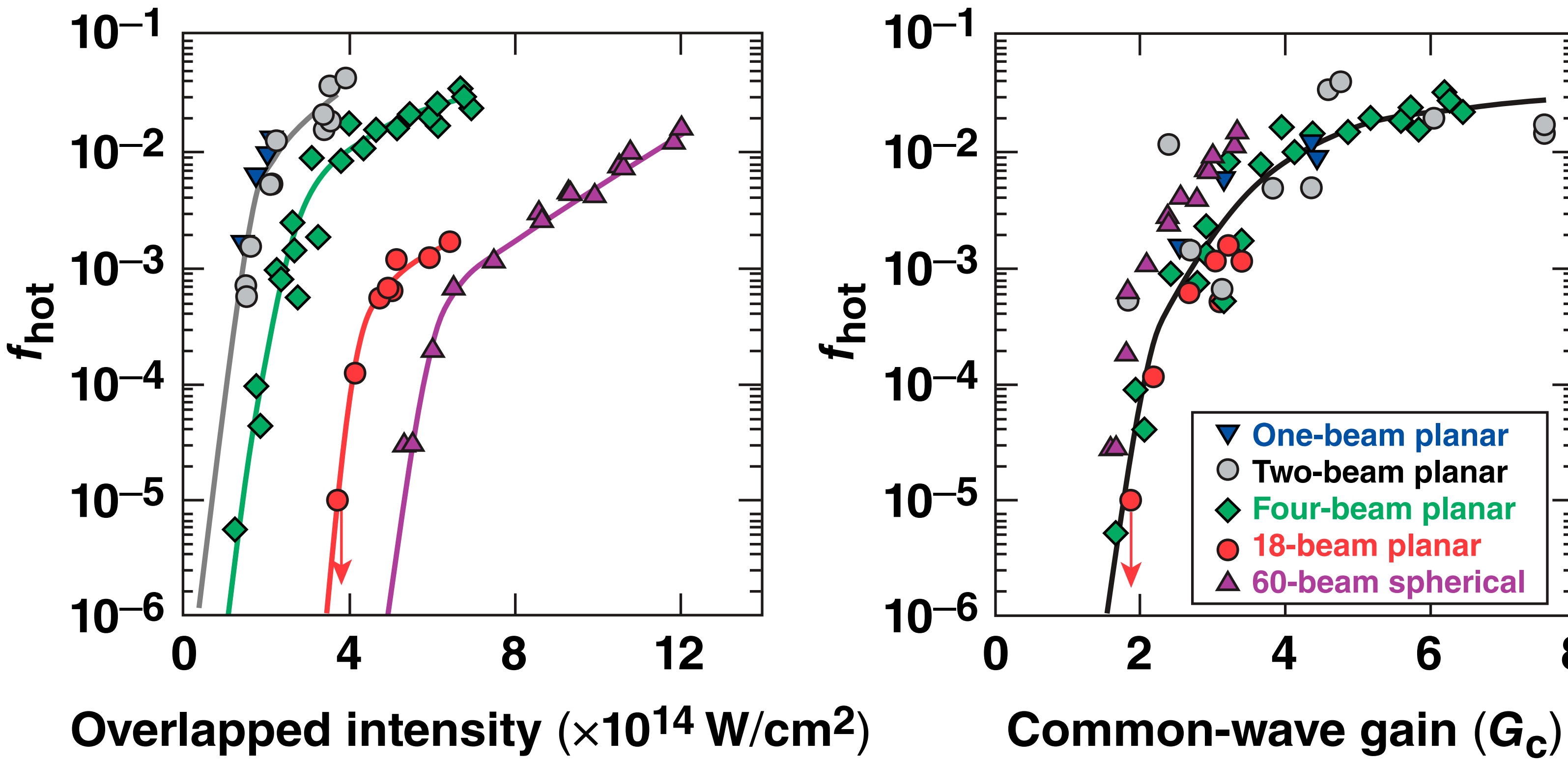
Experimental Validation of the Two-Plasmon–Decay Common-Wave Process



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Summary

A common-wave gain model allows for the two-plasmon–decay (TPD) threshold to be predicted for many different experimental configurations

- A resonant common electron plasma wave (EPW) is driven by multiple laser beams in the region bisecting the beams' wave vectors
- Different intensity thresholds are observed for various laser-beam geometries in planar and spherical configurations
- The resonant convective common-wave gain is consistent with the experimental observables*
- Several theoretical models are being developed to understand TPD in the direct-drive–ignition regime

The laser-beam geometry must be taken into account to calculate the TPD gain.

*D. T. Michel *et al*., Phys. Rev. Lett. 109, 155007 (2012).

Collaborators

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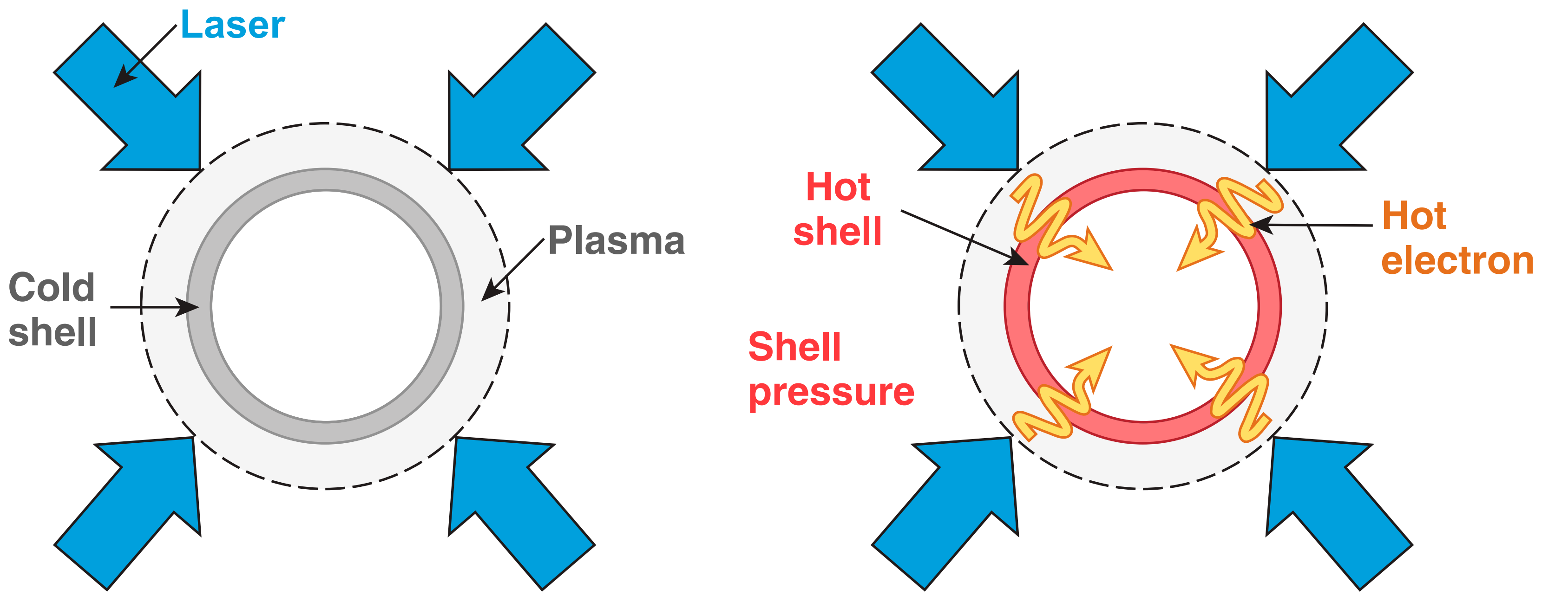
Laboratory for Laser Energetics
University of Rochester

Hot electrons can preheat the shell and reduce the compression efficiency



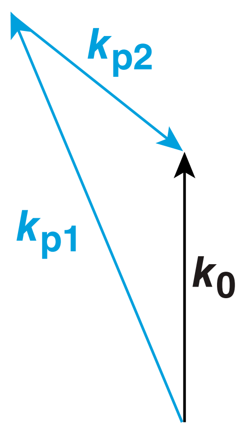
Hydrodynamic simulations indicate that low-adiabat ignition designs can sustain ~0.1% preheat.*

*LLE Review Quarterly Report 79, 130, Laboratory for Laser Energetics, University of Rochester, Rochester, NY, LLE Document No. DOE/SF/19460-317, NTIS Order No. DE2002762802 (1999).

