Update on the characterization of neutron irradiated IMB-CNM SiC planar diodes

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Outline

- Sample description and fluence points
- Experimental TPA-TCT setup
- TPA characterization results
- Experimental TRIBIC setup
- TRIBIC characterization results

- Discussion and Summary

Silicon carbide detectors

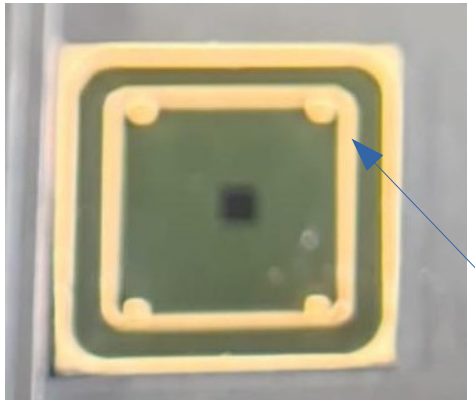
SiC sensors:

CNM SiC planar pad diodes P in N

Neutron-irradiated (ATI Vienna) July/Aug 2021

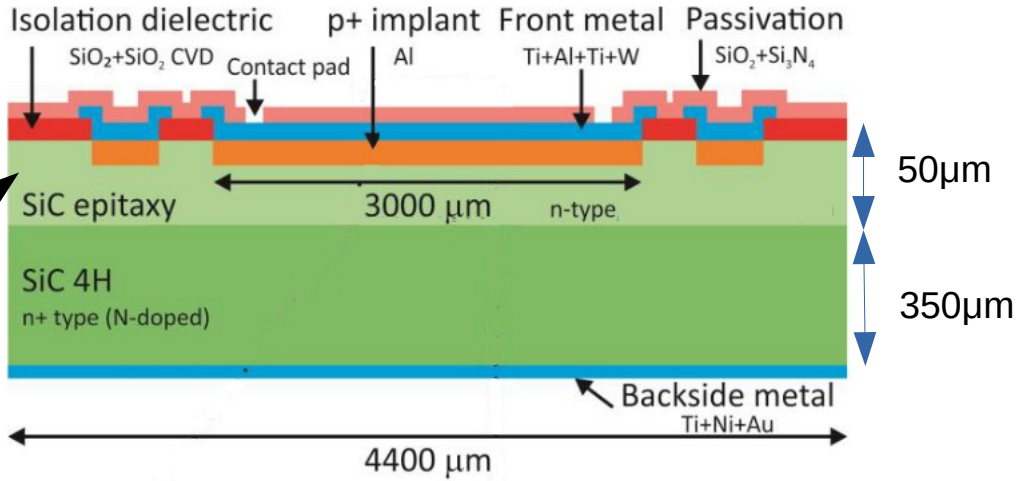
Samples (**non metallized contact**):

→ 1MW2 (Non-irradiated)
→ F2W1 (1e15 n_{eq}/cm^2)
→ K6W1 (4e14 n_{eq}/cm^2)

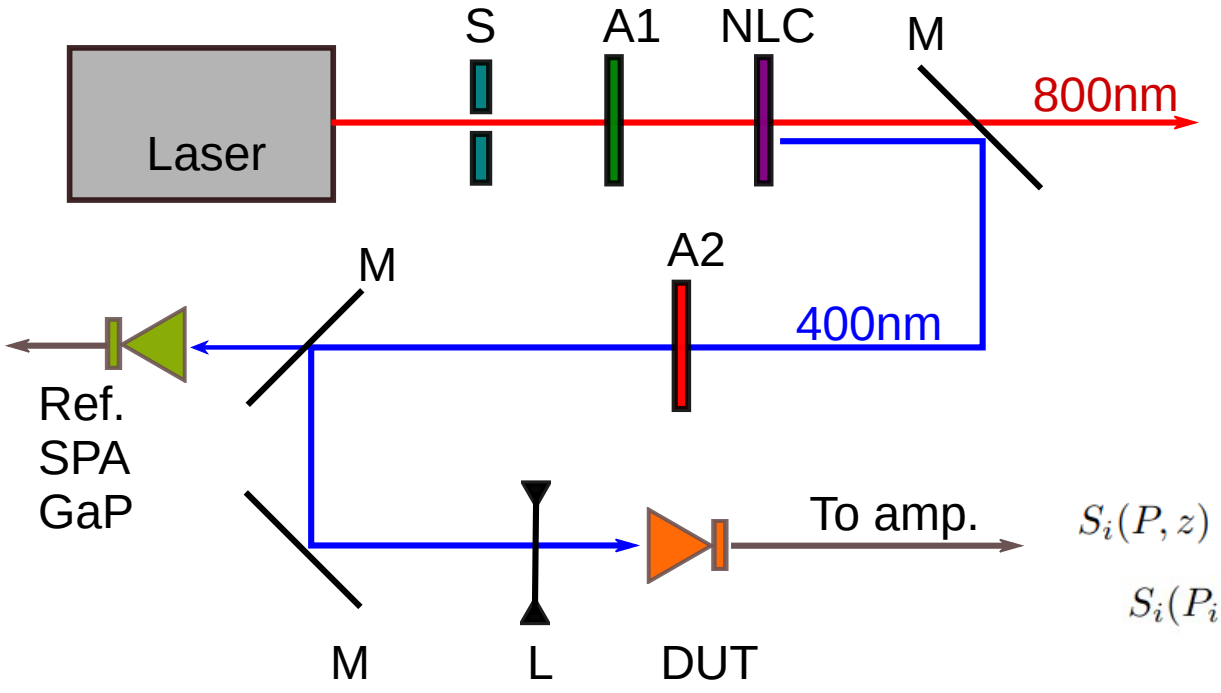


Signal collection ring

N_{eff}= 1.5e14 /cm^3



Experimental setup for TPA-TCT

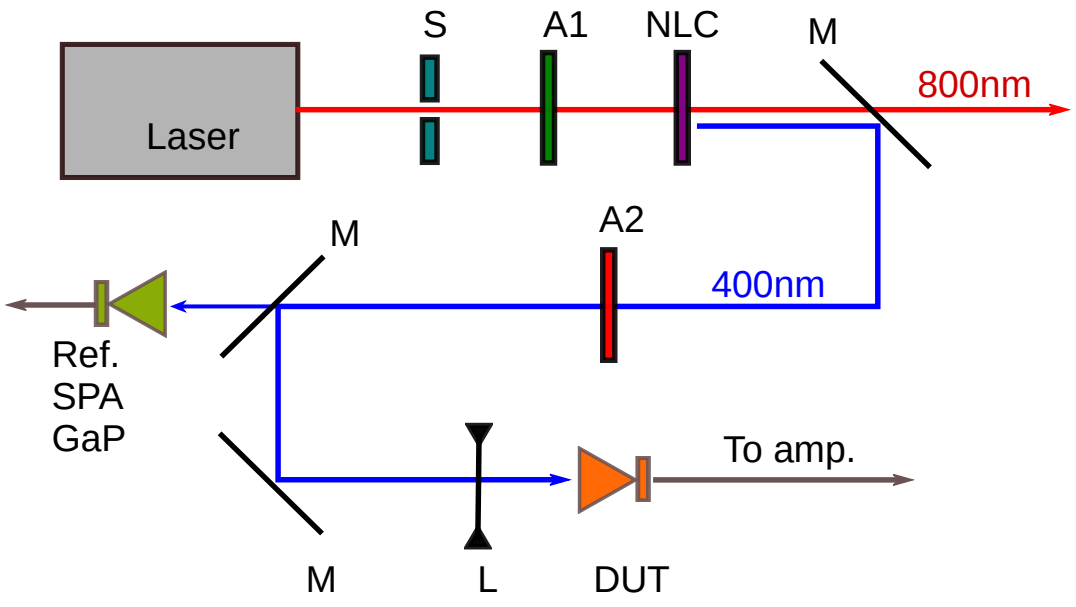


S: Shutter
A1: Attenuator
NLY: Non linear crystal
M: Mirrors
A2: Attenuator
Ref.: Laser power reference
L: focusing lens
DUT: Device under test

$$S_i(P,z) = S_i^{SPA}(P) + S_i^{TPA}(P,z)$$

$$S_i(P_i,z_i) = \alpha P_i + \beta(z_i) P_i^2$$

Setup improvements (Run 1 → Run 2)

