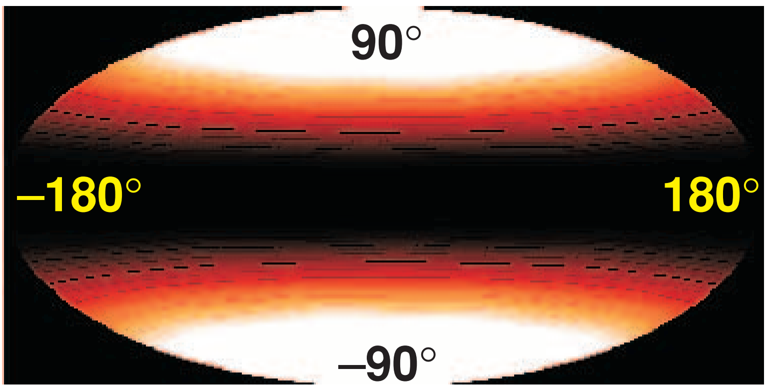
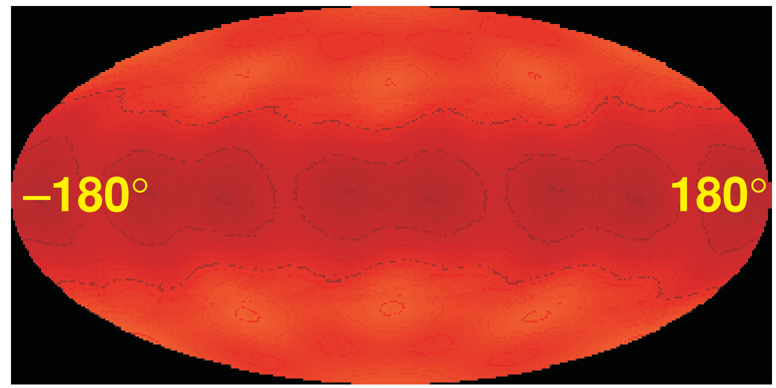
Prospects for Direct-Drive Ignition on the NIF



σ_{rms} = 48%
peak-to-valley = 157%



σ_{rms} = 6%
peak-to-valley = 22%

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American Physical Society
Division of Plasma Physics
Orlando, FL
11–15 November 2002

Summary

Significant experimental and theoretical progress is being made in direct-drive ICF

UR LLE

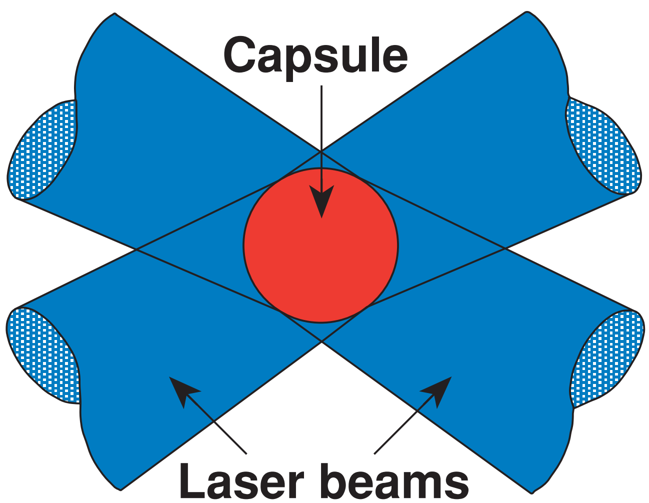
- LLE's research covers all aspects of direct-drive inertial confinement fusion.
- High-performance cryogenic target implosions are in progress.
- The baseline direct-drive, "all-DT" NIF ignition design is predicted to have a gain of 45 (1-D), 30 (2-D), at 1.6 MJ.
- Recent advances are leading to higher gain and more robust ignition targets:
  - Wetted foam targets to increase laser energy absorption
  - Pulse shaping to tailor the target adiabat
- LLE is exploring the possibility of performing direct-drive implosions in an x-ray drive (asymmetric) configuration on the NIF.
- Recent progress is highlighted in the following talks:
  - RI1.006 Sangster, RI1.004 Goncharov, RI1.005 Li, QI1.005 Smalyuk

Progress of direct-drive ICF gives increasing confidence in achieving ignition on the NIF.

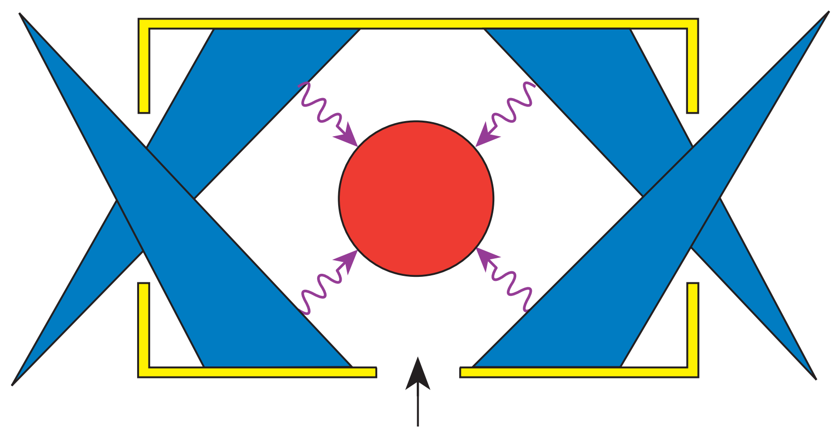
I1374

A number of key physics issues associated with capsule implosions are common to both direct and indirect drive