E21640

Hot electrons can be generated by the TPD instability

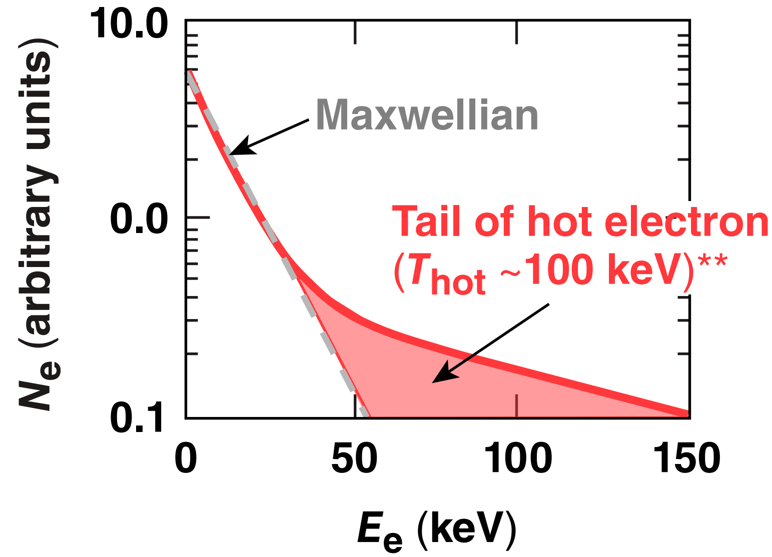
TPD:



Hot electrons are accelerated by the enhanced electron plasma waves (EPW's)*

The TPD instability develops at $n_c/4$

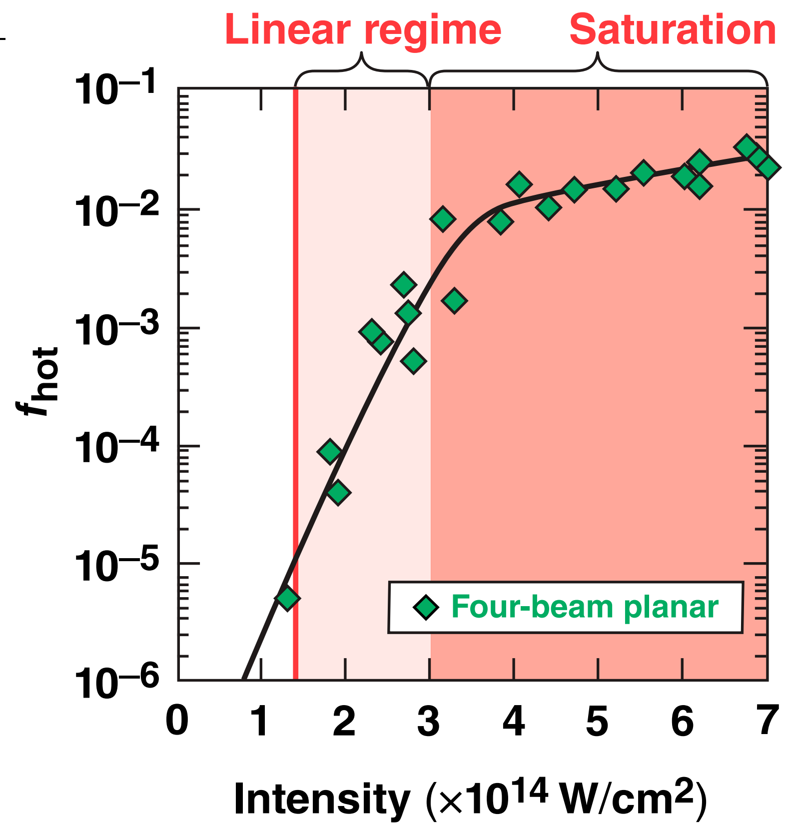
Electron-distribution function



*N. A. Ebrahim *et al.*, Phys. Rev. Lett. 45, 1179 (1980).
**J. F. Myatt *et al.*, Phys. Plasmas 19, 022707 (2012).

TPD is investigated through experimental measurements of the hot-electron energy

$$f_{hot} = \frac{\varepsilon_e}{\varepsilon_{laser}}$$



To guide target design, the convective gain is used as a criteria for hot-electron production.

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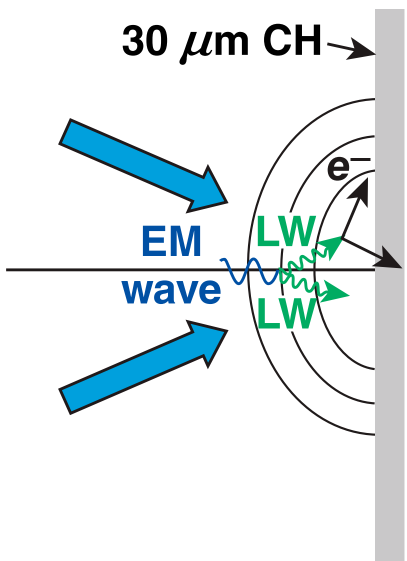
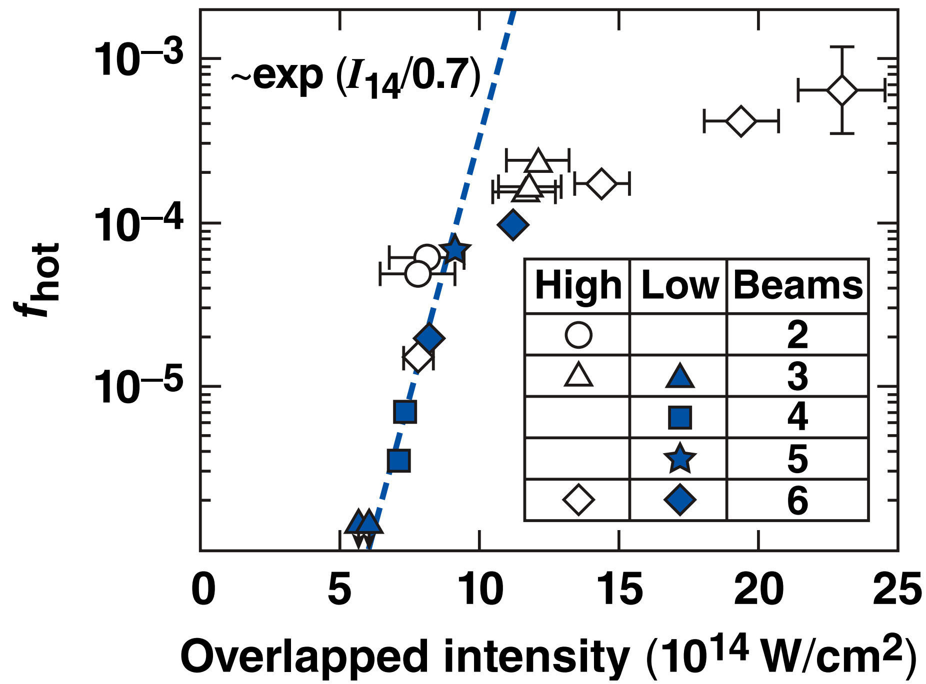
Hot-electron production was shown to depend on the overlapped intensity*





These experiments suggested that TPD is driven by multiple laser beams.

