# In-room characterization, using an anthropomorphic, of a novel detector exploiting secondary charged particles emission for on-line dose monitoring in light PT treatments

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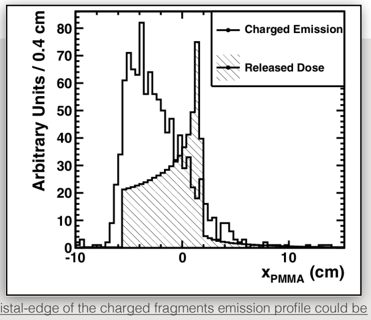
Particle Therapy (PT) exploits accelerated charged ions, typically protons or carbon ions, for cancer treatments. In PT a high accuracy on the dose release over the tumor volume is achieved, preserving healthy tissues and Organ At Risk (OAR) around tumor better with respect to the conventional radiotherapy. The high cancer cells killing power of PT 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.




The distal-edge of the charged fragments emission profile could be correlated to the Bragg peak position

Beam range monitoring using charged fragments could be a way particularly suitable for $^{12}C$ ion treatment thanks to some nice features:

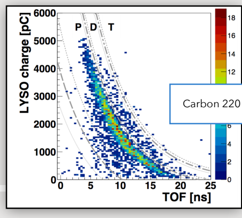
- High detection efficiency
- Easy back-tracking

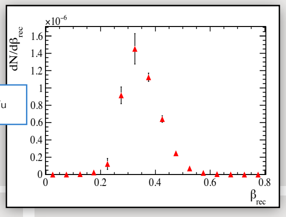
Anyway, the :

- Suffer multiple scattering inside the patient ( ∝ $E^{-1}$, ∝ $\sqrt{x}$ ) —> impact on the back-tracking resolution
- In a treatment room, very often the positions at low $\vartheta$ are not available to a monitor device, in particular in the treatment configuration where the patient body is aligned with the beam axis. Large detection angles have to be used, reducing the collection statistics.

## Charged secondary fragments production @ large angles

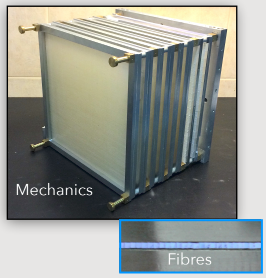
In 2012 and 2014 the charged fragments production has been studied with PMMA targets 5x5x15 cm³ impinged by $^{12}C$ and $^{4}He$ ion beams. A non negligible production has been observed at 60° and 90° with respect to the beam direction [1], [2],[3]. Fragments are mainly protons, with a kinetic energy between 50-150 MeV

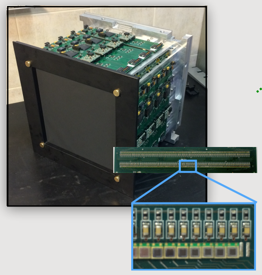


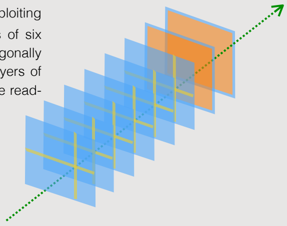




## Dose Profiler

The Dose Profiler (DP) is an innovative detector tailored to monitoring the beam range exploiting charged fragments [4]. It has been designed to track the secondary protons by means of six **scintillating fibres planes** (19.2 x 19.2 cm²), 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**.



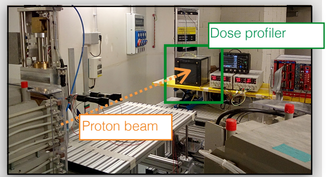


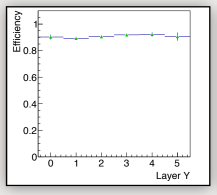
**Read-out electronics:** the SIPMs read-out is provided by BASIC32_ADC [3], controlled by FPGAs.

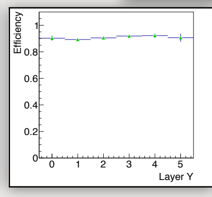
Silicon Photomultipliers (1 mm² area), resulting in a ~300 μm spatial resolution

## Test-beam @ Trento proton therapy center

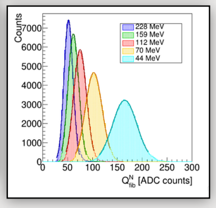
The first data taking campaign took place in May 2017 at Trento ProtonTherapy center, with the aim to characterize the DP with protons having the energy expected (50-150 MeV) for the secondary fragments produced during a Carbon ion treatment.



