Using Superintense Radiation Pressure to Accelerate Ions

Andrea Macchi

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About polyLAB

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polyLAB tries to start an activity on plasma processing of polymers and searches for collaborations.

Coworkers

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Tatiana V. Liseykina[1]

Department of Physics, University of Pisa, Italy

[1]*On leave from Institute for Computational Technologies, Novosibirsk, Russia*

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IRCEP, School of Mathematics and Physics, Queen's University of Belfast, UK

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- Ion acceleration in gas targets: similarities
- A proposed application: ultrashort neutron sources

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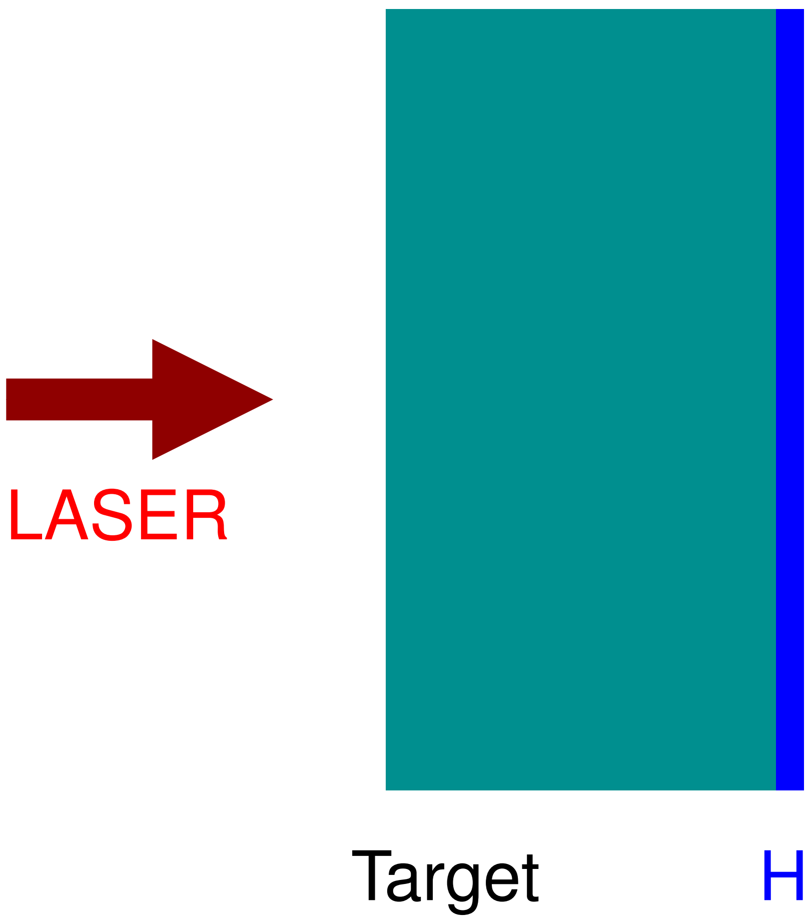

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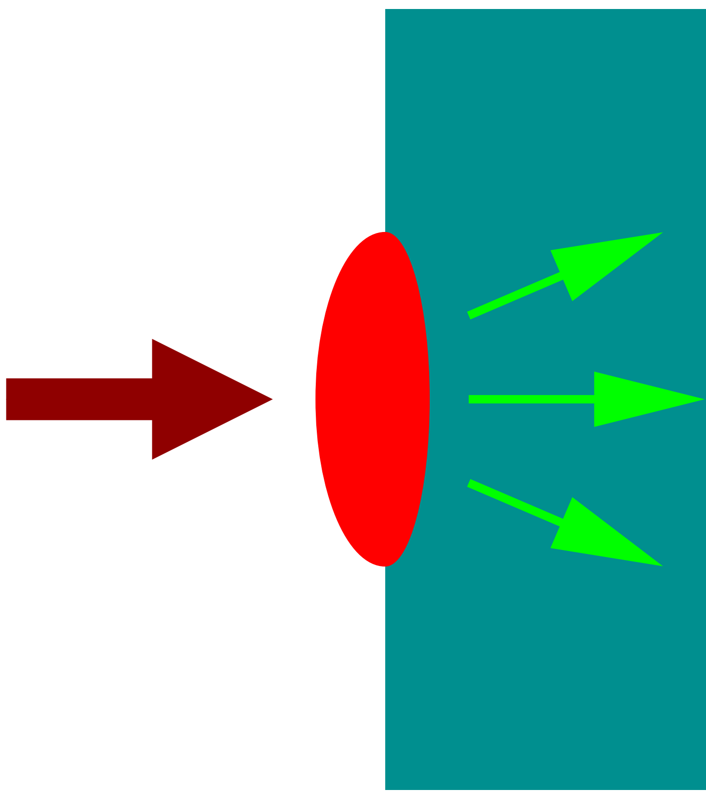

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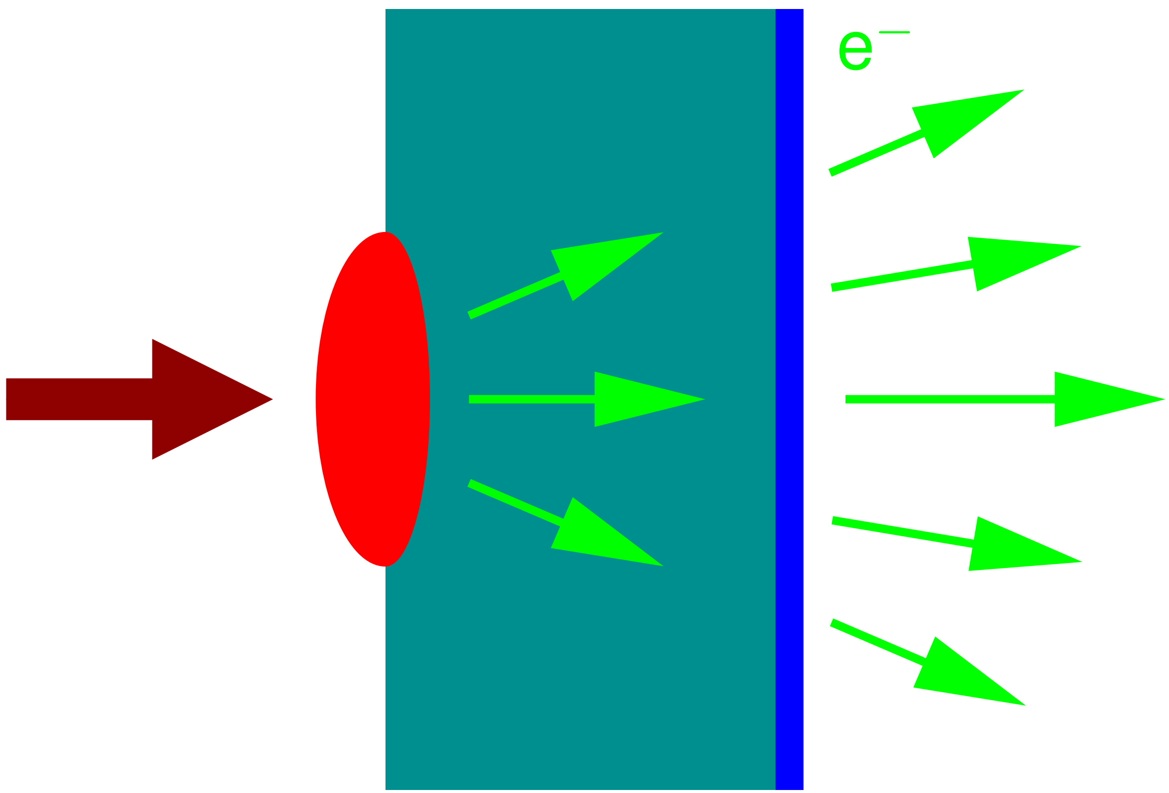

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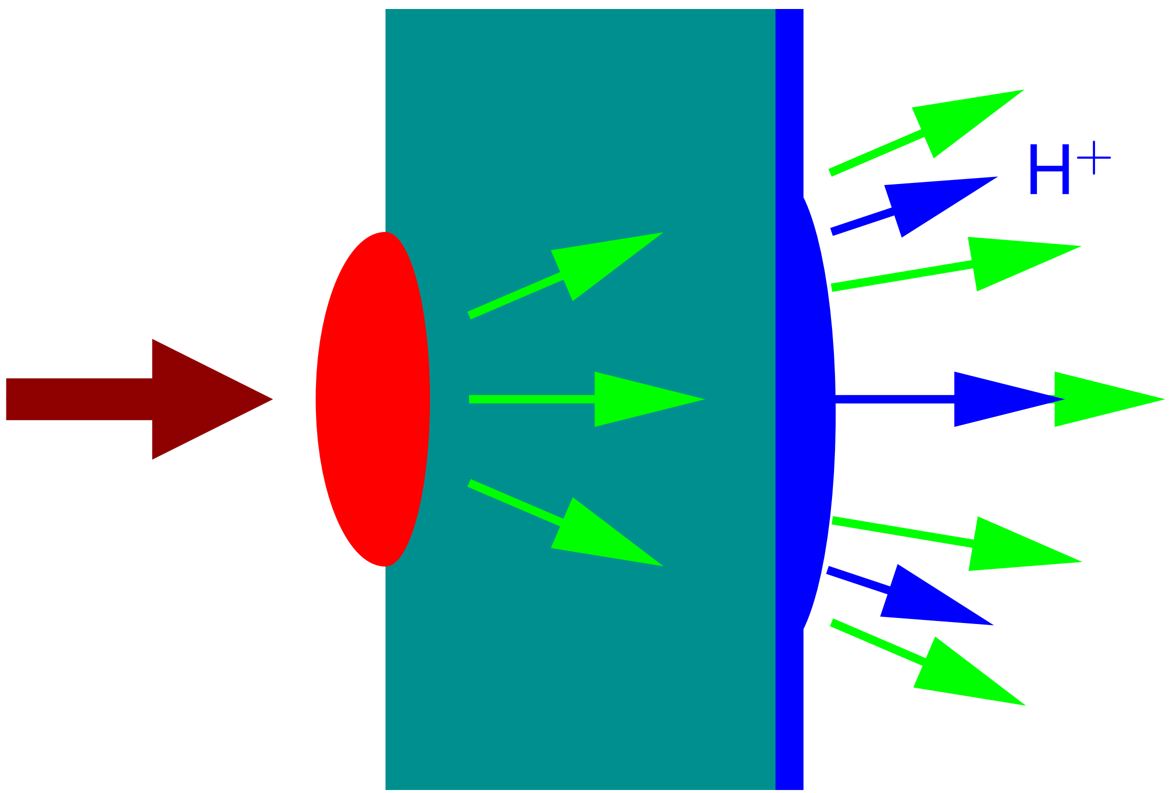

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- Ions (protons) are accelerated in the sheath field

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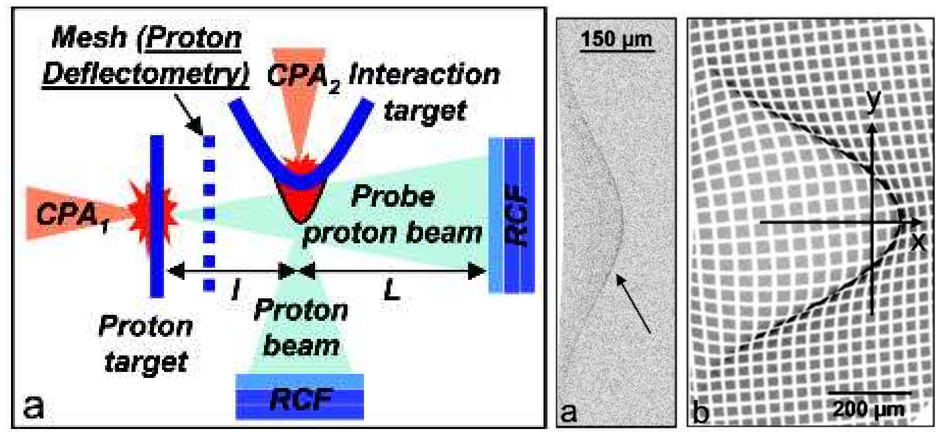

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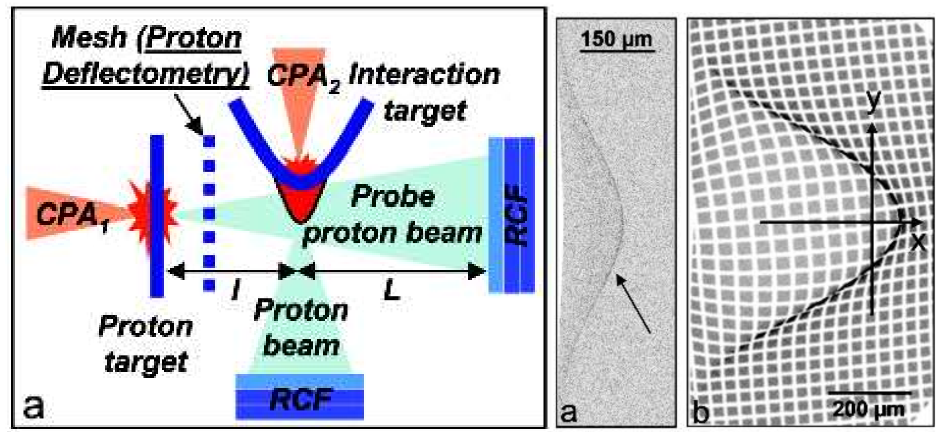

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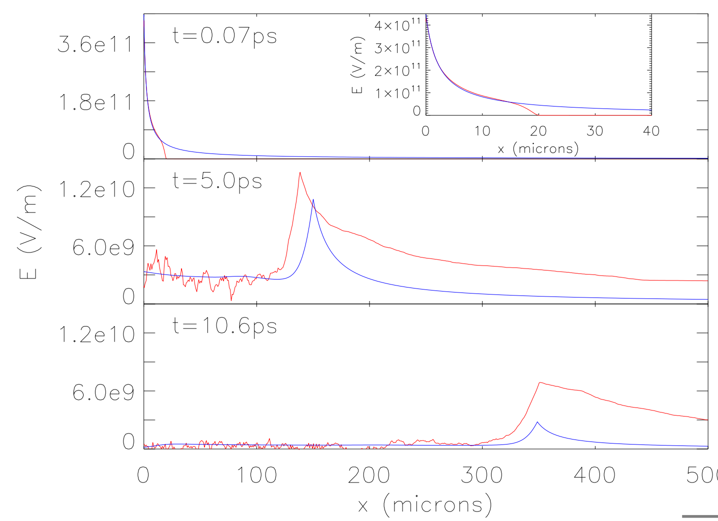
Modeling:
Fluid:
Mora, PRL **90**, 185002 (2003)
PIC:
Betti, Ceccherini, Cornolti, Pegoraro,
PPCF **47**, 521 (2005)



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- Proposed scaling laws suggest that ion energy will keep to increase with growing laser intensity

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- Is TNSA always the best route to ion acceleration?
- Are there other acceleration mechanisms, and do we understand them?

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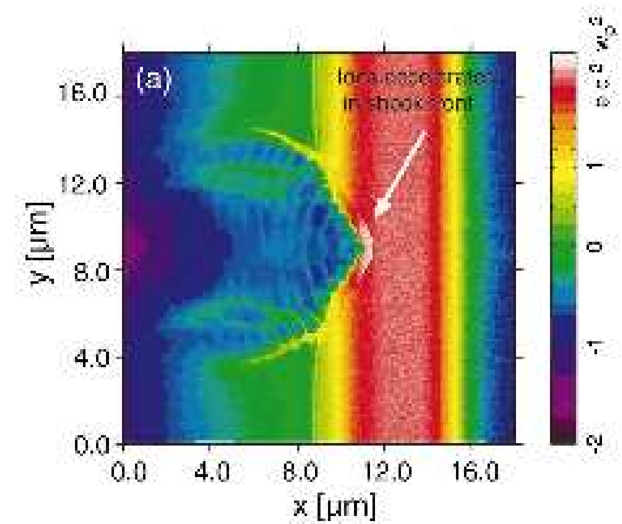

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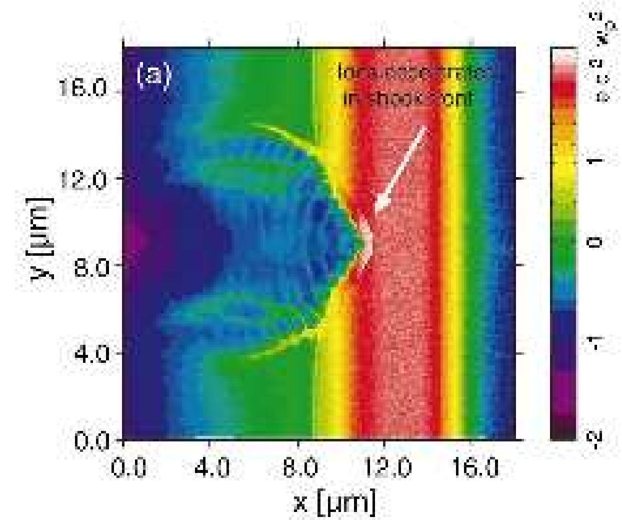

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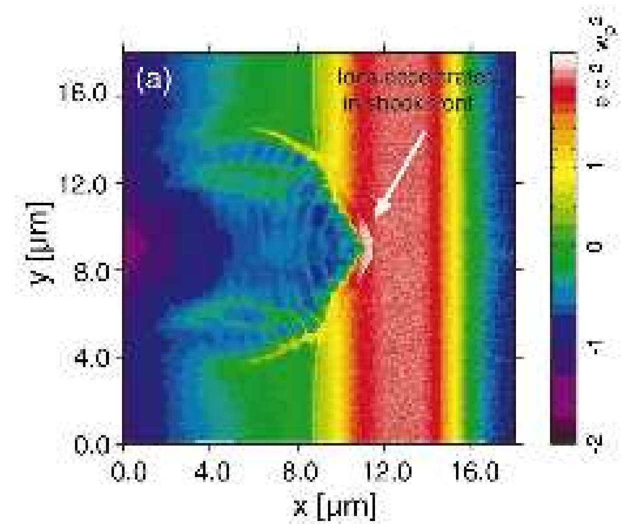

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$v_s \approx v_{hb} \simeq \sqrt{2I/m_i n_i c}$

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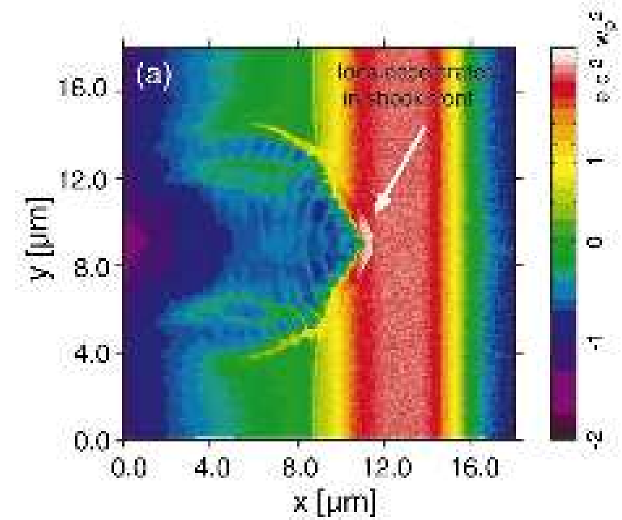

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High-speed shocks $\rightarrow$ high-energy ions

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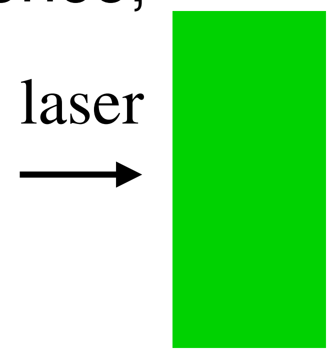
1D PIC simulation, 26 cycles pulse, normal incidence, linear polarization, $a = 16.0$, $n_{e0}/n_c = 10$.
($\lambda = 1\mu$m $\rightarrow I = 3.5 \times 10^{20}$ W/cm^2, $\tau_L = 86$ fs, $n_e = 10^{22}$ cm^{-3}.)



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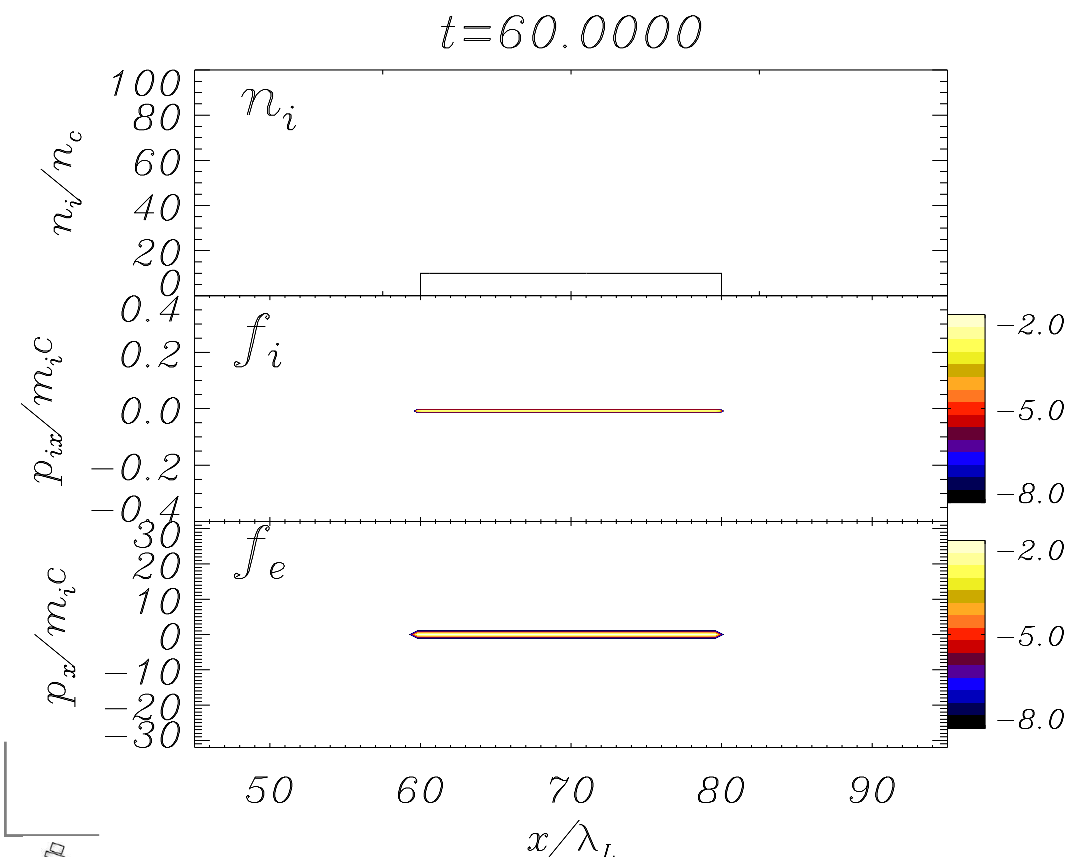

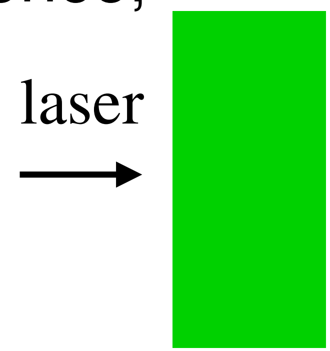

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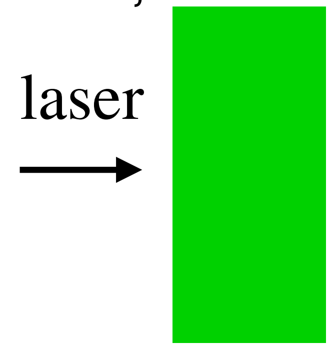

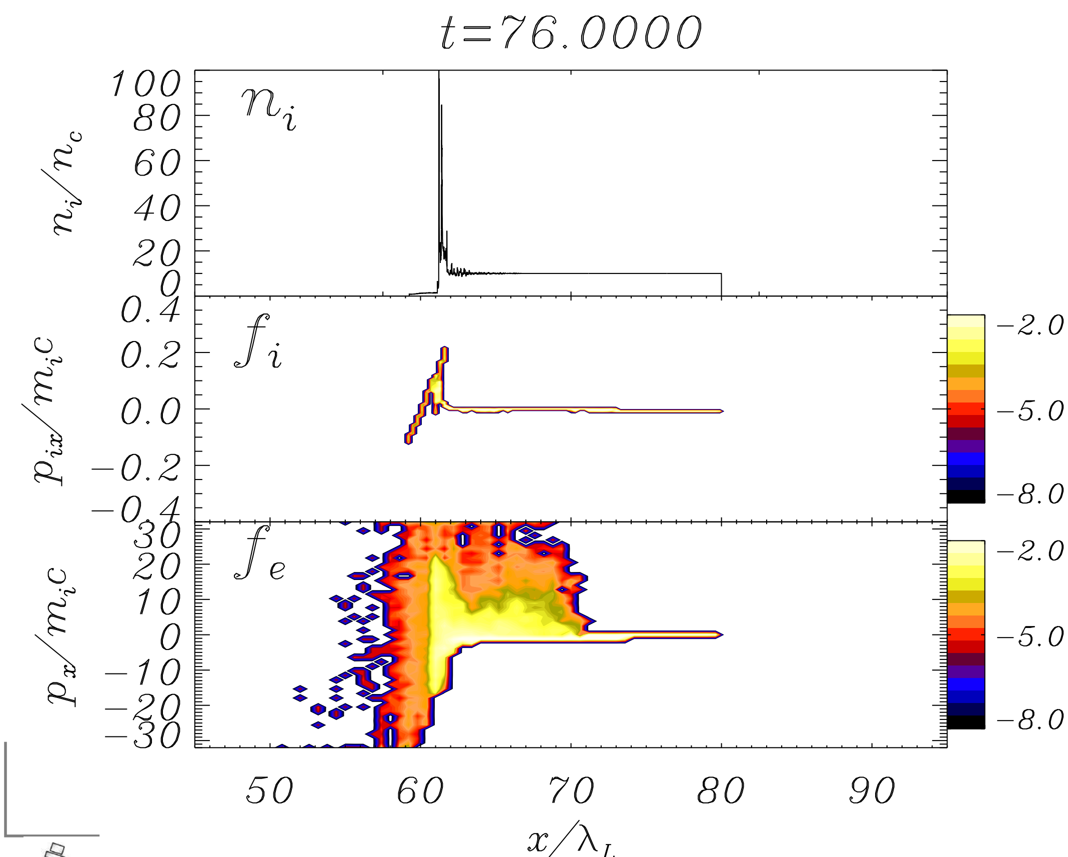

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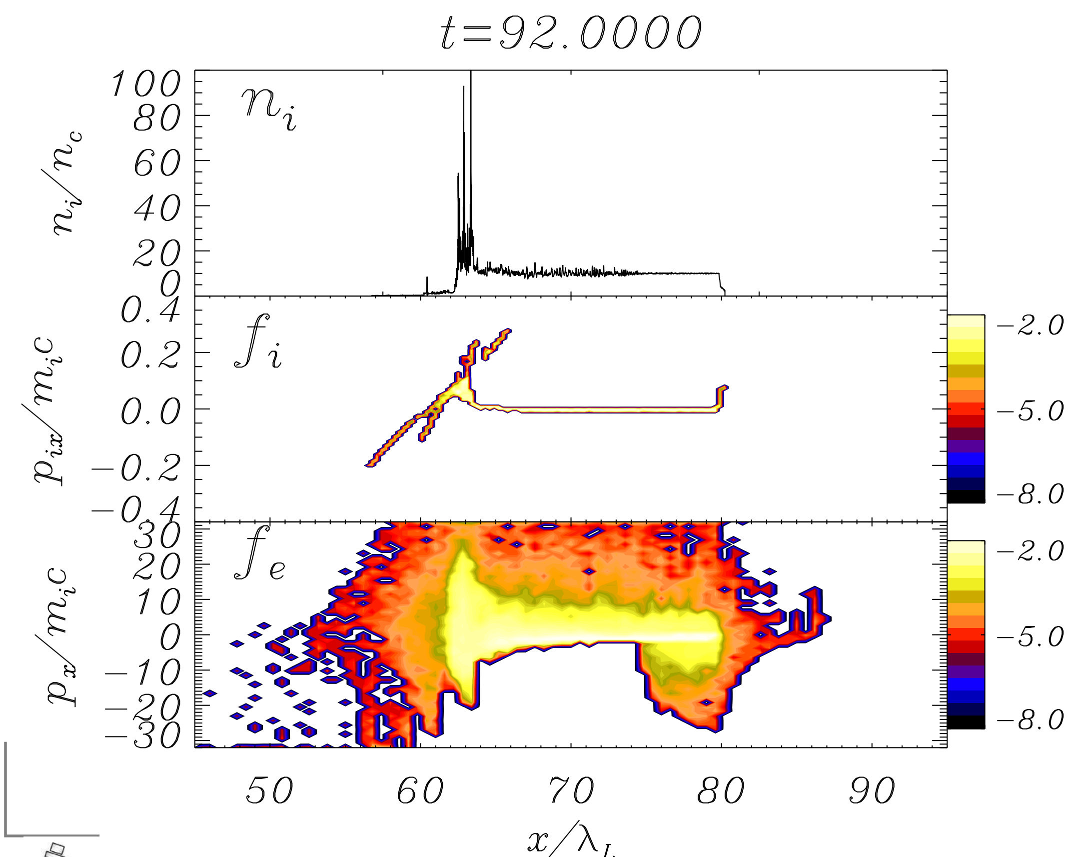

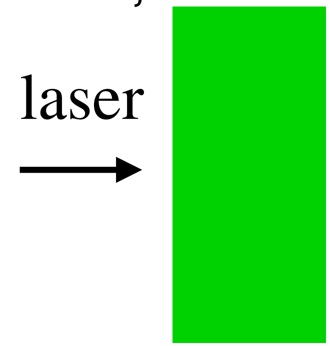

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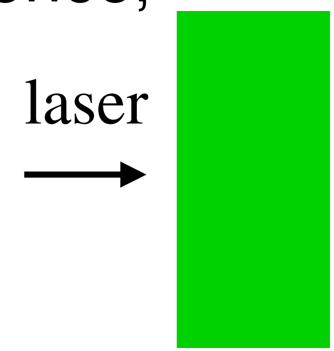

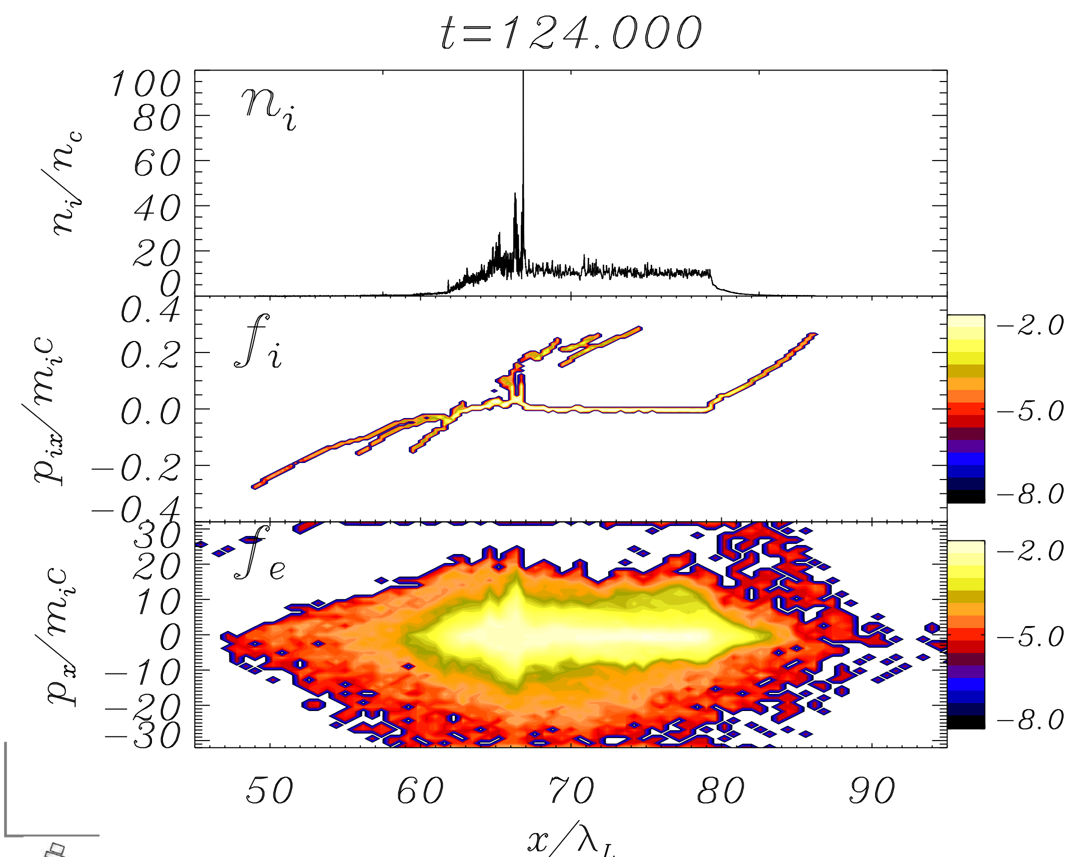

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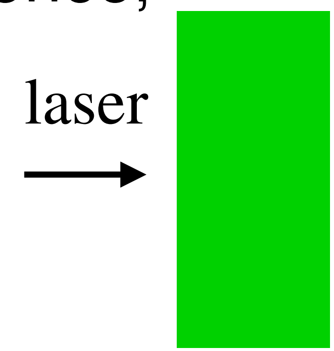