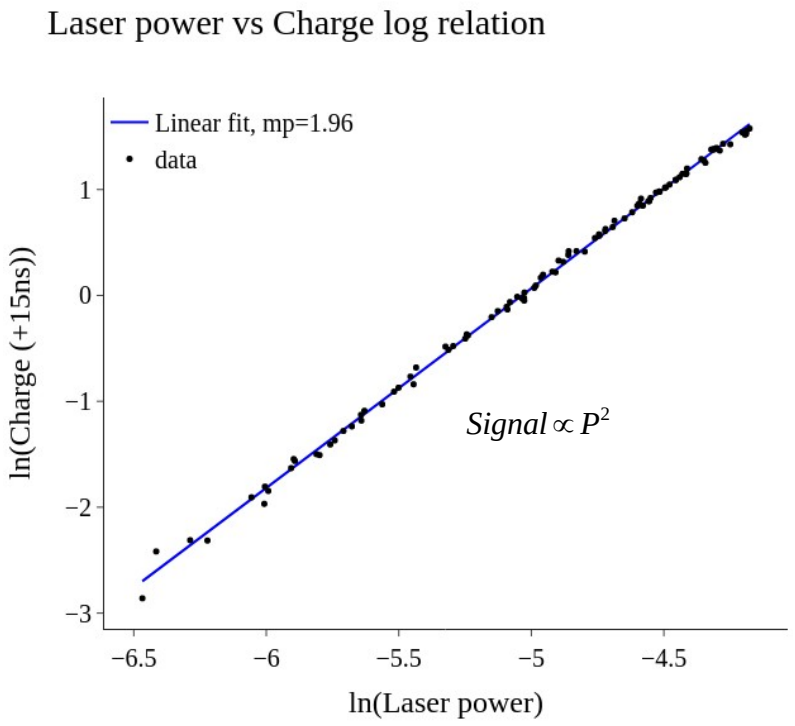


- Better stability:
  - → Pumping module of the laser's amplifier replaced.
  - → Attenuation procedure
  - → Energy monitoring
  - → BBO polarization coupling optimized.
- Better resolution
  - → Coupling between the laser ray and the objective enhanced.
  - → Increment of the effective numerical aperture (more sensitive to aberrations)
- Better signal
  - → Measurements close to the conductive ring
  - → Different TCT ampifier

Raw data corrections: Energy fluctuations

→ Analysis of the variations on laser's power emission.
→ Power variation done with a variable attenuator

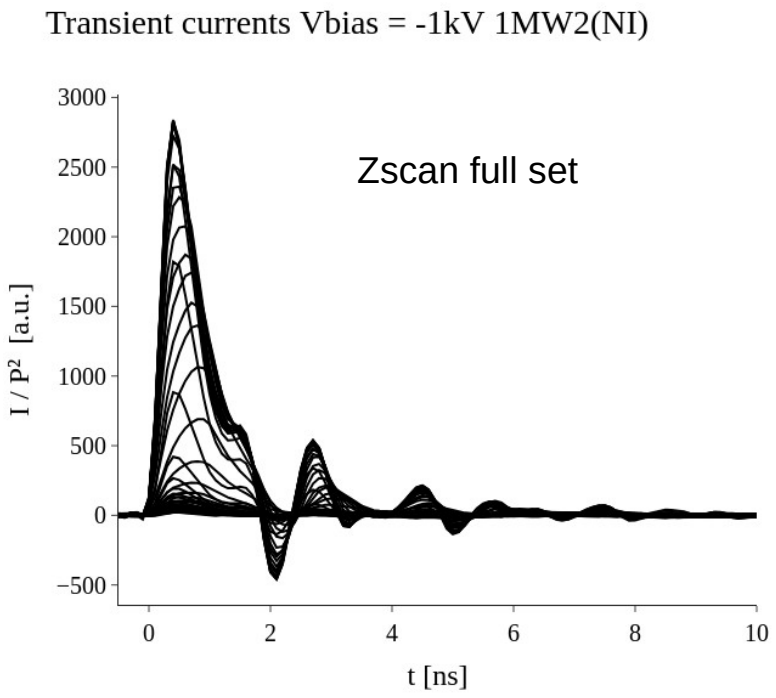
→ Correlation between the laser power and the signal.
→ Power of two correlation → TPA

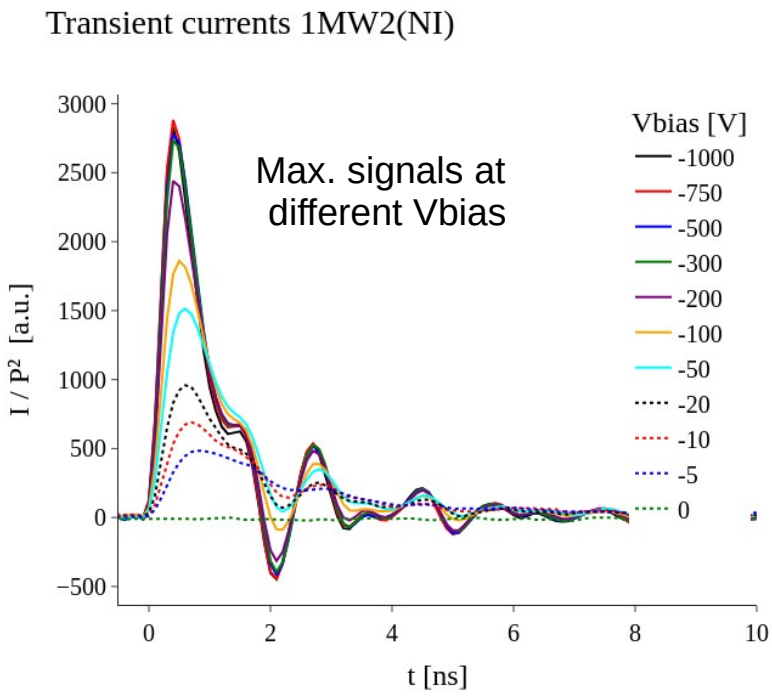


Non irradiated detector: Transient currents

→ Analysis of the WF profiles and durations at different Vbias
→ The duration of the pulses has decreased (20 um close to the collecting ring)

→ Monotonically increasing of the maximum current
→ Profile dependence with the bias voltage

