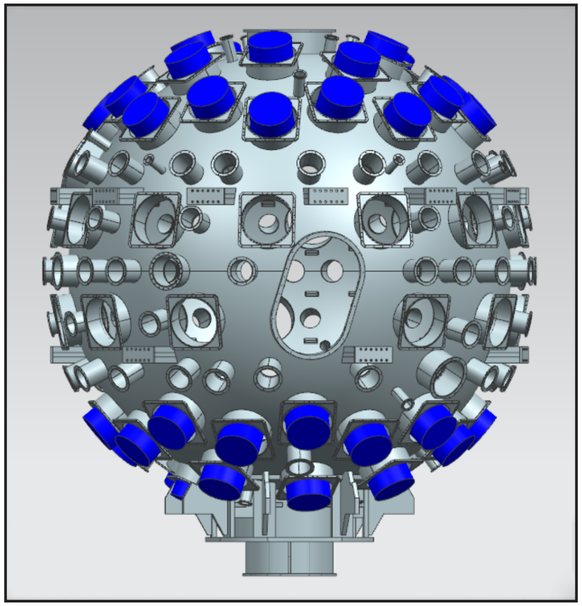
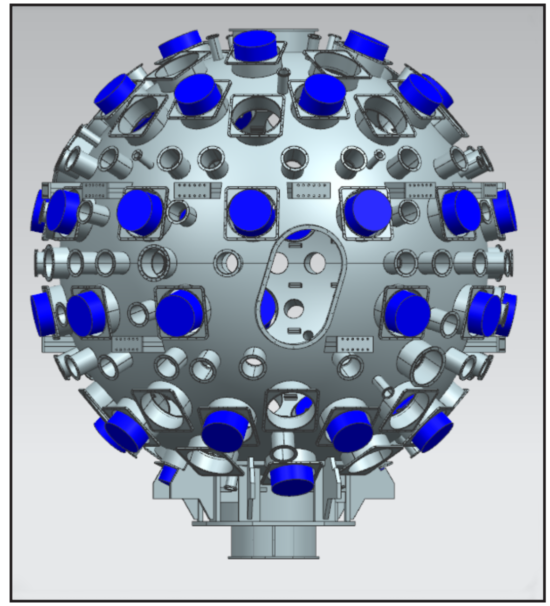
Polar-Direct-Drive Experiments at the National Ignition Facility





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American Physical Society
Division of Plasma Physics
New Orleans, LA
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Summary

Polar-direct-drive (PDD) ignition is the alternative path to ignition at the National Ignition Facility (NIF)

- **First integrated PDD implosion experiments explore the coupling of laser energy to the imploding CH shell in low-convergence experiments**
- **Radiography data of the imploding shell are in reasonable agreement with the simulations**
- **Hot-electron generation by the two-plasmon–decay (TPD) instability is reduced by using mid-*Z* ablators**
- **A Laser Path-Forward working group is actively engaged in adding beam-smoothing capabilities**

Future focused experiments will examine laser–plasma and hydrodynamic instabilities.

Collaborators

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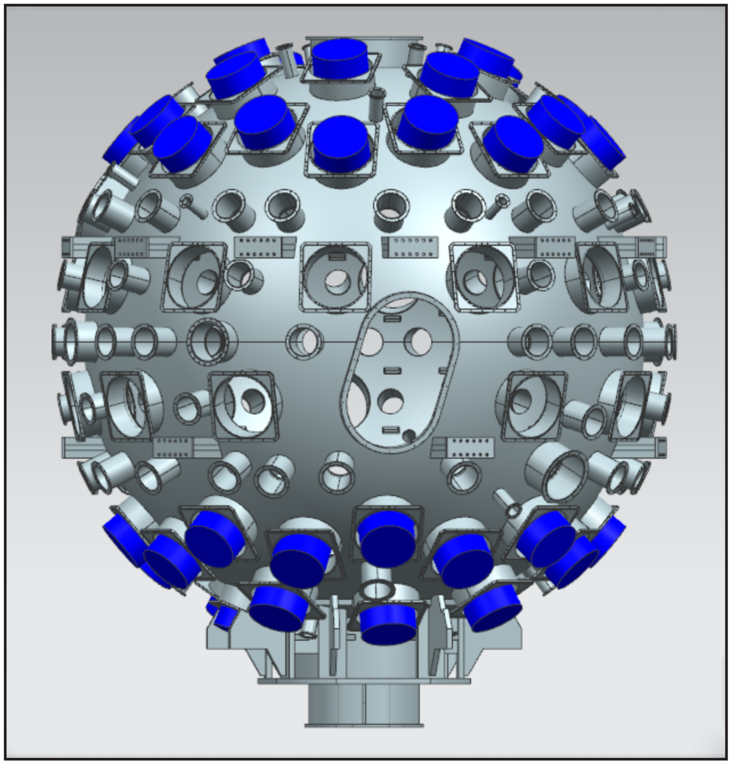
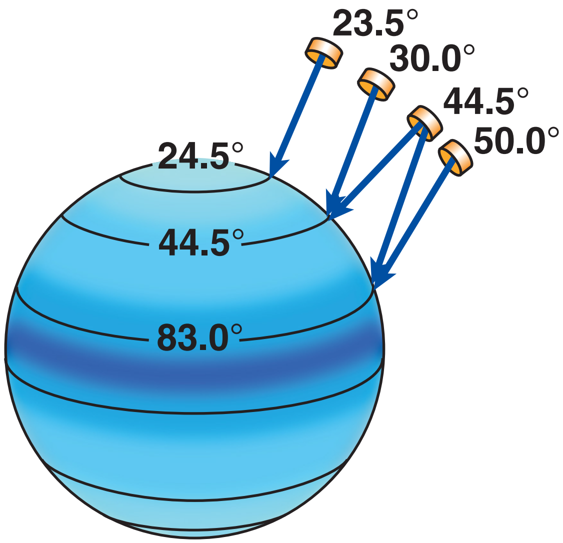
Outline

- Polar-direct-drive ignition on the NIF
- Early NIF experiments (12 shots to date)
  - trajectory
  - symmetry
  - laser–plasma interactions
- The path forward
- Conclusions

LLE is developing PDD:* a platform for direct-drive inertial confinement fusion (ICF) on the NIF using the x-ray-drive beam geometry

X-ray drive
(beams around the poles)





- **Increasingly oblique irradiation near the equator**
  - **reduced absorption**
  - **reduced hydro-efficiency**
  - **lateral heat flow**
  - **cross-beam energy transfer (CBET)**

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

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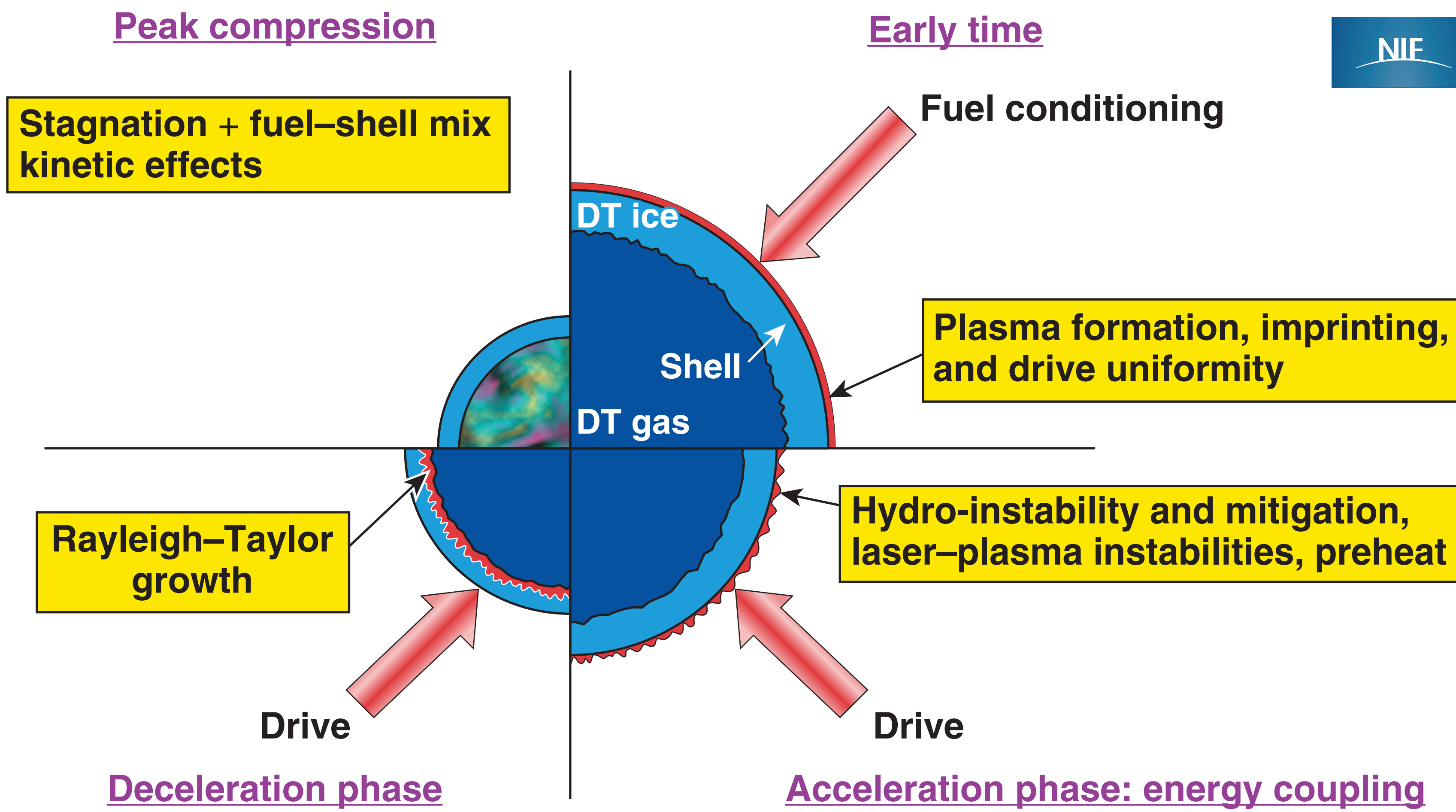
The key physics areas for PDD are energy coupling, implosion symmetry, imprinting, and laser–plasma interactions (LPI's)



