Radiation damage studies of new p-n junction SiC detectors

17th "Trento" Workshop on Advanced Silicon Radiation Detectors

SiCILIA collaboration

Silicon **C**arbide Detectors for **I**ntense **L**uminosity **I**nvestigations and **A**pplications

SiCILIA strategy

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)

institutions and Companies

CNR-IMM – Catania
CNR-INO – Pisa
PSI – Switzerland
ENEA- Frascati
Fondazione Bruno Kessler (**FBK**) – Trento
ST Microelectronics – Catania
LPE – Catania (**LPE**)

Why Silicon Carbide for radiation detection?

Property	Si	Diamond	Diamond	4H SiC
Material	MCz, FZ, epi	Polycrystal	single crystal	epitaxial
E_g [eV]	1.12	5.5	5.5	3.3
$E_{breakdown}$ [V/cm]	$3 \cdot 10^5$	10^7	10^7	$2.2 \cdot 10^6$
μ_e [cm^2/Vs]	1450	1800	>1800	800
μ_h [cm^2/Vs]	450	1200	>1200	115
v_{sat} [cm/s]	$0.8 \cdot 10^7$	$2.2 \cdot 10^7$	$2.2 \cdot 10^7$	$2 \cdot 10^7$
Z	14	6	6	14/6
ε_r	11.9	5.7	5.7	9.7
e-h energy [eV]	3.6	13	13	7.6
Density [g/cm3]	2.33	3.515	3.515	3.22
Displacem. [eV]	13-20	43	43	25
e-h/μm for mips	~80	36	36	55

- **Wide band-gap** (3.3eV)
  ⇒ **Visible blind**
  ⇒ Low 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 hardness** more than Silicon
- **Signal**
  ⇒ Less charge than Si, SiC≈Si/2
  ⇒ A problem for MIP!
  ⇒ No problem in all other case

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

GOALS
- **Epitaxial growth SiC beyond the state of the art**
- **Processing** ➡ Schottky **=> p-n junctions**

Defects in Silicon Carbide

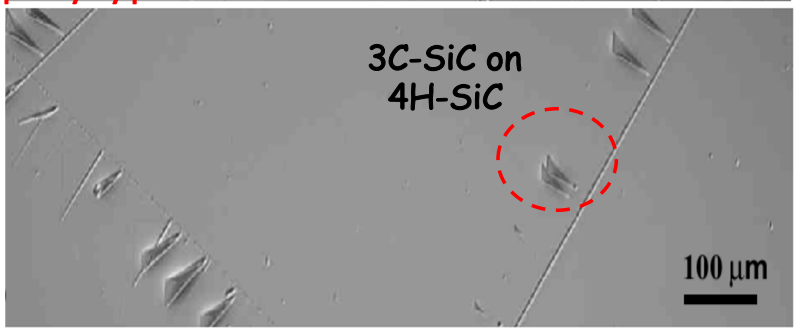
Macroscopic defects
- polytype inclusions
- micropipes
- comets, carrots

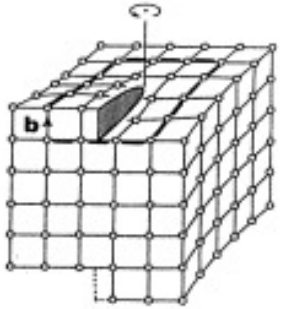
Microscopic defects
- dislocations
- stacking faults
- interstitial, vacancies
- divacancies, antisites

