39th RD50 Workshop, Valencia, Spain

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

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https://indico.cern.ch/event/1074989

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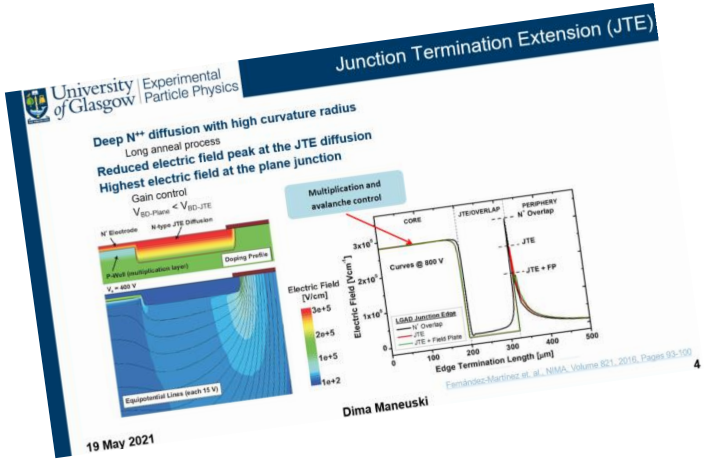
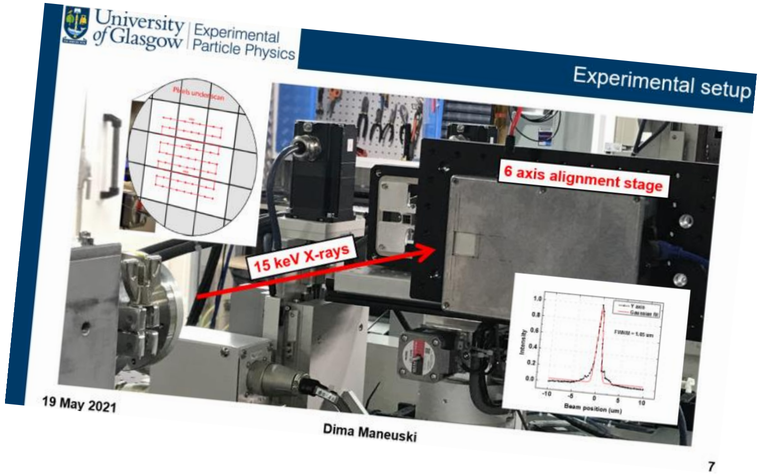




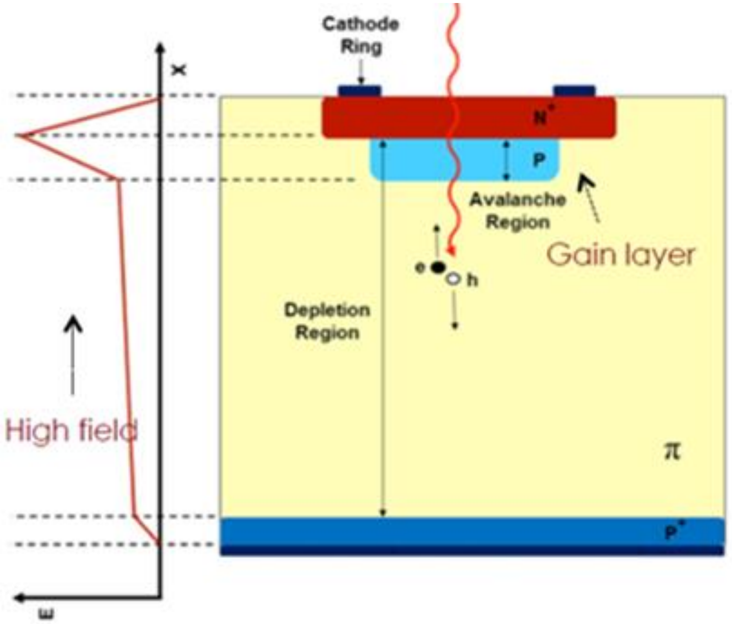
Research agenda and motivation

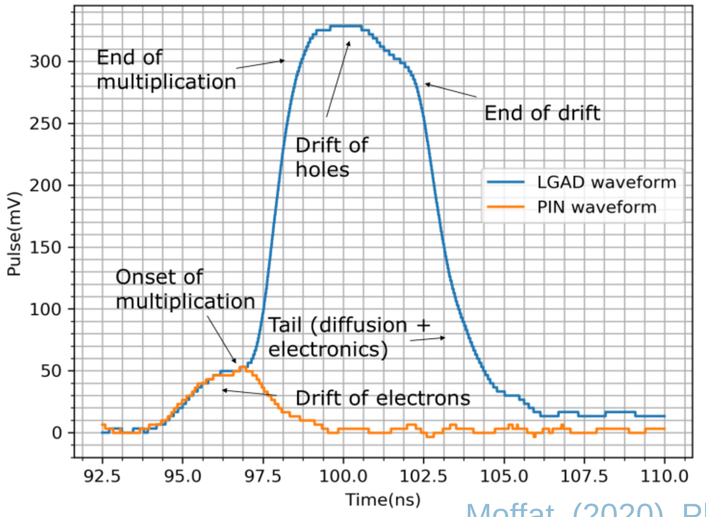
- Fast timing silicon pixel detectors (sub 100 ps)
- "Tender" energy x-rays detectors (and below)

- 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

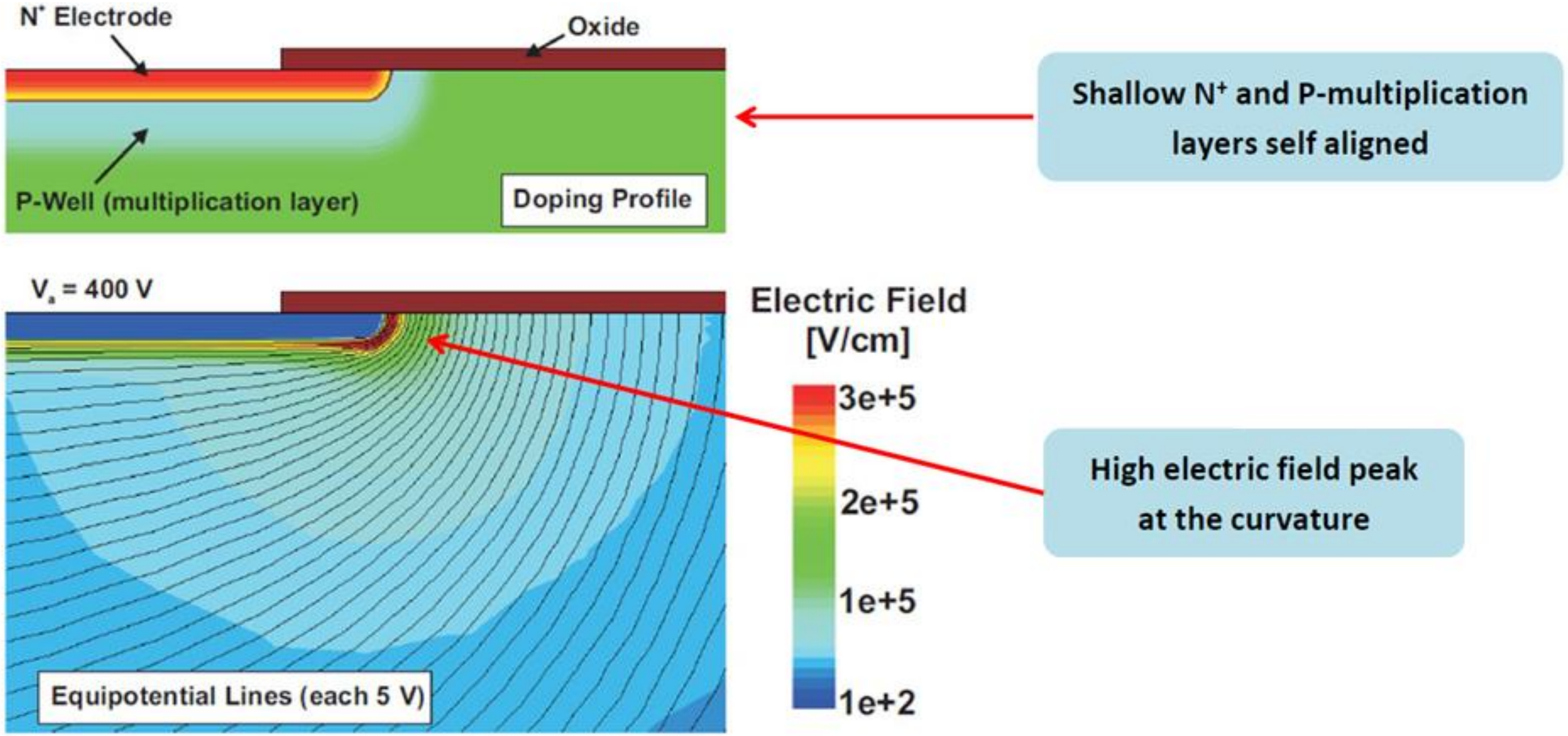
Edge termination: why is it needed?

