PIC and Fluid Simulations of Two-Plasmon-Decay Instabilities Relevant to Direct Drive/Shock Ignition

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Shock Ignition Workshop

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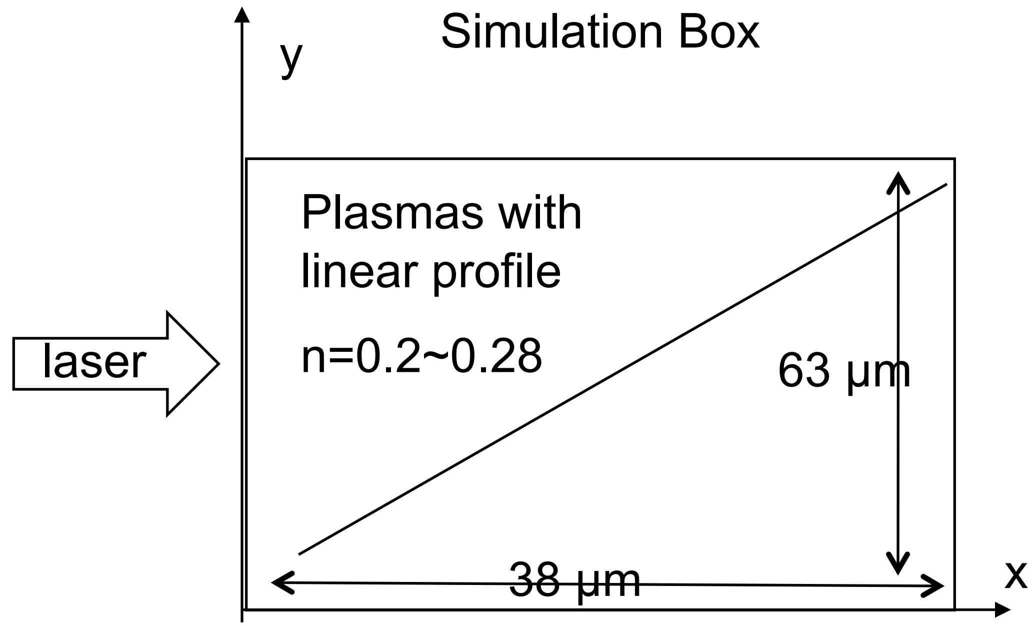
Outline

- We have good understanding of the linear stage of TPD
  - Absolute mode growth rates from PIC agree with theory/fluid simulations
  - Convective modes seen in PIC and can be modeled with our fluid code
- Most hot e- are only produced in the nonlinear stage of TPD
  - No hot e- observed below TPD threshold
  - The appearance of >100 keV e- is correlated to new modes that are not seen in the linear stage
  - The new modes provide the first stage in a staged-acceleration mechanism
- Forward hot e- (>50 keV) flux from plane-wave, 2D PIC is >10X of experiment measurements
  - How to account 3D effects like speckles?
  - LPI and hydro are difficult to decouple
- Some good news for shock ignition?

We have performed PIC and fluid simulations with OMEGA parameters

- **PIC set up [OSIRIS, R. A. Fonseca, et al., Lect Notes Comput Sc 2331, 342 (2002)]**
- **Boundary conditions for fields:**
  - **Periodic in the y direction**
  - **Open in the x direction**
- **Boundary conditions for particles:**
  - **Periodic in the y direction**
  - **Thermal reflecting in the x direction**

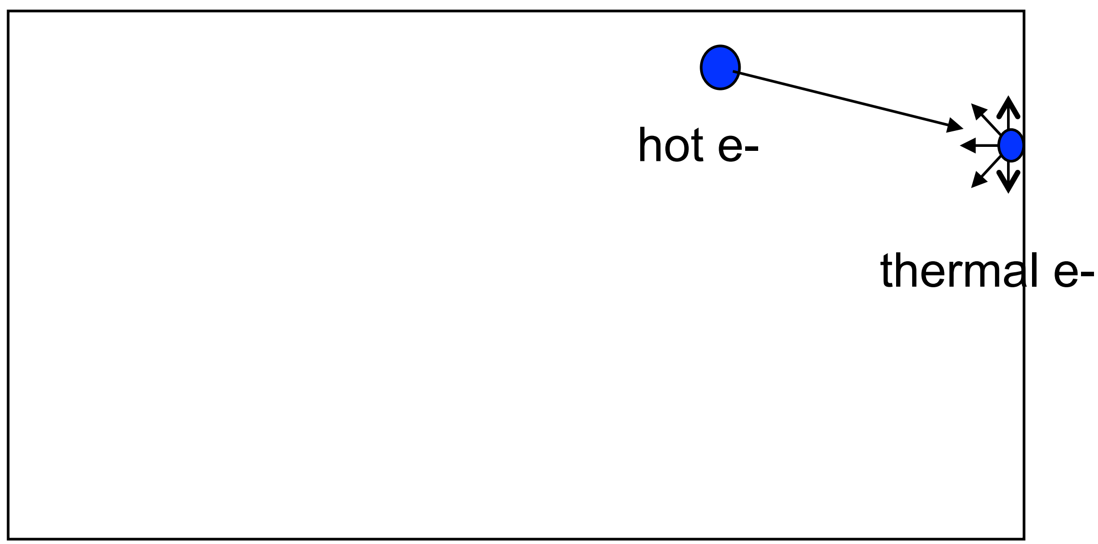


- **Fluid code (Yan et al., PoP 2010)**
  - **Solves the linear TPD equations in arbitrary density profiles**
  - **Can study TPD under ion density fluctuations**