Direct-drive target



Indirect-drive target



Hohlraum **using a cylindrical high-Z case**

Key Physics Issues

- Energy coupling
- Drive uniformity
- Hydrodynamic instabilities

E6426a

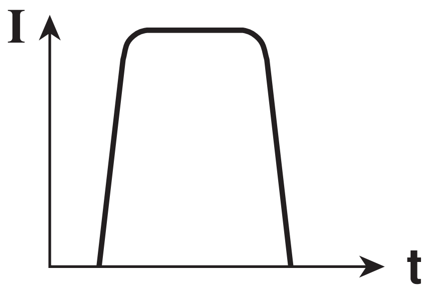
The target adiabat (α) determines both the target gain and stability

- **The adiabat (α) is the ratio of the fuel to Fermi-degenerate pressure:**

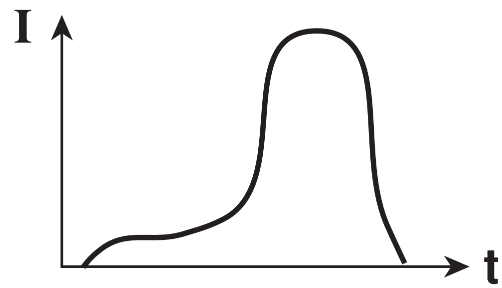
$$\alpha = \frac{P_{\text{fuel}}}{P_{\text{Fermi}}}$$

- **The lower α, the higher the compressed density, increasing the target gain.**
- **The higher α, the more stable the target.**
- **A target designer's dilemma is to balance gain and stability:**
  - **choose an intermediate value of α;**
  - **tailor α in the target to optimize gain and stability.**

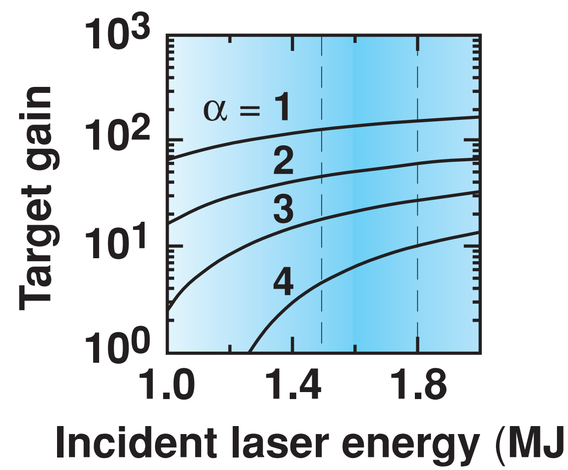
High α-pulse



Low α-pulse



UR/LLE 351-nm direct-drive gain curves "all-DT" designs



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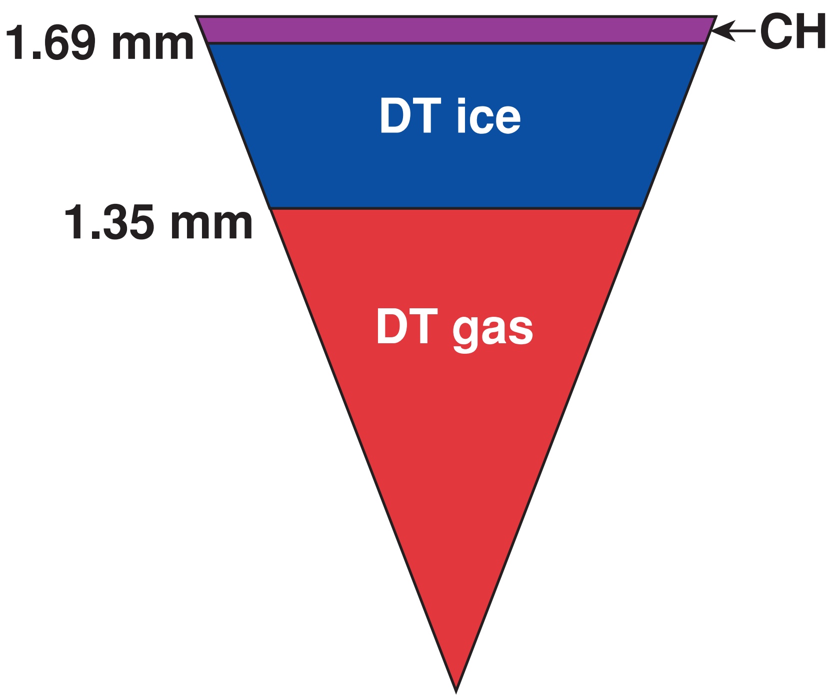
The NIF base-line direct-drive ignition target is a thick DT-ice layer enclosed by a thin CH shell