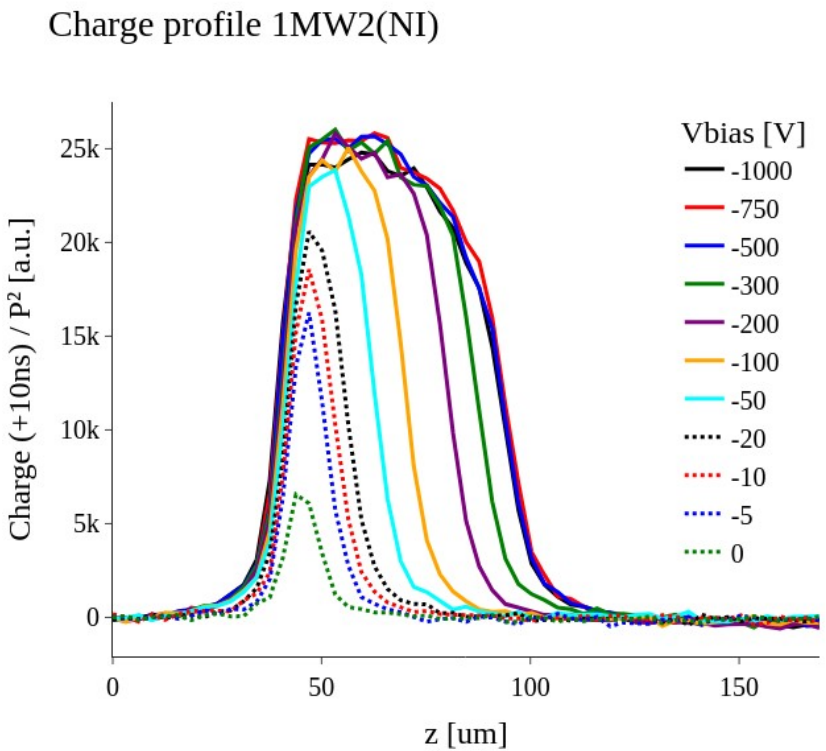




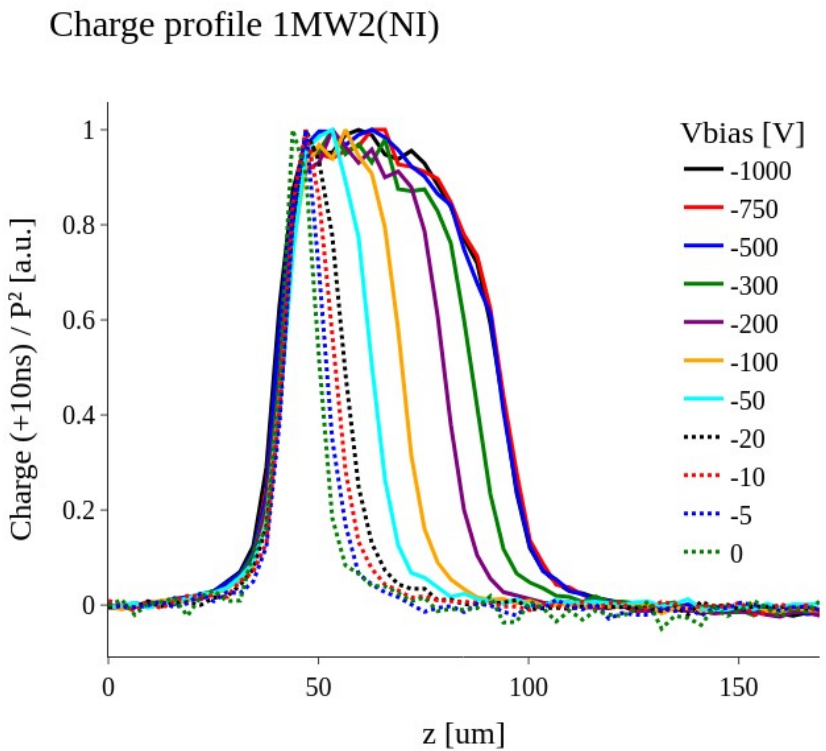
Z-scan charge profiles: non-irradiated diodes

→ Characteristic behavior of diodes, except for drop in charge due to **spherical aberration**
→ Profile dependence with bias voltage

→ Monotonically increasing of the depletion width (zdep)
→ Depletion with saturation between -300 to -500 V



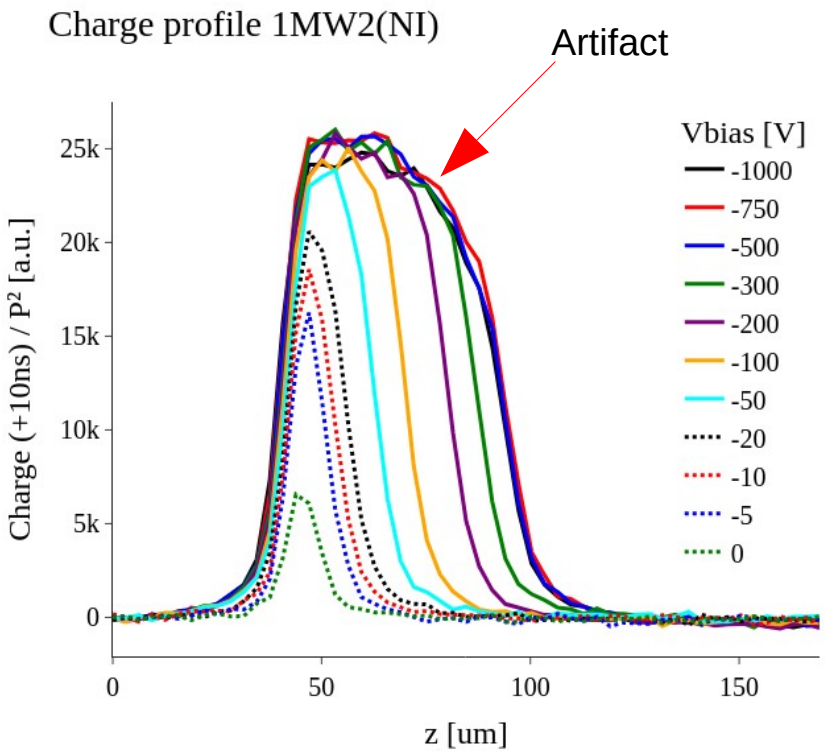
Normalize



Z-scan charge profiles: theoretical fit

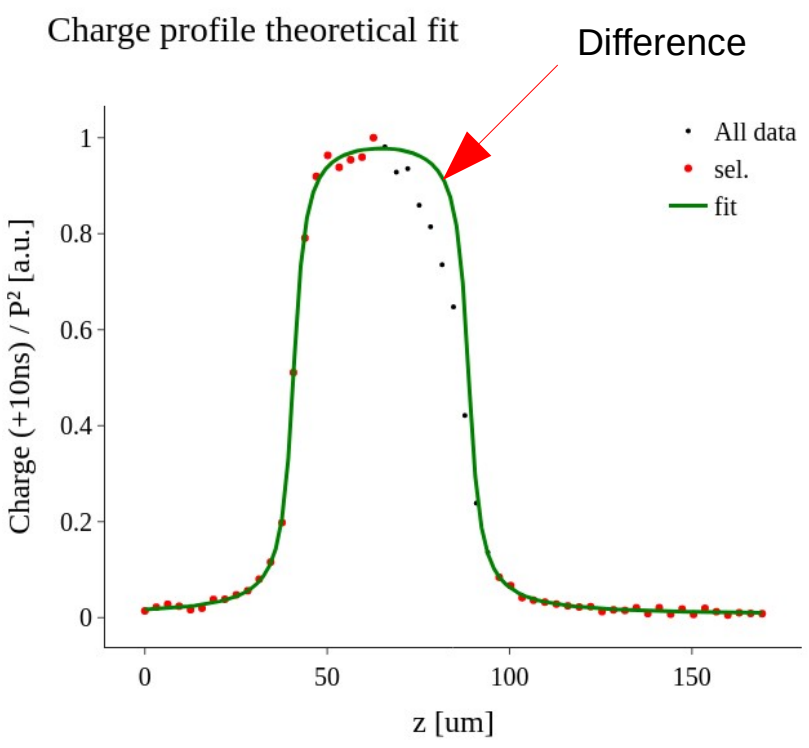
→ The spherical aberration causes a drop in the charge profile
→ Generation region gets elongated with depth → TPA

→ Correction with selection of date and theoretical fit
→ Depletion width correction



Fit

Development of a Two-Photon Absorption - TCT system and Study of Radiation Damage in Silicon Detectors
-
Wiehe, Moritz Oliver
- CERN-THESIS-2021-225

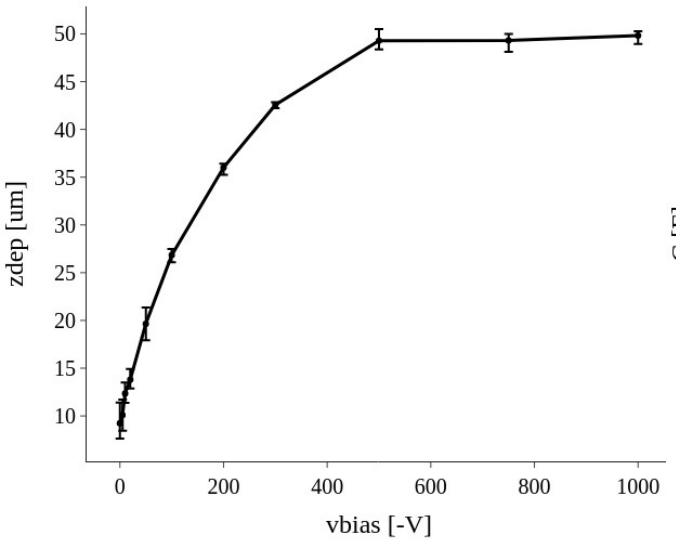


Depletion width vs bias: non irradiated

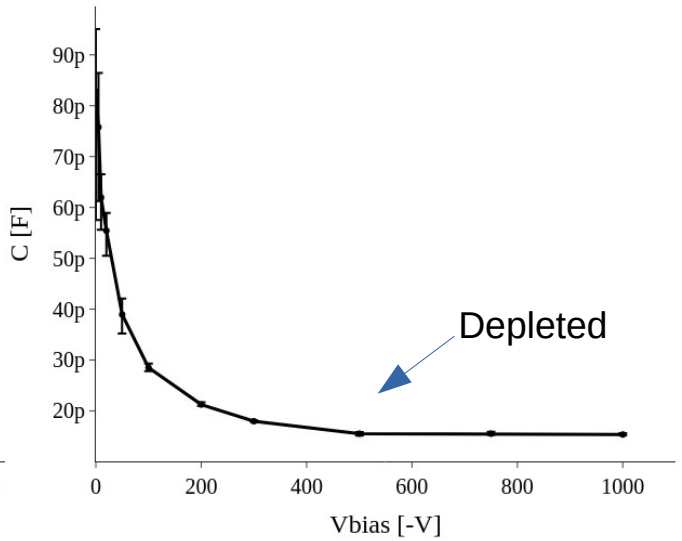
→ Diode behavior
→ Diode fully depleted between 400-500 volts.
→ Homogeneity in the sensor depletion

