Determination of the Relative Defect Density in Semiconductors Using SPA-TCT and TPA-TCT Method

C. Torres-Muñoz[1], M. Fernández-García[,4,5], J. García-López[1,2], M. Rodríguez-Ramos[1] , M. Moll[5,] I. Vila[4], M. Muehlnikel[5], J. Villegas-Domínguez[1] , M.C. Jiménez-Ramos[1,3]

ctorres1@us.es

[1] Centro Nacional de Aceleradores (U. Sevilla, CSIC, J. de Andalucia), 41092 Seville, Spain

[2] Dpto. de Física Atómica, Molecular y Nuclear, Universidad de Sevilla, 41012, Seville, Spain

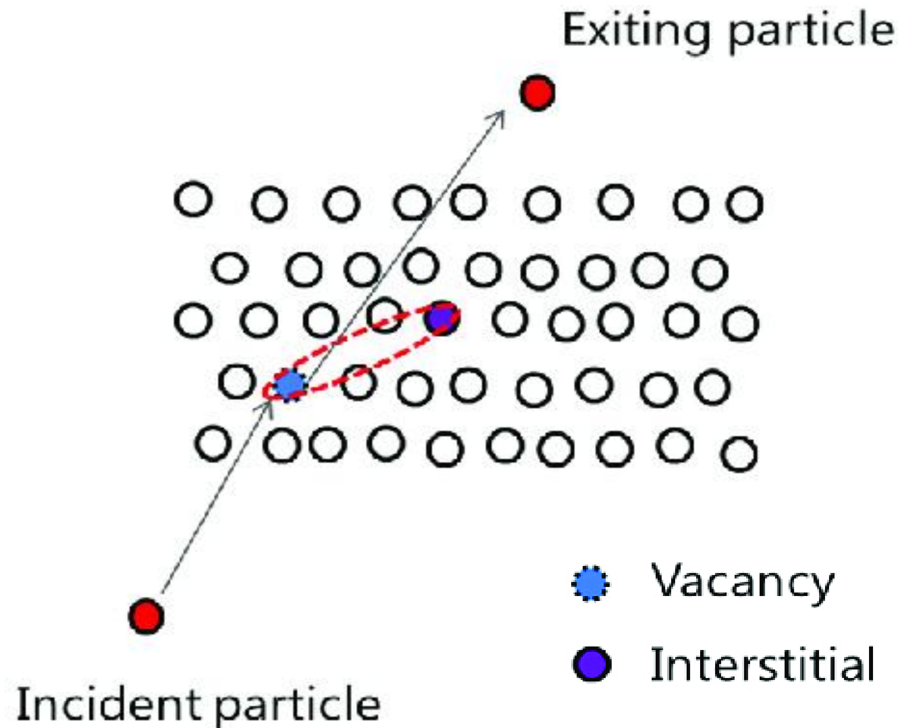
[3] Dpto. de Física Aplicada II, Universidad de Sevilla, 41012, Seville, Spain

[4] Instituto de Física de Cantabria (IFCA), 39005, Santander, Spain

[5] Conseil Européen pour la Recherche Nucléaire (CERN), Switzerland

Motivation

Centro Nacional de Aceleradores | Infraestructuras Científicas y Técnicas Singulares | Universidad de Sevilla



Source: Madiba *et al.* (2023), *Materials Today: Proceedings*

Effect of Lattice Damage on Semiconductor Performance

- **Ion implantation** displaces atoms, creating vacancies and interstitials.
- These **defects** introduce trap levels and recombination centers in the bandgap.
- Carrier mobility, lifetime, and **charge collection efficiency decrease**.
- Leakage current increases and the **detector response degrades**.

Goal:

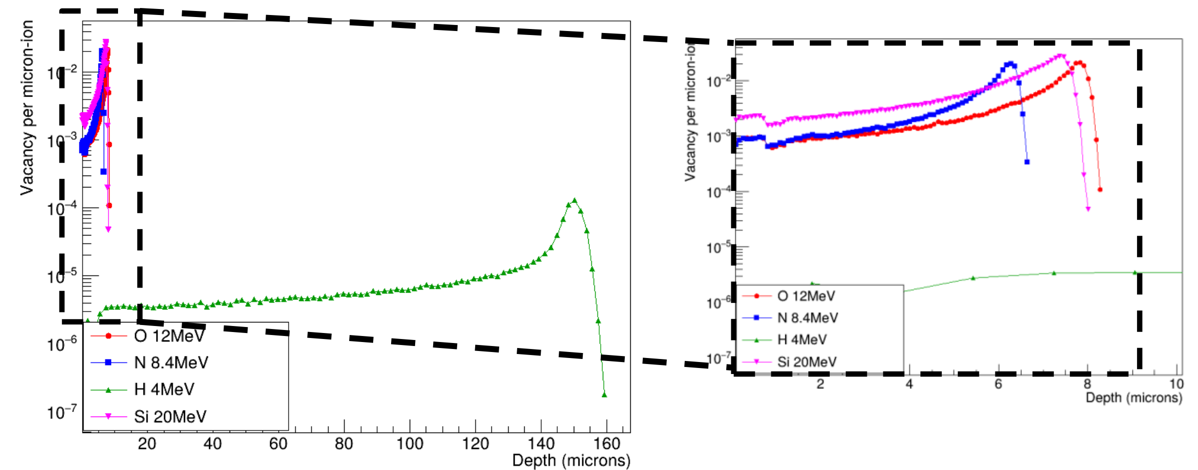
To study the sensitivity of SPA-TCT and TPA-TCT to ion implantation-induced damage

