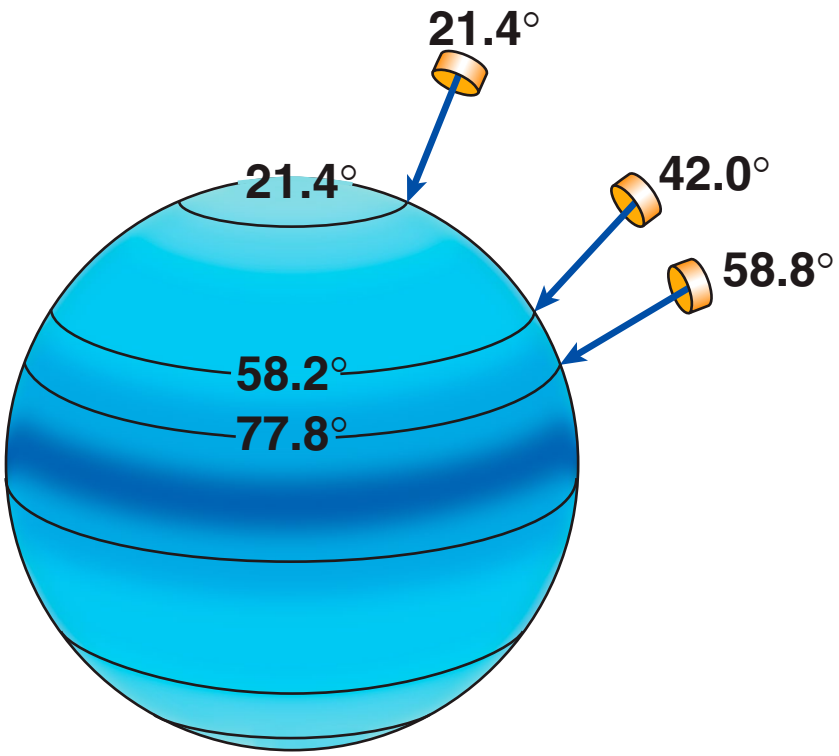
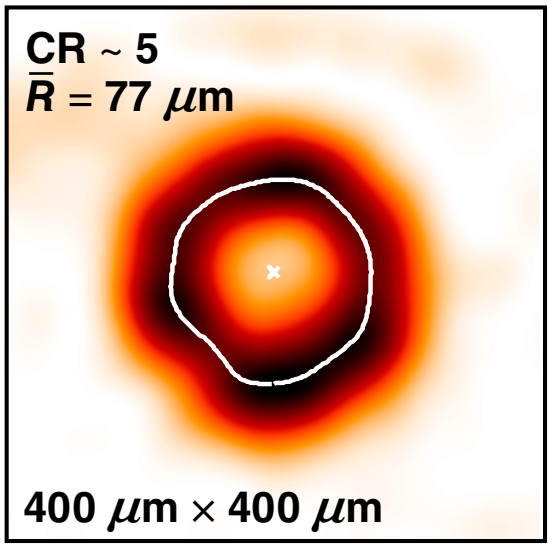
# Polar Drive on OMEGA and the NIF

UR LLE

**OMEGA polar-drive geometry**




**Backlit x-ray image**
**OMEGA polar-drive implosion**





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Summary

# OMEGA and NIF experiments are setting the physics basis for polar-drive (PD) ignition

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- OMEGA experiments are addressing key aspects of PD ignition
  - areal density and symmetry are well-modeled with the hydrodynamic code *DRACO*
- PD cryogenic implosion studies will begin in the near term
- Better scaling of OMEGA implosions with the National Ignition Facility (NIF) PD ignition designs will be obtained with new PD-specific phase plates
- Early NIF experiments will be used to study the symmetry and laser–plasma interactions

# Collaborators

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**J. A. Frenje and R. D. Petrasso**

**The Plasma Science and Fusion Center**
**Massachusetts Institute of Technology**

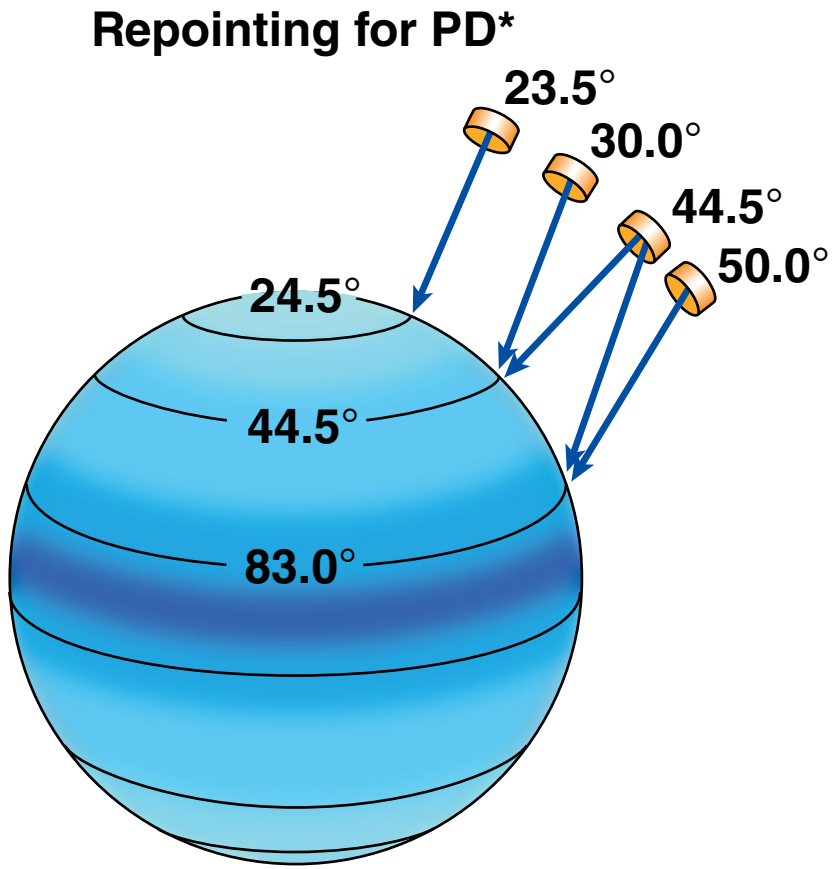
# Outline

- Polar drive
- OMEGA experiments
- Future PD OMEGA experiments
- Early NIF experiments

# Outline

- **Polar drive**
- OMEGA experiments
- Future PD OMEGA experiments
- Early NIF experiments

# Polar drive (PD) enables direct-drive ignition experiments on the NIF in the x-ray-drive configuration

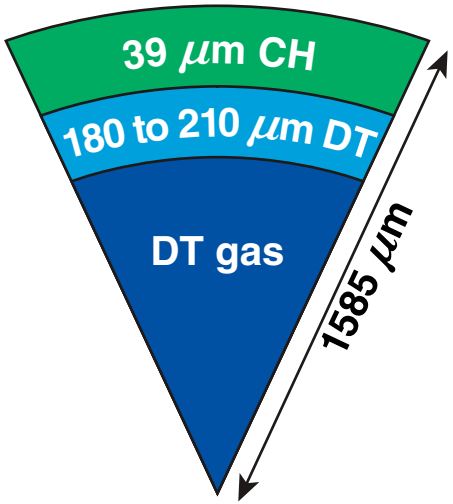



- Oblique irradiation near the equator is at lower densities ($n = n_{crit} \times \cos^2\theta_{inc}$)
  - nonradial beams
  - reduced absorption
  - reduced hydro-efficiency
  - lateral heat flow



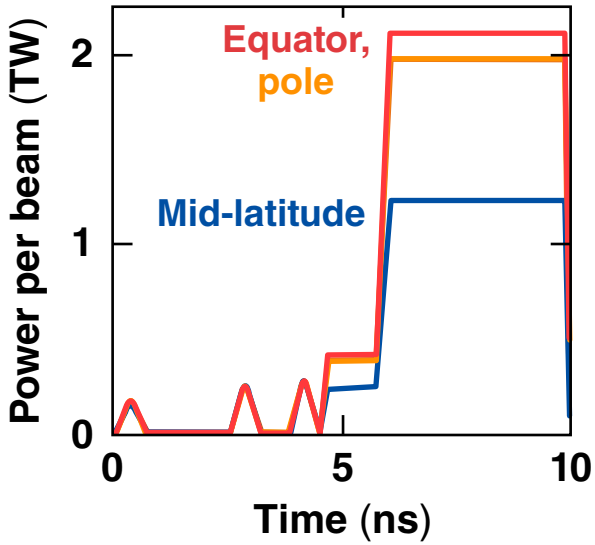
*S. Skupsky *et al.*, Phys. Plasmas 11, 2763 (2004).

