Summary of experimental results with scintillator and ALLS ionization chamber

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Frida General Meeting
04/03/2026

Overview of activities on plastic scintillator dosimetry

Plastic Scintillator Configurations:

- Scintillating fibres
- Scintillating sheets
- 3D scintillating cube

Experimental Campaigns

- Electron beams at CPFR
- Trento Proton Therapy center

Experimental tests

Scintillating fibers @CPFR

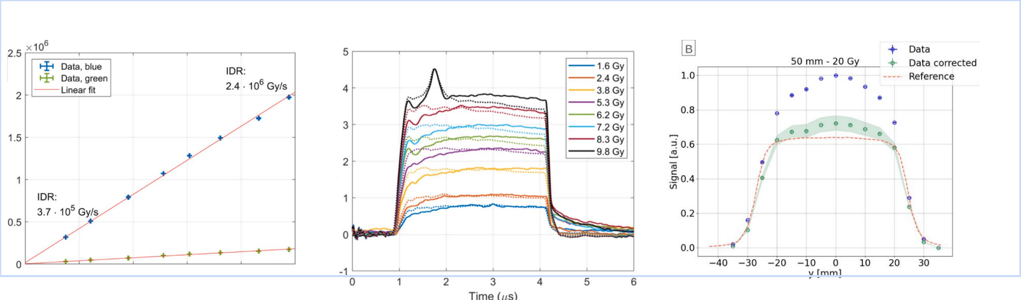
Ciarrocchi et al., 2023, and Ravera et al., 2024

Scintillating sheet @CPFR

Morrocchi et al., 2025

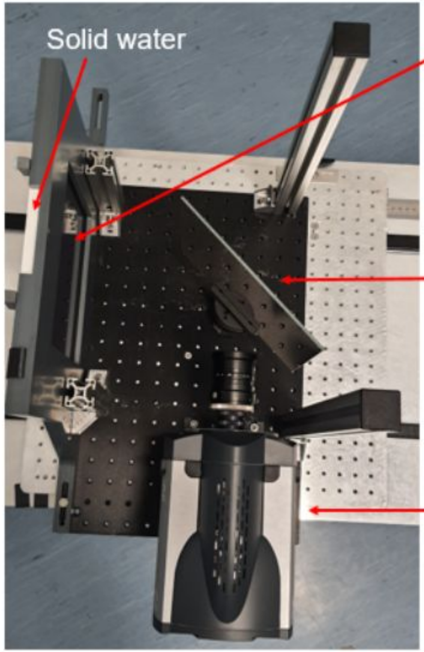
Scintillating fibers and scintillating sheet @ Trento

Scintillating block @CPFR



Further tests at CPFR with scintillating **block** – scheduled for **Friday, March 6**

Plastic scintillating sheet with electrons

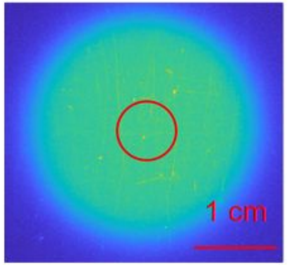


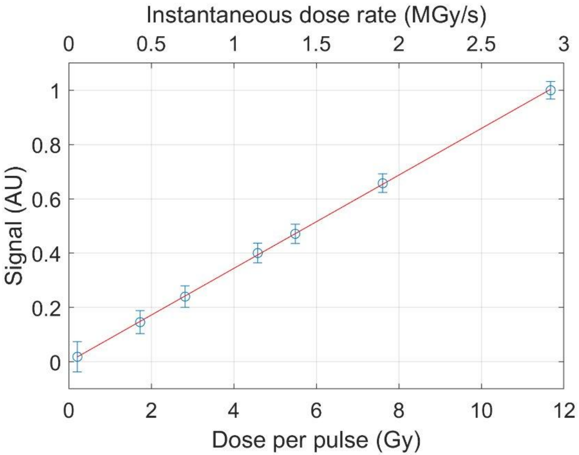
0.5-mm thick EJ212 plastic scintillator sheet

Thorlabs ME8S-G01 8" mirror

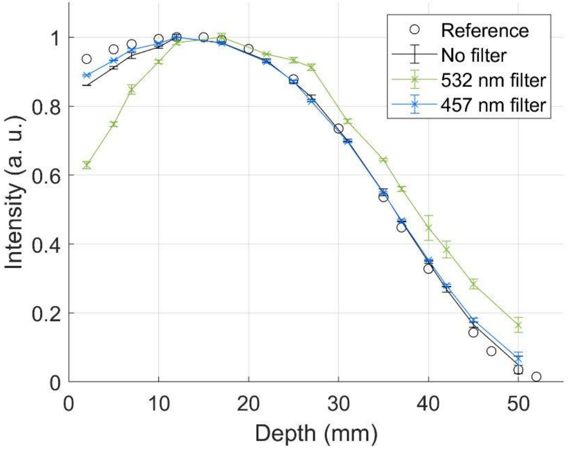
- MVL75M1 f/1.8-75mm objective
- 20-mm spacer
- Andor iXon Ultra 888 CCD camera (1 Mpixel)

