An Implosion-Velocity Survey for Shock Ignition at the National Ignition Facility

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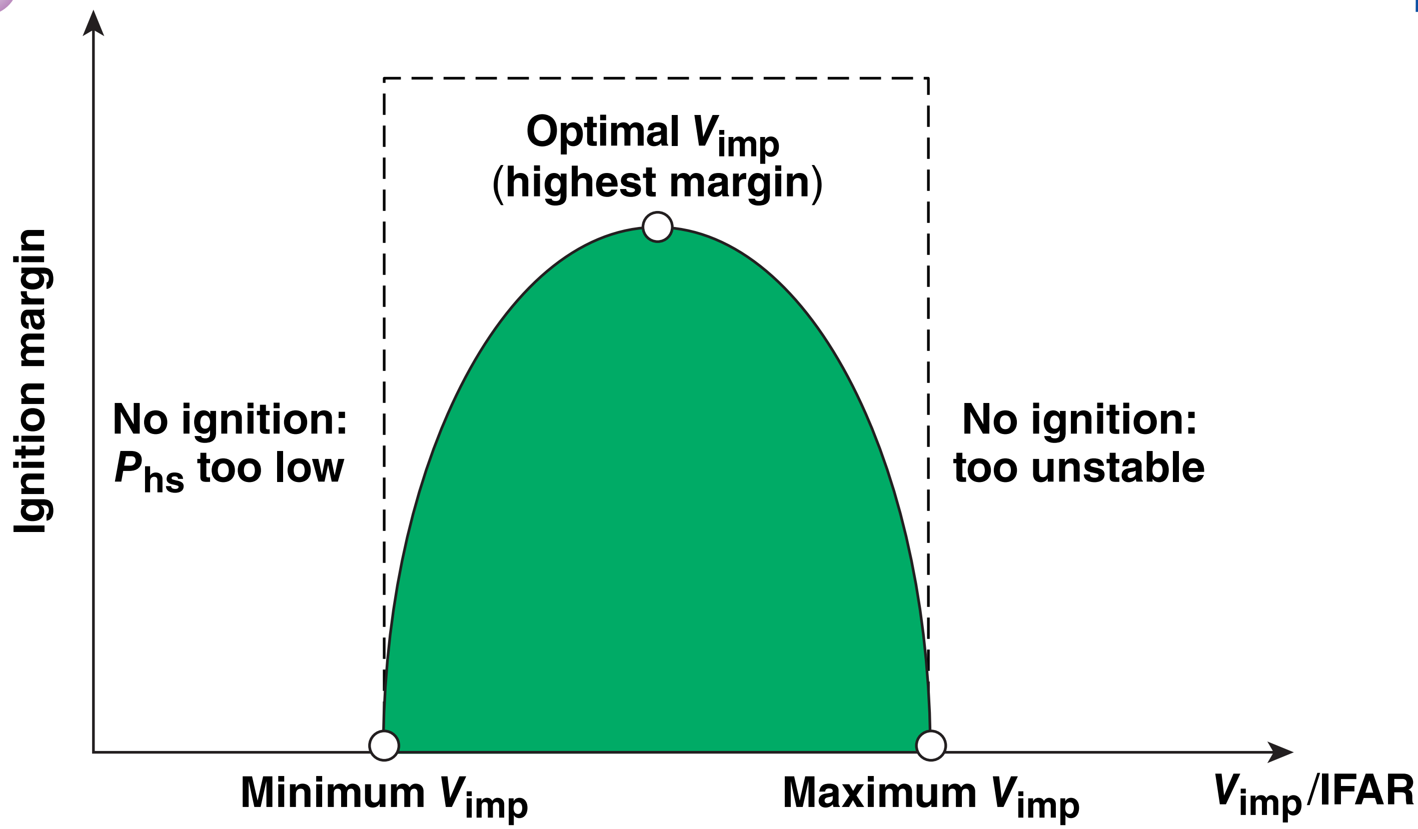
Summary

Simulations of shock ignition (SI) at the National Ignition Facility (NIF) indicate best performance and stability at velocities below 3×10^7 cm/s

- A parameter study was performed, varying the implosion velocity and quantifying target robustness in 1-D and 2-D for plastic-ablator cryogenic capsules
- This study used polar-drive beam geometry to evaluate long-wavelength perturbations and laser imprint to study short wavelengths
- The target margin in 2-D with polar drive was relatively constant with implosion velocity
- Low-velocity capsules showed less sensitivity to laser imprint

The optimal implosion velocity for shock ignition is constrained by both one-dimensional dynamics and multidimensional stability characteristics



The optimal implosion velocity for shock ignition depends on adiabat and ignitor shock strength.

