The role of Montecarlo simulations in the characterization of diamond detectors for hadrontherapy

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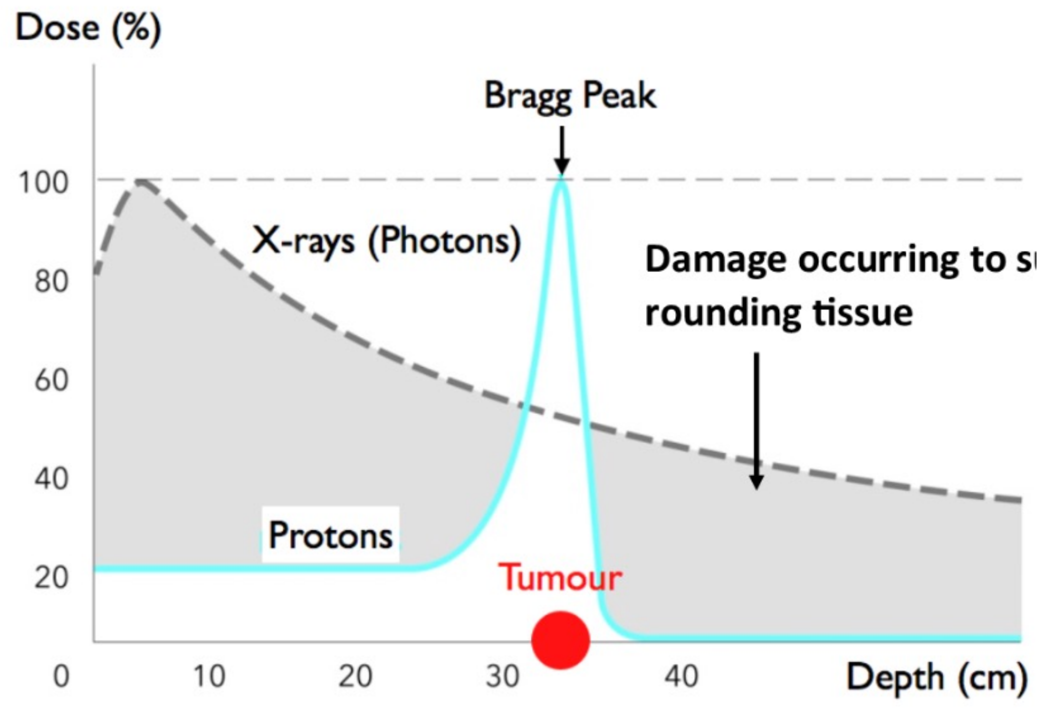
Introduction

Ionizing radiations -> kill malignant cells and treat different types of tumor

Hadrontherapy
- high energy ion beams
- higher ballistic capability of the delivered dose
- higher biological efficacy (RBE>1)

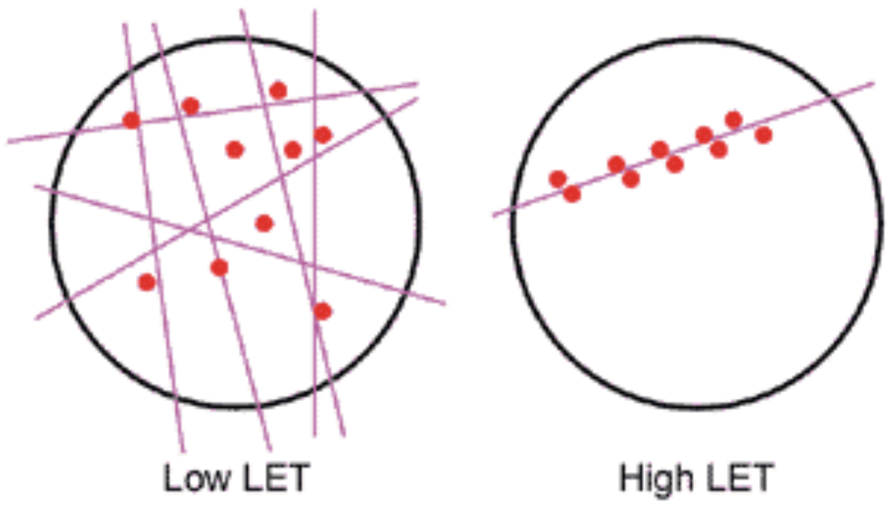


Common aim: Decrease the absorbed dose to healthy tissue without compromising the prescribed target coverage

Introduction

Absorbed dose to water → physical quantity routinary used for clinical prescription

→ can be measured by commercial dosimeters



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Dosimetry shows strong limitations with high LET particles

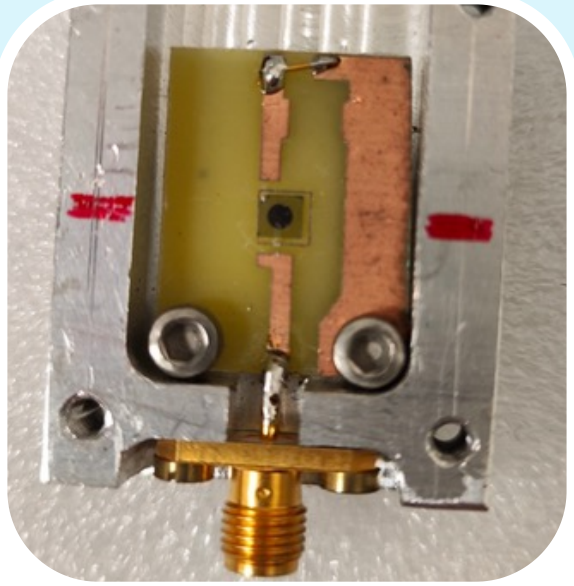
Microdosimetry takes into accounts stochastic nature of particle interaction with matter

