Gain Suppression Study in LGADs with Different Gain Layers

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The Study Case

- Gain suppression affects all the LGAD

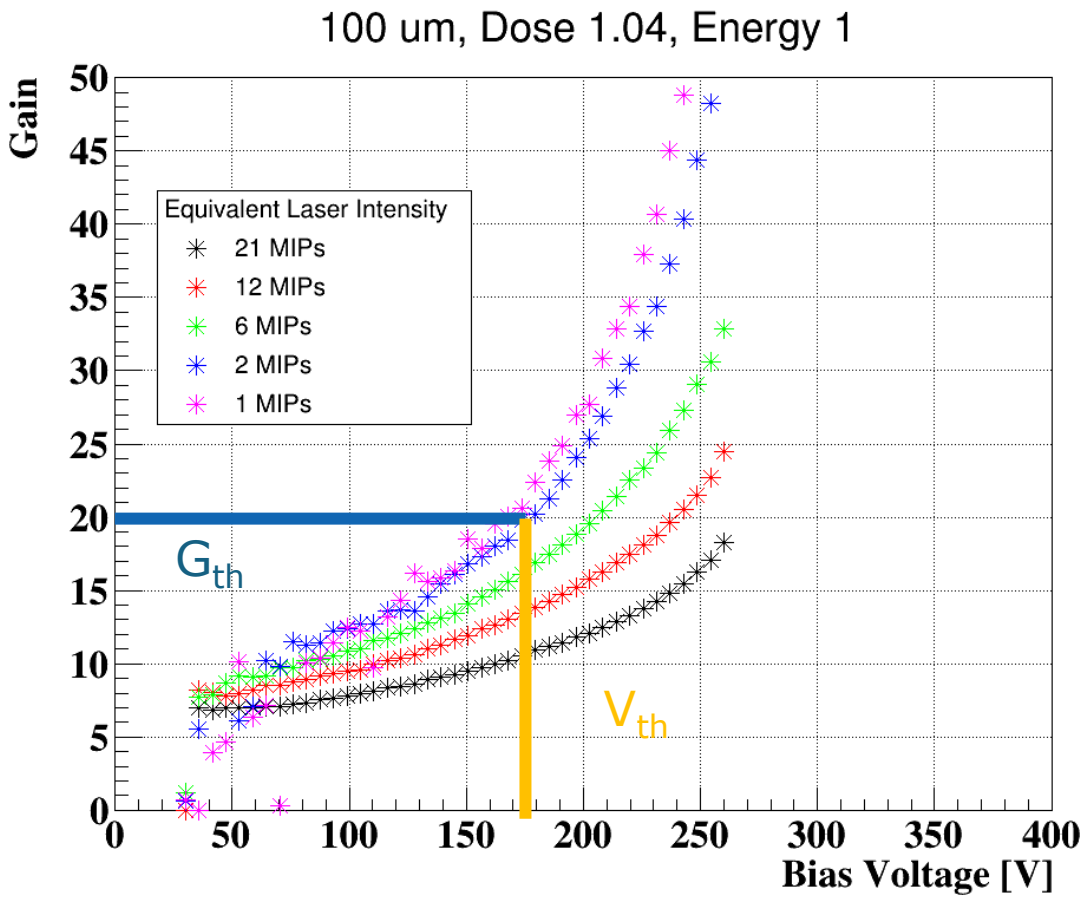
  (First observation by Curras 2021)
- It depends on the starting gain of the sample and on the density of the charge carriers.

Question: Can we manufacture a gain layer that is less affected by this mechanism? Anything else that counts?

Benefit: Linear response of the detector in a broader spectrum of energy → heavy ions, X-rays

How to measure?

- Transient Current Technique to measure the gain as a function of the bias voltage
- Set a threshold in gain G_{th}
- Find the bias voltage on the 1 MIPs curve where the threshold is passed, V_{th} (different for each sample)
- Find the value of gain at V_{th} for different charge injections, and normalize over G_{th}



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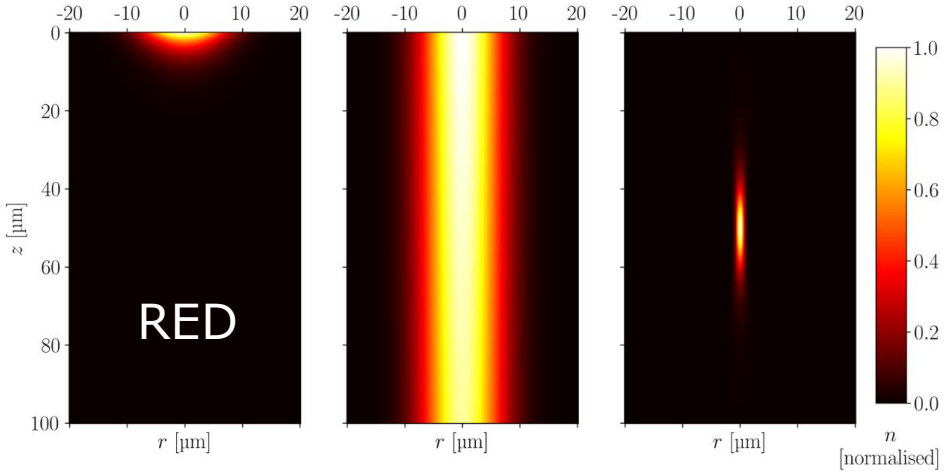
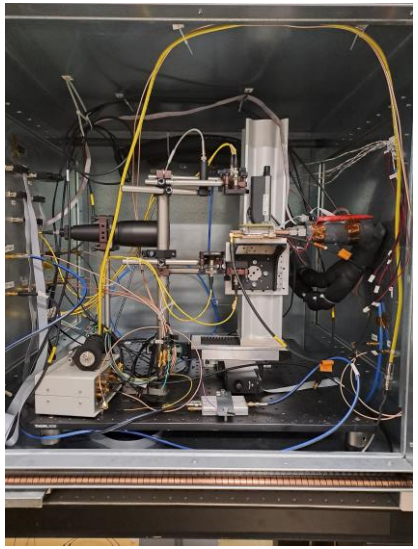
Transient Current Technique (TCT) in Brief

A pulsed laser is used to simulate the passage of particles inside the detector
Amplified signal fed to an oscilloscope:
2.5 GHz bandwidth
20 GS/s



[Kramberger 2015](#)
[Pape 2023](#)

EP-DT-SSD Group Setups were used for this investigation



Single Photon Absorption (SPA)

1060 nm laser

Illumination form top, bottom, edge

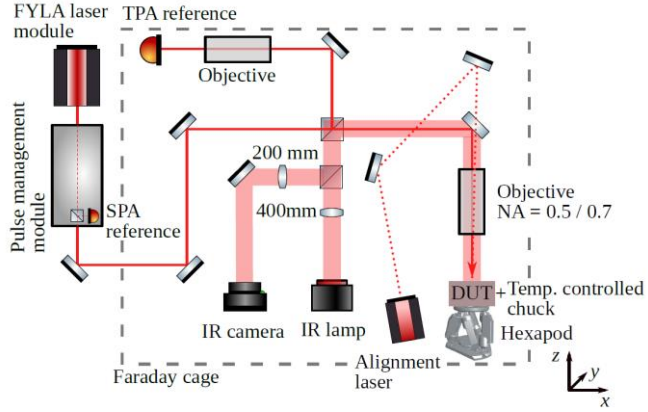
Macroscopic behavior

Two Photons Absorption (TPA)

1550 nm laser

3D resolution
→ In Depth Scans

Illumination from top, bottom



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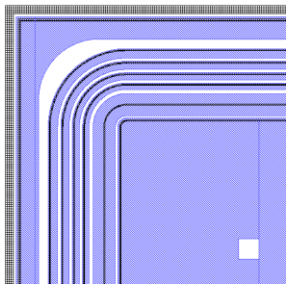
Samples

PINs and LGADs produced by FBK

Thickness [µm]	Gain Dose	Gain Energy
100	1.04	1 (FBK standard)
100	1.46	0.5 (shallower)
150	1.46	0.5 (shallower)
150	1.04	1 (FBK standard)