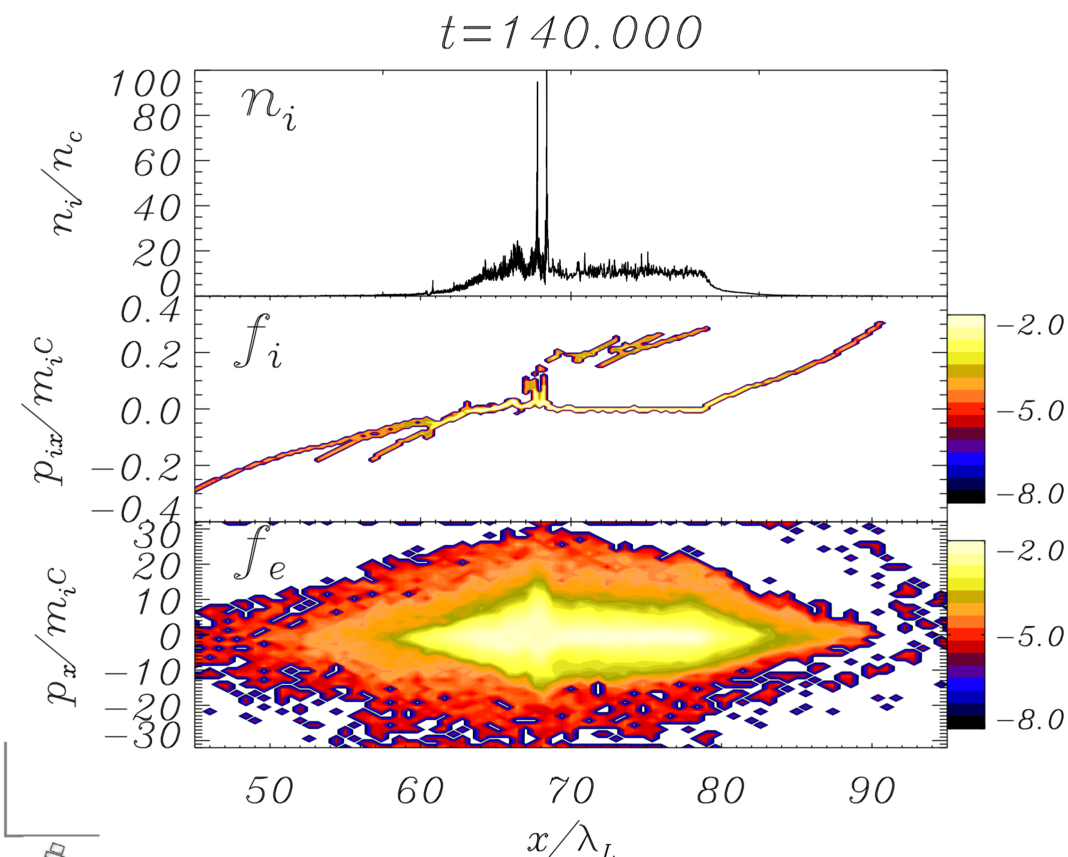

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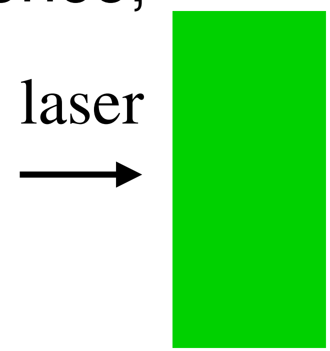

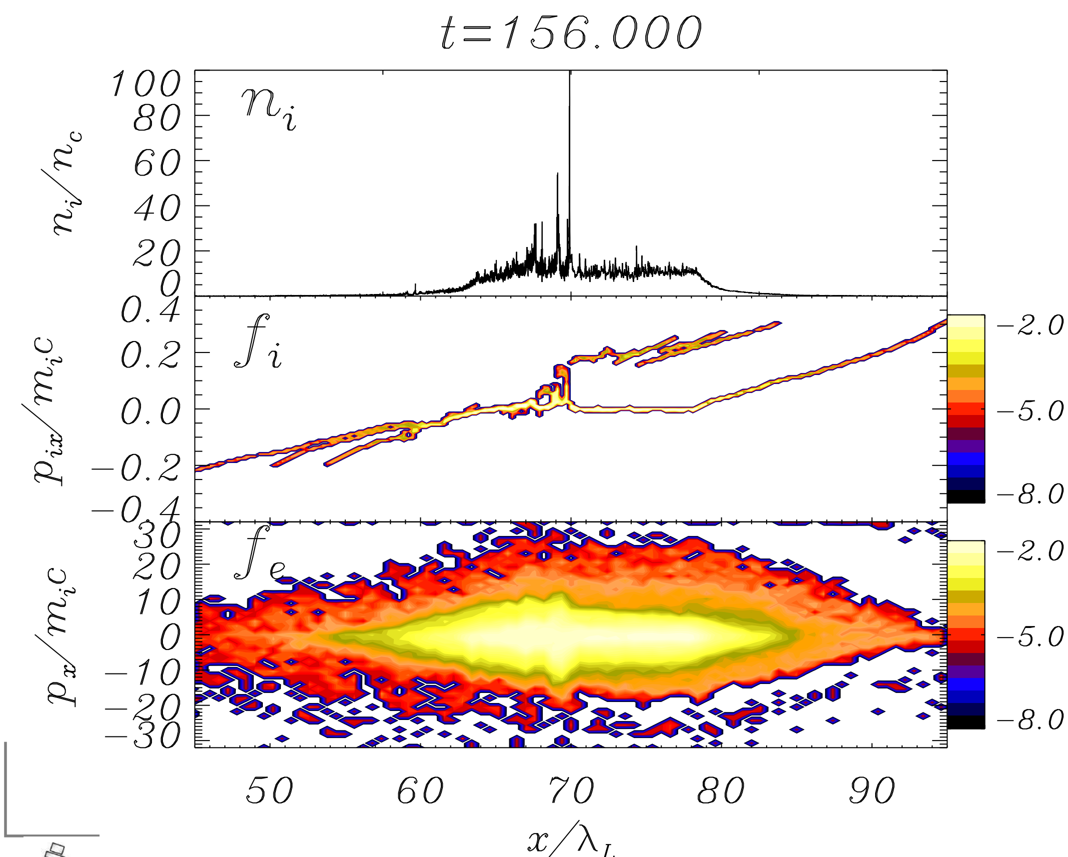

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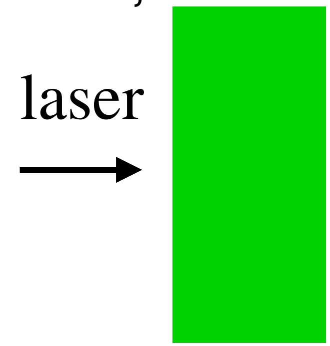

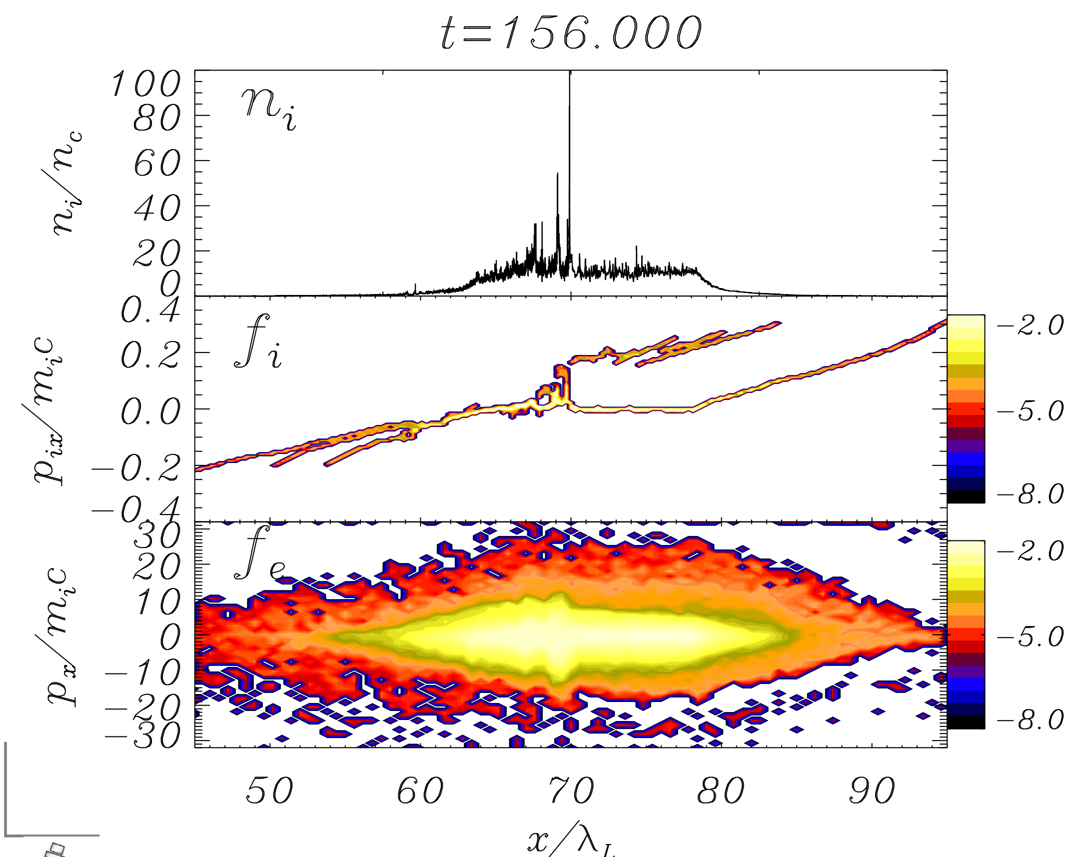

At least three sources of MeV ions: FSA, TNSA (back), TNSA (front)

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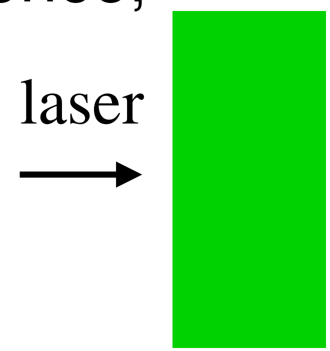

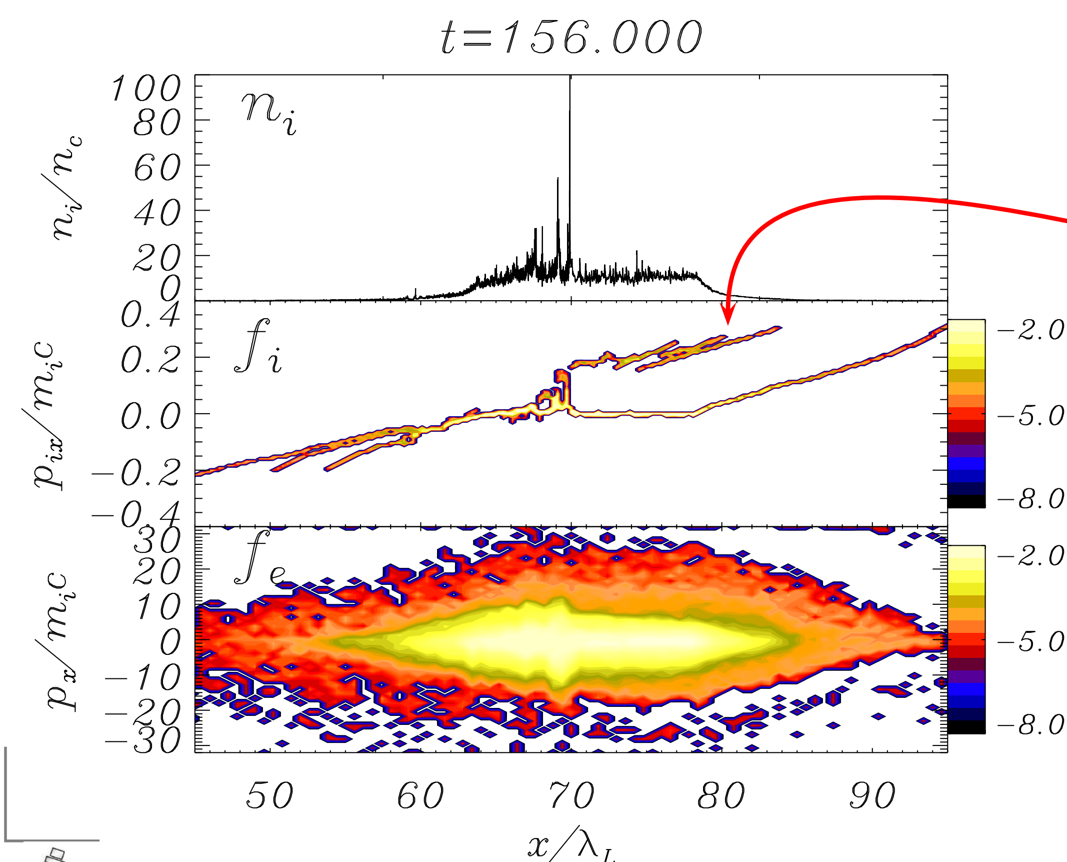

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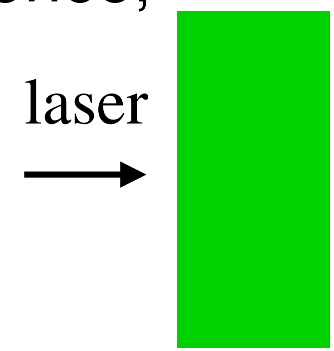

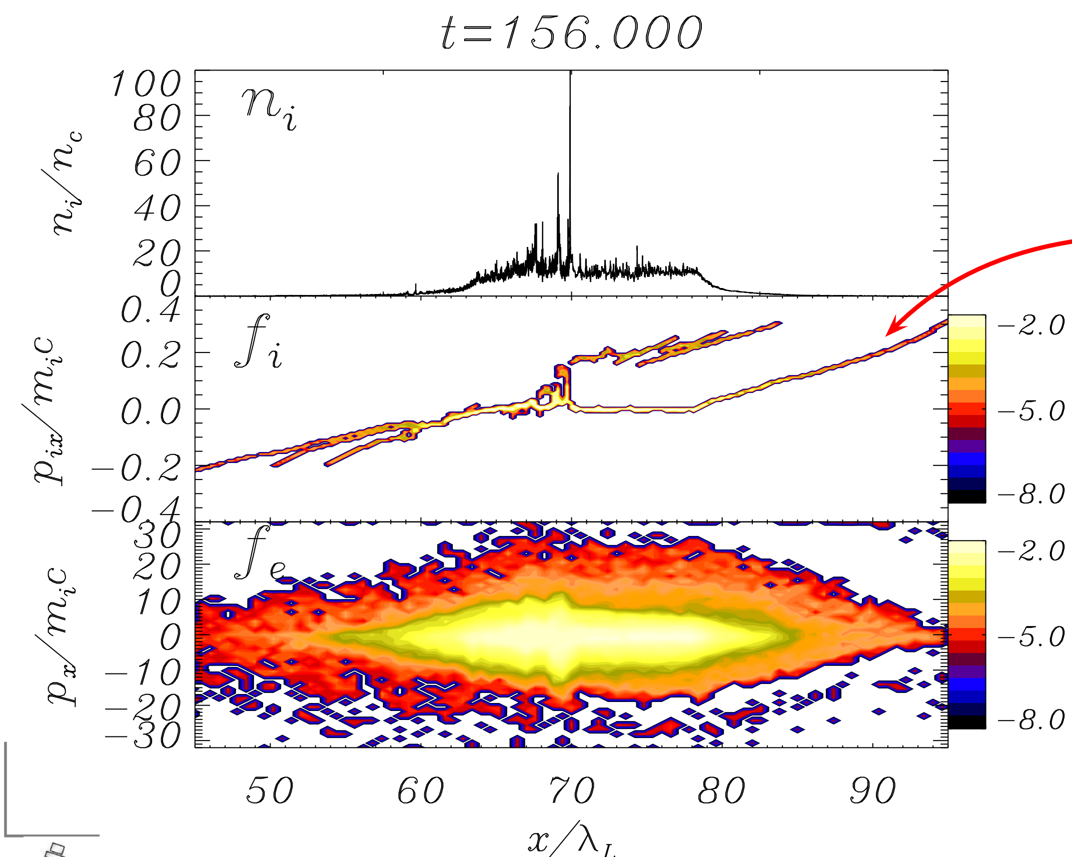

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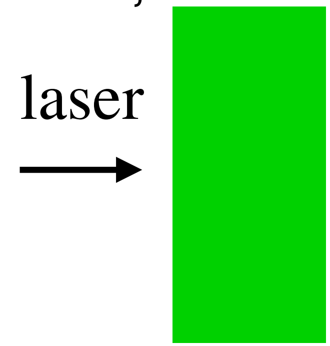

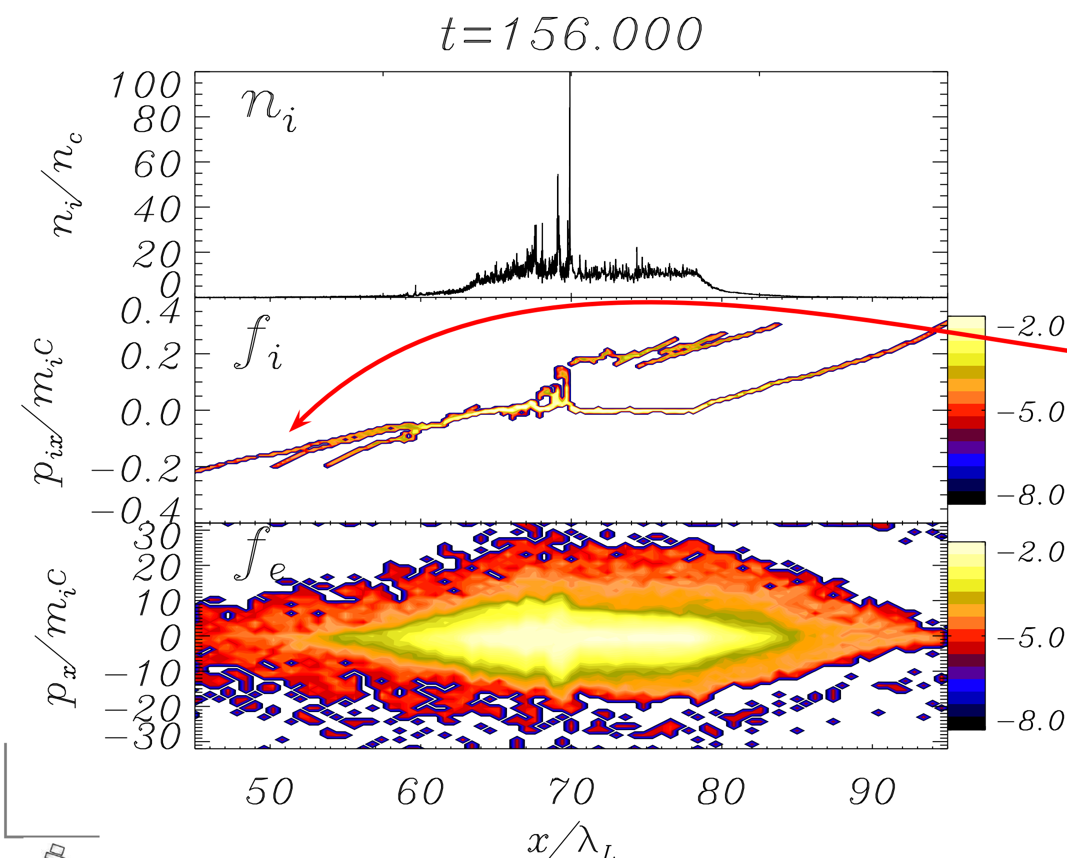

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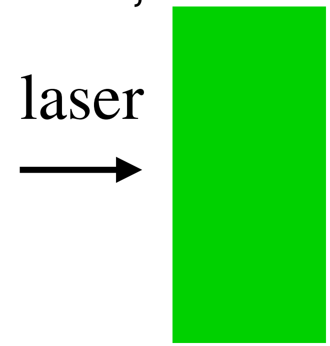

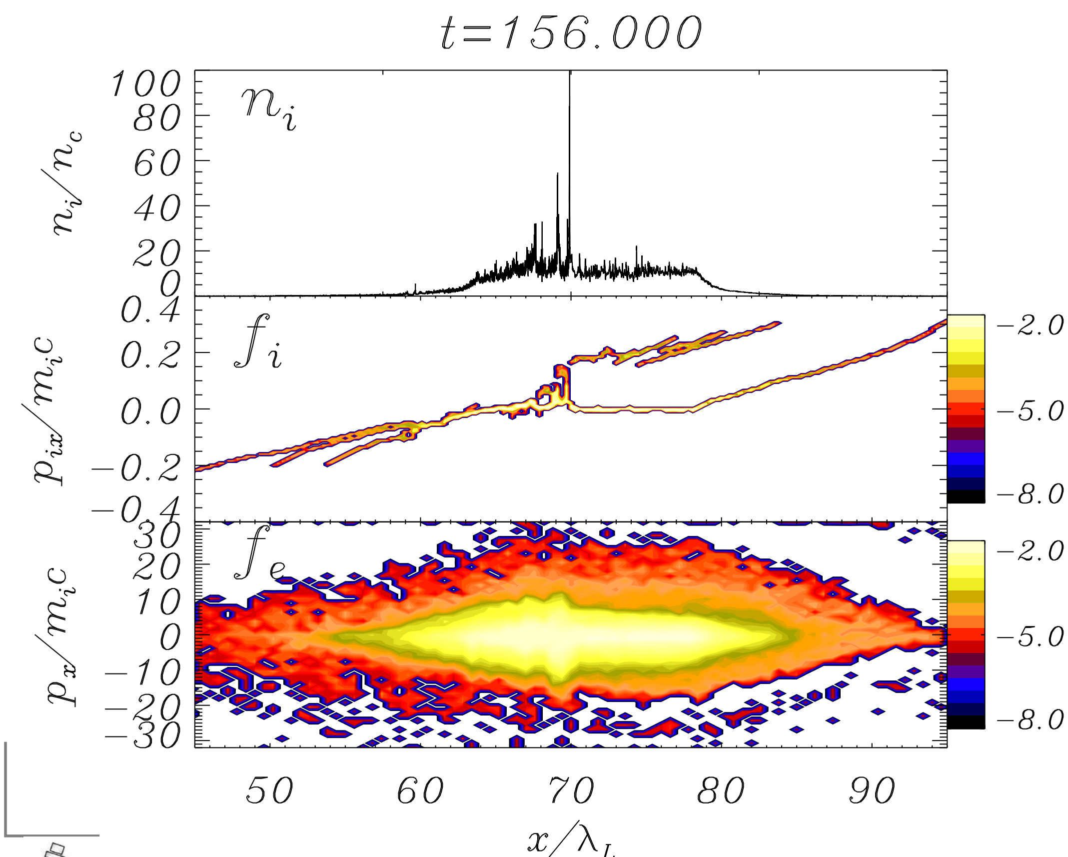

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Electrons are heated up to several tens of MeV

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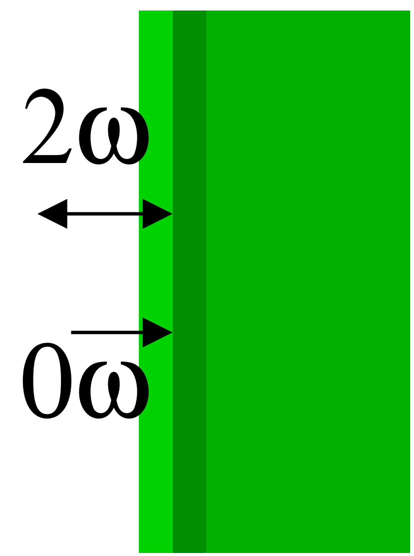

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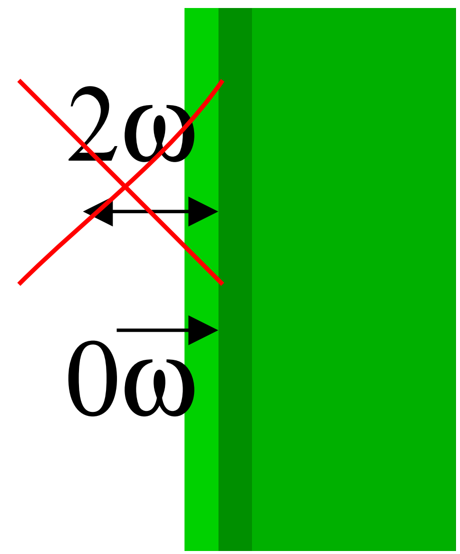

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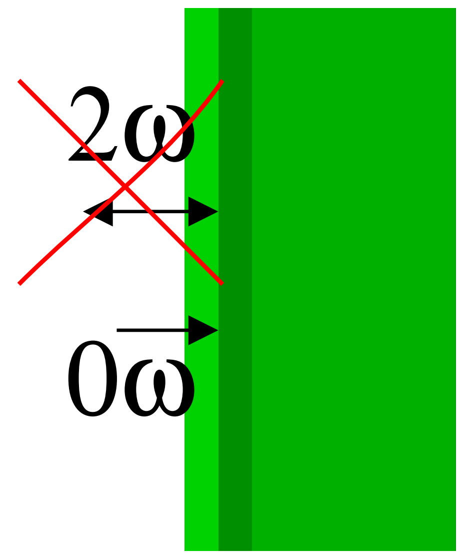
$\Rightarrow$ Ion acceleration is driven directly by radiation pressure



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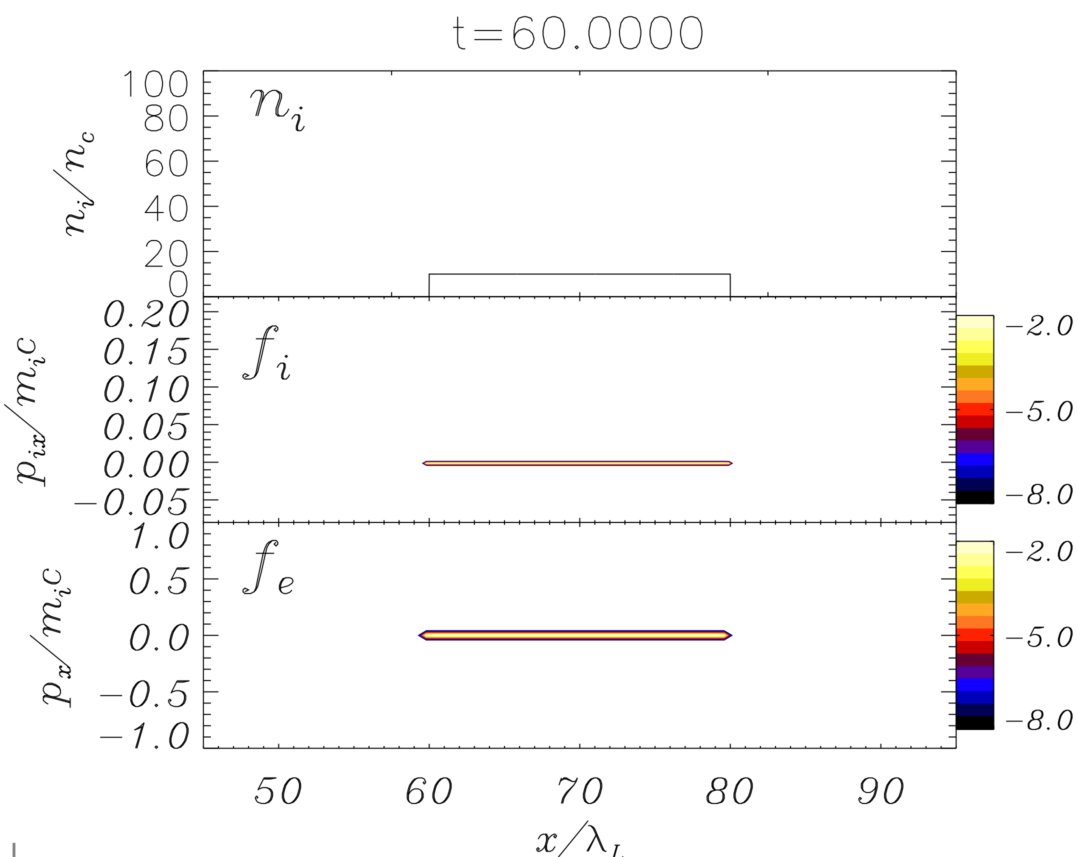

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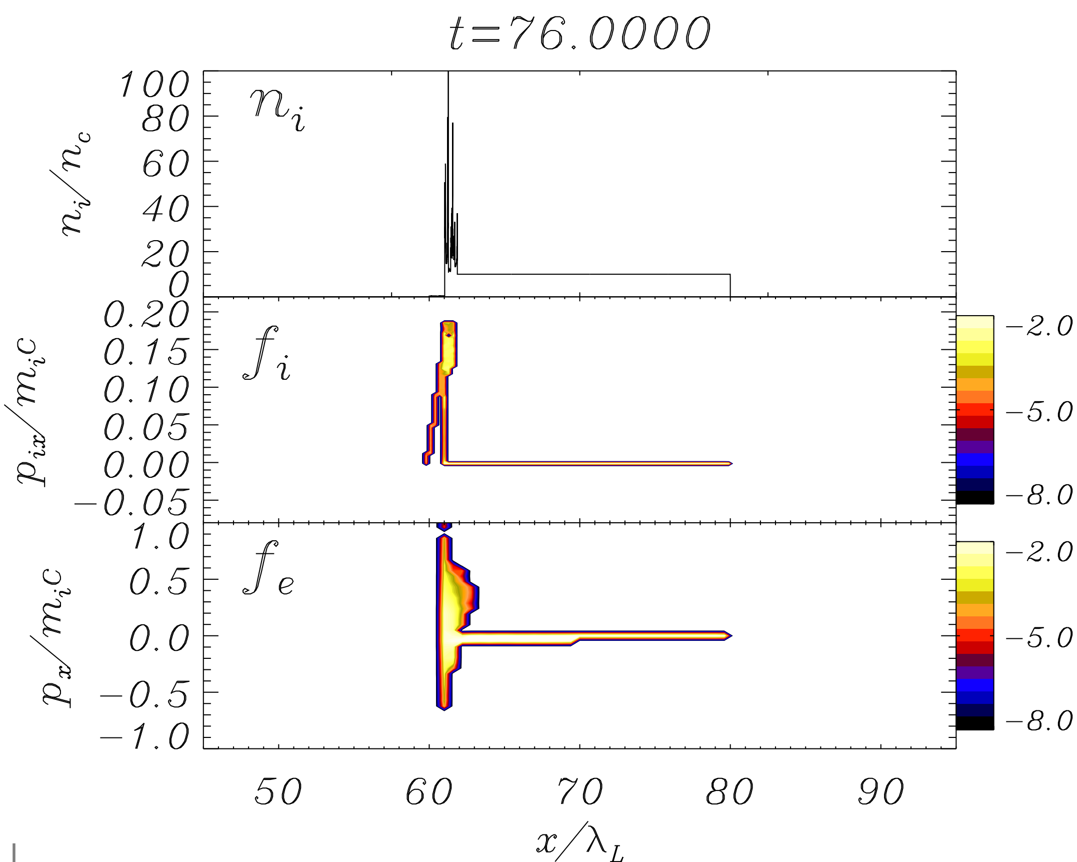

