Microdosimeters for Fluence Rate Measurement and Linear Energy Transfer mapping

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Francesco MAZZA-SCHUH

RÉGION NORMANDIE

CINaM

IPHC
Institut Pluridisciplinaire
Hubert CURIEN
STRASBOURG

LPC
CAEN

Introduction

- For Hadron therapy:
  - Preclinical irradiation platforms are a fundamental element in the development of new treatments.
  - It is essential to control dosimetry with high precision on these platforms.
  - Development of instruments capable of accurately measuring irradiation parameters under challenging conditions, such as low-energy radiation fields and short particle ranges.
  - The objective here is to develop a microdosimeter that could be used to perform this type of measurement.

I. The project and its objectives

1) Material

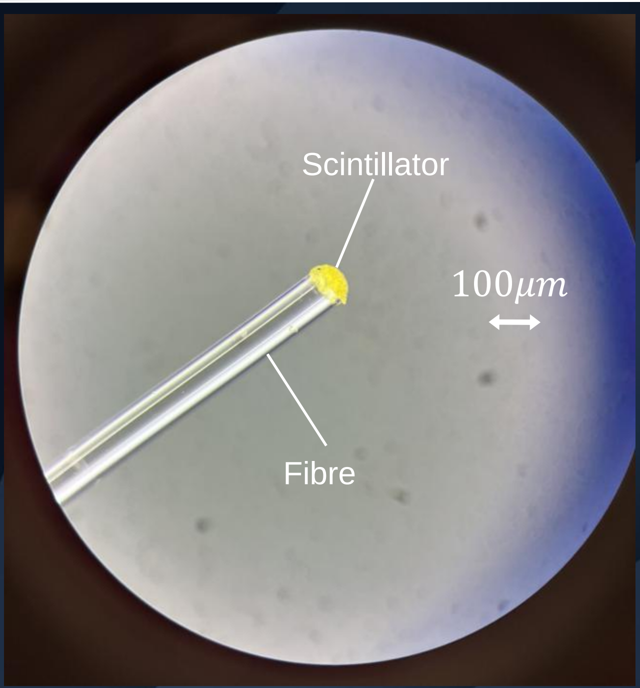


Figure 1.1 : The detector, microscope view, in yellow, the scintillator.

Detector composition:

- Optical fibre of very small dimensions
- At extremity is mounted a scintillator composed of
  - $(\mathrm{Zn},\mathrm{Cd})\mathrm{S}:\mathrm{Ag}$ or $\mathrm{Y}_3\mathrm{Al}_5\mathrm{O}_6:\mathrm{Ce}$ clusters
  - Embedded in PMMA

I. The project and its objectives

1) Material

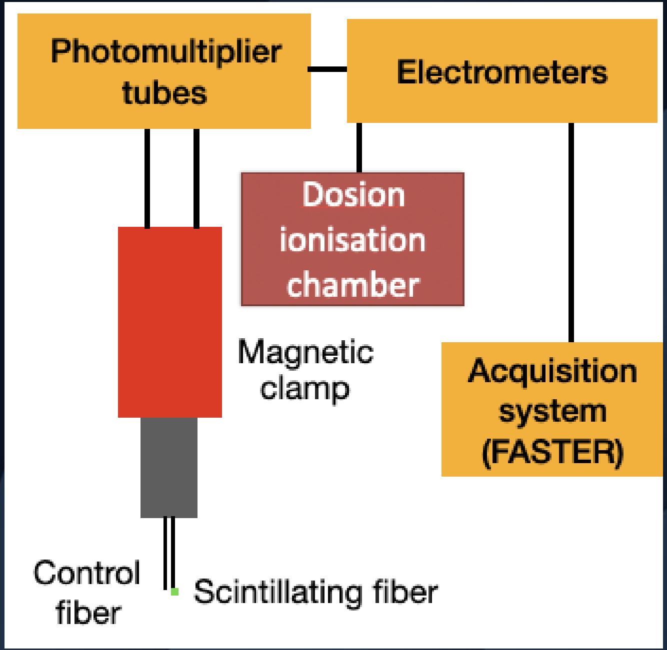


Figure 1.2 : Full signal acquisition chain

- The fiber itself is connected to a photomultiplier for signal collection
- Signal is acquired with FASTER electrometer cards.
- An ionisation chamber DOSION is used for beam intensity fluctuations monitoring
- Another fiber without a scintillator is used as a control fiber to correct stem effects

The detector measures the energy deposition rate.

