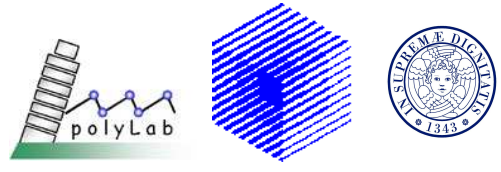
Laser Acceleration of Ultrashort Ion Bunches and Femtosecond Neutron Sources

Andrea Macchi

macchi@df.unipi.it

polyLAB, INFM-CNR, University of Pisa, Italy



Coworkers

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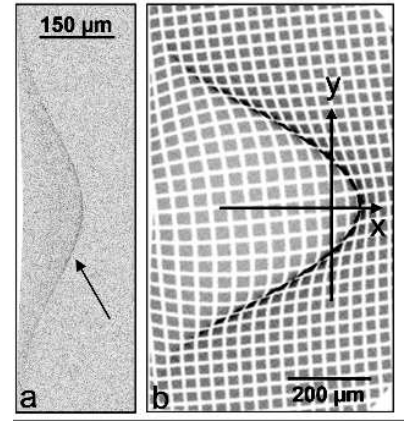

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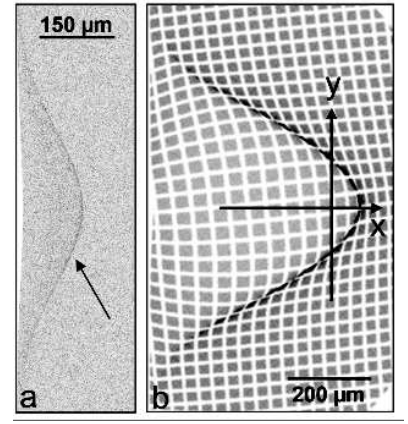
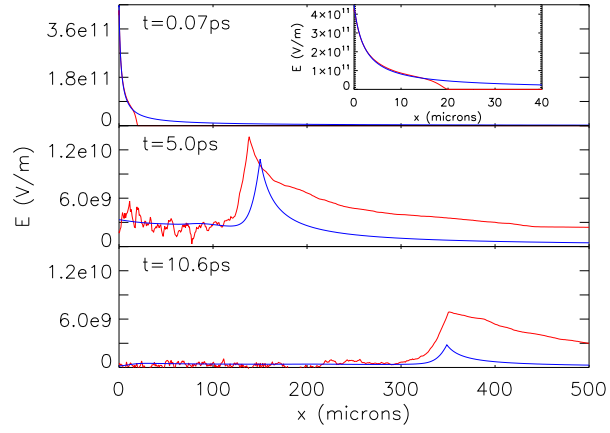


Modeling:
Mora, PRL **90**, 185002 (2003)
Betti, Ceccherini, Cornolti, Pegoraro,
Plasma Phys. Contr. Fus. **47**, 521 (2005)
(*see talk by P. Mora*)



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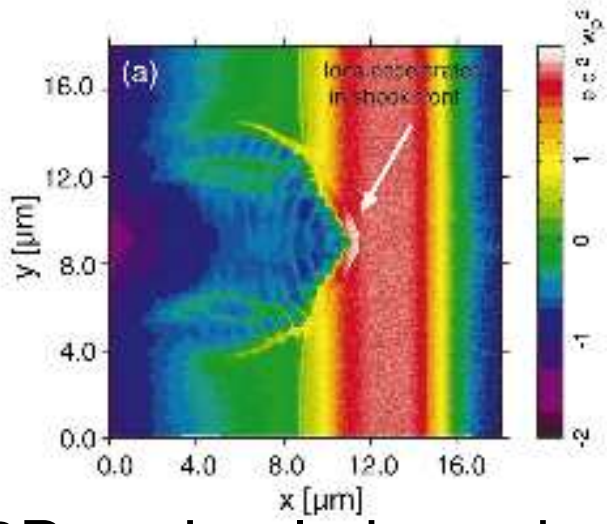

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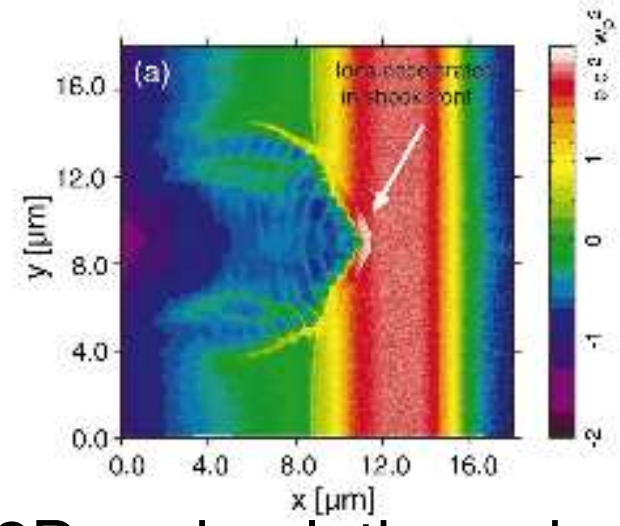

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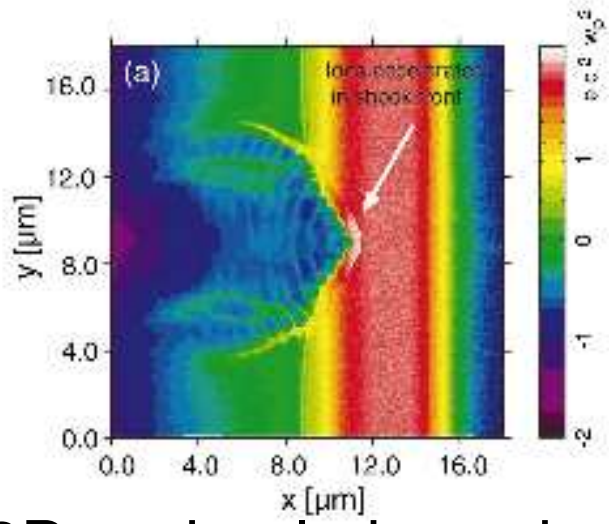

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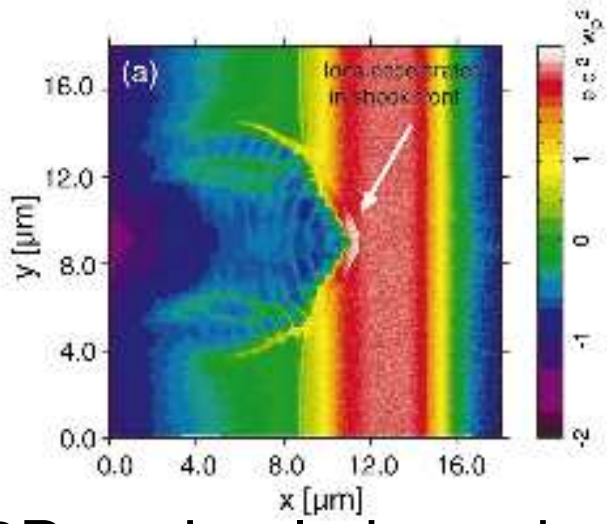

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Is FSA also related to fast electrons?

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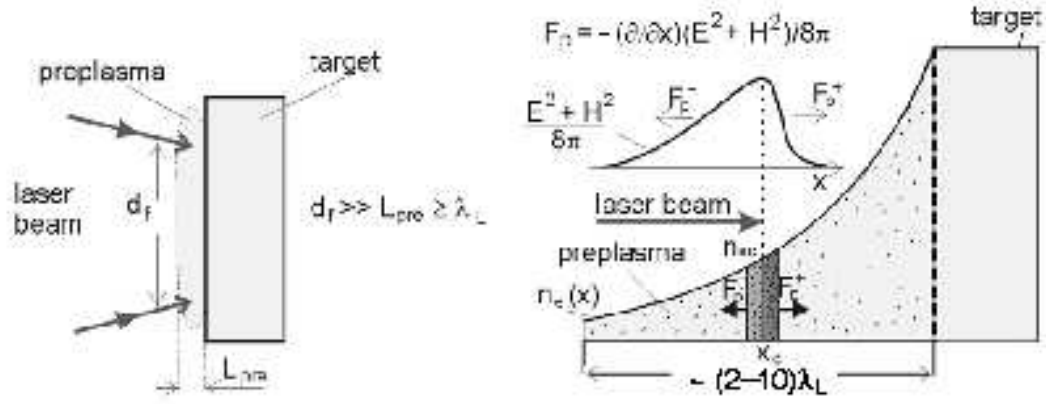
Concept: the steady ponderomotive force accelerates "plasma blocks" of high density and moderate energy ($\sim$ 0.01 MeV/nucleon) at the critical surface.



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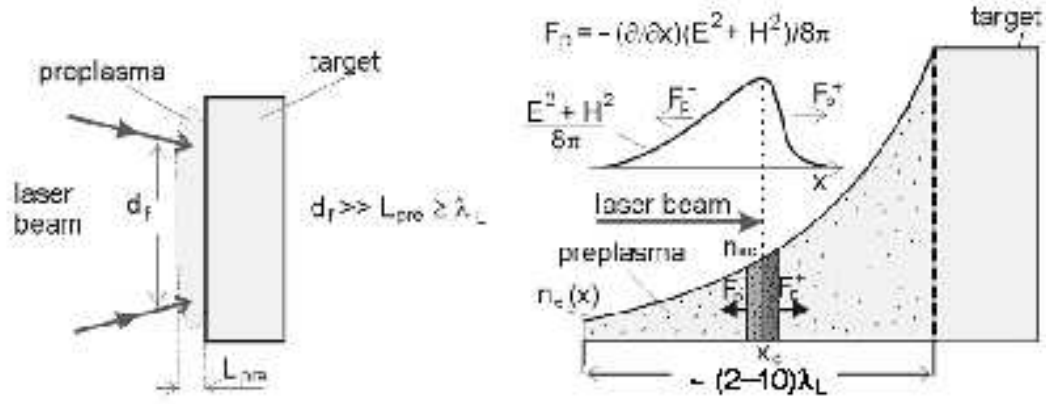

Role of fast electrons, scaling to higher intensity, competition/overlap with FSA are yet to be understood.

A simulation example

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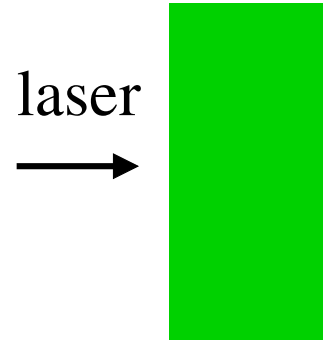
1D PIC simulation, “long” pulse,
normal incidence, linear polarization,
$a = 2.0$, $n_{e0}/n_c = 5$.



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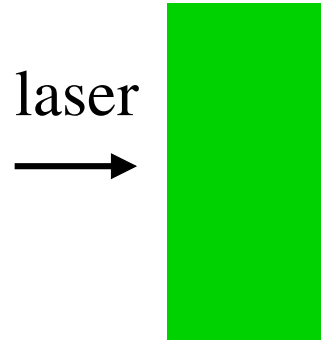

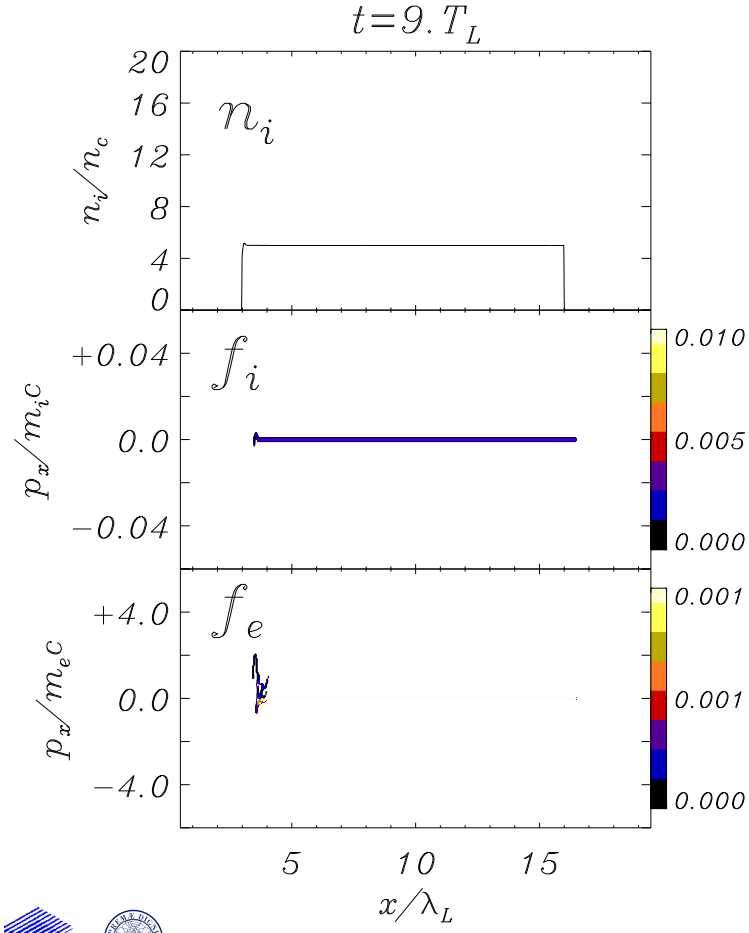

- Interaction starts

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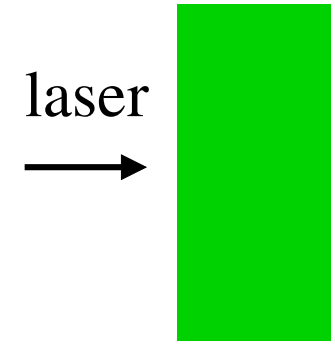

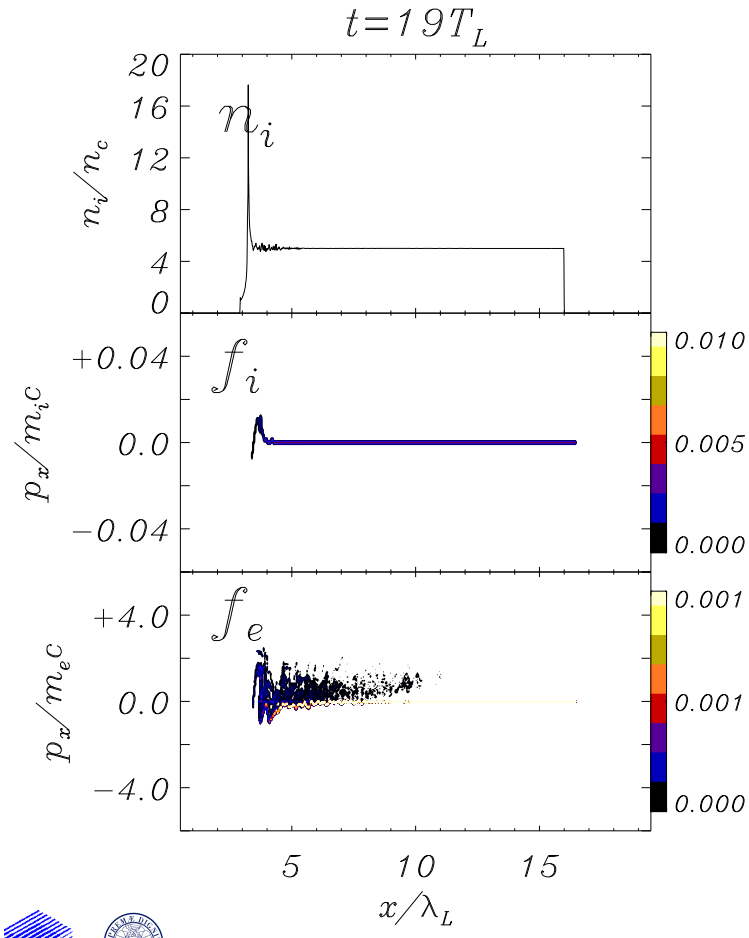

- Interaction starts
- generation of fast electrons + ion spikes at front

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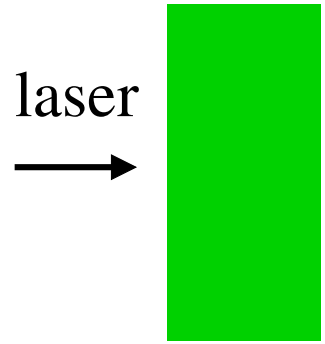

