Study of gain suppression in LGADs using IBIC and TRIBIC

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Outline

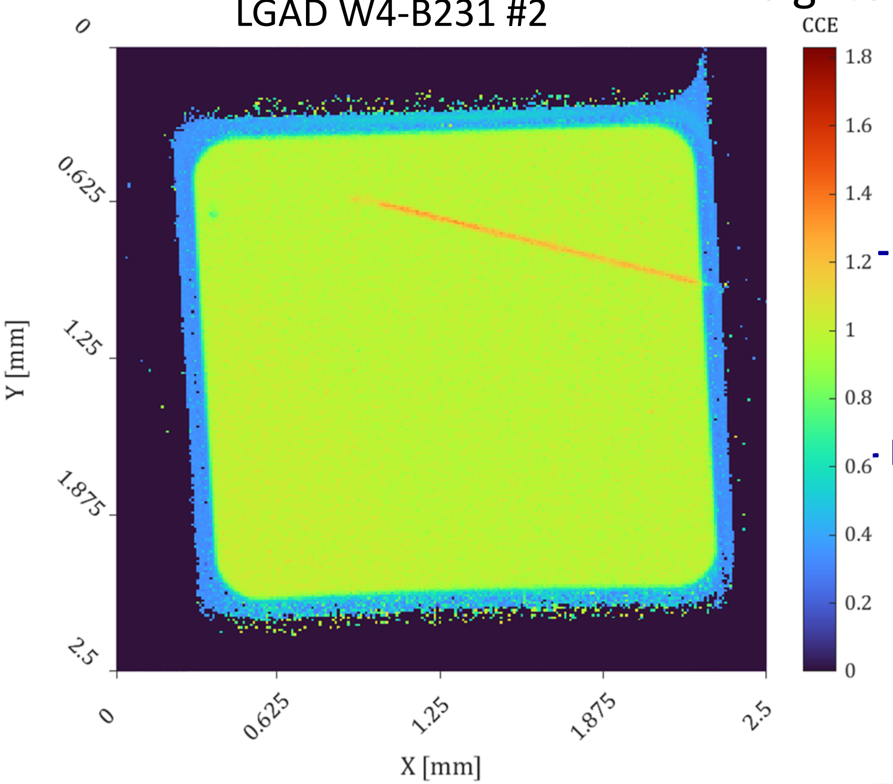
- MOTIVATION: HOW THE IONISATION DENSITY UNDER THE MULTIPLICATION LAYER AFFECTS THE RESPONSE OF LGADS.
- ANGULAR MEASUREMENTS BY IBIC ON A PIN TO DETERMINE THE STRUCTURE OF THE DETECTOR.
- GAIN SUPRESSION IN LGAD USING IBIC.
- TIME-RESOLVED MEASUREMENTS: TCT (LASER) VS TRIBIC (ION BEAM).
- GAIN SUPRESSION IN LGAD USING TRIBIC.
- GAIN SUPRESSION WHEN THE BRAGG PEAK IS DEPOSITED WITHIN THE LGAD

IBIC MEASUREMENTS ON FOUR SECTORS 50 µm LGAD & PIN

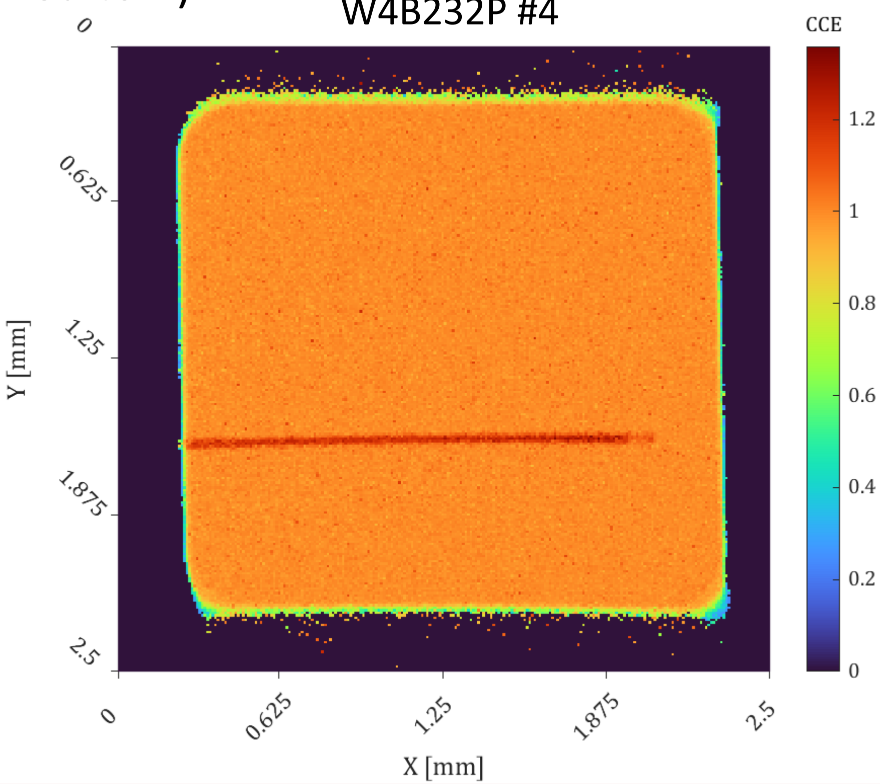
3 MeV protons V=+40V ΔE in 50 µm of Si =1.16 MeV

Weighted mean CCE (normalized to 1)

Run: 10478



- Bonding and electrical characterization by IFCA/CERN
- Dedicated PCB for laser and IBIC measuremts

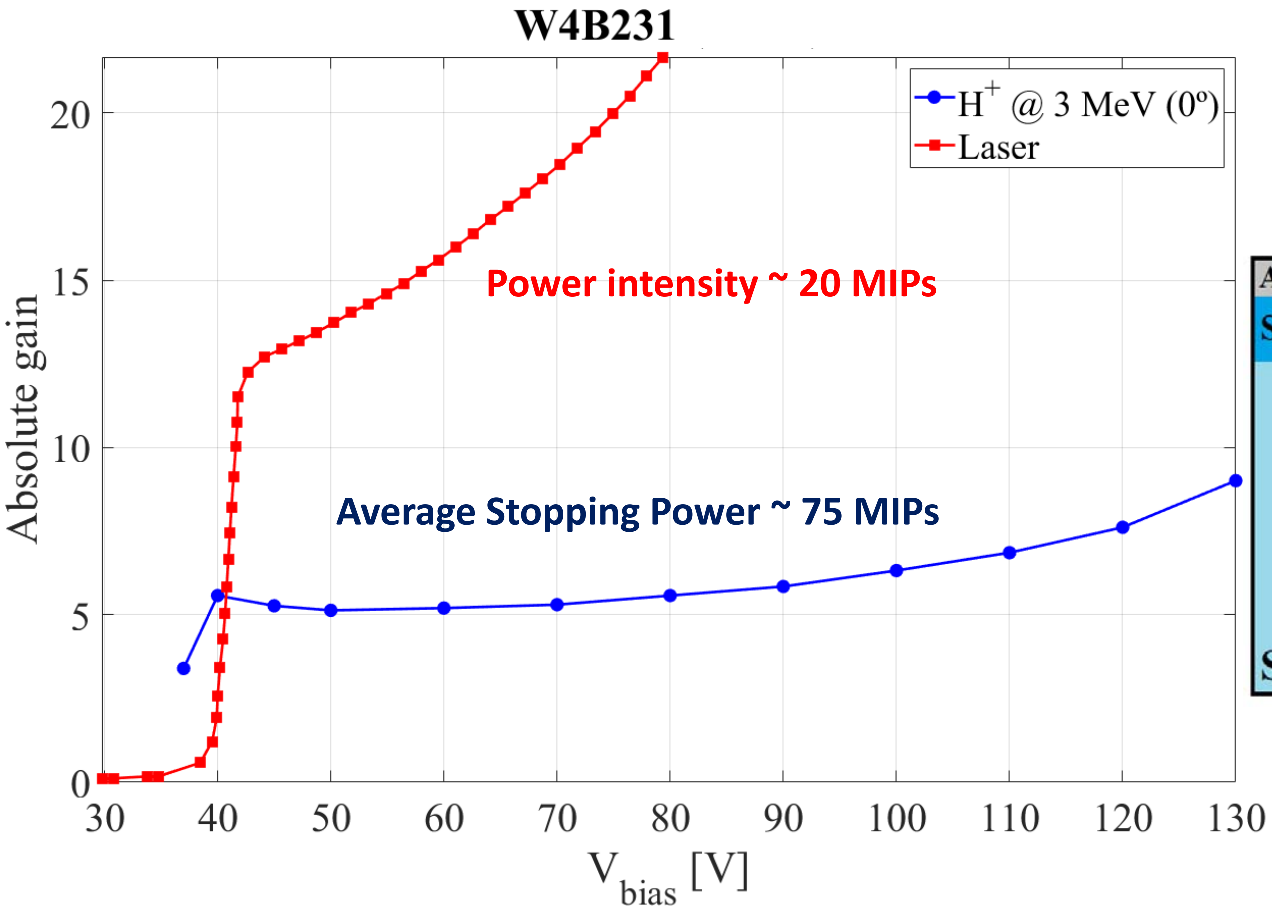


We confirm that the active areas are homogeneous. LGAD better than 4% and PIN better than 2%.

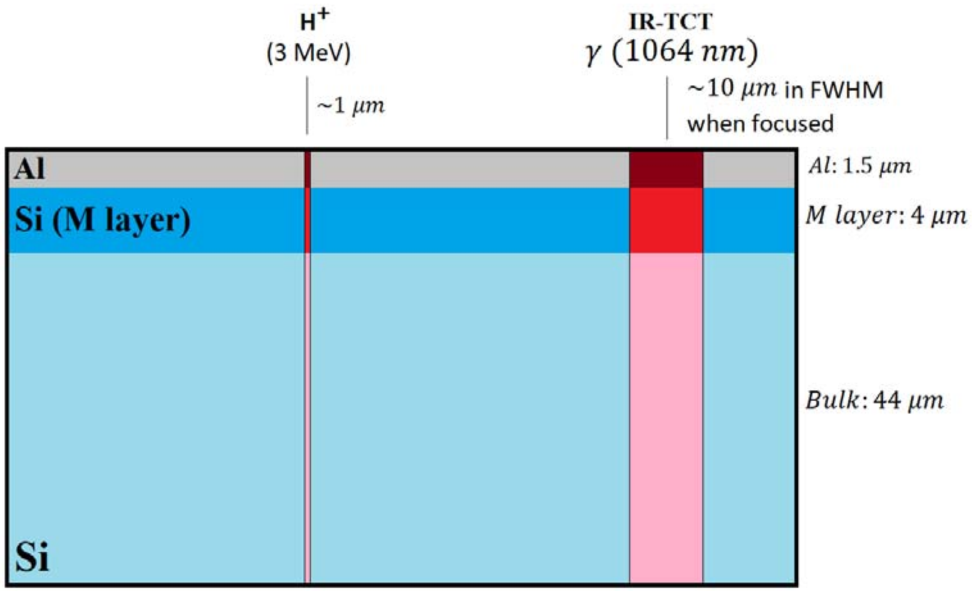
The LGAD has an region of lower CCE that appears after the multiplication layer while in the PIN we only see a continuous value of CCE.

Motivation: How does the change in ionization density under the multiplication layer affects the response of LGADs?.

