Low statistics activity reconstruction methods with the DoPET system

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Purpose

Proton beam irradiations can deliver conformal dose distributions thanks to their characteristic dose profiles. The interactions between the ions and the irradiated tissues generate β^+ emitters. This activity signal can be used for treatment monitoring by means of dedicated PET prototypes.

Experimental data taking was performed at the Trento Proton Therapy Centre with 130 MeV pencil beams to study the dependence of the activity width uncertainty versus the number of delivered protons.

The DoPET scanner

The DoPET system is a planar dual-head PET scanner. Each head is composed of 9 detector modules consisting of a LYSO matrix of 23 × 23 pixels, coupled to a position sensitive photomultiplier tube model H8500 (Hamamatsu Photonics). A dedicated front-end electronics, which gives the position and trigger signals sent to the main acquisition board, is implemented.

The heads are stationary and placed in-beam at a distance of 48 cm. Acquisition is FPGA-based and works with a coincidence time window of about 3 ns (Figure 1).

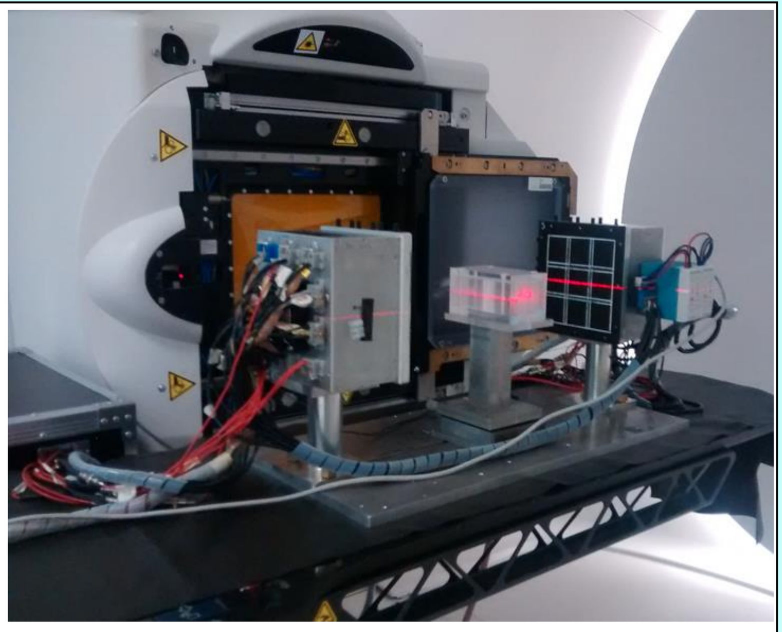
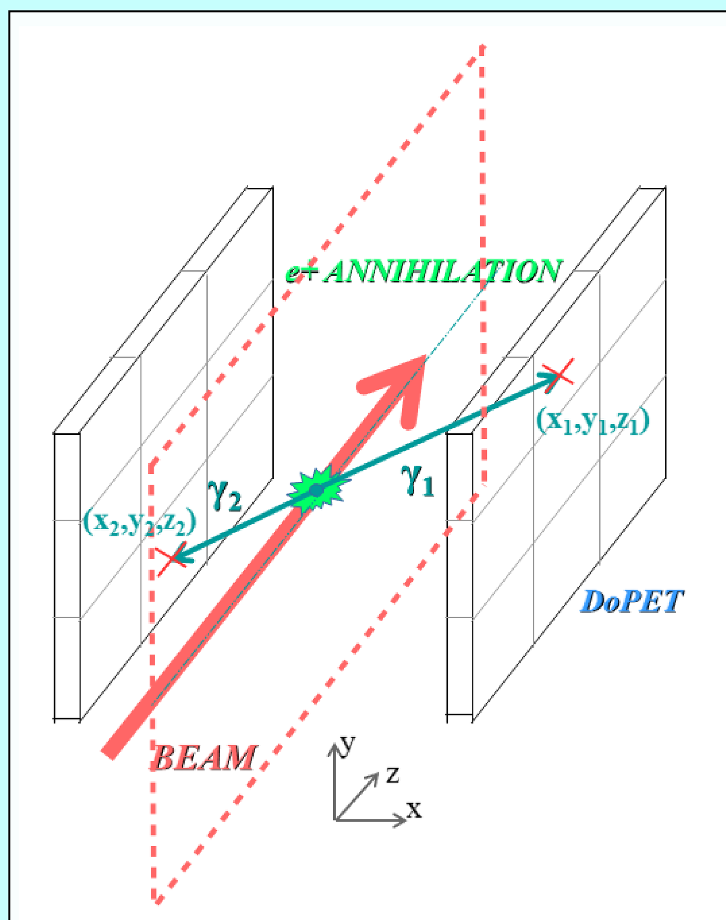


Figure 1: The DoPET system on the Trento treatment couch.