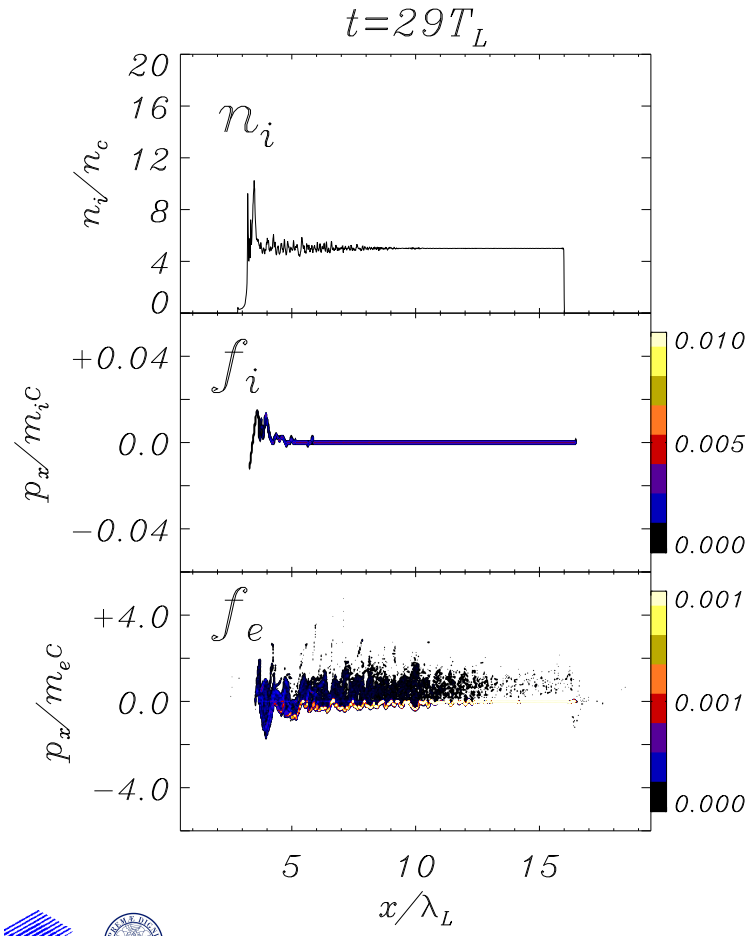

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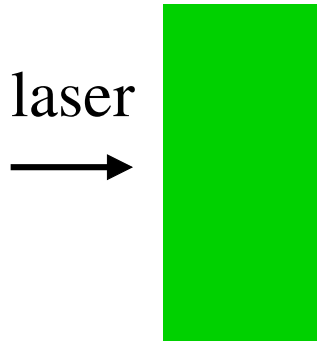

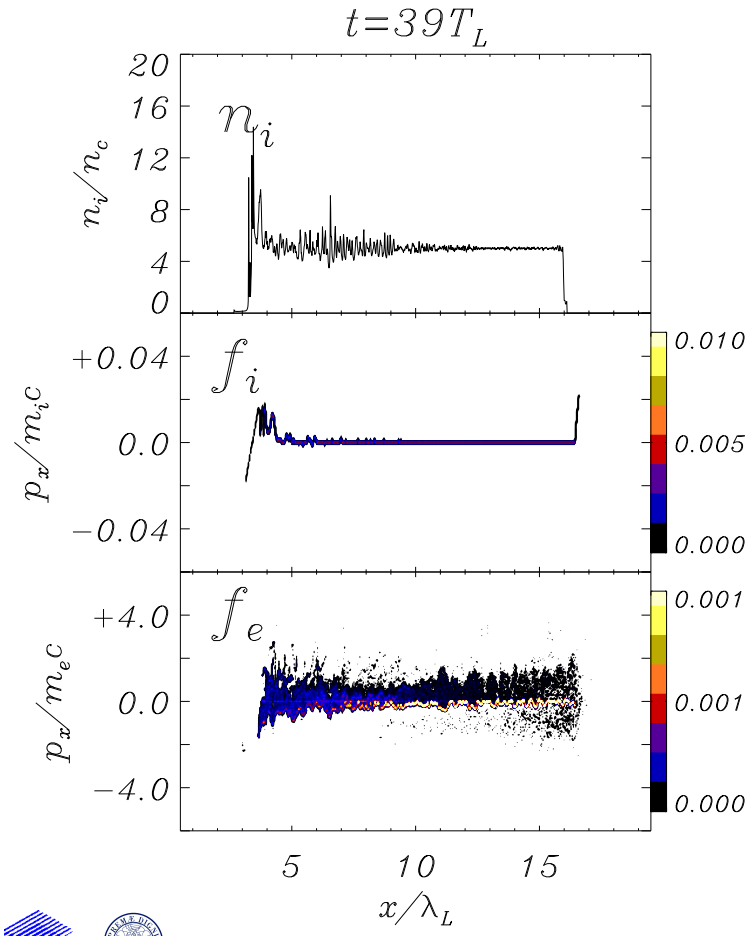

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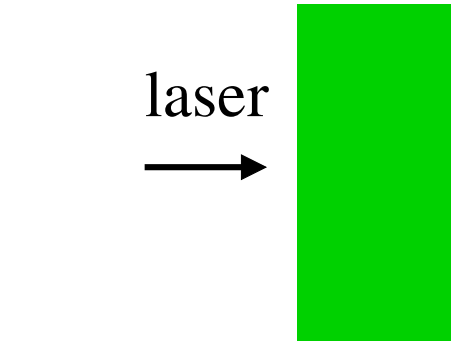

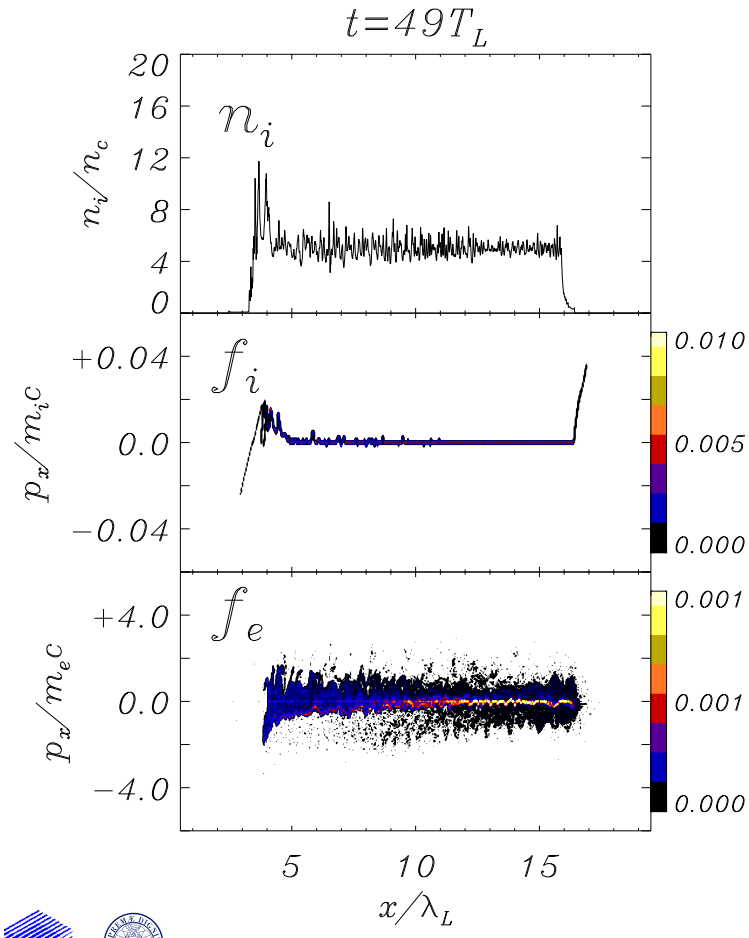

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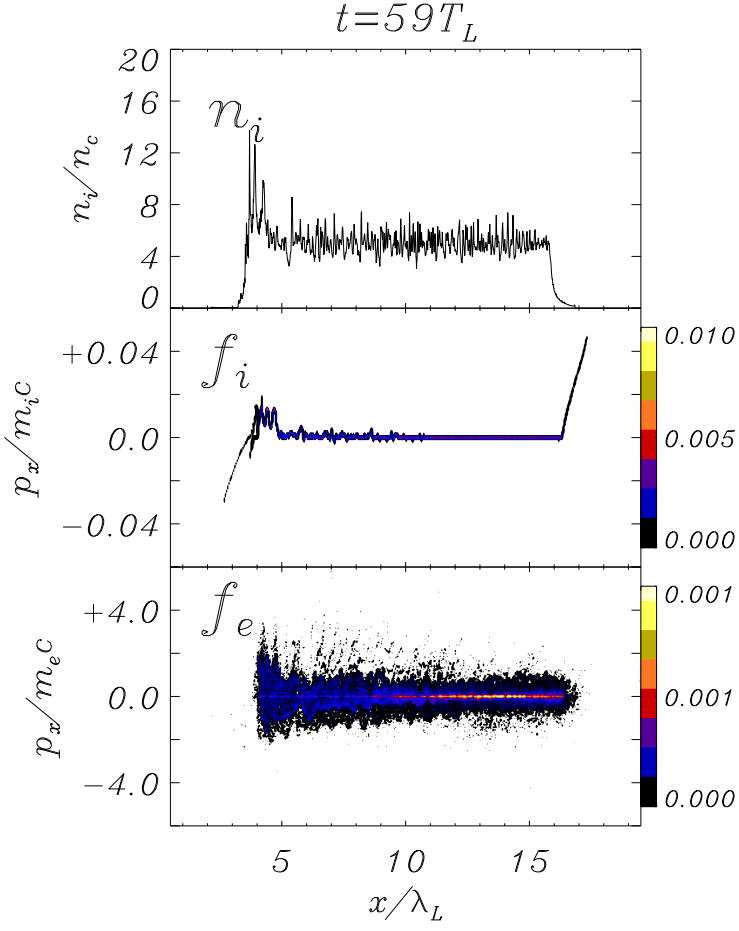

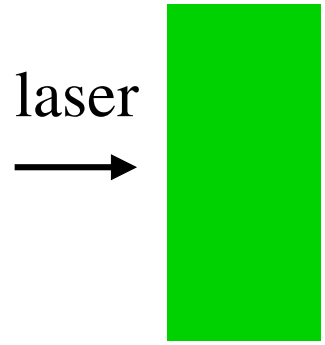

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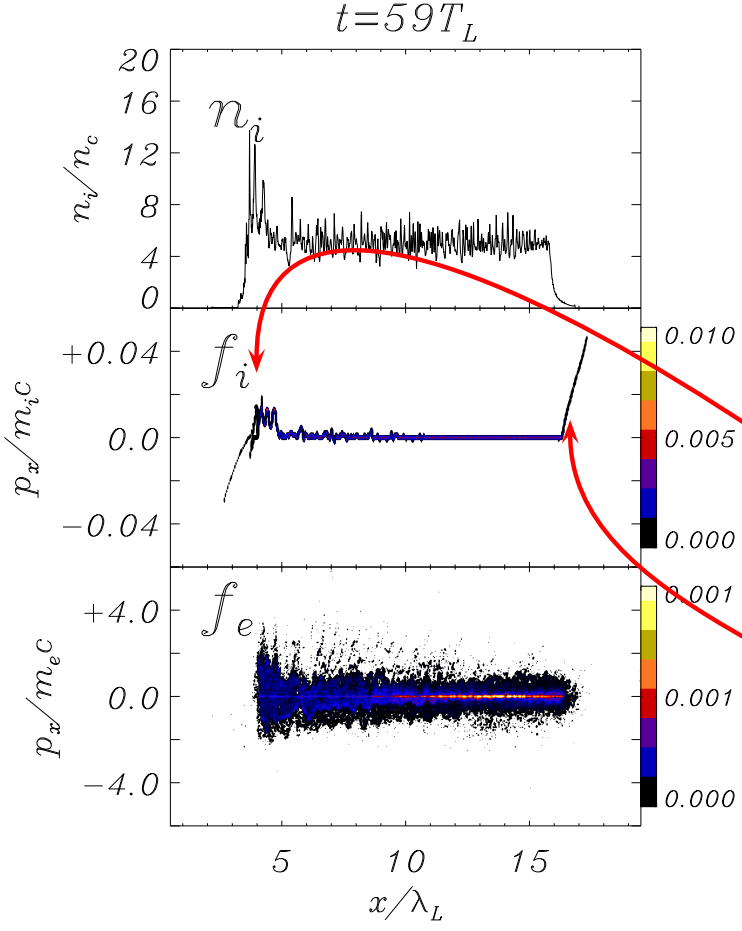

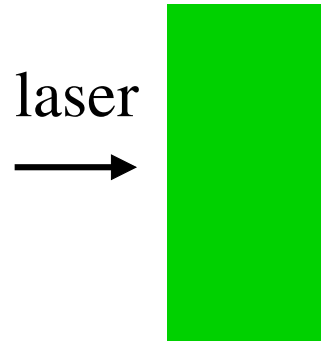

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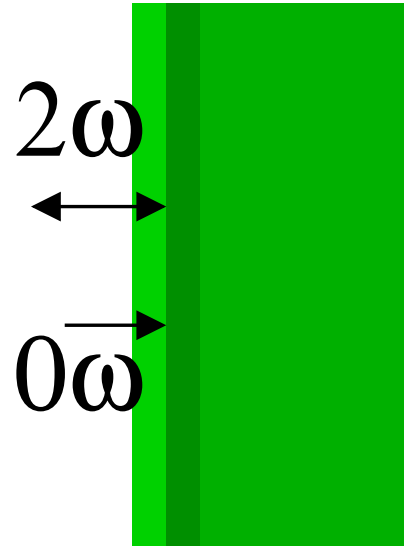

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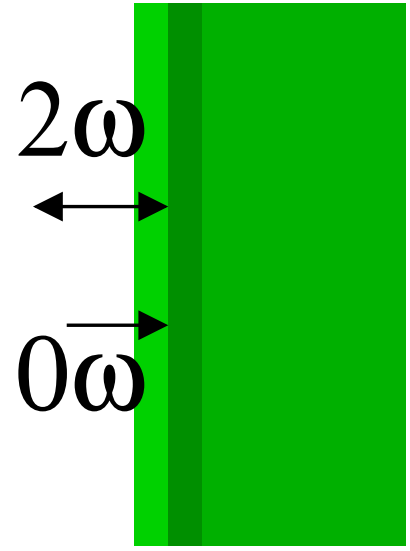

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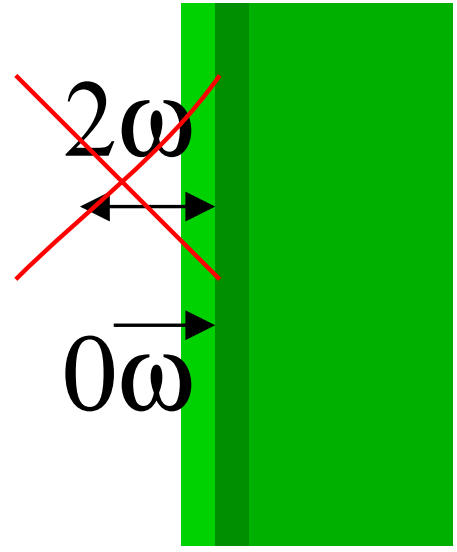
- Does ion acceleration occur for circular polarization, and how does it look like?



Ion bunches

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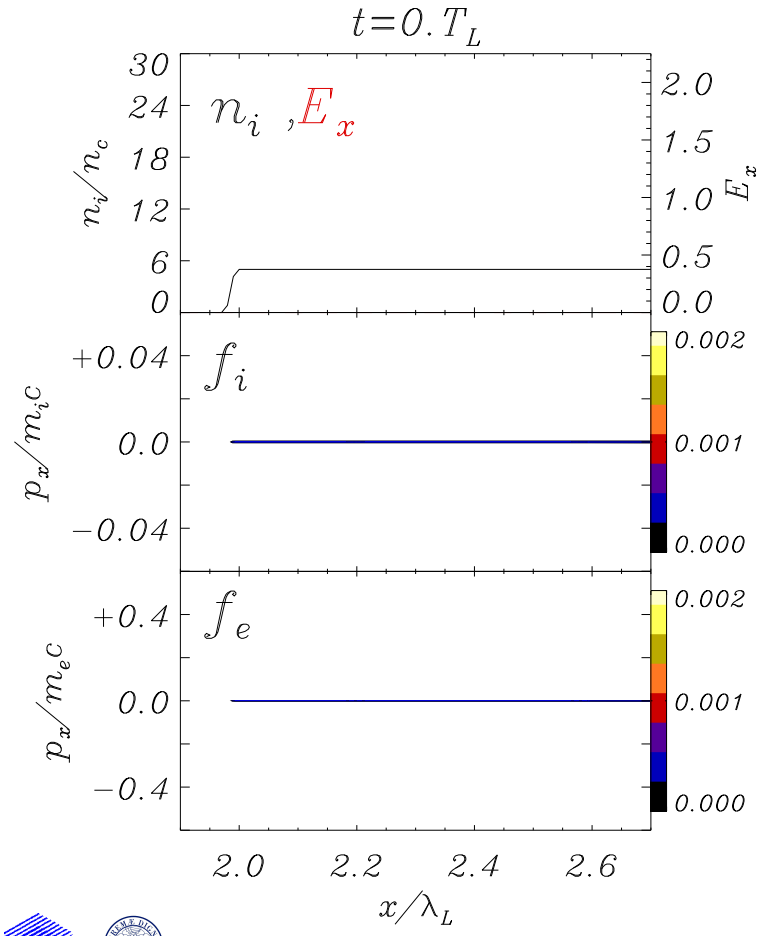

