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DEVELOPMENT OF A DOSE PROFILER FOR BEAM RANGE MONITORING IN PARTICLE THERAPY TREATMENTS

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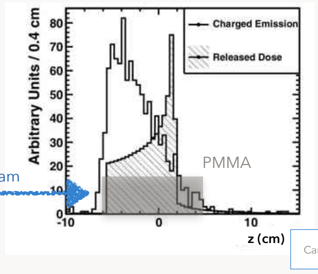
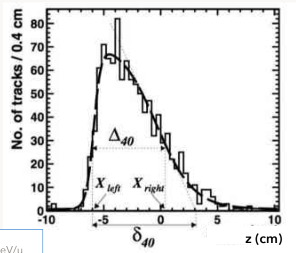
Introduction

Particle Therapy (PT) exploits accelerated charged ions, typically protons or carbon ions, for cancer treatments. In PT a high accuracy on the dose release over the tumor volume is achieved, preserving healthy tissues and Organ At Risk (OAR) around tumor better with respect to the conventional radiotherapy. The high cancer cells killing power of this technique requires a precise control of the ion beam delivery, and hence target voxel localization, to take into account a possible patient mis-positioning or biological or anatomical changes. The development of an on-line dose conformity monitoring device is of paramount importance to assure an high quality control accuracy in PT treatments. We propose a novel detector named Dose Profiler (DP) tailored for dose range monitoring applications in PT. The beam range inside the patient will be monitored detecting charged secondary fragments.

Charged secondary particles production

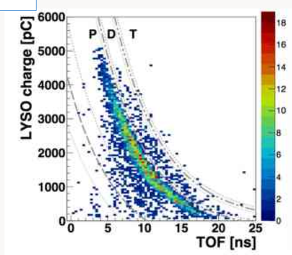
Primary beam particles cannot be used for dose range monitoring, since they don't escape from the patient. A promising approach consists in the detection of the secondary particles produced by the strong interactions between the primary beam and the crossed tissues [1], [2], [3], [4]. It has been observed that the emission spatial coordinate distribution of charged secondary particles detected at large angles (60°, 90°) with respect to the beam direction is correlated to the Bragg Peak position. Such a correlation can be used to monitor the beam range.





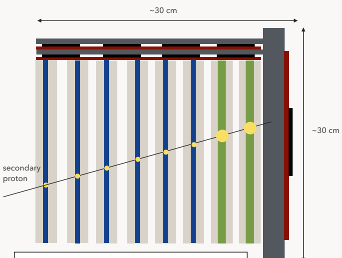
Carbon 220 MeV/u

- Particularly suitable for Carbon beam treatments, in which the number of charged secondary particles exiting from a patient is sufficient to reconstruct the profile with a good statistic.
- Mostly protons produced [5].
- Charged particles easy to back-track.
- Larger the detection angle, higher the tracking reconstruction resolution.



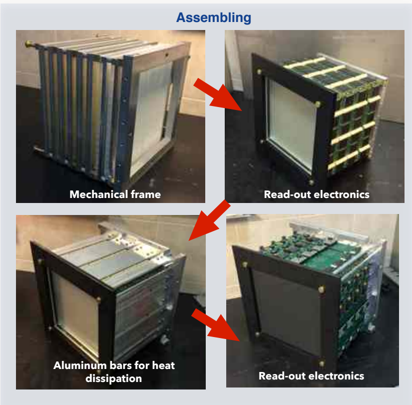
Dose Profiler design

The Dose Profiler is specifically designed and optimised to track the secondary protons by means of six **scintillating fibres planes** (20 x 20 cm^2), each one composed by two layers of orthogonally placed fibers. Two **plastic scintillator planes**, each one composed by x-y segmented layers of plastic scintillator 6 mm thick, follow the fiber planes. Both the fibers and the scintillators are read-out by Silicon PhotoMultipliers.

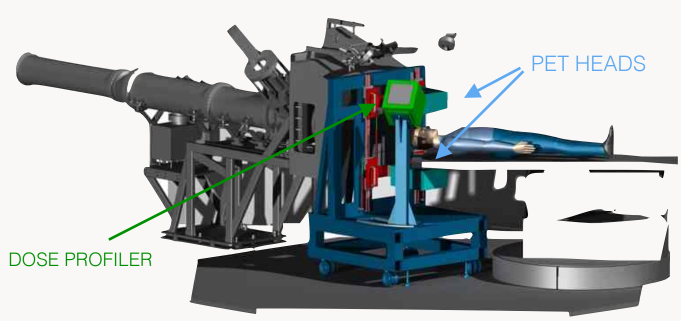


Scintillating Fibres features:

- Saint-Gobain BCF-12, double cladding
- Squared section, 0.5 x 0.5 mm^2
- Trapping efficiency 7.3%
- Light yield ~8000 ph./MeV
- Attenuation length: 2.7 m

