Silicon Carbide Detectors for Intense Luminosity Investigations and Applications

Istituto Nazionale
di Fisica Nucleare

SiCilia is one of the winners at the Call GrV 2015

Other SiC
In CSN V

ClasSiC (P. Lenzi, grant for young researchers 2015)
- Dual read-out hadronic calorimetry
- TOF-PET with sensitivity to Cherenkov light (☒ 10 ps resolution)
- Need for single-photon sensitivity
  - Final target: device with intrinsic amplification ($10^3 - 10^4$)

Why is SiC interesting?

Property	D	Si	4H–SiC
Bandgap (eV)	5.5	1.12	3.27
Relative dielectric constant	5.7	11.9	9.7
Breakdown field (MV cm^{-1})	10	0.3	3.0
Density (g cm^{-3})	3.5	2.3	3.2
Atomic number Z	6	14	14–6
e–h creation energy (eV)	13	3.6	7.78
Saturated electron velocity (10^7 cm s^{-1}) at 300 K	2.2	1.0	2
Electron mobility (cm^2 V^{-1} s^{-1}) at 300 K	1800	1300	800
Hole mobility (cm^2 V^{-1} s^{-1}) at 300 K	1200	460	115
Threshold displacement energy (eV)	40–50	13–20	22–35
Minimum ionizing energy loss (MeV cm^{-1})	4.7	2.7	4.4

In short

- Develop HI sensors able to work in high BK environments and under high fluences
- Triggers: NUMEN project (WhatNext INFN) and Nucl Reactions studies in Laser Plasmas @ ELI-NP
- Try to take SiC based sensors to the grade of the Si technology
- Good features: the 'same' as Silicon   with the additional much larger radiation hardness (expected up to 4-5 o.o.m more). Visible light insensitivity.

The aim of SiCILIA is to develop innovative processes, which allow a massive production of thick and large area (about 1 cm2) SiC detectors with unprecedented level of defects

The aim

- Small 4H-SiC Shottcky diodes developed in the past. No very good doping uniformity. Defects per unit area rather abundant
- Recent years, strong improvement of epitaxy with reduction of defects thus opening the door to (large) p-n junctions
- Hope to build detectors with low rev current and better S/N ratio (100 and 1000 micron, possibly, and 1cm2 area)

Shottcky development will be carried out at **FBK**

Epitaxial P-n junctions will be built at **ST-microelectronics**

Then comparisons on the basis of the 'final users' expertises and requests

Work done

Two workshops at LNS:

- Dic 2015: kick-off meeting
- April 2016: a plenary wide 'conference' with participation of many different actors from various fields. Also a presentation by GC:

R&D on silicon detectors within the FAZIA collaboration: results and perspectives