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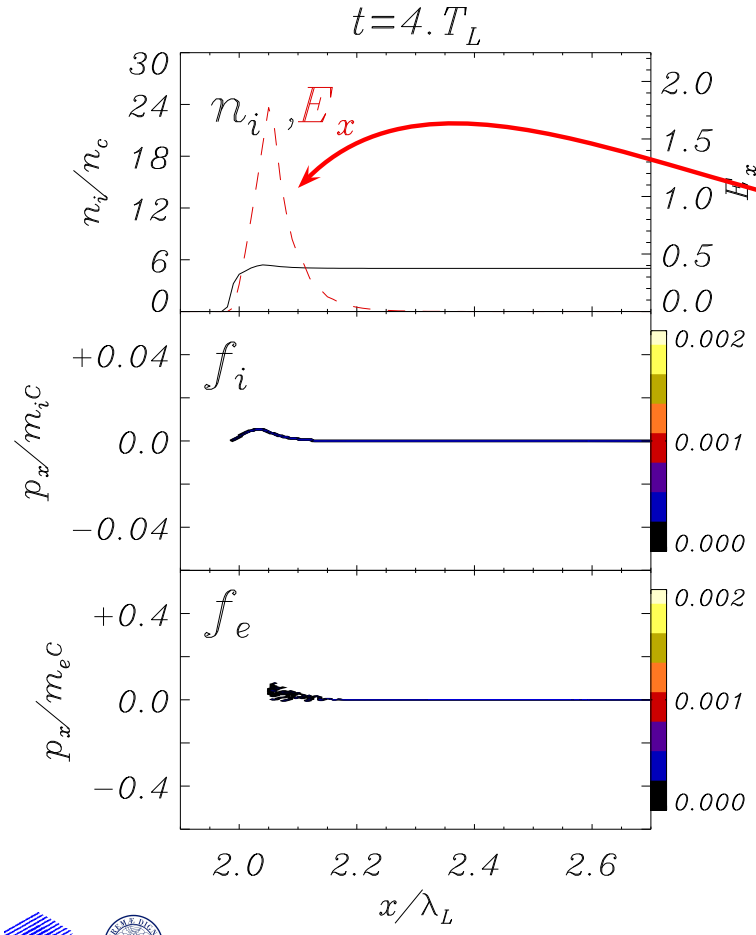

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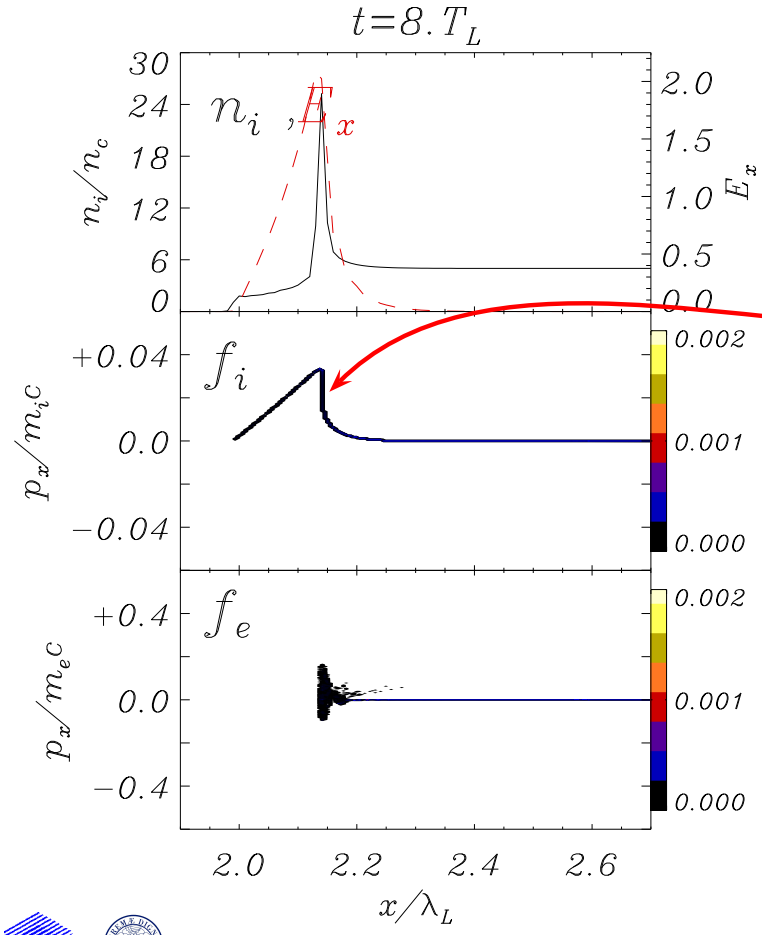

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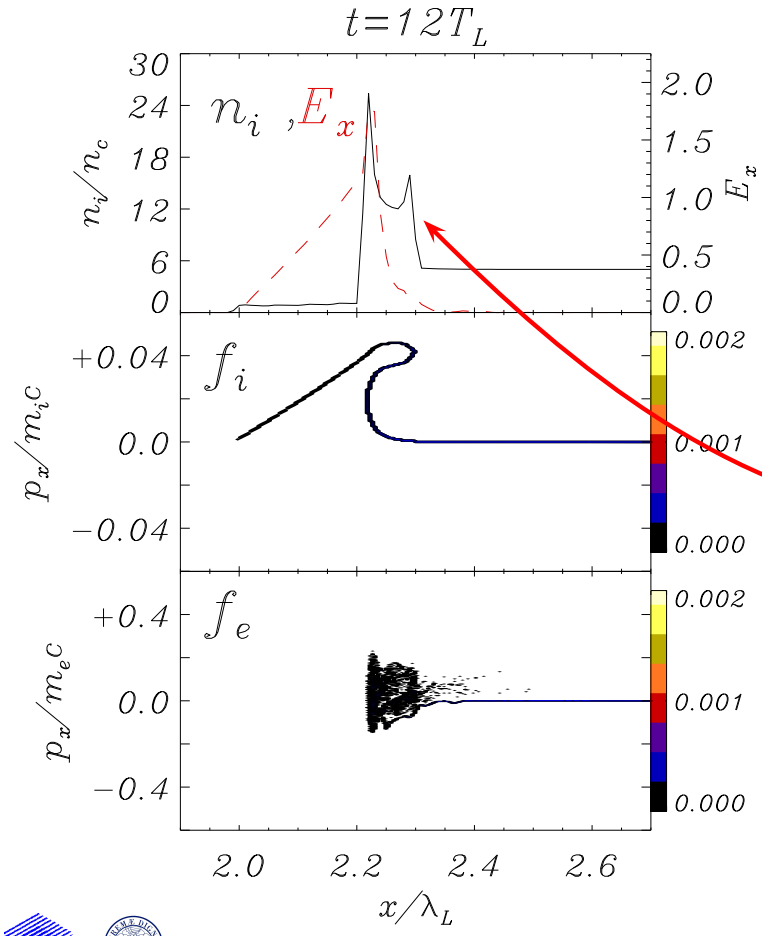

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- electrostatic field created
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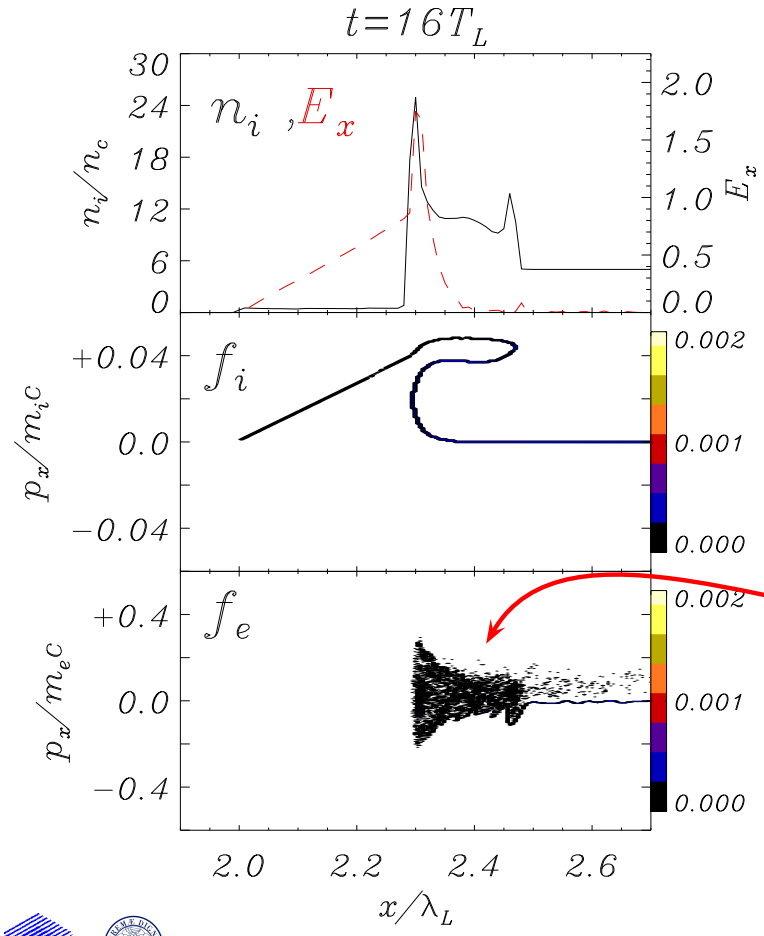

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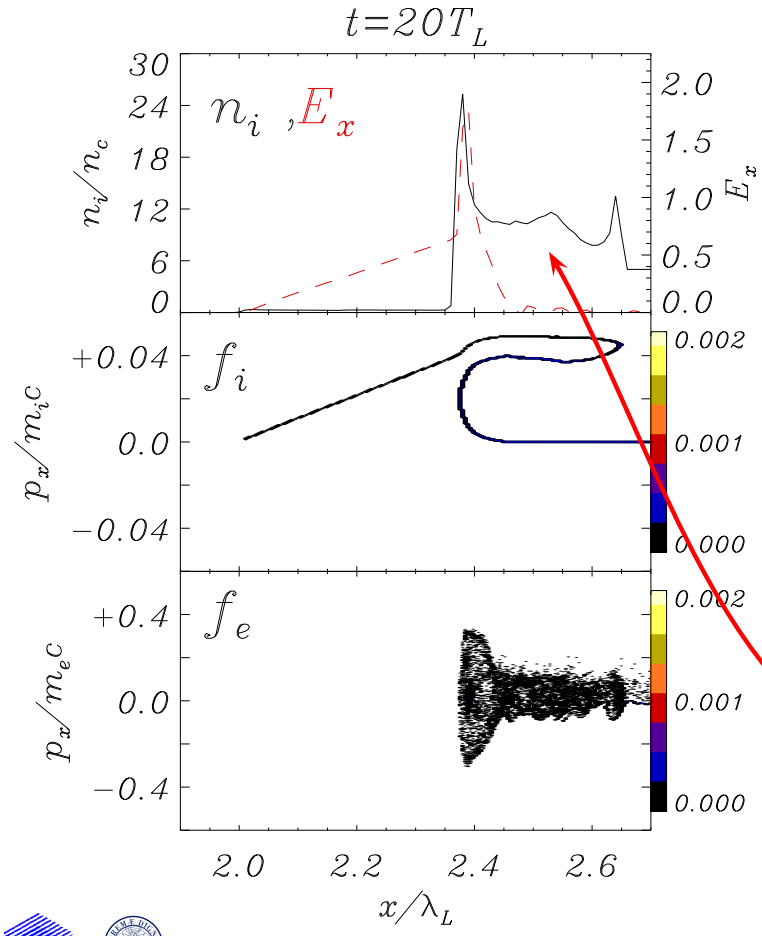

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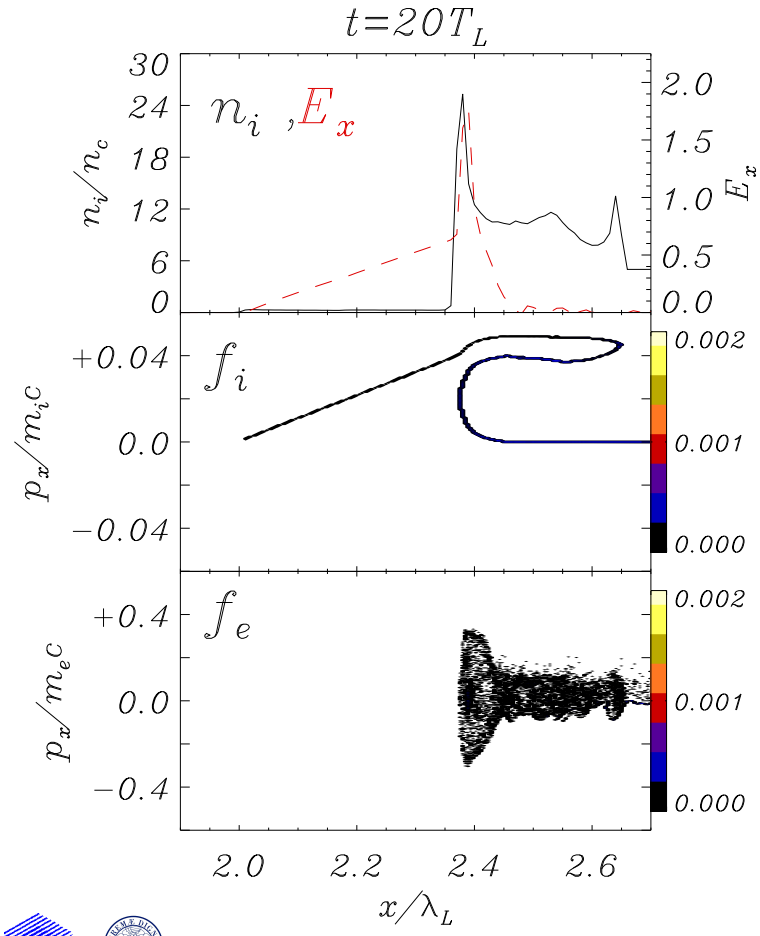

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Simple model

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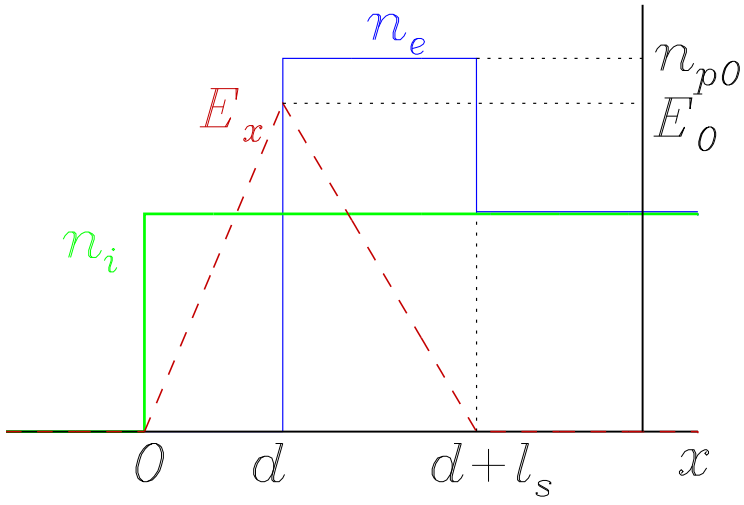
Basic idea: electrons pile up leading to a quasi-equilibrium between the electrostatic field and the ponderomotive force. Ions are accelerated by the electrostatic field until breaking.

- Assume simple profiles . . .



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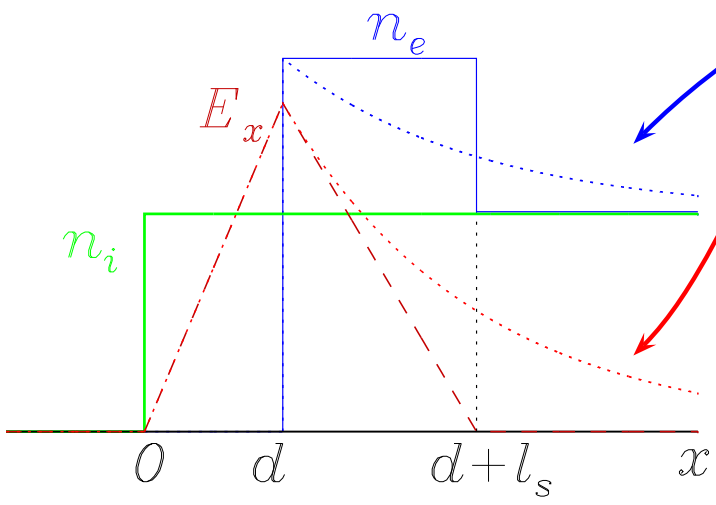

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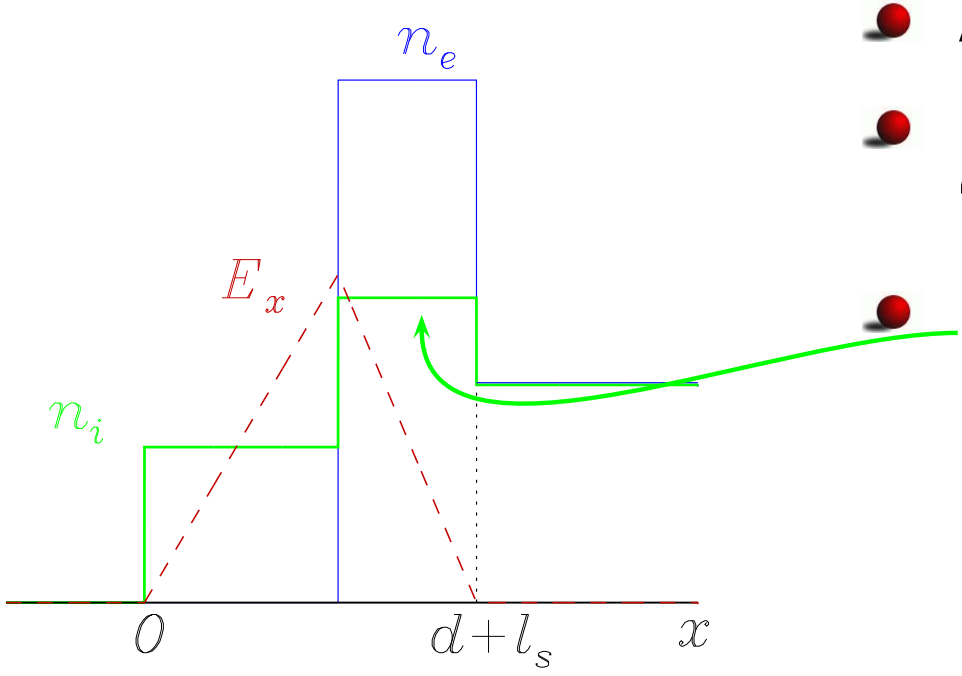

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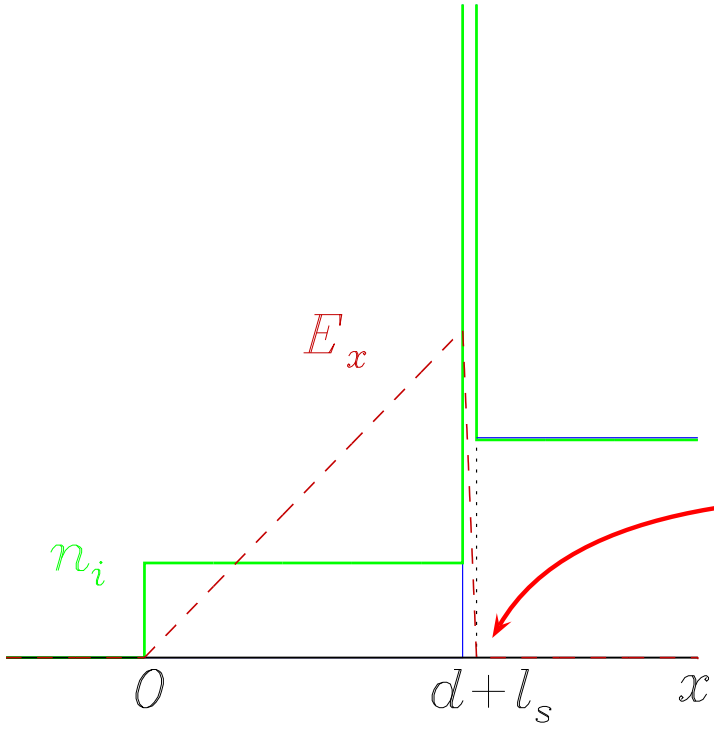

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! To be NOT confused with shock acceleration!

