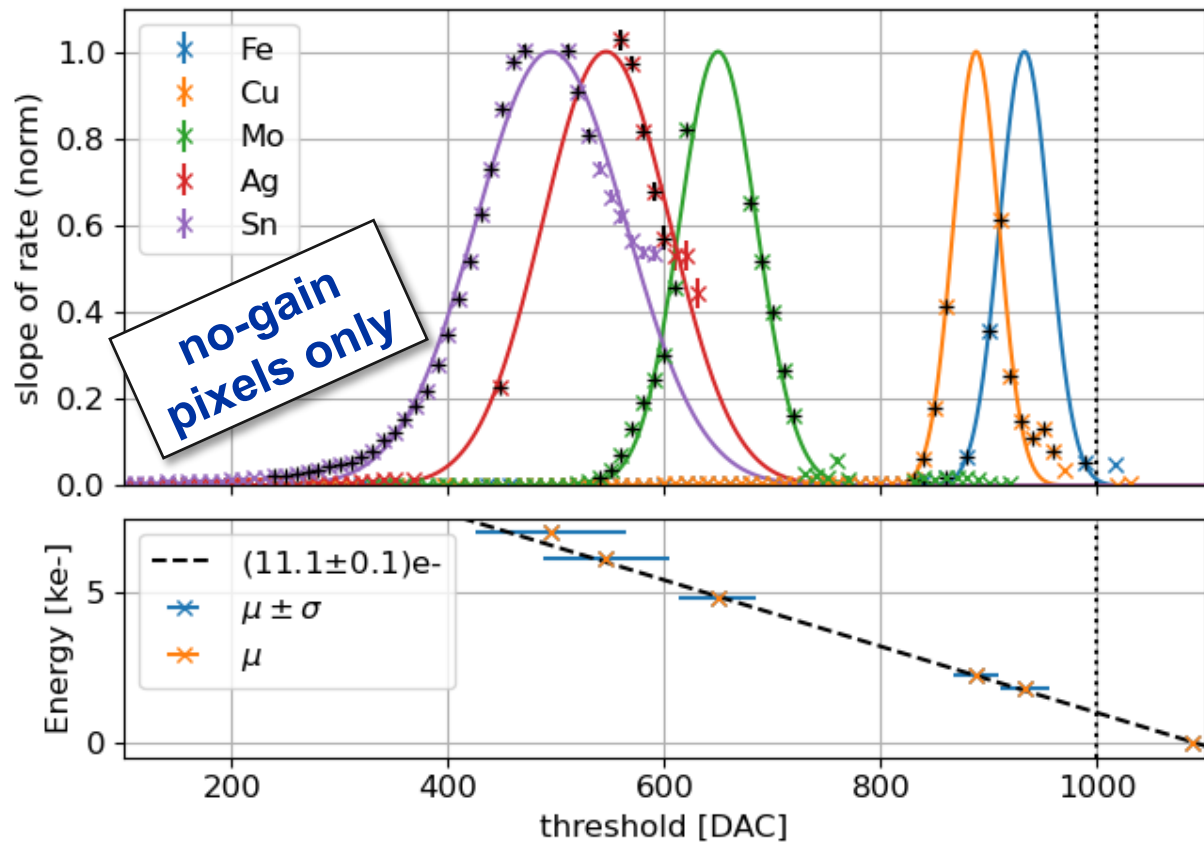
W0068_I11 threshold = 983.1 e-

all pixels
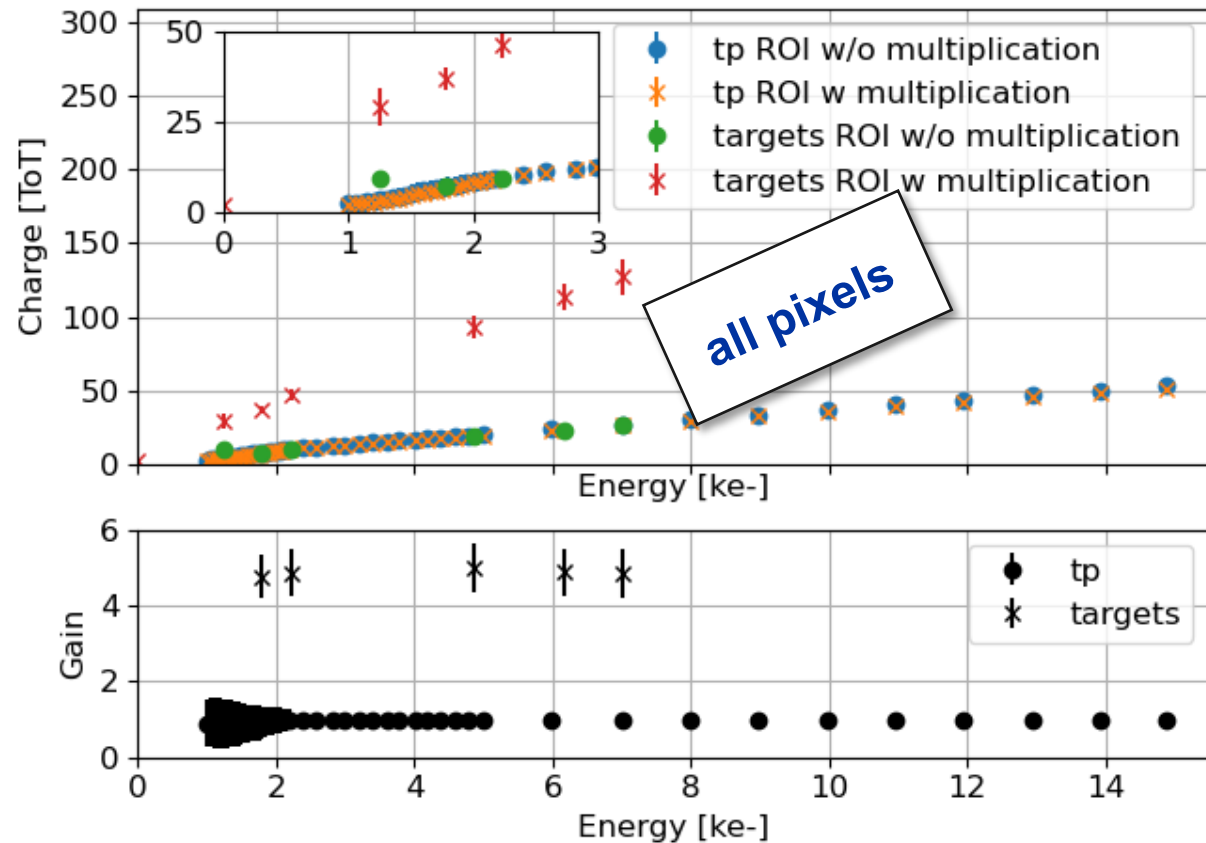
1 DAC = 11.1 e-

gain = 4.86 +/- 0.08

SPS beam test – CLICdp Timepix3 telescope setup
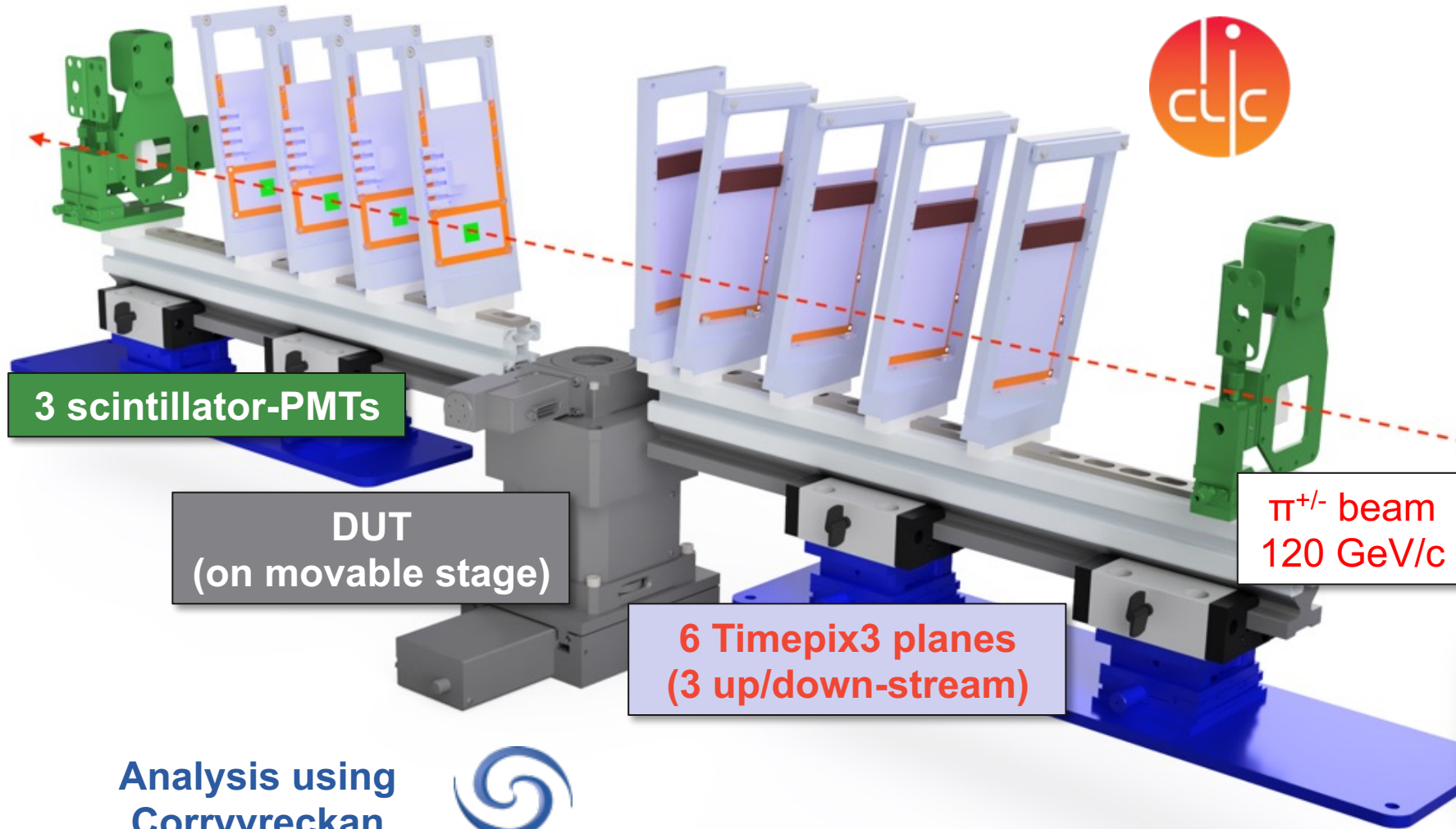
End of SPS H6-beamline (CERN North Area)

- **~1.5 µm** spatial resolution

- **~ 200 ps** time resolution for tracks on DUT

- MCP-PMT timing <**~10 ps**

- Rates up to **~80M hits/s** (in H6: **~1M hits/s**)

3 scintillator-PMTs

DUT
(on movable stage)

