Ion irradiation and semiconductor detector characterization at the Centro Nacional de Aceleradores

J. Garcia Lopez[1,2], M. C. Jimenez-Ramos[1,2] and J. Gómez-Camacho[1,2]

1. *CNA. (J. Andalucia, Univ. of Sevilla, CSIC). Spain*
2. *Dept. of Atomic, Molecular and Nuclear Physics. University of Sevilla. Spain*

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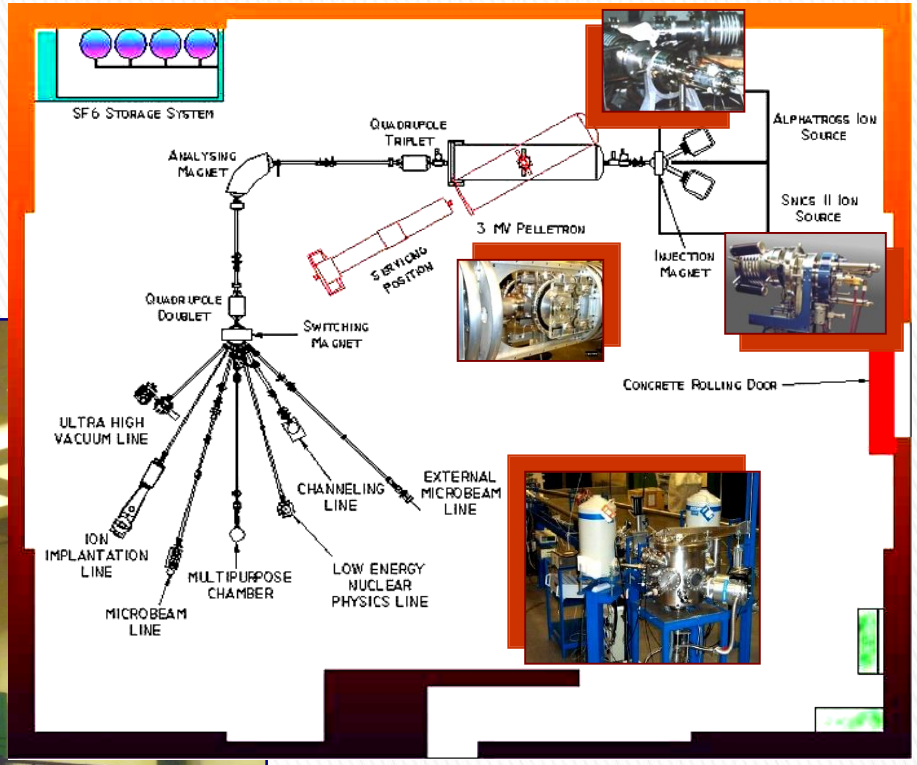
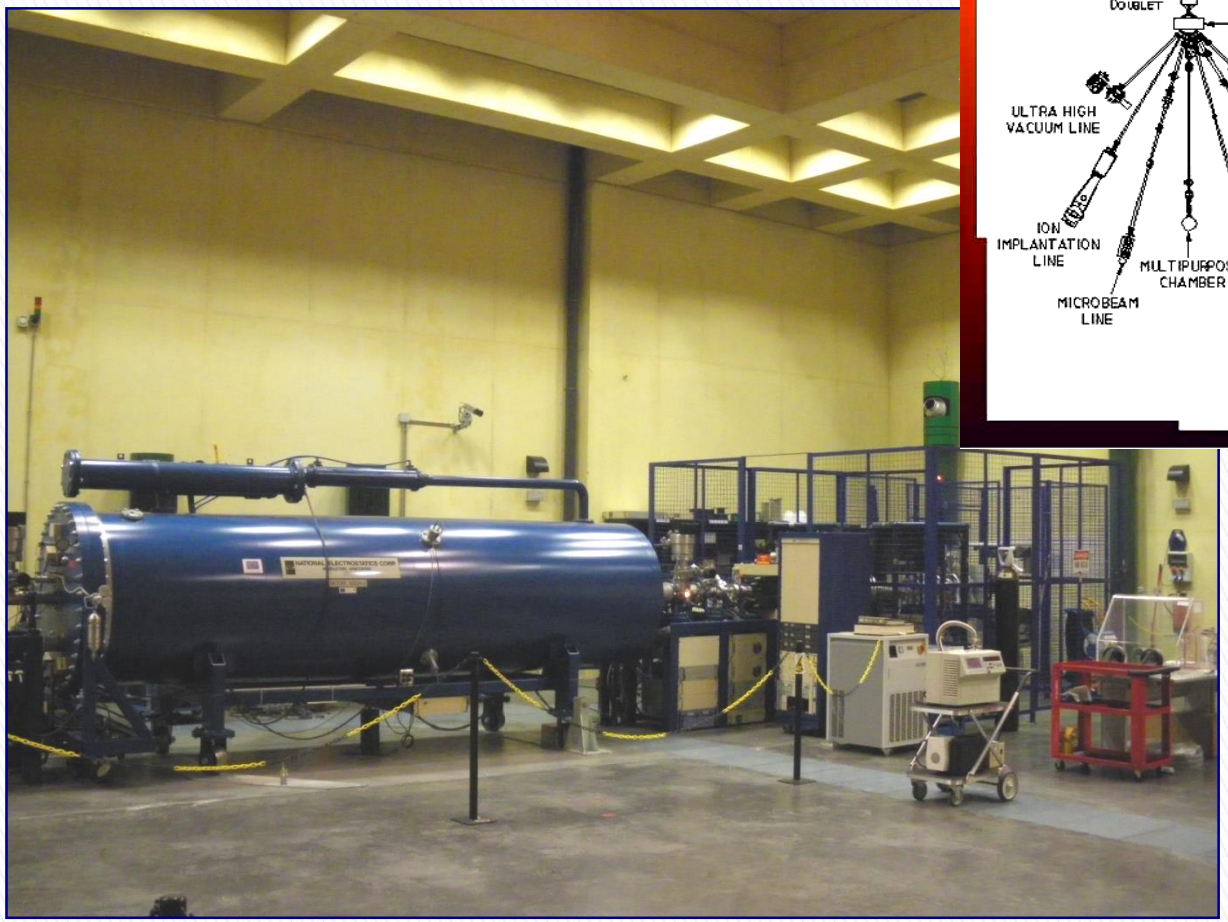
Possibilities of CNA within the RD50

* Irradiation facility

* Characterization of semiconductor detectors using Ion Beam Techniques

- All stable ions available: H – Au
- Energy range: 600 keV – few MeV
- Beam currents: μA – pA
- Continuous and pulsed beams