Extended defects

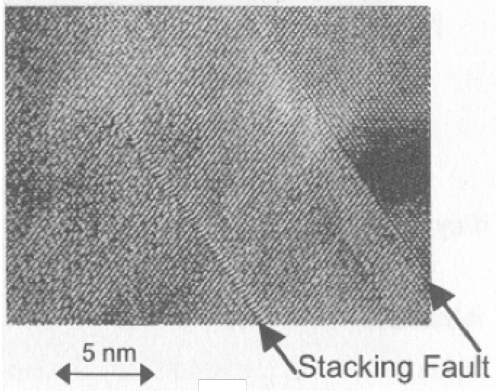
Micro-pipe

polytype inclusions

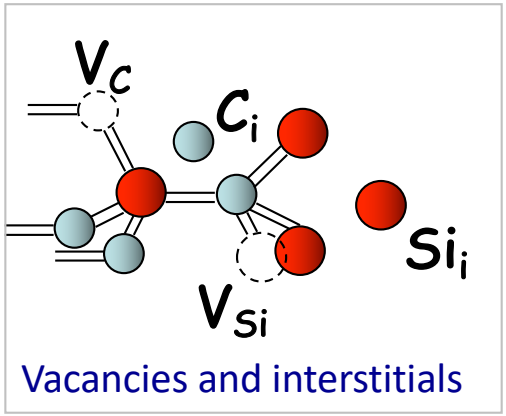




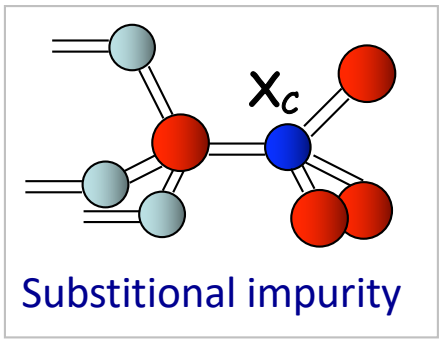
dislocations



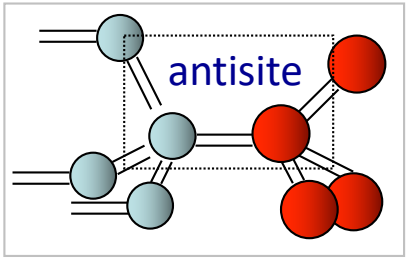
Point and Point-like defects



Vacancies and interstitials



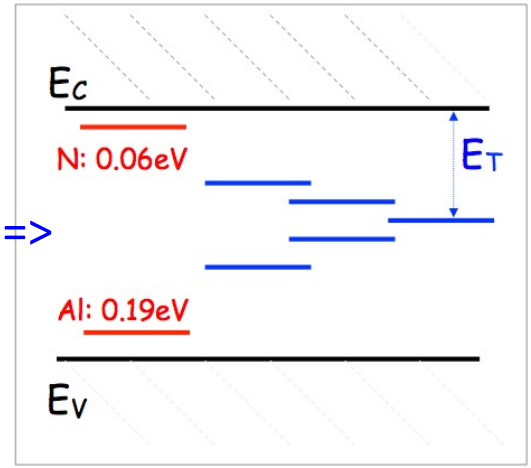
Substitional impurity



Donor & Acceptor Impurities

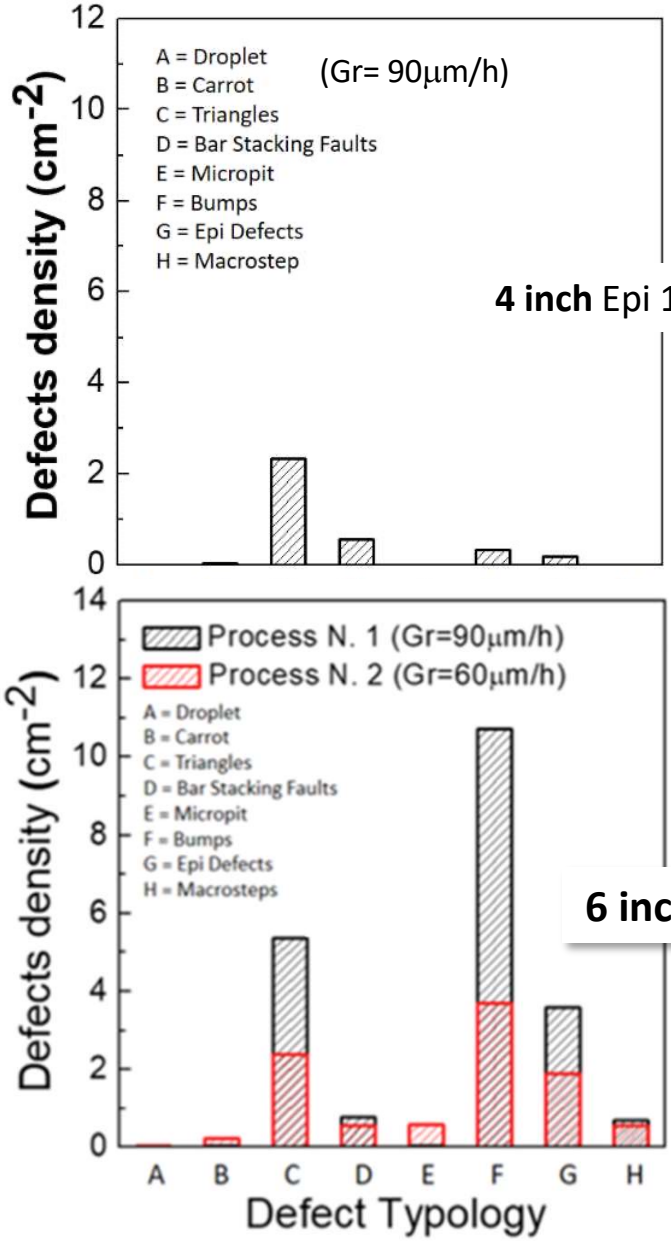
Deep levels in the gap =>

Defect-Levels



Epi-Layers beyond the state of the art

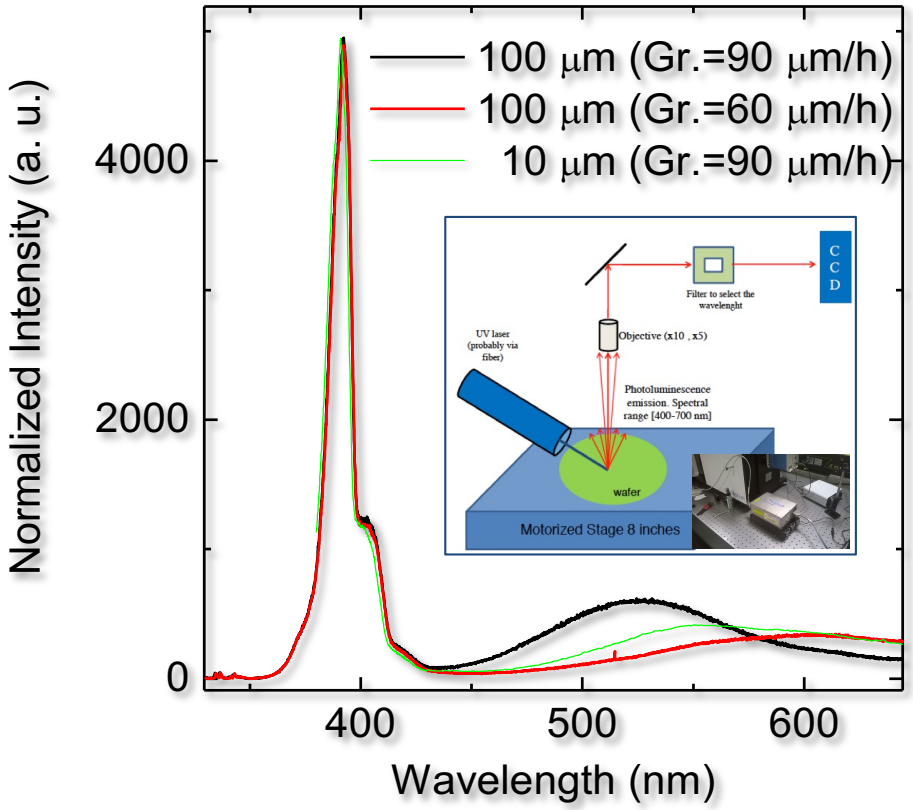
Epitaxial growths



4 inch Epi 10 micron

6 inch Epi **100 µm**

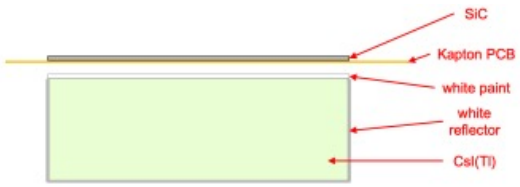
Micro-photoluminescence analysis



Epi 100 µm => 200 µm is possible!

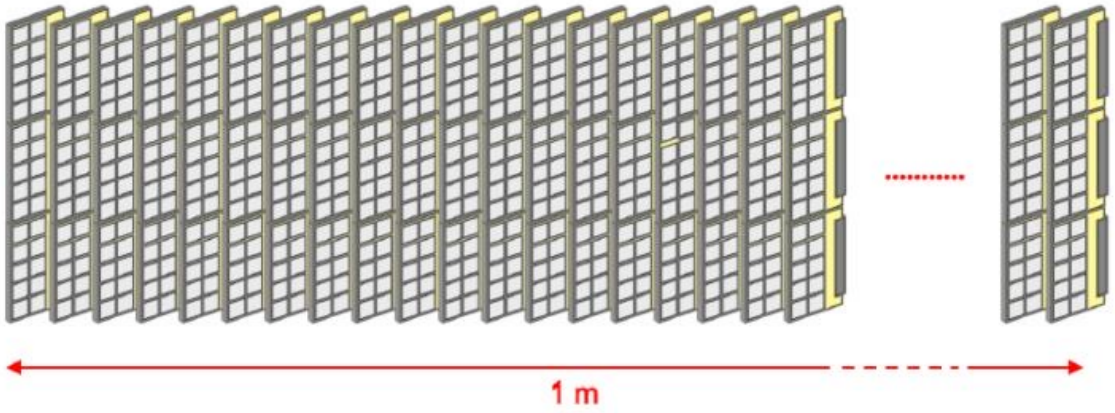
S. Tudisco et al. SENSORS Vol. 18 (2018) 2289