→ Capacitance value matches the direct capacitance measurements
→ Effective doping of the bulk over the real doping value: SiC vs Si at room temperature

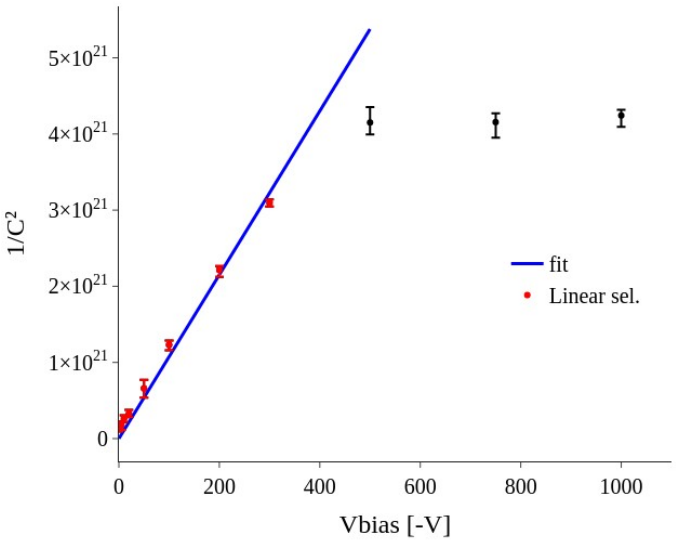
Depletion width (fit) for NI DUT



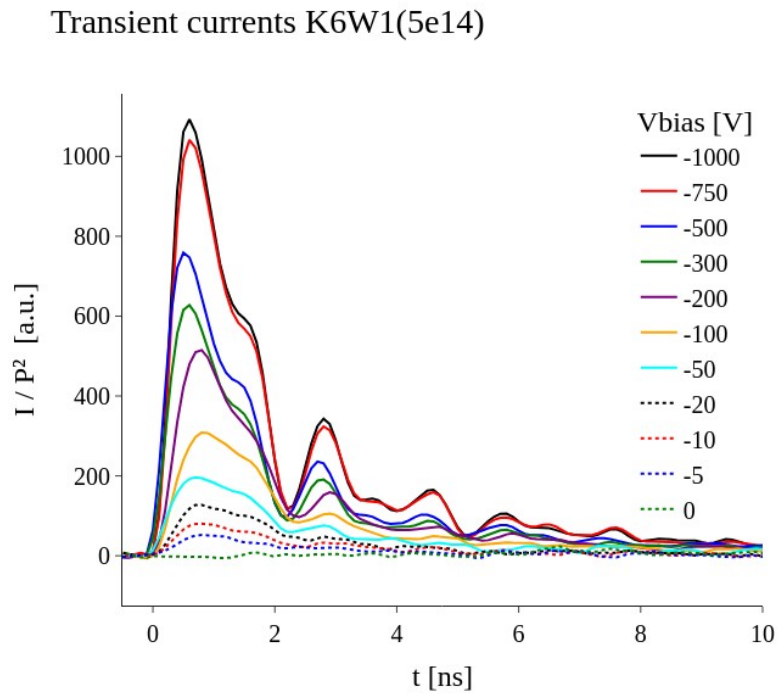
Capacitance vs. Vbias

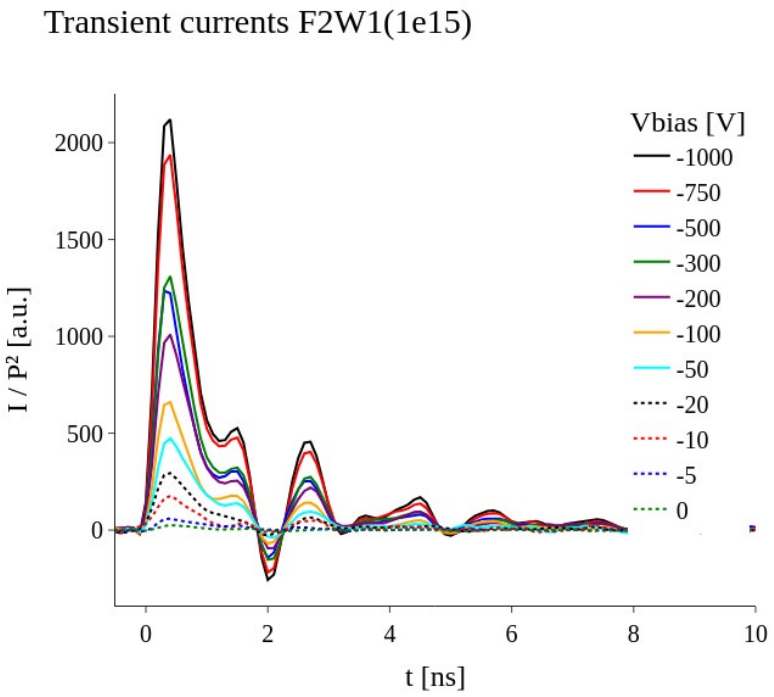


Effective doping study



Irradiated detector: Transient currents



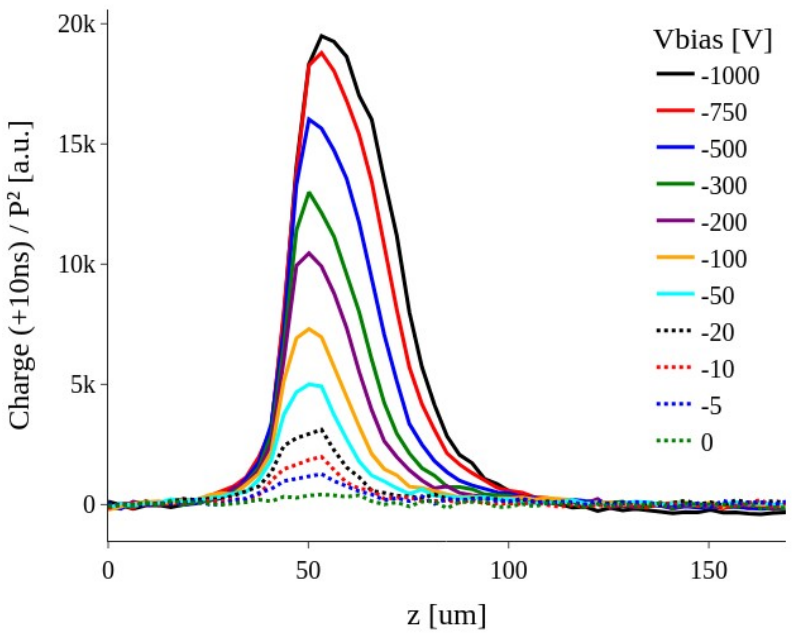


Z-scan charge profiles: irradiated diodes

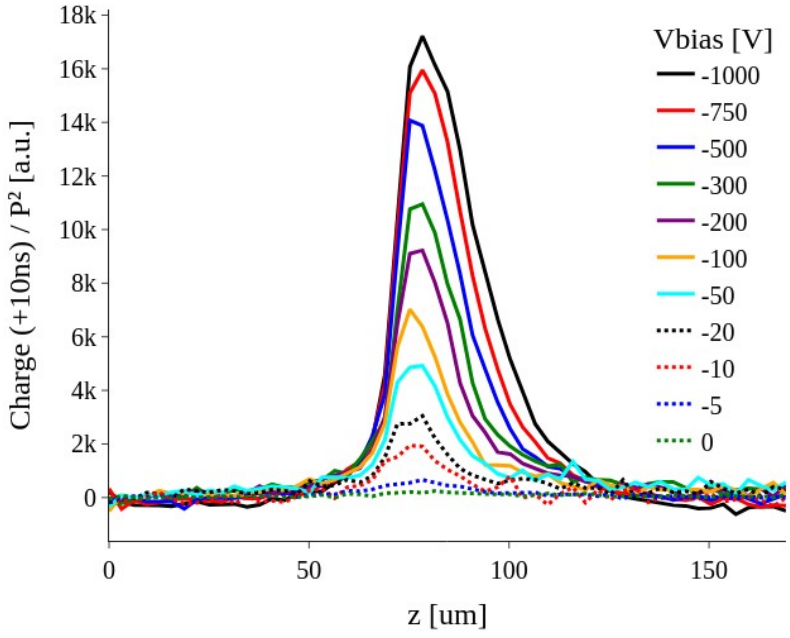
→ The diode behavior partially lost.
→ Capacitor-like charge collection
→ No charge collection saturation with bias

