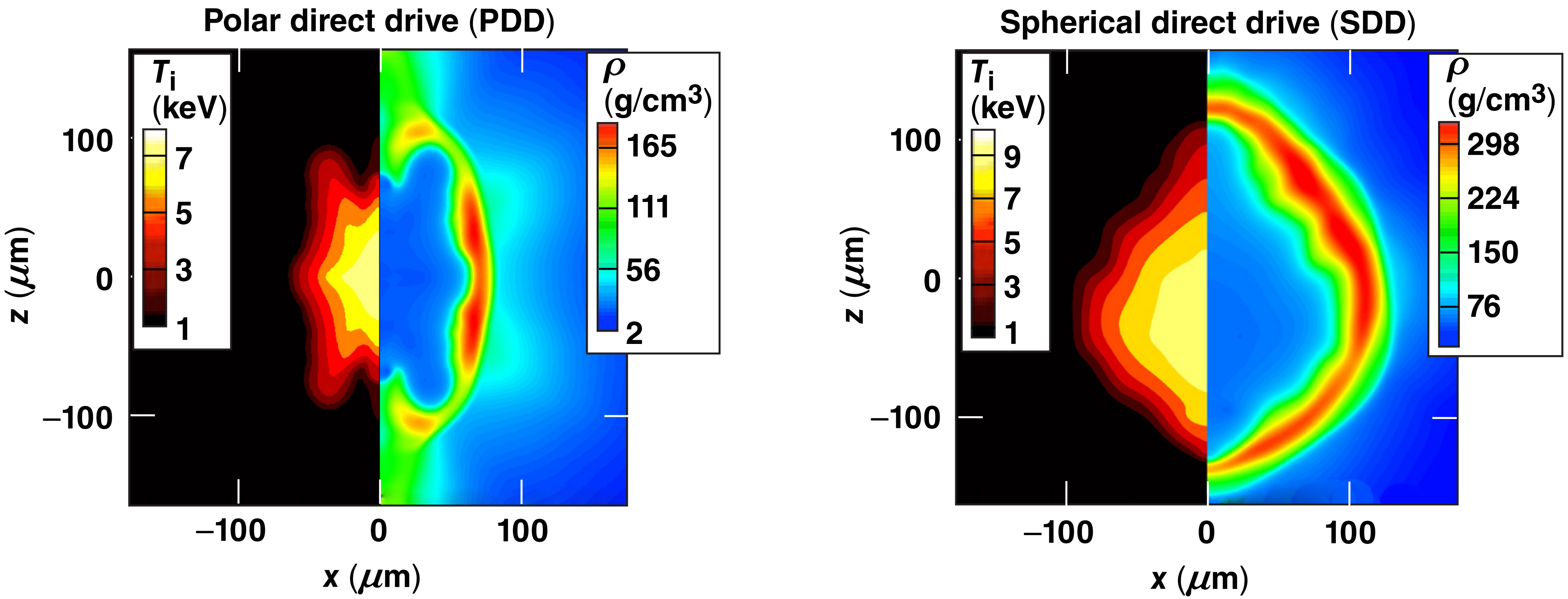
Advances in Modeling Direct-Drive Ignition-Scale Designs for the National Ignition Facility



Low-IFAR alpha-burning designs with over ×2 yield multiplication

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Summary

Wavelength detuning for cross-beam energy transfer (CBET) mitigation is the cornerstone of ignition-scale designs for direct drive on the NIF*

- Wavelength detuning is effective for both polar direct drive (PDD) and spherical direct drive (SDD)
- Using wavelength detuning, we are able to achieve a high-adiabat, alpha-burning PDD design that is predicted to generate a yield over 300 kJ, as well as an igniting design with gain ~30
- Both designs have low in-flight aspect ratios (IFAR's), indicating they are robust with respect to imprint
- An SDD alpha-burning design has been developed that makes use of the equatorial NIF beam ports, generating a yield of 160 kJ

*NIF: National Ignition Facility

Collaborators

J. A. Marozas, D. Cao, J. A. Delettrez, P. W. McKenty, P. B. Radha, and S. Skupsky

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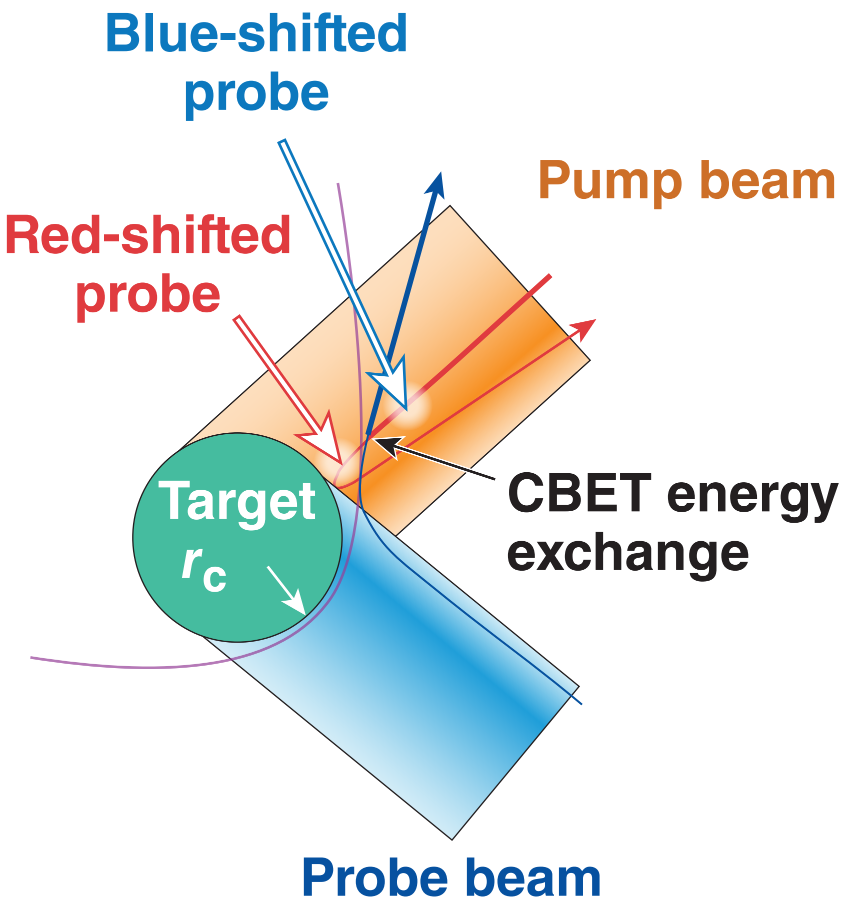
CBET reduces the laser drive by as much as 30%

- The CBET effect increases scattered light through the stimulated Brillouin scattering (SBS) of outgoing rays, removing energy from incoming, high-energy rays
- Detuning the laser beam wavelengths by $\pm\Delta\lambda$ shifts the CBET resonance volume sufficiently to mitigate CBET*
- Laser wavelength detuning has been used for power balance in indirect-drive experiments; for direct drive it is used for CBET mitigation
- Detuning can introduce north–south asymmetries in PDD and SDD

