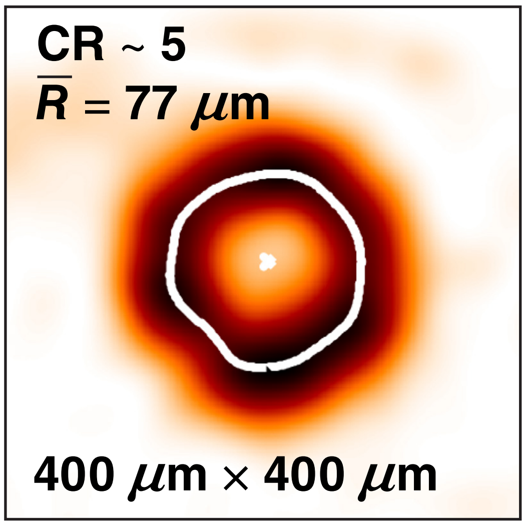
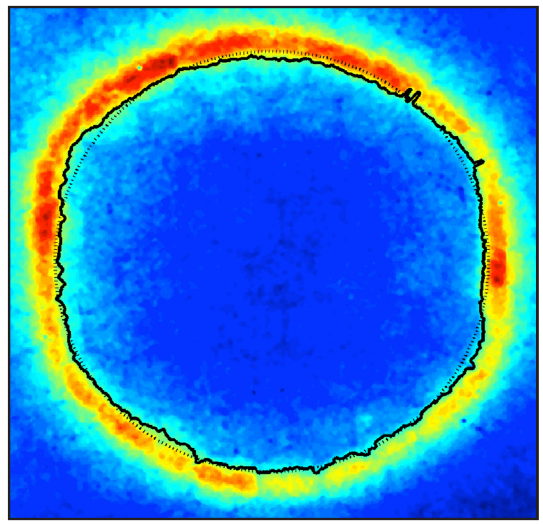
Recent Results from Polar-Drive Implosions on OMEGA and the NIF

Backlit x-ray image
OMEGA polar-drive implosion



Self-emission image
NIF polar drive implosion



CR~2
$\overline{R}$ = 552 μm

600 μm × 600 μm

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Omega Laser Facility Users
Group Workshop
Rochester, NY
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Collaborators

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Summary

Implosion physics in polar-drive (PD) geometry is being explored on OMEGA and the NIF for a range of implosion parameters

- Symmetry can be controlled in OMEGA PD implosions through beam pointing, energies, and target shimming
- NIF implosions indicate reduced shell velocities; simulations reproduce the observed shapes apart from the ℓ=2 mode
- Cryogenic PD implosions on OMEGA will begin later this year
- NIF implosions will systematically explore intensity and coronal density scale-length regimes with the goal of reaching ignition-relevant parameters

Outline

- Polar-drive (PD) implosion physics
- PD ignition
- OMEGA experiments
- NIF experiments
- Future plans

Outline

- **Polar-drive (PD) implosion physics**
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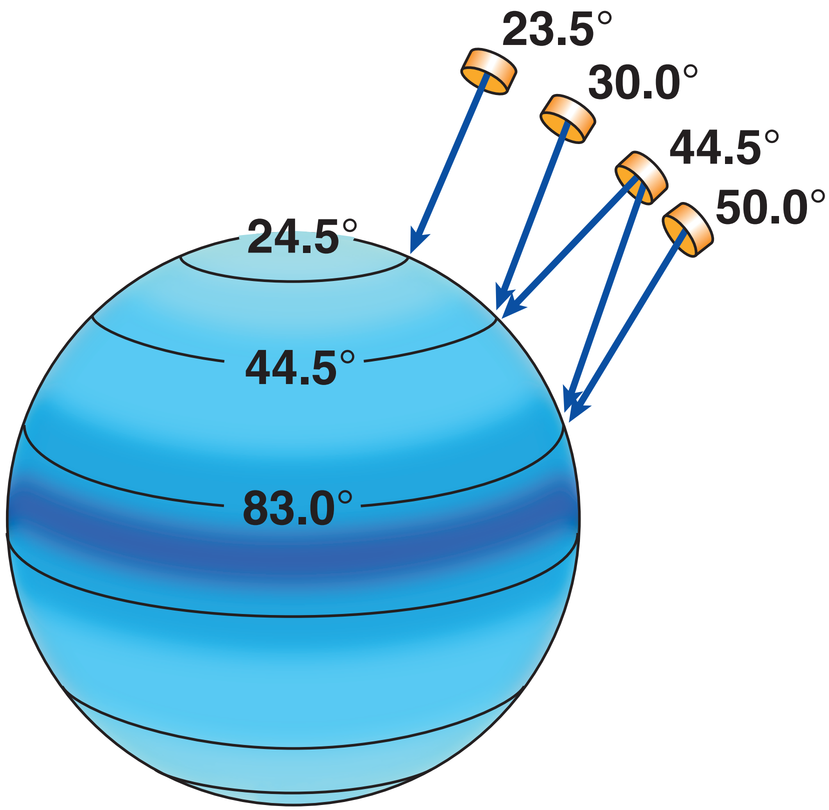
TC10550a

PD enables direct-drive-ignition experiments on the NIF in the x-ray-drive configuration

Repointing for PD*

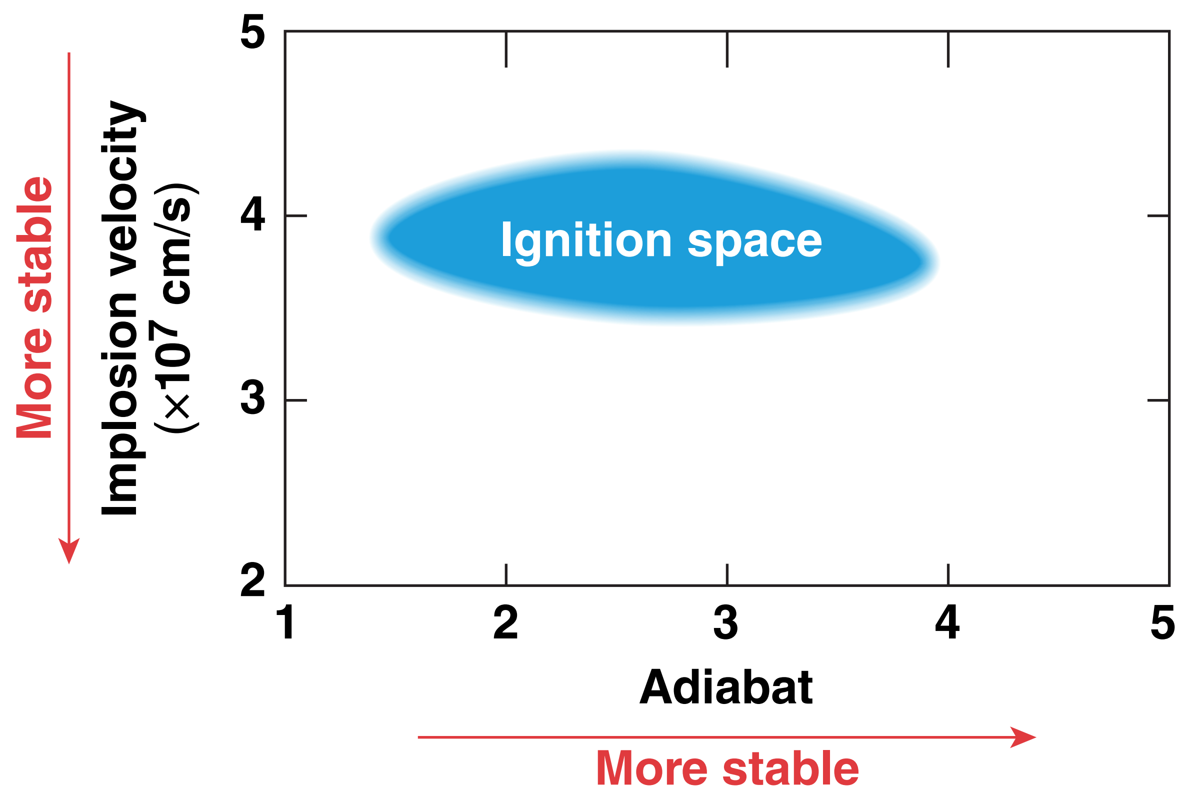


- Oblique irradiation near the equator is at lower densities ($n = n_{crit} \times \cos^2\theta_{inc}$)
  - nonradial beams
  - reduced absorption
  - reduced hydro-efficiency
  - lateral heat flow

TC9532h

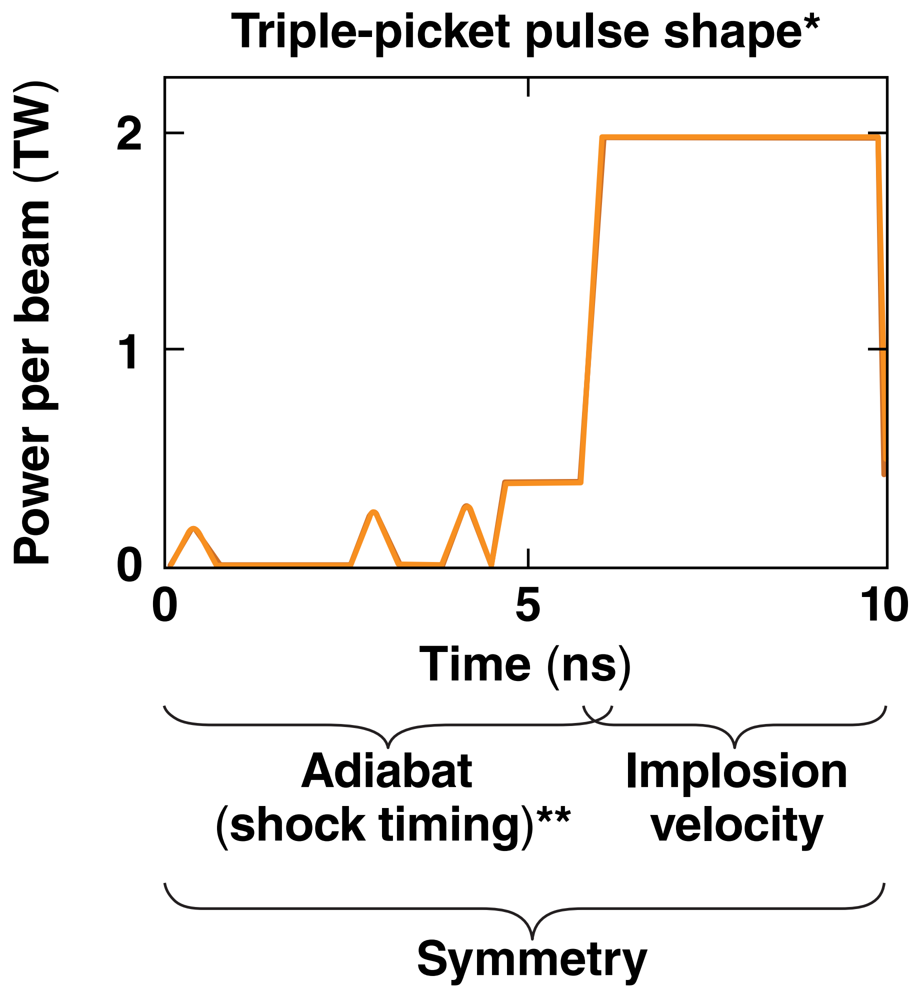
*S. Skupsky *et al.*, Phys. Plasmas 11, 2763 (2004).

PD ignition space is similar to symmetric drive



- Analytical theories help to identify key parameters that affect the onset of ignition
- Ignition target designing is based on hydrodynamic simulations
- Simulation models are continuously being refined based on experimental data from OMEGA and the NIF for symmetric and polar drive

Both shocks and the main drive contribute to asymmetry

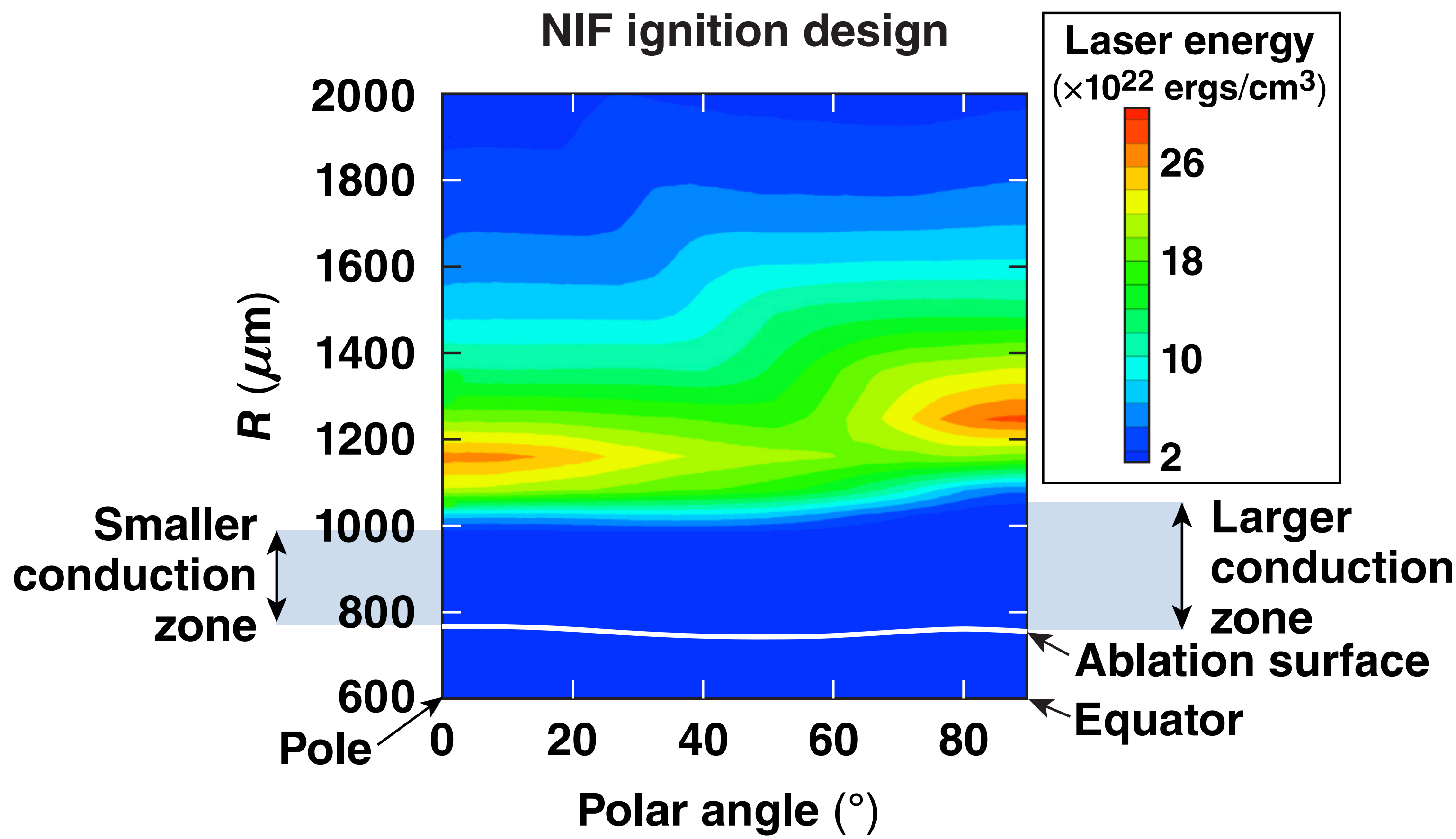


*V. N. Goncharov *et al.*, Phys. Rev. Lett. 104, 165001(2010);
P. B. Radha *et al.*, Phys. Plasmas 18, 012705 (2011).
**P. B. Radha *et al.*, "Polar Drive on OMEGA," submitted to the European Physical Journal.

