Innovation in Online Hadrontherapy Monitoring: An In-Beam PET and Prompt-Gamma-Timing Combined Device

V. Ferrero[1,2], P. Cerello[2], E. Fiorina[3,4], V. Monaco[2], M. Rafecas[5], R.J. Wheadon[2], and F. Pennazio[2]

[1] University of Torino, Department of Physics, Torino, Italy. [2] INFN Torino, Torino, Italy. [3] INFN Pisa, Pisa, Italy. [4] National Center of Oncological Hadrontherapy, Pavia, Italy. [5] University of Lübeck, Institute of Medical Engineering, Lübeck, Germany.

I3PET

In-beam
Coordination with fast monitoring detectors

Innovative
Multi-modality detector

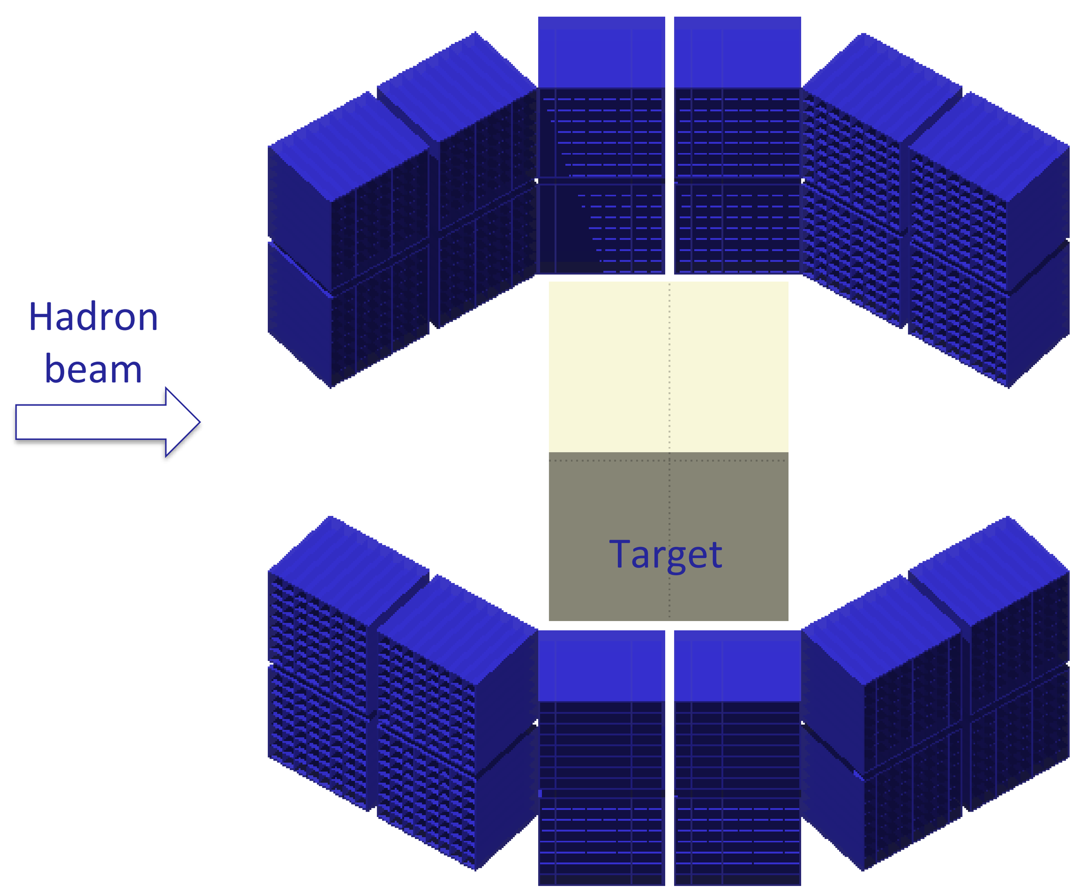
Imaging
Dedicated image reconstruction

The **I3PET project** goal is to enhance online monitoring performances in hadrontherapy thanks to:

- The information given by **In-beam PET** fast isotopes.
- **Innovation** of performing PET and Prompt-Gamma-Timing (PGT) measurements within the same detector.
- Dedicated image reconstruction software to empower the **Imaging** capability of the technique.