IR-laser vs IBIC Gain measurements on LGAD (at 20º)



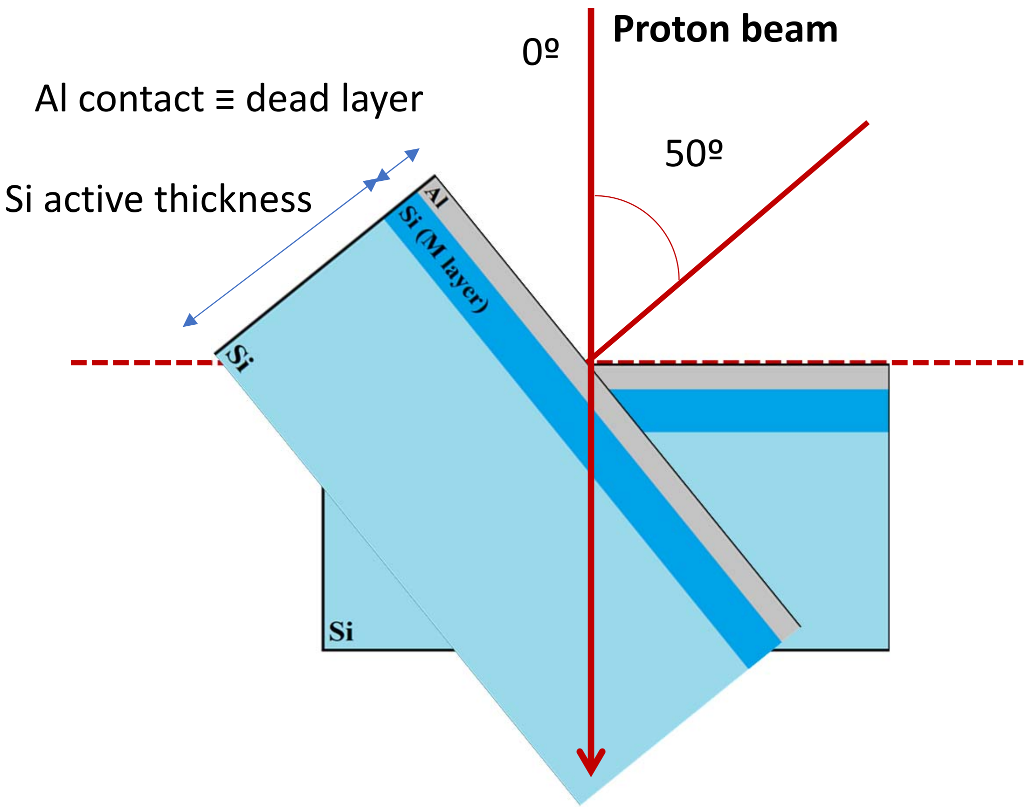
IR-laser measurement: Esteban Currás SSD- CERN

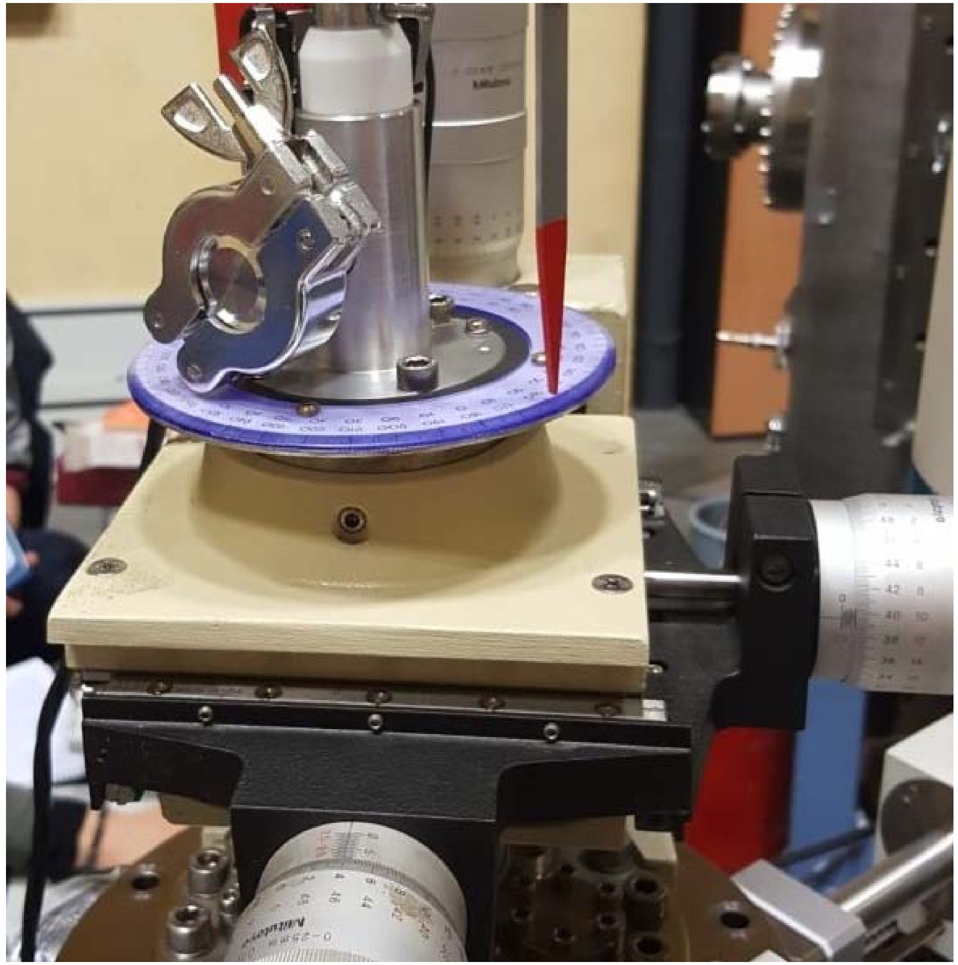


Charge density:
IBIC 30 times higher than IR-laser

Sample holder for IBIC measurements at different angles (0º-90º)

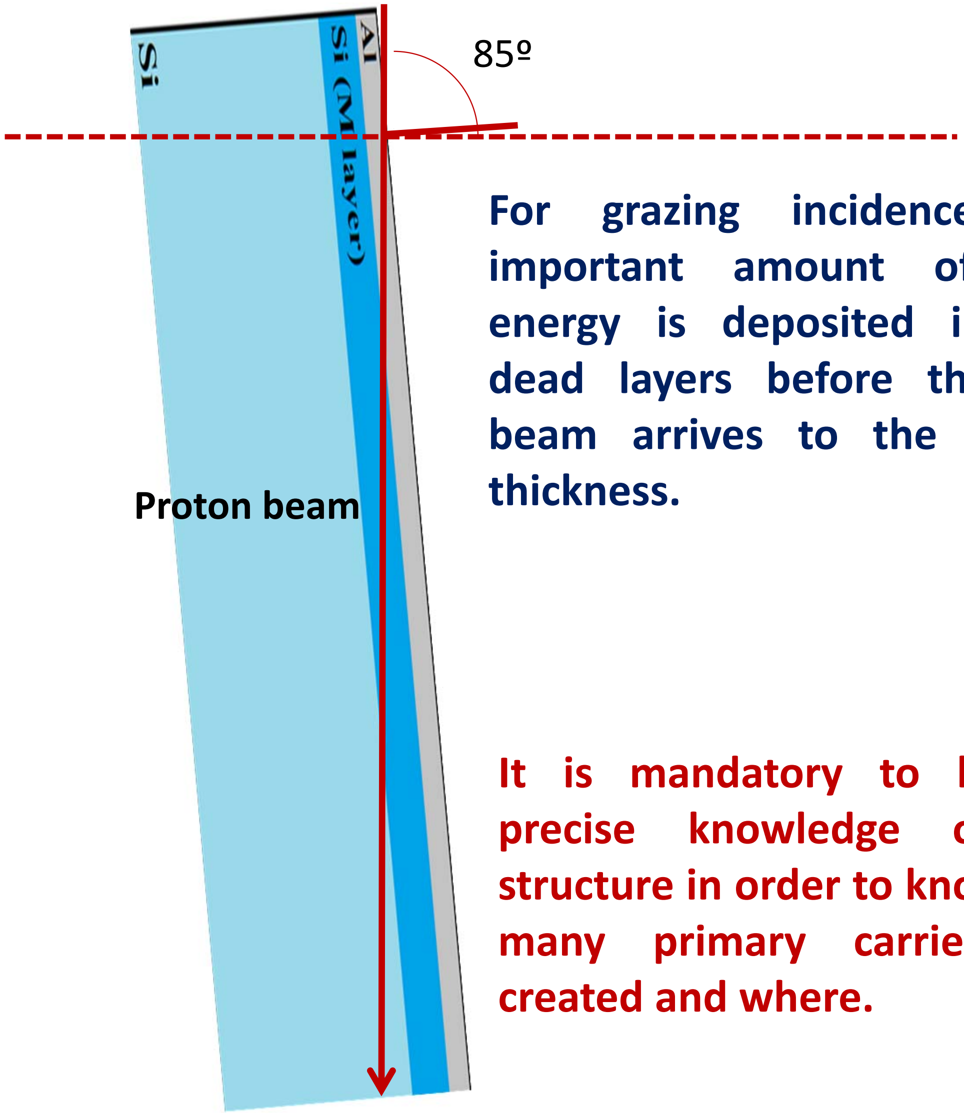
To modify the ionization density under the multiplication layer we have carried out an experiment by turning the detector.





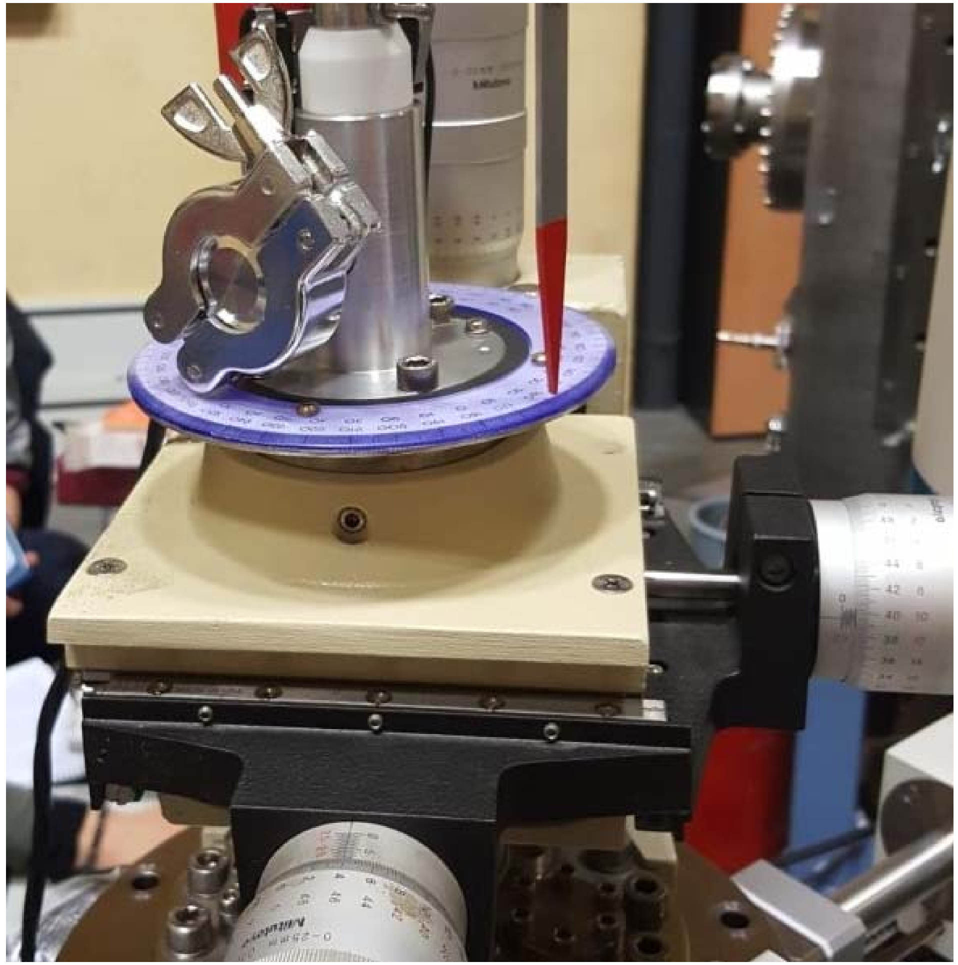
Accuracy: 1º

Sample holder for IBIC measurements at different angles (0º-90º)



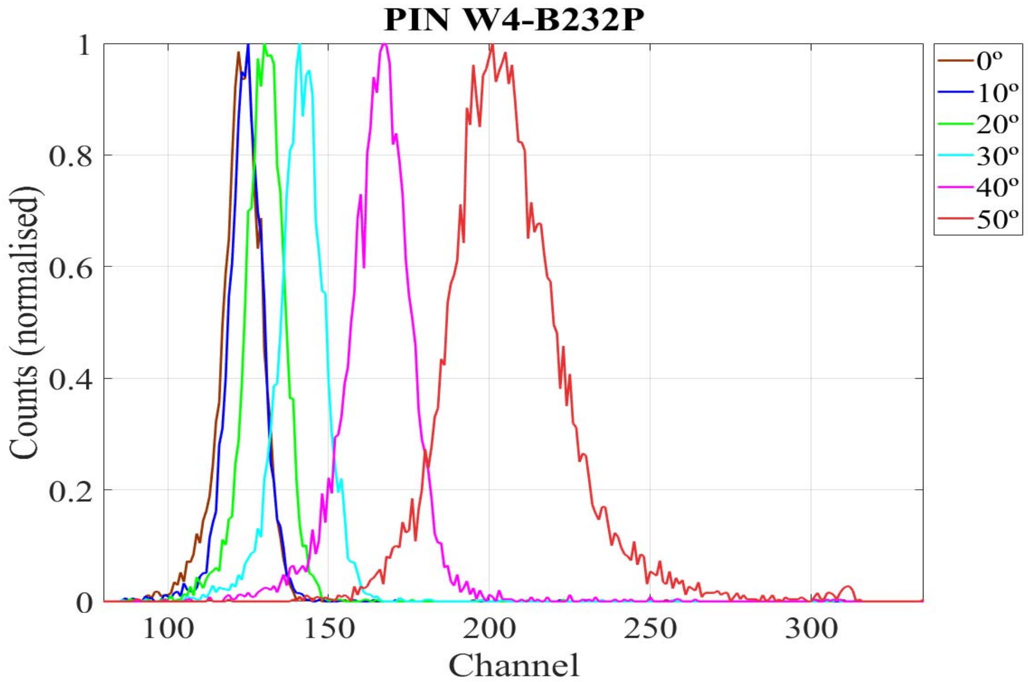
For grazing incidence, an important amount of the energy is deposited in the dead layers before the ion beam arrives to the active thickness.

