Fast Prompt Gamma detection system based on Cherenkov radiator

A. André[1], M. Pinson[1], C. Hoarau[1], Y. Boursier[2], A. Cherni[2], M. Dupont[2], M.-L. Gallin Martel[1], A. Garnier[2], J. Hérault[3], J.-P. Hofverberg[3], P. Kavrigin[1], D. Maneval[3], C. Morel[2], J.-F. Muraz[1] and S. Marcatili[1]

1. LPSC and Grenoble-Alpes University, Grenoble, France
2. CPPM and Aix-Marseille University, Marseille, France
3. Centre Antoine Lacassagne, Nice, France

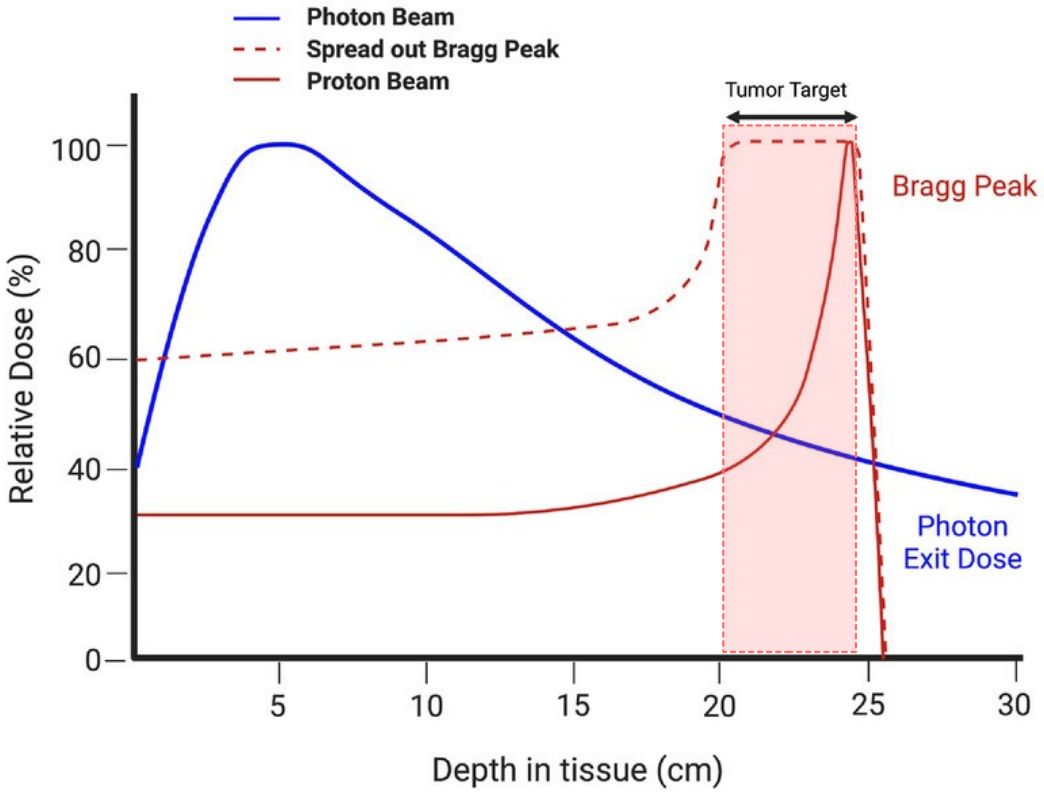
June 3, 2024 - Photodetection with semiconductors meeting

Context – Proton therapy

Dose (1Gy = 1J/kg)

- High ballistic precision of the dose deposition (**Bragg peak**)

- Less dose deposition in surrounding healthy tissue



Context – Prompt Gamma for proton range monitoring

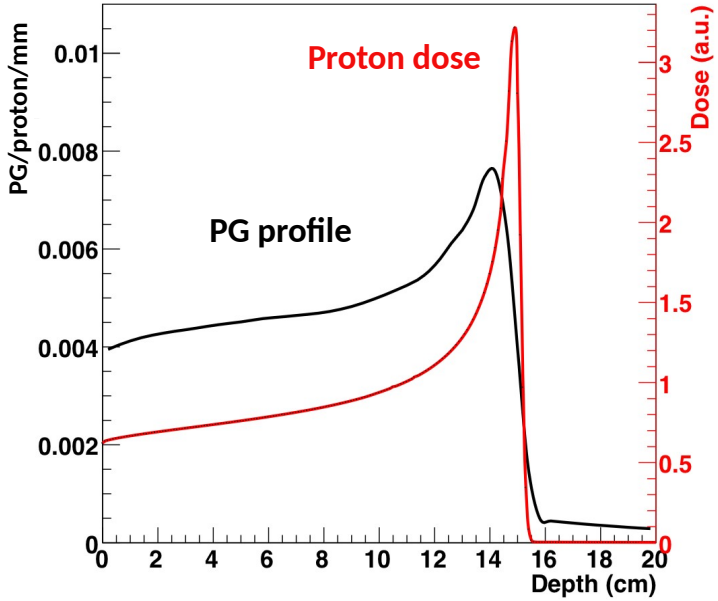
Real time control by secondary radiations detection