$$\frac{dE}{dt} = \Delta E \times \dot{N}$$

I. The project and its objectives

2) Methods

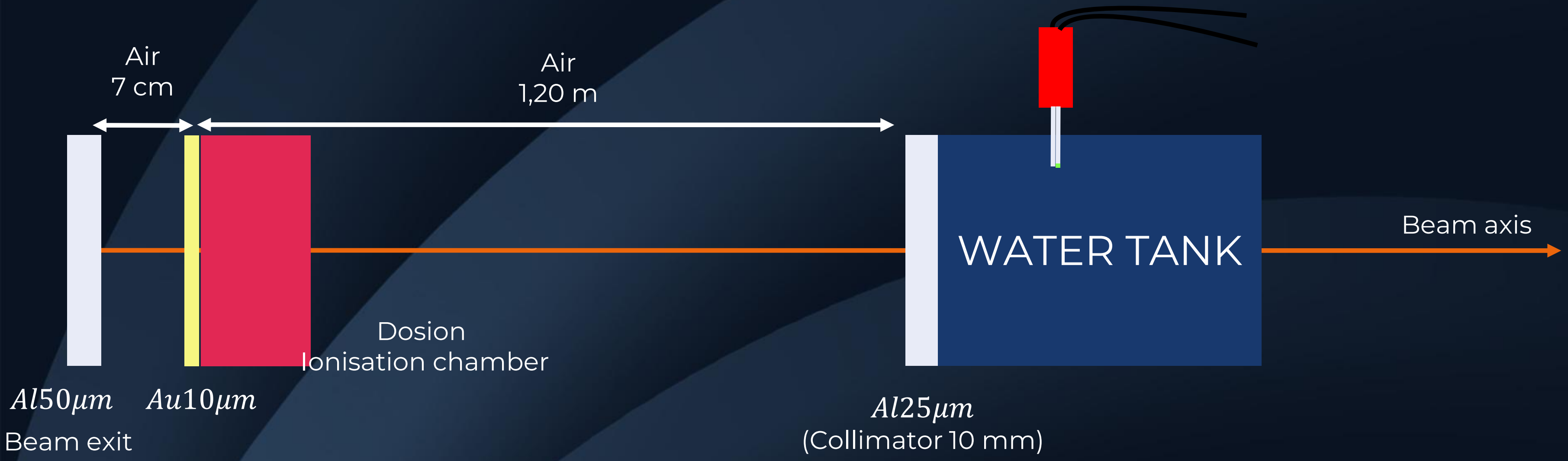


Figure 1.3 : Scheme of the experimental setup used at Arronax

- Diffused Flat Beam

I. The project and its objectives

2) Methods

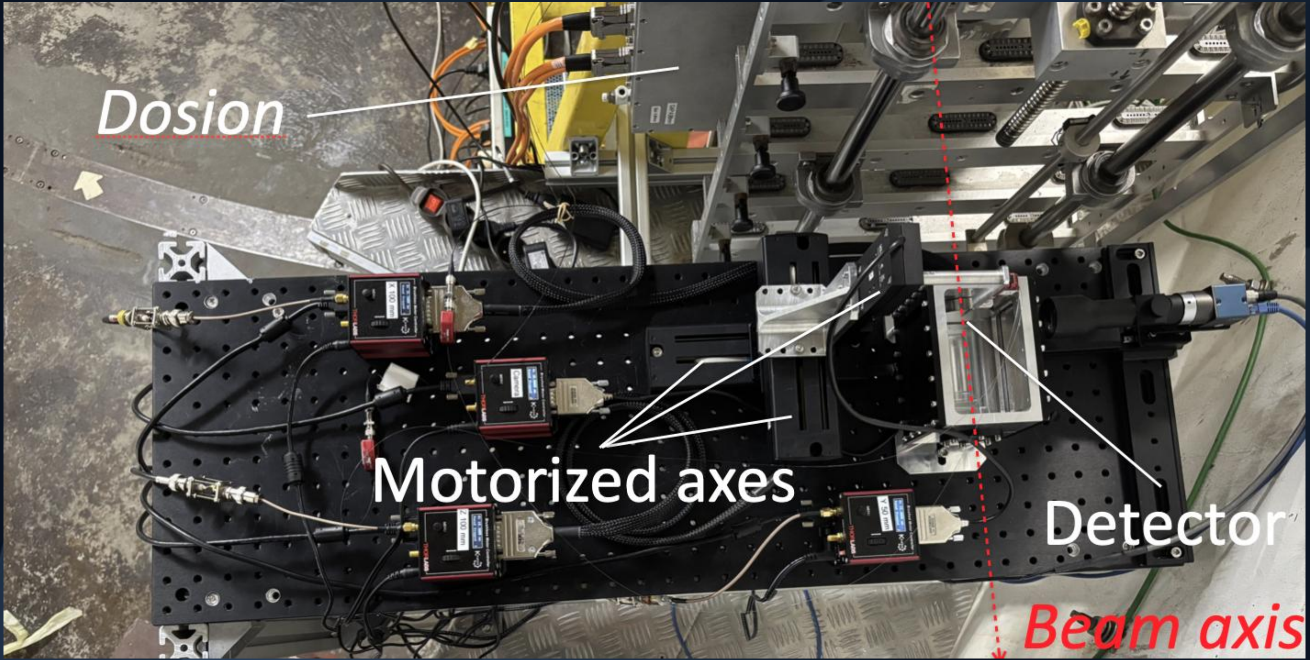


Figure 1.4 : Full experimental setup (GANIL, July 2025)

- Telecentric camera for initial detector positioning
- The motors are interfaced with the QDC cards to provide time synchronization between the motor motion and the data acquisition system.

II. Experiments and results

1) Quenching effects and modelisation

The scintillator emits photons proportionally to the energy deposited in the material.