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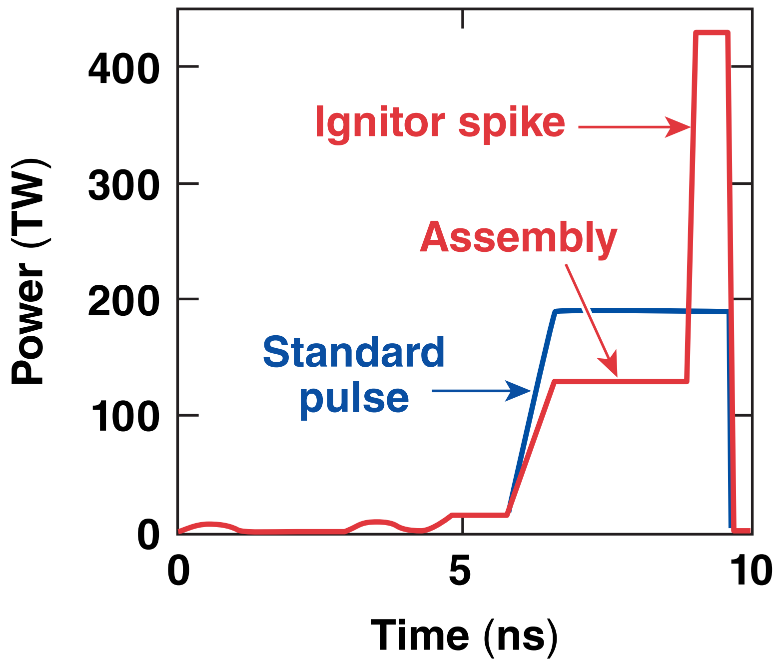
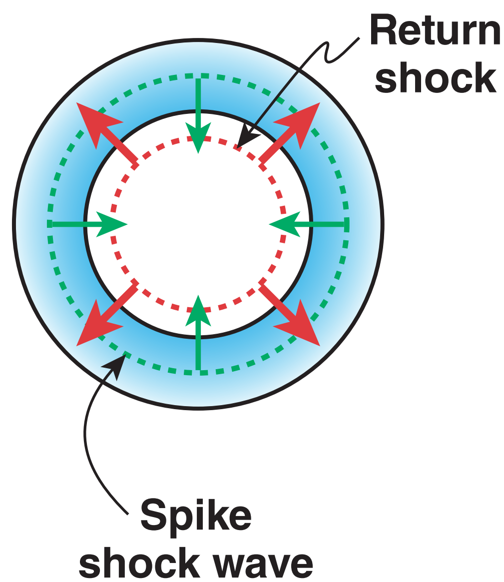
Shock ignition separates the fuel-assembly phase from the ignition phase using a single laser system





The late-time shock amplifies the hot-spot pressure.

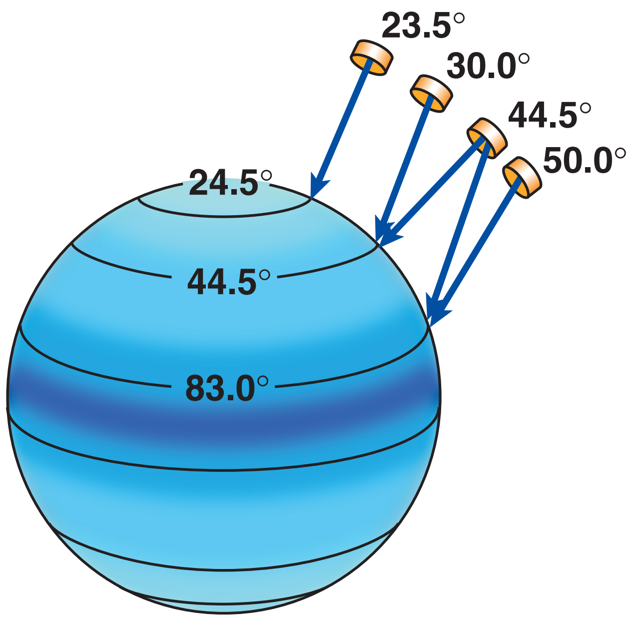
TC10153c

R. Betti *et al.*, Phys. Rev. Lett. 98, 155001 (2007).

Robustness to long-wavelength modes was evaluated using polar-drive nonuniformities and to short-wavelength modes using laser imprint

