

## §17. Holistic Simulations for Fast Ignition with Cone-Guided Targets

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The fast ignition approach to inertial fusion energy has been investigated by experiments with cone-guided targets because this scheme is expected to reduce criteria for fuel burning. Simulations should play an important role in estimating the scheme performance, and we have been promoting the Fast Ignition Integrated Interconnecting code (FI<sup>3</sup>) project.<sup>1,2)</sup> In this project, the Arbitrary Lagrangian Eulerian hydro code (PINOCO), the collective Particle-in-Cell code (FISCOF1), and the relativistic Fokker-Planck code (FIBMET) are integrated via data exchanges.

To explore fast ignition experiments with Au cone-guided targets with holistic simulations, the heating laser is set to Gaussian pulse of  $\lambda_L=1.06[\mu\text{m}]$ ,  $\tau_{\text{FWHM}}=750$  [fs] and  $I_L=10^{20}[\text{W}/\text{cm}^2]$  to adapt the experimental laser condition. Because of the long simulation duration up to 6 [ps], ion dynamics cannot be ignored. So we introduce mobile Au ions with real mass and  $Z=50$ , which is estimated from an average ionization degree of Au calculated by PINOCO, and we model the simulation plasma profile according to PINOCO results in FISCOF1 as follows. Since the scale length of the preformed plasma affects the ion dynamics, the preformed plasma is assumed to have an exponential profile of the scale length ( $L_{\text{pre}}$ ) 0, 0.25, 1 and 5 [ $\mu\text{m}$ ] with density from  $0.1n_c$  up to  $100n_c$ , where  $n_c$  is the critical density. Behind the preformed plasma, the cone tip is assumed as a 10 [ $\mu\text{m}$ ] width and  $100n_c$  density plasma, following the imploded plasma of the exponential profile of the scale length 10 [ $\mu\text{m}$ ] with density from  $10n_c$  up to  $100n_c$  (24 [ $\mu\text{m}$ ] long). Thus there is the density gap between the cone tip and the imploded plasma. At the rear of the imploded plasma, the compressed core plasma of  $100n_c$  is placed in 26 [ $\mu\text{m}$ ] long. The energy of fast electrons is observed at the middle of the cone tip (Obs1), and at  $20n_c$  point in the imploded plasma (Obs2).

To see the effect of the ion dynamics, we run FISCOF1 with immobile/mobile ions and  $L_{\text{pre}}=1[\mu\text{m}]$ . In case of mobile ions, the preformed plasma is pushed by the Ponderomotive force and profile steepening occurs. Since the underdense plasma is cleared away due to the profile steepening, backward electrons are directly pushed back by the Ponderomotive force, and perfectly reflected at the boundary. In addition, fast electron bunches are periodically launched by the oscillating Ponderomotive force and therefore the forward current increases, building up the potential at the gap in turn, finally trapping electrons within the cone tip. After laser irradiation, no Ponderomotive force can trap electrons but a static potential is easily developed at the boundary because of the steep profile, and electrons are still circulated. As

confinement of sloshing electrons is degraded due to the ion expansion/diffusion and some fractions of them are continuously released from there even after the laser pulse is dropped off, the electron beam intensity at Obs2 is much larger than that of the immobile ion case and this effect is good for core heating.<sup>3)</sup>

Time averaged electron energy spectra for different  $L_{\text{pre}}$  at Obs1 are shown in Fig. 1(a). The preformed plasma with longer scale length has wider underdense region, where the laser-plasma interaction dominantly takes place, and higher energy electrons are generated. But such high-energy electrons ( $>2[\text{MeV}]$ ) have long mean-free-path and do not efficiently heat the core.<sup>3)</sup> On the other hand, shorter scale length leads to steepening the profile and to increases sloshing electrons, which are released and heat the core at a later time. When the scale length is too short, slight laser-plasma interaction causes little high-energy electrons, hence little sloshing electrons. Thus there will be an optimum scale length for core heating.

Time averaged ion energy spectra for different  $L_{\text{pre}}$  at Obs2 are shown in Fig. 1(b). If the scale length is long enough, a laser pressure causes an extremely large charge separation, which accelerates ions to  $\sim 500[\text{MeV}]$ , in the underdense plasma at early stage. These energetic ions reach at Obs2 in later time. The static potential is also built up at the gap, and ions are accelerated up to 100 [MeV]. Ion phase space for  $L_{\text{pre}}=1[\mu\text{m}]$  is shown in Fig. 2, and two mechanisms for the ion acceleration are clearly seen.

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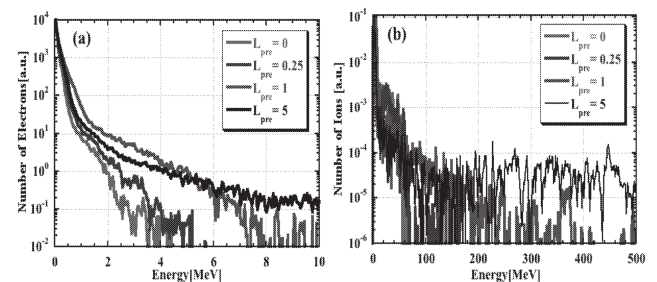


Fig.1. (a) Time averaged electron energy spectra at Obs1, and (b) time averaged ion energy spectra at Obs2 for  $L_{\text{pre}}=0, 0.25, 1$  and  $5[\mu\text{m}]$ .

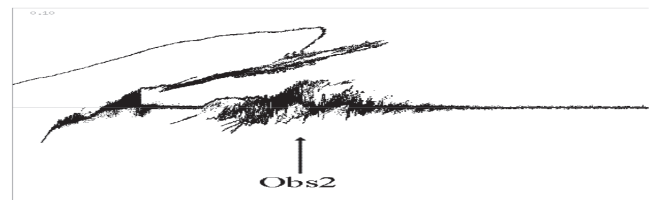


Fig. 2. Ion phase space for  $L_{\text{pre}}=1[\mu\text{m}]$  at  $t=2000$  [fs].

### References

- 1) Sakagami, H., and Mima, K. : Laser and Particle Beams **22** (2004) 41.
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