π$^{+/-}$ beam
120 GeV/c

6 Timepix3 planes
(3 up/down-stream)

Analysis using Corryvreckan framework

Corryvreckan
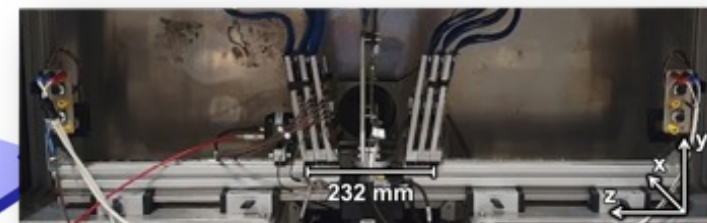
SPS beam test – resolutions (300 V, threshold 983 e-)

columns
mean   = - 0.86 µm
RMS$_{95\%}$ =   8.45 µm

rows
mean   = 0.36 µm
RMS$_{95\%}$ = 9.32 µm

χ^2 / ndf	5480 / 3
Constant	1.832e+06 $\pm$ 1.184e+03
Mean	13.44 $\pm$ 0.00
Sigma	1.26 $\pm$ 0.00
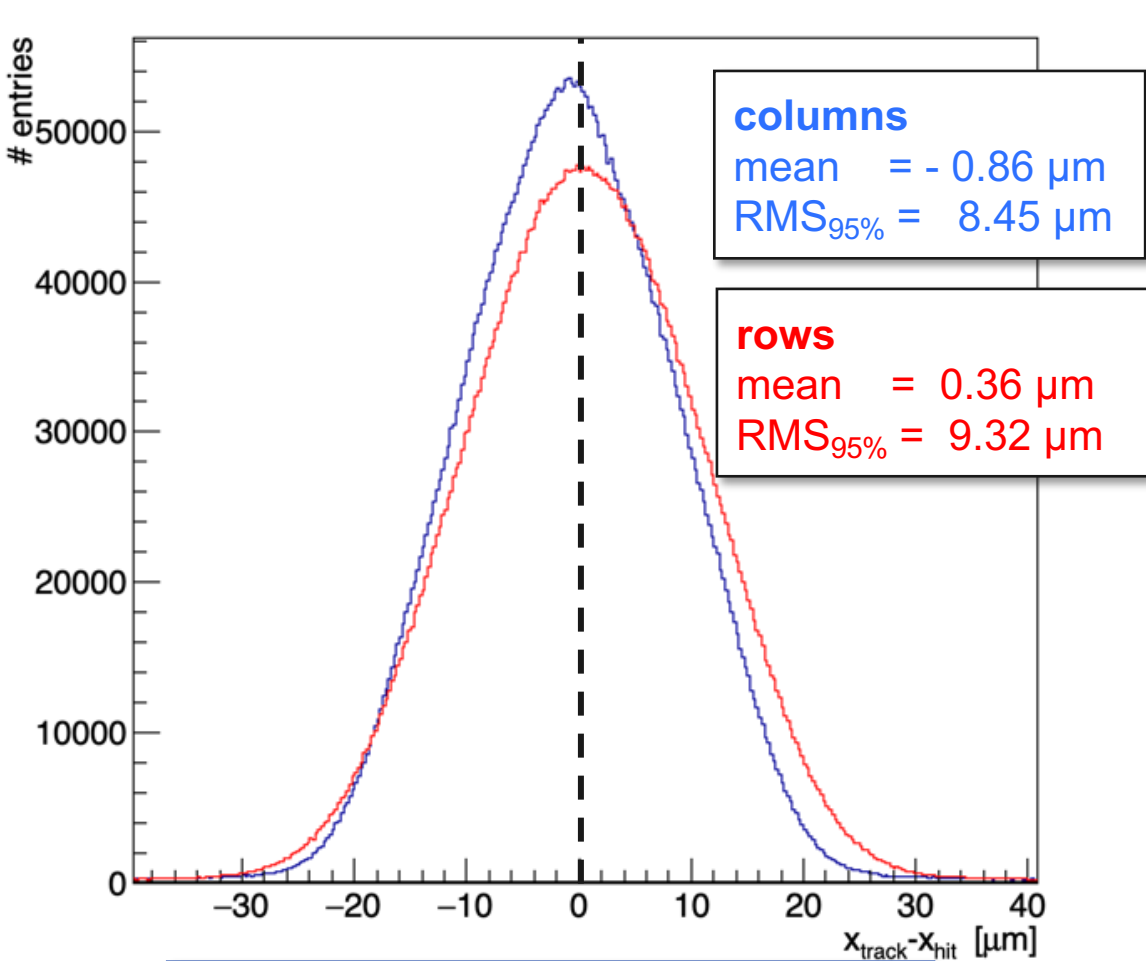
resolution ~9 µm
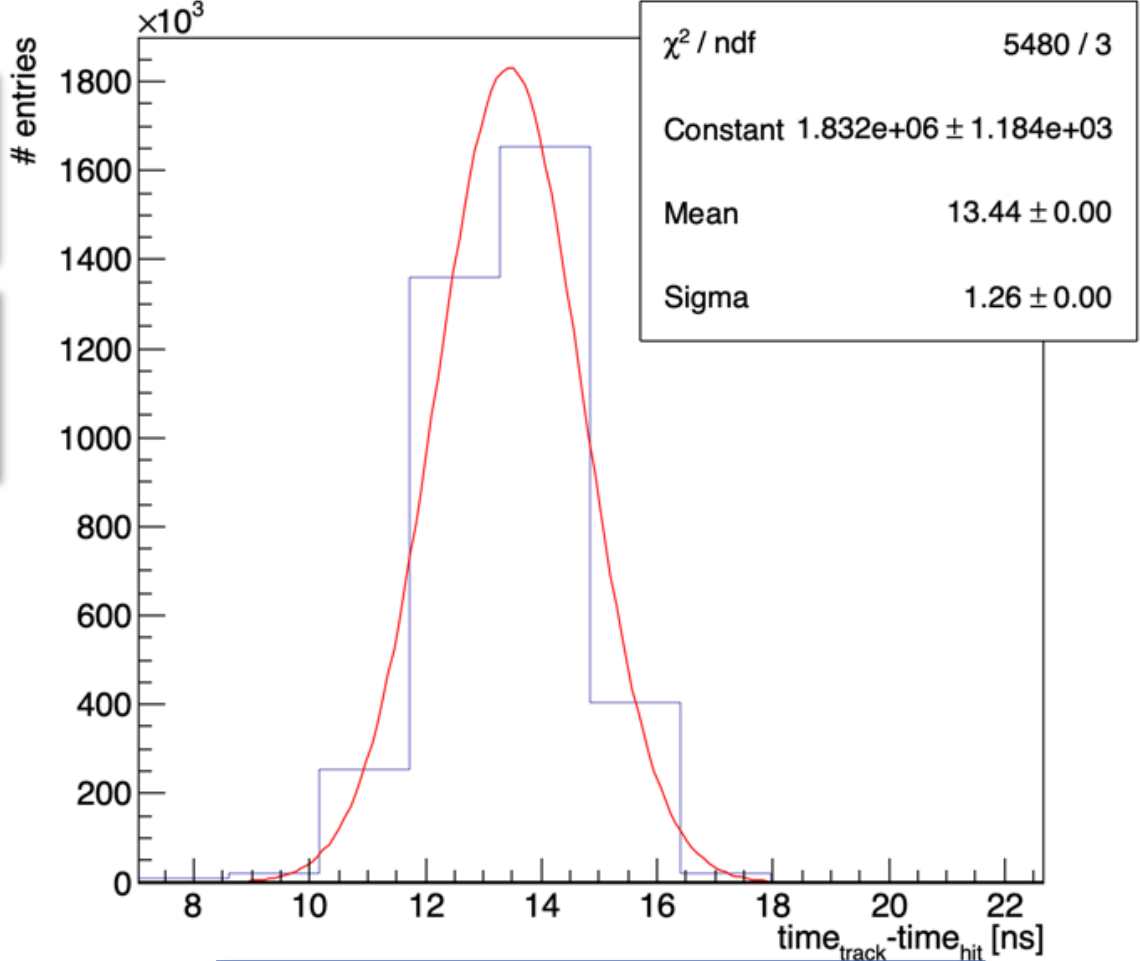
σ_t = 1.26 ns
without any timewalk correction!!

SPS beam test – voltage-threshold scans

- **Scanning voltage-threshold**

  - V = {140 V, 160 V, 180 V, 200 V, 300 V}
    full depletion at 150V

  - threshold = from 900 e- to 12 000 e-

- **Multiple runs to cover the DUT
  with telescope acceptance**
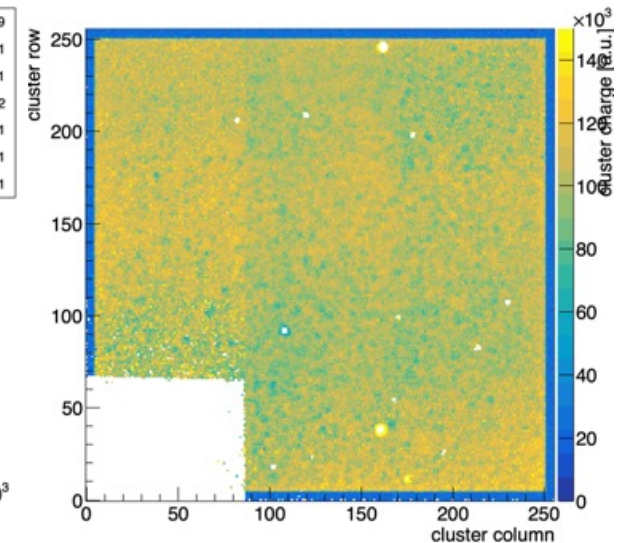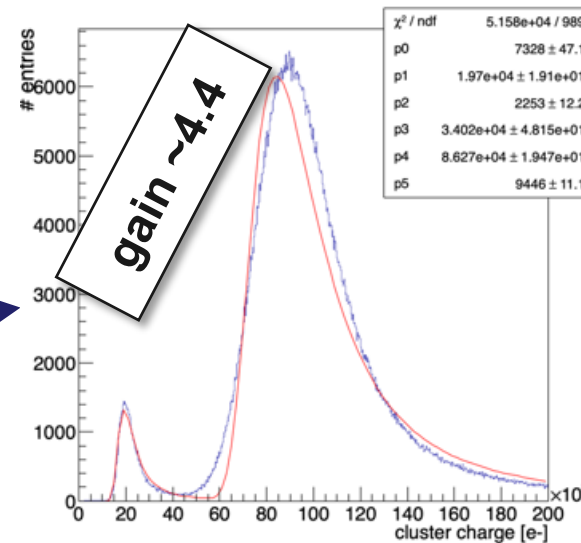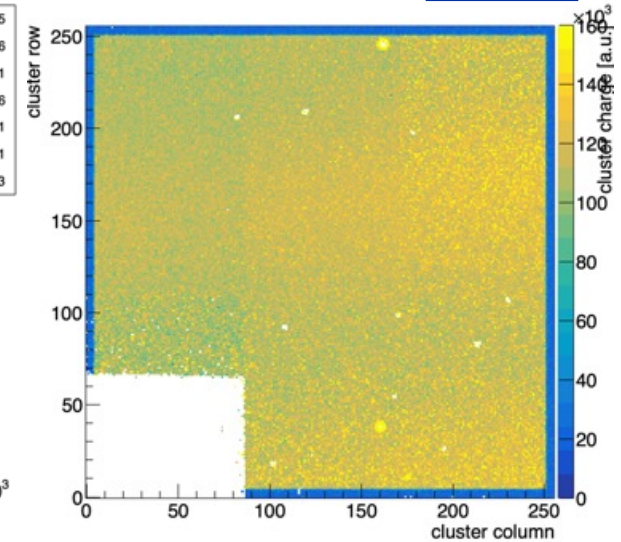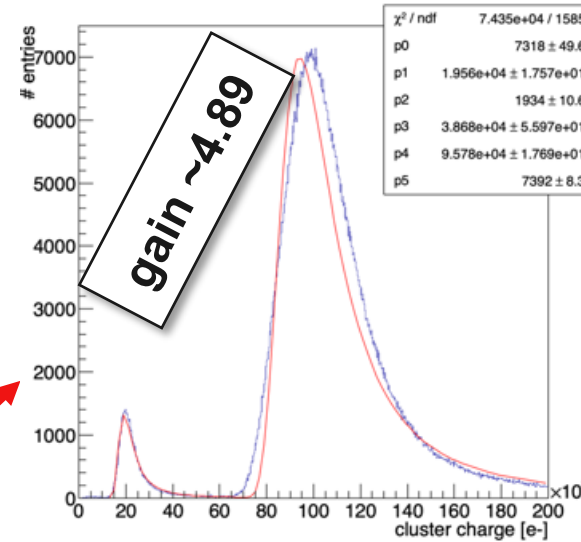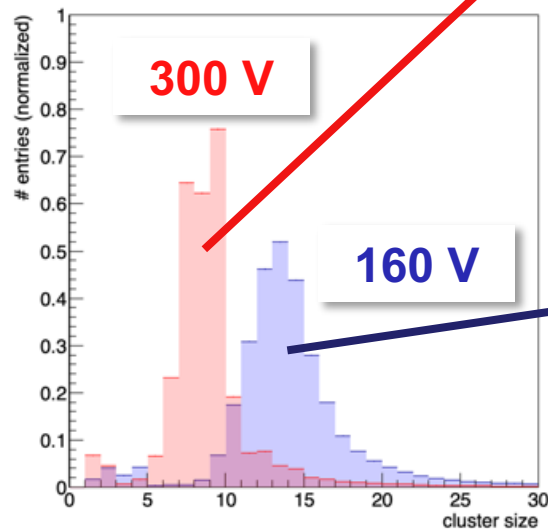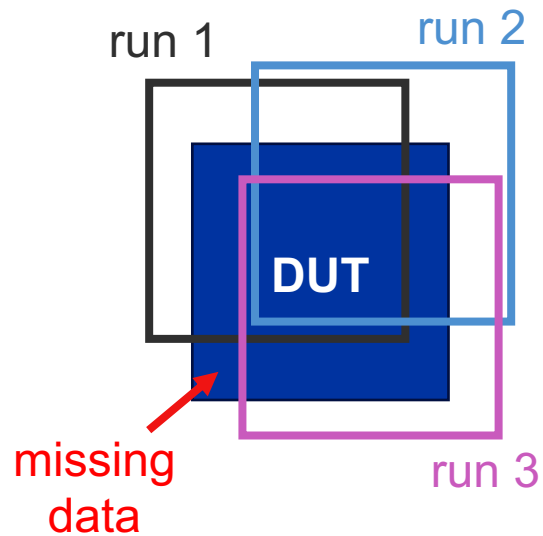
run 1
run 2
DUT
missing
data
run 3