Introduction

Practical problem: radiobiological measurements are costly and time consuming

Dosimeter

Only dosimetric system are routinely adopted for treatment plan verification and quality assurance purposes



Microdosimeter

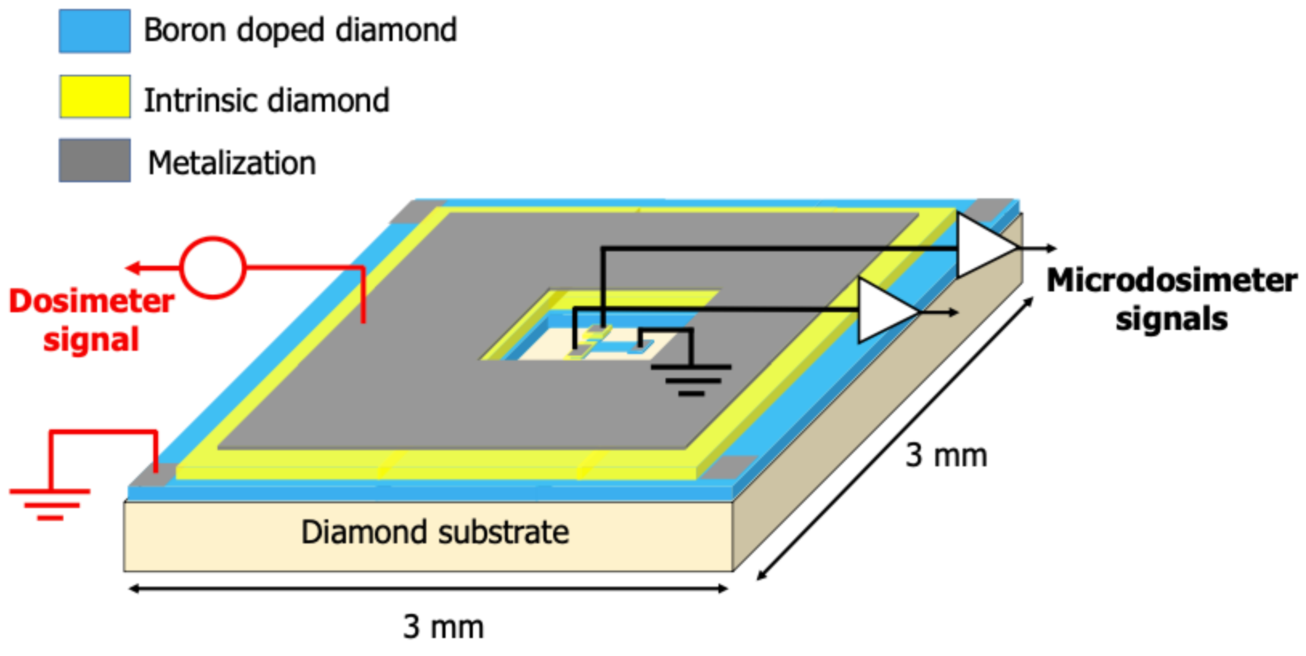
Several issues TEPCs clinical practice

- Sustainable beam current
- Physical size detector
- High operation voltages

<u>No practical and easy-to-use detector is available</u>

DIODE (Diamond Integrated devices fOr haDrontherapy) project

Development and test of a novel detection system based on synthetic single crystal diamond able to simultaneously perform dosimetric and microdosimetric characterization of clinical hadron beams



Fast and exhaustive beam characterization

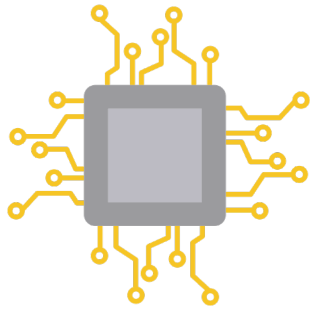
Reduction of the experimental uncertainties (detector positioning)

Small error in detector positioning -> wrong evaluation LET -> wrong evaluation of RBE

Objectives

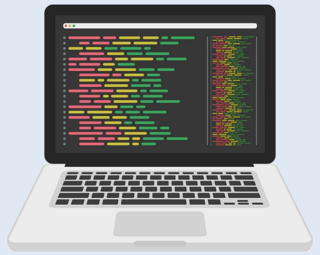
Diamond detectors

Development of novel diamond technology methods to realize different monolithic devices



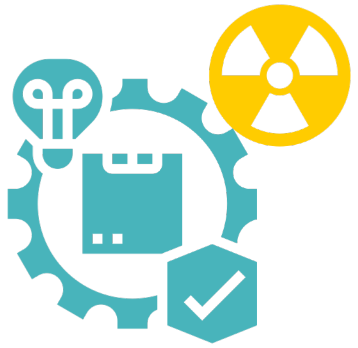
Front-end Electronic

Development of a dedicated and optimized electronic readout to be connected as close as possible to diamond devices



Monte Carlo simulations

- Reproduce the effect of radiation passage inside detector
- Estimate the system capability to reproduce single particle energy-deposited spectrum
- Calculate dosimetric and radiobiological quantities of interest

