Online beam monitoring detector for FLASH irradiations

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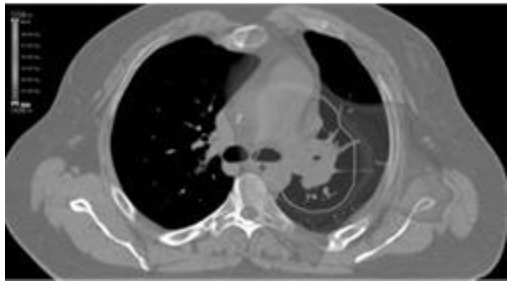
FLASH Effect

CONVENTIONAL -RT

Dose/fraction: **1-2 Gy**
Delivery time ~ **days/weeks.**

0 Gy

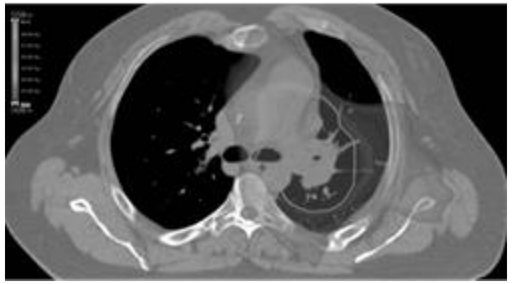


0.01-0.1 Gy/s

FLASH-RT

Dose/fraction: **10-40 Gy**
Delivery time ~ **µs - ms**

0 Gy



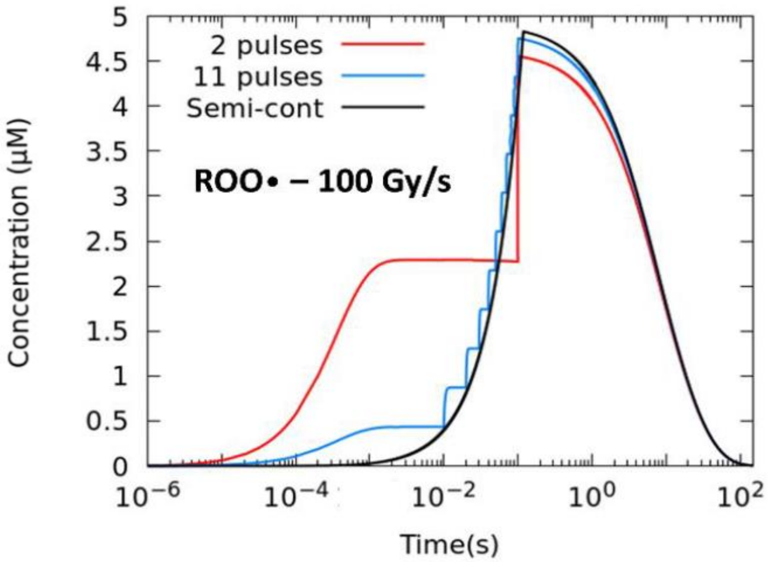
> 40 Gy/s

FLASH effect:

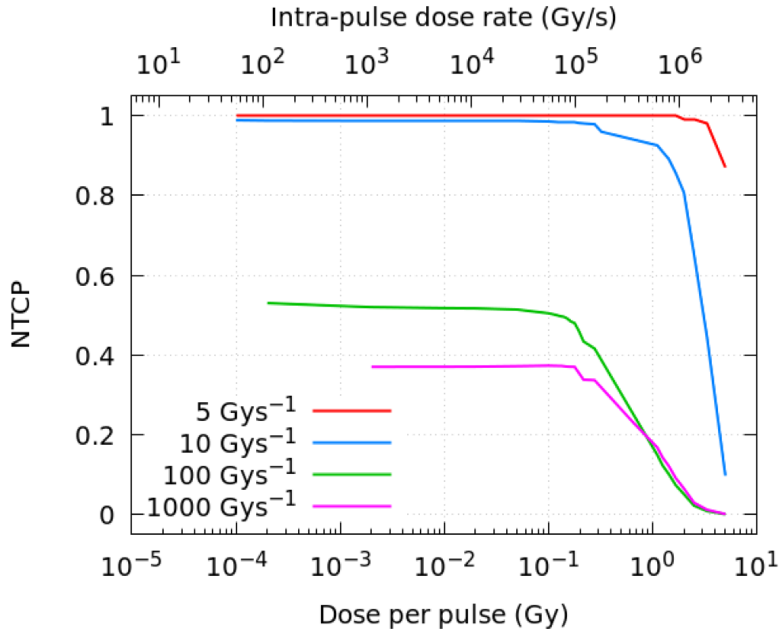
1. Reduced radiation-induced damage in healthy tissue
2. Similar antitumor effectiveness

FLASH Effect

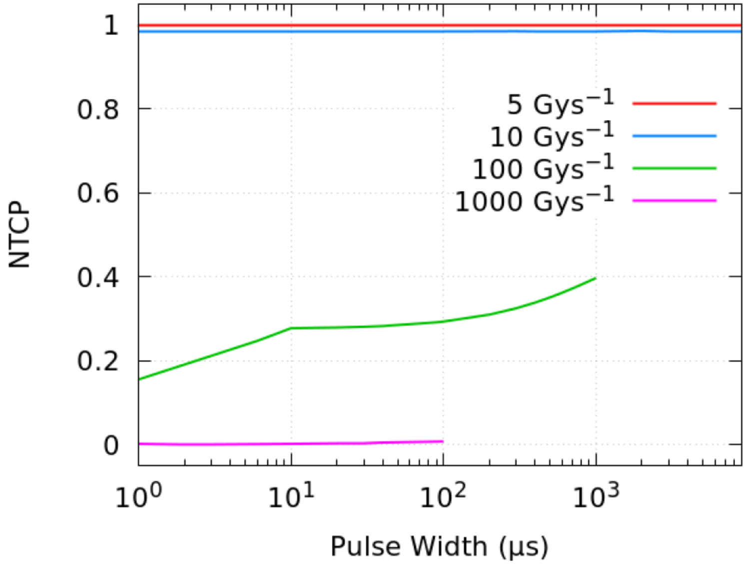
- Deeply influenced by beam pulse structure
  - Average dose rate
  - Dose rate in the pulse
  - Pulse repetition frequency
  - Dose per pulse