E21304a

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

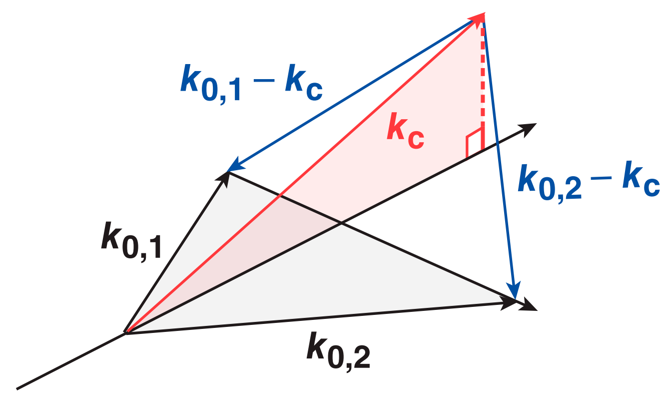
Linear theory shows that a resonant EPW is shared by multiple beams in the region bisecting the wave vectors of the beams

- The dispersion relation of each daughter beam $(k_{0,i} - k_c)$ must be satisfied:

$$(\omega_c - \omega_0)^2 = \omega_{pe}^2 + 3\underbrace{(k_{0,i} - k_c)^2}_{\text{Term must be conserved}} v_{th,e}^2$$

- Therefore, the common-wave volume is defined by:

$$\left| k_{0,i} - k_c \right| = \text{constant}$$

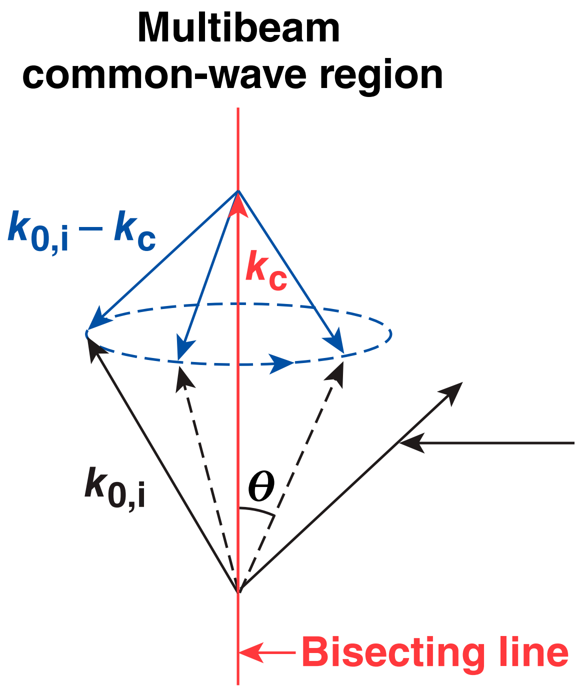


The resonant common-wave region for two beams forms a plane.

E21301a

*D. T. Michel *et al.*, Phys. Rev. Lett. 109, 155007 (2012).

The resonant common-wave region for three or more beams forms a line



$$|k_{0,i} - k_c| = \text{constant}$$

This wave vector does not share a common EPW with the other

Resonant multibeam coupling requires each beam to have the same angle to the common-wave vector.

The resonant common-wave gain is calculated in the common-wave region*

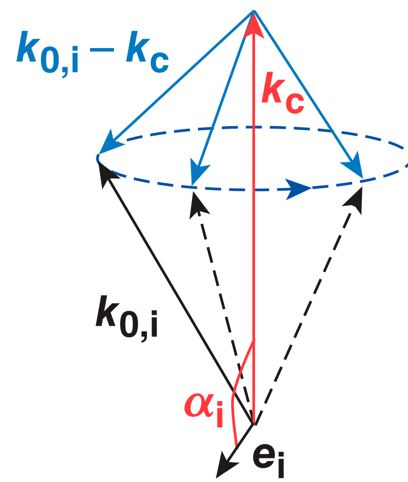
Laser-beam configuration — Plasma parameters

$$G_c = \left(f_g N_\Sigma^{sym}\right)\left(\frac{I_{14}^{SB} L_n[\mu m]}{47\, T_e[\text{keV}]}\right)$$

$$f_g = \max_{k_c}\left\{\frac{1}{N_\Sigma^{sym}}\left[\frac{k_c^2 - (k_c - k_{0,1})^2}{k_{0,1}\,|k_c - k_{0,1}|}\right]^2 \sum_i \cos^2(\alpha_i)\right\}$$

$$\alpha_i = \text{angle}(e_i, k_c)$$

N_Σ^{sym} is the number of symmetric beams

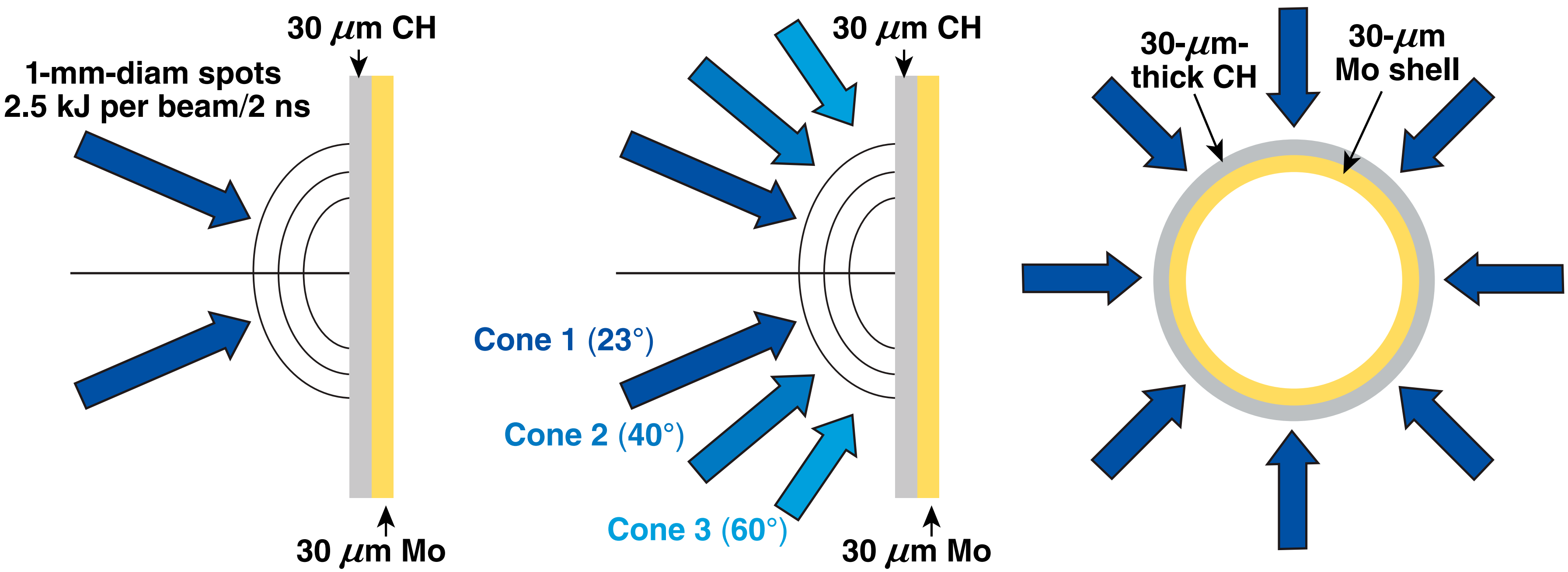


*M. N. Rosenbluth, Phys. Rev. Lett. 29, 565 (1972).

