Characterization of non-metalized SiC detectors using the IBIC technique

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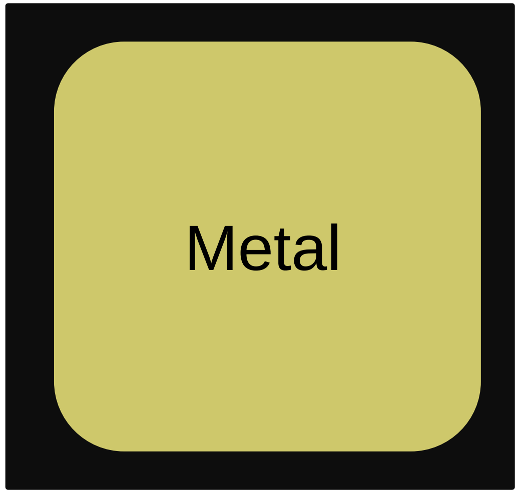
Context



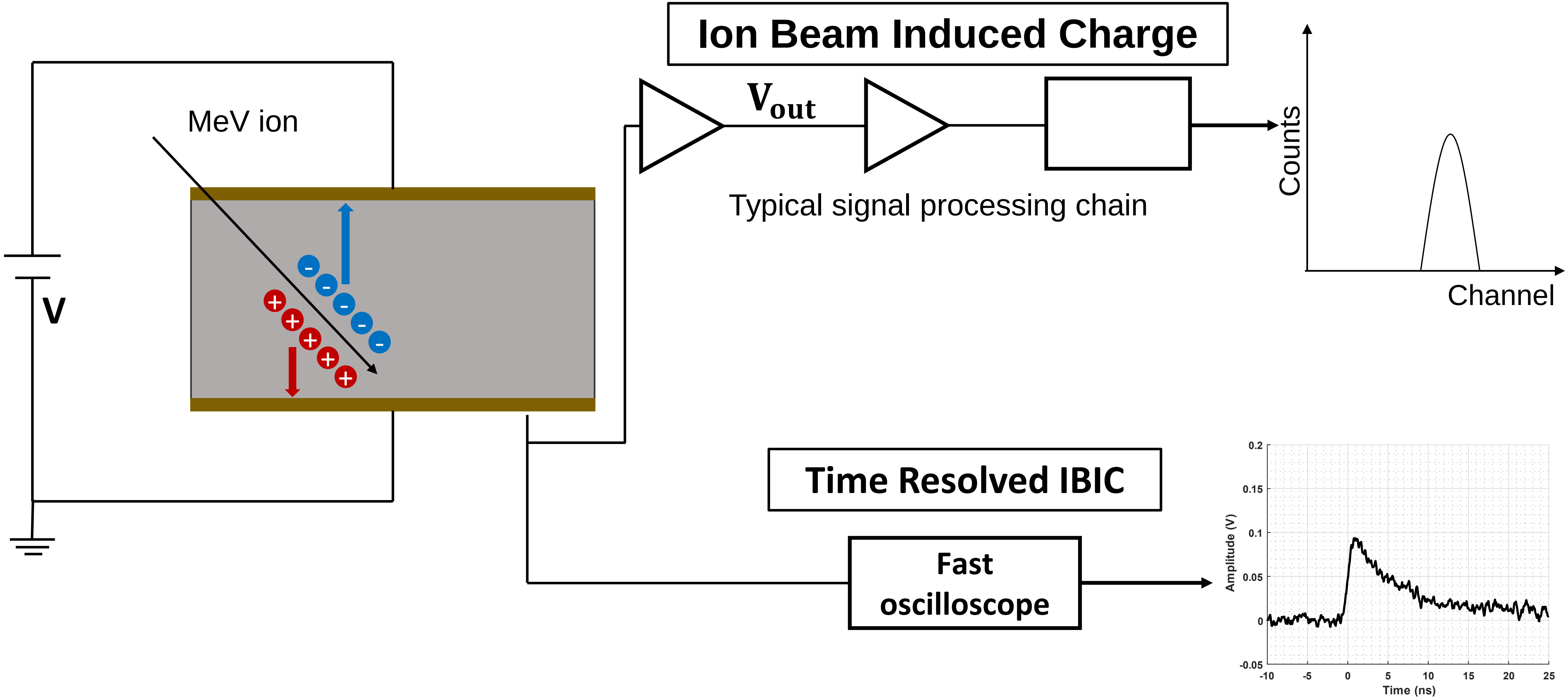
→ M. C. Jiménez-Ramos *et al.*, 'IBIC analysis of SiC detectors developed for fusion applications', *Radiation Physics and Chemistry*, vol. 177, p. 109100, 2020.

E. Currás et al., ' Caracterization of neutron irradiated IMB-CNM SiC planar diodes with TPA-TCT', 2022.

- ❑ **Positional dependence** of the signal profile
- ❑ The width of the **sensitive region depends on the fluence**
- ❑ Neutron irradiated simples do **not present a diode-like behaviour**

Due to the **unexpected results** obtained with **TPA-TCT (Lasers)** , an experimental campaign was programmed to analyze these results using the **IBIC and TRIBIC techniques (Ion)** at CNA.

IBIC and TRIBIC technique

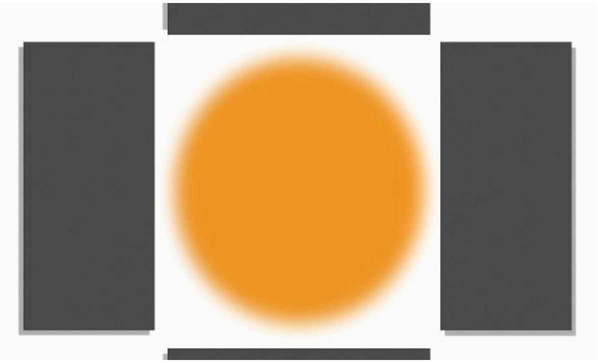


Nuclear microprobe at Tandem3 MV

❶ RATE

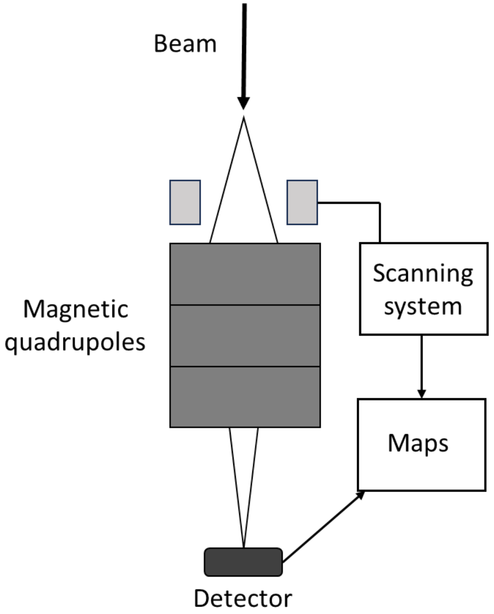
10^{10} p/s

Micrometric slits



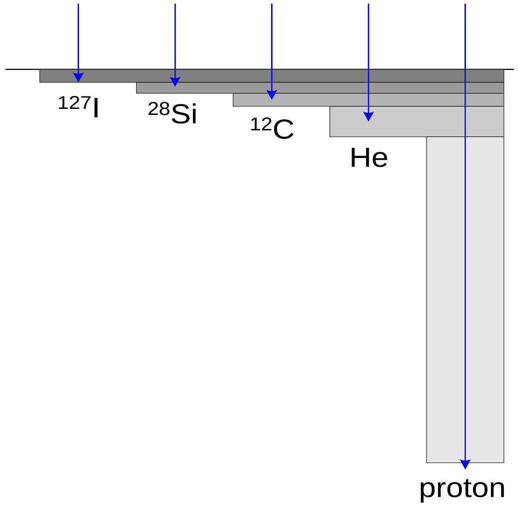
❷ POSITION

- Focusing and scanning



❸ IONS/ENERGIES

- p, α, Li, C, O,..



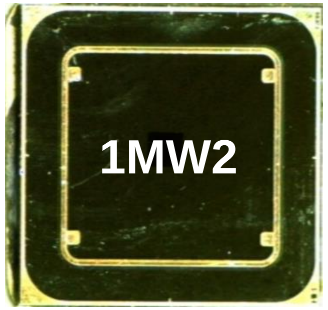
- ❑ Low count rate: **avoid additional damage (IBIC technique)**

$$1 - 10^3 \text{ p/s}$$

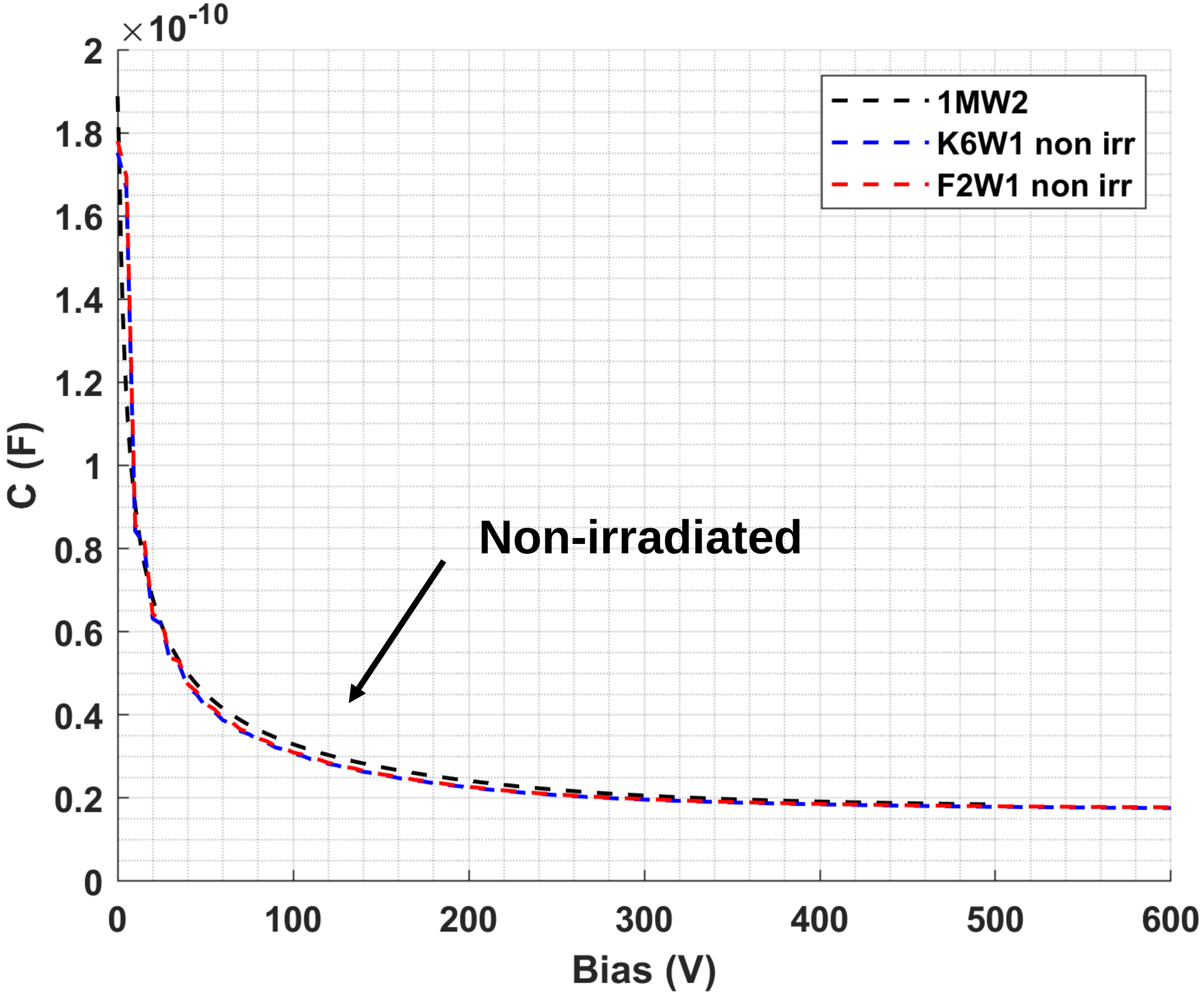
- ❑ Scanning system: **few mm²**
- ❑ Synchronous signal acquisition system with scanning: **mappings**
- ❑ Wide range of ions and energies: **explore different depths**

Neutron irradiated detectors do not present a diode-like behaviour

Non-metallized SiC detector with a passivation layer

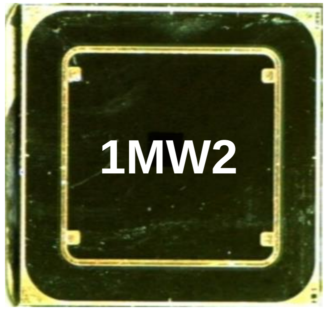


Pristine

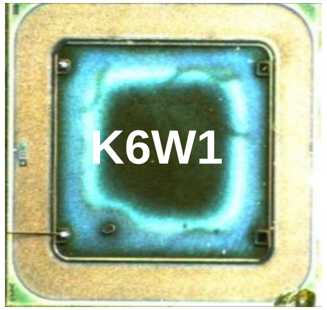


Neutron irradiated detectors do not present a diode-like behaviour

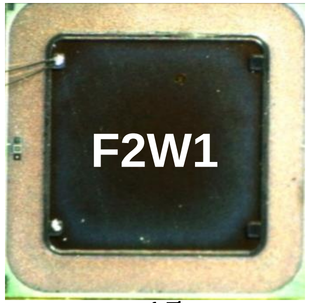
Non-metallized SiC detector with a passivation layer



