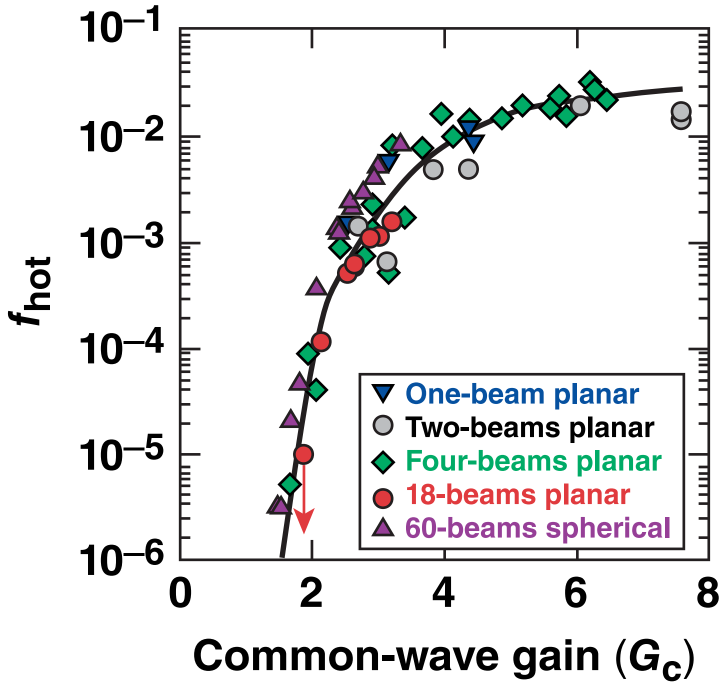
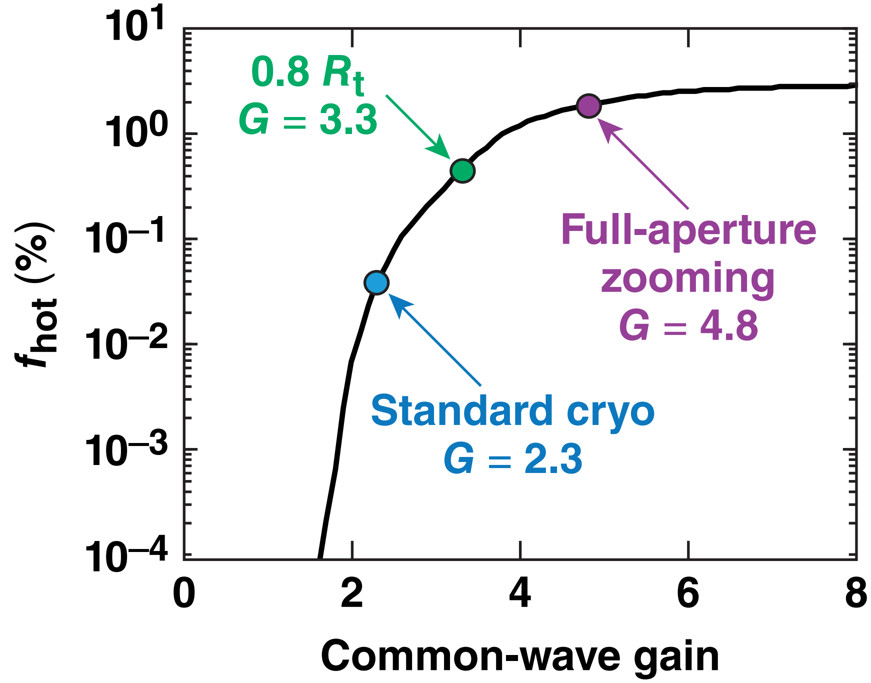
Two-Plasmon–Decay Scaling for Improved-Performance Cryogenic Implosion Strategies





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Summary

Hot-electron production at the Omega Laser Facility scales empirically with the two-plasmon–decay (TPD) common-wave gain and can guide experimental design

- The TPD common-wave scaling indicates that cross-beam energy transfer (CBET) reduces the hot-electron production in current OMEGA cryogenic implosions by an order of magnitude
- If CBET is mitigated to achieve ignition hydrodynamic equivalence then TPD mitigation will likely be required
- The TPD scaling predicts that mitigation with mid-Z layers will reduce the hot-electron production in advanced OMEGA cryogenic implosions

Collaborators

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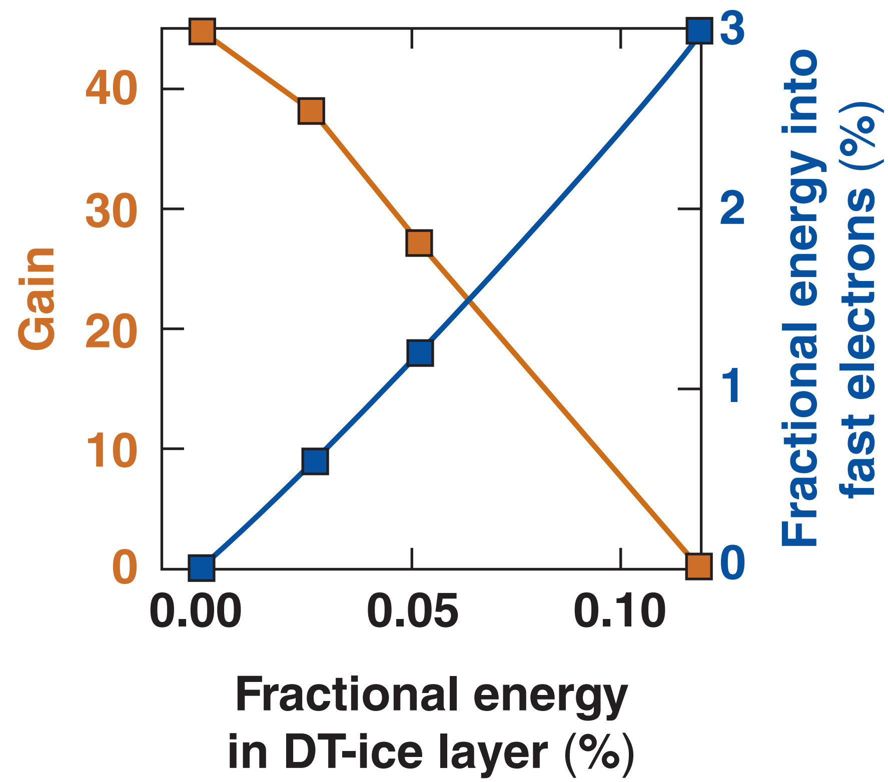
Ice-layer preheat from hot electrons must be kept below 0.04% of the laser energy for ignition

