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MICRON SEMICONDUCTOR LIMITED

medipix collaboration

Performance studies of Low Gain Avalanche Detectors coupled to the Timepix3 ASIC

Dima Maneuski, University of Glasgow
Jerome Alozy, CERN
Richard Bates, University of Glasgow
Mark Bullough, Micron Semiconductor Ltd
Lars Eklund, University of Uppsala
Lojius Lombigit, University of Glasgow
Neil Moffat, CNM Barcelona
Nicola Tartoni, Diamond Light Source
Mark Williams, University of Edinburgh

iWoRiD 2022
23rd International Workshop on Radiation Imaging Detectors
26 – 30 June 2022
Riva del Garda, Italy

https://indico.cern.ch/event/1120714

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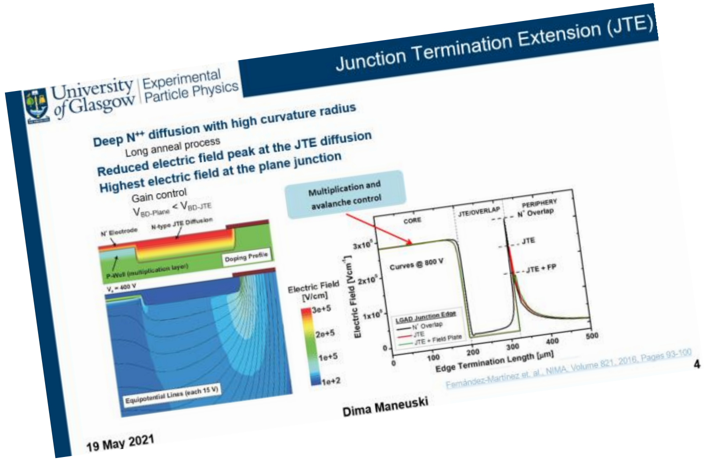
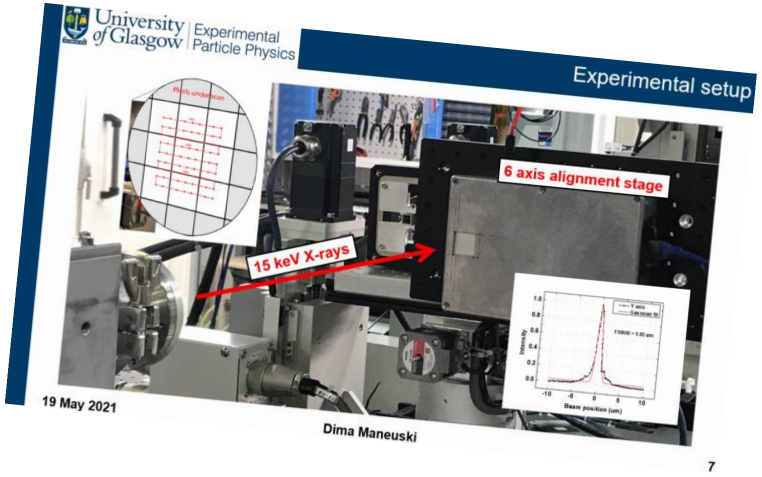




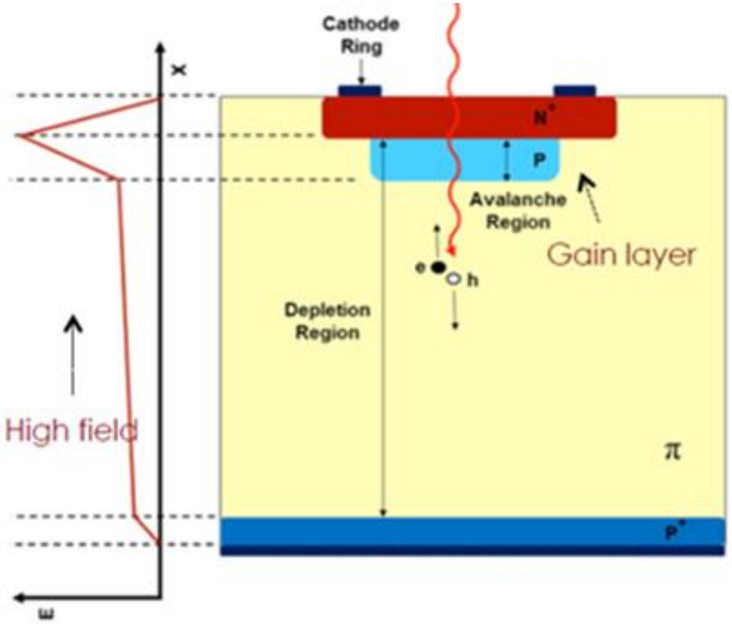
Research agenda and motivation

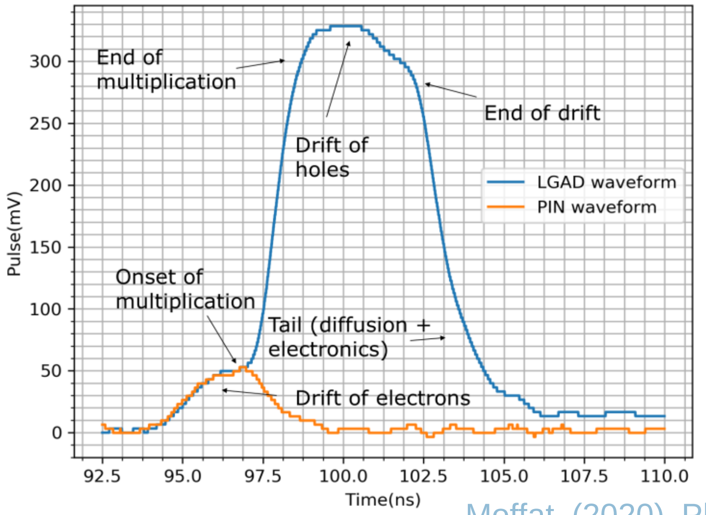
- Fast timing silicon pixel detectors (sub 100 ps)
- “Tender” energy x-rays detectors (and below)

- Understand LGAD technology
- Create simulation models
- Develop fabrication process
- Build characterisation infrastructure
- Explore potential applications

- Synchrotron applications
- LHCb VELO upgrade

LGAD principle





Moffat, (2020), PhD thesis

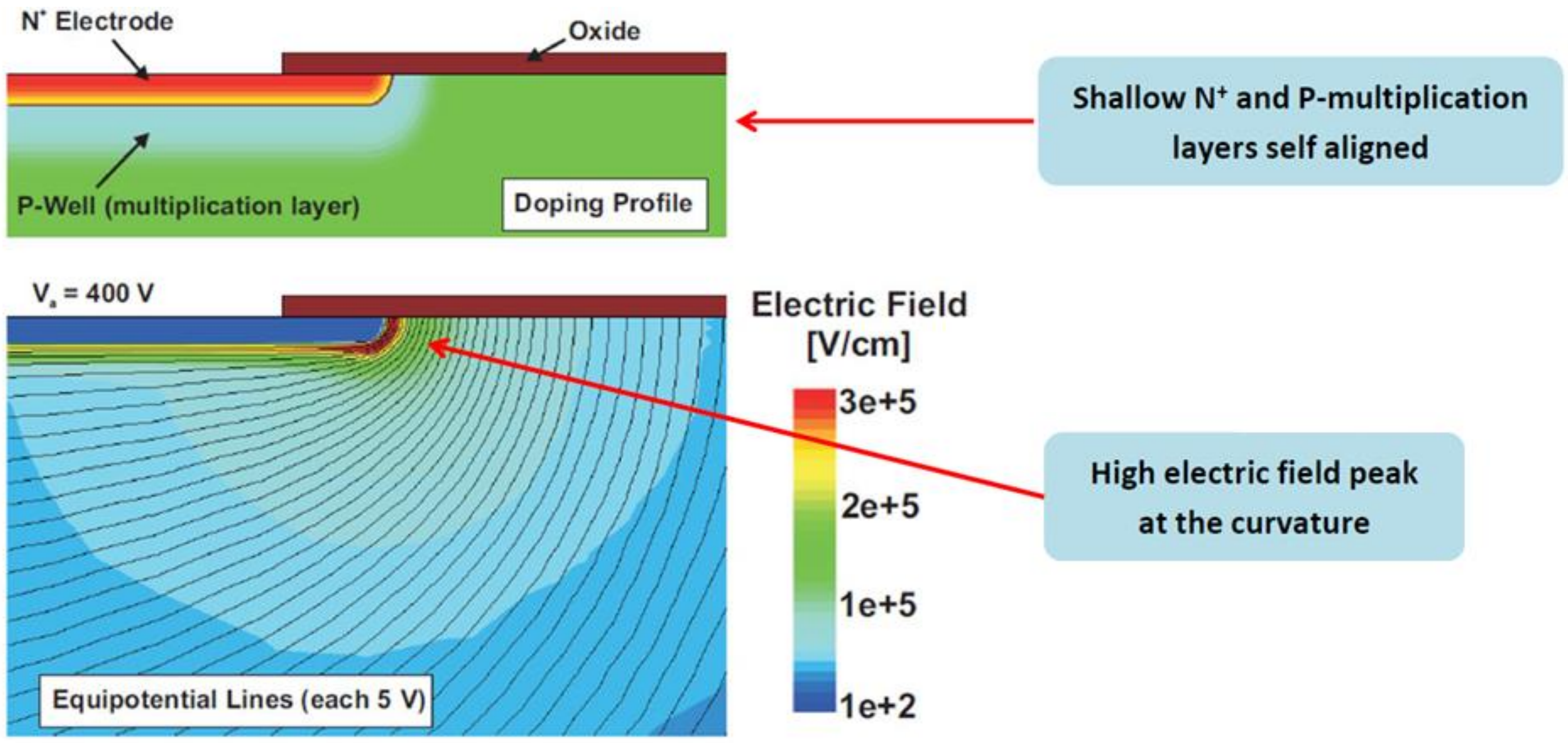
Edge termination: why is it needed?