Microprobe beam line at CNA

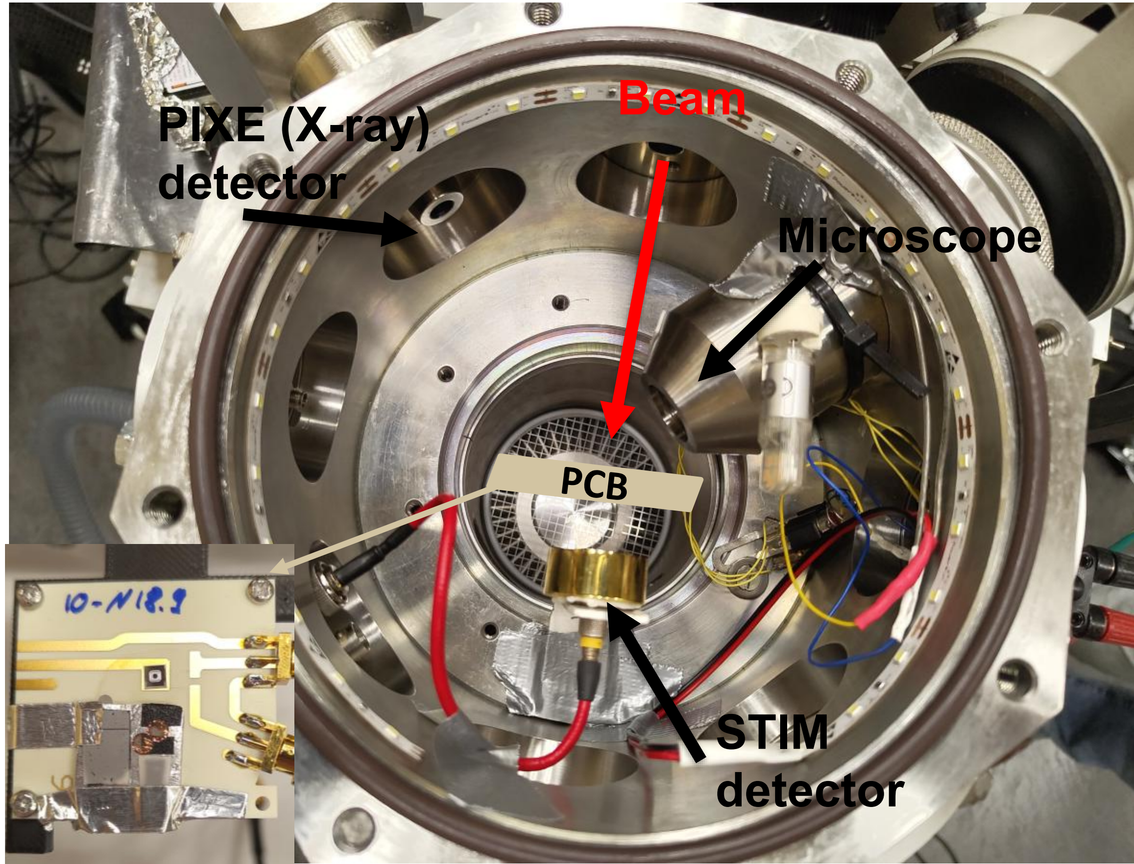
Nuclear Microprobe line

Different ion implantations in silicon **PIN** diodes :

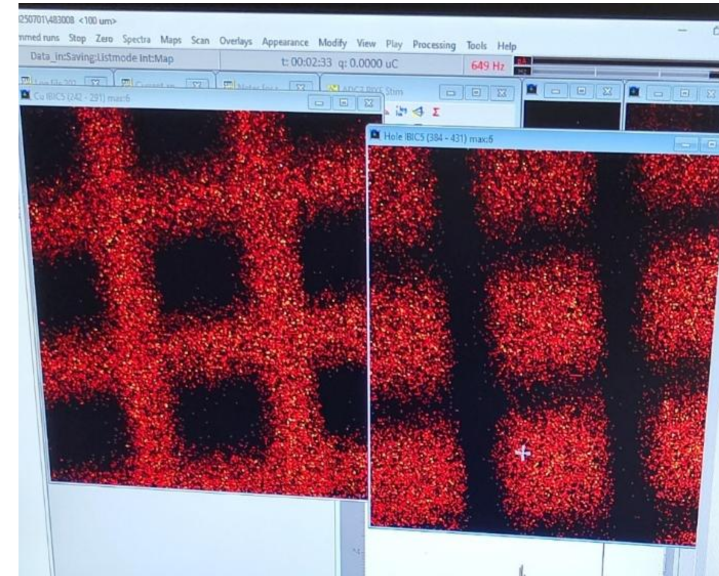
- 4 MeV H^{+}
- 12 MeV O^{5+}
- 20 MeV Si^{8+}
- 8.4 MeV N^{4+}



Experimental setup at CNA



Nuclear Microprobe chamber



<u>Grid dimension</u> :

Pitch : 83 μm

Bar width : 25 μm

Hole width : 58 μm

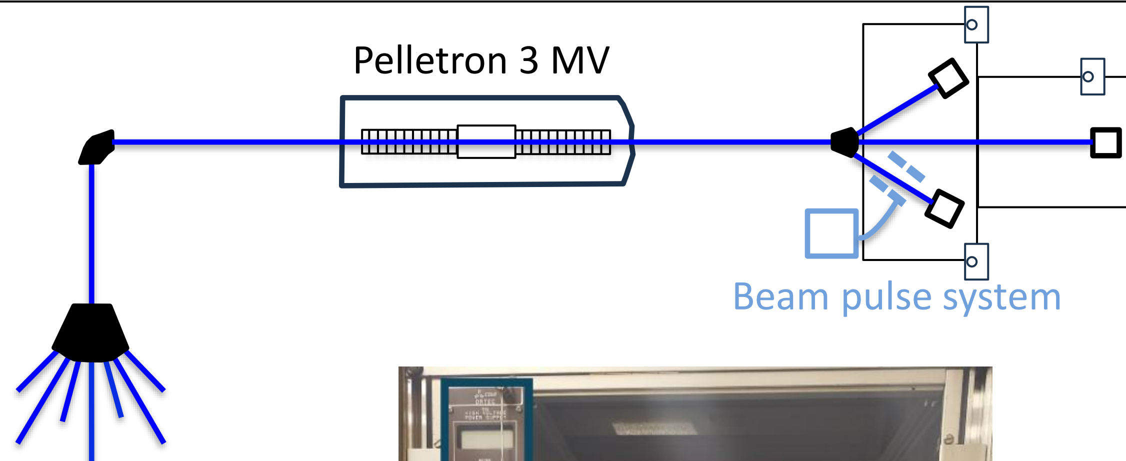
Raster scan : 200 x 200 μm

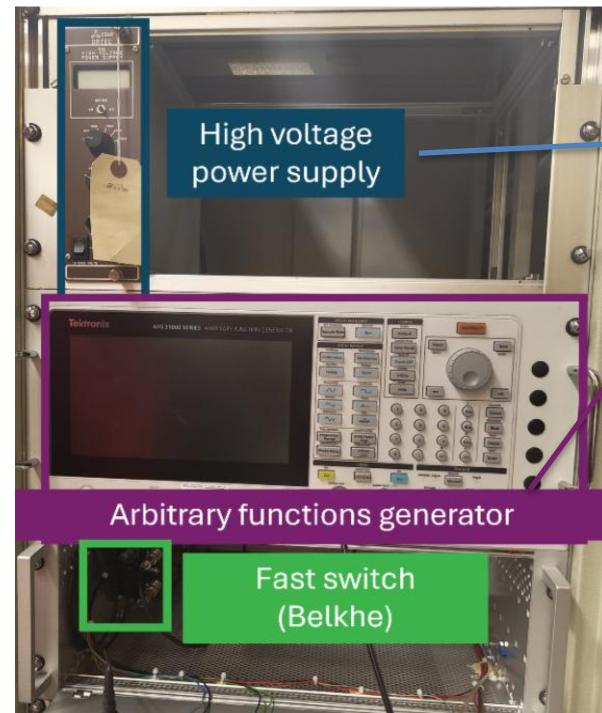
<u>STIM (Scanning trasmission ion microscopy) technique</u>

