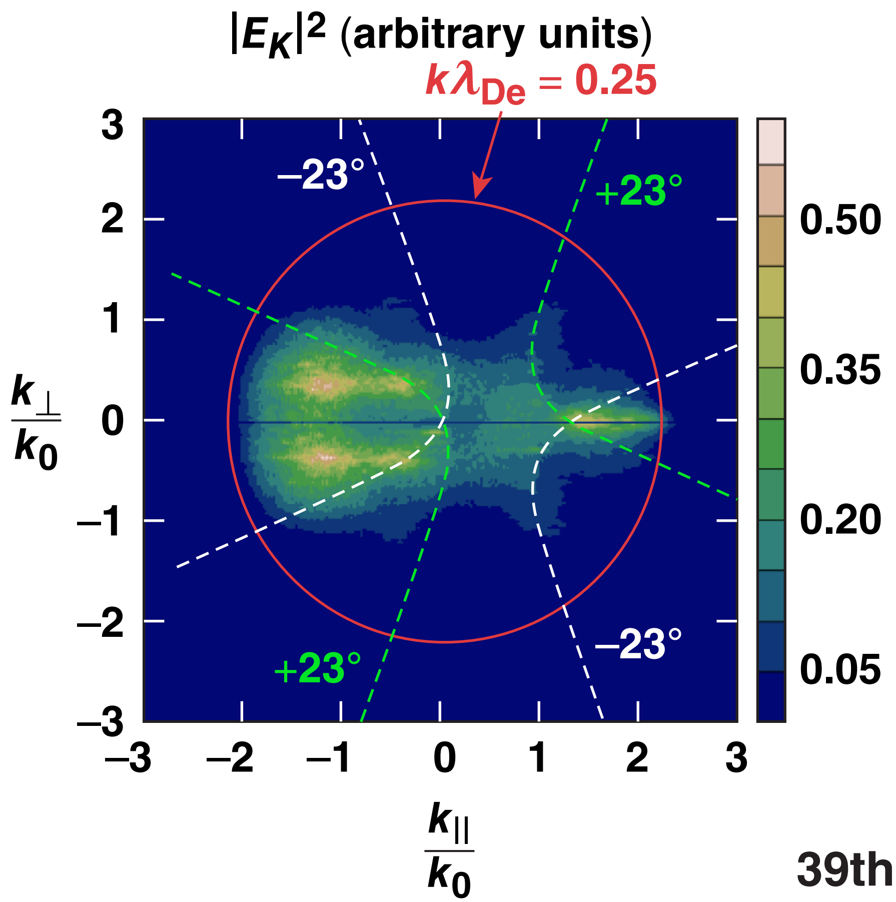
Extended Zakharov Modeling of the Two-Plasmon-Decay Instability in Inhomogeneous Direct-Drive ICF-Relevant Plasma



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39th Annual Anomalous Absorption Conference
Bodega Bay, CA
14–19 June 2009

Summary

A fluid-type Zakharov model is used to model TPD decay for parameters of OMEGA implosion experiments

- The waves saturate through the LF (ion) plasma response
  - profile modification and LDI signatures are observed
  - the LW level is sensitive to the IAW damping rate
  - a possible mitigation strategy could use high-*Z* dopants
- The LW spectrum extends right to the Landau cutoff
- Evidence of cooperative TPD between multiply overlapped beams is observed in the calculations

TC8451

Collaborators

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Two-dimensional "Zakharov" simulations of OMEGA implosion experiments have been performed

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- The Zakharov equations[1] were introduced as a model for strong plasma turbulence[2]
- "Averaging" over LW period, hydrodynamic equations (requires a strict separation of time scales)
- Both the equations for the Langmuir wave, and the sound waves are linear
- Kinetic effects beyond linear Landau damping are currently neglected
- Quasi-linear evolution of the distribution function (previous successes in ionosphere)
- Comparison with kinetic calculations (RPIC) (See H. X. Vu's talk)

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[1] V. E. Zakharov Zh. Exp. Theor. Phys. 62, 1745 (1972); V. E. Zakharov, in *Handbook of Plasma Physics*, Vol. 2 (Elsevier, Amsterdam, 1984), p. 81; V. D. Shapiro and V. I. Shevchenko, in *Handbook of Plasma Physics*, Vol. 2 (Elsevier, Amsterdam, 1984), p. 124.

[2] M. V. Goldman, Rev. Mod. Phys. 56, 709 (1984).

The "Zakharov" equations are extended when applied to the two-plasmon-decay problem

- "Extended" Zakharov equations used in Zak*

$$\nabla\cdot\left[D_{LW}-\omega_0^2(\delta n+\delta N)/n_0\right]E=\underbrace{(e/4m_c)\nabla\cdot\left[\nabla(E_0\cdot\bar{E})-E_0\nabla\cdot\bar{E}\right]}_{\text{TPD source term}}+S_E$$

$$D_{IAW}\delta n=\nabla^2|E|^2/(16\pi m_i)+S_{\delta n}$$

TPD source term

Dispersion relations for LW and IAW

$$D_{LW}=\left[2i\omega_{p0}(\partial_t+\nu_e{*})+3\nu_e^2\nabla^2\right]$$

$$D_{IAW}=\left(\partial_t^2+2\nu_i{*}\partial_t-c_s^2\nabla^2\right)$$

Wave envelopes

$$\tilde{E}=1/2\,E(x,y,t)\exp\left[-i\left(\omega_{p0}t\right)\right]+c.c$$

$$\tilde{E}_0=e_y\sum_i|E_0|_i\exp\left[i\vec{k}_{0i}\cdot\vec{x}-i\left(\omega_0-2\omega_{p0}\right)t\right]$$

*D. F. DuBois *et al.*, Phys. Rev. Lett. 74, 3983 (1995); D. A. Russell and D. F. DuBois, Phys. Rev. Lett. 86, 428 (2001).