- Single 4-µs pulses
- 9-MeV electron beam
- 12-mm depth

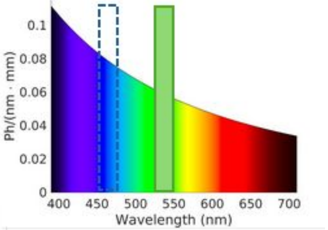




✓ Linearity at high DPP

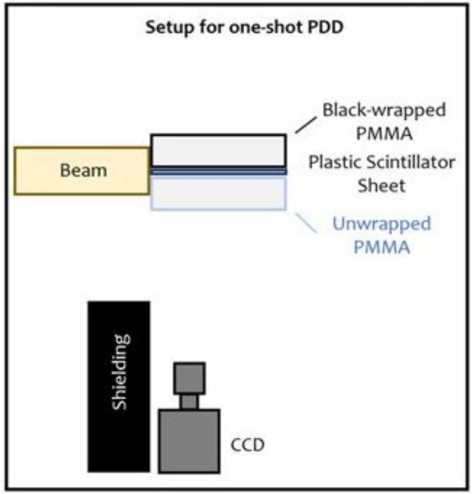


✓ Measurement and subtraction of the Cerenkov contribution

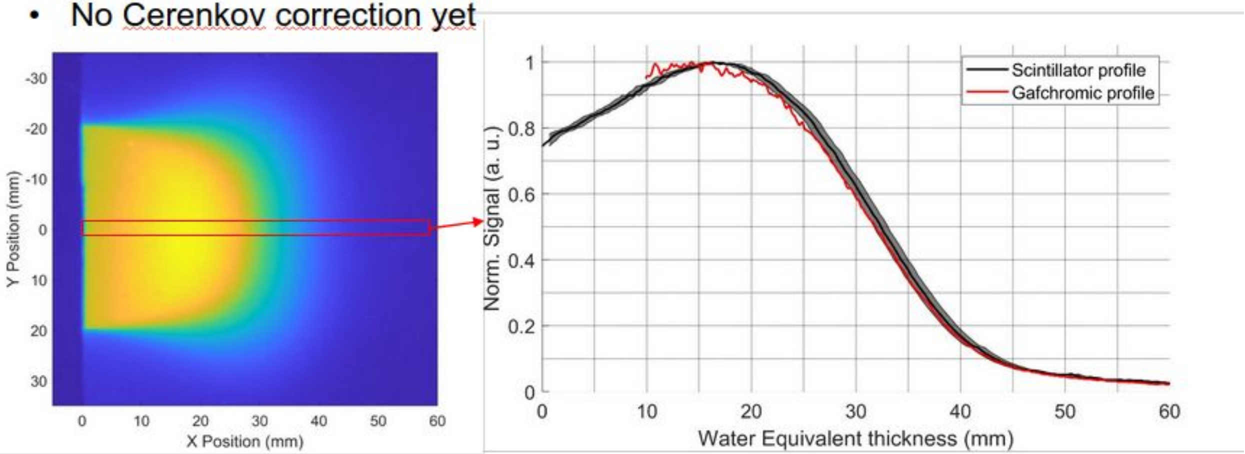


Percentage depth dose: longitudinal

- Single 4-μs pulses
- 9-MeV electron beam
- 3-mm thick scintillator
- Max dose ~5 Gy
- Different imaging system



- 2-mm vertical averaging of profiles
- Uncertainties in the alignment of the scintillator and gafchromic film images
- No Cerenkov correction yet



[mm]	R_{80}	R_{50}	R_{20}
Gafchromic	25.0 ± 0.8	31.8 ± 0.2	38.6 ± 0.2
Scintillator	26.2 ± 0.7	32.3 ± 0.7	39.0 ± 0.7