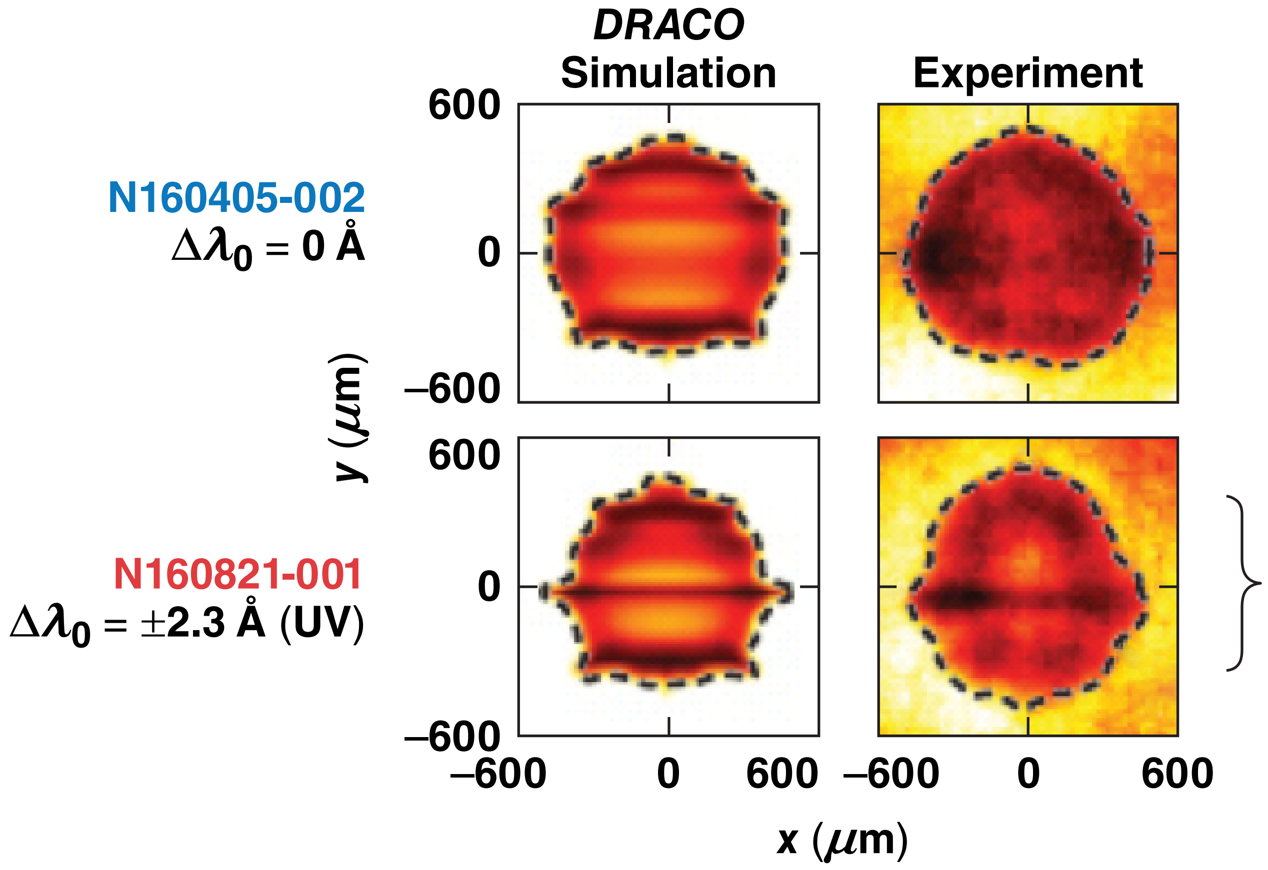


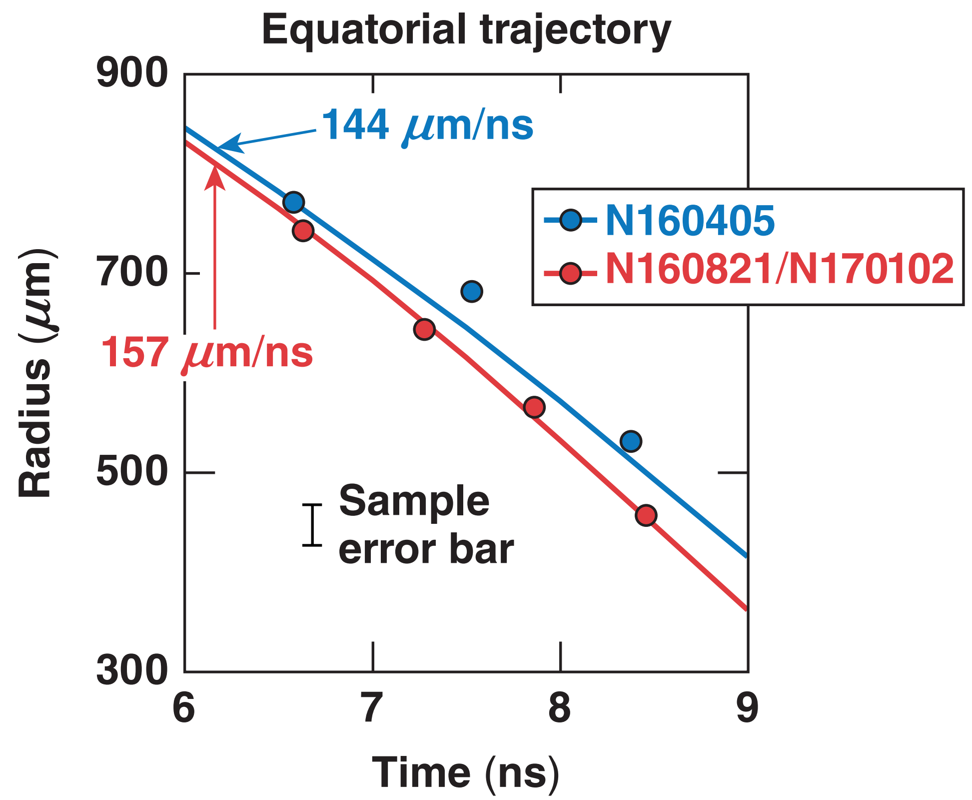
TC12247a

*J. A. Marozas *et al.*, presented at the 44th Annual Anomalous Absorption Conference, Estes Park, CO, 8–13 June 2014.

The models in *DRACO* reproduce the implosion morphology and equatorial drive in NIF detuning experiments*

- A ±2.3-Å (UV) wavelength separation produced an observable change in the implosion shape



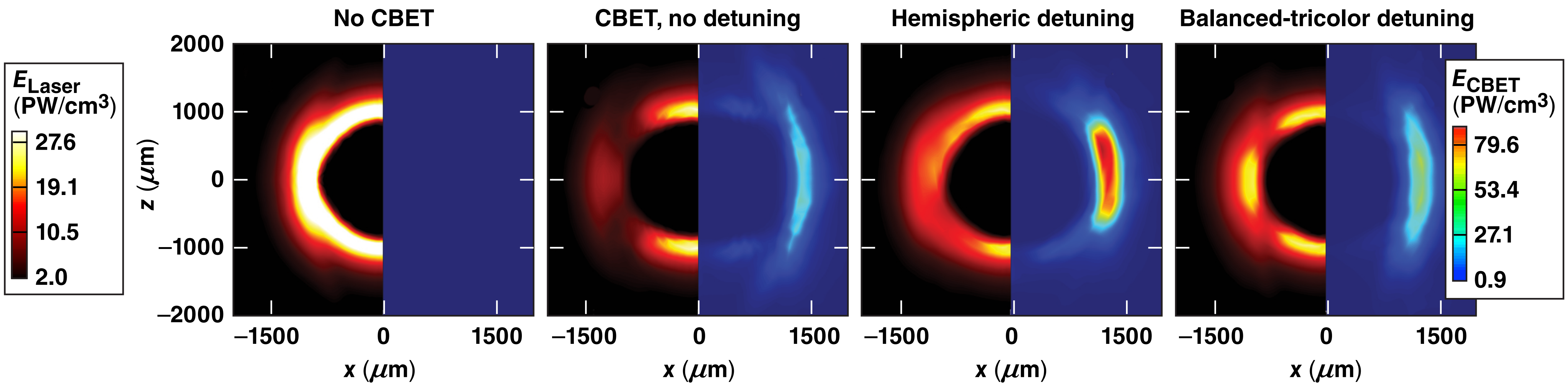


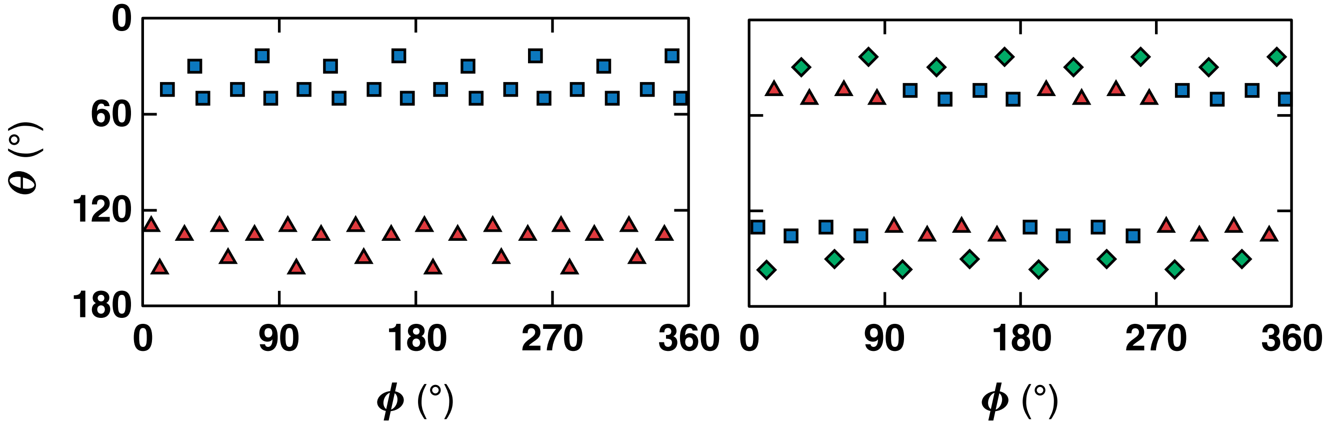
*J. A. Marozas *et al.*, "First Observation of Cross-Beam Energy Transfer Mitigation for Direct-Drive Inertial Confinement Fusion Implosions Using Wavelength Detuning at the National Ignition Facility," submitted to Physical Review Letters; J. A. Marozas, TI2.00002, this conference.

TC13794

The balanced tricolor wavelength-detuning configuration was found to achieve the best performance and implosion symmetry for PDD

- Balanced tricolor detuning removes the north–south asymmetry while maintaining good coupling