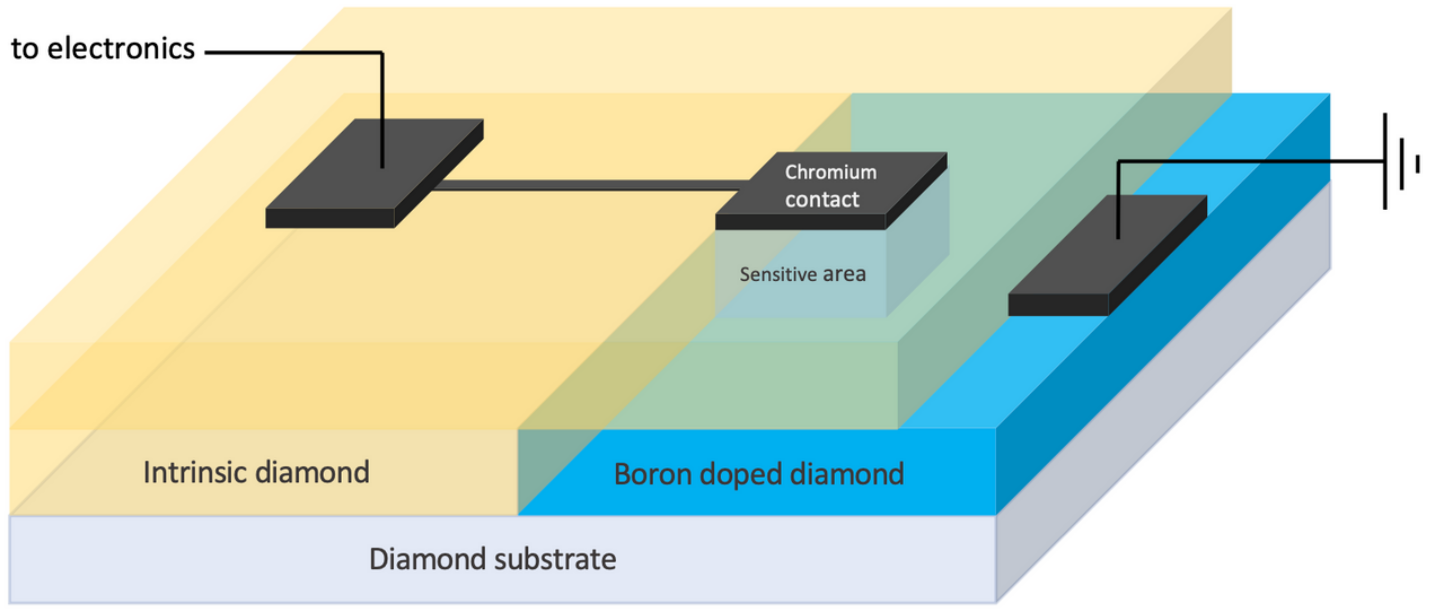


Test vehicle and prototype characterization

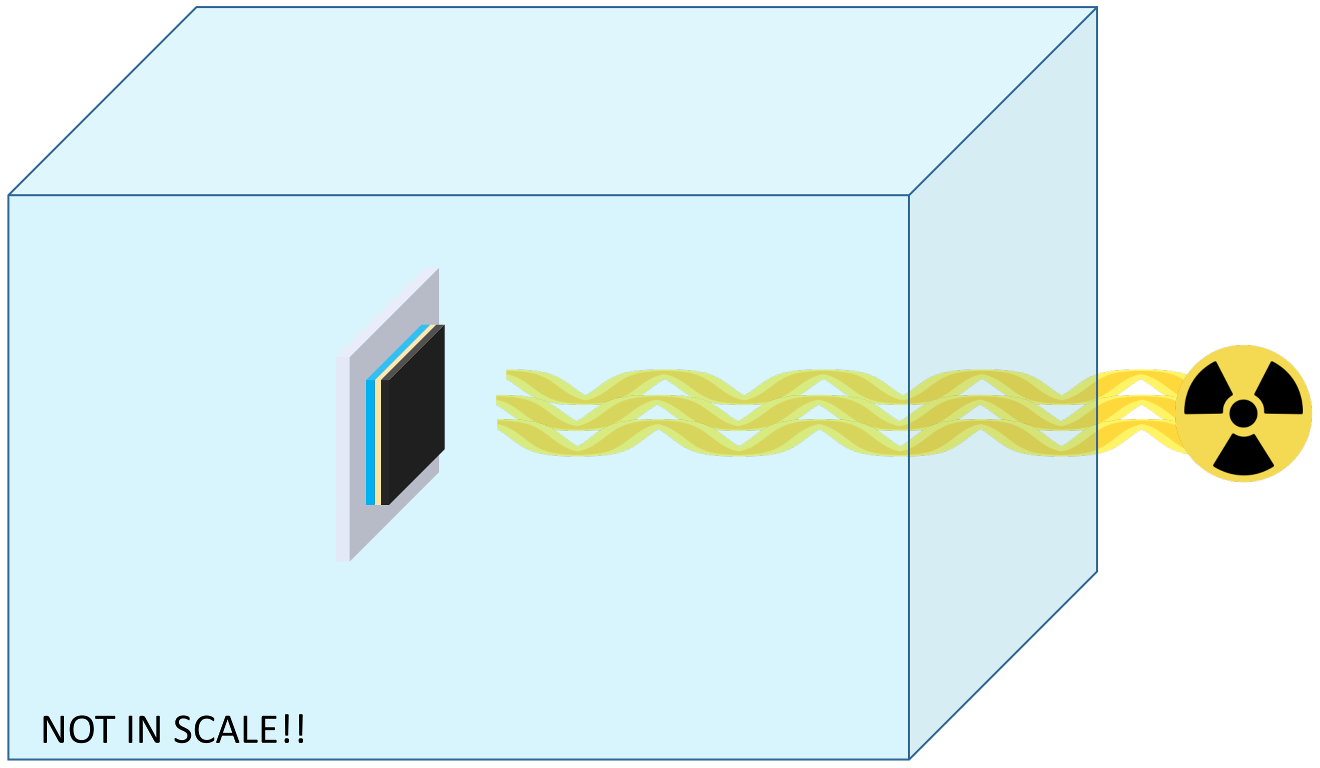
Realization and test of a novel, practical and compact detection system