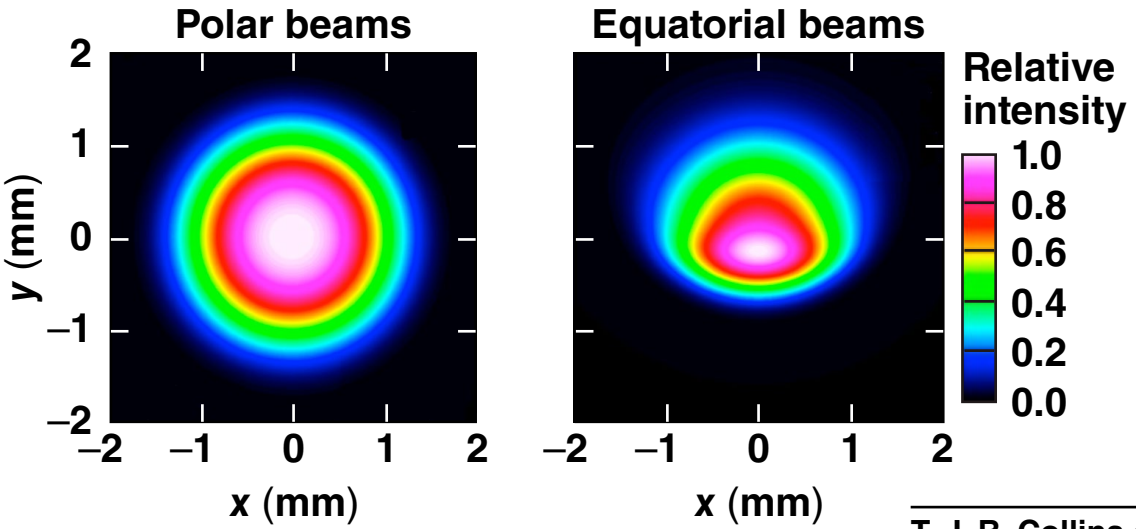
# Tailored laser pulse shapes and beam profiles are used to adequately irradiate the equator in the ignition design




| | |
|---|---|
| $E$ | 1.5 MJ |
| $V_{imp}$ | (3.5 to 4.3) × $10^7$ cm/s |
| $\alpha_{inn}$ | 2.2 to 2.6 |

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



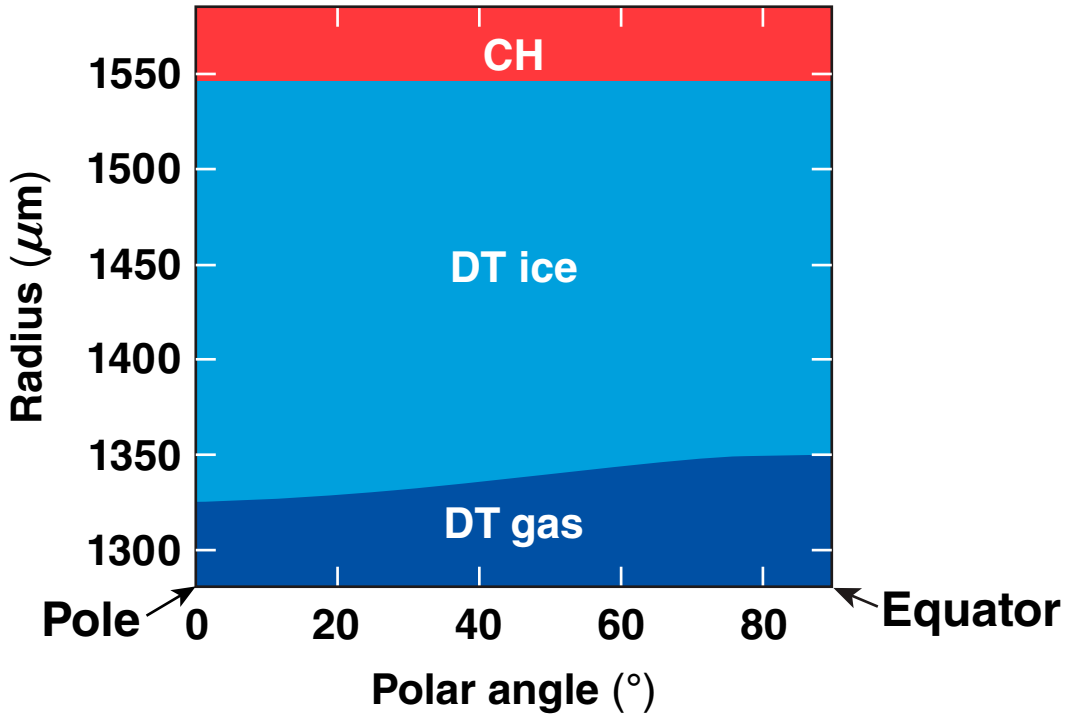




- Custom spot shapes preferentially irradiate the equator, improving symmetry

T. J. B. Collins *et al.*, Phys. Plasmas 19, 056308 (2011);
T. J. B. Collins, JO4.00010, this conference.

TC10138

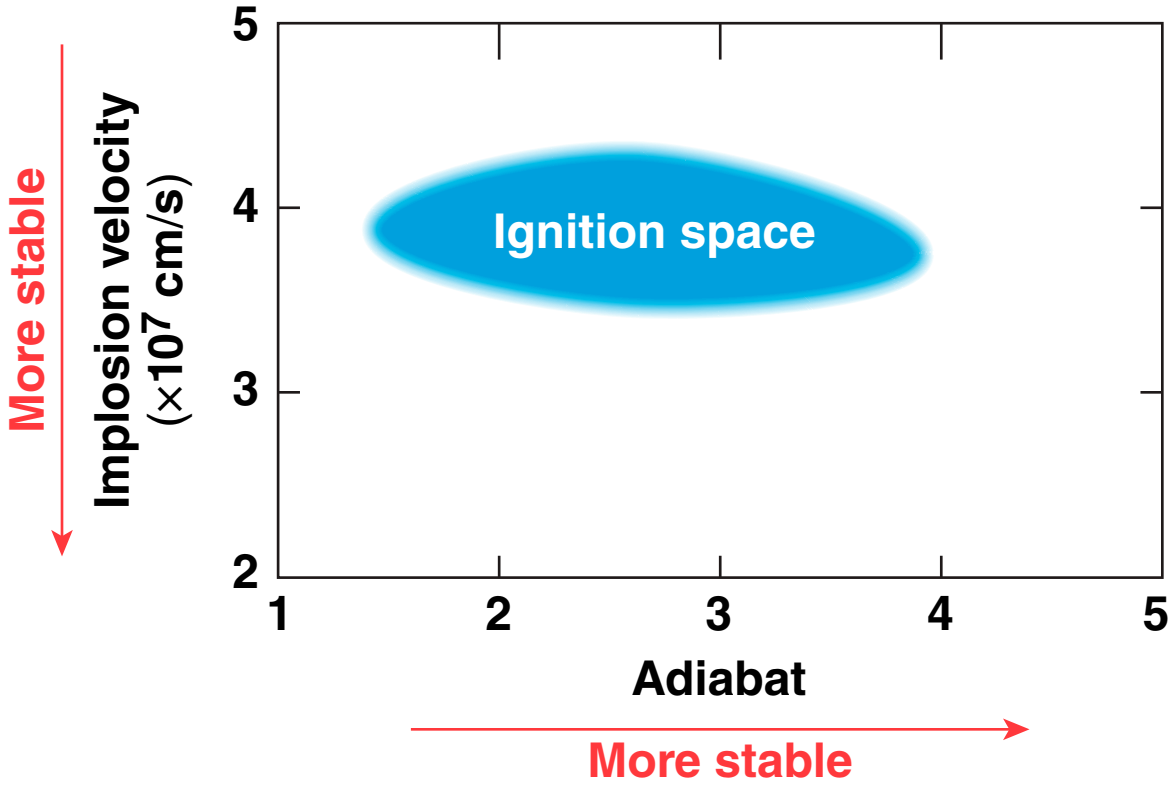
# Shimming can provide an additional parameter to control symmetry




- 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);
T. J. B. Collins, JO4.00010, this conference.

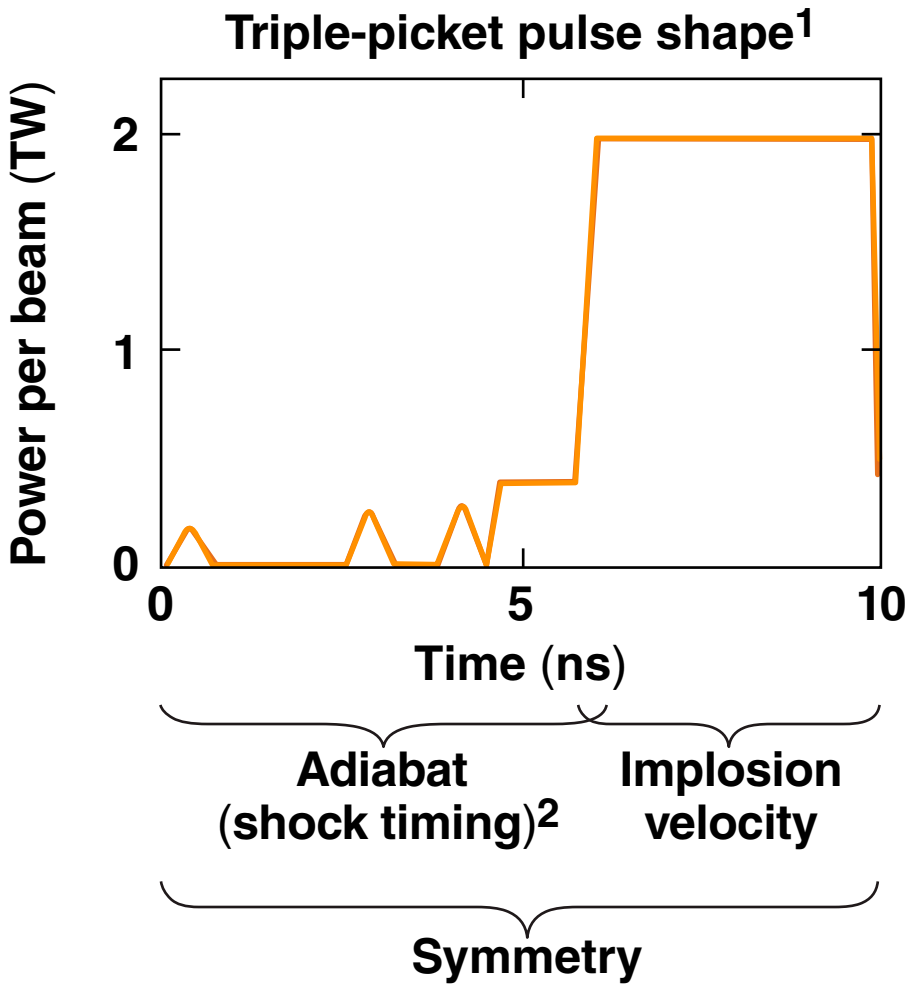
# PD ignition space is similar to symmetric drive