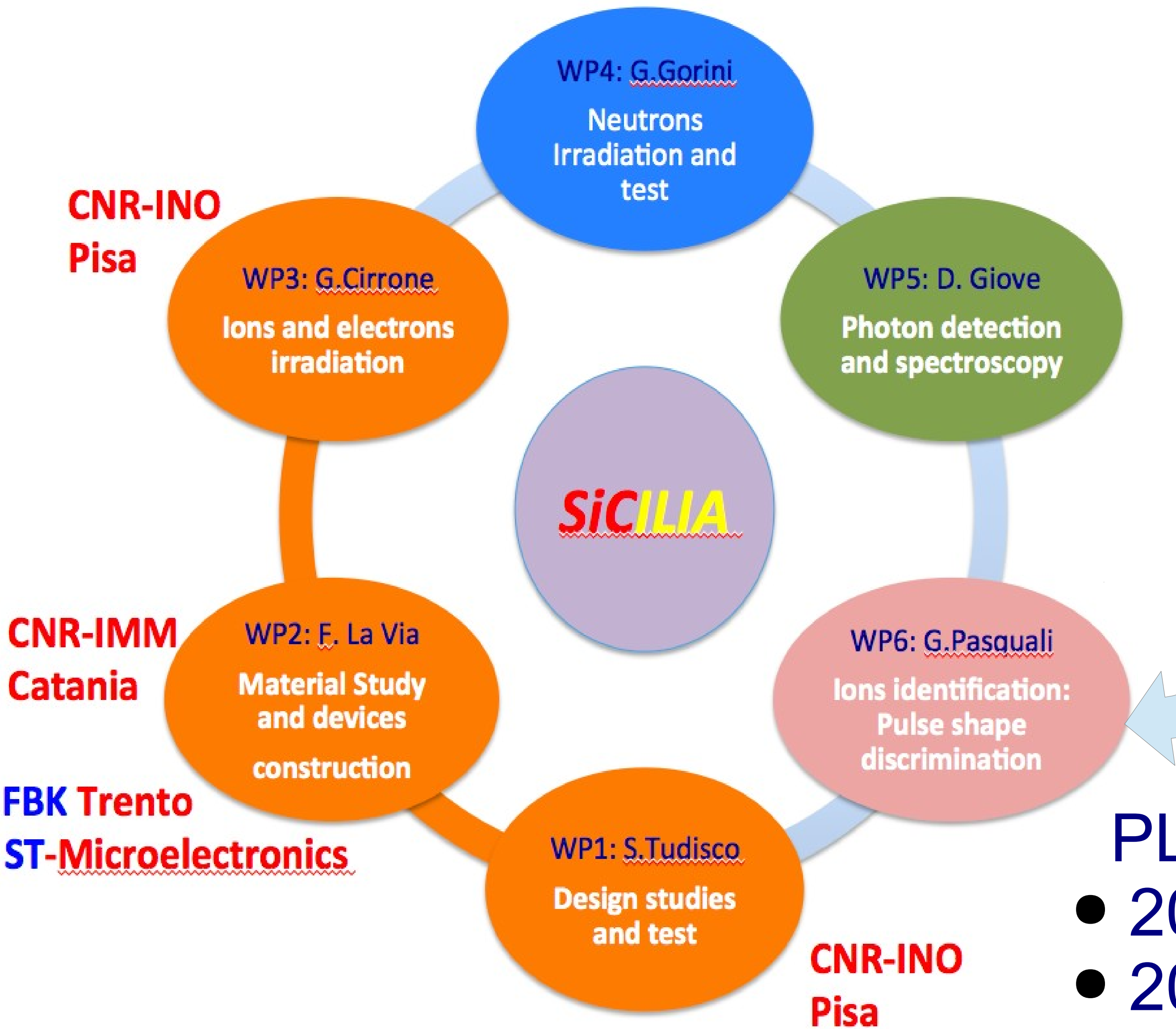
https://agenda.infn.it/conferenceTimeTable.py?confId=11096#20160407

CSN V was importantly present

From Buonvicini's summary

Collaboration with Industry and other Research Institutes is strategic in order to improve the technology and make it available to the INFN research community;

People,WP's,money



Florence PEOPLE

	FTE
Gabriele Pasquali RL	0.25
Giovanni Casini	0.2
Sandro Barlini	0.2
Andrea Stefanini	0.2
Giacomo Poggi	0.2
Giuseppe Pastore PhD	0.2

PLANNING

- 2016 449ke; Firenze 3ke
- 2017 326ke; Firenze 8ke (3ke travels)
- 2018 156ke

Why Florence in this field?

Nuclex and FAZIA collaborations studied
Ion identification in silicon detectors and pointed out critical aspects

Structure and configuration effects

Crystalline nature of Silicon and channeling
Doping inhomogeneities in Silicon bulk
Mounting geometry

And for SiC?

