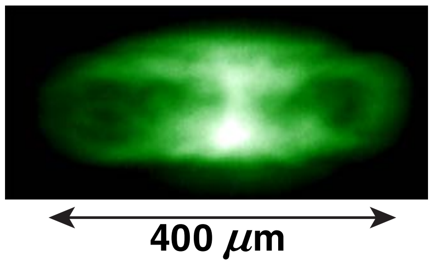
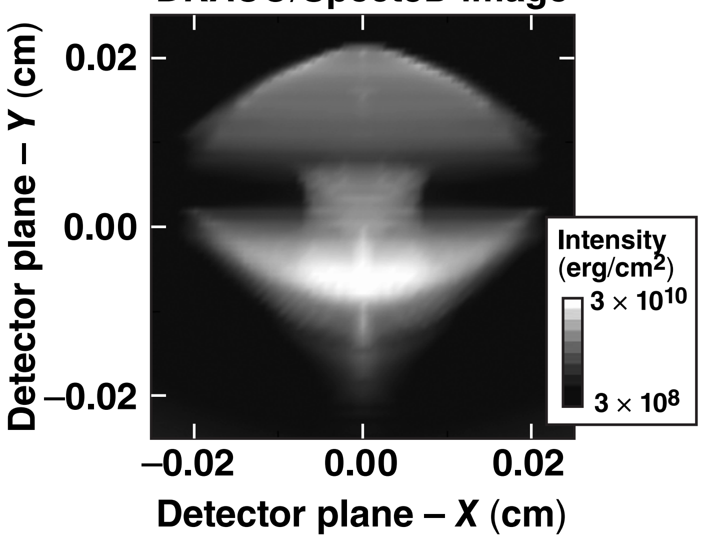
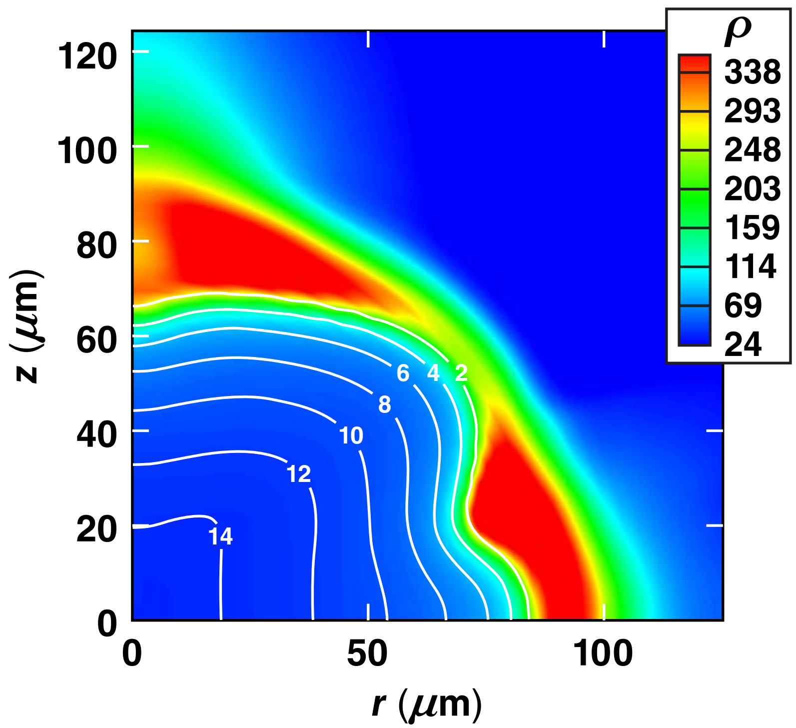
Preparing for Polar Drive on the National Ignition Facility

NIF image-plate data



DRACO/Spect3D image





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40th Annual Anomalous Absorption Conference
Snowmass Village, CO
13–18 June 2010

Summary

Simulations and initial NIF experiments indicate that polar drive is a viable ignition alternative for the NIF

- Polar-drive (PD) experiments on OMEGA are well described by simulations
- Initial polar-drive diagnostic commissioning shots on the NIF achieved the design goals of D_2 neutron yield $Y_n \sim 10^{10}$ and $T_{ion} > 5$ keV
- Multiple-picket pulses are used to facilitate experimental shock timing and increase stability
- 2-D simulations of PD ignition designs show gains of >10 with drive and target nonuniformities included

Contributors

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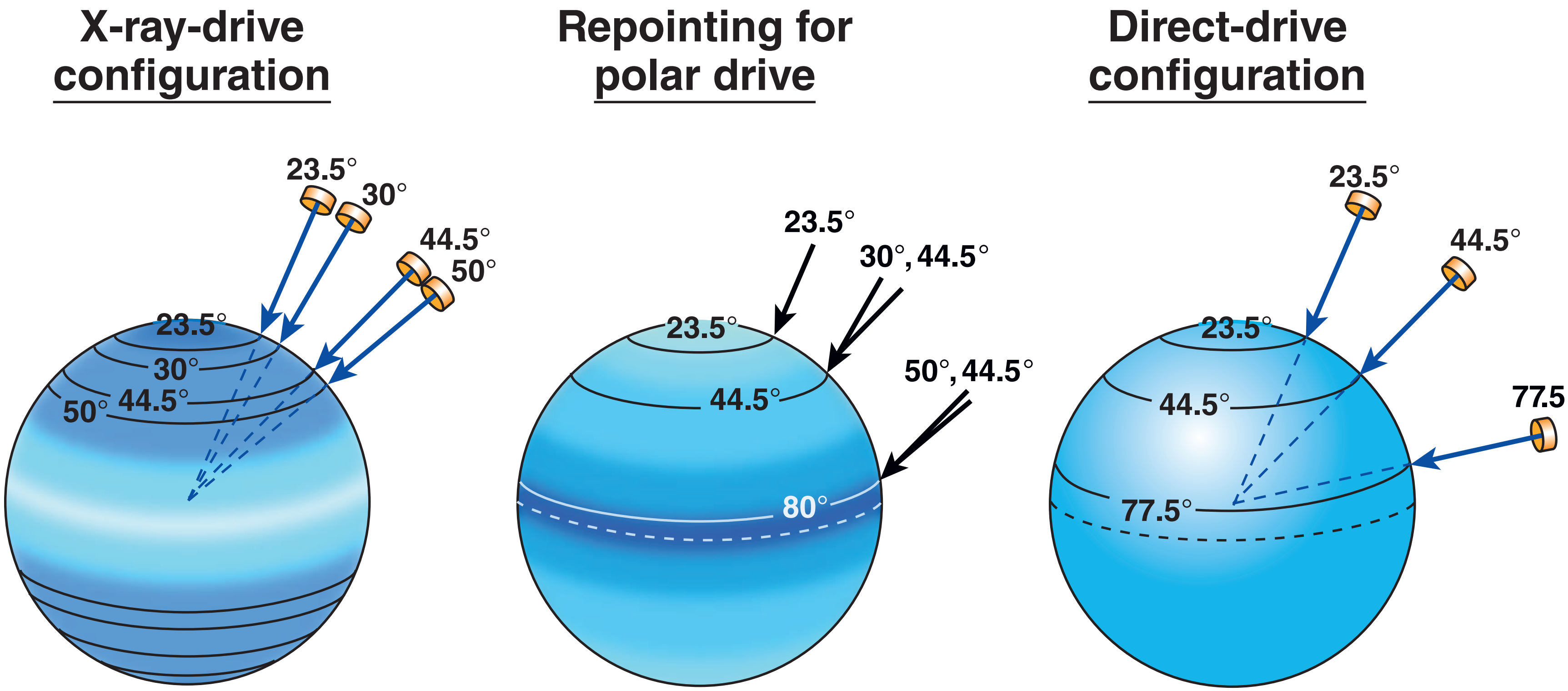
MIT

Outline

- **The polar drive (PD) concept**
- PD experiments on OMEGA
- PD experiments on the NIF
- Wetted-foam continuous-pulse design
- CH-ablator triple-picket designs

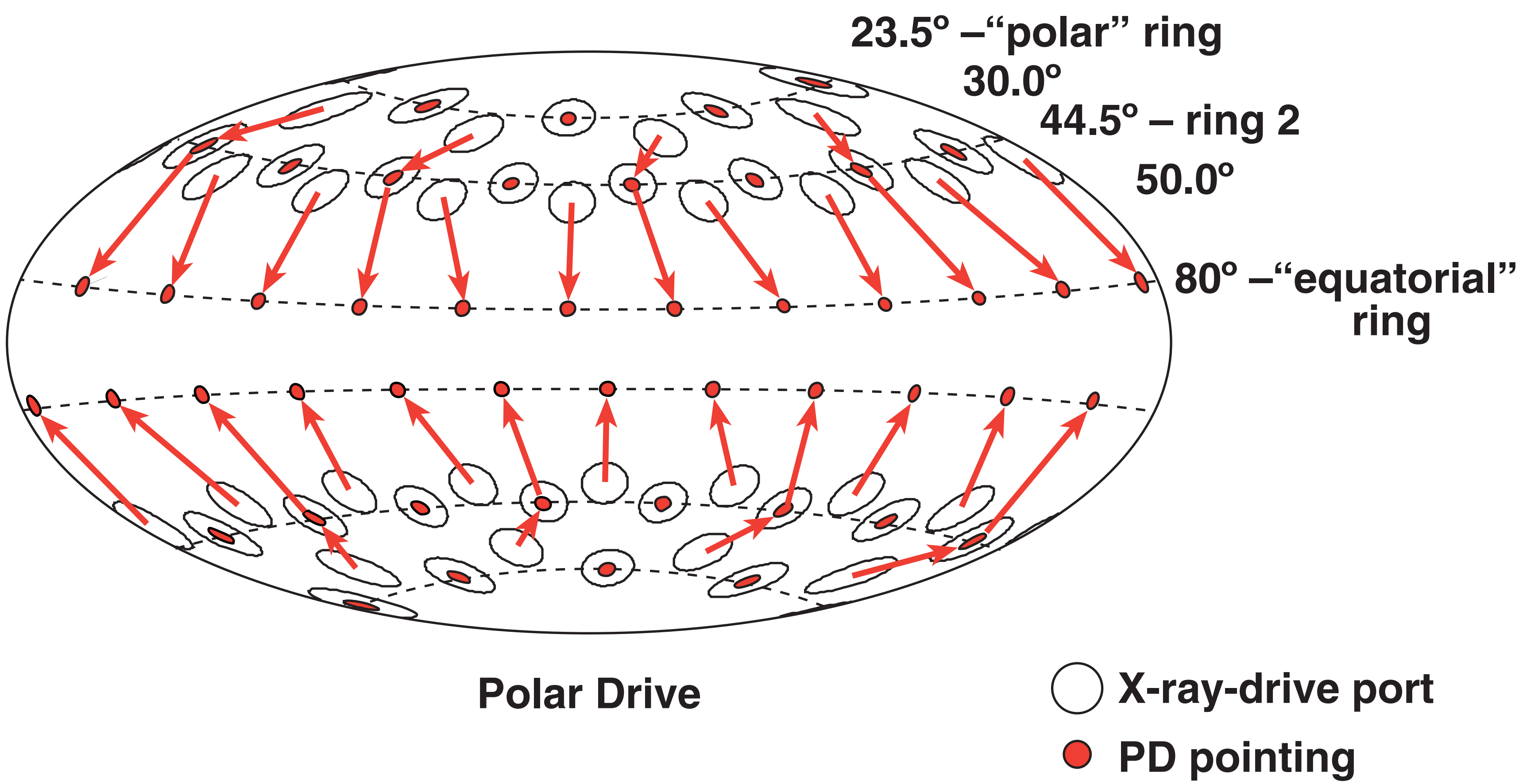
Polar drive (PD) is the optimal platform for direct-drive ignition experiments while the NIF is in the x-ray-drive configuration