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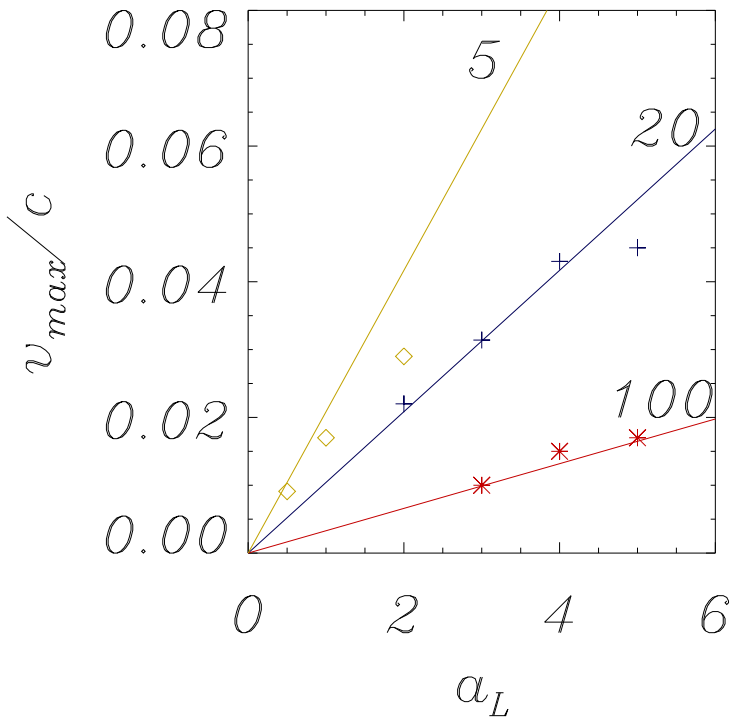

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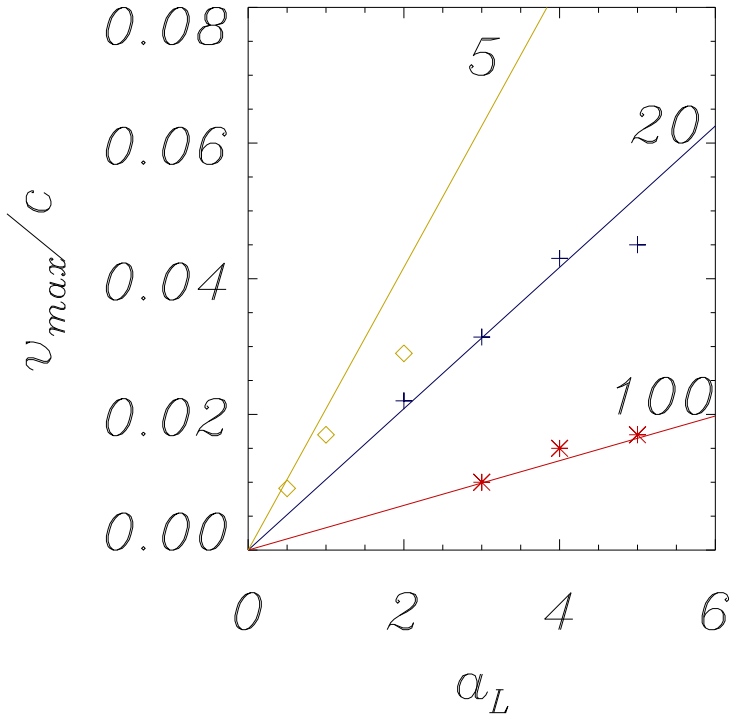

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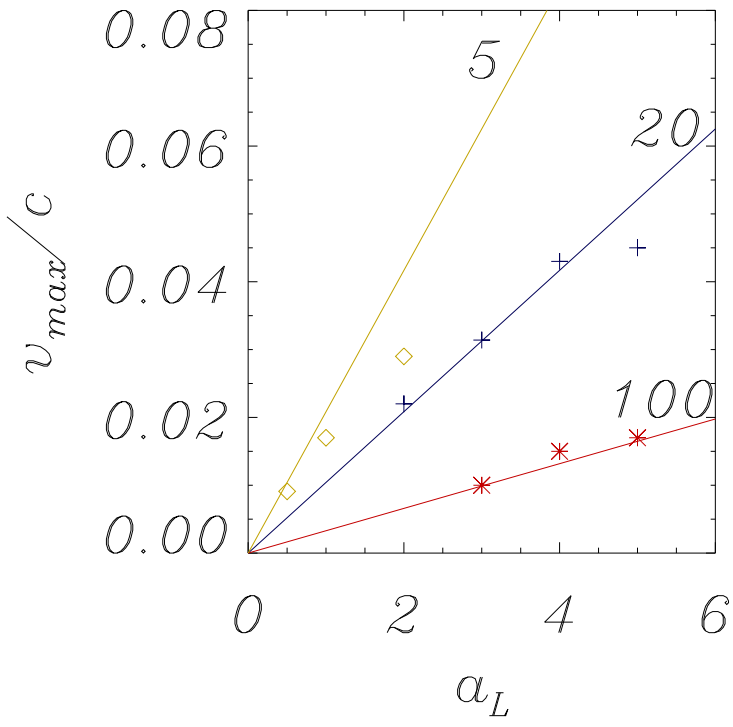

Other simulation features (e.g. non-white spectrum) are understood on a qualitative basis.

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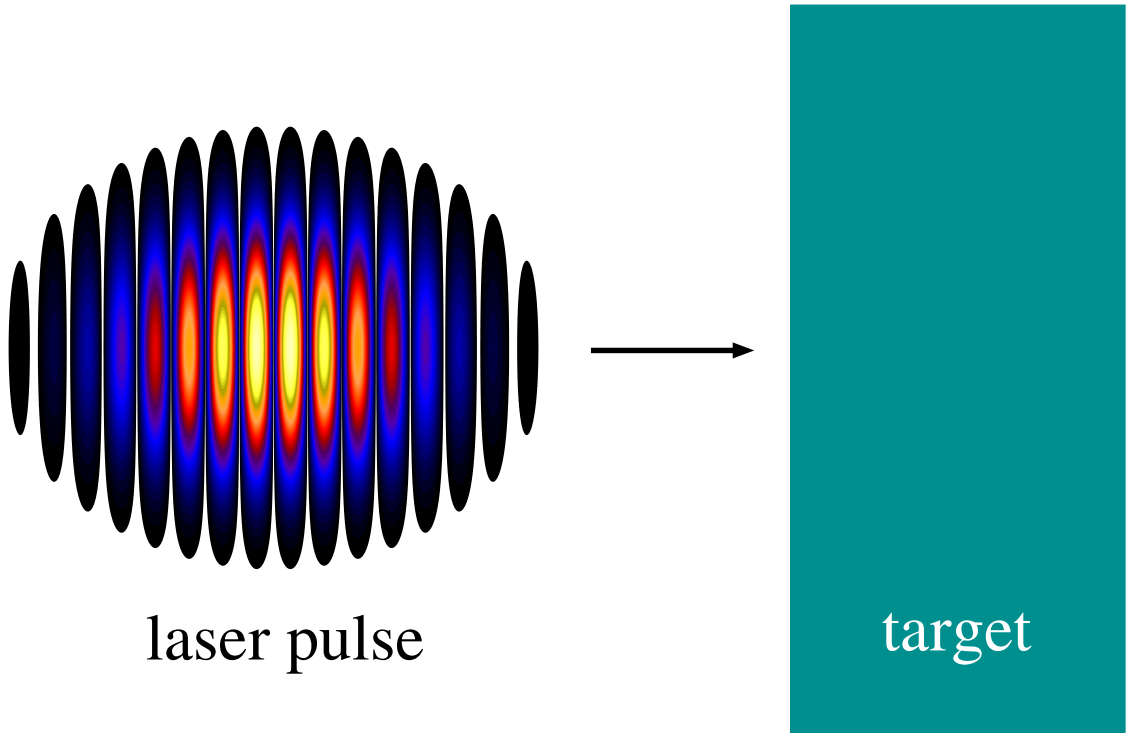

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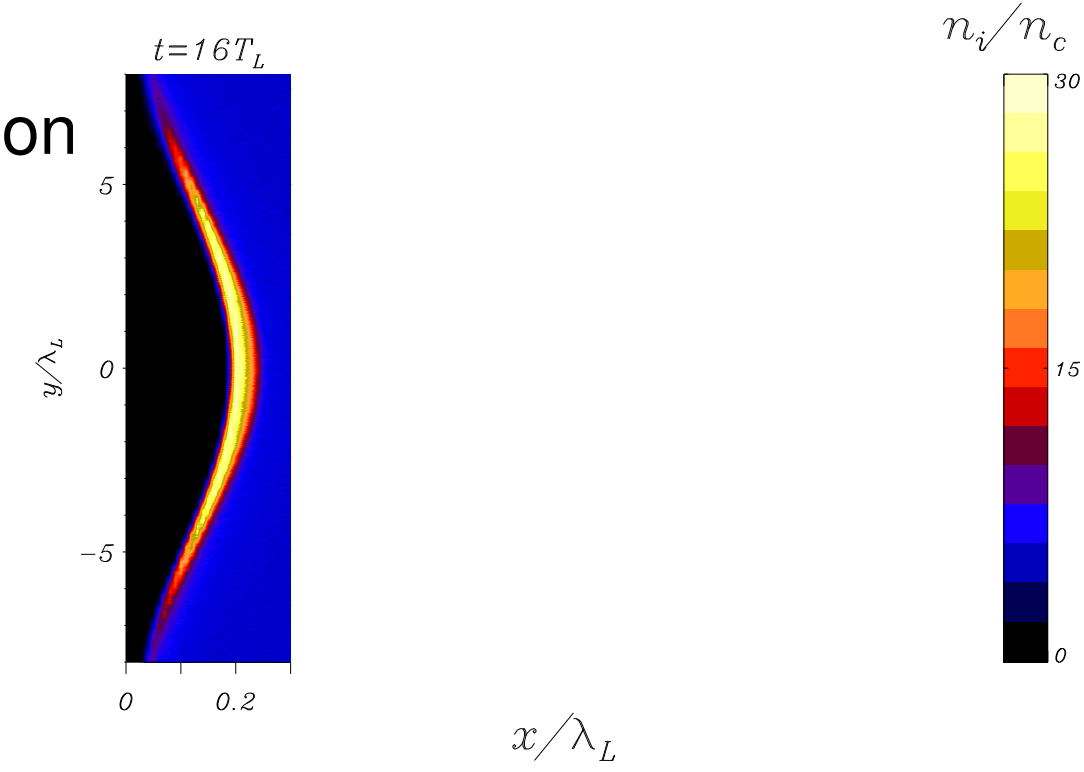

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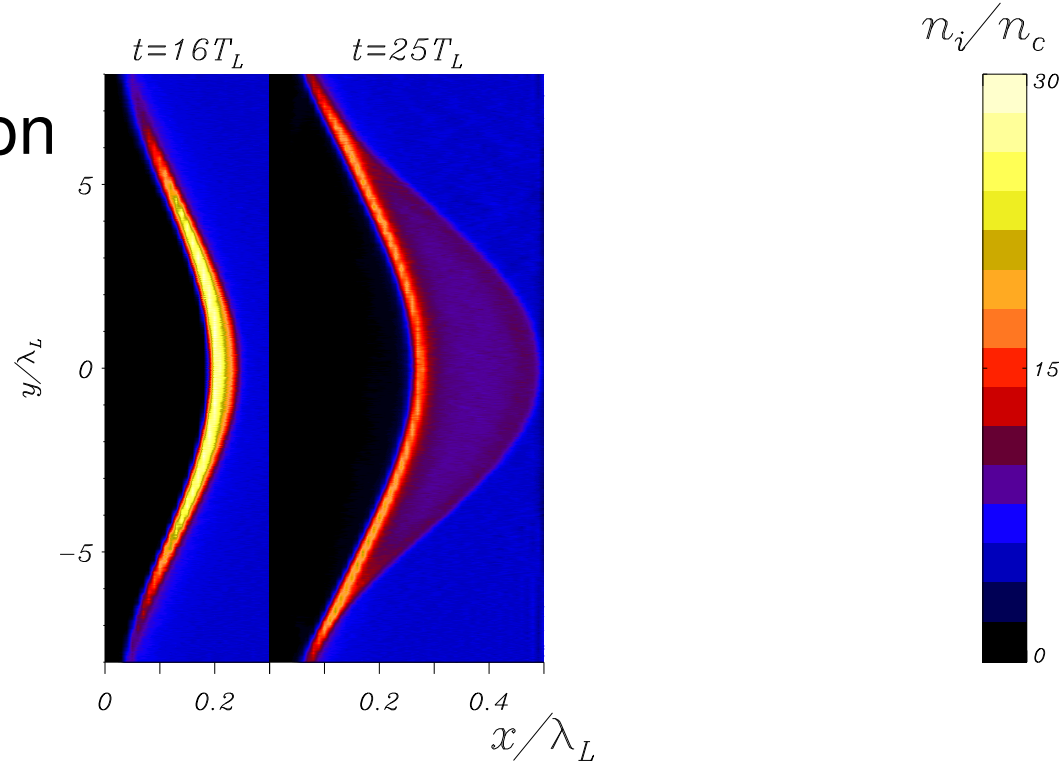

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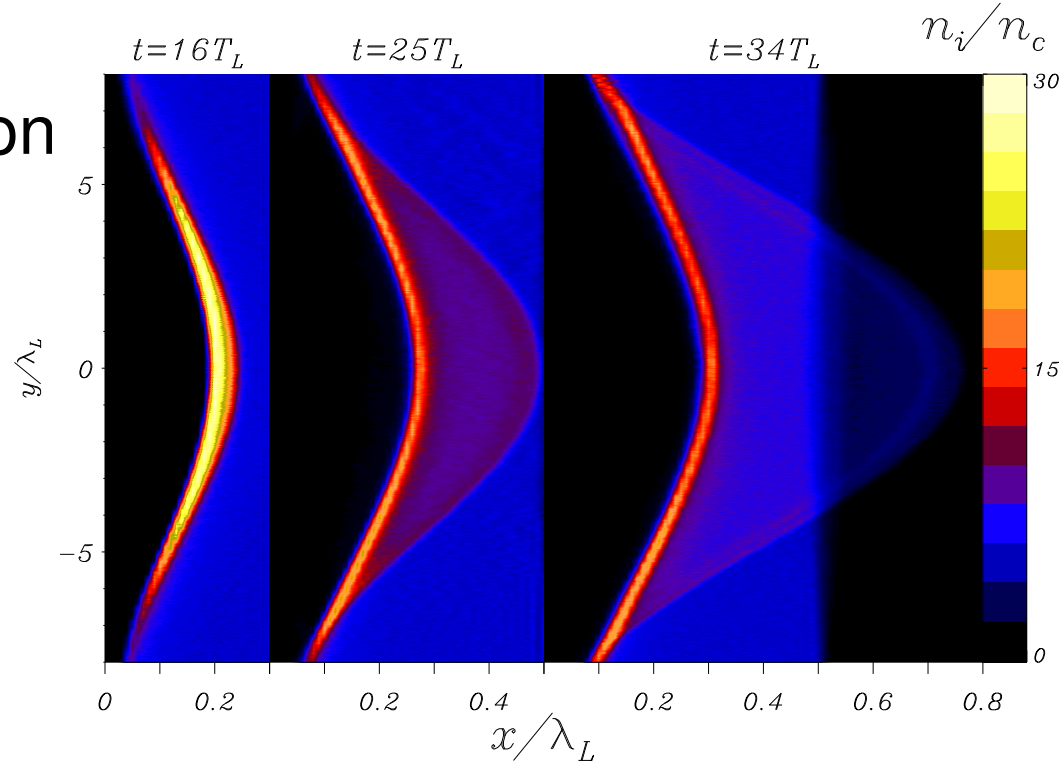