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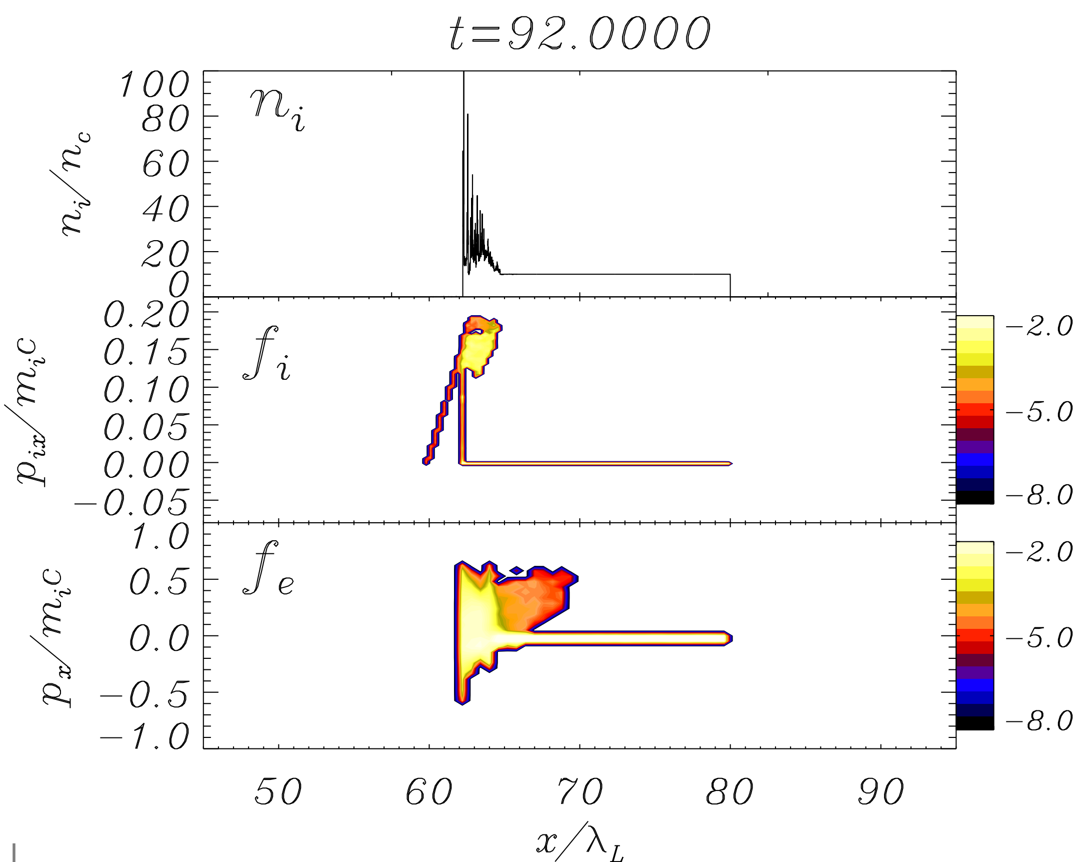

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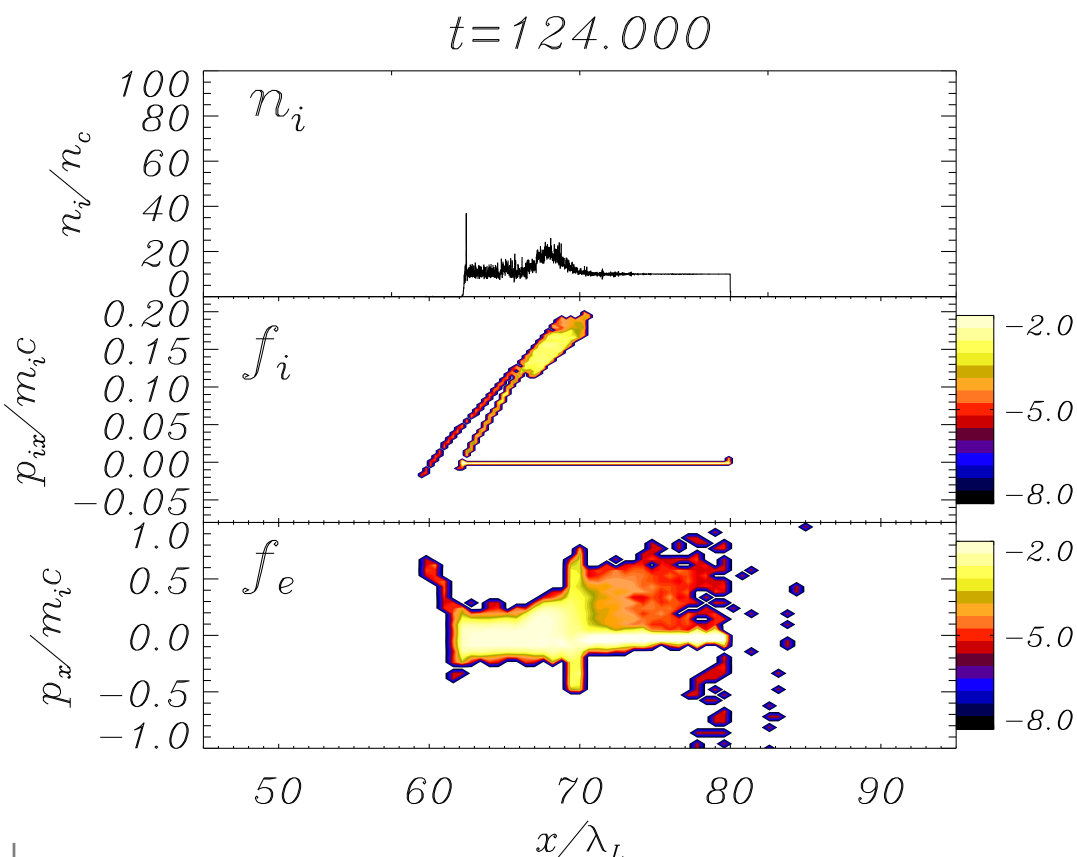

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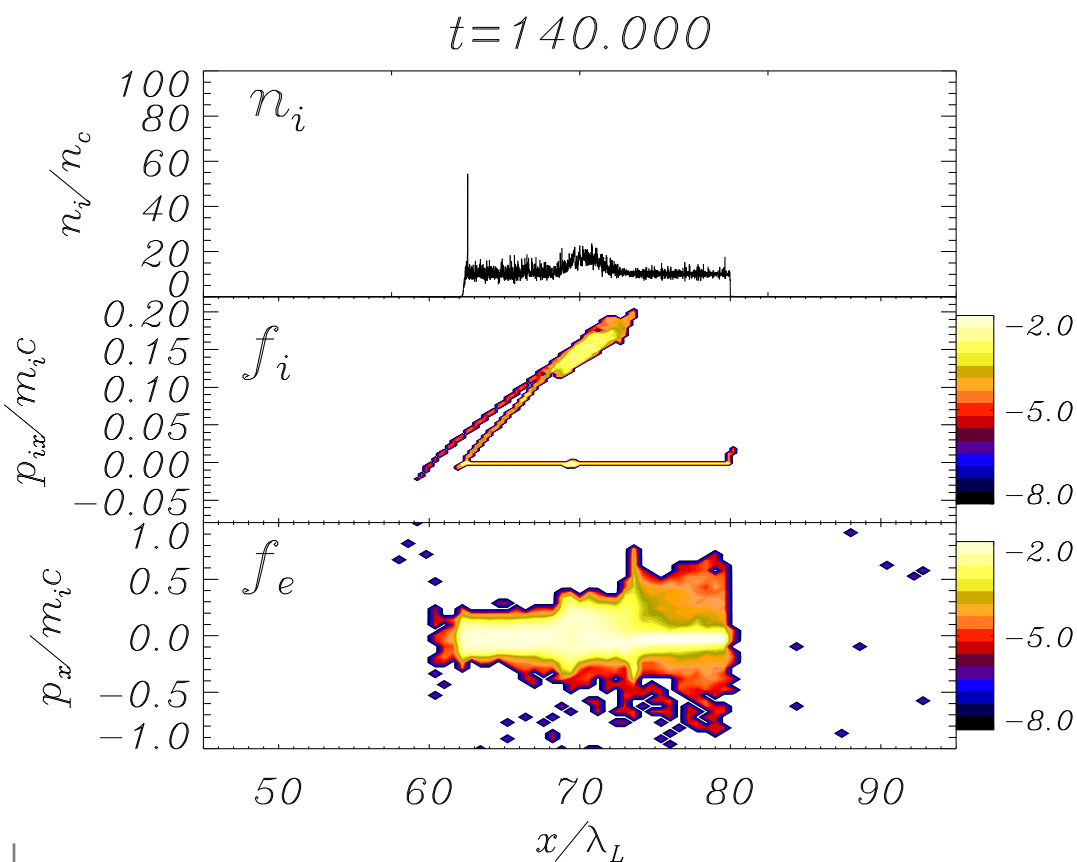

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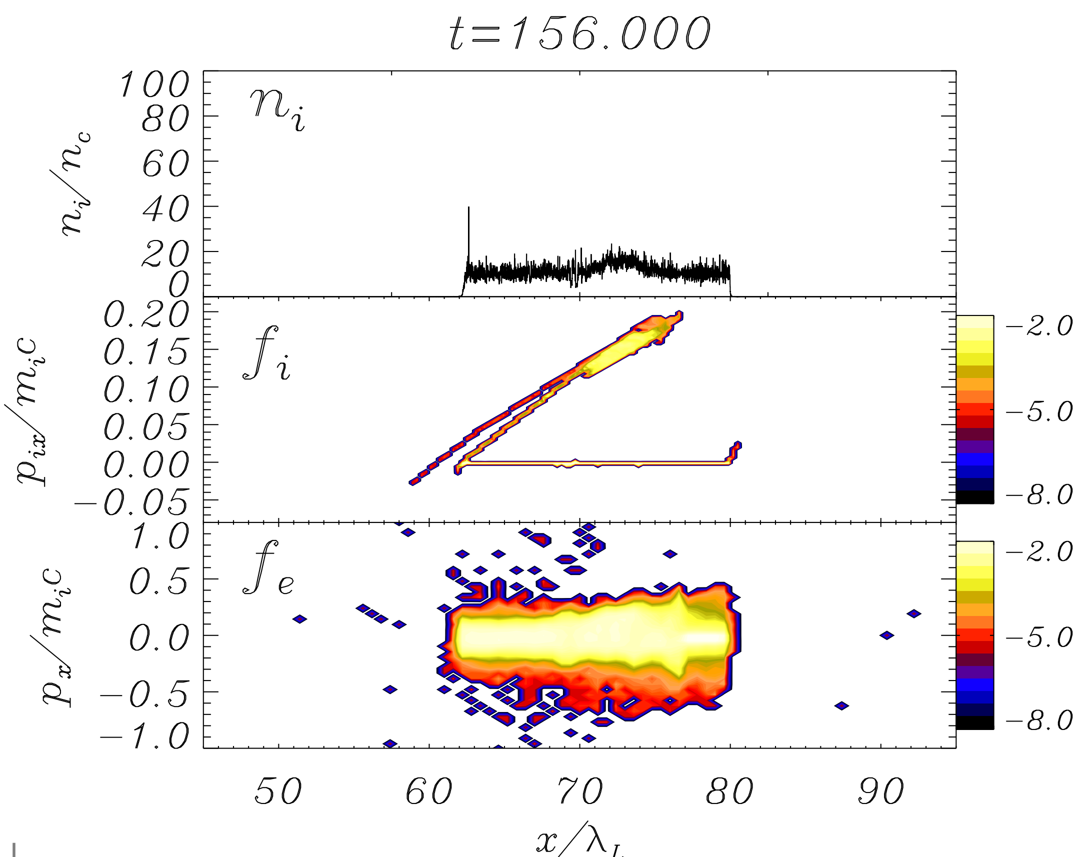

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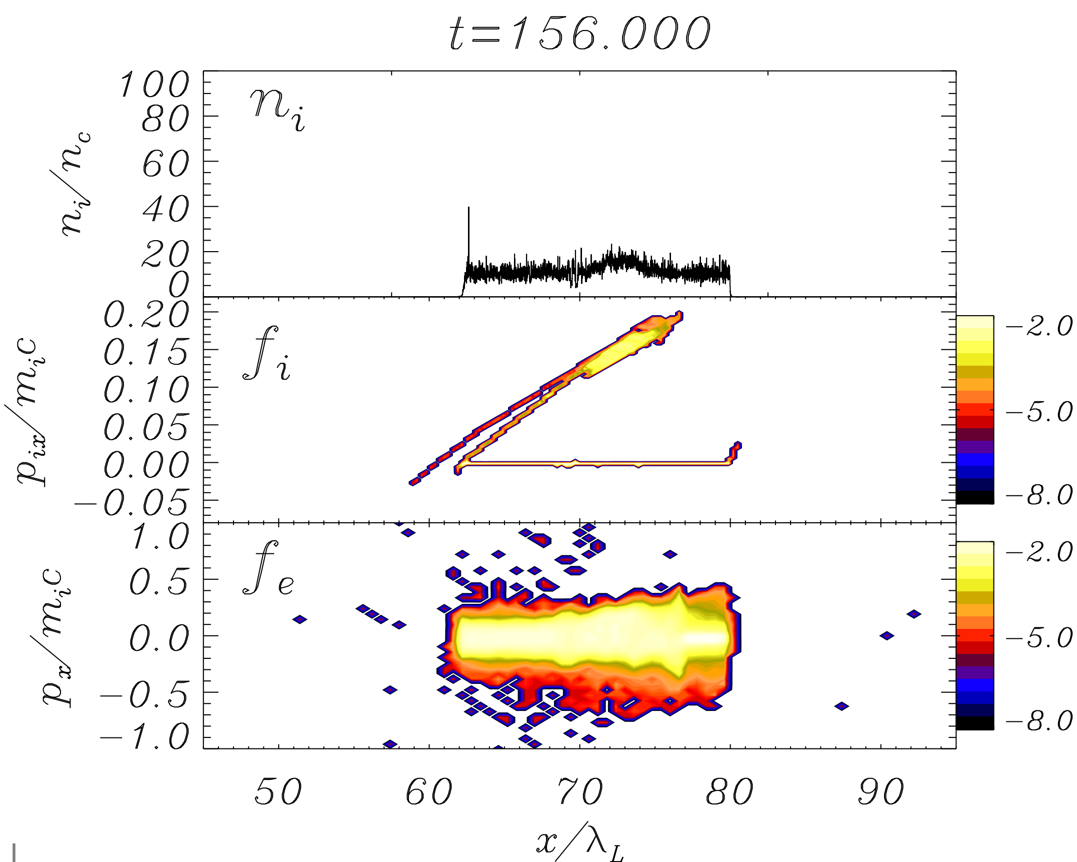

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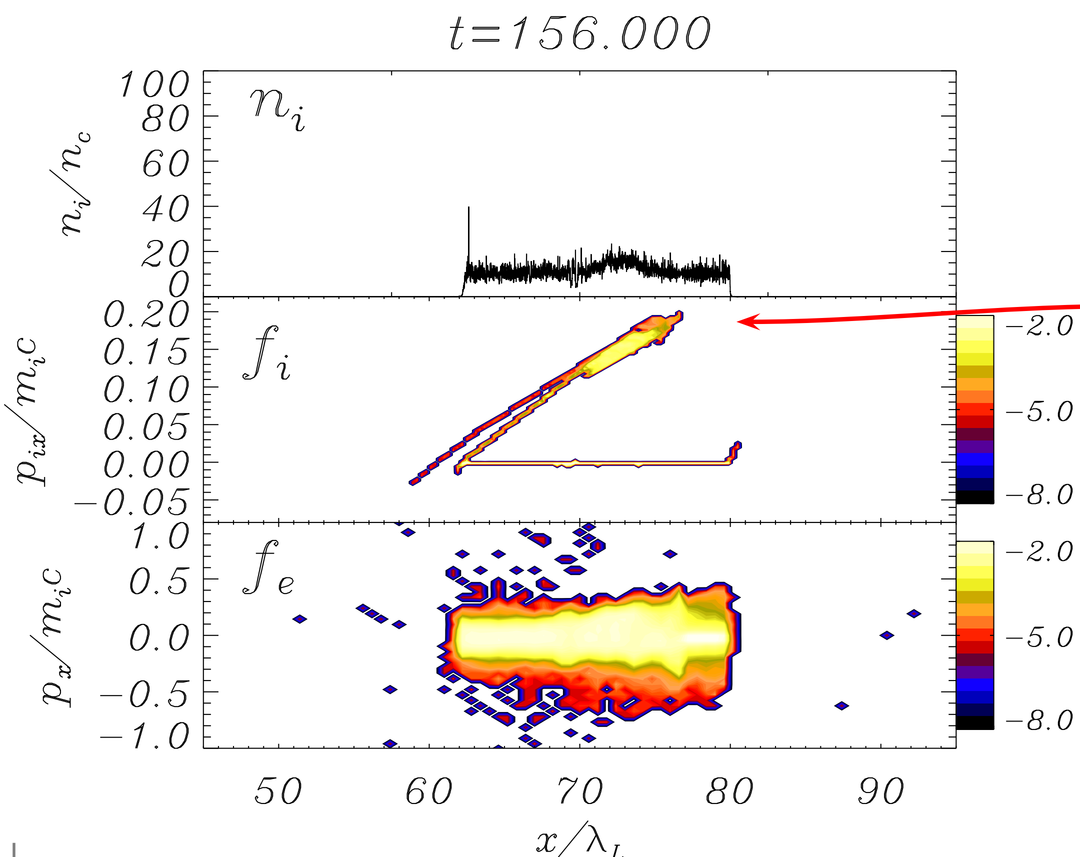

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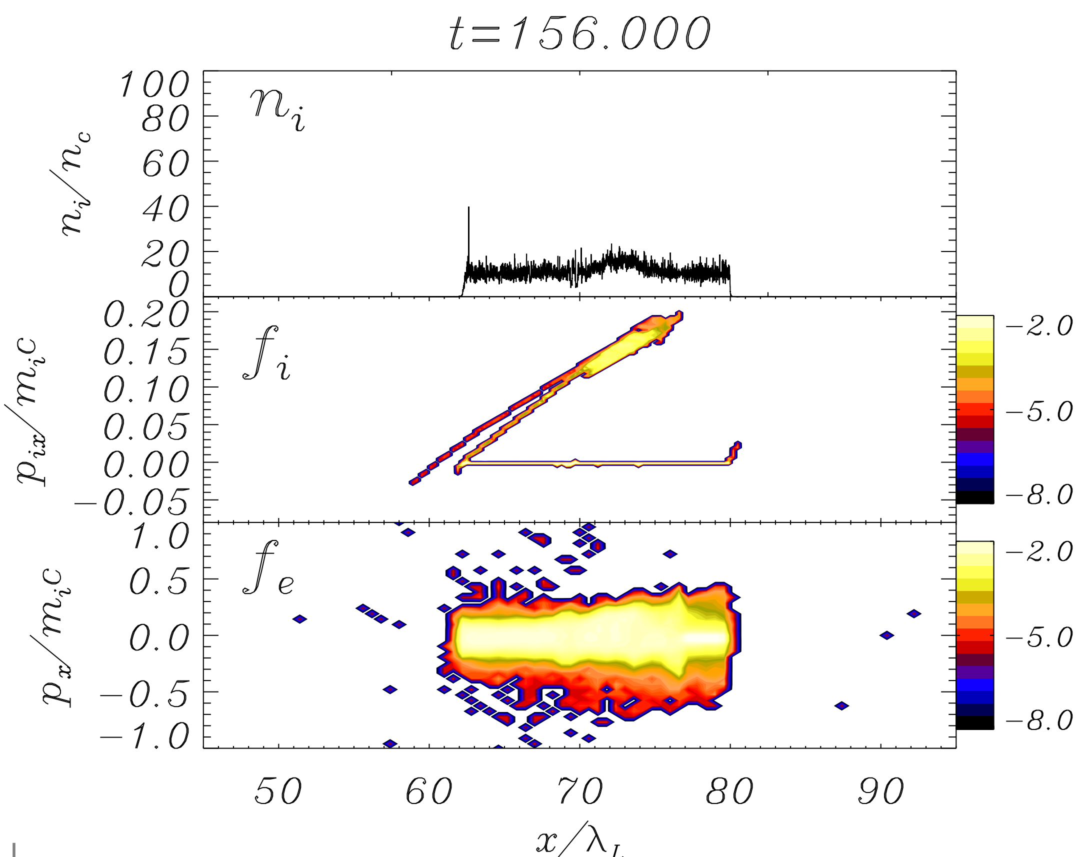

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Electron energy is below 1 MeV;
no fast electrons

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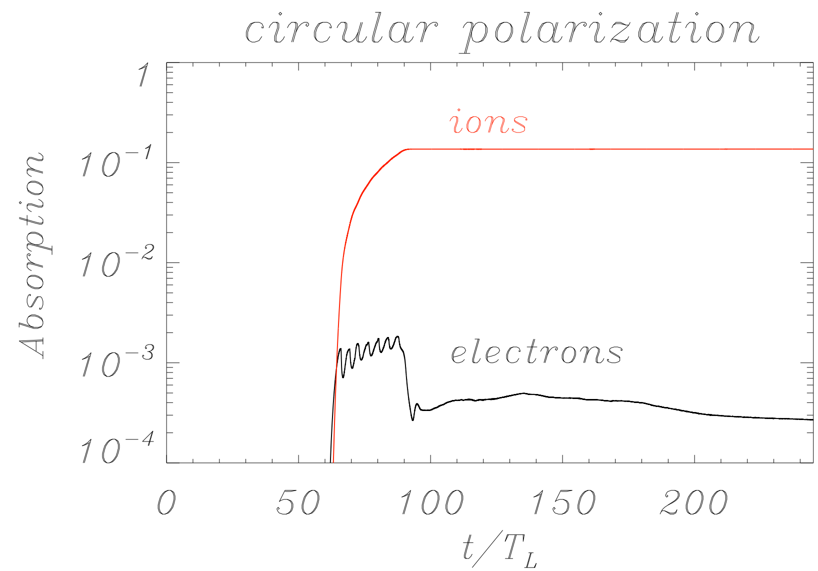

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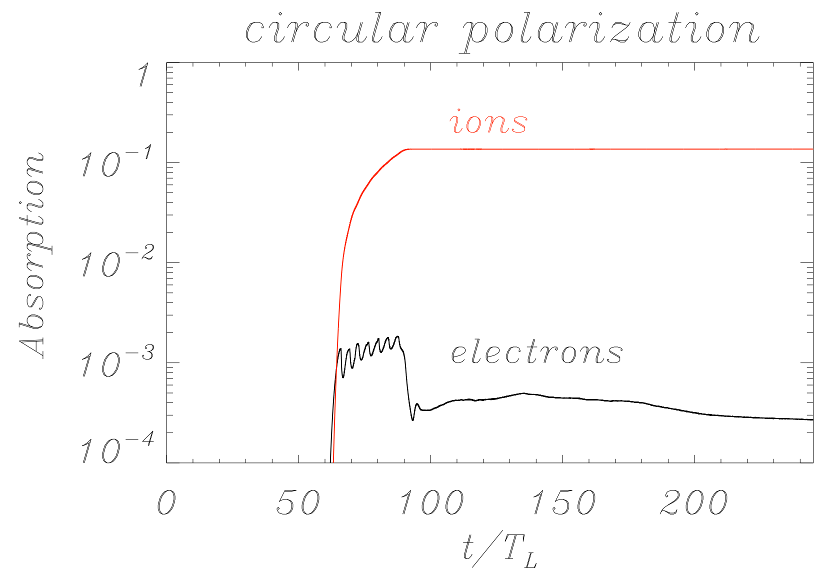

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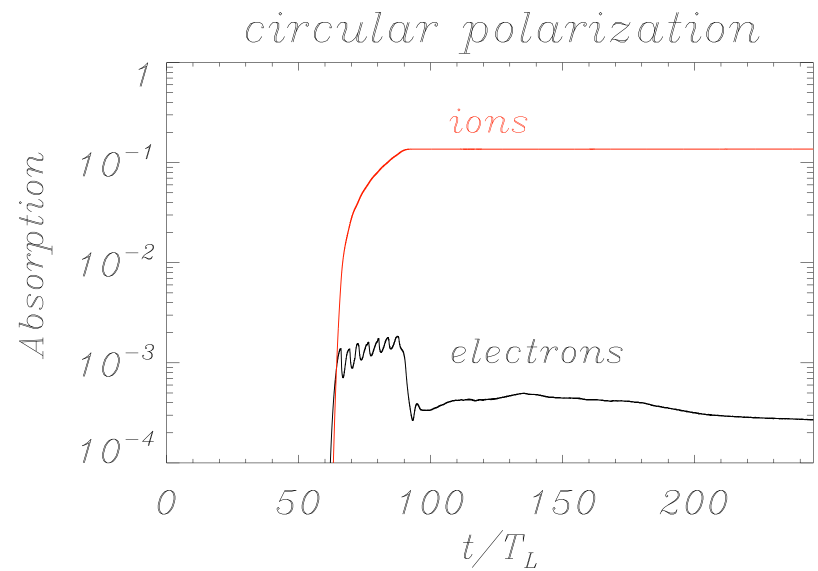

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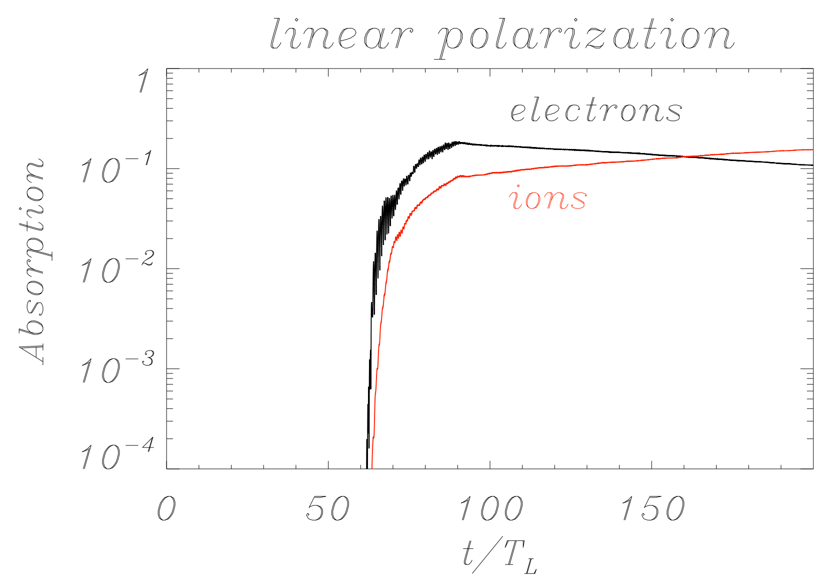

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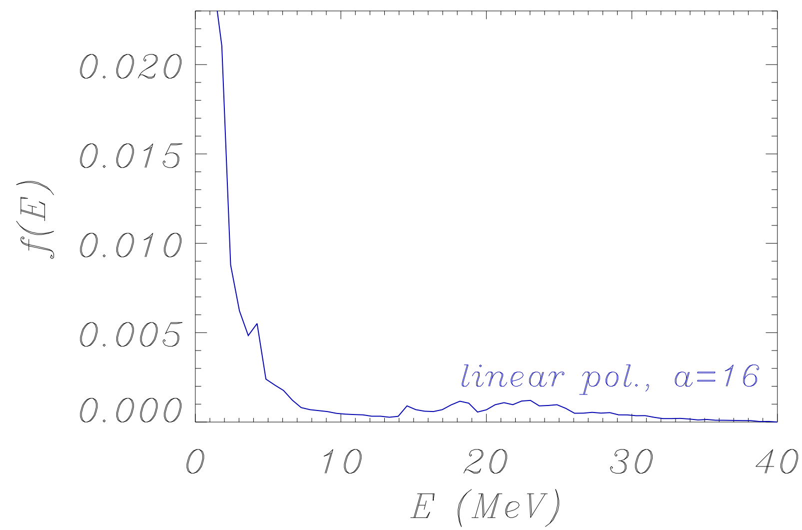

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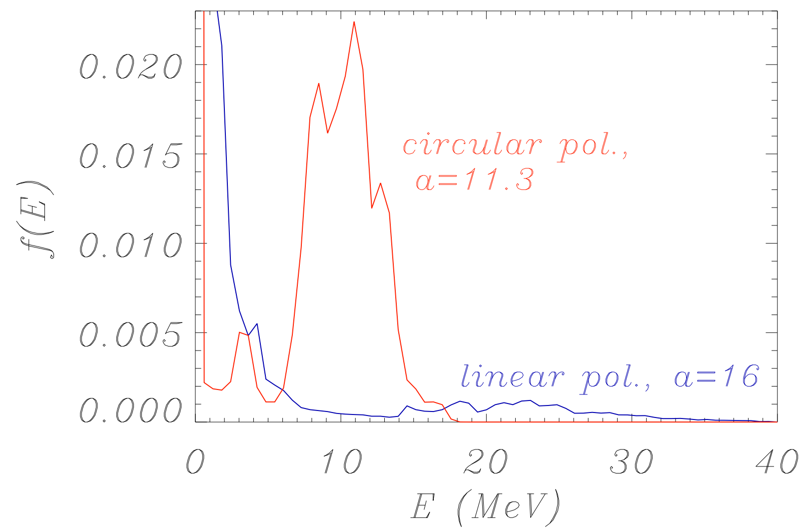

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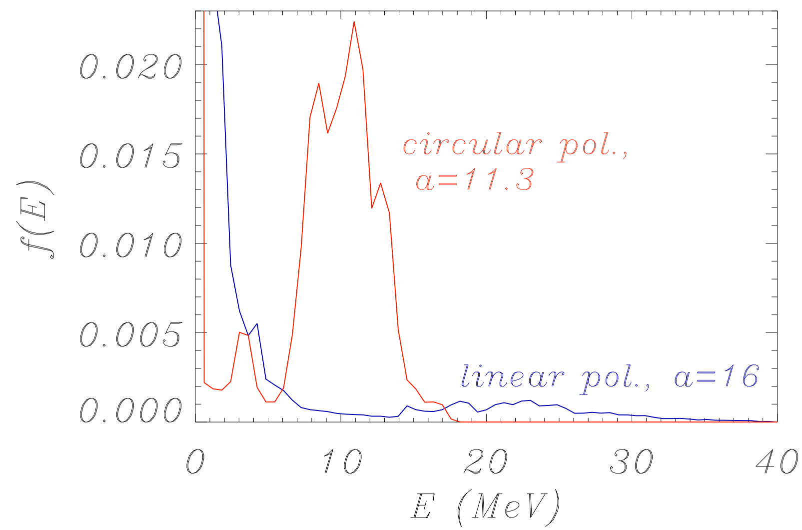

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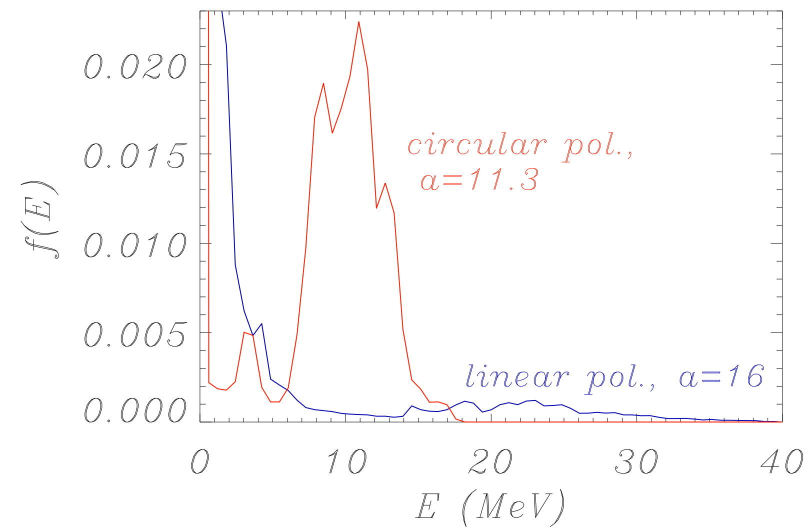

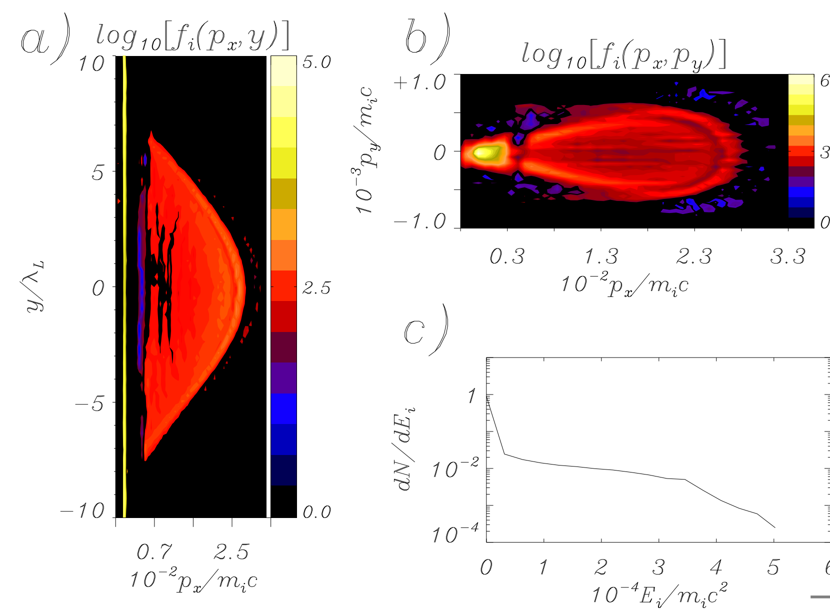

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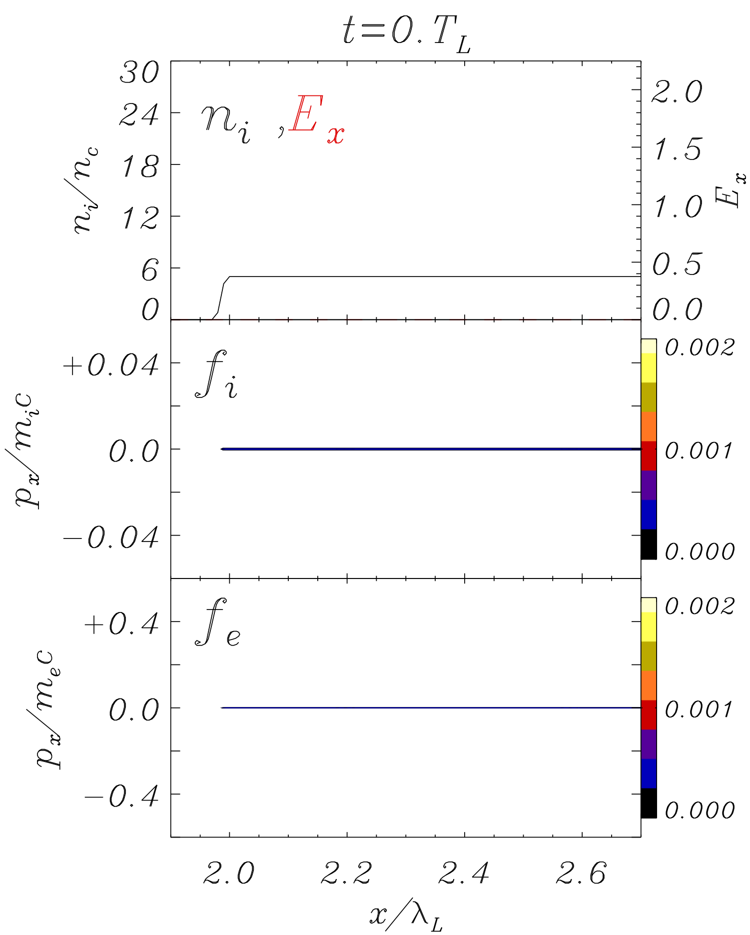