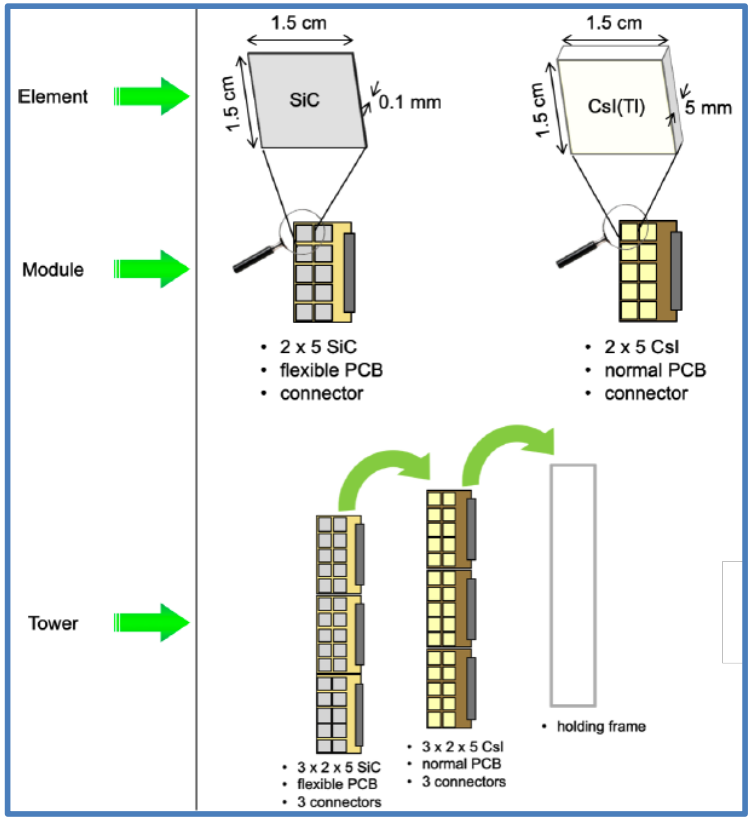
New p-n junction SiC detectors

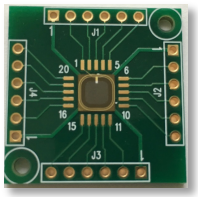


Geometry of the final PID wall

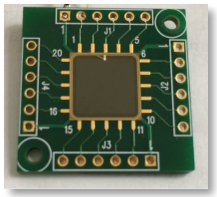
40 columns
1200 telescopes

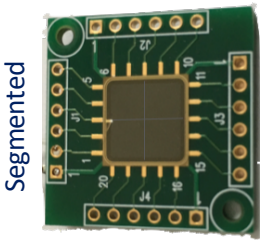






5x5 mm^2 10/100 μm

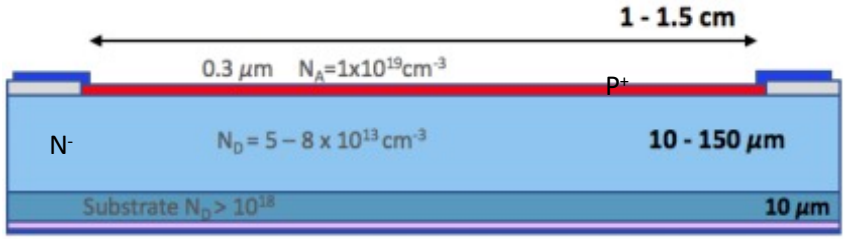




0.5x0.5 / 1x1 cm^2 10/100 μm

STMicroelectronics

SiC *ΔE detectors*

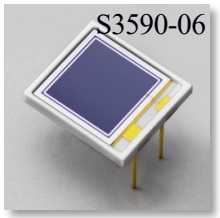


Large area p-n junction devices => 1.5x1.5 cm^2

Energy Resolution and Timing

p-n$_{diodes}$

Hamamatzu

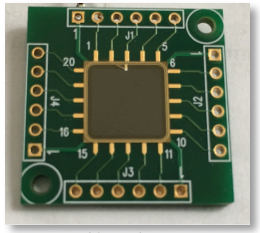


300 um

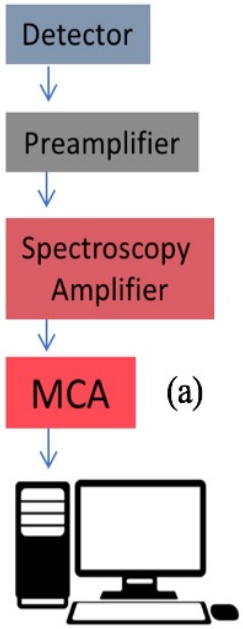
Si % SiC

1x1 cm^2

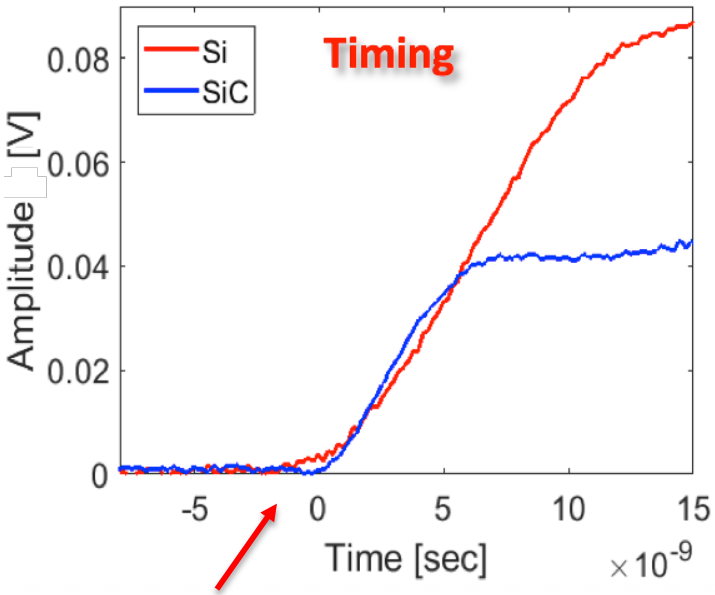
100 um



p-n diode

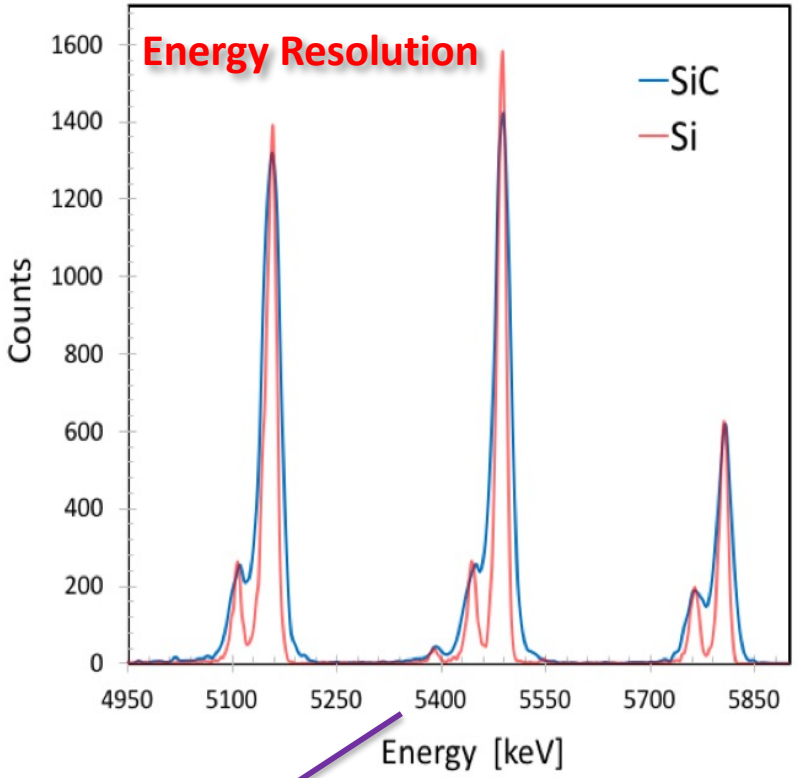


Test with radioactive ^{241}**Am Alpha** source



SiC ~ Preamp limit!

Test with radioactive ^{241}**Am Alpha** source



SiCILIA INFN

SiC → $FWHM_{exp}$ = 42.8 keV (0.4%)

Si → $FWHM_{exp}$ = 21.4 keV (0.22%)

