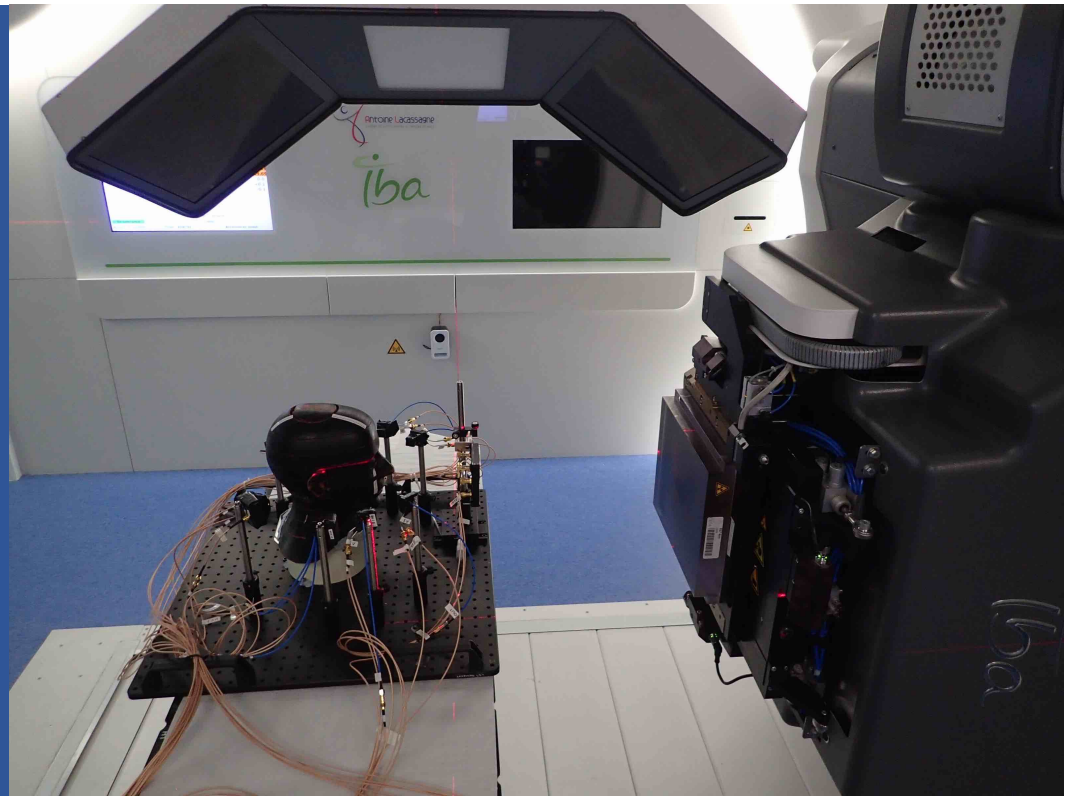
PGTI

Prompt Gamma Time Imaging: a new medical imaging technique for real-time monitoring of proton therapy treatments



Sara Marcatili

LPSC - Laboratory of Subatomic Physics and Cosmology

LPSC GRENOBLE | MODANE

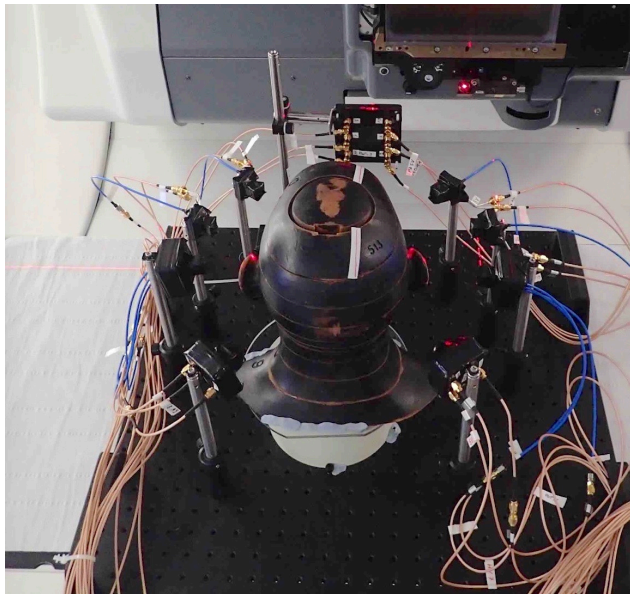
Antoine Lacassagne CENTRE DE LUTTE CONTRE LE CANCER unicancer NICE