- 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

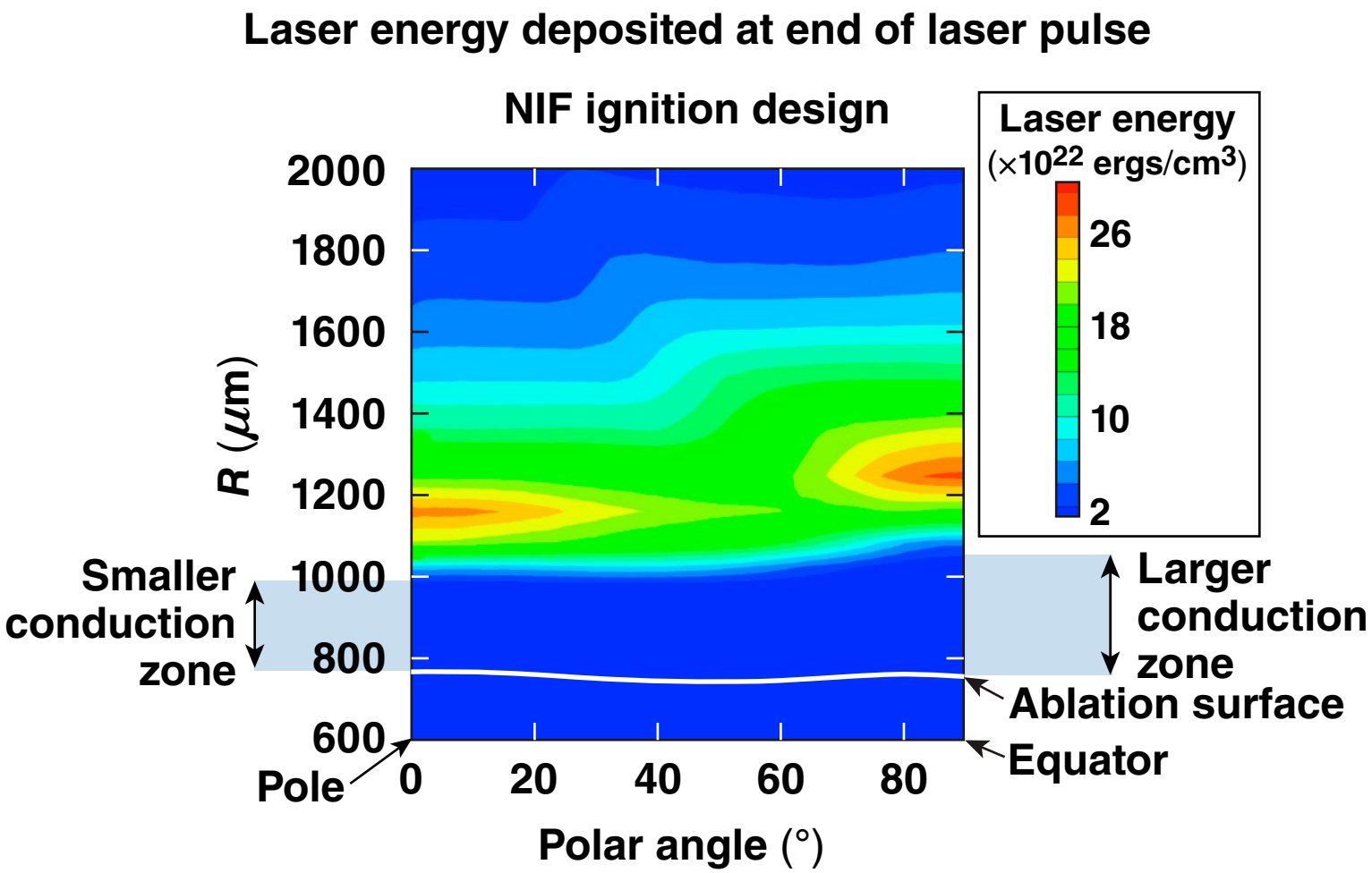
T. C. Sangster, NI2.00002, this conference
V. N. Goncharov, JO4.00001, this conference

# Both shocks and the main drive contribute to asymmetry




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

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

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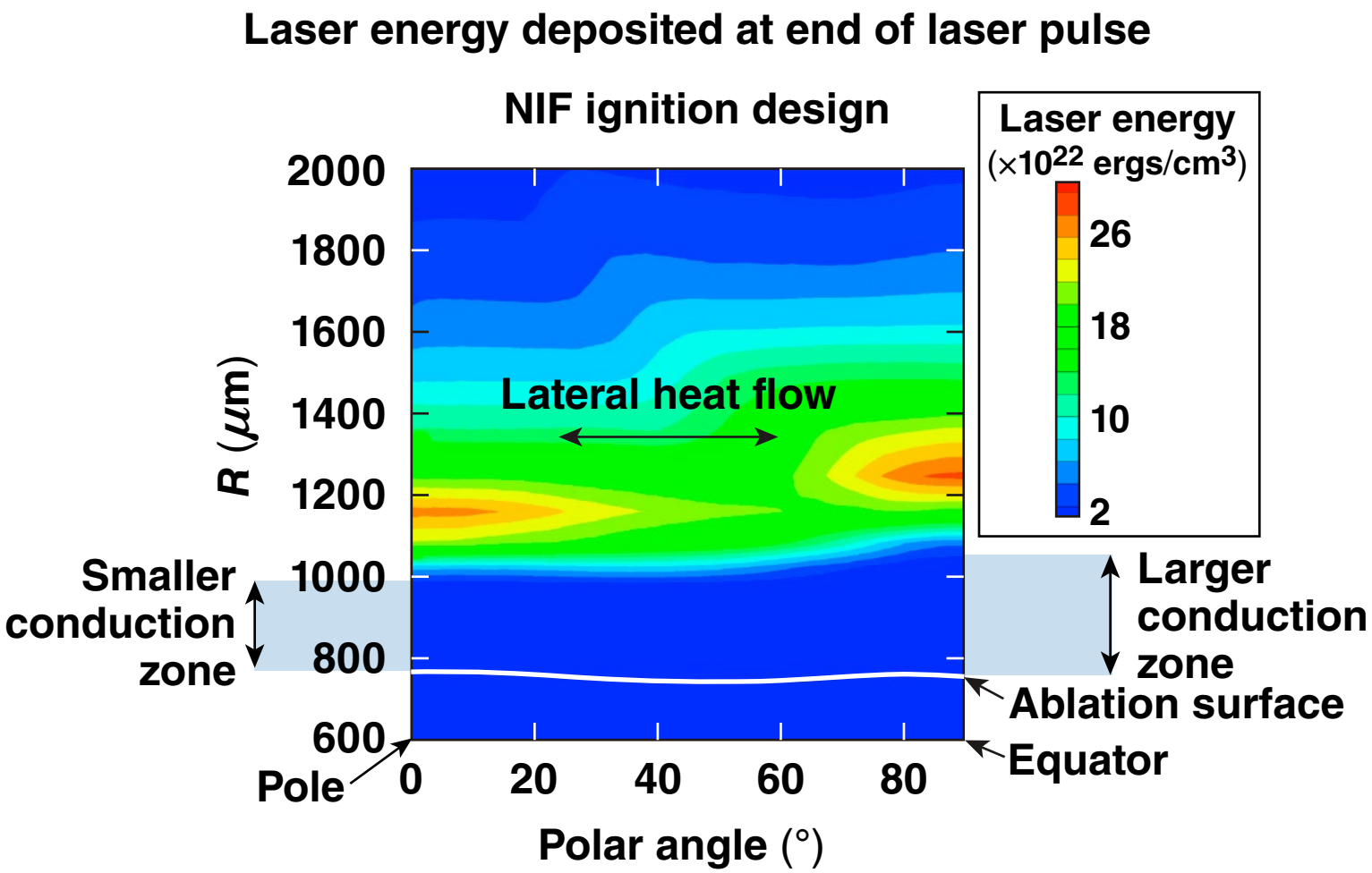
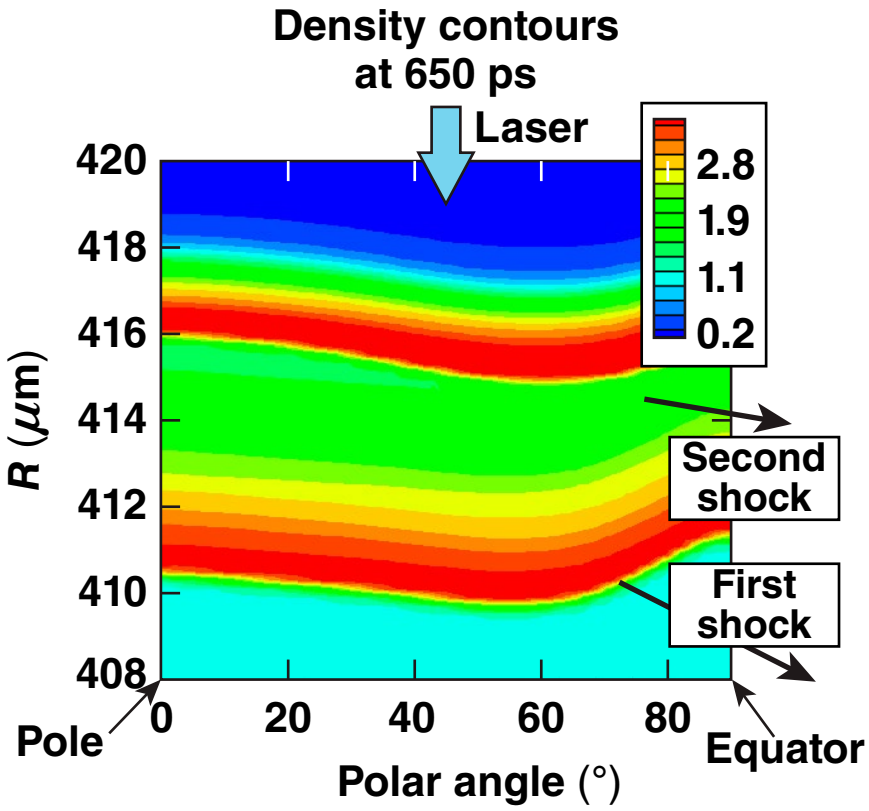
# Models of laser deposition and heat conduction are crucial to determining symmetry of implosion

