

Development of diamond-based microdosimeters for hadrontherapy

Prof. Claudio Verona

Dip. Industrial Engineering, University of Rome “Tor Vergata”, Italy

e-mail: claudio.verona@uniroma2.it



Motivation

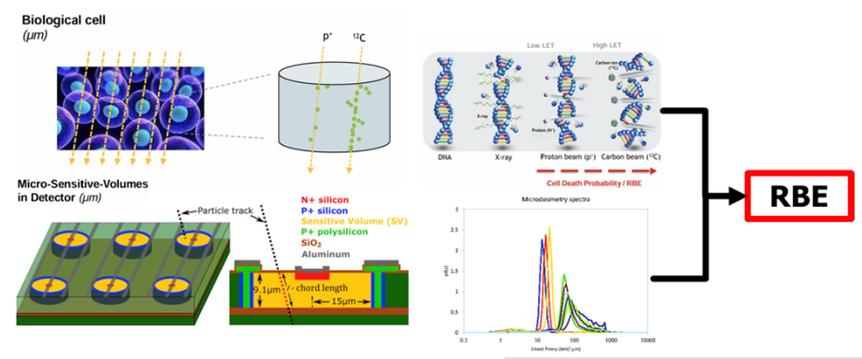
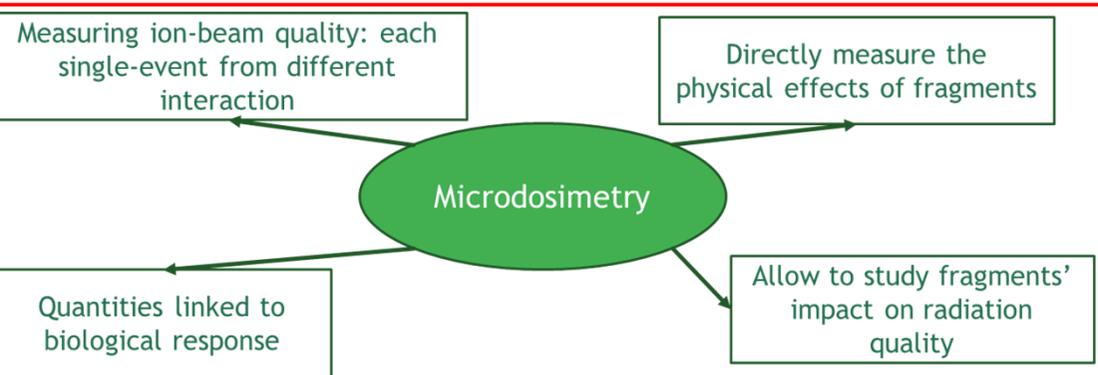
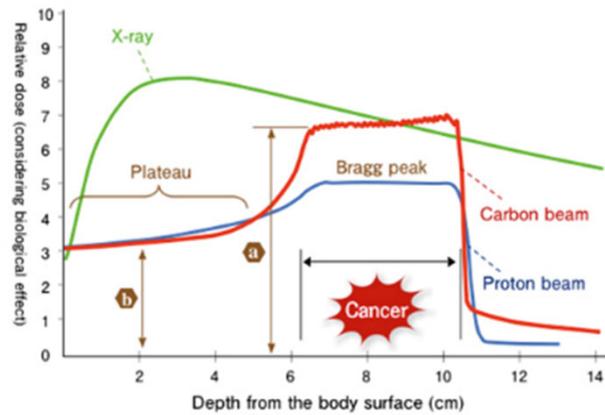


Hadrontherapy is a techniques which make use of high energy protons or ions beams (i.e. He, C and O) to irradiate tumors. Its main advantage is the ability to more precisely localize the delivered dose.

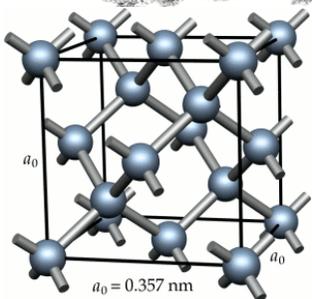
Protons and ions produce high local ionization density.

Projectile and target fragmentation produce secondary particles that contribute to dose and must be considered in treatment planning.

The biological effectiveness (RBE) of high LET particles can be very different from that of high energy photons (RBE > 1).



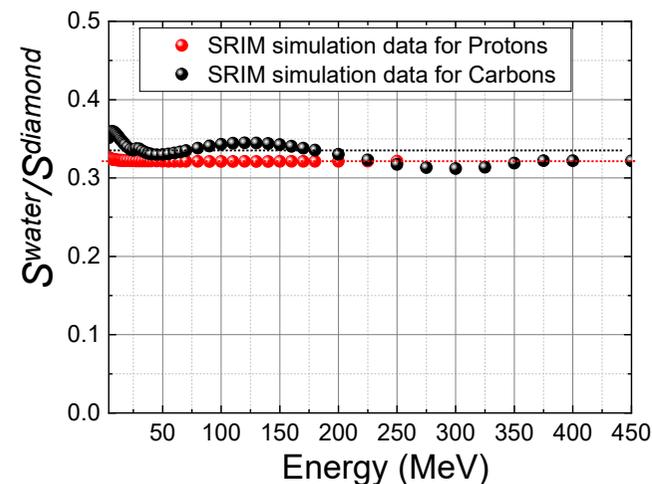
Why Diamond ?



Single crystal diamond is also a good material to produce small detectors for **dosimetry and microdosimetry** of hadron therapy beam.

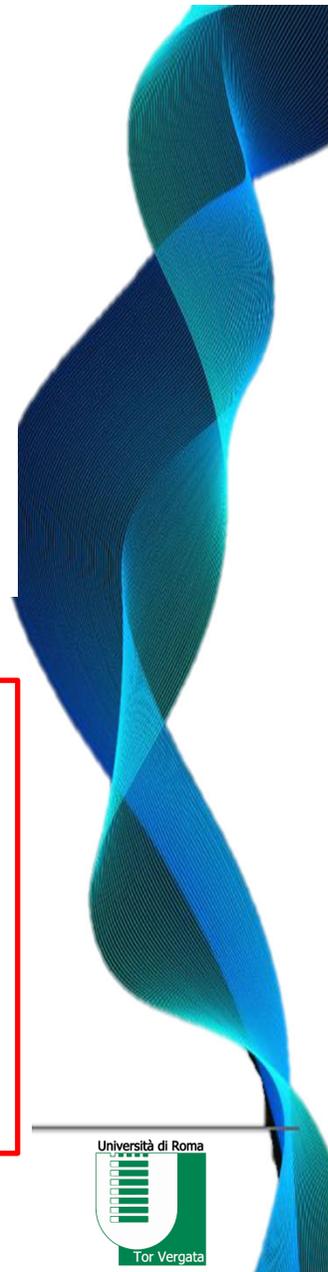
Diamond Key Features

- $Z = 6$ (same as water)
- Very high displacement energy ($\sim 42 \text{ eV}$)
- Nearly constant diamond/water stopping power ratios (protons and ions)
- High bandgap (5.5 eV)
- Low dielectric constant (5.7)
- High specific sensibility ($\sim 270 \text{ C/Gy}\cdot\text{m}^3$)
- High electron-hole mobility