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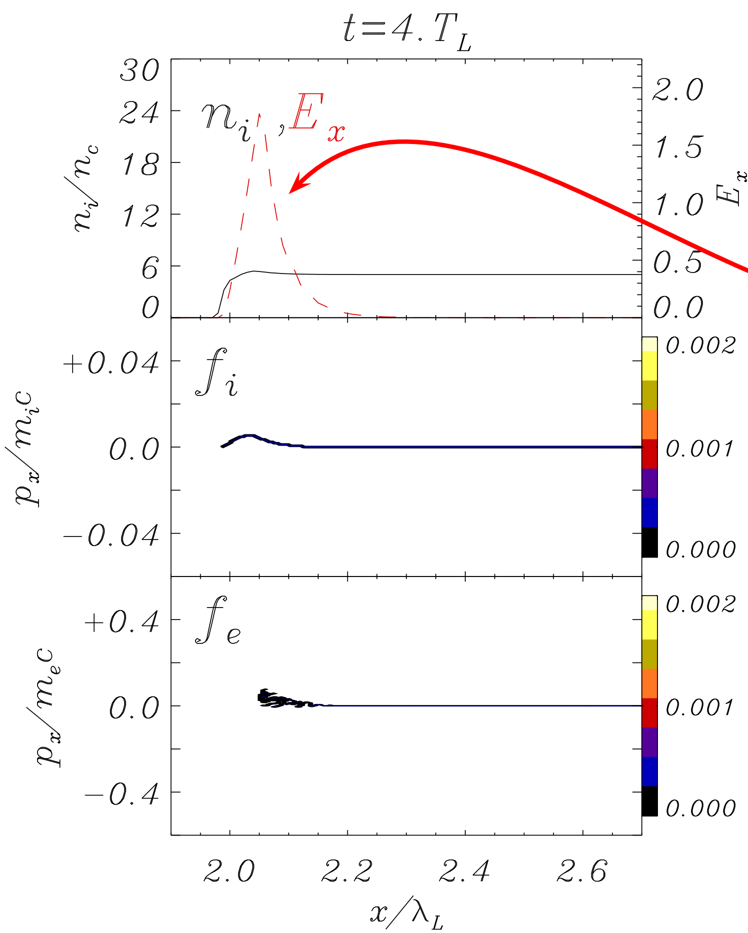

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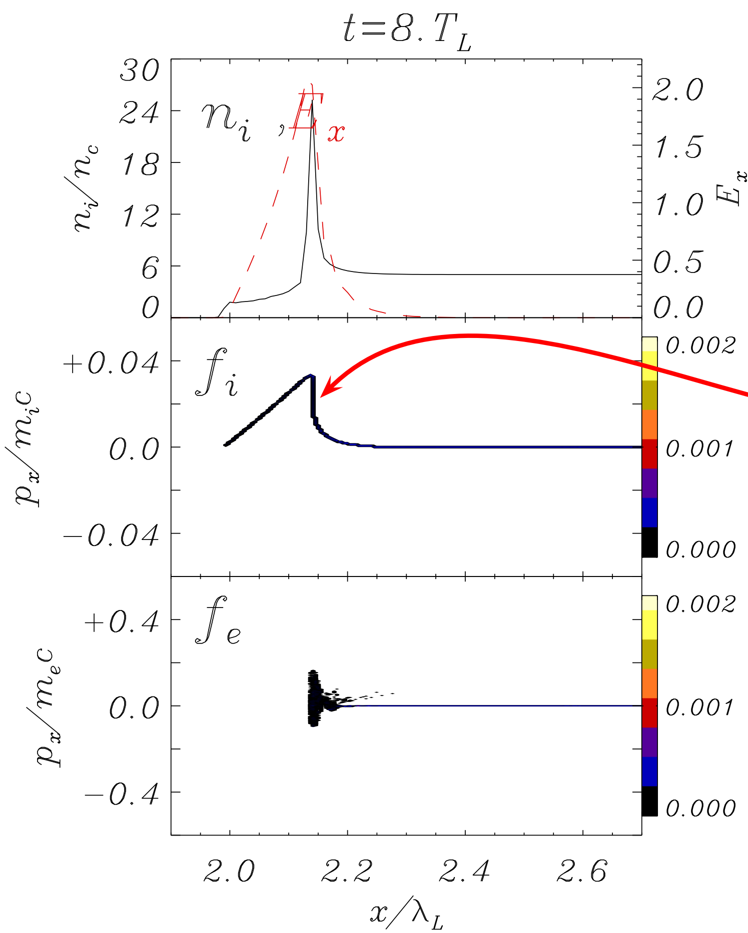

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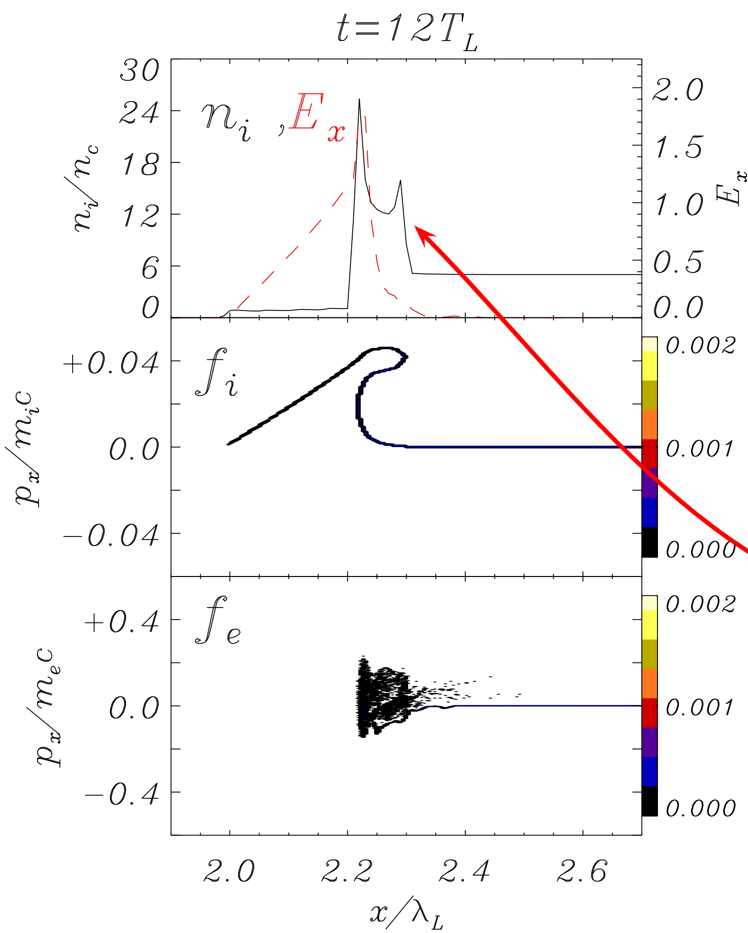

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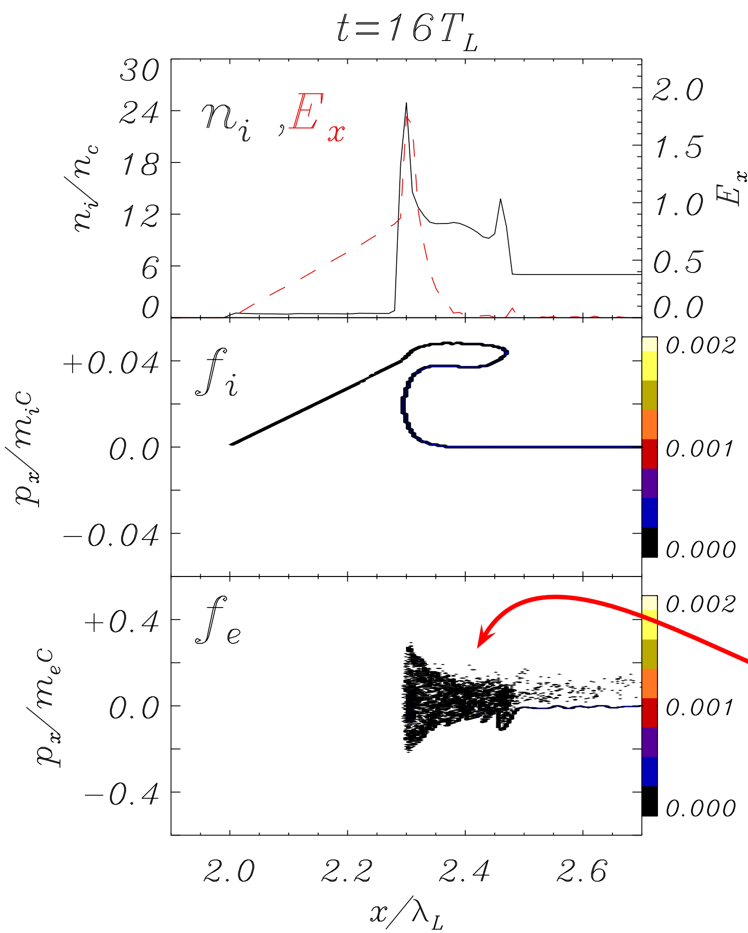

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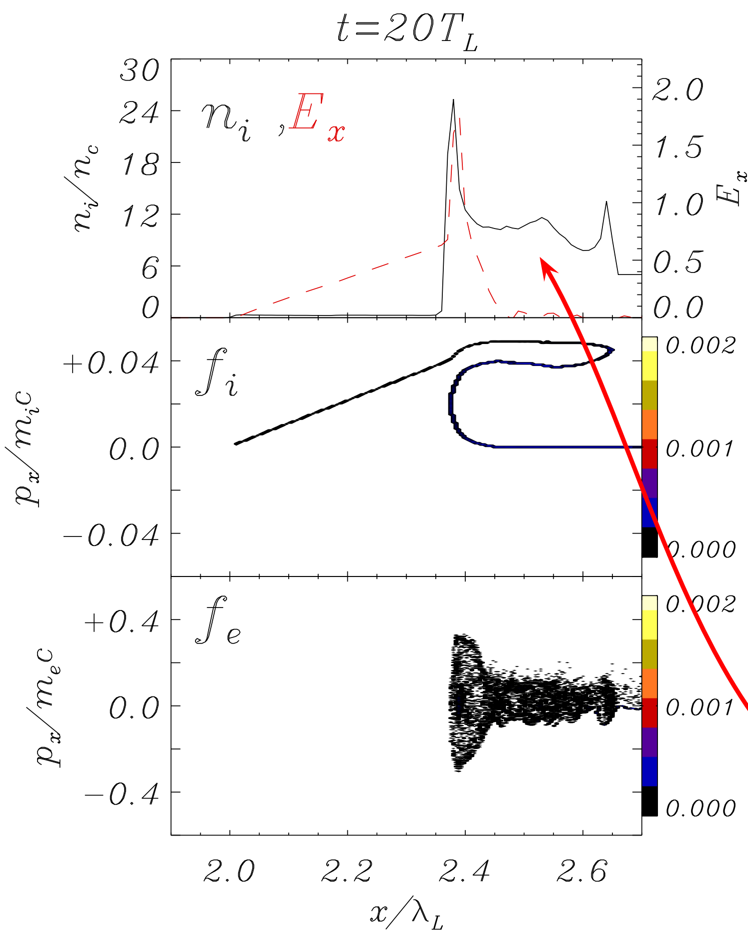

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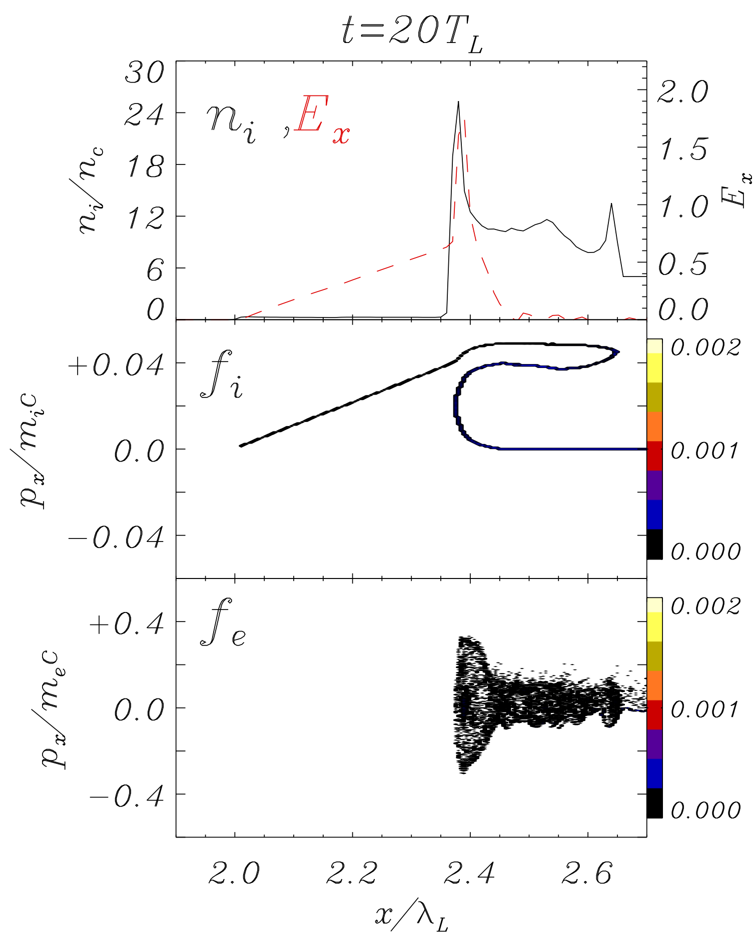

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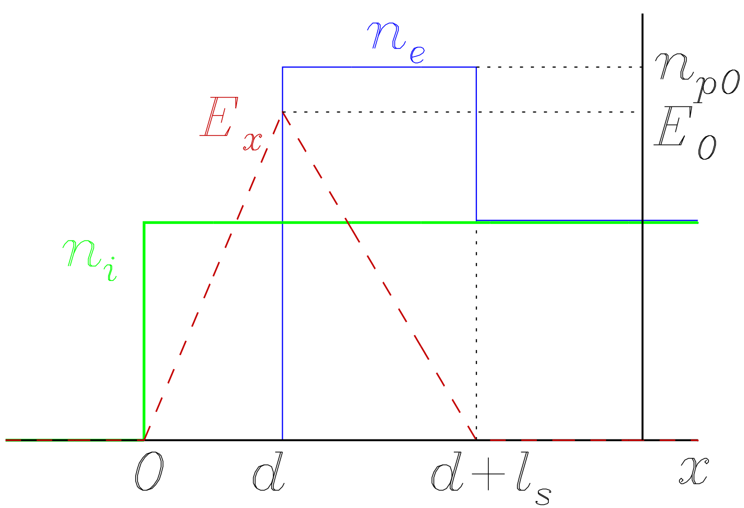

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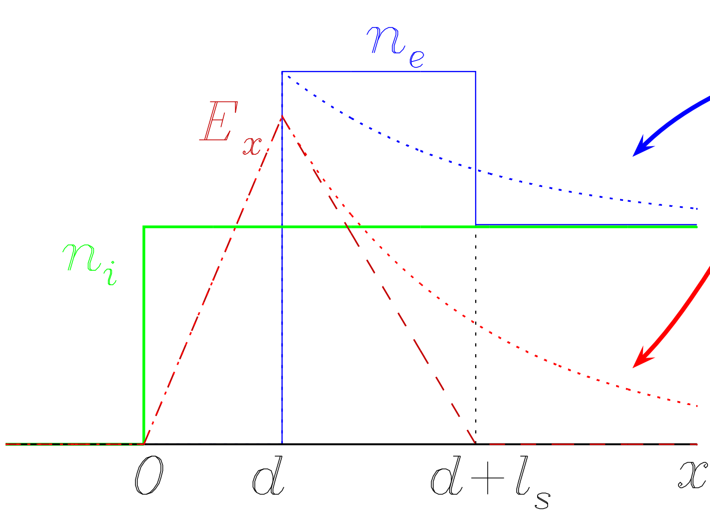

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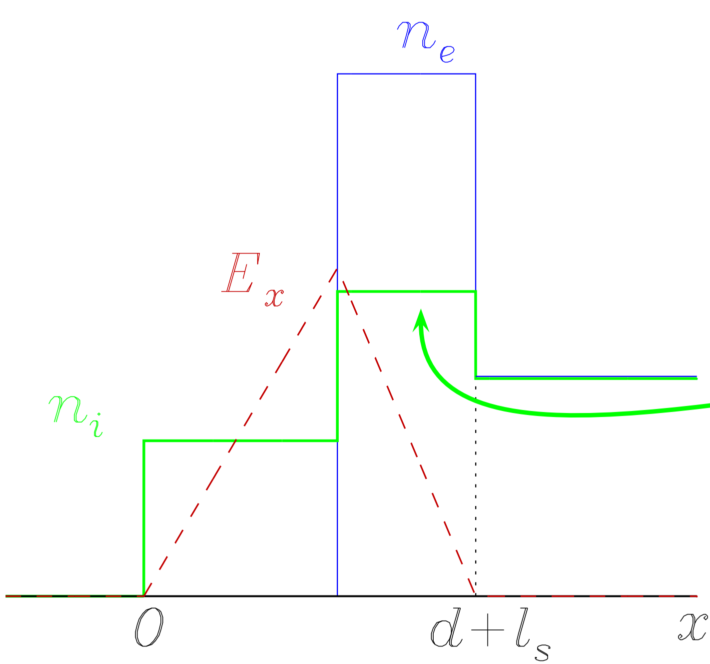

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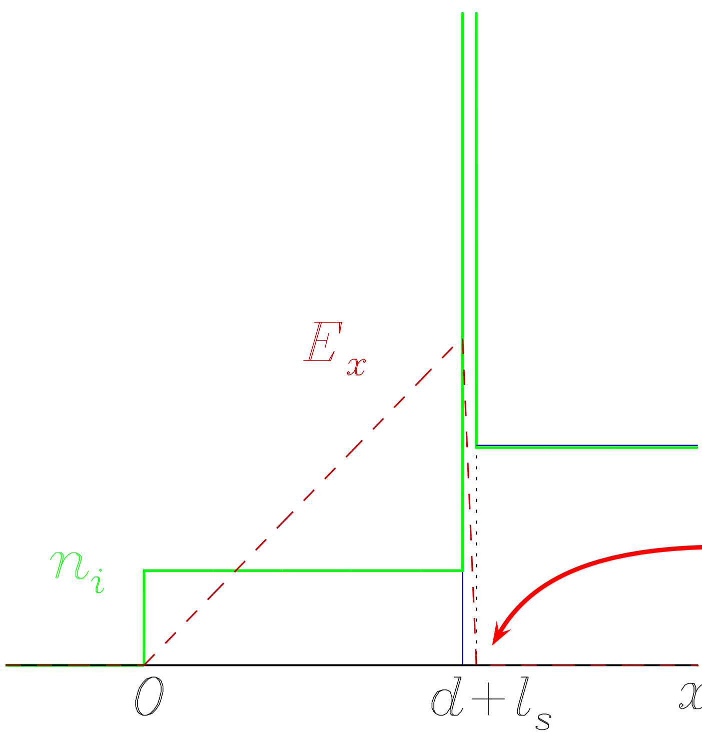

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  Similar predictions, but different physics with respect to the “shock” acceleration picture

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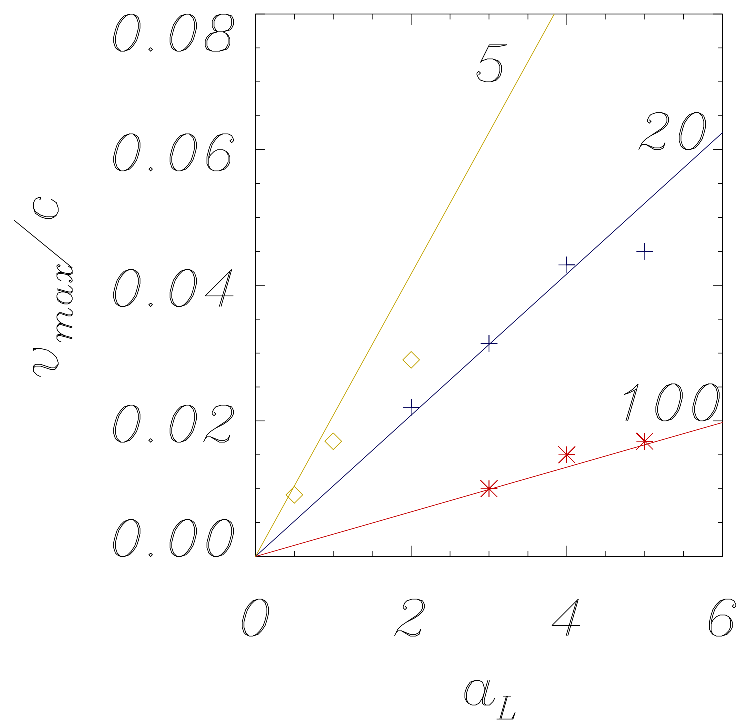

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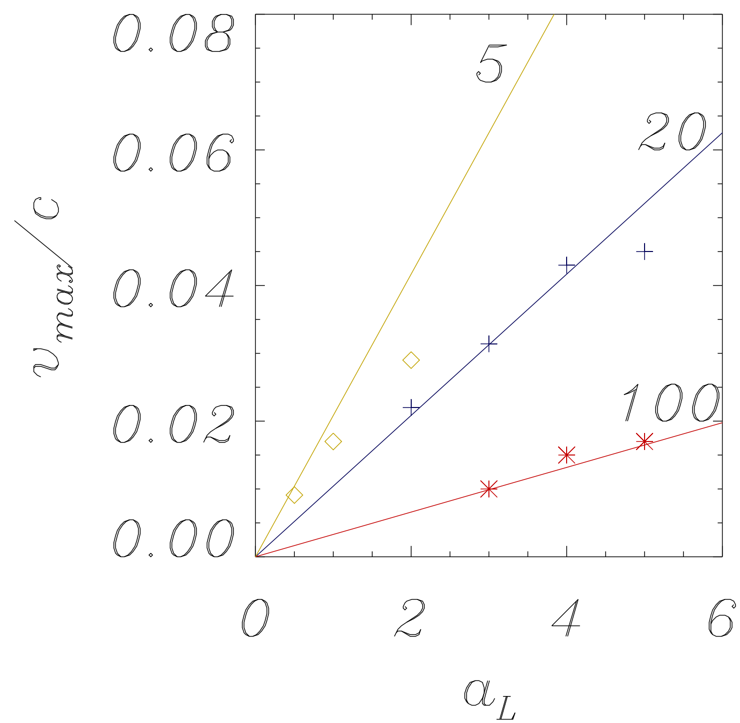

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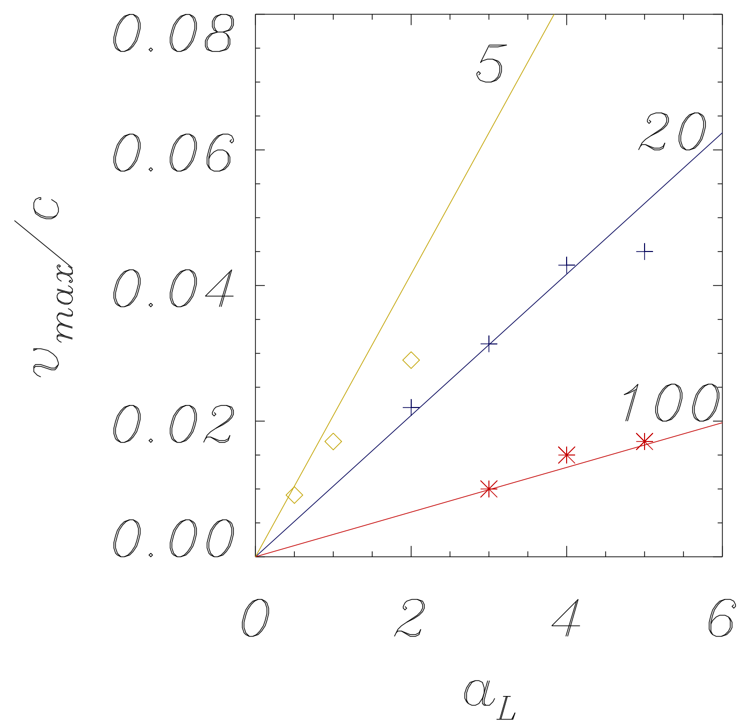

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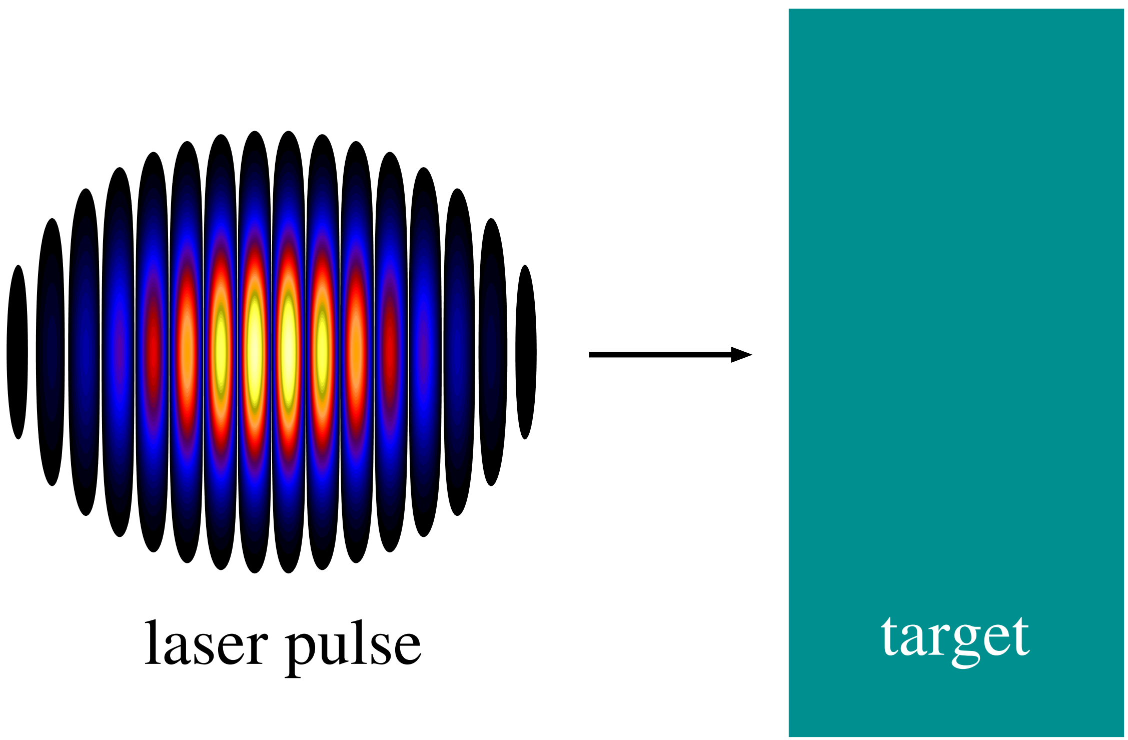

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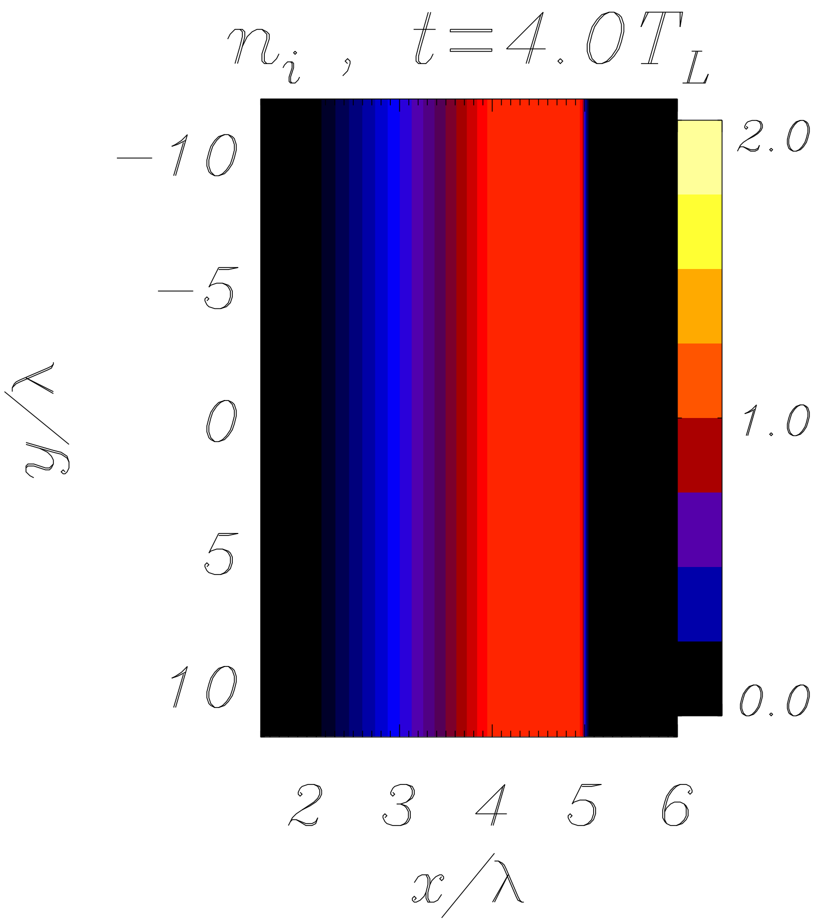

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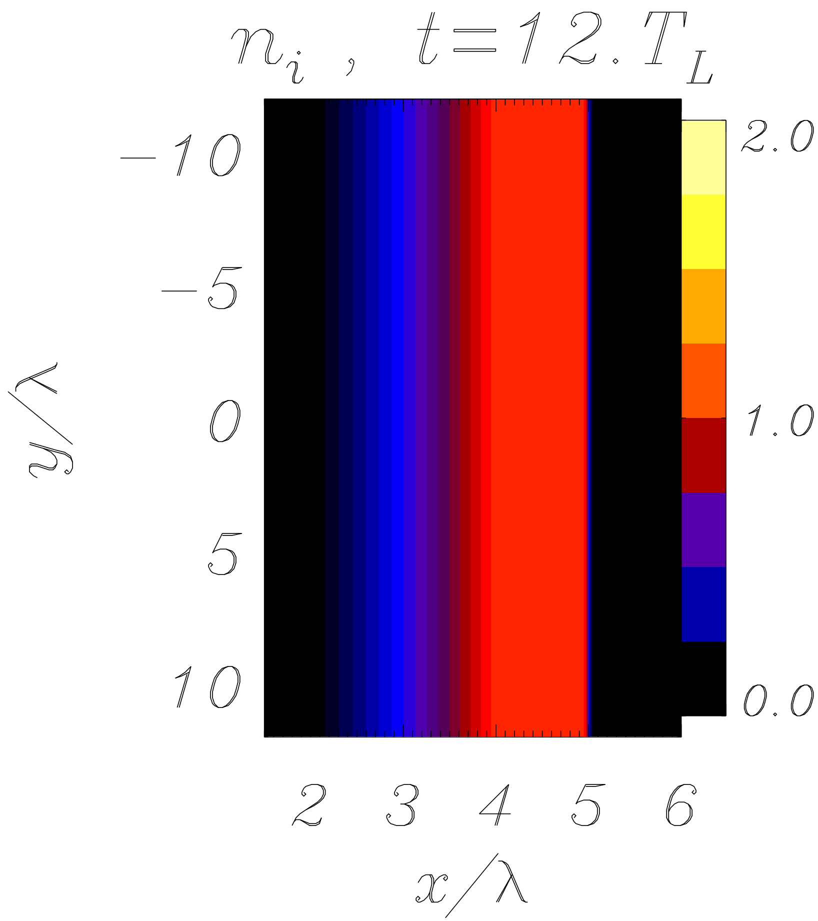