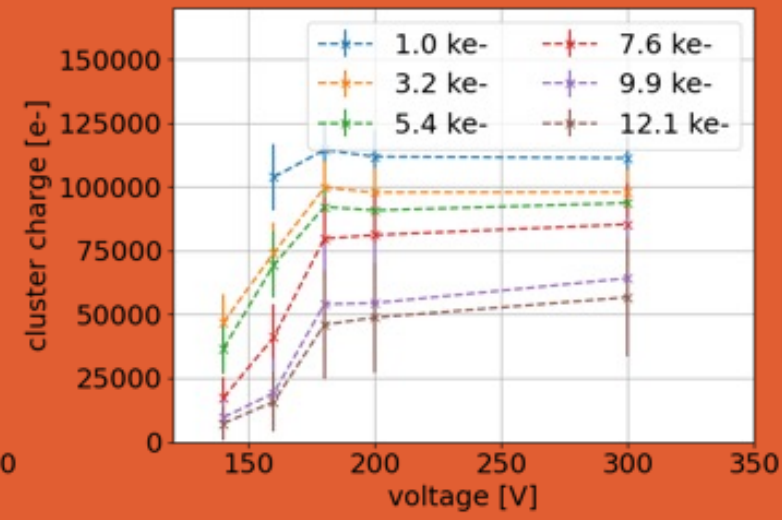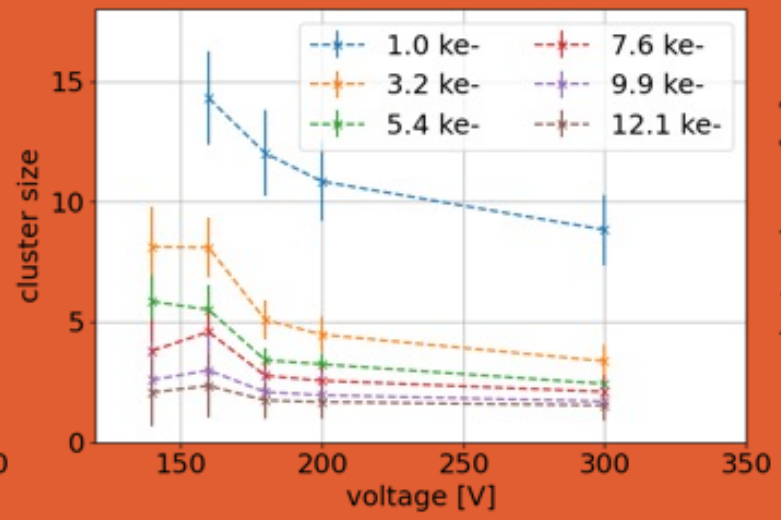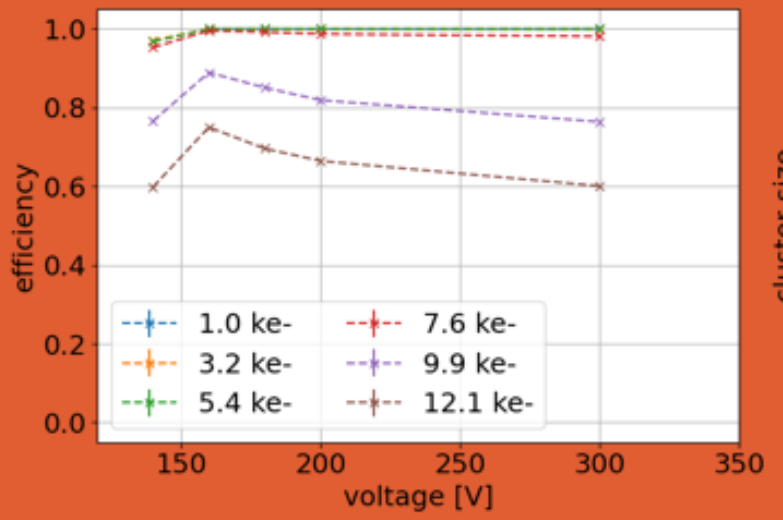300 V

160 V

gain ~4.89

gain ~4.4
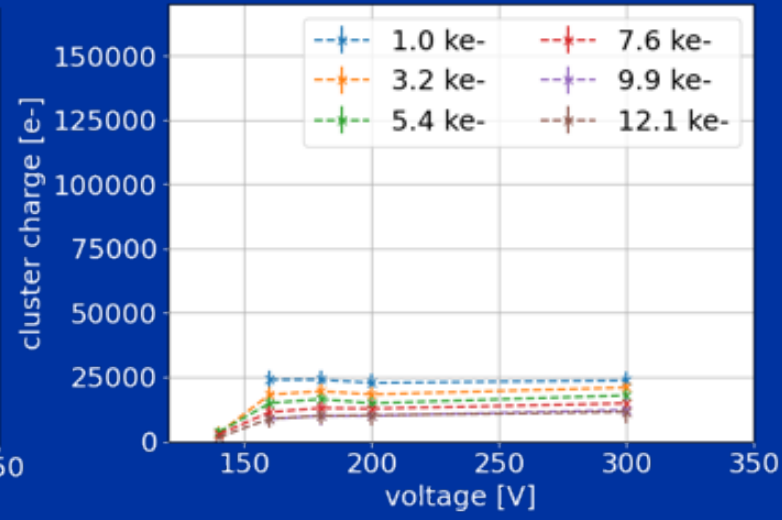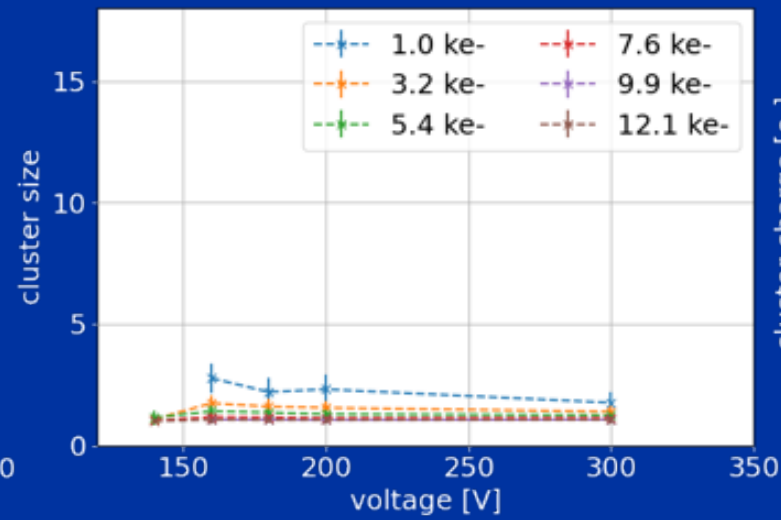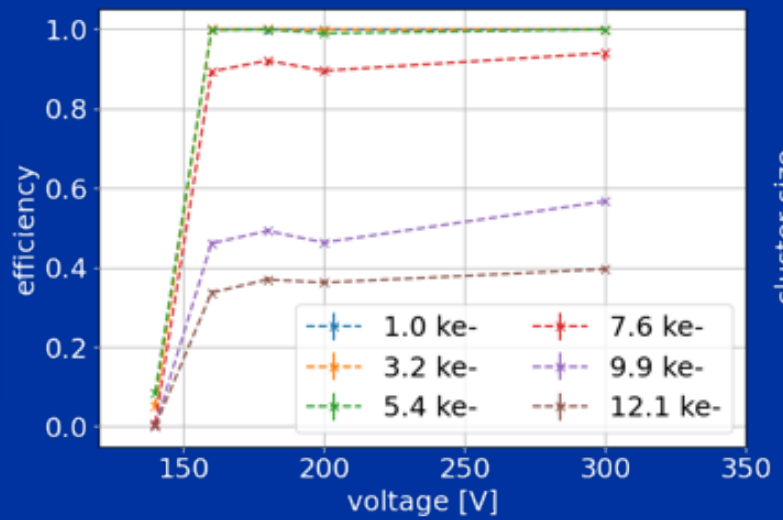
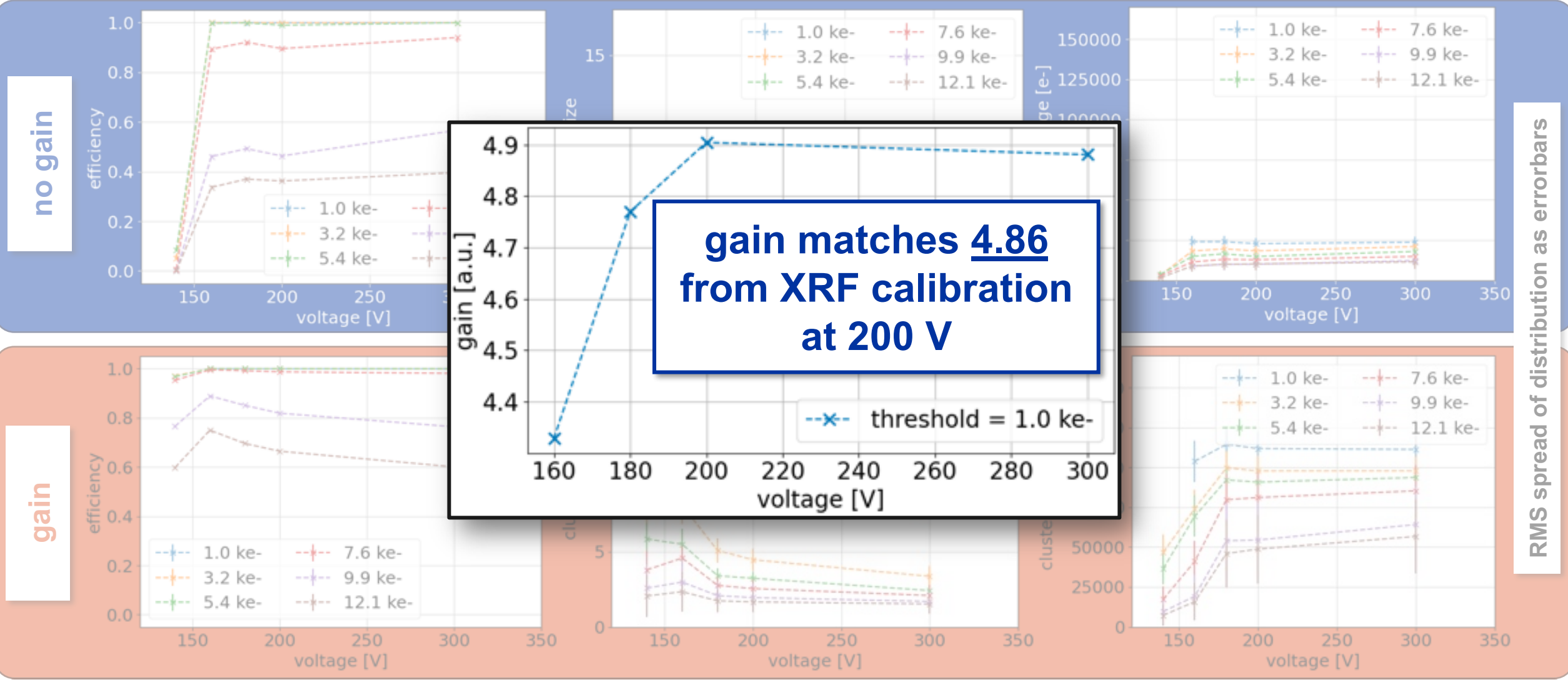# SPS beam test – results (voltage dependency)

