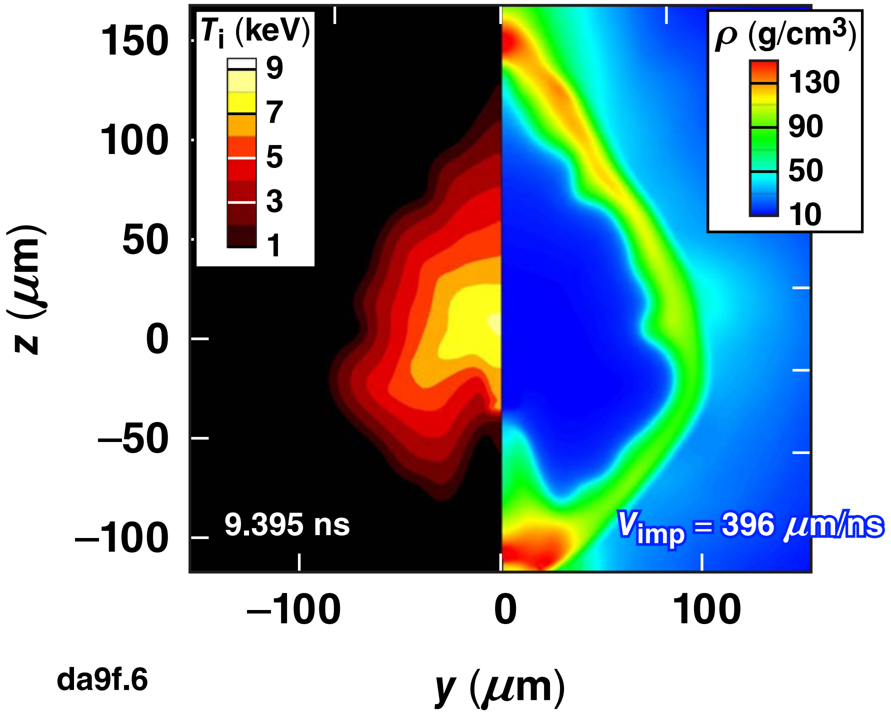
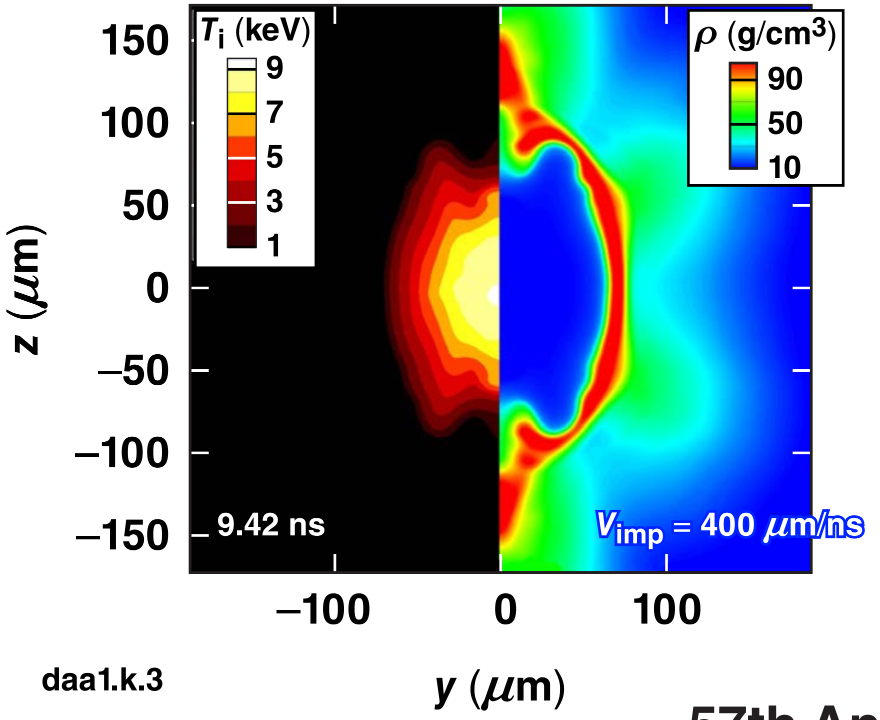
Design Options for Polar-Direct-Drive Targets: From Alpha Heating to Ignition

Alpha-burning design
10^{17} neutrons, IFAR = 21
Tricolor wavelength detuning



da9f.6

Ignition design
Gain = 41, IFAR = 23
"Balanced-tricolor" wavelength detuning



daa1.k.3

T. J. B. Collins
University of Rochester
Laboratory for Laser Energetics

57th Annual Meeting of the
American Physical Society
Division of Plasma Physics
Savannah, GA
16–20 November 2015

Summary

A polar-direct-drive (PDD) design achieves high gain in the presence of cross-beam energy transfer (CBET)

- Wavelength detuning schemes were developed, which mitigate some of the loss of drive caused by CBET
- A PDD ignition design using the balanced-tricolor detuning configuration achieves a gain of 41 with an in-flight aspect ratio (IFAR) of 23 and an implosion velocity of 400 μm/ns
- A robust alpha-burning design using the tricolor detuning configuration has been developed that generates 10^{17} neutrons with an IFAR of 21 and an implosion velocity of 396 μm/ns

TC12414

Collaborators

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

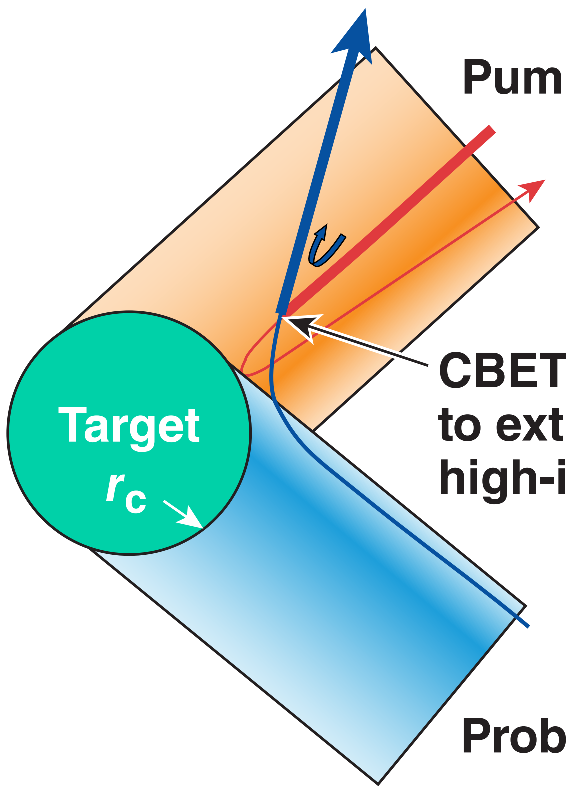
University of Rochester
Laboratory for Laser Energetics