Detector Key Features

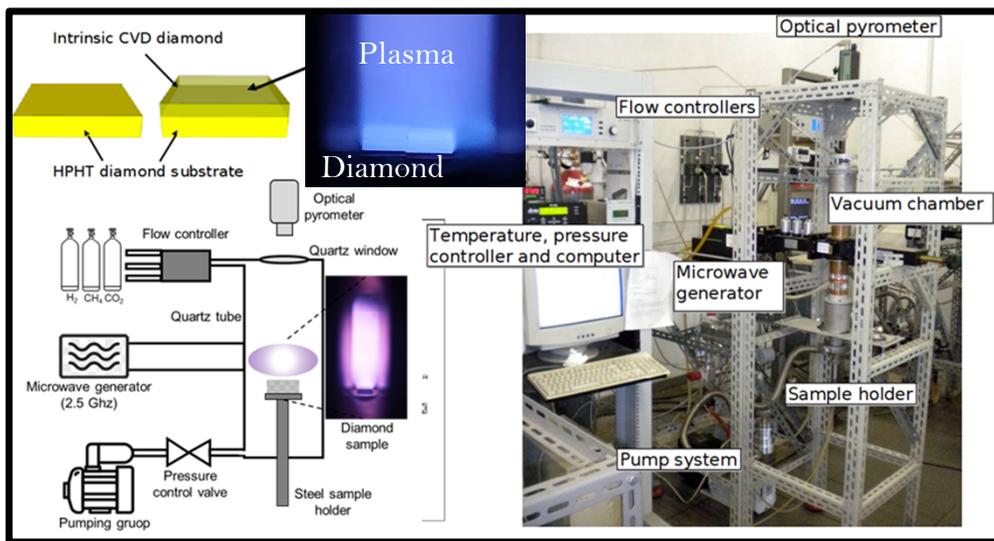
- Near tissue equivalence
- Excellent radiation hardness
- Low energy dependence
- Low leakage current / noise
- Low capacitance
- Small size, high spatial resolution and able to work under high particle flux
- Fast response time ($\sim 1 \text{ ns}$)



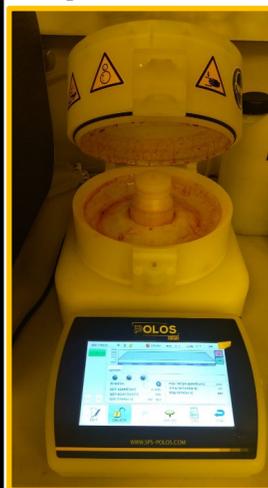
Diamond laboratory at Tor Vergata

- ✓ Diamond films are deposited by Microwave Plasma Enhanced Chemical Vapour Deposition (MW-CVD).
- ✓ Three MW-CVD reactors (doping, production, research)
- ✓ The devices are realized in a monolithic structure combining both microwaves enhanced chemical vapor deposition (CVD) of synthetic single crystal diamond and photolithography techniques;
- ✓ Housing fabrication and wiring

Microwave plasma CVD



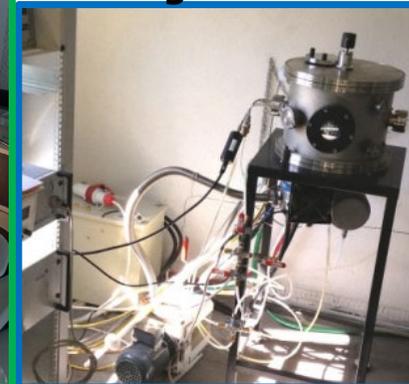
Spin Coater



Wire microbonding



Thermal evaporator and E-gun



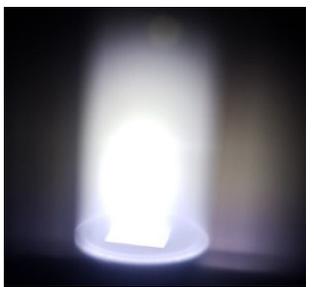
Mask Aligner



Fabrication of diamond integrated device: dosimeter and microdosimeter

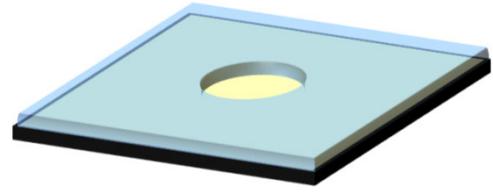
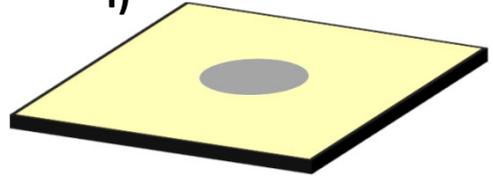


-  Boron doped diamond
-  Intrinsic diamond
-  Cr electrode

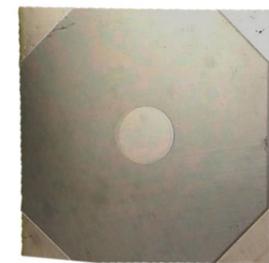
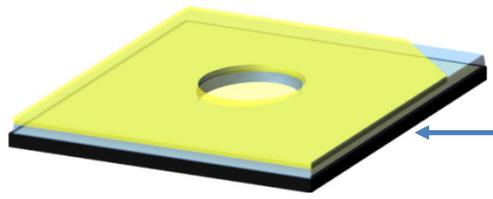
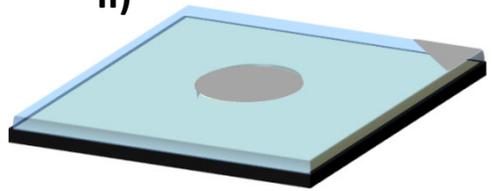


Cr pattern (200 nm) **Selectively CVD deposition of B-doped diamond and intrinsic diamond**

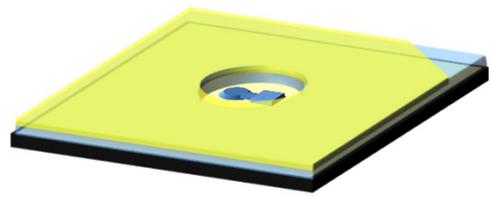
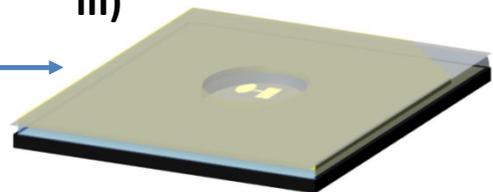
I)



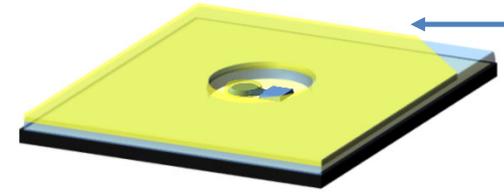
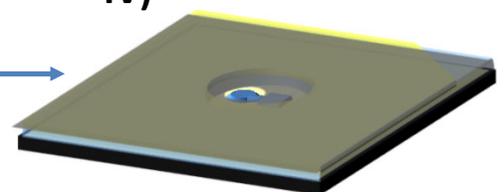
II)



III)



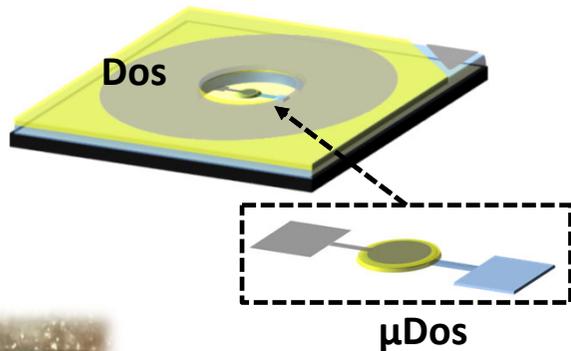
IV)



