16TH PISA MEETING ON ADVANCED DETECTORS

Silicon Carbide devices for radiation detection: a review of the main performance

S. Tudisco

INFN - Laboratori Nazionali del Sud

Frontier Detectors for Frontier Physics
La Biodola • Isola d'Elba • Italy 26 May - 1 June, 202

Finanziato dall'Unione europea NextGenerationEU
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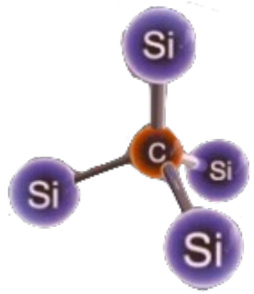

Outline

- ✓ Why Silicon Carbide for radiation detection
- ✓ INFN-SiCILIA, R&D on SiC detectors
- ✓ SiC Epitaxial growth
- ✓ SiC processing
- ✓ Performance overview
- ✓ SiCILIA Users
- ✓ Perspectives for new devices

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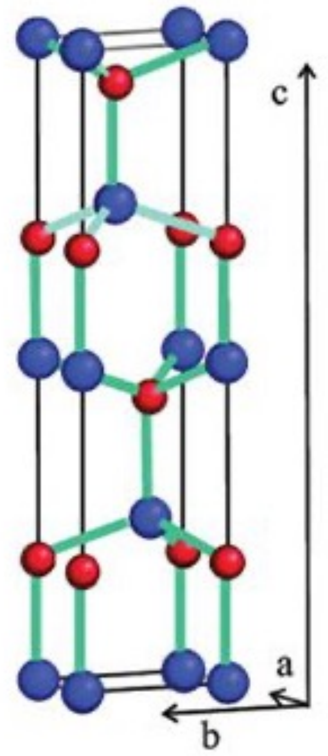
Why Silicon Carbide for radiation detection

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

4H-SiC



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

Rad Hard devices !

INFN R&D on SiC detectors

2017 - INFN call CSN5 - SiCILIA

Silicon Carbide Detectors for Intense Luminosity Investigations and Applications

New Radiation Hard detectors besed on SIC tecnology

SiCILIA strategy

institutions and Companies

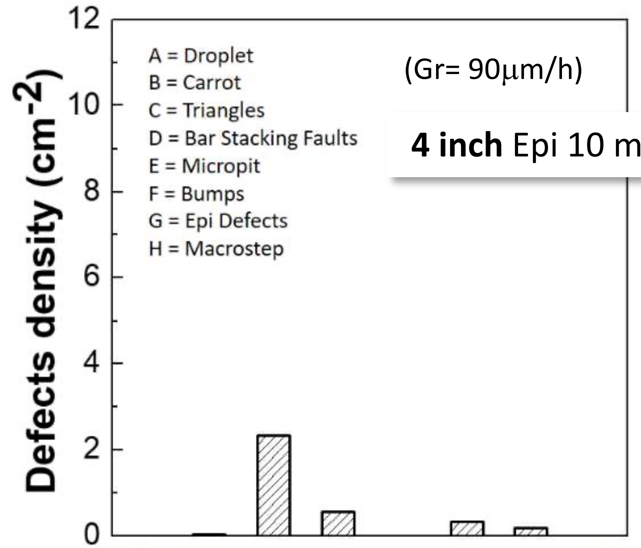
CNR-IMM – Catania
CNR-INO – Pisa
PSI – Switzerland
ENEA- Frascati
Fondazione Bruno Kessler (**FBK**) – Trento
ST Microelectronics – Catania
LPE – Catania (**LPE**)

SiCILIA Aims

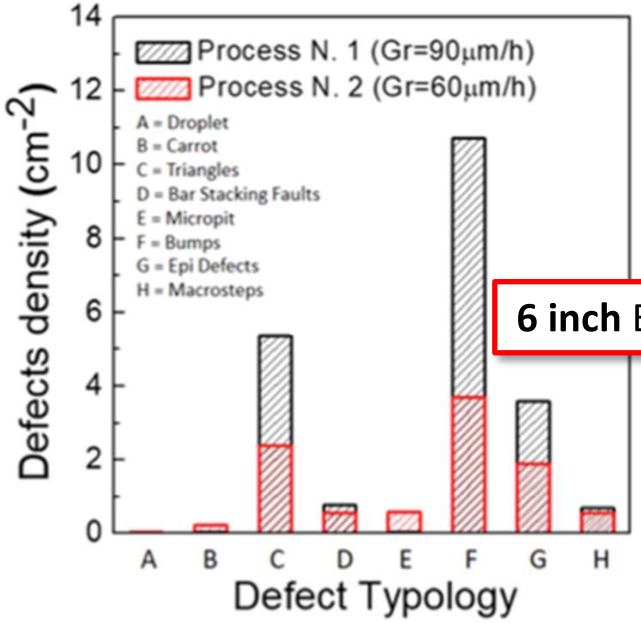
Epitaxial growth SiC beyond the state of the art (~30 μm)

Processing ➡ Schottky **=> p-n junctions**

SiCILIA results: Epitaxial growths

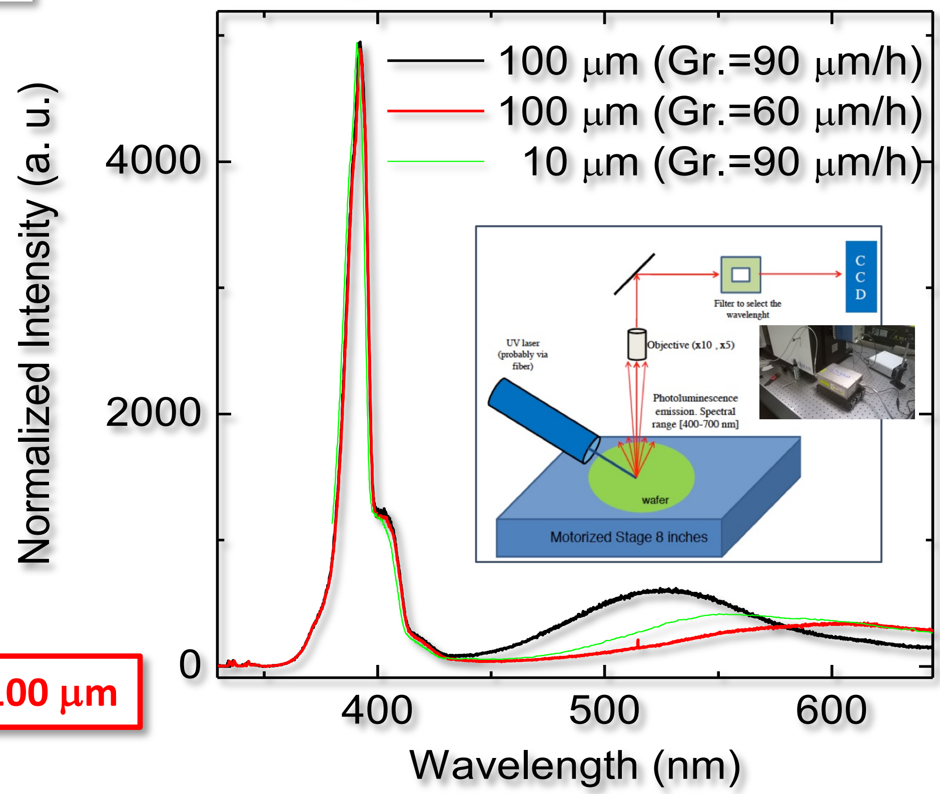


4 inch Epi 10 micron



6 inch Epi **100 μm**

Micro-photoluminescence analysis



6 inch Epi **100 μm**

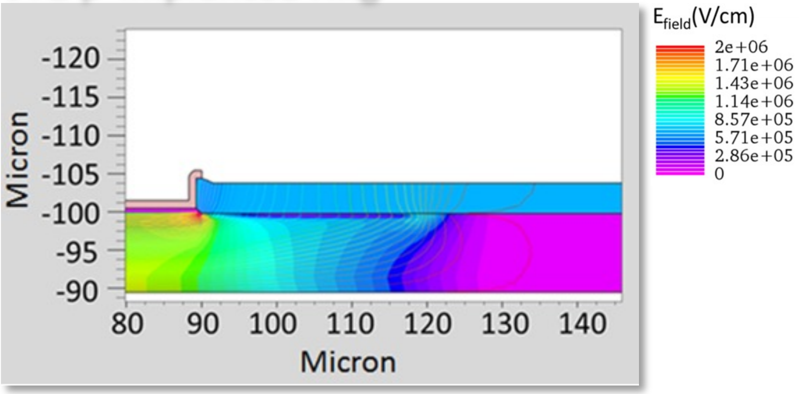
Epi 100 μm

Target

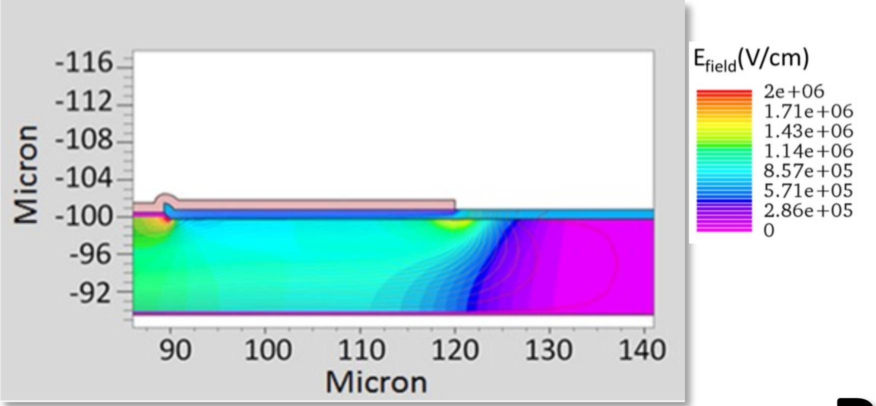
SiCILIA results: Processing

Breakdown
≥ 1.5 kV

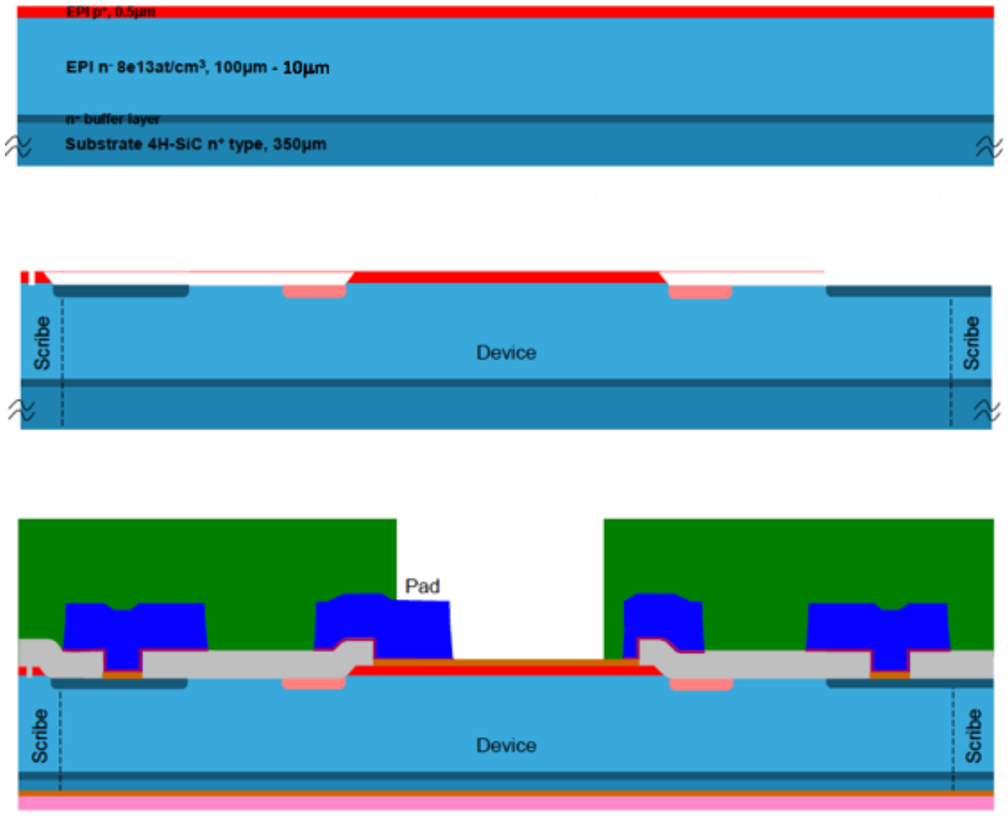
JTE p⁻ implanted ring



Metal Field Plate



p-n diodes

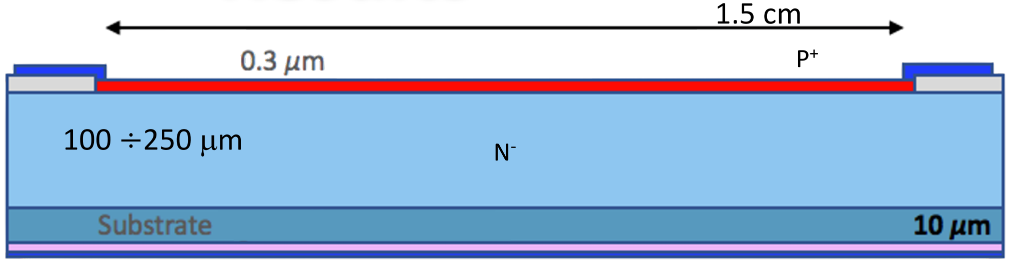


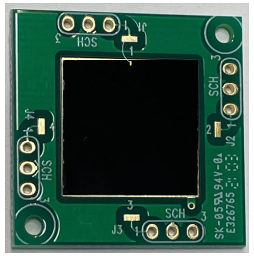
Mechanical Substrate Thinning (~10 µm)

