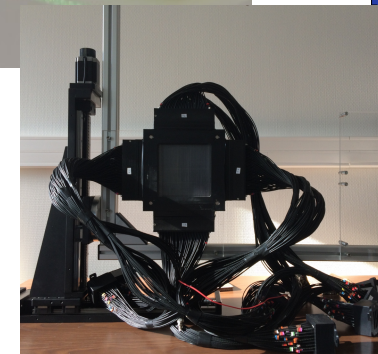
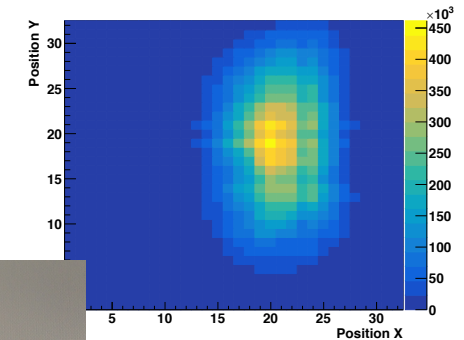
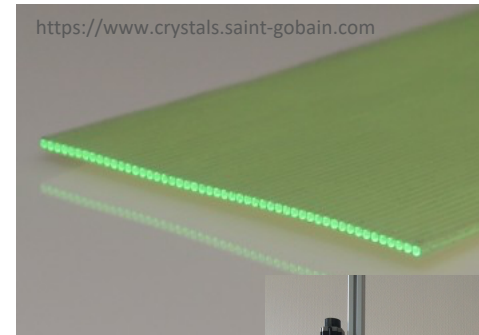


Characterization of a beam-tagging hodoscope for hadrontherapy monitoring

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- ❖ Introduction
- ❖ The scintillating fibers hodoscope
- ❖ The performance tests
- ❖ Results
- ❖ Discussion/Conclusion



I. Introduction

Introduction

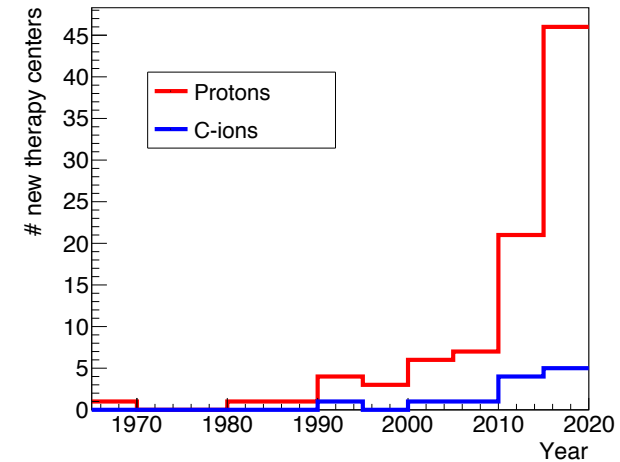
The beam-tagging hodoscope

The performance tests

Results

Discussion

Ion beam therapy facilities have known a rapid spread this last decade.

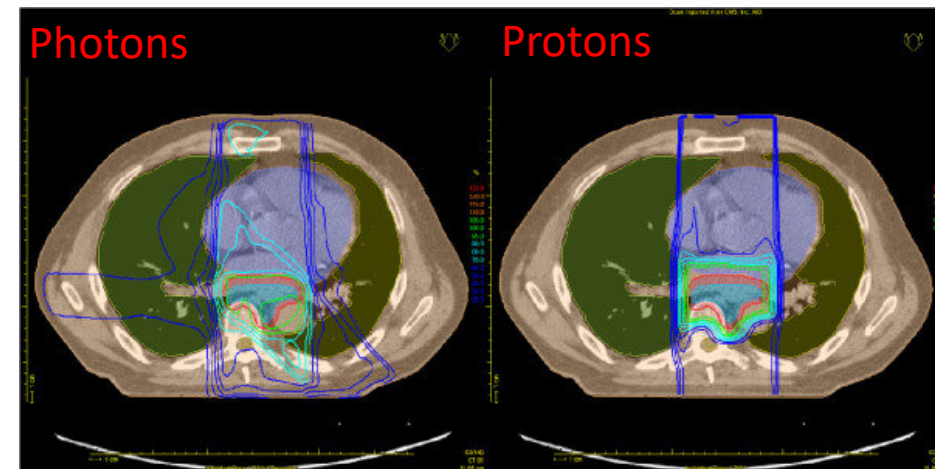


Data obtained from <https://www.ptcog.ch/index.php/facilities-in-operation> - July 2020

The benefits offered by the physical properties of ions are:

- A limited energy deposition at the entrance of the patient
- Most energy deposition at the end of their range in the tissue (Bragg peak)