Dynamical effects

Radiation damage

for SiC reasonably better

Electronics and digital treatment

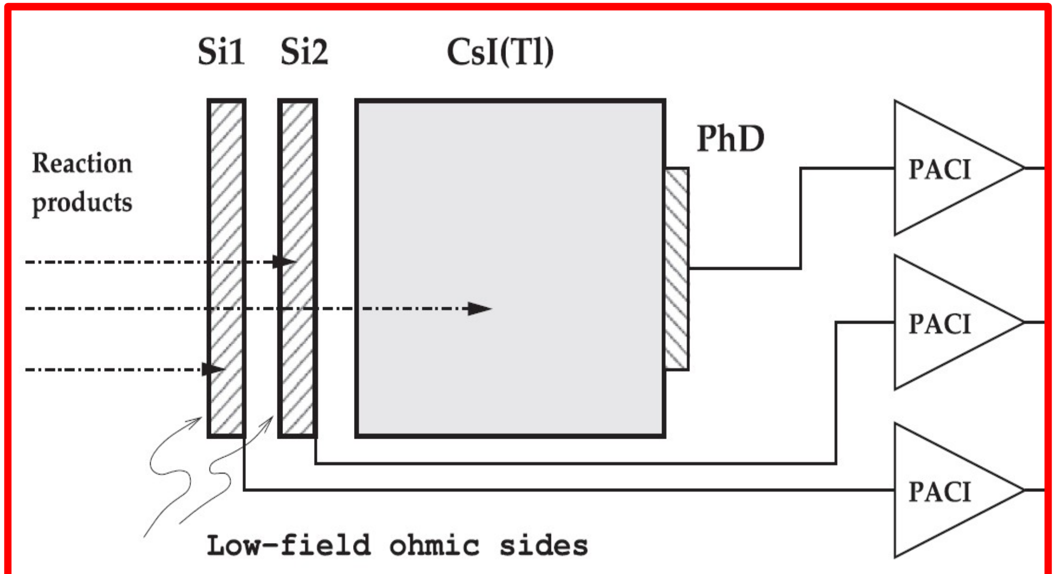
Noise sources and sampling freq limits

Same issues as for Silicon

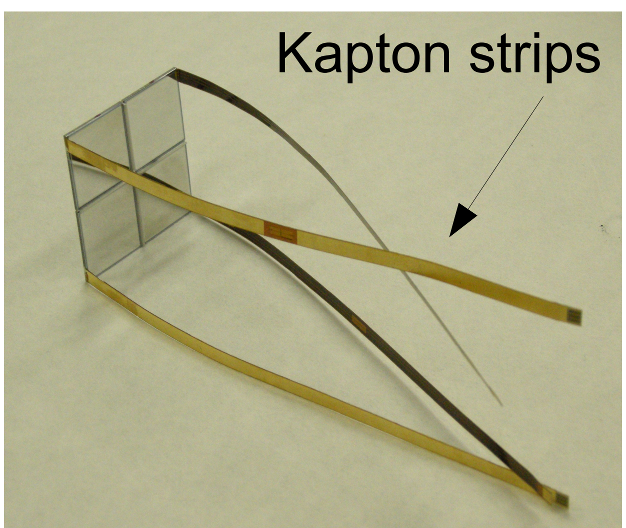
The FAZIA telescope

Valuable work of
E.Scarlini on Sliicons;
G.Tobia on CsI

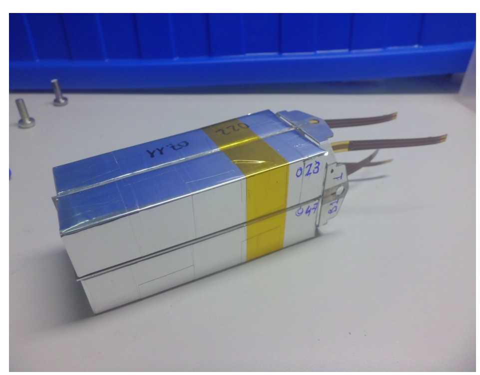
Silicons
20x20mm2
nTD type
ρ~3-4000 ohm*cm
300 and 500 μm
8deg cut off <100>



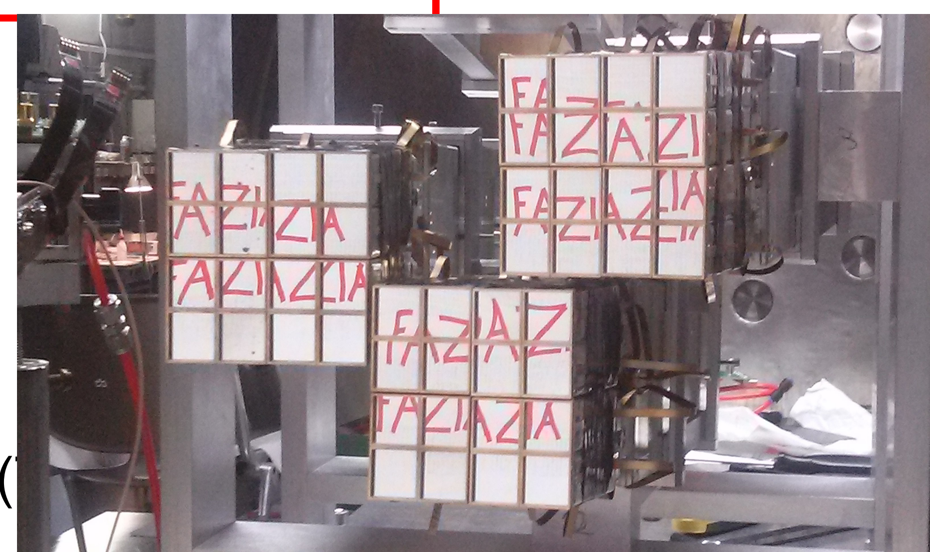
CsI(Tl)
20x20mm2
tapered
1500-2000ppm Tl-doping
Uniform doping
10 cm thick



