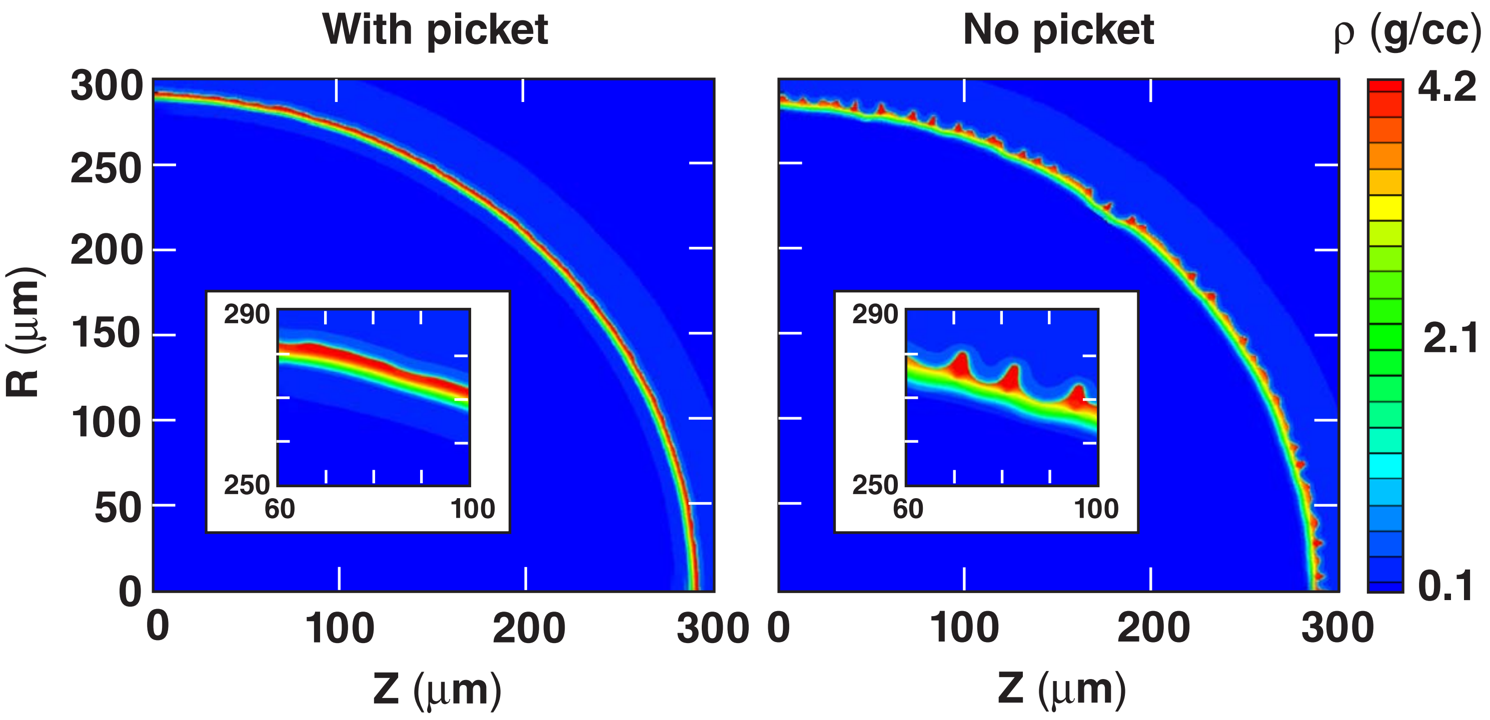
Improved Target Stability Using Picket Pulses to Increase and Shape the Ablator Adiabat



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Summary

Pickets coupled to low-adiabat drive reduce both imprinting and perturbation growth

- Shell-adiabat shaping has the potential to improve target stability without significantly increasing the energy needed for compression.
- Planar experiments with pickets
  - Low-intensity picket reduces growth for 20-μm perturbations.
  - High-intensity picket stabilizes 20-μm perturbations.
  - Picket pulses were as effective as 1-D, 1.5-Å SSD at the reduction of short-wavelength imprinting.
- Spherical target experiments with pickets
  - A decaying shock-wave picket increases both absolute and normalized yields.
  - A relaxation picket increases experimental yield.
- Simulations show the performance of cryogenic implosions will improve with picket pulses.