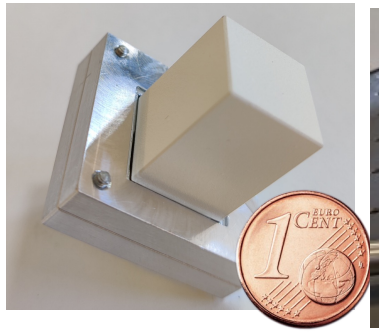
TOR VERGATA UNIVERSITÀ DEGLI STUDI DI ROMA

CENTRE DE PHYSIQUE DES PARTICULES DE MARSEILLE CPPM

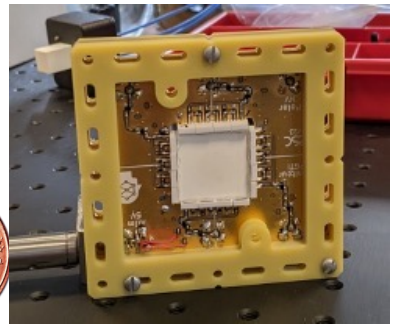
Objectifs et defis scientifiques

Axis 1. Detector development

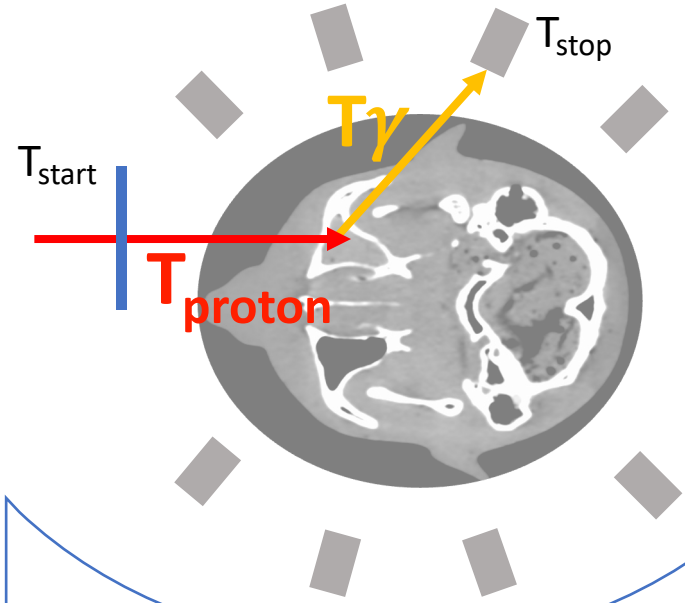




Gamma module based on Cherenkov radiators



Fast beam monitor



Objectives

- ✓ Range monitoring
- ✓ Detection of anatomical changes
- • Dose reconstruction (AI-based)