StraightForward Reconstruction (SFR)

- The annihilation position of each event is reconstructed by evaluating the intersection between the beam axis position provided by the Treatment Planning System and the coincidence line detected by the scanner (**Figure 2**).
- Each coincidence event is weighted to take into account its detection geometrical probability.
- The reconstruction takes a few seconds.

Figure 2: Sketch of the SFR reconstruction method

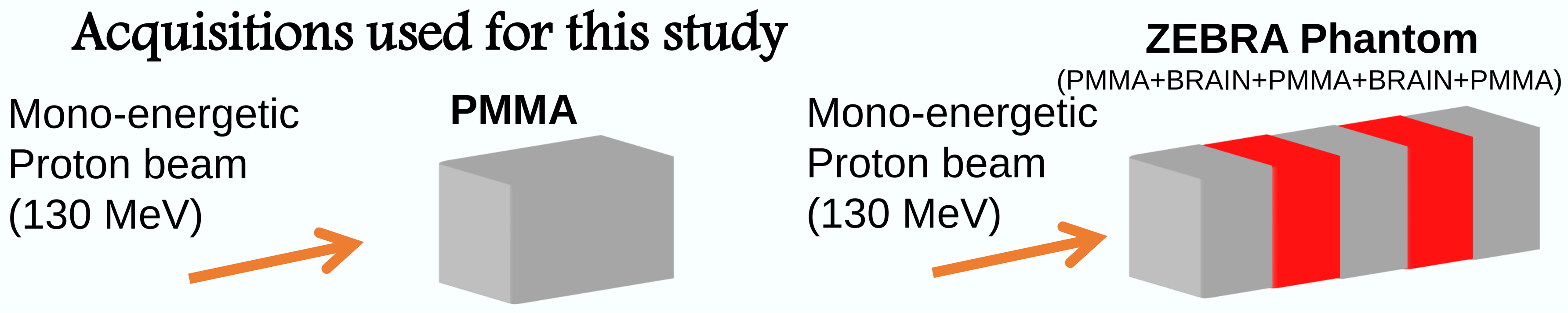
Maximum Likelihood Estimation Maximization (MLEM)

- Standard PET reconstruction method presented in [2,3]
- Iterative algorithm based on statistical model

Monte Carlo Simulations

- Experimental set-up simulation of the conditions in Trento, with FLUKA code [4] development version
- Recorded β^+ activity and annihilation products in space and time
- Implemented the detector geometry
- Expected activity distribution reconstructed with the same reconstruction process used for the experimental data

Acquisitions used for this study



Results

Data taking using the homogeneous and the zebra phantom were performed to evaluate the reconstruction capabilities of the two methods. Samples of different statistics were created and the activity width was evaluated. Data were considered in 120 s after irradiation.

- Reconstruction of the (y,z) plane with the SFR method in Figure 3 as an example of the capability of the method using 10^9 primary protons.
- The longitudinal profiles (beam axis) were reconstructed using MLEM and SFR and are reported in Figure 4 together with the MC simulation. Both data and simulation present compatible shapes. The width of each profile is calculated as the distance of the half maximum of the rising edge to the half maximum of the distal edge ($\Delta W_{50\%}$).
- The error on $\Delta W_{50\%}$ of the two methods with variable statistical conditions is shown in Figure 5. For spots of $2 \cdot 10^8$ and 10^9 protons, the error is 1.5 mm and 0.5 mm, respectively.
- For 10^8 primary protons the shapes of the activated profiles loose reliability (Figure 6) but the information on the $\Delta W_{50\%}$ is preserved with an error of ~2.5 mm.