The I3PET scanner demonstrator is under development. It will feature 6 detector modules arranged in a 3 vs. 3 partial ring configuration with 160-mm diameter, so as to permit phantom imaging with clinical hadron beams. Each detector block will feature 16x16 pixels (3.2 mm pitch) of segmented lutetium fine silicate (LFS) scintillator crystals, coupled one-to-one to Hamamatsu MPPCs.

The I3PET scanner was simulated using the FLUKA Monte Carlo simulation tool. Results demonstrate the feasibility and synergy of the proposal.



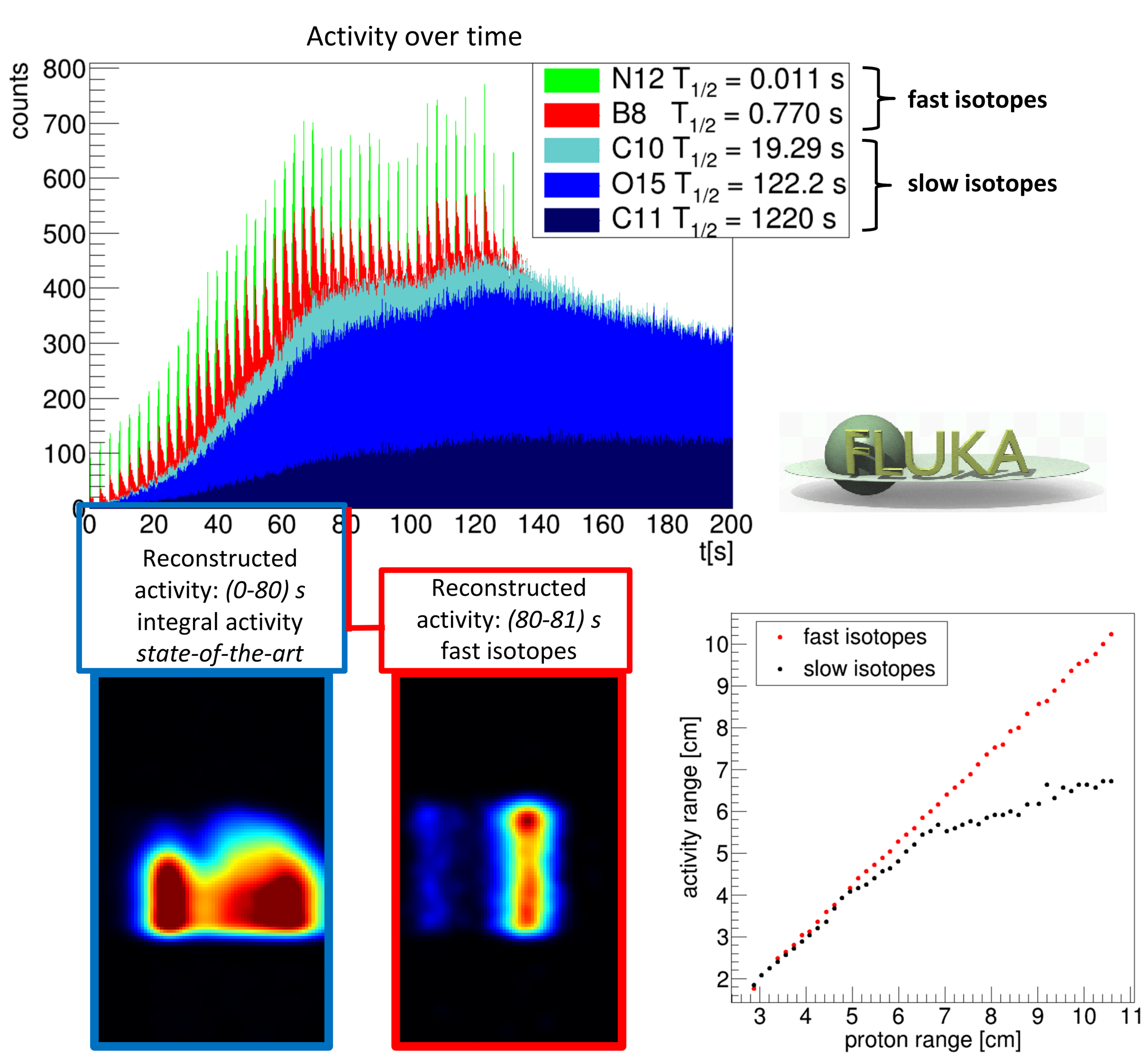
I3PET scanner demonstrator.