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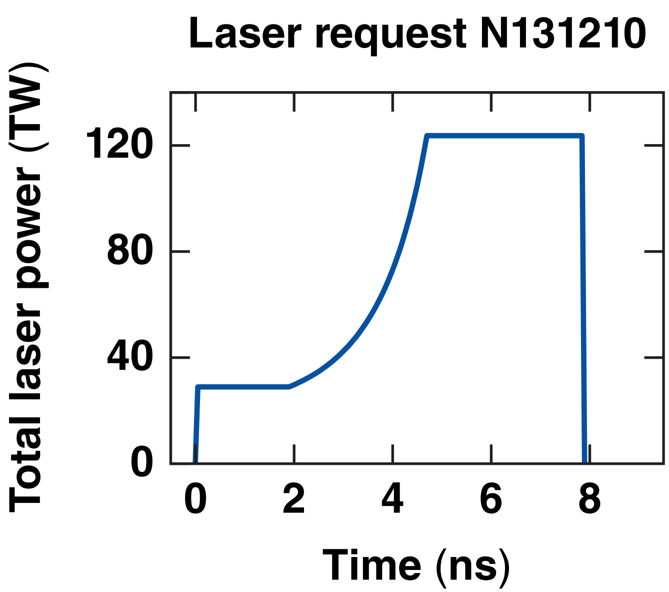
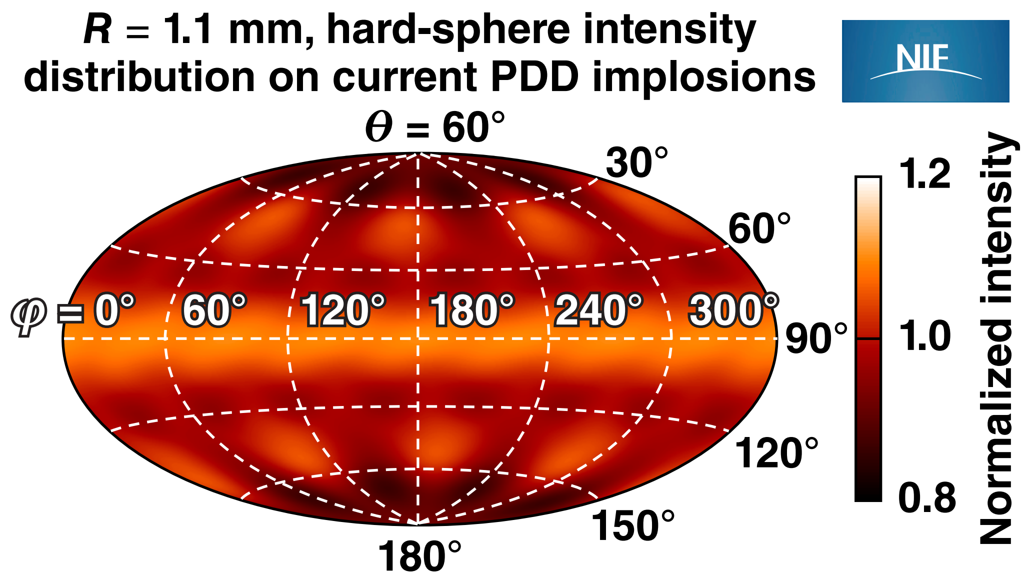
PDD Platform

Early NIF implosions are using existing hardware to study implosion hydrodynamics and LPI at ignition-relevant conditions





E ~ 600 kJ, I ~ 8×10^{14} W/cm^2

A combination of beam-power balanced and beam pointing is used to optimize the implosion symmetry

Current NIF beam smoothing precludes high-convergence implosion experiments.

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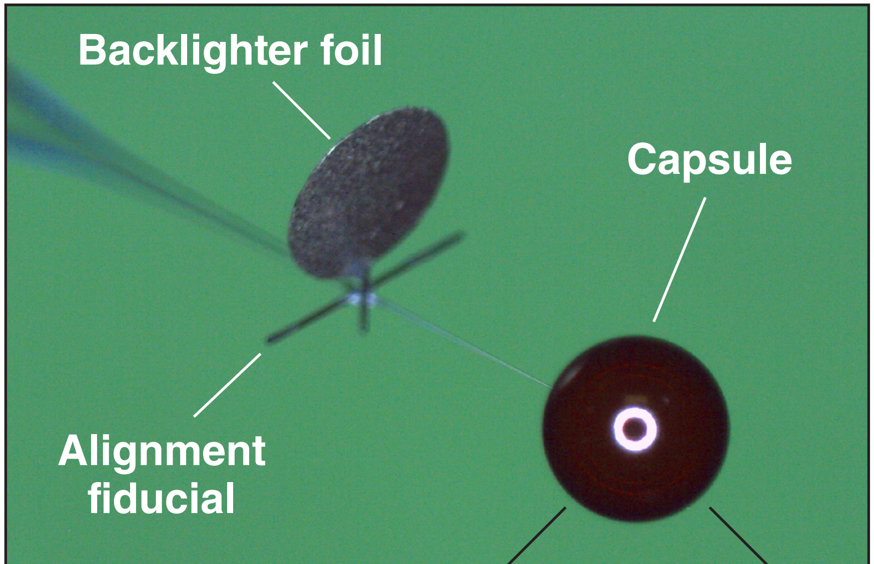
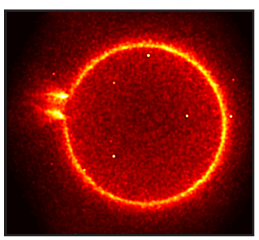
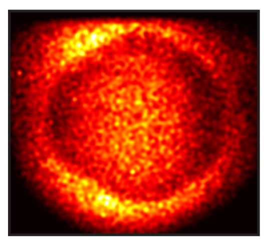
PDD Platform

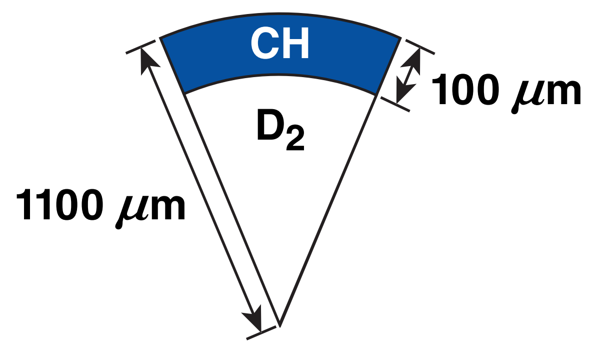
A suite of diagnostics is used to measure the shell trajectory, symmetry, and plasma parameters