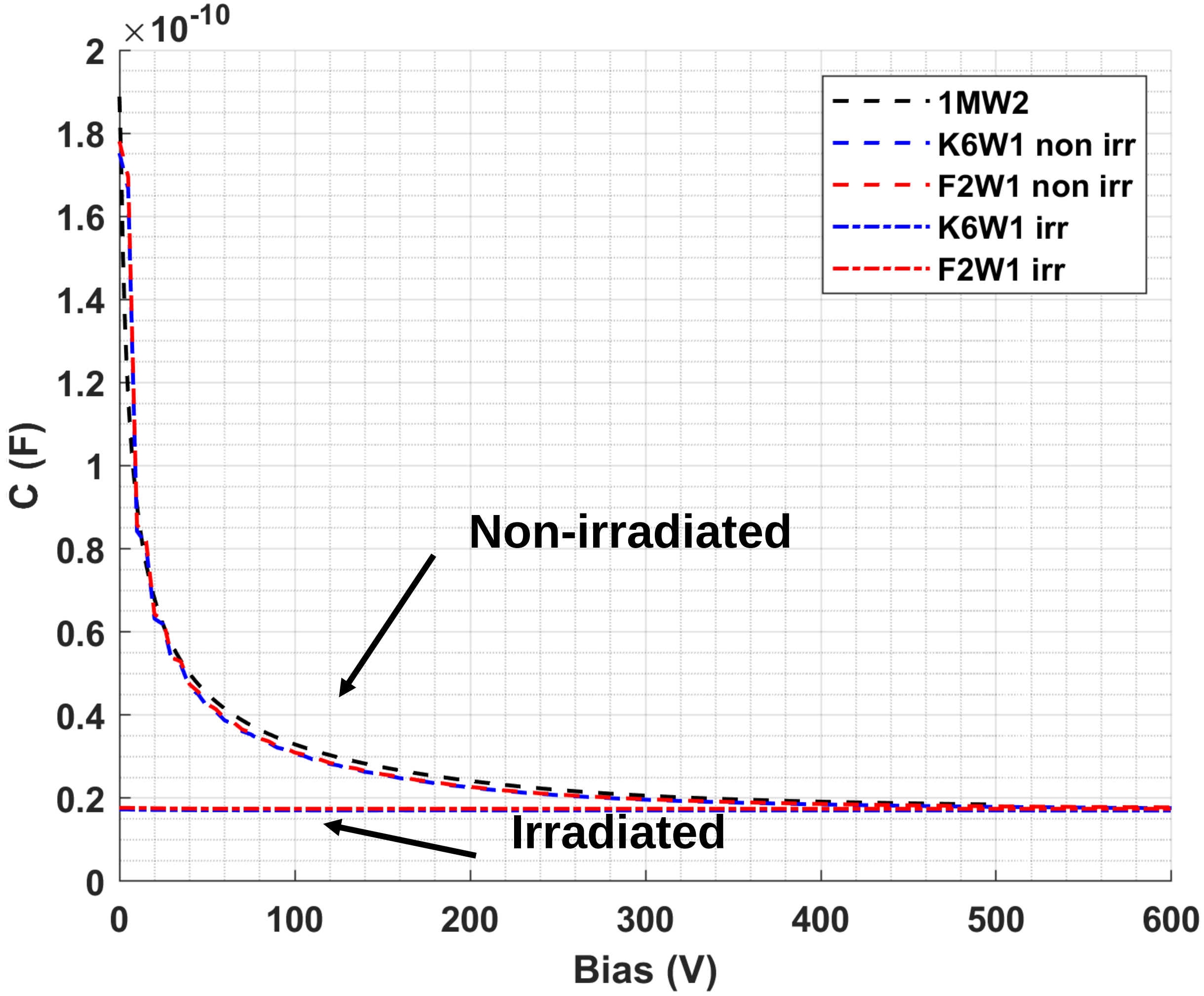
Pristine



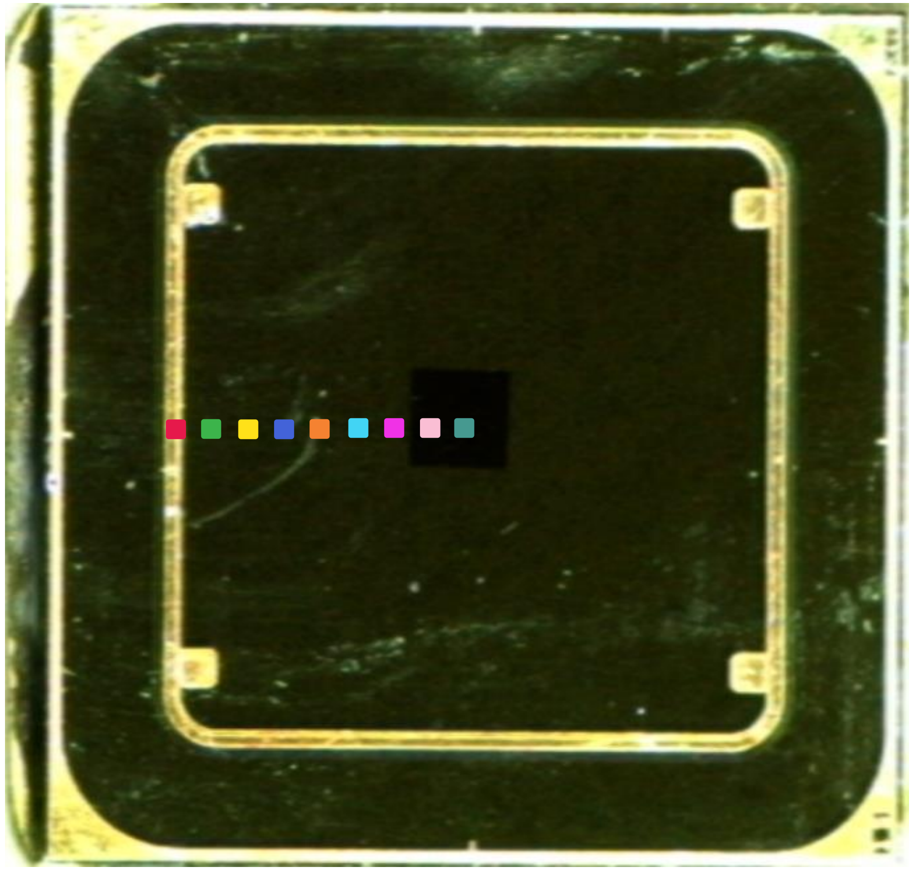
$4 \times 10^{14}\ n_{eq}/cm^2$

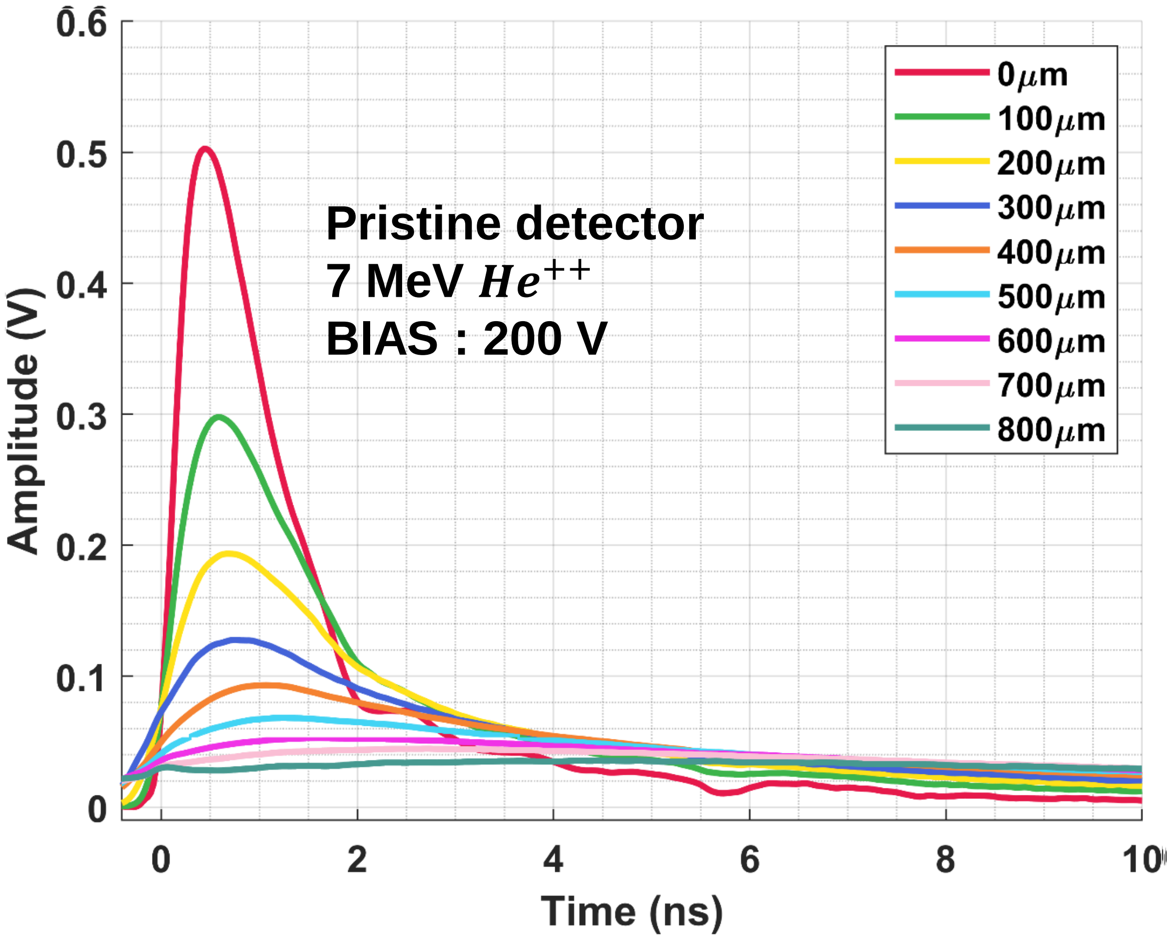


$1 \times 10^{15}\ n_{eq}/cm^2$

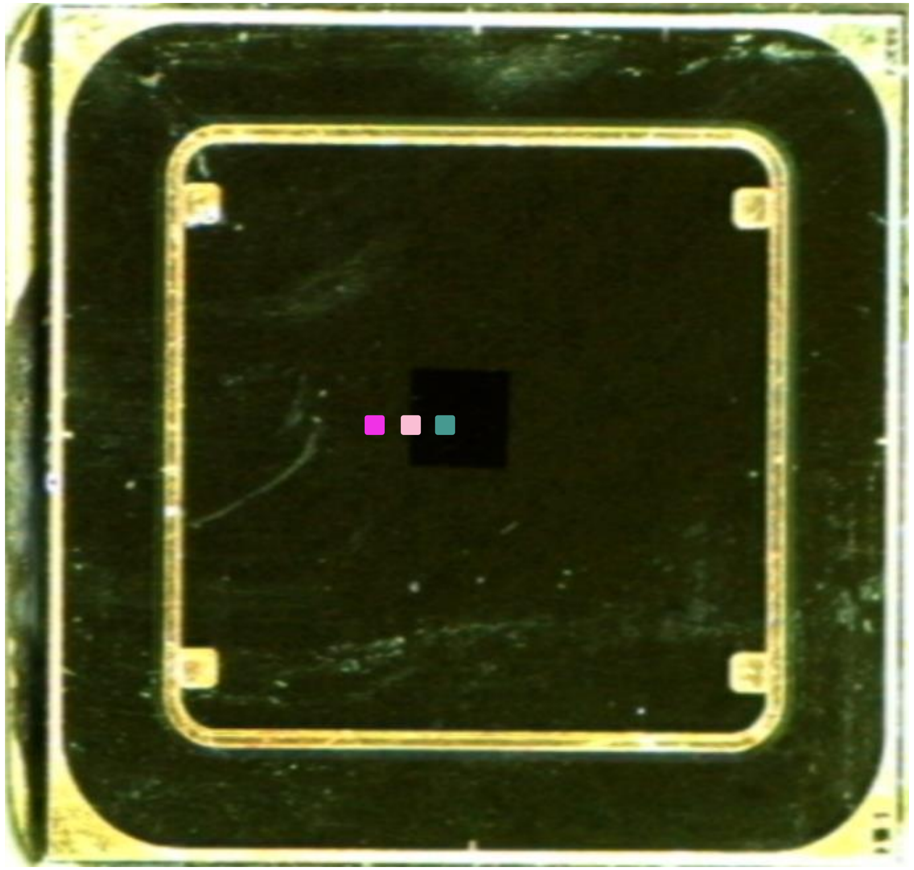


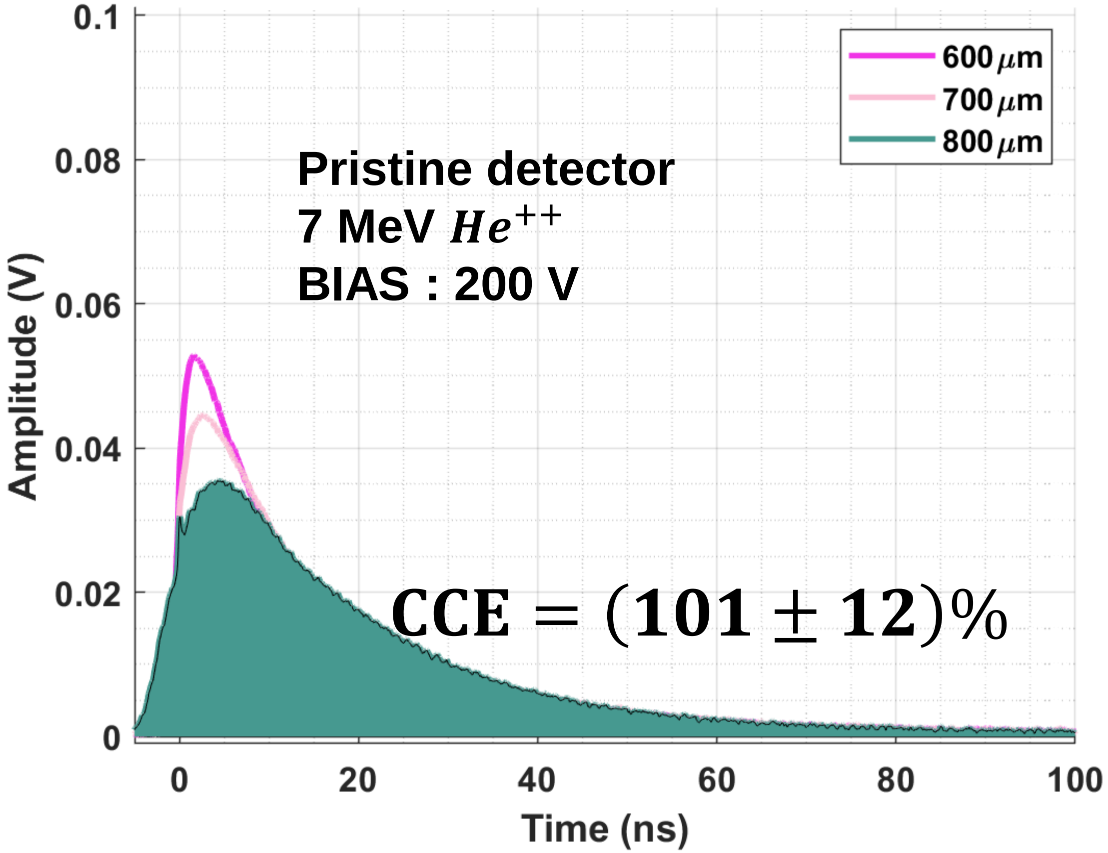
Waveform depends on position





Detector with 100% of CCE

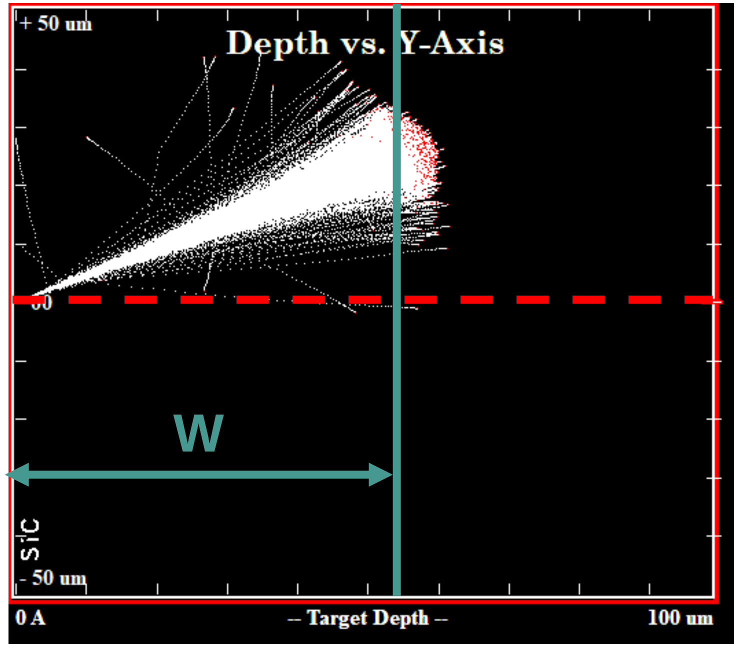




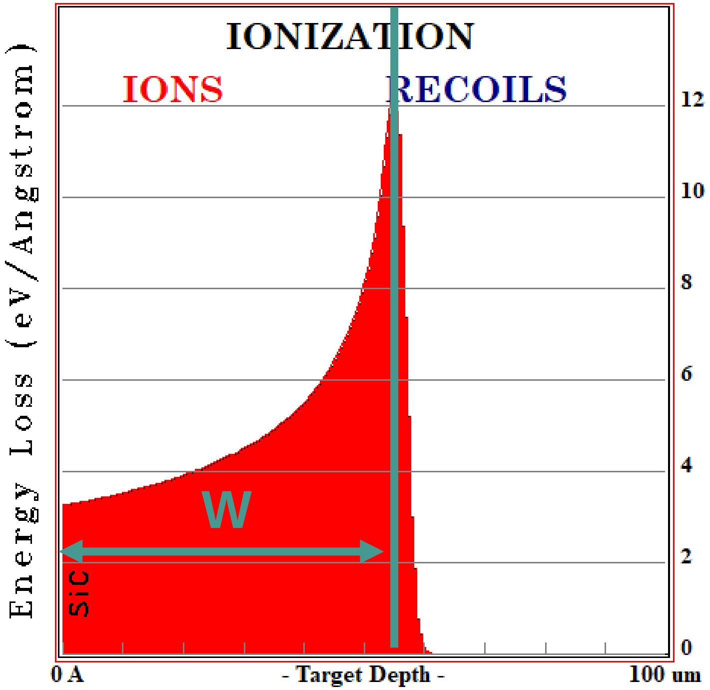
Charge Collection Efficiency (CCE)

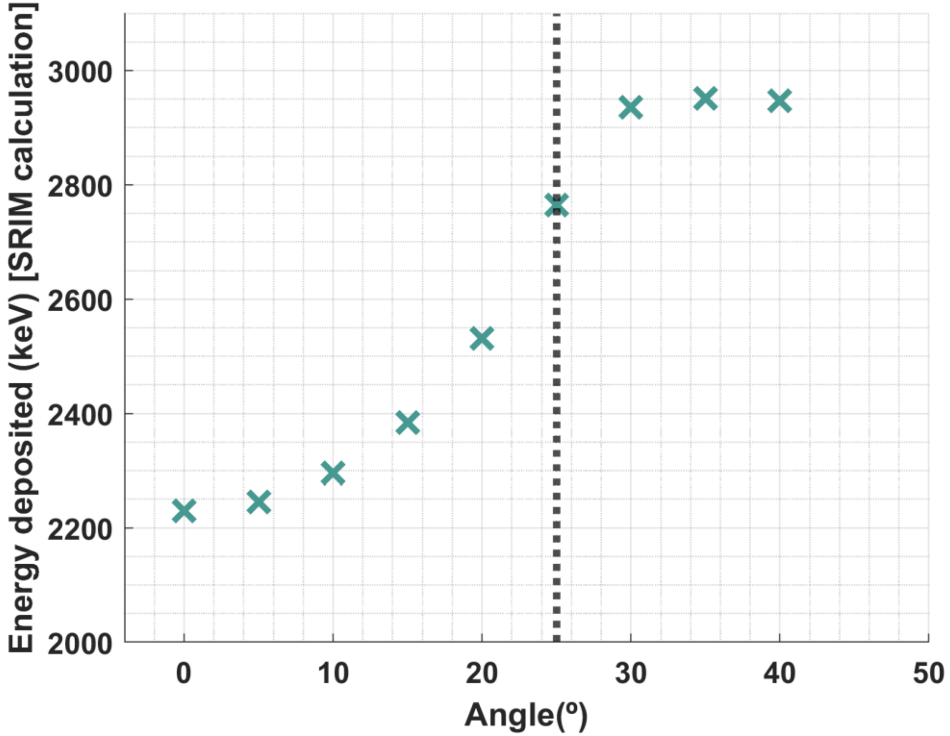
$$CCE = \frac{\text{Charge induced}}{\text{Charge generated}}$$