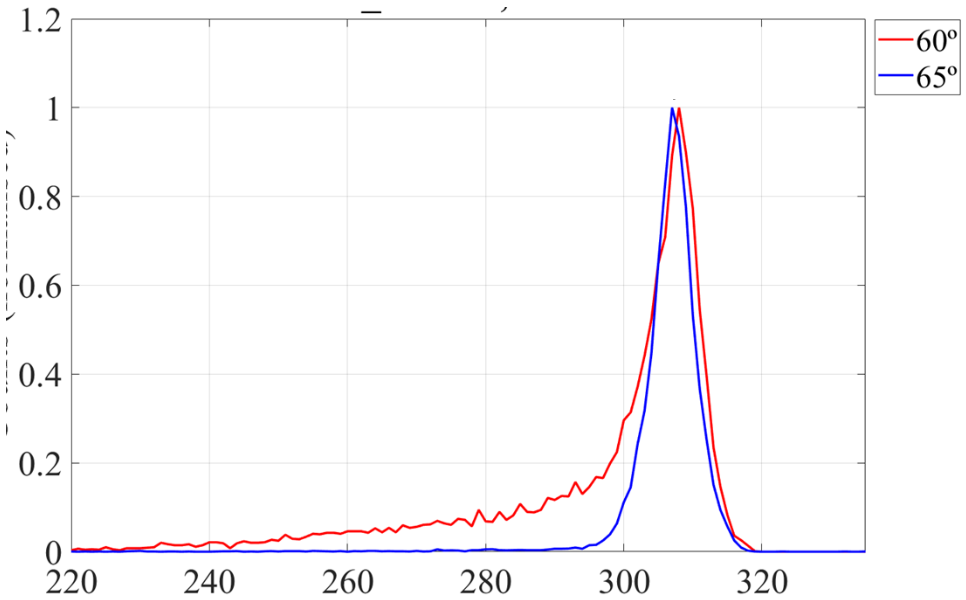
It is mandatory to have a precise knowledge of the structure in order to know how many primary carriers are created and where.

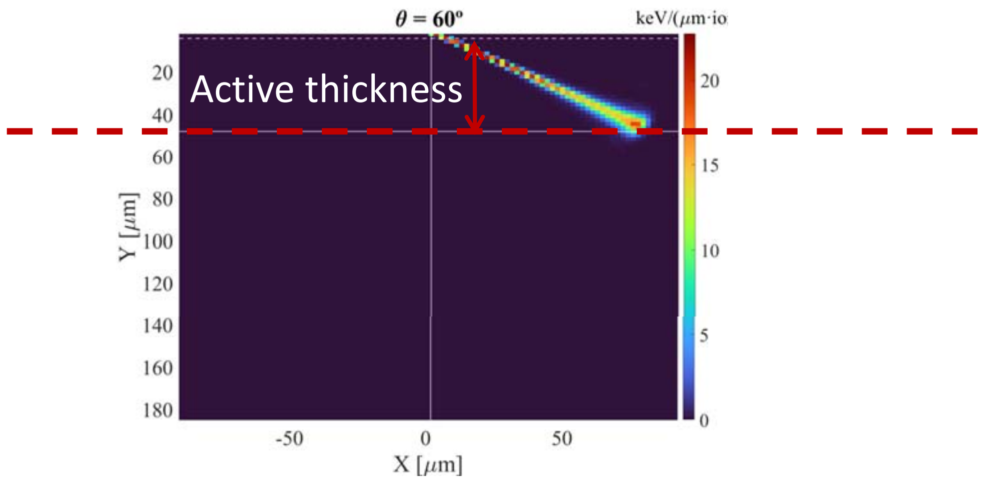


Accuracy: 1º

Structure of the detector : Thicknesses of the Al electrode and Si active layer



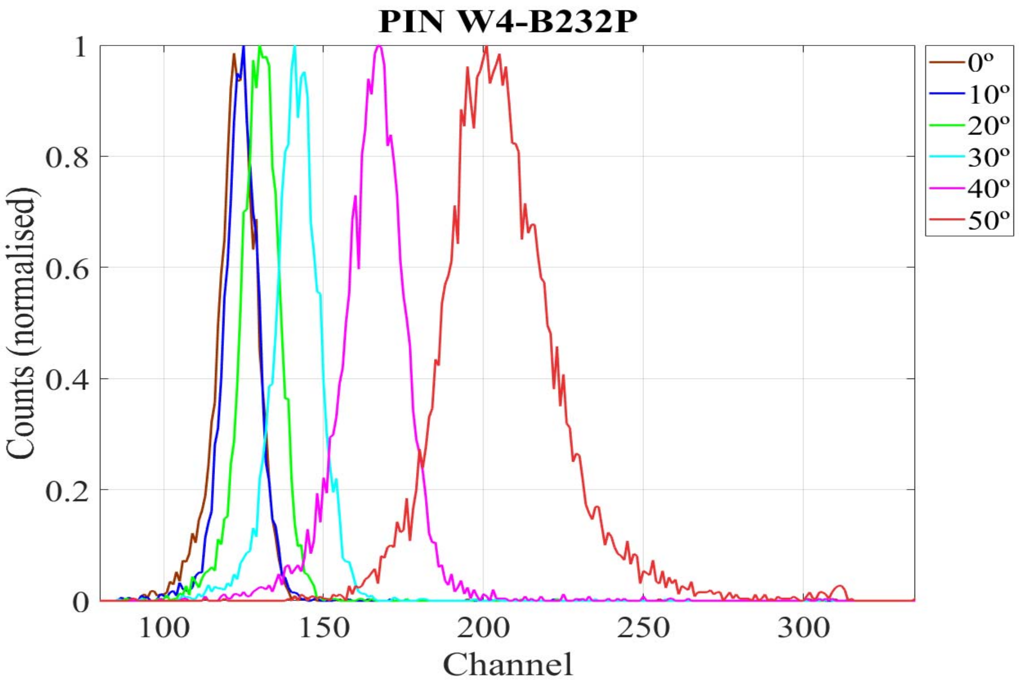




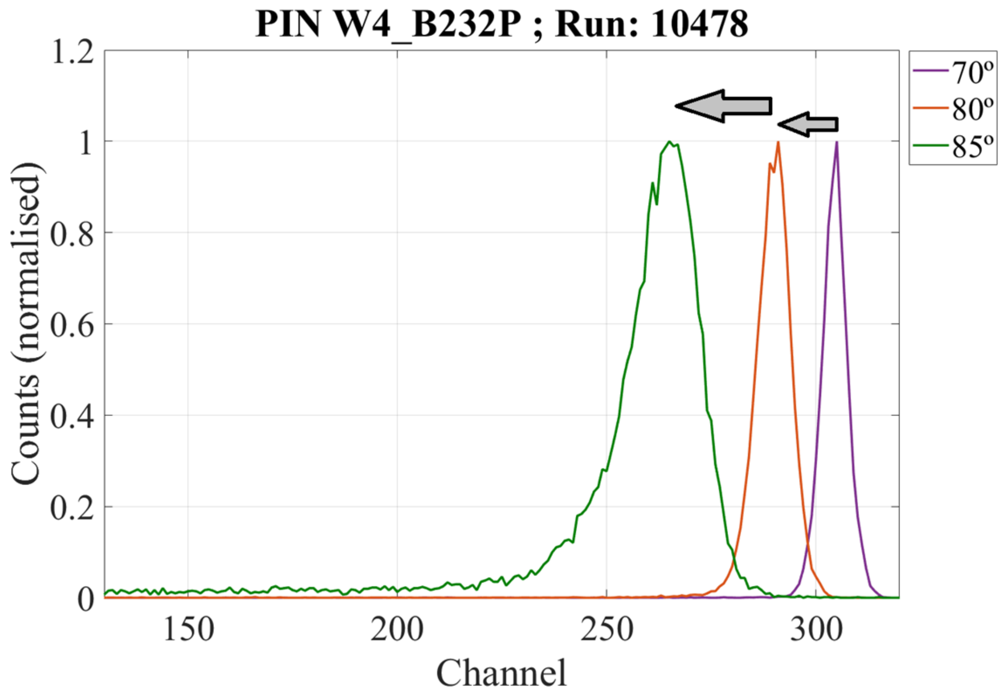
Larger angle → Larger ionization path → Energy straggling

- Peak widens as the beam straggling increases.
- Peak shifts to the right because more energy is deposited as the ionization path increases.

Structure of detector : Thicknesses of the Al electrode and Si active layer



Peak position at low angles determines the Si active thickness.



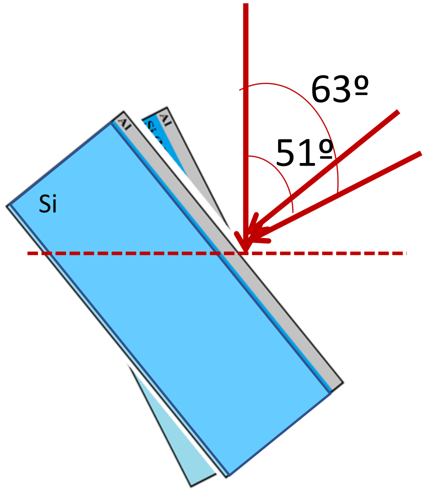
Peak position at very large angles (70º, 80º and 85º) allows an accurate determination of the "Al contact equivalent" thickness.

Structure of detector : Thicknesses of the Al electrode and Si active layer

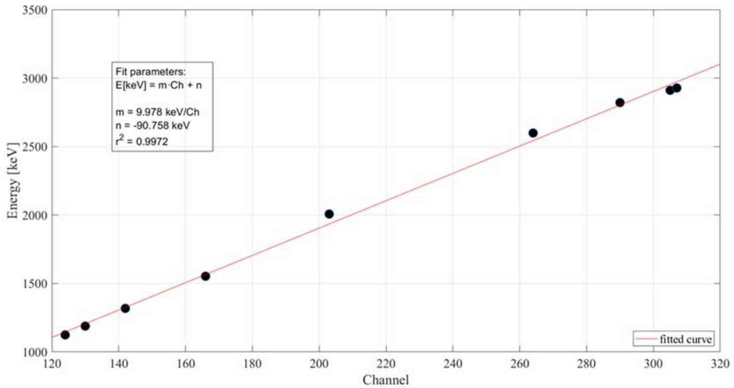
ITERATIVE PROCESS

Equivalent thickness of Al (contact and passivation layers and other dead layers) and active Si.

For this structure, the deposited energies for each measured angle are simulated with SRIM.

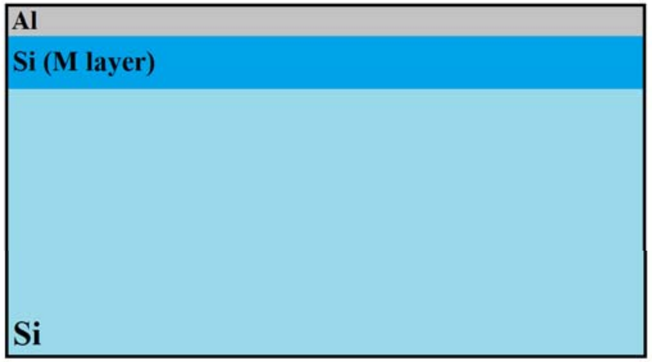


The simulated energies vs. experimental channels are plotted and the line of best fit is obtained.