Prompt Gamma (PG)

0 < E < 10 MeV
Emission within < 1 ps
Production rate ~ 1% /cm /p

Constraints:

Low statistics
Background (neutron)

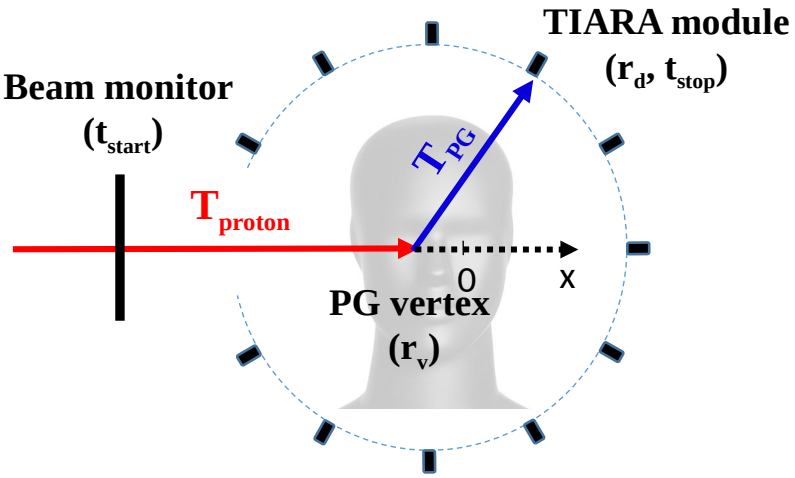


Correlation between the dose deposition and the PG emission profiles

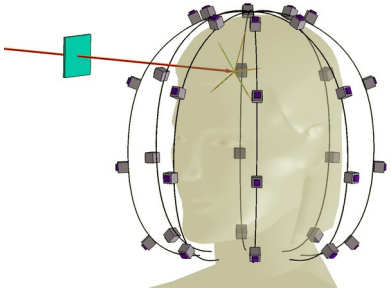
Context – PGTI (Prompt Gamma Time Imaging)

Reconstruction of the proton range through time-of-flight (TOF) measurement.

Proton plus Prompt Gamma TOF measurement



$$TOF = T_{hadron}(r_v, v) + \frac{1}{c}||r_d - r_v||$$



TIARA = TOF Imaging ARrAy

Final detection system
~ 30 TIARA modules

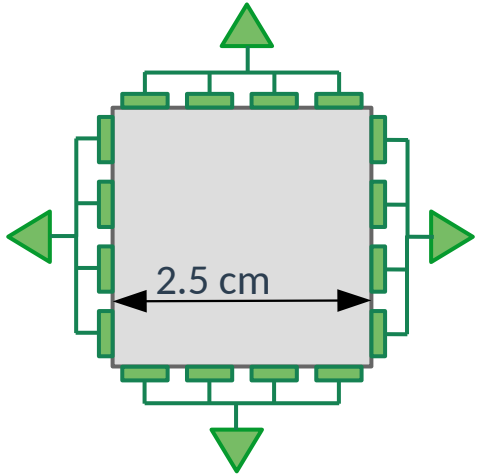
PGTI **sensitivity** depends on events **statistic** and the system **Coincidence Time Resolution (CTR)**

For a millimetric PGTI sensitivity
a detection system of
235 ps FWHM CTR is required

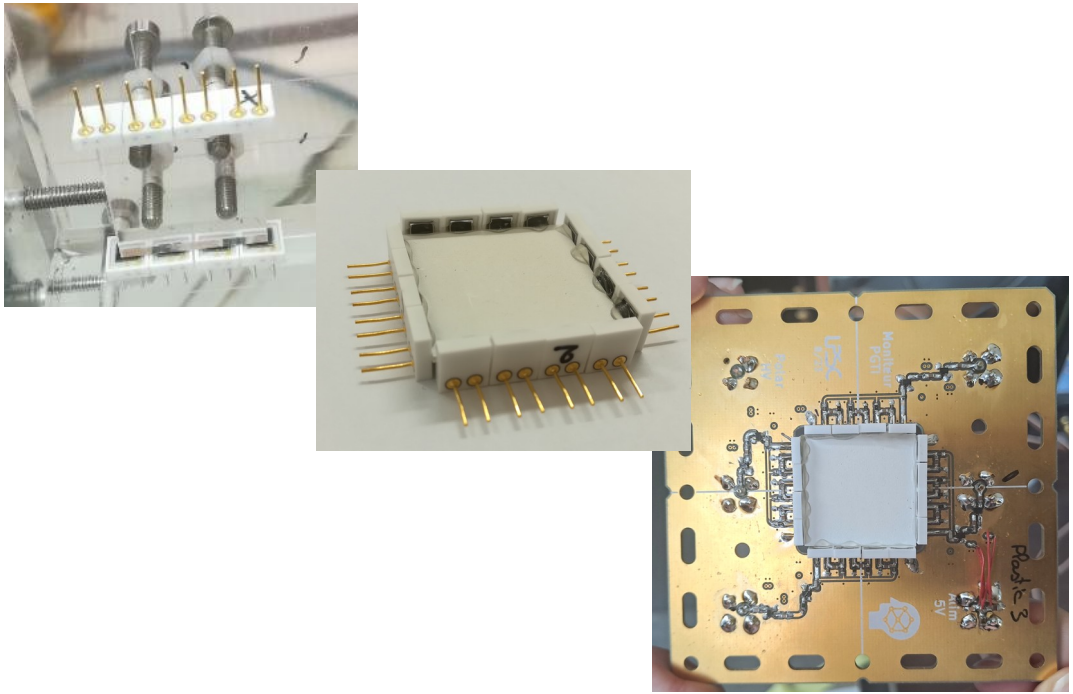
Detectors development – Plastic scintillator beam monitor