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

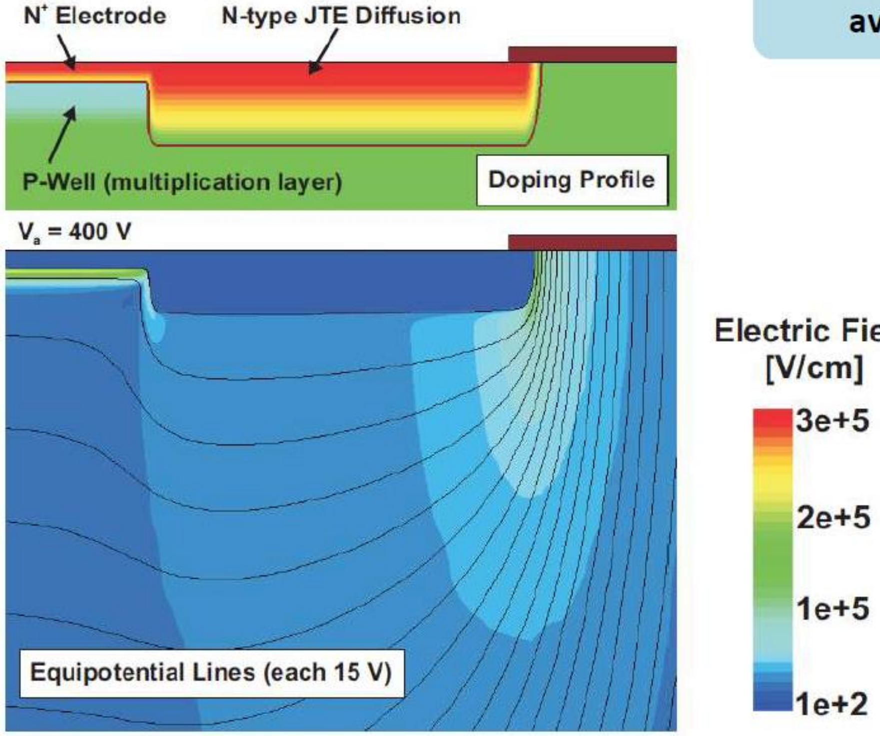
Long anneal process

Reduced electric field peak at the JTE diffusion

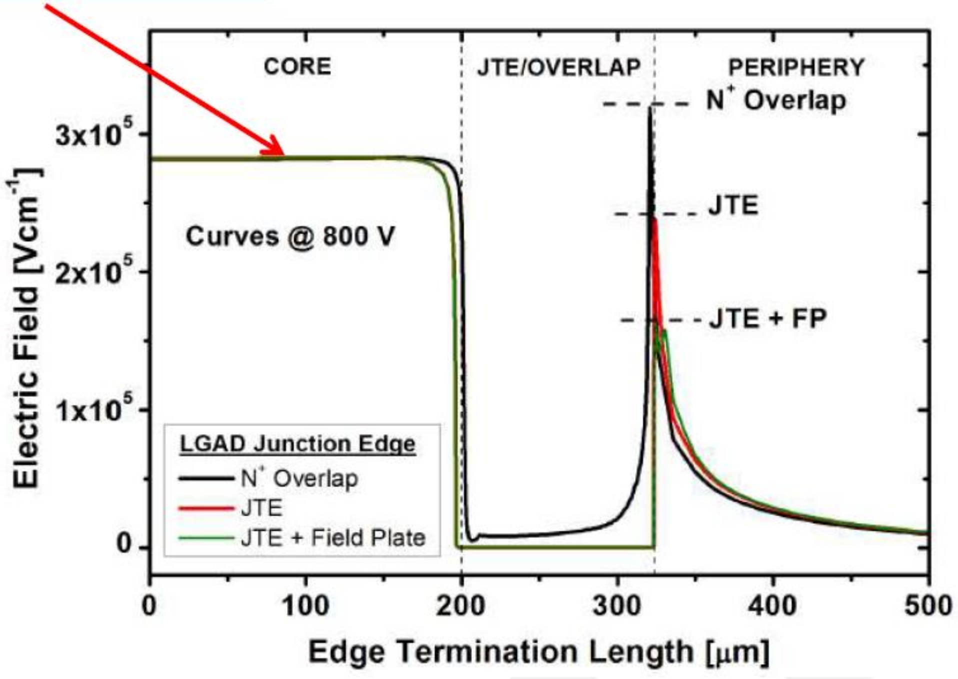
Highest electric field at the plane junction

Gain control

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



Multiplication and avalanche control



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

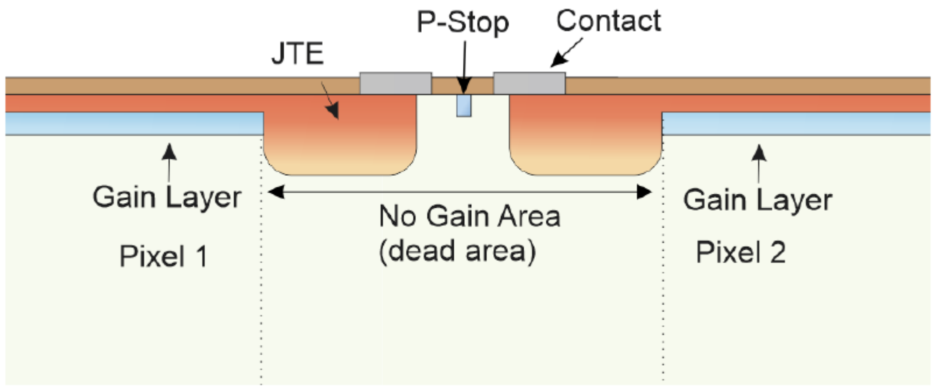
Small pixels – poor fill factor

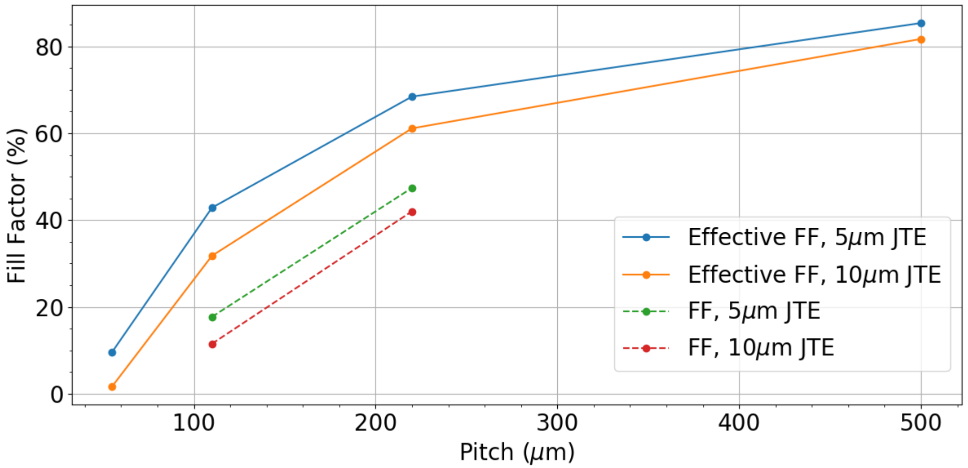
Geometric fill factor

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

Caused by JTE around each pixel

Need to take into account diffusion on JTE





50 x 50 μm^2 pixel – JTE 10 μm -> fill factor < 10%

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

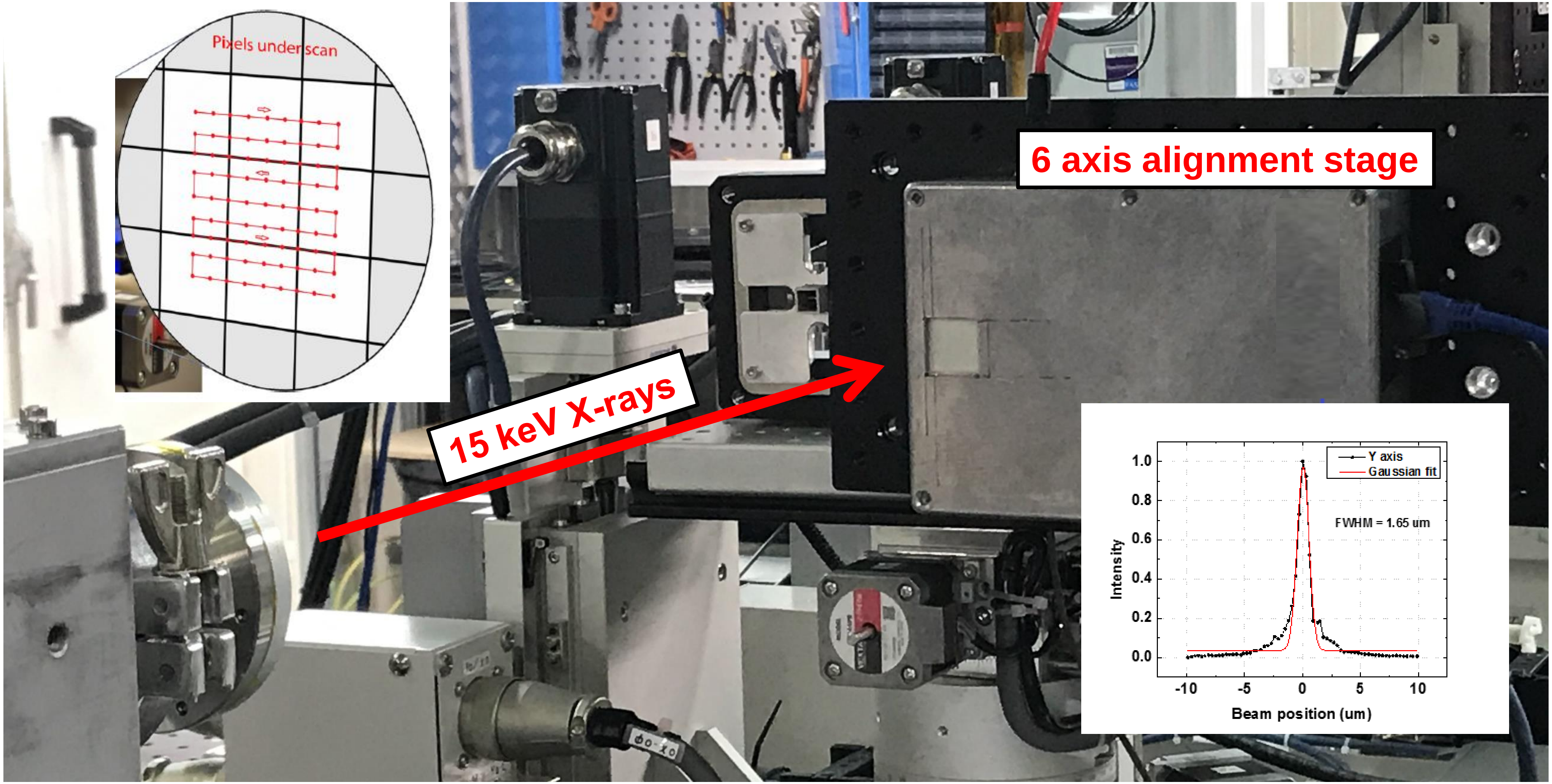
B16: Test Beamline

- 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

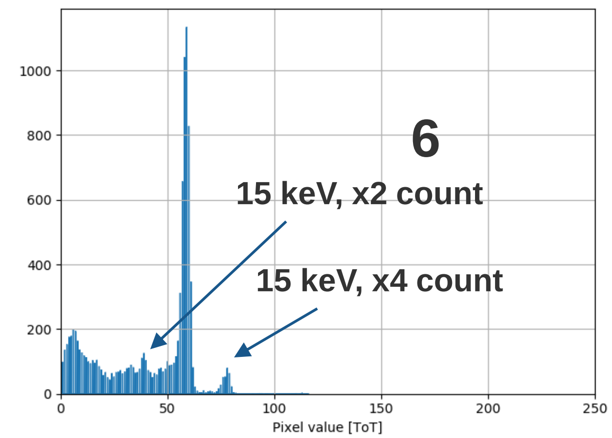
- Line scan over Pixel of Interest (POI) @ V
- Voltage scan in the middle of PoI
- 2D scan @ Vmax