→ Same effect in both detectors
→ Charge collection drops with irradiation

Charge profile K6W1(5e14)



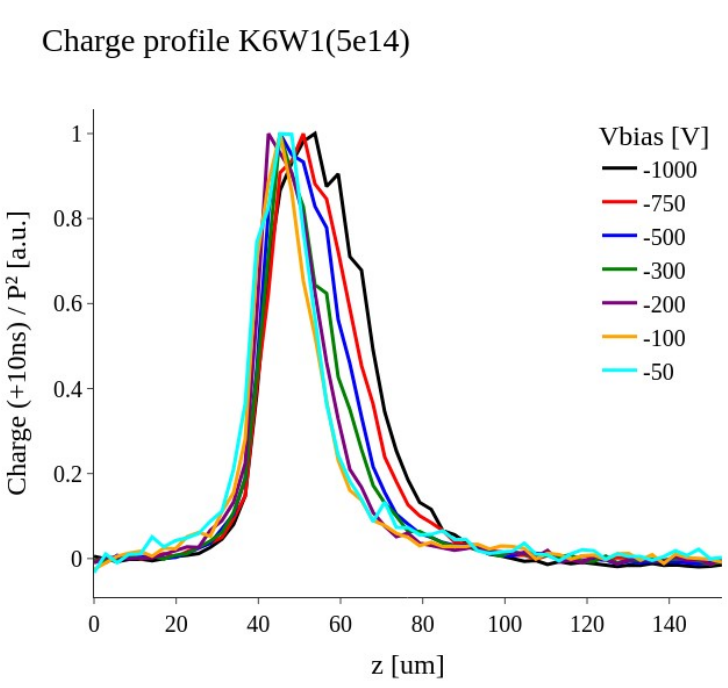
Charge profile F2W1(1e15)

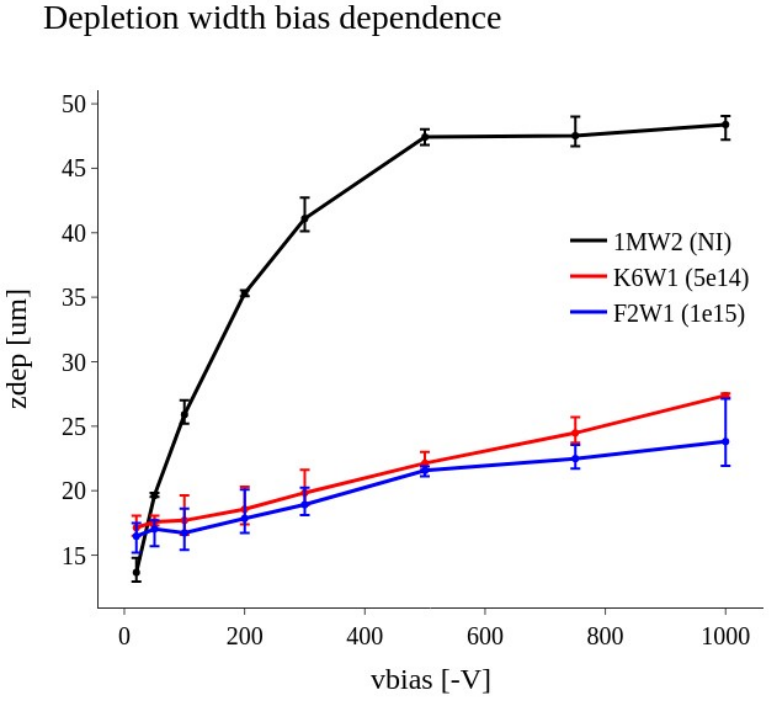


Depletion width vs bias: irradiated

→ Both figures show that the depletion width slightly increases with Vbias, but there is no saturation.
→ Bad SNR at 0 and very low Vbias

→ The depletion width is different if we compare irradiated and non-irradiated detectors, but also between the irradiated ones.
→ The higher the fluence the smaller the depletion width



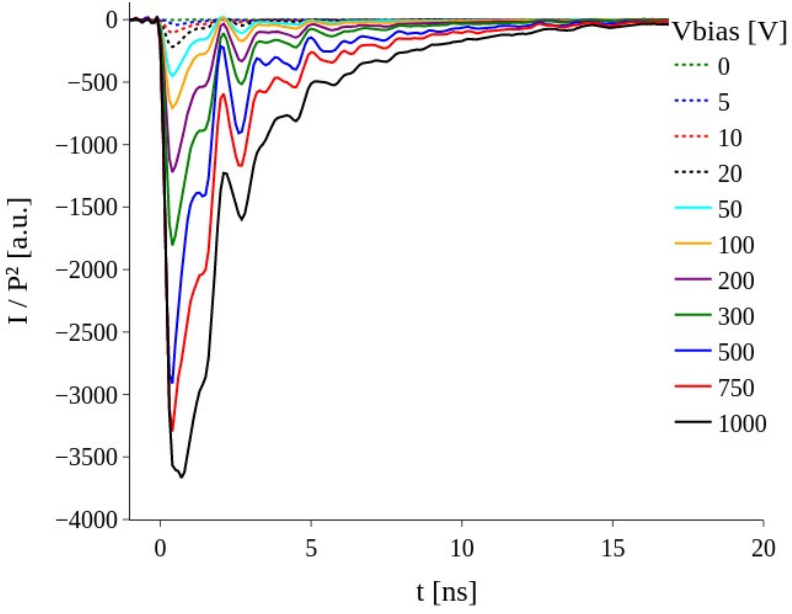


Forward biasing (most irradiated detector)

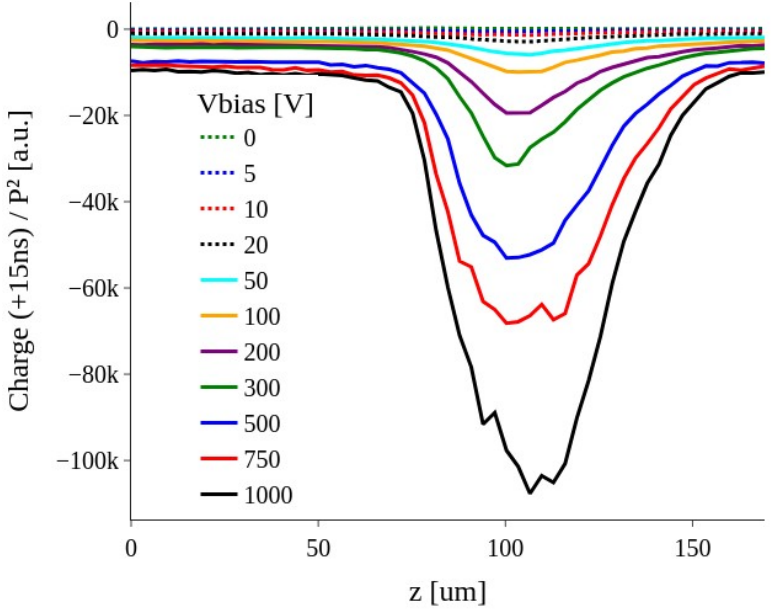
→ Pulse duration and shape do not depend on the bias voltage
→ Very low amplitude at low Vbias compared with high Vbias.

→ Charge collection increases with forward biasing
→ The depletion width increases with Vbias.

Transient currents F2W1 (1e15) - direct polarization



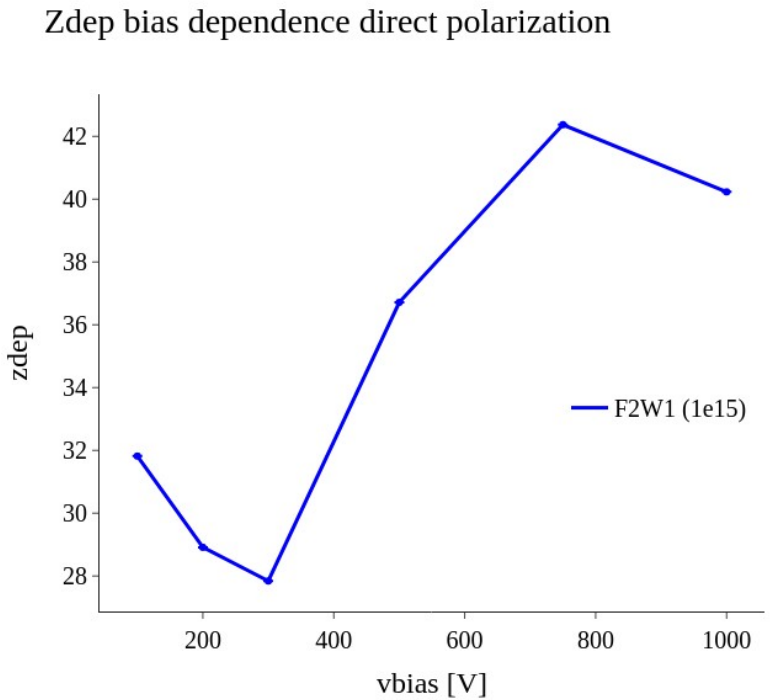
Charge profile F2W1 (1e15) - direct polarization



