Characterization by IBIC of neutron irradiated SiC detectors at CNA

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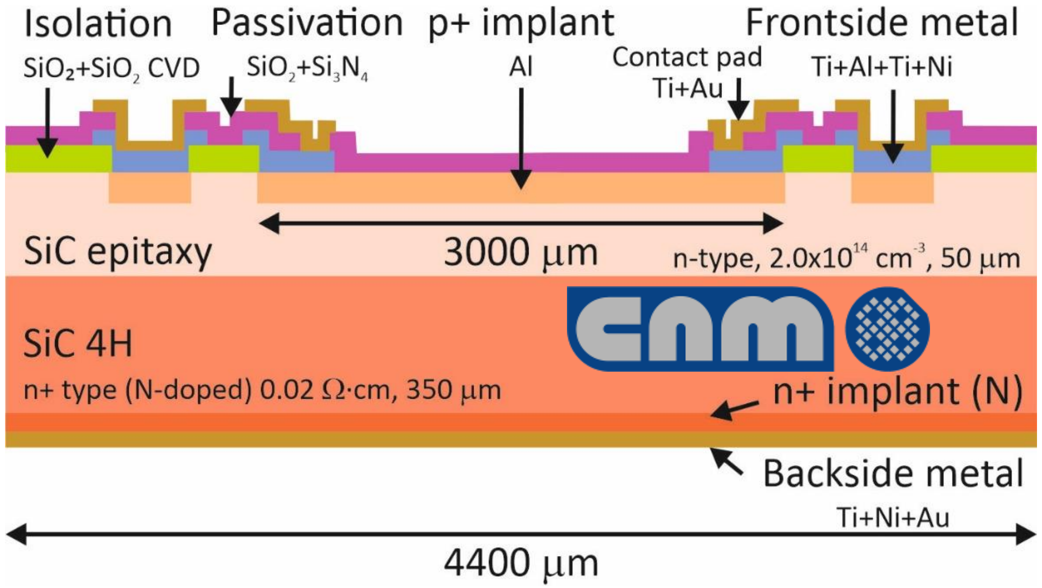
[5] Instituto de Microelectrónica de Barcelona (IMB-CNM-CSIC)

05/12/2024

Context

Design and development of devices



Characterization using laser (TPA-TCT)

More info in Ivan Vila's talk!!

"Observation of signal multiplication in neutron irradiated SiC detectors characterized using TPA-TCT"

Characterization using ions (IBIC)

- C. Quintana et al, "Update on the characterization of neutron irradiated IMB-CNM SiC planar diodes", 41st RD50 Workshop (2022)
- E. Currás et al., "Radiation Tolerance Study of neutron-irradiated SiC pn planar diodes," 18th "Trento" Workshop (2023)

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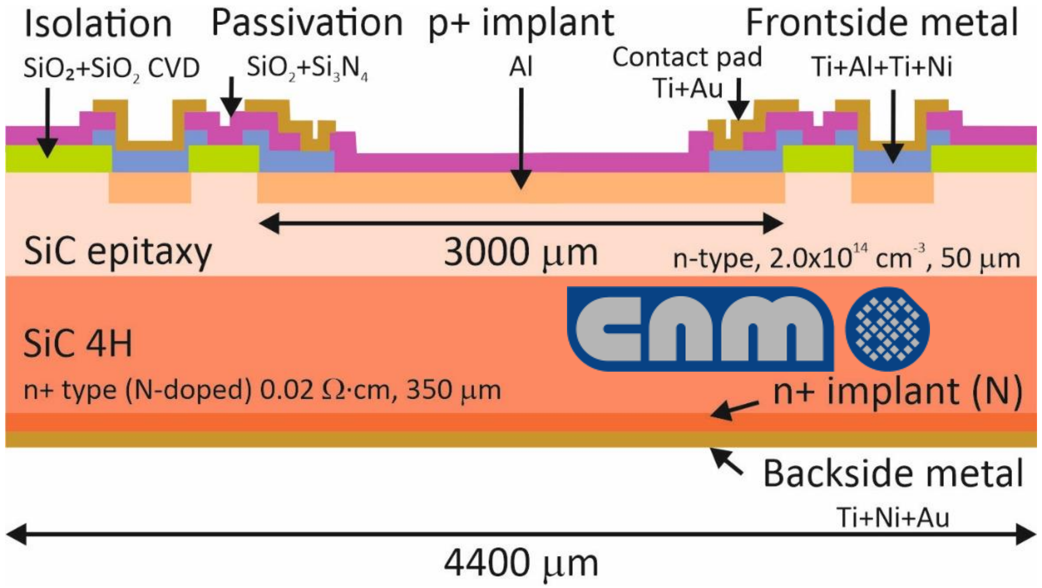

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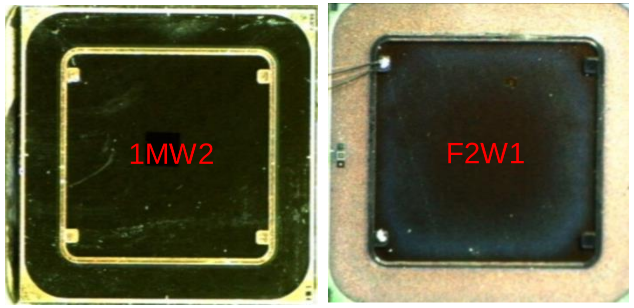
Not metalized SiC detector

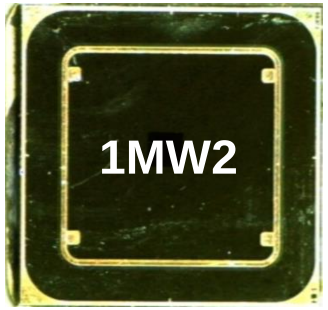
- 1MW2 (pristine)
- F2W1 (1X10^{15} n_{eq}/cm^2)

SiC epitaxy : 50 μm

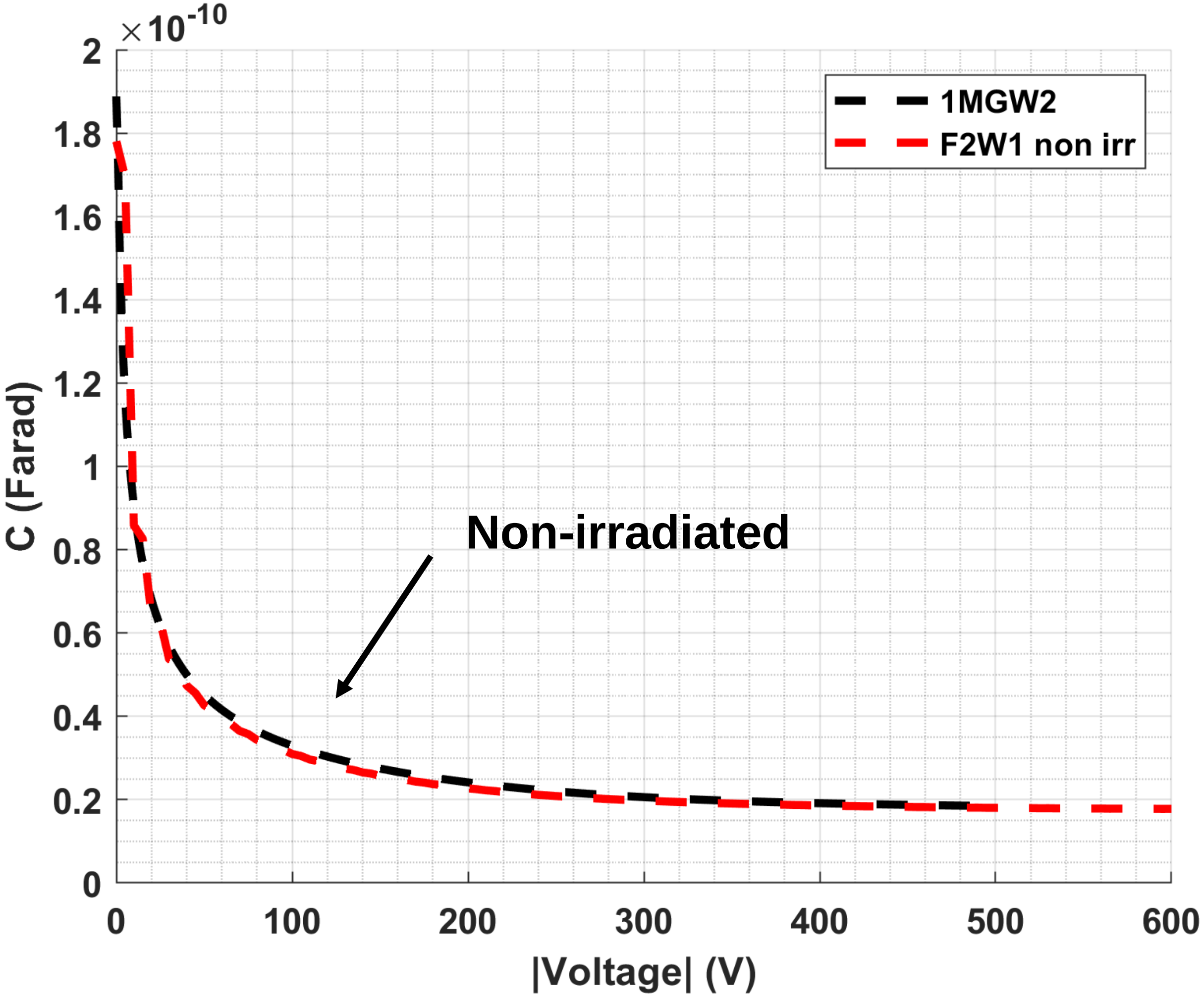
Neutron irradiated detector does not present a diode-like behaviour