Quartetto of Si mounted on Al (Ergal) support



Quartetto of CsI(



3 BLOCKS of 16 Telescopes

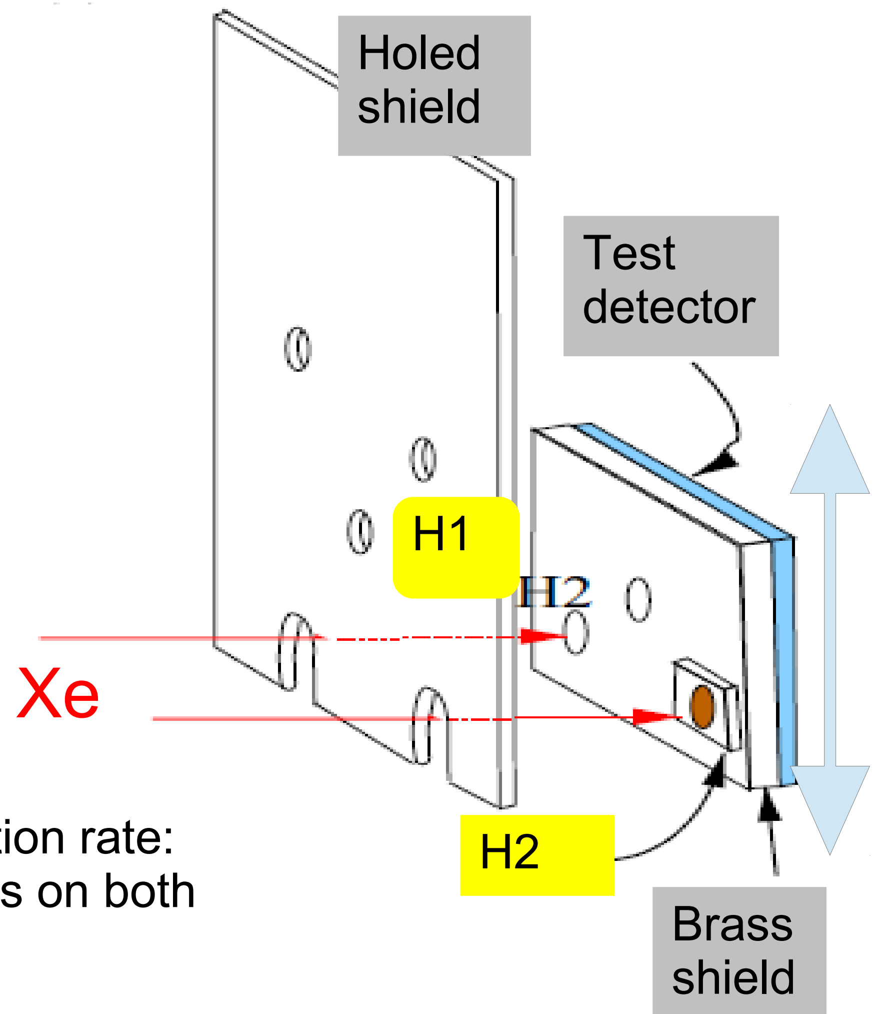
PSA and radiation damage

S.Barlini NIM A 707 2013

- A specific study @LNS using 129Xe ions at 35MeV/u
- Damage induced in Silicons by stopped or trasmitted Xe-ions (monoenergetic)
- Used typical FAZIA 300mic and 500mic detectors, 20x20mm2
- ADC 12bit 125MSs