Forward biasing – Depletion width

→ FWHMs of the zscan charge profiles
→ Different behavior at different Vbias

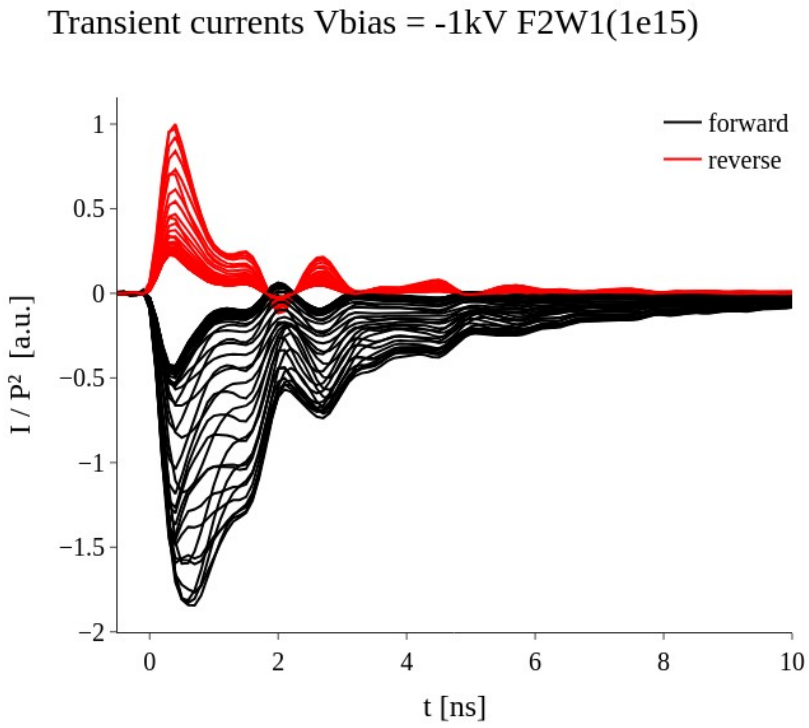
→ The depletion width is higher than the depletion with at the same absolute voltage for reverse bias

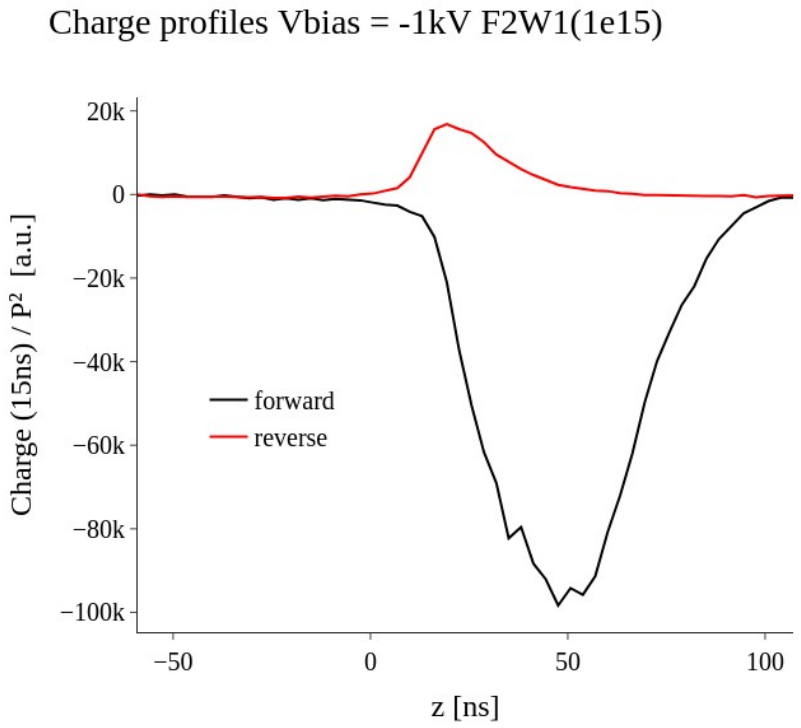


Forward vs Reverse biasing

→ Comparison between two zscans at same Vbias but opposite polarization.
→ Different pulse duration and profile

→ The total collected charge is significantly greater in forward biasing.
→ The profiles are different, including the depletion width.



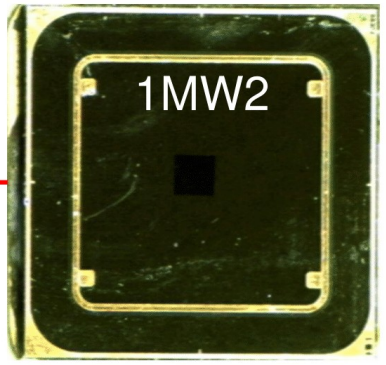


Time-Resolved Ion Beam Induced Charge (TRIBIC)

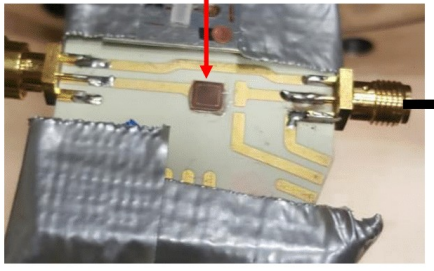
- Sample: 1MW2 (Non irradiated): Not metalized

