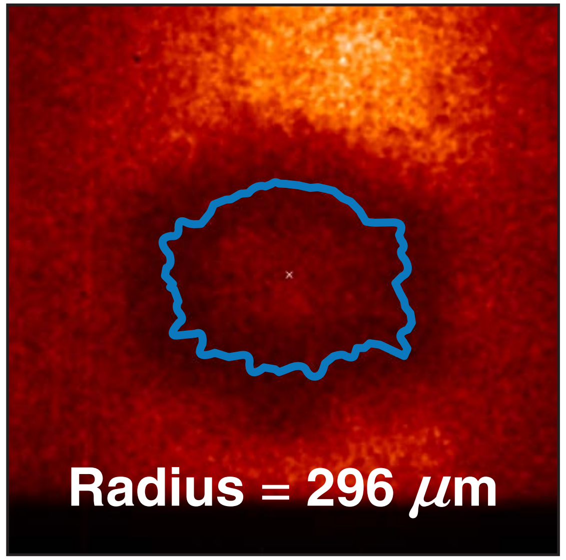
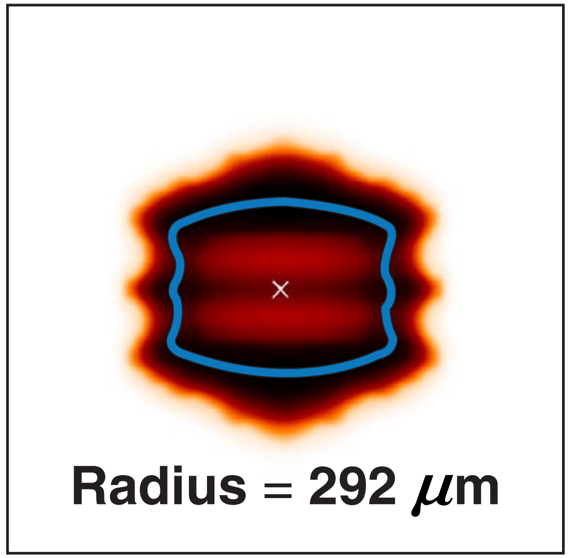
Direct Drive: Simulations and Experiments at the National Ignition Facility

Backlit image N150118-002 (CR ~ 3.5)

Observed
***t* = 7.9 ns**



Simulated
***t* = 8.0 ns**



1500 × 1500-μm region

P. B. Radha
University of Rochester
Laboratory for Laser Energetics

57th Annual Meeting of the
American Physical Society
Division of Plasma Physics
Savannah, GA
16–20 November 2015

Summary

National Ignition Facility (NIF) experiments are being used to validate direct-drive–implosion models in regimes approaching ignition relevance

- Models relating to energetics have been developed using OMEGA experiments
- Trajectories and scattered-light data indicate that energetics is captured well by models that include the effect of cross-beam energy transfer (CBET) and nonlocal heat conduction
- Focused experiments relating to shock timing, imprint, and preheat are ongoing
- The major goal of the next few years is to demonstrate mitigation of CBET and preheat from two-plasmon decay

Collaborators

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Massachusetts Institute of Technology

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Lawrence Livermore National Laboratory

J. W. Bates, M. Karasik, and S. P. Obenschein

Naval Research Laboratory

D. D. Meyerhofer

Los Alamos National Laboratory

Direct-drive designs are in a less hydrodynamically challenging regime than x-ray drive

- Direct-drive couples ~3 to 5× more energy into the imploding shell than x-ray drive

$$P_{hs} \sim (E_{hs})^{-1/2}$$

$$C_r^{ign} \sim (E_{kin})^{-1/6}$$

- Direct drive: $C_r^{ign} > 22$ and $P_{hs} > 120$ Gbar
- X-ray drive: $C_r^{ign} > 30$ to 40 and $P_{hs} > 350$ Gbar

V. N. Goncharov *et al*., UO4.00005, this conference;
S. P. Regan, CI3.00005, this conference (invited).

Two major direct-drive goals are being pursued on the NIF over the next two years

UR LLE

NIF

Validation of models

- CBET
  - reduces implosion velocity and ablation pressure
- Nonlocal heat conduction
  - couples more energy into the shell
  - increases ablation pressure
- Laser imprint and Rayleigh–Taylor (RT) growth

Mitigation of laser–plasma interactions

- CBET
  - zooming approach on OMEGA[1]
  - wavelength detuning on the NIF[2]
- Two-plasmon decay
  - mid-*Z* layers[3]
- Laser imprint and RT growth
  - doped[4] or high-*Z* ablators[5]

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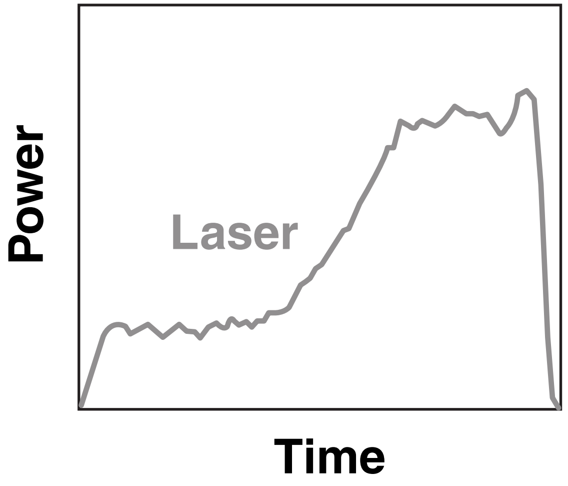
[1] I. V. Igumenshchev, Phys. Rev., Lett. 110, 145001 (2013).
[2] J. A. Marozas *et al*., JO5.00005, this conference.
[3] M. Hohenberger *et al*., Phys. Plasmas 22, 056308 (2015).
[4] G. Fiksel *et al*., Phys. Plasmas 19, 062704 (2012).
[5] S. P. Obsenschain *et al*., Phys. Plasmas 9, 2234 (2002).

TC12579

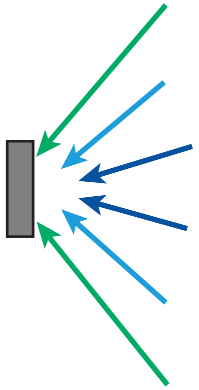
A variety of platforms have been developed on the NIF to study direct drive