TC7193b

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

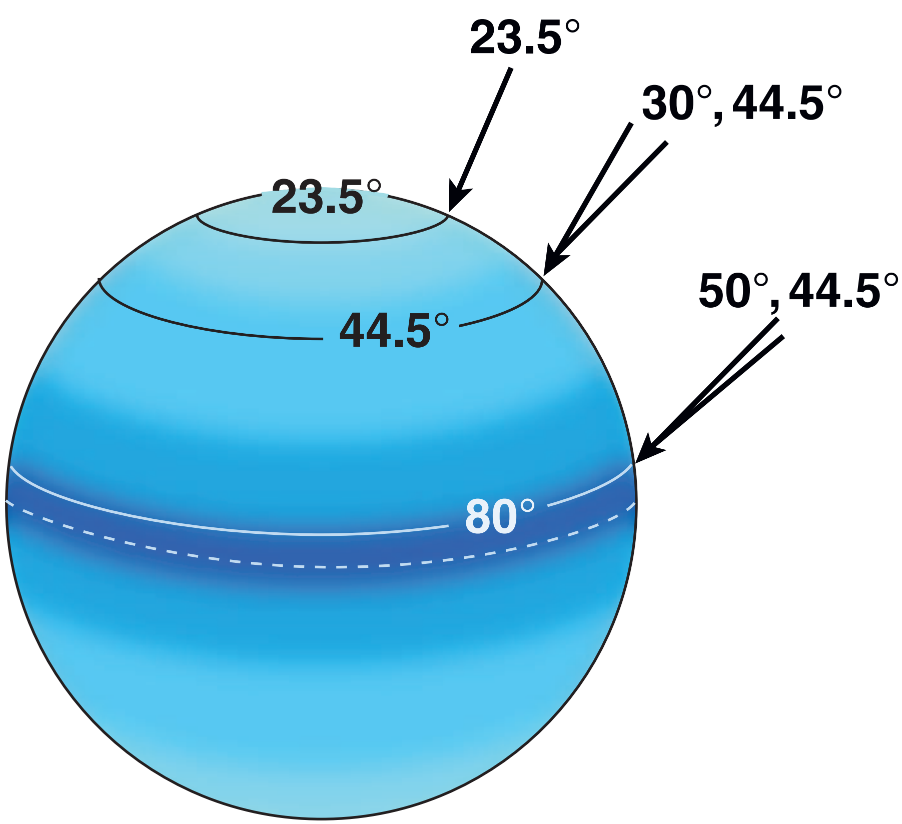
The NIF x-ray-drive beams are pointed to six latitude rings on the target for PD



TC6149e

Uniform target drive requires increased intensity at the equator to compensate for oblique irradiation

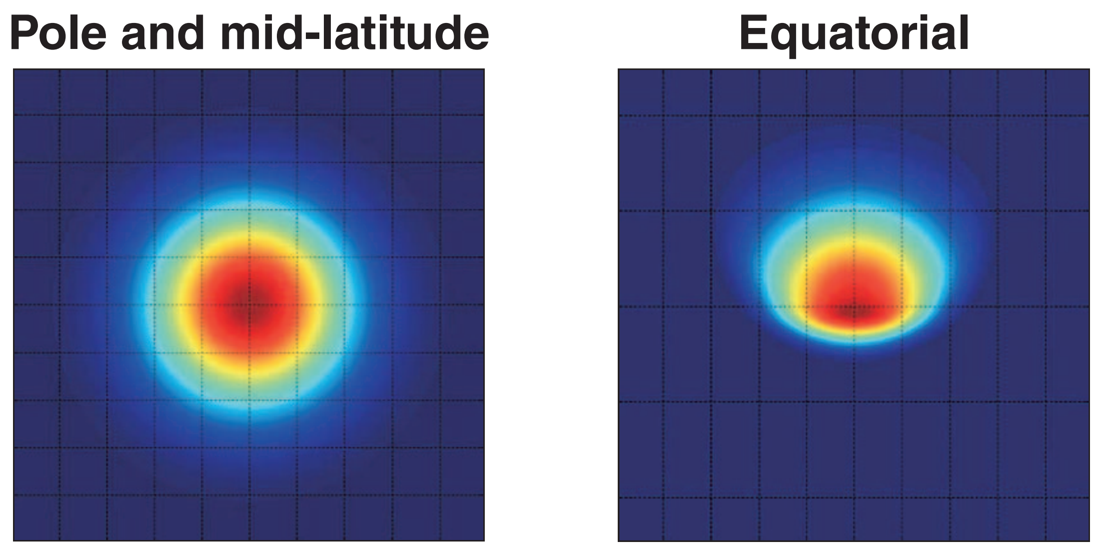
Repointing for PD



- PD issues at the equator
  - reduced absorption
  - reduced hydro-effciency
  - lateral heat flow

TC6300m

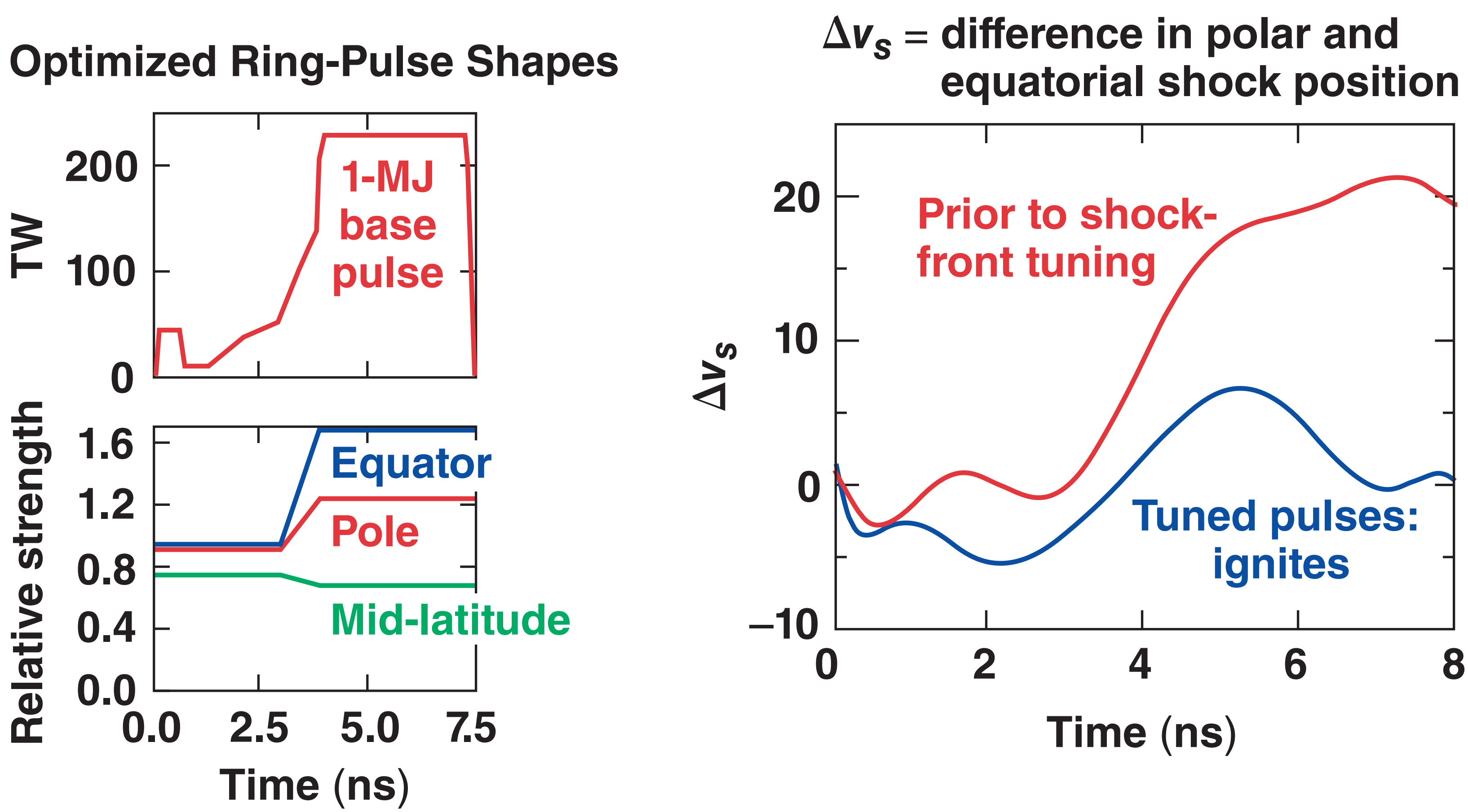
Equatorial beam coupling can be increased using tailored phase plates



- Lower super-Gaussian orders are preferred for PD because they offer greater control of the energy density on the target
- The equatorial spot shape combines a round spot with an elliptical spot to mitigate loss of coupling near the equator
- The resulting spot is asymmetric to reduce loss of energy over the horizon

Maintaining both shell and shock-front uniformity is critical to obtaining substantial gains

- Time-dependent control of the relative pulse strengths is required



TC7125a

Outline

- The polar drive (PD) concept
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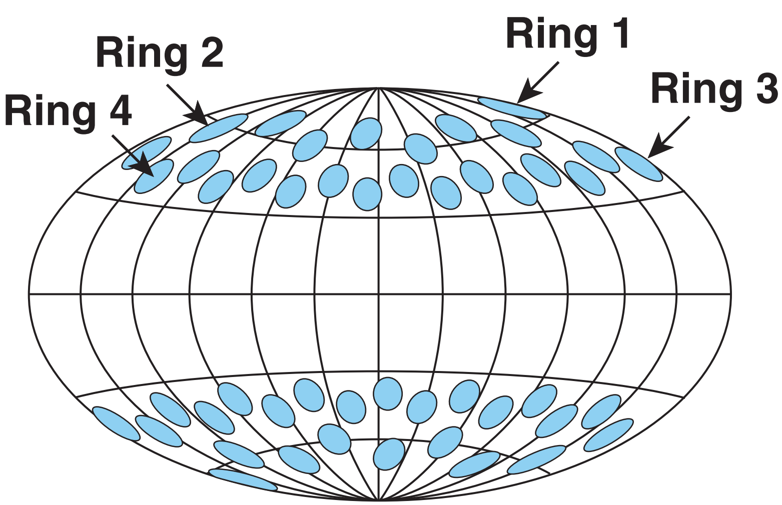
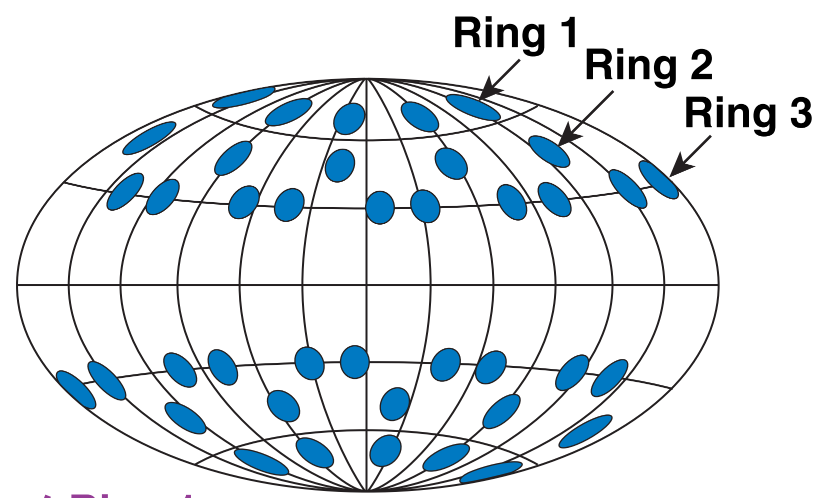
A 40-beam subset of the 60-beam OMEGA laser is used to emulate the NIF x-ray-drive configuration

