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TimePix detector for mixed radiation field characterization in particle therapy

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Proton and ion beams are commonly used worldwide for radiation therapy, offering advantageous dose distribution and increased relative biological effectiveness (RBE) compared to photons. While the RBE is assumed to vary with linear energy transfer (LET) of particles, currently only the constant RBE is taken into account in treatment planning due to a lack of tools for its experimental validation. Here, we present an approach for experimental characterization of proton LET using pixel semiconductor TimePix detectors aiming at advancing RBE modeling in proton therapy.
Extensive measurements (>300) were performed in a gantry treatment room of Krakow proton therapy facility with pencil beams of various energies. A compact TimePix MiniPIX detector was protected by a waterproof cover and placed inside a water phantom (Figure 1. a, b). The unique TimePix capability of individual particle tracking and energy deposition measurement allowed distinguishing protons from other particles using a convolutional neural network and computing their LET. Corresponding GATE/Geant4 Monte Carlo simulations were performed for comparison with experimental data.
The deep-learning particle identification model was trained using the homogeneous data sets and then used for proton identification with an accuracy over 90%. Figure. 1. c shows the LET spectrum of protons for a 150 MeV proton pencil beam, at the depth of Bragg peak in water, and 45 mm away from the beam axis. The measured dose-averaged LET of protons is 5.8 keV/µm, while for simulation results it is 5.3 keV/µm. What is also important, a wide range of proton LET values in mixed radiation fields causes different complexity of DNA damage. In general, we obtained a good agreement comparing measured and simulated LET spectra and dose-averaged LET of protons.
Any LET-based variable RBE model, to be applied in the clinical routine of treatment planning, requires accurate simulation and measurement methods for validation and quality assurance. Presented results demonstrate the ability of commercially available TimePix detectors, enhanced by artificial intelligence, for wide-range event-by-event characterization of mixed radiation field and LET measurements in proton radiation therapy. Our simple and accessible methodology can be applied in any proton radiation therapy facility.

Primary authors: Ms STASICA, Paulina (Institute of Nuclear Physics Polish Academy of Sciences, Krakow, Poland); Prof. GRANJA, Carlos (ADVACAM, Prague, Czechia); Prof. KOPEĆ, Renata (Institute of Nuclear Physics Polish Academy of Sciences, Kraków, Poland); Mr KRZEMPEK, Dawid (Institute of Nuclear Physics Polish Academy of Sciences, Kraków, Poland); Mr MAREK, Lukáš (ADVACAM, Prague, Czechia); Ms NGUYEN, Hanh (Baylor University, Waco, TX, United States); Dr OANCEA, Cristina (ADVACAM, Prague, Czechia); Dr RUCINSKI, Antoni (Institute of Nuclear Physics Polish Academy of Sciences, Kraków, Poland); Dr RYDYGIER, Marzena (Institute of Nuclear Physics Polish Academy of Sciences, Kraków, Poland); Prof. SCHUBERT, Keith (Baylor University, Waco, TX, United States); Prof. SCHULTE, Reinhard (Loma Linda University, Loma Linda, CA, United States of America); Dr GAJEWSKI, Jan (Institute of Nuclear Physics Polish Academy of Sciences, Kraków, Poland)

Presenter: Ms STASICA, Paulina (Institute of Nuclear Physics Polish Academy of Sciences, Krakow, Poland)

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