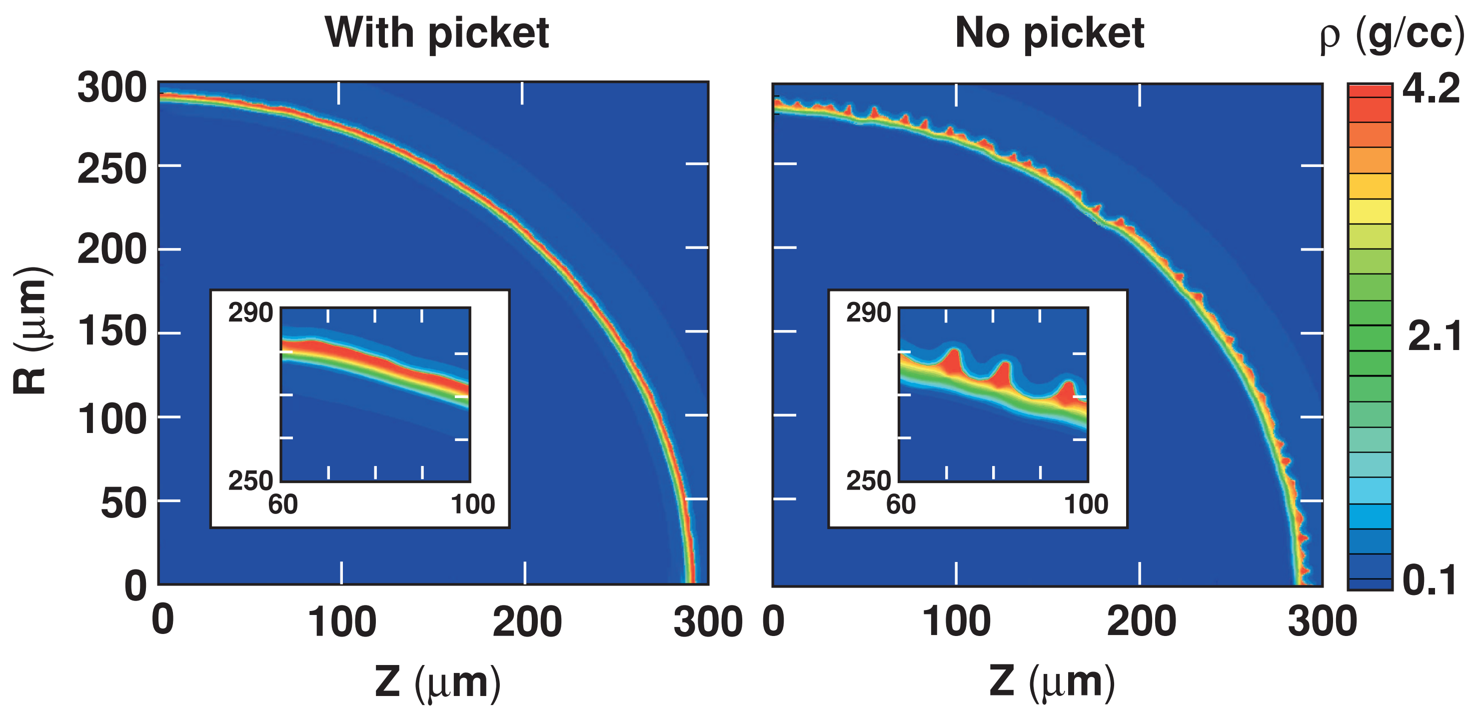
Improved Performance of Direct-Drive ICF Target Designs with Adiabat Shaping Using an Intensity Picket



V. N. Goncharov
University of Rochester
Laboratory for Laser Energetics

44th Annual Meeting of the
American Physical Society
Division of Plasma Physics
Orlando, FL
11–15 November 2002

Summary

Adiabat shaping produced by an intensity picket significantly improves target stability

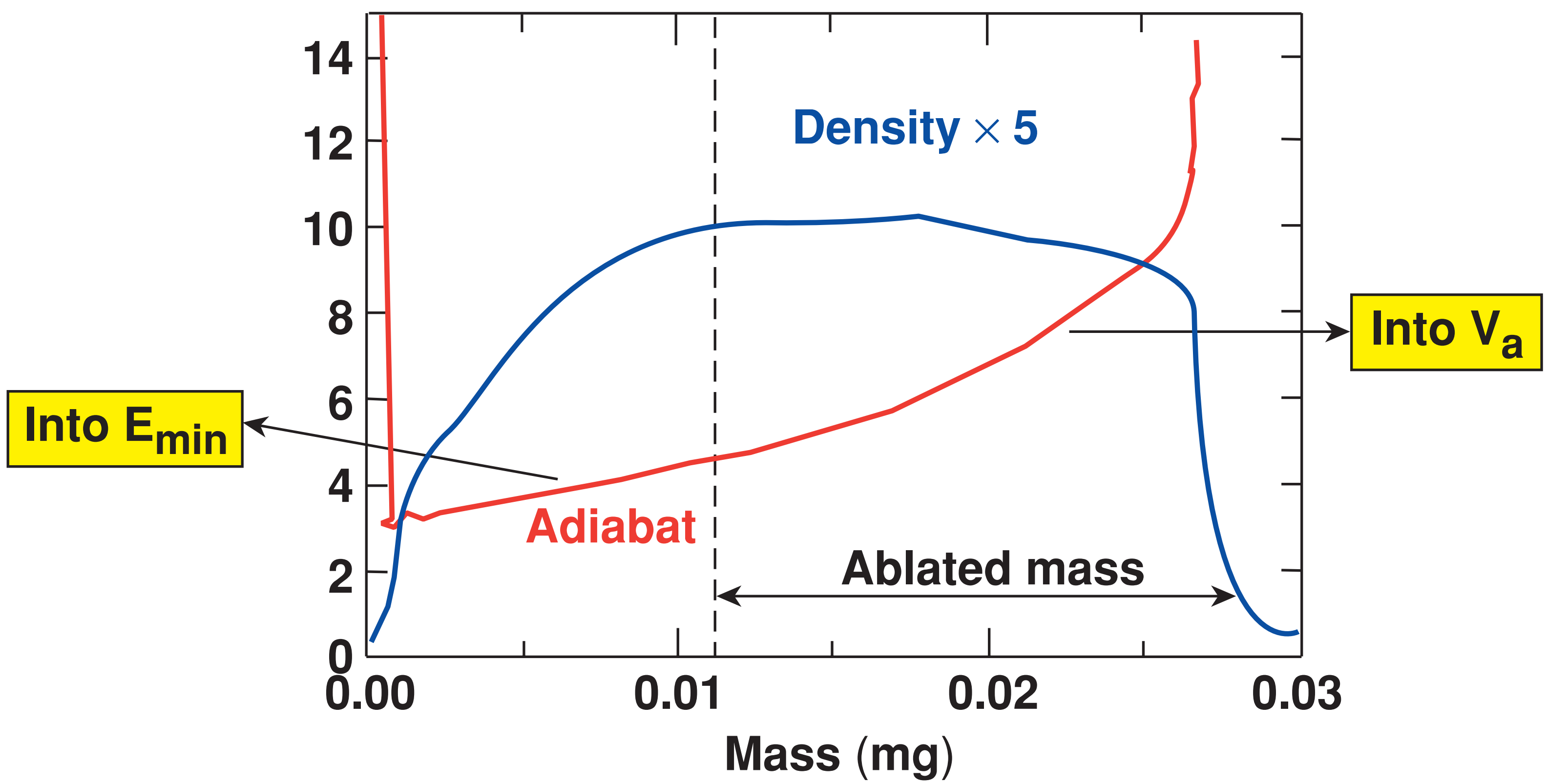
- A technique is proposed to reduce the perturbation growth without compromising the target yield.
- Shaping the adiabat of the main fuel and ablator reduces both seeding and the growth of the Rayleigh–Taylor instability.
- The adiabat is shaped using an intensity picket that launches a decaying shock into the shell.
- The shock places the outer portion of the shell (ablator) on the higher adiabat, keeping the inner part (main fuel) on the lower adiabat.
- The stabilizing effect of the adiabat shaping is confirmed both theoretically and experimentally.