TEST DETECTOR

20 × 20 mm
FBK
310 μm
120 V
140 V
n-type
2970 Ωcm
2.3%
301 cm
0.3°/1.4°



Irradiation rate:
700 pps on both holes

TWO REGIONS in the Silicon

H1: passing through ions

H2: stopped ions

PSA and radiation damage

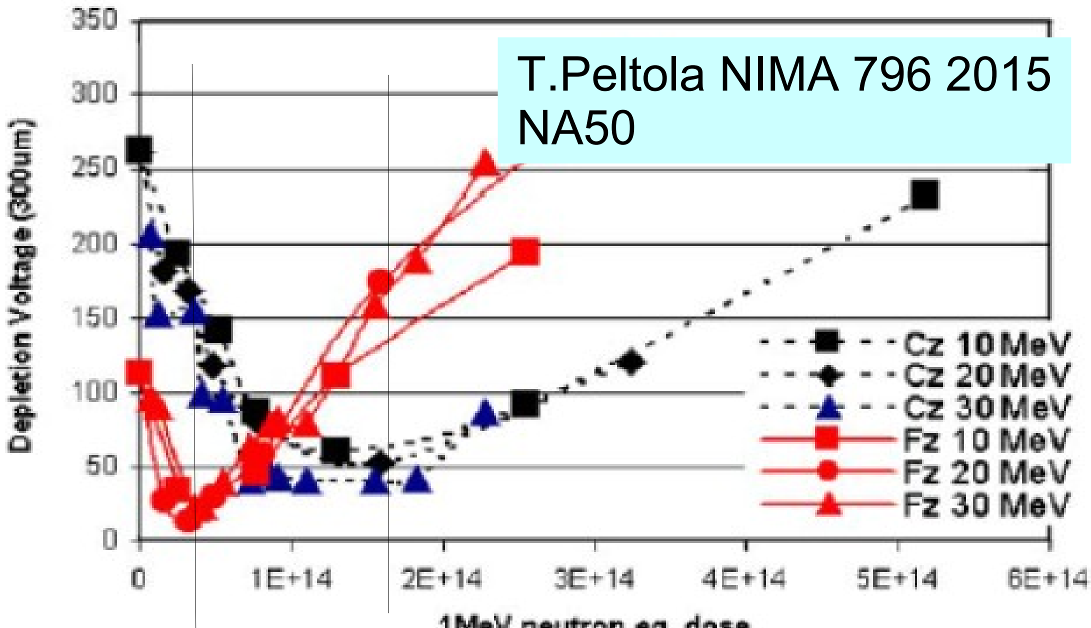
S.Barlini NIM A 707 2013

$$D(E) = \frac{A}{N_A} NIEL(E)$$

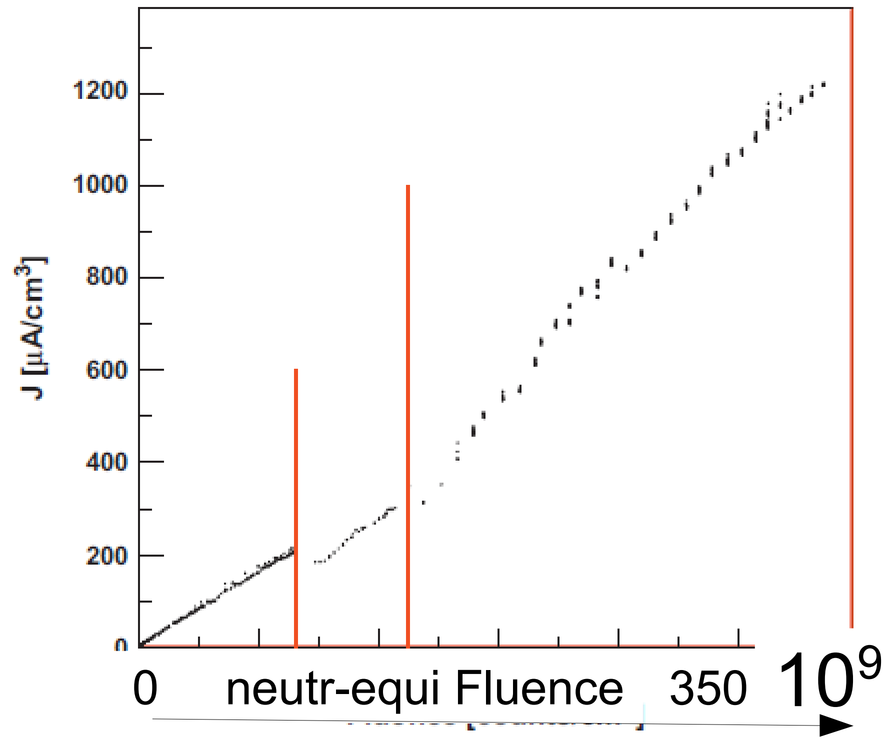
$$\Phi_{eq} = k\Phi = k\int \phi(E)\,dE = \frac{\int D(E)\phi(E)\,dE}{D(E_n = 1\ \mathrm{MeV})}$$

