Ponderomotive Ion Acceleration in Laser-Plasma Interactions: Physics and Applications

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Coworkers

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

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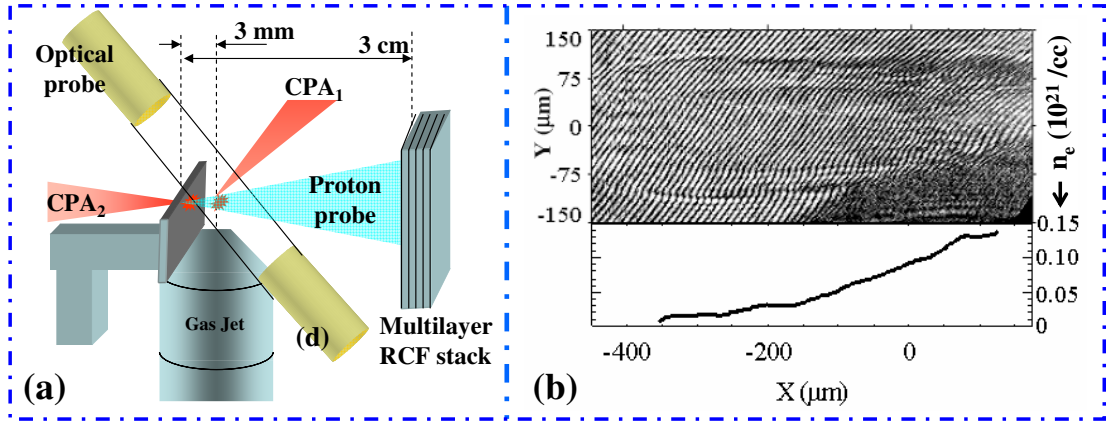

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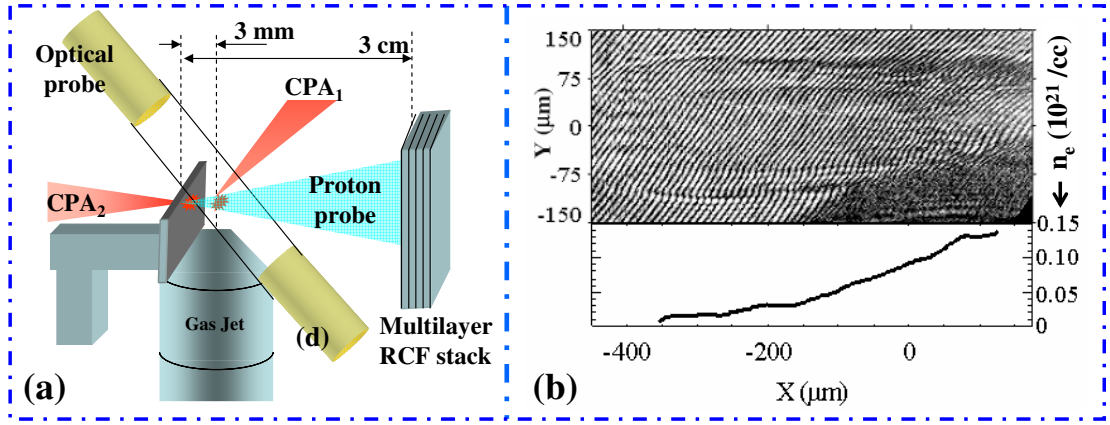

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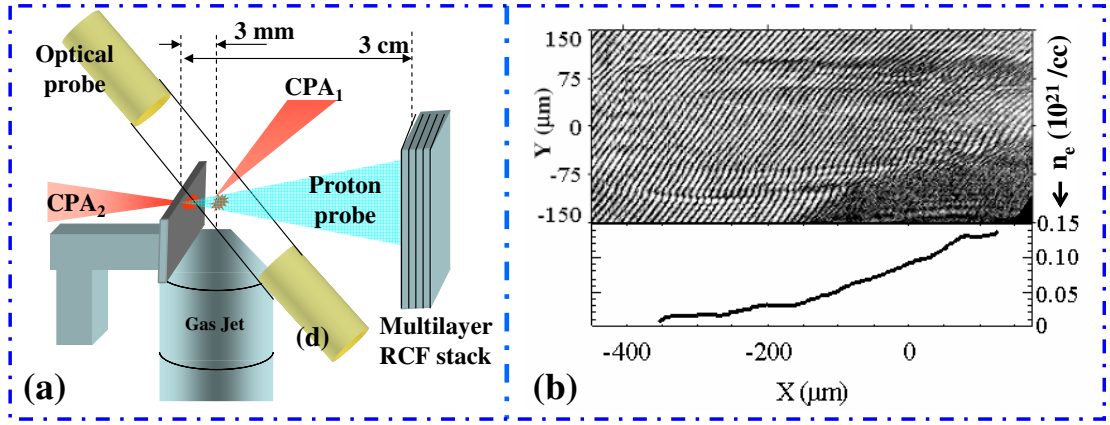

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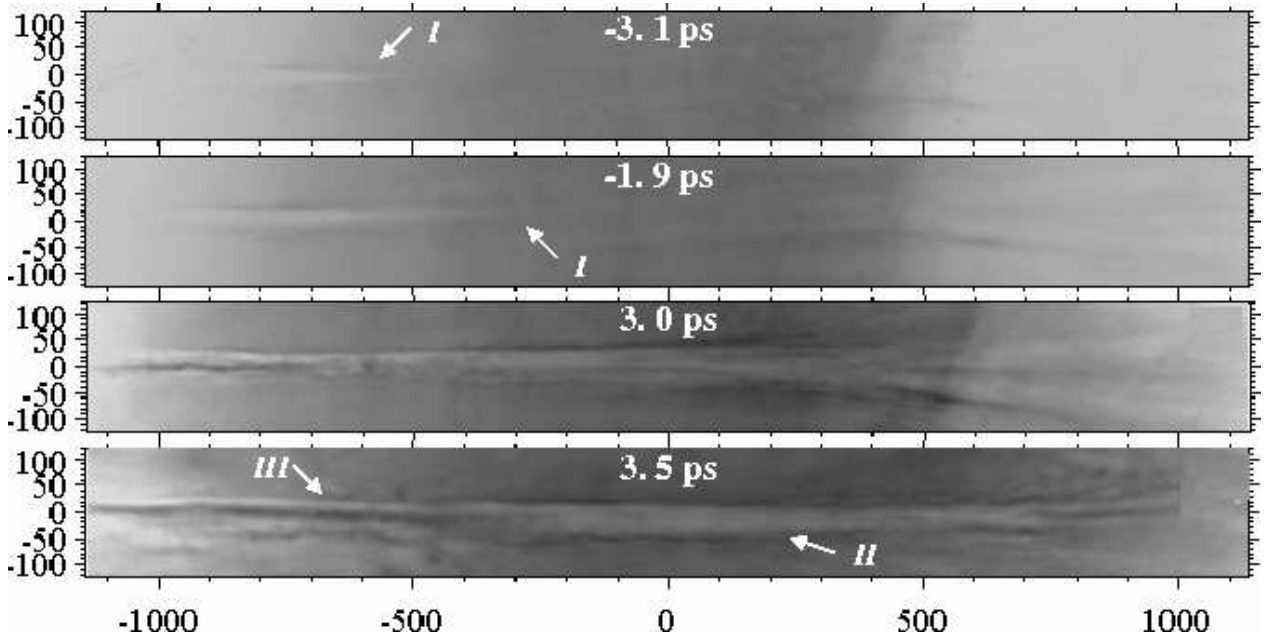

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1D electrostatic PIC simulation, cylindrical geometry (r, p_r)

External driving force on electrons

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

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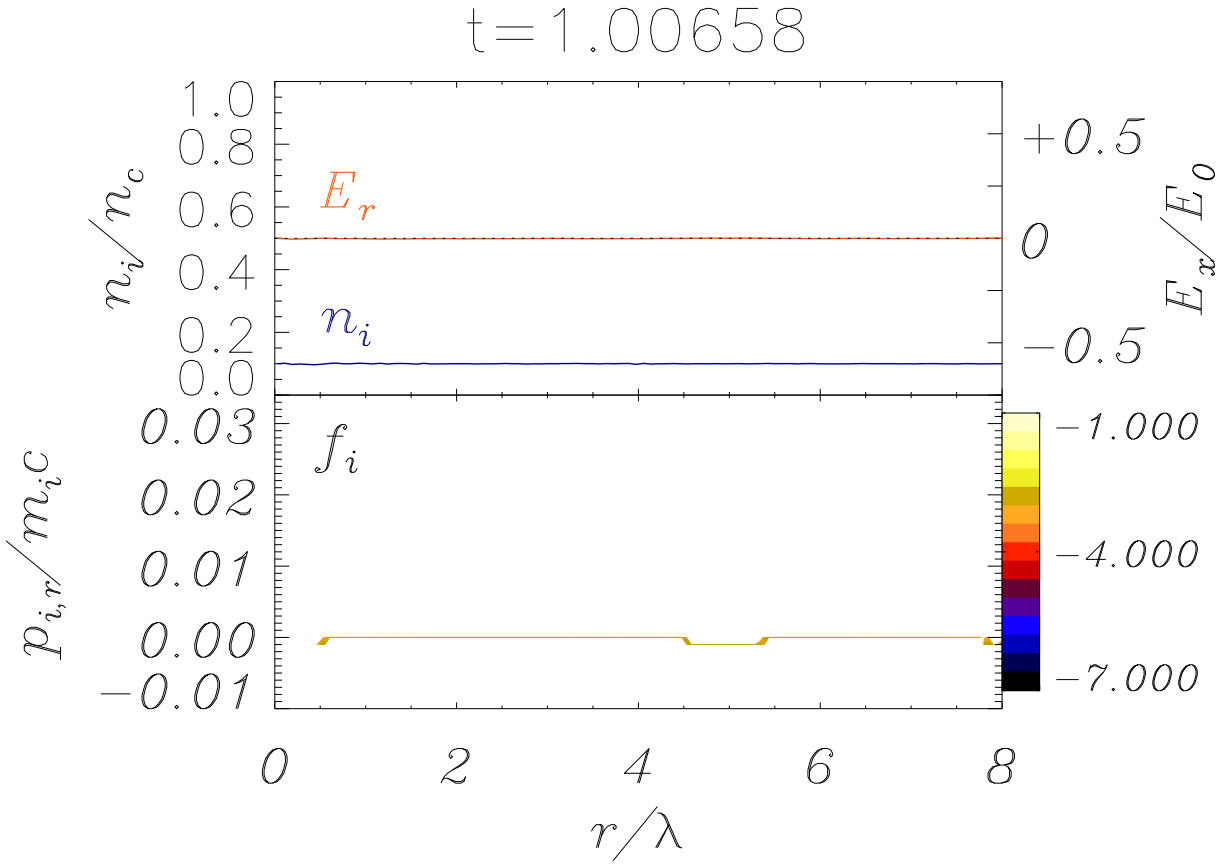

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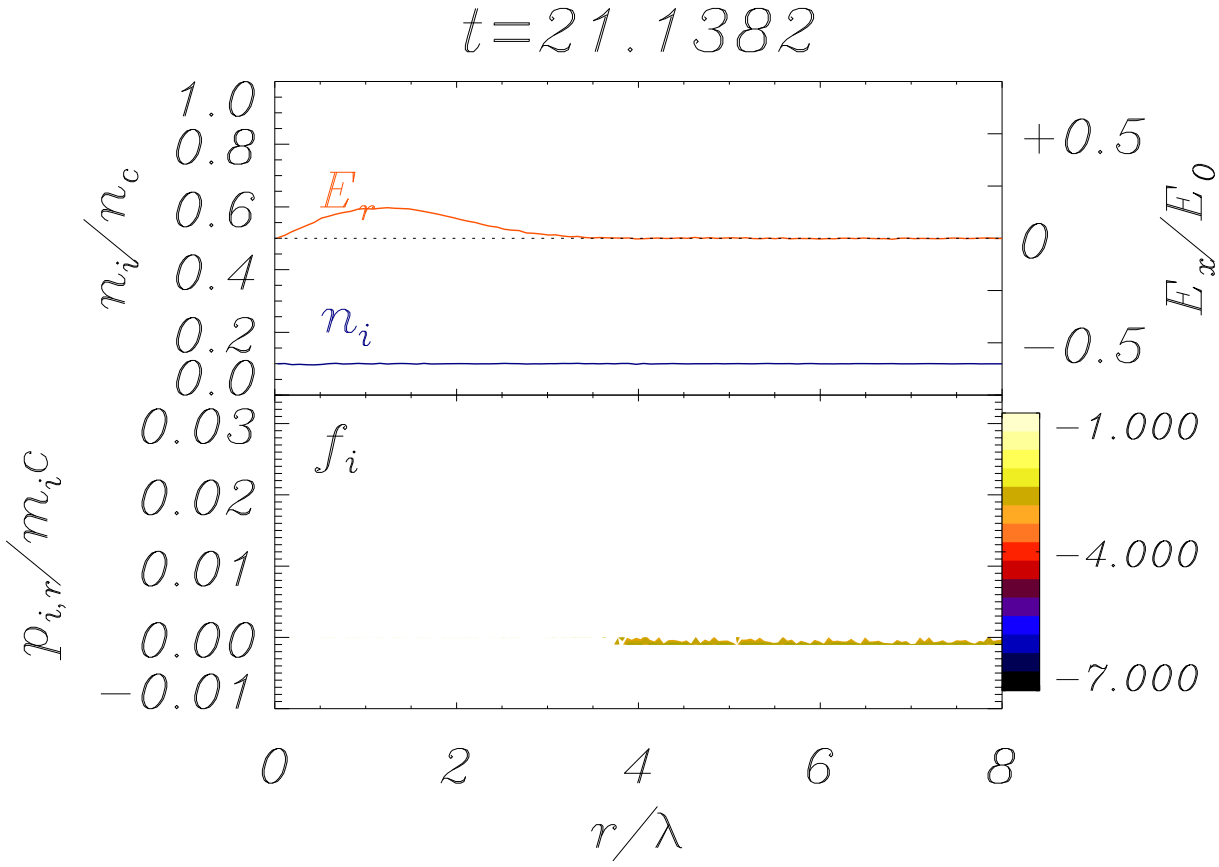

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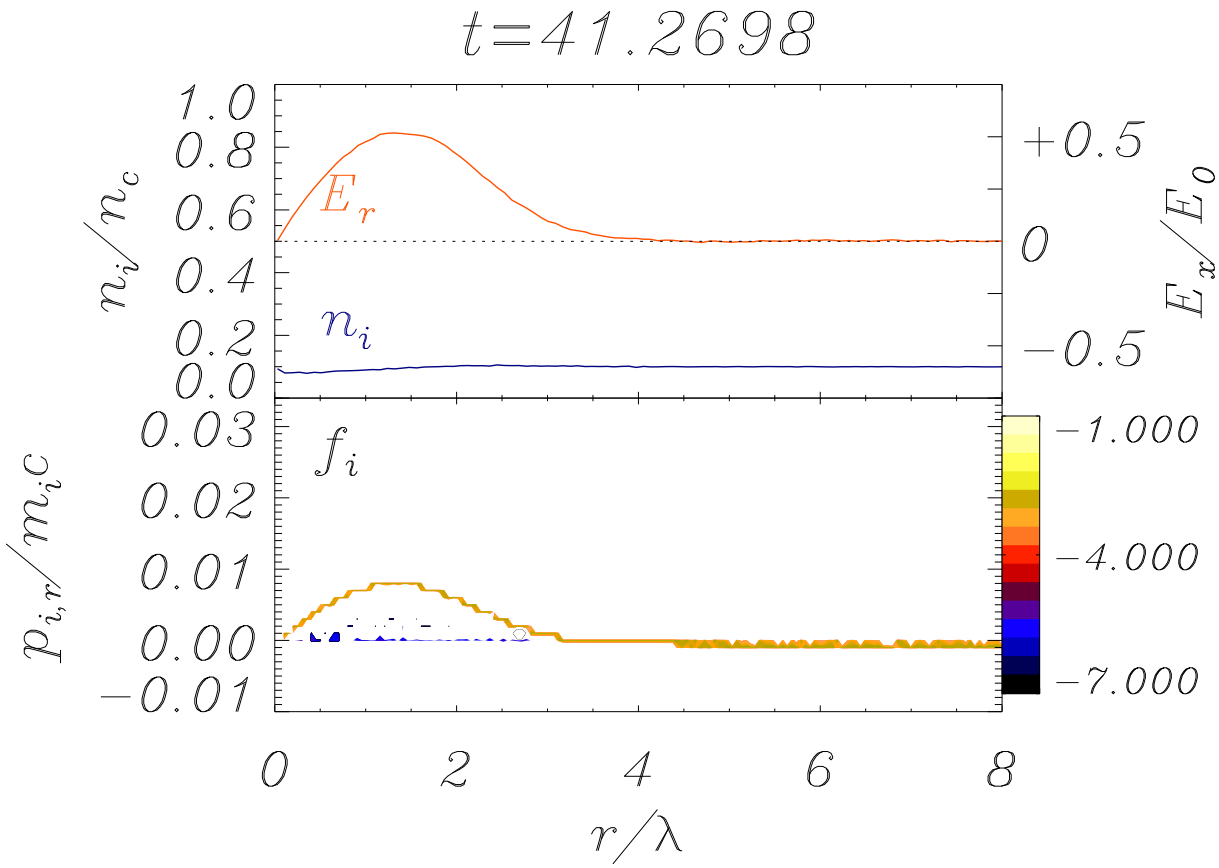