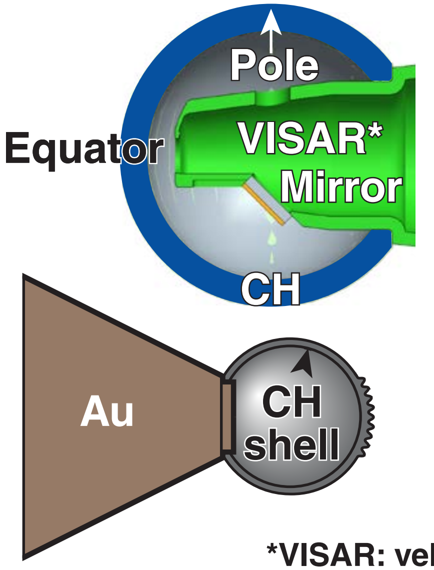


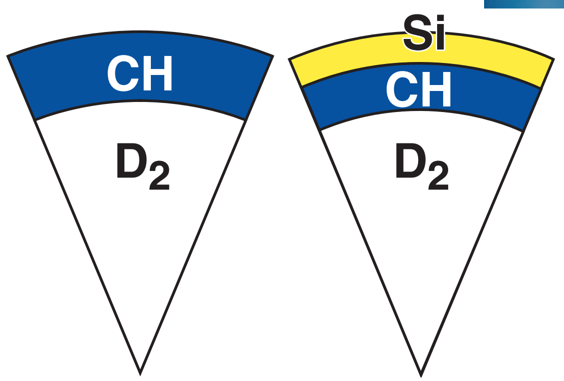
Shock timing | Implosion velocity

Symmetry/nonuniformity

Preheat





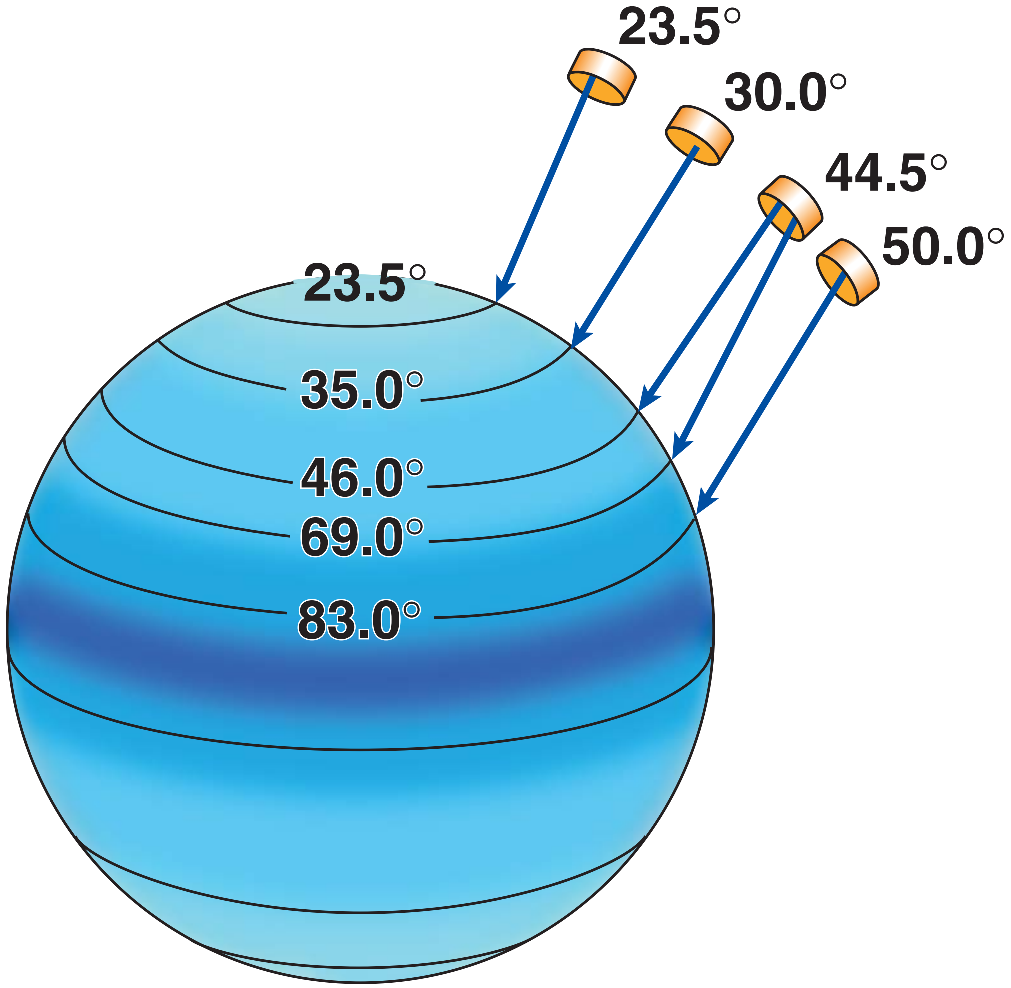


*VISAR: velocity interferometer system for any reflector

	Planar targets	Cone-in-shell targets	Room-temperature CH shells
Adiabat	Fast-electron preheat[1]	Shock timing	ρR diagnostics
Nonuniformity	Imprint[2]	Imprint and Rayleigh–Taylor growth[2]	Shape
Energetics		Shock timing[3]	V_{imp}: trajectory, shape, bang time, and scattered light[4] Shape

[1]A. A. Solodov *et al.*, NO5.00007, this conference.
[2]M. Hohenberger *et al.*, JO4.00006, this conference.
[3]T. R. Boehly *et al.*, BO4.00015, this conference.
[4]W. Seka *et al.*, JO5.00009, this conference.

Polar direct drive* (PDD) permits direct-drive experiments on the NIF to explore implosion physics



- **Beams are displaced toward the equator to improve symmetry**
- **Existing NIF hardware (beam smoothing, phase plates) are used for ongoing experiments—*target performance is not the goal***
- **Validation of models and mitigation of imprint and laser–plasma interactions will be studied**

TC7194r

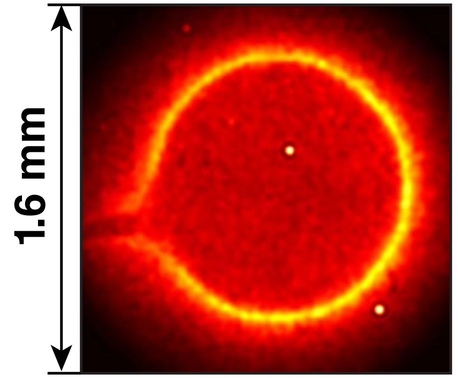
*S. Skupsky *et al*., Phys. Plasmas 11, 2763 (2004).

Trajectory, symmetry, and scattered light provide information about energetics in room-temperature implosions on the NIF

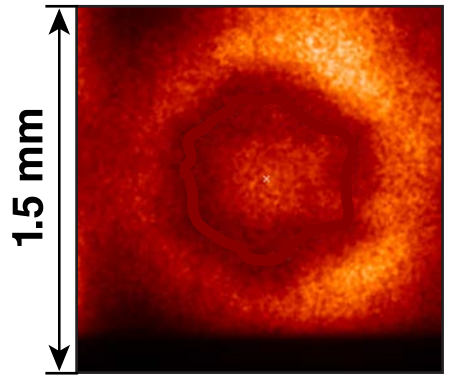
UR LLE
NIF

Trajectory symmetry:

Self-emission image[1] (pole)
N131210-001



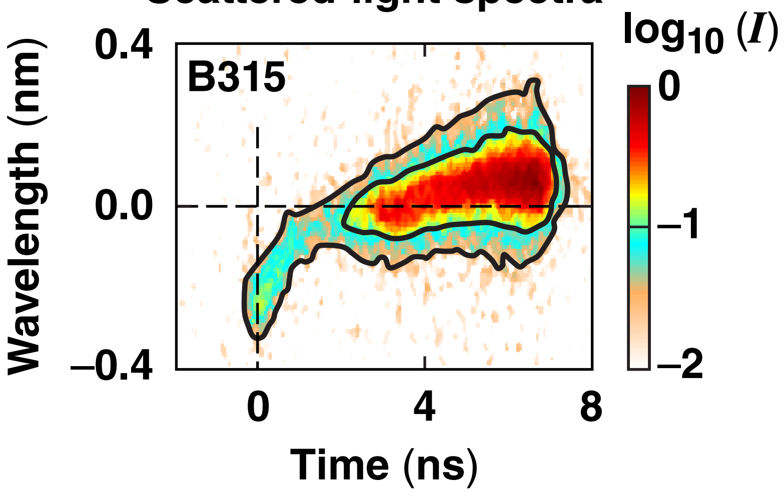
Backlit image[2] (equator)
N140612-001



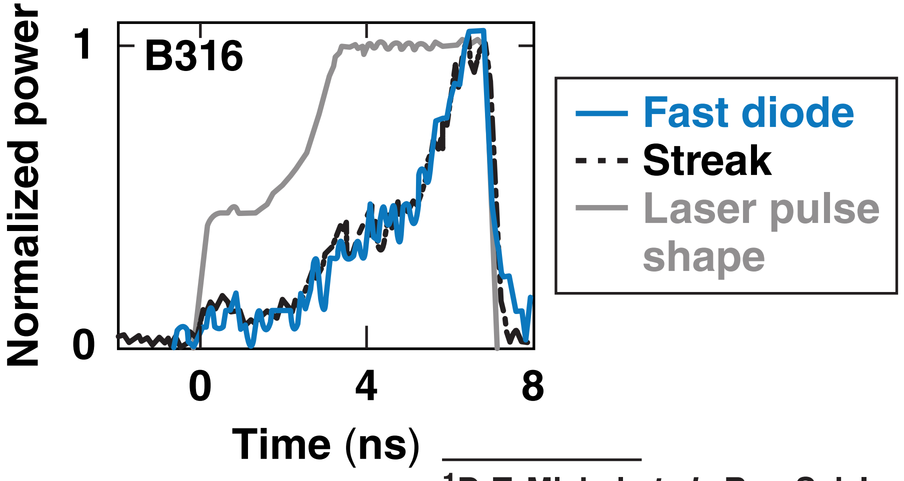
Scattered light:

N130128-001 (Q31B)

Scattered-light spectra[3]



Time-resolved scattered light



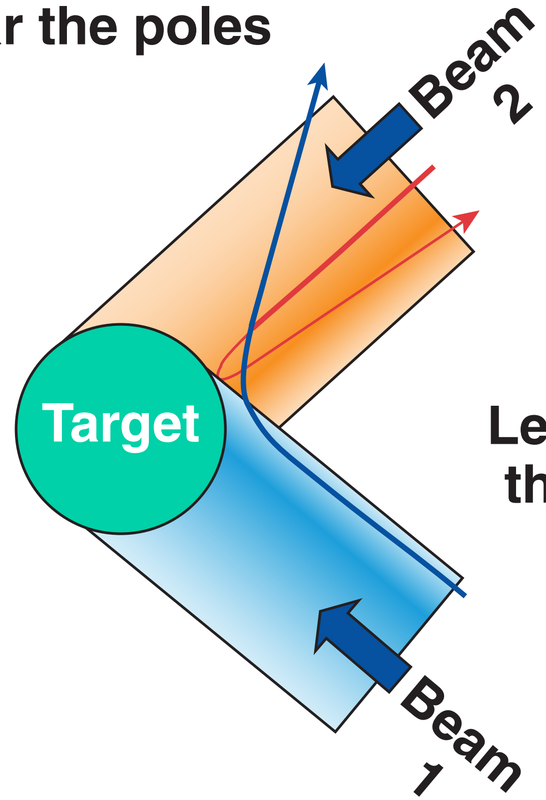
[1]D. T. Michel *et al*., Rev. Sci. Instrum. 83, 10E530 (2012).
[2]F. J. Marshall *et al*., Phys. Rev. Lett. 102, 185004 (2009).
[3]W. Seka *et al*., JO5.00009, this conference.