Evaluation of NIEL for 129Xe from SRIM:
1.37GeV*g/cm2 gives k=700
Xe ion are 700 time more effective to produce damage than neutrons

At leat 3 orders of magnitudes less than the region of doping inversion in n-type bulk according to proton-neutron HEP test at LHC



First effect: rev. Current increase



Doping inversion effect for FZ or CZ silicon detectors irradiated with neutrons

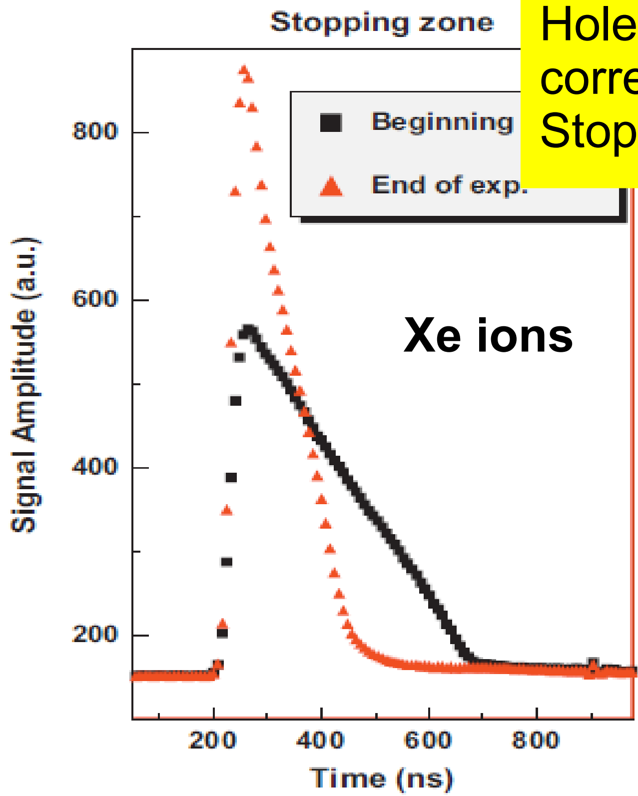
PSA and radiation damage

S.Barlini NIM A 707 2013

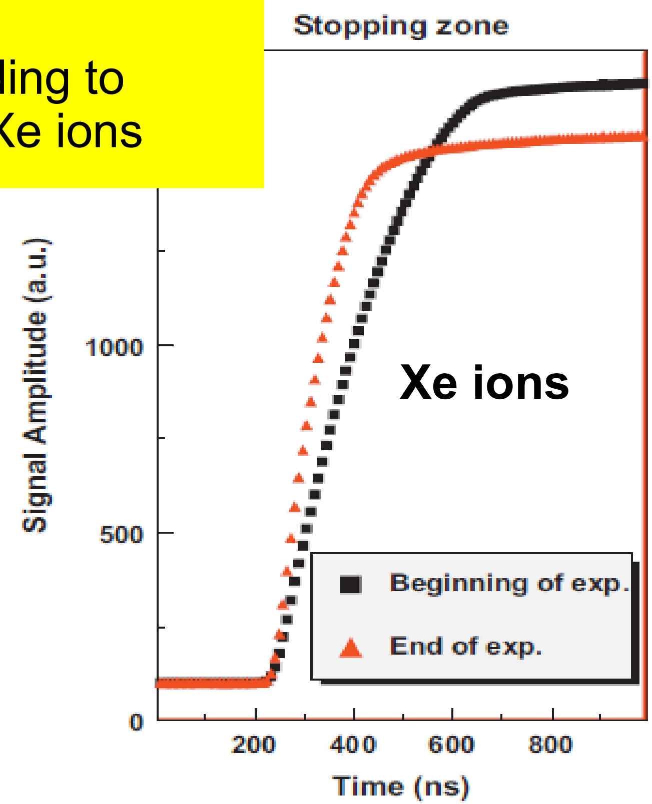
Second Effect: changes in signal evolution

A semi-expected phenomenon: change in pulse shape (ok) but in the unexpected direction: a decrease of collection times

