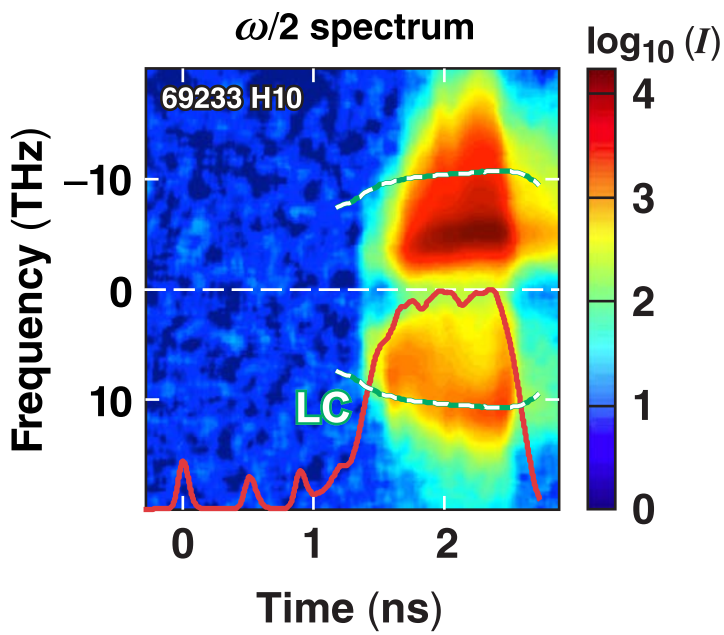
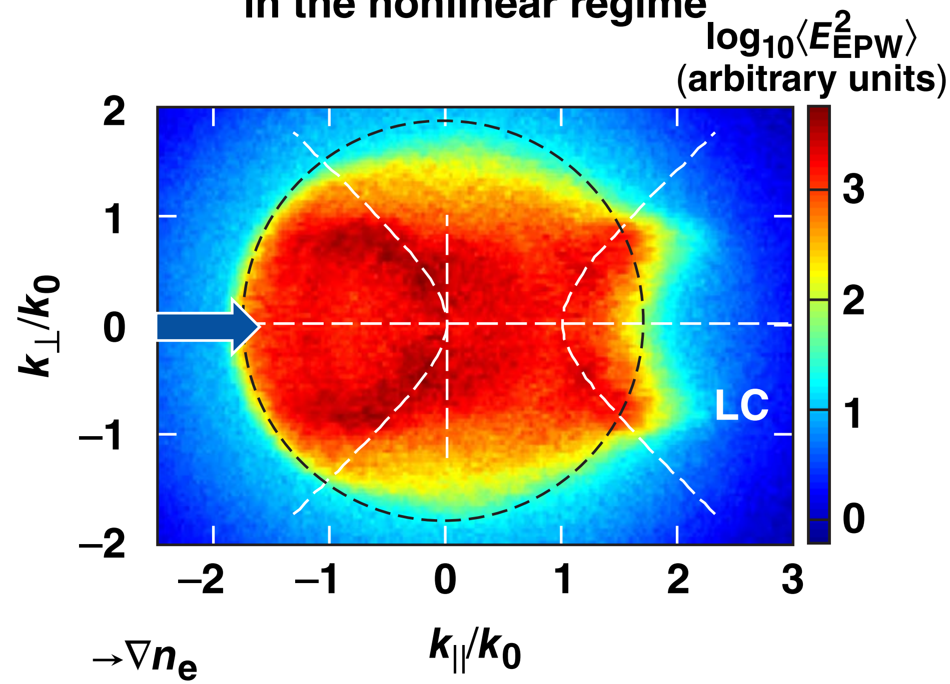
The Nonlinear Behavior of the Two-Plasmon–Decay Instability





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Summary

Our understanding of multibeam two-plasmon decay (TPD) and its nonlinear behavior has significantly advanced over the past decade

- Multibeam TPD has been firmly established
- Zakharov models of the TPD instability agree with single and multibeam analytical thresholds and reduced-description particle-in-cell (RPIC) results in the nonlinear regime
- Nonlinear coupling of primary TPD waves with ion waves leads to a broad Langmuir wave (LW) spectrum evident in $\omega/2$ and $3\omega/2$ spectra
- Zakharov simulations including quasi-linear diffusion can predict energetic electron production and allow for the investigation of mitigation strategies
- Half-harmonic ($\omega/2$) spectra have identified temperature islands on the target surface via localized T_e measurements

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Collaborators

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The extended Zakharov model of TPD is used to analyze the threshold and nonlinear behavior of the TPD instability

- *ZAK3D*[1] is an excellent tool for studying the linear stability of multibeam-driven TPD
- *ZAK3D* includes coupling to ion waves → LW turbulence
- *QZAK*[2] (2-D version of *ZAK3D*) evolves the distribution function → hot-electron production
- *QZAK* simulations agree with kinetic RPIC[3] in the nonlinear state in the regimes where they have been compared
- *ZAK3D* includes multiple beams, extendable to incoherent and multicolor beams

[1] J. Zhang *et al*., this conference, and to be submitted to Phys. Plasmas; D. F. DuBois and D. A. Russell earlier work.
[2] J. F. Myatt *et al*., Phys. Plasmas 19, 022707 (2012).
[3] H. X. Vu *et al*., Phys. Plasmas 19, 102703 (2012).

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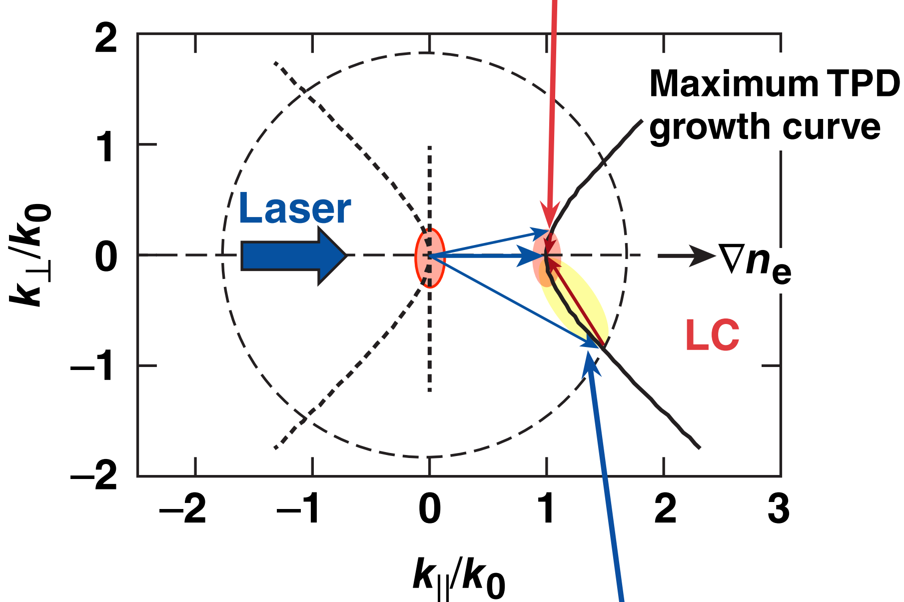
The various TPD regimes are clearly visible in single-beam *ZAK3D* simulations

