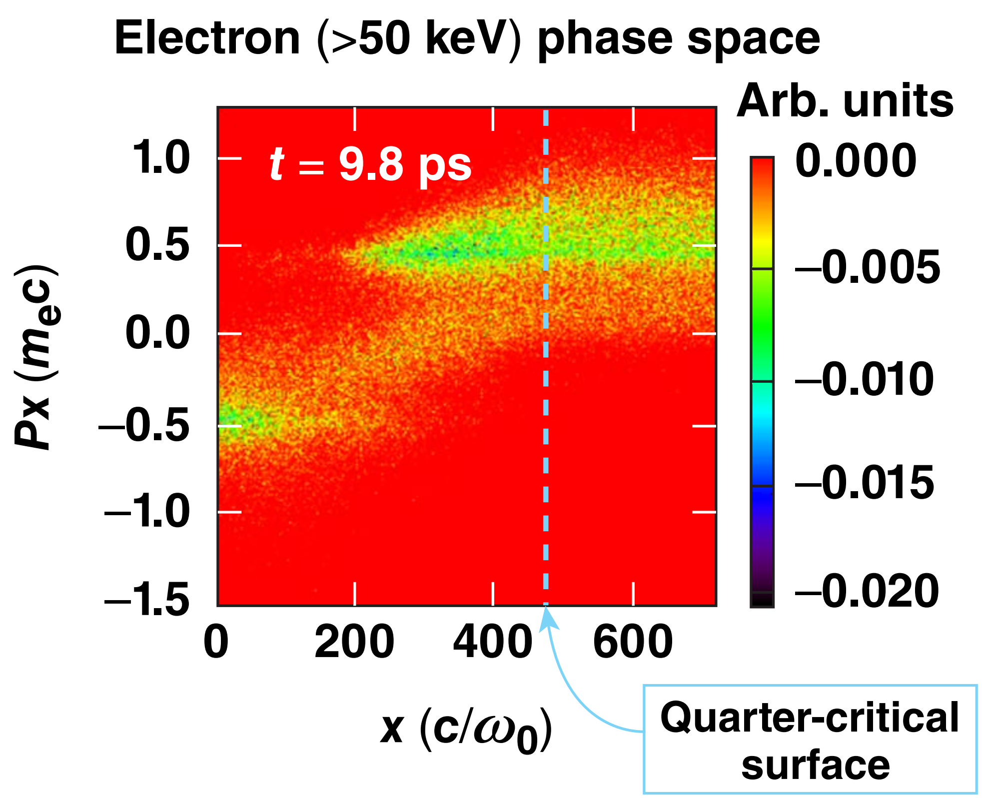
Energetic–Electron Generation in Two-Plasmon-Decay Instabilities in Inertial Confinement Fusion



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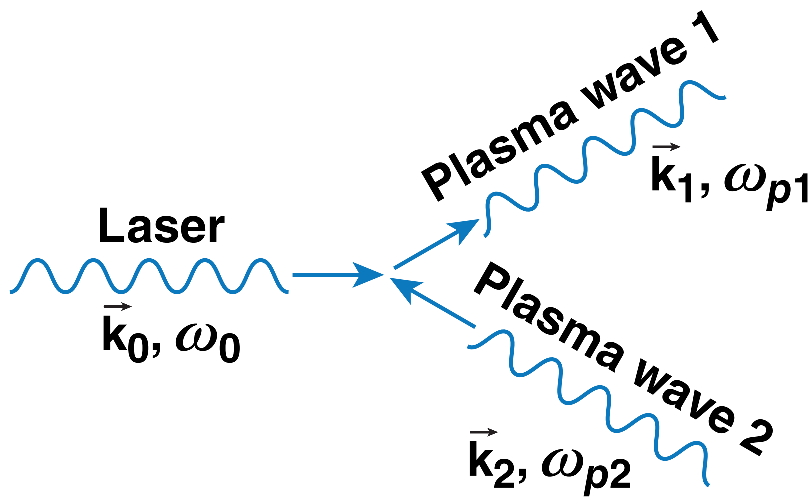
Summary

PIC simulations up to 10 ps for OMEGA parameters show saturation of two-plasmon decay (TPD) and hot-electron generation

- In PIC simulations, significant laser absorption and hot-electron generation occur in the nonlinear stage
- Generation of hot electrons is correlated with new TPD modes in the lower density region during the nonlinear stage
- The new TPD modes are correlated with ion-density fluctuations
- Hot electrons are accelerated from the low-density region to the high-density region through a staged process
- In fluid simulations with a linear TPD code, a spectrum similar to PIC simulations is observed with static ion-density fluctuations

The two-plasmon decay (TPD) is important to direct-drive ICF

- Energetic (hot) electrons generated from laser–plasma interactions can preheat the shell and degrade the implosion
- Low-energy hot electrons from TPD may be beneficial to the shock-ignition scheme*
- It is important to know the spectrum and amount of the hot electrons caused by TPD