3rd version of the prototype (18 month R&D)

Article in preparation



- Plastic scintillator (EJ-204) 1x25x25 mm^3
- Read-out by 16 Silicon Photomultipliers (Hamamatsu SiPM 3x3 mm^2)

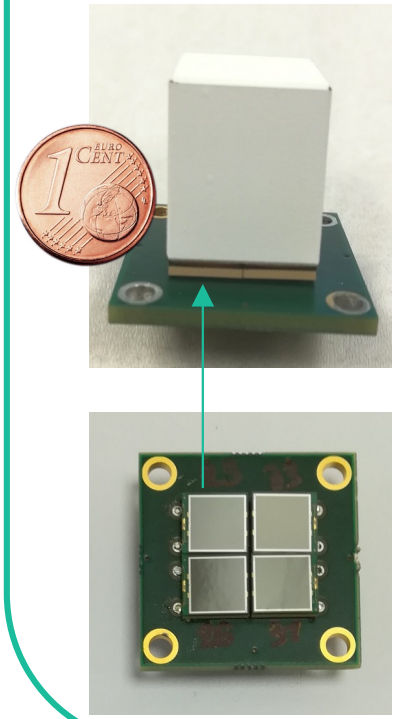


4 SiPM strips surrounding the scintillator

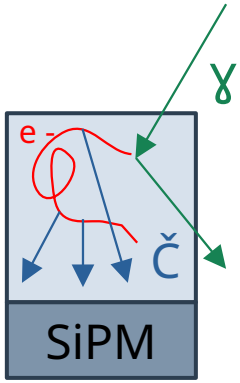
Each SiPM strip is amplified and acquired separately

Detectors development – Prompt Gamma module

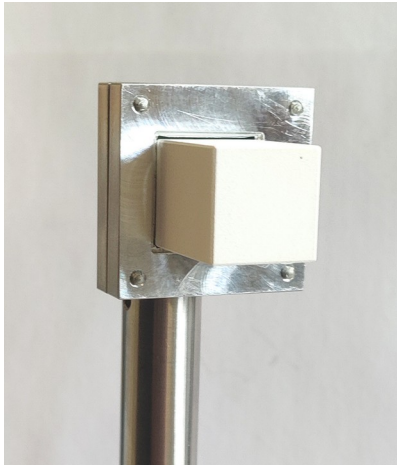
Final version of the prototype (18 month R&D)



Cherenkov radiator
2 x 1.5 x 1.5cm^3 lead fluoride cristal (PbF_2)



Read-out by 4 Silicon Photomultipliers (SiPM)

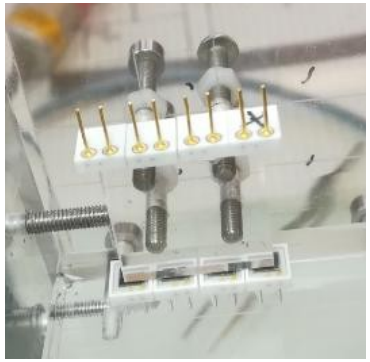


- Fast signal
- High density (detection efficiency)
- Very low sensitivity to background
- No energy measurement

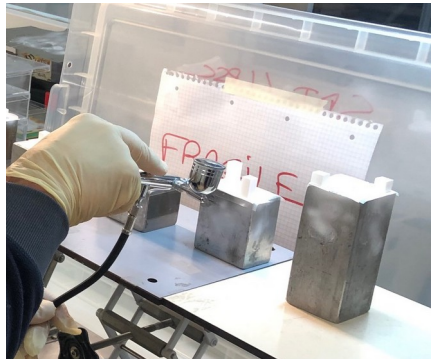
Detectors development

Detectors and electronics are developed at LPSC (SDI, SE)

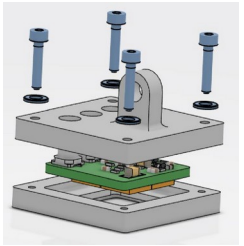
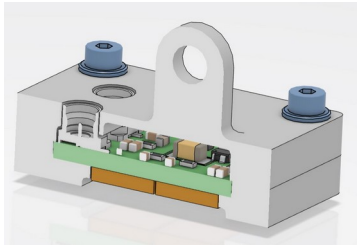
Optical coupling

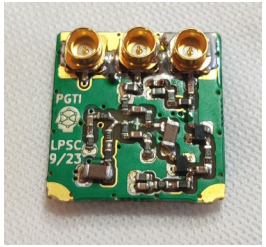
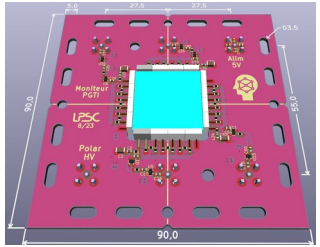
Reflective paint covering