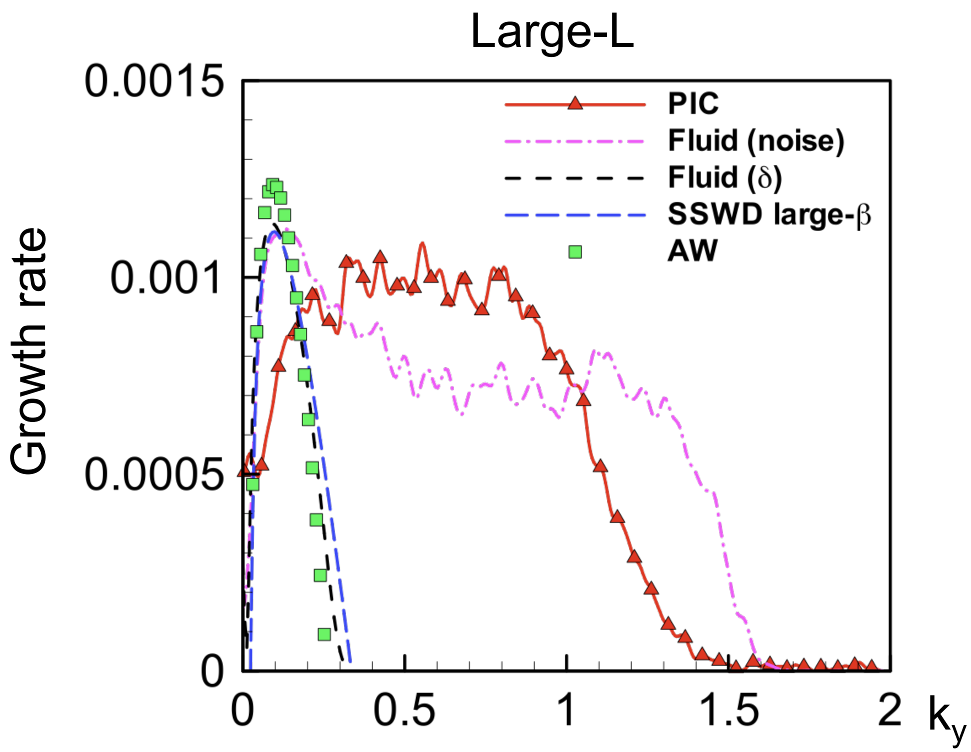
Typical parameters:
Grid: 3600 x 6000, 100ppc
I=4-20x10^{14}W/cm^2
Te=1-3 kev, Ti=1-3 kev
M/m=1- 2.5x 1846
L=150 micron

Diagnostics in PIC simulations

- The boundary diagnostic records the energy difference of the particles going out of and coming into the box.
- It also records the energy distribution of the particles going out of the rear boundary.



There is general agreement for linear growth among theory, PIC, and fluid simulations



$I=10^{15}$ W/cm^2, L=150 micron
$T_e=T_i=2$ keV, $M_i/m_e=3410$
(Yan et al., PRL'09)

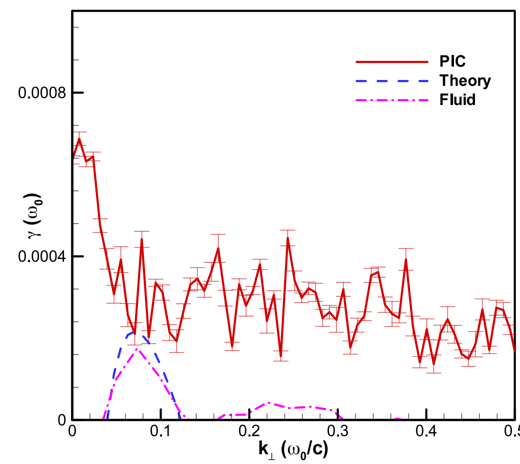
- **Both PIC and fluid simulations saw absolute and convective modes**
- **The lower PIC growth rates in low k_y were due to pump depletion**

‘Typical’ compression phase sees Raman and TPD absolute and convective modes

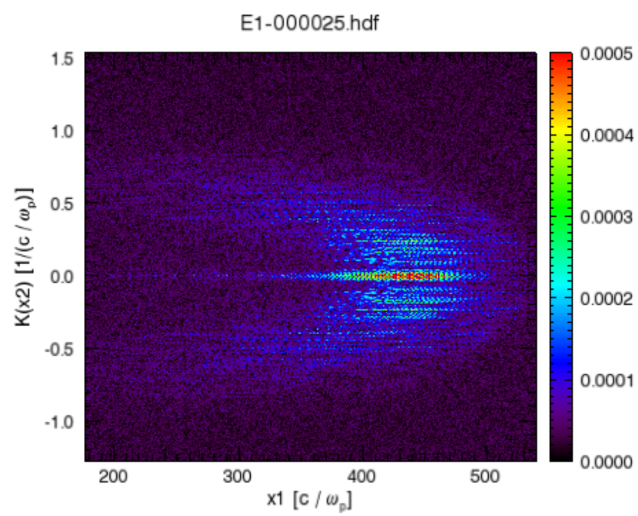
Parameters:

$I=6x10^{14} W/cm^2$
Te=3 kev, Ti=1.5 kev
L=150 micron
η=1.2
M/m=3410 (CH)