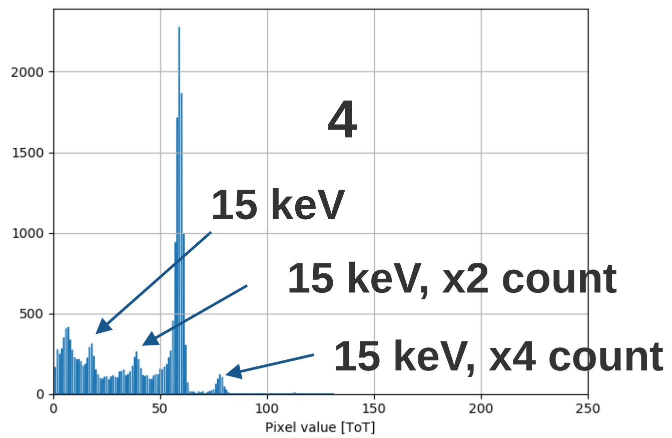
TPX3 settings

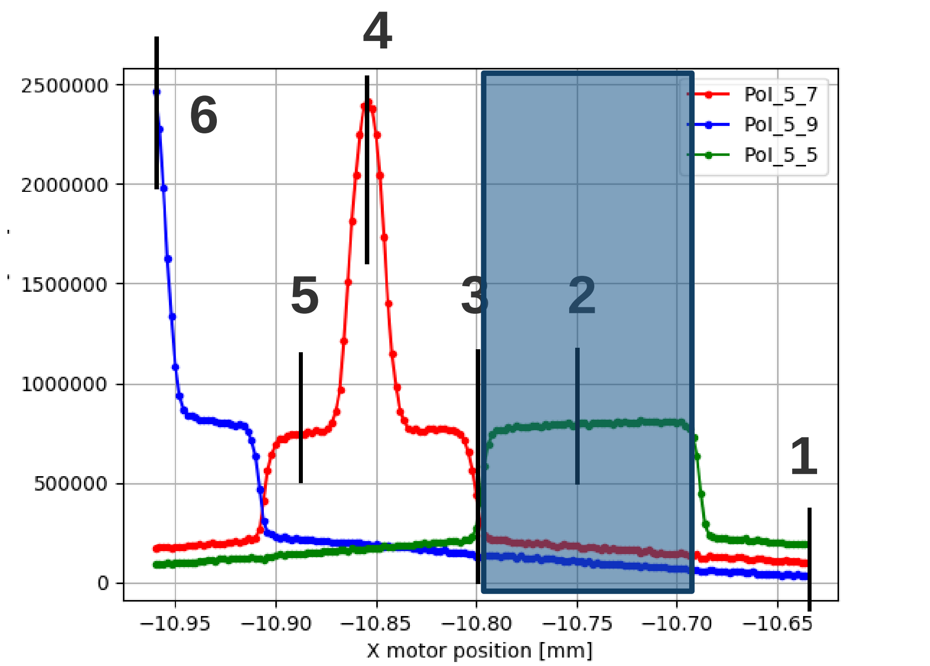
- ToT+ToA mode, data-driven
- AdvaDAQ TPX3 USB3.0

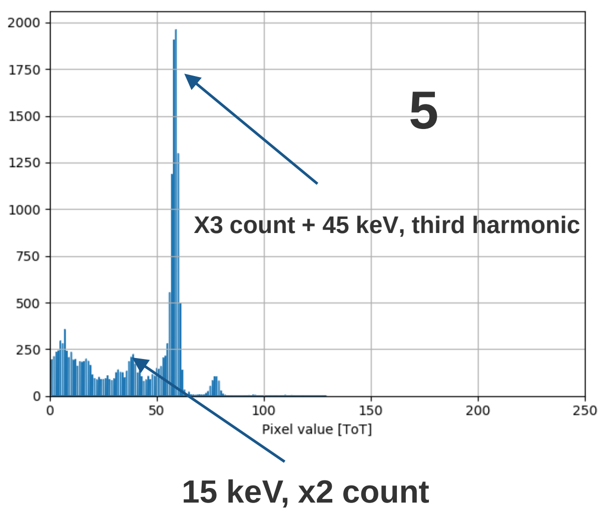
- I will show 110 um, 10 um JTE in detail
- I will show 110 um, 20 um JTE as comparison to 10 um JTE
- I will show 55 um, 5 um JTE

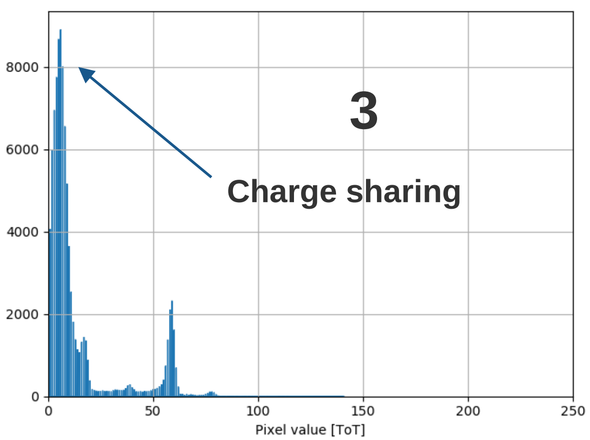
1D line scan, no gain pixel (5, 5), -350V

