A 3D imaging system for dosimetry in FLASH radiotherapy

E. Ravera[1,2], R. Anzalone[1,2], A. Cavalieri[1], E. Ciarrocchi[1,2], D. Del Sarto[1,2], F. Di Martino[3,4,2], M. Morrocchi[1,2], and M. G. Bisogni[1,2]

1) Università di Pisa, 2) Istituto Nazionale di Fisica Nucleare - sezione di Pisa, 3) U.O. Fisica Sanitaria, 4) Azienda Ospedaliera Universitaria Pisana

eleonora.ravera@phd.unipi.it

Motivations and challenges

To develop a detector for **online 3D dosimetry** in quality assurance protocols and beam characterization for **FLASH-RT**, a new radiotherapy modality characterized by Ultra High Dose Rate *>40 Gy/s*, whereas conventional radiotherapy *1 Gy/min*.

Issues [1]
- → **Linearity** at high-dose-rate
- → **3D measurement** with high resolution
- → **Real-time** capability

Proposed detector

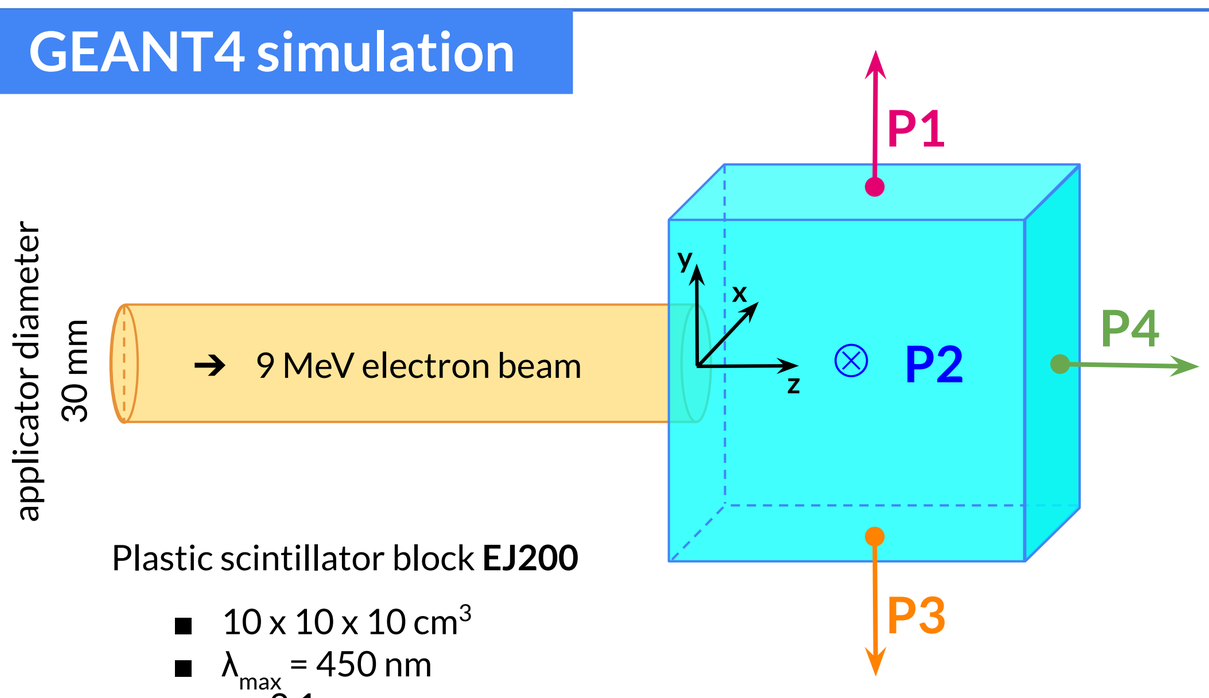
The detector consists in a **monolithic block of plastic scintillator EJ200** read out by four scientific cameras, each measuring a different projection of scintillating light.

The acquisition of four light projections enables a **tomographic reconstruction** of the volumetric dose distribution released by a **9-MeV electron beam** within the scintillator

Why plastic scintillators? [2]

- ✓ **Linear response** within high dynamic range, suitable for FLASH applications [3]
- ✓ Spatial resolution **~ 100 µm**
- ✓ **Time response in ~ ns**
- ✓ **Prompt readout**, if coupled to a camera
- \+ Good for treatment plan verification:
  - ✓ **tissue equivalent**
  - ✓ **reusable** and **cost-effective**