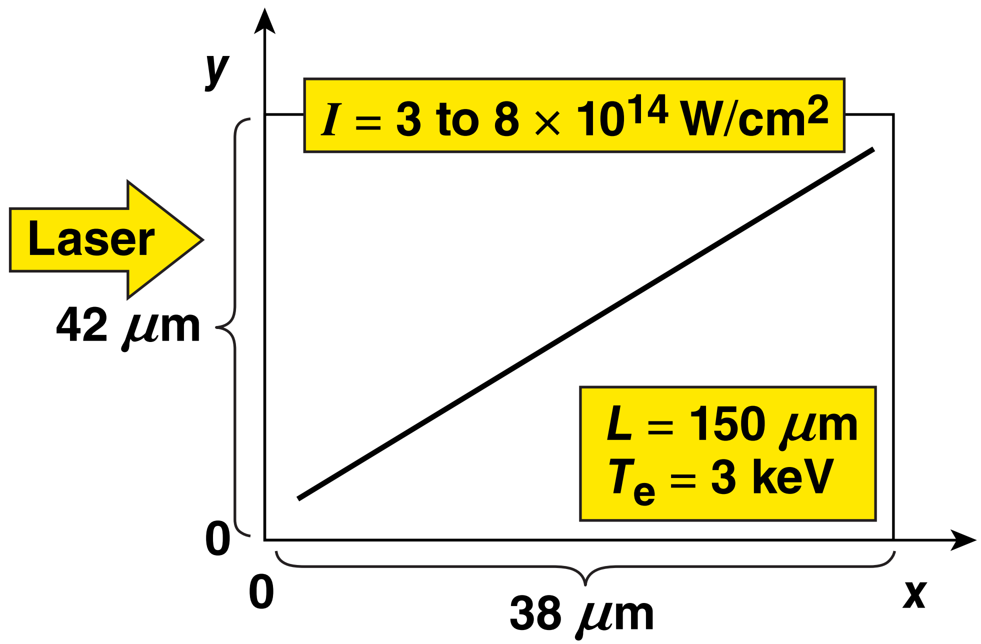


TC9116

*R. Betti *et al*., Phys. Rev. Lett. 98, 155001 (2007).

Long-time-scale PIC simulations with *OSIRIS** have been conducted for a range of OMEGA parameters

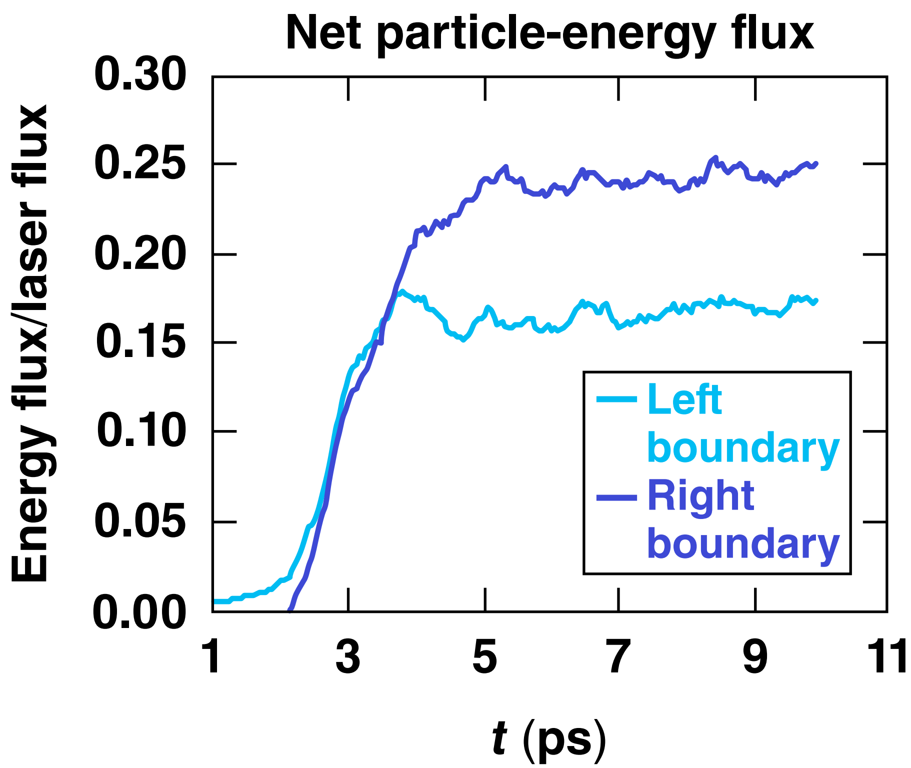
- Plane wave and Gaussian beams are used
- The simulation box is transversely periodic
- The open boundaries are used for fields and the thermal-reflecting boundaries are used for particles in the longitudinal direction
- Boundary diagnostics record the energy distribution of the particles going out of the thermal-reflecting boundaries



Simulation configuration for OMEGA parameters

*R. A. Fonseca *et al.*, Lect. Notes Comp. Sci. 2331, 342 (2002).

