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Effect of an External Magnetic Field on Laser-Driven Ion Acceleration
レーザー駆動イオン加速における外場磁場の効果

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Laser-driven proton acceleration is investigated by one-dimensional Particle-In-Cell (PIC) simulations. We solve the interaction of a short pulse laser with a thin foil and simulate numerically the Target Normal Sheath Acceleration (TNSA) process. In this work, we introduce an external magnetic field in the standard TNSA scheme, and examine the effects of the magnetic field on the energy spectrum of accelerated protons.

1. Background

These days, proton therapy is getting a lot of attention in the medical field, especially as a new cancer therapy. Laser-driven proton acceleration is one of the promising mechanisms for the medical application. The advantage of the laser acceleration is that the system size can be much smaller and then the cost can be cheaper than the other traditional accelerators.

2. Current Situation of Laser Ion Acceleration

Several physical mechanisms of laser acceleration have been proposed. When a short pulse laser is injected into a thin metal foil, fast electrons can be accelerated by the intense laser from the surface of the foil in the forward direction. Within about picoseconds, those electrons build up a quasi-static electric field at the rear surface. Then, protons and/or positively charged ions on the back surface of the foil will be accelerated by the field which acts normally to the target surface until they compensate the electron charge [1]. This model is called the Target Normal Sheath Acceleration (TNSA) model.

The maximum energy of ion beams produced by TNSA is of the order of tens of eV [2,3]. However, this energy is still insufficient to the minimum requirement for the medical application, which is about 200 eV. Recently, several attempts are performed experimentally by the use of a thinner foil made of Diamond Like Carbon (DLC) [4] and a cluster target [5]. However, the achievement of 200 eV proton has not been realized yet.

3. Numerical Method of Our Study

In this work, we will investigate proton acceleration by TNSA using one-dimensional Particle-In-Cell (PIC) simulations. We perform numerically the interaction between a short pulse laser and a thin target foil. In terms of the laser conditions, we adopt laser pulses containing hundreds of mJ with the pulse duration of about hundred fs. Then the intensity corresponds to I≧10^{19} W/cm^2 on target. For the other parameters of the initial setup, we refer the data of previous laser experiments. The foil thickness is of the order of μm with the density is about 10 n_c, where n_c is the critical density.

Although a thinner target is better for getting higher proton energy, we have to consider the distribution of ablation plasma generated by the effect of pre-pulse. For the medical use, heavier ion beam (e.g., carbon) is desired rather than proton beam. However, we consider only the proton acceleration in this study just for the simplicity.

In this work, we focus on the effect of an external magnetic field. It is expected that the magnetic field can cause better directionality of the beam. Thus we will investigate the dependence of the spectral features of accelerated protons on the presence of the magnetic field. We will also discuss about the effects of the external field strength and direction on the TNSA process.

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