- Theory suggests that TPD will vary as $I \cdot L_n / T_e$ at $n_e/4$
  - I = laser intensity
  - L_n = density scale length
  - T_e = electron temperature
- TPD transfers laser energy to Langmuir waves that produce hot electrons



Calculations suggest that the fraction of laser energy converted to hot electrons should be kept low*.

*LLE Review Quarterly Report 79, 121, LLE Document No. DOE/SF/19460-317, NTIS Order No. DE2002762802 (1999); C. Stoeckl *et al.*," Phys. Plasmas 9 (5), 2195-2201 (2002).

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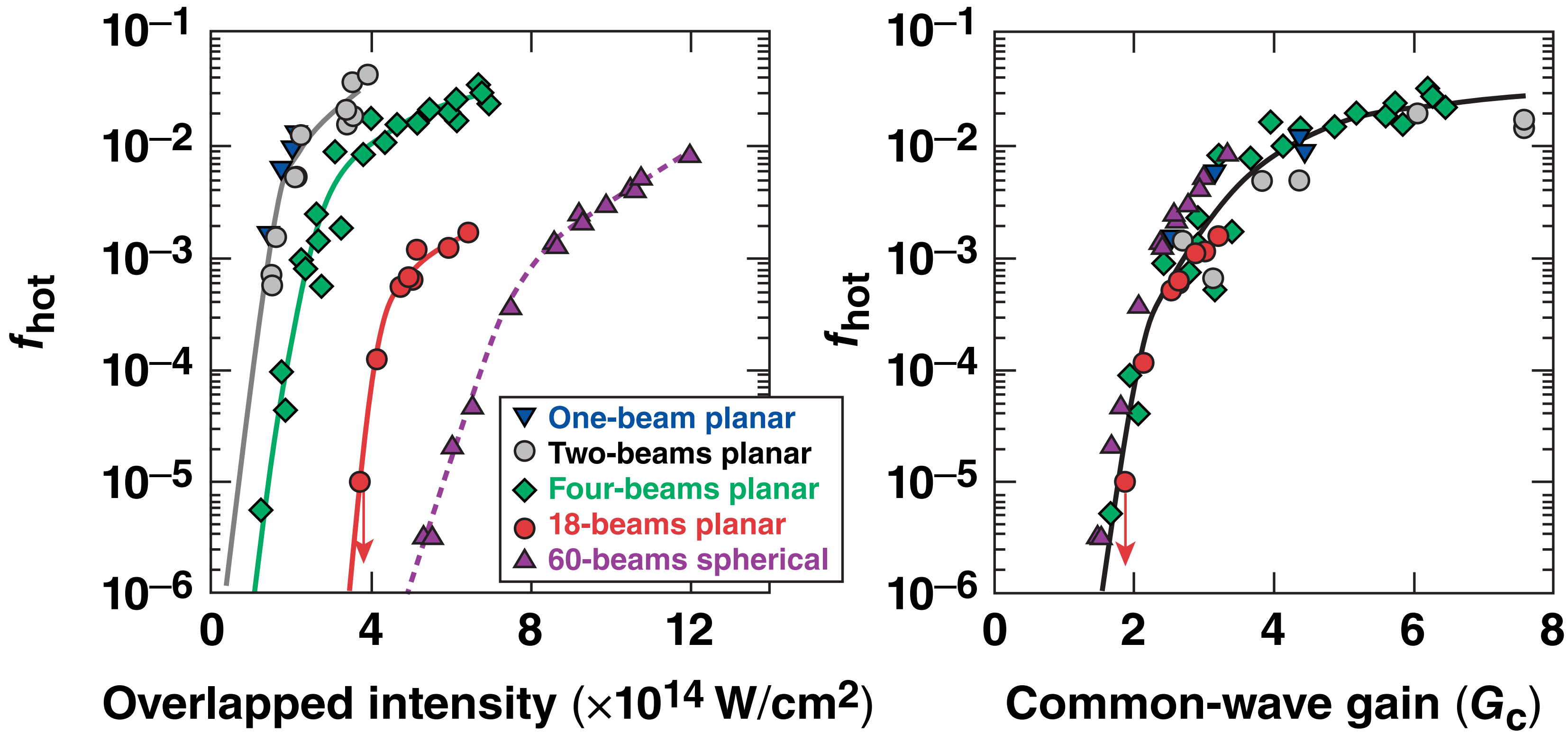
Common-wave gain

The common-wave gain provides a useful empirical scaling that unifies different experimental geometries*



- Intensity was scanned during each study
- During these intensity scans, L_n/T_e differed between studies but was roughly constant within each scan

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*D. T. Michel *et al.*, Phys. Plasmas 20, 055703 (2013).