Area 6.2 mm^2
Standard metallization and contacts →

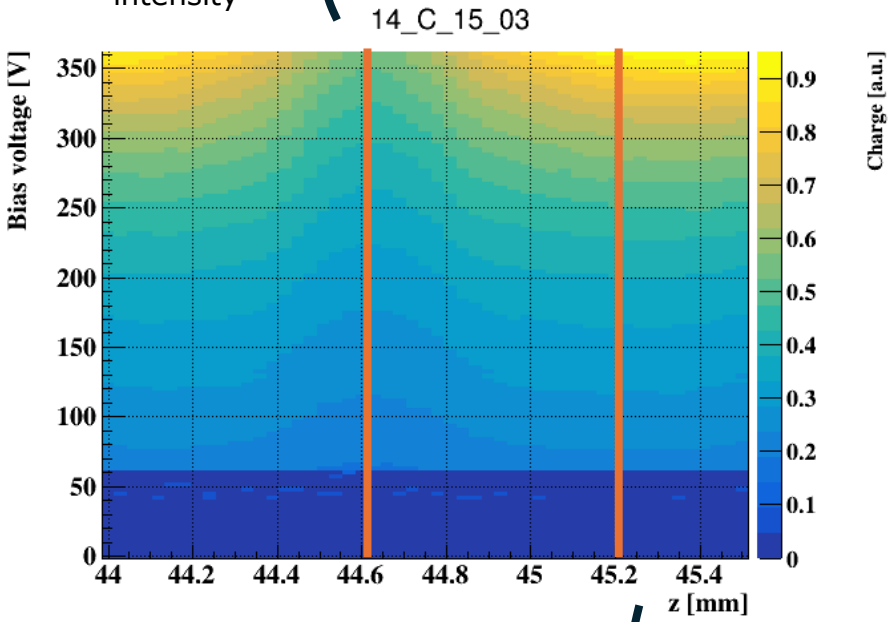


Bias and reading from the top
Injection at the center of the pad through 100 µm aperture in the metallization
GR is floating

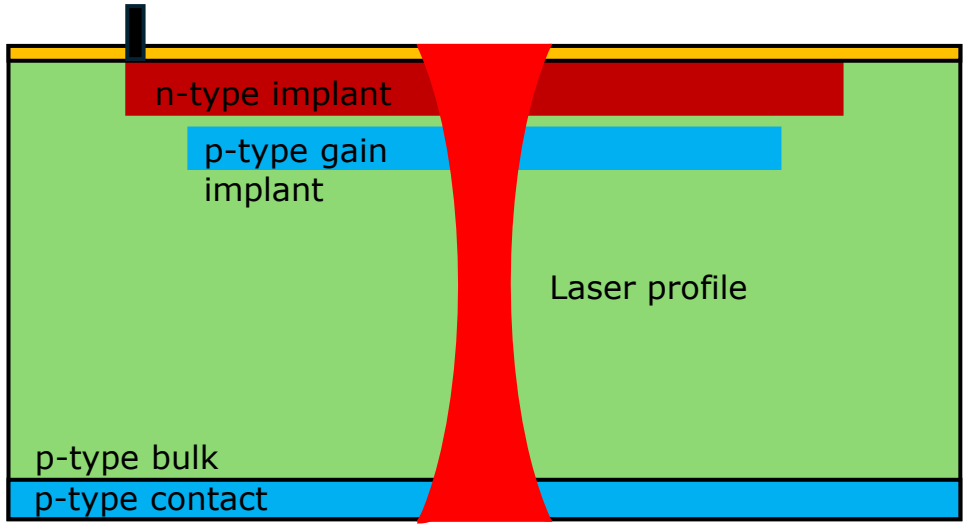
Testing with SPA-TCT the 8 samples
Two LGADs marked in red were also tested with TPA-TCT

