Injection dynamics of direct-laser-accelerated electrons in a relativistically transparent plasma

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High-energy electron beams are useful in many applications, including fast ignition of inertial confinement fusion, radiography, novel sources of light and neutrons, etc. Since they can produce huge (>100 GV/m) electric fields within a tiny distance, laser-based plasma accelerators promise to revolutionize the accelerator technology and have thus attracted much research attention. Two distinct methods of high-energy electron beam production by laser-plasma interaction have been proposed, namely, laser wake-field acceleration (LWFA) and the direct laser acceleration (DLA). In LWFA, quasimonoenergetic electron beams with energies up to several GeV have been obtained. However, the low-density ($<10^{20}$ cm^{-3}) plasma used in this scheme limits the total charge of accelerated electrons to about 100 pC, making this approach unsuitable for applications requiring high-charge electron beams.

DLA of electrons is possible in relatively dense plasmas, and high-charge (>10 nC) electron beams with energies up to hundreds MeV can be obtained. In this regime the electron betatron oscillation frequency in the laser-driven plasma channel matches the Doppler-shifted laser frequency, and several schemes have been proposed for enhancing the electron energy. However, so far, little attention has been paid to the electron injection process, which can significantly affect the quality of the accelerated electrons. Electron injection in the plasma channel has been found to be rather complicated. In a relatively low-density plasma, the laser field excites a plasma wake, which traps and pre-accelerates the electrons so that they can enter the DLA phase. However, in a relativistic transparency regime of near-critical-density plasma, the injection dynamics of the DLA electrons is still unclear. In particular, the effect of the background ions, which can be dragged by the large charge separation electric fields, cannot be neglected.

Here we present an investigation on the injection dynamics of the DLA electrons in the relativistic transparency regime. It is shown that ion density spikes, which are excited by the longitudinal charge-separation electric field, play a crucial role on the electron injection process. In particular, the localized electric field induced by the ion motion acts as a series of potential wells that trap and guide a portion of electrons from the edge of the plasma channel into the central region so that they can be directly accelerated by the laser field. In addition, it is found that with an increase in the azimuthal magnetic field self-generated by the accelerated electron beam, the injected electrons are deflected away from the laser-field region so that the electron injection process is gradually terminated

References

[1] K. Jiang, C. T. Zhou, T. W. Huang, C. N. Wu, L. B. Ju, H. Zhang, S. Z. Wu, T. X. Cai, B. Qiao, M. Y. Yu, and S. C. Ruan, Injection dynamics of direct-laser-accelerated electrons in a relativistically transparent plasma. Physical Review E **98**, 033206 (2018)

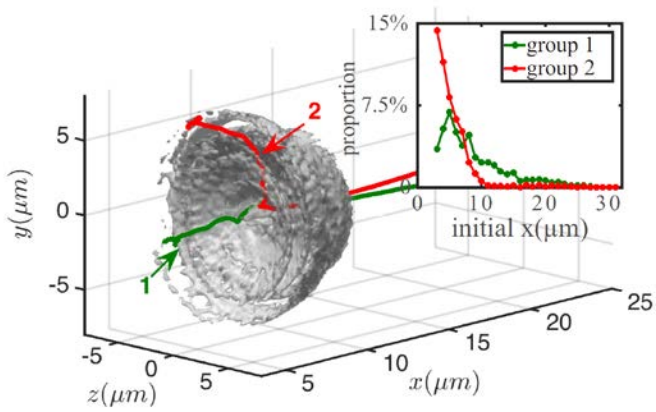

Figure 1. Trajectories of sample electrons and the isosurface distribution of ion density (gray). The colored curves marked by numbers correspond to trajectories of individual electrons; The inset shows the proportion of the two groups of electrons in the final energetic electron bunch (with $\gamma > 50$) as a function of their initial x coordinate. Group 1 has a total proportion of 48%, and group 2 has a total proportion of 52%, which is resulted from summing up their proportions at different initial x coordinates.