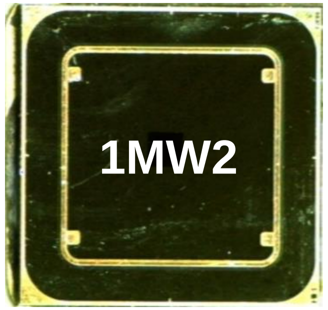
Diode-like behaviour : non-irradiated



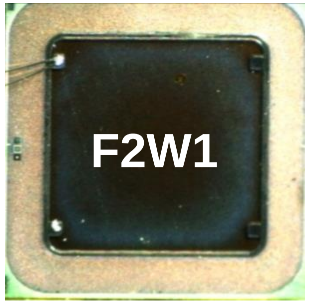
Pristine



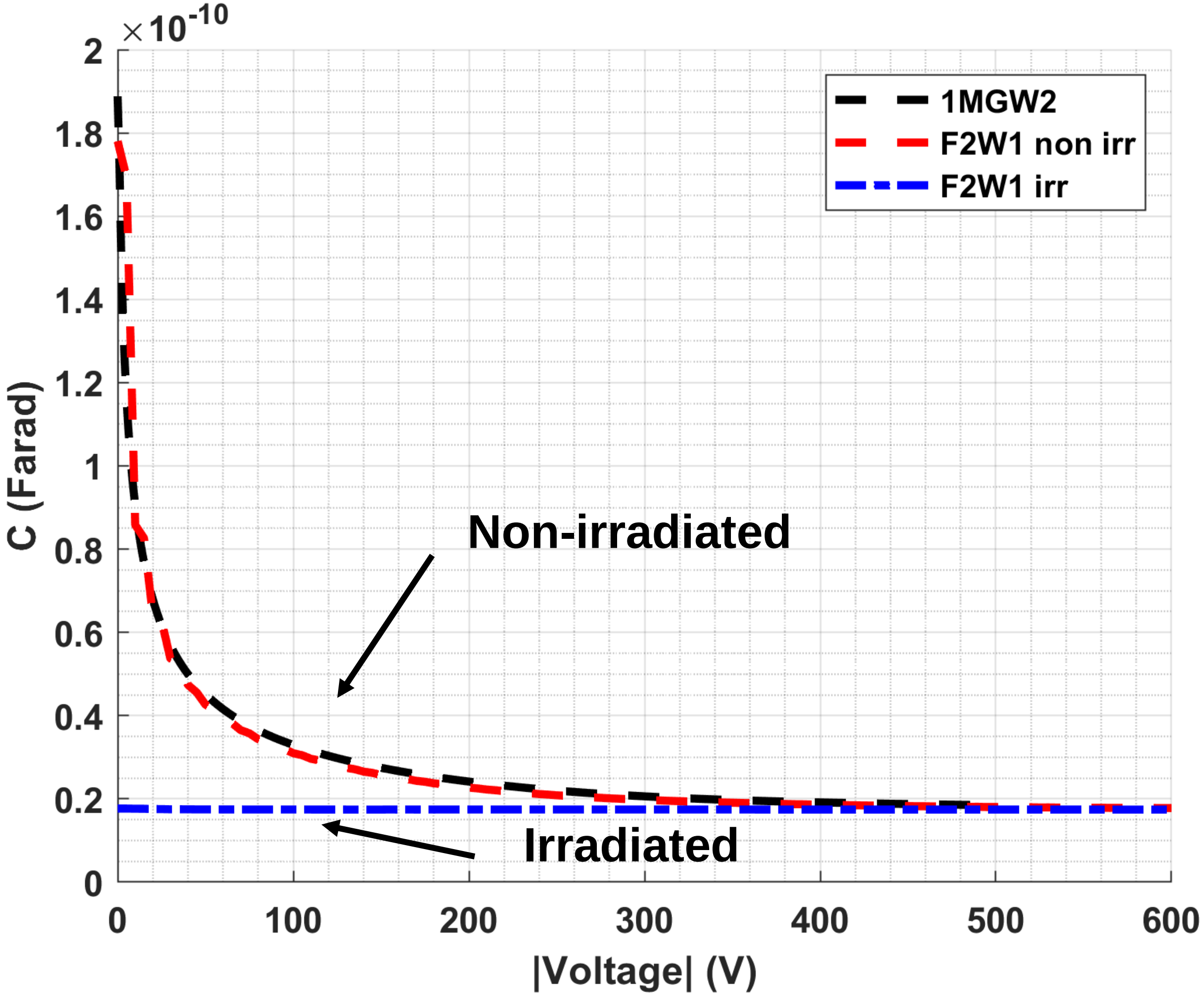
No diode-like behaviour : irradiated



Pristine



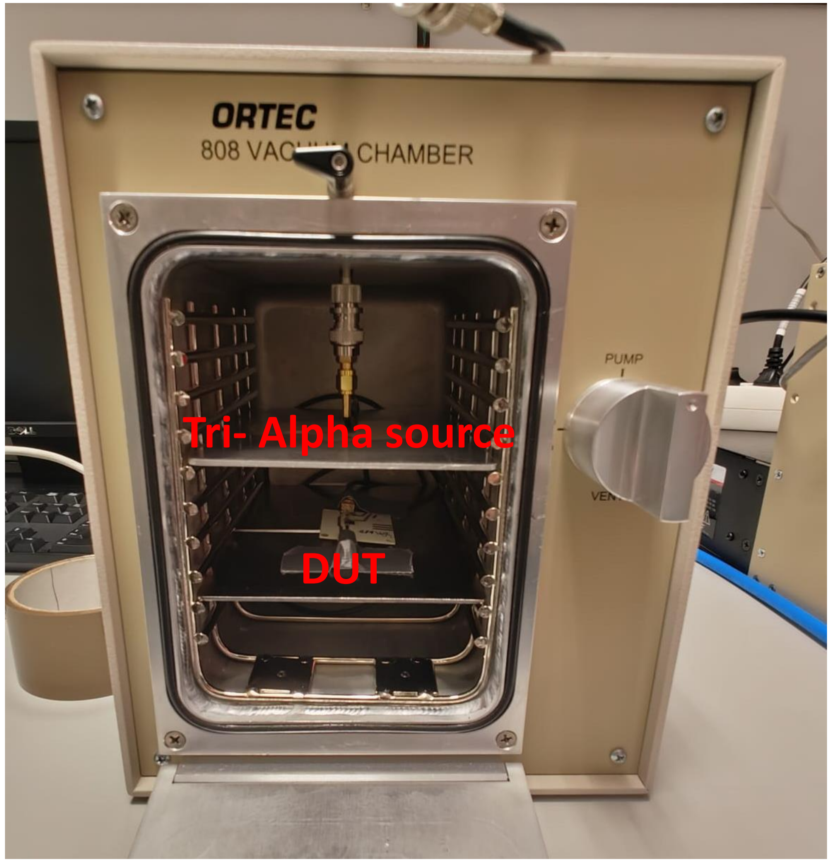
$1 \times 10^{15}\, n_{eq}/cm^2$



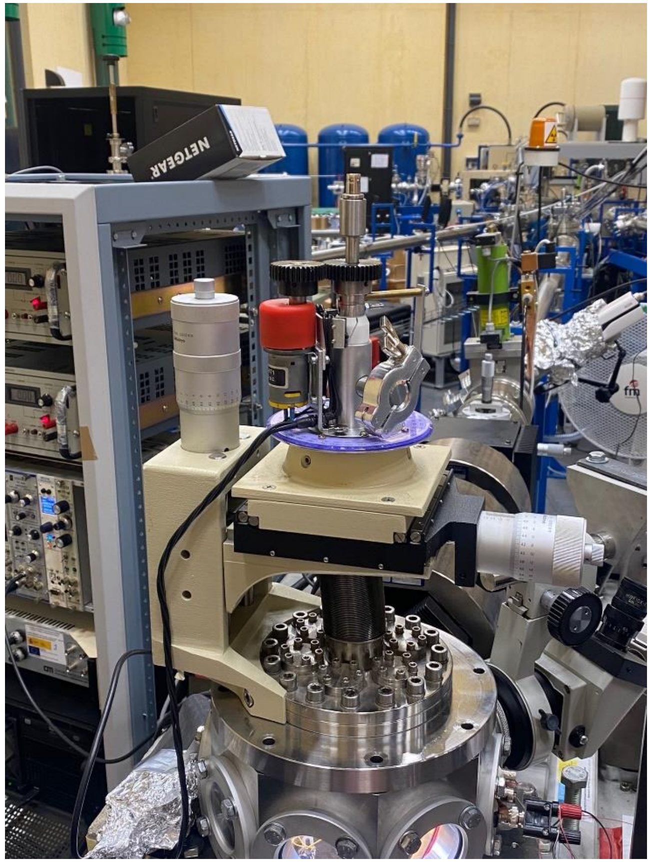
Non-irradiated

Irradiated

Characterization with ions



Triple alpha source measurements in vacuum chamber (239Pu, 241Am, 244Cm)



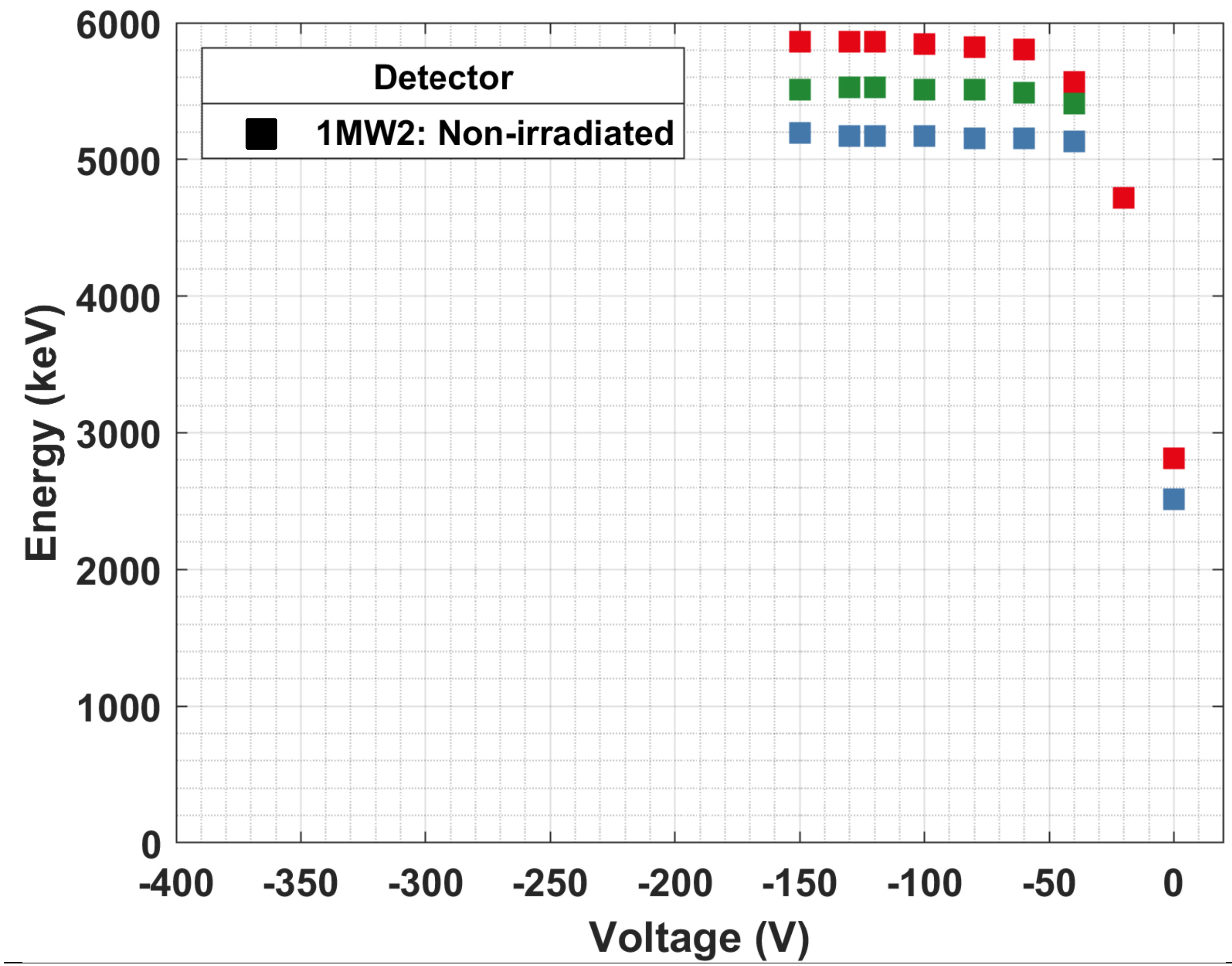
Proton measurements in microprobe beam line (2.7 MeV proton beam)

- **CCE absolute measurements**
- **Different polarization conditions**

SiC epitaxy : 50 μm

Element	Energy (keV)	Range SiC (μm)
244Cm	5746	19,8
241Am	5424	18,3
239Pu	5093	16,4
1H	2700	52,0

Triple alpha source measurements



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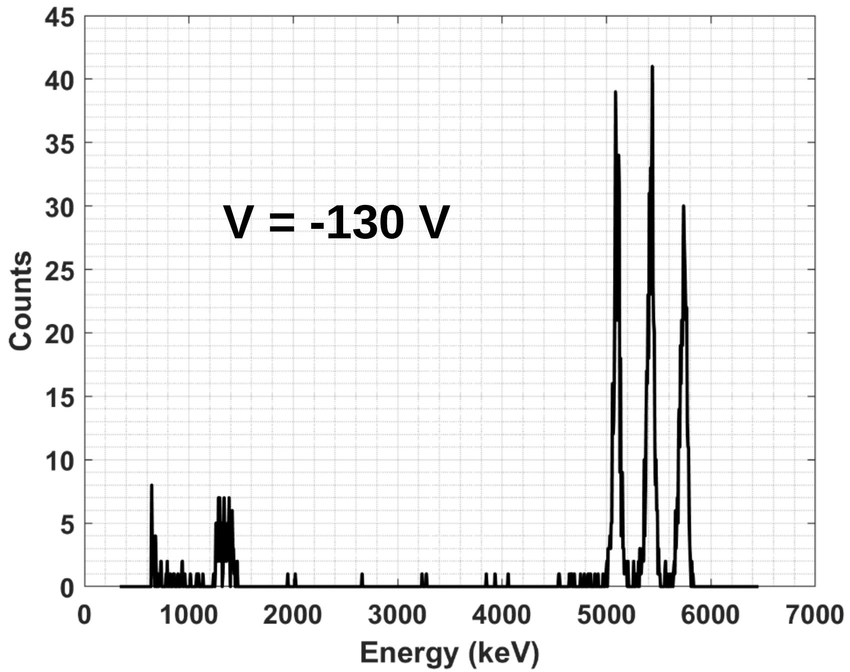
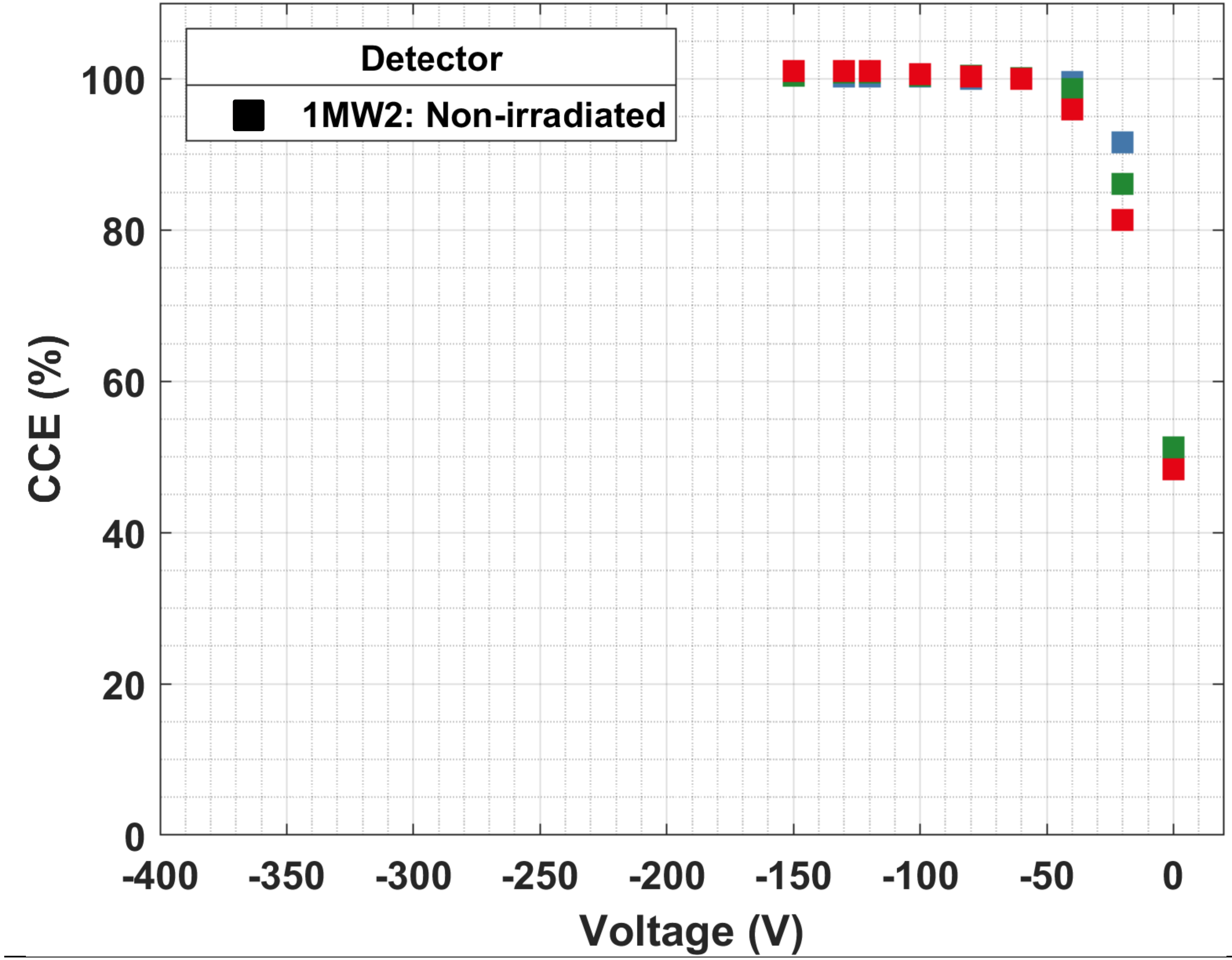