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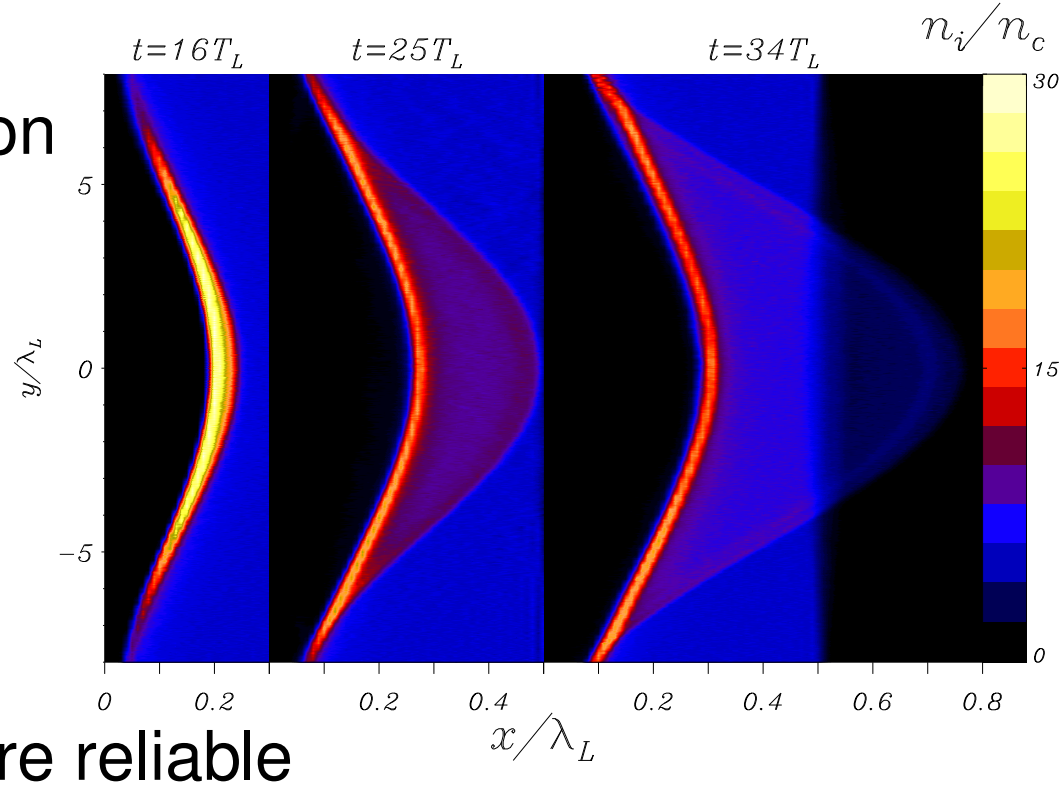

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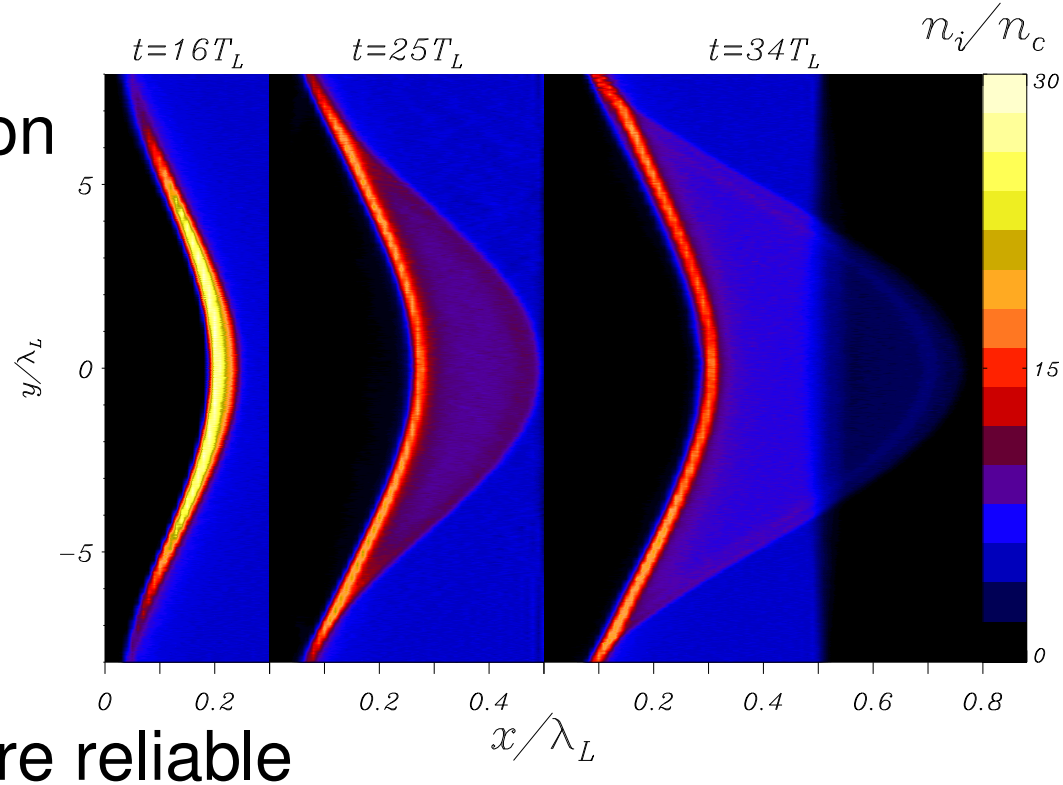

1D scenario & modeling are reliable

Rippling of the laser-plasma interface is weak or absent

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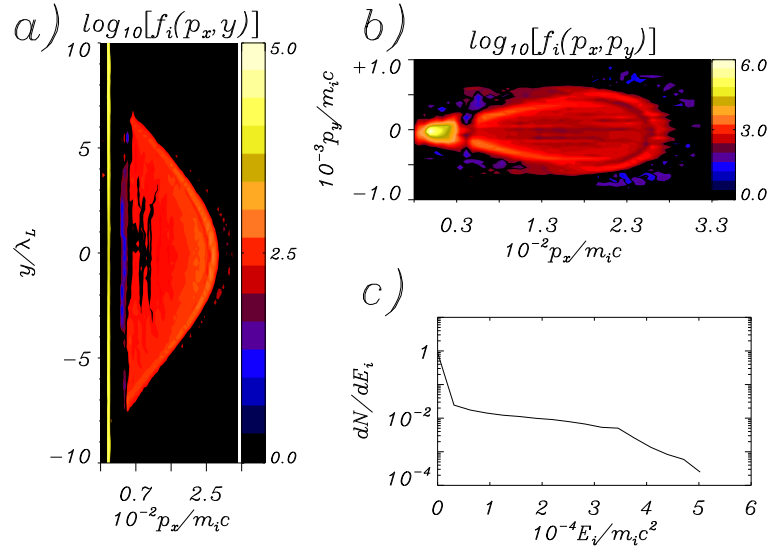

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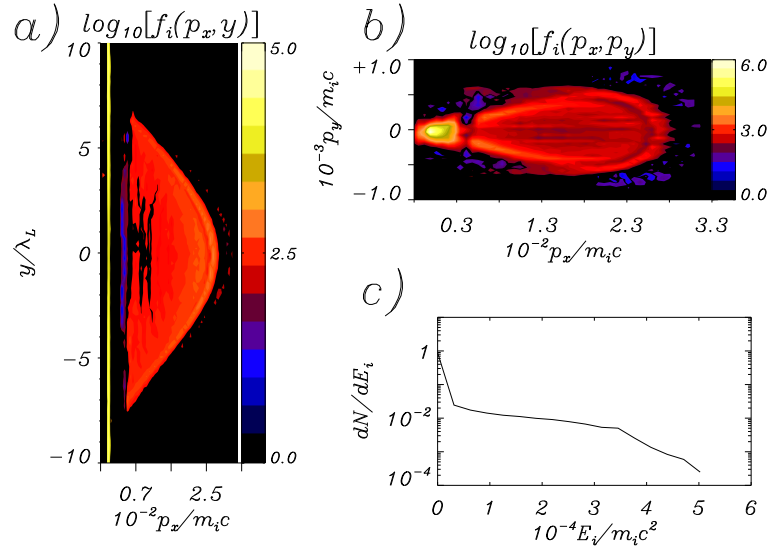

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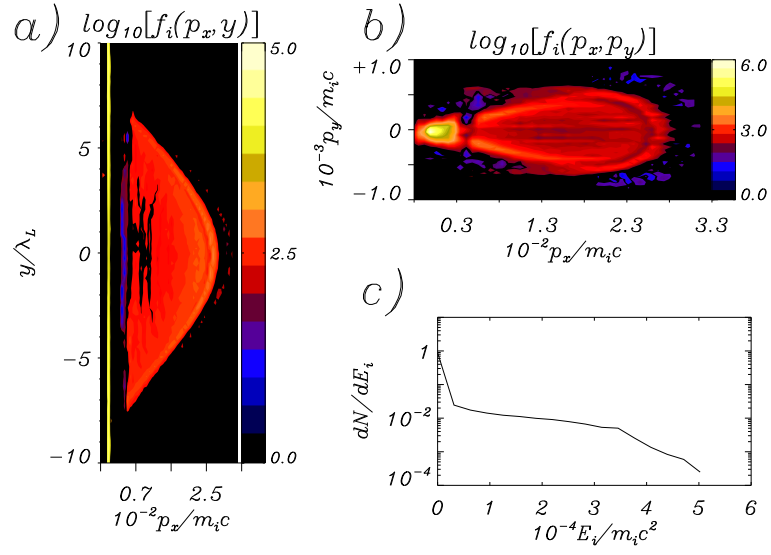

Are these features useful for some application?

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

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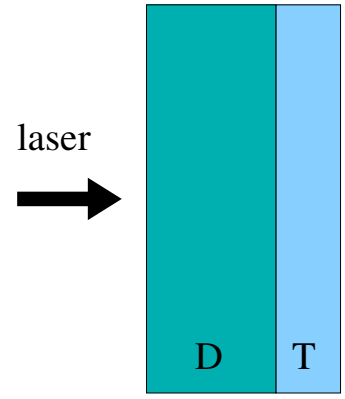

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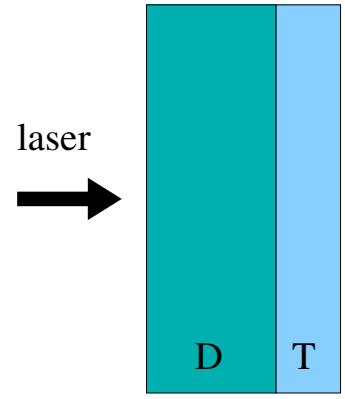

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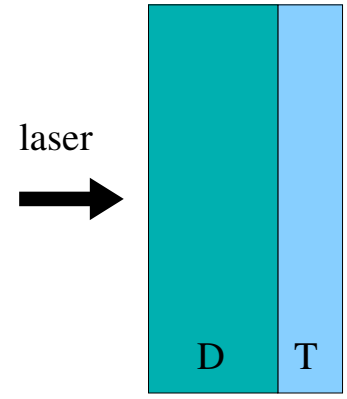

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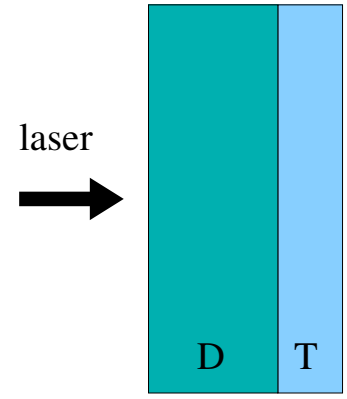

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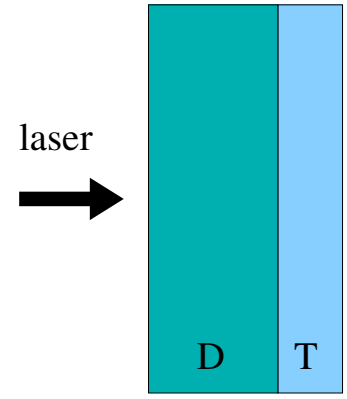

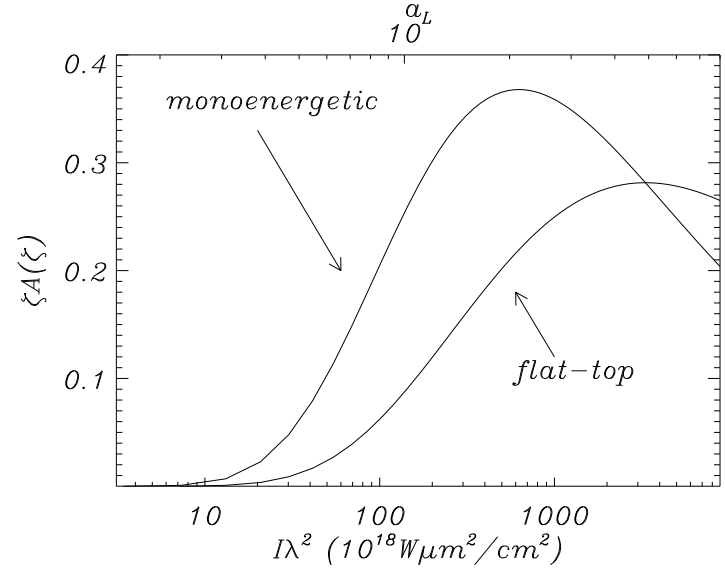

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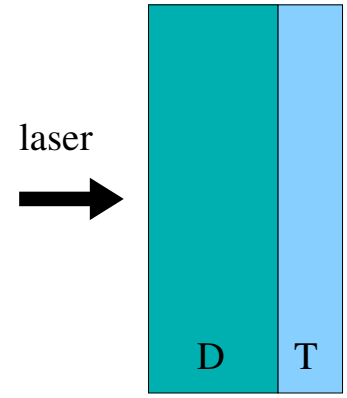

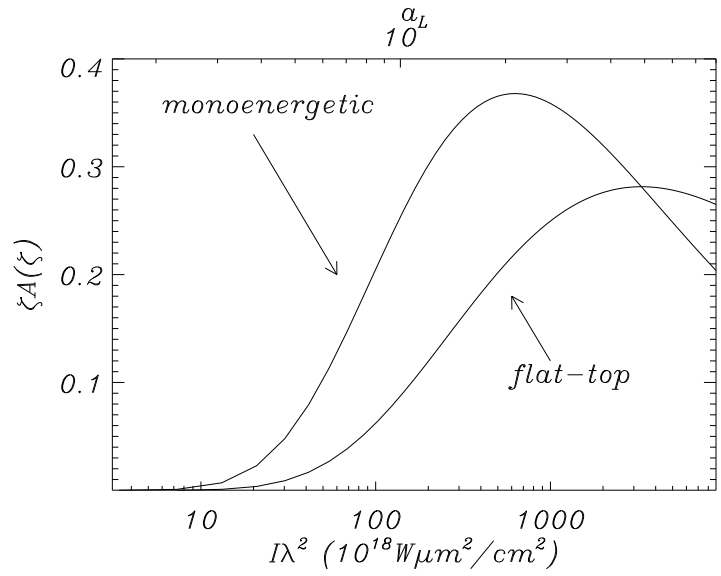

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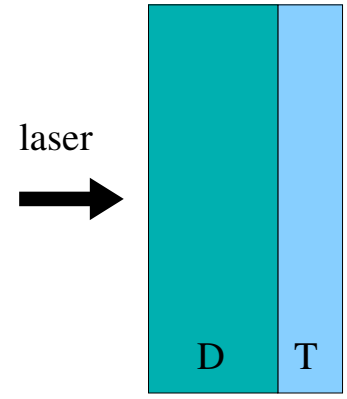