E21643

To study the multibeam TPD thresholds, three target configurations were used

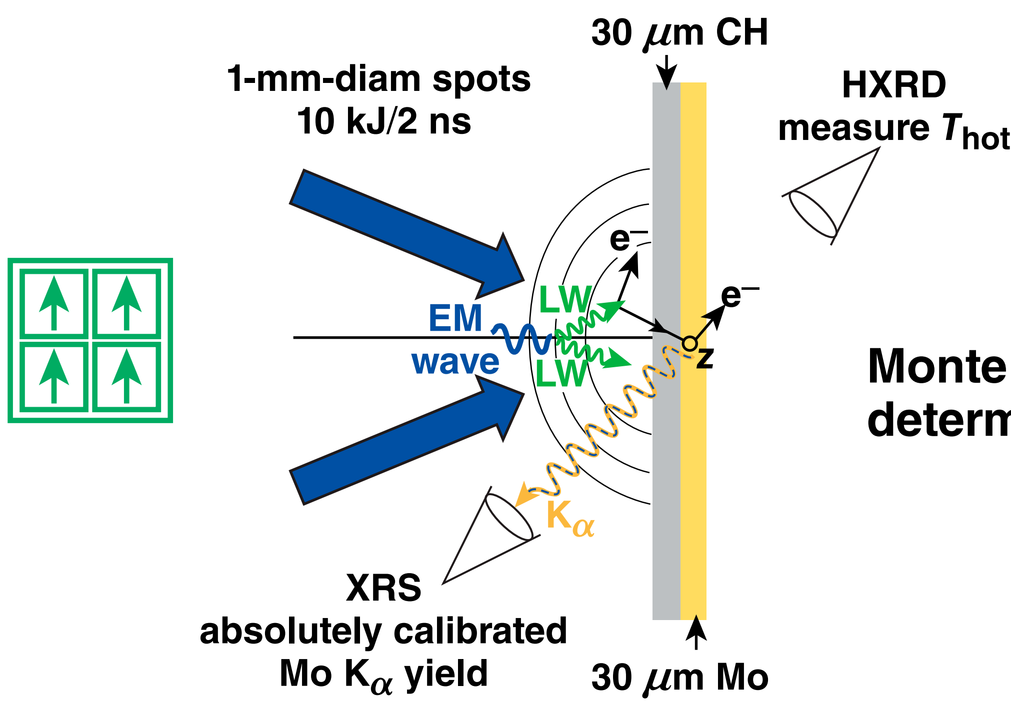
OMEGA EP planar	OMEGA planar	OMEGA spherical
One cone of four beams	Three cones of six beams	60 beams



Each configuration varies a different parameter in the gain $\left(f_g, N_{\Sigma}^{sym}, L_n/T_e\right)$.

E21698

OMEGA EP provides a planar-target platform to study multibeam TPD near ignition coronal-plasma conditions



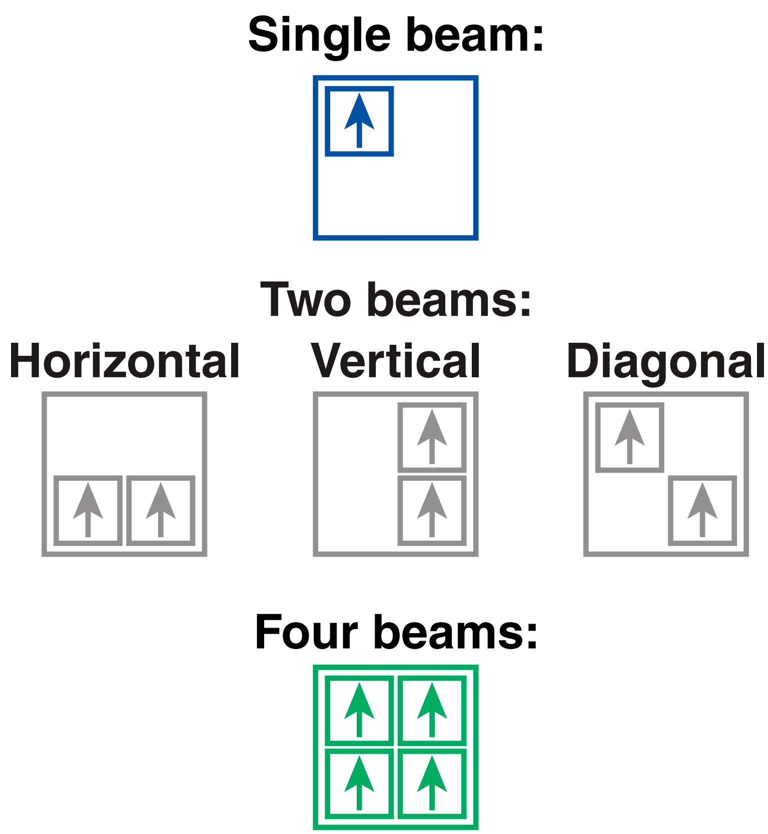
Monte Carlo simulations determine E_e from K_α and T_{hot}

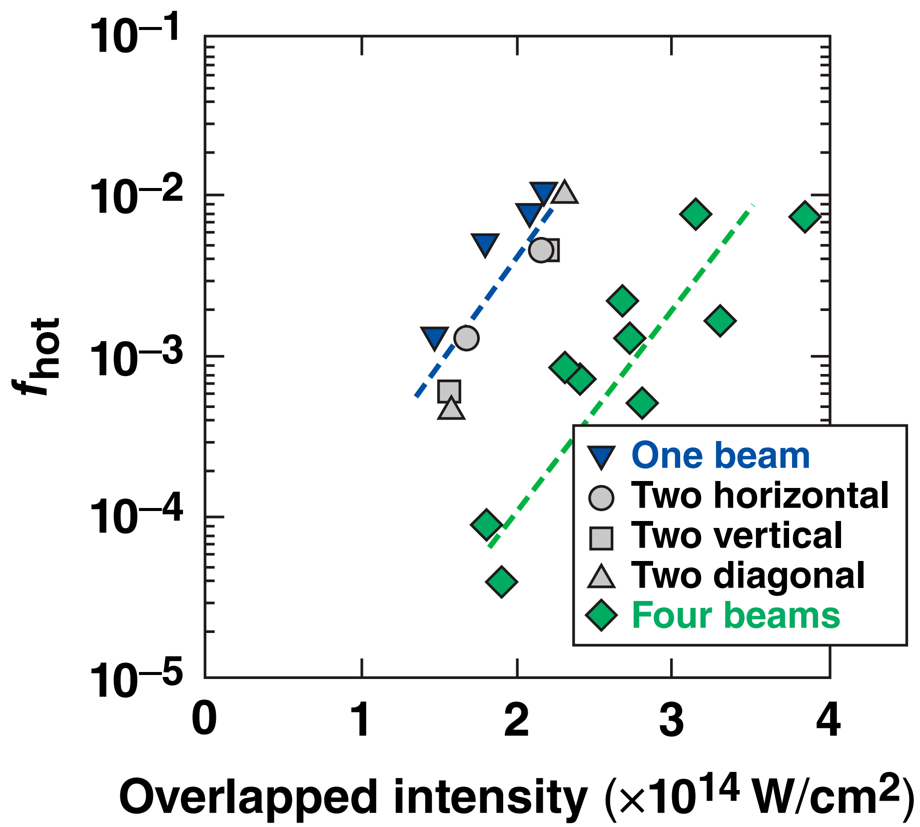
This target platform accounts for all electrons generated by TPD; the energy coupled to the direct-drive shell will be reduced.*

E21298a

*D. H. Froula, TO5.00002, this conference.

These experiments show that the hot-electron production can have different dependences on the overlapped intensity





A significant increase in the TPD threshold is observed when four beams are used with the same overlapped intensity.