However, at high LET values, non-radiative processes (i.e., quenching) can occur, leading to a loss of this proportionality.

Birks empiric law:

$$\frac{dL}{dx} = \frac{Y}{1 + k_B \frac{dE}{dx}} \frac{dE}{dx} \quad (2.1)$$

L is the light produced by the scintillator

Y is the photon yield

k_B Birks constant

II. Experiments and results

2) Depth measurements

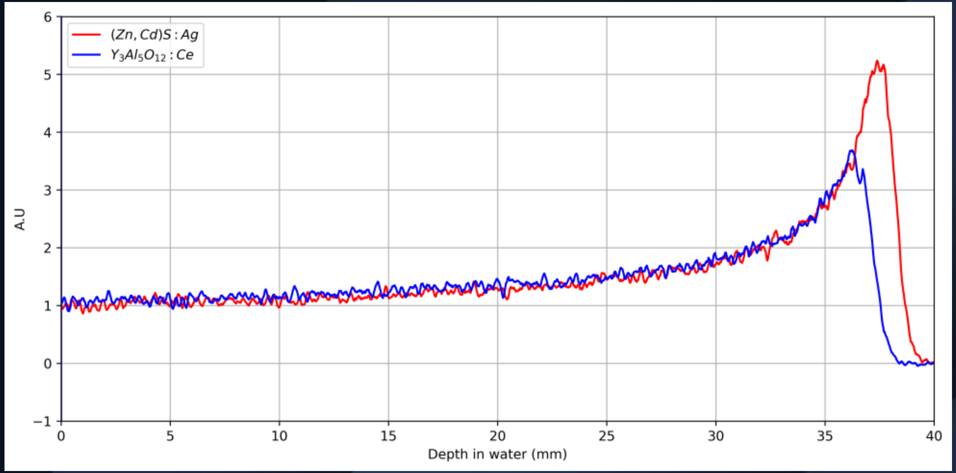


Figure 2.1: Depth measurements in water for a 68 MeV proton beam (Arronax platform)(arbitrary units).
Y axis normalised (plateau = 1)

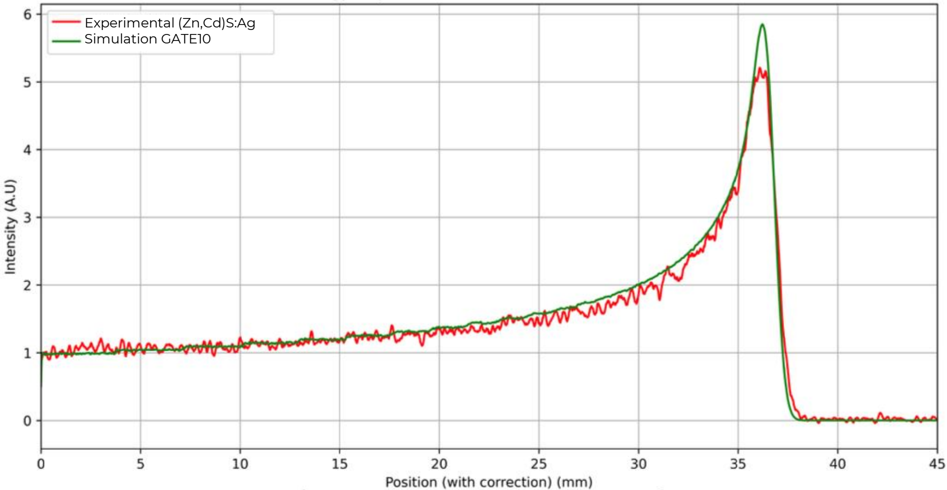


Figure 2.2 : Comparison with simulation for a 68 MeV proton beam (arbitrary units)
Y axis normalised (plateau = 1)
X-axis correction applied to align the two peaks for comparison.