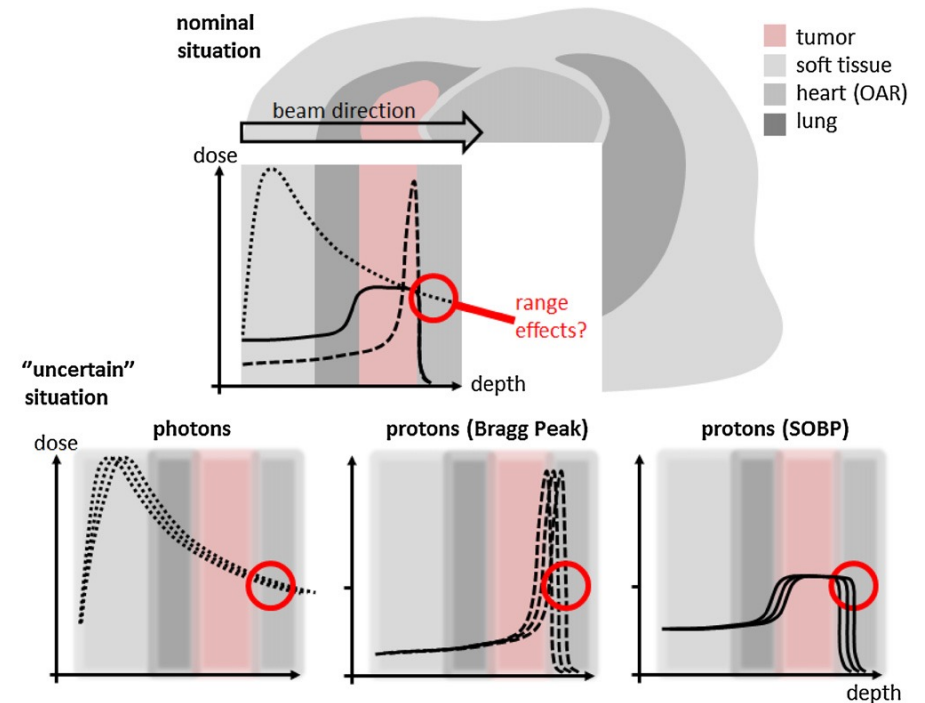
- ↳ Higher local control of the tumor
- ↳ Lower probability to damage the healthy tissues
- ↳ Potential rapid recovery



Lühr, A., Löck, S., Roth, K. *et al.* Concept for individualized patient allocation: ReCompare—remote comparison of particle and photon treatment plans. *Radiat Oncol* **9**, 59 (2014).

However, a limitation still remains to fully exploit the benefits of the ions: **The uncertainty on the ion range**

- Conversion of CT number to HU
- Anatomical changes of the patient during the treatment
- Organ motion during the treatment
- Approximations used in dose calculation



Antje-Christin Knopf and Antony Lomax 2013 *Phys. Med. Biol.* **58** R131

Several techniques are investigated to reduce this uncertainty:

In vivo monitoring from the use of secondary emissions

Improvement of planning imaging

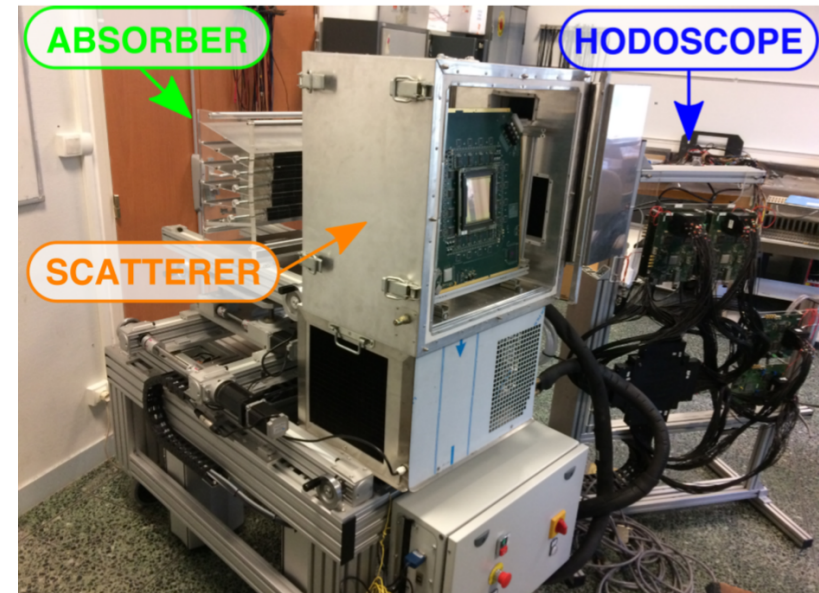
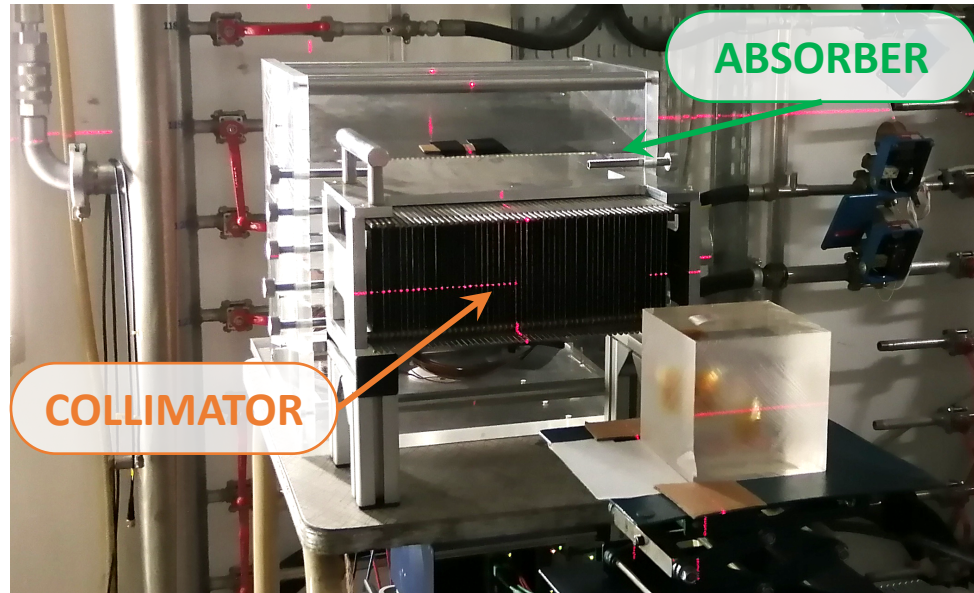
- Annihilation γ -rays
- Bremsstrahlung rays
- Ionoacoustic waves
- Prompt-gammas (PGs)