Fabrication of diamond integrated device: dosimeter and microdosimeter

-  Boron doped diamond
-  Intrinsic diamond
-  Cr electrode

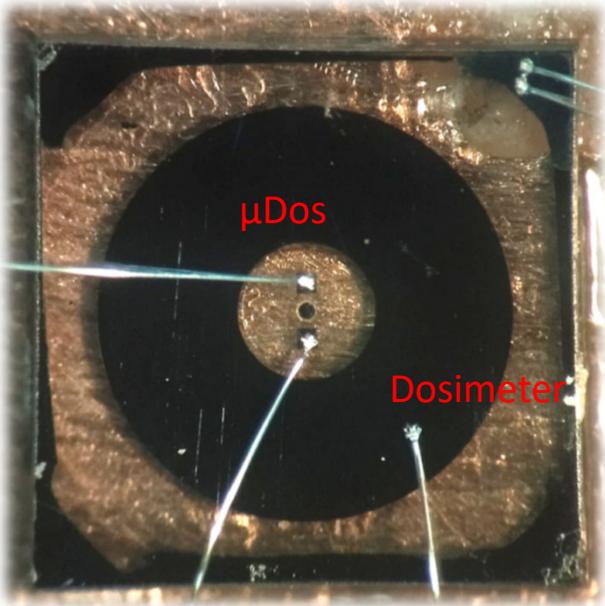
v) Thermal evaporation of metallic electrodes



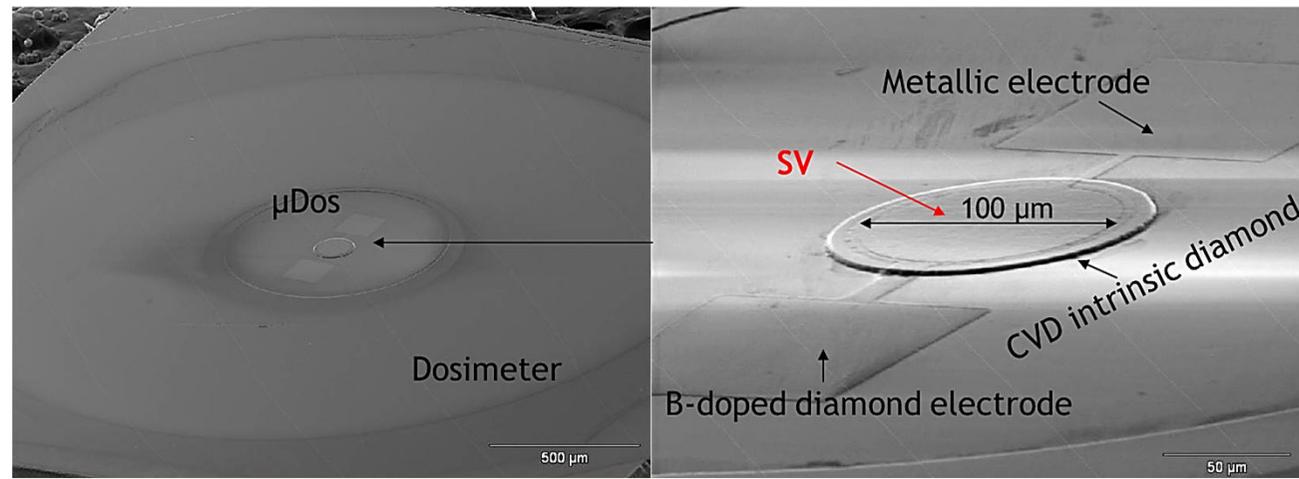
Schottky diodes in a boron-doped/intrinsic diamond/Cr configuration

	μDos	Dos
B-doped diamond thickness	0,3-0,5 μm	1 μm
Intrinsic diamond thickness	2-10 μm	0,5-1 μm
Cr contact	50 nm	50 nm
Sensitive area	0,0078 mm²	4 mm²
Bias	6-30 V	0 V

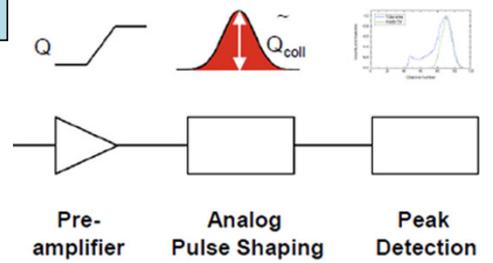
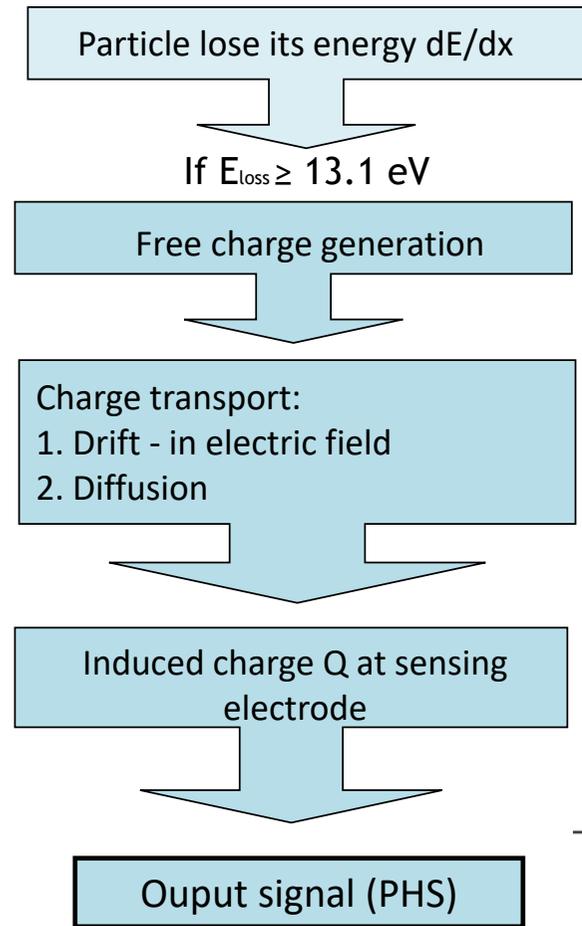
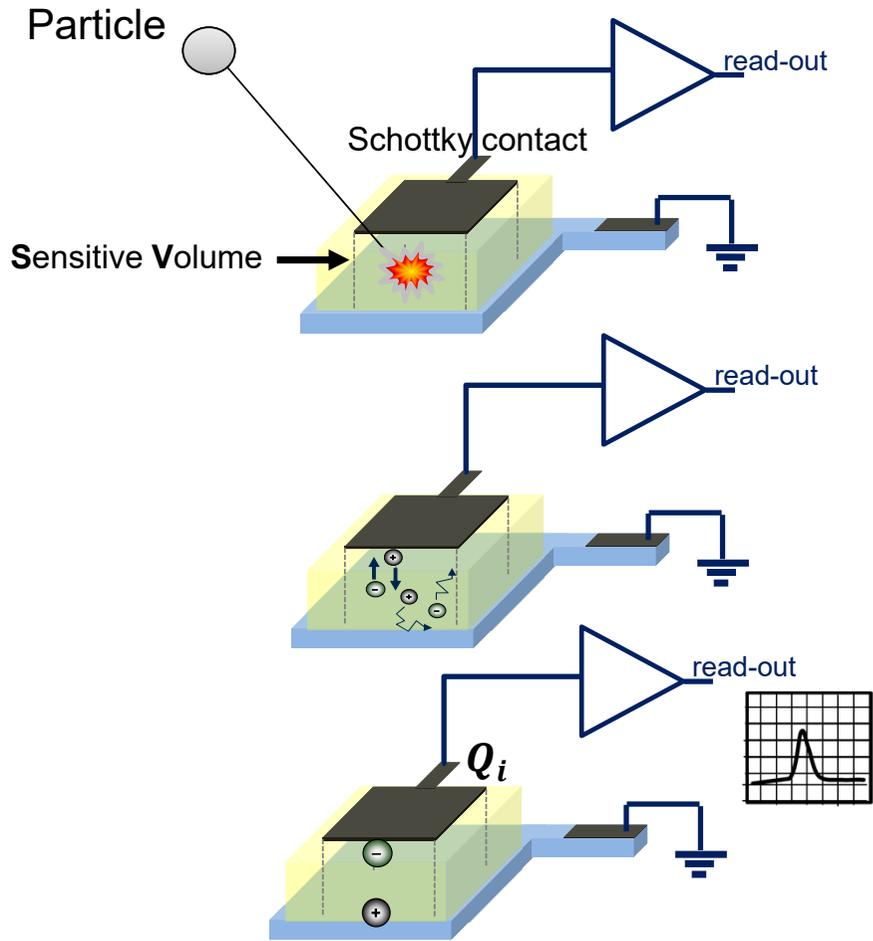
Optical images



SEM images

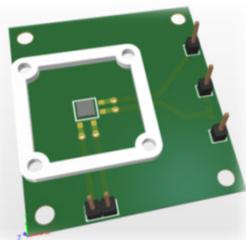


How diamond microdosimeter works?