Effecinccy 30%

Results

New p-n junction devices



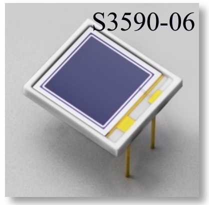


Large area
1.5x1.5 cm²

Performance overview: Energy Resolution

p-n diodes

Hamamatzu

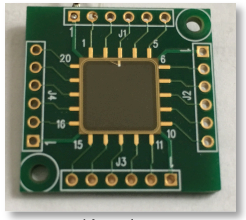


300 um

Si % SiC

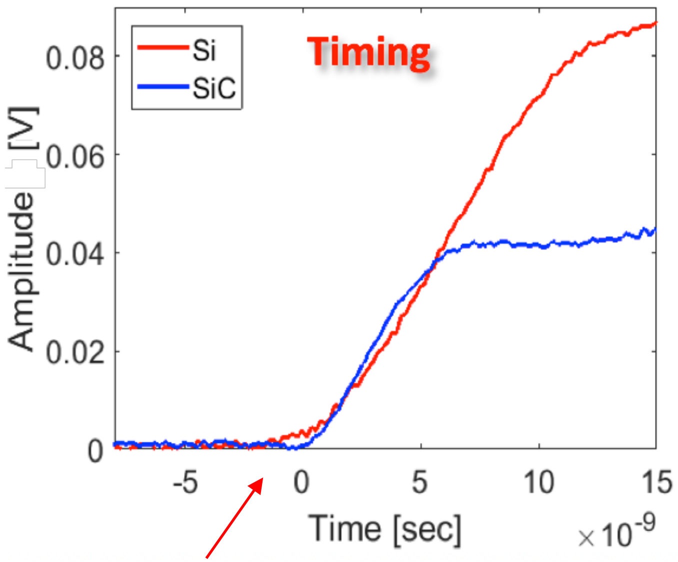
1x1 cm^2

100 um

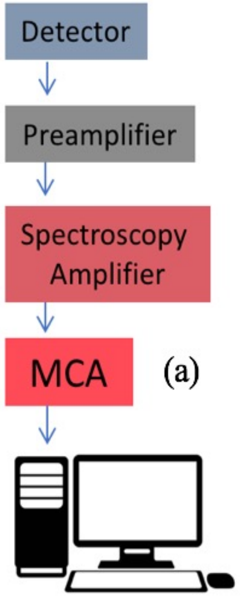


p-n diode

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



SiC ~ Preamp limit!



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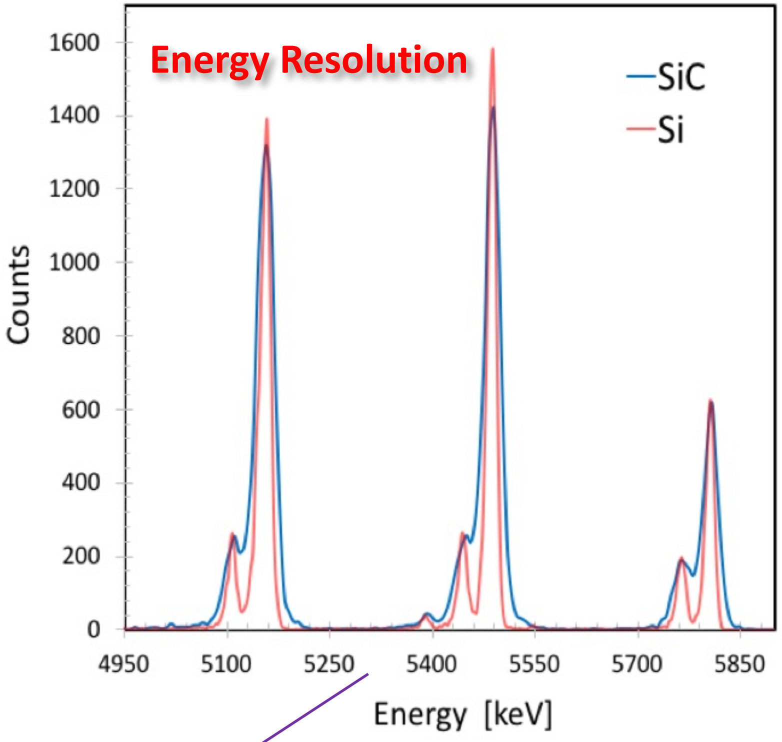


SiC → $FWHM_{exp}$ = 42.8 keV (0.4%)

Si → $FWHM_{exp}$ = 21.4 keV (0.22%)

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

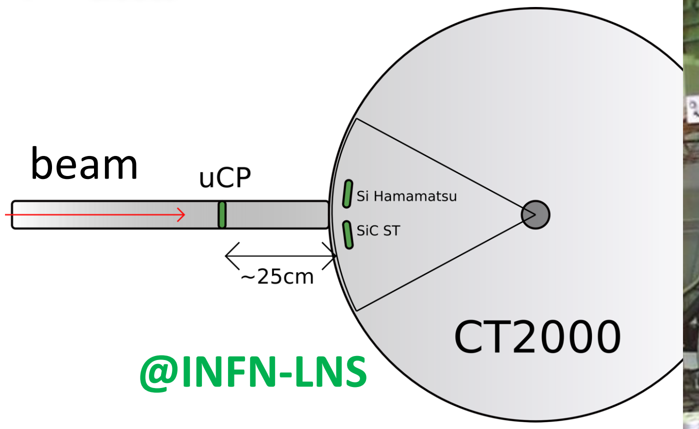
Electronic Noise

Si=7.3 keV

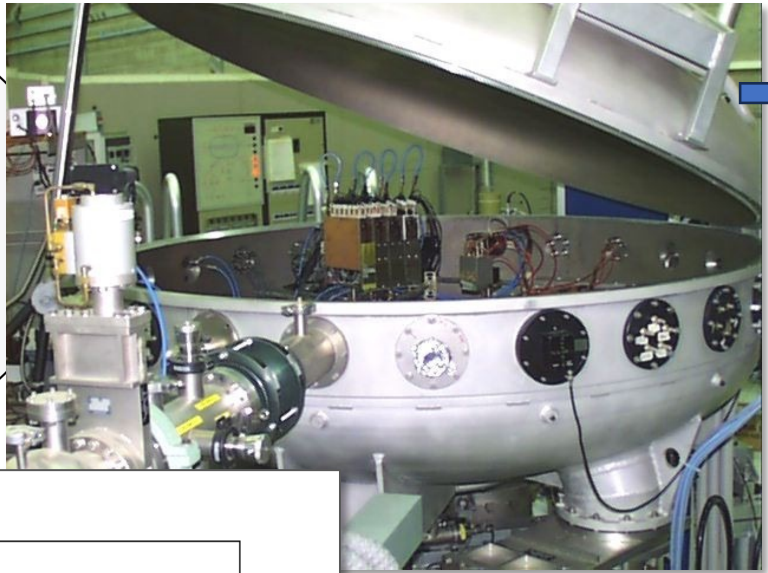
SiC=10.3 keV

Performance overview: SiC-Timing

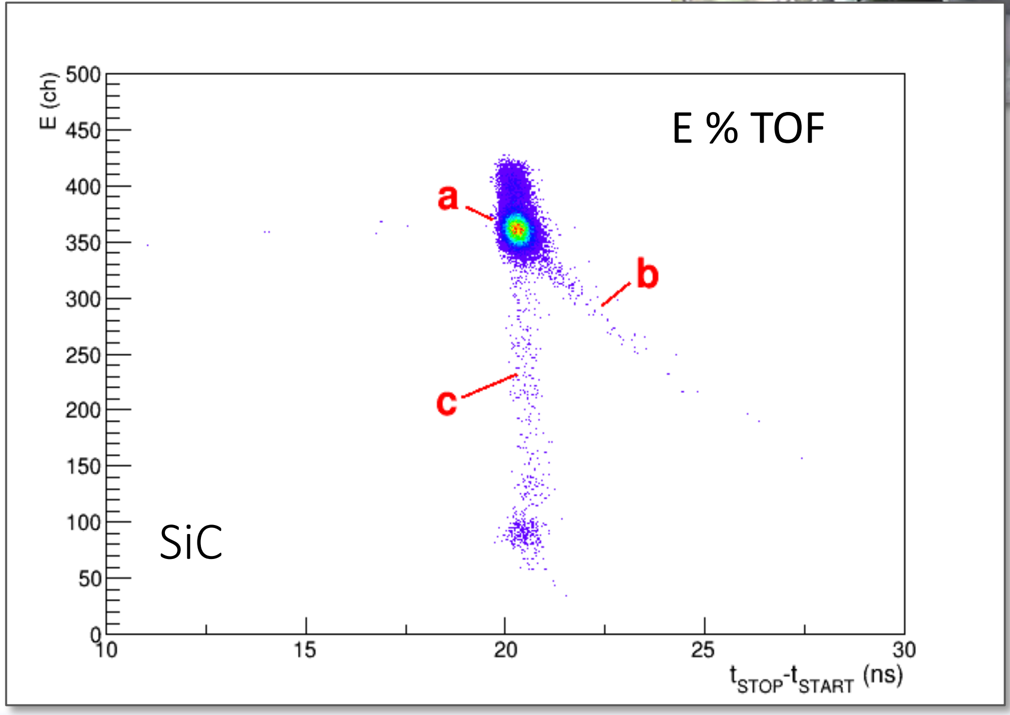
p-n diodes



@INFN-LNS



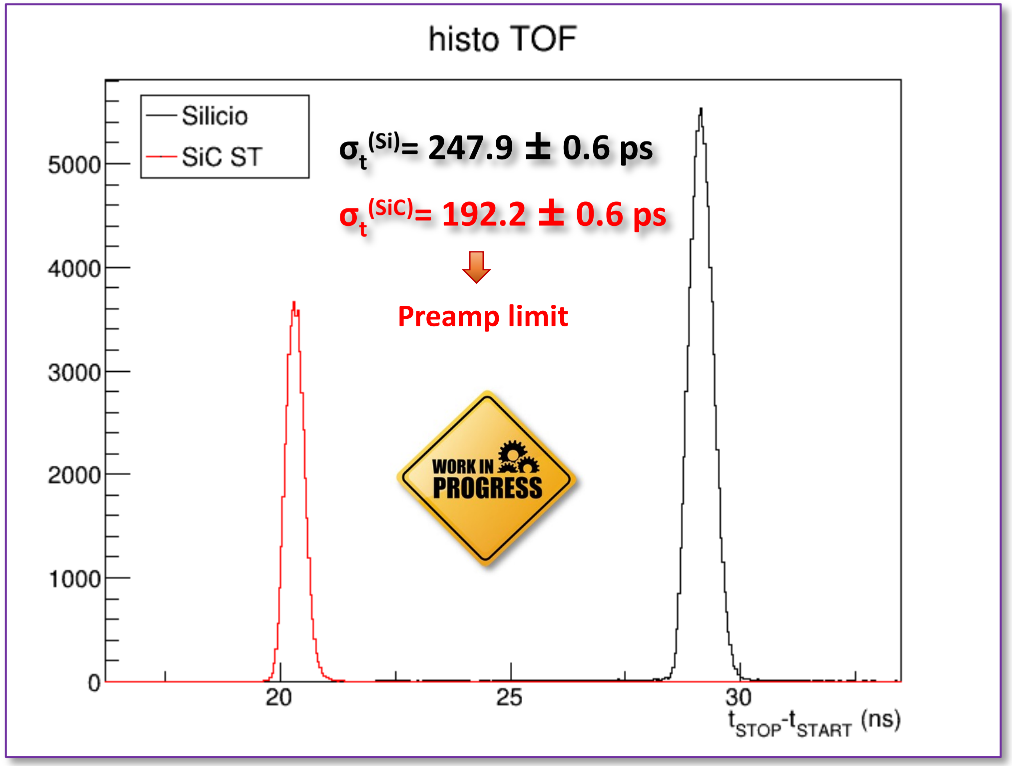
- Beam ^{58}Ni @ 60MeV, 70MeV
- Digitazer CAEN DT5751
- START: **μCP**, STOP: Si Hamamatsu o SiC STM