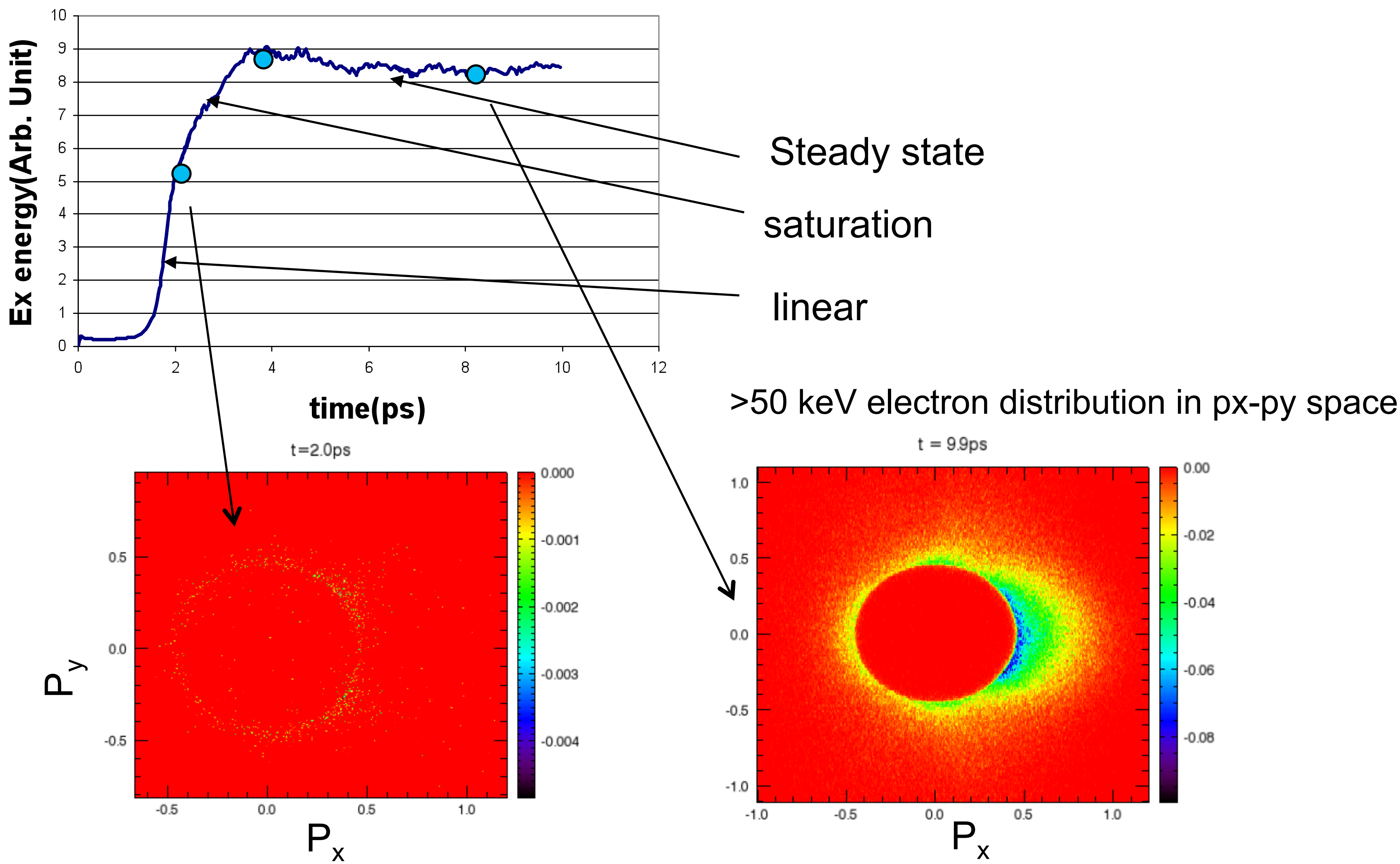
Linear growth rate



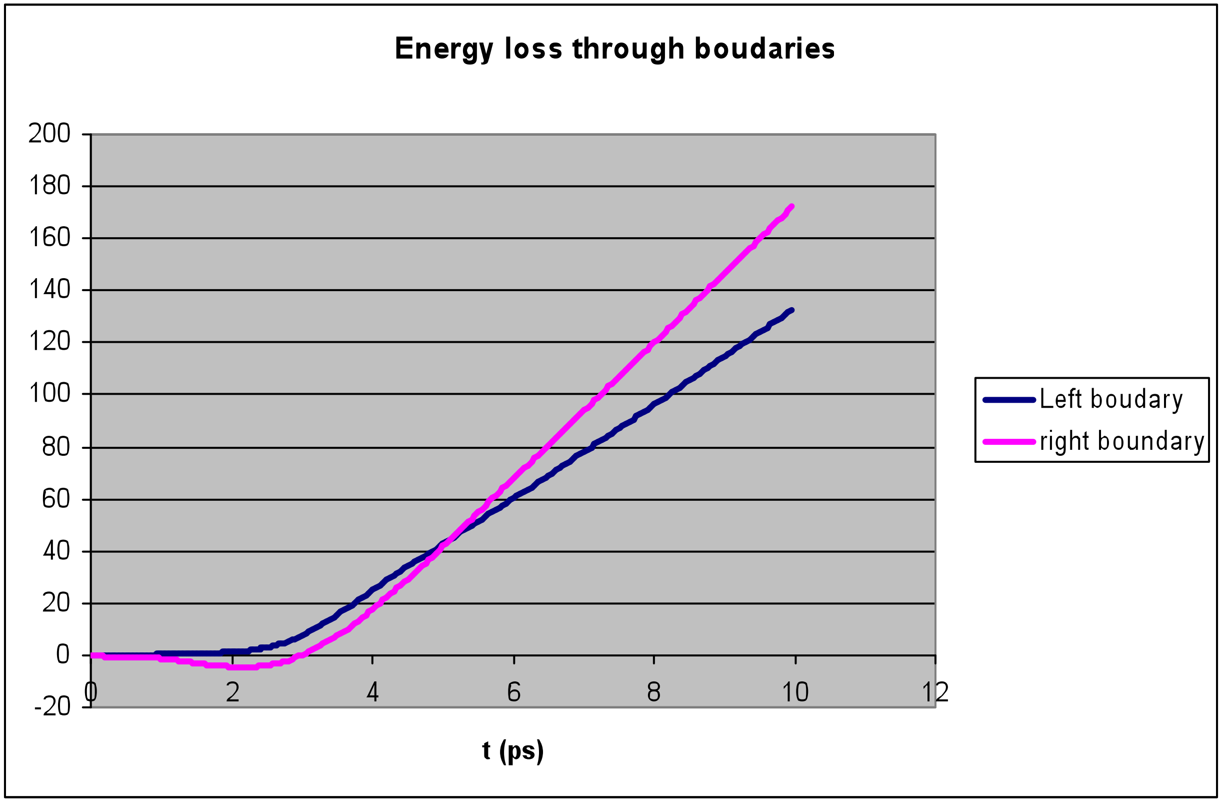
Convective modes (larger k_y) locate at lower density region