Outline

Improved target stability using picket pulses to increase and shape the ablator adiabat

- Motivation for adiabat shaping

- Planar-target experiments
  - growth reduction
  - imprint reduction

- Spherical-target experiments
  - decaying shock-wave picket
  - relaxation picket

- Extension to cryogenic targets

A large ablation interface adiabat reduces RT growth and a small interior adiabat minimizes compression energy

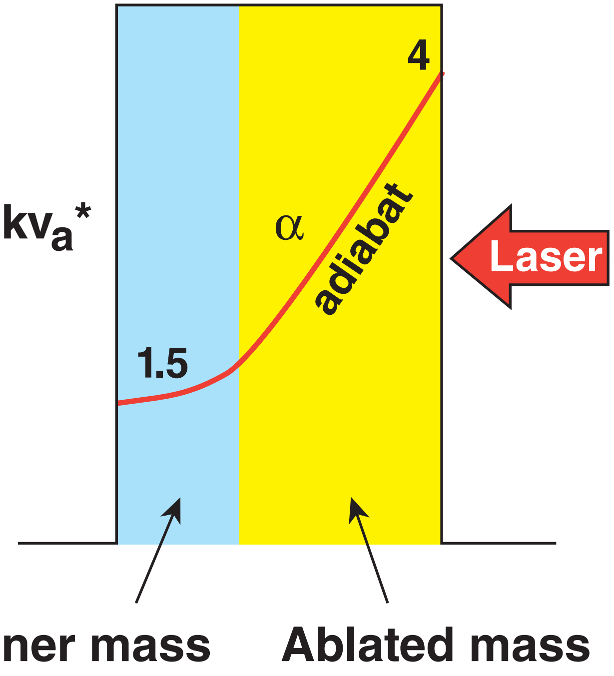
$$\alpha \equiv \frac{P}{P_{\text{Fermi}}} \rightarrow \alpha_{DT} = \frac{P(\text{Mb})}{2.2\left[\rho\left(\text{g/cm}^3\right)\right]^{5/3}}$$

$\gamma_{DT} = \sqrt{A_T(L_0,\nu)kg - A_T^2(L_0,\nu)k^2 v_a v_{bo}} - (1 + A_T(L_0,\nu))kv_a$ *

$$v_a \propto \alpha_{\text{ablation}}^{3/5}$$

$E_{\text{ignition}} \propto \alpha_{\text{inner}}^{1.9\ (2.4)}$ **

Shell at start of acceleration



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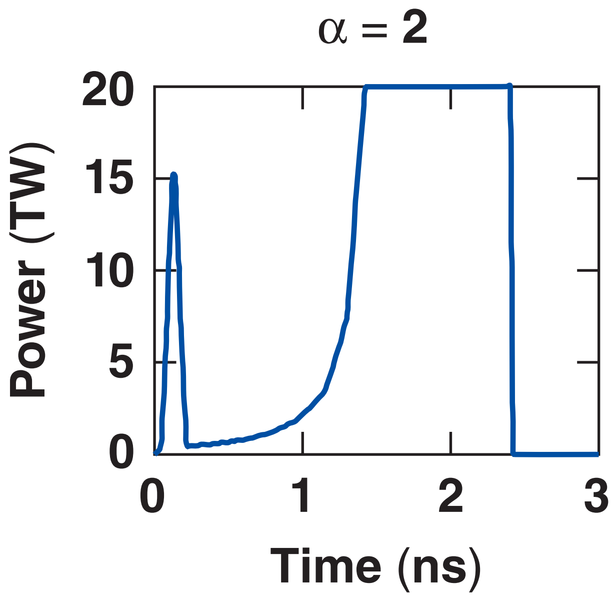
[*] R. Betti *et al*., Phys. Plasmas 5, 1446 (1998).