Hole H2 corresponding to Stopping Xe ions



Current signal



Charge signal

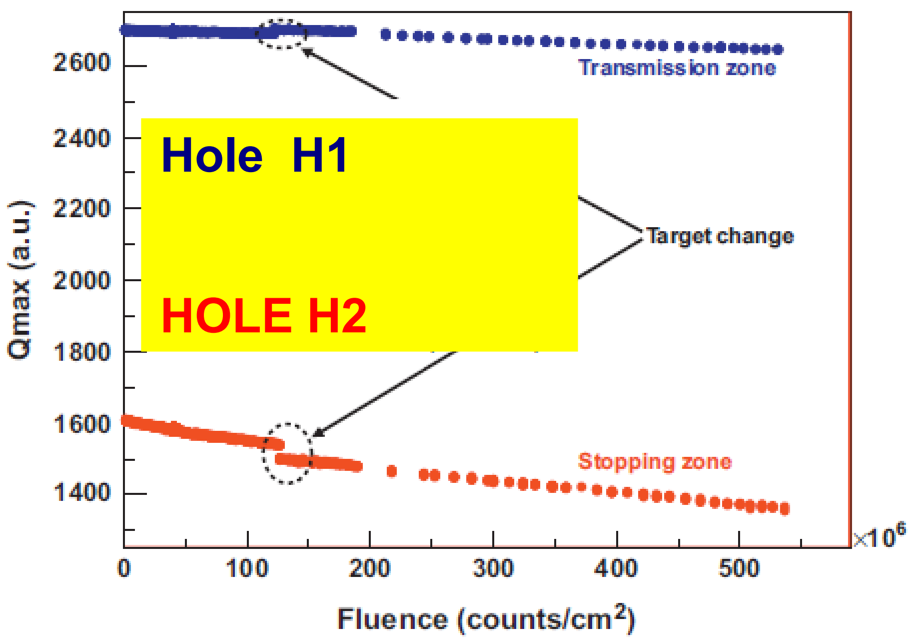
Much less effect for Xe passing in H1, the hole where ions are transmitted

PSA and radiation damage

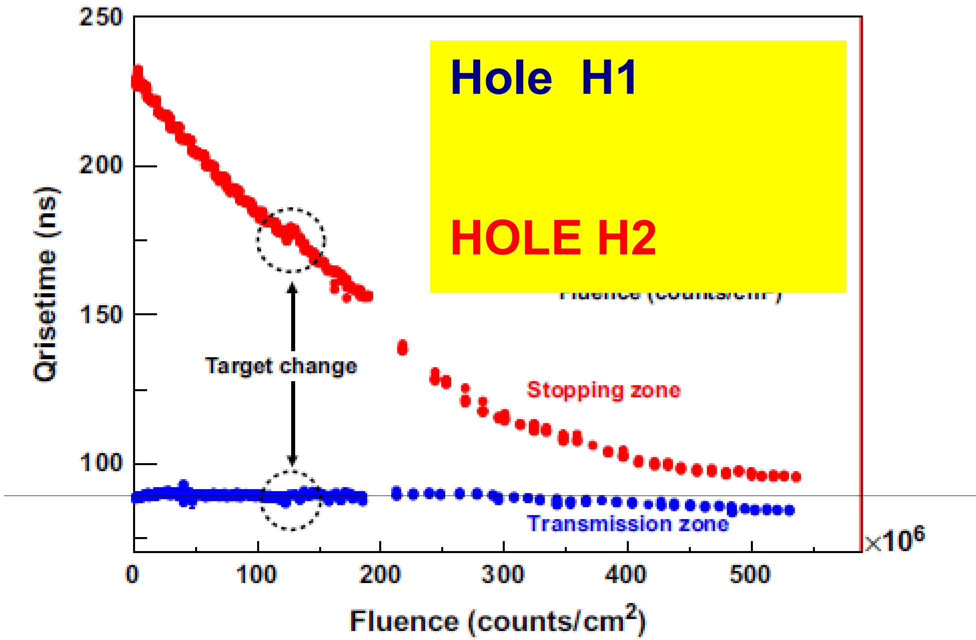
S.Barlini NIM A 707 2013

Second Effect: decrease of CCE and change of shape

For stopped ions: 15% reduction of CCE along time (fluence)
For stopped ions: strong reduction of typical collection times



