Silicon Carbide Detectors for Intense Luminosity Investigations and Applications

European Nuclear Physics Conference *2018*

Salvo Tudisco

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Why Silicon Carbide for radiation detection

Property	Diamond	GaN	4H SiC	Si
E_g [eV]	5.5	3.39	3.28	1.12
$E_{breakdown}$ [V/cm]	10^7	$4 \cdot 10^6$	$3\text{-}4 \cdot 10^6$	$3 \cdot 10^5$
μ_e [cm^2/Vs]	1800	1000	800	1450
μ_h [cm^2/Vs]	1200	30	115	450
v_{sat} [cm/s]	$2.2 \cdot 10^7$	-	$2 \cdot 10^7$	$0.8 \cdot 10^7$
Z	6	31/7	14/6	14
ε_r	5.7	9.6	9.7	11.9
e-h energy [eV]	13	8.9	7.6-8.4	3.6
Density [g/cm3]	3.515	6.15	3.22	2.33
Displacem. [eV]	43	≥15	30-40	13-15

- Wide band-gap (3.3eV)
  ⇒ Visible blind
  ⇒ Lower Leakage current
- High Breakdown
  ⇒ Advantage for Radiations hardness
- Different e-h mobility
  ⇒ Charge Identification pulse shape analysis
- Fast devices
  ⇒ Timing applications
- Higher displacement threshold
  ⇒ Radiation harder then Silicon
- Signal
  ⇒ Less charge than Si, SiC≈Si/2
  ⇒ A problem for MIP!

Diamond	36 e/μm
SiC	51 e/μm
Si	89 e/μm

  ⇒ No problem in all other case

Applications

- UV - Soft-X detection
- Charged Particle detection and identification
- Neutron detection

Radiation Hard detectors for Nuclear Physics experiments and Nuclear applications

Call GRV-INFN

SiCILIA strategy

Epitaxial growth SIC: beyond the state of the art (small number of defects)

New Tecnology

- Schottky junctions
- p-n junctions

STMicroelectronics

FONDAZIONE BRUNO KESSLER

Participating INFN research units

*INFN Laboratori Nazionali del Sud di Catania (**LNS**)*

*INFN Sezione di Catania and "Gruppo collegato di Messina" (**CT-ME**)*

*INFN Sezione di Milano Bicocca (**MI-B**)*

*INFN Sezione di Milano (**MI**)*

*INFN Sezione di Firenze (**FI**)*

*INFN Sezione TIFPA (**TN**)*

*INFN Sezione Pisa (**PI**)*

External institutions

CNR-IMM – Catania
CNR-INO – Pisa
PSI – Switzerland
ENEA- Frascati

Companies

Fondazione Bruno Kessler (**FBK**) – Trento
ST Microelectronics – Catania
LPE – Catania (**LPE**)

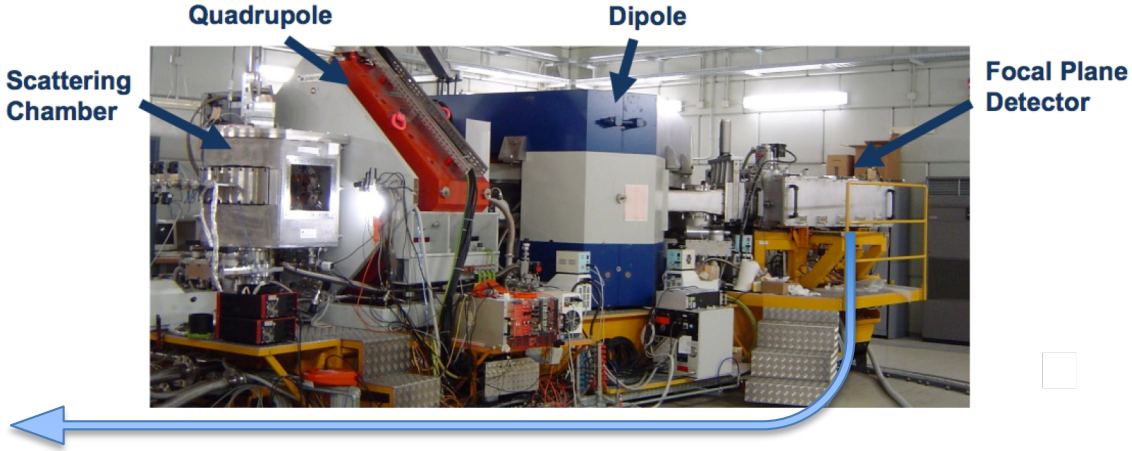
NUMEN project

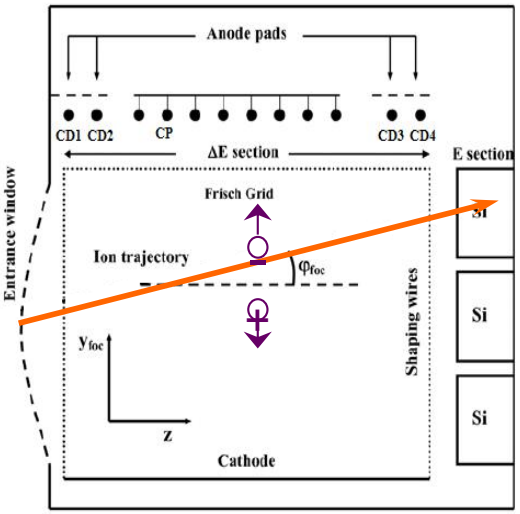
NUclear **M**atrix **E**lements of **N**eutrinoless Double Beta Decays by Heavy Ion **D**ouble **C**harge **E**xchange Reactions