Methodology to calculate depletion zone

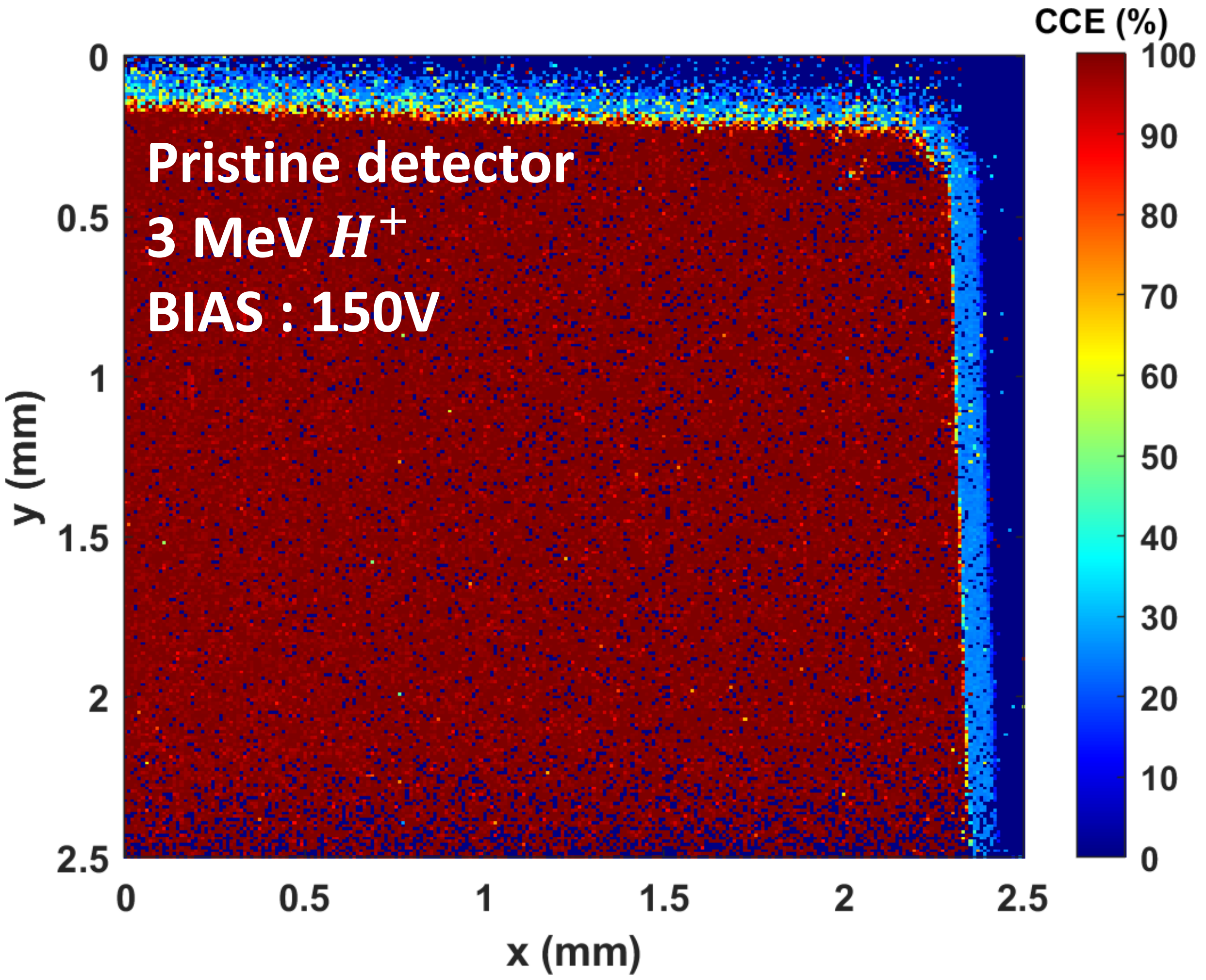


$$E_{dep}(W,\theta) = \int_0^W \frac{dE}{dx}(\theta)dx$$





CCE homogeneity



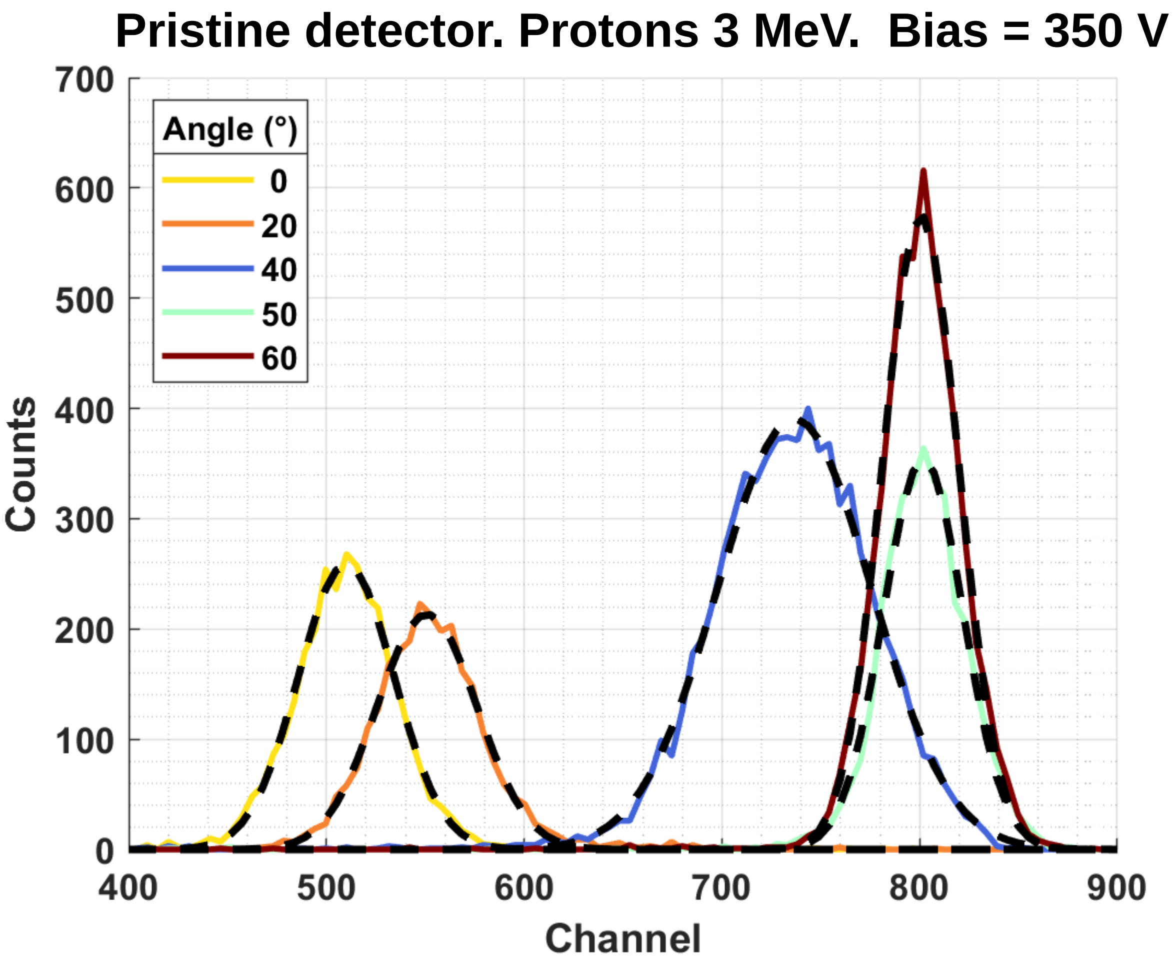
IBIC Map. Scan size: $2.5 \times 2.5\ mm^2$

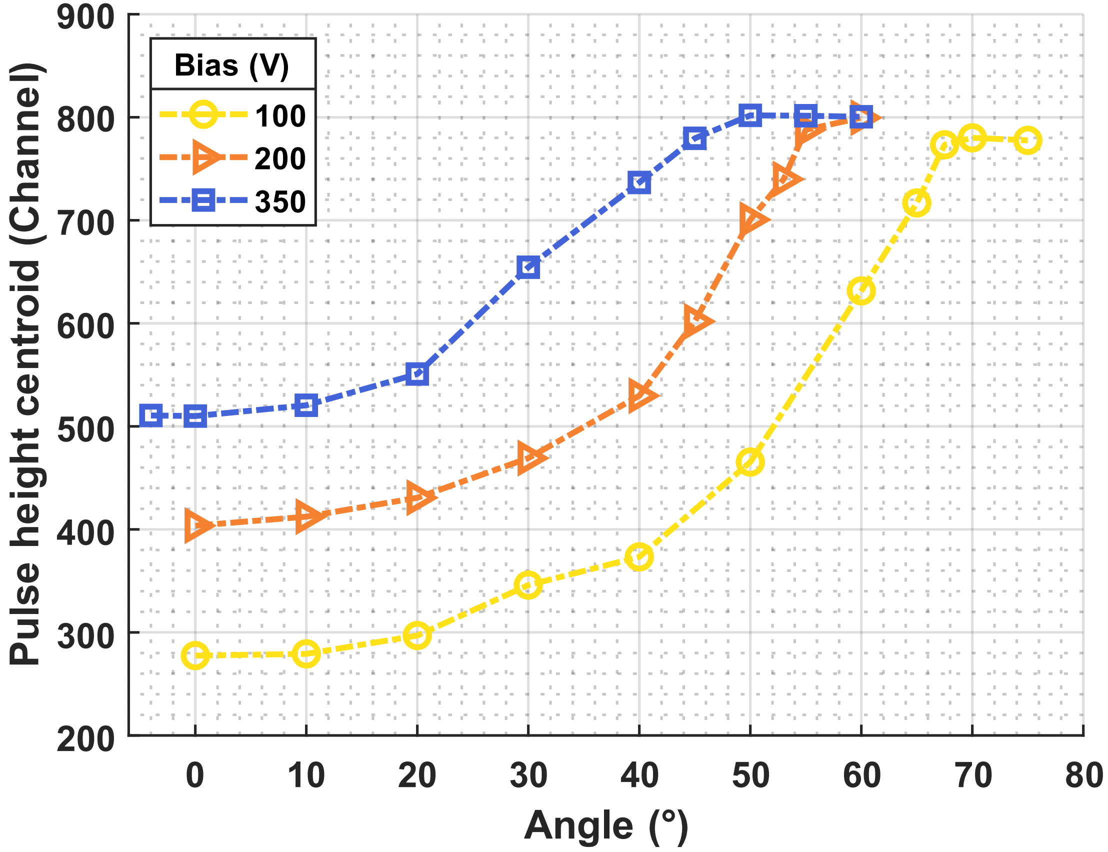
Even though position-dependence of waveform