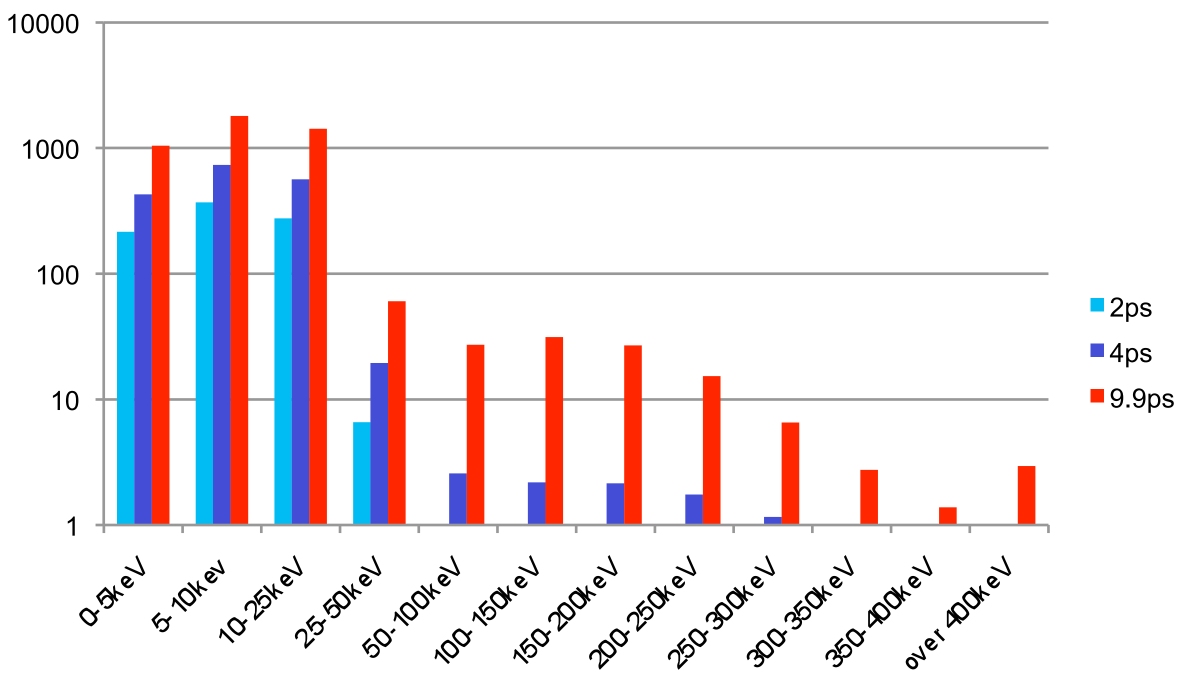
Most hot e- are produced in the nonlinear stage



