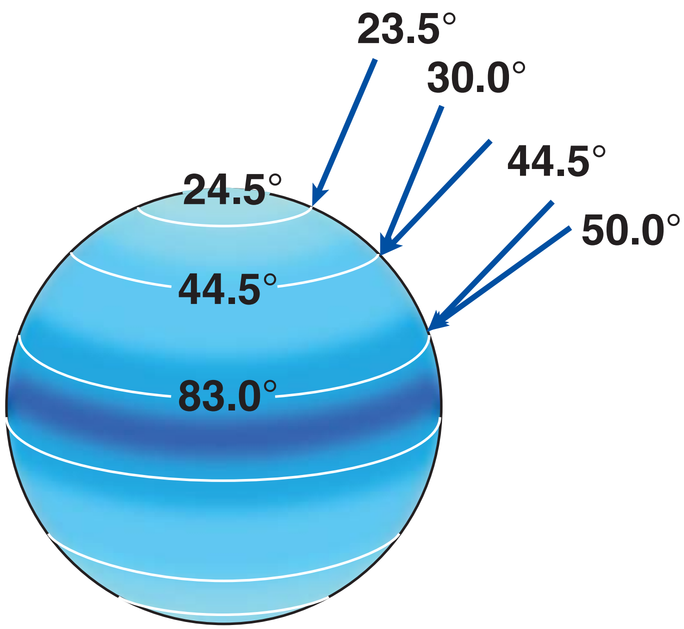
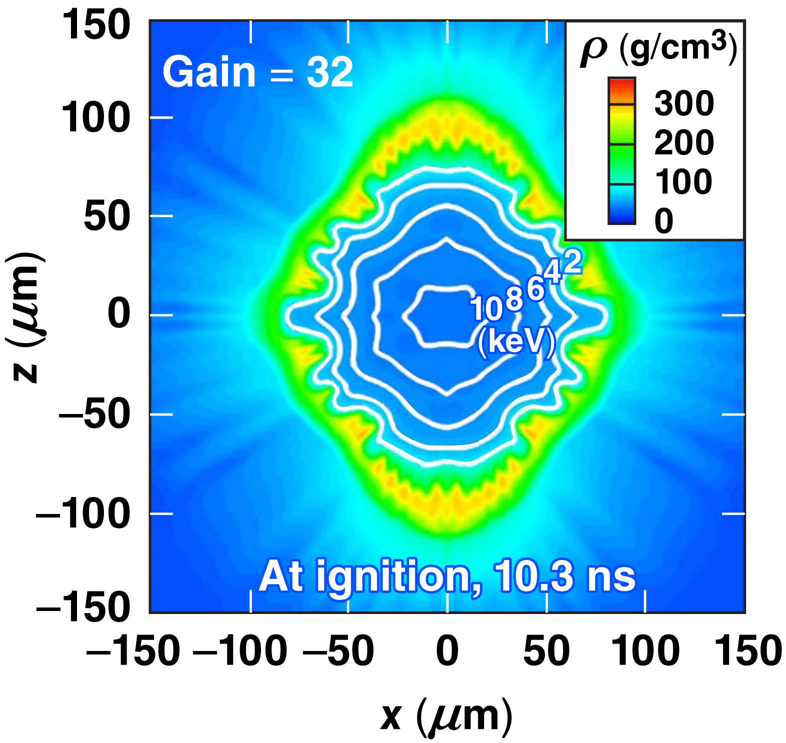
Preparing for Polar Drive at the National Ignition Facility





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Summary

Polar drive provides a viable alternative for hot-spot ignition on the NIF

- A 2-D polar-drive design gives a gain of 32 with NIF-specific target and laser nonuniformities
- UV beam smoothing includes polarization smoothing and Multi-FM 1-D smoothing by spectral dispersion (SSD)
- SSD smoothing is required only during the picket pulses
- Polar-drive experiments on OMEGA and NIF have addressed several aspects of PD including adiabat, symmetry, and drive
- One-dimensional, Multi-FM single-beam smoothing is being tested on OMEGA EP

Implementation of polar drive for ignition on the NIF requires modest additional capabilities.

Collaborators

J. A. Marozas, V. N. Goncharov, S. Skupsky, P. W. McKenty, P. B. Radha, A. Shvydky, K. S. Anderson, J. D. Zuegel, R. Betti, J. A. Delettrez, F. J. Marshall, D. R. Harding and R. S. Craxton

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Outline

- The polar-drive point design
- Sensitivity analysis of the polar-drive point design
- Recent experiments on OMEGA and the NIF

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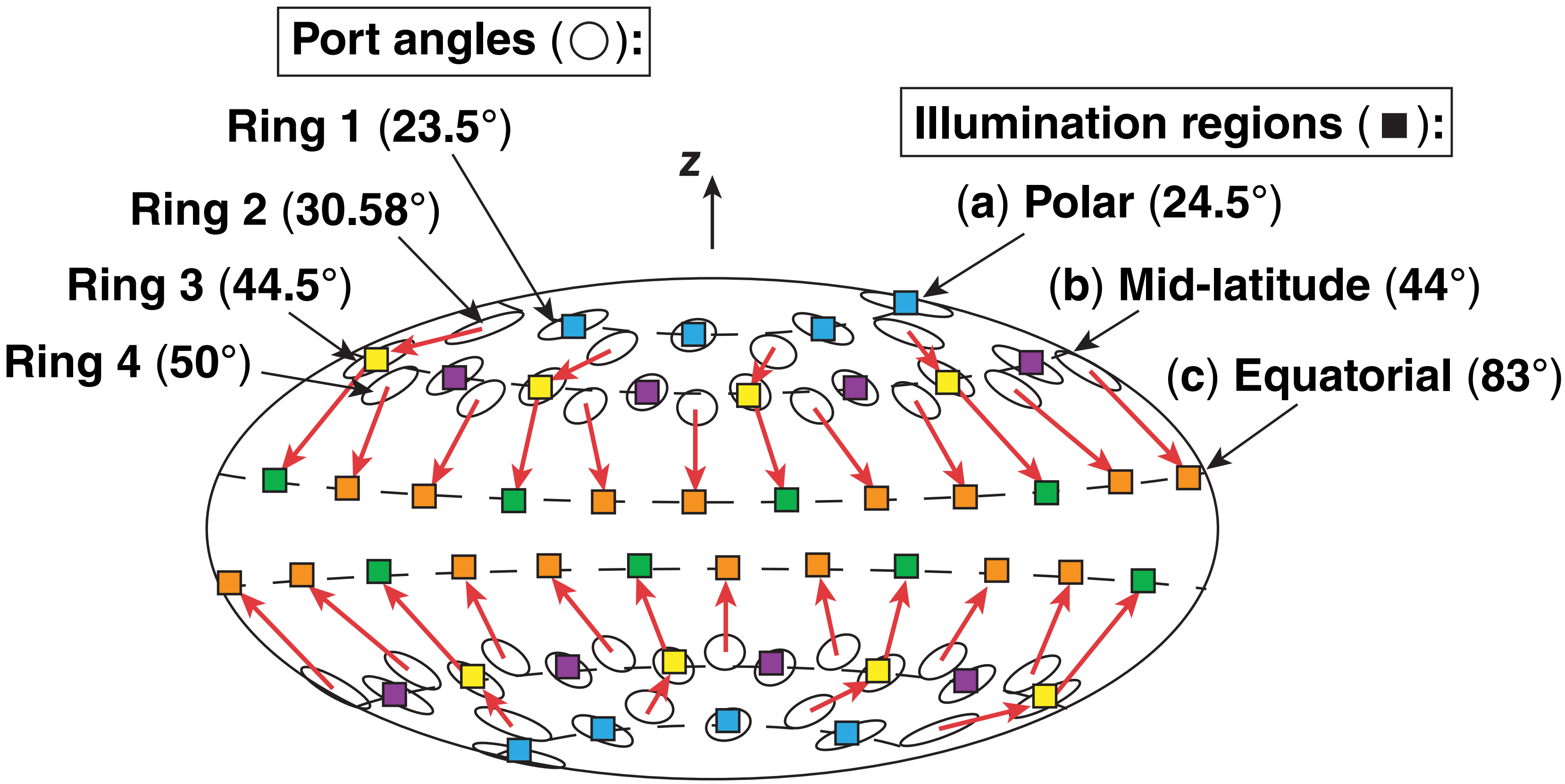
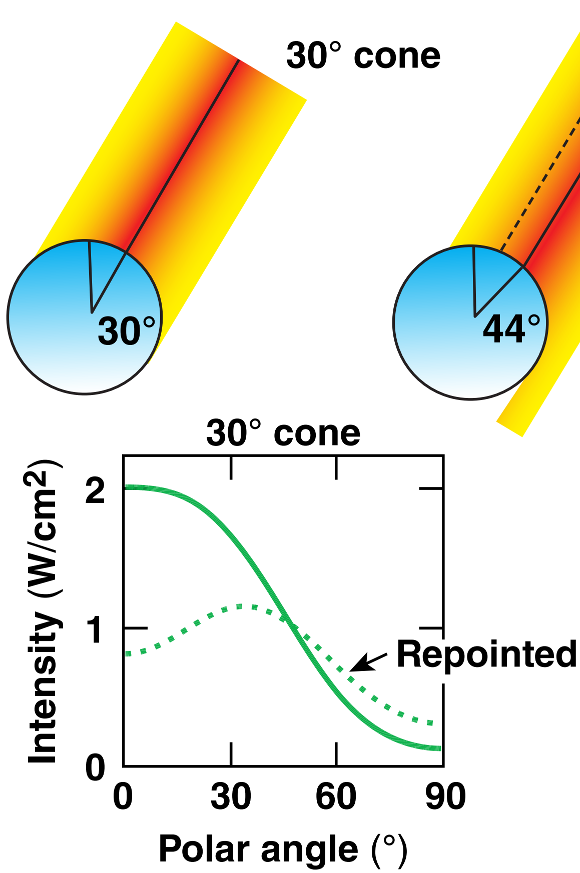
In polar drive, the four NIF beam cones per hemisphere are repointed to three regions on the target