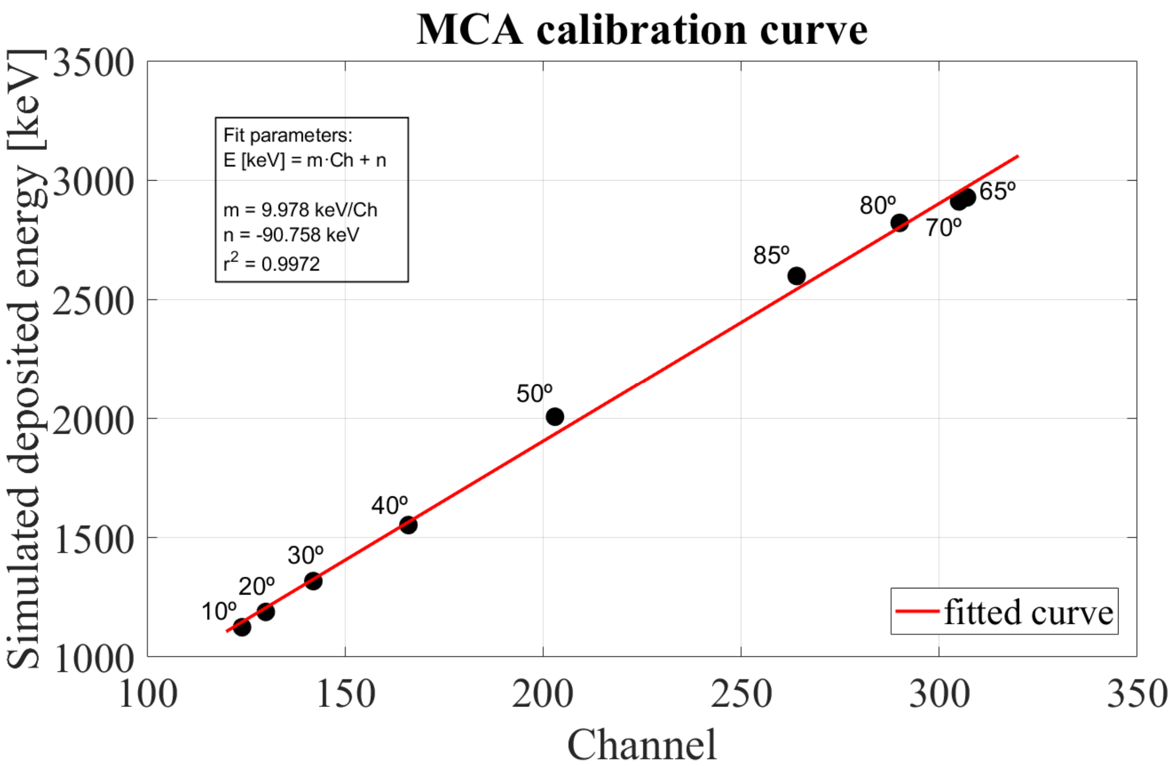
Detector structure and MCA calibration

The structure found coincides with the nominal one provided by the CNM.



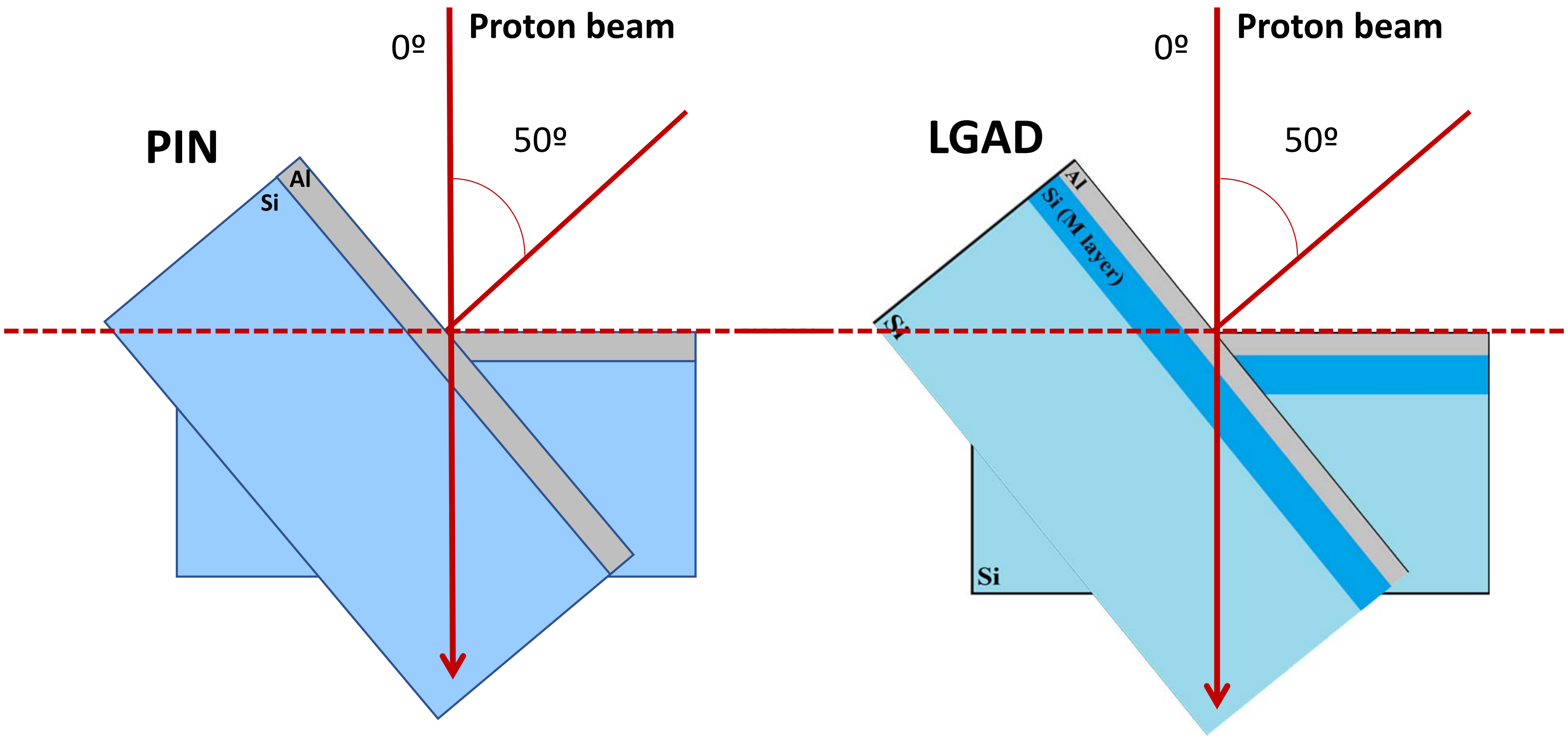
$$1.5\ \mu m\ (Al) + 48\ \mu m\ (Si)$$

$$48\ \mu m\ (Si) = 4\ \mu m\ (M\ layer) + 44\ \mu m\ (Substrat)$$



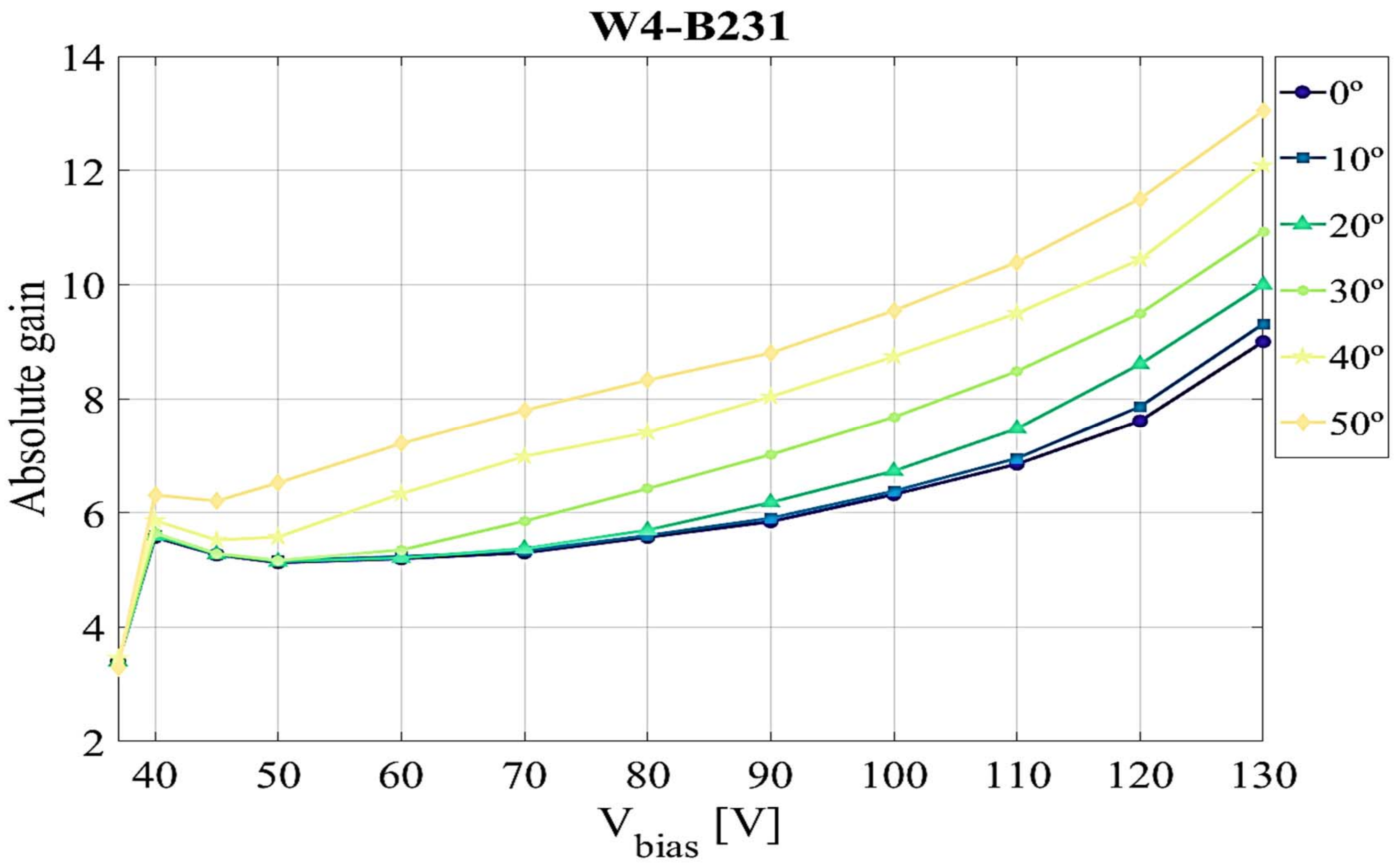
Gain definition

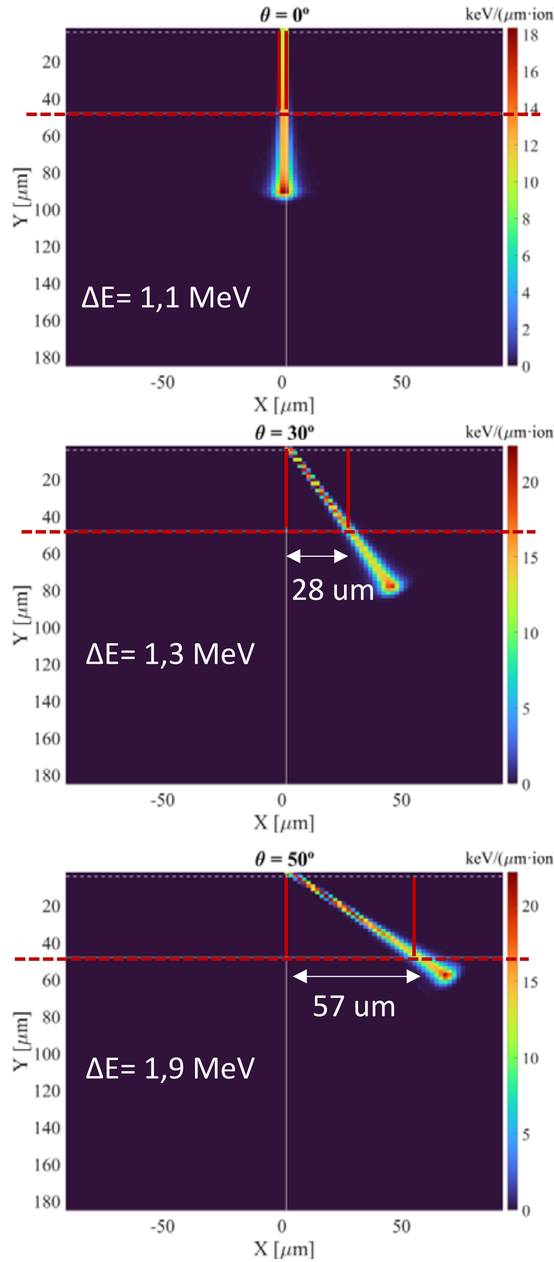
Gain definition: $G(V) = E(V)_{LGAD}/E_{PIN}$ For all θ



All geometrical effects are well determined and are corrected by normalizing by the PIN.