Net particle energy flux has reached a quasi-steady state

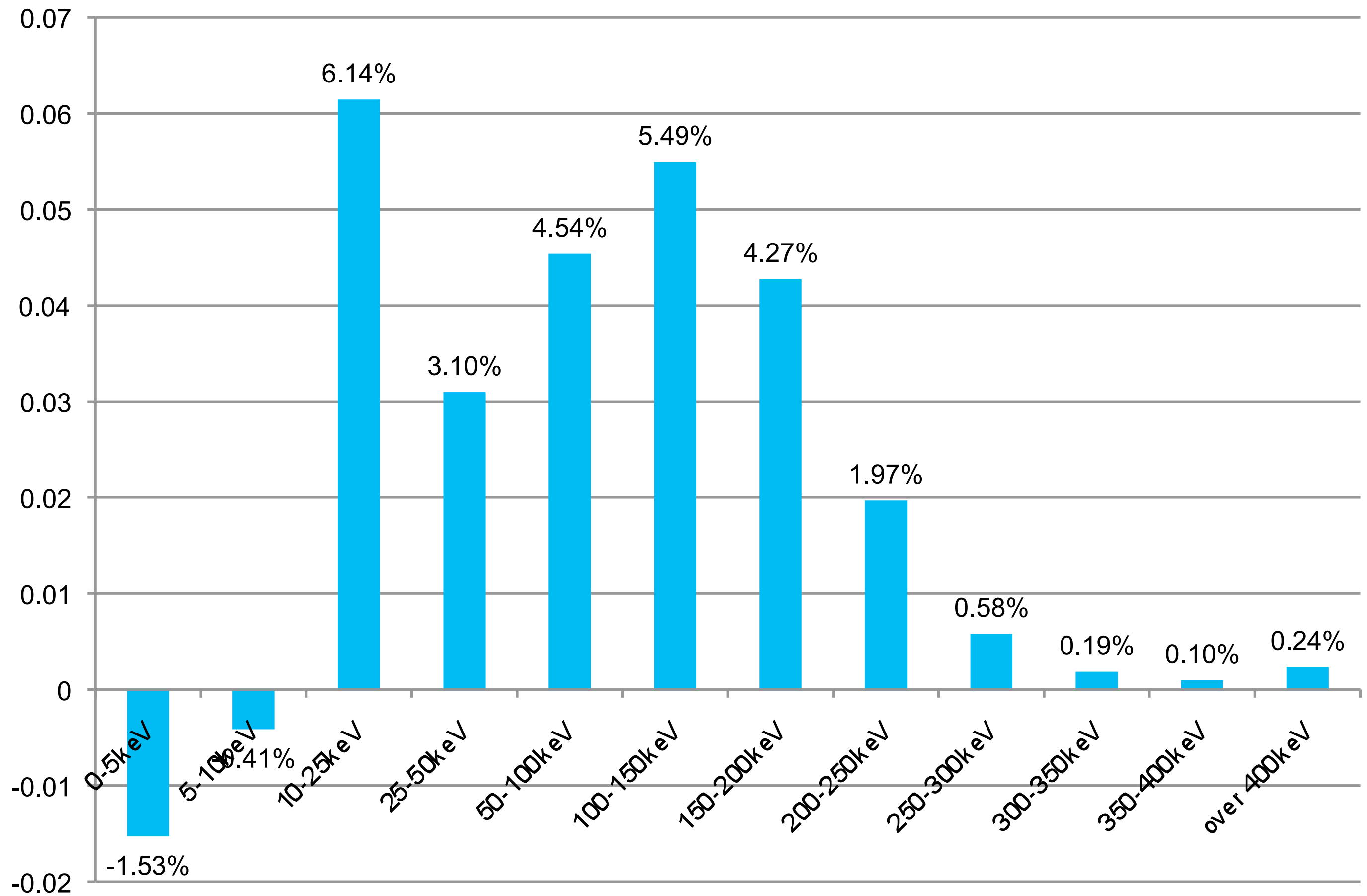


Most hot e- are generated in the nonlinear stage



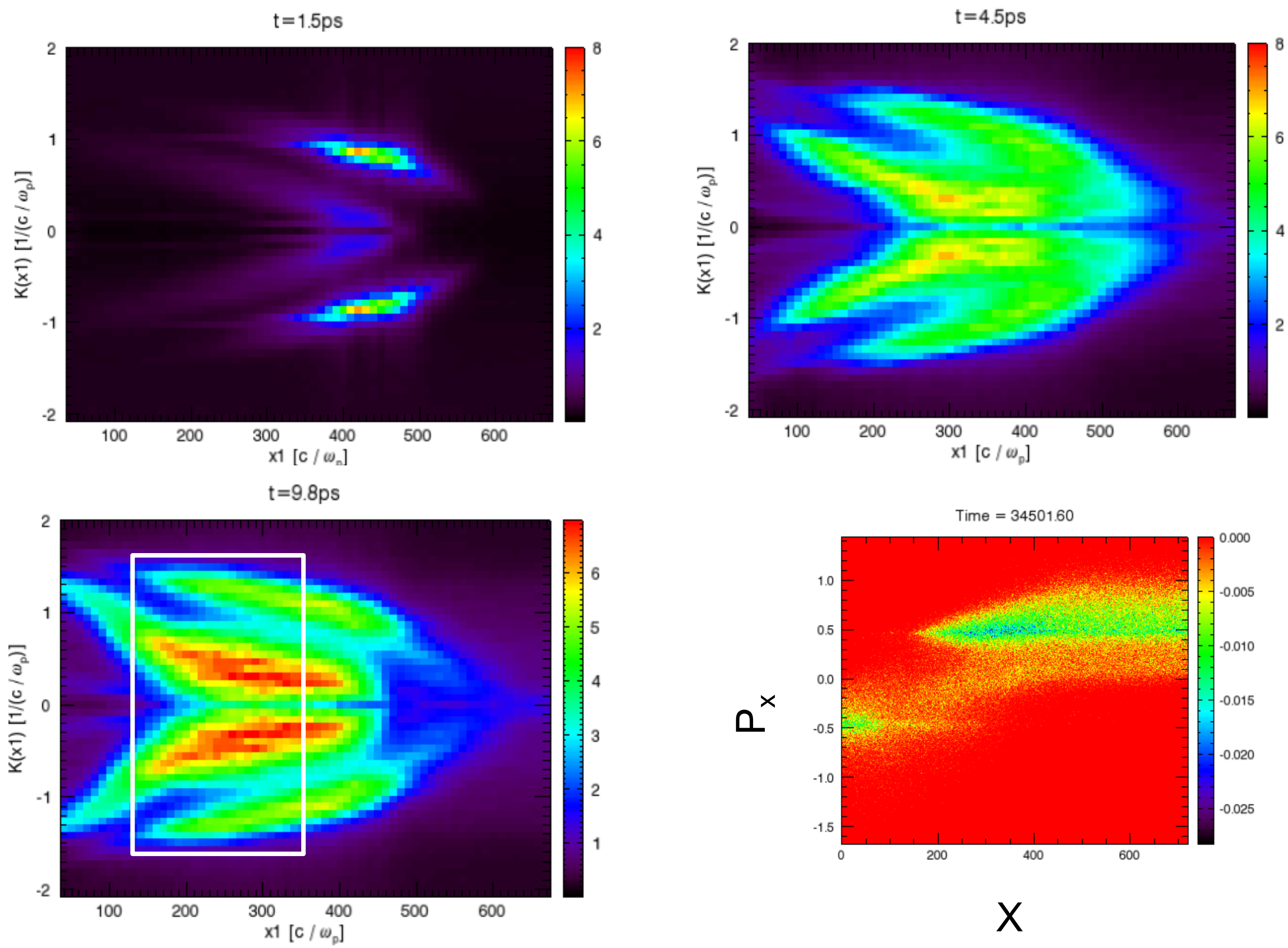
The existence of >100 keV e- is consistent with hard X-ray diagnostic

At steady state, 17% of laser energy is in the forward hot e- energy flux



Yakkobi et al. 2009 measured <0.3% hot e-

The appearance of hot e- (>100 keV) is correlated to new modes that are not seen in the linear stage