TC10361a

Models of laser deposition and heat conduction are crucial to determining implosion symmetry

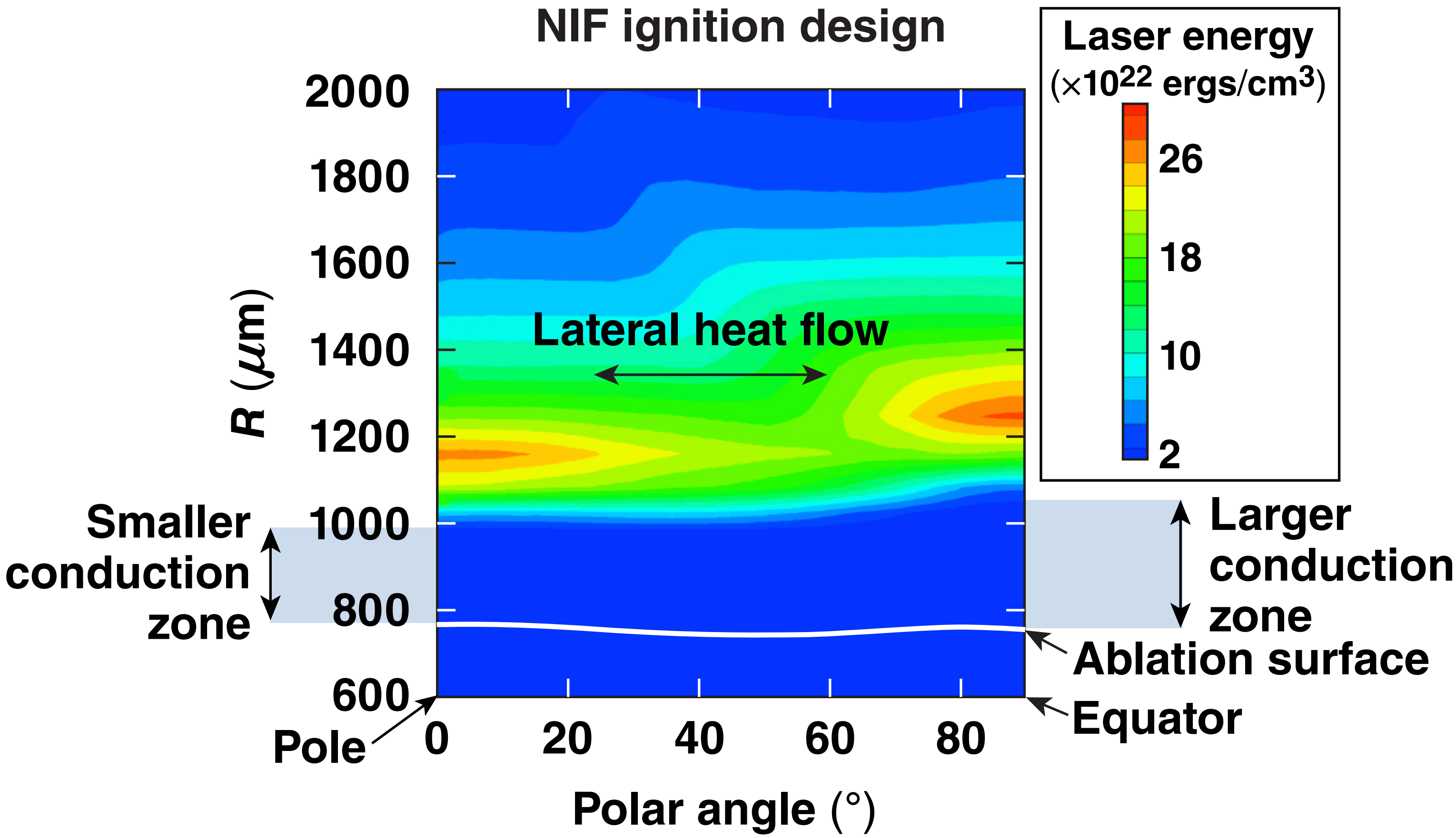
Laser energy deposited at end of laser pulse



TC10140

Models of laser deposition and heat conduction are crucial to determining implosion symmetry

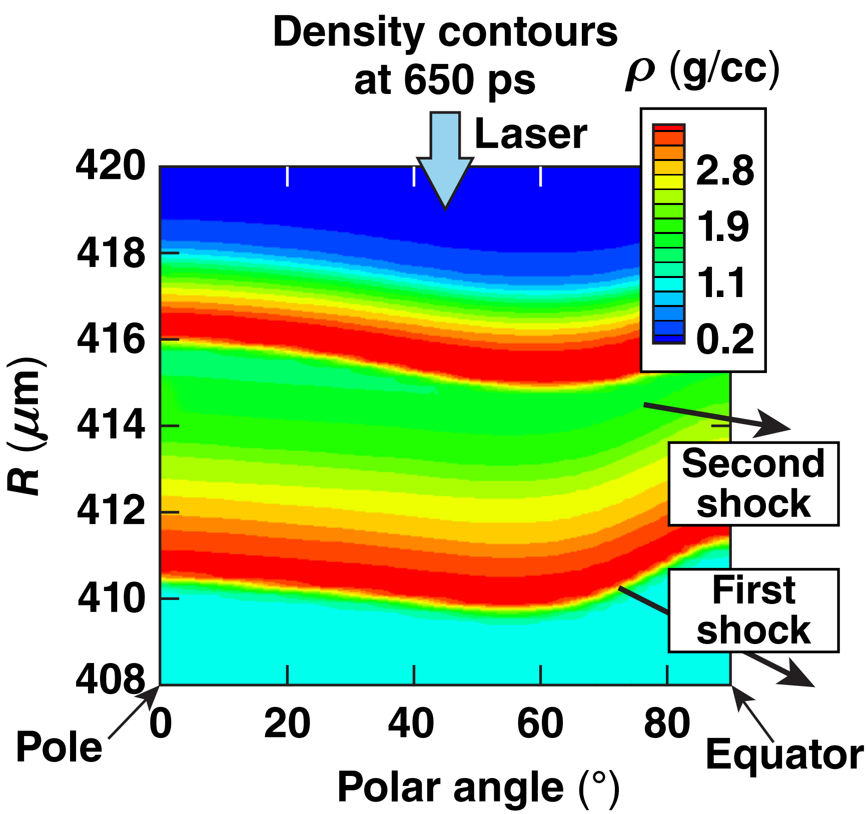
Laser energy deposited at end of laser pulse

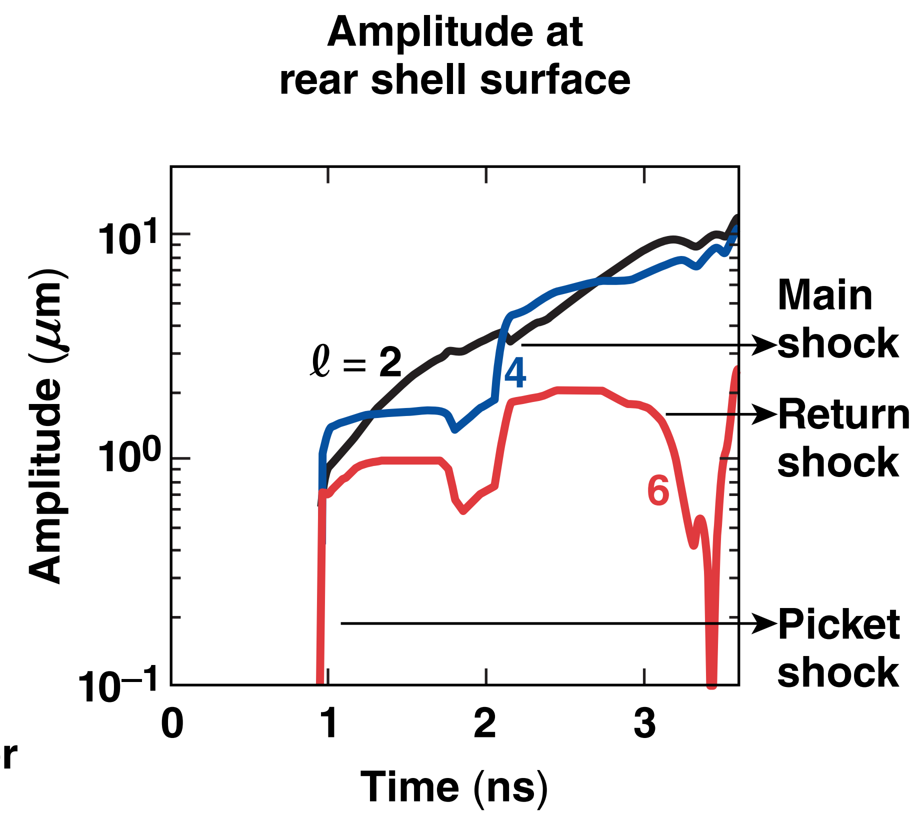


TC10140a

Minimizing asymmetry is an important goal of OMEGA experiments and hydrodynamic modeling

- Nonuniform shock fronts contribute significantly to the asymmetry





TC10357

Outline

- Polar-drive (PD) implosion physics
- **PD ignition**
- OMEGA experiments
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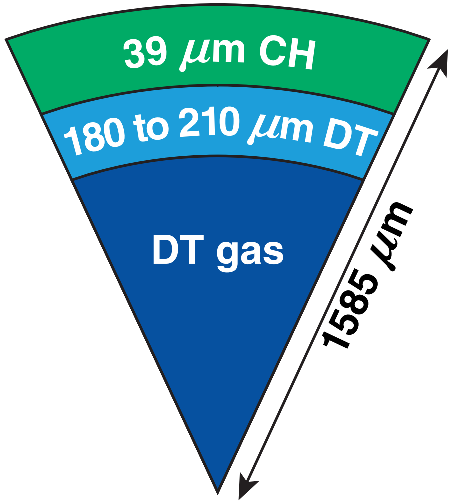
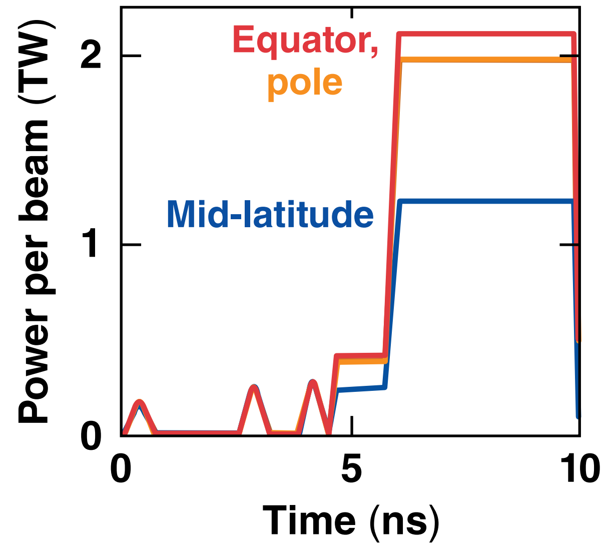
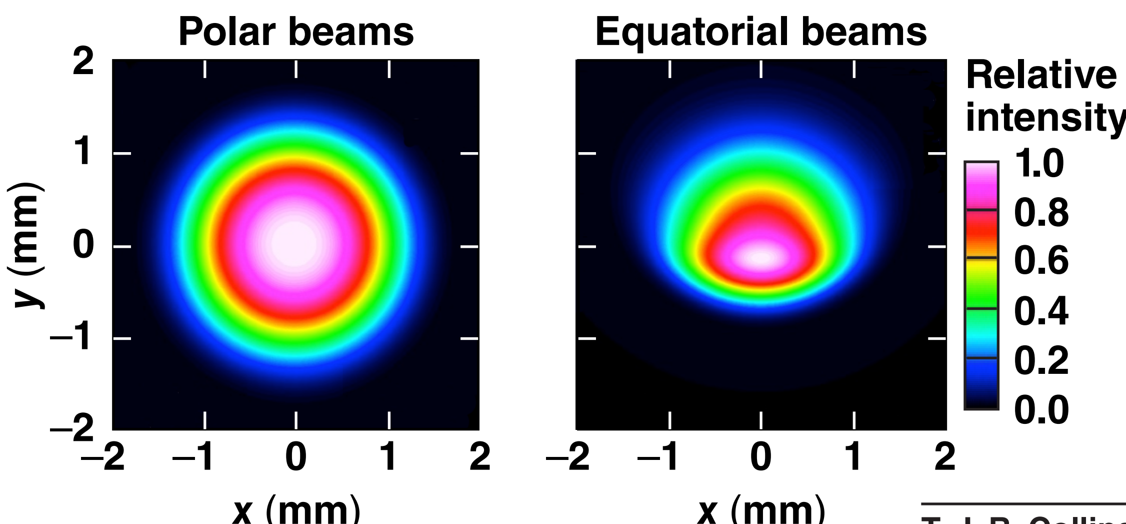
Tailored laser pulse shapes and beam profiles are used to adequately irradiate the equator in the ignition design