Operating configurations

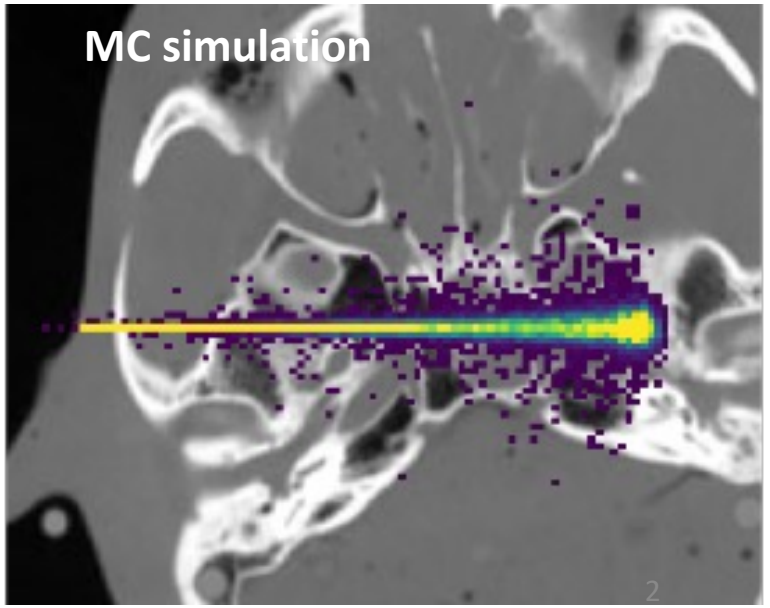
- ✓ Protons/carbon ions
- ✓ S2C2, synchrotrons and cyclotrons
- ✓ Low Intensity (patient positioning)
- • Clinical intensity => current work

Axis2. Data reconstruction

From Time-of-Flight measurement to dose distributions

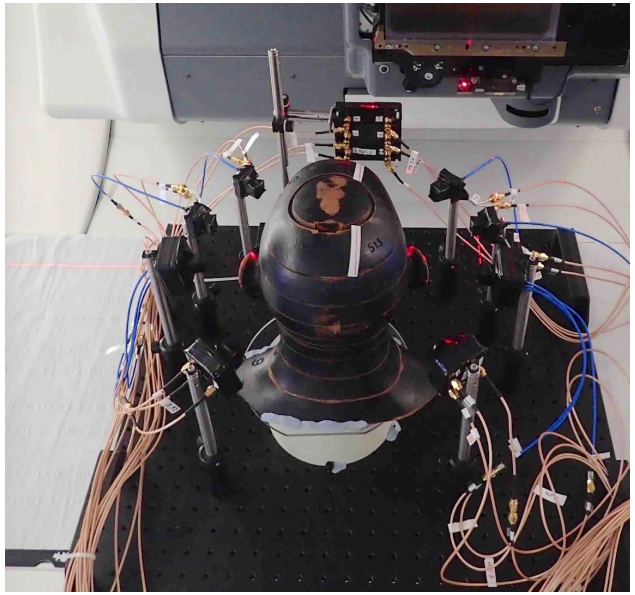
$$TOF = t_{stop} - t_{start} =$$

$$= T_{proton}(\mathbf{r}_v, \mathbf{v_p}) + T_\gamma(\mathbf{r}_v, \mathbf{r}_d)$$



Fait marquant: Going beyond range monitoring with PGTI

8-channels TIARA prototype

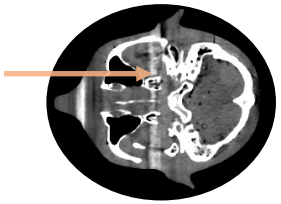


The PG vertex distribution (r_v) is reconstructed from the 8 TOF histograms solving the inverse problem:

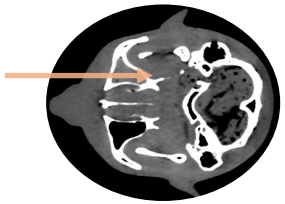
$$TOF = t_{stop} - t_{start} =$$

$$= T_{proton}(\mathbf{r}_v, \mathbf{v_p}) + T_\gamma(\mathbf{r}_v, \mathbf{r}_d)$$

Example (experiment at P1, CAL)

