Rise time effect of laser on proton acceleration through TNSA mechanism

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Abstract

One of the most common ion acceleration mechanisms is the TNSA. Research is ongoing to improve the quality of the accelerated proton beam, such as its maximum energy. In this work, by considering the real target profile at the moment of main laser pulse interaction with the pre-plasma, proton acceleration mechanism has been studied and its results are compared with the ideal step-like target. According to the results, the proton beam is accelerated 20 % more in the laser interaction with the smooth shaped target in comparision with step like target.

Keywords: TNSA, proton accelereation, PIC simulation code

Introduction

Over the past two decades, plasma-based proton acceleration has attracted much attention in research due to unique characteristics of multi-MeV proton energies, short pulse duration and low emittance[1]. Such proton beams which are produced as a result of laser interaction with plasma can be used in various applications such as ultra fast radiography[2], novel fusion scheme[3], etc. Depending on laser and target parameters, proton acceleration are described by different mechanisms in which target normal sheath acceleration (TNSA)[4] is the most common sheme. Here the laser intensity range (10^{18}-10^{20} W/cm^2) and the target thickness (l_f = 0.1 - 50 μm) used in the TNSA scheme make it more feasible from experimental point of view. Physically fast electrons generated due to resonance laser energy absorbtion propaget through the target and the resulting ambipolar electric field accelerates the ions from the reart surface of the target[5]. Attempts to improve the quality of the accelerated ion beam, including the cut-off energy, the number of accelerated particles, are still the subject of most ongoing research[6]. One of the unavoidable characteristics of a laser pulse that causes uncontrollable changes in the interaction of a laser with a solid is the presence of a pre-pulse or a rising edge of the pulse intensity. Recently Wei-jun Zhou et. al have analysed the effect of laser rising edge within 2 ps before the peak intensity. Their simulation results indicate 250 MeV proton energy in a nonometer target[7]. One of the main goals of performing various simulations is to compare the results by using different parameters and setting the optimal parameters in the experiments. Therefore, the bringing the simulation conditions close to the reality is one of the important issue in this field. So far, most of the works have applied the ideal pulse with a Gaussian profile and the solid target with a step like density profile in the simulations. While the pulse shape used in the main laboratories is not in fact an ideal Gaussian one. Thus, in this work, by focusing on the Atlas fasility , the laser pulse shape has been digitized for 20 ps before the main pulse, and the fitted function has been used as an input in the fluid code to extract the electron density profile. Then the initial conditions are employed in the PIC code for obtaining ion acceleration parameters. The results are compared with the case when using a step like target.

Simulation tools

Fig.1 shows the Atlas laser pulse shape. As can be seen from Fig. 1, a pre-plasma is formed during the interaction of the initial laser tail with a solid foil target. In order to obtain the electron density profile in the time of main pulse interaction with the target, the MULTI[8] hydrodynamic code has been used. Then, using Smilei[9] PIC code, the results of two cases; a normal step like density profile and a target with appropriate fitted density function have been compared. **Smilei is a relativistic electromagnetic particle code that runs in the parallel platform. It elaborately includes the physics of atomic ionization according to the ADK mode. Field ionization is a process of particular importance for laser-plasma interaction in the ultra-high intensity regime. A common numerical method for the investigation of ultrafast ionization phenomena in laser-matter interaction is based on PIC simulation description which considers field ionization using the Monte Carlo method. In this paper, the simulation results have been analyzed by using Smilei code. A Monte-Carlo module for field ionization has thus been developed in Smilei.**

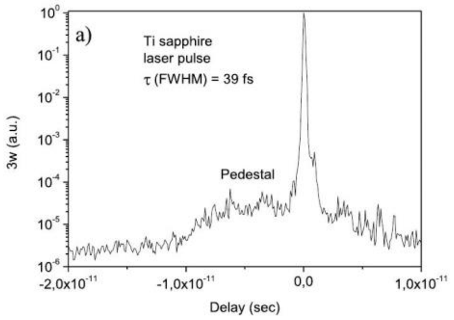

Figure 1. Typical laser pulse shape of Atlas fasility[10]

Smilei is a relativistic electromagnetic particle code that runs in the parallel platform. Several simulations have been carried out by considering initial cold ions (k_BTi = 0, with Boltzmann constant k_B) for two cases and their results were compared with each other. Case I was related to a step-like density profile of 0.25 µm Al foil target coupled with a 50 nm H^+ layer with $n_e = 4\ n_{cr}$; and in case II, the real target profile after interaction of pre-pulse with solid Al target was employed. The electron density, n_0, was 40 n_{cr} in case I and a fiitted function in case II with n_{cr} as the critical density. Simulation box length was considered to be [100×30] µm with spatial resolution dx ≈ [0.01×0.05] µm and there were 64 particles per cell. The laser pulse at wavelength 0.8 µm and P polarization propagated with specific digitized time profile and Guassian spatial one. The normalized laser intensity a_0 was 10. The parameters of the quantities, position x and the electric field E, were normalized to c/ω_0, $\omega_0 m_e c/e$, respectively; here ω_0 is the laser frequency**.**

Results and discussion

Fig. 2 showes proton energy spectrum at the end of simulation time. It is clear from Fig.2 that applying a smooth density gradian leads to 20% increas of proton cut off energy in comparision with step like density profile. The reason is because of longitudinal electric field which is responsible for proton acceleration. Hence, in Fig.3 longitudinal component of electric field for two cases are plotted at time exactly before disintegration of the target rear surface. One can see from Fig. 3 that the amplitude of E_x in case of target with pre plasma (case II) is higher than a rigid target (case I). It means that within interaction of intense laser pulse with a slowly increasing target density, electron energy absorbtion efficiency is increased. Therefore, electron temperature and consequently E_x will be amplified.

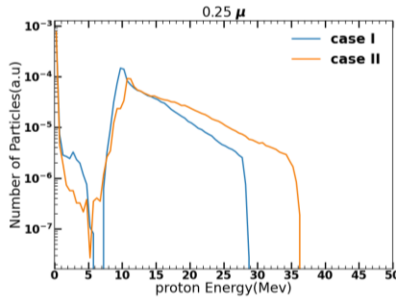

Figure 2. Proton energy spectrum of case I & II.

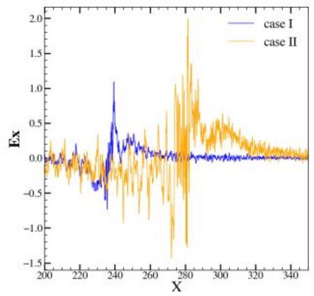

Figure 3. Longitudinal electric field for case I & II

Conclusions

In the present work by using simulation tools, the effect of pre-pulse on the proton acceleration performance has been studied. The results indicate that slow changes of the electron density profile in the case of main pulse assistant with a pre-pulse improves the energy absorption efficiency of the electrons and thus the acceleration field. For this reason, the observed cutoff energy shows a 20 % increase compared with the step like density profile. It is worth mentioning that this research has been carried out by the aim of getting close to the real laboratory conditions in the simulations.

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