E	1.5 MJ
V_{imp}	(3.5 to 4.3) × 10^7 cm/s
α_{inn}	2.2 to 2.6

$$\alpha_{inn} = \frac{P}{P_f}$$



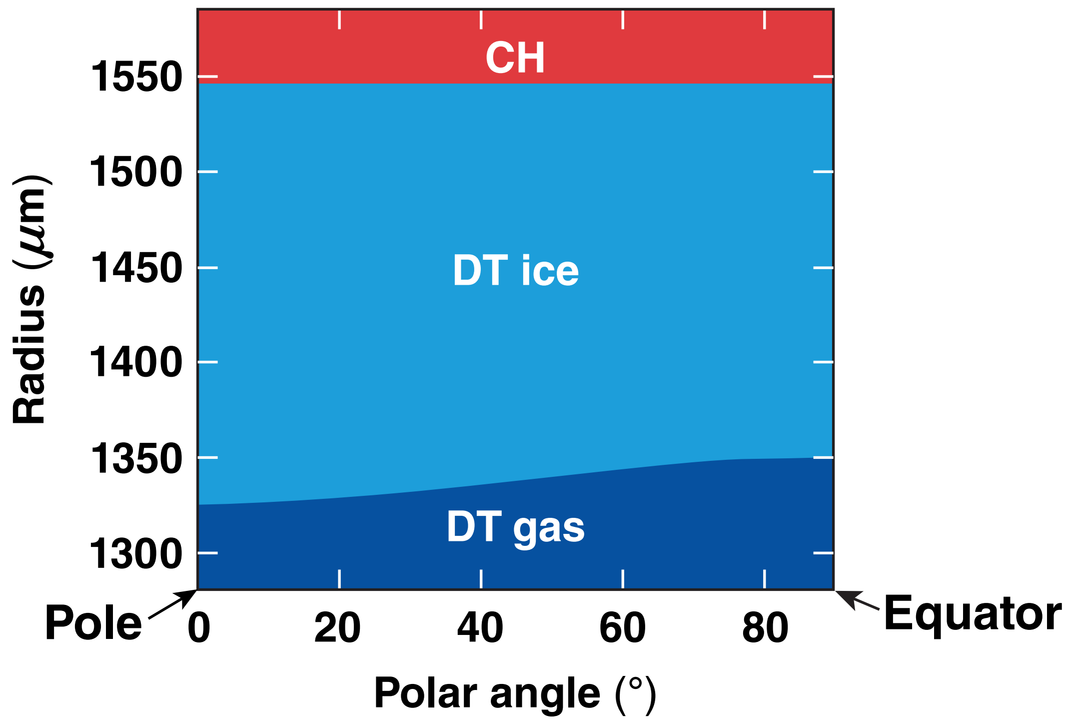


- Custom spot shapes preferentially irradiate the equator, improving symmetry

T. J. B. Collins *et al.*, Phys. Plasmas 19, 056308 (2012); T. J. B. Collins, J. A. Marozas, and P. W. McKenty, Bull. Am. Phys. Soc. 57, 155 (2012).

TC10138

Shimming can provide an additional parameter to control symmetry



- Different shimmed profiles permit
  - variation in symmetry
  - adequate symmetry with lower-intensity equatorial beams than without a shim

T. J. B. Collins *et al.*, Phys. Plasmas 19, 056308 (2011).

Outline

- Polar-drive (PD) implosion physics
- PD ignition
- **OMEGA experiments**
- NIF experiments
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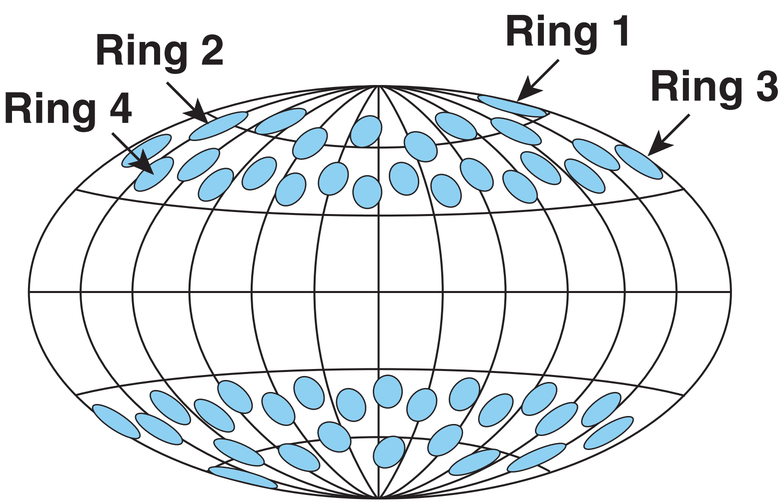
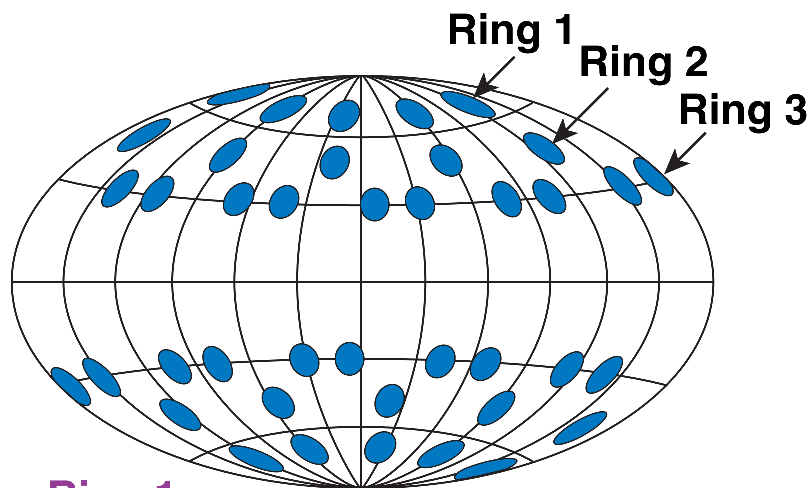
40 OMEGA beams emulate the 48-quad (192-beam) NIF configuration

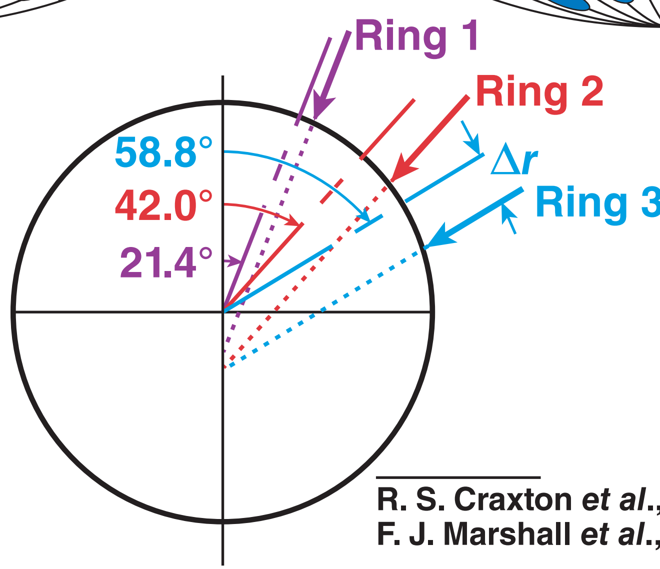
NIF configuration



OMEGA PD configuration



- The remaining beams are used to backlight the shell



- Beam shifts are parametrized by: $\Delta r_1, \Delta r_2, \Delta r_3,$

R. S. Craxton *et al*., Phys. Plasmas 12, 056304 (2005).
F. J. Marshall *et al*., J. Phys. IV France 133, 153 (2006).

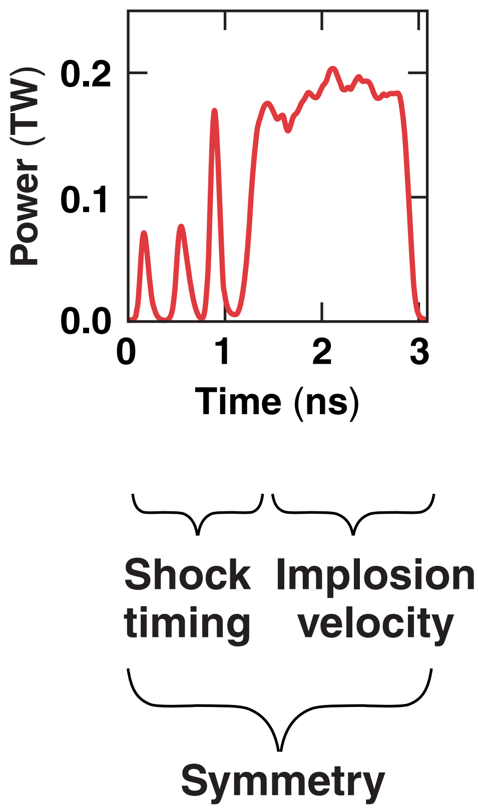
TC7194e

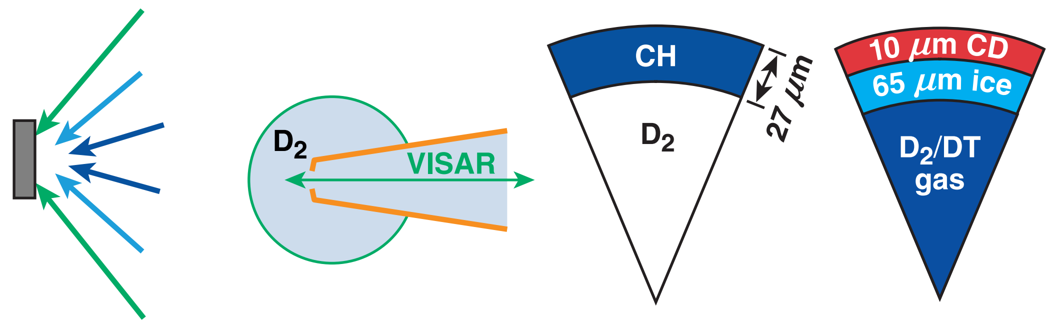
PD implosions are being studied for a range of parameters

OMEGA		NIF current implosions
R = 430 μm	R = 300 μm	R = 1100 μm
E = 16 kJ	E = 16 kJ	E = 350 kJ
α ~ 2 to 3	α ~ 2 to 3	α ~ 2 to 3
$V_{imp} = 3.6 \times 10^7$ cm/s	$V_{imp} = 3.6 \times 10^7$ cm/s	$V_{imp} = 1.8 \times 10^7$ cm/s
$I = 4 \times 10^{14}$ W/cm^2	$I = 1 \times 10^{15}$ W/cm^2	$I = 4 \times 10^{14}$ W/cm^2
$L_{nc/4}$ = 150 μm	$L_{nc/4}$ = 110 μm	$L_{nc/4}$ = 360 μm
Low intensity	Ignition-relevant intensity	Long coronal density scale length

TC10551

Different OMEGA platforms are used to infer the adiabat, symmetry, and implosion velocity in the polar-drive configuration



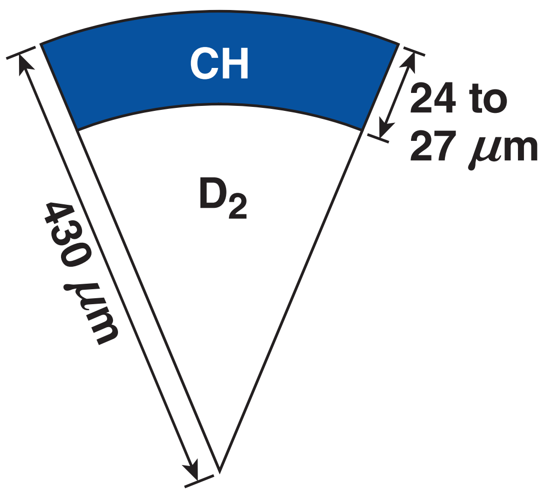


	Planar targets	Cone-in-shell targets	Warm CH shells	Cryogenic implosions
Adiabat	Hard x-ray preheat	Shock timing	ρR diagnostics	ρR diagnostics
Symmetry			Backlighting, self-emission	Backlighting
Energetics (V_{imp})	Trajectory		Bang time, scattered light	Bang time, scattered light

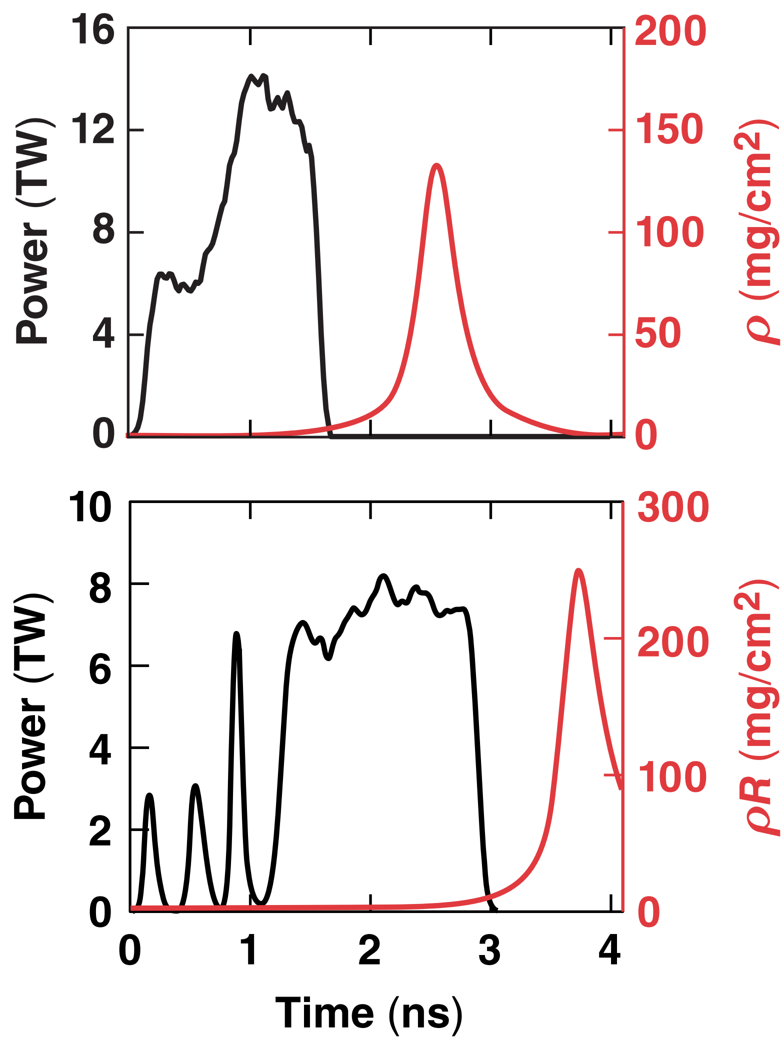
TC9520a

Adiabat

Several low-adiabat laser pulse shapes have been studied in the PD configuration



- Higher areal density is obtained by eliminating shell coasting after the laser drive is off