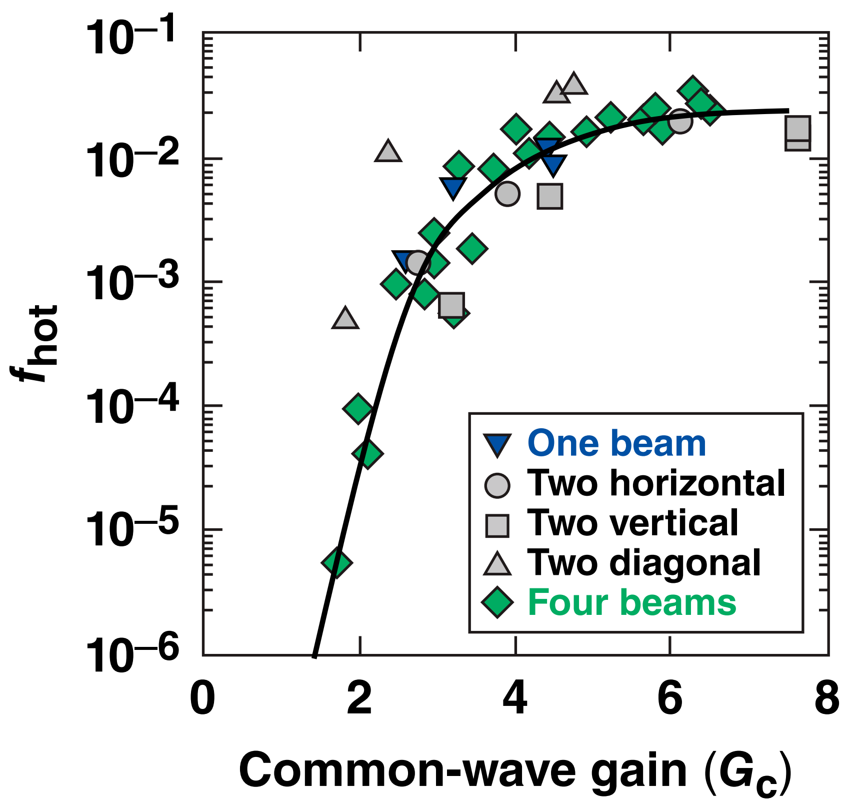
E21300a

For the four-beam configuration, the TPD threshold is reduced by the geometric factor

UR LLE

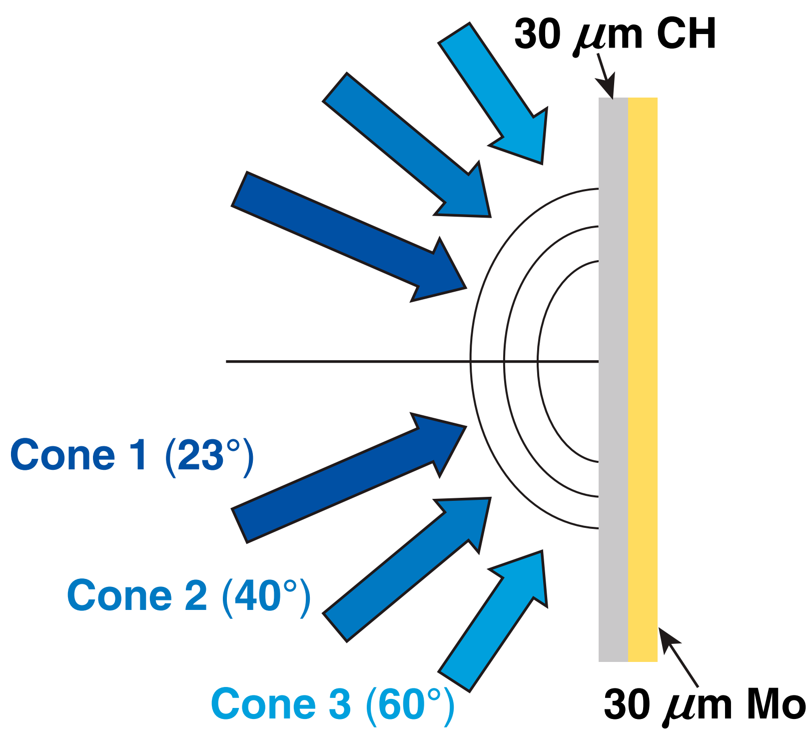
$$G_c = \left(f_g N_\Sigma^{sym}\right)\left(\frac{I_{14}^{SB} L_n}{47\, T_e}\right)$$

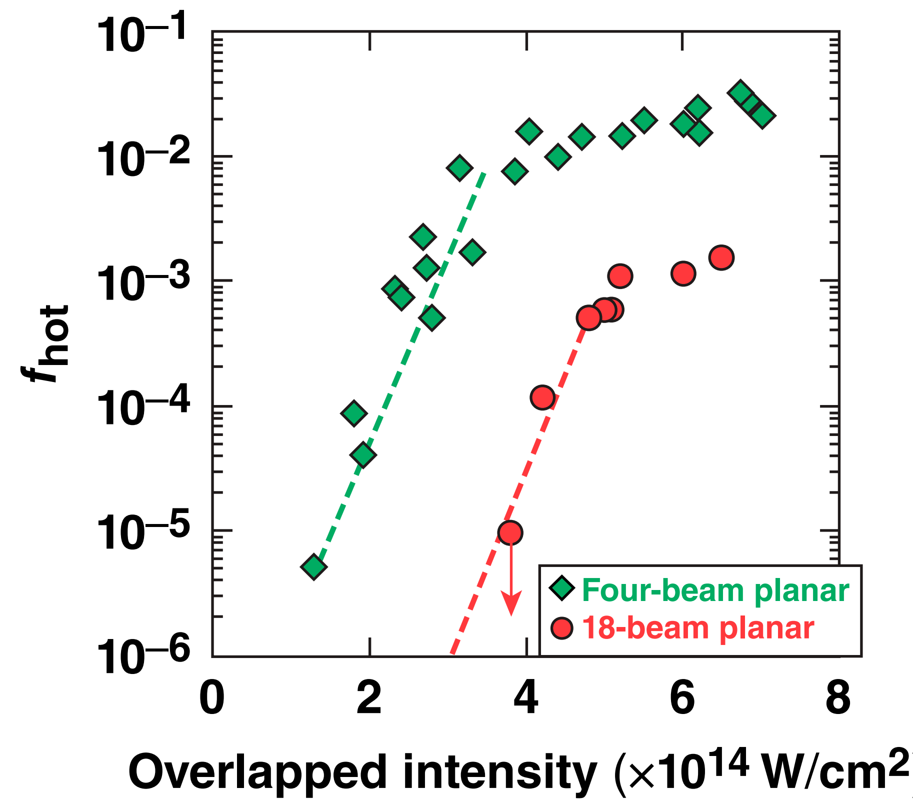
N_{beam}	f_g	N_Σ^{sym}	L_n/T_e
One	1.0	1	175
Two horizontal	0.8	2	175
Two vertical	1.0	2	175
Four diagonal	0.6	2	175
Four	1.0	4	175



E21644

For the 18-beam configuration, a further decrease of hot-electron production with overlapped intensity is measured





In the 18-beam planar experiment, a factor-of-~3 increase is observed in the TPD threshold.