The electric field at the corner curved section of the N^{++}/P^{+} junction is much higher than that of the flat junction region

where Gain is required

Avalanche at the N^{+}/P^{+} curvature at a very low reverse voltage

-> premature breakdown



Fernández-Martínez et. al., NIMA, Volume 821, 2016, Pages 93-100

Junction Termination Extension (JTE)

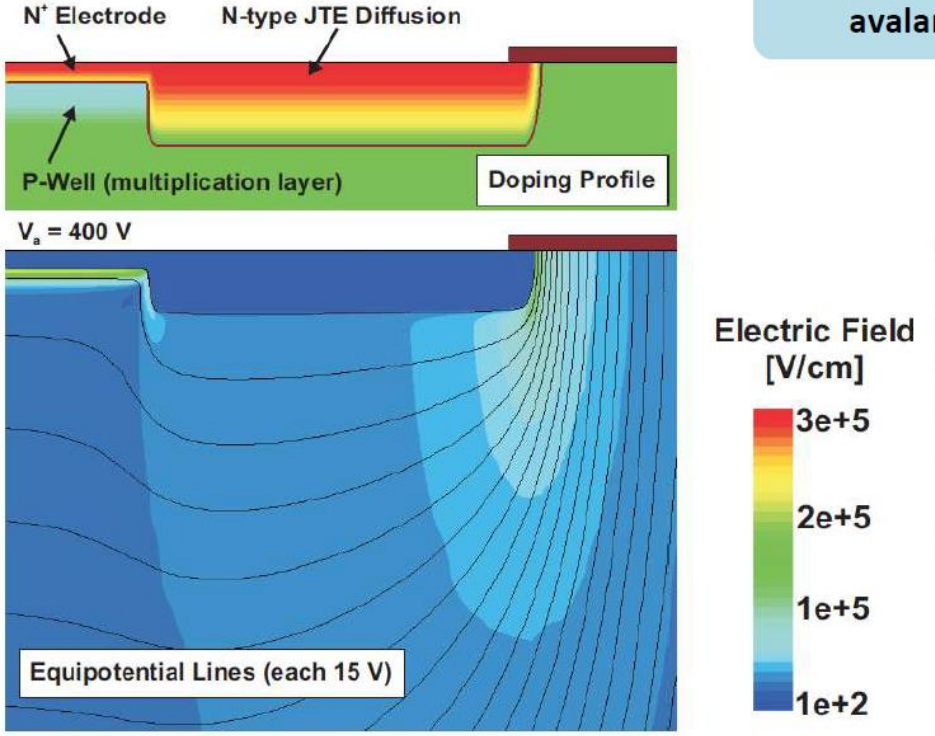
Deep N^{++} diffusion with high curvature radius

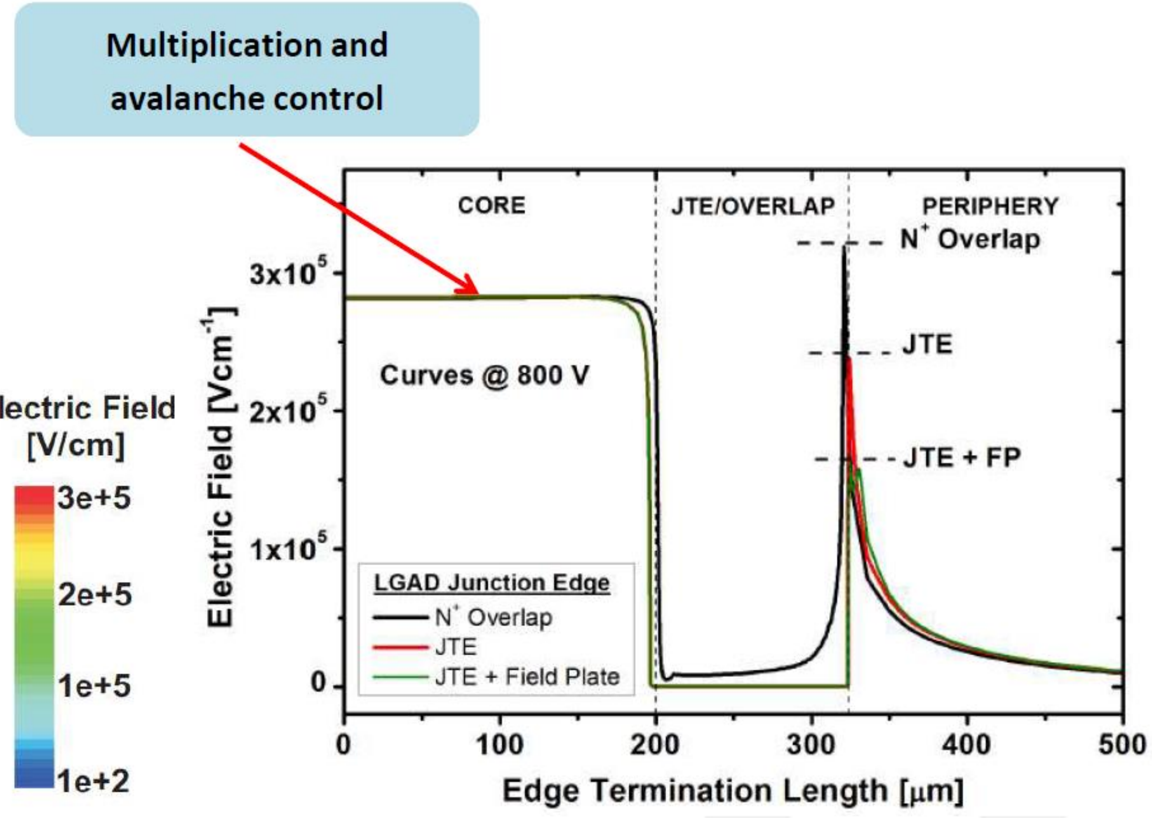
- Long anneal process

Reduced electric field peak at the JTE diffusion

Highest electric field at the plane junction

- Gain control
- $V_{BD\text{-}Plane} < V_{BD\text{-}JTE}$





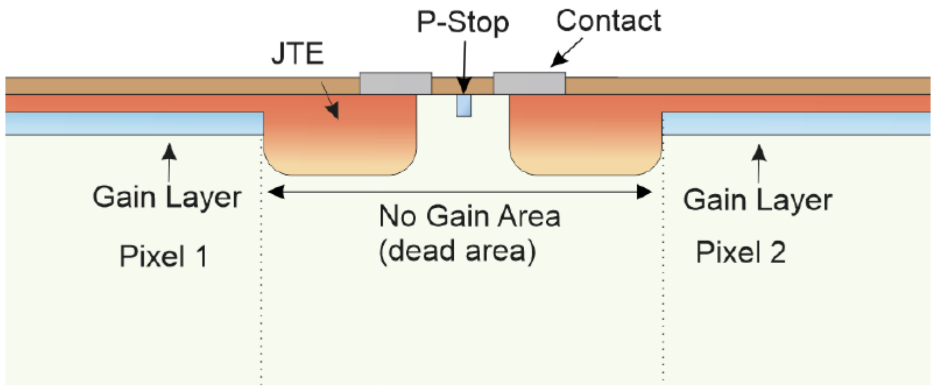
Fernández-Martínez et. al., NIMA, Volume 821, 2016, Pages 93-100

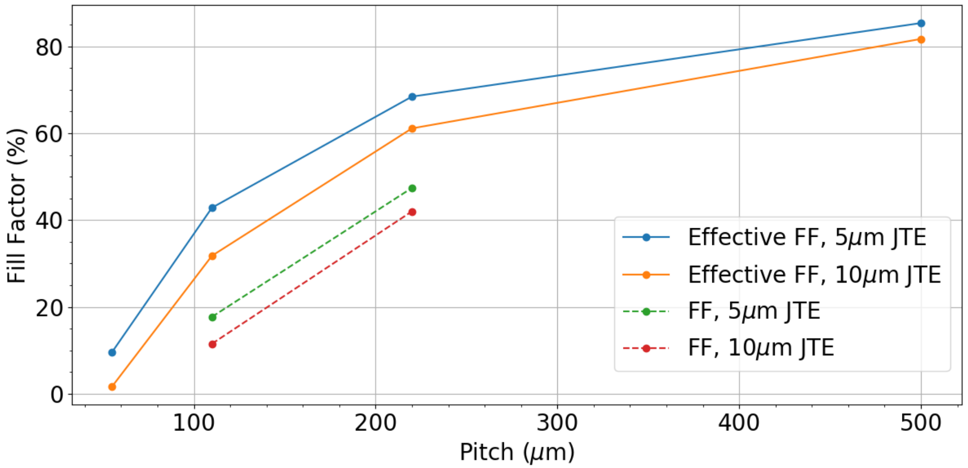
Small pixels – poor fill factor

Geometric fill factor

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

- Caused by JTE around each pixel
- Need to take into account diffusion on JTE





50 x 50 μm² pixel – JTE 10 μm -> fill factor < 10%

Moffat and Bates, NIMA, Volume 1018, 2021, 165746

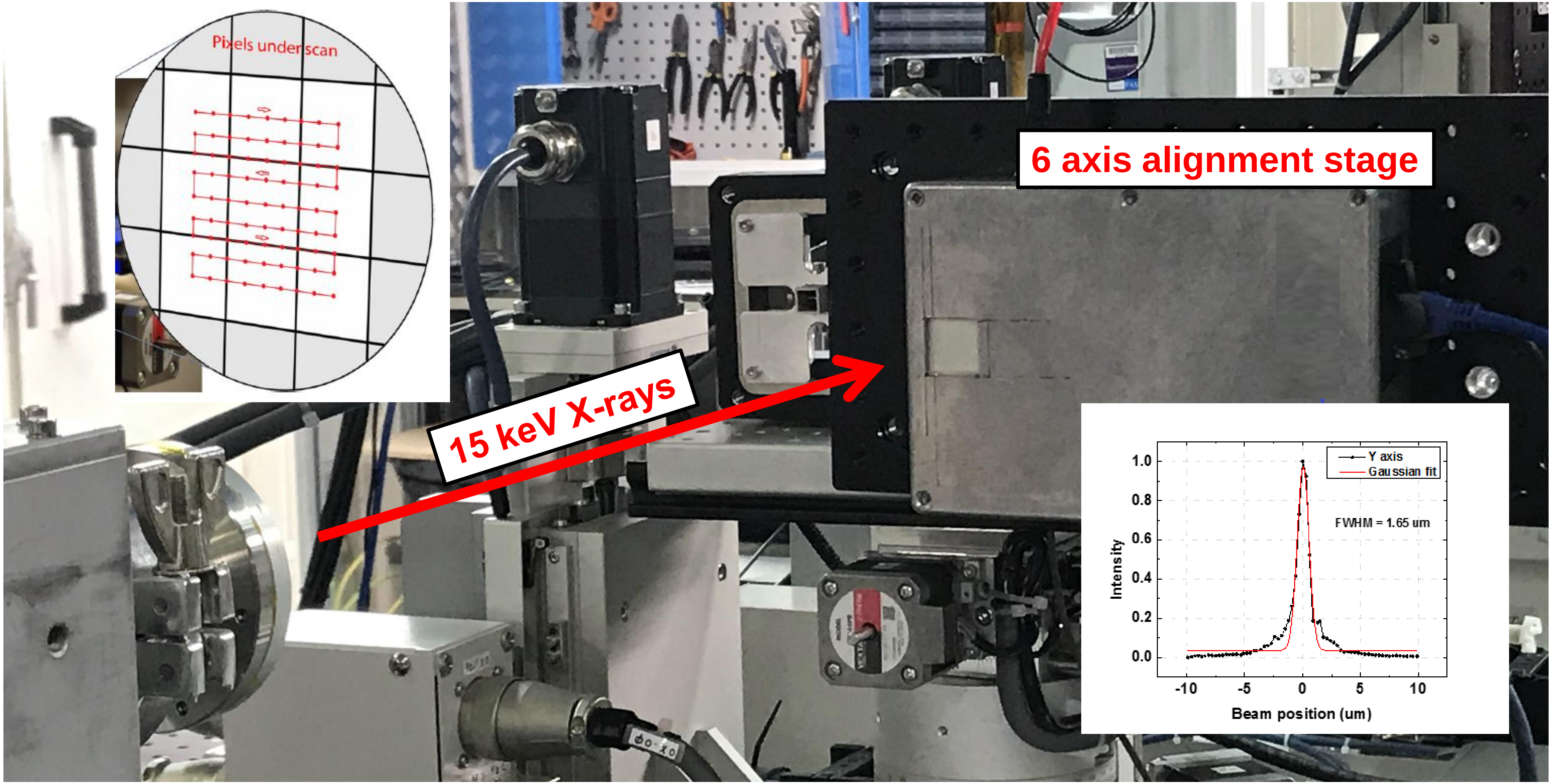
B16: Test Beamline

- Flexible and versatile beamline for testing new developments in optics and detector technology and for trialling new experimental techniques
- 4 – 45 keV photon energy range
- Operational modes:
- Focused, unfocused
- Monochromatic, white beam
- High flux

