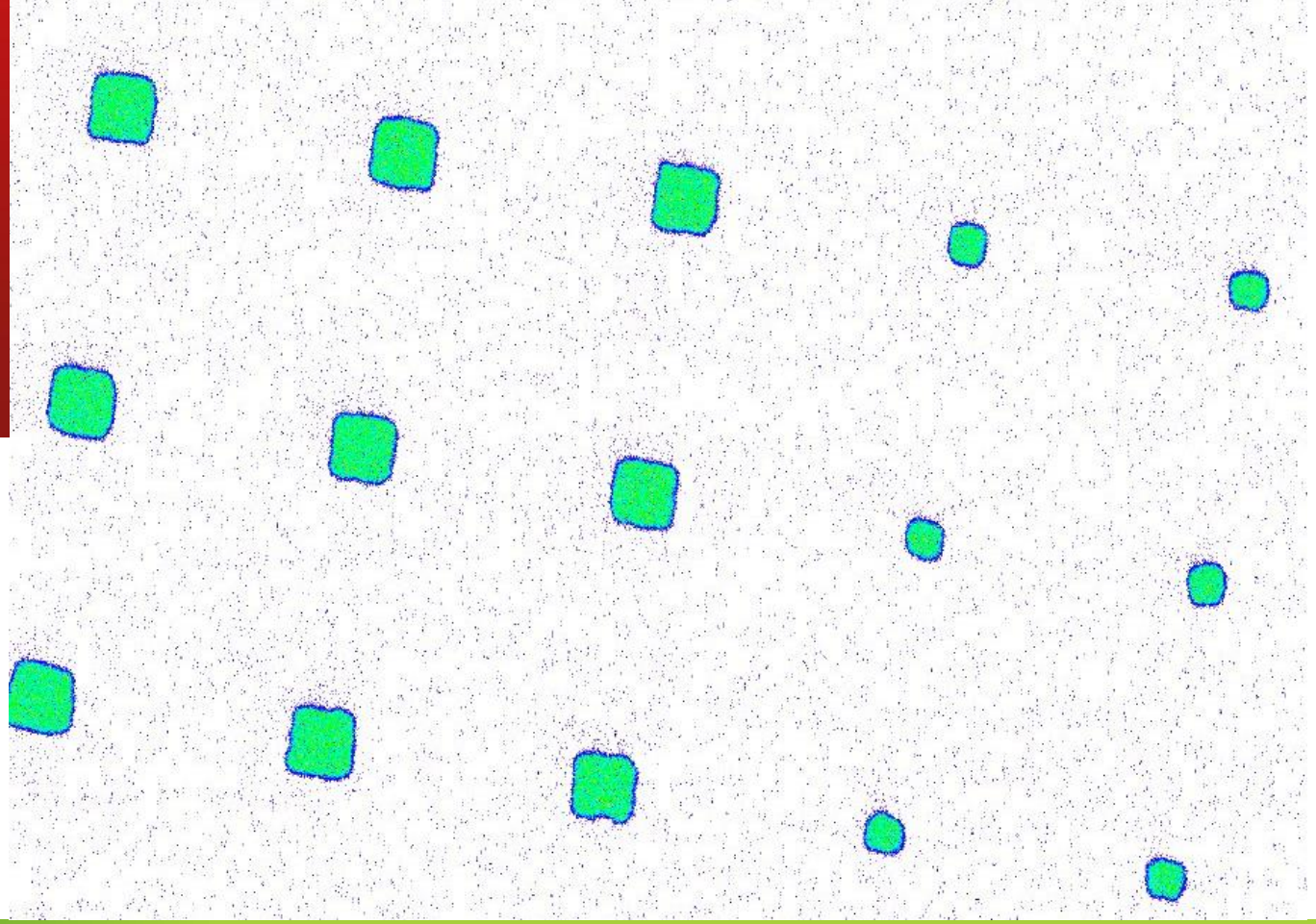


Microdosimeter for Hadron Therapy based on a Single Crystal CVD Diamond Membrane

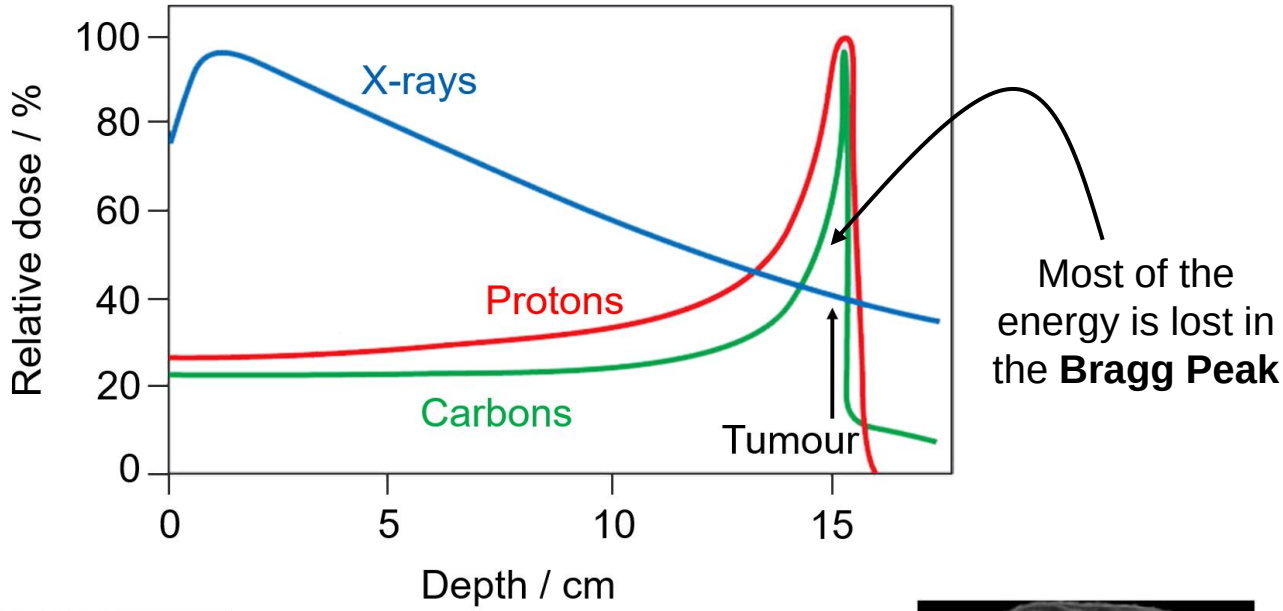
Izabella Anna Zahradnik

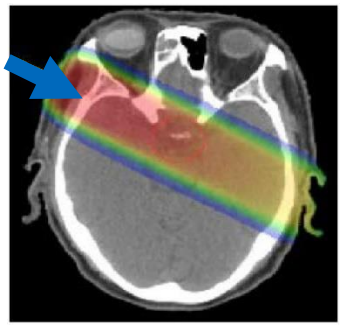
Journée thématique du réseau détecteurs semiconducteurs IN2P3 – IRFU 2018, **Les détecteurs à pixels**