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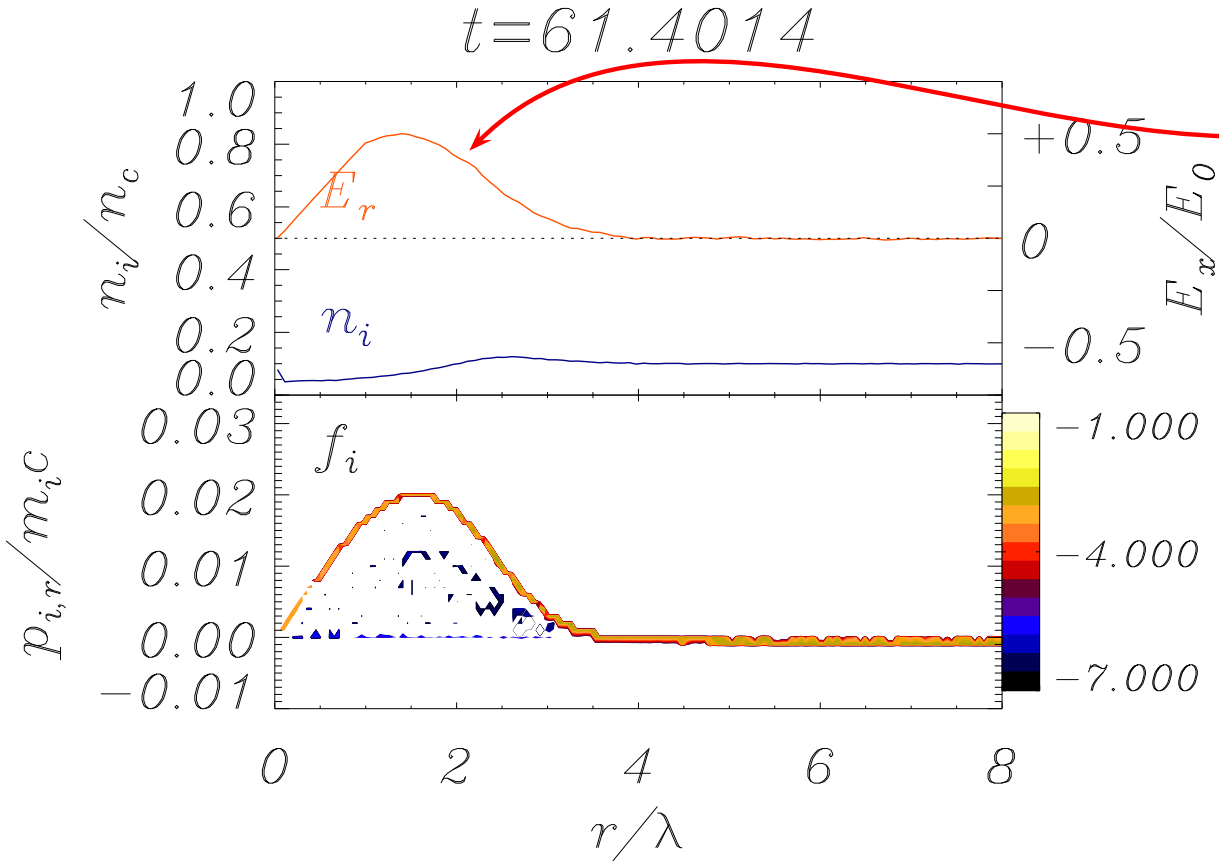

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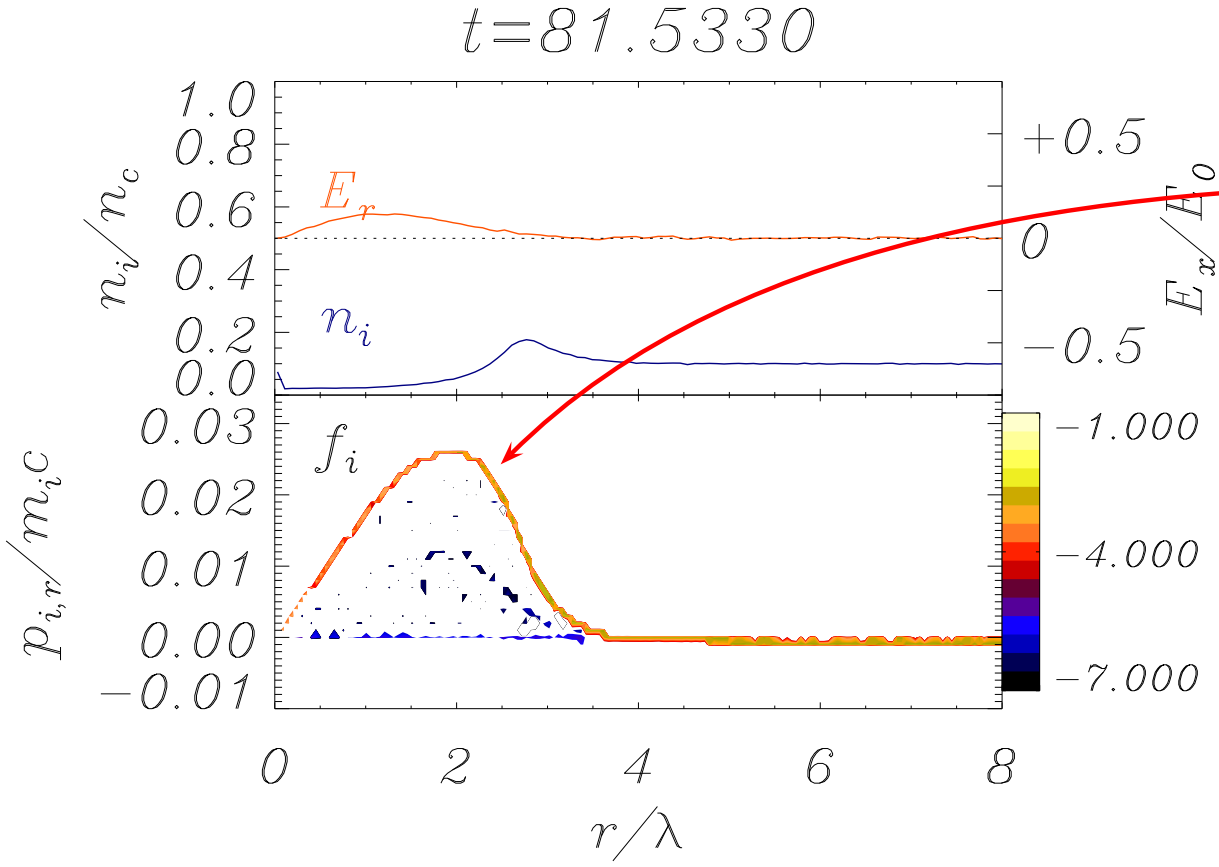

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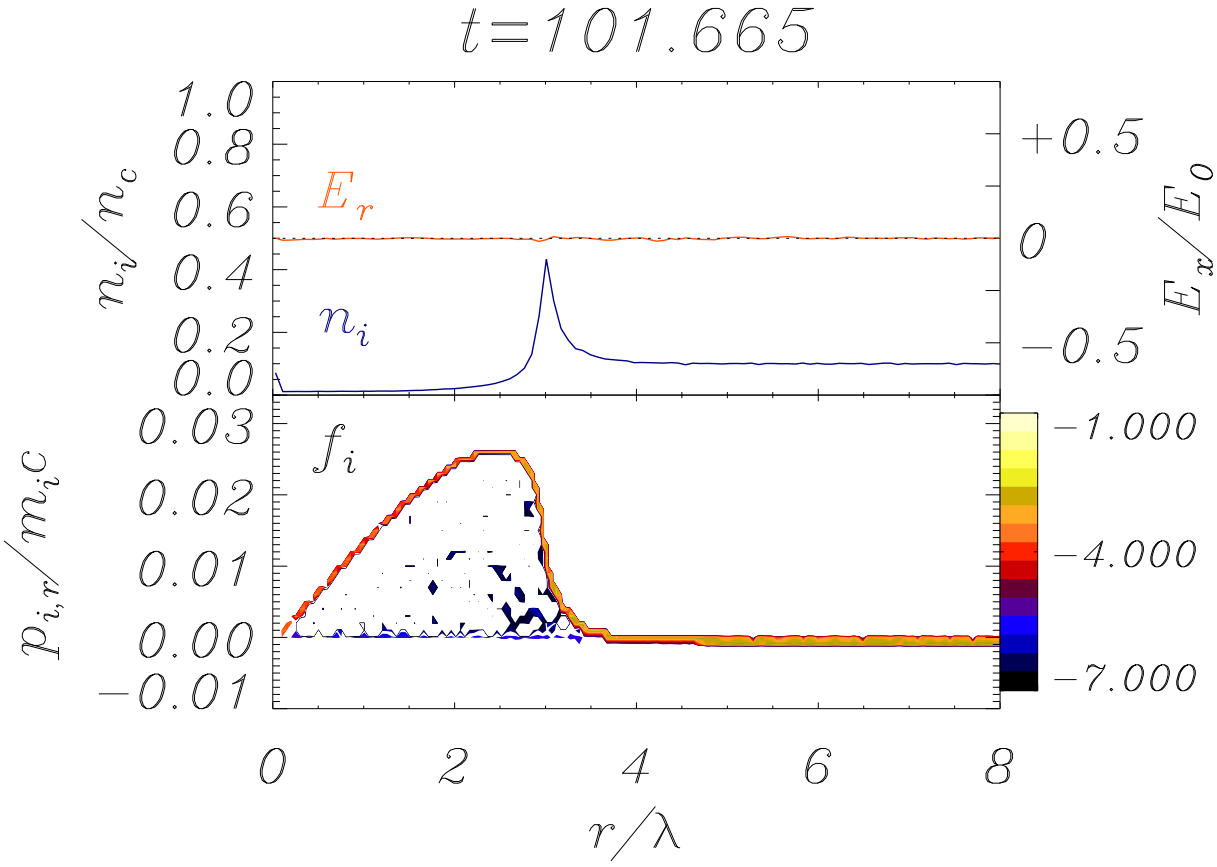

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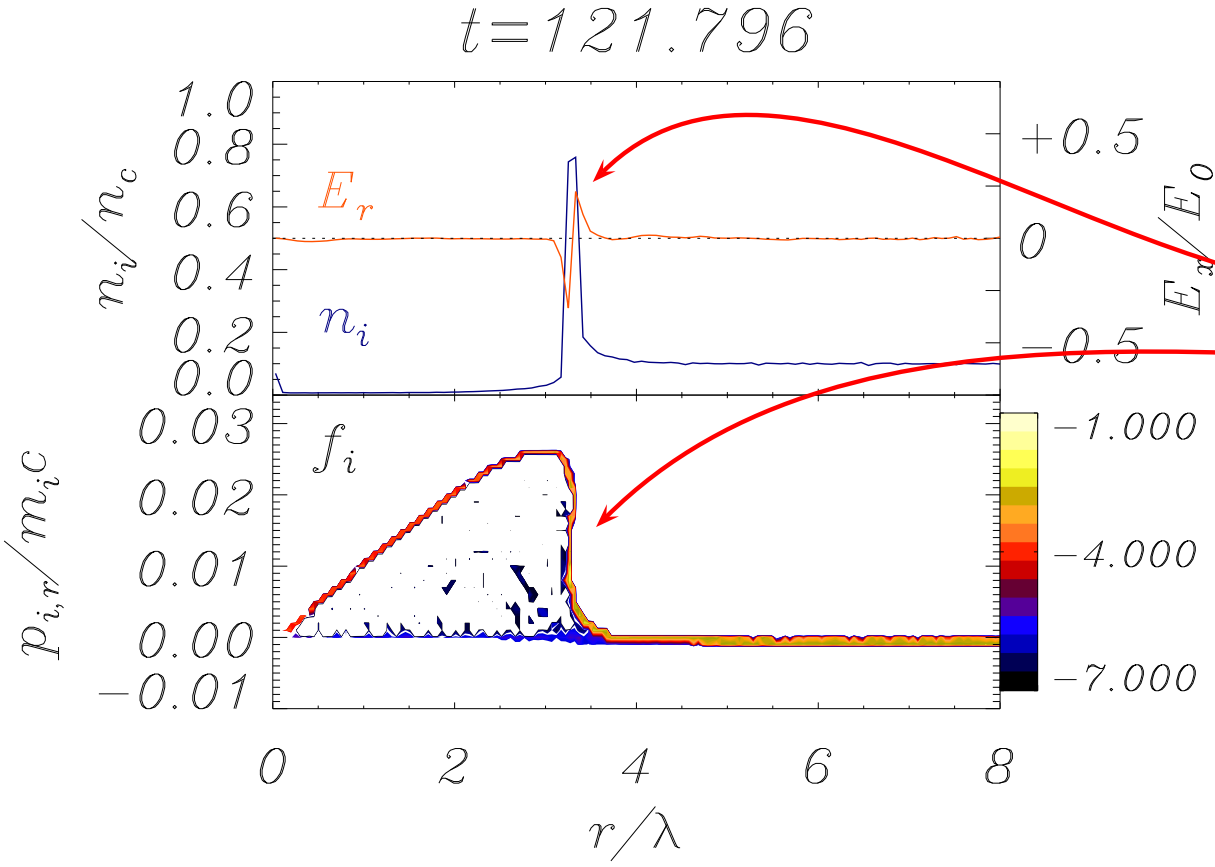

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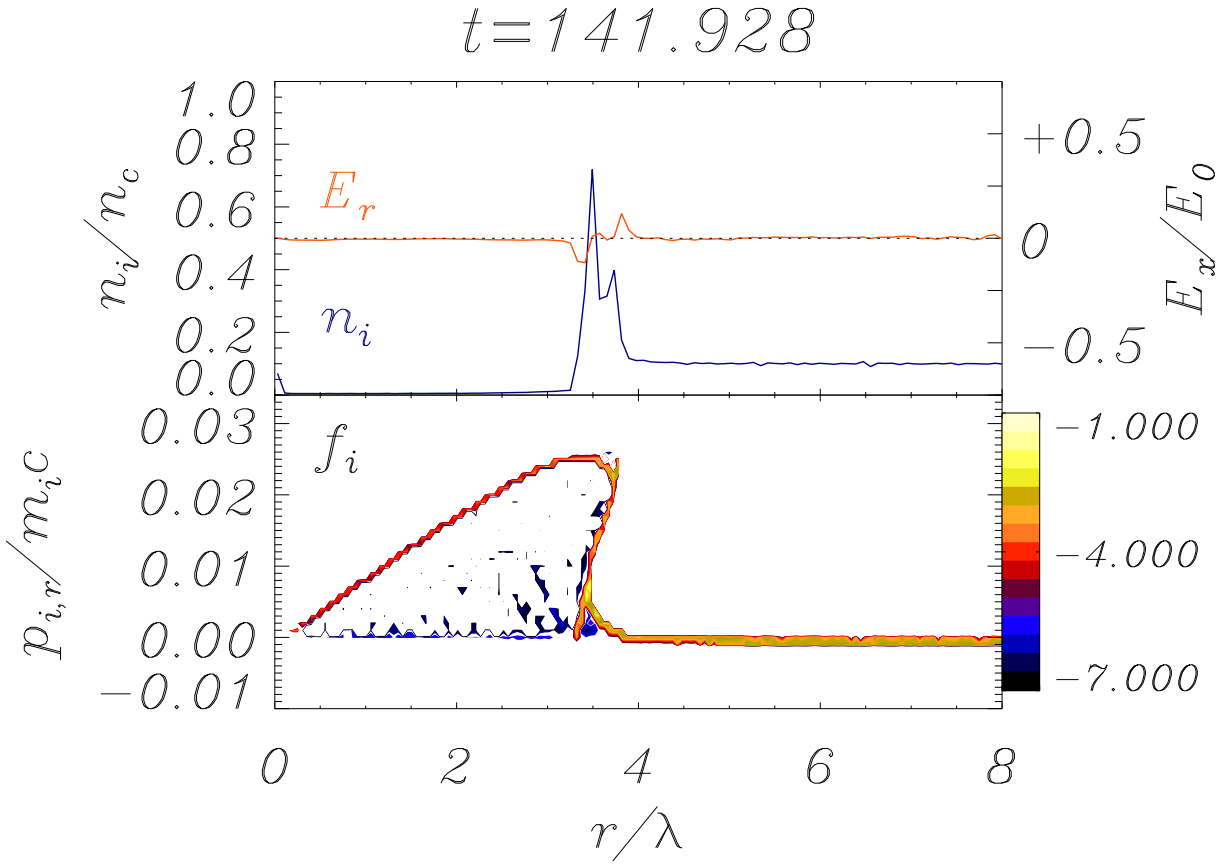

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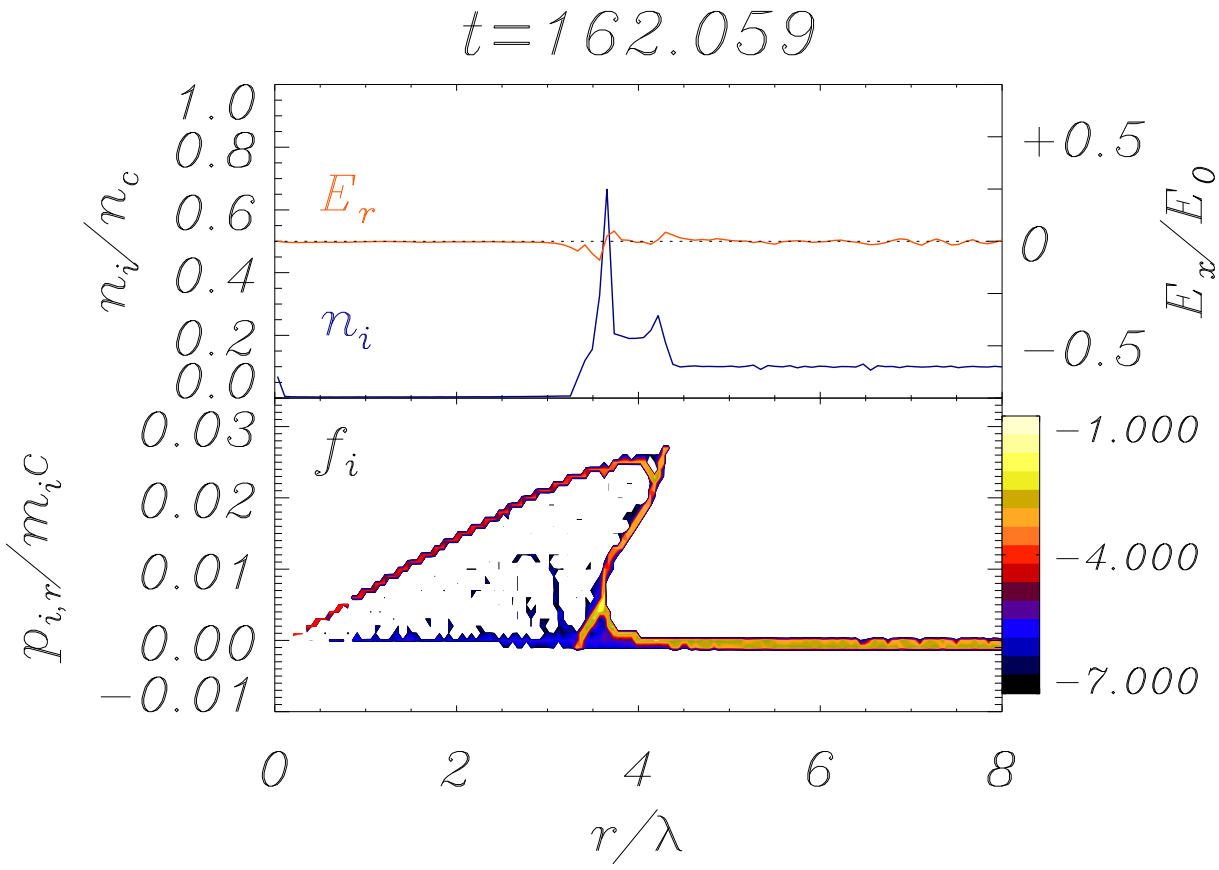