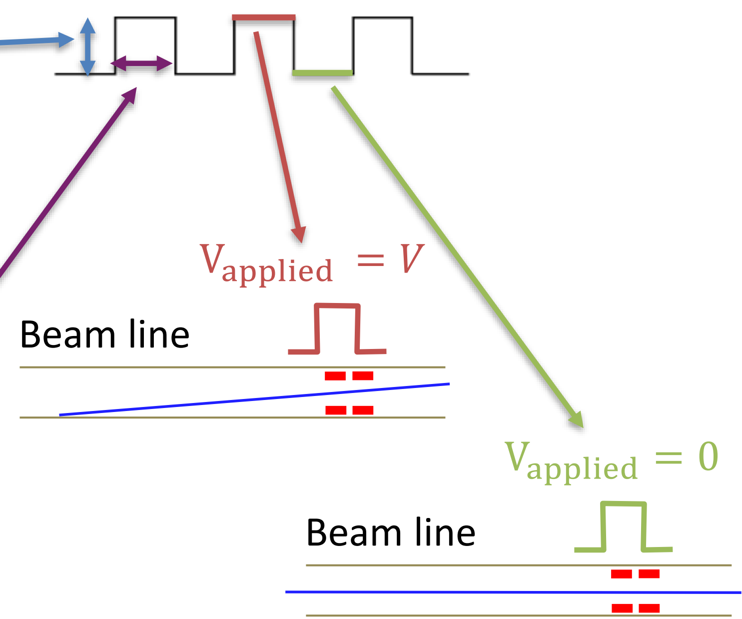
- Accurate **beam size.**
- Silicon detector used for STIM allows to select the ion rate and the **electronic chain gain** before irradiating the diodes with each different ion beam..

Implantation experiment at CNA

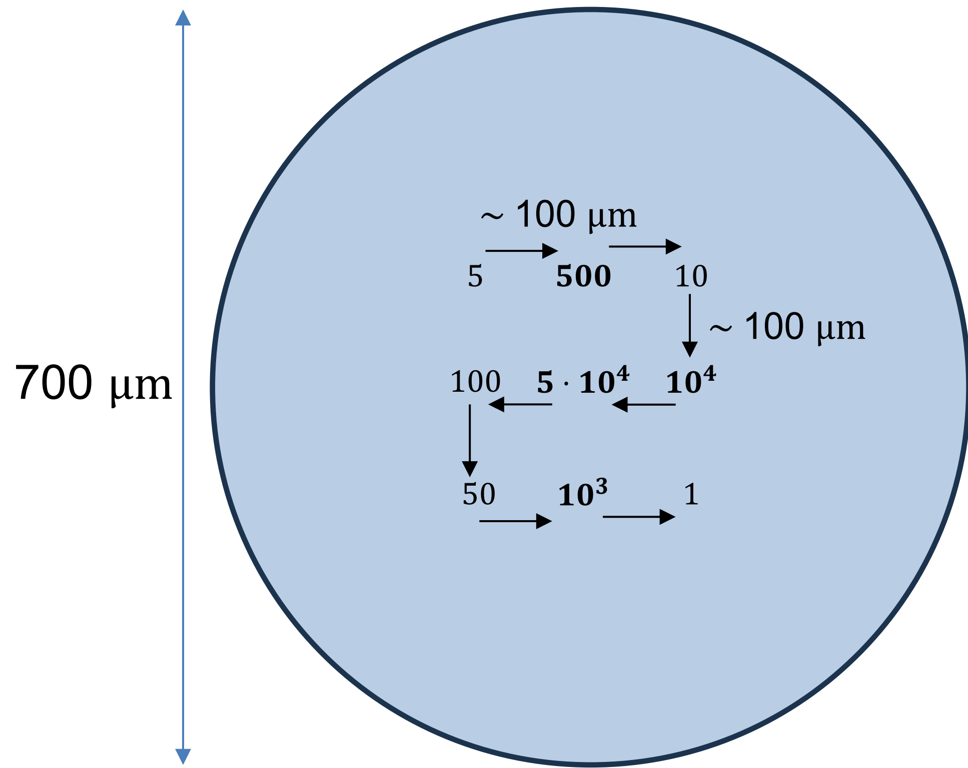
- Stable beam conditions are required for implantation.
- Goal: implant from 1 to $\sim 10^5$ ions per zone.
- Microprobe slits reduce beam current to ~1000 ions/s.
- Beam pulse system enables control of implanted zones with very few ions.