Net particle-energy flux reaches a quasi-steady state after ~5 ps

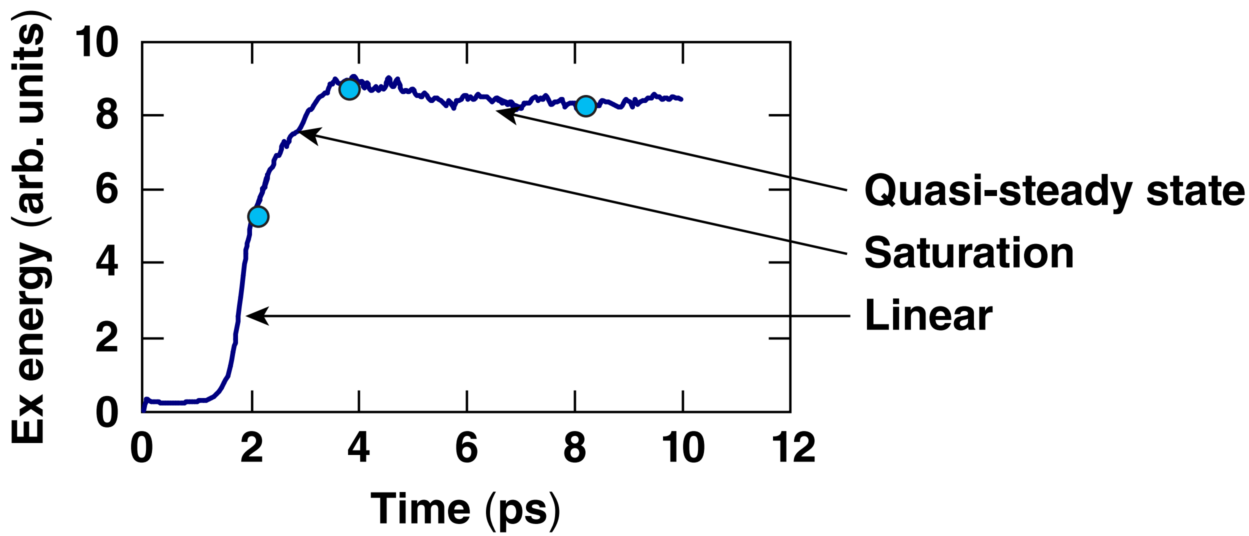


$I = 6 \times 10^{14}$ W/cm^2
$L = 150\ \mu$m
$T_e = 3$ keV

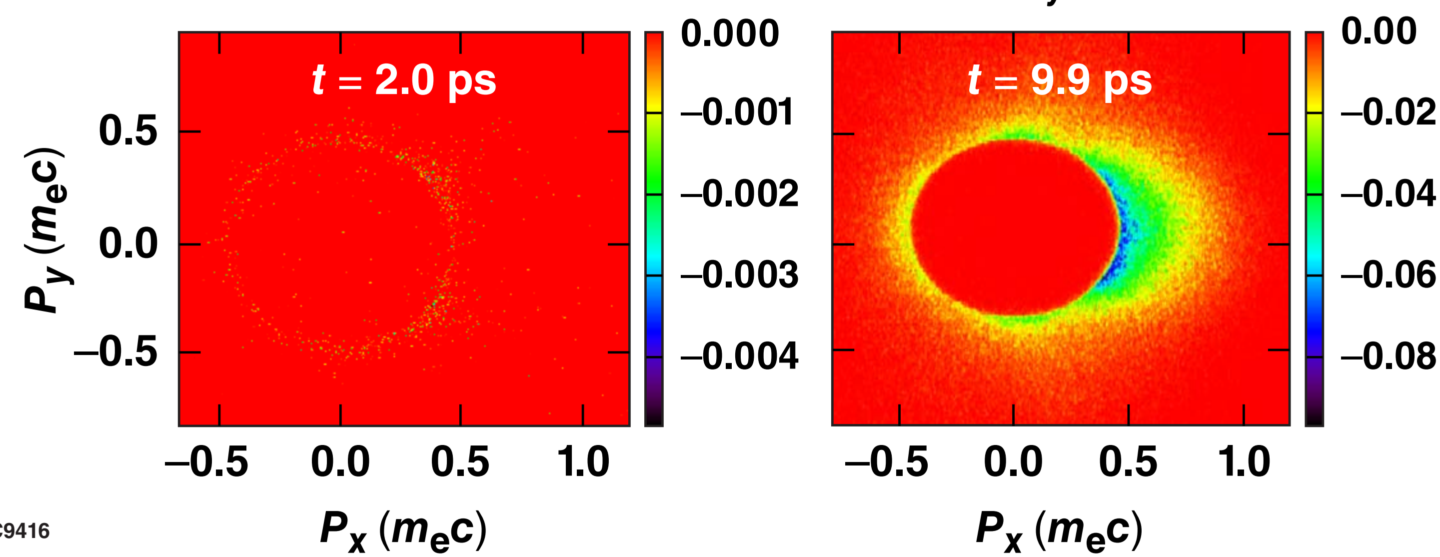
In the quasi-steady state

- absorbed laser energy is balanced by the energy flux exiting the box
- the particle and field energies in the simulation box are essentially constant