What we use

- 15 keV monochromatic beam
- Focused to about a micron FWHM

Experimental setup



DUTs and tests

Devices produced and tested

- C04 - 110 um pixel, 10 um JTE
- C06 - 110 um pixel, 20 um JTE
- D04 - 55 um pixel, 5 um JTE

- Each device has control no-multiplication region of 9x9 pixels in the right bottom corner

Tests performed

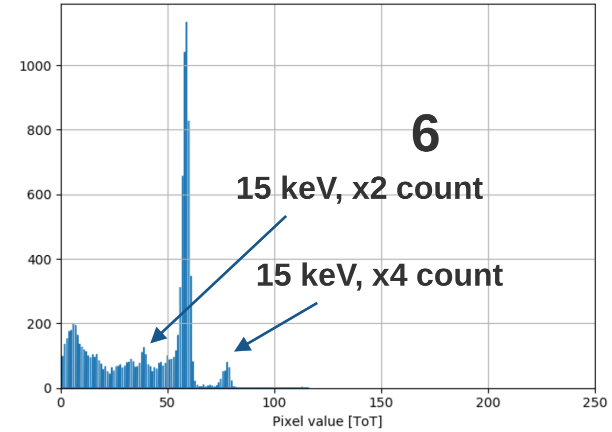
- Line scan over Pixel of Interest (PoI) @ V
- Voltage scan in the middle of PoI
- 2D scan @ Vmax

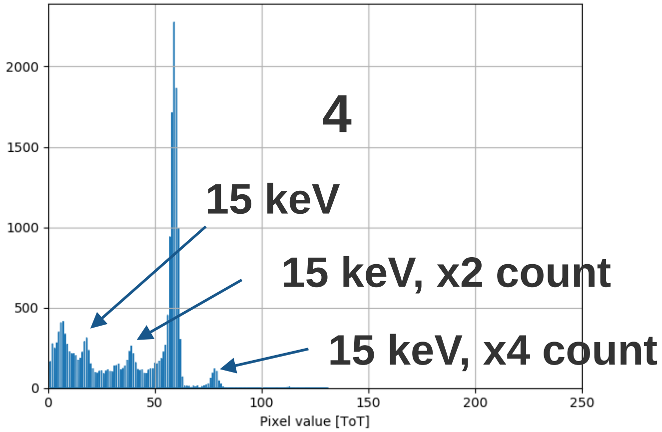
TPX3 settings

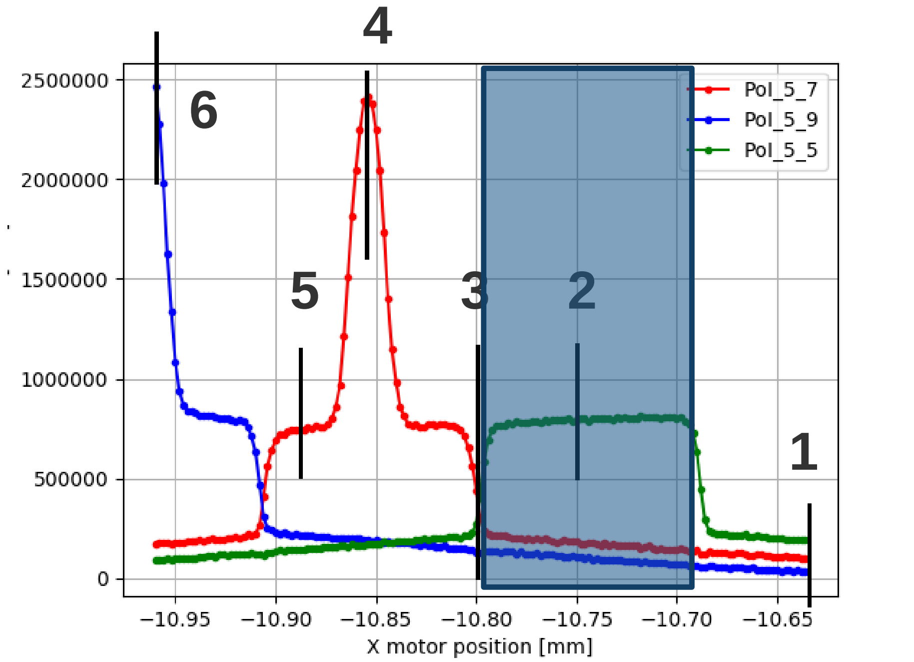
- ToT+ToA mode, data-driven
- AdvaDAQ TPX3 USB3.0

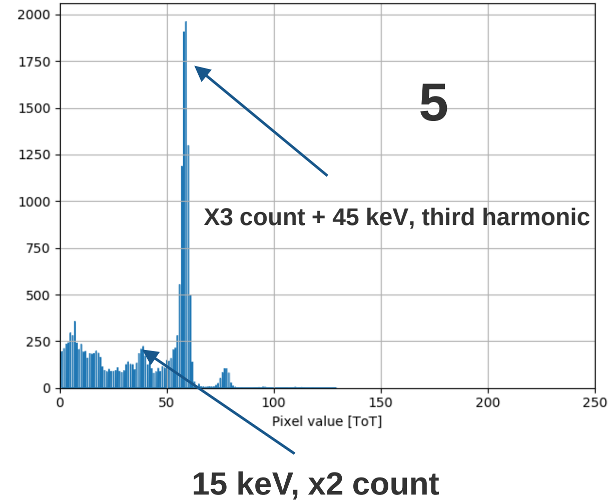
- I will show 110 um, 10 um JTE in detail
- I will show 110 um, 20 um JTE as comparison to 10 um JTE
- I will show 55 um, 5 um JTE

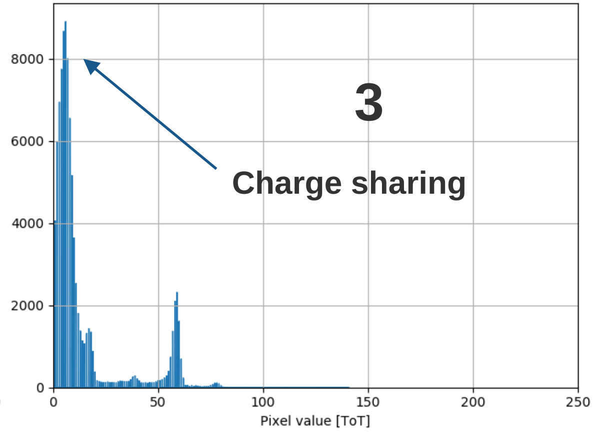
1D line scan, no gain pixel (5, 5), -350V

