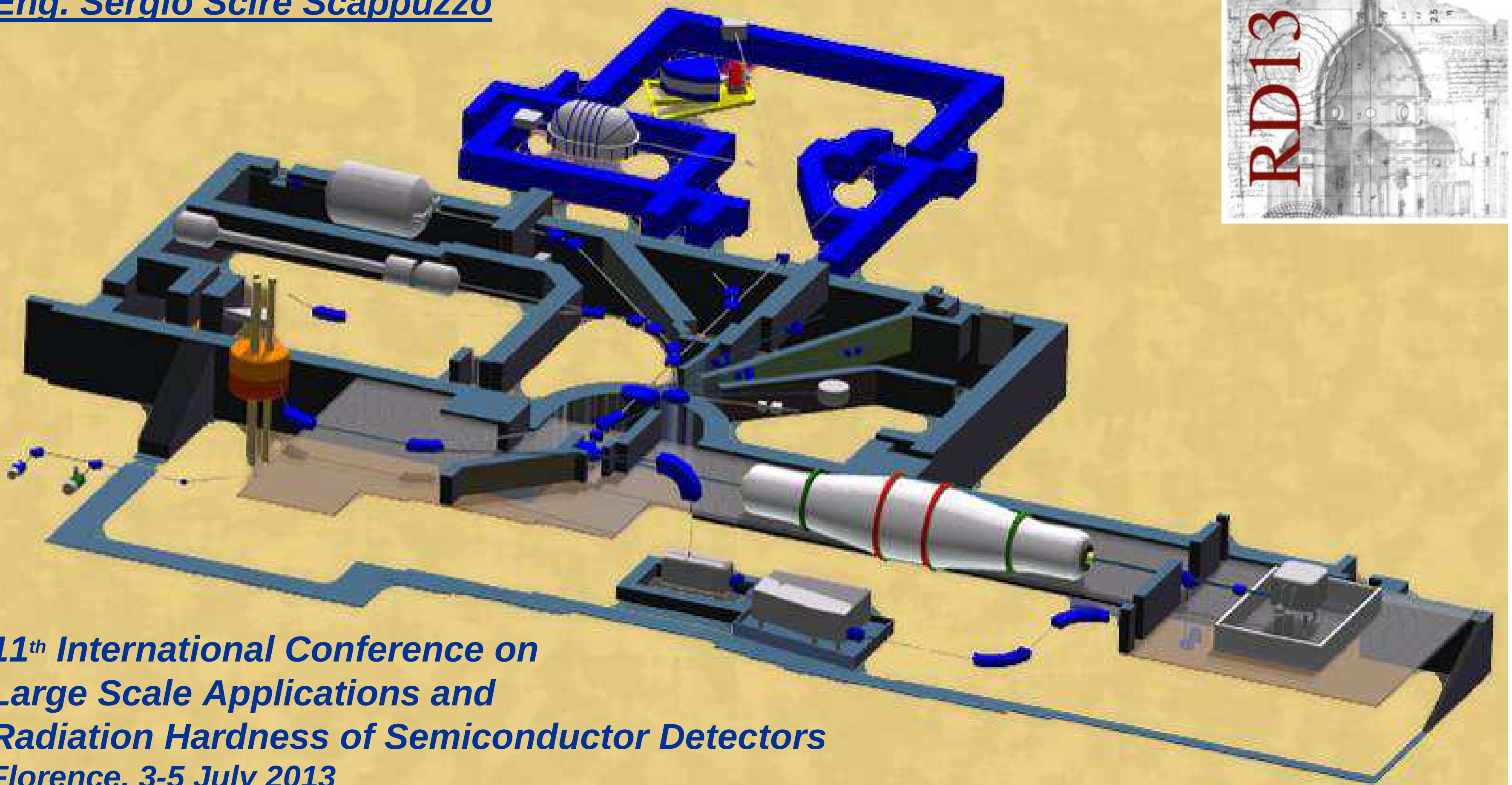
Istituto Nazionale di Fisica Nucleare

Laboratori Nazionali del Sud

Single Event Effects Irradiation Tests at INFN-LNS

Eng. Sergio Scirè Scappuzzo



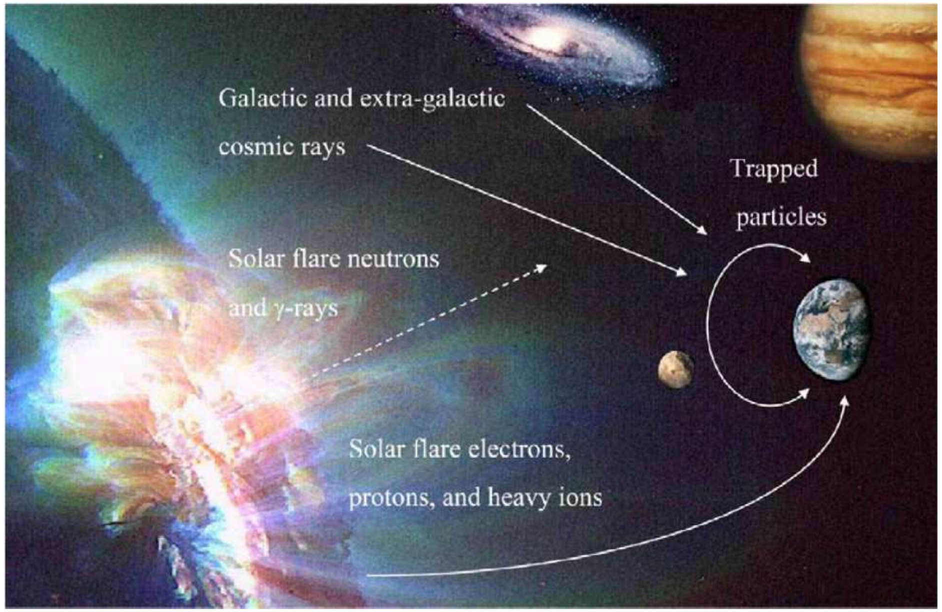
11th International Conference on Large Scale Applications and Radiation Hardness of Semiconductor Detectors

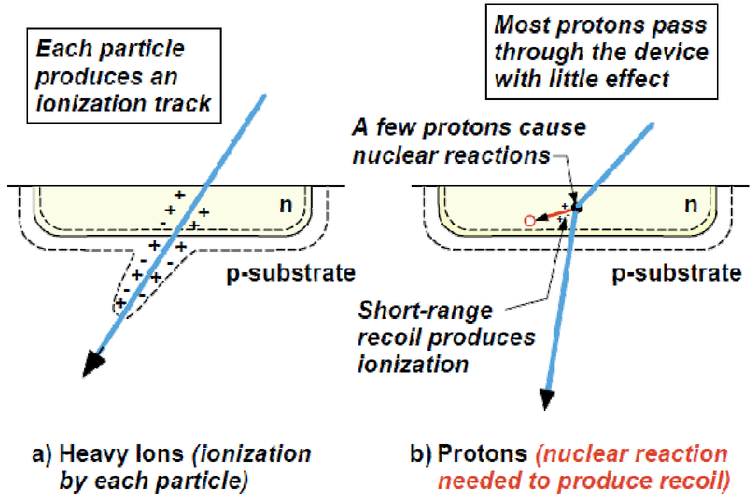
Florence, 3-5 July 2013

Introduction

Photons, electrons, protons and heavy ions produce ionization when they travel through matter

The use of microelectronic devices in spacecraft requires that these devices preserve their functionality in the radiation environment found in space





Need to reproduce in laboratory radiation damage into electronic devices

Radiation effects

Total Ionizing Dose (TID)
Usually dominated by protons

→ Trapped charge can affect **device performance**, e.g., create a threshold voltage shift in MOSFET devices

Displacement Damage (DD)

→ Occur in semiconductor materials **due to scattering interactions** of incident particles, with the atoms of the semiconductor lattice

Single Event Effects (SEE)
- Hard / Permanent
- Soft / Recoverable
- SEU, SET, SEL, SEGR, SEB …

→ Occur when a single energetic particle is capable of creating an **observable effect** in a device

Guidelines for SEE tests

Required facility equipment:

- Radiation Source
- Dosimetry
- Accurate positioning system
- Vacuum chamber
- Test Board and Cabling
- Availabilty of suitable Linear Energy Transfer (LET)

ESCC European Space Components Coordination

Guidelines for SEE tests used:

→ ESCC Basic Specification No. 25100

→ Military standard MIL-STD-750E

Source: heavy ions

Range in Silicon: > 30 μm

Variable flux: 10^2-10^5 ions/cm^2/s

Preferably in-vacuum

Accurate alignment and rotation of device to the beam

Flux

continuous monitoring with ±10% accuracy

Source: protons

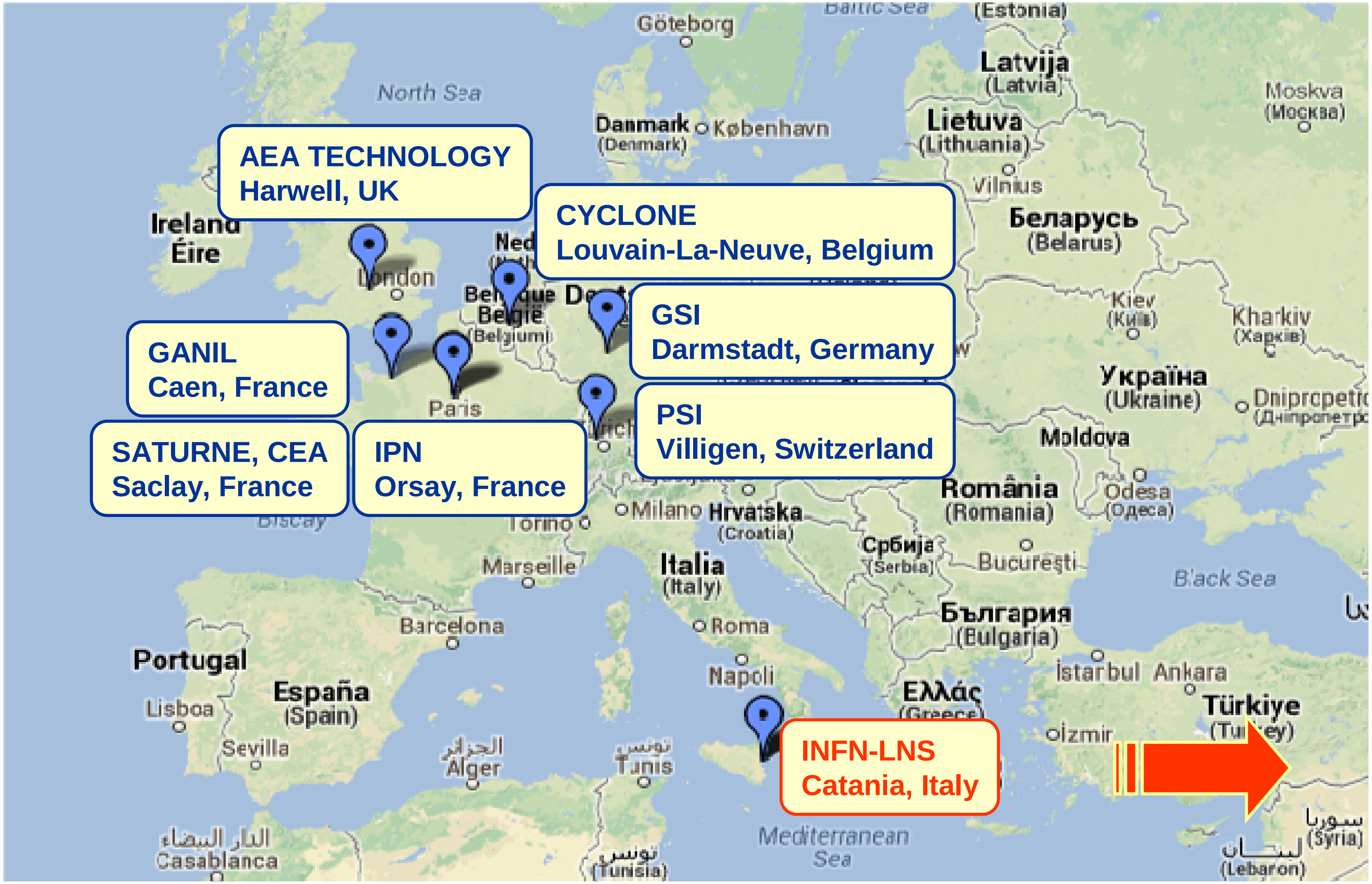
Energy: 20-200 MeV

Variable flux: 10^5-10^8 p/cm^2/s

Preferably In-air

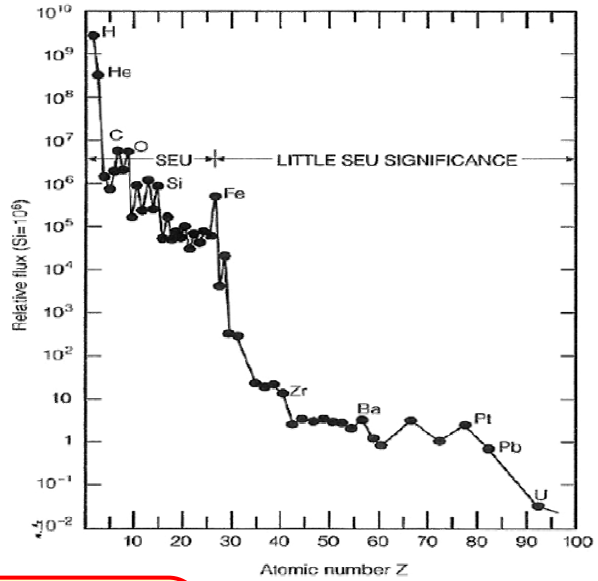
Exposure of device normal to the beam

Some European Facilities commonly used for SEE testing



The Superconductive Cyclotron at LNS

compact 3-sector machine
magnetic field 2.2 - 4.8 T
superconducting Nb-Ti coils @ 4.2 °K



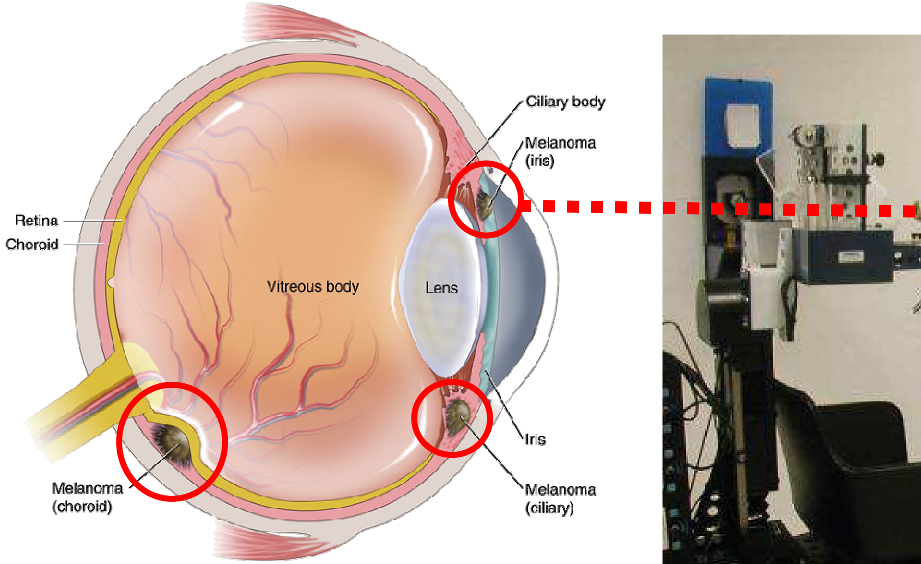
p, ^{12}C beams for radiobiology
p, ^{20}Ne, ^{40}Ar, ^{84}Kr, ^{129}Xe, ^{197}Au beams for radiation hardness tests

Change of ion beam takes approximately 5 hours. The "ions cocktail" allows to change the accelerated species with few minutes tuning

^{A}X	E (MeV/a.m.u.)
H_2^+	62,80
H_3^+	30,35,45
$^{2}D^+$	35,62,80
^{4}He	25,80
He-H	10, 21
^{9}Be	45
^{12}C	23,62,80
^{13}C	45,55
^{14}N	62,80
^{16}O	21,25,55,62,80
^{18}O	15,55
^{19}F	35,40,50
^{20}Ne	20,40,45,62
^{24}Mg	50
^{36}Ar	16,38,42
^{40}Ar	15,20,40
^{40}Ca	10,25,40,45
^{48}Ca	10,45
^{58}Ni ,45	16,23,25,30,35,40
^{64}Ni	25,35
$^{68,70}Zn$	40
^{74}Ge	40
^{78}Kr	10
^{84}Kr	20
^{86}Kr	10,15,20,25
^{93}Nb	15,17,23,30,38
^{112}Sn	15.5,35,43.5
^{116}Sn	23,30,38
^{124}Sn	15,25,30,35
^{129}Xe	20,21,23,35
^{197}Au	10,15,20,21,23
^{208}Pb	10