Absolute instability,* $k_p/k_0 \lesssim 0.1$

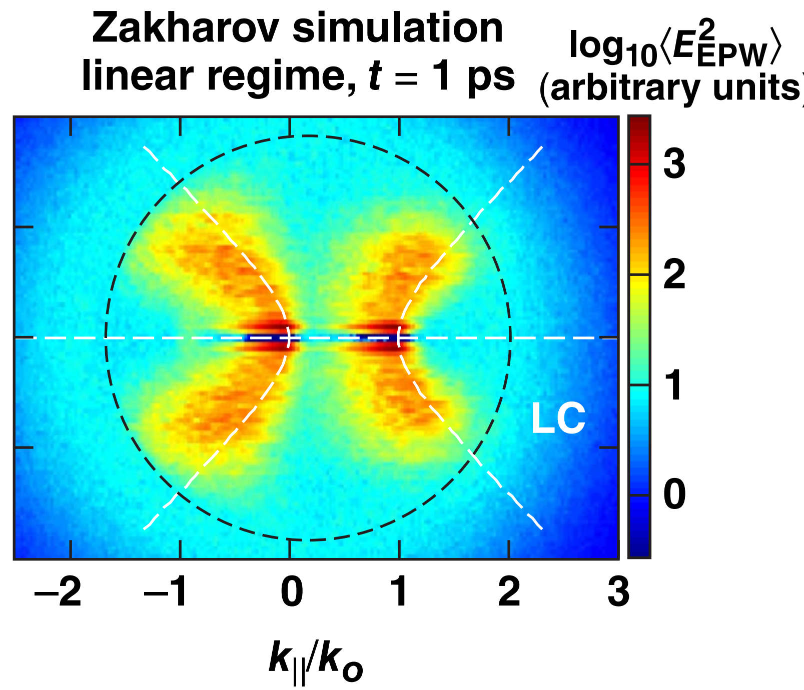
$$\eta \approx \frac{I_{14} L_\mu}{233\, T_{\text{keV}}} > 1$$



Rosenbluth convective gain,

$k_p/k_0 < k_{p,\text{max}}$, $G_c = 2\pi$

$$\eta_{\text{conv}} \cong 1.25\, \eta_{\text{abs}}$$



Landau cutoff (LC):
$k_p \lambda_{\text{De}} = 0.25$

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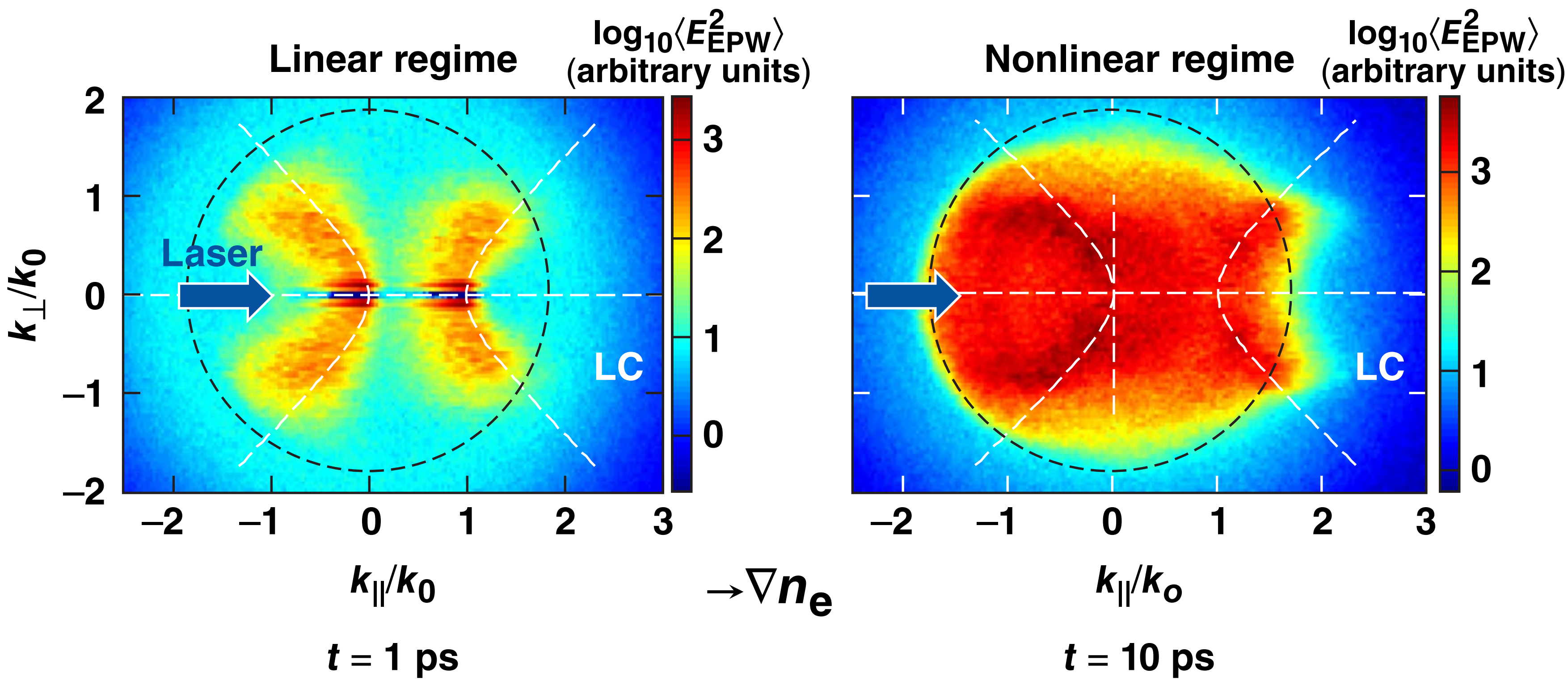
*A. Simon *et al*., Phys. Fluids 26, 3107 (1983).

Above the absolute threshold, the TPD Langmuir waves rapidly fill *k* space to the Landau cutoff limit

Single beam, η = 1.3, L_n = 150 μm, T_e = 3 keV, CH plasma



For a single beam there is a very limited linear convective regime.