Triple alpha source measurements



Element	Energy (keV)	Range SiC (μm)
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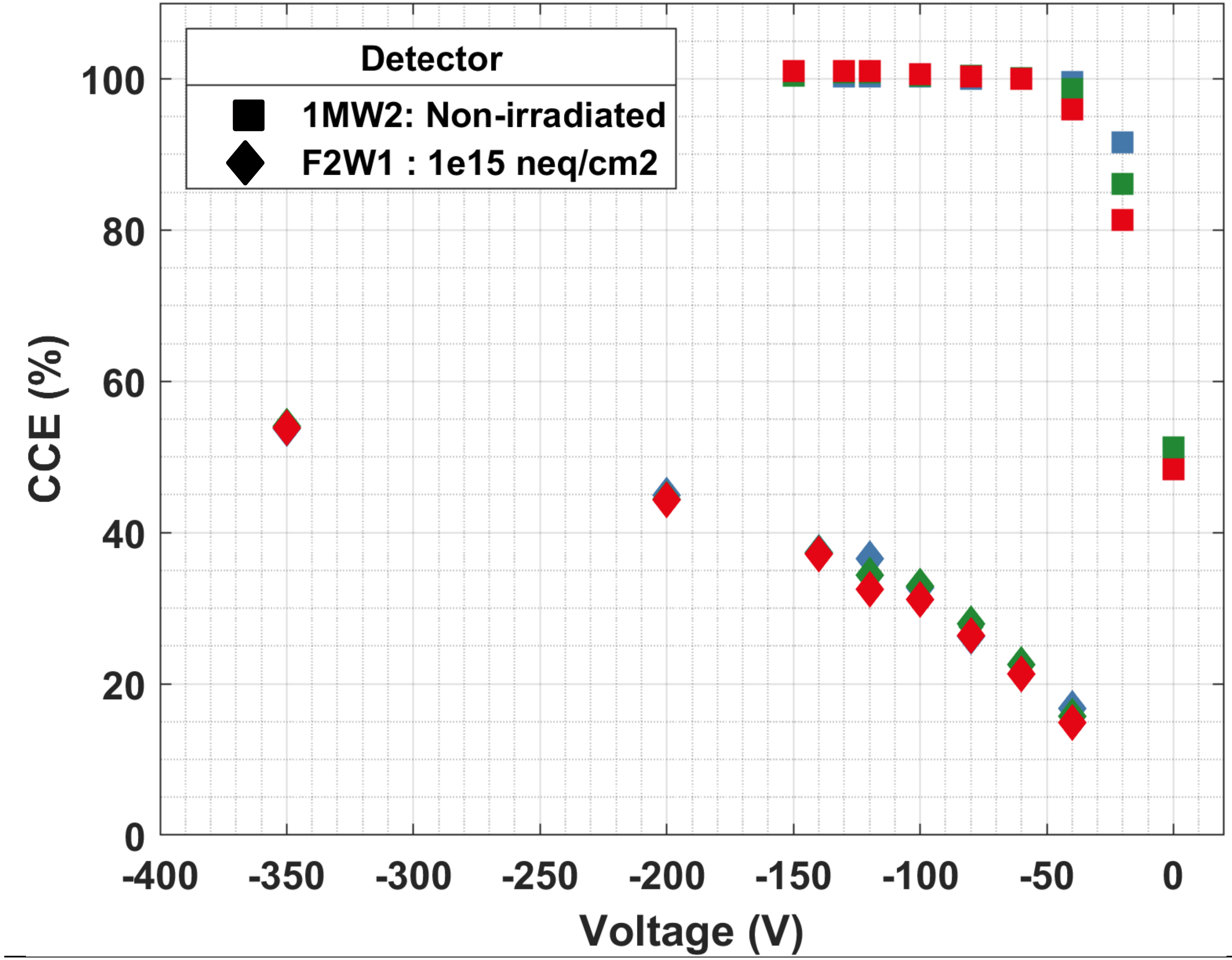
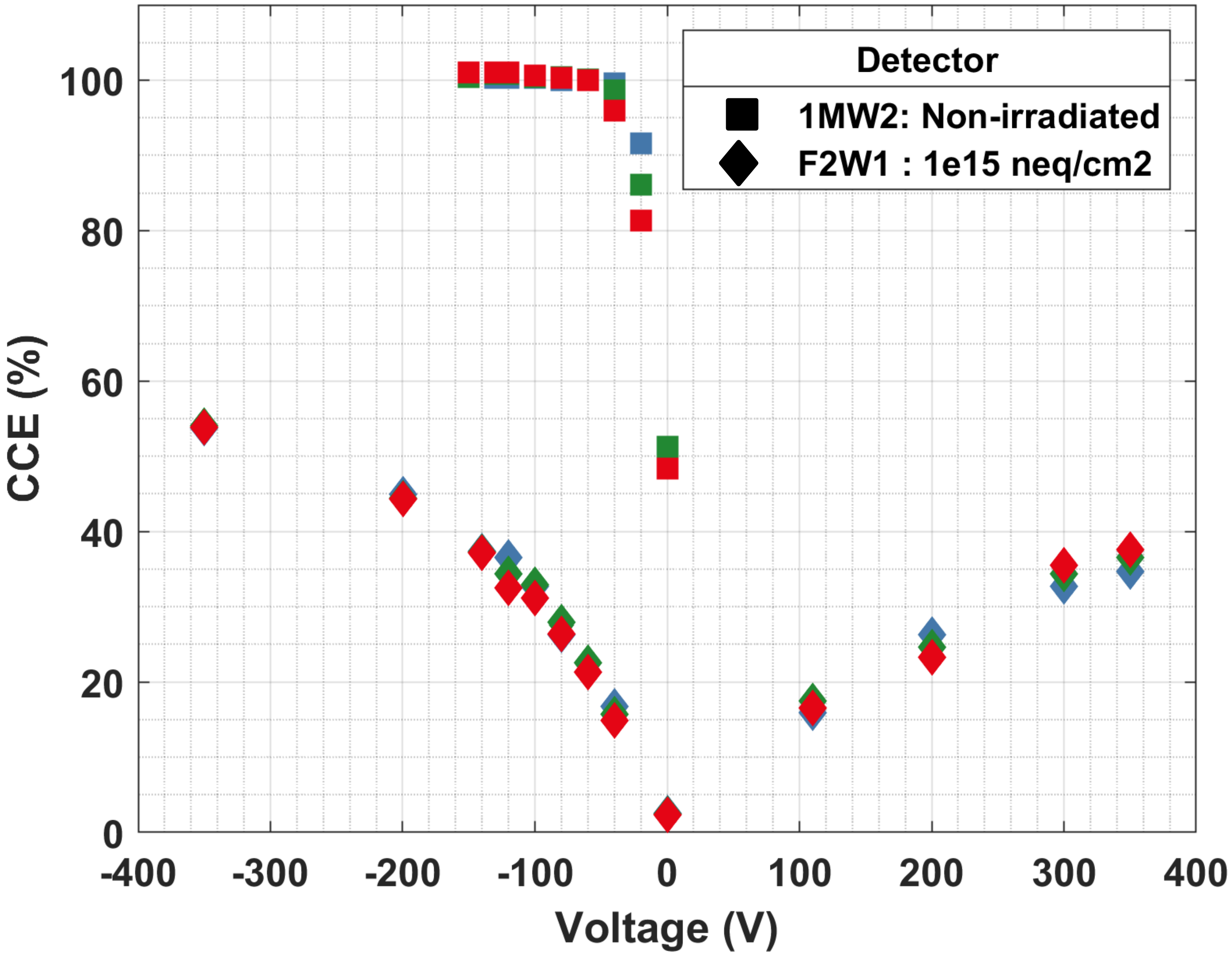
- **TRIBIC measurement confirms 100 % CCE of pristine detector.**
- **Voltage limited by readout**
- **Plateau reached from 80 V.**

Triple alpha source measurements



- Absolute CCE decrease of irradiated device
- No plateau reached in irradiated device
- Signal increase with bias

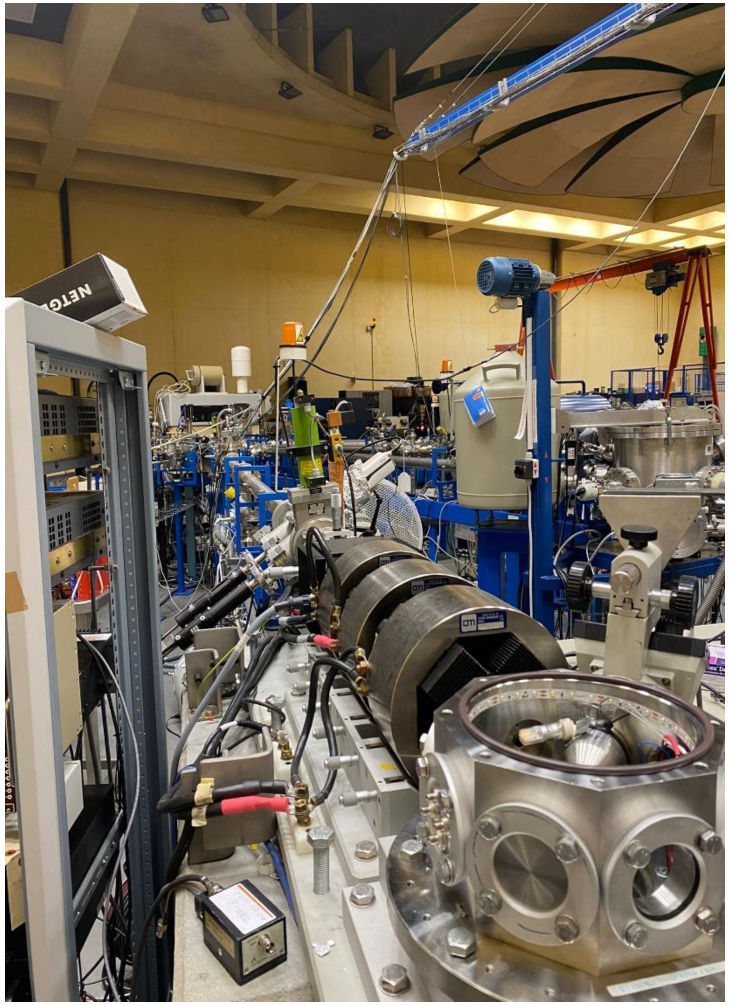
Triple alpha source measurements



-Forward polarization in irradiated device

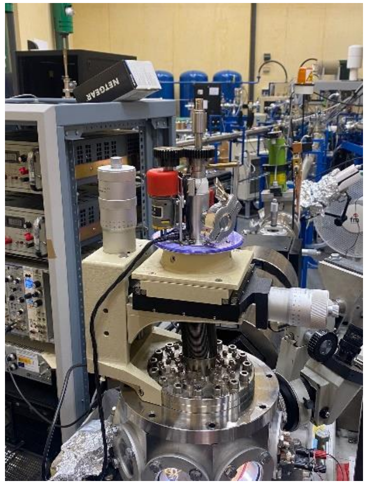
- Smaller signal in forward than in reverse polarization

Microprobe beam line at CNA



Nuclear Microprobe line

Tandem room

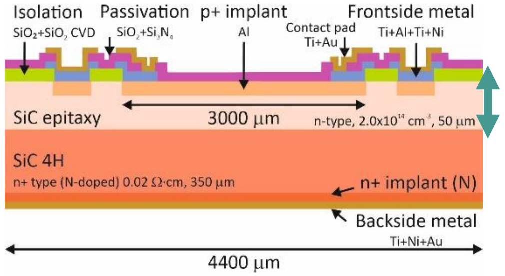


Rotating sample holder

Why use the microprobe beam line?

- Small samples (3x3 mm^2)
- Good lateral resolution desired
- Low rate (to avoid damage) $\sim 100\ \mathrm{Hz}$
- Rotating sample holder with accuracy of 1º
  - Angle-resolved IBIC

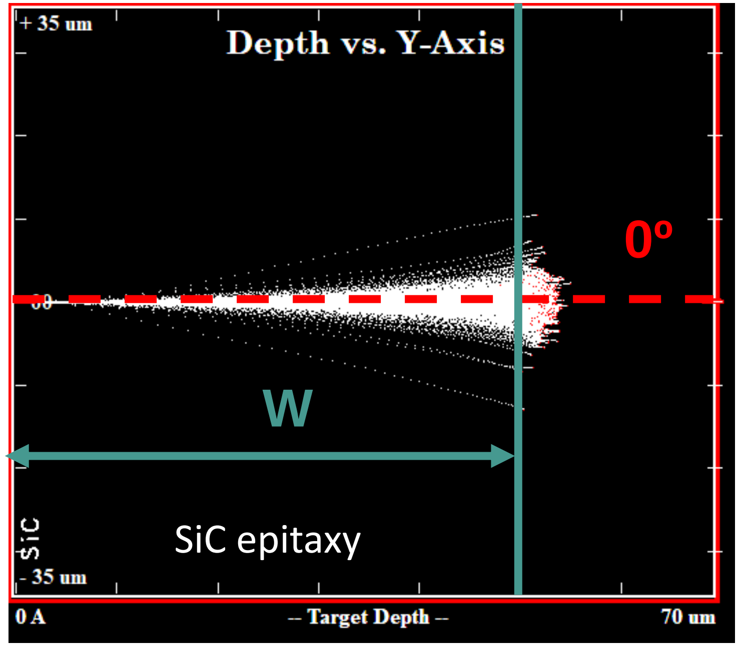
Angle-Resolved IBIC

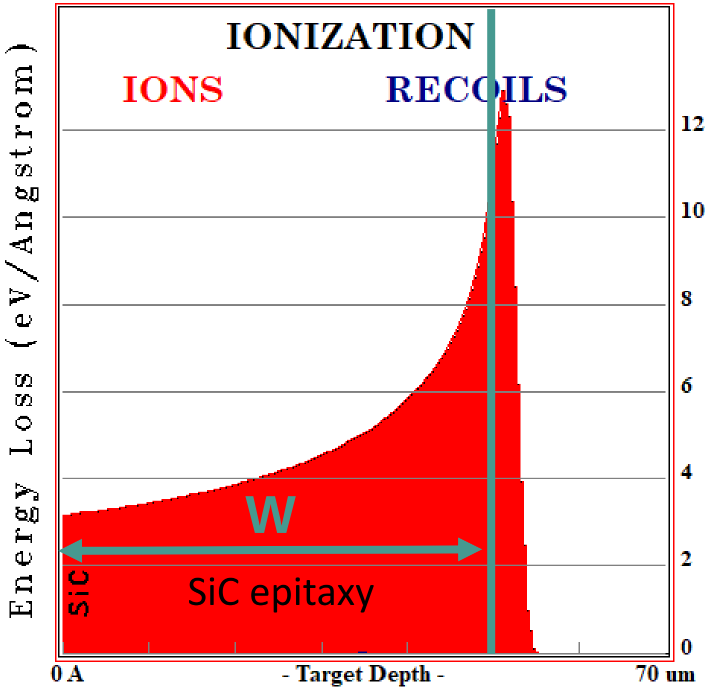


SiC epitaxy → 50 μm

Range of 2.7 MeV H^+ in SiC ($3{,}22\ g/cm^3$)→ 52 μm [SRIM simulation]