↓

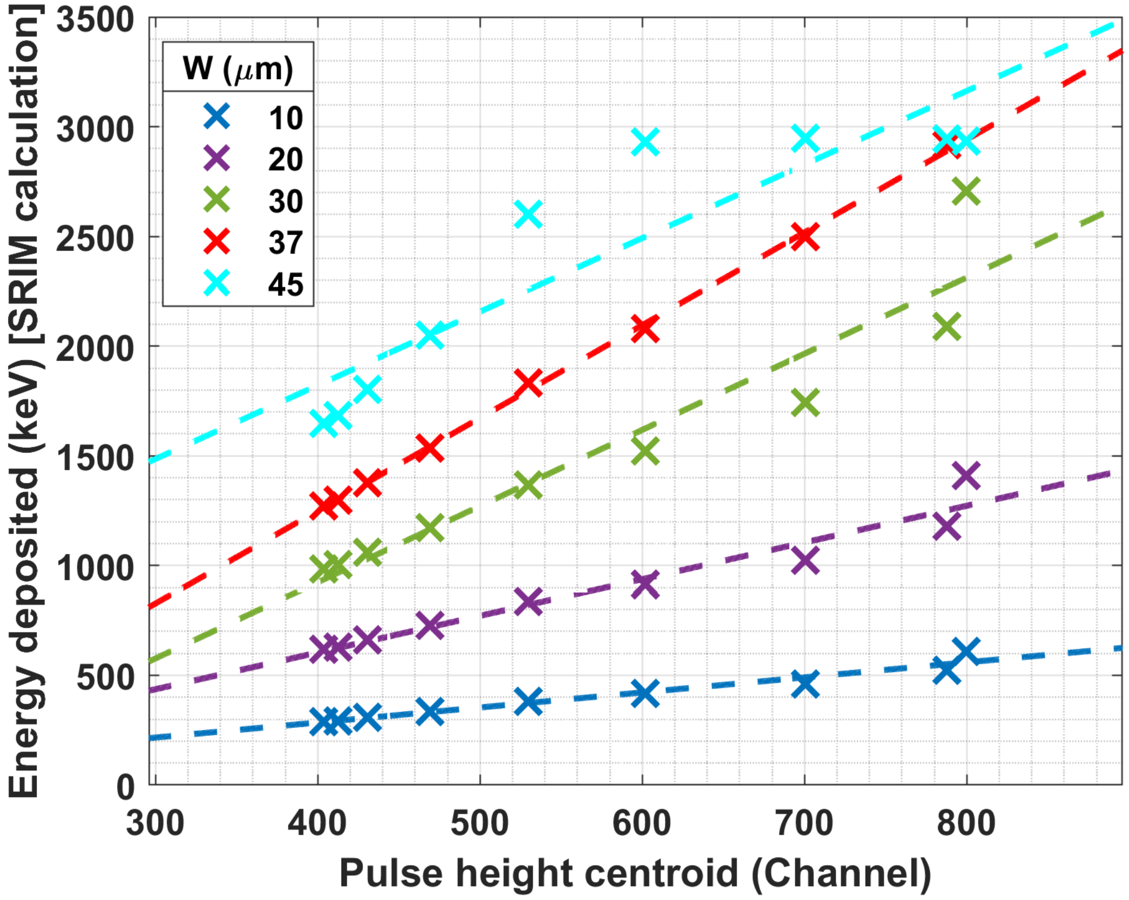
CCE is not radial position dependent

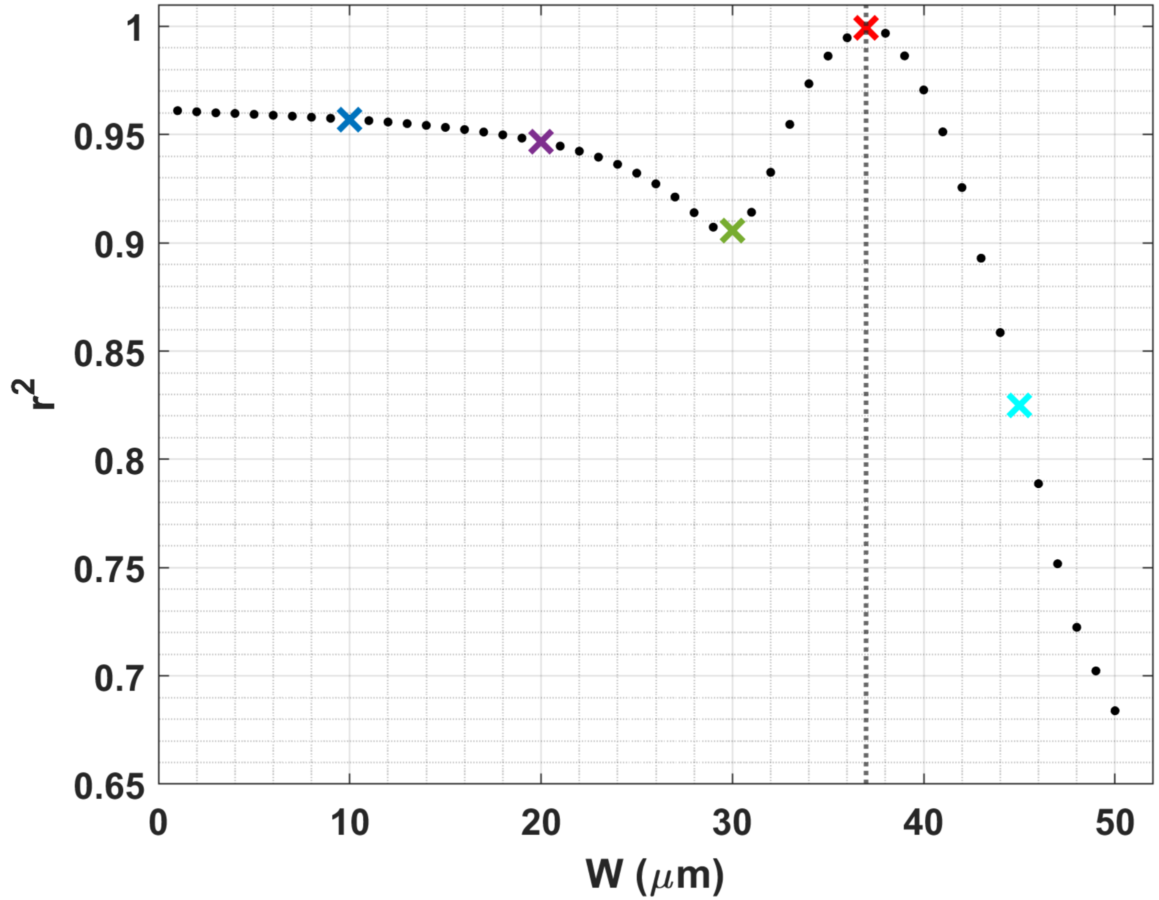
Pristine detector experimental curves





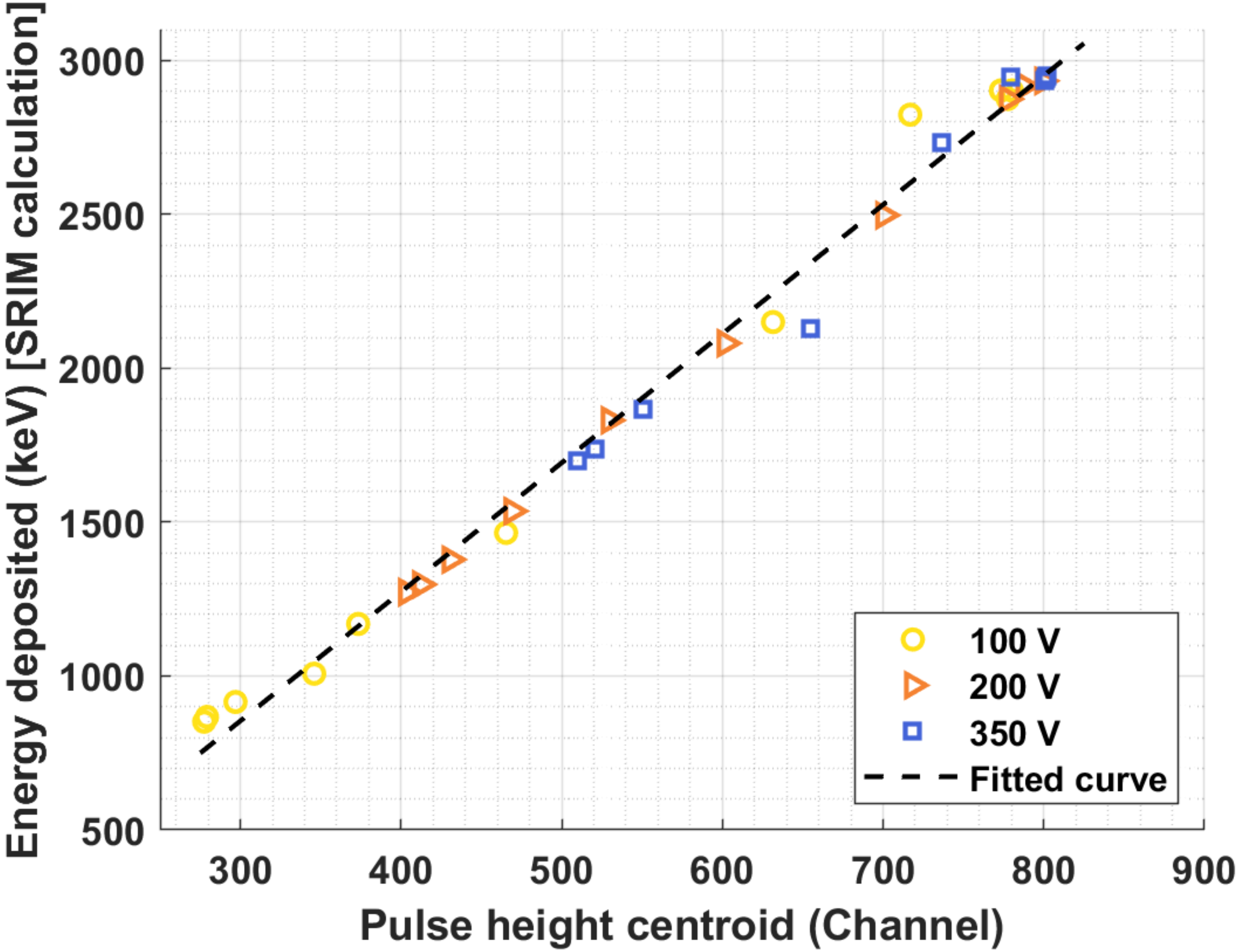
Calibration calculation using SRIM





Pristine detector. Protons 3 MeV. Bias = 200 V

Calibration energy-channel

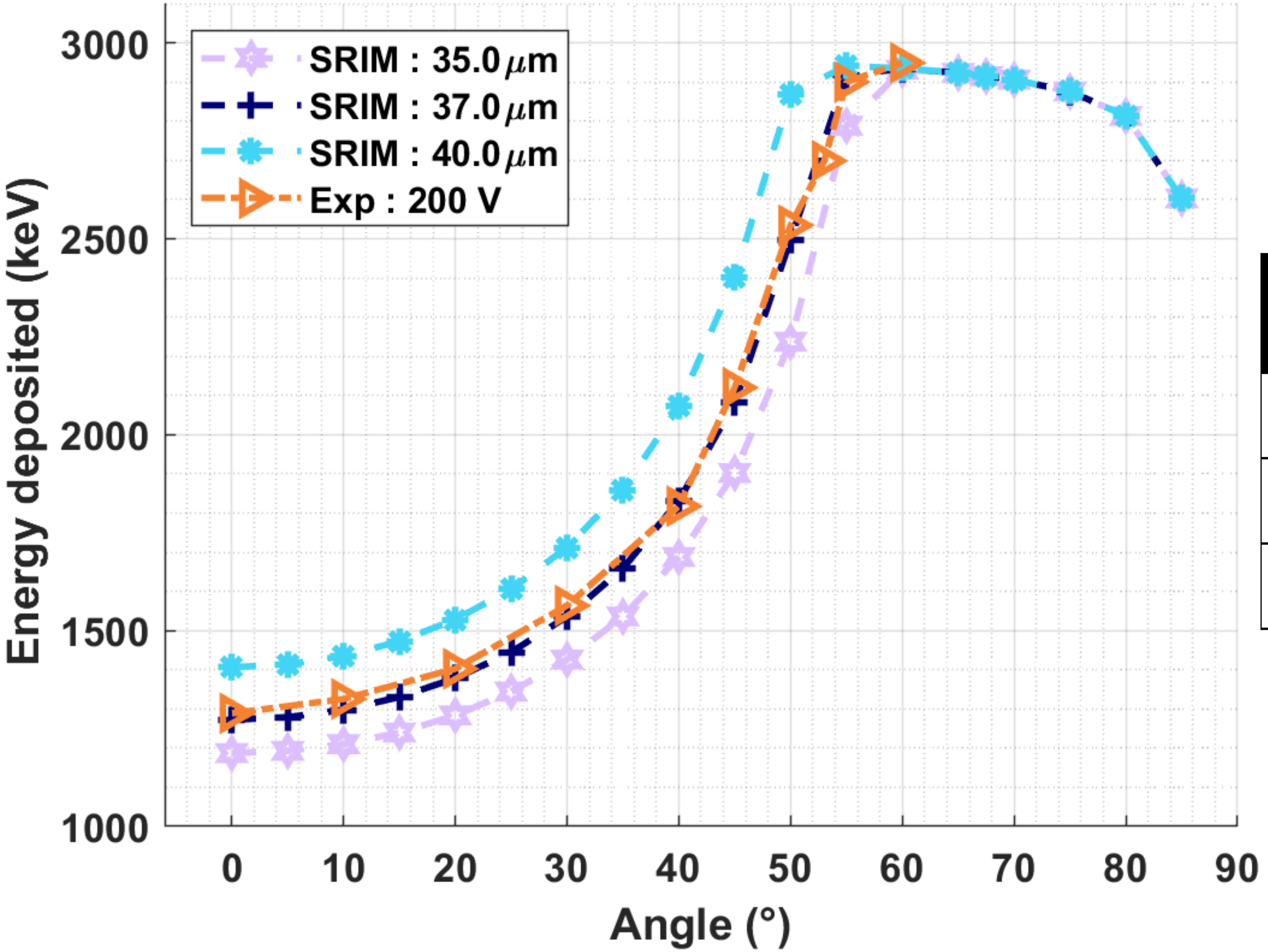


Pristine detector. Protons 3 MeV.

- Detector with 100% of CCE (TRIBIC)
- Theoretical deposited energy (SRIM) for each W and rotation angle
- Calibration with all experimental data
- The obtained W corresponds to the line with the best r^2

Agreement of experimental and simulated curves

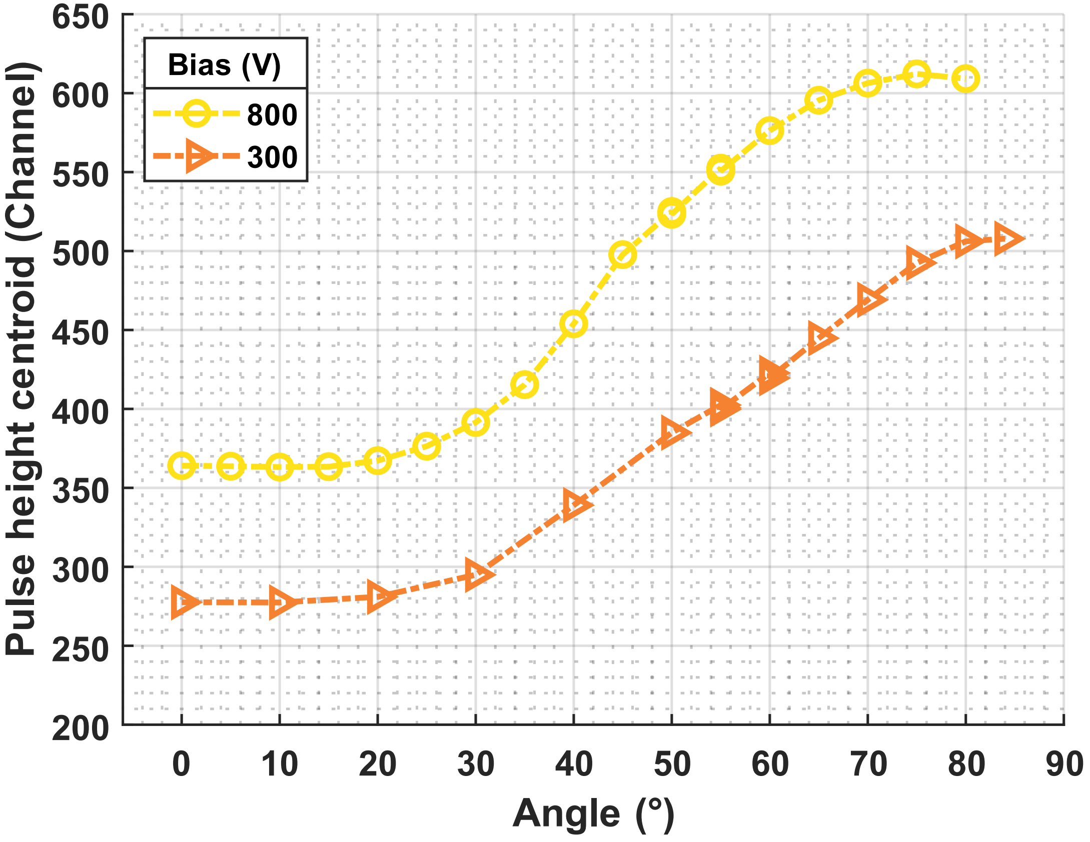
Pristine detector. Protons 3 MeV. Bias = 200 V



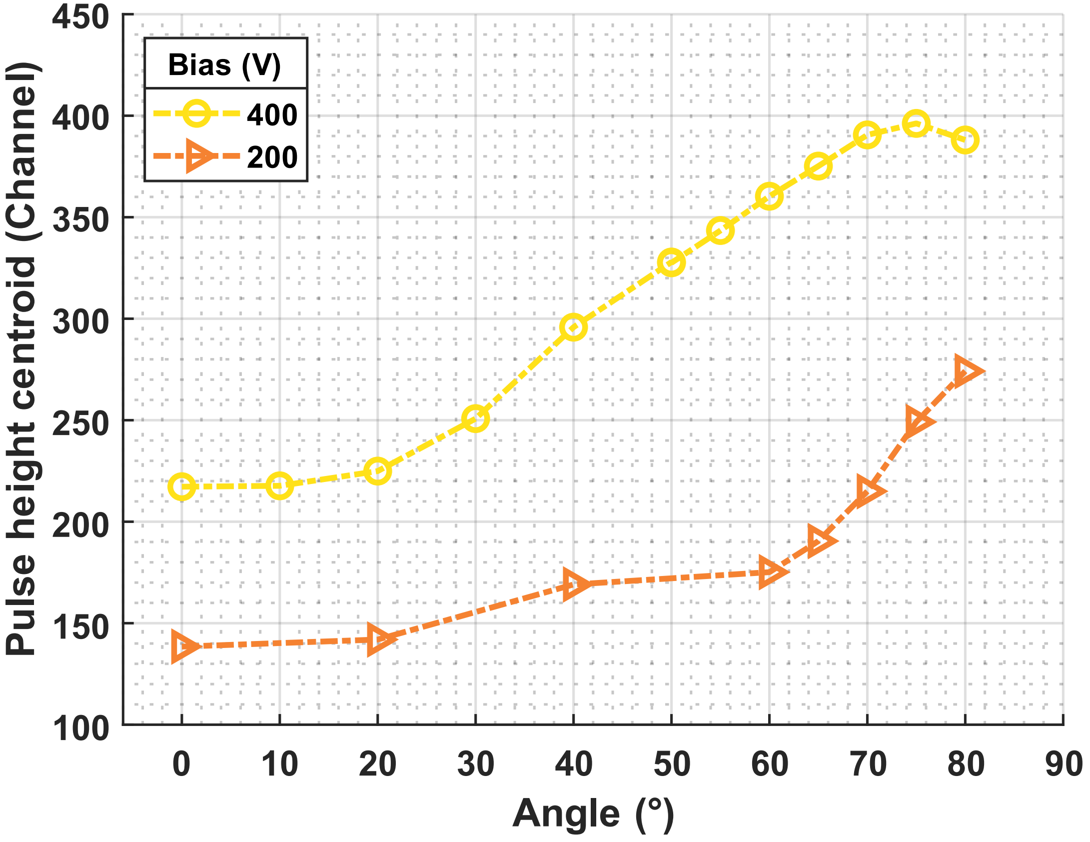
Bias (V)	(W-IBIC±1) (µm)	W-TPA (µm)	W- CV (µm)
350	46	43	39
200	37	36	32
100	27	27	23

Irradiated detectors experimental curves

K6W1 $(4 \times 10^{14}\ n_{eq}/cm^2)$



F2W1 $(1 \times 10^{15}\ n_{eq}/cm^2)$



Calculated depletion zone

Detector	Bias (V)	(W-IBIC± 1) (µm)	W-TPA (µm)	W-CV (µm)
Pristine	350	46	43	39
	200	37	36	32
	100	27	27	23
$4 \times 10^{14} n_{eq}/cm^2$	800	20-25	25	45
	300	15-20	20	46
$1 \times 10^{15}\, n_{eq}/cm^2$	400	20-25	20	44
	200	15-20	17	44

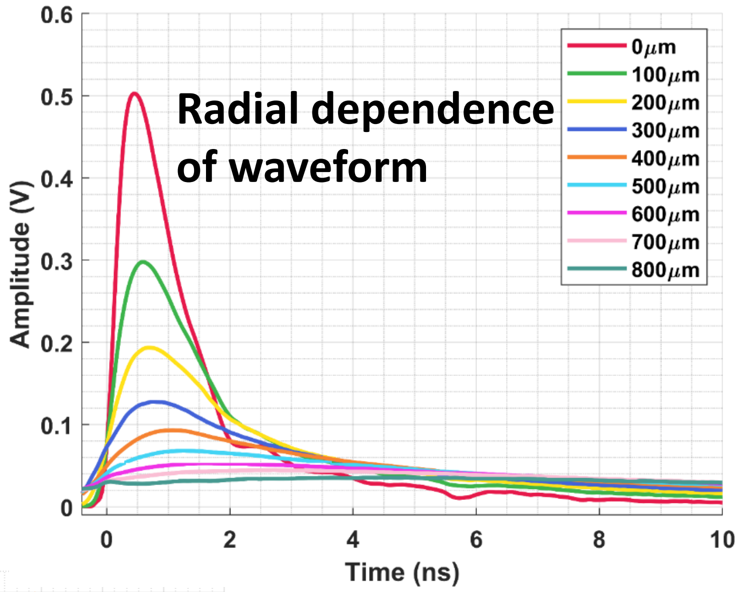
- Results in agreement with TPA-TCT results
- The size of the depletion zone decreases with neutron fluence.
- Variation with voltage in irradiated detectors is small

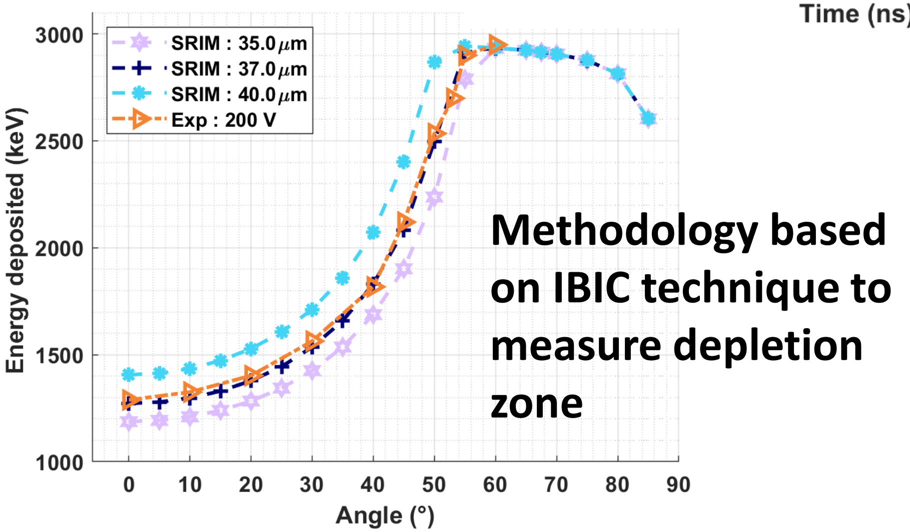
Conclusions

- **Methodology based on IBIC technique to measure depletion zone**

- **Radial dependence of waveform**: Signals varied with radial position, with signals at the edges being faster and those in the center slower.

- The results obtained with the TRIBIC and IBIC techniques are compatible and confirm the results obtained with the TPA-TCT technique.





Thanks for your attention!

M.C. Jiménez-Ramos acknowledges the support to this work through a VI PPIT-US contract

Back-up

Why Silicon Carbide radiation detectors ?