Gain curves vs V at angles up 50º

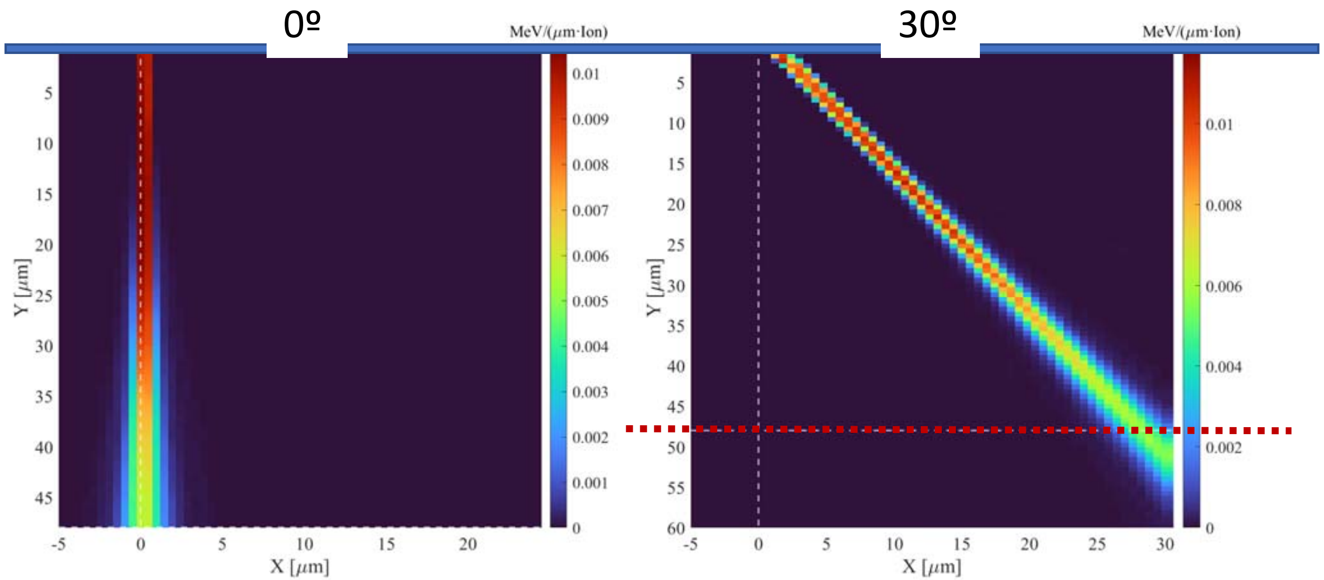


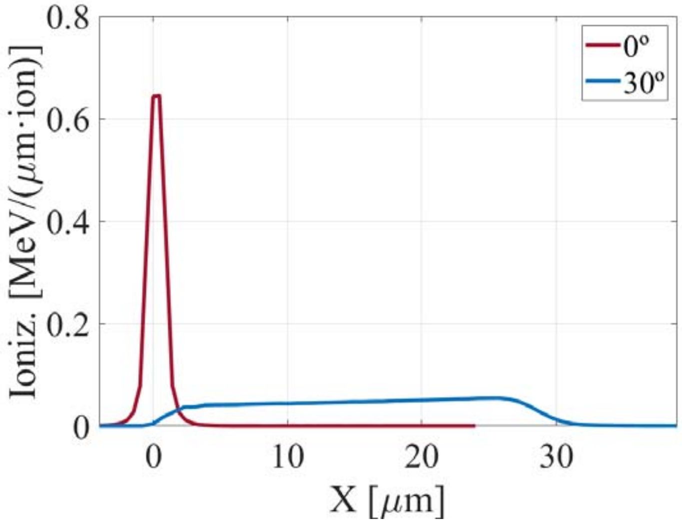


Lower charge density under gain layer → Higher gain

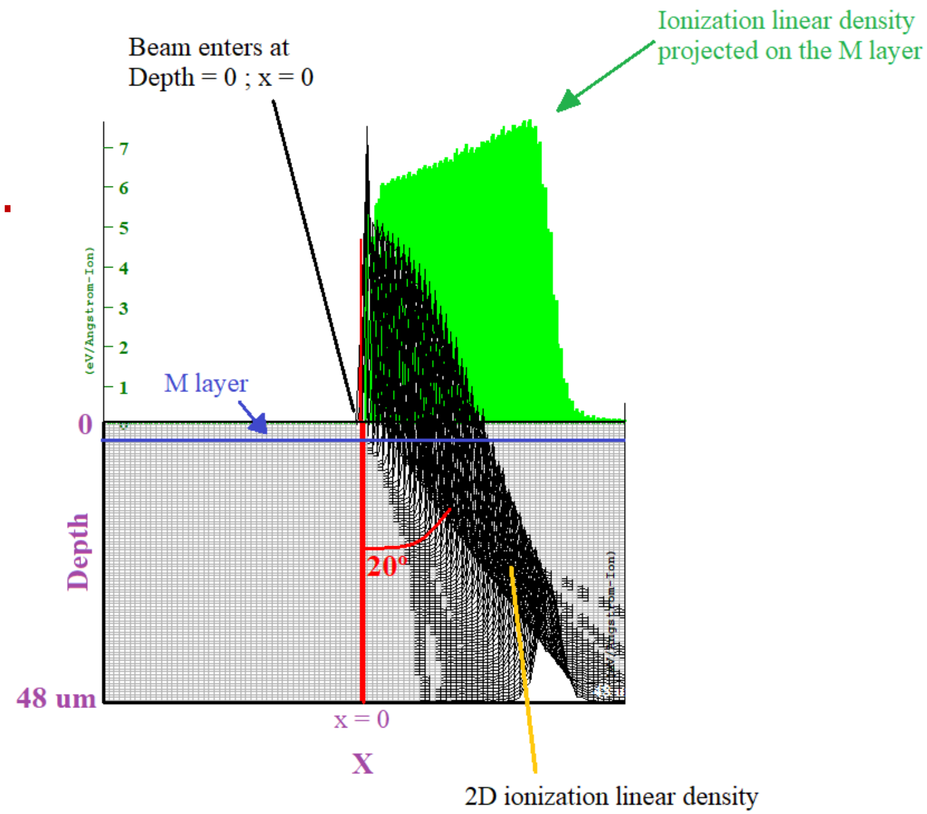
Ionization linear density definition

SRIM 2013 Simulations

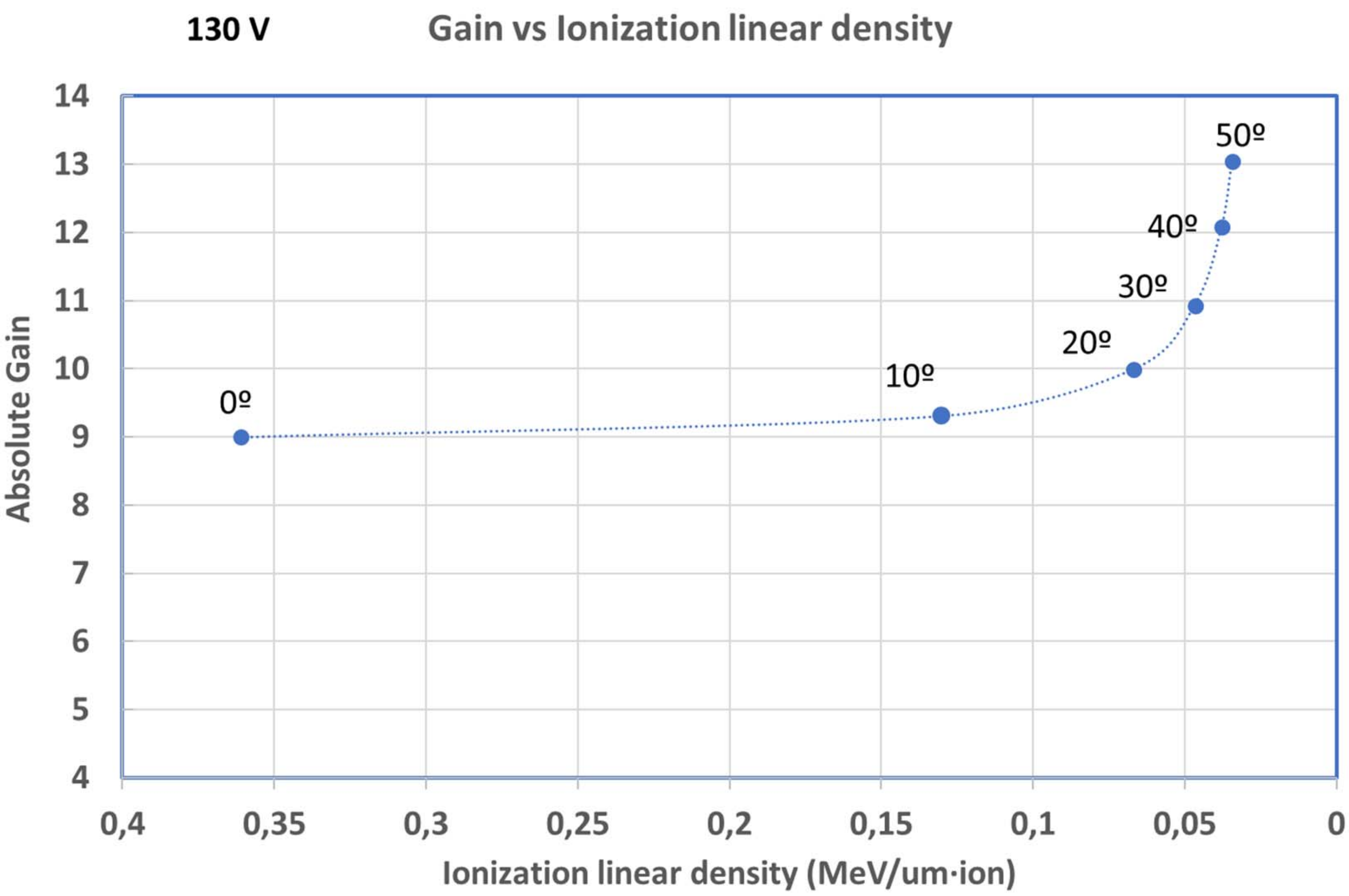




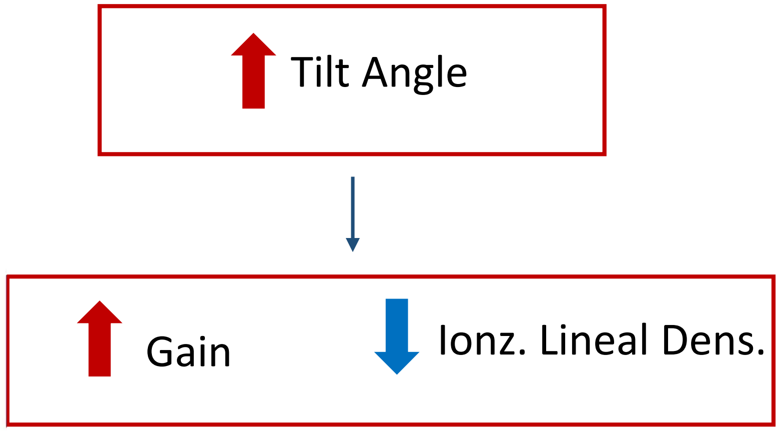
Gain layer; We take the ionization linear density along the trace of the ion projected on the Gain Layer.