SPS beam test – results (voltage dependency)

gain matches <u>4.86</u> from XRF calibration at 200 V

SPS beam test – angular scans

front view:

no-gain border

gain
250 x 250 pixels

top view:

beam

angle

perpendicular beam is measured as 0°

~85°

bias = 300V
threshold = 983 e-

ideal: 300 μm sensor, 55 μm pitch
cluster width
cluster height

$$ideal = \left\lceil \tan(angle) \frac{300}{55} \right\rceil$$

ideal: MIP 80e-/μm; no-gain
ideal: MIP 80e-/μm; gain x4.86
measured charge
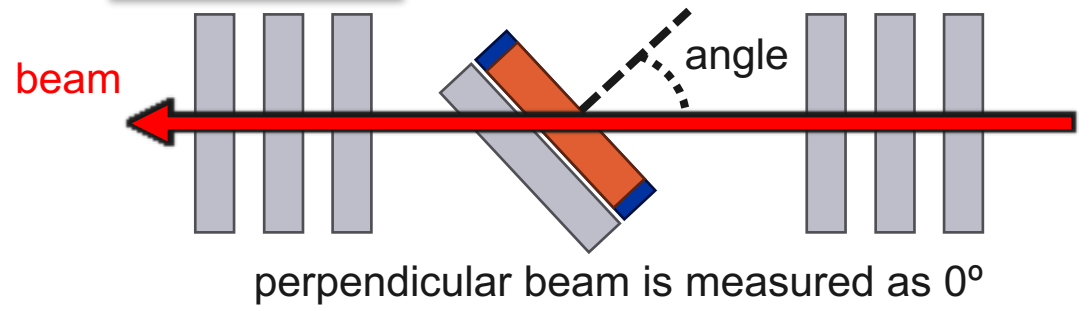
$$ideal = 80 \frac{300}{\cos(angle)}$$
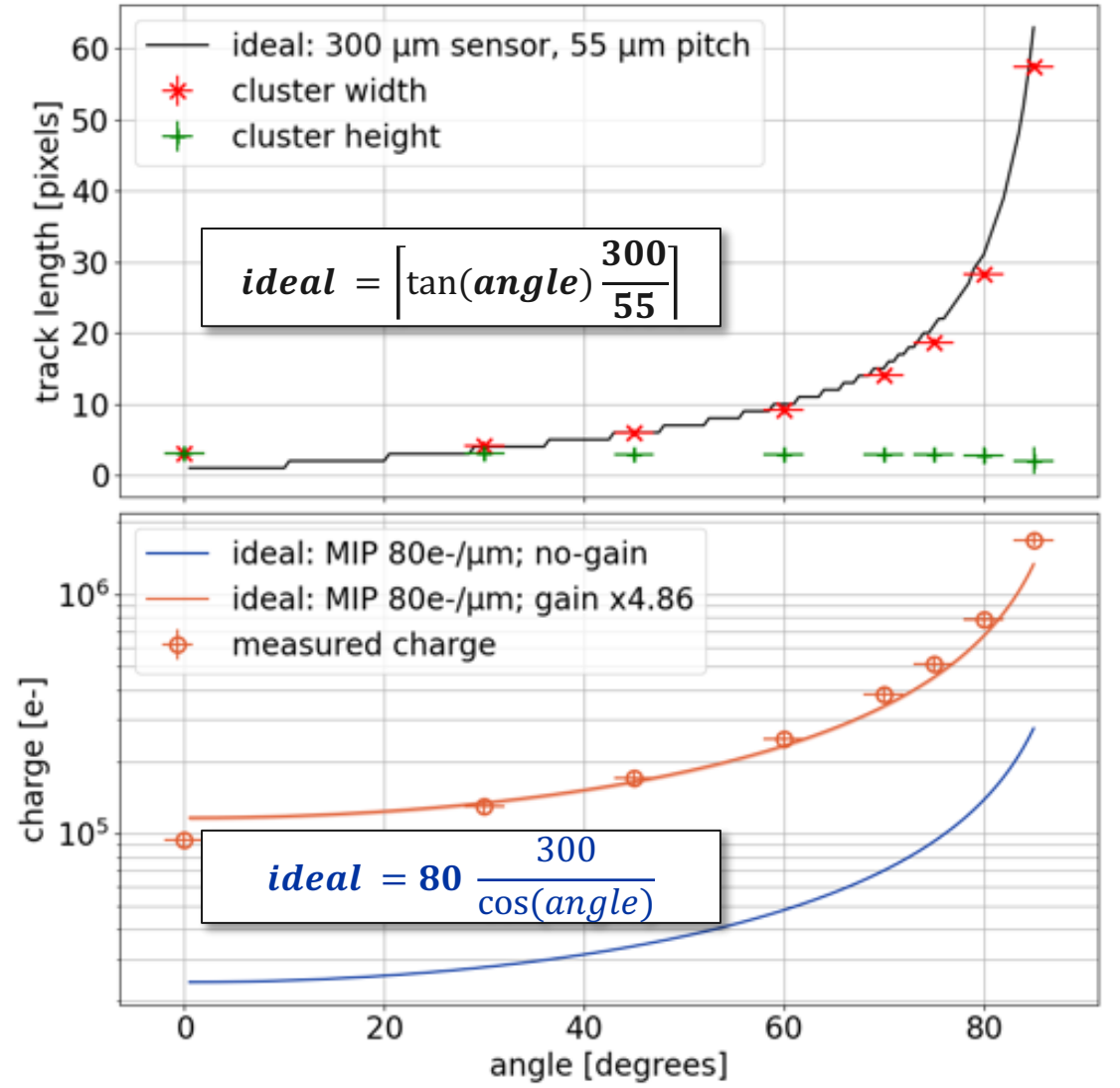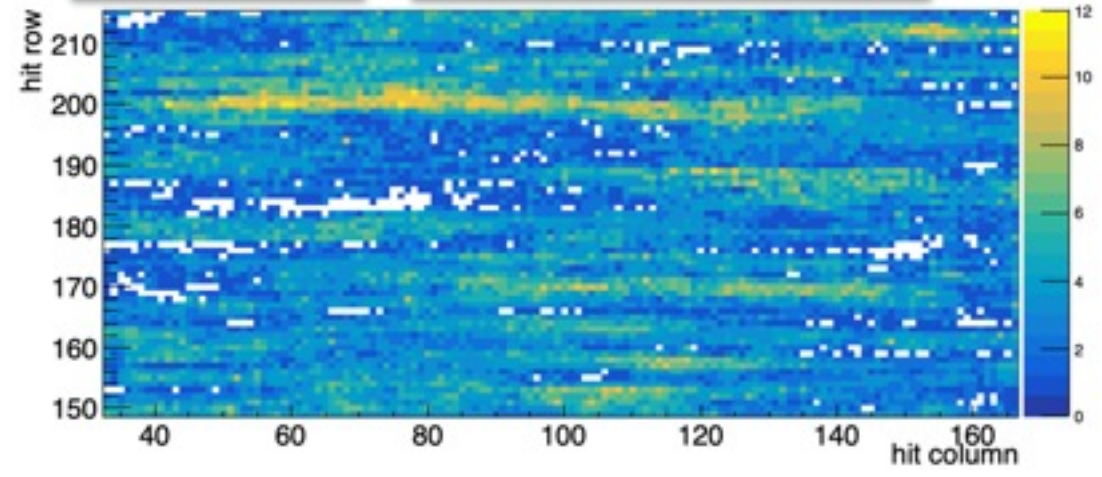
Conclusions

