TREDI

Radiation Tolerance Study of neutron-irradiated SiC pn planar diodes

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Outline

- Sample description and fluence points
- Experimental Setups: TPA-TCT & TRIBIC
- Depletion width vs fluence.
- Charge collection efficiency vs fluence
- Forward biasing of irradiated diodes.
- Summary

Silicon carbide detectors

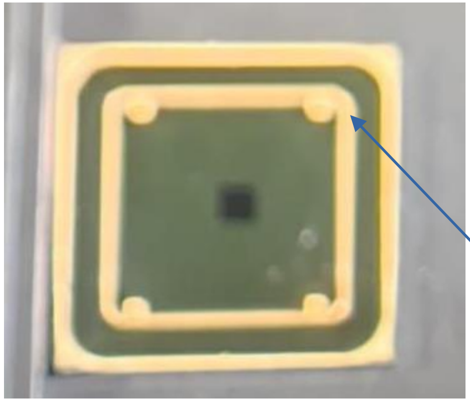
SiC sensors:

CNM SiC planar pad diodes P in N

Neutron-irradiated (ATI Vienna) July/Aug 2021

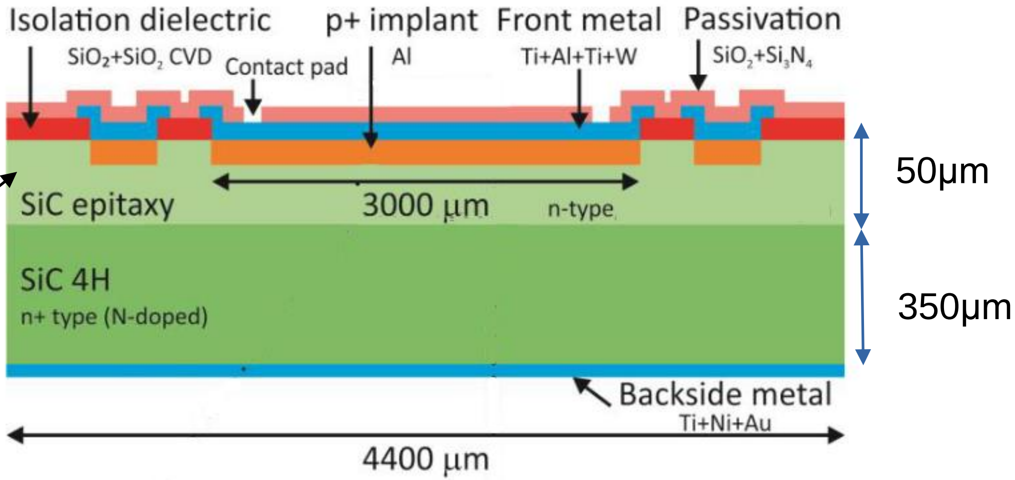
Samples (**non metallized contact**):

→ 1MW2 (Non-irradiated)
→ F2W1 (1e15 n_{eq}/cm^2)
→ K6W1 (5e14 n_{eq}/cm^2)

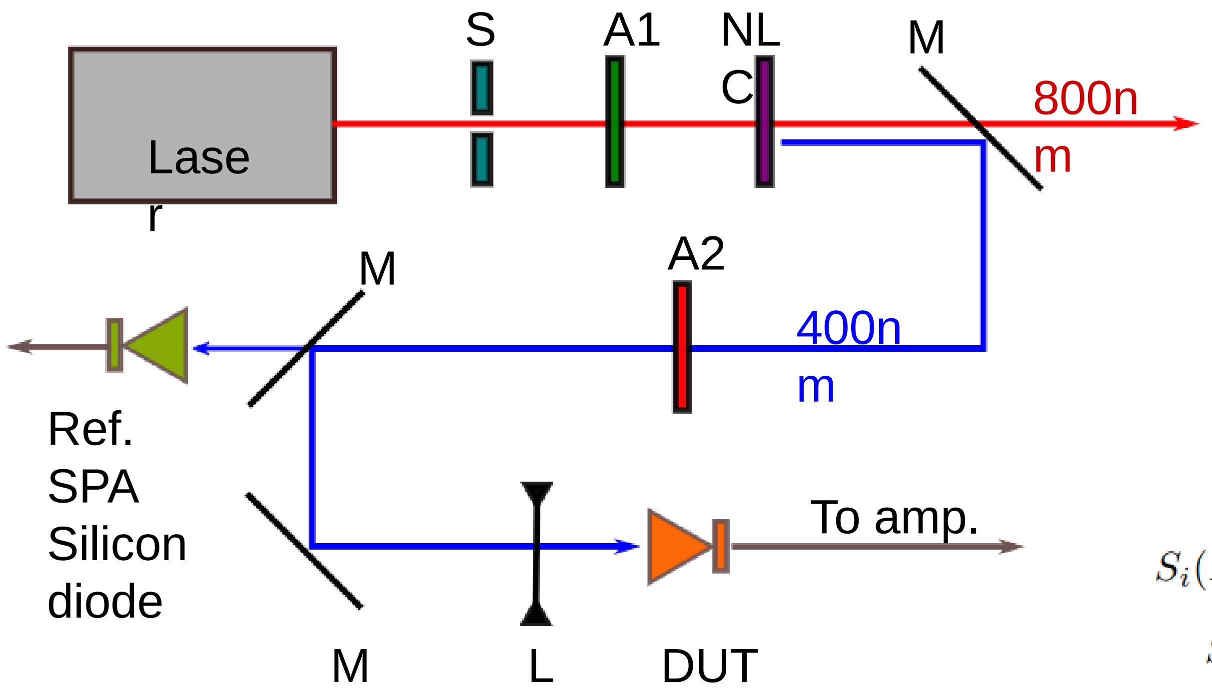


Signal collection ring

$N_{eff} = 1.5e14\ /cm^3$



Experimental setup for TPA-TCT



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

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

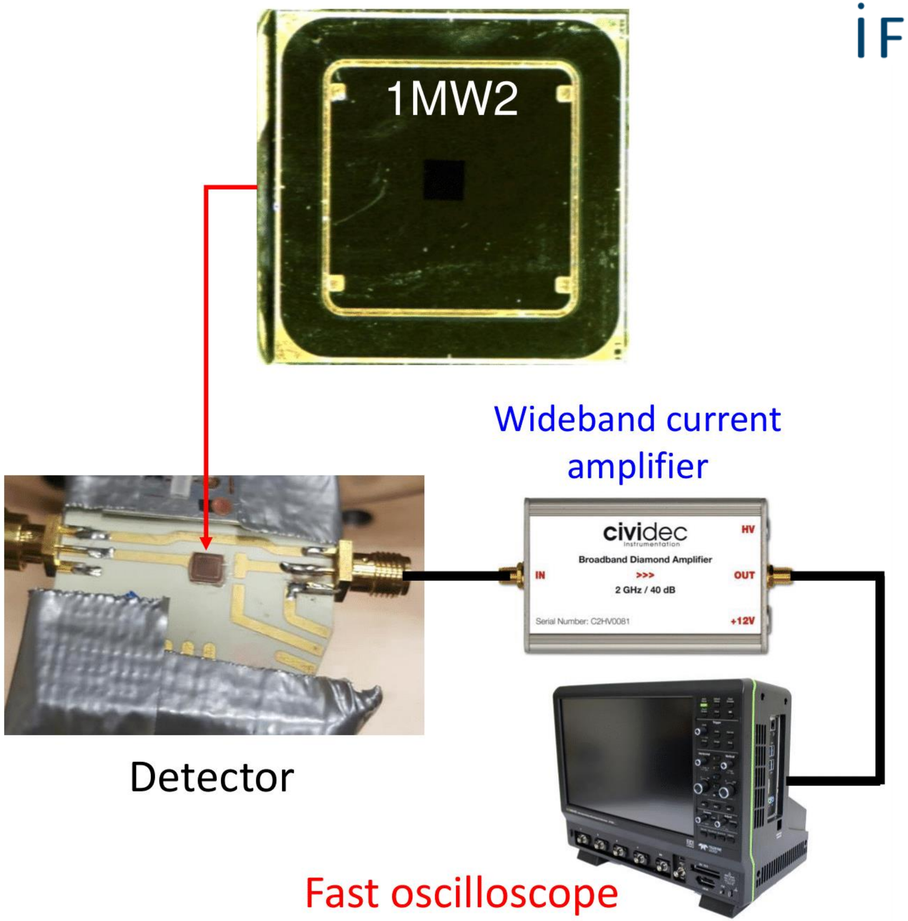
$$S_i(P_i, z_i) = \alpha P_i + \beta(z_i) P_i^2$$

Readout for TPA-TCT (Laser) & TRIBIC (Ions)

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

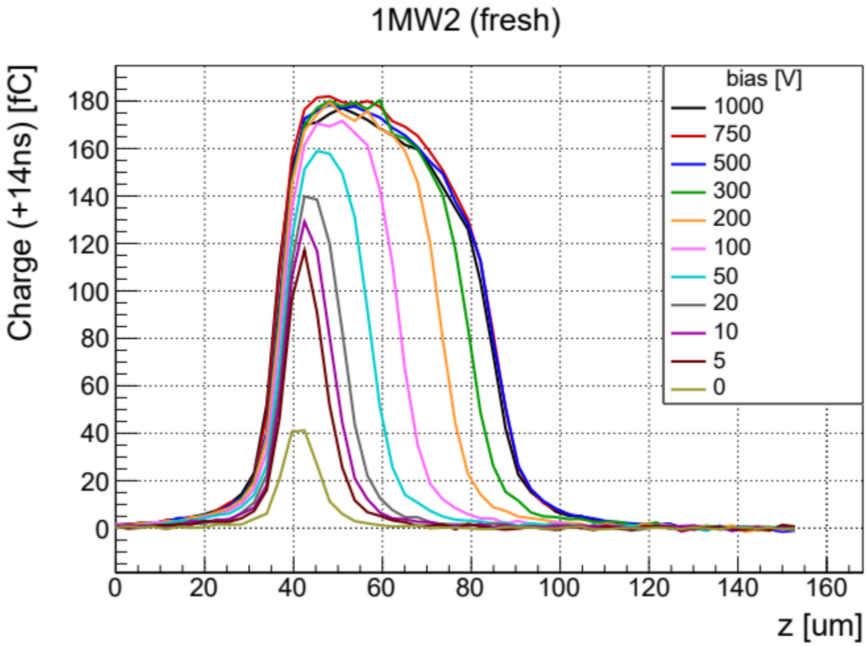
- PIBs: 7 MeV He^{++}. Range≈26 µm;
- Beam size: 5x5 μm^2
- Γ_{rate} ~ 200 Hz