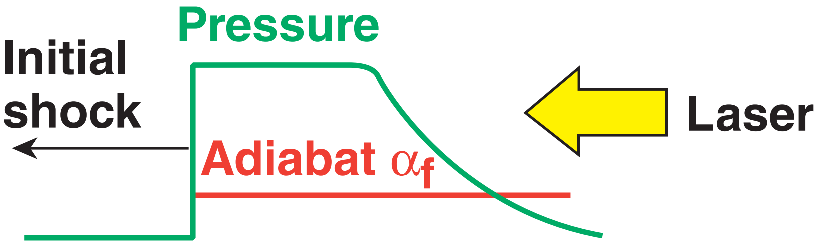
[**] M. C. Hermann *et al*., Nucl. Fusion 41, 99 (2001).
R. Betti *et al*., Phys. Plasmas 9, 2277 (2002).

Adiabat shaping is achieved using a high-intensity picket to create a decaying shock wave[1]

$$\alpha = \frac{P(\text{Mb})}{2.2\rho\left(\text{g/cm}^3\right)^{5/3}}$$



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

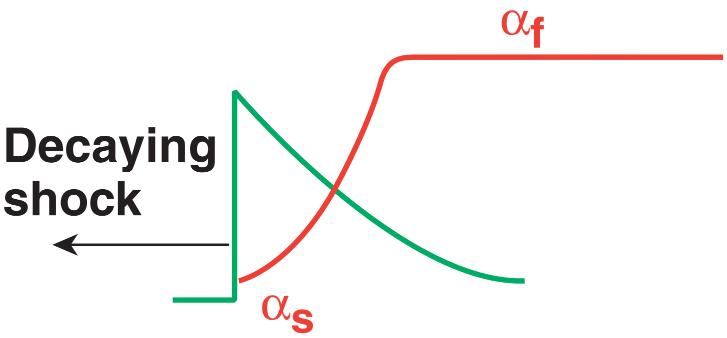

Initial shock

Pressure

Adiabat α_f

Laser

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


α_f

Decaying shock

α_s

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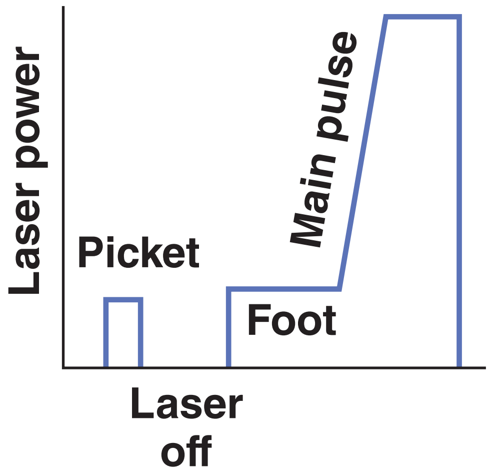