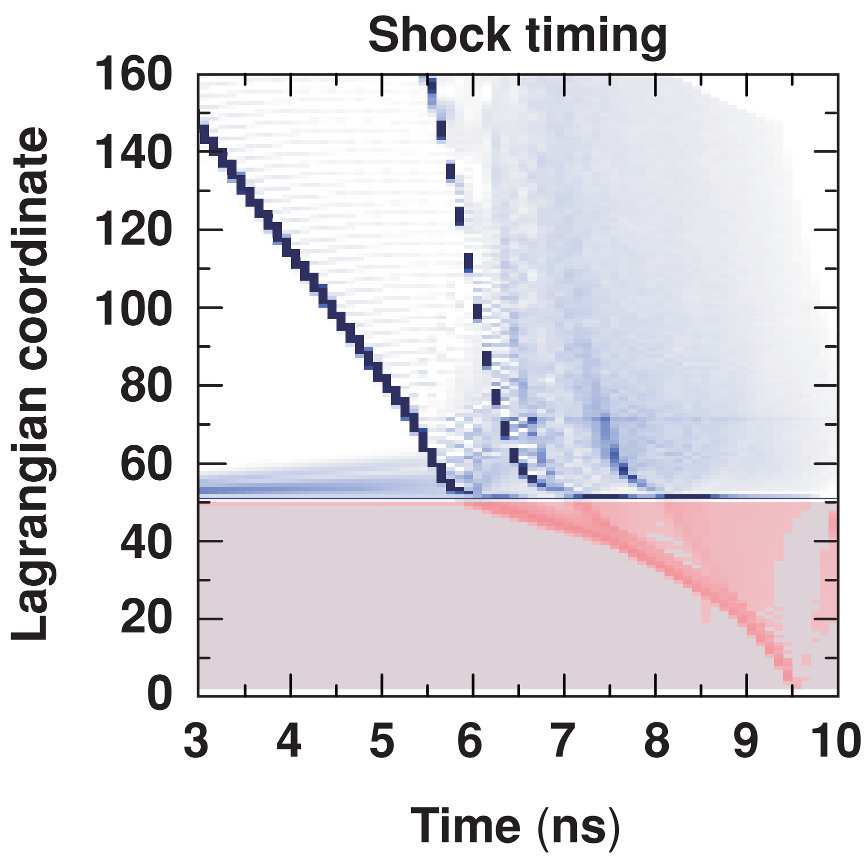
- Target designs are characterized by the isentrope parameter α:

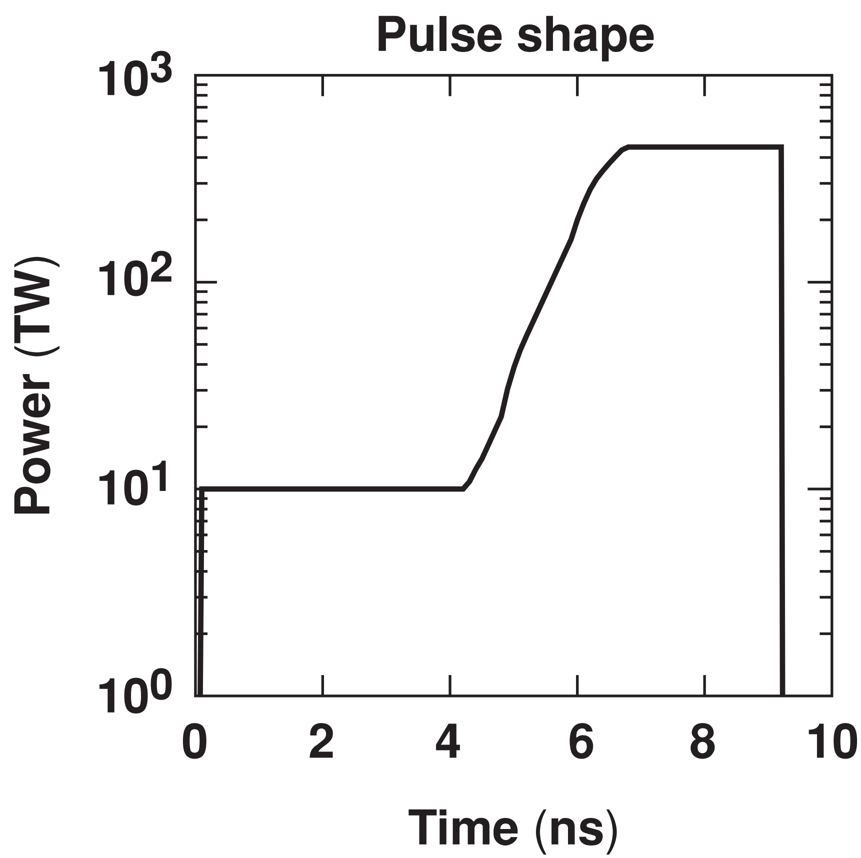
$$\alpha = \frac{\text{Electron pressure}}{\text{Fermi-degenerate pressure}}$$



Laser energy	1.5 MJ
Pulse shape	$\alpha = 3$
Gain	45
Yield	2.5×10^{19}
ρR_{peak}	1.3 g/cm^2
$\langle T_i \rangle_n$	30 keV
Hot-spot CR	28
Peak IFAR	60