- 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

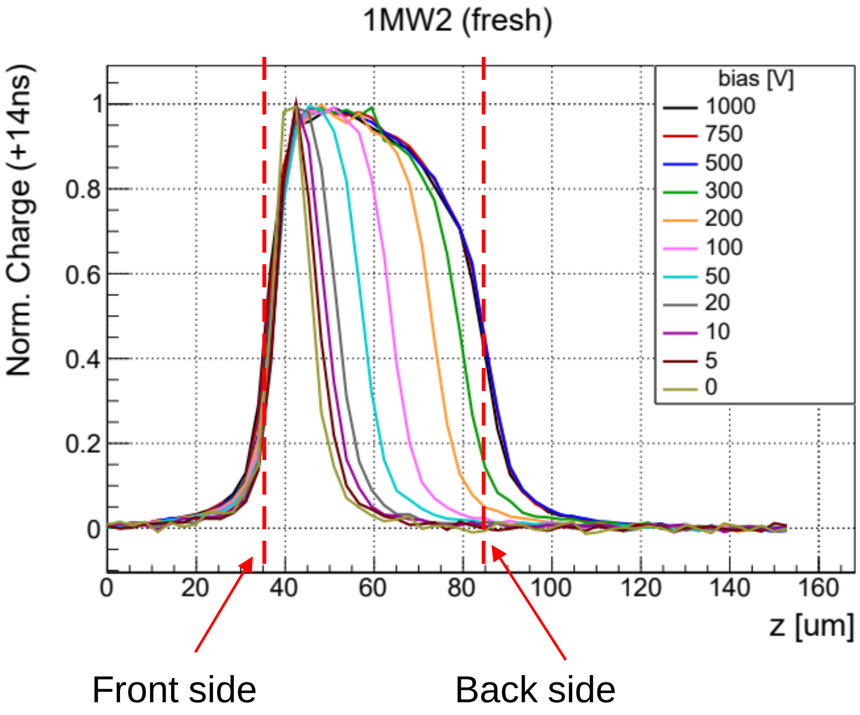


TPA: Z-scan charge profiles: non-irradiated diodes

- As expected, the depletion width increases with the bias voltage.
- Full depletion between 300-500 V.



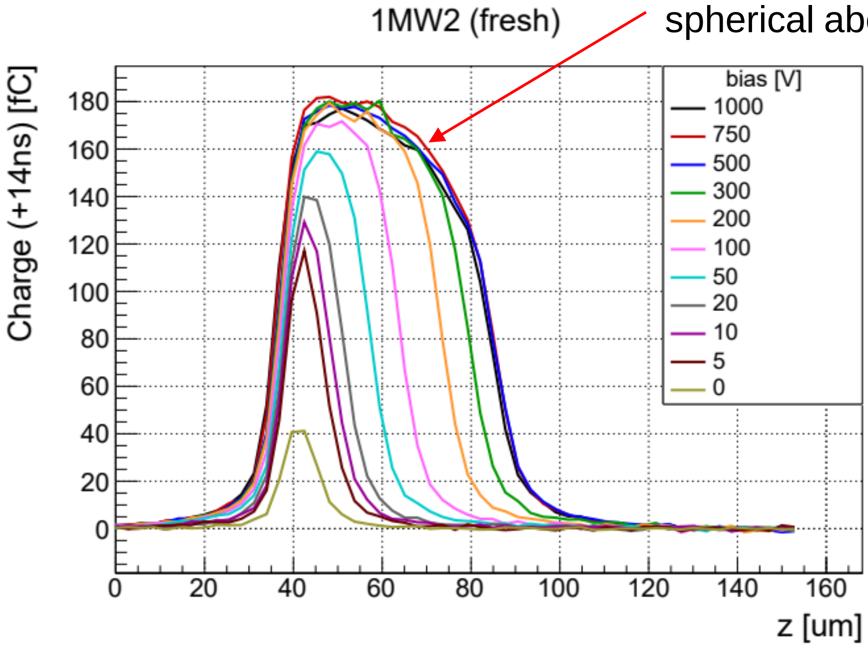
Normalize



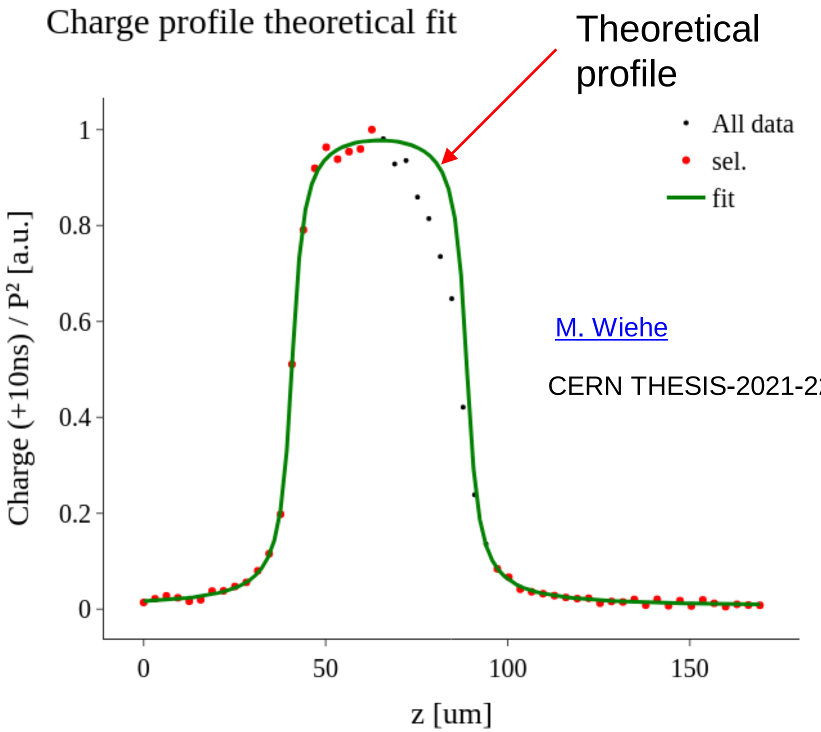
TPA-TCT: Depletion width estimation

- Asymmetric z-scan charge profile for the larger depletion widths due to spherical aberration.
- Estimation of the depletion width using the FWHM of the z-scan profiles

Charge drop induced by spherical aberration



Theoretical profile



M. Wiehe

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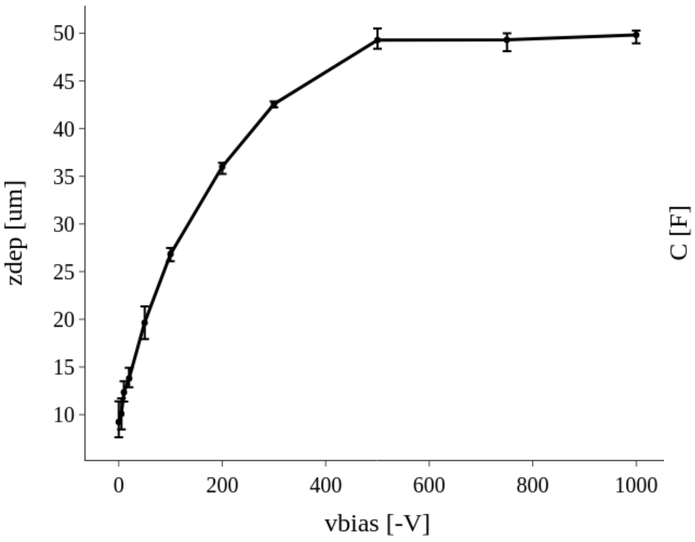
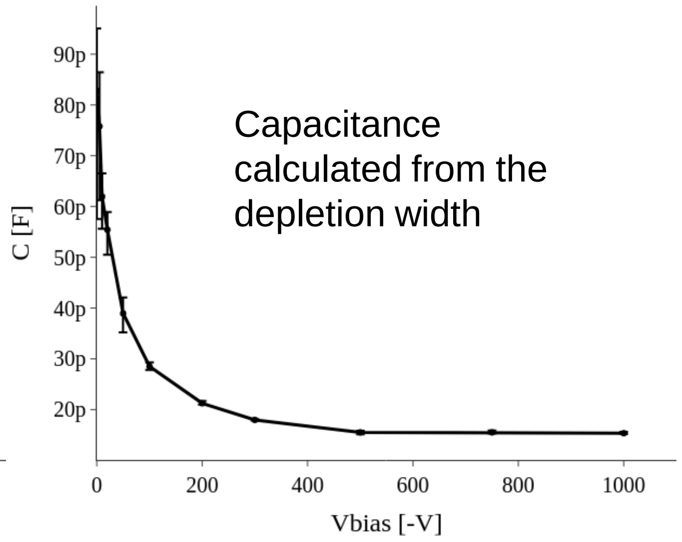
TPA-TCT: Depletion width vs bias / non-irradiated

- Diode fully depleted between 400-500 volts.
- Capacitance value matches the electrical capacitance measurements.
- Effective doping of the bulk from CV equal to the the nominal doping value.