$$FWHM^2_{exp} = FWHM^2_{det} + FWHM^2_{Ele}$$

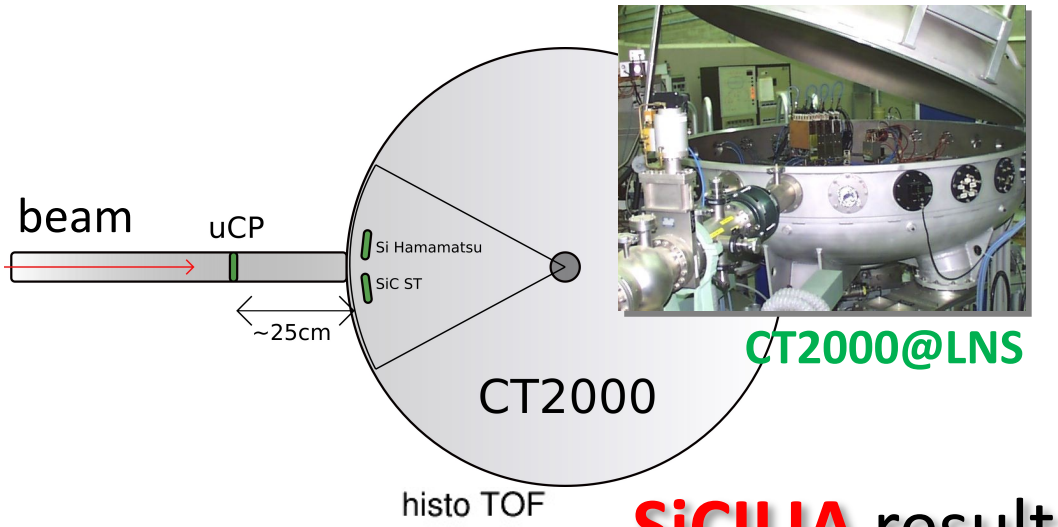
Electronic Noise

Si=7.3 keV

SiC=10.3 keV

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

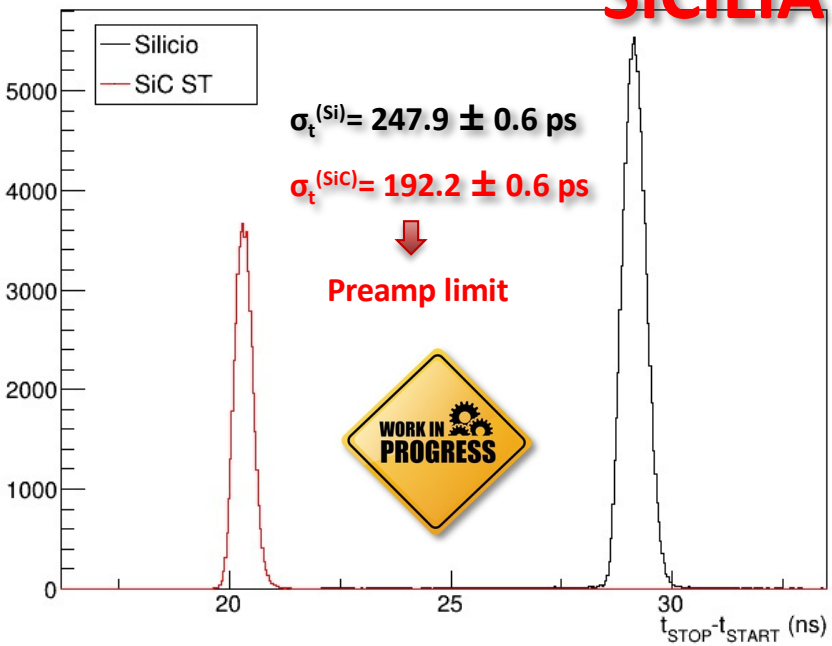
SiC-Timing p-n$_{diodes}$

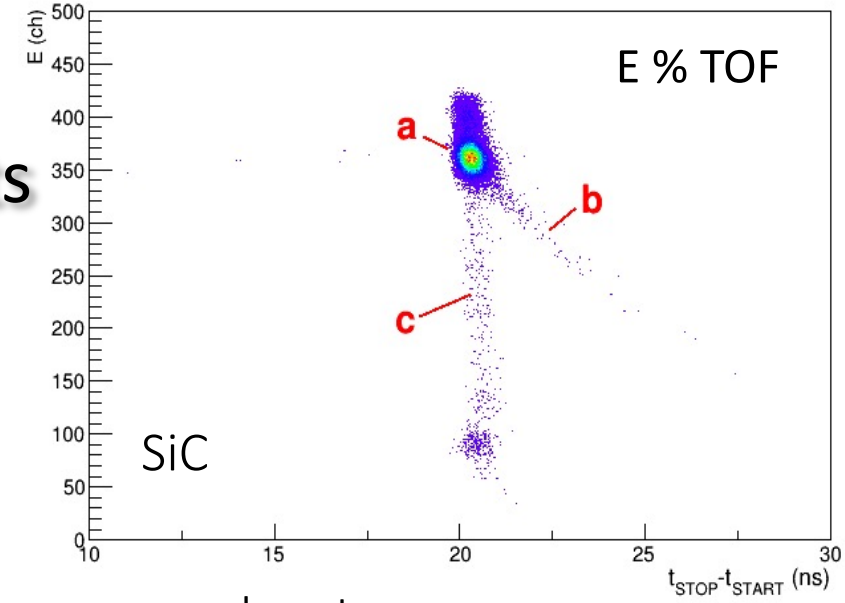


CT2000@LNS

- Beam ^{58}Ni @ 60MeV, 70MeV
- Digitazer CAEN DT5751
- START: **µCP**, STOP: Si Hamamatsu o SiC STM