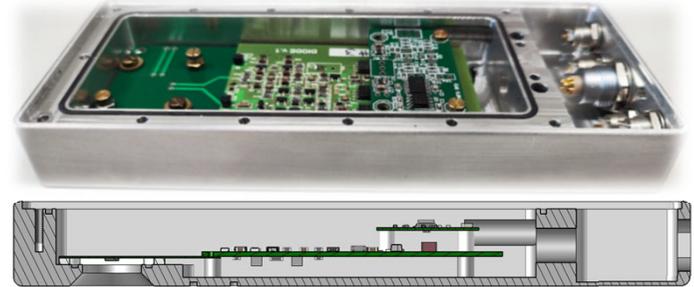


DIODE detector

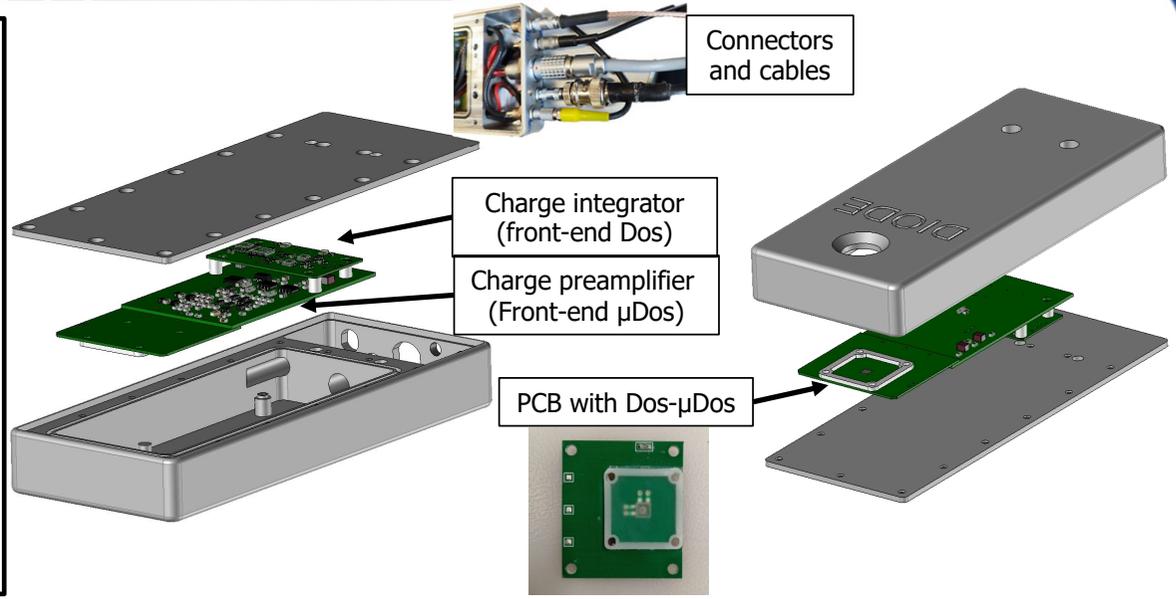
❑ The detector was wire-bonded onto a printed circuit board (PCB) made of Teflon



❑ The detector, along with the dedicated front-end electronics, was then placed in a specifically designed aluminium housing



- ✓ **Housing**
 - Made of aluminum
 - Dimensions: **6.5 × 16 × 2 cm³**
 - Equipped with **O-rings** for use in **water phantoms** (e.g., in ion beam therapy centers)
- ✓ **Connectors:**
 - **4 Lemo connectors:**
 - 2 for output signals (Dos and μ Dos)
 - 1 for μ Dos bias voltage
 - 1 for Dos integrator reset signal
 - **1 six-pin connector:** provides $\pm 12V$ and $\pm 6V$ power supply with common ground



DIODE detector



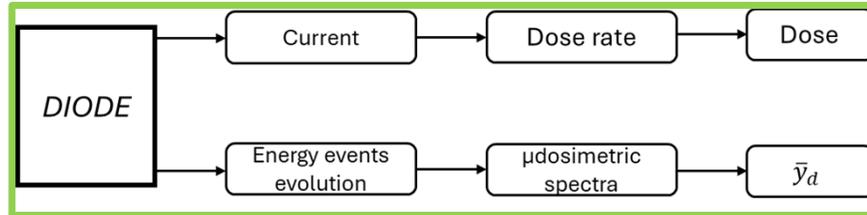
Cables

MCA 527
GBS Elektronik

μcontroller/ADC

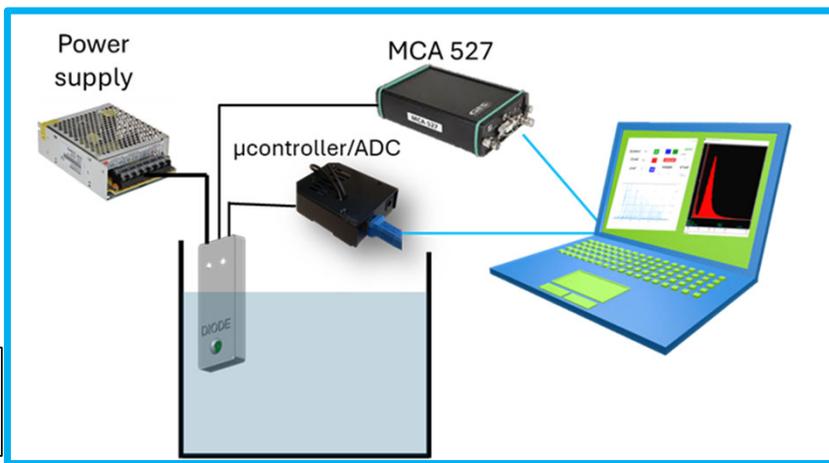
DIODE detectors

HV modules



❑ The DIODE detector is fully **waterproof** and suitable for use in water phantoms

❑ **Compact** and **portable** diamond-based detection system for dosimetry and microdosimetry in ion beam therapy