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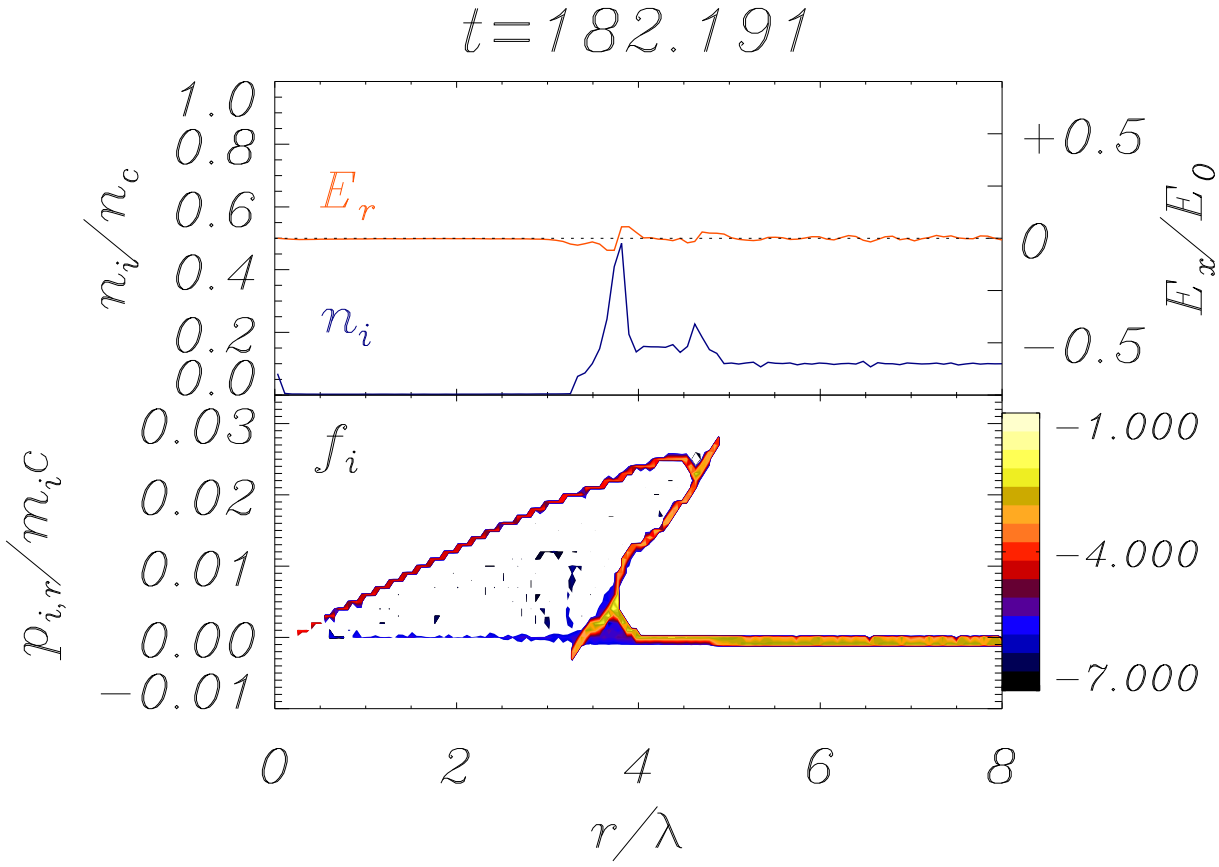

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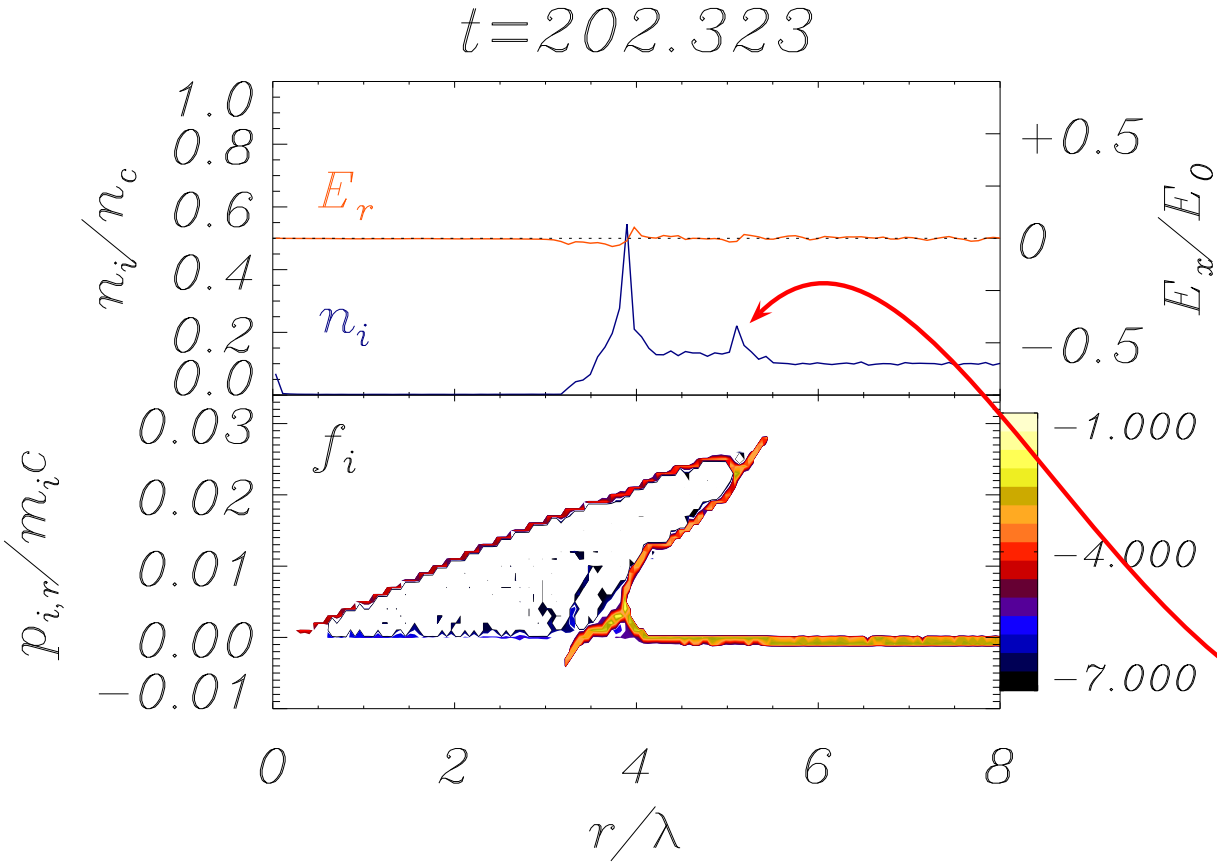

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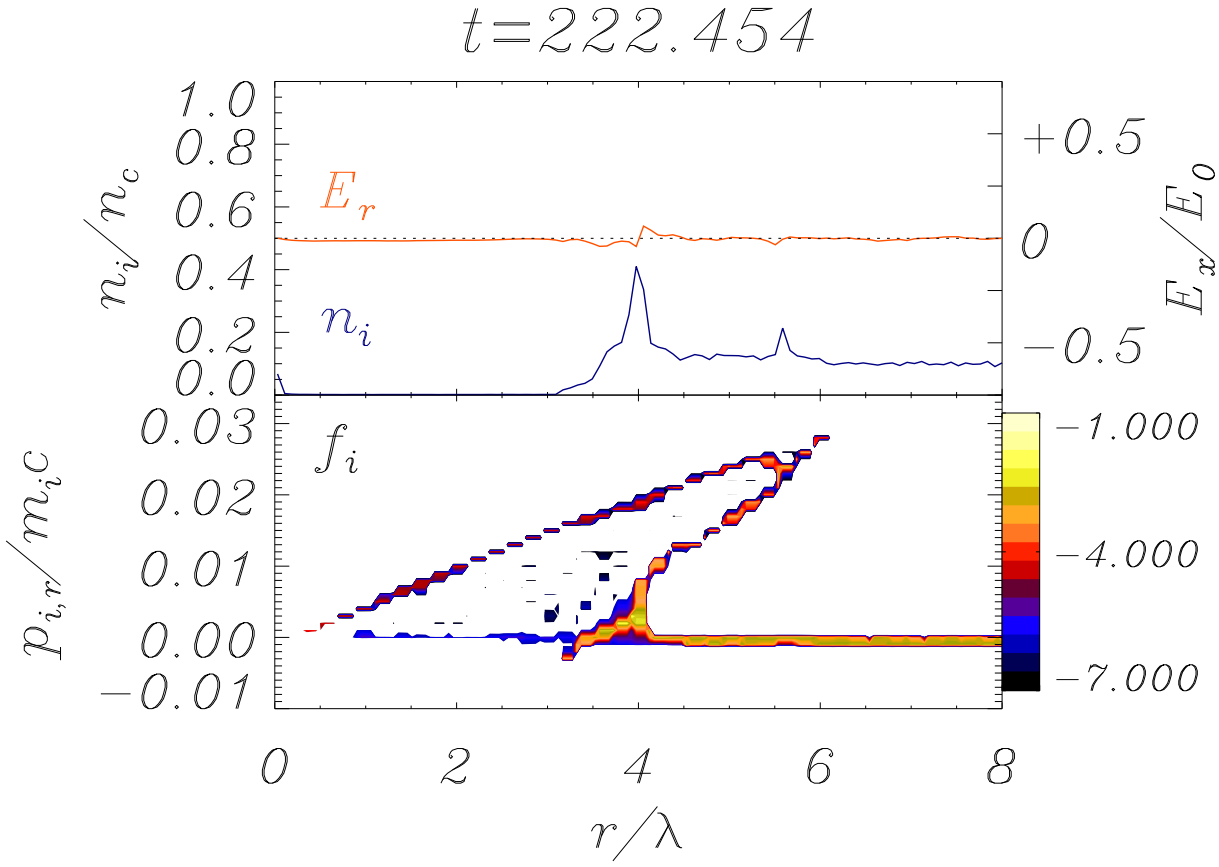

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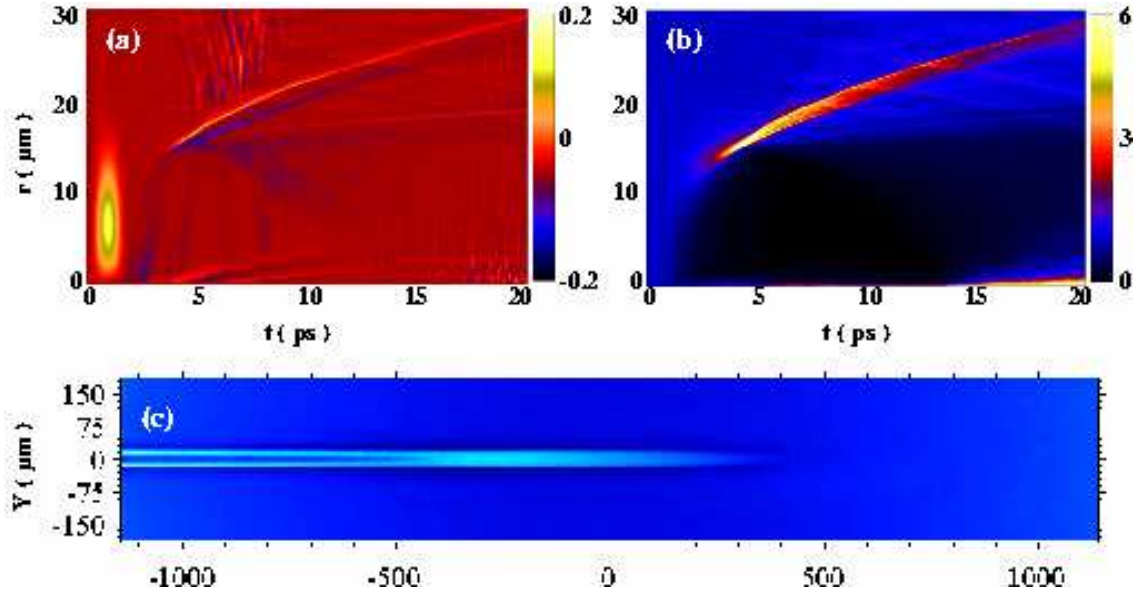

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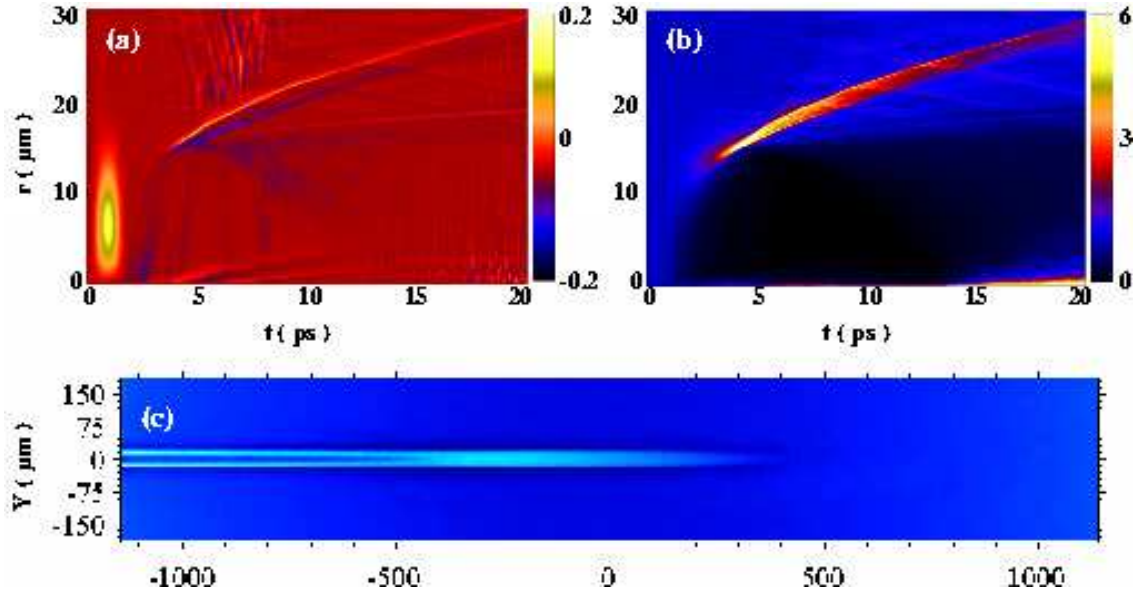

The ion spectrum was not measured in the experiment, but in similar conditions evidence of a tail of MeV ions was provided:
see e.g. Sarkisov et al, JETP **66**, 828 (1997); Fritzler et al, PRL **89**, 165004 (2002).

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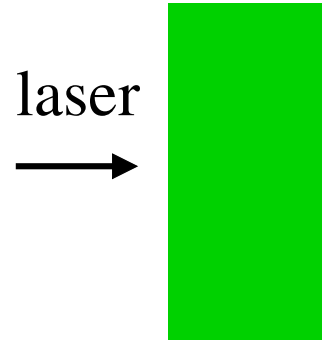
Idea: producing a laser-solid interaction *without* fast electrons



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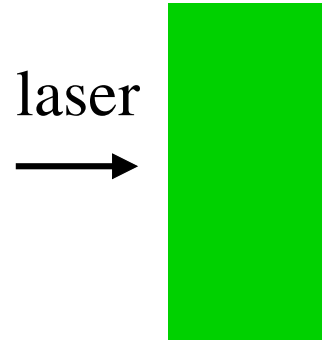

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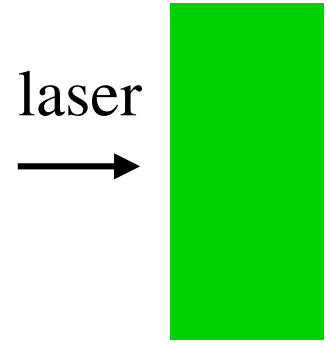

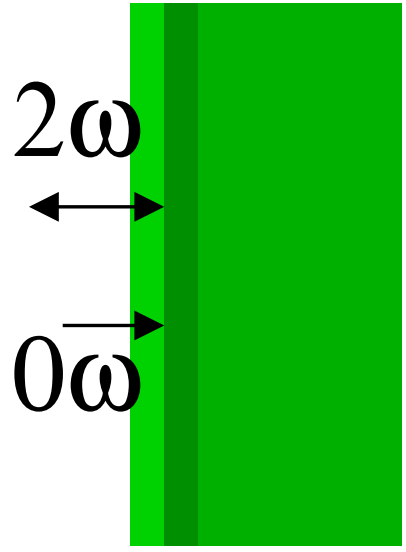

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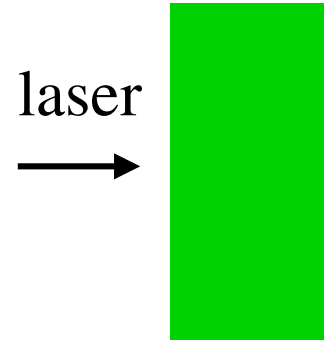

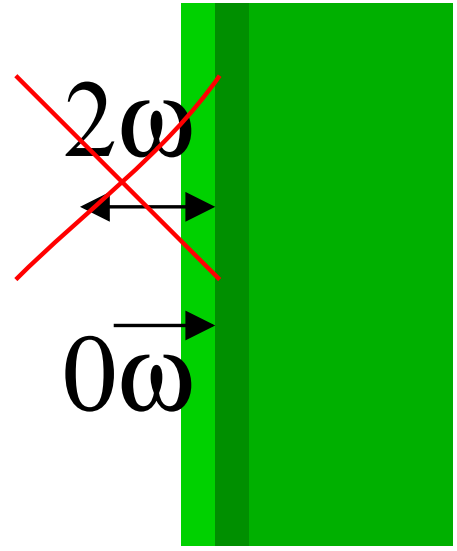

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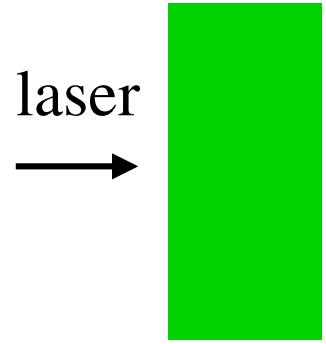

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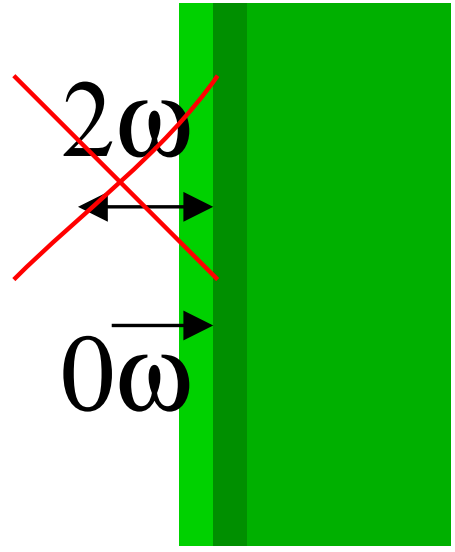
$\Rightarrow$ Ion acceleration is driven directly by the steady ponderomotive force