- PG Imaging
- PG Peak Integral
- PG Timing
- PG Spectroscopy

- Collimated cameras
- Compton cameras

The CLaRyS collimated/Compton camera prototype

- Introduction
- The beam-tagging hodoscope
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- Results
- Discussion



Absorber : 32 BGO blocks
8x8 pseudo-pixels / block
4 photomultiplier tubes (PMTs) / block

Collimator : 1.5x120x170 mm³ tungsten alloy slabs

Scatterer : 7 Double Sided Silicon Detector layers
96x96x2 mm³
64 strip segmentations per detector side

Time structure of the clinical accelerators

Introduction

The beam-tagging hodoscope

Role of the hodoscope:

Provide a time tagging per bunch or per ion

The performance tests

Results

Discussion

		synchrotron		cyclotron (IBA, Varian)	synchro-cyclotron (S2C2, IBA)
		Carbon	Protons		
Typical intensity (ions/s)		10 ⁷	10 ⁹	10 ¹⁰	~ 10 ¹⁰
Macrostructure	Period (s)	1 – 10		∅	10 ⁻³
Microstructure	Bunch width (ns)	20 – 50		0.5 – 2	8
	Period (ns)	100 – 200		10	16 (variable)
	Ions/bunch	2 – 5		200	4000

Table 3: Typical time structures of various clinical accelerator types.

J. Krimmer, D. Dauvergne, J.M. Létang, and É. Testa, *Prompt-gamma monitoring in hadrontherapy: A review.*, *Nucl. Instrum. Meth. A*, **878** (2018) pg. 58–73

II. The scintillating fibers hodoscope

❖ Specifications

Introduction

The
beam-tagging
hodoscope

The
performance
tests

Results

Discussion

- Detection efficiency with a logical AND on both planes : $\sim 90\%$
- Time resolution : $< 2\text{ ns}$
- Counting rate capabilities: up to 100 MHz
- Radiation hardness : operationnal for at least 1000 clinical irradiations

Introduction

The beam-tagging hodoscope

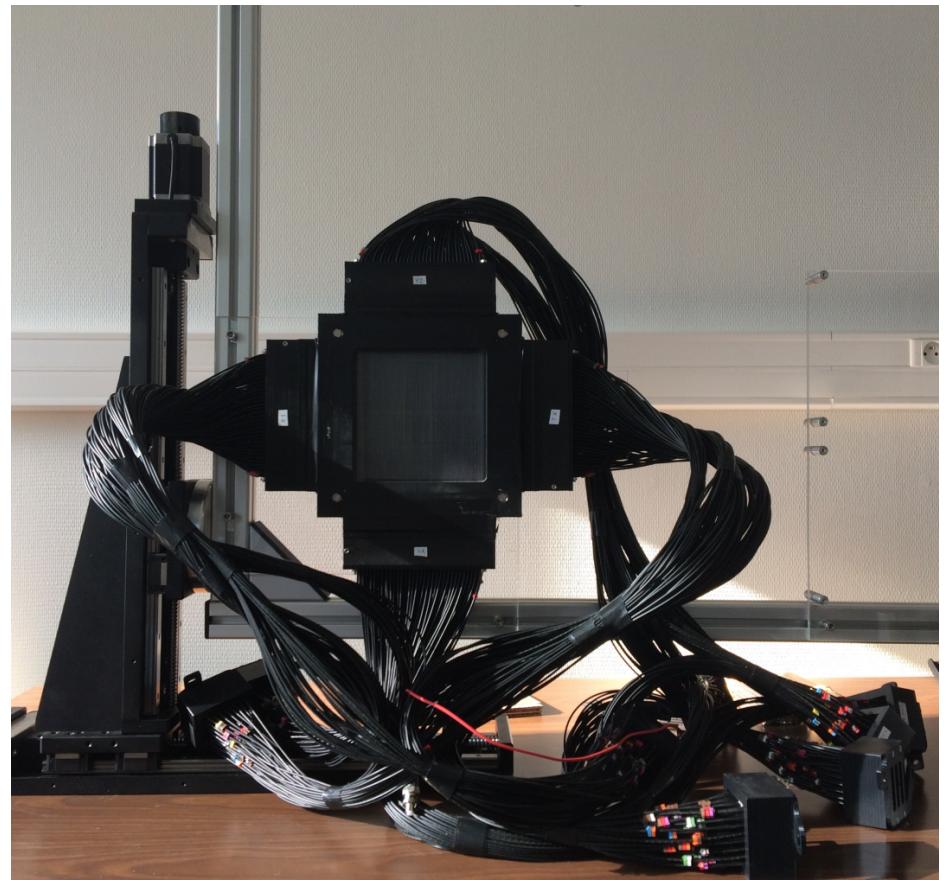
The performance tests

Results

Discussion

❖ Characteristics

- 2 perpendicular planes for a 2D mapping
- 128 polystyrene scintillating fibers BCF-12 per plane
- 1 mm² squared section
- 8 multi-anode PM tubes for a two side read-out