Outline

- Importance of the shell adiabat for the target yield and shell stability
- Adiabat shaping using an intensity picket
- Improved-performance direct-drive target designs for NIF and OMEGA
- Reduction of the laser imprint and RT growth rates due to the picket
- Additional instabilities created by adiabat shaping
- Main results of adiabat-shaping experiments

Shell stability and compressibility depend on the adiabat

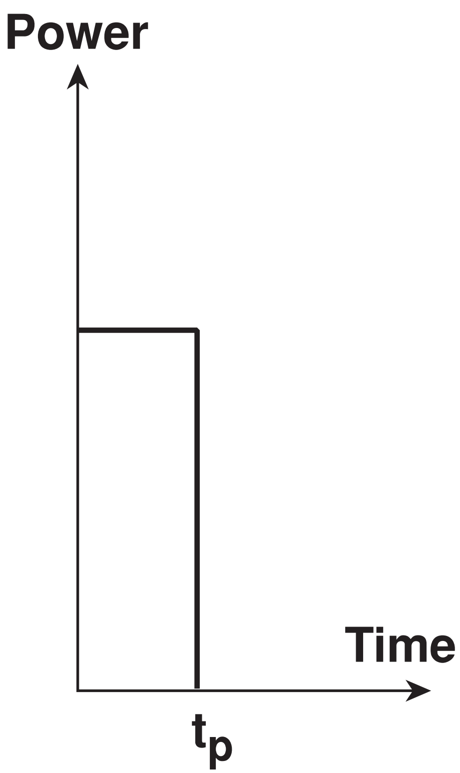
- Mimimum energy required for ignition:[1,2] $E_{min} \sim \alpha^{1.88}$ $\alpha = P/P_{Fermi}$
- Rayleigh–Taylor instability growth $\gamma = \alpha_{RT}(kg)^{1/2} - \beta_{RT}kV_a$ $V_a \sim \alpha^{3/5}$



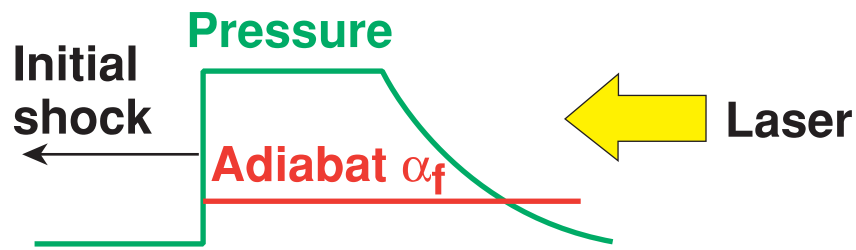
[1]M. Herrmann *et al.*, Phys. Plasmas 8, 2296 (2001).
[2]R. Betti *et al.*, Phys. Plasmas 9, 2277 (2000).

TC5950

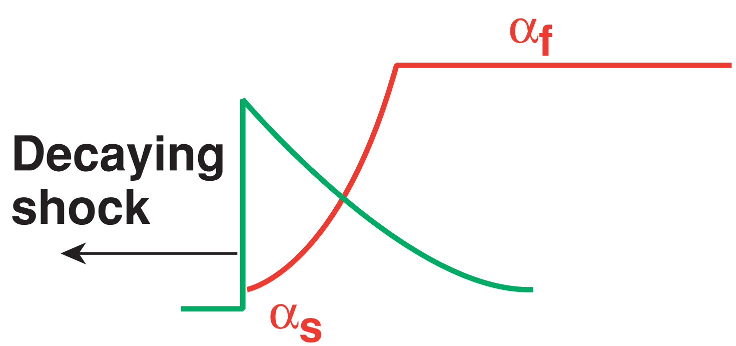
Adiabat shaping is done using an intensity picket



- $t = 0$ Picket creates a strong shock
- $t = t_p$ Rarefaction wave (RW) is launched at $t = t_p$.