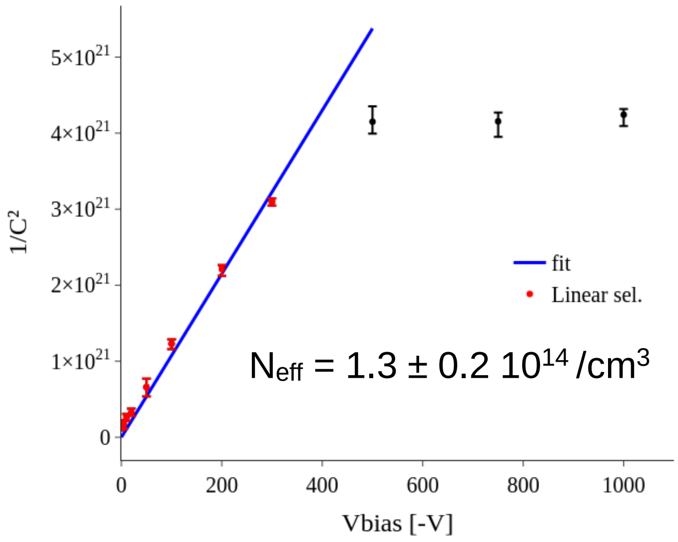
Depletion width (fit) for NI DUT



Capacitance vs. Vbias

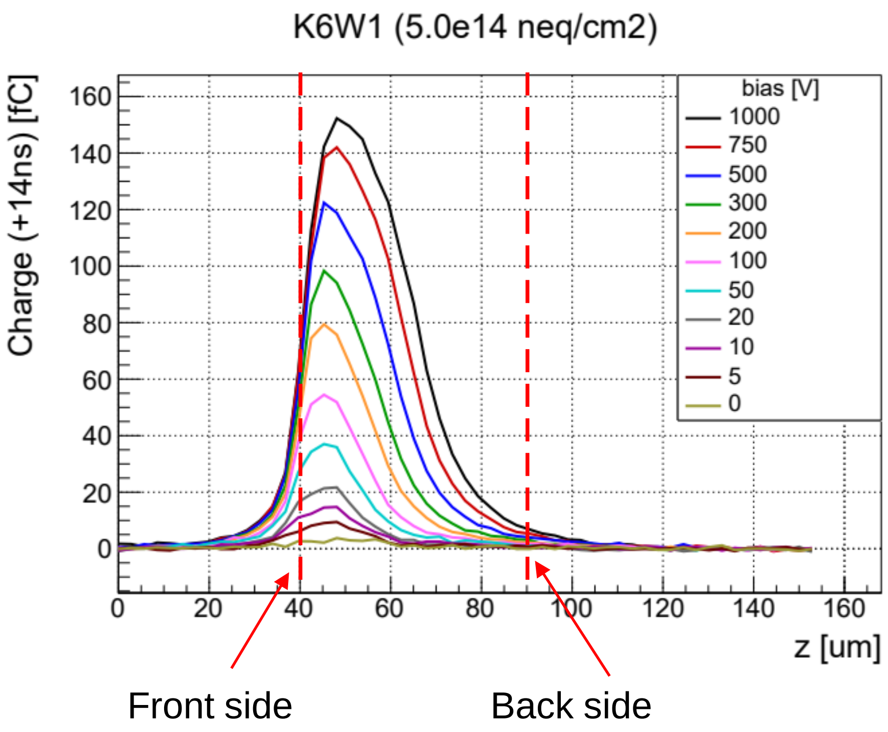


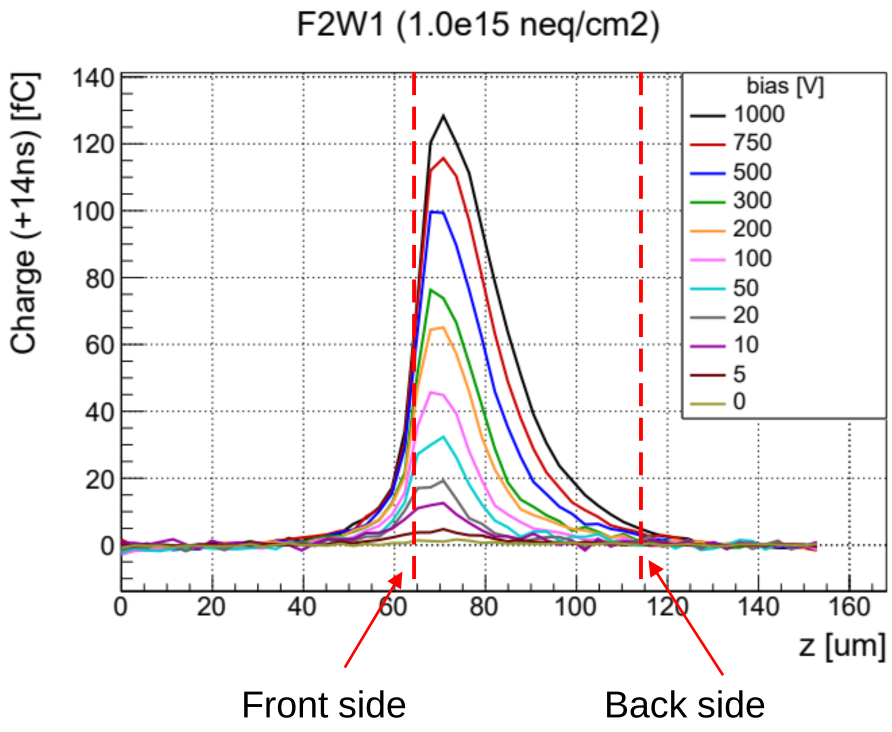
Effective doping study



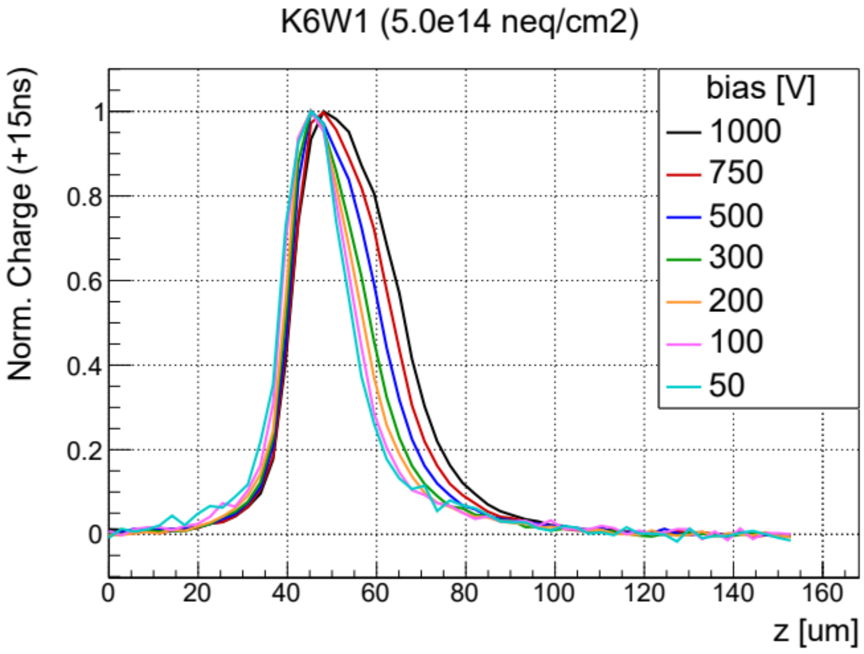
TPA-TCT Z-scan charge profiles: irradiated diodes

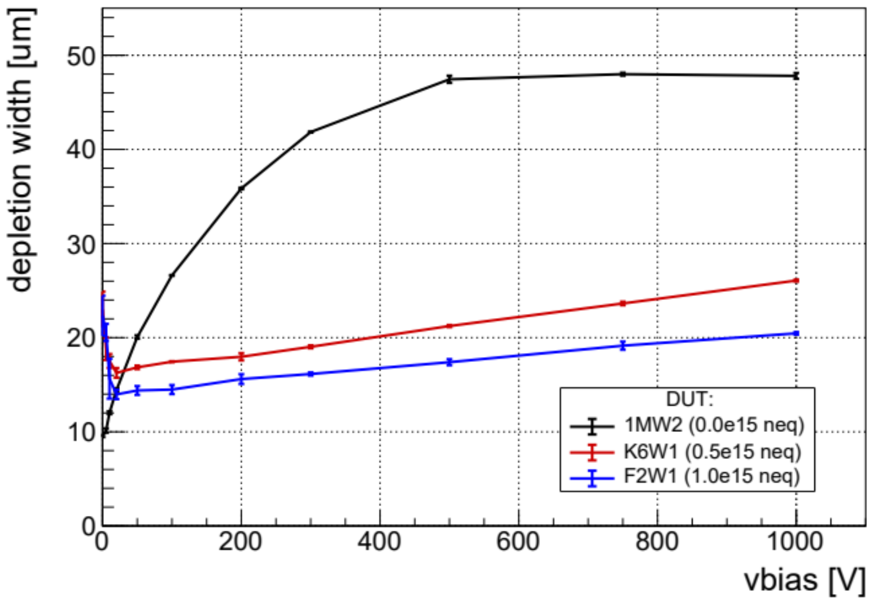
→ Collected charge and depletion width reduced by irradiation
→ Collected charge does not plateau as bias voltage increases





TPA-TCT: Depletion width vs bias - irradiated

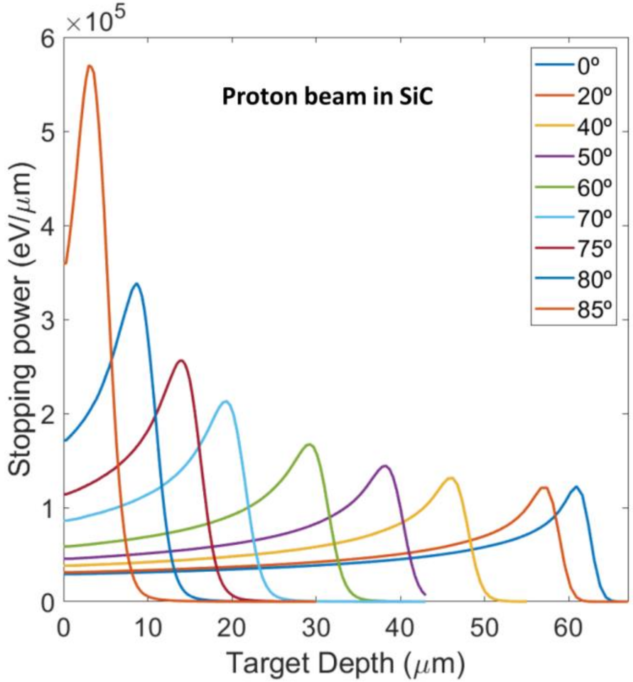




IBIC angular scans: Depletion width

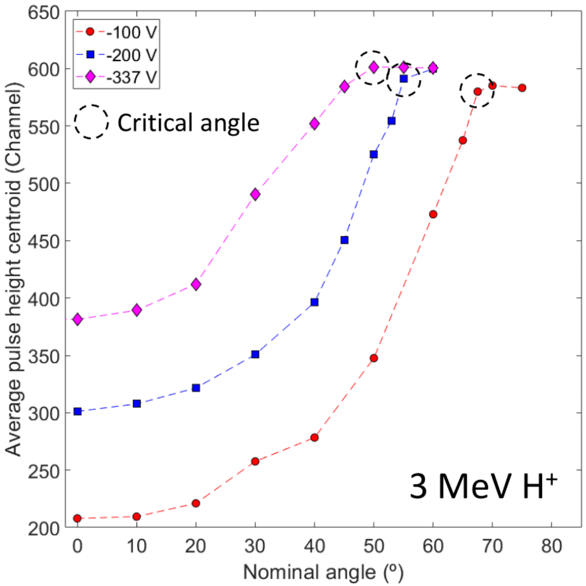
To modify the ion beam deposition depth we have carried out experiments by tilting the detector.

