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#09-150 Development of a proton bunch monitor for accurate particle therapy treatment verification

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Treatment verification is expected to improve targeting precision in particle therapy. A promising technique to achieve this goal is the detection of prompt gamma rays emitted along the particle tracks inside the patient. The range of the particle beam can be inferred by determining the time distribution of these gamma-rays relative to the radio frequency of the accelerator, a method commonly referred to as Prompt Gamma-Ray Timing.

However, the translation of this method into a clinical setting is currently hindered by instabilities of the phase relation between the arrival of the proton bunches and the radio frequency of the accelerator. These instabilities include two effects, which have been studied at the clinical treatment facility of the University Proton Therapy Dresden. Firstly, a long-term drift of the proton bunch phase relative to the radio frequency in the order of several hundred picoseconds per hour was observed, which may be caused by small temperature changes in the cyclotron's magnet resulting in magnetization variations in its iron parts. Secondly, strongly damped oscillations in the mean of measured prompt gamma-ray timing spectra with an amplitude in the order of few hundred picoseconds occur for about two seconds after each change of the particle energy during pencil beam scanning. This oscillation is caused by ramping the acceleration voltage back to its nominal value, which is reduced between energy layers to minimize the dark current of the accelerator and the resulting excess dose to the patient.

While the former effect is only of secondary importance for the treatment due to its comparably long time scale, the phase oscillation has a considerable negative impact on the accuracy of the Prompt Gamma-Ray Timing method, which has to detect time shifts in the order of a few picoseconds for the detection of millimeter range changes. Therefore, the development of a method to monitor the arrival time of the proton bunches independently from the accelerator radio frequency, a so-called proton bunch monitor, is crucial.

To this end, a bunch monitor prototype was developed consisting of scintillating fibers placed in the halo of the proton beam. The fibers were read out on both ends by silicon photomultipliers. A thick acrylic glass target with cylindrical air cavities of varying thickness and different tissue-equivalent inserts was irradiated with protons of clinically relevant energies and typical beam currents. The mean proton arrival time, determined from the time spectra of the proton bunch monitor, was used to correct the prompt gamma-ray timing spectra acquired by Ø2"x2"CeBr3 high-resolution scintillation detectors. This correction allowed to resolve differences in the prompt-gamma ray timing spectra acquired with the different cavities and inserts.

In conclusion, the developed proton bunch monitor was successfully integrated to the Prompt Gamma-Ray Timing method and is expected to enable the clinical application of this method for clinical treatment verification in particle therapy.

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