Most hot electrons are produced in the nonlinear stage



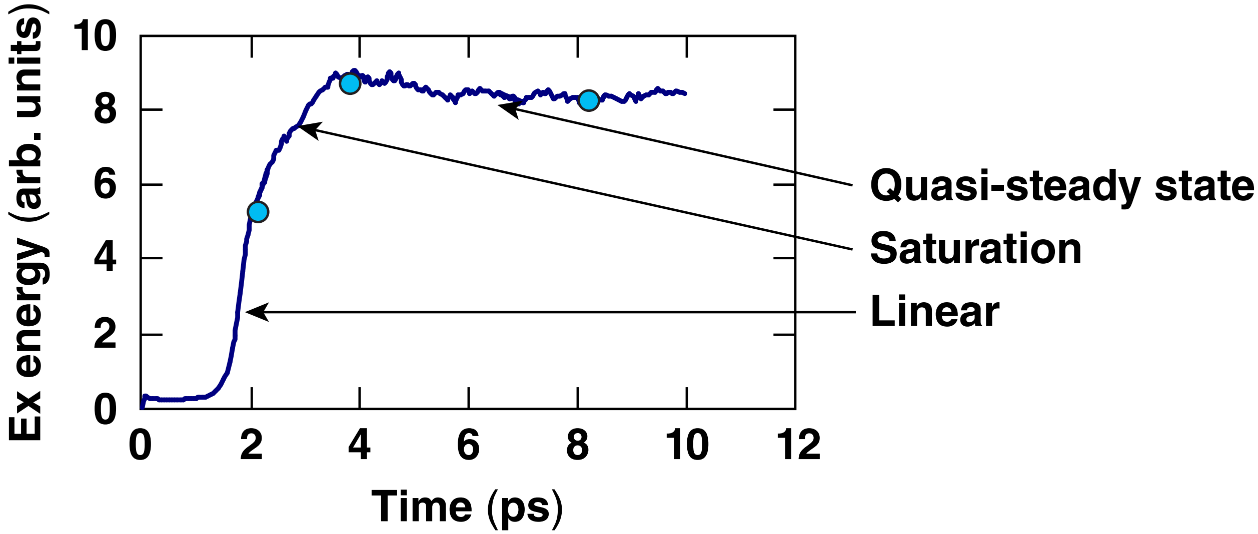
Electron >50-keV distribution in P_x–P_y space