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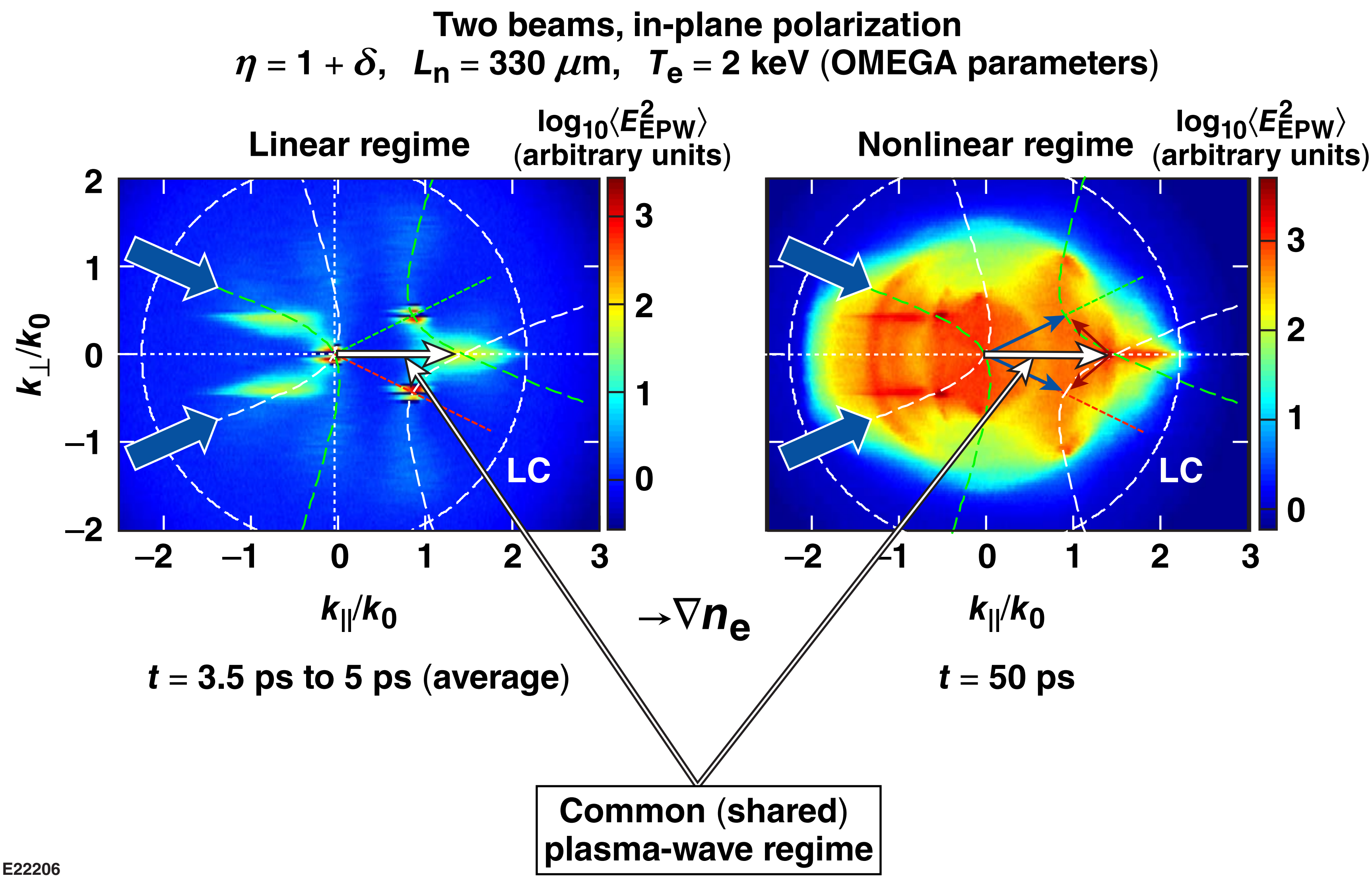
Multibeam simulations show very similar behavior



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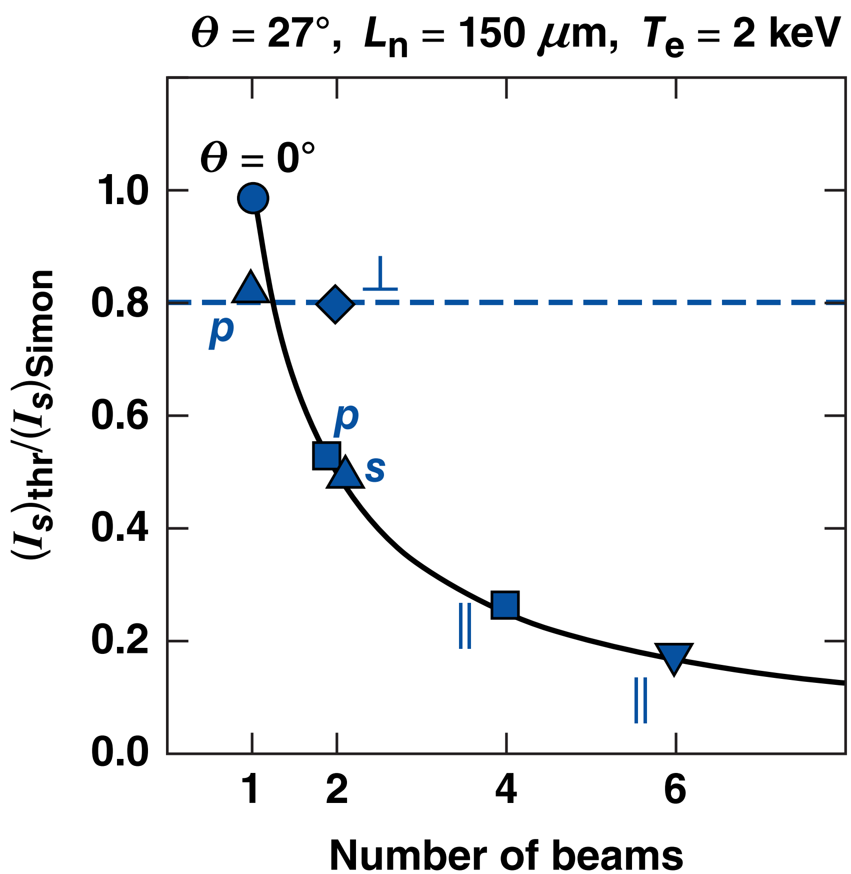
Multibeam absolute TPD thresholds have been computed analytically and with *ZAK3D*