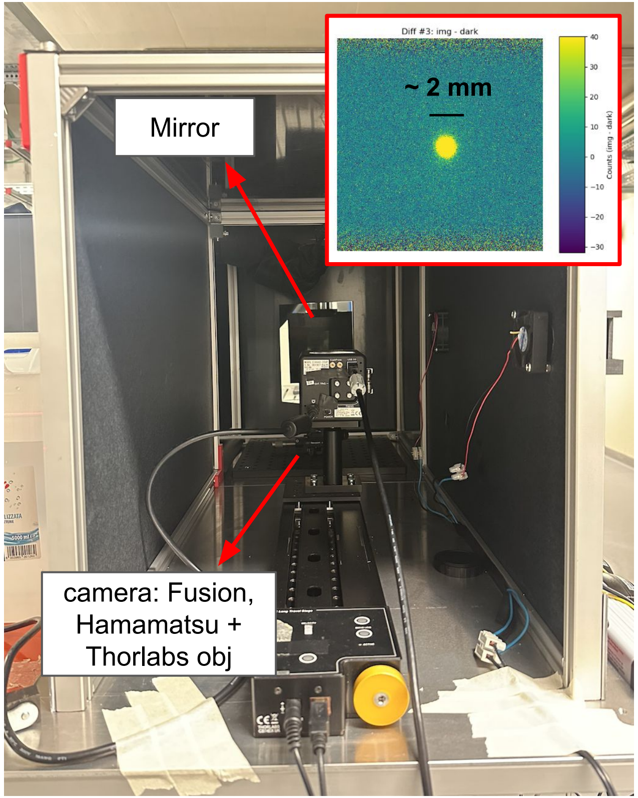
Morrocchi et al., 2025

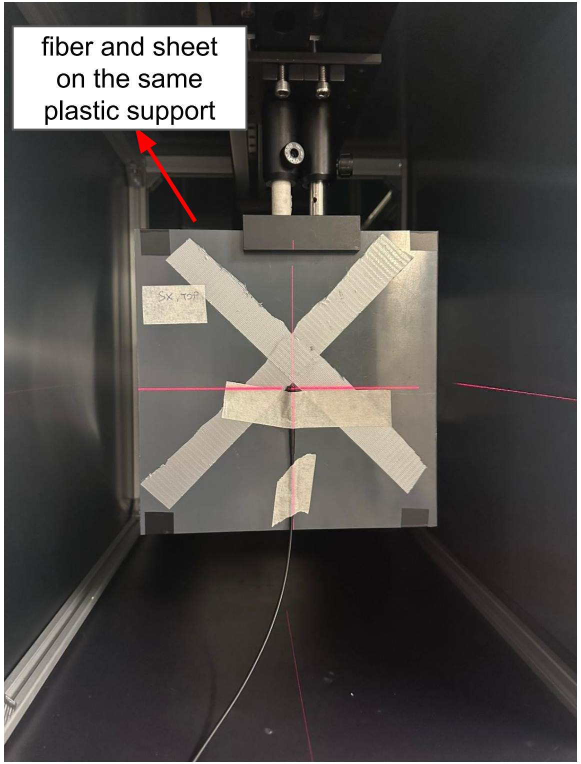
NEW

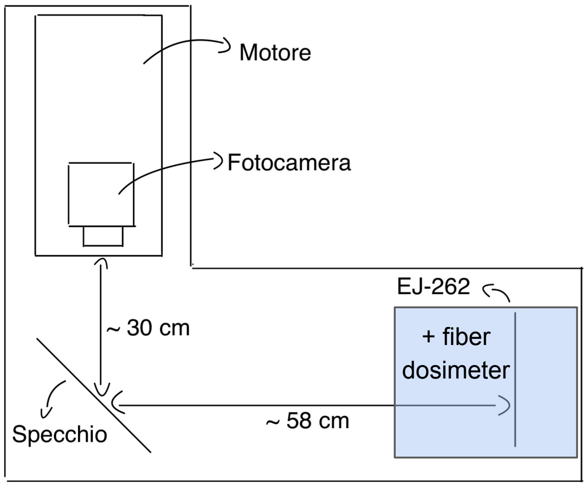
Scintillating Setup at TIFPA

PROTONTERAPIA TRENTO

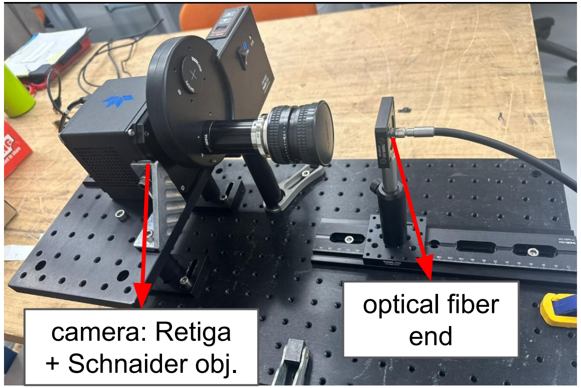
- sheet: EJ-2 10x10 cm^2, thickness 0.5 mm
- 5 mm scint. fiber, diameter 1 mm, Kuraray SCSF-78J







Water tank dimensions: **25 × 30 × 45 cm³**



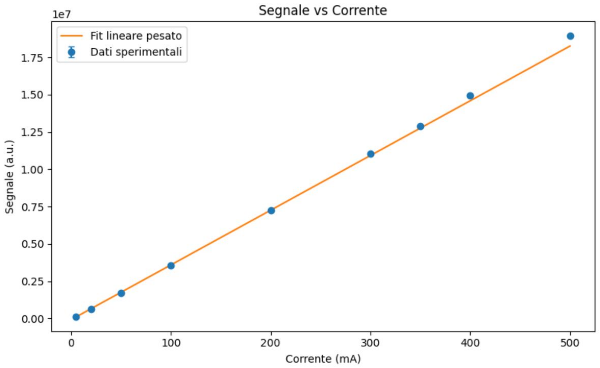
- **Direct measurement of scintillation light from the sheet**, with redirection via a mirror
- **Optical fiber (15 m)** used to transport the signal to the fiber dosimeter