Time evolution of the ROO• radical for different degrees of pulsatility (10 Gy)



NTCP vs dose per pulse for different mean dose rates (10 Gy)



NTCP vs pulse width for different mean dose rates (10 Gy)

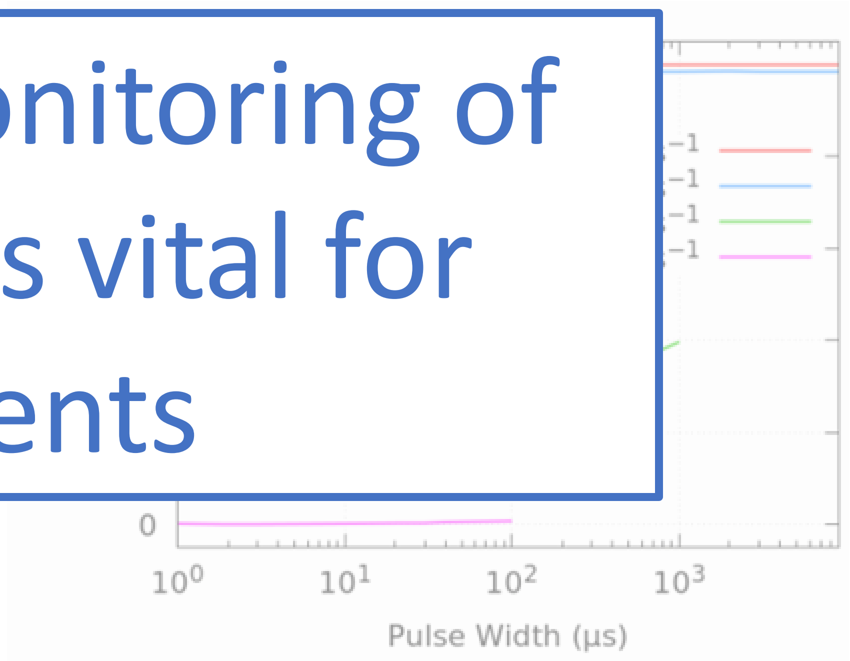
Espinosa-Rodríguez et al. Int. J. Mol. Sci. 2022, 23, 13484

FLASH Effect

- Deeply influenced by beam pulse structure
  - Average dose rate
  - Dose rate in the pulse
  - Pulse repetition frequency
  - Dose per pulse

Fast and accurate monitoring of the time structure is vital for FLASH treatments

Time evolution of the ROO• radical for different degrees of pulsatility



NTCT vs pulse width for different mean dose rates

Espinosa-Rodríguez et al. Int. J. Mol. Sci. 2022, 23, 13484

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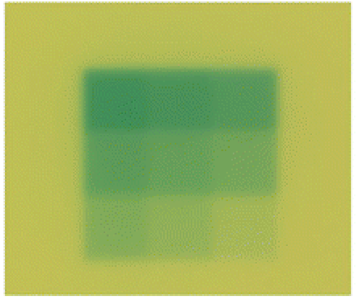
Online beam monitoring detector. FLASH irradiations

Requirements:

- Extended dynamic range
- High temporal resolution
- Radiation hardness

Radiochromic film dosimetry & TLD



Not online information

Conventional ionization chambers

Recombination

Ultra-thin parallel ionization chamber[1]

Prototype

Diamond detectors

Under research at UHDR

[1] F. Gómez et al. *Med. Phys.* 2022, 49: 4705

Online beam monitoring detector. FLASH irradiations

Requirements:

- Extended dynamic range
- High temporal resolution
- Radiation hardness

Organic plastic scintillators

Online beam monitoring detector. FLASH irradiations

Requirements:

- ✓ Extended dynamic range
- ✓ High temporal resolution
- ✓ Radiation hardness

Organic plastic scintillators

\+

- ✓ Water equivalent
- ✓ Energy independent
- ✓ Dose and dose rate linearity
- ✓ Wide variety of geometries and sizes

Online beam monitoring detector. FLASH irradiations

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Organic plastic scintillators

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- ✓ Water equivalent
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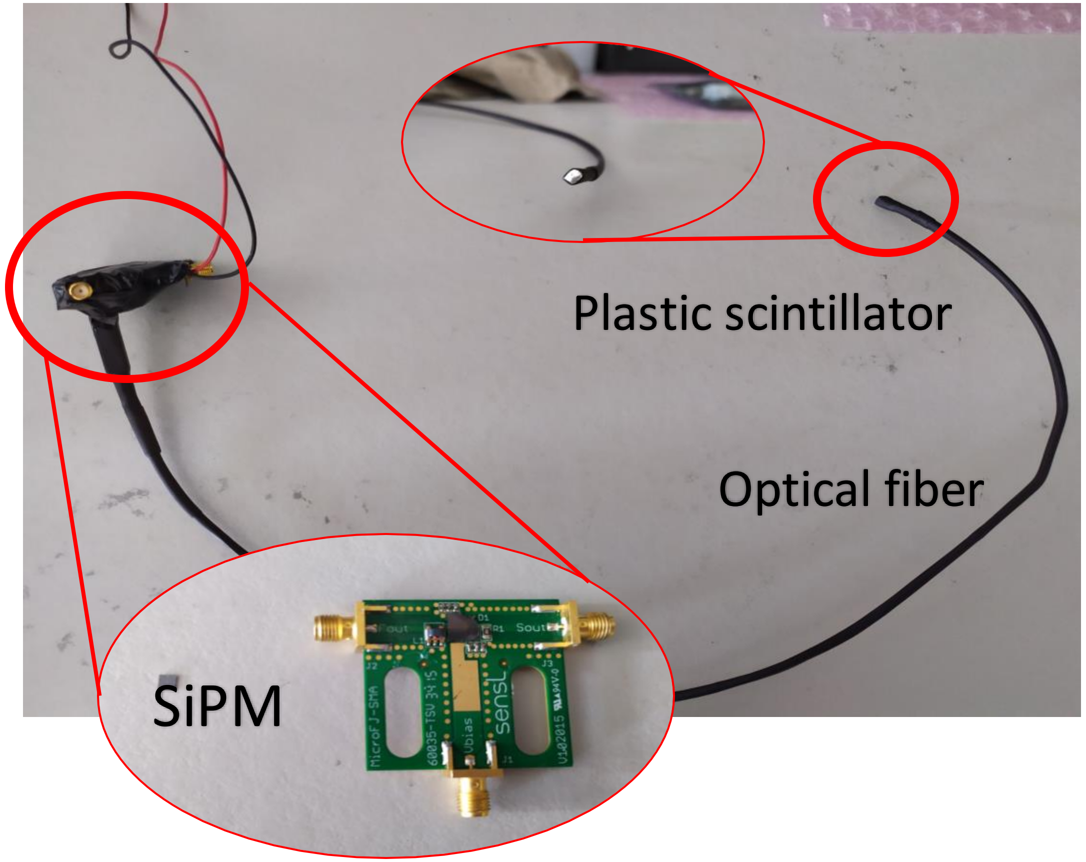
Perfect candidate for an online beam monitor detector