The CATANA proton irradiation room

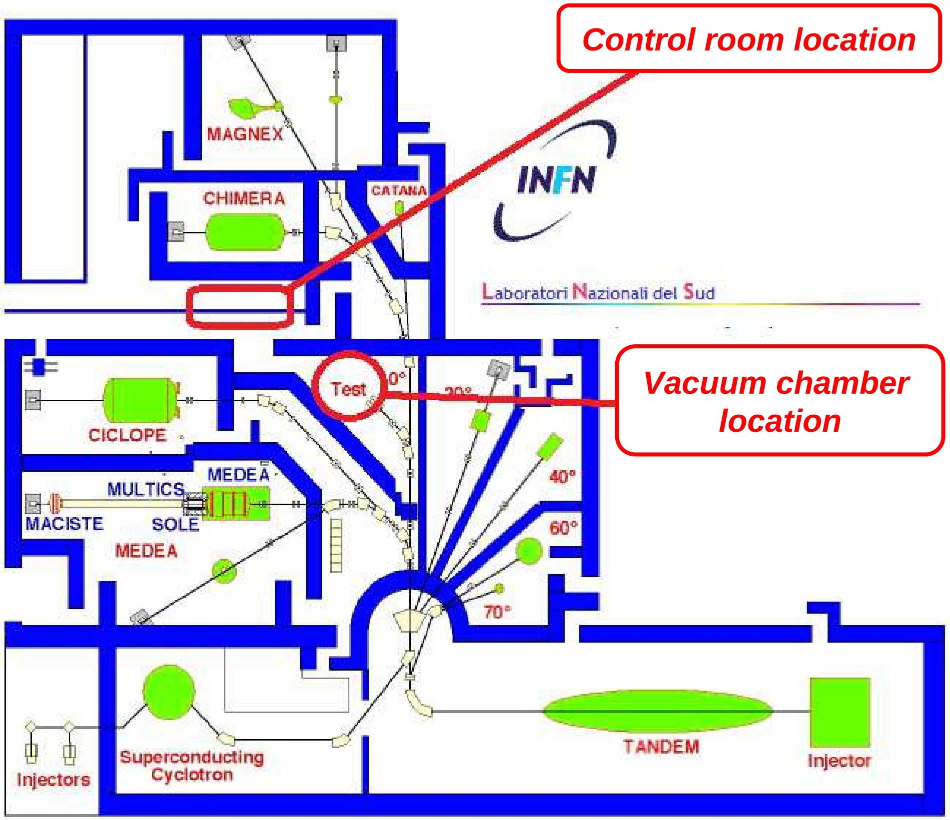
- *In-air only*
- *Mainly dedicated to proton therapy*
- *Dosimetry and radiobiology experiments*
- ***Tests for radiation hardness of electronic components***
- *Quick and easy positioning systems (resolution < 1 mm)*
- *Proton dose rates range: 1 to 100 Gy/min*

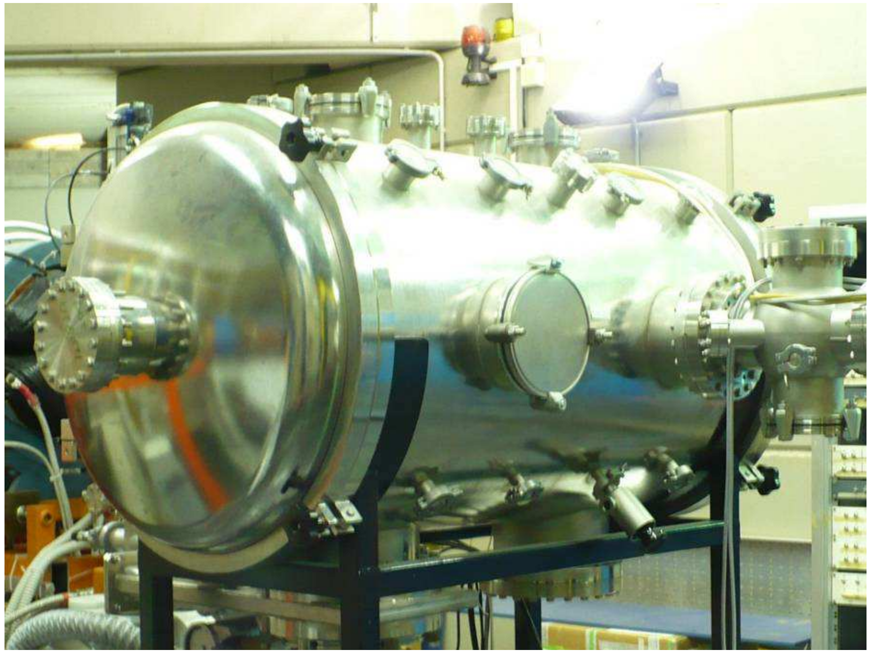


Treatment of eye melanoma

The "0 degree" irradiation chamber

Multi flanged vacuum chamber
300 liters volume (diameter 60 cm, length 100 cm)
High level vacuum (below 10^{-5} mbar in two hours)
Distance to Control Room about 20 m