DCE => ^{12}C, ^{18}O, ^{20}Ne to energies between 15 and 30 MeV/u

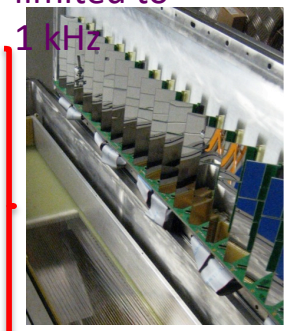
MAGNEX

Multiwire gas tracker and ΔE stage





limited to 1 kHz



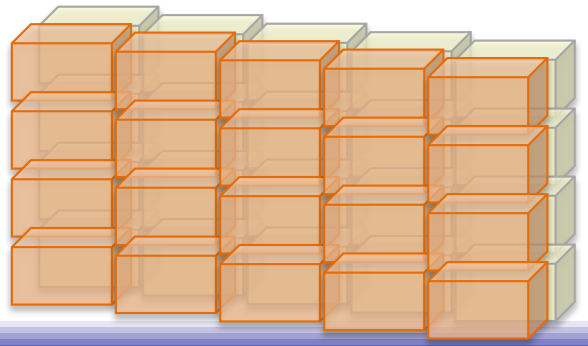
From Multiwire gas tracker → to GEM gas tracker

From 7 X 5 cm² silicon Wall → **to 1 cm² telescopes wall**

F. Cappuzzello et al. EPJ A 54 Iss. 5 n. 72 (2018)

R. H. → 10^{14} ions/cm² in ten years of activity

(Si detector dead @ 10^9 implanted ions/cm²)



1 cm² *ΔE-E* telescope

SiCILIA

INFN

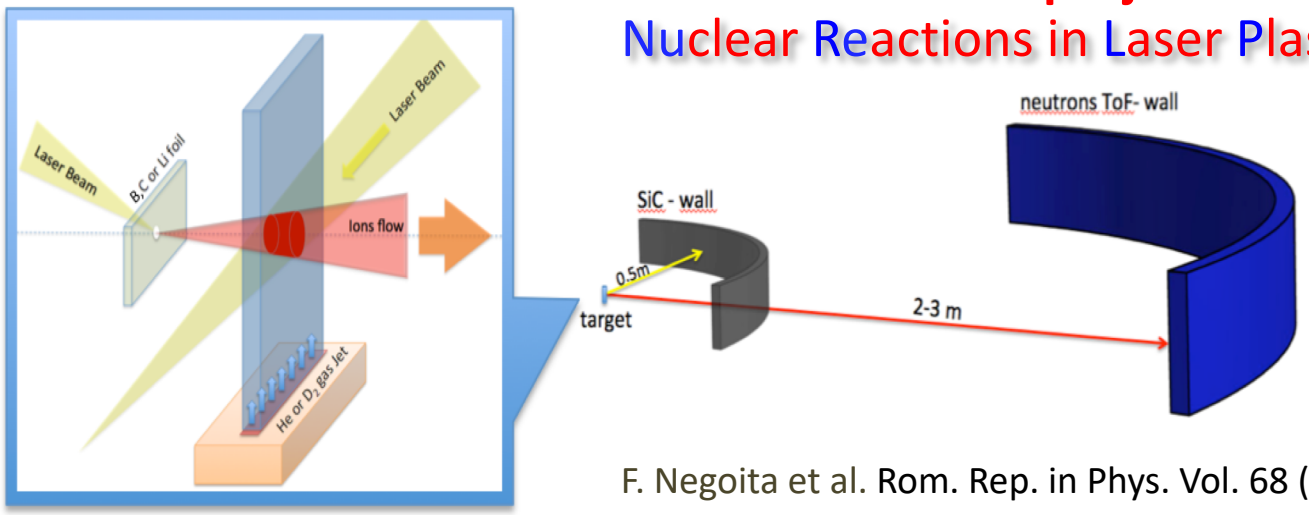
Detectors working in plasmas environment

Requirements

- ✓ Radiation Hardness
- ✓ Timing
- ✓ Insensibility to the visible radiation
- ✓ X-ray sensitivity

NuReLP project

Nuclear Reactions in Laser Plasmas

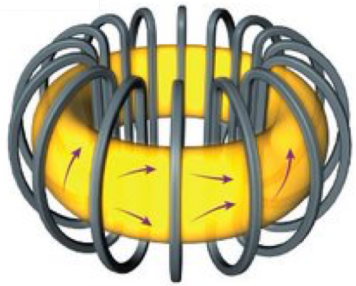


eli-NP
extreme light infrastructure

F. Negoita et al. Rom. Rep. in Phys. Vol. 68 (2016) S37-S144

Applications

- ✓ ELIMED-diagnostic
- ✓ High temperature X-Ray spectroscopy (Space applications…)
- ✓ Neutrons detection (Reactors, Tokamaks…)
- ✓ Dosimetry, beam diagnostic and medical Imaging



Defects in Silicon Carbide

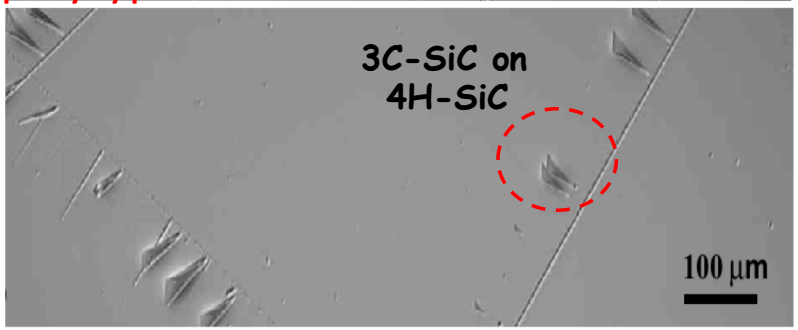
Macroscopic defects
- polytype inclusions
- micropipes
- comets, carrots