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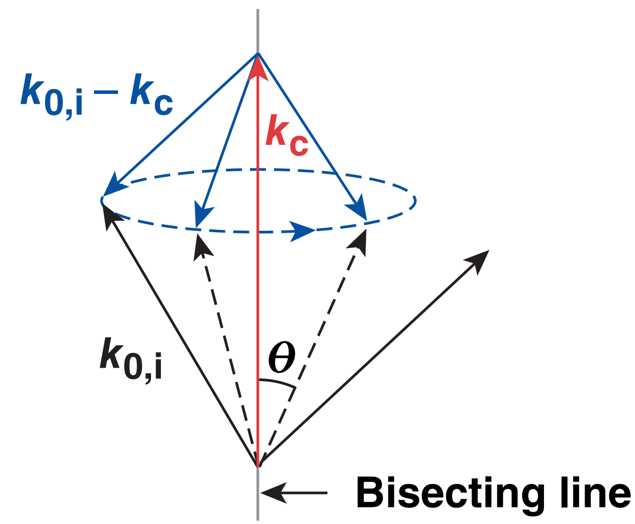
The maximum TPD growth rate is driven by beams with a common angle to the electron plasma wave (EPW)

- Experiments suggest that TPD is driven by multiple beams*
- Linear theory shows that a resonant EPW is shared by multiple beams in the region bisecting the wave vectors of the beam**
- A hydrodynamic post-processing code finds the maximum gain from all possible beam groups at each point in the quarter-critical surface
  - ray tracing finds the intersection of the beams with the quarter-critical surface (positions and *k* vectors) and their intensities (including CBET)



Intensity at $n_c/4$ that contributes to the dominant mode

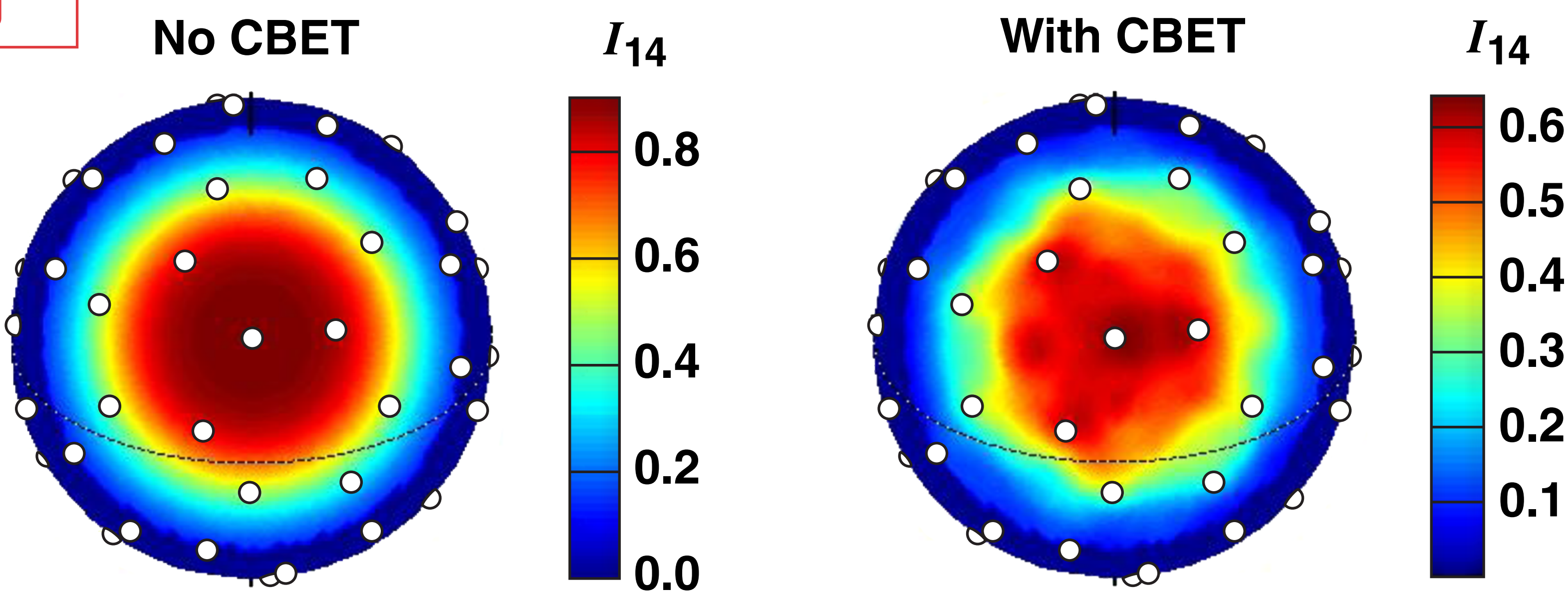
$$G_c \approx \frac{I_\Sigma\left(\mathrm{W/cm^2}\right) L_n\left(\mu\mathrm{m}\right)}{T_e\left(\mathrm{keV}\right)} \times 10^{-16}$$

*C. Stoeckl *et al.*, Phys. Rev. Lett. 90, 235002 (2003).
**D. T. Michel *et al.*, Phys. Rev. Lett. 109, 155007 (2012).