G. Moses

University of Wisconsin

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
- The energy exchange can be reduced by modifying the spot to reduce the wings of the laser spot (zooming,* spot masking**)
- CBET can also be mitigated by "detuning" the wavelengths of the interacting beams***
- Laser wavelength detuning is used for power balance in indirect-drive experiments; for direct drive it is used for CBET mitigation

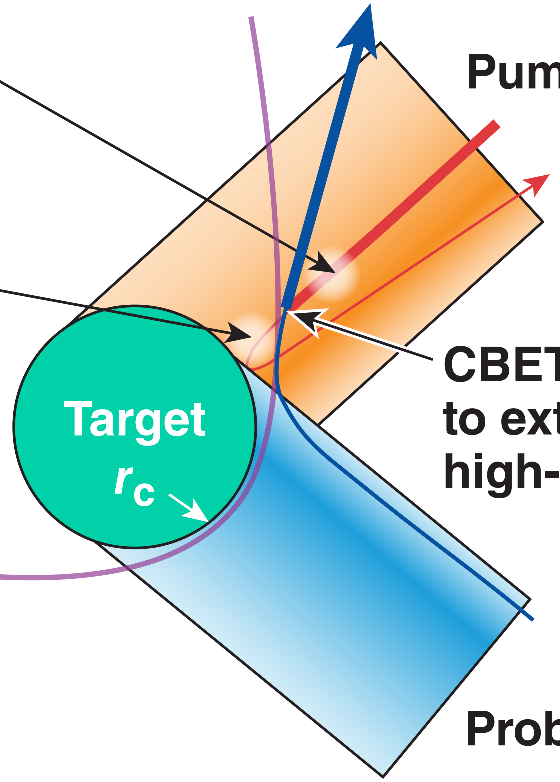


*D. H. Froula *et al*., Phys. Plasmas 20, 082704 (2013).
**J. A. Marozas *et al*., presented at the 44th Annual Anomalous Absorption Conference, Estes Park, CO, 8–13 June 2014
***See also Marozas, JO5.00005; McKenty, JO5.00008, this conference

Successful wavelength detuning shifts the resonance location sufficiently to mitigate CBET

When probe rays are blue-shifted, the resonance shifts to a higher Mach number, where intersecting probe rays are negligible

When probe rays are red-shifted, the resonance shifts to a lower Mach number, where probe rays are blocked and/or have negligible intensity

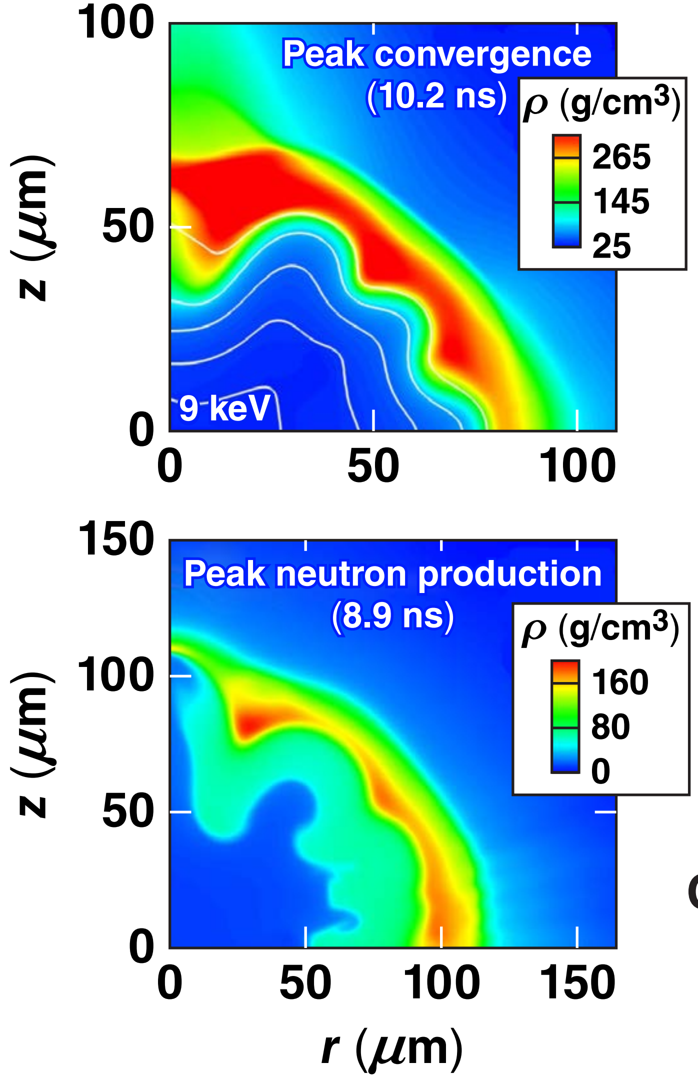


- The magnitude of $\Delta\lambda$ determines the mitigation duration
  - the larger the $\Delta\lambda$, the greater the time before the resonance region enters the deposition region
  - north–south asymmetries exist for sufficiently small $\Delta\lambda$
  - detuning may be used for both spherical drive and PDD

TC11766d

A PDD ignition design incorporating nonlocal heat transport is the basis of the CBET ignition designs

- Nonlocal heat transport is modeled with the implicit Schurtz–Nicolai–Busquet (iSNB) model*
- Increased hydrodynamic efficiency leads to high gain (53), V_{imp} (414 km/s), and IFAR (35), all of which are brought back to levels characteristic of previous designs when CBET is included
- The beam-pointing angles, ring energies, and spot shapes were also the basis for the intermediate spot-shape design of D. Cao,** and will be used in the 700-kJ PDD experiments*** at the National Ignition Facility (NIF)