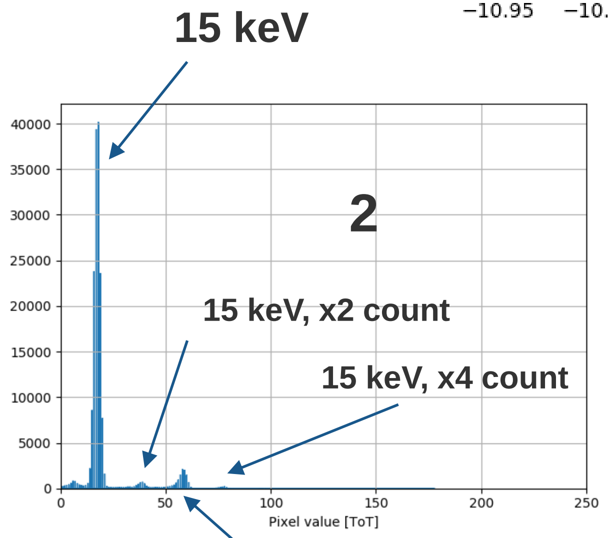


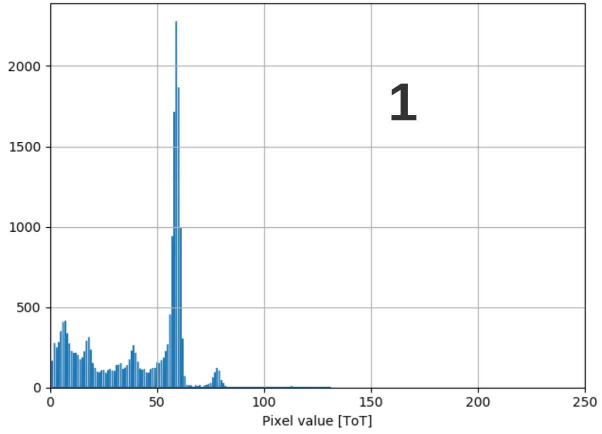




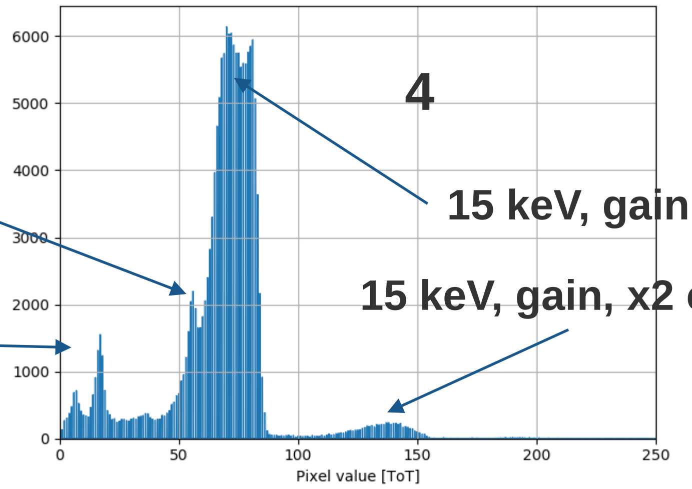


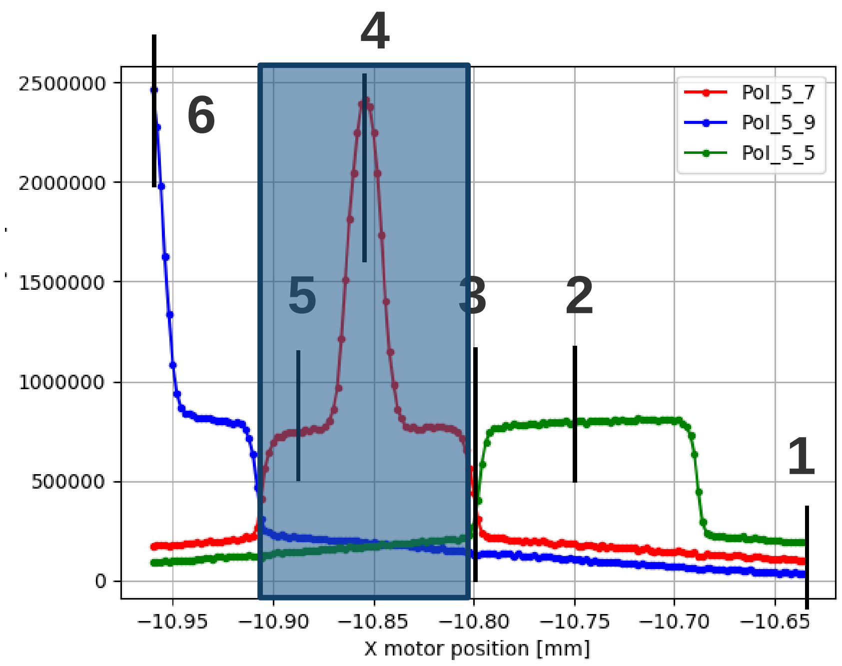


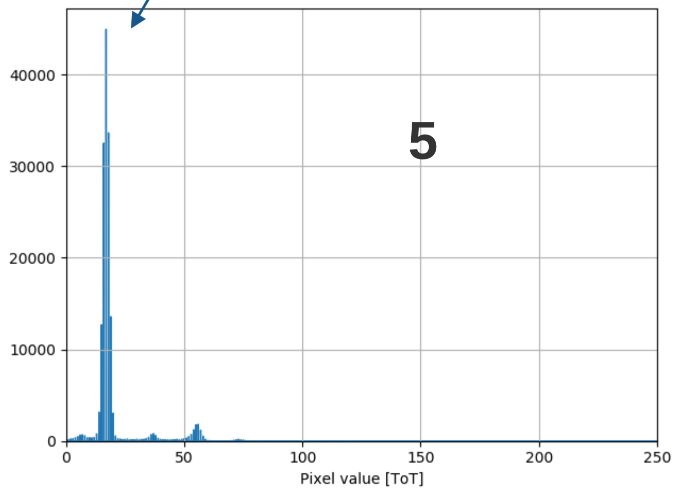


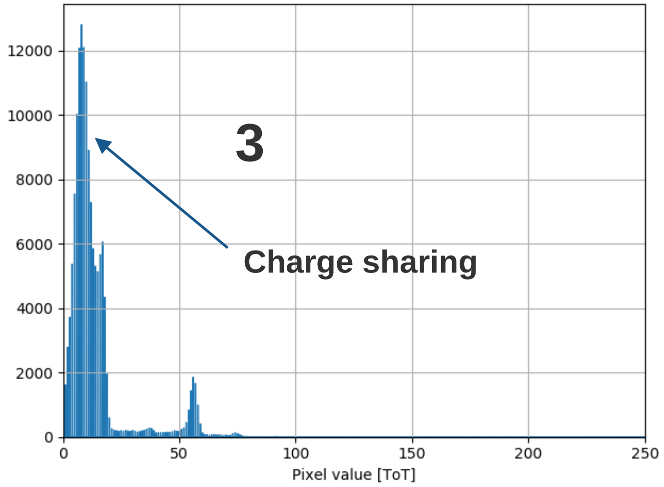


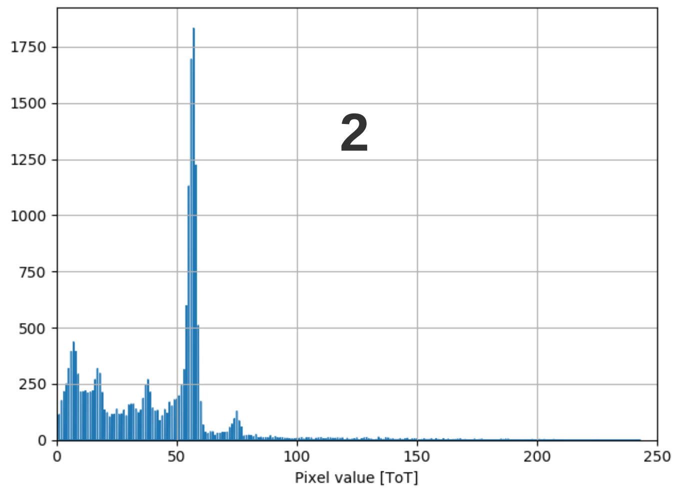
1D line scan, gain pixel (5, 7), -350V



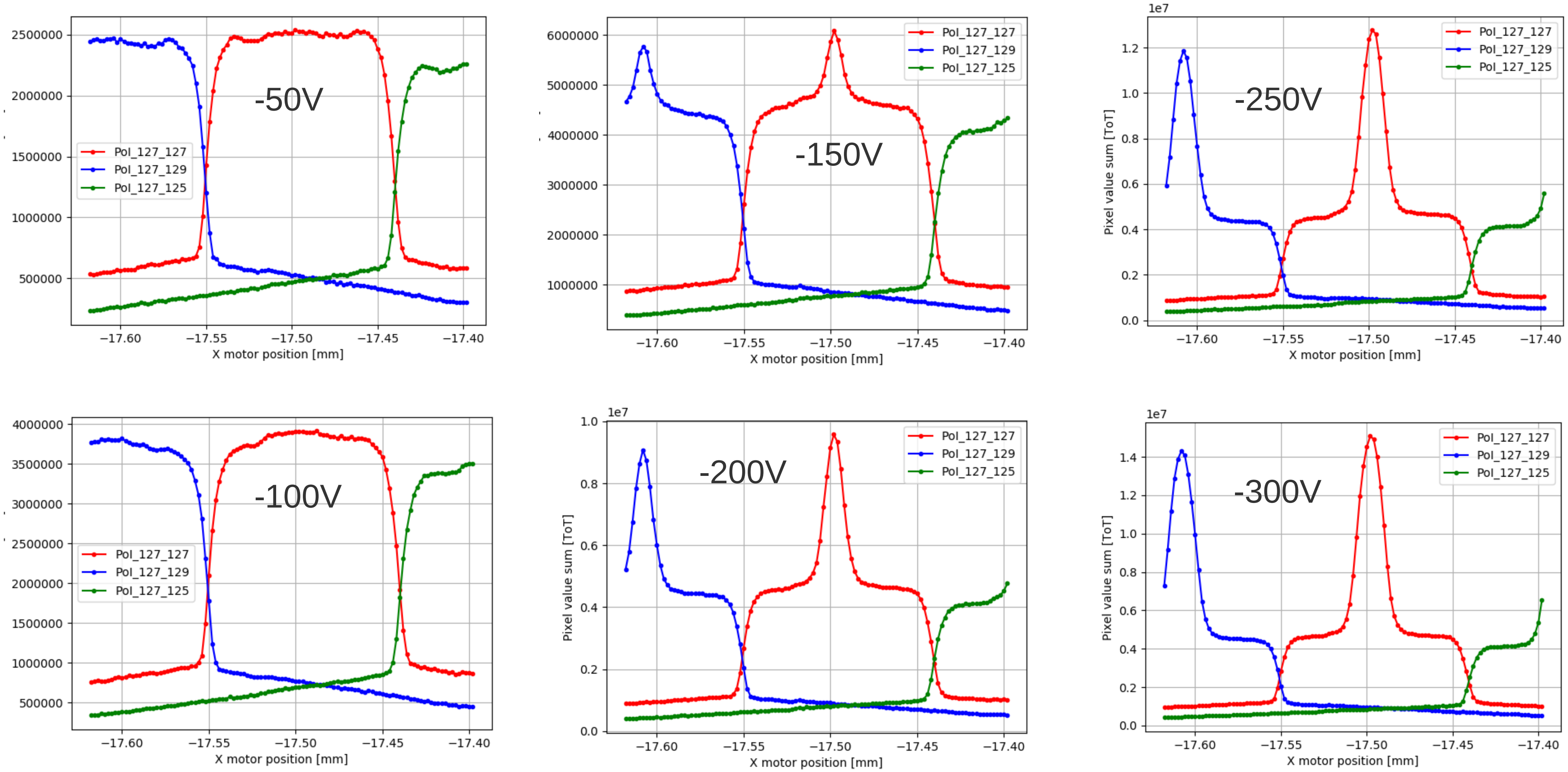




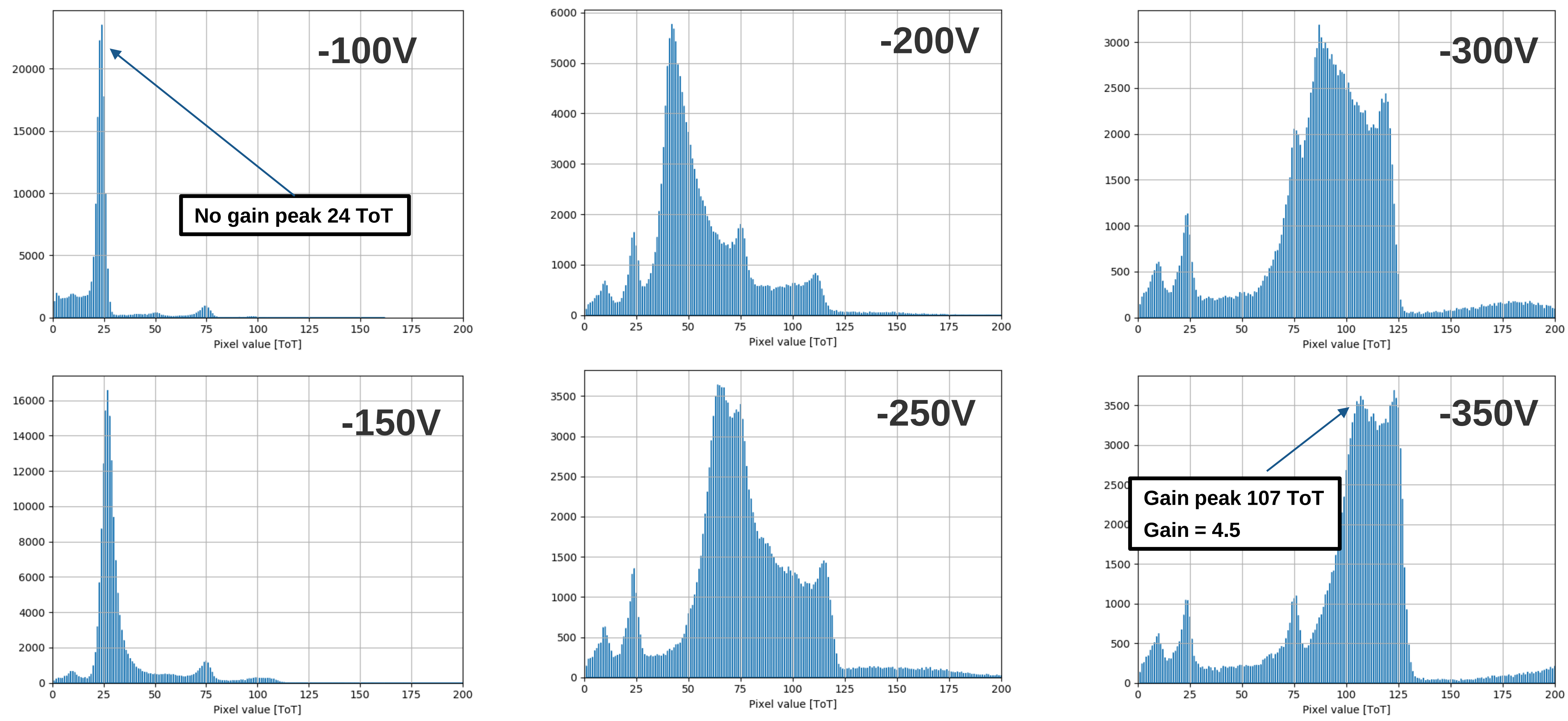




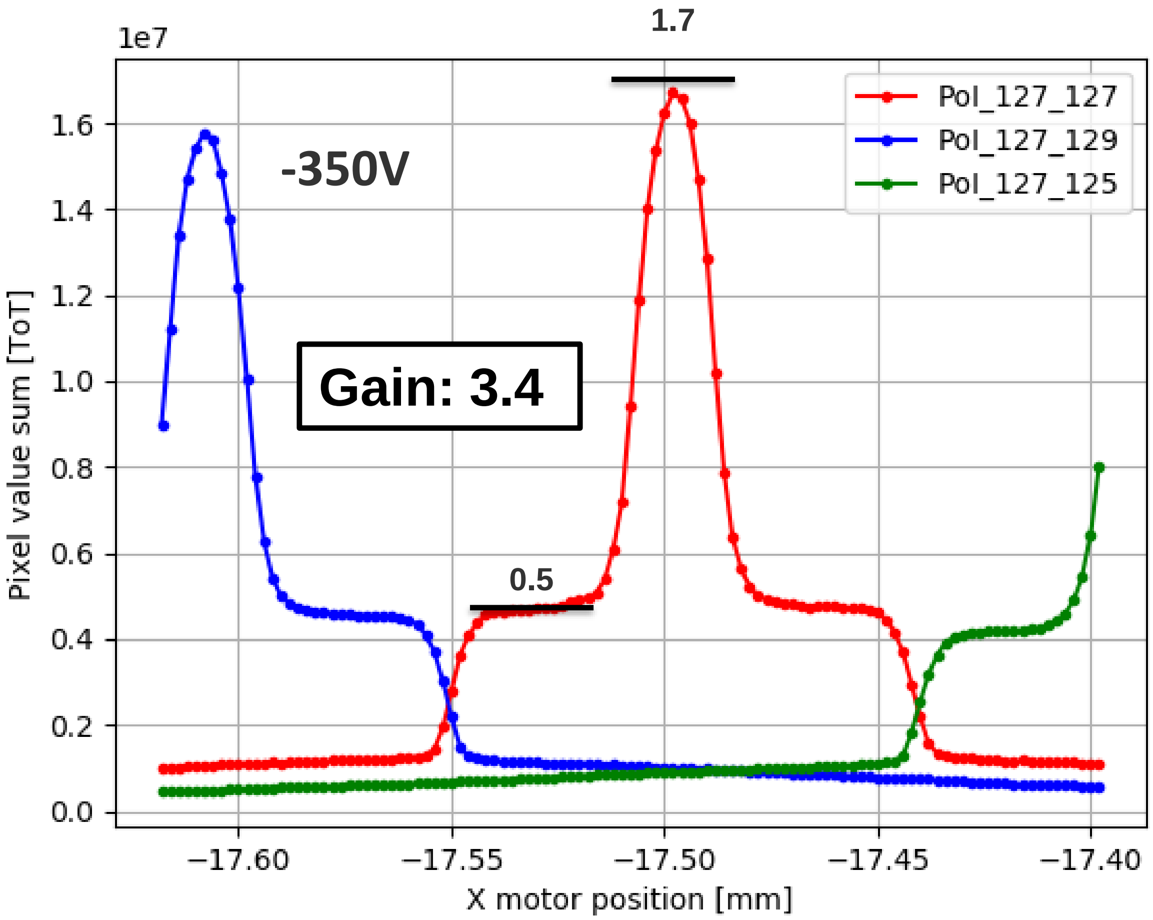
1D line scans @ voltages, gain pixel (127, 127)

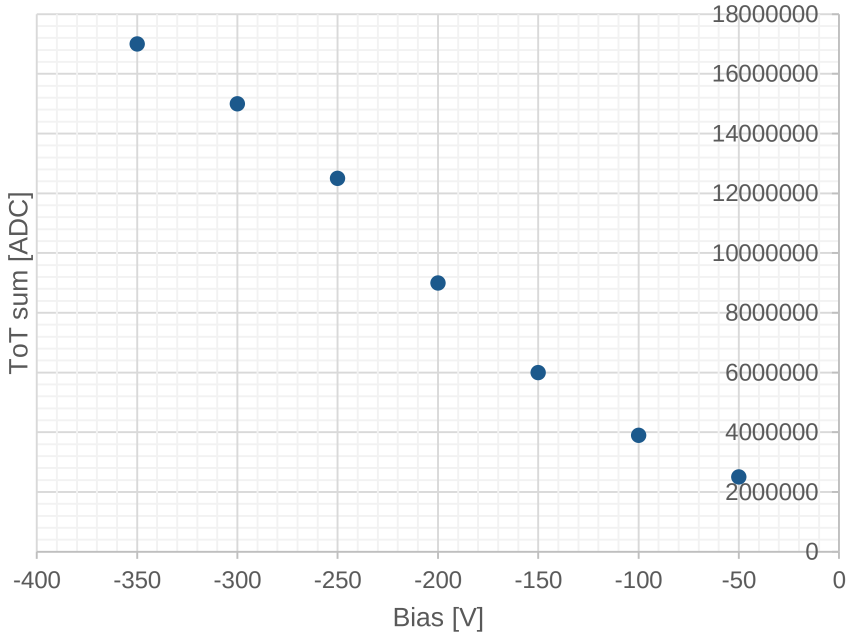


Spectrum in the middle of gain pixel (127, 127)

