In-water fast-time-sensitive measurements with Timepix3 detector for dosimetry and tracking characterization of stray radiation fields produced by FLASH proton beams

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Introduction and Purpose

Emerging technologies such as FLASH radiotherapy require the development of new detectors to be able to cope with ultra-high-pulse-dose-rates (UHPDR) beams. The purpose of this work is to characterize the stray radiation produced in a water-phantom irradiated with so-called "FLASH" proton beams using an optimized Timepix3 detector. The data are valuable to develop traceable and validated methods for the characterization of stray radiation outside the UHPDR primary proton beam.

Materials and Methods

The beam, provided at the University Proton Therapy Dresden (UPTD), OncoRay – National Center for Radiation Research in Oncology, Dresden, Germany, was fixed to irradiate the water phantom. The measurements were performed in FLASH mode, with dose rates (DR) exceeding 160 Gy/s delivered by a pencil proton beam (PB) of 220 MeV energy. Scattered radiation was registered at different positions lateral to the beam direction and behind the Bragg peak. A schematic representation of the measured positions inside the water phantom can be seen in Fig. 2. Two customized detectors based on Timepix ASIC [1] chip with Silicon (Si) sensors of 100 and 650 μm thickness were immersed inside the IBA Blue water-phantom and inclined 45° towards the beam core. For data acquisition, the detectors were moved, in turns, laterally at different depths during irradiation to measure the scattered particles. Using a compact semiconductor pixel detector, equipped with a 5 cm flexible cable extension, separating the sensor from vulnerable electronic (Fig. 1), we measured the composition, spatial, time and spectral characteristics of mixed radiation fields.

Timepix3 Detectors

The detector module for FLASH radiotherapy is based on the “MiniPIX-Timepix3-Flex” device produced by ADVACAM (see Fig. 1 right). It is adapted for operation immersed in a water phantom. Its material composition is made tissue equivalent to minimize disturbances of the measured radiation field (Fig. 3). The novel Timepix3 detector can improve the current technology and metrology to cope with mixed radiation fields especially under conditions of Ultra-High Pulse Dose Rate [2]. The sensitivity area of its semiconductor sensor is segmented to 256x256 very small pixels (55 μm each). Moreover, the pixelated detector provides the image of track for each detected particle, its imaging capability allows for distinguishing the particle types and their directions (see Fig. 4 left). The neutron sensitivity can be provided by a suitable converter layer (e.g. 6LiF). Therefore, not only the total energy and intensity are recorded but the composition of the radiation field can be extracted as well analyzing the shapes of the particle tracks. The additional value for flash beam comes from Timepix3 ability to record the arrival time for each particle with a precision of 1.6 ns which allows Time-of-Flight (ToF) spectroscopy. The specialized software tool evaluates the shape parameters for each particle track recorded by the Timepix3 detector e.g. deposited energy, time of flight, track area, track length, roundness, flatness, linearity, polar angle. Such characterization is possible for scattered particles with a flux of about 10E8 particles/cm²/s. For higher fluxes, the detector can be operated in frame mode (Event “iToF”) and measure the total per-pixel deposited energy (iToF which provides spectral/dosimetry information) and the number of hits in each pixel (counts, intensity information). In this study, both detectors were operated in frame mode (Event “iToF”) with a 5 keV threshold.

Results and Conclusion

Spectral- and intensity- sensitive characterization of UHPDR proton beams were done using the customized MiniPIX-Timepix3-Flex Si. Two sensors were tested to identify the most suitable detectors and settings to be used for the characterization of scattered particles inside a water phantom. In Fig. 5 can be seen the spatial distribution of integrated deposited energy at position B5, 50 mm and position B6, 100 mm behind BP for a 2 ms proton pulse measured with both detectors MiniPix-Timepix3 tested. Results showed a detector equipped with a thin silicon sensor, 100 μm, is more suitable for UHPDR PB measurements. A thinner Si sensor, 100 μm, provides a radiation-sensitive volume of smaller dimensions which thus:

- Reduces the detection efficiency for high energy X-rays and gamma rays
- Reduces the event count rate, see Fig. 7
- Reduces the amplitude (“charge created per pixel”) of the detected signals
- Reduces the pixel size of the signal, allowing to register higher event count rate
- Signals of smaller amplitude are collected faster and allows to register more particles.

In Fig. 6 can be seen measurements of lateral penumbra from 50 mm up to 200 mm distance from the BP. The detector’s per-pixel saturation level was tested and in this setup, they were not achieved. The overall sum of per-pixel hits is below 6.7E7, which could allow for measurements at positions closer to the primary beam (Fig. 7).

Our preliminary measurements showed the customized version of MiniPix Timepix3-Flex with a silicon sensor of 100 μm thick is the most suitable detector tested to be used for characterizing high fluxes of stray radiation produced in UHPDR proton pencil beams. Further work includes testing other detectors for both primary and stray radiation in proton and electron beams.

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Bibliography

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