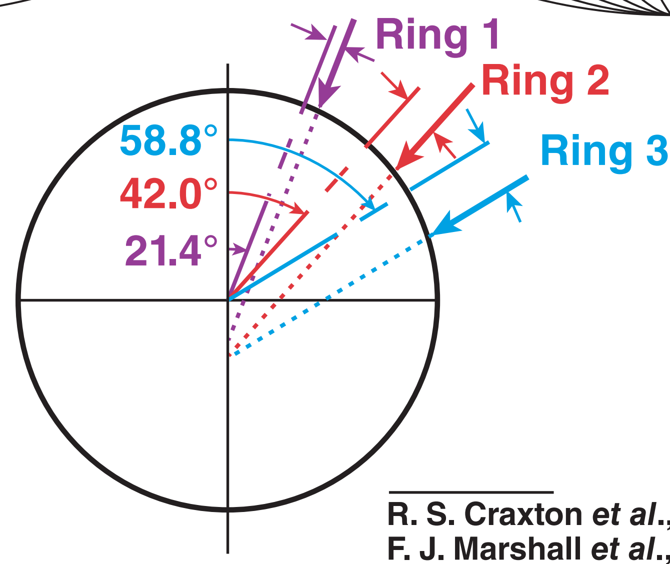
NIF configuration



OMEGA PD configuration



- OMEGA experiments serve as a proof of principle for the NIF

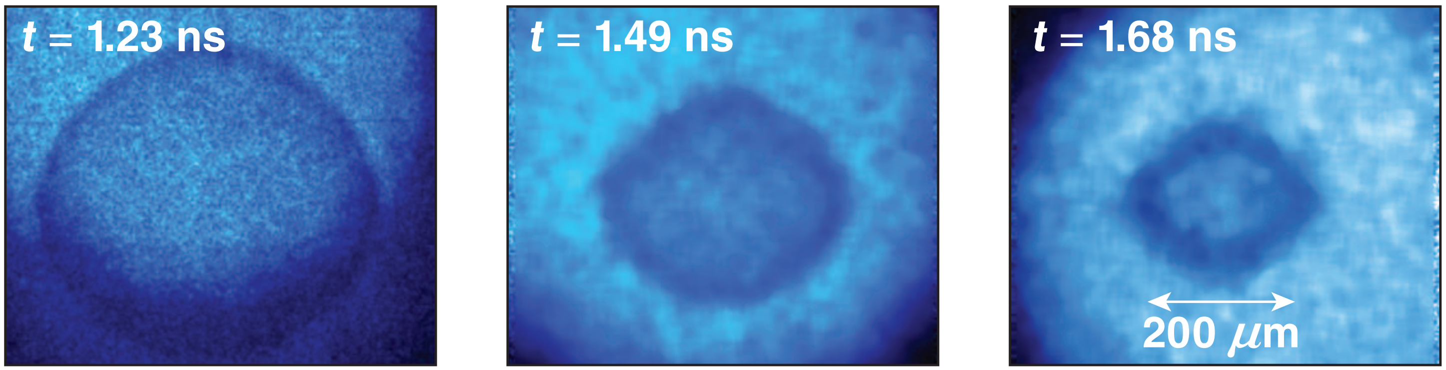


R. S. Craxton *et al*., Phys. Plasmas 12, 056304 (2005).
F. J. Marshall *et al*., J. Phys. IV France 133, 153 (2006).

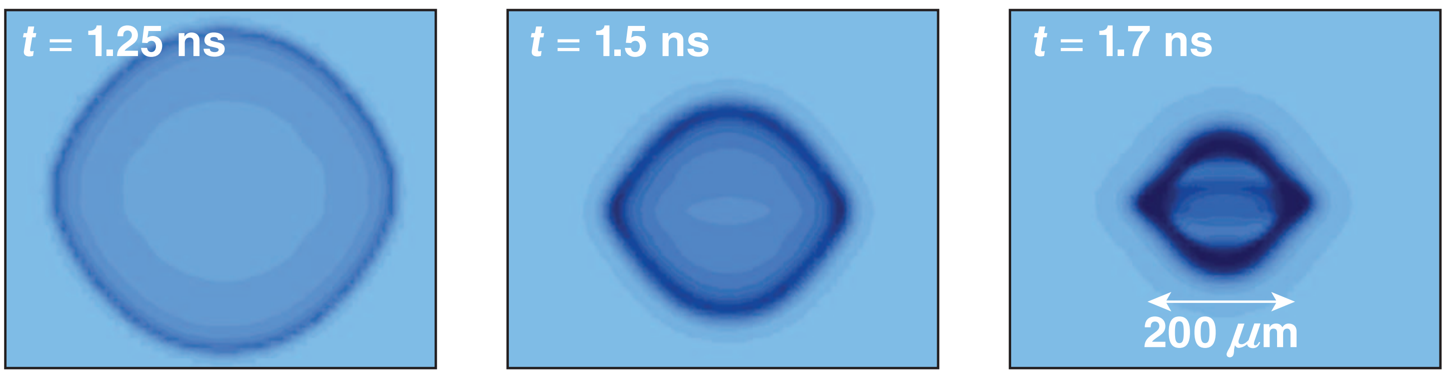
Experimental and simulated backlit images show excellent agreement

- High-adiabat implosions

OMEGA shot 38502 (TIM-5 view)
X-ray framing camera with a 2.0- to 2.5-keV Au backlighter foil



***DRACO*/Spect3D* (simulation)**

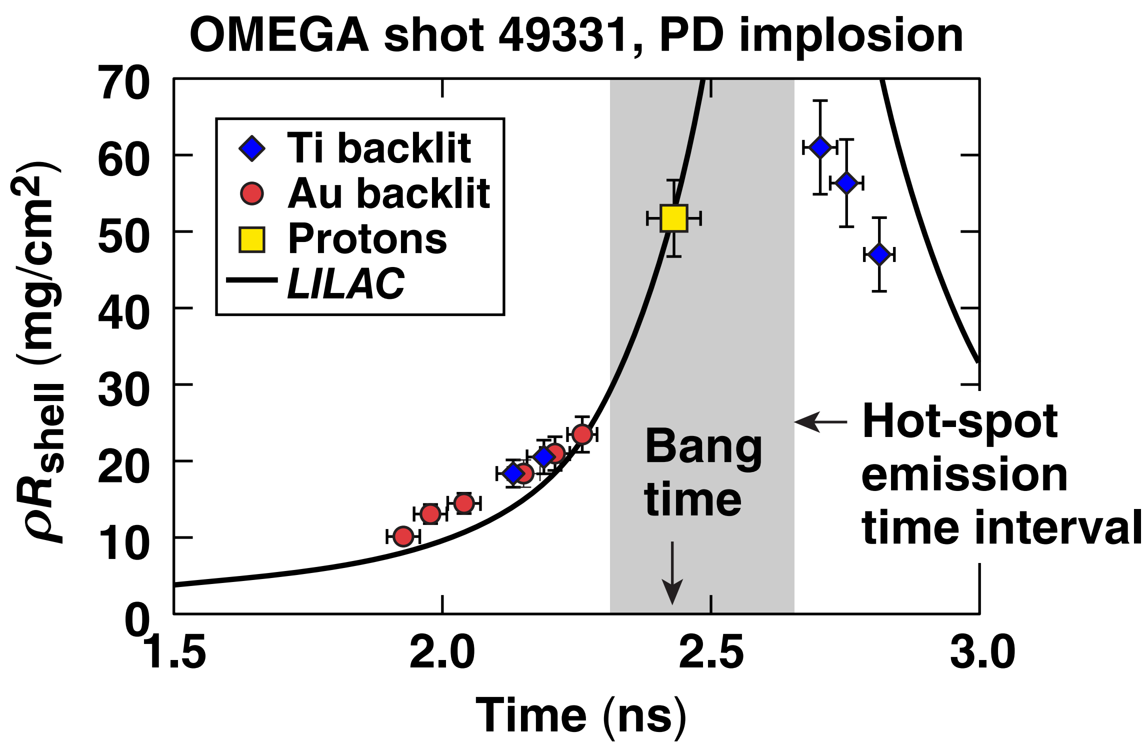


J. A. Marozas *et al*., Phys. Plasmas 13, 056311 (2006).

*Post-processed with Spect3D, PRISM Computational Sciences, Madison, WI

In moderate-adiabat ($\alpha \sim 3$) experiments, the measured areal-density time history is consistent with 1-D simulations up to bang time

- **The density distributions at various times are inferred from shell radiographs**



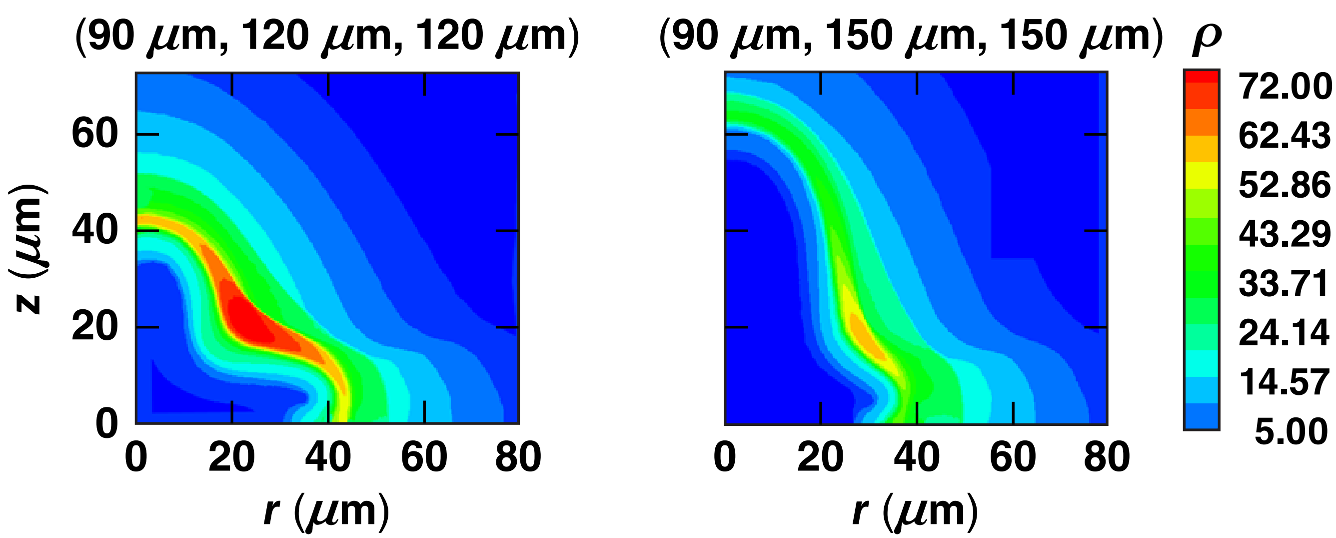
E17532a

F. J. Marshall *et al*., Phys. Rev. Lett 102, 185004 (2009).

High-convergence PD experiments will be performed on OMEGA in the fall of 2010

- These experiments will use a triple-picket pulse for adiabat shaping, to obtain high-areal densities
- The equatorial ring will be driven with higher energy to compensate for the decreased coupling
- Optimal pointing will be explored, as well as measurement of shock timing for the oblique beams

At peak neutron production



- Preliminary *DRACO* simulations indicate the sensitivity of pointing

P. B. Radha and F. J. Marshall

Outline

- The polar drive (PD) concept
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- **PD experiments on the NIF**
- Wetted-foam continuous-pulse design
- CH-ablator triple-picket designs

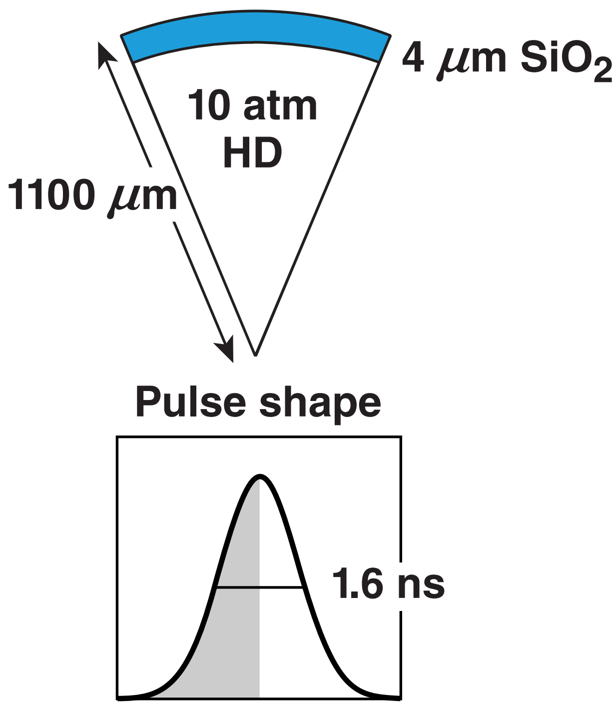
Polar-drive exploding pusher targets are being used to commission nuclear diagnostics on the NIF

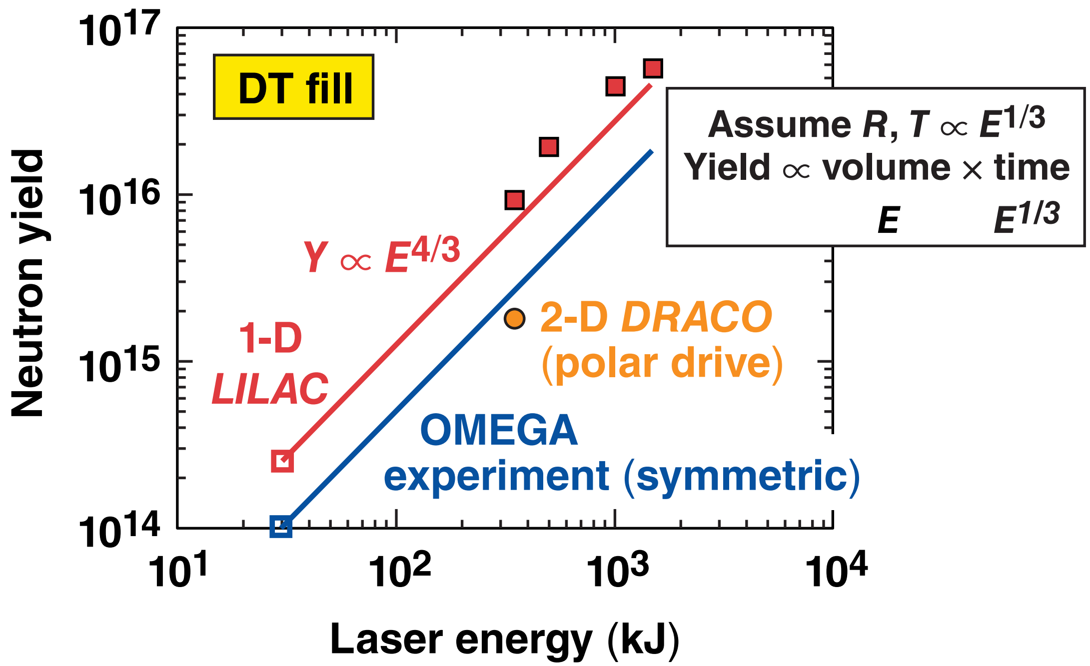
UR LLE

- The first two NIF polar-drive experiments, designed to produce high-neutron yields with low-shell areal densities, were performed in November 2009
  - first time that two NIF implosion shots were executed in a single day
  - the second shot achieved the experimental design goals
    - D_2 neutron yield $\sim 10^{10}$
    - neutron-averaged ion temperature in excess of 5 keV
- These results are consistent with 2-D modeling of the experiments