II. Experiments and results

2) Depth measurements

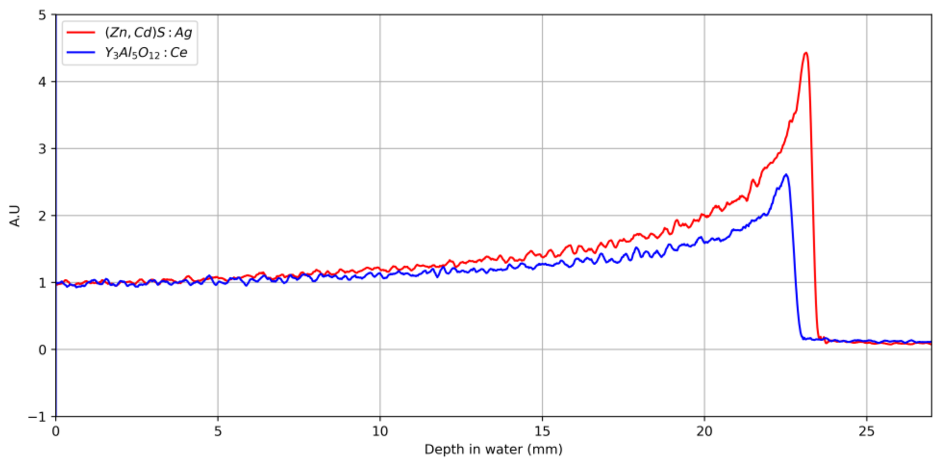


Figure 2.3: Depth measurements in water for a 95 MeV/A Carbon 12 ions beam (arbitrary units).

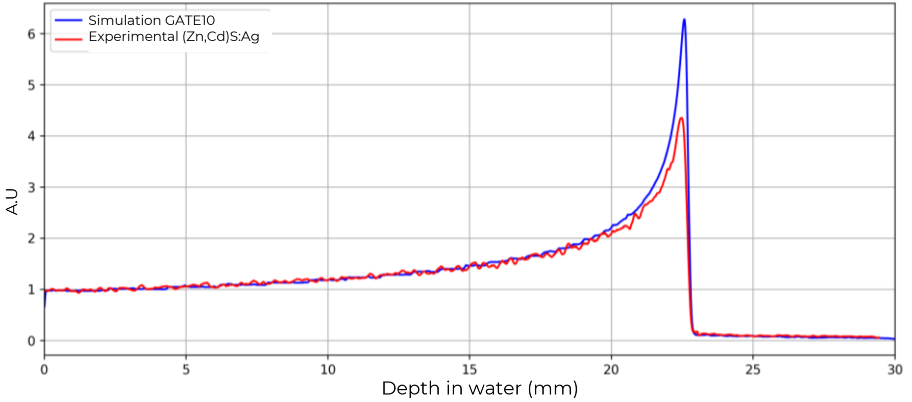
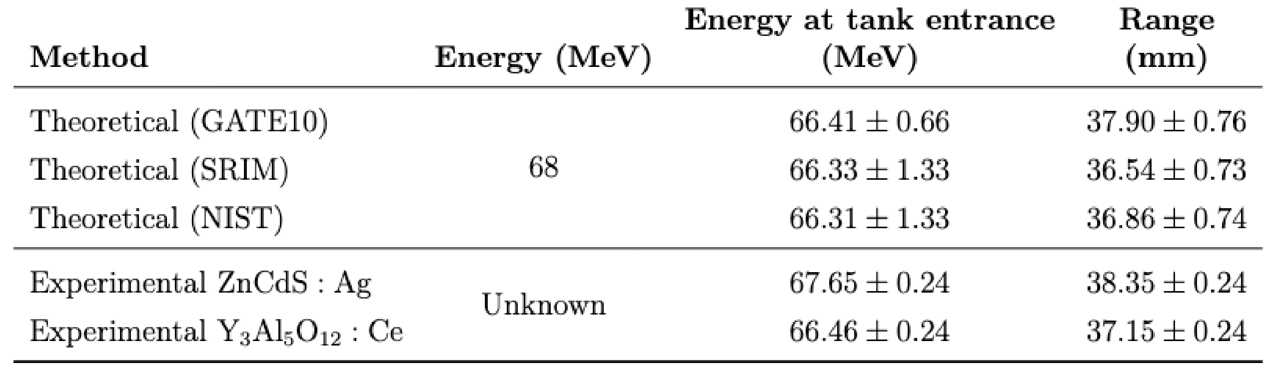