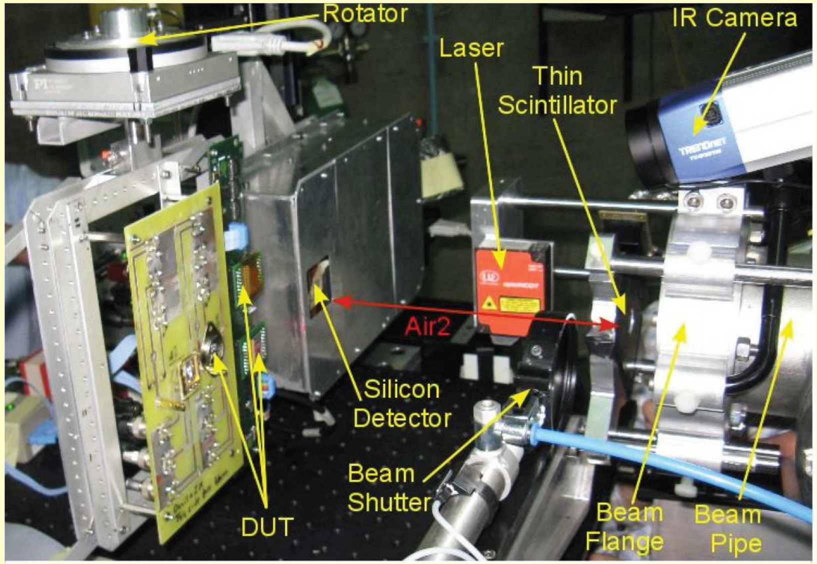




Irradiation experties at INFN-LNS with italian companies

since 2007

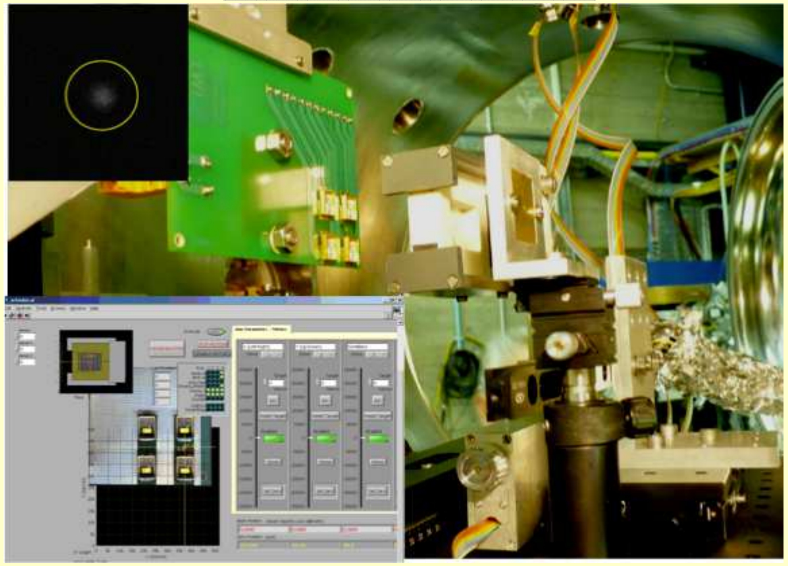
MAPRad



In-air irradiation

since 2011

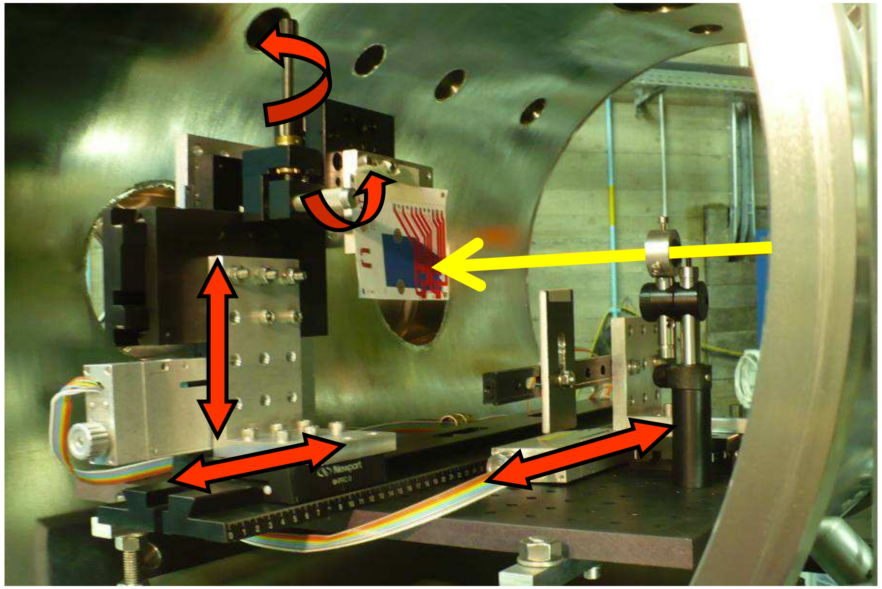
IMT
Ingegneria Marketing Tecnologia



In-vacuum irradiation

Forthcoming collaborations with ASI and ESA ?

In vacuum irradiation setup



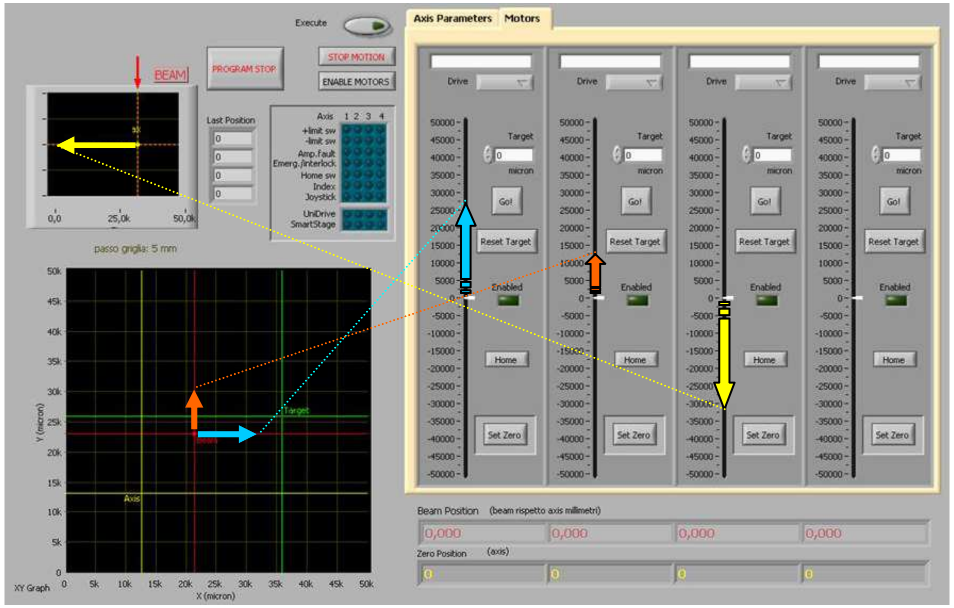
X-Y configuration linear stage actuators

→ *50 nm encoder resolution*

→ *Available exposure area 40x40 mm²*

θ_Y θ_Z *manual rotation*

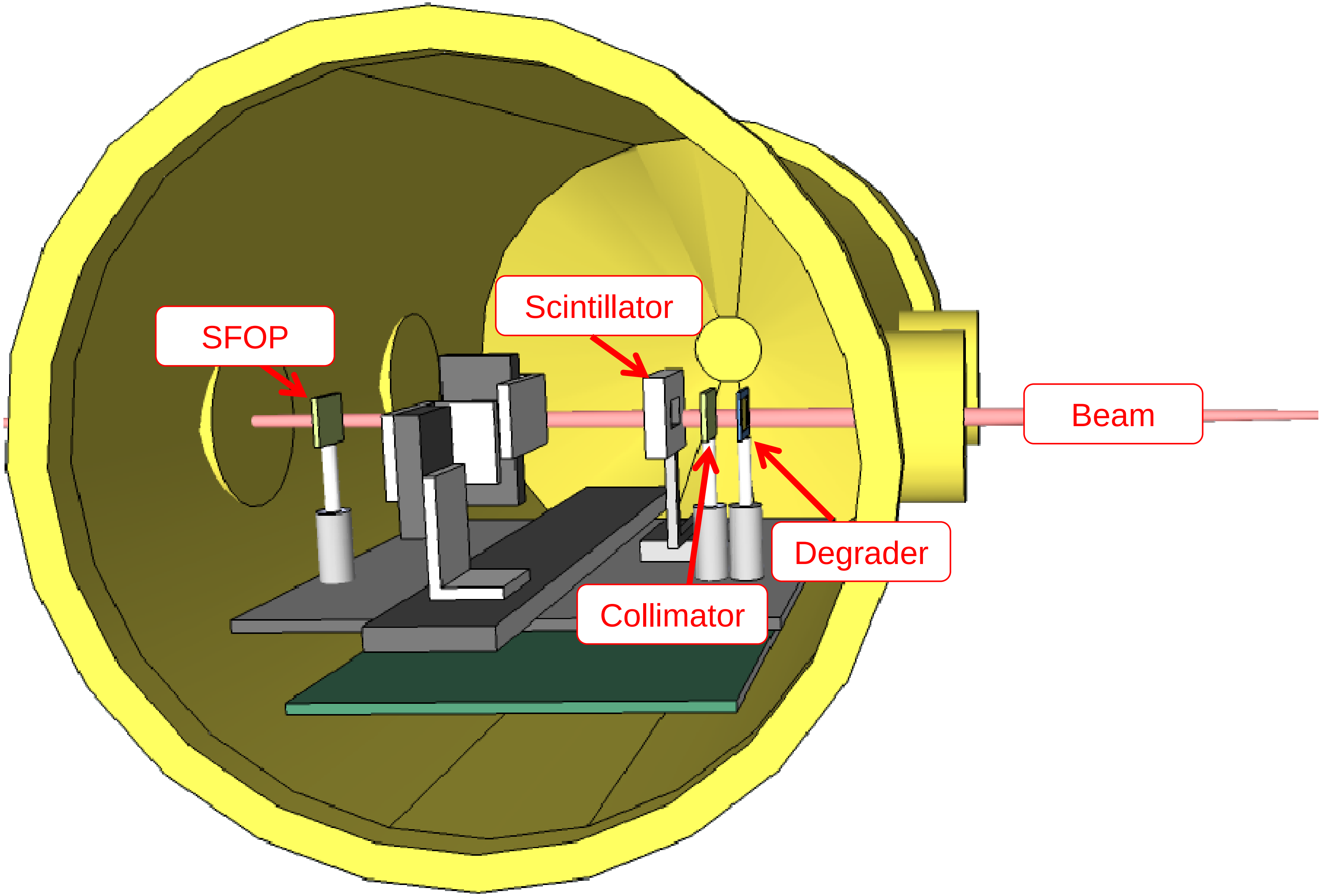
Removable dosimetric apparatus



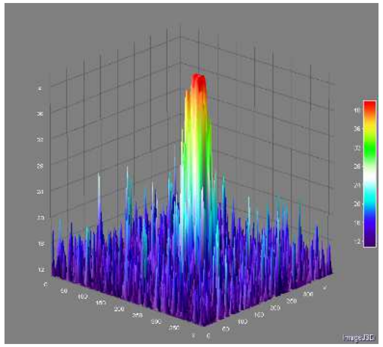
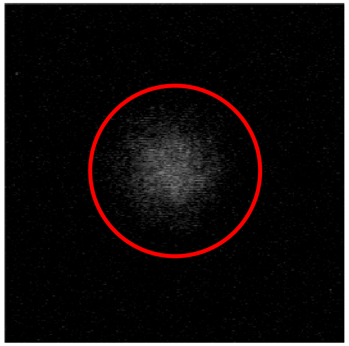
- *Exposure area view*
- *Absolute and relative coordinates*
- *Beam spot in respect to devices*
- *Irradiation point targeting*

