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Characterisation of a double-sized Timepix3 mini-tracker for nuclear fragment detection in carbon-ion radiotherapy

Carbon-ion therapy is a form of external-beam radiotherapy used for highly precise cancer treatment. The characteristic depth-dose deposition curve of carbon ions exhibits a large dose gradient at the end of the beam range, the so-called Bragg peak. The position of the Bragg peak in the tumour is sensitive to anatomical changes such as tumour shrinkage or cavity filling. Therefore, the measurement of the beam range in the patient during treatment would allow improving the accuracy of carbon-ion radiotherapy. This real-time treatment verification could potentially be achieved by detecting charged fragments produced in nuclear interactions of the carbon ions with the patient. A fraction of those fragments emerges from the patient as secondary radiation. The quality of the conclusions drawn for an individual patient increases with increasing number of detected fragments, thus motivating the development of detectors with a large sensitive area.

In this work, a novel mini-tracker made of a pair of double-sized Timepix3 detectors (AdvaPIX TPX3 1x2x2 Stack, ADVACAM s.r.o., Prague, Czech Republic) is investigated for its suitability for measuring nuclear fragments that emerge from an irradiated head model. Each of the two detectors has a sensitive area of 2.8x1.4 cm2 divided into 512x256 pixels with a pixel size of 55x55 um2. The thickness of the silicon layer is 500 um. The two detectors are arranged one behind another at a distance of 20.3 mm, enabling the reconstruction of fragment tracks via cluster matching. The measurements were performed at the Heidelberg Ion Beam Therapy Centre (HIT, Heidelberg, Germany). The head model was irradiated with different clinical carbon-ion beams in order to generate a realistic fragment field (carbon-ion pencil beam energies range from 168 to 239 MeV/u). The experimental method has previously been described in Felix-Bautista et al. (2019) [1].

The pixel detector performance was characterised in the mixed fragment field. Cluster size, detector synchronisation as well as precision and accuracy of the track reconstruction were analysed. This analysis allowed finding the optimum working point in terms of bias voltage, energy threshold, detection angle with respect to the beam axis and detector distance to the head model. Moreover, the detector performance at high fragment intensity is of particular interest due to the large number of fragments generated in certain anatomies. The results help to inform the design of a detection system that will be used in an upcoming clinical trial.

[1] R Felix-Bautista et al 2019 Phys. Med. Biol. 64 175019

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