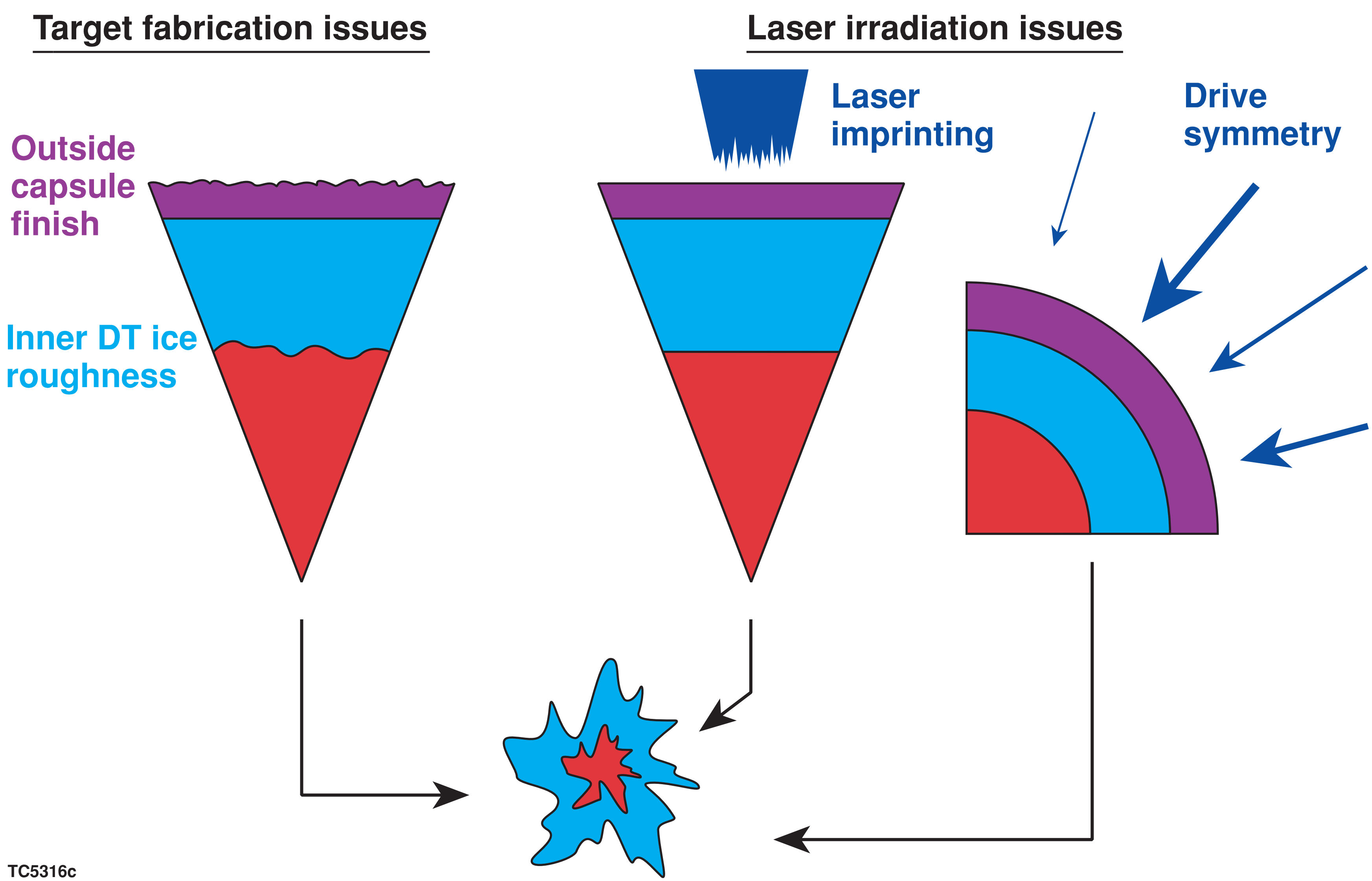
The “all-DT” cryo-target design has two distinct shocks





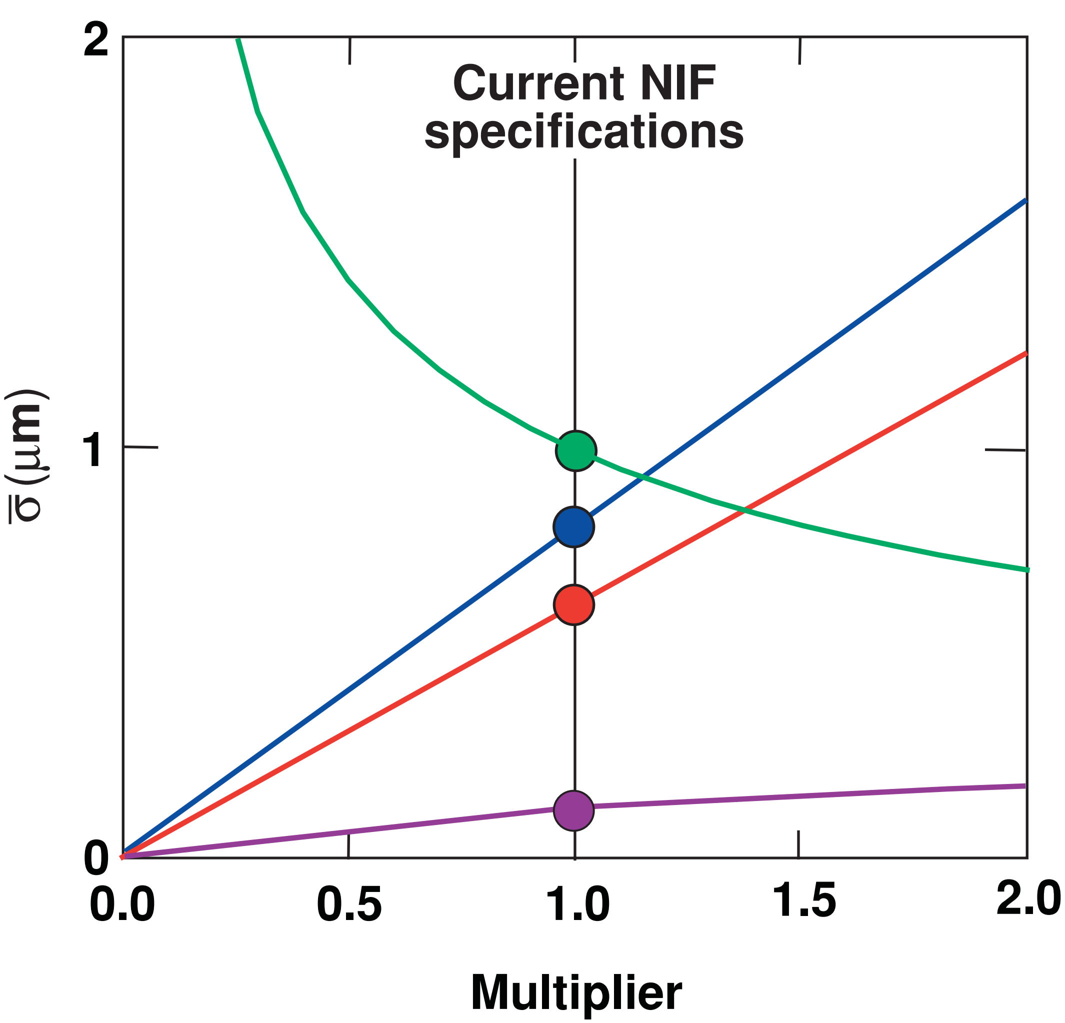
Shock timing can be controlled by changing the length or intensity of the foot of the laser pulse.