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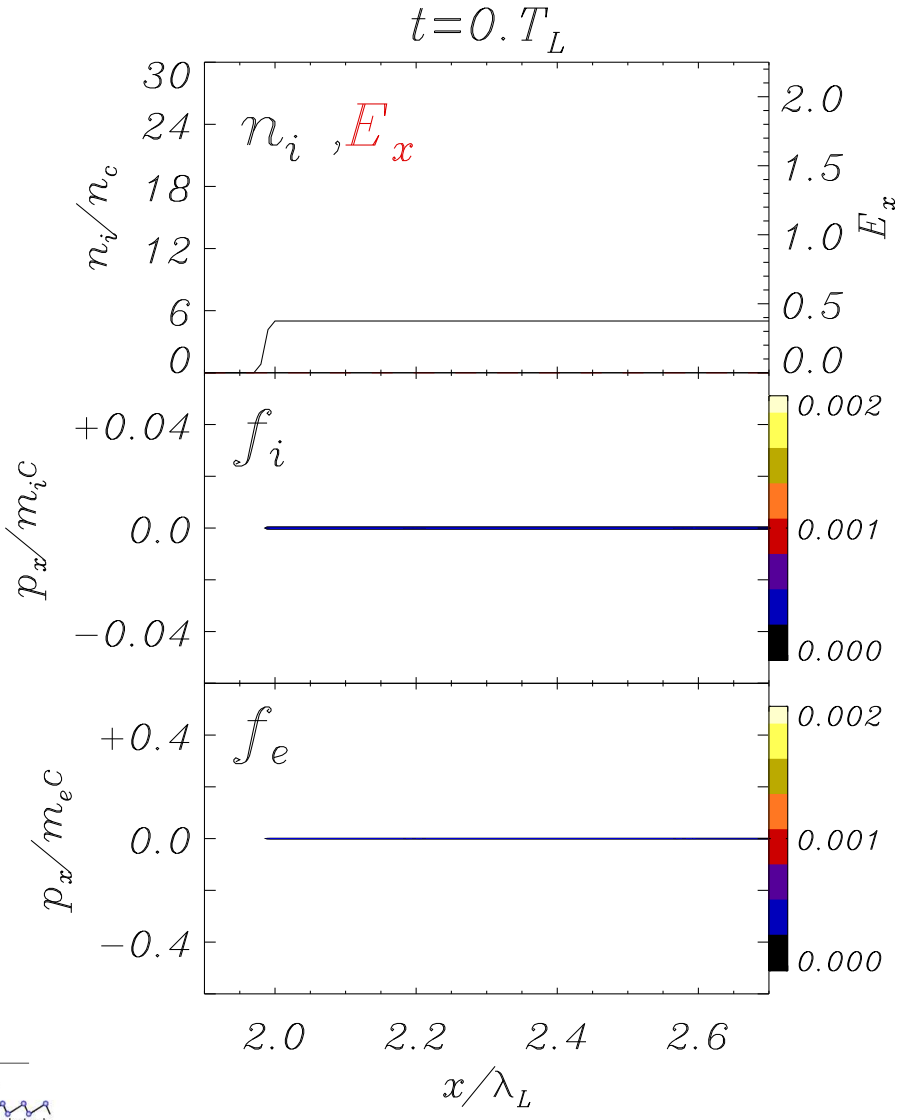

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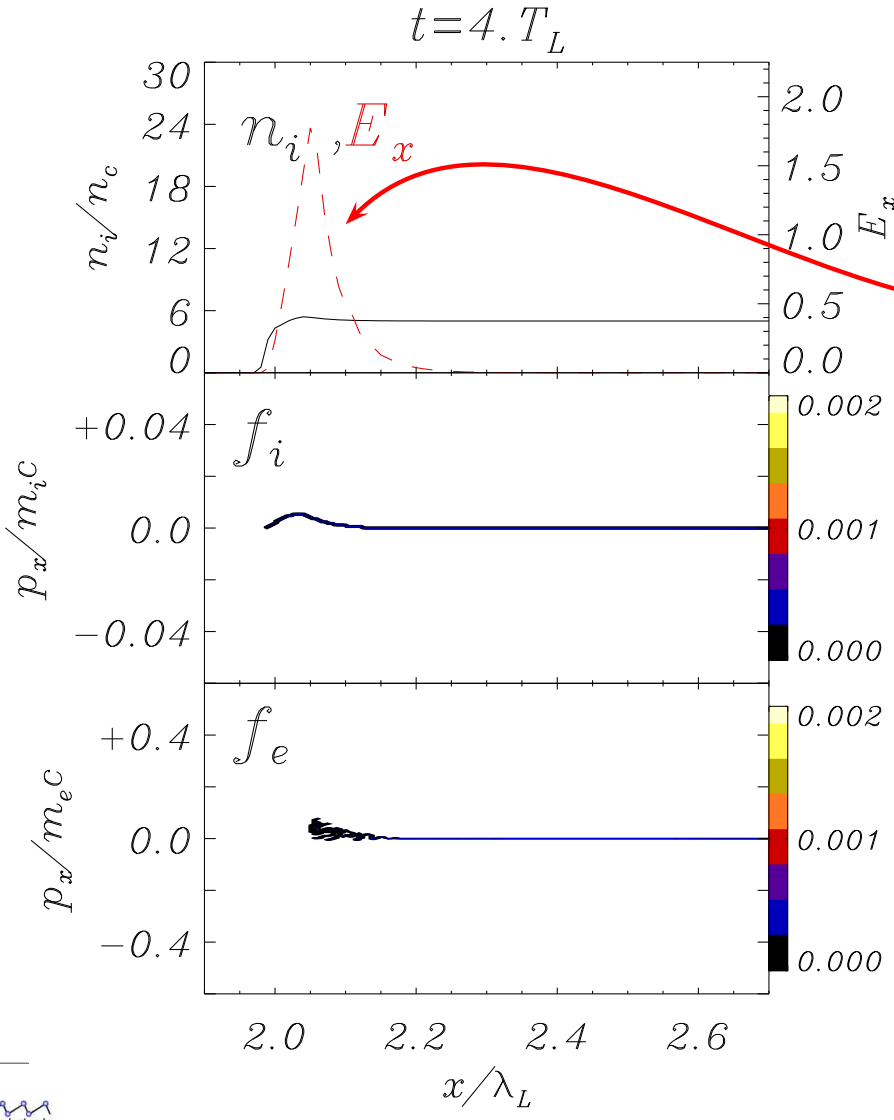

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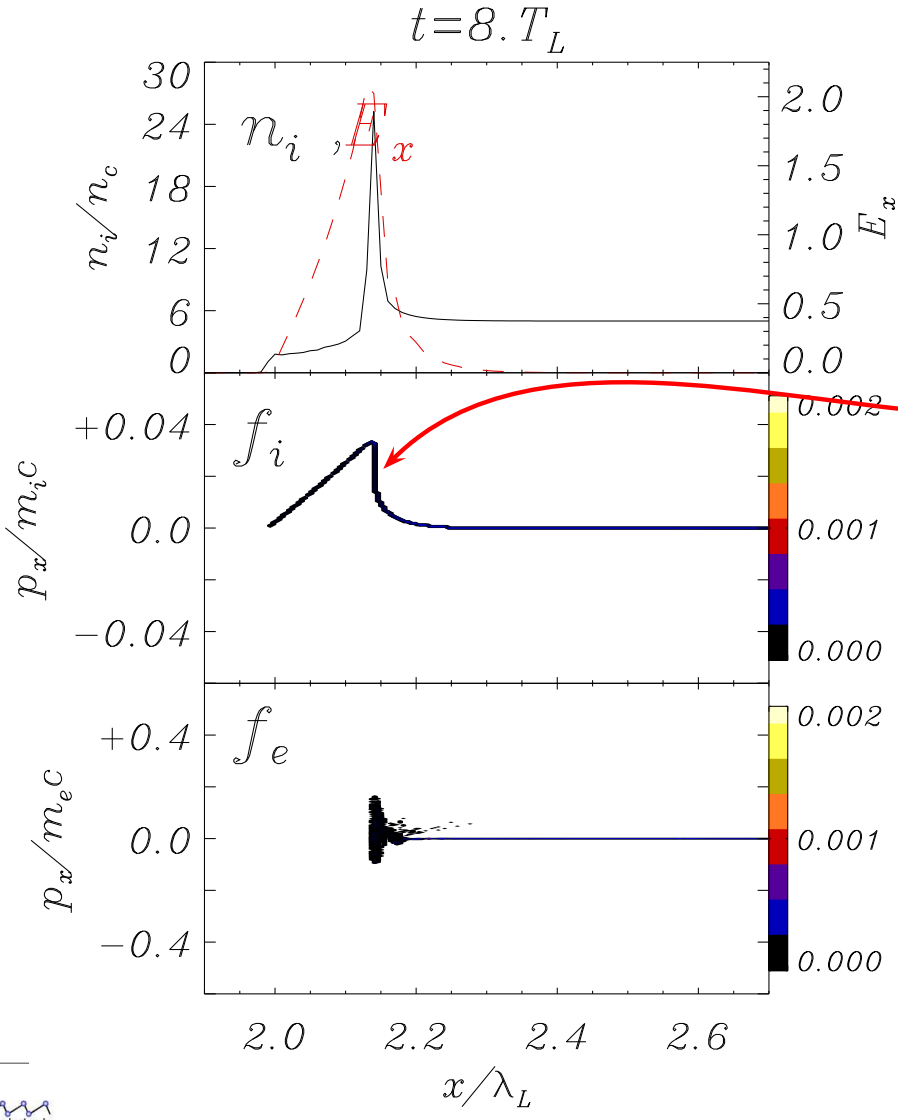

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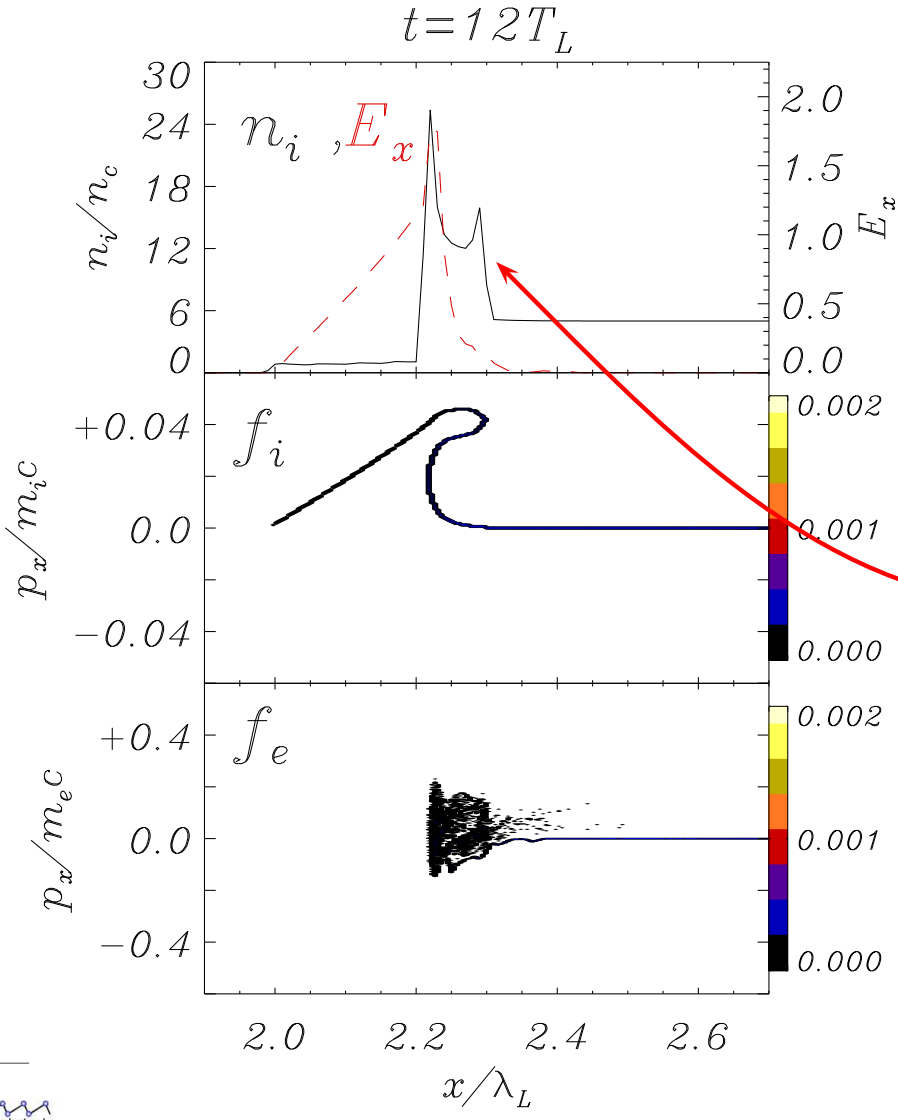

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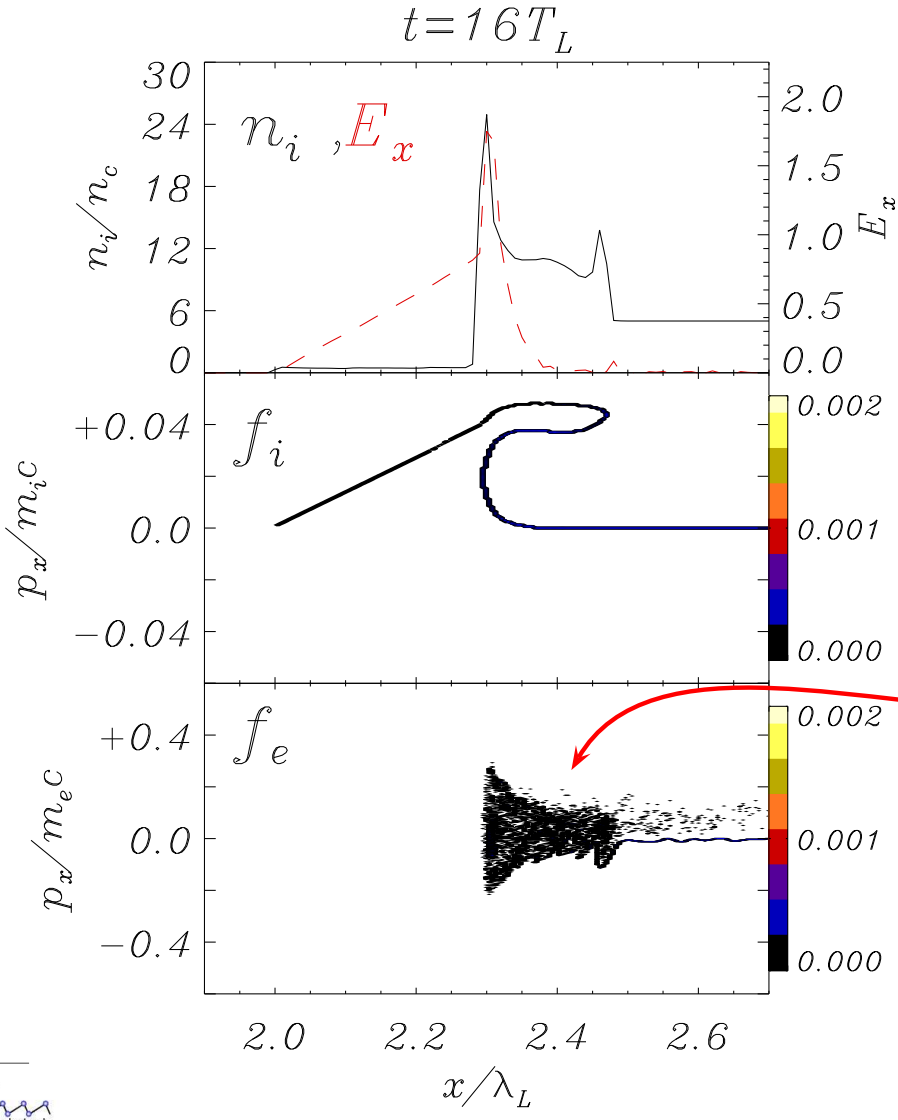

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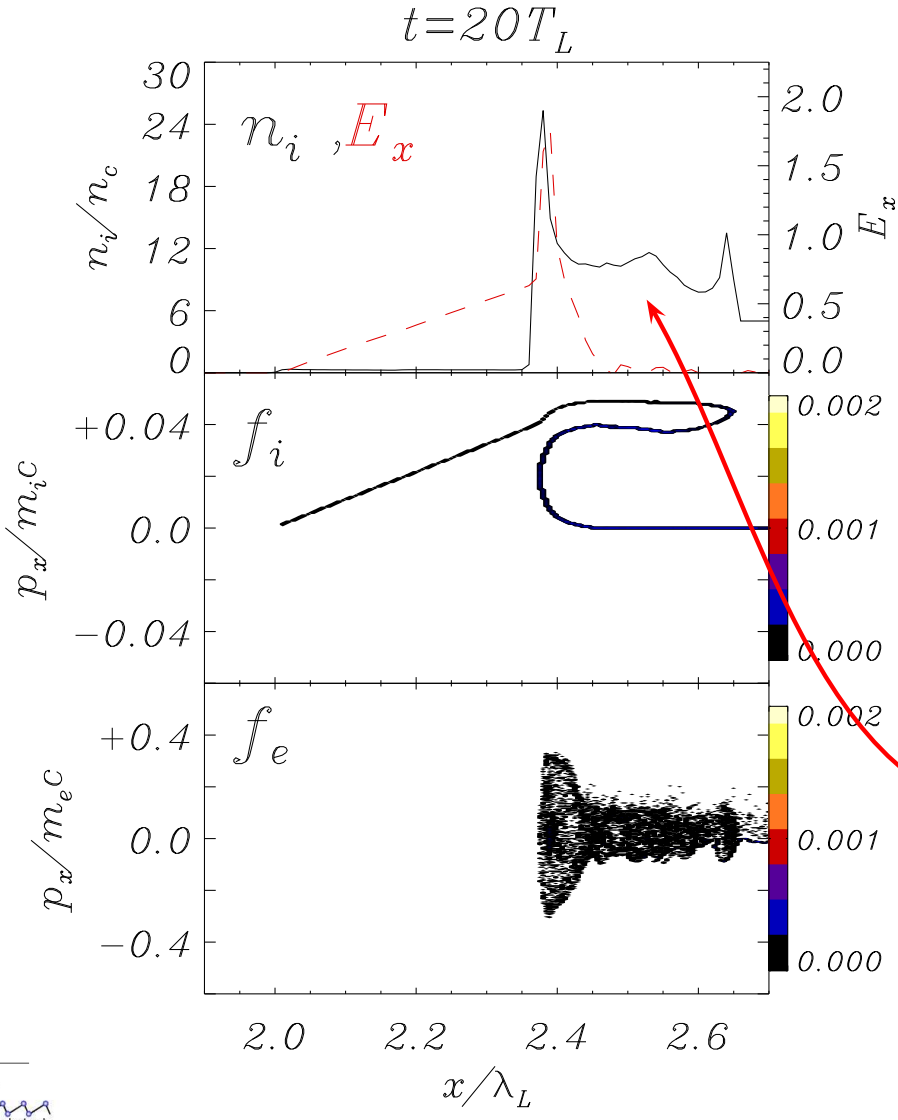