Angle (º)	Projected range (μm)
0	52
20	50
40	39
60	26
80	9





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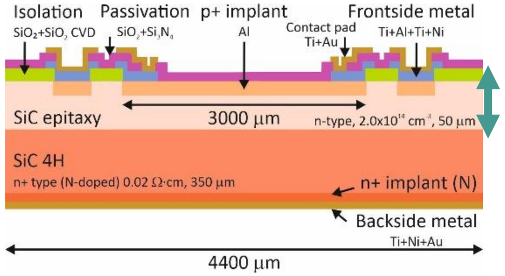

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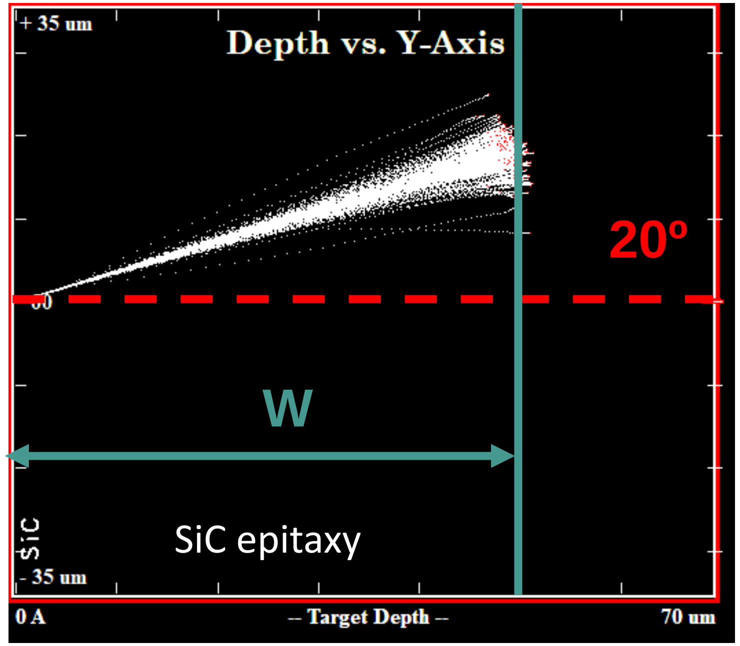

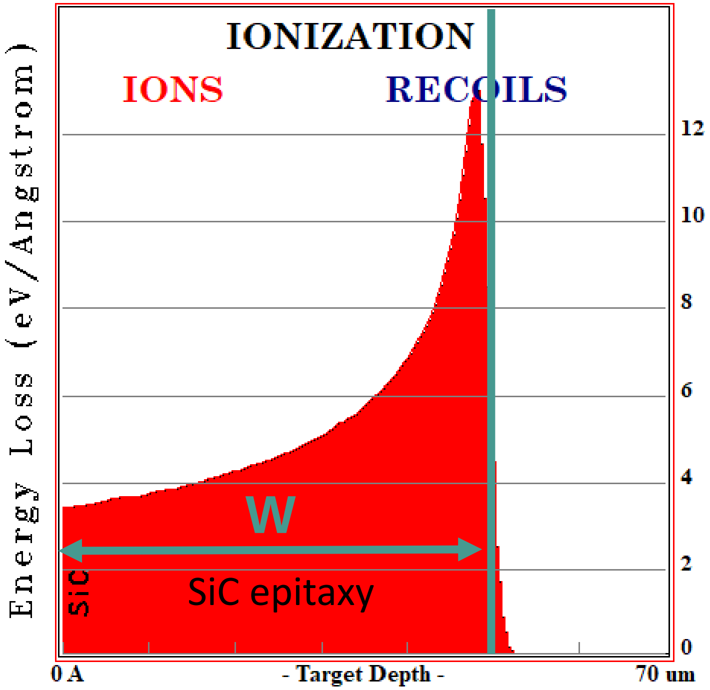

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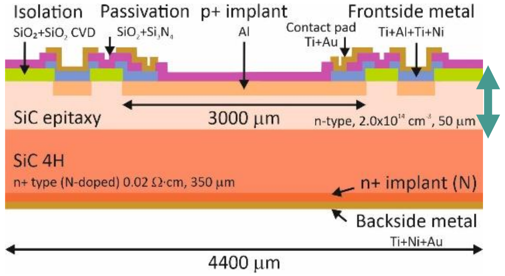

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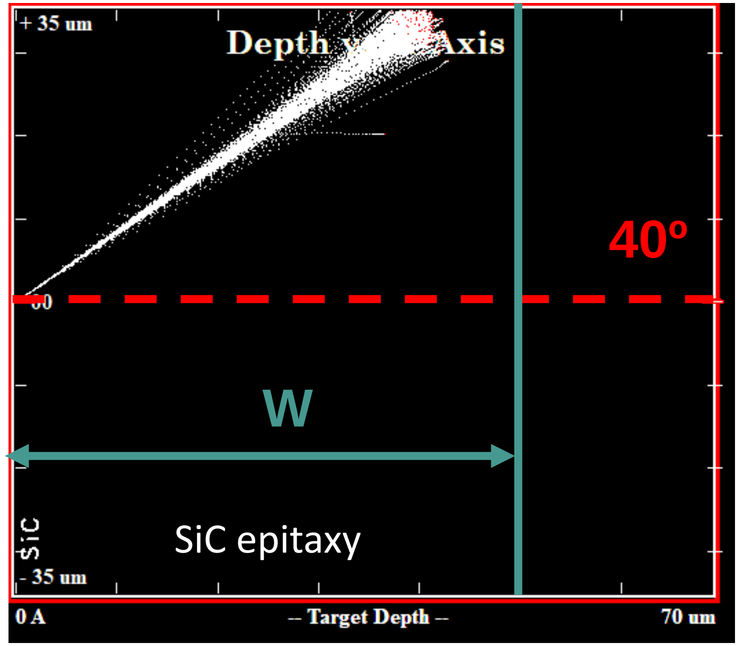

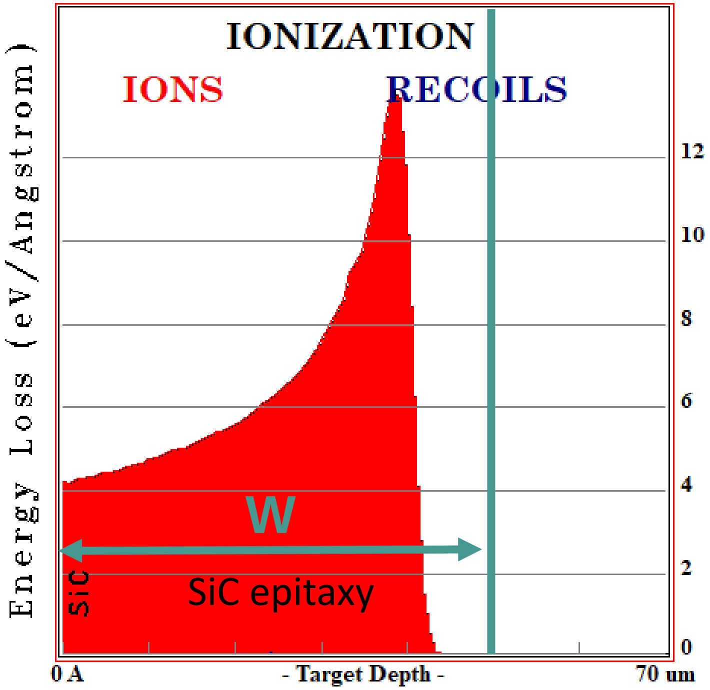

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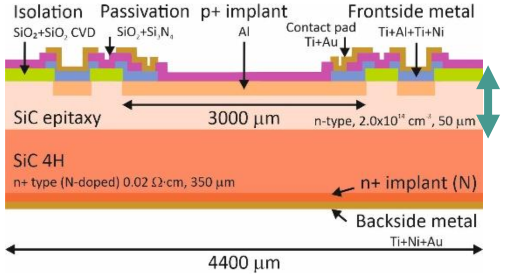

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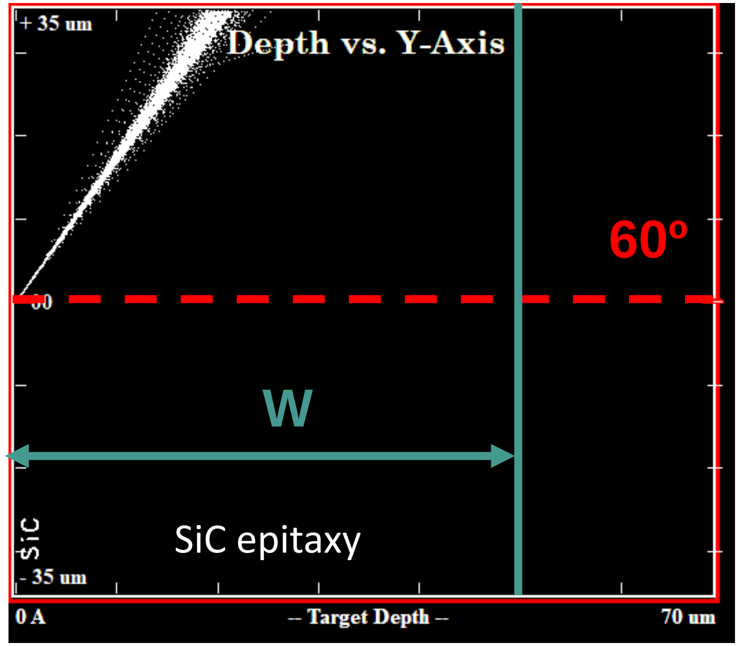

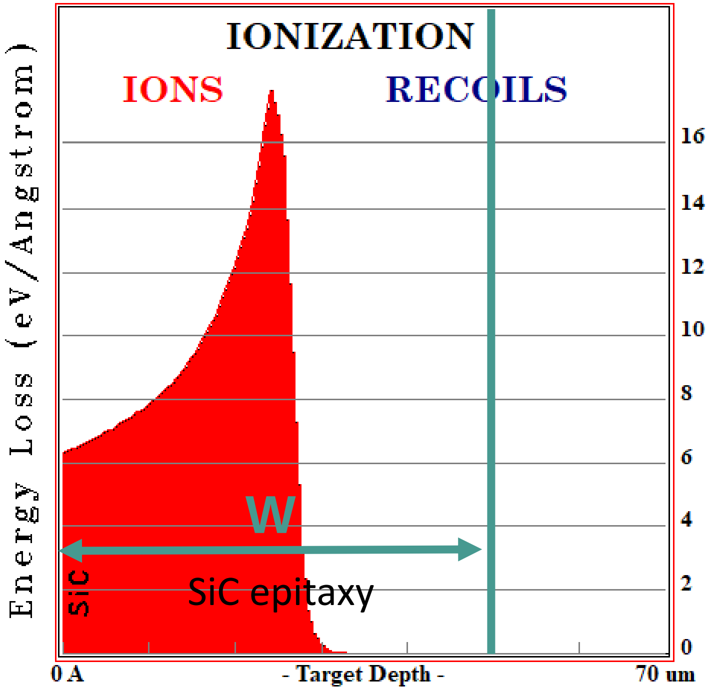

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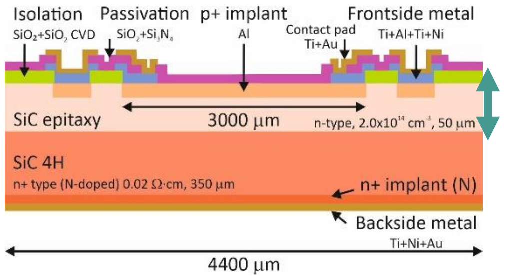