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



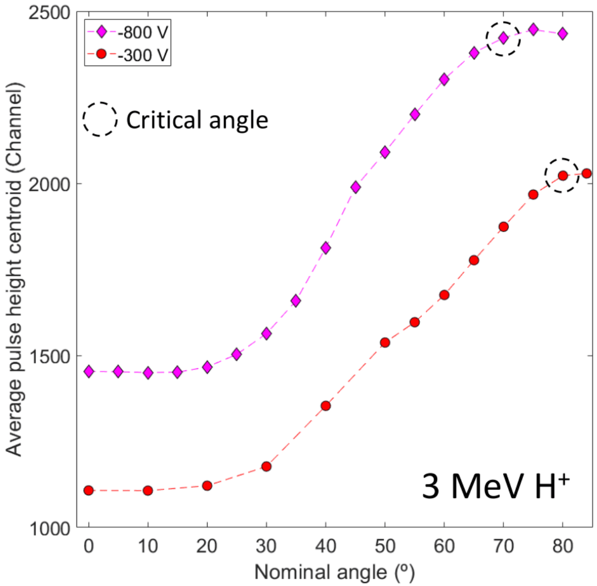
IBIC vs TPA: depletion width

1MW2 (non irradiated)



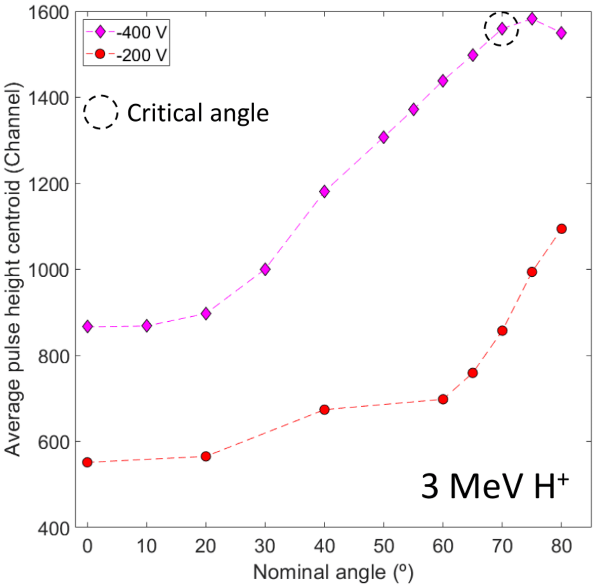
Reverse bias (V)	CV Depletion (μm)	IBIC depletion (μm)	TPA depletion (μm)
-100	23	22	26
-200	32	32	35
-337	39	40	41

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

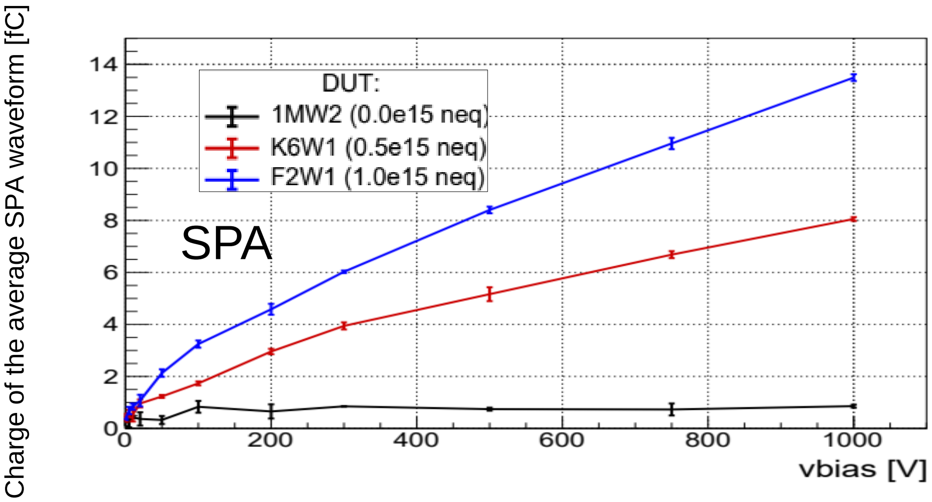
F2W1 (1x10^{15} n/cm^2)

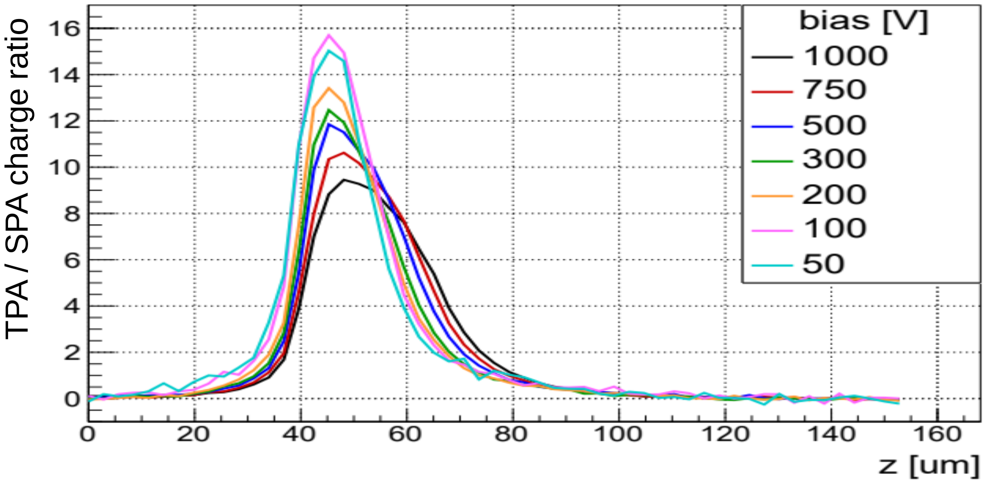


Reverse bias (V)	CV Depletion (μm)	IBIC depletion (μm)	TPA depletion (μm)
-200	44	X	17
-400	44	21	20

TPA and SPA: relative signal strength

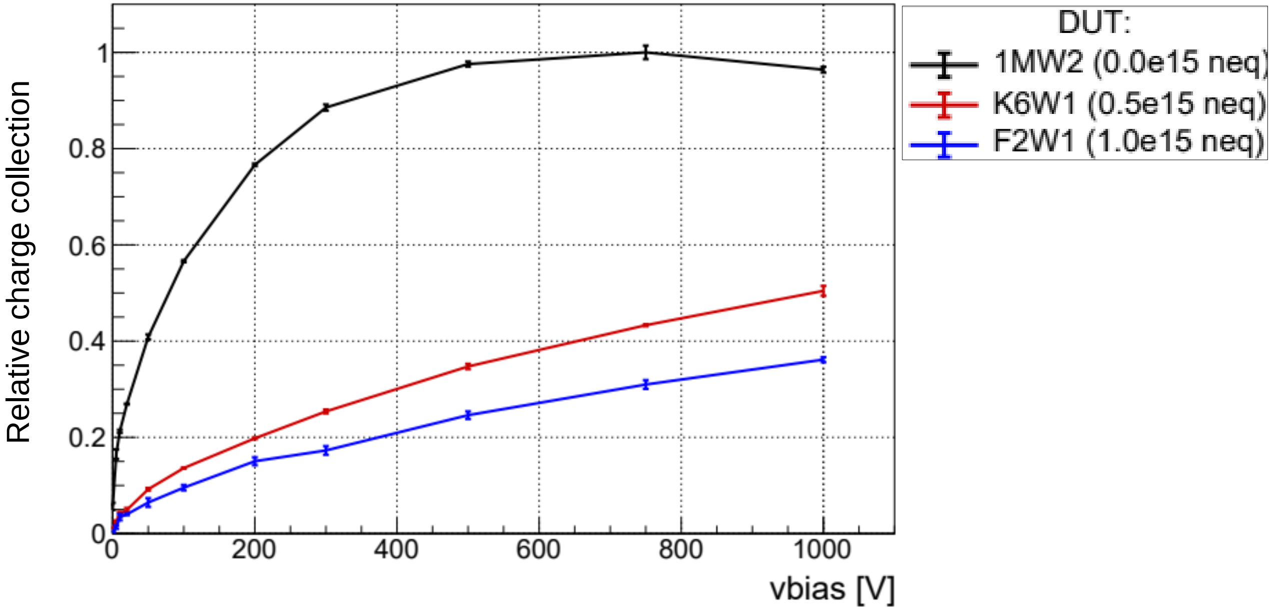
- SPA average waveform signal obtained when the laser focus is outside the active volume of the diode
- TPA Signal /SPA Signal ratio determined at different z integrating the waveforms of the SPA and TPA signals at that z position.





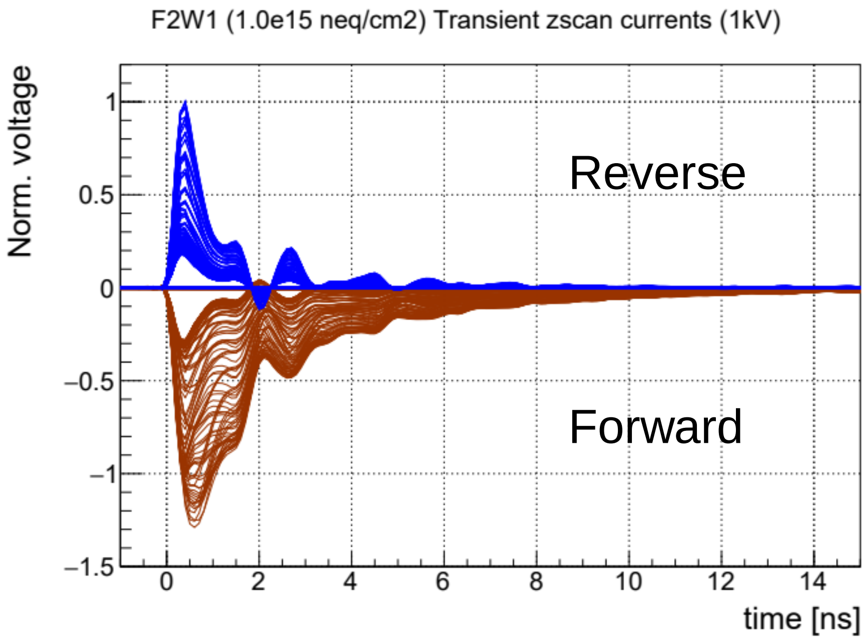
TPA-TCT: Relative charge collection vs fluence