Outline

- **Introduction and motivation**
  - Hadron therapy and microdosimetry
- **Diamond microdosimeter**
  - Concept and fabrication
- **Probing charge transport properties – ion microbeam**
  - Micro Sensitive Volumes
  - Charge collection efficiency
  - Radiation hardness
- **Preliminary test in clinical environment**

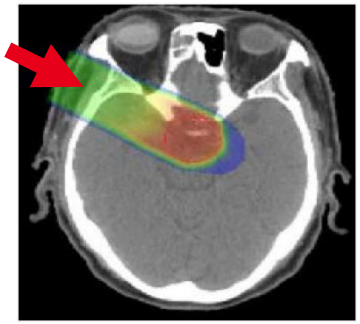
Hadron Therapy





[A. Rosenfeld]

Photons



[A. Rosenfeld]

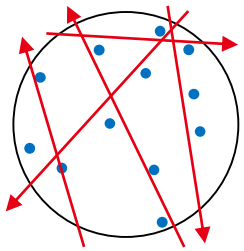
Ions

Linear Energy Transfer

SPARSELY ionizing radiation:

e.g.: X-rays, Gammas

[M. Scholz]

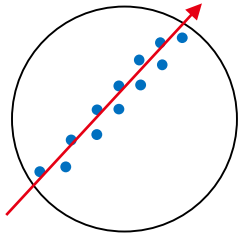


Low LET

DENSELY ionizing radiation:

e.g.: Carbon ions

[M. Scholz]

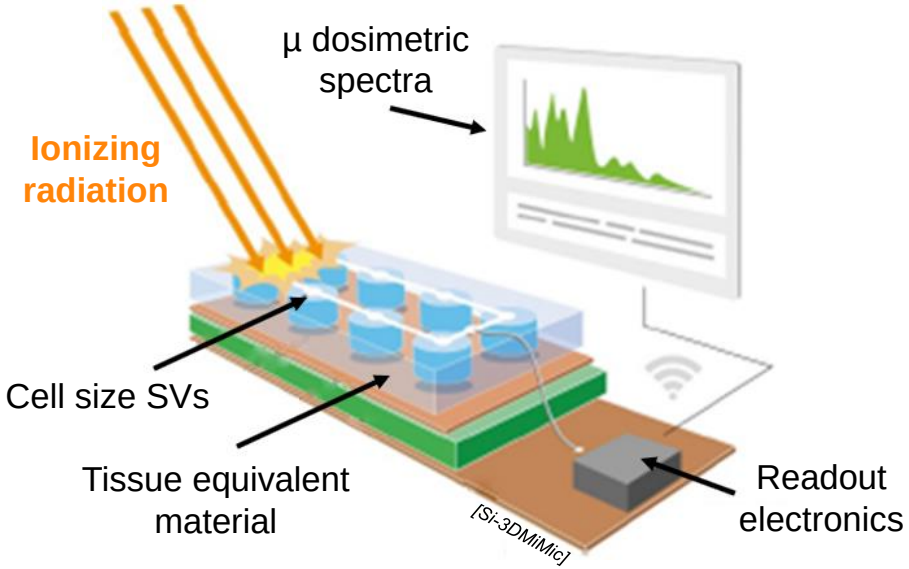


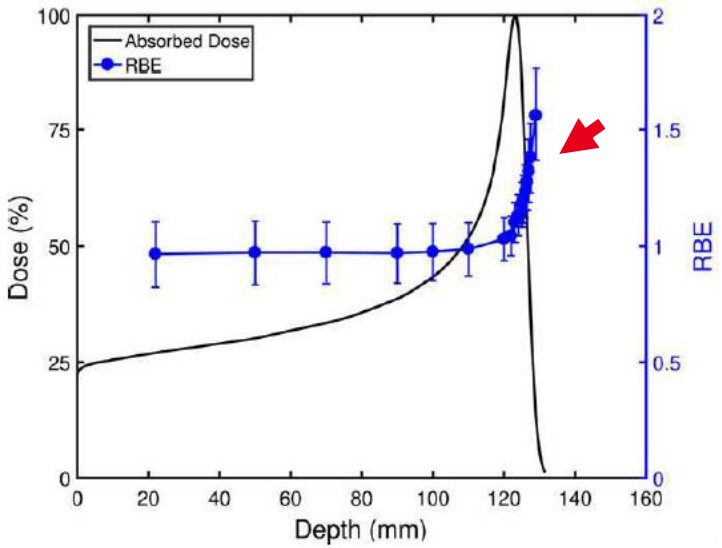
High LET

Microdosimetry & Radiation Quality

*"**MICRODOSIMETRY** is a method which involves measurements or calculations of stochastic energy deposition distribution in a micron size sensitive volume (SV) within any arbitrary mixed radiation field."*

Concept of solid state microdosimetry:





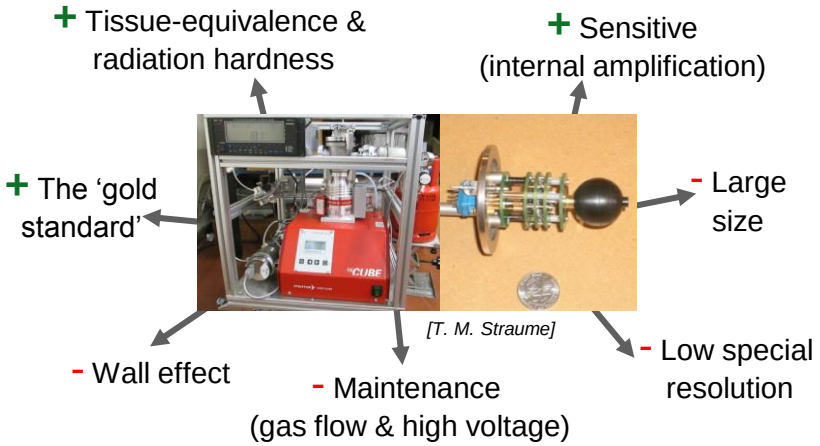
- Single-particles (low charge)
- ns to µs integration time (10^9 p/cm^2)
- Pulse-height spectra
- SV from micro to nano size

(30 µm cell → 10 µm cell nucleus → << 1µm DNA)

[Tran, Rosenfeld et al., Med. Phys., 44 (11), November 2017]

Why Diamond? - State of the Art

Tissue Equivalent Proportional Counter (TEPC):



Diamond solid state microdosimeter:

Large band-gap (5.5 eV) semiconductor

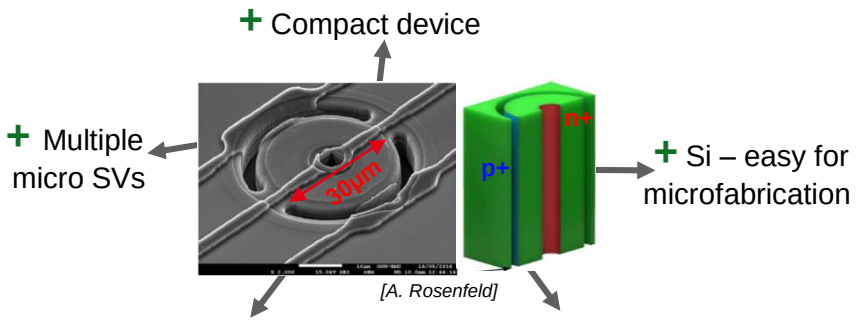
more tissue equivalent (Z = 6) and radiation hard