a: good events

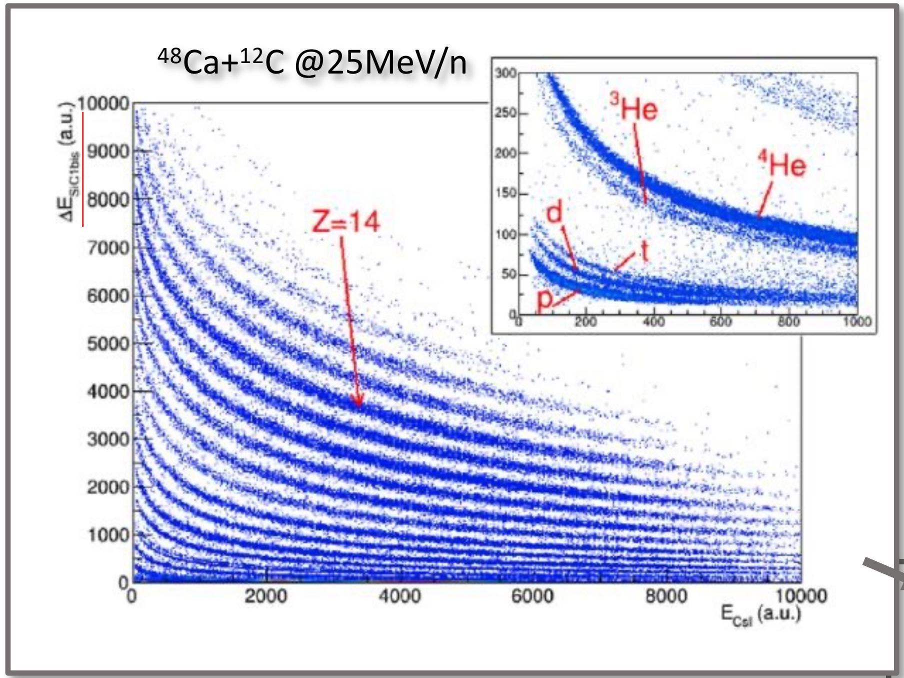
b: **μCP**-wires contribution

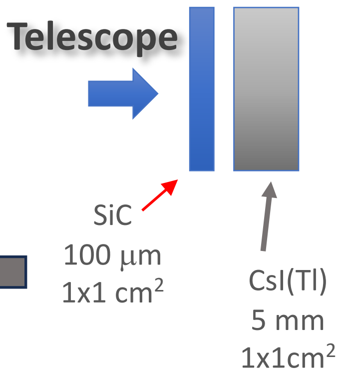
c: SiC edge effects SiC

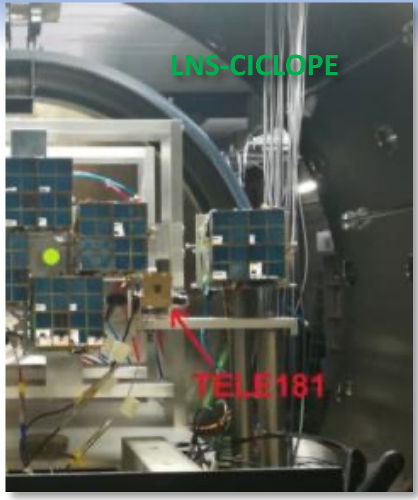


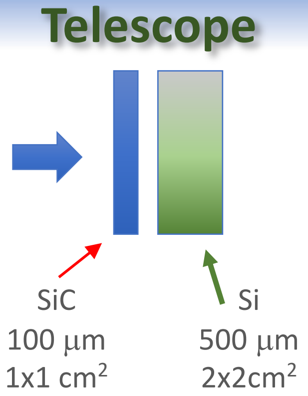
New beam test are in preparation

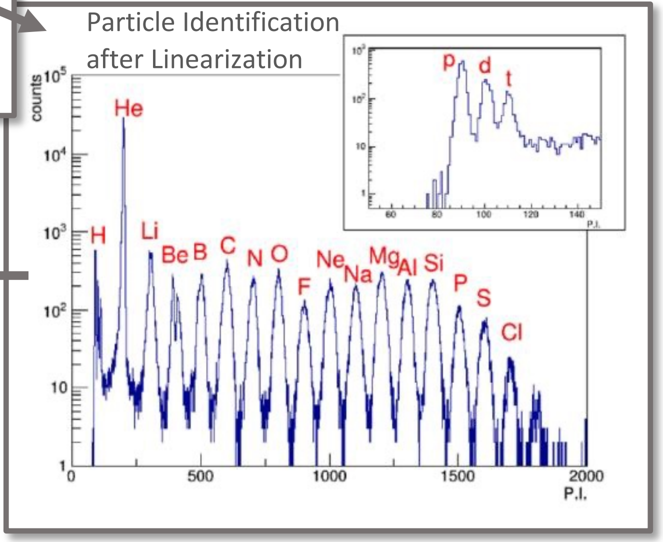
Performance overview : particles identification

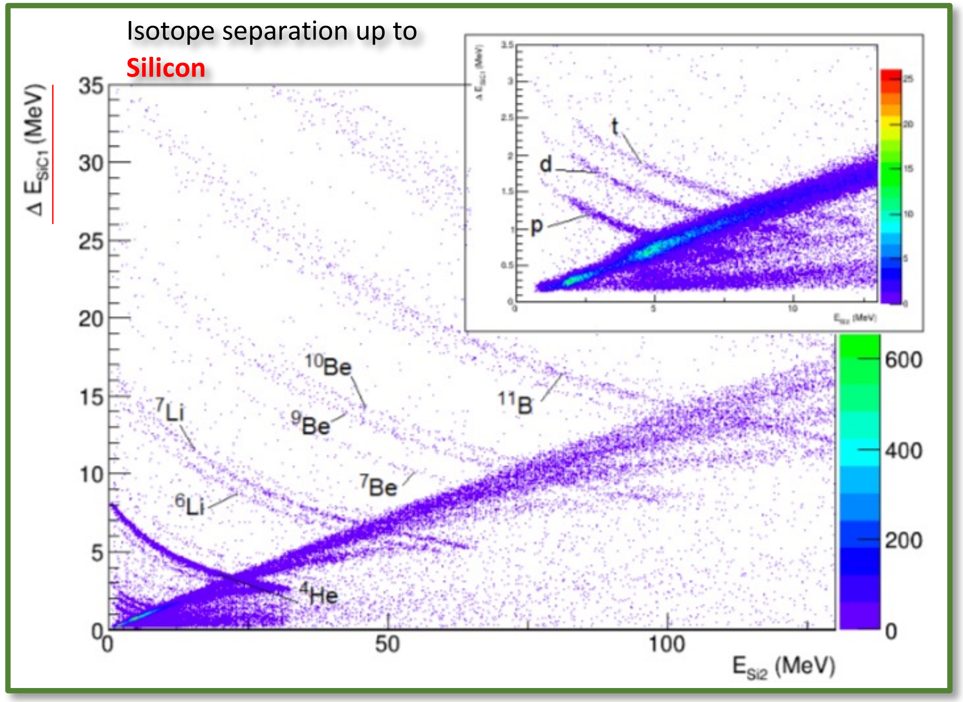












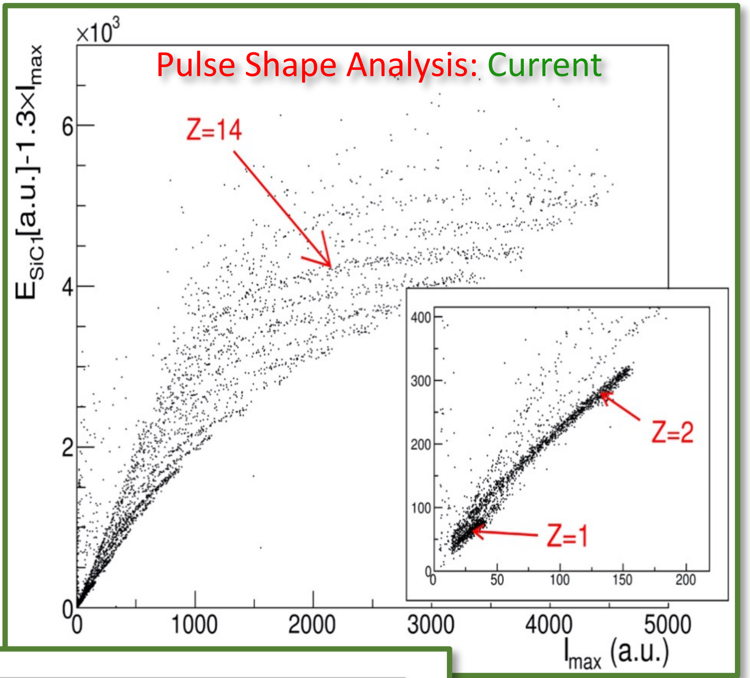
Isotopes	FoM	Elements	FoM	Elements	FoM
p-d	1.4	B-C	1.9	Na-Mg	1.6
d-t	1.1	C-N	1.9	Mg-Al	1.5
^{7}Be-^{9}Be	0.7	N-O	1.9	Al-Si	1.5
		O-F	1.8	Si-P	1.6
		F-Ne	1.6	P-S	1.5
		Ne-Na	1.6	S-Cl	1.6