- $t = t_{rw}$ RW meets the shock
- $t > t_{rw}$ Shock strength decreases in time



Calculations show

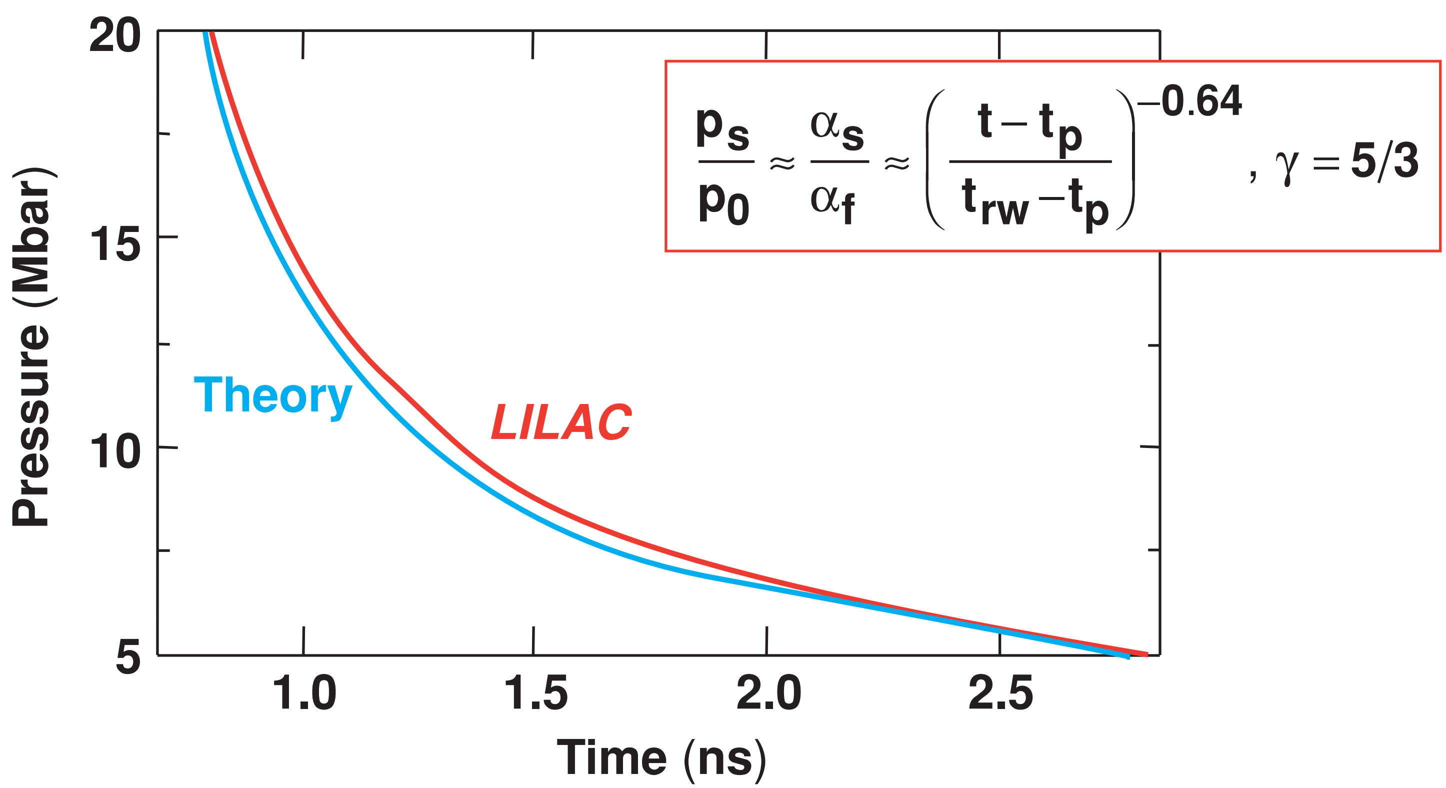
$$\frac{p_s}{p_0} \approx \frac{\alpha_s}{\alpha_f} \approx \left(\frac{t - t_p}{t_{rw} - t_p}\right)^{-\frac{\sqrt{2\gamma(\gamma-1)}}{2\gamma-1}}$$

valid for $\gamma > 1.2$.

TC5951

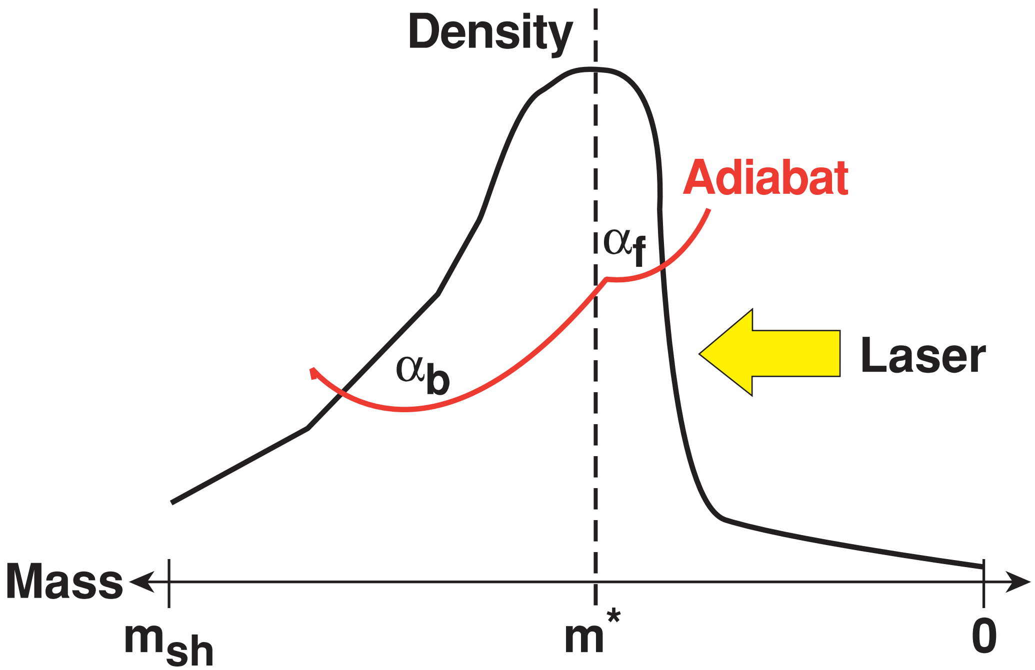
Numerical simulations confirm the shock decaying rate

The 300-μm-DT foil is driven by 500-ps, 100-TW square pulse.