Charge signal shaped MAX



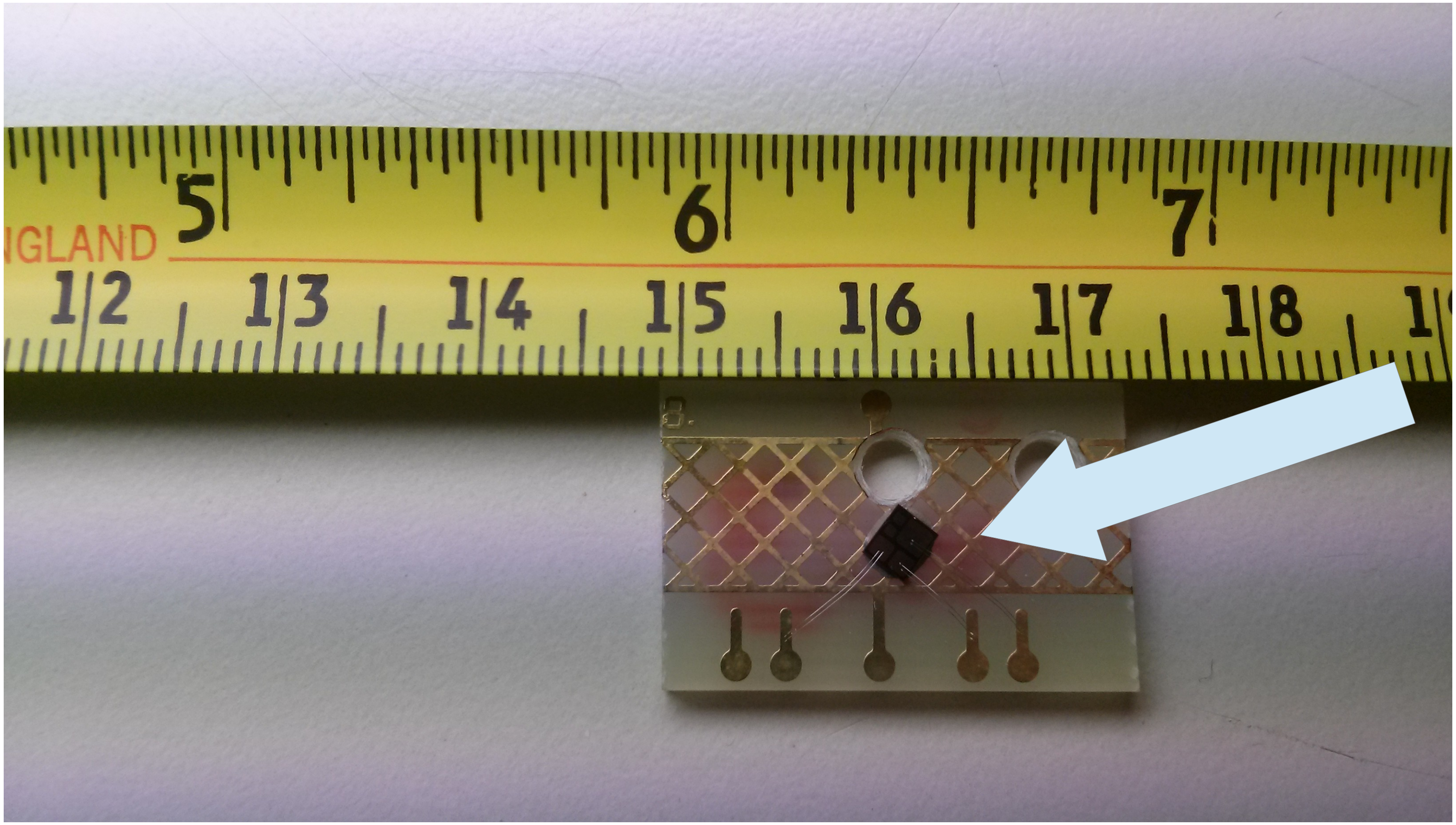
Charge signal shaped RISETIME

Much less effect for Xe passing in H1, the hole where ions are transmitted

Subject that could be further investigated, also with SiC

Let's start with SiC

Very first and very small SiC pads (Schottky and not epitaxial) in order to start playing with
Dimensions: 1x1 and 0.5x0.5 mm2
Thickness 300micron



Conclusions

Aspects related to the optimum use of Si detectors for heavy ion spectroscopy have been evidenced by FAZIA

Parameters to be kept under control for PSA and DE-E
Orientation of processing and mounting
Homogeneity of the doping
Metalization of surfaces
Radiation Damage

Other subjects with Si
thin detectors
Underbiasing and PSA
Charge collction in Zero Field regions
Best filters (analysis of samples)
Timing

FAZIA expertise can be useful for SiCilia developments in the field of Heavy Ion collisions