In-Beam PET Fast Isotopes

In-beam PET monitoring has the main potential of providing early treatment assessment with respect to the clinical prescription [1]. The detected activity distribution carries information about the beam range. **Fast isotopes imaging** is crucial to increase the **sensitivity** in range detection, since their short-lasting signal provides almost real-time information, but it is presently not fully experimentally exploited.

FLUKA-based Monte Carlo simulations of a realistic treatment were performed to demonstrate the expected sensitivity increase.

Fast isotopes imaging: Result of a simulation study.
Proton treatment plan on a PMMA phantom.
Pencil beam scanning, E = [62, 129] MeV/u, 45 spills.
Scoring of simulated isotopes.

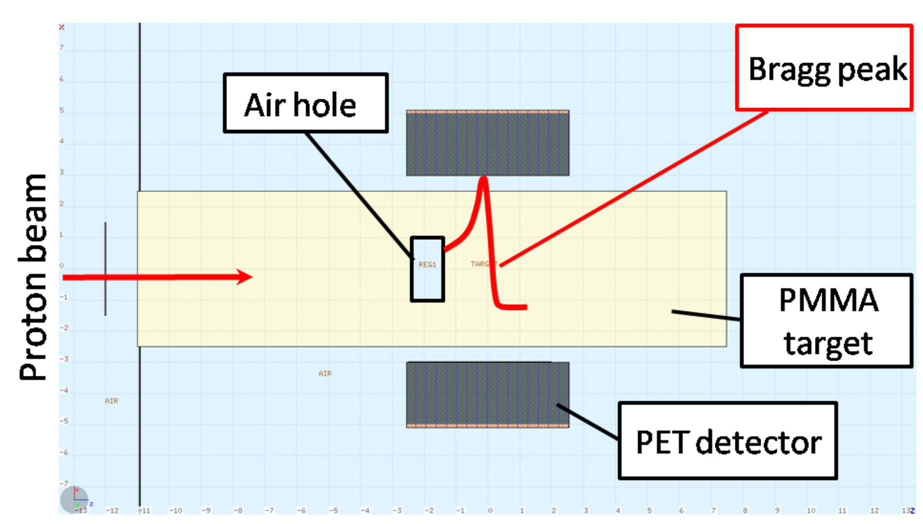


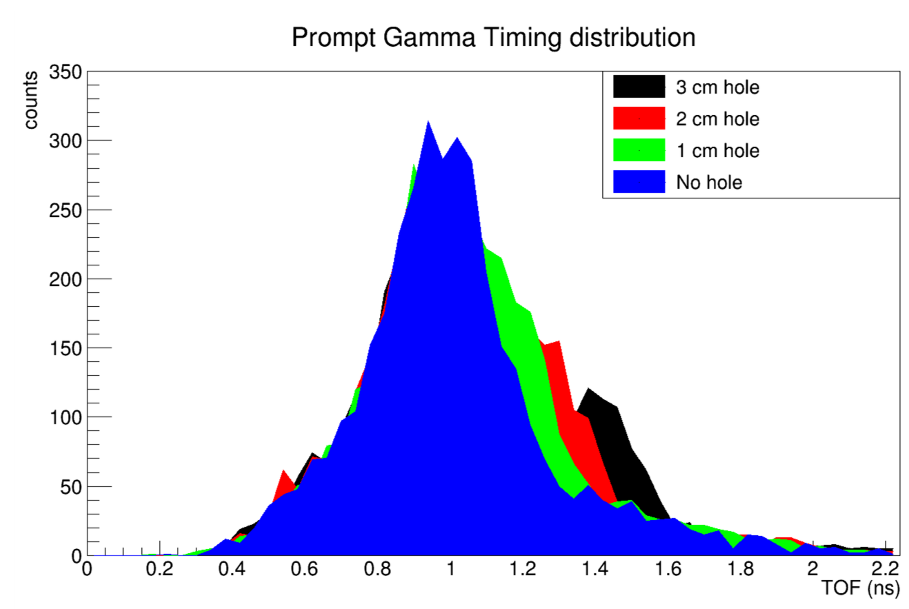
Spill by spill, fast isotopes carry information about the expected particle range, which restores the linearity with the measured activity.