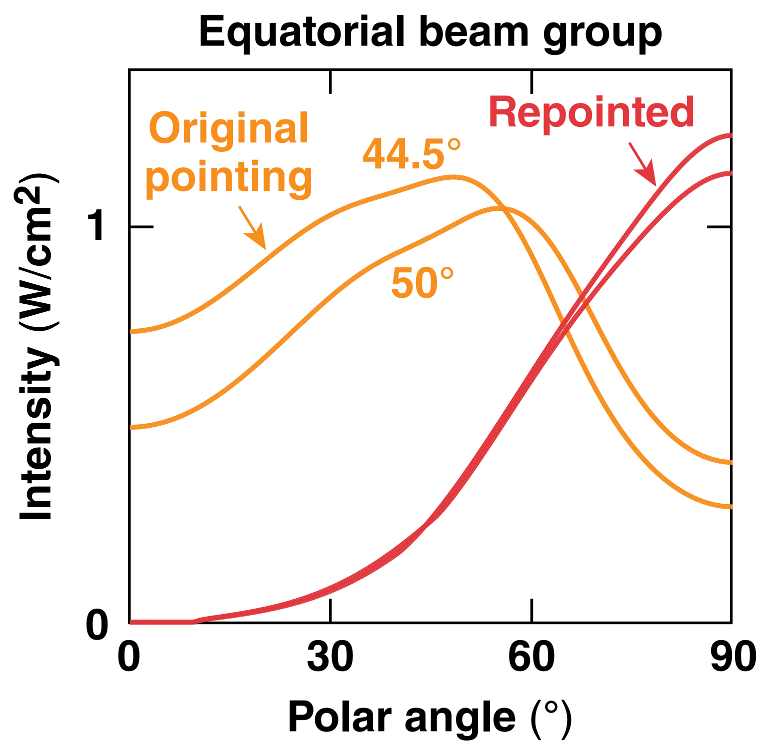


TC9695

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

Repointing corresponds to a lateral translation of the beam in the target plane



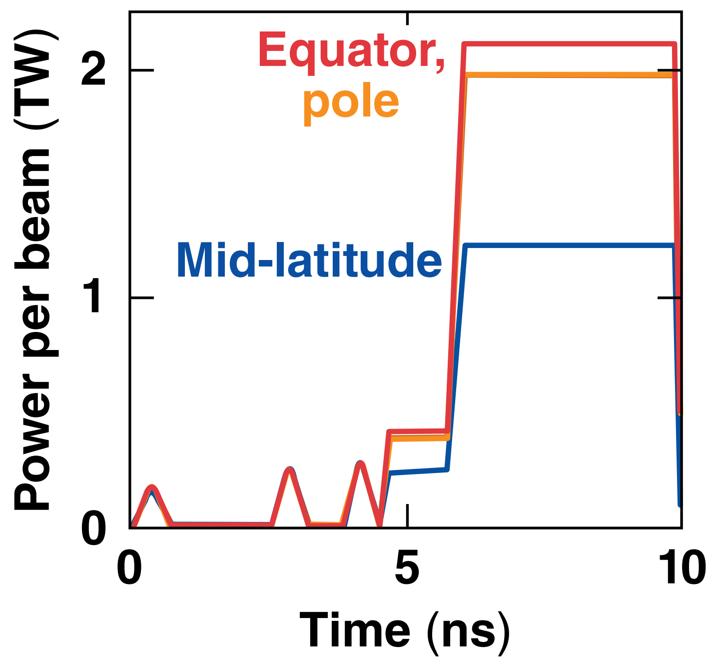


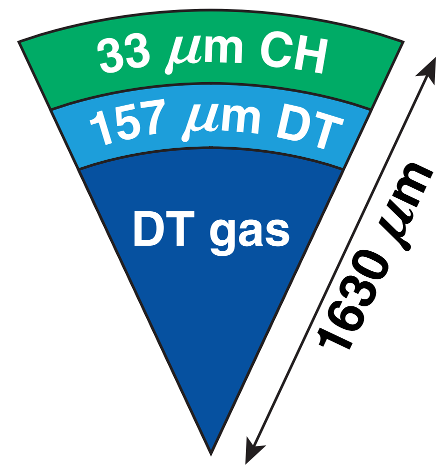
Repointing equatorial beams moves energy to the equator

- Oblique irradiation near the equator is at lower densities, causing
  - reduced absorption
  - reduced hydrodynamic efficiency
  - lateral heat flow

TC9696

A multiple-picket, multiple-shock laser pulse is used to shape the adiabat





- This is based on a triple-picket design* that achieved an areal density of 300 mg/cm^2** in OMEGA experiments
- Individual pulses lie within NIF limits for energy (9.3 kJ/beam) and power (~2.3 TW/beam peak power)

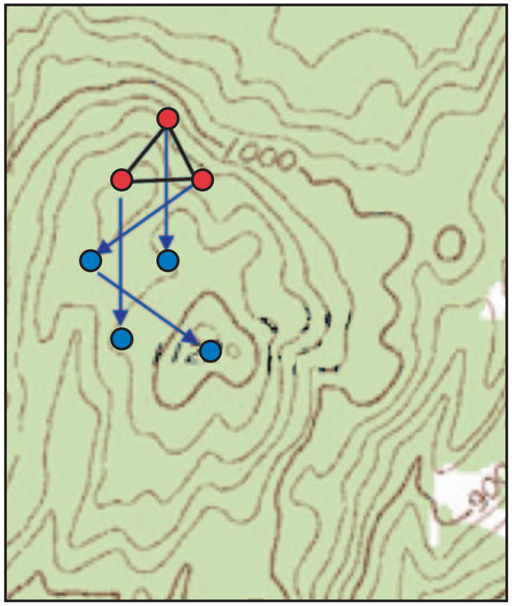
*V. N. Goncharov *et al*., Phys. Rev. Lett. 104, 165001 (2010).
**T. C. Sangster *et al*., Phys. Plasmas 17, 056312 (2010).

TC9697

The triple-picket polar-drive-ignition design was optimized in 1-D with the optimizer *Telios*

UR LLE

- *Telios* is a C++ implementation of a downhill simplex method used to diagnose and generate 1-D designs
- The pulse and target design are varied, maximizing the gain while remaining within laser-damage limits
- This method allows for tuning more variables than would be feasible by hand (e.g., 12+)
- This design has an $ITF_{1\text{-}D}$ = 4.6, where the $ITF_{1\text{-}D}$ is the ratio of the capsule kinetic energy to the minimum needed for ignition*



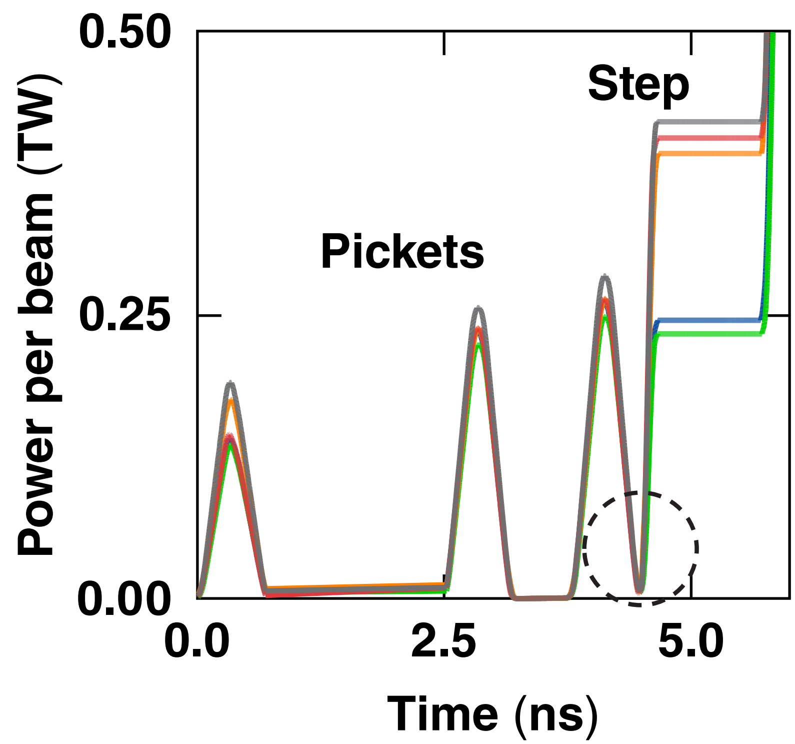
A simplex on a topographical map optimizing for maximum height

TC9698

*S. W. Haan *et al.*, Phys. Plasmas 18, 051001 (2011).

