Electron Acceleration in a Plane Laser Beam Arising from Randomizing the Electron Motion by an Additional Laser Beam

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Abstract: We demonstrate through numerical modeling that electrons can be accelerated in a single plane laser beam if an additional (secondary) perpendicularly propagating plane laser beam with a randomized phase is present. The acceleration rate and the spread of the direction of the accelerated electrons can be to a certain degree controlled by the power flux intensity of the additional beam. The additional laser beam can have a much lower power flux intensity than the main laser beam. The laser beam frequencies and electric field intensities chosen for computations match the parameters available at the PALS laser.

1. Introduction

Through numerical modeling of the relativistic test particle motion of an ensemble of electrons in a plane laser beam, we show in the present contribution that a significant electron acceleration arises if an additional perpendicularly propagating transverse plane laser beam with a randomized phase is present. The acceleration mechanism is analogous to the electron acceleration due to dephasing of the electron motion in a plane transverse laser beam by random kicks, as found in [1]. The „random kicks" are now provided by the additional randomized laser beam, which propagates perpendicularly to the direction of propagation of the main laser beam, and which is polarized along the direction of the main laser beam propagation. The power flux intensity of the additional beam can be typically much lower than the power flux intensity of the main laser beam. As the acceleration rate can be to a certain degree controlled by the power flux intensity of the additional beam, we present the dependence of the maximum and average energy of the accelerated electrons on the electric field intensity of the additional beam. We assume that the additional transverse laser beam can be spontaneously randomized either by plasma turbulence, or artificially by random phase plates. The relativistic equation of electron motion is for a single set of initial conditions always solved in 700 numerical experiments for various realizations of the random phase of the additional laser beam. The laser frequency and laser beam electric field intensities chosen for the test particle computations match the parameters available at the Prague Asterix Laser System (PALS) [2]. Then, even thermal plasma electrons having energies of several eV may be accelerated to energies of several MeV.

2. Theoretical model and computational results

The novel accelerator configuration consists of the main (primary) plane laser beam, propagating in the direction of the axis z, + *the perpendicularly propagating additional transverse laser beam, which is propagating along the axis y.* The additional transverse laser beam can be spontaneously randomized by plasma turbulence, or artificially by random phase plates, and it can have much lower intensity than the main laser beam. A test particle model is used - the test electron is moving in the plane wave of the main laser beam + the electromagnetic field of an additional perpendicularly (along the y-axis) propagating and randomized laser beam. The relativistic equation of motion is always solved in 700 numerical experiments for various realizations of the random field.

Important features of the electron acceleration can be seen from the computational results, which are presented in the following four figures. The electric field intensity of the main laser beam is 450 MV/cm, the electric field intensity of the additional laser beam varies as indicated in the figures, up to the maximum of 300 MV/cm. The frequency of the both laser beams was chosen to be the same, corresponding to the wave length of 1.315 µm. We note

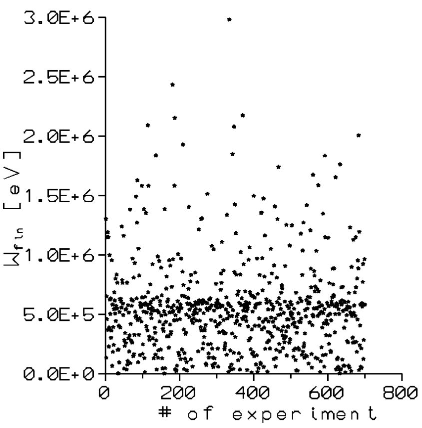

Fig.1: Final energy of accelerated electrons for electric field intensity 20 MV/cm of the additional laser beam.

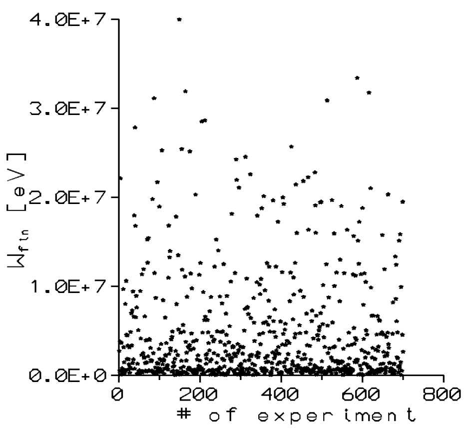

Fig. 2: Final energy of accelerated electrons for electric field intensity 300 MV/cm of the additional laser beam.

that these electric field intensities correspond to beam power flux intensities slightly above 10^{14} W/cm^2 for the laser wavelength of about 1 µm The initial electron energy was assumed to be 3 eV, i.e., thermal plasma electrons were accelerated. The electron motion was followed for a time period corresponding to 10^4 of the wave periods at the laser wavelength of 1.315 µm, i.e. for the time period of 4.38 x 10^{-11} sec. In this time period, the strongly accelerated electrons from the ensemble travel about 1 cm in the direction of the main laser propagation. Let us note that there arises also a minor electron acceleration and corresponding electron motion in the direction of the additional laser propagation. Evaluation of this effect will be a topic of our next study. Figure 1 shows the distribution of the final energy of accelerated electrons for a relatively low electric field intensity, 20 MV/cm, of the additional laser beam. Figure 2 shows the final electron energy distribution for a relatively high electric field intensity, 300 MV/cm, of the additional laser beam. It can be seen that the maximum accelerated electron energy is almost 40 MeV. The following two figures, 3 and 4, show the velocity distribution in the V_y and V_z plane for the same set of computations as presented in Figs. 1 and 2, respectively. The angle distribution of the accelerated electrons is spread more in the direction of the propagation of the main laser

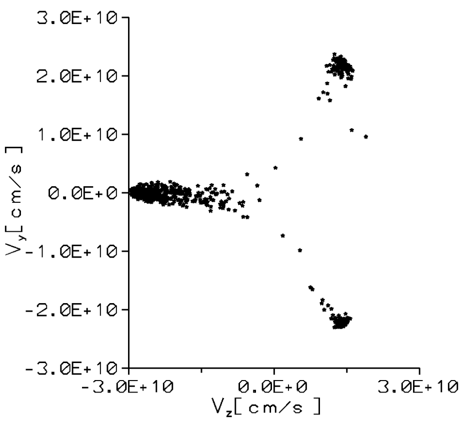

Fig.3: Velocity components of accelerated electrons for electric field intensity 20 MV/cm of the additional laser beam.