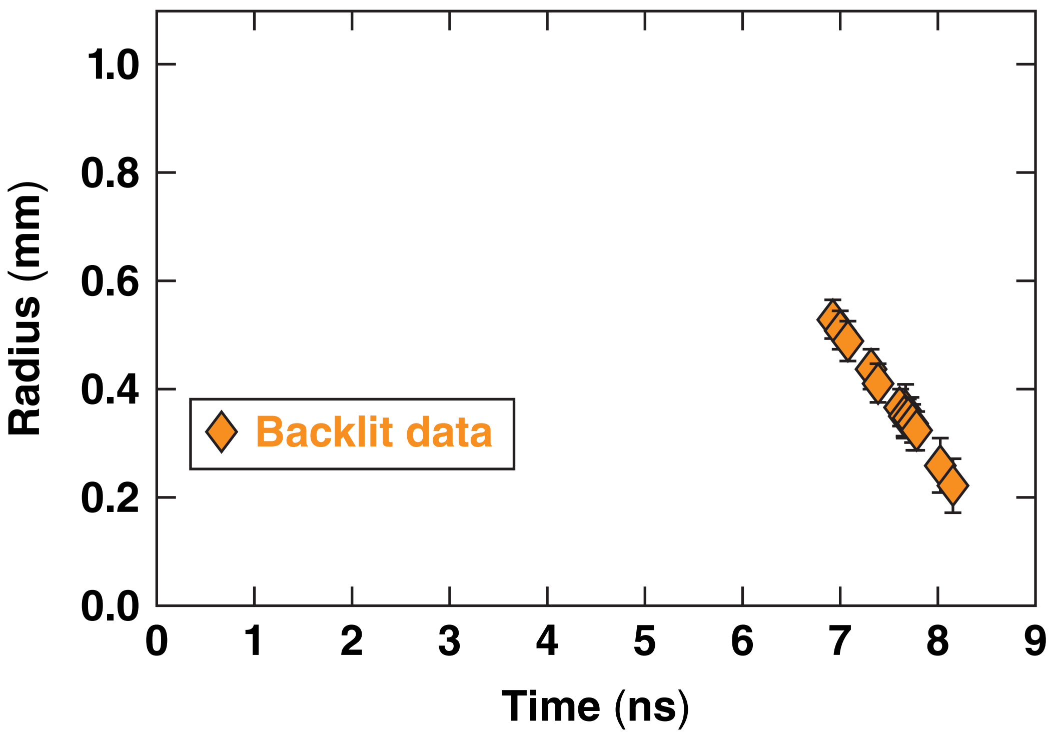


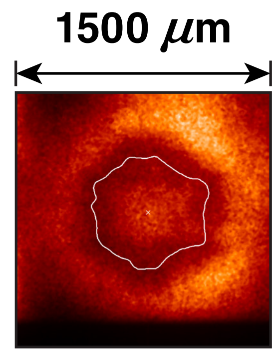
- Additional diagnostics include
  - scattered light—FABS/NBI
  - hard x-ray emission—FFLEX
  - soft x-ray emission—Dante
  - yield and n-bang time—nTOF's, pTOF
  - areal density—WRF



FABS: full-aperture backscatter station
NBI: near backscatter imager
FFLEX: filter-fluorescer x-ray diagnostic
WRF: wedge range filter

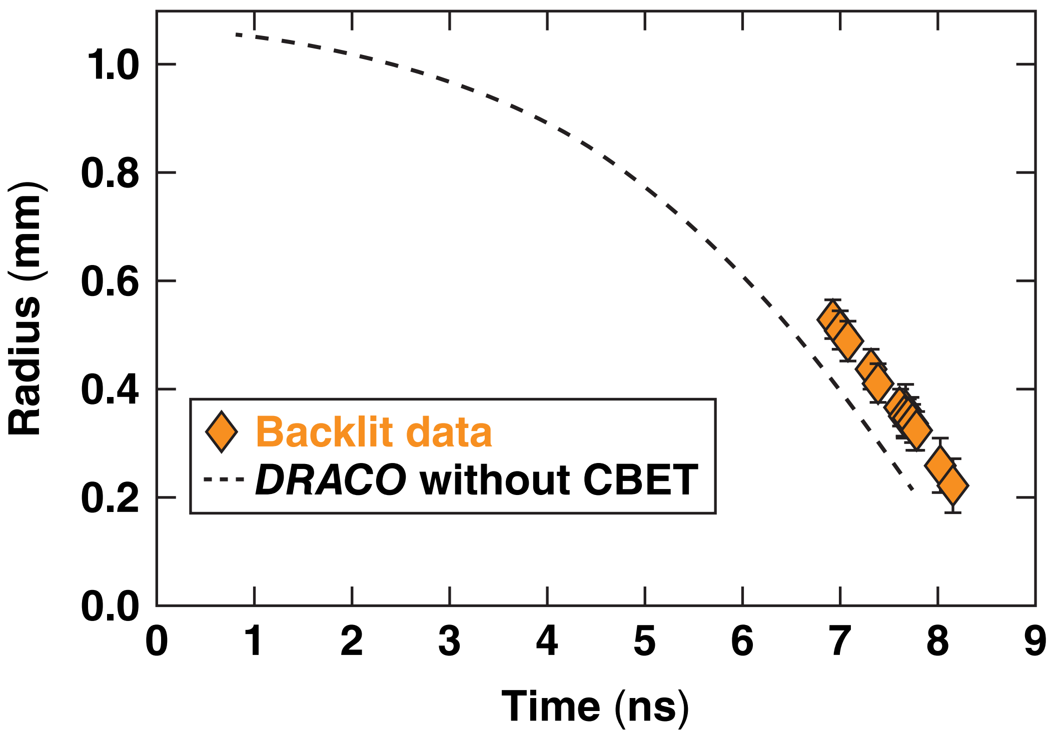
Radiography data is used to extract the shell trajectory

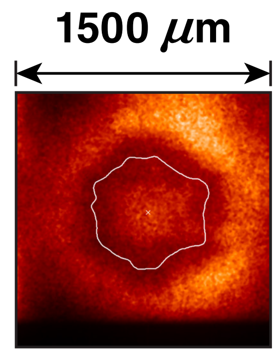




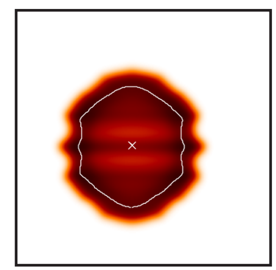
N140612
t = 7.75 ns

Two-dimensional *DRACO* simulations without cross-beam energy transfer (CBET) do not match the shell trajectory