Polar drive

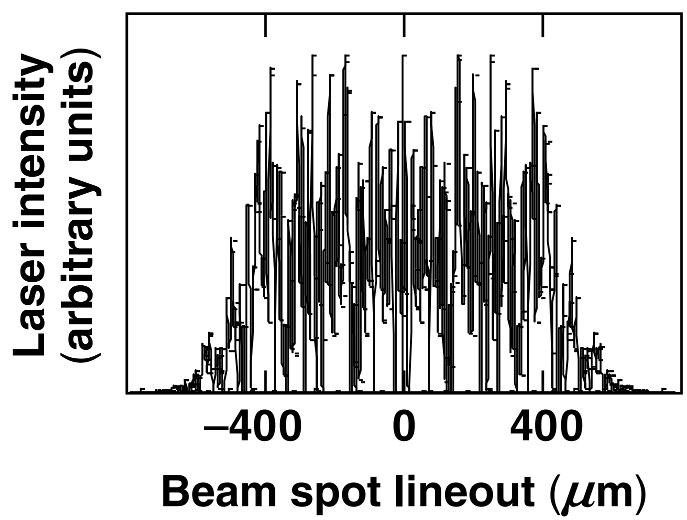
Beams are repointed toward the equator to ensure adequate symmetry



Generates long-wavelength perturbations, $\ell \leq 20$

Single-beam speckle from phase plate

Radial lineout of laser intensity



Generates short-wavelength perturbations, $\ell > 20$

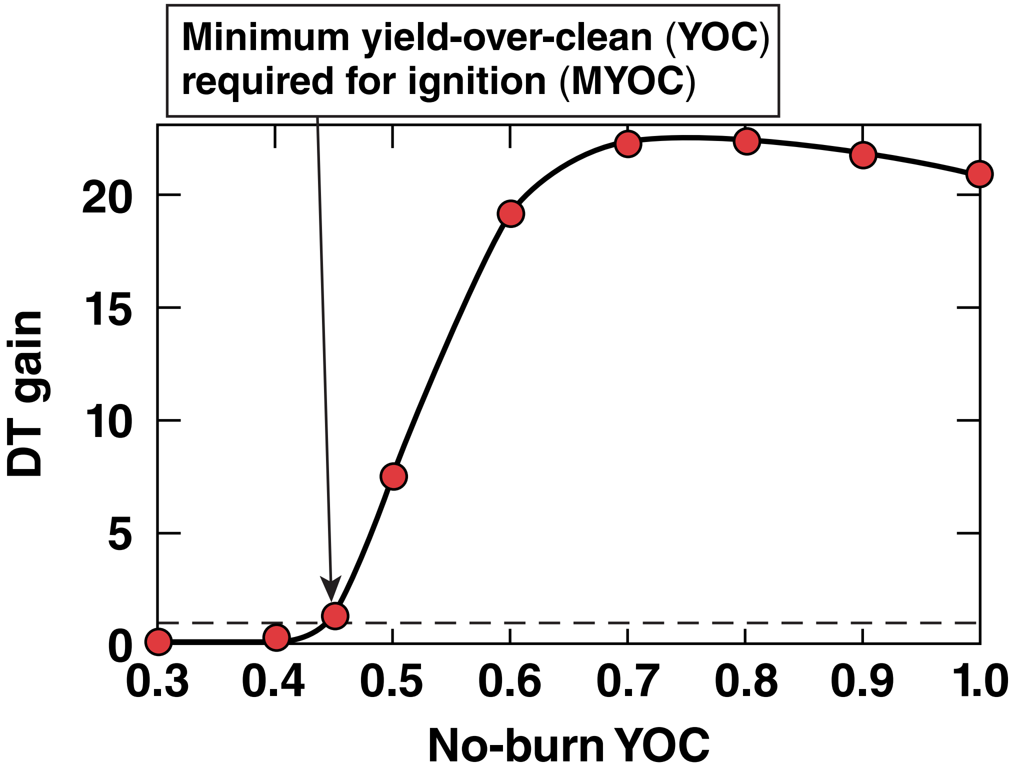
Laser imprint modeled using multi-FM SSD*