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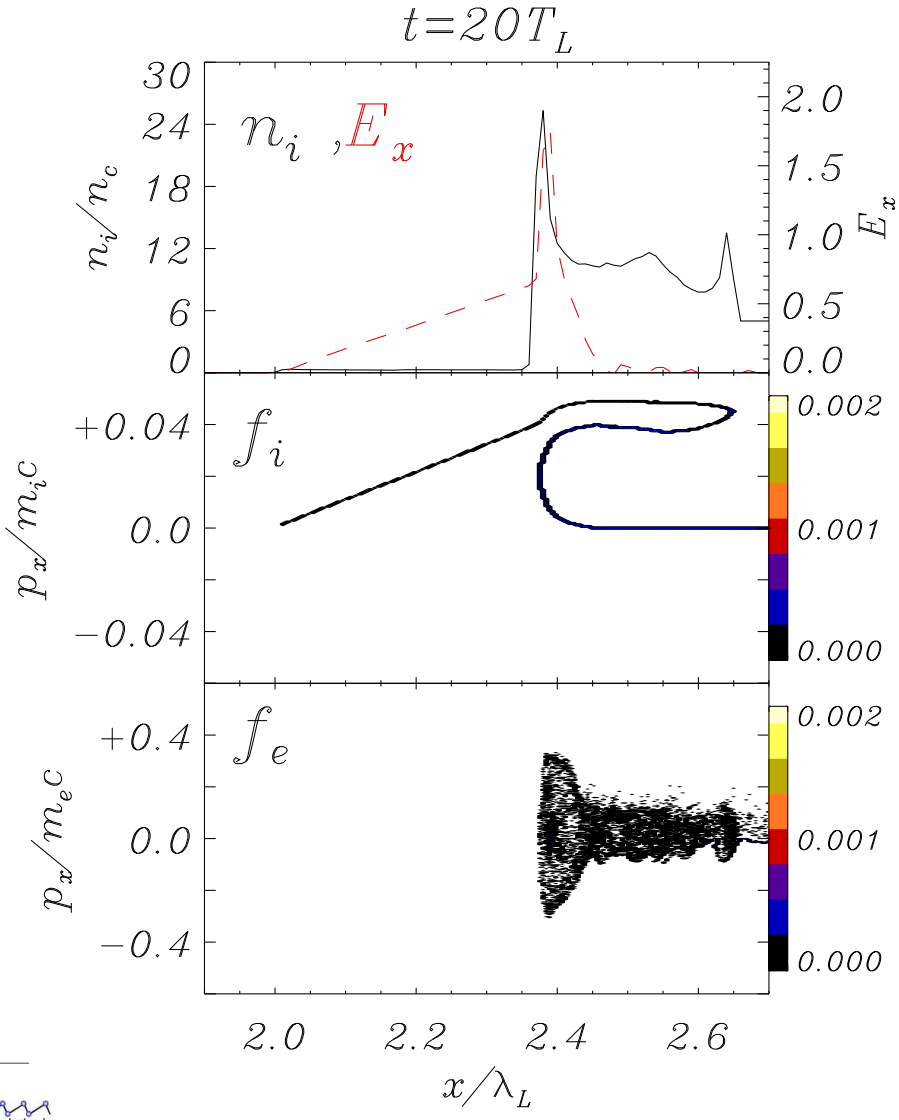

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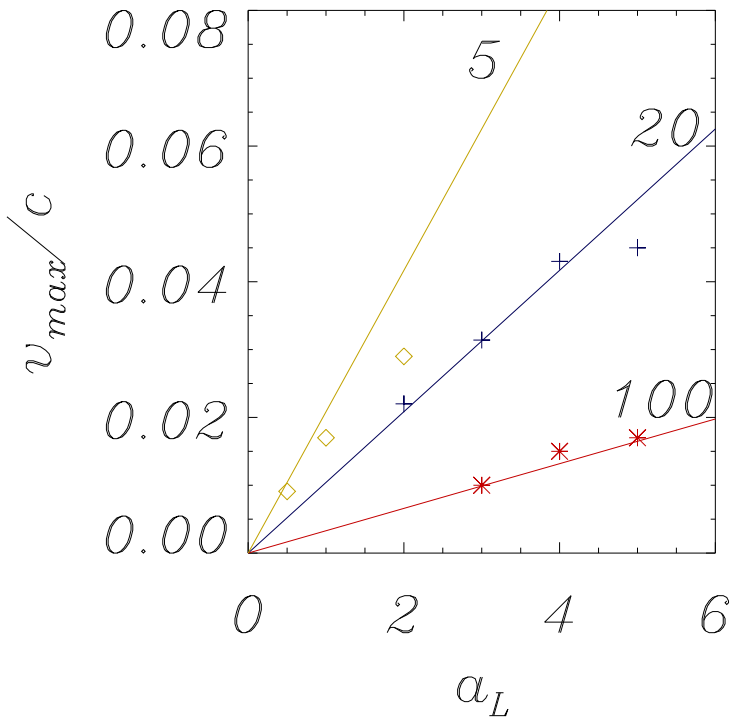

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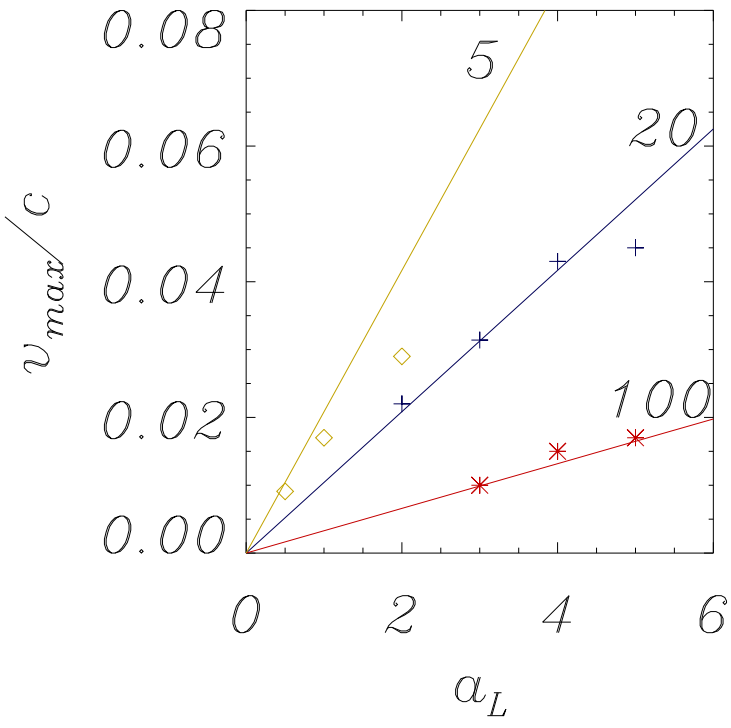

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- number of ions in the bunch/cm^2 $\simeq n_{i0} l_s$, $l_s \simeq c/\omega_p$

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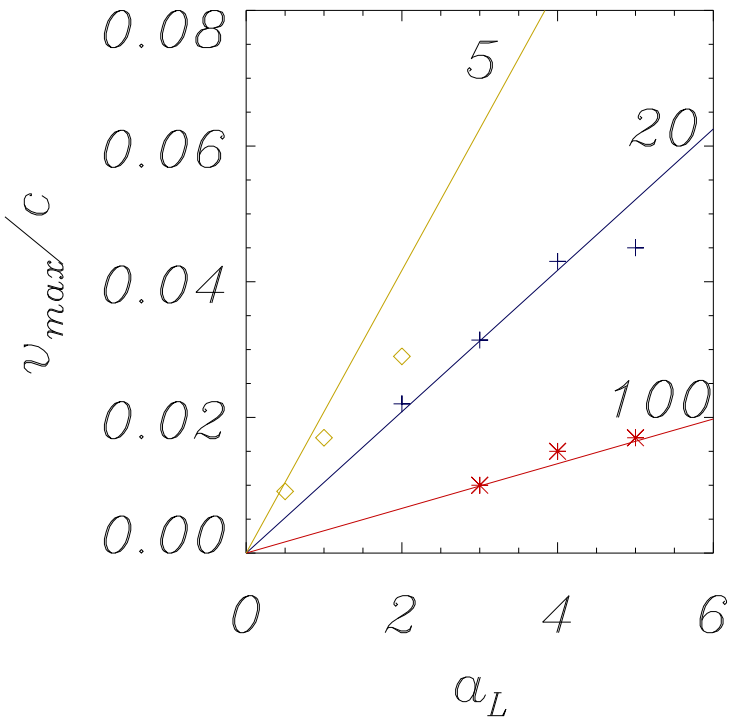

good agreement with simulations:

- number of ions in the bunch/cm^2 $\simeq n_{i0} l_s$, $l_s \simeq c/\omega_p$

- absorption degree in ions $\simeq v_m/c$

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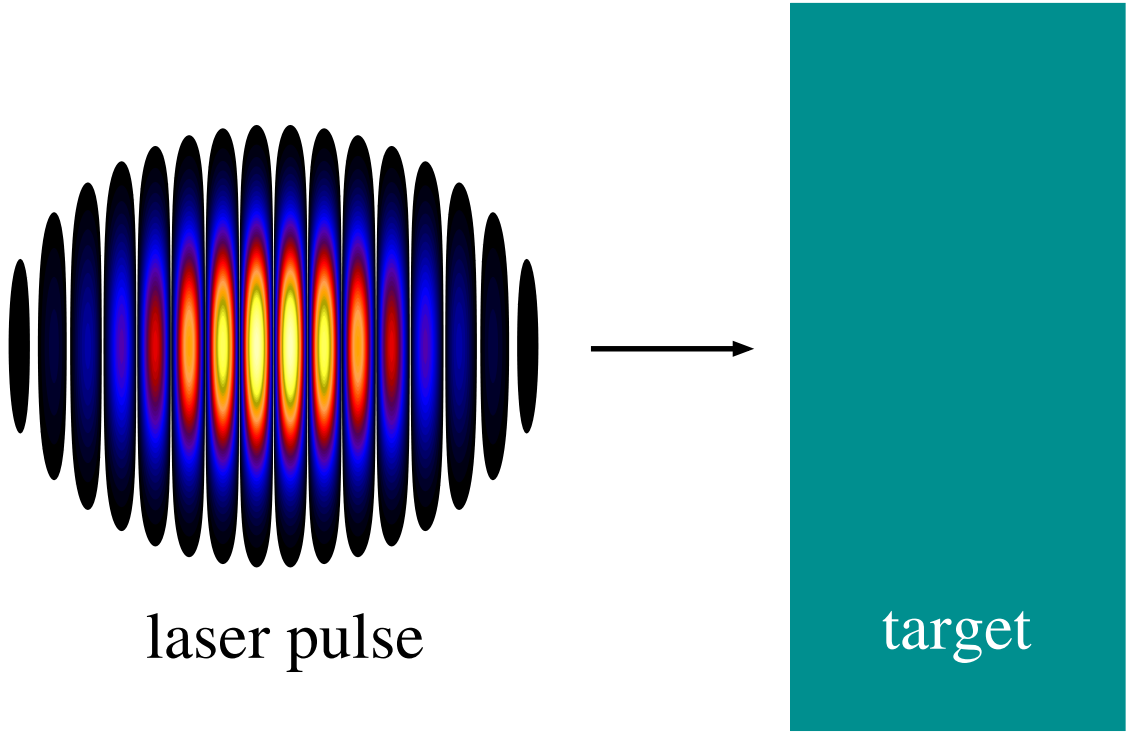

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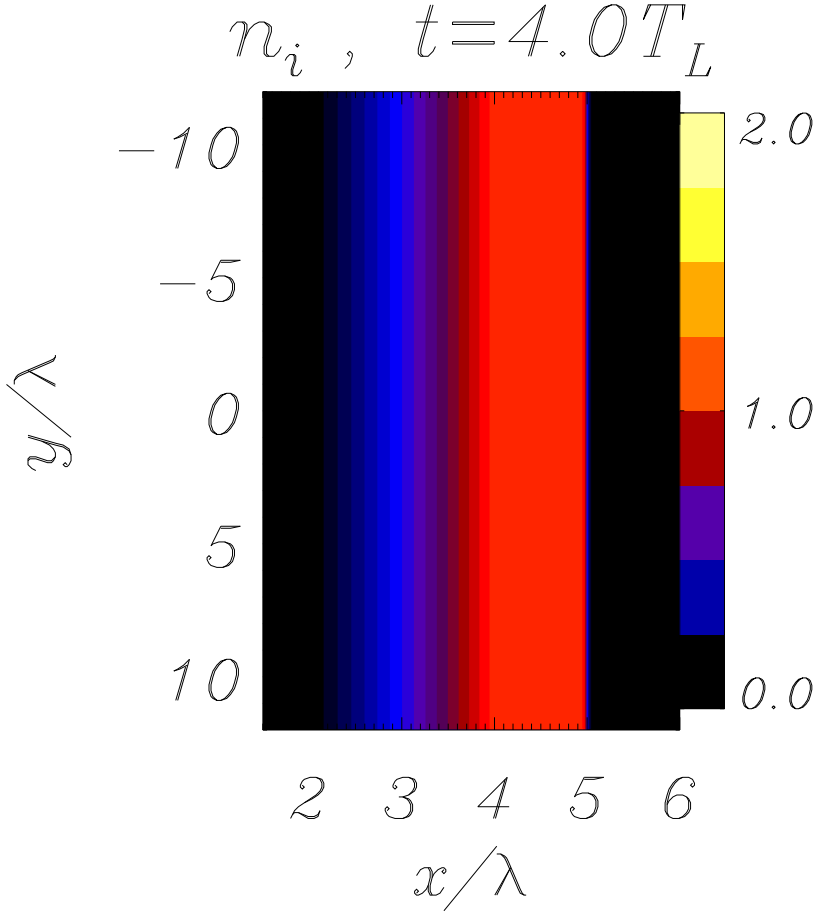

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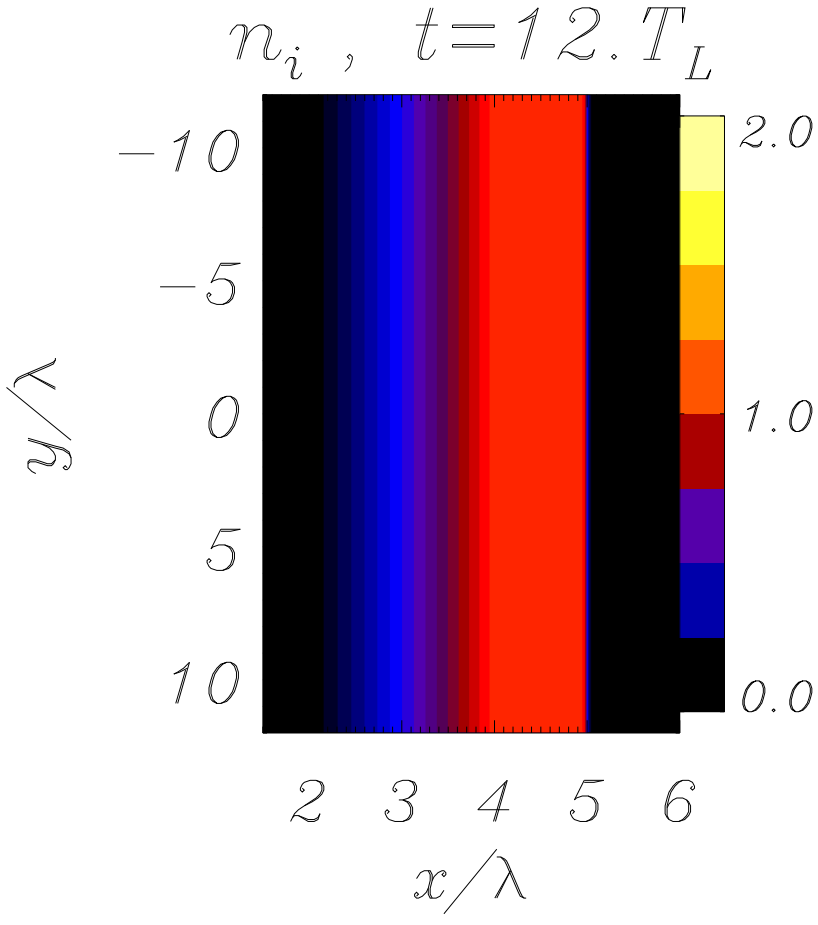

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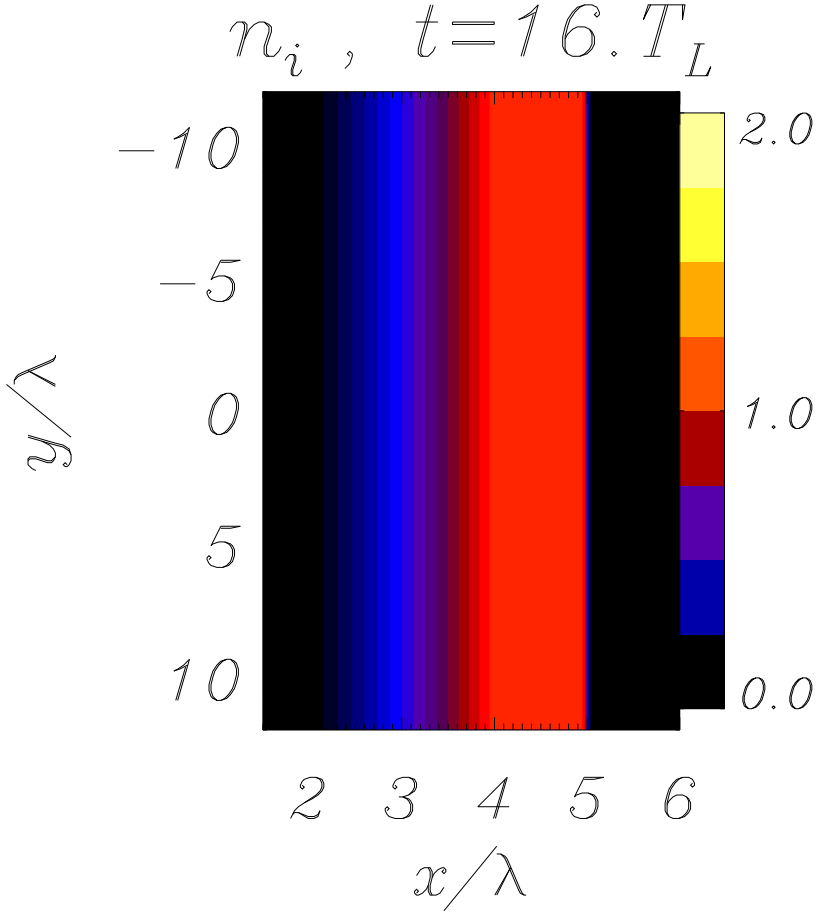