CBET significantly lowers the single-beam peak intensity that reaches the quarter-critical surface

Standard
OMEGA
cryo design
SG4s
26 kJ

Single-beam intensity at $n_c/4$ surface



$I_{max} = 9.1 \times 10^{13}$ W/cm^{-2}

$I_{max} = 6.4 \times 10^{13}$ W/cm^{-2}

30% reduction in peak intensity from CBET

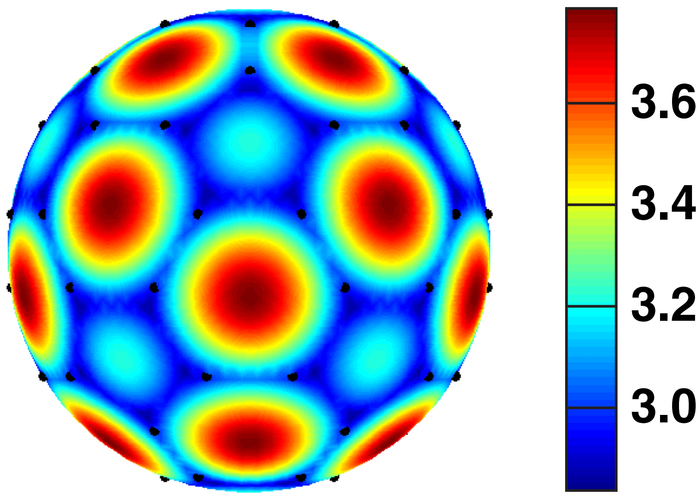
CBET significantly lowers the common-wave gain and changes its distribution across the target surface

Standard OMEGA cryo design

SG4s
26 kJ

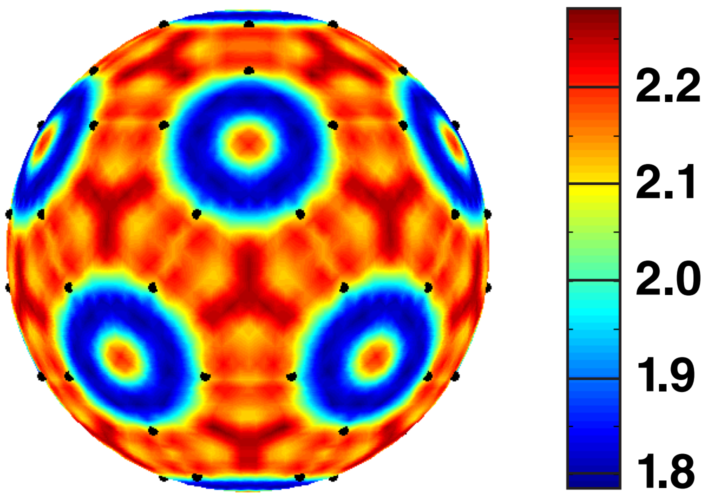
Maximum common-wave gain

Without CBET:
$G_{max} = 3.8$



$f_{hot} \rightarrow 0.95\%$

With CBET:
$G_{max} = 2.3$



$f_{hot} \rightarrow 0.035\%$

If CBET is mitigated,* hot-electron production could increase.

*D. H. Froula *et al.*, this conference.

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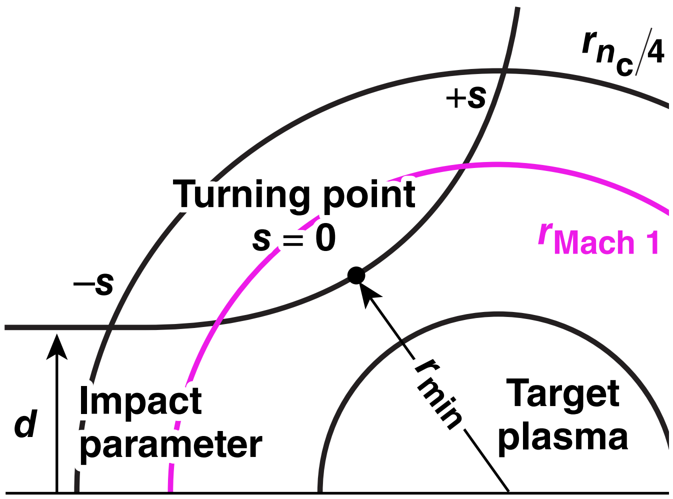
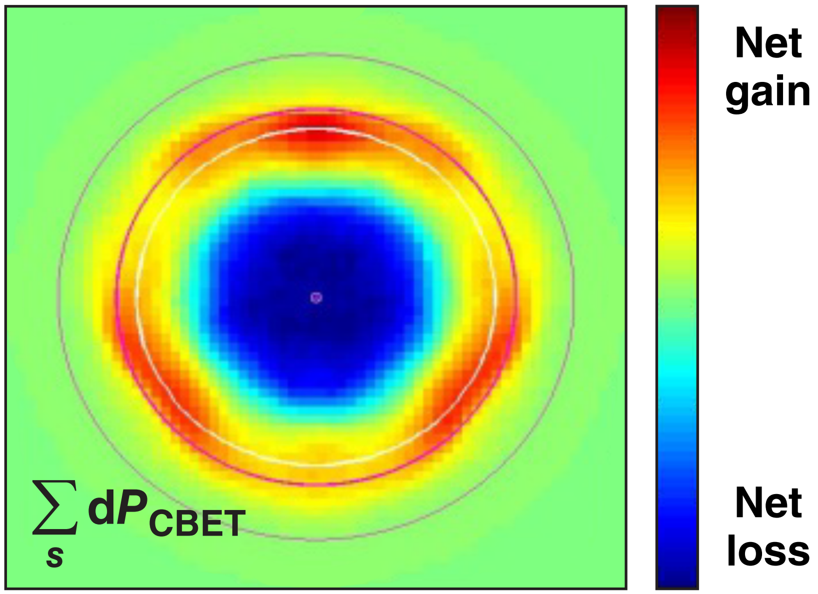
CBET mitigation strategies based on reduced beam size are being evaluated for implementation on OMEGA*

- CBET typically results in transfer of power from the center of the ingoing beam to the edge of the outgoing beam
- Decreasing the beam profile diameter reduces the edge seed that takes power from the ingoing beams