Prompt-Gamma-Timing

PGT has been proposed as an alternative to collimated imaging systems for prompt-gamma ray monitoring in hadrontherapy. PGT relies on the **Time Of Flight (TOF)** information between the primary particles delivery and the prompt-gamma detection time. TOF distribution encodes essential information about the **depth of emission** of secondary gamma rays, since its shape depends on the primaries penetration depth and the traversed materials [2]. PGT peculiarity is the absence of collimators, so that the technique is in principle implementable with a PET detector.

PGT + PET detector preliminary simulation.
Pencil beam impinging on a PMMA phantom.
Protons, E = 125 MeV/u, 2.5 10^6 particles.
PET detector, 215 ps coincidence time resolution.



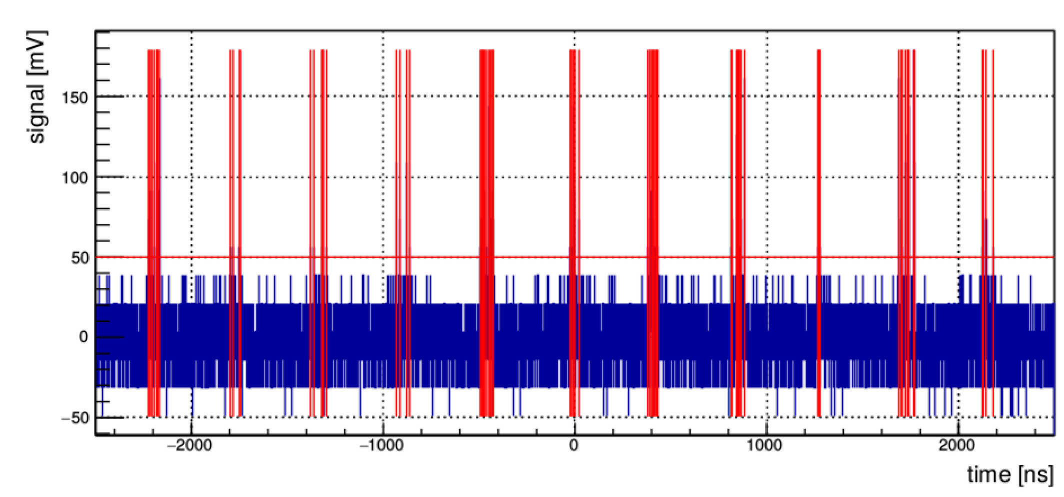


PGT distribution encodes information about range. Simulations including air holes of different thickness in the phantom show a shift in the distribution, which can be related to the shift of the Bragg peak.

Ultra-Fast-Silicon-Detectors

A precise measurement of the delivery time of the primary particles is needed to maximize PGT performance and exploit in-beam PET fast isotopes. **Ultra-Fast-Silicon-Detectors** (UFSD) are silicon sensors with controlled internal gain, and can be used to this purpose. Preliminary experimental results with prototypes irradiated with proton beams indicate **single-particle detection** capability and a **time resolution** of about **35 ps** [3]. UFSD-based particle counters of about 30x30x0.1 mm^3 size are being developed by the MoVeIT (Modeling and Verification for Ion beam Treatment) collaboration for beam monitoring.

UFSD preliminary experimental results.
Time structure of a therapeutic beam acquired by a 1 mm^2 UFSD detector.
Protons, E = 227 MeV/u, 2 10^8 particles.



The snapshot of the beam time structure shows UFSD capability to provide information about the particle bunch.

References

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PM18 – 14th Pisa Meeting on Advanced Detectors, 27 May – 2 June 2018, La Bidola, Isola d'Elba, Italy

Contacts: veronica.ferrero@to.infn.it, francesco.pennazio@to.infn.it