Box design

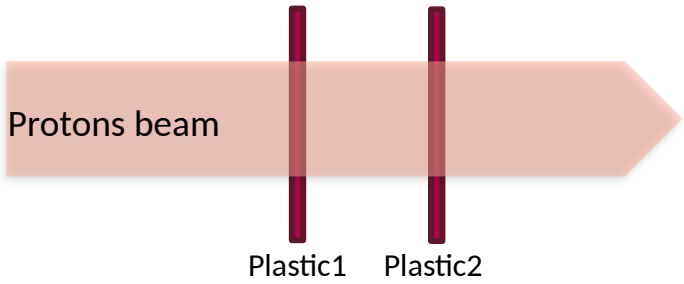
Electonics design *(C. Hoarau's talk)*

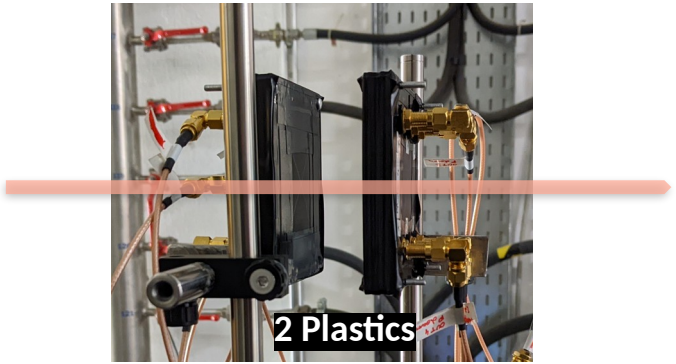



Same reflective paint, optical glue and electronics used for TIARA modules and plastic monitor