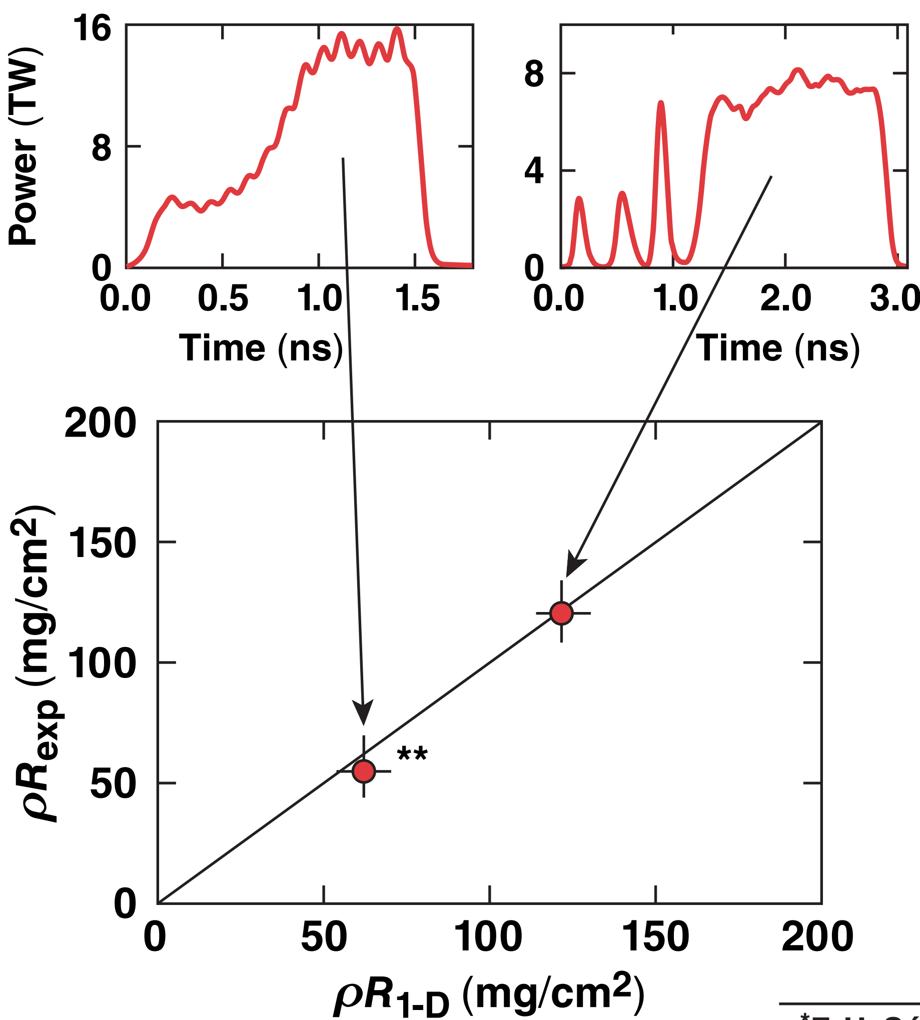
$I = 6 \times 10^{14}$ W/cm^2
CR ~ 12
E ~ 14 kJ
α ~ 3

$I = 3.5 \times 10^{14}$ W/cm^2
CR ~ 19
E ~ 14 kJ
α ~ 3

TC10141

Symmetry

Areal density* is well modeled over a range of different pulse shapes in the PD configuration



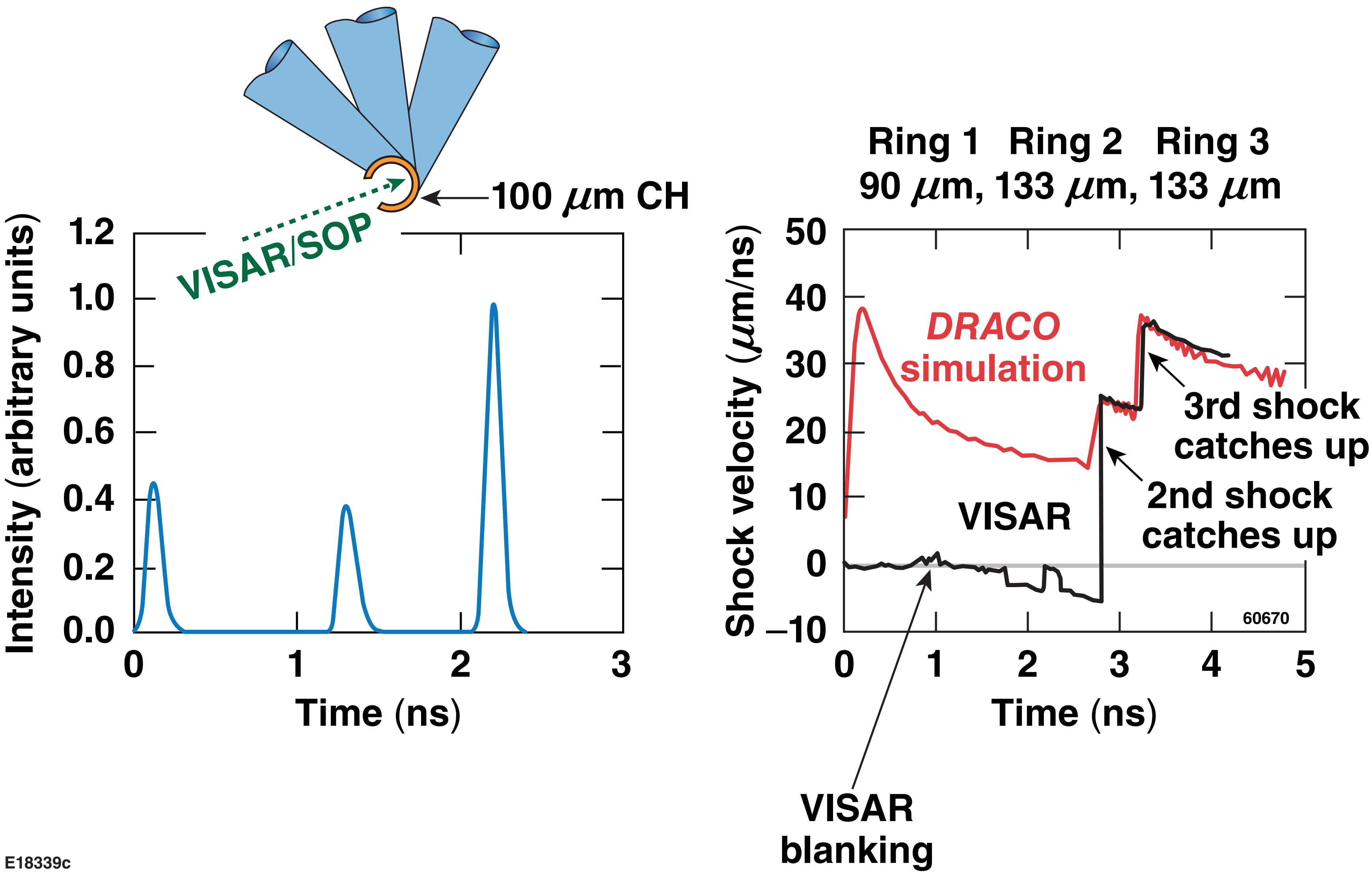
- **Areal density depends on the adiabat*****

$$\langle \rho R \rangle_n = \frac{1.8\, E_L^{1/3}(\text{MJ})}{\alpha^{0.54}}$$

*F. H. Séquin *et al*., Phys. Plasmas 9, 2728 (2002).
**F. J. Marshall *et al*., Phys. Rev. Lett. 102, 185004 (2009).
***C. D. Zhou and R. Betti, Phys. Plasmas 14, 072703 (2007).

TC9479i

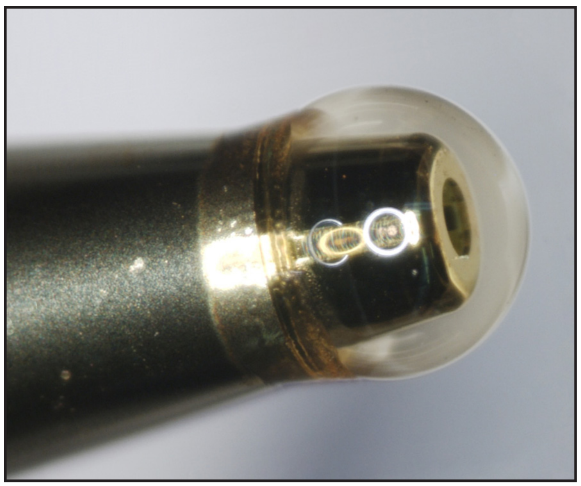
Shock timing from the three pickets preceding the main pulse are well modeled in the PD configuration



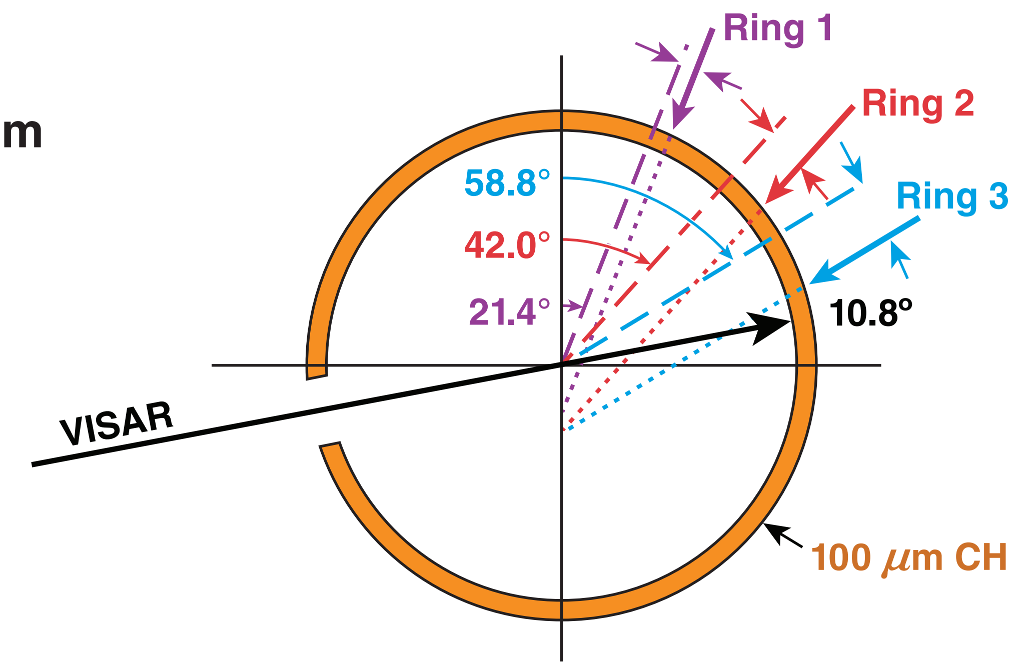
E18339c

Shock velocities have been inferred close to the equator in the PD configuration

Velocity interferometry system for any reflector (VISAR)