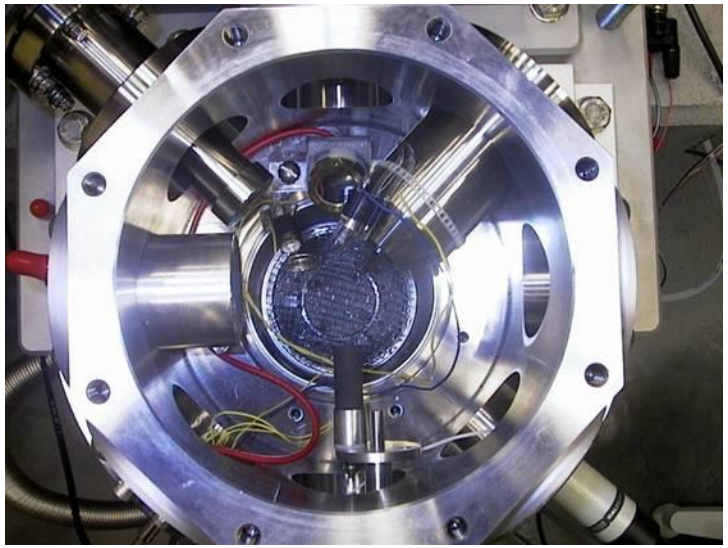
3 MV TANDEM Laboratory

Vacuum micro beam line

- Particle detectors (PIPS)

- X-ray detector (SiLi)

-Microscope



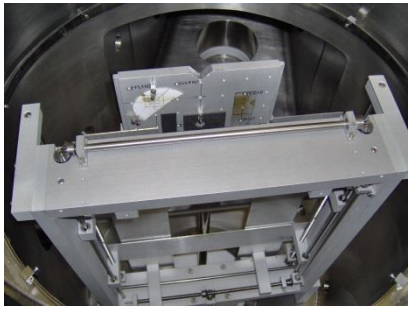
- Ion beam size ~ 4x4 μm^2

- Beam current: nA to few pps (micrometric slits)

- Scanning system: few mm^2

-Synchronous signal acquisition system with scanning: mappings

Ion Implantation and Irradiation beamline



- Sample holder

- 20x16 cm^2
- X-Y movement
- Complete turnabout
- Heating possibility
  (RT to 450ºC)
- Isolated variable slits set

- Scanning system
  Double magnetic coils
  High stability power supplies
  Variable scanning frequency

- Others
- Lighting possibility
- Temperature control
- Opto-electrical feedthroughs to bias and monitor “in situ” the device response

Cyclotron 18 MeV H^+/ 9 MeV D^+

-Radioisotope production for PET
-Irradiation of materials, high energy PIXE

Pulsed beam (2.4 ns pulse every 24 ns)

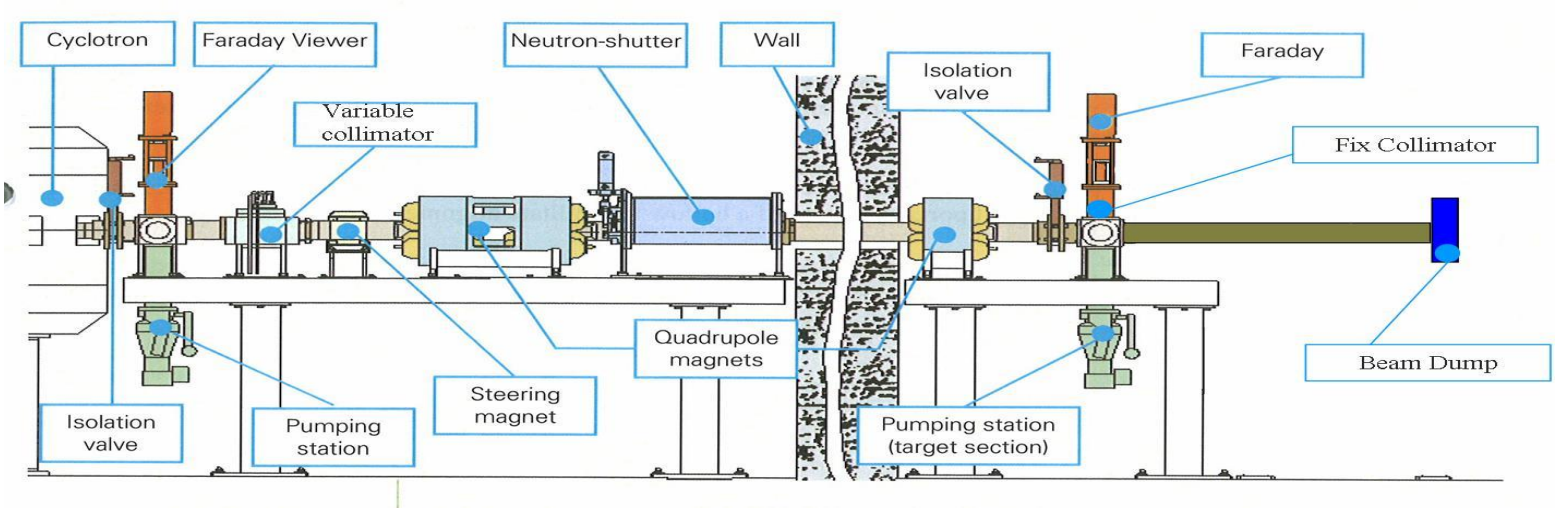
FWHM 200 KeV (1.1%)

Maximum currents ~ tens of µA

Remote control variable collimator & FC
(beam current can be drastically reduced)