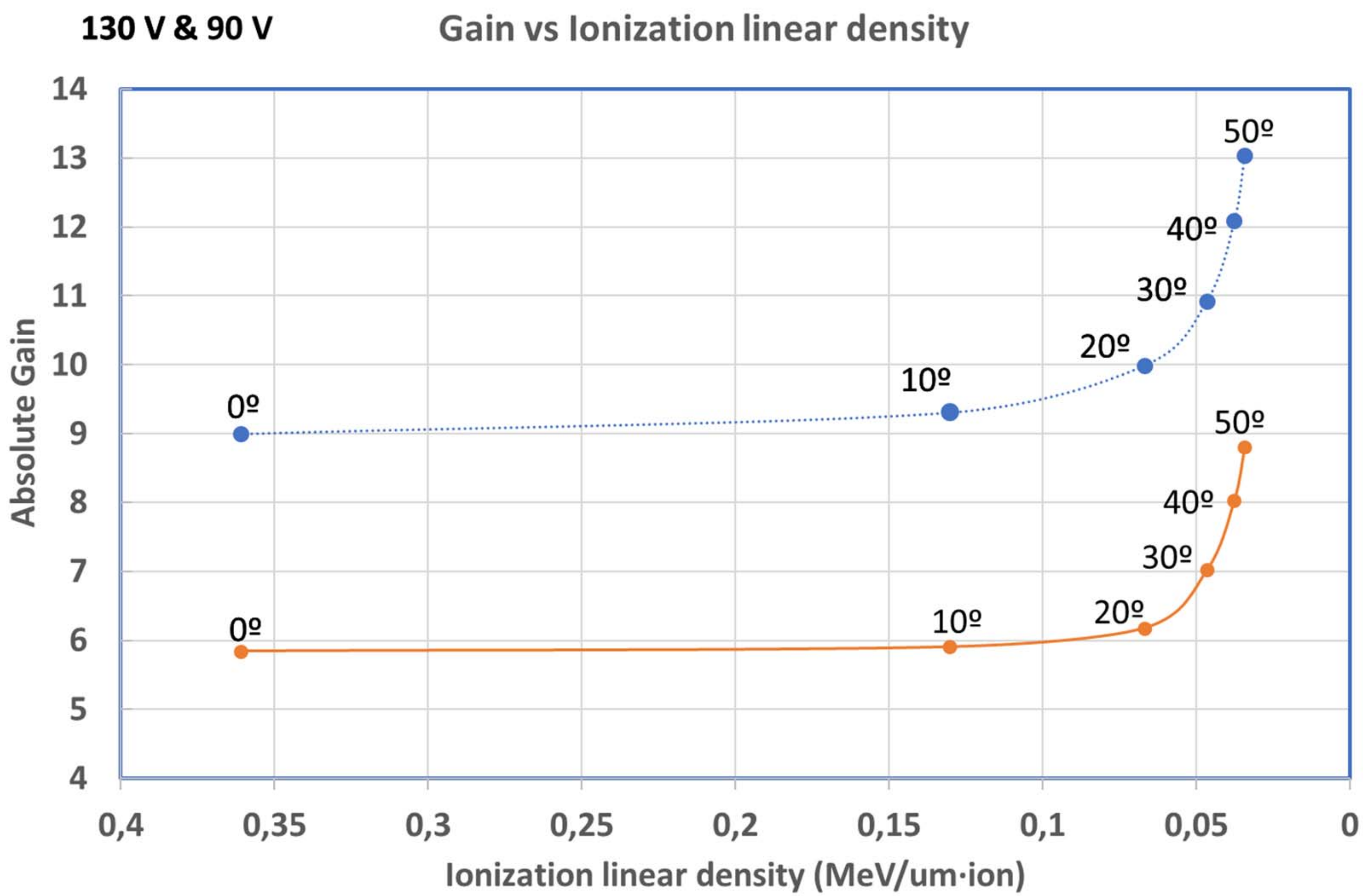
Absolute Gain @ 130 V vs Ionization linear density



The mean ionization density projected on the multiplication layer decreases up 50º while gain increases with tilt angle.



Absolute Gain @ 130 V vs Ionization linear density



The mean ionization density projected on the multiplication layer decreases up 50º while gain increases with tilt angle.

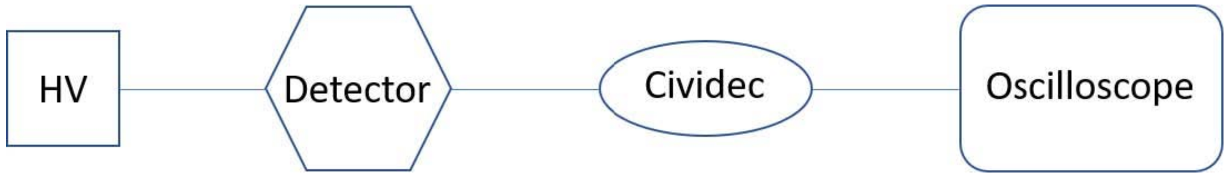
↑ Tilt Angle

↓

↑ Gain ↓ Ionz. Lineal Dens.

Time-Resolved Ion Beam Induced Charge (TRIBIC)

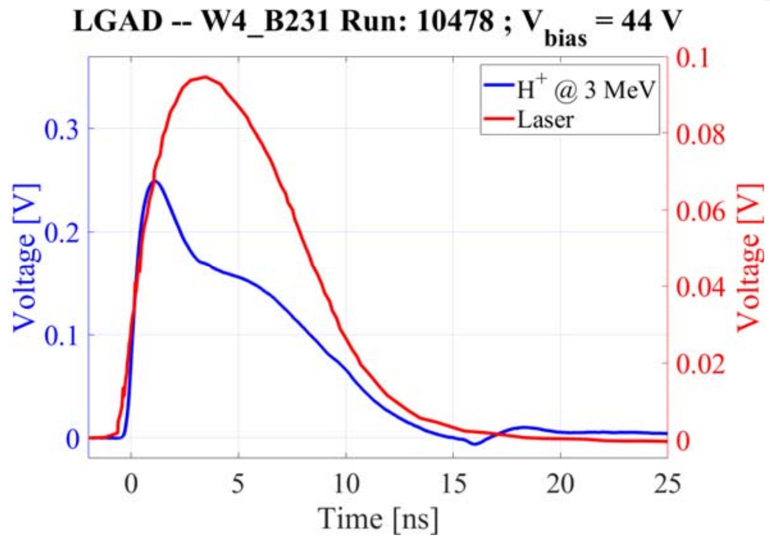
Protons measurements

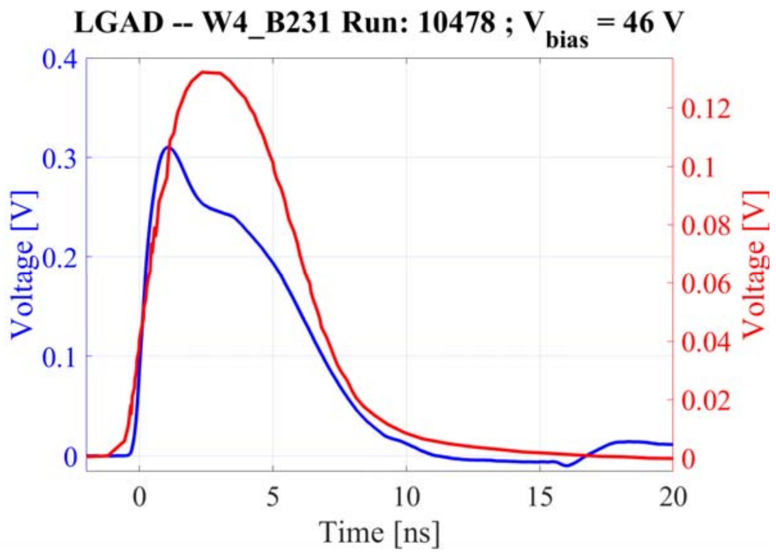


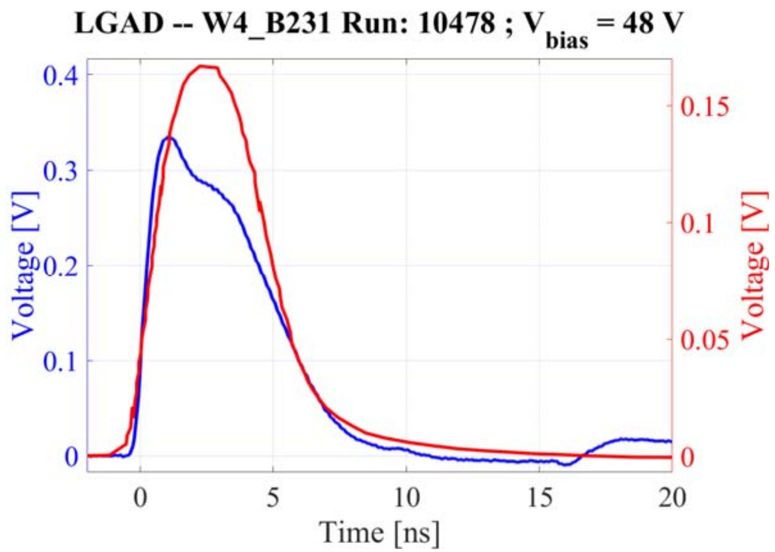
- 3 MeV protons: ΔE in 50 µm of Si =1.16 MeV
- Beam size: 10x10 μm^2
- Γ ~ 200 Hz
- 200 x 200 μm^2
- Room Temperature
- Amplifier: CIVIDEC C2, 2 GHz, 40 dB.
- Oscilloscope: TeledyneLecroy HDO9404, 4 GHz, 40 Gsa/s
- Self trigger: all signals are corrected so that they have t = 0 at 30% of the maximum signal
- Averaging of 1000 to improve SNR
- 25 ps steps

Time-Resolved Measurements: TCT (Laser) vs TRIBIC (Ion beam)

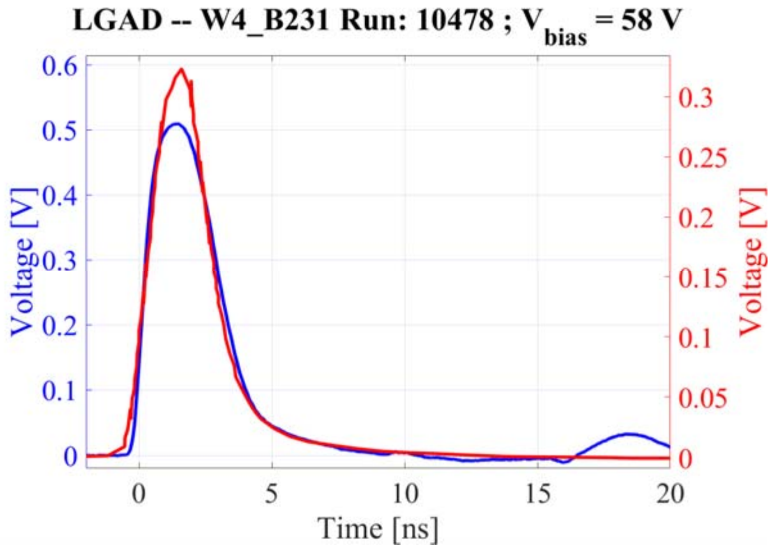
Comparison of TCT and TRIBIC to study the shape of current pulses at different voltages.

