Enhancement of Electron Acceleration in Plasma Beat-Wave Accelerators by an Additional Laser Beam

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Abstract
The usual configuration of a plasma beat-wave accelerator (PBWA) consists of two parallel laser beams that resonantly excite a plasma wave in a background plasma. The plasma density must be precisely controlled in order to fulfill the resonant condition. Through numerical modeling of the test particle motion of an ensemble of relativistic electrons in the combined longitudinal plasma wave and transverse waves of the two PBWA laser beams, we show in the present contribution that a strong enhancement of electron acceleration arises if an additional perpendicularly propagating transverse laser beam is present. We show that electrons are also strongly accelerated in such PBWA configurations, where a significant acceleration by the plasma wave would not occur without the presence of the additional laser beam. The additional laser beam is polarized along the direction of the plasma wave propagation. This effect of acceleration enhancement is strongest when the phase of the additional laser beam is randomized. Even thermal plasma electrons may be accelerated, as will be demonstrated for PBWA parameters that match the experiments of F. Amiranoff et al., IEEE Plasma Sci. 24 (1996) 296. The threshold intensity of the additional laser beam is typically much lower than the intensity of any of the two PBWA laser beams. It is to be noted that synergetic effects of transverse, longitudinal, and random electric fields on electron acceleration in laser plasmas were recently studied by V. Petrzilka and J.A. Tataronis [ULIA-2 Euroconference, Book of Abstracts, p. 44].

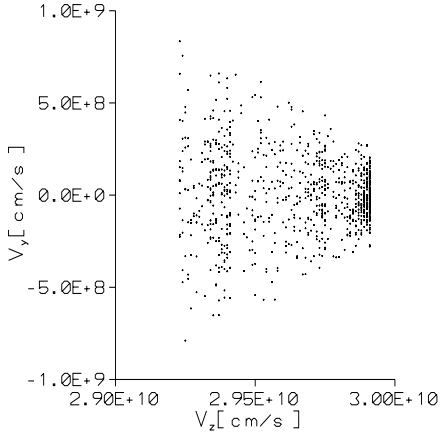
Important key ideas - acceleration enhancement
PBWA fields (2 laser beams and a longitudinal plasma wave) + *a perpendicularly propagating additional transverse laser beam*. The additional transverse laser beam can be spontaneously randomized by plasma turbulence, or artificially by random phase plates.

Theoretical model
Test particle model - the test electron is moving in the PBWA plasma wave + the two usual PBWA transverse laser beams (these waves are propagating along the z-axis), and in 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 900 numerical experiments for various realizations of the random field.

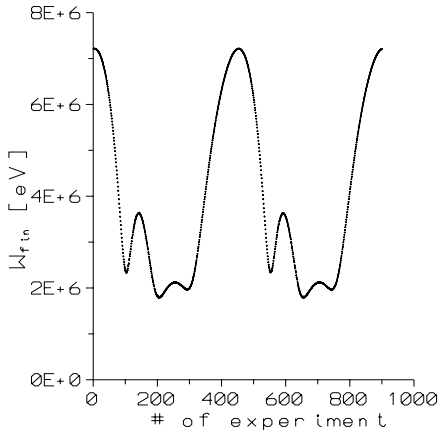
Important input parameters for test particle computations
The parameters chosen for the test particle computations match the experiments of F. Amiranoff et al., IEEE Plasma Sci. 24 (1996) 296: 1st laser beam – 1.3×10^{14} W/cm^2; 2nd laser beam – 7.6×10^{14} W/cm^2; resonant electron density – 1.115×10^{17} cm^{-3}; plasma wave – 0.7

GV/m. The additional laser beam intensity is either equal to the intensity of the 1st laser beam, or 10 times lower (this lower intensity will be indicated in what follows).

PBWA - 3 MeV electron beam - no additional laser beam

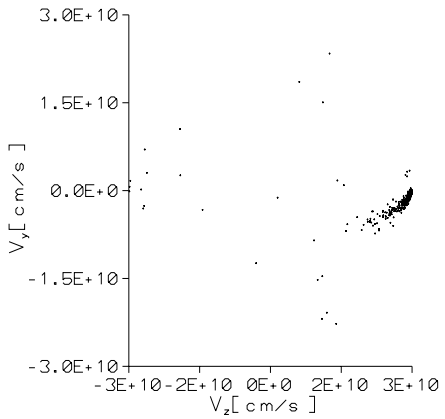


The figure shows the velocity distribution of 900 electrons injected into the PBWA fields with energy of 3 MeV

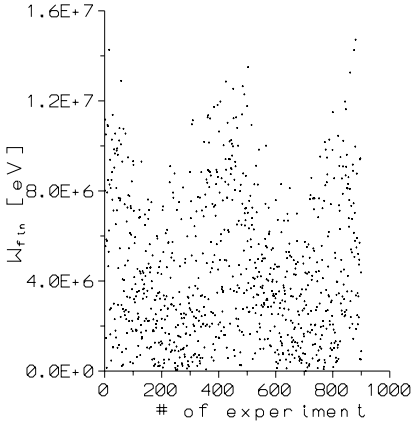


The figure shows the energy distribution of 900 electrons injected into the PBWA fields with energy of 3 MeV.The electrons are injected stepwise on a spatial interval of one longitudinal PBWA wavelength on order to include all initial phases of the wave