P. W. McKenty, presented at the 19th Target Fabrication Meeting, Orlando, FL, 21–26 February 2010.

Simple PD designs employing existing NIF indirect-drive (ID) phase plates are used for diagnostic qualification





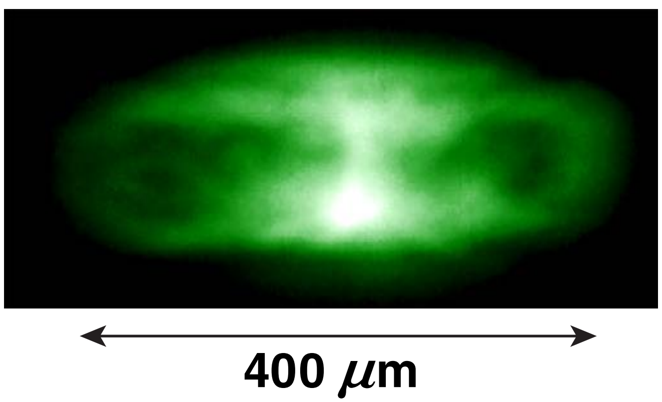
- A thin-shelled "exploding-pusher" target is driven by a Gaussian pulse
- The beams are defocused to obtain sufficient far-field uniformity
- The pulse is truncated and fill gas chosen to select the desired yield
- The shock yield is used to test neutron diagnostics

TC8498d

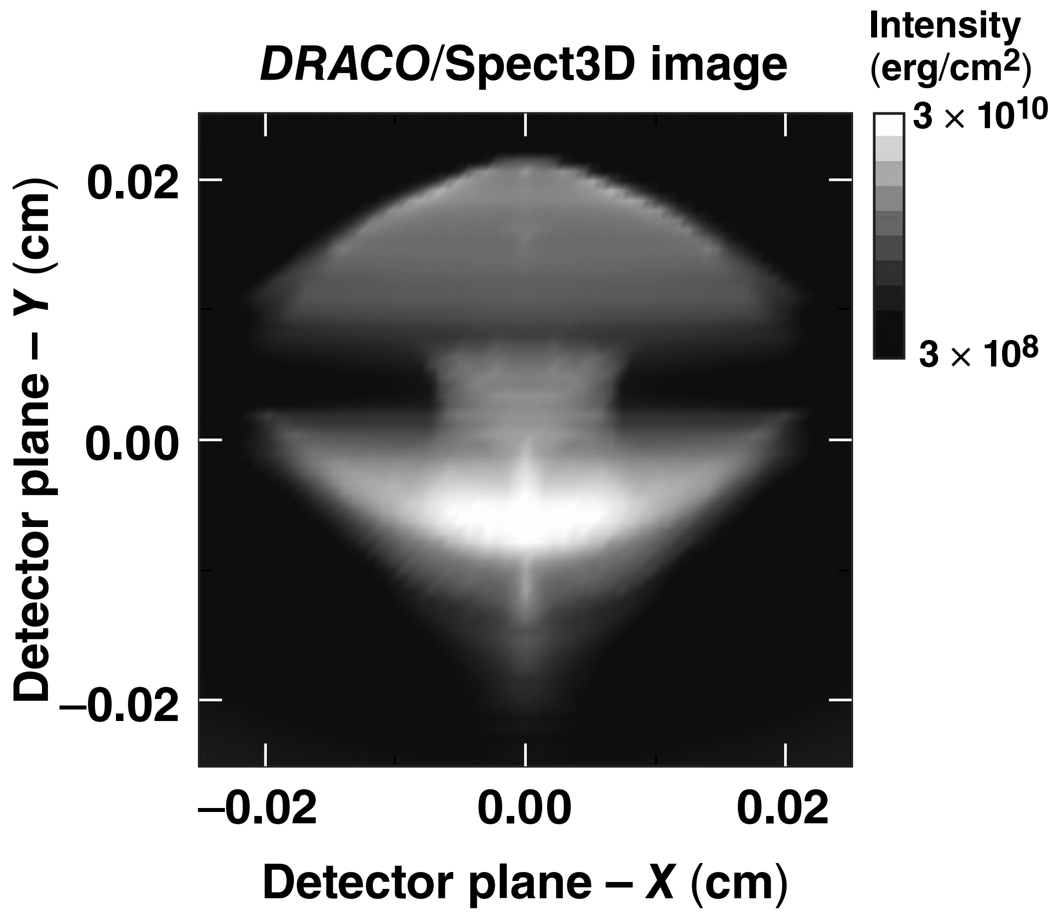
Simulated time-integrated image shows an illuminated oblate imploded shell and a self-emitting prolate core

- Simulations show similar morphology to experiment

NIF image-plate data



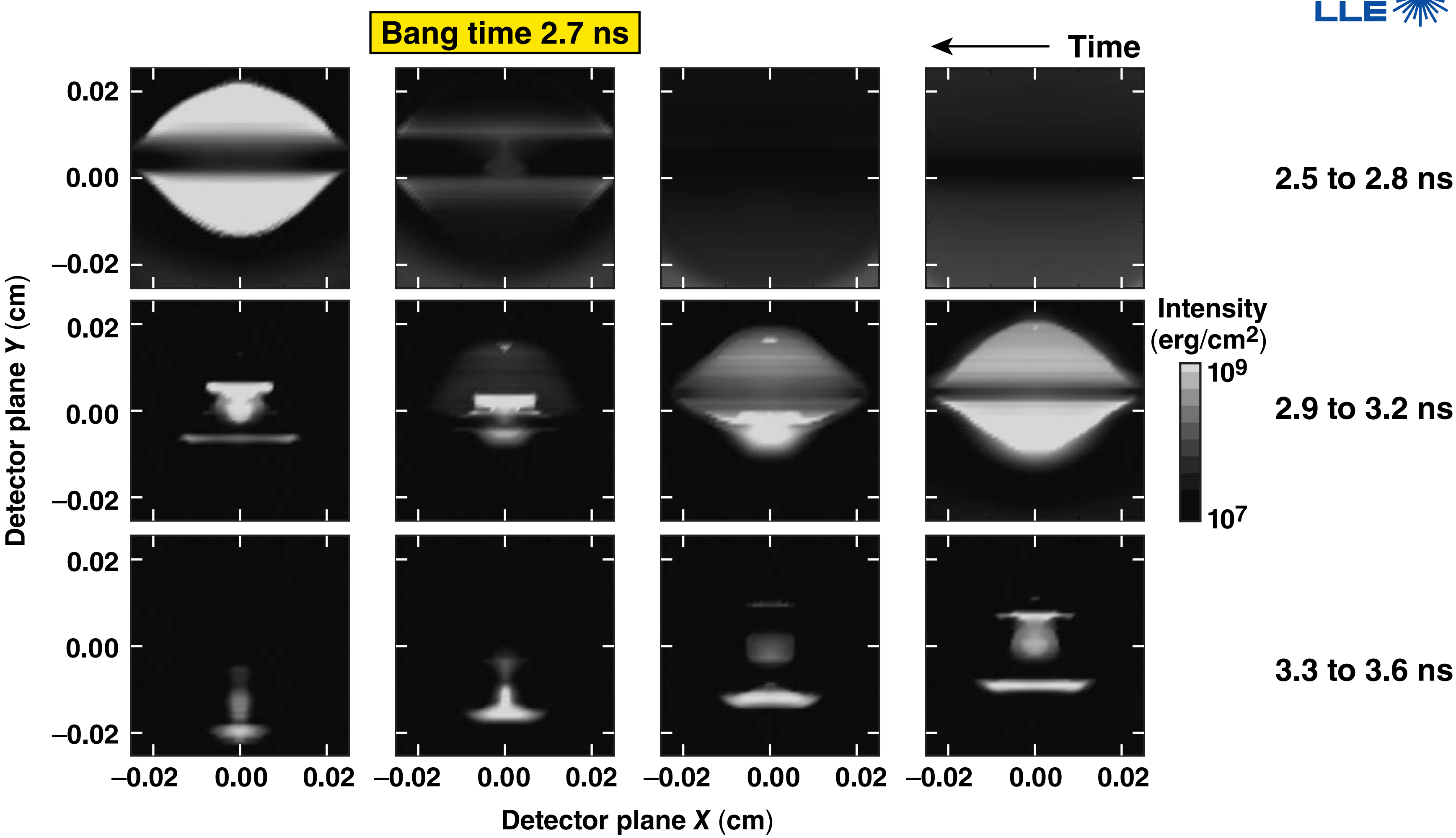
DRACO/Spect3D image



With filtering (approximately hν > 5.5 keV) and GXD response

TC8745a

Spect3D analysis of the 2-D *DRACO* simulation indicates dim emission at bang time followed by bright emission of the decelerating shell leading to glass stagnating on-axis at ~3.4 ns



2-decade logarithmic contour scale

2.5 to 3.3.6 ns in 100 ps steps, 50-ps windows

TC8863

Initial polar-drive commissioning shots achieved the design goals of $Y_n \sim 10^{10}$ and $T_{ion} > 5$ keV

- Current 2-D modeling shows performance reductions that are within 20% of the experimental yield and 1.0 keV of the inferred T_{ion}
- Spect3D post-processing indicates a strong x-ray signal corresponding to the stagnation of glass-shell remnants late in the implosion
- Time-integrated experimental x-ray image shows the same qualitative features as the simulation result, but is significantly more oblate
- New pulse shapes are under design that will be tested by NIF laser operations to improve power balance, which will improve performance
- The NIF experiments with DT-fill gas are planned for August 2010

TC8734a

Outline

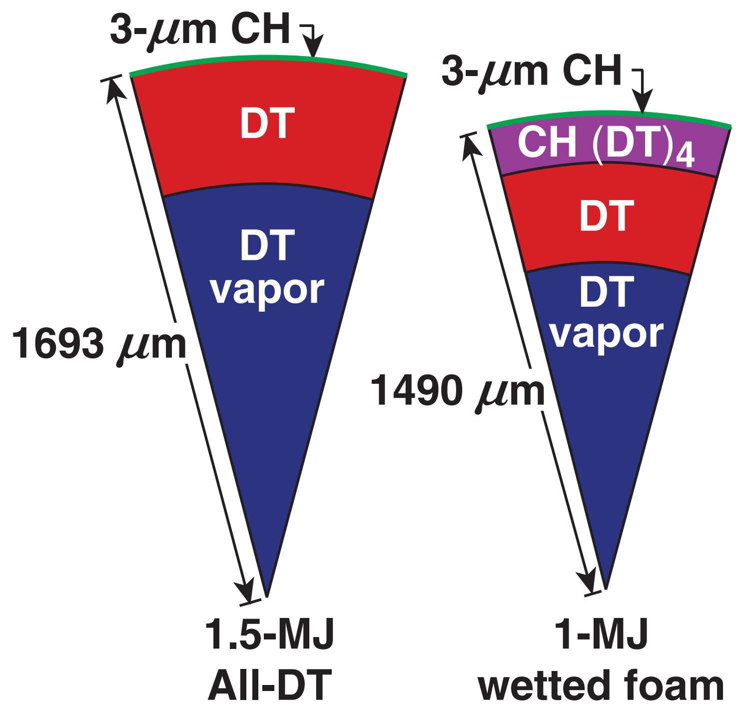
- The polar drive (PD) concept
- PD experiments on OMEGA
- PD experiments on the NIF
- **Wetted-foam continuous-pulse design**
- **CH-ablator triple-picket designs**

