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Enhanced ion acceleration from a non-ideal laser pulse contrast

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The major challenges of compact proton sources driven by an ultrashort high-intensity laser are currently to establish precise control over proton beam parameters and shot-to-shot stability. Shooting ultrathin targets has shown to yield higher proton energies, which became recently accessible due to temporal laser pulse shape control using plasma-mirror techniques. We find that the intensity ramp, transmitted to the target by the plasma mirror during the last picosecond before the pulse peak, becomes significantly decisive for the subsequent acceleration performance. Reliable characterization of this ramp with modern laser diagnostics remains challenging and immense computational needs required to fully resolve the plasma kinetics leave it mostly unexplored in today's simulations of laser-solid interaction. We present the results of 3D large-scale simulations with PIConGPU, taking into account realistic contrast conditions, bridging the scales from picosecond pre-plasma formation over transient, non-equilibrium dynamics of the tens of femtosecond laser duration down to attosecond plasma oscillations. Adding to beneficial acceleration conditions presented by hybrid acceleration mechanisms and onset of relativistic transparency, we show that the maximum proton energy can be optimized by a specific leading pulse edge via a combination of pre-thermal and thermal TNSA, surpassing the performance of the ideal diffraction limited Gaussian pulse.

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