Vacuum laser acceleration using a plasma mirror as an electron injector

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Abstract

Accelerating particles to relativistic energies over very short distances using lasers has been a long standing goal in physics. Among the various proposed schemes, vacuum laser acceleration has attracted considerable interest and has been extensively studied theoretically because of its appealing simplicity: electrons interact with an intense laser field in vacuum and can be continuously accelerated, provided they remain at a given phase of the field until they escape the laser beam. Here, we solve this long-standing experimental problem for the first time by using a plasma mirror to inject electrons in an ultraintense laser field, and obtain clear evidence of vacuum laser acceleration of electrons up to 10 MeV with nC of accelerated charge.

Vacuum Laser Acceleration (VLA) [1] is a promising method for accelerating electrons to very high energy in very short distances. The method is appealing because of its simplicity and most fundamental nature: electrons interact with an intense laser field in vacuum and exchange energy with the field. With intensities exceeding 10^{19} W/cm^2, the laser electric field reaches >10 TV/m, providing the highest fields that can be produced in nature or in the laboratory. These enormous fields can then be used to accelerate charged particles with extreme accelerating gradients.

While the literature on VLA is prolific, there have been relatively few experimental results clearly showing unambiguously that VLA can be exploited to accelerate particles to relativistic energies. This is probably because VLA occurs efficiently only for electrons injected in the laser field with specific initial conditions that are extremely challenging to fulfill experimentally. Indeed, in order to stay in phase with the laser field, electrons need to have initial velocities close to c along the laser propagation axis. In addition, they should start interacting with the intense laser beam already close to its spatial and temporal maxima, and even be injected at appropriate phases of this field. Thus, the proper injection of electrons into the intense laser field has proven difficult to solve experimentally.

We will show how by using a plasma mirror, we have been able to solve this long-standing problem. A plasma mirror is an overdense plasma with a very sharp density gradient (<λ/10) at its front surface [2]. The interaction of an intense laser pulse with such a plasma mirror leads to the production of energetic electrons at specific phases of the field and collinear to the reflected laser pulse. This interaction provides electrons with initial conditions that are ideal for injecting electron into the reflected field and permits efficient vacuum laser acceleration. Our experimental results show that electrons can surf a single laser cycle and gain about 10 MeV in a 80 µm distance. The accelerated charge in the 10 MeV beam is very large: up to 3 nC, showing that this process is quite efficient [3].

In this talk, we will review the principles of VLA and provide some simple scaling laws of this process. We will explain the concept and the physics of the plasma mirror as an electron injector. We will show how our experimental results can be clearly interpreted in terms of VLA, providing clear evidence that an electron beam with a large charge can be efficiently accelerated to relativistic energies using this process.

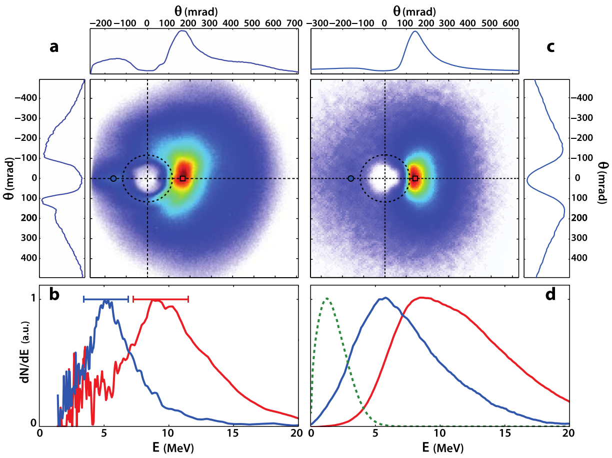

Fig. 1. a) Experimental angular distribution of the electron beam obtained by injecting electrons from a plasma mirror into an intense laser field. b) Experimental spectra of the electron beam. c) and d) represent the same quantities obtained using a hybrid model (PIC simulations and particle test model).

References

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