Linearity with protons at TIFPA

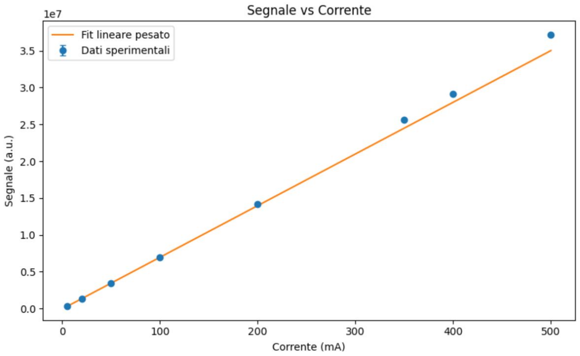
PROTONTERAPIA TRENTO

- E = 228 MeV, in FLASH regime
- Pulse duration: 10 ms
- Measurements performed in the **plateau region**
- Three measurements per working point
- Dark signal monitoring
- The raw signal (not dose-normalized) shows a linear trend in both configurations

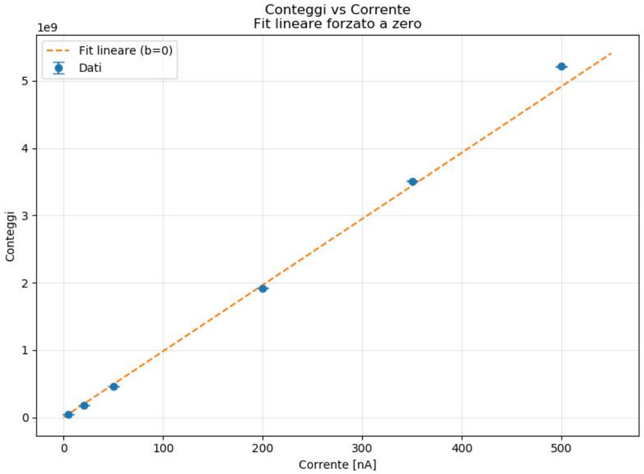
Fibers in water



Fibers in air



Sheet in air

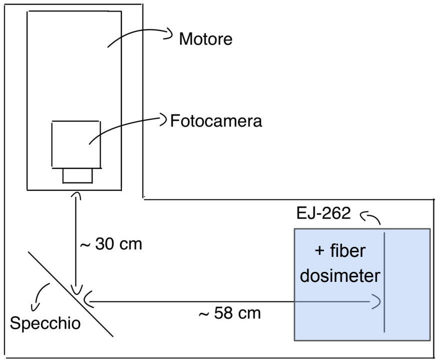


Energy dependence study – analysis ongoing

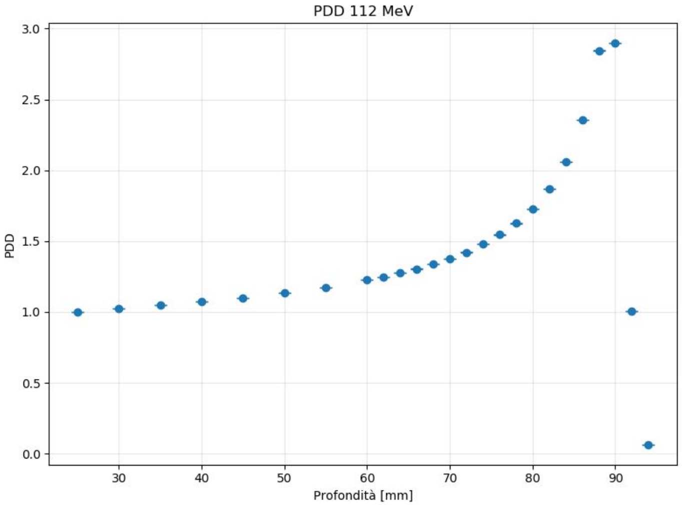
Bragg peak measurements with plastic sheet

PROTONTERAPIA
TRENTO

- Measurements with the p**lastic scintillating sheet in the water tank**, at different depth
- **Discontinuous depth sampling** in the peak region limits the accuracy of the Bragg peak reco.
- **Expected peak-to-plateau ratio ≈ 4 → resolution too low for reliable comparison**
- PDD uncertainty was quantified from the local PDD gradient