TC11725b

CBET reduces drive preferentially near the equatorial region in polar direct drive

Additional scattered light visible near the poles

Polar drive

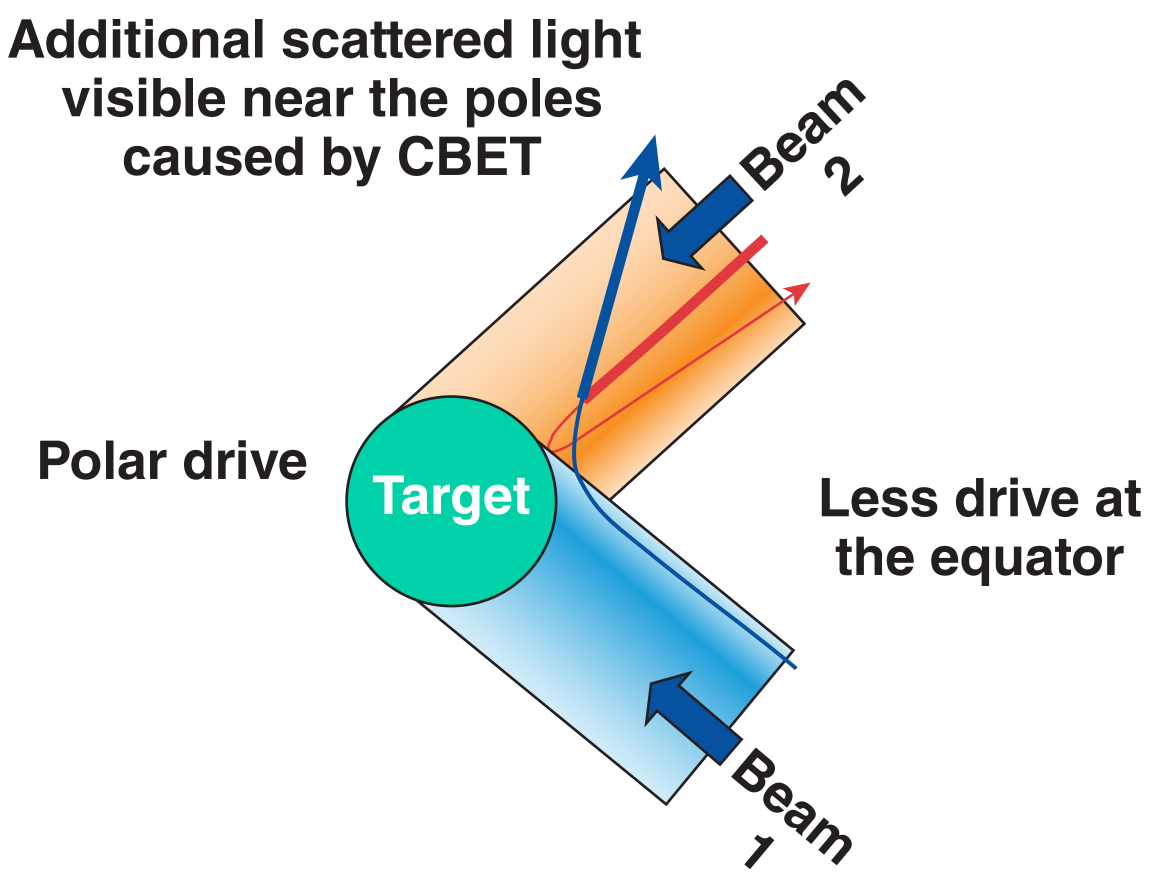


Less drive at the equator

- Compared to only collisional absorption mechanism of laser deposition, CBET results in
  - more scattered light visible near the poles relative to equator
  - reduced velocity (by ~15%) and ablation pressure (by ~45%)
  - more oblate implosions
- PDD is a more-stringent test of modeling compared to spherical drive

TC12389a

CBET reduces drive preferentially near the equatorial region in polar direct drive



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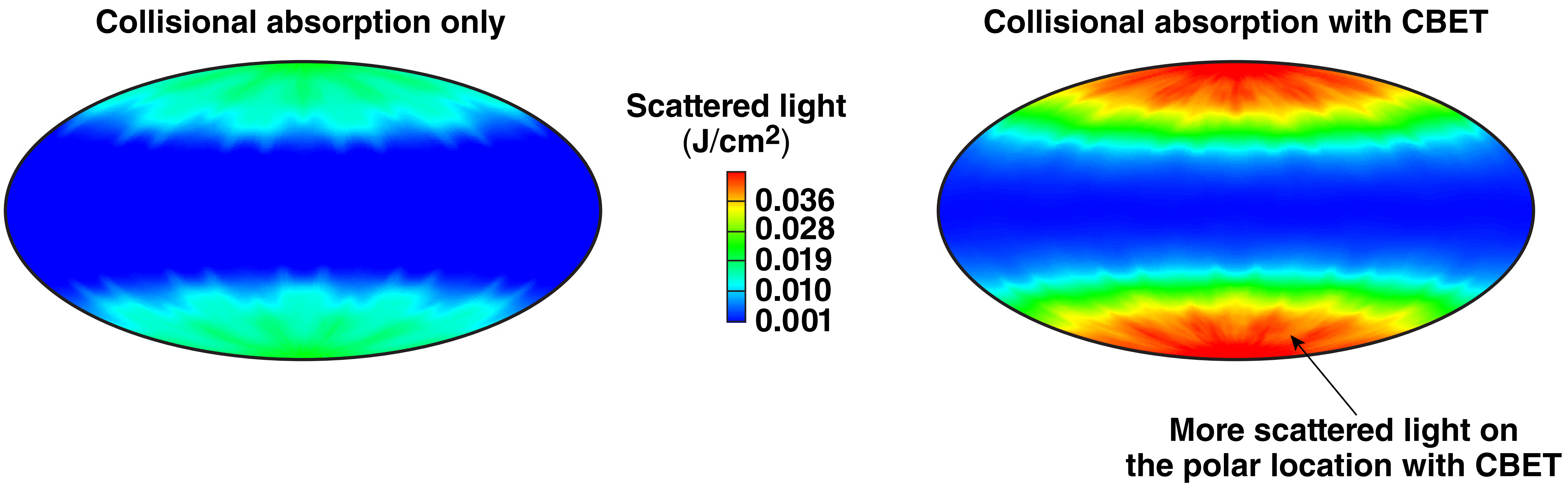
TC12389b

Scattered light from the equatorial region of the target is observed at the polar locations in the target chamber

UR LLE

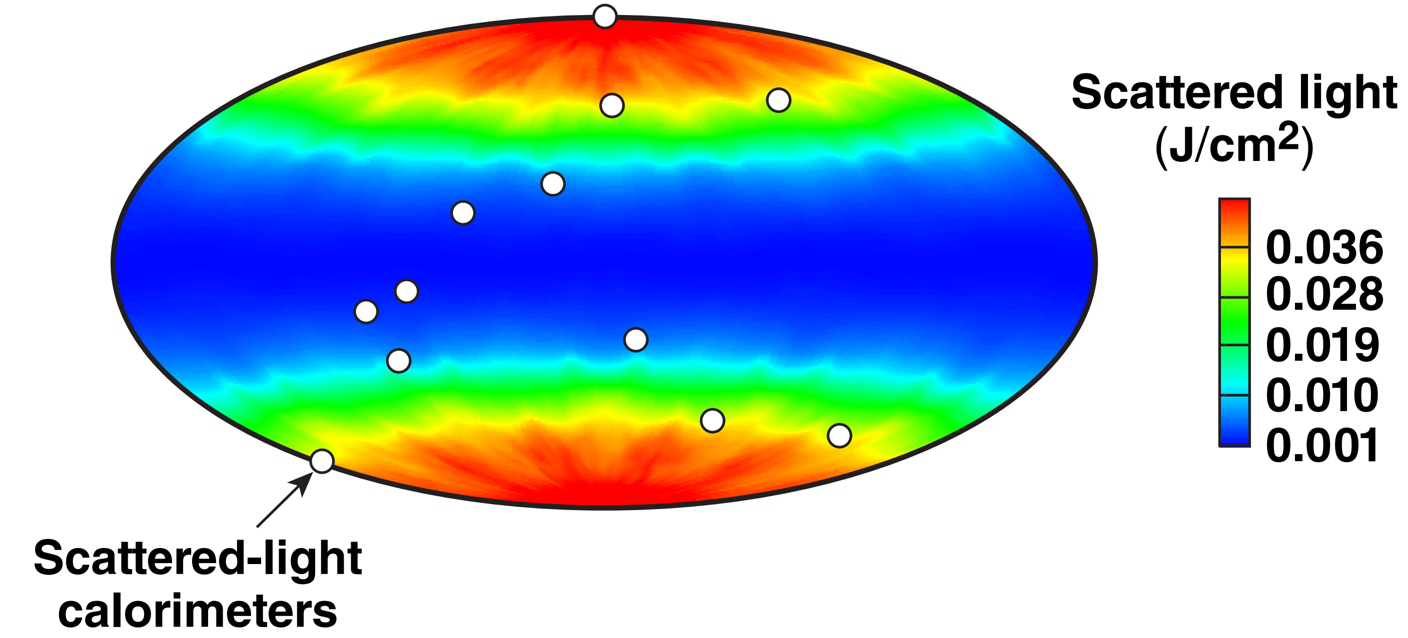
DRACO simulation
OMEGA PDD shot 64099
Scattered light is observed at the target chamber surface