Figure 2.4 : Comparison with simulation for a a 95 MeV/A Carbon 12 ions beam (arbitrary units)

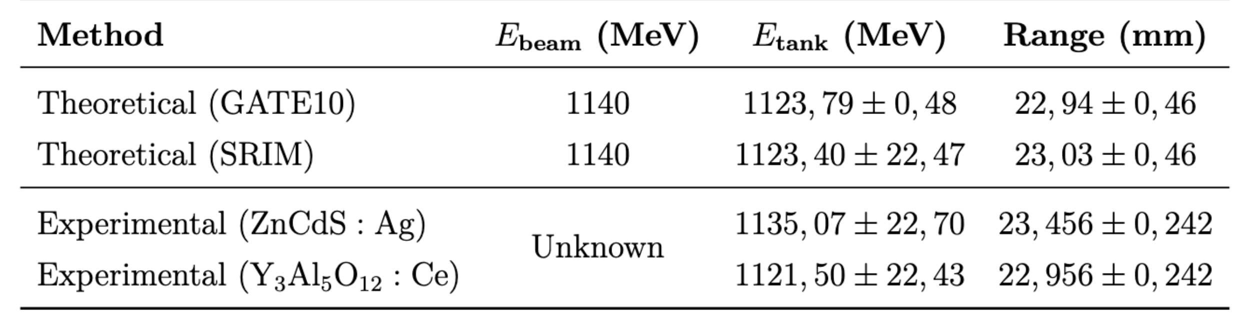
II. Experiments and results

2) Depth measurements



Method	Energy (MeV)	Energy at tank entrance (MeV)	Range (mm)
Theoretical (GATE10)	68	66.41 ± 0.66	37.90 ± 0.76
Theoretical (SRIM)		66.33 ± 1.33	36.54 ± 0.73
Theoretical (NIST)		66.31 ± 1.33	36.86 ± 0.74
Experimental $ZnCdS : Ag$	Unknown	67.65 ± 0.24	38.35 ± 0.24
Experimental $Y_3Al_5O_{12} : Ce$		66.46 ± 0.24	37.15 ± 0.24

Table 2.1: Results obtained by different methods for a 68 protons beam



Method	E_{beam} (MeV)	E_{tank} (MeV)	Range (mm)
Theoretical (GATE10)	1140	$1123,79 \pm 0,48$	$22,94 \pm 0,46$
Theoretical (SRIM)	1140	$1123,40 \pm 22,47$	$23,03 \pm 0,46$
Experimental ($ZnCdS : Ag$)	Unknown	$1135,07 \pm 22,70$	$23,456 \pm 0,242$
Experimental ($Y_3Al_5O_{12} : Ce$)		$1121,50 \pm 22,43$	$22,956 \pm 0,242$

Table 2.2: Results obtained by different methods for a 95 MeV/A Carbon ions beam

II. Experiments and results

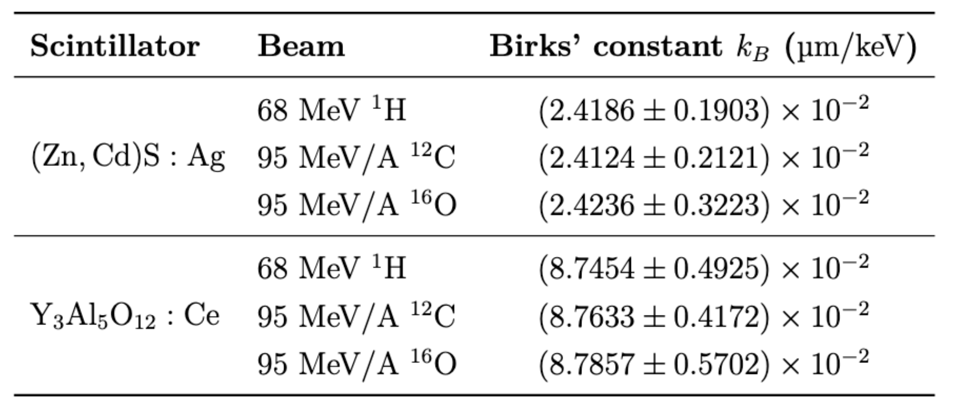
2) Depth measurements

- Calculating the LET inside the scintillator at different depths using Monte Carlo simulations.
- Using the simulated LET and experimental measurements to fit Birks' law and estimate the quenching constant k_B