Detector system

Detector proposed: Plastic scintillator coupled to a SiPM via an optical fiber



Scheme of the detector. It consists of a plastic scintillator (right) attached via an optical fiber to a SiPM (left).

Detector system

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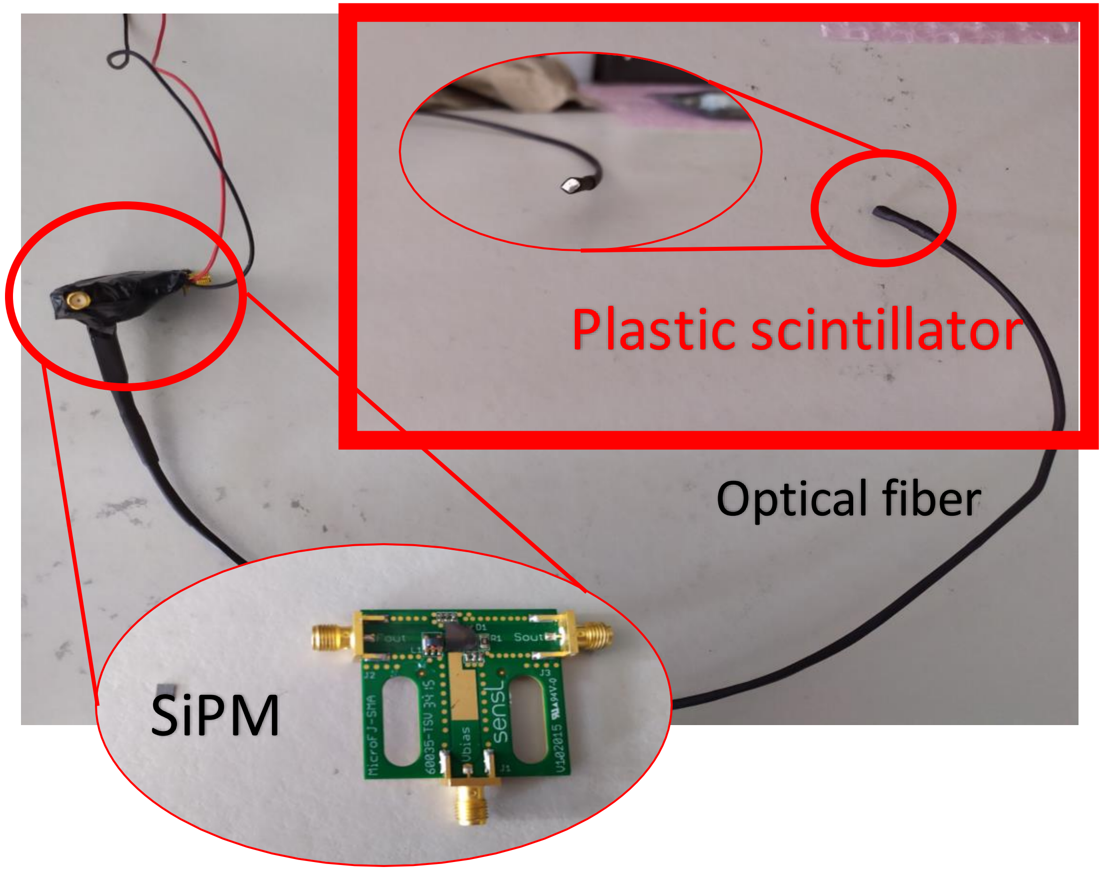
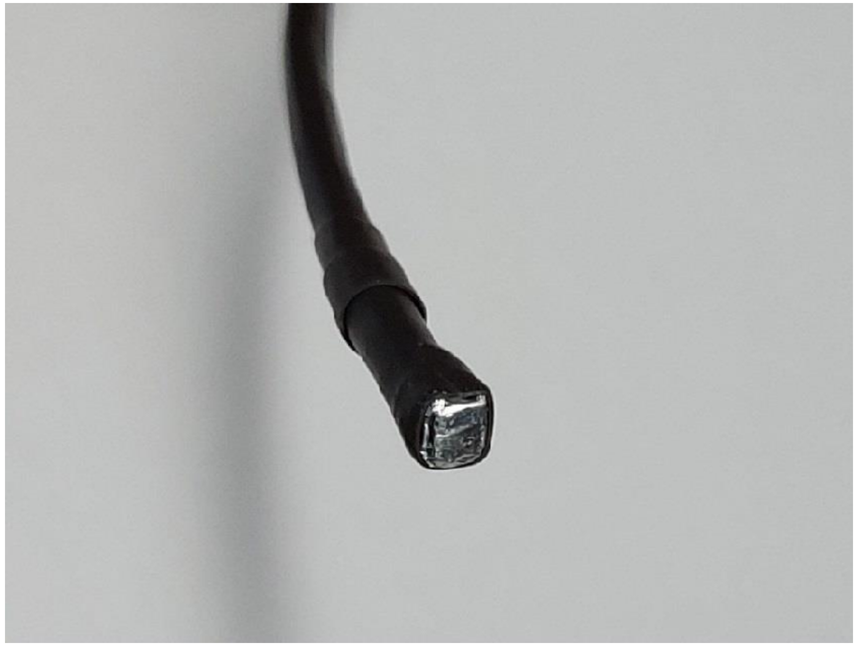
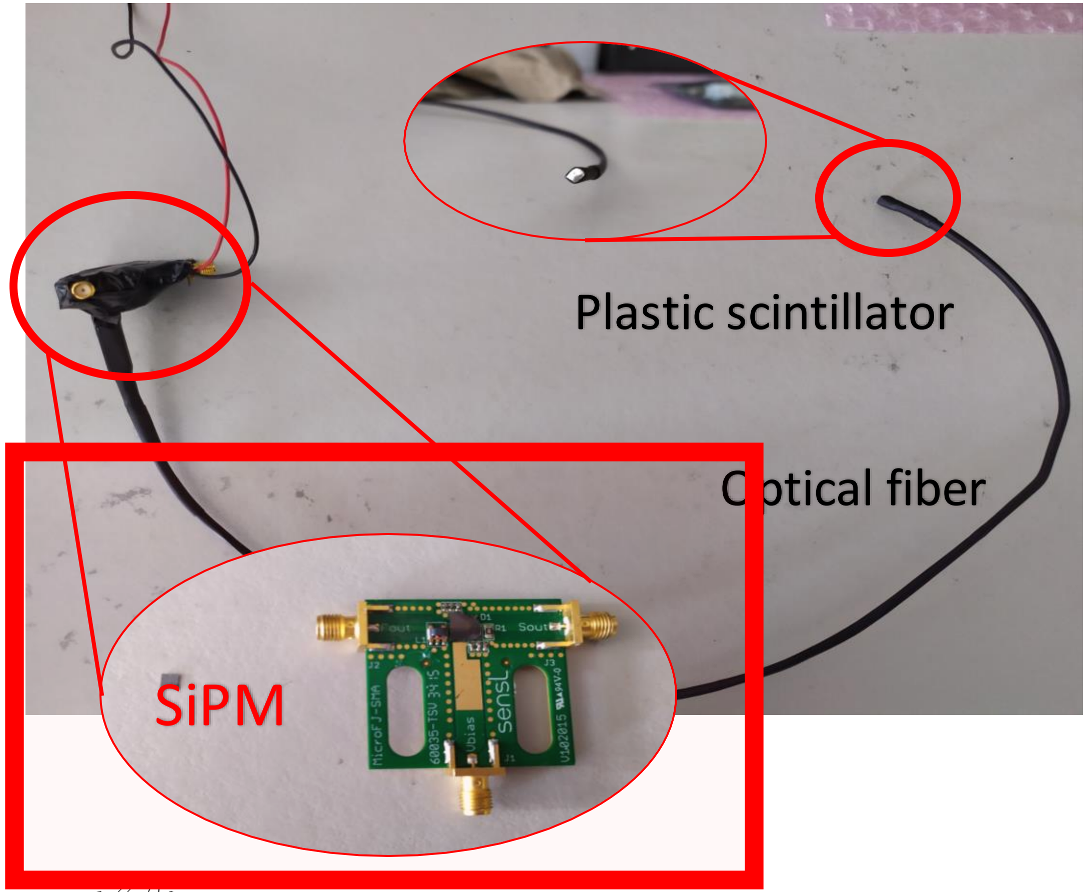