- **Design matched gain of ~5**

  - Both from XRF as well as beam tests

- **Timing performance limited by readout ASIC**

- **Angular scans match charge collection and cluster sizes**

- **Demonstrated 55 um pixel uniform iLGAD device with excellent efficiency**
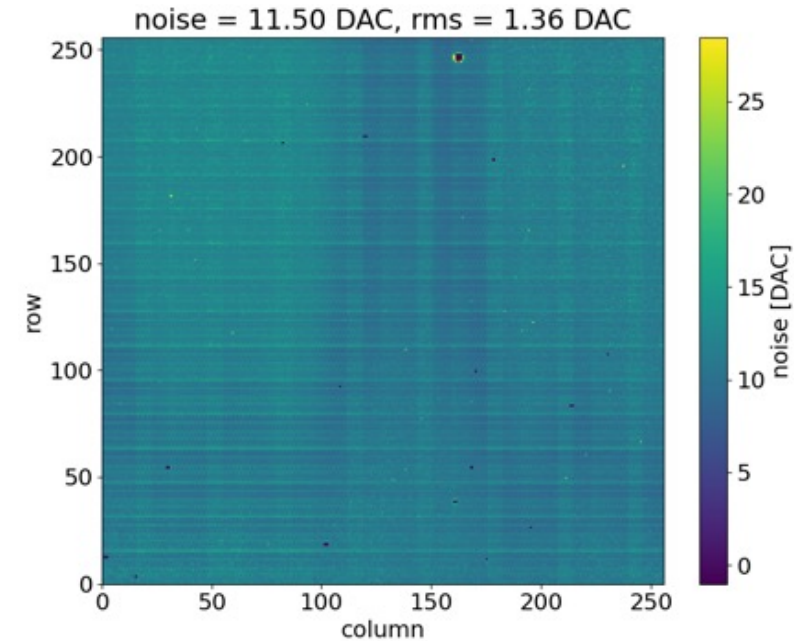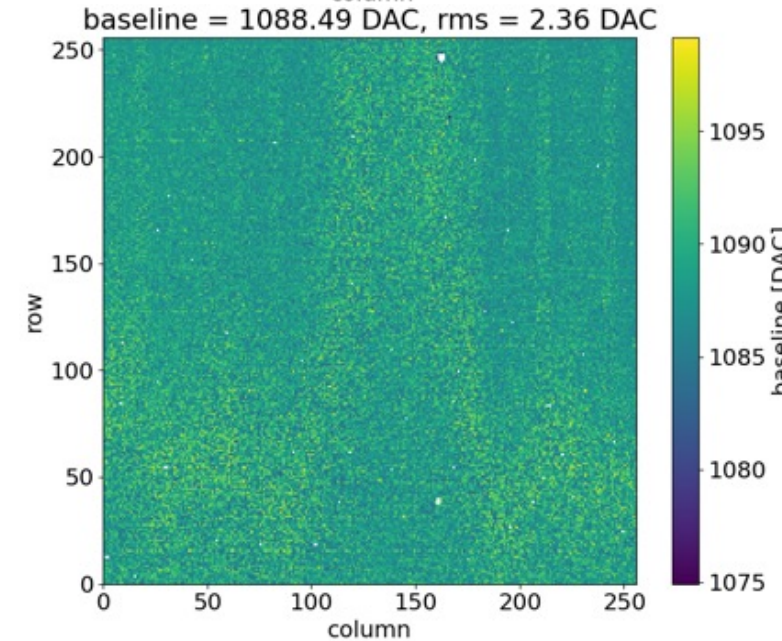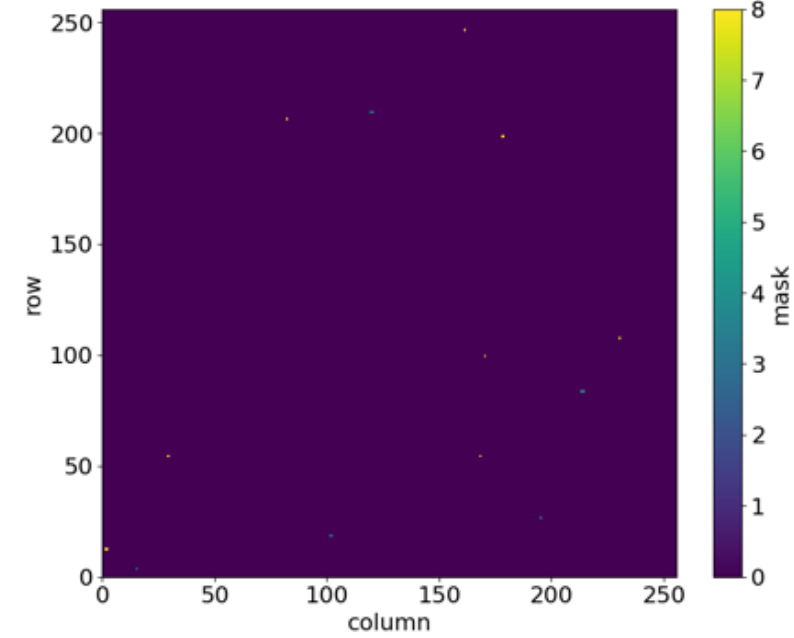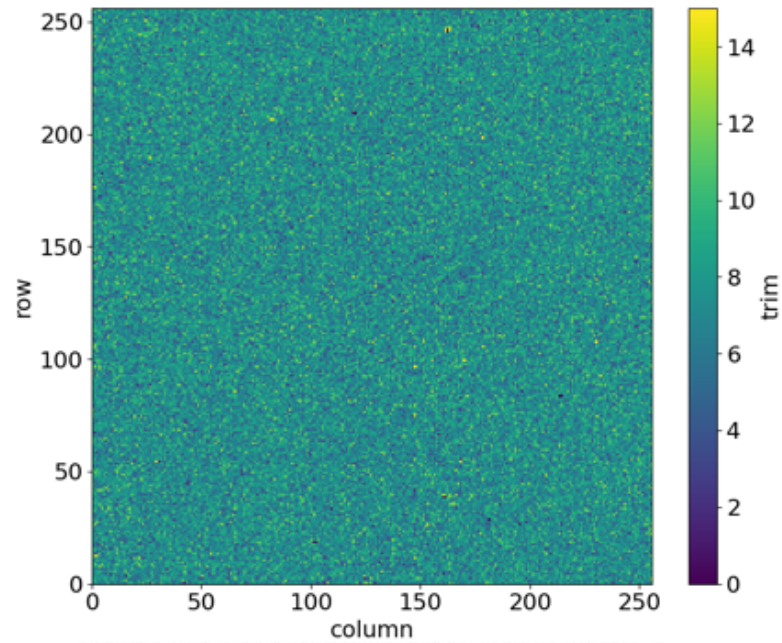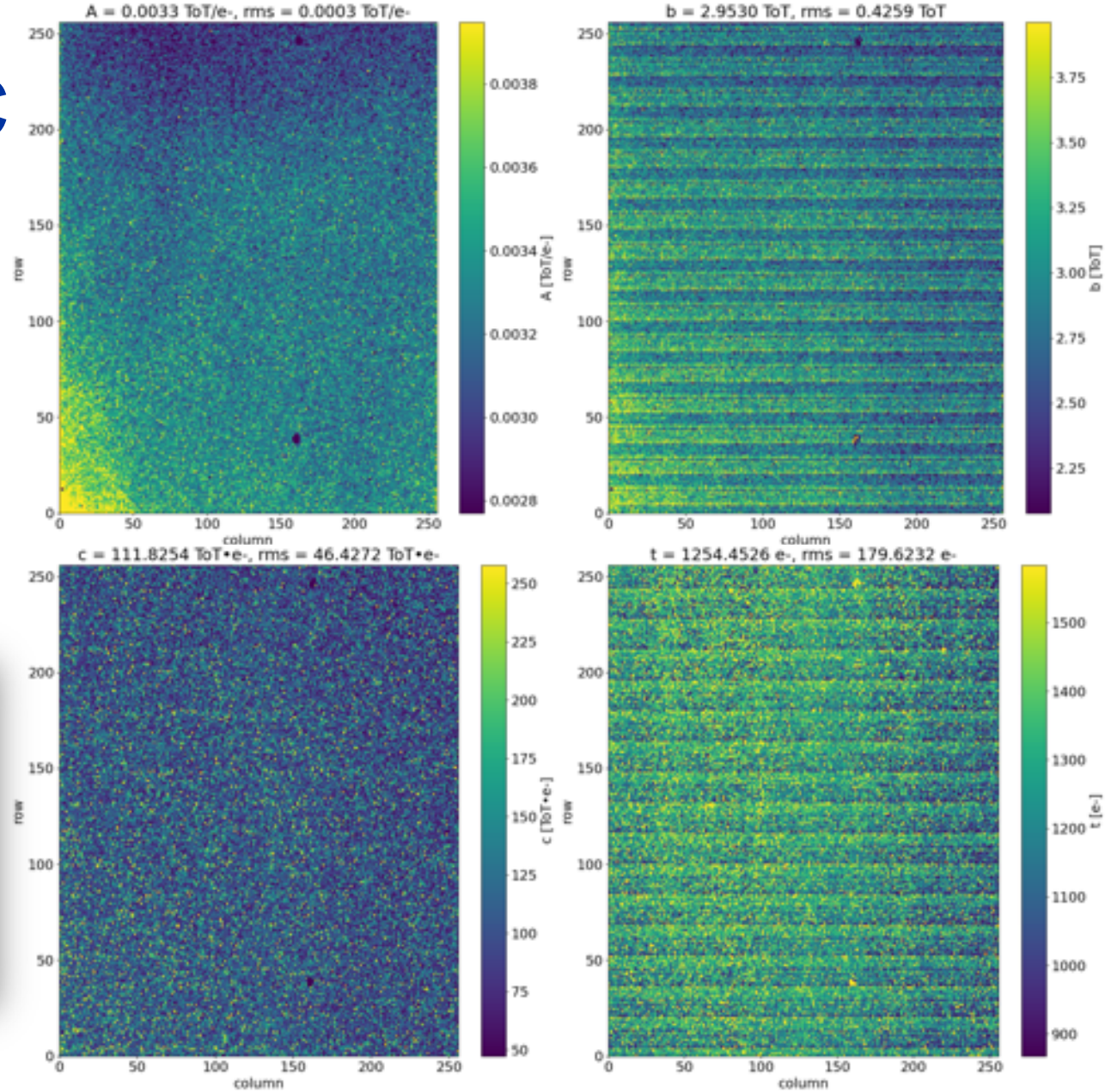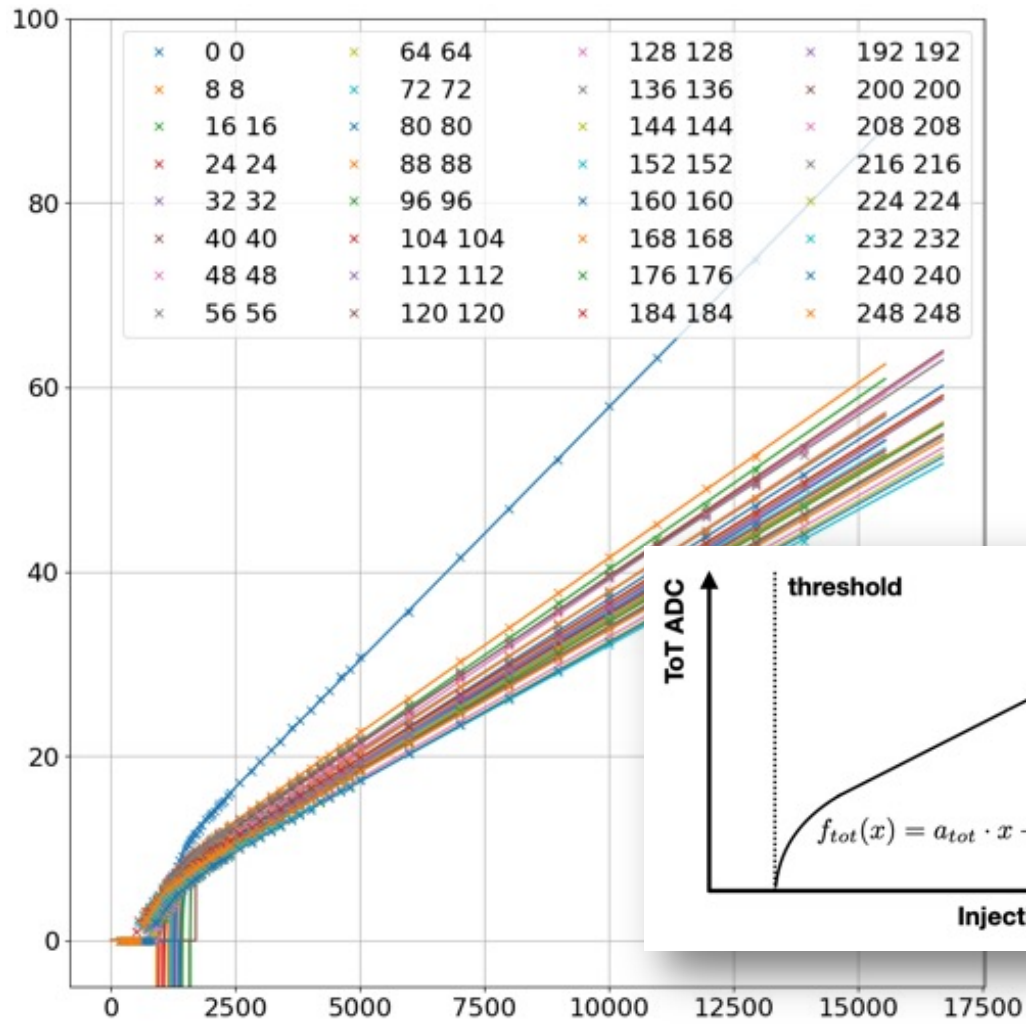
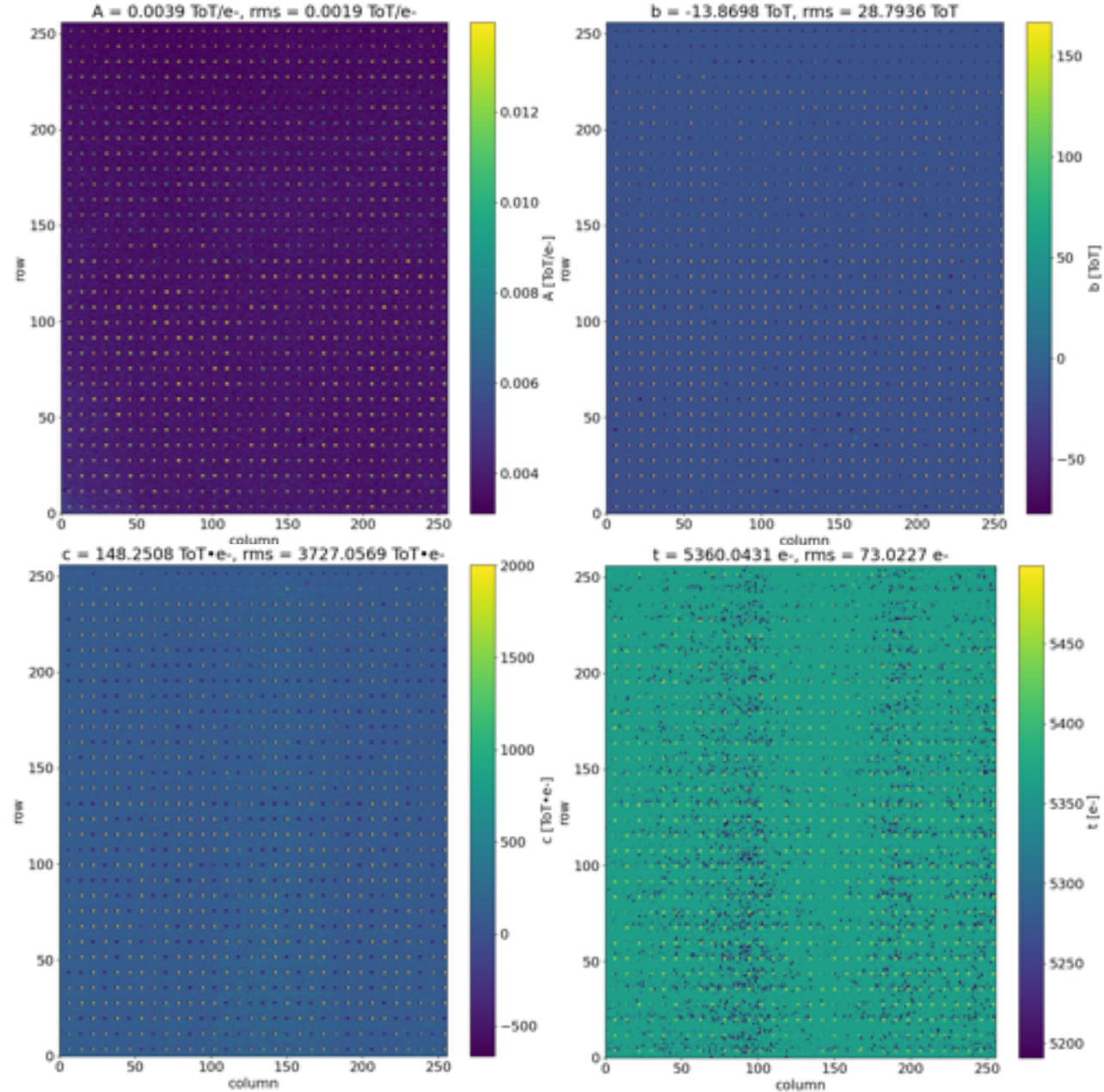W0068_I11 Pixel efficiency map (in-pixel ROI)
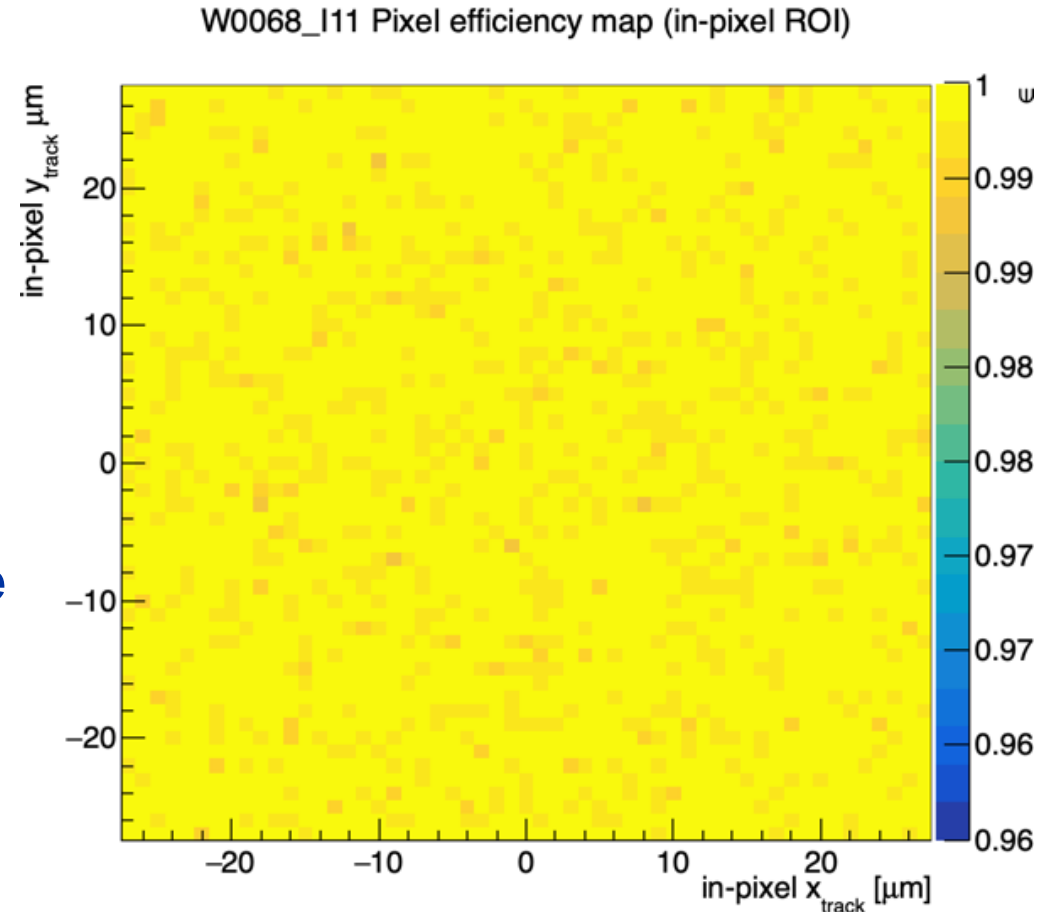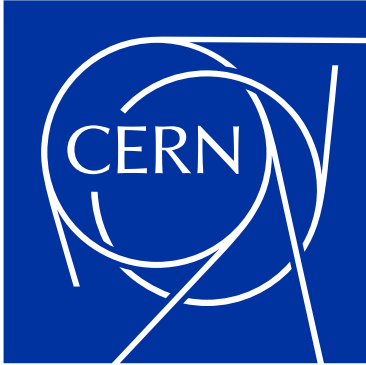
home.cern