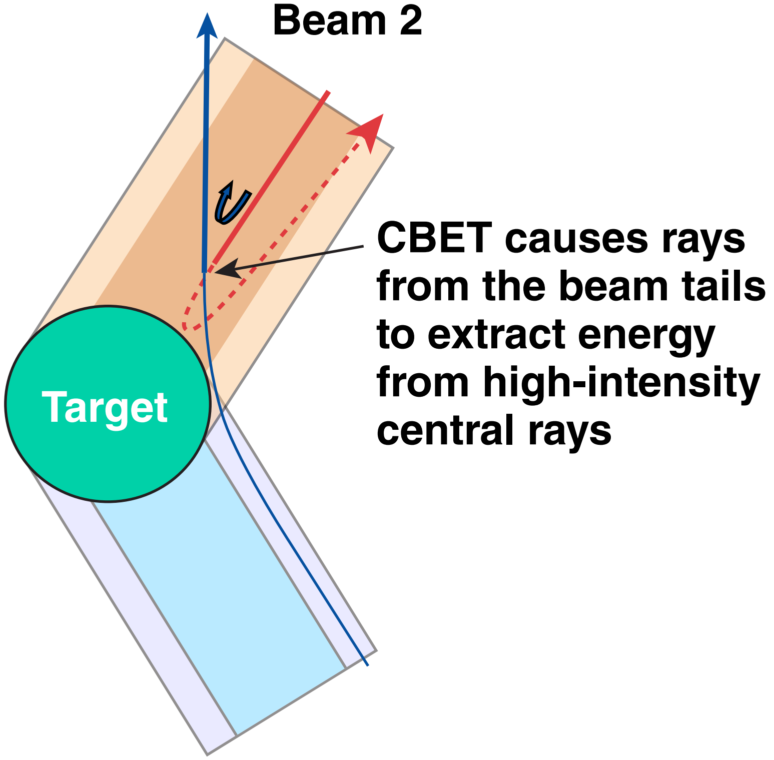


N140612
t = 7.75 ns

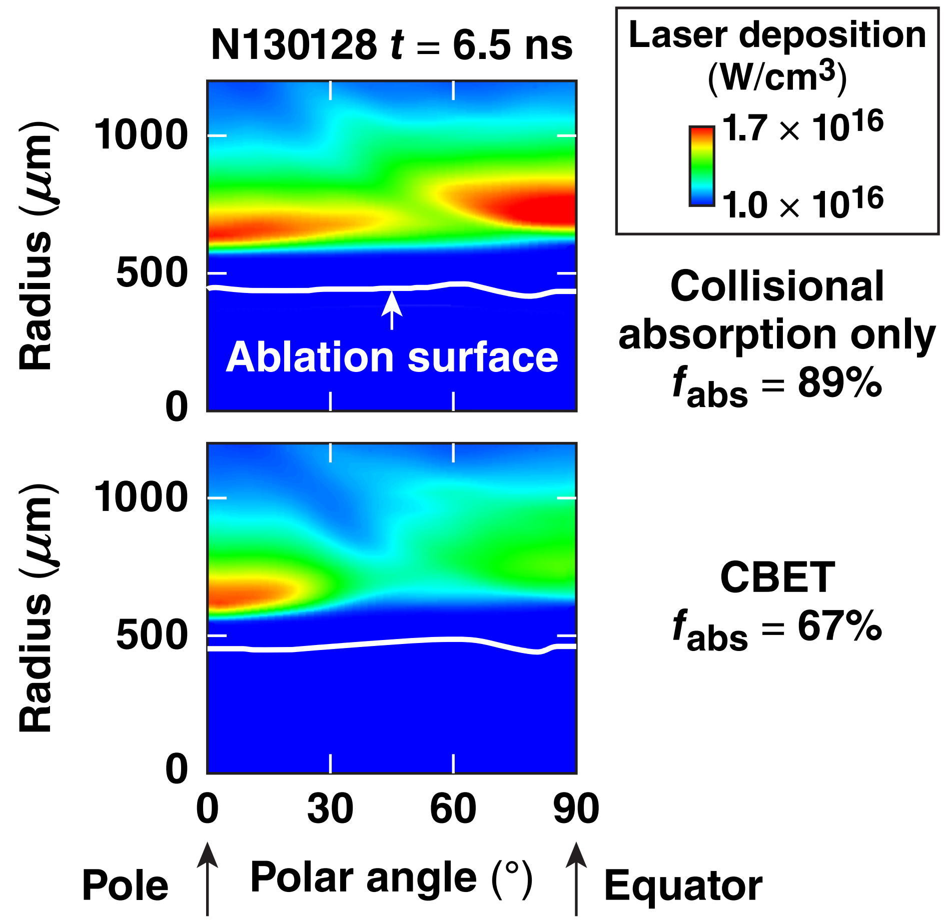


DRACO without CBET
t = 7.3 ns

CBET redistributes energy between intercepting beams and reduces laser absorption near the equator

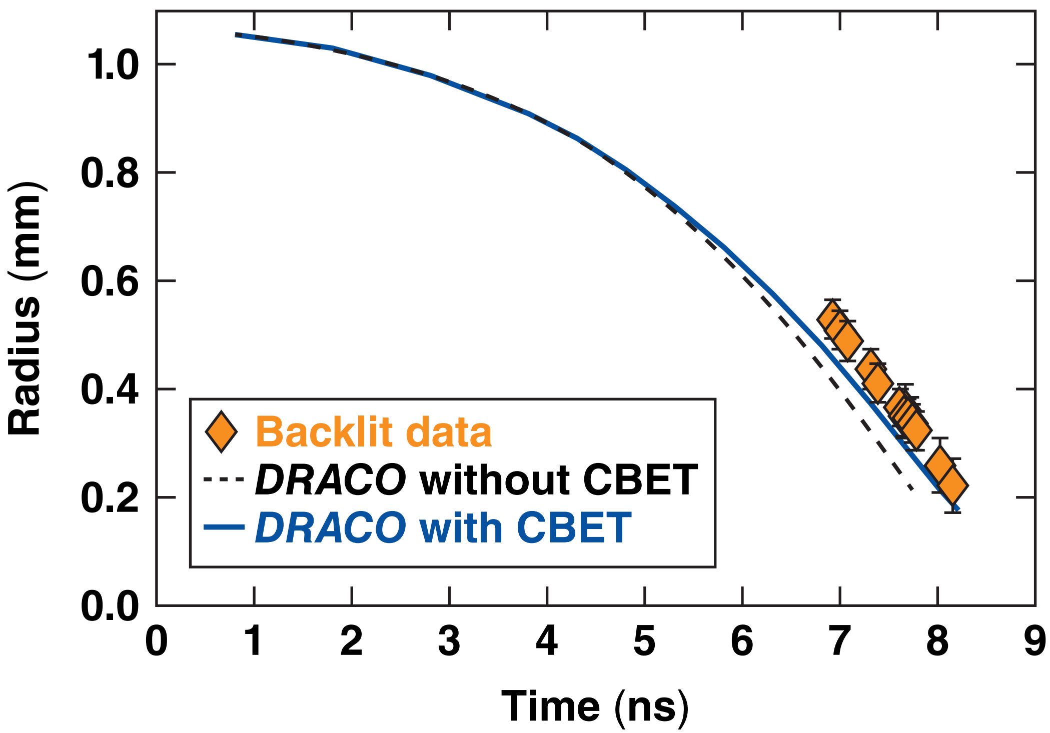


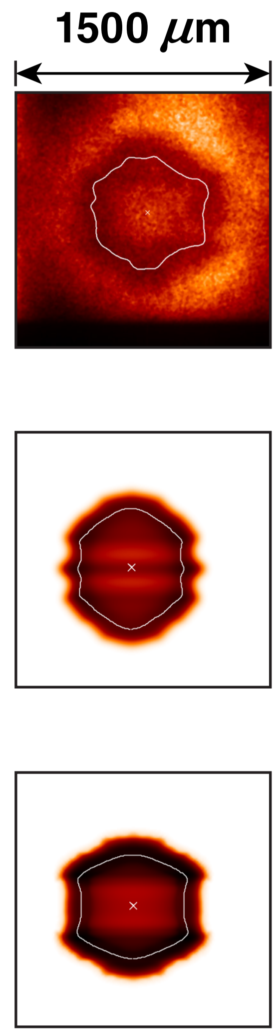
Instantaneous deposited laser power at convergence ratio CR ~ 2



Trajectory

Including CBET in the *DRACO* simulations improves the agreement with the measured trajectory





N140612
t = 7.75 ns

DRACO without CBET
t = 7.3 ns

DRACO with CBET
t = 7.5 ns

- Discrepancy between simulations and data may indicate Rayleigh–Taylor (RT) growth

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P. B. Radha *et al.*, JO4.00013, this conference.