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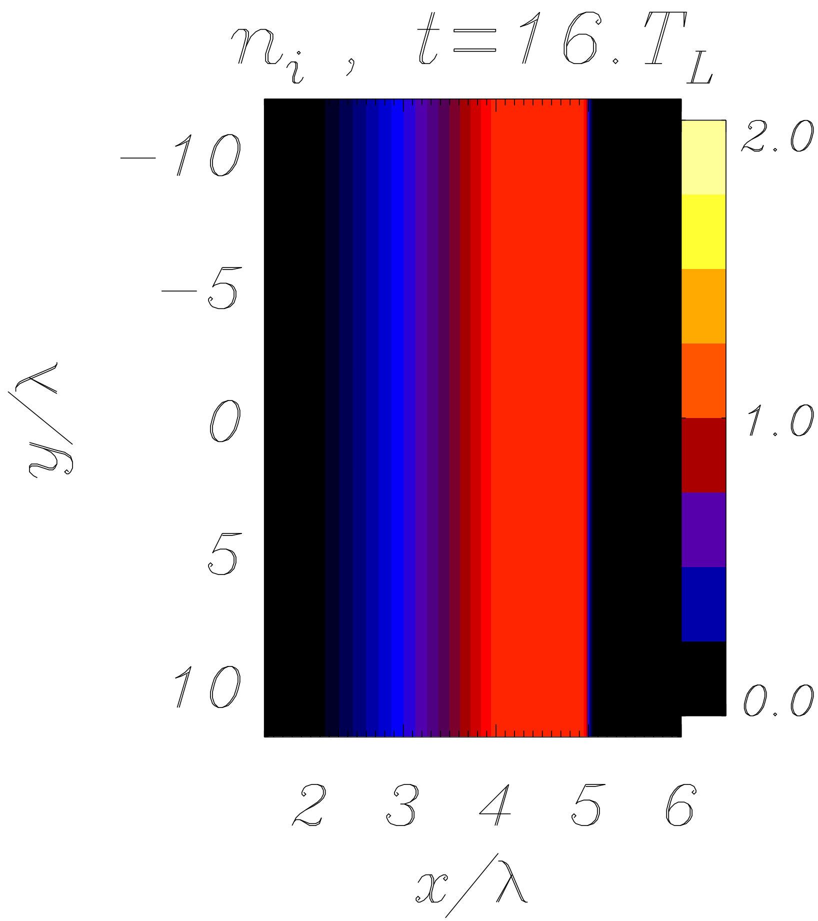

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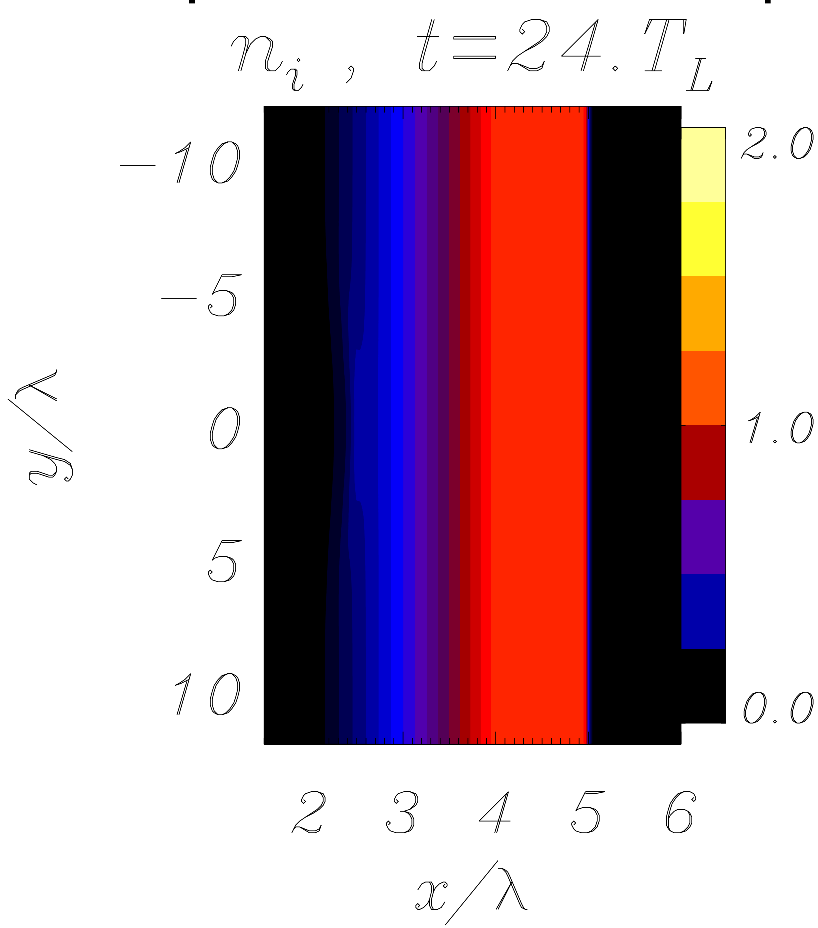

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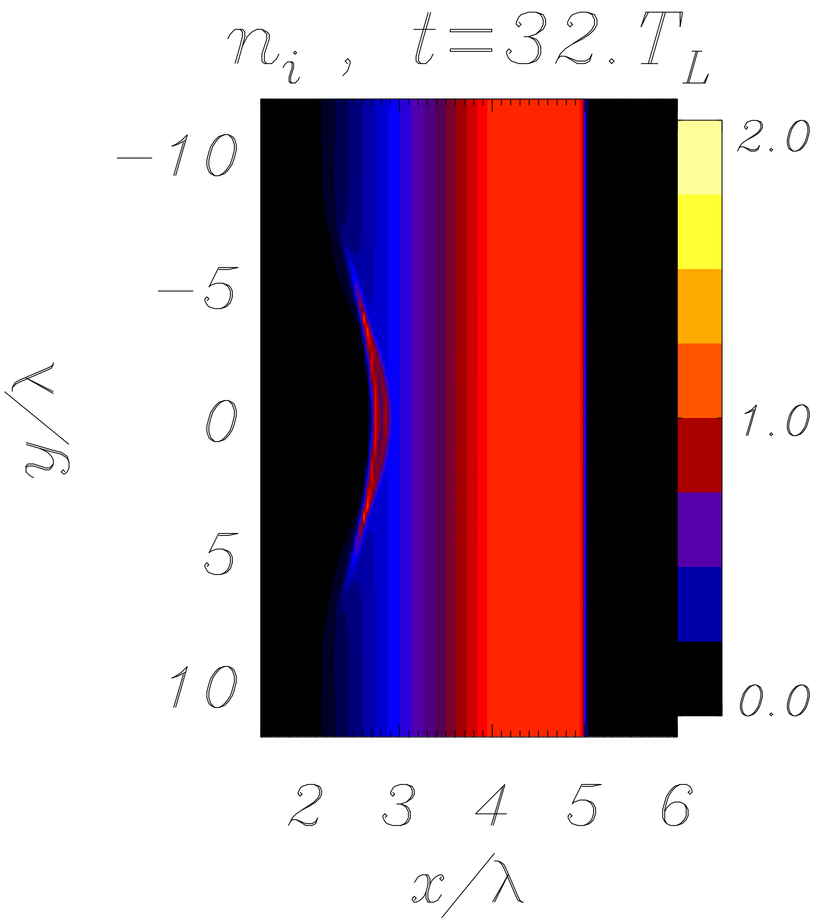

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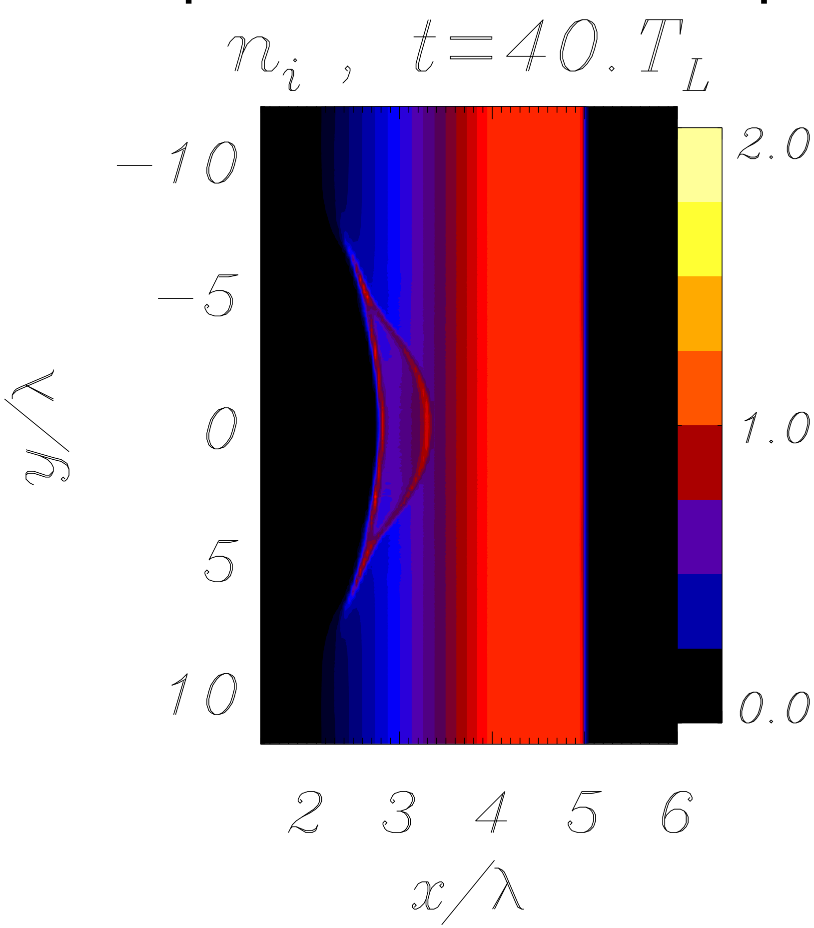

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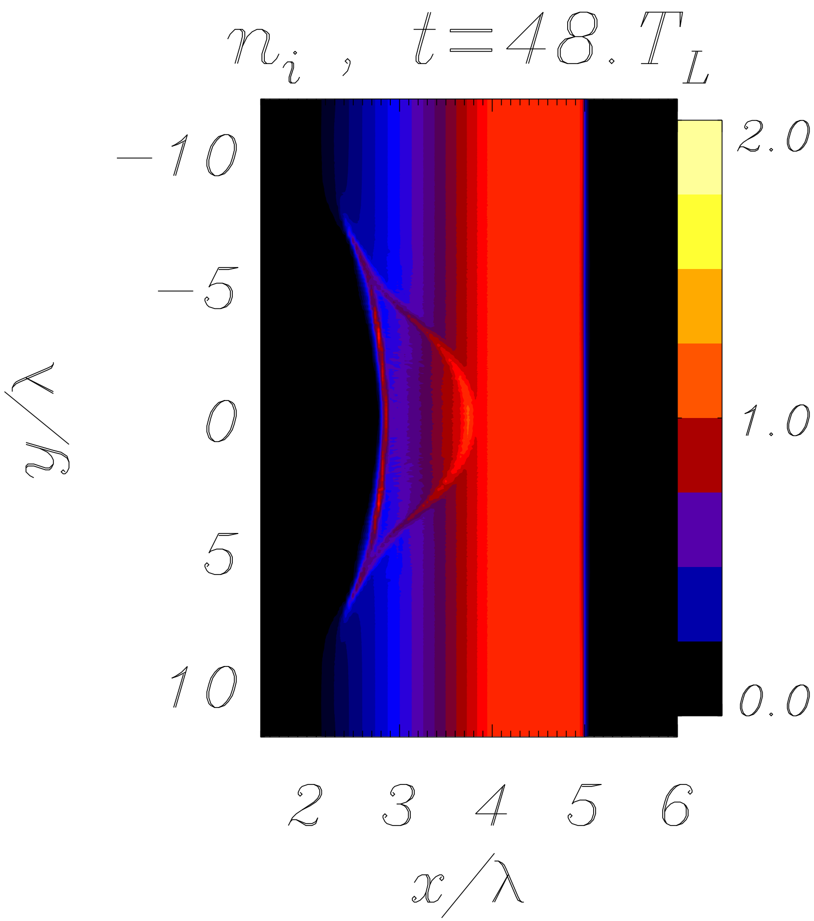

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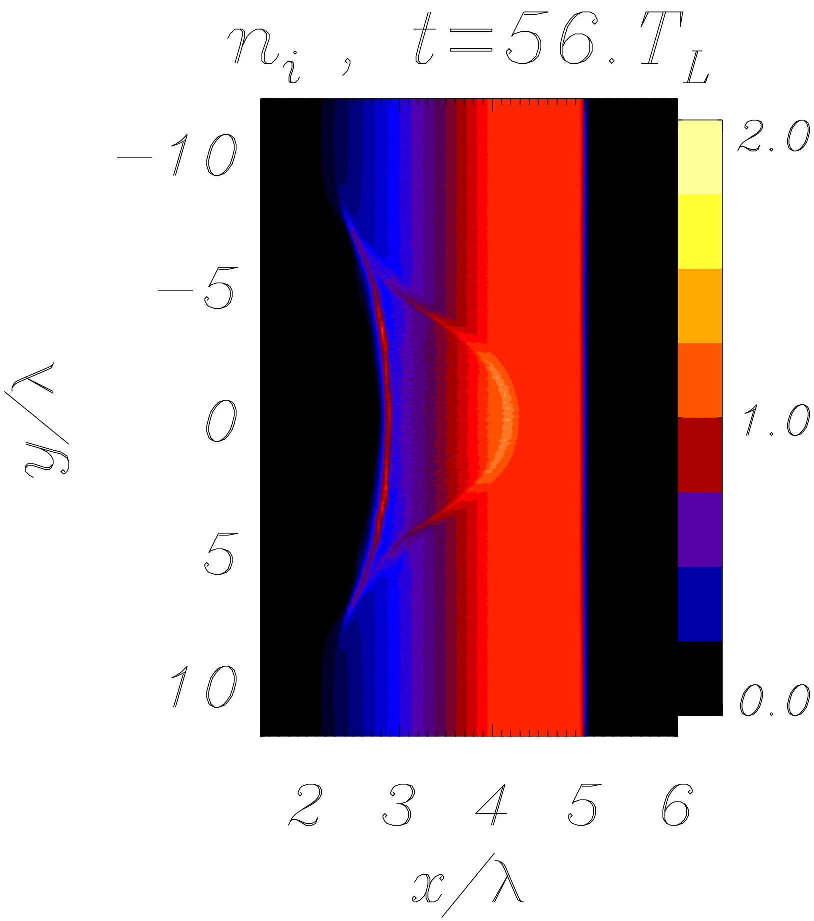

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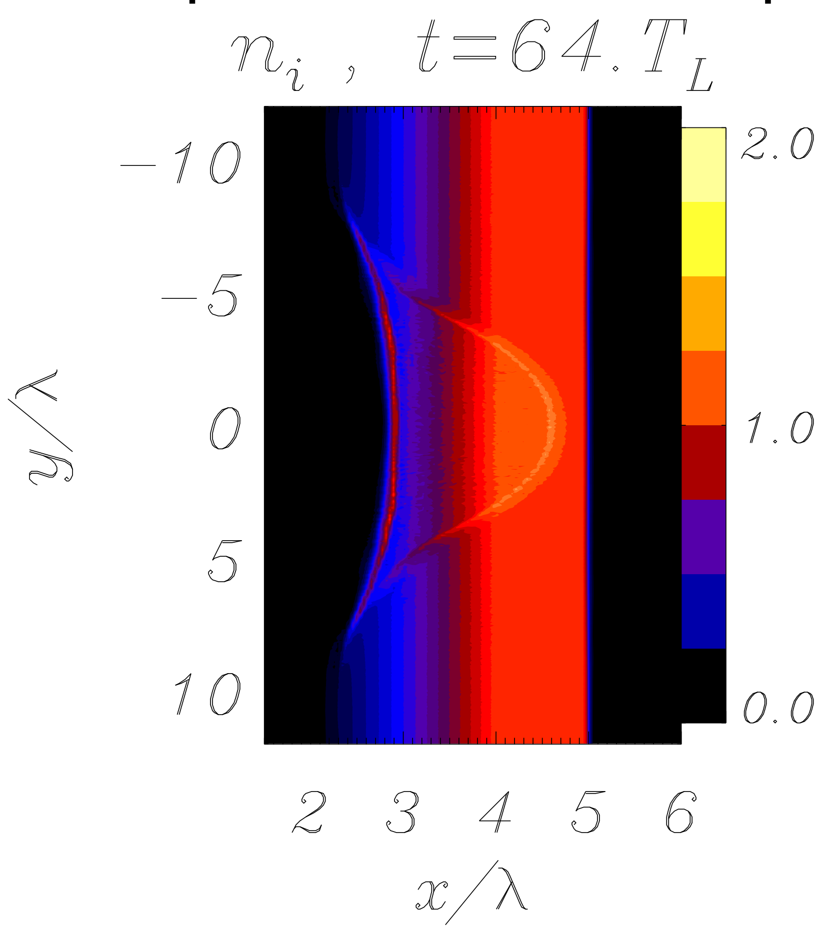

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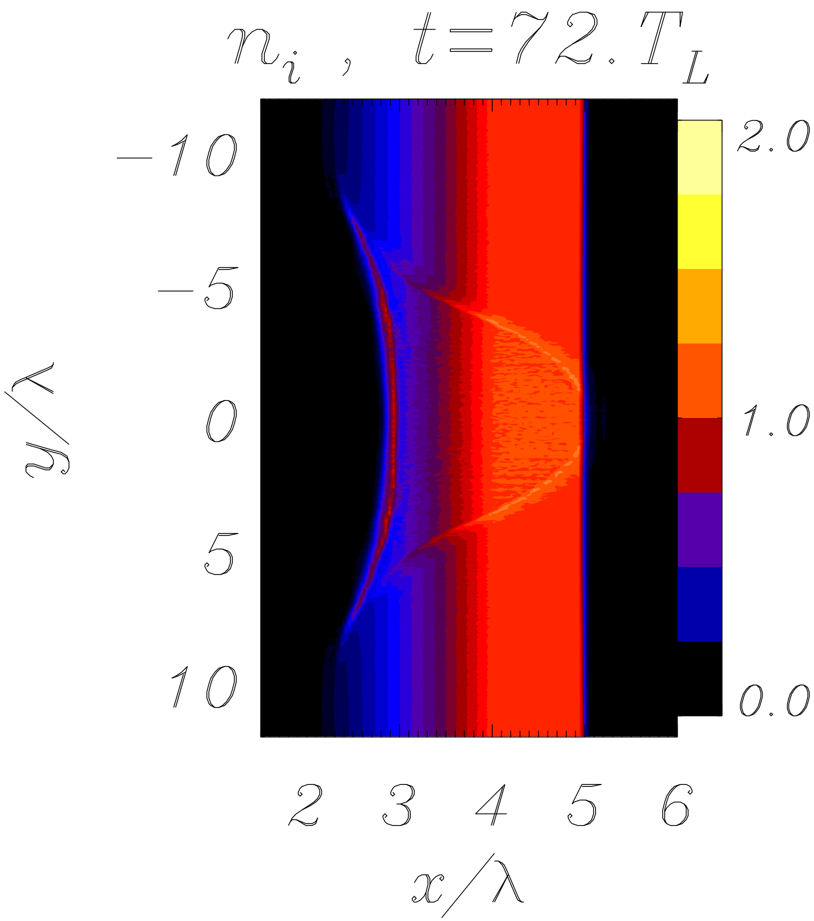

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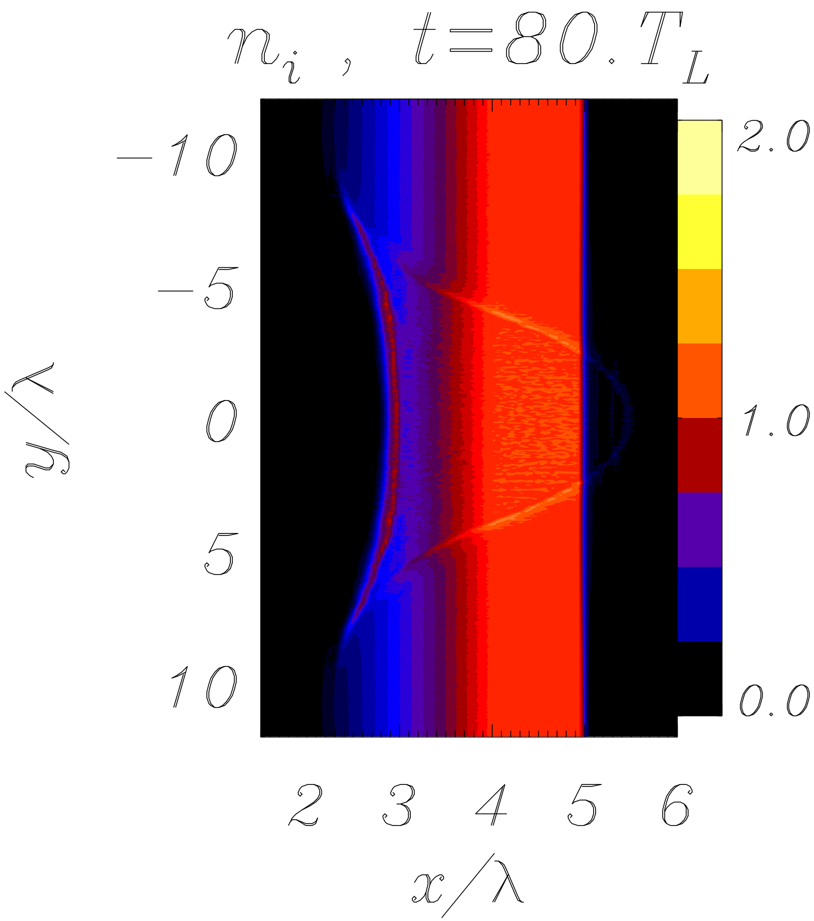

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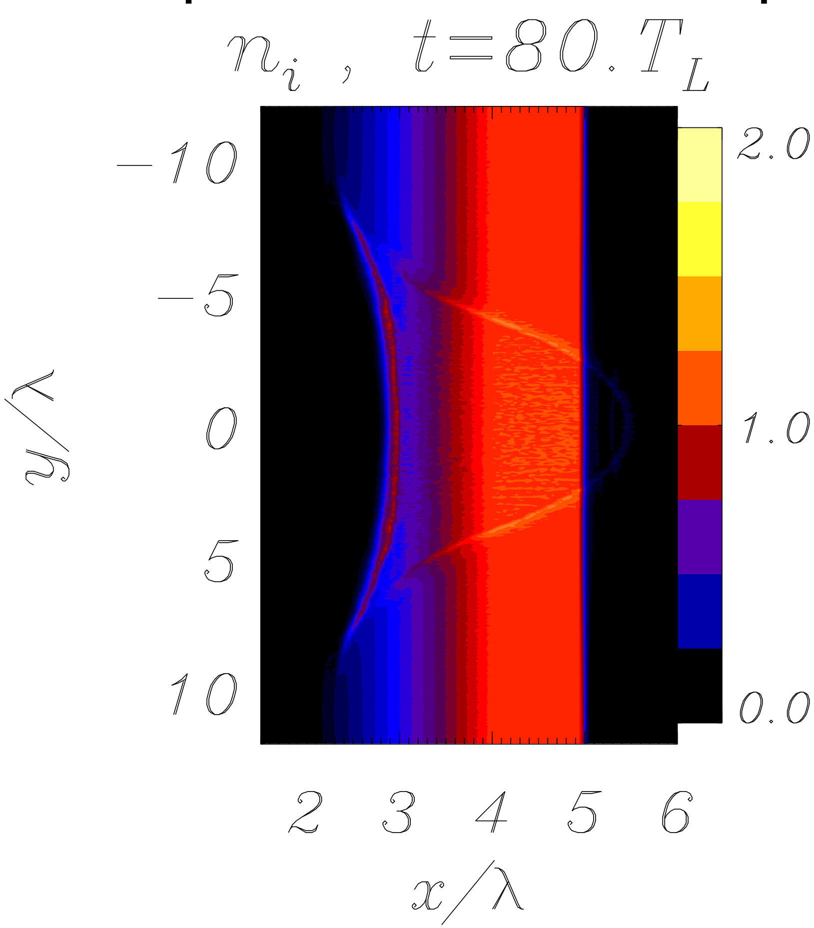

Simulation parameters ($a = 2$, $\tau = 10T_L$ and plasma profile are similar to an experiment at JAERI [Kado et al., Las. Part. Beams **24** (2006), in press] giving preliminar indications of a collimated ion beam without fast electrons (H. Daido, private communication).

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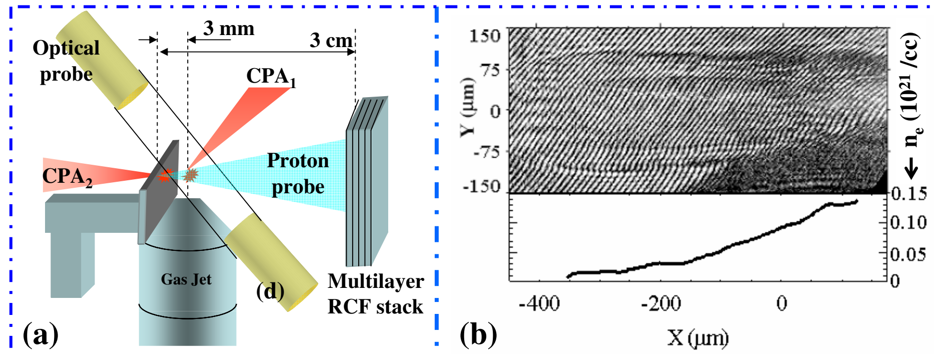

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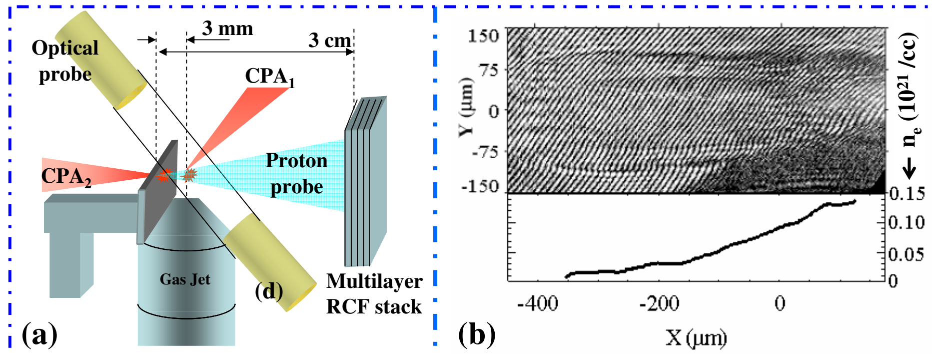

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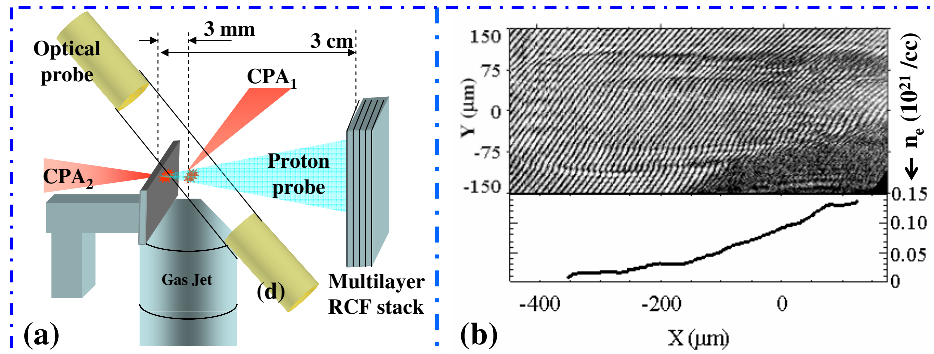

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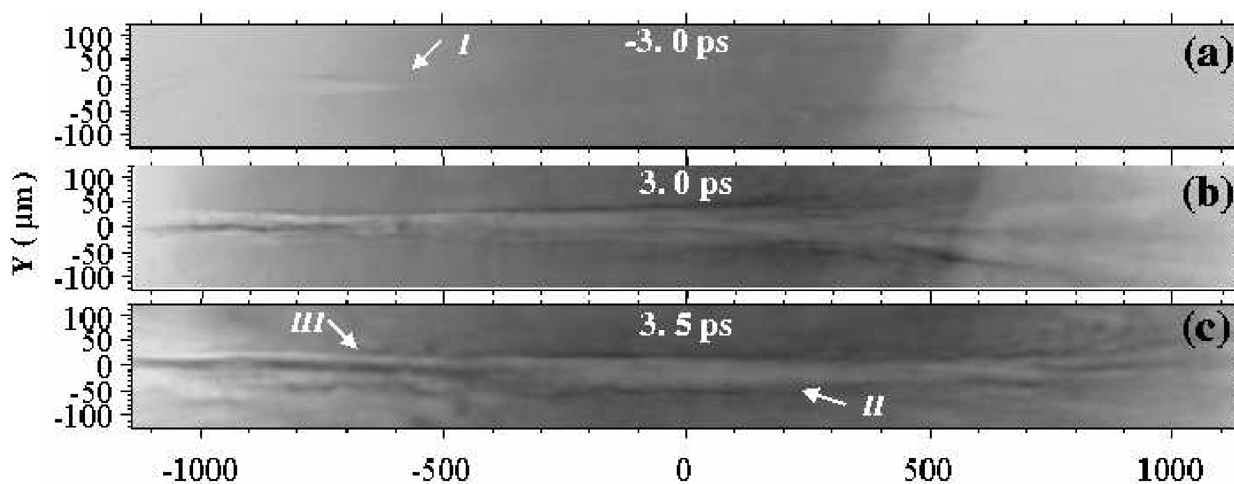

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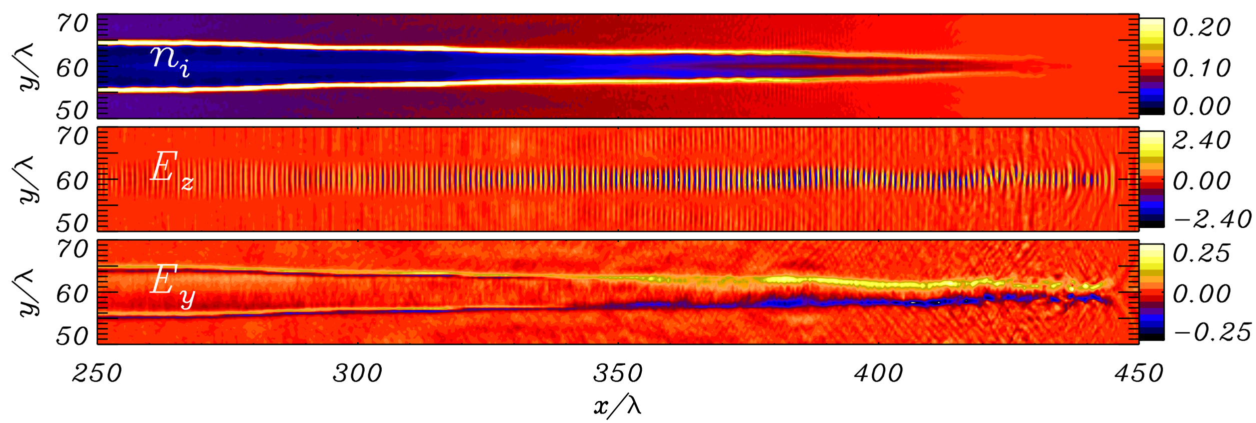

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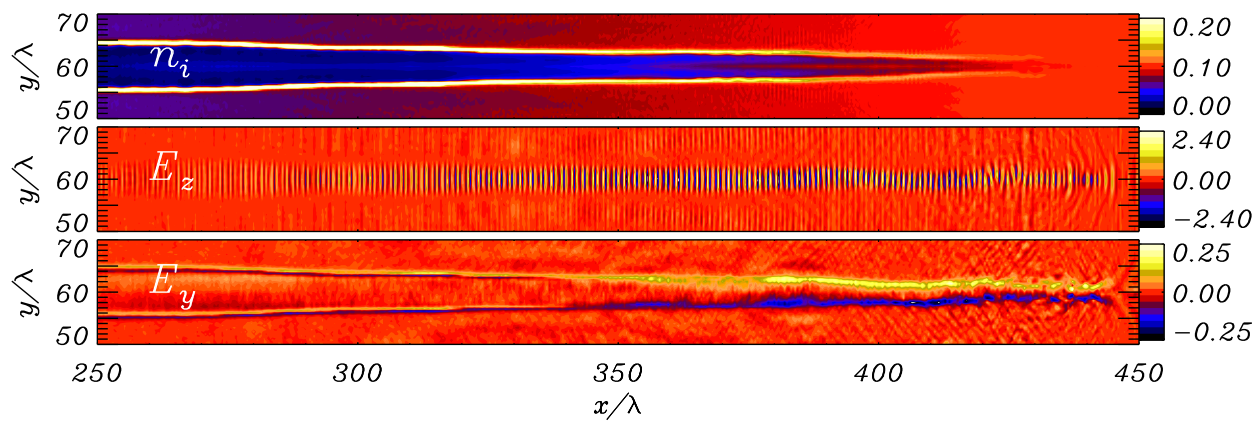