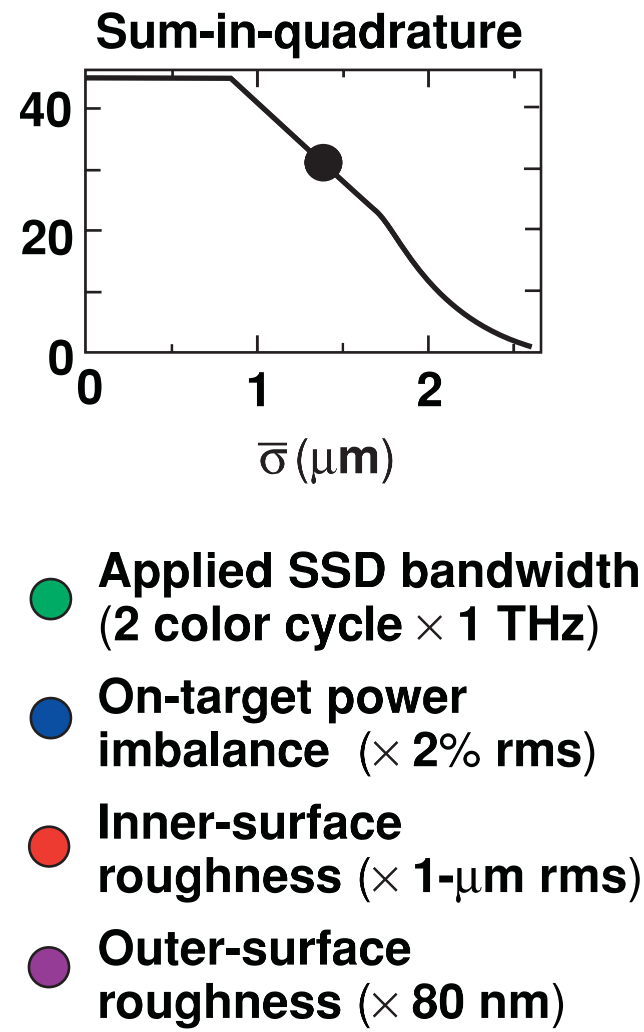
A direct-drive capsule must tolerate four sources of perturbations to ignite and burn



TC5316c

Scaling gain with $\bar{\sigma}$ allows forming a global nonuniformity budget for the direct-drive point design