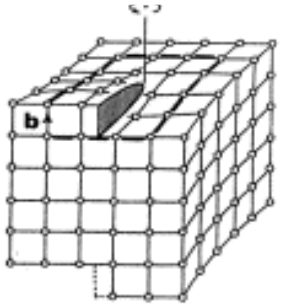
Microscopic defects
- dislocations
- stacking faults
- interstitial, vacancies
- divacancies, antisites

Extended defects

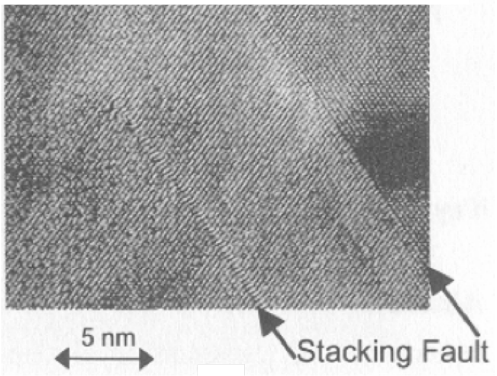
Micro-pipe

polytype inclusions

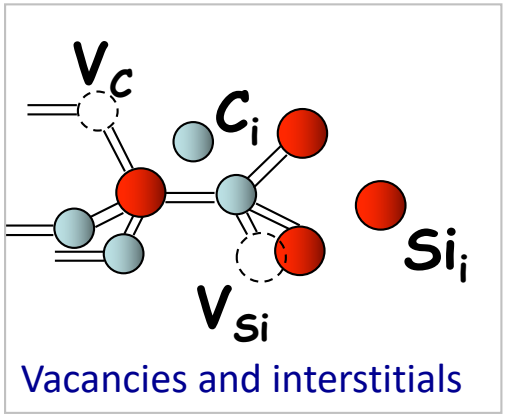




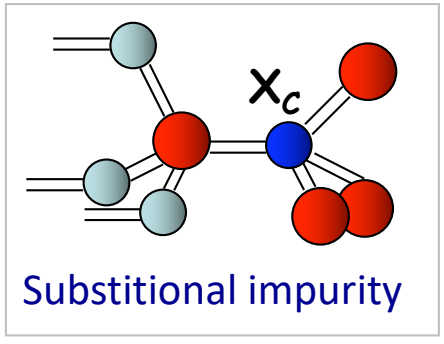
dislocations



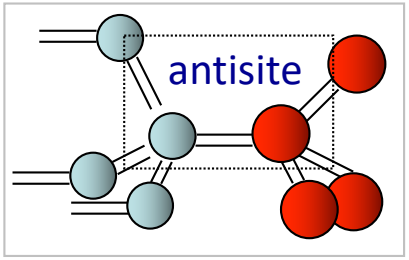
Point and Point-like defects



Vacancies and interstitials