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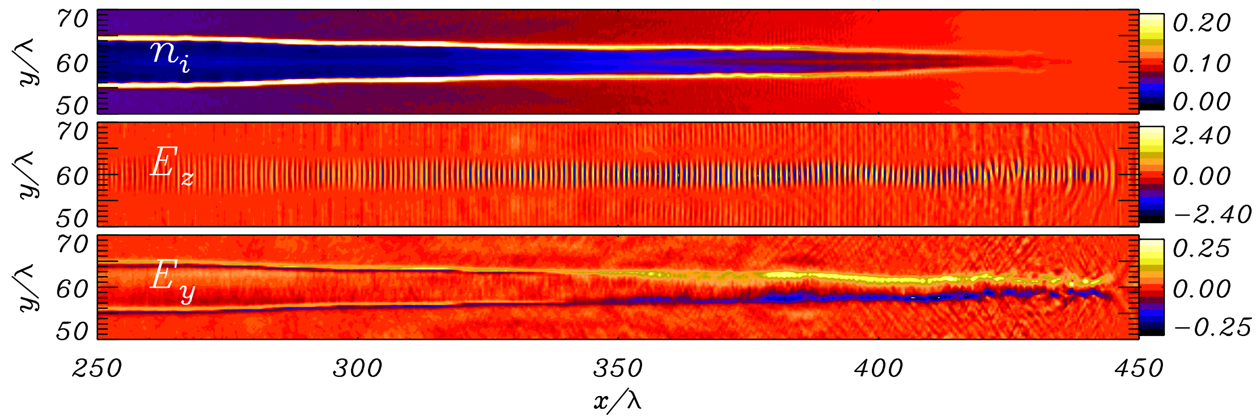

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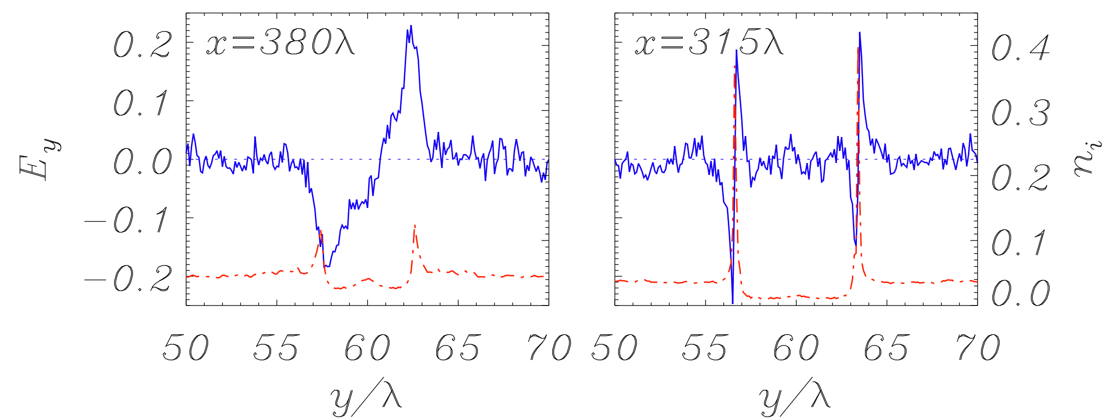

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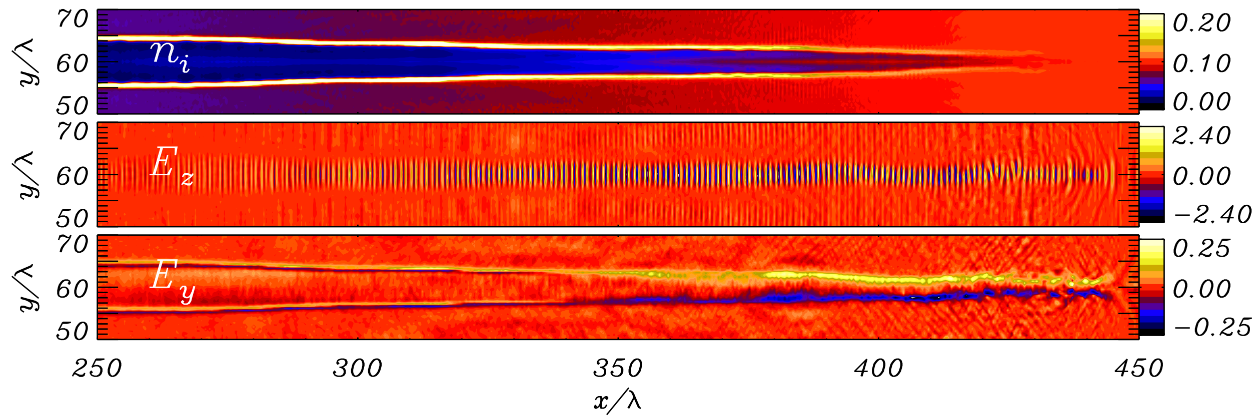

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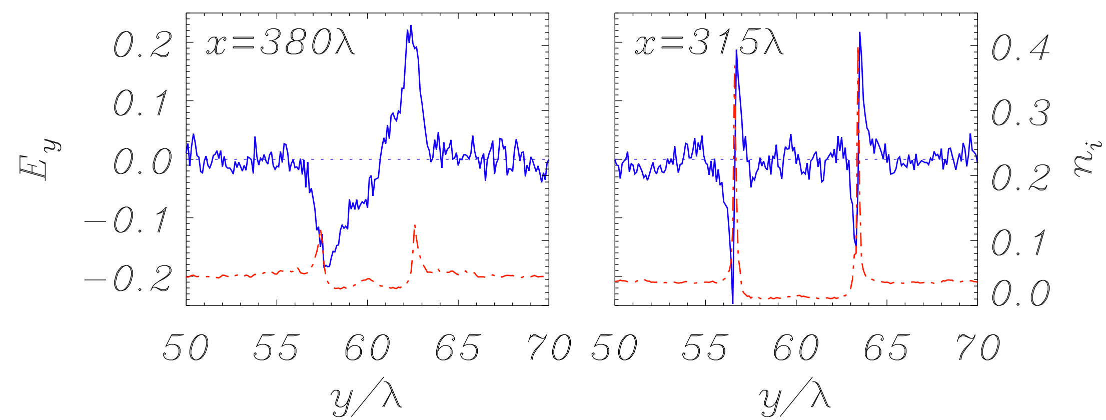

Can we describe this dynamics by a *simpler* numerical model?

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1D electrostatic PIC simulation, cylindrical geometry (r, p_r)
External driving force on electrons

$$F_p = -m_e c^2 \nabla \sqrt{1 + a^2(r,t)}\,, \qquad a^2(r,t) = a_0^2 e^{-r^2/r_0^2}$$

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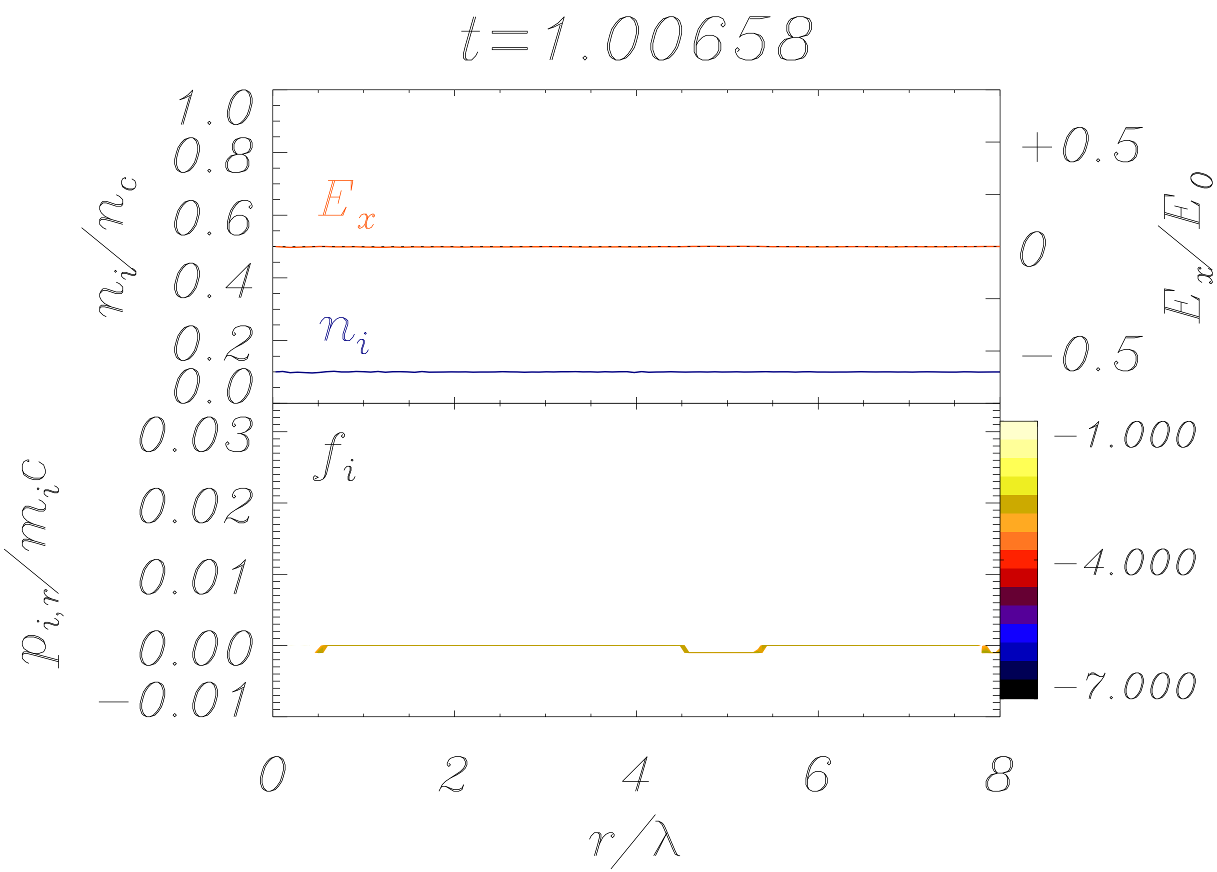

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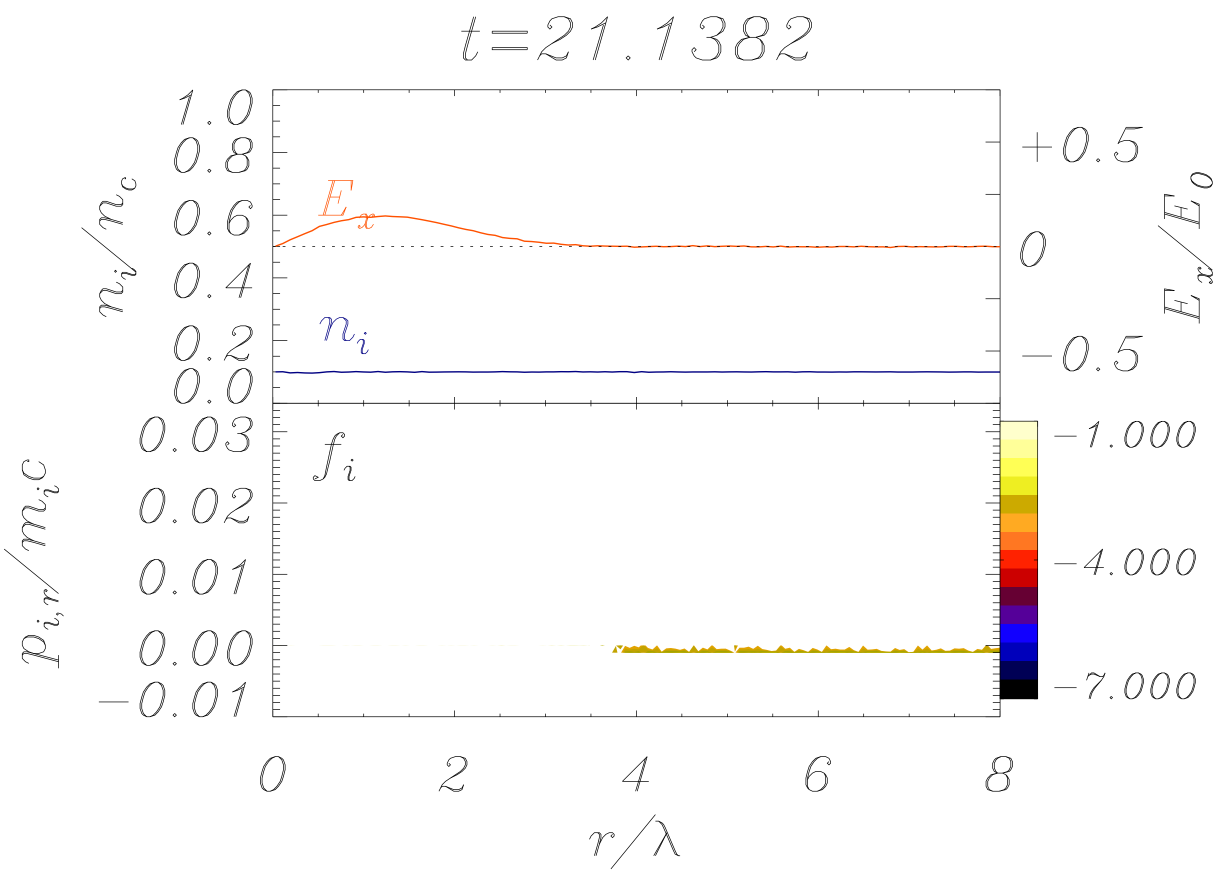

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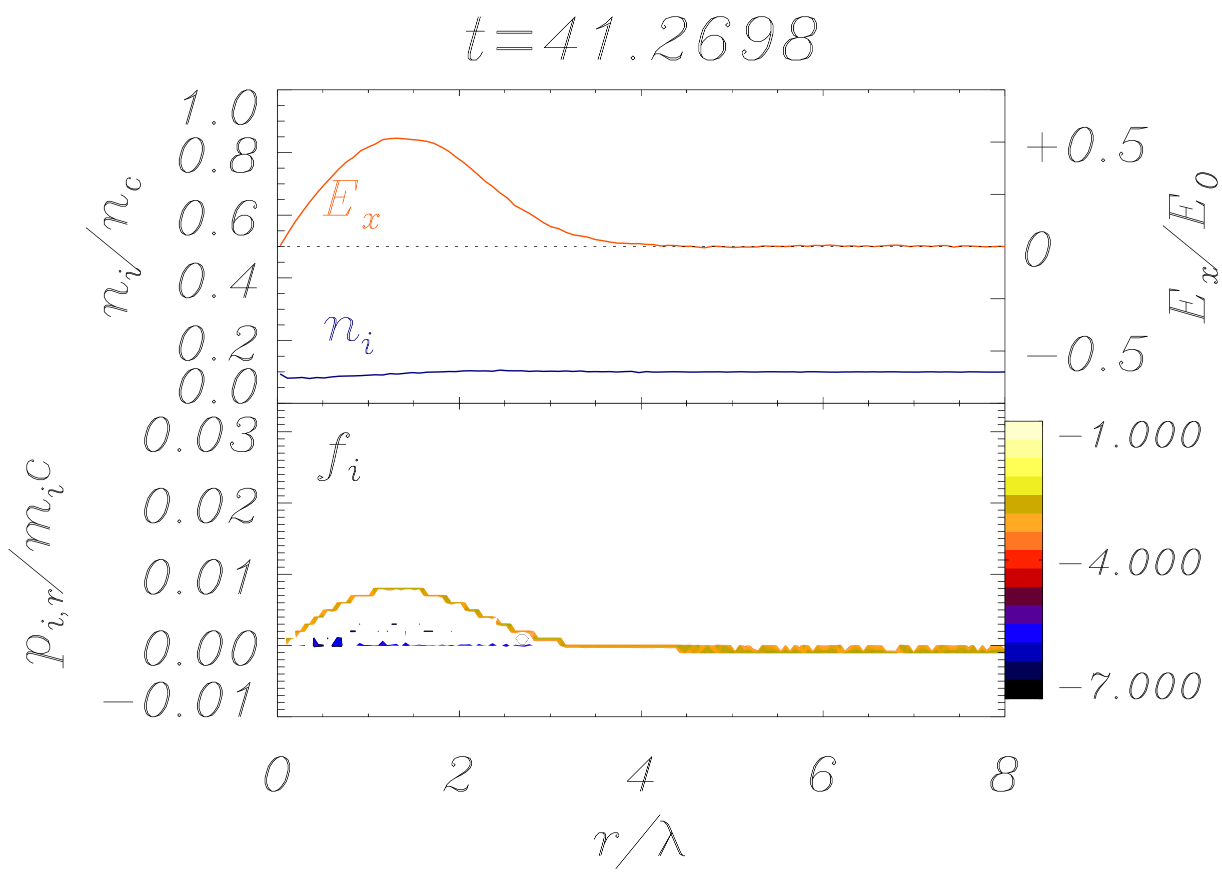

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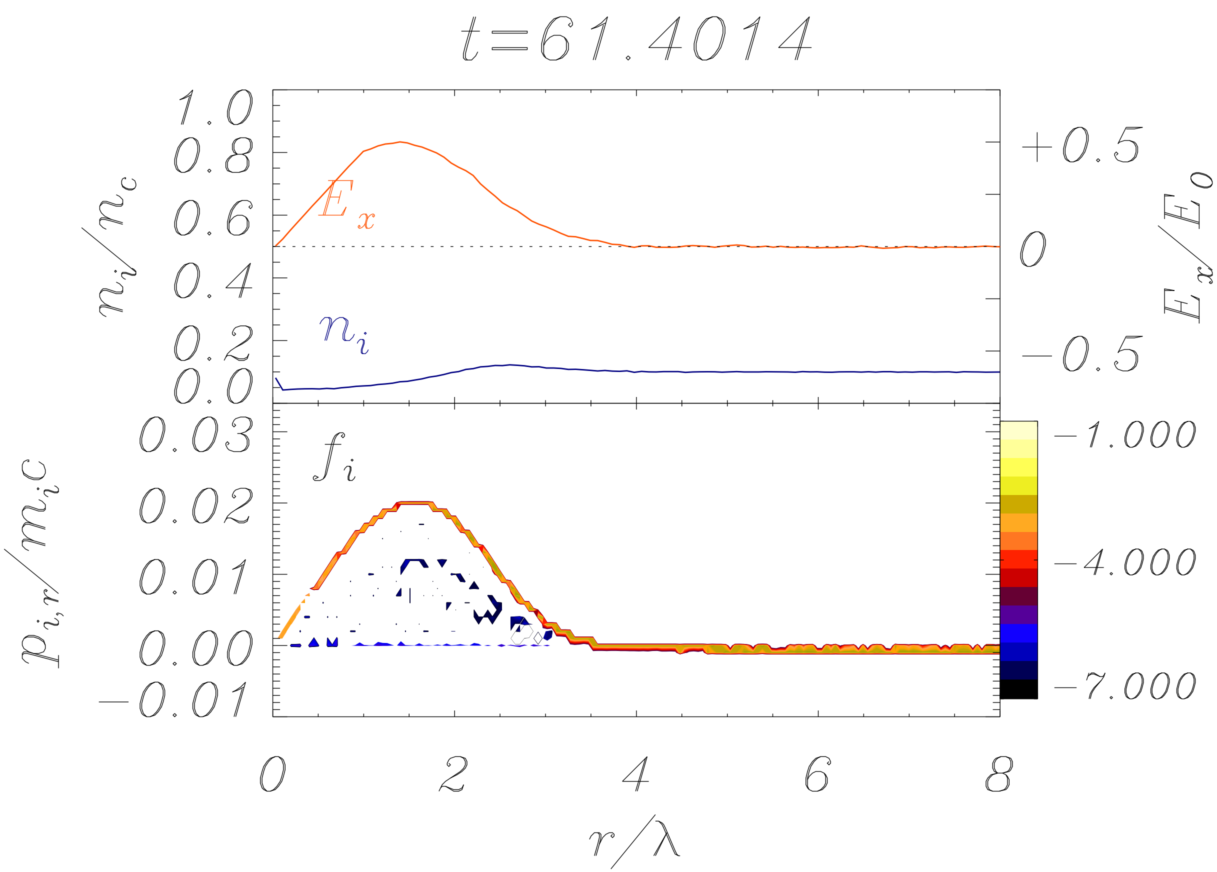

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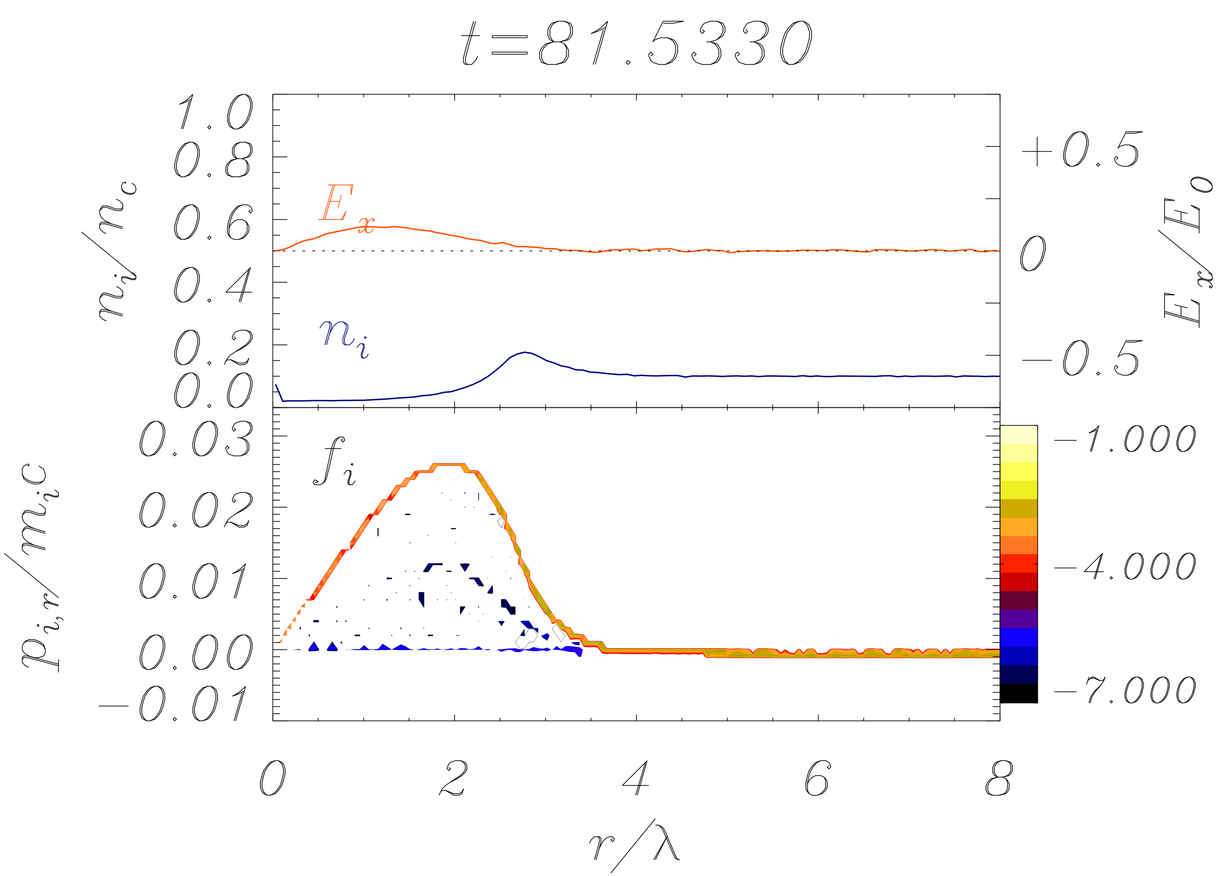

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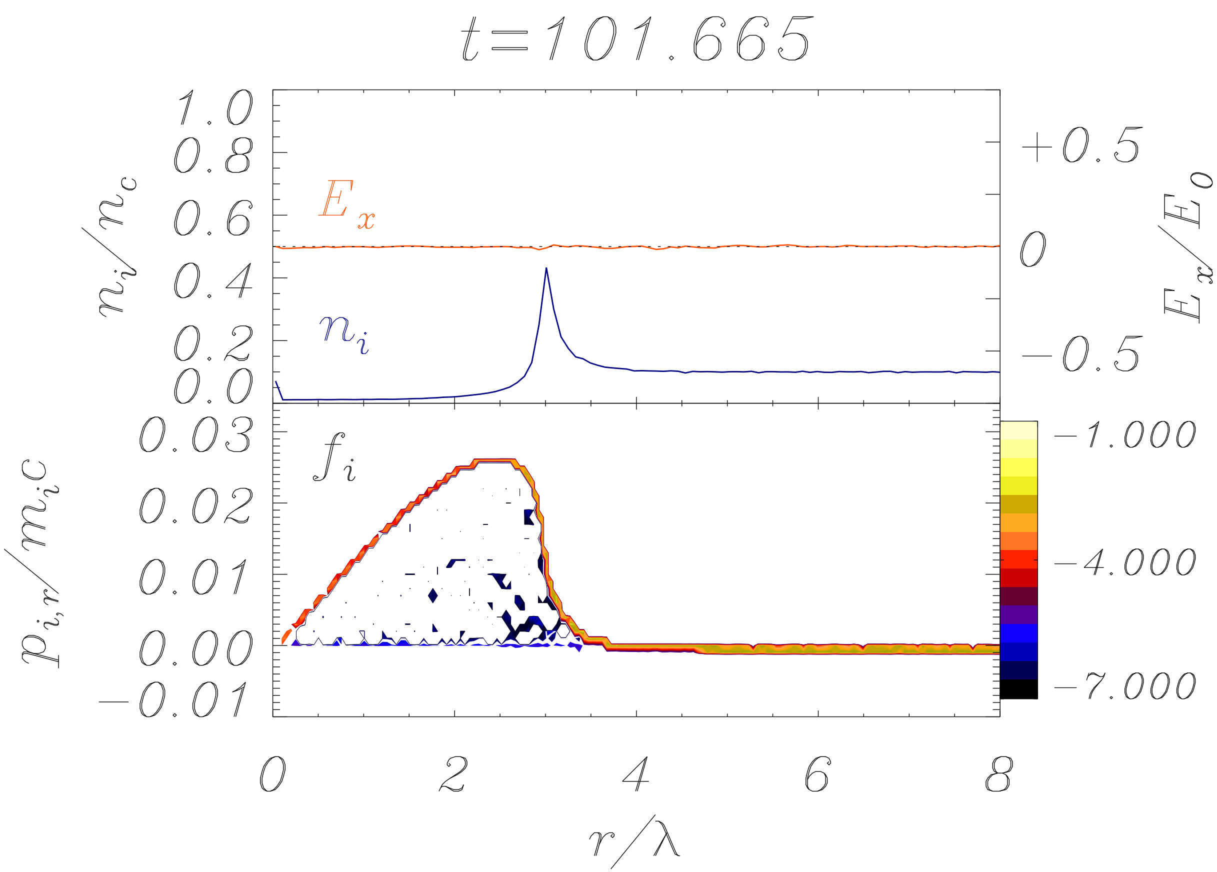

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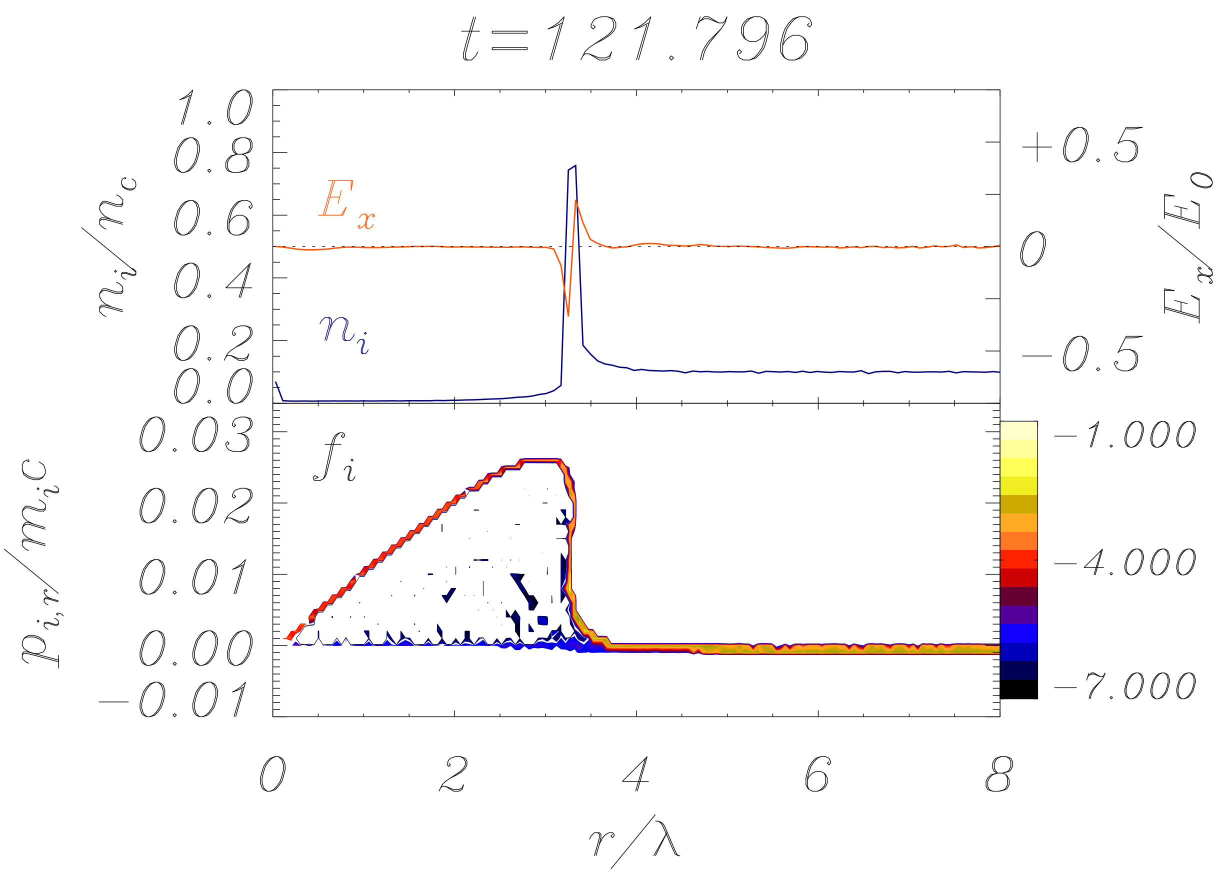

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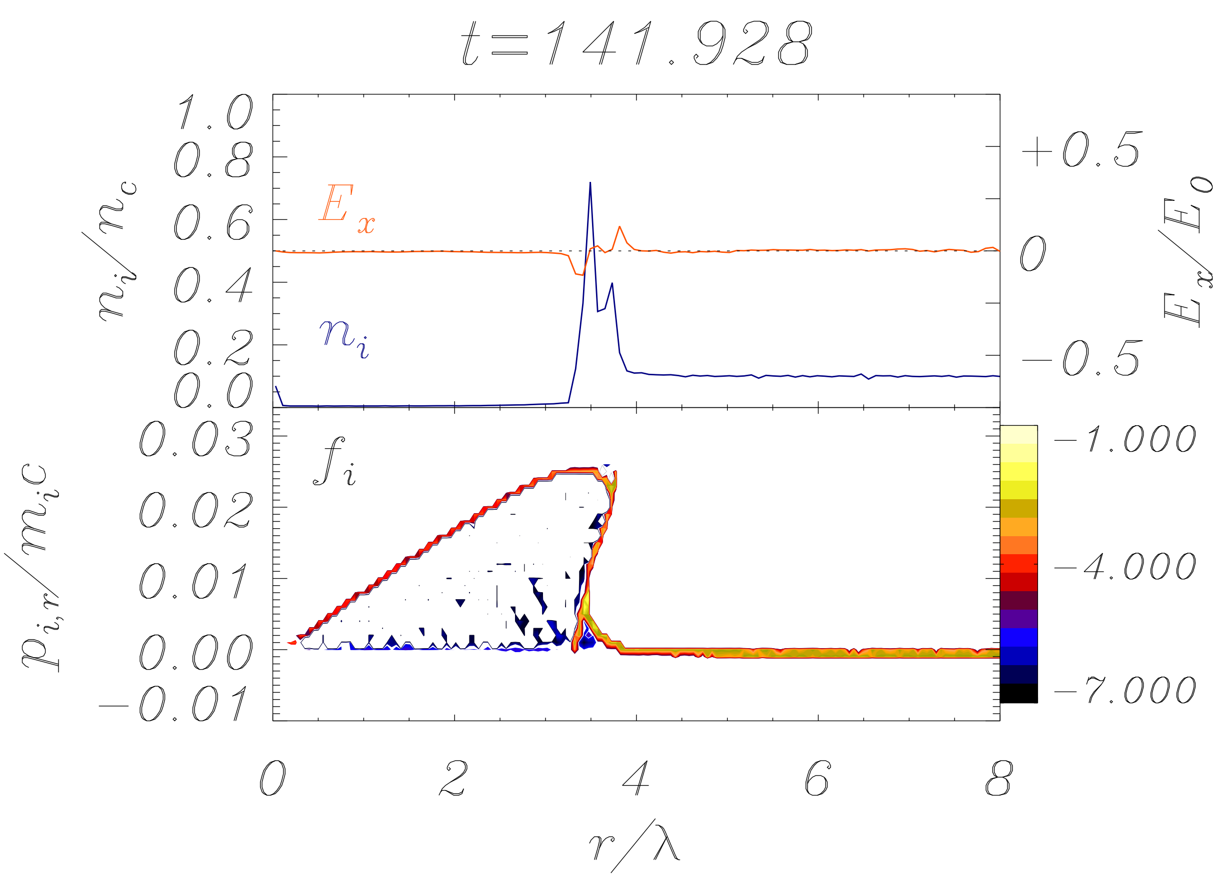