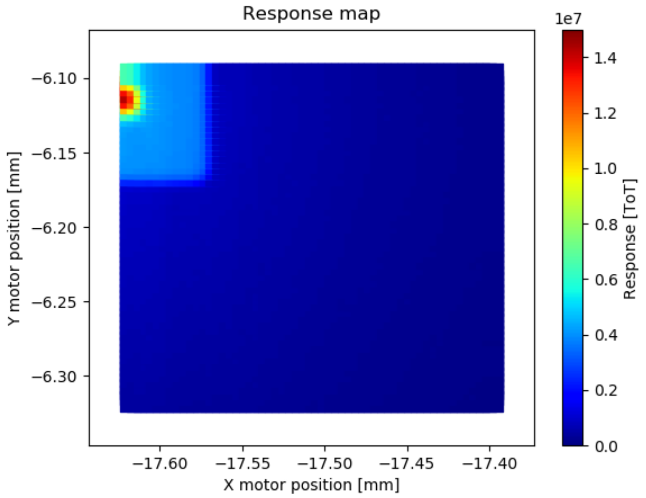


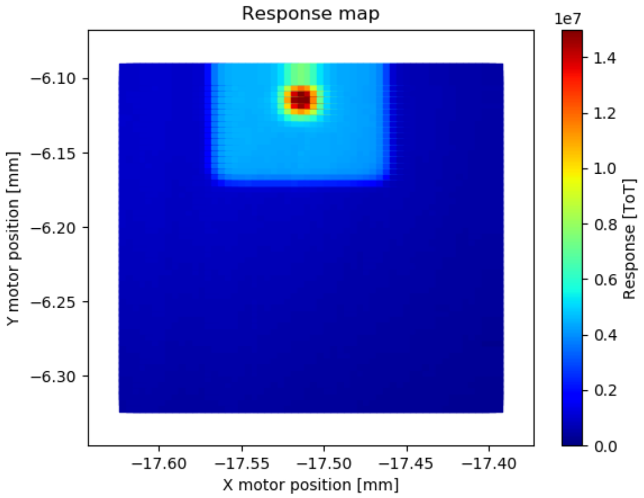
Gain @ voltages, gain pixel (127, 127)





2D scan (-350V)


Response map
1e7
Y motor position [mm]
X motor position [mm]
Response [ToT]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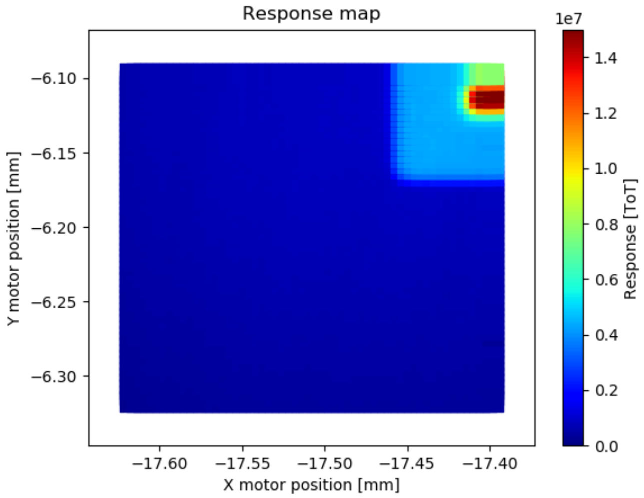
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Y motor position [mm]
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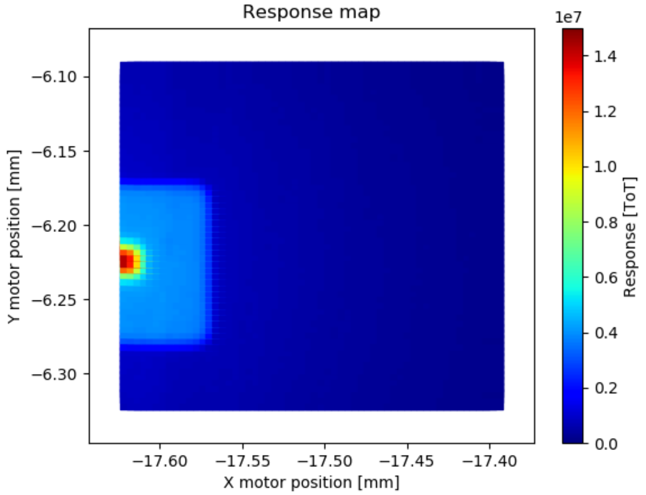
Response [ToT]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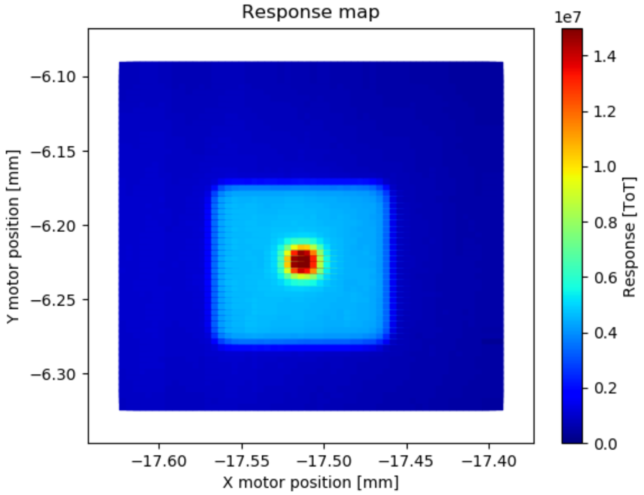
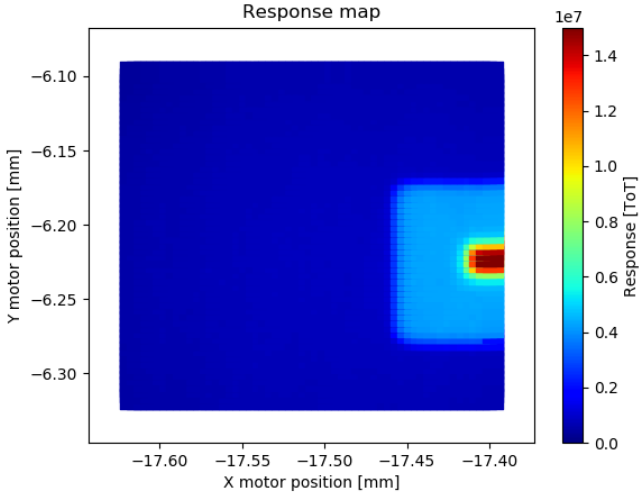
Response [ToT]