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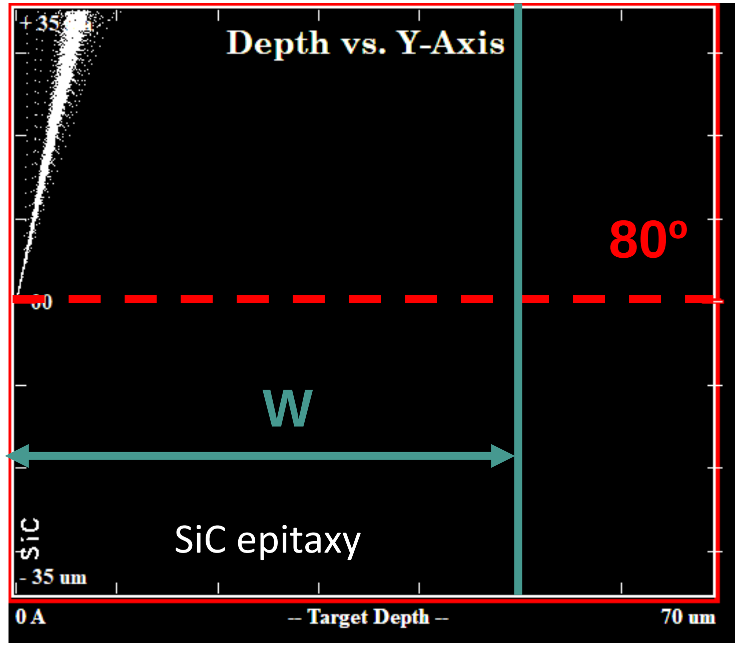
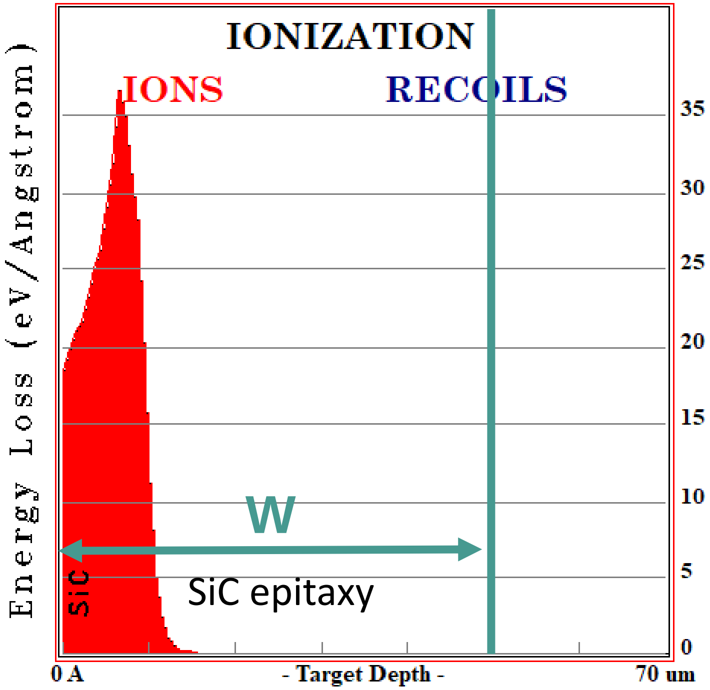
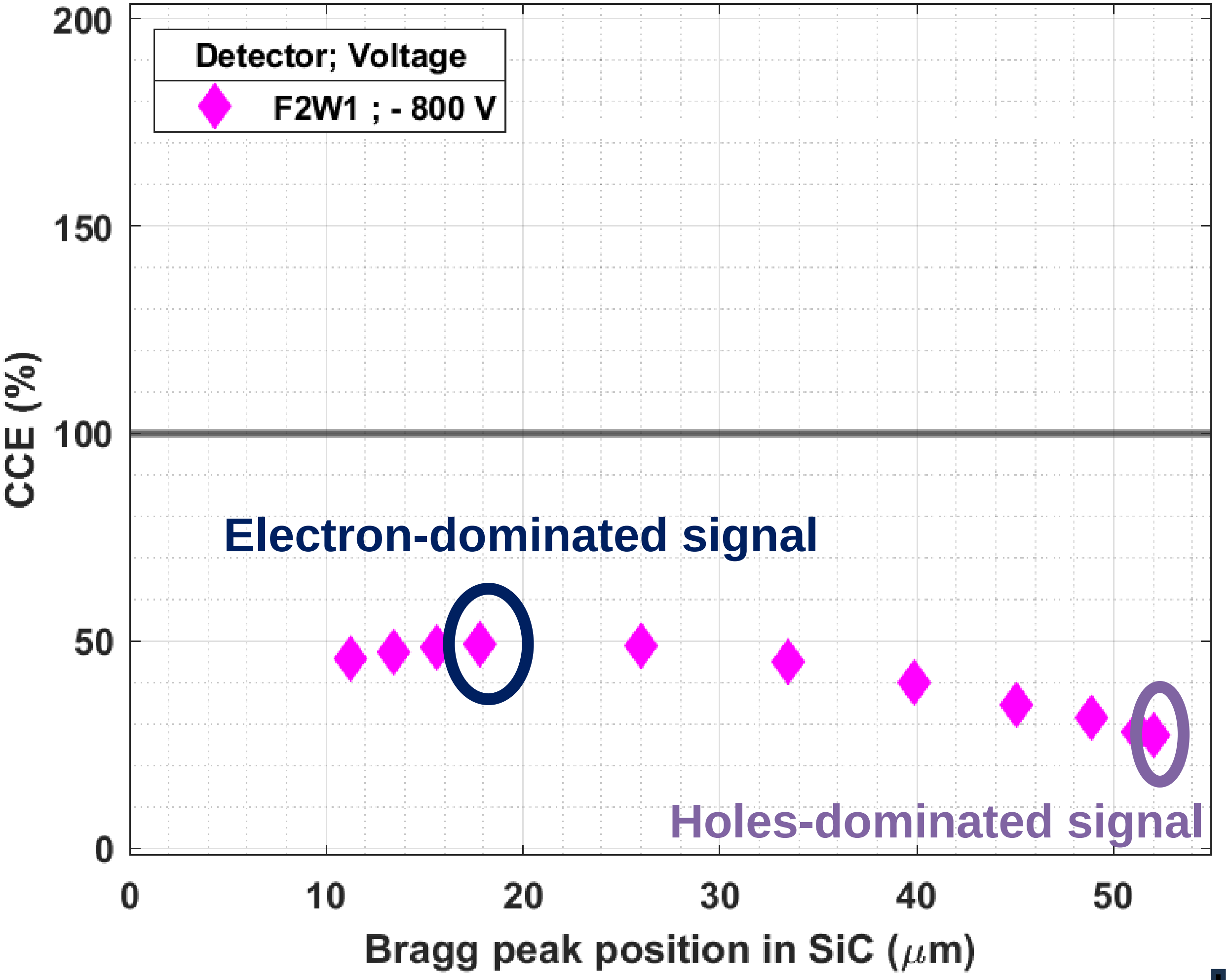
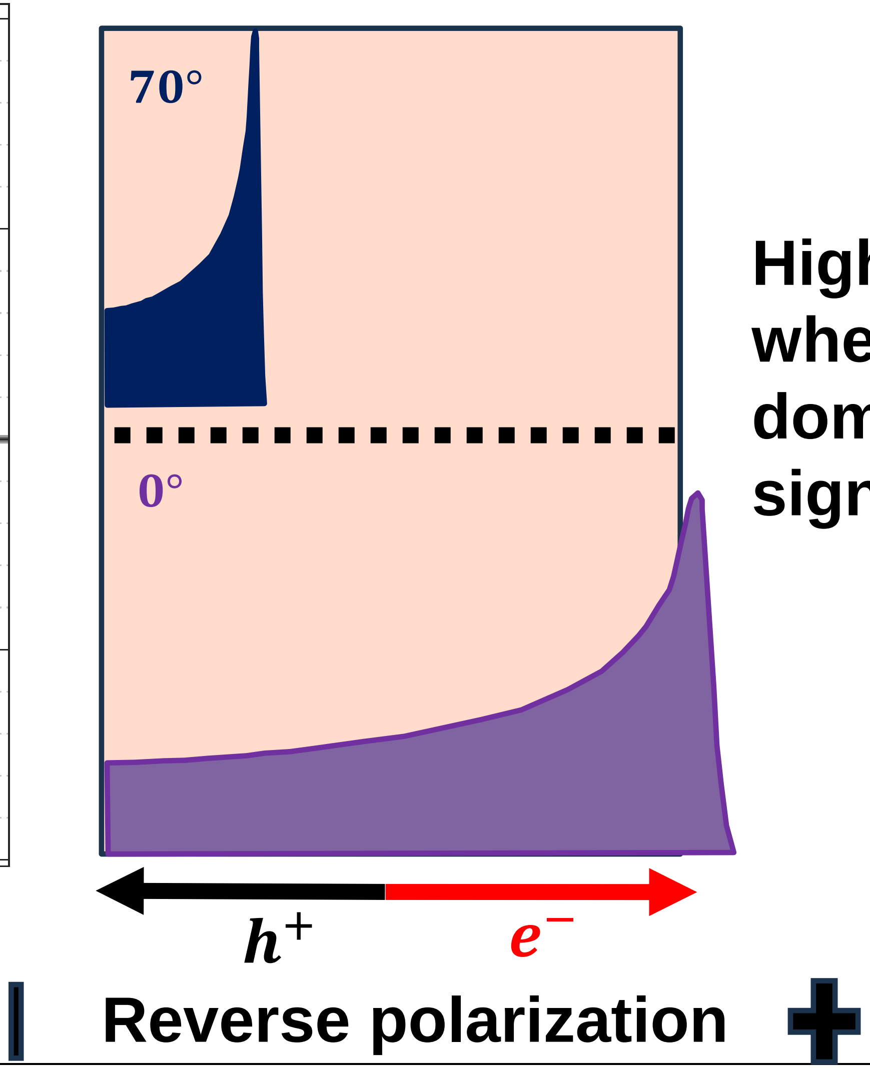