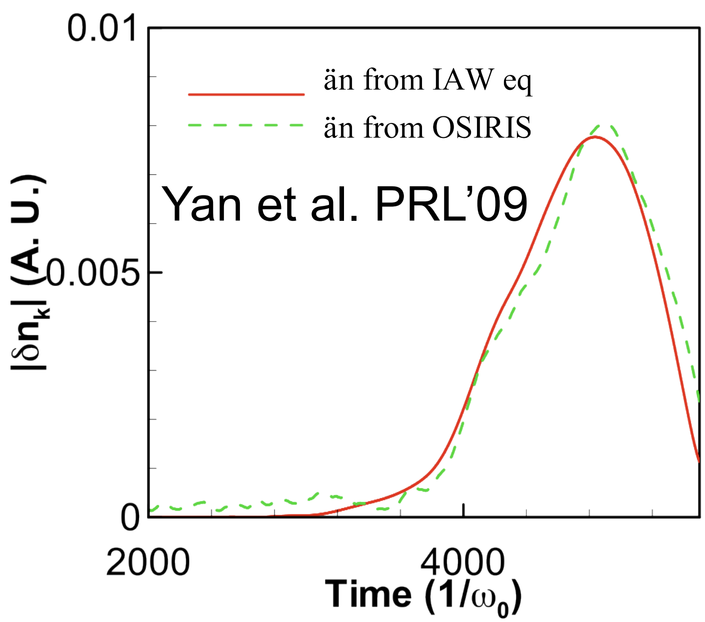


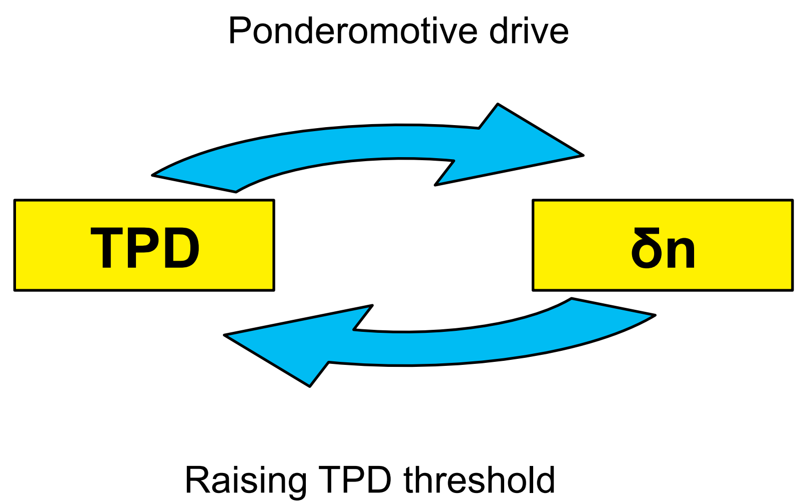
Nonlinearly, the ponderomotive pressure of the plasma waves drives ion density fluctuations

- **The ion density fluctuations calculated from the ion acoustic equation match the PIC results**
- **Ion acoustic wave (IAW) eq:**

$$(\partial_{tt} - C_s{}^2\nabla^2)\delta n = \nabla^2 |E|^2 /(16\pi m_i)$$

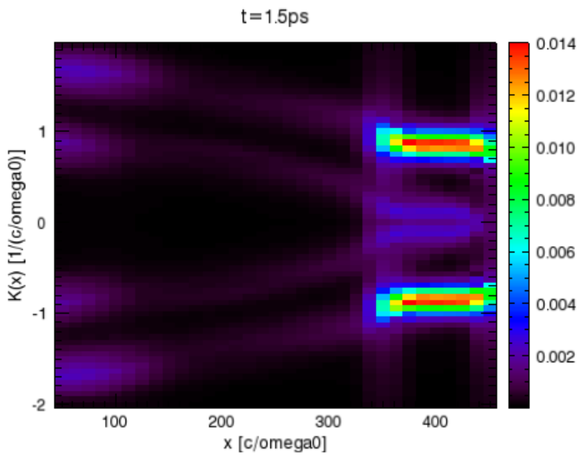
Drop $\nabla_{\parallel}^2$, Since $\nabla_{\parallel}^2 << \nabla_{\perp}^2$