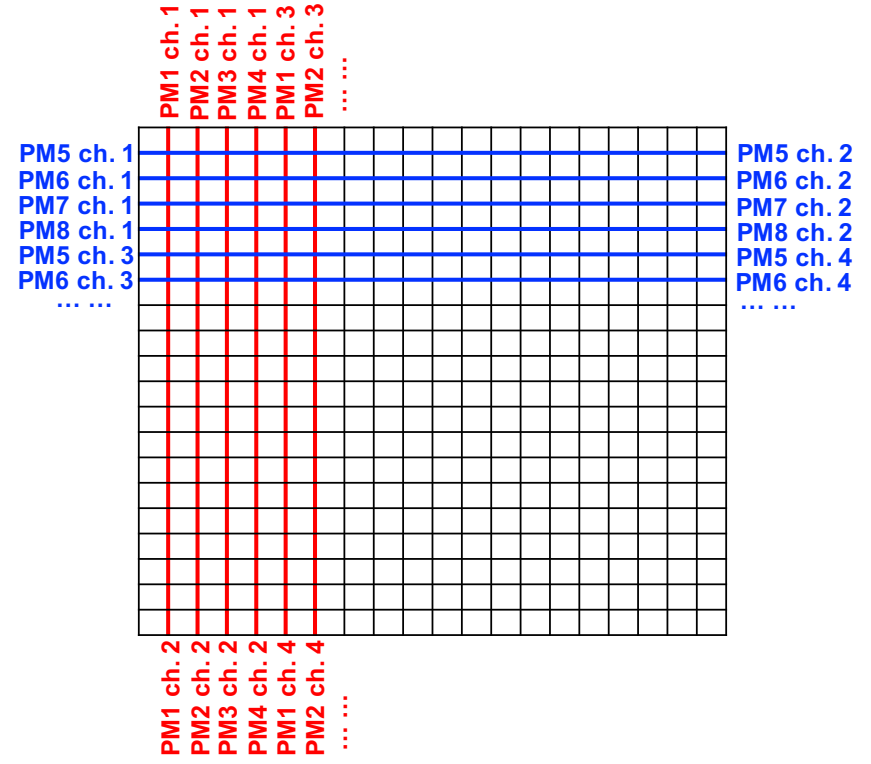
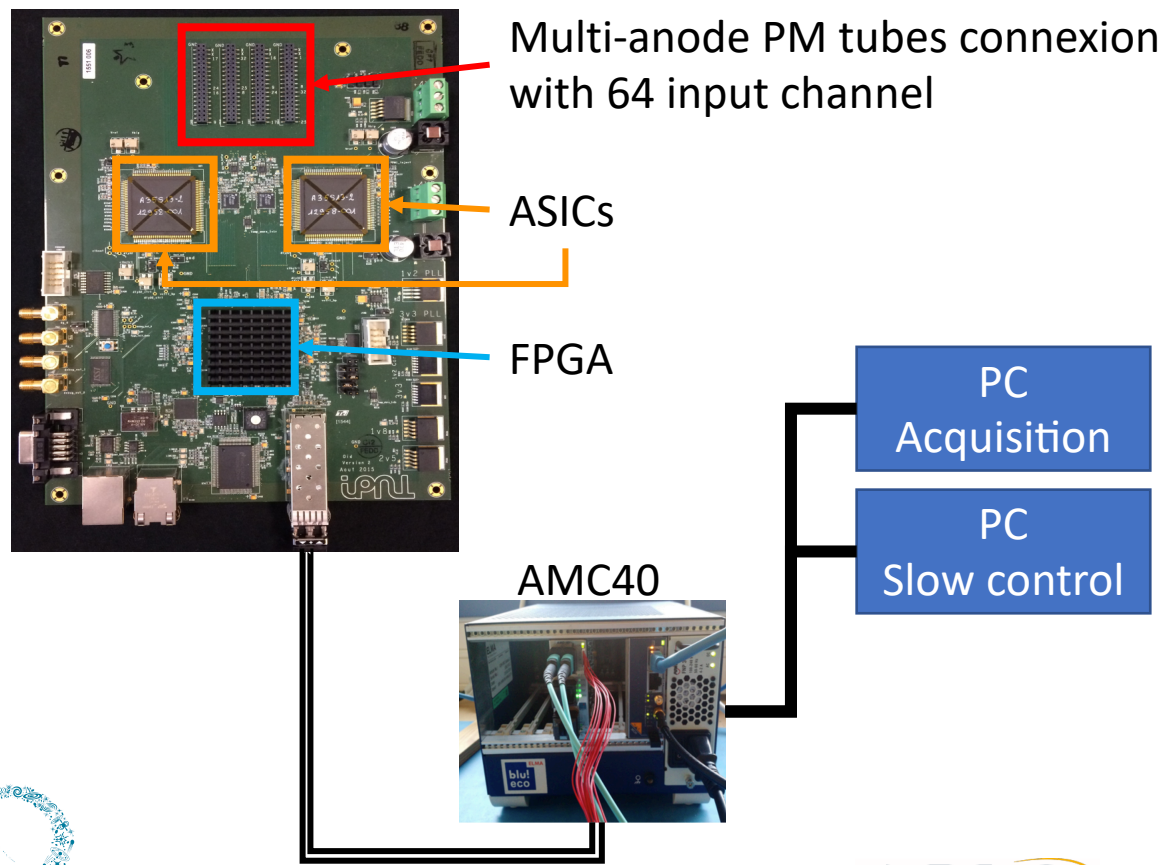


