Characterization of stray radiation produced in FLASH electron beams using customized Minipix Timepix3 detectors

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Introduction

The technological necessities in detectors range are in continuous discovery, and state-of-the-art ideas are under development process [1, 2]. The challenge for scratching a detector to be suitable for the FLASH treatments is to solve the three features: dose-rate behavior, spatial resolution and the detector's time behavior. Having a clear picture of those physical characteristics, a detector could be implemented in the dosimetric protocols when dealing with ultra-high dose rate pulses (UHDpulse) or ultra-short duration pulses of electrons [3].

A hybrid pixel detector based on the ASIC position semiconductor technology from the Medipix family can measure and characterize the impact that an external beam could have on the irradiated medium [4, 5]. Timepix3 is an active detector with an impressive wide use in different domains, like dosimetry requets in the clinical field (particle identification, linear-energy transfer, dose rates), spectroscopic X-ray imaging.

This work aims to characterize the UHDpulse electron beams using customized detectors based on the Timepix3 ASIC chip. The Timepix3 detector was used to measure the composition, spatial, time and spectral characteristics of the primary and secondary radiation fields at the Microtron electron Accelerator from the Nuclear Physics Institute CAS (UJF CAS), Prague, Czech Republic.

Methodology

For beam data colection, a customized Minipix Timepix3 Flex semiconductor pixel detector with a flexible structure in its design (see Figure 1) was used. Two types of detectors, with different thickness, 100 and 500 µm were tested in dose rates up to 40 Gy/s, in order to study their suitability for the characterization of stray UHDpulse beams.

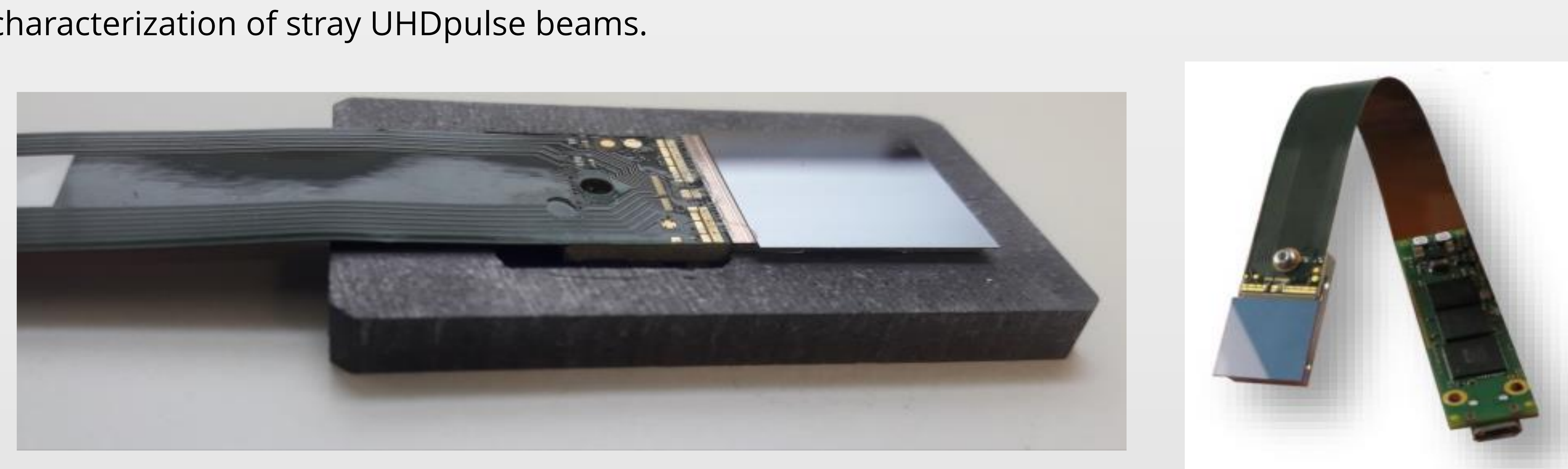

Figure 1. Optimized Minipix TimePIX3 Flex free of metal holders, screws, and chillers (all metal parts replaced by carbon and ABS plastic) to be tissue equivalent as much as possible. The electronic design is moved a few cm from the active structure to minimize the internal scattering produced by the detector.

For secondary beam measurements, a PMMA plate of 1 cm thickness was placed in front of the electron beam, with a pulse duration of 3.5 µs. The Timepix3 detectors (with silicon sensors of 100 and 500 µm) were placed on a shifting stage allowing for data acquisition at various lateral positions to the beam core (see Figure 2). Also, a cooling system was used for the constant temperature maintenance of the detector.