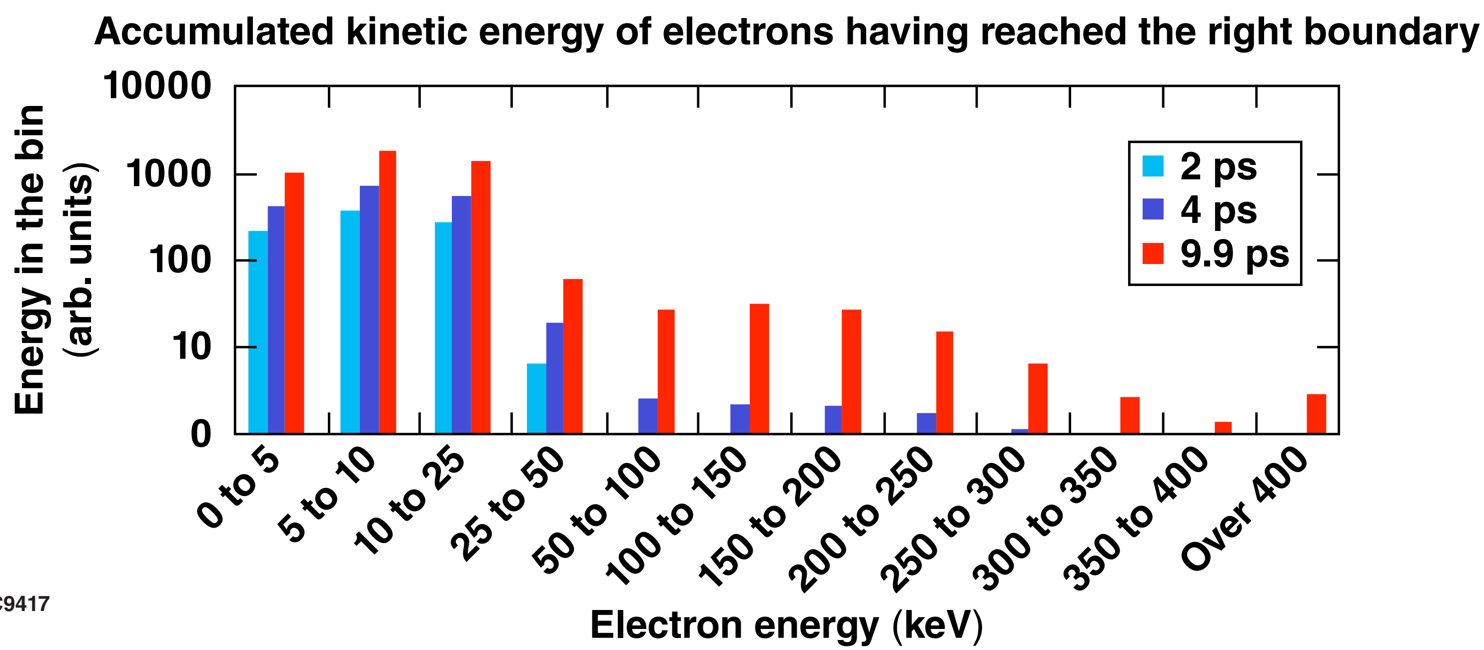


L = 150 μm
T_e = 3 keV
I = 6 × 10^{14} W/cm^2

TC9416

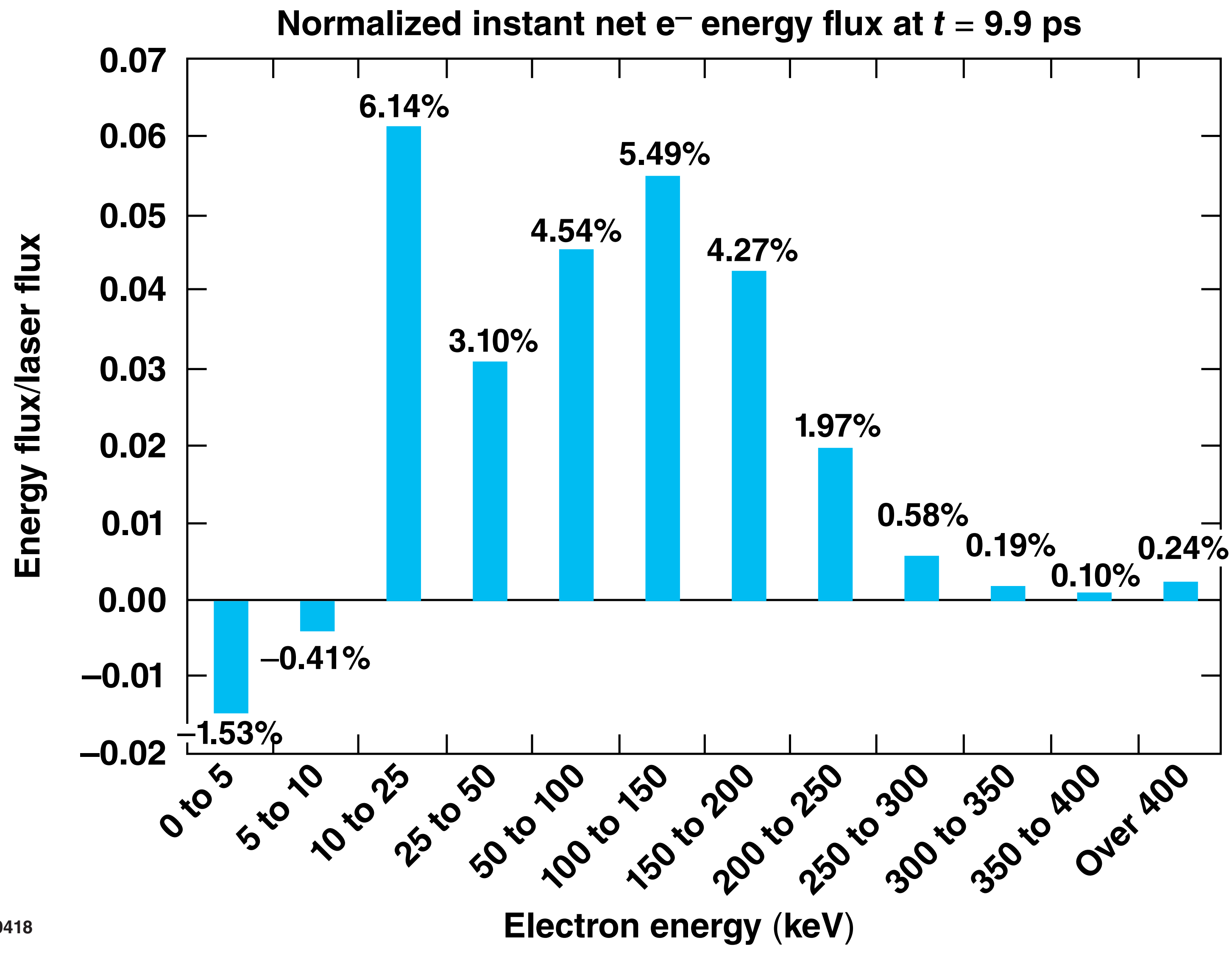
Many more hot electrons reached the rear boundary during the nonlinear stage than during the linear stage