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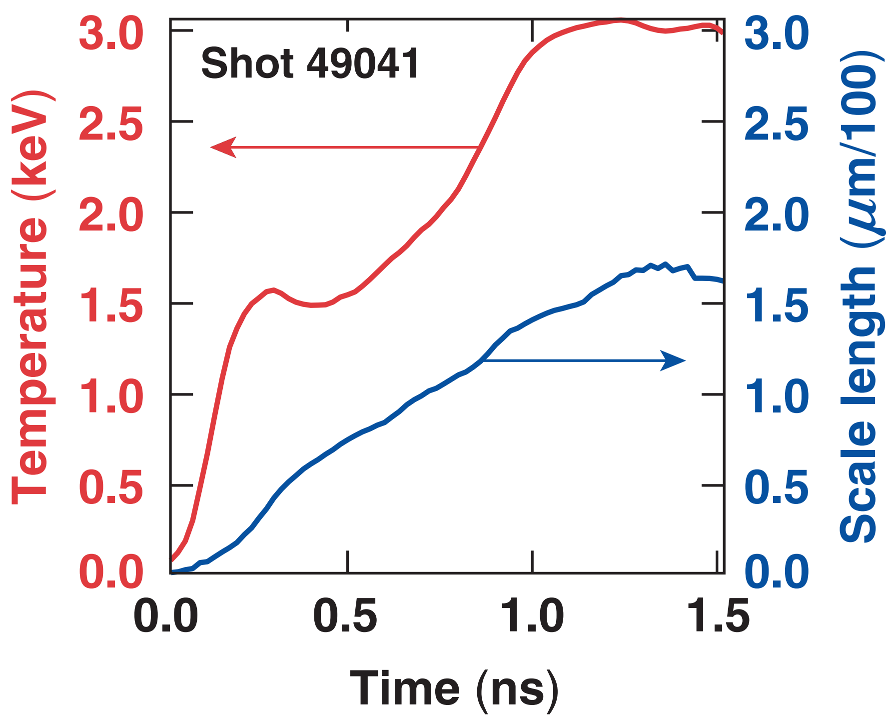
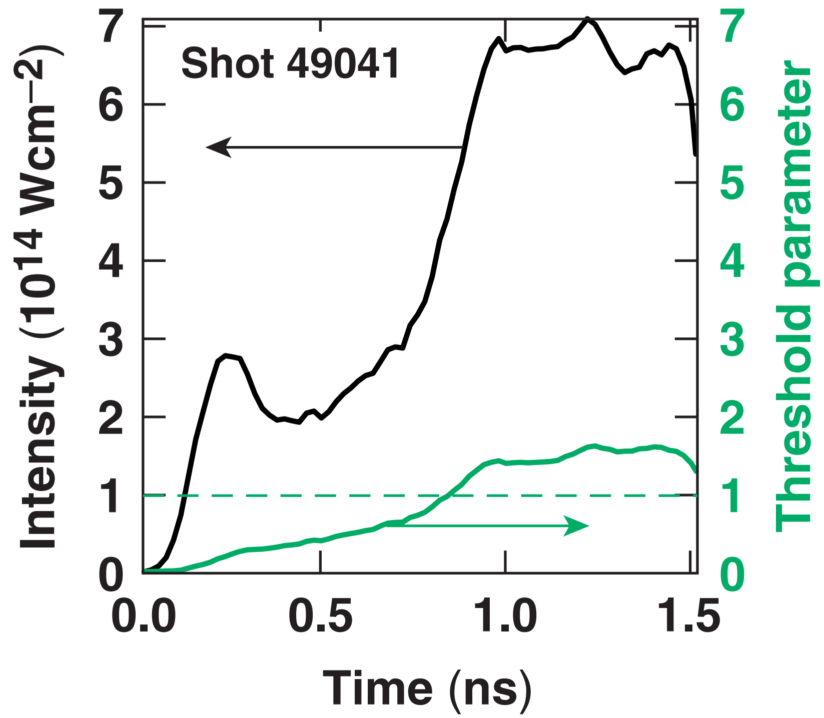
Two-dimensional "Zakharov" simulations of OMEGA implosion experiments have been performed

$$(I_{14})_{\mathrm{Th}} = 3.6\ (T_e/2\ \mathrm{keV})\ (150\ \mu\mathrm{m}/L_n)$$