2.7 MeV H^+: F2W1 reverse polarization

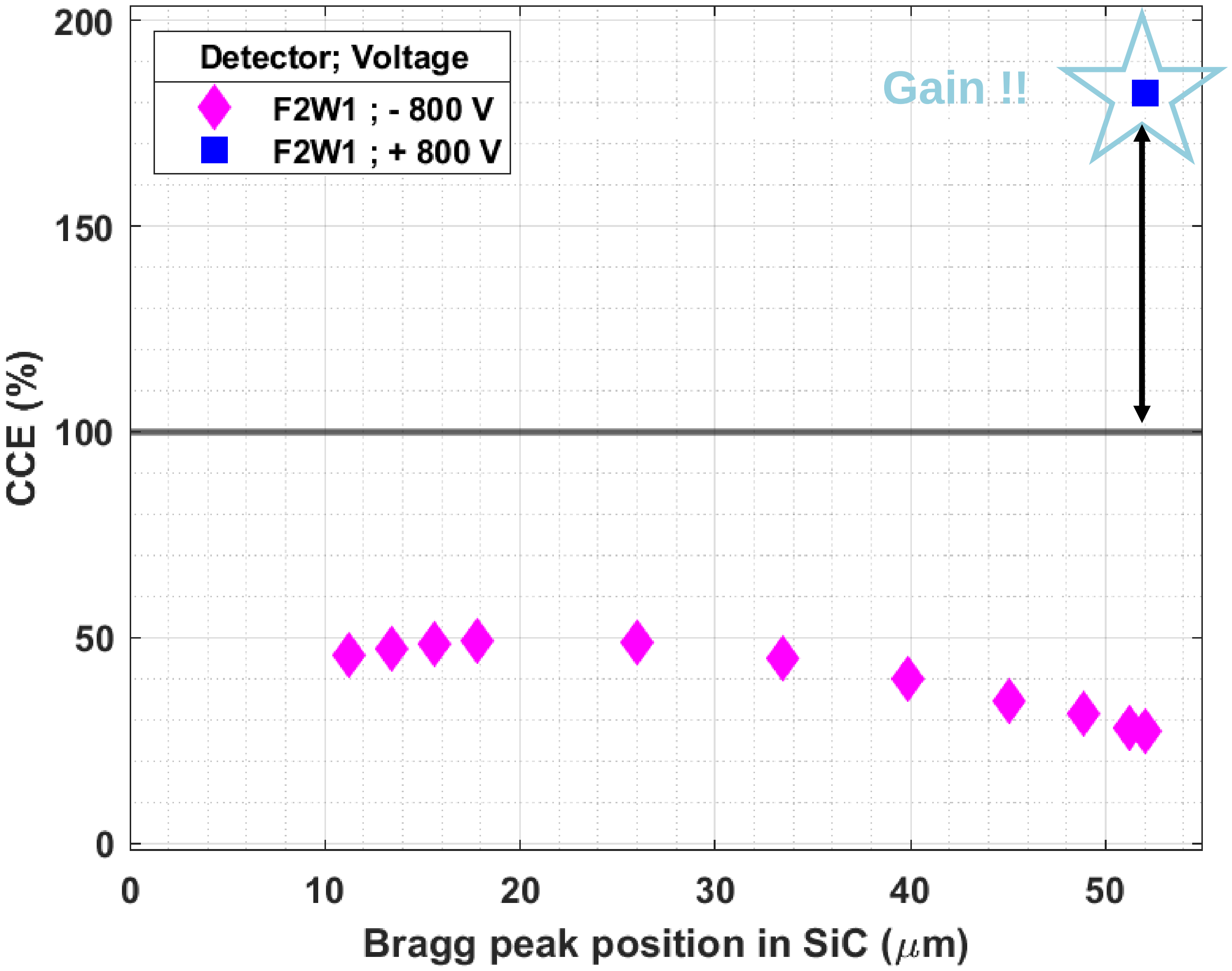


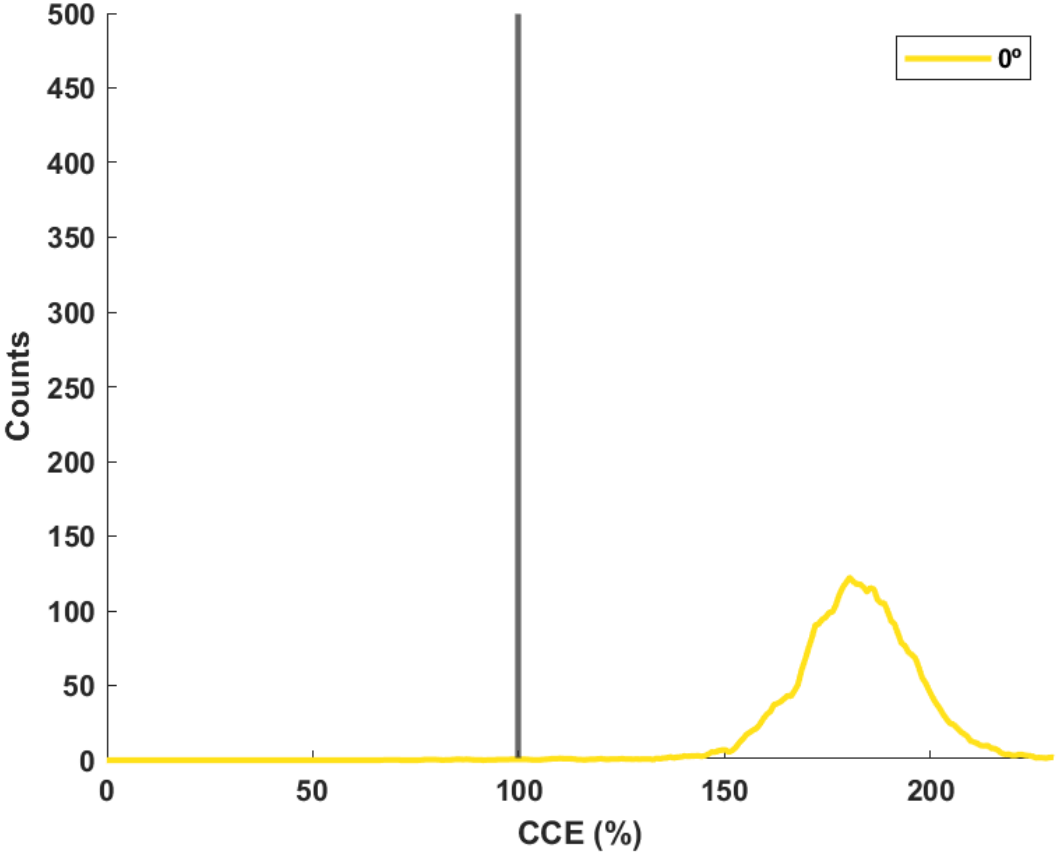


Reverse polarization

Higher signal when electron-dominated signal

2.7 MeV H^+: F2W1 forward polarization





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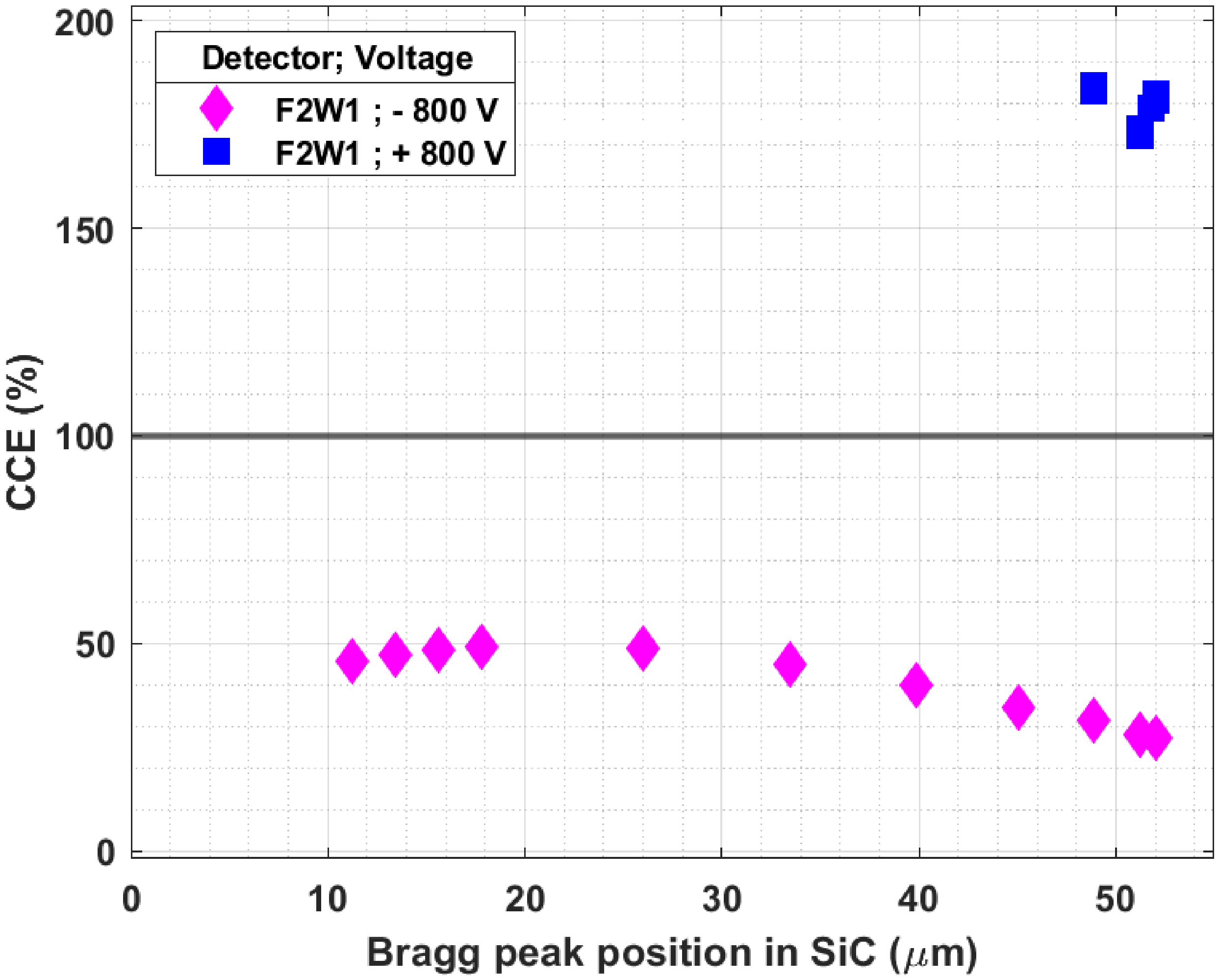

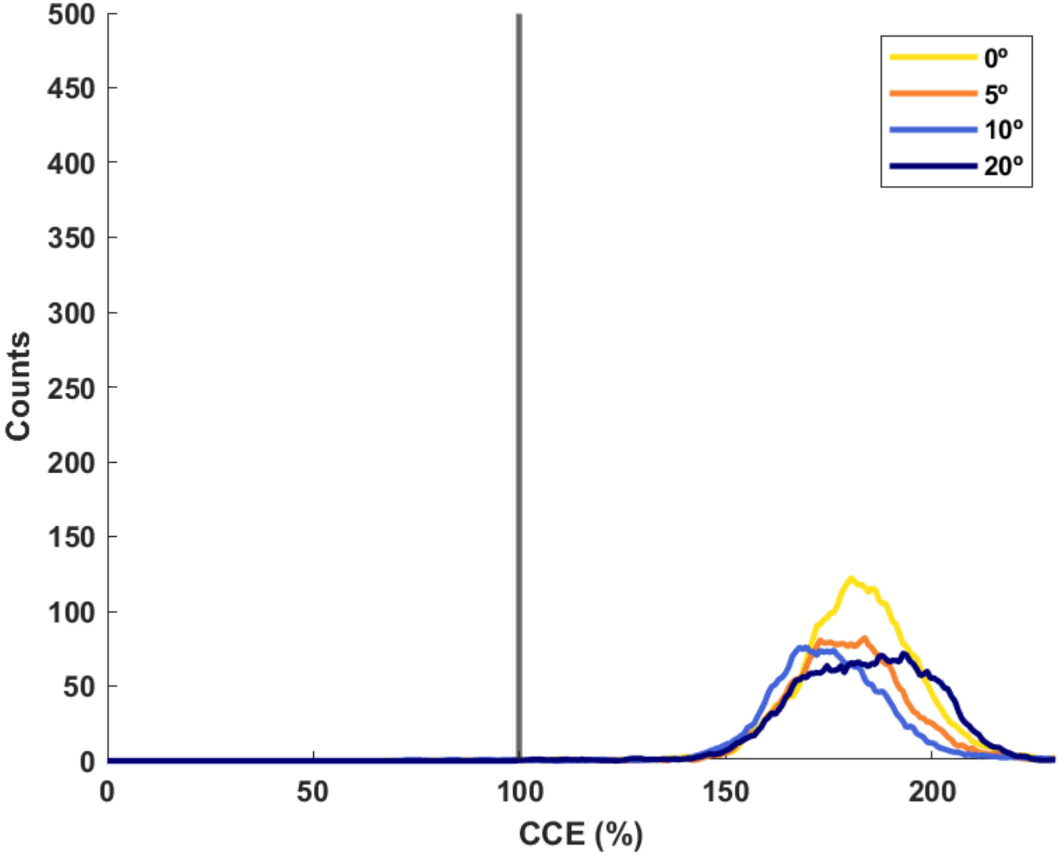

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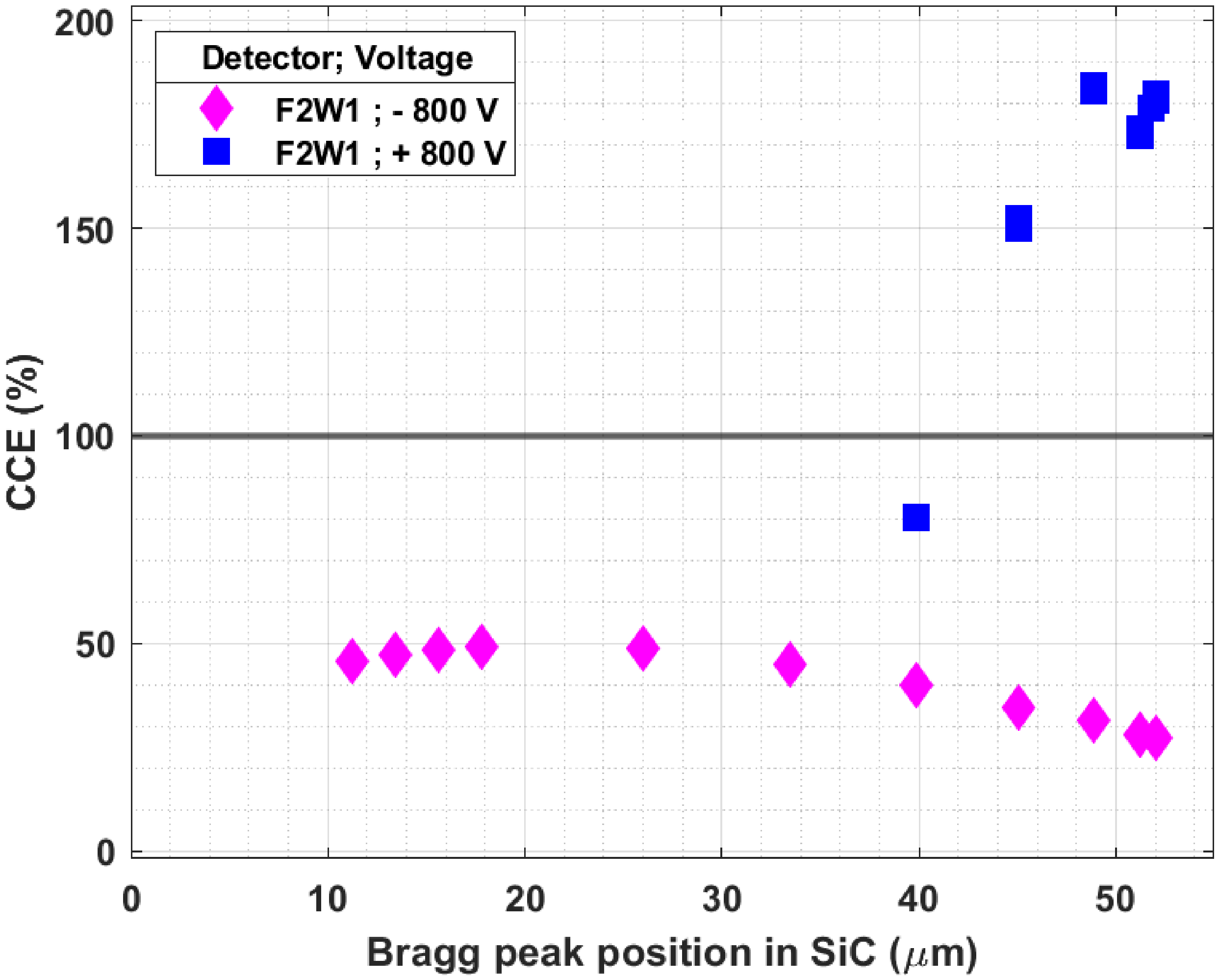