TC11002a

*Multi-frequency-modulated smoothing by spectral dispersion

The target margin is quantified using the ignition threshold factor (ITF)*

$$\int_{V_{\text{clean}}} \langle \sigma \nu \rangle dV \approx \int_{V_{\text{1-D}}} \langle \sigma \nu \rangle dV \frac{V_{\text{3-D}}^{\text{clean}}}{V_{\text{1-D}}} \approx \int_{V_{\text{1-D}}} \langle \sigma \nu \rangle dV \times \text{YOC}$$



ITF = MYOC$^{-1.5}$

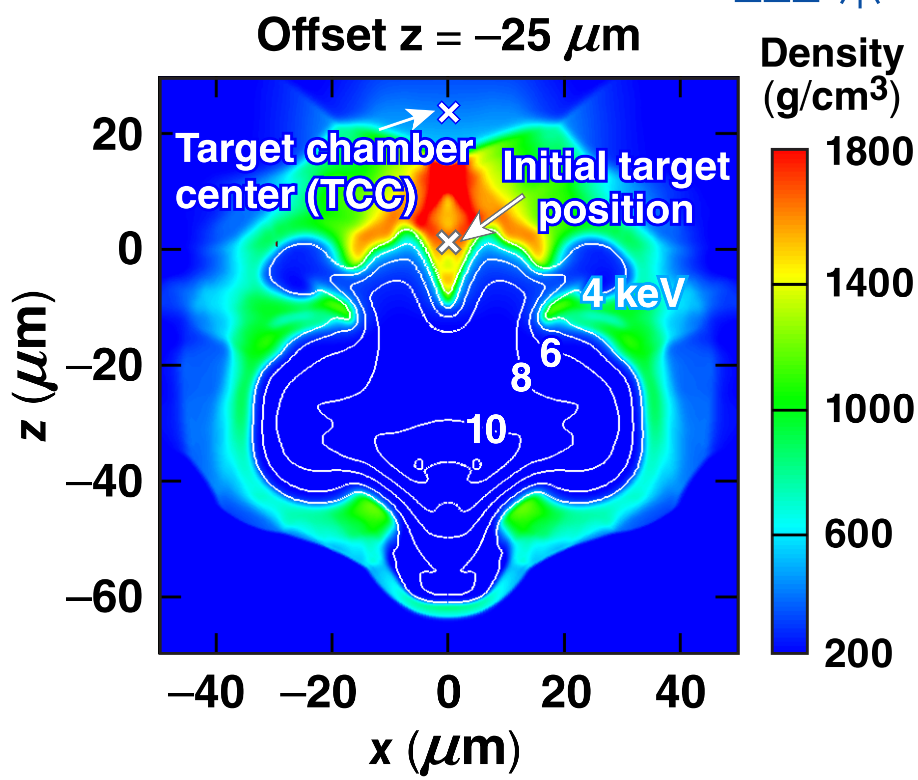
*D. S. Clark *et al.*, Phys. Plasmas 15, 056305 (2008);
P. Y. Chang *et al.*, Phys. Rev. Lett. 104, 135002 (2010);
B. K. Spears *et al.*, Phys. Plasmas 19, 056316 (2012).