Detectors characterization – Plastic scintillator beam monitor

Experimental set-up

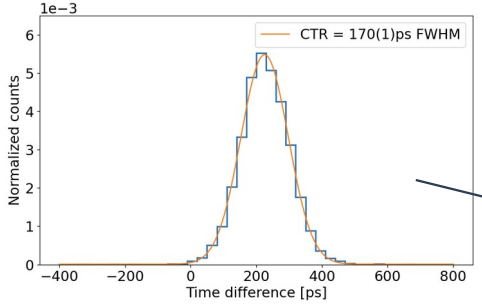


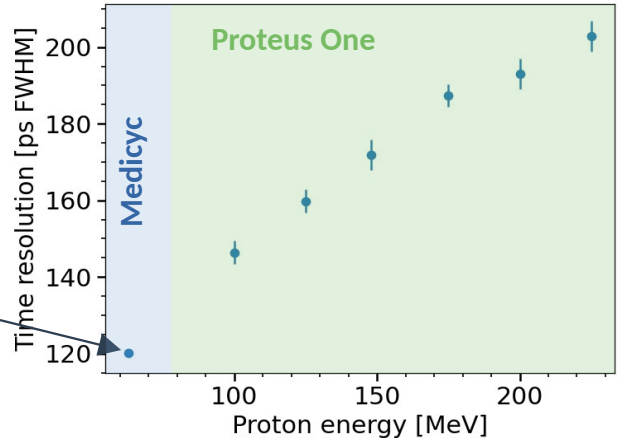


Read-out: Wavecatcher IJCLAB

Time resolution < 235 ps FWHM in the relevant energy range

TOF between the 2 monitors at 63 MeV

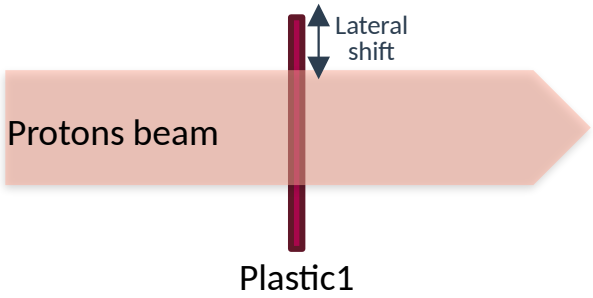


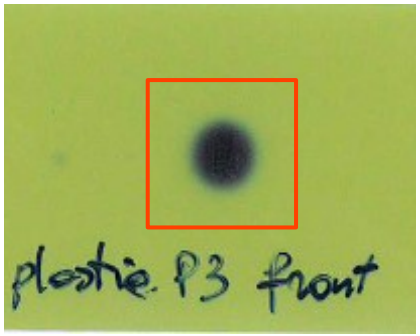


100 % detection efficiency

Detectors characterization – Plastic scintillator beam monitor

Experimental set-up

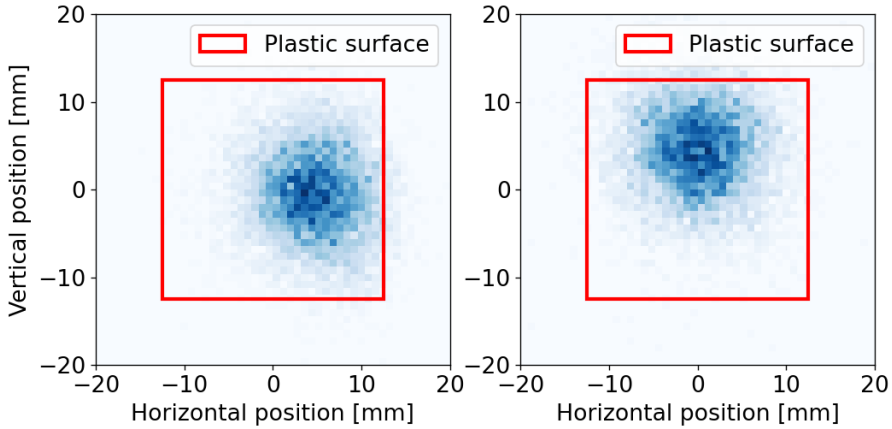




Radiation sensitive film (Gafchromic)

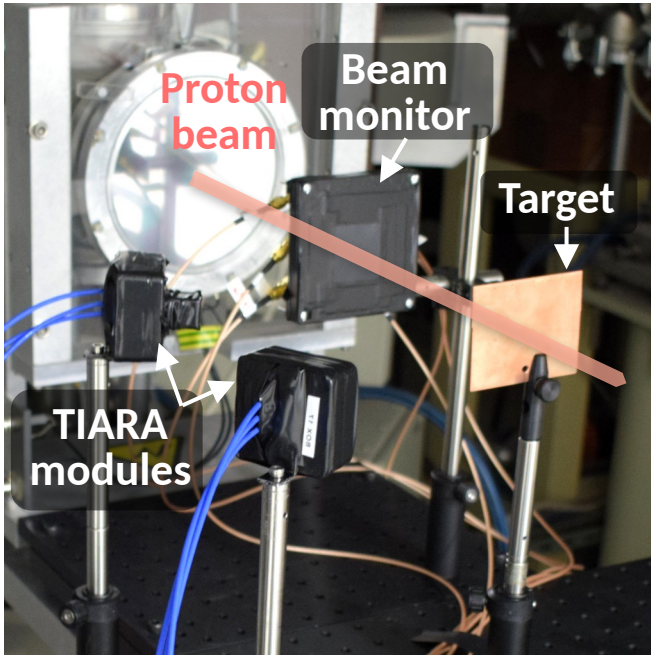
Spatial resolution = 1.8 mm σ/ incident proton (at 63 MeV)

Beam images for 2 positions (5mm,0) and (0,5mm)



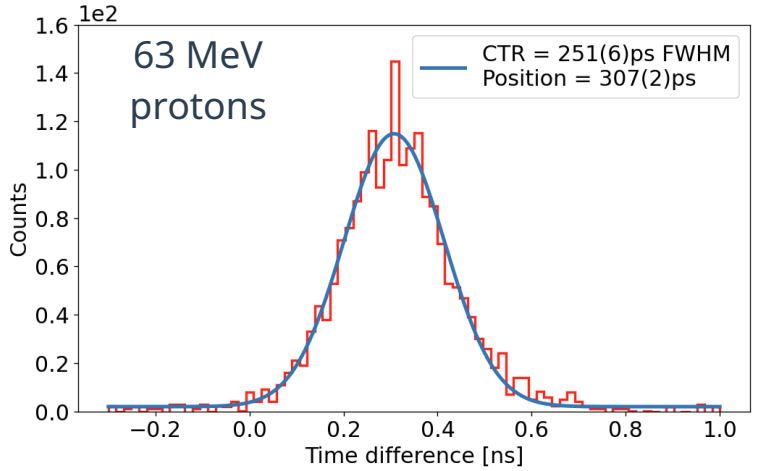
Detectors characterization – Prompt Gamma module

Time resolution characterization set-up



The thin copper target is used as a point-like PG source

Coincidence Time Resolution = 251ps FWHM



Last version of the TIARA module (March 2024)

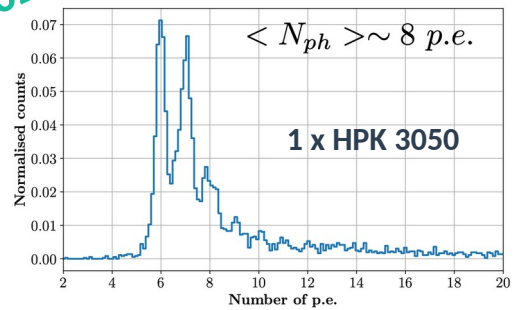
Gamma detector time resolution = 220 ps FWHM

Detectors optimization

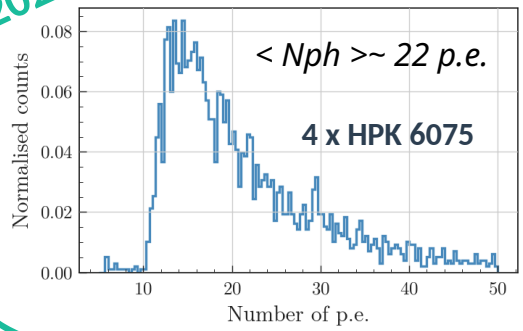
TIARA module response

2021

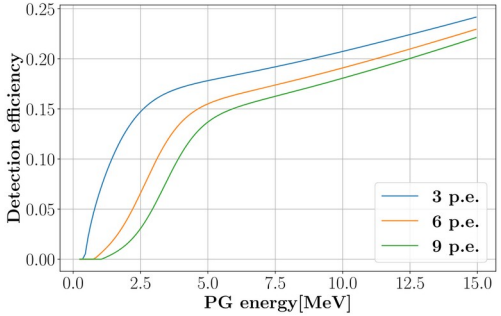
Energy response (experiment)