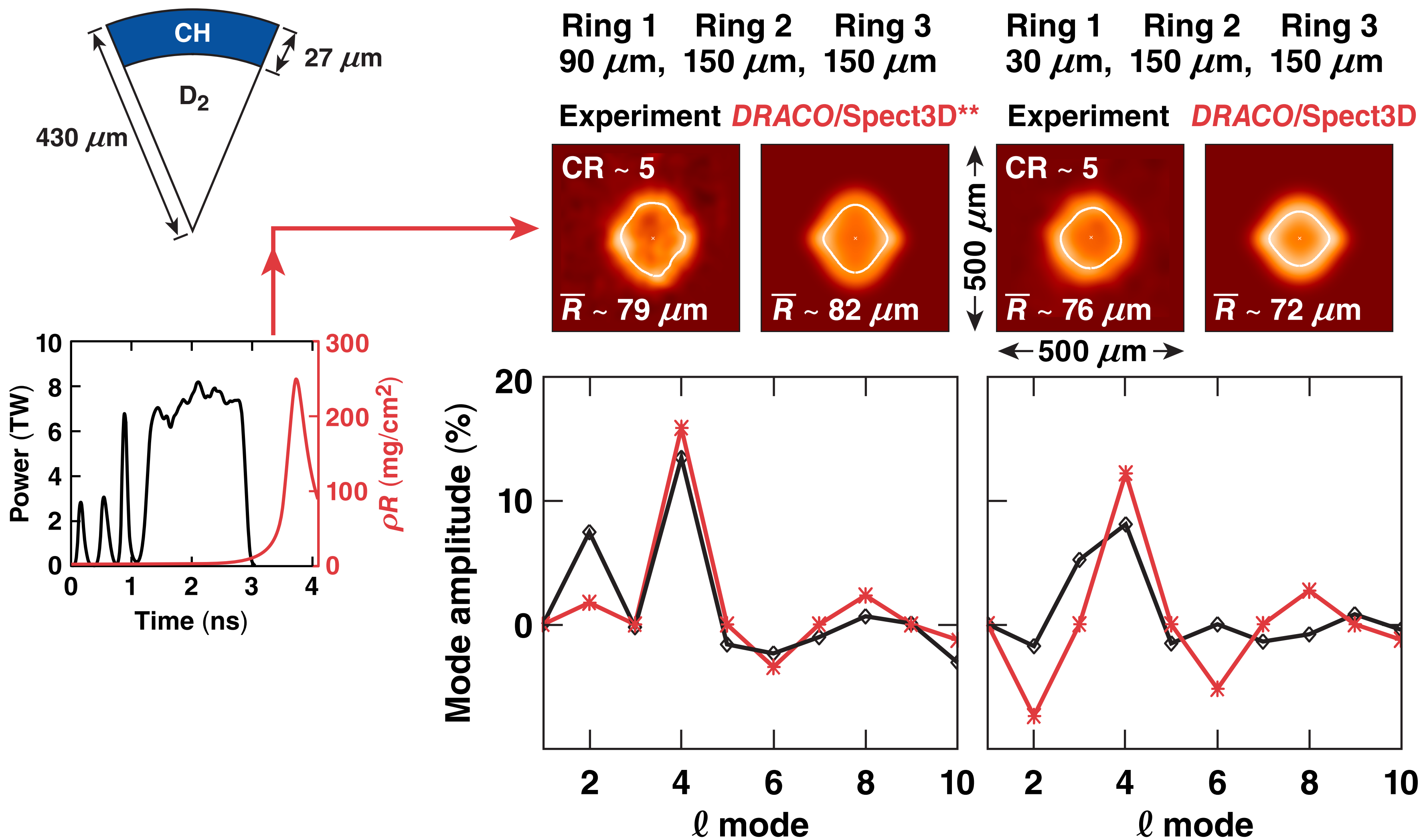
Capsule/cone detail



TC8905b

T. R. Boehly *et al.*, Phys. Plasmas 16, 056302 (2009).

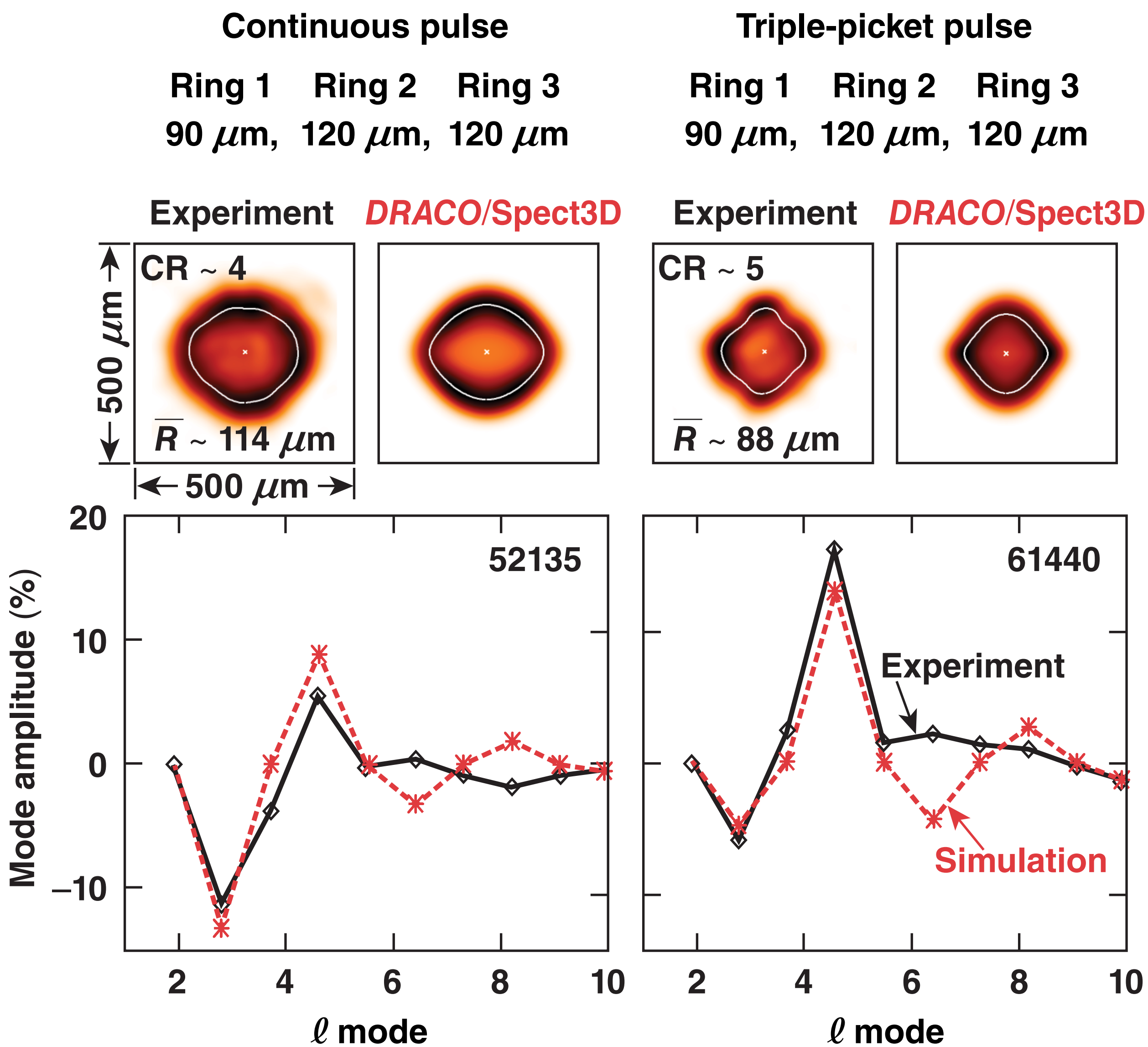
Good agreement is obtained in the symmetry of the compressed shell*



TC10355

* P. B. Radha *et al.*, "Polar Drive on OMEGA," submitted to the European Physical Journal.
**J. J. MacFarlane *et al.*, High Energy Density Phys. 3, 181 (2007).

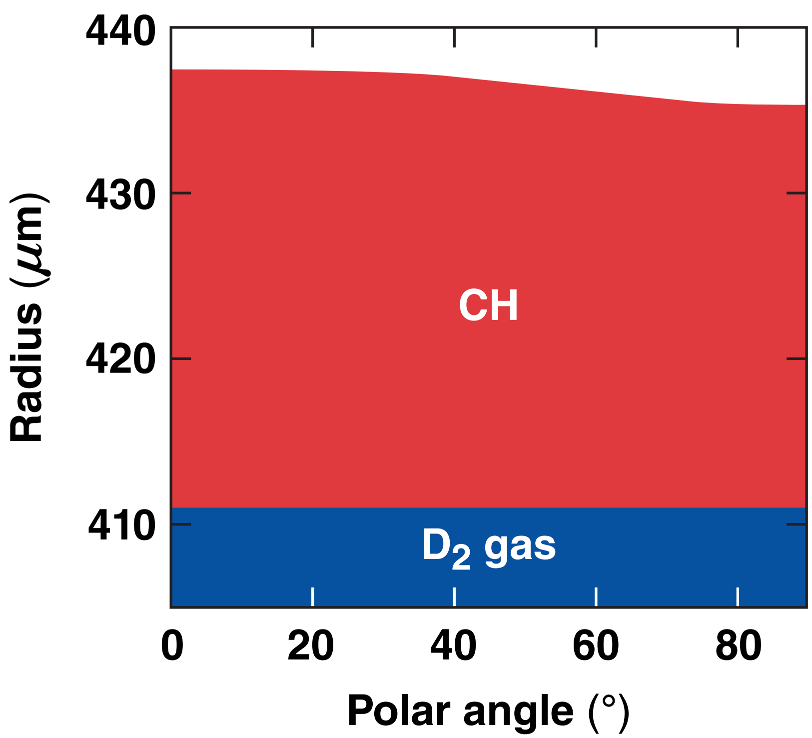
Differences in shape with differing pulse shapes are reproduced in simulation

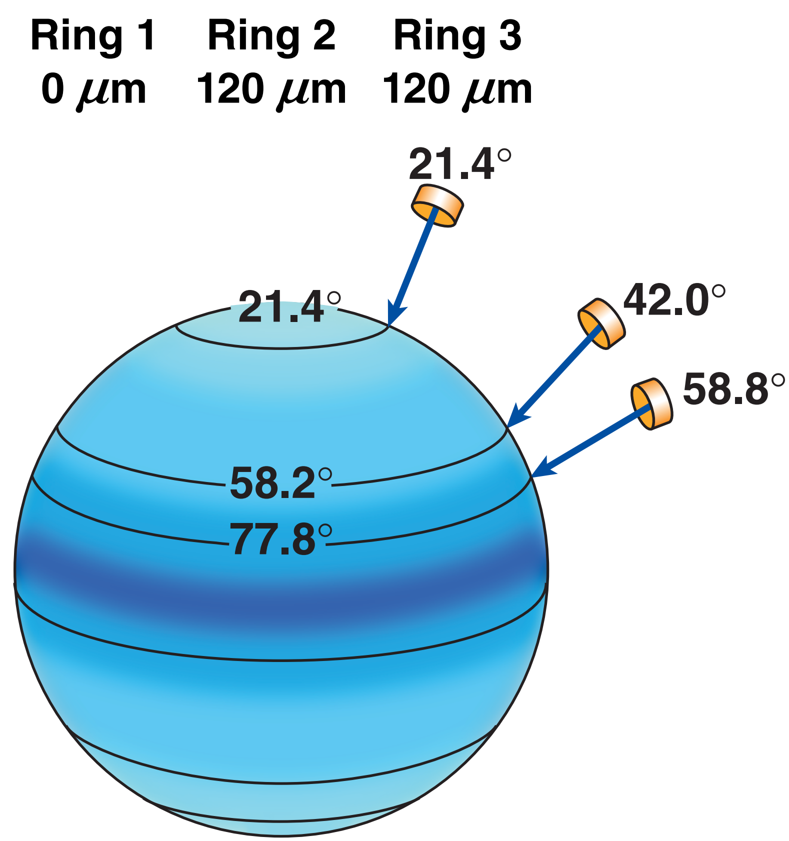


TC10418

Symmetry has been studied with shimmed shells

- A pointing scheme that minimizes nonuniformity is chosen with *DRACO*

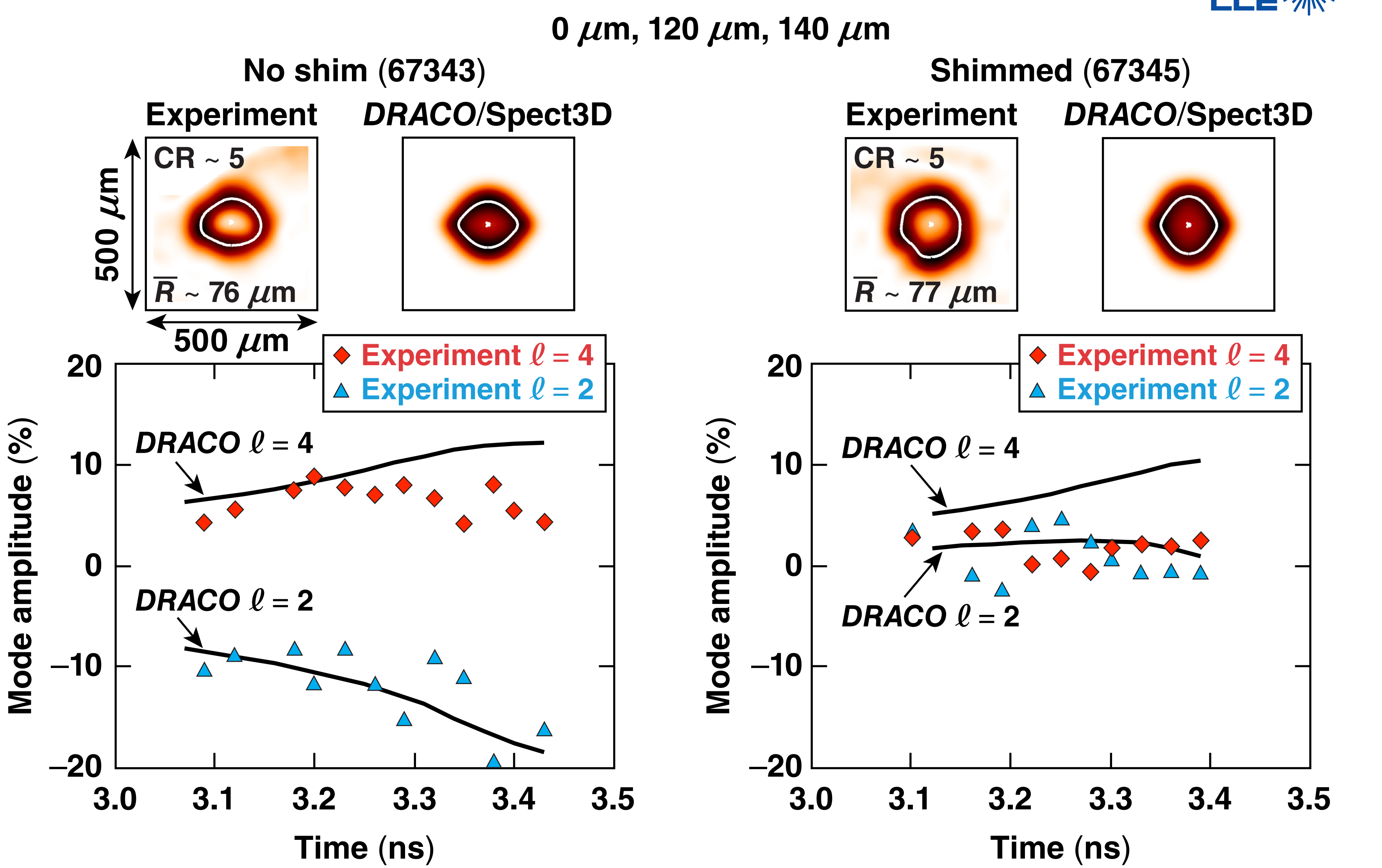




TC10144

F. J. Marshall *et al.*, Bull. Am. Phys. Soc. 57, 155 (2012).

Improved symmetry has been demonstrated with shimmed shells

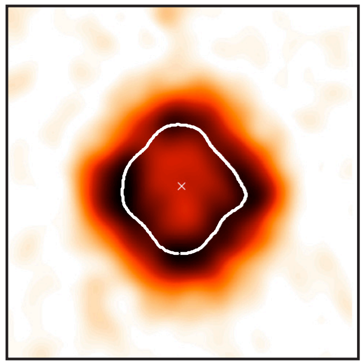


TC10362

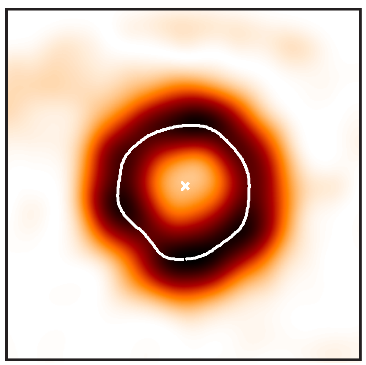
The best symmetry in PD implosions on OMEGA has been achieved with shimmed shells

X-ray radiographs with peak fits

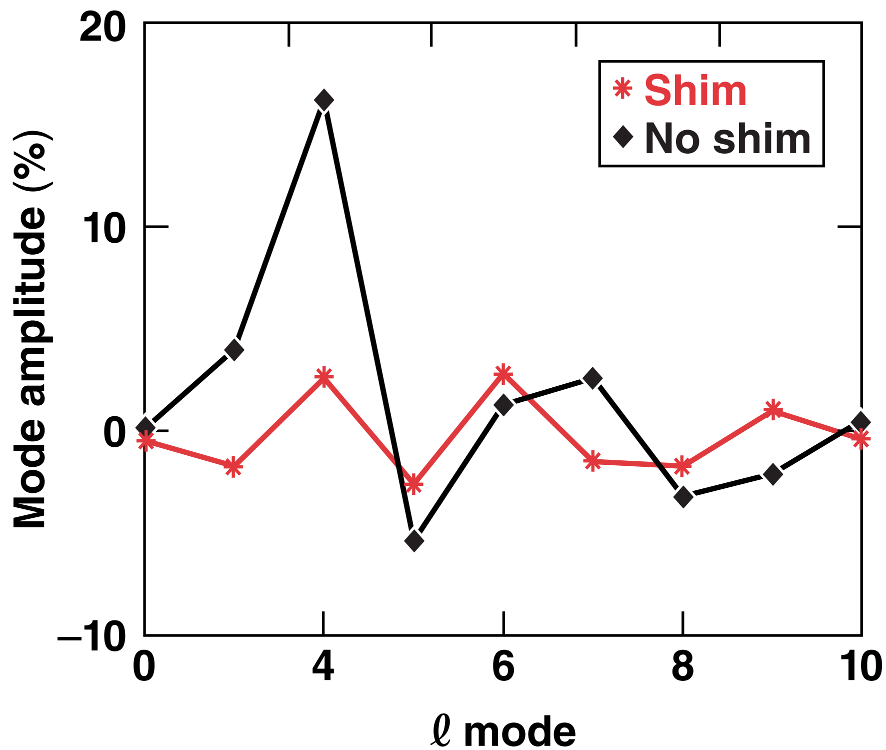
Shot 60661
No shim
90 μm, 133 μm, 133 μm
CR ~ 6
$\overline{R}$ = 65 μm