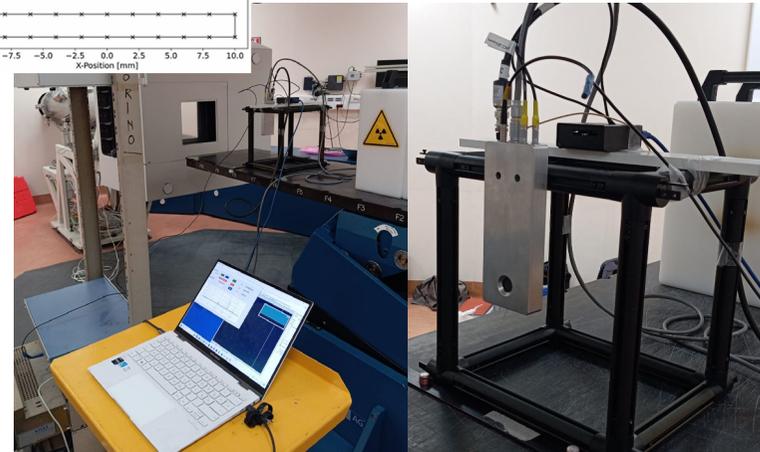
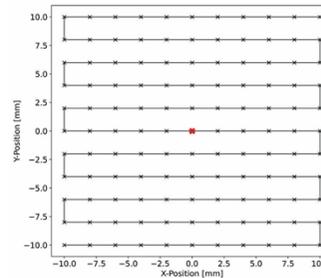
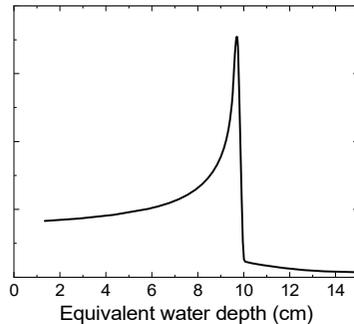
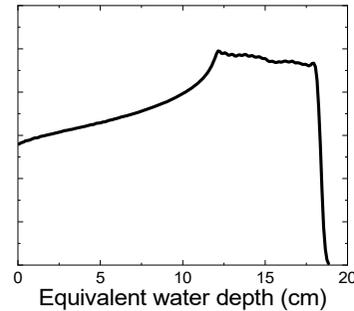
Test at CNAO

- ✓ Performance of the DIODE detector was evaluated at CNAO using protons and carbon ion beam.
- ✓ Dose and lineal energy distributions were measured simultaneously and at the same time at different water equivalent depths.



Proton beam: SOPB (16 energies)
Beam size: 4x4 cm²
Phantom: Solid water (RW3)
Particles per spill: $8 \cdot 10^8$ p/s

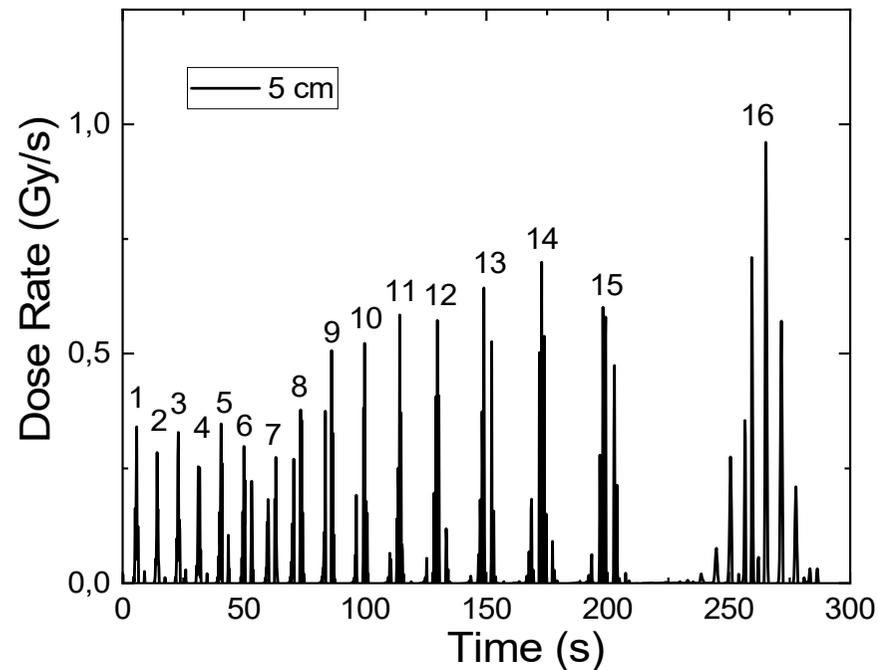
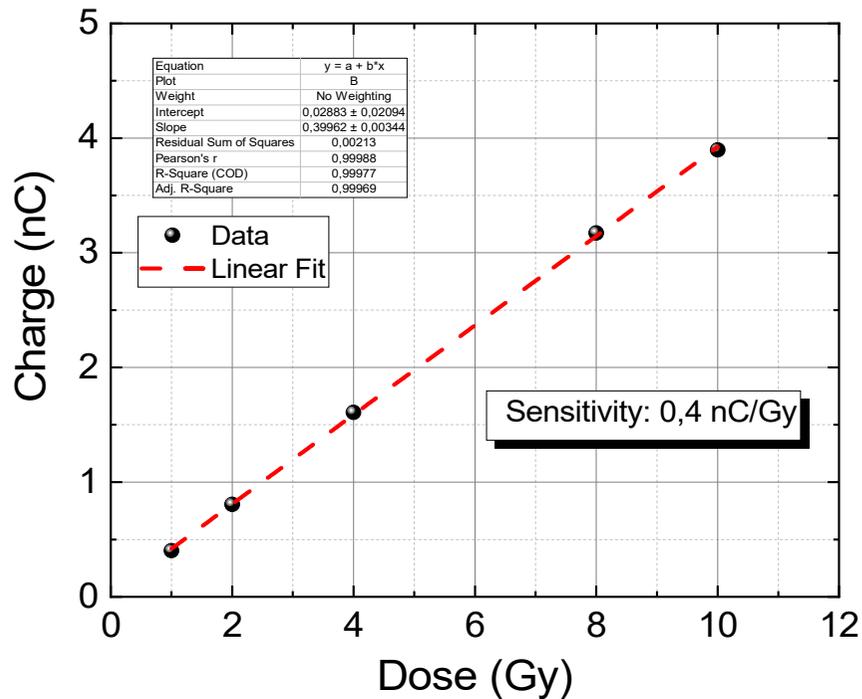
Carbon ion beam: 221.45 MeV/u
Beam size: 2x2 cm²
Phantom: Solid water (RW3)
Particles per spill: 10^7 p/s



Characterization of DIODE DETECTOR: Linearity and time response

- ❑ The detector shows a good linearity with the dose.
- ❑ The current curves recorded by the DIODE detector during irradiations at different water depths. The measured current exhibited a high signal-to-dark ratio.