Property	4H-SiC	Si
$E_g\ at\ (300\ K)[eV]$	3.23	1.12
$\rho\ [g/cm^3]$	3.22	2.33
$\mu_e\ [cm^2/V \cdot s]$	800	1450
$\mu_h\ [cm^2/V \cdot s]$	115	450
$Thermal\ conductivity\ [W/m \cdot K]$	490	130
$E_{breakdown}\ [MV/cm]$	$3-4$	2.2
$Atomic\ displacement\ threshold\ [eV]$	$22-35$	$13-20$
$e^- - h^+\ energy\ [eV]$	7.28	3.6
$v_{sat}\ [10^7 cm/s]$	2	0.8

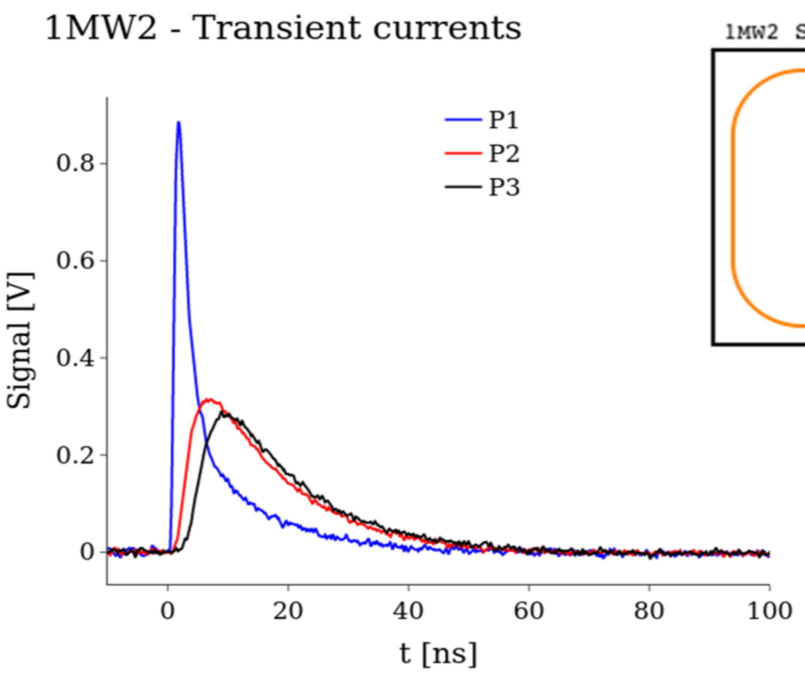
Wide bandgap :

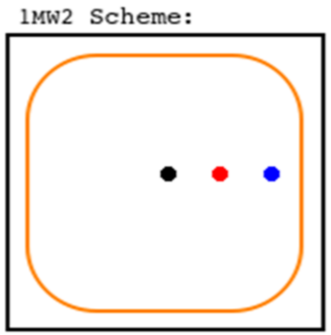
- Reduces the leakage current and noise level
- Visible blind

Higher Breakdown and higher displacement threshold :

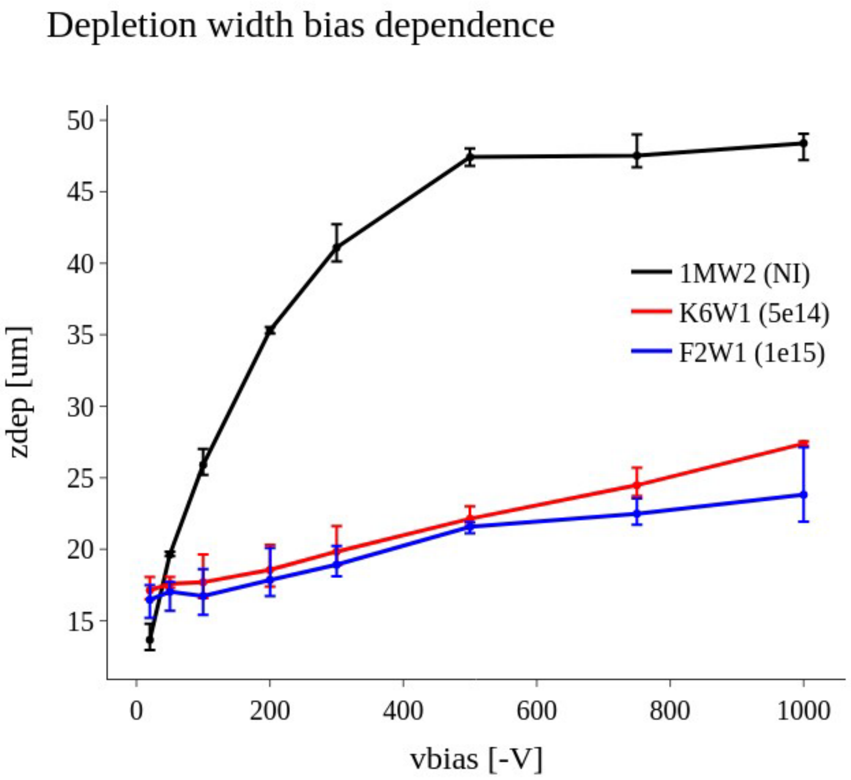
- Advantage for Radiations hardness

TPA-TCT results





Samples (**non metallized contact**):
→ 1MW2 (Non-irradiated)
→ F2W1 ($1 \times 10^{15}\ n_{eq}/cm^2$)
→ K6W1 ($4 \times 10^{14}\ n_{eq}/cm^2$)

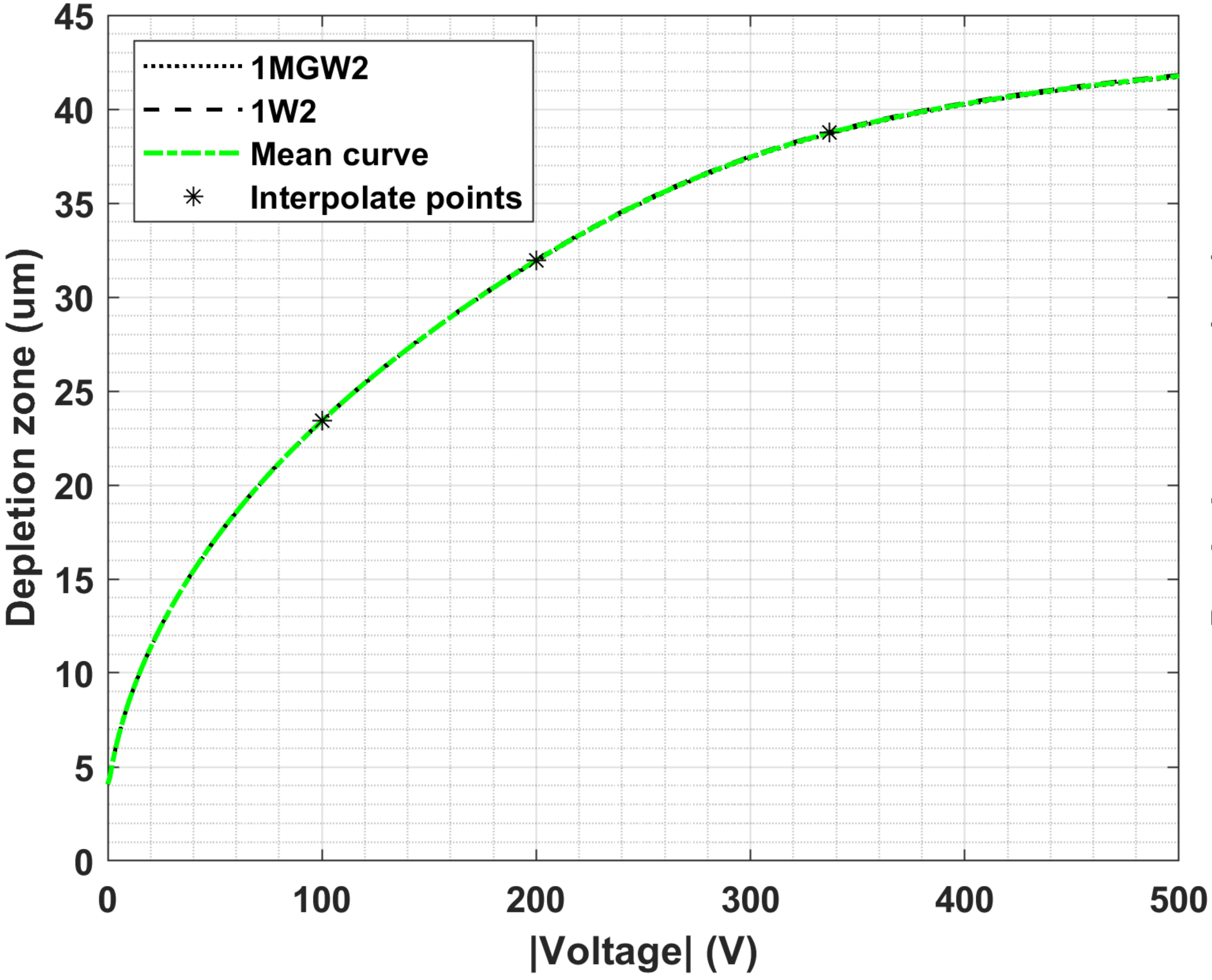


“ Caracterization of neutron irradiated IMB-CNM SiC planar diodes with TPA-TCT”:

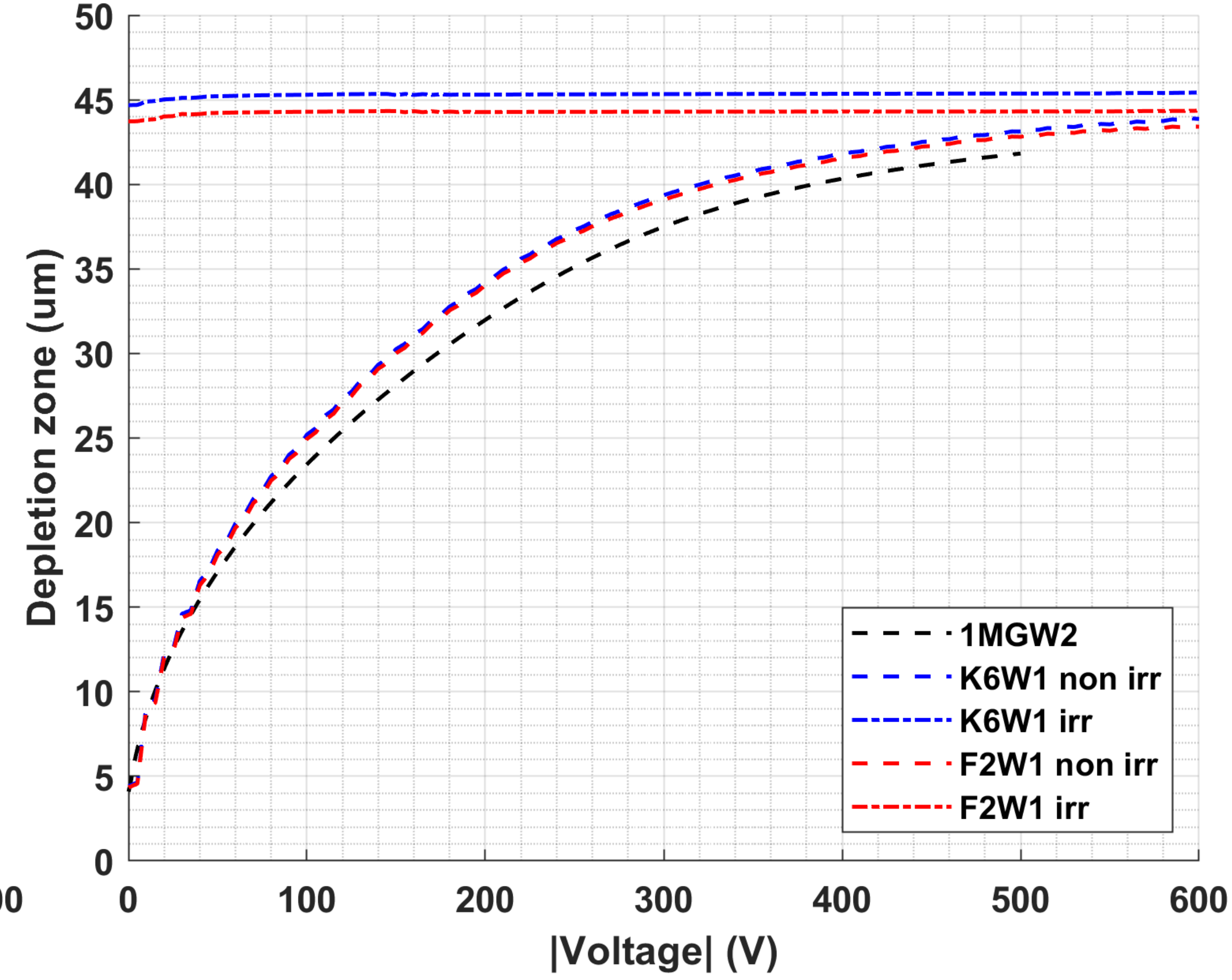
- Positional dependence of the signal profile
- The width of the sensitive region depends on the fluence

Electric measurements

Pristine detector

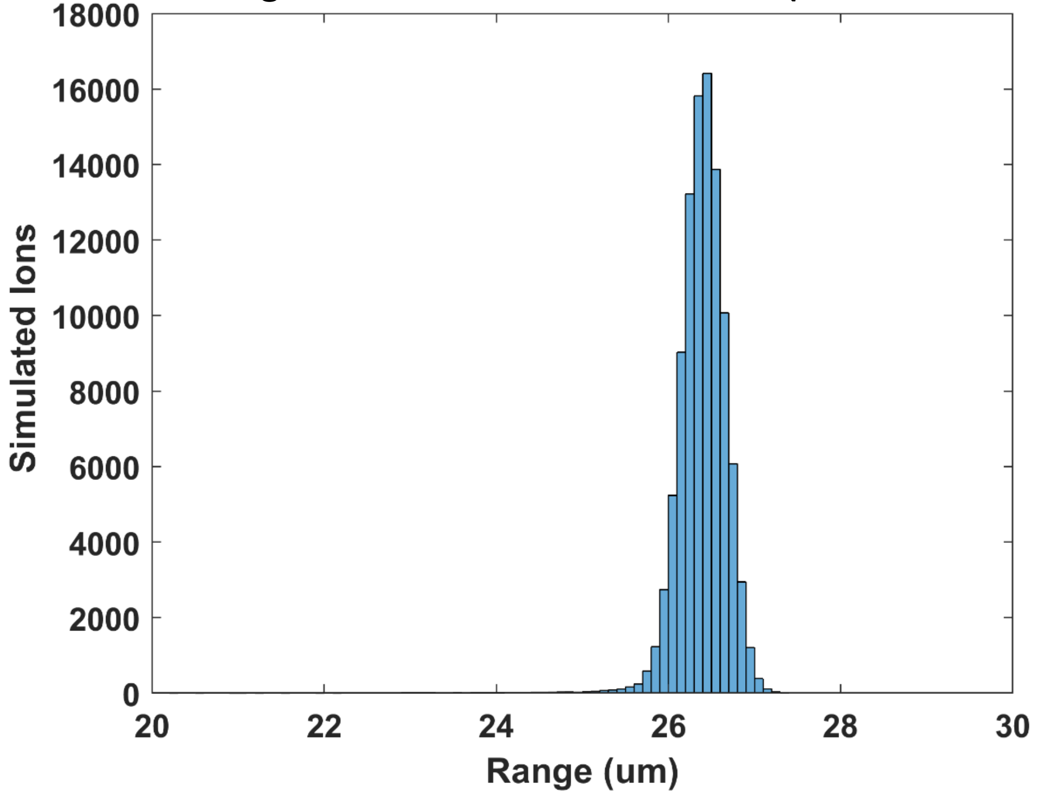


Irradiated detectors

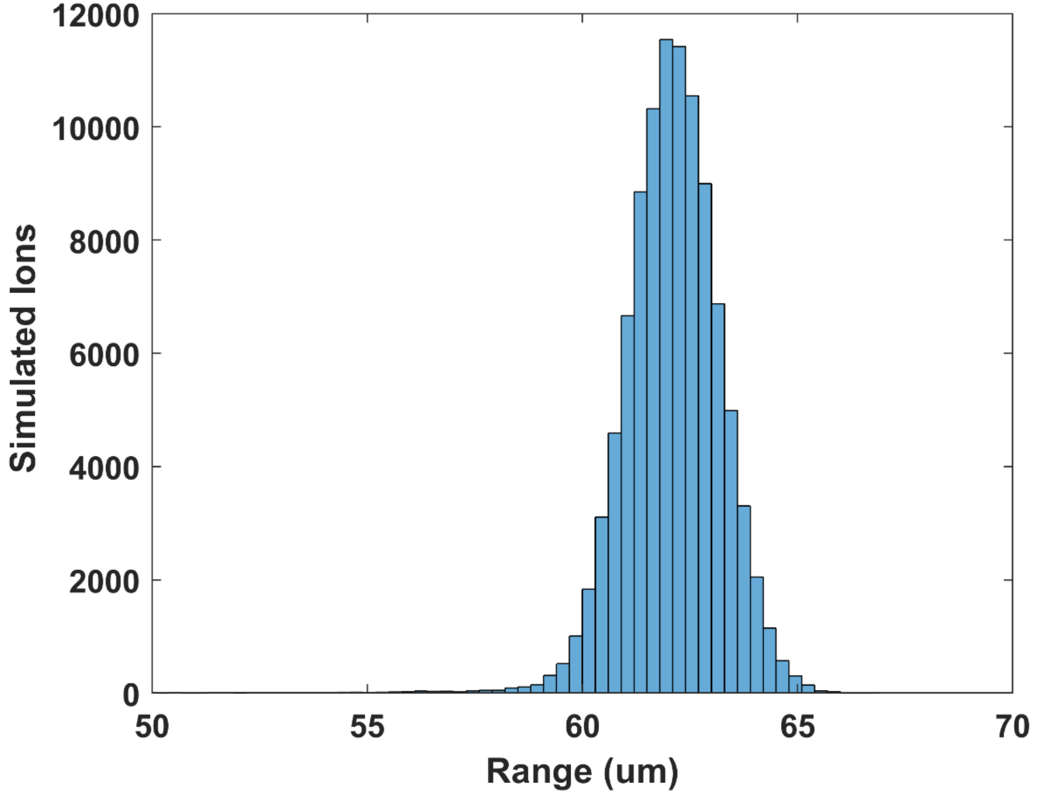


SRIM Simulation (Range on SiC)