Nonlocal ignition design

Intermediate energy NIF design

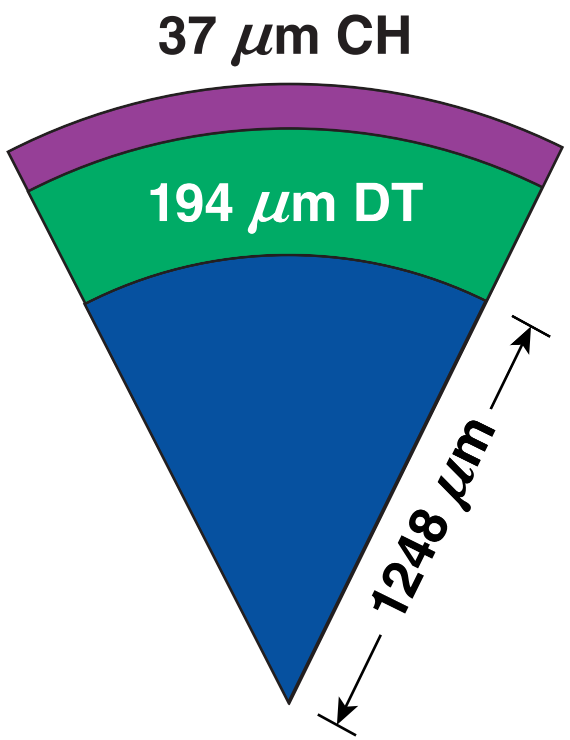
Convergence ratio ~20

*D. Cao *et al*., Bull. Am. Phys. Soc. 58, 310 (2013).
**D. Cao *et al*., BO4.00014, this conference.
***P. B. Radha *et al*., CI3.00004, this conference (invited).

TC12251a

An alpha-burning design was developed based on the detuning configuration with the greatest absorption

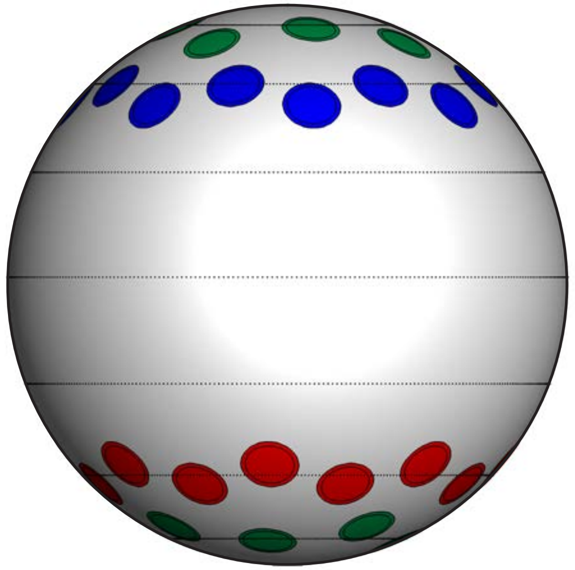
- The tricolor configuration has an absorption fraction of 72%, compared to 62% without detuning
- The target was modified by
  - increasing the equatorial ring energy
  - repointing all beams further toward the equator (~2°)
  - reducing the shell thickness and radius by 7%
- A triple-picket pulse is used for enhanced adiabat shaping



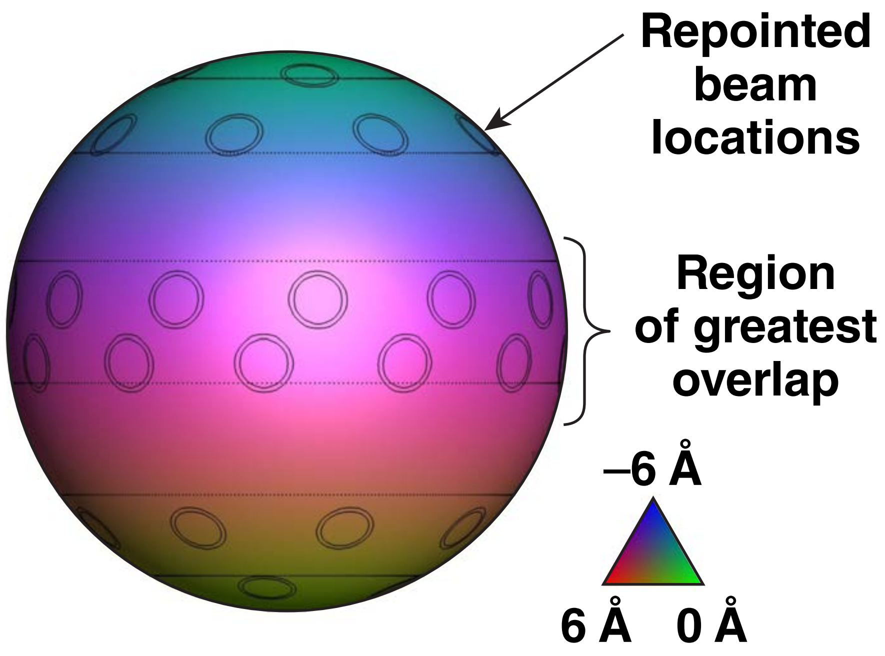
TC12255a

The PDD alpha-burning design was developed with a clean yield of 10^{17} neutrons

- This design uses the "tricolor" detuning configuration which uses a hemispherical wavelength shift but with $\Delta\lambda = 0$ for the polar rings to reduce intrahemispherical CBET
- The tricolor configuration restores over half of the laser energy scattered by CBET interactions
- The odd perturbation modes must be compensated by modified ring energies and pointing angles
- The alpha-burning design uses a mass-weighted, end-of-pulse adiabat of 4.6, leading to a low IFAR of 21 for target stability