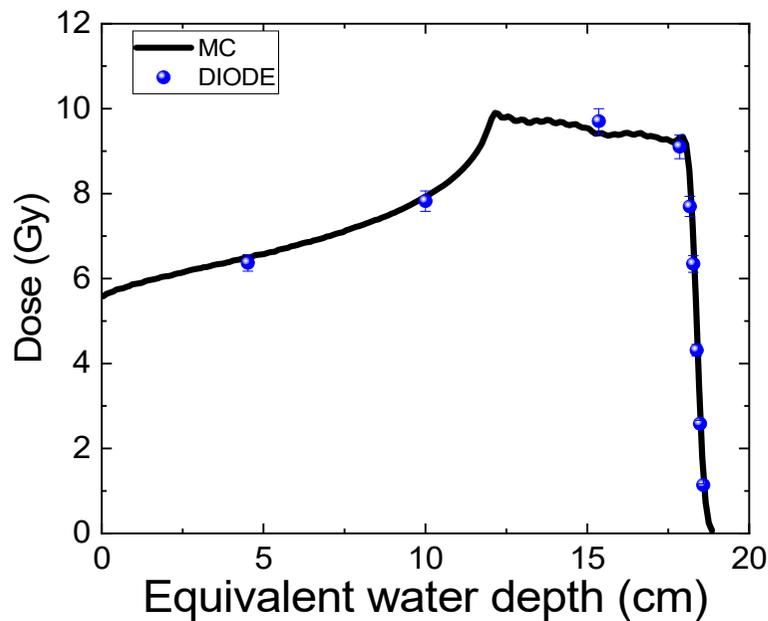
SOBP Protons



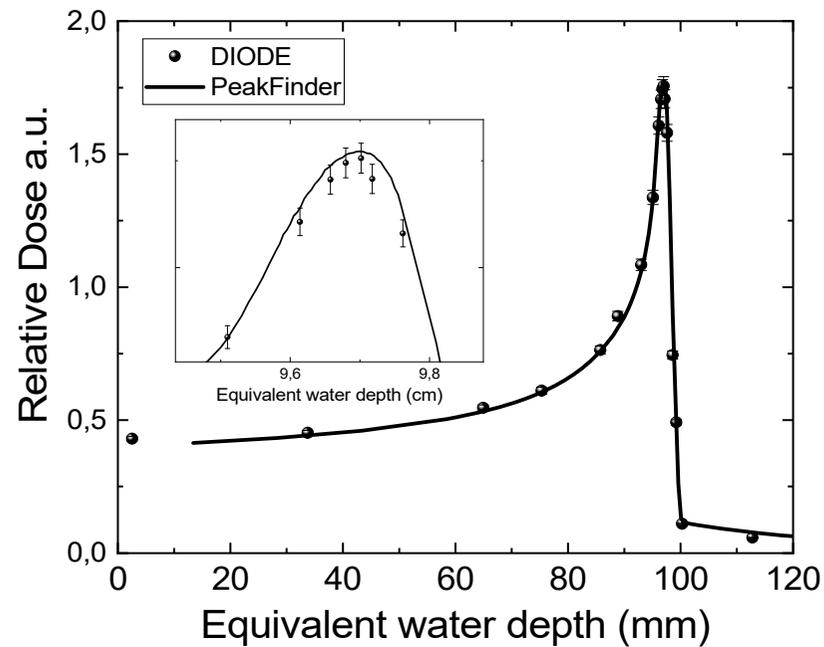
Characterization of DIODE DETECTOR: Dose Profiles

- Depth-dose profile curves measured with the DIODE detector.
- A reasonable agreement between the depth-dose curves obtained with DIODE and Peak finder as well as Monte Carlo simulation is observed.

SOBP Protons



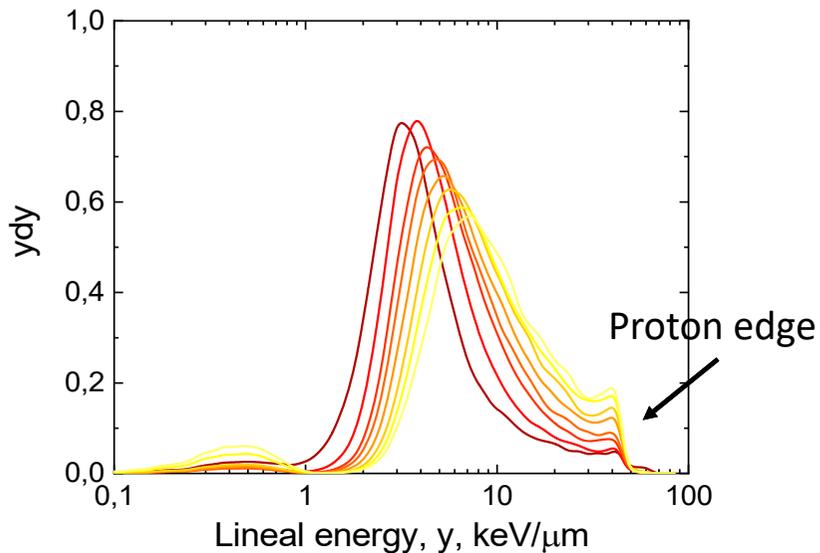
Carbon ions



Characterization of DIODE DETECTOR: Microdosimetric spectra

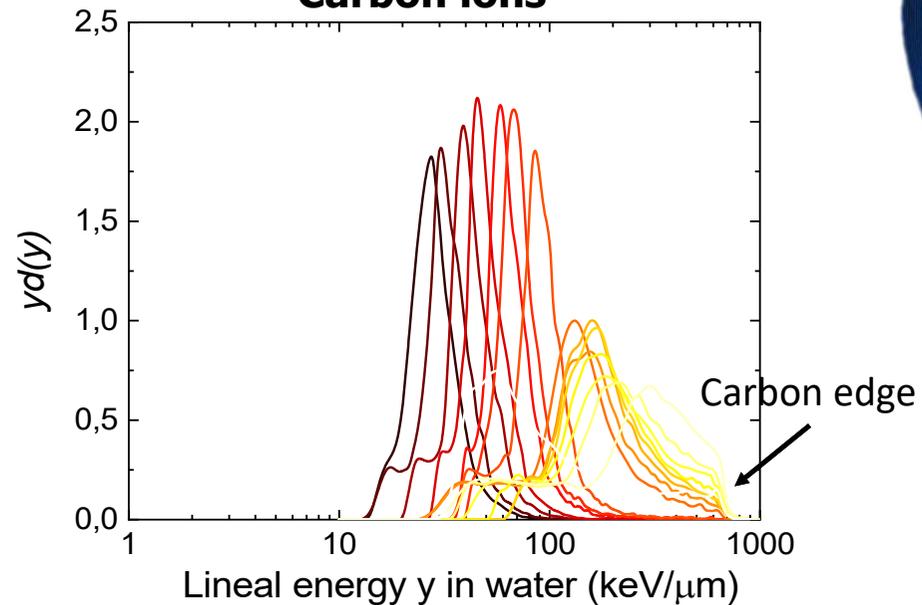
- Microdosimetric spectra were simultaneously measured with the DIODE detector
- The microdosimetric distributions shift towards higher lineal energy values with increasing depth in water and with increasing the LET of the particles.

SOBP Protons



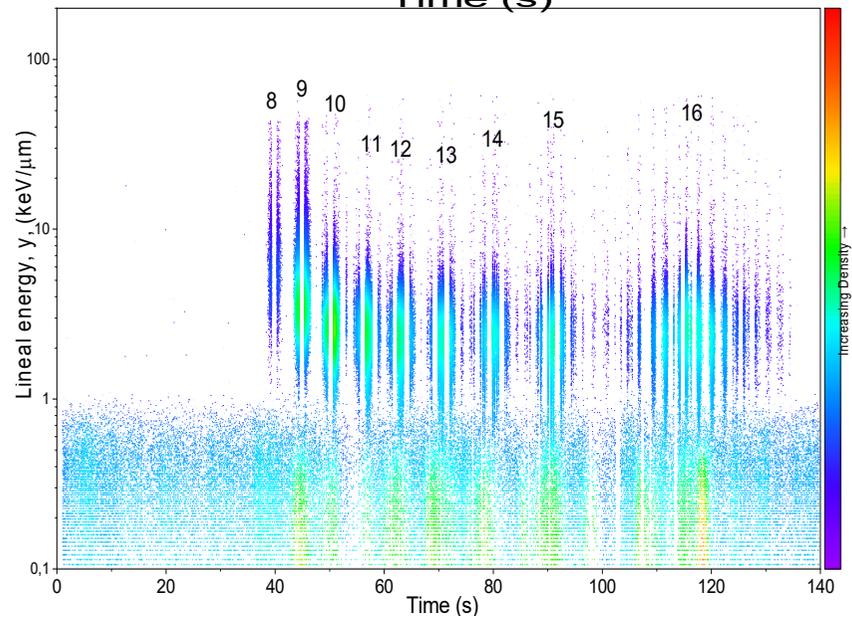
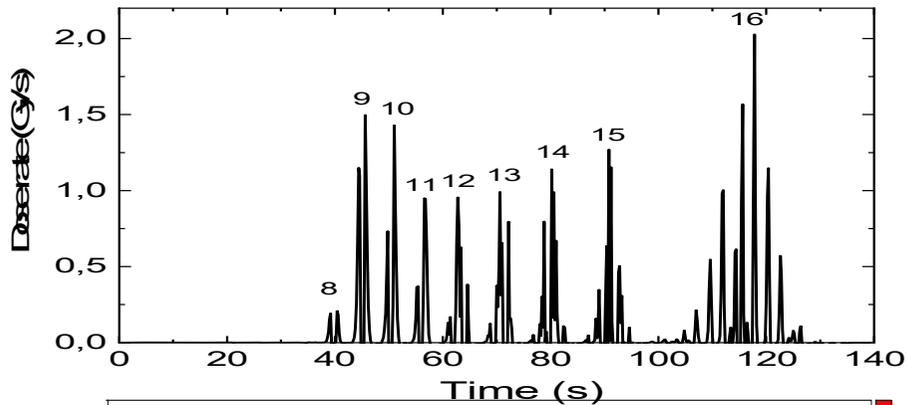
The maximum energy released by protons in 6.3 μ m of diamond is approximately 860 keV, which corresponds to a lineal energy in water of about 44 keV/ μ m.