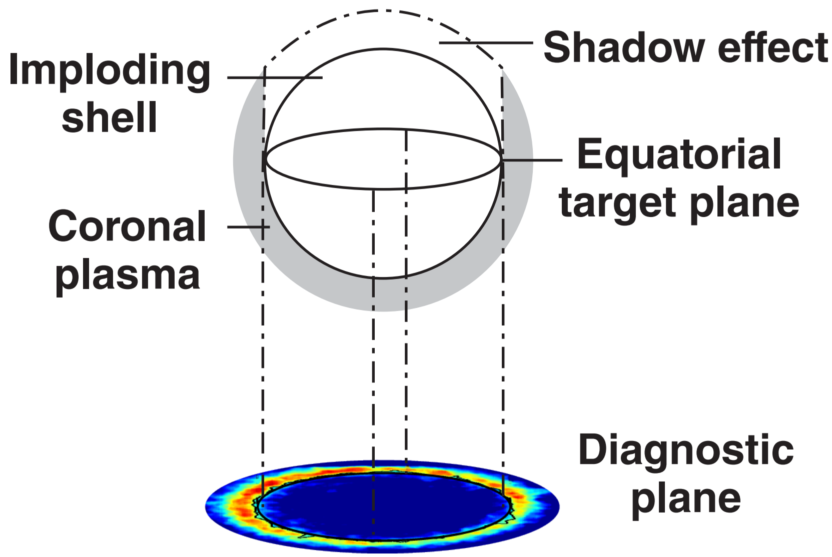
UNIVERSITY of ROCHESTER

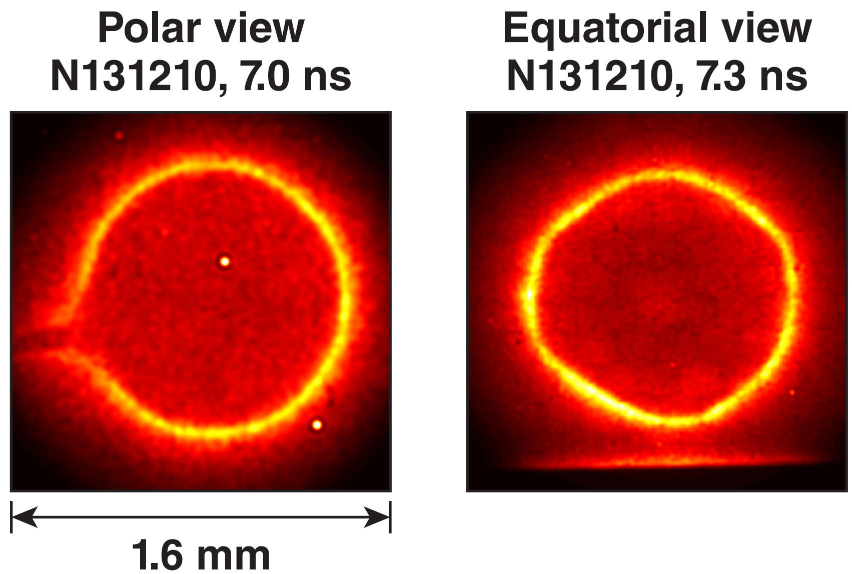
Shape

Coronal self-emission imaging probes the region close to the ablation surface*

UR LLE

NIF





Self-emission imaging makes it possible to measure low-mode asymmetries without backlighting.

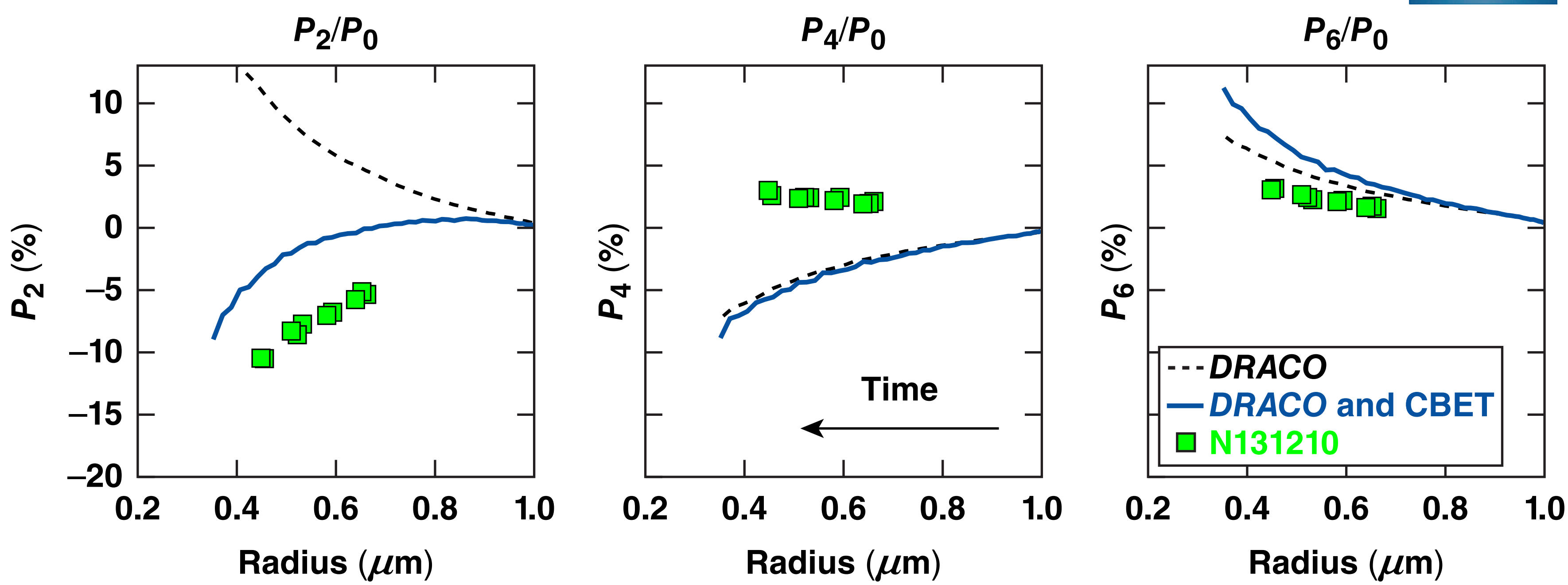
*D. T. Michel *et al*., Phys. Rev. Lett. 109, 155007 (2012).

Shape

The agreement in equatorial shape between simulation and experiment improves when including CBET in the calculations

UR LLE

NIF



- The difference between experimental data and simulations are likely a result of 3-D effects not captured by 2-D calculations

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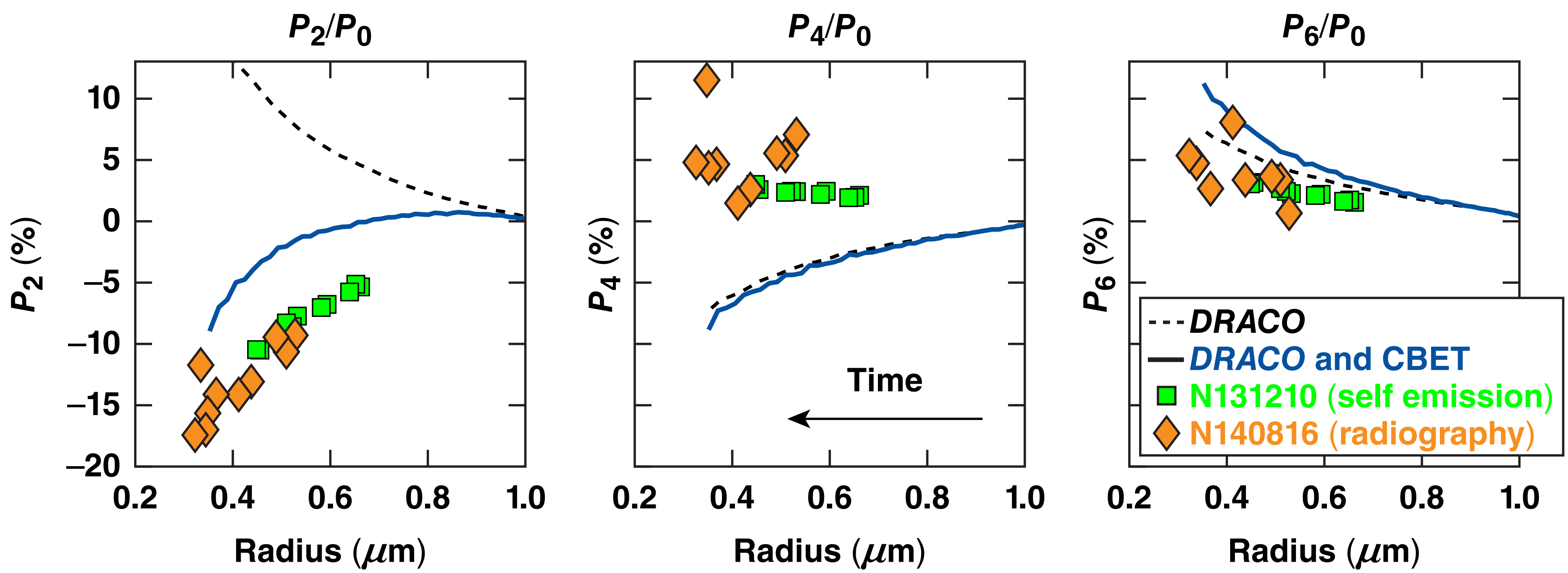
Shape

The self-emission inferred shape evolution matches the radiography data very well