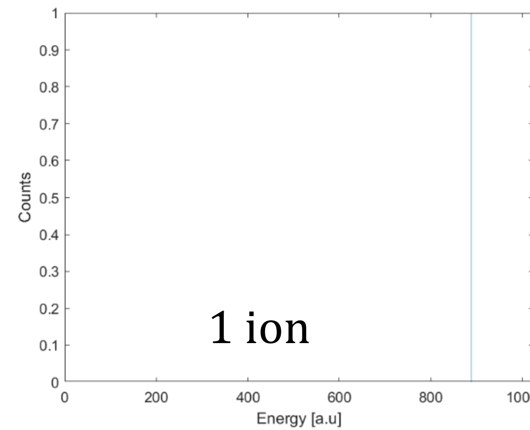


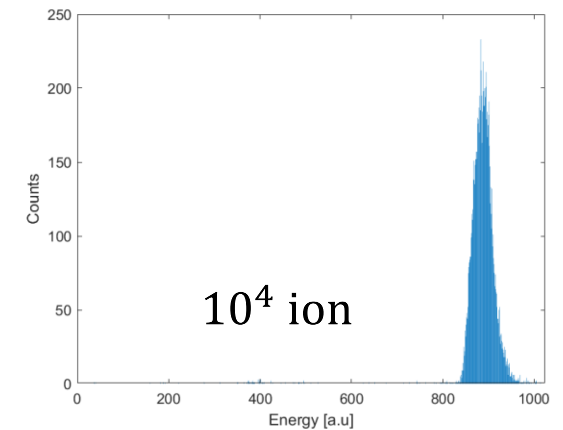


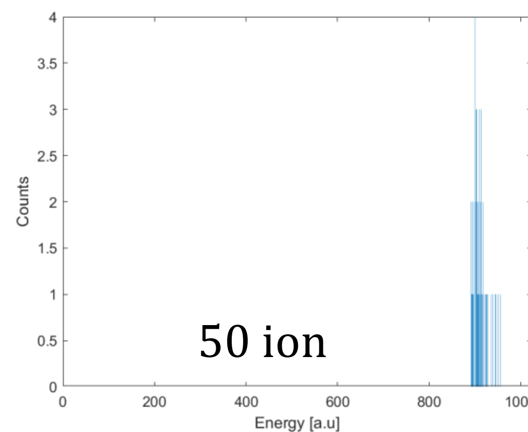
Implantation experiment at CNA

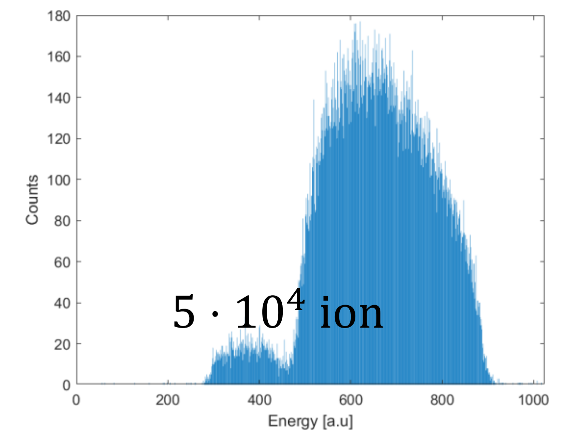


Number of ions implanted



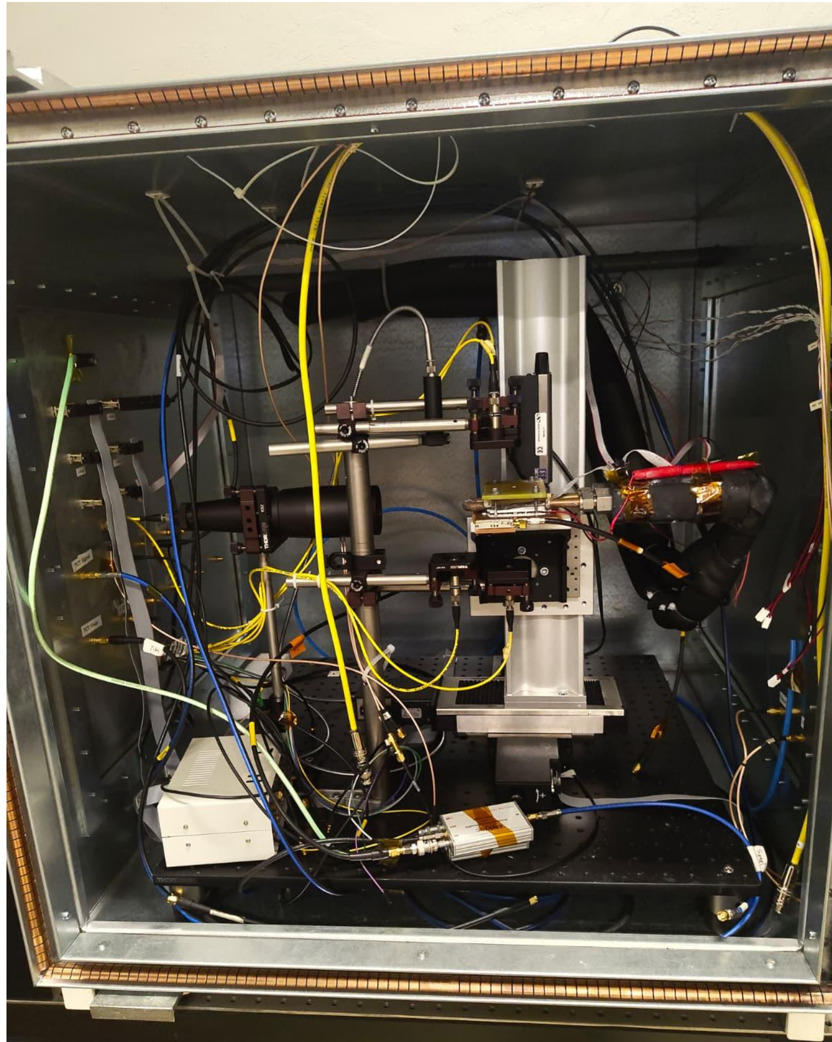






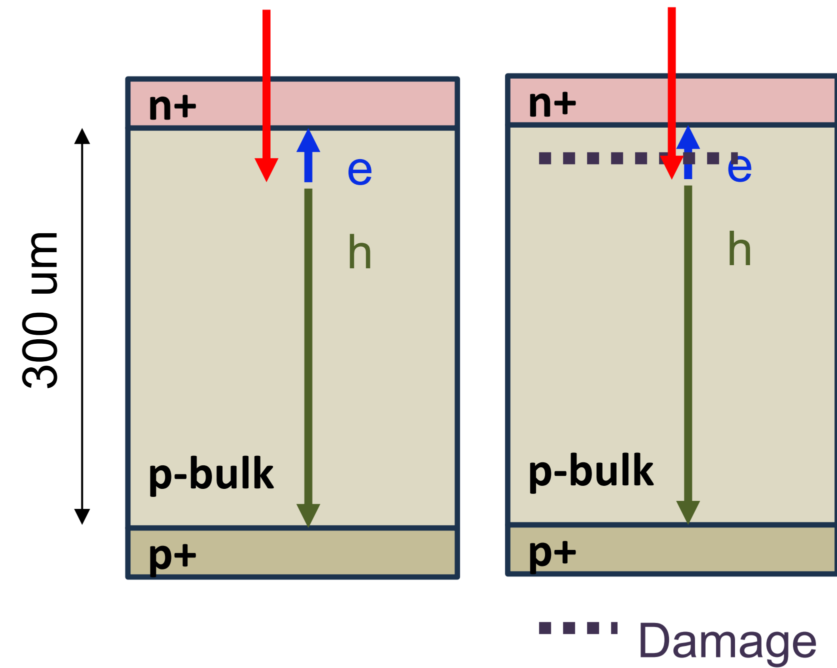
Ion implantation measured with DUT (V = 80 V)