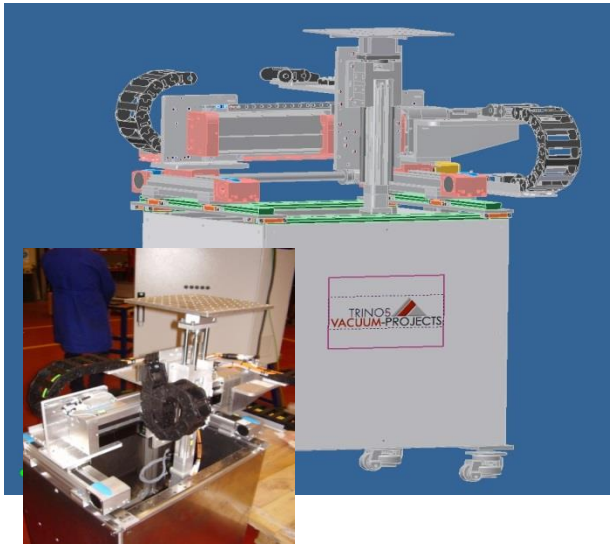
Q-poles & XY steerers

Cyclotron External Beam Line



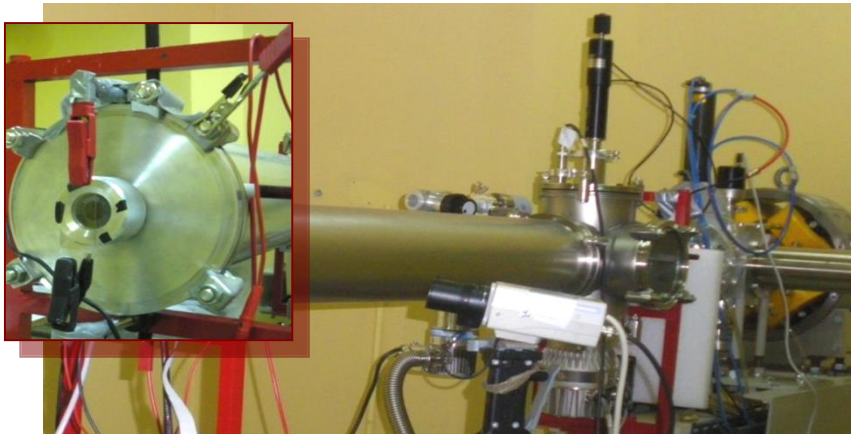
SAMPLE HOLDER

Remote control (step 0.06 mm)
X 200 mm; Y 200 mm; Z 100 mm
Manual movable structure



EXIT FLANGE

Various sizes available
Internally covered with a 5 mm carbon film to avoid the activation.
Different graphite collimators with several hole diameters
Several windows



Strain response of proton-irradiated optical fiber sensors to be used at Large Hadron Collider – CERN

Instituto de Física de Cantabria (IEEE TNS 59, N. 4 (2012) 937)

Radiation sensitivity of Fiber Bragg Gratings – Suitable deformation monitors

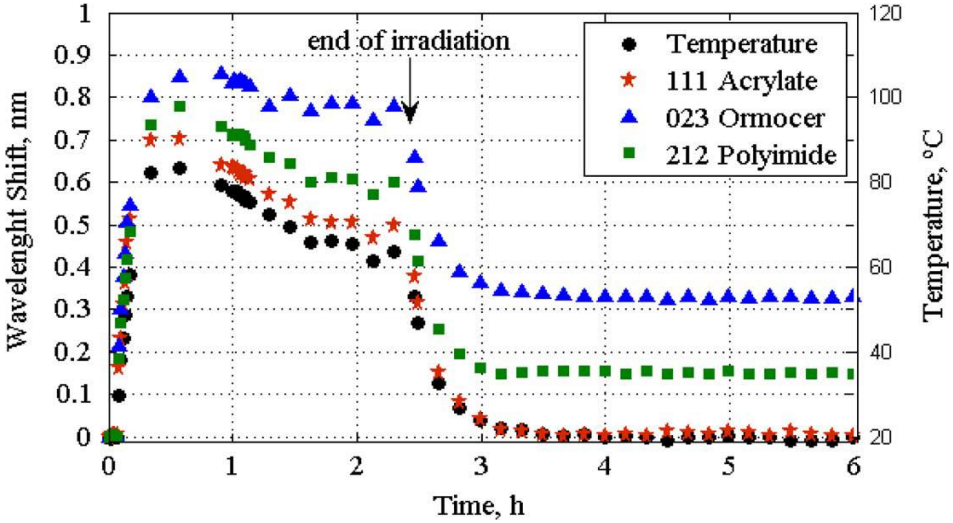
Temperature monitoring on line

Protons 13.5 MeV

Flux $3x10^{11}$ p/cm^{2}s

Fluence up to $3.3x10^{15}$ p/cm^2

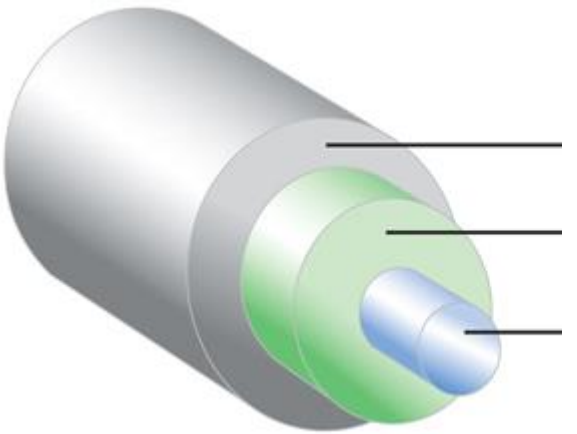
(absorbed dose 15 MGy(SiO_2))



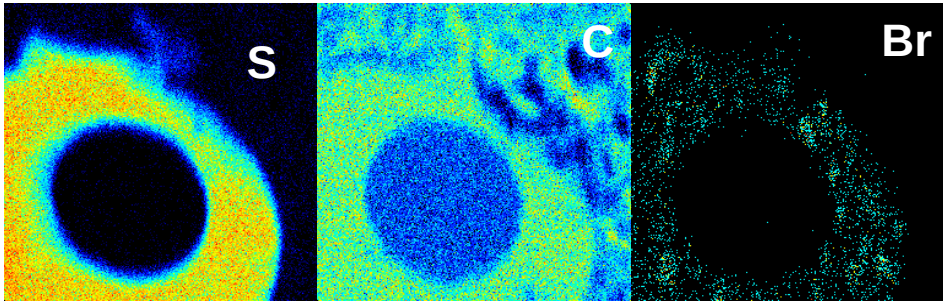
Sensitivity depends on the type of coating

Dependence on fiber composition?

Compositional study of Optical Fibers (microbeam)



Ion beam analytical techniques (PIXE, RBS, NRA) allows quantification and lateral distribution of elements



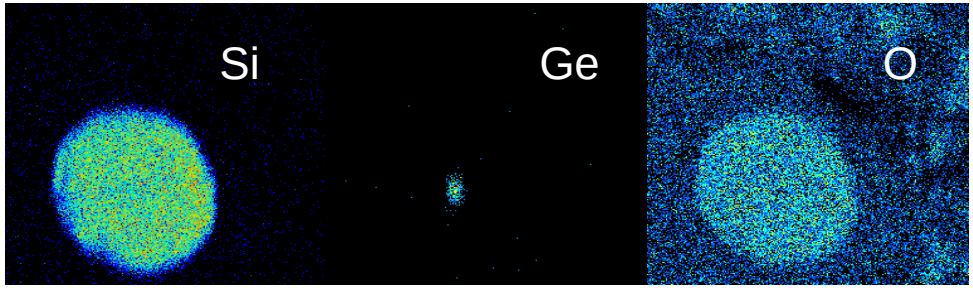
Coating

200x200 μm^2 maps

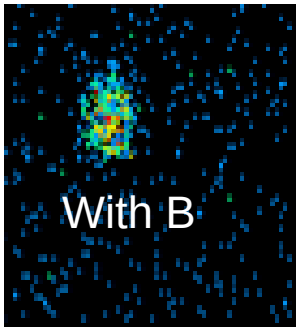
Boron enriched core (1% at)

