Coulomb-Explosion Driven Proton Focusing in an Arched CH Target

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Abstract : High-energy-density state, i.e., matter and radiation at energy densities in excess of 10^11 J/m^3, is related to material, nuclear physics, astrophysics, and geophysics. Laser-driven particle beams are better suited to heat the matter as a trigger due to their unique properties of ultrashort duration and low emittance. Compared to X-ray and electron sources, it is easier to generate uniformly heated large-volume material for the proton and ion beams because of highly localized energy deposition. With the construction of state-of-art high power laser facilities, creating of extremely conditions of high-temperature and high-density in laboratories becomes possible. It has been demonstrated that on a picosecond time scale the solid density material can be isochorically heated to over 20 eV by the ultrafast proton beam generated from spherically shaped targets. For the above-mentioned technique, the proton energy density plays a crucial role in the formation of warm dense matter states. Recently, several methods have devoted to realize the focusing of the accelerated protons, involving externally exerted static-fields or specially designed targets interacting with a single or multi-pile laser pulses. In previous works, two co-propagating or opposite direction laser pulses are employed to strike a submicron plasma-shell. However, ultra-high pulse intensities, accurately temporal synchronization and undesirable transverse instabilities for a long time are still intractable for currently experimental implementations. A mechanism of the focusing of laser-driven proton beams from two-ion-species arched targets is investigated by multi-dimensional particle-in-cell simulations. When an intense linearly-polarized laser pulse impinges on the thin arched target, all electrons are completely evacuated, leading to a Coulomb-explosive electric-field mostly originated from the heavier carbon ions. The lighter protons in the moving reference frame by the ionic sound speed will be accelerated and effectively focused because of this radially isotropic field. At a 2.42×10^21 W/cm^2 laser intensity, a ballistic proton bunch with its energy-density as high as 2.15×10^17 J/m^3 is produced, and the highest proton energy and the focusing position agree well with that from the theory.

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