3 x 3 x 3 mm³ fast plastic scintillator
Eljen Technology EJ-232Q quenched with 0.5% benzophenone



Detector system

Detector proposed: Plastic scintillator coupled to a SiPM via an optical fiber



3 x 3 mm² SiPM
MicroFJ-SMA-30035, Onsemi (former sensL)
Biased at 28 V (Tenma 72-2550)
Mounted on a PCB board (MicroFJ-SMA-30035-GEVB, Onsemi)

Detector system

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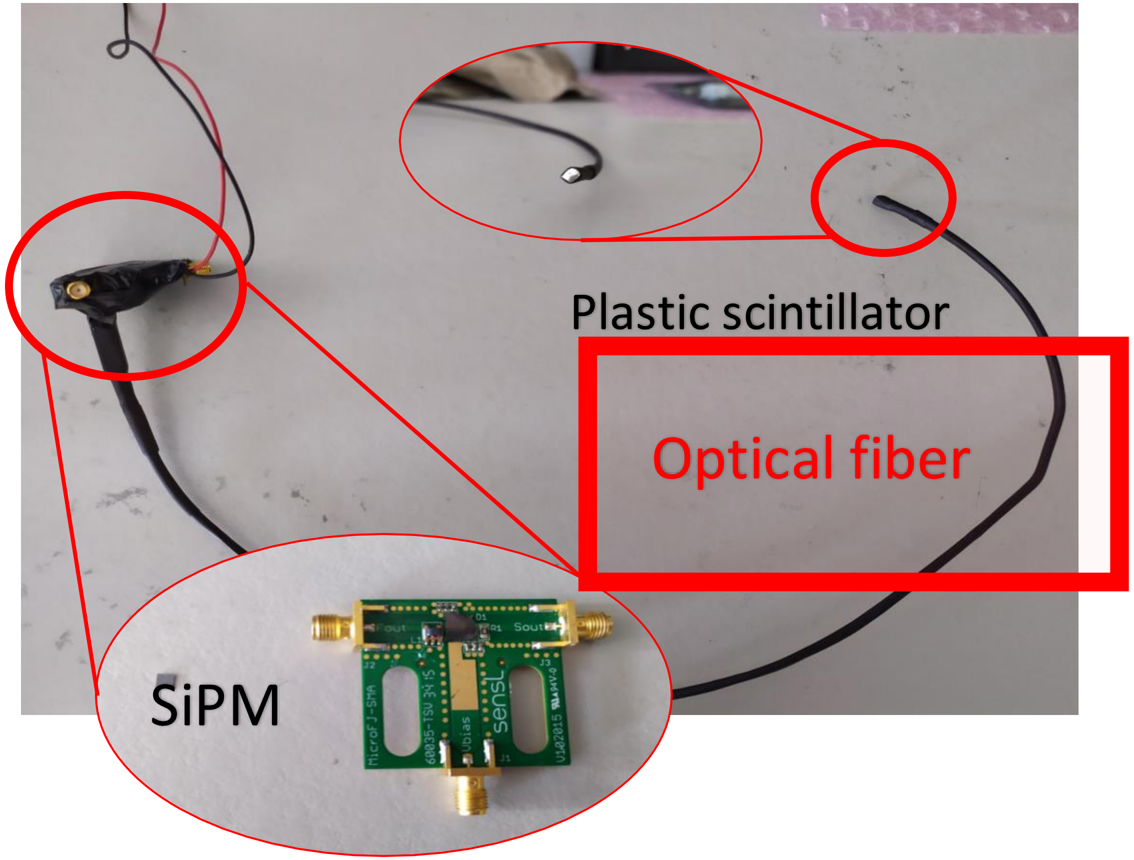

Optical fiber
Assembly of 10 optical fibers.
Diameter 0.8 mm each
Length: 63 cm
Norland Optical Adhesive 61 applied between the optical fibers, SiPM and plastic.