TC5952

The adiabat at the ablation front depends on the picket intensity and picket width



For $\gamma = 5/3$:

$$\alpha = \alpha_f \left[1.5 \left(\frac{m}{m^*} - 1 \right) + 1 \right]^{-0.94}$$

$$\alpha_f = \alpha_b \left[1.5 \left(\frac{m_{sh}}{m^*} - 1 \right) + 1 \right]^{+0.94}$$

$$m^* \sim \rho_0 U_{sh} t_p$$

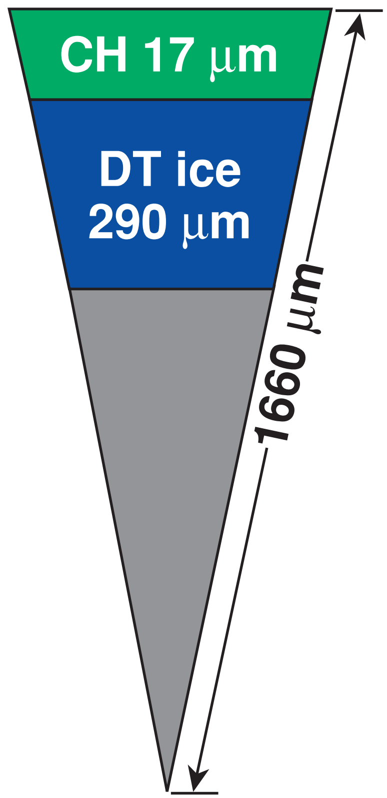
Picket optimization gives $t_p(\text{ns}) \simeq 10^{-3} \Delta_0 (\mu\text{m}) / \sqrt{\alpha_b}$

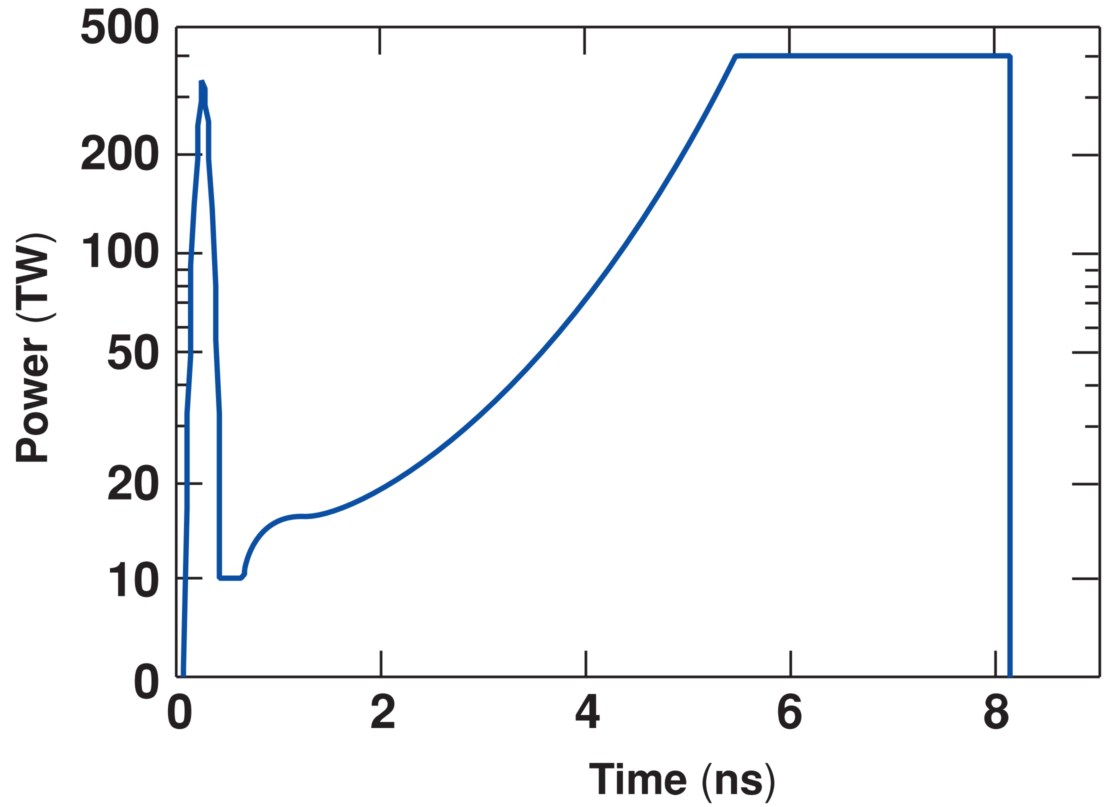
$\text{Pressure}_{\text{picket}} (\text{Mbar}) \simeq 16\, \alpha_b$

t_p ~ 50 ps for OMEGA; t_p ~ 200 ps for NIF
pressure ~ 50–60 Mbar; $\alpha_b = 3$