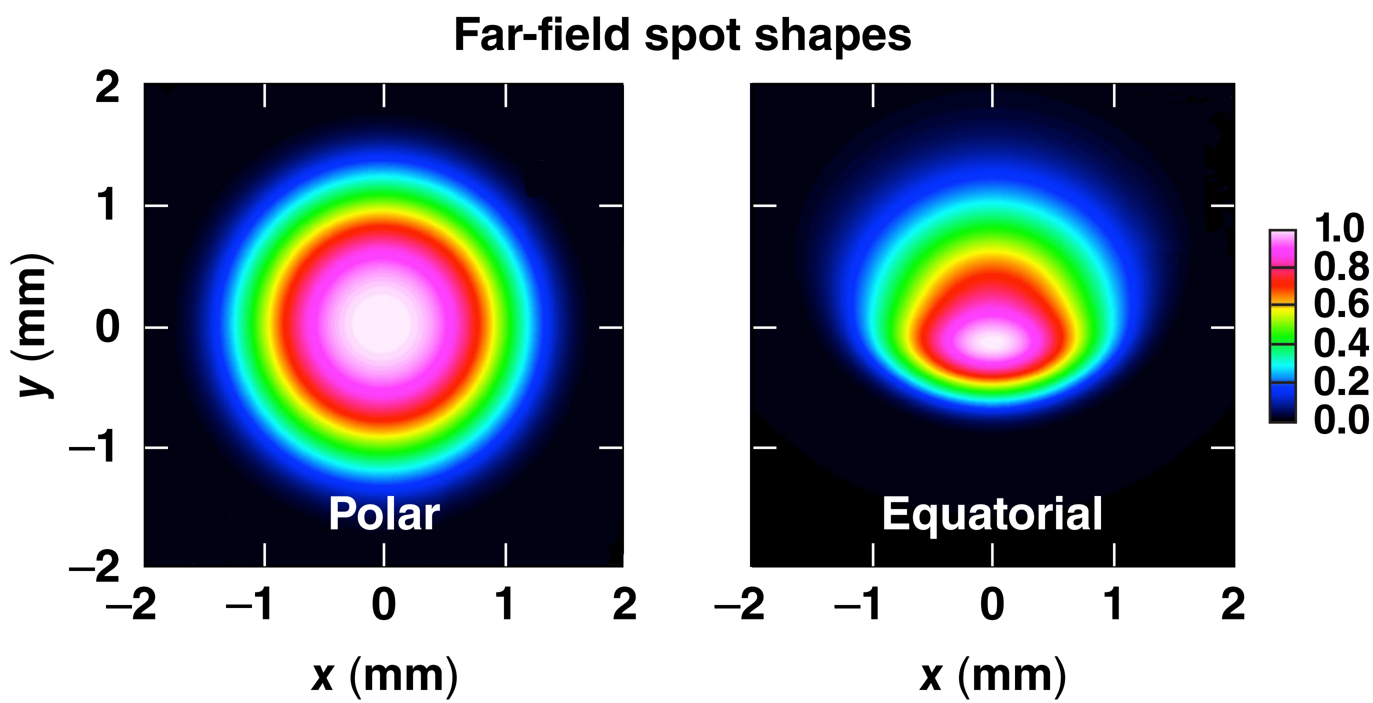
The picket pulses are followed by a rapid-rise drive pulse

- Picket pulses are readily tuned experimentally*
- Multiple pickets provide greater adiabat shaping and decreased shell instability**
- Subsequent pickets must have diminishing spacing, limiting the number of pickets***
- The 2-D gain is insensitive to minimum power between the third picket and step pulse below 0.1 TW/beam



*T. R. Boehly *et al*., Phys. Plasmas 16, 056302 (2009).
**K. S. Anderson and R. Betti, Phys. Plasmas 11, 5 (2004).
***V. N. Goncharov *et al*., Phys. Rev. Lett. 104, 165001 (2010).

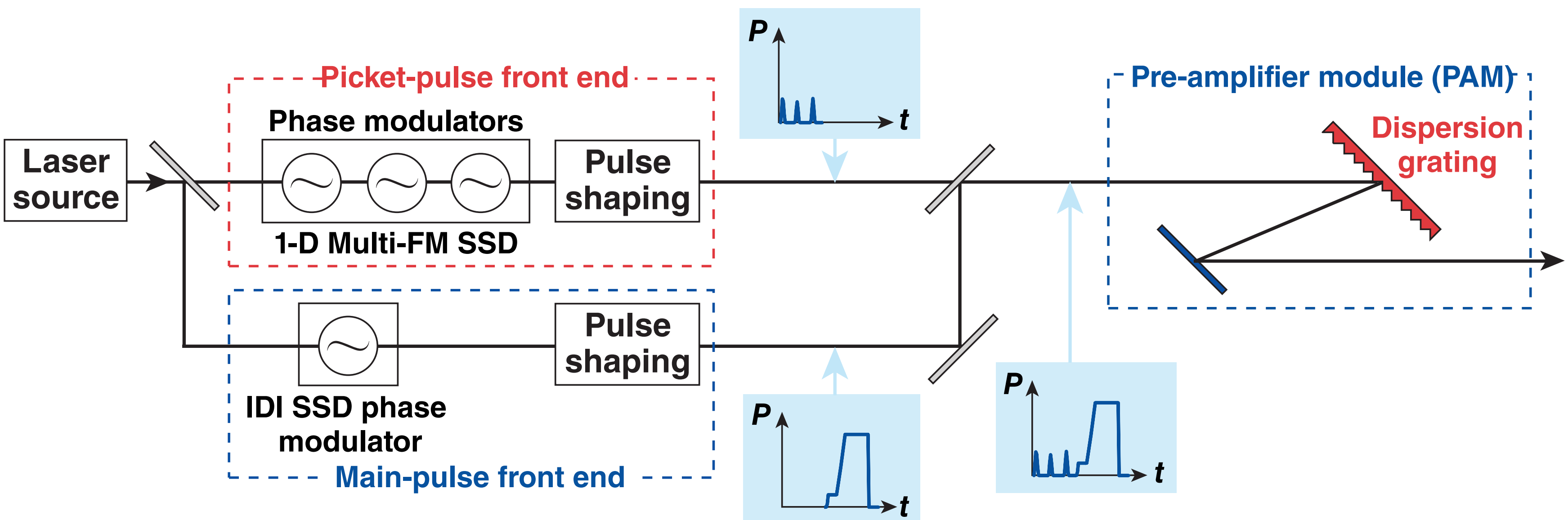
The equatorial beam coupling is increased using tailored phase plates



- Nearly Gaussian spots are more center peaked than higher-order spots, offering greater control of the energy deposition on the target
- The equatorial spot shape further combines a round spot with an elliptical spot to mitigate loss of coupling near the equator
- All spots are further enveloped with a high-order super-Gaussian centered on the target

Multi-FM SSD beam smoothing and polarization smoothing are used to reduce single-beam nonuniformities

- Multi-FM 1-D SSD* employs technology developed for the telecommunications industry
  - microwave phase modulators and drive electronics (~20 to 40 GHz)
  - an effective UV bandwidth of 500 GHz
  - a divergence of 100-μrad half angle at full beam width
- Multi-FM uses a three-modulator configuration that achieves high gain in polar-drive simulations
- Polarization smoothing is also included to reduce single-beam nonuniformities

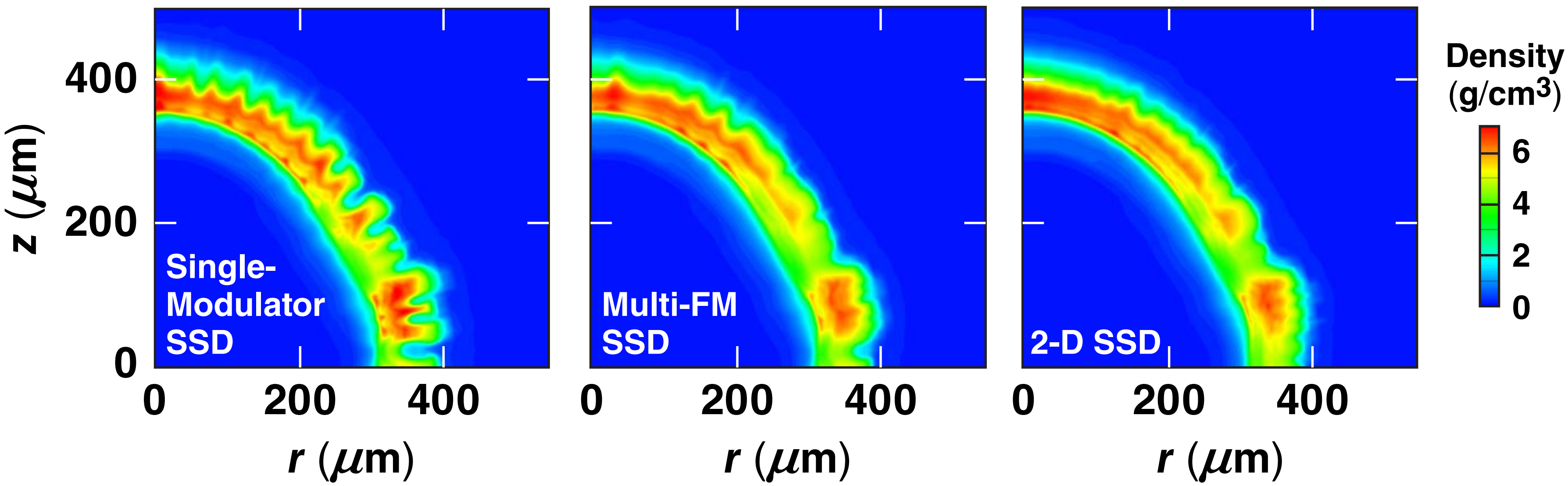


*J. A. Marozas, J. D. Zuegel, and T. J. B. Collins, Bull. Am. Phys. Soc. 55, 294 (2010).
LLE Review Quarterly Report 114, 73 (2008).