Figure of Merit: $FoM = \frac{|PI_2 - PI_1|}{(FWHM_2 + FWHM_1)}$

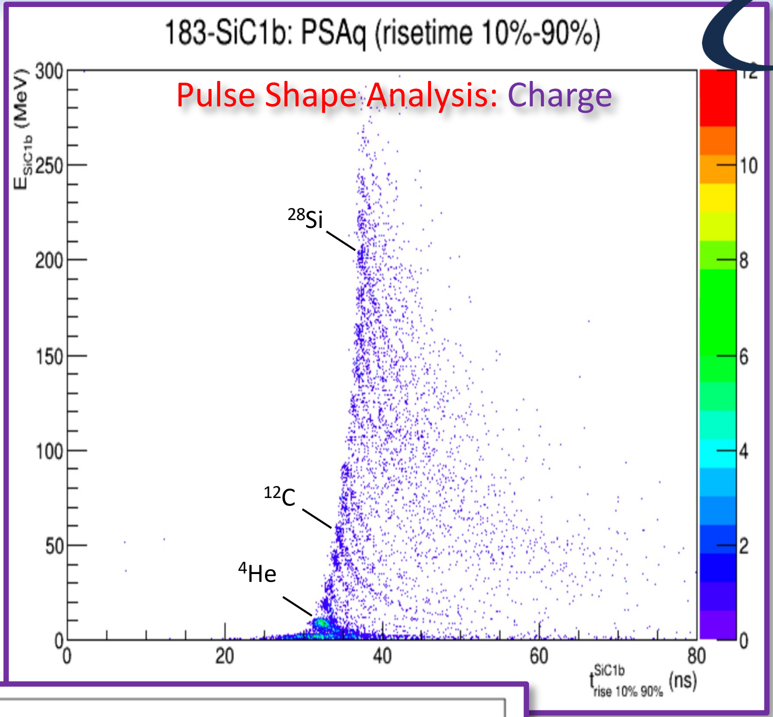
good separation if $FoM > 0.7$

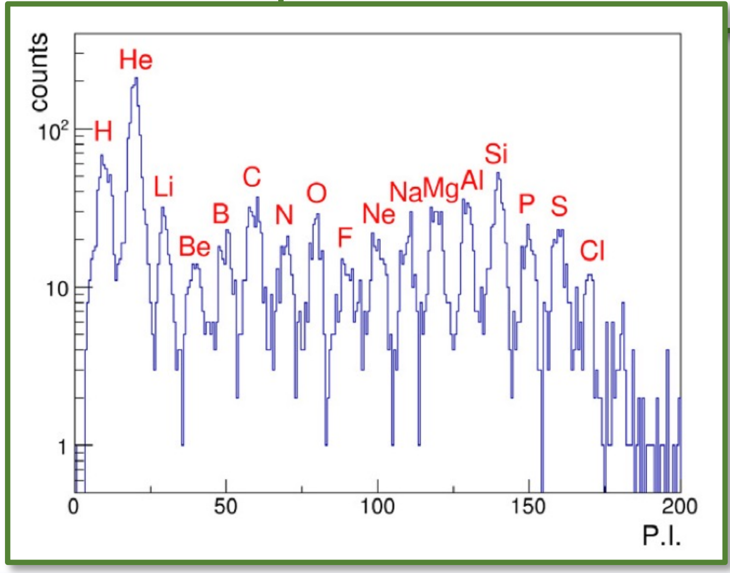
C. Ciampi et al. NIMA 925 (2019) 60-69

Performance overview : particles identification

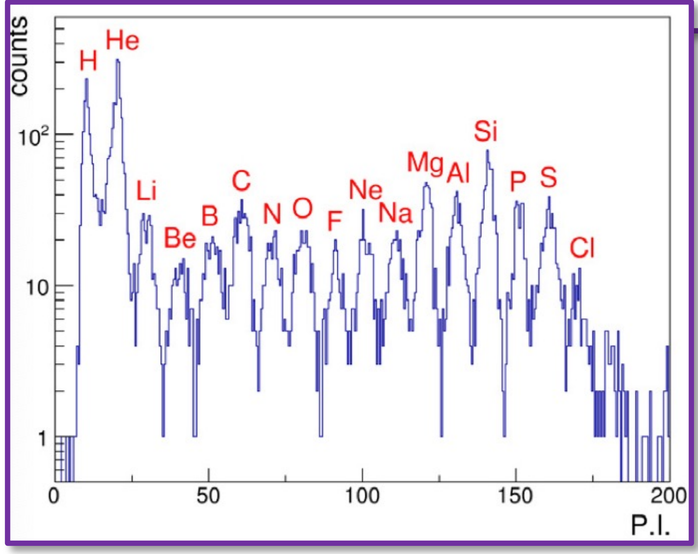


Pulse Shape Analysis





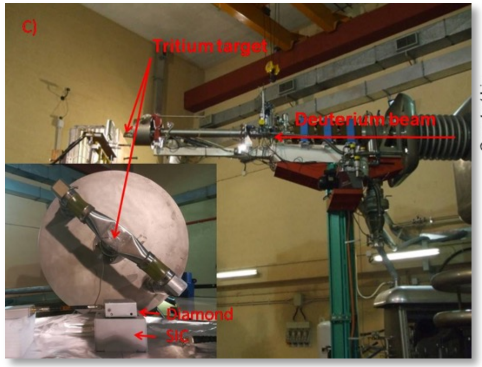
Pair	FoM	Pair	FoM
H-He	5.1	F-Ne	1.0
He-Li	3.1	Ne-Na	1.2
Li-Be	1.7	Na-Mg	1.2
Be-B	1.4	Mg-Al	1.2
B-C	1.3	Al-Si	1.3
C-N	1.3	Si-P	1.4
N-O	1.4	P-S	1.2
O-F	1.1		

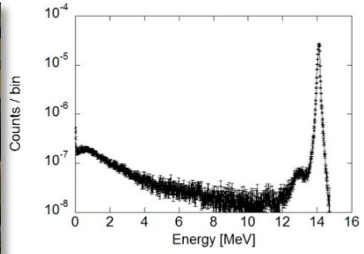


C. Ciampi et al. NIMA 925 (2019) 60-69

Performance overview : Neutrons detections

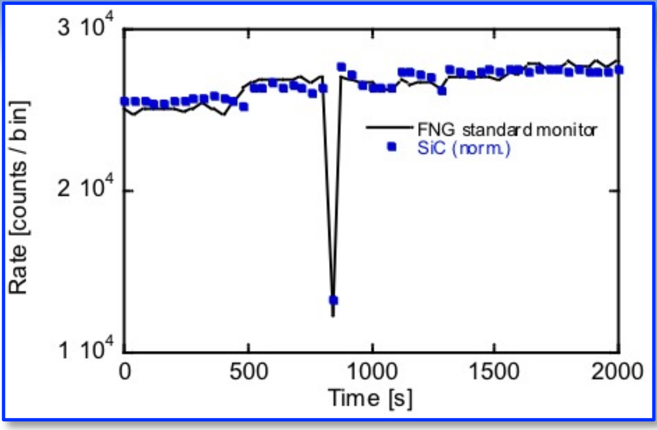
p-n diodes

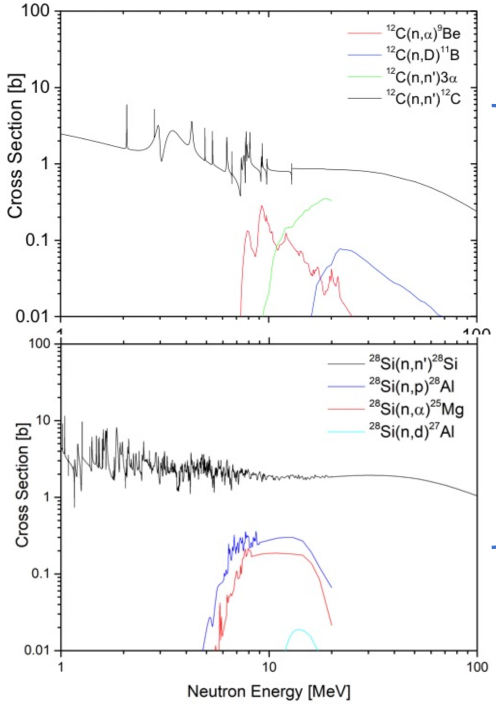




FNG ENEA - Frascati

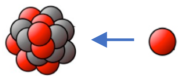
SiC neutron Beam Monitor



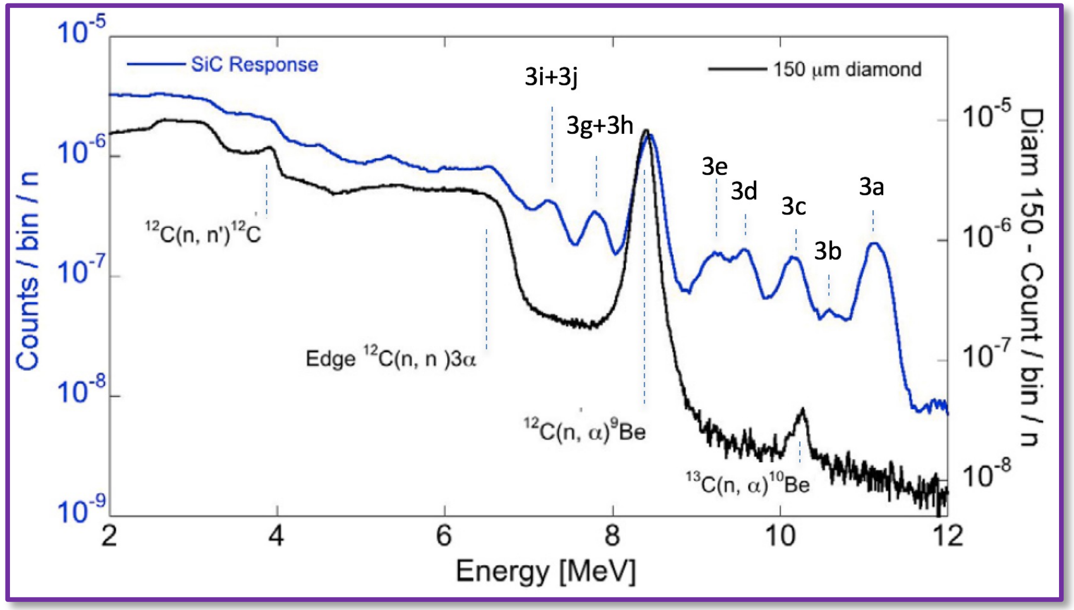


Energy deposition

n + ^{12}C



n + ^{28}Si



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

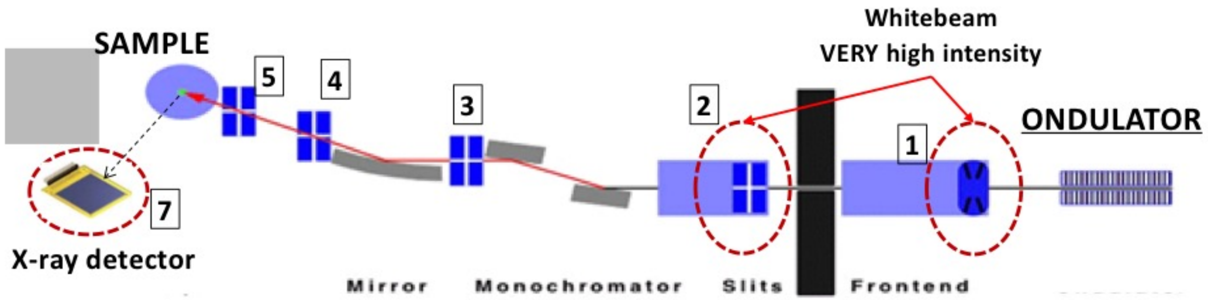
Efficiency

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)

Performance overview : X-Ray detection

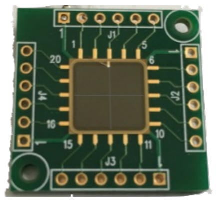
p-n diodes



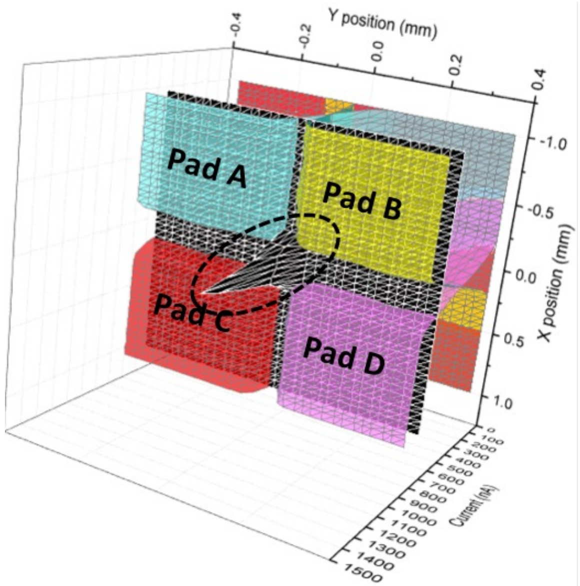
Beam Position Monitor (XBPM) 1,2,3,4,5
- Transparency
- Extreme radiation hardness
- Fast response