TC5953

A shaped-adiabat ignition target has been designed for the NIF facility





FWHM = 200 ps

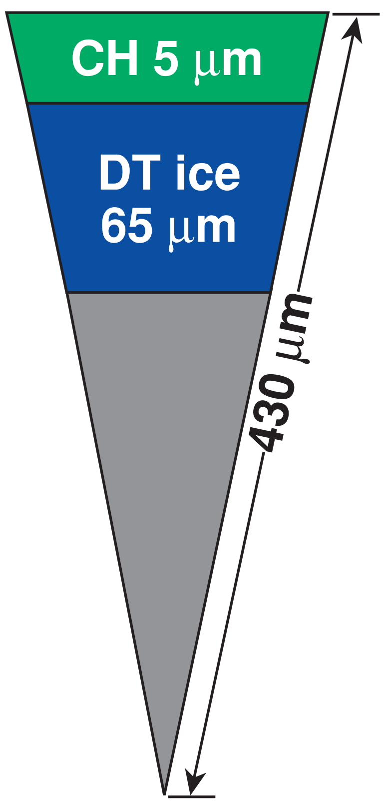
P_{picket} = 350 TW

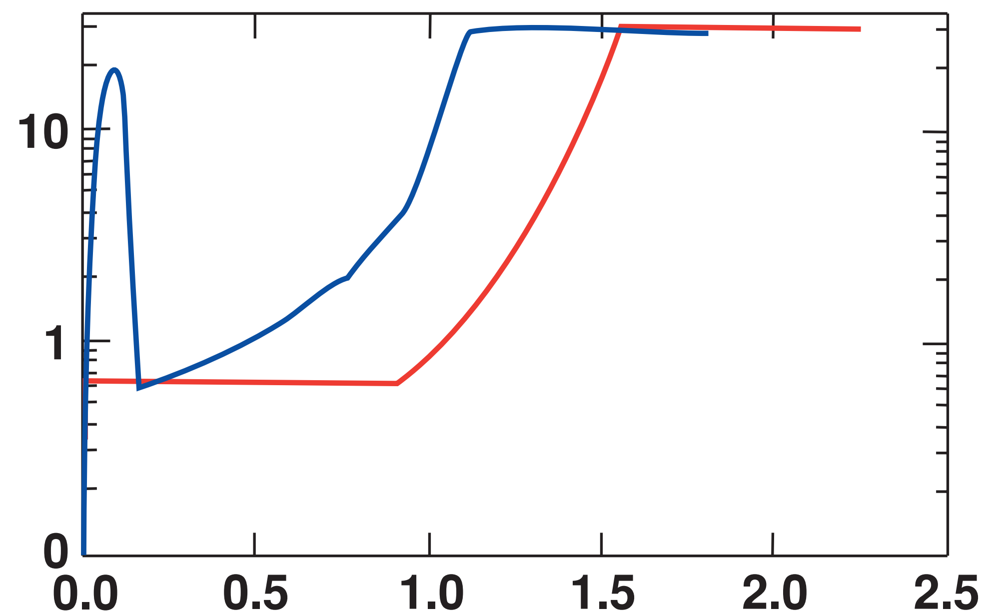
ρR = 1.45 g/cm^2

Gain = 55

TC6000

Greater shell stability is predicted for high-performance OMEGA cryogenic target designs with an intensity picket





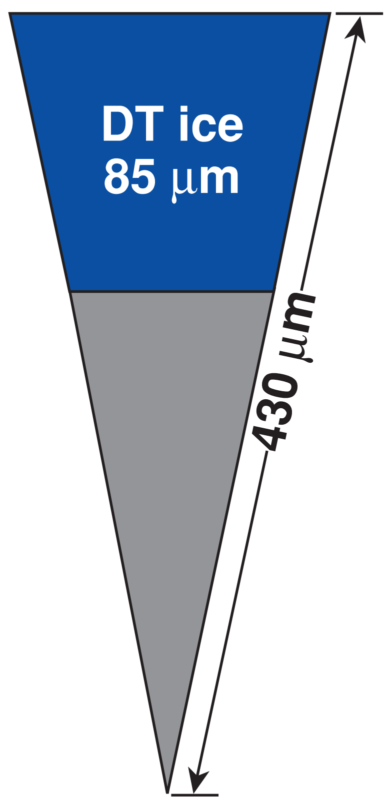
		Picket
ρR (mg/cm^2)	330	305
Y ($\times 10^{14}$)	6.5	6
A_{bubble}/Th (%)[1]	>100	55

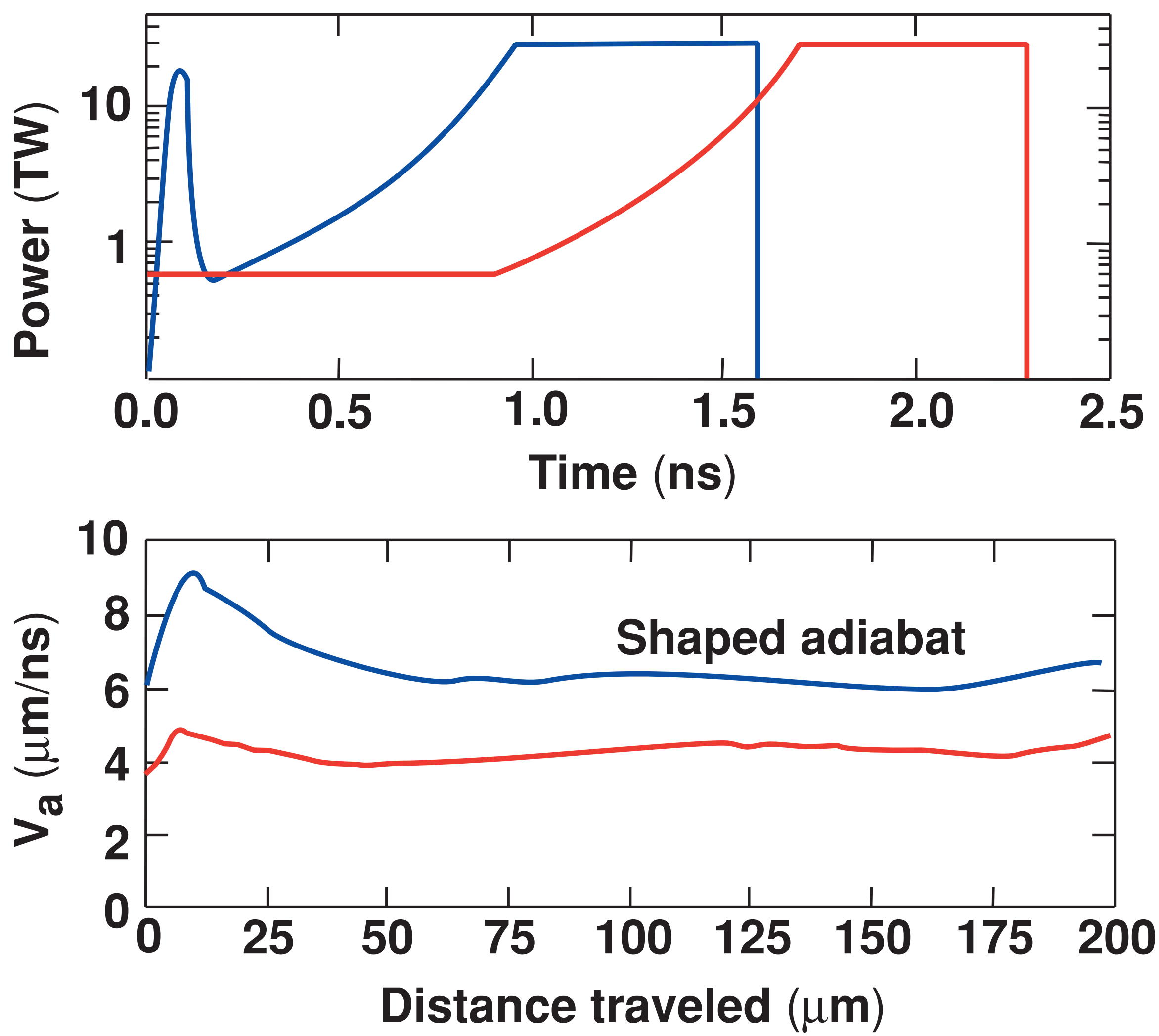
TC5956

[1]V.N. Goncharov *et al.*, Phys. Plasmas 7, 5118 (2000)

Stabilizing effects of the adiabat shaping were numerically tested on the "all-DT," α = 3 OMEGA target design