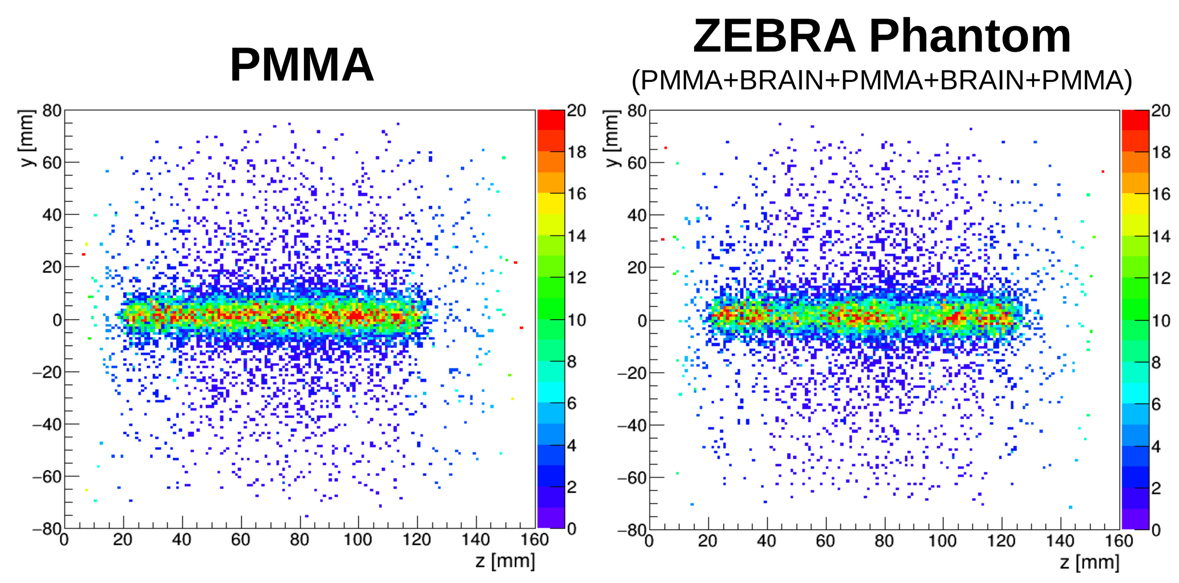


Figure 3: Reconstruction of the (y,z) plane with the SFR method

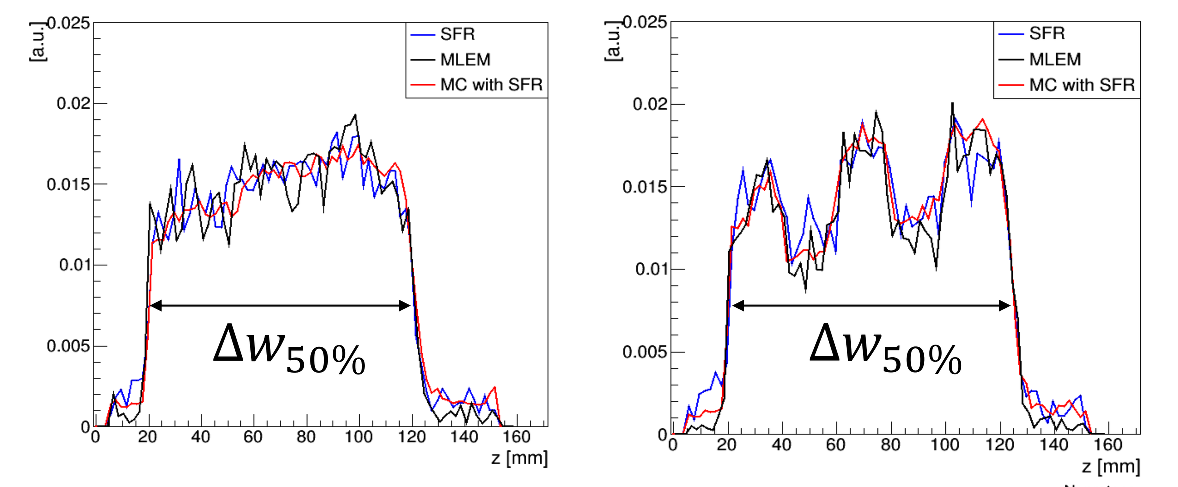


Figure 4: Reconstructed longitudinal profiles (beam axis). Data reconstructed with MLEM (black) and SFR (blue). The FLUKA prediction (red) reconstructed with SFR