$$Y = A_{Factor}^{Normalisation} \times \frac{LET}{1 + k_B LET}$$

II. Experiments and results

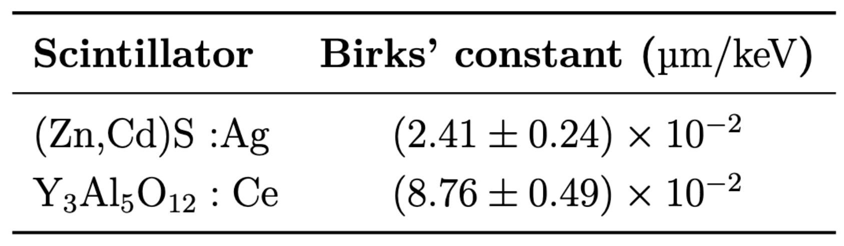
2) Depth measurements



Scintillator	Beam	Birks' constant k_B (µm/keV)
$(Zn, Cd)S : Ag$	68 MeV ^{1}H	$(2.4186 \pm 0.1903) \times 10^{-2}$
	95 MeV/A ^{12}C	$(2.4124 \pm 0.2121) \times 10^{-2}$
	95 MeV/A ^{16}O	$(2.4236 \pm 0.3223) \times 10^{-2}$
$Y_3Al_5O_{12} : Ce$	68 MeV ^{1}H	$(8.7454 \pm 0.4925) \times 10^{-2}$
	95 MeV/A ^{12}C	$(8.7633 \pm 0.4172) \times 10^{-2}$
	95 MeV/A ^{16}O	$(8.7857 \pm 0.5702) \times 10^{-2}$

Table 2.3: Birks' constant obtained for the two types of scintillator with different beams and energy

Applying the fit for each detectors with different beams and energy.



Scintillator	Birks' constant (µm/keV)
$(Zn,Cd)S :Ag$	$(2.41 \pm 0.24) \times 10^{-2}$
$Y_3Al_5O_{12} : Ce$	$(8.76 \pm 0.49) \times 10^{-2}$