Detector system

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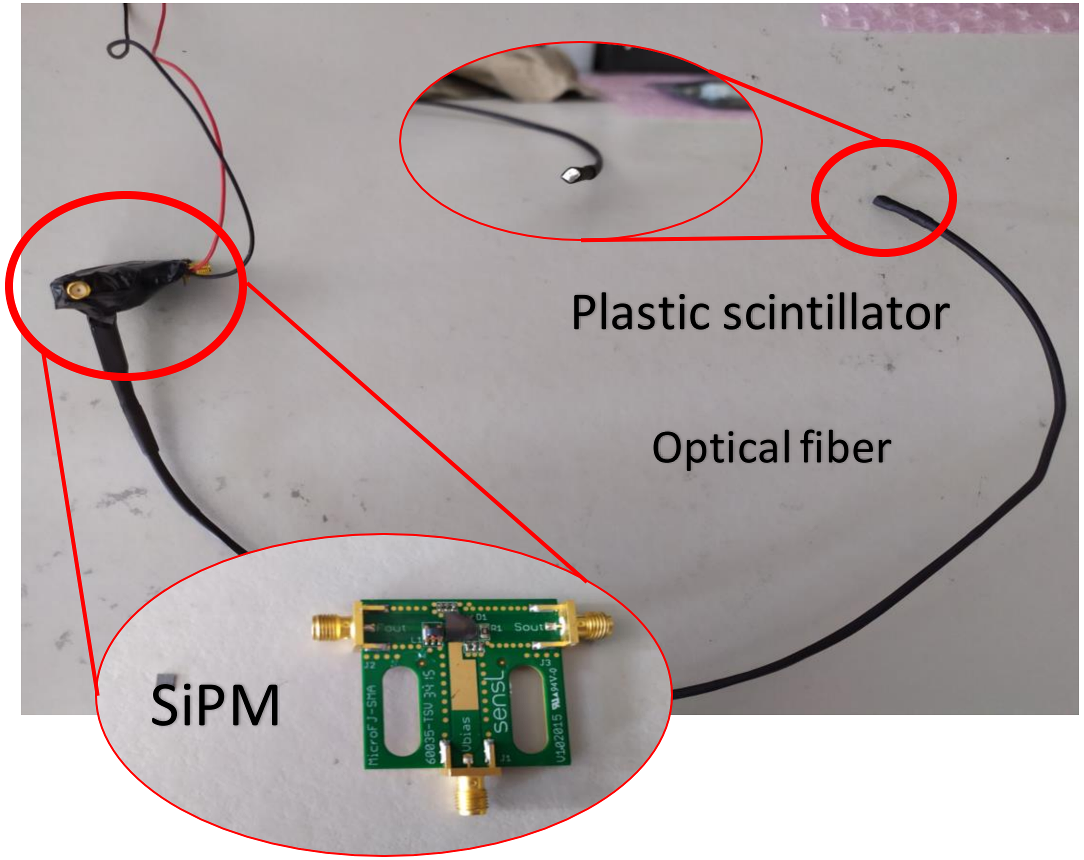
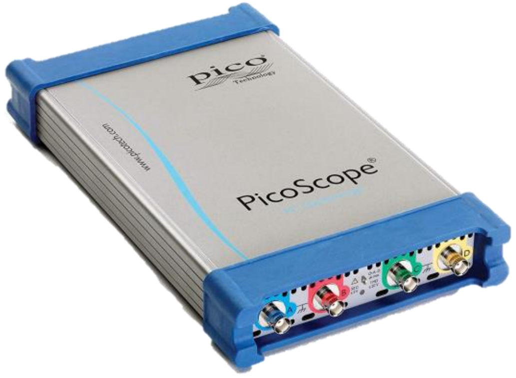
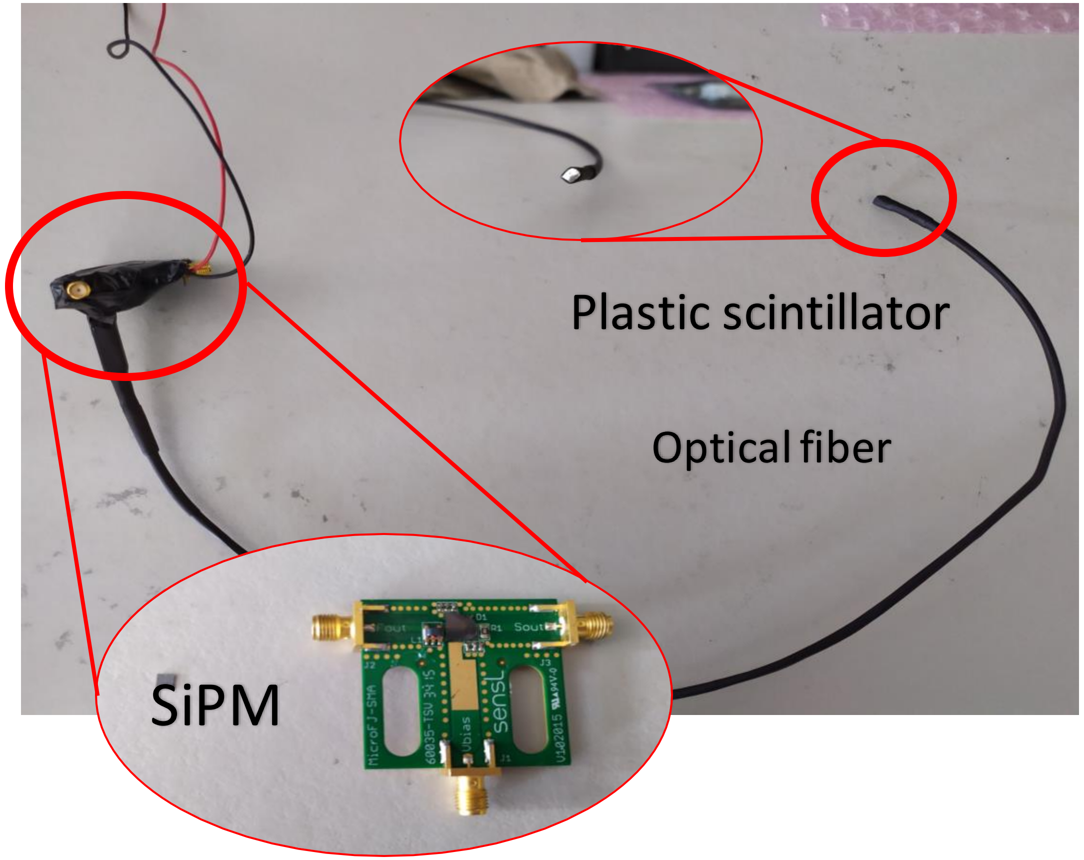