Monte Carlo simulations

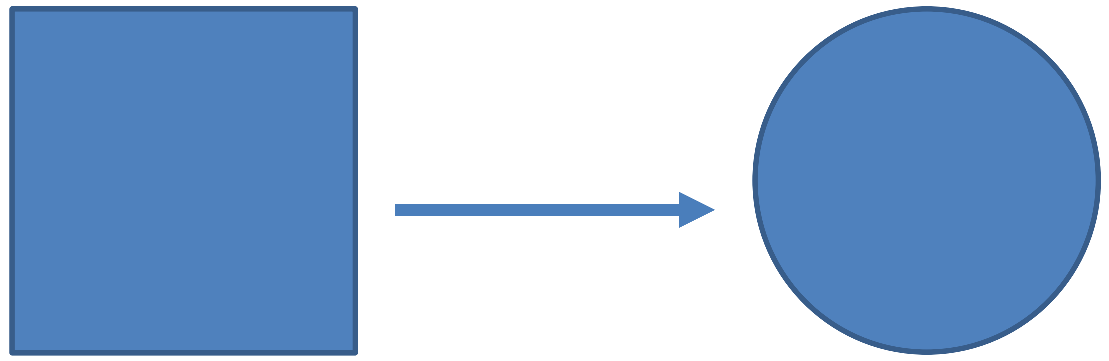
Geant4 Monte Carlo simulation toolkit to support detector design