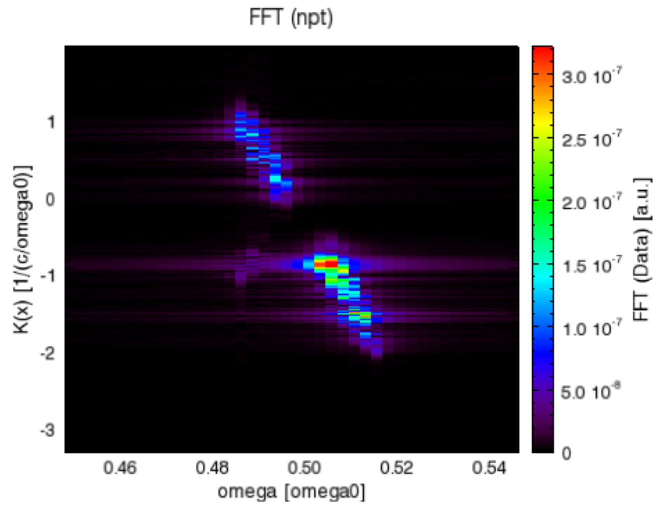


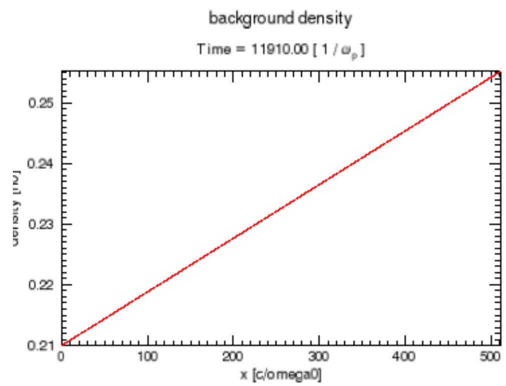


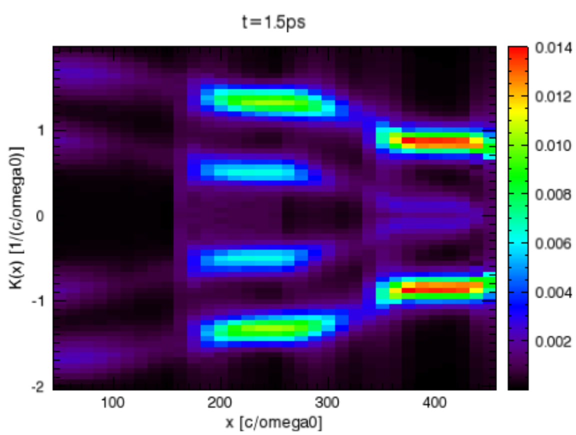
Yan et al., APS 2010

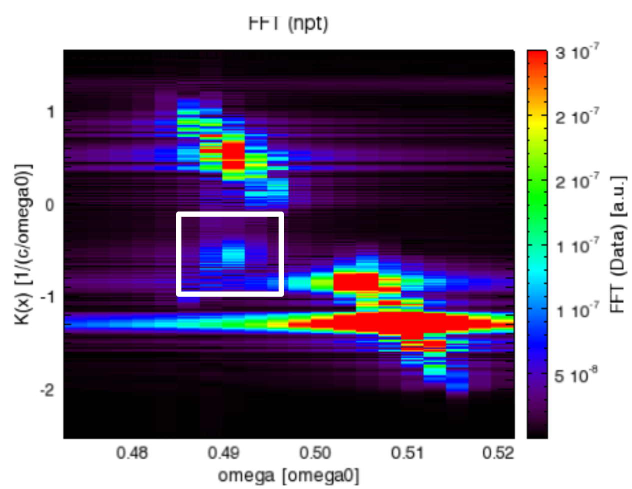
Ion density fluctuations can produce low-k, forward plasma waves

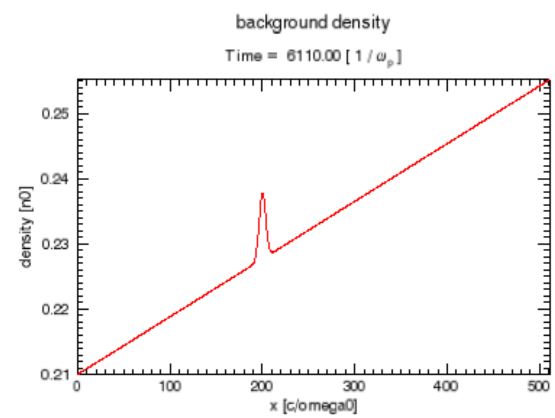


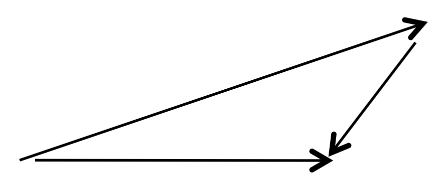












Plane-wave, 2D PIC simulations gave 10-100X more hot electrons than HXR measurements

Max I_{14}	T_e(keV)	Ti(kev)	$L_{\mu m}$	Mi/me	Run time	Forward Hot e-(>50kev)	Abs	η
4	3	1.5	150	3410	5ps	~0 (100 ptc per cell)	~0	0.8
6	3	1.5	150	3410	10ps	17% (100 ptc per cell)	42%	1.2

B. Yaakobi et al., Phys. Plasmas **16**, 102703 (2009):
hot e- <0.3% of laser energy

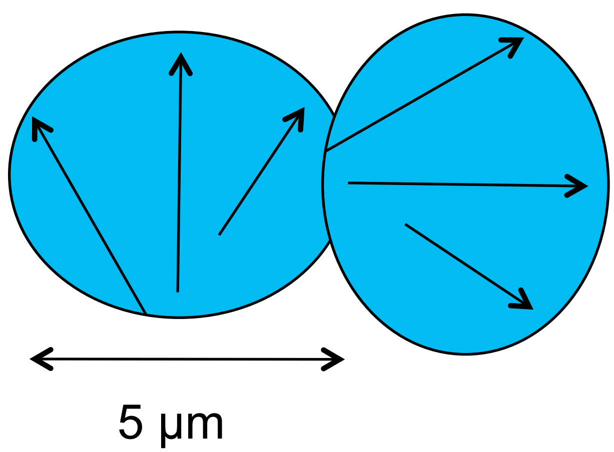
Things to check about the validity of the PIC results

- Hot e- are due to TPD
  - All $\eta>1$ runs have significant absorption
  - Oblique incidence should increase effective η (Afeyan)
- We believe we have reached steady state (<10 ps)
- Most hot e- go forward
- Are the hydro conditions used in the PIC simulations right?
  - LPI and hydro are coupled
- Is 2D, plane-wave model the right one?
  - What about the speckles?