Response map
1e7
Y motor position [mm]
X motor position [mm]
Response [ToT]


Response map
1e7
Y motor position [mm]
X motor position [mm]
Response [ToT]

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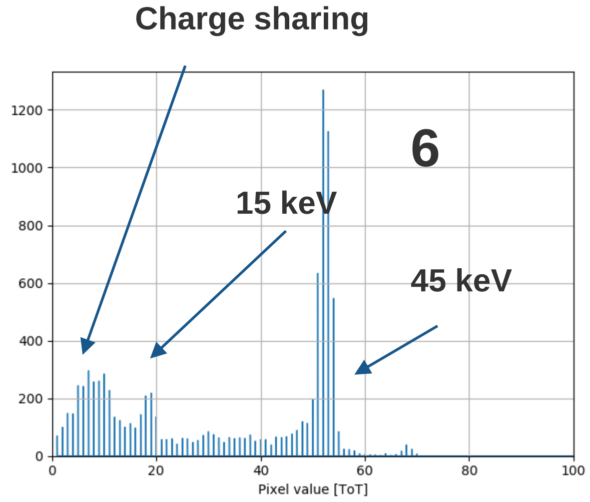
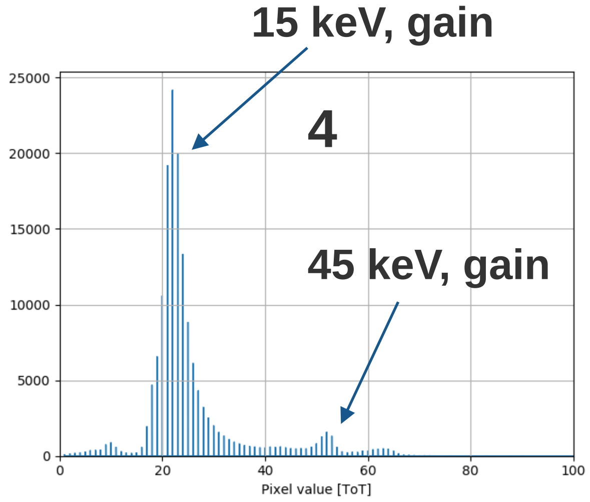
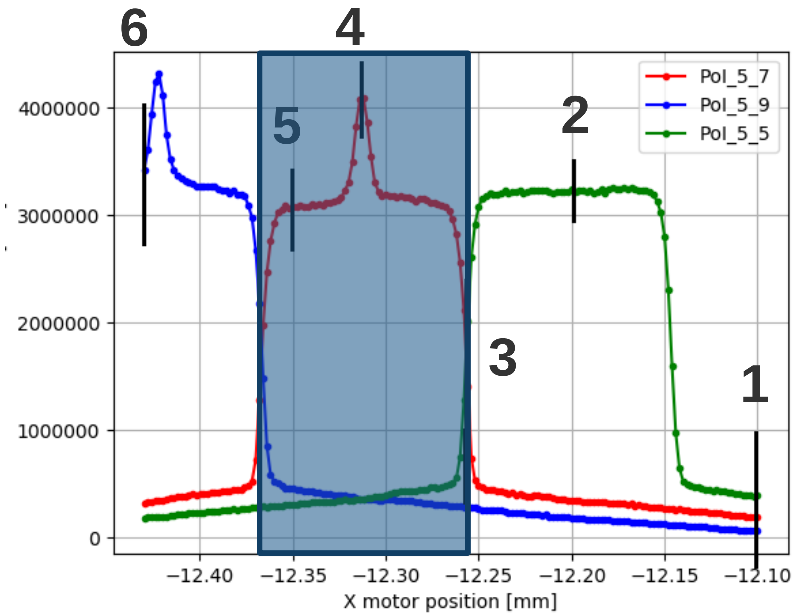
110 um pixel, 20 um JTE

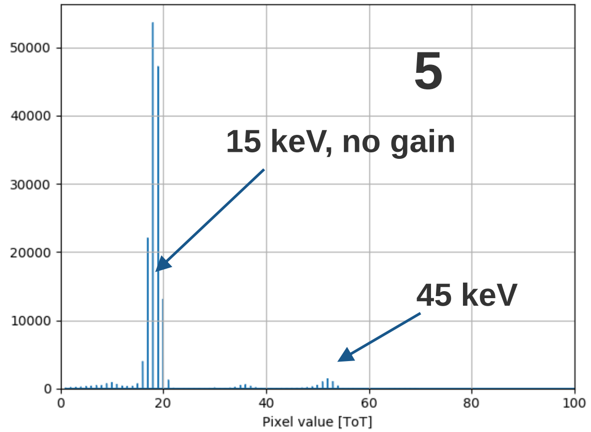
1D line scan, gain pixel (5, 7), -350V

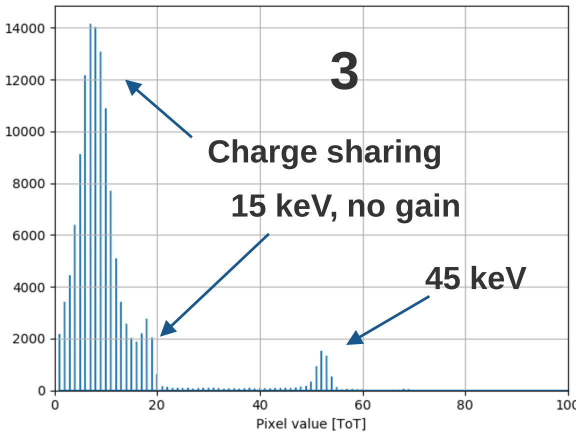
Note! No x2 count peak, so 45 keV is 3rd harmonic only!