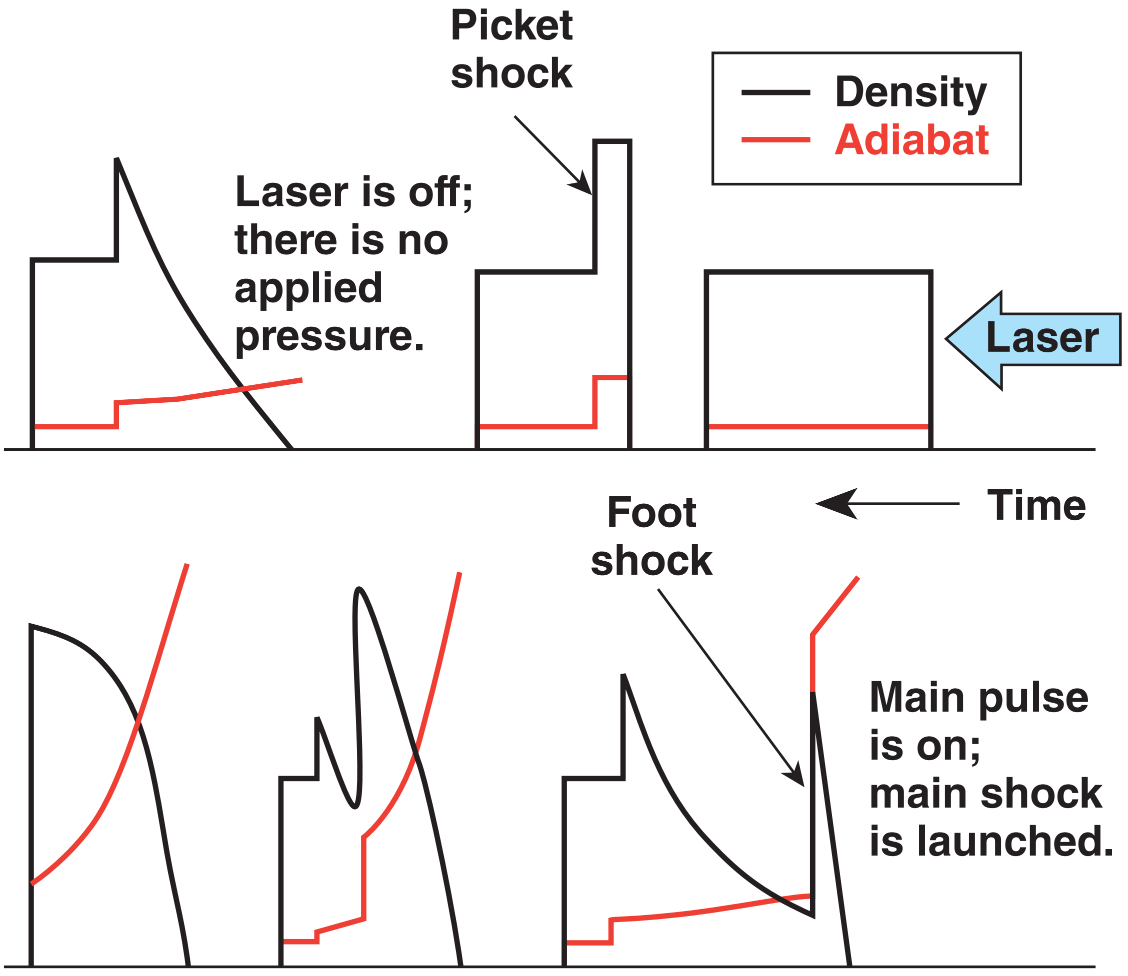
[1] V. N. Goncharov *et al.*, Phys. Plasmas 10, 1906 (2003).
K. Anderson and R. Betti, Phys. Plasmas 10, 4448 (2003).

The shock wave (from the main pulse foot) shapes the adiabat as it travels up a relaxed density profile[1]

$$\alpha = \frac{P(\mathrm{Mb})}{2.2\,\rho\left(\mathrm{g/cm^3}\right)^{5/3}}$$





Laser is off; there is no applied pressure.

Main pulse is on; main shock is launched.

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[1] K. Anderson and R. Betti, Phys. Plasmas 11, 5 (2004).

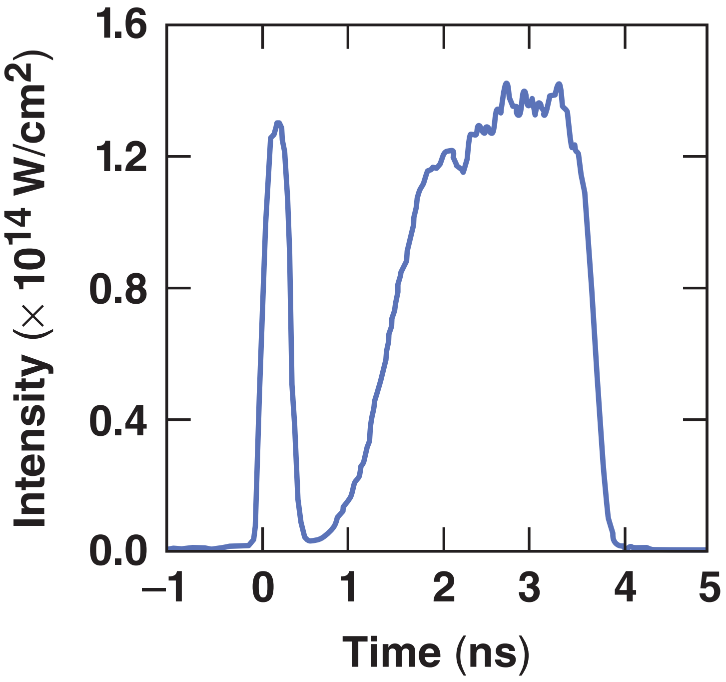
Perturbation growth at the ablation interface was measured for three wavelengths