Synchrotrons radiation

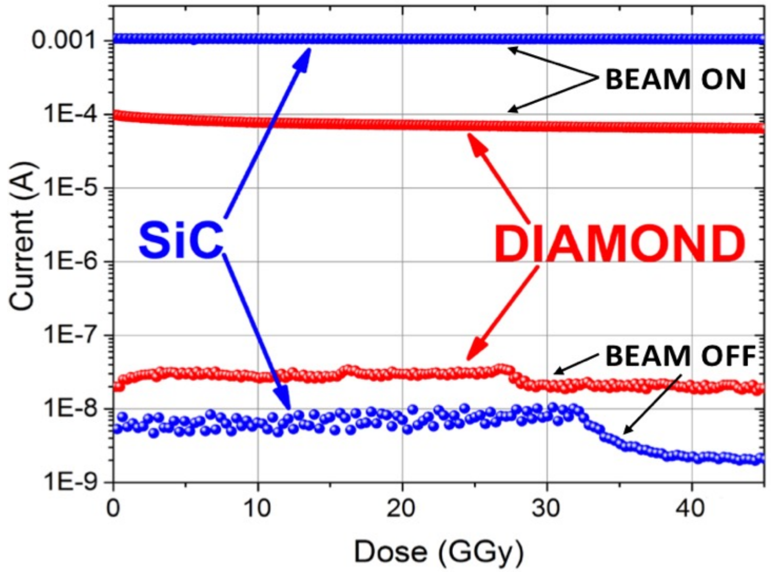
X-ray beam 10x10 μm², 5E10 ph/sec @ 12.4keV



