

Timepix detectors for development of novel imaging techniques for ion beam radiotherapy

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Ion radiotherapy is used to treat tumors located close to critical structures such as the brainstem, spinal cord, or optic nerves. In these cases, it is crucial to deliver an adequate dose to the tumour to halt its progression, while minimizing exposure to adjacent healthy tissues. Even minor variations in dose distribution—on the order of several millimeters—can have significant clinical consequences. These variations may arise from anatomical changes occurring during the course of treatment, which typically spans several weeks. Factors such as tumor shrinkage, tissue swelling, filling or draining of natural cavities, can alter the range of the ion beam within the body. Such changes can lead to overdosage of healthy tissues or underdosage of the tumour itself. Our research group is currently developing two methods to address this challenge:

1) Helium ion beam imaging is intended to be performed when the patient is ready for the treatment on the couch. We have developed a dedicated imager prototype using six Timepix1 detectors [1]. Two pairs of detectors serving as front and rear tracker are followed by an energy deposition unit providing the image contrast [2]. This unique concept replaces the bulky calorimeters used in other designs. The information about eventual changes of the internal patient geometry has the power of deciding whether the treatment has to be adjusted before the patient is irradiated.

2) In vivo monitoring of carbon ion beam treatments by tracking secondary ions relies on detecting nuclear fragments created in the patient during the irradiation. The core idea is to measure the distribution of secondary around the patient on two treatment days and to compare these distributions. If significant differences are detected, the treatment to be delivered on the next day can be adjusted accordingly. Since changes in the secondary ion emission profiles are very subtle, a major challenge lies in accurately detecting and interpreting these signal in terms of their spatial location and intensity. After more than a decade of experimental research, a clinically viable device based on Timepix3 detectors [3] has been developed and delivered by the Advacam s.r.o. Prague, Czech Republic [4]. The corresponding clinical trial called InViMo has been in progress since late 2023.

Both techniques were implemented at the Heidelberg Ion Beam Therapy Center in Germany. The presentation will demonstrate the performance of precision imaging by helium ion beams, together with the recent clinical results from the InViMo trial.

[1] X. Llopart, R. Ballabriga, M. Campbell, L. Tlustos and W. Wong 2007: Timepix, a 65k programmable pixel readout chip for arrival time, energy and/or photon counting measurements NIM A 581, 485 (2007)

[2] M. Metzner, D. Zhevachevska, A. Schlechter, F. Kehrein, J. Schlecker, C. Murillo, S. Brons, O. Jäkel, M. Martišíková and T. Gehrke: Energy painting: helium-beam radiography with thin detectors and multiple beam energies, Physics in Medicine and Biology 69, 055002 (2024)

[3] T. Poikela et al.: Timepix3: a 65K channel hybrid pixel readout chip with simultaneous ToA/ToT and sparse readout, JINST 9, C05013 (2014)

[4] L. Kelleter, L. Marek, G. Echner, P. Ochoa Parra, M. Winter, S. Harrabi, J. Jakubek, O. Jäkel, J. Debus, M. Martiskova: An in-vivo treatment monitoring system for ion-beam radiotherapy based on 28 Timepix3 detectors. Nature Scientific Reports 14, 15452 (2024)

Workshop topics

Applications

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