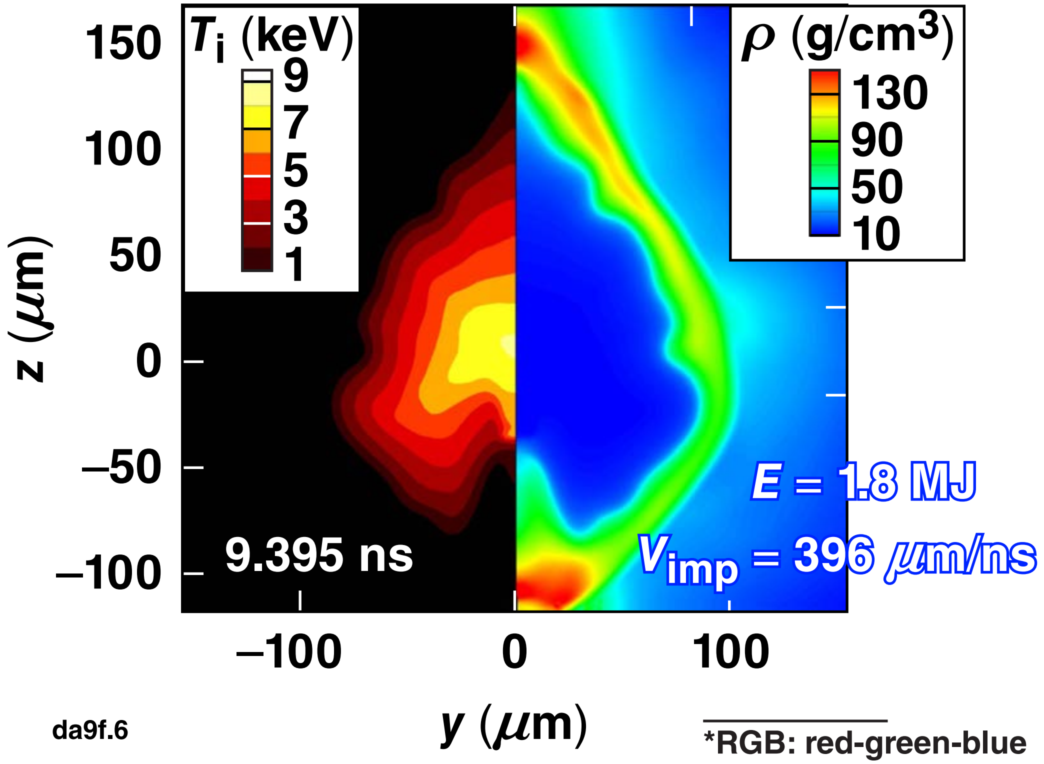


NIF beam ports



On-target color projection

Alpha-burning design



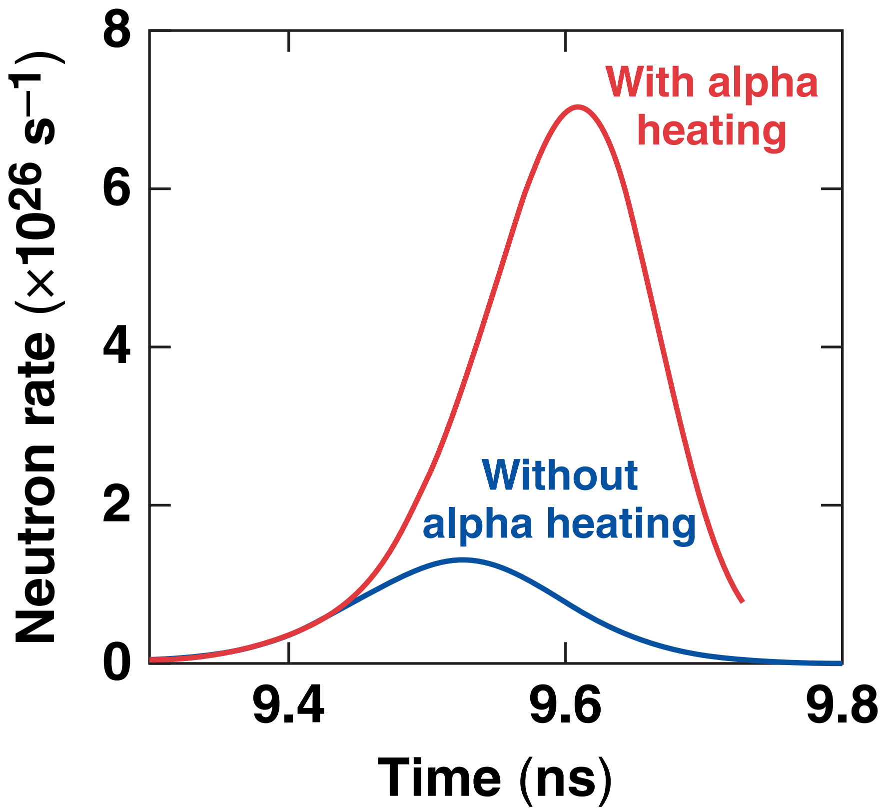
TC12535

da9f.6

*RGB: red-green-blue

The predicted ion temperatures achieved are sufficient to demonstrate “bootstrap” heating

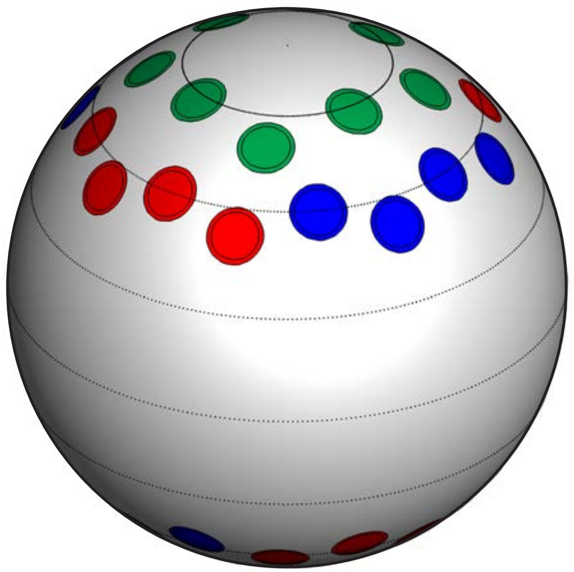
- The areal density and peak ion temperature, while insufficient to produce a sustained burn wave, generate an alpha-deposition neutron yield greater than the neutron yield generated by compression alone
- $Y/Y_{\text{no } \alpha} = 4.5$; the yield caused by bootstrap heating is over three times the compression yield



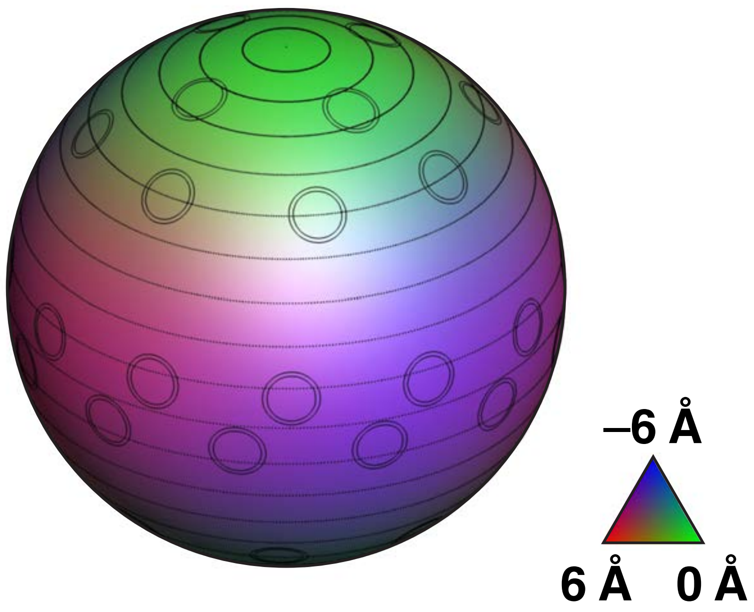
TC12261a

The balanced-tricolor detuning configuration produces a gain of 41 and a more-uniform hot spot