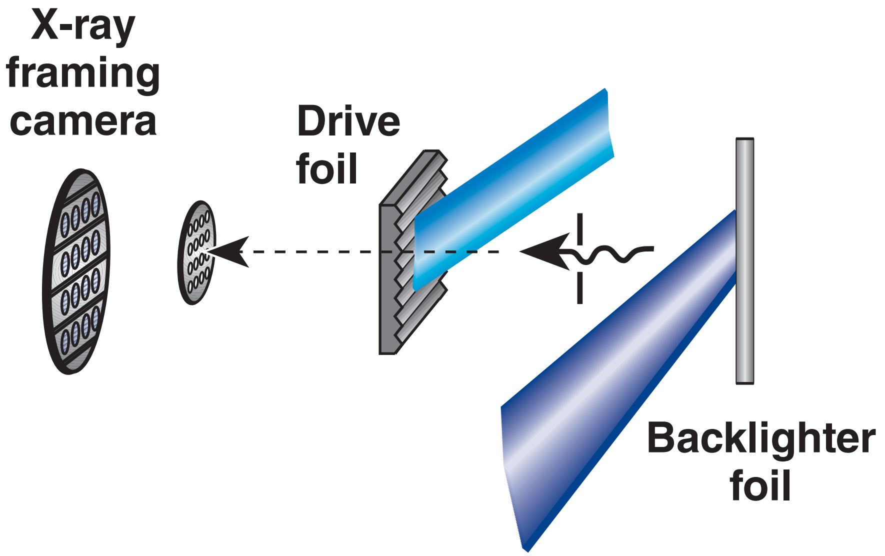
Picket pulse

$\langle I_p \rangle$ = 0.7 to 1.4 × 10^{14} W/cm^2

$\langle$FWHM$\rangle$ = 0.30 ns

$\langle$separation$\rangle$ = 1.9 ns