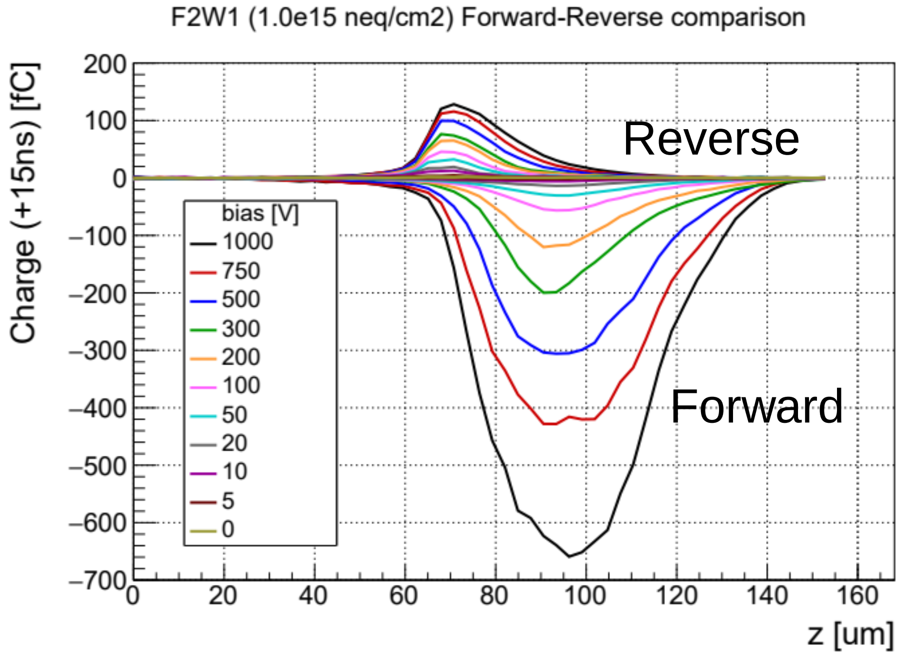
- Relative charge collection obtained from the ratio of the charge integral of the z-scan profiles with subtracted SPA contribution
- Normalized to the charge integral of the z-scan profile of the fully depleted non-irradiated



TPA-TCT: Forward biasing of Irradiated diodes

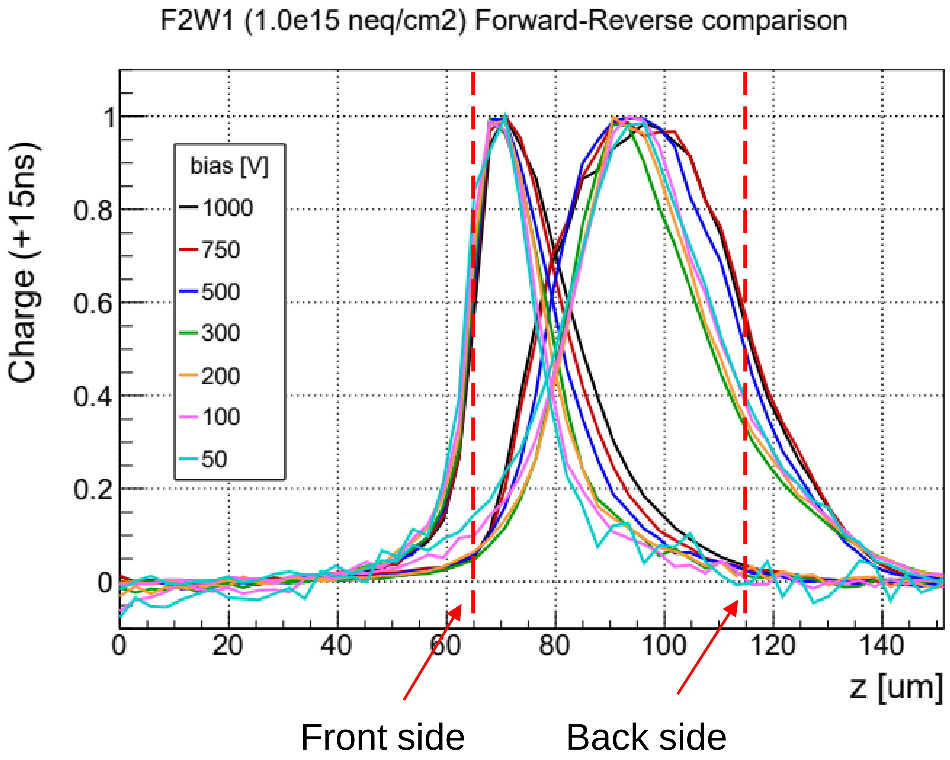
- Comparison between two z-scans at same HV bias but opposite polarization.
- The signal amplitude is significantly greater in forward biasing than reverse biasing.
- Large increase of the depletion width.

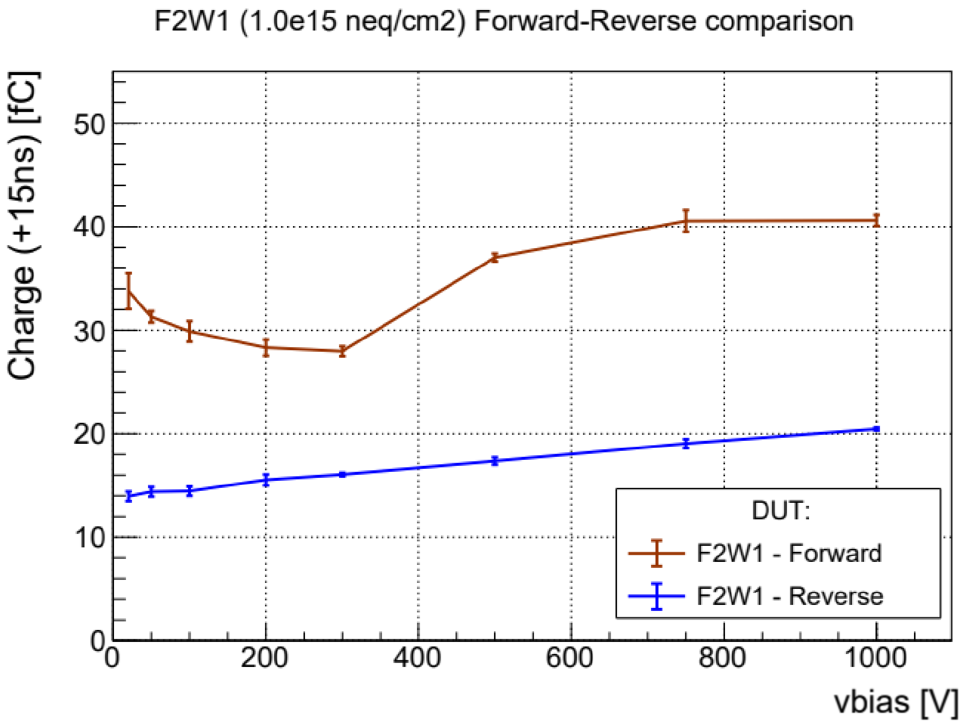




Forward biasing – Depletion width

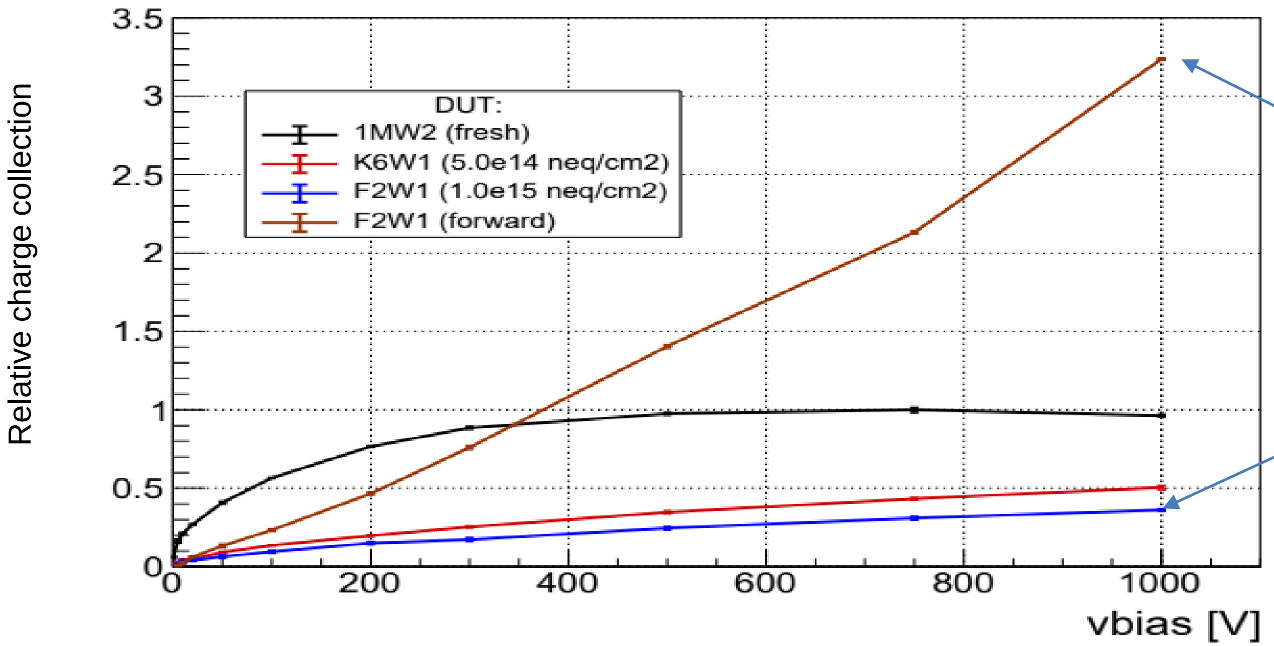
- When forward biased, the **depletion region is at the back side of the diode**.
- Non monotonous dependence of depletion width on bias (forward) voltage.