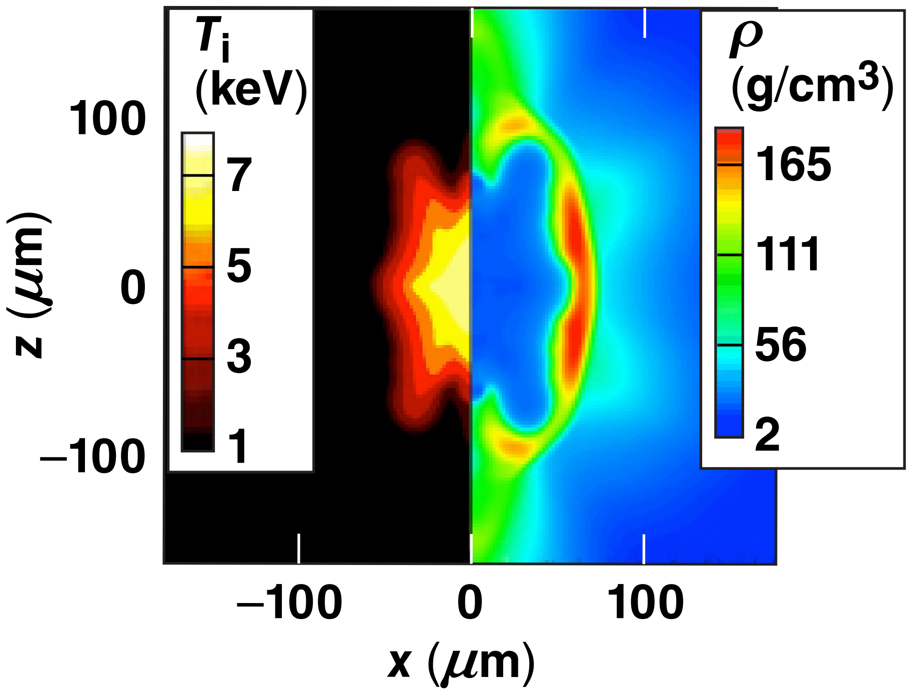


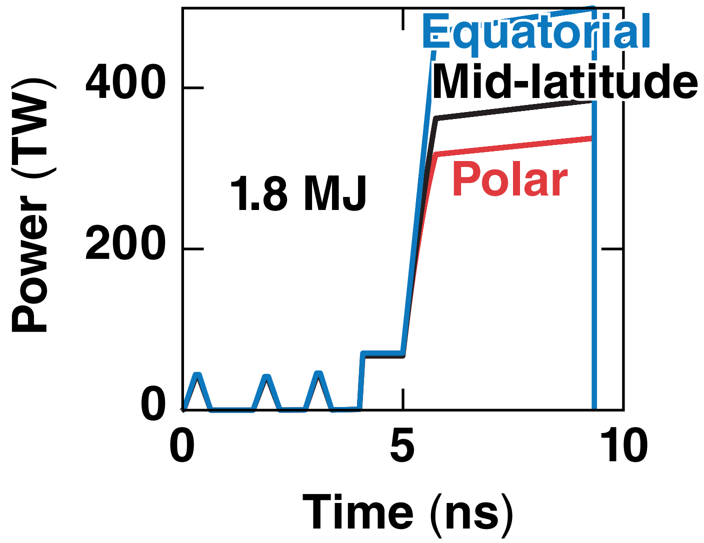


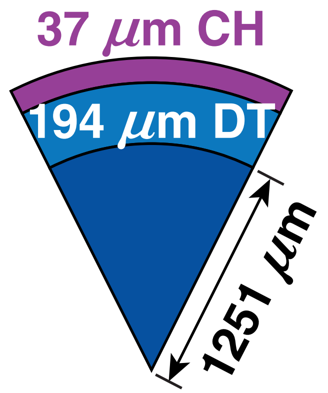
TC13706

A new PDD alpha-burning design has been developed that is within NIF damage limits but requires additional facility capabilities

- This design uses $\Delta\lambda = \pm 12$ Å (UV), increasing the absorption fraction to 72%
- As an alpha-burning design, it has no ignition cliff and is less sensitive to drive and target imperfections







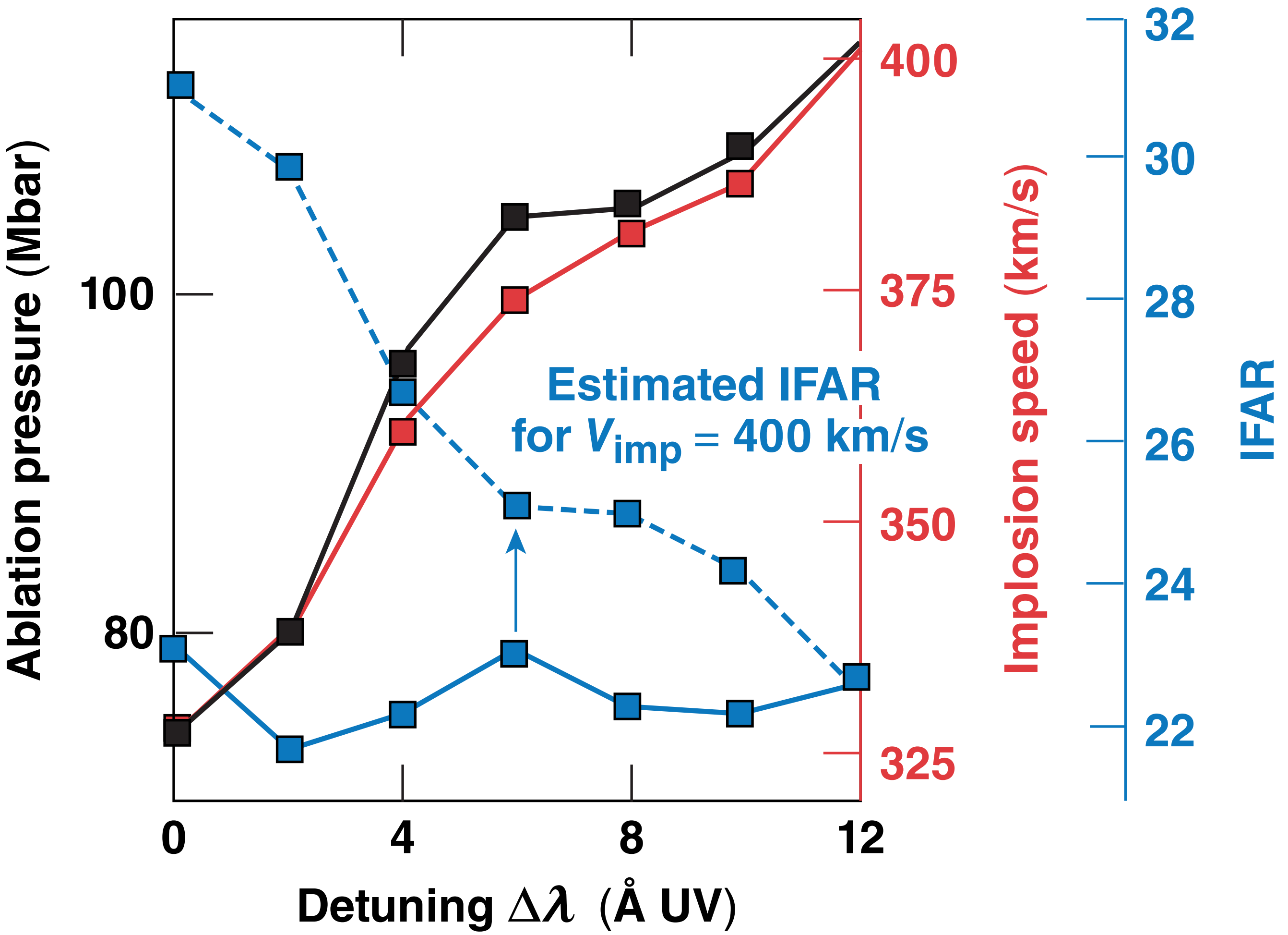
Neutron yield	327 kJ
Absorption fraction	72%
V_{imp}	392 km/s
IFAR	20
Minimum end-of-pulse α	4.8
Convergence ratio	28
Peak $\langle \rho R \rangle$	1.4 g/cm^2
Ablation pressure (Mbar)	115

An ignition design has also been developed with a gain of 27, IFAR of 23, and $\alpha \sim 3$.

TC13707

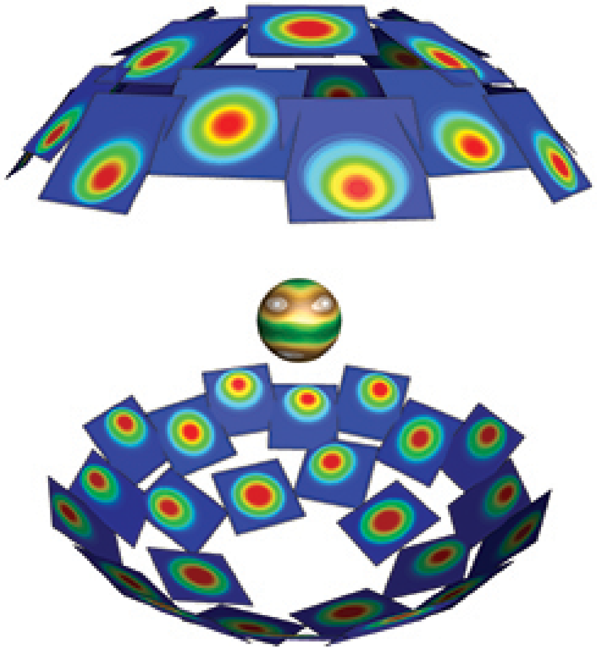
Reduced detuning bandwidth $\Delta\lambda$ may be accomodated by reduced shell mass

- The implosion speed for $\Delta\lambda = \pm 6$ Å (UV) may be restored to ~400 km/s through a reduction in shell mass, increasing the IFAR by ~10%