Real microdosimeter



Simulation model



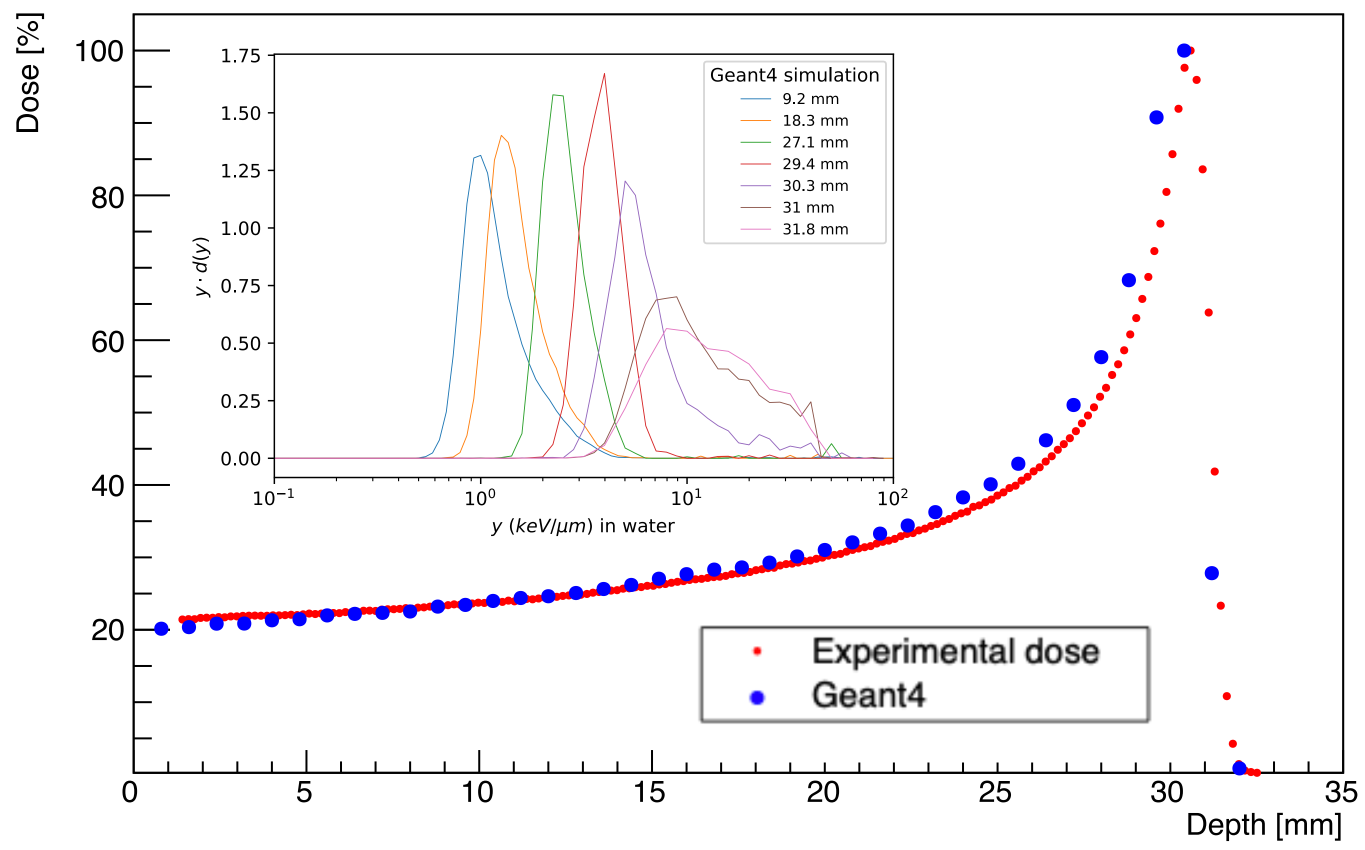
Square shape

Circular shape

Test simulation model

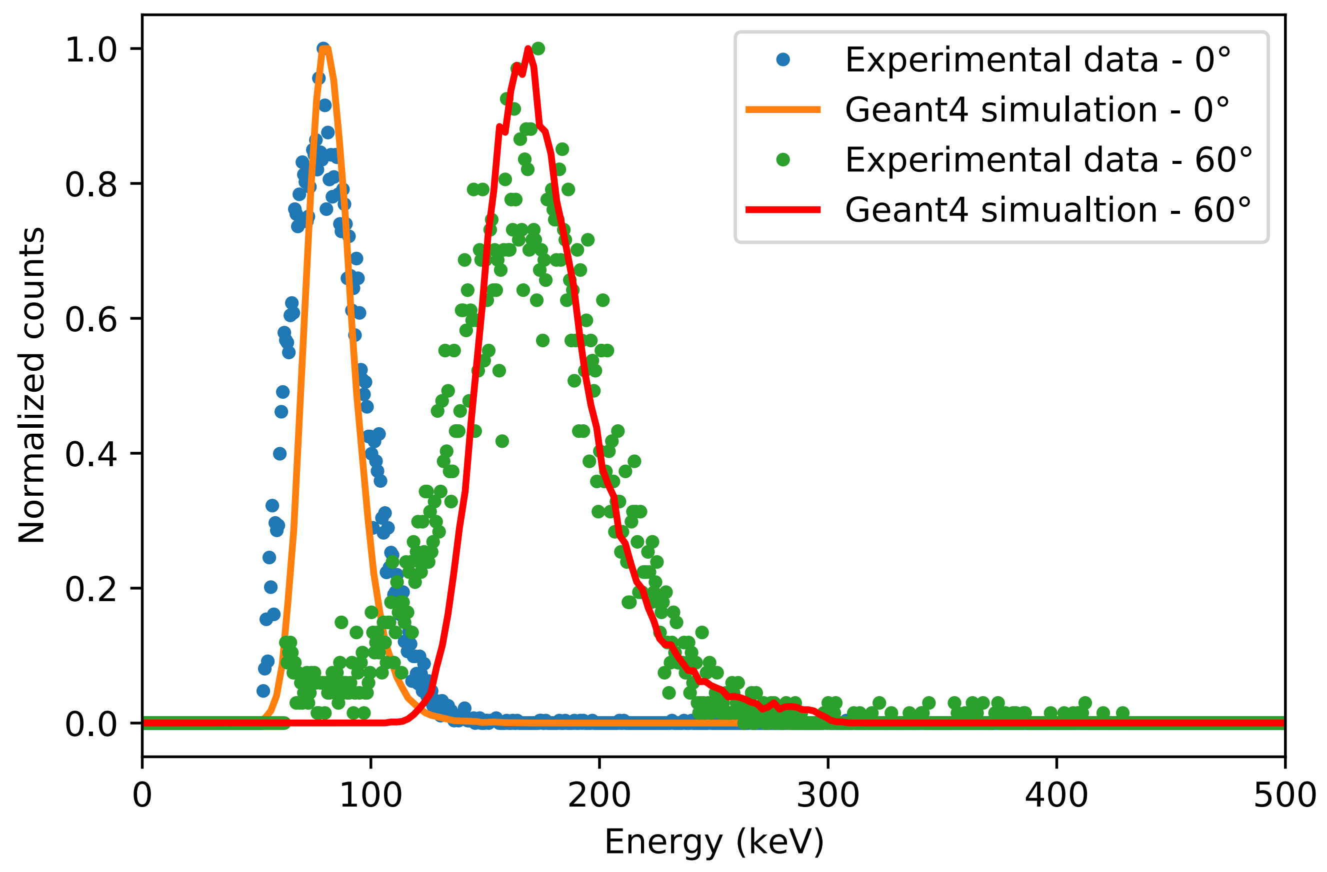