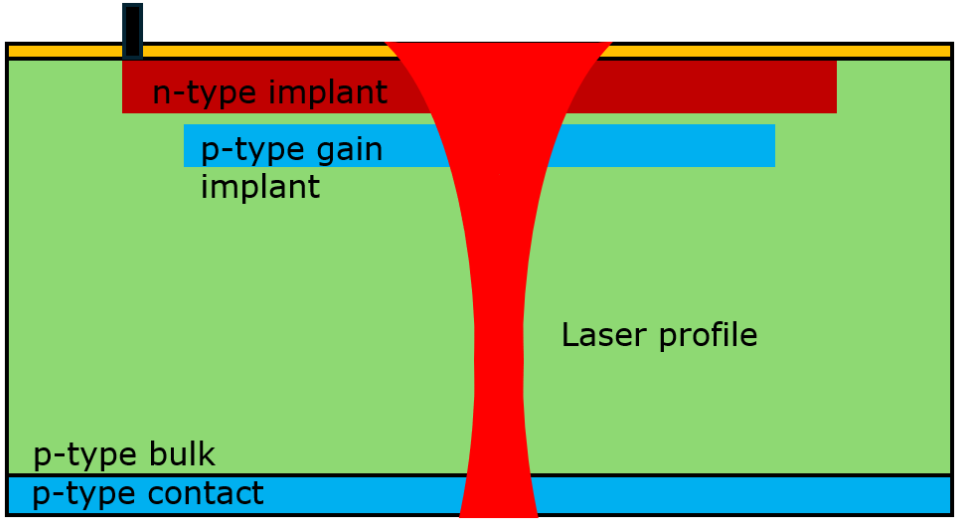
SPA-TCT: Moving Focal Plane

5 MIPs intensity



The shape of the laser profile is unchanged





More illuminated volume, same amount of charge deposited

Density of the deposited charge diminishes out of focus

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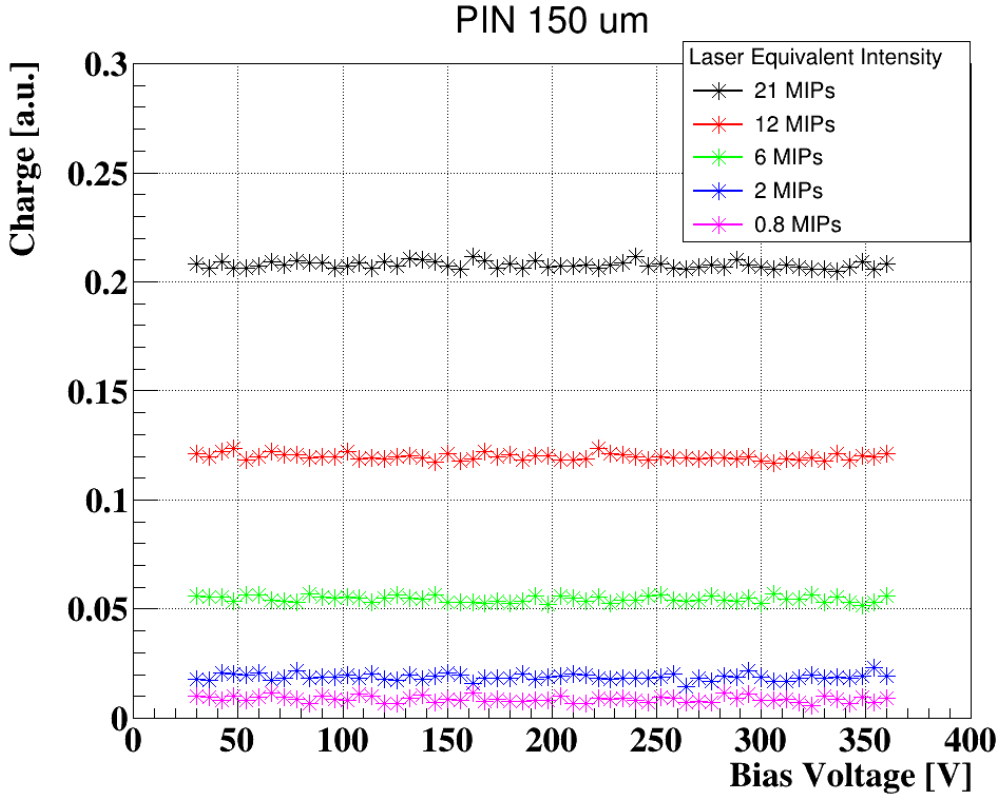
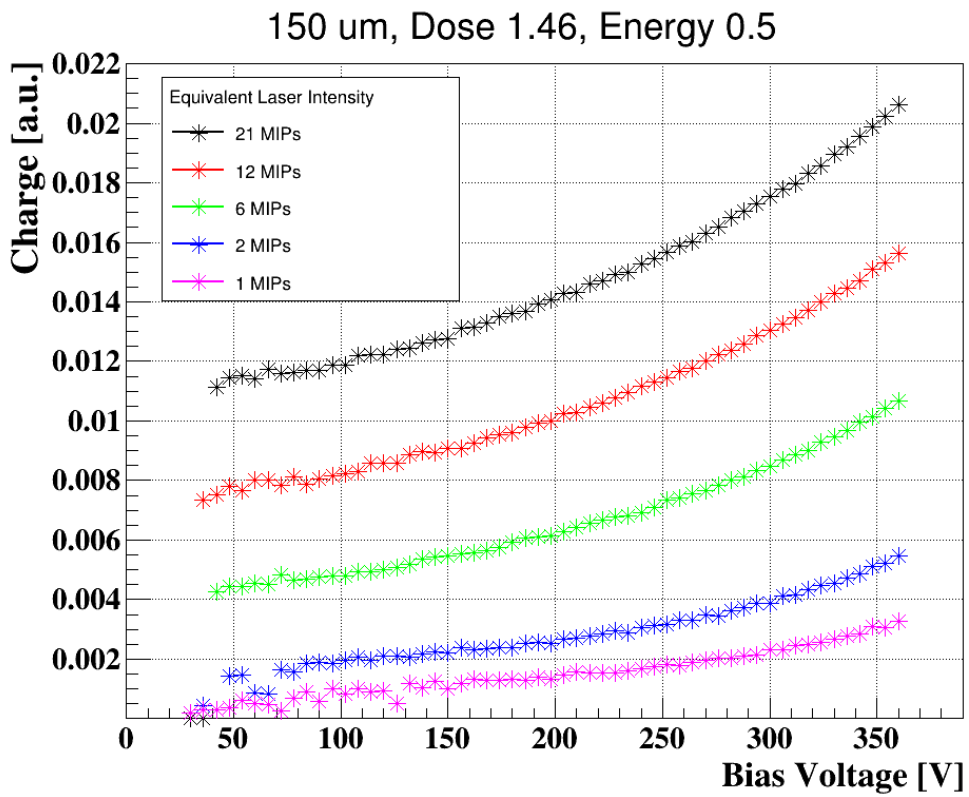
SPA-TCT: Change Laser Intensity



Increasing the laser intensity means more charge deposited in the same volume, as it is visible in the PIN diodes



The collected charge in the LGAD increases consequently

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SPA-TCT: Change Laser Intensity

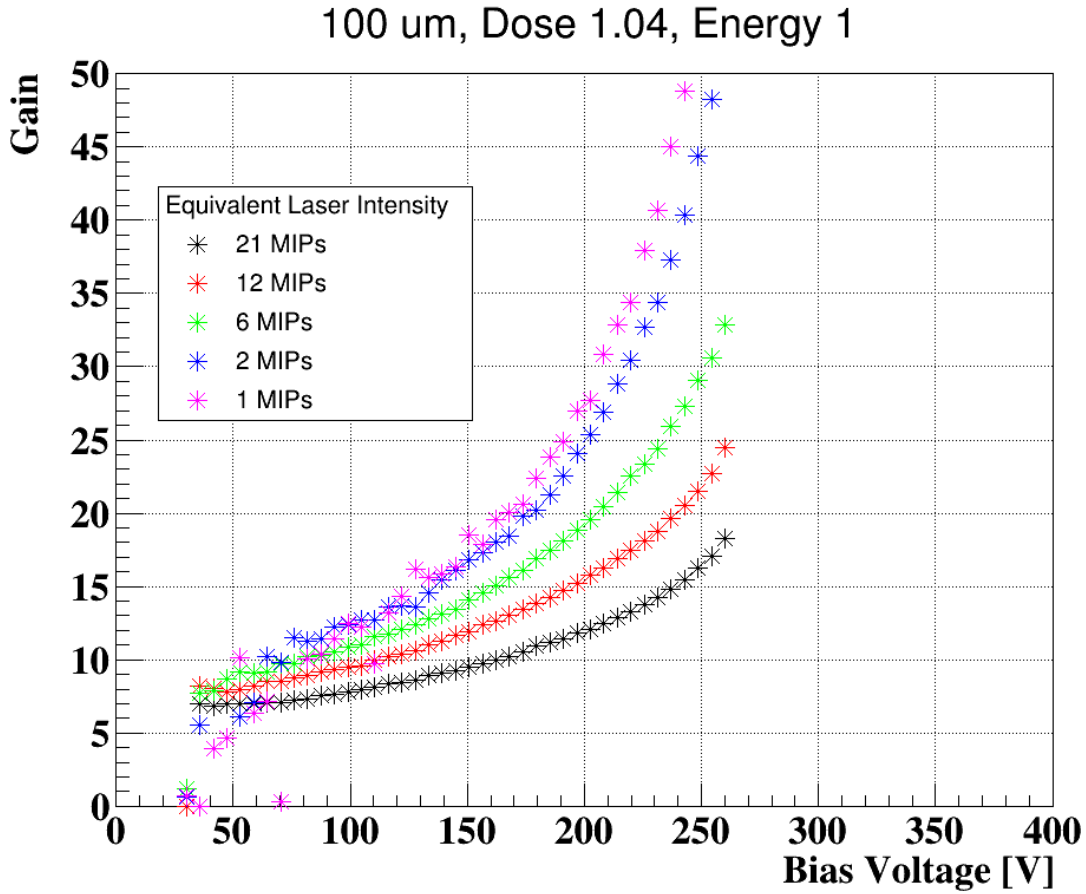
Gain from impact ionization is suppressed in the LGAD

$$Gain = G(Bias, T, \varrho)$$

ϱ = Density of charge carriers

The dependence of gain on deposited charge is triggered by the shielding of the electric field in the gain layer caused by the multiplication of the charge carriers.

[Curras 2021 , Braun 2024]



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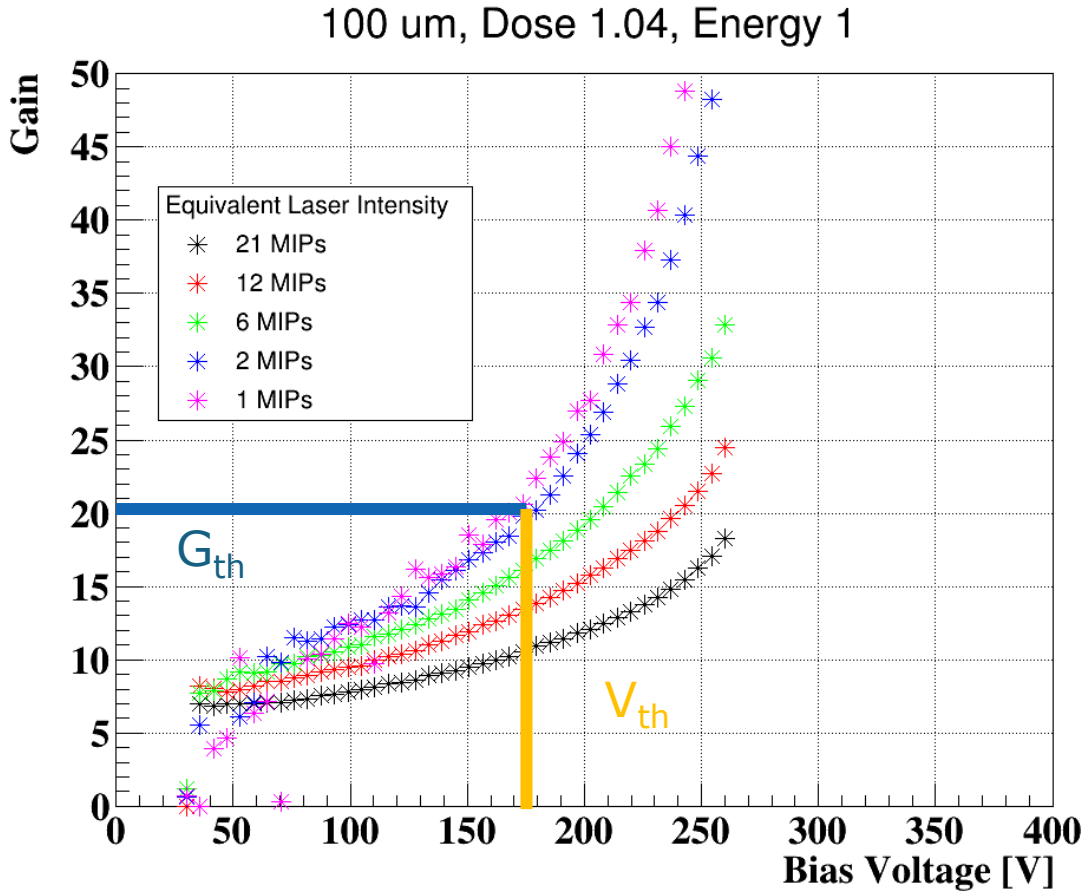
[Curras 2021 , Braun 2024]