Net CBET along beamlets



Power transferred in/out of beamlets is integrated along the path of each beamlet

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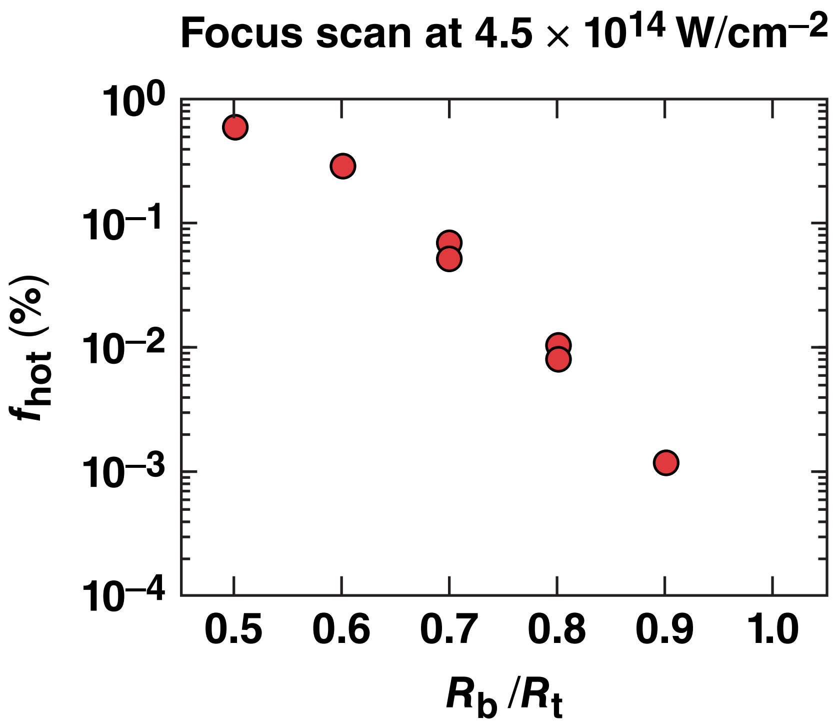
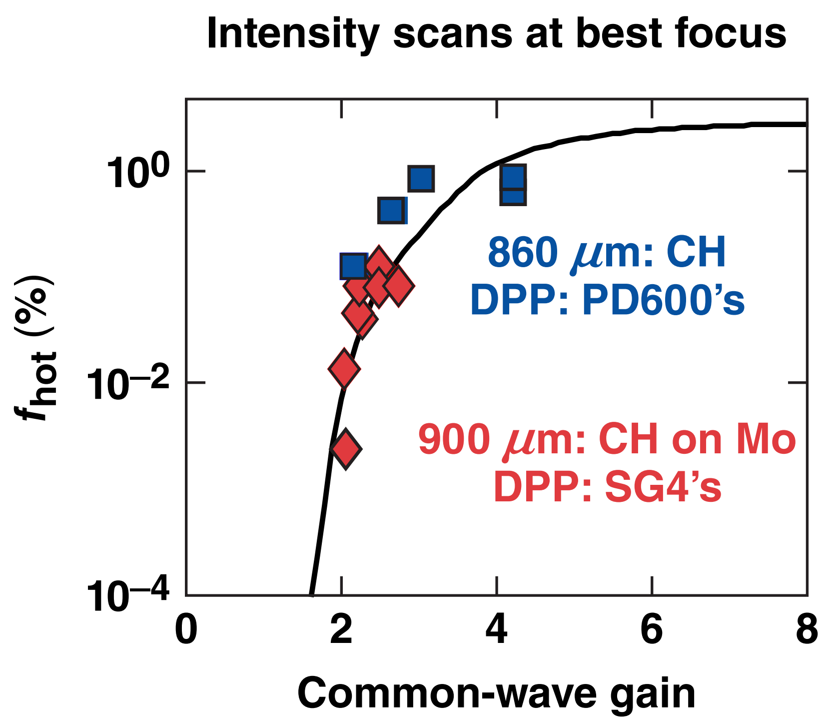
*D. H. Froula *et al.*, this conference.

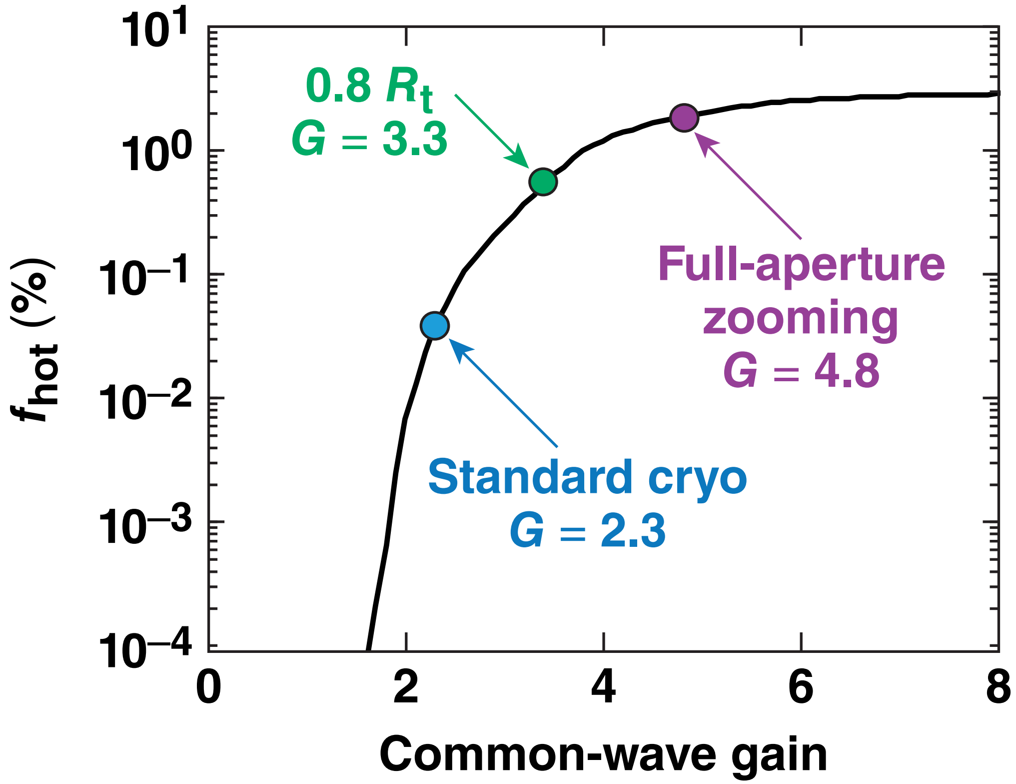
Experiments have shown that reducing the beam radius increases the hot-electron production