\+
- No leakage current
- Temperatur stability, not v. light sensitive
- Fast drift velocity for e-h
- Low capacitance

\-
- High ~13 eV/e-h – lower signal
- Diamond - 6' wafers rather difficult

Since 2002 high purity electronic grade CVD diamond available commercially

Silicon solid-state microdosimeters:



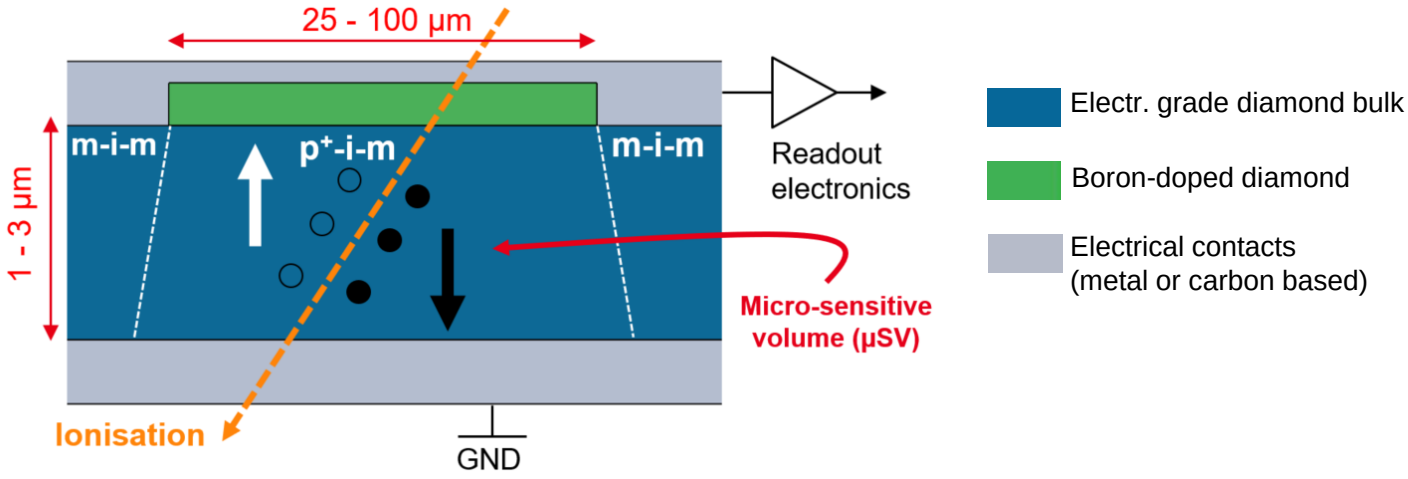
Interests for diamond microdosimeter in the research community

Università di Roma „Tor Vergata" – Prof. Marinelli

University of Wollongong – Prof. Rozenfeld

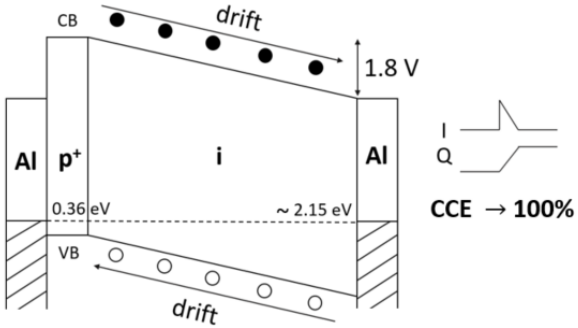
Diamond Microdosimeter Concept

scCVD diamond self-biased µSV (external bias @ 0V):

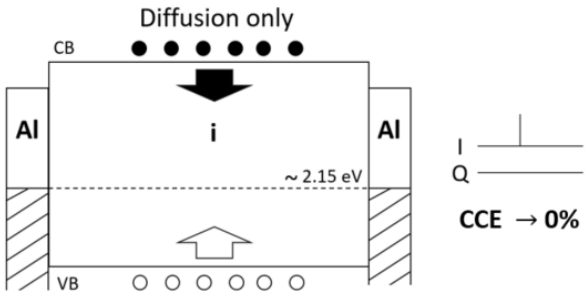


Charge transport @ 0V:

p+ and intrinsic diamond (p-i-m):



intrinsic diamond (m-i-m):



Diamond membrane microdosimeter prototypes

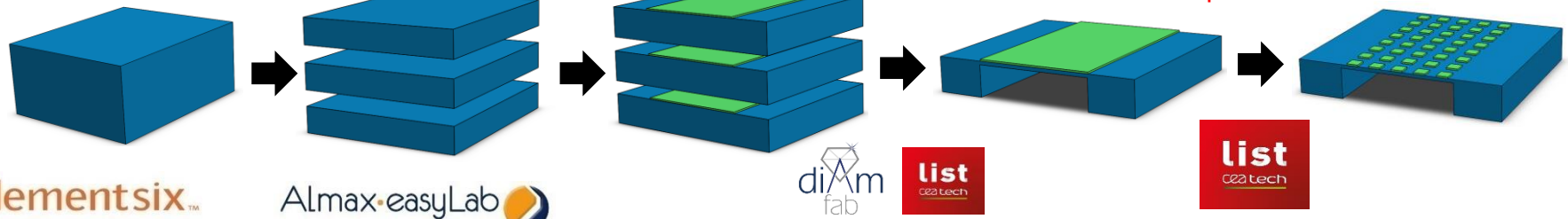
scCVD diamond membrane microdosimeter fabrication:

1. Slicing and polishing — 300 – 500 µm

2. p+ CVD growth — 30 – 60 µm

3. Ar/O deep etching — < 10 µm

4. Patterning Ar/O shallow etching



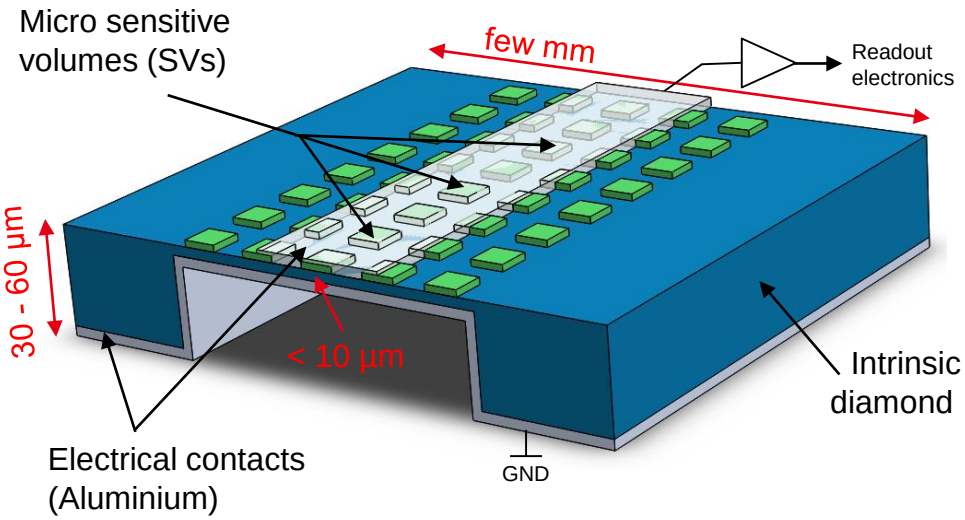
element six

Almax easyLab — science under pressure

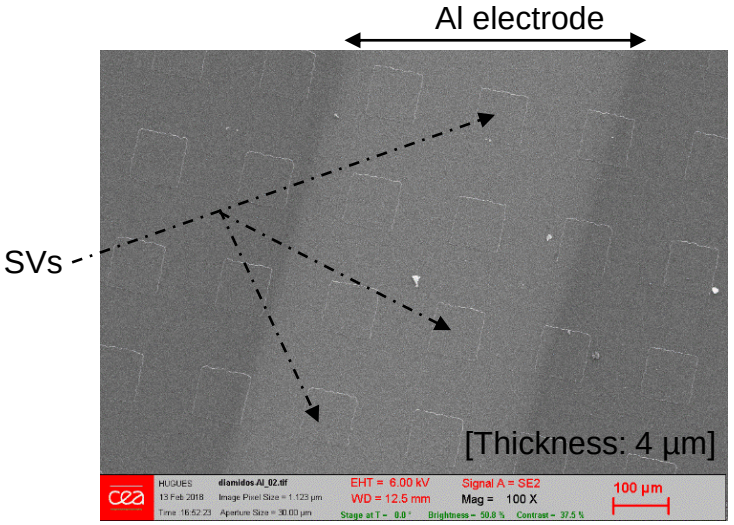
diamfab

list cea tech

scCVD diamond membrane microdosimeter:



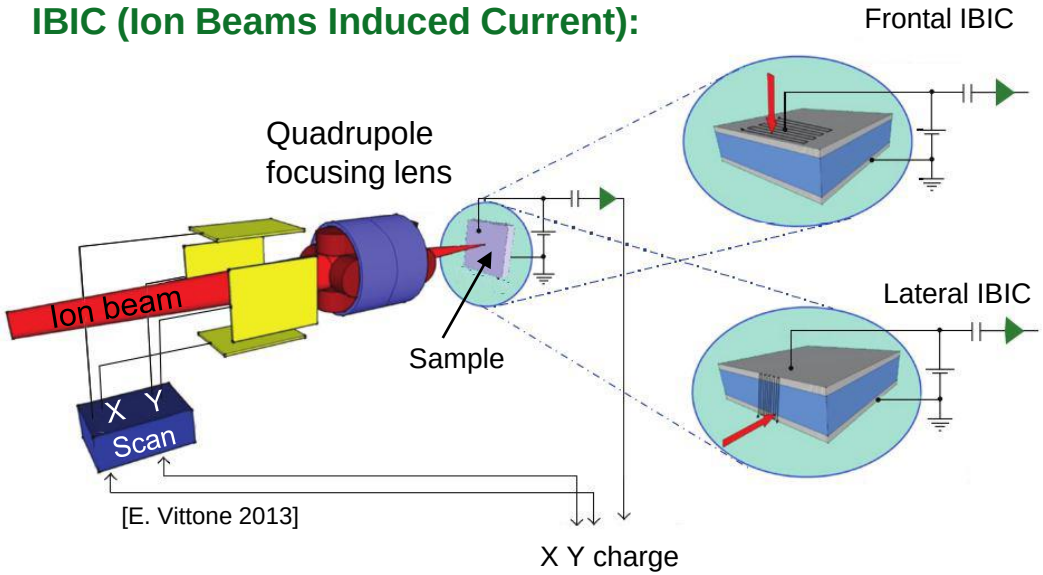
SEM Image:

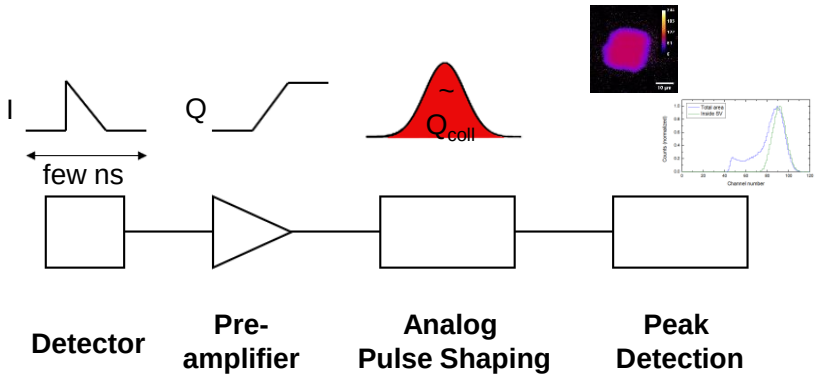


INSTITUT CARNOT CEA LIST — université PARIS-SACLAY

Probing Charge Transport with IBIC

IBIC (Ion Beams Induced Current):





CENBG

Proton 2.0 MeV

50 keV/µm (diamond)

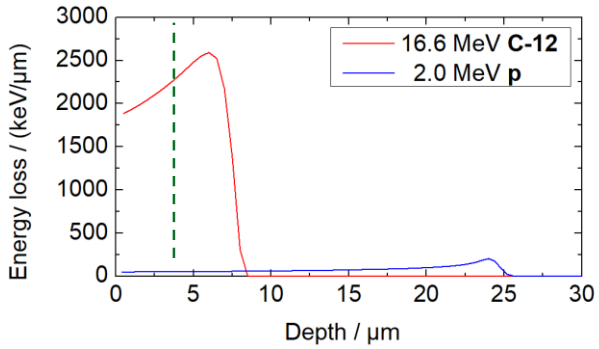
Carbon 16.6 MeV

1863 keV/µm (diamond)

- Single ion irradiation (precision: 1 micron)
- Raster scanning + pulse height spectra
- Charge transport maps (µSV definition)
- Well controlled projectile energy and LET

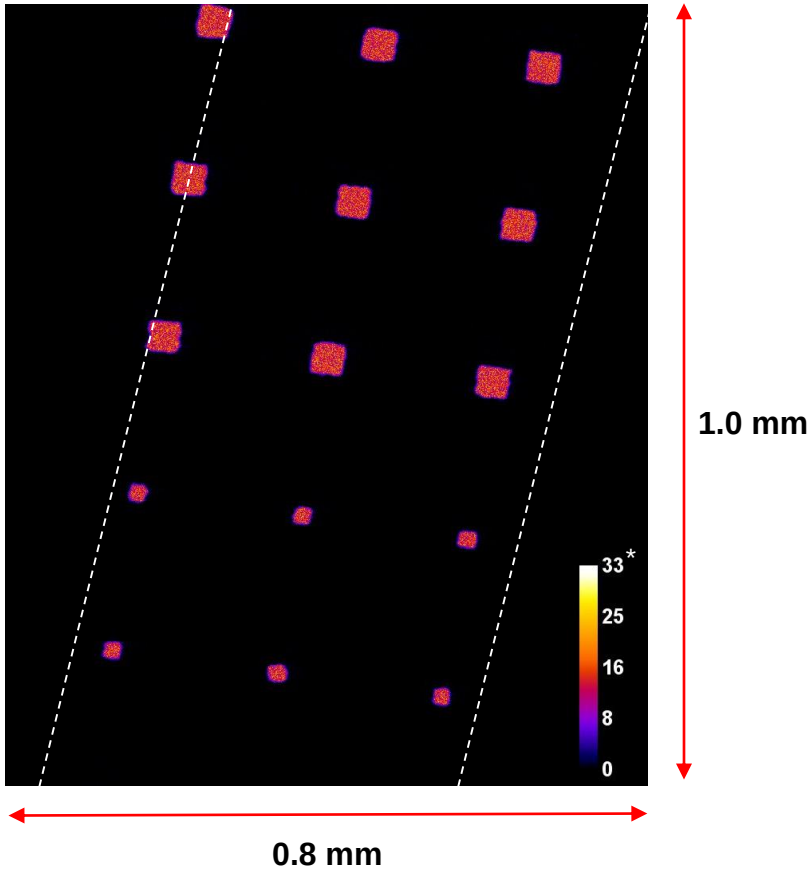
Perfect tool to test new types of microdosimeters before implementing in clinical conditions (less control)