2024



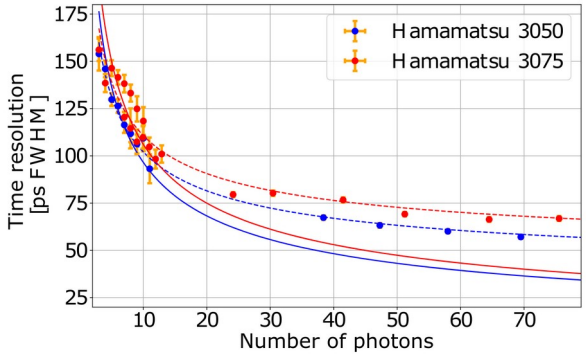
Module detection efficiency based on Monte Carlo simulations (MC)



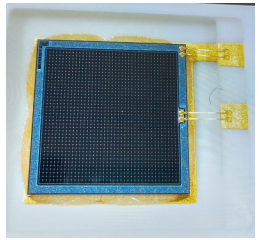
MC simulation on-going but : Higher and less sensitive to p.e. threshold detection efficiency is expected

SiPM Time Resolution

Data from 2020 (obsolete front-end), shown as an example



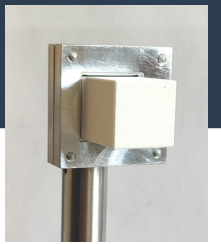
HPK 3050 = 3x3 mm³ SiPM with 50 µm microcells



SiPM characterization performed with LASER

The **maximization of the photodetector surface** is chosen (as the number of Cherenkov photons generated is low) to optimize the detection efficiency without degrading the time resolution

TIARA module characterization



Summary of the different versions of the TIARA module

Version	SiPM number	Crystal (mm^3)	Front-end	PG module DTR (ps) FWHM	When
1	1	10^3	Commercial	275	June 2021
2	1	20*10*10	LPSC, single	202	April 2022
3	4	15^3	LPSC, hybrid	211	December 2022
4	4	15*15*20	LPSC, parallel	197	June 2023
5 (final version)	**4**	**15*15*20**	**LPSC, hybrid compact**	**220**	**November 2023**

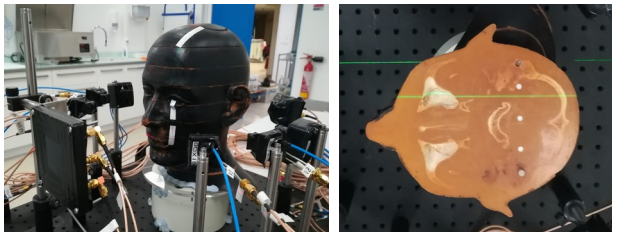
Final version of the TIARA module is a compromise to optimize:
the **time resolution**, **detection efficiency** and **compactness**

8 TIARA modules developed for the last beam test (**March 2024**)

PGTI measurement

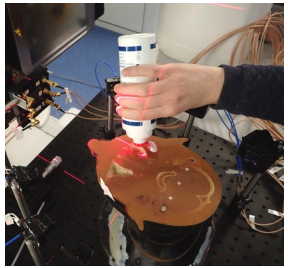
8-channels detection system to measure an anatomical change in a clinical phantom

Head phantom



Clinical proton beam (IBA ProteusOne)

Set-up realized



PGTI
PROMPT GAMMA TIME IMAGING

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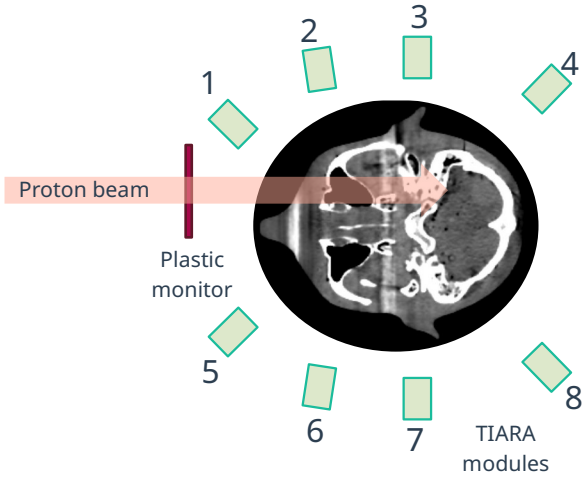
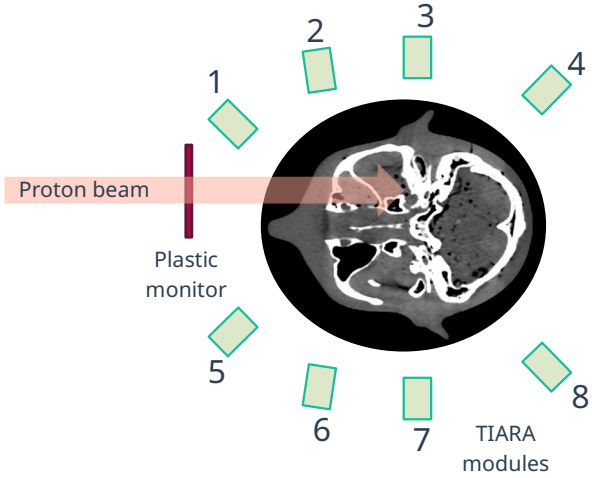
Empty sinus (air cavity)