SiCILIA results





a: good events

b: **µCP**-wires contribution

c: SiC edge effects SiC

New beam test are in preparation

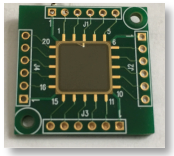
SiCILIA results Radiation Hardness

p-n diodes

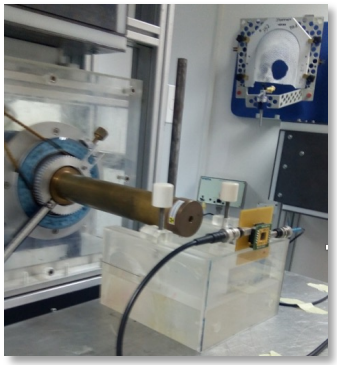
Protons beam irradiation

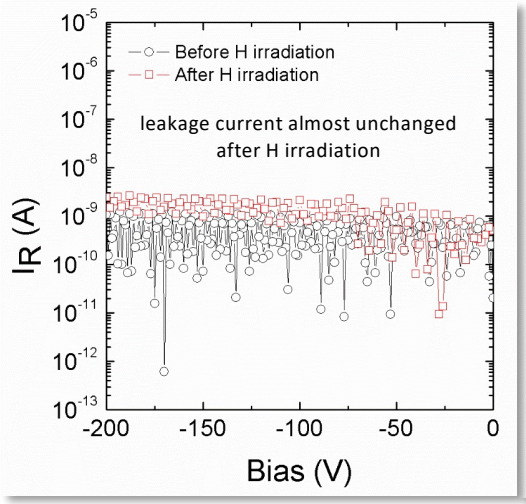
LNS CATANA line

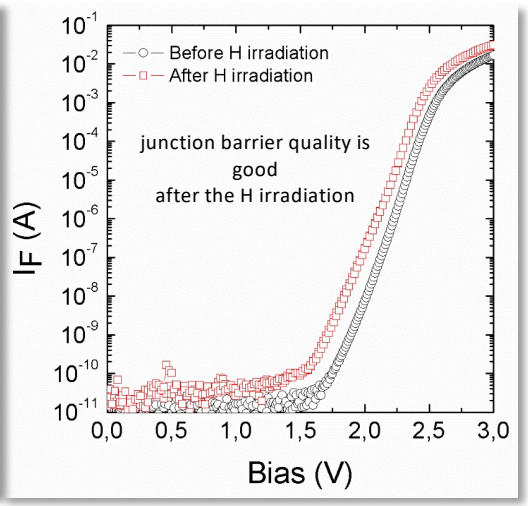
60 MeV H^+ → SiC 10µm 1x1 cm^2

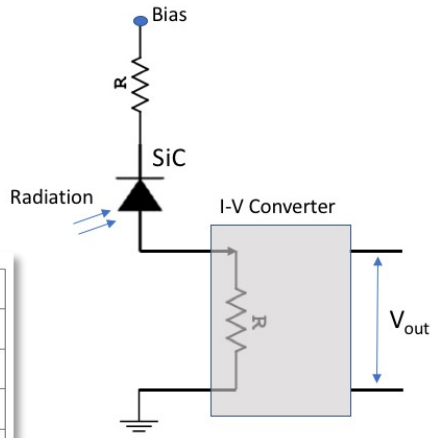


5 x 10^{13} H^+/cm^2 3 kGy

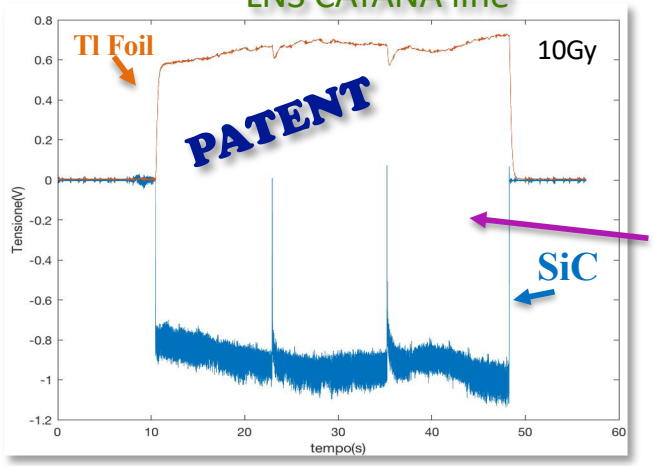




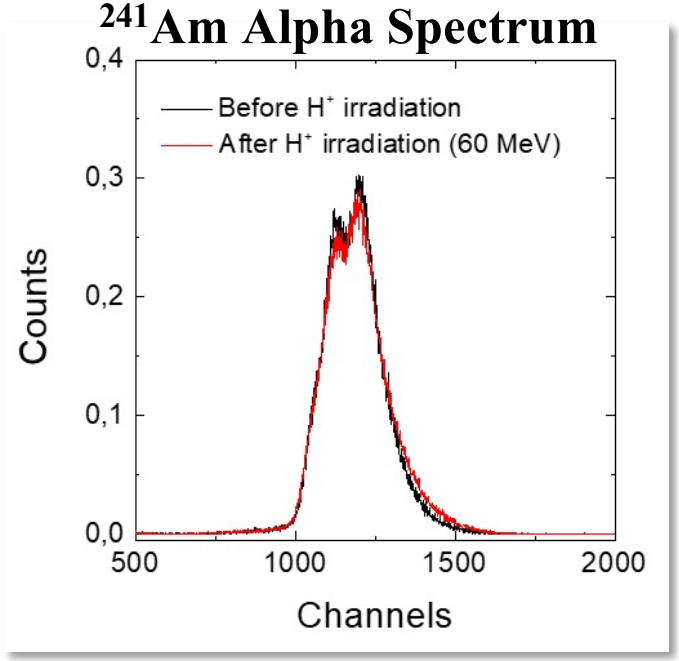




LNS CATANA line



Beam Monitor and dosimetry applications



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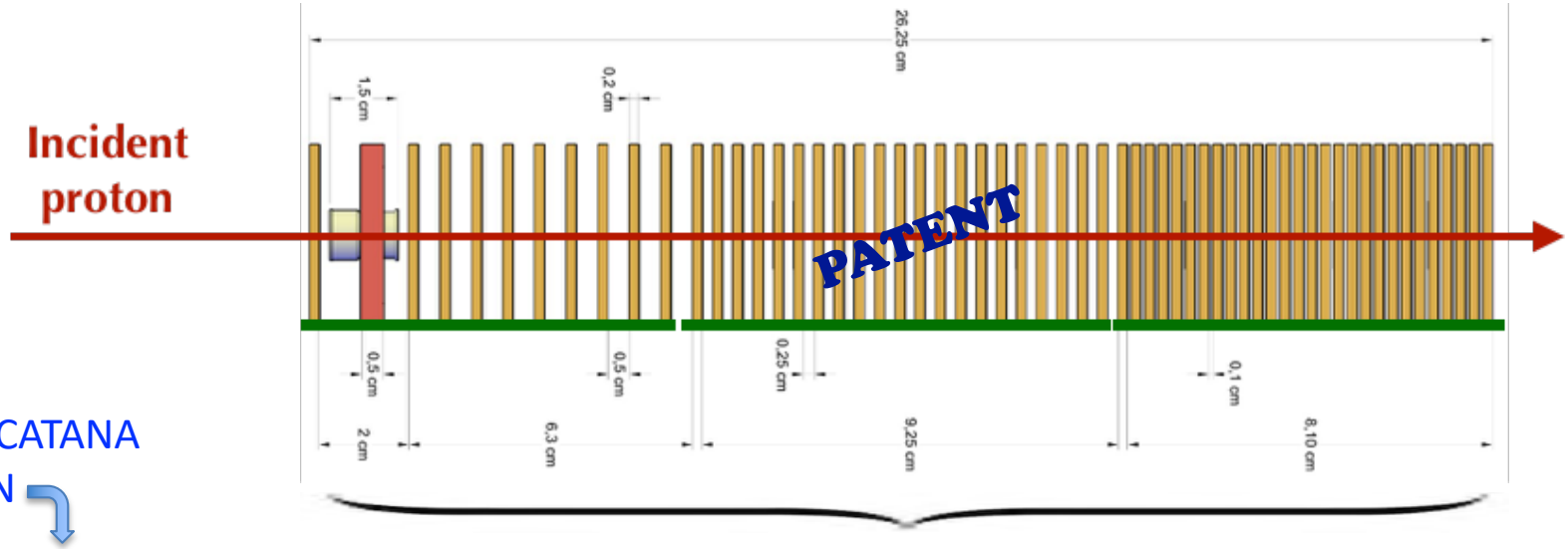
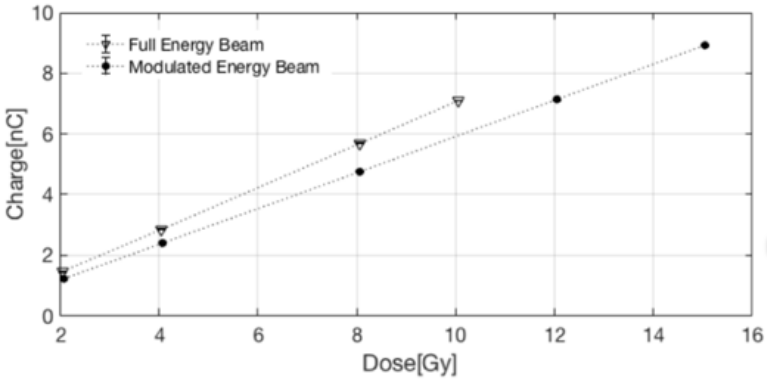
PRAGUE - Particle RAnGe measure Using silicon carbidE

Incident proton

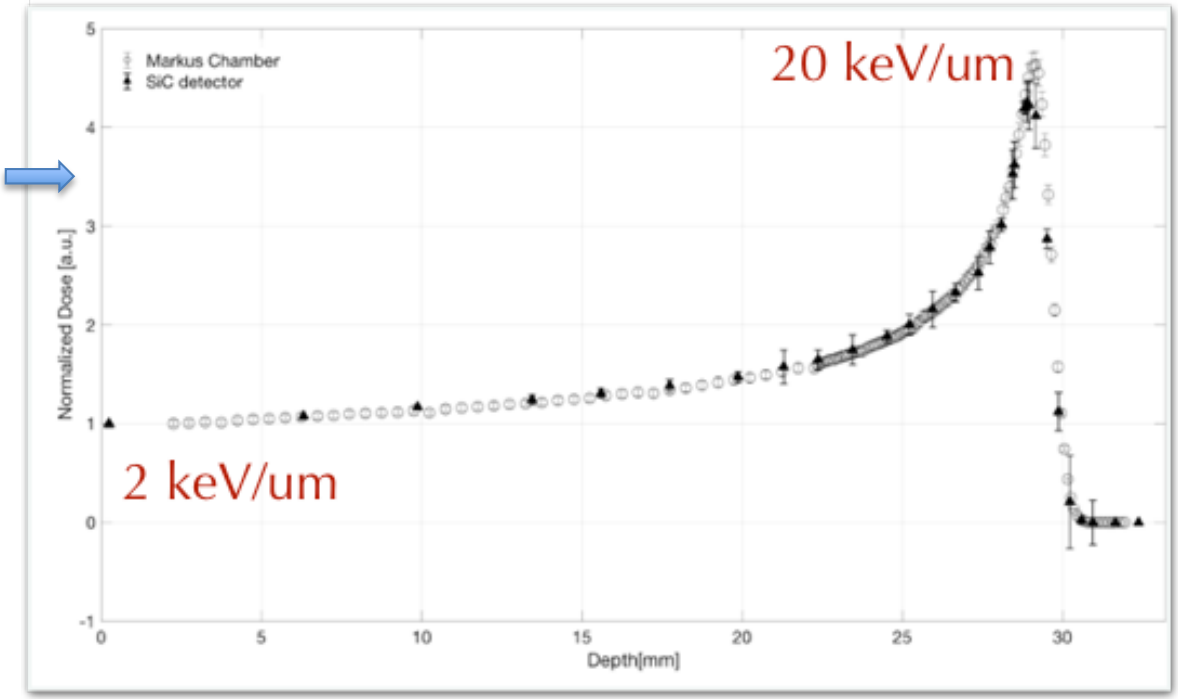


60 SiC 1.5x1.5 cm^2

Experiental test @CATANA
Facility of LNS-INFN



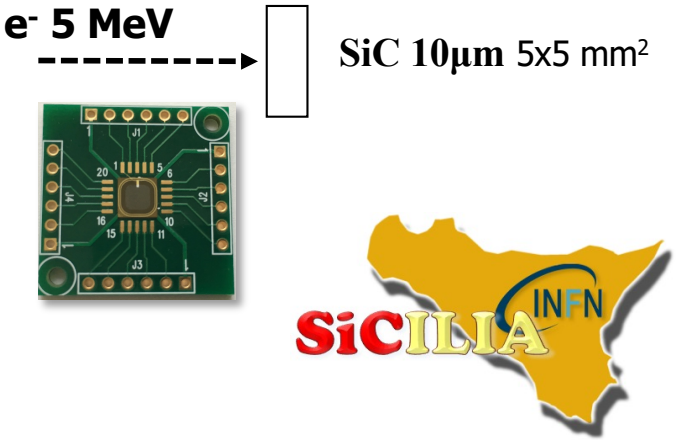
62 MeV proton beam,
Modulated and Pristine beam,
Beam Current: 10^6-10^8 p/cm^2