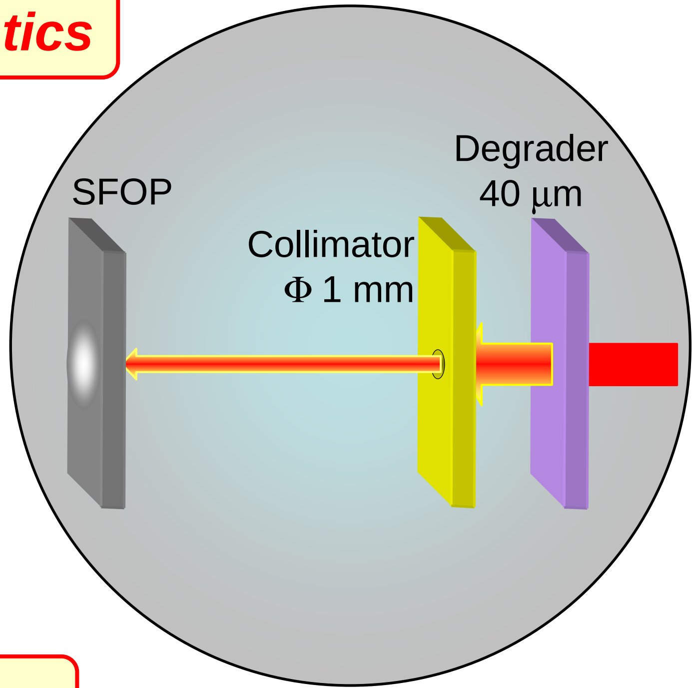
PCB alignment and removal from beam line