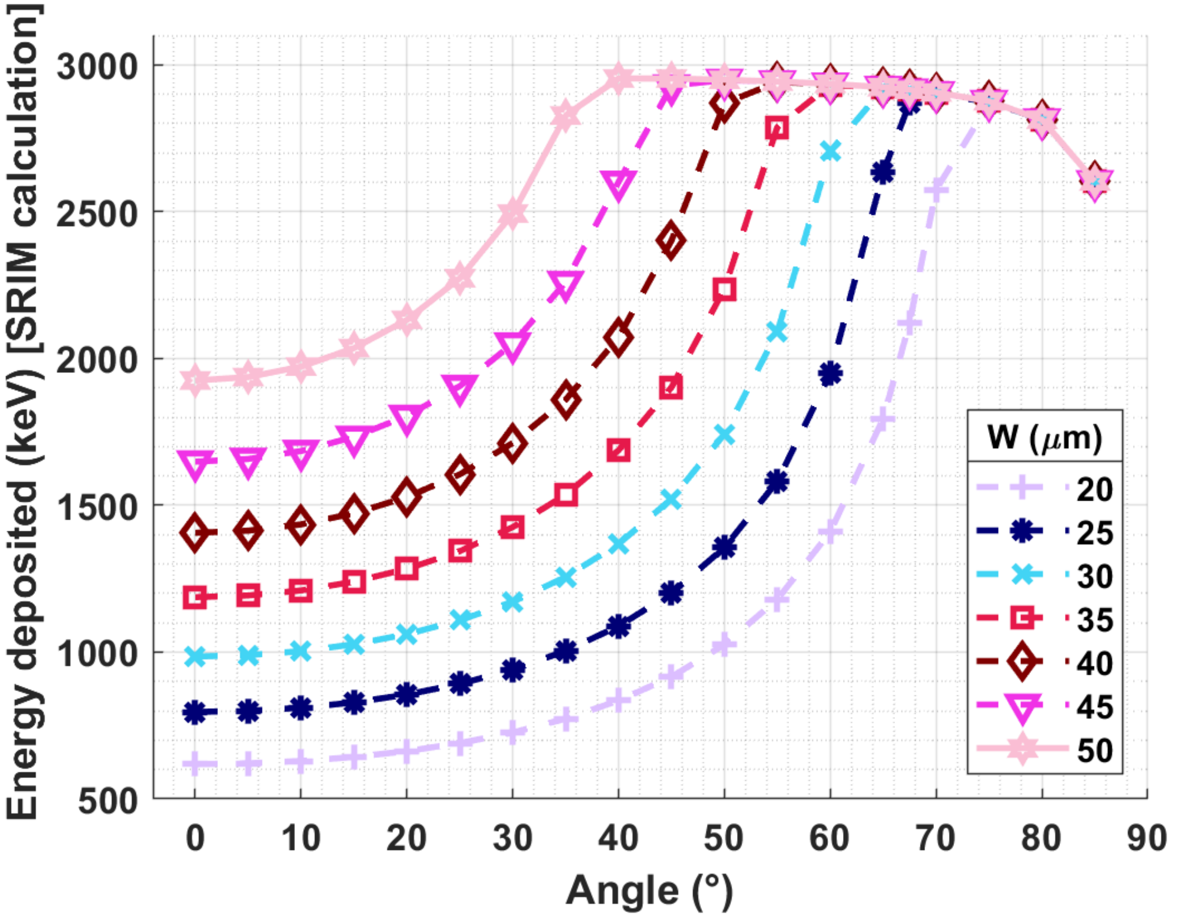
Range He^{++} 7 MeV → 26.43 μm



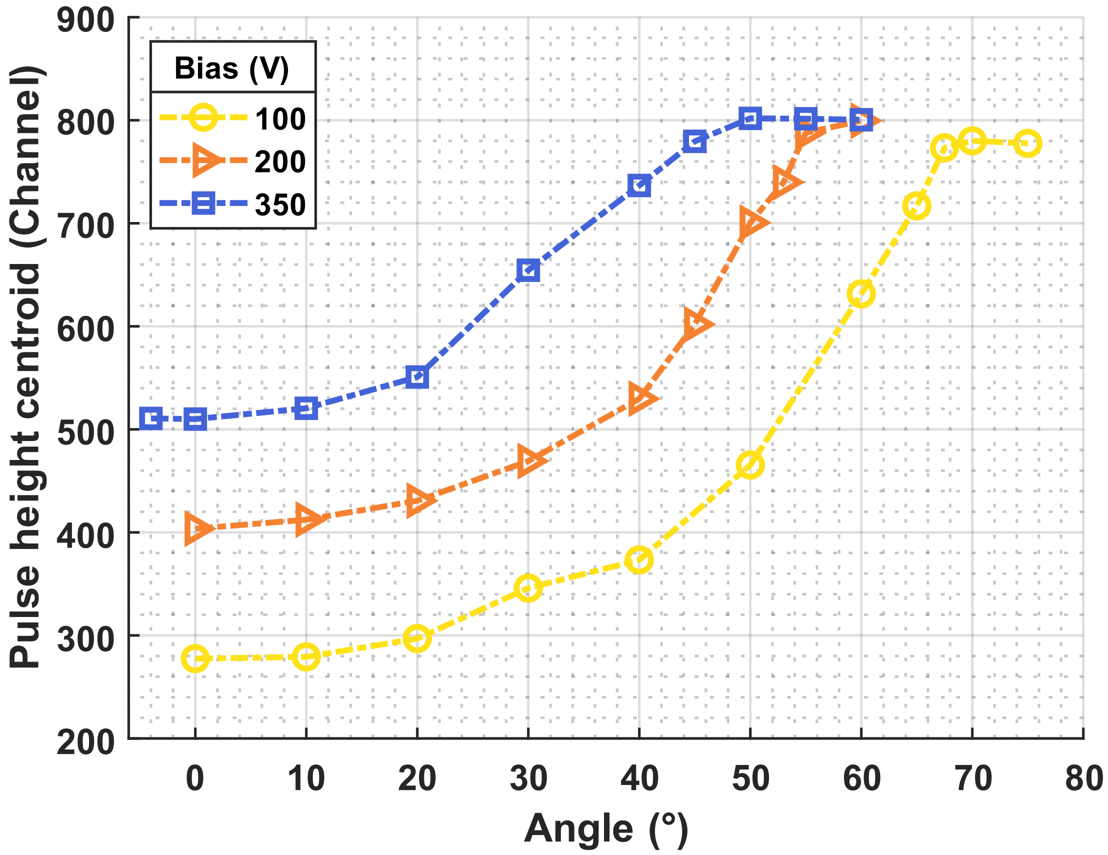
Range H^{+} 3 MeV → 62.16 μm



Simulations and experimental results

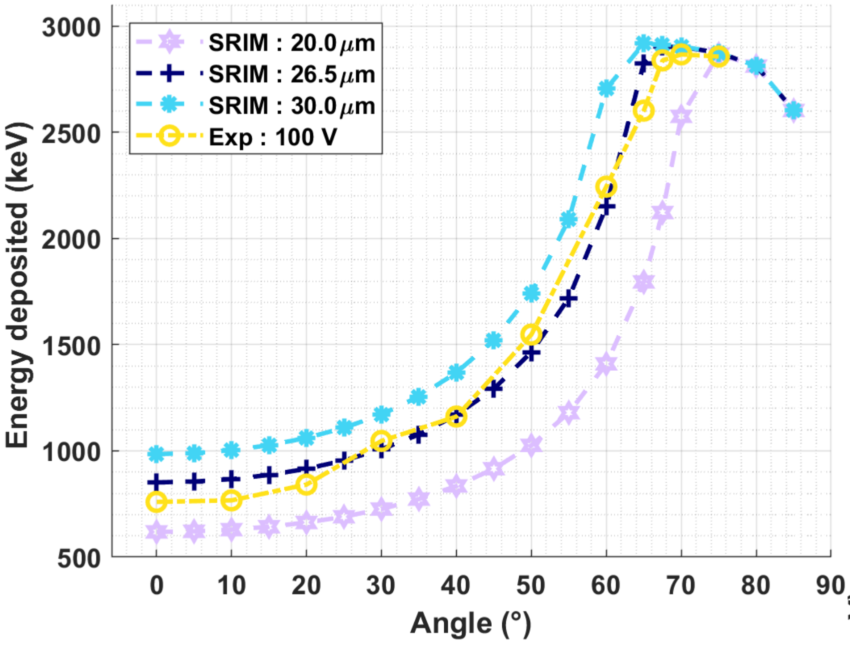


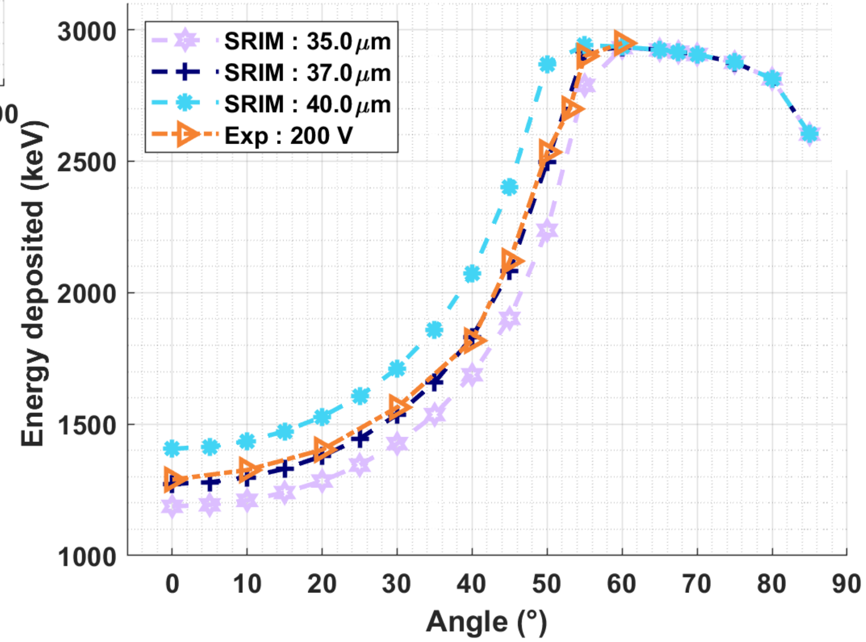
Simulated curves obtained with SRIM

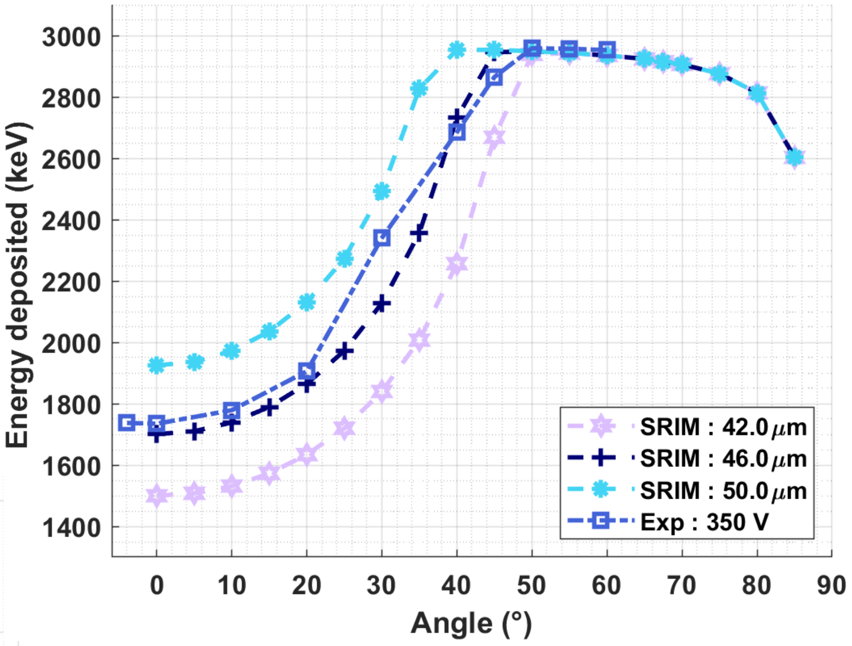


Experimental results (Pristine detector)

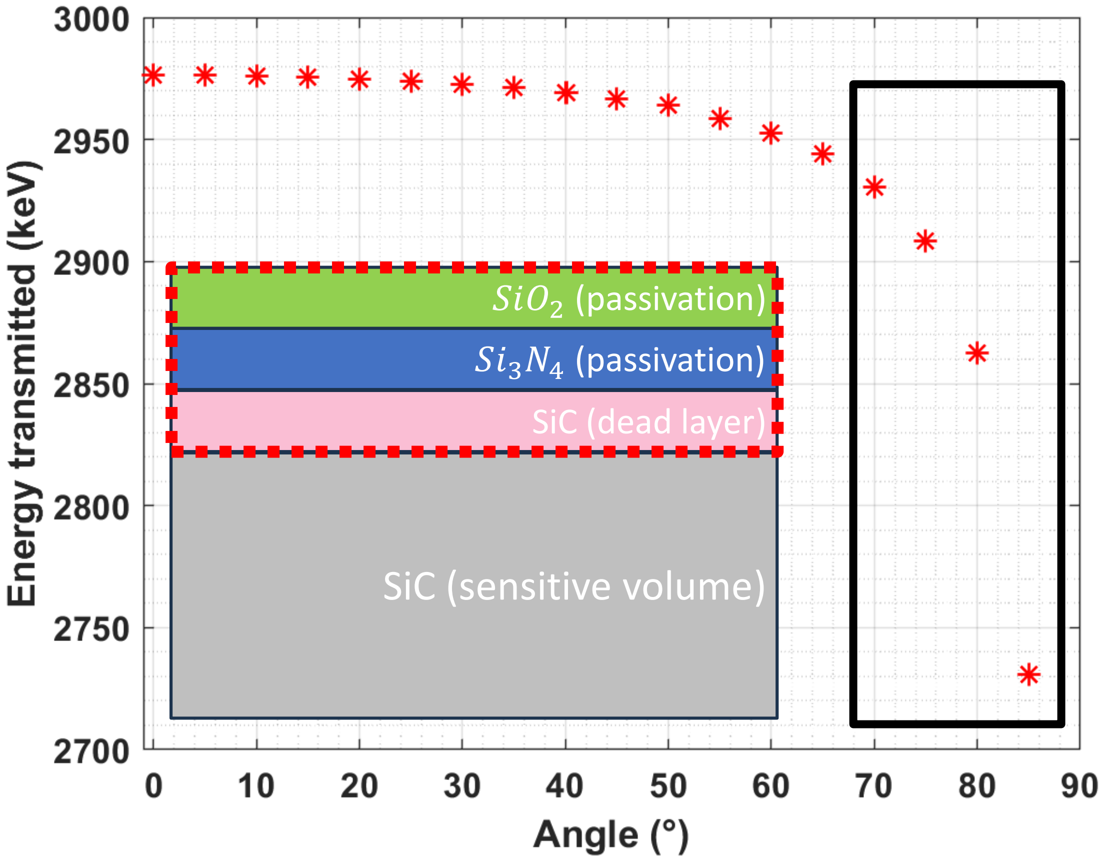
Calibrated experimental curves

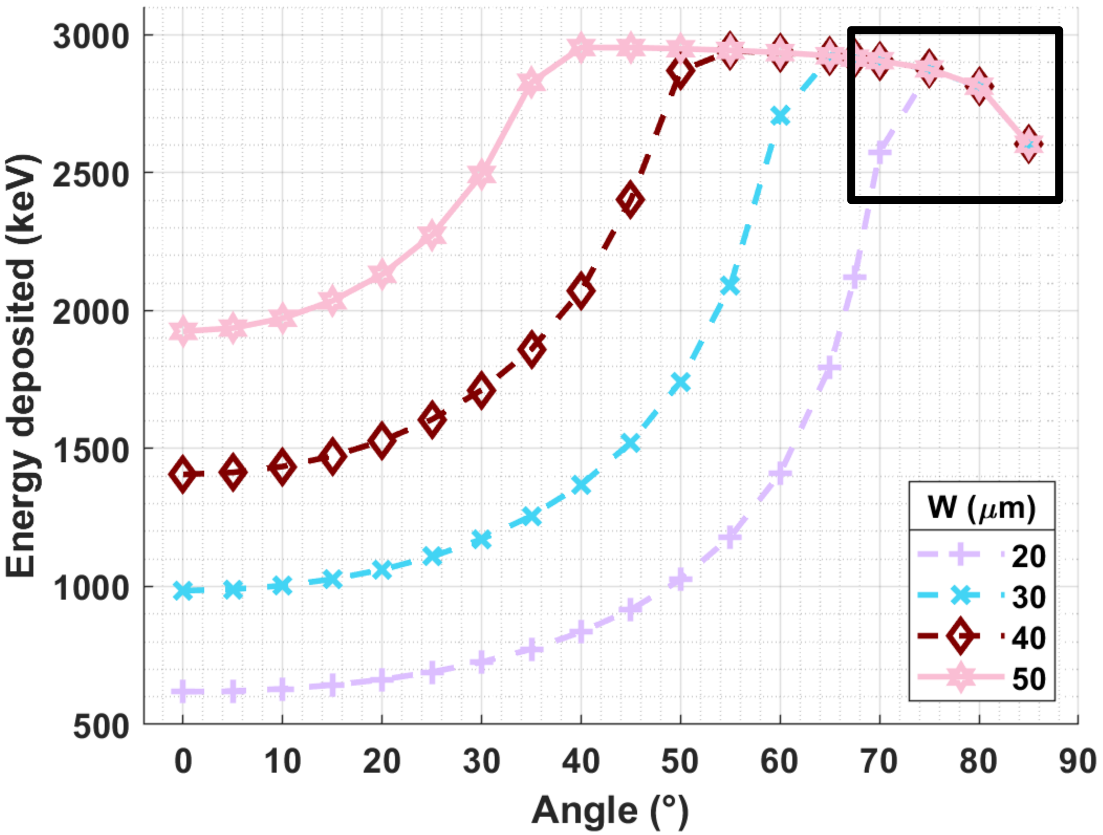






SRIM simulations (3 MeV H^+)





Calculation of the absolute CCE value for the pristine detector

Theoretical calculation :

- Deposited energy in detector [SRIM simulation] : $E = (6861 \pm 22)\ keV$
- Electron-hole pair creation energy (4H-SiC) : $\epsilon_{e^- - h^+} = 7.28\ eV$
- Elementary charge : e = 1.60 x 10^{-19}C

$$Q = \frac{E \cdot e}{\epsilon_{e^- - h^+}} = (1.510 \pm 0.005) \times 10^{-4}\ \mathrm{nC}$$