II. The scintillating fibers hodoscope

- Introduction
- The beam-tagging hodoscope
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- Results
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❖ The read-out electronics

- Each PM tube is readout by an “HODOPIC” FE board



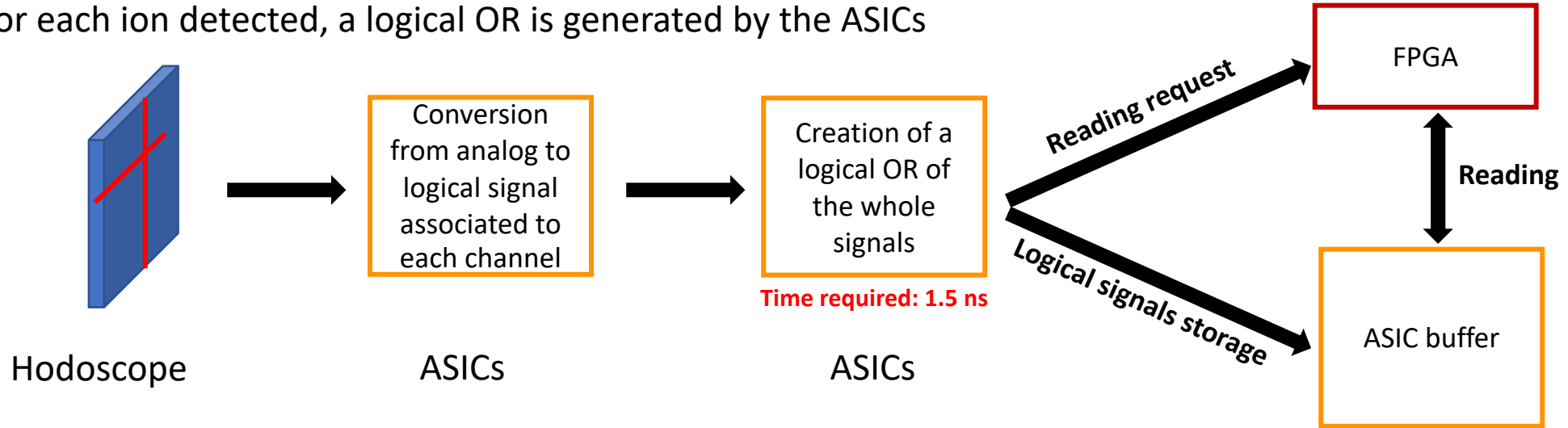
Specific connexion to maximize the counting rate:

- Two adjacent fibres are handled with different PM tubes.
- Every fibres are read-out by two neighboring channels

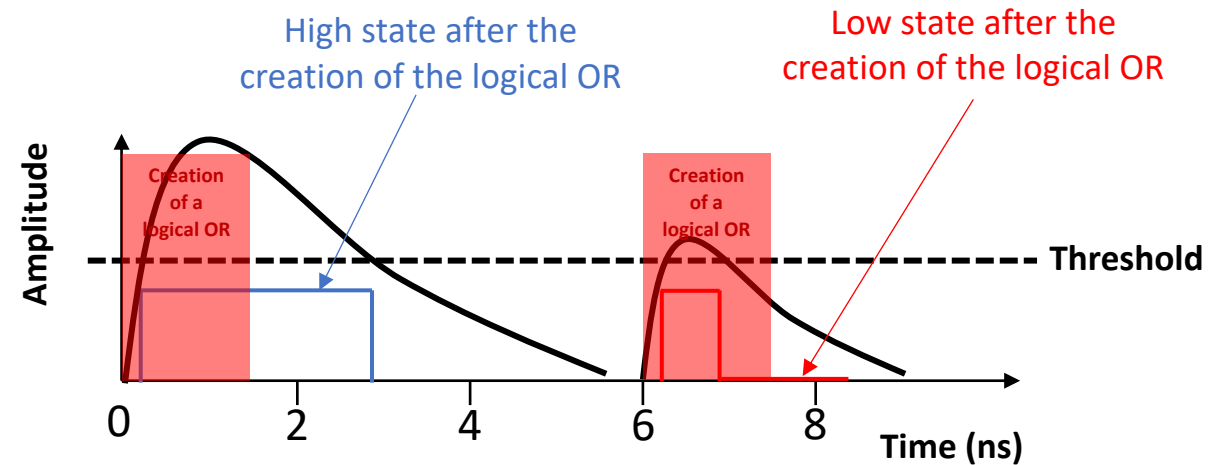
❖ Criteria and settings methodology

Logical signal generation:

- For each ion detected, a logical OR is generated by the ASICs



- Logical signals associated to hit channels can have two states:
 - State high** if the duration of the analog signal over the threshold is higher than 1.5 ns
 - State low** if the pulse duration over the threshold is shorter than the time to create the logical OR



Introduction

The beam-tagging hodoscope

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❖ Criteria and settings methodology

Two types of events exist:

- **good events (GEs)**: events for which at least one logic signal state is high
- **events with short pulse (ESPs)**: undesired events for which the logic signal is not long enough to have a high state when the reading of the channel states by the FPGA is requested by the ASIC.