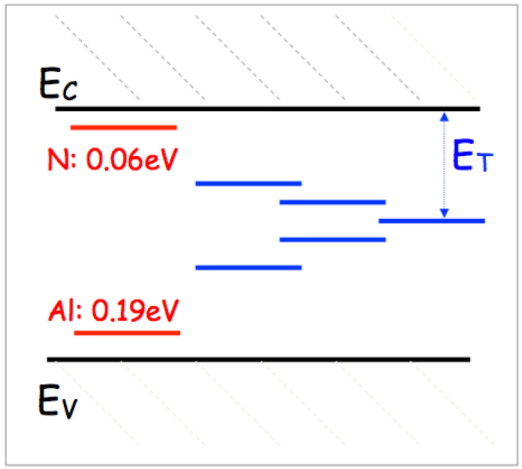
Substitional impurity



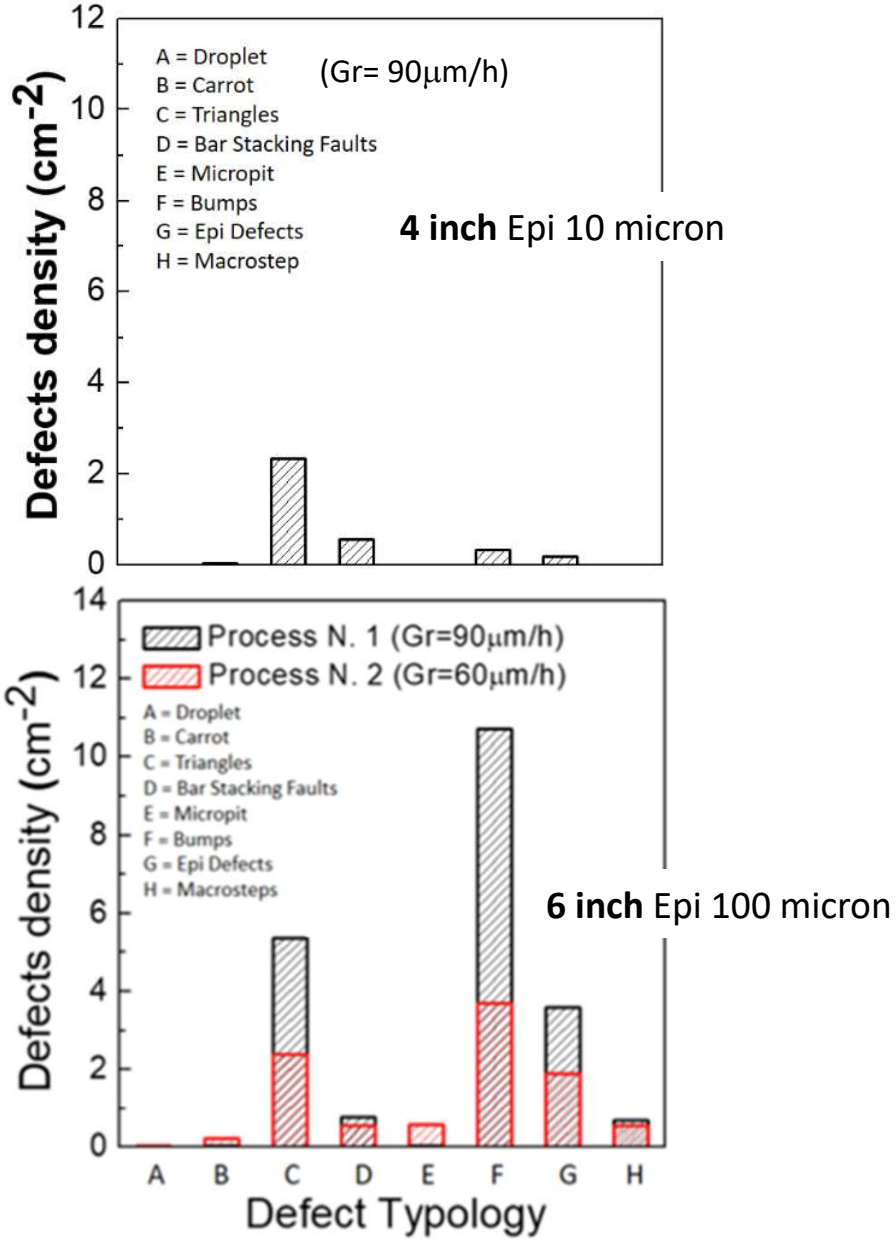
Donor & Acceptor Impurities

Deep levels in the gap =>

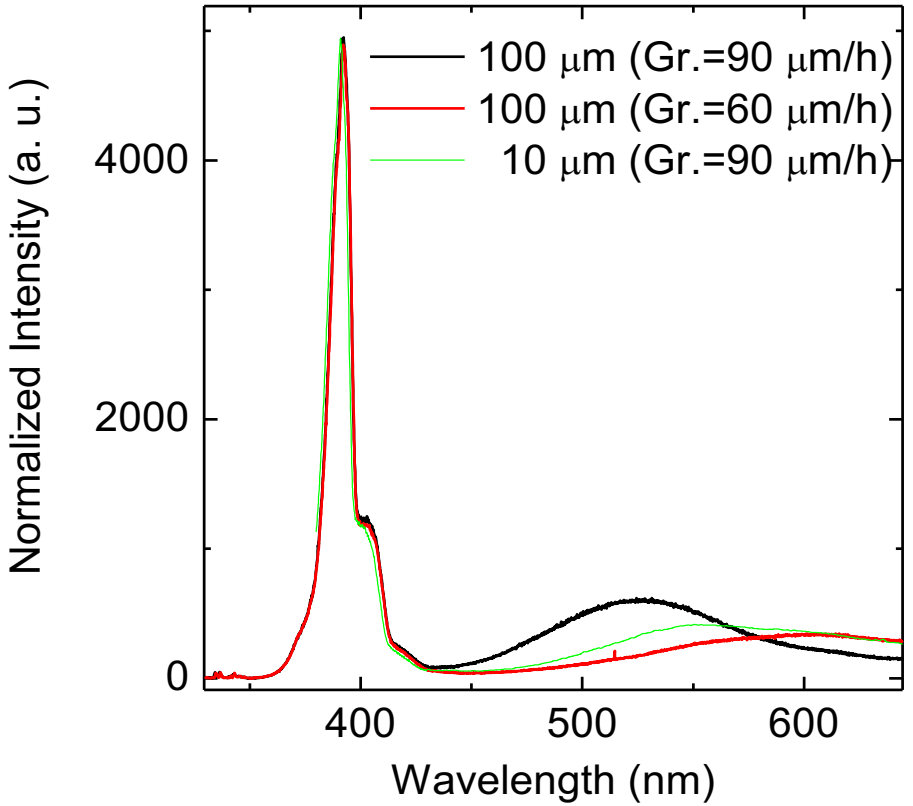
Defect-Levels



Epitaxial growths



Micro-photoluminescence analysis



S. Tudisco et al. SENSORS Vol. 18 (2018) 2289

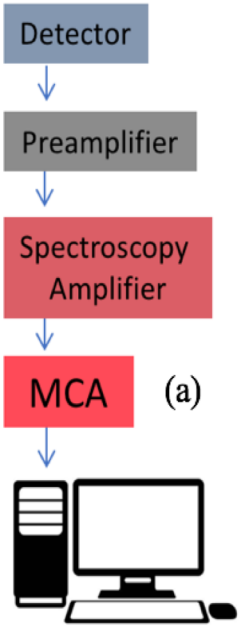
Energy Resolution

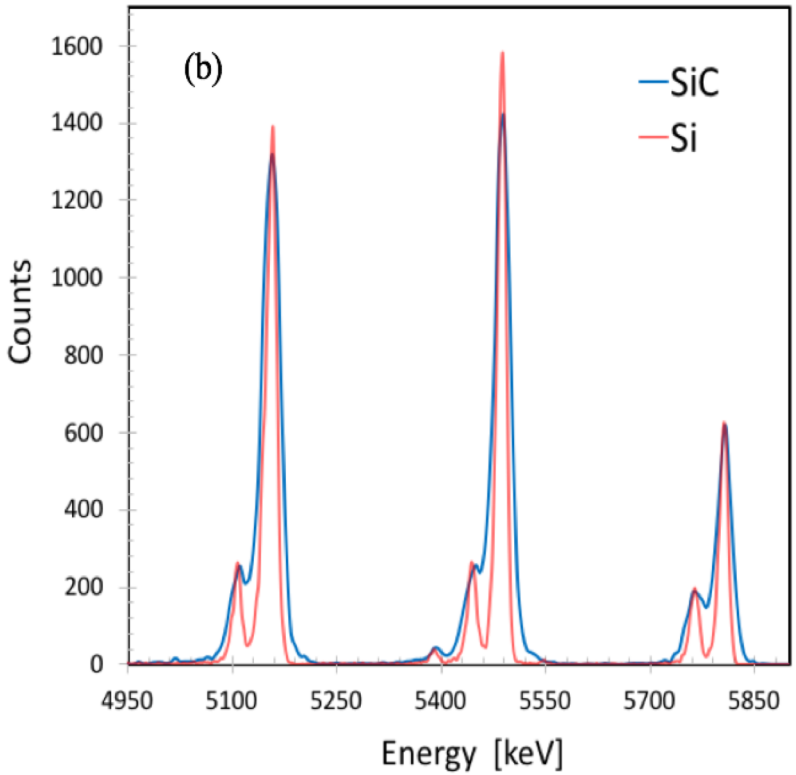
Test => Radioactive ^{241}Am Alpha source