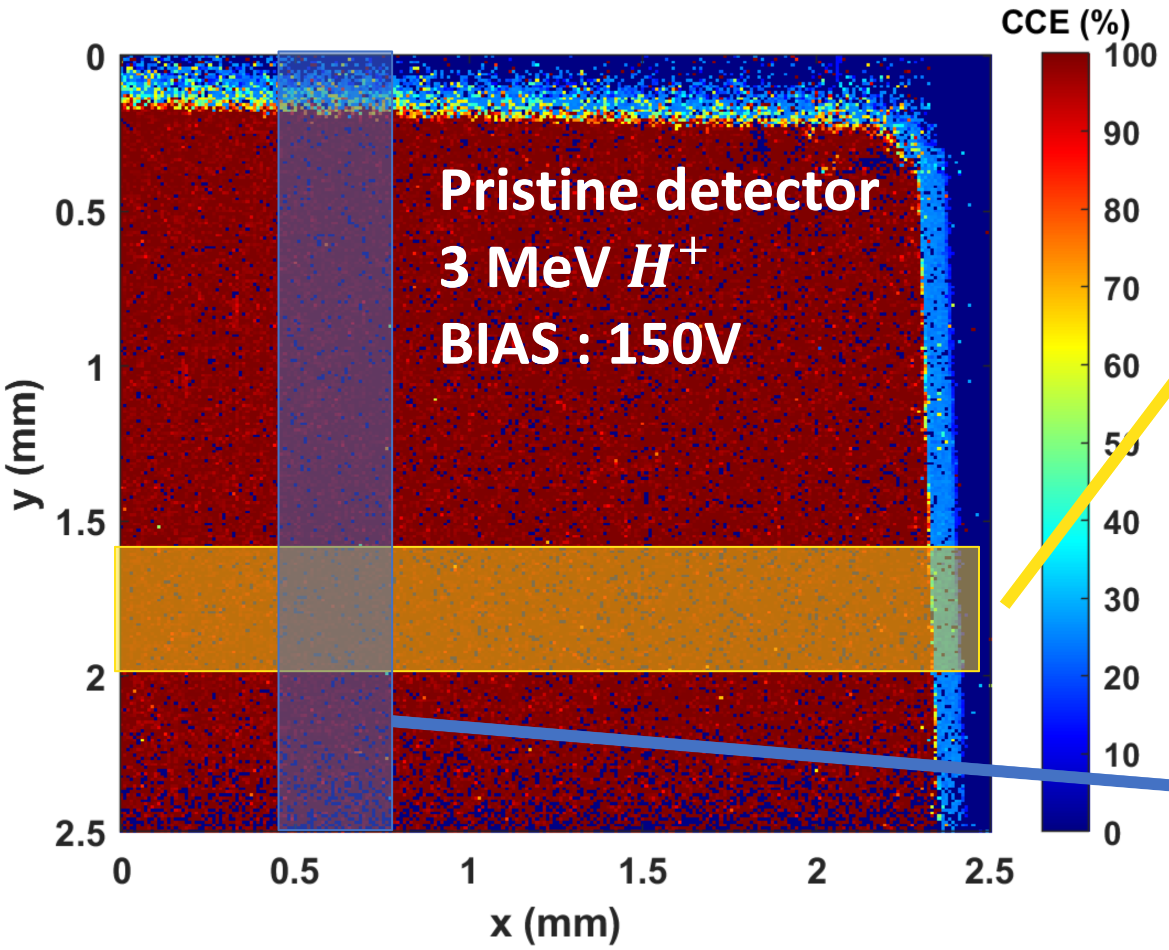
Experimental results :

- Integral = $(0.99 \pm 0.04) nWb$
- Amplifier gain : (130 ± 10)
- Oscilloscope resistance : R = 50 Ω

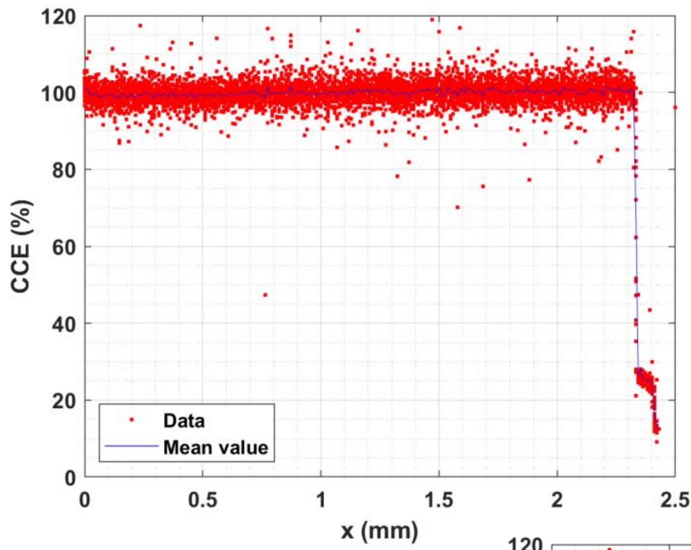
$$Q = \frac{I}{R \cdot G} = (1.52 \pm 0.18) \times 10^{-4}\ \mathrm{nC}$$

$$\mathbf{CCE = (101 \pm 12)\%}$$

CCE homogeneity



IBIC Map. Scan size: $2.5 \times 2.5\ mm^2$



Average value of the x and y profiles constant in detector volume

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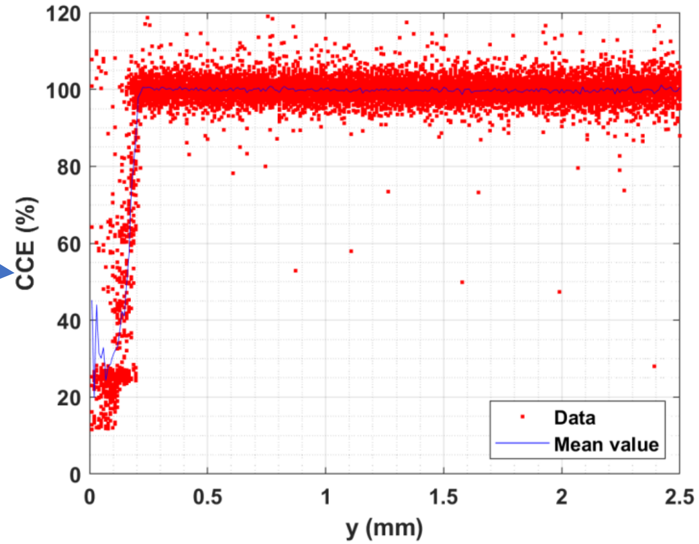
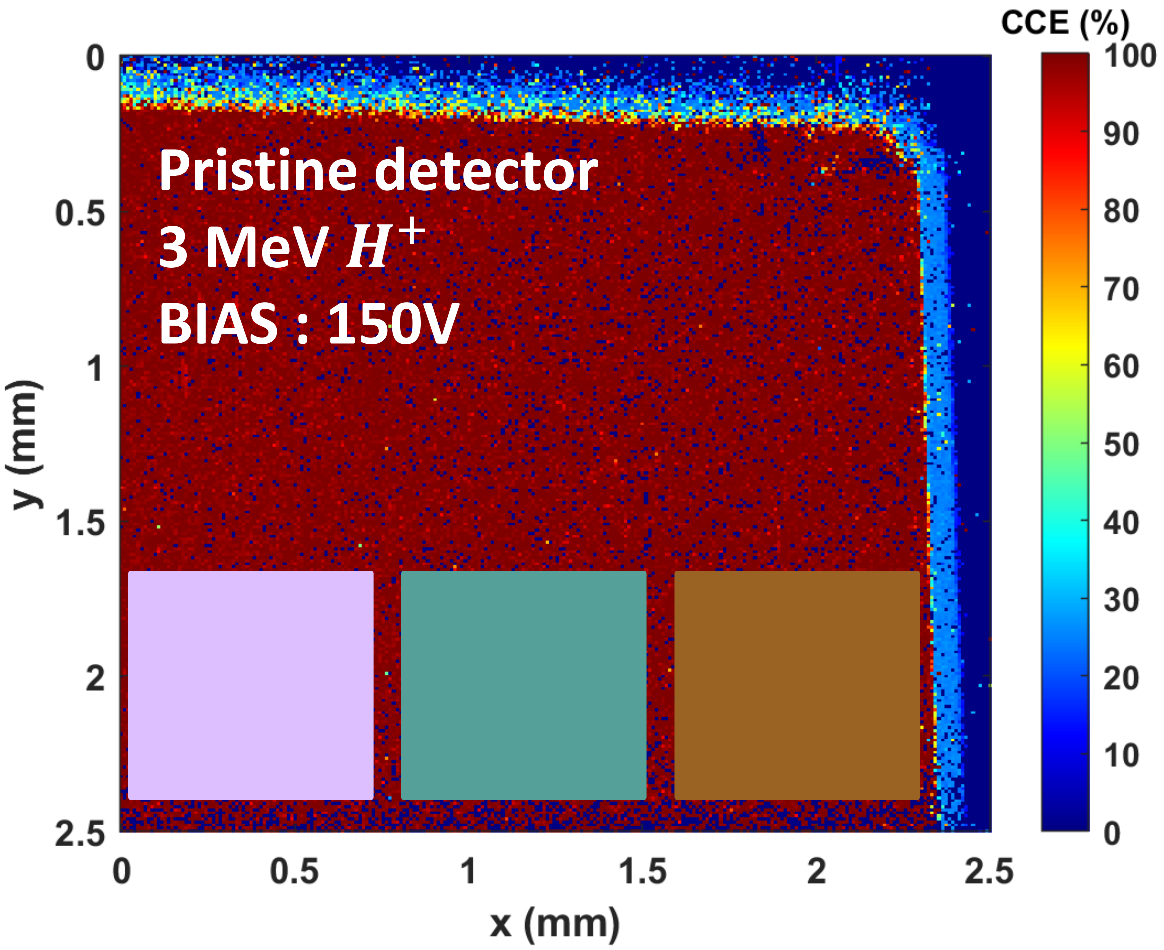
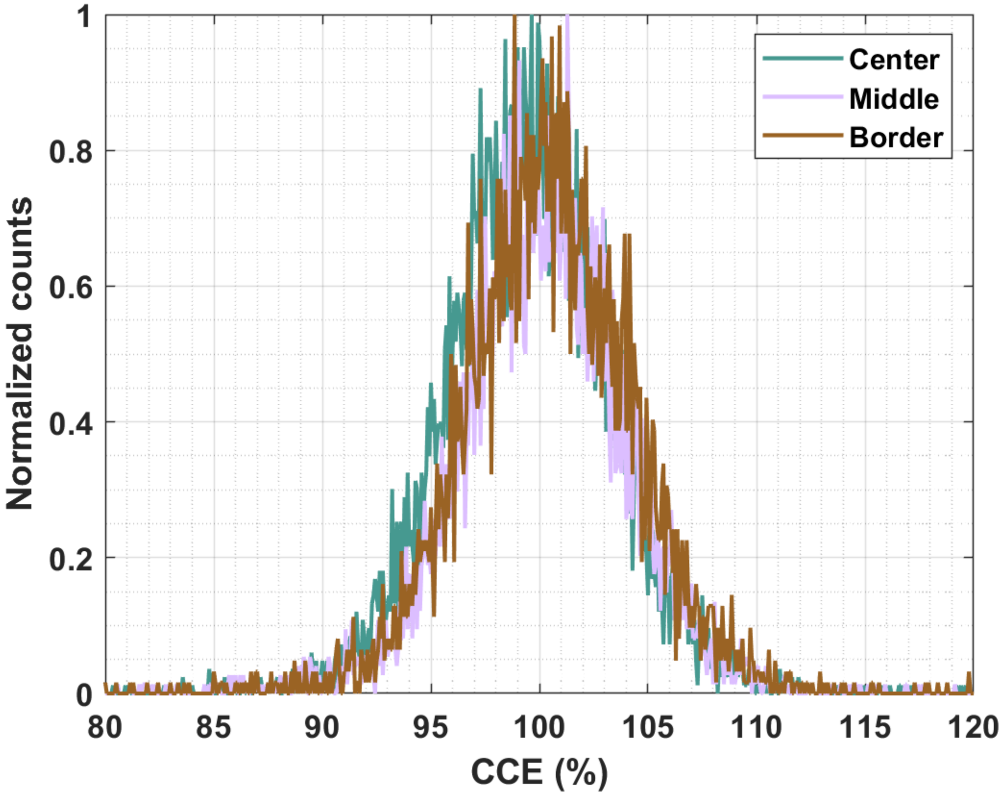
Homogeneous CCE in detector volume



CCE homogeneity

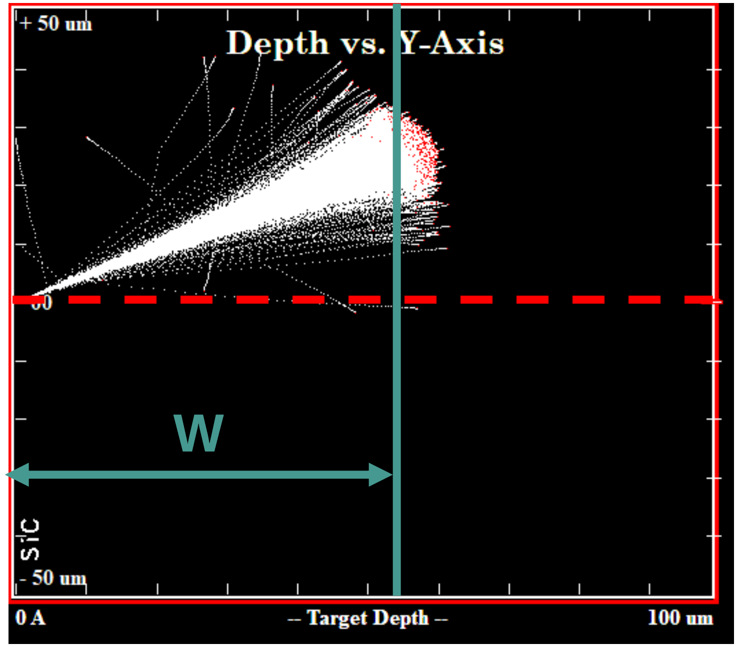


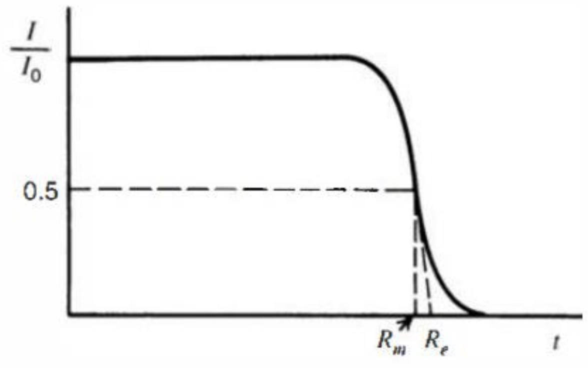
IBIC Map. Scan size: $2.5 \times 2.5\ mm^2$



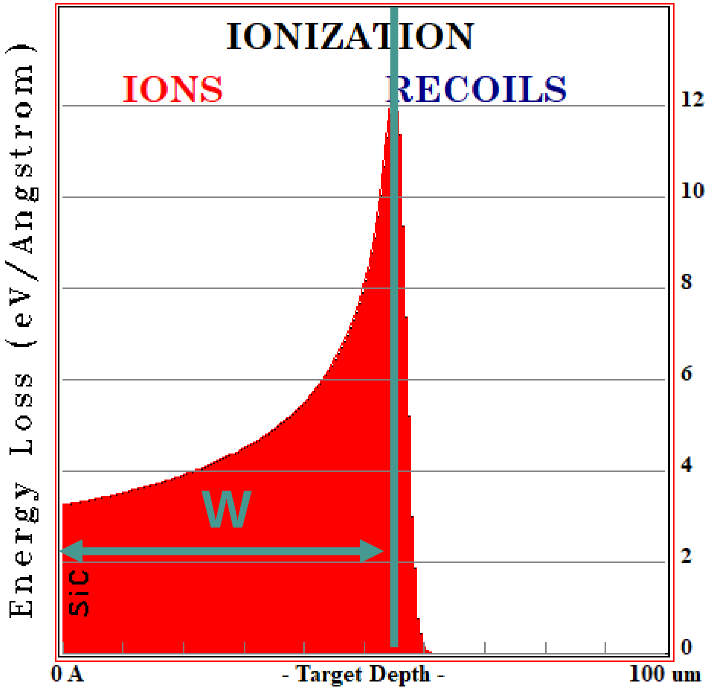
Identical position-dependent local spectra → CCE is not radial position dependent