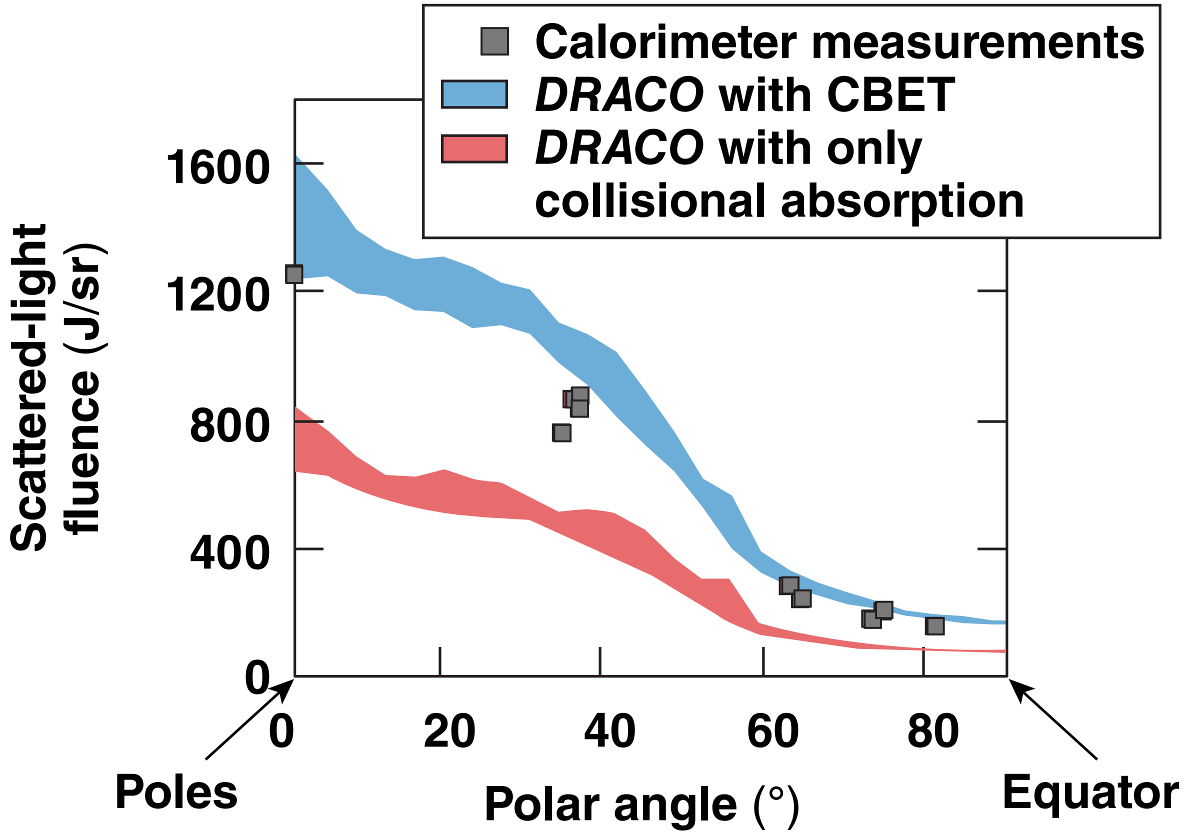


TC12585

OMEGA experiments indicate more scattered light at the polar region of the target chamber, consistent with CBET modeling

Scattered light around the target chamber
DRACO simulation [CBET,[1] nonlocal transport,[2] first-principles equation of state (FPEOS[3])] OMEGA PDD shot 64099



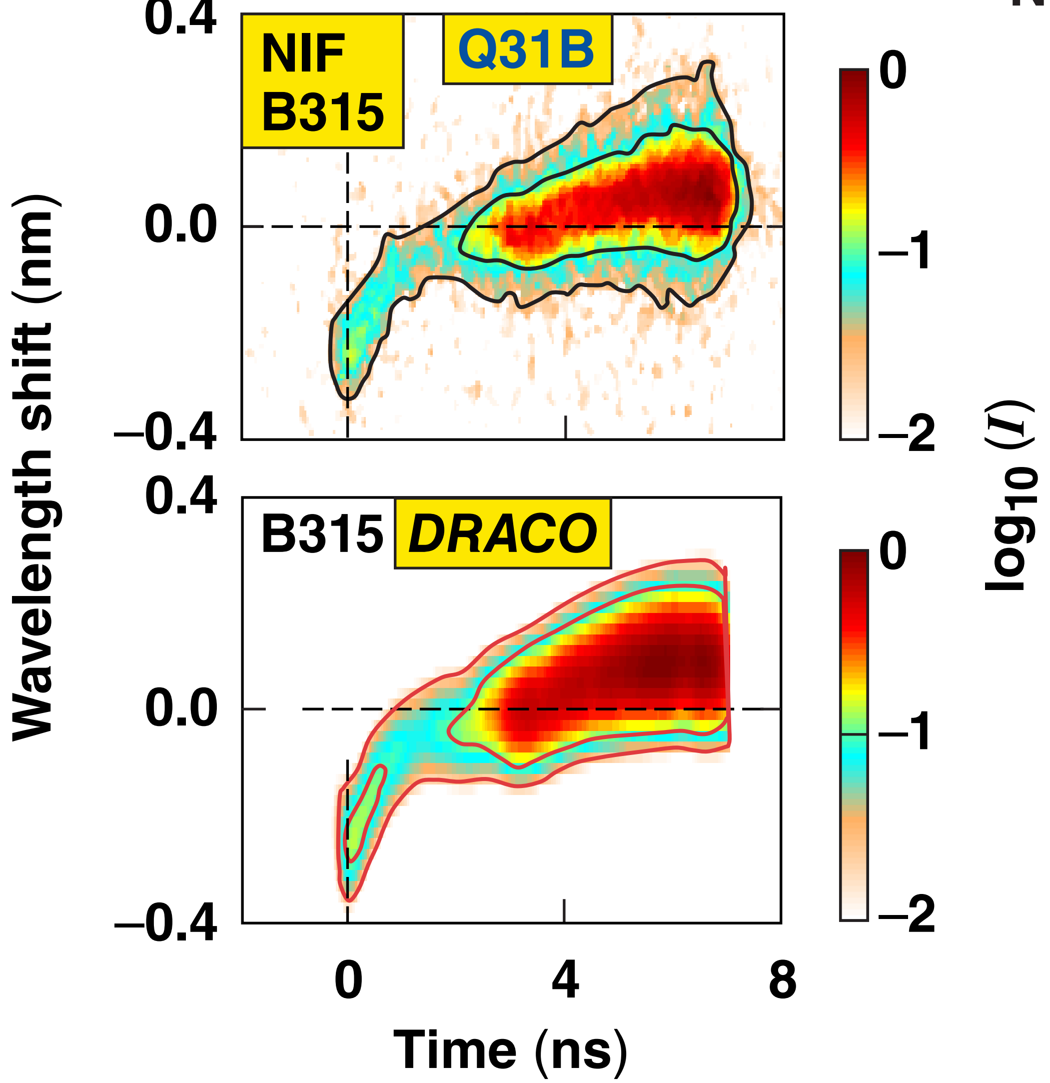


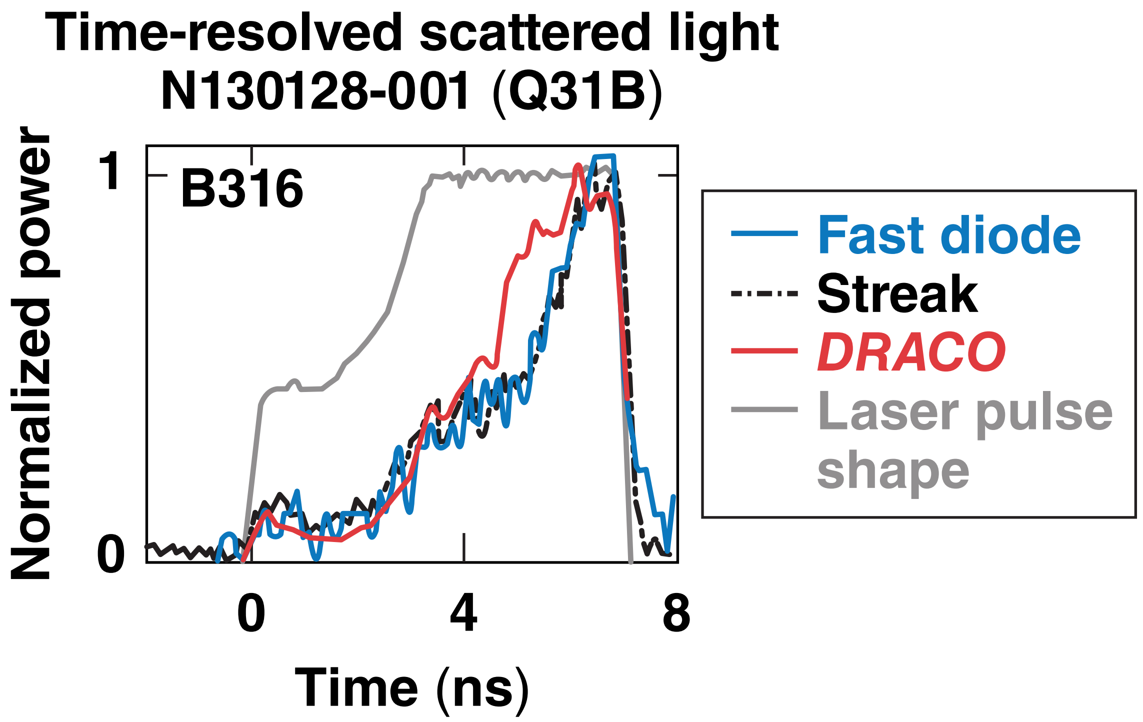
[1]C. J. Randall, J. R. Albritton, and J. J. Thomson, Phys. Fluids 24, 1474 (1981); J. A. Marozas *et al*., JO5.00005, this conference.
[2]D. Cao, G. Moses, and J. Delettrez, Phys. Plasmas 22, 082308 (2015).
[3]S. X. Hu *et al*., Phys. Rev E 92, 043104 (2015).