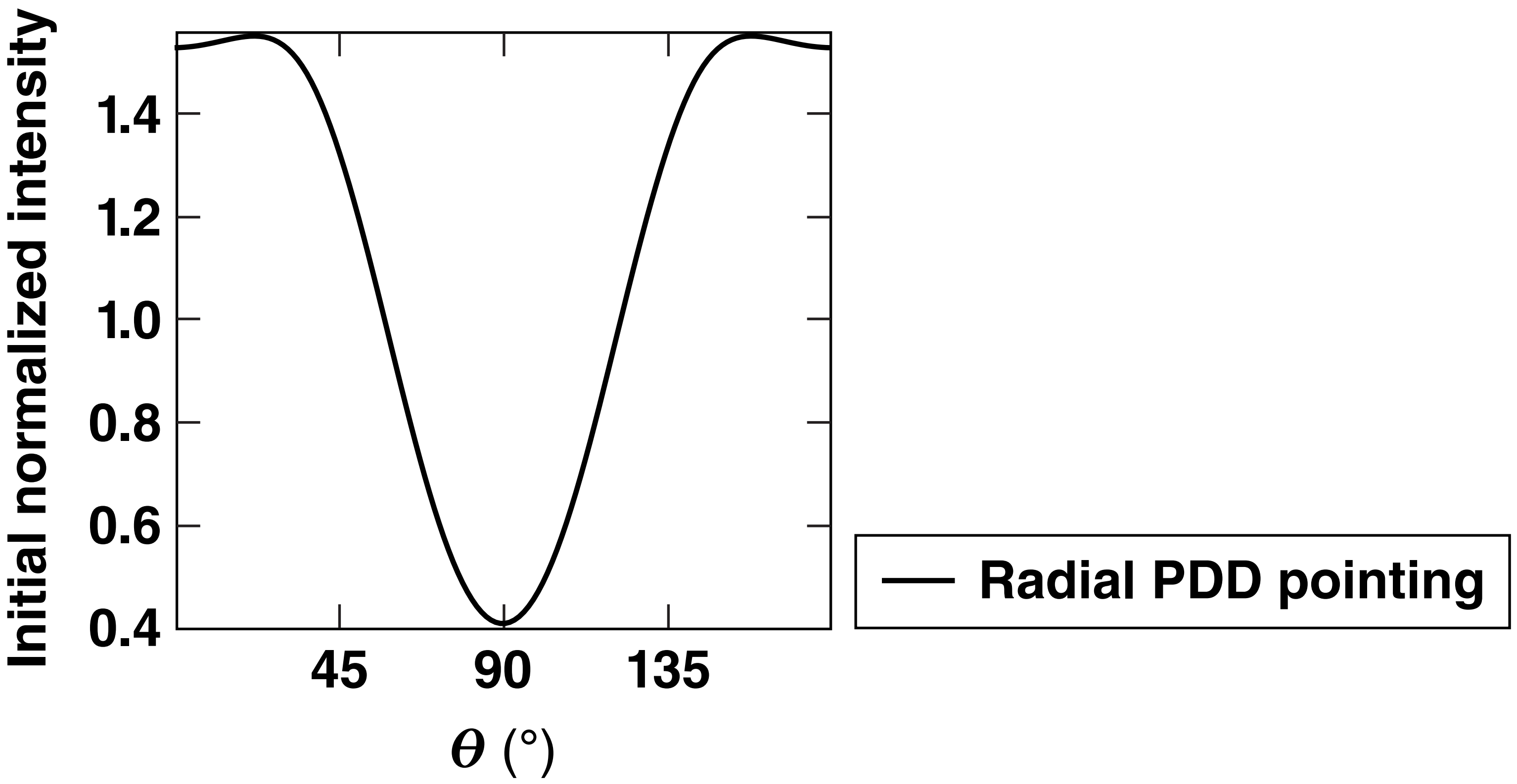


TC13709

PDD drive uniformity is optimized using beam repointing, cone power multipliers, and tailored spot shapes

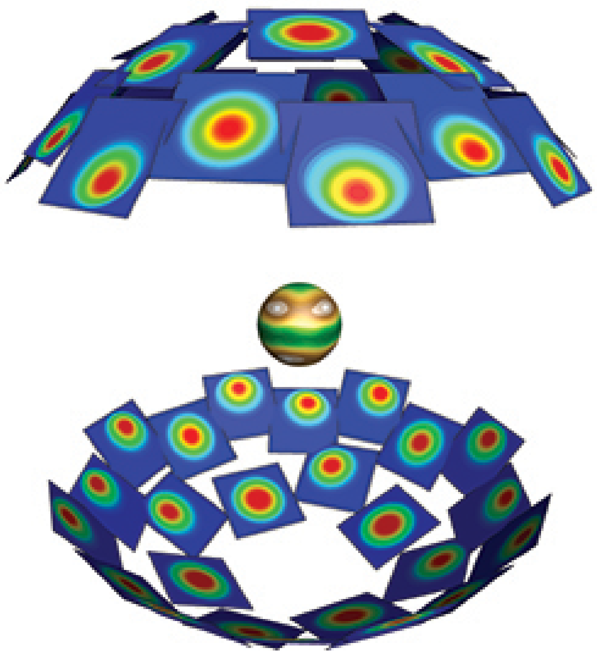


PDD

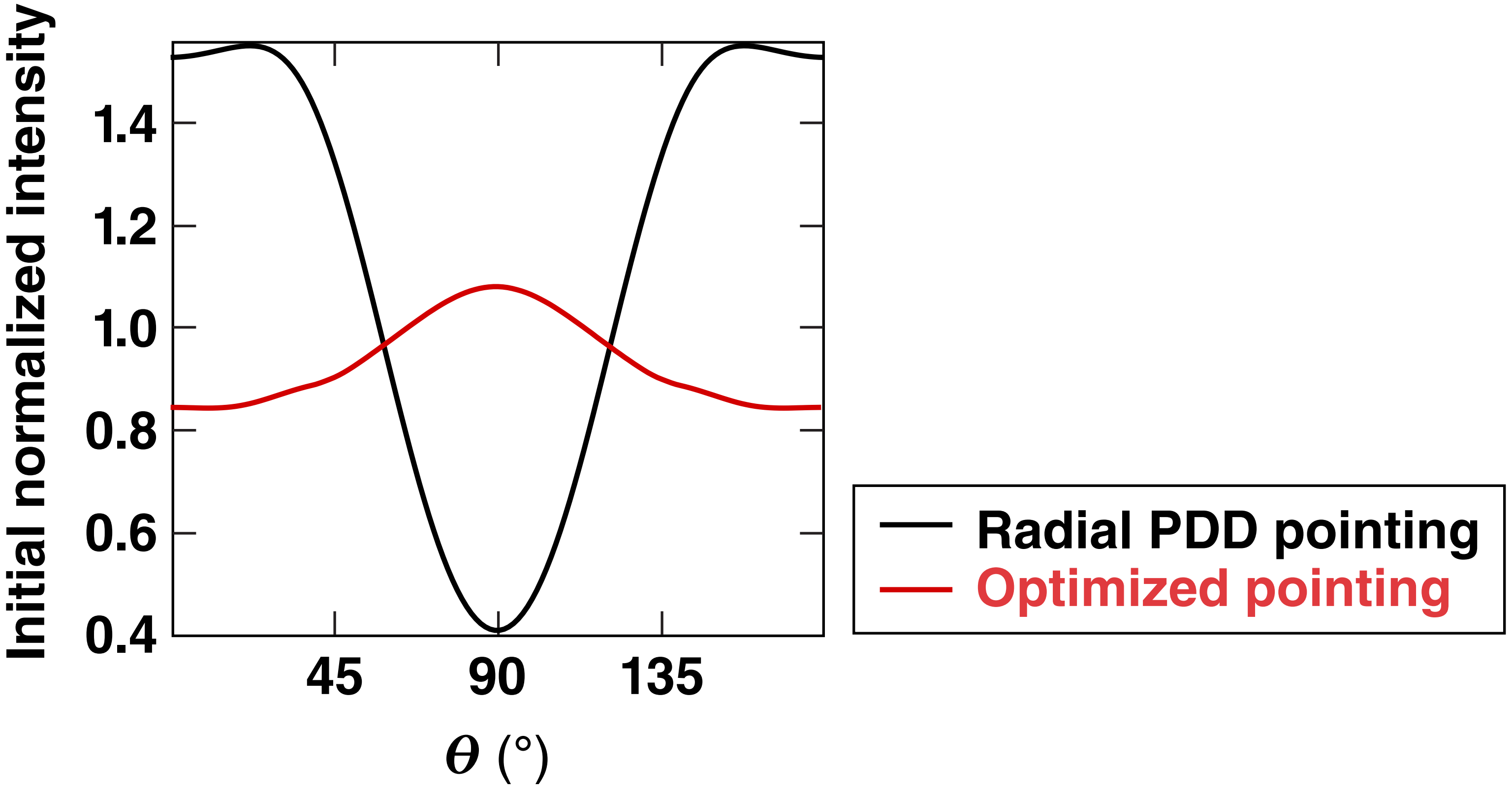


TC13795a

PDD drive uniformity is optimized using beam repointing, cone power multipliers, and tailored spot shapes

