

## Laser-triggered Ion Jets at Moderate Intensity and Pulse Duration

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### Introduction

The rapid recent development of high intensity laser made it possible to access a new field of laser driven ion acceleration up to energies of several tens of MeV. Although the investigation of extremely high – energy ions seems to attract most of the interest, effective production of ions with energy  $\leq 10$  MeV is of topical interest for a number of important practical applications, such as, for example, neutron sources and short lived isotope production. For the production of such ions to be successful, it is essential that the required laser energy be at a moderate laboratory level. Such moderate intensities of a laser pulse are discussed in this paper. The advancement in our understanding of high – energy particle production in laser – plasma interactions depends upon the study of different regimes of laser operation. Most PIC simulations with relativistically strong laser pulses,  $a > 1$ , and pulse durations of few hundreds femtoseconds, indicate that ion acceleration is dominant in the forward direction. The ions are accelerated via the space – charge separation fields set up by the laser – produced energetic electrons. Ion acceleration continues until the hot electrons are energetically depleted due to the losses in the target or by the adiabatic cooling. This mechanism of ion acceleration was used for interpretation of the processes with relativistically strong laser pulses. For longer pulses of moderate intensities,  $a \sim 1$ , the comparative study of the efficiency of ion acceleration in the forward and in the backward directions is still incomplete. Such a comparison should involve different parameters of the accelerated ions. The knowledge of such properties of the accelerated ions may shed a light on the understanding of the “efficiency” itself, including the maximum ion energy, the number of high – energy ions, and the averaged energy of hot ions. In this paper, 2D PIC simulations of ion generation from a dense plasma interacted with a laser pulse of intensity  $1.4 \times 10^{18}$  W/cm<sup>2</sup>, wavelength 1  $\mu$ m, and duration 0.6 ps are presented for both backward and forward acceleration. We study the correlation between the properties of high energy ions and those of hot electrons and also compare the numerically obtained ion spectra with the analytical model of isothermal plasma expansion. Computer simulation is carried out by UMKA2D3V code [1] on massive parallel computer MVS-15000M (Joint Computer Center RAS, Moscow, Russia). Calculations up to 400 laser periods (1.3 ps for 1 $\mu$ m laser wavelength) took approximately 5000 hours of processor time.

## Acceleration of particles in a backward and forward directions

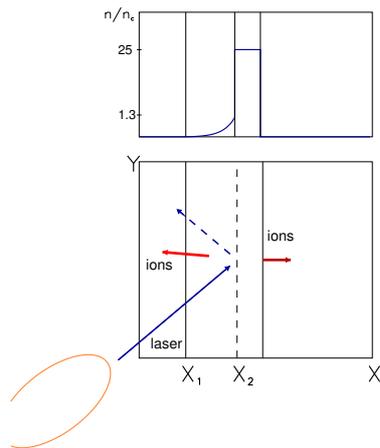


Figure 1: Initial configuration and plasma density profile

2D PIC simulations were performed for P-polarized laser pulse at oblique incidence. The initial plasma density profile is shown in Fig. 1. The laser pulse with  $9\mu\text{m}$  focal spot and 0.6 ps duration enters the rectangular box ( $0 < x < 80\mu\text{m}$ ,  $0 < y < 150\mu\text{m}$ ) under  $\theta = 45^\circ$  angle of incidence. The density of the foil,  $n$ , is 25 times higher than the critical density  $n_{cr}$ . The sizes of preplasma and a foil are equal  $9.5\mu\text{m}$  and  $5\mu\text{m}$ , accordingly. The density in preplasma grows exponentially in  $X$  from 0 to  $1.3 n_{cr}$ . The charge of carbon ions in a  $\text{CD}_2$  target is equal to 4.

Studying of electron generation from a frontal surface of a target (in a backward direction, with  $P_x < 0$ ) has revealed formation of fast electrons propagating in a direction close to specular direction, in qualitative conformity with results of [2],[3].

However, eventually this electron bunch disappears and the angular distribution of fast electron becomes almost symmetric concerning a normal to a target surface. Electron distribution function in a backward direction is shown in a Fig. 2. Although the number fast electrons grows continuously as the laser pulse pumps, for  $t > 0.9$  ps the electrons distribution function evidences a Maxwellian tail with characteristic temperature  $T_h = 0.38$  Mev.