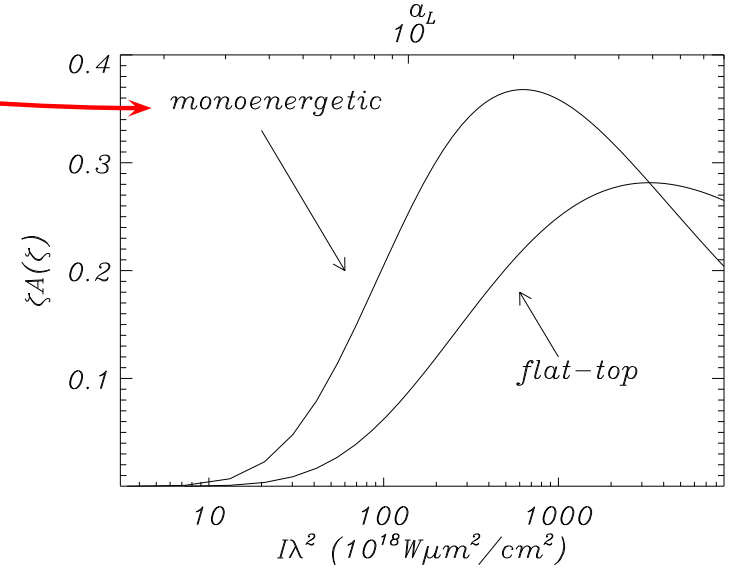

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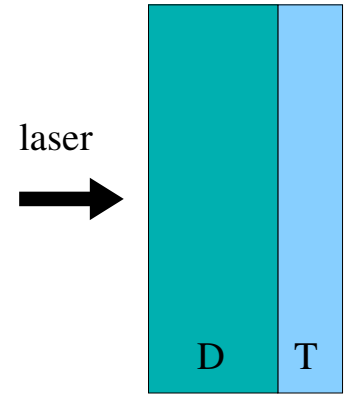

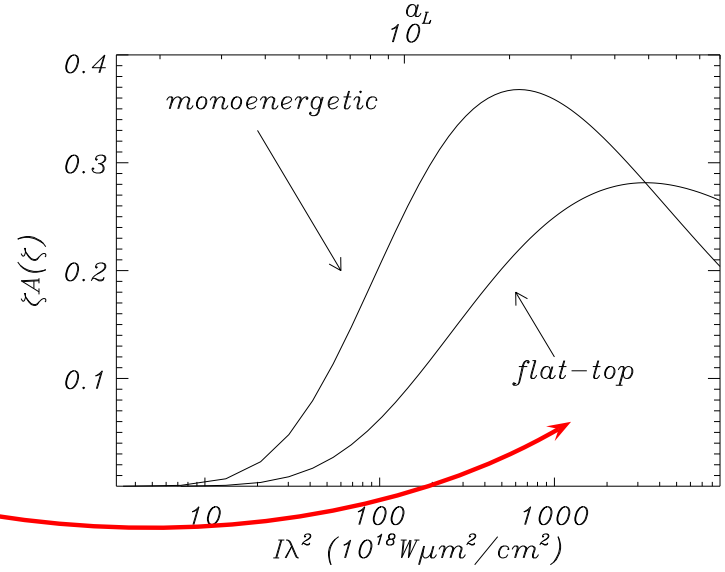

D-T, single bunch scheme

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

Assume $l_D \simeq l_s$ for optimal "projectile"

Shortest attainable duration

$\boxed{\tau_n \simeq l_b/v_m}$ if $l_T < l_b$

Neutron yield estimated analytically

$$\boxed{N \simeq 1.3 \times 10^{11}\ \mathrm{cm}^{-2} \kappa^{-1} \zeta \mathcal{A}(\zeta)}$$

$\zeta \equiv \sqrt{\mathcal{E}_g/\mathcal{E}}$

(monoenergetic or flat-top spectra)

$\boxed{\sim 10^8\ \text{neutrons in}\ \tau_n \sim 1.2\ \mathrm{fs}}$

at $I\lambda^2 \geq 10^{19}$ W/cm^2

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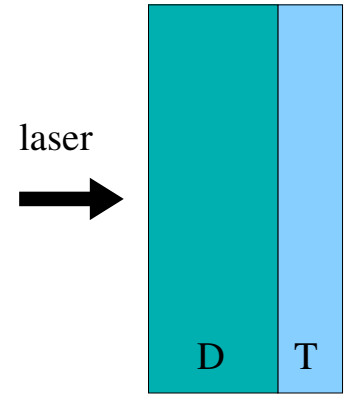

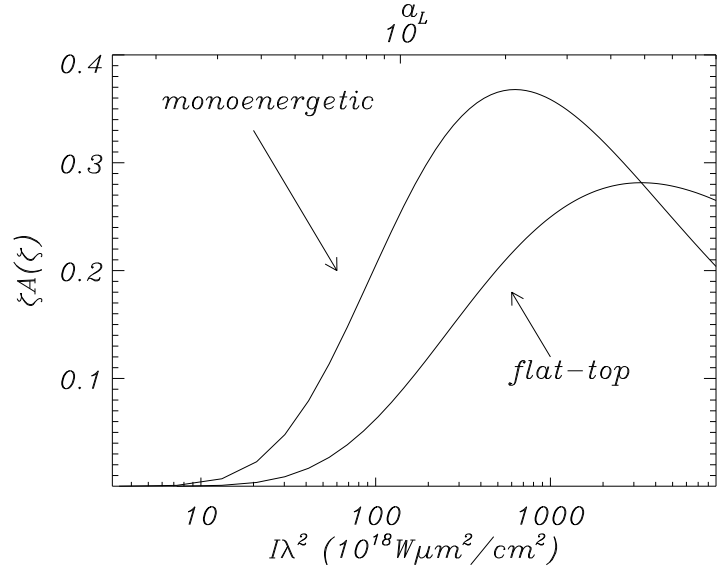

D-D, colliding bunches scheme

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$\mathrm{D} + \mathrm{D} \rightarrow {}^{3}\mathrm{He} + \mathrm{n}\ (2.45\ \mathrm{MeV})$

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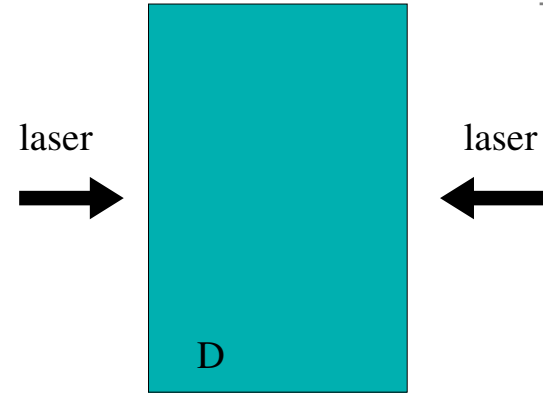

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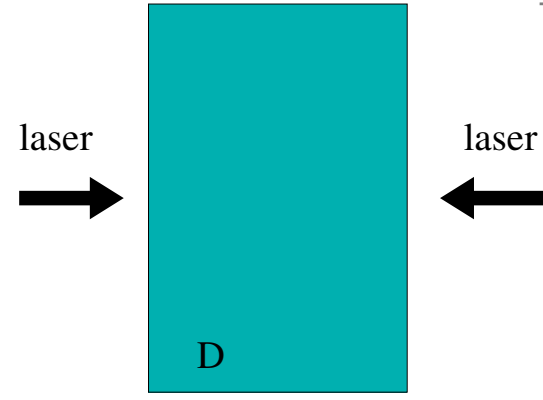

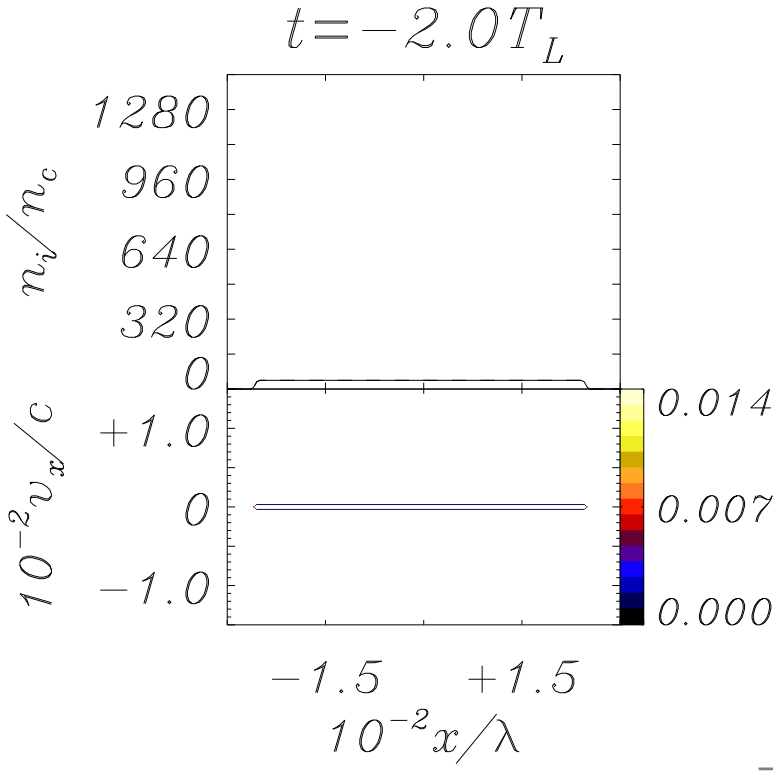

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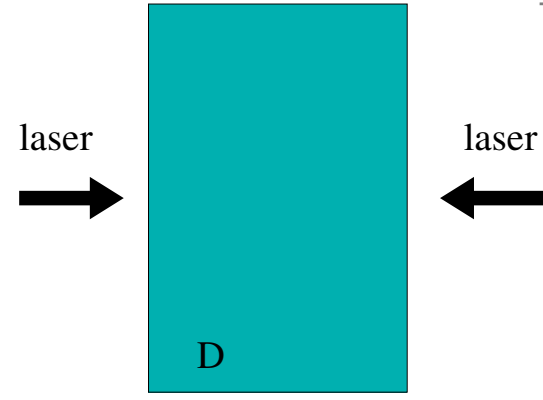

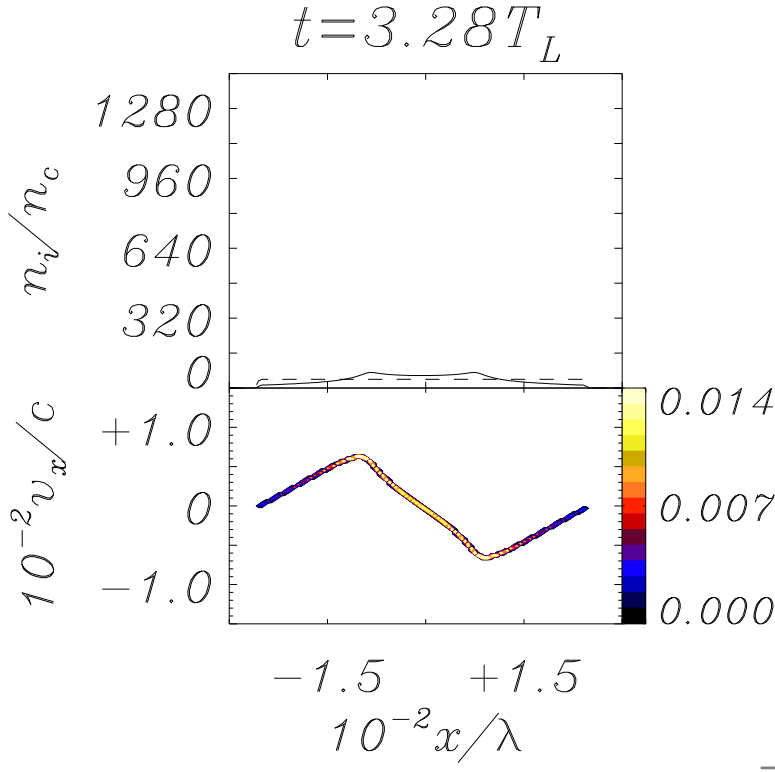

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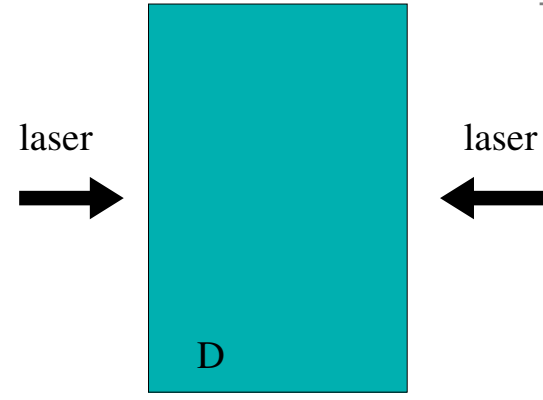

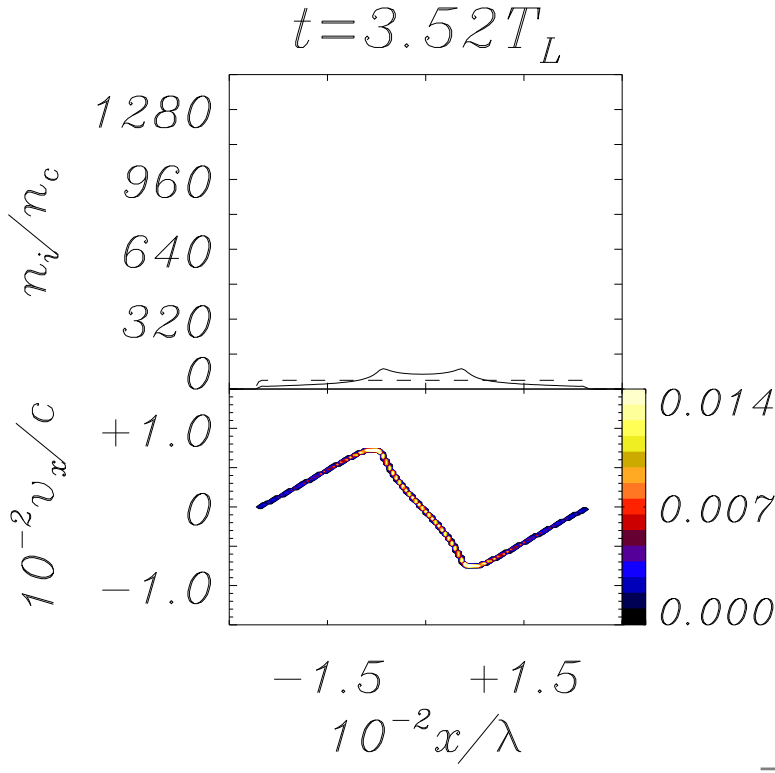

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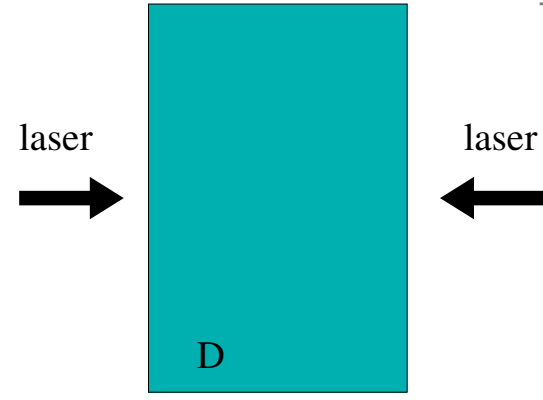

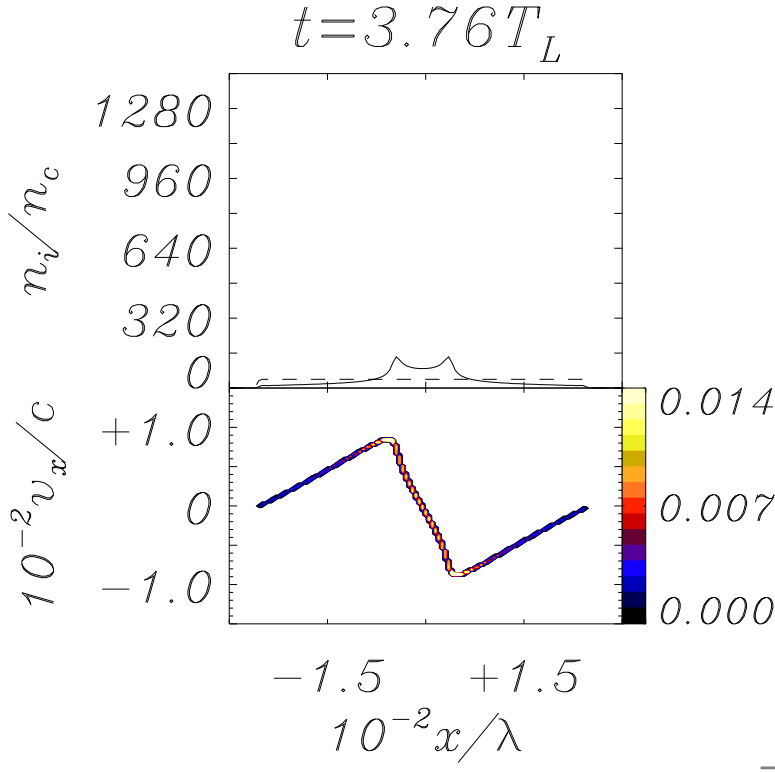

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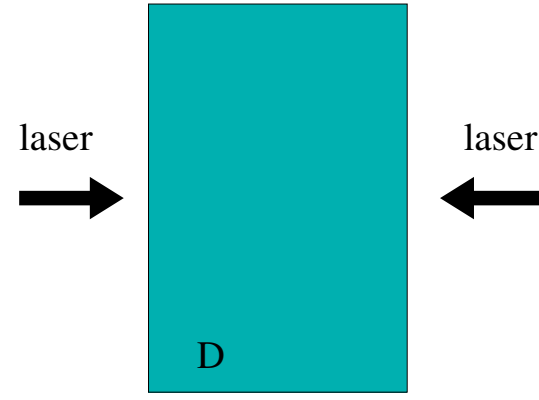