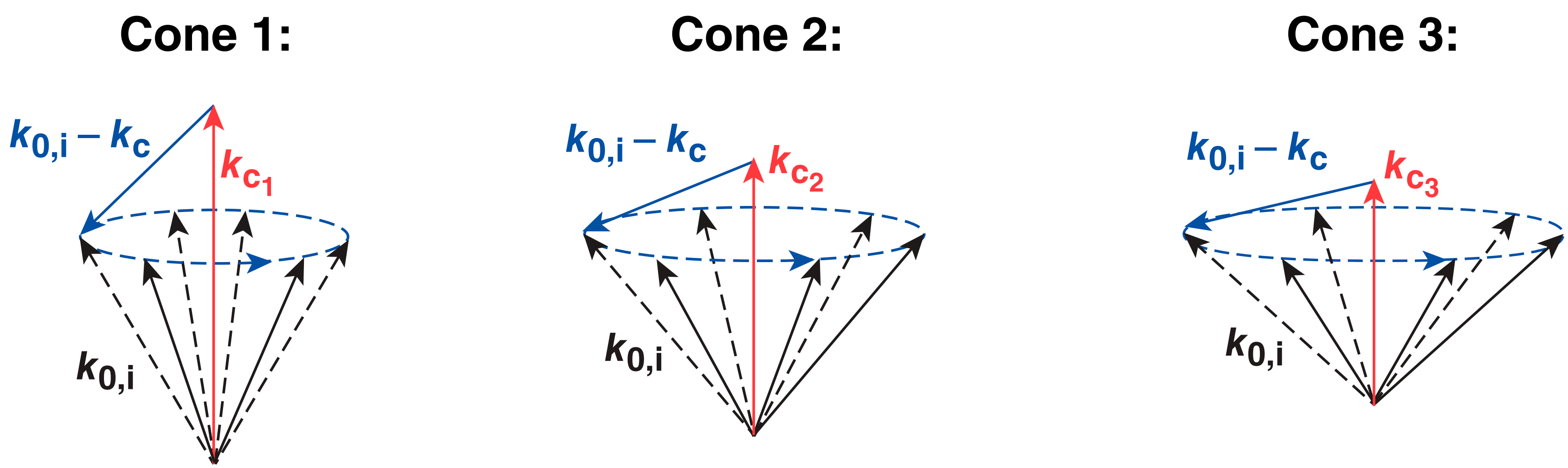
E21306c

The beams in each cone drive independent common EPW's

- **Each common wave requires:**

$$\left| k_{0,i} - k_c \right| = \text{constant}$$

- **This is not satisfied between different cones on OMEGA:**



$I^{sym}_{\Sigma,q} = 0.3\, I_{ovr}$ $\qquad$ $I^{sym}_{\Sigma,q} = 0.15\, I_{ovr}$ $\qquad$ $I^{sym}_{\Sigma,q} = 0.05\, I_{ovr}$

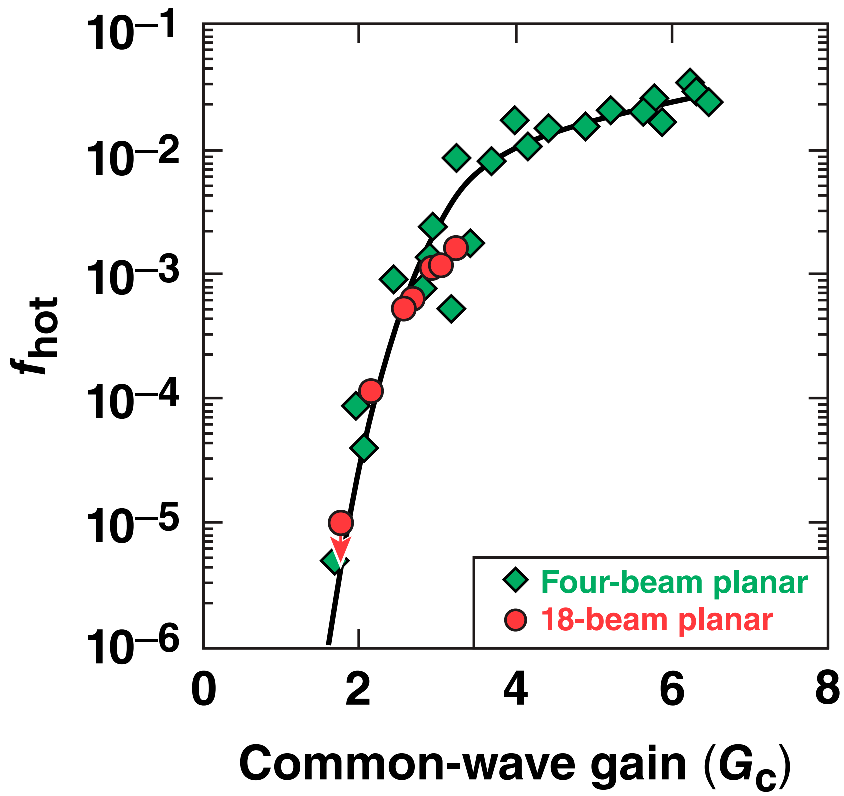
The gain is proportional to the overlapped intensity that contributes (i.e., Cone 1) to the maximum common-wave gain.

E21307a

For the 18-beam configuration, the TPD threshold is reduced by limiting the number of symmetric beams

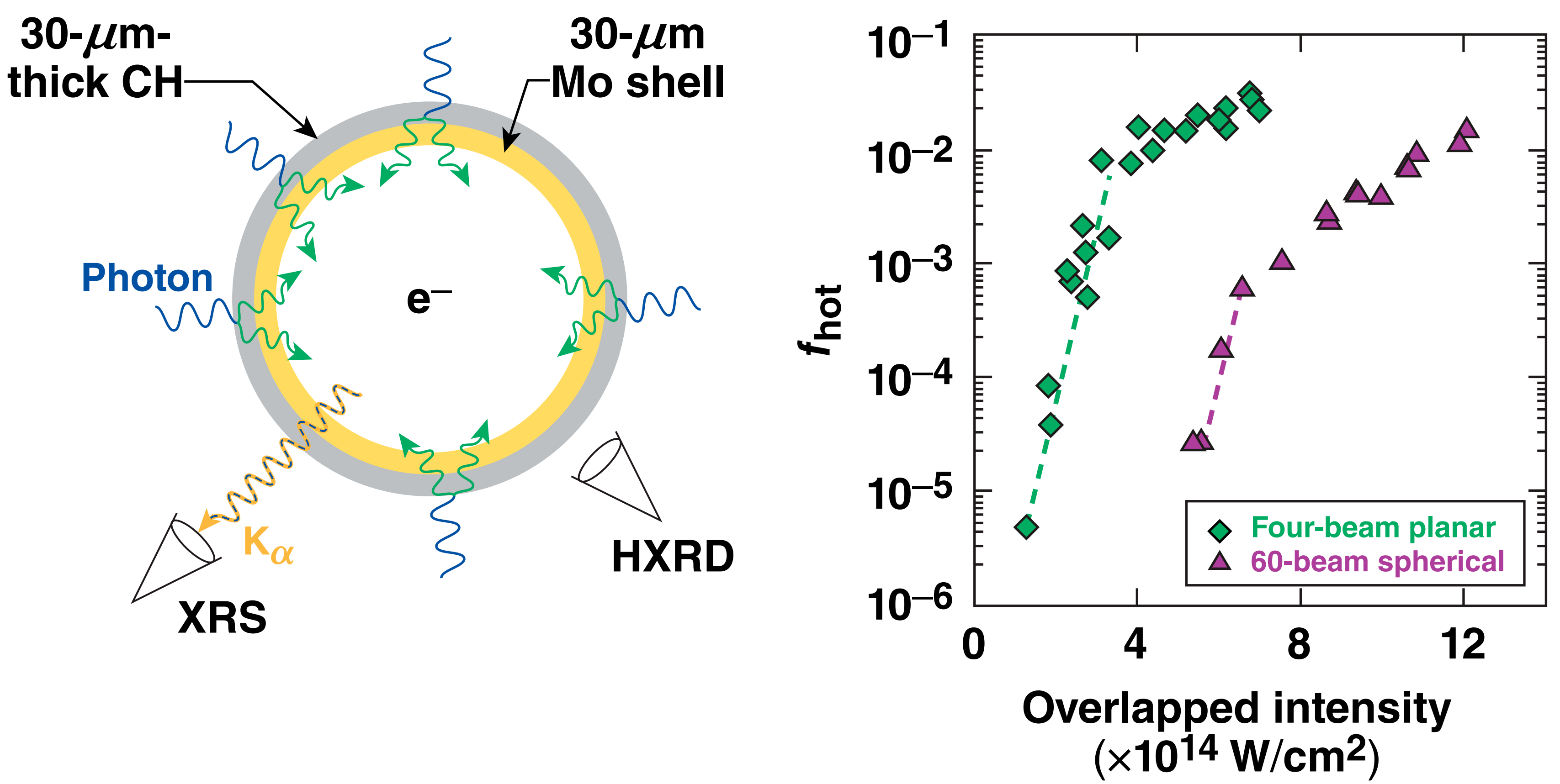
$$G_c = \left(f_g N_\Sigma^{sym}\right)\left(\frac{I_{14}^{SB} L_n}{47\, T_e}\right)$$