TC5577c

Hydrodynamic stability during acceleration is determined by the fuel adiabat

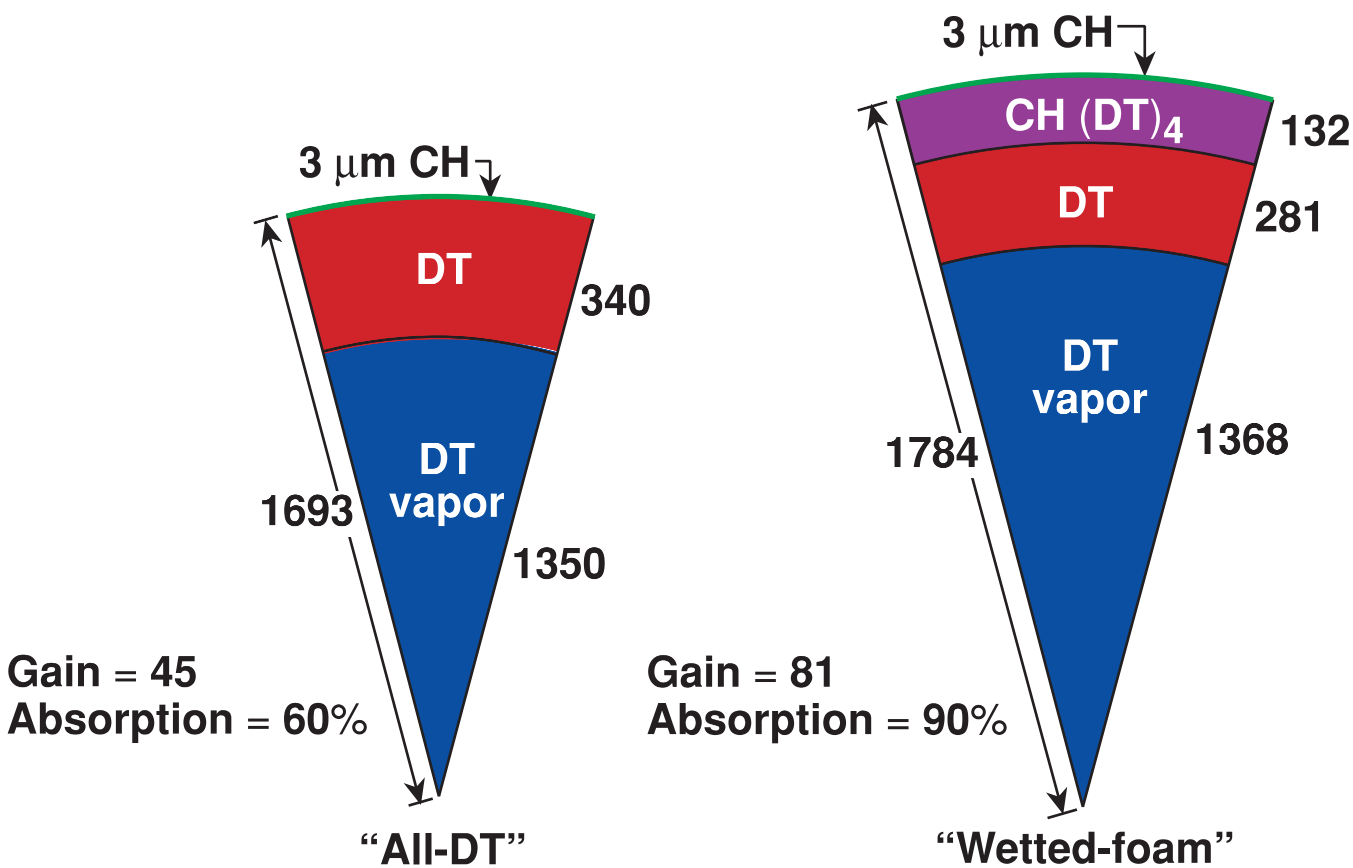
"All-DT," 1.5-MJ Design				
	α = 2	3	4	5
Gain	66	45	39	10
Peak ρR (g/cm^2)	1.6	1.2	1.2	0.96
Shell thickness/mix	2	3	5	7
$\bar{\sigma}$ (μm)	2.6	1.5	1.4	1.4
Pulse width	13.0	9.3	8.8	8.0
Pulse contrast ratio	62	43	27	20

- Nonuniformity: 1-THz SSD, 1-μm inner-surface roughness
- $\bar{\sigma}$ = effective inner-surface nonuniformity after acceleration ($\bar{\sigma}$ = 1.5 corresponds to gain = 30 for α = 3 design.)

Advanced Targets

Wetted-foam targets have higher laser absorption and more fuel, resulting in higher target gain

- Foams have been used previously to selectively radiatively preheat the ablator.[1]



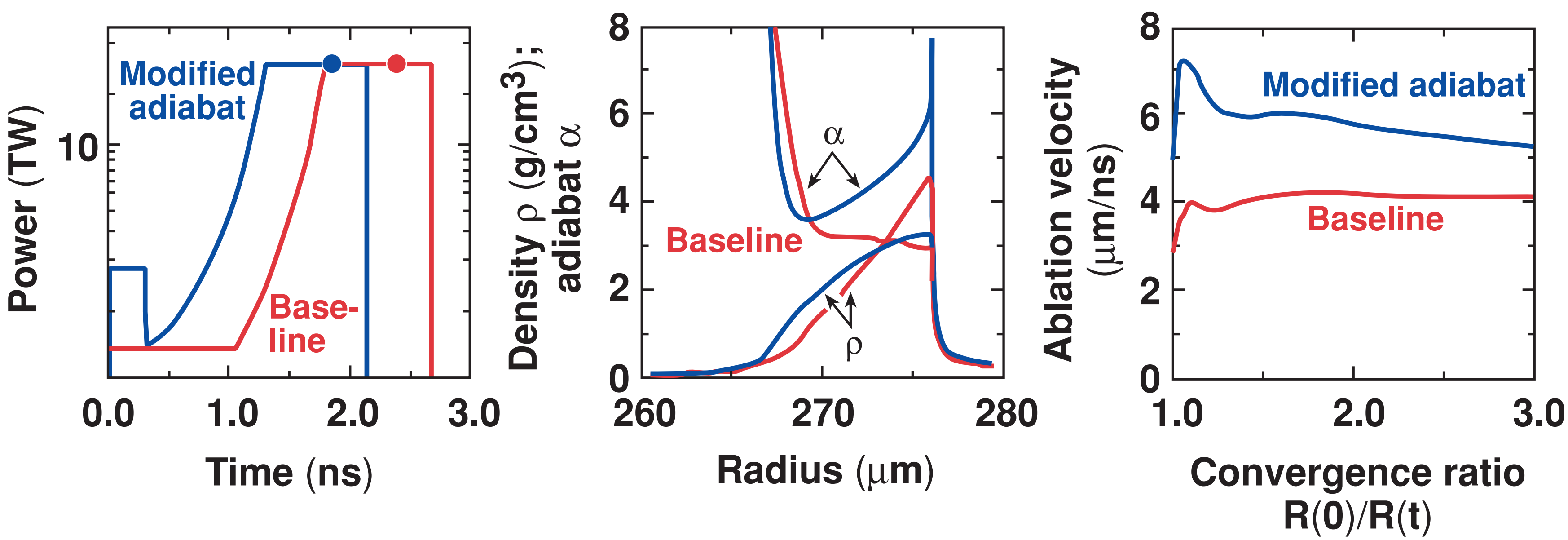
- The foams protects the fuel from preheat due to radiation from the CH.