Carbon ions

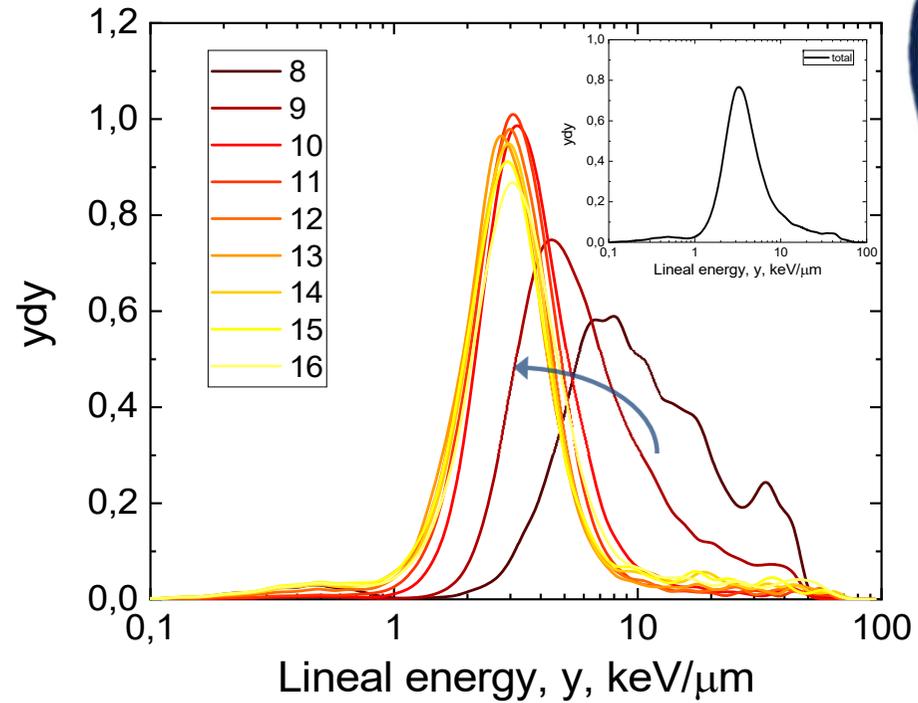


The maximum energy released by carbon ions in 4.7 μ m of diamond is approximately 10.5 MeV, which corresponds to a lineal energy in water of about 690 keV/ μ m.

Characterization of DIODE DETECTOR: Microdosimetric spectra resolved in time



SOBP Protons
Water depth: ~ 15 cm

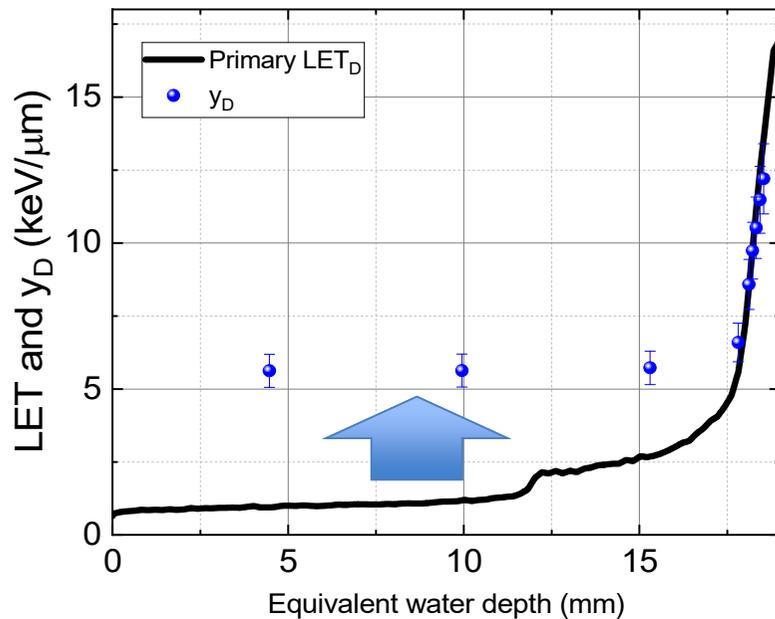


Characterization of DIODE DETECTOR: Dose mean lienal energy

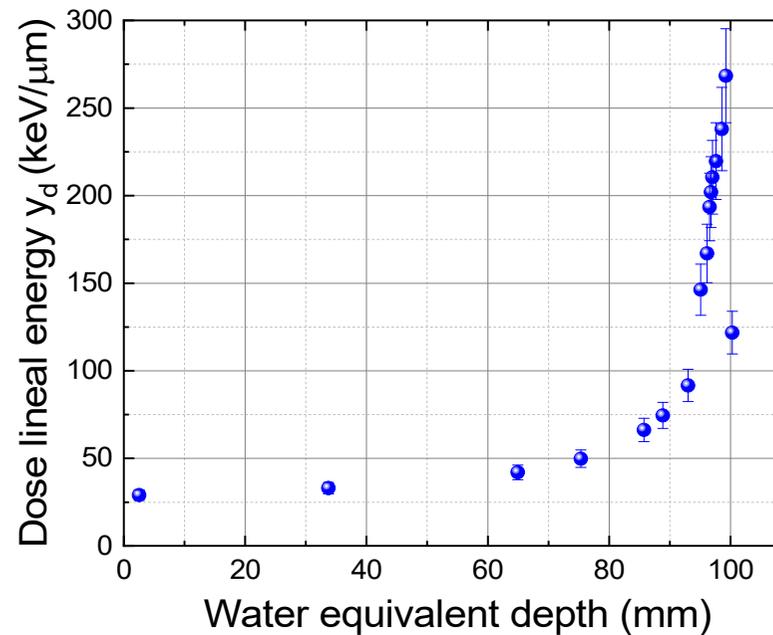
- Dose-mean lineal energy (from the microdosimetric spectra) values were measured at the same point and depth in water equivalent.
- μ Dos characterizes in the same position the stochastic fluctuations of energy deposition within micrometer scale, providing simultaneously detailed information on the LET dose of the radiation field.