SRIM calculation for energy loss for C and p

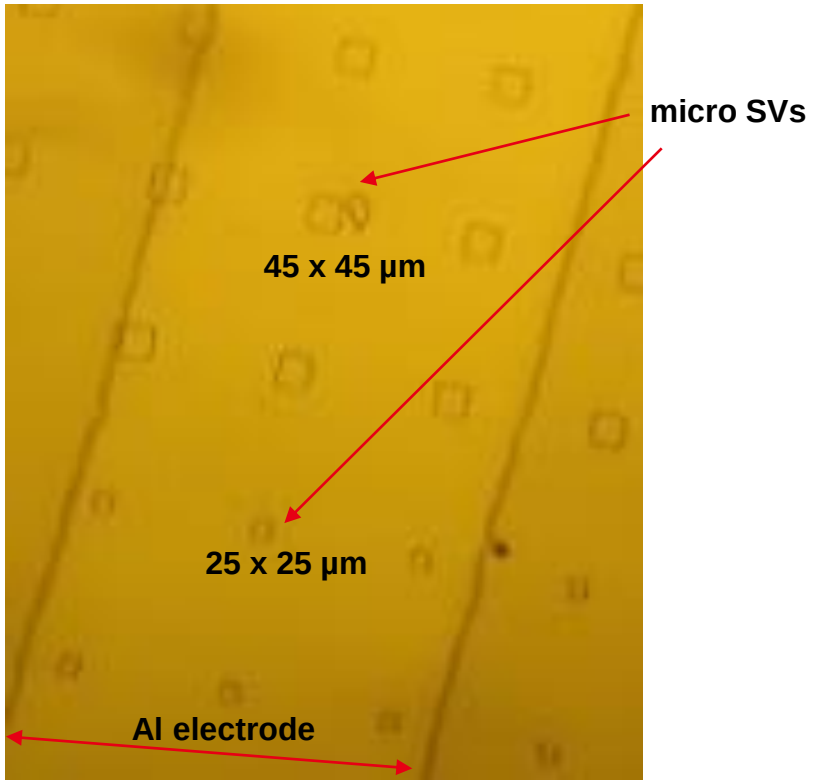


IBIC – 2.0 MeV proton Microbeam

Raster scan of device @ 0 V



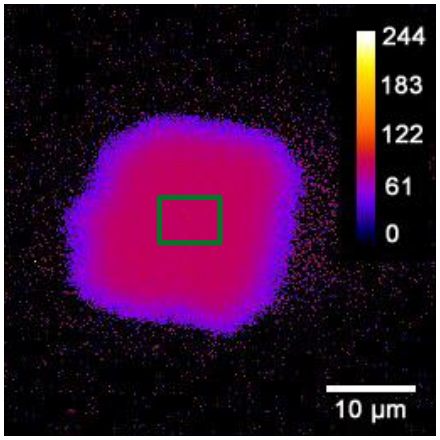
Microscopic Image

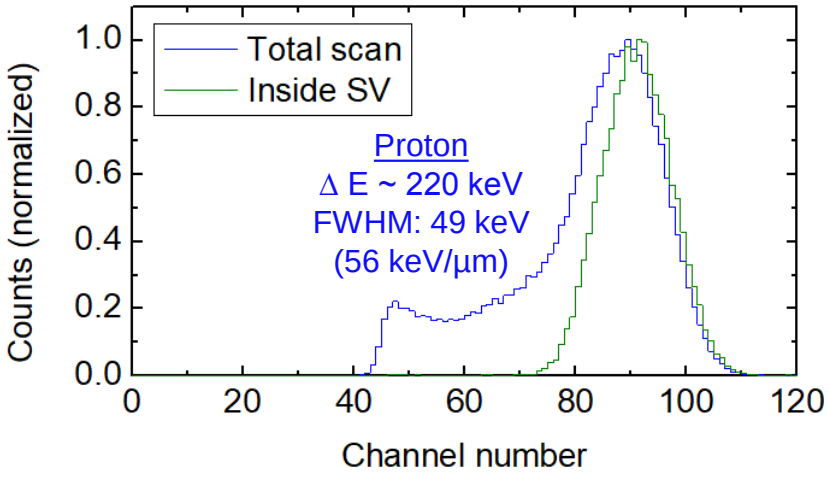


*** Number of detected ions / pixel**

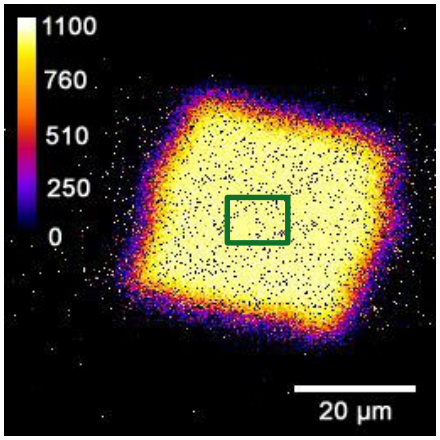
IBIC – Diamond Signal @ 0 V

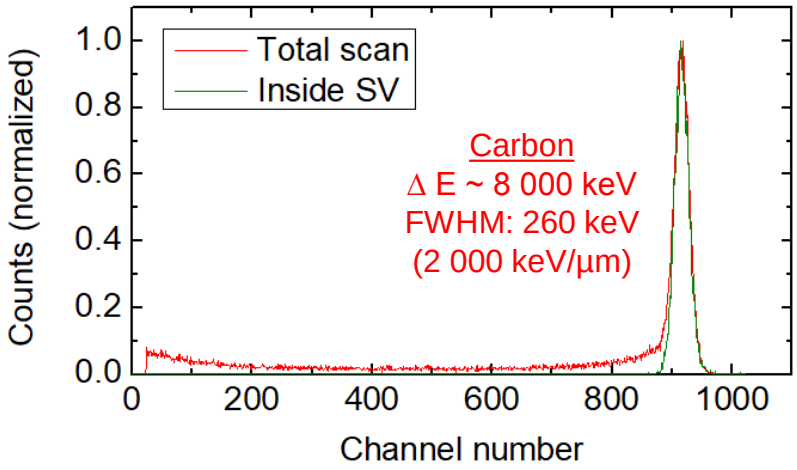