- The coupling is only 3% less than the tricolor configuration, and is still high enough to produce a high implosion velocity
- This configuration addresses the north to south asymmetry of the tricolor configuration while retaining three wavelengths for intrahemispherical detuning
- The greater uniformity increases the clean volume and target margin
- The minimum end-of-pulse adiabat is 2.8, giving an IFAR of 23 and good target stability

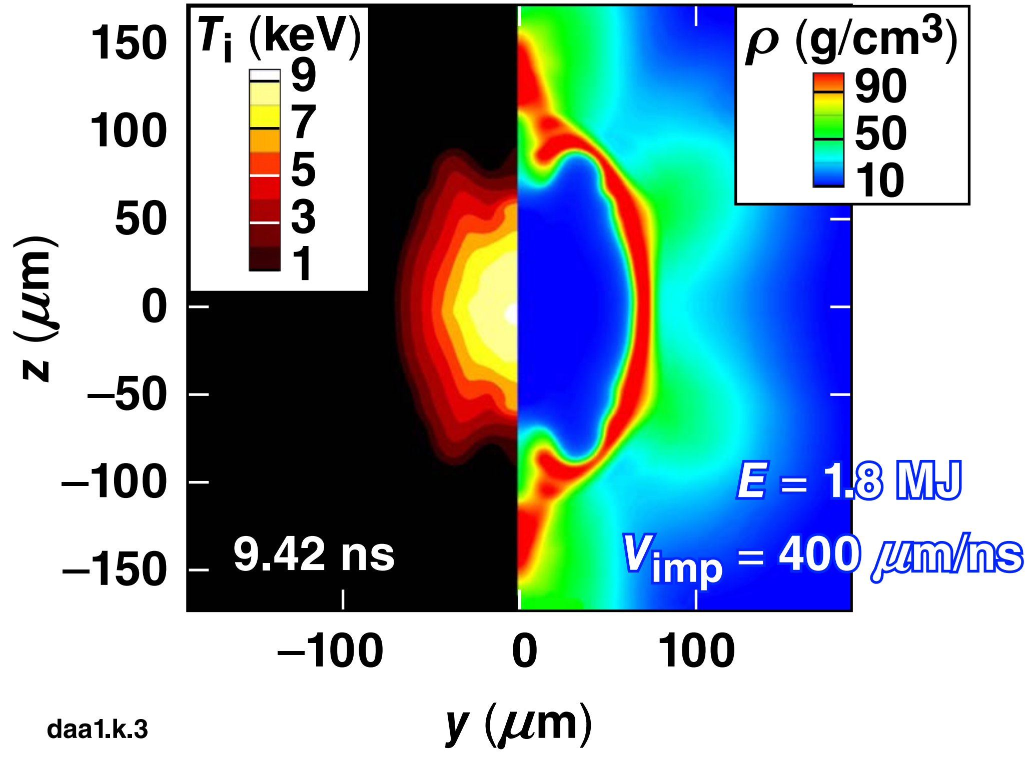


NIF beam ports



On-target color projection

Balanced tricolor ignition design



The ignition margin for the balanced design is being increased by means of other mitigation schemes

- Wavelength detuning is completely compatible with spot-shape modifications like aperturing to remove the low-energy edge rays of each beam
- The average equatorial power divided by the quarter-critical spherical surface area is $\sim 1.2 \times 10^{15}$ W/cm^2
- Both reduction in the spot size to $0.95 \times R_0$ and an equatorial shim are being used to increase margin and reduce the equatorial power
- Alternate ablators will be explored for use in reduction of two-plasmon decay

This PDD design is the basis for a spherical-direct-drive ignition design using wavelength detuning.