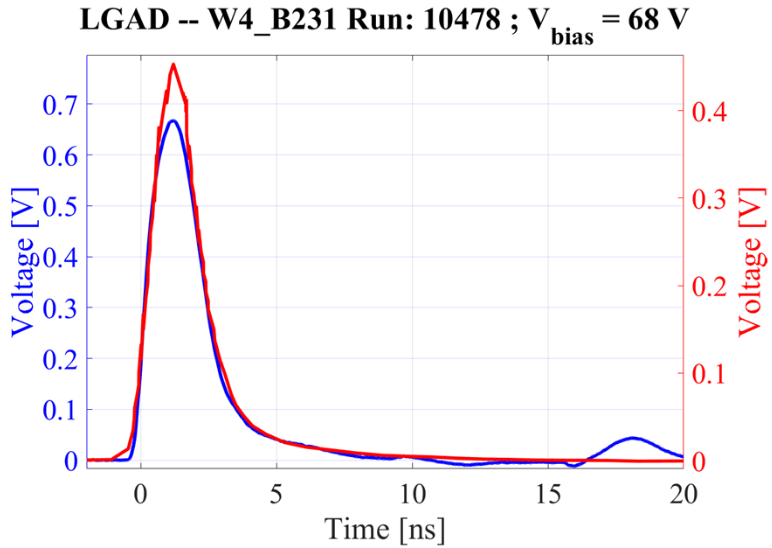


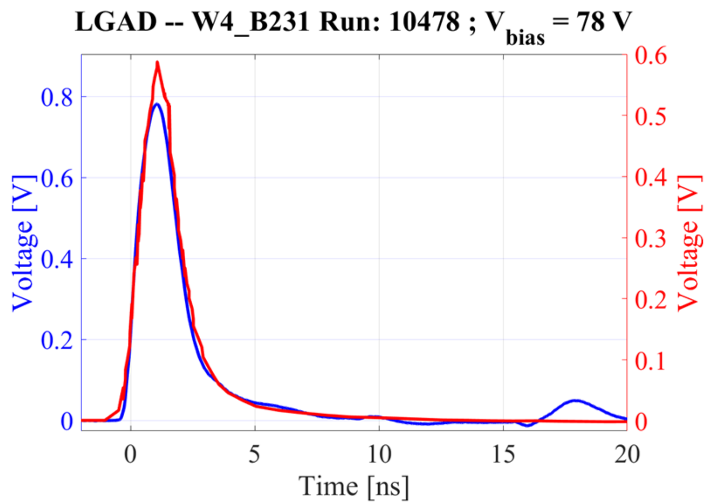




Time-Resolved Measurements: TCT (Laser) vs TRIBIC (Ion beam)

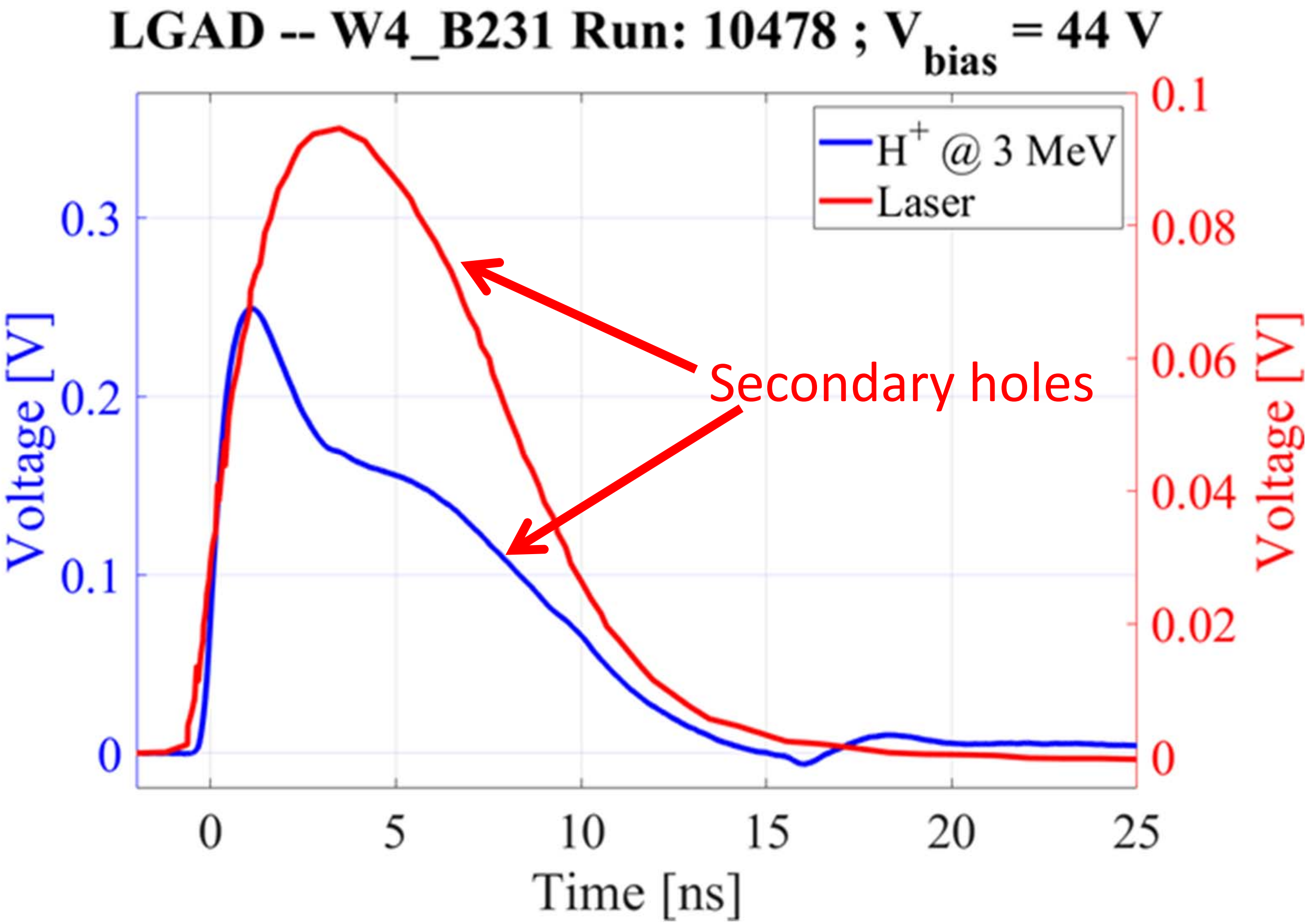






At low voltages the signal is long enough to distinguish the different components of the pulse.
However, at high voltages, the waveform becomes very short the signal structure is lost and laser and TRIBIC look very similar.

Time-Resolved Measurements: TCT (Laser) vs TRIBIC (Ion beam)



TCT: Large gain

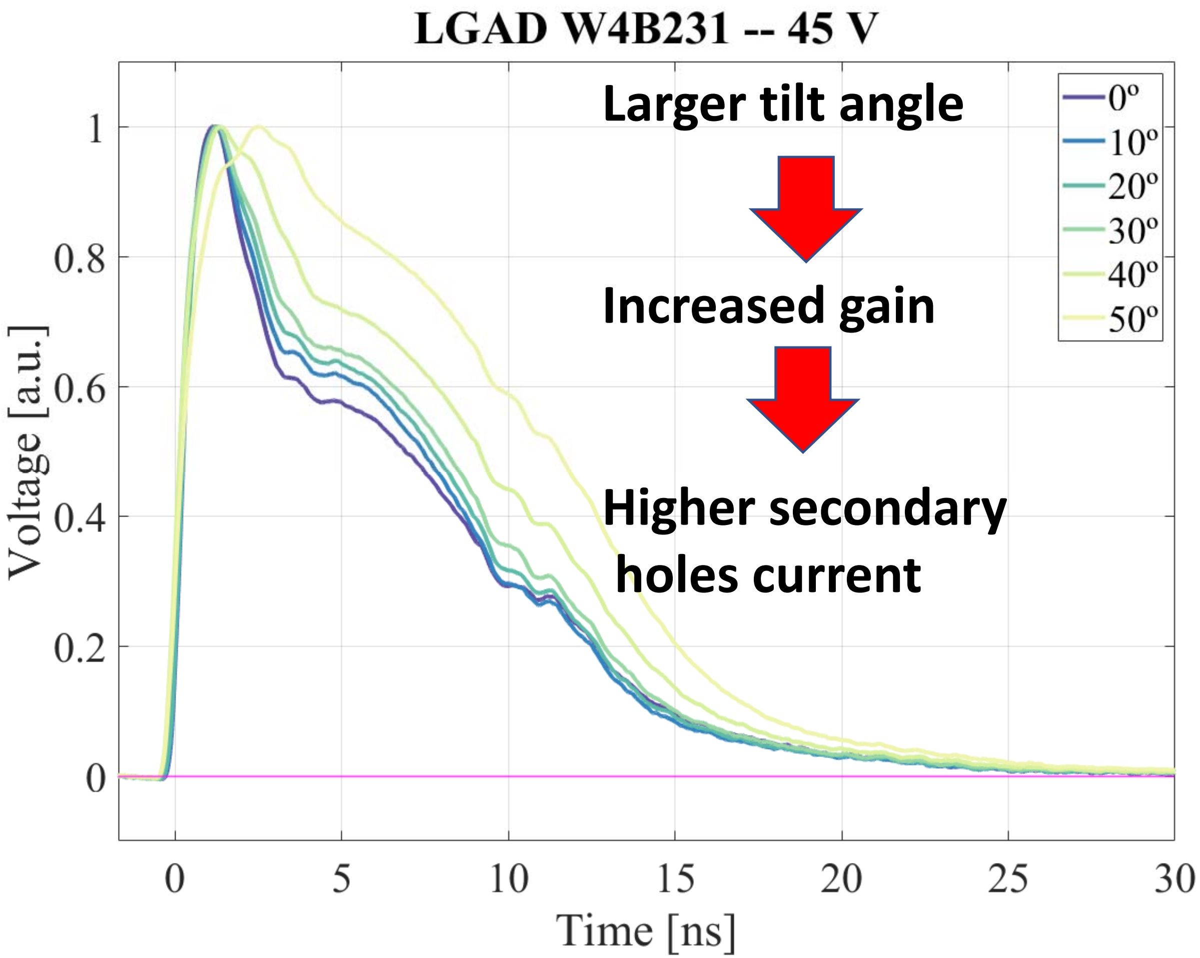
High secondary holes current

The width of the signals is the same, indicating that there is no microplasma.

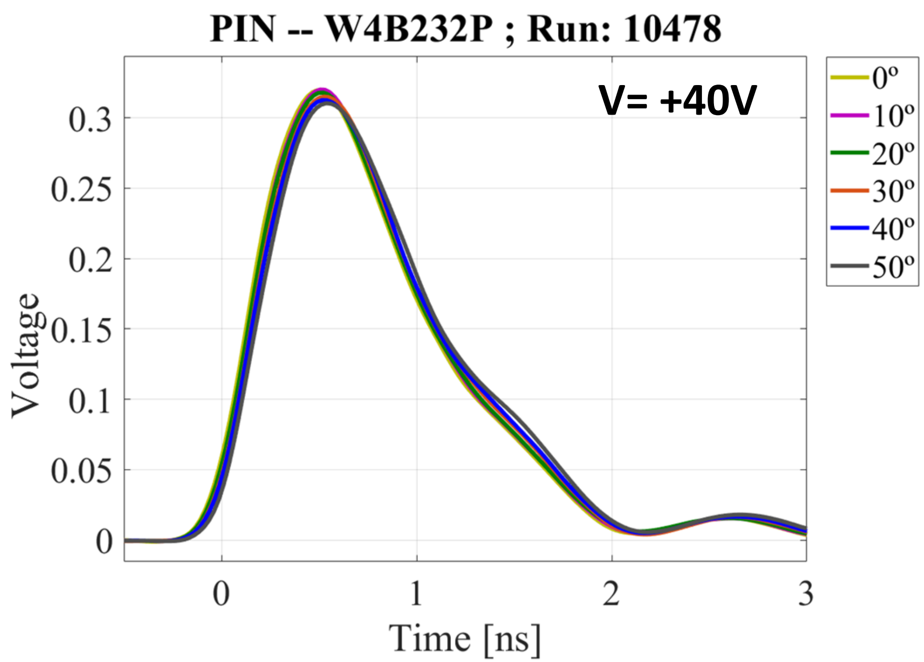
TRIBIC: Low gain

Secondary holes current is lower

Gain suppression in LGAD by TRIBIC



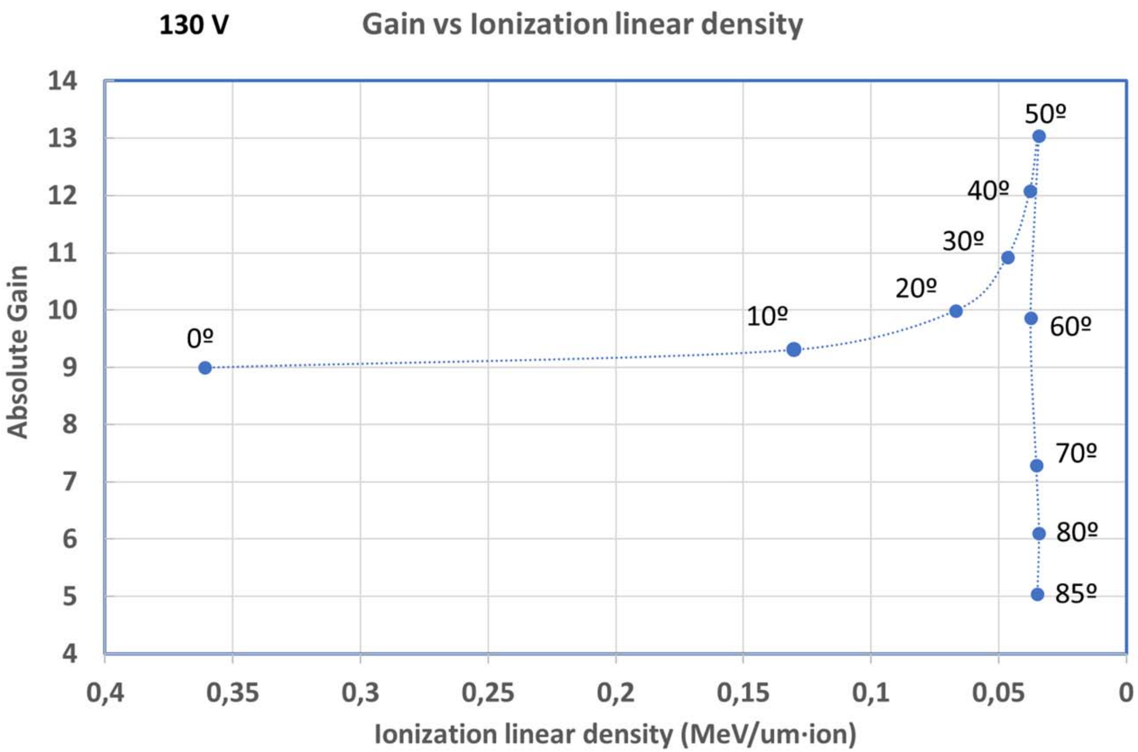
The waveforms are normalized to the maximum of the signals.