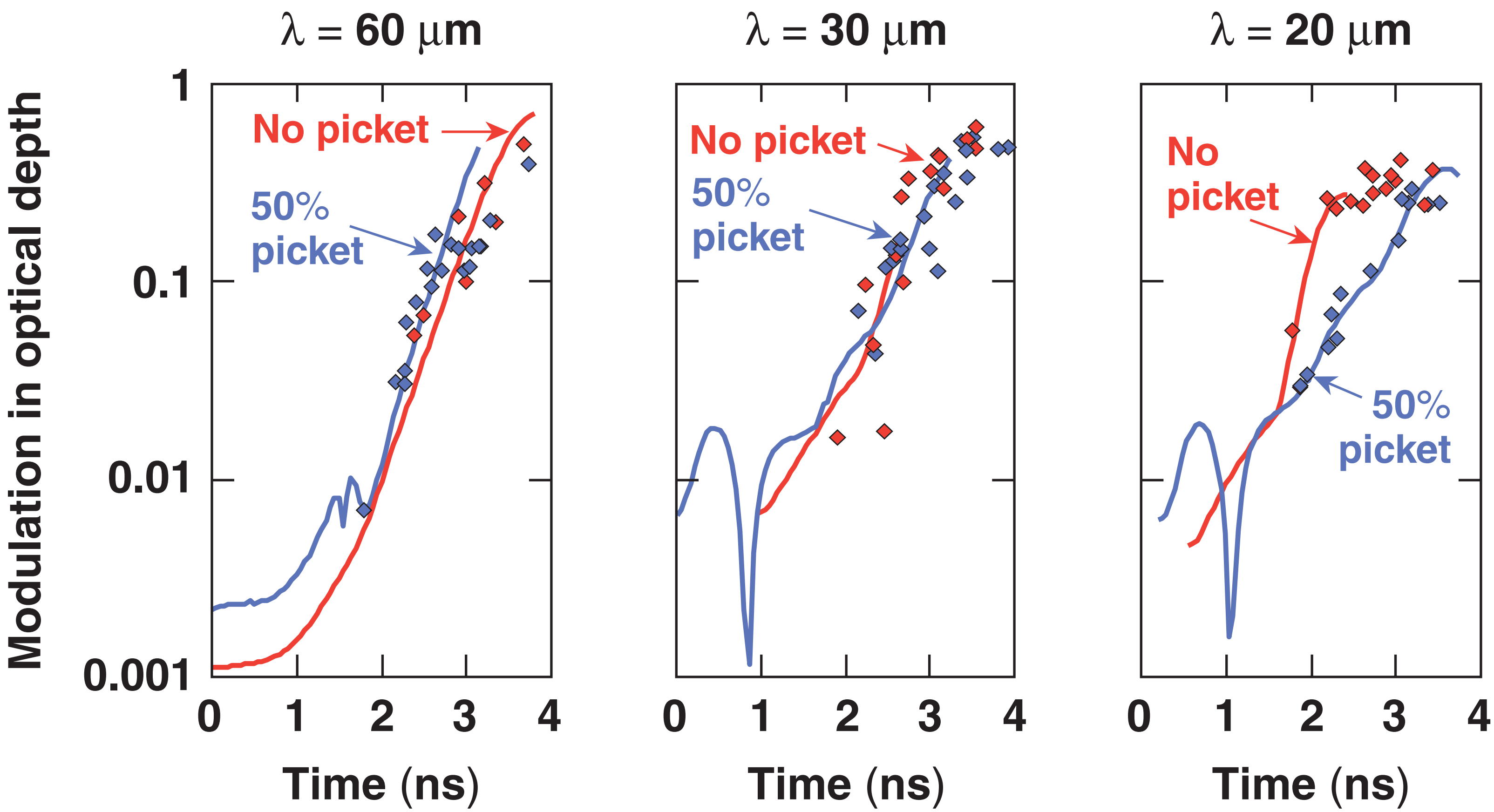




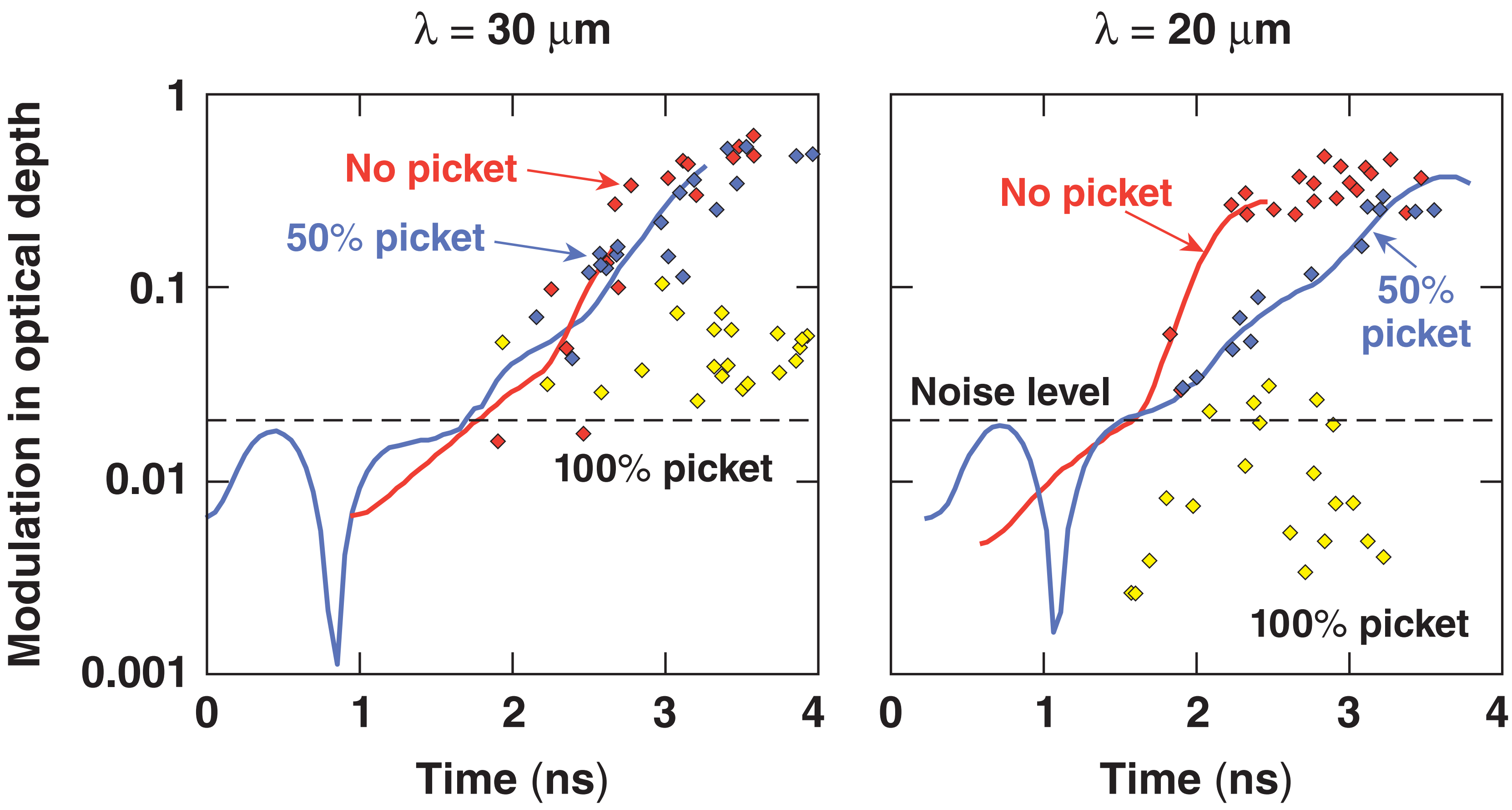
- 20-μm-thick CH targets
- Perturbation wavelengths were 60 μm, 30 μm, and 20 μm

