High-resolution characterization of scattered radiation in proton therapy by Timepix3 detectors behind phantoms with and without dental implants

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Proton therapy is expanding its application to a greater number of patients. Therefore, the number of cases that will undergo treatment include patients with implants and other metallic objects. This should be considered in the planning system and their impact regarding the dose deposition must be precisely evaluated [1], [2]. For this reason, in this work we experimentally investigate the composition and spectral characterization of scattered particles and the secondary field produced behind the Bragg peak (BP) in tissue-equivalent phantoms with titanium (Ti) dental implants placed along the primary beam path.

Using high-spatial resolution and time-sensitive imaging detectors in a high granularity pixelated array provided by the ASIC chip Timepix3 with silicon sensor, we measure in detail the scattered radiation field with spectral and tracking analysis [3]. The mixed particle field was produced by a collimated 170 MeV proton beam. PMMA plates (140 mm H_20) were inserted in the beam path to reach the BP at the region of the metallic implants. Two pixel detectors with Si sensors of different thicknesses, 500 and 300 µm respectively, were placed behind the phantom (see Fig. 1a) along the axis of the incident proton beam. The detailed registration of scattered particles measured by Timepix3 behind the phantom is shown in figure 1b. The scattered radiation is analyzed in terms of LET spectra and composition Recognition of particle type events [3] is based on extensive experimental calibrations in well-defined radiation fields as well as with AI and machine learning algorithms [4]. The resulting particle flux in both setups are resolved: high-energy transfer particles (HETP) namely protons and low-energy transfer particles (LETP) namely electrons together with X and low-energy gamma rays. Protons are the predominant particle responsible for dose deposition after the BP. Without significant variation in particle flux when the Ti implants are placed in the beam's path, 285 particles$\cdot$cm$^{-2}\cdot$s^{-1} without them, and 263 particles$\cdot$cm$^{-2}\cdot$s^{-1} with metallic inserts, the contribution of particles like electrons, X rays, gamma particles to the particle fluxes is affected by the present of high Z material in the irradiation field. Comprehensive evaluation of the scattered radiation field provides a detailed understanding of the impact of Ti materials on dose deposition escalation to highlight the possible radiobiological implication in proton treatments.

References:

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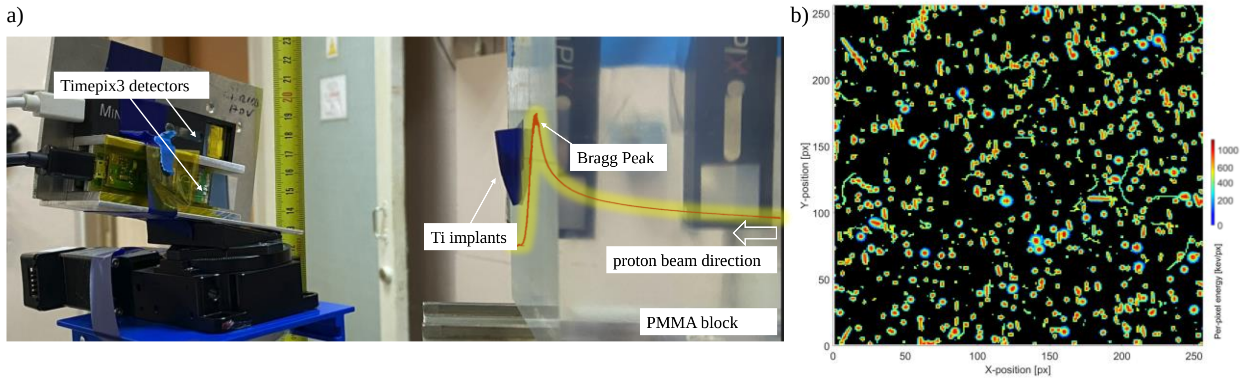

Figure 1. a) *Experimental setup using a single chip MiniPIX-Timepix3 camera (top) and a MiniPIX-Timepix3 2x stack particle telescope (bottom) placed behind a PMMA phantom with Ti implants. A collimated proton beam with a nominal energy of 170 MeV was used from the JINR phasotron accelerator.* ***b)*** *Particle tracks (1k particles) of scattered and secondary radiation behind the phantom with Ti implants measured by Timepix3 with 500 µm Si sensor. The per-pixel energy registration is displayed by the color bar. The full detector pixel matrix is shown (256×256 pixels = 14mm×14mm = 1.98 cm²)*

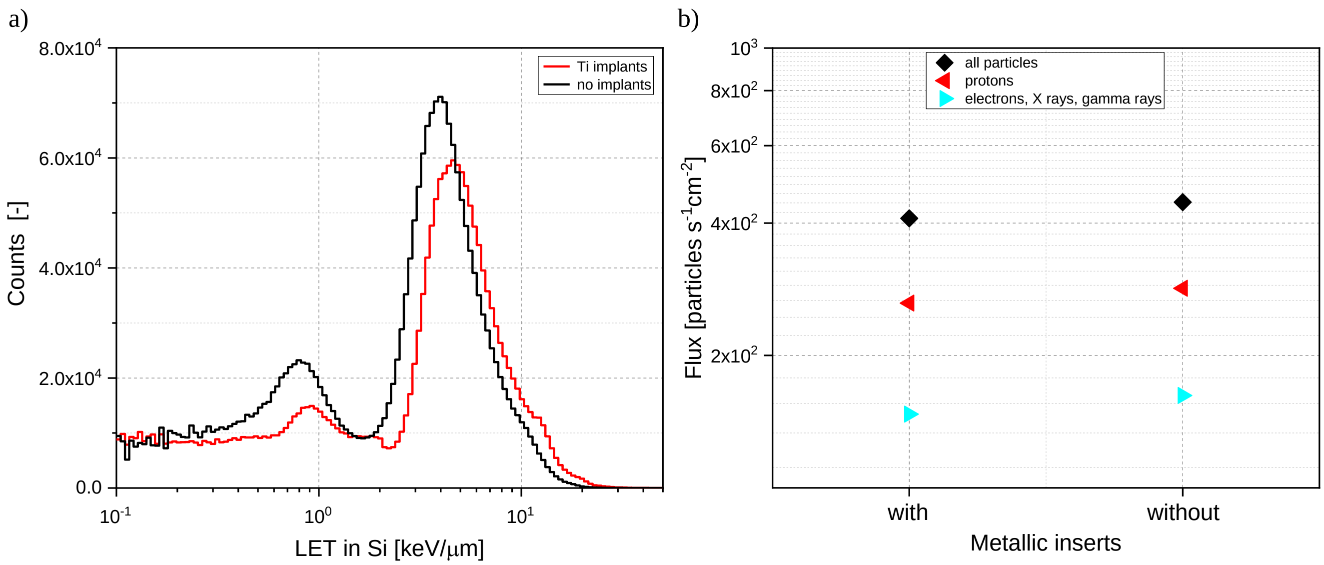

Figure 2*. a) LET spectra of the scattered-radiation field behind the PMMA phantom with (red) and without (black) Ti implants. Measured by a Timepix3 500 µm Si sensor and by a Timepix 300 µm Si sensor, respectively. All particles registered by the detectors are given. b) Corresponding particle flux for all particles (black), scattered protons (red) and secondary particles: electrons, X rays, low-energy gamma ray (cyan).*