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Ultrafast temporal response of materials to proton irradiation

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Proton accelerators driven with ultra-intense short pulse lasers provide proton beams with extraordinary characteristics. The extreme acceleration fields (typically exceeding TV/m) allow very compact accelerators (acceleration lengths on the micrometer scale) to reach energies of 10s of MeV with up to 2 1013 particles per bunch and excellent spatial beam quality (transverse emittance). The short duration of the acceleration fields excited by the laser provides the basis for proton bunches with ultrashort pulse duration. Such short proton pulses raise the possibility of investigating the temporal dynamics of the fundamental interaction of protons and ions with matter directly. Here we report on the temporal characterisation of few picosecond (ps, 10-12 s) laser driven proton bunches for this purpose. Prompt transient opacity for optical probe radiation from protons stopping in high purity fused silica (a-SiO2) provides the basis for single-shot characterisation of laser-accelerated proton bunches. The rapid ionisation dynamics allow the measurement of proton pulse durations as short as 3.5 ± 0.7 ps in a 0.4 ± 0.05 MeV bandwidth. This corresponds to an ultra-low longitudinal emittance of (1.75 ± 0.25) × 10-6 eV s and is in excellent agreement with numerical modelling. These observations pave the way to generating seed pulses for proton-driven wakefield acceleration of electrons in advanced lepton collider concepts.

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