SiC => 42.8 keV FWHM (37.9 keV)

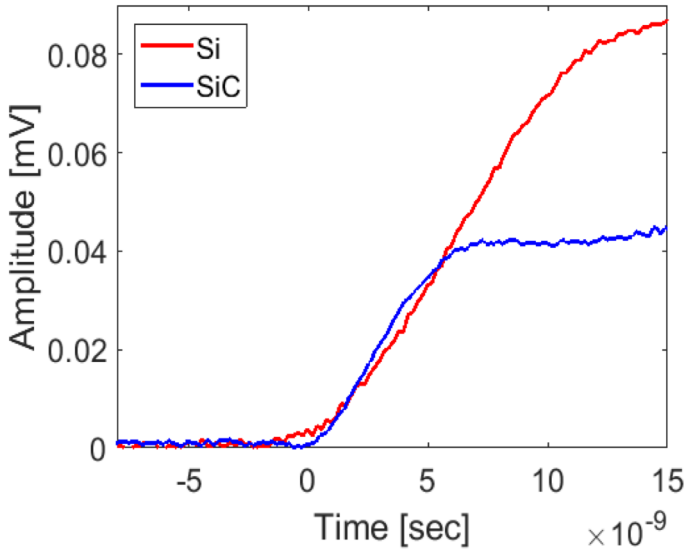
Si => 21.4 keV FWHM (17.1 keV)

