Acceleration of low-divergence proton beams at kHz rate

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Laser-plasma acceleration of protons promises compact and versatile sources of energetic protons for applications in material science, nuclear physics and medicine. Present day multi-TW and PW lasers produce protons via the target normal sheath acceleration (TNSA) which provides $10-100$ MeV energies, but also high beam divergence ($\sim 30°$) and low average brightness. Alternatively, the higher average proton flux and brightness can be reached using few-TW kHz lasers, which comes at a cost of lower particle energies [1]. As was found in early studies, the corresponding acceleration process relies on the electron dynamics in the laser field and differs significantly from TNSA, providing different energy scalings [2]. Recent experimental studies with thin liquid sheet targets demonstrated kHz acceleration of multi-MeV protons, which is of high interest for applications [3].

Here we report proton beams with 100 pC charge, 0.5 MeV cutoff energy and 3° divergence produced from the solid target by few-mJ pulses of the kHz laser *Salle Noir* (LOA) [4]. Plasma target and interaction conditions were controlled by varying laser pulse duration in the range from a few femtoseconds to picosenconds and the pre-pulse delay. Both spatial and spectral beam profiles were scanned using the absolute charge calibrated small aperture time-of-flight detector, and the Thomson parabola spectrometer. With the help of numerical simulations and theoretical model we have reproduced the measurements, explained the physical process as the radiation pressure assisted Coulomb explosion, and obtained its quantitative scalings to higher energies.

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