*DPP: distributed phase plate

A hydro-equivalent experiment on OMEGA will likely require TPD mitigation



If CBET mitigation is needed to get a stable hydro-equivalent implosion, the TPD gain and hot-electron production will increase.

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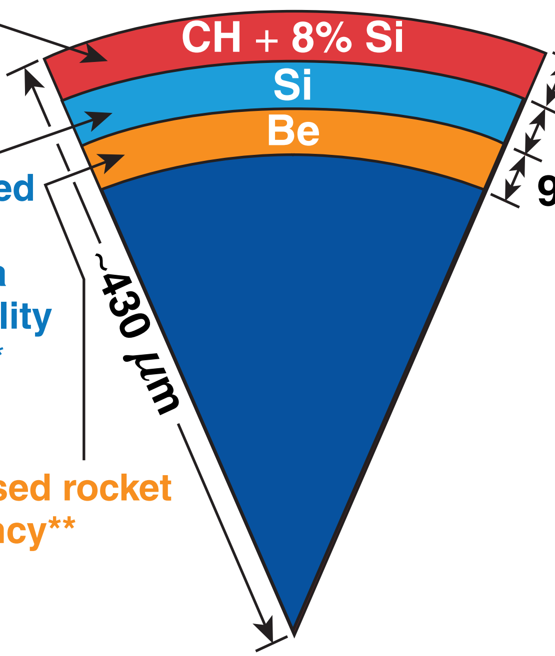
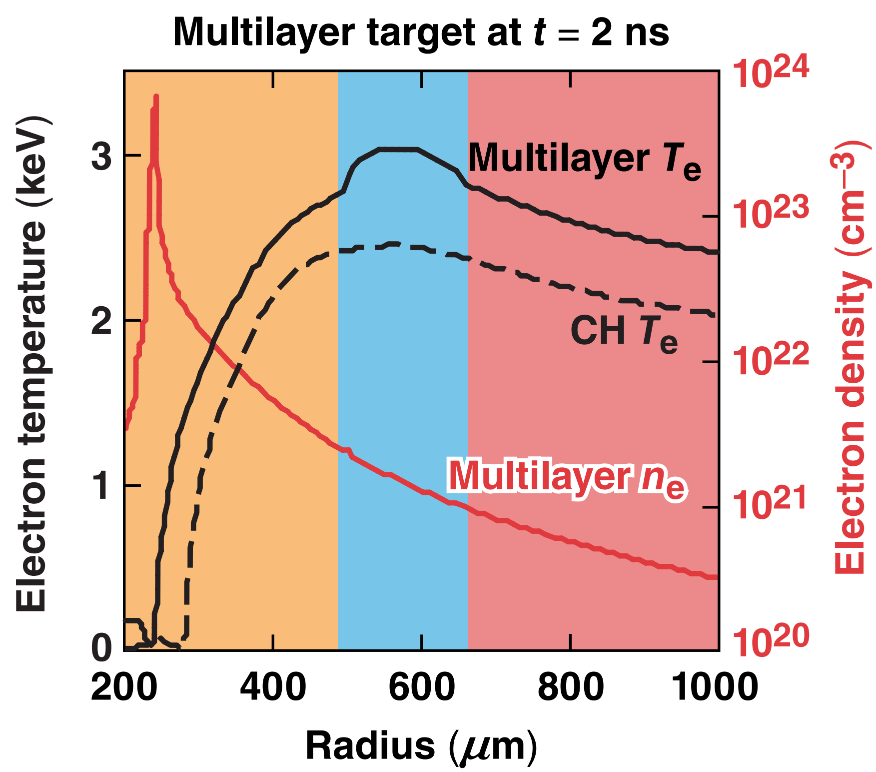
D. H. Froula *et al.*, this conference.

Multilayer targets are designed to reduce TPD by increasing the temperature at quarter critical





* S. X. Hu *et al*. Phys. Rev. Lett. 108, 195003 (2012); G. Fiksel *et al*., Phys. Plasmas 19, 062704 (2012).