Relative charge collection vs fluence (forward biasing)

- Normalized to the charge integral of the z-scan profile of the fully depleted non-irradiated diode



Almost a X10 increase of the signal for 1e15 n_{eq}/cm^2

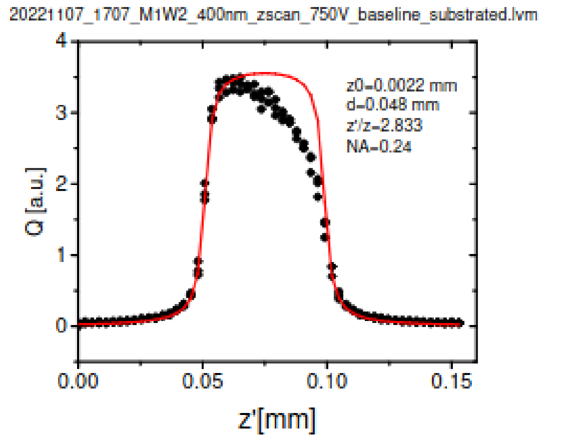
Conclusions

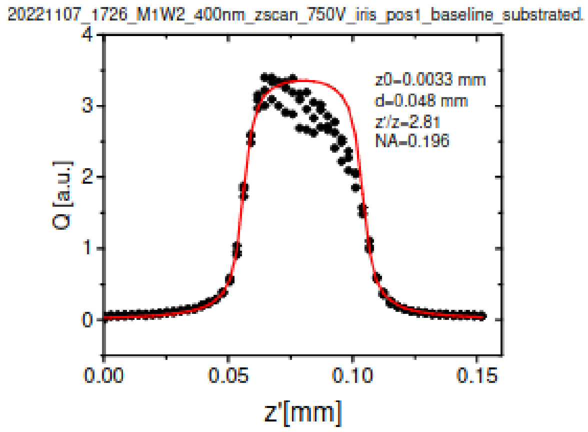
- A relative charge collection of 50% (5e14) and 35% (1e15) is achieved.

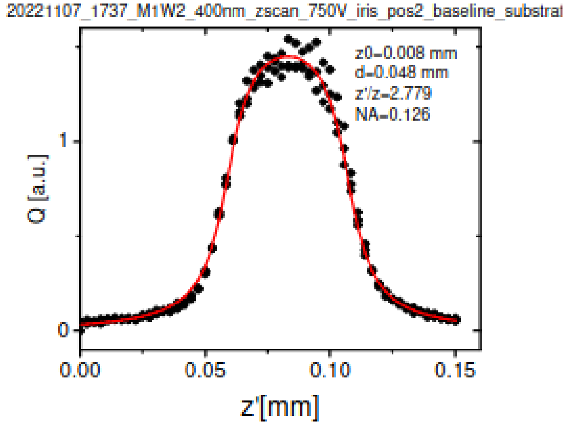
- After neutron irradiation, SiC pn diodes non fully depleted for a HV bias up to 1000V.
- Forward biased diode, irradiated up to 1e15, is just depleted at the back-side.
- Depletion width in forward biasing is twice the depletion width in reverse biasing.
- **Relative charge collection in forward biasing is increased by factor of 10 with respect to the reverse biasing.**