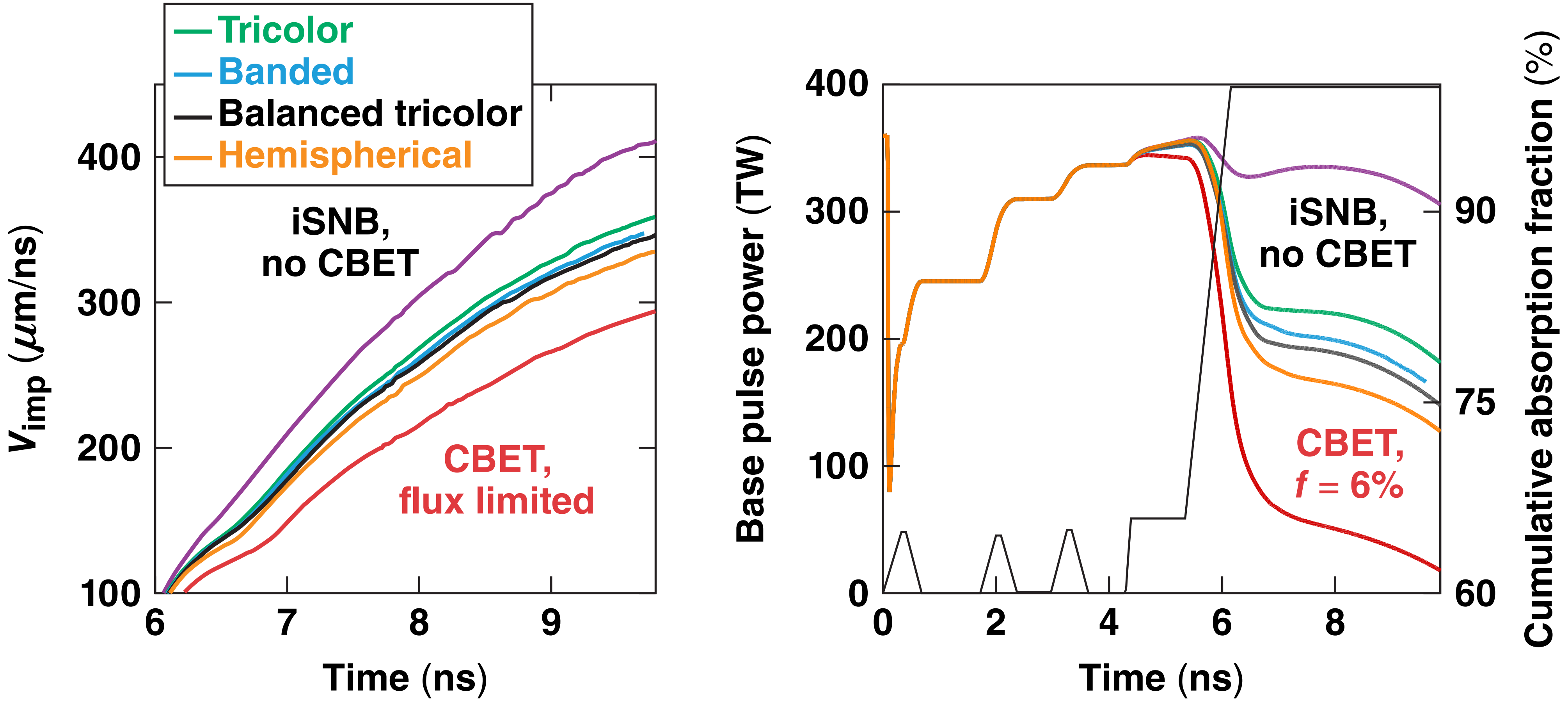
TC12263a

A polar-direct-drive (PDD) design achieves high gain in the presence of cross-beam energy transfer (CBET)

- Wavelength detuning schemes were developed, which mitigate some of the loss of drive caused by CBET
- A PDD ignition design using the balanced-tricolor detuning configuration achieves a gain of 41 with an in-flight aspect ratio (IFAR) of 23 and an implosion velocity of 400 μm/ns
- A robust alpha-burning design using the tricolor detuning configuration has been developed that generates 10^{17} neutrons with an IFAR of 21 and an implosion velocity of 396 μm/ns

Several wavelength detuning configurations were assessed for coupling efficiency and symmetry

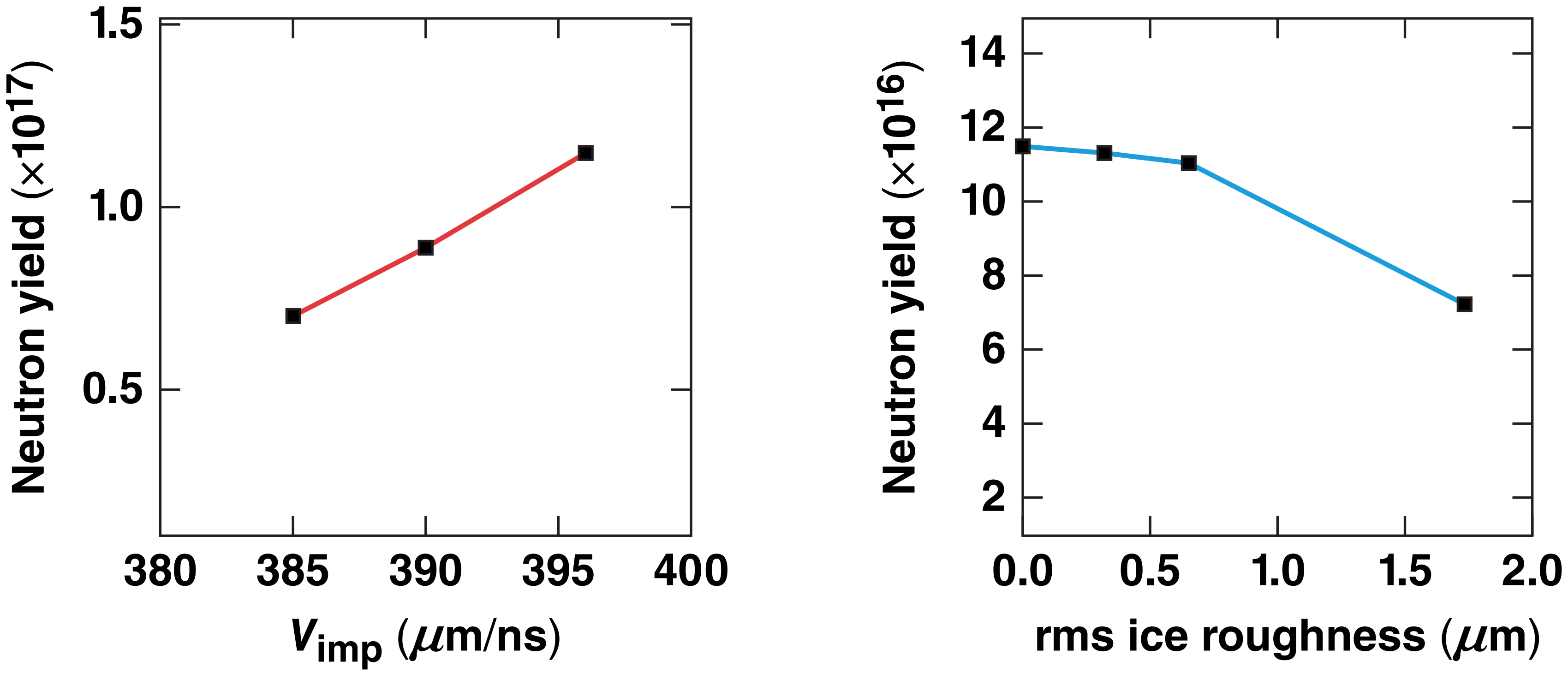
- Tricolor detuning provides the greatest absorption
- Balanced-tricolor detuning has a lower absorption than the tricolor configuration because of interactions in the azimuthal direction, but is close to tricolor



TC12254a

The alpha-burner implosion velocity can be reduced with corresponding reduction in the neutron yield

- The implosion velocity was reduced by lowering the peak drive power
- The alpha-burning design is also relatively insensitive to ice roughness perturbations, since it has no "ignition cliff"