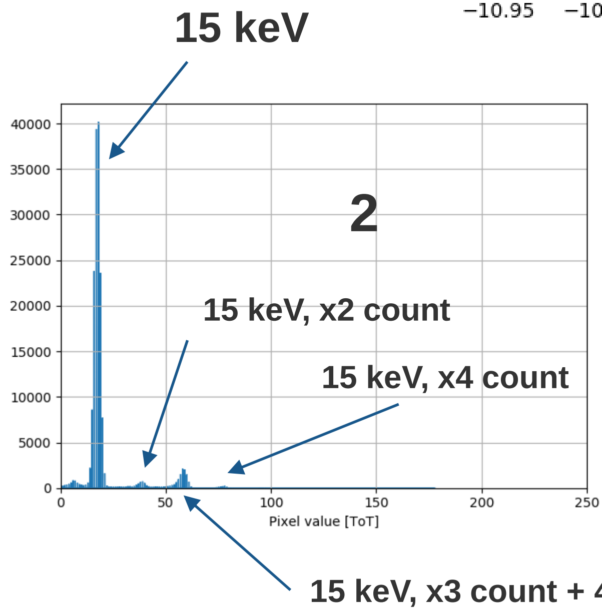


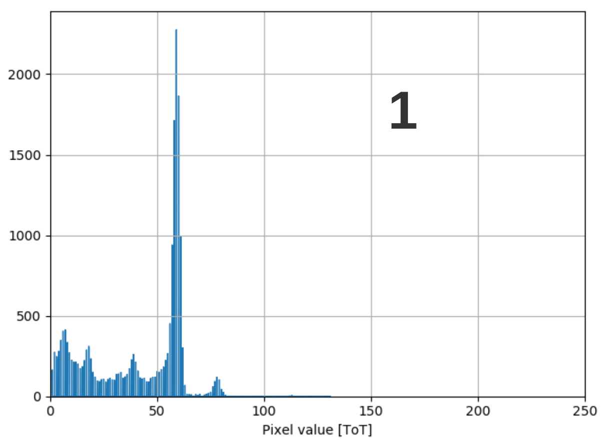




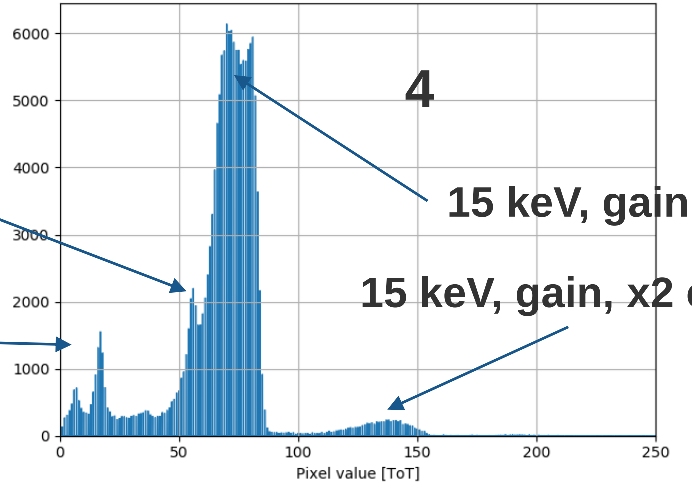








1D line scan, gain pixel (5, 7), -350V

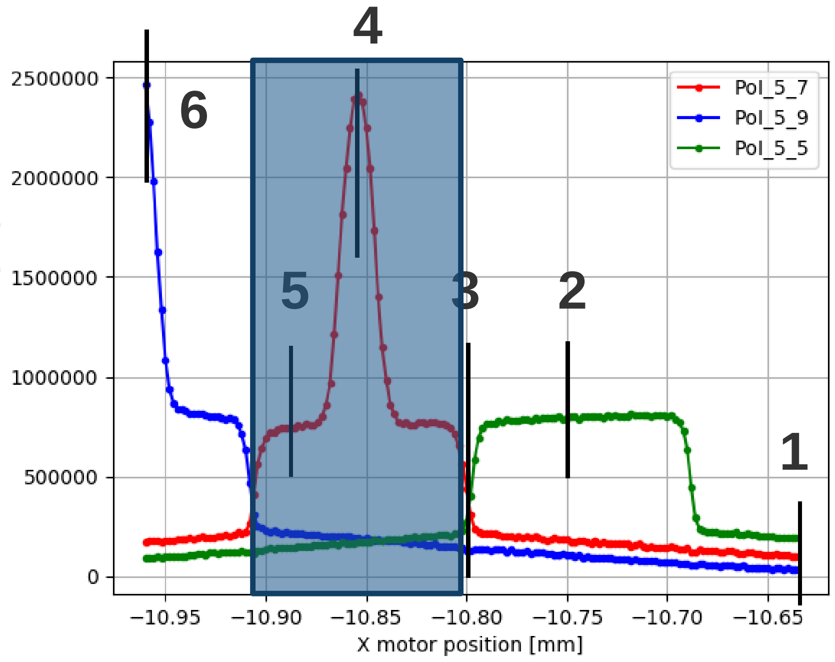


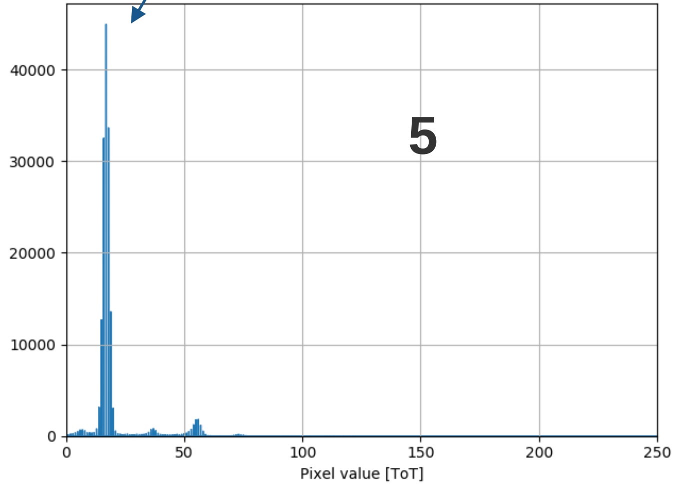
45 keV, 3rd harmonic

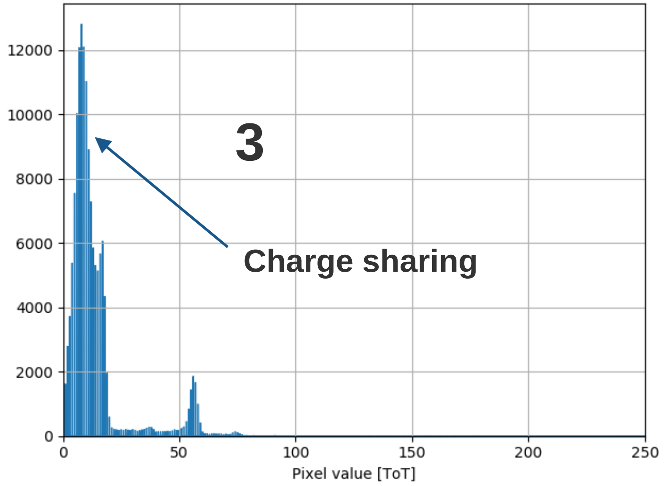
15 keV, gain

15 keV, no gain

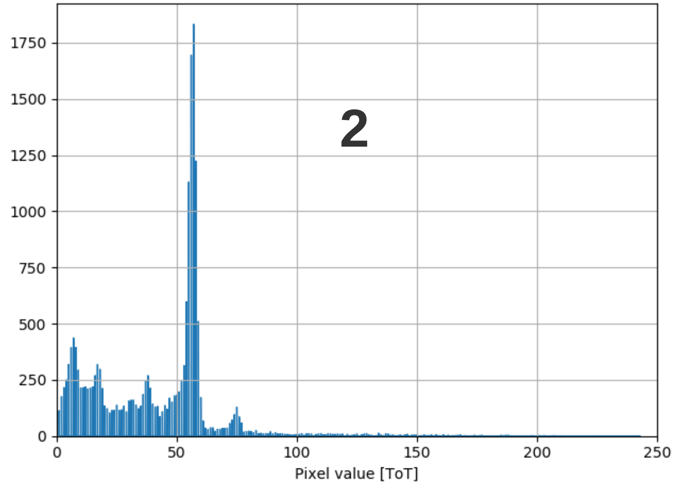
15 keV, gain, x2 count



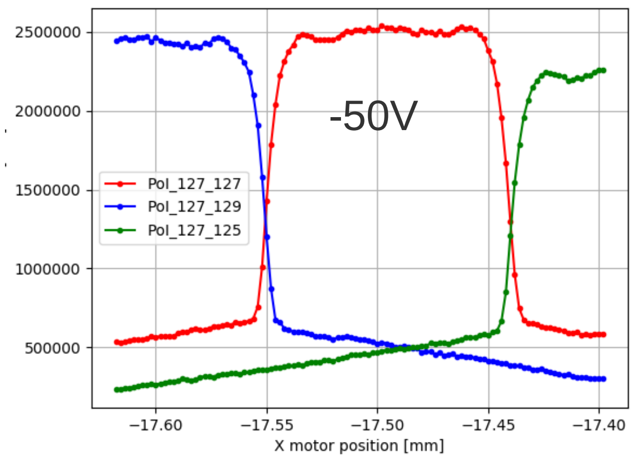


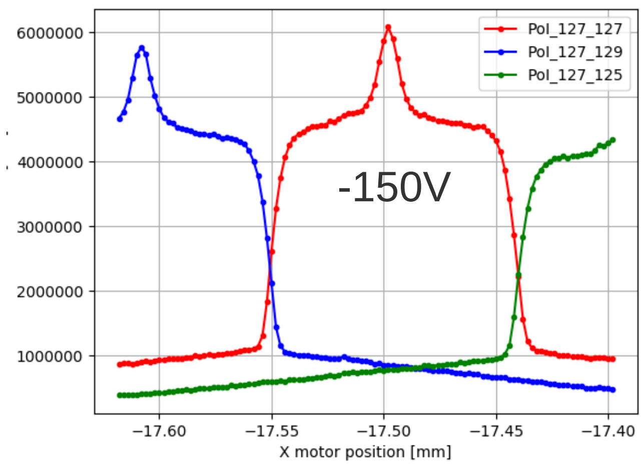


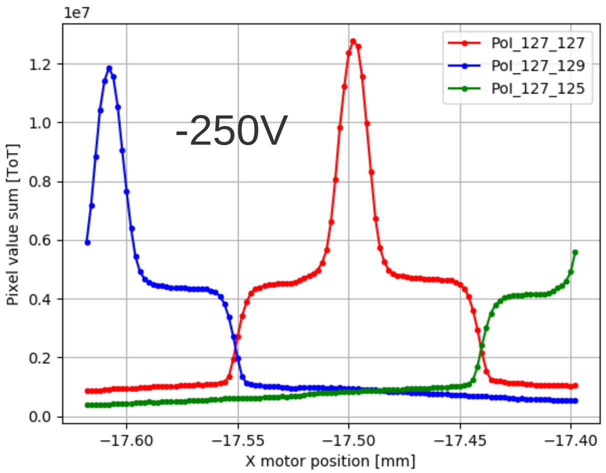
Charge sharing

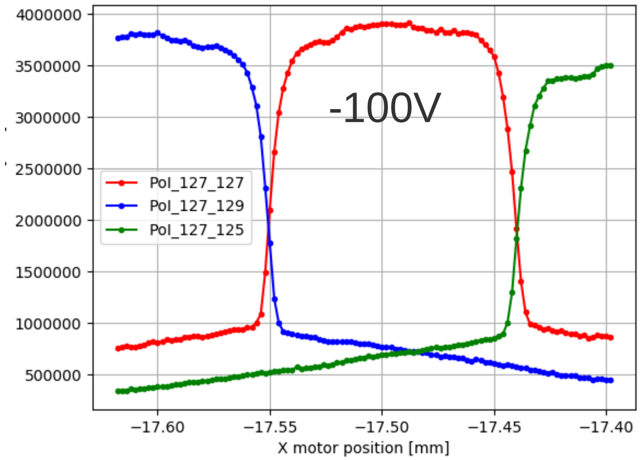


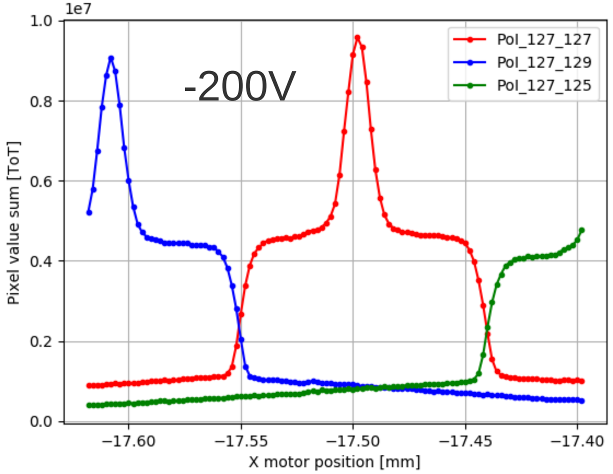
1D line scans @ voltages, gain pixel (127, 127)