Shot 67345
With shim
0 μm, 120 μm, 140 μm
CR ~ 5
$\overline{R}$ = 77 μm

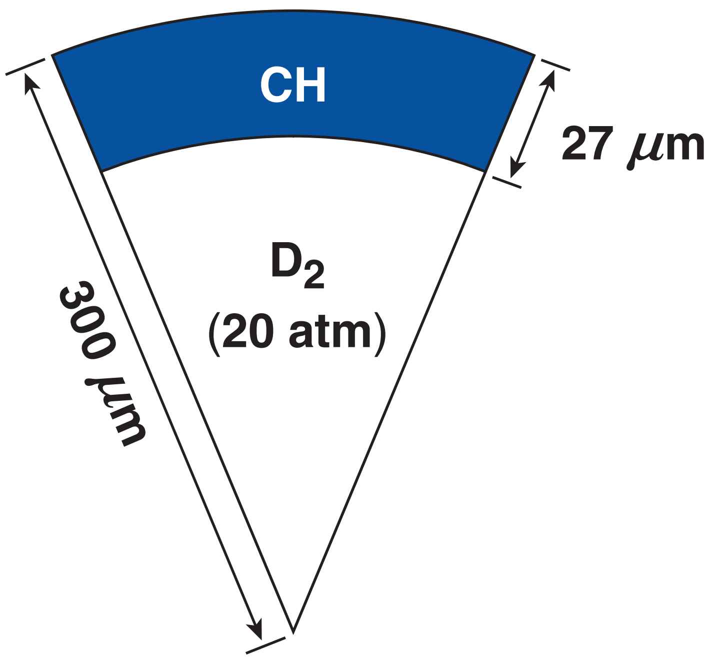


400 × 400-μm regions

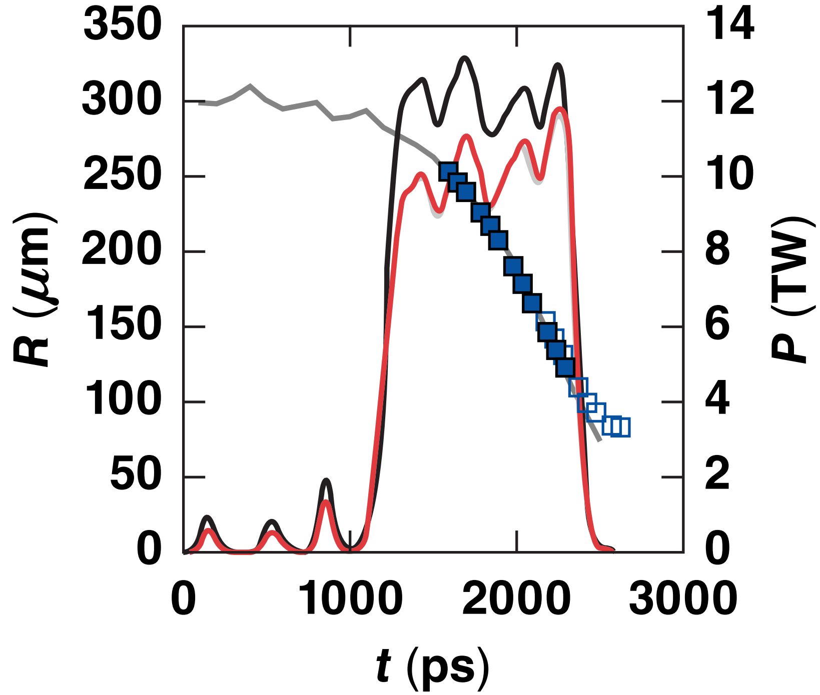


Experimentally inferred velocities are reproduced by *DRACO* simulations at high intensities

$I = 9 \times 10^{14}$ *W/cm*^{2}



Trajectory from framing camera images (68205, 68207)

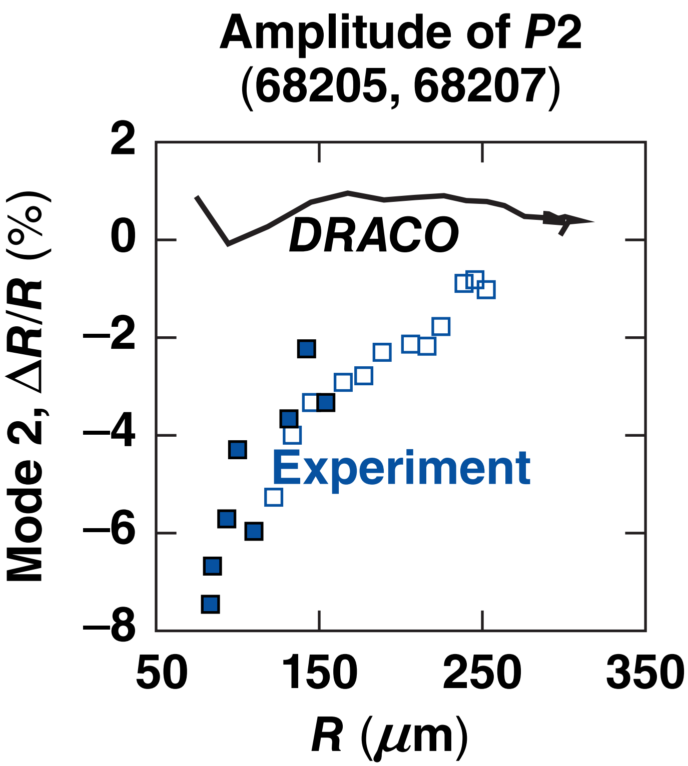


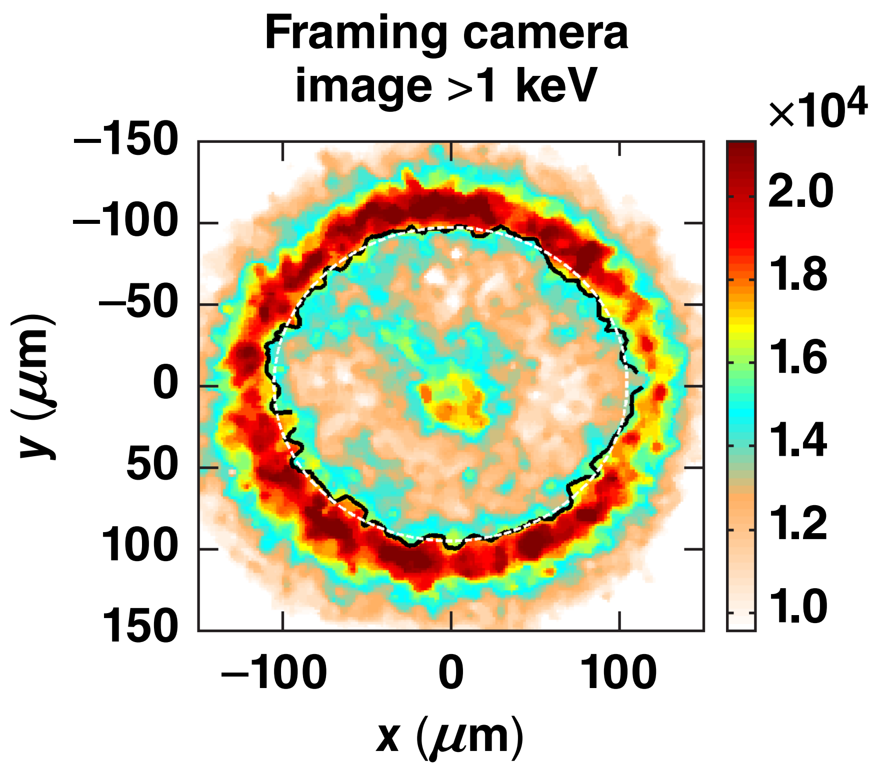
TC10552a

D. T. Michel *et al*, Rev. Sci. Instrum. 83 10E530 (2012).

The equater is under-driven in high intensity PD implosions compared to simulation

$I = 9 \times 10^{14}\ W/cm^2$

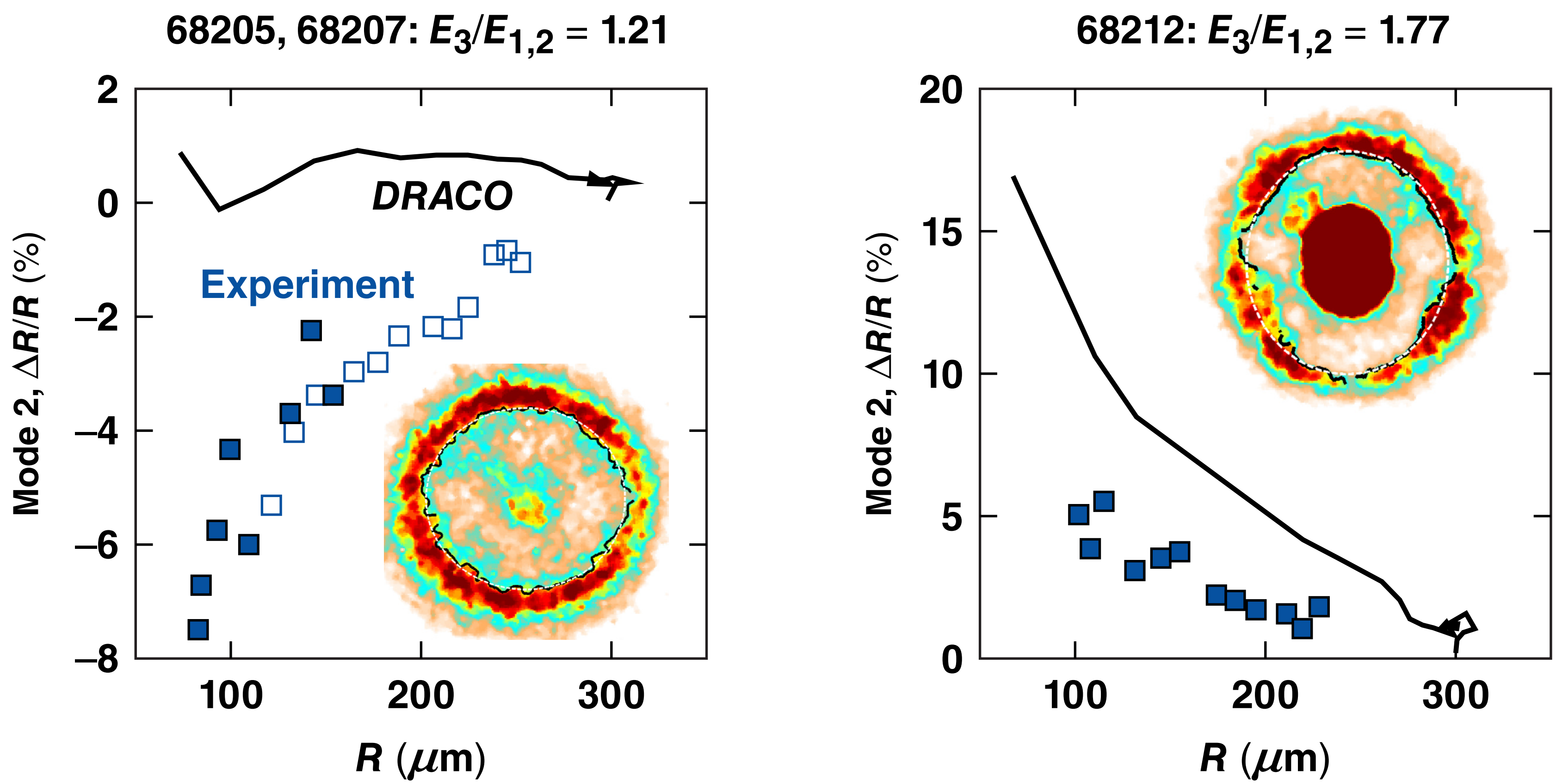




- The under-driven equator may be due to cross-beam-energy-transfer (CBET)

TC10552

Symmetry can be empirically changed in high-intensity OMEGA PD experiments



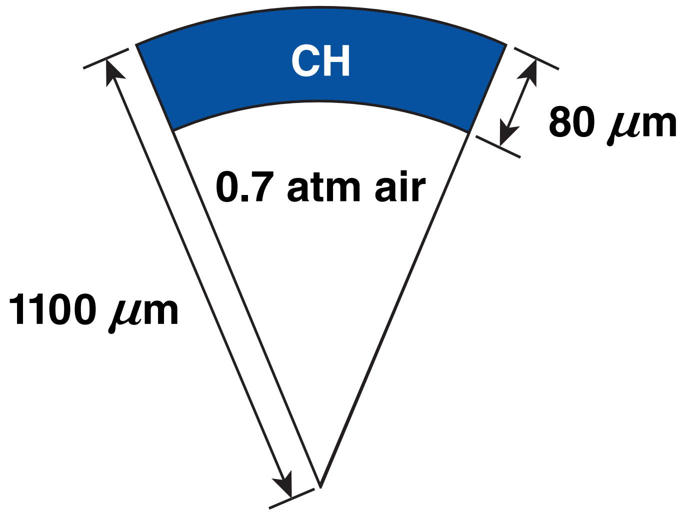
TC10553

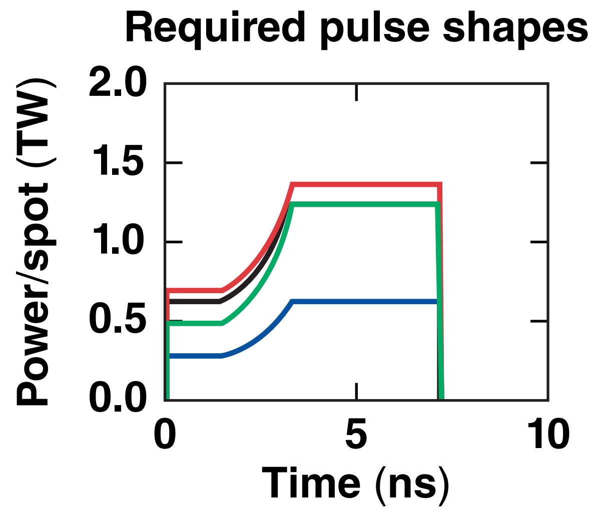
Outline

- Polar-drive (PD) implosion physics
- PD ignition
- OMEGA experiments
- **NIF experiments**
- Future plans