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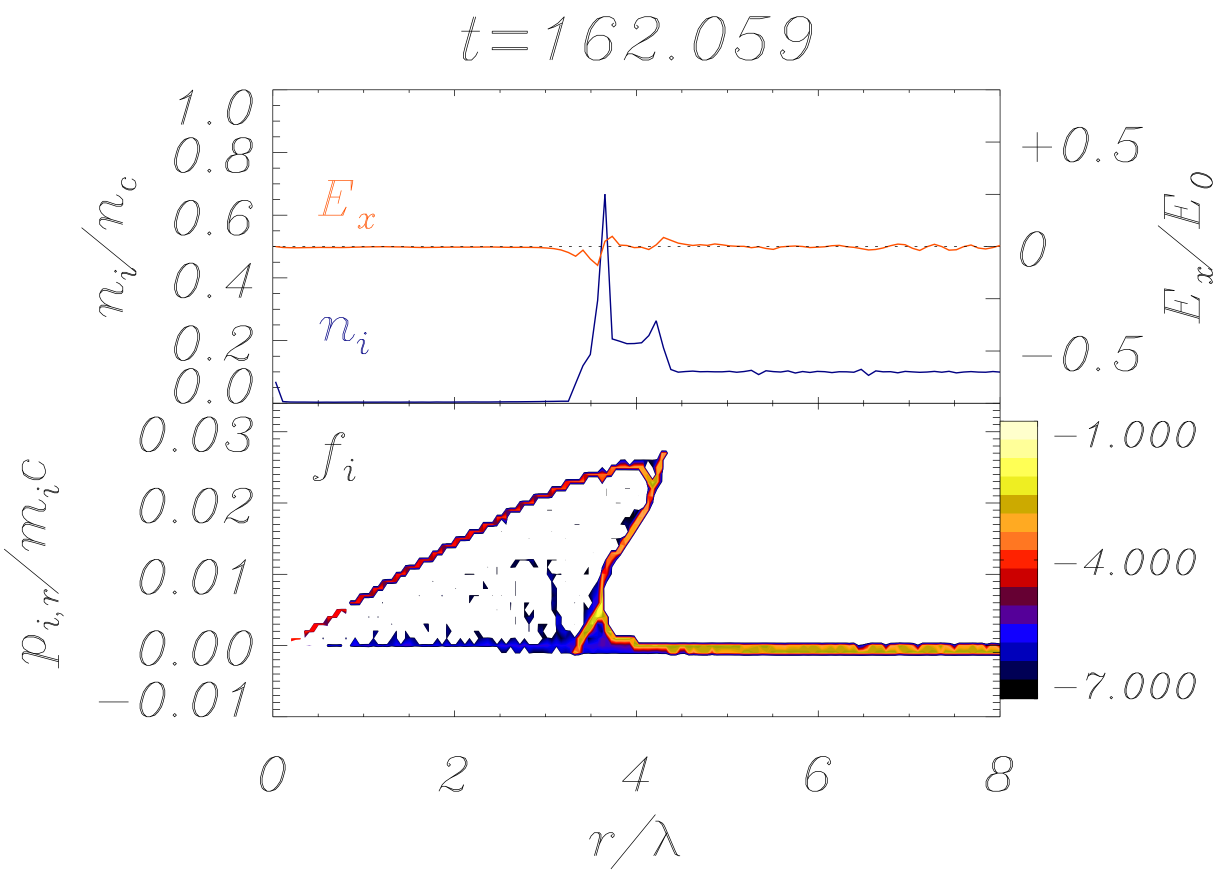

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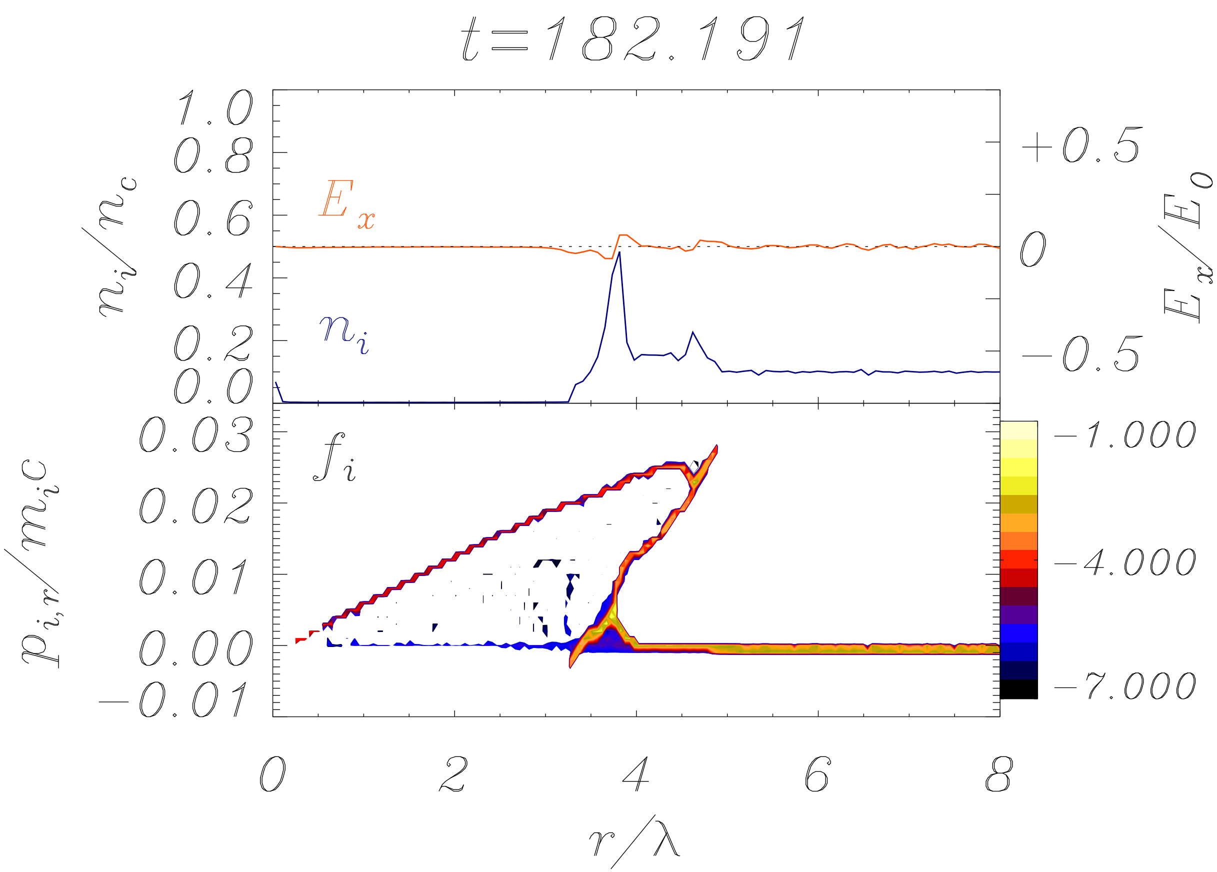

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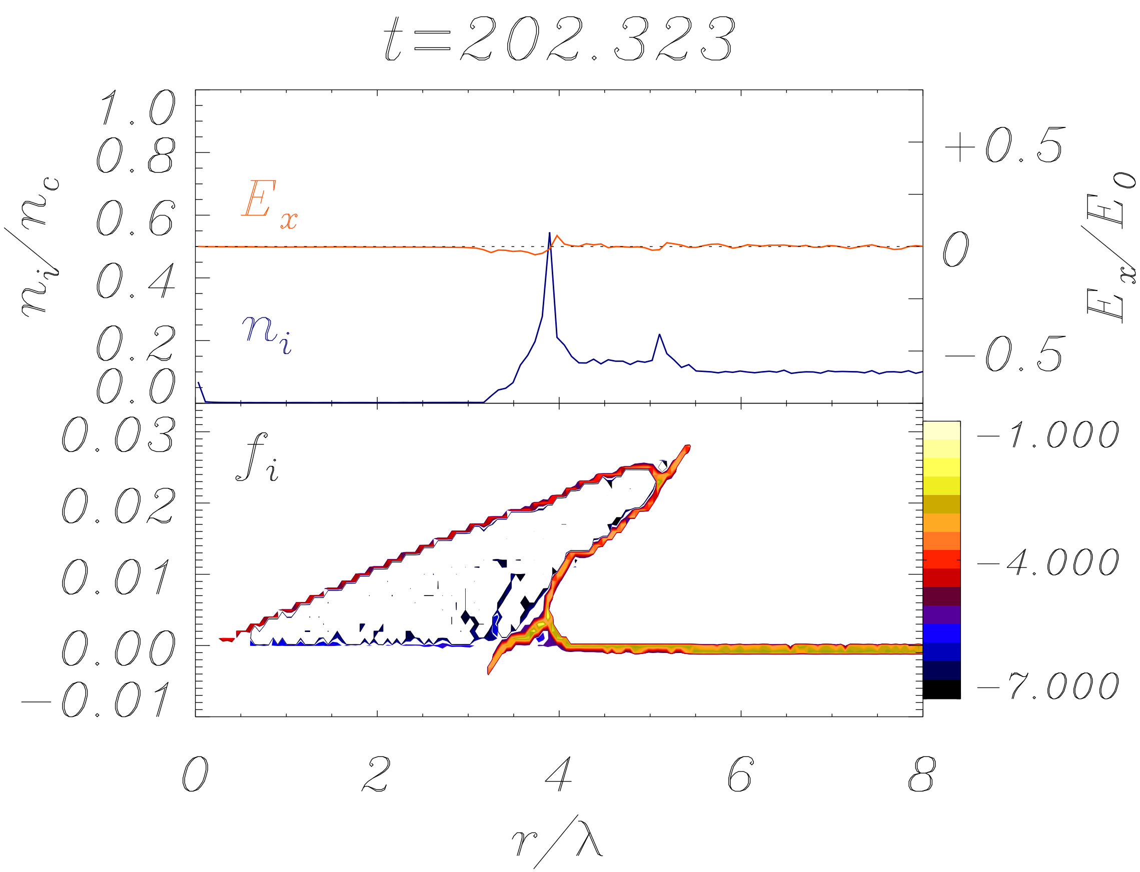

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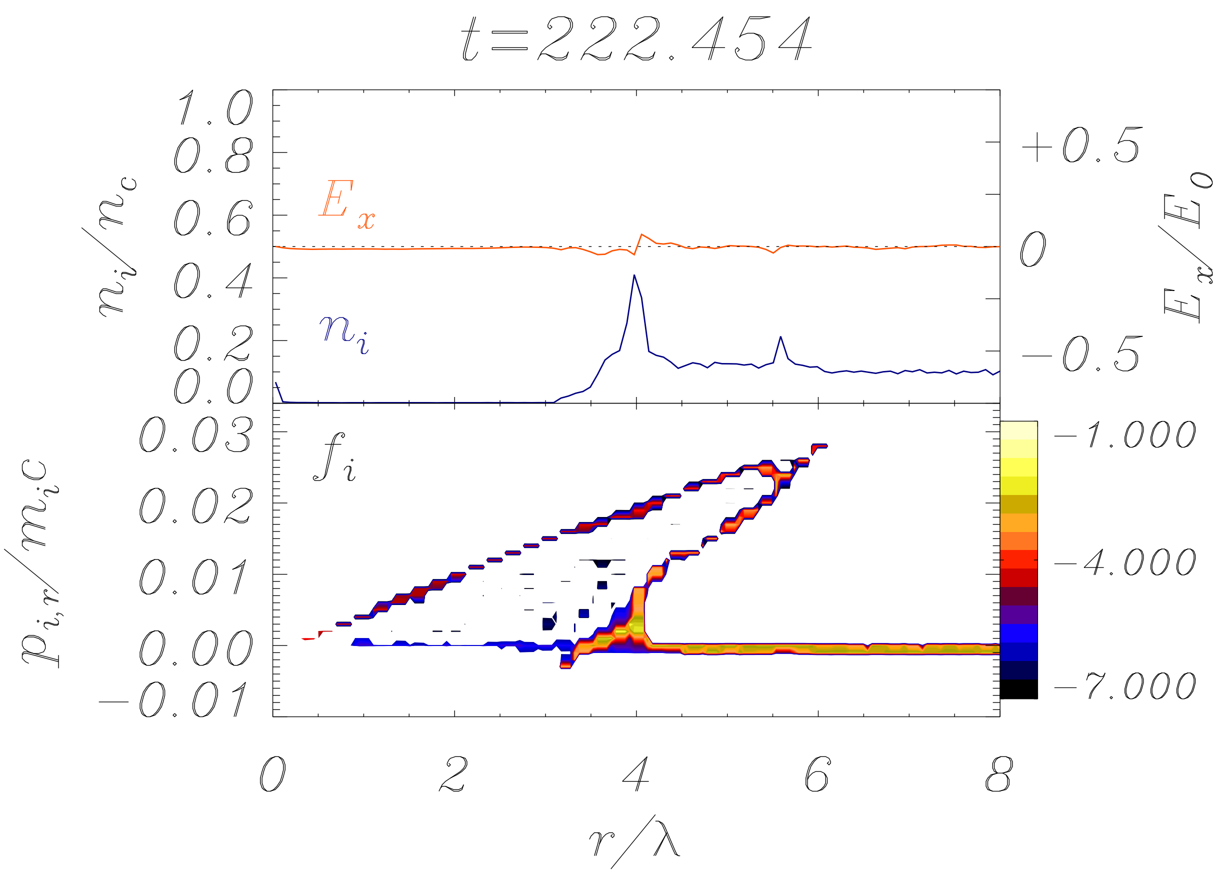

Ion dynamics is very similar to the case of planar acceleration by the circularly polarized pulse: ions pile up, density "breaks", and a "fast" bunch is produced.

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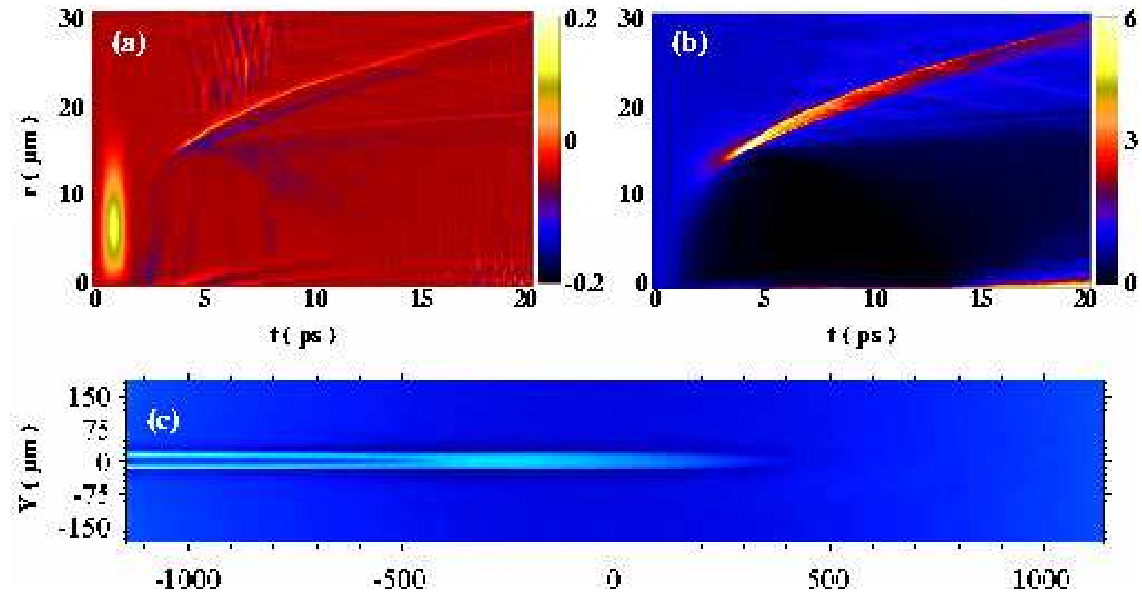

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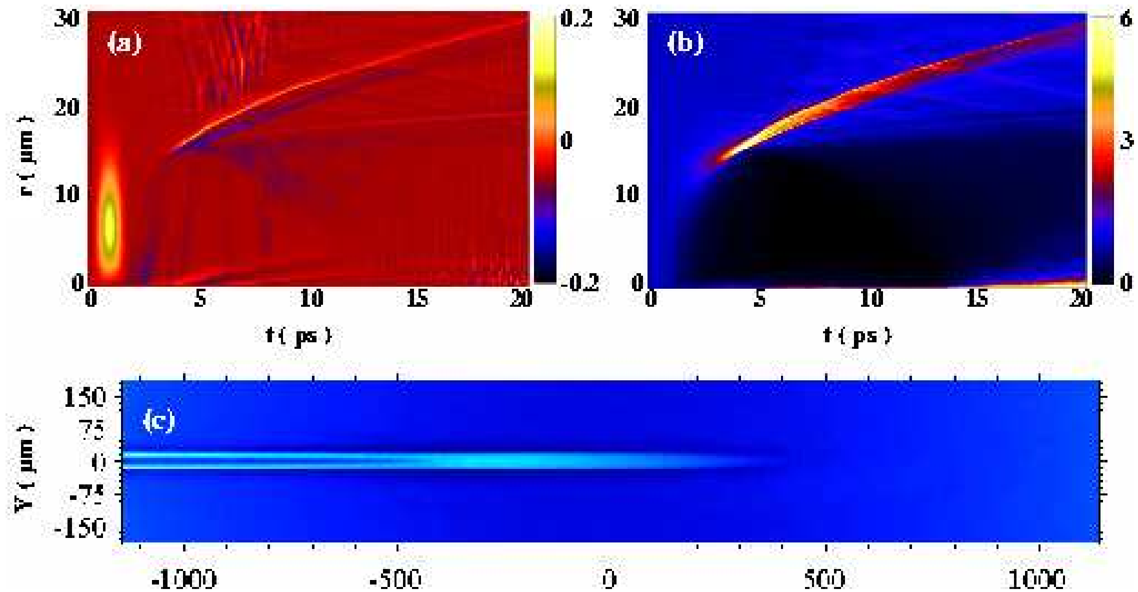

The ion spectrum was not measured in the experiment, but in similar conditions evidence of a tail of MeV ions was provided:
see e.g. Sarkisov et al, JETP **66**, 828 (1997); Fritzler et al, PRL **89**, 165004 (2002).

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Are these features useful for some application?

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$\Rightarrow$ One may obtain a significant neutron yield within the bunch duration.

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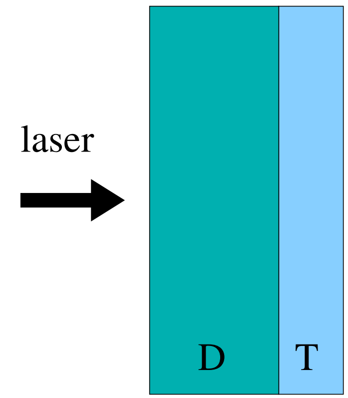
$\mathsf{D} + \mathsf{T} \rightarrow \alpha + \mathsf{n}\ (14\ \mathsf{MeV})$

Double layer target:



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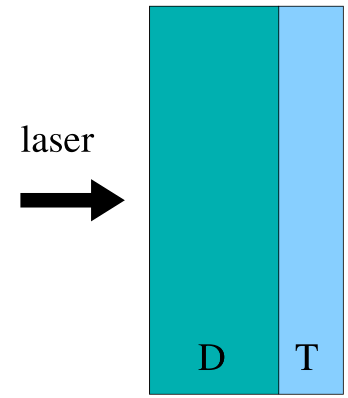

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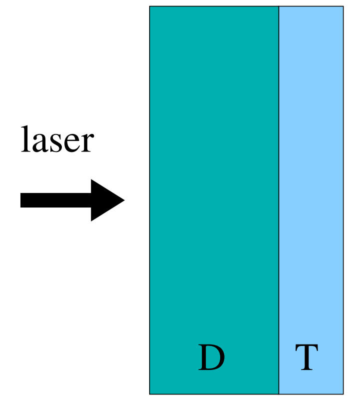

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1D PIC simulation:
$> 10^6$ neutrons/Joule
in $\tau_n \sim 2$ fs
at $I = 10^{19}$ W/cm^2,
$\tau_L = 15$ fs

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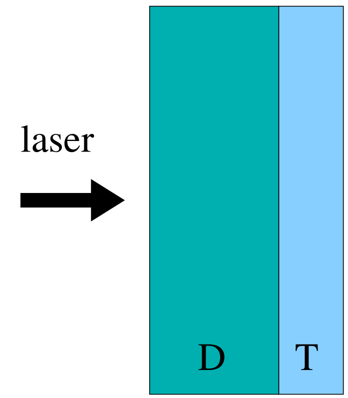

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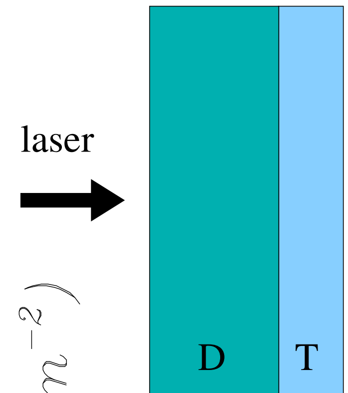

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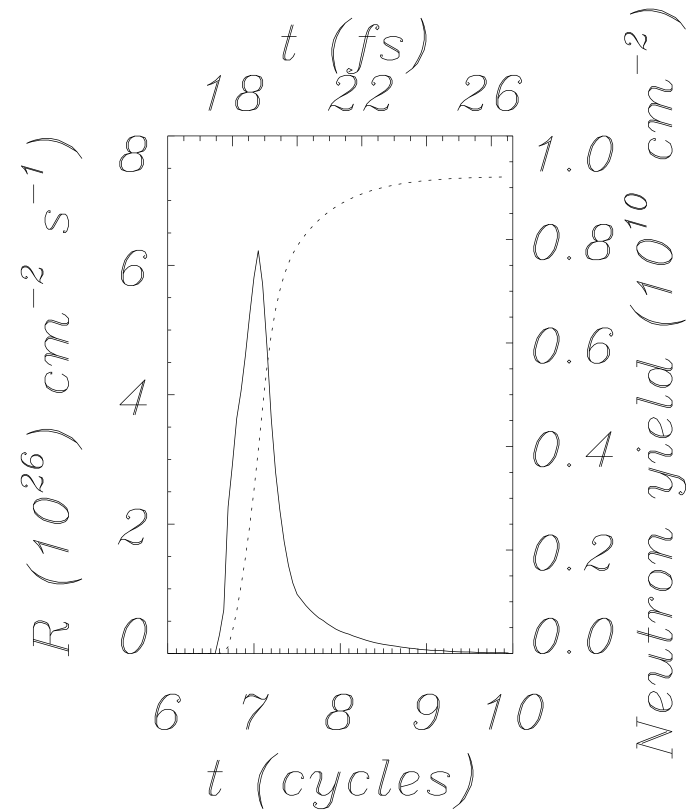

D-D, colliding bunches scheme

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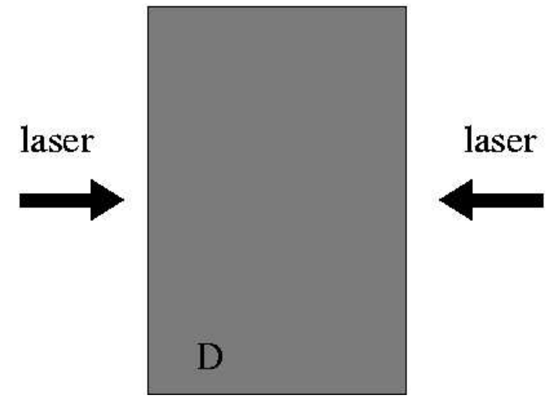
Optimal thickness $\ell = 2l_s$



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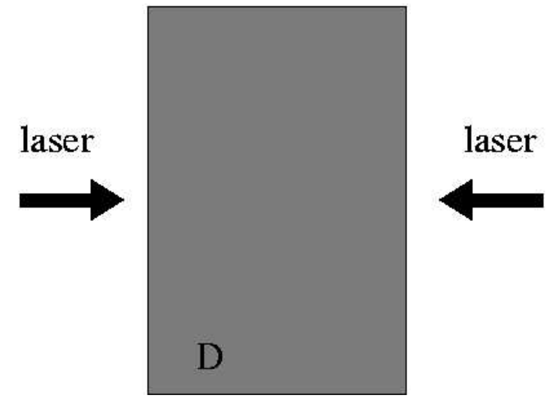
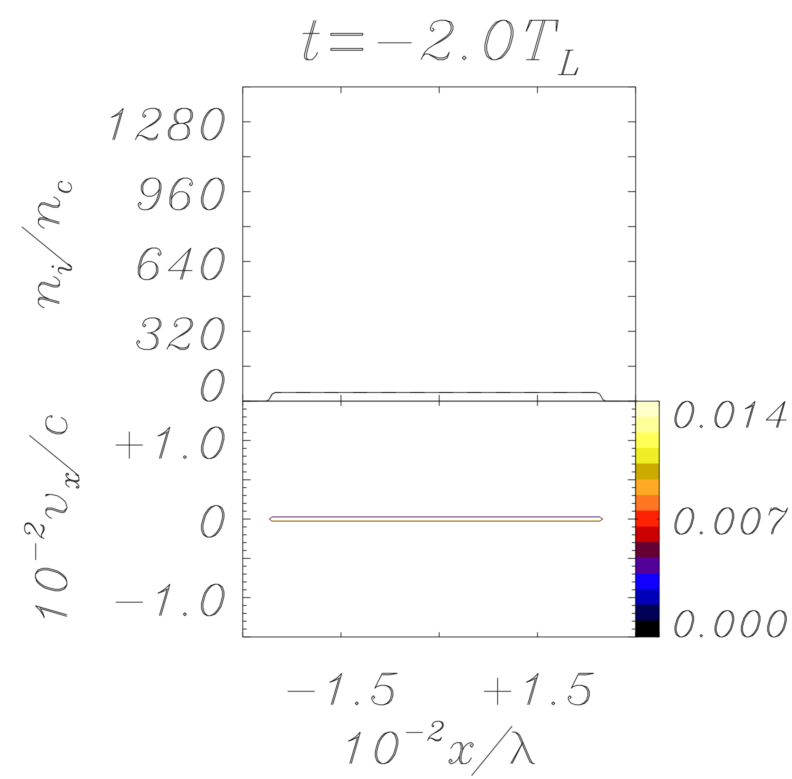


Dynamics of colliding bunches from PIC simulation:



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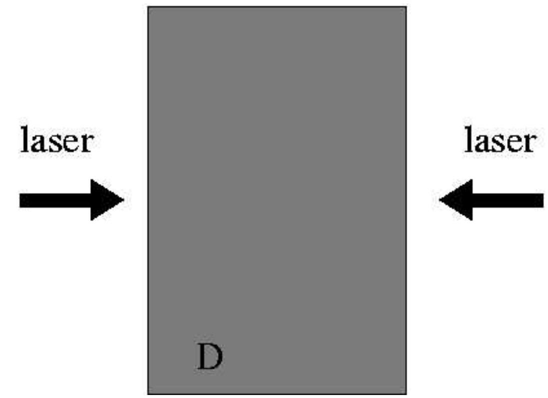

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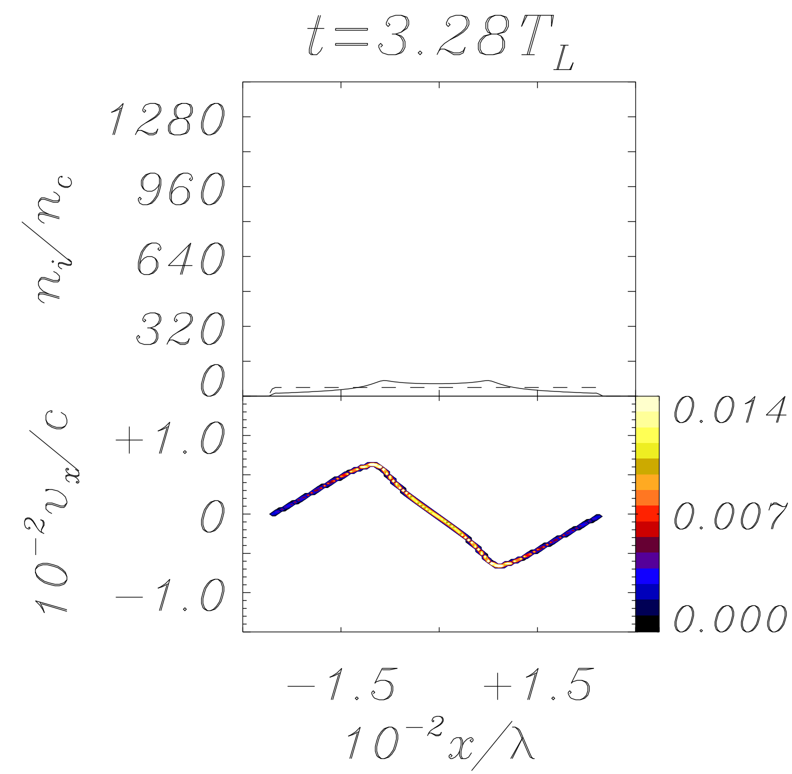

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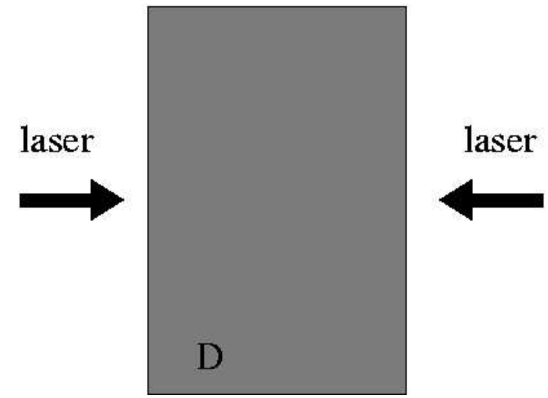

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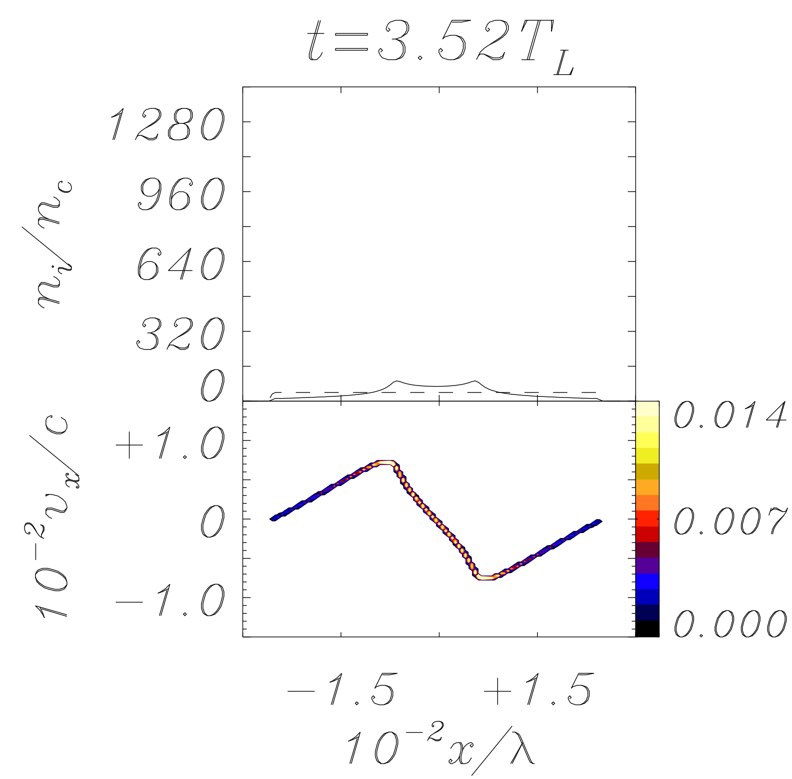