TC9701

Imprint mitigation with Multi-FM is comparable to that of 2-D SSD

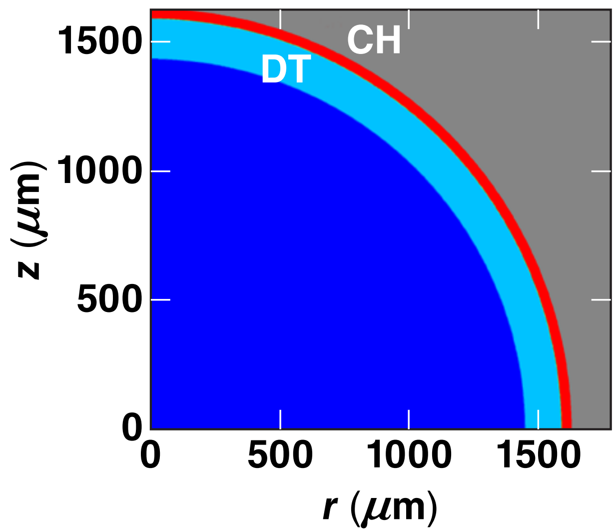
- With single-modulator SSD the target fails to ignite; with Multi-FM or 2-D SSD it achieves full gain

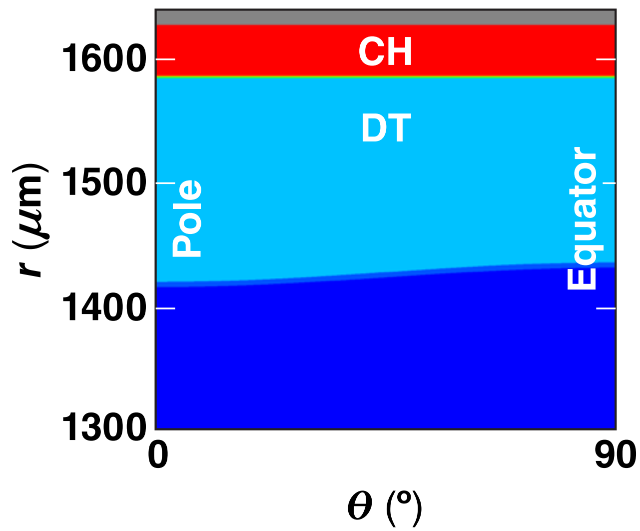


At the end of the acceleration phase: 9.8 ns

TC9702

An ~10-μm-amplitude ice-layer "shim" is used to lower the equatorial mass and reduce the laser energy required to drive the equator





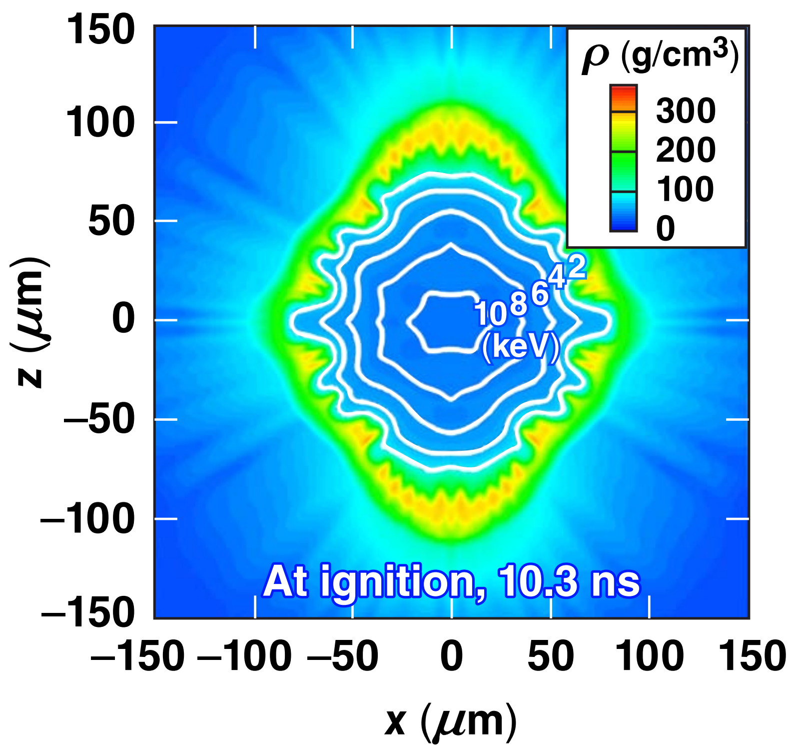
- This perturbation may be introduced by shimming the cryogenic layering sphere itself or adding an IR source around the equator
- A 10-μm shim allows for a ~10% reduction in equatorial beam power, allowing greater overall power while remaining below laser-damage thresholds
- Alternately, shimming permits lower equatorial intensities, reducing plasma instabilities
- When the shim is removed and the design scaled to 1.4 MJ and retuned, the gain with nonuniformities is reduced by 20%

The polar-drive design with target and beam nonuniformities and Multi-FM beam smoothing achieves a gain of 32

- Simulations use flux-limited thermal transport with a 6% flux limiter
- Initial gas density = 0.225 mg/cm^3
- The sum of the outer- and inner-rms surface perturbations is only 25% of the shell thickness at the start of shell deceleration

Energy	1.52 MJ
Gain	32
V_{imp}*	432 μm/ns
$IFAR_{2/3}$	36
In-flight α**	3
Convergence ratio	23
Peak ρR	1.42 g/cm^2

$$IFAR_{2/3} = \frac{R}{\Delta R} \text{ at } R = 2/3R_0$$



*$V_{imp} = (2E_{kin}/M)^{1/2}$
**At peak shell speed

TC9704

The polar-drive design has been simulated with all relevant sources of implosion nonuniformity

Nonuniformities (NIF specification)	
Target	Surface roughness (115 nm rms)
	Ice roughness (1-μm rms)
Single beam	Imprint
Multibeam	Power imbalance (8%)
	Beam mistiming (30 ps)
	Beam mispointing (50 μm)

- Single-beam nonuniformities are modeled including polarization smoothing

Experiments and simulations are planned to investigate further aspects of this design

Hydrodynamics	This design will be simulated in 3-D using *HYDRA*
Energetics	• Nonlocal thermal transport using a modified Schurtz algorithm[1] has been implemented in *DRACO* • A crossed-beam energy transfer (CBET) model is being implemented in *DRACO*[2] • Experiments on OMEGA suggest that CBET may be mitigated using beams that underfill the target[3]
Preheat	A possible mitigation strategy for two-plasmon decay is given by experiments on OMEGA that found decreased hard x-ray signals with Si- and Ge doped targets[4]

- Cryogenic PD experiments of relevant targets will be performed on OMEGA

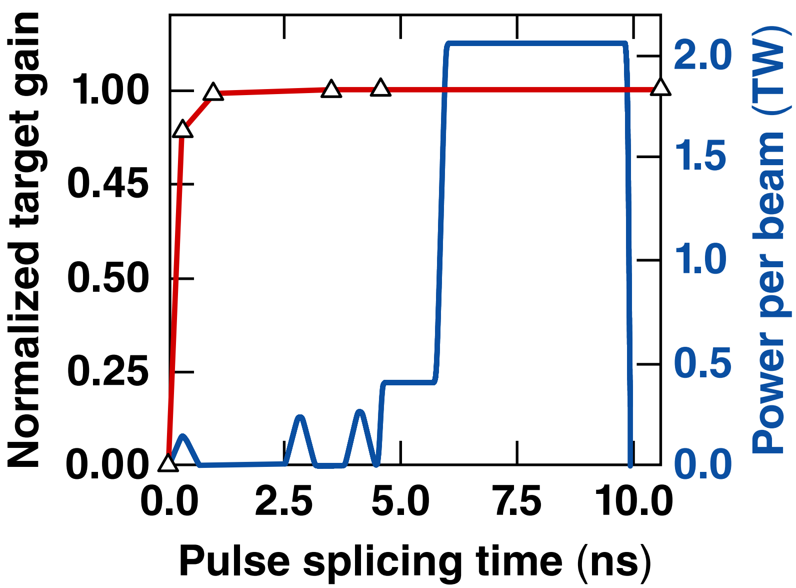
[1]Ph. D. Nocolaï, J.-L. A. Feugeas, and G. P. Schurtz, Phys. Plasmas 13, 032701 (2006).
[2]See J. A. Marozas, PO8.00003.
[3]See I. V. Igumenshchev, YI3.00001.
[4]P. B. Radha *et al*., Bull. Am. Phys. Soc. 52, 143 (2007).