2.0 MeV Proton Microbeam
25 x 25 µm² SV





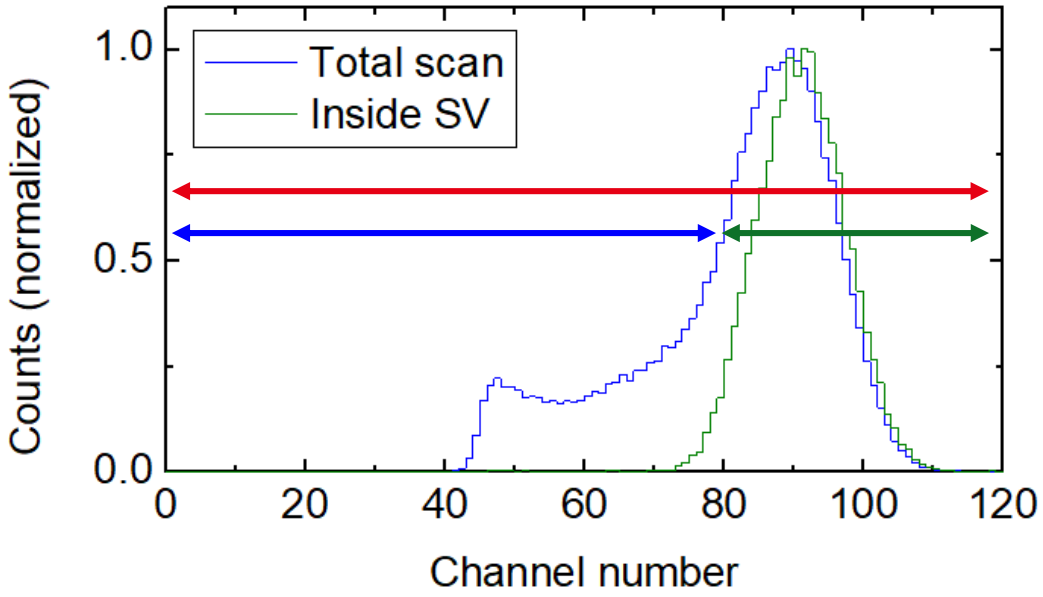
16.6 MeV Carbon Microbeam
45 x 45 µm² SV



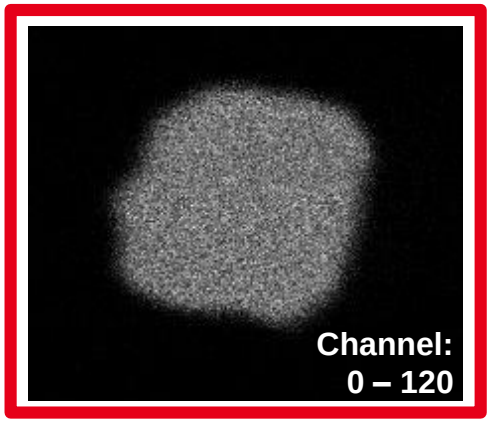


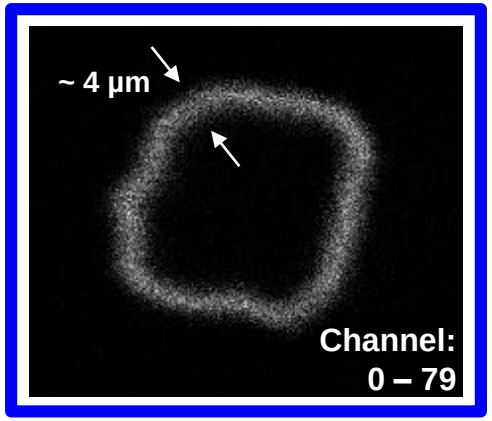
IBIC – Diamond Signal (Hit Maps) @ 0 V

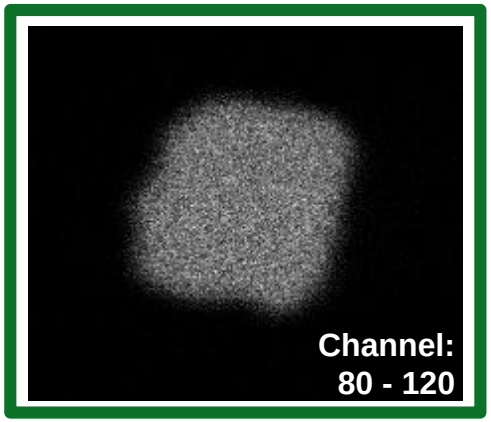
2.0 MeV Proton Microbeam



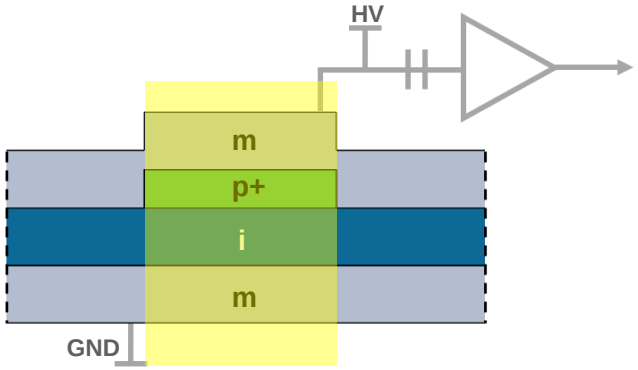
→ **Optimization of the SV's edges needed**