Table 2.4: Birks' constant obtained for the two types of scintillator

II. Experiments and results

3) Transverse measurements

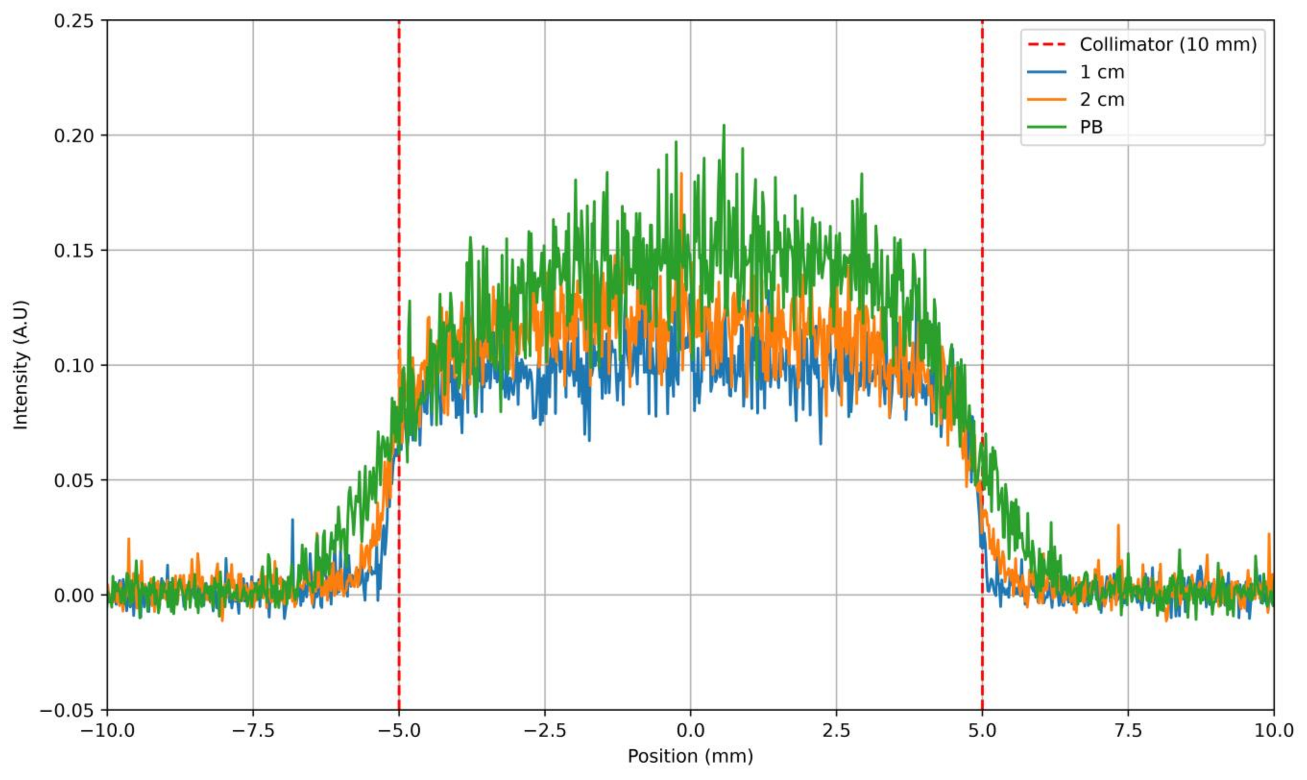


Figure 2.5: Exemple of transverse measurements of a 95 MeV/A Carbon 12 ions beam (Collimator 10 mm)

III. Futur orientations and new devices

1) BAHRCODE

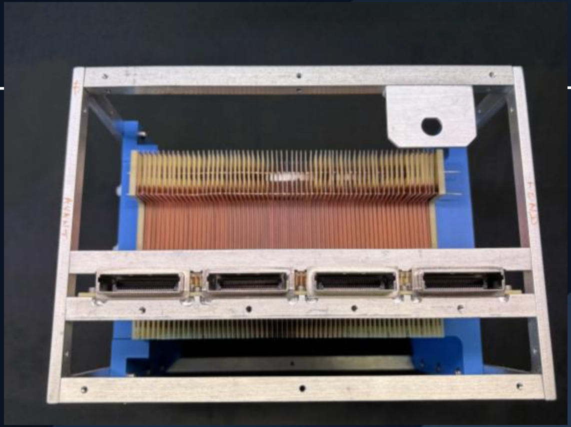
BAHRCODE : Bragg At High Resolution COmpact DEtector

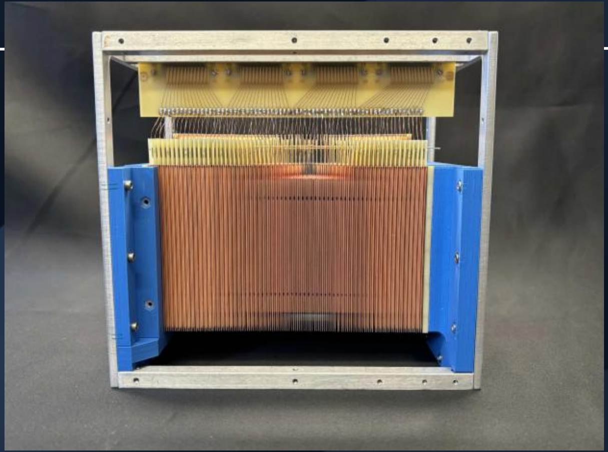
Objective: To perform very precise depth dose measurement with a high spatial resolution:

- The detector consists of 128 ionisation chambers (1 mm thickness) separated by 200 μm PCB layers, providing 128 measurement points.
- Estimation of a 400 μm Water Equivalent Thickness meaning a LET measurement on a Δx of 10^{-3} mm WET every 400 μm WET.
- Validation of simulations and results of microscintillator by comparison of the measurements.

III. Futur orientations and new devices

1) BAHRCODE





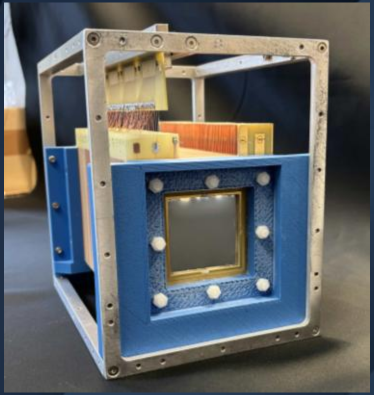


Figure 3.1 : BAHRCODE
Bragg At High Resolution COmpact DEtector

III. Futur orientations and new devices

2) BRASSMETER

BRASSMETER : Bragg Range Assessment with Scintillation Sensor for Measuring Energy Transfer and Event Rate