Threshold parameter predicts onset of TPD signatures in OMEGA experiments



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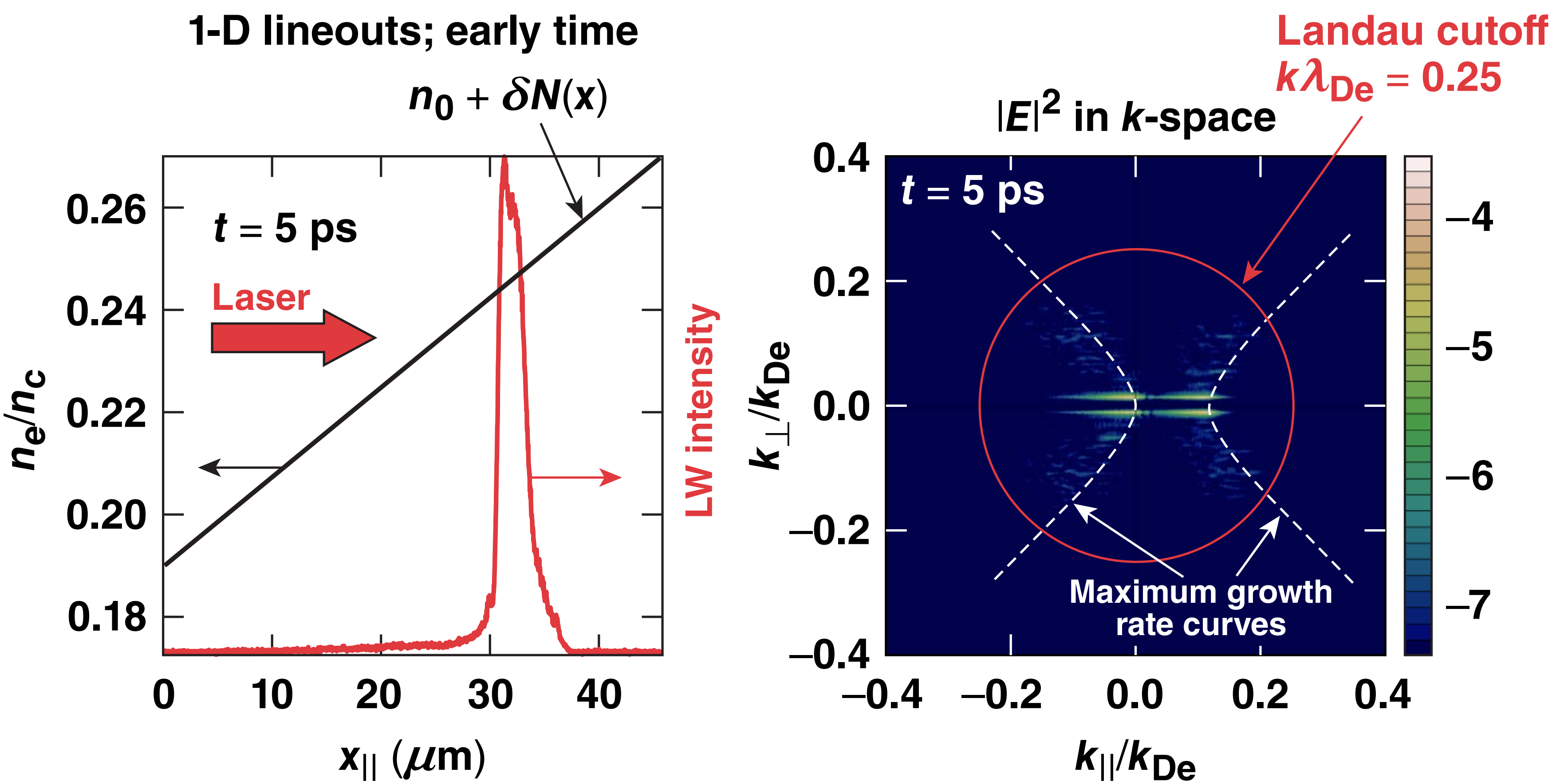
[1] A. Simon *et al.*, Phys. Fluids 26, 3107 (1983).

The linearly unstable eigenmode is located close to the quarter-critical density surface



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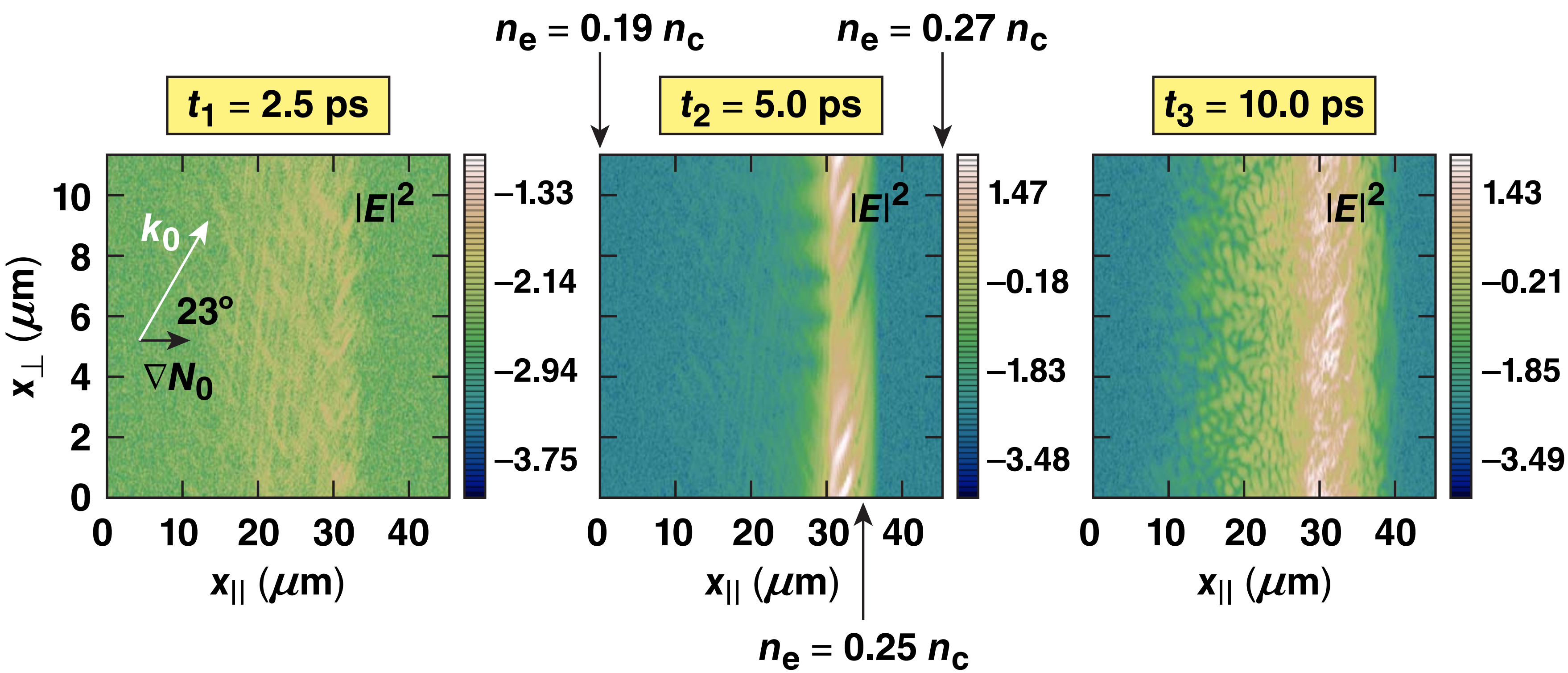
The absolutely unstable mode collapses, exciting a broad spectrum of perturbations in the plasma density (δn)