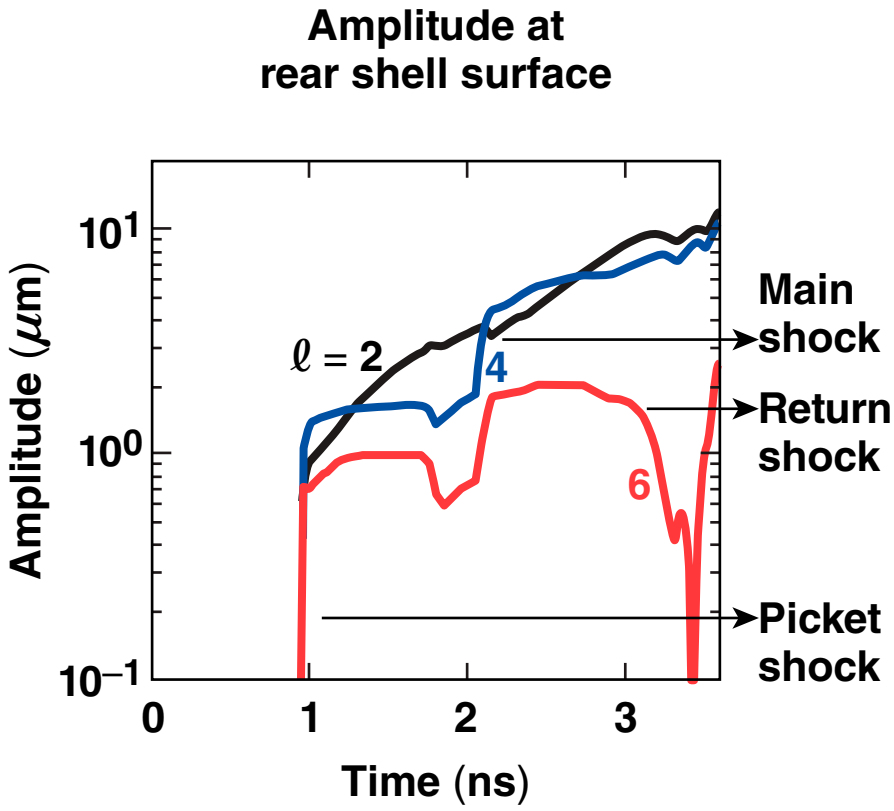



TC10140a

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

- Nonuniform shock fronts contribute significantly to the asymmetry




TC10357

# Outline

- Polar drive
- **OMEGA experiments**
- Future PD OMEGA experiments
- Early NIF experiments

# 40 OMEGA beams emulate the 48-quad (192-beam) NIF configuration

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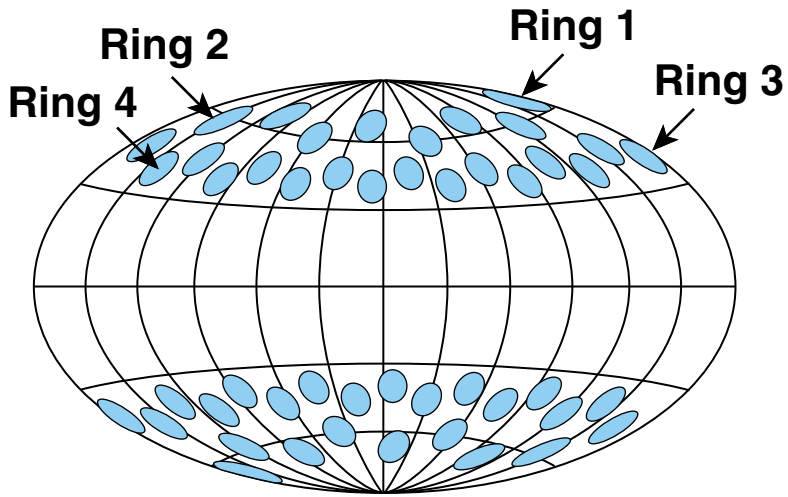
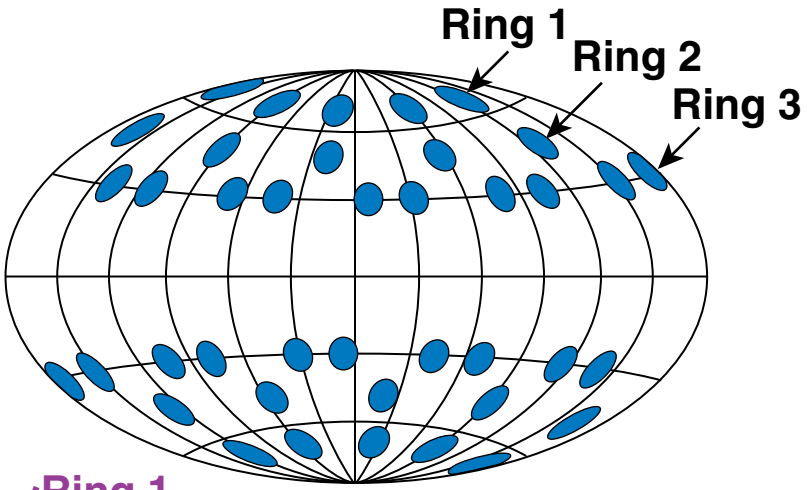
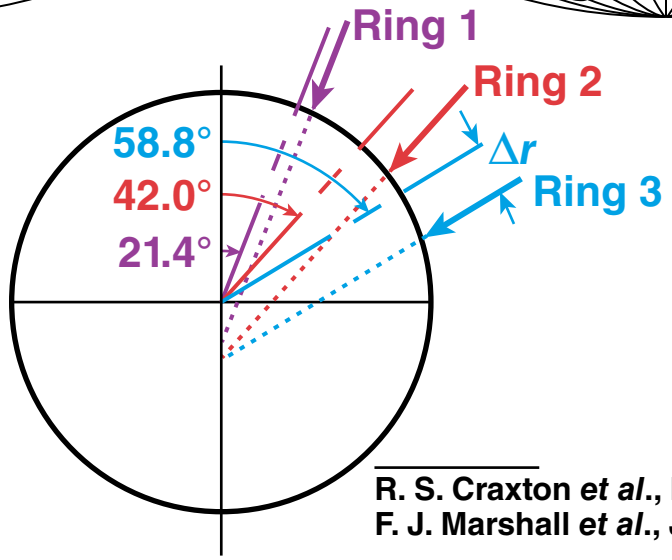
## NIF configuration