SPA-TCT at CERN



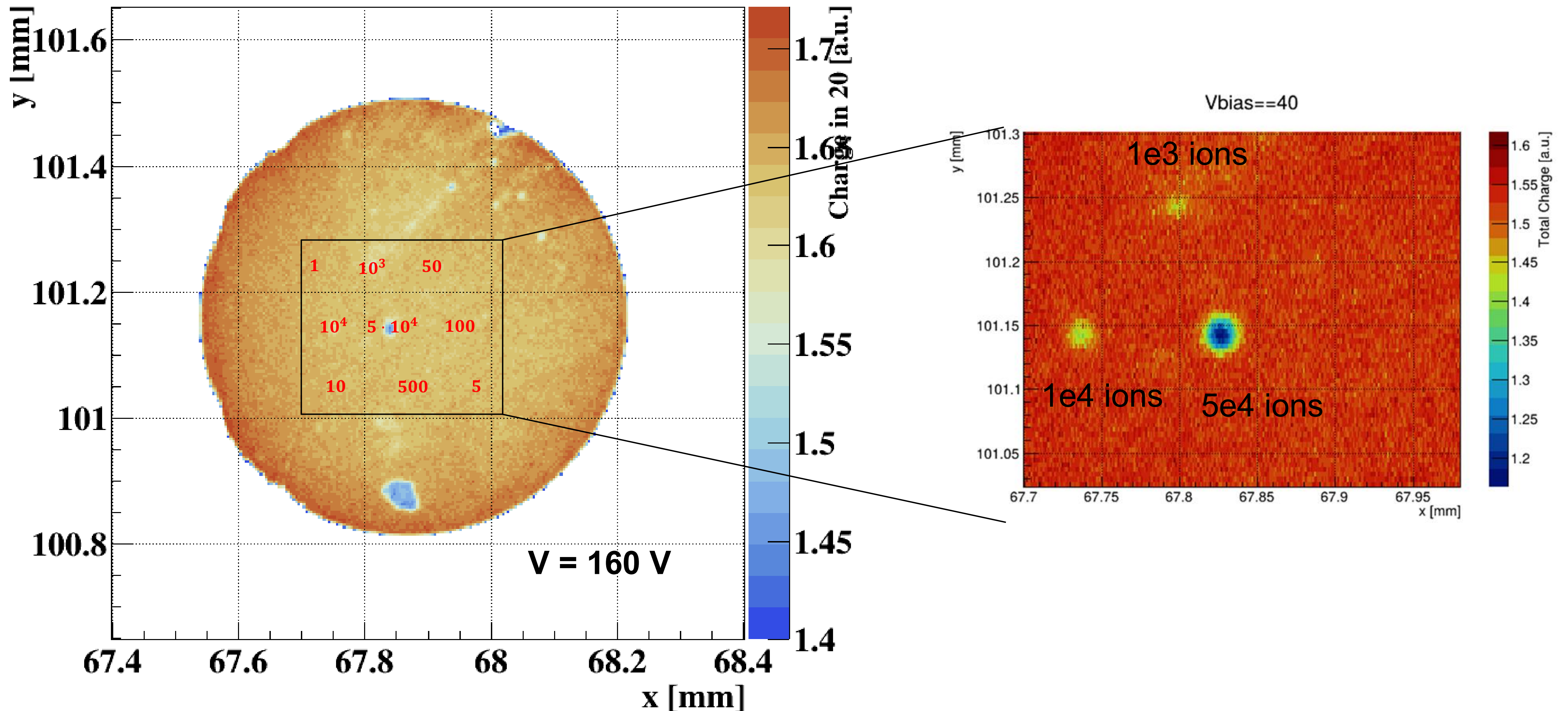
TCT: red laser (650nm = 1.9 eV)

- short penetration depth: carriers created in a few μm from surface
- front and back TCT: study electron and hole drift
- 2D spatial resolution (5-10μm)

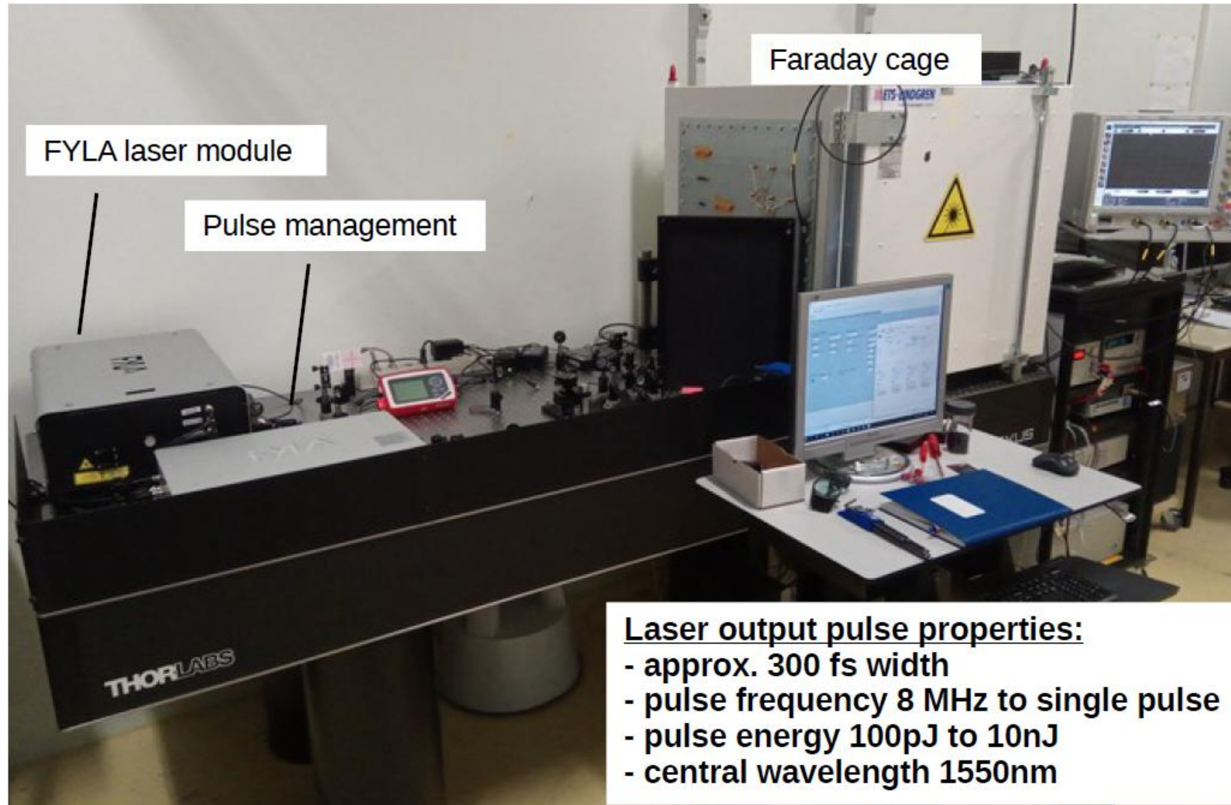


SPA-TCT on Si implanted DUT

TCT: red laser (650nm = 1.9 eV)

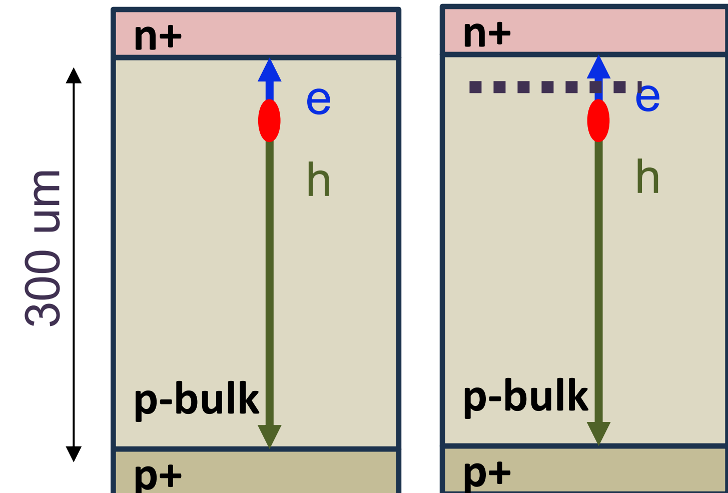


TPA-TCT at CERN



TPA-TCT: SWIR laser (1550nm = 0.8 eV)