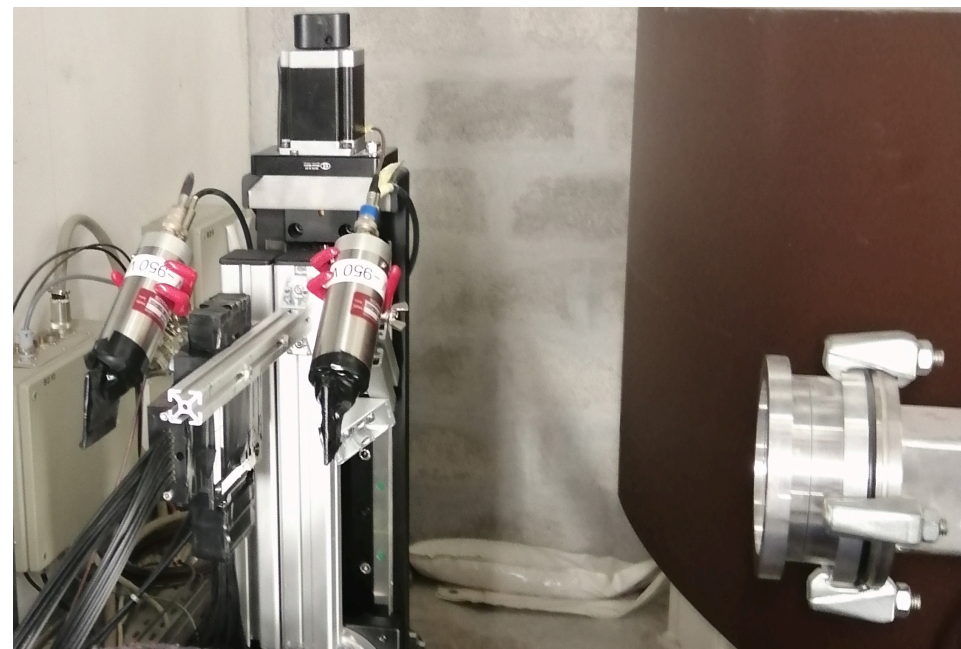
Objective:

Optimize the efficiency

Adjustable settings:

- A **common threshold** for all channels connected to a same ASIC
- A **specific gain** for each channel

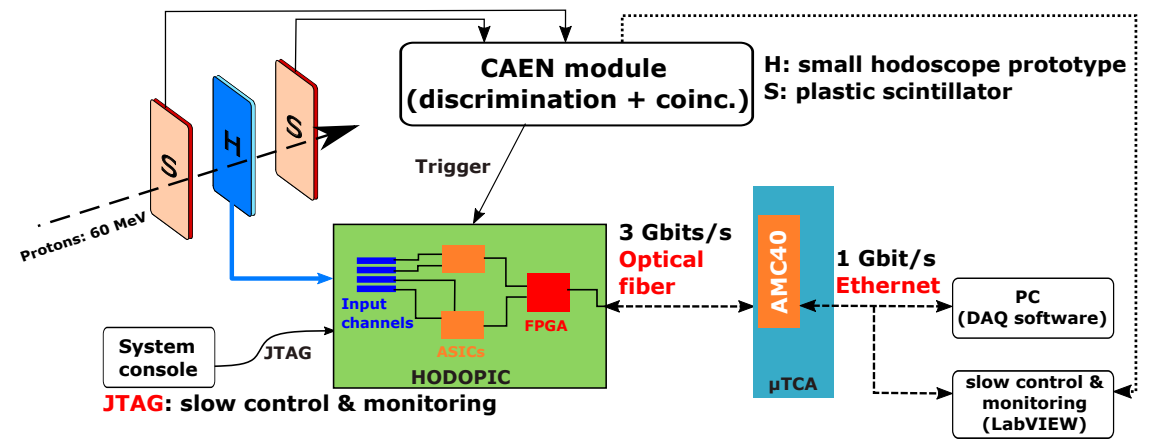
III. The in-beam performance tests



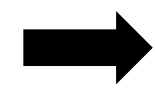
Experimental setup used in centre Antoine Lacassagne to assess the performance of the hodoscope with the small size hodoscope (32 channels per plane read by 1 front-end card)

General principle :

The hodoscope is placed between two plastic scintillators (PS). An external trigger signal is provided by the coincidence signal generated from the two PS when a proton impinges the hodoscope.



Scheme of the experimental setup with the data acquisition chain

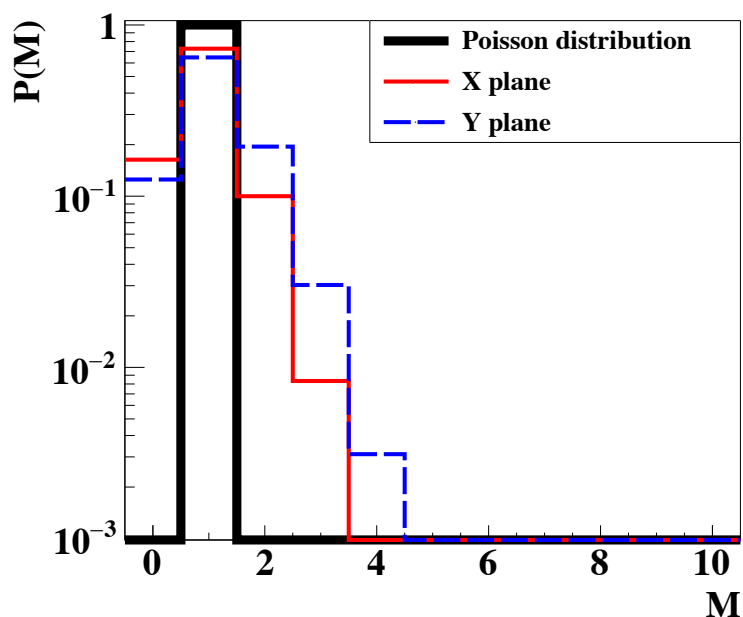


- Assessment in terms of:
- Detection efficiency
 - Multiplicity
 - Time resolution
 - Radiation hardness