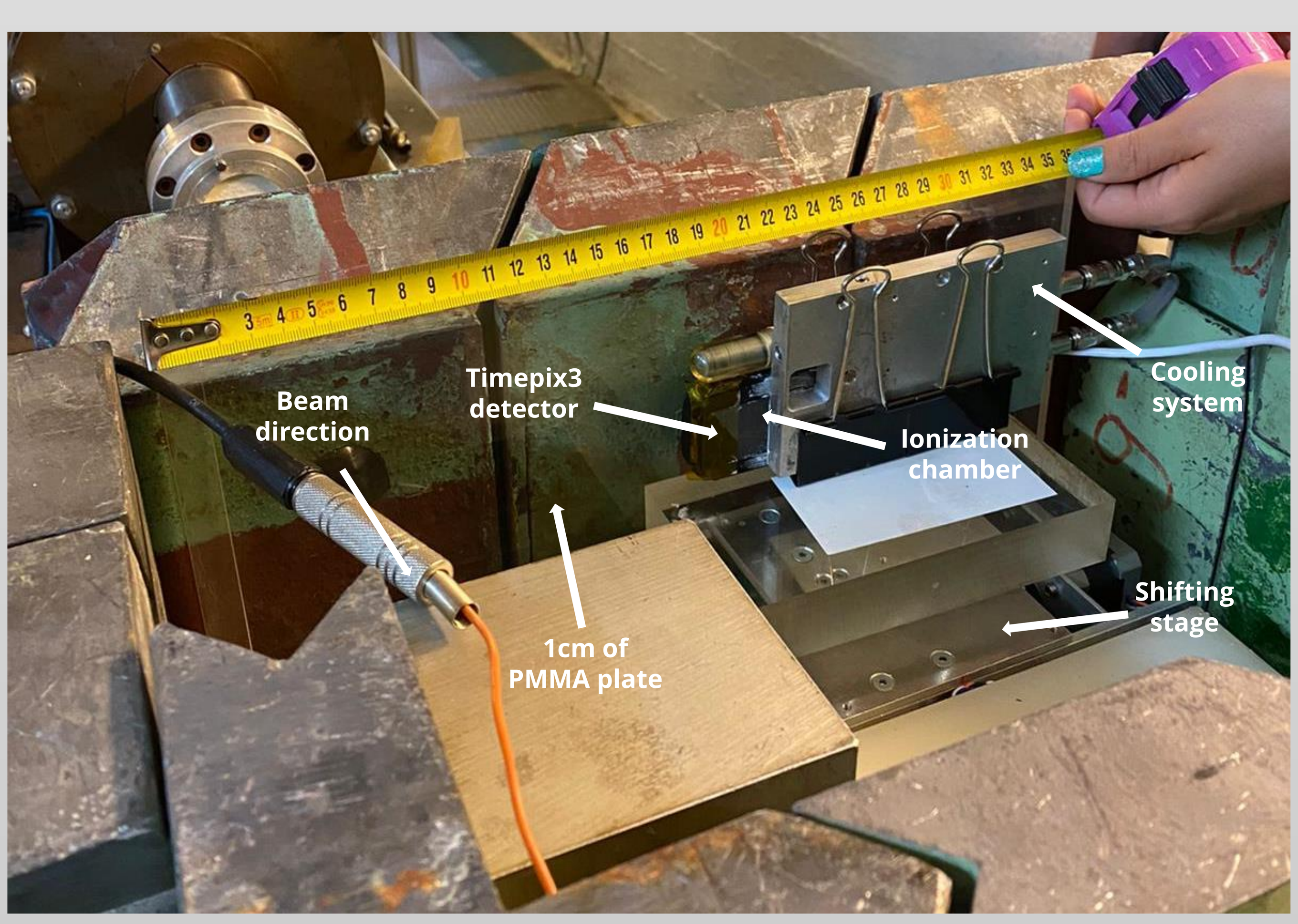

Figure 2. Set-up used for secondary radiation characterization: Timepix3 detector is placed behind 1 cm PMMA plate, 18 cm lateral from the incident electron beam, on a shifting stage. The setup is placed inside a massive Pb shielding to avoid intense background from the accelerator.

Measurements of the *per-pixel counting* and the *per-pixel energy* offer valuable information about the radiation field intensity and deposited energy, thus gives information on the dose.

References

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Results

Two types of Minipix Timepix3 Flex were used to measure the scattered radiation. The Timepix3 detector show the total integrated energy of the particles at different dose rates of the secondary beam (see Figure 3).