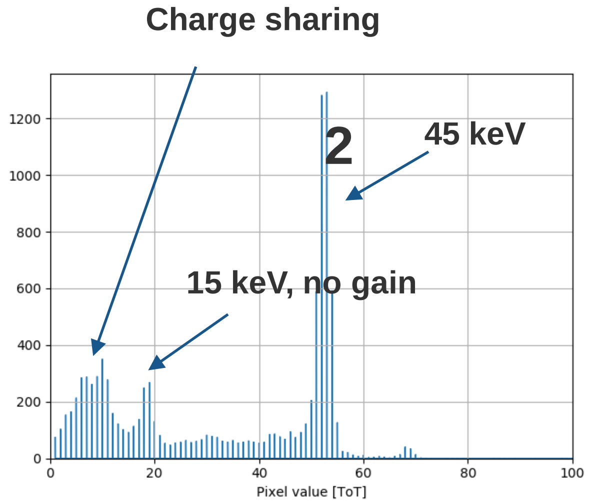


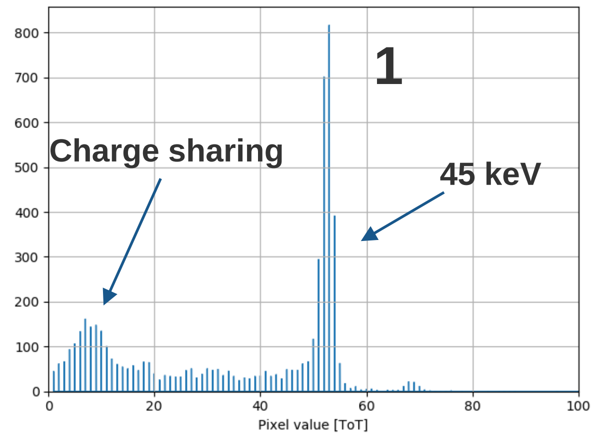






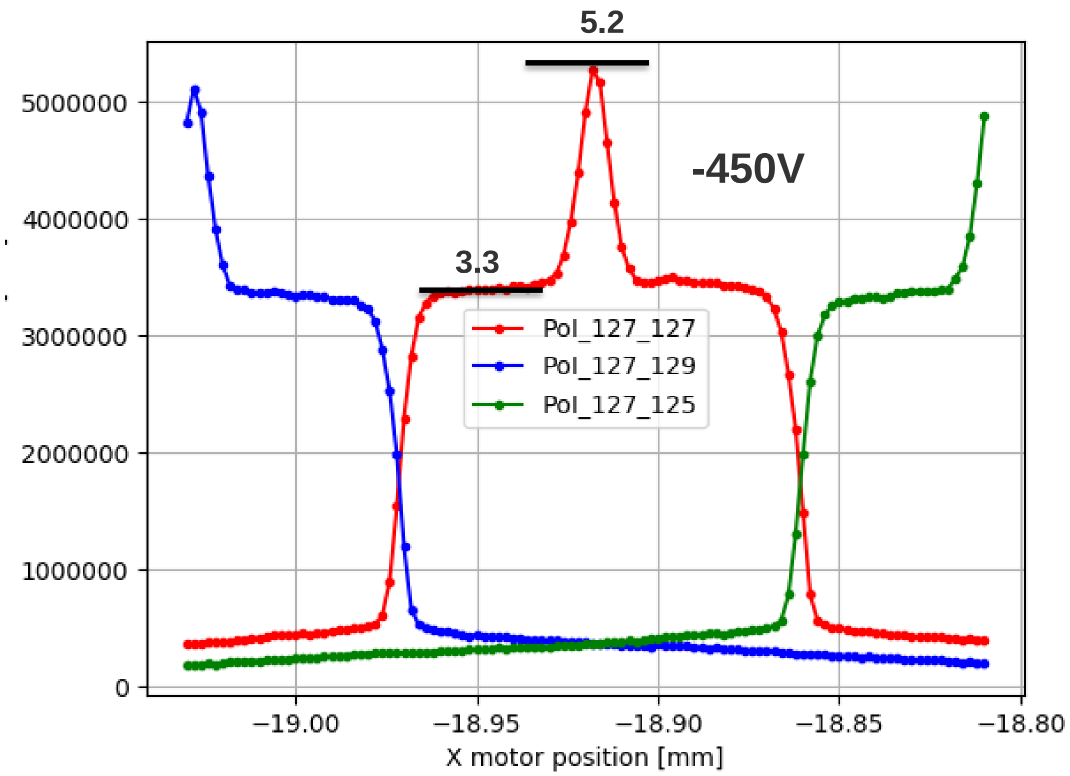






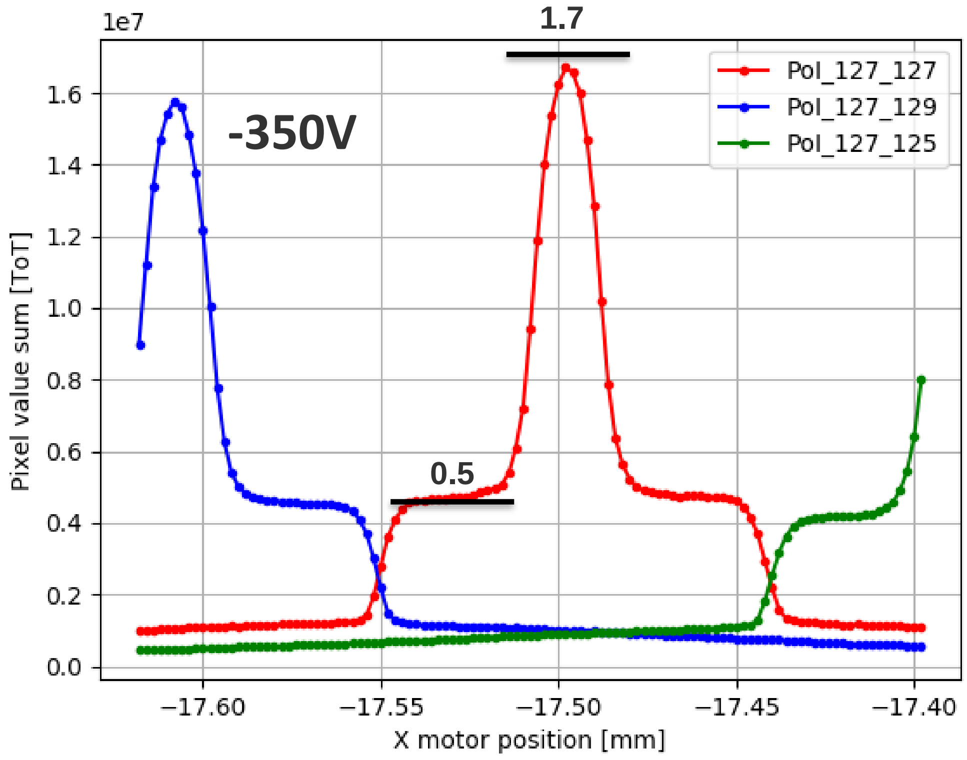
110 um pixel, 20 vs 10 um JTE

110 um pixel, 20 um JTE



Gain: 1.6

110 um pixel, 10 um JTE

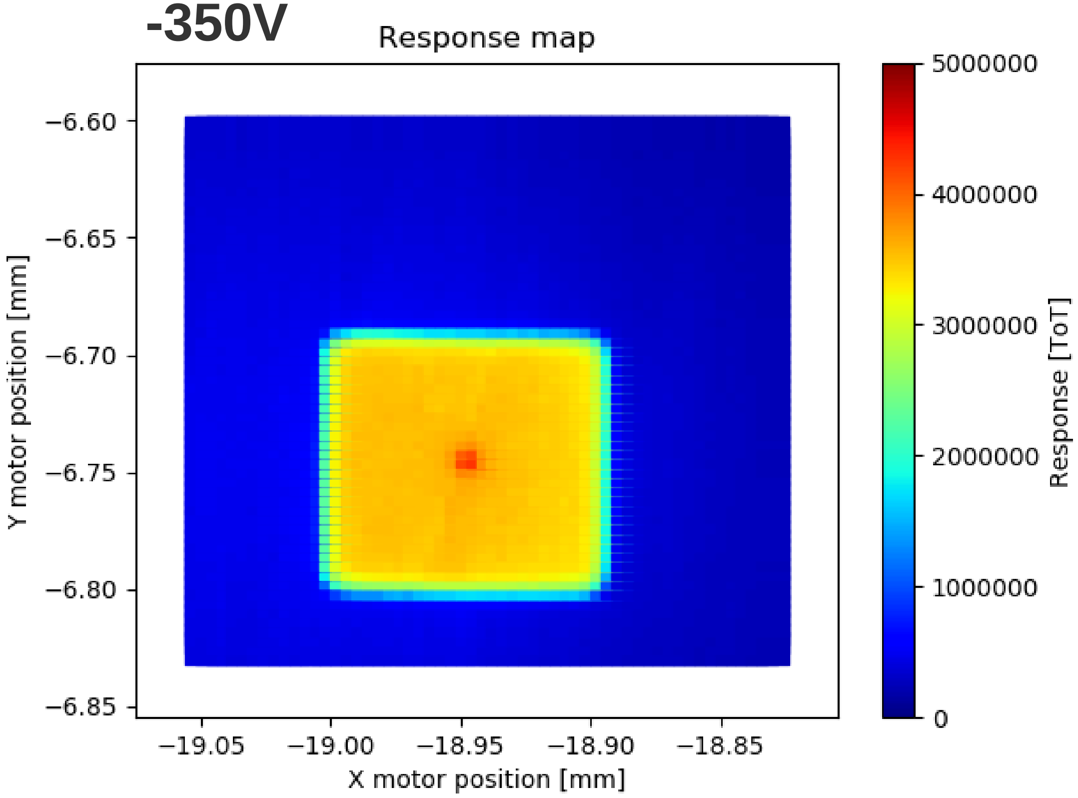


Gain: 3.4

110 um pixel, 20 vs 10 um JTE

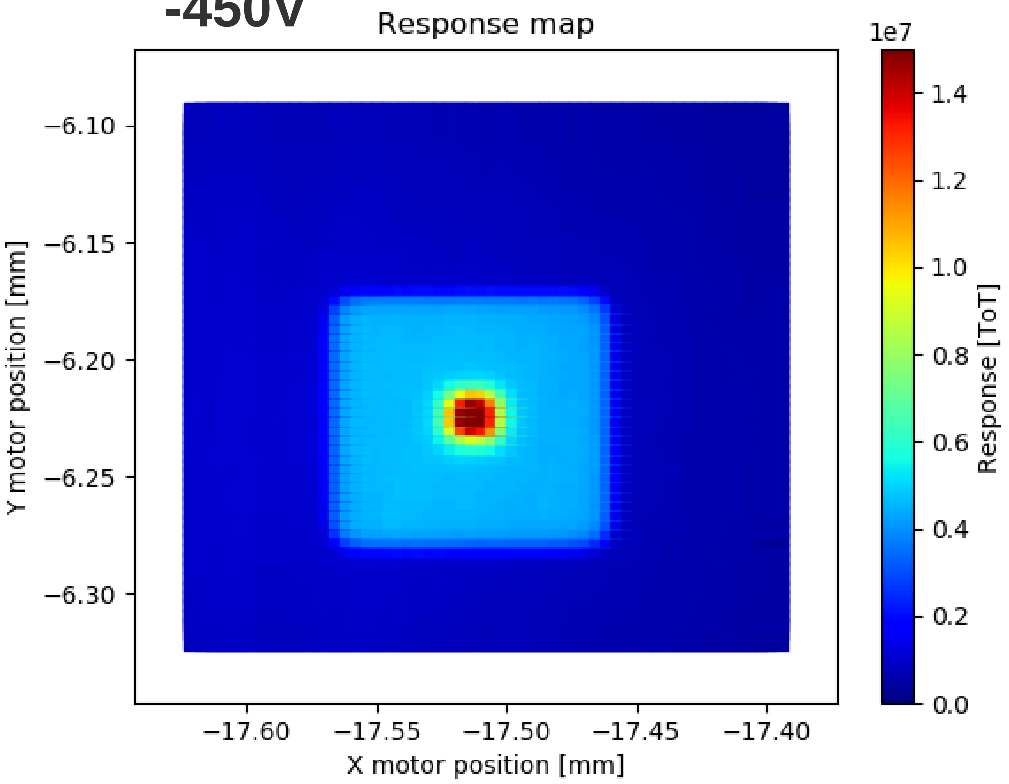
110 um pixel, 20 um JTE

-350V

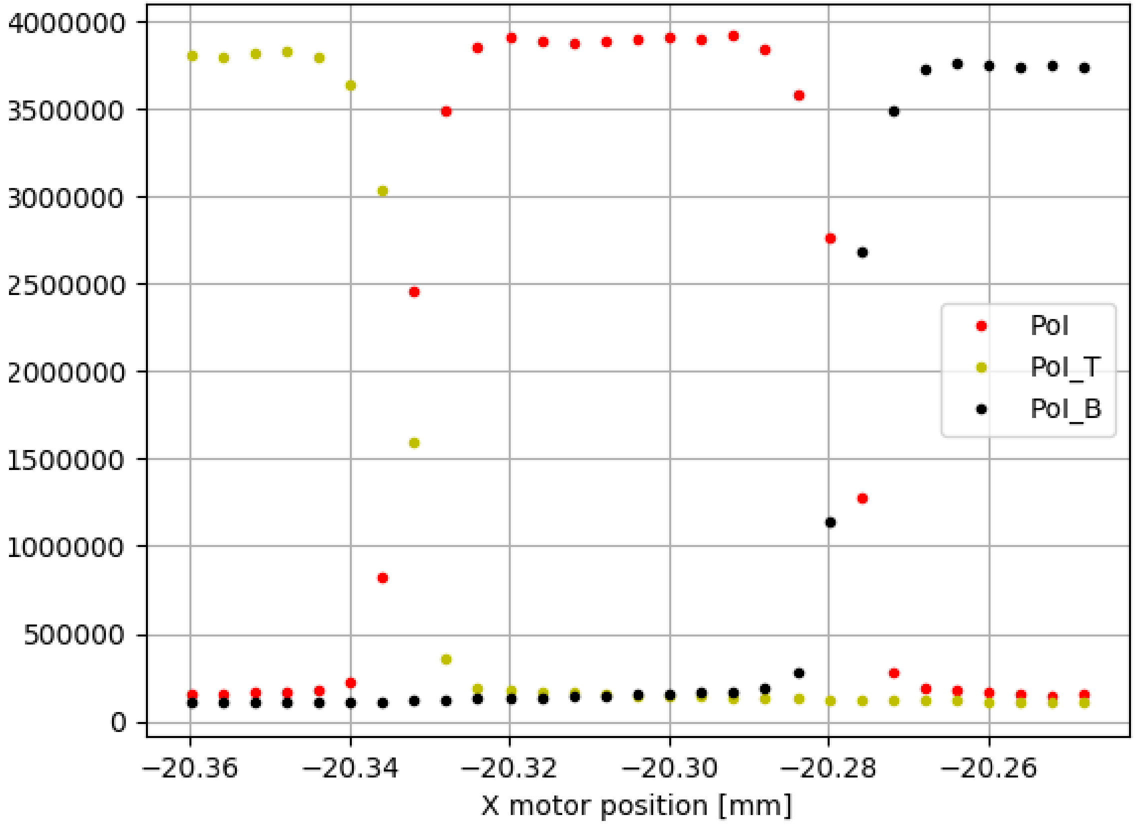


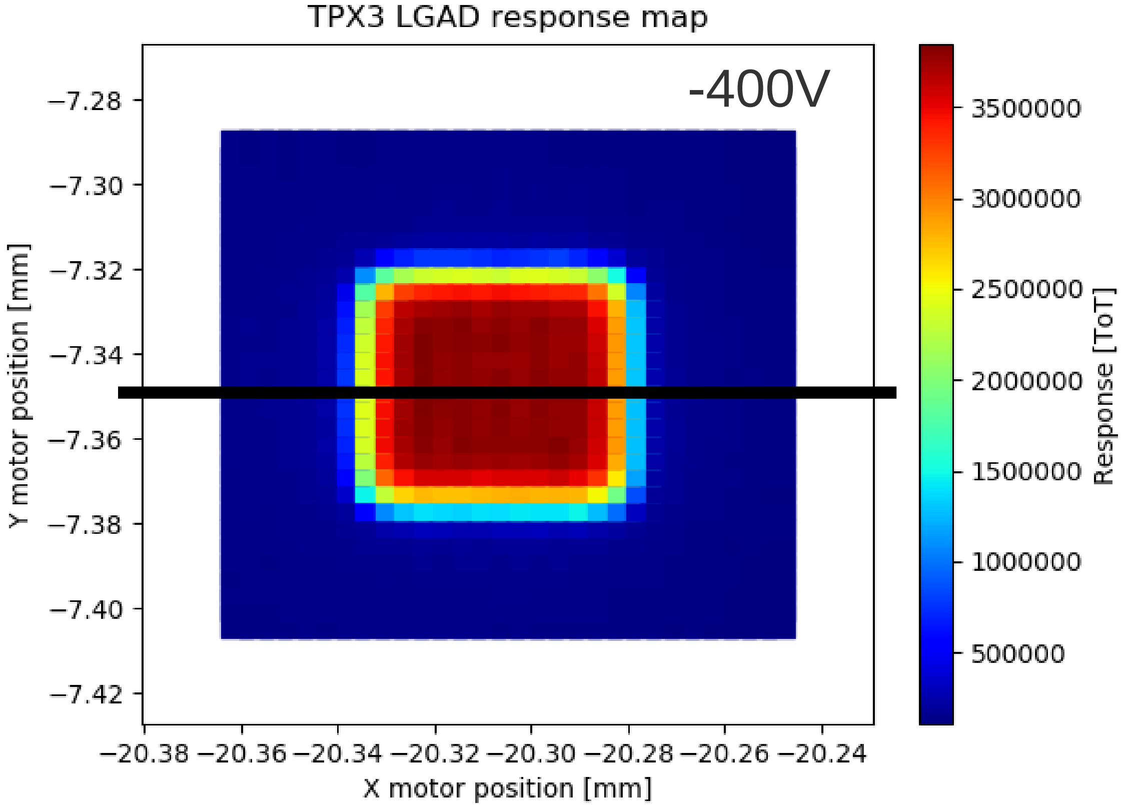
110 um pixel, 10 um JTE

-450V



55 um pixel, 5 um JTE





No gain observed as expected

Options for small pixels - Inverse LGAD

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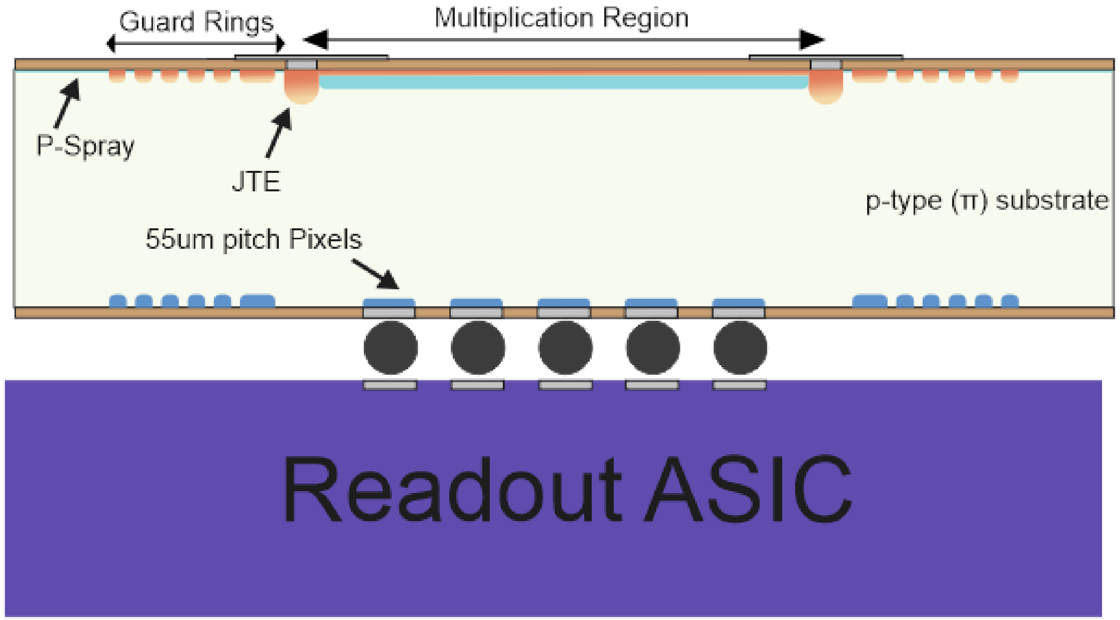
- Segmentation at the ohmic contact: strip and pixels.
- Multiplication extended over all the device.
- P-type collector ring at the ohmic side to extract leakage current.
- JTE to protect the n+/p curvature and channel stopper to avoid the depletion reaches the end of the detector.
