Topic: IF

The Interaction of Super-Intense Quasi-Neutral Particle Beams With Plasma: A Numerical Investigation*

H. Ruhl, T.E. Cowan, and P.B. Parks,
General Atomics, P.O. Box 85608, San Diego, California 92186-5608 USA
e-mail: ruhl@fusion.gat.com

M. Borghesi
Queens University Belfast, United Kingdom

O. Willi
University of Düsseldorf, Germany

Given the unique properties of laser-accelerated ion beams novel experiments with ion beams interacting with plasma can be envisioned. Some of these may be relevant for a future Fast Ignition (FI) concept based ion beams which will require the deposition of a few kilojoules of energy stored in ions within a few picoseconds on spatial scales of a few ten microns.

Recent experiments performed at LULI with a laser of 20 J pulse energy and 0.3 ps duration show that a few times 10^{12} ions per laser shot can be obtained from the rear surface of an irradiated solid. The source diameter of the emitted ions is less than 50 μm in these experiments depending on the energy of the ions. The laser generated ion beam is surrounded by hot electrons and has a wide energy spectrum with a slope of several mega-electron-volts. Total ion currents of a few kiloamperes are obtained. Depending on the shape of the rear surface the ions can be focused. For ion drift lengths of about 1.0 mm which are close to scales discussed in the context of FI and no ballistic focusing of the ions the beam diverges to about 100.0 μm diameter. The achievable ion beam density after a drift of 1.0 mm is still about 10^{17} cm^{-3} while the current density is roughly 10^{11} A/m^2. Taking the possibility of ballistic focusing of the ions into consideration three to four orders of magnitude in beam and current density can be obtained. This represents a novel particle source.

Investigations of ion beam-plasma interaction frequently concentrate on single particle aspects of the beam-plasma interaction. However, collective beam-plasma effects may become dominant for the parameters of laser-generated ion beams. A number of numerical simulations in two (2-D) and three (3-D) spatial dimensions taking full account of collective effects and the electro-magnetic nature of the beam-plasma interaction will be presented. Issues of beam stability in vacuum and plasma, beam energy loss in plasma, and beam focusability will be addressed. An example is shown in Fig. 1 where an proton beam interacts with a sharp-edged plasma a situation that may occur for recent cone target designs for FI. At the interface a strong magnetic field evolves which kinks and disperses the beam. Based on protons of about 10 MeV the concept of FI requires proton beam densities in the range of 10^{23} cm^{-3} and proton currents up to 10^9 A many times the Alfvén current of 4.5 MA for these protons. While these simulations are not possible at present simulations exceeding the Alfvén current of the co-propagating electrons substantially will be presented. Beam stability for this condition will be discussed. Implications of our results for an ion based FI concept will be addressed.

*This work has been performed with corporate support of General Atomics, with support of the Max-Born-Institute of Nonlinear Optics in Berlin, the University of Düsseldorf, and the Queens University of Belfast.

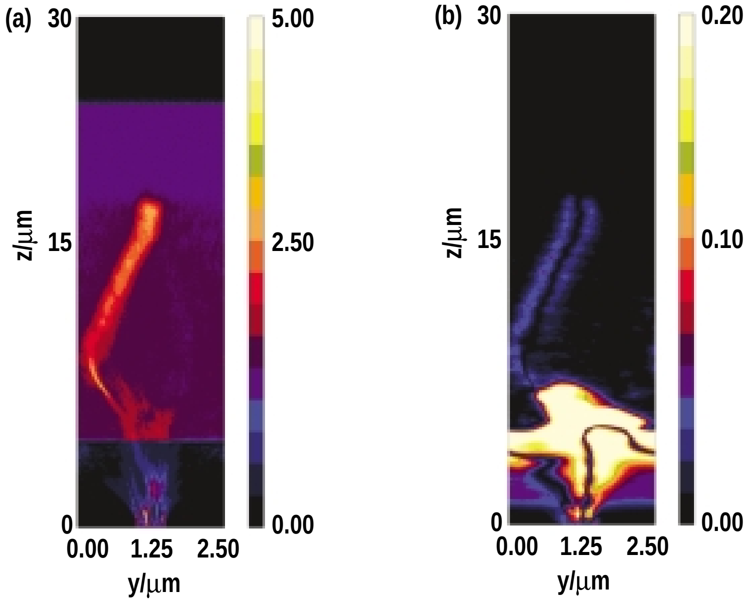

Fig. 1. 2-D simulation. A quasi-neutral proton beam with 10 MeV protons, diameter 0.5 μm, and beam density $5.0 \cdot 10^{21}$ cm^{-3} is penetrating a sharp-edged plasma with the same density (a). A beam instability at the plasma-vacuum interface triggered by magnetic field evolves which propagates back into the beam. Plot (b) shows the total magnetic field $B = \left(B_x^2 + B_z^2\right)^{1/2}$ in units $B_0 = 6.5 \cdot 10^4$ Vs/m^2.