- PIBs: 7 MeV He^{++}. Range≈26 µm;
- Beam size: 5x5 μm^2
- Γ_{rate} ~ 200 Hz

- 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 to improve SNR



Wideband current amplifier

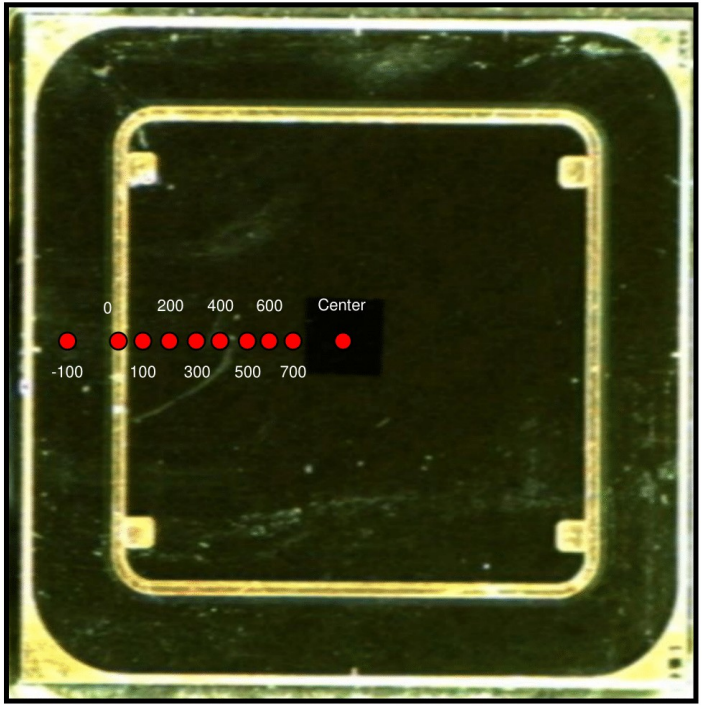


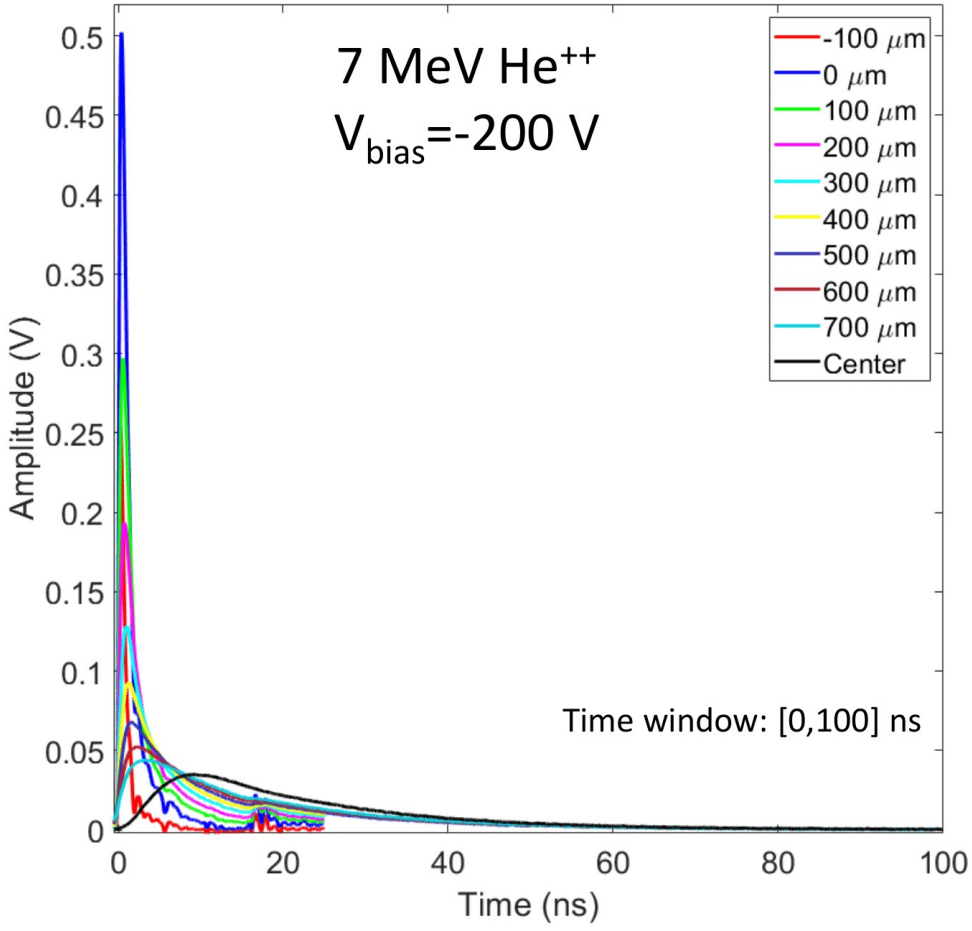
Detector

Fast oscilloscope

The waveform shapes change as we approach to the center of the detector

1MW2

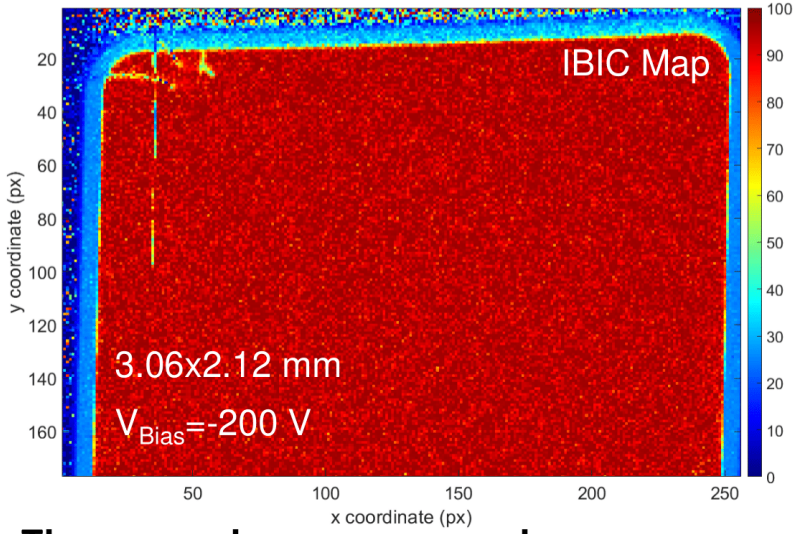


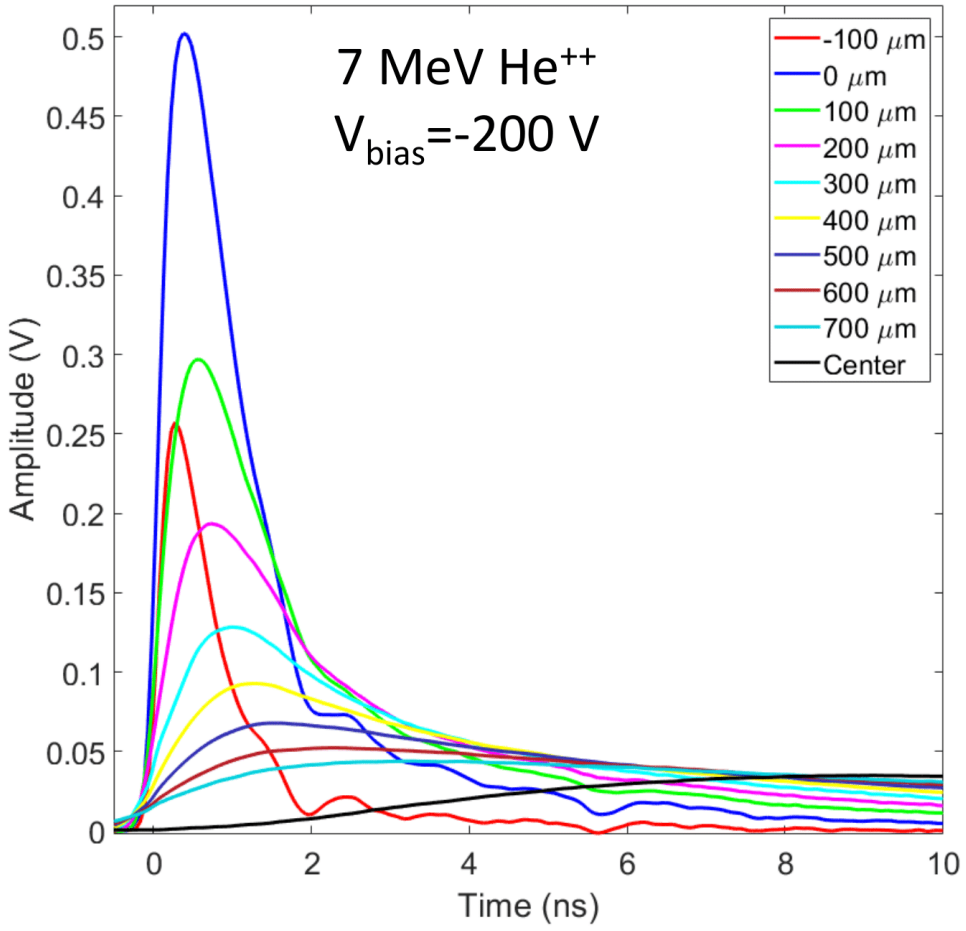


Homogeneity of the charge map

1MW2

Close to the edge of the detector the waveforms are faster. However, close to the center, the waveform becomes slower decreasing the signal amplitude.



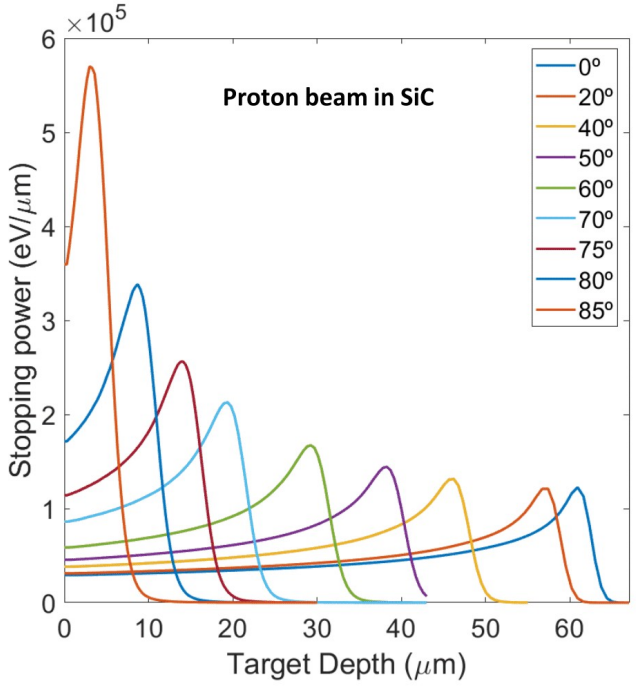


The mean charge maps are homogeneous even though the TRIBIC signals change with position.