[1] D.G. Colombant *et al.*, Phys. of Plasmas 7, 2046 (2000).

TC5787b

Advanced Targets

The addition of a prepulse to the all-DT ignition design puts the outer part of the shell on a higher adiabat, reducing the RT growth rate

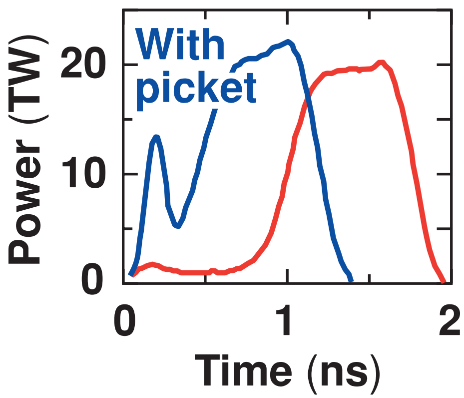


$$\gamma_{RT} \sim \alpha_1\sqrt{kg} - \beta k V_a$$

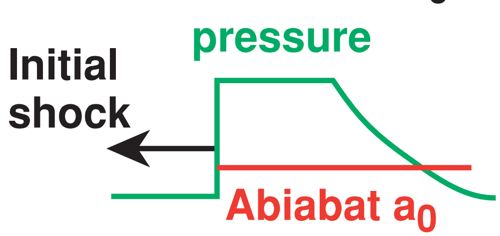
TC5821a

Advanced Targets

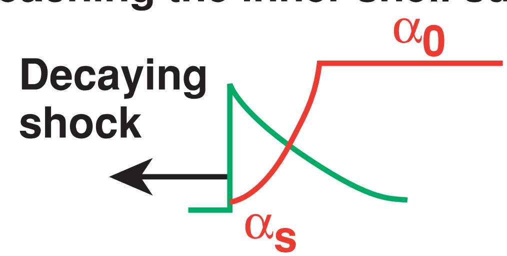
Advanced direct-drive target designs rely on adiabat shaping to optimize target performance and gain



Rarefaction wave is launched after t = t_0.

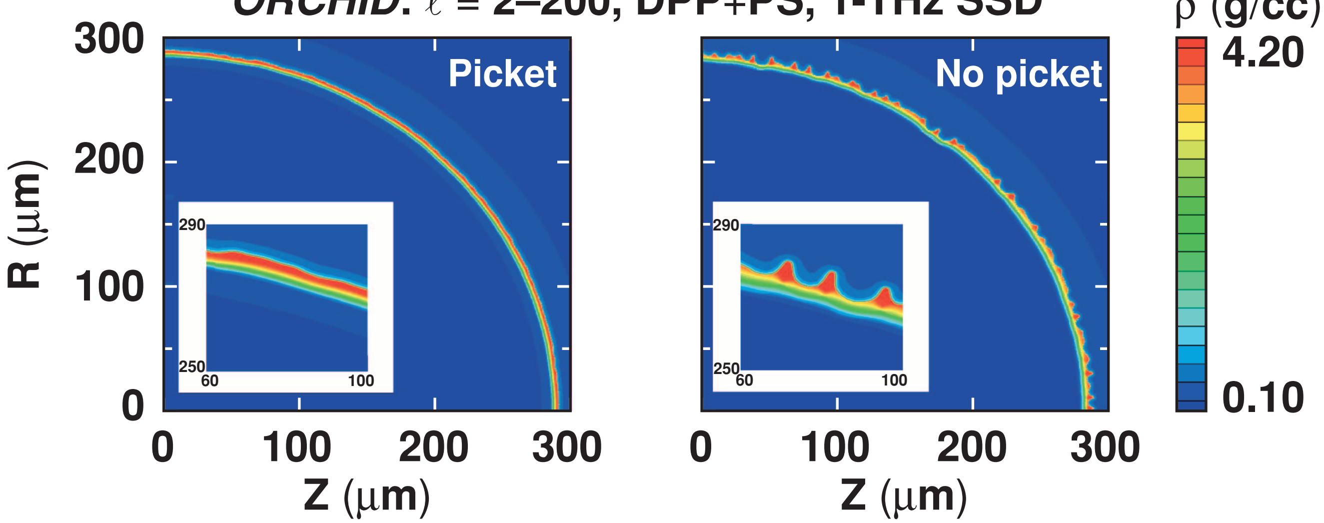


RW meets the shock before reaching the inner shell surface.