PRAGUE → ELI-MED

New p-n junction SiC detectors

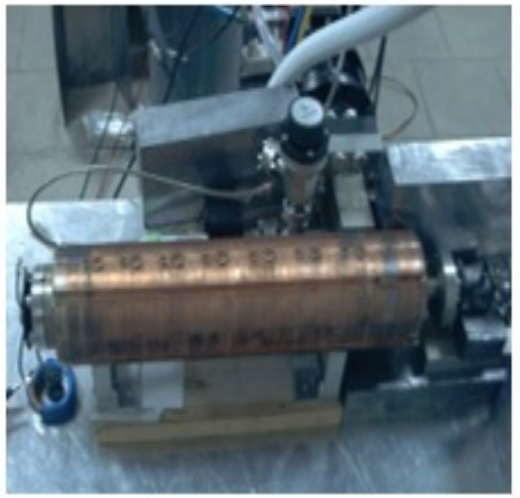
Radiation Hardness



LINAC @ UniMe

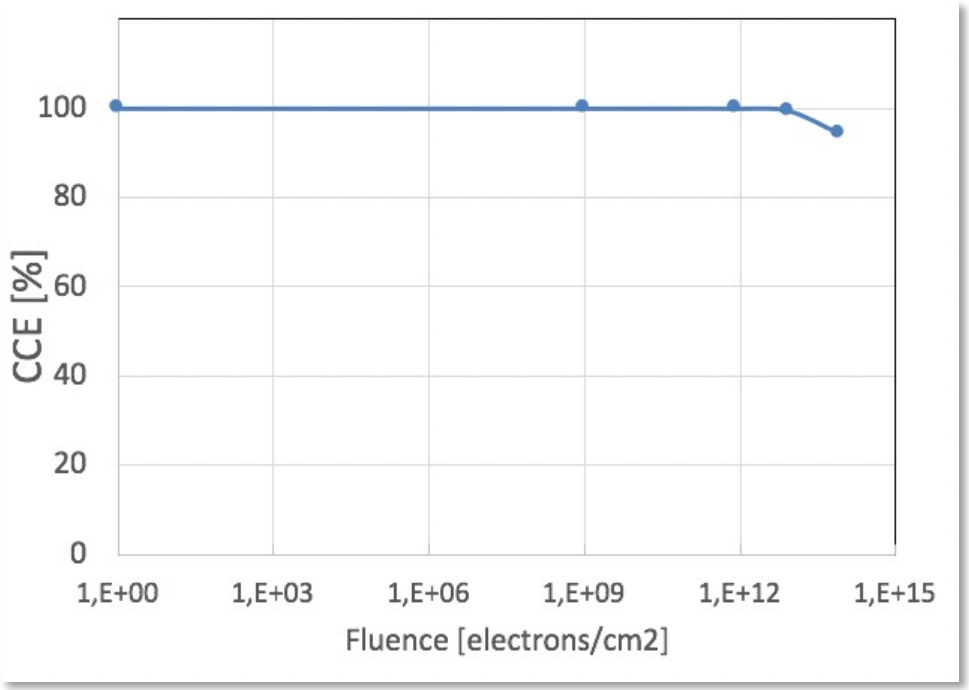
Electrons irradiation

- Energy	5 MeV
- Current	1-200 mA
- Rep. Rate	1-300 Hz
- Pulse duration	3 µsec



SiCILIA results

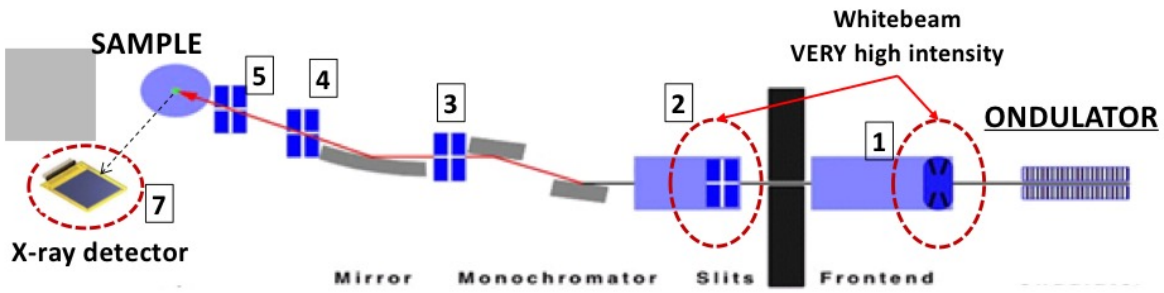
Electrons Beam Monitor



SiCILIA results X-Ray detections

Synchrotrons radiation

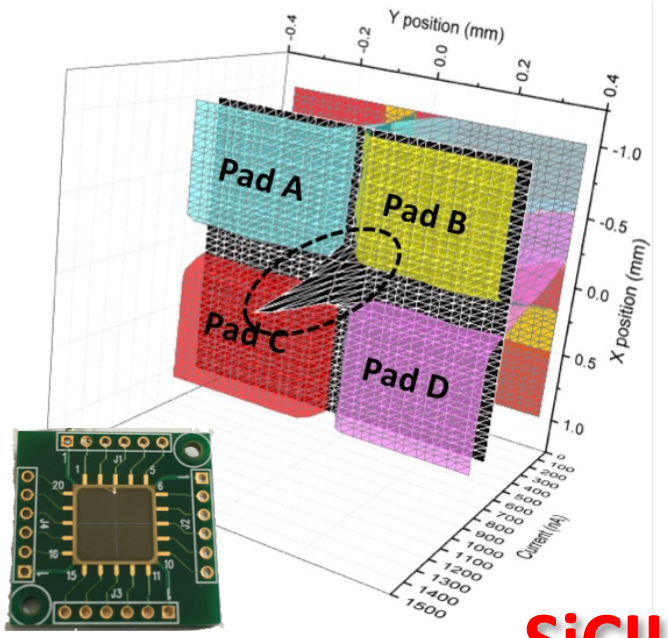
PAUL SCHERRER INSTITUT PSI



Beam Position Monitor (XBPM)
1,2,3,4,5

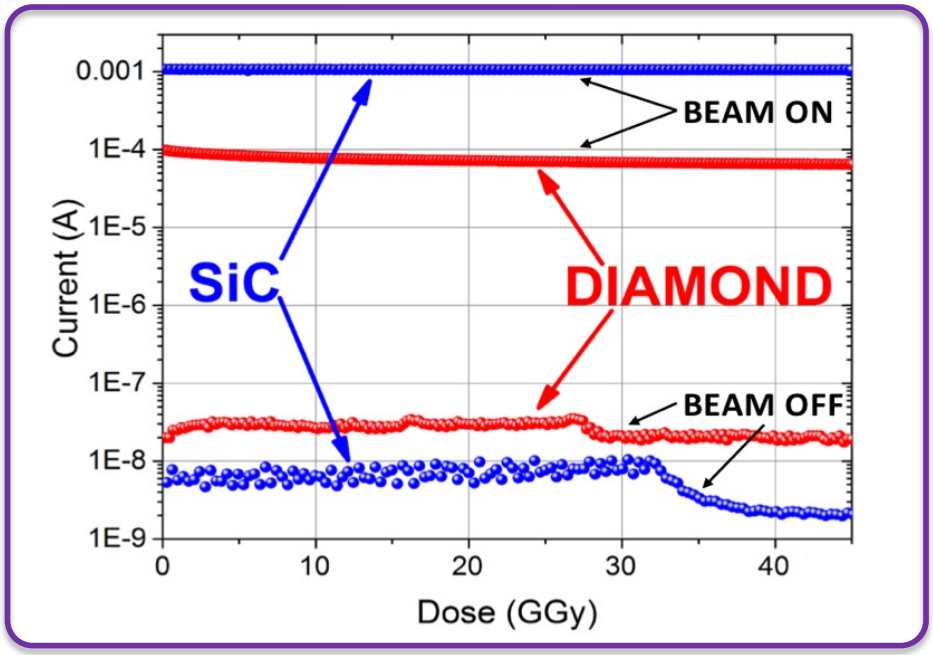
- Transparency
- Extreme radiation hardness
- Fast response

X-ray beam 10x10 µm², 5E10 ph/sec @ 12.4keV



SiC 100 µm

Radiation hardness

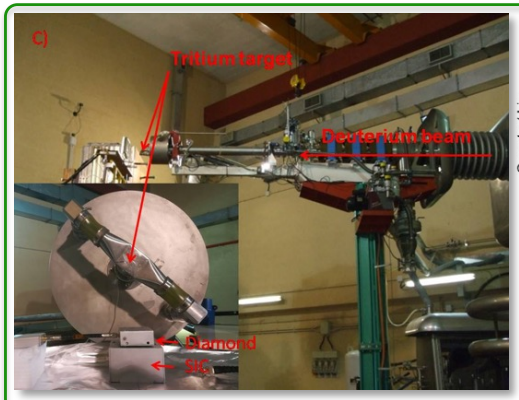


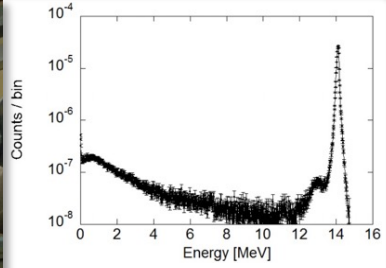
S. Nida et al. Jour. of Sync. Rad. 26 (2019) 28-35