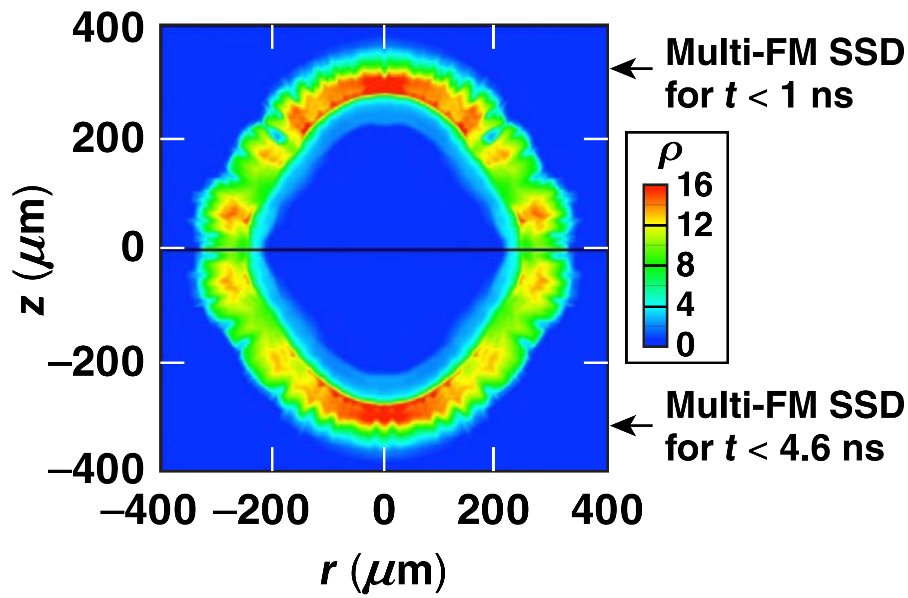
Outline

- The polar-drive point design
- **Sensitivity analysis of the polar-drive point design**
- Recent experiments on OMEGA and the NIF

Simulations show little gain reduction when Multi-FM SSD is active for only the first picket*

- Splicing in a separate pulse for the pickets means the drive pulse can operate with less bandwidth
- **Motivation:** using only native single-modulator SSD during the drive pulse reduces the risk of damage to the laser
- Single-beam smoothing asymptotes on 1-ns time scales**

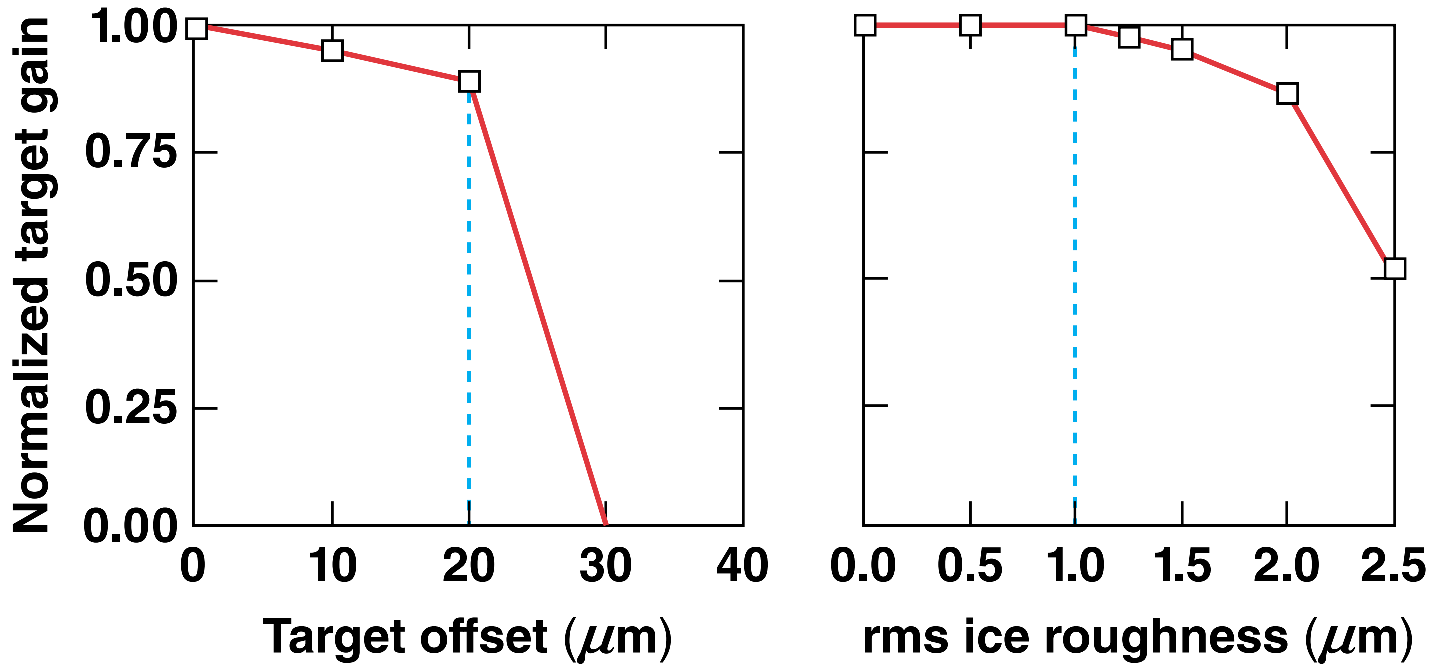




*P. W. McKenty *et al*., Bull. Am. Phys. Soc. 51, 295 (2006).
**J. A. Marozas, presented at the International Workshop on ICF Shock Ignition, Rochester, NY, 8–10 March 2011.

TC9706

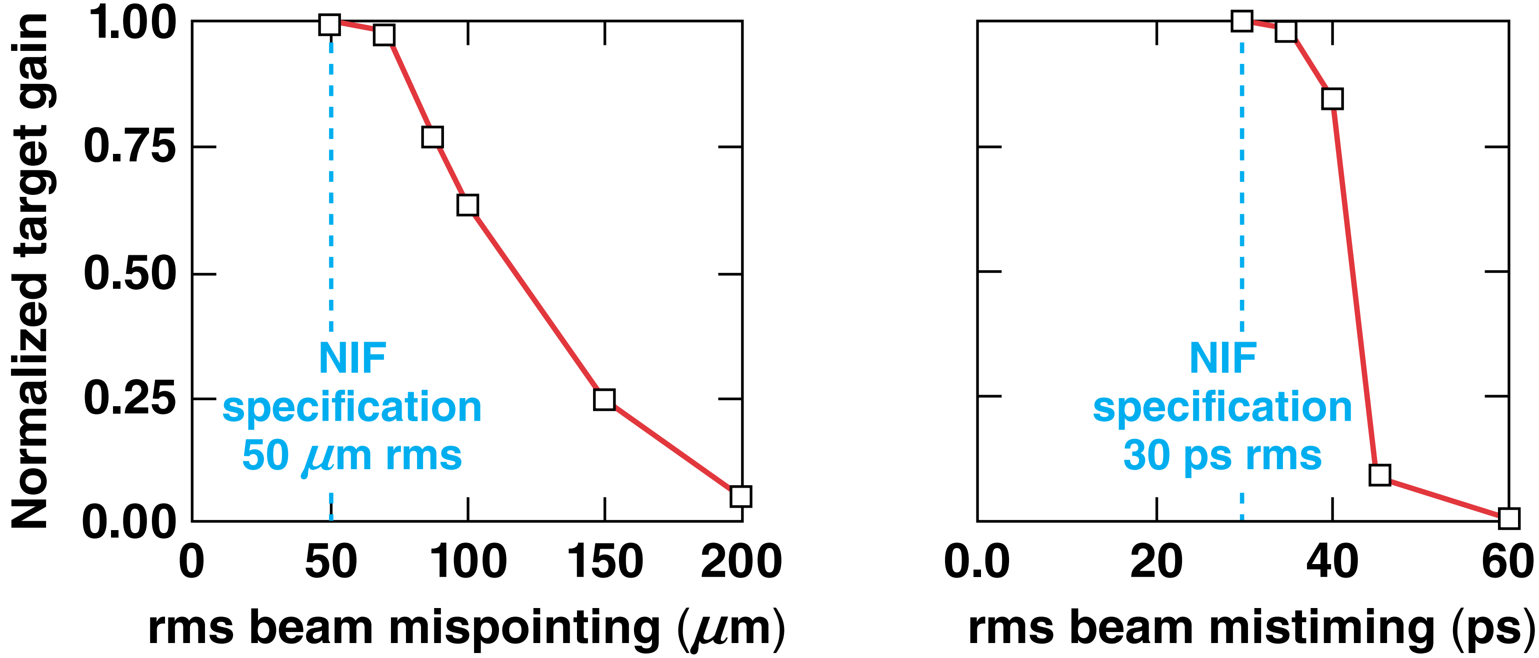
Target performance is sensitive to positioning but less sensitive to ice roughness



- Simulations indicate that an offset of ~20 μm is tolerated
- An ice-roughness power-law spectrum ~ℓ^{-1} is used, not including the shim, based on shadowgraphy measurements
- This design tolerates an ice roughness of over 2-μm rms

The target is insensitive to mispointing and mistiming errors within the NIF specifications

- **Pulse mistiming primarily impairs target performance caused by large-amplitude, low-mode illumination perturbations during the rise and fall of the pickets and drive pulse***