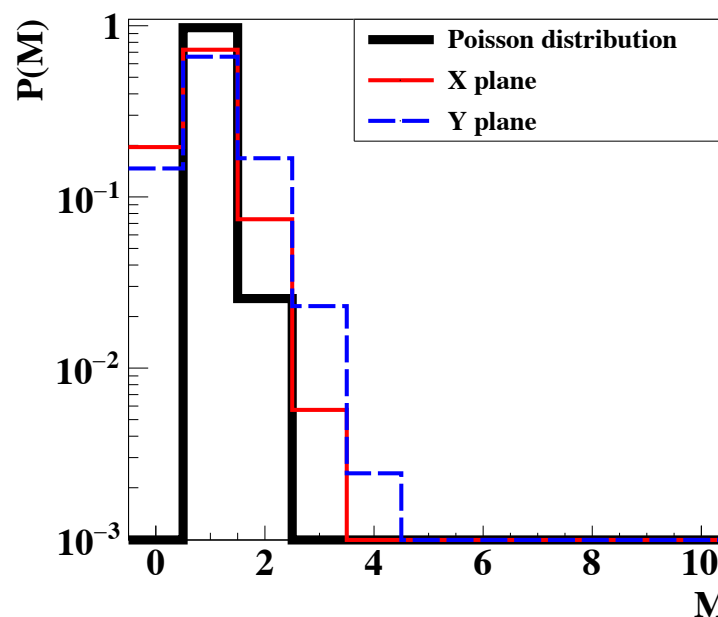
❖ Multiplicity

Multiplicity (M) = Number of involved fibers per plane when a trigger is generated

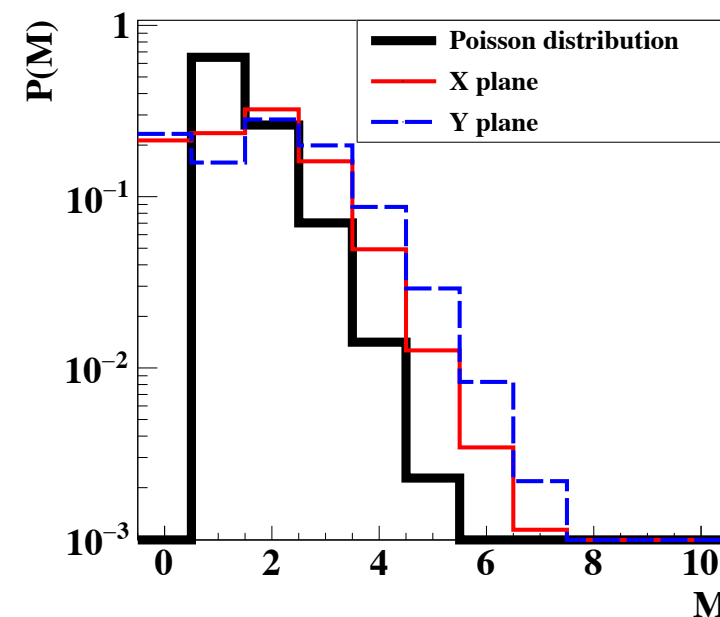
Measurements with 65 MeV protons



17 kHz



1 MHz



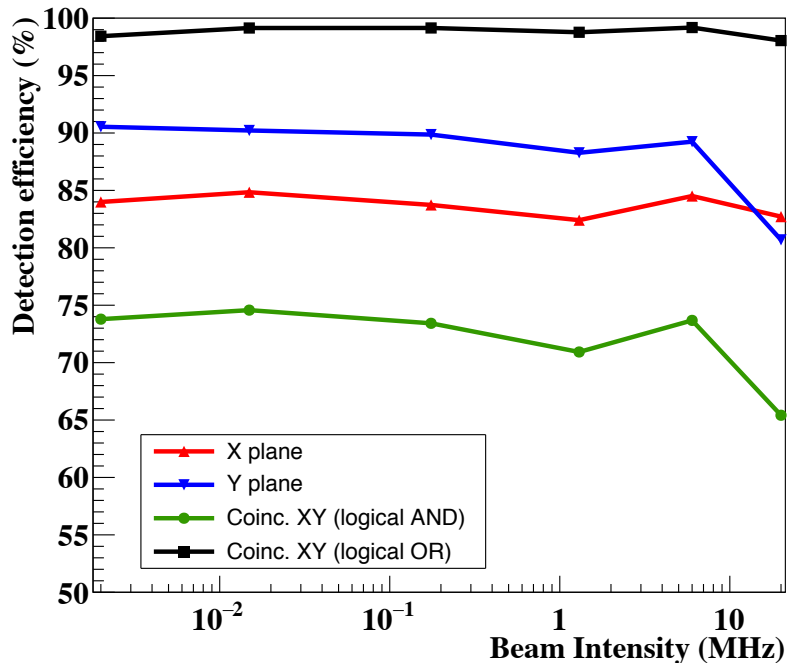
20 MHz

- For intensities < 1 MHz, more than 70% of events have a $M = 1$
- The probability of event with $M > 1$ increases when the intensity is over 1 MHz (ground fluctuations in the ASICs)
- Events with $M = 0$ correspond to empty events including ESP

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❖ Detection efficiency (DE)