$$\bar{y}_D = \int_{y_{min}}^{\infty} y d(y) dy$$

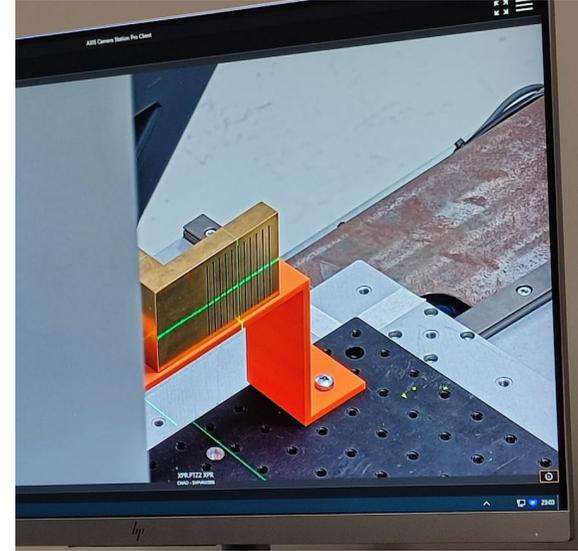
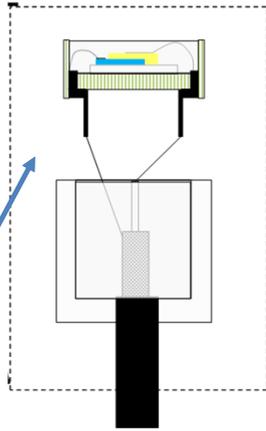
SOBP Protons



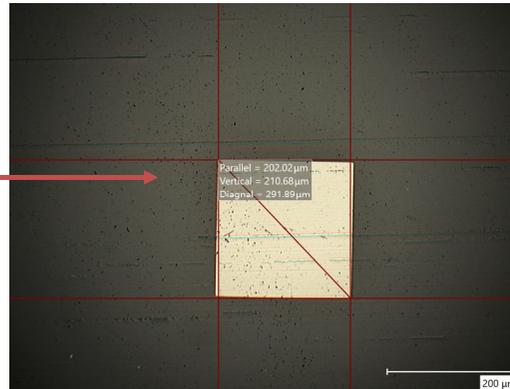
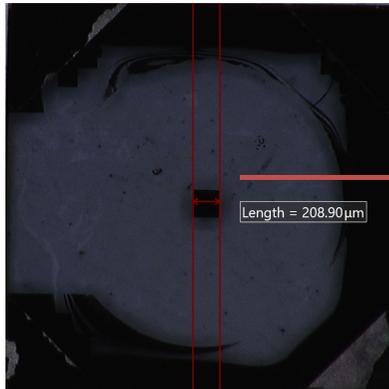
Carbon ions



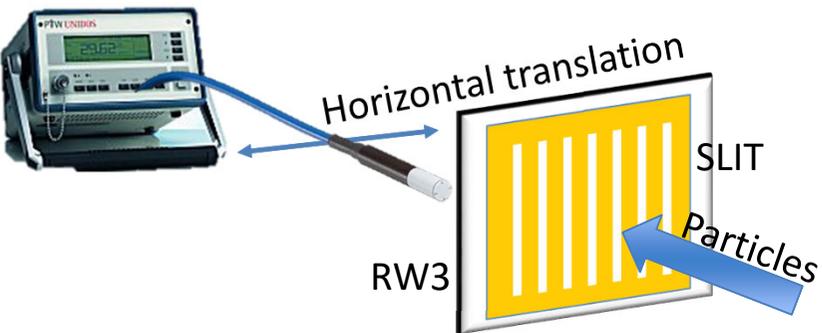
Diamond dosimeter for characterization of minibeam



Sensitive Thickness: $2 \mu\text{m}$
Sensitive Area: $\sim 200 \times 200 \mu\text{m}^2$



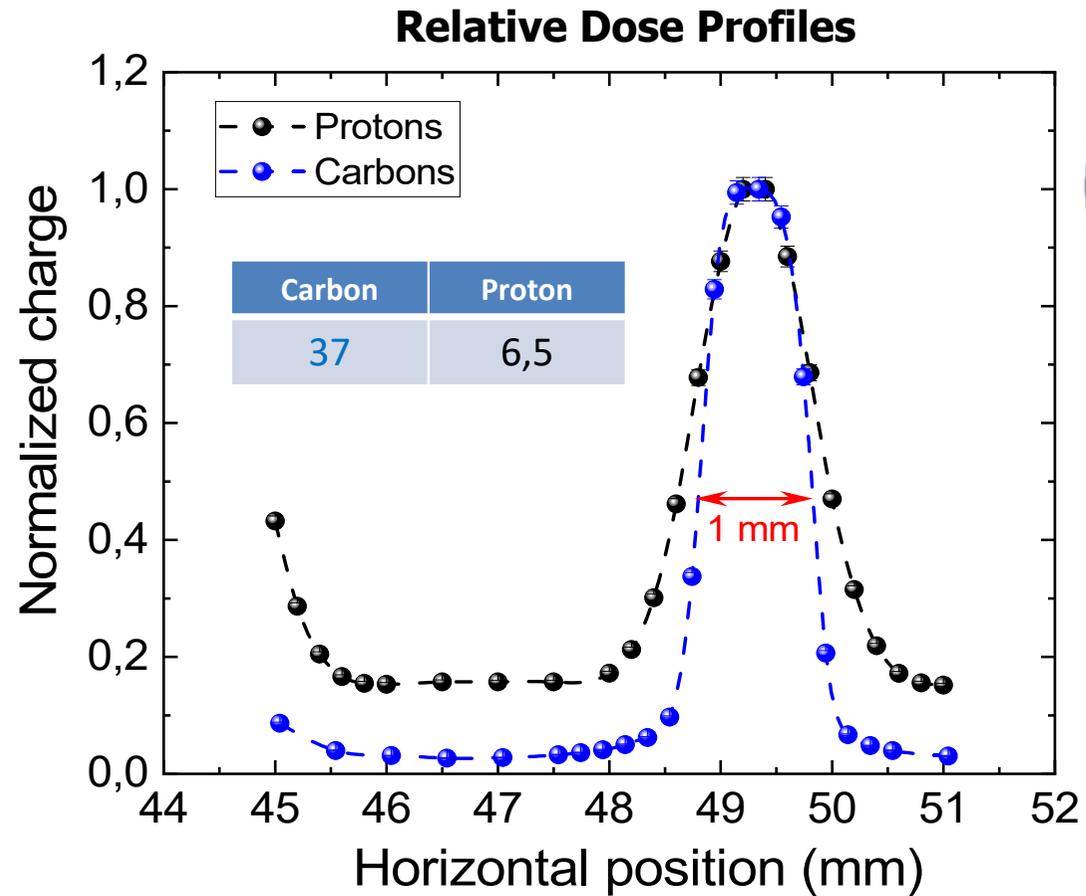
First measurements with proton and carbon minibeam



Proton beam: 62 mm
Particles: $6 \cdot 10^8$ p/spot

Carbon beam: 62 mm
Particles: $1.4 \cdot 10^7$ p/spot

Beam size: 5×5 cm²
Phantom: Solid water (RW3)



Conclusions



- ✓ Synthetic single crystal diamond-based dosimeters and microdosimeters were fabricated in boron doped/intrinsic diamond/Schottky metal diode configuration in the same substrate combining photolithography processes and CVD diamond deposition.
- ✓ Dosimetric and microdosimetric characterization of clinical proton and carbon-ion beams were successfully performed at CNAO. The experimental results showed that these detectors can be suitable tools for the characterization of radiation quality of clinical ion beams.
- ✓ A first prototype of diamond dosimeter with μSV was also developed for characterization of proton and carbon minibeam.
- ✓ Preliminary measurements show promising results.