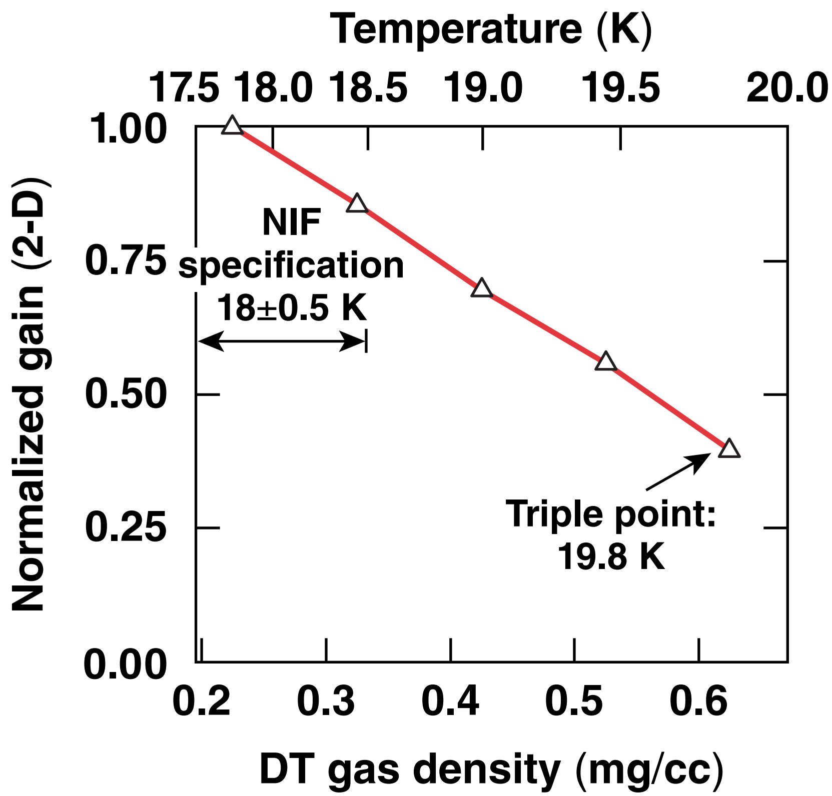


TC9708

*R. Epstein *et al.*, Bull. Am. Phys. Soc. 50, 114 (2005).

The target gain is sensitive to the initial target temperature

- The NIF specification is 18±0.5 K
- As the target warms, it pauses at the triple point (19.8 K) because of the phase change in DT
- Operating at the triple point reduces the 2-D target gain by 60%



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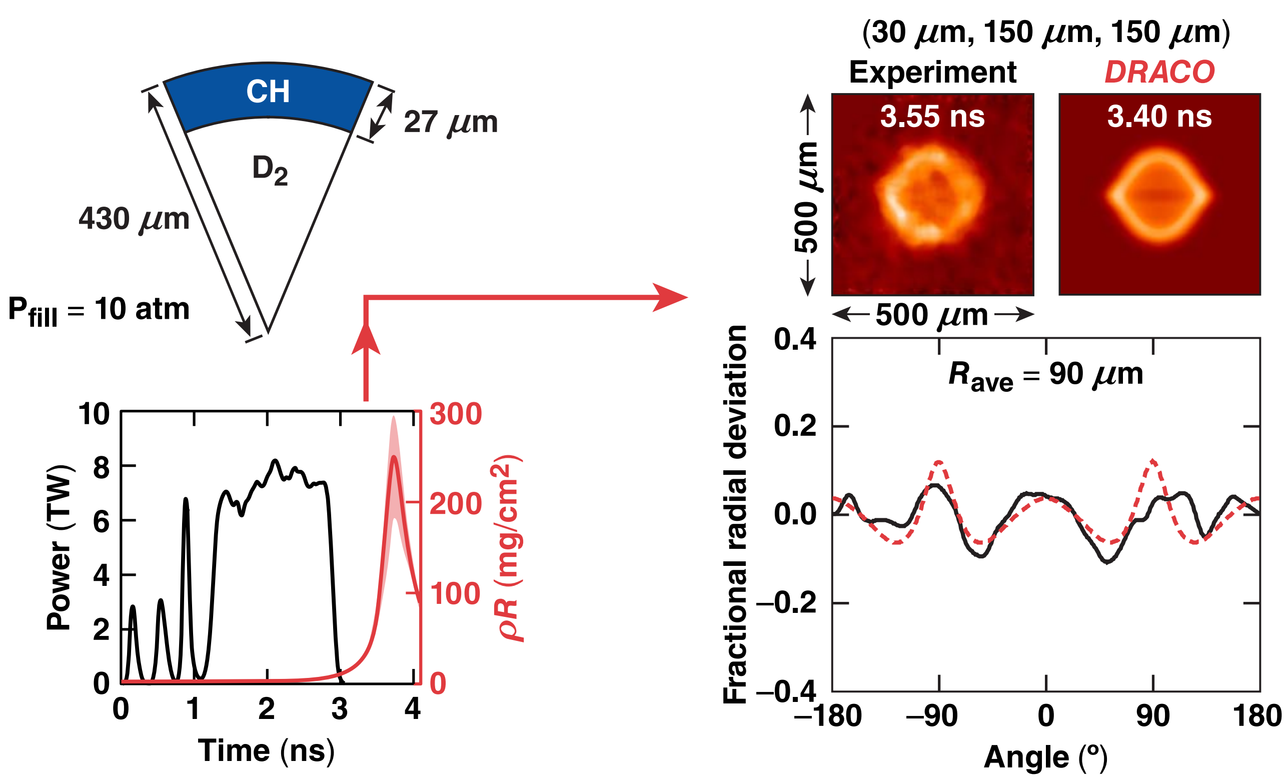
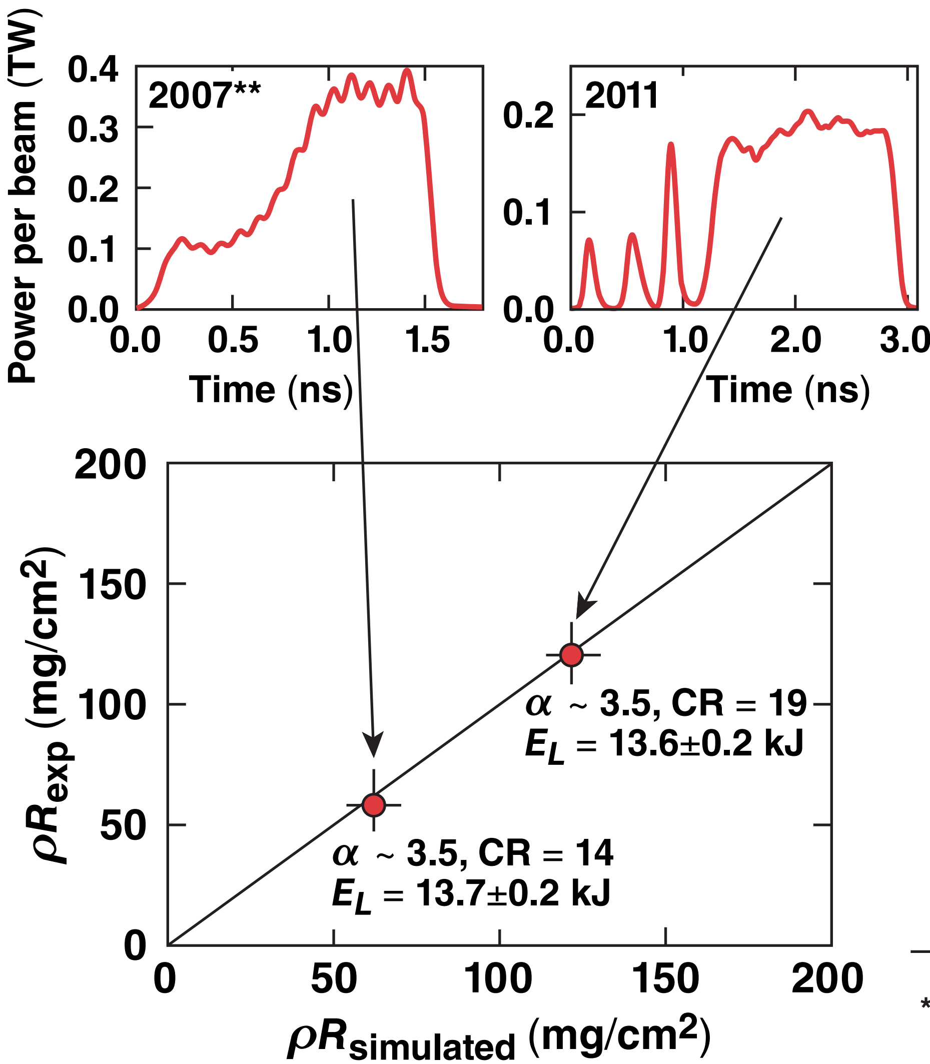
Polar-drive experiments on OMEGA have addressed several aspects including adiabat, symmetry, and drive*

- Low-adiabat pulses were used to drive high-convergence implosions of warm plastic shells
- Simulated equatorial shock speeds are within 5% of those measured by VISAR
- Backlit images of the compressed shells are in good agreement with simulated morphology



*P. B. Radha *et al.*, presented at the 7th International Conference on Inertial Fusion Sciences and Applications, Bordeaux, France, 12–16 September 2011.
See F. Marshall, PO8.00007; P. B. Radha, PO8.00008.

