Development of an innovative Dose Profiler for range monitoring in particle therapy treatments

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Particle Therapy (PT) is an emerging technique that exploits accelerated charged ions (mostly proton or Carbon ions) for cancer therapy. The dose release of X-Rays used in conventional radiotherapy follows a decreasing exponential distribution as a funciton of the depth in the crossed medium, while a charged particle travelling through the matter loses most of the kinetic energy at the end of its range, in a narrow region called *Bragg Peak* (BP). It follows that in a PT treatment it is possible to achieve more spatial accuracy in dose deposition on the tumor region: this allows to preserve healty tissues and organ at risk around tumor, decreasing the possibility of negative secondary consequences for the patient. Furthermore the higher ionizing density that characterizes the dose release mechanism of charge particle with respect to photons results in an higher efficiency to killing the cancer cells. From the above considerations it appears that PT is mostly appropriate in case of tumors placed in deep area where it is not possible to perform surgery, or in case of radioresistent tumors.

On the other hand during a treatment of PT a not negligeable mismatch between the planned dose and the deposited dose may occur for different reasons, i.e. the quality and calibration of the Computed Tomography (CT) images, possible morphologic changes occurring between CT and treatment, patient mis-positioning and organ motion during the treatment itself. Therefore a novel monitoring technique, capable to provide a high precision in-treatment feedback on the dose release position, is required to fully profit from the therapy spatial selectivness, in order to avoid an over-dosage in the healty tissues and under-dosage in the tumor region. Since the particles of the primary beam don't excape from the patient, a promising approach consists in the detection of the secondary particles produced by the strong interaction between the primary beam and the crossed tissues, namely charged particles produced by projectiles or target fragmentation, prompt photons emitted by nucleus de-exitation, 511 keV pair photons generated by the annihilation of the positrons of β^+ emitters produced in the fragmentation process. The correlation between the emission spatial coordinate distribution of the aforementioned secondary radiation and the BP position has been proved in several experiments [1], [2], [3], [4], [5], [6].

An innovative detector named Dose Profiler (DP) was designed to perform on-line dose monitoring with secondary charge fragments emitted at large angle with respect to the beam direction. Such a device is under development in the framework of INSIDE project collaboration (INnovative Solutions for In-beam DosimEtry in hadrontherapy) funding by MIUR, INFN and Centro Fermi. DP is composed by a tracker that provides the direction of the interacting secondary charged particle (mostly protons), and a calorimeter that perform the measurement of energy. The first one is made-up of six layers (20×20 cm^2) of square scintillating fibers (0.5×0.5 mm^2), read-out by SiPMs; the second one by a matrix of 4×4 LFS pixellated crystals (5×5 cm^2) read-out by multi-anode PMTs. The design and optimization of the DP are peformed using Monte Carlo simulations, based on the results of experimental measurements mentioned in the previous text.

My Ph.D. thesis will be focused on the development of the DP. During the first year of Ph.D. I also gave my contribution to perform the analysis of data collected during a test-beam at HIT (Heidelberg Ion-beam Therapy Center) facility in 2014, as a continuation of the master degree thesis. In that occasion a PMMA (PoliMetilMetaCrylate) target has been irratiated by different beams of ^{12}C, ^{16}O, ^{4}He ions, in order to measure the energy spectra and the fluxes of the outcome radiation produced by non conventional ions, since Oxygen and helium ions are not employed for clinical treatments at the moment. At the same time I performed a full test of the first prototype of front-end board of DP and of read-out electronics, with two different dedicated experimental setup. In the two next years my task will be the implementation and test of the trigger and data-acquisition system by means of a matrix of FPGAs, in which I am currently involved, followed by several specifics measurements (cosmic rays data taking and test-beam) in order to perform a very accurate calibration and test of the detector. The completed apparatus will be also installed in Pavia at CNAO (Centro Nazionale di Adroterapia Oncologica), in preparation for a clinical application in a PT treatment. Therefore a very high reliability on the performaces of the DP is strongly required: one of the most important final achievement of my thesis job will be a strict hardware charaterization and a solid control on the software of the device.

References

[1] Riccardo Faccini and Vincenzo Patera, *Dose monitoring in particle therapy*, Mod. Phys. Lett. A 30, 1540023 (2015)

[2] L. Piersanti et al., *Measurement of charged particle yields from PMMA irradiated by a 220 MeV/u 12C beam*, Phys. Med. Biol. 59 (2014) 1857

[3] C. Agodi et al., *Charged particle's flux measurement from PMMA irradiated by 80 MeV/u carbon ion beam*, Phys. Med. Biol. 57 (2012) 5667

[4] C. Agodi et al. *Precise measurement of prompt photon emission for carbon ion therapy*, JINST 7 (2012), P03001.

[5] I. Mattei et al. *Prompt-γ production of 220 MeV/u ^{12}C ions interacting with a PMMA target*, JINST 10 (2015), P010034

[6] C. Agodi et al., *Study of the time and space distribution of β^+ emitters from 80 MeV/u carbon ion beam irradiation on PMMA*, Nuclear Instruments and Methods in Physics Research, Section B: Beam Interactions with Materials and Atoms 283 (2012), pp. 1–8.