TC12586

The shape of the scattered-light time histories and spectra are reproduced when CBET is included in the calculation

N130128-001



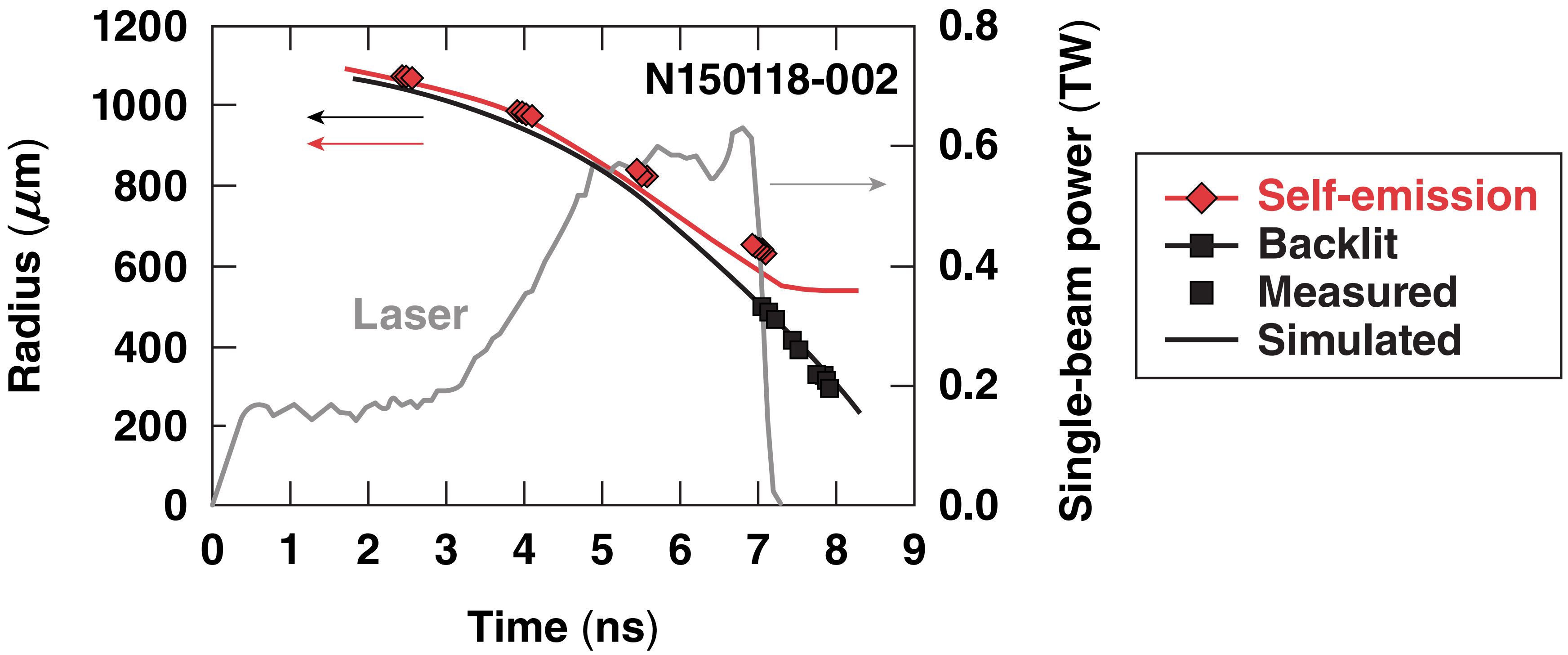


- Quantitative inference of the scattered-light energy requires detector calibration

TC11725c

The backlit shell trajectory is well-modeled by simulation

- The 2-D *DRACO* simulation includes the effect of CBET,[1] nonlocal transport,[2] and FPEOS[3]

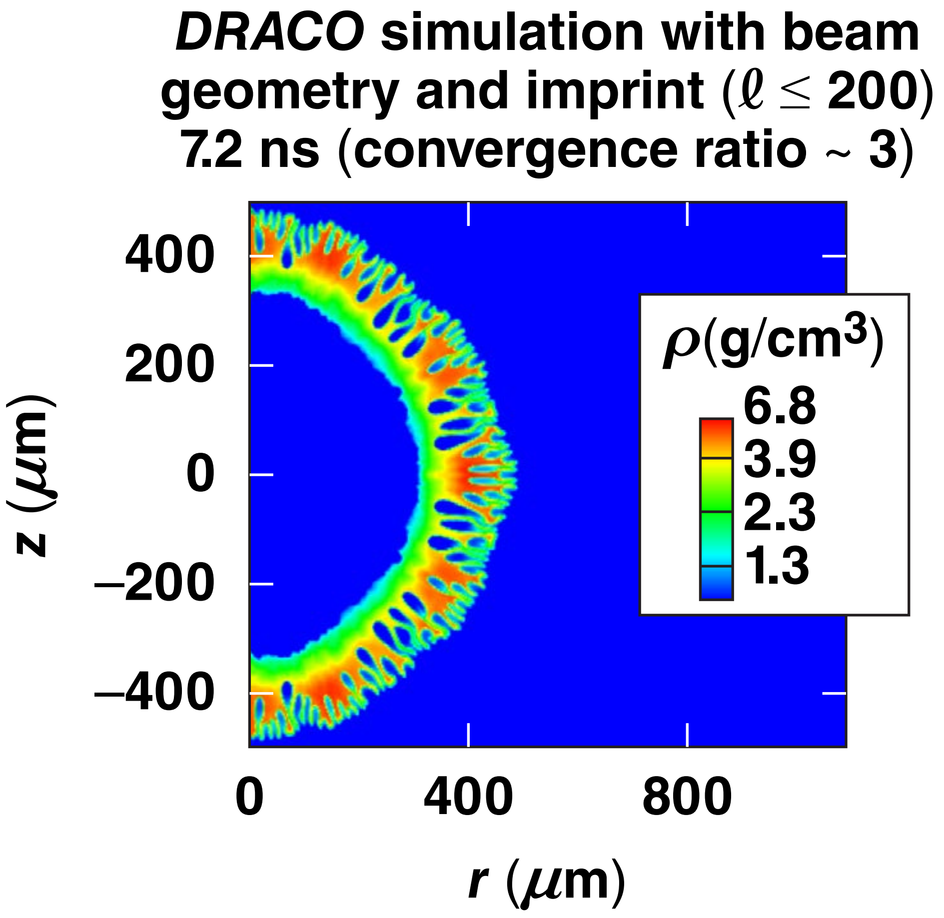


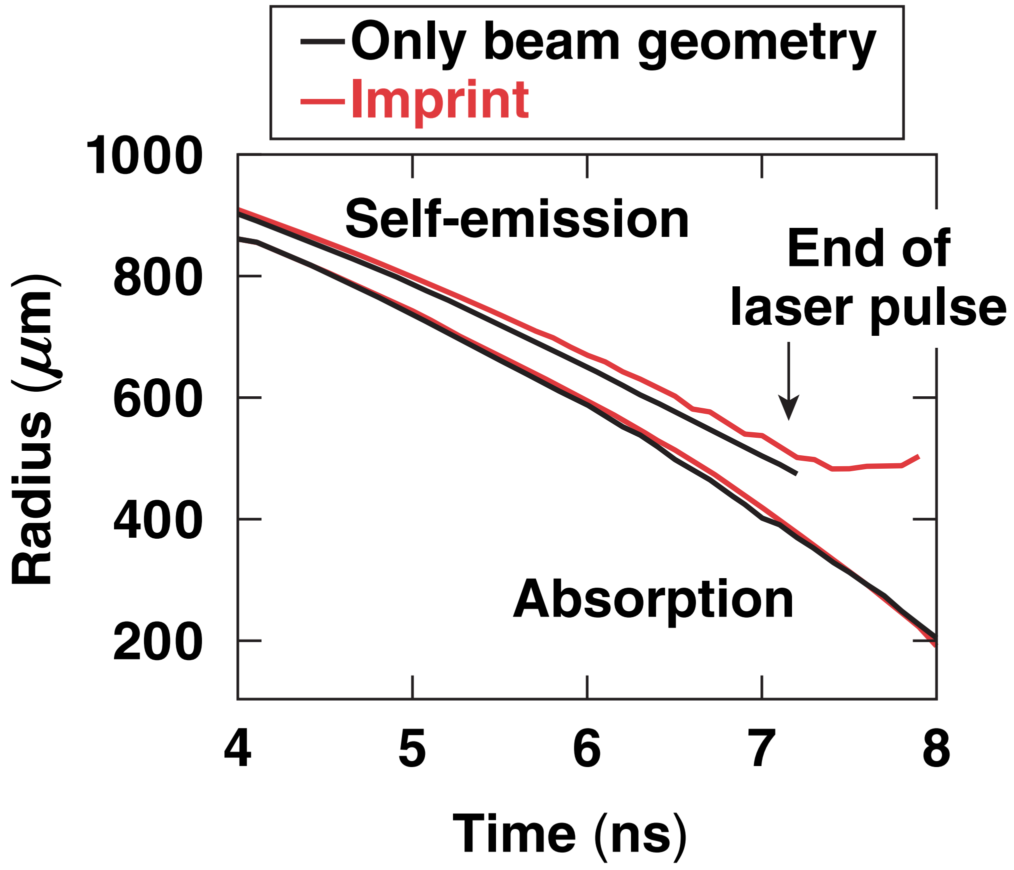
- Possible reasons for ablation-surface decompression include
  - preheat (radiative and/or fast electrons); a lower-intensity implosion is being investigated to identify if this is a cause
  - single-beam nonuniformity

[1] C. J. Randall, J. R. Albritton, and J. J. Thomson, Phys. Fluids 24, 1474 (1981); J. A. Marozas *et al*., JO5.00005, this conference.
[2] D. Cao, G. Moses, and J. Delettrez, Phys. Plasmas 22, 082308 (2015).
[3] S. X. Hu *et al*., Phys. Rev E 92, 043104 (2015).