TC8570c

The previous high-velocity ($v = 3.1 \times 10^7$ cm/s) SI design of 2012 was shown to be largely insensitive to most sources of nonuniformity

Ignites in polar drive with

- 5× NIF-spec inner ice roughness
- 5× NIF-spec outer surface roughness in modes 2 to 50
- 10% rms (root mean square) beam-to-beam power imbalance
- 100-ps rms beam-to-beam mistiming
- 100-μm rms beam mispointing
- Expected level of imprint with multi-FM* SSD in modes 2 to 100
- Target offset up 25 μm



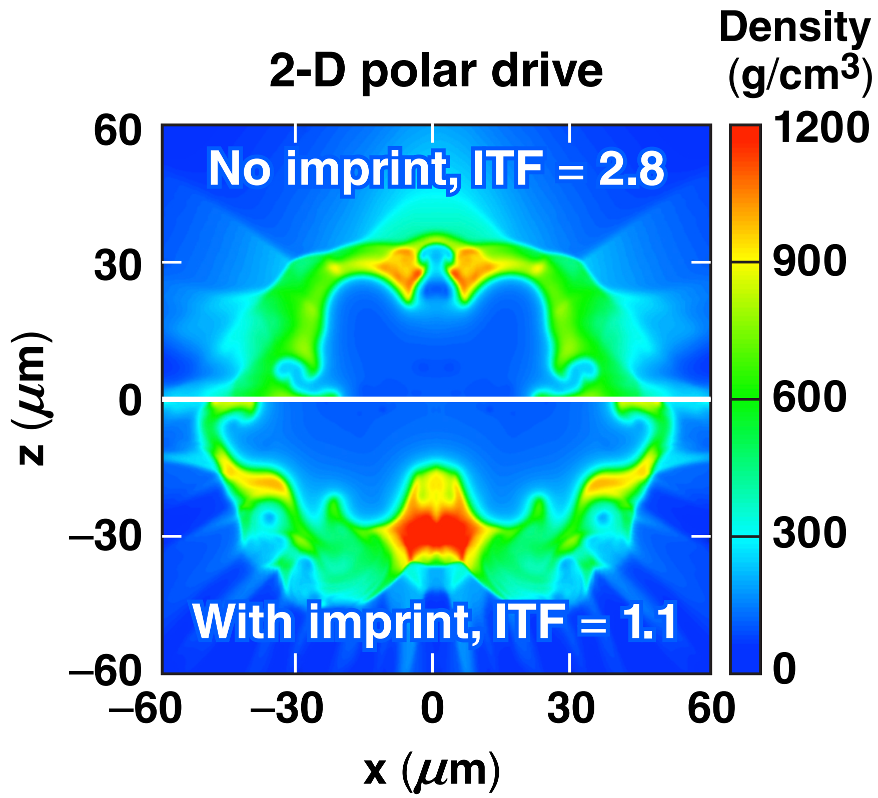
Ignites with a gain of 38 with all expected levels of nonuniformity and system uncertainty.

TC10162c

*LLE Review Quarterly Report 114, 73, LLE Document No. DOE/NA/28302-826 (2008).

The previous SI* design for the NIF showed the strongest sensitivity to polar-drive beam geometry and laser imprint

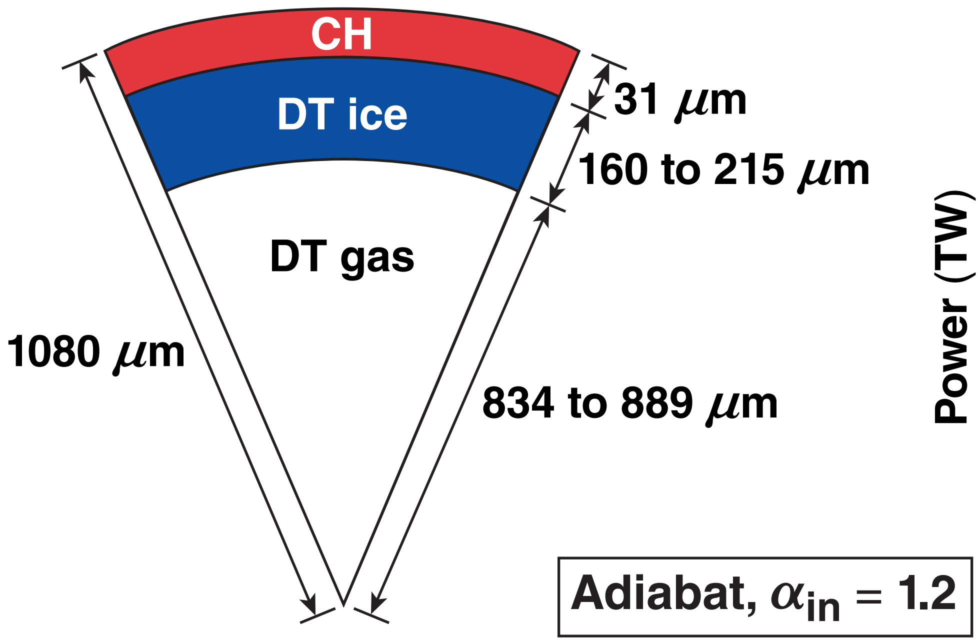
$V_{imp} = 3.1 \times 10^7$ cm/s
ITF (1-D) = 4.1
IFAR = 22