- **Along the solid line the absolute TPD threshold condition is**

$$\eta \approx \frac{I_{14} L_\mu}{233\, T_{keV}}$$

$$I_{14} = \sum I_{14,\text{single beam}}$$

- **The threshold depends on polarization and angle of incidence**

R. W. Short's absolute TPD threshold calculations[1] in 2-D and 3-D agree with Zakharov simulations.[2]

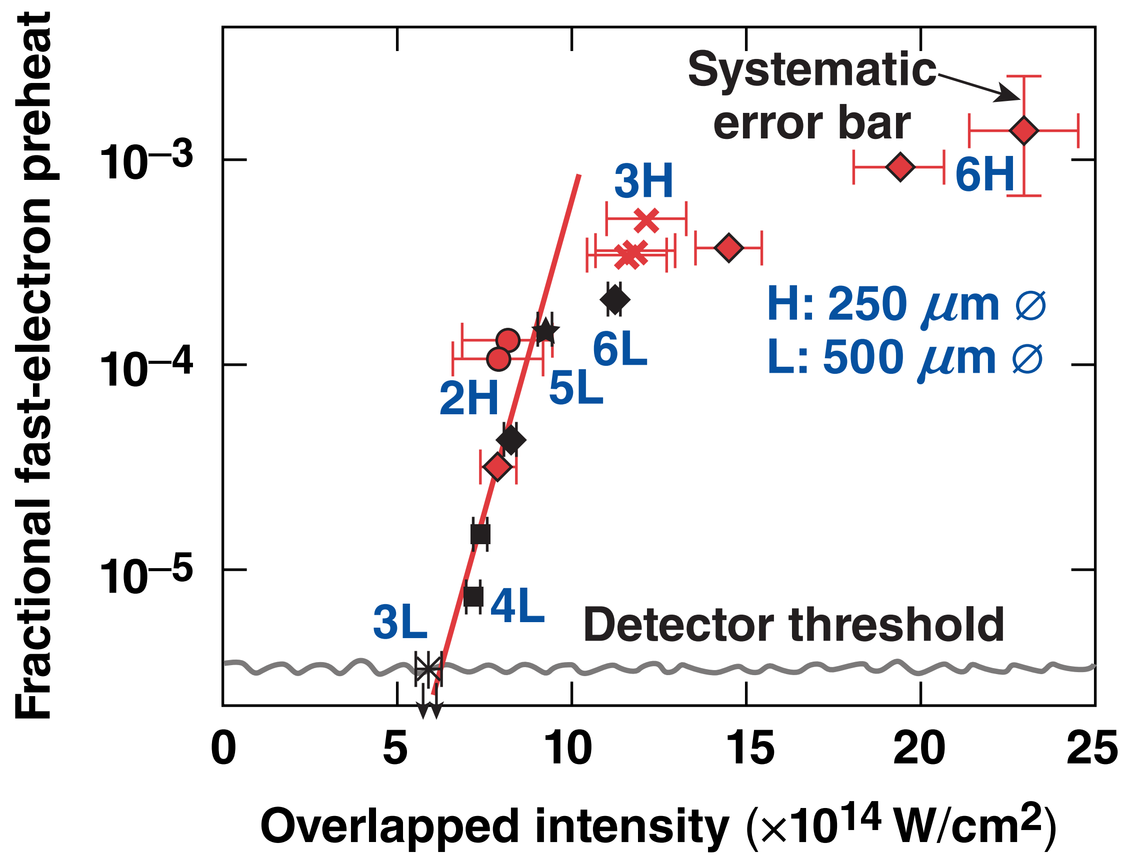
[1] R. W. Short *et al.*, this conference.
[2] J. Zhang *et al.*, this conference.

E22207

The TPD instability has several characteristic experimental signatures

- $\omega/2$ and $3\omega/2$ emission spectra
  - TPD occurs from $n_c/4$ to the Landau cutoff (~$n_c/5$)
  - wavelength splitting and emitted power scale very nonlinearly with intensity
- Hard x-ray emission
  - the onset is generally observed after that of $\omega/2$ and $3\omega/2$ emission
  - result of energetic electrons generated by plasma waves turbulence
  - E_x and T_e scale nonlinearly with intensity
- The *QZAK*/*ZAK3D* simulations are consistent with some of the experimental observations
  - broad-angle hot-electron production
  - threshold scaling with overlapped intensity
  - broadband LW spectrum → LC

Multibeam TPD was established in 2003 in planar and implosion experiments using hard x-ray emission



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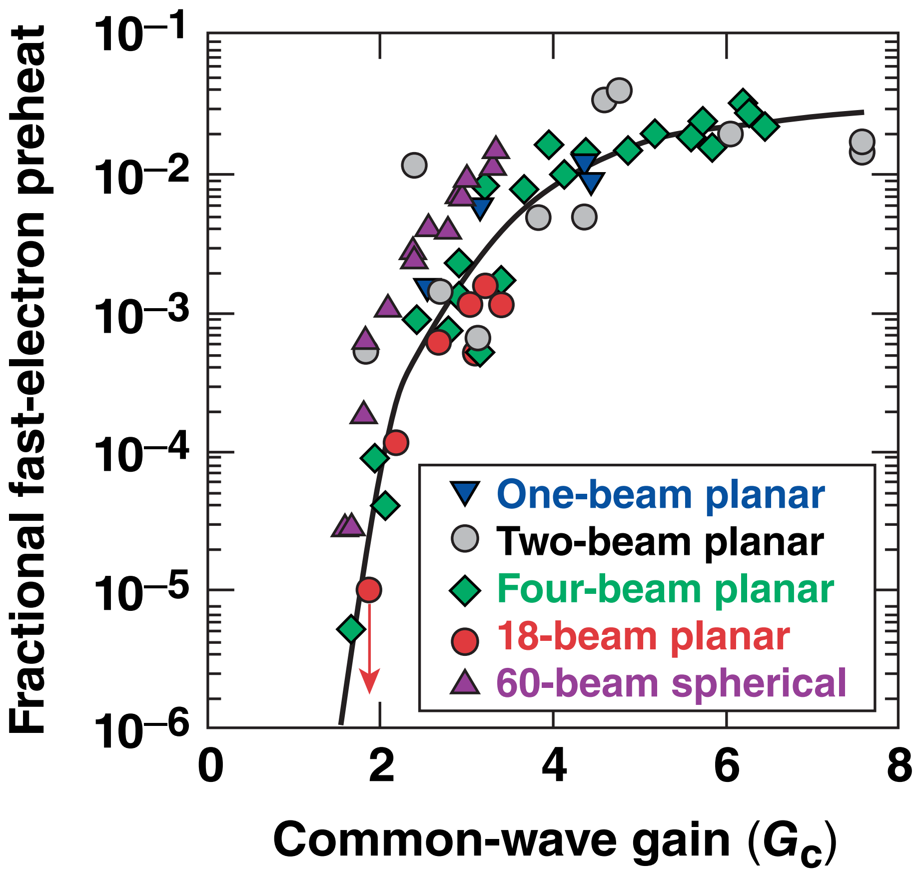
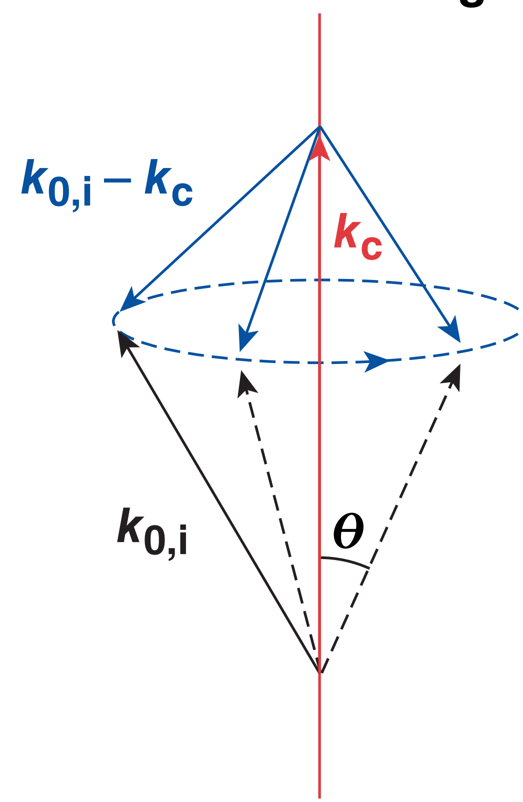
C. Stoeckl *et al*., Phys. Rev. Lett. 90, 235002 (2003).