- Single beam, oblique incidence with respect to the gradient
- Figures show snap shots of plasma wave intensity $|E|^2$ in real space
- TPD plasma waves are generated; this is followed by collapse and "burn out"



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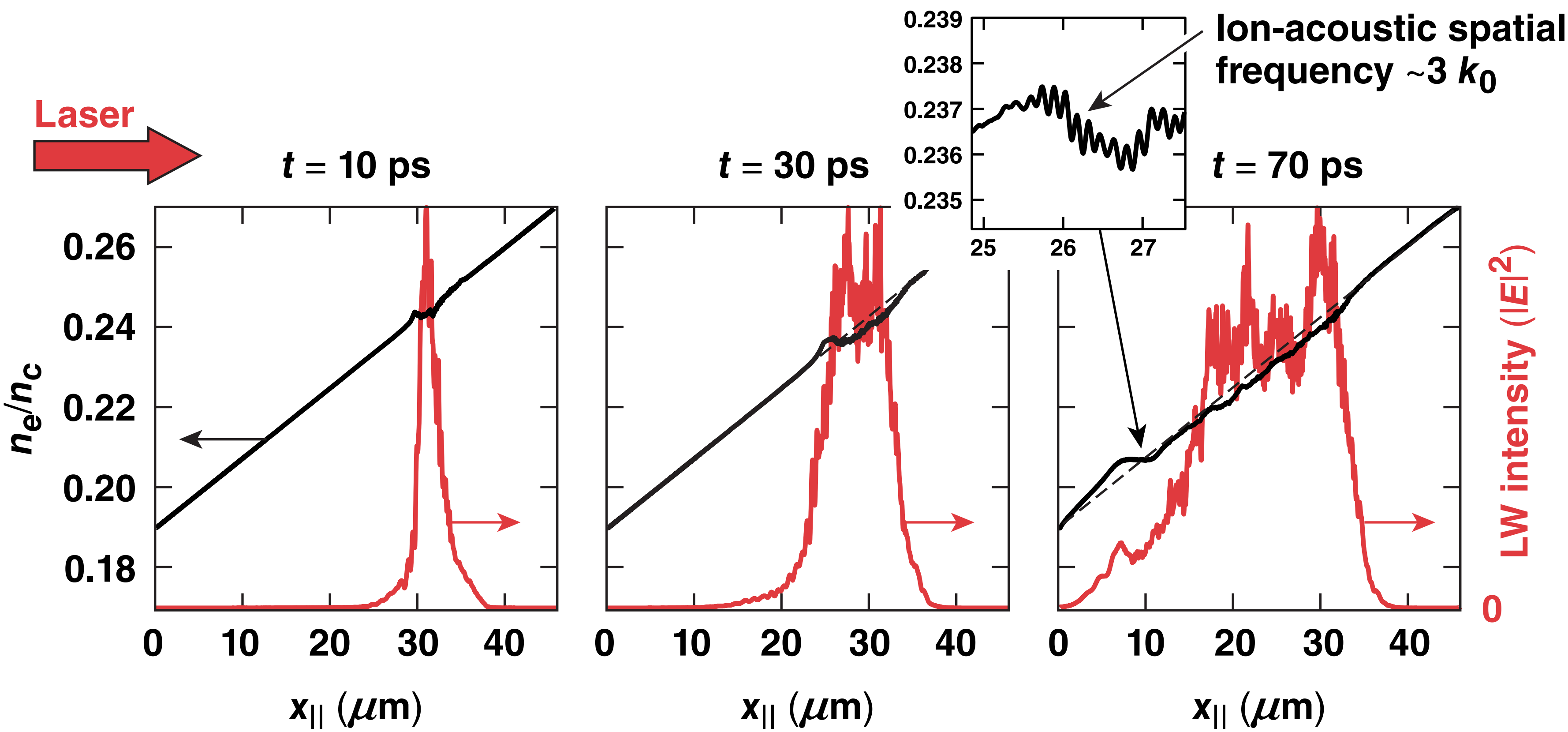
The region of plasma-wave excitation rapidly spreads down the density gradient, modifying the density profile as it does so

- The LW electric field and the nonlinear density perturbations are averaged over the transverse coordinate