SiCILIA results

Neutrons detections

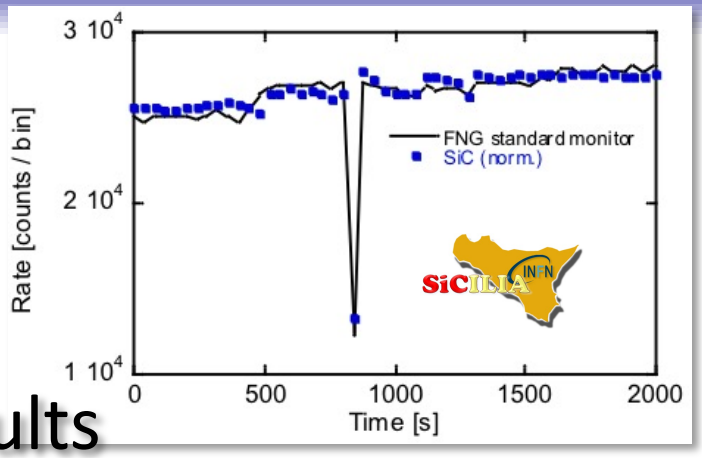
p-n$_{diodes}$



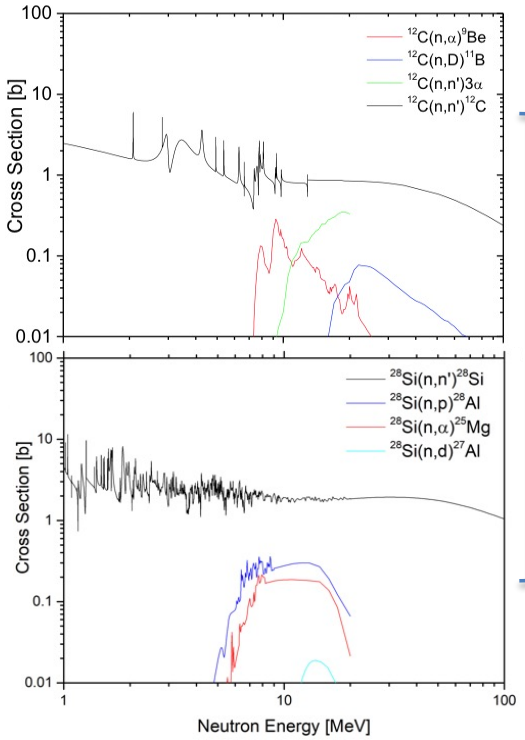


FNG ENEA - Frascati

SiC neutron Beam Monitor



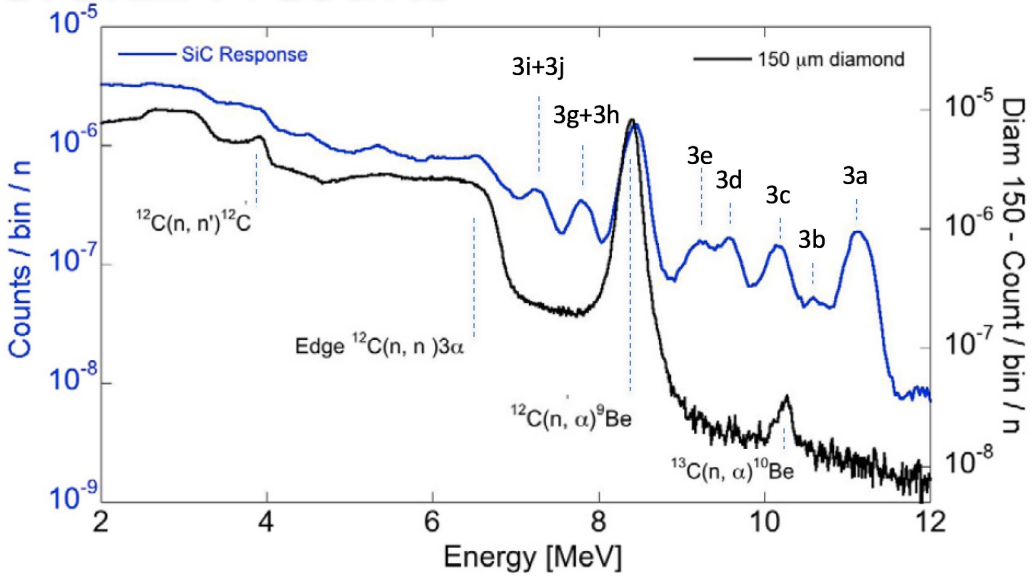
SiCILIA results



Energy deposition

n + ^{12}C

n + ^{28}Si



Absence of instabilities for 14 MeV neutron up to **5*10^{11} n/cm^2**

Efficiency

Detector	Atomic/molecular density [cm^{-3}]	Efficiency measured for E_d> 1.2 MeV [and normalized per atom]	Efficiency measured in the ^{12}C(n, α)^{9}Be peak
SCD 150 μm	1.76*10^{23}	(1.59 ± 0.25)*10^{-3} [2.97*10^{-24}]	(0.91 ± 0.15)* 10^{-4}
SiC 100 μm	4.8*10^{22}	(5.69 ± 0.78)*10^{-4} [4.74*10^{-24}]	(2.02 ± 0.30)*10^{-5}

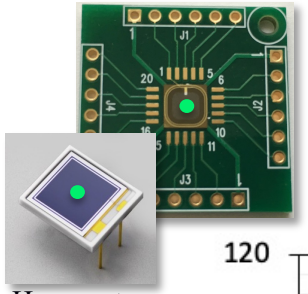
M. Rebai et al. NIMA Vol. 946 (2019)