62 MeV CATANA therapeutic proton beam in water

DOI: 10.1002/mp.14466



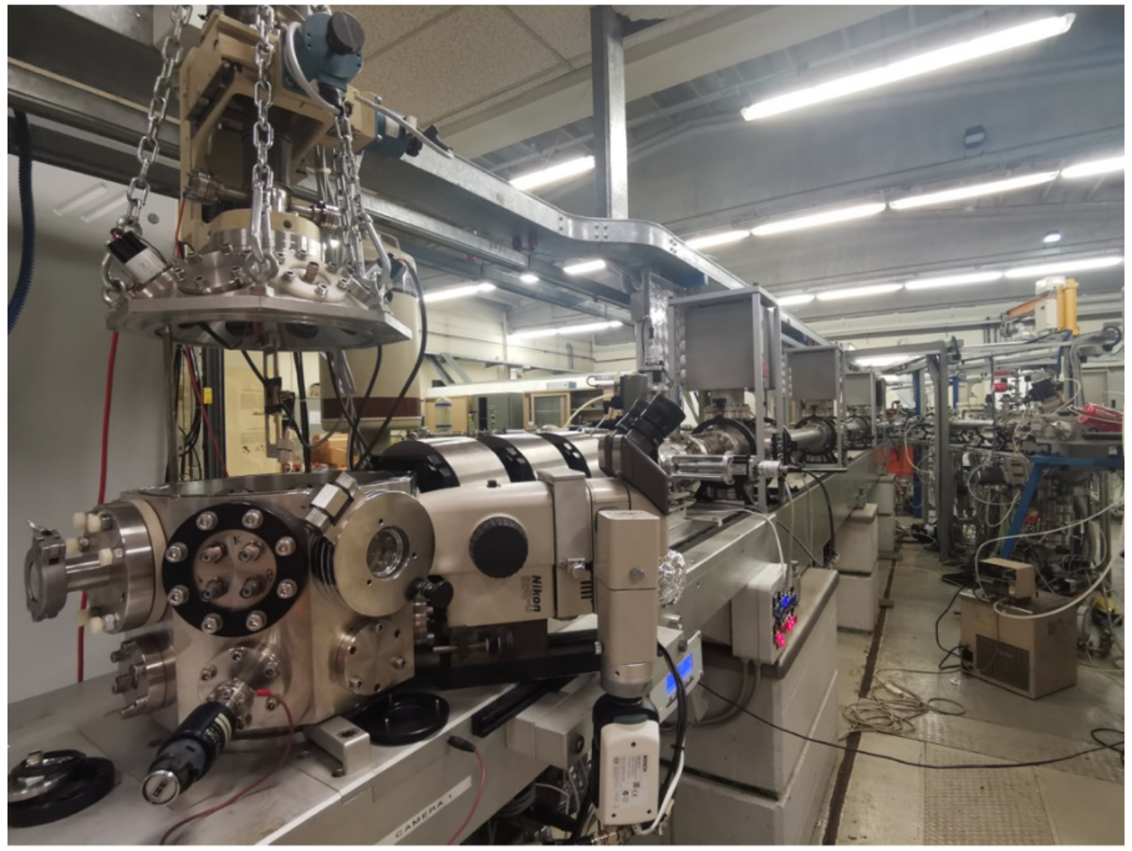
600 keV protons Ruder Boskovic institute (RBI) ion microprobe facility in vacuum