## OMEGA PD configuration



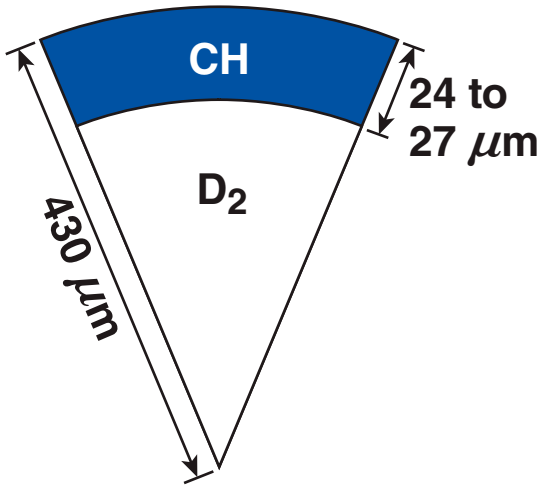

- The remaining beams are used to backlight the shell



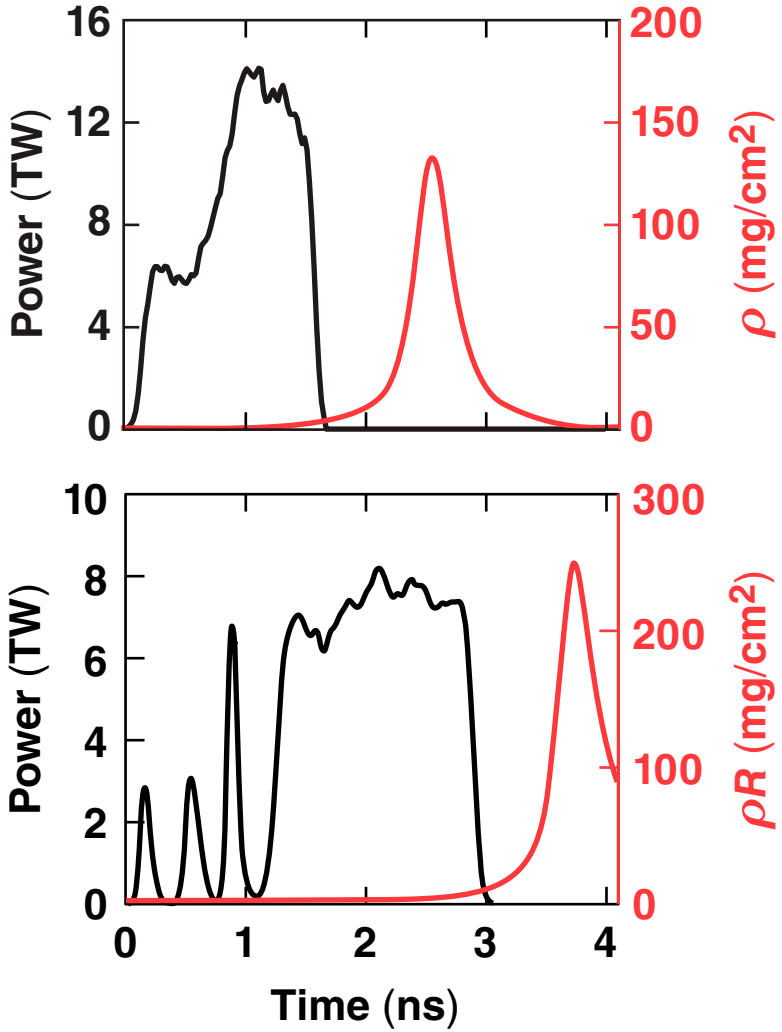

- Beam shifts are parametrized by: $\Delta r_1$, $\Delta r_2$, $\Delta r_3$,

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

# 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.

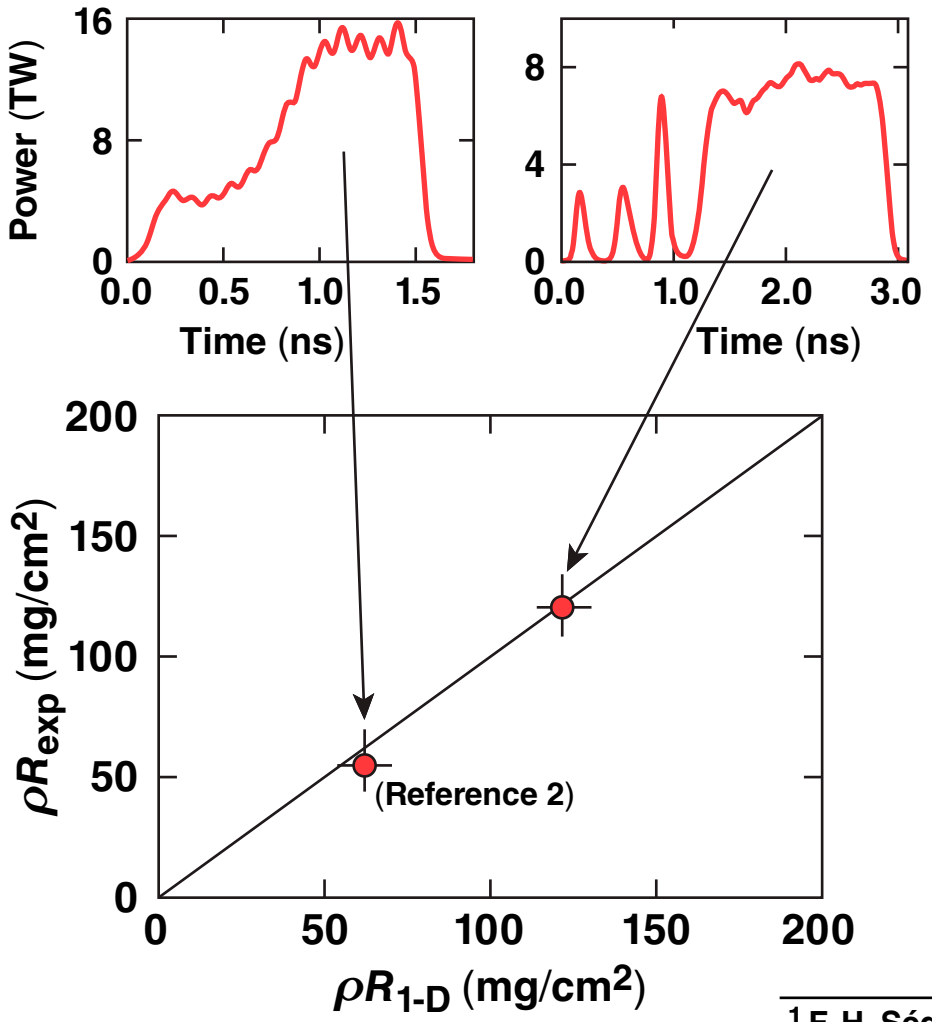



$I = 6 \times 10^{14}$ W/cm$^2$
CR ~ 12
$E$ ~ 14 kJ
$\alpha$ ~ 3

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

TC10141

# Areal density[1] is well modeled over a range of different pulse shapes in the PD configuration



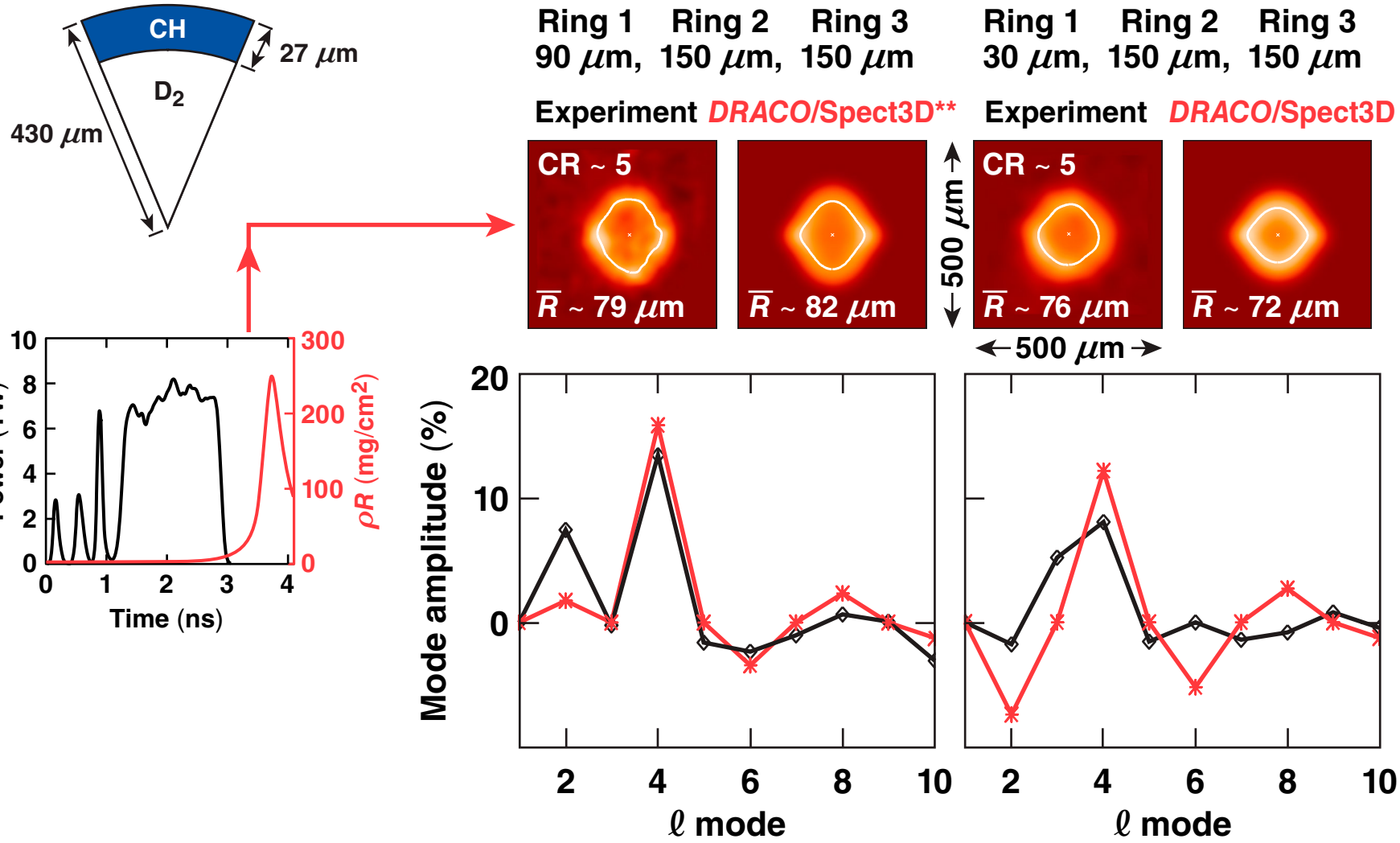

- **Areal density depends on the adiabat[3]**

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

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