Areal densities up to 125 mg/cm^2 were recently demonstrated in polar drive implosions on OMEGA*



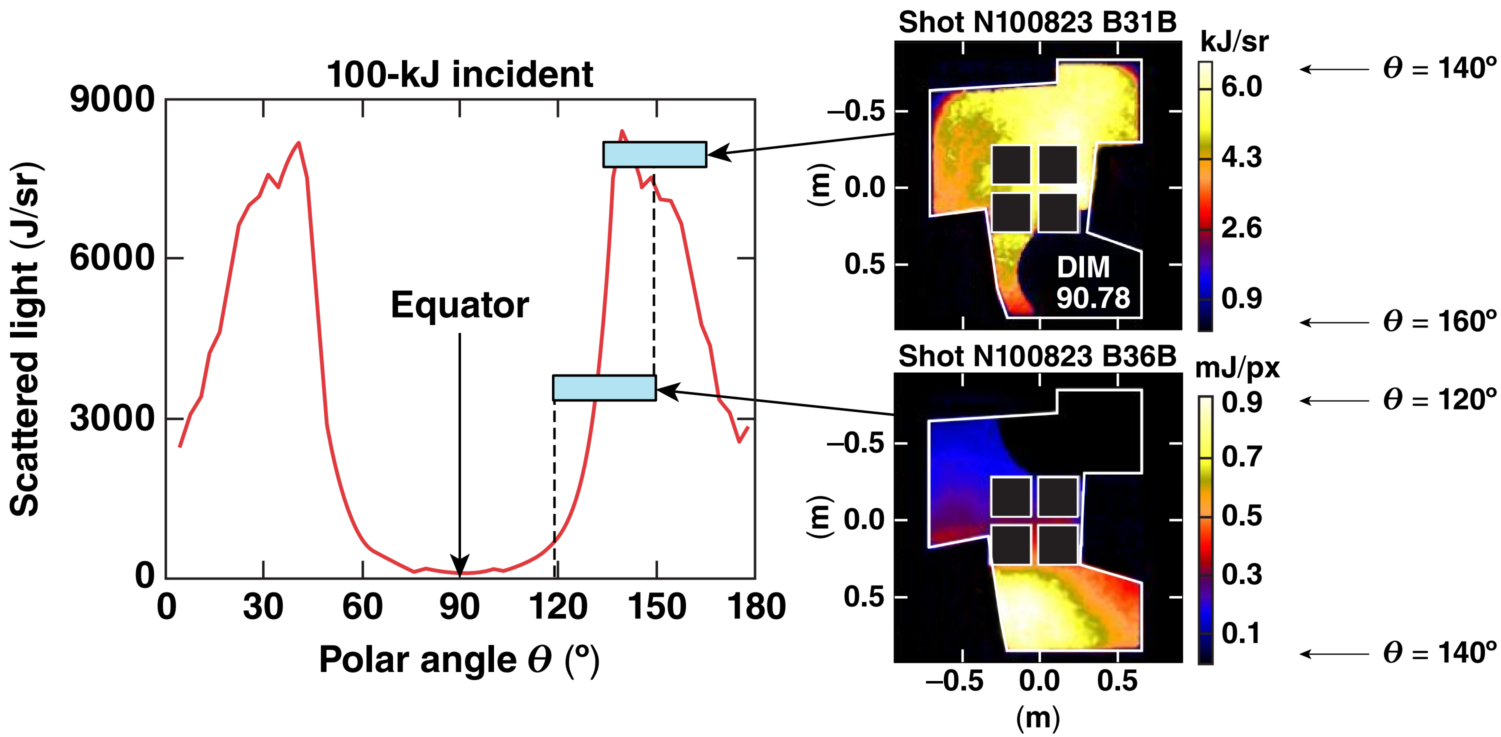
- **Higher areal density is obtained by eliminating shell coasting after the laser drive is off**

See F. Marshall, PO8.00007; P. B. Radha, PO8.00008.
*P. B. Radha *et al.*, presented at the 7th International Conference on Inertial Fusion Sciences and Applications, Bordeaux, France, 12–16 September 2011.
**F. J. Marshall *et al.*, Phys. Rev. Lett. 102, 185004 (2009).

TC9479f

Exploding-pusher neutronics calibration experiments are providing a first test of polar drive on the NIF*

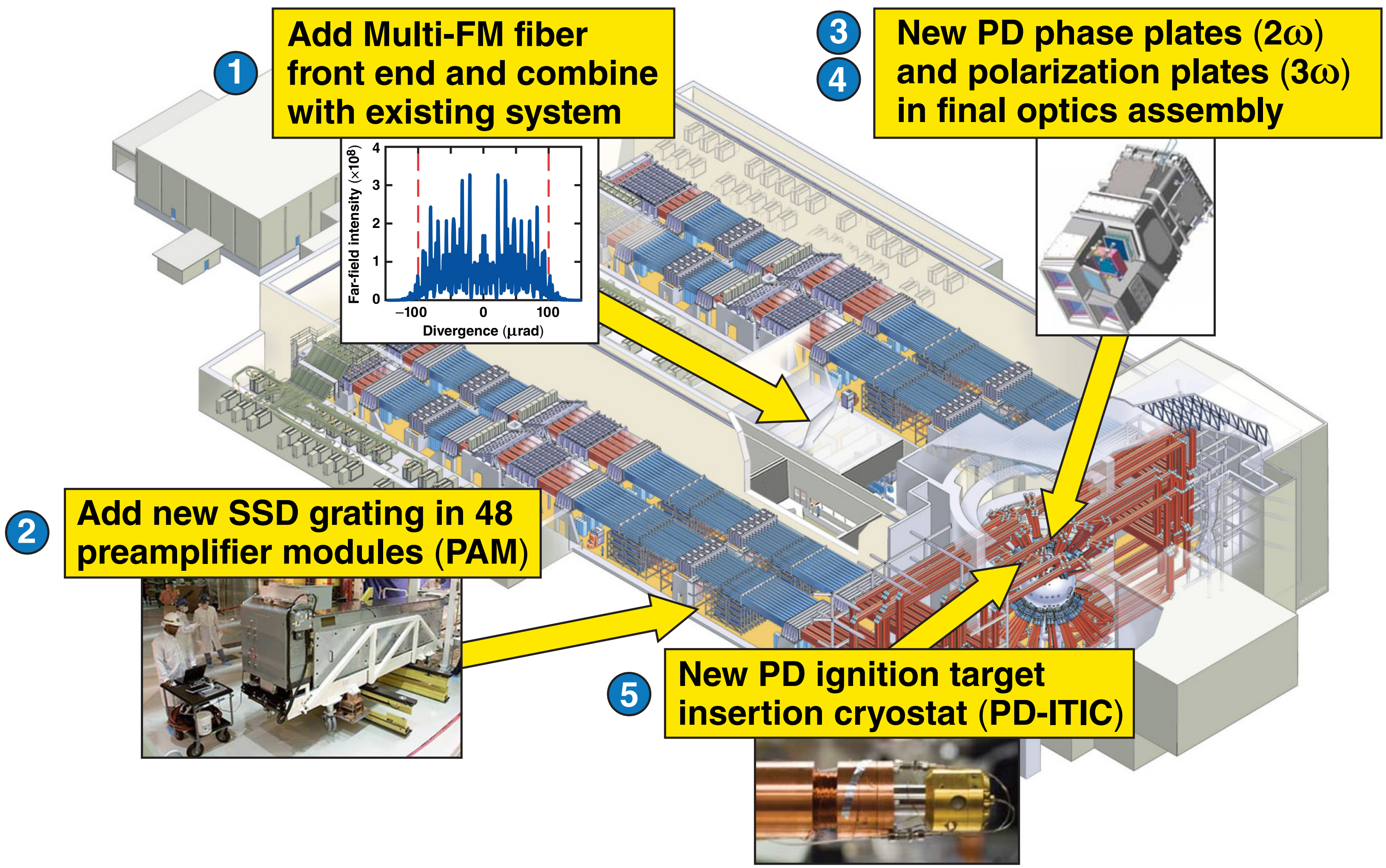
- The first NIF PD DT shot was taken on 17 September 2010
- The observed scattered 3ω light** was 34 mJ/cm^2 as measured by backscatter plates and the flux predicted by *SAGE* was 31 mJ/cm^2
- Gated x-ray images of shot N100917 show a circular stagnating glass shell
- Neutron yields for 1.5-mm-diam targets have been within 10% of projections



* P. W. McKenty *et al.*, presented at the 7th International Conference on Inertial Fusion Sciences and Applications, Bordeaux, France, 12–16 September 2011.
** See R. S. Craxton, UO8.00001

TC9095b

Implementing polar drive requires five additional capabilities on the NIF for an ignition demonstration



E19668g

Multi-FM SSD is being tested on OMEGA EP.