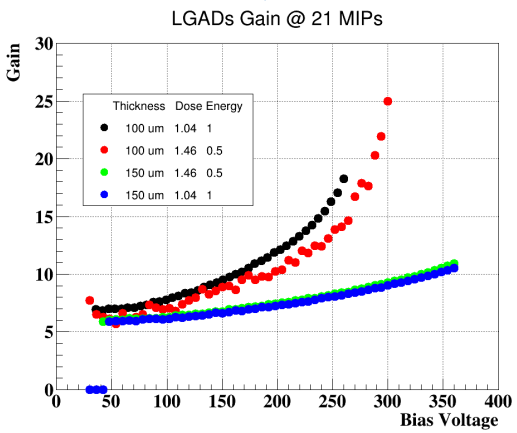
Set the thresholds (G_{th}, V_{th}) to compare the samples

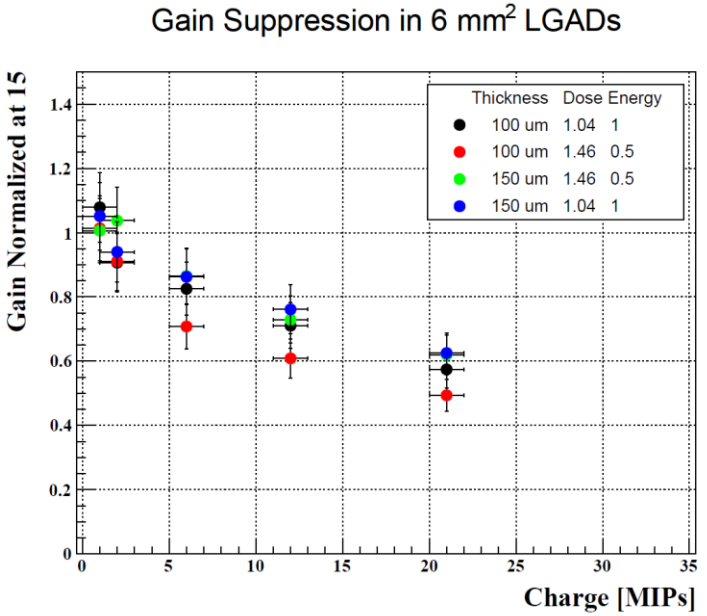


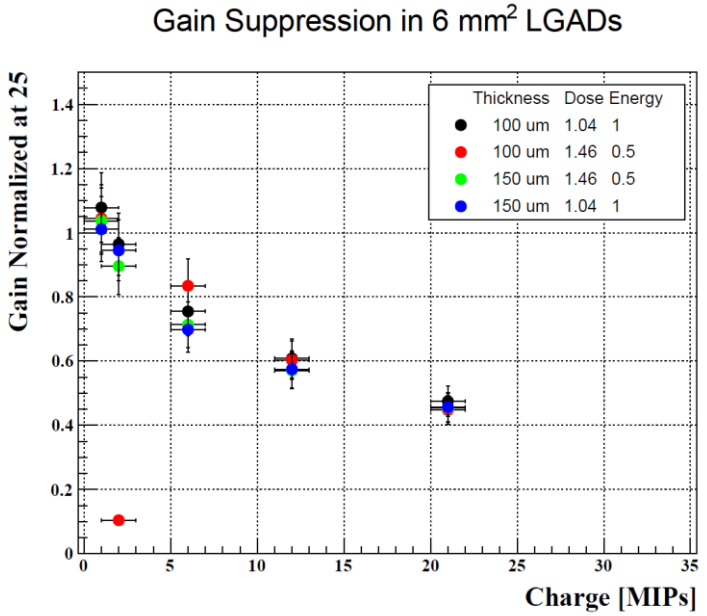
SPA-TCT: Results

- ✓ The gain drops following the same fashion in all the LGADs
- ✓ No evident difference according to the thickness or to the gain layer profile
- ✓ Where the gain is higher, the damping is higher

The samples do not have the same gain, in general



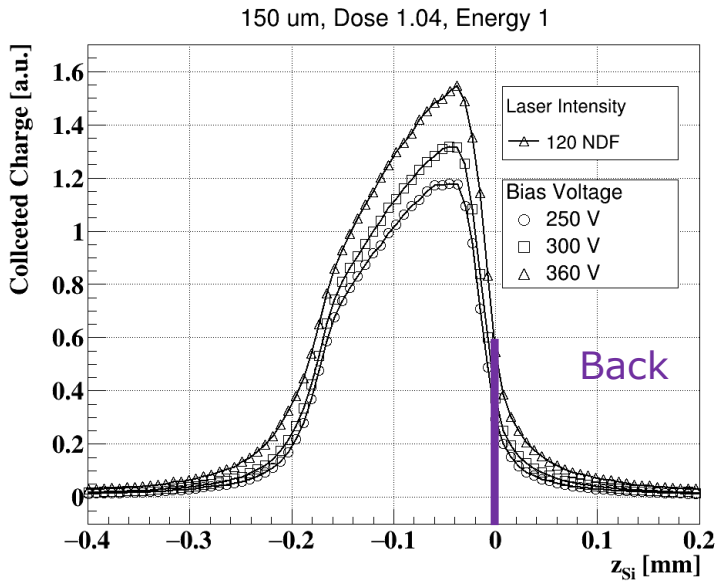


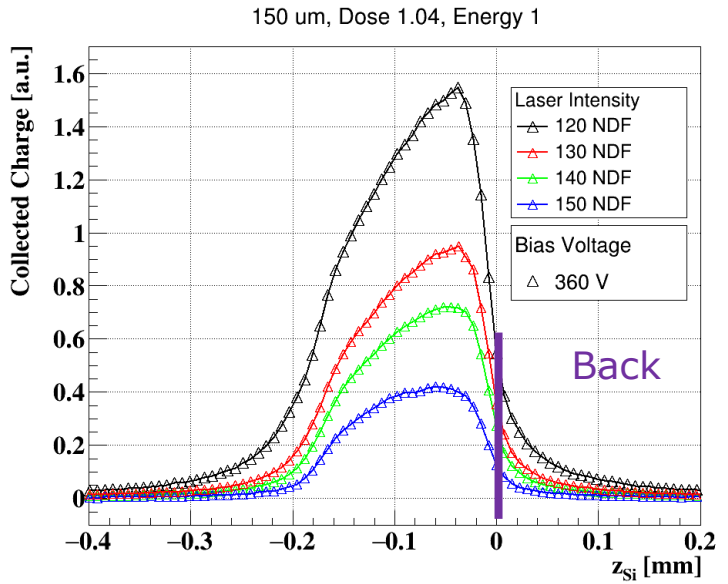


TPA-TCT: In Depth Scans

- ✓ Shark-fin shape of the charge profile confirms the gain suppression in the LGADs
  - Generating at the back gives to the carriers more time to diffuse [Pape 2024]
- ✓ Increasing the bias voltage the dumping becomes strong
  - Electric field is stronger
- ✓ Increasing the laser intensity the dumping is more pronounced
  - Higher number of charge injected in the same volume
  - **Greater NDF → Lower Laser Intensity**