NIF experiments

The goal of NIF experiments is to understand energetics and other laser plasma interaction (LPI) issues that may affect target performance



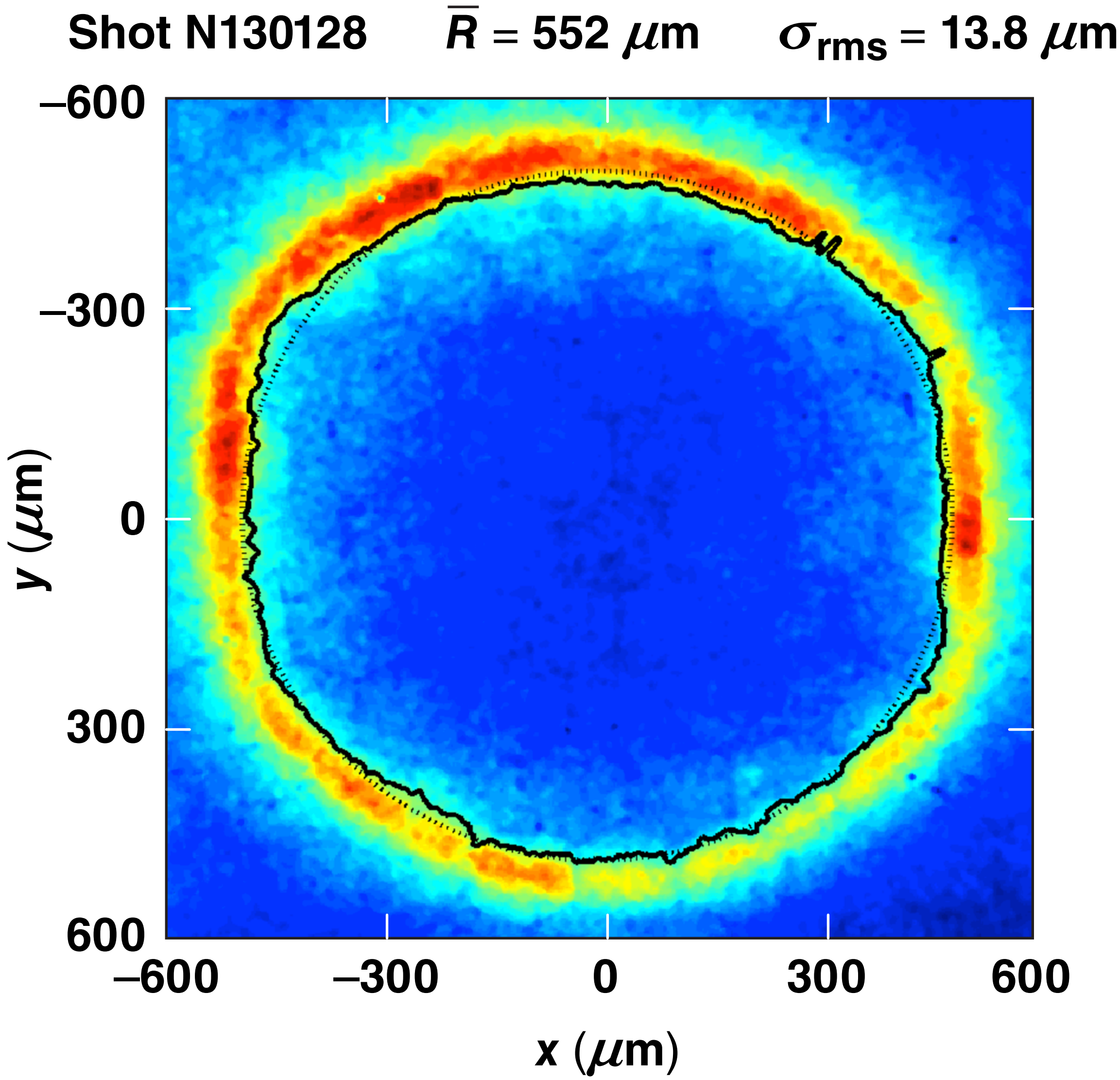


Energy (kJ)	350
On-target intensity ($\times 10^{14}$ W/cm^2)	4
Adiabat	3
Implosion velocity (cm/s)	1.8×10^7

- Beams are de-focused and re-pointed for better symmetry

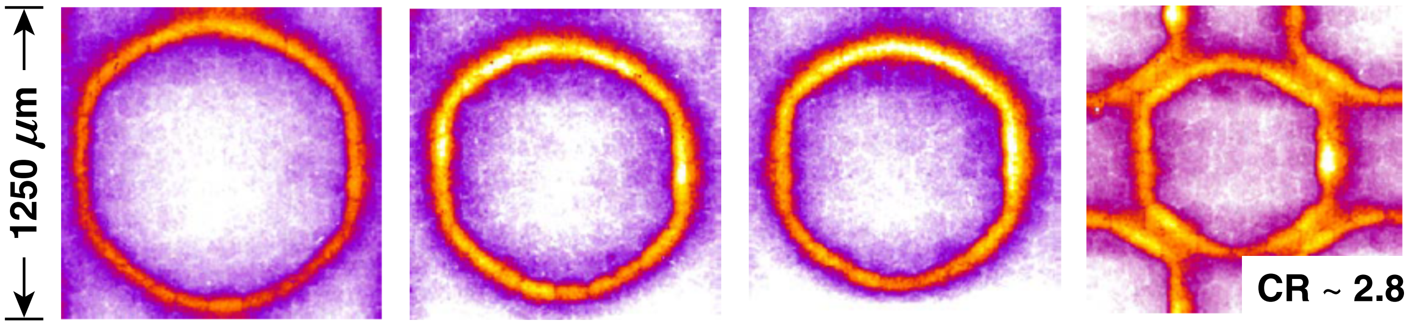
TC10554

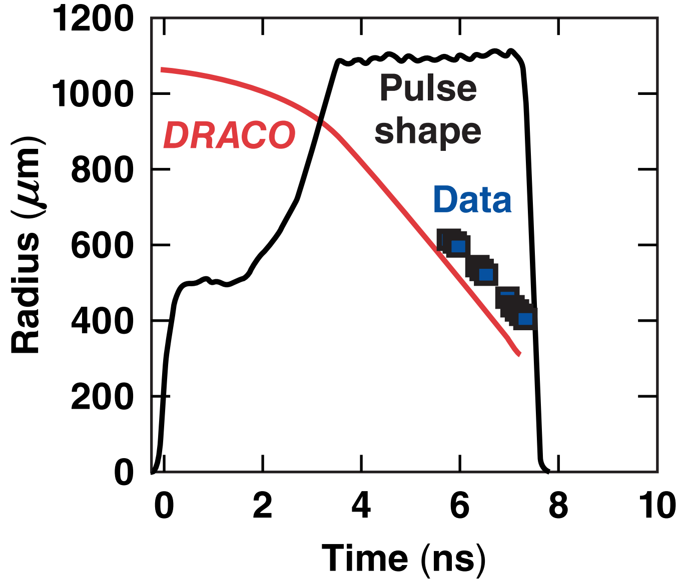
Framing-camera self-emission images from LLE's second polar-drive shot are almost round but show features ±30° from the equator

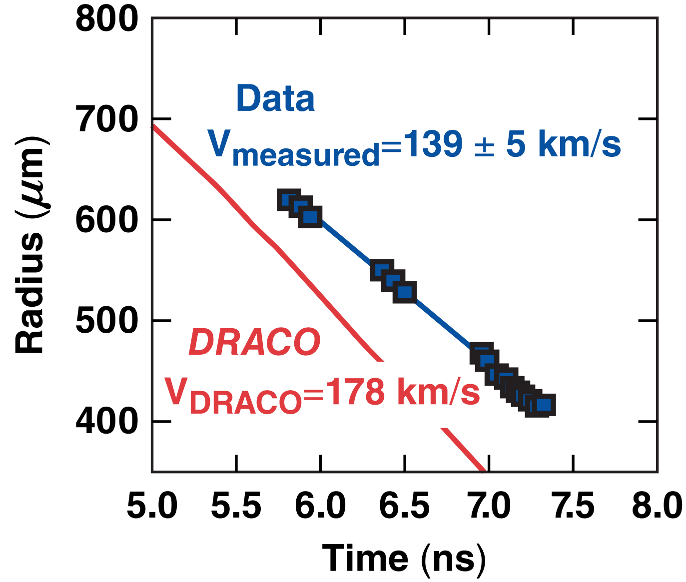


TC10471

Shell trajectory measurements show a reduction in velocity relative to simulations at $I \sim 4\times10^{14}$ W/cm^2

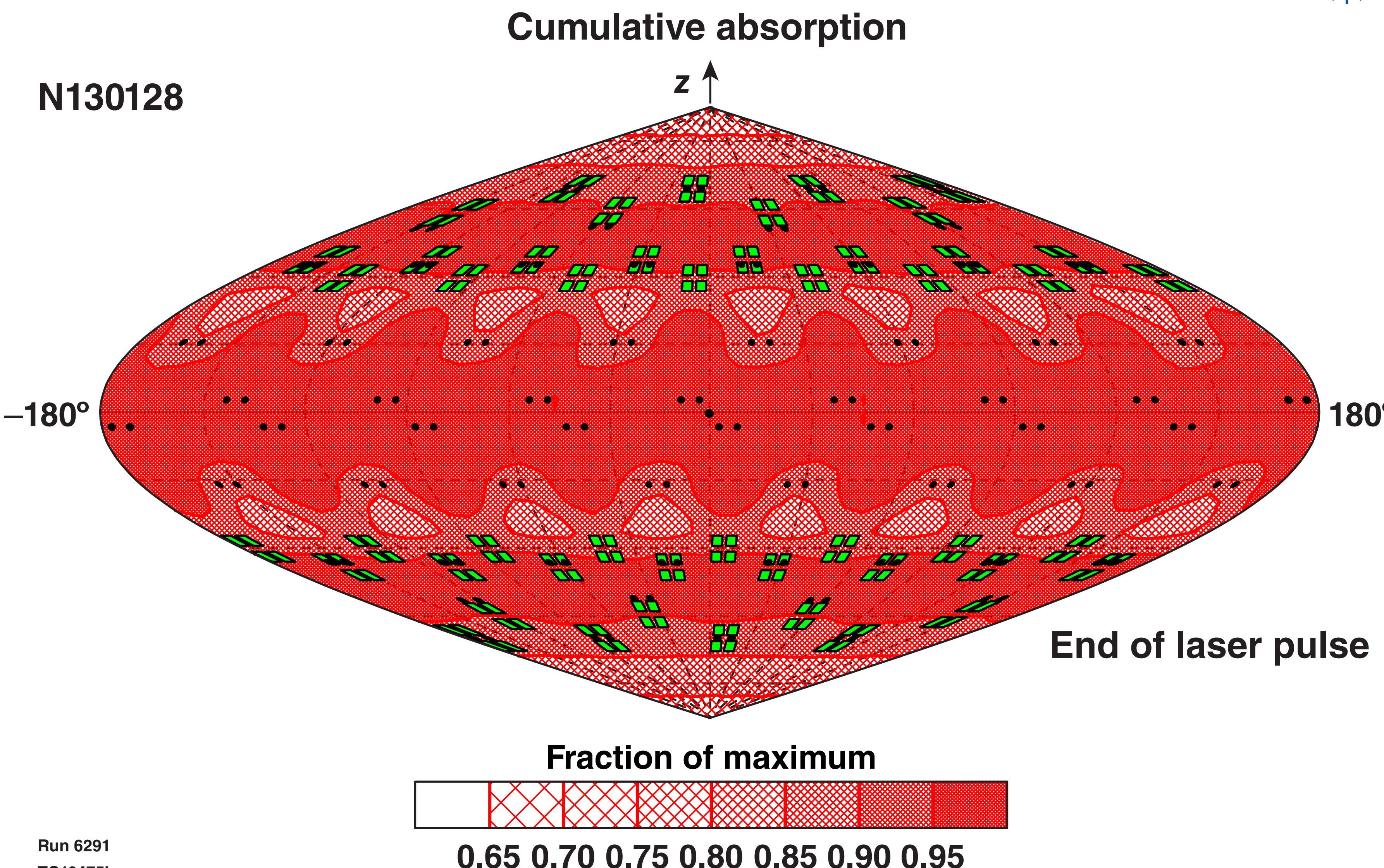






- An Ar-doped D_2 fill will be used in future shots to obtain neutron and x-ray bang time
- The reduced velocity may be due to the effect of CBET