The baseline 1-MJ PD design uses a wetted-foam ablator

- Wetted foam provides higher laser absorption, allowing for a thicker shell and greater stability than the all-DT baseline target at 1 MJ
- The foam density balances higher absorption with increased radiative preheat
- The foam-layer thickness is chosen so the foam is entirely ablated

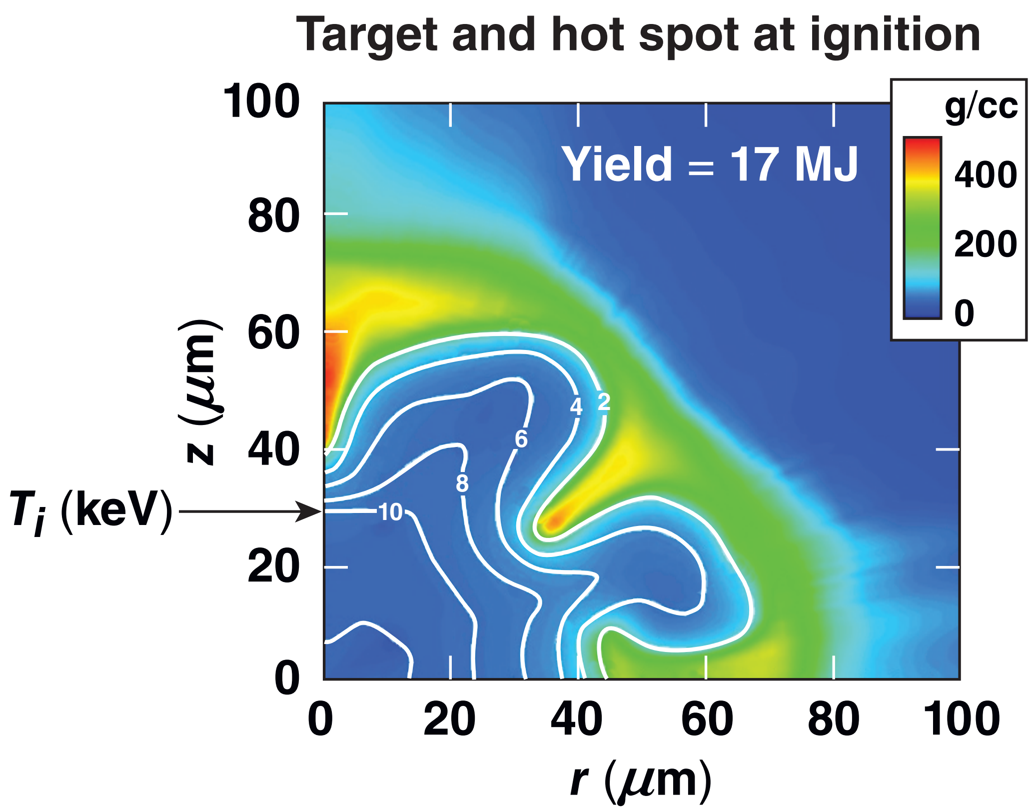
	All-DT	Scaled All-DT	Wetted-foam
Energy (MJ)	1.5	1.0	1.0
Target radius (μm)	1695	1480	1490
Absorption (%)	65	59	86
$A/\Delta R$ (%)	30	33	11
1-D gain	45	40	49

- All designs use a flux limiter of 6% for thermal transport



The 1-D, 1-MJ wetted-foam target gain is 49

The wetted-foam PD design achieves a yield of 17 MJ with all current levels of NIF nonuniformities included in the calculation

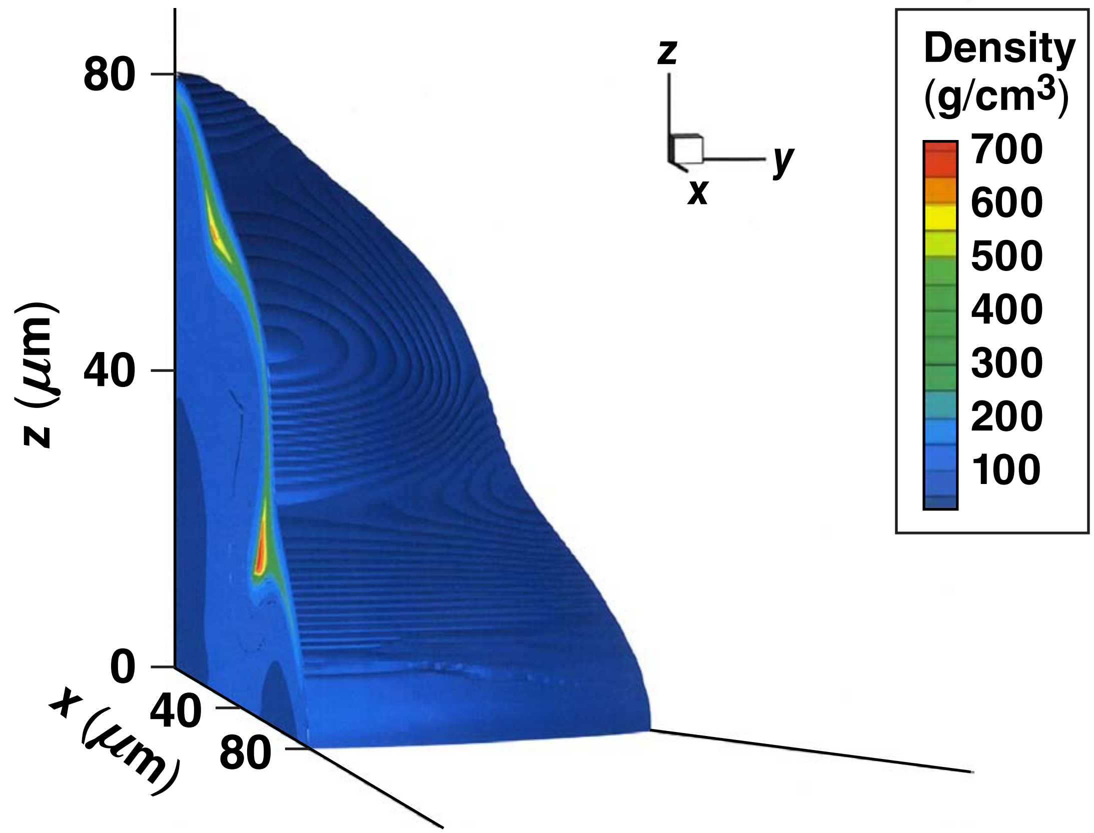


- Nonuniformities modeled include single-beam imprint with 2-D SSD, power imbalance, ice roughness, and surface roughness
- Adiabat ~ 2

TC7741k

Initial 3-D *HYDRA** simulations of the polar-drive point design, evaluating the dominant perturbation modes, show ignition and gain ~ 11

Imploded target at ignition

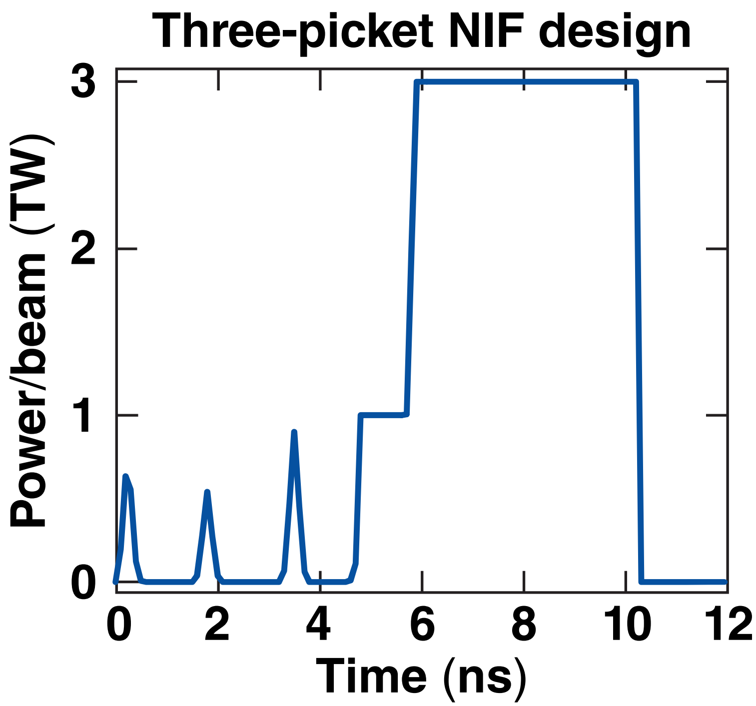


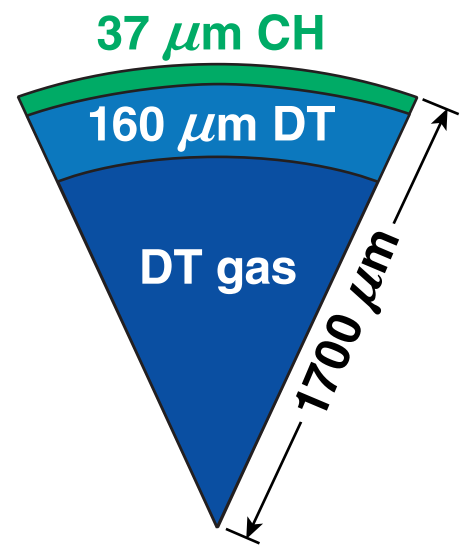
TC8497a

*M. Marinak *et al*., Phys. Plasmas 5, 1125 (1998).

A second ignition design uses a multi-picket, multi-shock drive instead of the continuous low-intensity foot

Gain$_{1\text{-}D}$ = 48, symmetric-drive energy = 1.5 MJ





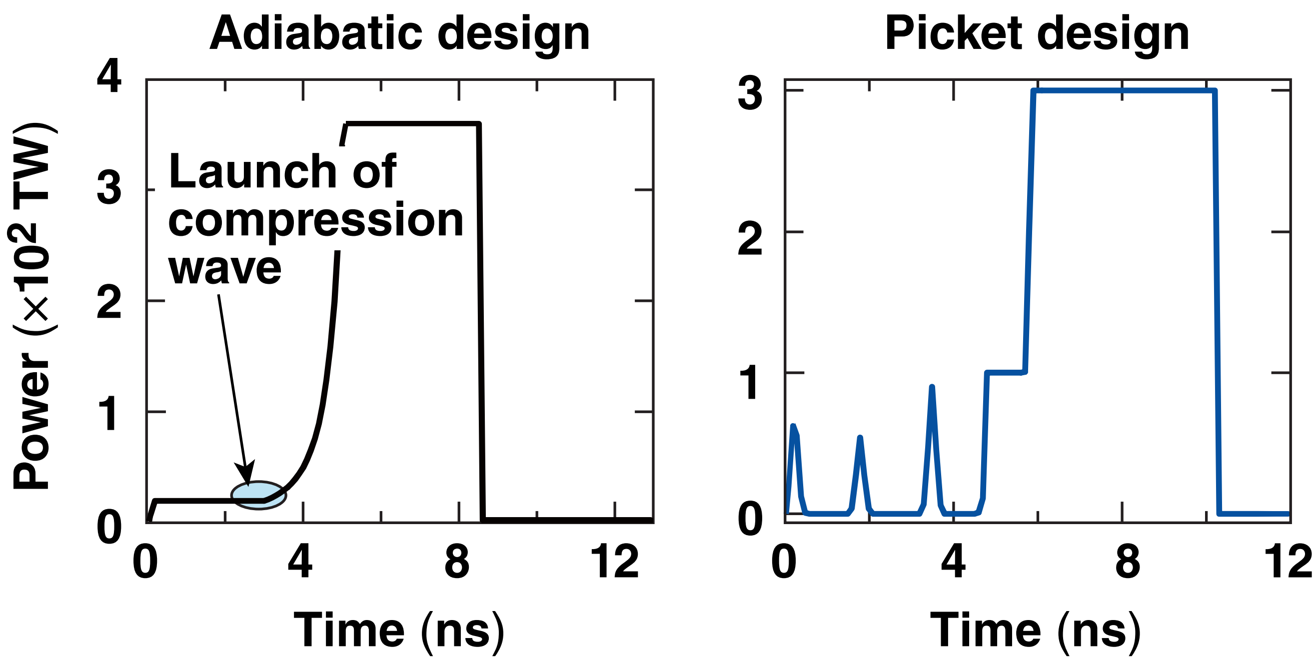
- OMEGA cryogenic targets are ~1/4 scale of the NIF target

The multiple-picket design is more stable, energetically more favorable for IR to UV conversion, and is easier to tune for shock coalescence.