Symmetry

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

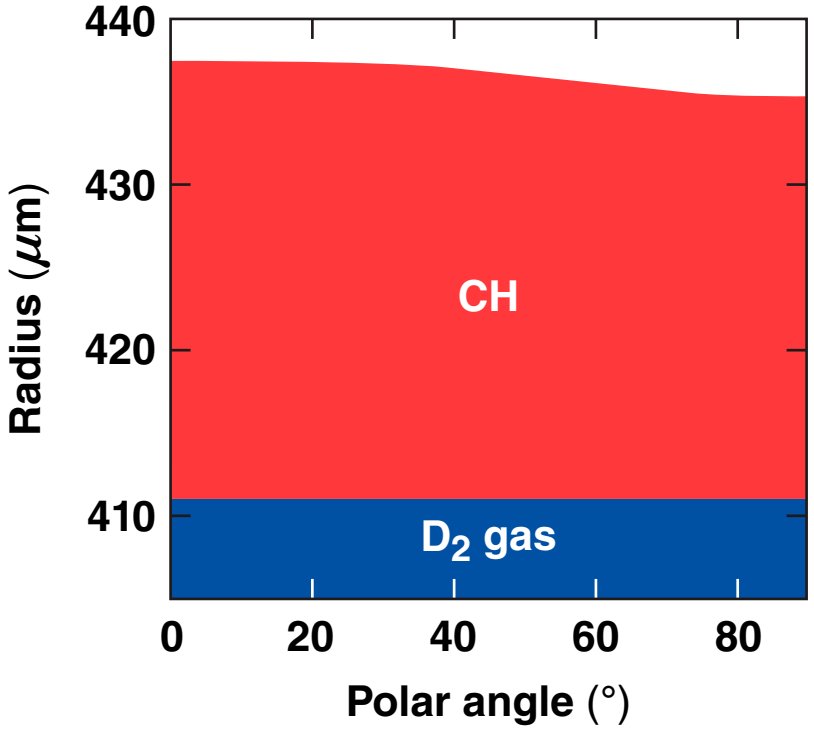


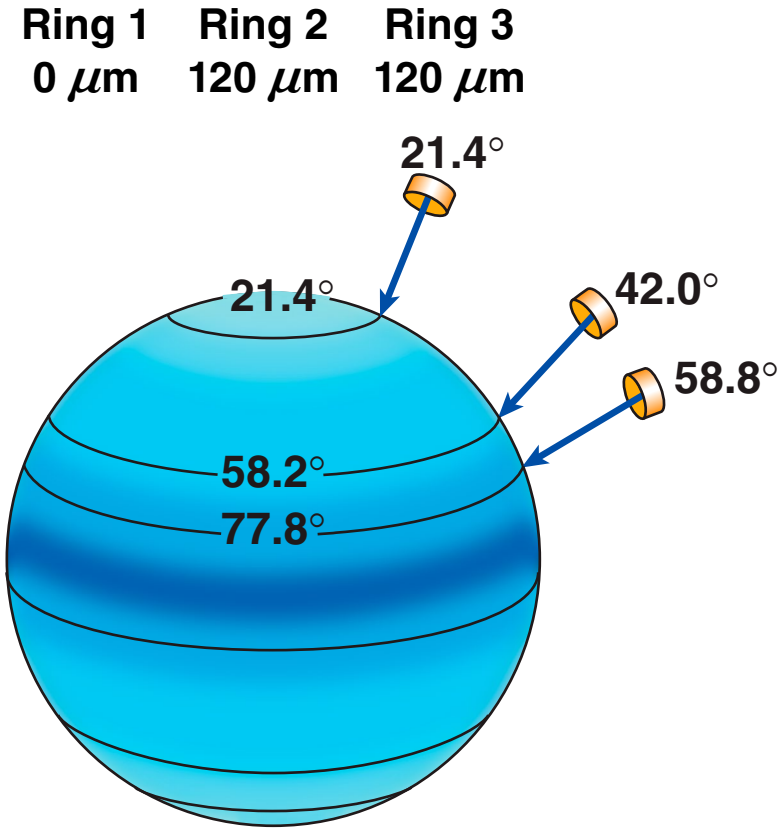

TC10355

*P. B. Radha *et al.*, "Polar Drive on OMEGA," submitted to the European Physical Journal.
**Spect3D – J. J. MacFarlane *et al.*, High Energy Density Phys. 3, 181 (2007).

# Symmetry has been studied with shimmed shells

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

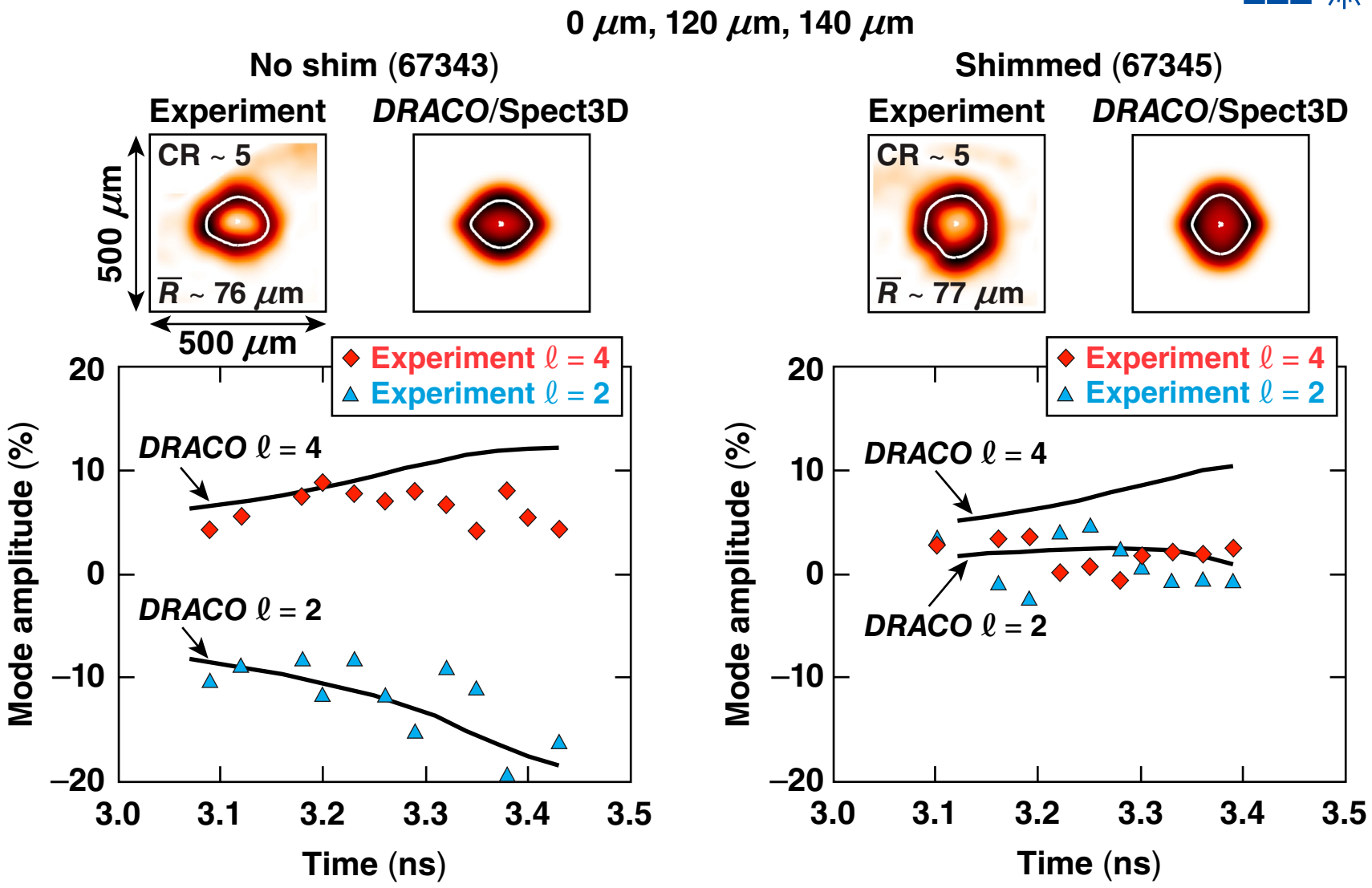



TC10144

F. J. Marshall, JO4.00015, this conference

# Improved symmetry has been demonstrated with shimmed shells




TC10362

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

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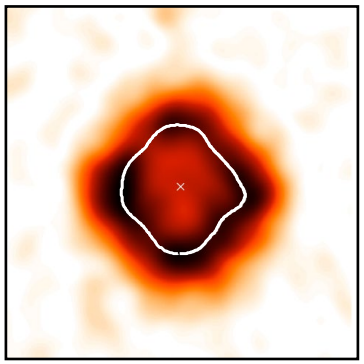
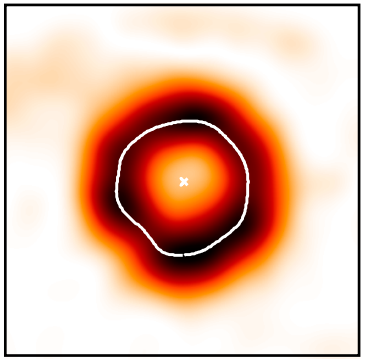
X-ray radiographs with peak fits