The back of the sensor is at z_{Si} = 0 mm





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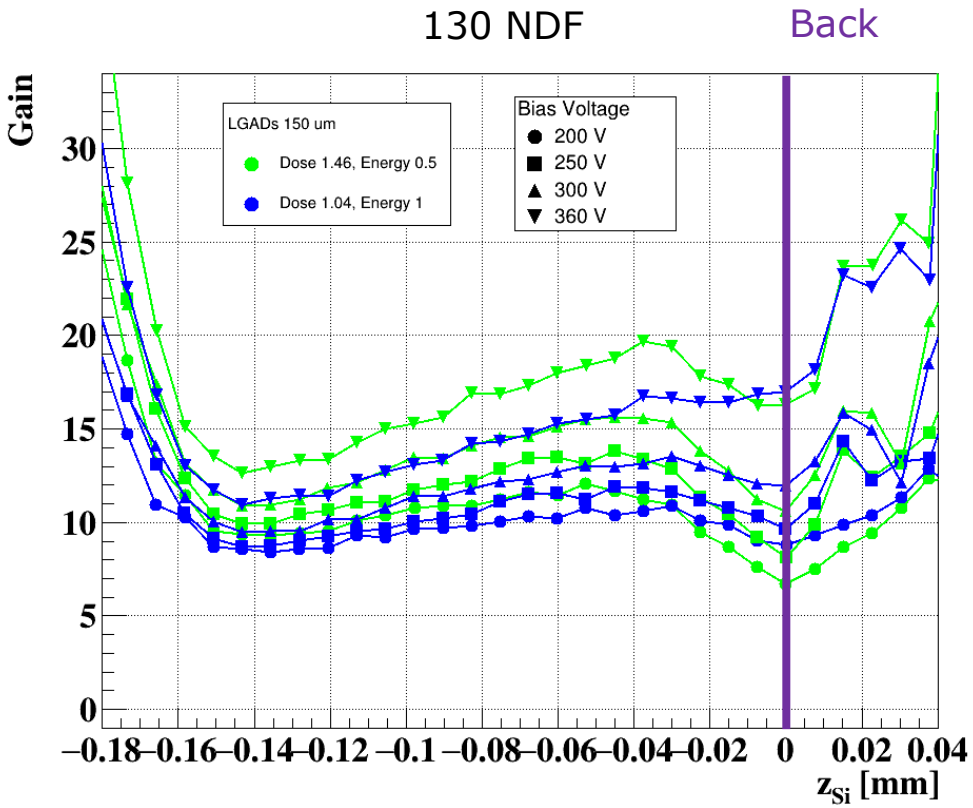
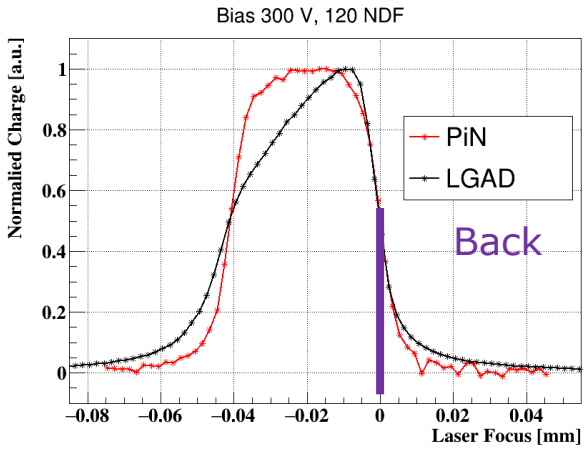
TPA-TCT: Gain



Error bars are not shown but a 10-15% uncertainty on gain is considered

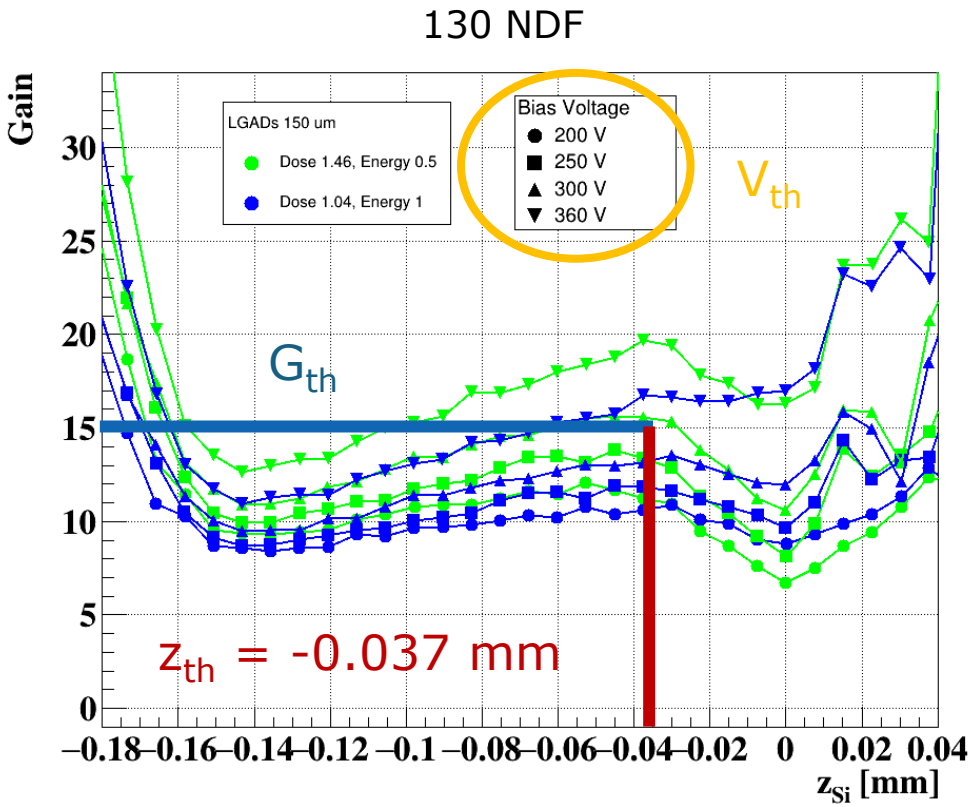
$$Gain(V, z_{Si}) = \frac{Q_{LGAD}}{Q_{PIN}}\bigg|_{V,z_{Si}}$$



For the alignment of the charge profiles, it is selected a threshold of 30% CFD in the backside rising edge.