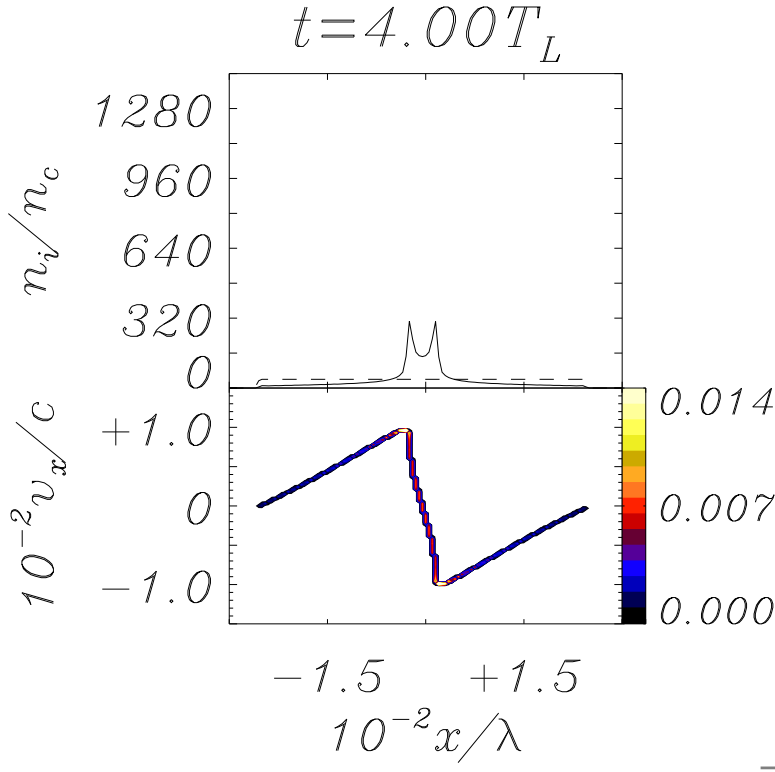

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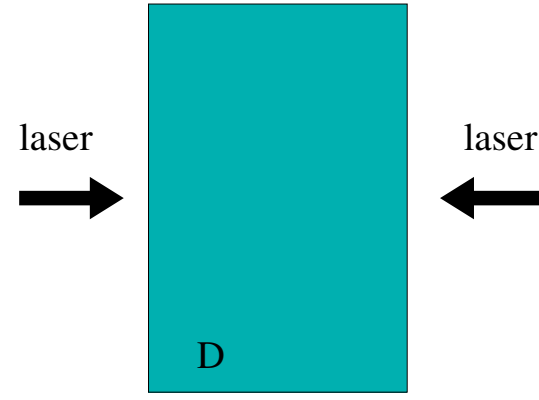

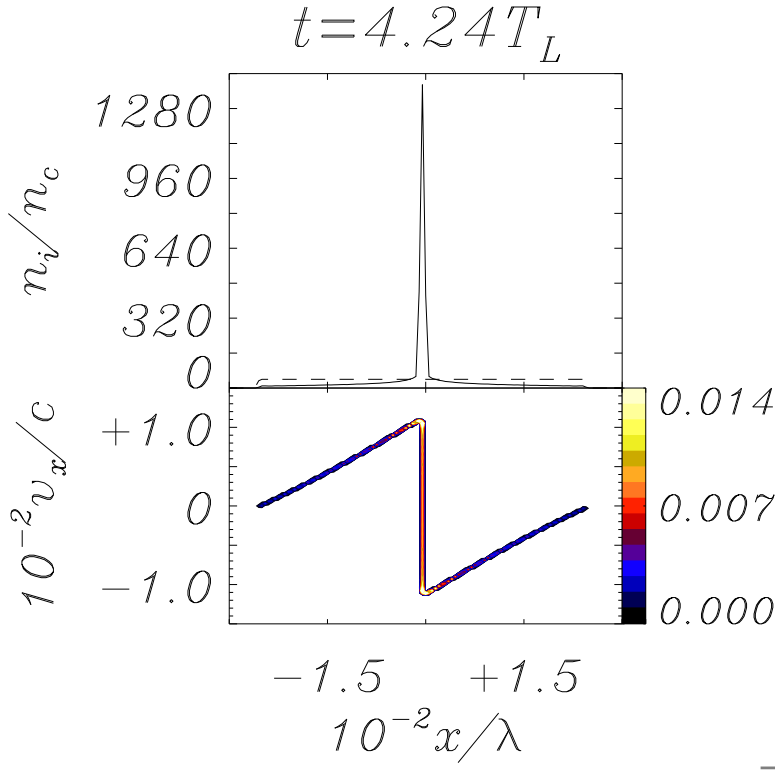

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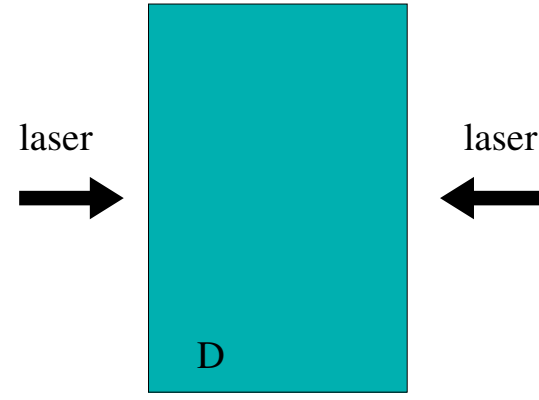

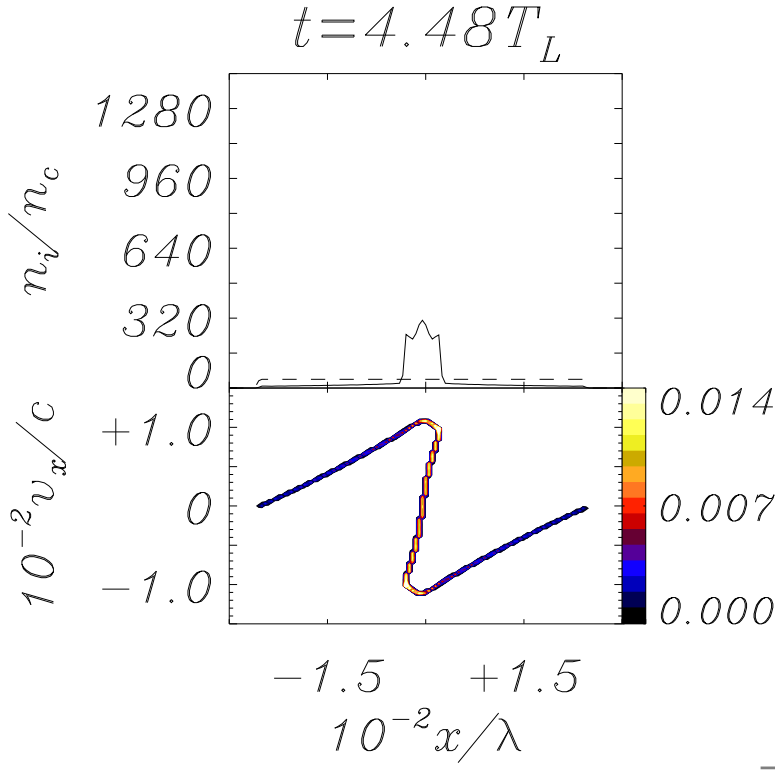

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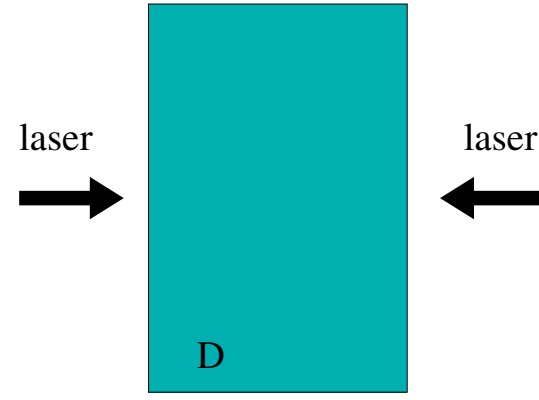

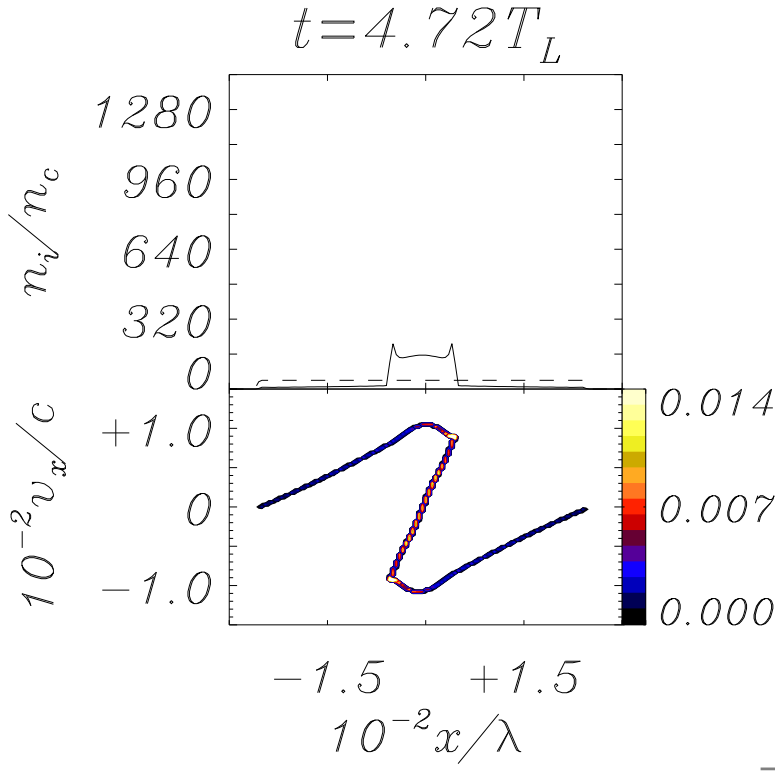

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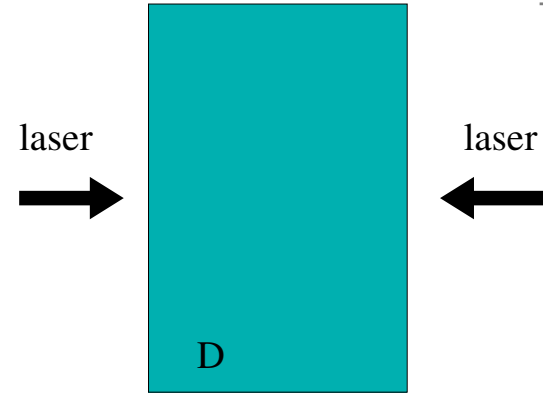

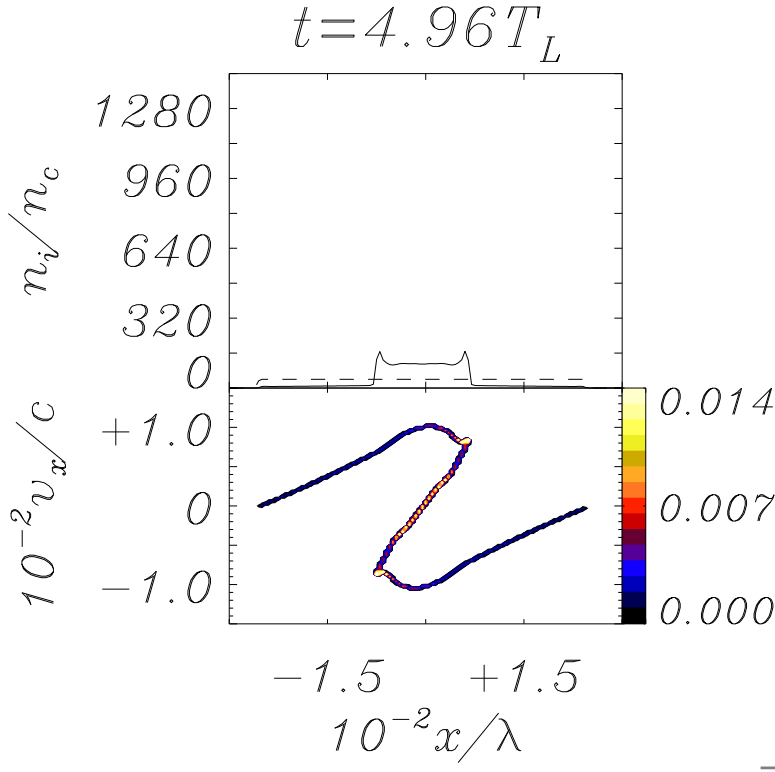

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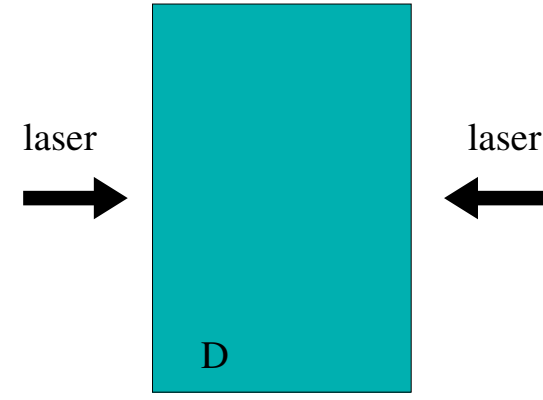

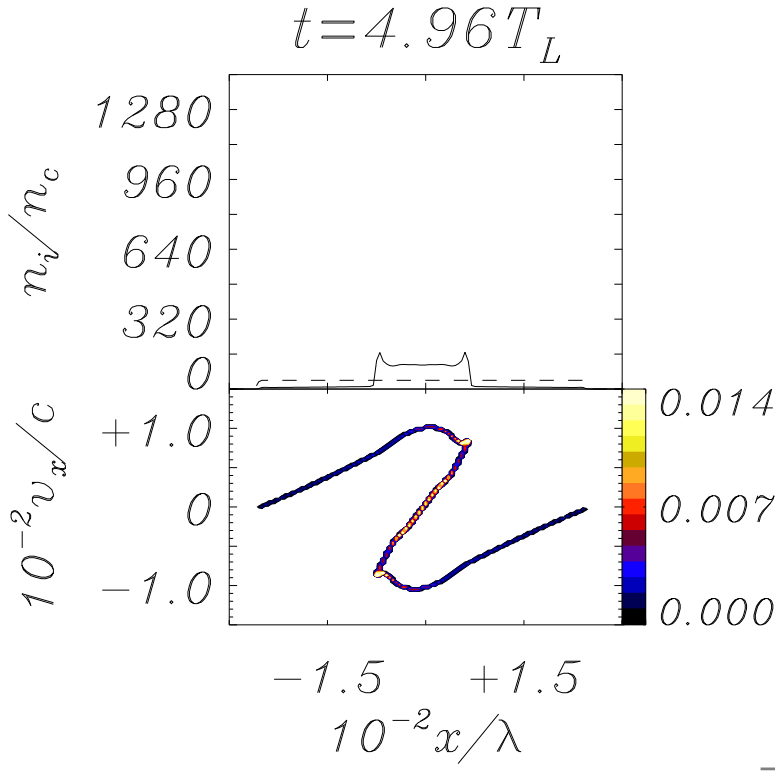

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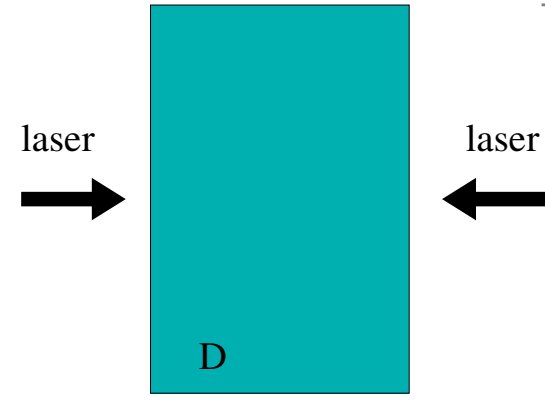