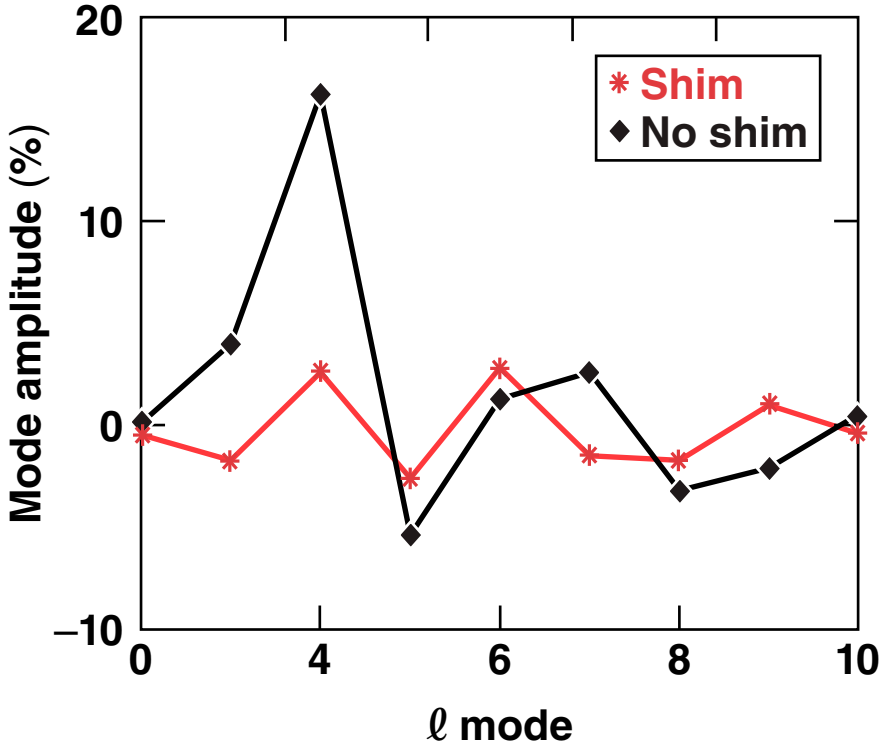
Shot 60661
No shim
90 $\mu$m, 133 $\mu$m, 133 $\mu$m
CR ~ 6
$\overline{R}$ = 65 $\mu$m



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



400 × 400-$\mu$m regions

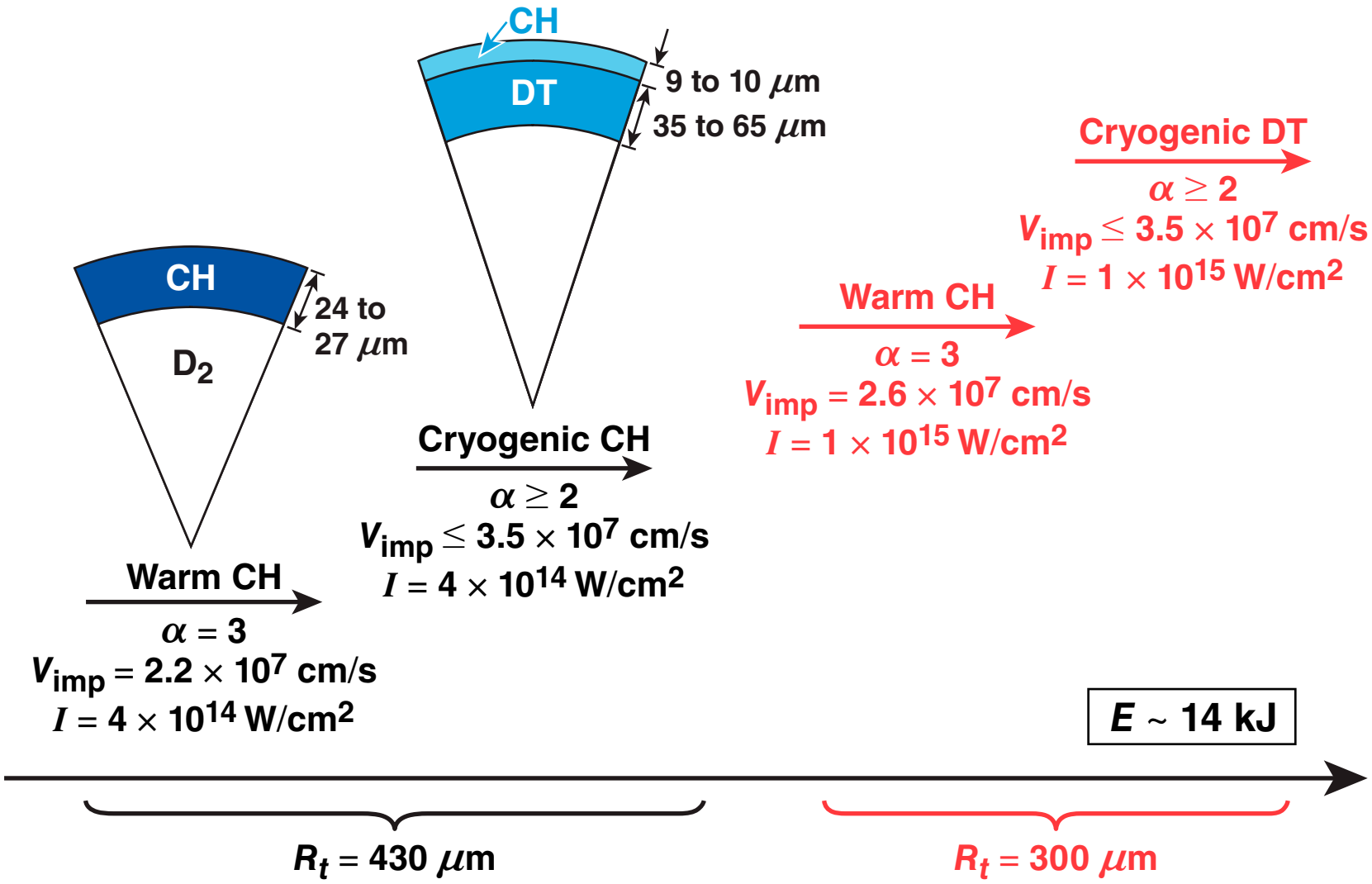



TC10145

# Outline

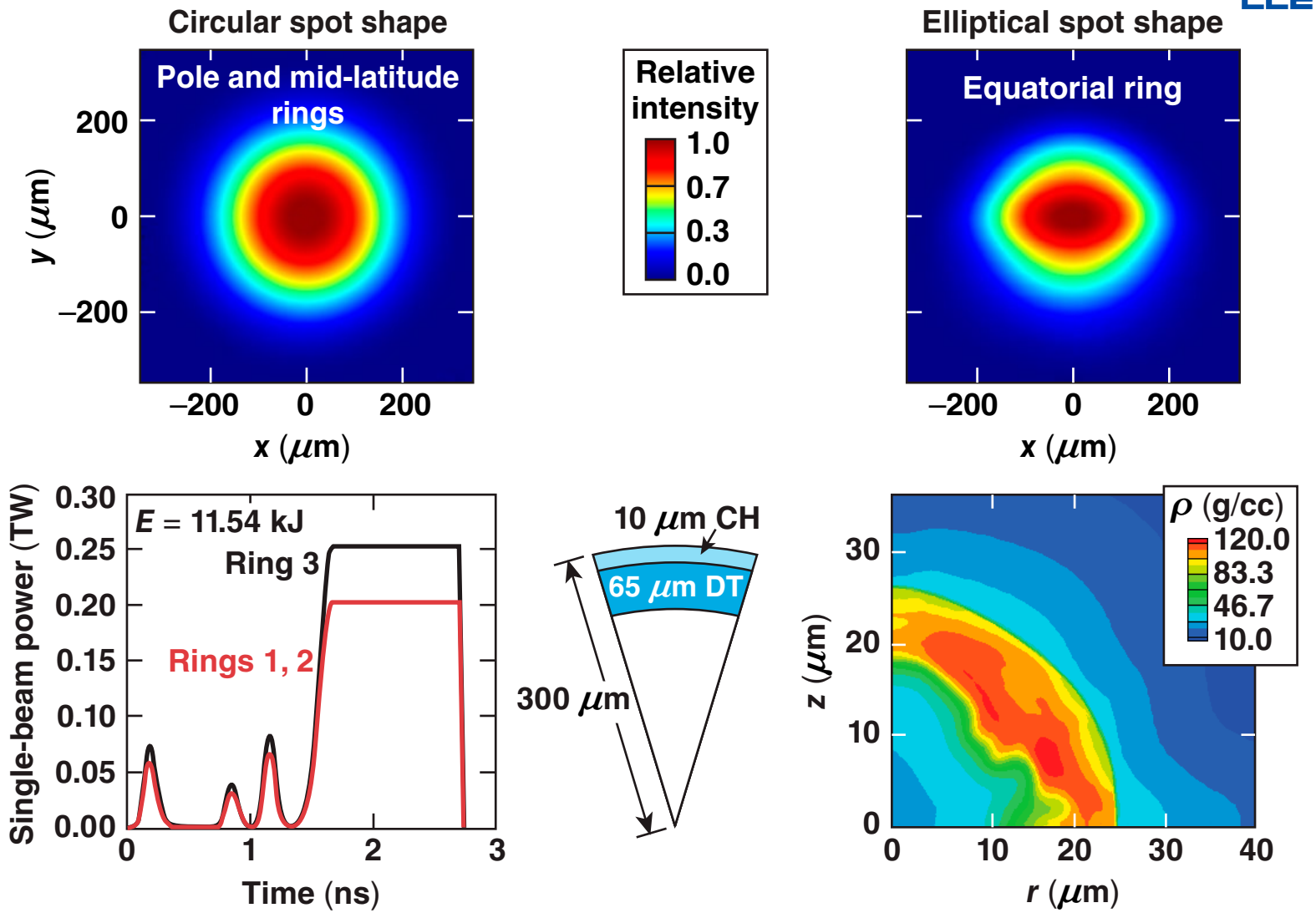
- Polar drive
- OMEGA experiments
- **Future PD OMEGA experiments**
- Early NIF experiments

# Near-term experiments will address some limitations of current OMEGA experiments




TC10146

# PD warm and cryogenic implosions will be studied with new phase plates on OMEGA




TC10356

P. B. Radha *et al.*, Phys. Plasmas 19, 082704 (2012).

# Outline

- Polar drive
- OMEGA experiments
- Future PD OMEGA experiments
- **Early NIF experiments**