Electronic Noise



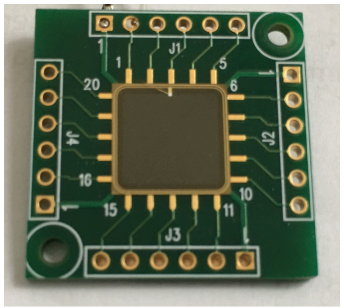


Timing

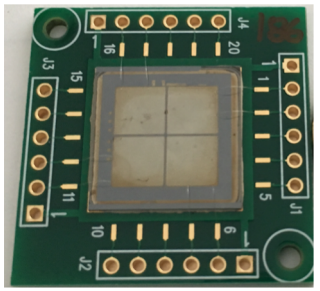


SiC ~ 2 ns

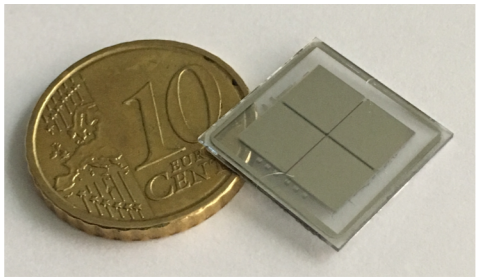
Prototypes



10µm 10x10 mm²



100µm 4 pad da 5x5 mm²



500µm 4 pad 5x5 mm² Intrinsic

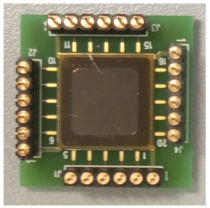
Radiation Hardness

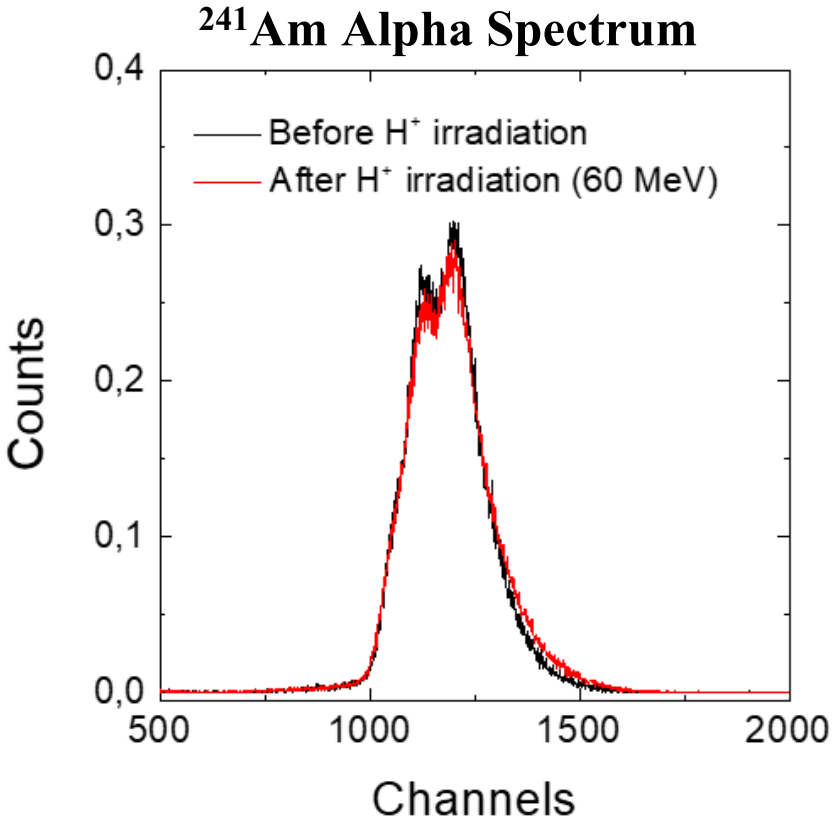
Protons beam irradiation

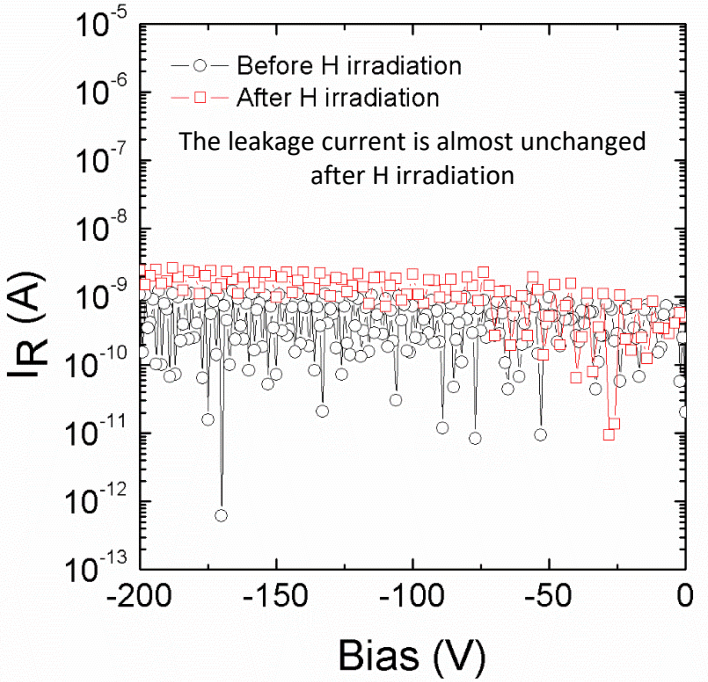
60 MeV H^+ → SiC 10µm 1x1 cm^2

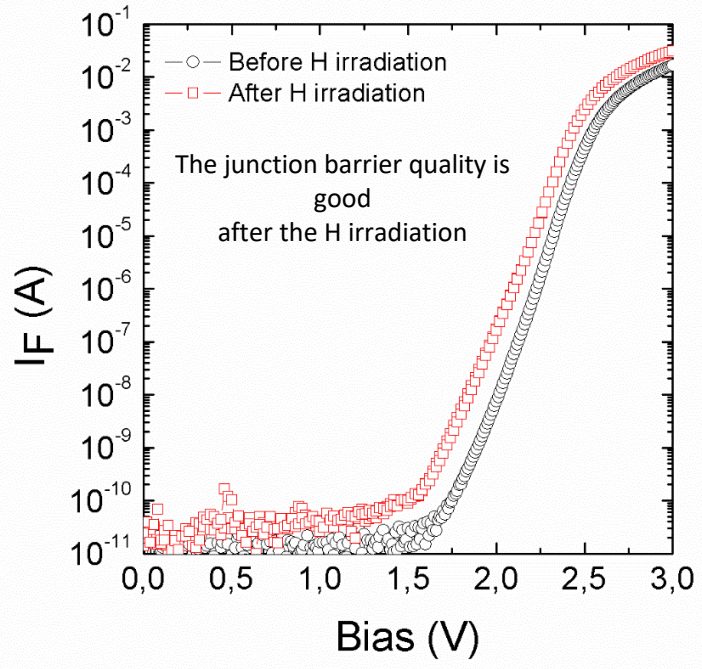
2KGy (2.5 x 10^{12} H^+/cm^2)