Processing board
(Picoscope 6403D)
8-bit digital scope
Bandwidth 350 MHz
Sampling rate 5GS/s

Detector system



Objective

Evaluation of the **timing capabilities** of a novel plastic scintillator fiber optic detector coupled to a SiPM and read out by an ultrafast data acquisition system in a clinical proton beam.

Clinical Facility

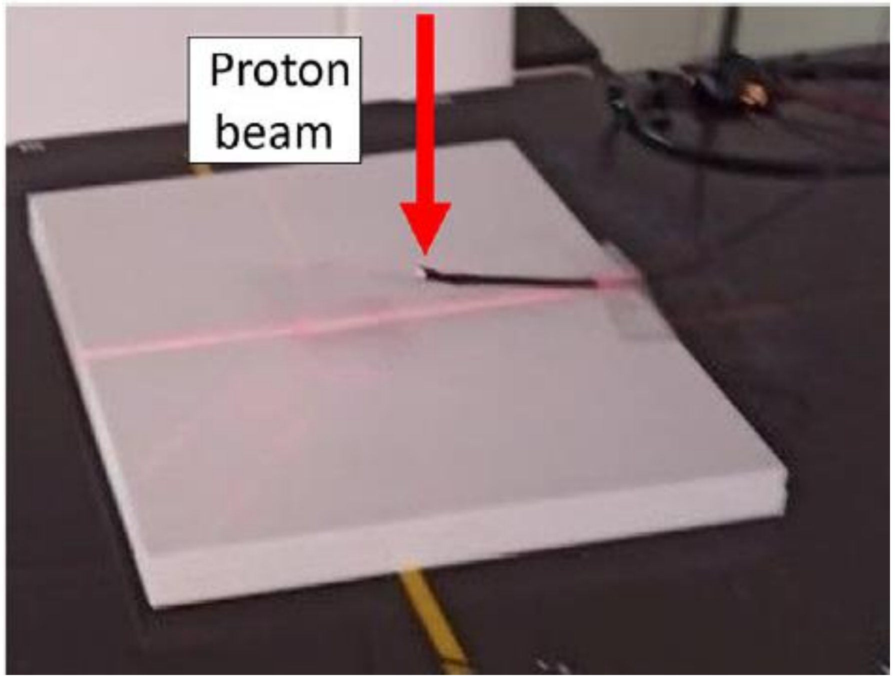
Quironsalud Protontherapy Center (Madrid)

IBA Proteus-One

Synchrocyclotron S2C2, RF 60-90 MHz
Proton energies: 70-230 MeV
Pulse repetition rate: 1000 μs
Pulse width: 10 μs

Experiment

Quironsalud Protontherapy Center (Madrid)



Irradiation conditions:

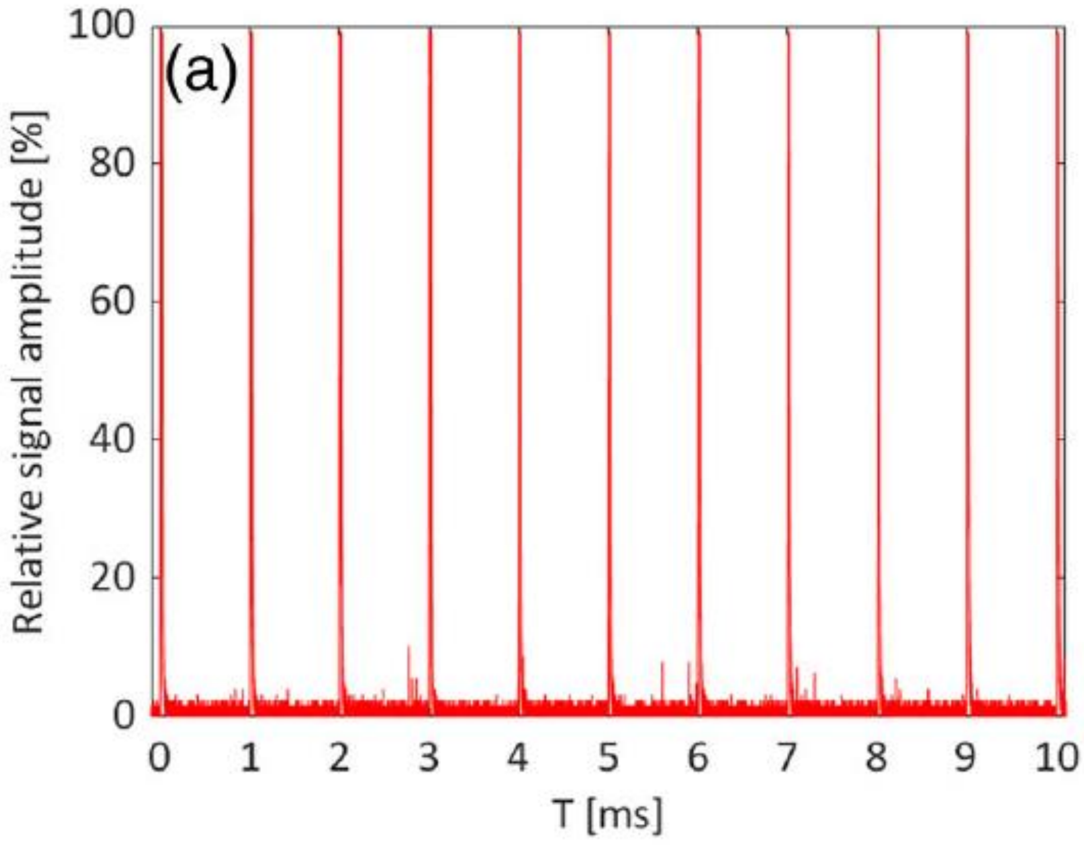
70 MeV proton beam
8 mm^2 sigma spot size
Beam current: 8.98 nA
Detector perpendicular to the beam
Irradiations at the isocenter