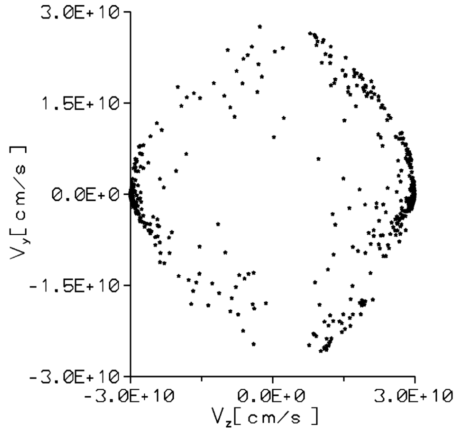

Fig. 4: Velocity components of accelerated electrons for electric field intensity 300 MV/cm of the additional laser beam.

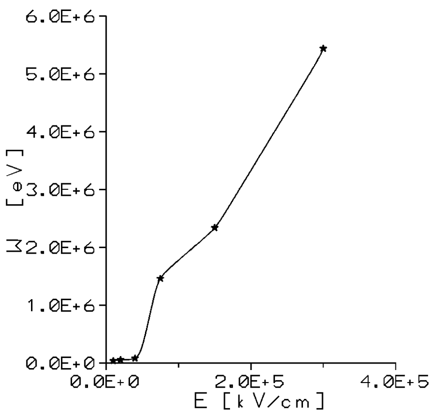

Fig. 5: Ensemble averaged maximum electron energy, in dependence on the intensity of the additional laser beam.

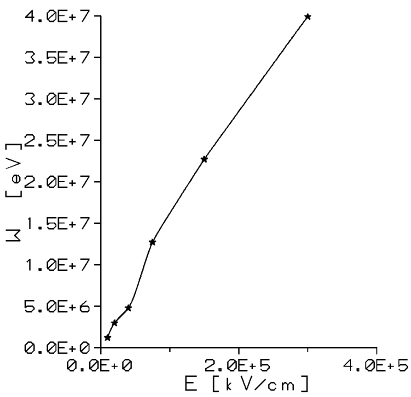

Fig. 6: Maximum electron energy in the ensemble, in dependence on the intensity of the additional laser beam.

beam than in the opposite direction. Angle spreading is smoother for a higher electric field intensity of the additional laser beam (Fig. 4) than for a lower one (Fig.3). Figures 5 and 6 then show the dependence of the average and maximum energy of accelerated (initially thermal) electrons on the electric field intensity of the additional laser beam. Apparently, there is no threshold for electron acceleration resulting from the effects of the additional laser beam. The energy of the accelerated electrons steadily grows with increasing electric field intensity of the additional laser beam. The electron energy gain is almost linear for higher electric field intensities of this additional beam. The computational results demonstrate that it is possible to accelerate very low energy electrons in a very simple configuration consisting essentially of one laser beam and one lower intensity additional beam. However, it is necessary to ensure that the additional laser beam has randomized phases. In the computations, the phase of the wave field of the additional laser beam randomly varied after 3 periods of the field. The sensitivity of the results is rather low as regards the time period between the phase changes. We think that the above results might be verified on the Prague Asterix laser (PALS), provided that the phase randomizing of the additional beam will be performed.

4. Conclusions and discussion.

We demonstrated that it is possible to accelerate very low energy electrons in a very simple configuration consisting essentially of one main plane laser beam and one additional plane laser beam of lower power flux intensity, propagating perpendicularly to the main laser beam. The acceleration rate and the spread of the direction of the accelerated electrons varies with the intensity of the additional beam. However, it is necessary to ensure that the additional laser beam has a randomized phase. For the laser frequency and the electric field intensity available at the PALS device, the maximum attainable electron energy is about 40 MeV in 10^4 wave periods. We also think that the above results might be verified on the Prague Asterix laser (PALS), provided that the phase randomizing of the additional beam will be performed. The electron acceleration in the novel configuration consisting of two plane transverse laser beams is not limited by effects of detuning of the particle motion with the accelerating longitudinal plasma wave field, as it is in the case of PBWA (Plasma Beat Wave Accelerator) and LWFA (Laser Wakefield Accelerator) type accelerators. In the main plane laser beam, the electron performs also a forward oscillating motion because of the effects of the magnetic field intensity of the beam, in addition to the oscillating motion in the direction of the electric field intensity of the main beam. Then, the acceleration mechanism apparently consists of accumulating the forward electron motion in the direction of the main laser beam propagation due to phase changes provided by the additional laser beam, similarly to the findings in [1] for random kicks of unspecified origin. The acceleration is supported by the mechanism of stochastic heating in the field of the additional randomized laser beam. However, it would be interesting to explore how the acceleration rate depends on the laser wavelength also in the novel configuration, even if there are no obvious limitations of the acceleration as in PBWA and LWFA. There is also no limitation on the lower value of the injected electrons velocity, as it is in PBWA and LWFA, because of the necessity of the acceleration at the suitable slope of the longitudinal wave field, i.e., because of the trapping effects by the wave in PBWA and LWFA.

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References

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