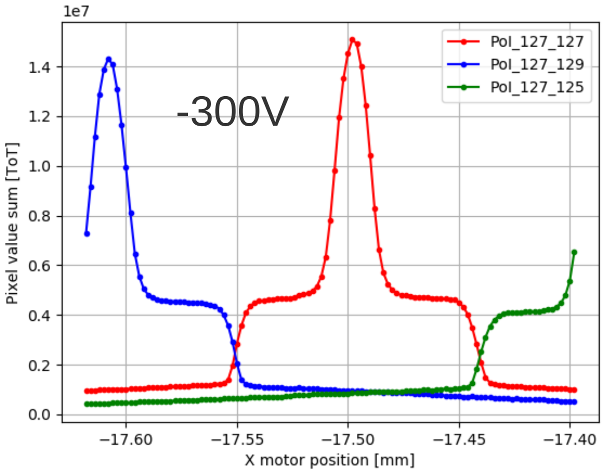




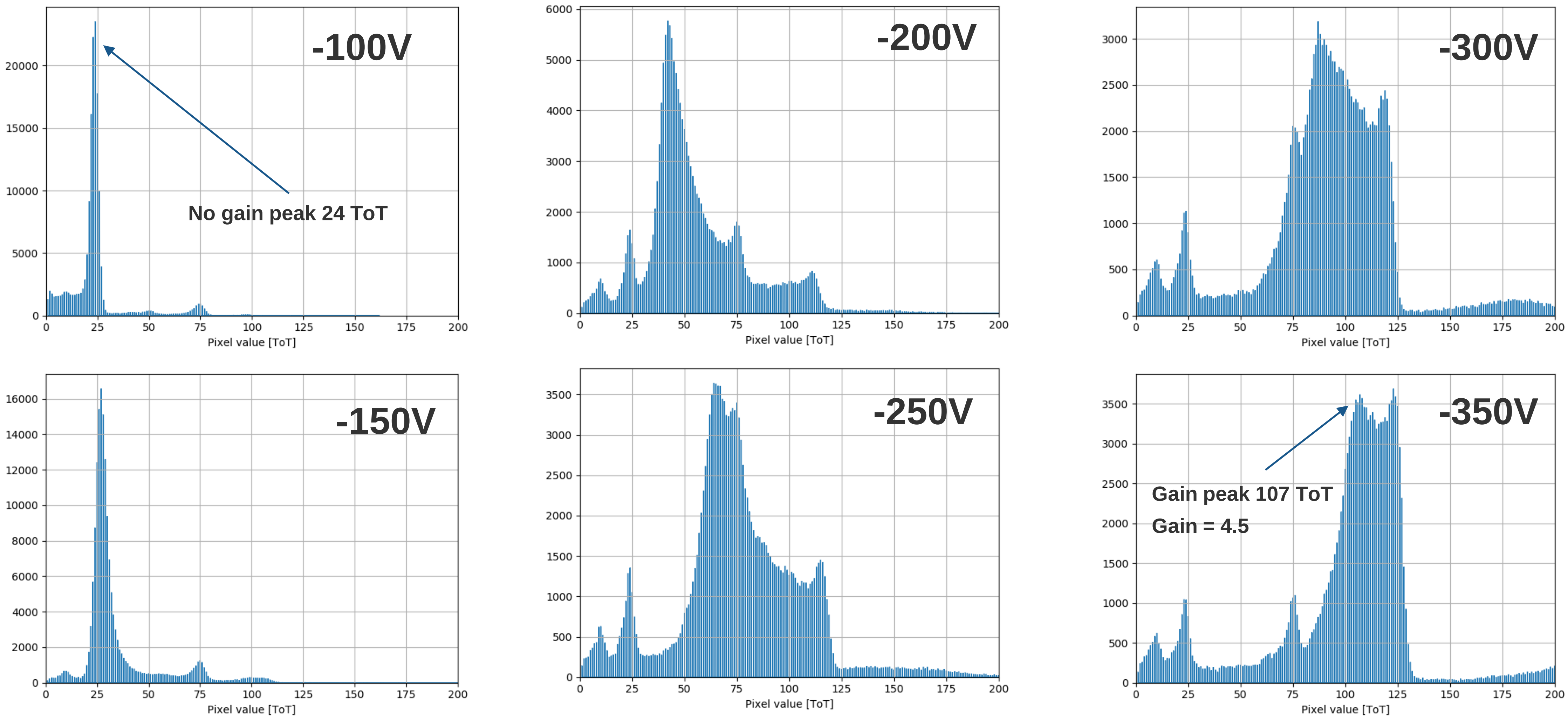




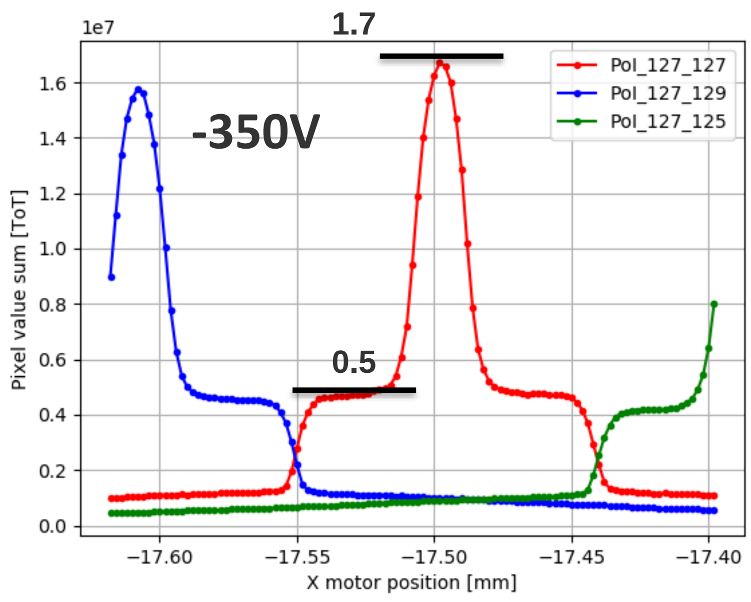




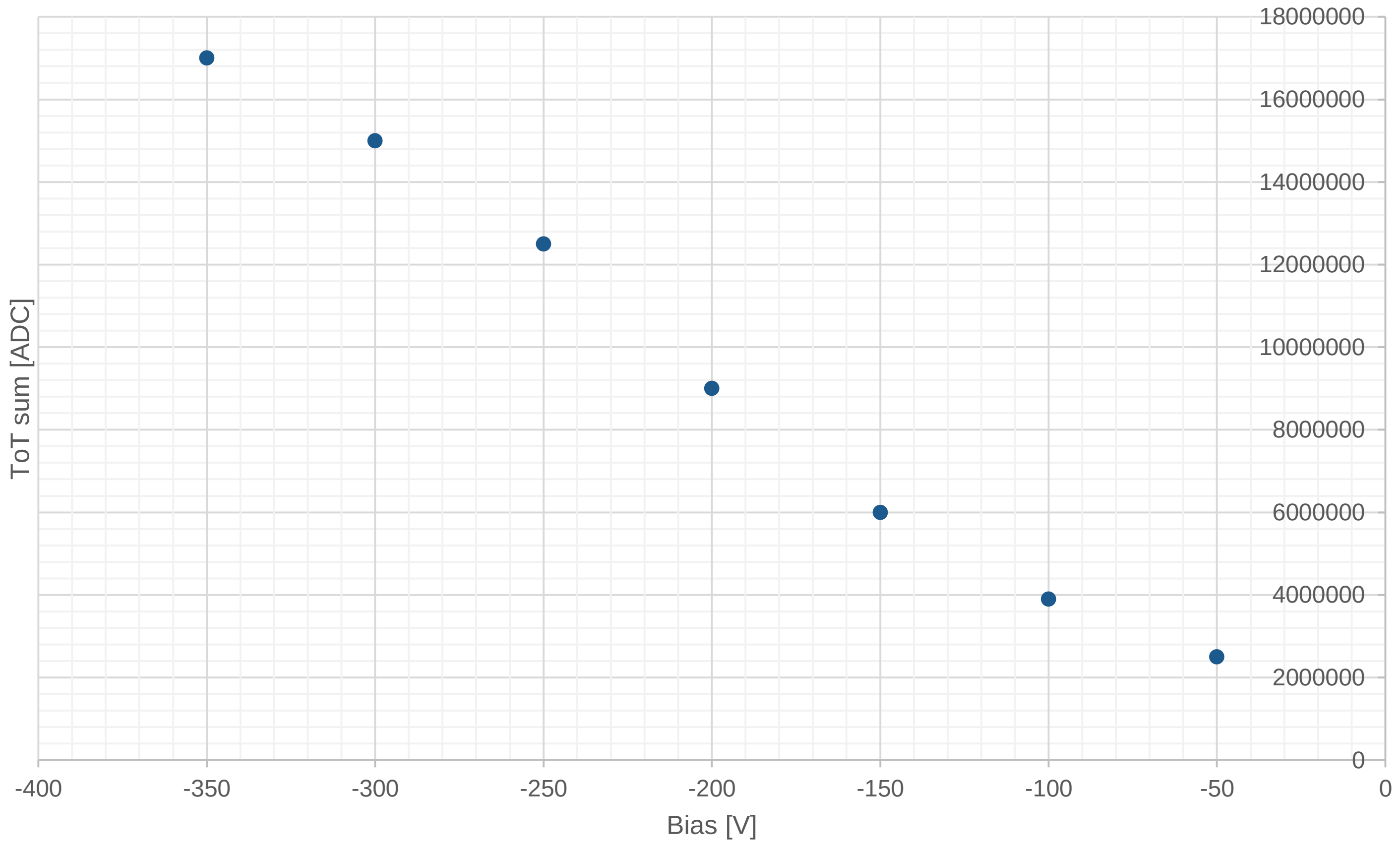
Spectrum in the middle of gain pixel (127, 127)