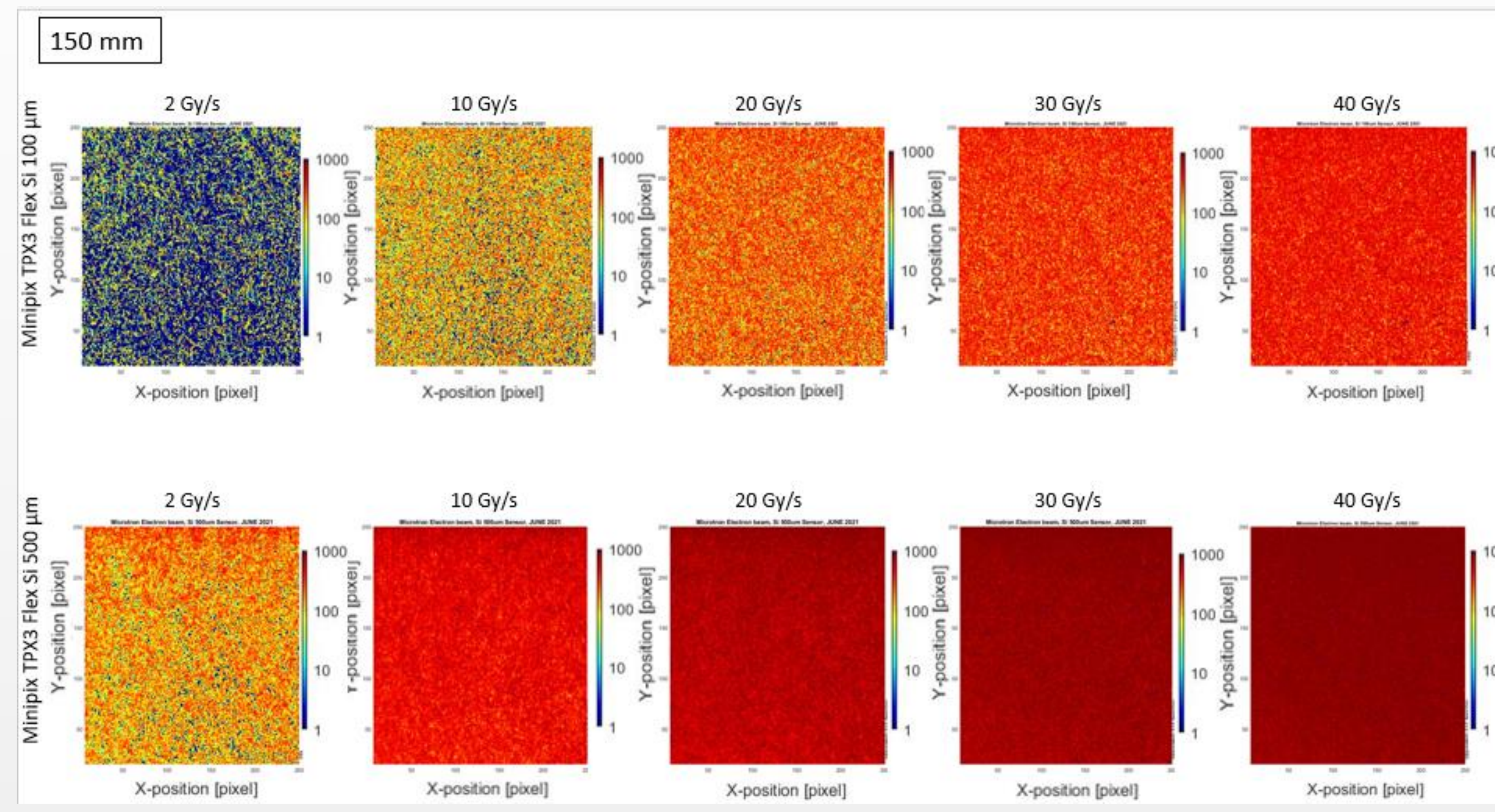

Figure 3. Per-pixel radiation signal (integrated per-pixel energy) measured using the Minipix Timepix3 Flex with 100 µm Si sensor (top row) and a Minipix Timepix3 Flex 500 µm Si sensor (bottom row) at a pulsed field of 15.7 MeV electrons. Each frame contains 256x256 pixels and represents the response of individual pulses with a length of 3.5 µs. The acquisition time of the detector was set 500 µs. Data measured at 15 cm distance lateral to the beam core.