A scaling for the hot-electron fraction for many experimental configurations was obtained by D. T. Michel *et al.** using a common-wave model





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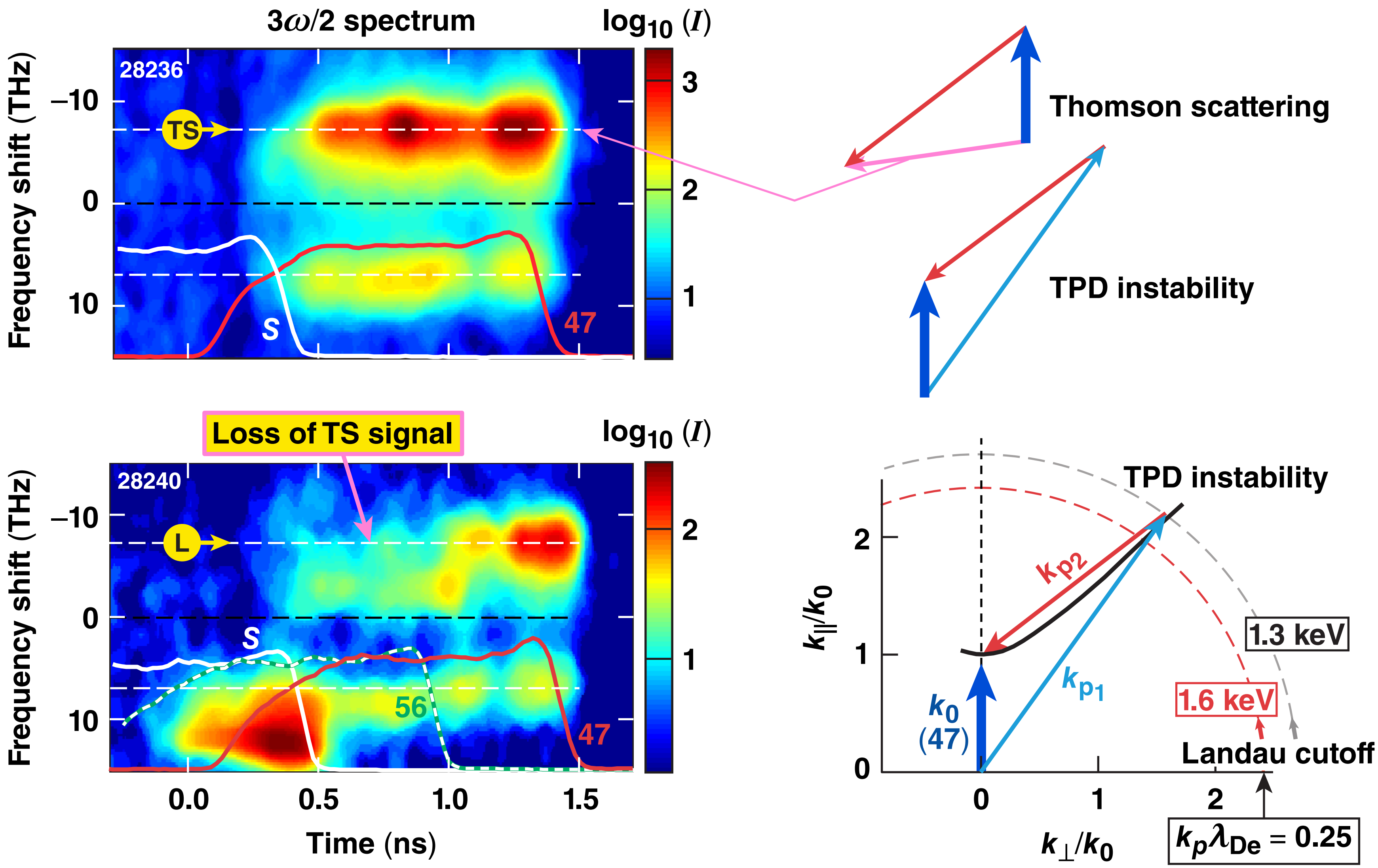
*D. T. Michel *et al.*, Phys. Plasmas 20, 055703 (2012).

Thomson scattering confirms the Landau cutoff limit*



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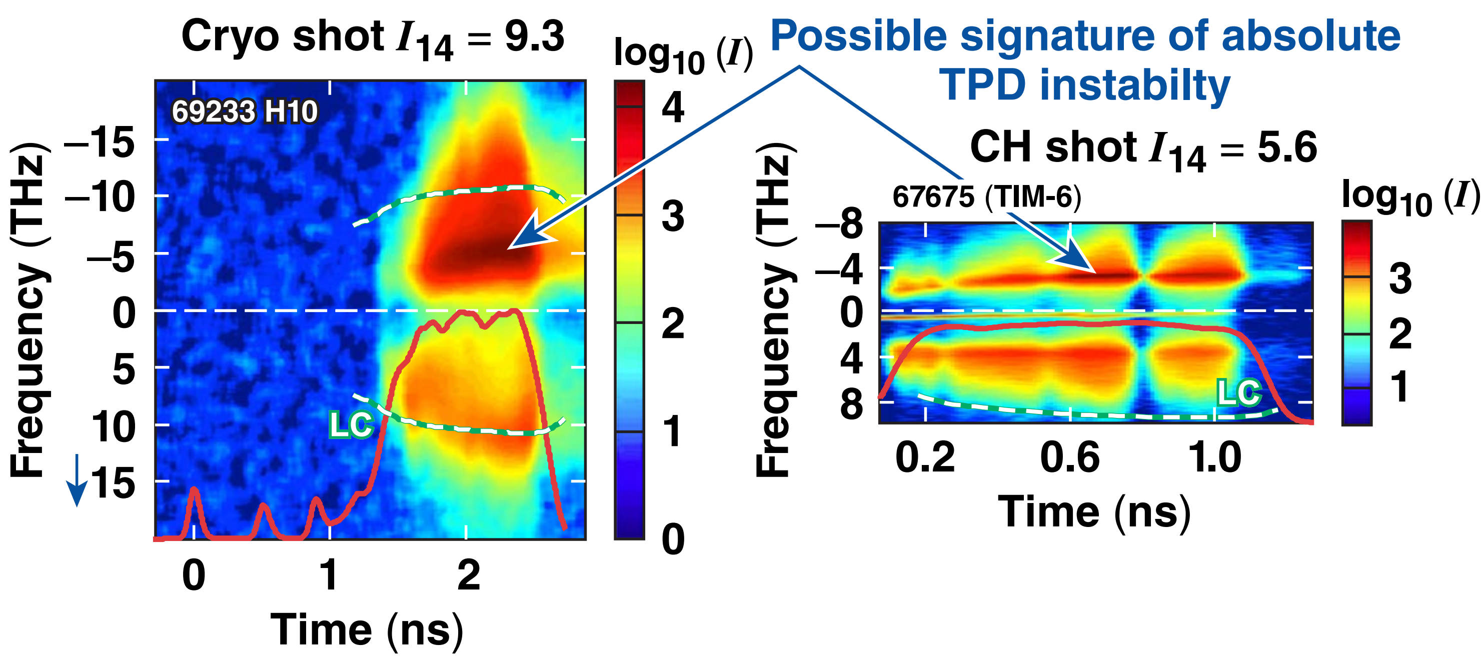
*W. Seka *et al.*, Phys. Plasmas 16, 052701 (2009).