The sharp rising for z_{si} < -0.14 mm and z_{si} > 0 mm is not considered a real physical effect, but a consequence of the much longer fall time in the LGADs' tails compared to the PINs

TPA-TCT: Gain



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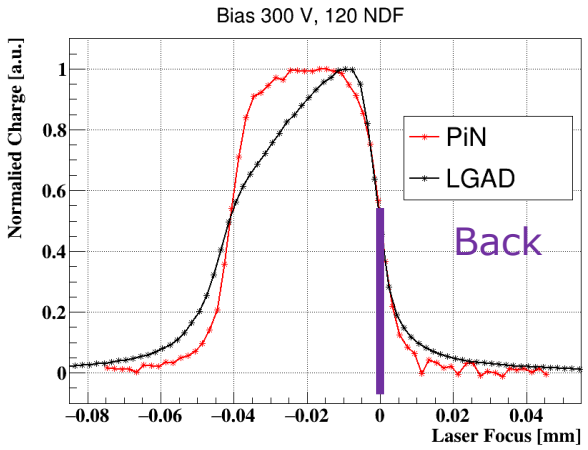

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Evaluating the gain at various G_{th} , fixed z_{th} , and using as reference the lower laser intensity (150 NDF)

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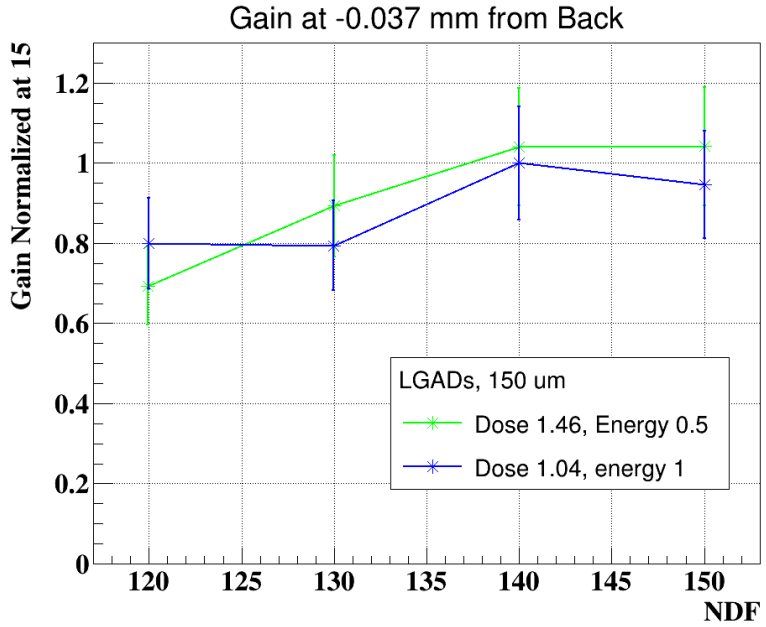
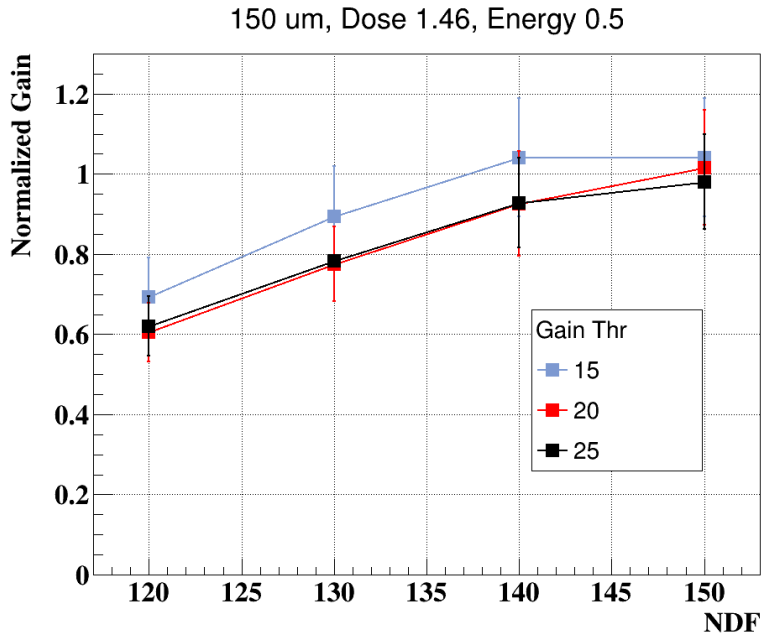
TPA-TCT: Outcomes

- The two detectors show the same decrease in gain as a function of the laser intensity.
- No evident distinction in the two gain layer performances

Detector in green





Greater NDF → Lower Laser Intensity

The results from SPA and TPA cannot be directly compared because of the (momentary) unknow conversion from NDF to MIPs

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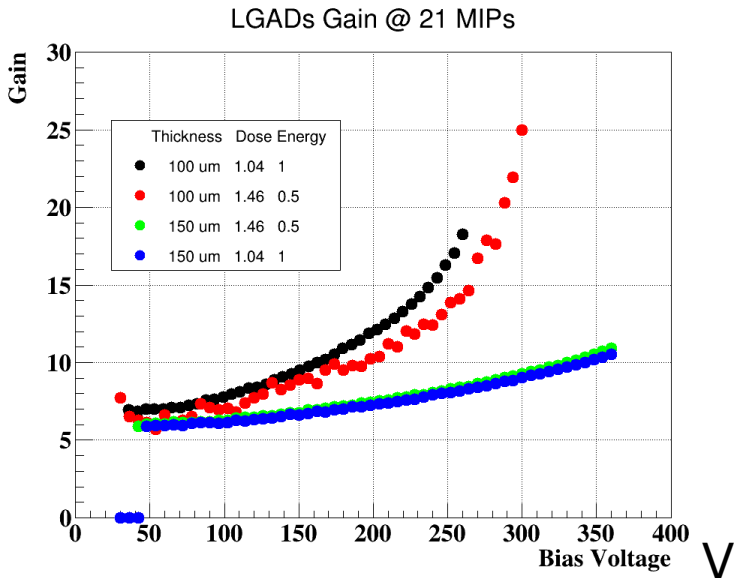
Summary and Conclusion

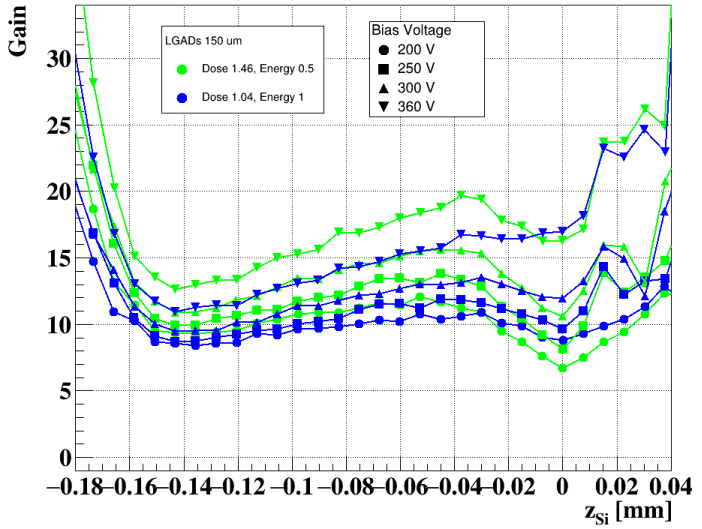
For the first time, a set of LGADs with different gain layer doping profiles was compared according to their resilience to gain suppression.

- No significant difference was highlighted in the explored intensity regime in both SPA- and TPA-TCT
  - The initial gain is what matters
  - Higher intensity?

- The thickness of the detector does not affect the way the suppression occurs (according to the measurements)
  - Developing a model for the gain suppression in LGADs [Pape 2024]
  - In TPA-TCT more diffusion is expected in 150 μm than 100 μm, at the same injection depth from the back



130 NDF



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Questions?