$^{11}B(p, \alpha)2\alpha$

50x50 μm^2 maps



Cladding + core



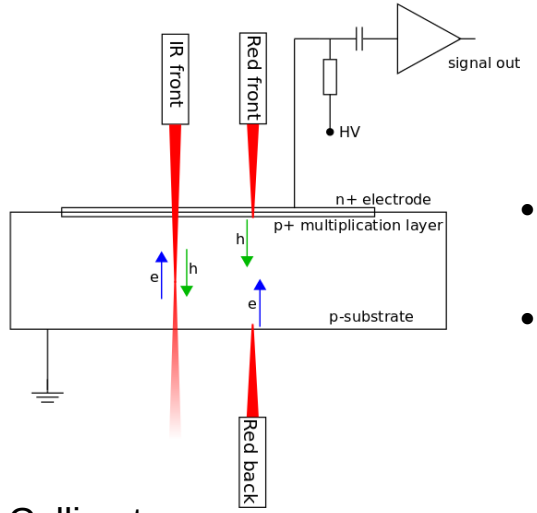
Charge Collection Efficiency of radiation detectors
How to measure it?

RD 50 recommendations for MIP CCE measurements (A. Chilingarov; TN RD50-2004-01)

Pulsed laser

675 nm → Absorption lenght 4 μm

830 nm → Absorption lenght 13 μm

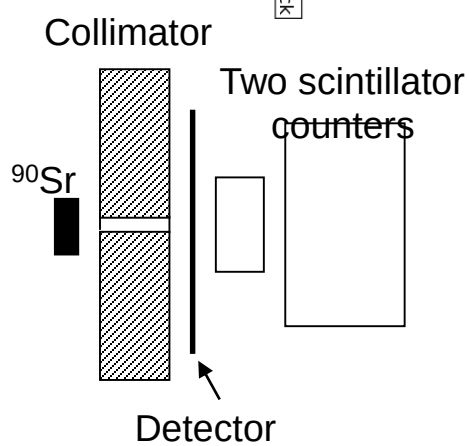


- Lateral resolution ~ 5 μm
- Needs opening in metal

^{90}Sr e$^-$ source

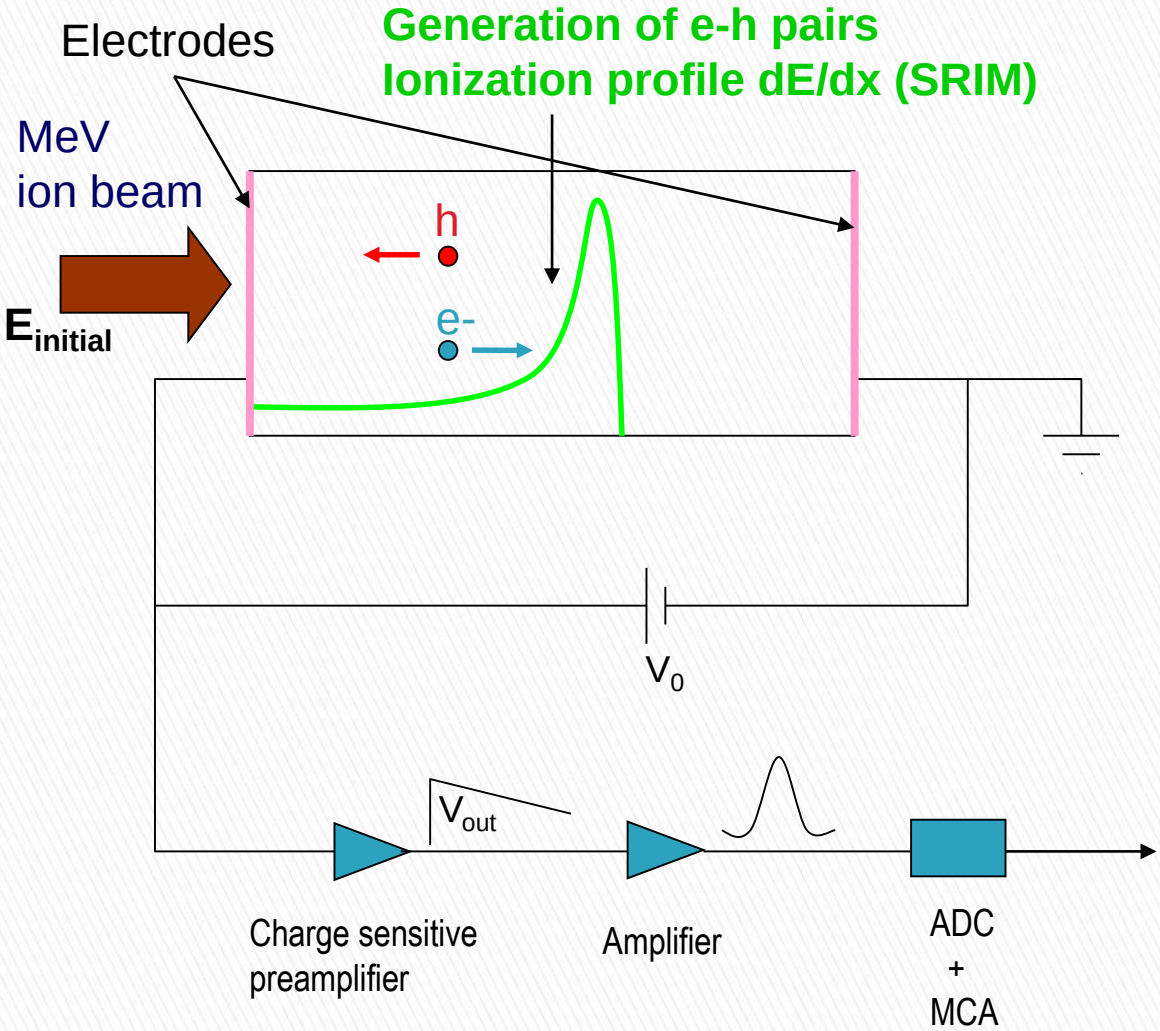
0.55 MeV → Range 1 mm

2.28 MeV → Range 4 mm



- Lateral resolution defined by the collimator
- Low S/N for thin sensors
- Trigger to separate low and high energy β