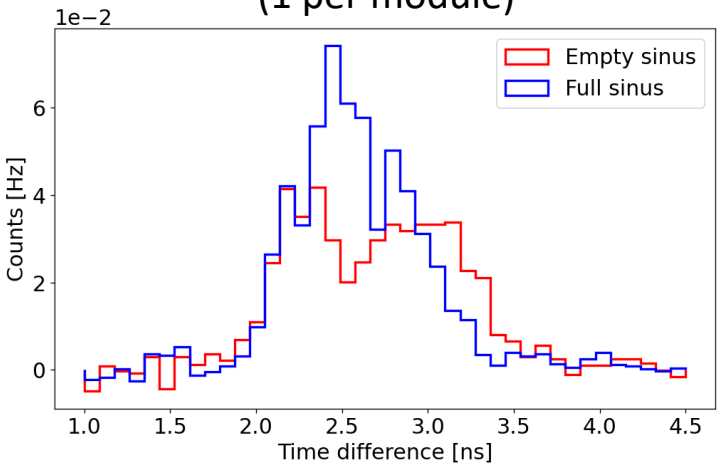


Exp. 1. (Treatment planning)
the sinus is empty

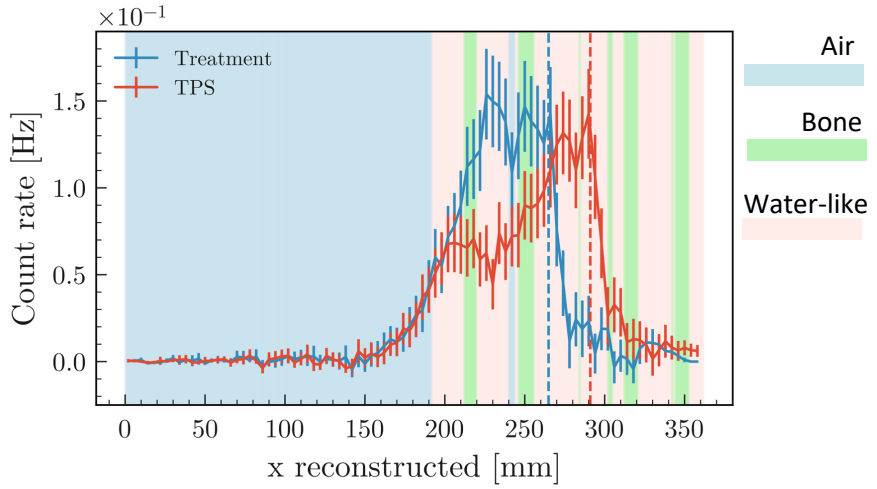


Exp 2. (Treatment)
the sinus is filled

× 8 TOF distributions acquired (1 per module)

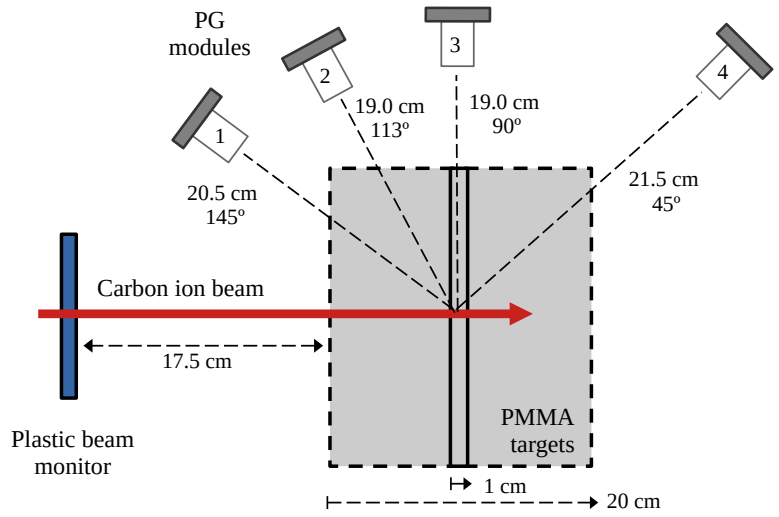


The reconstructed PG vertex distribution allows the identification of anatomical changes from treatment planning to delivery. Patient's tissues in treatment configuration are shown as background colours.