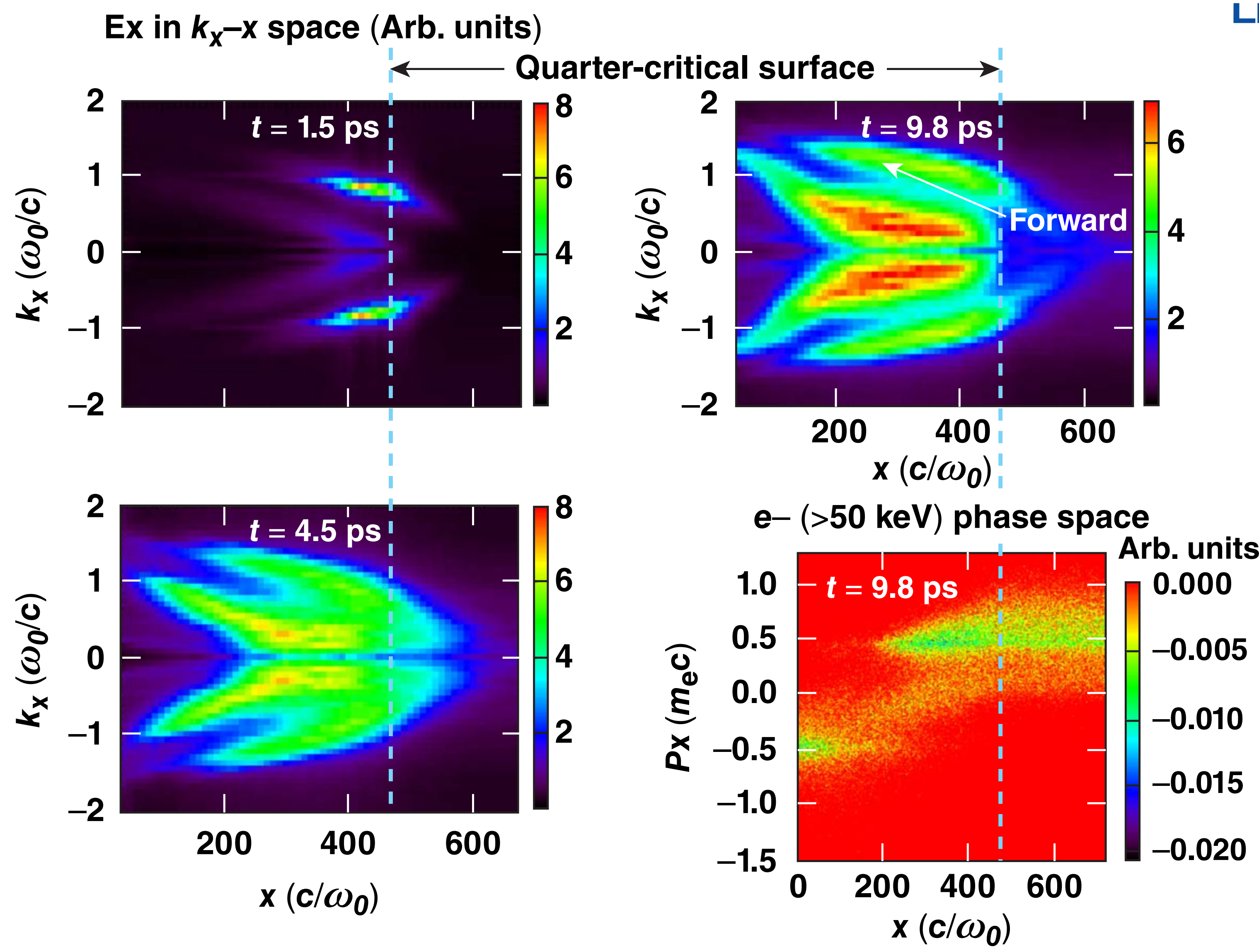
TC9417

The net energy flux exiting the right boundary includes significant contribution from the hot electrons



TC9418

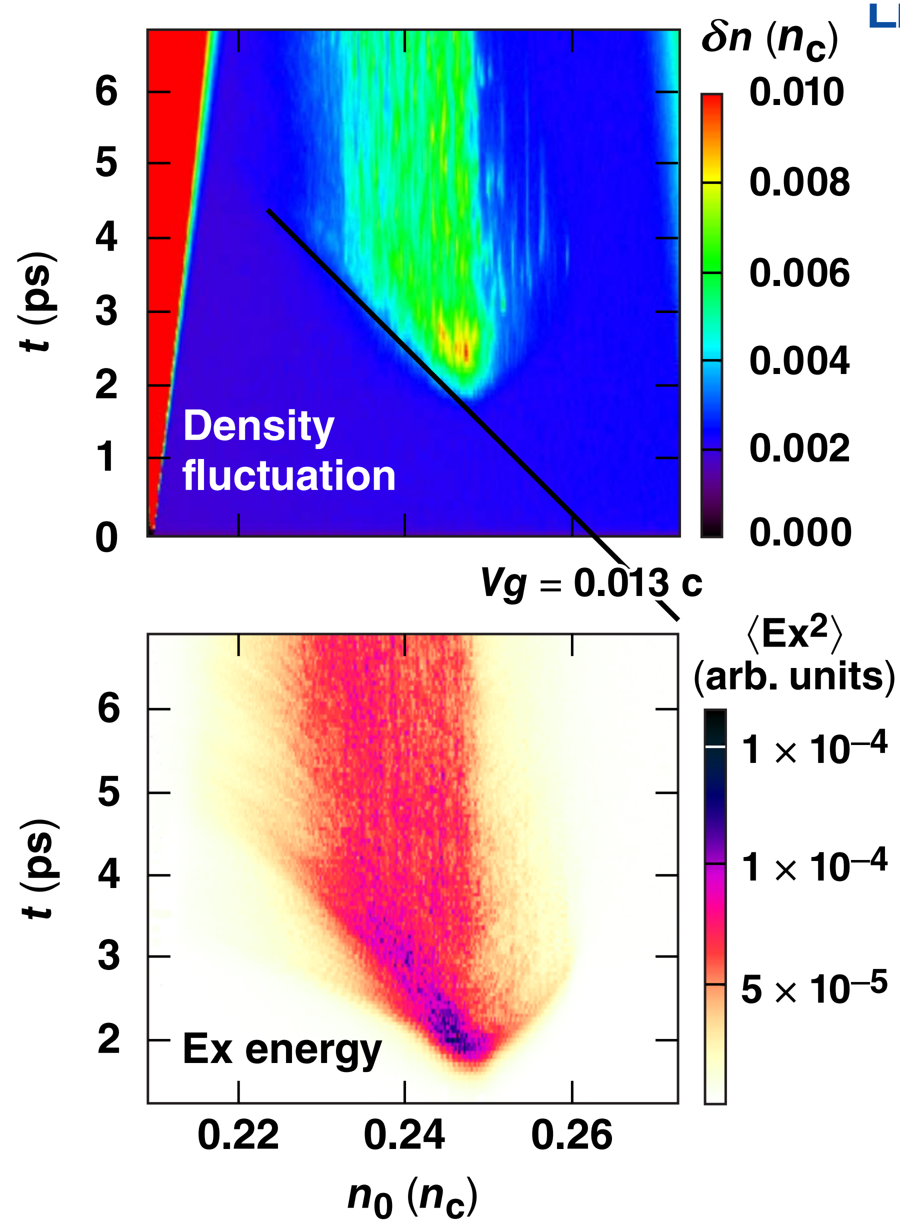
The hot electrons are generated through staged acceleration initiated by new TPD modes with low phase velocity in the nonlinear stage