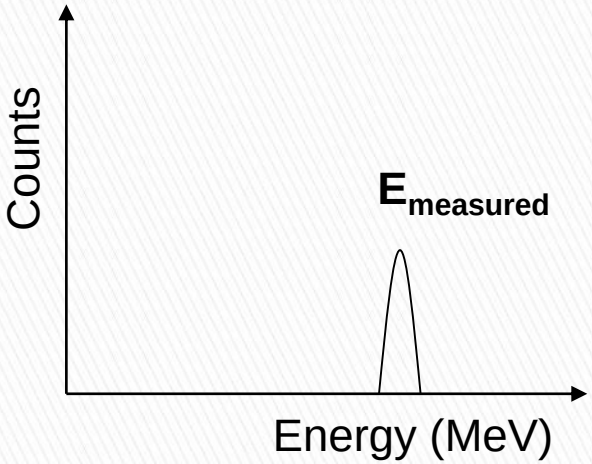
Ion Beam Induced Charge (IBIC)



- Lateral resolution ~ 4 μm
- Use of different ions/energies to explore various depths

Range (H, 4 MeV) ≈ 150 μm
Range (He, 1 MeV) ≈ 15 μm

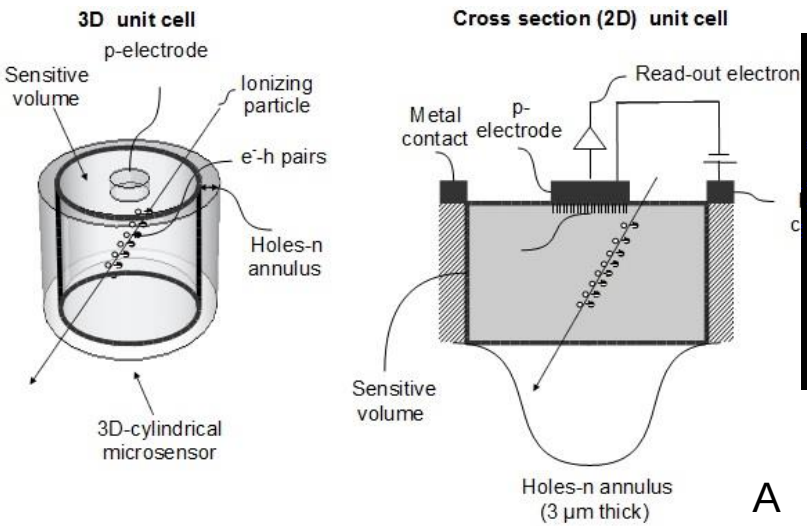
- Plasma effect for heavy ions
- Ion induced damage



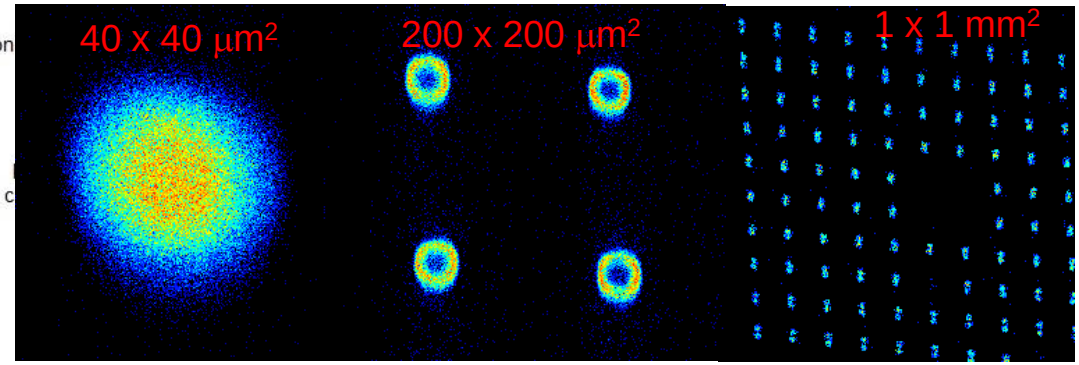
Same electronic chain as used in nuclear spectroscopy

