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Collisionless shocks and particle acceleration in laser-driven laboratory plasmas

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Collisionless shocks are pervasive in space and astrophysical plasmas, from the Earth's bow shock to Gamma Ray Bursters; however, the microphysics underlying shock formation and particle acceleration in these distant sites is not yet fully understood. Mimicking these extreme conditions in laboratory is a grand challenge that would allow for a better understanding of the physical processes involved. Using *ab initio* multi-dimensional particle-in-cell simulations, shock formation and particle acceleration are investigated for realistic laboratory conditions associated with the interaction of intense lasers with high-energy-density plasmas. Weibel-instability-mediated shocks are shown to be driven by the interaction of an ultraintense laser with overcritical plasmas. In this piston regime, the laser generates a relativistic flow that is Weibel unstable. The strong Weibel magnetic fields deflect the incoming flow, compressing it, and forming a shock. The resulting shock structure is consistent with previous simulations of relativistic astrophysical shocks, demonstrating for the first time the possibility of recreating these structures in laboratory. As the laser intensity is decreased and near-critical density plasmas are used, electron heating dominates over radiation pressure and electrostatic shocks can be formed. The electric field associated with the shock front can reflect ions from the background accelerating them to high energies. It is shown that high quality 200 MeV proton beams, required for tumor therapy, can be generated by using an exponentially decaying plasma profile to control competing accelerating fields. These results pave the way for the experimental exploration of space and astrophysical relevant shocks and particle acceleration with current laser systems.