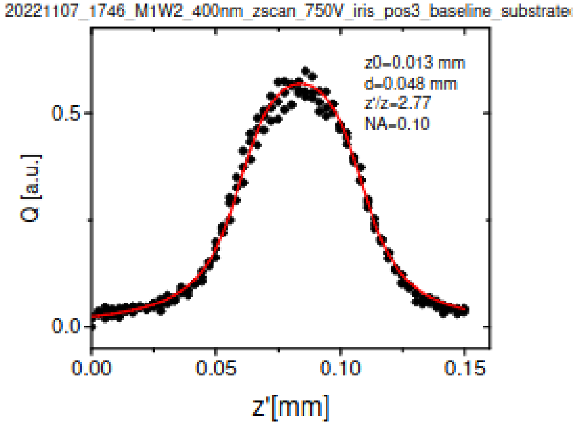
Thank you for your attention

Spherical aberration and numerical aperture

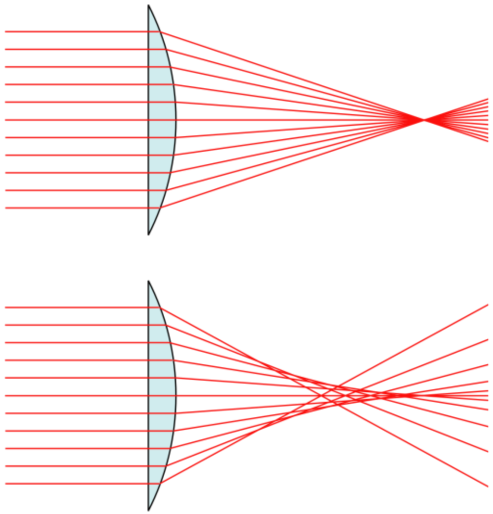






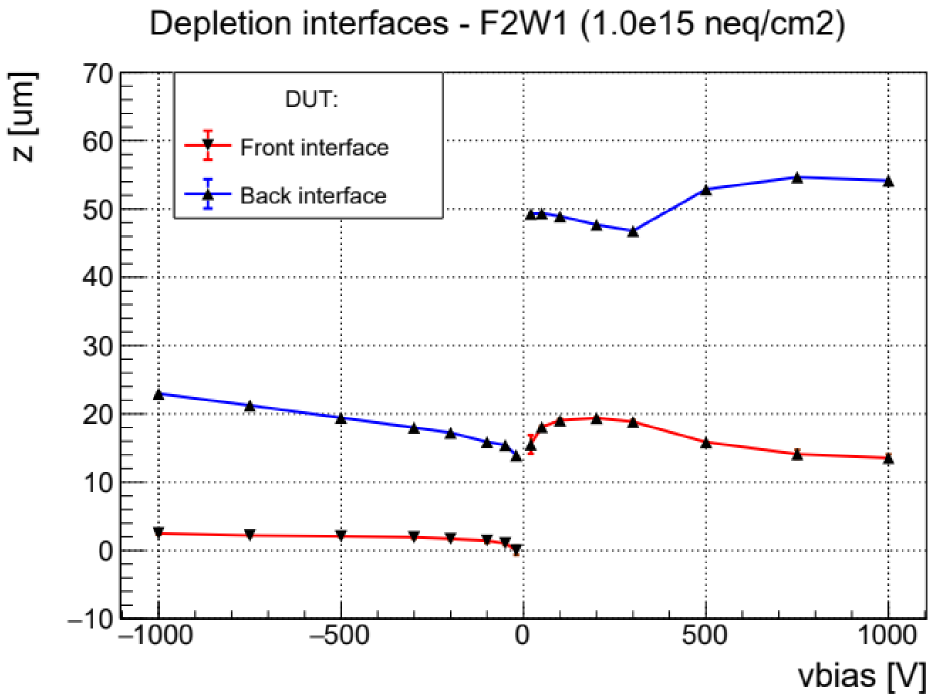


Spherical aberration

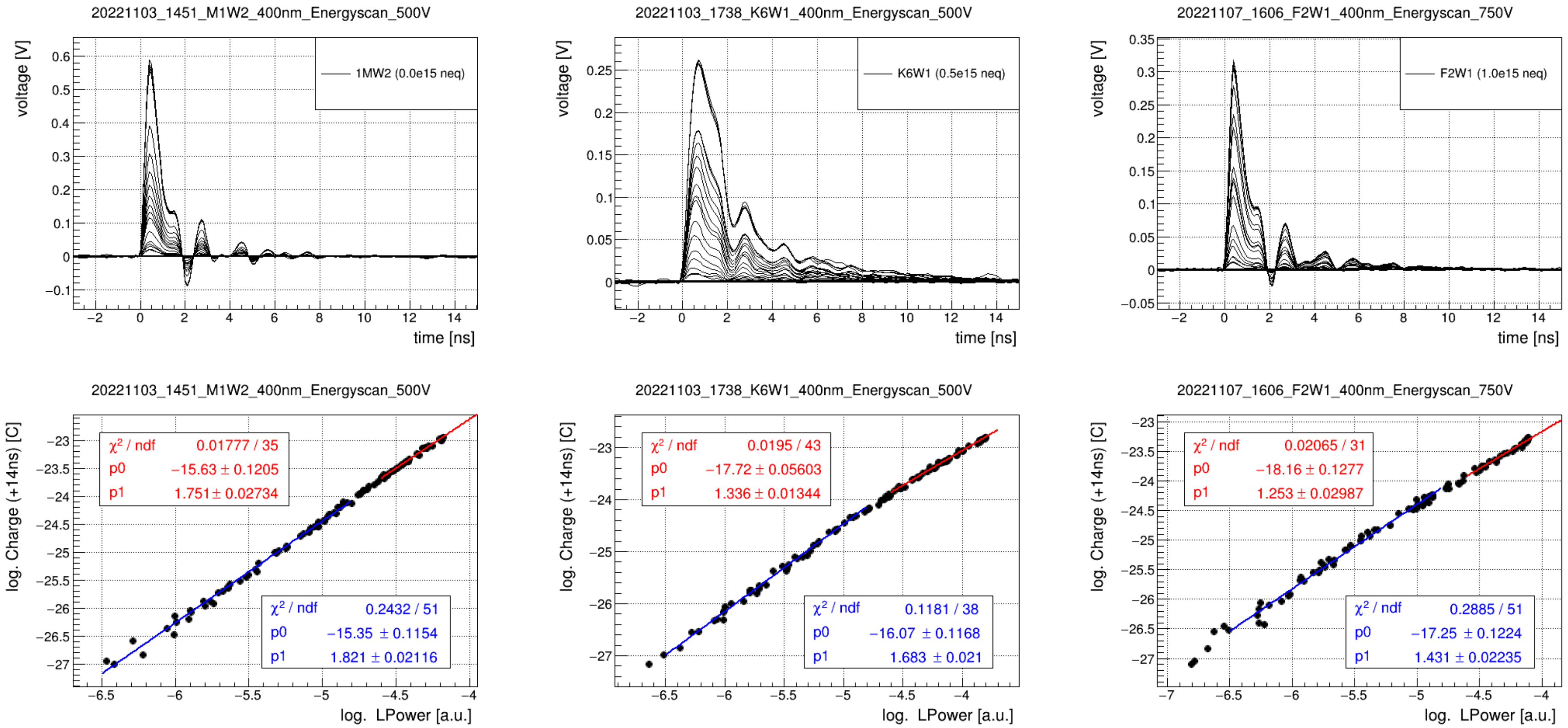


wikipedia.org : Spherical aberration

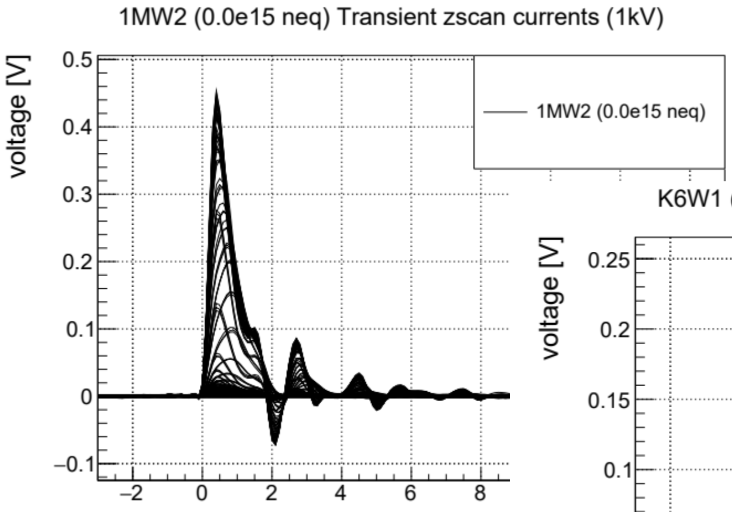
Depletion width

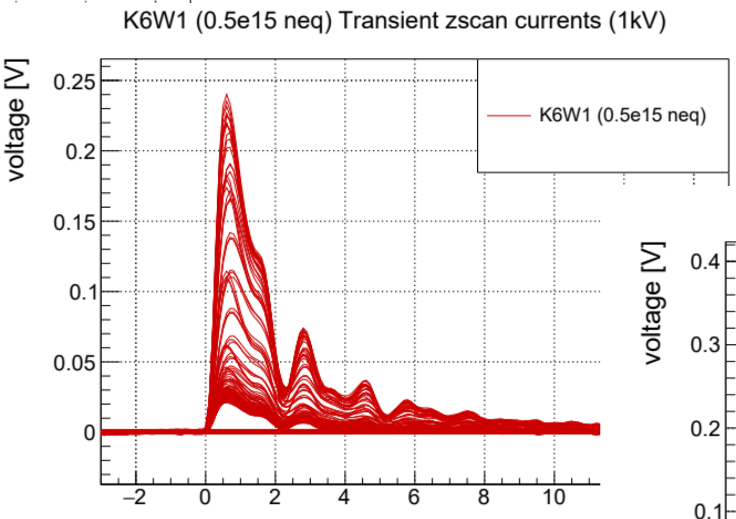


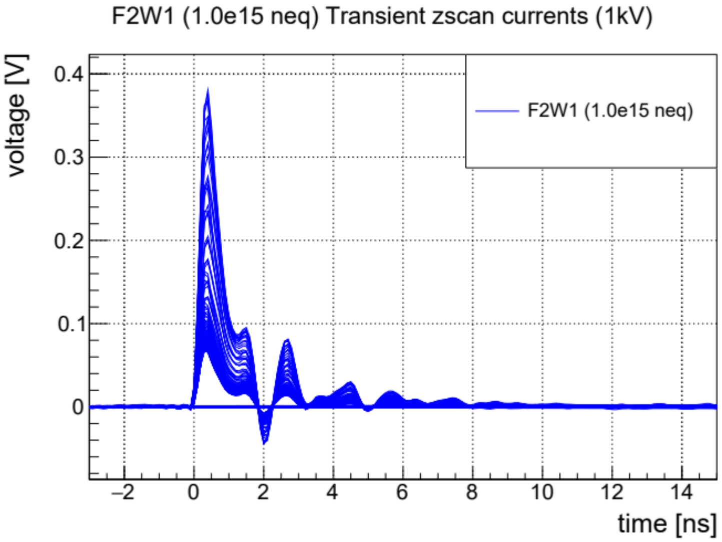
SPA signal contamination



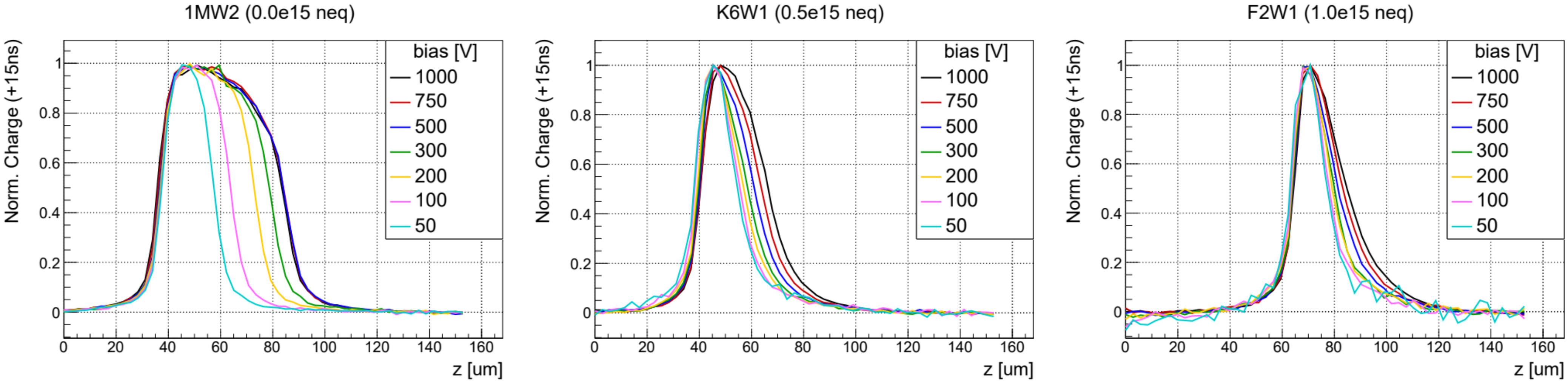
Transient current comparisons



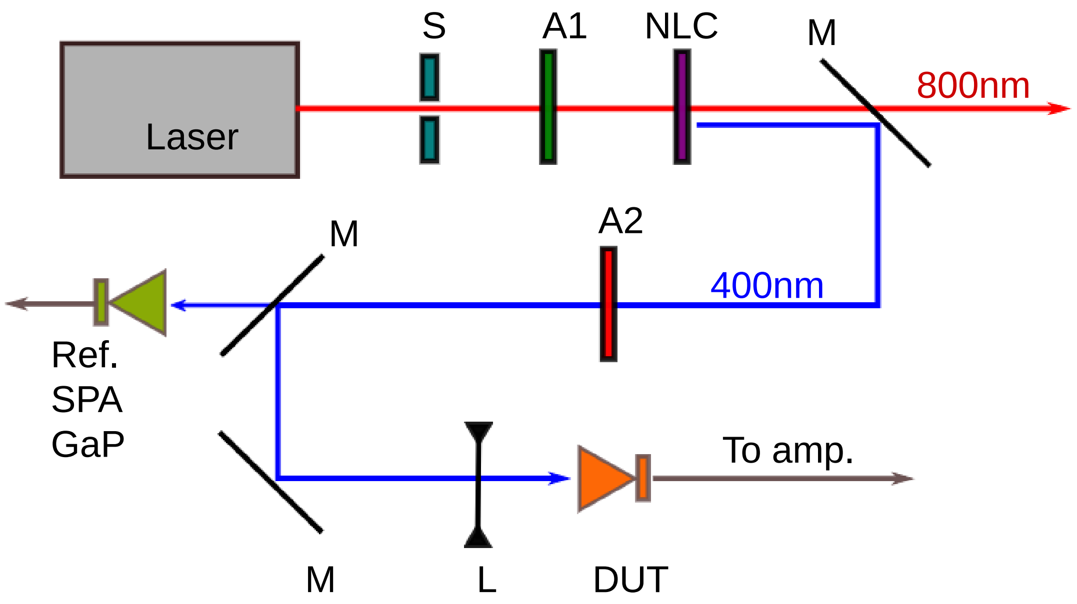




Zscans normallization



Setup improvements (Run 1 → Run 2)

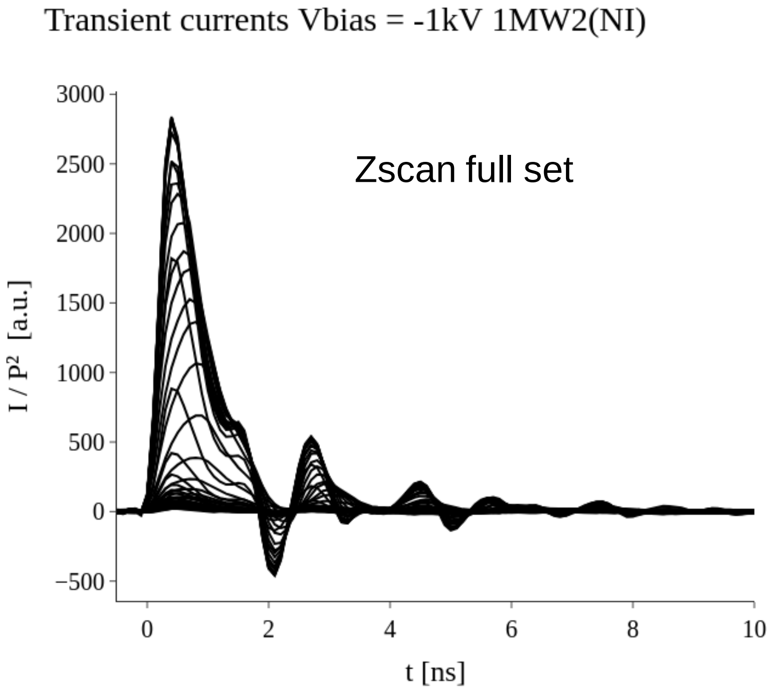


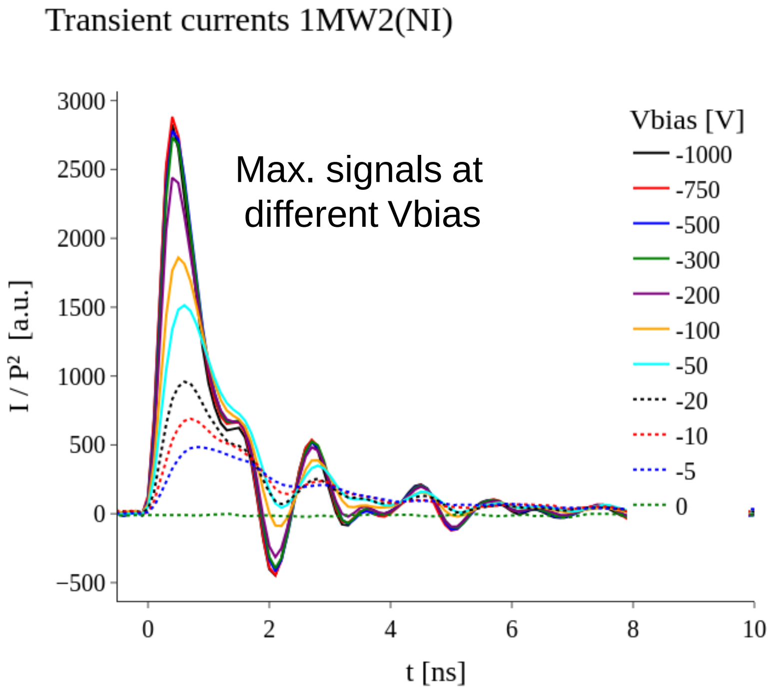
- Better stability:
  - → Pumping module of the laser's amplifier replaced.
  - → Attenuation procedure
  - → Energy monitoring
  - → BBO polarization coupling optimized.
- Better resolution
  - → Coupling between the laser ray and the objective enhanced.
  - →Increment of the effective numerical aperture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

