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Titel des Beitrags: Ionoacoustic characterization of the proton Bragg peak with submillimeter accuracy.

Abstract: Range verification in ion beam therapy relies to date on nuclear imaging techniques which require complex and costly detector systems. A different approach is the detection of thermoacoustic signals that are generated due to localized energy loss of ion beams in tissue (ionoacoustics). Aim of this work was to study experimentally the achievable position resolution of ionoacoustics under idealized conditions using high frequency ultrasonic transducers and a specifically selected probing beam. A water phantom was irradiated by a pulsed 20 MeV proton beam with varying pulse intensity and length. The acoustic signal of single proton pulses was measured by different PZT-based ultrasound detectors (3.5 and 10 MHz central frequencies). The proton dose distribution in water was calculated by Geant4 and used as input for simulation of the generated acoustic wave by the matlab toolbox k-WAVE. In measurements from this study, a clear signal of the Bragg peak was observed for an energy deposition as low as $10^{12}$ eV. The signal amplitude showed a linear increase with particle number per pulse and thus, dose. Bragg peak position measurements were reproducible within ±30 μm and agreed with Geant4 simulations to better than 100 μm. The ionoacoustic signal pattern allowed for a detailed analysis of the Bragg peak and could be well reproduced by k-WAVE.
The authors have studied the ionoacoustic signal of the Bragg peak in experiments using a 20 MeV proton beam with its correspondingly localized energy deposition, demonstrating submillimeter position resolution and providing a deep insight in the correlation between the acoustic signal and Bragg peak shape. These results, together with earlier experiments and new simulations (including the results in this study) at higher energies, suggest ionoacoustics as a technique for range verification in particle therapy at locations, where the tumor can be localized by ultrasound imaging. This acoustic range verification approach could offer the possibility of combining anatomical ultrasound and Bragg peak imaging, but further studies are required for translation of these findings to clinical application.