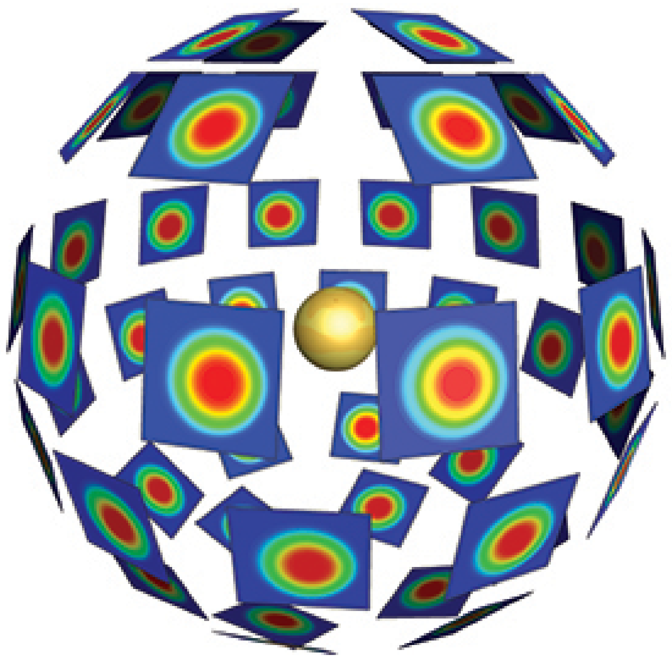


PDD

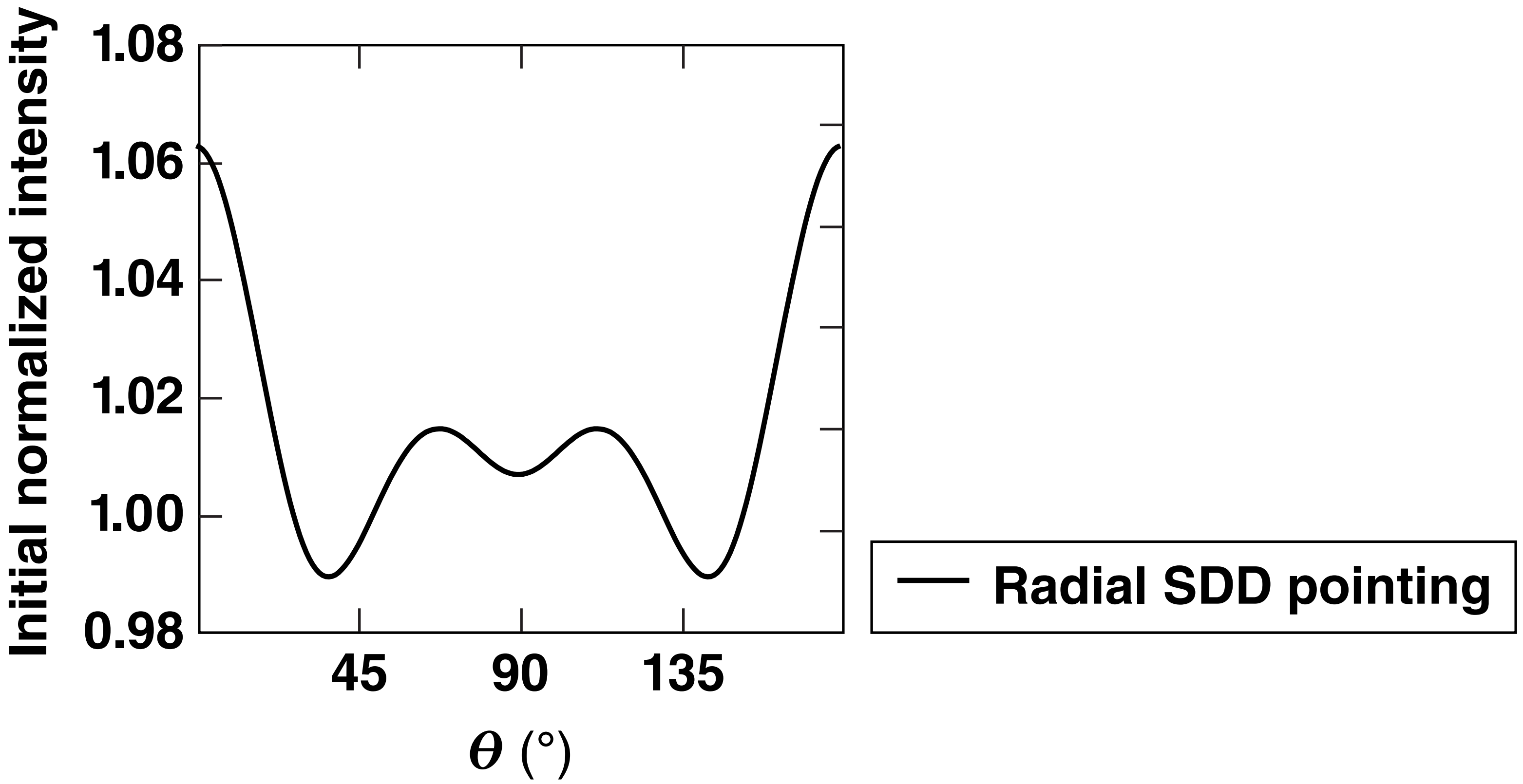


TC13795b

The NIF SDD configuration's superior illumination uniformity was further improved by optimized beam pointings



SDD

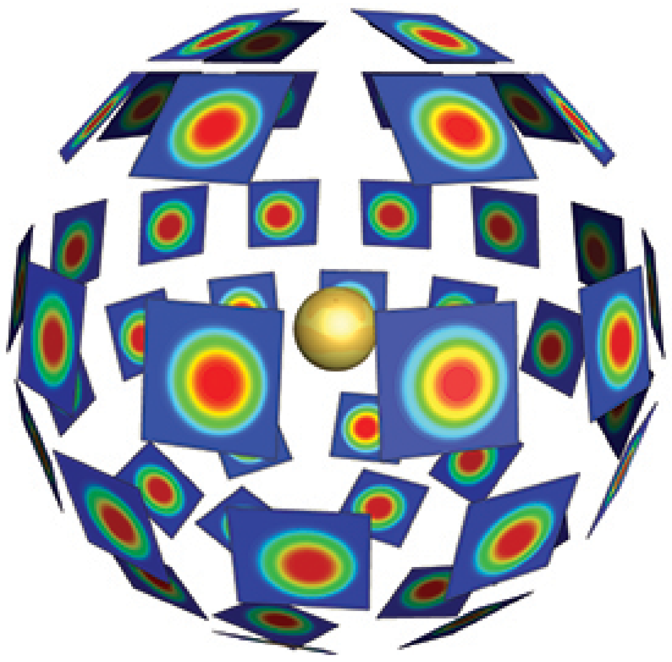


- The equatorial illumination is closer to normal, raising the overall absorption efficiency from ~70% to ~80%

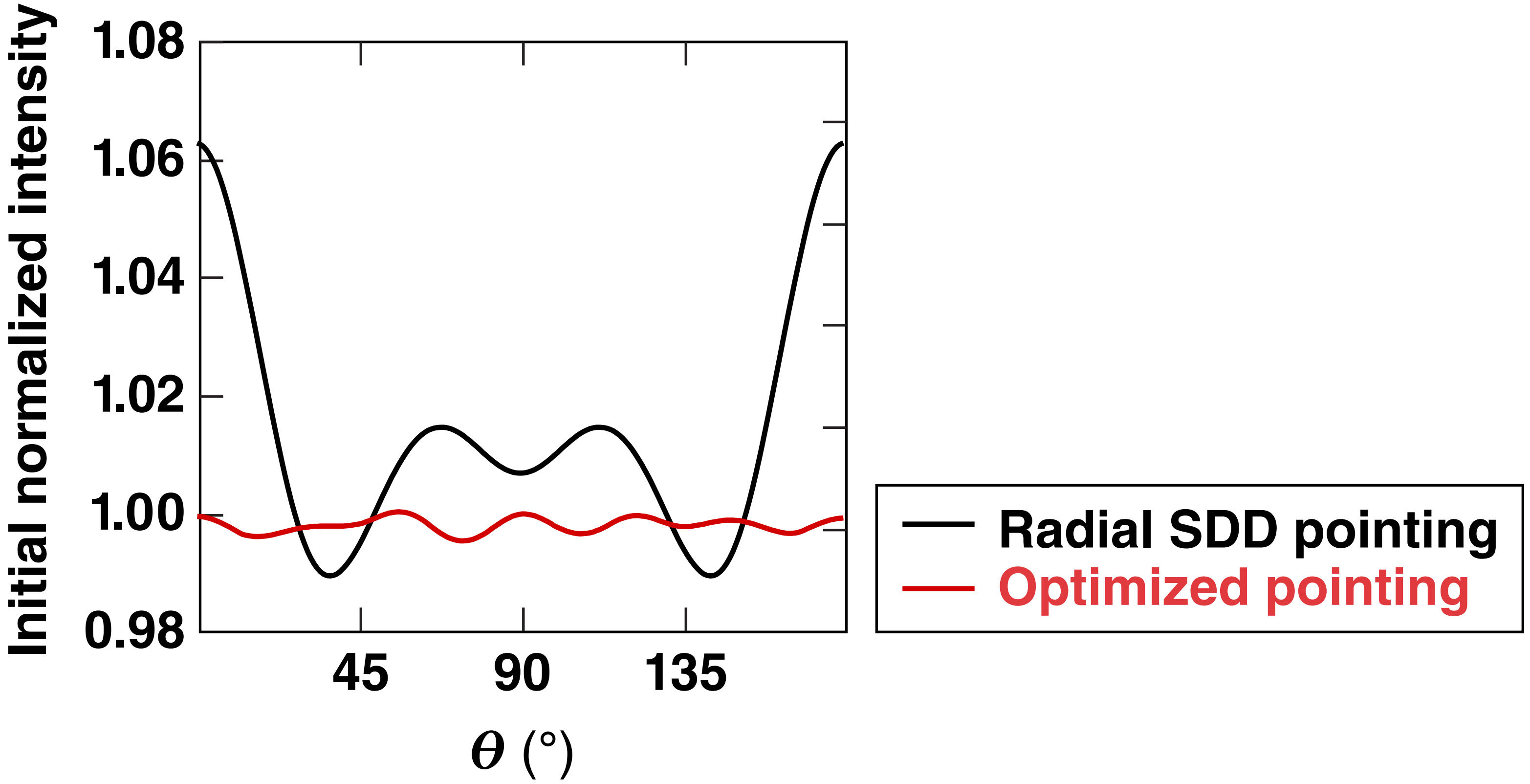
TC13795c

SDD

The NIF SDD configuration's superior illumination uniformity was further improved by optimized beam pointings