Schematic view of the experimental setup

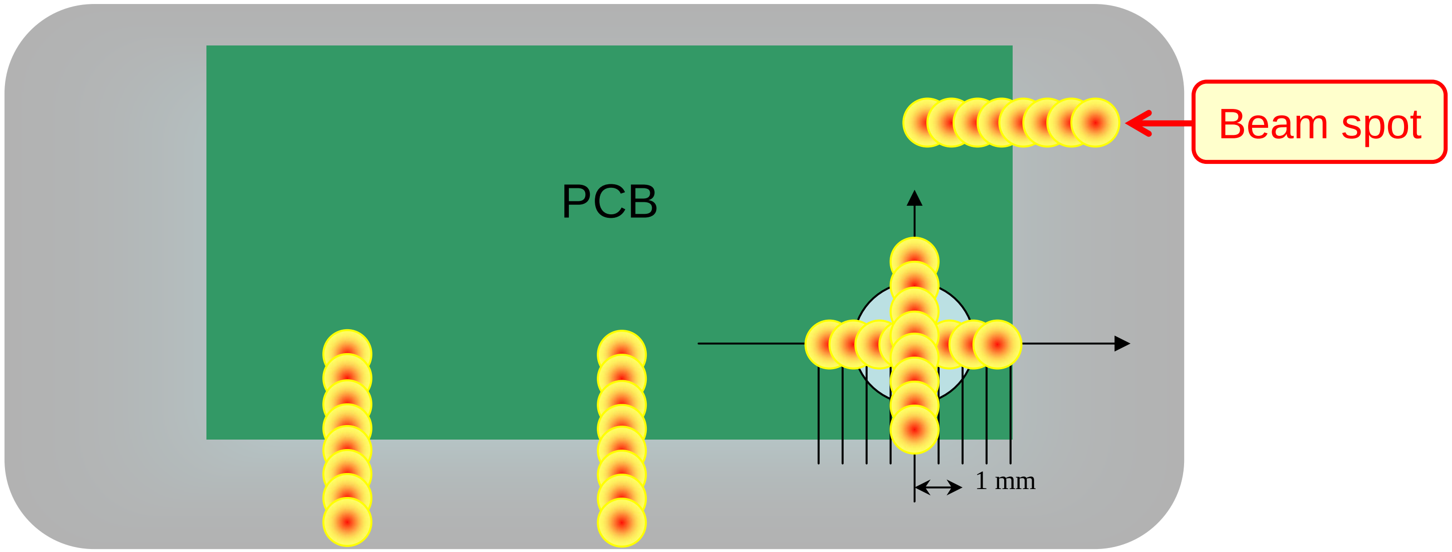


Beam diagnostics

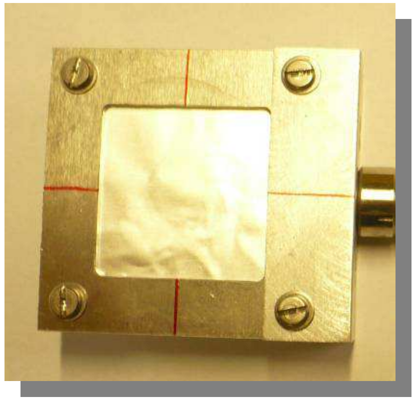


PCB alignment

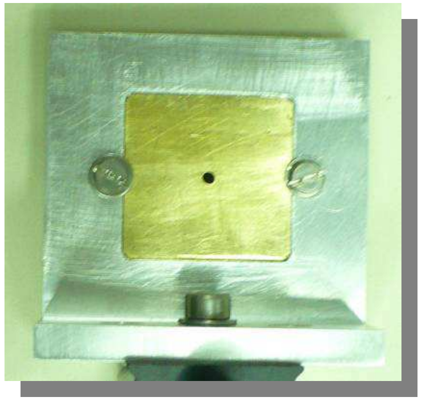


Experimental setup equipment

Aluminum degrader

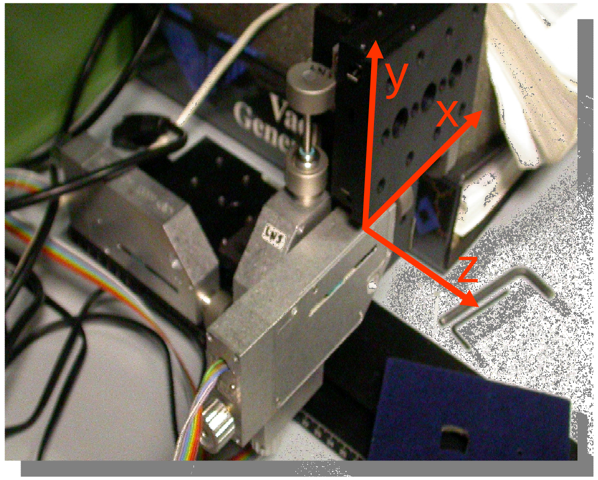


Beam collimator

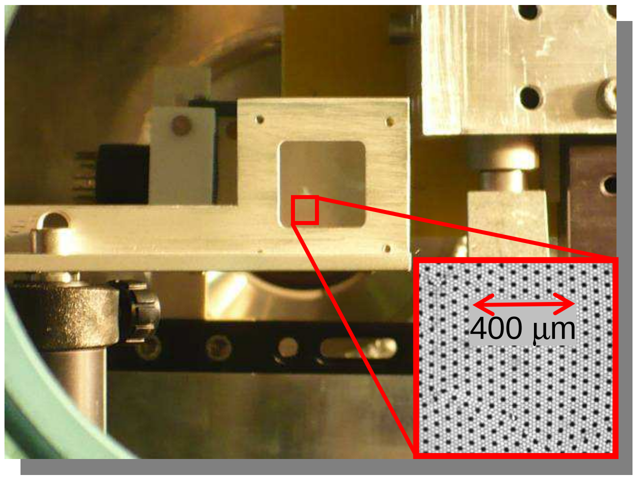


Scintillator thin (200 μm) plate with PMT

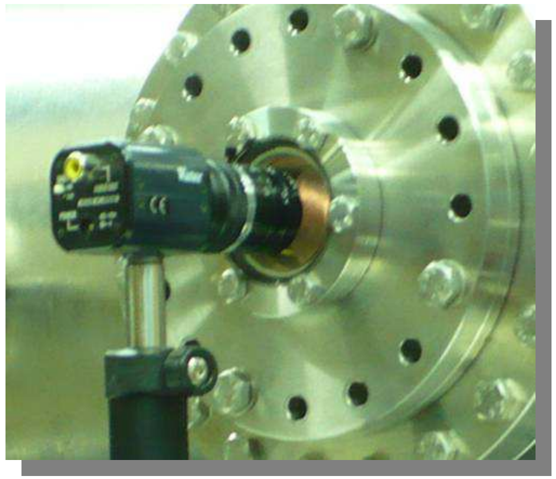
Linear translation stages



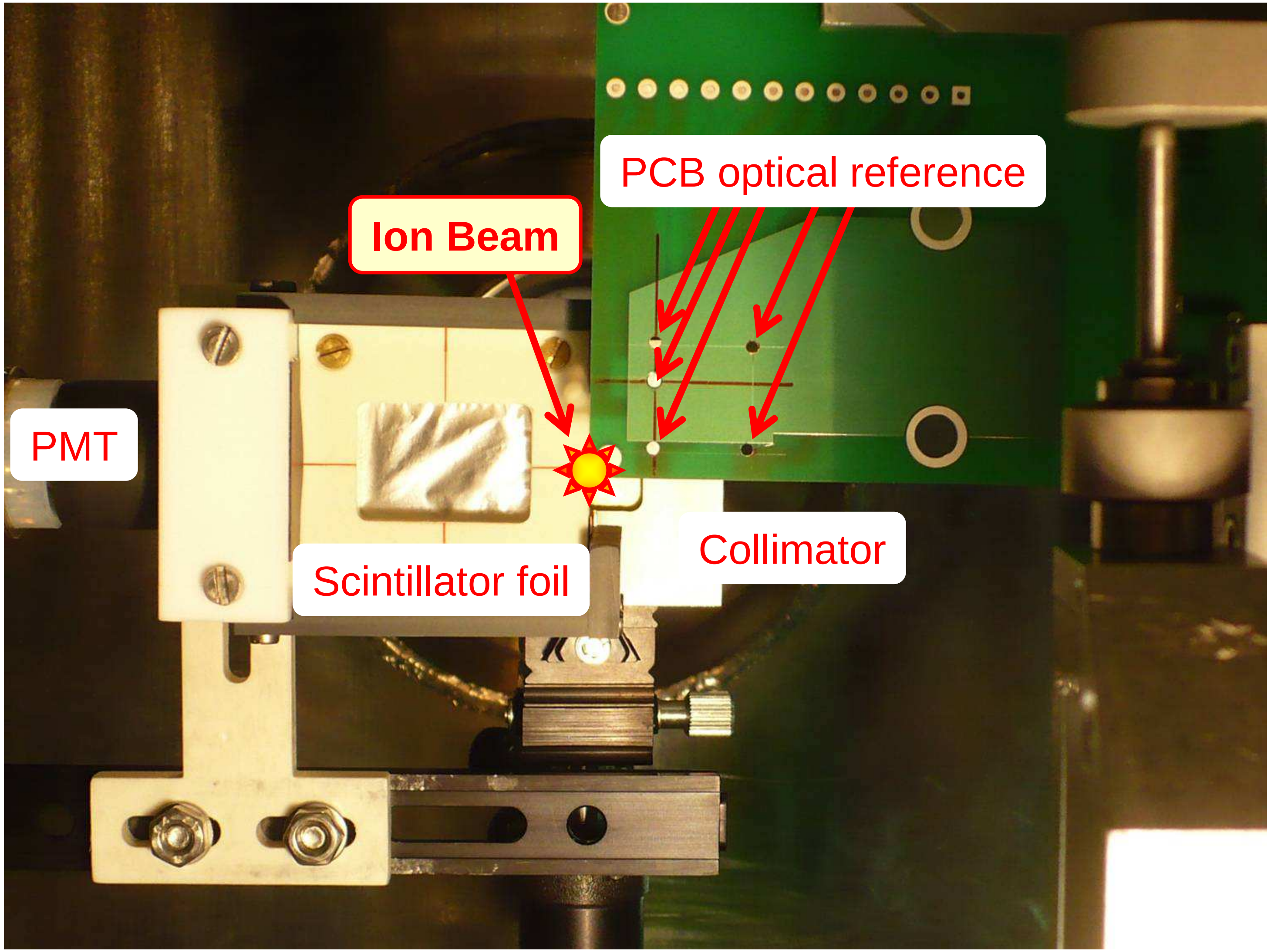
SFOP (Scintillating Fiber Optic Plate)



High sensitivity CCD Camera



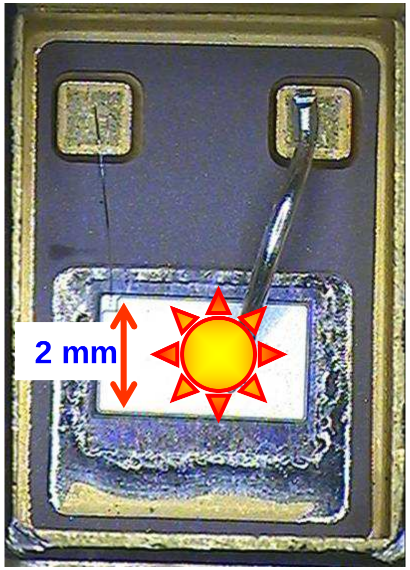
Back view



PCB optical reference
Ion Beam
PMT
Collimator
Scintillator foil

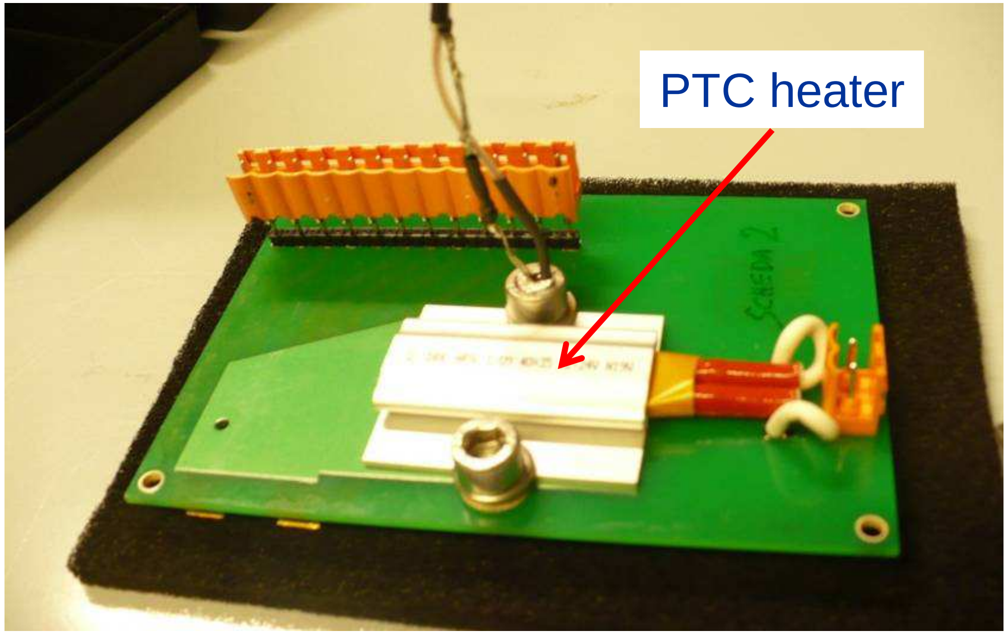
SEE measured at INFN-LNS
June 2012 test

Device Under Test
"Power MOSFET"



Two different tests performed on DUTs:
- ***SEB (Single Event Burnout)***
- ***SEGR (Single Event Gate Rupture)***

A PTC heater was assembled on the back side of the irradiation board, near the DUTs and powered when necessary to perform the test at high-temperature (80 °C).