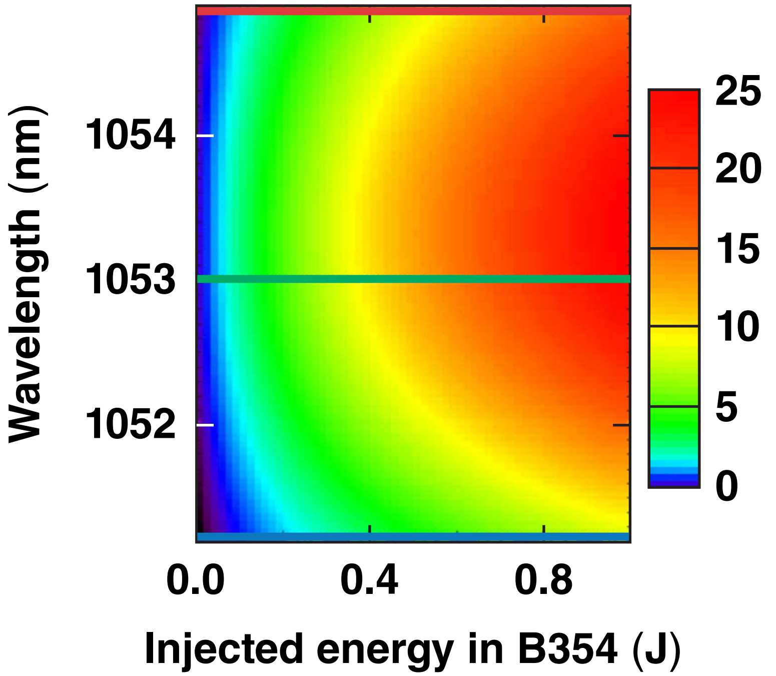


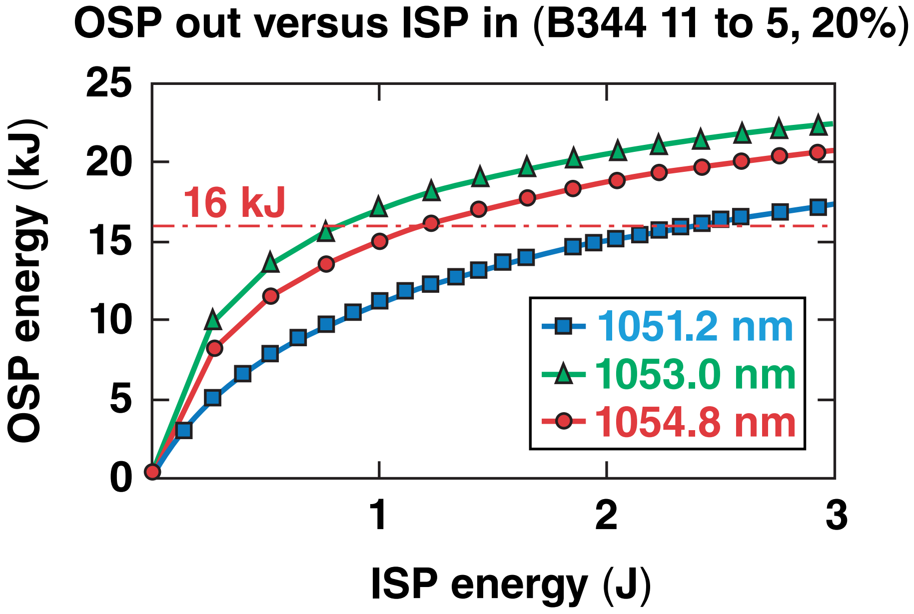
- A high-yield, lower-implosion-velocity design will be investigated by lowering the adiabat but increasing the coupling, using spot masking in addition to wavelength detuning and using the balanced tricolor configuration

TC12262a

The desired $\Delta\lambda_0$ of ±6 Å UV seems achievable on the NIF with modifications to the reflection absorption baffles

- The regen and main amplifiers on the NIF are predicted to support the desired ±6-Å UV detuning*



