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Particle drift, diffusion, and acceleration in quasi-static fields generated by ultrashort relativistically intense laser pulse channeling in near-critical density targets

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***Abstract*—The dynamics of charged particles in the self-generated quasistatic fields of channels produced by the interaction of an ultrashort relativistically intense laser pulse with near-critical density plasmas has been studied numerically and analytically. We identify distinctive mechanisms of drift, diffusion, and acceleration of electrons in quasi-static fields generated in the laser plasma channel produced by ultrashort intense laser pulses.**

***Index Terms*—interaction of an intense laser pulse with a near-critical-density plasma, particle dynamics behind the bubble**

I. Introduction

The noticeable contrast between the energy of an intense laser pulse and the energy converted into high-energy laser-accelerated particles is consistent with the fact that a significant portion of the laser energy absorbed by plasma electrons is ultimately accumulated in quasi-stationary fields [1]. For the commonly used bubble regime, based on the use of gas targets, the charge of accelerated bunch electrons is usually not noticeably more than 1 nC, which limits its use for many applications [2]. They require that, on the one hand, a stable propagation of the laser pulse over many Rayleigh lengths, and on the other hand - propagate in a sufficiently dense plasma (near critical), which could provide significantly higher total charge of accelerated particles. This can be achieved in the so-called the relativistic self-trapping regime [3] that requires certain matching of the laser spot size with the plasma density and the pulse intensity.

II. Particle dynamics in presence of quasi-static fields in plasma channel

The picture of the interaction of an ultrashort relativistically intense laser pulse ($a_0 \gg 1$, where a_0 is the dimensionless amplitude of the laser pulse) with a plasma of near-critical density was discussed in [4]. In crossed fields, when both a quasi-static electric field and a quasi-stationary magnetic field [5] are present in the channel, an effective exchange of energy between the electric field of the channel and the particles is possible, and effects due to the drift of charged particles arise. We have obtained a closed system of averaged relativistic equations of electron motion in azimuthal magnetic and radial electric fields created in the channel and tested it for quasi-static field distribution discussed in [5]. It is shown that along the channel axis the electron moves with a drift velocity, which is a superposition of electric and toroidal (the sum of gradient and centrifugal drifts) drifts. We have found an approach to generalize the result to the case for which the assumption that the speed of one or several drifts is small relative to the total speed of the particle is not applicable any longer. It is demonstrated that a transition to the case of a channel formed behind the bubble in which ion filaments and electron jets are present in accordance with the results of PIC simulation [4]. We have consecutively considered the effect of nonstationarity of quasi-static fields using test particle modeling approaches, and presented an analysis of the stability of electron trajectories and its chaotic dynamics, diffusion in the energy space using Lyapunov exponents.

III. Conclusion

We have employed single test particle simulations linked up with the drift theory of charged particles to reveal the character of the interaction leading to particle collimation and effective particle-field energy exchange in ultrashort relativistically intense laser pulse interaction with near-critical density targets. We identify distinctive mechanisms of drift, diffusion, and acceleration of electrons in quasi-static fields generated in the laser plasma channel.

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