Radiation Damage p-n$_{diodes}$

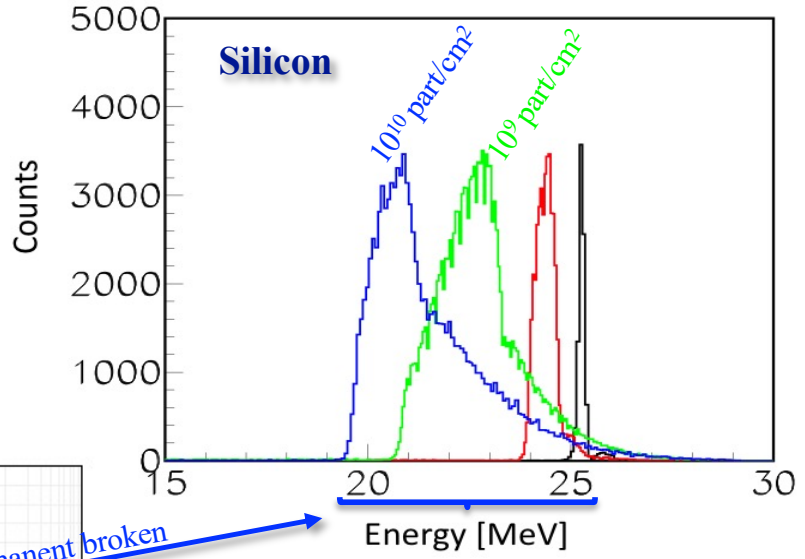
^{16}O, ^{27}Al beam

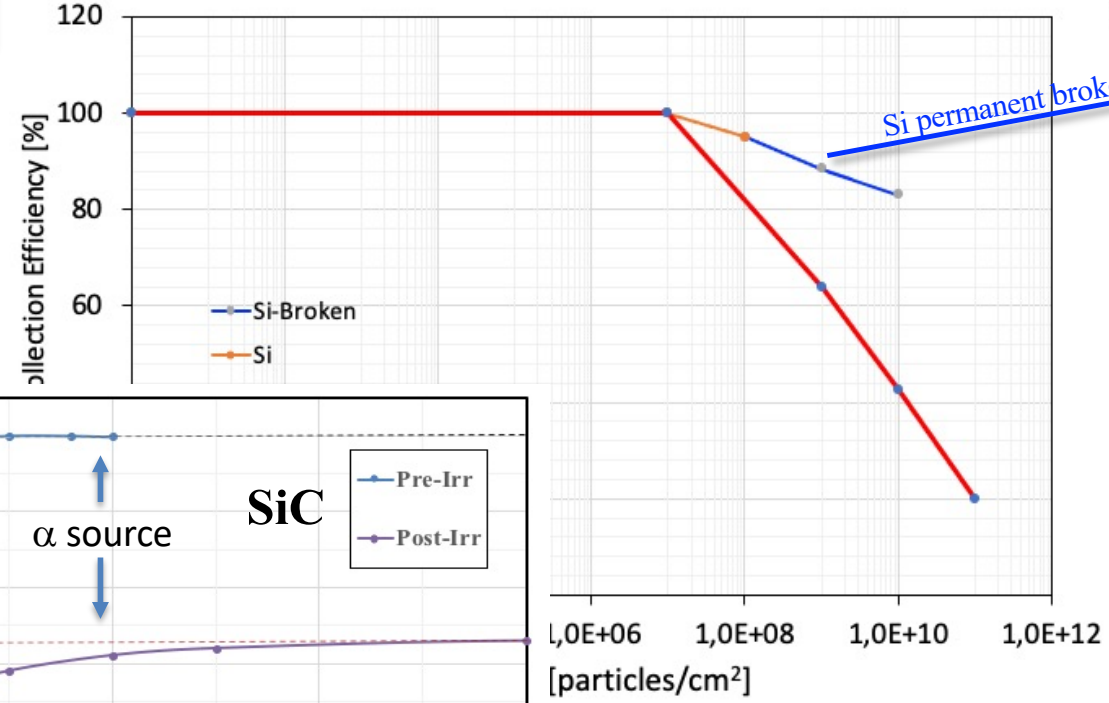
SiC 10µm 5x5 mm^2
Si 300µm 1x1 cm^2

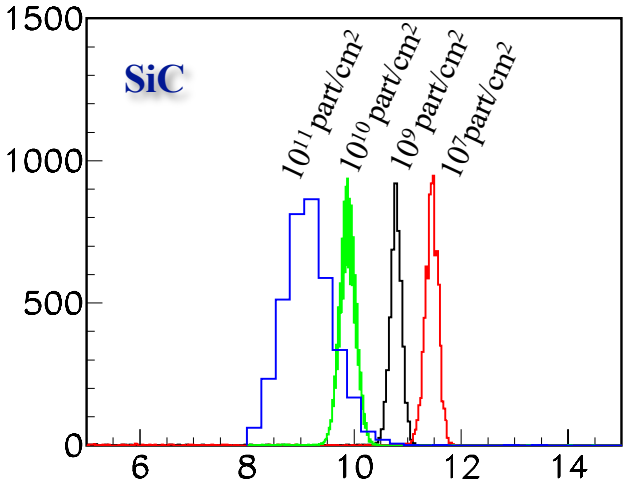
Si % SiC

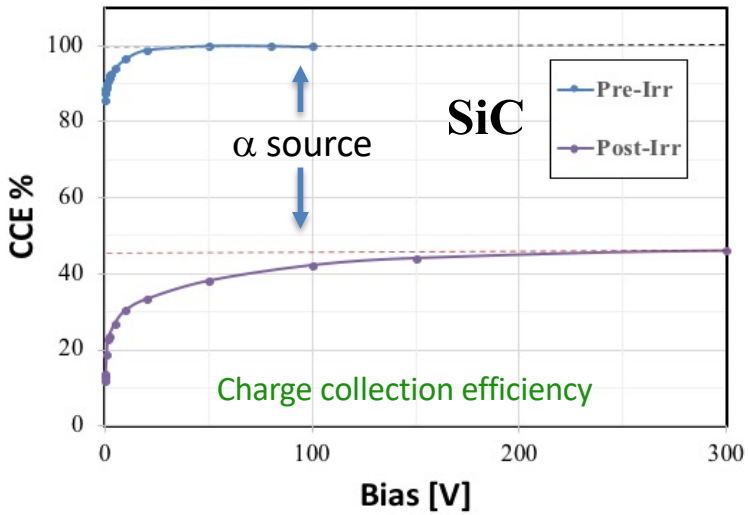


Hamamatzu
S3590-06

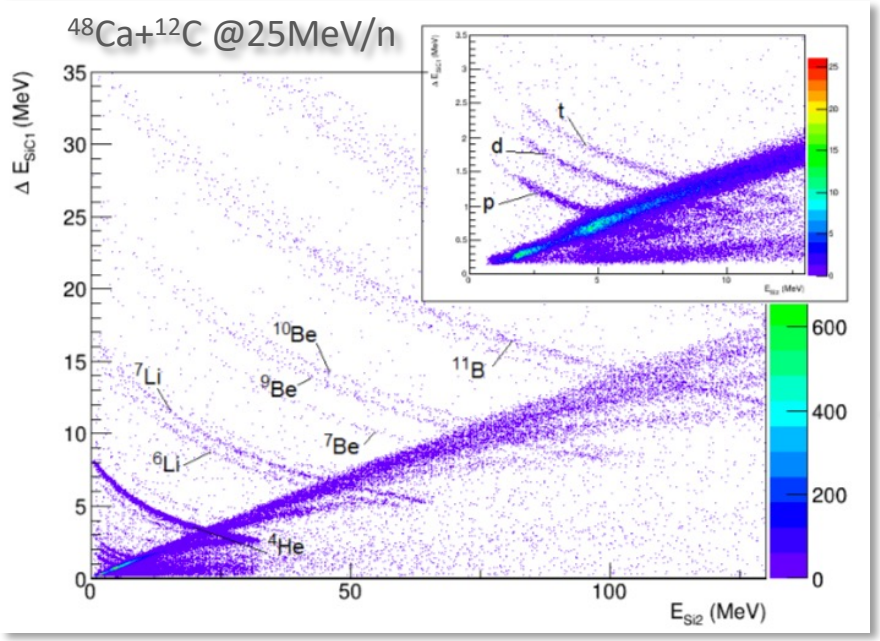




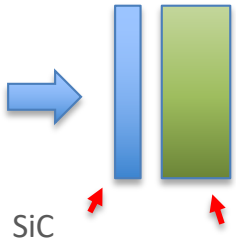




Charge particles identification



Telescope

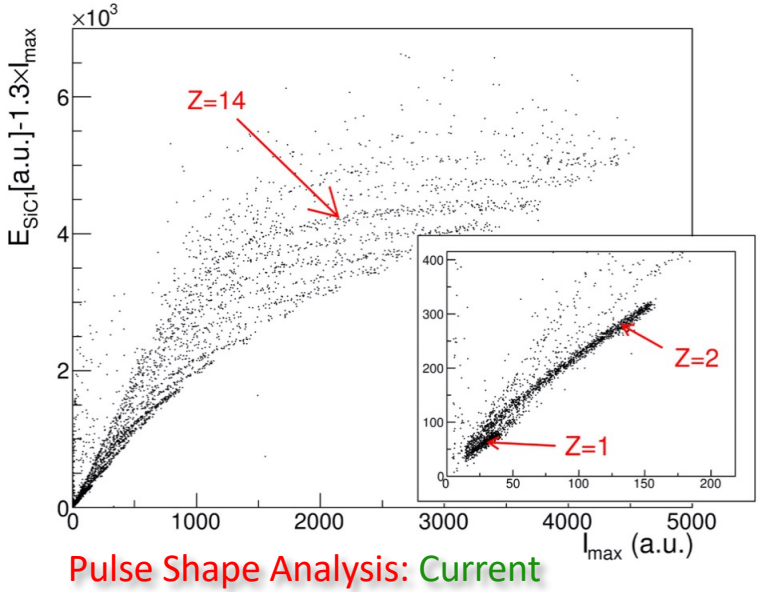


SiC
100 µm
1x1 cm^2

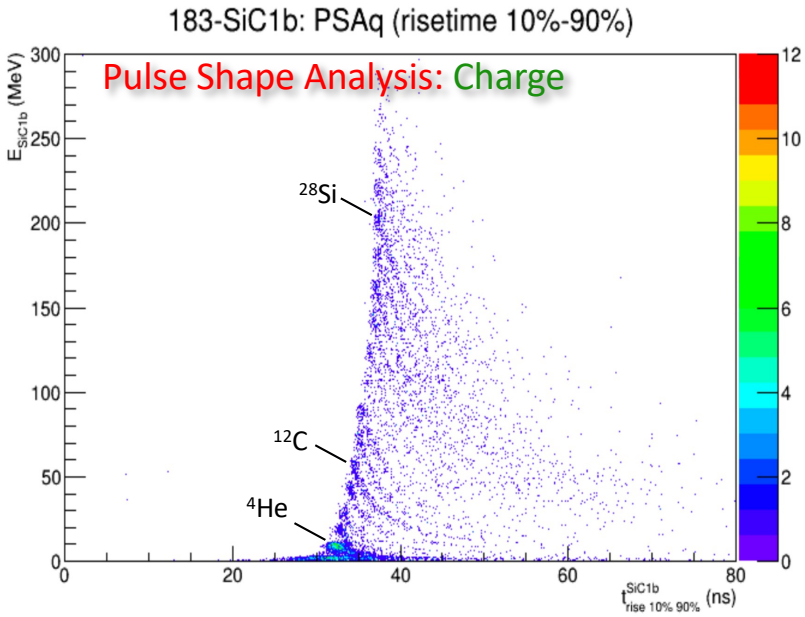
Si
500 µm
2x2cm^2

Isotope separation
up to **Silicon**

SiCILIA results



Pulse Shape Analysis: Current



C. Ciampi et al. NIMA 925 (2019) 60-69

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Thanks for your attention !

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