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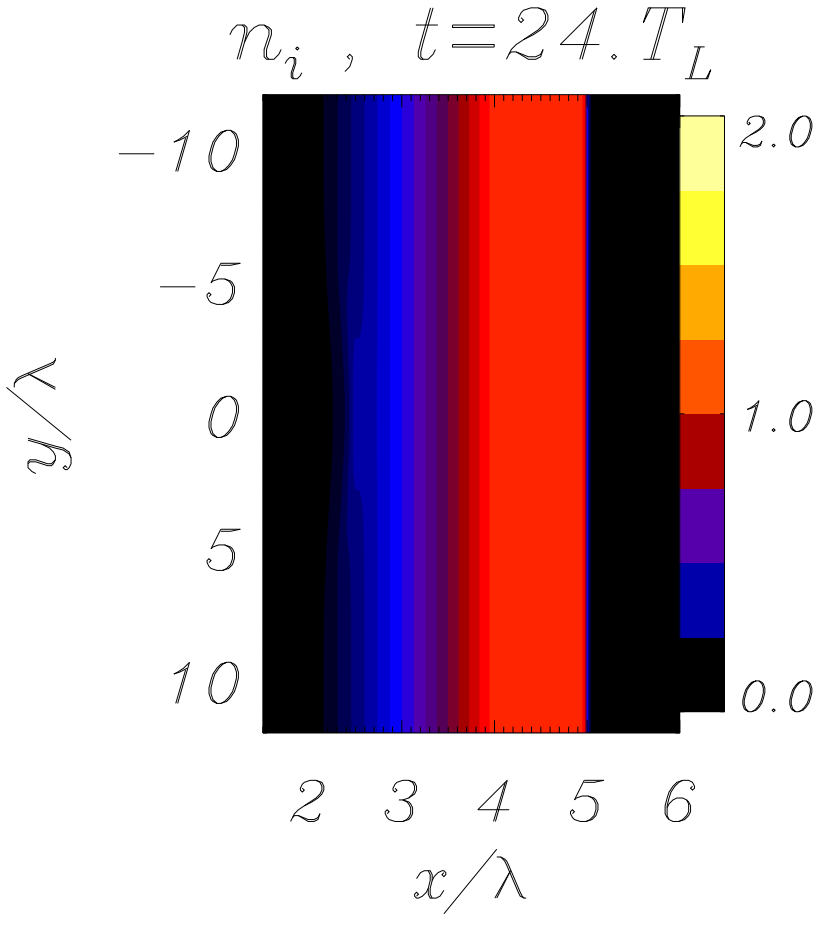

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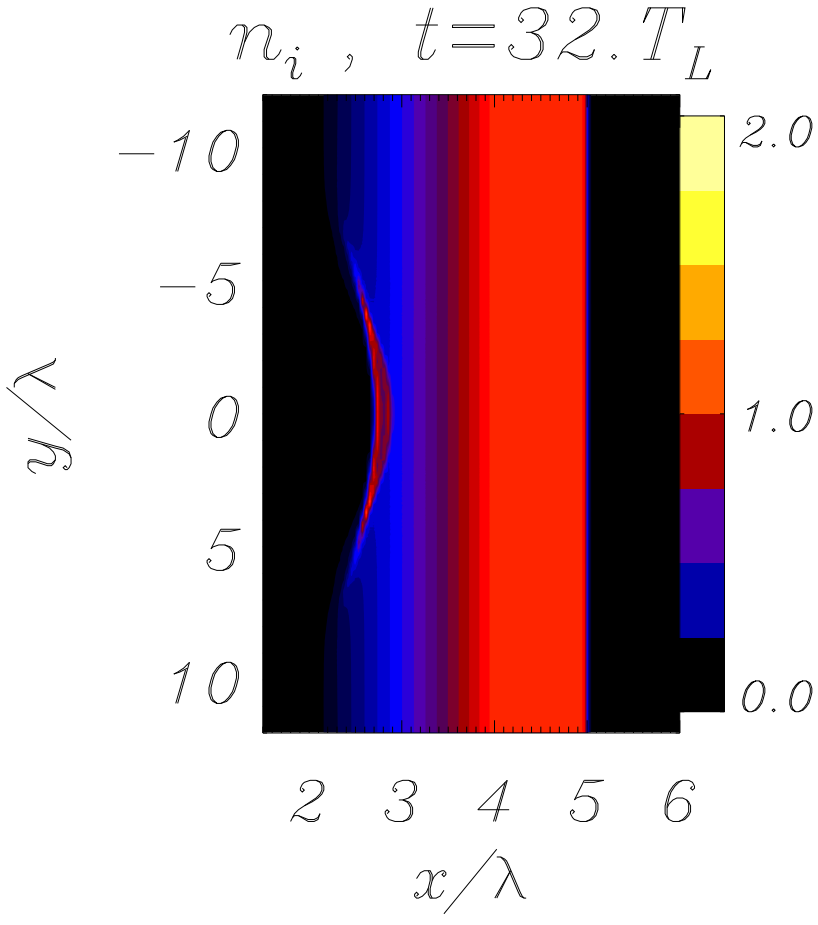

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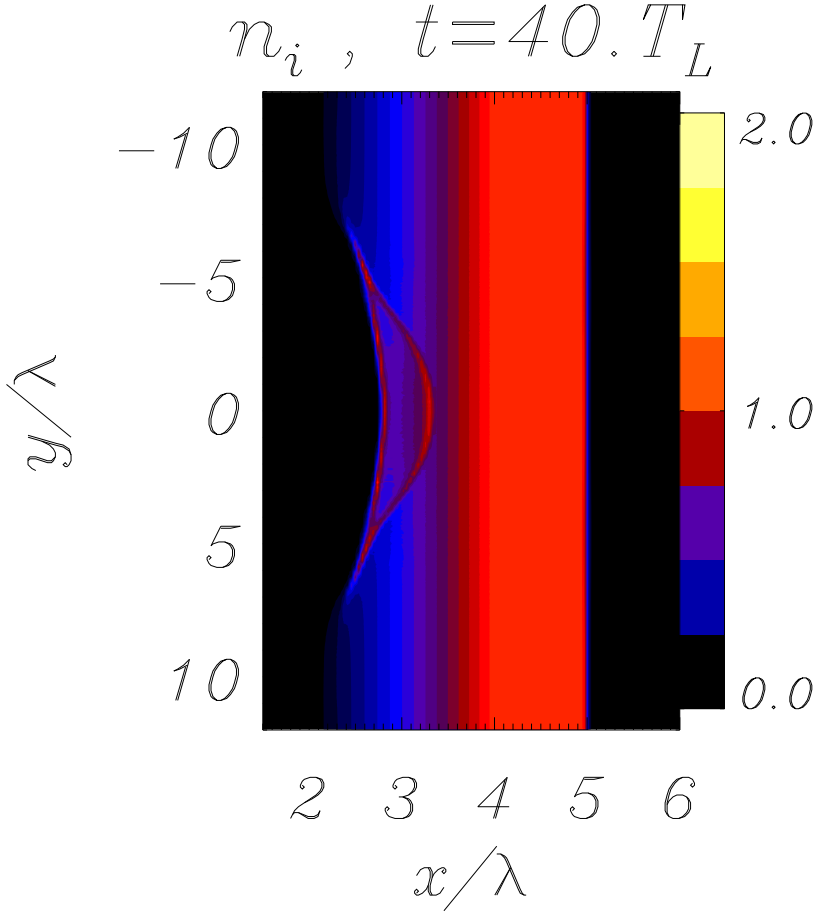

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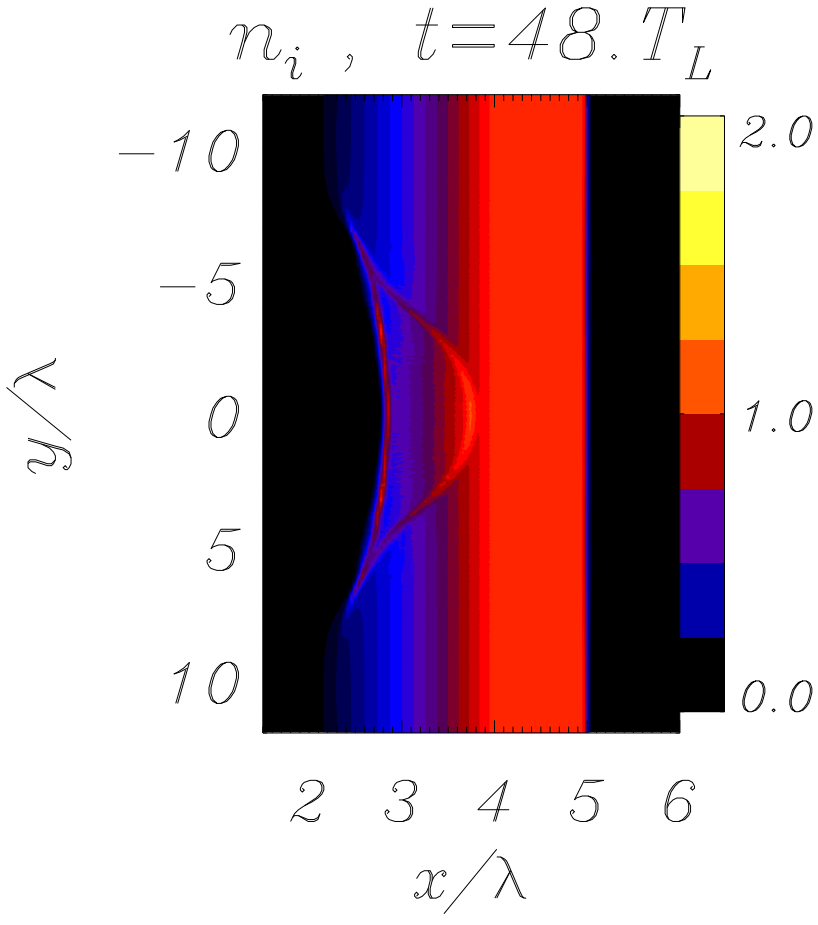

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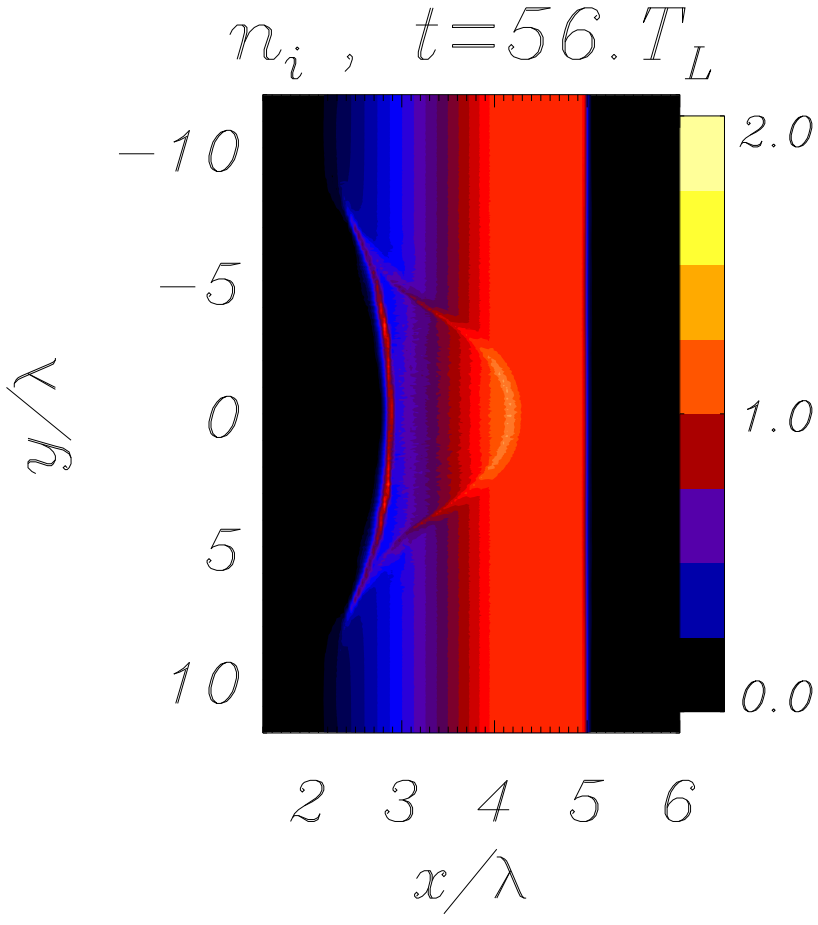

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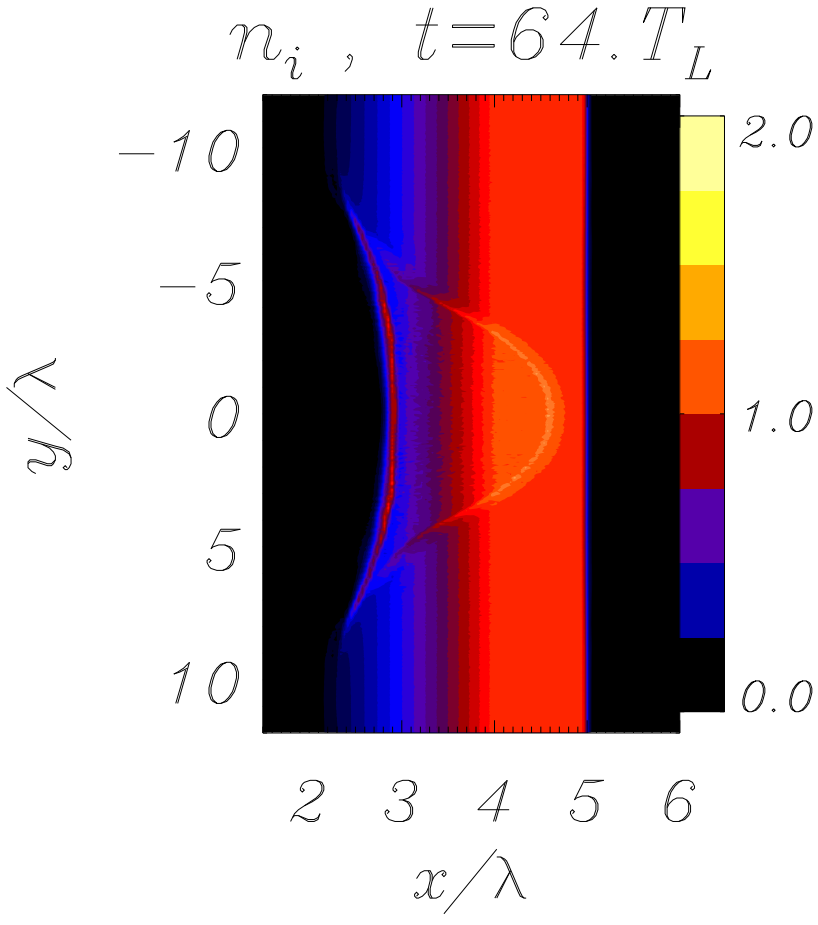

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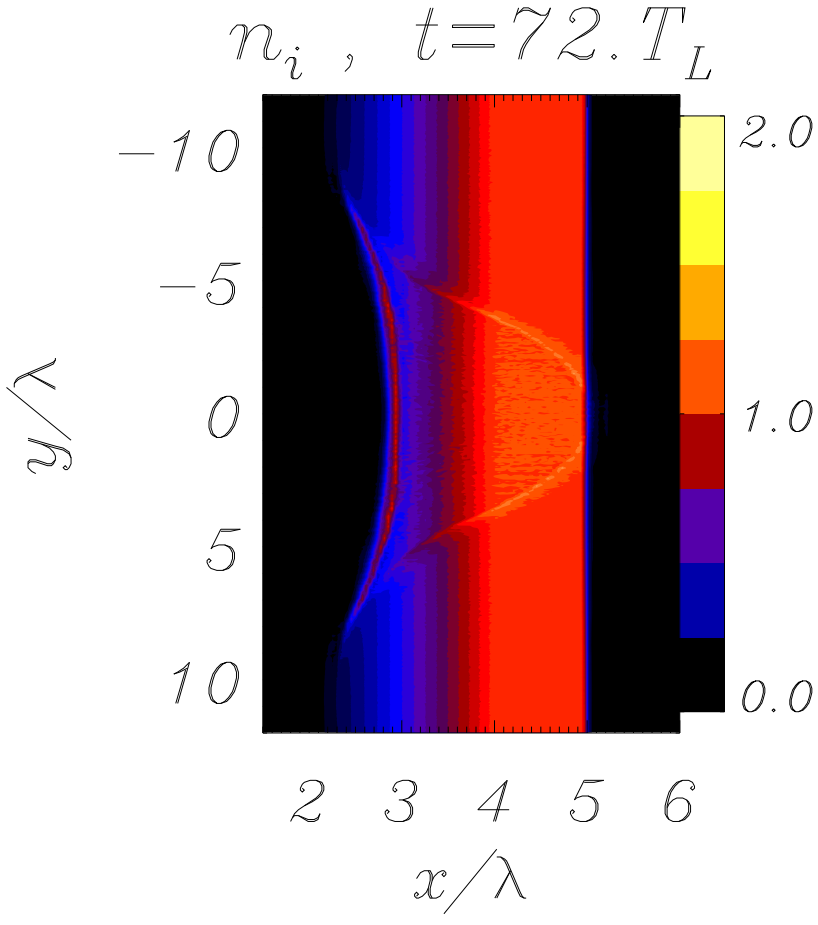