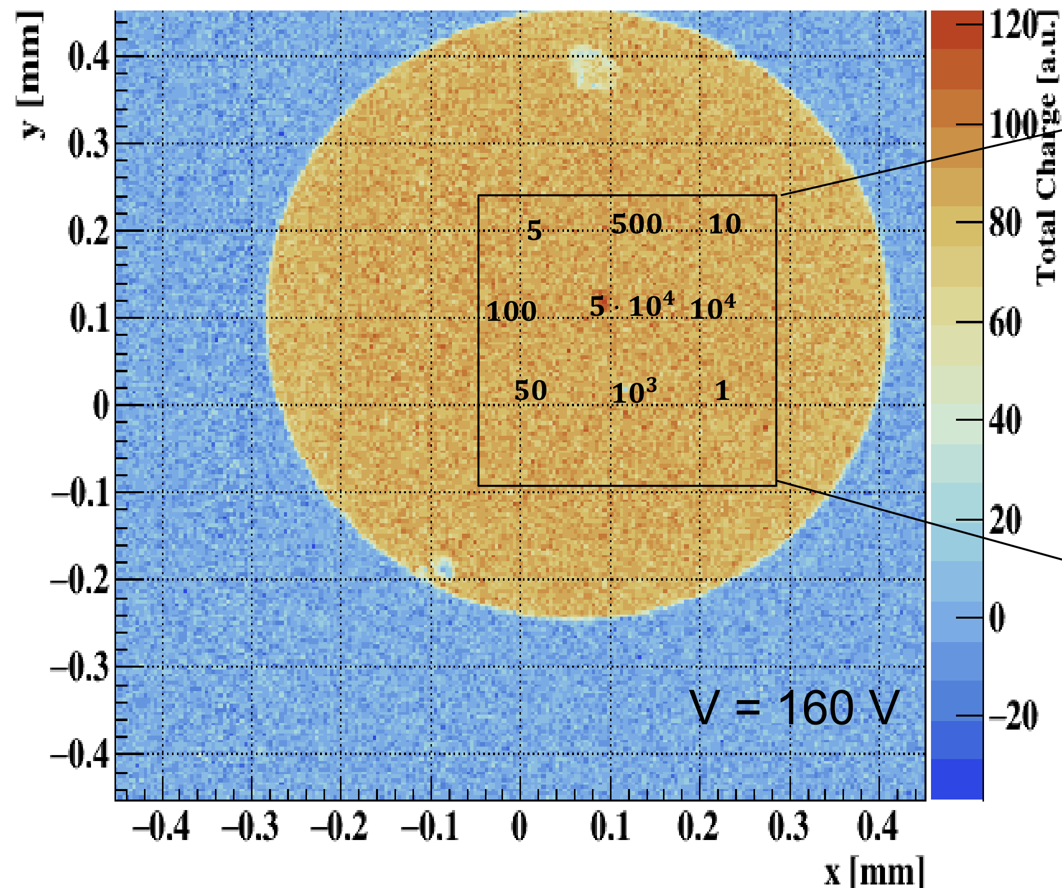
- No single photon absorption in silicon
- 2 photons produce one electron-hole pair
- Point-like energy deposition in focal point
- 3D spatial resolution ($1 \times 1 \times 10\ \mu m^3$)

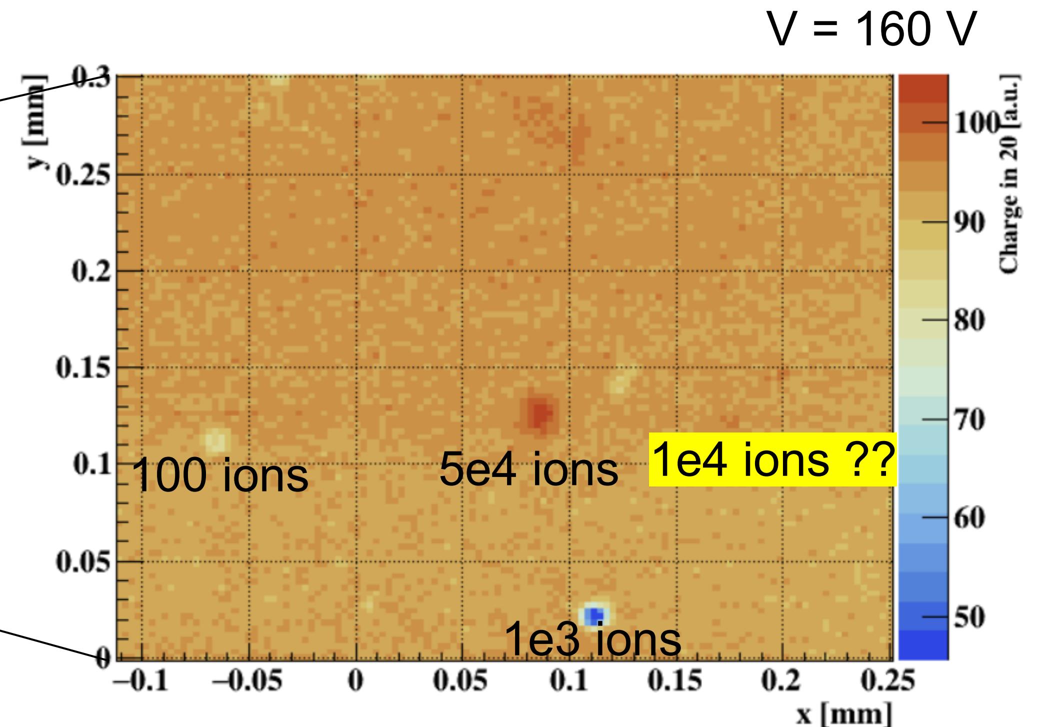


For more information: see PhD thesis M. Wiehe (2021), S. Pape (2024)

TPA-TCT on Si implanted DUT

TPA-TCT: SWIR laser (1550nm = 0.8 eV)