E18400d

V. N. Goncharov *et al.*, Phys. Rev. Lett. 104, 165001 (2010).

Low-adiabat fuel compression can be achieved using a variety of target designs

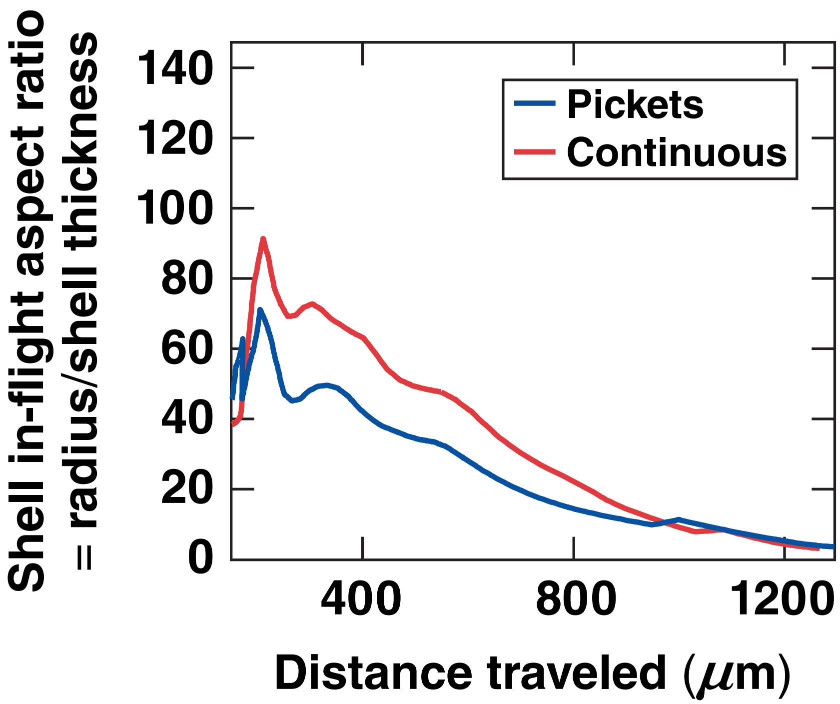


- Target-design selection is based on accuracy of shock tuning and target stability
- OMEGA experiments have demonstrated that picket pulses are better suited to experimental shock tuning*

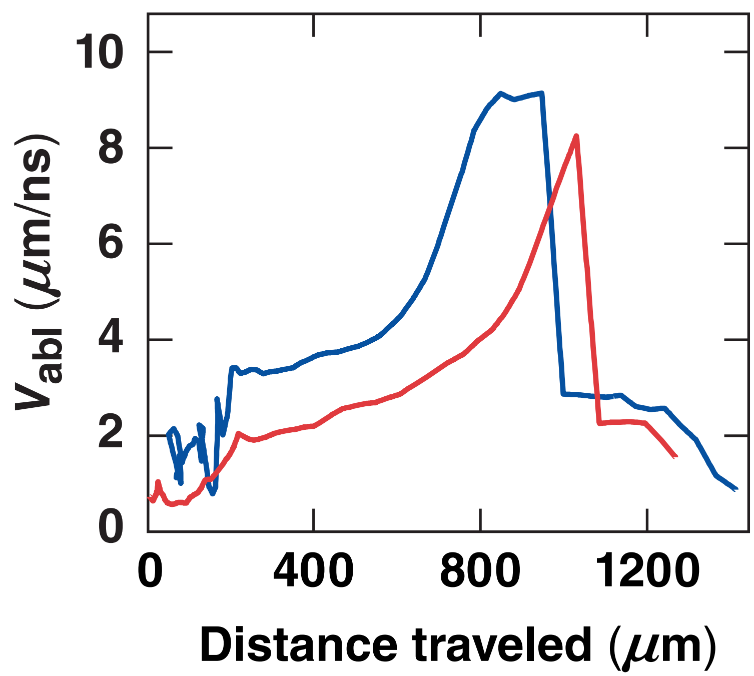
TC8436b

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

Shell stability improves with multiple-picket designs

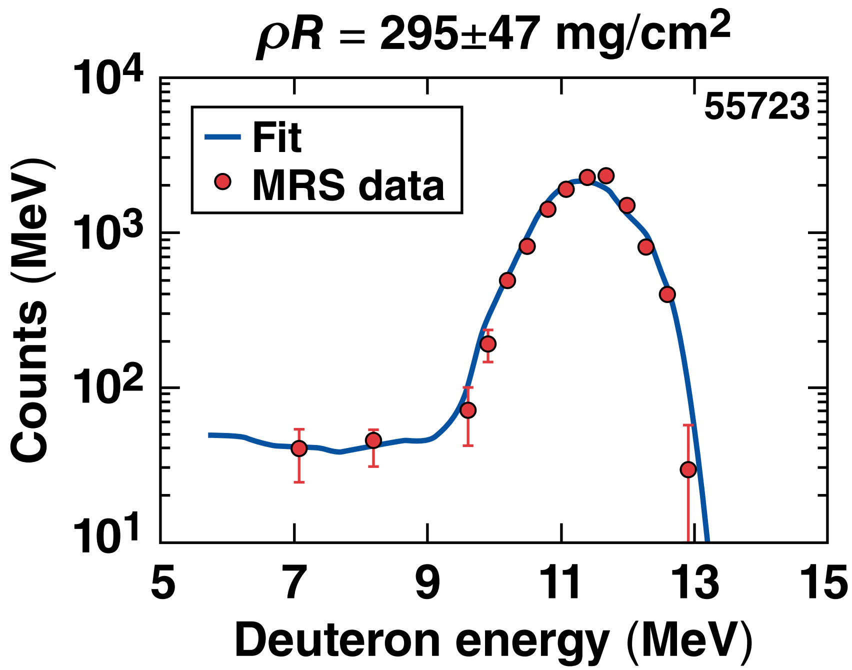


$$\gamma_{RT} = \alpha\sqrt{kg} - \beta kV_{abl}$$



TC8288b

Recent symmetric-drive multiple-picket cryogenic-DT implosions have produced an areal density of nearly 300 mg/cm^2

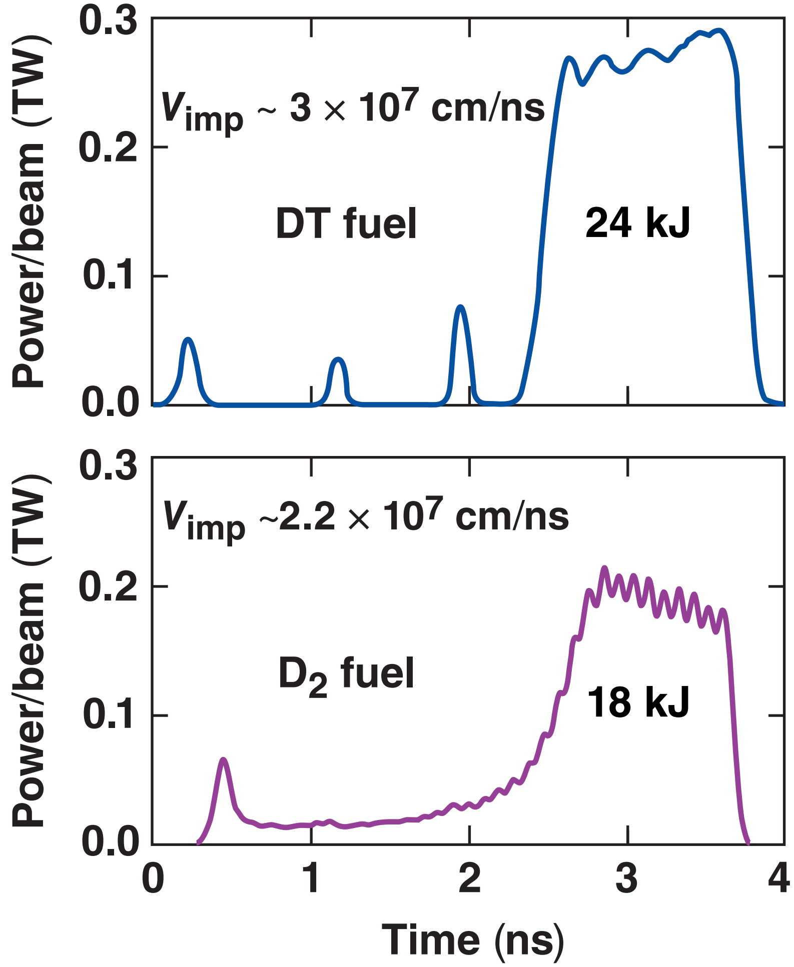


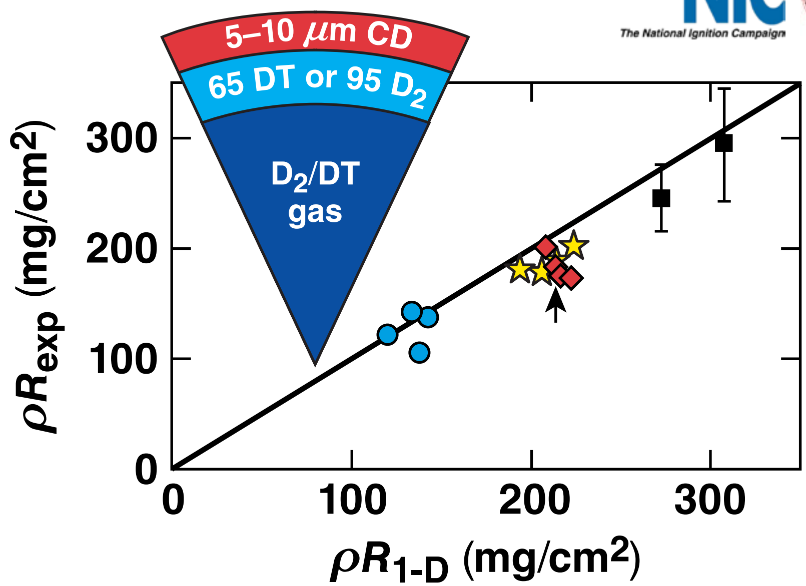
The error bar is dominated by the hit statistics.

This is by far the highest areal density achieved in a cryogenic target implosion.

Two-body T-T neutron peak removed in the modeling.
T. C. Sangster *et al*., Phys. Plasmas 17, 056312 (2010).
V. N. Goncharov *et al*., Phys. Rev. Lett. 104, 165001 (2010).

Measured areal densities are consistent with 1-D performance at velocities up to 3 × 10^7 cm/s





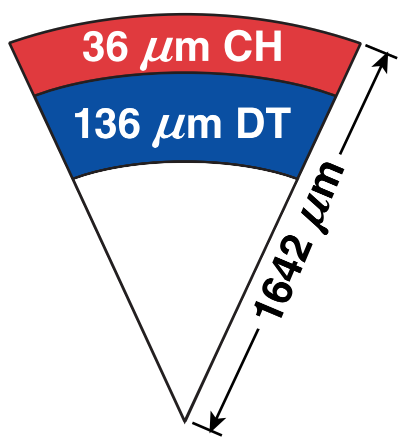
- ■ V_{imp} ~ 3 × 10^7 cm/s, I ~ 8 × 10^{14} W/cm^2 65-μm-thick DT, α ~ 2.0
- ◆ V_{imp} ~ 3 × 10^7 cm/s, I ~ 8 × 10^{14} W/cm^2 65-μm-thick DT, α ~ 2.5
- ☆ V_{imp} ~ 2.2 × 10^7 cm/s, I ~ 5 × 10^{14} W/cm^2 95-μm-thick D_2, α ~ 2.5
- ● V_{imp} ~ 2.2 × 10^7 cm/s, I ~ 3 × 10^{14} W/cm^2 95-μm-thick D_2, α ~ 2.5

E18406d

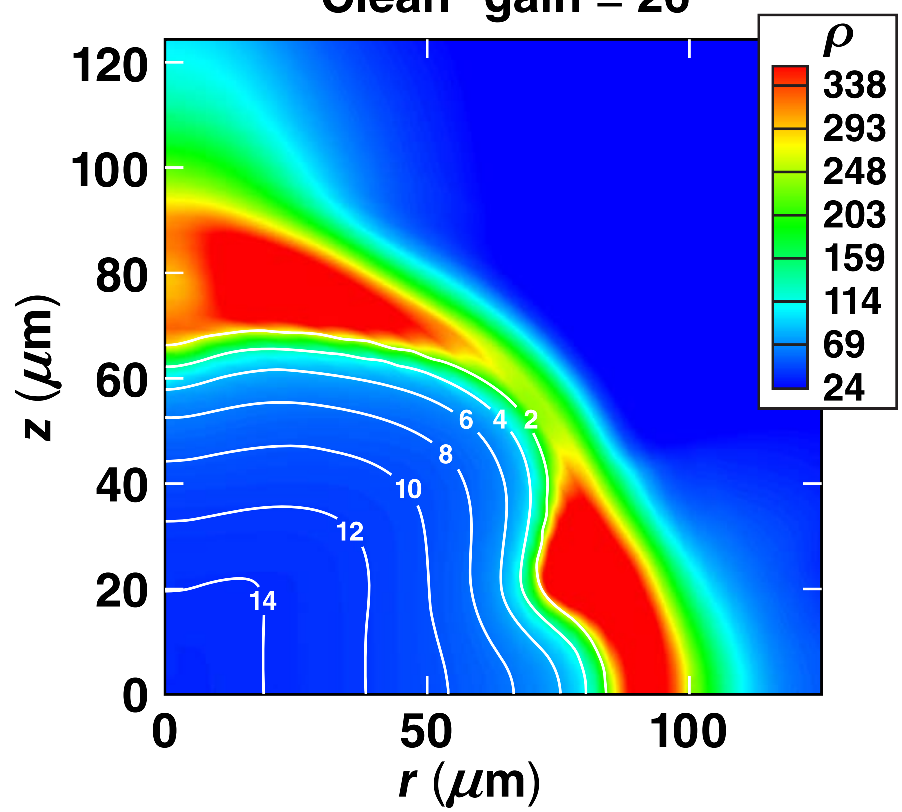
A triple-picket PD ignition design has been developed

