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A Study of Monitoring Performances with the INSIDE System

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The INSIDE collaboration aims to build an on-line hadrontherapy monitoring system, based on a dual-head in-beam PET scanner and a secondary charged particles profiler. In this work preliminary experimental results are presented. The validation of the FLUKA-based Monte Carlo simulation tool is shown together with the expected scanner performances.

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1. Introduction

The INSIDE monitoring system is based on the combination of a fiber tracker and a dual-head PET scanner, to be used during the hadrontherapy treatment for range verification. Monte Carlo (MC) simulations are fundamental in in-beam PET not only to predict the expected detector performance and to assess the requirements for electronics and acquisition, but also to compare the predicted and acquired image. This approach [1, 2] allows the in-beam PET scanner to be used as a hadrontherapy treatment monitoring system. The MC framework FLUKA [2, 3] is used for simulating the PET signal and secondary particles tracking. A C++ tool is developed for post-processing the FLUKA events and to obtain a time-based signal. A detector model is implemented taking into account the expected detector time and energy resolution. Multiple particles hitting the same detector element in intervals shorter than the scintillator light emission are merged. We include not only true coincidences, but also the random and multiple coincidences.

2. In-beam PET simulations

2.1. Simulation validation

Two tests measurement were performed at the CNAO facility (National Centre of Oncological Hadrontherapy, Pavia, Italy), irradiating PMMA phantoms with test and treatment beams of protons and carbon ions. The periodic beam structure is 1 s spill (in-spill) + 4 s pause (inter-spill). Particles were detected with 5 channels at different positions. Each channel is made of a scintillator crystal ($3.2 \times 3.2 \times 20$ mm^3 LYSO) coupled to a 3.2×3.2 mm^2 SiPM by FBK-irst. The front-end is based on the 64 channel TOFPET chip [3]. Data were acquired during the full irradiation interval and afterwards, with typical rate of 1 kHz (in-spill) and 100 Hz (inter-spill) depending on irradiation time.

The single-channel acquisition has been validated by reproducing in a simulation the setup of the CNAO preliminary test. About 60 proton spills of a 95 MeV monochromatic beam with 2×10^9 pps intensity has been sent towards a PMMA phantom. The measured detection rate during the irradiation and the inter-spill energy spectrum have been correctly reproduced by the simulation (Fig. 1 left). A further simulation code validation has been provided by the DOPET [4, 5] in-beam PET scanner (INFN RDH experiment). Figure 1 right shows the agreement between the simulated and acquired activity profile for the DOPET detector.

2.2. Expected PET data acquisition

Since a limited amount of space is available for installing the in-beam PET scanner in treatment room, a compact planar PET system was proposed, with limited angular acceptance. The simulation of each treatment primary particle is not feasible in reasonable time by a single computer or server. Therefore a small fraction of the treatment was simulated to assess the expected amount of coincidences detected by the INSIDE

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PET scanner. The expected amount of LORs acquired is about 3×10^5 for a 4 Gy treatment.

2.3. In-beam acquisition and data quality

A simulation was performed to compare the data quality between in-spill and inter-spill data acquisition. A single proton spill directed along the z axis was sent towards a PMMA phantom and the true e^+–e^- annihilation points were scored. During the spill a significant part of annihilations are from prompt radiation, resulting in a large distance between the beam axis and the annihilation points. For inter-spill acquisition, the distance is much smaller (Fig. 2).

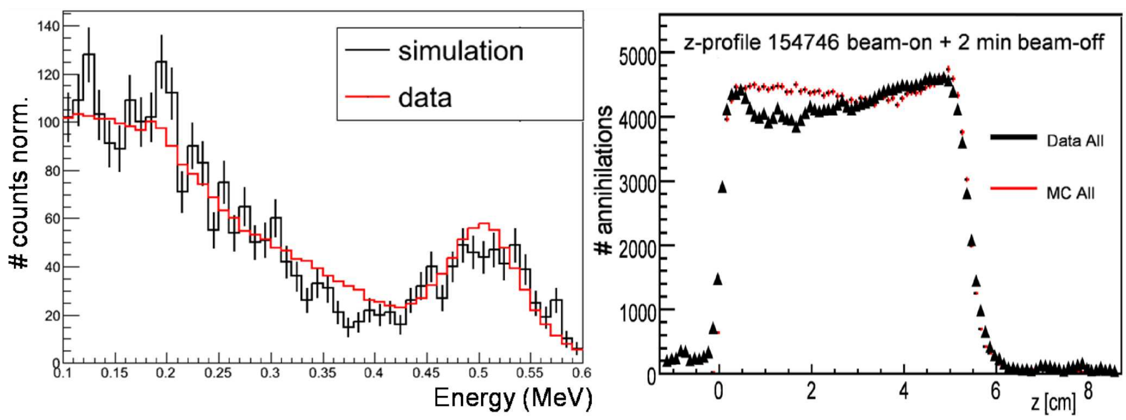

Fig. 1. Single-channel spectrum validation (left) and measured and simulated activity profile (right, courtesy of RDH-DOPET).