The depletion width can be estimated using the IBIC measurements at different angles (0º-85º)

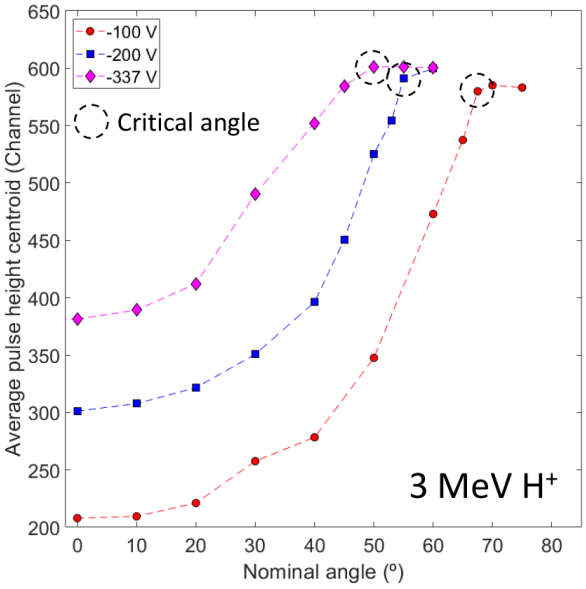
To modify the ion beam deposition depth we have carried out experiments by tilting the detector.

PIBs: 3 MeV H^+. Range≈61.8 µm;
Beam size: 5x5 µm2
Γrate ~ 200 Hz



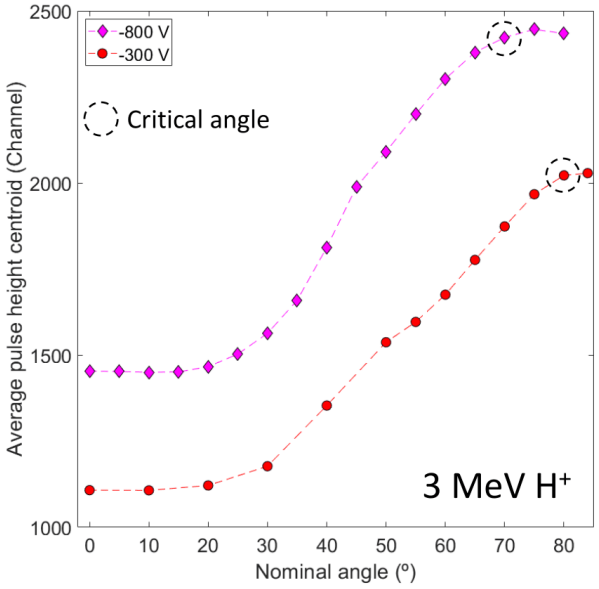
IBIC depletion widths

1MW2 (non irradiated)



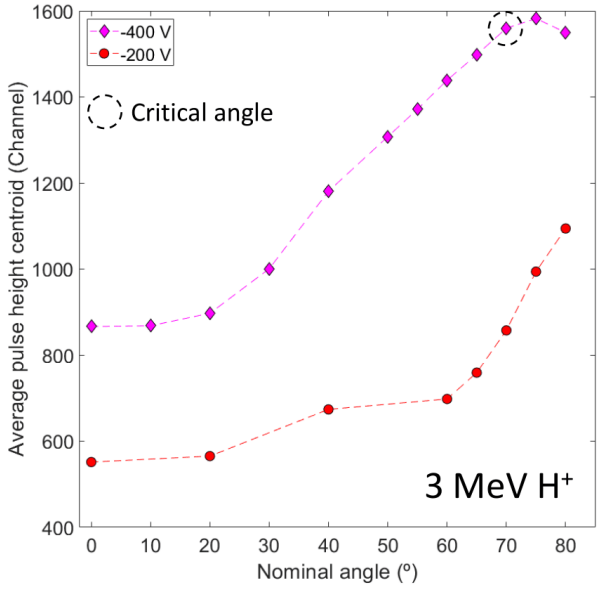
Reverse bias (V)	CV Depletion (μm)	IBIC depletion (μm)	TPA depletion (μm)
-100	23	22	26
-200	32	32	35
-337	39	40	41

K6W1 ($4x10^{14}$ n/cm^2)



Reverse bias (V)	CV Depletion (μm)	IBIC depletion (μm)	TPA depletion (μm)
-300	45	11	20
-800	46	21	25

F2W1 ($1x10^{15}$ n/cm^2)



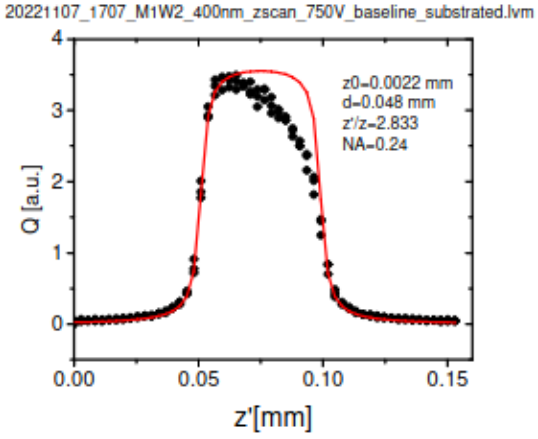
Reverse bias (V)	CV Depletion (μm)	IBIC depletion (μm)	TPA depletion (μm)
-200	44	X	17
-400	44	21	20

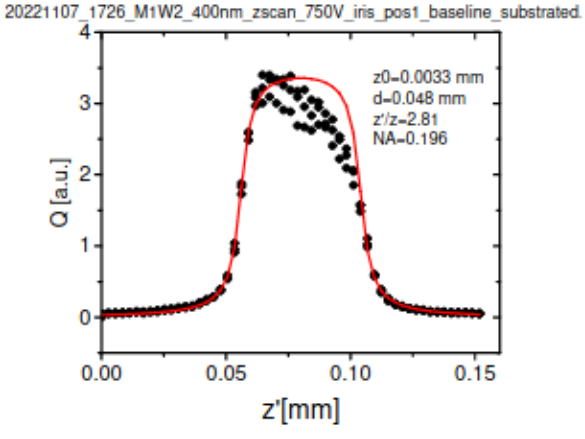
Conclusions:

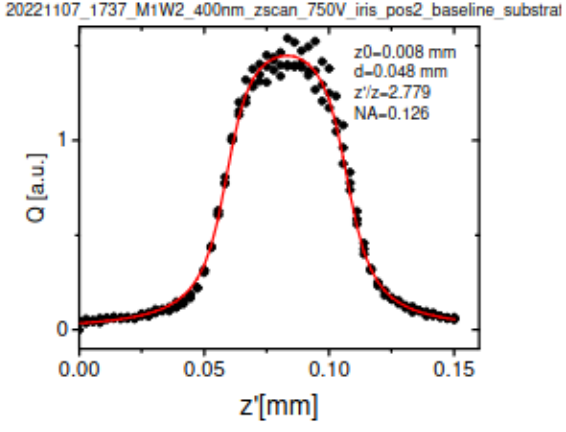
- The new TPA-TCT run confirms the previous results and clarifies the dependence between the bias voltage and the depletion width in irradiated sensors.
- TRIBIC measurements are compatible and confirm TPA-TCT results.
- BIG SURPRISE! Very large increase of the signal amplitude and depletion width for irradiated forward-biased diodes.

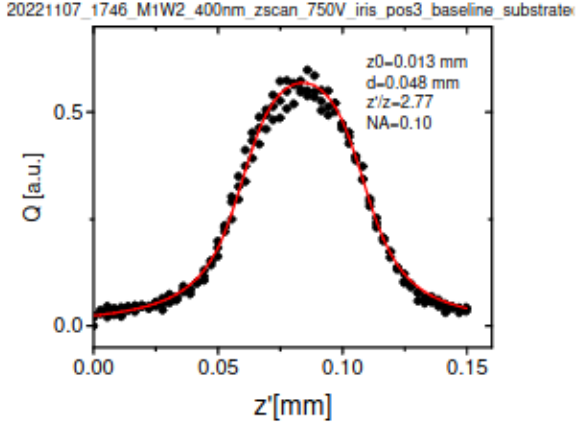
Thanks for your attention

Spherical aberration and numerical aperture

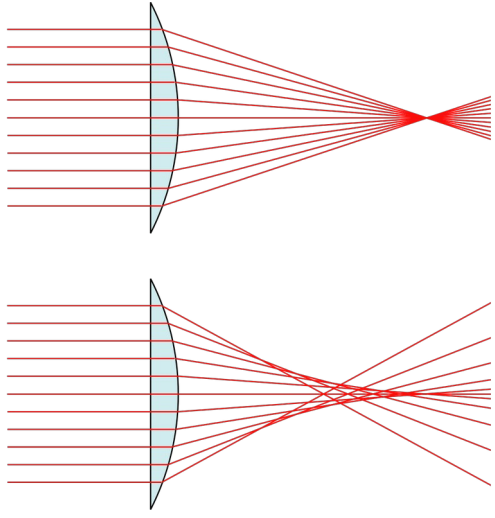








Spherical aberration



wikipedia.org : Spherical aberration