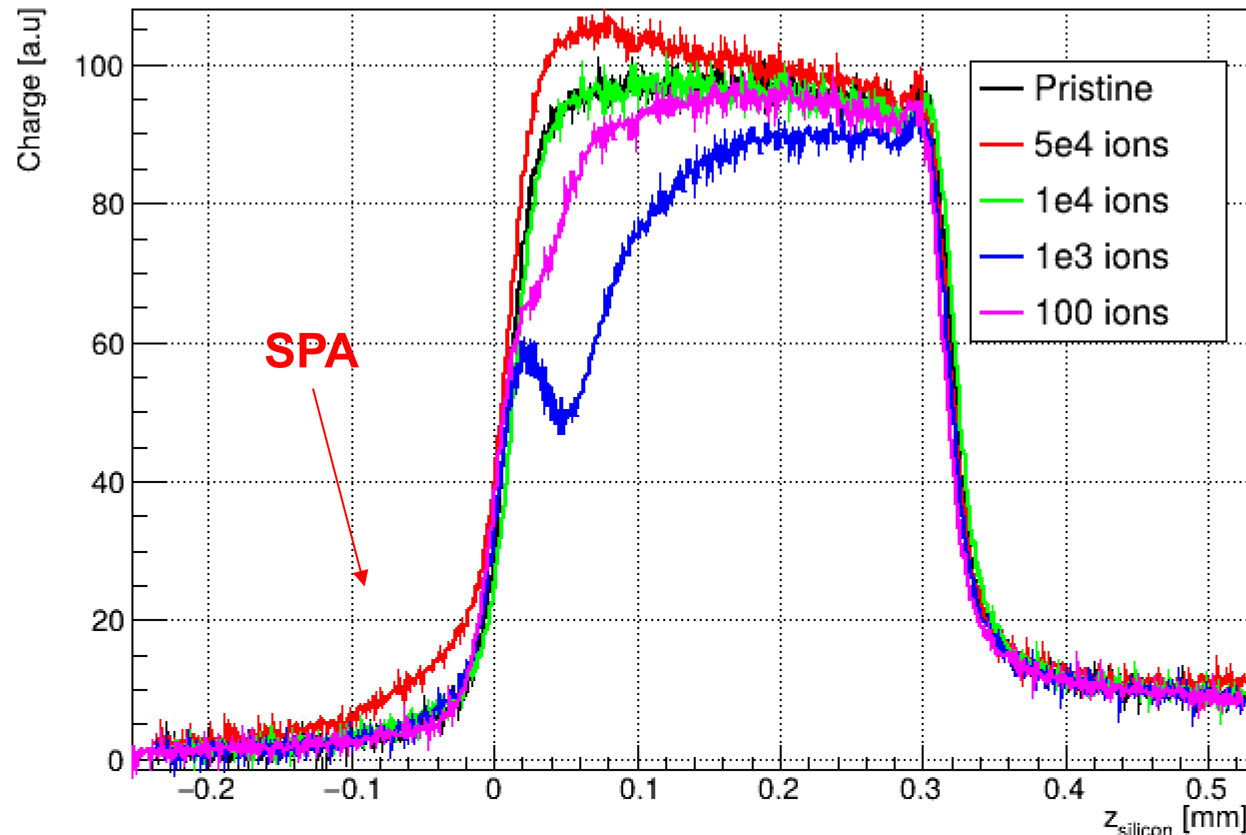
XY scan done at around 50 microns into silicon
(Maximum difference in Charge versus z plots)

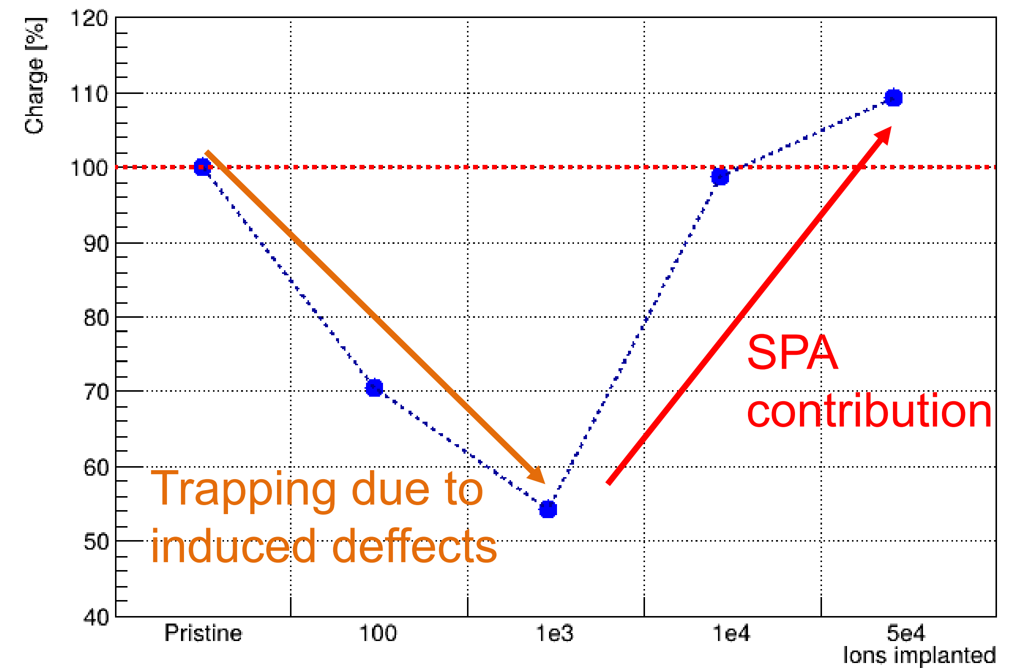
TPA-TCT on Si implanted DUT

Centro Nacional de Aceleradores
Infraestructuras Científicas y Técnicas Singulares
Universidad de Sevilla

TPA-TCT: SWIR laser (1550nm = 0.8 eV)