LNS CATANA line



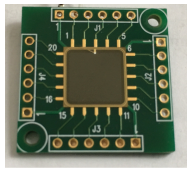


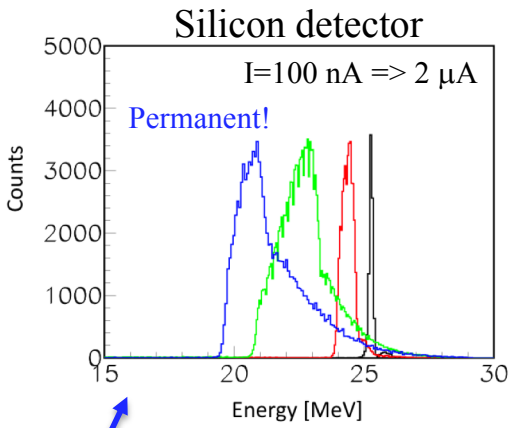


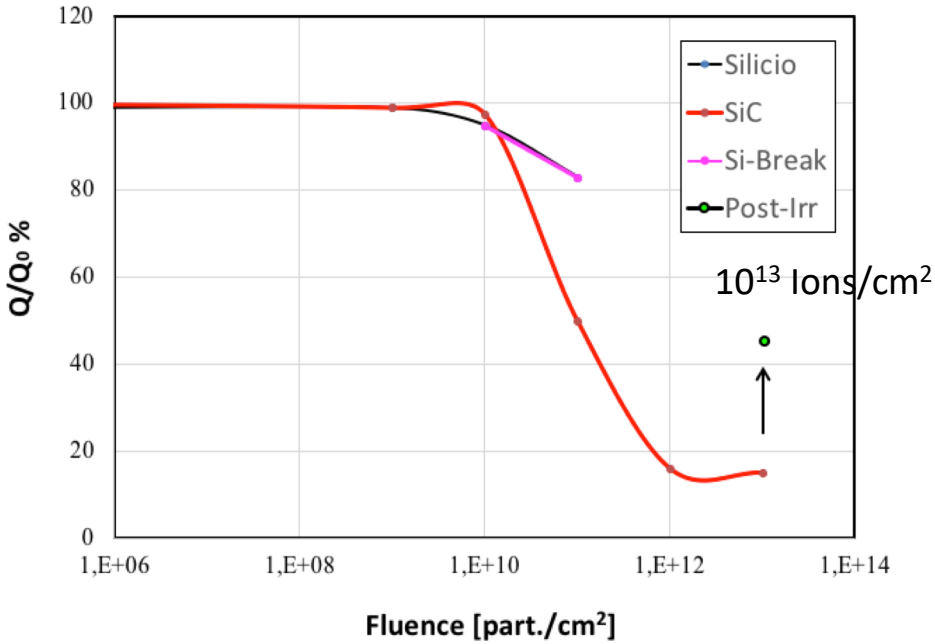


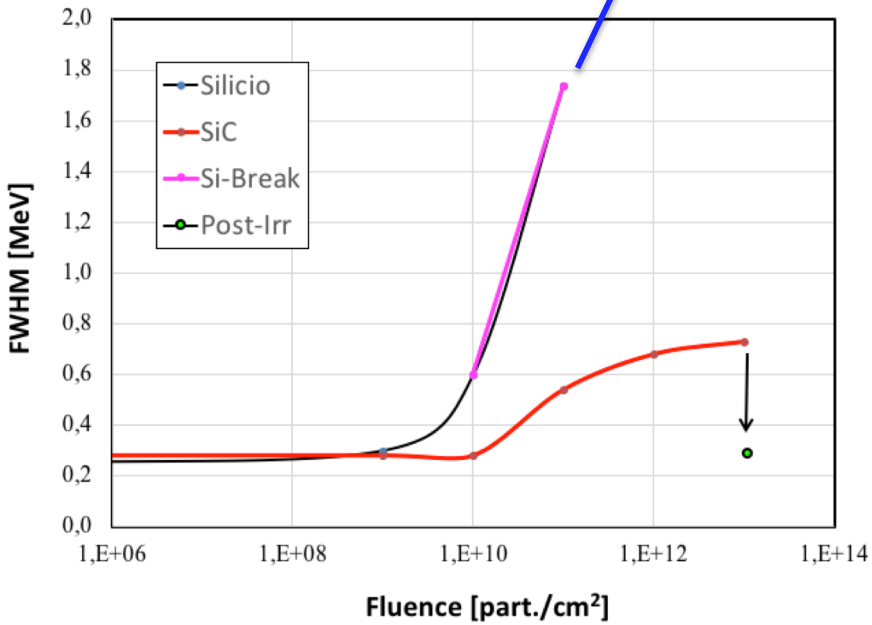
Radiation Hardness

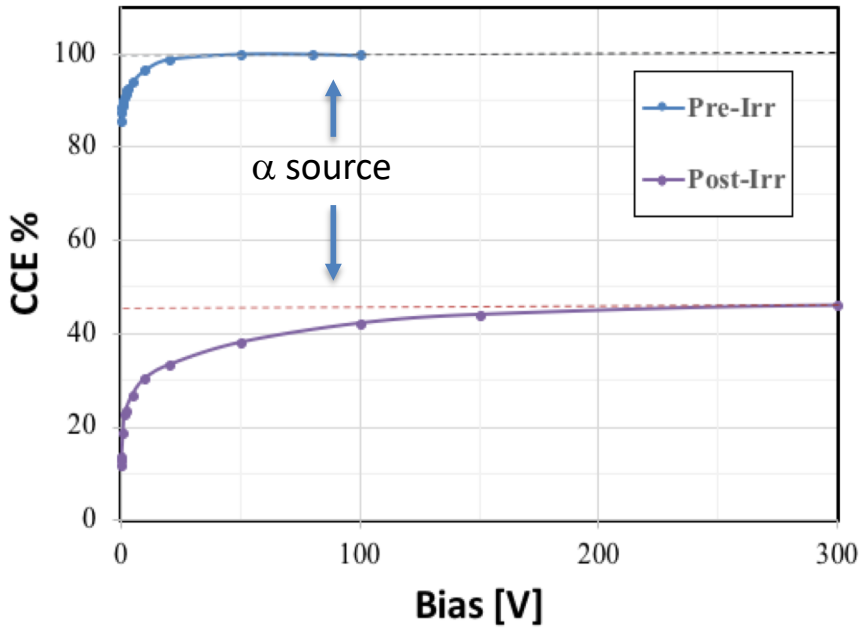
^{16}O 15 MeV ⟶ SiC 10µm 5x5 mm²



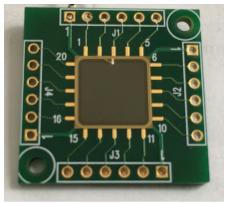




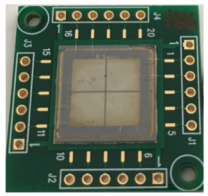




Telescope configuration



10 µm