Two recording lengths:

- Sampling rate of 4.76 MS/s (210 ns in between samples)
- Sampling rate of 1.25GS/s (0.8 ns in between samples)

Experiment. Results

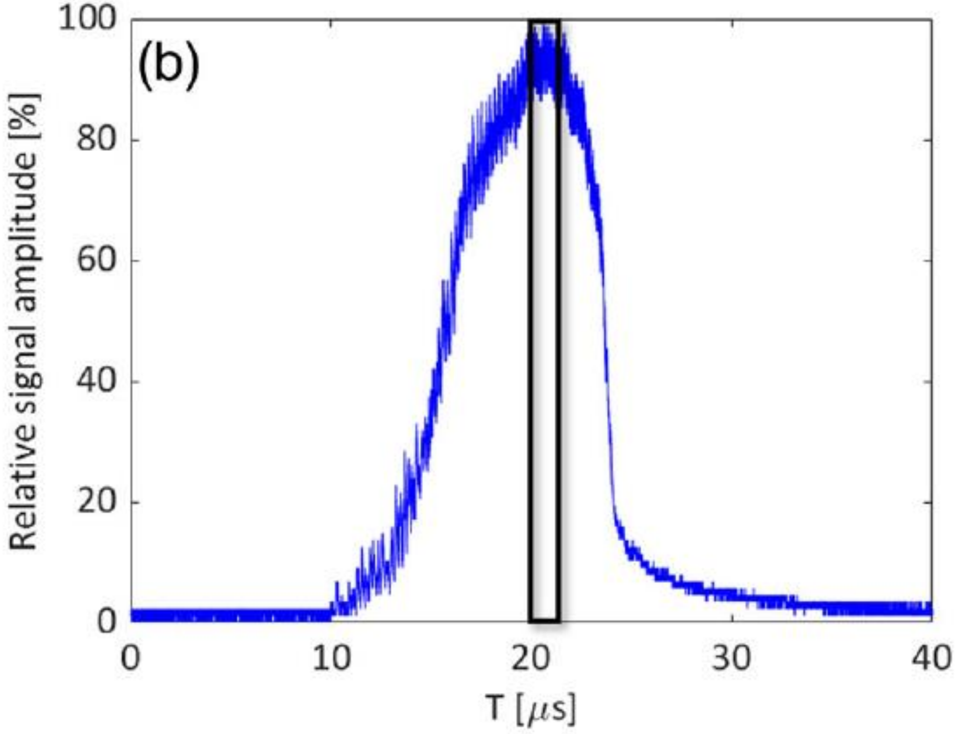
Characteristic pulse structure. 10 ms region



- Signal intensity for a sequence of 10 spots
- 1 ms repetition rate.
- 10 μs width macro-pulses
- Sampling period 210 ns

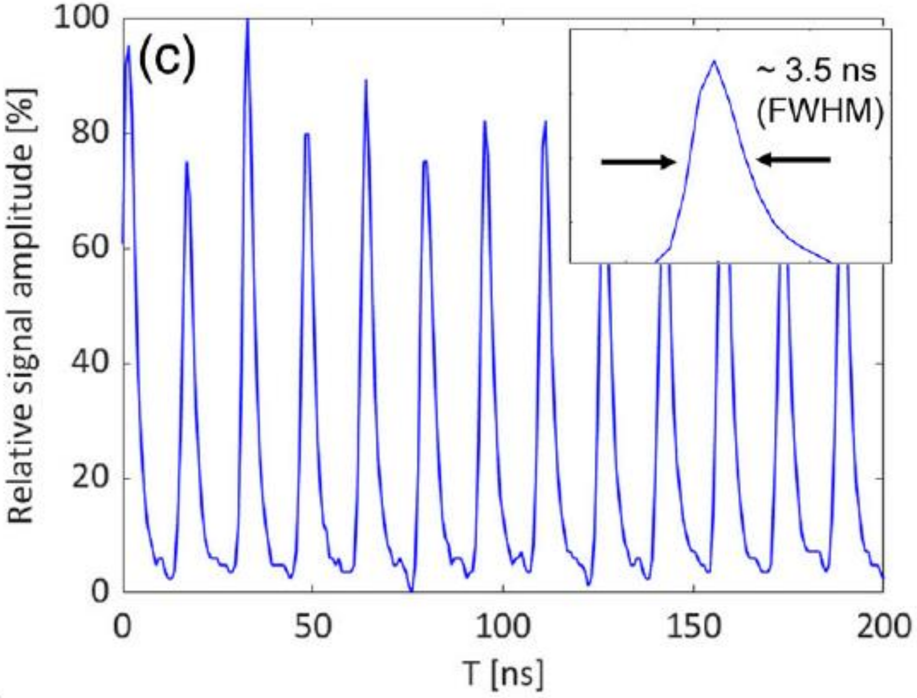
Experiment. Results

Individual measurement of a single pulse



- Characteristic width of 10 μs
- Ripples are observed due to the accelerator RF system