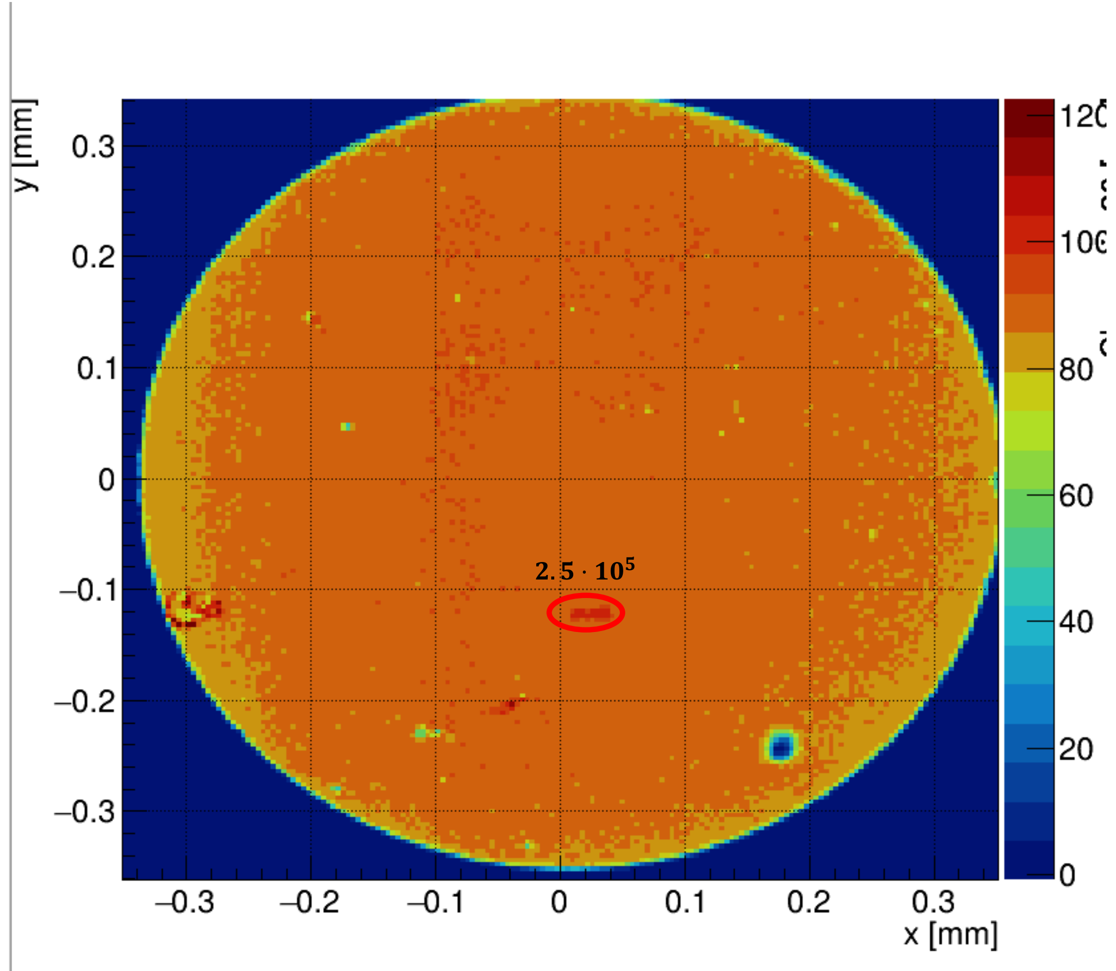
V = 160 V

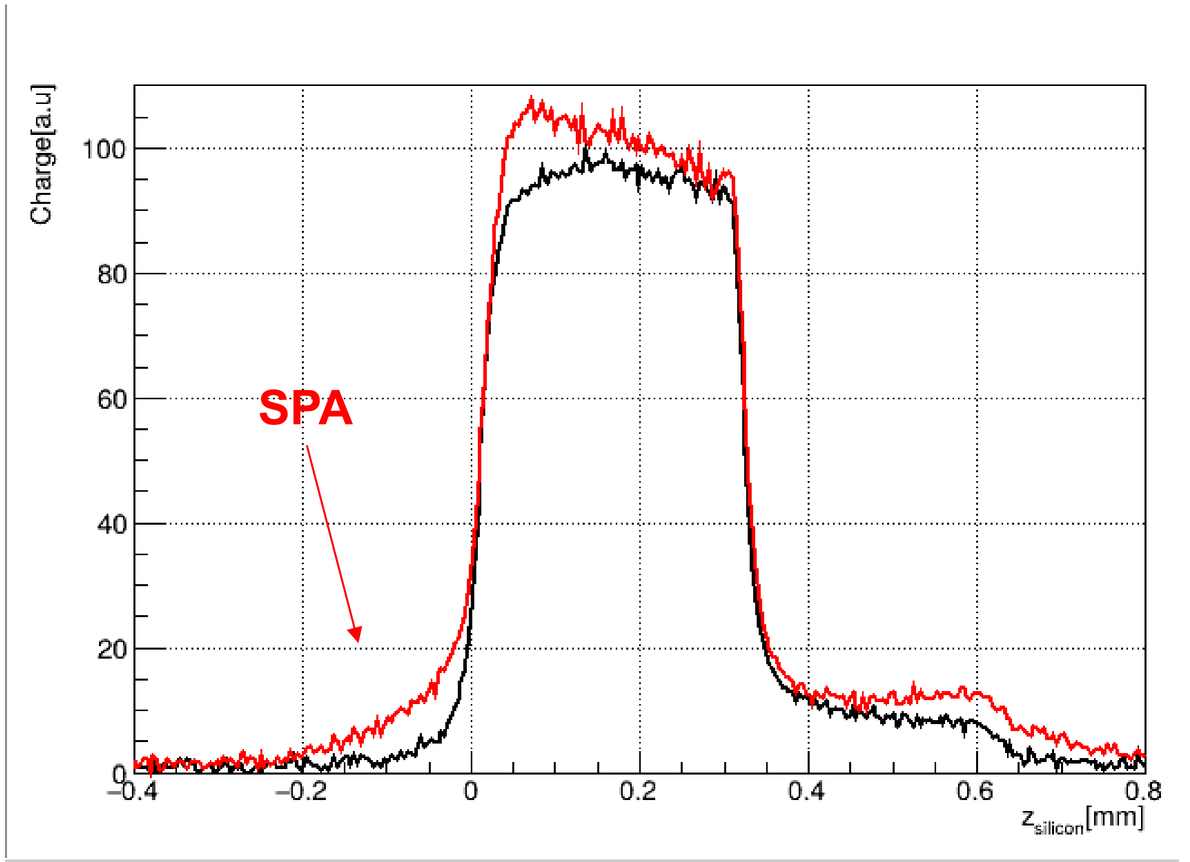




TPA-TCT on O implanted DUT

TPA-TCT: SWIR laser (1550nm = 0.8 eV)





Summary

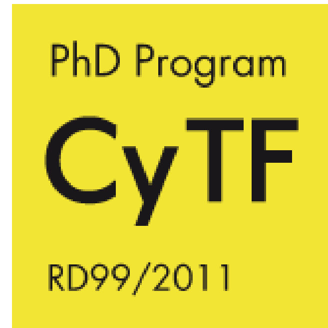
Centro Nacional de Aceleradores
Infraestructuras Científicas y Técnicas Singulares
Universidad de Sevilla

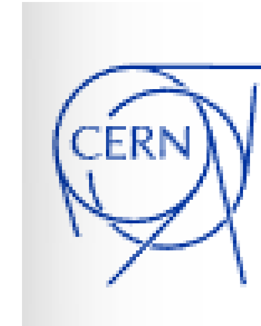
- **Controlled ion implantation** of H, O, Si, and N at CNA — down to **a single ion** per spot.

- SPA-TCT and TPA-TCT used at CERN to detect and localize implantation-induced damage.

- **TPA-TCT** shows **high 3D sensitivity**, revealing **charge loss and defect distribution** in silicon.

Acknowledgments





Actividades del CNA para los "upgrades" de alta luminosidad de CMS y DRDs del ECFA **(PID2023-148418NB-C44).**

C. Torres Muñoz acknowledges support from the University of Seville (Short Stay Grant, VII PPIT-US).

Actuación 1.1 Irradiación de detectores con aceleradores. (ASTRO21/1.1/1).

Back-up slides

Ion implanted