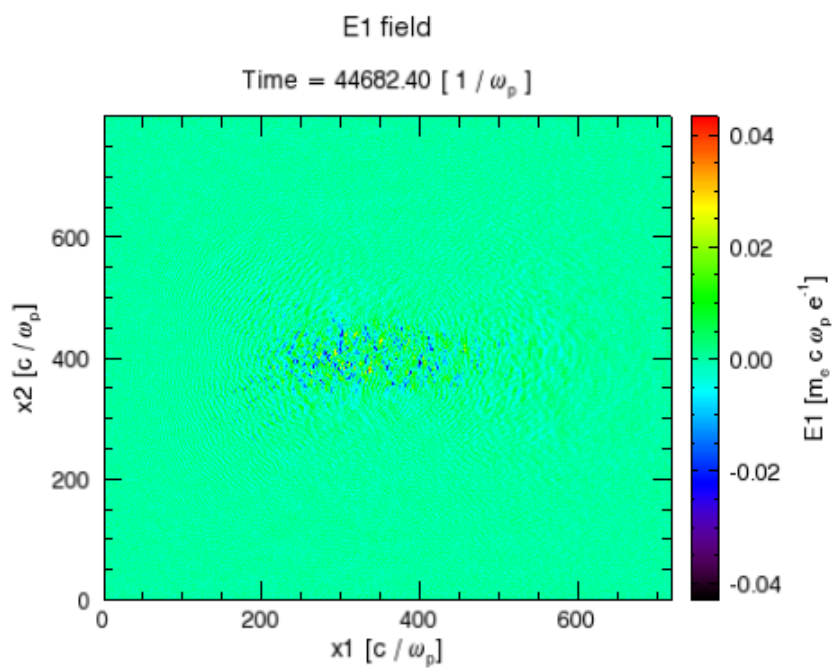
TPD of speckles is intrinsically 3D

- Each beam is made up of many speckles (grass in a lawn model)

- Within each speckle, the polarization is not constant



Simulations with well-separated speckles did show reduced absorption



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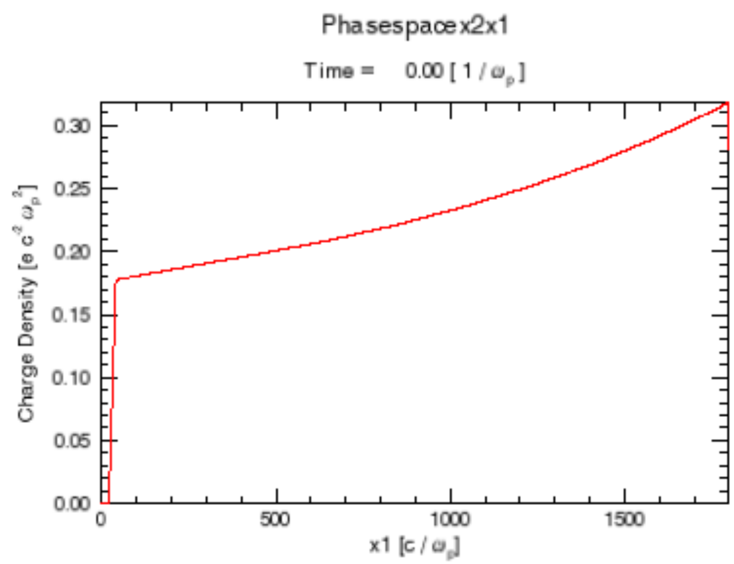
8	3	1.5	150	3410	9ps	5% (100 ptc per cell, W=4micron)	22%	1.4

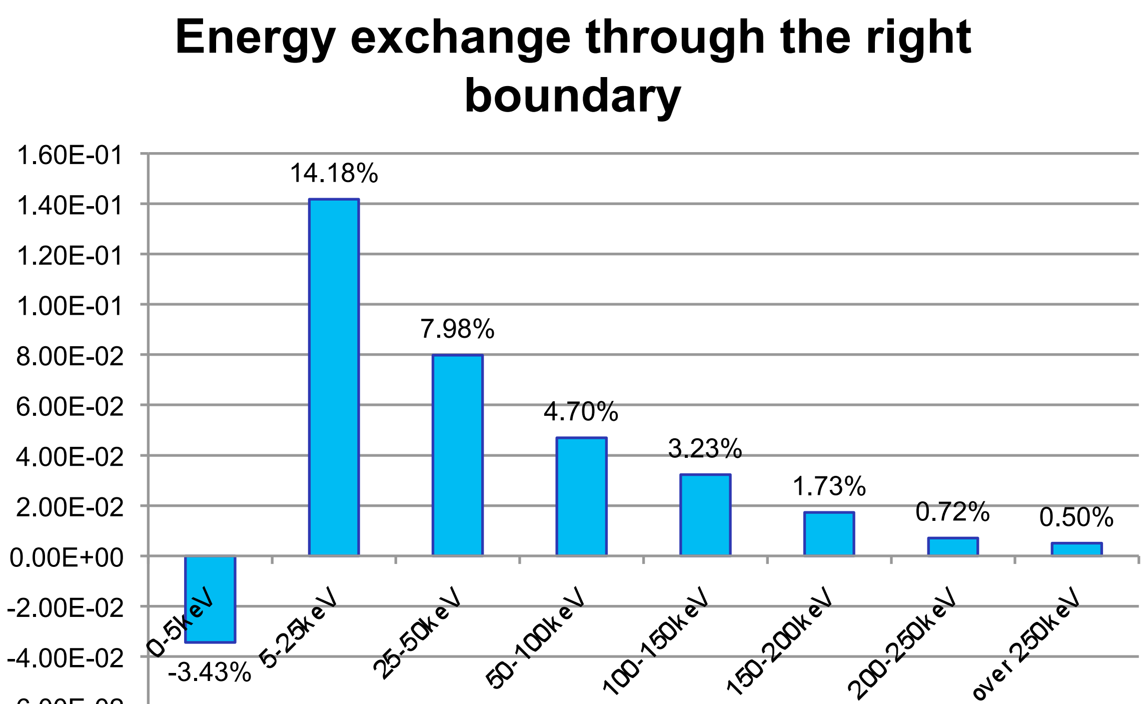
A simulation with higher laser intensity

- **The profile comes from the hydro simulation e52490**
  - **Lilac simulation by K. Anderson**



I=2e15W/cm^2
Te=1.6kev
Ti=550ev
M/m=3978
L=163.5micron (fit to exp function)

This run shows 52% absorption with only 6% in >100 keV e-



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