Two pulse shapes were considered



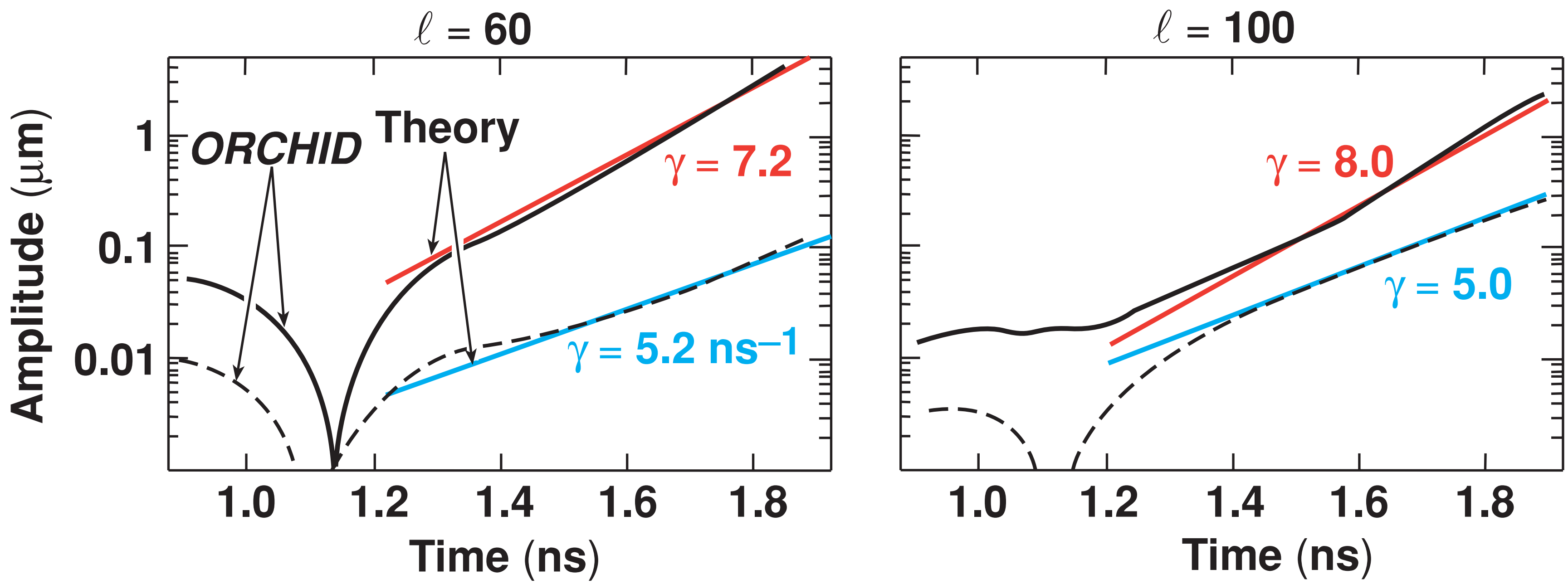


TC5954

The intensity picket reduces both the growth rate and laser imprint[1]

- Imprint simulation using 2-D Lagrangian code *ORCHID*

1% laser-intensity modulations; no SSD



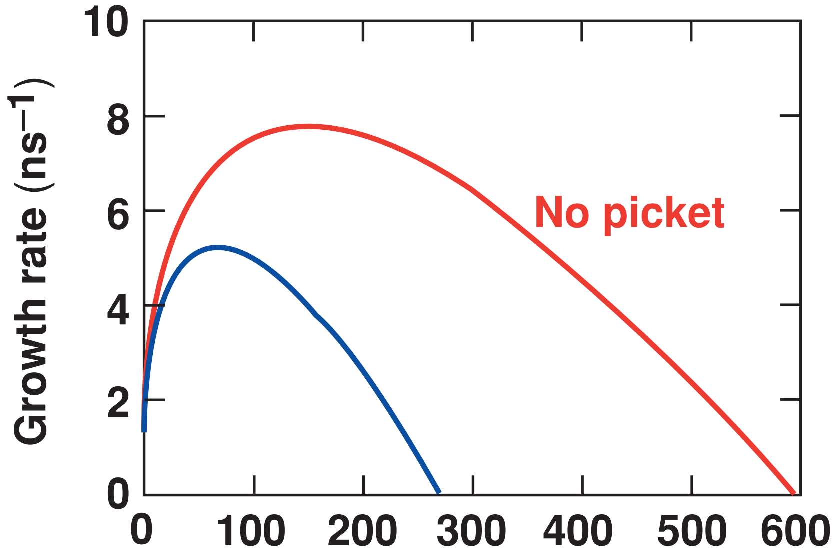
For DT foils:[2] $\gamma = 0.94\sqrt{kg} - 2.6\ kV_a$

[1]T. J. B. Collins, S. Skupsky, Phys. Plasmas 9, 275 (2002).
[2]R. Betti *et al.*, Phys. Plasmas 5, 1446 (1998).

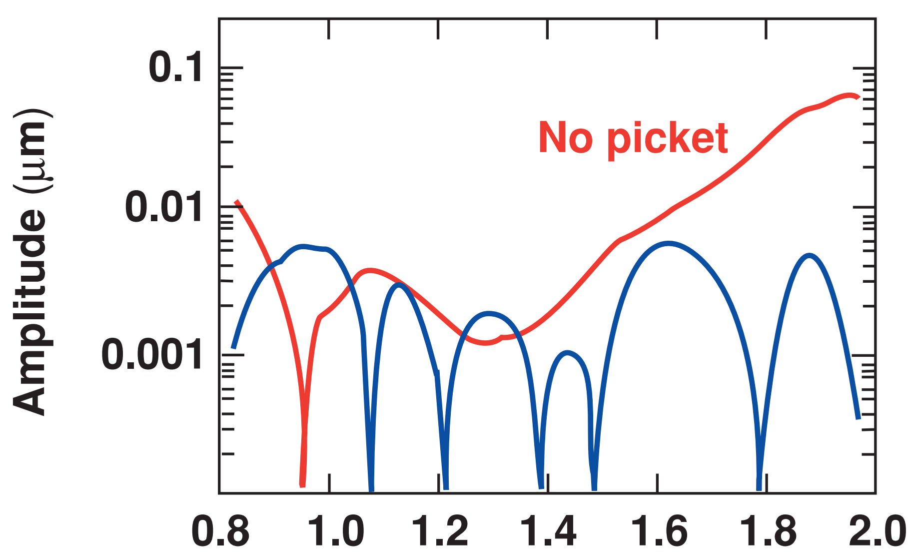
TC5955

Mode ℓ = 300 is totally stabilized in the picket design

Theoretical prediction[1]