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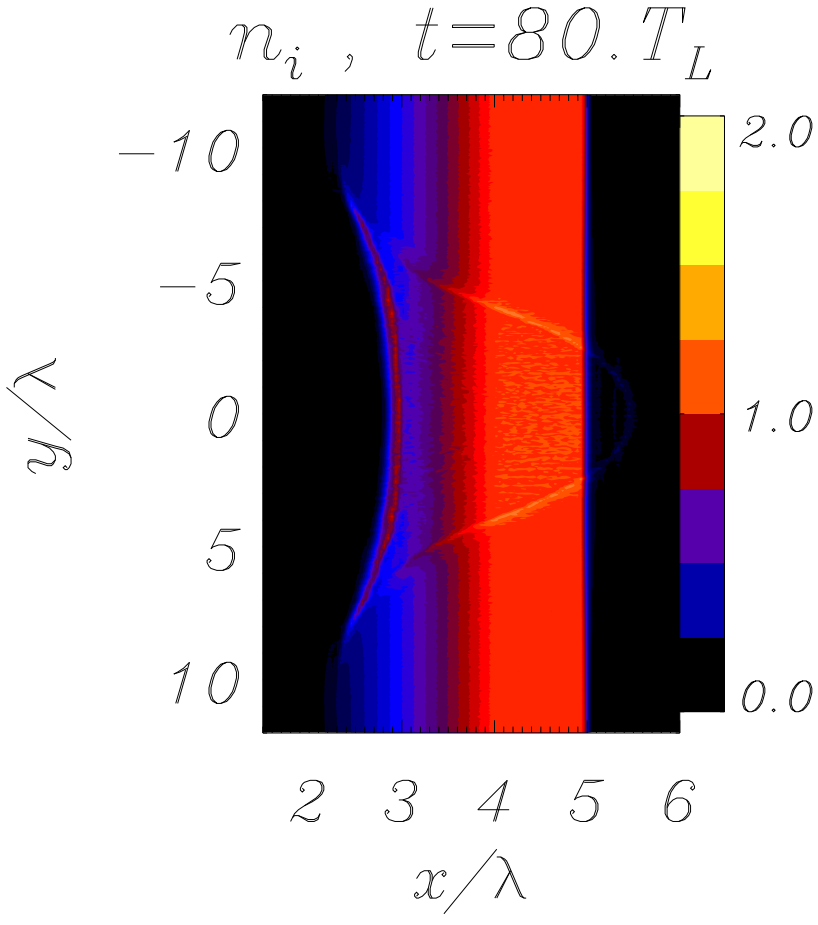

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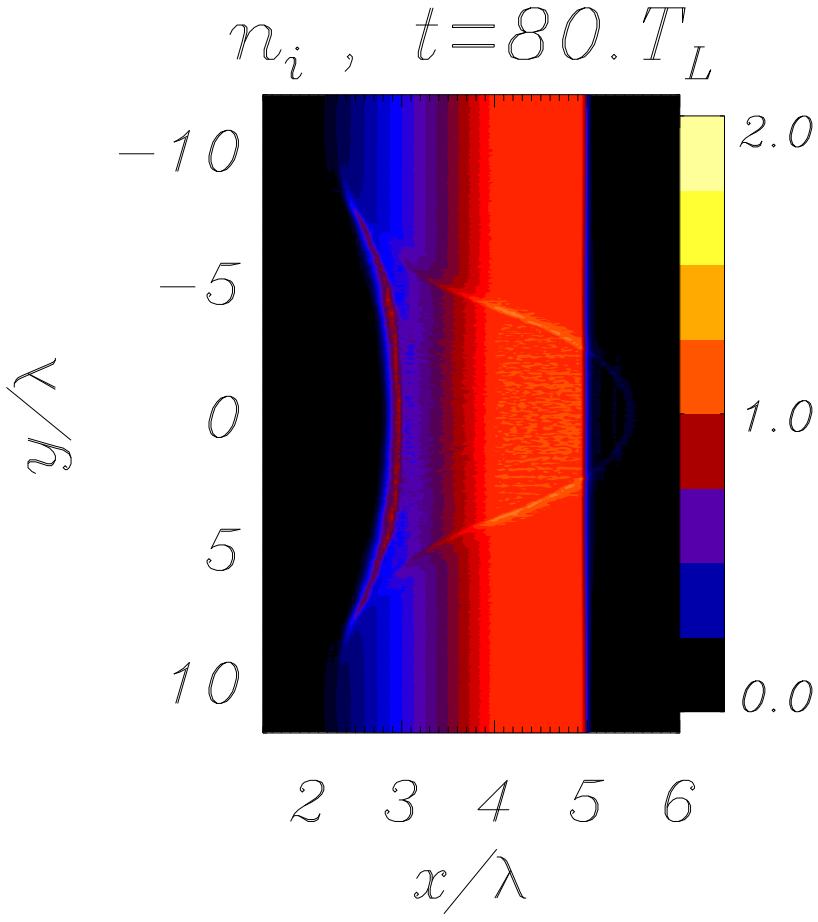

Simulation parameters ($a = 2$, $\tau = 10T_L$) and plasma profile are similar to an experiment at JAERI [Kado et al., Las. Part. Beams **24** (2006), in press] giving preliminar indications of a collimated ion beam without fast electrons (H. Daido, private communication).

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Experimental investigation seems worth!

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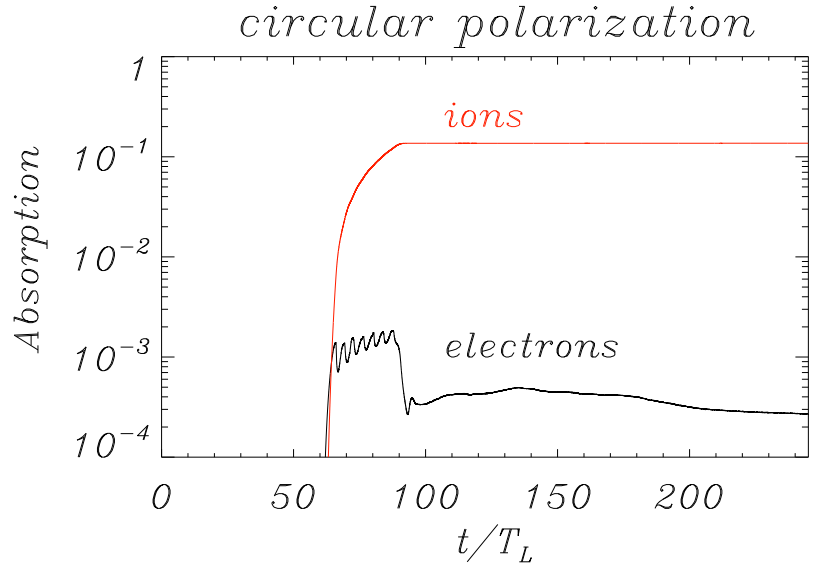

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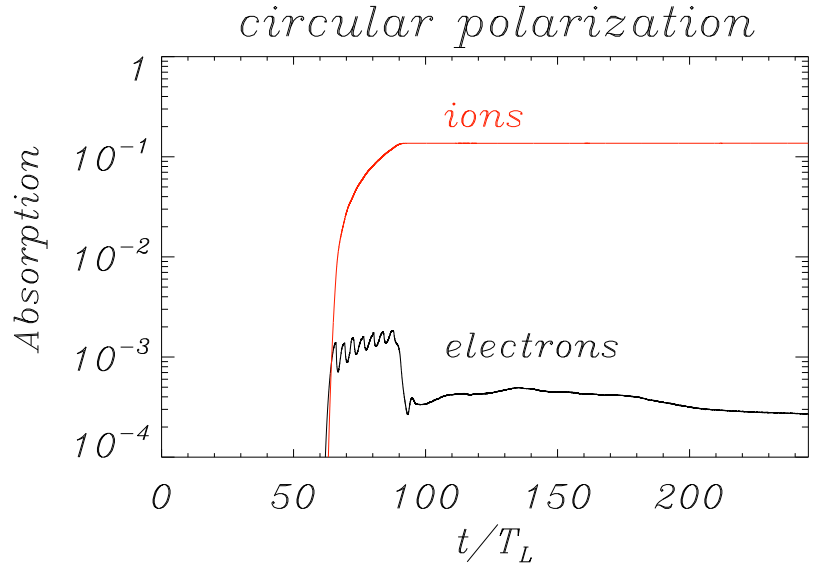

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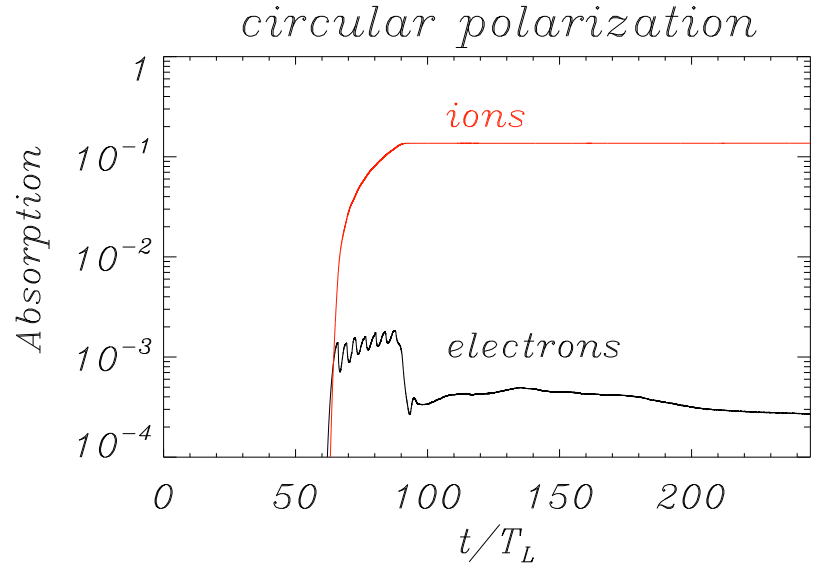

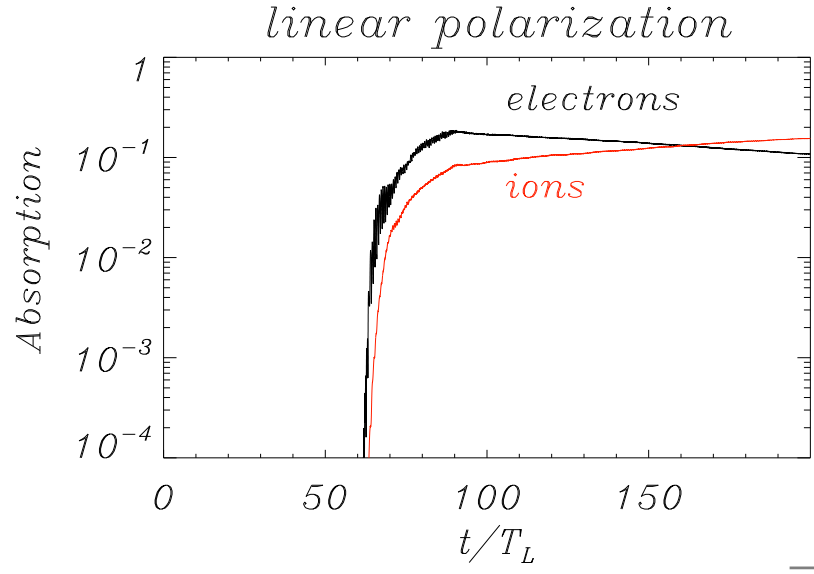

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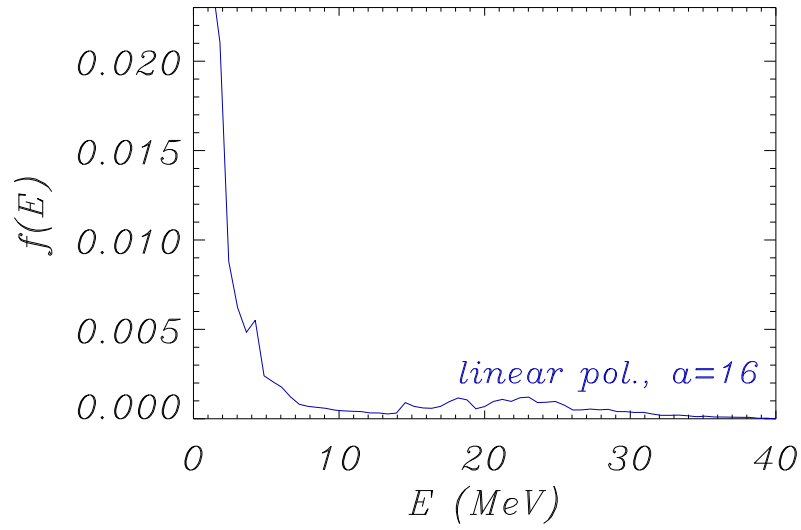

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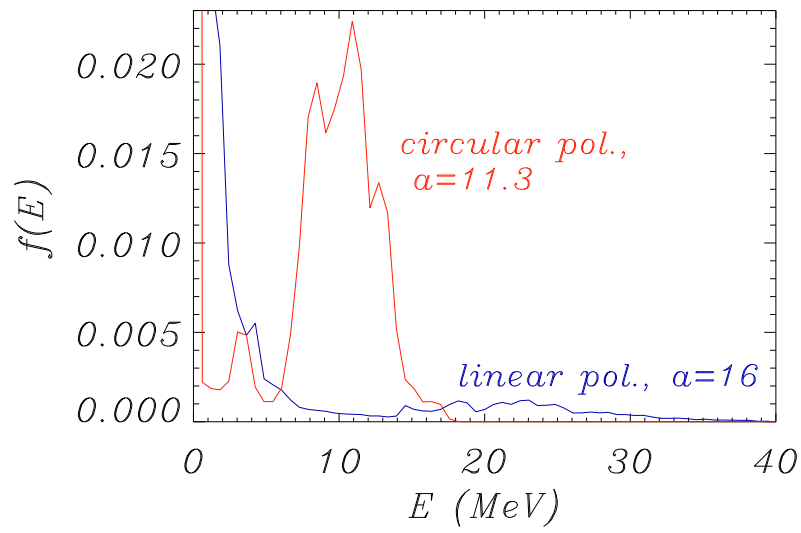

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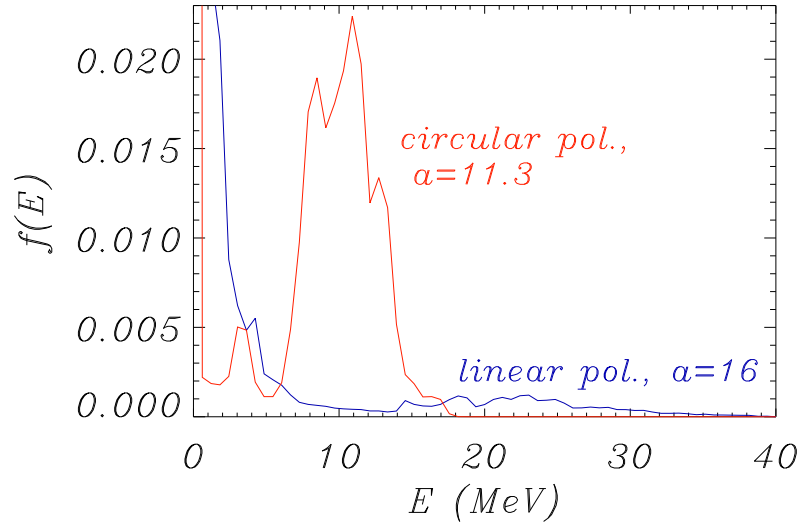

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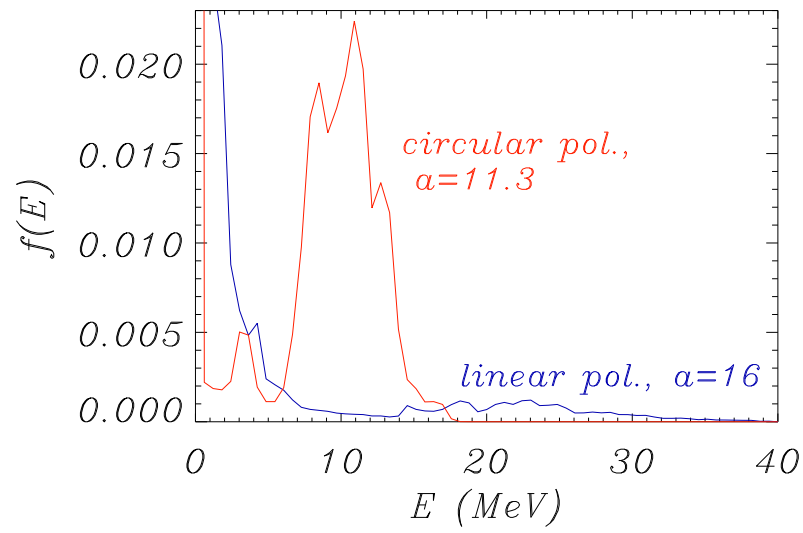

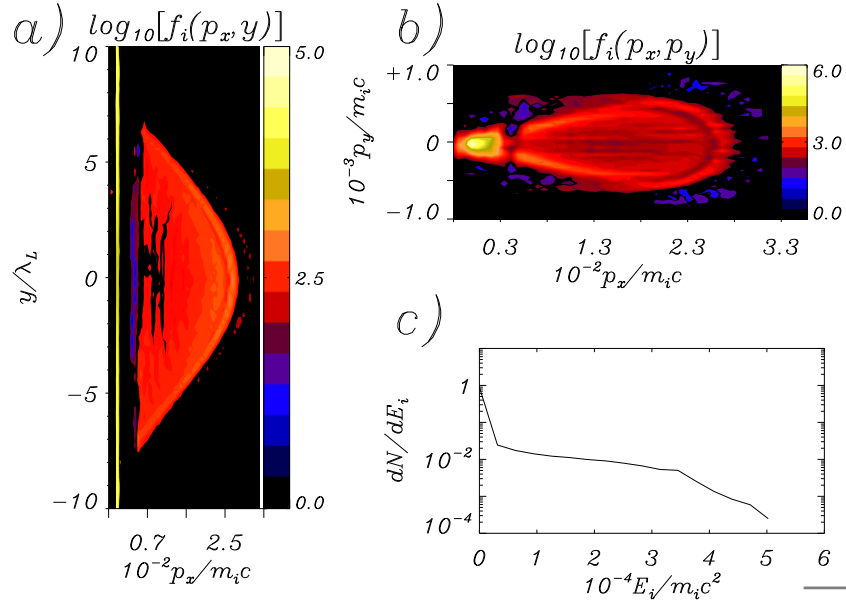

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$\Rightarrow$ One may obtain a significant neutron yield within the bunch duration ~ 1 fs .