- Readout is made by the strips/pixels: holes collection.

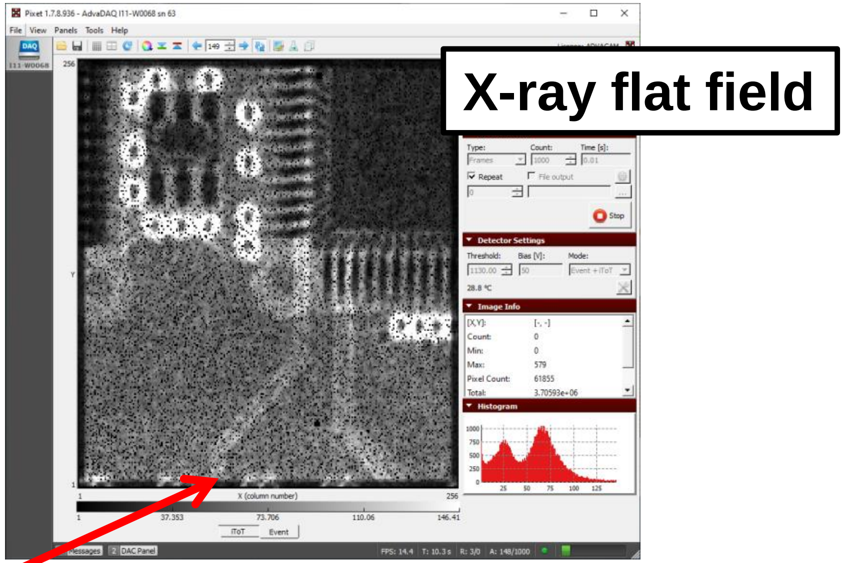


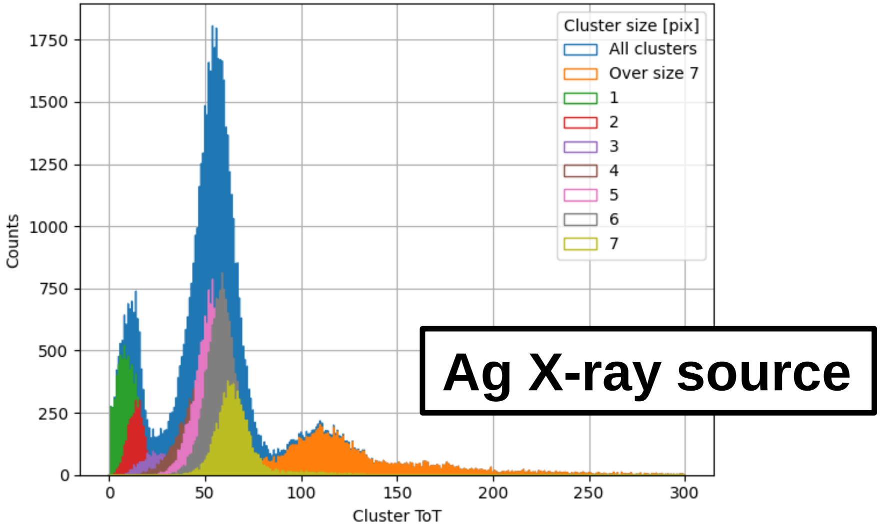
Cons
- Double side processing
- Backside sensitive to scratches
- Needs to be fully depleted

Status

- Wafers with two gain implants
- Pixels 55, 110, 220 um
- Program to:
- Measure and understand spectra
- In-pixel gain uniformity:
  - Test beam at Diamond (Mid July)
  - Test beam at CERN SPS (Mid August)

3 pixel no gain rim around the detector



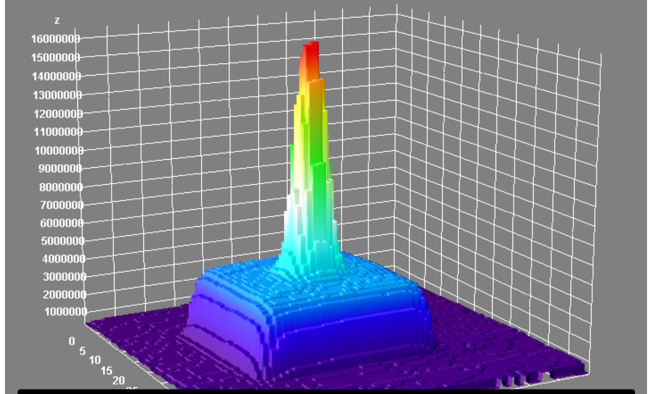


Summary and conclusion

Summary

- Strong program to design, produce and test LGAD devices
  - TCAD simulations
  - Mask design, device fabrication
  - Device characterisation by means of IV, CV, TCT and X-rays
- Predicted and demonstrated gain in small pixel devices
  - Various pixel sizes
  - Various JTE sizes
- Pathway to overcome existing limitations
  - Inverse LGAD design (fabricated, characterisation just started)
  - Trench isolation design (work in progress)

3D representation



110 um pixel, 10 um JTE