** D.T. Michel *et al*. "Demonstration of the Improved Rocket Efficiency in Direct-Drive Implosions using Different Ablator Materials," submitted to Physical Review Letters;

*** V. N. Goncharov *et al*., Phys. Plasmas 21, 056315 (2014).

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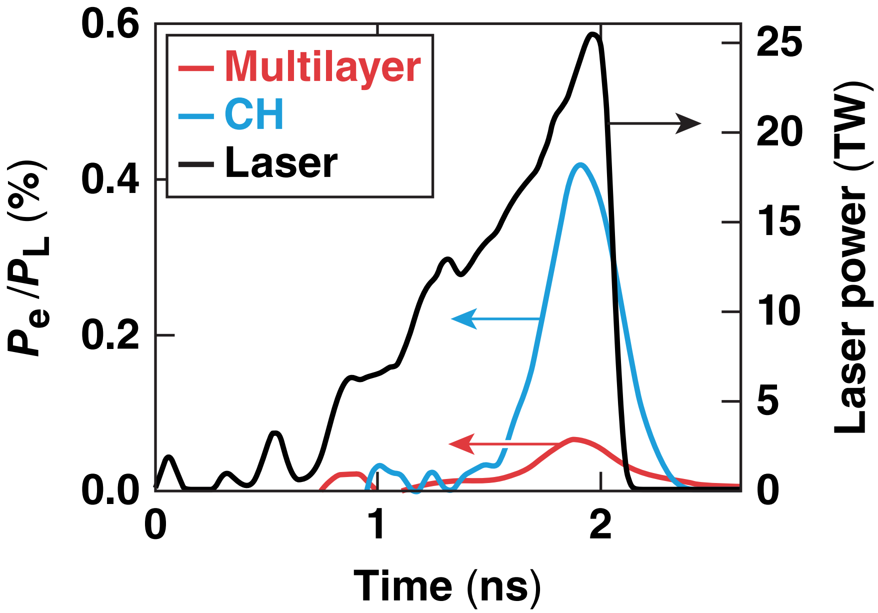
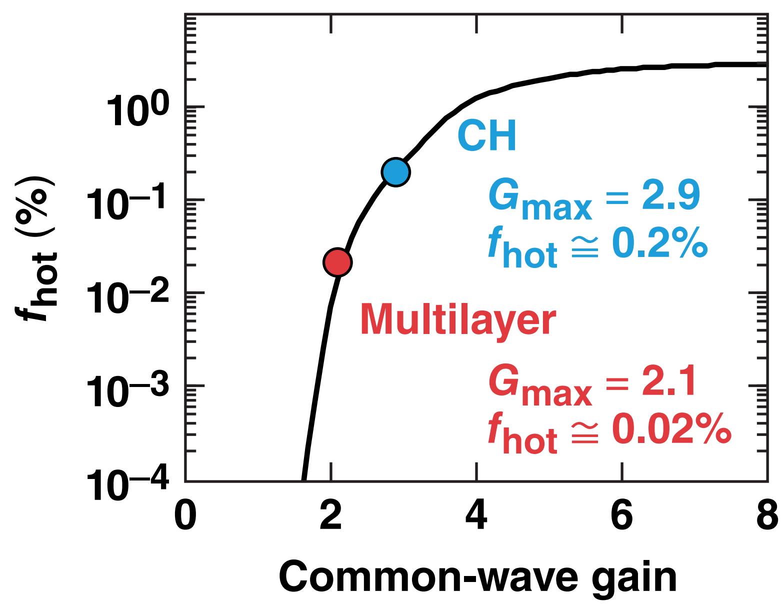
Experimental tests of multilayer targets produced many fewer hot electrons than CH targets

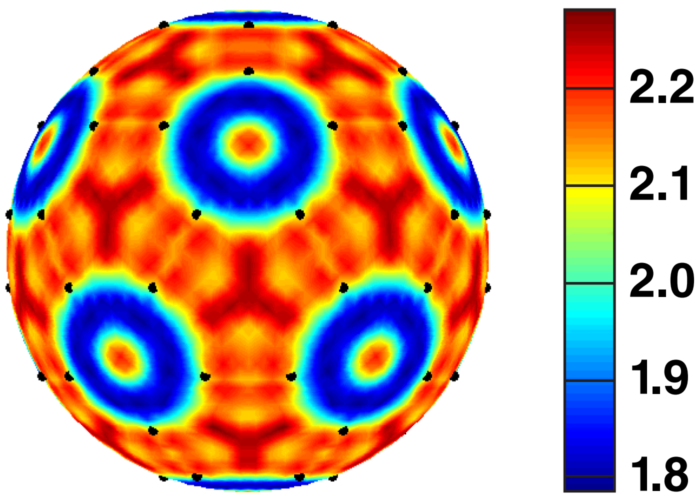




- The higher coronal temperatures in the mid-*Z* layer reduce the TPD-produced hot electrons

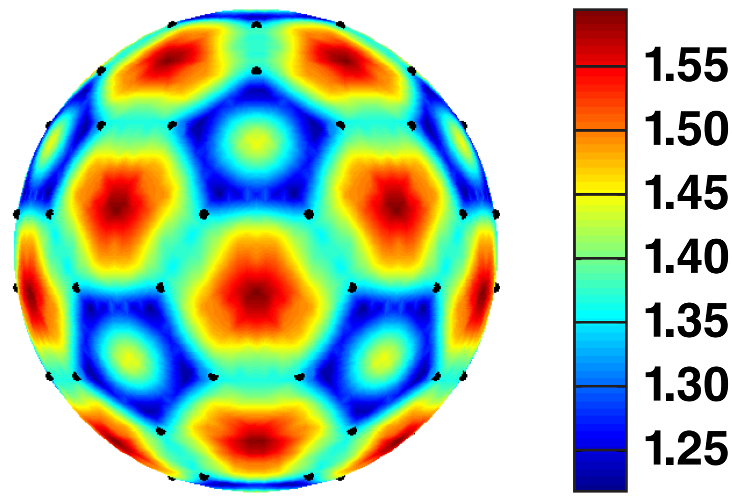
Mid-Z multilayers are predicted to significantly reduce hot-electron production