E24440b

Imprint can cause an apparent decompression in the trajectory of peak self-emission





- Cone-in-shell and planar platforms are being developed to study imprint*
- Improved beam smoothing (multi-FM)** will be implemented on one NIF quad to study imprint mitigation

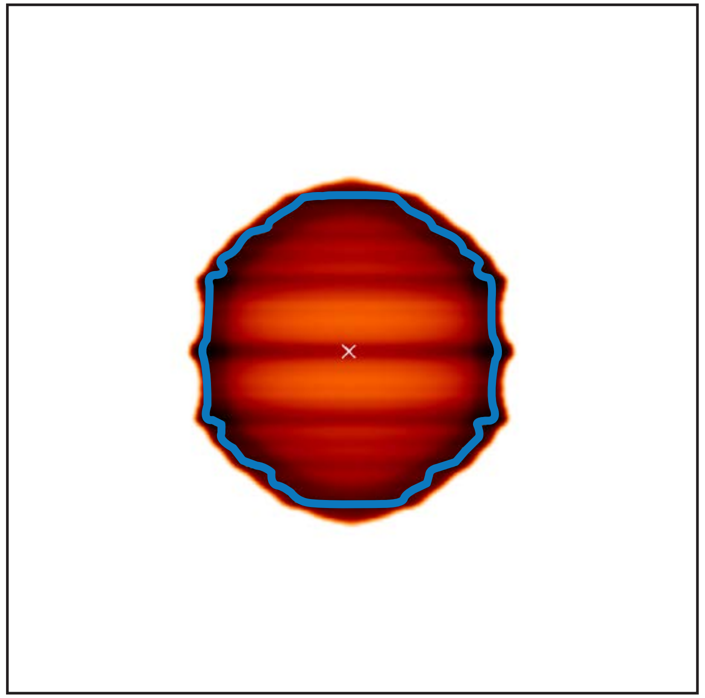
*A. Shvydky *et al*., GO5.00005; M. Hohenberger *et al*., JO4.00006, this conference.
**Laboratory for Laser Energetics LLE Review 91, 116, NTIS Order No. PB2006-106662 (2002).

TC11730b

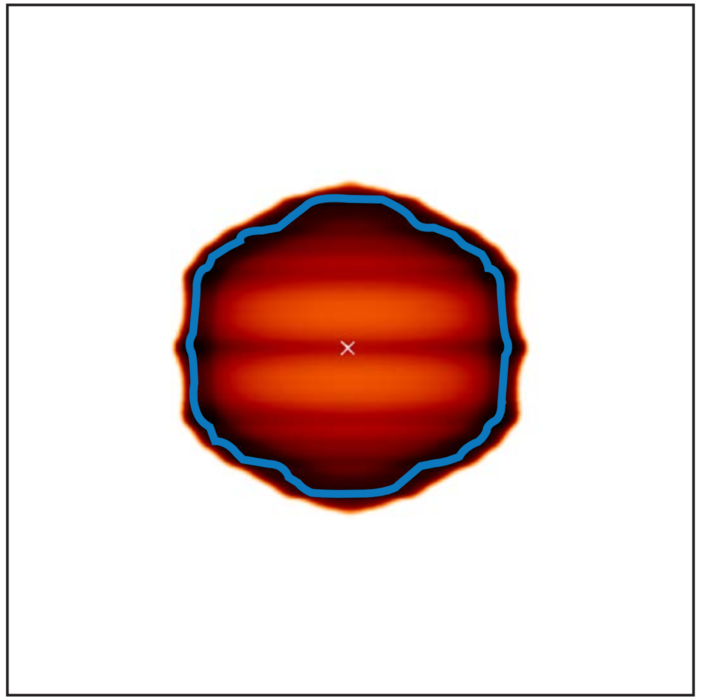
Shape

CBET results in a very different shape of the imploding shell

NIF implosion simulation post-processed with *Spect3D**
N150118-002



Collisional absorption only
t **= 6.9 ns**
R **= 526 mm**

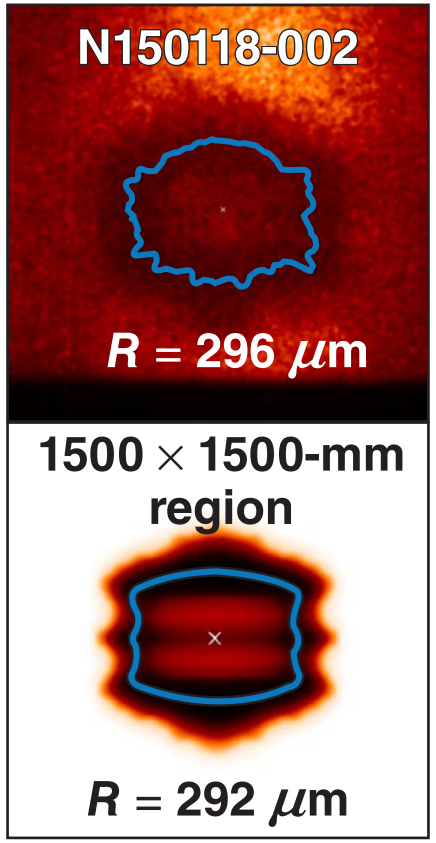


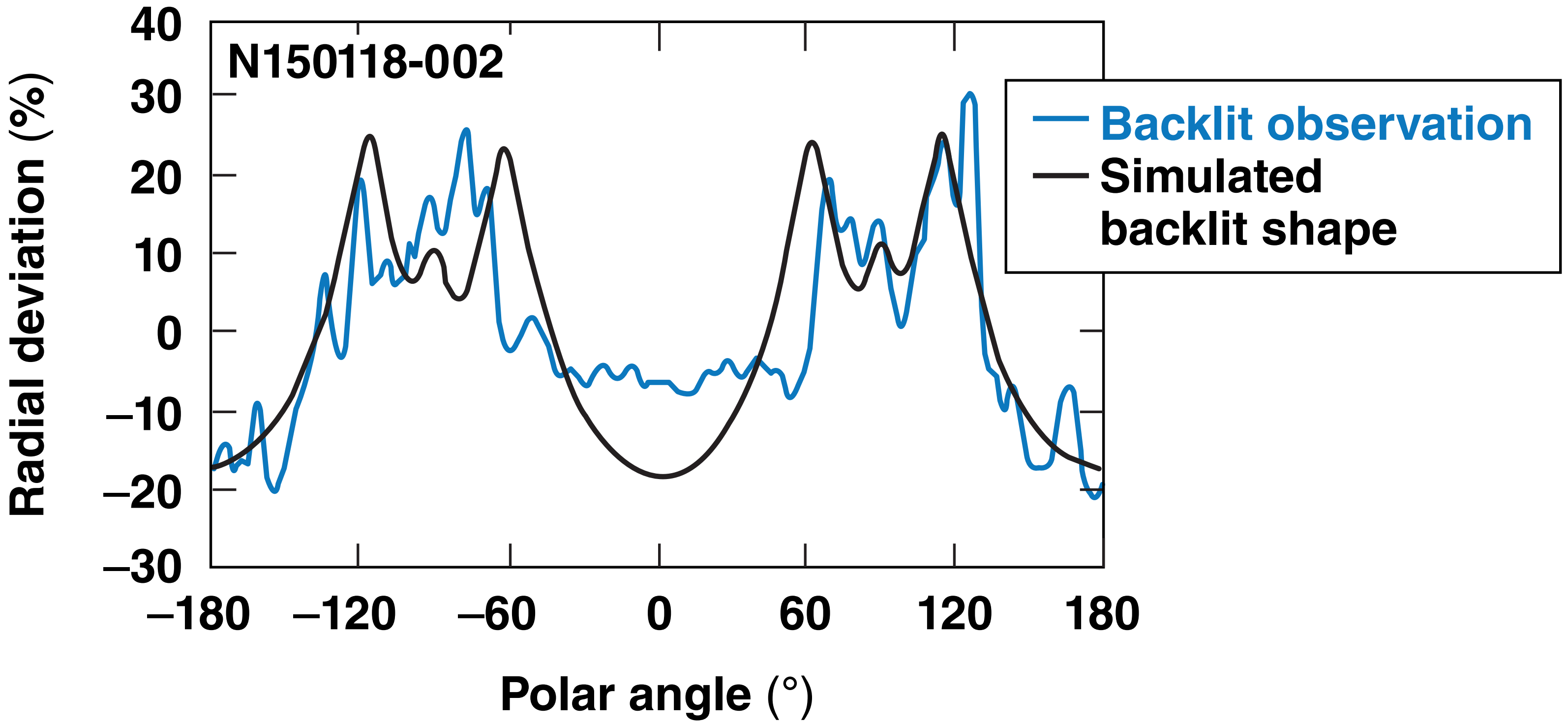
CBET model
t **= 7.1 ns**
R **= 531 mm**

*J. J. MacFarlane *et al*., High Energy Density Phys. 3, 181 (2007).