SDD



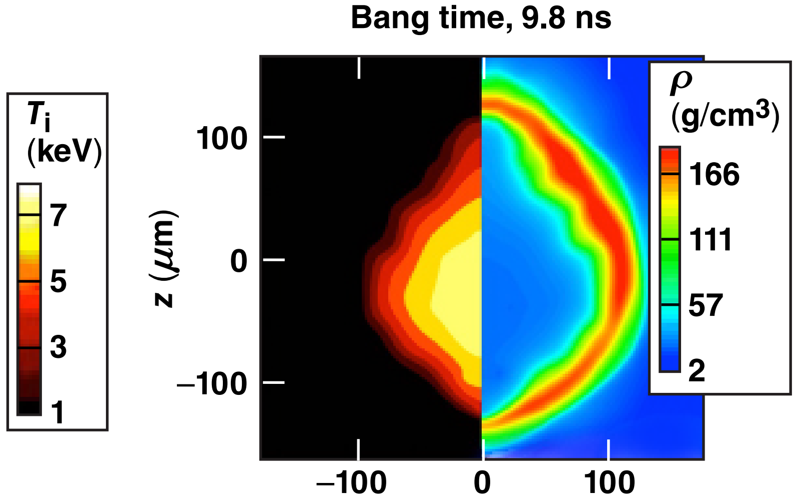
- The equatorial illumination is closer to normal, raising the overall absorption efficiency from ~70% to ~80%
- *Telios** was used to optimize initial beam pointings, reducing nonuniformity by over 10× uniformity
- The detuning configuration was determined through a second optimization process with a fully evolved plasma, further reducing the nonuniformity by 2×

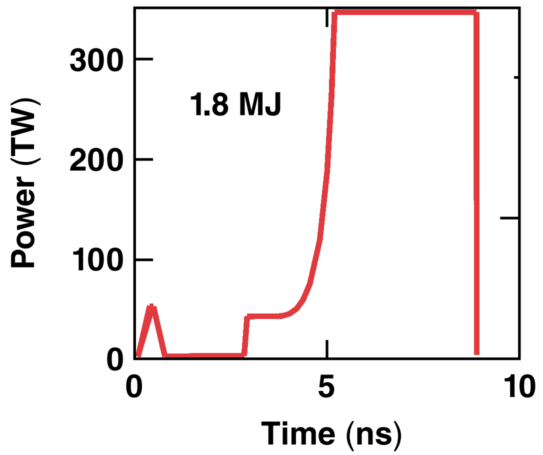
TC13795d

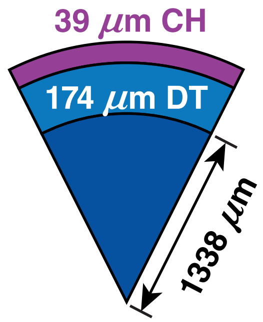
*T. J. B. Collins *et al.*, Phys. Plasmas 19, 056308 (2012).

A new alpha-burning design has been developed for NIF SDD

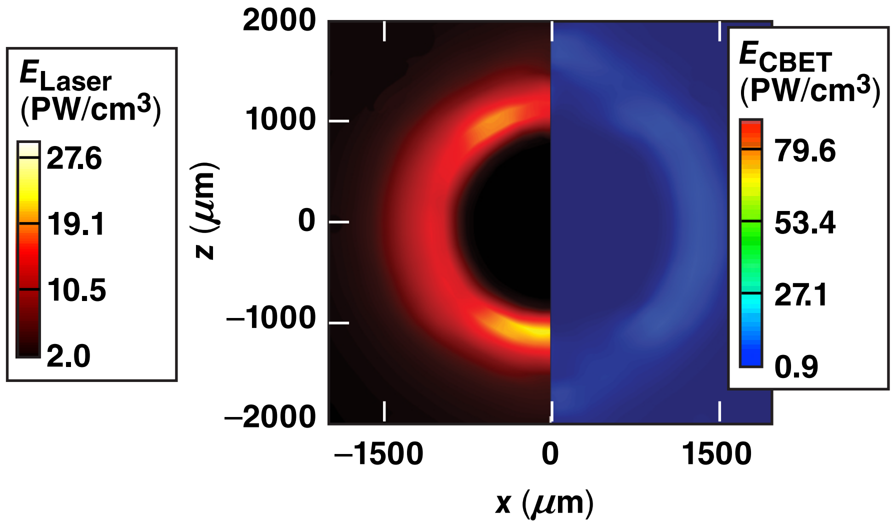
- The hot-spot volume is 3.5× greater than the PDD alpha-burning design and the convergence ratio correspondingly smaller, reducing the sensitivity to laser mispointing and making the hot-spot conditions easier to diagnose







Neutron yield	5.6 × 10^{16} 160 kJ
Absorption fraction	83%
V_{imp}	361 km/s
IFAR	22
Adiabat	4.3
Convergence ratio	19
Peak $\langle \rho R \rangle$	0.9 g/cm^2
Ablation pressure (Mbar)	90



- A CBET multiplier of 1 was used
- An increased CBET multiplier can be offset by increased drive power

TC13796

Wavelength detuning for cross-beam energy transfer (CBET) mitigation is the cornerstone of ignition-scale designs for direct drive on the NIF

UR LLE

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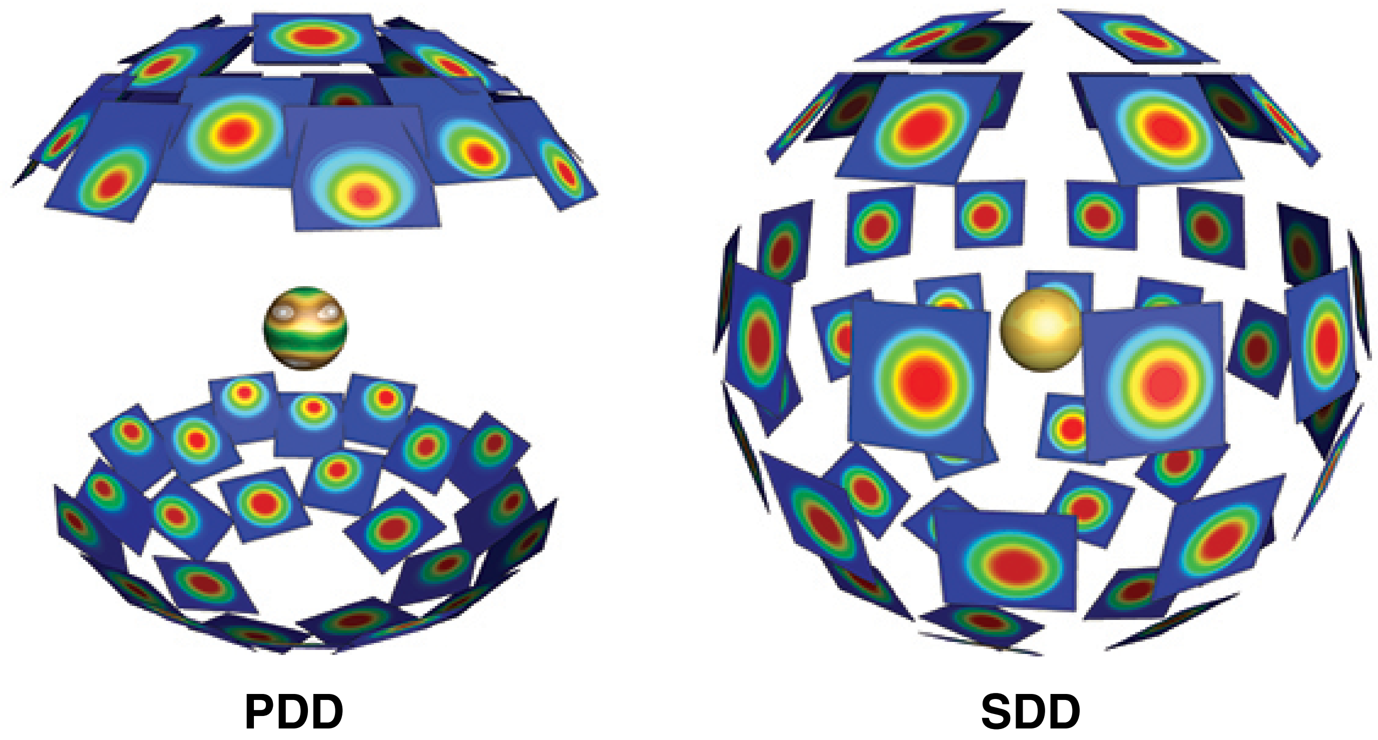
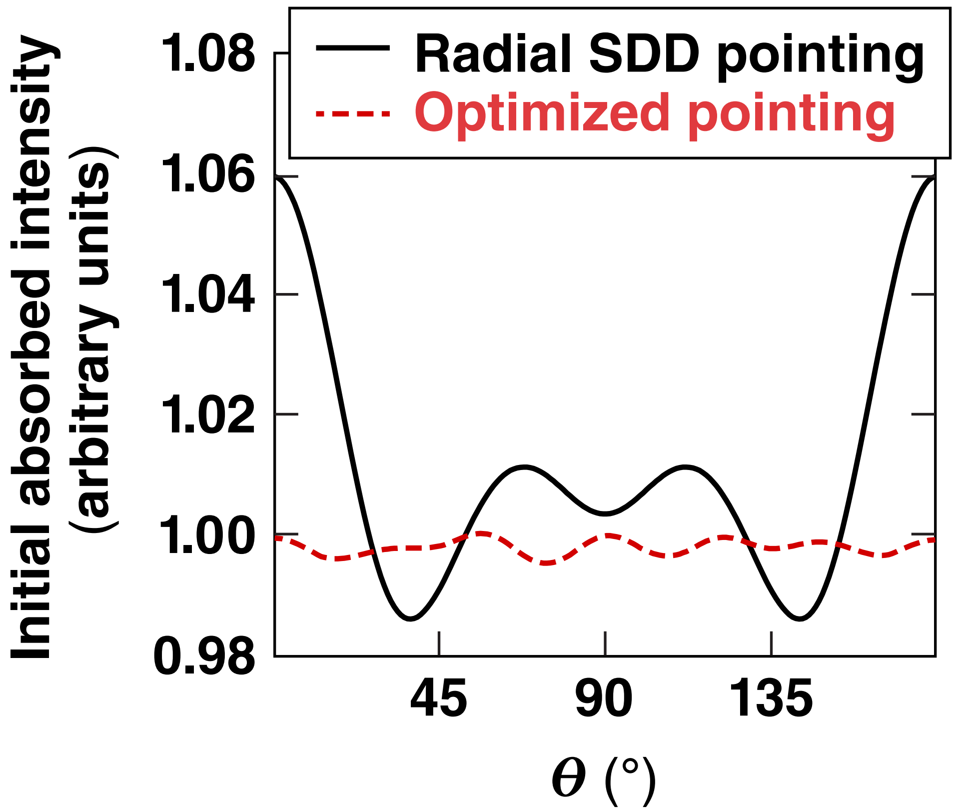
The NIF SDD configuration's superior illumination uniformity was further improved by optimized beam pointings