N_{beam}	f_g	N_Σ^{sym}	L_n/T_e
4	0.5	4	175
18	0.5	6	135



E21645

Hot electrons were measured in spherical geometry by varying the laser energy

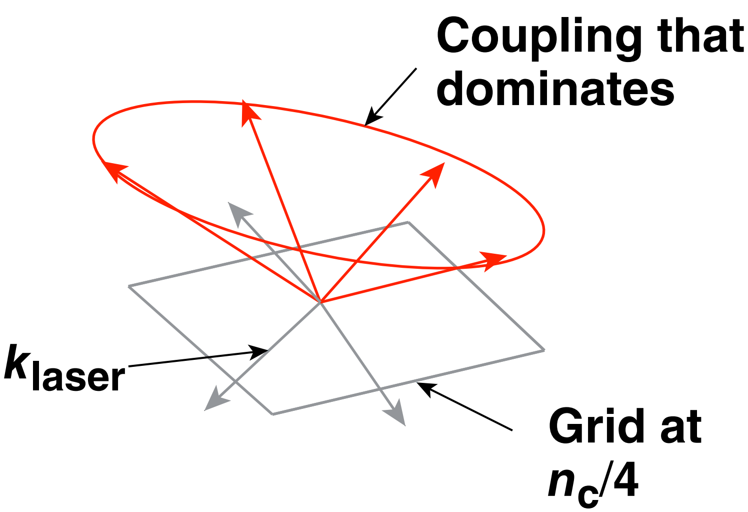


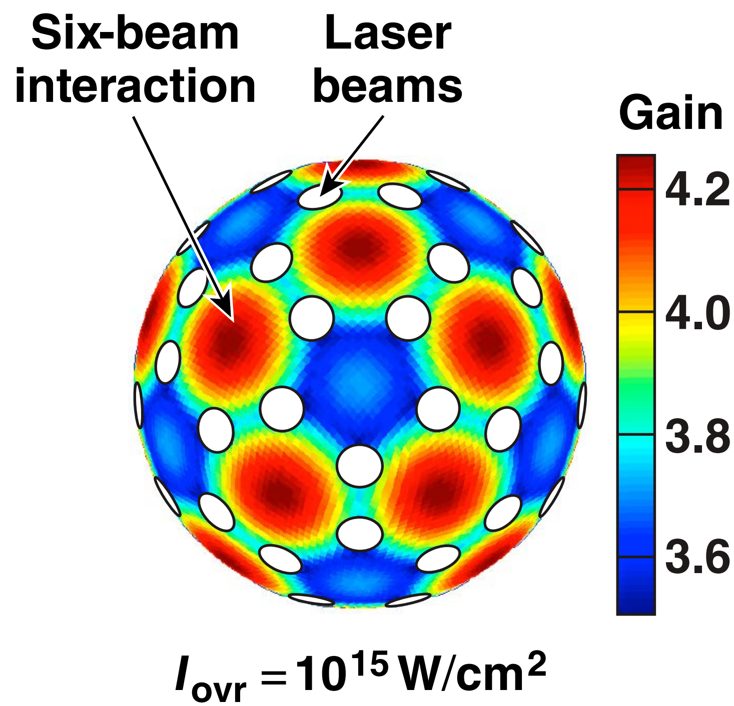
In the 60-beam spherical experiments a factor-of-~3 increase is observed in the TPD threshold.

E21309b

The TPD model is extended to 3-D to calculate the gain in spherical geometry

- Each beam is propagated through the plasma
- The plasma parameters are determined by hydrodynamic simulation (*LILAC*)





The gain is dominated by six-beam interaction.

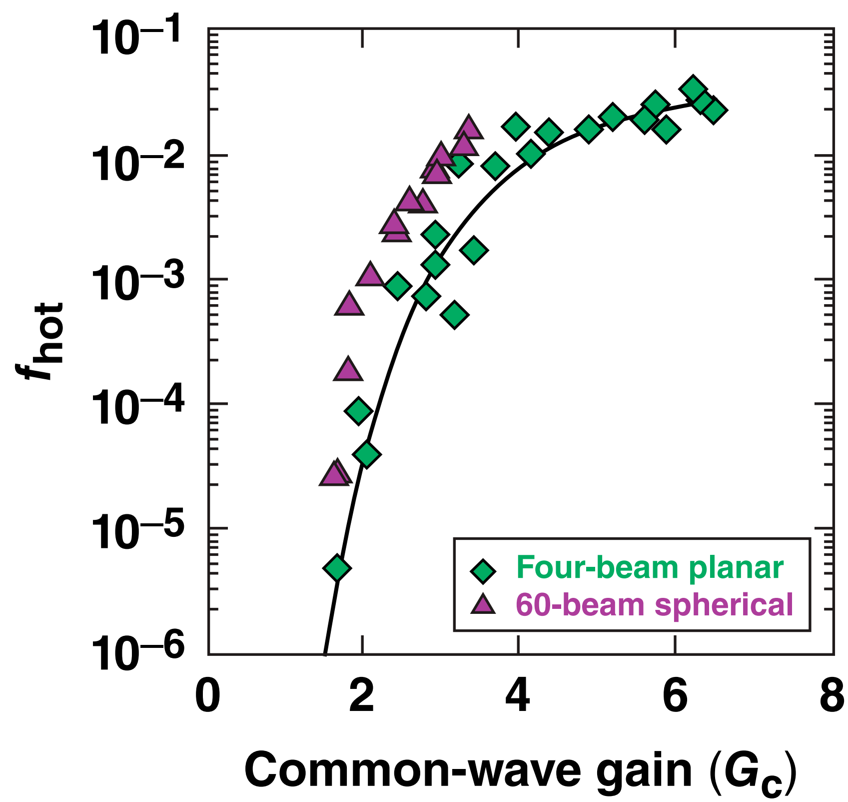
E21646

The 3-D model reproduces the measured threshold

UR LLE

$$G_c = \left(f_g N_\Sigma^{sym}\right)\left(\frac{I_{14}^{SB} L_n}{47\, T_e}\right)$$

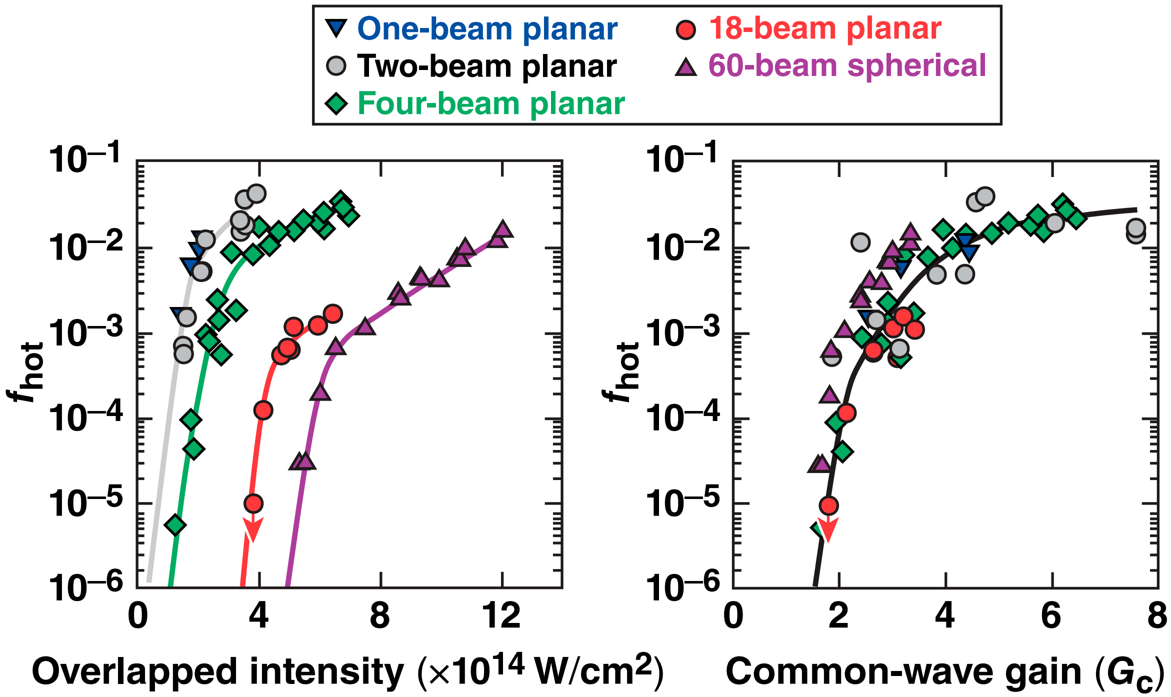
N_{beam}	f_g	N_Σ^{sym}	L_n/T_e
4	0.5	4	175
60	0.5	6	50