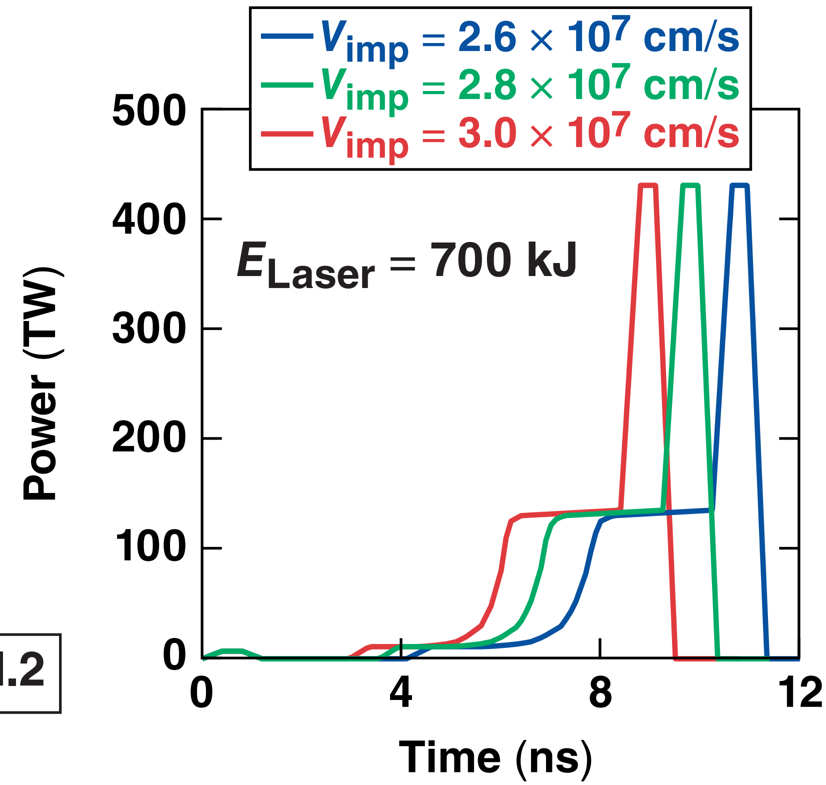


*K. S. Anderson *et al*., Phys. Plasmas 20, 056312 (2013).

TC10738a

Three new designs were analyzed; the velocities were varied by changing the target thickness