Imprint simulations

ORCHID: ℓ = 2–200, DPP+PS, 1-THz SSD

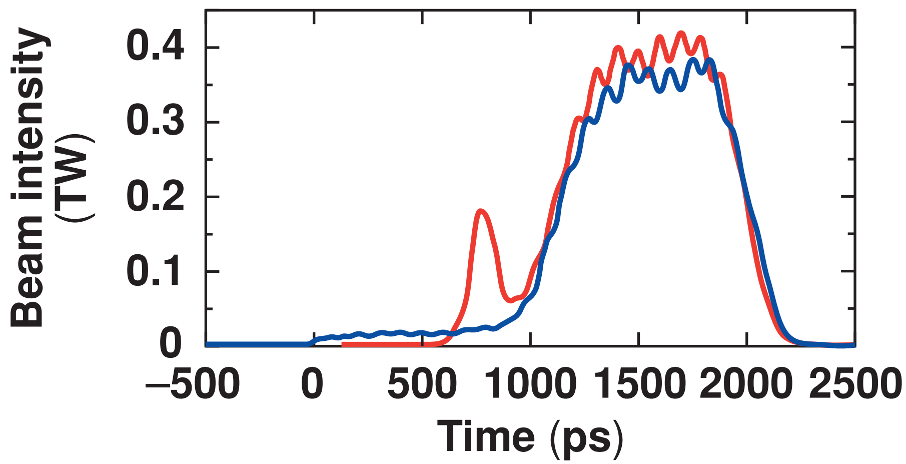


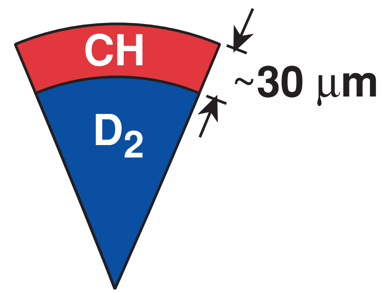
- By reducing the RT growth rate and laser imprint, the shell is significantly less distorted with a picket pulse.
- Initial experimental results are very encouraging.

E11831b

Advanced Targets

Initial adiabat shaping experiments with CH shells show a dramatic improvement in target performance



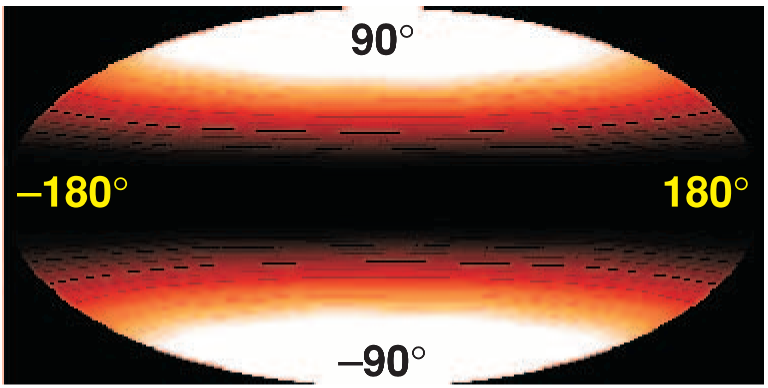


	Exp Measurements			Exp/Simulation		
Target	Yield			Yield		
Without picket	(DD)	(DT)	(D^3He)	(DD)	(DT)	(D^3He)
D_2(15)CH[33]	4.14×10^9	7.99×10^6	2.96×10^6	0.035	0.026	0.018
D_2(3)CH[33]	1.06×10^9	8.00×10^5	1.83×10^6	0.025	0.008	0.029
^3He(12)D_2(6)CH[33]	9.32×10^8	9.30×10^5	2.94×10^6	0.061		
D_2(15)CH[27]	1.98×10^{10}	3.89×10^7	1.83×10^7	0.079	0.059	0.044
With Picket						
D_2(15)CH[33]	1.27×10^{10}	3.57×10^7	7.26×10^6	0.19	0.30	0.090
D_2(3)CH[33]	1.98×10^9	1.83×10^6	1.88×10^6	0.17	0.13	0.16
^3He(12)D_2(6)CH[33]	1.44×10^9	1.77×10^6	5.75×10^6	0.18		
D_2(15)CH[27]	2.96×10^{10}	5.22×10^7	2.96×10^7	0.15	0.13	0.10

I1370

It may be possible to carry out direct-drive implosions on the NIF in indirect-drive configuration

Aitoff projection of intensity on a capsule



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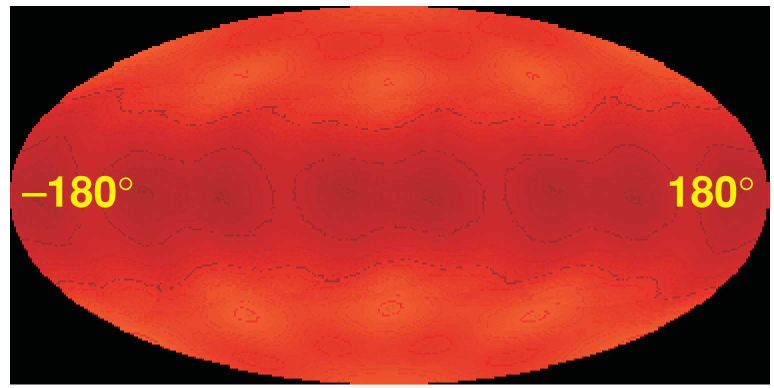
NIF direct-drive distribution using 24 (×4) beams in indirect-drive illumination



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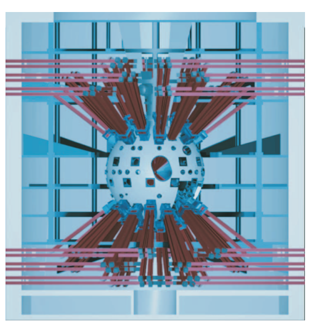
NIF direct-drive intensity distribution with 24 (×4) beams repointed to a pattern similar to OMEGA 24



The penalty from asymmetric illumination may be mitigated by the clever use of phase plate design, beam pointing, pulse shaping, and ice layer/ capsule shimming.

E11720b

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