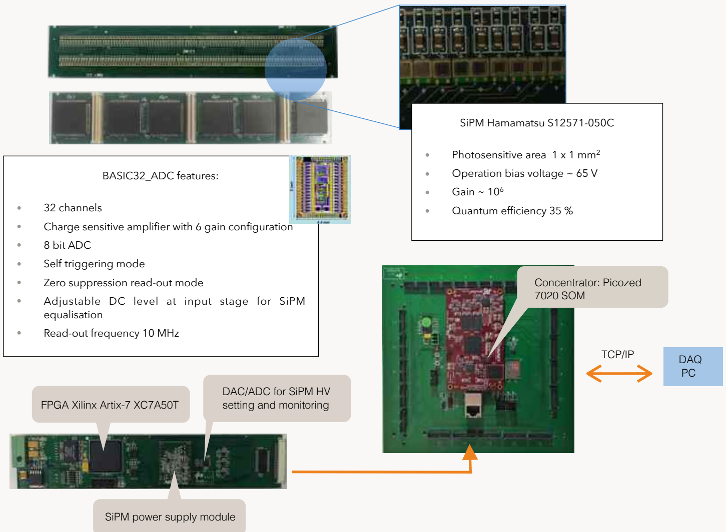


The DP, developed within the INSIDE collaboration, will be integrated in a multi-modal monitor system able to detect, at the same time, the charged secondary particles and the ß+ emitters activity by means of two planar PET heads that measure the 511 keV annihilation photons. The DP will be tested



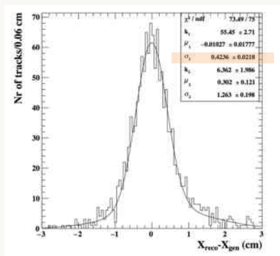
Dose Profiler Read-Out system

The signals of SiPMs are processed by a set of 96 ASICs named *BASIC32_ADC* [6], the last version of a family of multichannel ASICs developed in Politecnico di Bari to read-out Silicon PhotoMultiplier detectors for medical imaging applications. The tracker front-end board contains six BASIC32_ADC and 192 SiPMs. The read-out of all BASIC32 is performed by a set of 16 FPGAs. The FPGA-board contains one FPGA and HV power supply modules for SiPMs. An additional SoC (System on a Chip) device named ``concentrator'' provides the trigger signal and read-out of all FPGAs; the ethernet protocol is used to communicate with a PC for data storage.



Simulation

A simulation has been performed in order to optimize the performances of the Dose Profiler: a parametrized generator, based on experimental data [7] collected at HIT (Heidelberg Ion Therapy center), has been used to reproduce secondary protons distribution exiting from a cylindrical target of PMMA (r=2.5 cm) irradiated by Carbon ion beam at 220 MeV/u.



Single proton resolution

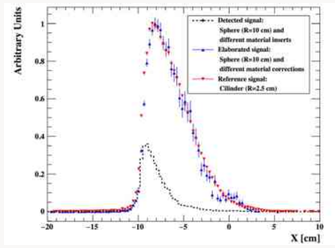
The track candidates are first parametrized as straight lines and a χ^2 fit is performed to obtain an estimate of the track parameters. A Kalman filter is also applied to take into account the multiple scattering in the detector material [7].

Single proton resolution: $\sigma \sim 0.4$ cm on beam axis

Angular resolution: 35 mrad, dominated by multiple scattering inside the phantom

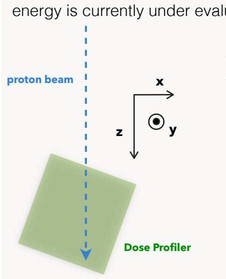
Secondary proton absorption in a real treatment

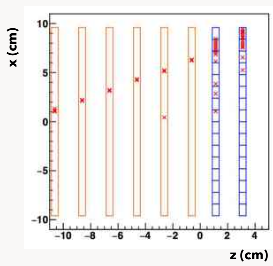
Any complex target geometry, like the case of the patient, having different materials, densities and thicknesses, will produce an emission profile which is distorted with respect to the reference case. Using the CT information it's possible to retrieve the reference signal scaling the detected signal with weighting values, based on the double Fermi-Dirac model parameters calculated for all the different crossed materials [7].

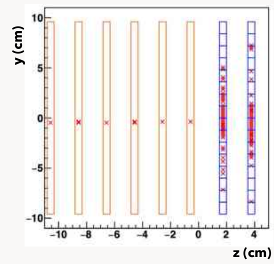


Data taking campaign

The first data taking campaign took place in May 2017 at Trento ProtonTherapy center, with the aim to calibrate the DP detector with protons having the energy expected (50-150 MeV) for the secondary fragments produced during a Carbon ion treatment. The tracking efficiency as a function of the proton energy is currently under evaluation .







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