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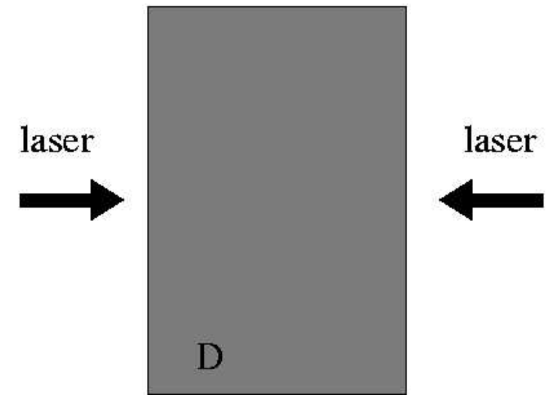

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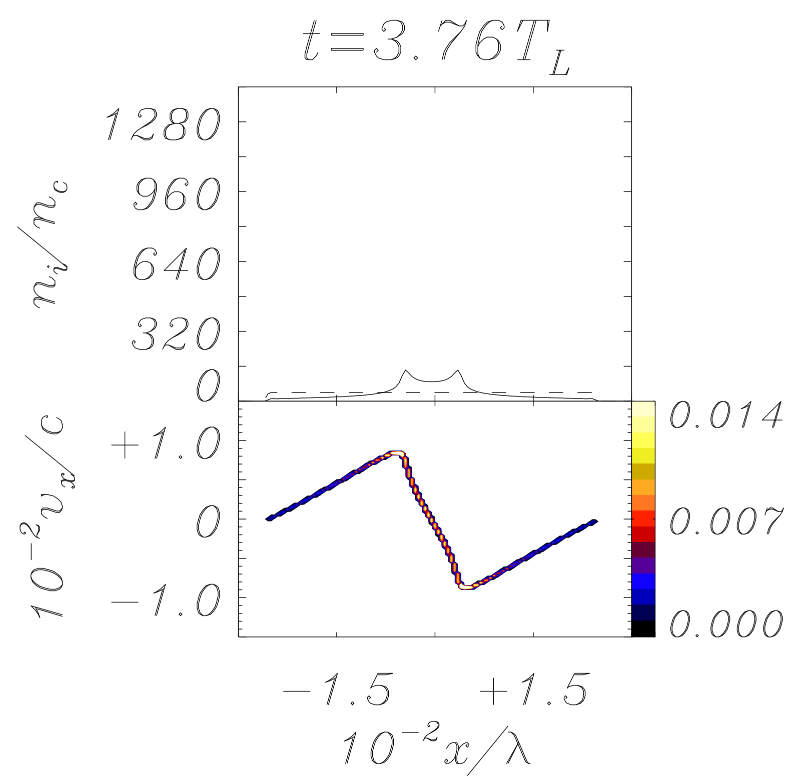

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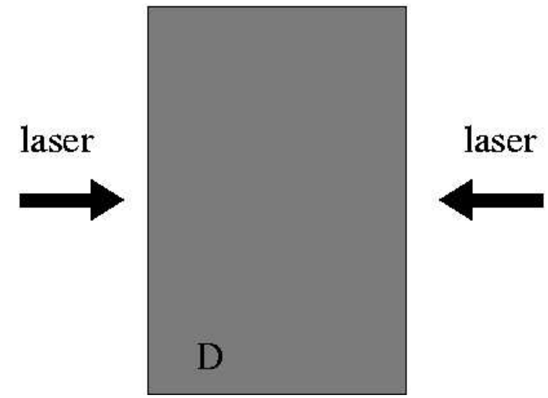

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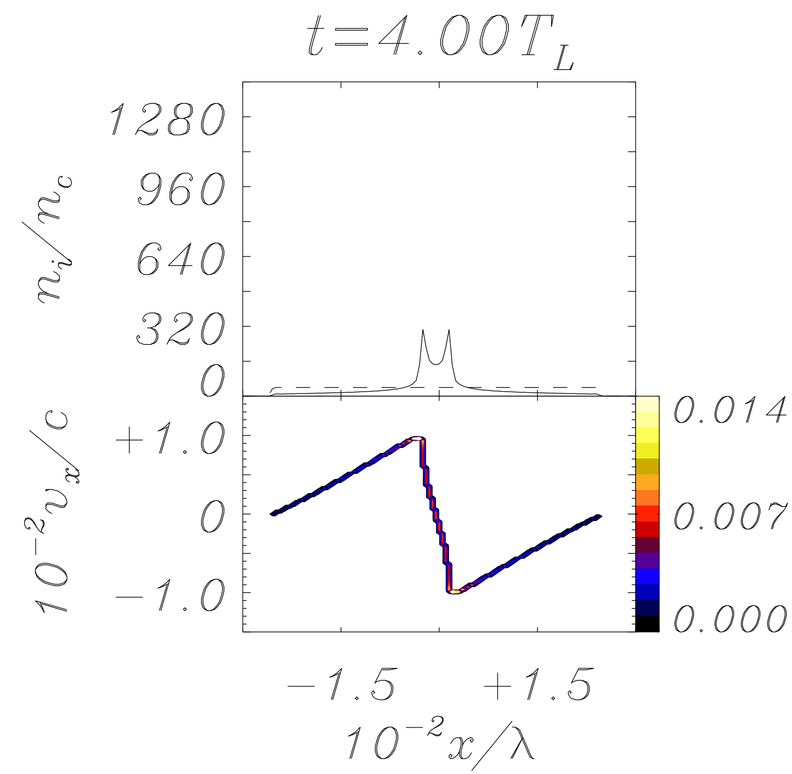

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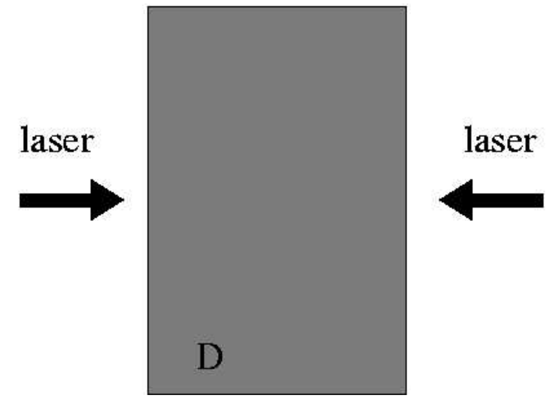

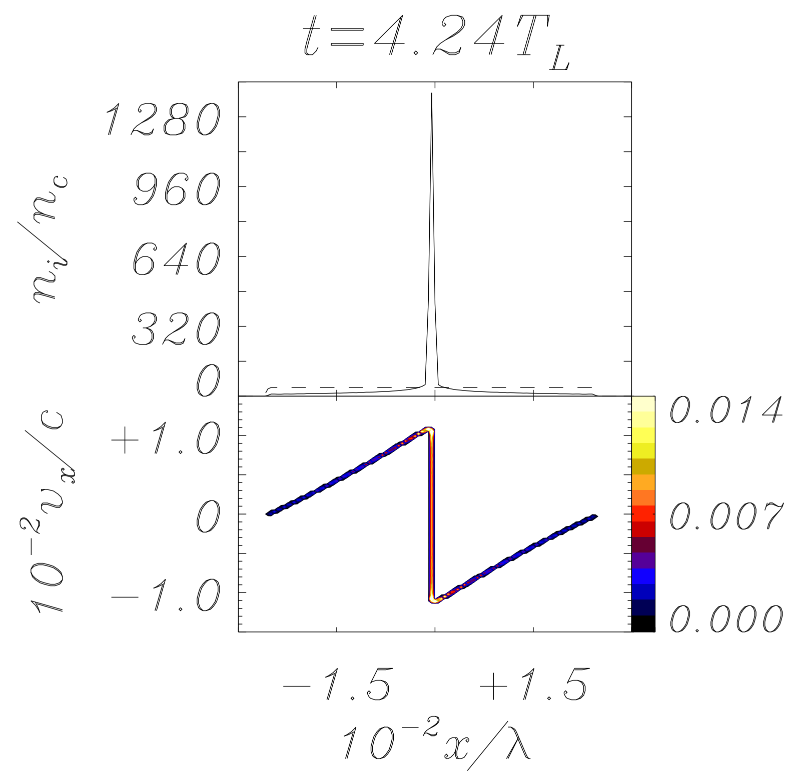

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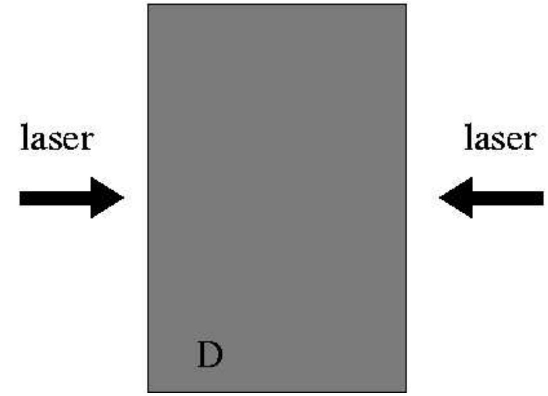

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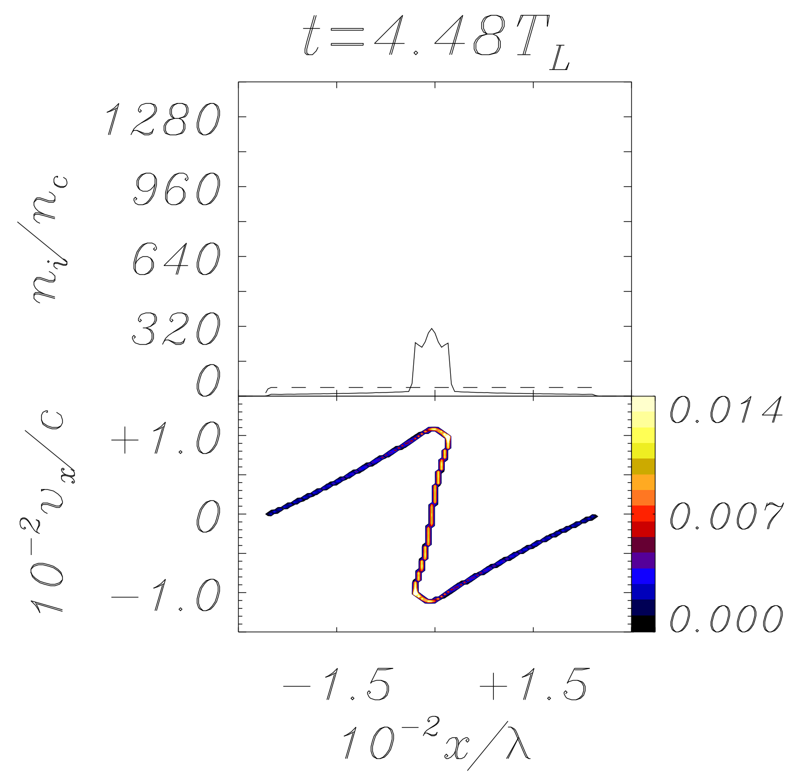

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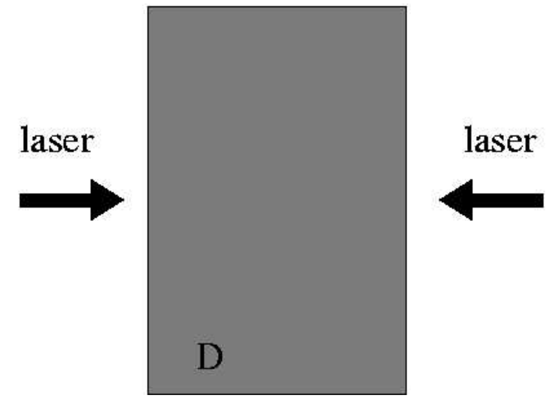

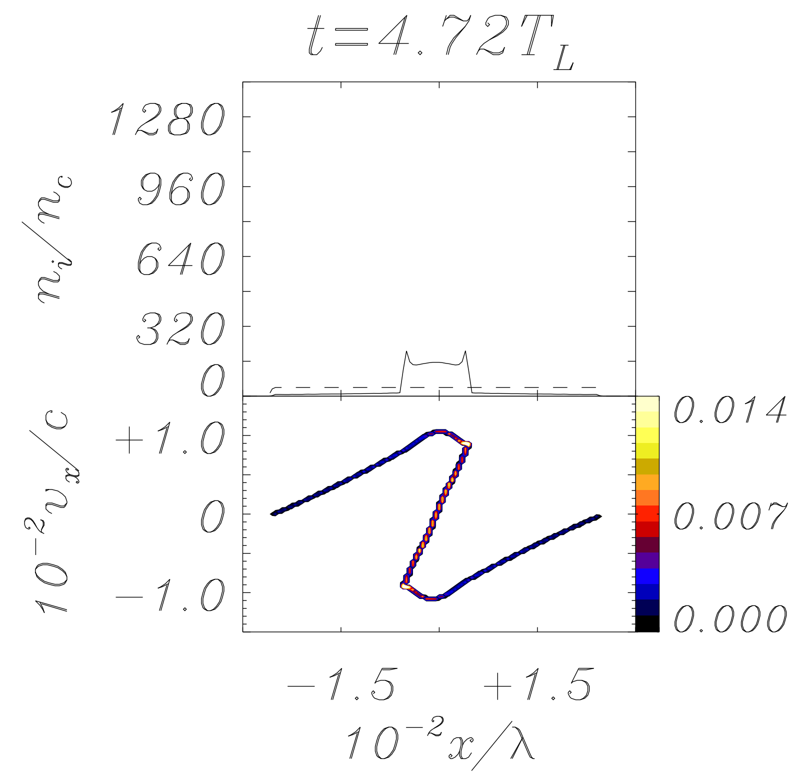

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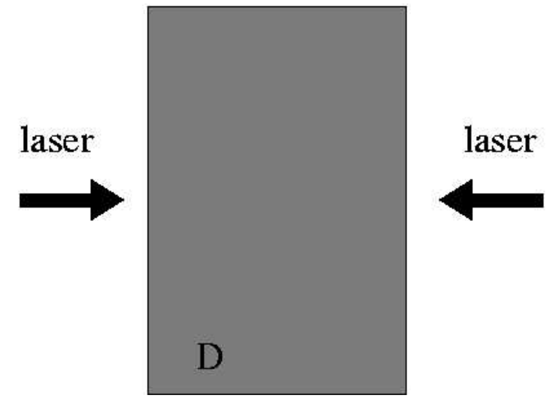

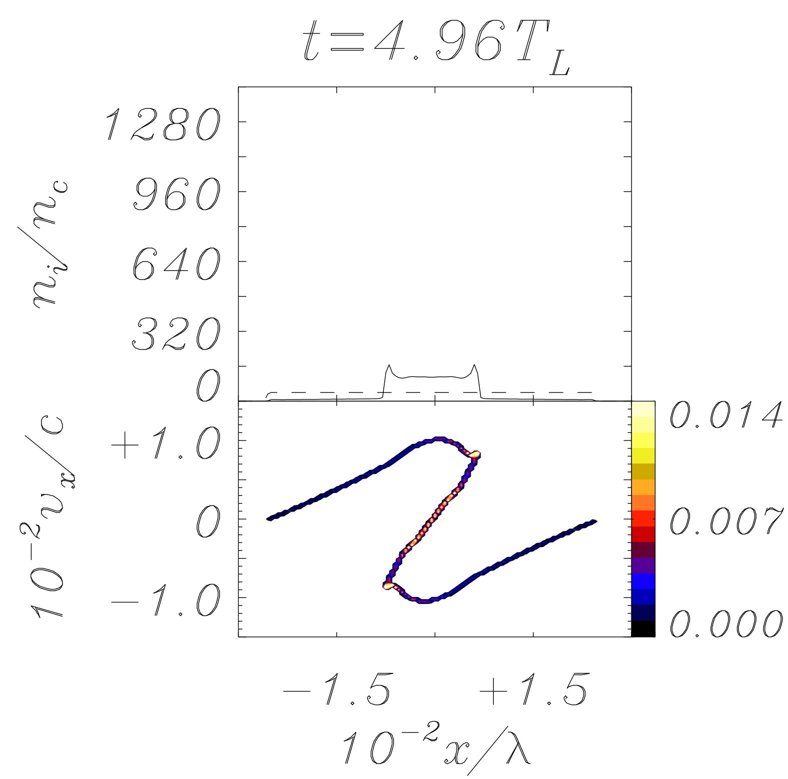

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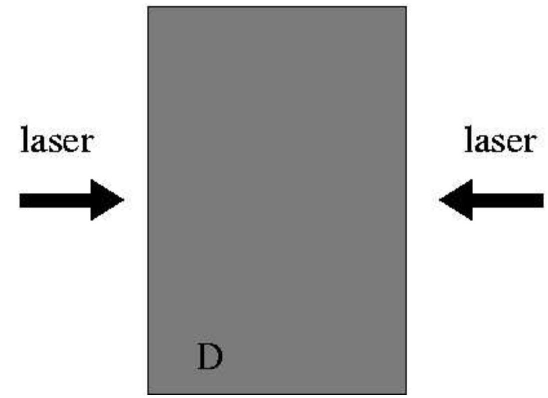

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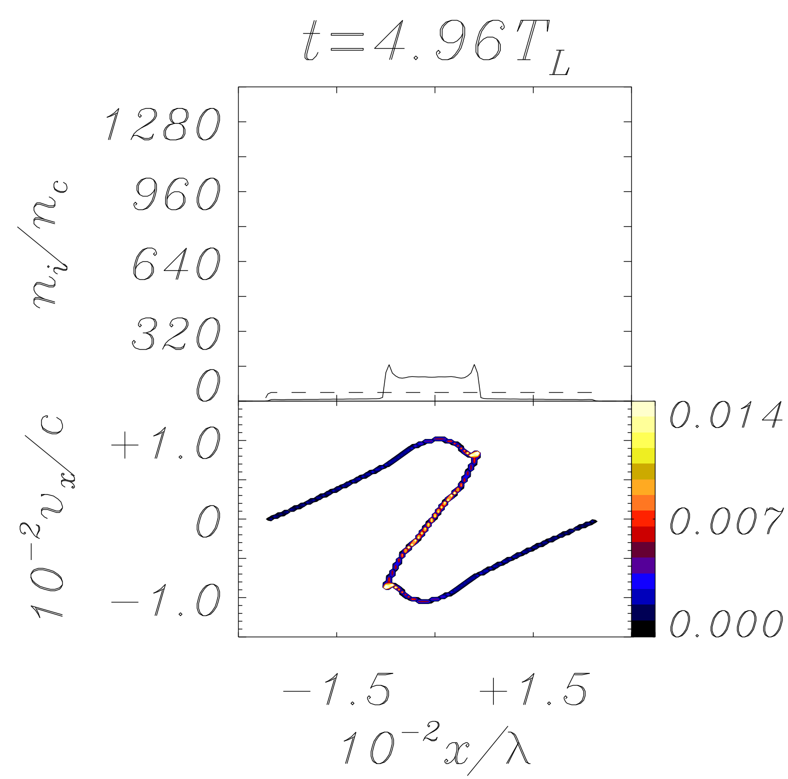

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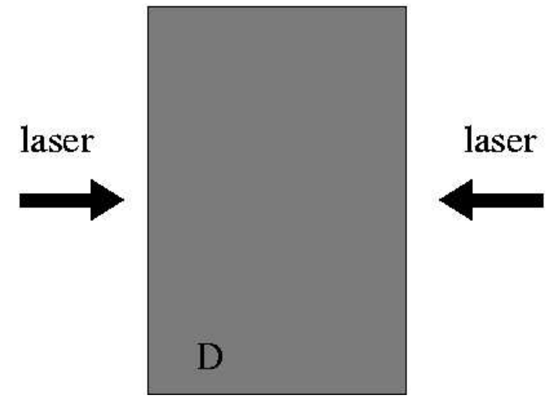

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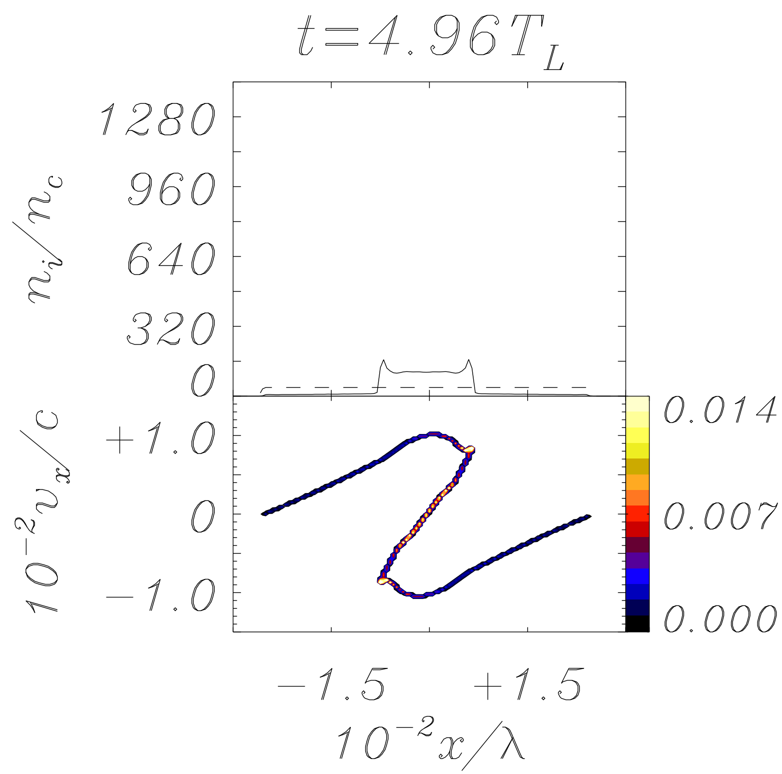

Thin foil of pure frozen D would be optimal (low $n_e/n_c \simeq 40$)
but $C_x D_y$ foil ($n_e/n_c \simeq 250$) is more realistic

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Neutron rate estimated from the simulation data.

Pulse duration: 15 fs

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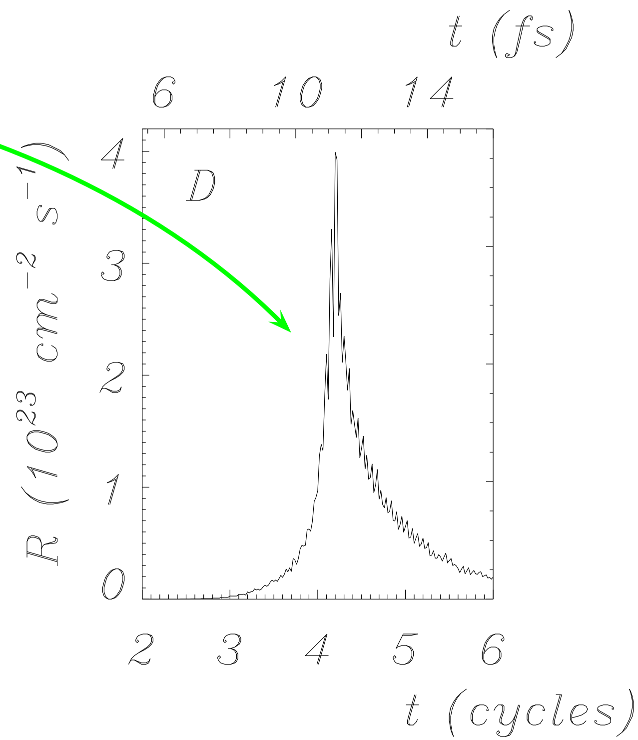

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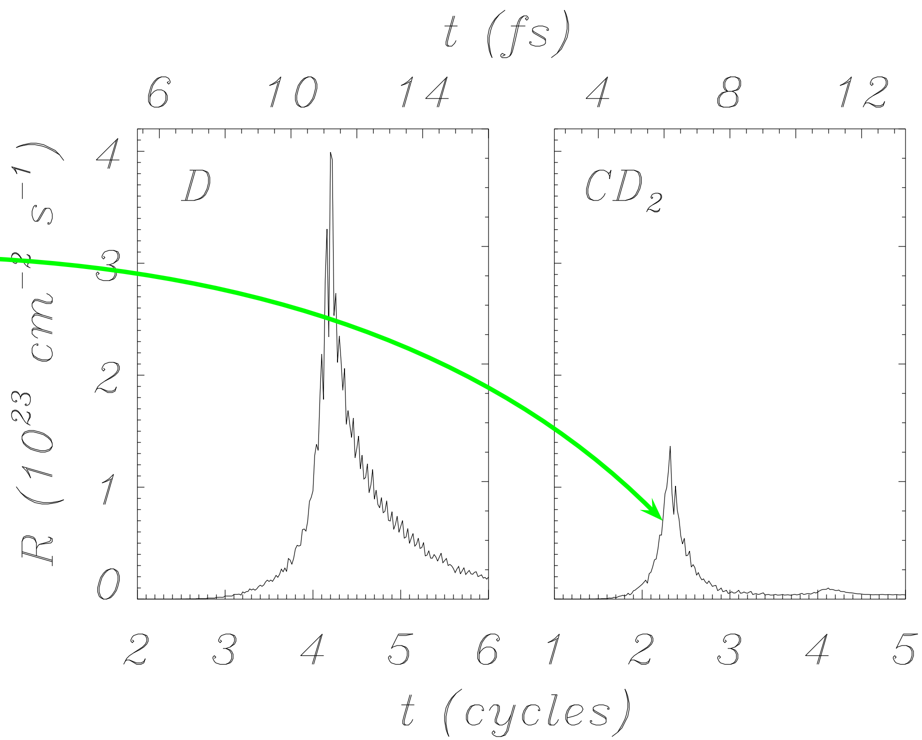

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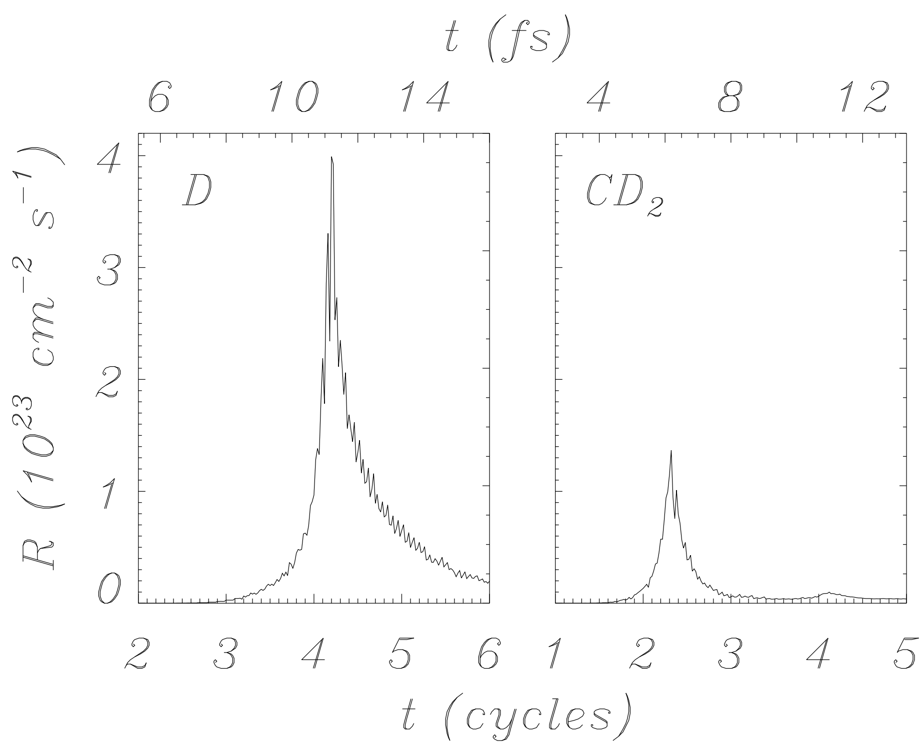

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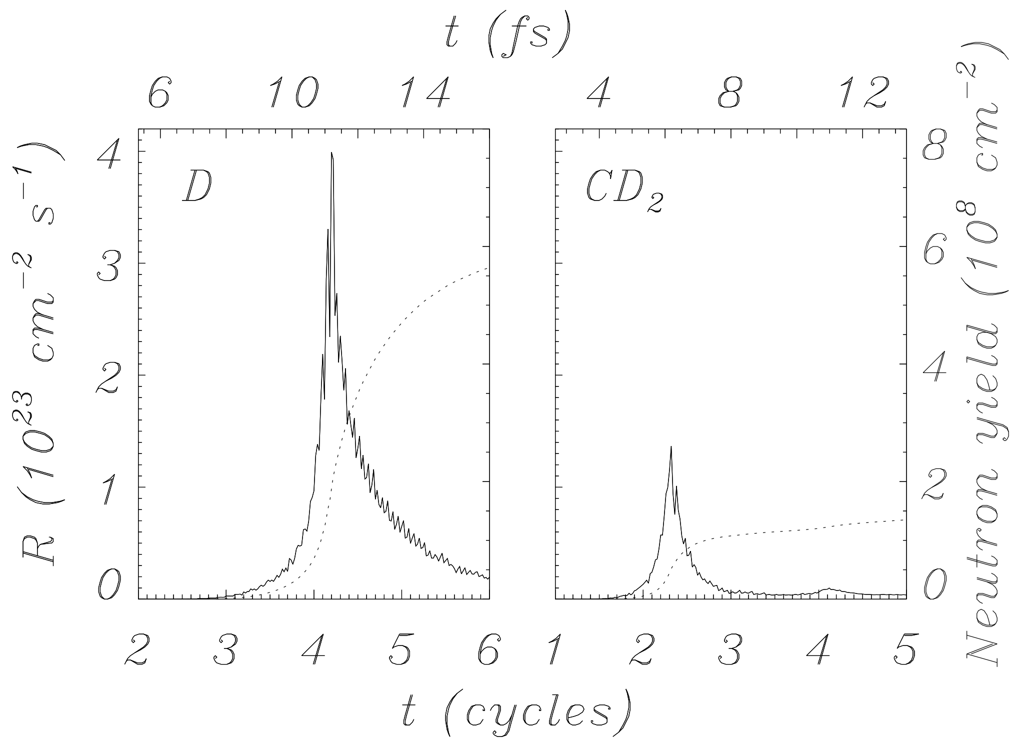

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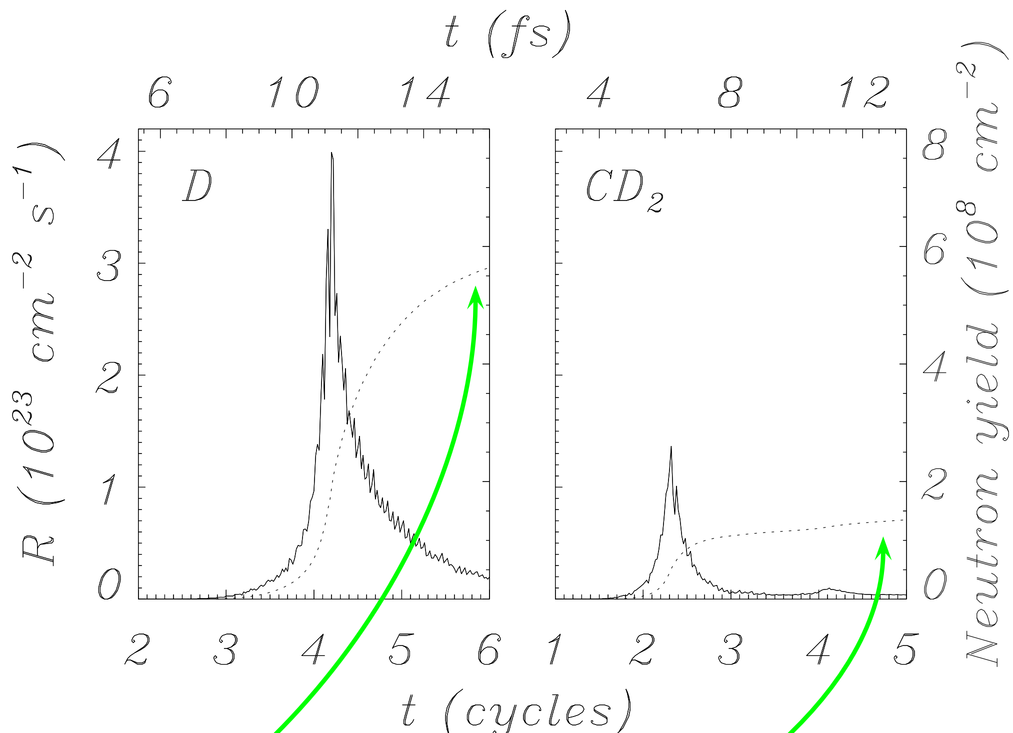

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  - suggests a novel regime of ion acceleration (we wait for experimental data!)
- A very similar dynamics has been observed in the radial ion acceleration following charge-displacement self-channeling in underdense plasmas.
- The ion bunches produced in this regime may open a perspective to bring the duration of fusion neutron sources down in the sub-femtosecond regime

References

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- ion acceleration with circular polarization:
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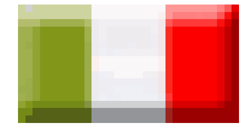

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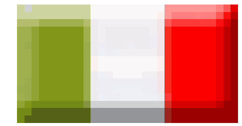

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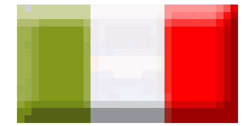

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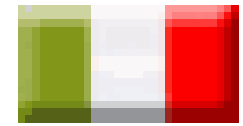

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