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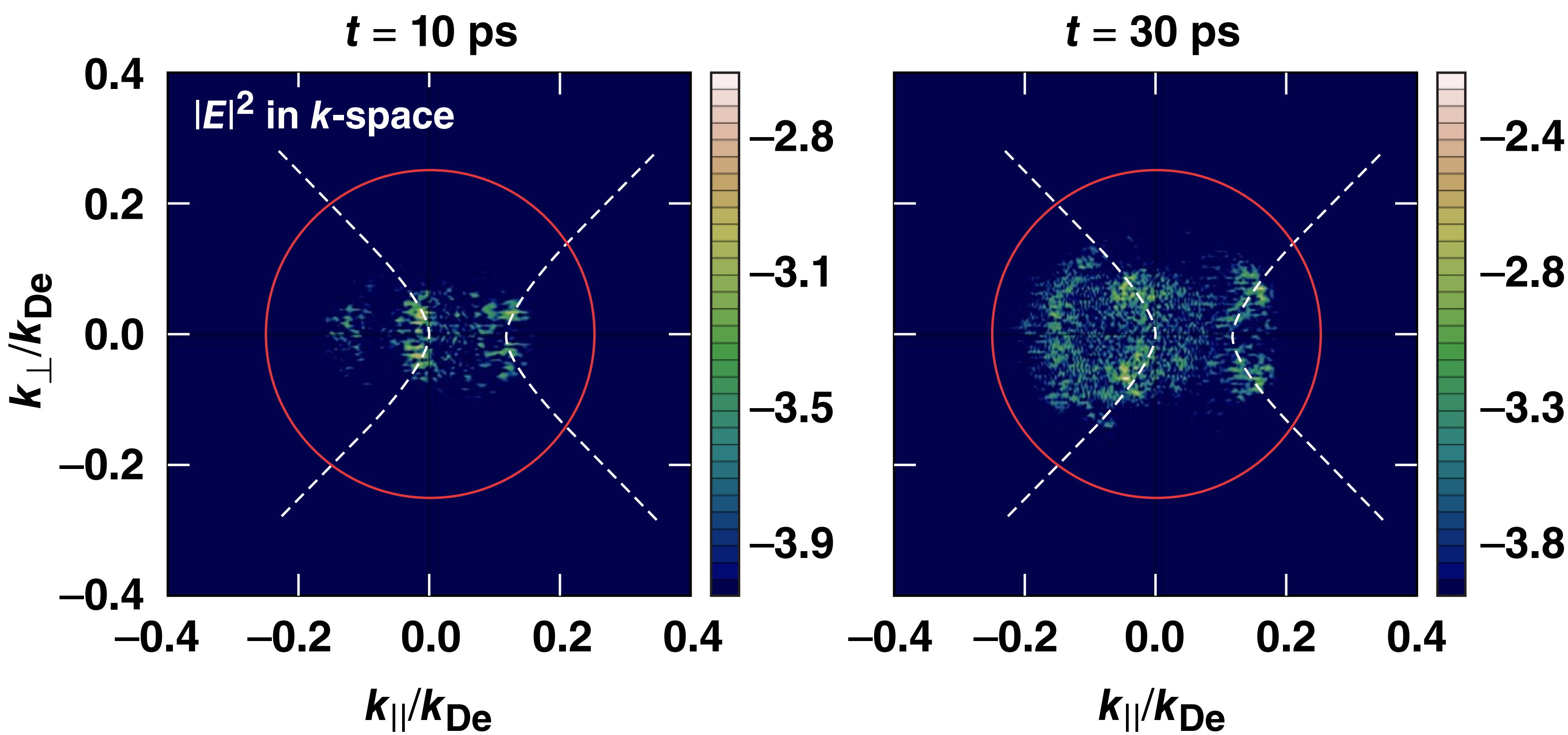
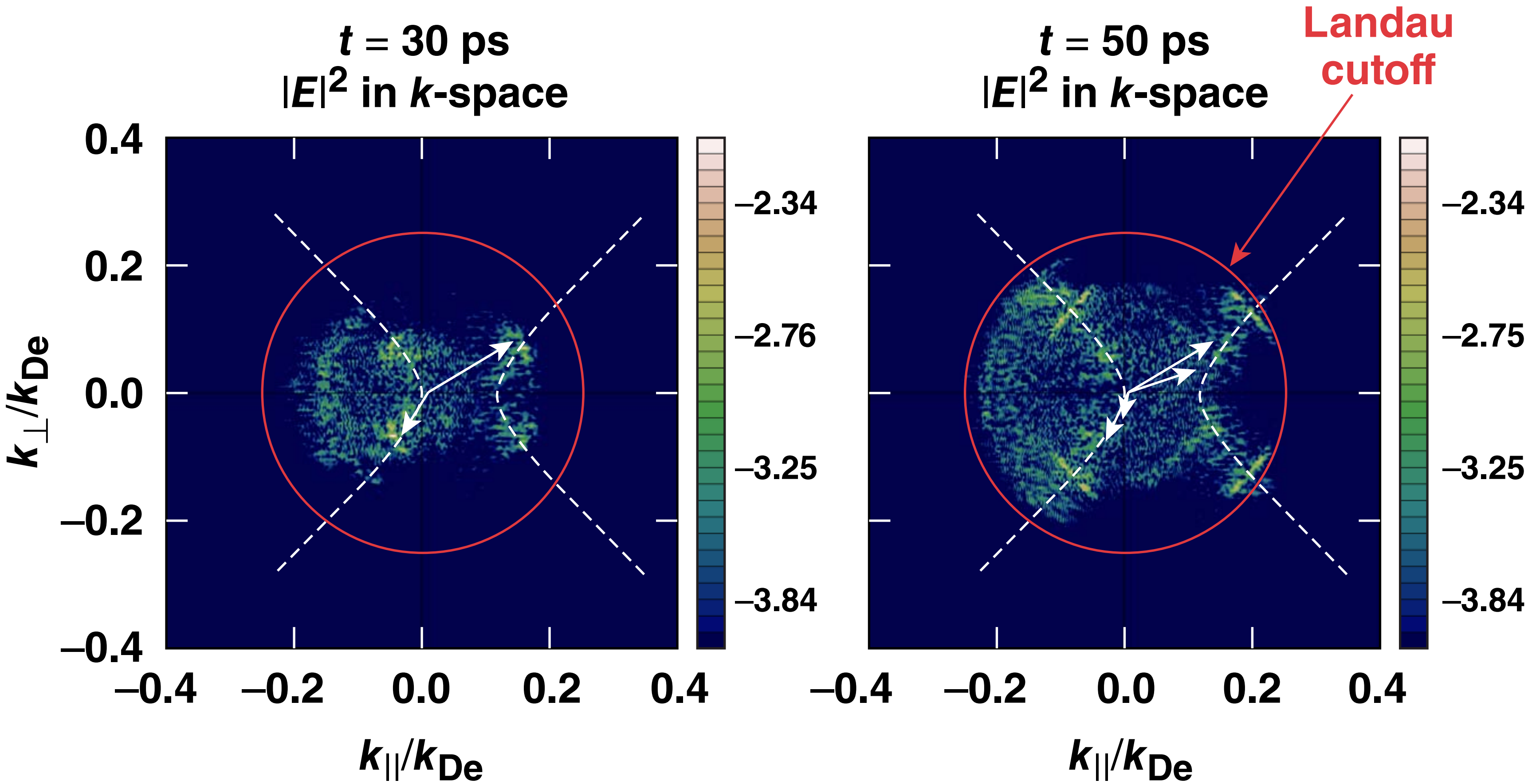
The spectrum of plasma waves evolves to reflect the excitation of plasma waves at lower density