- A thick CH ablator is used to minimize the risk of hot-electron preheat
- A 7-μm, $\ell = 2$ shim is used to reduce mass at the equator and increase shell uniformity

Gain	26
IFAR	35
Peak ρR	1 g/cm^2
V_{imp}	404 μm/ns
Adiabat	1.4



“Clean” gain = 26

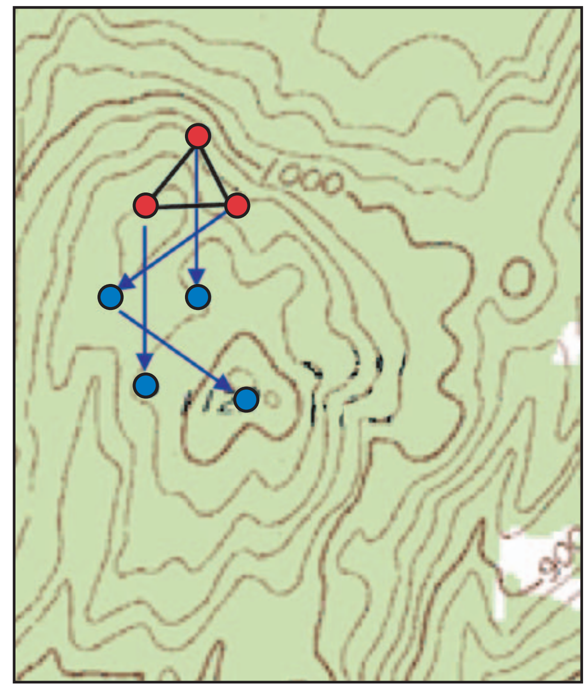


Target and hot spot shown at the time of ignition

TC8825

The triple-picket PD ignition design has been optimized in 1-D with a simplex method

- A *simplex* is a polyhedron in *n* dimensions with *n* + 1 vertices
- The lowest point is reflected across the plane connecting the others
- The points in the pulse shape (power, time) and target dimensions may be optimized
- This design was optimized to maximize gain, requiring peak power to stay below optics damage threshold limits; this in turn fixes the implosion velocity



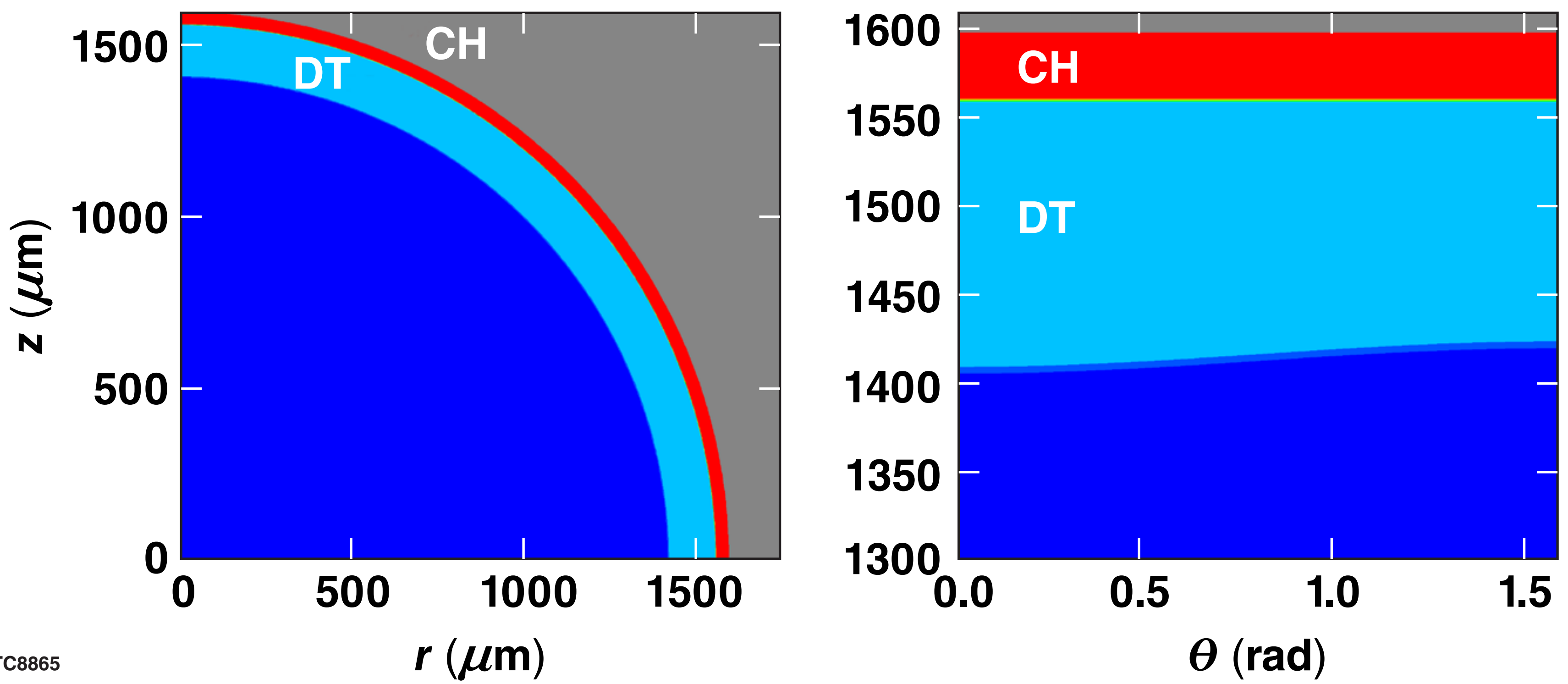
A simplex on a topographical map optimizing for maximum height

This method allows for tuning of more variables than would be feasible by hand (in this case, 12)

TC7716a

Target "shimming" is used to reduce the need for higher equatorial drive

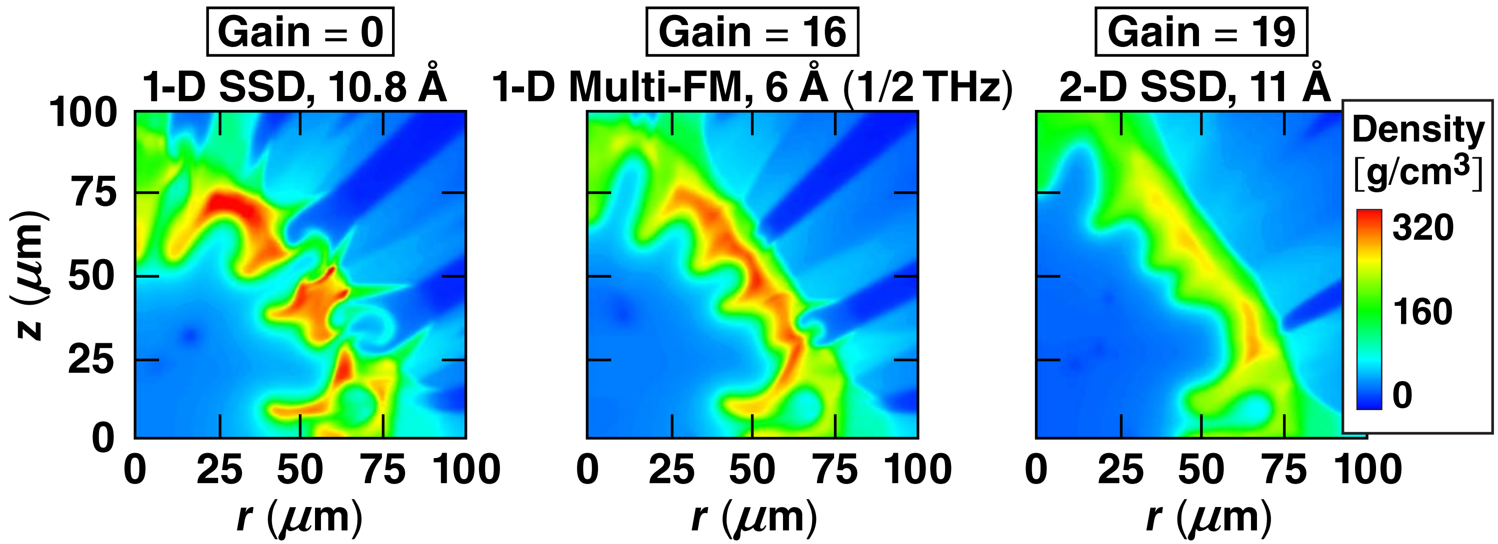
- A ~10 mm amplitude $\ell = 2$ perturbation on the inner-ice surface has been employed in the triple-picket ignition simulations
- This perturbation could be introduced by shimming the cryogenic layering sphere itself or adding an IR source around the equator
- The resulting perturbation would be repeatable but not necessarily precise

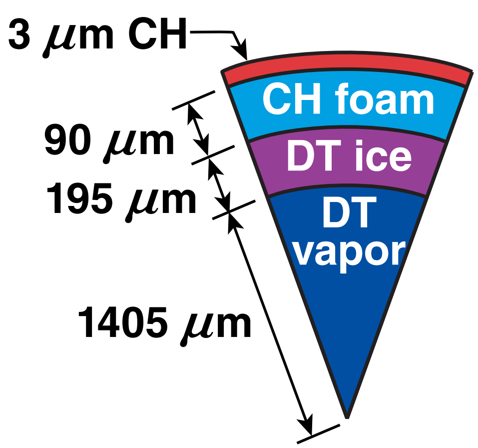


TC8865

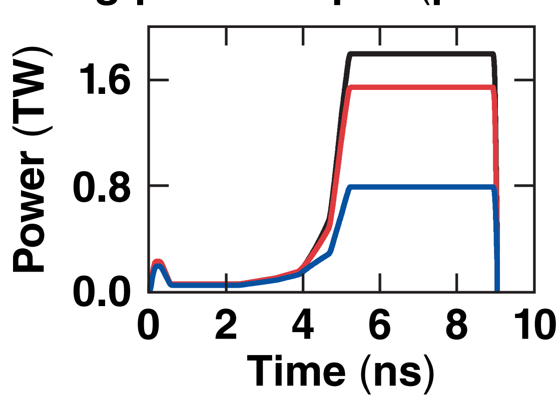
One-dimensional Multi-FM beam smoothing has been developed to relax the need for 2-D SSD on the NIF

Polar-drive simulations of 1.2-MJ CH-foam ignition target





Ring-pulse shapes (per beam)