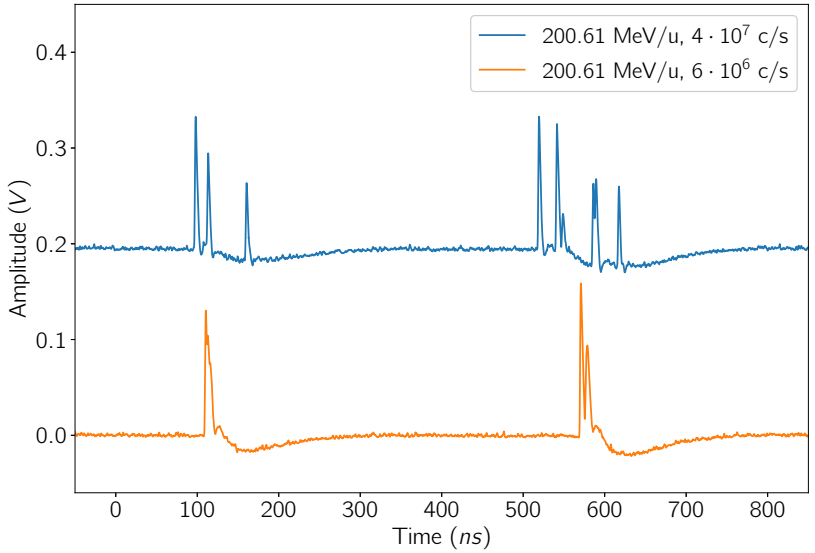


Range shift: Actual = 27 ± 1 mm Measured = 26 ± 4 mm

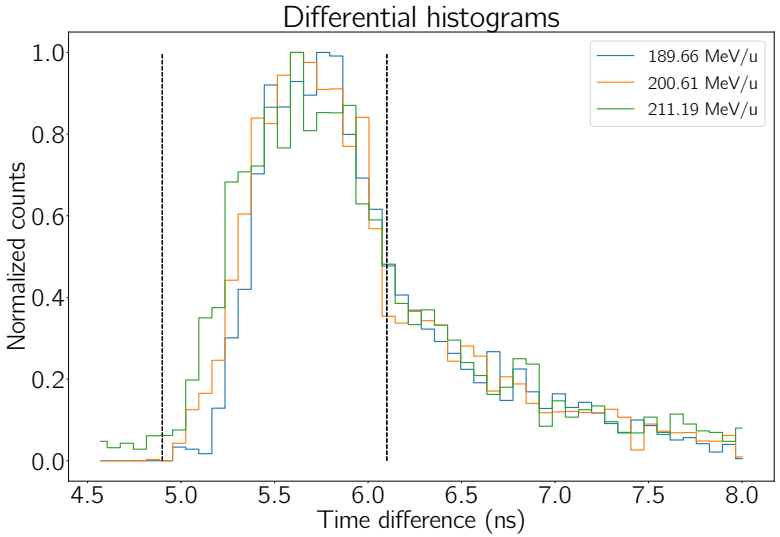
Fait marquant: TIARA for carbon therapy



Hodoscope response to different intensities



Measurement of range accuracy



Beam energy was varied to produce progressive range shifts of ~3.5 mm in PMMA.

Clinical spots	Number of ions	N_{PG} (Counts)	$R_{acc,2\sigma}$ (mm)	
			$2 \cdot 10^6$ ions/s	$2 \cdot 10^7$ ions/s
1	$2.4 \cdot 10^6$	1400	5.07 ± 0.30	9.30 ± 0.70
2	$4.8 \cdot 10^6$	2800	3.40 ± 0.22	6.64 ± 0.50
4	$9.6 \cdot 10^6$	5600	2.47 ± 0.15	4.74 ± 0.36

M. Pinson et al. Under review in Scientific Report (https://arxiv.org/abs/2602.18318)

Structure du projet

Responsabilité scientifique
S. Marcatili (LPSC)

Responsabilité technique
C. Hoarau (LPSC)

WP1: Detector development
S. Marcatili (LPSC)

- ✓ Block detector développent
- TIARA construction

WP2: Data reconstruction
Y. Boursier (CPPM)
N. Toschi (Uni Roma)

- Analytical reconstruction (1D)
- ML-based reconstruction (3D)
- Restrospective clinical study

WP3: Detector commissioning & test
D. Maneval (CAL)

- ✓ Protons at low intensities
- Protons at clinical intensities
- ✓ Carbon ions

Current team

LPSC
S. Marcatili (CR)
M-L. Gallin Martel (DR)
C.Hoarau (IR)
J-F. Muraz (IR)
G. Fanciulli (PhD)
P. Kavrigin (Postdoc)

CPPM
Y. Boursier (McF)
C. Morel (Prof.)
M. Dupont (IR)
C. Abid (Postdoc)

CAL
D. Maneval (Med. Phys.)