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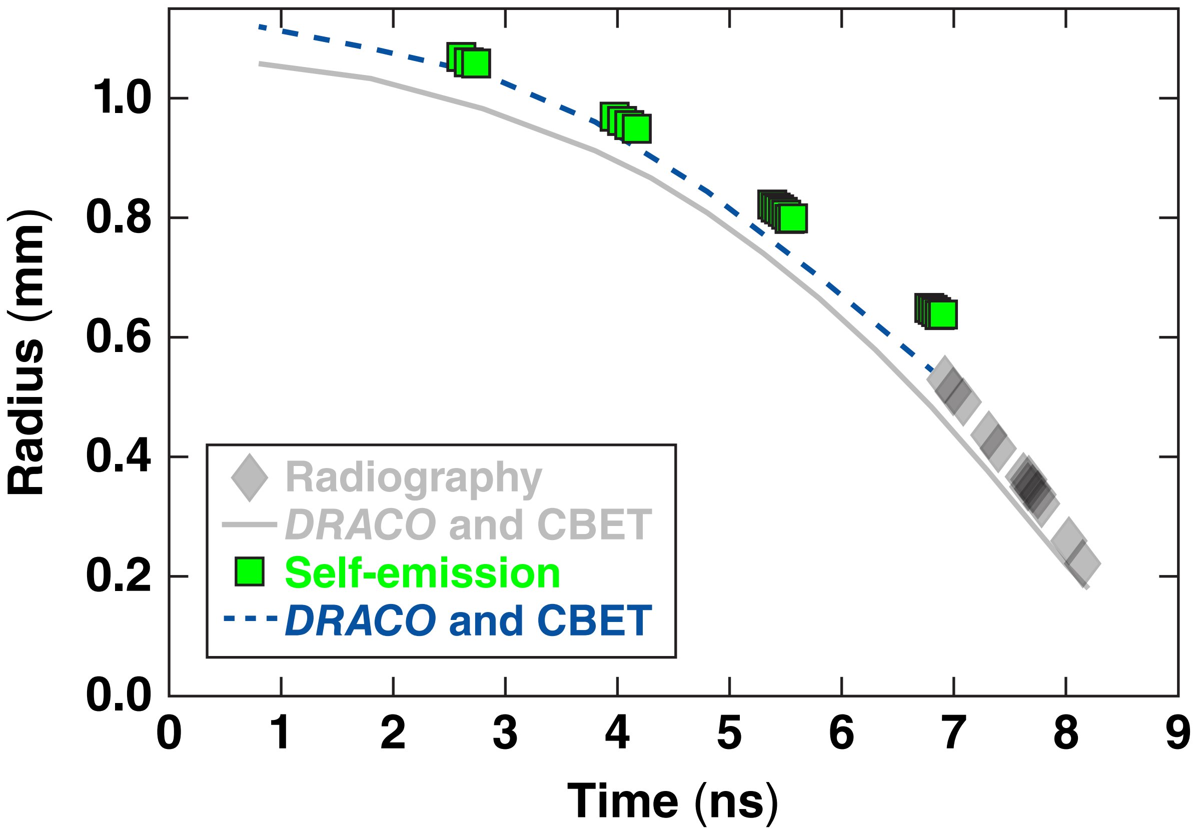
Trajectory

The self-emission trajectory is delayed compared to simulations

UR LLE

NIF



- The discrepancy between backlit and self-emission trajectory is currently not fully understood

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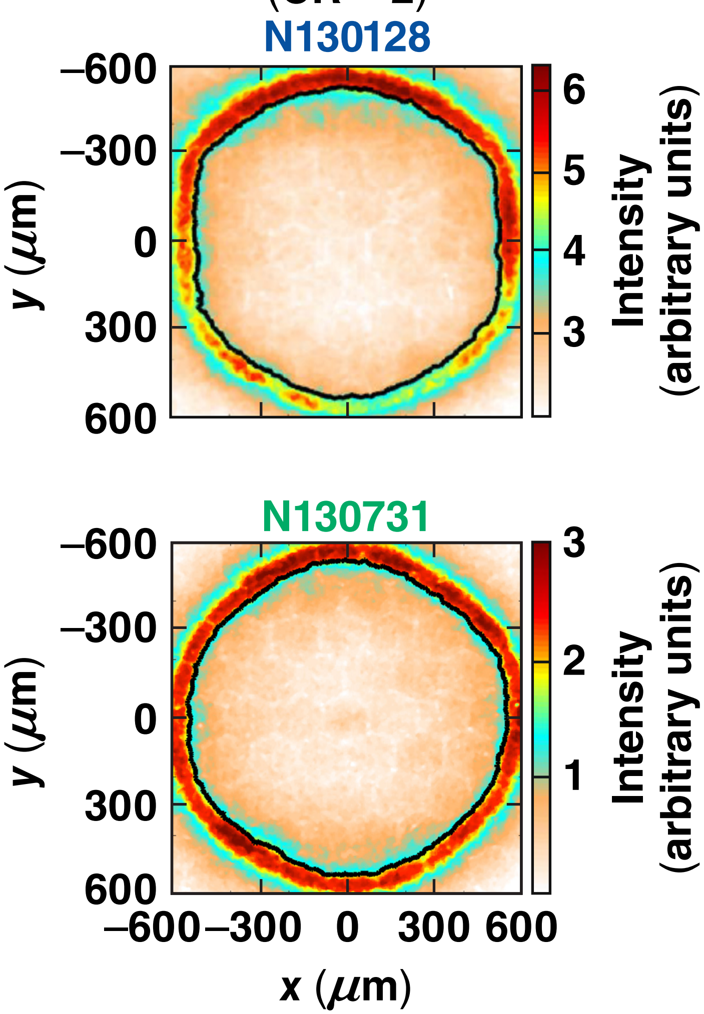
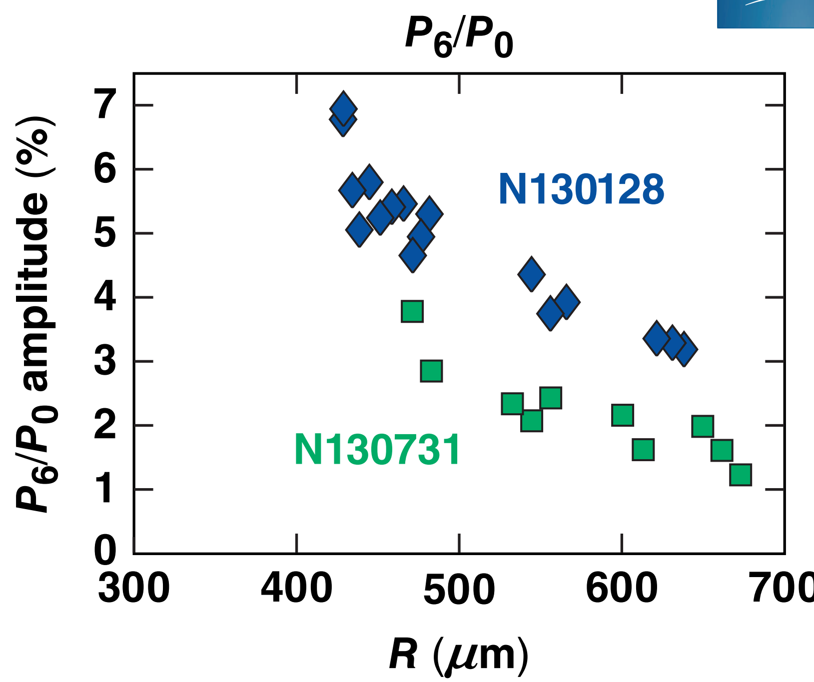
P. B. Radha *et al*., JO4.00013, this conference.

Shape

Beam pointing, defocus, and energy balance have been used to control and improve symmetry

Framing-camera images
(CR ~ 2)





Further improvements in symmetry will require dedicated PDD phase plates and well-characterized beam-spot profiles.