Single beam, normal incidence



The region of excitation extends all the way out to the Landau cutoff—also an experimental observation

Single beam, normal incidence



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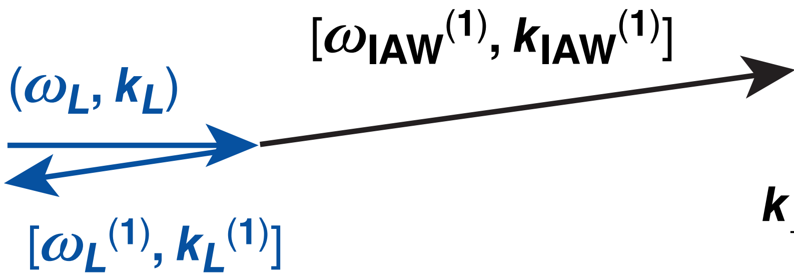
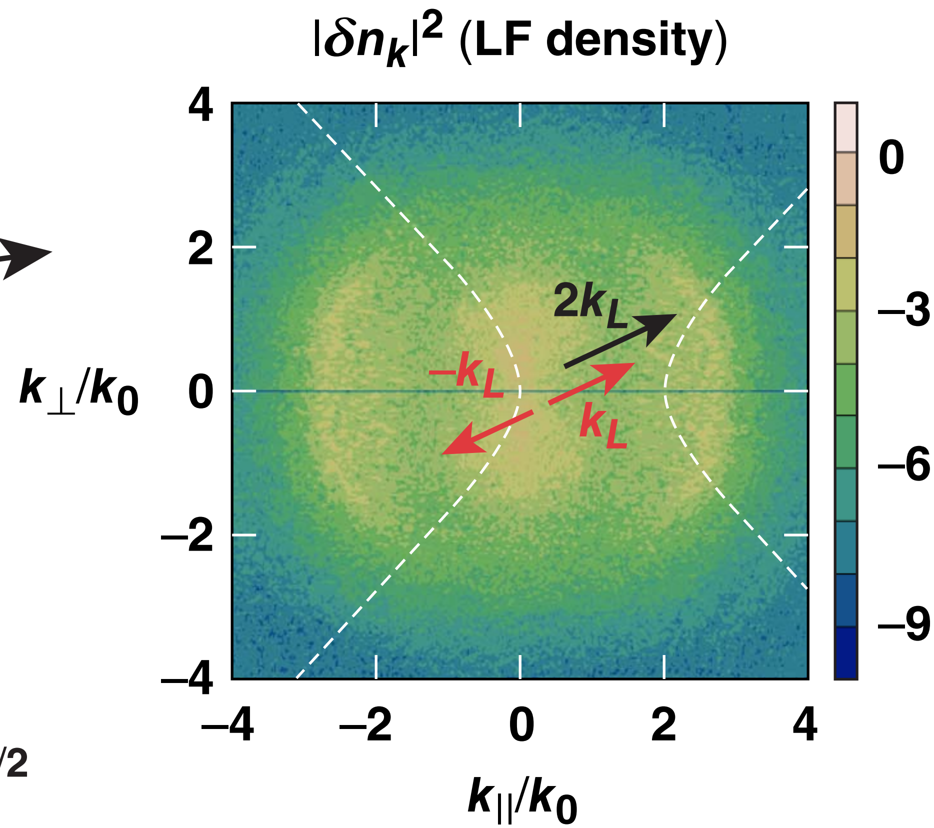
Strong signatures of Langmuir decay (LDI) are observed in the preceding calculation for times, $t > 5$ ps

- **In LDI the plasma wave decays into a scattered LW and an ion-acoustic wave**





$$k_L^{(1)} = -k_L + \Delta k$$

$$\Delta k = (2/3)\, k_{De} \left(Zm_e/m_i\right)^{1/2}$$

The level of Langmuir wave fluctuations (plasmons) can be reduced by decreasing the ion-wave damping rate