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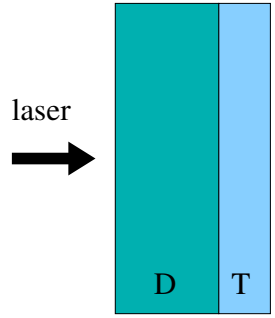

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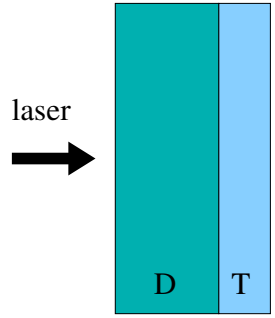

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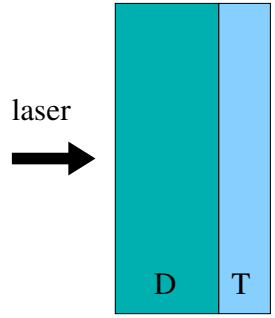

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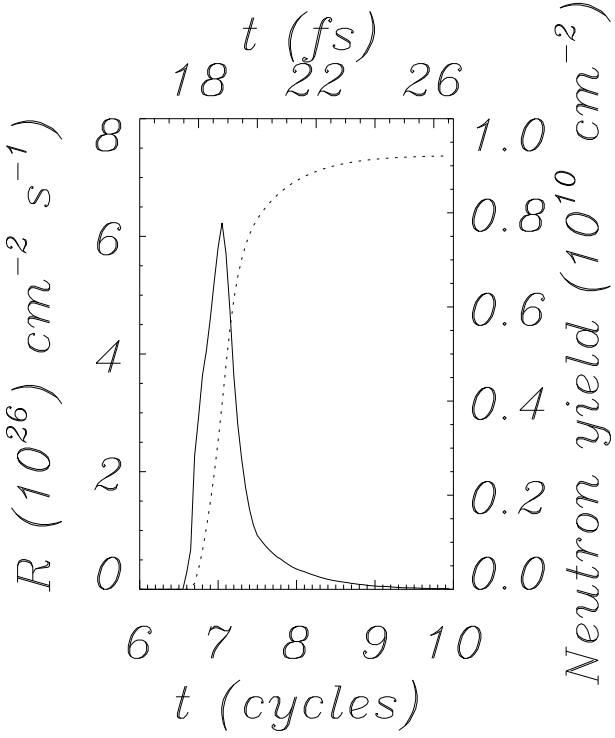

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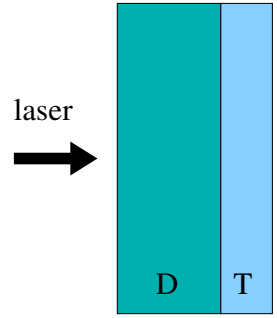

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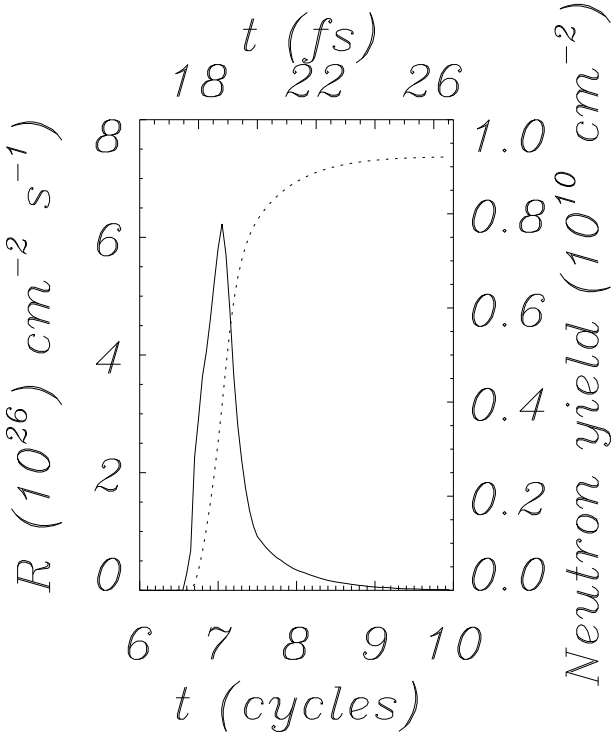

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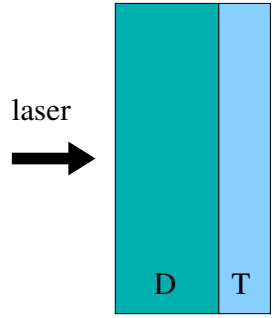

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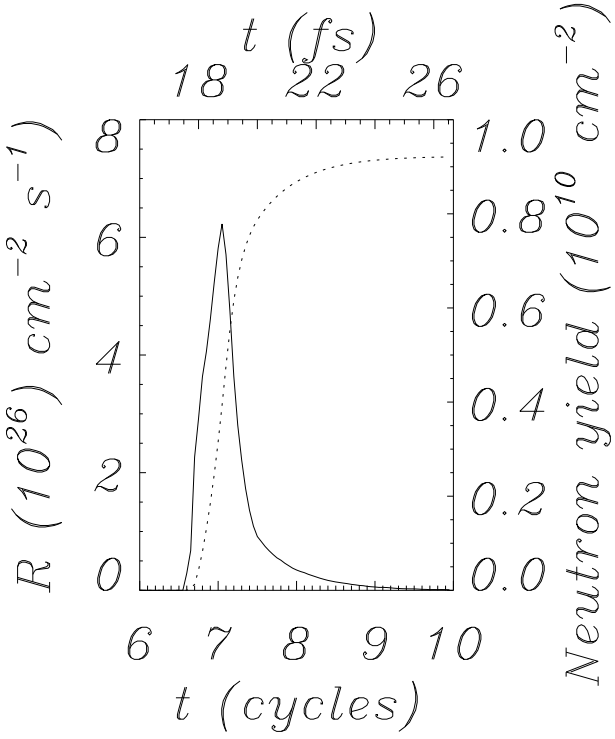

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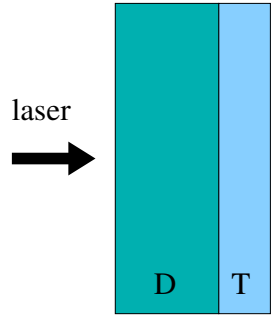

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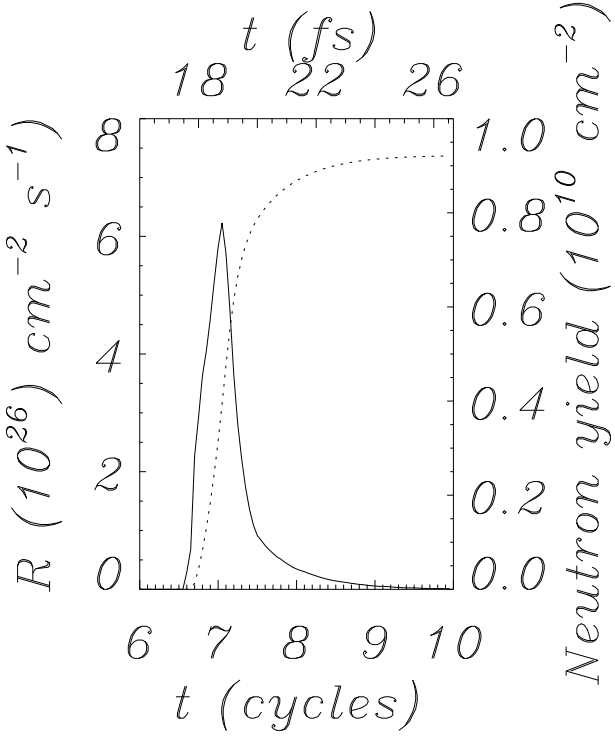

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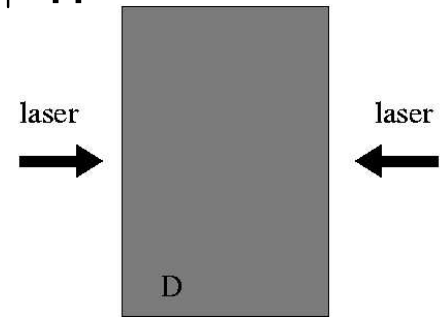

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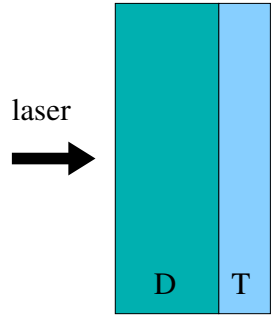

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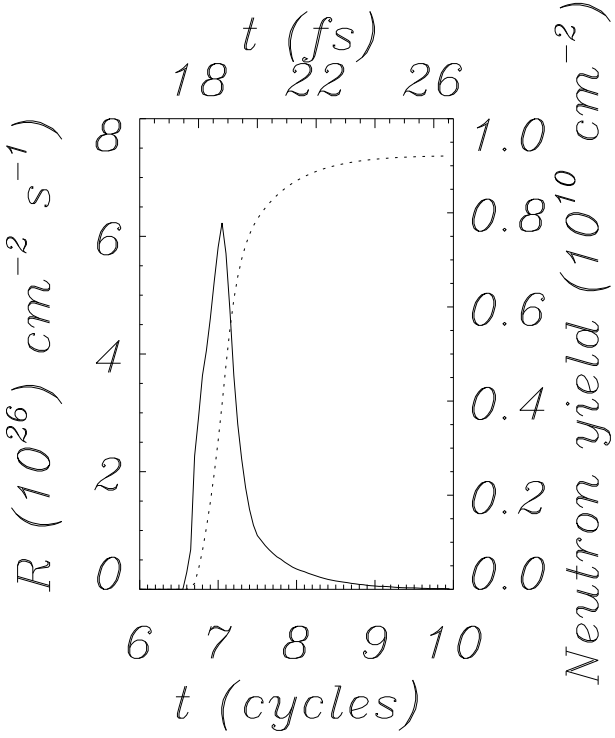

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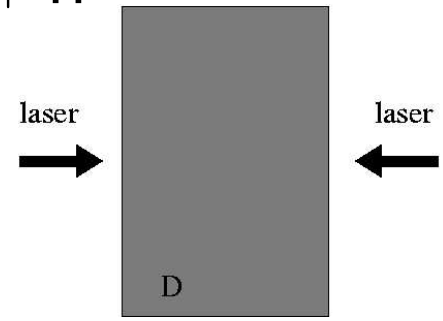
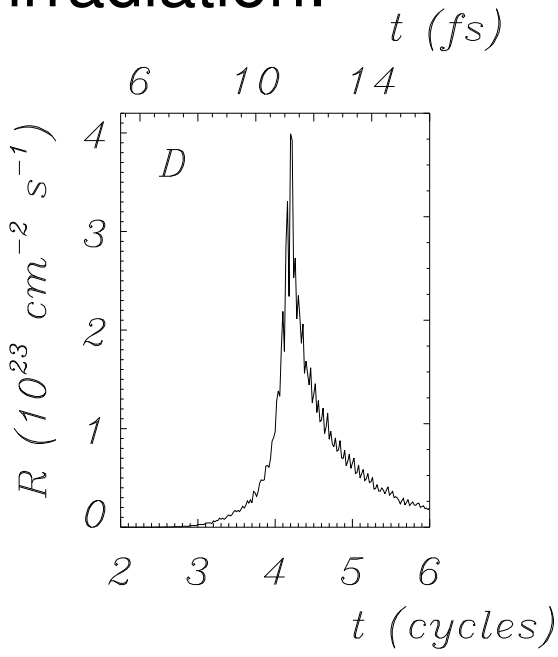


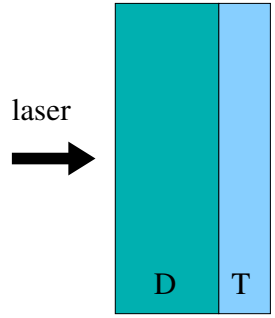


$> 10^6$ neutrons/J in $\tau_n \sim 2$ fs

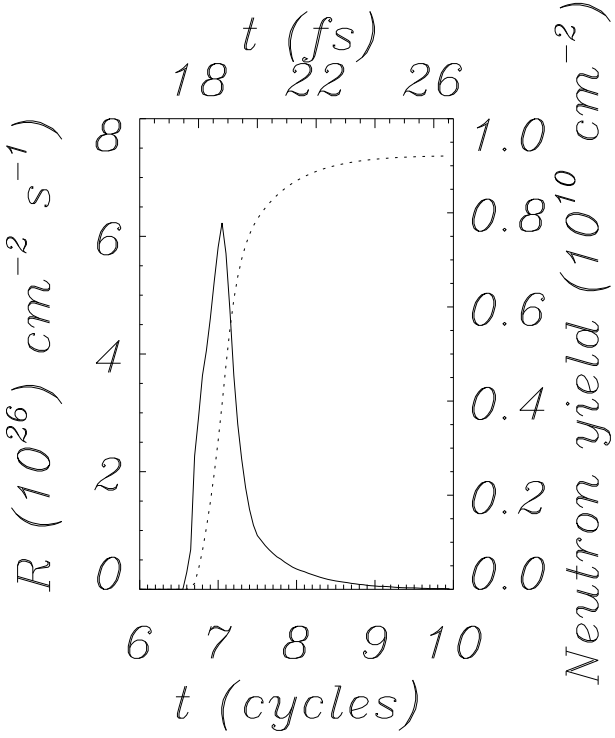
Proposed Schemes: DT, DD

$D + T \rightarrow \alpha + n$

Double layer target:

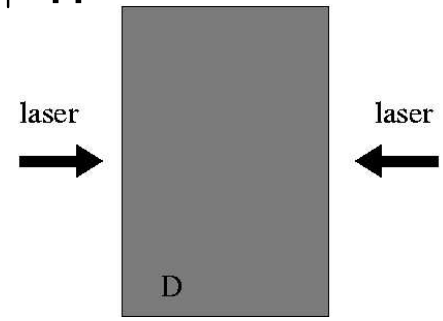


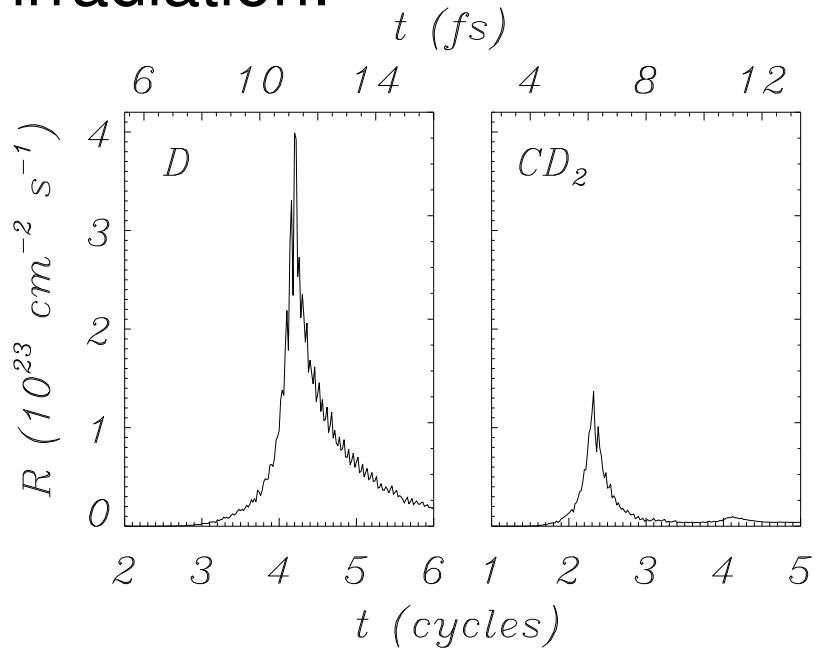
1D PIC simulation (10^{19} W/cm^2, 15 fs pulse)



$D + D \rightarrow {}^3He + n$

Thin foil target, two-side irradiation:





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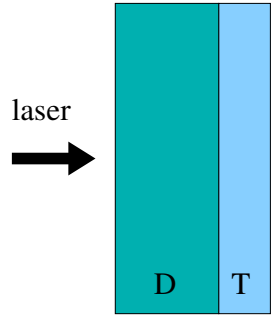

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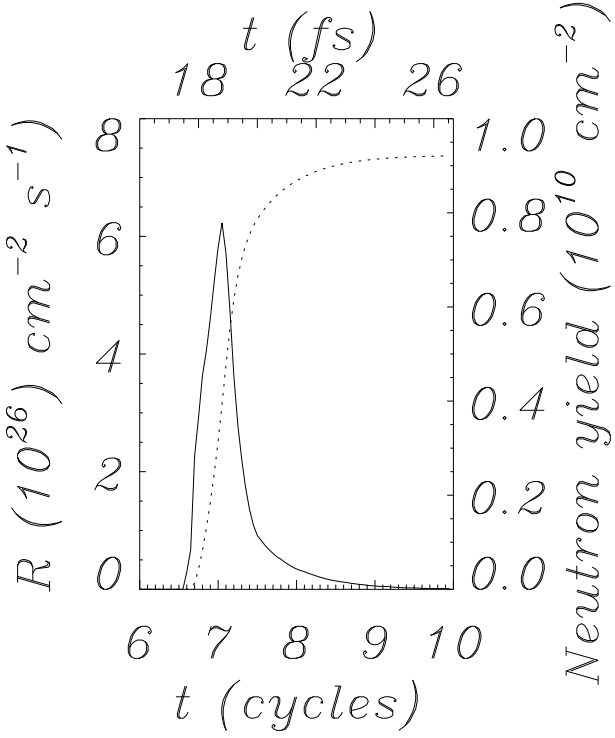

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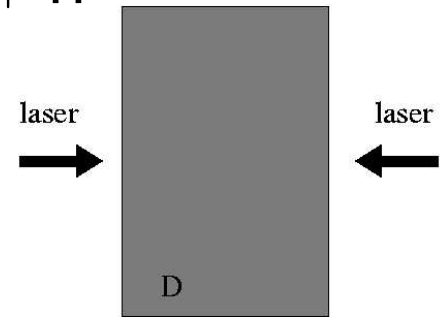

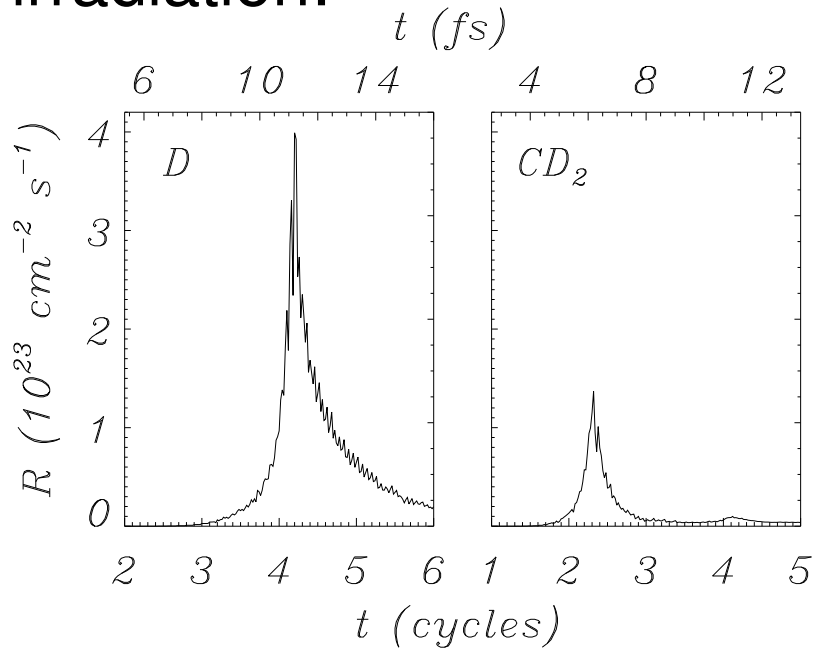

$\sim 10^2$ J^{-1} (CD_2) in $\simeq 0.7$ fs

Conclusions

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References

References

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