TPA-TCT

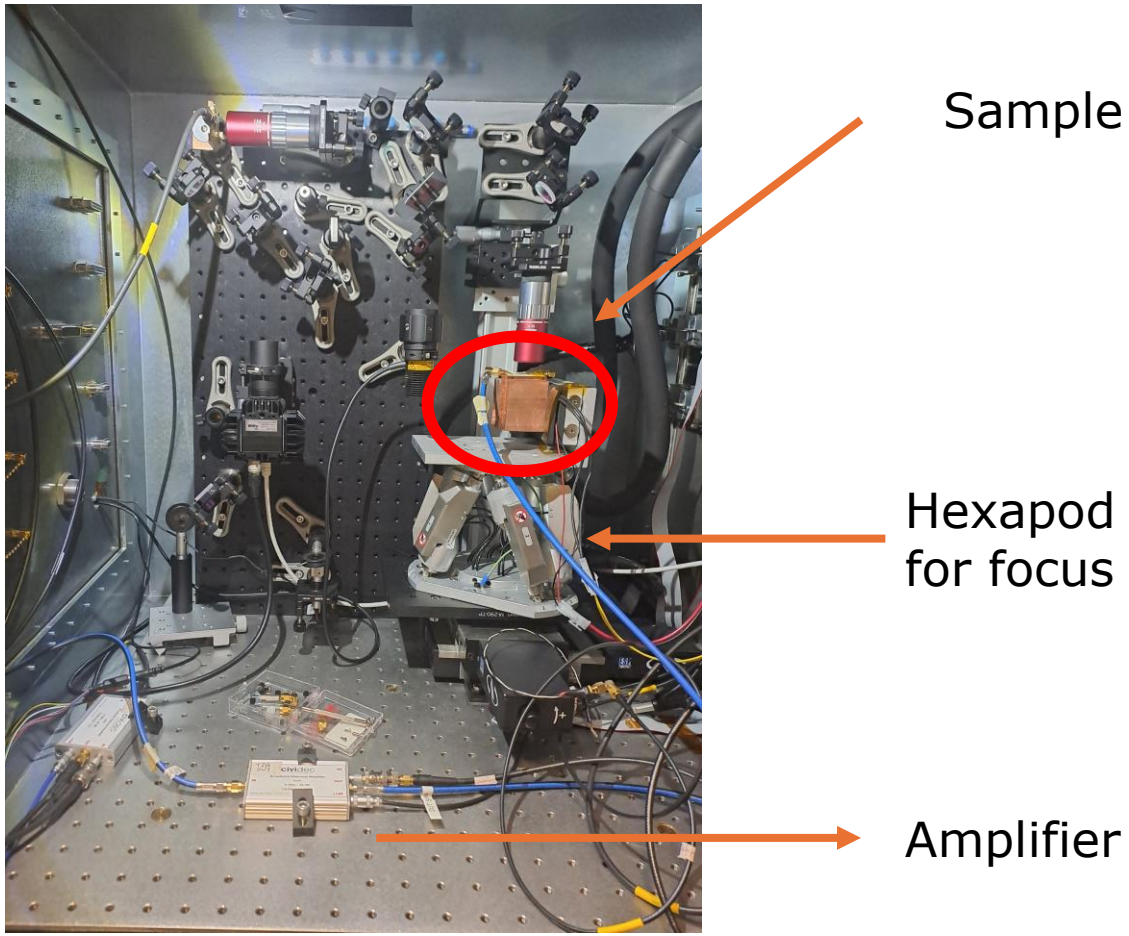
PINs and LGADs

Thickness [um]	Gain Dose	Gain Energy
150	1.46	0.5
150	1.04	1

Want to probe dependence over:

- Depth of the generation
  → In depth scan
- Electric field shape
  → In depth scan
- Charge carriers' density
  → Laser intensity scan (NDF)

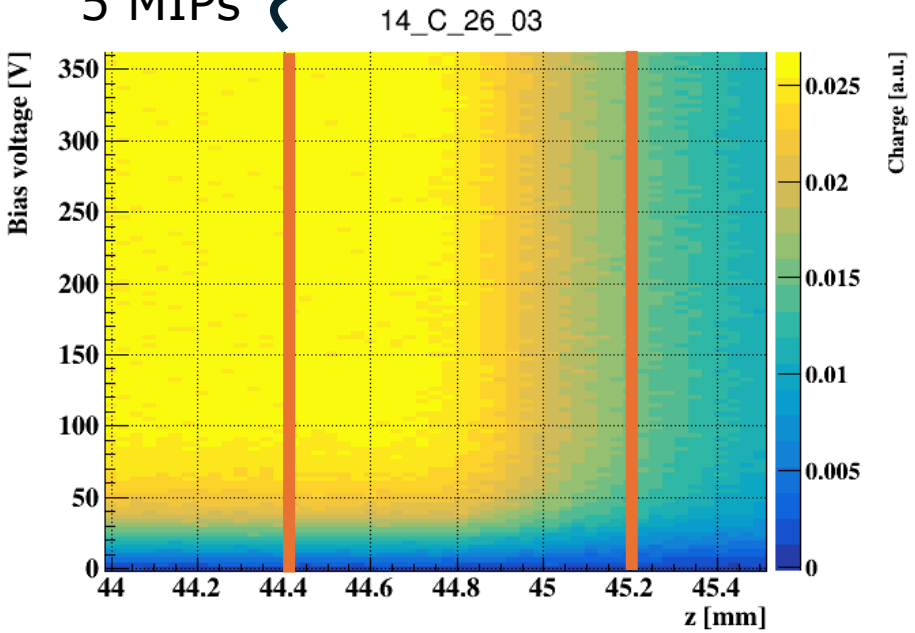
$z_{si} = 3.77\ z_{stage}$ mm



EP-DT-SSD Laboratory Setup

SPA-TCT: Change in Focus (PIN)

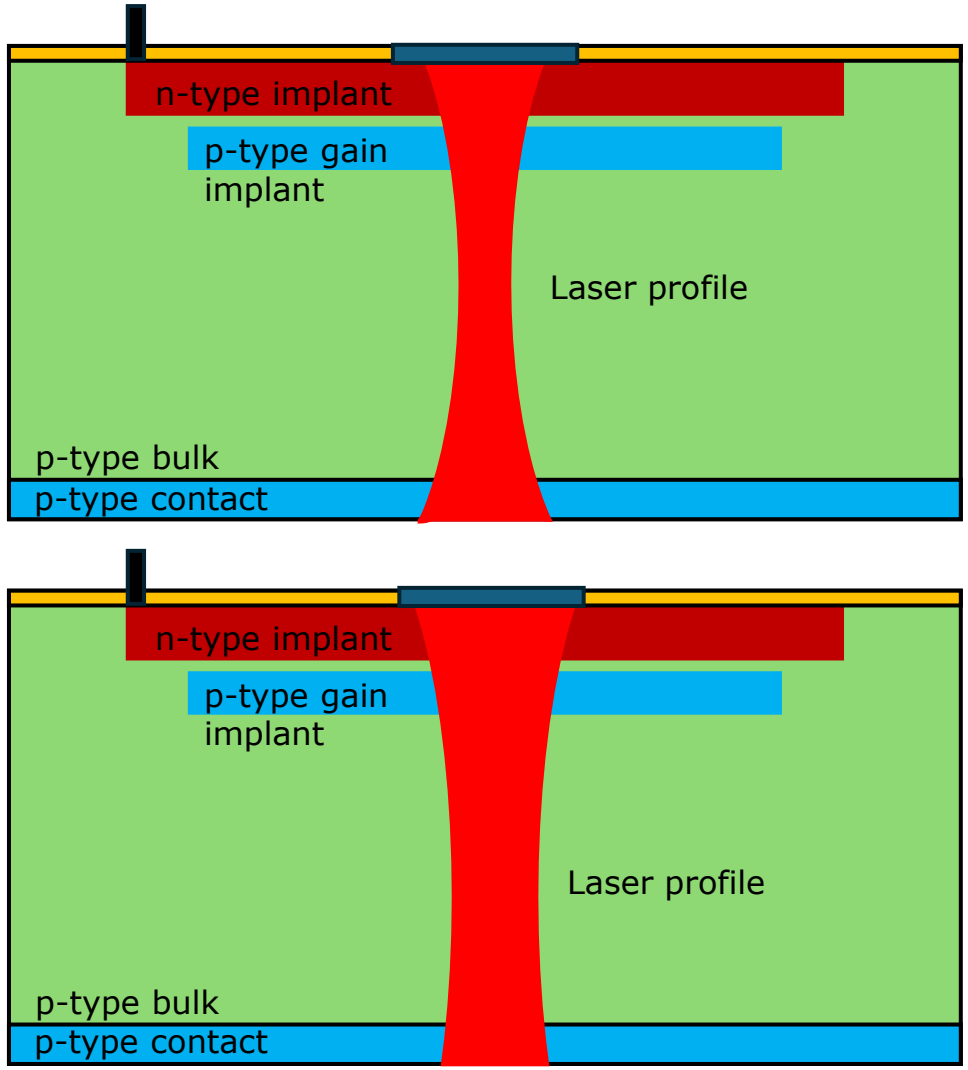
5 MIPs



The laser can fall out of the aperture

The laser profile changes with the focus.
The deposited charge remains the same.