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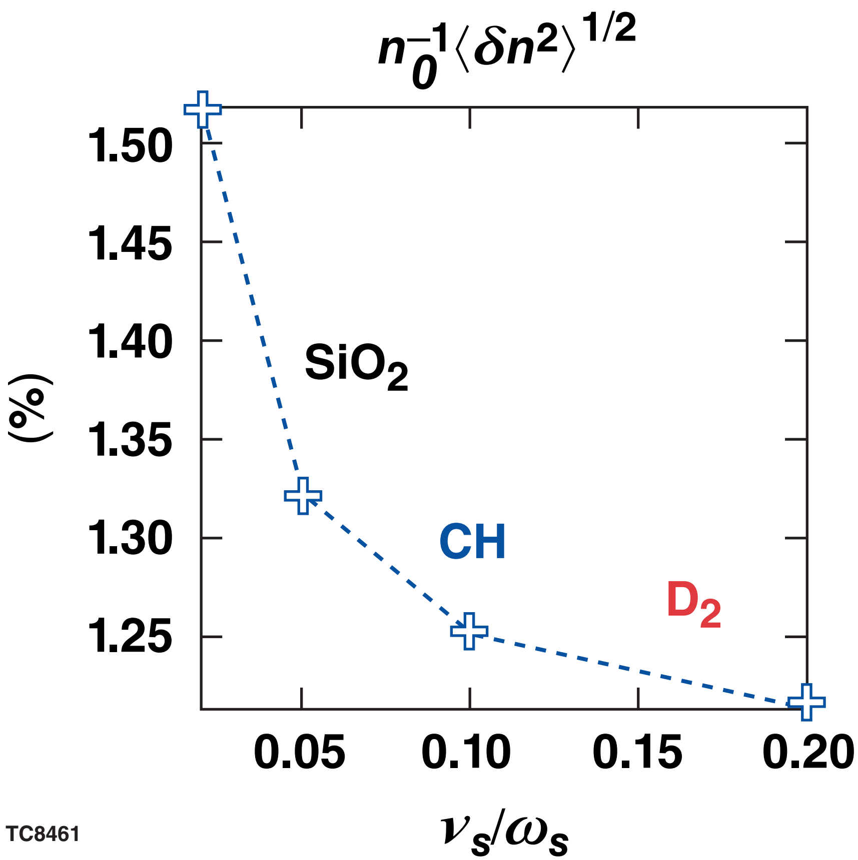
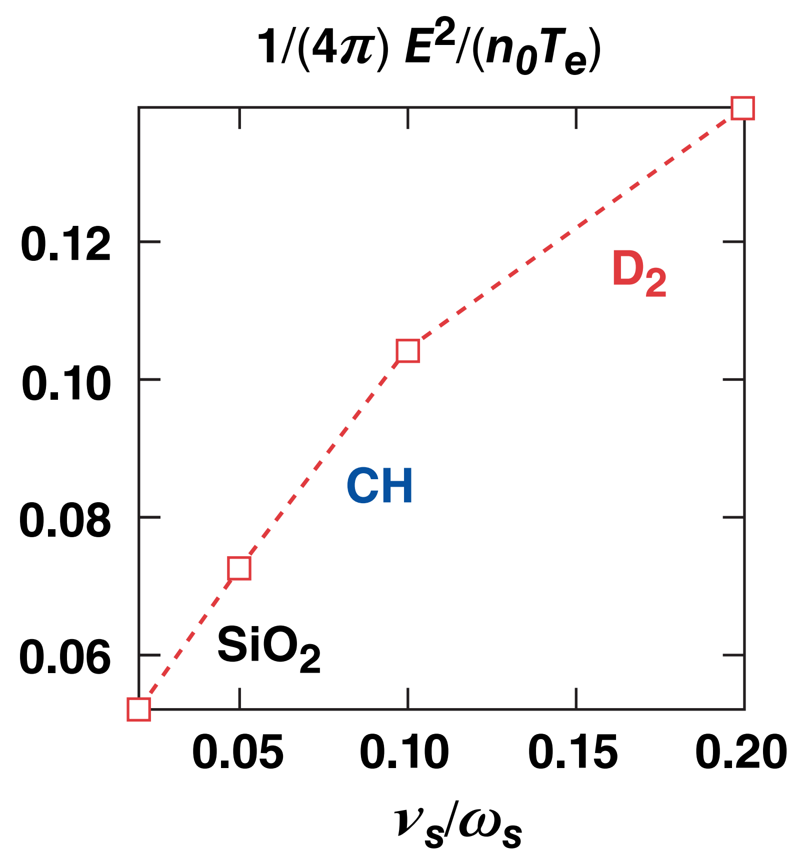
- Reducing IAW damping rate leads to a lowering of the threshold value of E^2 for the onset of LDI
- Suggests that high-Z dopants might be useful for controlling saturated levels of TPD





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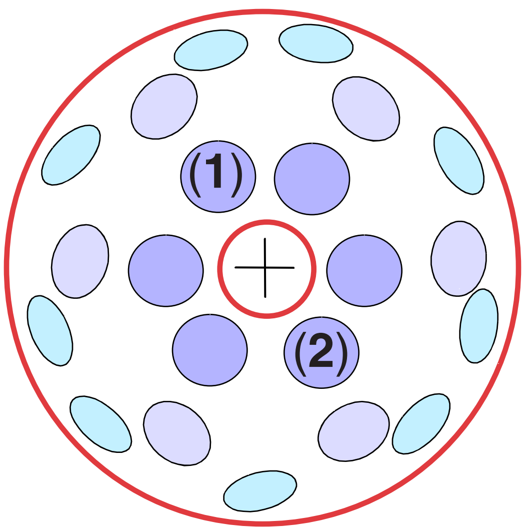
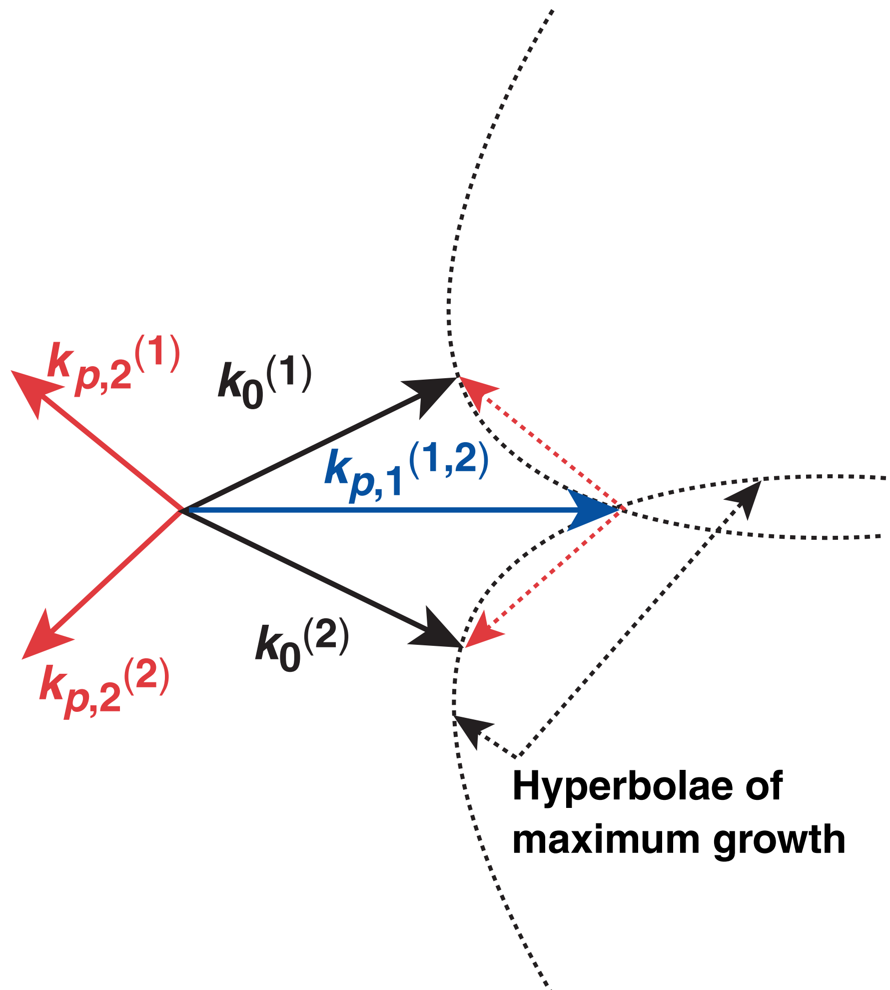
Experiments on OMEGA are characterized by many overlapping beams

