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Integration mode proton imaging with pixelated large-area CMOS sensor

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A novel irradiation platform for pre-clinical proton therapy studies foresees proton imaging for positioning and accurate treatment planning [1]. While proton imaging at synchrocyclotron-based proton therapy centers is challenging in single particle tracking mode due to high instantaneous particle fluxes, it is feasible in integration mode. Large-area CMOS sensors allow the determination of a small-animal sized object's water-equivalent thickness (WET) by variation of the incoming proton beam energy (here called probing energy). Previous work has shown the feasibility of such proton imaging for preclinical studies. We present results from proton radiography experiments at two proton therapy centers with a CMOS detector.

Image contrast is achieved by recording the proton energy deposition in the detector pixels for several probing energies and applying a signal decomposition method to retrieve the WET. Proton imaging of a micro-CT calibration phantom was performed by placing the 12×14 cm² CMOS sensor Lassena (Nordson, Ohio, USA) with 50µm pixel pitch behind it to acquire up to 2000 frames with 60ms integration time in each frame. Experiments were performed at the Danish Centre for Particle Therapy (DCPT, Aarhus, Denmark) and the Centre Antoine-Lacassagne (CAL, Nice, France) with automated energy switching to generate the probing energies suitable for small-animal sized objects.
To assess WET accuracy, a micro-CT calibration phantom (SmART scientific solutions, Maastricht, The Netherlands) with 10 inserts of tissue-mimicking materials was imaged. The phantom-to-detector distance was varied to be 0 cm, 1 cm, 2 cm and 3 cm at DCPT and 0 cm for the proof of feasibility at CAL in order to determine the influence of the air gap on the measurement quality. Calibration measurements were done with PMMA plates of 5 mm, 10 mm and 20 mm for the experiments at DCPT and 10 mm at CAL, all of which the WET was measured with the peakfinder (PTW, Freiburg, Germany). FLUKA Monte Carlo simulations were used to complement the lookup-table that will be used to determine the WET for each pixel with a linear signal decomposition [2].

Proton radiographs obtained with the beam from the isochronous synchrotron at DCPT reached an average relative WET error of 1% for 0 cm phantom-detector distance and 1.5% for 1 cm and a spatial resolution of 0.2 mm and 0.4 mm, respectively. For larger phantom-detector distances, proton scattering considerably impacts the spatial resolution so that WET determination gives 10% and 25% relative WET error.
Imaging time for one radiograph was 45s and dose below 2 cGy.
At the synchrocyclotron facility, results prove feasibility of integration mode proton radiography at high particle flux and give 0.2 mm spatial resolution without air gap. Detailed data analysis is ongoing and final results will be presented.

This study demonstrates that proton radiographs with promising WET accuracy and spatial resolution are achievable at isochronous cyclotron and synchrocyclotron with the compact setup including the new Lassena detector.

[1] Parodi, K. et al., Acta Oncologica. 58(10) (2019), 1470–1475
[2] Meyer et al., PMB. 62(2017), 1096-1112

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