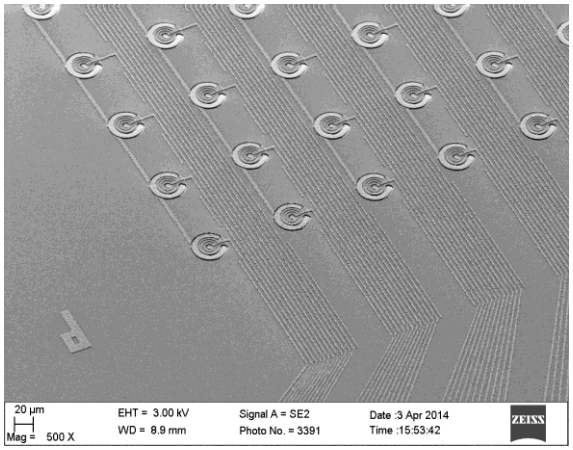
3D Si Detector Characterization by IBIC

JINST 10 (2015) P10001



IBIC maps -5 MeV He^{2+} in microdosimeters

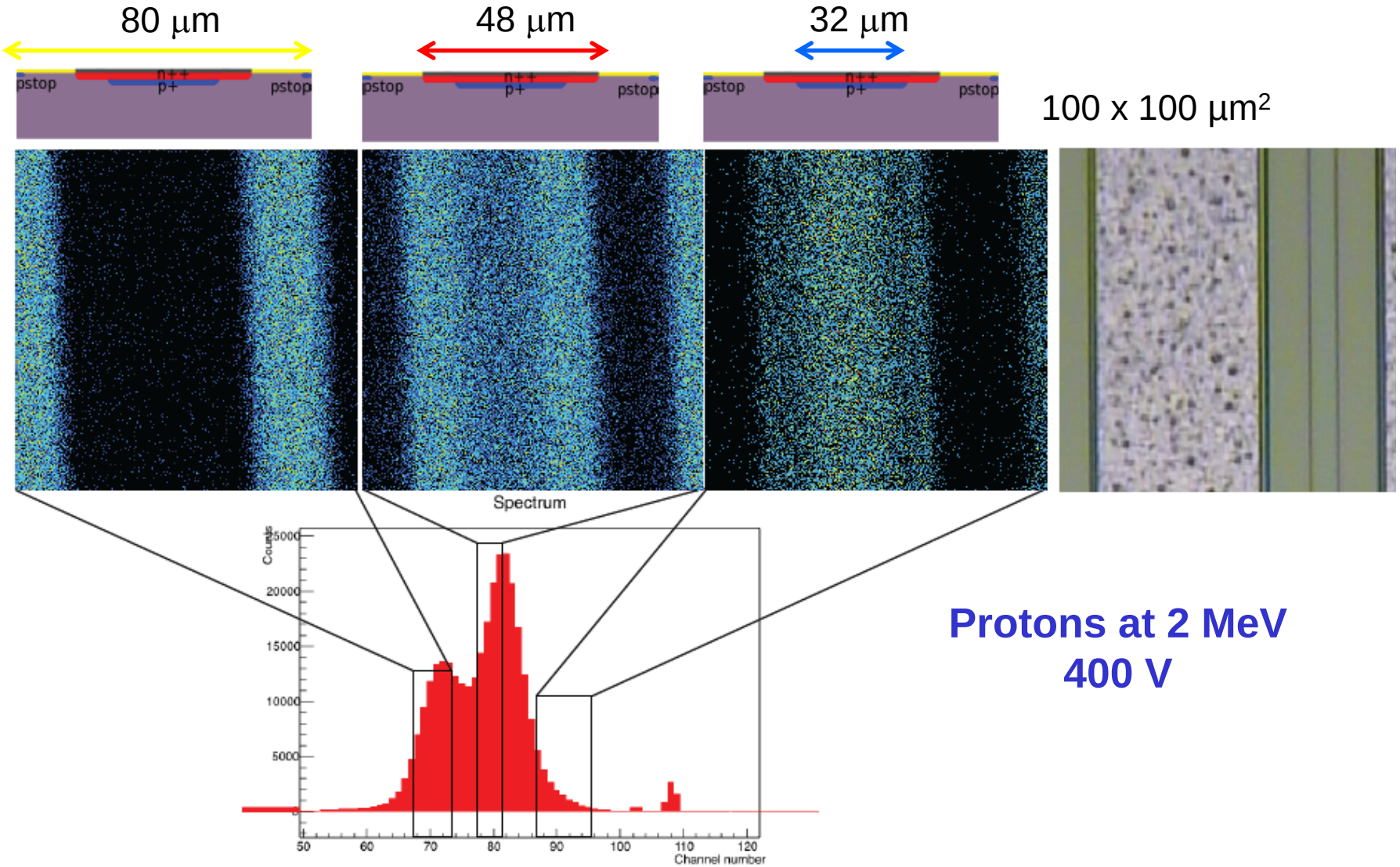




A charge collection study with the ion beam-induced charge collection technique, with microbeams of He^{2+} and H^{+}, has **shown full collection efficiency in the active area of the microsensors at voltages as low as 3 V**, with the **effective radius reduced by 2.5 µm due to the highly doped regions near the cylindrical electrode**.

The IBIC maps also show a 100% yield of active cells in a microdosimeter array, with each microsensor acting as an independent active site.

