Direct acceleration of a positron beam driven by a Laguerre-Gaussian laser pulse

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As a kind of the most accessible antiparticles, positrons have diverse applications in a variety of areas, such as electron-positron collider, positron emission tomography (PET) and positron annihilation spectroscopy (PAS). In order to study the Higgs Boson using electron-positron colliders or the voids and defects in bulky solids using the PAS technique, positron beams with high and tunable energy are required. However, the accelerating gradients of the conventional radio-frequency (RF) accelerators are limited by the RF-induced breakdown threshold and can only reach several MV/m. Therefore, novel acceleration methods for positrons are highly desirable to improve the beam quality at an acceptable cost and size of the accelerating structures.

With the rapid development of laser technologies, many novel acceleration methods based on laser-plasma interaction have been proposed. Among them, direct laser acceleration (DLA) is an appealing acceleration mechanism. In the DLA regime, charged particles are directly accelerated by the laser fields with the acceleration gradients up to 10s TV/m. High quality electron beams with several nC or even hundreds of nC charge can be produced using laser fields with special structures such as left-hand circularly-polarized Laguerre-Gaussian (LG) laser pulses [1, 2] or radially polarized laser pulses [3].

In order to figured out whether DLA is suitable for positrons and whether the DLA of positrons exhibit new characteristics, we have investigated the direct acceleration of a positron beam driven by a LG laser pulse through single particle simulations and three-dimensional particle-in-cell simulations. It is found that even anisotropic thermal positron beams can be stably accelerated because they are collimated by the transverse electric field of the LG laser pulse. Besides, in the longitudinal direction, the low-density positron beam can be compressed to form a quasi-isolated positron beam. In the azimuthal direction, the angular momentum of the LG laser pulse can be transferred to positrons. Furthermore, the energy of the positron beam can be tuned by modulating the carrier-envelope phase (CEP). The dynamics of acceleration, focusing, and angular momentum transfer are discussed in detail.

This work is supported by National Key R&D Program of China (Grant No. 2018YFA0404802); National Natural Science Foundation of China (Grant No. 11775305, 11875319, 11991074); Science Challenge Project (Grant No. TZ2018005) and Fok Ying-Tong Education Foundation (Grant No. 161007).

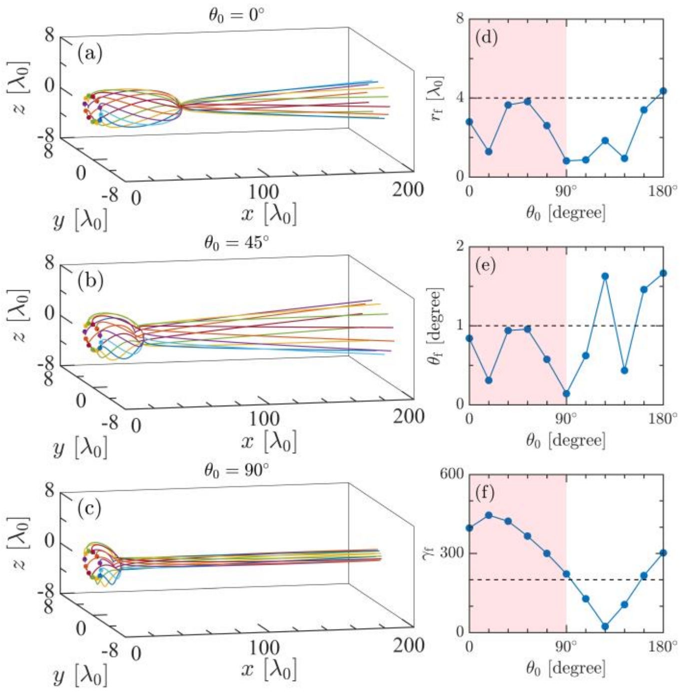

Figure 1. Trajectories of positrons at the initial divergence angles of 0° (a), 45° (b) and 90° (c), where the divergence angle is defined as $\theta = \arctan(p_\perp/p_x)$, i.e., the angle between the momentum and the x-axis. The evolution of the final radial position (d), the final divergence angle (e) and the final γ factor (f) over the initial divergence angle. The pink areas in (d, e, f) correspond to cases where the positron is moving forward. The positrons in (a, b, c) are initially distributed on circles in the yz plane with $(0,0,0)$ as the center and $2\lambda_0$ as the radius.

References

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