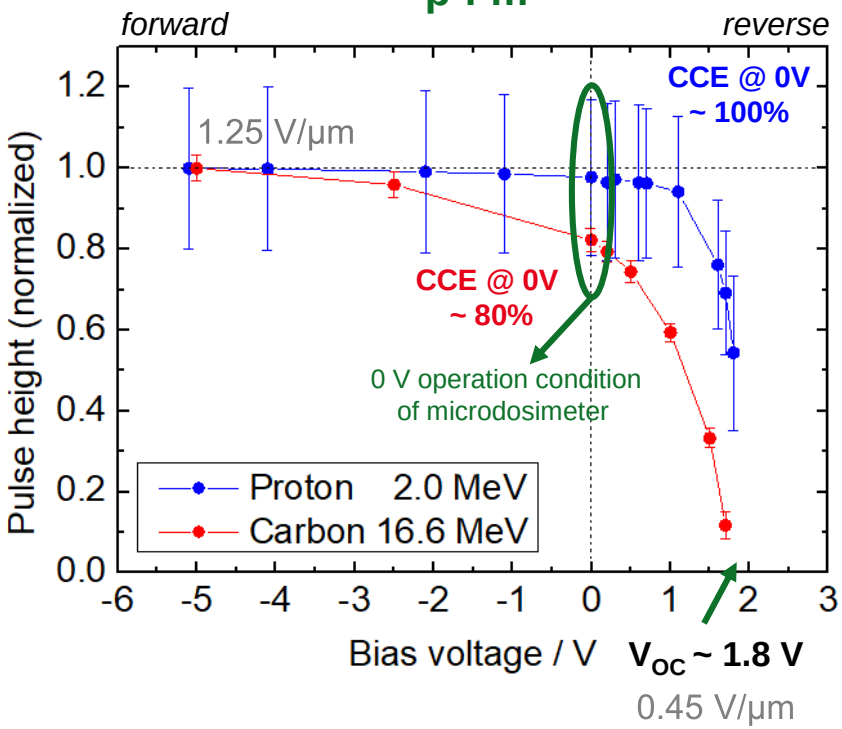


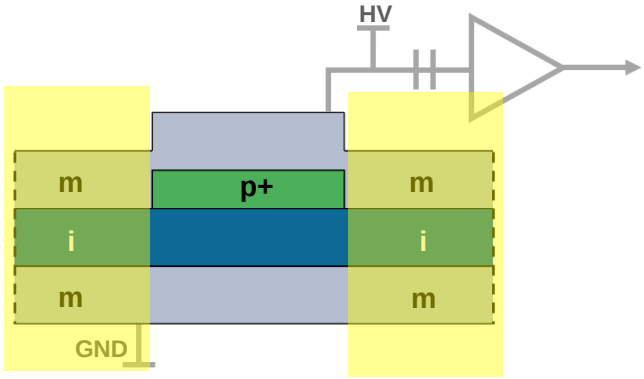


Charge Collection Efficiency vs. Bias

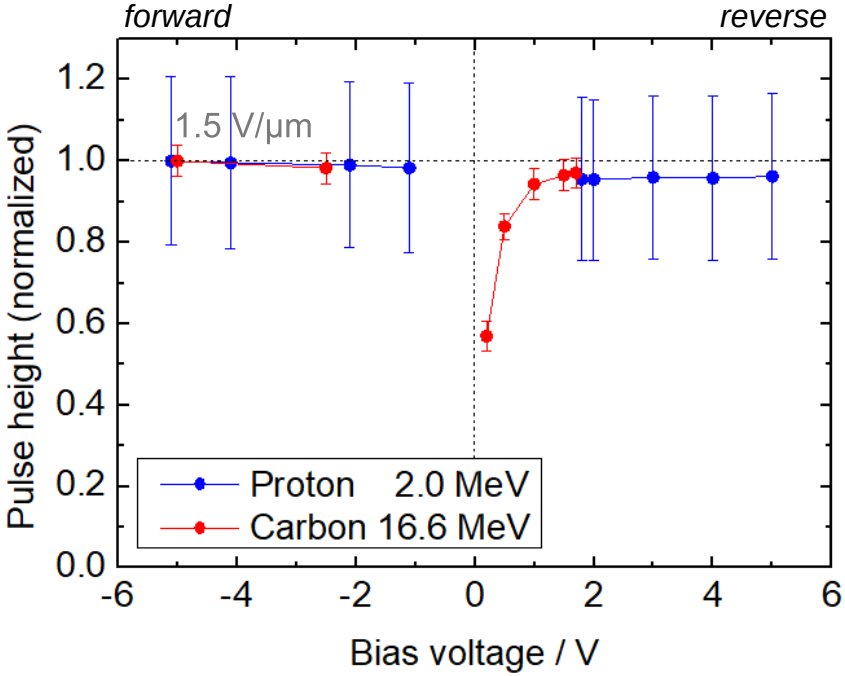


p-i-m



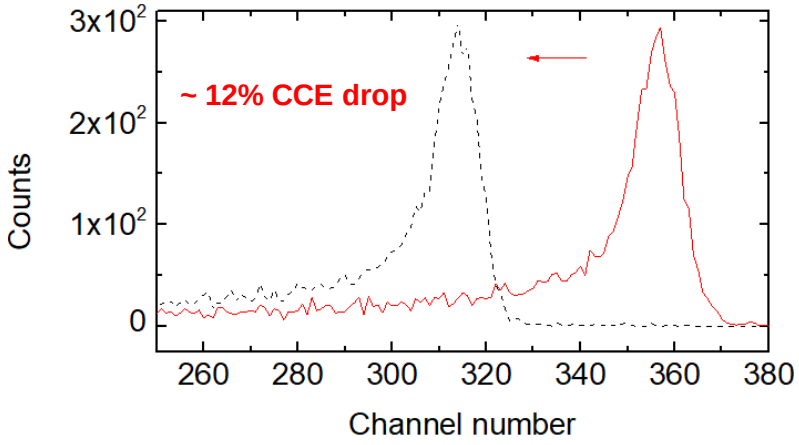


m-i-m

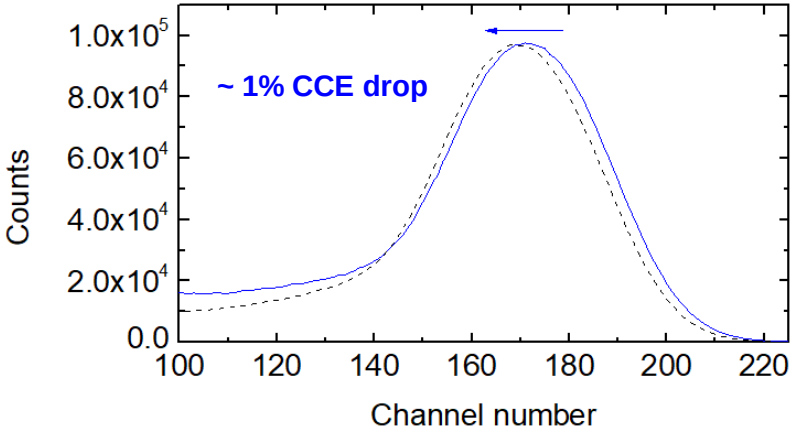


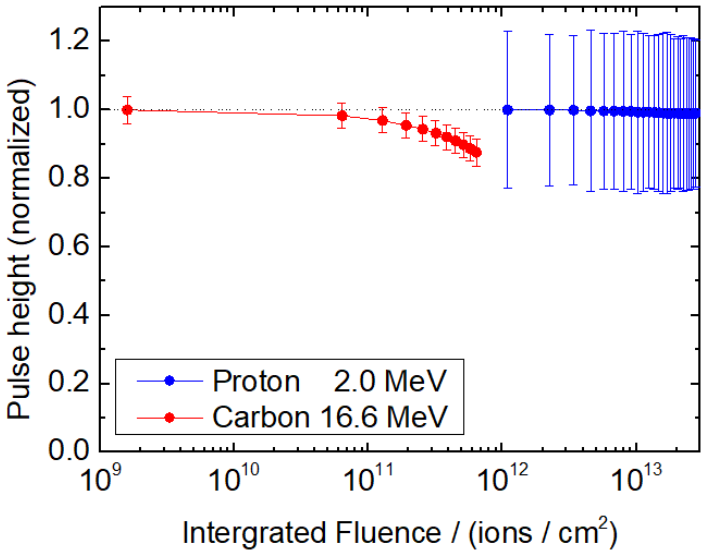
Radiation Hardness

Carbon after 0.64 x 10^{12} ions / cm^2



Proton after 2.5 x 10^{13} ions / cm^2





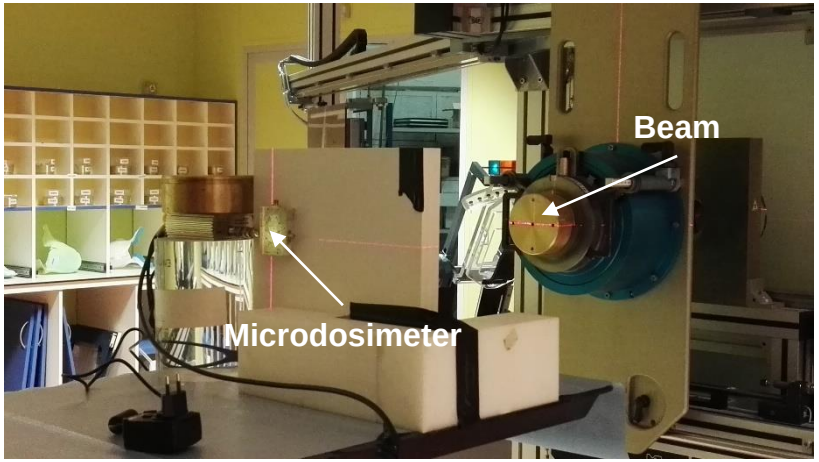
Proton-Therapy
~ 2500 Protons / cancer cell