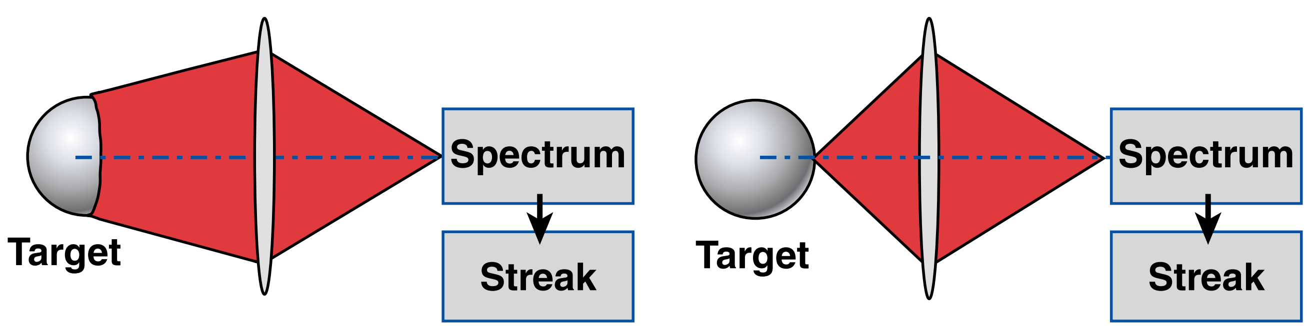
Half-harmonic generation can be caused by inverse resonance absorption, Thomson scattering, or inverse parametric decay

- The absolute TPD instability ($k_{\perp}/k_0 \leq 0.1$) is close to the turning point of one of the TPD plasmons → ideal for plasmon-to-photon conversion via inverse resonance absorption
  - these photons have the smallest red shift from $\omega_0/2$ and are emitted along the density gradient
- Thomson scattering using any one of the incident or reflected beams
  - phase-matching conditions are difficult to satisfy for any of the primary TPD plasmons; scattered plasmons are more easily Thomson scattered
- The relative importance of the three processes is being investigated by D. A. Russel and D. F. DuBois

Evidence of nonlinear behavior of the TPD instability is best seen in $\omega/2$ spectra viewing the entire target sphere

Broadband $\omega/2$ spectra are visible immediately at the start of the TPD instability and are consistent with broad LW spectra in *ZAK* simulations.





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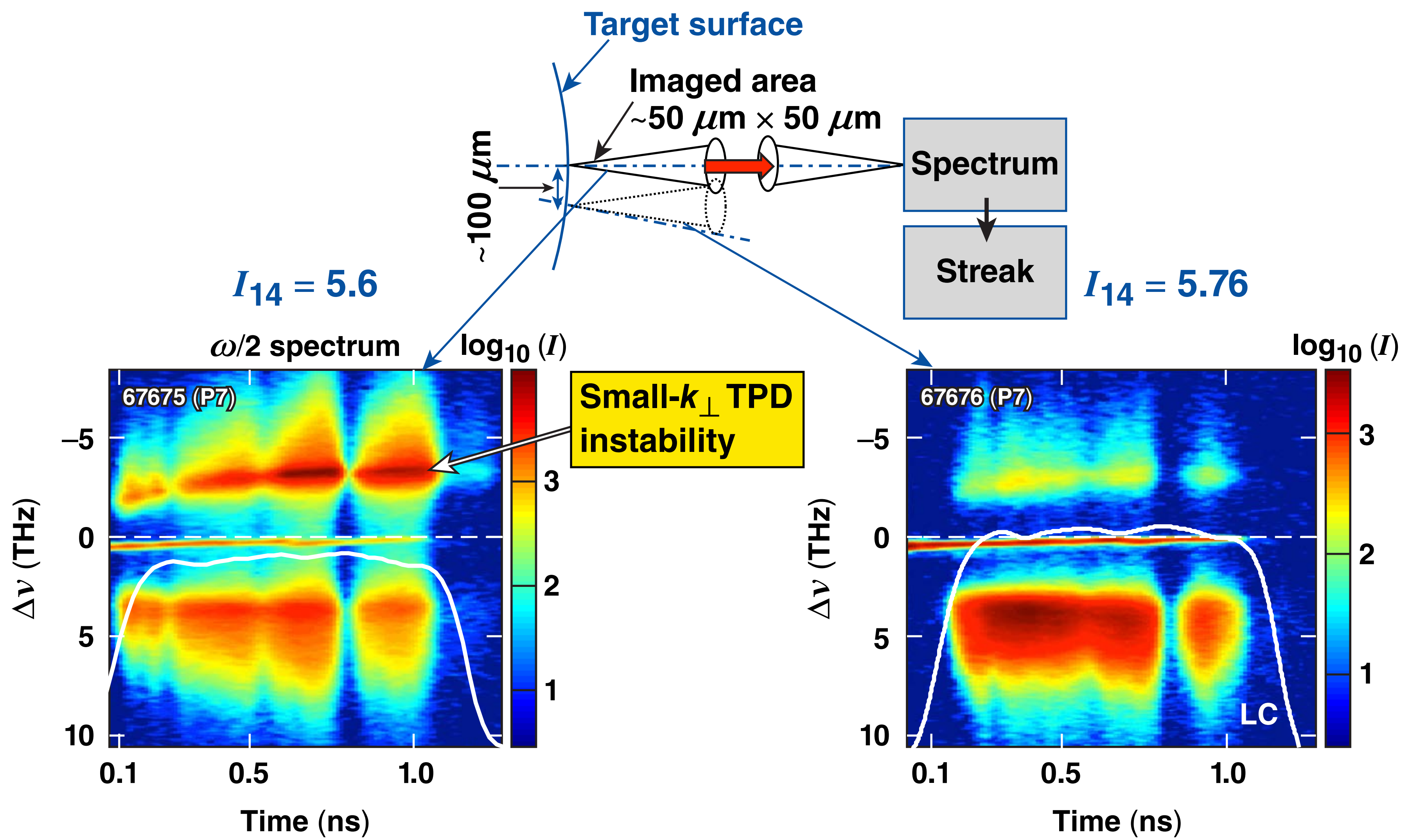
The spectral signature of small-$k_\perp$ TPD instability can only be observed by viewing along the density gradient