Roma Tor Vergata University
N. Toschi (Prof.)
D. Psarras

Irradiation platforms

CAL, CNAO

Vision 2030

Axis 1. Detector development

- Dedicated DAQ based on digital TDC under development at SE
- Mechanical support is being conceived at SDI
- Assembly of the remaining 20 modules in the next month at SDI

Axis2. Data reconstruction

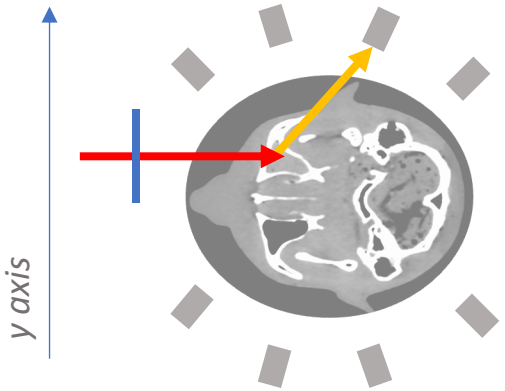
1. Classifier-based 1D reconstruction for tissue identification along the beam path
2. AI based 3D reconstruction for dose maps
3. Analytical reconstruction (CPPM)

Patient's image database from CAL available

Experiments

- Performances for protons at clinical intensity (dedicated test at CAL in April 2026).
- Clinical Intensity already validated for carbon ions.

Nouvelles collaborations: determination of lateral beam displacement with COG

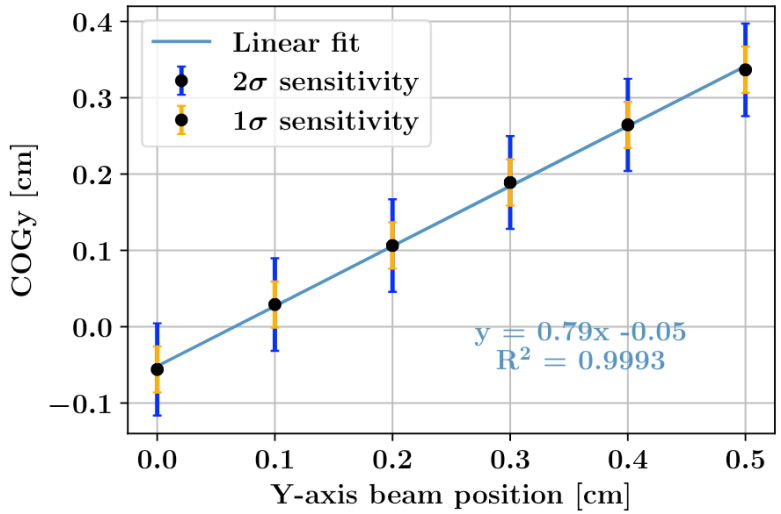


$$Y_{COG} = \frac{1}{N}\sum_{i=1}^{N_{Det}} y_i n_i$$

N = total number of PG detected
n_i = number of PG detected in module $_i$
Y_i = x coordinated of gamma detector

SIMULATION

10^8 protons / ~30000 PGs



Jacquet et al. Phys. Med. Biol. 66 (2021) 135003

Possible to distinguish a lateral beam displacement of **2 mm (2σ) at PB scale**

Stage M2: Elena Lopez-Miguelez

- MC simulation of RANDO phantom experiment in GATE
- Validation against experimental data

Perspectives

- Use of vpgTLE algorithm
- Further development of COG algorithm

AaP en cours et visés (2-5 ans)

2022-2028 - ERC Starting Grant

PGTI: a novel technique for the real time monitoring of hadrontherapy

Besoins 2027