TC11025d

The overall shape of the imploding core agrees well with simulations





- Custom phase plates can significantly improve symmetry*
- Residual differences may be caused by
  - uncertainties in beam profiles
  - 3-D effects
  - shot-to-shot variations

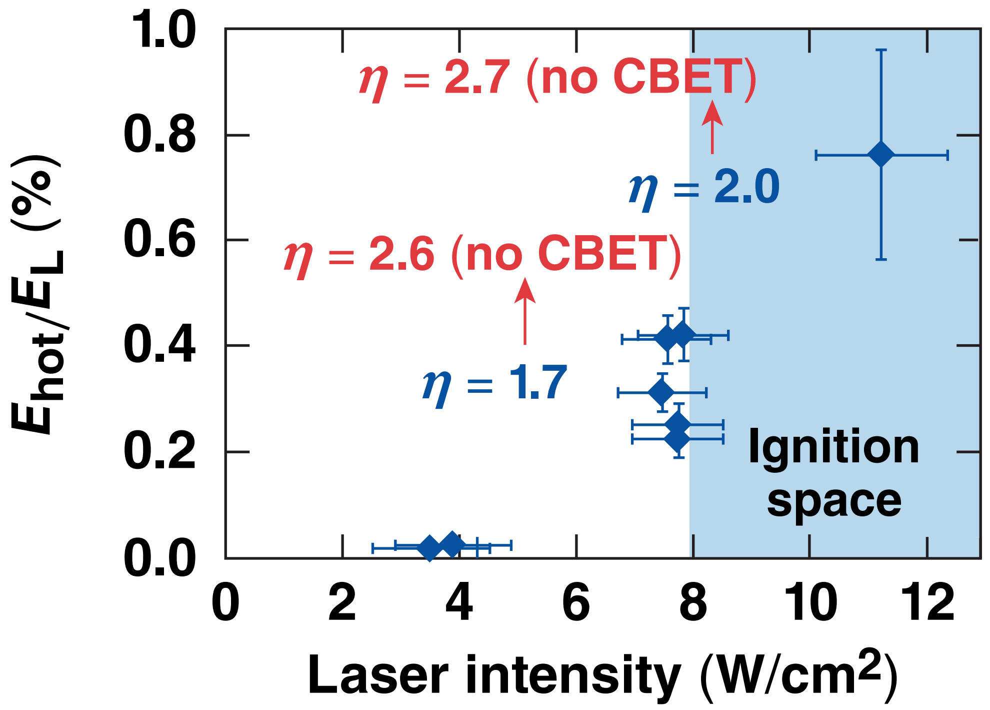
*D. Cao *et al*., BO4.00014, this conference.

TC12379a

Mitigating CBET is expected to increase the energy in hot electrons from two-plasmon decay (TPD)

- CBET mitigation studies using wavelength detuning* will be studied on the NIF next year

Energy in hot electrons as a percentage of laser energy



Threshold parameter:**

$$\eta = \frac{I_{n_c/4}\,(10^{14}\,\mathrm{W/cm^2})\,L_n\,(\mu\mathrm{m})}{233\,T_e\,(\mathrm{keV})}$$

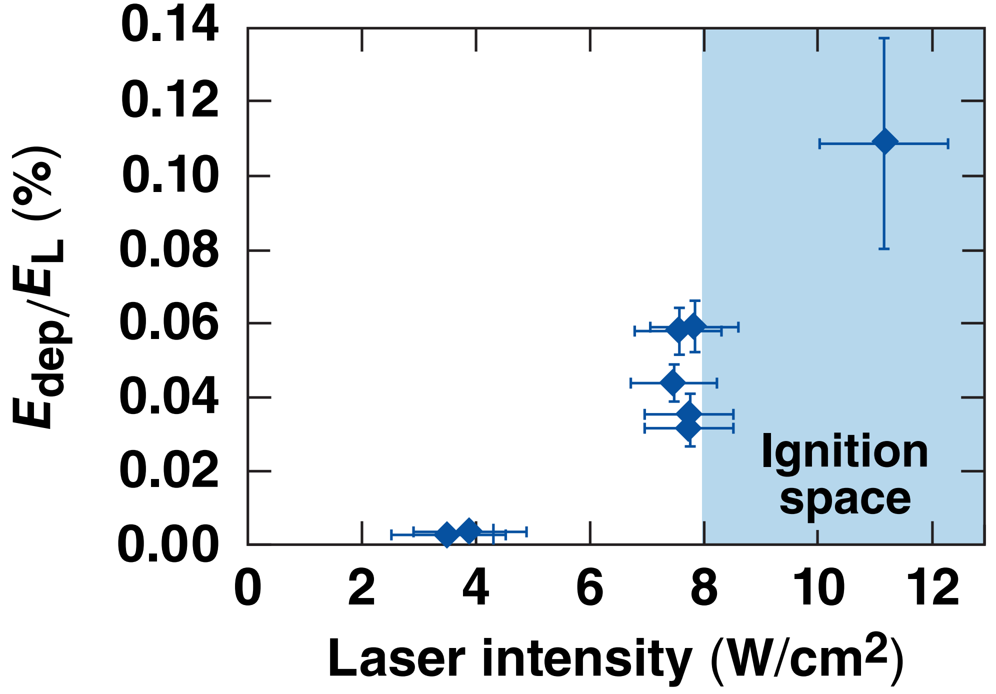
- The higher η without CBET is primarily because of a higher intensity at the quarter-critical surface

*J. A. Marozas *et al.*, JO5.0005, this conference.
**A. Simon *et al.*, Phys. Fluids 26, 3107 (1983).

TC12436

Ongoing experiments indicate tolerable preheat at the lowest possible intensity for ignition

Energy deposited in the unablated shell as percentage of laser energy

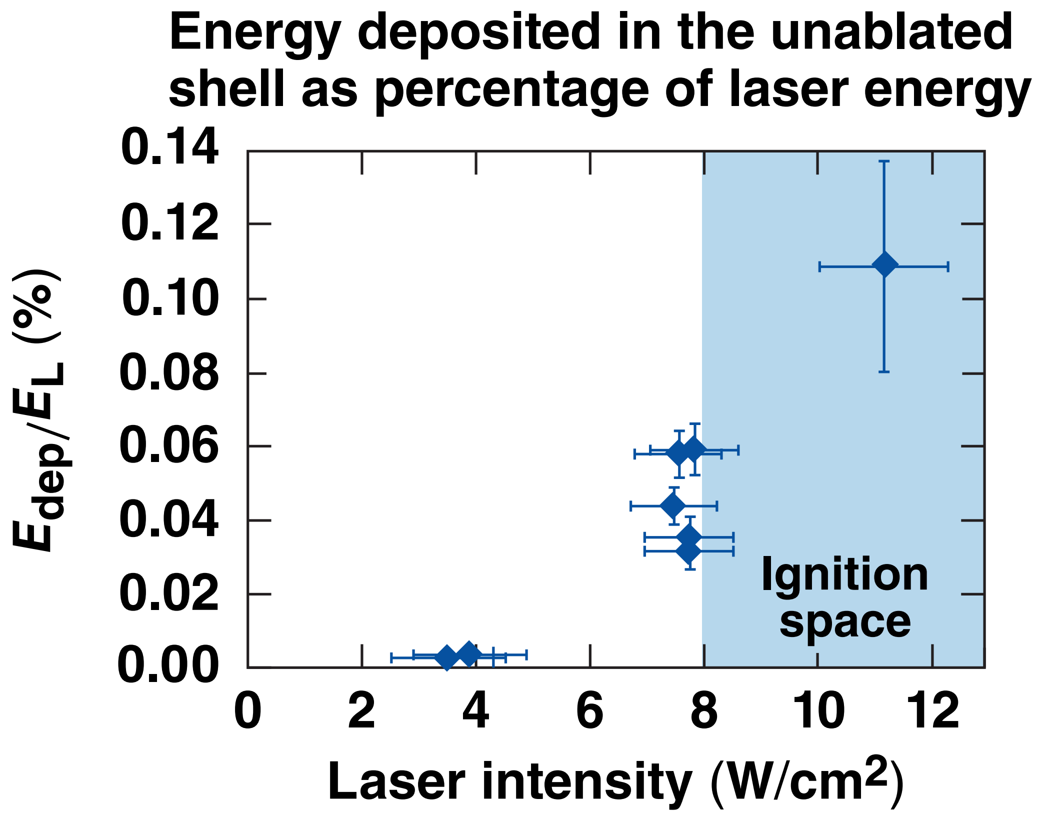


- From OMEGA experiments,* ~1/7 of the hot-electron energy is deposited in the unablated shell

TC12438

*A. R. Christopherson *et al.*, presented at IFSA 2015, Seattle, WA, 20–25 September 2015.

Ongoing experiments indicate tolerable preheat at the lowest possible intensity for ignition



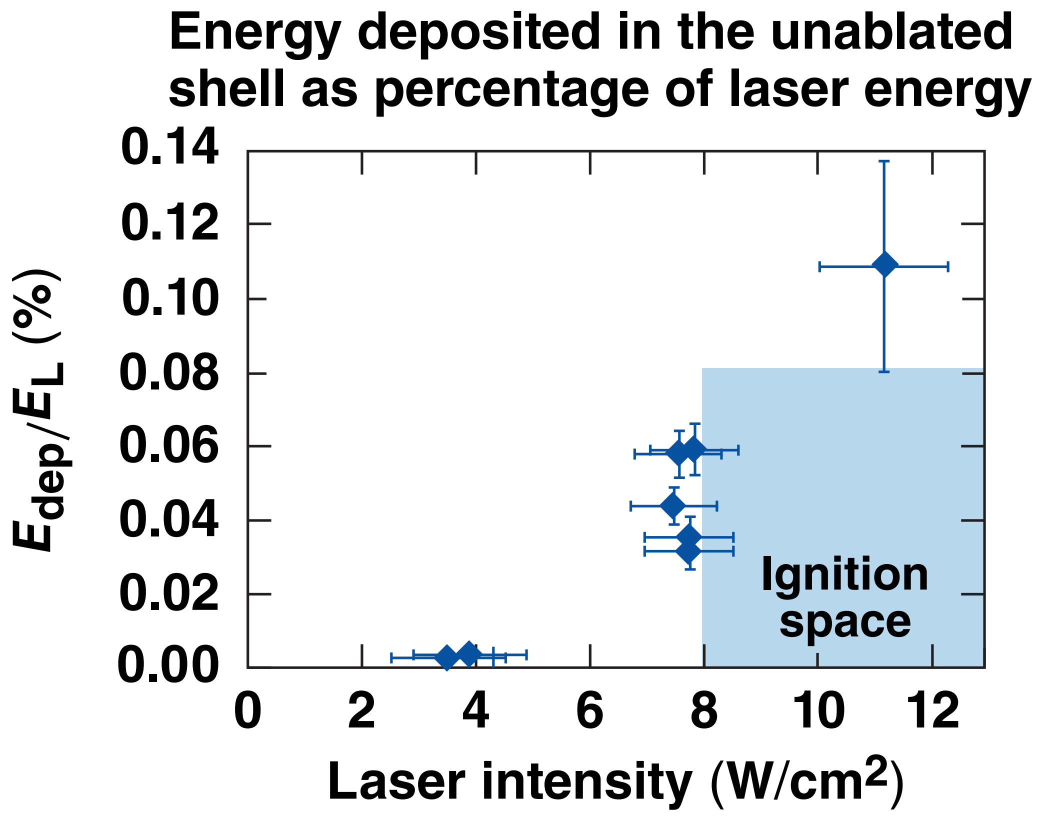
- From semi-analytic estimates,* $\lesssim$1.5% of shell kinetic energy into hot electrons can be tolerated by ignition designs

$$E_L = 1.5\ \text{MJ};\ E_{kin} \sim 80\ \text{kJ}$$
$$E_{dep} \lesssim 1.2\ \text{kJ}$$
$$E_{dep}/E_L \lesssim 0.08\%$$

TC12438a

*Laboratory for Laser Energetics LLE Review 130, 72, LLE Document No. DOE/NA/28302-1058 (2012).