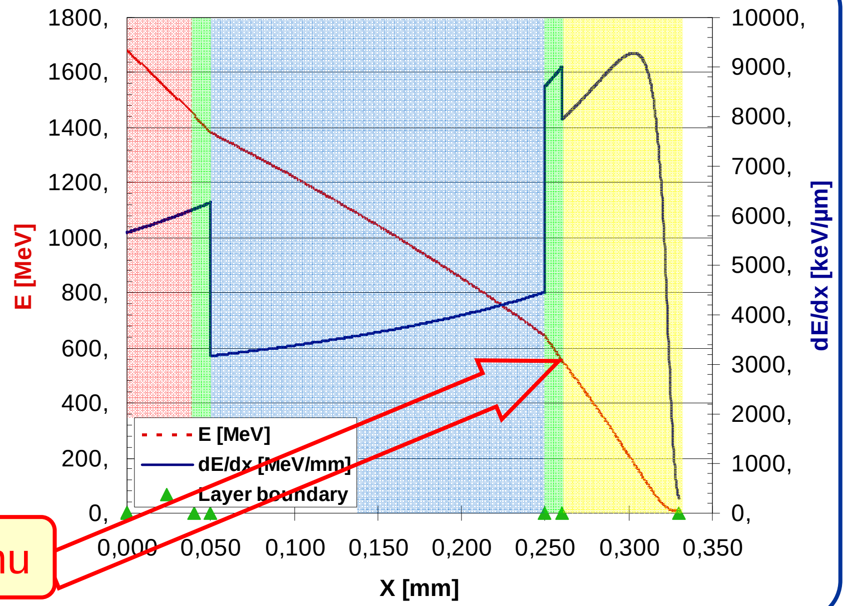


LET prediction in Silicon target

SRIM Simulation: Energy loss

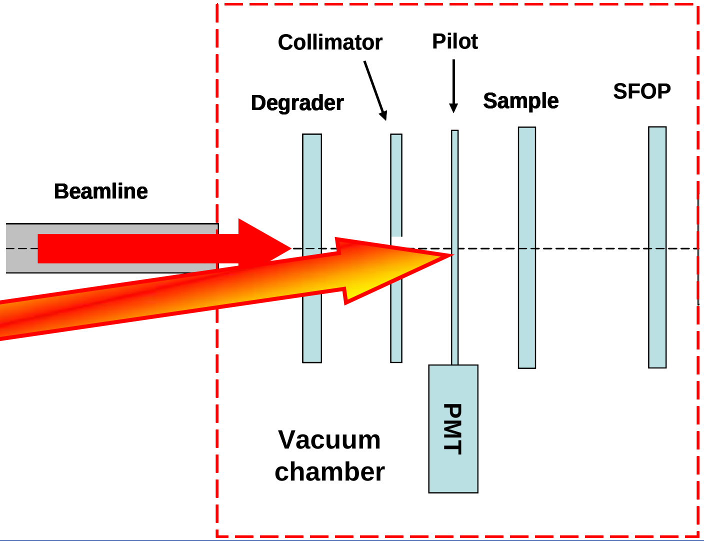
	Material	Thickness [µm]	Input Energy [MeV]	Energy loss [MeV]
Degrader	Al	40	1680.00	235.46
Reflector	Al	10	1444.54	62.00
Scintillator	Pilot U	200	1382.54	740.51
Reflector	Al	10	642.03	88.03
Target	Si		554.00	554.00

^{84}Kr @ 20 MeV/amu → ^{84}Kr @ 6.6 MeV/amu

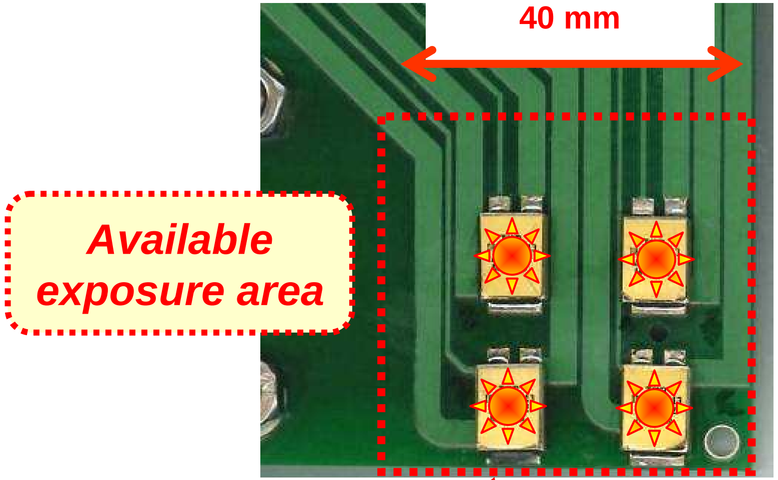


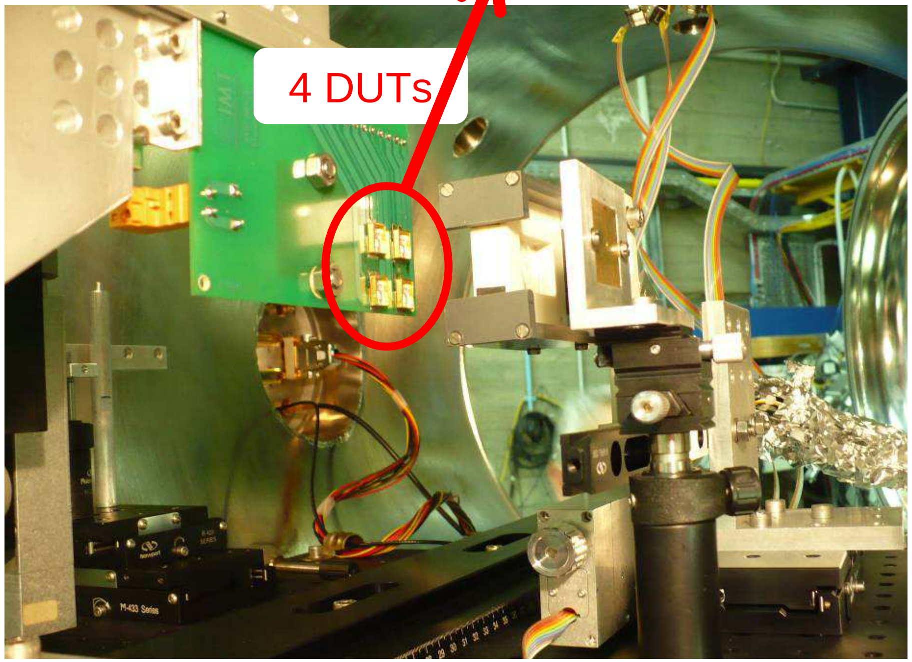
SRIM Simulation: LET at different Degrader thickness

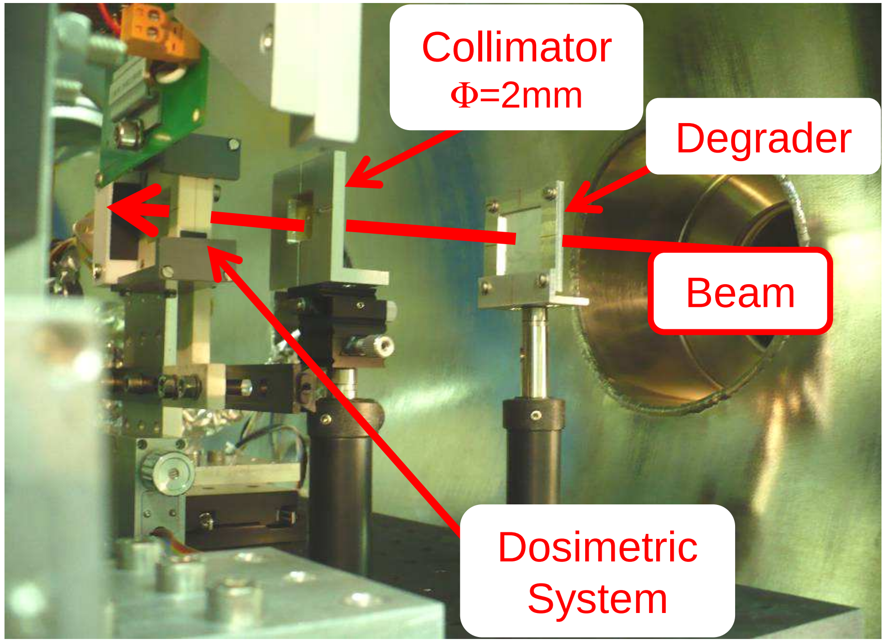
Al thickness [µm]	PMT present	Input Energy [MeV]	Range in Silicon [µm]
0	Yes	891.20	111
40	Yes	554.00	67
80	Yes	142.48	22
40	No	1444.54	210