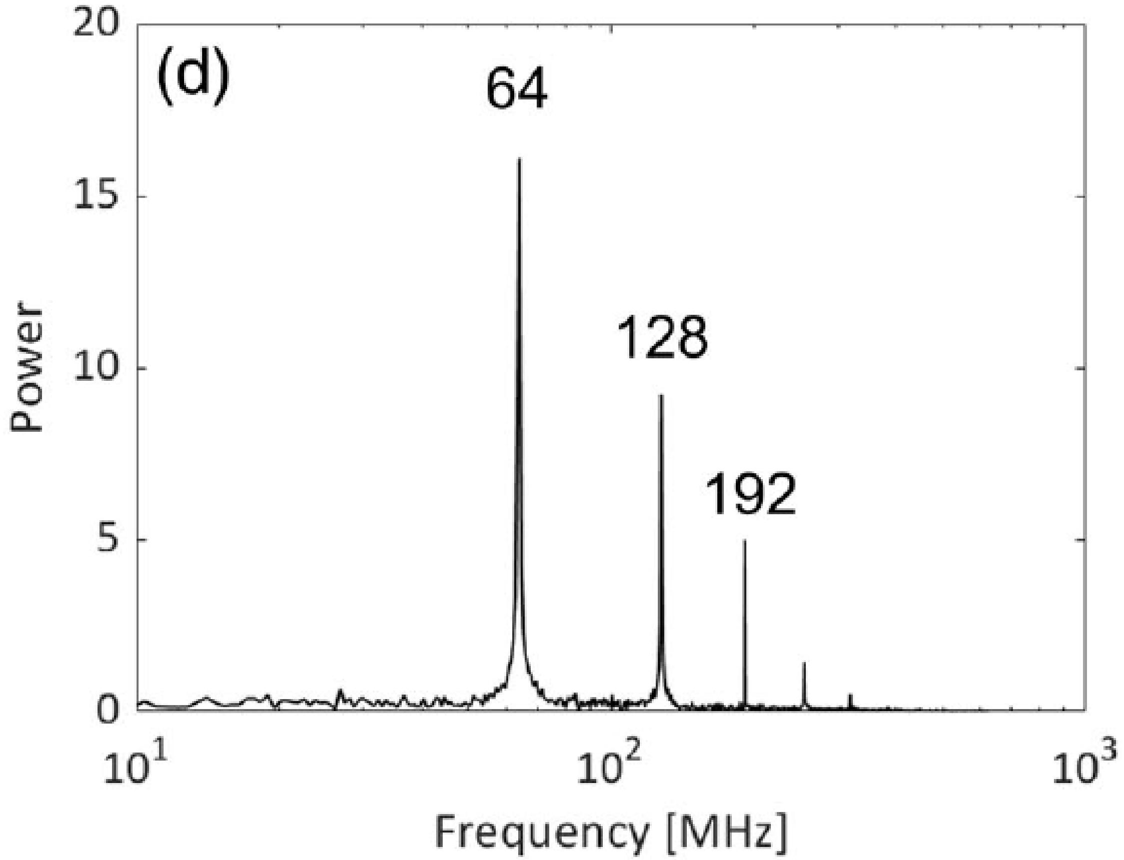
200 ns zoom. Micro-bunch



- Micro-bunch period of 16 ns
- FWHM of about 3.5 ns.

Experiment. Results

Frequency spectra



- Fast Fourier Transform (FFT) spectrum analyzer tool in MATLAB (R2021b).
- Analysis of 2048 samples ($\sim 1.6\ \mu s$)
- Sampling period 0.8 ns
- Good agreement with the synchrocyclotron frequency

Each pulse presents a sub- µs structre, with a characteristic frequency of 64 MHz, measured with a sampling period of 0.8 ns

Conclusions & Future work

The proposed system was able to measure the fine time structure of a clinical proton accelerator online and with sub-ns time resolution.

What's

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TECHNICAL NOTE

MEDICAL PHYSICS

Technical note: Measurement of the bunch structure of a clinical proton beam using a SiPM coupled to a plastic scintillator with an optical fiber

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Abstract

Background: Recent proposals of high dose rate plans in protontherapy as well as very short proton bunches may pose problems to current beam monitor

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Conclusions & Future work

The proposed system was able to measure the fine time structure of a clinical proton accelerator online and with sub-ns time resolution.

What's next?

- **Other combination of SiPM + optic fiber**

Time resolution (FWHM) for different SiPM + plastic scintillator measured from coincidences for 511 keV gamma photons from a ^{22}Na source

	SiPM	Fiber	Length (cm)	Time resolution (ps)
	S13360-3075CS	Plastic coupled directly		58 (10)
	MicroFJ-SMA-30035	Plastic coupled directly		128 (4)
	S13360-3075CS	Set of fibers	60	638 (5)
This work	MicroFJ-SMA-30035	Set of fibers	60	715 (5)
	S13360-3075CS	Solid	10	176 (4)
Next work	S13360-3075CS	Solid	60	329 (5)

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Conclusions & Future work

The proposed system was able to measure the fine time structure of a clinical proton accelerator online and with sub-ns time resolution.

What's next?

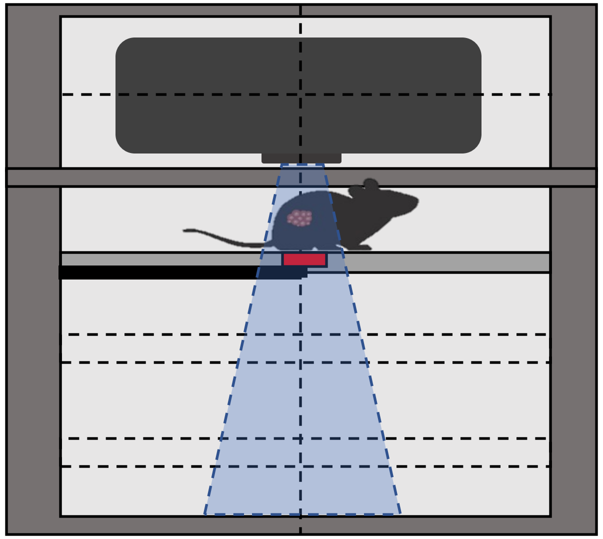
- Other combination of SiPM + optic fiber
- **Study potential to measure absolute dose**

Conclusions & Future work

The proposed system was able to measure the fine time structure of a clinical proton accelerator online and with sub-ns time resolution.

What's next?

- Other combination of SiPM + optic fiber
- Study potential to measure absolute dose
- **Incorporate the detector in a FLASH X-ray based preclinical irradiator**



Thank you for your attention!

Espinosa-Rodriguez, *Radiat. Phys. Chem.*, 2023 110760.

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