MONDO: a neutron tracker for particle therapy secondary emission fluxes measurements

M. Marafini[a,b,*], V. Patera[a,b,c], D. Pinci[a], A. Sarti[c,d], A. Sciubba[a,b,d], E. Spiriti[c]

[a] *INFN Sezione di Roma, Roma, Italy*
[b] *Museo Storico della Fisica e Centro Studi e Ricerche "E. Fermi", Roma, Italy*
[c] *Laboratori Nazionali di Frascati dell'INFN, Frascati, Italy*
[d] *Dipartimento di Scienze di Base e Applicate per Ingegneria, Sapienza Università di Roma, Roma, Italy*

Abstract

Cancer treatment is performed, in Particle Therapy, using accelerated charged particles whose high irradiation precision and conformity allows the tumor destruction while sparing the surrounding healthy tissues. Dose release monitoring devices using photons and charged particles produced by the beam interaction with the patient body have already been proposed, but no attempt based on the detection of the abundant secondary radiation neutron component has been made yet. The reduced attenuation length of neutrons yields a secondary particle sample that is larger in number when compared to photons and charged particles. Furthermore, neutrons allow for a backtracking of the emission point that is not affected by multiple scattering. Since neutrons can release a significant dose far away from the tumor region, a precise measurement of their flux, production energy and angle distributions is eagerly needed in order to improve the Treatment Planning Systems (TPS) software, so to predict not only the normal tissue toxicity in the target region, but also the risk of late complications in the whole body. All the aforementioned issues underline the importance for an experimental effort devoted to the precise characterization of the neutron production gaining experimental access both to the emission point and production energy. The technical challenges posed by a neutron detector aiming for a high detection efficiency and good backtracking precision will be addressed within the MONDO (MOnitor for Neutron Dose in hadrOntherapy) project. The MONDO main goal is to develop a tracking detector targeting fast and ultrafast secondary neutrons. The tracker is composed by a scintillating fiber matrix ($4 \times 4 \times 8$ cm^3). The full reconstruction of protons, produced in elastic interactions, will be used to measure energy and direction of the impinging neutron. The neutron tracker will measure the neutron production yields, as a function of production angle and energy, using different therapeutic beams at CNAO in Pavia (protons, 12C ions and possibly 4He and 16O ions).

Keywords: Tracking detectors, Neutrons, GEM, SPAD, Particle Therapy
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1. Introduction

During Particle Therapy (PT) treatments many secondary particles are produced. While the characterization of the production of gammas from β+ annihilations, prompt photons and charged particles is currently being performed in [2] [3] the neutron related component of the secondary radiation is still affected by large experimental uncertainties and almost, yet, unexplored. Neutrons, characterized by a small attenuation length, are contributing to a substantial dose deposition in body regions not directly targeted or crossed by the beam, and are representing the most abundant and harmful radiation exiting the patient's body. The risk of developing a radiogenic second malignant neoplasm (SMN), years or decades after undergoing a PT treatment is one of the main concerns in PT administration and planning [1]. The SMNs can be developed in tissues that are located in-field (along the beam path) and out-of-field (far from the beam path). Their occurrence has a direct impact on the quantity and quality of life in cancer survivors, in particular in pediatric treatments [1]. A complete characterization of the neutron production, and the related dose deposition, is of outmost importance in order to provide a better treatment plan to patients, maximizing the therapy effectiveness while reducing secondary effects.

Precise measurements of the production region, energy and rates are needed in order to our knowledge on:

1. Biological Effects: Secondary complication risks (SMN)
2. Radio-Protection: Shielding, staff safety, etc...
3. Induced radioactivity.

PT treatments are mainly producing ultra-fast neutrons e.g. in carbon ion treatments, production energies lie within the$20 - 600$ MeV range [4]. Their energy is degraded after several scattering interactions with the target nuclei so that a large flux of slow neutrons is anyway expected.