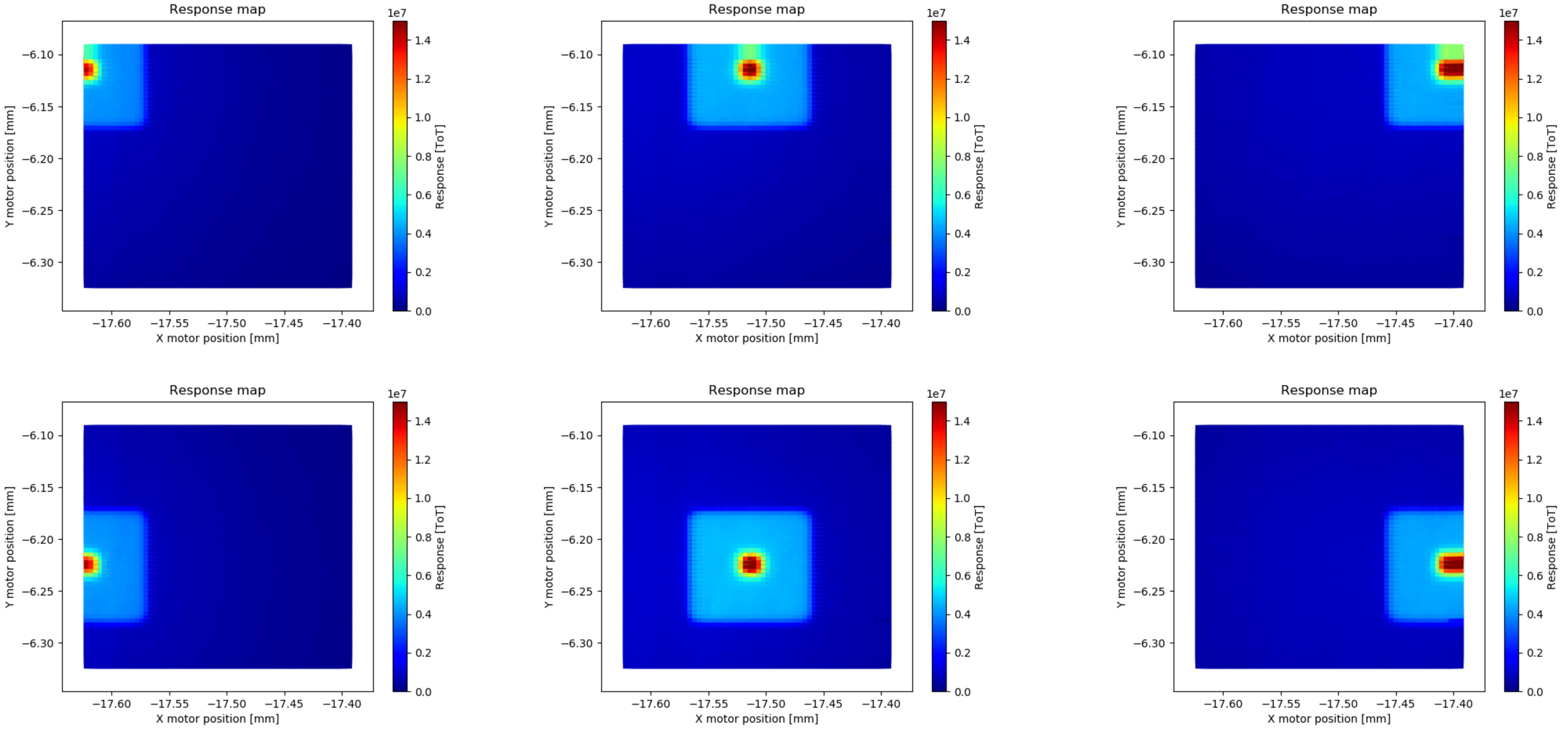
1D line scans @ voltages, gain pixel (127, 127)



Gain: 3.4

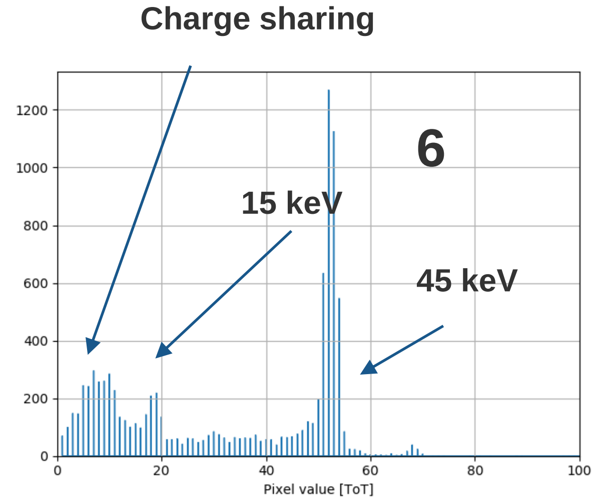


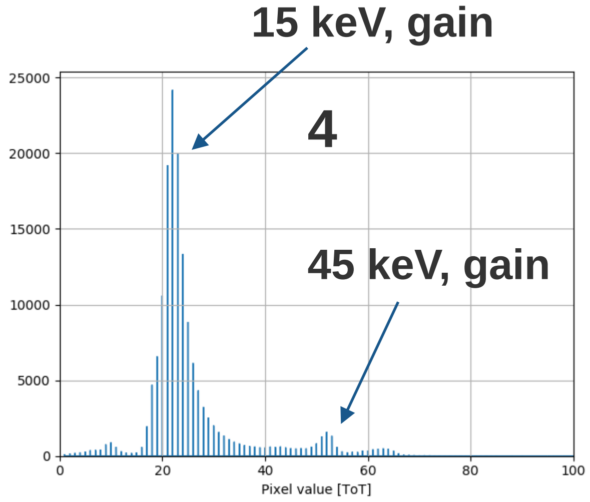
2D scan (-350V)

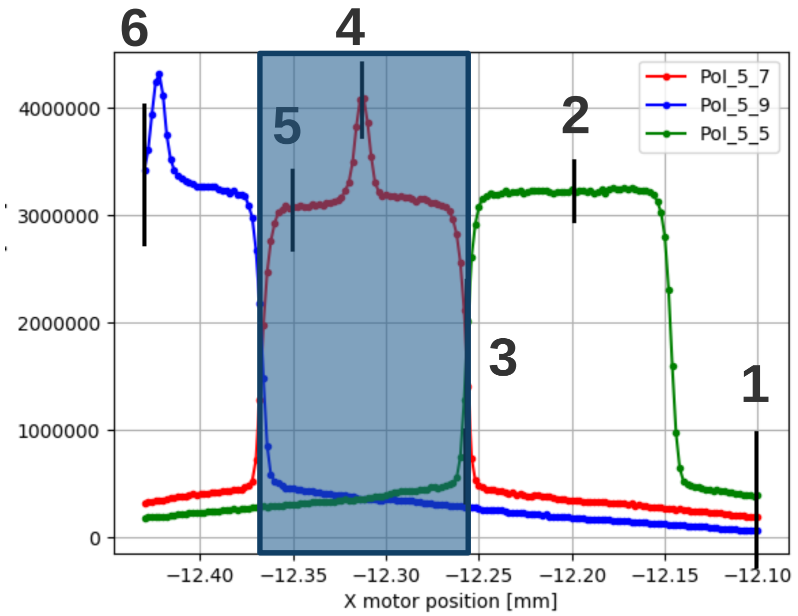

Response map
Response map
Response map
Response map
Response map
Response map
Y motor position [mm]
X motor position [mm]
Response [ToT]
1e7
−6.10
−6.15
−6.20
−6.25
−6.30
−17.60
−17.55
−17.50
−17.45
−17.40
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4

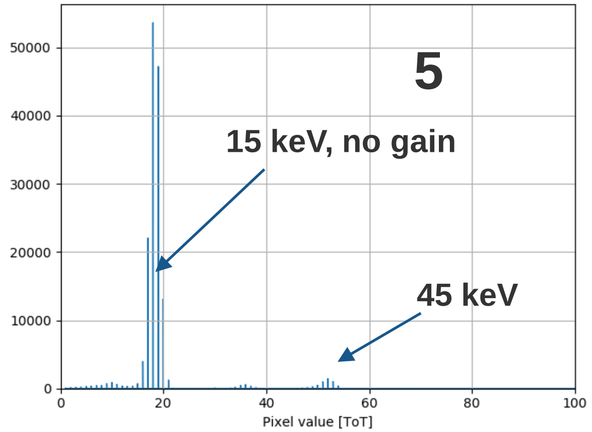
Note! No x2 count peak, so 45 keV is 3rd harmonic only!