- *Telios** was used to optimize initial beam pointings, reducing nonuniformity by over 10× uniformity
- The equatorial illumination is closer to normal, raising the overall absorption efficiency from ~70% to ~80%
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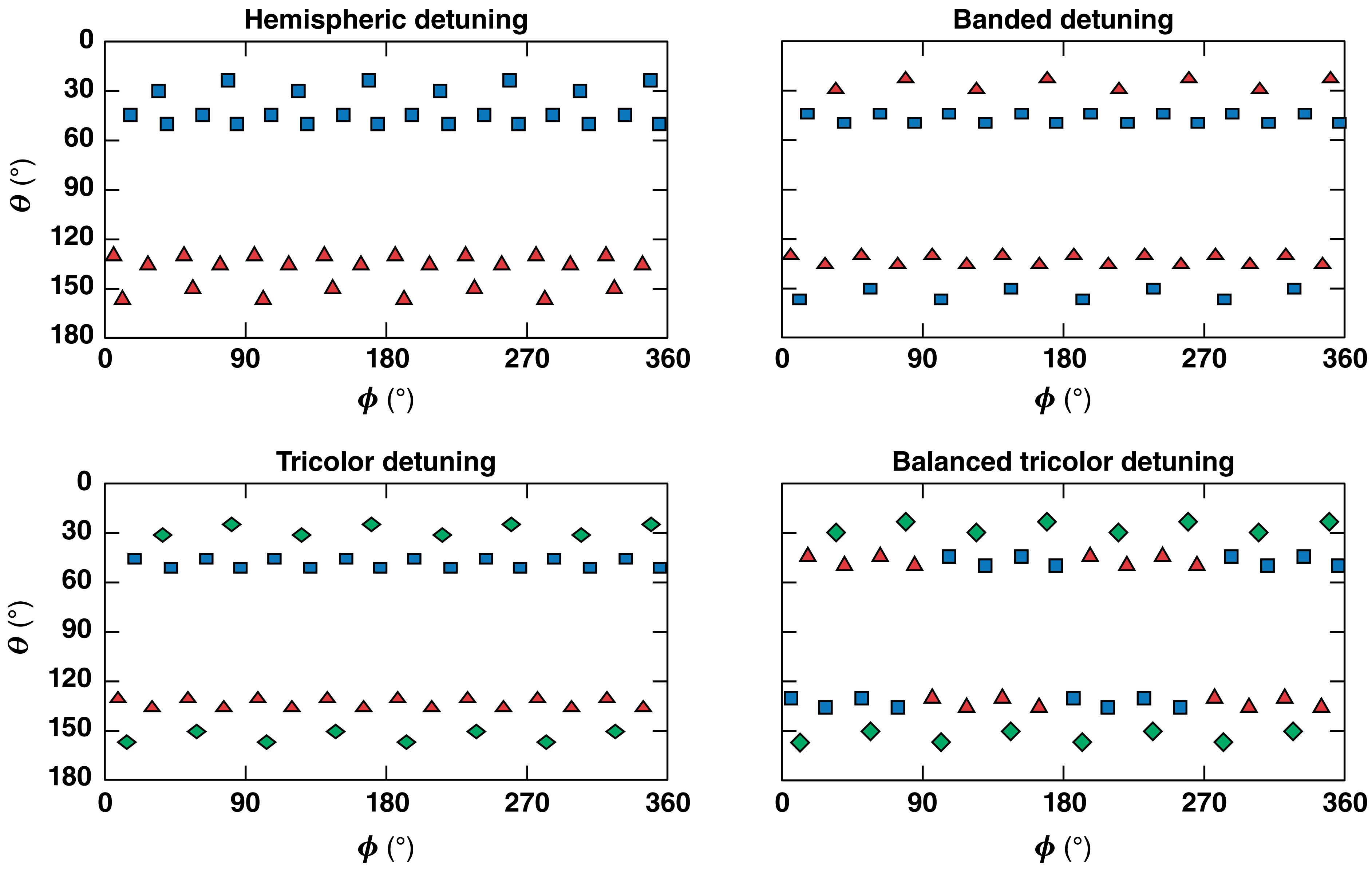
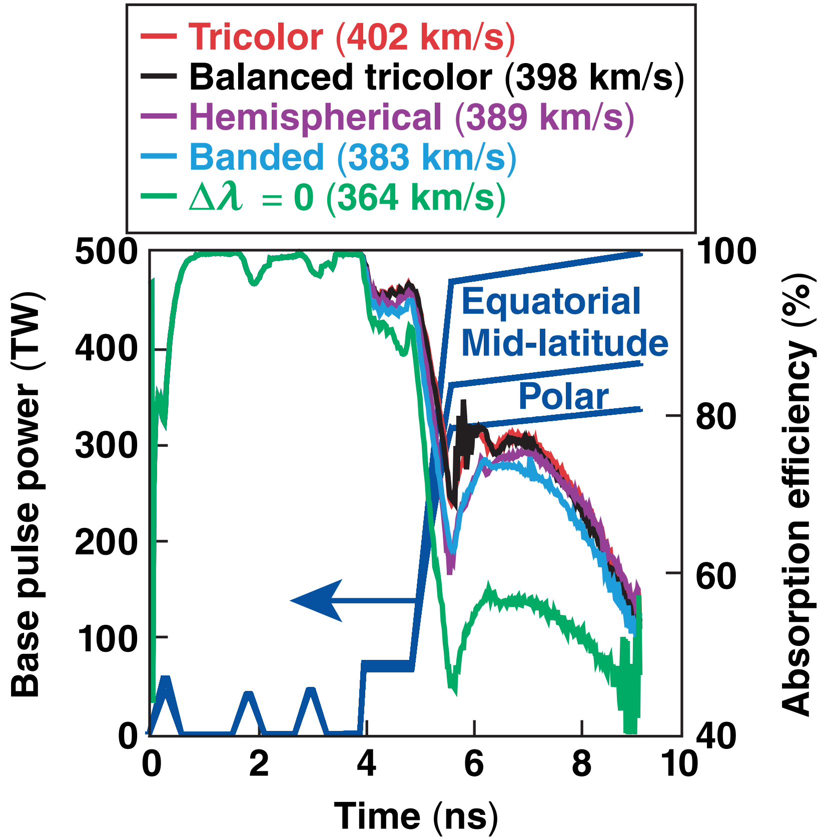
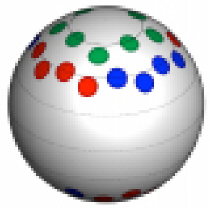
TC13795

* T. J. B. Collins *et al.*, Phys. Plasmas 19, 056308 (2012).

Many detuning configurations were explored for the PDD alpha-burning and ignition designs







NIF beam ports

TC13705

In PDD, NIF beams are repointed toward the equator to compensate for the missing equatorial beams

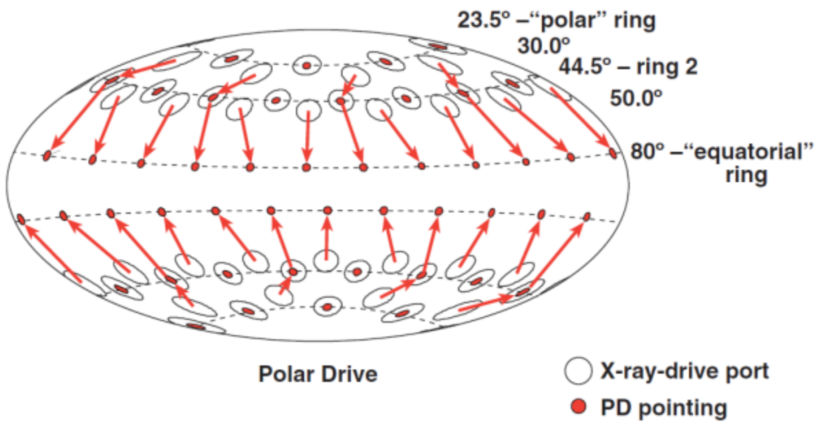
- Repointing beams gives greater path lengths and standoff distances through lower densities: $n = n_c \times \cos^2 \theta_{inc}$
- Reduced equatorial drive may be compensated with
  - tailored spot shapes including spot-masking apodization (SMA)
  - increased equatorial power
  - reduced equatorial shell mass ("shimming")
- Minimum energy required for ignition:

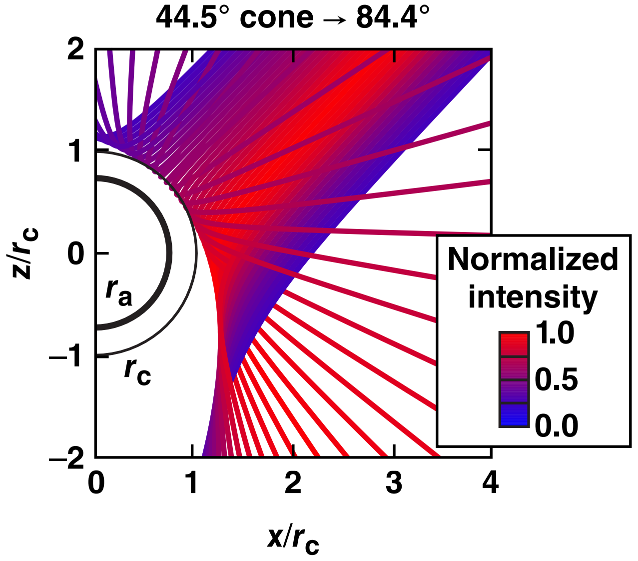
$$E_{min} \propto \alpha^{1.88} V_{imp}^{-5.89} P_{abl}^{-0.77}$$

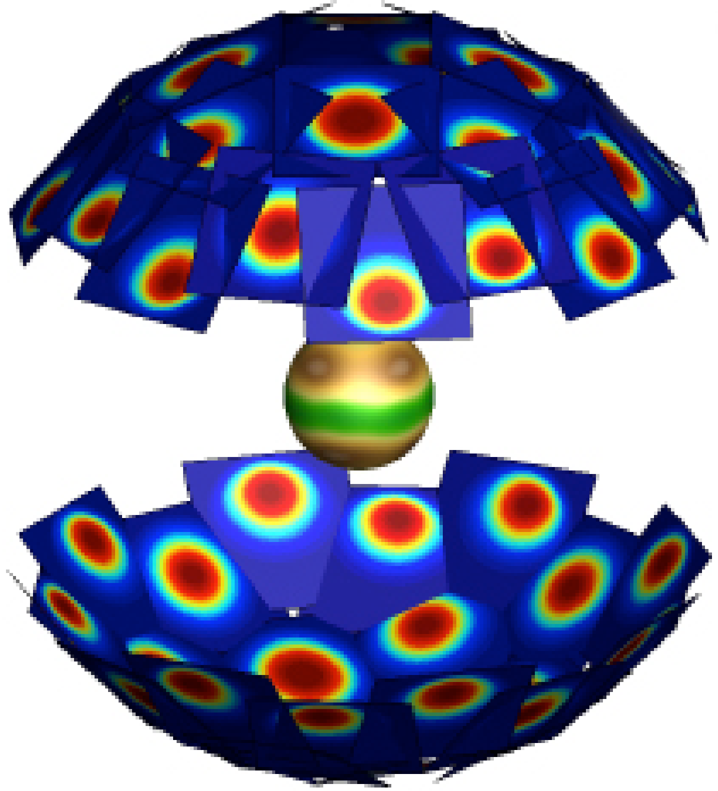
Elevated by TPD*, SRS**? (α)

Determined by P_{abl} and shell mass, related to IFAR (V_{imp})

The peak P_{abl} determined by power limits, CBET, NLET,† and θ_{inc} (P_{abl})





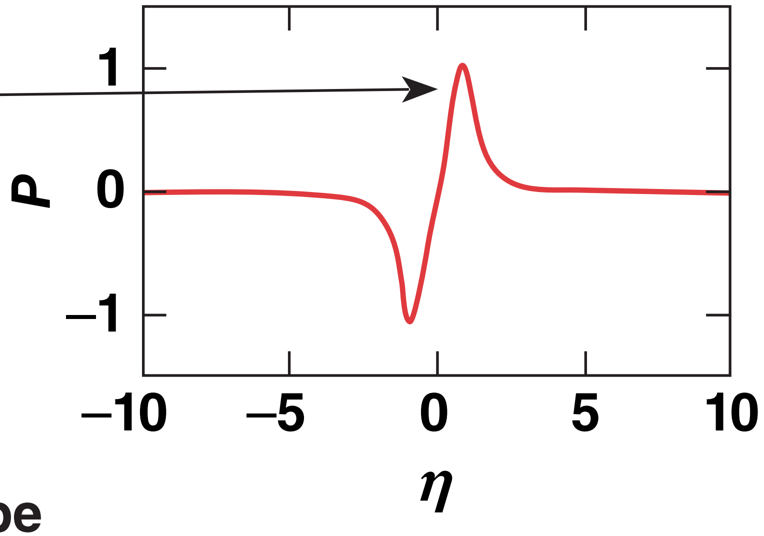


*TPD: two-plasmon decay
**SRS: stimulated Raman scattering
†NLET: nonlocal electron transport

TC13703

Wavelength detuning affects the region over which the CBET resonance occurs

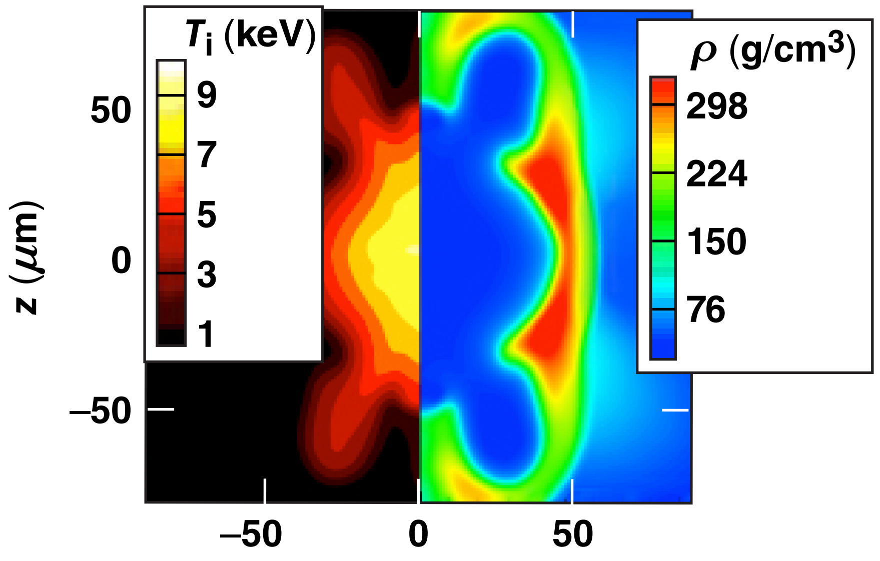
- The CBET attenuation is $d\tau_{\text{CBET}} \propto \zeta_{\text{pol}} P(\eta) I_{\text{pump}} ds$, where the resonance function P is given by $P(\eta) = \eta v_{\text{abl}} \Big/ \left[(\eta v_{\text{abl}})^2 + (1-\eta^2)^2\right]$ and $\eta = \left[(\omega_{\text{pump}} - \omega_{\text{probe}}) - \mathbf{k}_{\text{a}} \cdot \mathbf{v}\right] / (c_{\text{a}} k_{\text{a}})$
- The resonance function peaks at $|\eta| \sim 1$
- Without detuning $\eta \approx 1 \Leftrightarrow M\cos\theta_{\text{abl}} \approx 1$, where θ_{abl} is the angle between $\mathbf{k}_{\text{abl}}$ and $\mathbf{r}$
- Increasing $\Delta\omega$ changes the values of $\mathbf{k}_{\text{abl}} = \mathbf{k}_{\text{pump}} - \mathbf{k}_{\text{probe}}$ that resonate, changing the resonance region
- Red-shifting probe rays move resonance to lower Mach numbers, where probe rays may be blocked or have reduced intensity
- Blue-shifting probe rays shift the resonance outward, where there is reduced overlap
- The larger the wavelength shift, the longer the mitigation duration
- Wavelength shifting introduces north–south asymmetries

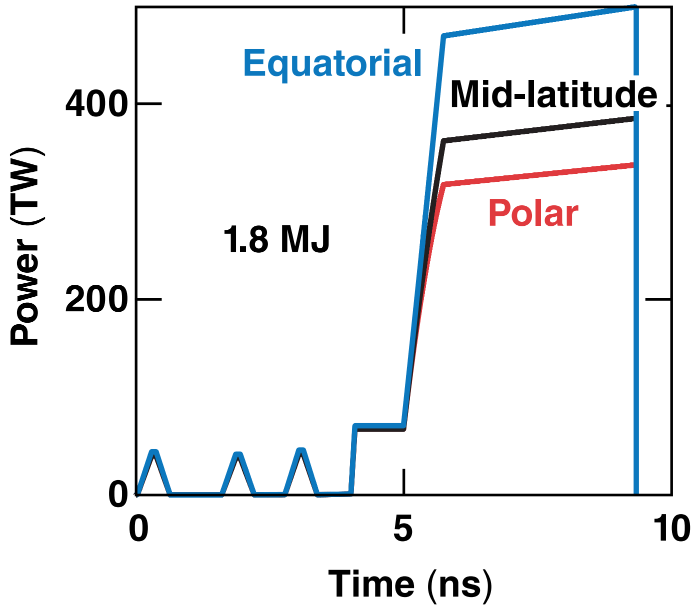


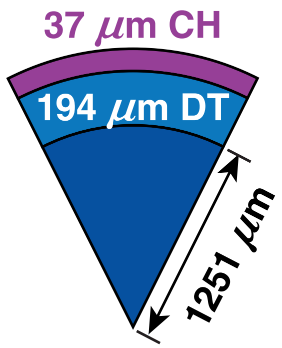
TC13704

A new PDD ignition design has been developed that is within NIF damage limits

- This design also uses $\Delta\lambda = \pm 12$ Å (UV)







Energy	1.8 MJ
Gain	27
Absorption fraction	72%
V_{imp}	398 km/s
IFAR	23
Minimum end-of-pulse α	2.8
Convergence ratio	28
Peak $\langle \rho R \rangle$	1.7 g/cm^2
Ablation pressure (Mbar)	111