2. MONDO Project

The MONDO (MOnitor for Neutron Dose in hadrOntherapy) project main goal is the development of a tracking detector tai-

*Corresponding author
Email address: michela.marafini@roma1.infn.it (M. Marafini)

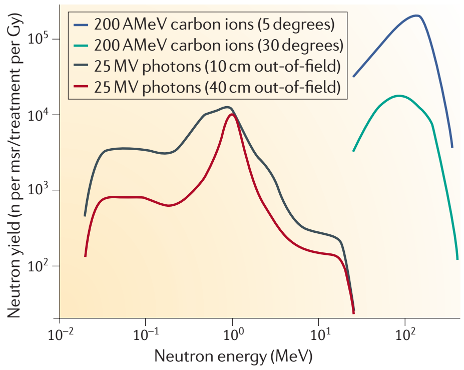

Figure 1: Emission shape of secondary neutrons produced in radio and particle therapy [4].

lored for the observation and measurement of the fast and ultrafast neutrons. The characterization of the neutrons flux and energy spectra, for different emission angles with respect to the beam direction on target of therapeutic interes are of interest for different primary beam (protons, carbon ions and eventually helium ions and also oxygen ions) used for particle therapy.

2.1. Detection strategy

The two main interaction mechanisms of fast and ultrafast neutrons in plastic scintillators are the elastic scattering with hydrogen nuclei (n-p) or the interaction with carbon nuclei (n-C). The n-p events are the most useful for neutron detection since the elastic scattering correlates the neutron and proton momenta. For those events in which the direction of the neutron is known, the measurement of the recoiling proton energy and direction can be used to compute the incident neutron energy: $E_n = E_p / \cos^2\theta$. If both direction and energy are unknown, the event cannot be reconstructed uniquely. In such a case the events with double elastic scattering can be exploited (see Fig. 2): if both proton recoils are measured, the neutron energy and direction can be reconstructed. The tracking and energy resolution achievable on the two recoiling protons drive the neutron energy and angular resolutions.

2.2. Detector

The proposed detector makes use of scintillating fibers as target for the elastic n-p scattering and as active detector for the recoiling protons. The square fibers (250 μm side) are organized in stacked orthogonal layers, covering a total active volume of $4 \times 4 \times 8$ cm^3. The orthogonal orientation of the layers ensures a stereoscopic view of the recoil proton ionization tracks.

Scintillating fibers will be readout, on one side, by means of a GEM chamber used as image intensifier [5]. The light produced within the GEM amplification phase will be acquired using CMOS Single Photon Avalanche Diode (SPAD - www.spadnet.eu) arrays (Fondazione Bruno Kessler).

A preliminary MonteCarlo simulation of the detector has been performed using the FLUKA software, in order to finalize the detector layout while maximizing the expected efficiency

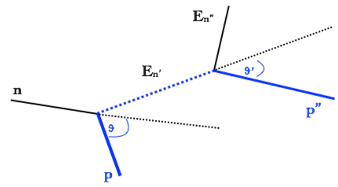

Figure 2: Double neutron elastic scattering. Measuring protons track, kinetic energy and angle, it is possible to close the kinematic and obtain neutron direction and energy informations.

and resolution of the detector.
The predicted efficiency for neutrons $\sim 4 \times 10^{-4}$ at 100 MeV increasing with energy up to $\sim 15 \times 10^{-4}$ at 600 MeV.

3. Conclusion

The neutron tracking detector being developed within the MONDO project has been tailored for the measurement of the flux and spectra of the secondary neutrons emitted in a PT treatment. A scintillating fibers layout, readout by means of a novel technique that uses GEM chambers as image intensifiers and SPAD arrays for the light detection, has been chosen to maximize the neutron reconstruction efficiency and emission point resolution. This information will help improving the Treatment Planning System (TPS) softwares used so far in hadrontherapy centers, that are based on MC simulations and analytical models that have not been yet fully validated against data, especially for the contribution to the total dose induced by neutrons in patient regions away from the tumor volume. Improving the neutron related dose release experimental knowledge will significantly help understanding and reducing the unwanted PT secondary effects.

Acknowledgments

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