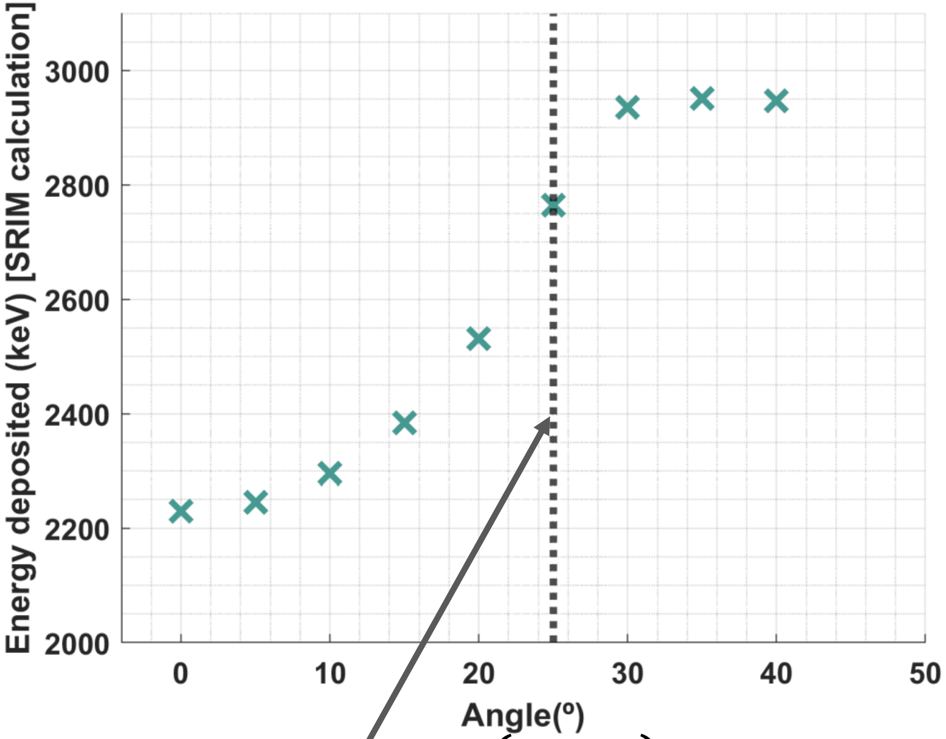
Critical angle





$$E_{dep}(W,\theta) = \int_0^W \frac{dE}{dx}(\theta)dx$$

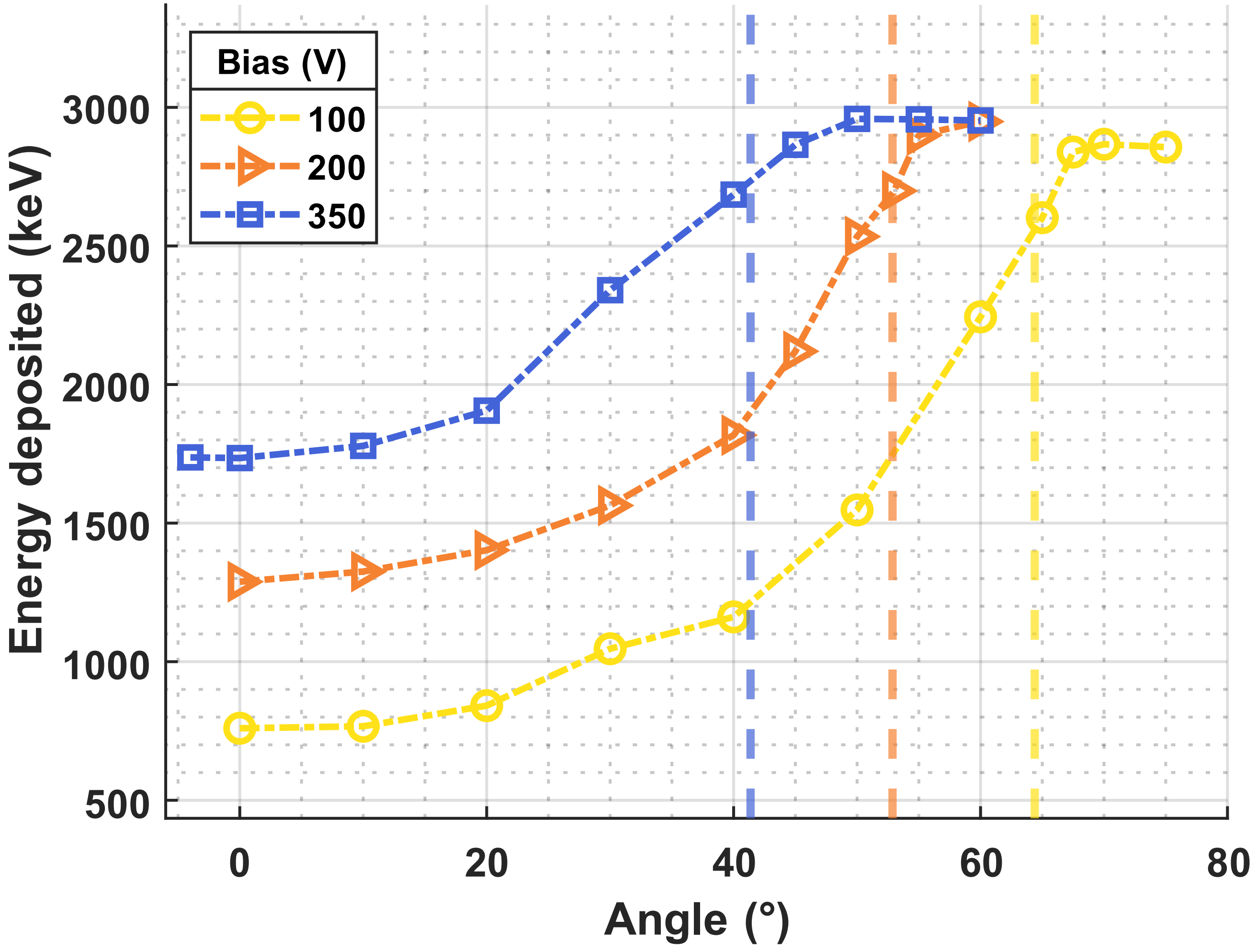




$$W[\mu m] = Range\left(E(\theta)\right) \times \cos(\theta)$$

$\theta \rightarrow$ critical angle

Critical angle

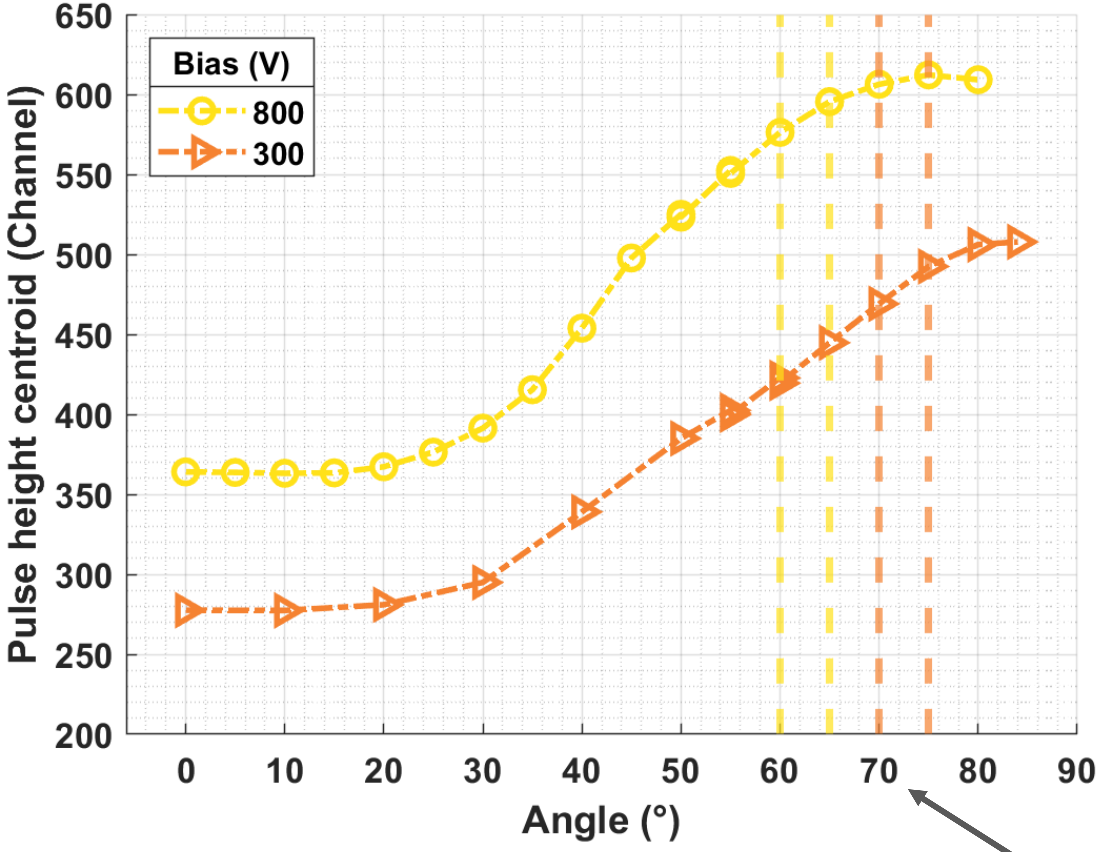


$$W[\mu m] = \text{Range}\big(E(\theta)\big) \times \cos(\theta)$$

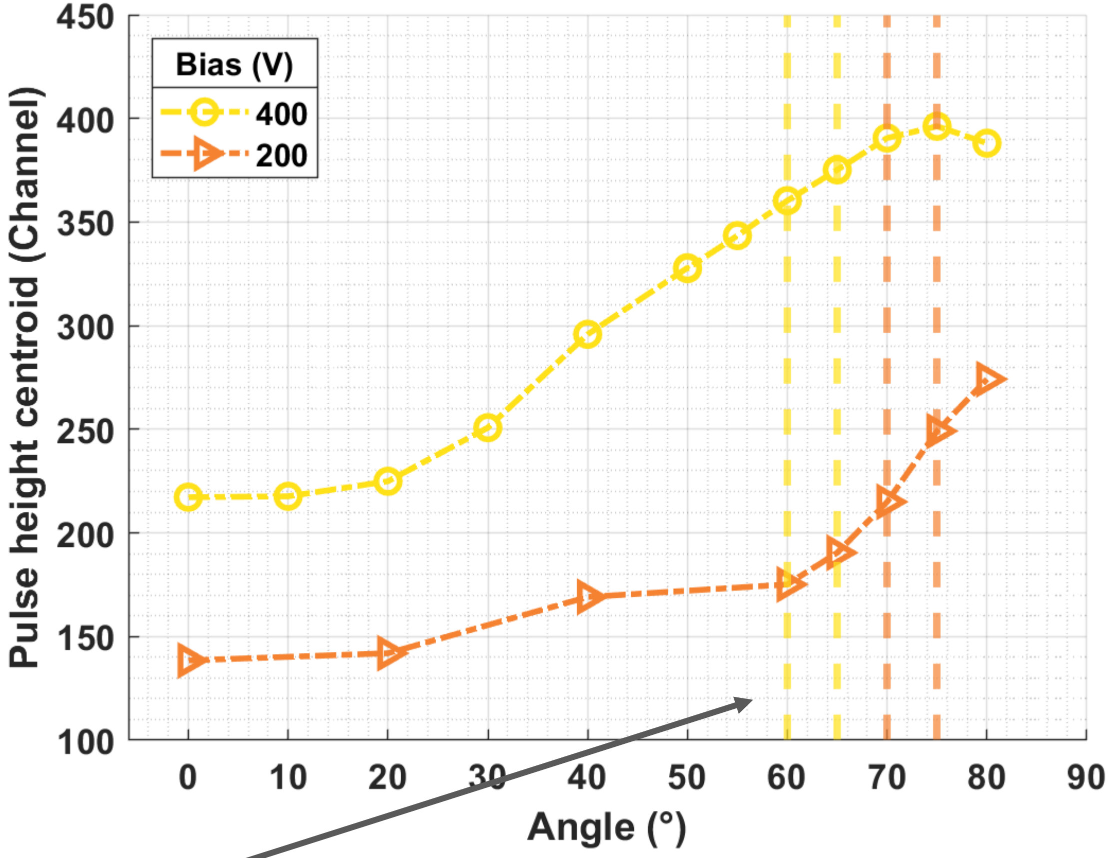
$$\theta \rightarrow \text{critical angle}$$

Experimental results : Irradiated detectors

K6W1 $(4 \times 10^{14}\ n_{eq}/cm^2)$



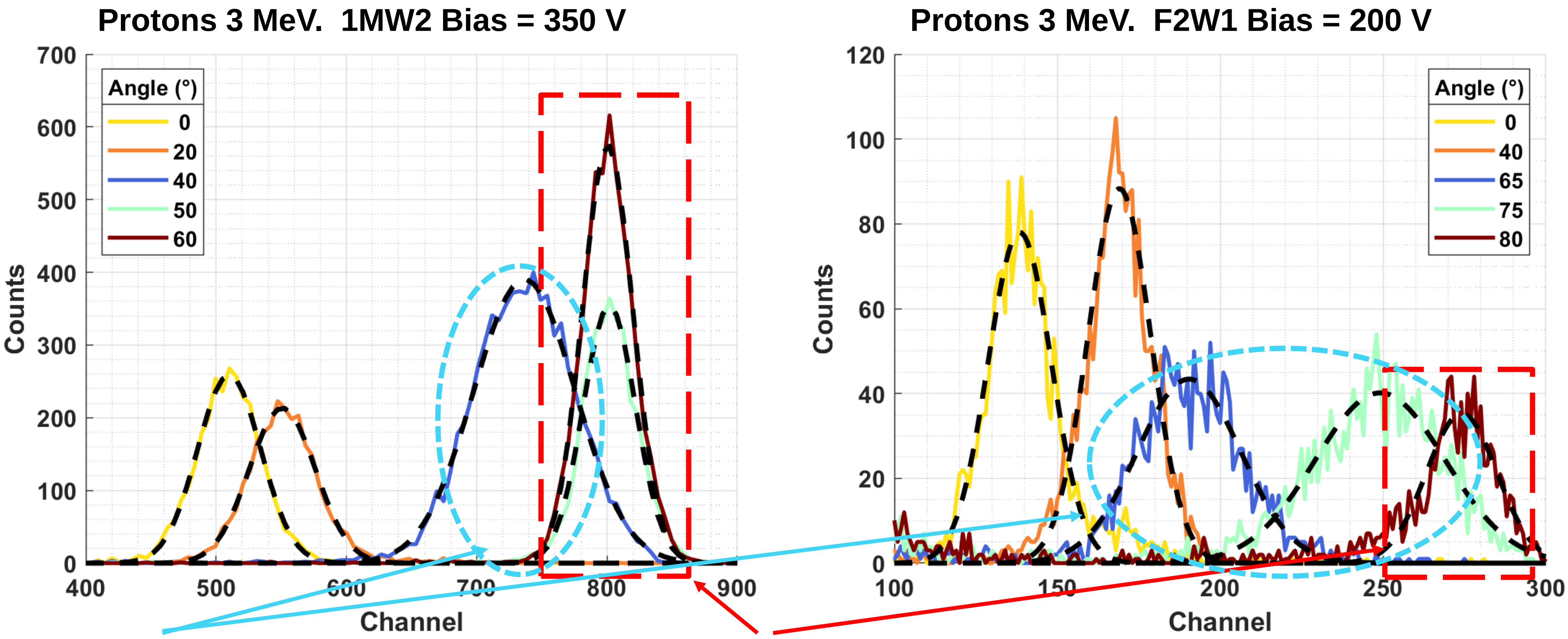
F2W1 $(1 \times 10^{15}\ n_{eq}/cm^2)$



critical angles

$$W[\mu m] = \text{Range} \times \cos(\theta)$$

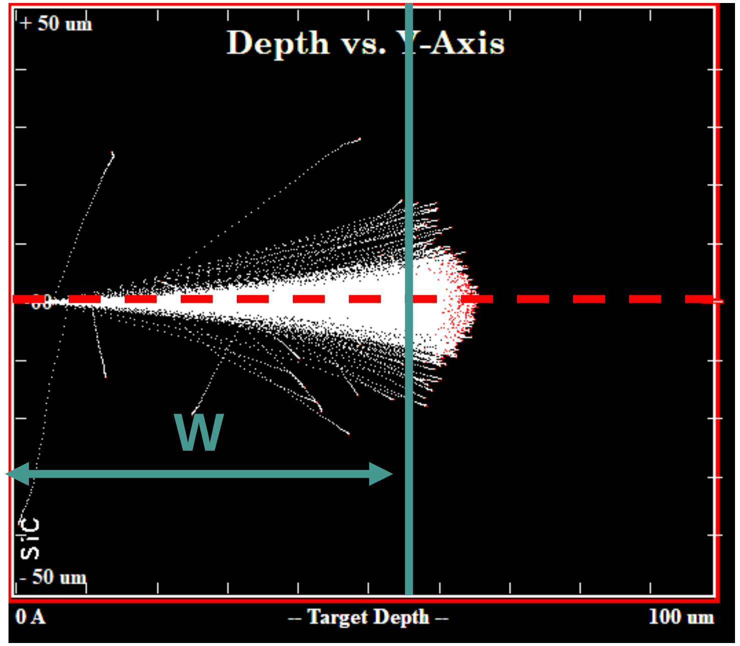
Experimental results : Irradiated detector F2W1. Bias: 200 V

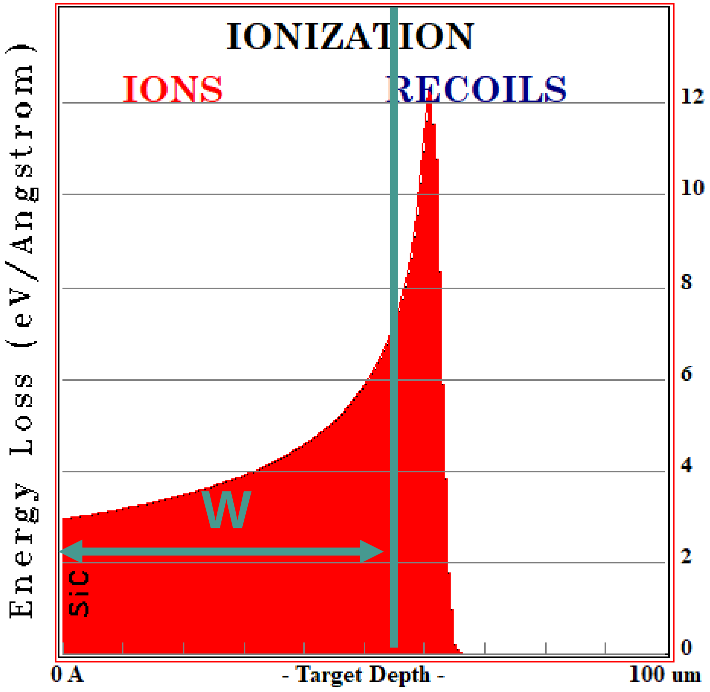


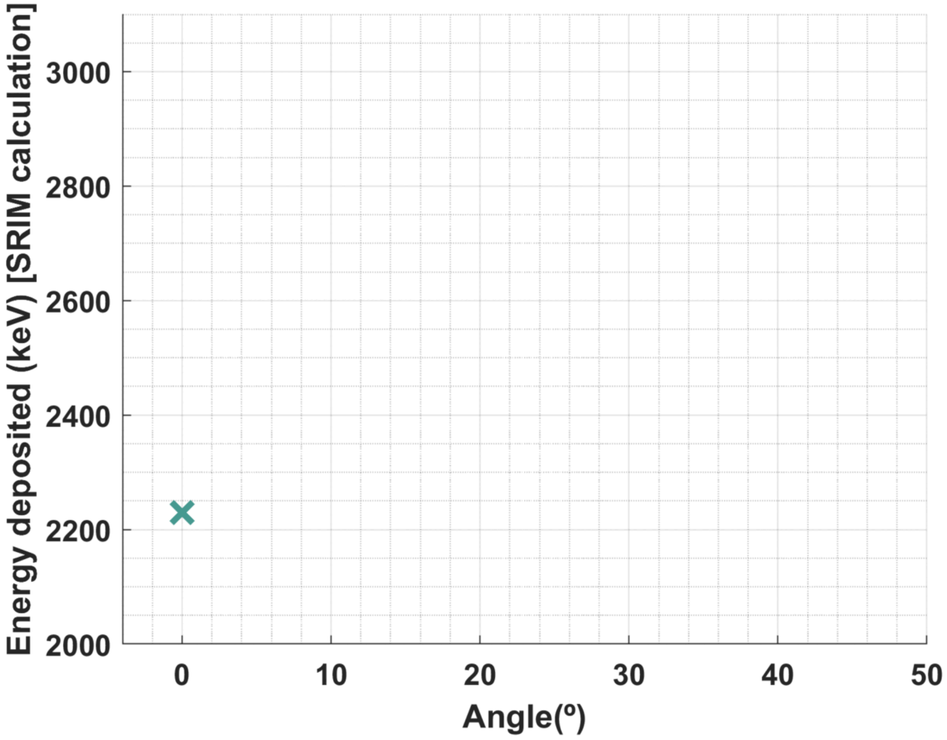
Critical angle → Angle before saturation angles

Saturation → Beam is completely within the sensitive volume

Methodology to calculate depletion zone







$$E_{dep}(W,\theta) = \int_0^W \frac{dE}{dx}(\theta)dx$$