ORCHID simulation (ℓ = 300)

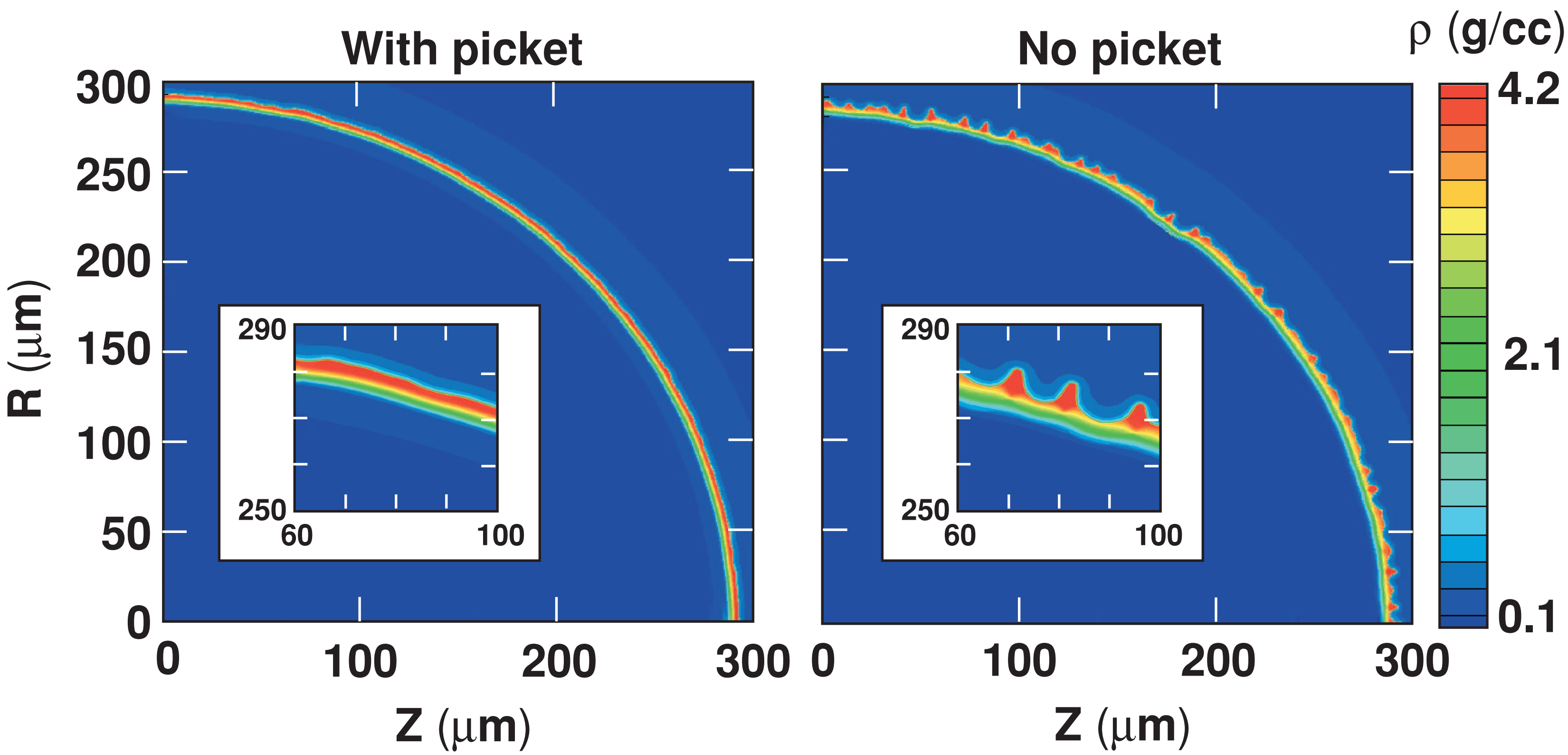


[1] R. Betti *et al.*, Phys. Plasmas 5, 1446 (1998).

TC5999

Multimode *ORCHID* simulations demonstrate better stability of the shaped-adiabat design

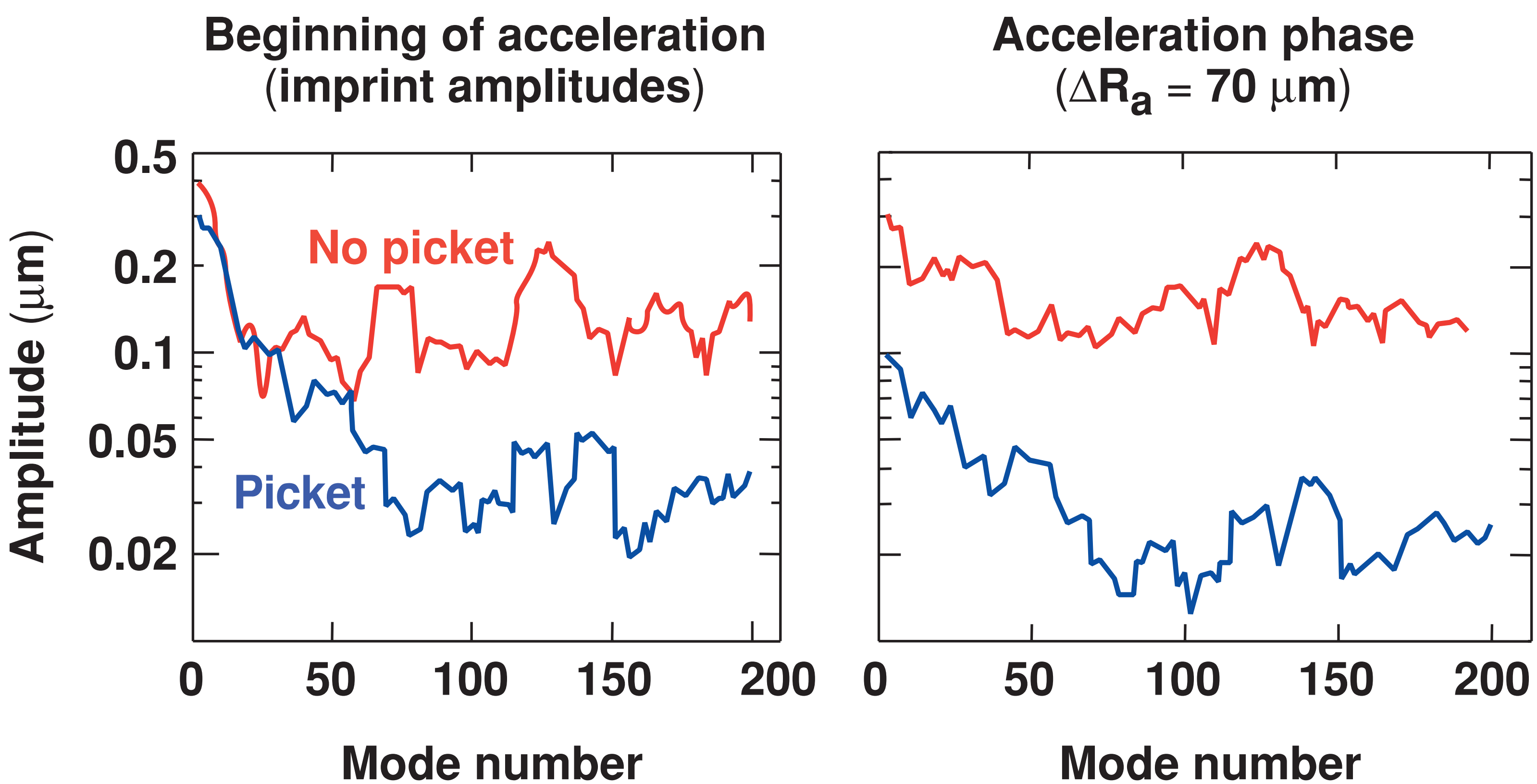
Imprint simulations: ℓ = 2–200, DPP + PS, 1-THz SSD; OMEGA design