Objective:

- Measurement of the average LET per particles
- Validation of simulations and results of microscintillator by comparison of the measurements

III. Futur orientations and new devices

2) BRASSMETER

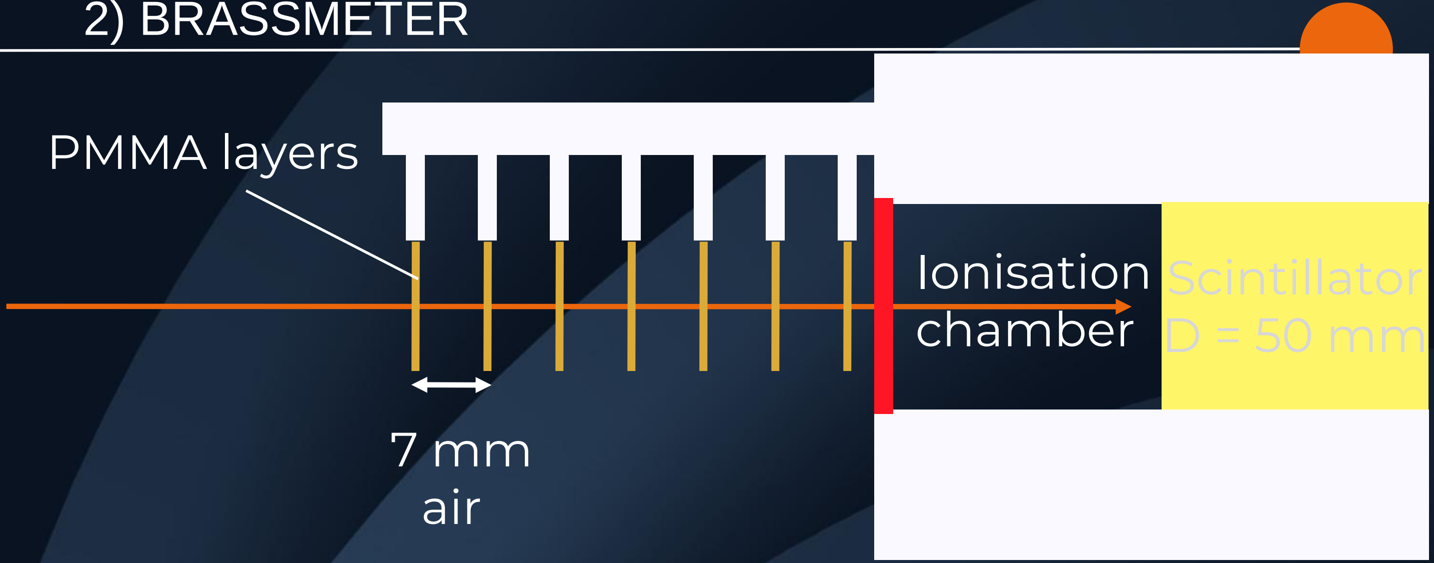


Figure 3.2 : Principles of BRASSMETER (unscaled)

Ionisation chamber to measure the deposited energyΔE during a time interval

Scintillator to measure the number of particles in the same time interval.

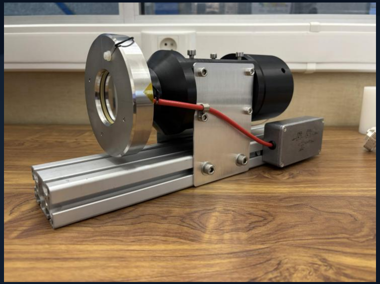
PMMA layers with thicknesses of 19.2, 9.6, 4.8, 2.4, 1.2, 0.6, 0.3, and 0.15 mm were used, providing a total thickness of 38.25 mm and enabling measurements at 150 µm intervals.

III. Futur orientations and new devices

2) BRASSMETER

Figure 3.3 : Scheme and photography of BRASSMETER

Conclusion



MICROSCINTILLATOR :

- Interesting detector for its spatial resolution
- Could measure LET at a cell scale
- Can be used for 3D measurements

BUT :

- Complex positioning of the fiber detector
- Quenching effects, correction needed

- BRASSMETER and BAHRCODE also enable LET measurements and, consequently, the determination of dose in targets significantly thicker than typical 3D cell culture models, such as spheroids and tumoroïds.
- They can and will be used to validate the simulations for microscintillators

Thanks you for your listening

Questions ? :)

De la recherche fondamentale, aux applications nucléaires pour la société

From fundamental research to nuclear applications for society