Standard cryo design
SG4s, 26 kJ



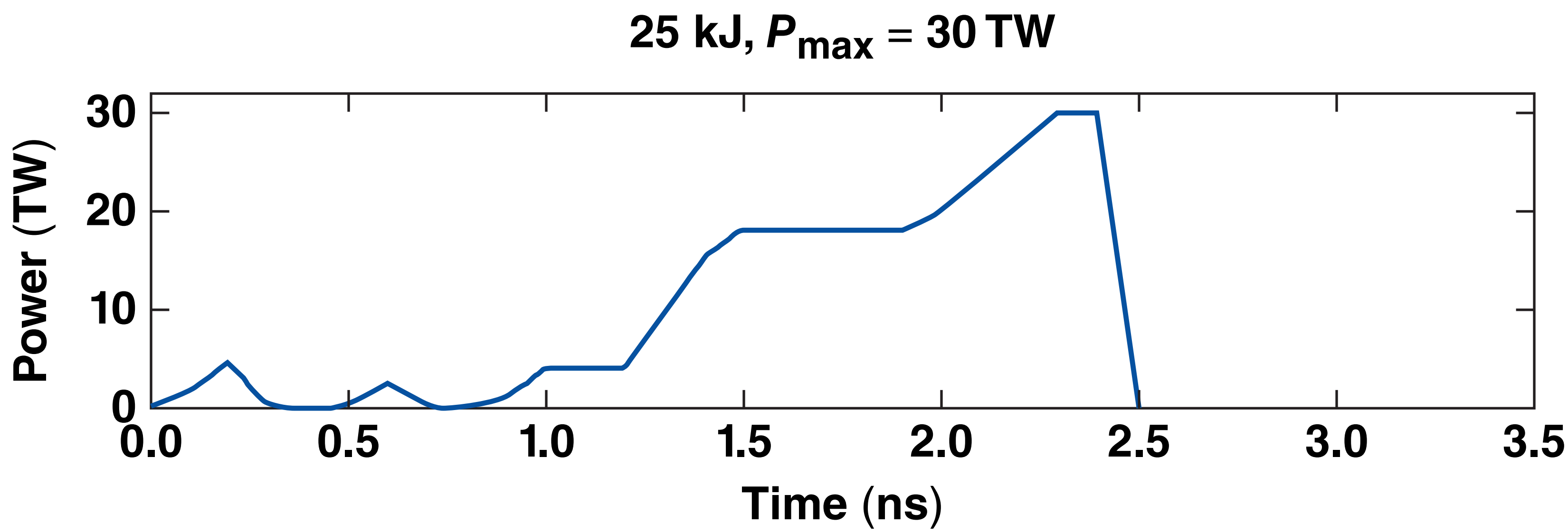
$G_{max} = 2.3$
$f_{hot} \rightarrow 0.035\%$

Multilayer cryo design
SG4s, 25 kJ



$G_{max} = 1.6$
$f_{hot} \rightarrow 10^{-4}\%$

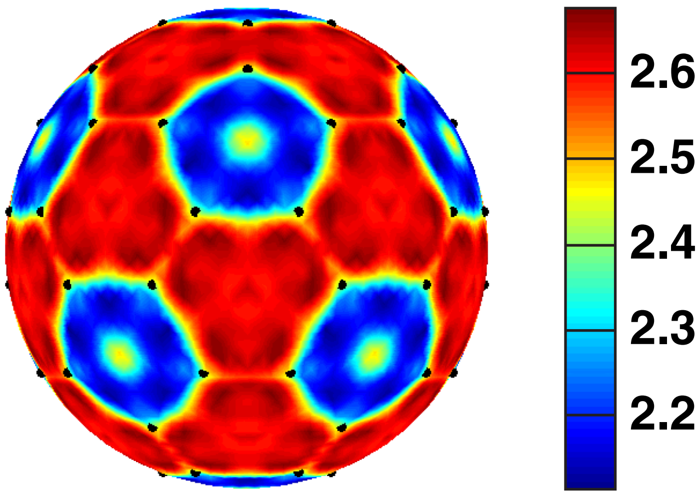
A new pulse shape with a high-intensity peak at the end of the pulse is being studied for cryo



- Putting more of the drive pressure at the end of the pulse improves performance by delaying shell deceleration

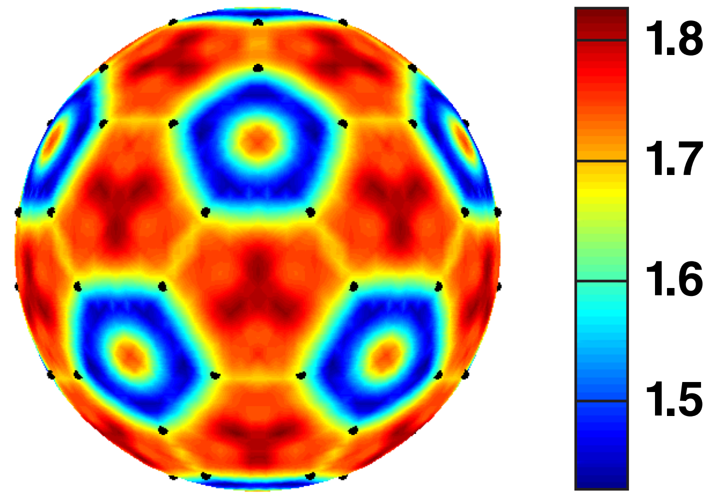
The proposed cryo pulse shape is predicted to keep the gain and electron production acceptably low

New pulse shape cryo design
SG4s, 26 kJ



G_{max} = 2.7
$f_{hot} \rightarrow$ 0.13%

Multilayer with new pulse shape
SG4s, 27 kJ



G_{max} = 1.8
$f_{hot} \rightarrow$ 0.001%

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