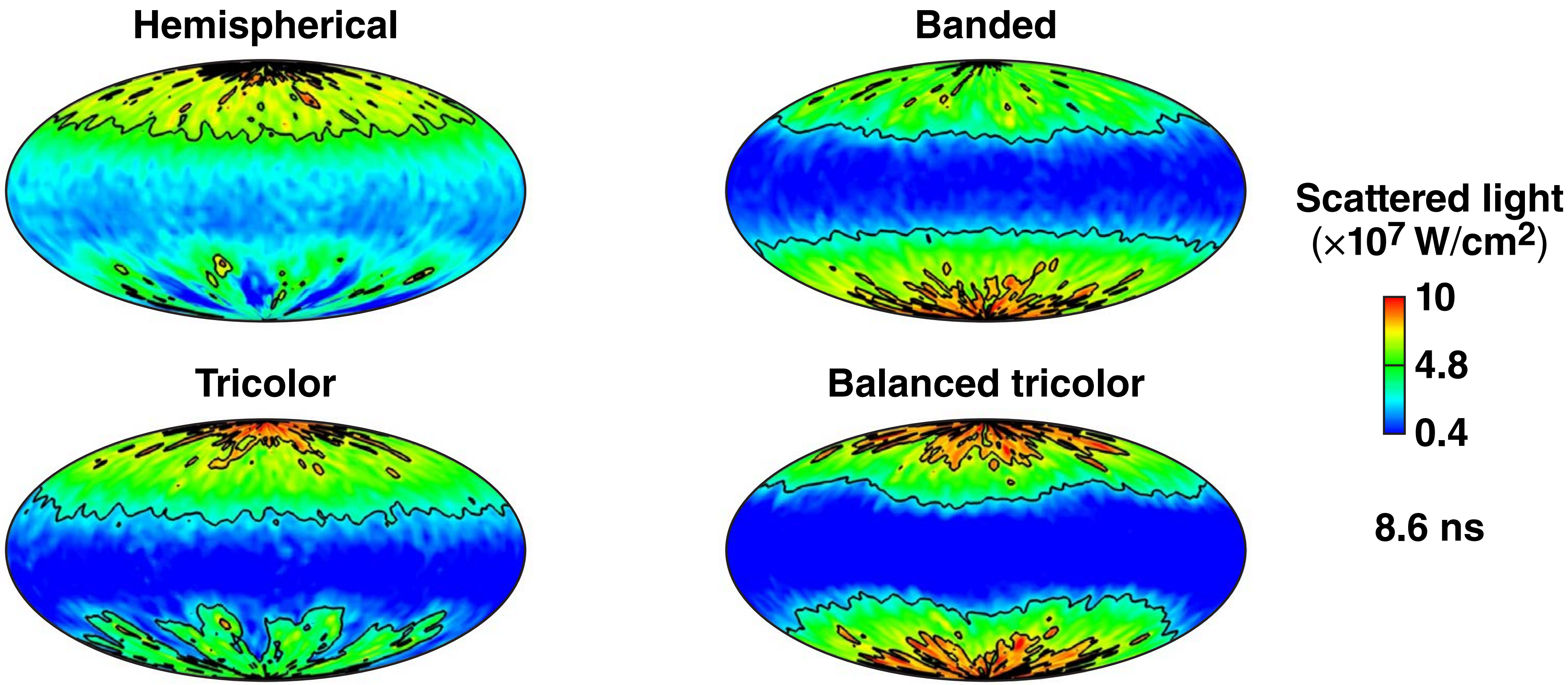


- Shiny metal clips supporting the Armor glass (baffles) currently prevent increasing the detuning range caused by the potential retroreflections
- Some beams may require new conversion crystals
- LLE and LLNL are working together to address meeting the goal of ±6-Å UV detuning

*S. Yang *et al.*, teleconference presented at Lawrence Livermore National Laboratory, Livermore, CA (11 March 2014).

TC11337b

The instantaneous scattered-light pattern indicates the differences between the detuning configurations

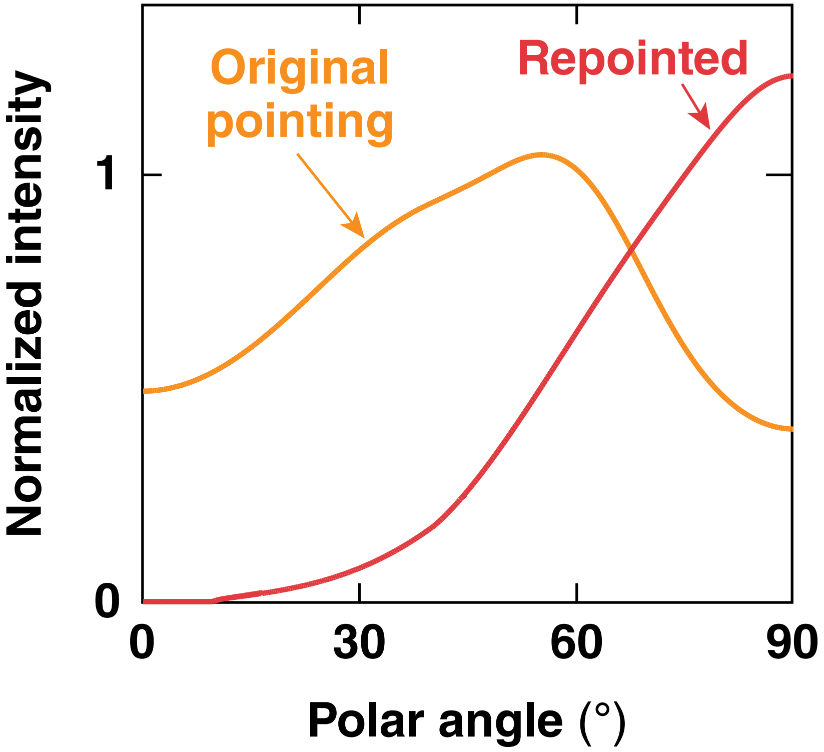


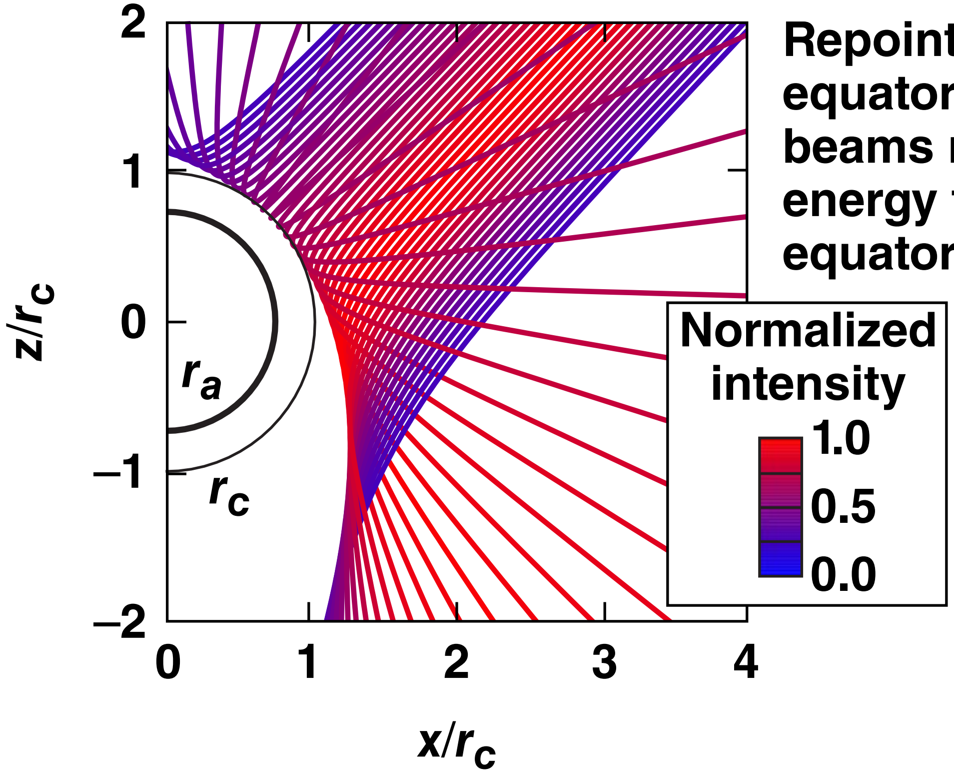
- Banded and tricolor detuning have less scattered light at the equator because of reduced intrahemispherical CBET and less scattering of the polar beams
- Tricolor detuning has less scattered light at the poles than banded because of reduced interhemispherical CBET and less scattering of the equatorial beams

TC12253a

The laser beams in PDD are repointed toward the equator to increase implosion uniformity

- The laser beams in PDD are repointed toward the equator to increase implosion uniformity
- Repointing beams leads to greater ray-path lengths, at a greater distance from the target, through lower densities ($n = n_c \times \cos^2\theta_{inc}$)
- The equatorial beam energy is increased to offset the reduced laser coupling





Repointing equatorial beams moves energy to the equator

TC10222b