- At peak compression, t = 9.8 ns

- Multi-FM beam smoothing will be tested on OMEGA EP

J. A. Marozas, presented at the 51st APS DPP Conference, Atlanta, GA, 2–6 November 2009.

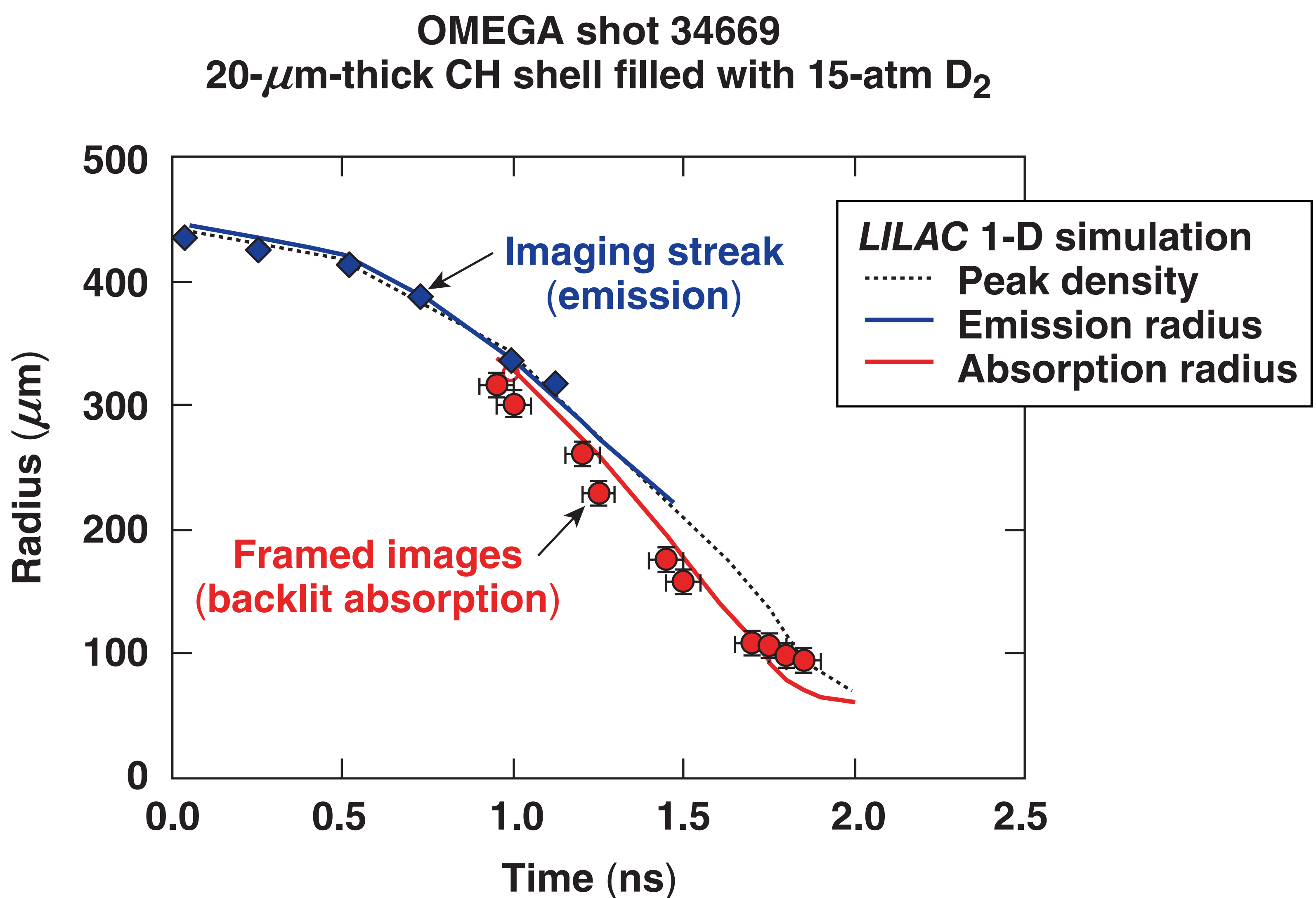
TC8623f

Summary/Conclusions

Simulations and initial NIF experiments indicate that polar drive is a viable ignition alternative for the NIF

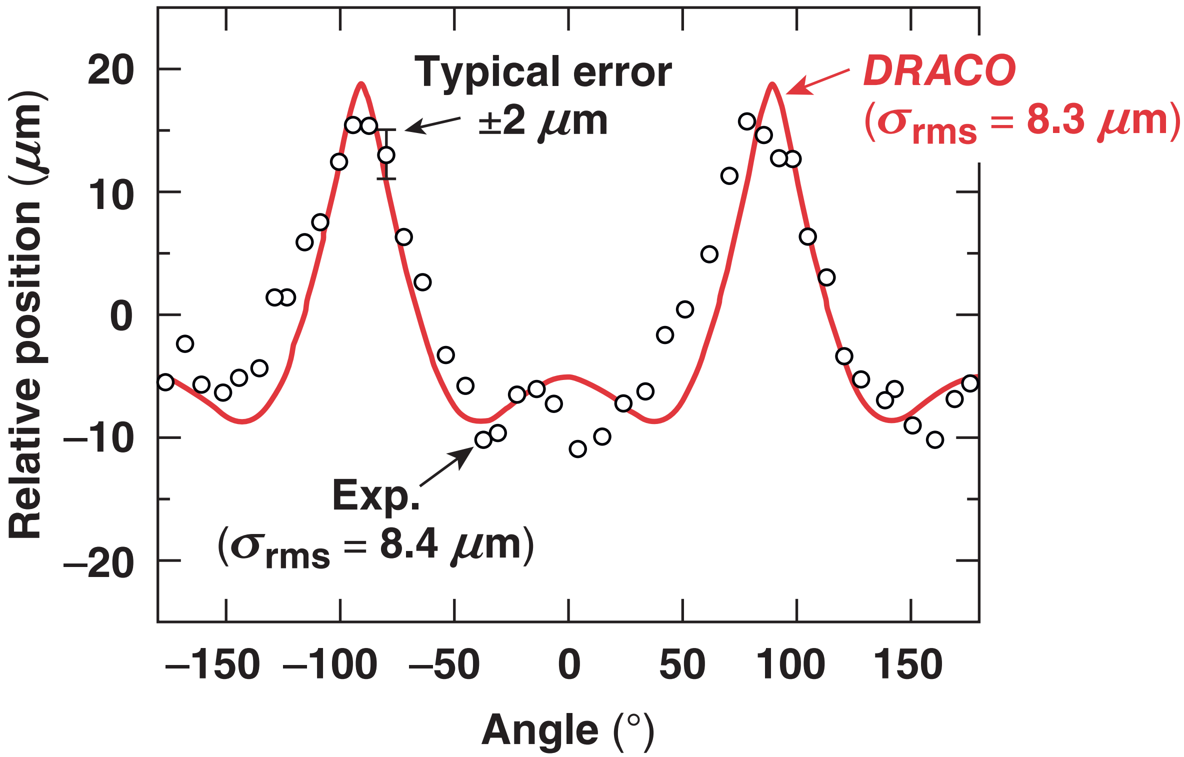
- Polar-drive (PD) experiments on OMEGA are well described by simulations
- Initial polar-drive diagnostic commissioning shots on the NIF achieved the design goals of D_2 neutron yield $Y_n \sim 10^{10}$ and $T_{ion} > 5$ keV
- Multiple-picket pulses are used to facilitate experimental shock timing and increase stability
- 2-D simulations of PD ignition designs show gains of >10 with drive and target nonuniformities included

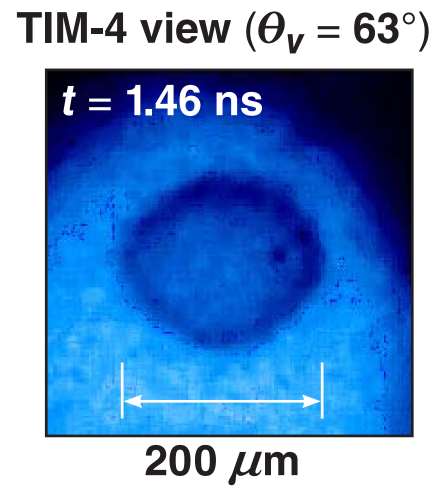
The shell position during OMEGA PD implosions agreed well with simulations

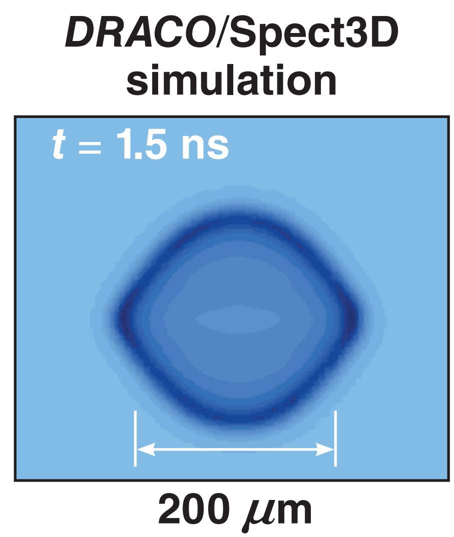


E14033c

Analysis of the experimental and simulated radiographs show an enhanced equatorial perturbation



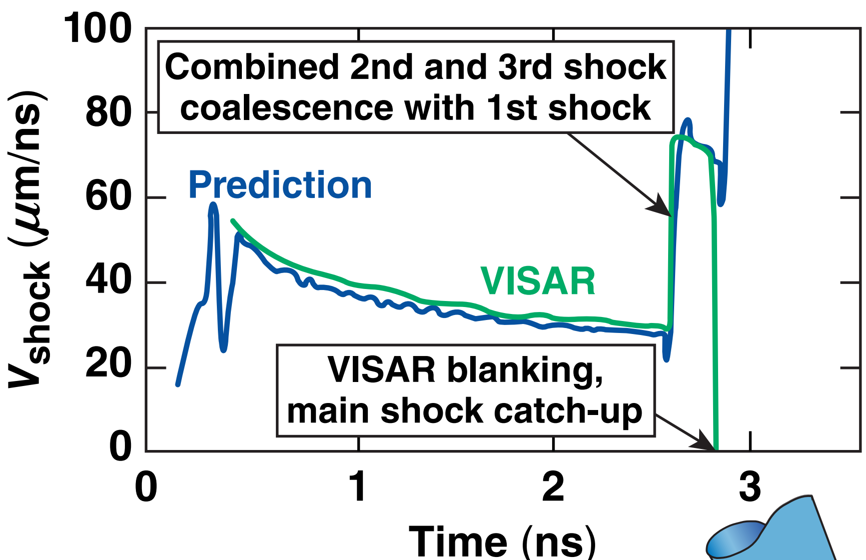


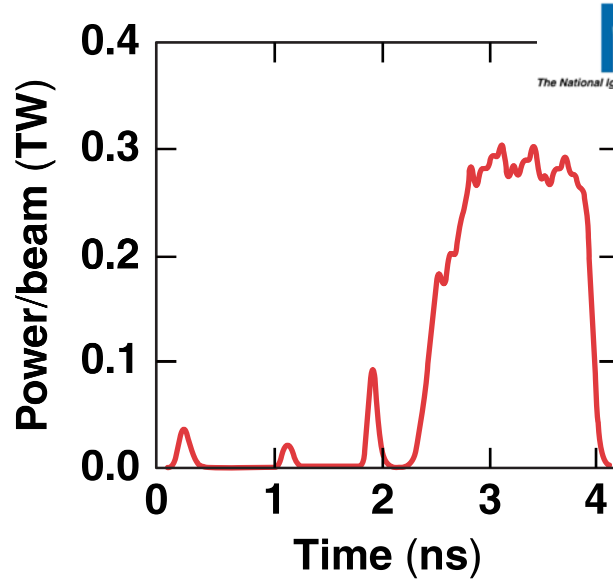


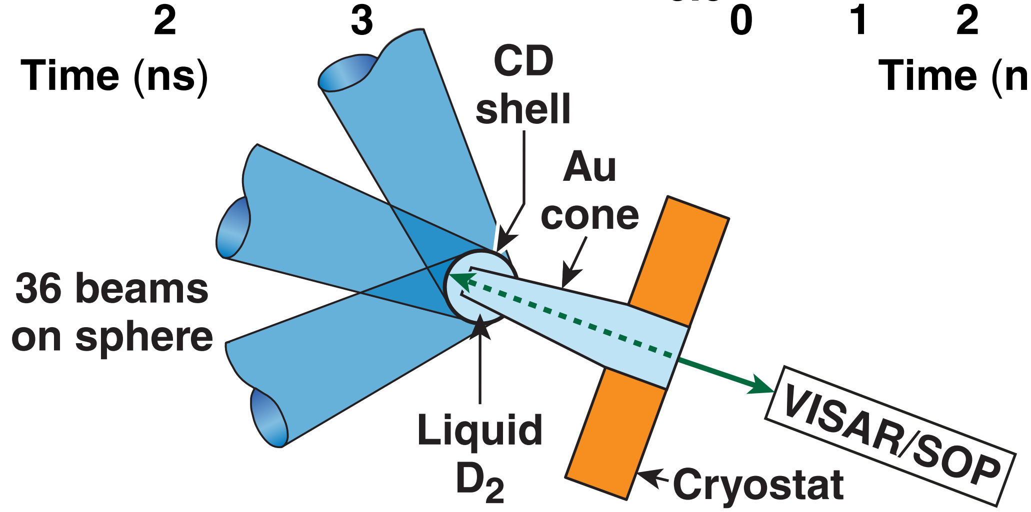
- NIF experiments will use enhanced equatorial drive to reduce or eliminate this perturbation
- Neutron yields in these shots were ~25% to 30% of energy-equivalent symmetric implosions

TC7119a

A recent cone-in-shell experiment on OMEGA showed excellent agreement between measured and predicted shock waves







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