Multiplication factor in LGAD developed at CNM/IMB

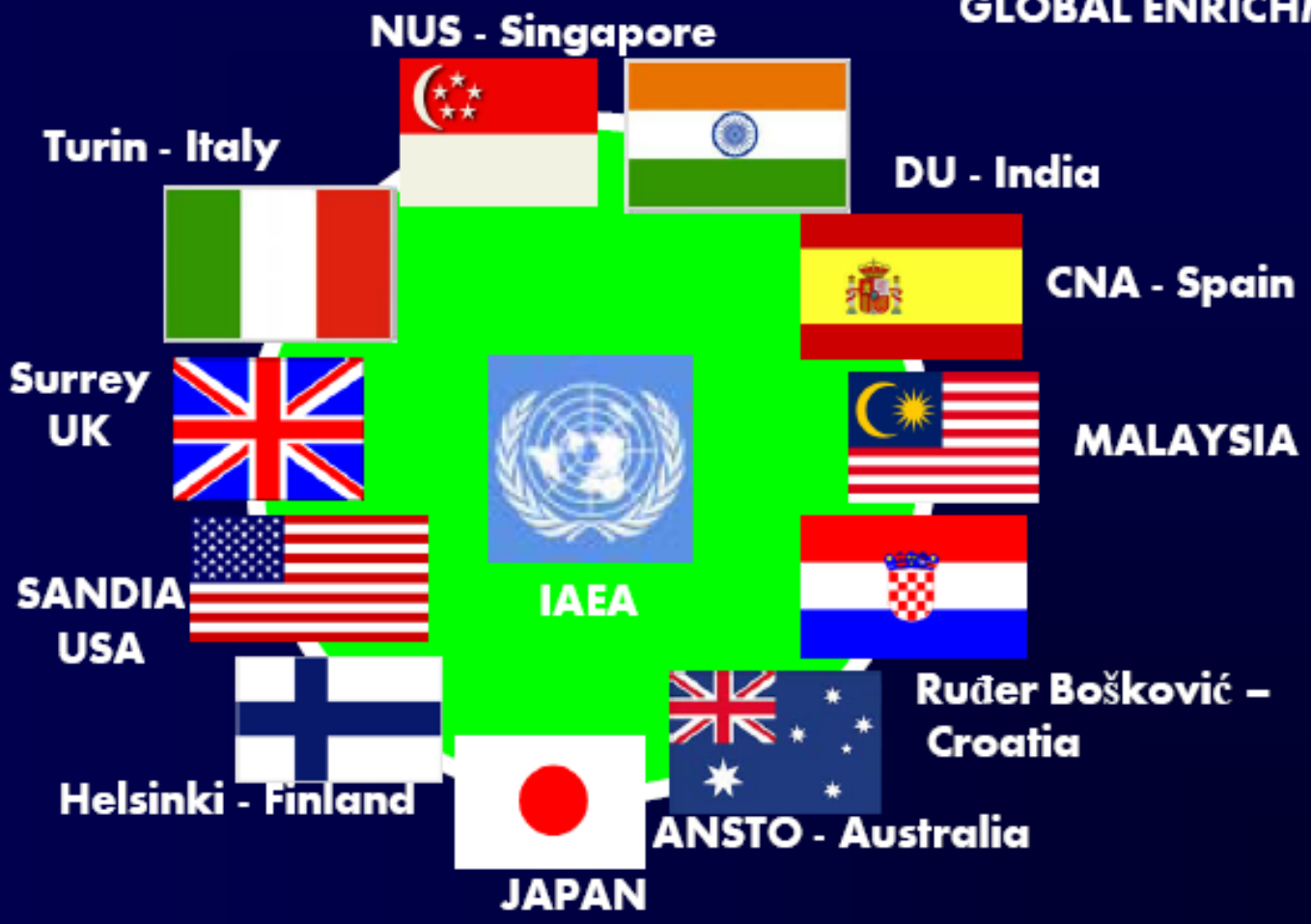


Protons at 2 MeV
400 V

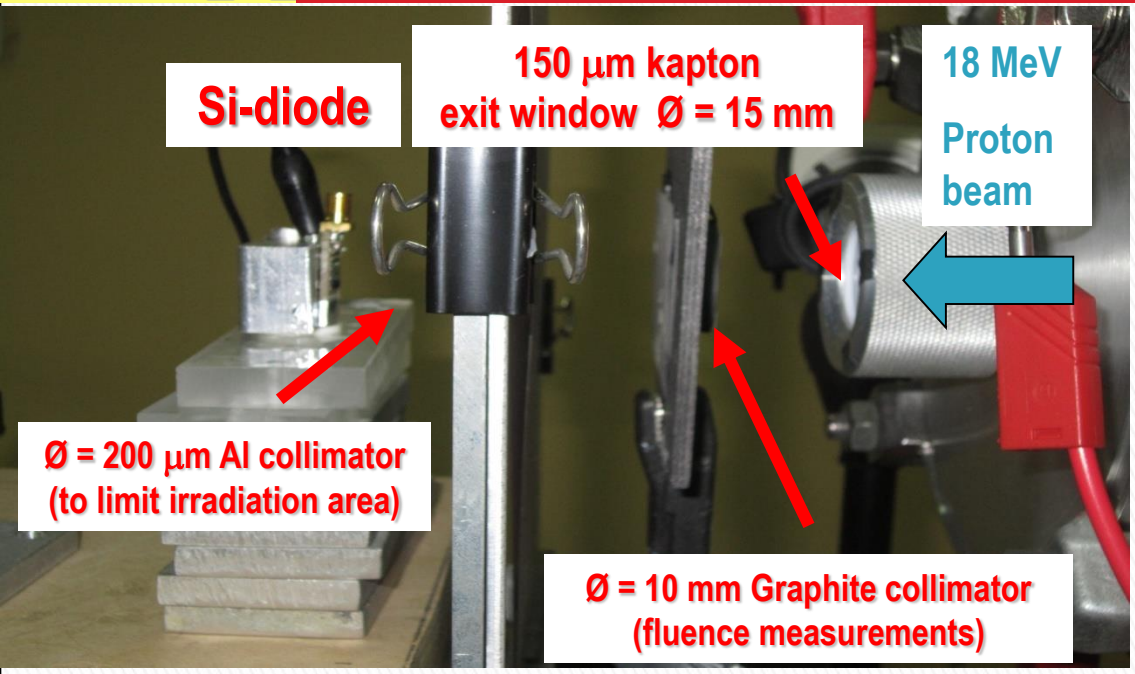
IAEA Coordinate Research Programme (CRP) F11016 (2011-2015)

"Utilization of ion accelerators for studying and modeling of radiation induced defects in semiconductors and insulators"

COOPERATION AND MUTUAL UNDERSTANDING LEAD TO GROWTH AND GLOBAL ENRICHMENT



Radiation hardness of Si diodes



Proton fluences

N-type Si: 5×10^{12} p/cm^2 - 1×10^{13} p/cm^2

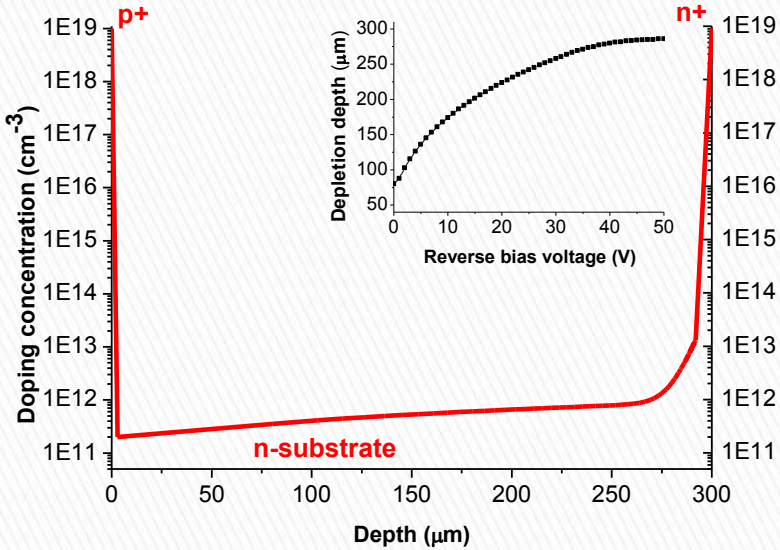
P-type Si: 1×10^{12} p/cm^2 - 5×10^{12} p/cm^2

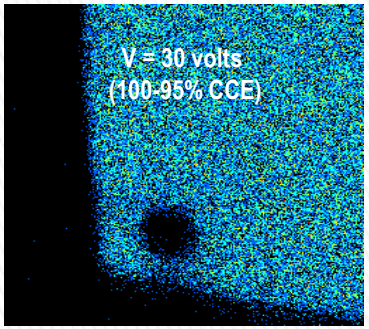
FZ p and n-type Si diodes

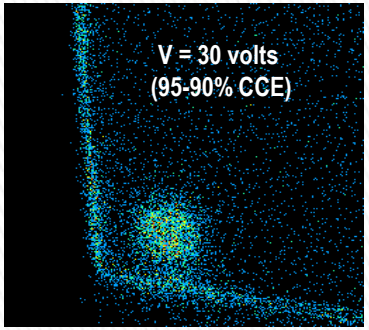
(Helsinki Institute of Physics)

300 μm intrinsic layer

Doping ~ 5×10^{11} at/cm^3

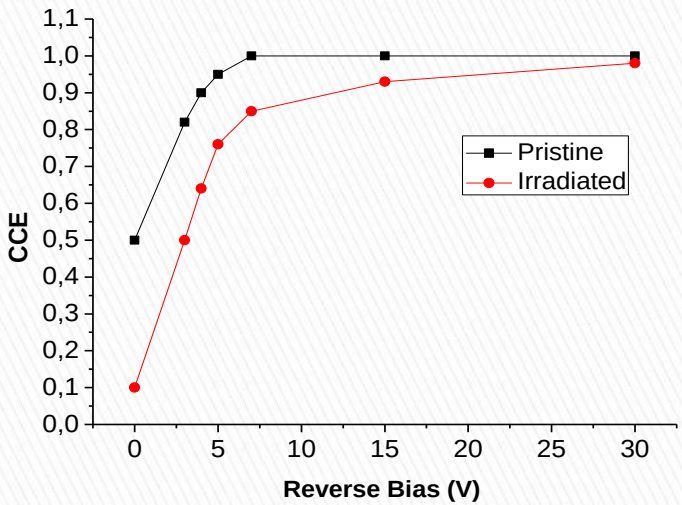






IBIC mappings 1x1 mm^2 of Si sample irradiated to 1×10^{13} p/cm^2

Voltage scans: study of transport properties



Mathematical model that takes into account the carriers recombination in the active and neutral part of the detector