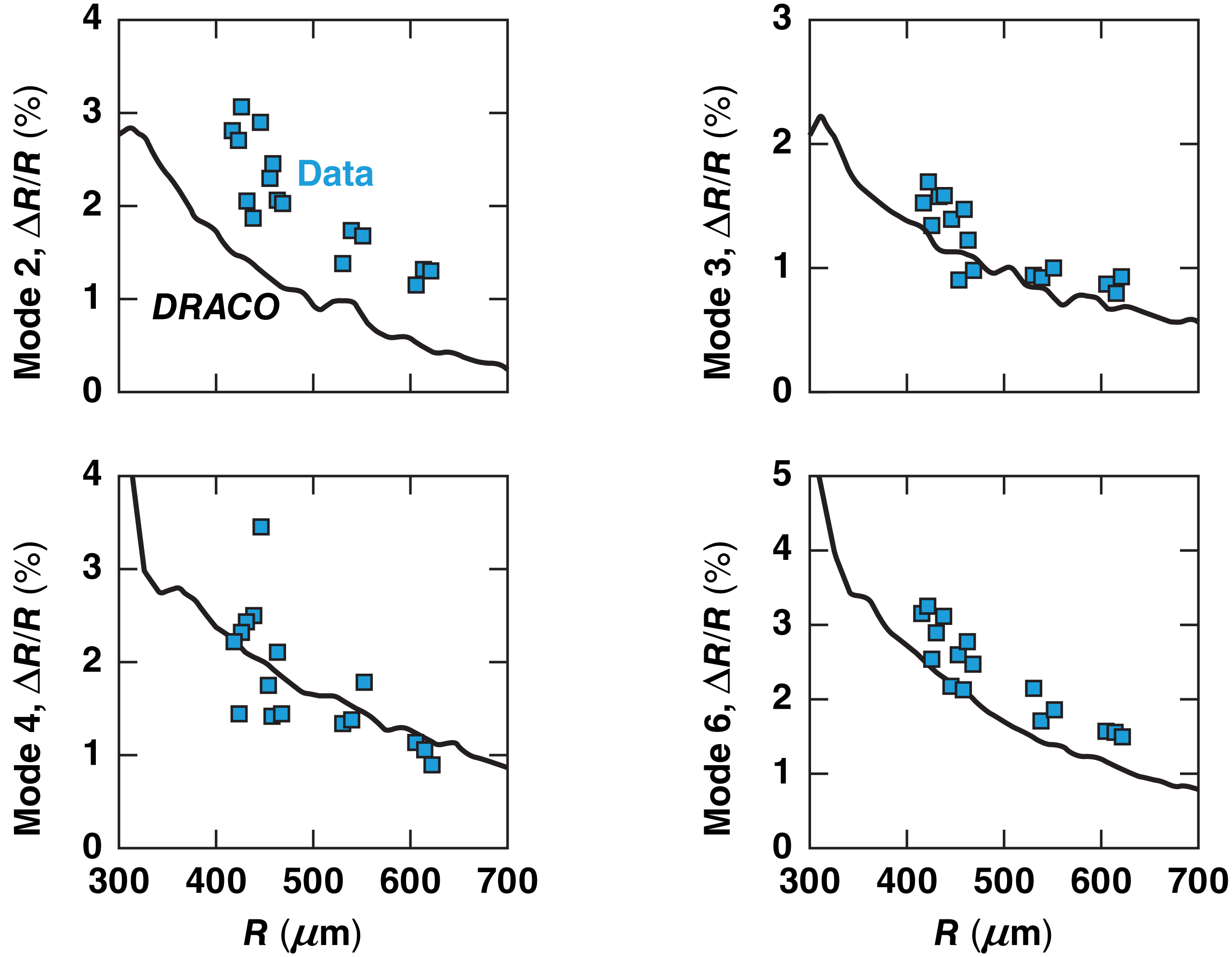
Azimuthal asymmetry must be considered while designing PD implosions



Run 6291

TC10475b

The measured symmetry trends are reproduced by the *DRACO* post-shot simulations



- The difference in mode 2 may be due to uncertainties in code input or physics such as CBET

Outline

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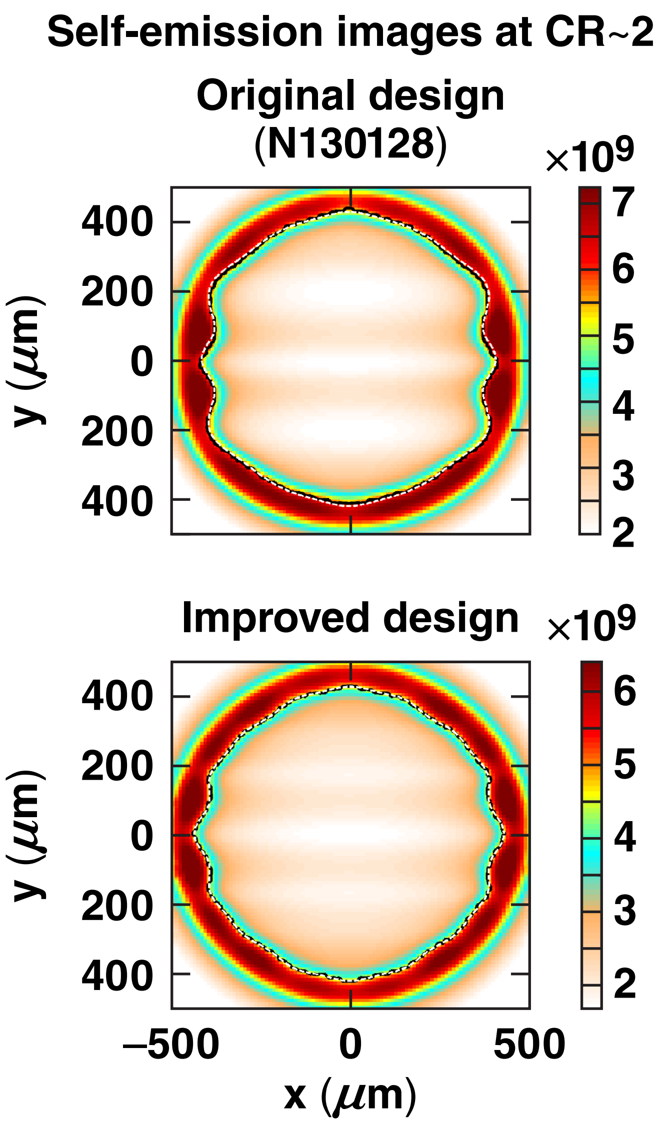
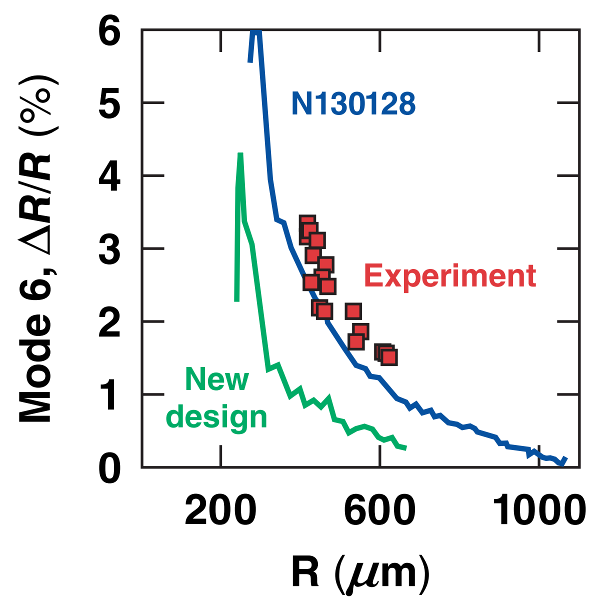
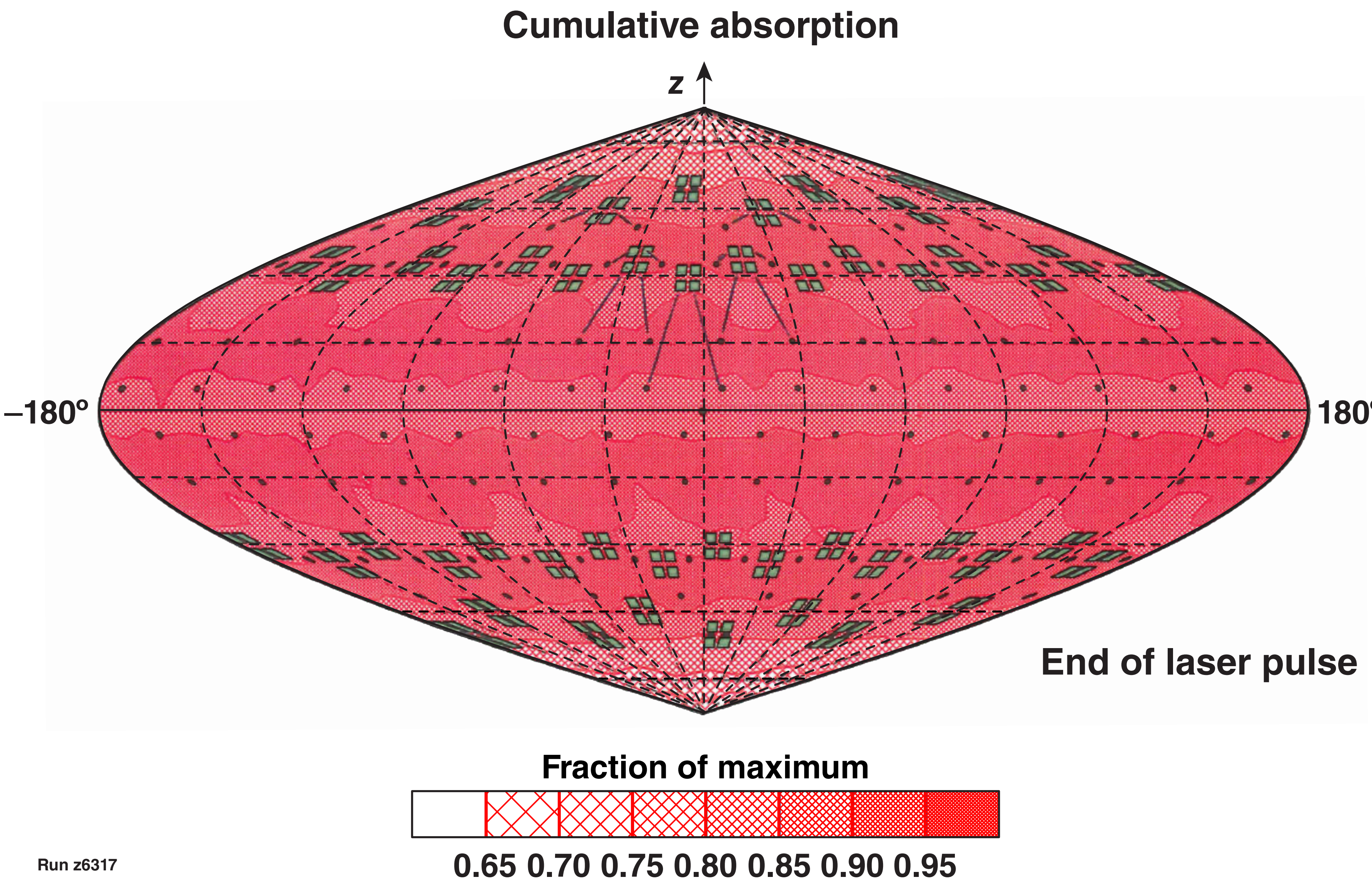
Improved uniformity can be obtained by changing pointing, defocus, and beam energies





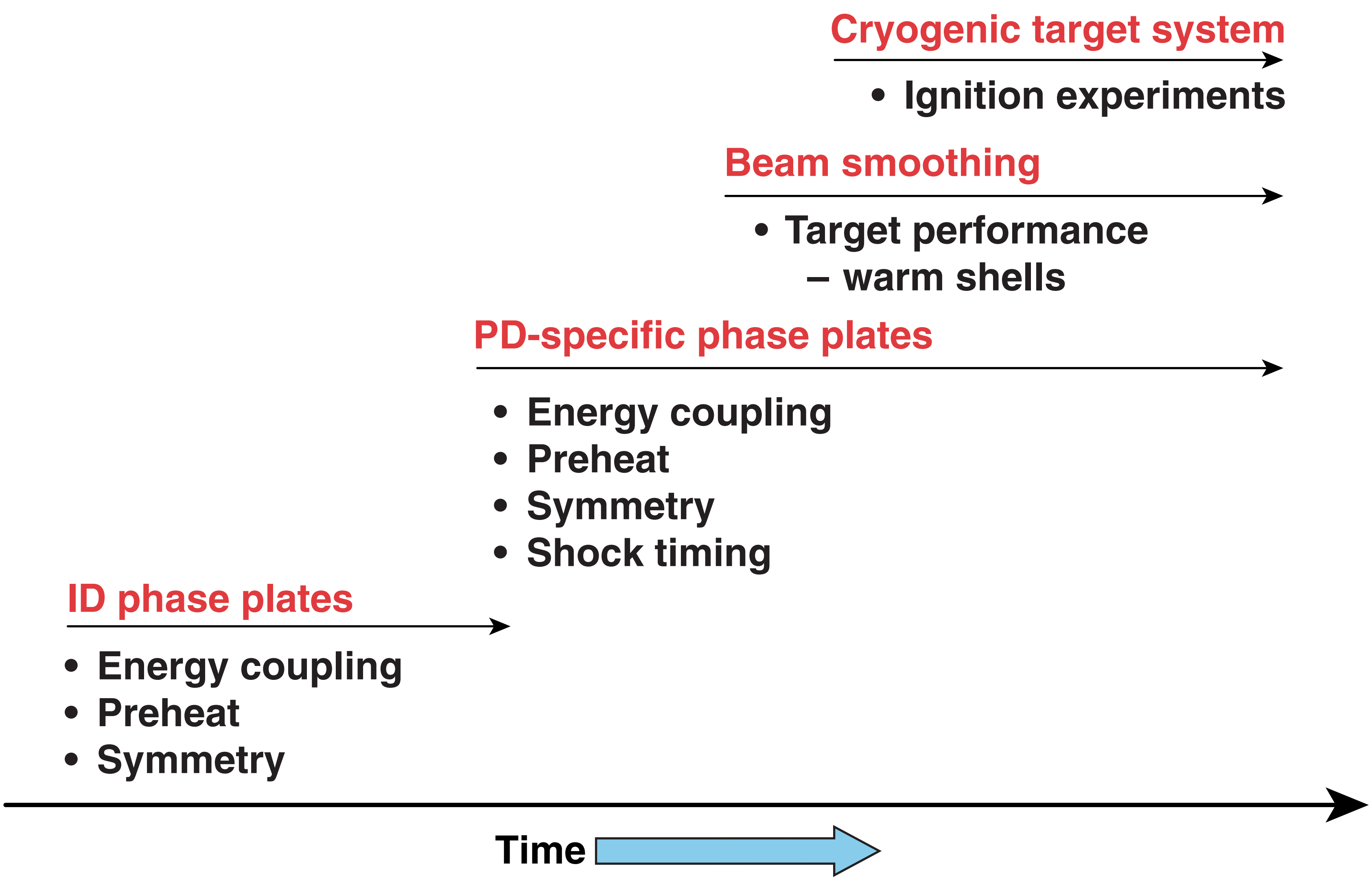
TC10557

Quad splitting in the azimuth reduces asymmetry



Run z6317
TC10558

NIF experiments will systematically explore the physics before the ignition campaign



TC10386

Summary/Conclusions

Implosion physics in polar-drive (PD) geometry is being explored on OMEGA and the NIF for a range of implosion parameters

UR LLE

- **Symmetry can be controlled in OMEGA PD implosions through beam pointing, energies, and target shimming**
- **NIF implosions indicate reduced shell velocities; simulations reproduce the observed shapes apart from the ℓ=2 mode**
- **Cryogenic PD implosions on OMEGA will begin later this year**
- **NIF implosions will systematically explore intensity and coronal density scale-length regimes with the goal of reaching ignition-relevant parameters**