Equalisation

- **Equalised to the noise edge**
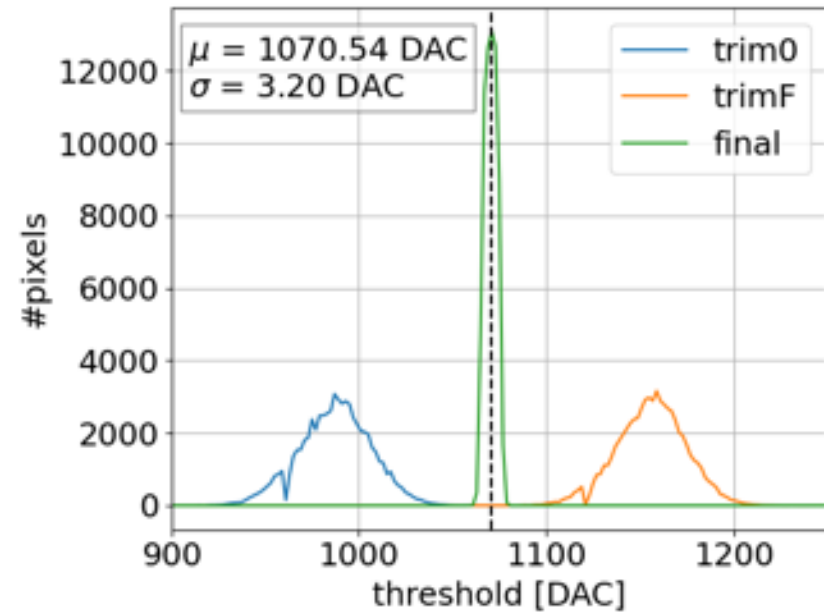
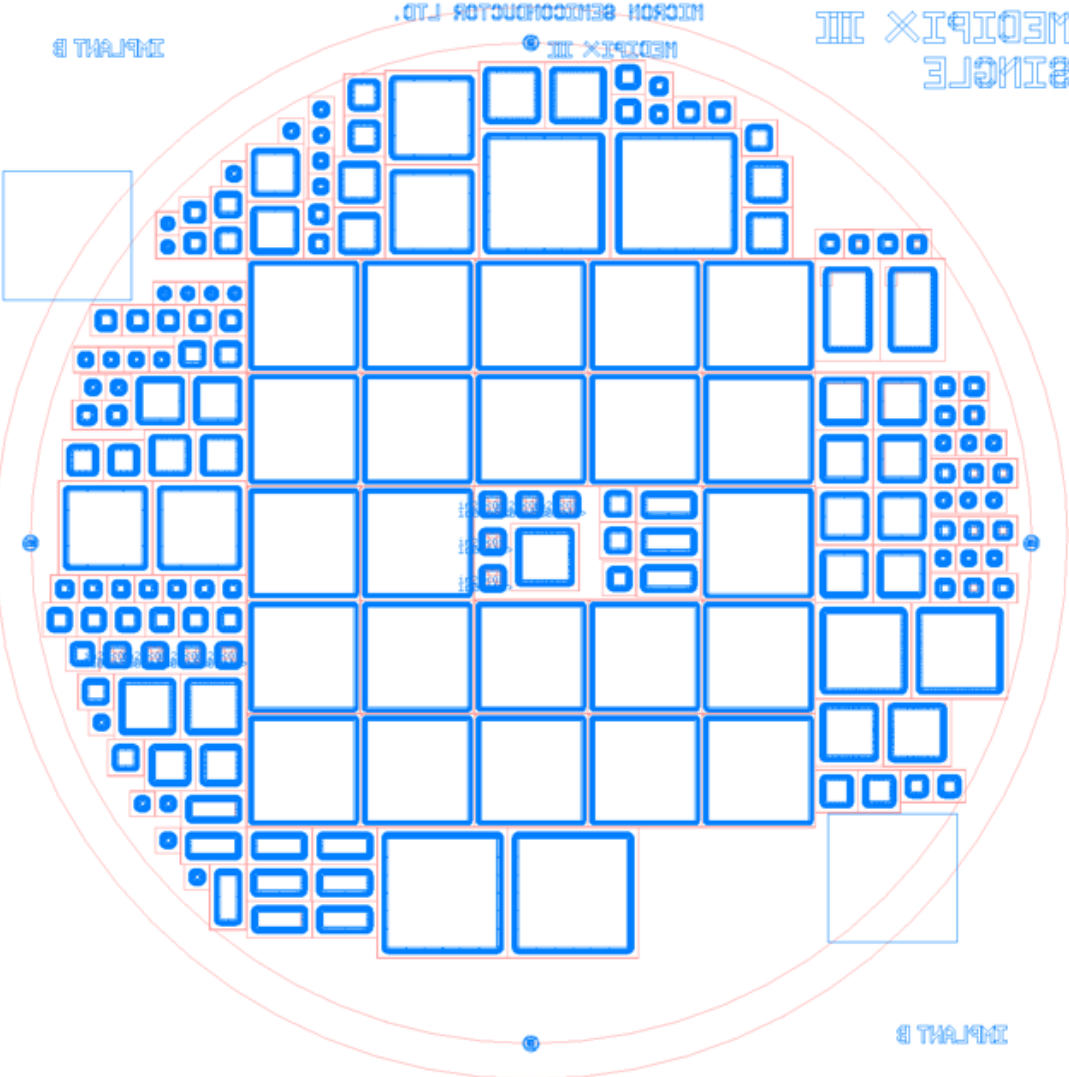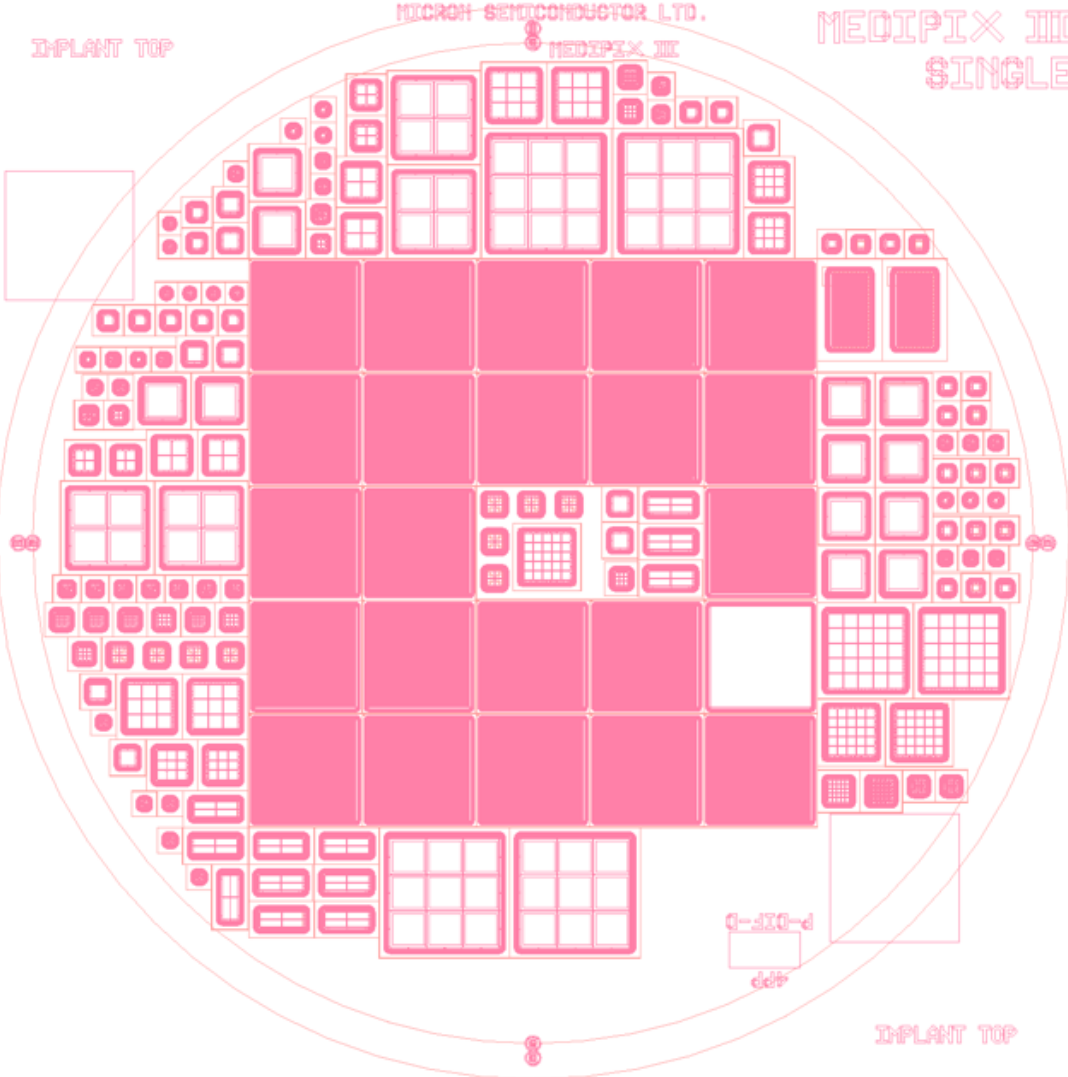# TP calibration at 1000DAC

$$f_{tot}(x) = a_{tot} \cdot x + b_{tot} - \frac{c_{tot}}{x - t_{tot}}$$

TP calibration at 600DAC
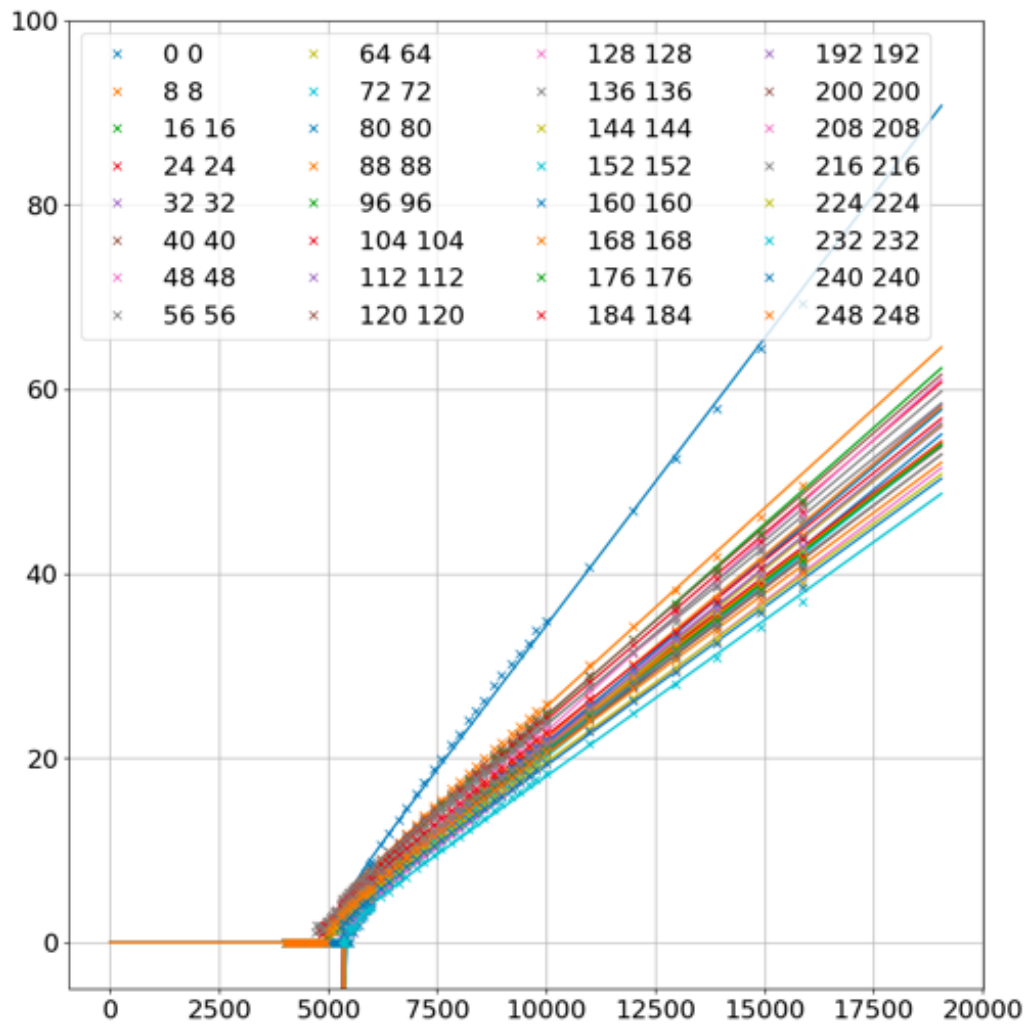
iLGAD implant masks