# Early NIF experiments will address key issues for PD ignition

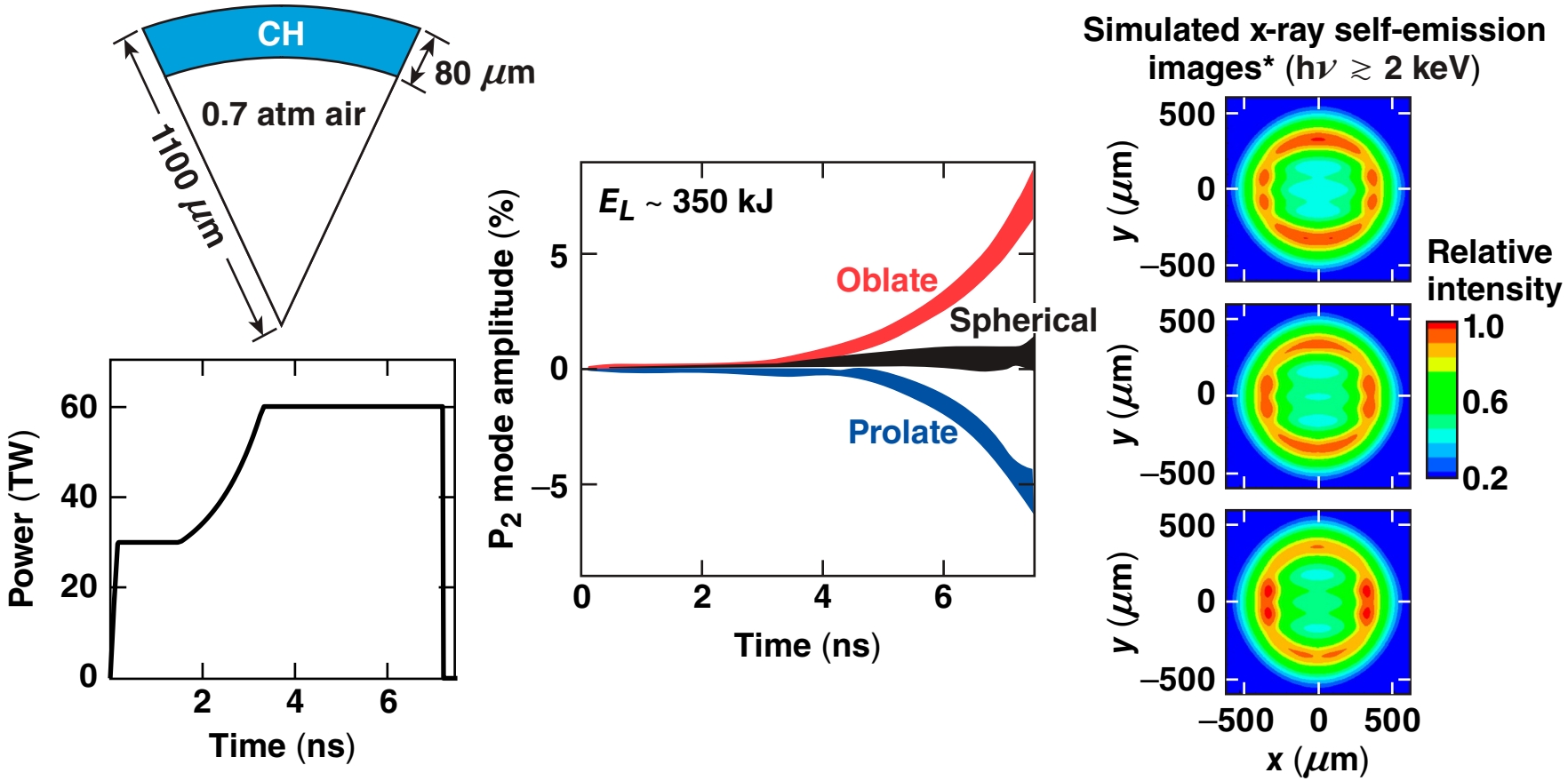
UR LLE

- The goal is to
  - demonstrate drive uniformity
  - measure laser coupling
  - identify and address laser–plasma interactions
    - longer coronal density scale lengths in NIF implosions may result in larger effects of cross-beam energy transfer[1] and fast-electron preheat from two-plasmon decay[2]
- These experiments will use the existing NIF configuration (phase plates and beam smoothing)
- The designs use a combination of beam defocus, repointing, and independent ring pulse shapes to achieve the required symmetry
- The first shot will be performed a few weeks from now

[1] J. A. Marozas, JO4.00015, this conference
D. H. Edgell, UO5.00001, this conference
[2] J. F. Myatt, TO5.00005, this conference
D. T. Michel, YI2.00002, this conference

# The primary goal of early NIF experiments is to predictably change implosion symmetry

- Implosion symmetry is varied by changing ring energies

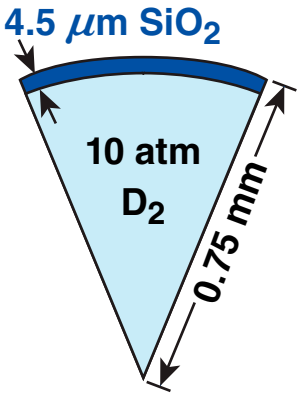


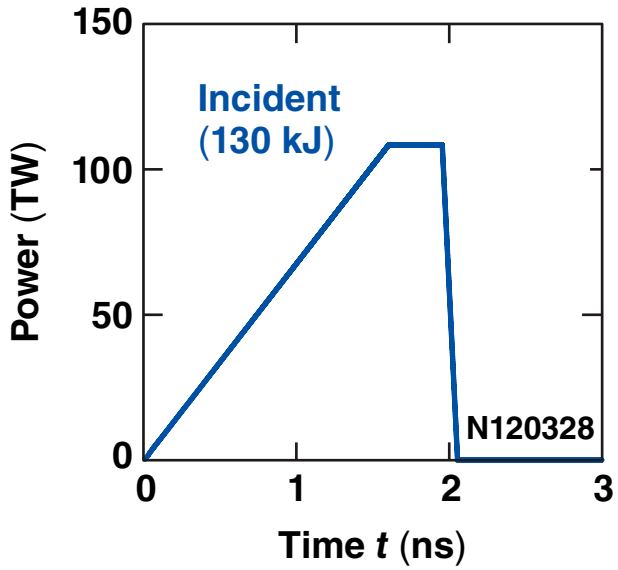

TC10148

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

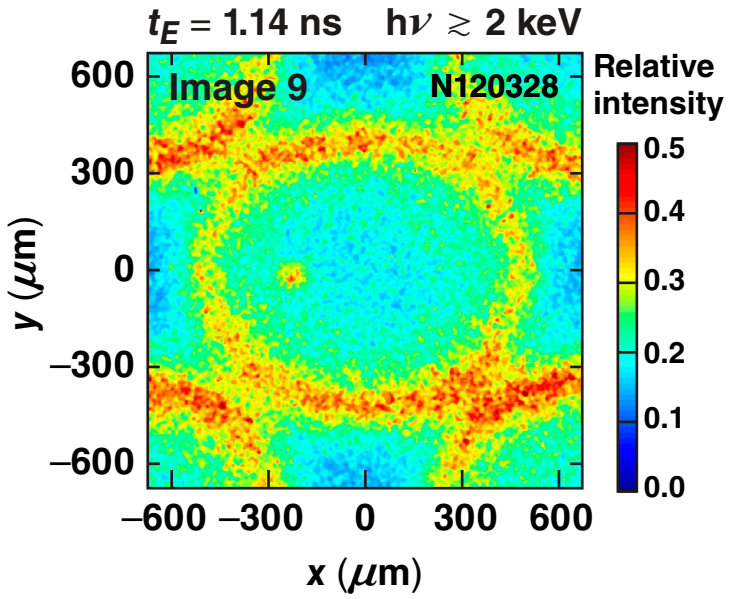
# Polar-drive platforms on the NIF have been used for diagnostic development[1] and mix studies[2]

- Exploding-pusher targets have been used to produce neutrons[1]




Gated framing camera images




- High-adiabat ($\alpha \sim 5$) and high-intensity ($I \sim 2 \times 10^{15}$ W/cm$^2$) PD implosions have been used to study mix on the NIF[2]

[1] R. S. Craxton, JO4.00012, this conference; P. W. McKenty, JO4.00011, this conference.
[2] M. J. Schmitt, YI2.00005, this conference; N. Krasheninnikova, TO4.00006, this conference; T. Murphy, TO4.00002, this conference; G Kyrala, TO4.00007, this conference.

# NIF experiments will systematically explore the physics before the ignition campaign

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**Cryogenic target system**

- Ignition experiments

**Beam smoothing**

- Target performance
  - warm shells

**PD-specific phase plates**

- Energy coupling
- Preheat
- Symmetry
- Shock timing

**ID phase plates**

- Energy coupling
- Preheat
- Symmetry

Time

TC10386

Summary/Conclusions

# OMEGA and NIF experiments are setting the physics basis for polar-drive (PD) ignition

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- OMEGA experiments are addressing key aspects of PD ignition
  - areal density and symmetry are well-modeled with the hydrodynamic code *DRACO*
- PD cryogenic implosion studies will begin in the near term
- Better scaling of OMEGA implosions with the National Ignition Facility (NIF) PD ignition designs will be obtained with new PD-specific phase plates
- Early NIF experiments will be used to study the symmetry and laser–plasma interactions