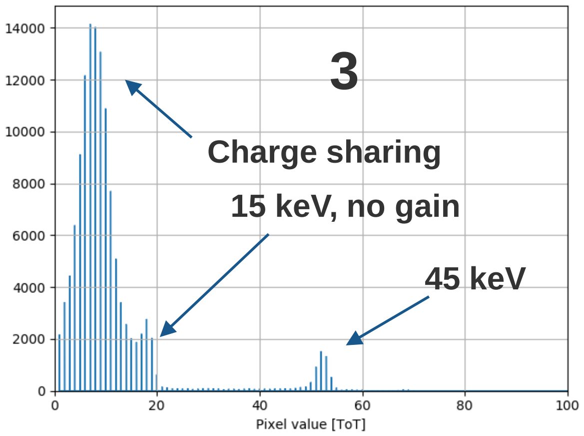
1D line scan, gain pixel (5, 7), -350V

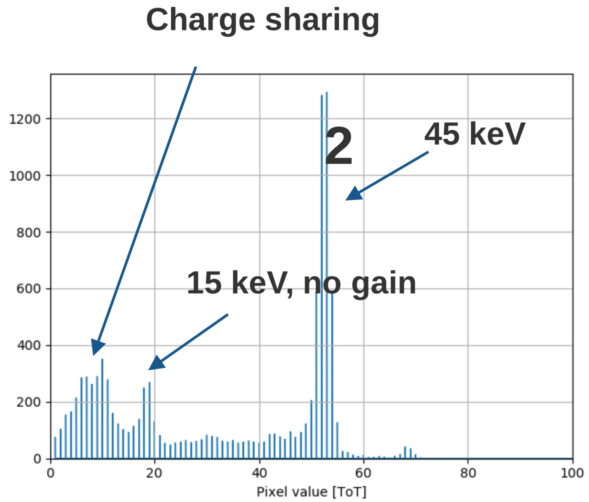


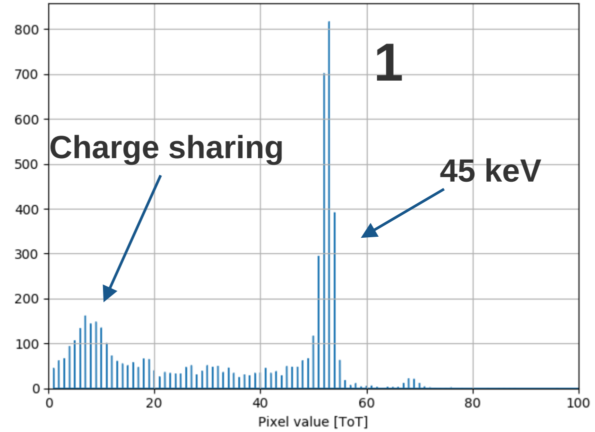






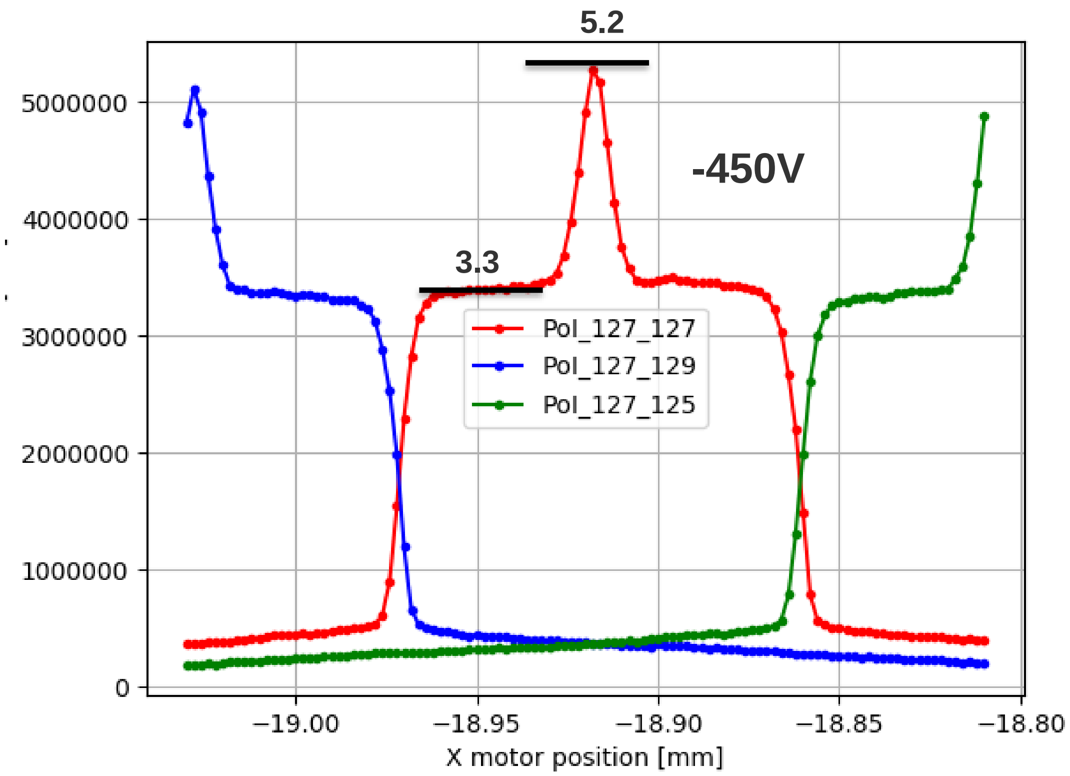






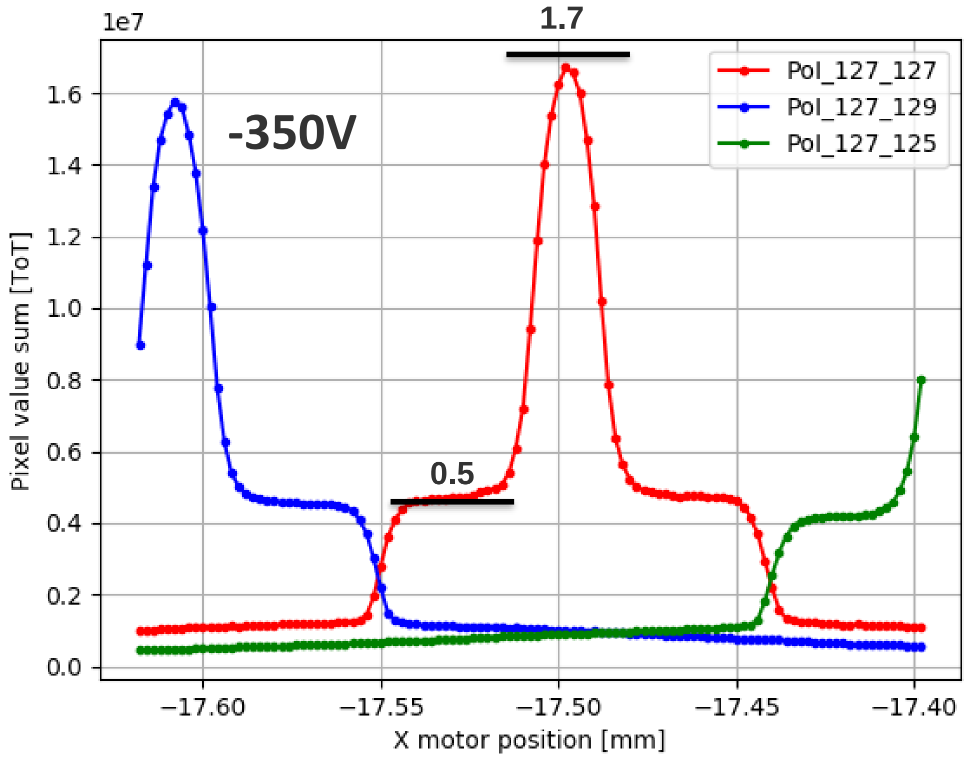
110 um pixel, 20 vs 10 um JTE

110 um pixel, 20 um JTE



Gain: 1.6

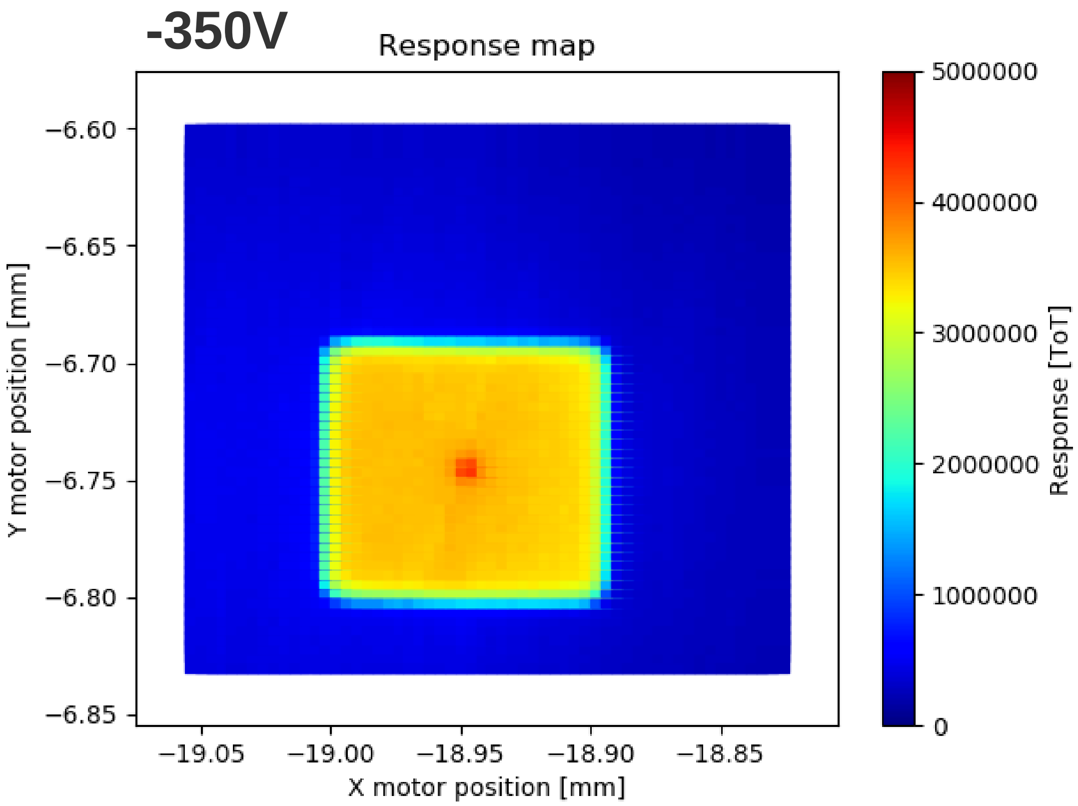
110 um pixel, 10 um JTE



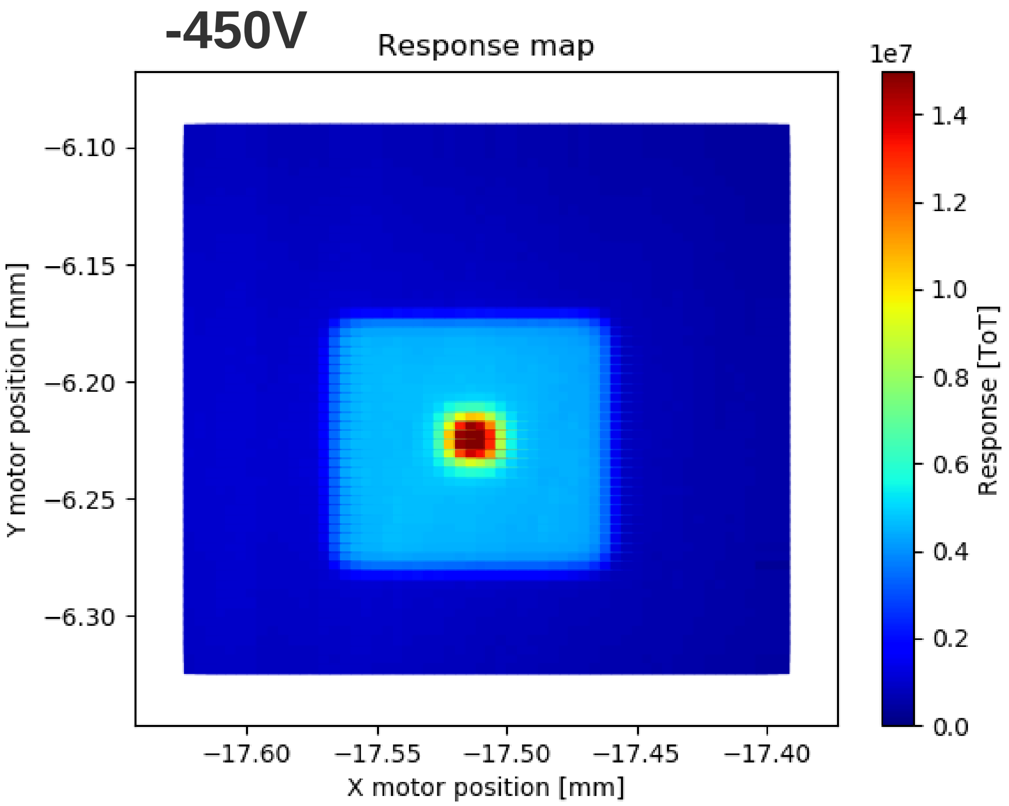
Gain: 3.4

110 um pixel, 20 vs 10 um JTE

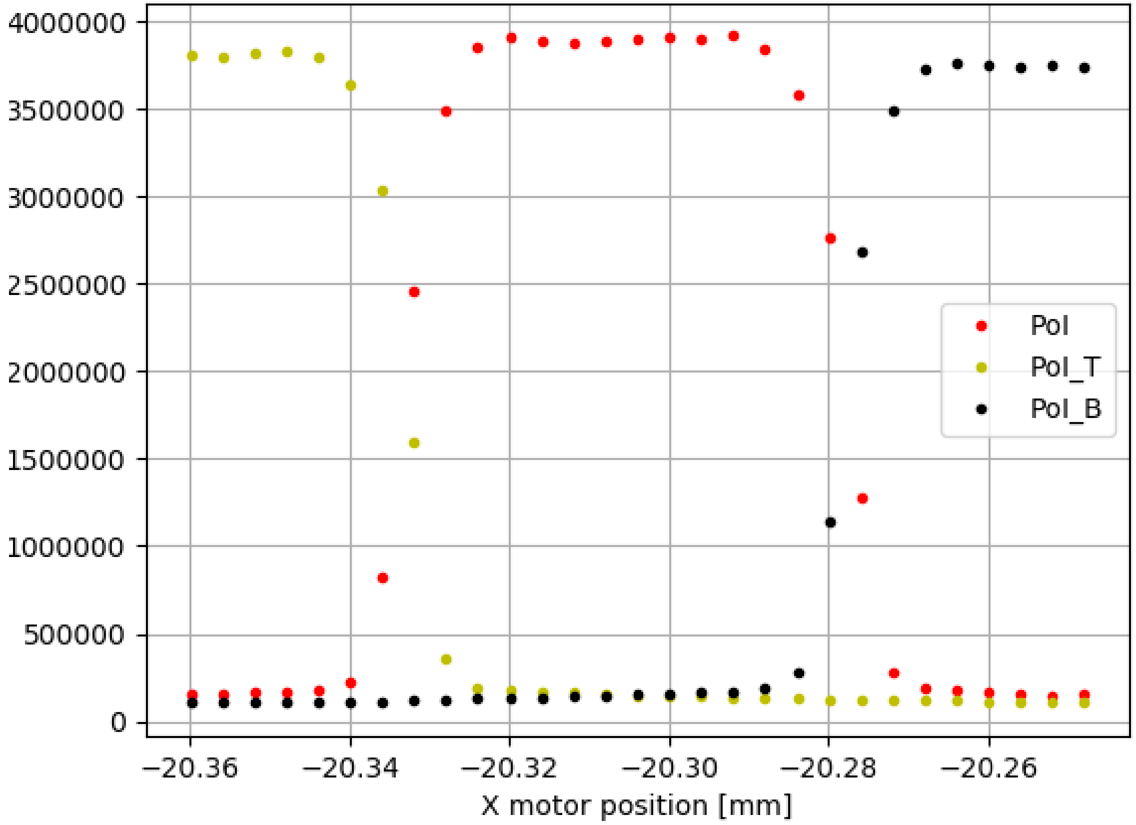
110 um pixel, 20 um JTE

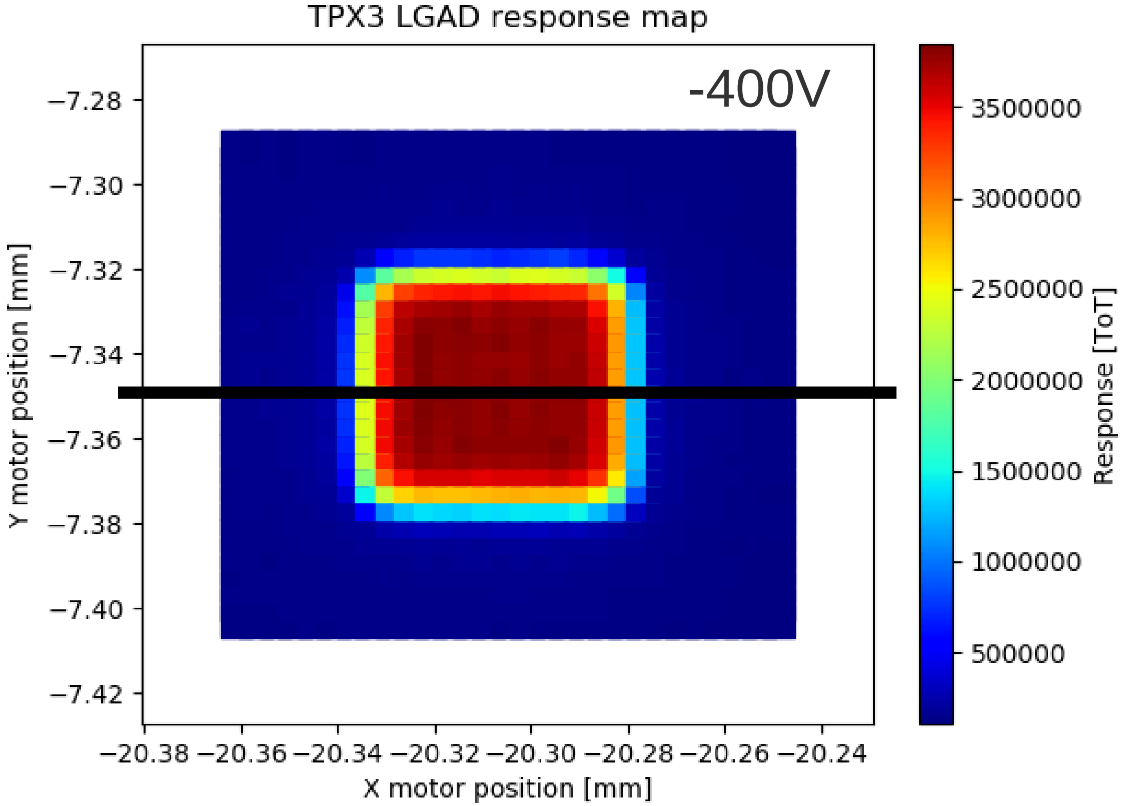