XRF table

| Element	Kα1	Kα2	Kβ1	Lα1	Lα2	Lβ1	Lβ2	Lγ1
22 **Ti**	**4510,84**	4504,86	4931,81	452,20	452,20	458,40		
26 **Fe**	**6403,84**	6390,84	7057,98	705,00	705,00	718,50		
29 **Cu**	**8047,78**	8027,83	8905,29	929,70	929,70	949,80		
42 **Mo**	**17479,34**	17374,3	19608,30	2293,16	2289,85	2394,81	2518,30	2623,50
47 **Ag**	**22162,92**	21990,3	24942,40	2984,31	2978,21	3150,94	3347,81	3519,59
50 **Sn**	**25271,30**	25044,0	28486,00	3443,98	3435,42	3662,80	3904,86	4131,12

https://xdb.lbl.gov/
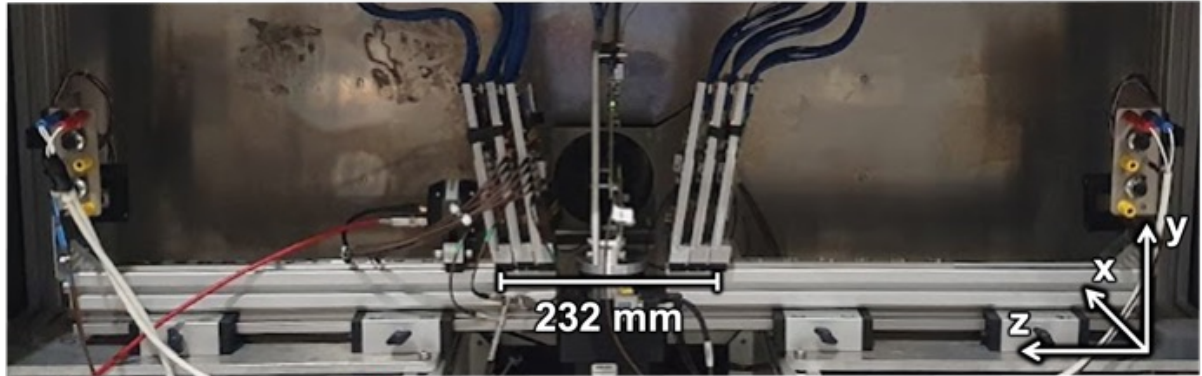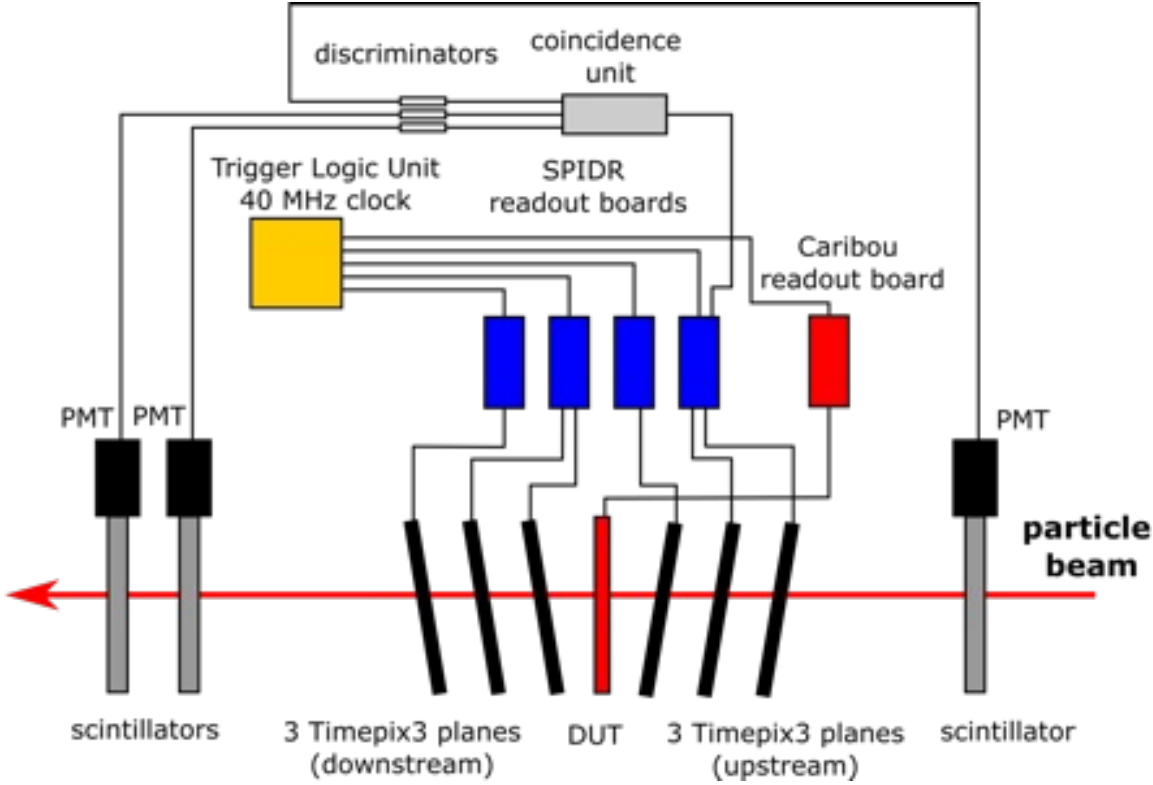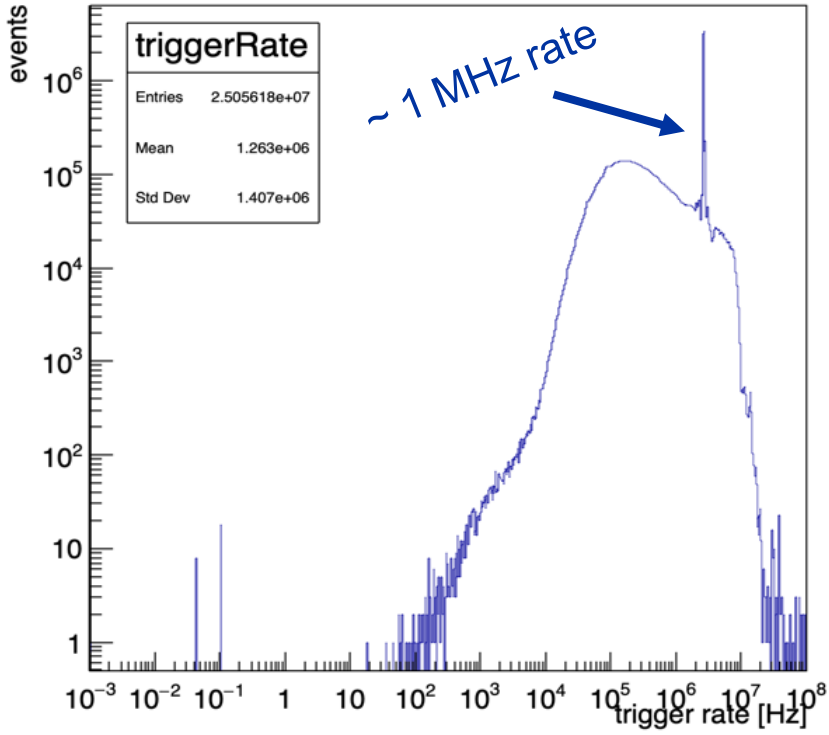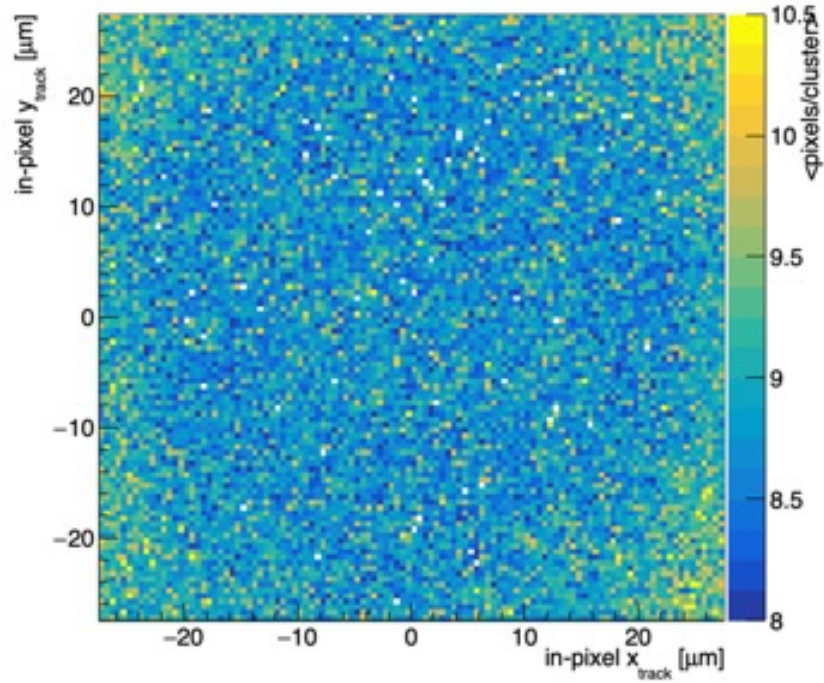
SPS beam test – results (threshold dependency)
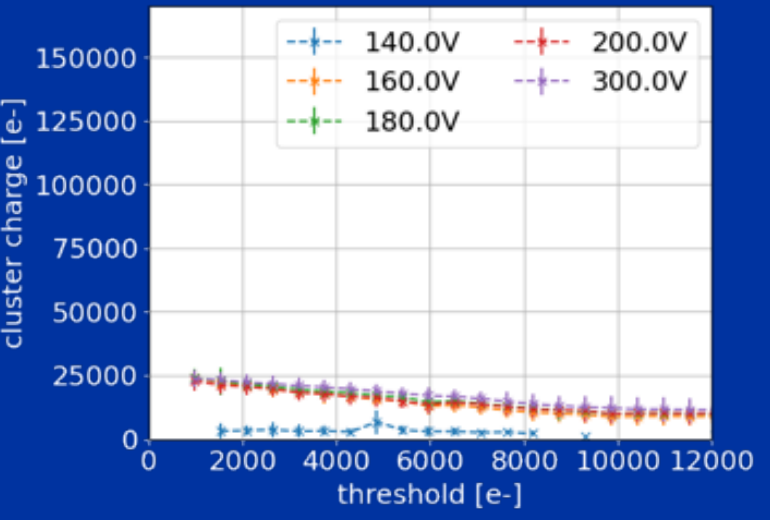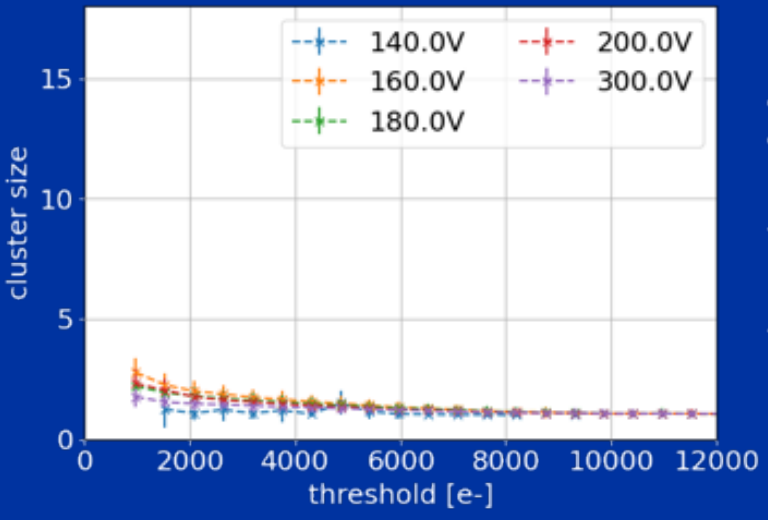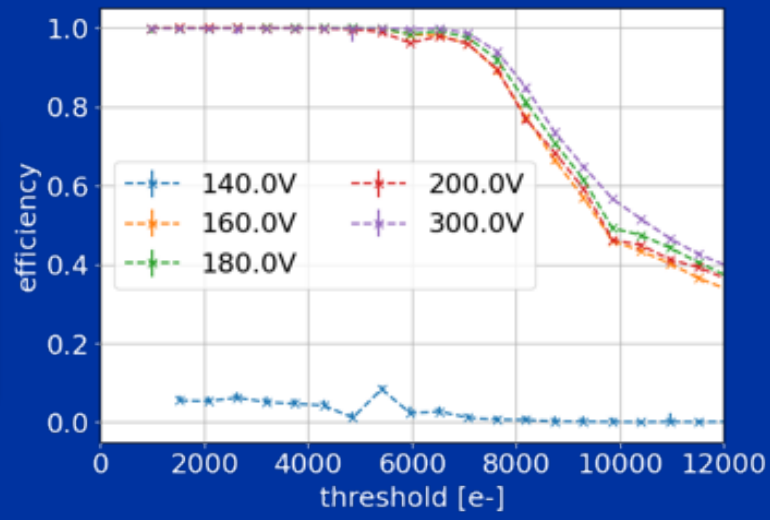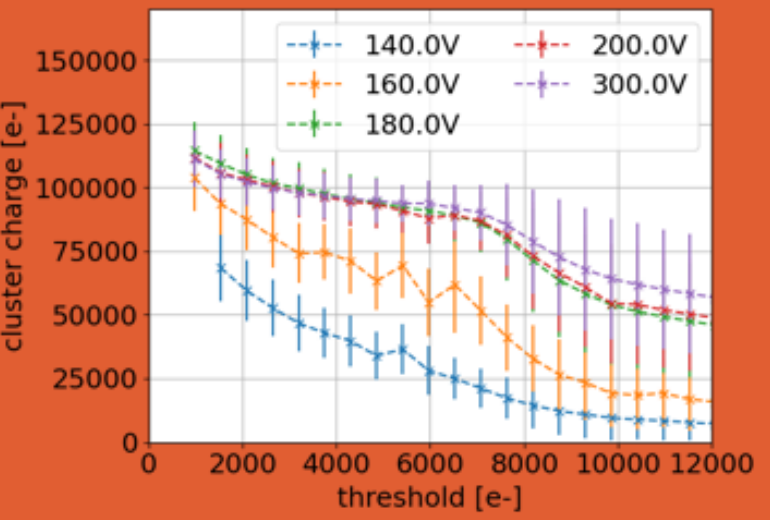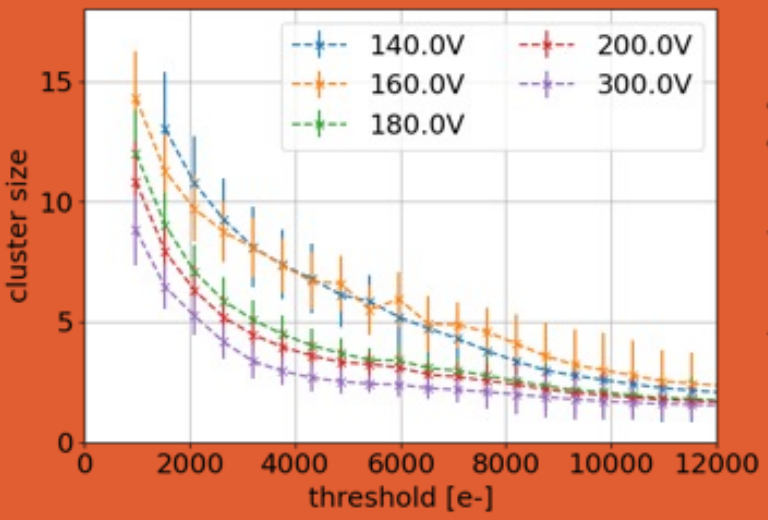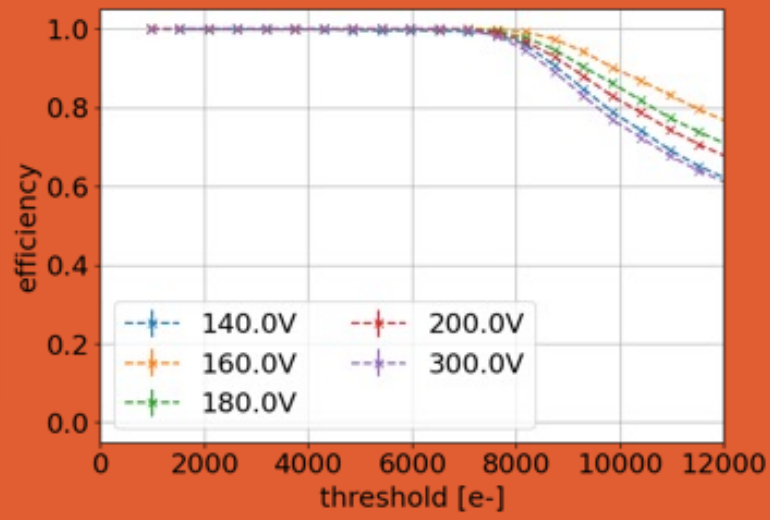
Beam telescope details