SiC 100 μm



Radiation hardness



Radiation Hardness

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

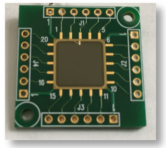
Performance overview : Beam Monitoring

p-n diodes

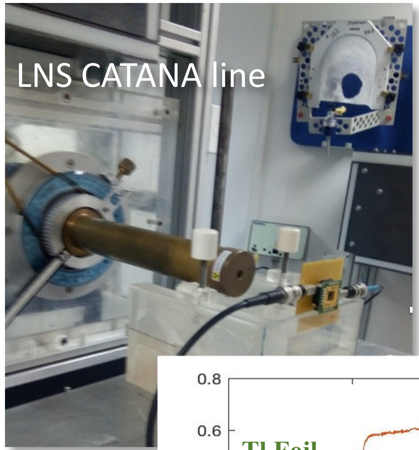
Protons beam

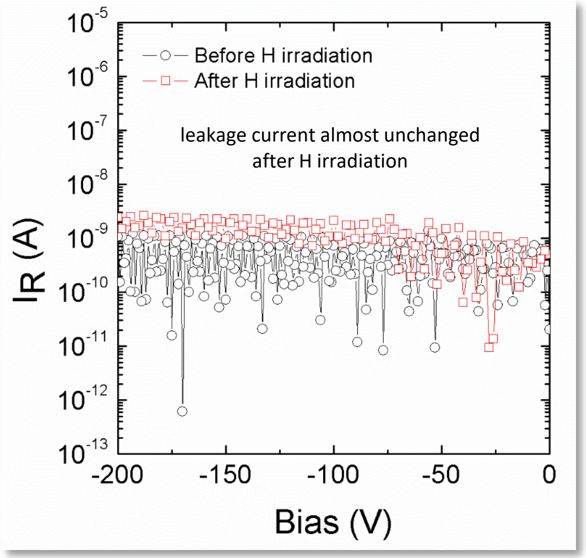
60 MeV H^+

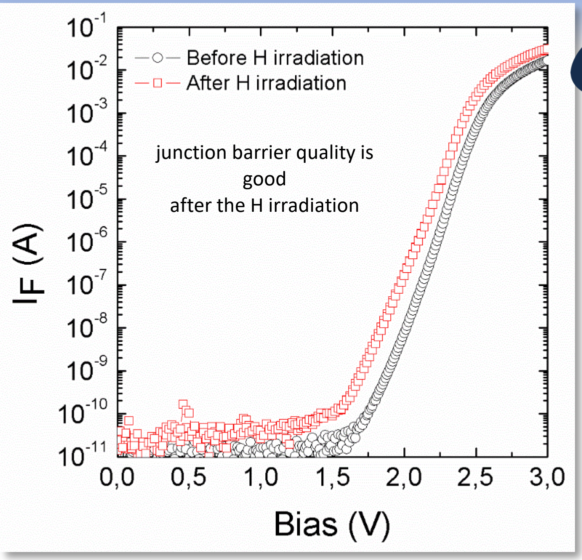
irradiation → SiC 10μm 1x1 cm^2



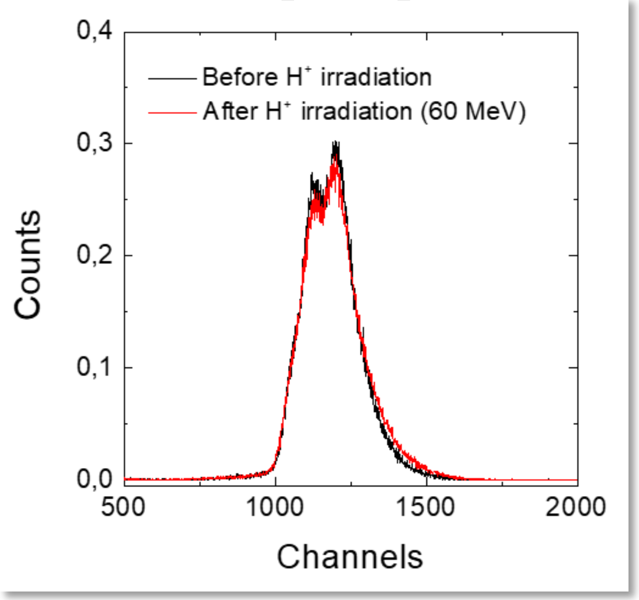
5 x 10^{13} H^+/cm^2 3 kGy

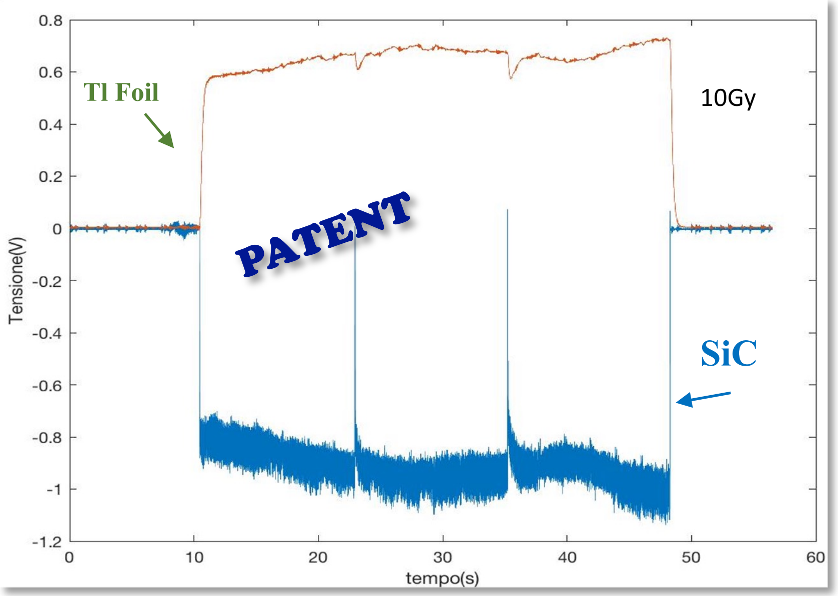


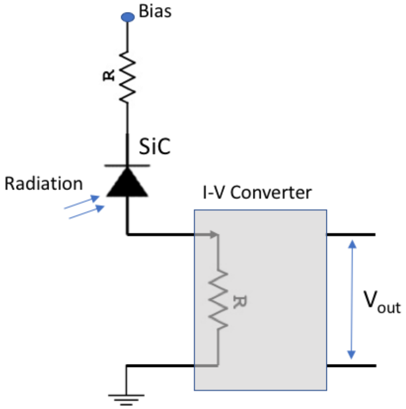




^{241}Am Alpha Spectrum





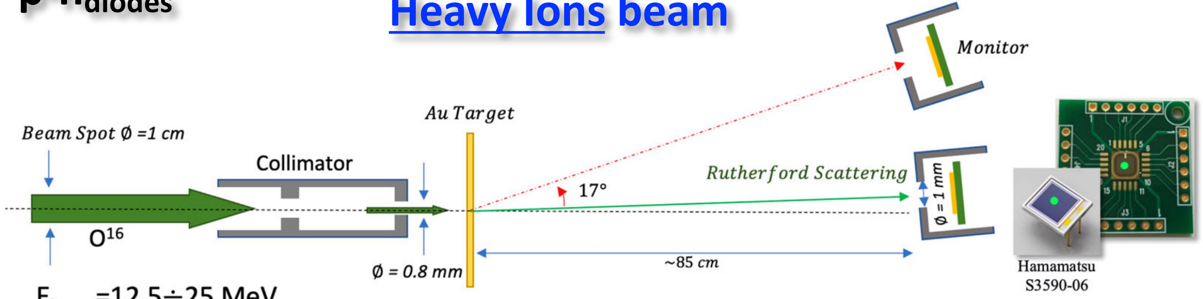


Beam Monitor and dosimetry applications

Performance overview: Radiation Hardness

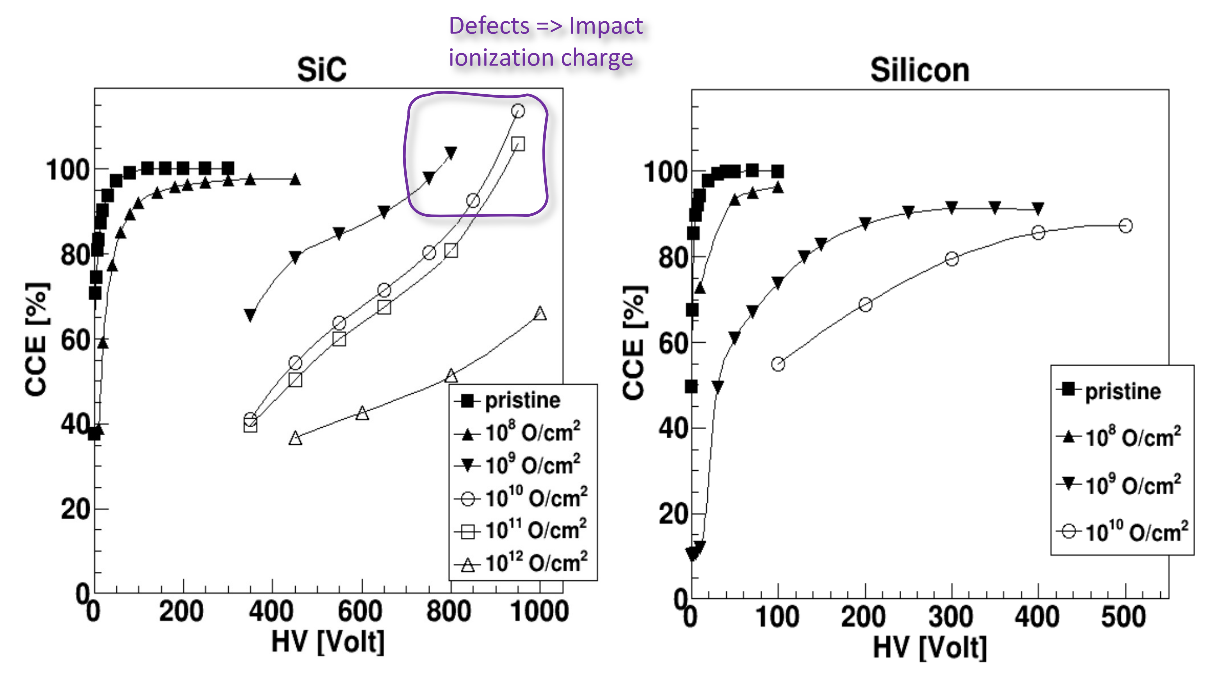
p-n diodes

Heavy Ions beam

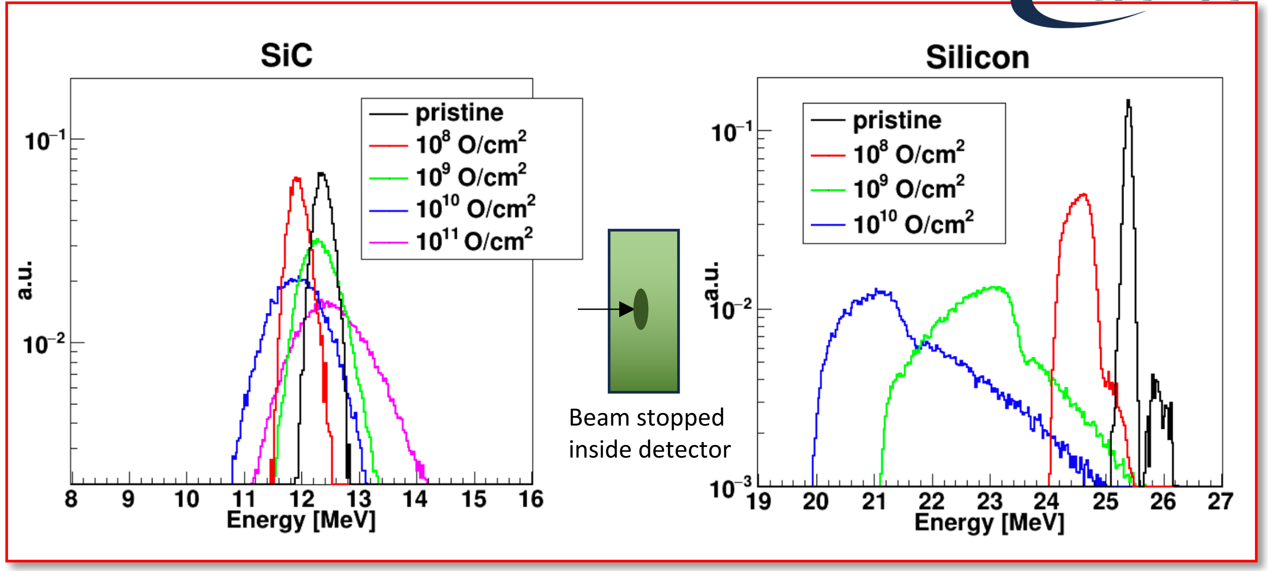


SiC/Si - DUT

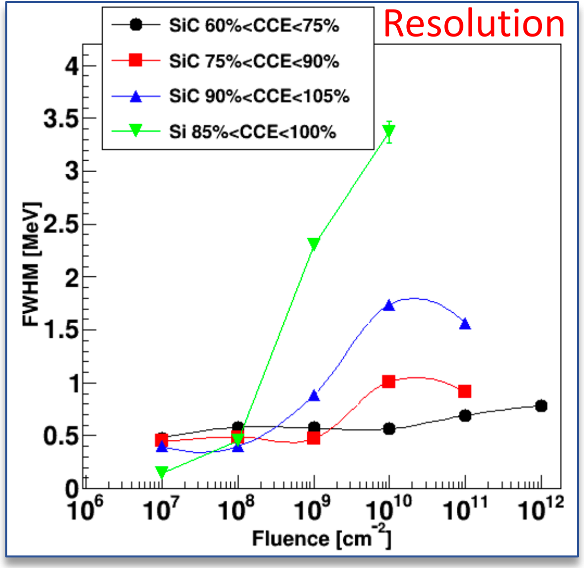
Charge Collection Efficiency

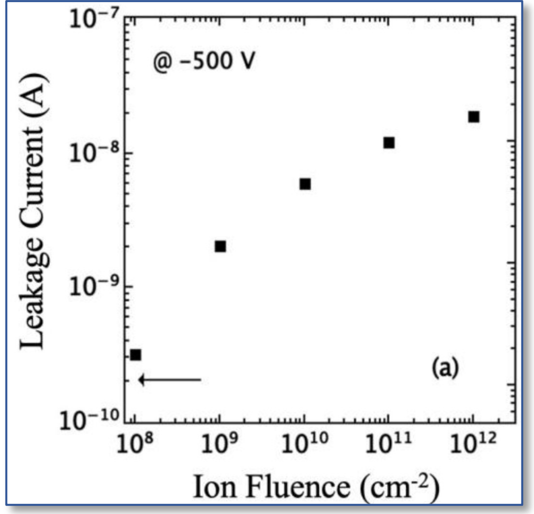


Energy spectra



Resolution





C. Altana *et al* Sensors 23 (2023) 6522

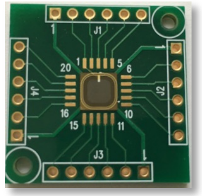
Performance overview : Radiation Hardness

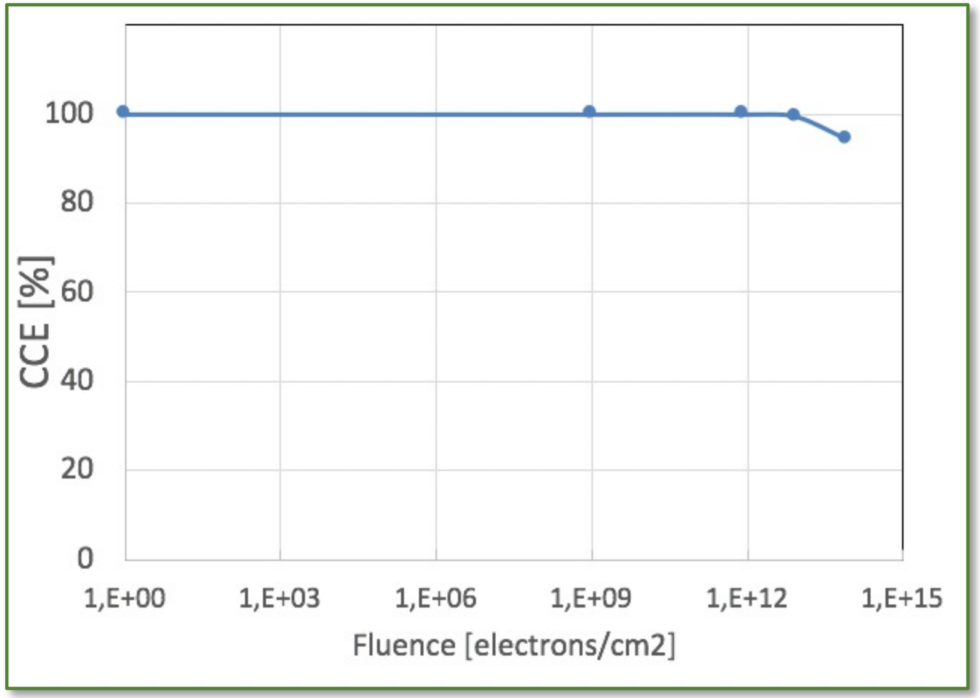
p-n diodes

electrons beam

e^- **5 MeV**

SiC 10μm 5x5 mm^2

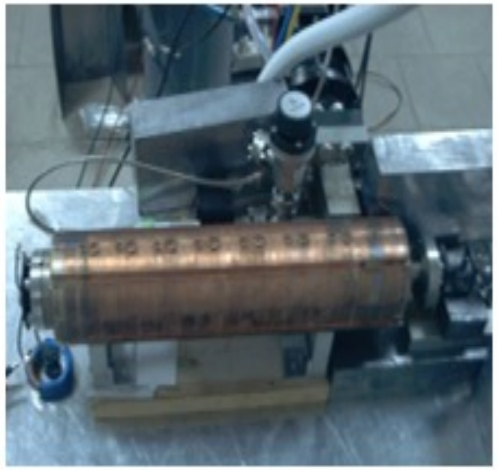




LINAC @ UniMe

Electrons irradiation

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



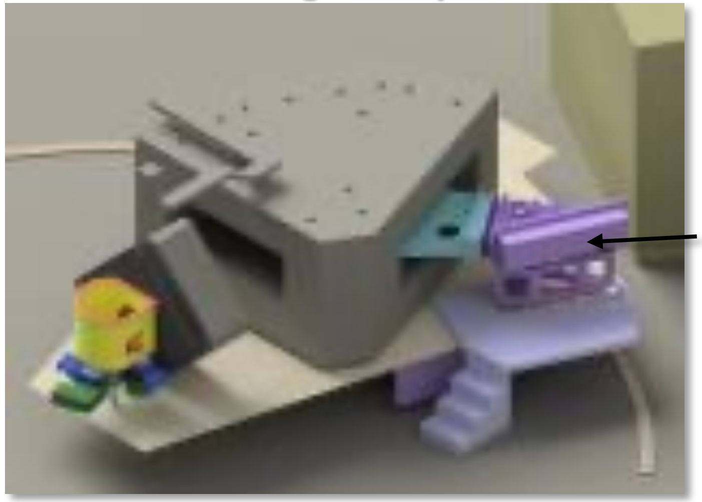
Electrons Beam Monitor

SiCILIA INFN

SiCILIA Users: NUMEM @ INFN-LNS

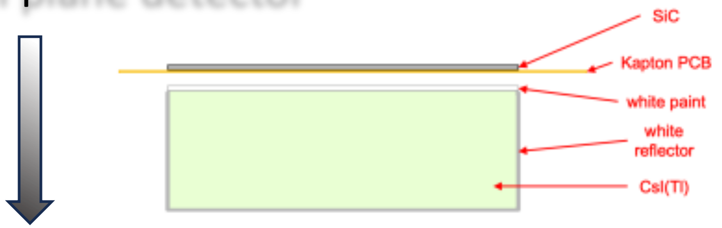
NUclear **M**atrix **E**lements of **N**eutrinoless Double Beta Decays by Heavy Ion **D**ouble **C**harge **E**xchange Reactions