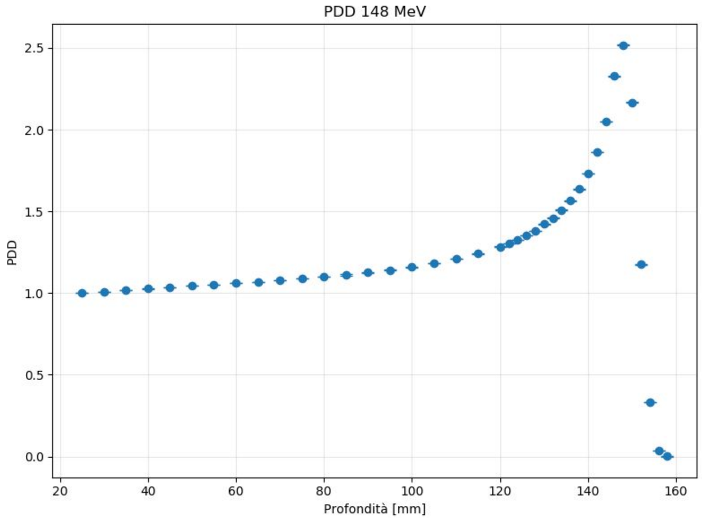


Water tank dimensions: **25 × 30 × 45 cm³**



@ 112 MeV

- Maximum slope at **z = 92 mm**
- d(PDD)/dz ≈−0.71 mm^{-1}
- **→ ~7% PDD variation per 0.1 mm shift**



@ 148 MeV

- Maximum slope at **z = 152 mm**
- d(PDD)/dz ≈−0.46 mm^{-1}
- **→ ~5% PDD variation per 0.1 mm shift**

3D real-time dosimetry with a plastic scintillator block

Goal: Obtain full 3D information on the deposited dose distribution:

- Extract **PDD curves**
- Extract **transverse profiles**
- Characterize **complex fields and shaped beams**
- Enable **single-pulse 3D reconstruction** (relevant also for radioprotection in FLASH)

Proposed Approach

- **Scintillator:** EJ-200 cube (10 × 10 × 10 cm^3)
- **Acquisition:** lateral light maps through a **pinhole imaging system**
- **Reconstruction:** tomographic algorithm (MLEM) to retrieve the **3D dose distribution**

Methodological Workflow

Implementation of the reconstruction algorithm for the present application

Algorithm validation and study on the Impact of the experimental setup on reconstruction *(num of views, num of pixel, distance from the scintillator)*

Study of Optical Photon Transport Effects:
Focus on refraction at the scintillator–air interface
→Must be corrected or, preferably, experimentally mitigated

Experimental Setup Refinement and Final Testing

Reconstruction with Geant4 Simulated Data

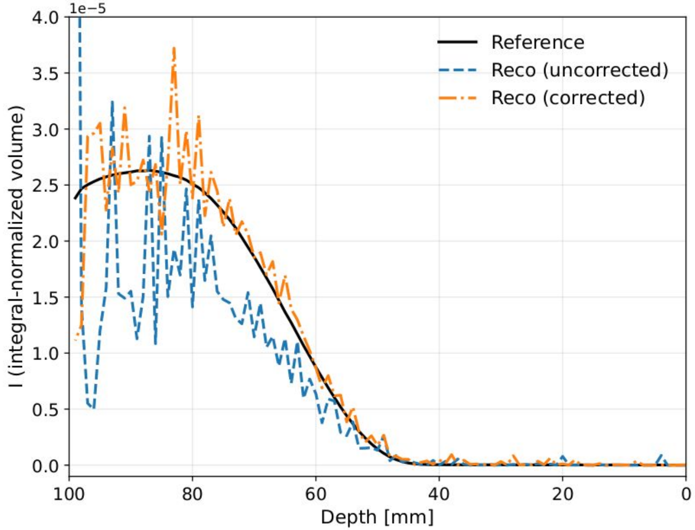
Reconstruction conditions:

- 4 long views + 1 transversal
- **200x200** pixel camera
- simulated dose of **2 mGy**
- applying refraction correction to simulated light maps

→ **γ-index > 90% (3% /3 mm)** with 4 L + 1 T

Higher accuracy acquiring more lateral projections:

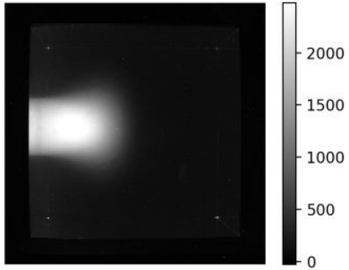
→ γ-index > 90% (1% /1 mm) with 8 L + 1 T



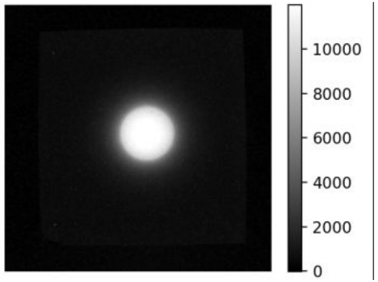
Experimental test @CPFR

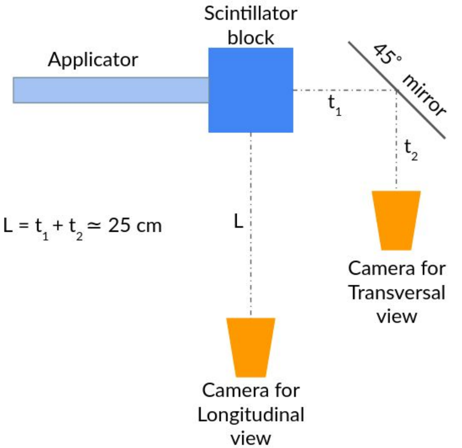
- Preliminary tests for setup optimization
- Acquisition with both **objective** (higher spatial resolution) and **pinhole** (simplified optical modelling)