TC9419

Ion-density fluctuations are driven by plasma waves propagating to lower density regions

- The region of ion-density fluctuations is spreading at the group velocity of plasma waves with the largest *k*
- Ion fluctuations at the low-density region can induce new TPD modes locally



TC9420

A linear–fluid code has been developed to study the spectrum of TPD with an arbitrary static background-density profile

- **The fluid code solves linear equations:**

$$\frac{\partial \psi}{\partial t} = \frac{e\phi}{m} - \frac{3\nu_e^2 n_p}{n} - \vec{\nu}_0 \cdot \nabla \psi$$

$$\frac{\partial n_p}{\partial t} + \vec{\nu}_0 \cdot \nabla n_p = -\nabla \cdot (n \nabla \psi)$$

$$\nabla^2 \phi = 4\pi e n_p$$

$$\vec{\nu} = \nabla \psi$$

$$\vec{E} = -\nabla \phi$$

BC's

- **The density fluctuation is modeled by a static** $n = n_0(x) + \delta n$

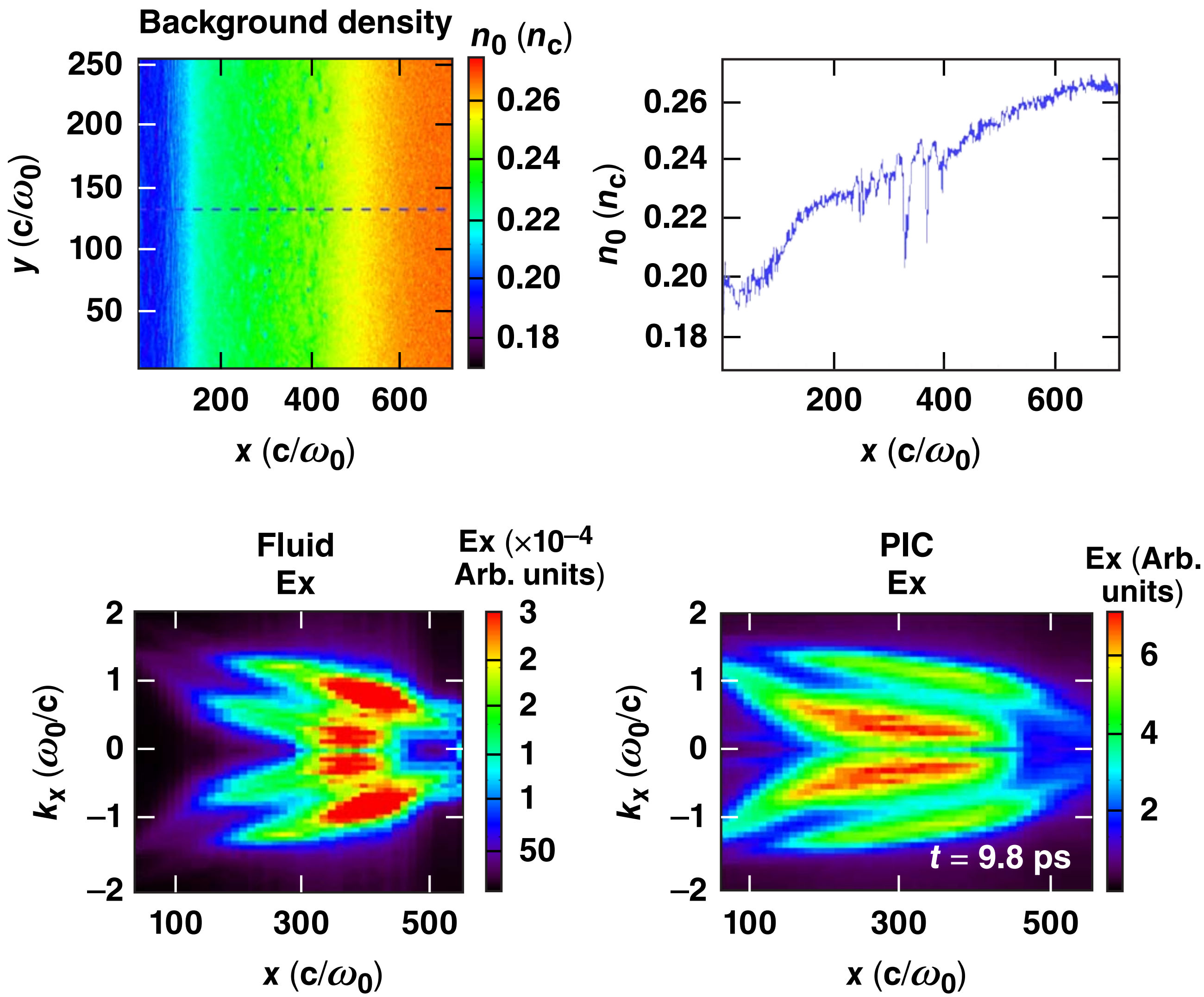
$$\partial_x \psi\big|_0 = \partial_x \psi\big|_L = 0$$