Ongoing experiments indicate tolerable preheat at the lowest possible intensity for ignition



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TC12438b

*Laboratory for Laser Energetics LLE Review 130, 72, LLE Document No. DOE/NA/28302-1058 (2012).

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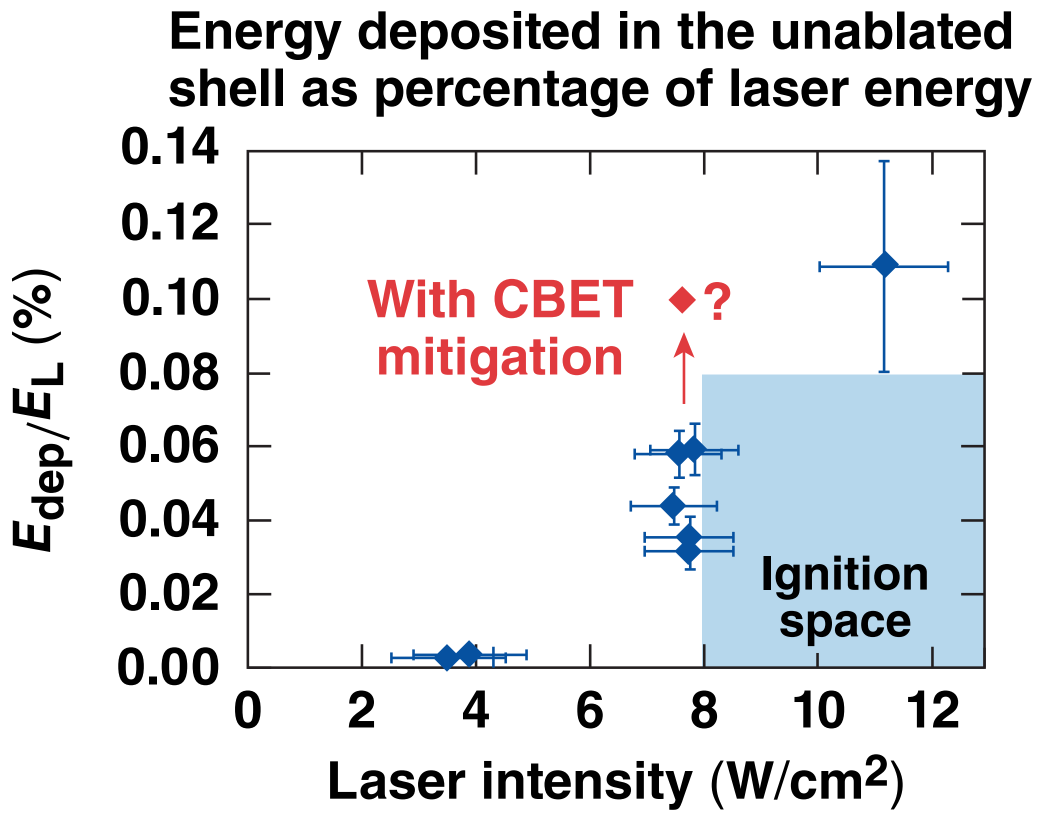

- From semi-analytic estimates,* ≲1.5% of shell kinetic energy into hot electrons can be tolerated by ignition designs

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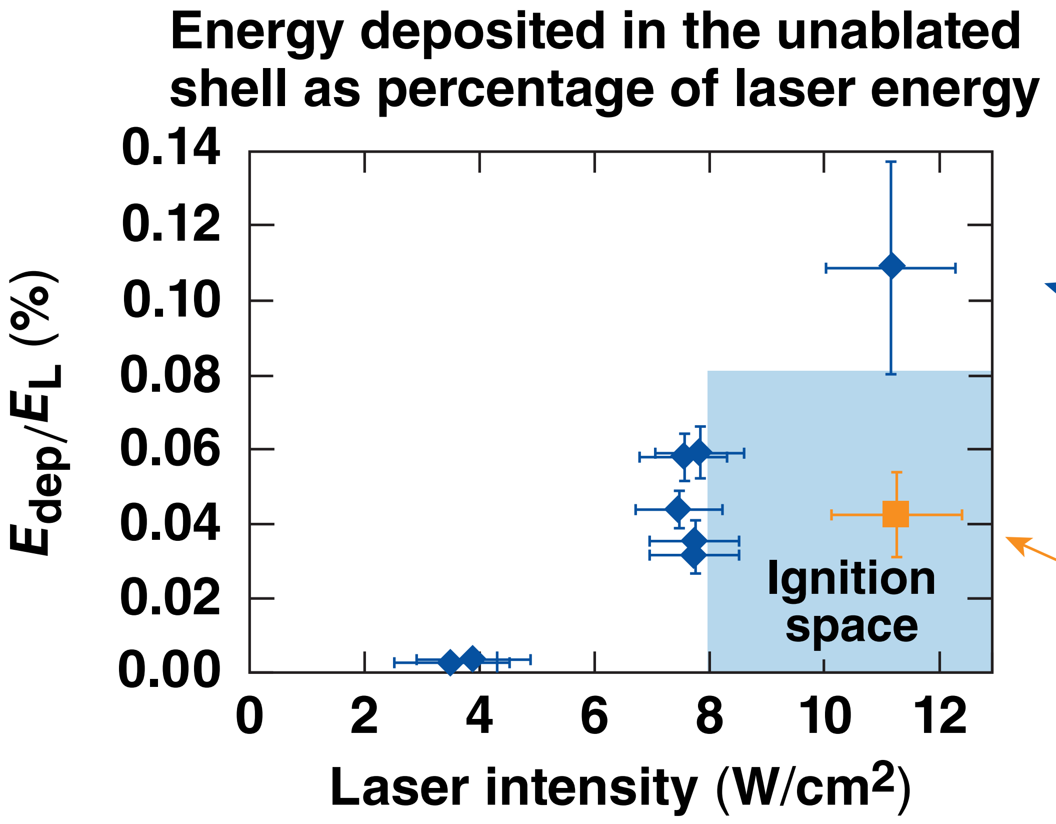
$$E_{dep} \lesssim 1.2\ \mathrm{kJ}$$

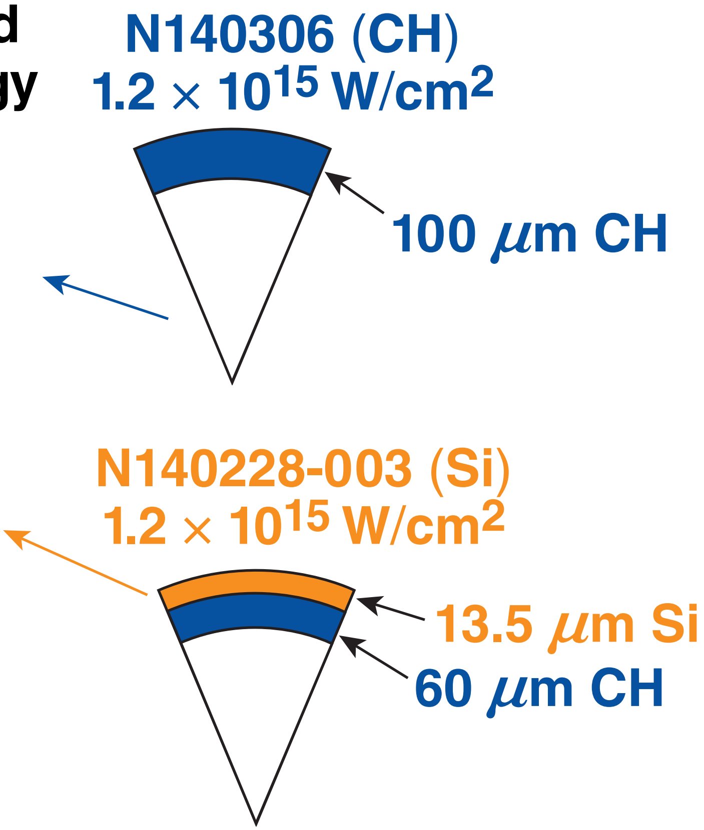
$$E_{dep}/E_L \lesssim 0.08\%$$

TC12438c

*Laboratory for Laser Energetics LLE Review 130, 72, LLE Document No. DOE/NA/28302-1058 (2012).

Mid-Z layers can be used to mitigate the hot-electron source





TC12437

Summary/Conclusions

National Ignition Facility (NIF) experiments are being used to validate direct-drive–implosion models in regimes approaching ignition relevance

UR LLE

NIF

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TC12425