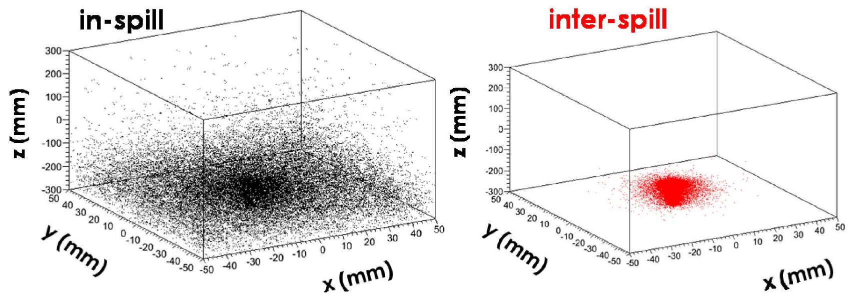

Fig. 2. Annihilation positions during the spill (left) and after the first spill (right).

3. Tracker simulations

3.1. Carbon ions simulation

FLUKA allows to import a CT of the patient to be used as target of the simulated beam. A simulation was performed of a carbon treatment plan to be delivered on a patient's head CT, including also the CNAO beam nozzle. The entire treatment simulation with carbon ions would require 20 days on a 24-core computer, so a subset (4%) of the particles of a single-energy slice has been simulated. The secondary particles coming out from the target have been scored on a sphere of 30 cm radius (Fig. 3 left). This simulated setup has also been used to assess the optimal angular position in order to maximize the detector acceptance for secondary protons (Fig. 3 right).

3.2. Tracker expected performance

The tracker expected efficiency and resolution have been studied by means of the simulation of proton sources placed inside a spherical phantom, with radius of 10 cm, composed of ICRU brain and cortical bone. A detailed tracker description was implemented. Protons of different energies are generated inside the phantom at 10 cm and 5 cm depth and tracked towards the detector. The efficiency and the resolution as a function of the primary energy have been studied (Fig. 4). The obtained single-track resolution is of few millimeters, but it is expected to scale down as statistics increases.

4. Conclusions and future work

The INSIDE collaboration aims to develop an on-line hadrontherapy monitoring system, combining a dual-head PET scanner and a fiber-based beam profiler. Beam test have been successfully performed at CNAO and GSI, moreover we have developed a FLUKA-based tool for MC simulations. Current work on the hardware side is focused on the construction of the mechanics as well as the development of the final acquisition system. The software under development is focused on optimizing the MC simulations. A fast dedicated MC generator to simulate the annihilations signal is being tested and used as input of a maximum likelihood expectation maximization image reconstruction algorithm. Moreover, since the MC simulation is presently fully analogue, several optimizations can be performed with the introduction of bias and particle weighting.

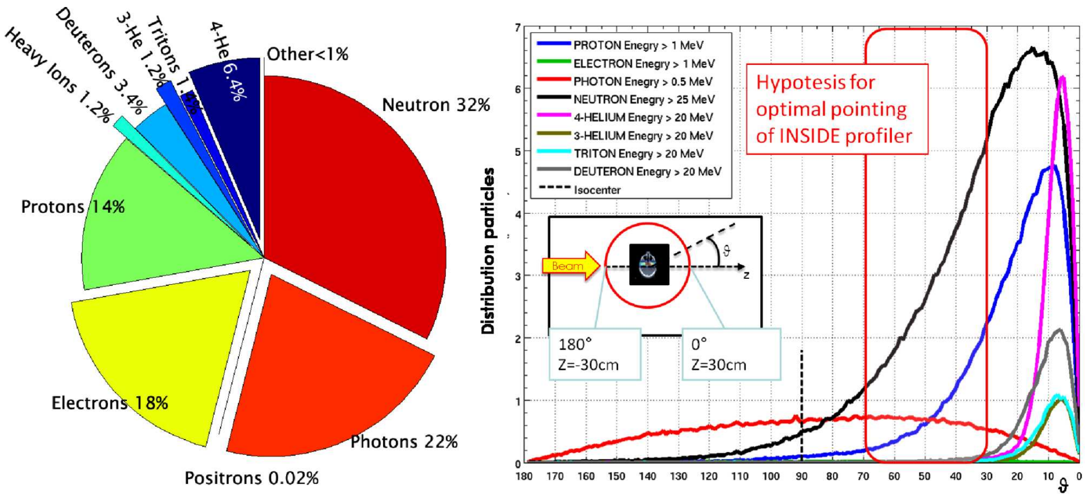

Fig. 3. Secondary radiation flavor in the case of carbon ion treatment (left), secondary particles angular distribution (right).

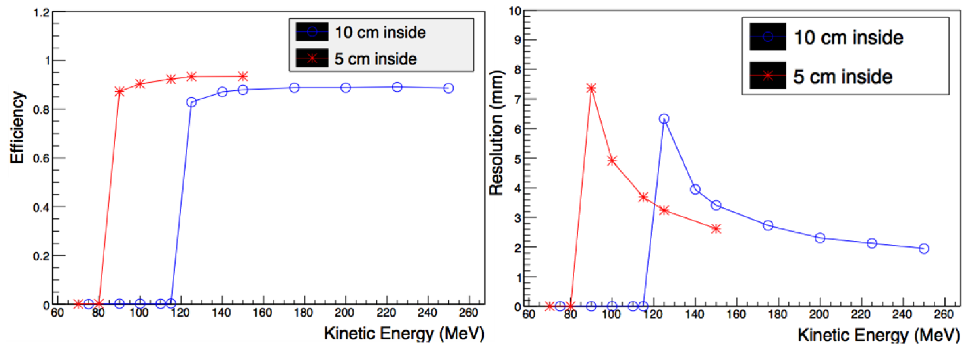

Fig. 4. PET block detector reference system (left) and scanner reference system (right).

Acknowledgments

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