In-pixel plots (300 V, 983 e-, all gain pixels)
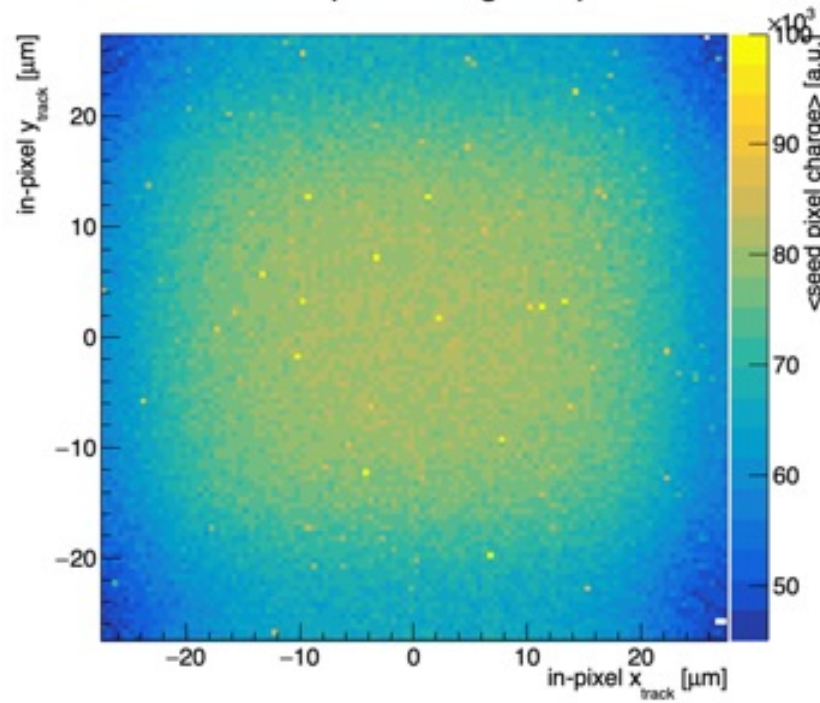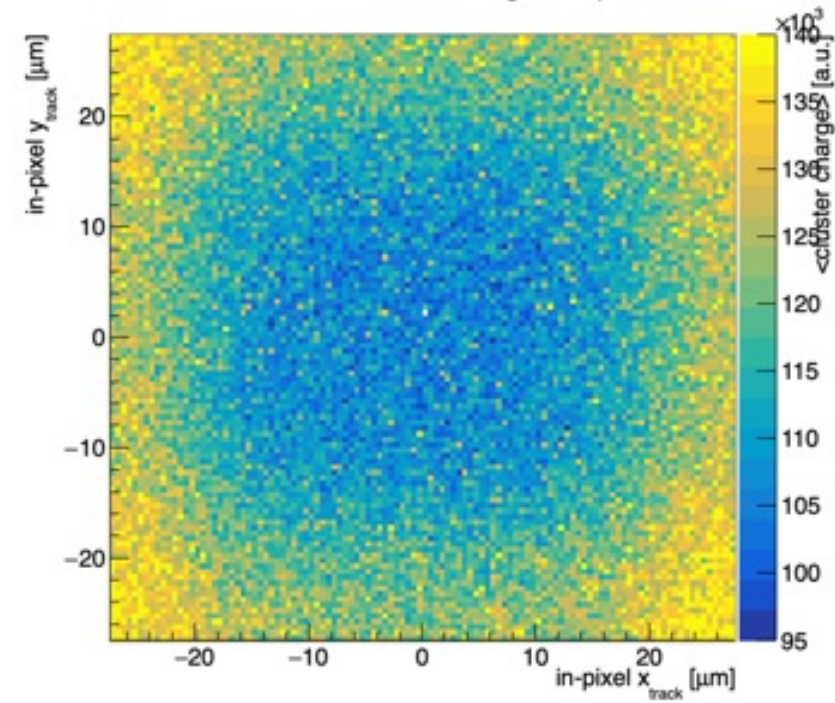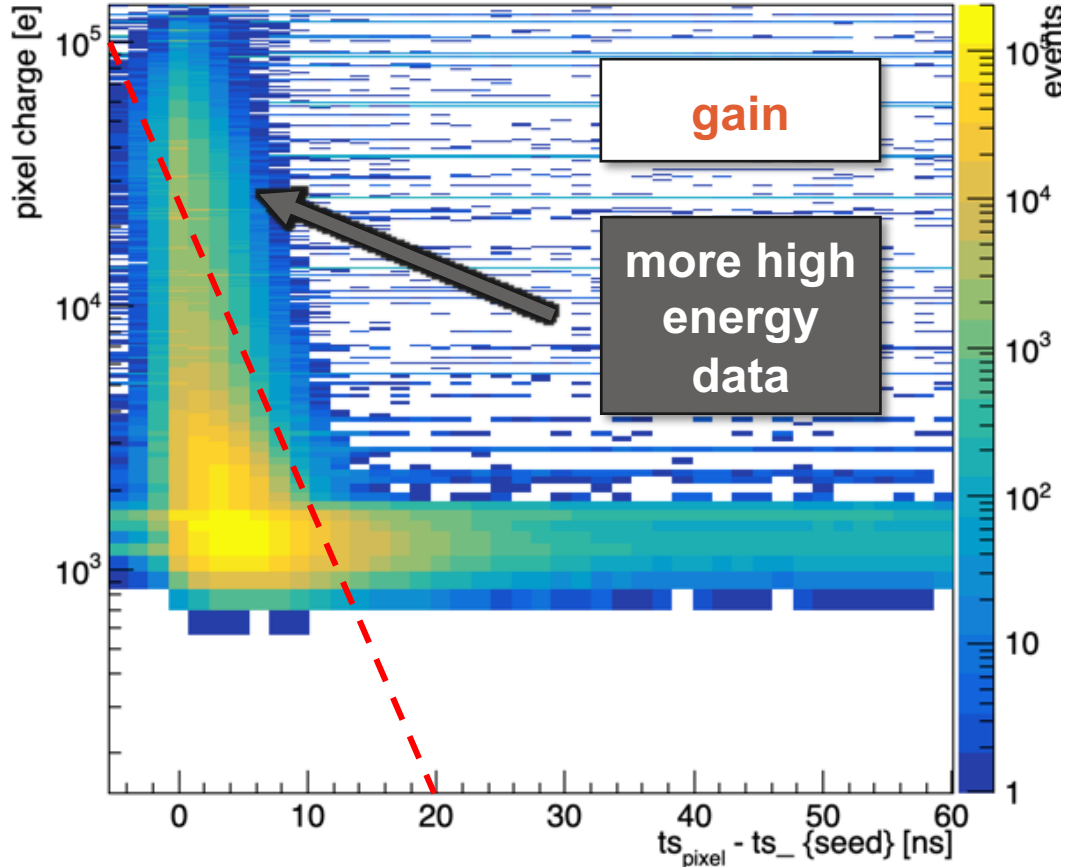
Comparison of timewalk effect for gain vs nogain

W0068_I11 pixel - seed pixel timestamp (all pixels w/o seed)

gain

more high energy data

W0068_I11 pixel - seed pixel timestamp (all pixels w/o seed)

no gain

longer tail