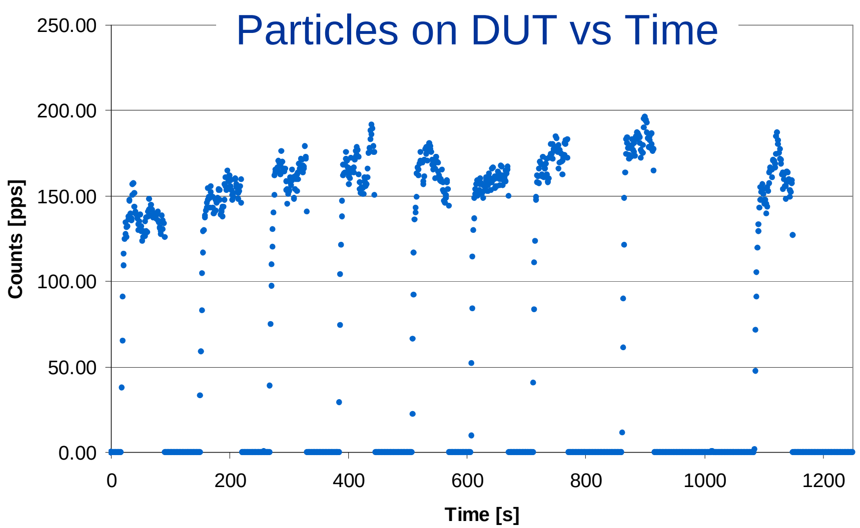


SEB-SEGR Test

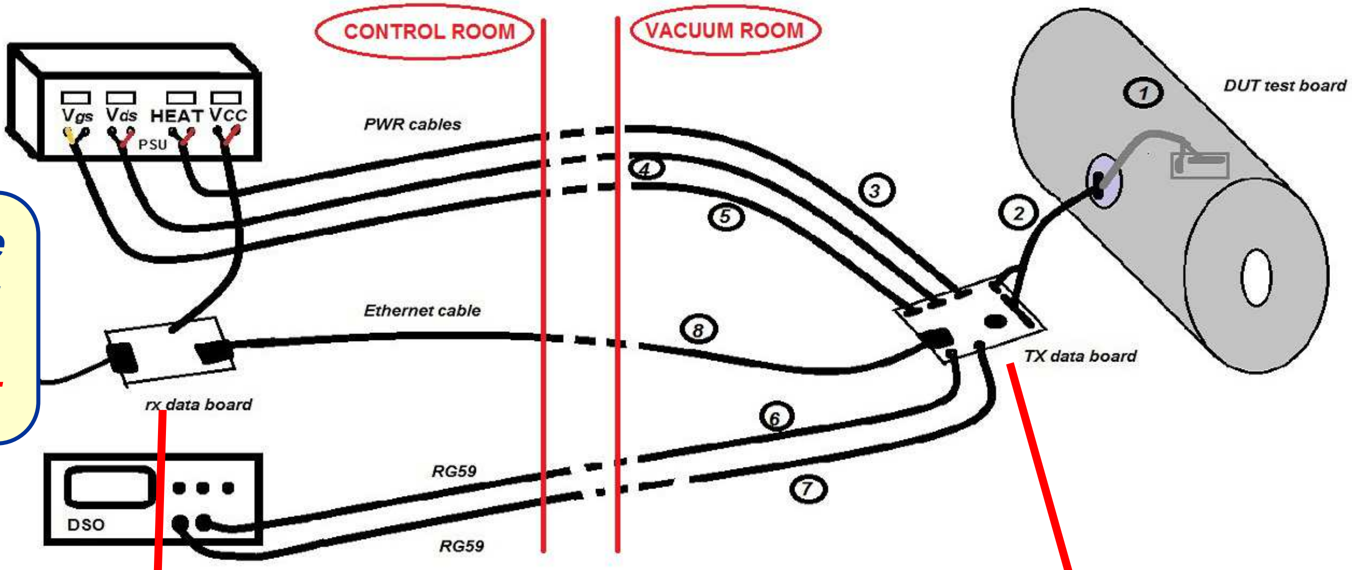






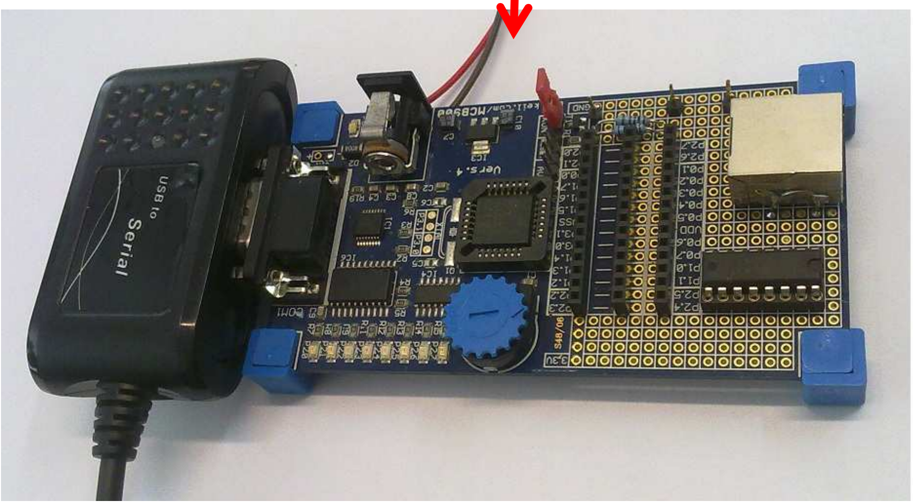


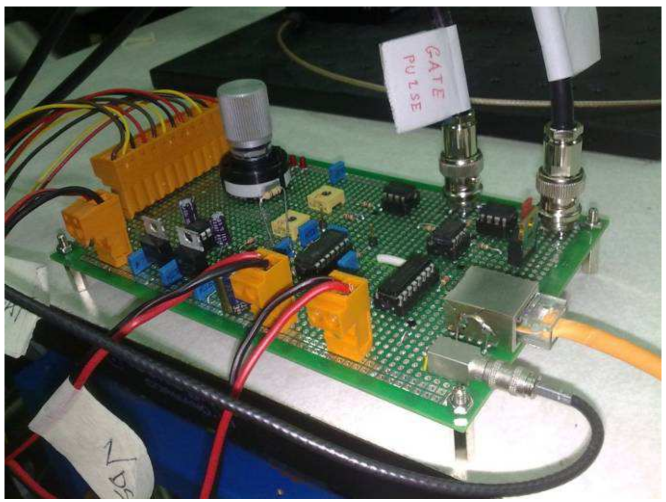
Electronic setup



Remote voltage devices setting

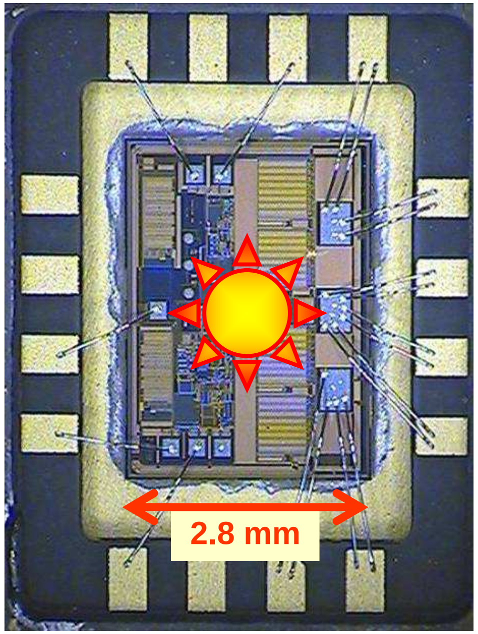
Switch ON/OFF





SEE measured at INFN-LNS
March 2013 test

Same experimental setup used during first campaign except:
- *Collimator diameter*
- *Degrader tickness*
- *Ion species*



SET (Single Event Transient) characterization ***was performed on adjustable positive voltage regulator at different load conditions.***

Still ongoing analisys

Ion	Energy (MeV)	LET (MeV mg^{-1} cm^{2})	Range in Si (μm)
^{40}Ar	507	8	180
^{84}Kr	747	30	93
^{129}Xe	612	60	50

Summary

- Able to work In-vacuum
- Micro-positioning system
- SEE tests successful performed
- Ability to fulfill customer specifications

Thank you for your attention