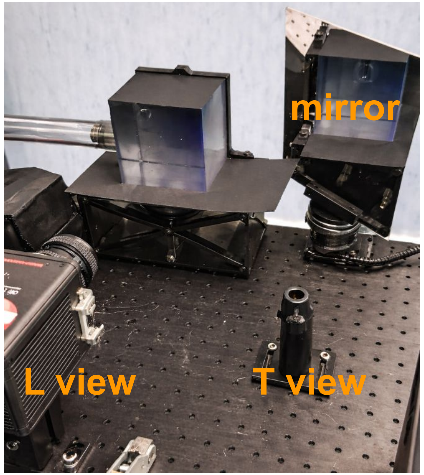
Longitudinal view



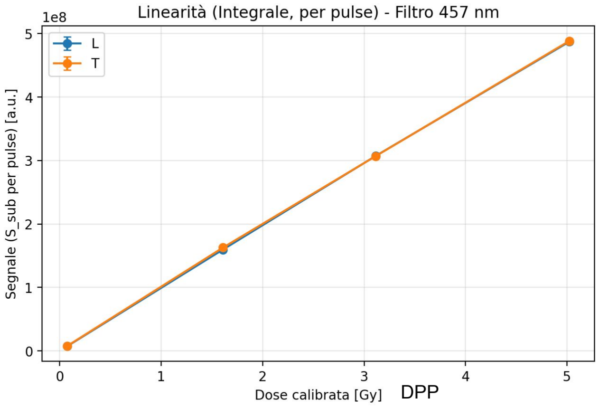
Transversal view

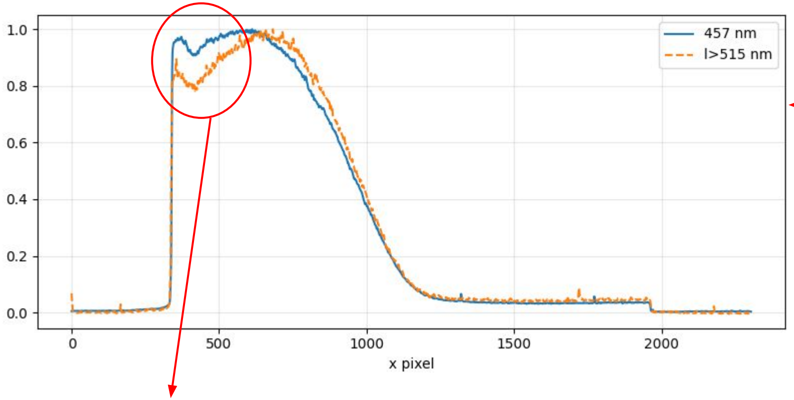


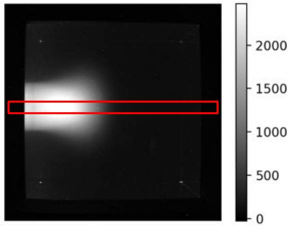


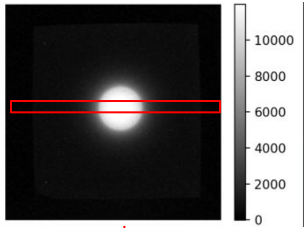


Experimental test @CPFR - Some results

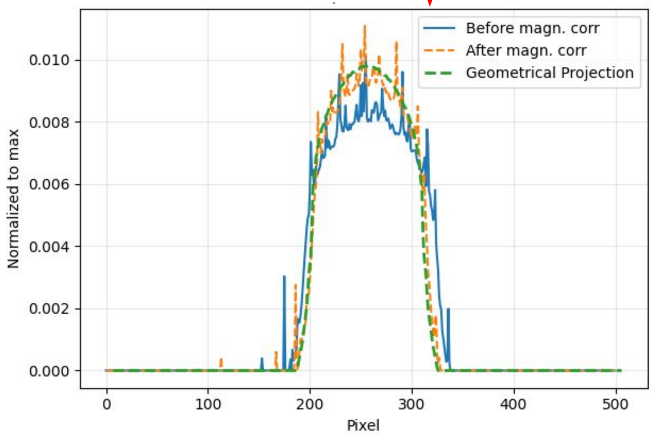








Effect to be further investigated with the obj configuration



- ✓ **Linearity** at high DPP
- ✓ **Cerenkov contribution** shape consistent with sheet measurement (dual-wavelength filtering)
- ✓ Pinhole light maps show **qualitative agreement with simulation**
- ✓ **Magnification correction** accurately restores transversal maps