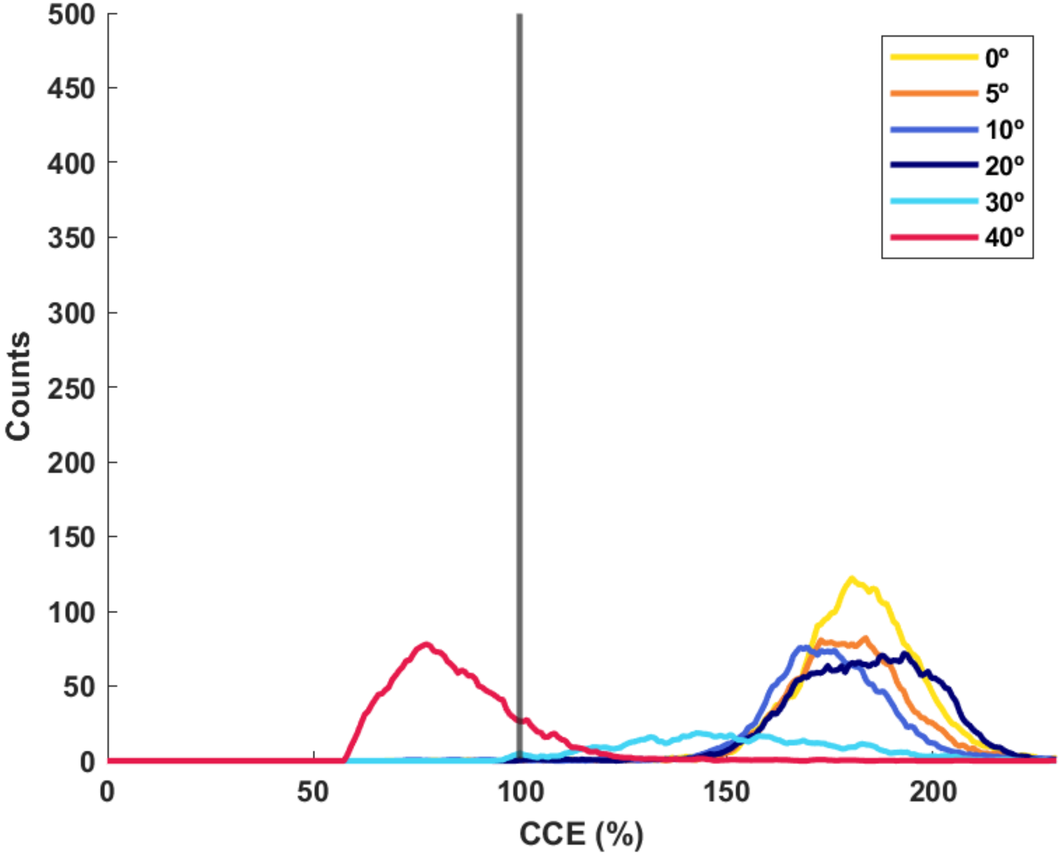

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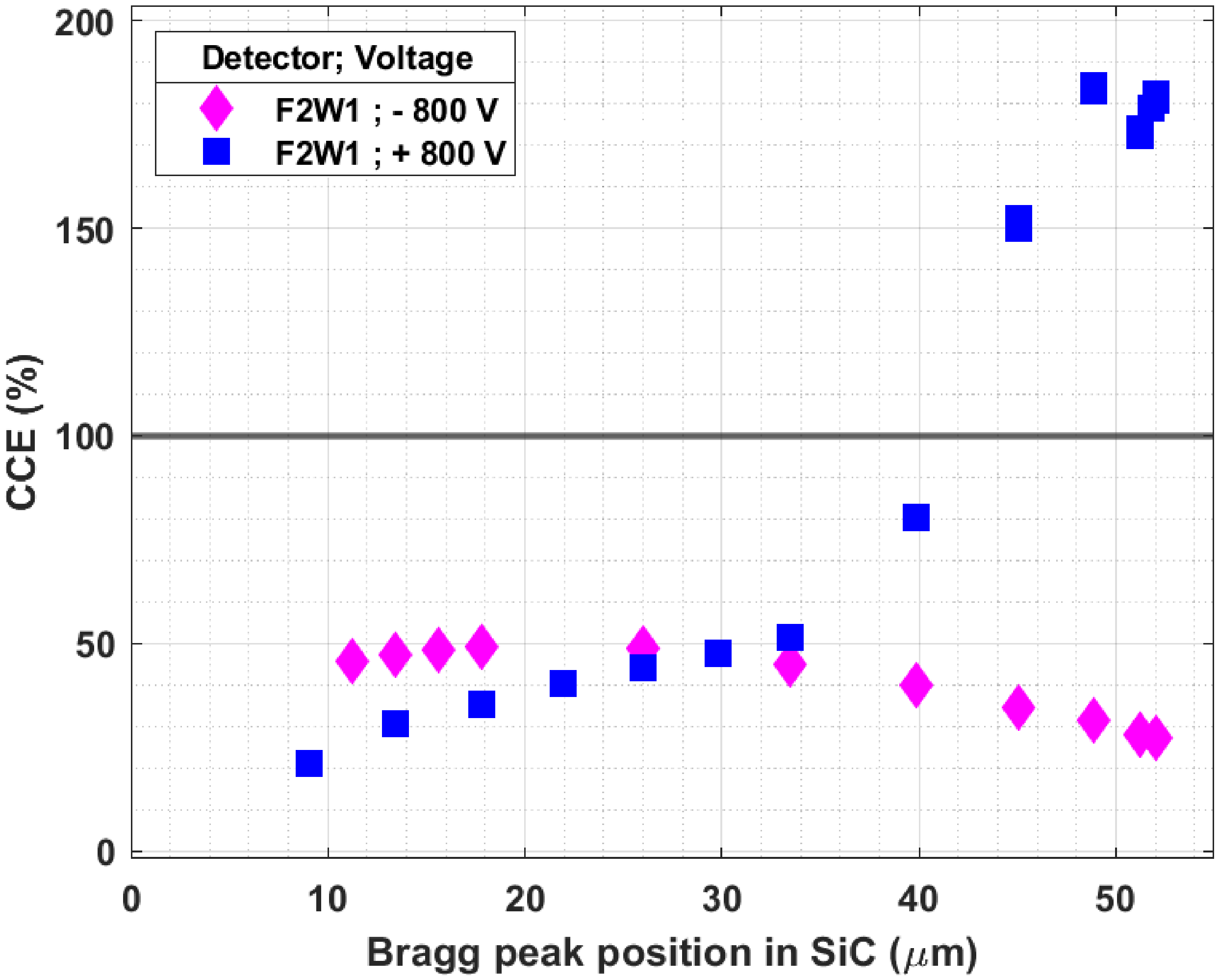

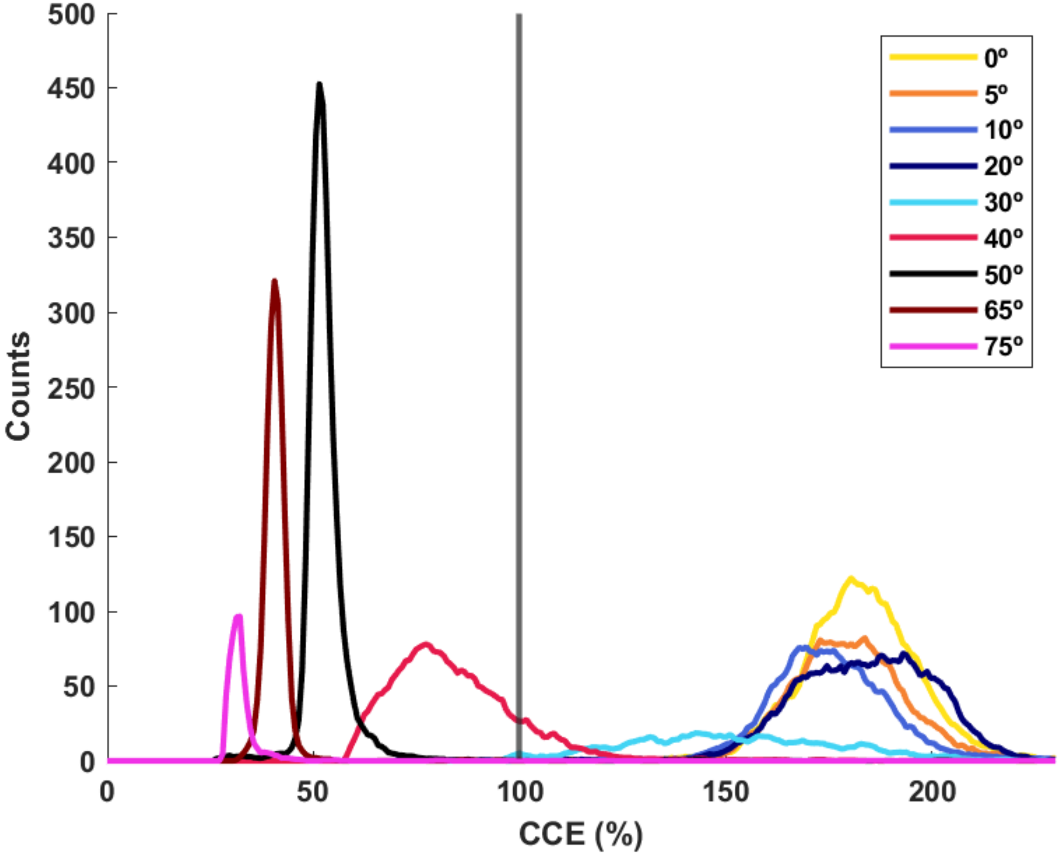

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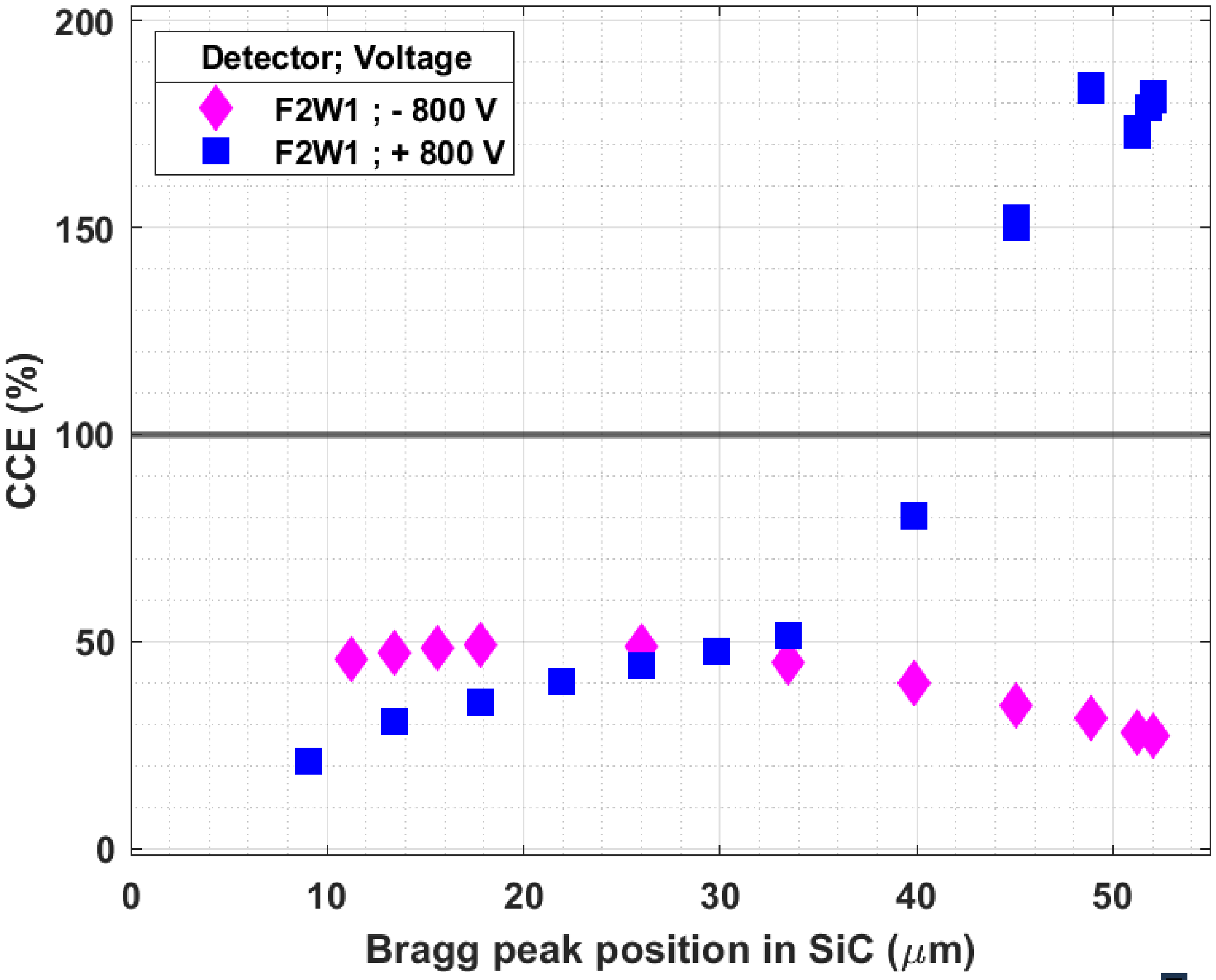

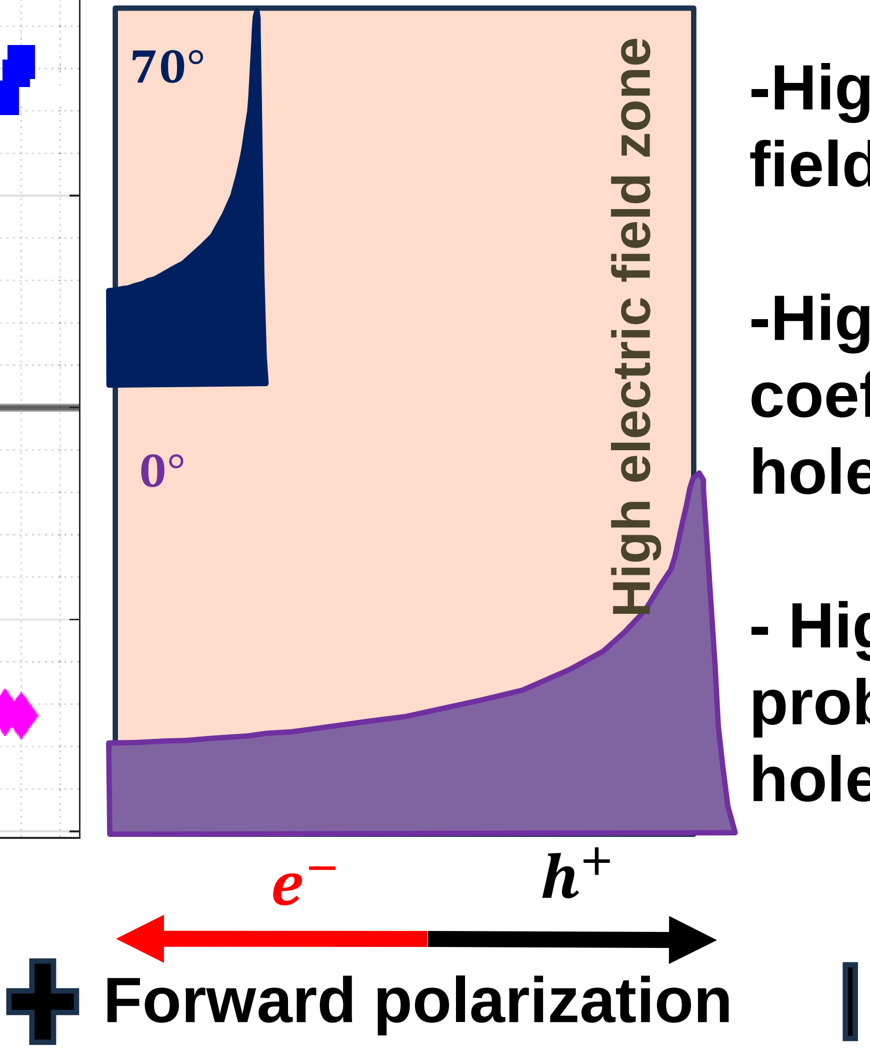

Forward polarization

- **High electric field zone**

- **Higher impact coefficient for holes in SiC**

- **Higher trapping probability for holes**

Summary

- Absolute measurement of the CCE as a function of voltage using ions in different polarizations.
- Irradiated devices higher trapping probability for holes.
- High electric field zone in forward polarization mode (holes multiplication).

Thank you !