- OMEGA experiments have been conducted with six beams at 23° from the target normal





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Computations made using overlapped beam irradiation confirm the existence of a strongly excited "shared" plasma wave

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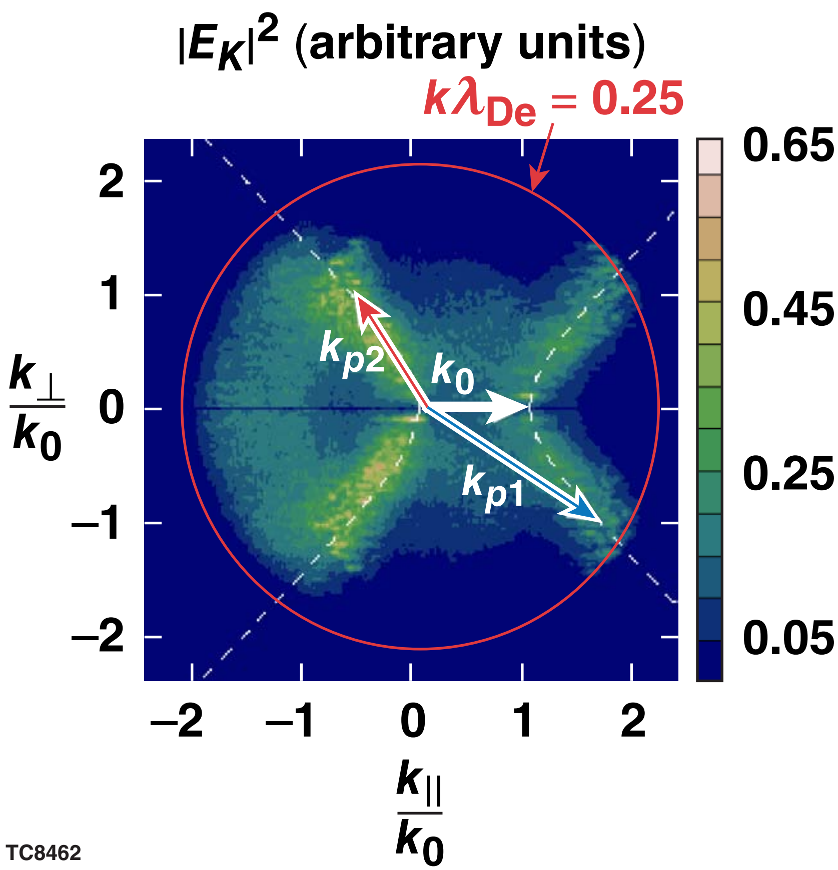
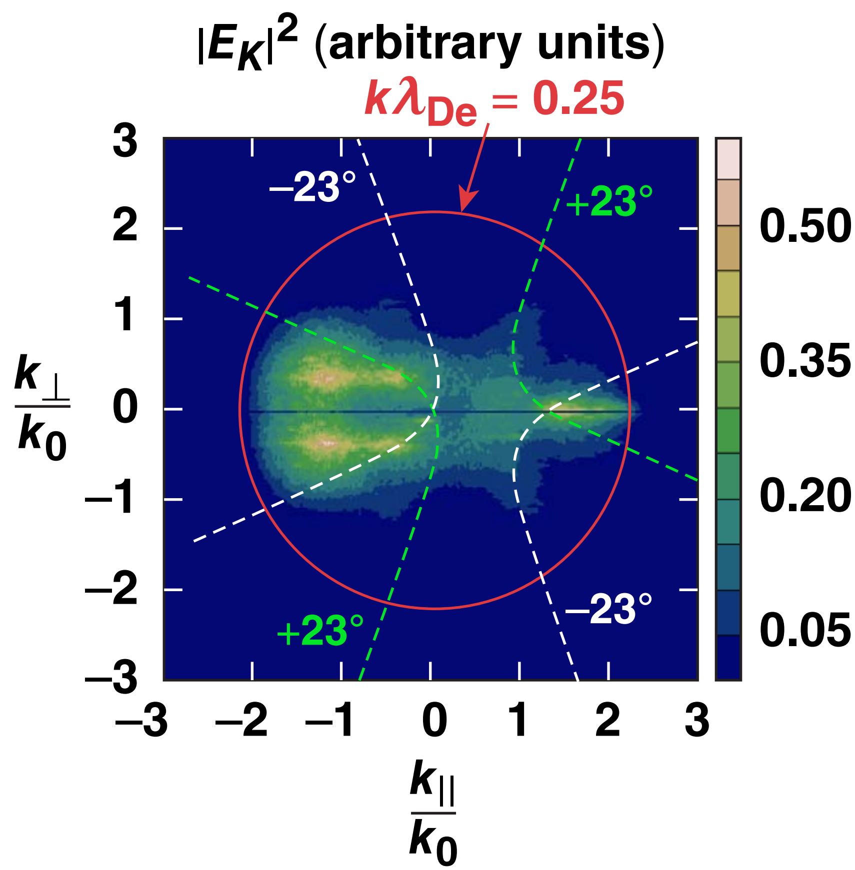
2-D simulation with single plane wave normal to density gradient

Two plane waves at ±23° with respect to the density gradient





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