DOI: 10.1016/j.radmeas.2018.02.001



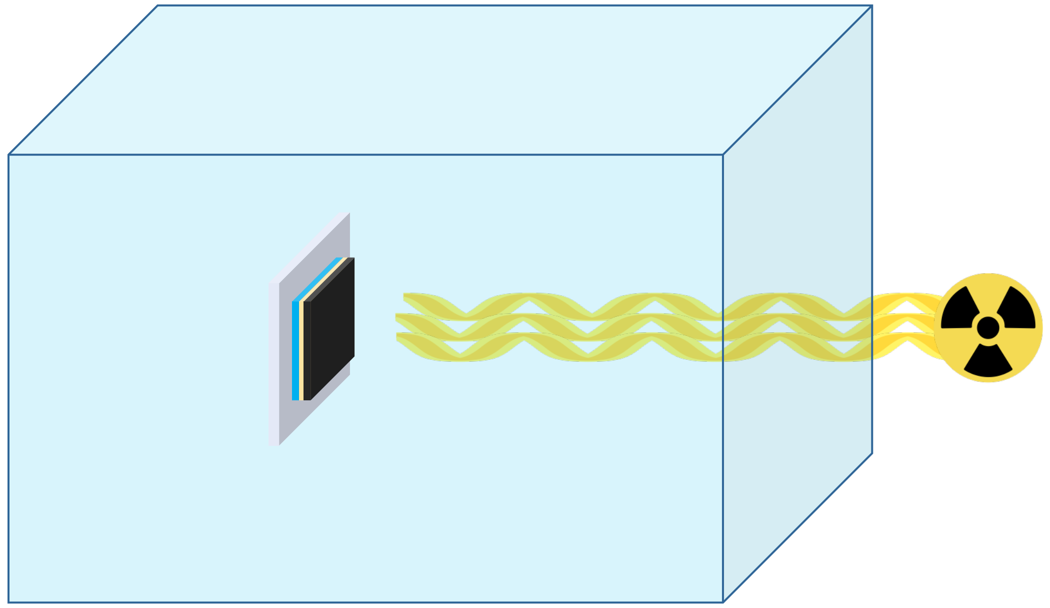
Overview

Experimental measurements



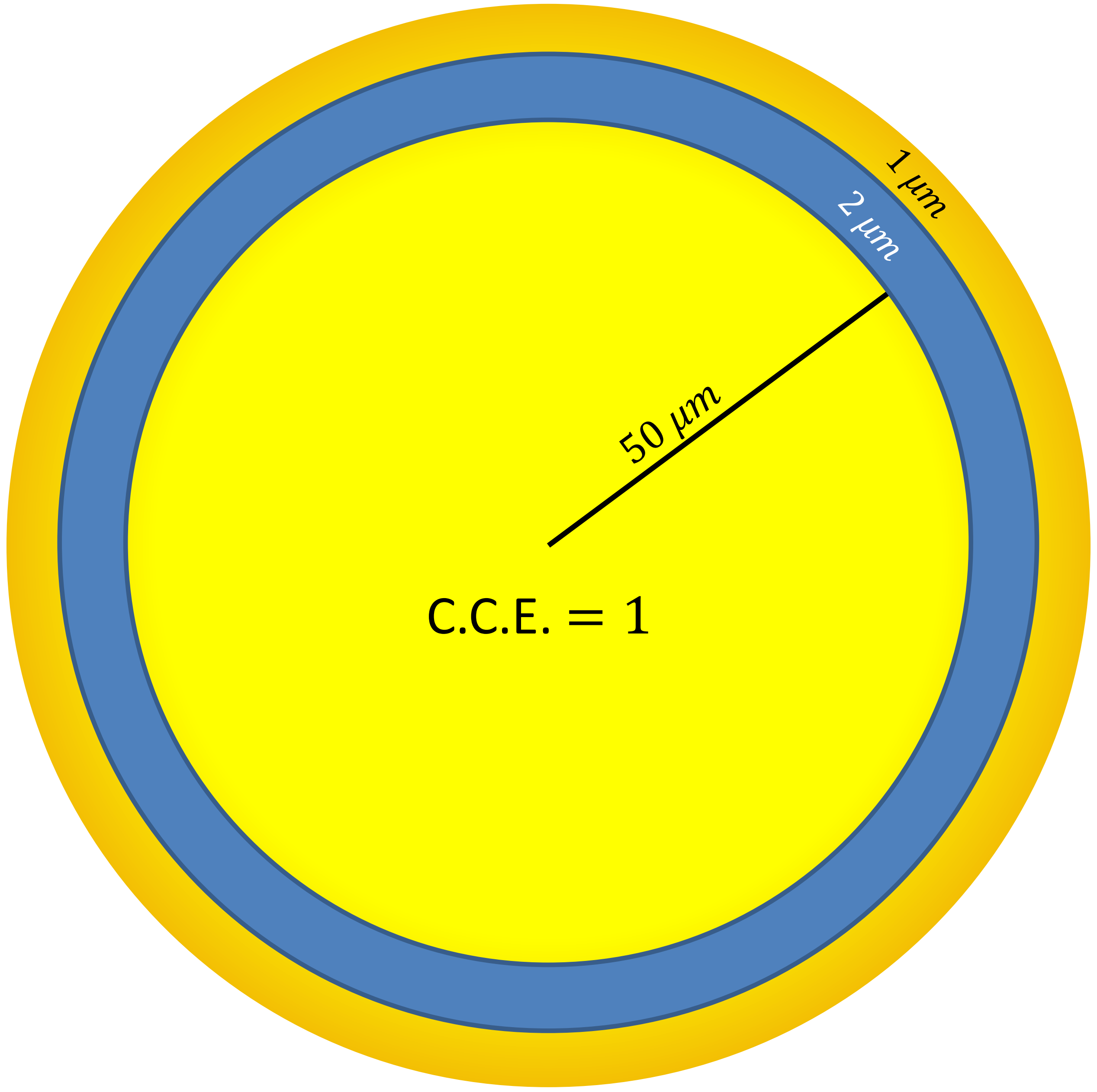
- AN200 INFN – Legnaro
- 1 MeV ^{1}H in vacuum
- Ion Beam Induced Charge (IBIC) maps