<u>Ongoing analysis for the full 3D reconstruction</u> - further measurements needed

First prototype of the ALLS chamber

PPIC prototype for low-pressure applications

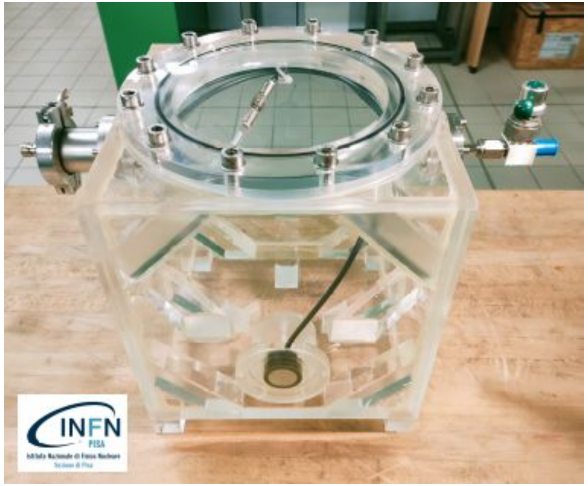
- PEEK for walls and components
- Metallized Al for electrodes (0.3 um thick)
- Optimal performance as conventional PPIC

Sealed environment

- PMMA cubic vessel
- Easily tunable filling gas and its pressure
- Possibility to explore different conditions

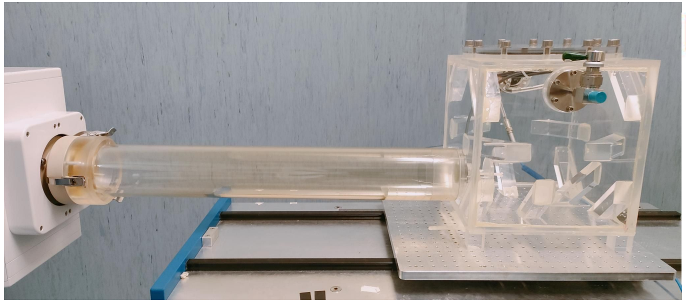
✓ **Dosimetric materials: plastic, water-equivalent**

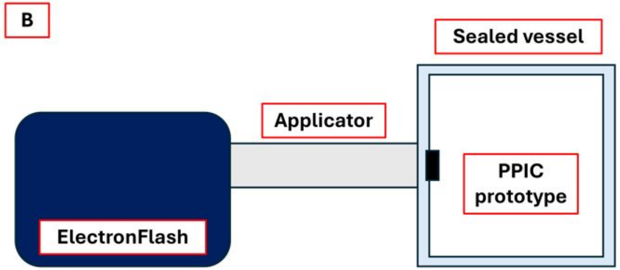
✓ **Suitable for low-pressure operation**



First experimental characterization @ CPFR

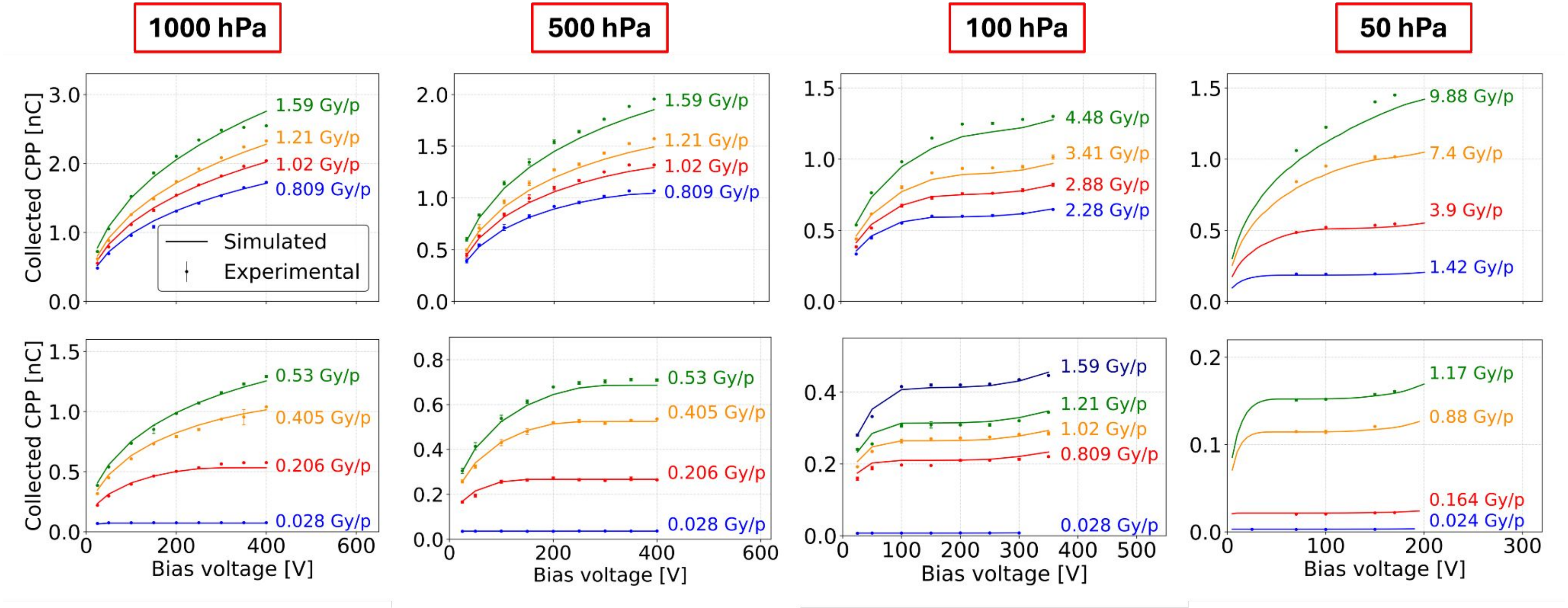
- Beam energy: 9 MeV
- Pulse repetition frequency: 20 Hz
- Pulse duration: 4 μs
- Filling gas: **nitrogen**