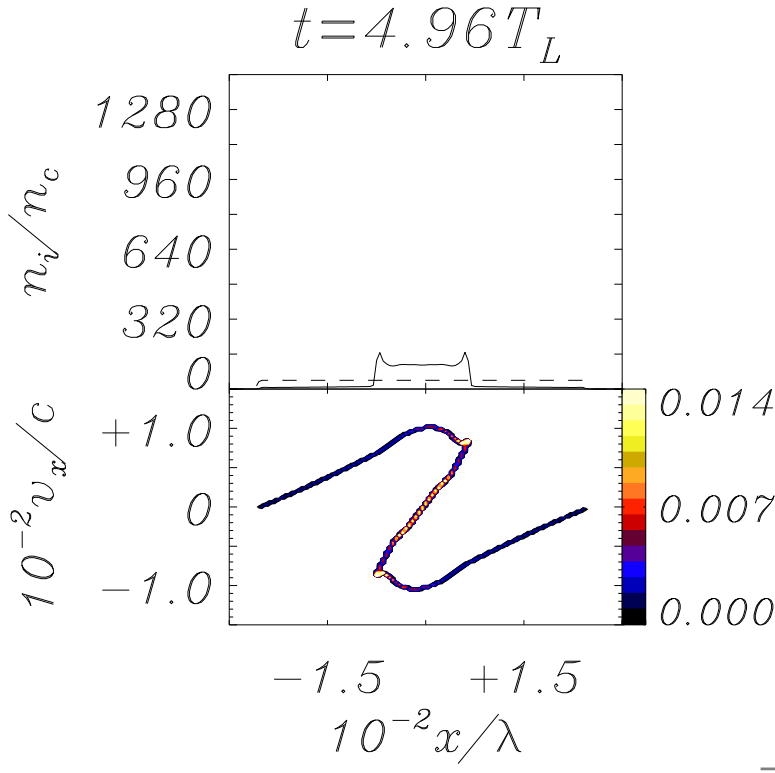

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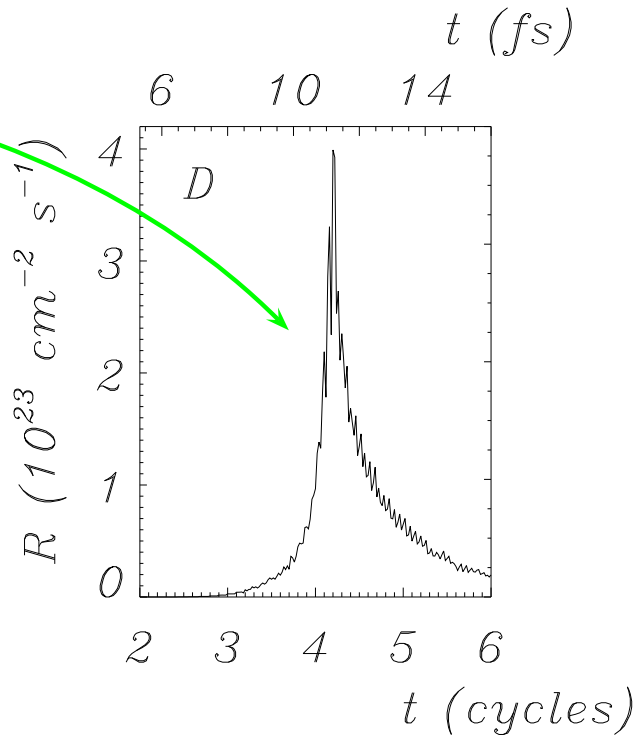

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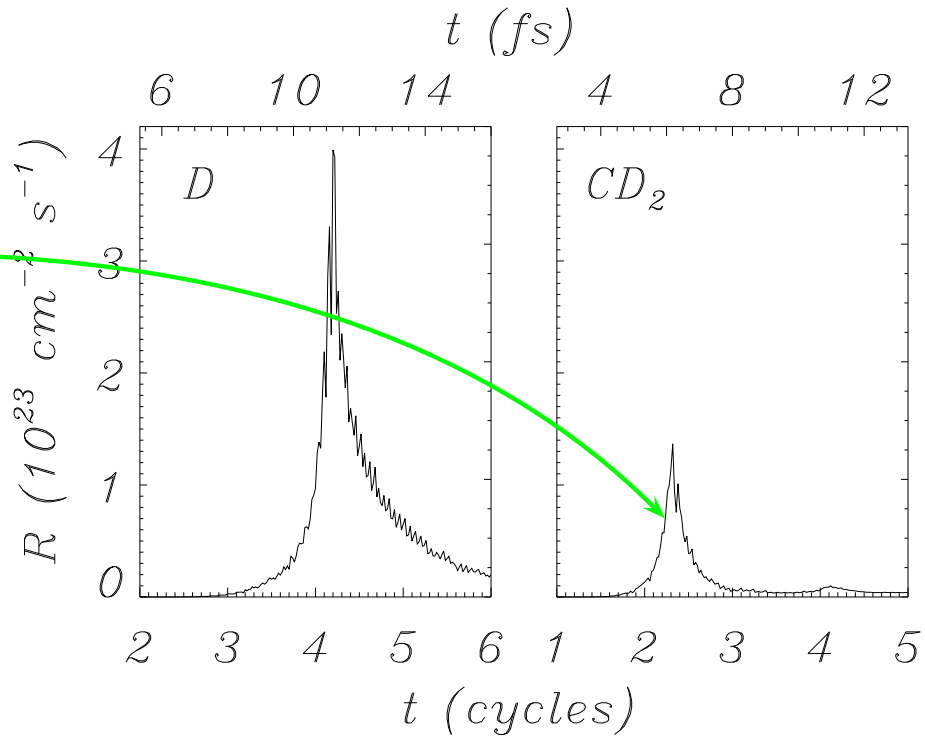

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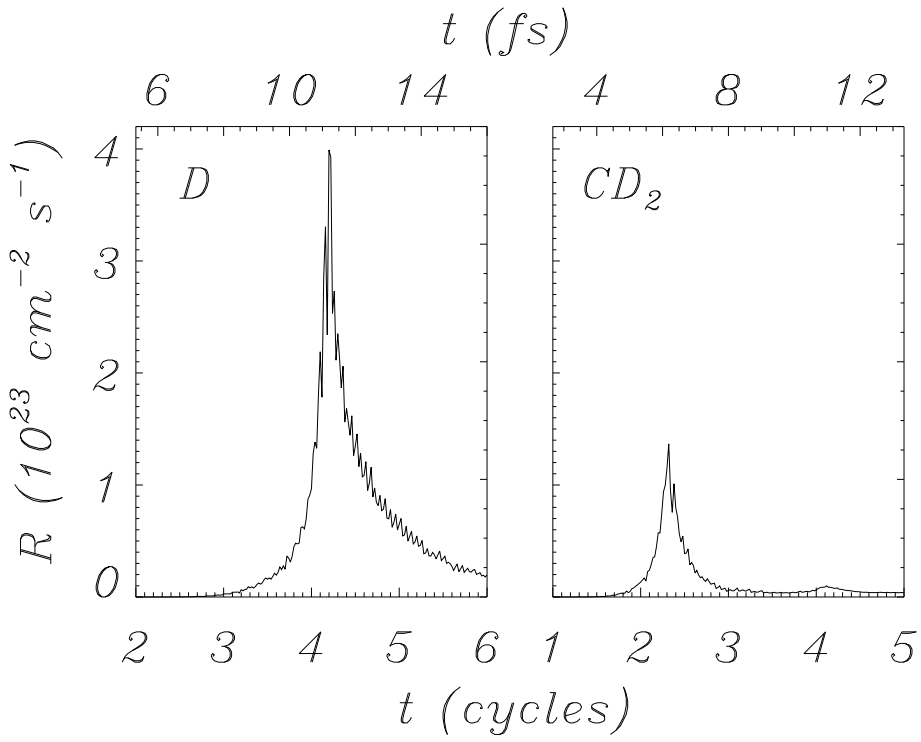

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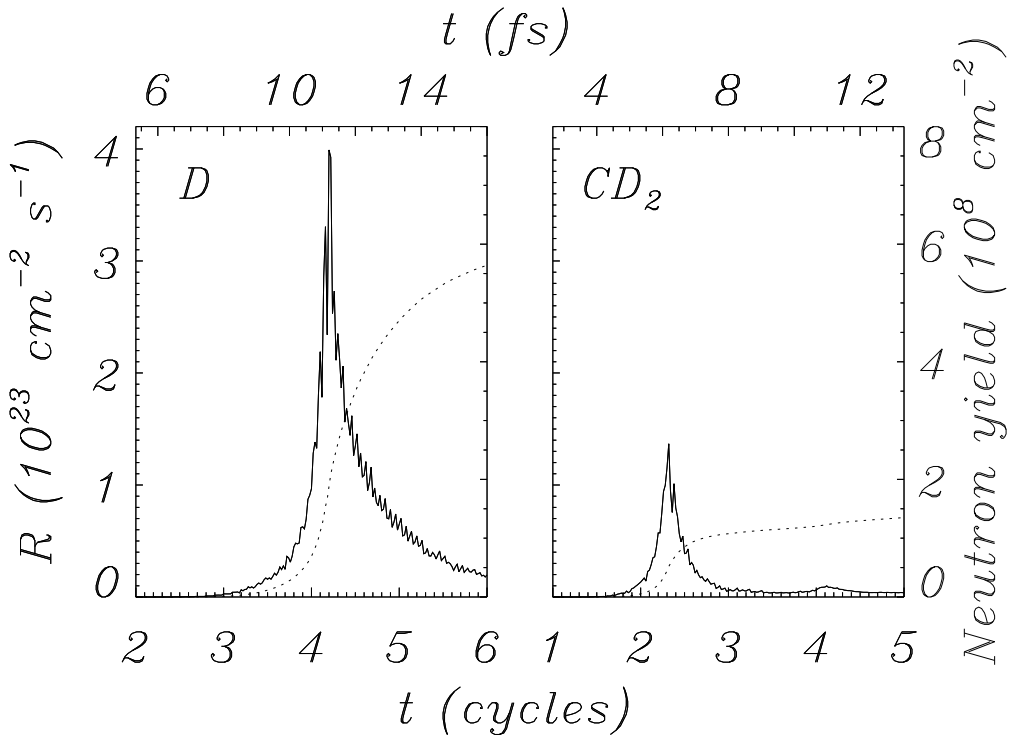

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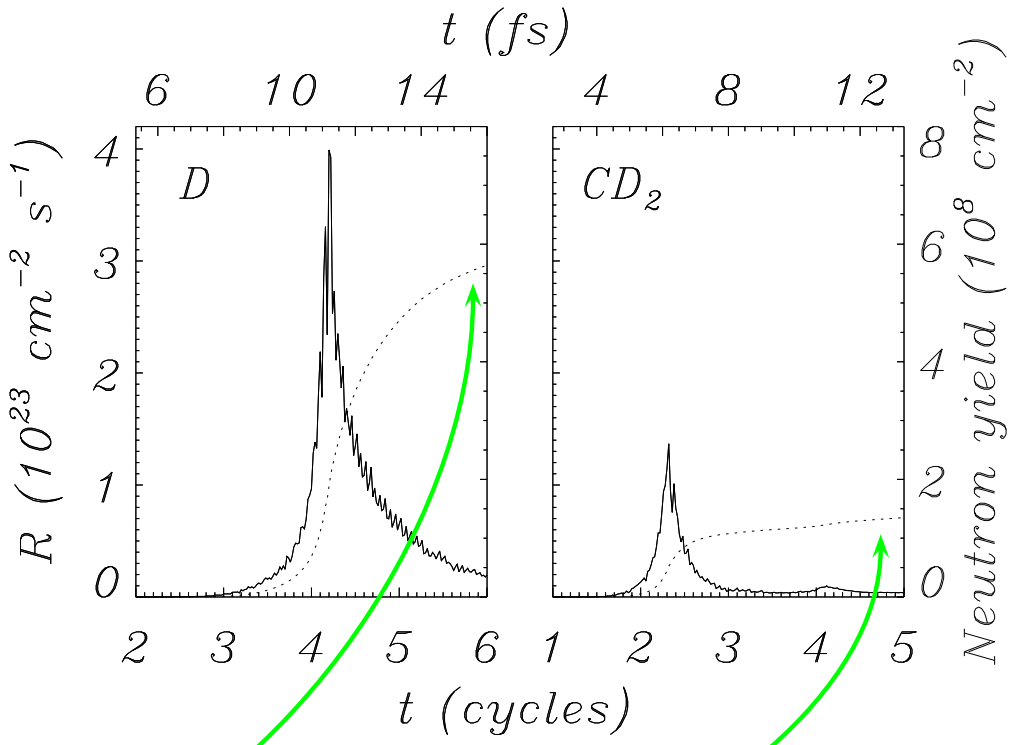

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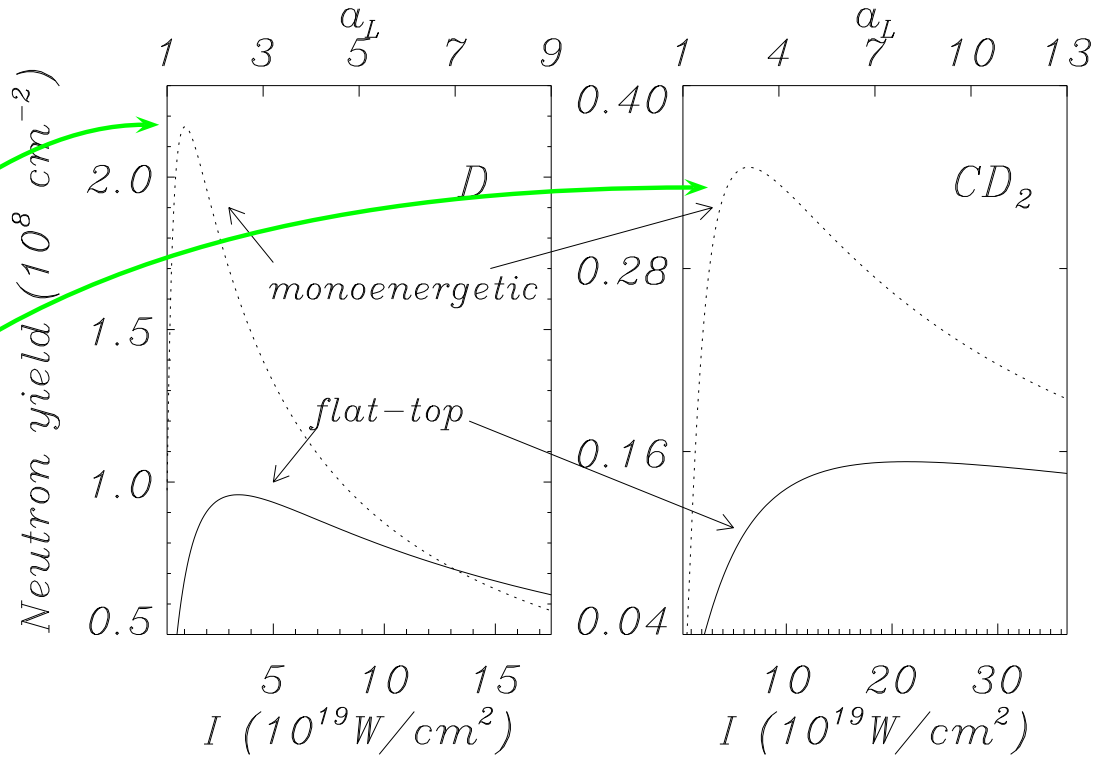

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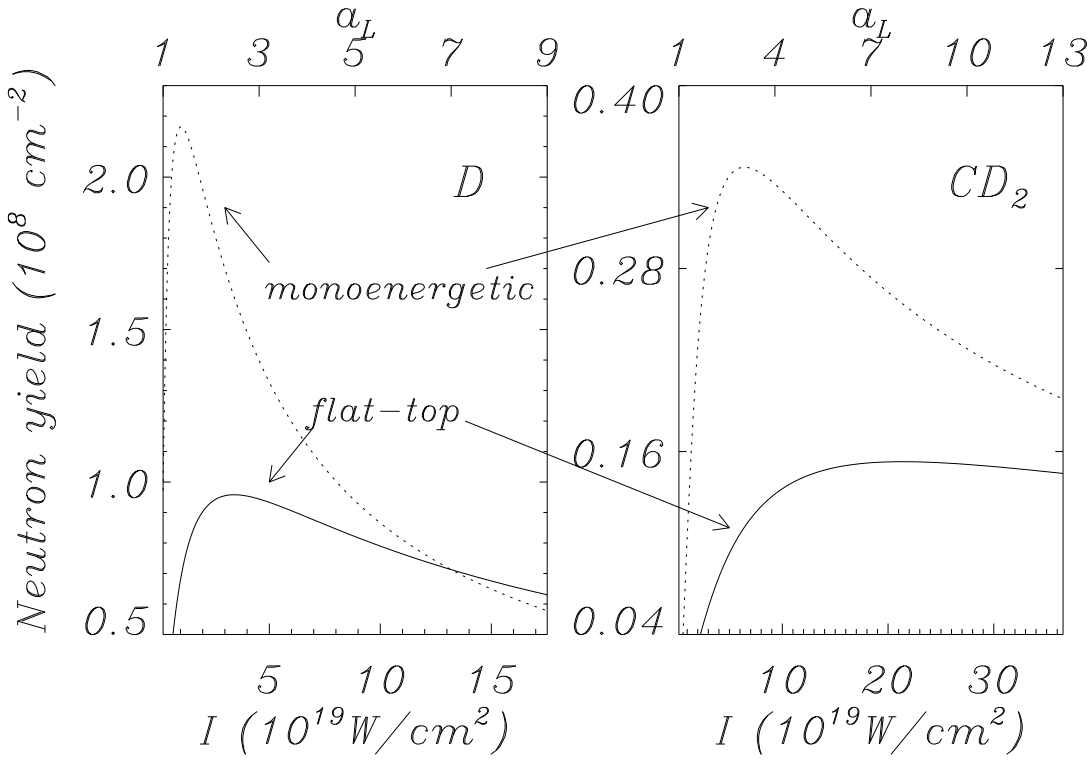

Maximum rate reached in the range $I_L = 10^{19} \div 10^{20}$ W/cm^2

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→ concept based on foil confinement and thermonuclear fusion; requires "long" pulses

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- Synchronization of the two pulses is critical to achieve a sub-fs neutron burst (but the burst duration remains in the few fs range anyway).
- Measurement of neutron burst duration is challenging (indirect measurement via “attosecond spectroscopy” techniques?)

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  - helps the understanding of the ion acceleration dynamics
  - suggests a novel regime of ion acceleration
- The ion bunches produced in this regime may open a persepctive to bring the duration of neutron sources down in the sub-femtosecond regime

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- Visit also http://www.df.unipi.it/∼macchi/research.html for movies, further details, or updates

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