GEANT4 simulation

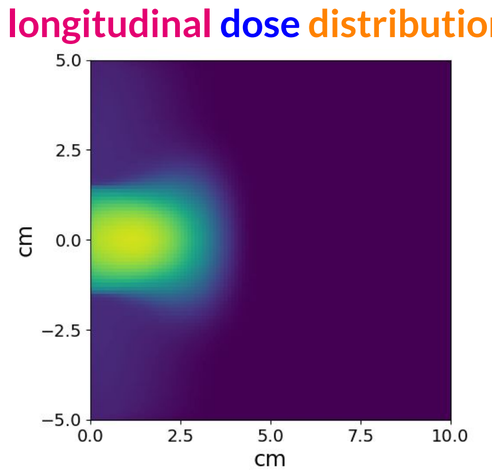


Plastic scintillator block **EJ200**

- 10 x 10 x 10 cm^3
- λ_{max} = 450 nm
- τ = 2.1 ns

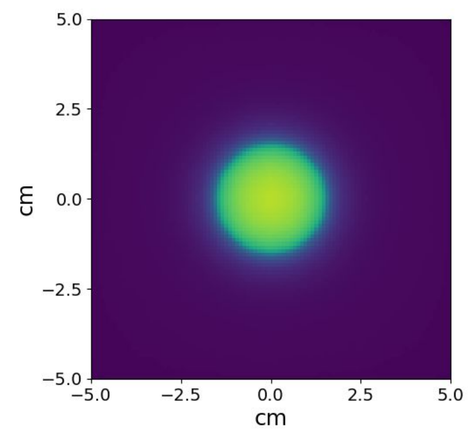
P1 P2 P3

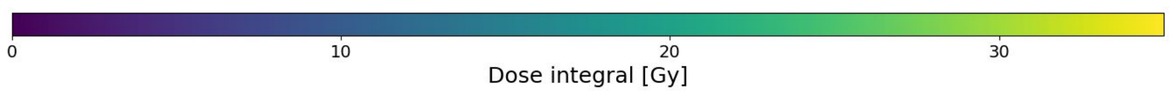
longitudinal dose distribution



P4

transversal dose distribution

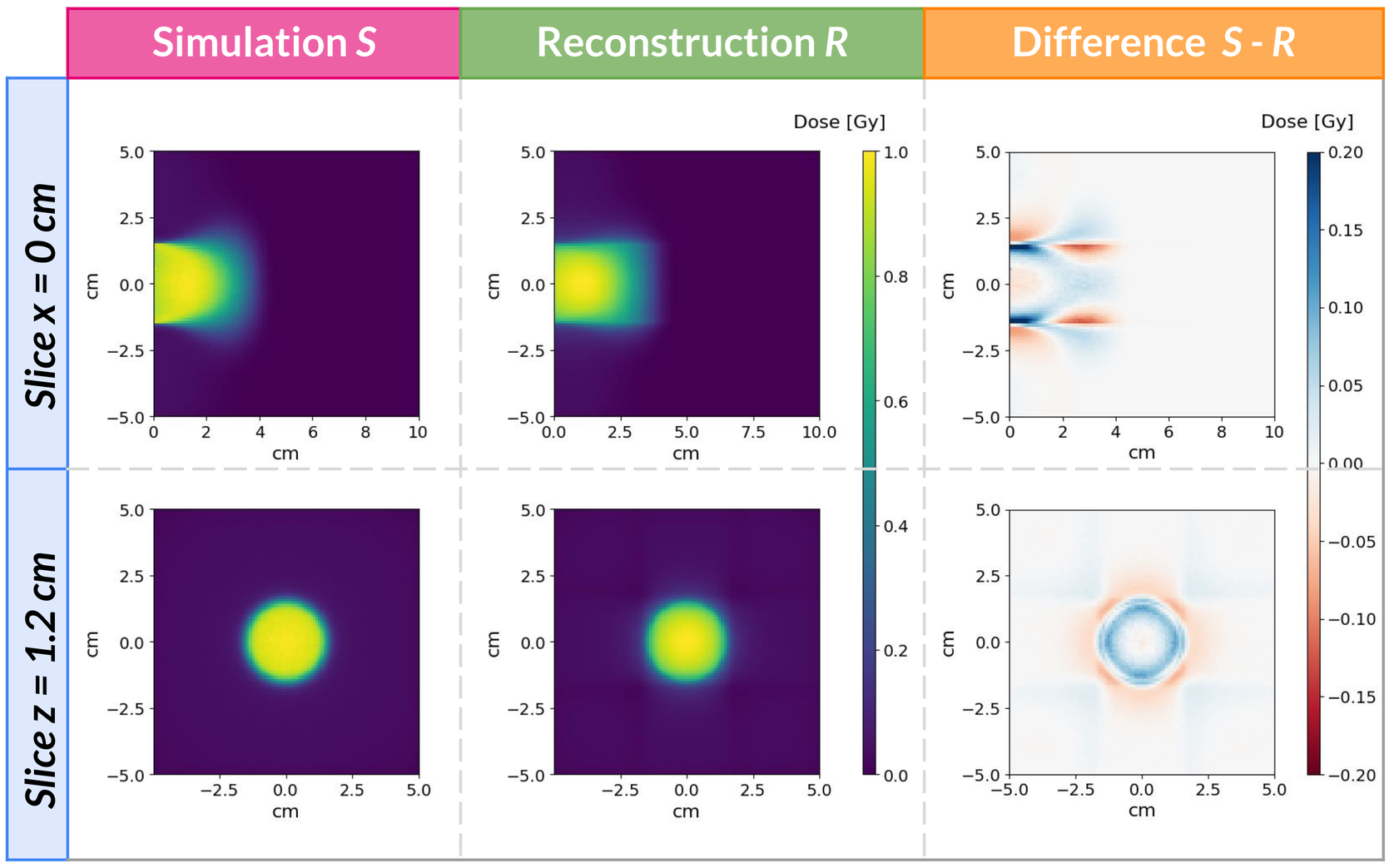




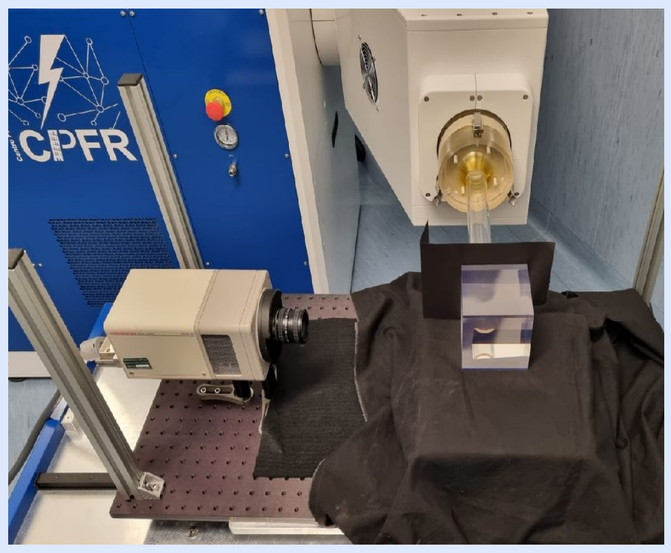
Parallel projection of the volumetric dose distribution
Dose Per Pulse = 1 Gy , Voxel = 1 mm^3

Tomographic reconstruction and comparison

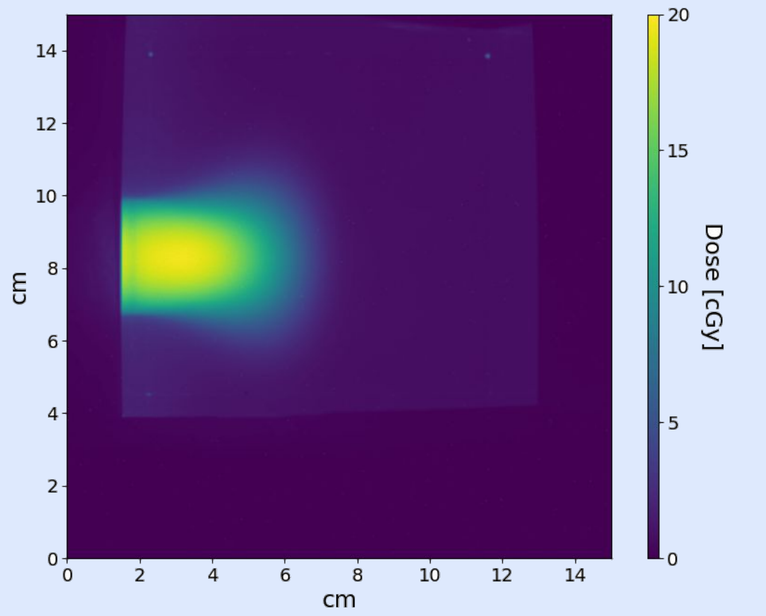
- ➢ Iterative methods, such as Maximum Likelihood Expectation Maximization ***MLEM***, due to the limited number of projections [4]
- ➢ **Poissonian likelihood** to account for the nature of scintillation-generated photons



Experimental results



Centro Pisano FLASH Radiotherapy **@ CPFR**



Longitudinal map with no selection on photon angle emission

Conclusions

- ➢ Despite the low number of projections, the tomographic algorithm reproduces the simulated signal with **< |0.1| Gy difference**
- ➢ Major discrepancies at the distribution edges, particularly in the PDD map (slice x = 0 cm) at the scintillator entrance (up to 0.3 Gy over 10 pixels)
- ➢ Improvement expected with reduced sampling step, using a scientific camera with resolution better than 1 mm
- ➢ Specific tests on reconstruction, including scintillation photon emission modeling and accelerator data acquisition, are necessary.

References

[1] F. Romano et al., 2022, Med. Phys., vol. 49
[2] M. R. Ashraf et al., 2020, Frontiers in Physics, vol.8
[3] E. Ciarrocchi et al.,2024, Physica Medica, vol. 121
[4] F. Kroll et al., 2012, Medical Physics, vol. 40

This work was funded by the following grants: (1) INFN CSN5 Call FRIDA; (2) Piano Nazionale di Ripresa e Resilienza (PNRR), Missione 4, Componente 2, Ecosistemi dell'Innovazione - Tuscany Health Ecosystem (THE), Spoke 1 "Advanced Radiotherapies and Diagnostics in Oncology" - Codice progetto ECS00000017 CUP I53C22000780001; (3) Università di Pisa under the "PRA – Progetti di Ricerca di Ateneo" (Institutional Research Grants) - Project no. 47 PRA_2022-2023_63 DRIFT: DosimetRic and in vItro studies of Flash radioTherapy effect. We also thank Fondazione Pisa for funding CPFR with the grant prog. n. 134/2021.