Fast electrons carry away ions which propagate almost normally to a target as a jet (Fig. 3). There is an insignificant indignation ( $y \simeq 85\mu\text{m}$ ) caused by initial emission of fast electrons in a direction close to specular. Angular distribution backward accelerated ions is shown in Fig. 4, where  $\theta$  is an angle counted from a normal to a target. Both light (deuterium), and heavy (carbon) ions show a strongly pronounced orientation along a normal to a target. Energy of deuterons achieves 1.5 MeV, and ions of carbon - 5.5 MeV. However, these values can not be considered as maximal energy of ions as far

as for the end of simulation the ions are still in an acceleration stage. The comparison of energy

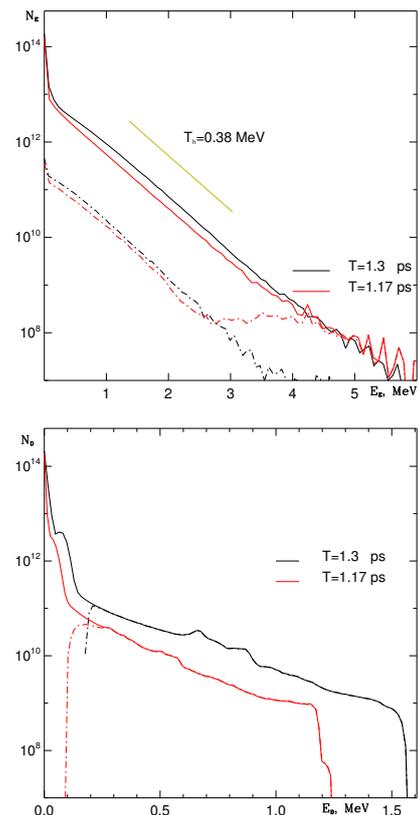


Figure 2: Electron and deuterium ion distribution function at  $t=1.17$  &  $t=1.33$  ps

spectrum of accelerated deuterons with the theory of isothermal scattering with temperatures of hot electrons  $T_h = 0.38$  MeV shows the good agreement with such a theory. That allows to use for a scaling of accelerated deuterons the following expression  $\sim E_D^{-1/2} \exp(-\sqrt{2E_D/T_h})$ .

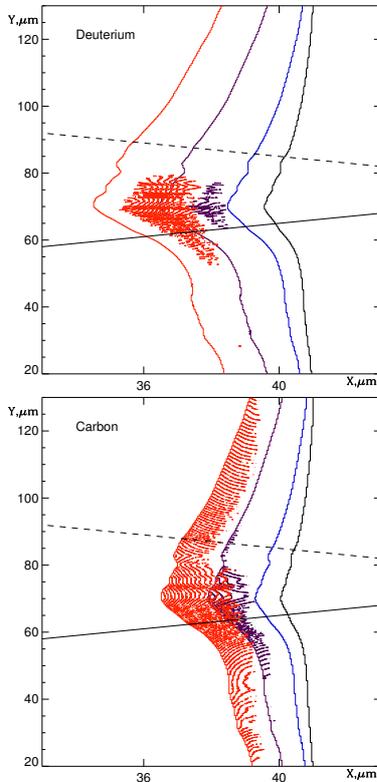


Figure 3: Deuterium and Carbon density distributions at  $t=1.17$  &  $t=1.33$  ps

Similarly above-stated, studying characteristics of the accelerated particles in a forward direction is carried out. At  $t > 0.9$  ps the fast electron distribution forms a Maxwellian tail with characteristic temperature  $T_h \simeq 0.44$  MeV. The forward acceleration from a rear foil surface begins earlier, than the backward acceleration from preplasma; the number of forward accelerated deuterons with energy  $> 100$  keV is approximately 2 times bigger, than the number of deuterons with the same energy, accelerated in the backward direction.

### Conclusion

Thus, the carried out computer simulation of ions generation from CD<sub>2</sub> solid-state foil for the laser pulse oblique incidence of moderate intensity has shown deuterons acceleration in forward and backward directions. Accelerated ions move mainly in the direction normal to the foil surface, and their spectrum is well described by theoretical model of isothermal scattering.

The number of the backward accelerated ions is of the same order then the number the ions accelerated in forward direction. So, it is possible to assume, that increasing of the target thickness this ratio will vary for the benefit of the ions accelerated in backward direction.

We demonstrate that the using of a pulse with relatively long duration and low intensity can provide good efficiency of backward generation of with an energy about 1 MeV. This may make a secondary catch-target which stops all the forward ejected

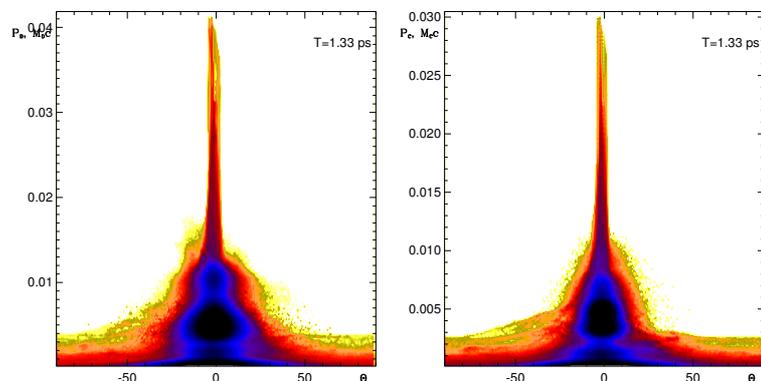


Figure 4: Deuterium and Carbon ions distributions in  $(P, \theta)$  plane at  $t=1.33$  ps

deuterons from a laser CD<sub>2</sub> target an attractive source for applications that require bright and short duration pulses of neutrons.

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