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Generation of a high-density high-energy proton jet from the interaction of an ultra-intense laser pulse with a thin solid target

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With the advent of high power lasers in the range of petawatt, it is now possible to study laser-plasma interactions in a new intensity regime. Recently, a Laguerre-Gaussian (LG) laser pulse, having a hollow shape, has drawn interests as a mechanism to transfer the angular momentum of the laser pulse to interacting particles. A laser light with an LG amplitude distribution has a well-defined orbital angular momentum (OAM) [1]. We propose a scheme to generate a high density relativistic proton jet from the interaction of an intense laser pulse with an ultrathin solid density electron-proton plasma target and demonstrate its feasibility by using three-dimensional particle-in-cell simulations.

We investigated the interaction of the intense circularly polarized Laguerre-Gaussian (CP LG) laser beam with a solid density thin plasma slab target using 3D PIC simulations. For a CP LG laser pulse with zero total angular momentum, i.e. the case of anti-parallel spin and orbital angular momenta, the target can be compressed to form a high density plasma column, spatially confined along the laser axis by the ponderomotive force of the laser pulse. We found that copious target electrons and protons are trapped at the center of the laser axis by the LG laser ponderomotive potential to form a high density plasma column and accelerated by the radiation pressure of the laser. The protons in the target are accelerated through the radiation pressure acceleration mechanism, and a portion of high energy protons forms a high density relativistic proton jet propagating along with the laser pulse. It is shown that the number of protons propagating in the narrow divergence angle around the laser axis was approximately two orders of magnitude larger than that accelerated by a circularly polarized Gaussian laser pulse.

For the PIC simulation, a CP LG laser pulse with intensity $I = 10^{23}$ W/cm^2 is used to irradiate on a thin plasma slab of 200 nm thickness composed of electrons and protons with a density of 200 n_c. The proton density distribution and laser pulse propagation at time t = 200 fs after the start of the interaction is shown in Figure 1. The high density proton jet is clearly seen to be maintained after the laser pulse is separated around t = 100 fs. Figure 2 shows the temporal evolution of the energy spectrum of protons with an emission divergence angle less 0.05. The spectrum saturates after 200 fs and still have 2 orders of magnitude higher proton number per unit energy that the result by using a CP Gaussian laser pulse having the equal power with the CP LG laser (not shown in the figure).

In conclusion, we propose a scheme to generate a high density relativistic proton jet from the interaction of an intense laser pulse with an ultrathin solid density electron-proton plasma target and demonstrate its feasibility by using three-dimensional particle-in-cell simulations. It is found that the intense LG laser beam can generate a high-density high-energy proton jet from a thin film target.

References
[1] L. Allen, M. W. Beijersbergen, R. J. C. Spreeuw, and J. P. Woerdman, Orbital angular momentum of light and the transformation of Laguerre-Gaussian laser modes, Phys. Rev. A **45**, 8185 (1992).

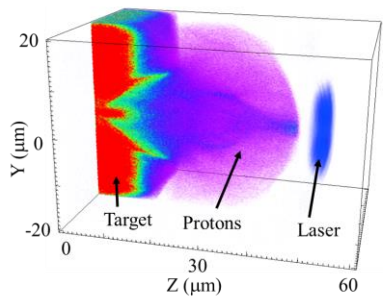

Fig. 1. The x = 0 plane cut view of proton density and laser pulse at t = 200 fs.

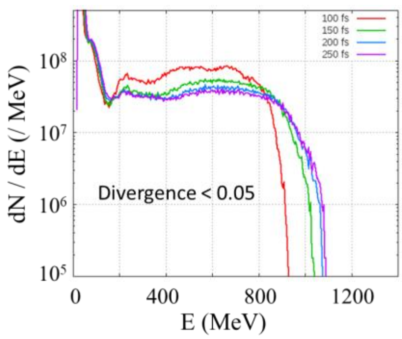

Figure 2. Temporal evolution of the energy spectrum of protons having a divergence angle of less than 0.05.