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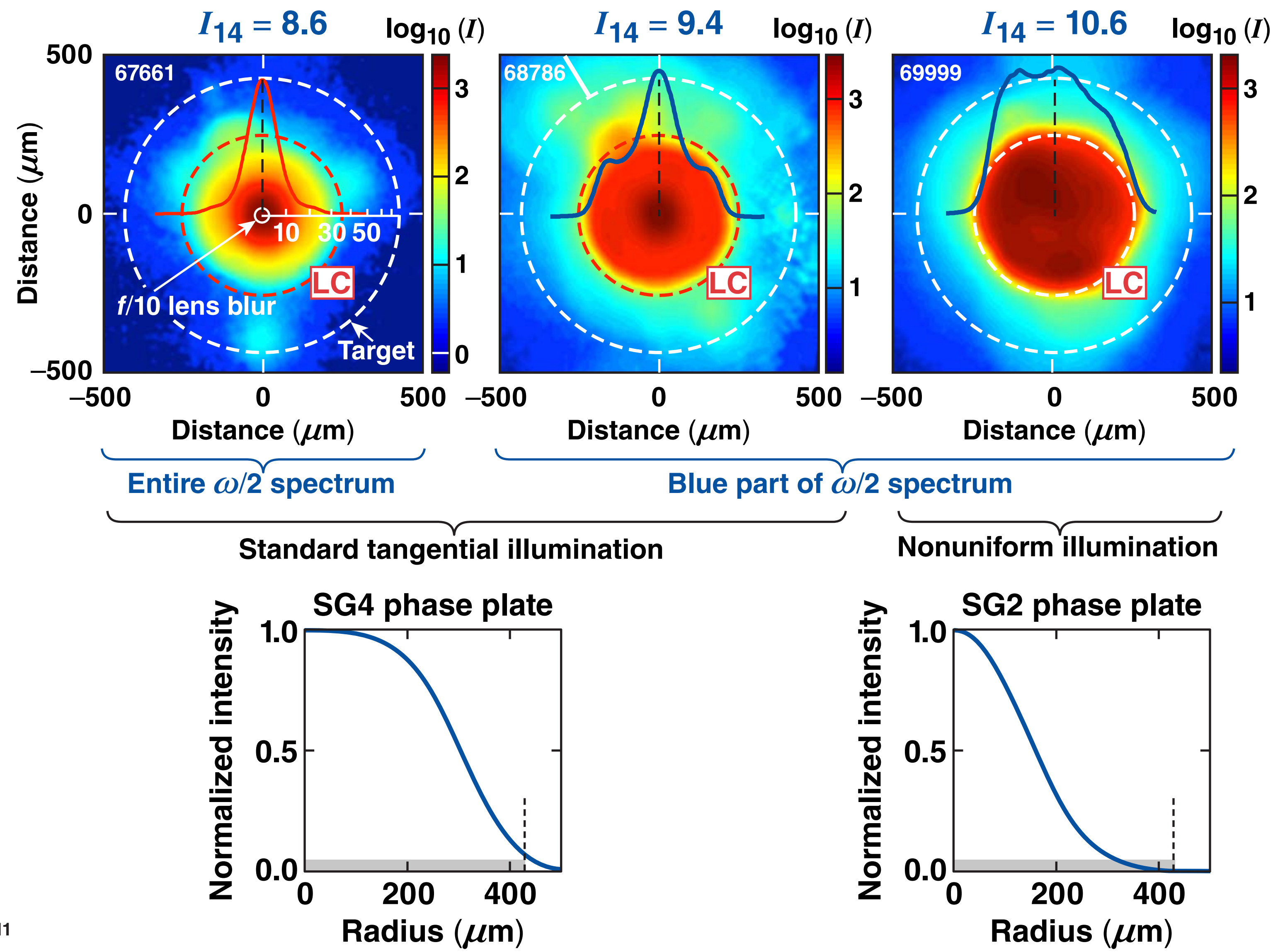
Half-harmonic images of imploding targets provide insight to the localized nature of the TPD instability



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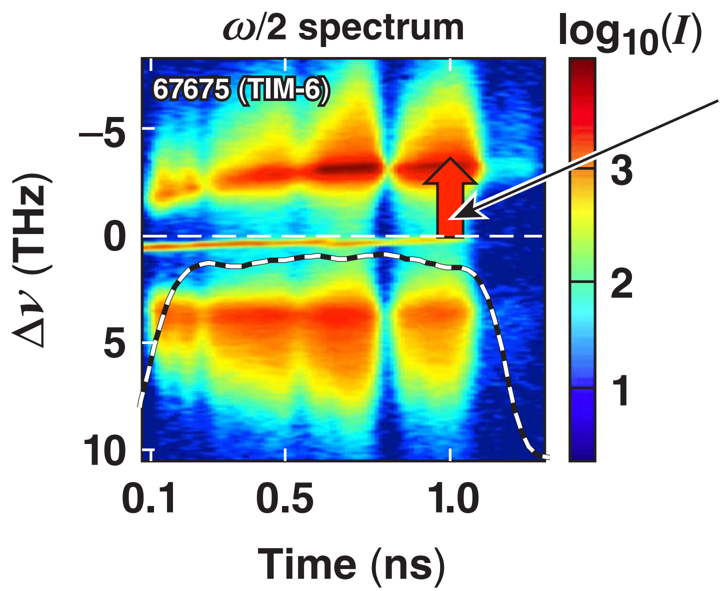
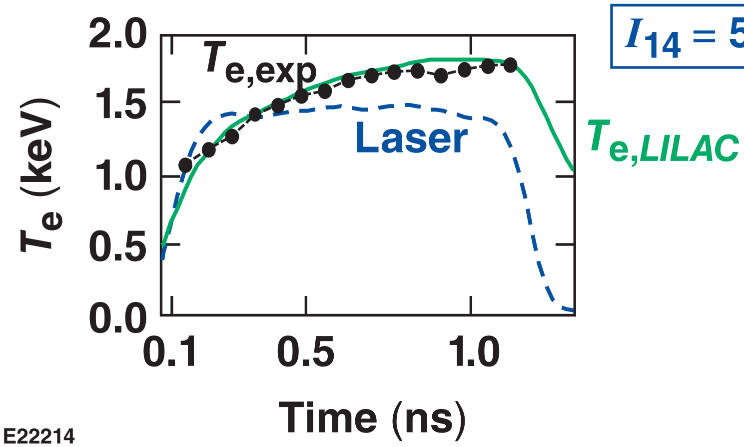
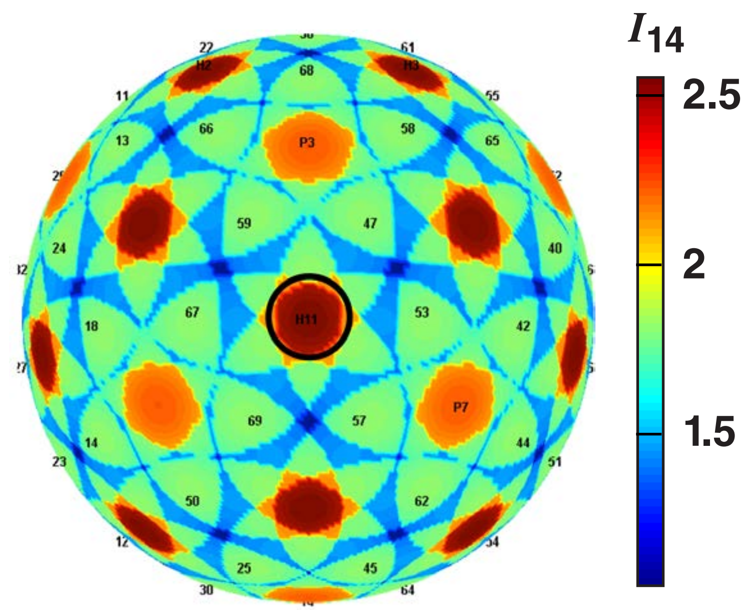
The spectral signature of the small-$k_\perp$ TPD instability near $n_c/4$ is a sharp red-shifted feature that can be used for T_e measurements



$\Delta\lambda_{nm} = 4.4 \times 10^{-3}\ T_{e,keV}$
small-$k_\perp$ plasmon-to-photon conversion assumed



$I_{14} = 5.6$



Intensity distribution at $n_c/5$ for incident angles <30° for shot 67675 with SG4 phase plates