$$\partial_x \phi\big|_0 = \partial_x \phi\big|_L = 0$$

$$n_p\big|_0 = n_p\big|_L = 0$$

Fluid simulations produce modes similar to PIC simulations

- **The background density profile is read from *OSIRIS* simulation results**
- **The spectrum obtained in the fluid simulation is similar to that from the PIC simulation**
- **The differences in the relative amplitudes may be due to electron acceleration**



TC9414

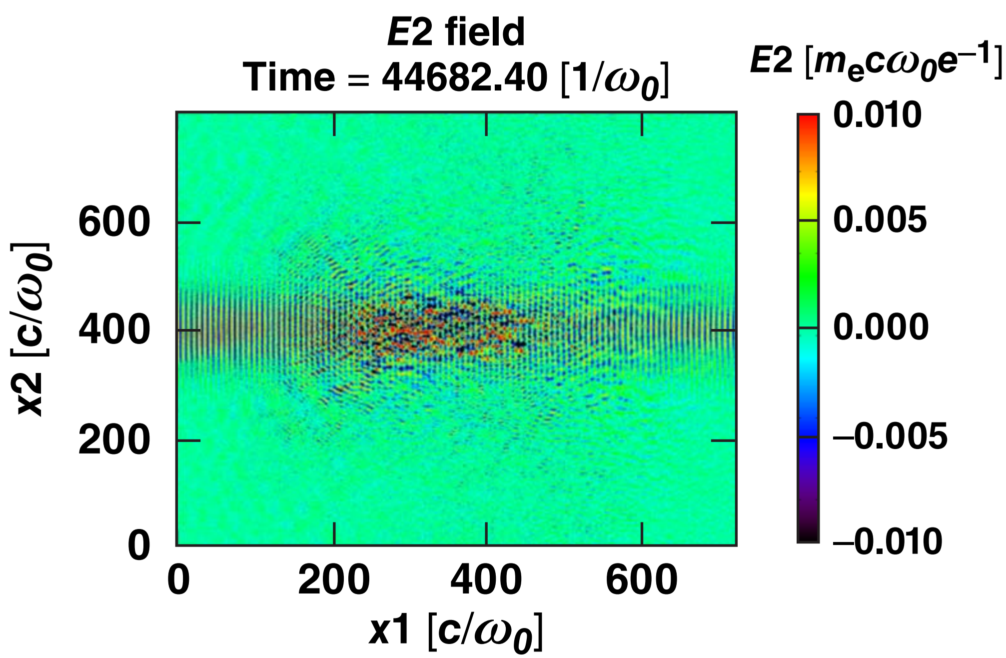
The energy carried by hot electrons in plane-wave PIC simulations is high

I_{14}max	T (keV)/ T_i (keV)	L	η*	Total absorption	Hot (>50-keV) electrons
3	3/1.5	150	0.6	~0	~0
6	3/1.5	150	1.2	42%	17%
8	3/1.5	150	1.4	39%	15%

*A. Simon *et al*., Phys. Fluids 26, 3107 (1983).

Important differences exist between the simuations and experiments

- Large absorption indicates that better coupling between PIC and hydro simulations is needed
- Speckles
  - in experiments, polarization smoothing changes laser polarization even within a single speckle, which needs 3-D modeling
  - simulation with a narrow beam has shown a reduced hot-electron generation



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8 (W = 4 μm)	3/1.5	150	1.4	22%	5%

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