Sinus fulled with ultrasound gel



PGTI measurement

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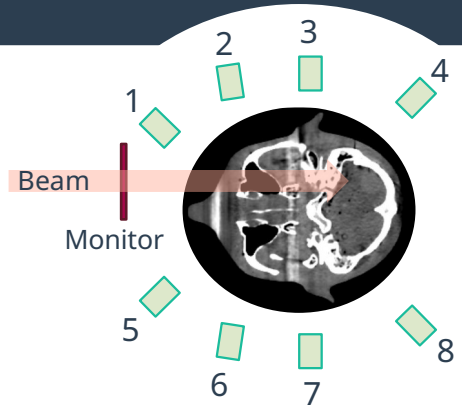
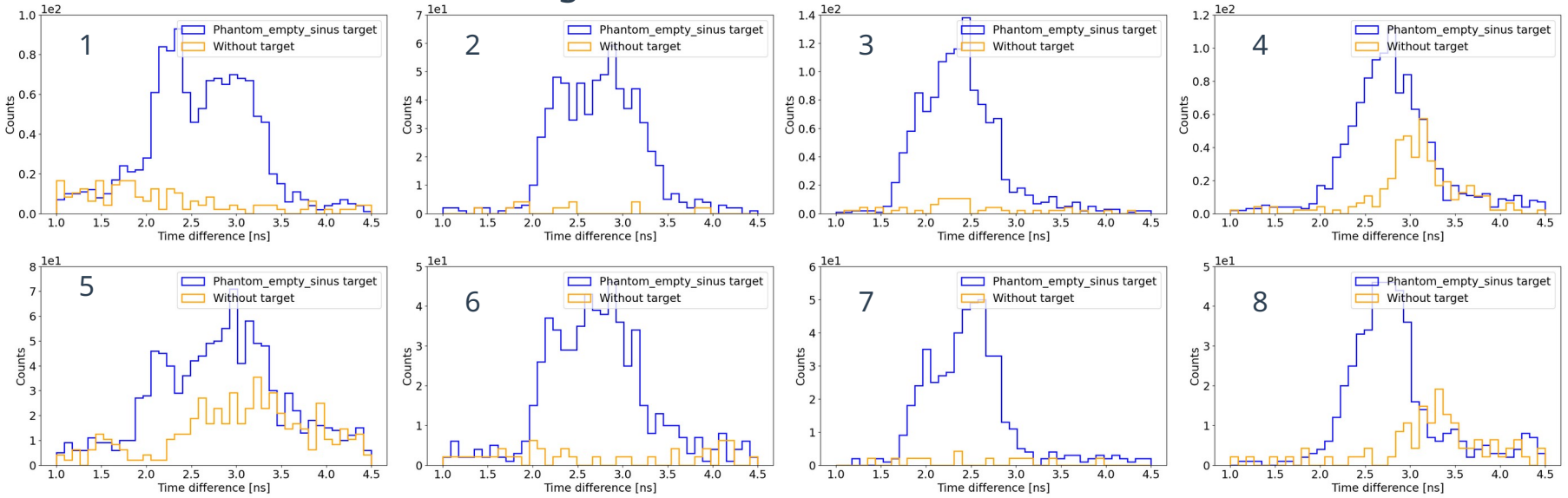
Set-up



High Signal to Noise Ratio (SNR)

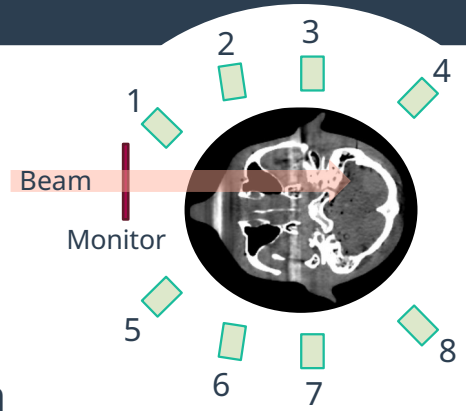
TIARA modules insensitive to neutrons background but sensitive to scattered protons