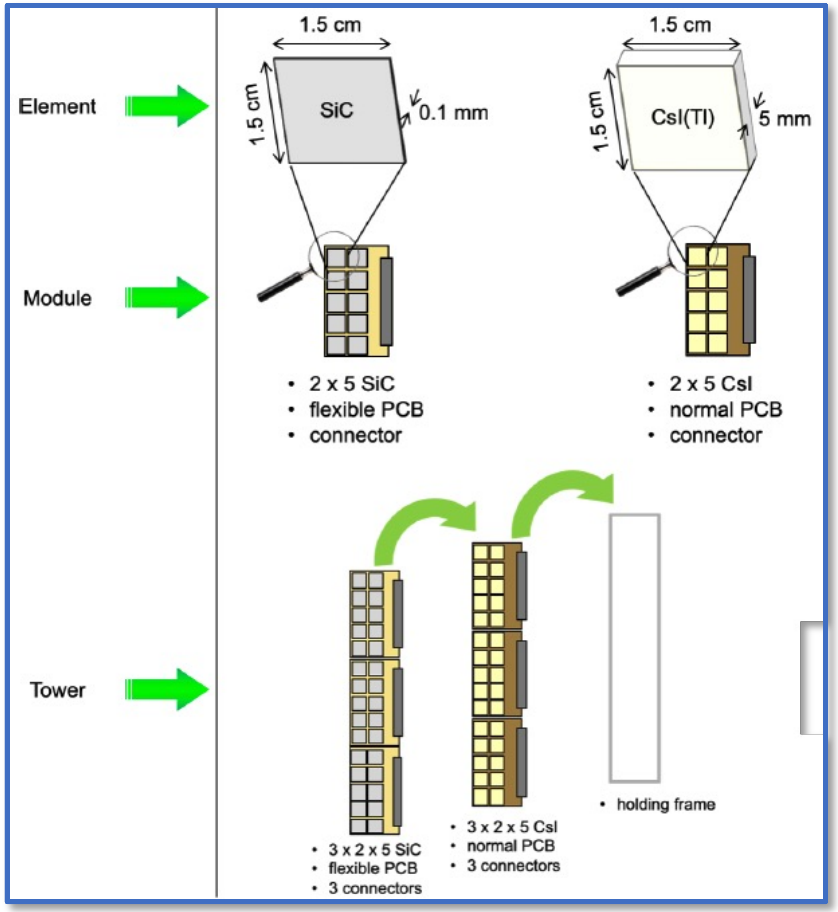
MAGNEX – Magnetic spectrometer



- ❑ Small nuclear cross-sections
- ❑ High intensity ions beams

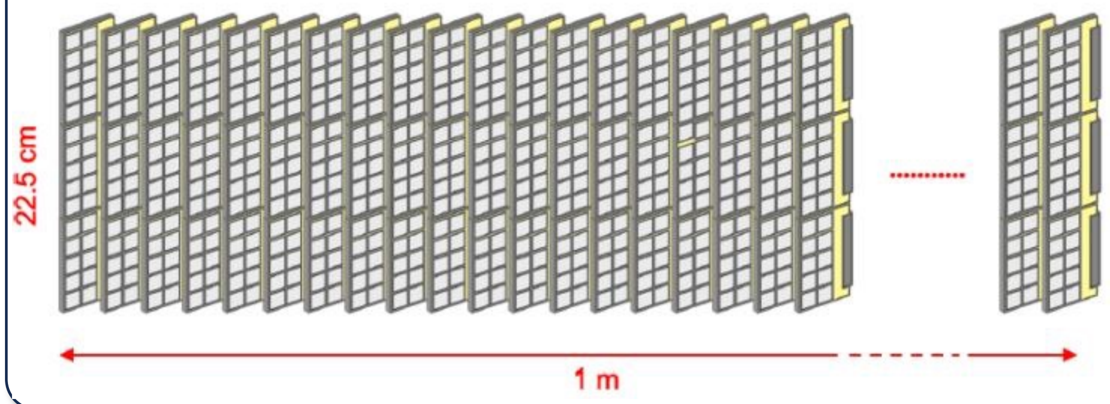
Focal plane detector





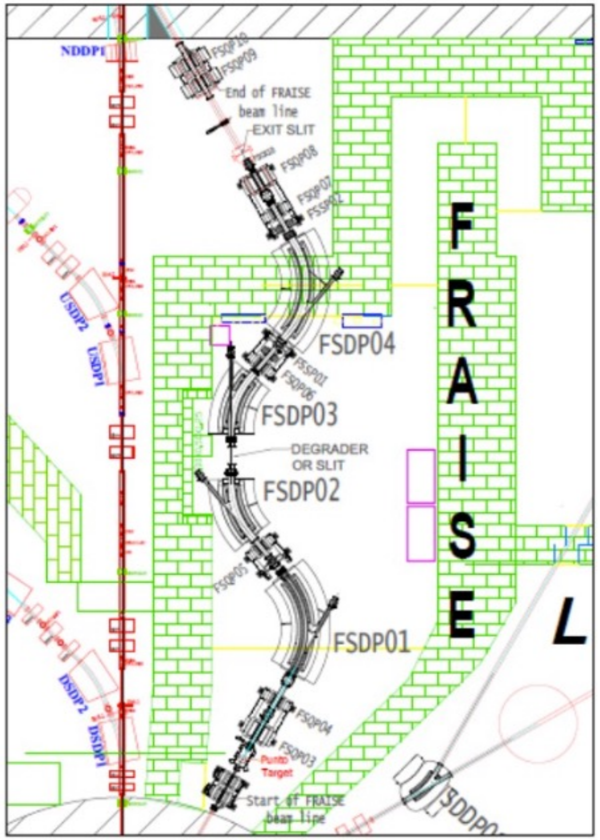
Geometry of the final PID wall

40 columns
1200 telescopes

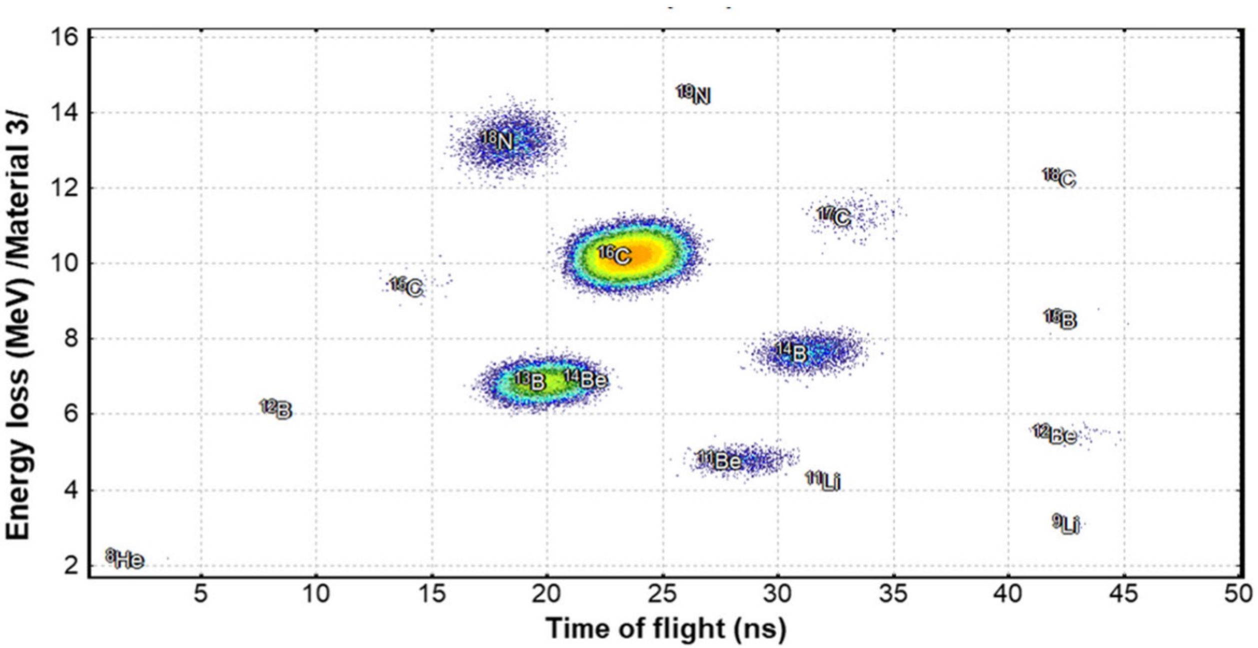


SiCILIA Users: FRAISE @ INFN-LNS

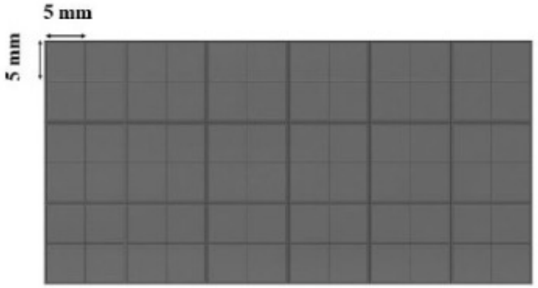
Will provide fragmetation beams with very high intensity (up to 10^7 p/s for ions like ^{16}C)



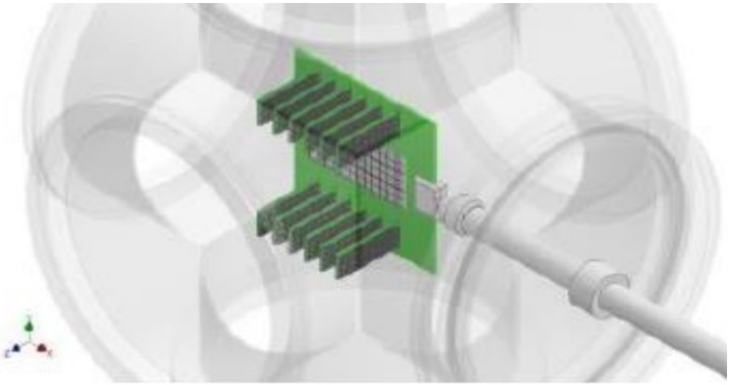
New fragment separator



Most of the produced beams will be «cocktail» and need event by event identification through the measurement of time of flight and energy loss



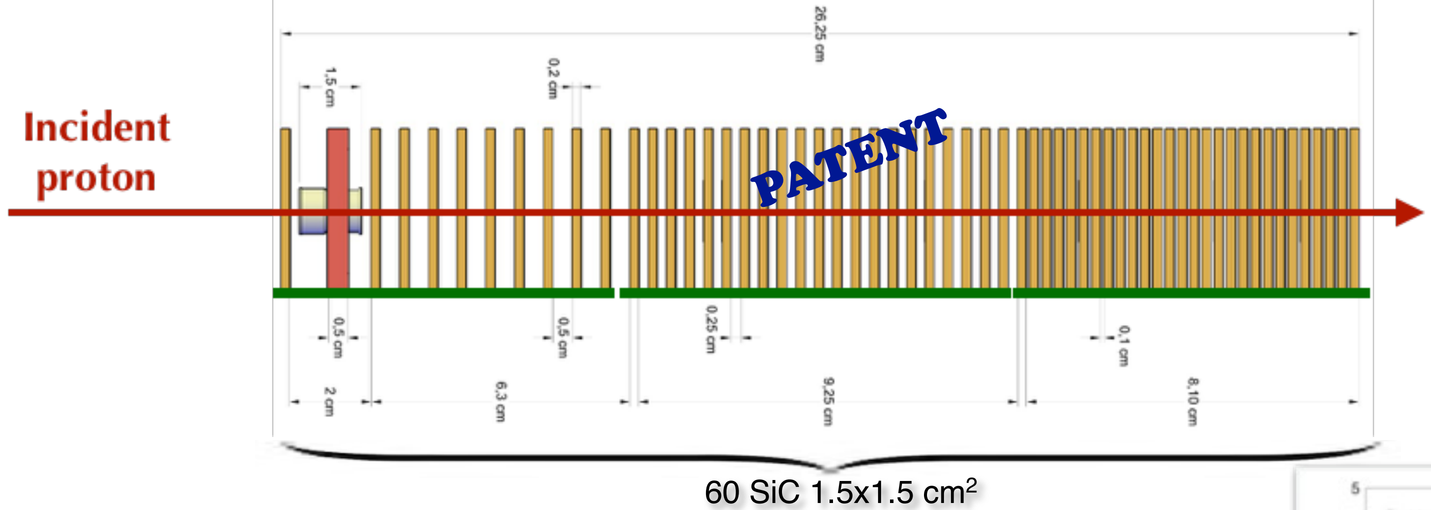
The new tagging device must be fast & radiation tolerant, therefore SiC was chosen as

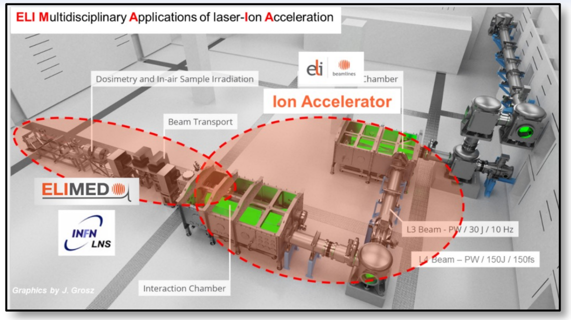


One of the studied configuration foresees the use an array of pads of 5 mmx 5mm able to cover a surface up to 6 cmx 5cm