Density of the deposited charge diminishes out of focus



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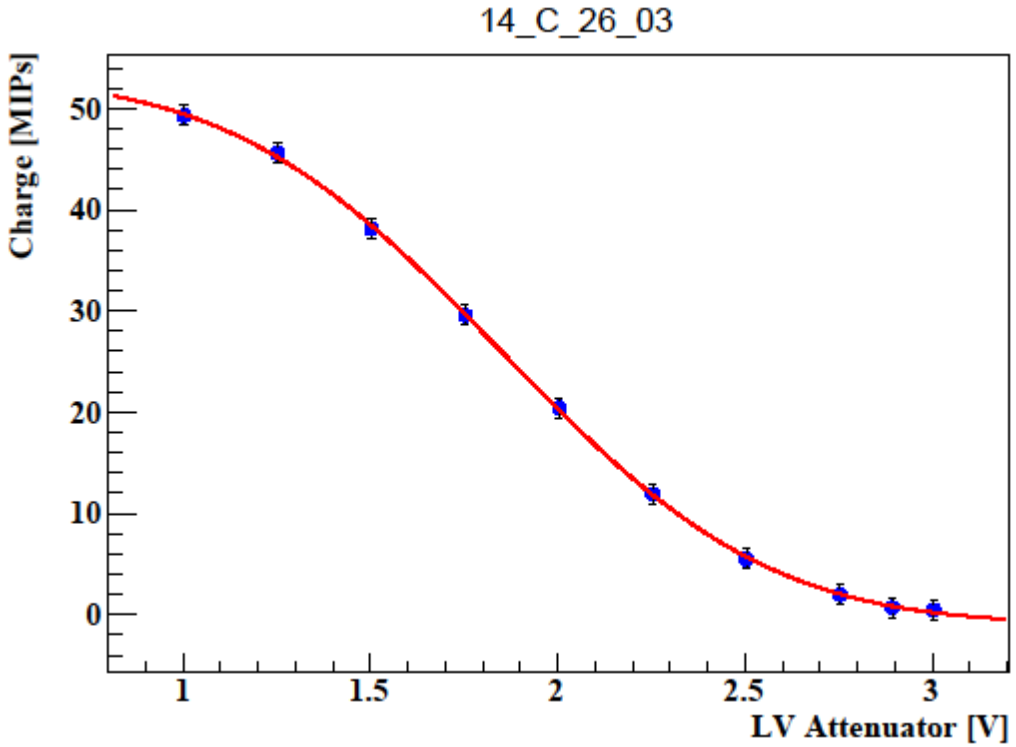
SPA-TCT: IR Laser Calibration

The four PIN sensors were used to calibrate the laser output supposing 75 eh/um are generated at room temperature



2 V = 21 MIPs 2.75 V = 2 MIPs

2.25 V = 13 MIPs 2.87 V = 1 MIPs

2.5 V = 6 MIPs 2.89 V = 0.8 MIPs

CHARGE
ch0->Draw("-Sum$((volt-vwv[0]->BlineMean)*(time>vwv[0]->tleft&&time<vwv[0]->tleft+30))*0.0625*1e6*3.162278/(50*211)/(75*Thickness*0.00016)")

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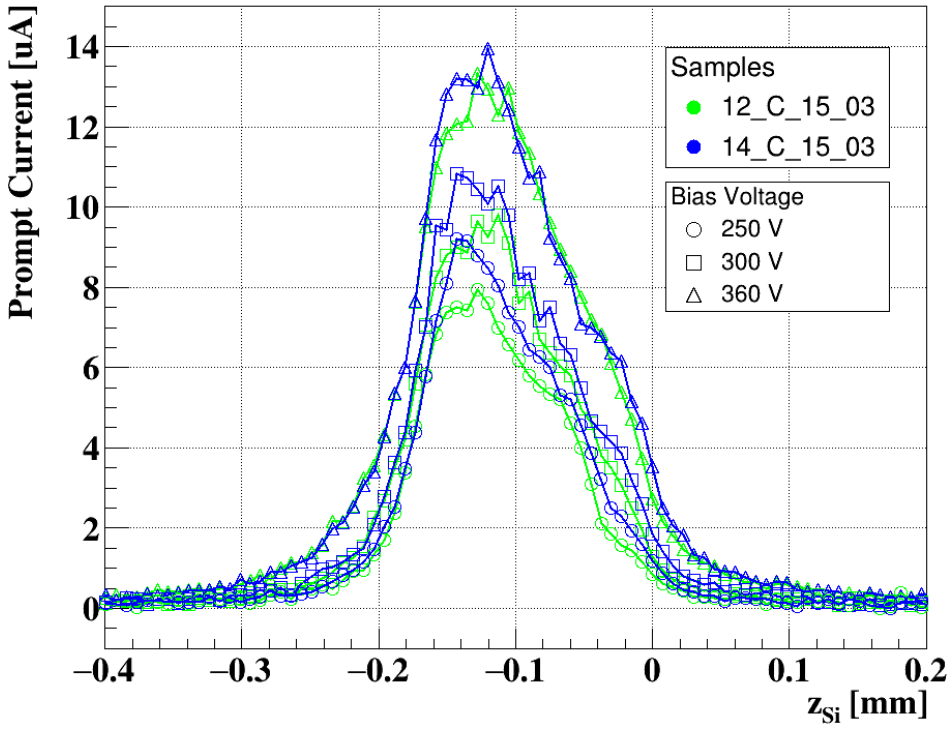
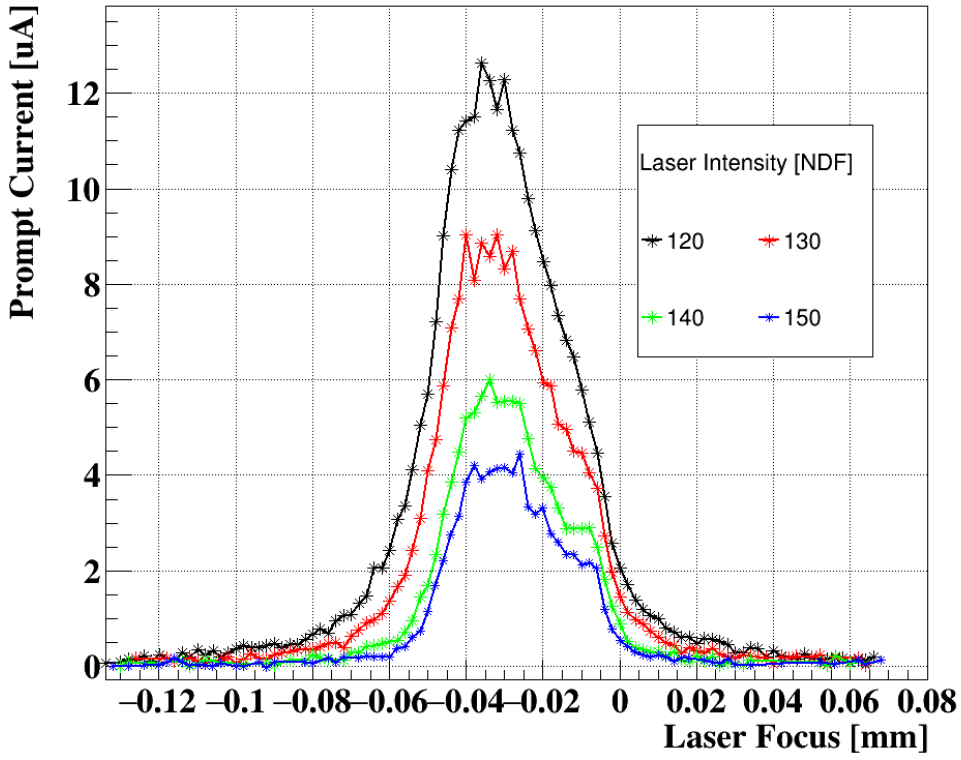
TPA-TCT: Prompt Current



PC is calculated in the first 600 ps, at 120 NDF

The electric field has the same shape in the two samples at the same bias voltage



PC is calculated in the first 600 ps, at 360 V, for 12_C_15_03

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