Phantom irradiation and background TOF



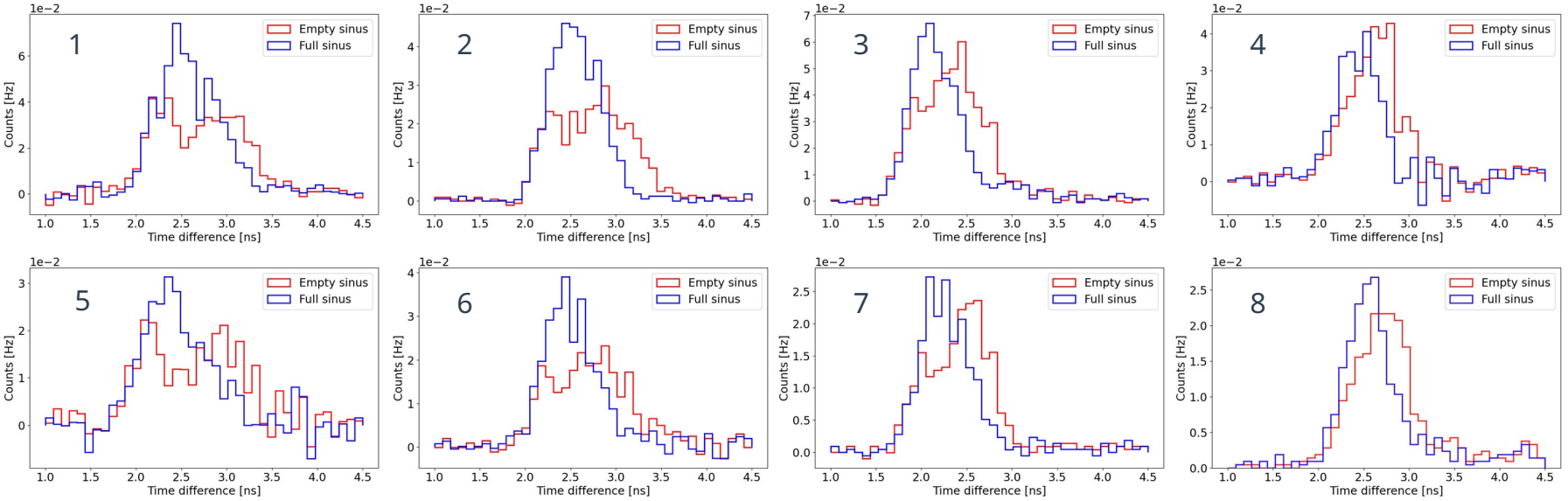
PGTI measurement

Set-up



Anatomical change visible on PGTI TOF measurement

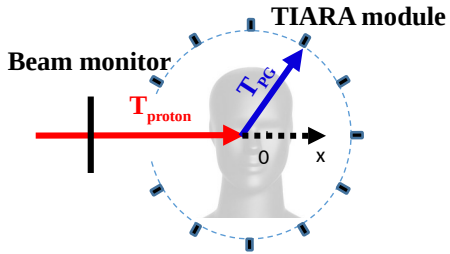
TOF comparison between the two set-up after background subtraction



Take-home message

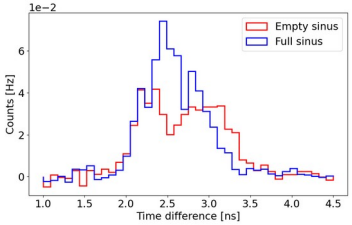
PGTI
PROMPT GAMMA TIME IMAGING

- **Proton therapy monitoring** based on **Prompt Gamma TOF measurement**



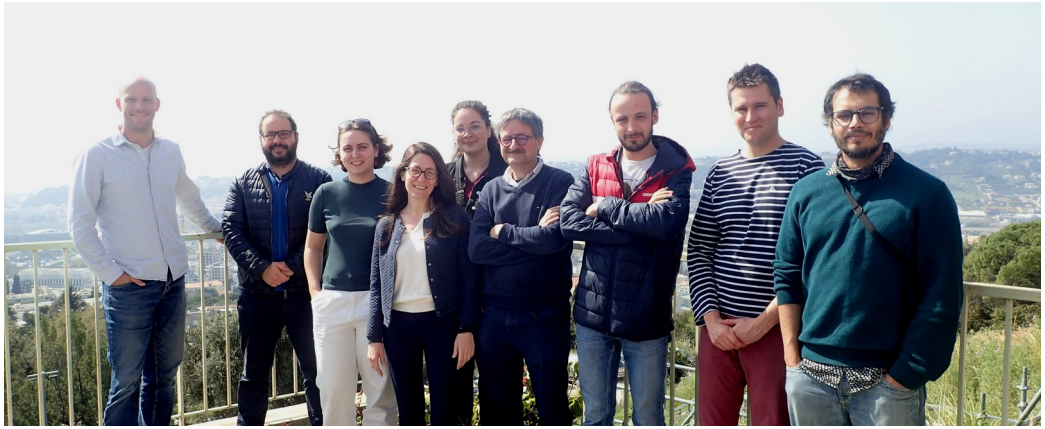
- **Fast detection system** with 251 ps FWHM CTR **and a very high SNR was developed at LPSC**

- **PGTI TOF measurement sensitive to anatomical changes**



Acknowledgements

PGTI
PROMPT GAMMA TIME IMAGING



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LPSC Grenoble

CENTRE DE PHYSIQUE DES PARTICULES DE MARSEILLE
CPPM

Antoine Lacassagne
CENTRE DE LUTTE CONTRE LE CANCER
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Inserm

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