110 um pixel, 10 um JTE



55 um pixel, 5 um JTE

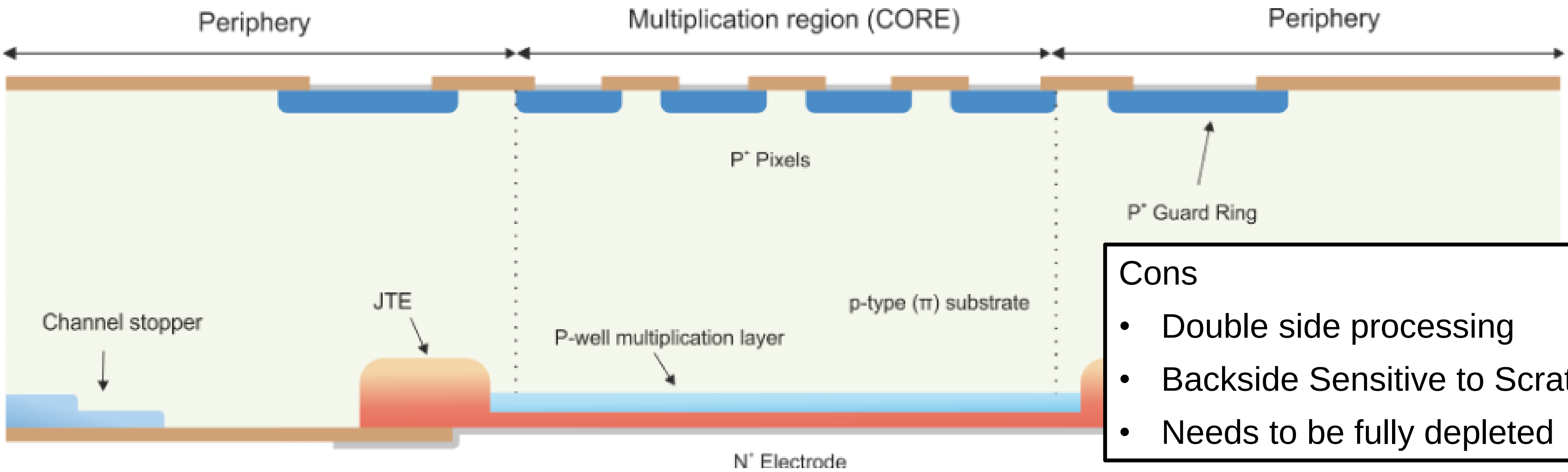




No gain observed as expected

Options for small pixels - Inverse LGAD

- Segmentation at the ohmic contact: strip and pixels.
- Multiplication extended over all the CORE.
- 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

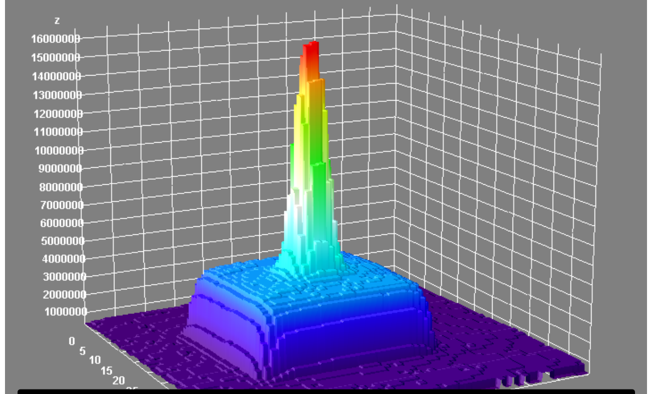
Albert Doblas Moreno, 16th Trento workshop, 2021

Summary and conclusion

Summary

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

3D representation



110 um pixel, 10 um JTE