The TPD instability is the dominant source of hot electrons in direct-drive ICF experiments

UR LLE

NIF

- Hot electrons can penetrate the ablator and preheat the fuel
- TPD gain scales as*
  - $\langle I \rangle$: overlapped beam intensity
  - L_n: plasma scale length
  - T_e: electron temperature

$$G \sim \frac{\langle I \rangle L_n}{T_e}$$

$$L_n^{\Omega\,\mathrm{EP}} \sim 350\ \mu\mathrm{m} \qquad L_n^{\mathrm{NIF}} \sim 500\ \mu\mathrm{m}$$

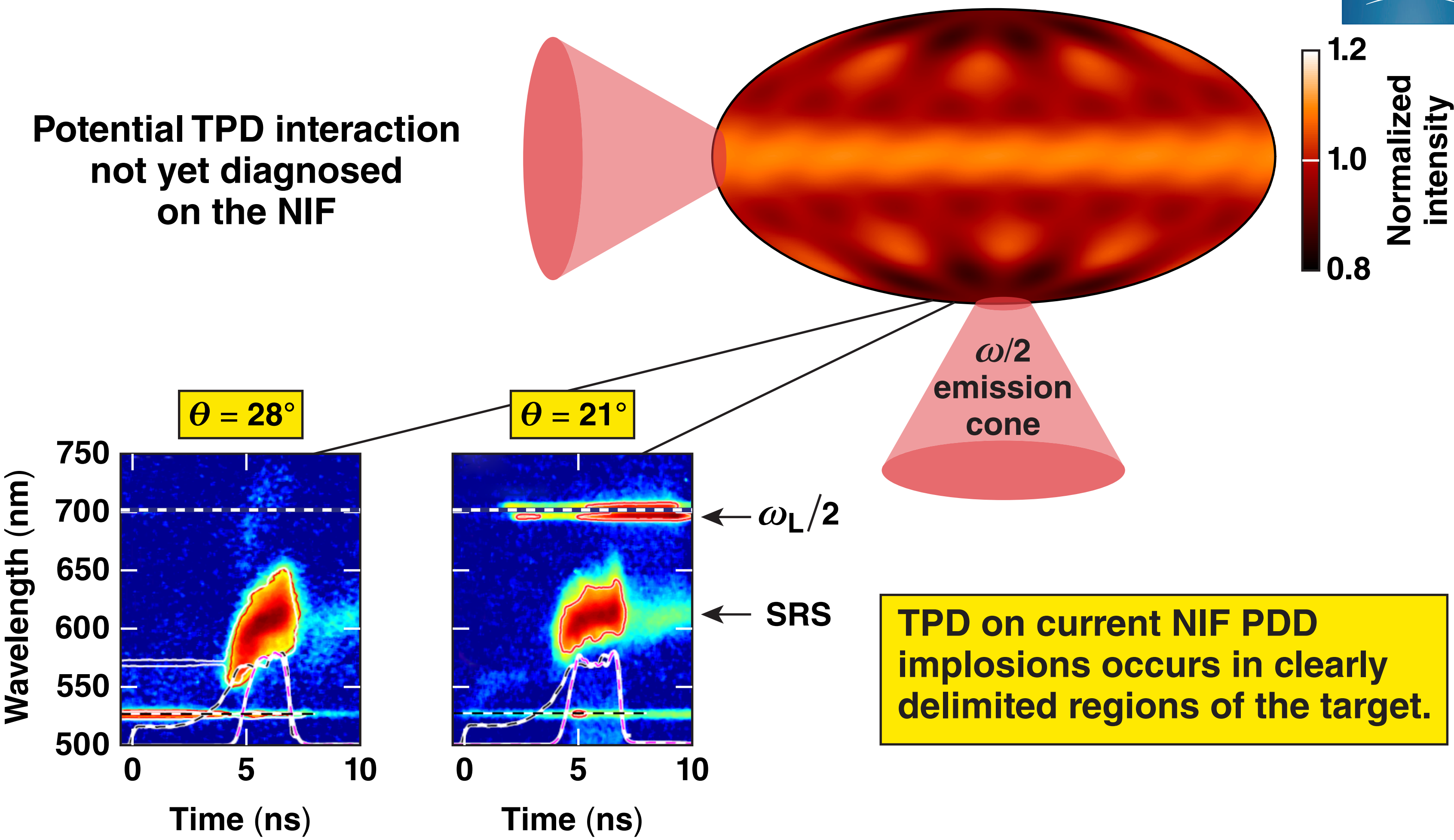
$$T_e^{\Omega\,\mathrm{EP}} \sim 2\ \mathrm{keV} \qquad T_e^{\mathrm{NIF}} \geq 3\ \mathrm{keV}$$

- TPD signatures
  - $\omega_L/2$ and $3/2\ \omega_L$ emission
  - hard x-ray emission >20 keV

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

LPI

$\omega/2$ emission is indicative of TPD in PDD implosions on the NIF*



TPD on current NIF PDD implosions occurs in clearly delimited regions of the target.

*W. Seka *et al.*, PO4.00011, this conference.

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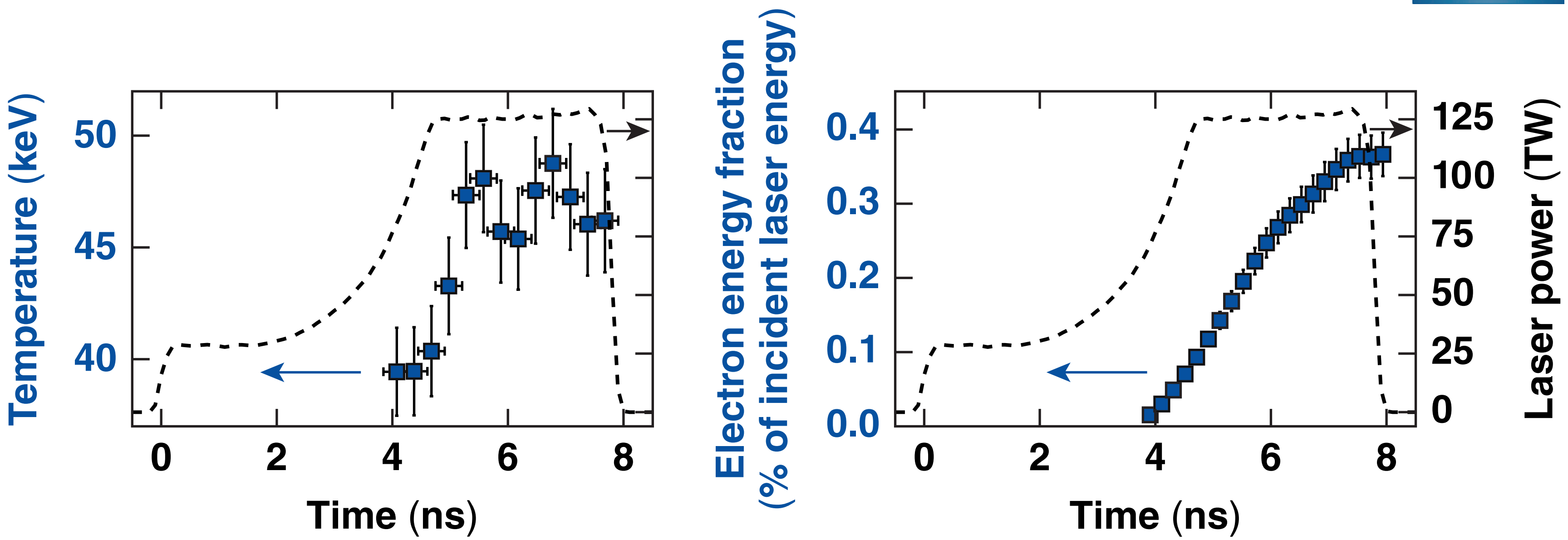
LPI