NIMB 371 (2016) 294-297

$$CCE(total) = CCE(drift) + CCE(diff)$$

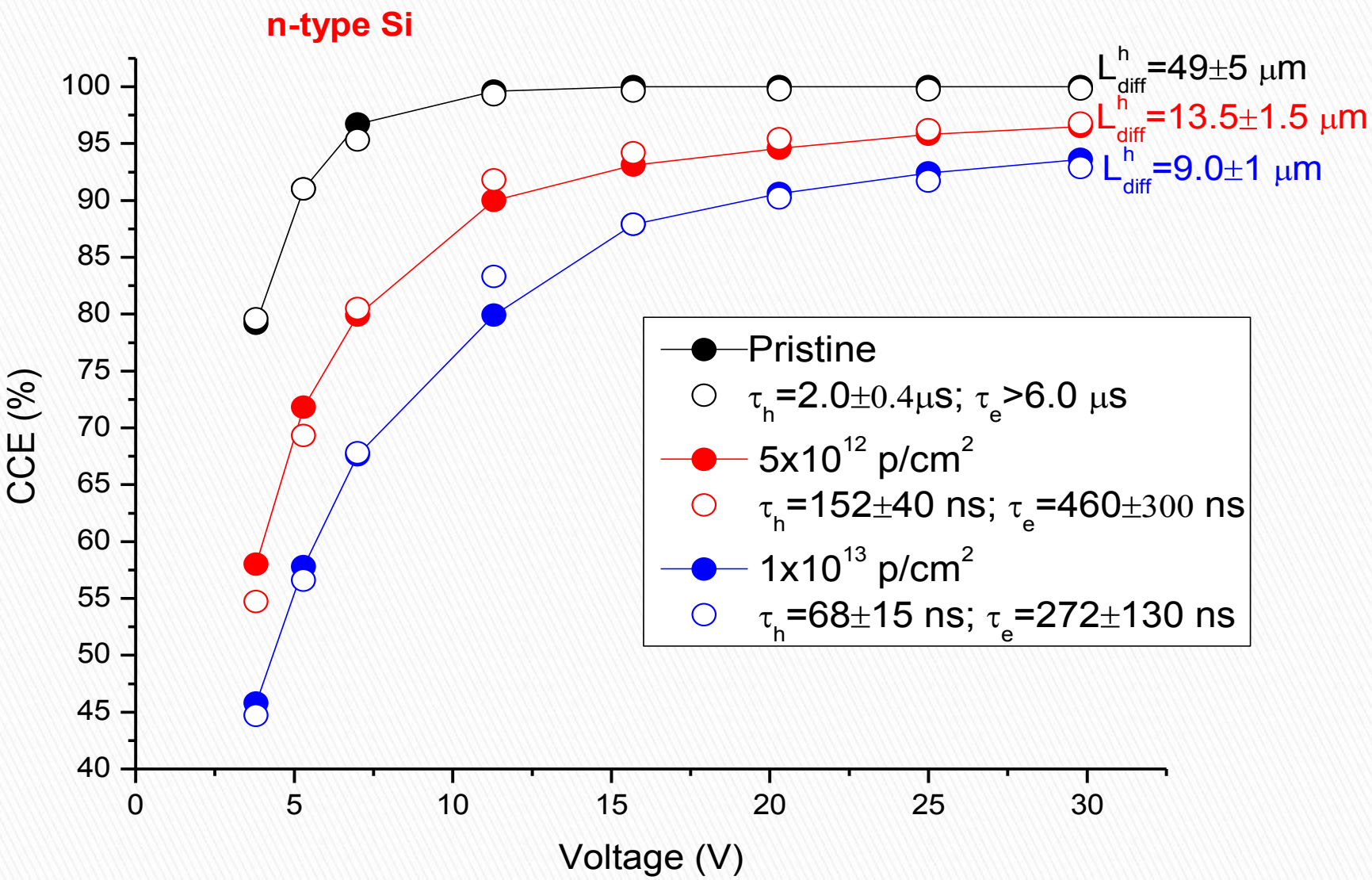
$$CCE(drift) = \frac{1}{E_0}\int_0^w \frac{dE}{dx}\,dx\left[\frac{1}{w}\int_x^w dy\; e^{-\int_x^y \frac{dz}{L_{maj}(z)}} + \frac{1}{w}\int_0^x dy\; e^{-\int_y^x \frac{dz}{L_{min}(z)}}\right]$$

$$CCE(diff) = \frac{1}{w}\int_0^w dx\; e^{-\int_x^w \frac{dy}{L_{min}(y)}}\,\frac{1}{E_0}\int_w^{R_p} \frac{dE}{dx}\; e^{-\frac{x-w}{L_{diff}}}\,dx$$

Inputs
- Electrostatics of the device
- Vacancy and ionization profiles

Free parameters: τ_e and τ_h

Results: n-type Si



One dimension Shockley-Read-Hall model

$$\tau(x,\Phi) = \frac{\tau_0}{1 + k \cdot V(x) \cdot \sigma \cdot v_{th} \cdot \Phi \cdot \tau_0}$$

$\tau(x, \Phi)$=Carrier lifetime after irradiation (experimental)

τ_0=Carrier lifetime for pristine material (experimental)

Φ=Particle fluence (experimental)

V_{th}=Thermal velocity of carriers (calculation)

V(x)=Vacancy profile (calculation SRIM)

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k=Average number of active traps per vacancy (unknown)

σ= Trap cross section (unknown)

(k xσ) is indicative of the relative radiation hardness of the semiconductor

Effective trapping cross section kσ

One dimension Shockley-Read-Hall model

$$\tau(x,\Phi) = \frac{\tau_0}{1 + k \cdot V(x) \cdot \sigma \cdot v_{th} \cdot \Phi \cdot \tau_0}$$

n-Si

$\Phi = 5\times10^{12}$ p/cm^2 : $(k\sigma)_h = 3.9 \pm 1.2 \times10^{-16}$ cm^2 $(k\sigma)_e = 0.9 \pm 0.6 \times10^{-16}$ cm^2

$\Phi = 1\times10^{13}$ p/cm^2 : $(k\sigma)_h = 4.5 \pm 1.1 \times10^{-16}$ cm^2 $(k\sigma)_e = 0.8 \pm 0.5 \times10^{-16}$ cm^2

From DLTS, the most prominent electrically active defect induced by swift-ion irradiation in low doped n-type Si is $V_2(-/0)$

(APL 98 (2011))

σ_h $V_2(-/0) = 5\times10^{-14}$ cm^2

σ_e $V_2(-/0) = 5\times10^{-15}$ cm^2

(Phys. Rev. B 65 (2002))

From $(k\sigma)_h$ and $(k\sigma)_e$

$$k \approx 1\text{-}2 \times10^{-2}$$

About 1-2 % of the vacancies created by 17 MeV protons form electrically active traps in low-doped n-type Si

CONCLUSION

- CNA is a user's facility

- Scientific collaborations are welcome.

Contact:

3 MV Tandem: Javier Garcia (fjgl@us.es)

External beam cyclotron: Carmen Jimenez (mcyjr@us.es)

Thanks for your attention !!!