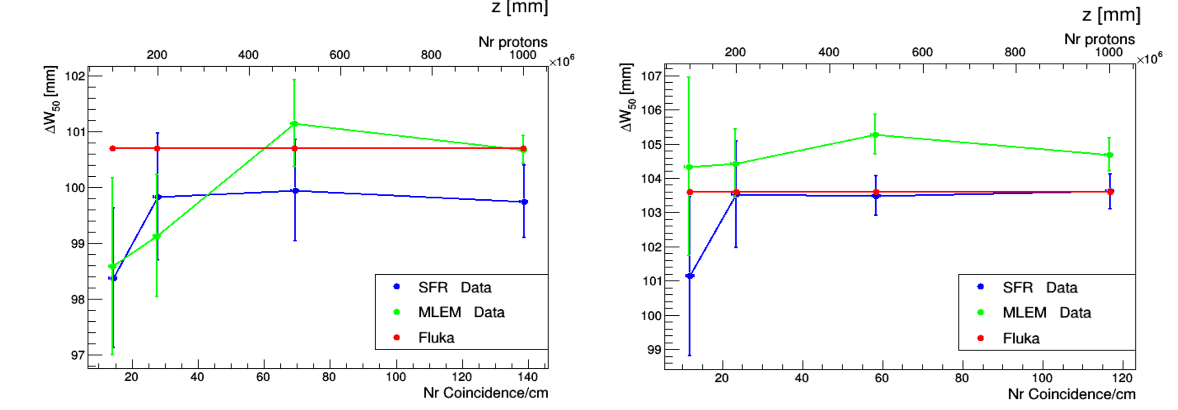


Figure 5: The $\Delta W_{50\%}$ reconstruction capability of the two methods in variable statistical conditions

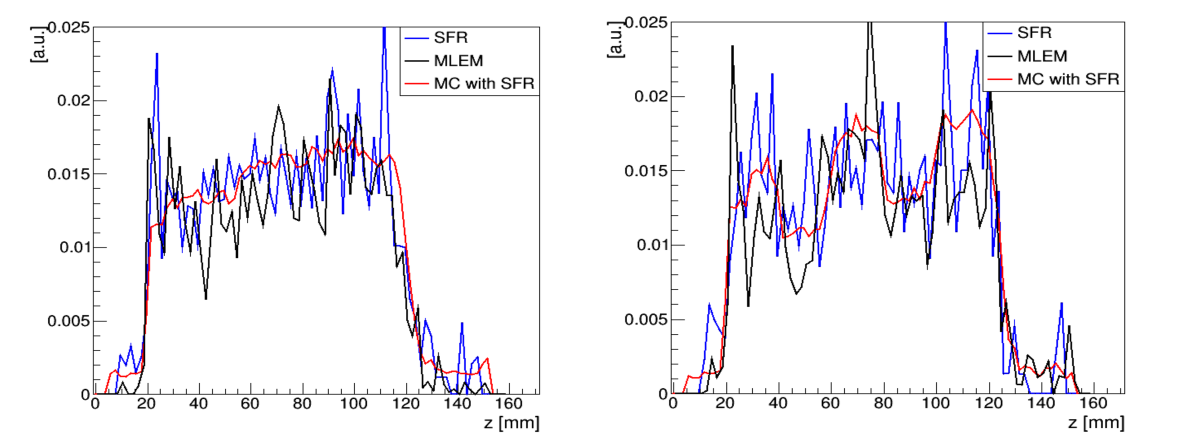


Figure 6: Longitudinal profiles corresponding to 10^8 primary protons. The zebra structure is not clearly recognizable anymore

Conclusions

A new reconstruction method for PET data was developed and gives comparable results with respect to MLEM and FLUKA predictions.

For monitoring purposes a localized geometrical information is advisable and is obtainable using pencil beams.

To have an error on the determination of $\Delta W_{50\%}$ lower than 1.5 mm we found that a number of protons greater than $2 \cdot 10^8$ is necessary both for homogeneous and heterogeneous phantoms. This number is comparable with the number of protons delivered for each cm^2 in the distal energy layer of a treatment plan of 1 Gy.

In view of safety margin reduction and dose escalation, this approach opens up the possibility to image guidance procedures with selected pencil beams.

References

[1] V. Rosso et al., *"DoPET: an in-treatment monitoring system for proton therapy at 62MeV"*, Journal of Instrumentation, 11, C12029 (2016), 1-8..
[2] L. A. Shepp and Y. Vardi, "Maximum Likelihood Reconstruction for Emission Tomography," *IEEE Trans. Med. Imaging*, vol. 1, no. 2, pp. 113–122, Oct. 1982.
[3] N. Camarlinghi et al, "An In-beam PET System For Monitoring Ion-beam Therapy: Test On Phantoms Using Clinical 62 MeV Protons", Journal of Instrumentation 9 C04005 (2014) 1-12
[4] G. Battistoni et al., "The FLUKA code: description and benchmarking," in AIP Conference Proc., 2007, vol. 896, pp. 31–49.