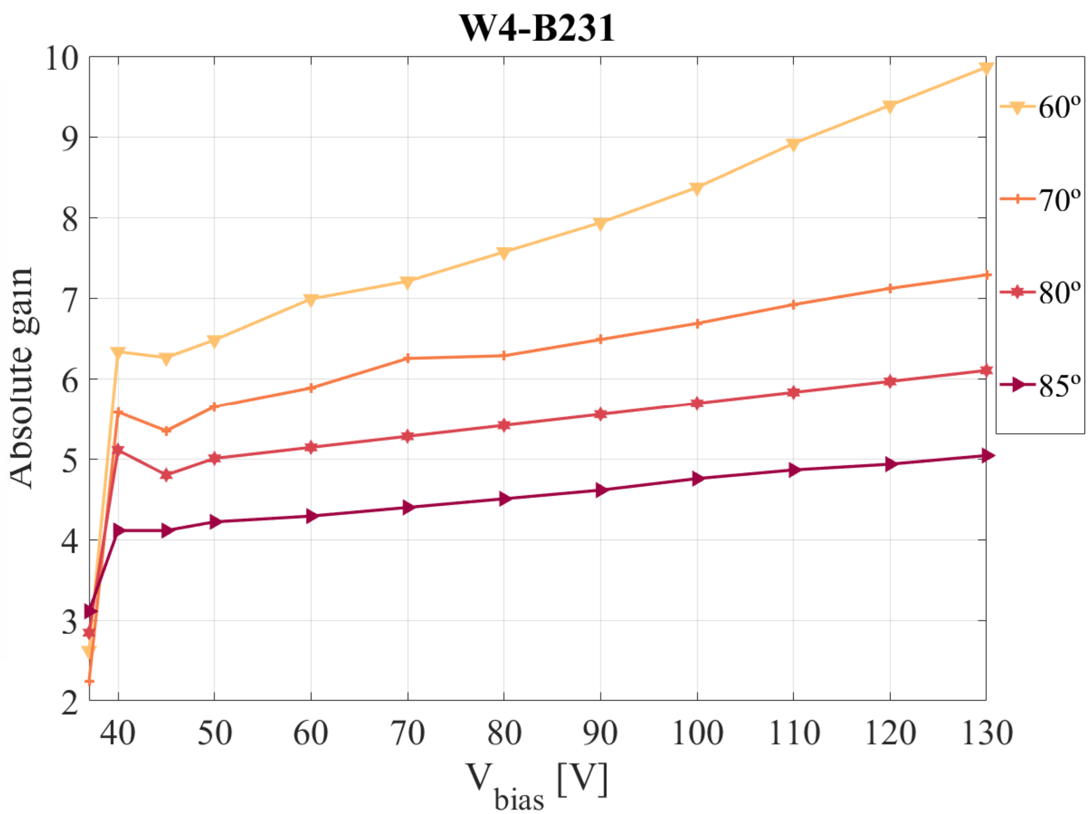


The signals are corrected for the excess charge deposited by increasing the path for increasing angles.

The PIN measurements up to 50° also show that there is no microplasma as the signal duration is only 2 ns.

Gain suppression when the Bragg peak is in the active volumen

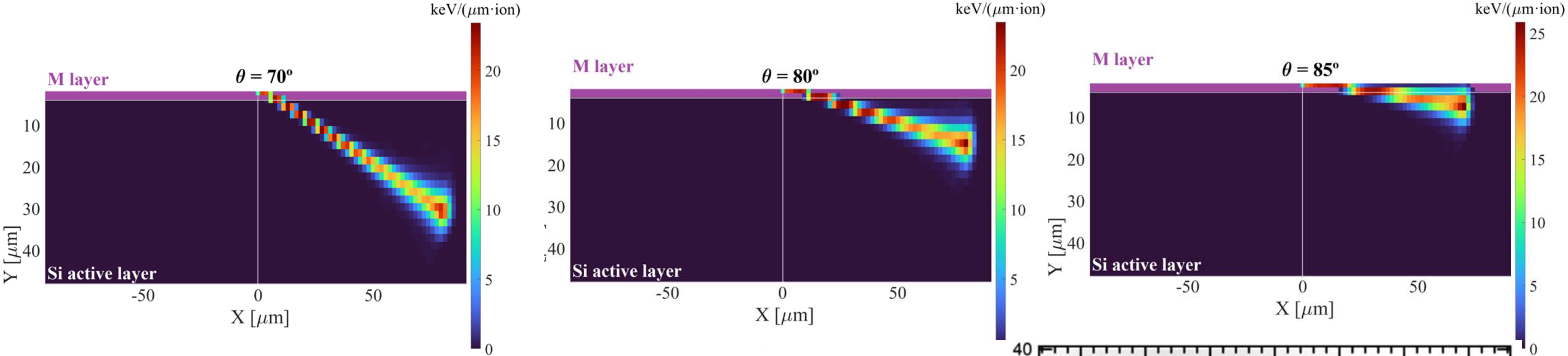




From 60° the Bragg peak is within the active volume of the detector. The linear ionization density remains almost constant, but the gain decreases drastically.

Gain suppression when the Bragg peak is in the active volumen

1) Between 70° and 85° the number of the electrons created closer to the anode becomes larger. The multiplication factor grows exponentially with the distance travelled by the electrons within the multiplication layer.



2) Due to ambipolar diffusion, the closer the Bragg peak is deposited to the gain layer, the higher the ionization density because the carriers have less time to diffuse in the direction perpendicular to the electric field.

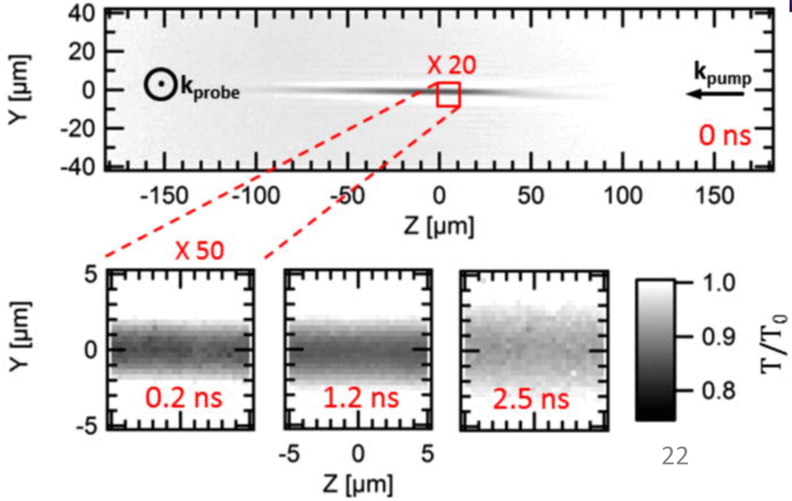


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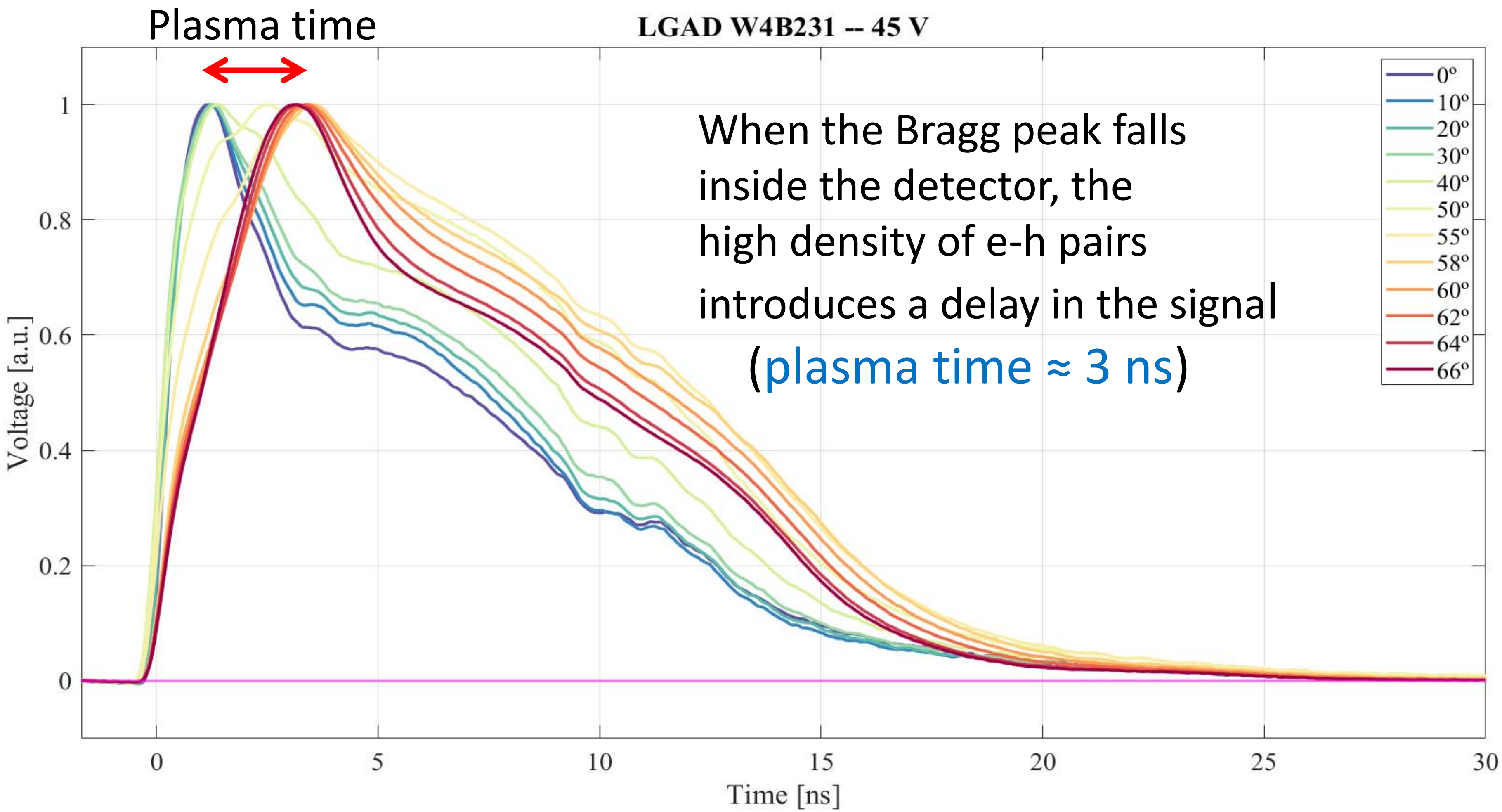
FIG. Direct observation of free-carrier diffusion inside silicon. A microplasma induced by two-photon ionization with a focused femtosecond laser pulse. High-resolution images acquired for different delays between pump and probe (bottom images) reveal directly the expansion of the microplasma by free-carrier diffusion.

Gain suppression when the Bragg peak is in the active volumen



Summary

- Gain measurements obtained by IBIC are considerably lower in comparison to IR-laser.

- Gain supression is due to the high ionization linear density, which in our IBIC experiments, was between 75-25 times larger than that created by a MIP.

- The TRIBIC waveforms show that there is a deficit in the secondary hole current signal.

- When the Bragg peak is deposited within the active volume a microplasma is generated and then:
  - The gain suppression is enhanced
  - The TRIBIC signals show a few ns delay

Thank you for your attention