Stray radiation was measured at different dose rates, using the Minipix Timepix3 detector placed at a distance of 10 cm from the direct beam, behind a PMMA plate. The sum of integrated energy of the overall particles that hit the detector is represented as a function of the initial dose rates used for measurements, at 2, 10, 20, 30, 40 Gy/s (see Figure 4).

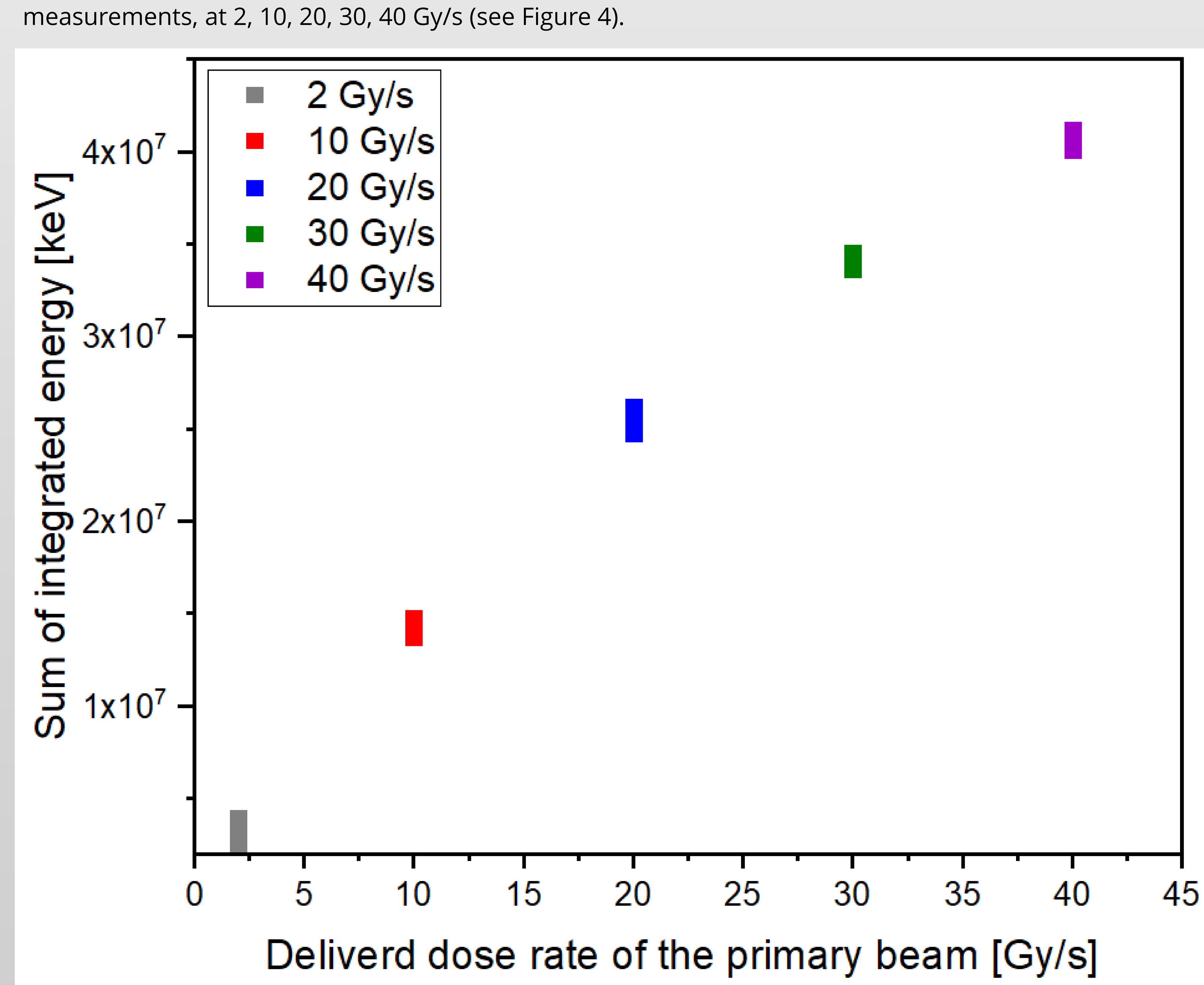

Figure 4. The sum of the integrated energy at different dose rates of the primary beam. The Timepix3 Flex detector with Si sensor with 100 µm thickness, was placed at 10 cm from the beam and measured the energy of the particles at different dose rates.

Conclusion

The results highlight the detector's ability to measure individual UHDpulses of electron beams in very short time, as well as the particles deposited energy and to estimate the doses in mixed radiation fields used in radiotherapy.

Acknowledgements

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