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

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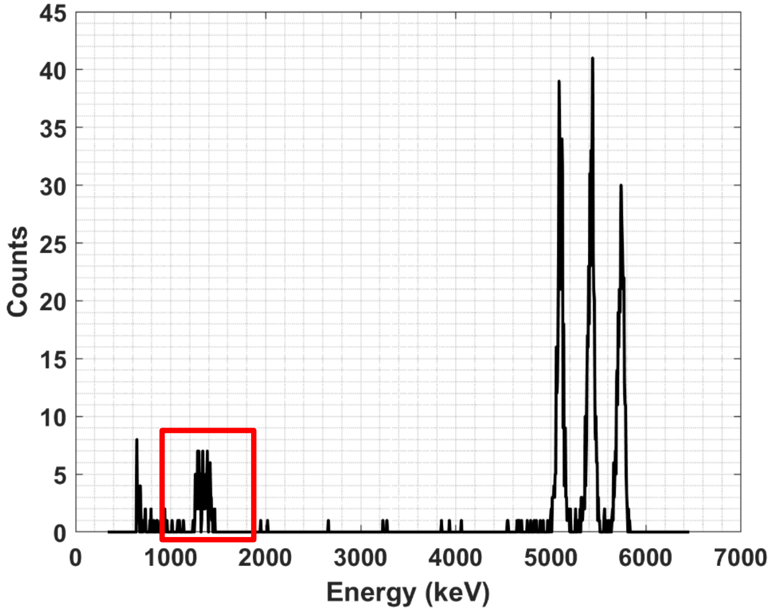
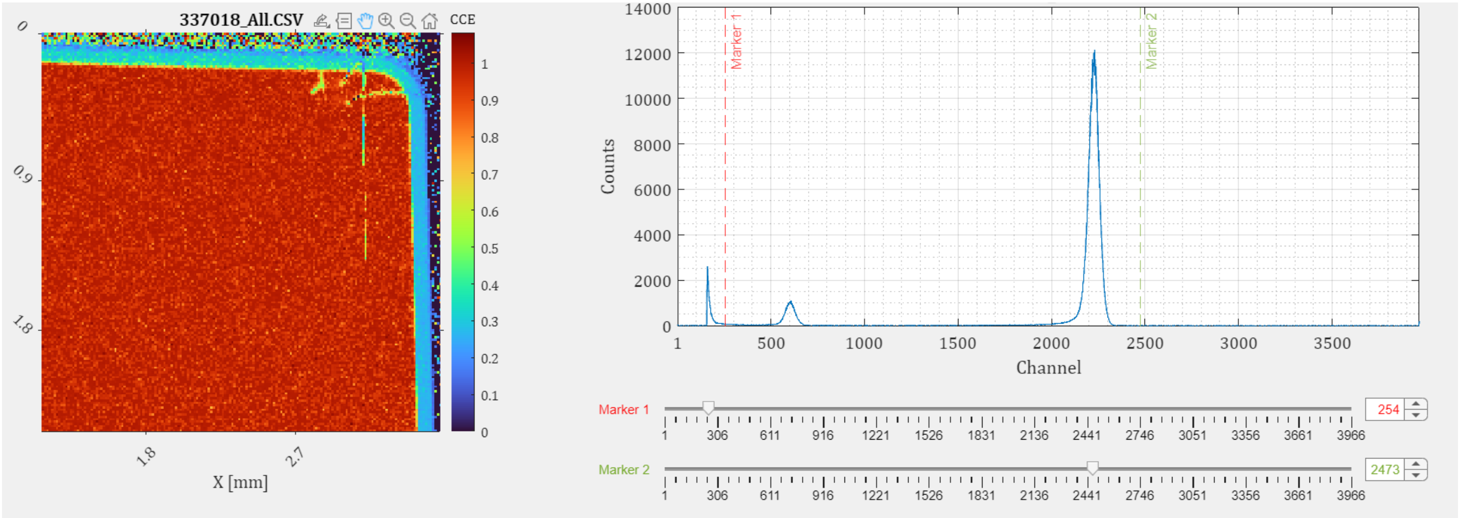
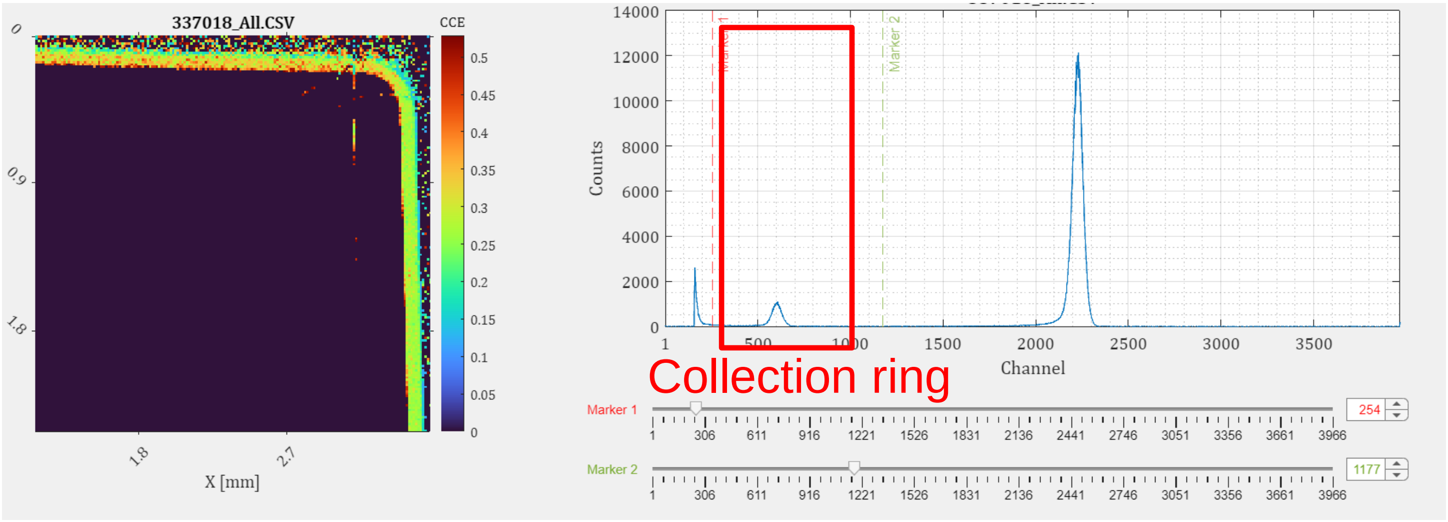
- This research was funded by the Spanish Ministry of Science, Innovation and Universities grant numbers PID2023-148418NB-C44.

Back-up slices

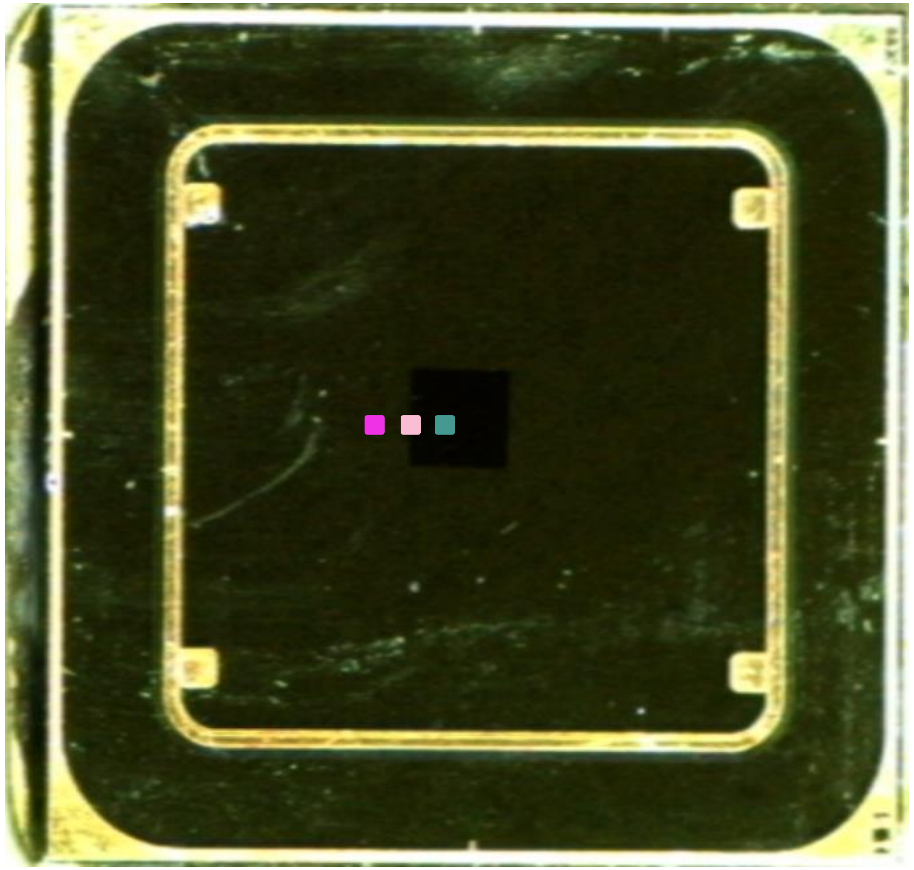


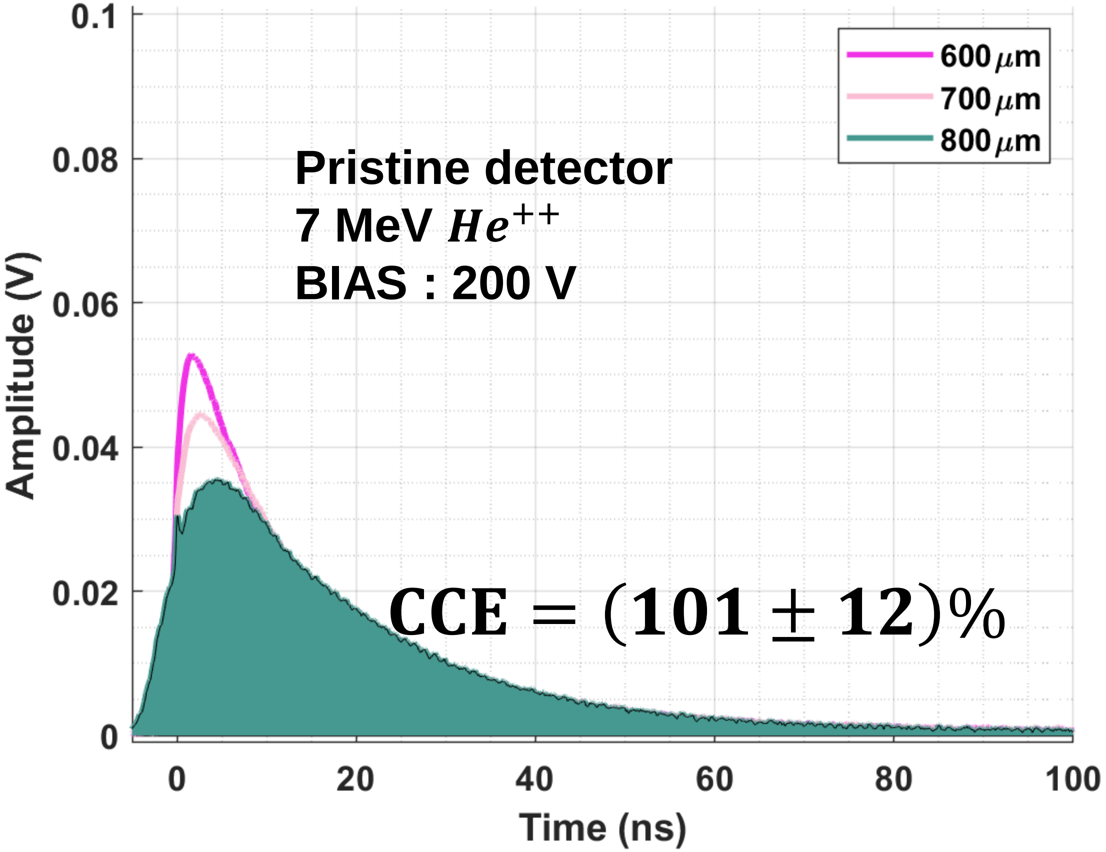




Collection ring

Calculation of the absolute CCE value for the pristine detector





Pristine detector
7 MeV He^{++}
BIAS : 200 V

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

Charge Collection Efficiency (CCE)

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

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 $10^{-19}\mathrm{C}$

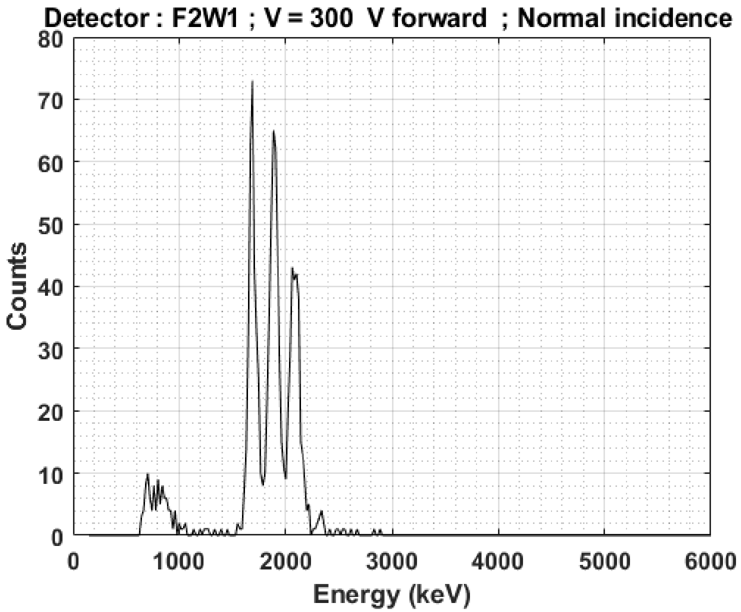
$$Q = \frac{E \cdot e}{\epsilon_{e^- - h^+}} = (1.510 \pm 0.005) \times 10^{-4}\ \mathrm{nC}$$

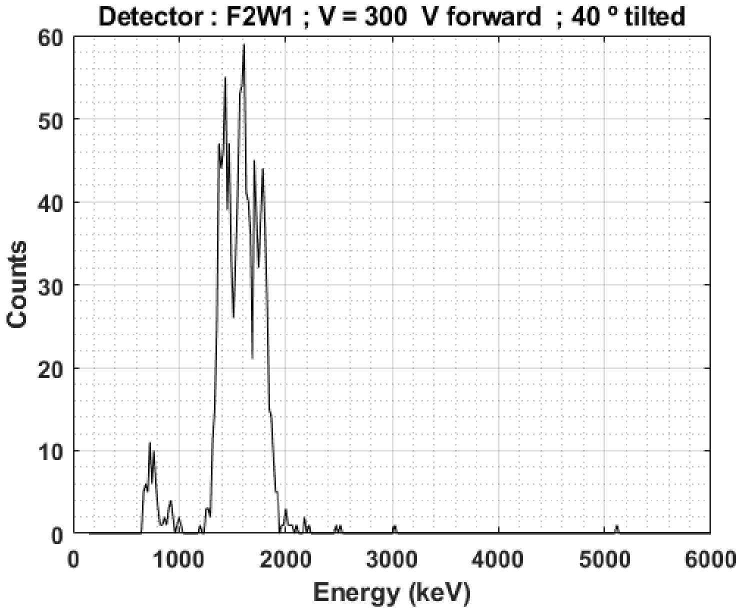
Experimental results :

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

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

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





$E_{emission}$ (keV)	E_{exp} [0º] (keV)	$\frac{E_{emision} - E_{exp}[0º]}{E_{emision}}$ (%)	E_{exp} [40º] (keV)	$\frac{E_{emision} - E_{exp}[40º]}{E_{emision}}$ (%)	E_{exp} [0º] $- E_{exp}$ [40º](keV)
5156	1688	67	1432	72	256
5486	1885	66	1610	71	275
5806	2101	64	1787	69	314

Element	Range SiC (μm)	Range SiC tilting 40 º (μm)
244Cm	19,8	15,2
241Am	18,3	14,1
239Pu	16,4	12,5