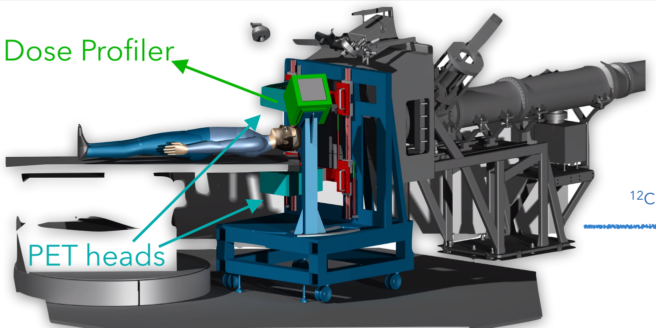




The **single layer efficiency** for tracker layers is **~90%** for both the views



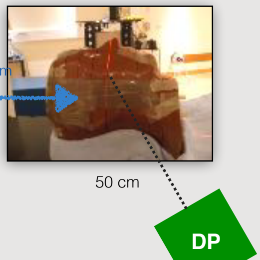

A 15-20% **energy resolution** has been measured

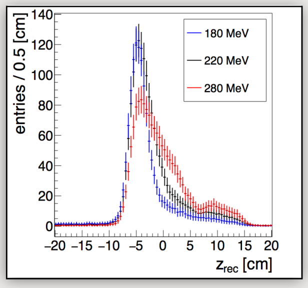



The DP, developed within the **INSIDE** collaboration, will be integrated in a multi-modal monitor system able to detect, at the same time, the charged secondary particles and the β+ emitters activity by means of two planar PET heads that measure the 511 keV annihilation photons. A clinical trial will start in summer 2018 at CNAO.

## Charged Secondary fragments production @ CNAO

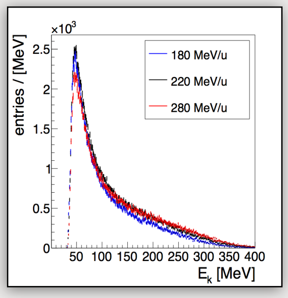
In July 2017 a data taking campaign has been performed at CNAO. The charged secondary fragments produced by an anthropomorphic phantom, impinged by Carbon ion beams at different energies in treatment-like conditions, has been collected by the DP at °60 with respect to the beam direction. The **charged fragments emission profile** along the beam axis has been measured.



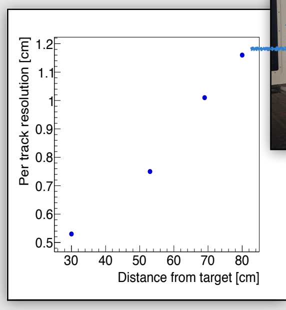



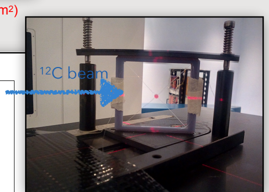

Between 1.2 and 1.6k tracks in total (per cm²)

~**100 tracks can be expected per pencil beam** in average conditions: strategies for 'PB packing' have to be envisaged in order to reach the desired precision (enough tracks per spot)




The **kinetic energy** distribution of the fragments escaped from the head phantom has been obtained using the Trento calibration.

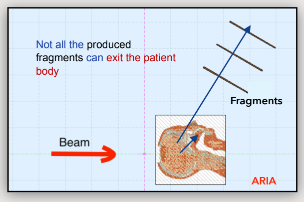


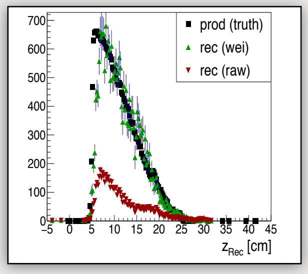




The **back-tracking resolution** has been measured using a small spherical plastic target (radius 2 mm), placed at the room isocenter.

## Correlation with the Bragg Peak

The final precision achievable on the BP position depends on how much statistics can be collected and how well the interaction of the ions beams and of the emitted fragments with the patient body is handled . 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.




A weighing algorithm is applied to take into account the material absorption. The weights are estimated using a full MC approach based on the study of fragments interactions with a water target (allows an experimental calibration)

[1] L. Piersanti et al. "Measurement of charged particle yields from PMMA irradiated by at 220 MeV/u C beam". In: Physics in Medicine and Biology 59 (2014), pp 1857–1872.
[2] C. Agodi et al. "Charged particle's flux measurement from PMMA irradiated by 80 MeV/u carbon ion beam". In: Physics in medicine and biology 57 (2012), p. 5667.
[3] A. Rucinski at al. "Secondary radiation measurements for particle therapy applications: Charged secondaries produced by 4He and 12C ion beams in a PMMA target at large angle", Phys. Med. Biol 63 (2018)
[4] G. Traini et al. "Design of a new tracking device for on-line dose monitor in ion therapy", 34 (2017), pp. 18-27

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