Non irradiated detector: Transient currents

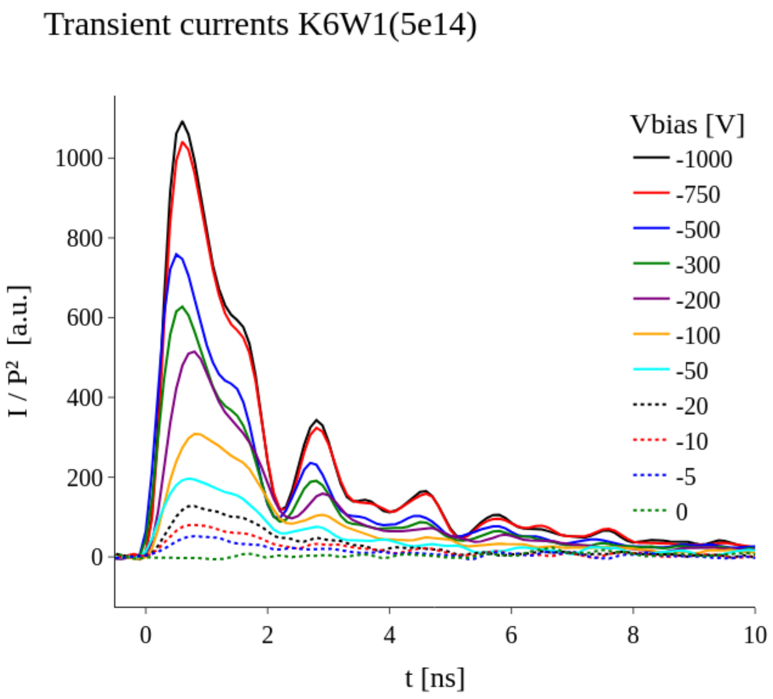
→ Analysis of the WF profiles and durations at different Vbias
→ The duration of the pulses has decreased (20 um close to the collecting ring)

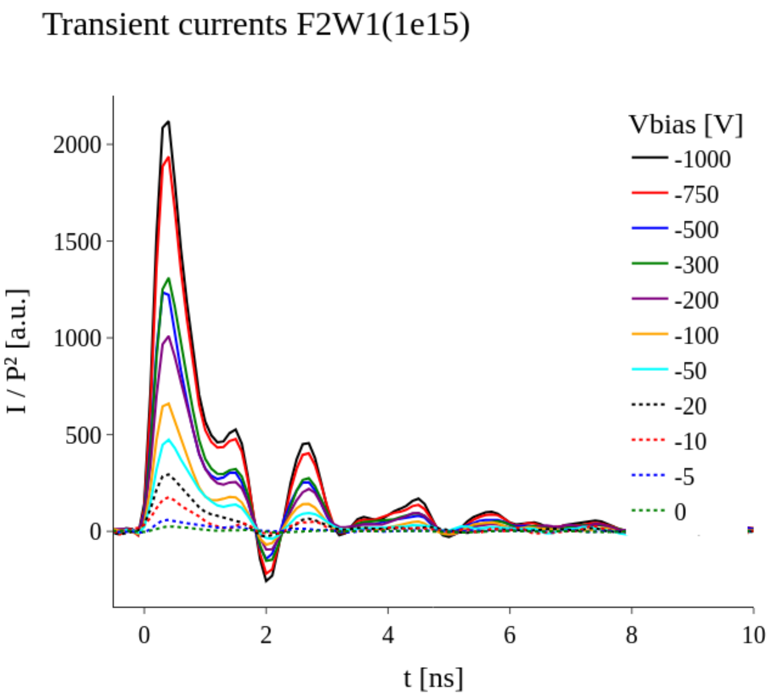
→ Monotonically increasing of the maximum current
→ Profile dependence with the bias voltage





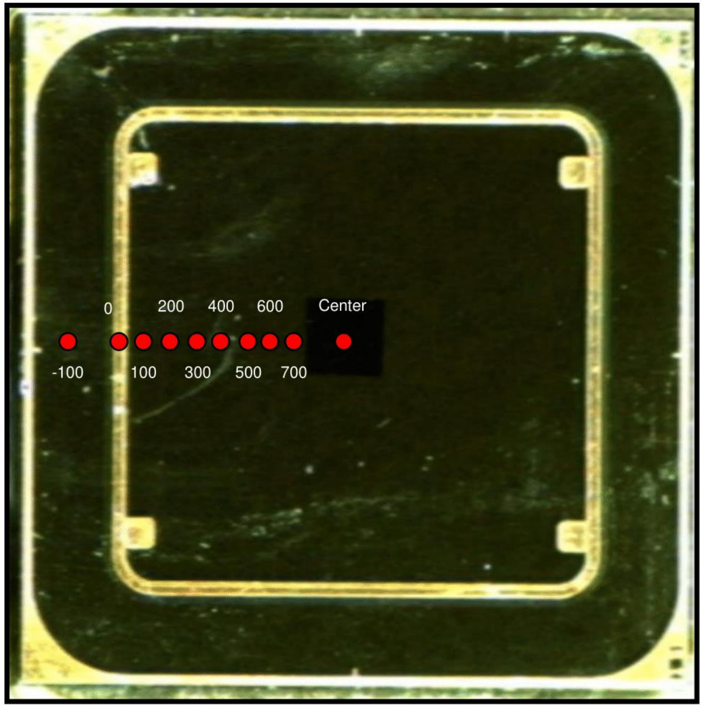
Irradiated detector: Transient currents

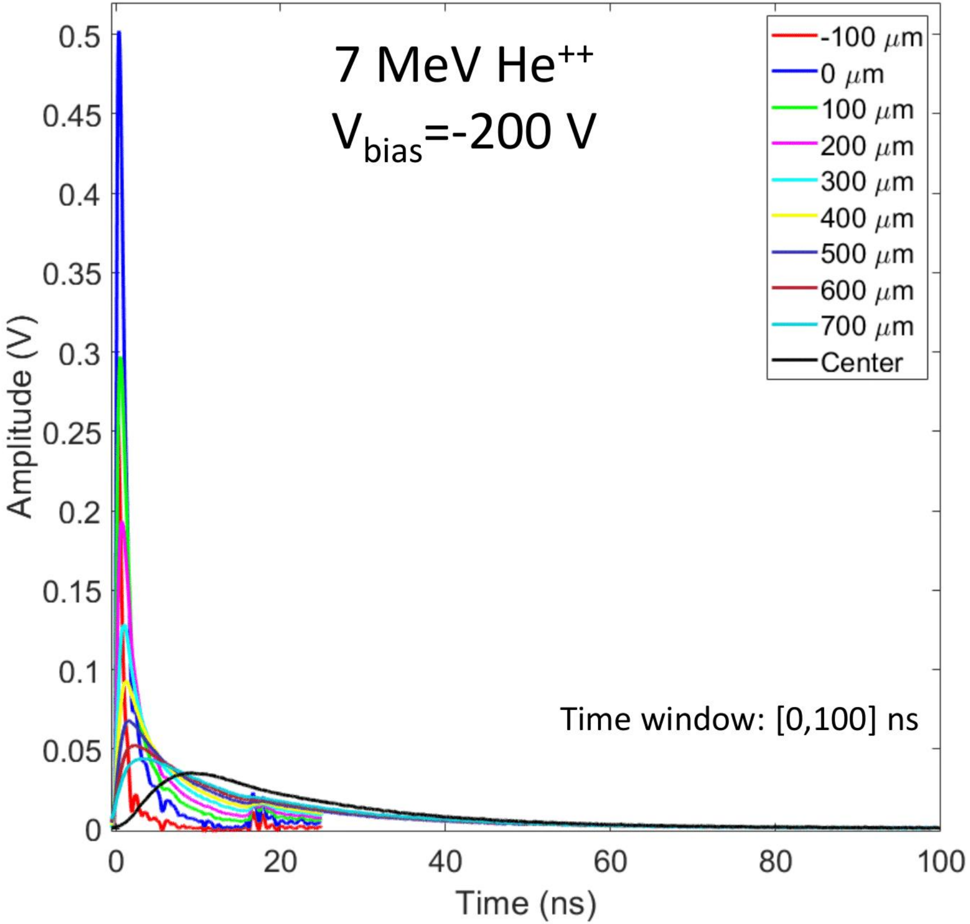




The waveform shapes change as we approach to the center of the detector

1MW2

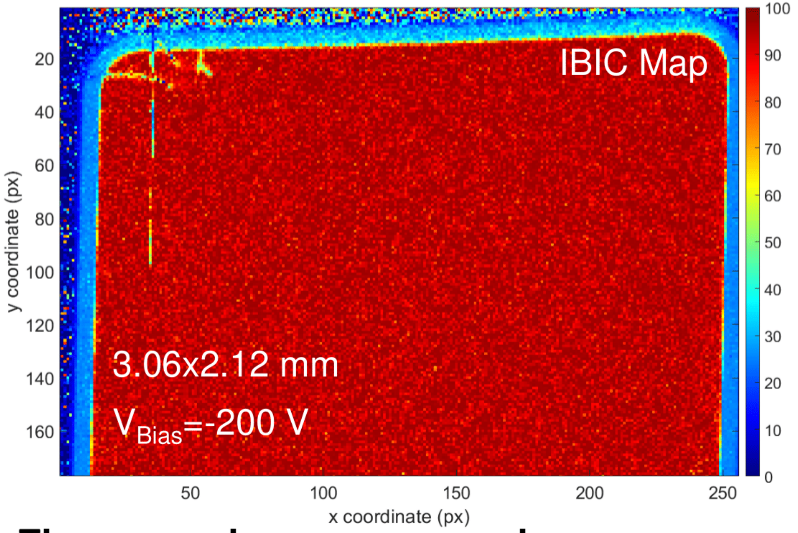




Homogeneity of the charge map

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.