Measurements with 65 MeV protons

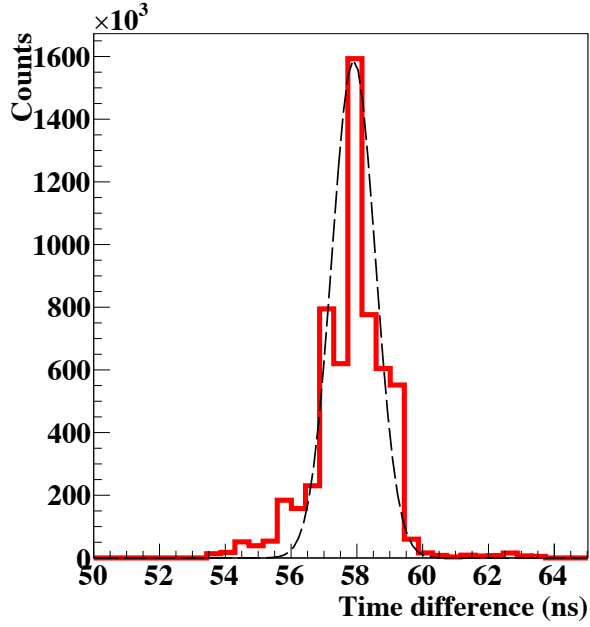
- DE is almost constant around **84%** and **90%** in X and Y planes respectively.
- DE with the **logical OR** condition on both planes is upper than **97%** whatever the beam intensity in the range 17 kHz to 20 MHz.
- DE with the **logical AND** condition on both planes is close to **74%** until a beam intensity of ~ 6 MHz.

Hardness resistance:

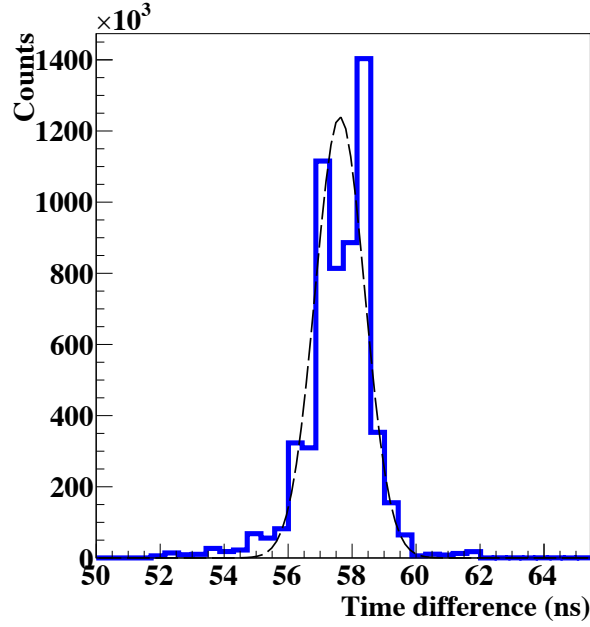
After an irradiation of 3.6×10^{12} C6+ 95 MeV/u ions·cm⁻² (more than 1000 irradiations), at GANIL, a slight decrease of $\sim 10\%$ of the DE was observed.

- Introduction
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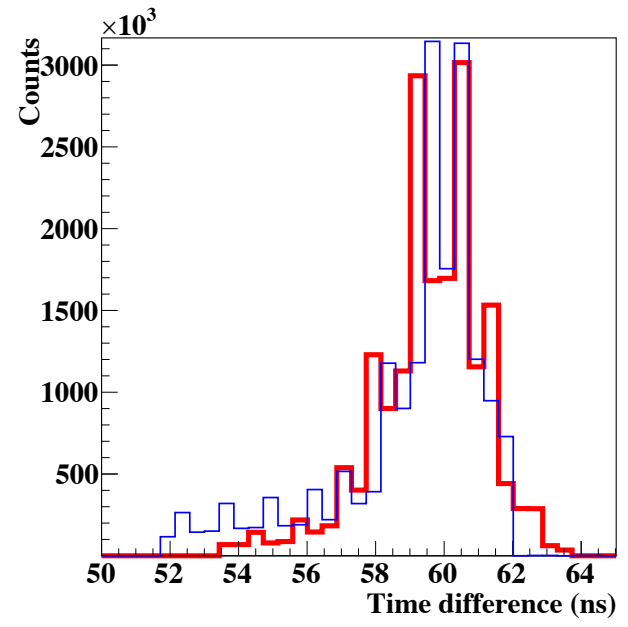
❖ **Time resolution**
Measurements with 65 MeV protons



X plane



Y plane



Superimposition of X and Y planes

Intensity: 43 kHz

Intensity: 10 MHz

- The **time resolution** is close to **1.5 ns** (FWHM) at low intensity (estimated with a Gaussian fit)
- **At 10 MHz**, an additional component can be noticed due to **ASIC oscillations**

V. Discussion and Conclusion

- Introduction
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	Specifications	Measured performance
Detection efficiency	~ 90 % (logical AND) at 100 MHz	66 % (logical AND) at 20 MHz 97 % (logical OR) at 20 MHz
Time resolution	< 2 ns	1.8 ns (10 MHz)
Radiation hardness	Operationnal for 1000 clinical irradiations	< 10 % loss of detection efficiency after an equivalent of 1000 clinical irradiations

Current limitations : **ground fluctuations in the ASICs**

Perspectives:

- Coupling of the hodoscope with the Compton camera foreseen within the next year.
- An improvement of the ASICs would allow to reach the specifications.