E21561

For several configurations, the resonant convective common-wave gain is consistent with the measured TPD threshold

N_{beam}	f_g	N_{Σ}^{sym}	L_n/T_e
1	1.0	1	175
2	1.0	2	175
4	0.5	4	175
18	0.5	6	135
60	0.5	6	50



The common-wave gain can be used as a TPD criteria in polar-drive–ignition target designs.

Although the convective gain is a reasonable guide, there are many limitations

- Hot-electron production is assumed to grow linearly with the electron plasma wave amplitude
- An experimental convective gain threshold of ~2 is observed (enhanced thermal noise, laser speckles....?)
- Saturation of the hot-electron production is not modeled

Several theoretical models are being used to further understand these experiments

- **Calculations of multibeam absolute thresholds (enhanced thermal noise)**
- **Particle-in-cell (*OSIRIS*,* *RPIC***) simulations provide insight into the mechanisms for hot-electron production and saturation**
- **An extended Zakharov model provides a practical middle ground**
  - ***ZAK*3D contains linear instability of multibeams in three dimensions*****
  - **incorporates the important nonlinearities that lead to saturation**
  - **a quasilinear Zakharov (*QZAK*) model computes hot-electron production**

These models will provide a complete physics understanding of TPD that will lead to mitigation strategies (if necessary).

*R. Yan *et al*., Phys. Rev. Lett. 108, 175002 (2012).
**H. X. Vu *et al*., Phys. Plasmas 19, 102703 (2012).
***J. Zhang, TO5.00004, this conference.

A common-wave gain model allows for the two-plasmon–decay (TPD) threshold to be predicted for many different experimental configurations

UR LLE

- A resonant common electron plasma wave (EPW) is driven by multiple laser beams in the region bisecting the beams' wave vectors
- Different intensity thresholds are observed for various laser-beam geometries in planar and spherical configurations
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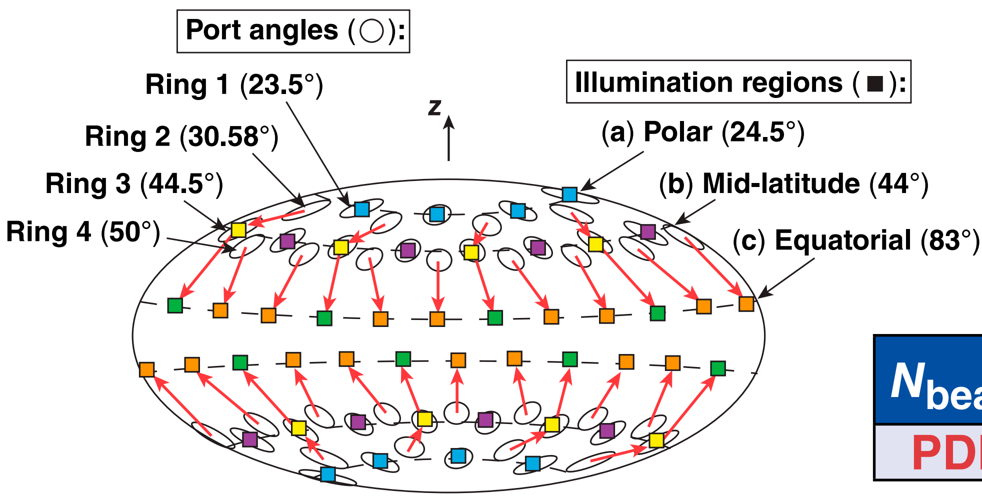
The laser-beam geometry must be taken into account to calculate the TPD gain.

*D. T. Michel *et al*., Phys. Rev. Lett. 109, 155007 (2012).

In polar-drive experiments, Ring 1 is likely to dominate



$$G_c = \left(f_g N_{\Sigma}^{sym}\right)\left(\frac{I_{14}^{SB} L_n}{47\, T_e}\right)$$

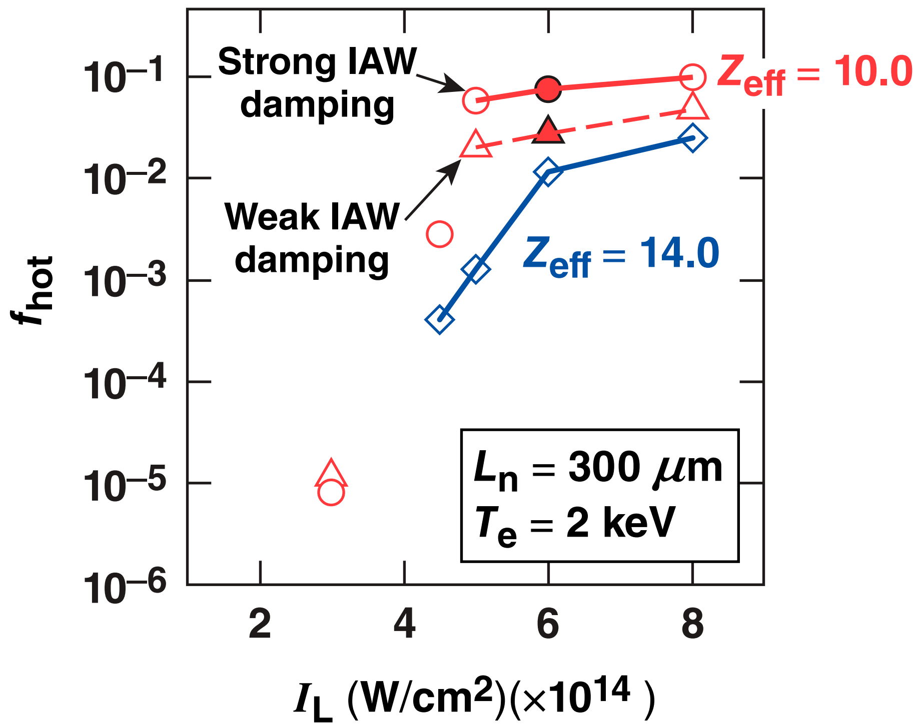
N_{beam}	f_g	N_{Σ}^{sym}	L_n/T_e	$G_c(10^{14}$ W/cm$^2)$
PDD	0.5	4?	100	3.2?

Initial estimates suggest that TPD is below threshold.

E21648

A quasilinear Zakharov model has been developed that also computes hot-electron production

- It computes the evolution (heating) of the electron distribution function (currently in 2-D)
- Quasilinear (kinetic) saturation in addition to low-frequency density perturbations
- It has been used to demonstrate the ablator material independence of the two-plasmon–decay instability*



*J. F. Myatt, TO5.00005, this conference.