Summary/Conclusions

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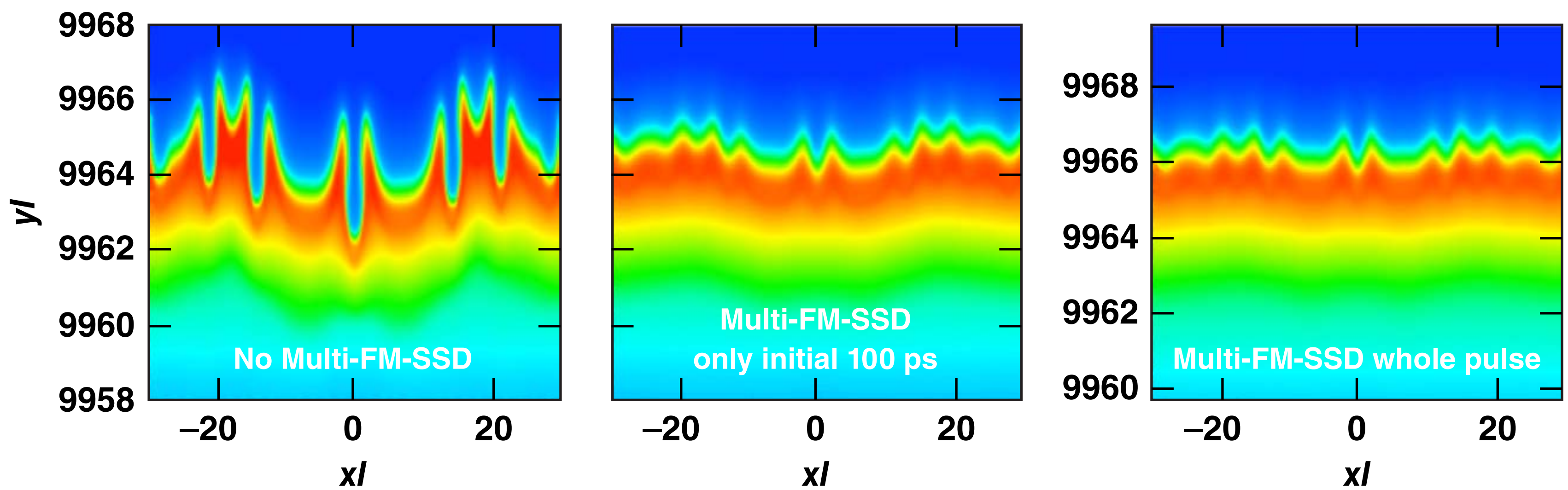
- UV beam smoothing includes polarization smoothing and Multi-FM 1-D smoothing by spectral dispersion (SSD)
- SSD smoothing is required only during the picket pulses
- Polar-drive experiments on OMEGA and NIF have addressed several aspects of PD including adiabat, symmetry, and drive
- One-dimensional, Multi-FM single-beam smoothing is being tested on OMEGA EP

Implementation of polar drive for ignition on the NIF requires modest additional capabilities.

Multi-FM SSD will be tested on OMEGA EP*

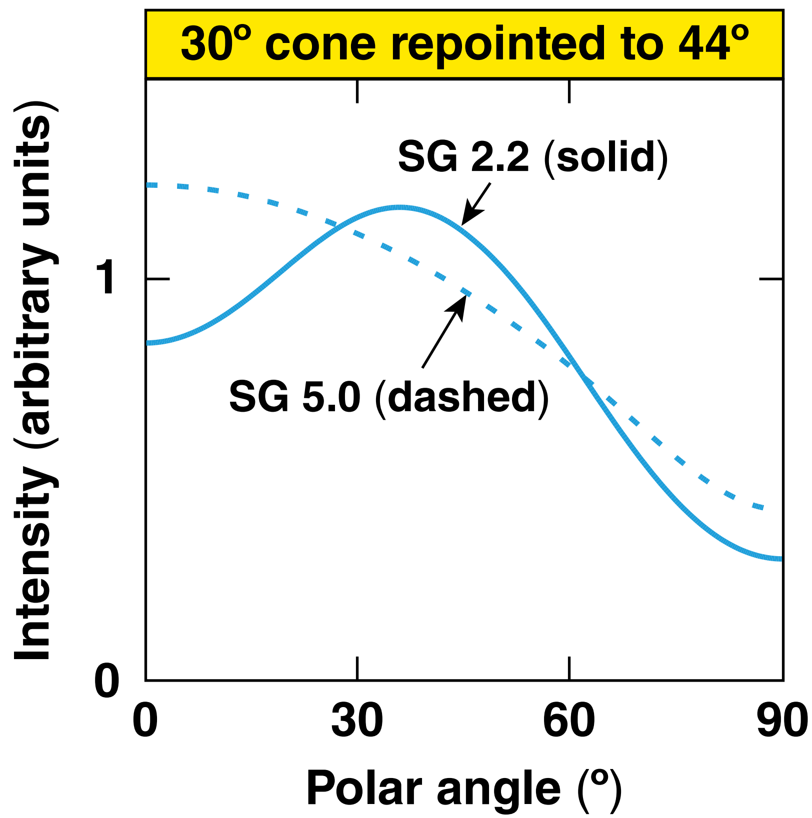
- A thin CH foil will be driven with 2.2 J in 3 ns
- The perturbation growth will be diagnosed with through-foil radiography, and the trajectory with side-on radiography
- Multi-FM SSD will be applied from the start of the pulse to up to 500 ps
- The duration of the smoothing will be varied, to test the use of ____?



TC9712

* A. Shvydky, PO6.00002.

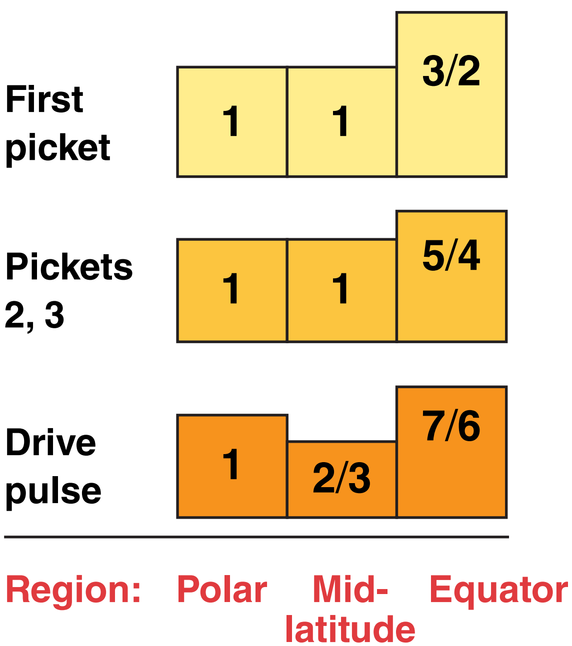
Lower super-Gaussian beam-shape orders offer greater control of the energy density on the target

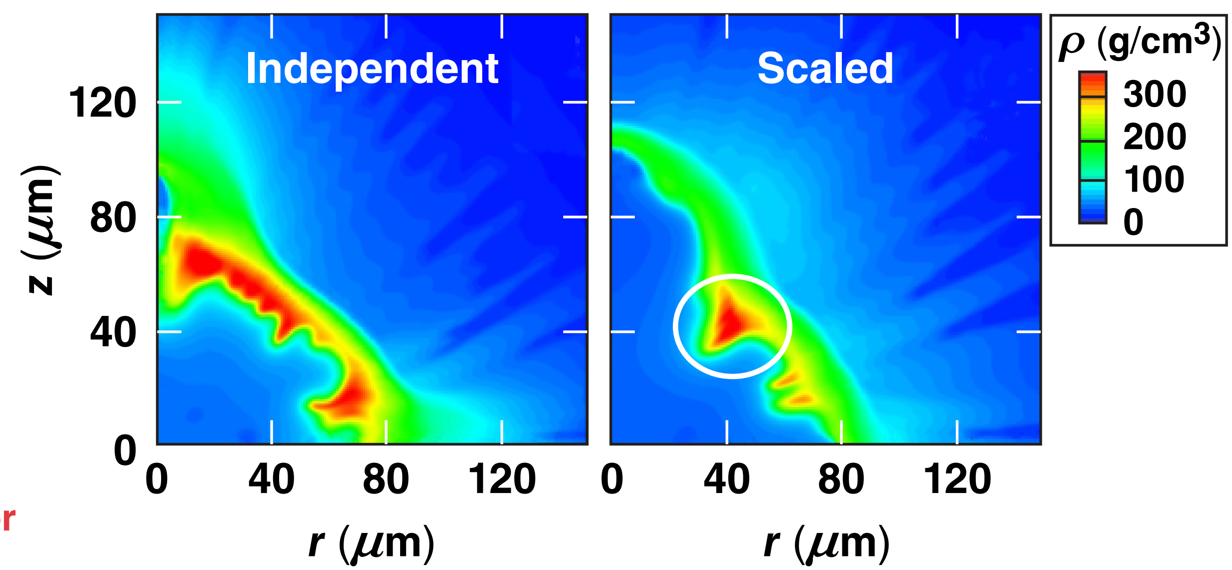


- Less energy is spilled over the horizon when lower super-Gaussian-order beams are repointed

Independent ring pulse shapes are used to compensate for variations in the angle of incidence

- The equatorial rings are driven at a higher power than the other rings
- The mid-latitude rings must be lowered because of beam overlap
- The polar ring power is raised for the same reason
- Pickets and drive pulse require different relative ring powers; using ring pulse shapes that are multiples of each other reduces this target's gain by 40% because of the prominent P_4





E19818a

Target performance shows a __% reduction in gain when the spot size is reduced by 20%

- Use of underfilling spots has been proposed to reduce the effects of crossed-beam energy transfer*
- When DPP spots are reduced by 20%, the gain is _

*I. V. Igumenshchev *et al.*, Phys. Plasmas 17, 122708 (2010).