SiCILIA Users: CATANA @ INFN-LNS

PRAGUE - **P**article **RA**n**G**e measure **U**sing Silicon Carbid**E**



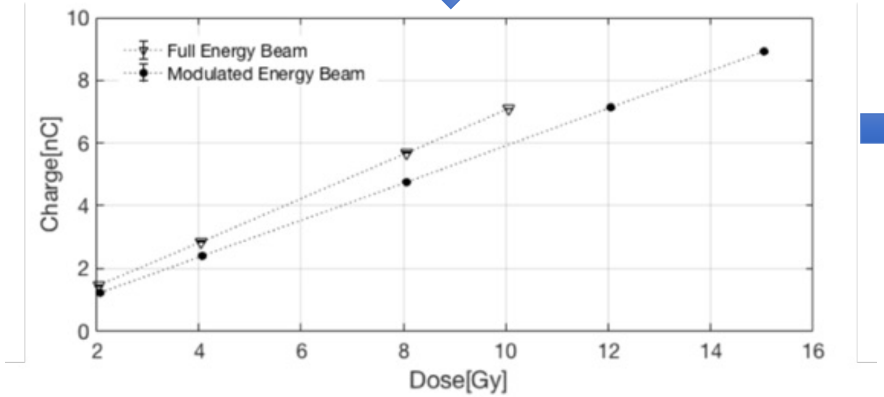


PRAGUE

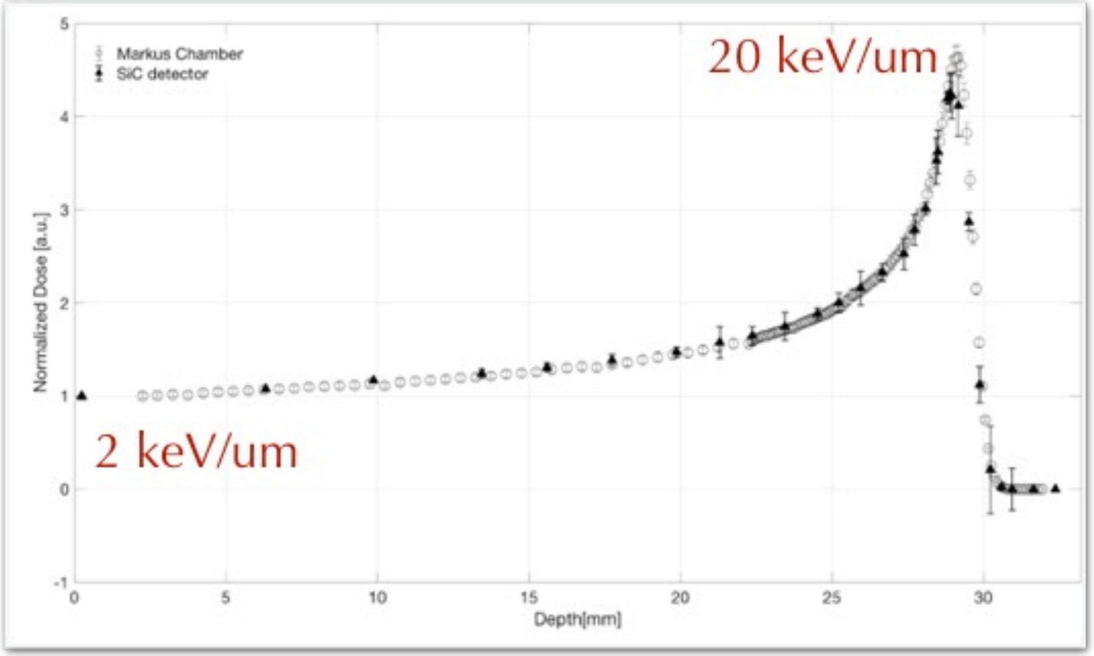
I-LUCE

INFN - Laser indUCEd radiation production

Experiental test @CATANA Facility of LNS-INFN

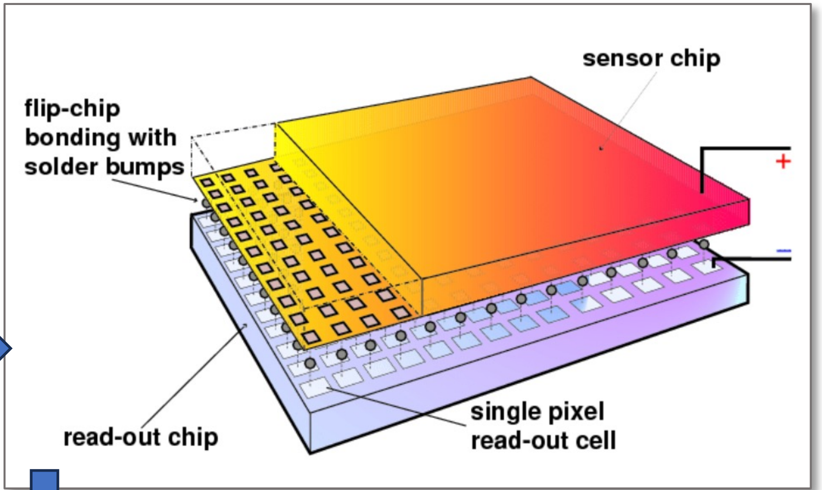


62 MeV proton beam, Modulated and Pristine beam, Beam Current: 10^6-10^8 p/cm^2



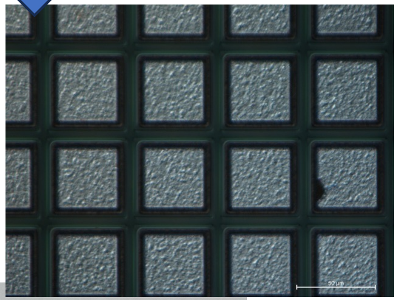
Perspectives for new devices

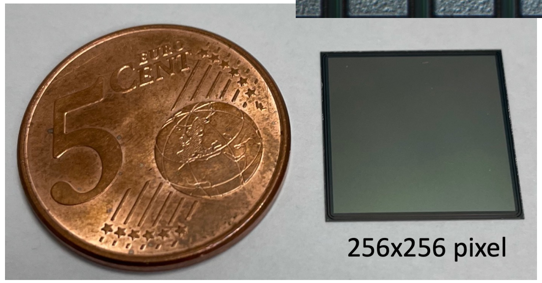
TIMEPIX



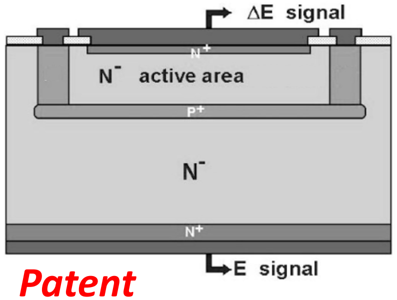
SiC-Pixel detector

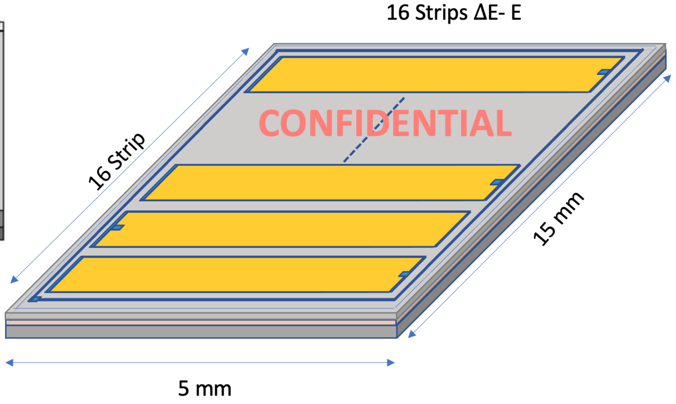
medipix collaboration





Monolithic Structure *SiC Buried anode*





Patent

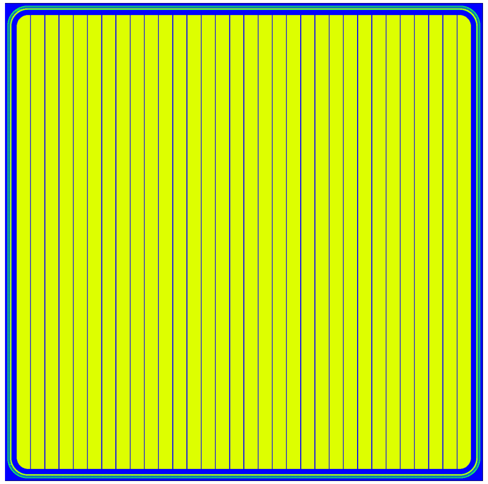
S. Tudisco et al.

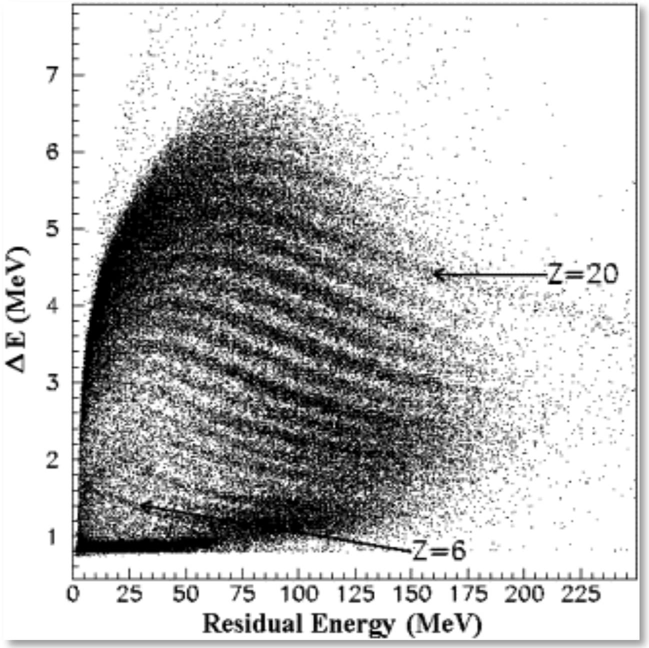
EU n° EP3821276A1

G. Cardella et al NIMA 378 (1996) 262
S. Tudisco et al NIMA 426 (1999) 436
F. Amorini et al NIMA 550 (2005) 248

SiC-Strip Detector

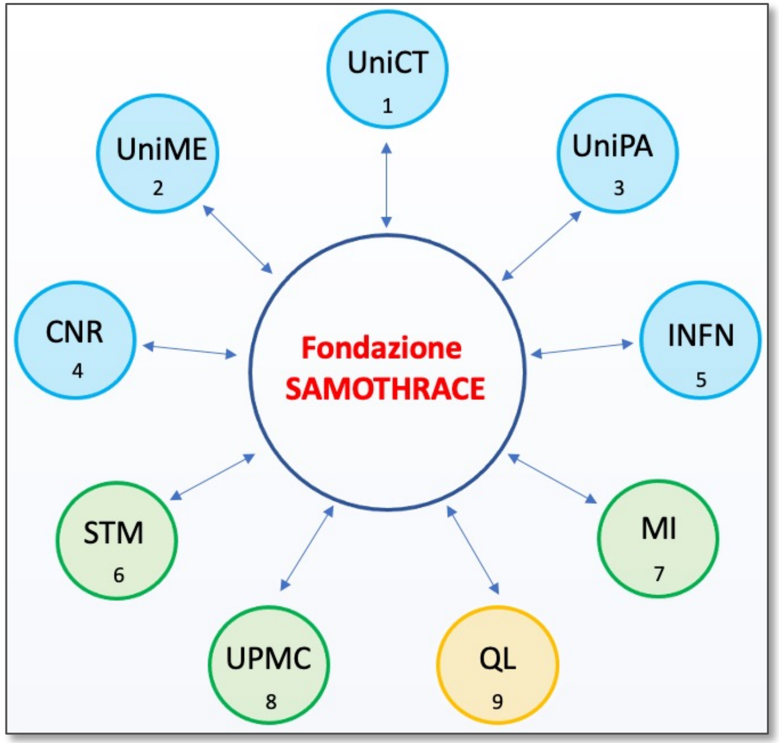
15x15 mm^2
32 strip





PNRR - SAMOTHRACE R&D on Medical devices

SiciliAn MicrOnanoTecH Research And Innovation CEnter



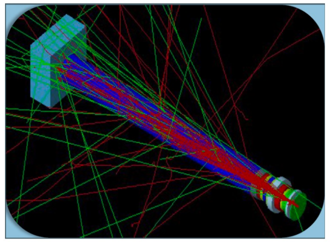
https://samothrace.eu

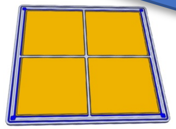
Funded by the European Union
NextGenerationEU

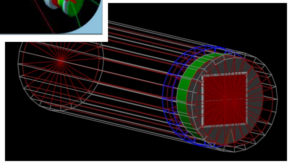
samothrace
Sicilian Micro and Nano Technology Research and Innovation Center

Wp4-**SiC Detectors** for particle therapy, dosimetry e micro-dosimetry

- **New SiC Radiation hard detectors** for: Particle therapy, dosimetry, beam monitoring, radio-protection
- **Micro-Dosimetry devices**
- **Imaging devices**







New devices
✓Dosimeters
✓Micro-dosimeters
✓beam-monitors
✓Imaging devices

Synergy
IMM-CNR, LPE, STM

Thanks for your attention !