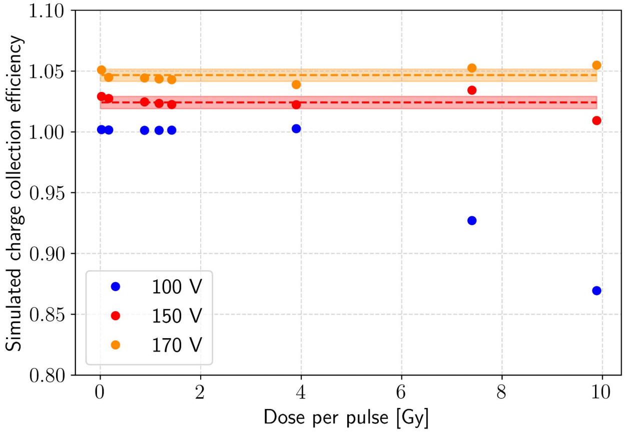
Validation of the numerical model

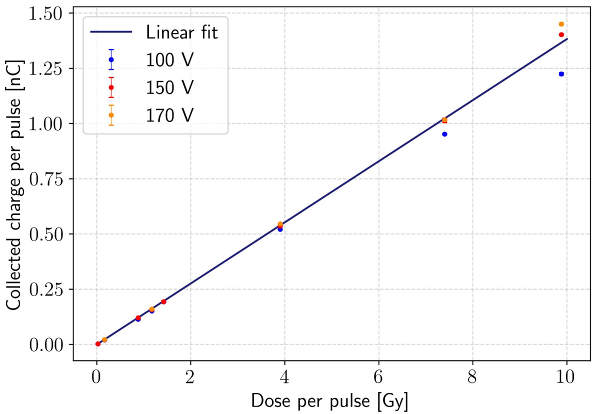
- Measurement of the saturation curves for different dose per pulse
- Four different pressures of nitrogen: 1000, 500, 100 and 50 hPa
- Numerical simulations of charge transport to model the chamber response for the explored conditions
- Comparison with simulated saturation curves → **experimental validation of the numerical model**



Experimental characterization @ CPFR

- Simulated CCE as reference to explore the operation regime of the system
- Constant CCE in a given range of dose per pulse $\rightarrow$ expected linearity of response
- Linearity verified up to 9.88 Gy/pulse at 150 V bias





- **Experimental validation of the numerical model for the adopted configurations**
- **Assessment of the linearity of response with the dose per pulse at 50 hPa up to ~ 10Gy/pulse**

M. Montefiori et al. "Numerical simulations of charge transport in depressurized noble gases for ultra-high dose per pulse applications" to Phys. Med. & Biol.
M. Montefiori et al. "First experimental characterization of a low-pressure nitrogen filled parallel-plate ionization chamber for UHDP electron beam dosimetry" to Medical Physics

NEW

Conclusions

- Plastic scintillator detectors (fibres, sheet and block) show **linear response** at high dose per pulse and allow **Cerenkov contribution assessment and subtraction**.

- Experimental campaigns with electrons at **CPFR** and protons at the **Trento Proton Therapy Center** show the potential of scintillator-based detectors **(fibres and sheet) for beam characterization**

- The scintillating block approach combined with tomographic reconstruction represents a promising solution for **3D real-time dosimetry**; **preliminary tests and simulations show encouraging results**.

- The **ALLS low-pressure ionization chamber** prototype was experimentally characterized, showing agreement with charge transport simulations and **linearity up to ~10 Gy/pulse**

Thank you for your attention!

A. Cavalieri, E. Ciarrocchi, F. Di Martino, C. D’Orazio, M. Massa, A. Moggi, F. Monchi, M. Montefiori, M. Morrocchi, J. Moscatelli, J. H. Pensavalle, E. Ravera, M. G. Bisogni

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