> 1000 fractions possible

before only 1% of CCE drop

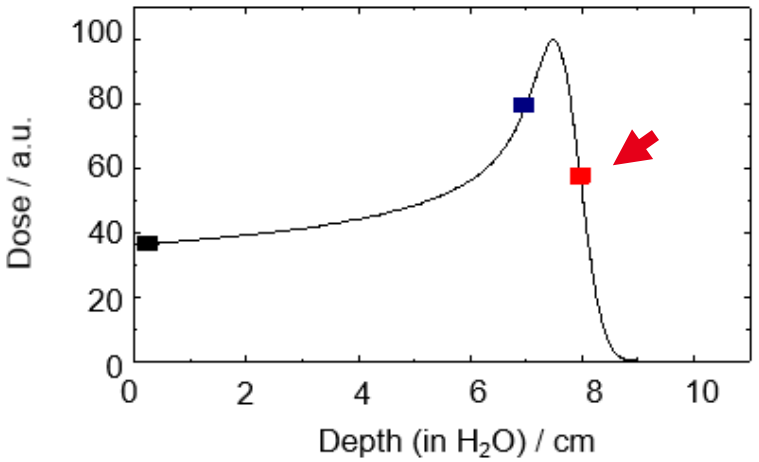
Lineal Energy Measurement – 100 MeV Proton Beam

Institute Curie Proton Therapy Center (Orsay, France)

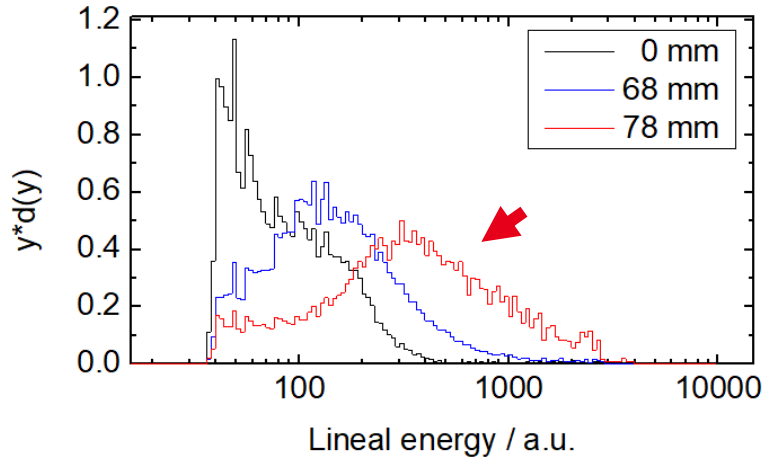


- Proton beamline for intracranial treatments
- **100 MeV p**
- 80 mm variable thickness solid-water phantom
- 300 µm SV diamond microdosimeter prototype

Bragg peak (IBA PP05)

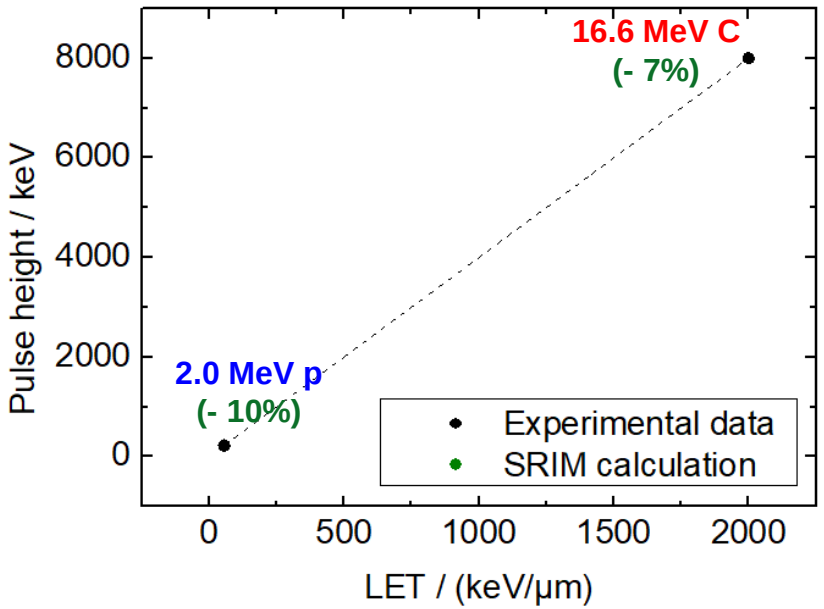


Diamond membrane microdosimeter



Summary and Outlook

- **scCVD diamond membranes have a great potential for solid-state microdosimetry**
  - Full CCE (proton and alpha) @ 0V, well-defined µSV, ΔE spectra, fast
  - Radiation hard (proton and carbon)
  - First Lineal Energy measurements in clinical proton beam (promising)
- **Issues to be addressed soon:**
  - µSV geometry optimization: 3D, implantation, thickness homogeneity
  - Pulse-height defect for high LET (carbon)
  - Dedicated electronics
  - Lineal measurements (mixed fields)



DIAmiDOS Collaboration – Programme transverse instrumentation CEA

CEA-LIST

CEA-DRF

Antoine Lacassagne
CENTRE DE LUTTE CONTRE LE CANCER DE NICE

IC-CPO, Orsay

TIRO, Nice

CENBG, Bordeaux

RBI, Zagreb, Croatia

Gunma University, Japan

Acknowledgement

DiamFab for growing excellent quality p+ diamond homoepitaxial layers
www.diamfab.eu

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 654168

AIDA 2020

Diamond Sensors Laboratory (LCD) for great support throughout the entire project

DIAmiDOS Collaboration – Programme transverse instrumentation CEA

CEA-LIST

CEA-DRF

Antoine Lacassagne
CENTRE DE LUTTE CONTRE LE CANCER DE NICE

IC-CPO, Orsay

TIRO, Nice

CENBG, Bordeaux

RBI, Zagreb, Croatia

Gunma University, Japan

Thank you for your attention

Commissariat à l'énergie atomique et aux énergies alternatives
Institut List | CEA SACLAY | Laboratoire Capteur Diamant (LCD) | BAT. 451 – PC 66 C
91191 Gif-sur-Yvette Cedex - FRANCE
www-list.cea.fr