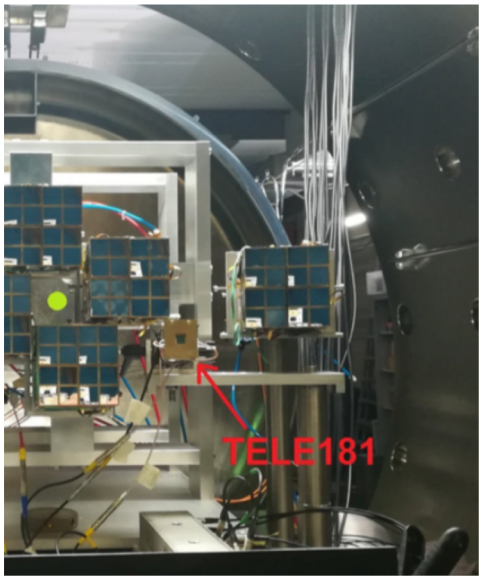


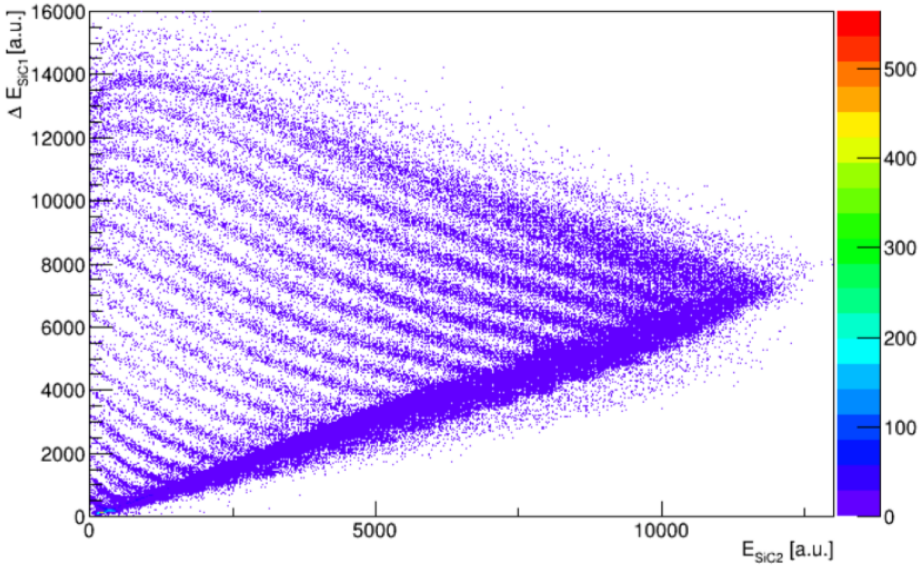
100 µm

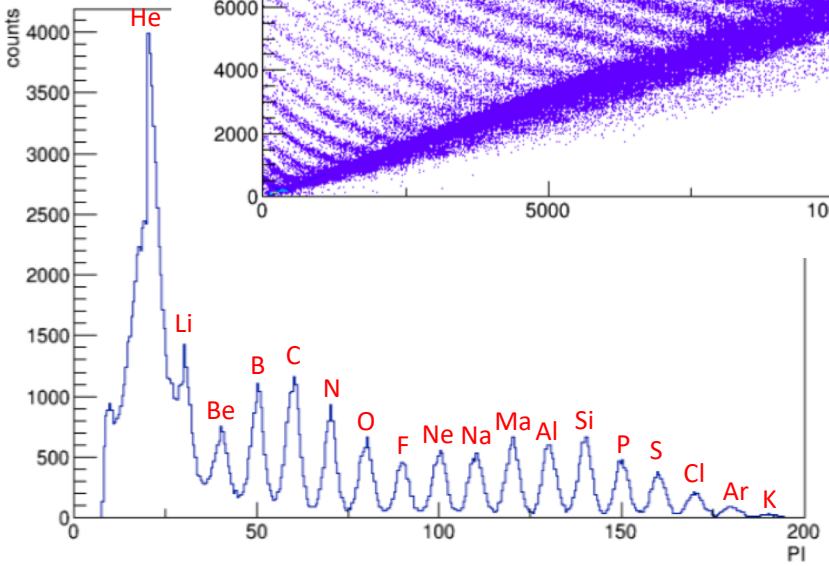
$^{48}Ca+^{12}C$ at 25 MeV/n

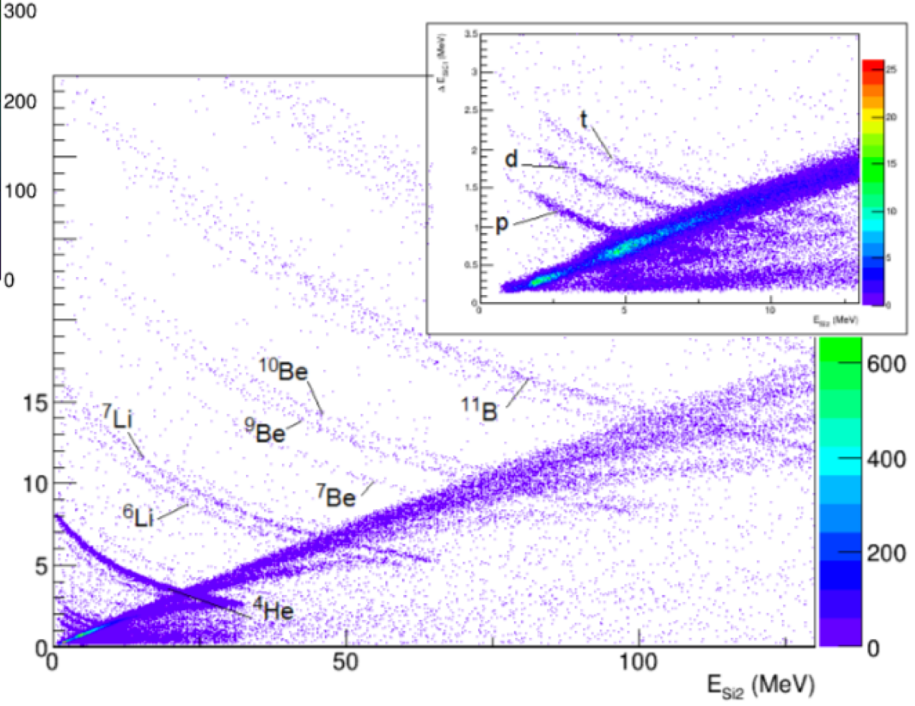
Stage 1
181-SiC1
100µm
dead layer
+
10µm SiC

Stage 2
181-SiC2
100µm SiC
+
300µm
dead layer









Particle Identification after Linearization

SiCILIA Collaboration

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