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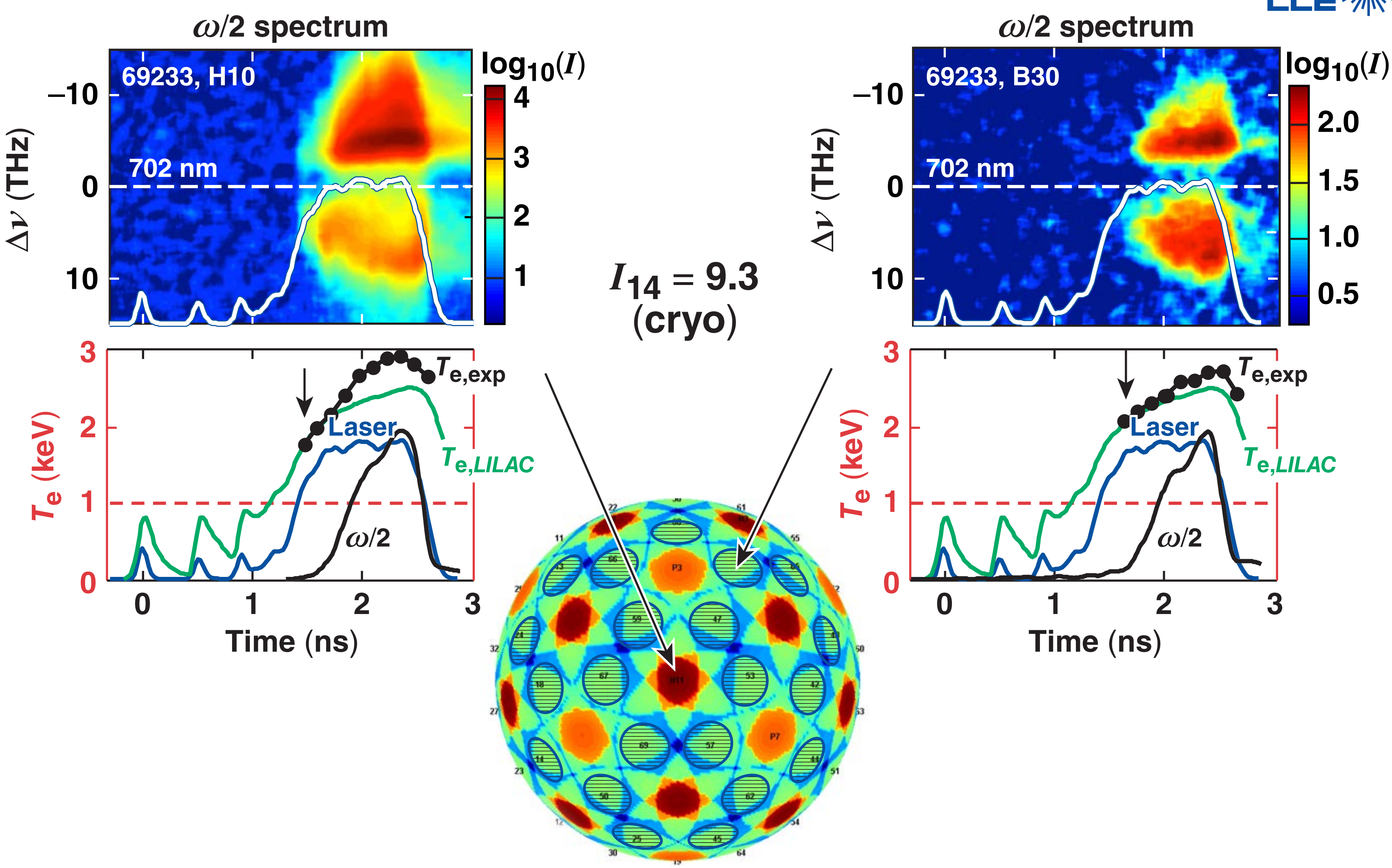
T_e varies over the target surface and can exceed *LILAC* predictions by 10% to 20%



Elevated temperature islands near $n_c/4$ vary across the target sphere.

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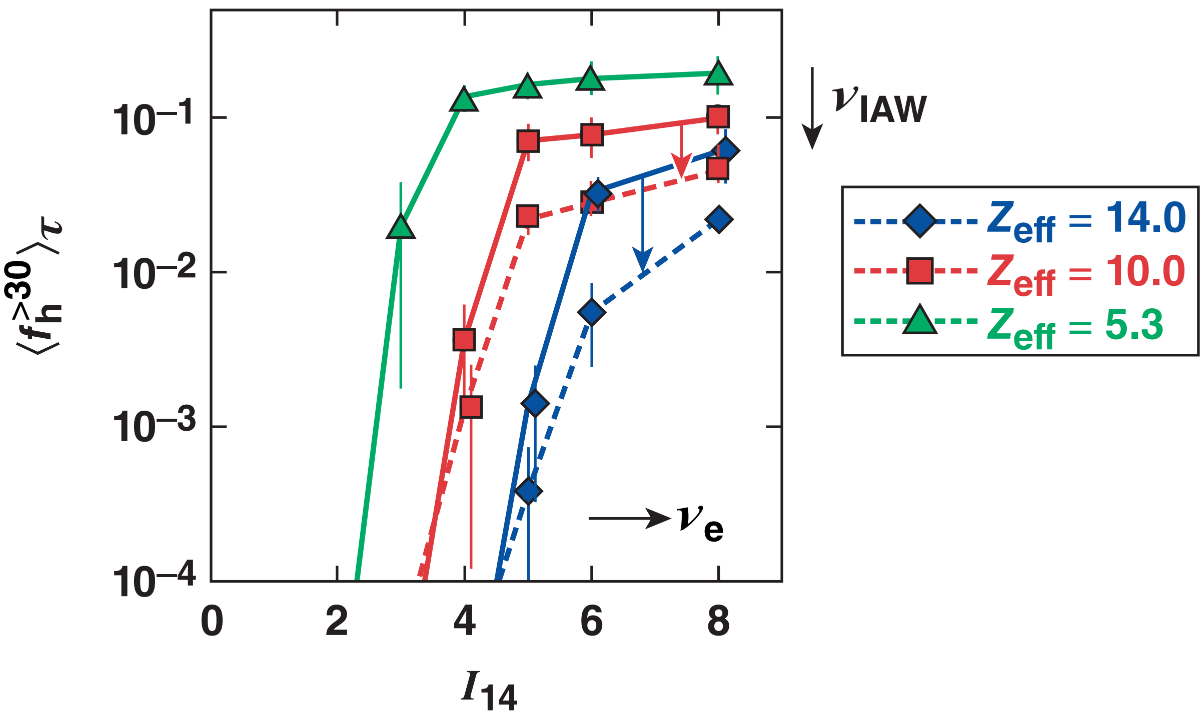
Two-dimensional and 3-D nonlinear TPD simulations are being used to investigate TPD mitigation strategies



- Ion-wave damping
  - saturated LW intensity and hot-electron production depends on ν_{IAW}*
- Collisional damping
  - for NIF-scale lengths, the LW collisional damping can become important*
- Broadband and multicolor beam TPD
  - will use *ZAK3D*

TC10463

*J. F. Myatt *et al*., Phys. Plasmas 20, 052705 (2013).

Future TPD simulations will center on quantitative prediction and mitigation options

- **Quantitative predictions for fast-electron production (*QZAK* extended to 3-D in the near future)**
- **Comparison of simulations with experimental fast-electron scaling laws**
- **TPD mitigation options**
- **TPD threshold behavior for beams with speckles**

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