Shell is significantly less distorted in the picket design.

TC5957

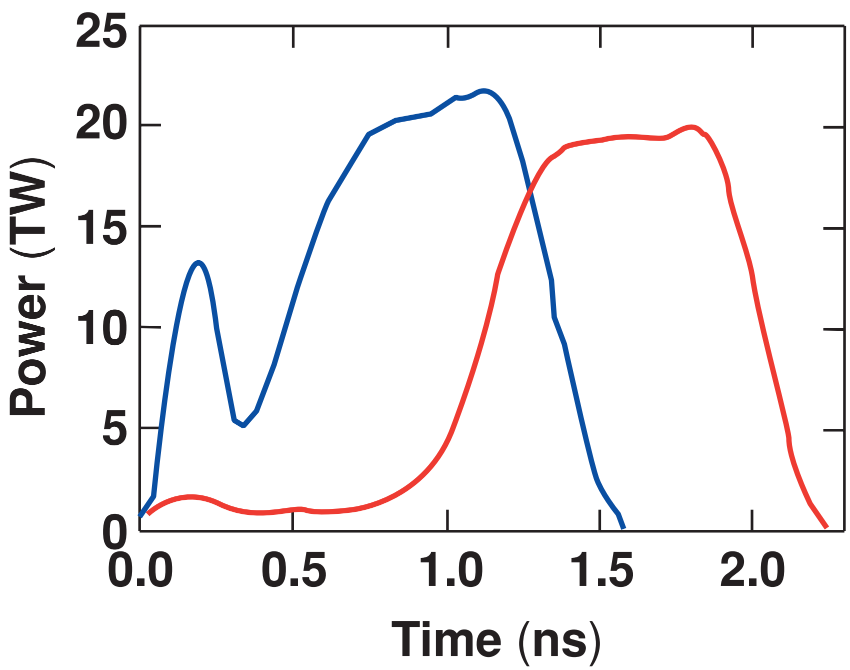
Mode decomposition shows the effect of the picket on the imprint amplitudes and growth rates

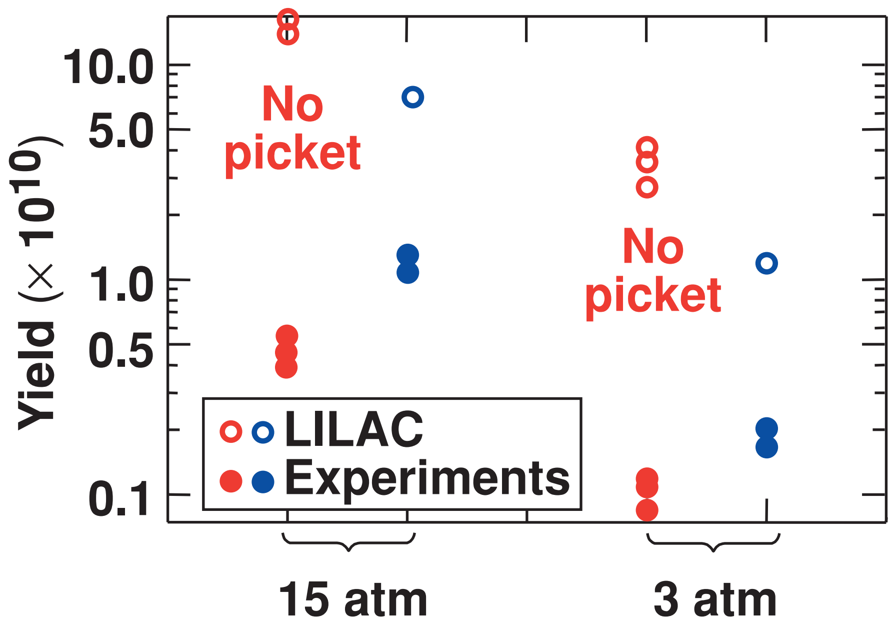


TC5958

The stabilizing effect of the adiabat shaping was studied experimentally using D_2-filled plastic shells[1]

$\alpha = 2$, 33-μm-CH shells filled with 3 atm and 15 atm D_2 gas





Y_{exp} / $Y_{1\text{-}D}$ (%)	4	18	3	15

TC5959

[1]For details see talk FO2.012 by J. Knauer

Summary/Conclusions

Adiabat shaping produced by an intensity picket significantly improves target stability

- A technique is proposed to reduce the perturbation growth without compromising the target yield.
- Shaping the adiabat of the main fuel and ablator reduces both seeding and the growth of the Rayleigh–Taylor instability.
- The adiabat is shaped using an intensity picket that launches a decaying shock into the shell.
- The shock places the outer portion of the shell (ablator) on the higher adiabat, keeping the inner part (main fuel) on the lower adiabat.
- The stabilizing effect of the adiabat shaping is confirmed both theoretically and experimentally.