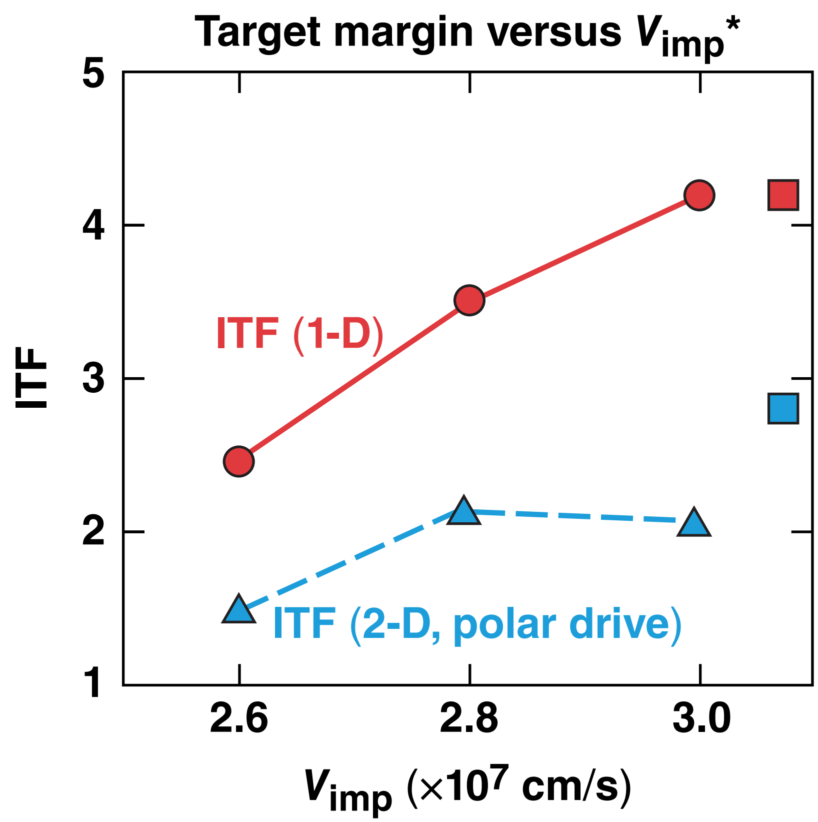




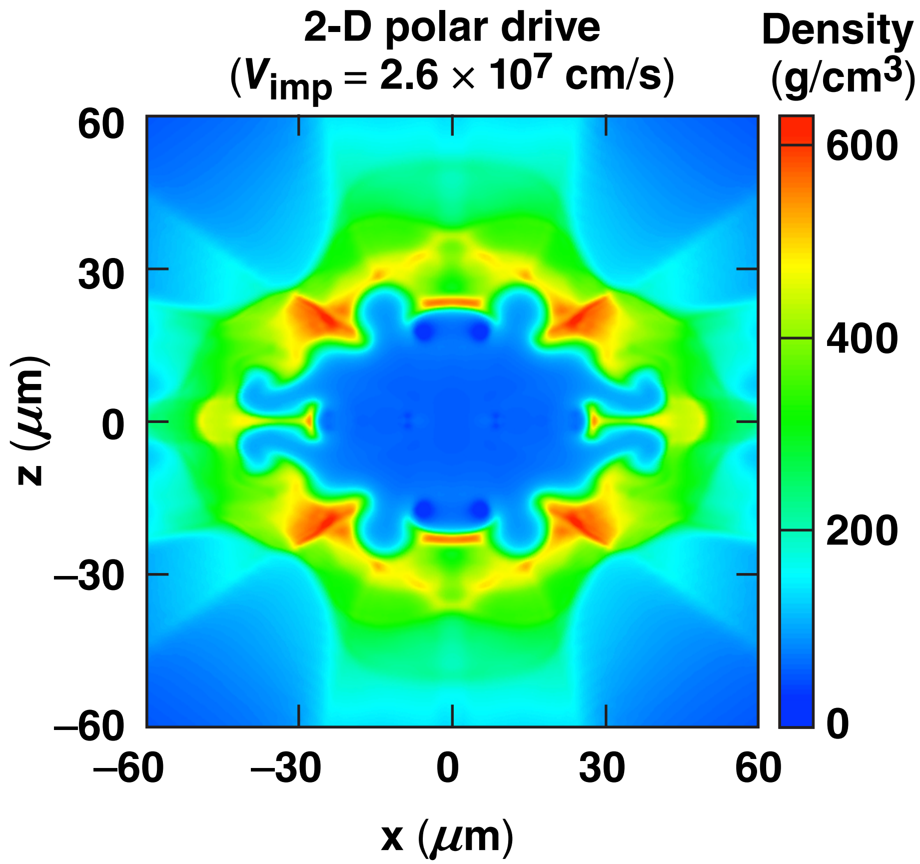
Velocity (cm/s)	2.6 × 10^7	2.8 × 10^7	3.0 × 10^7
Gain (1-D)	69	62	58
ITF (1-D)	2.5	3.5	4.2
$IFAR_{2/3}$	14	17	20

TC10739a

The margin in 2-D polar-drive (PD) simulations increases at higher implosion velocities