Geant4 simulation



- 1 MeV ^{1}H with 0.03 MeV energy spread
- Thickness of sensitive volume = 4.4 um
- QGSP_BIC_HP(G4EmStandardPhysics_option4)

Offline analysis



Diamond sensitive area

Simulation outputs:

- X , Y positions;
- Energy deposited in the sensitive volume.

Evaluation of Charge Collection Efficiency (C.C.E.) :

- IBIC maps
  - Steep reduction of charge collection as the beam exits the active volume, following the decrease of electric fields;
  - Particles that cross active volume within 3 um outside border can contribute to detectable signal.

C.C.E. = 1 $0\ um < r < 50\ um$

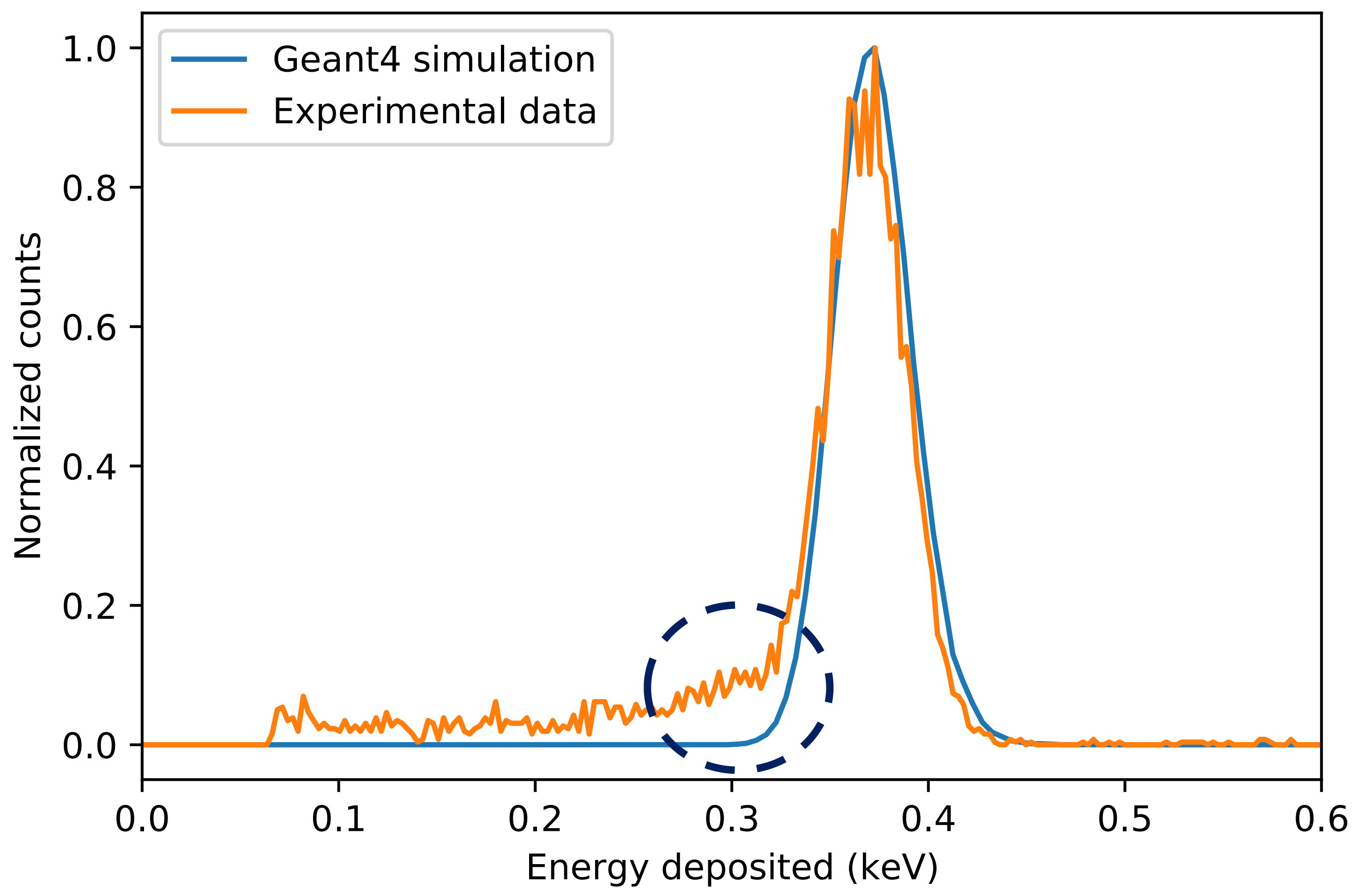
C.C.E. ~ 0.8 $50\ um < r < 52\ um$

C.C.E. < 0.8 $52\ um < r < 53\ um$

Offline analysis

C.C.E. = 1 $0\ um < r < 50\ um$

without edge effects

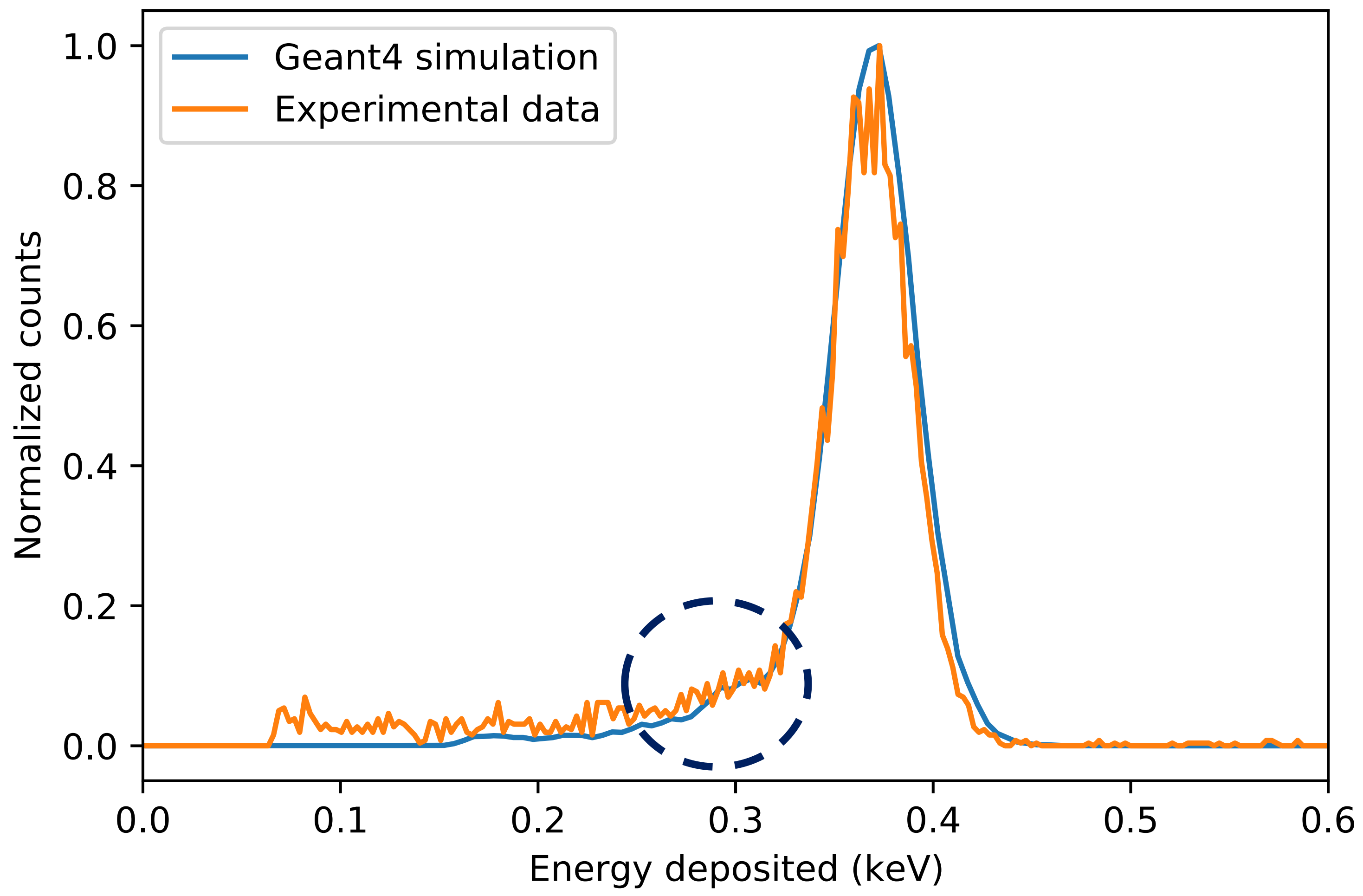


C.C.E. = 1 $0\ um < r < 50\ um$

\+ **edge effects**

C.C.E. ~ 0.8 $50\ um < r < 52\ um$

C.C.E. < 0.8 $52\ um < r < 53\ um$



Summary and outlook

- Monte Carlo simulations is performed using Geant4 Monte Carlo simulation toolkit to support detector design;
- In the preliminary assessment of C.C.E of microdosimeters, good agreement is observed between experimental data and simulations;
- A further optimization of the integrated device will be possible thanks to the design of new photolithography mask;
- The performance of the final prototype will be evaluated at CNAO & TIFPA facilities.

Thank you for your attention!

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