PBWA - 3 MeV electron beam - randomized additional laser beam

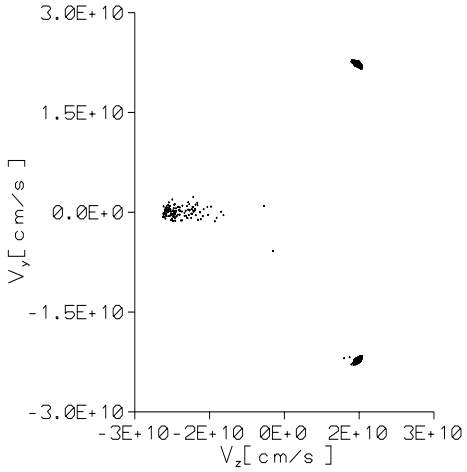


The figure shows the velocity distribution of 900 electrons injected into the PBWA fields with energy of 3 MeV

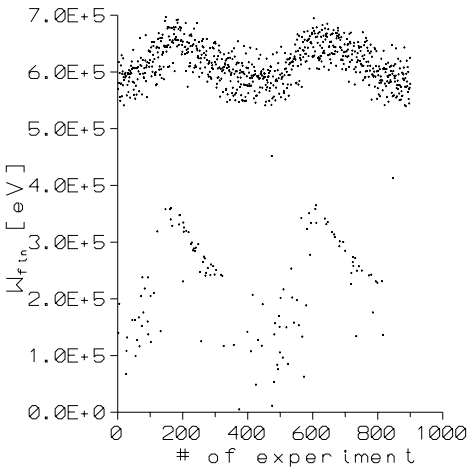


The figure shows the energy distribution of 900 electrons injected into the PBWA fields with energy of 3 MeV

PBWA – 10 keV electron beam - no additional laser beam

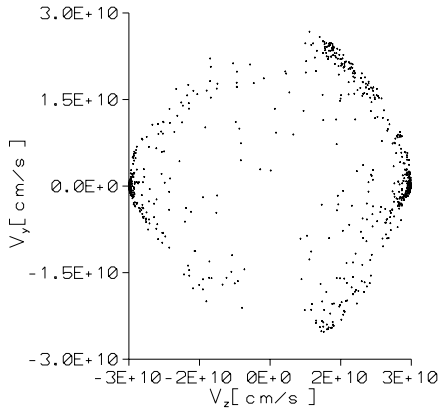


The figure shows the velocity distribution of 900 electrons injected into the PBWA fields with energy of 10 keV

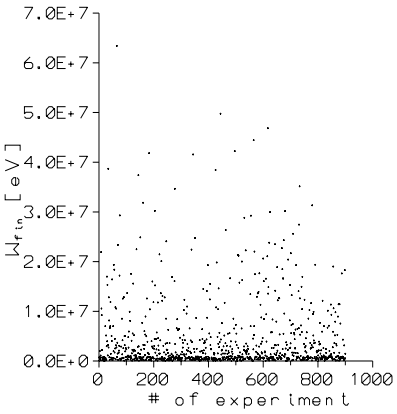


The figure shows the energy distribution of 900 electrons injected into the PBWA fields with energy of 10 keV. The electrons are injected stepwise on a spatial interval of one longitudinal PBWA wavelength in order to include all initial phases of the wave

PBWA – 10 keV electron beam - randomized additional laser beam

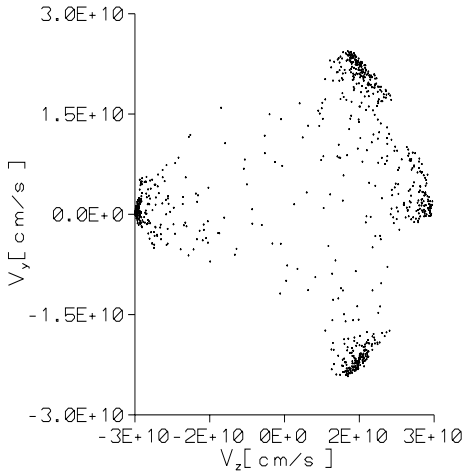


The figure shows the velocity distribution of 900 electrons injected into the PBWA fields with energy of 10 keV

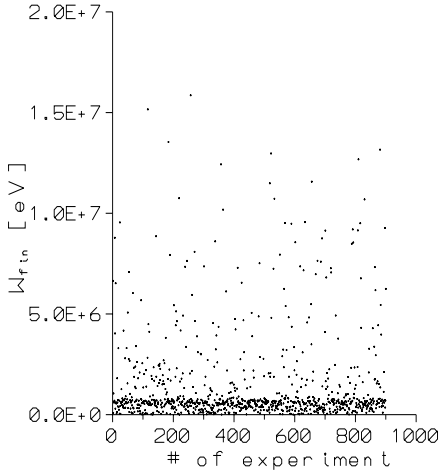


The figure shows the energy distribution of 900 electrons injected into the PBWA fields with energy of 10 keV

PBWA – 10 keV electron beam - randomized additional laser beam, but 10x lower intensity



The figure shows the velocity distribution of 900 electrons injected into the PBWA fields with energy of 10 keV



The figure shows the energy distribution of 900 electrons injected into the PBWA fields with energy of 10 keV

CONCLUSIONS

▪The electron acceleration in Plasma Beat-Wave Accelerators (PBWA) can be strongly enhanced by an additional randomized laser beam propagating perpendicularly to the direction of the beat wave propagation.

▪In the enhanced acceleration mode, electrons of rather low energy are also accelerated. These low energy electrons would not be accelerated without the additional laser beam.

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