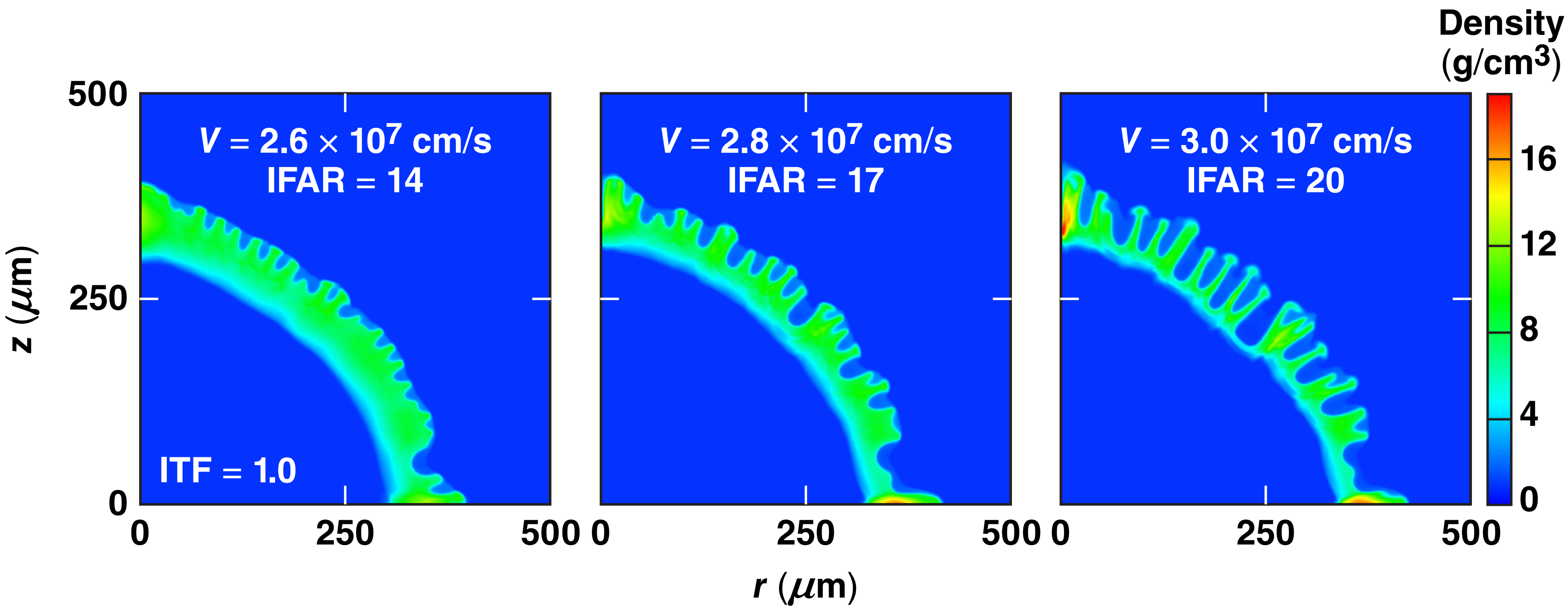
*Previous design (2012-squares) used 5-ring half-quad PD scheme



Each target is independently optimized for PD beam pointing and power balance

TC10740a

Low-velocity, low-IFAR targets show less susceptibility to imprint



ITF analysis with laser imprint is in progress.

TC10741

Abstract

Shock ignition (SI)* has been proposed as a low-energy, high-gain alternative path to ignition at the National Ignition Facility (NIF). In SI, a high-intensity (several times 10^{15} TW/cm^2) laser spike pulse added at the end of the main compression pulse launches a strong shock into the precompressed capsule, raising the hot-spot pressure and temperature. Because of this spike pulse, SI targets can achieve ignition temperatures at lower shell velocities than standard hot-spot implosions. As with hot-spot inertial confinement fusion, optimizing ignition margin in SI implosions requires finding an implosion velocity that balances 1-D target performance with multidimensional stability characteristics. Polar-drive SI designs for the NIF at 700 kJ will be reviewed and compared for stability and margin in 1-D and 2-D simulations at implosion velocities varying from 2.6 to 3.0×10^7 cm/s. Stability studies will include both polar-drive beam geometry and beam repointing as well as laser imprinted nonuniformities from laser speckle.

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*R. Betti *et al*., Phys. Rev. Lett. 98, 155001 (2007).