Hot electrons are generated predominantly during the main capsule drive

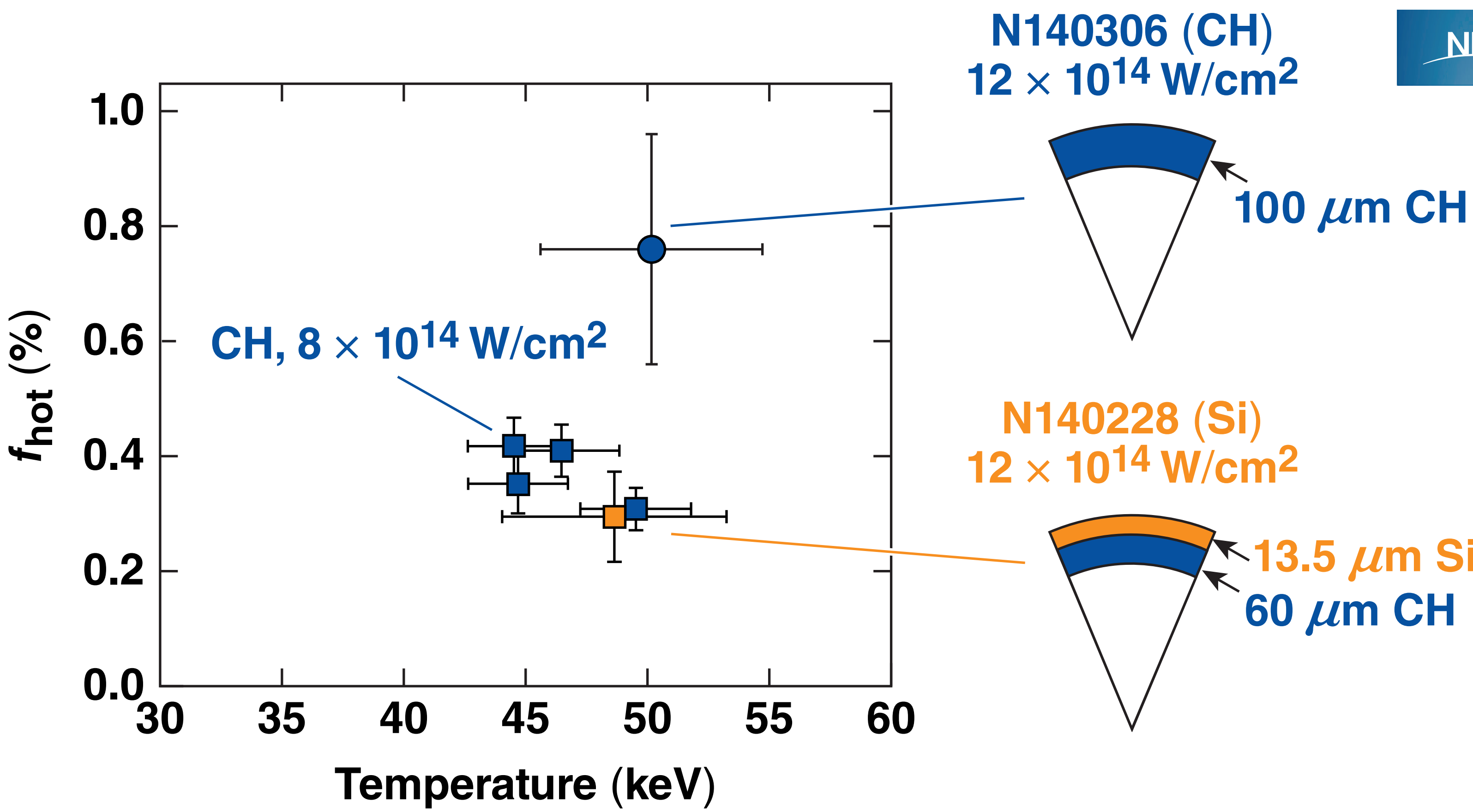
N131210: CH capsule, 600 kJ, $I = 8 \times 10^{14}$ W/cm^2



- Accumulated fraction of hot electrons versus deposited laser energy saturates at ~0.4% in CH ablators
- 0.4% or less conversion efficiency is required for ignition designs

E23678

TPD can be reduced by using mid-Z ablators*



The inferred preheat with the Si ablator is reduced by ~50%.

*J. F. Myatt, Phys. Plasmas 20, 052705 (2013);
W. Seka *et al*., Phys. Plasmas 16, 052701 (2009).

E23679

Future experiments will examine laser–plasma and hydrodynamic instabilities

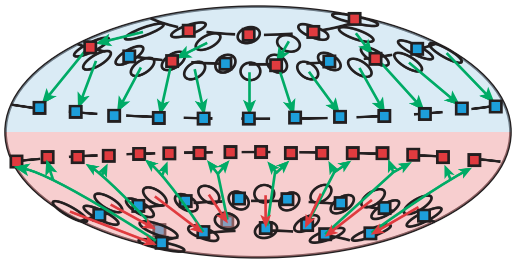
- Cone-in-shell experiments will investigate laser imprint and Rayleigh-Taylor growth at NIF conditions
  - A. Shvydky *et al*., UO4.00008, this conference
- Planar experiments will approximate the interaction conditions at pole and equator of a PDD target
  - investigate beam angle of incidence on TPD hot-electron production in the absence of CBET
- CBET mitigation via hemispheric $\Delta\lambda$ detuning will be investigated by repointing the outer cones in one hemisphere to the equator
  - J. A. Marozas *et al*., NO4.00014, this conference

Future NIF Experiments

Polar-direct-drive ignition requires additional capabilities on the NIF

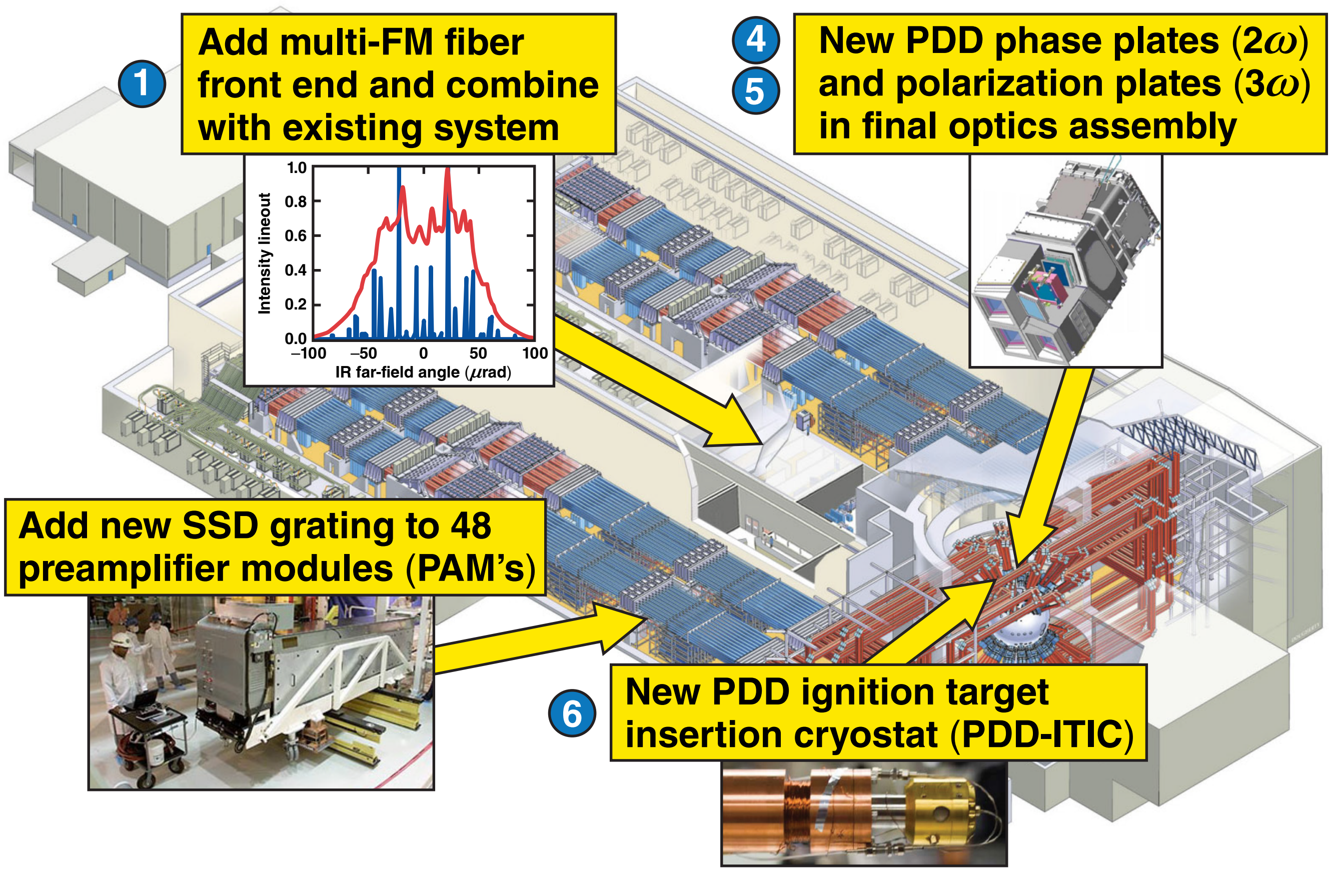
Hemispheric wavelength detuning

2



$\Delta\lambda \geq -6$ Å (UV) TBD
$\Delta\lambda \geq +6$ Å (UV) TBD

Current capability:
$\Delta\lambda \sim \pm 2$ Å (UV)



1 Add multi-FM fiber front end and combine with existing system

4 5 New PDD phase plates (2ω) and polarization plates (3ω) in final optics assembly

3 Add new SSD grating to 48 preamplifier modules (PAM's)

6 New PDD ignition target insertion cryostat (PDD-ITIC)

The NIF PDD Laser Path-Forward working group is actively engaged in adding beam smoothing, phase plates, polarization smoothing, and hemispheric Δλ.

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Summary/Conclusions

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- Radiography data of the imploding shell are in reasonable agreement with the simulations
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Future focused experiments will examine laser–plasma and hydrodynamic instabilities.