E10652a

Pickets with an intensity of 50% of the drive pulse show reduced growth for 20-μm perturbations

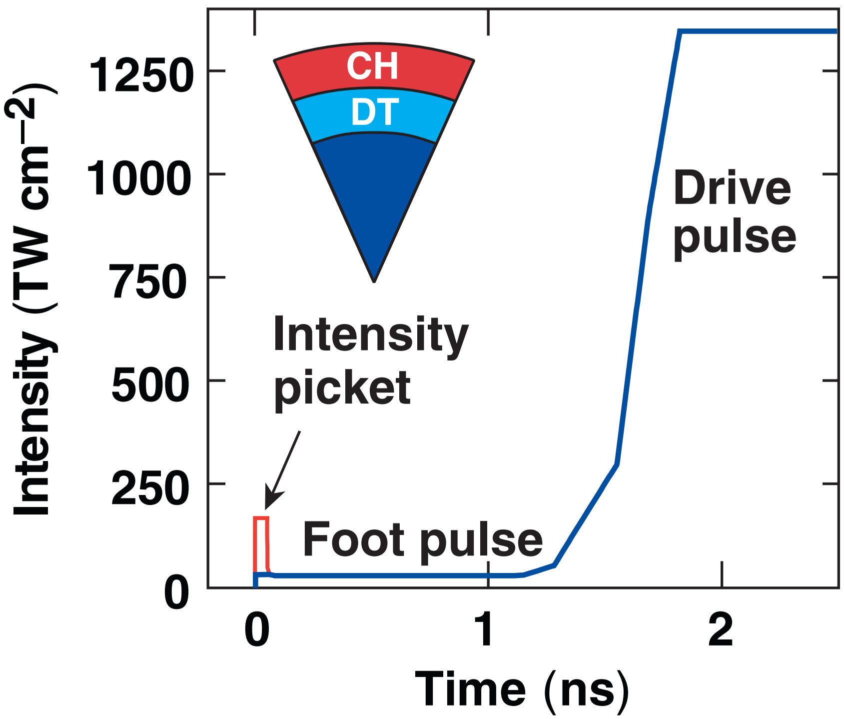


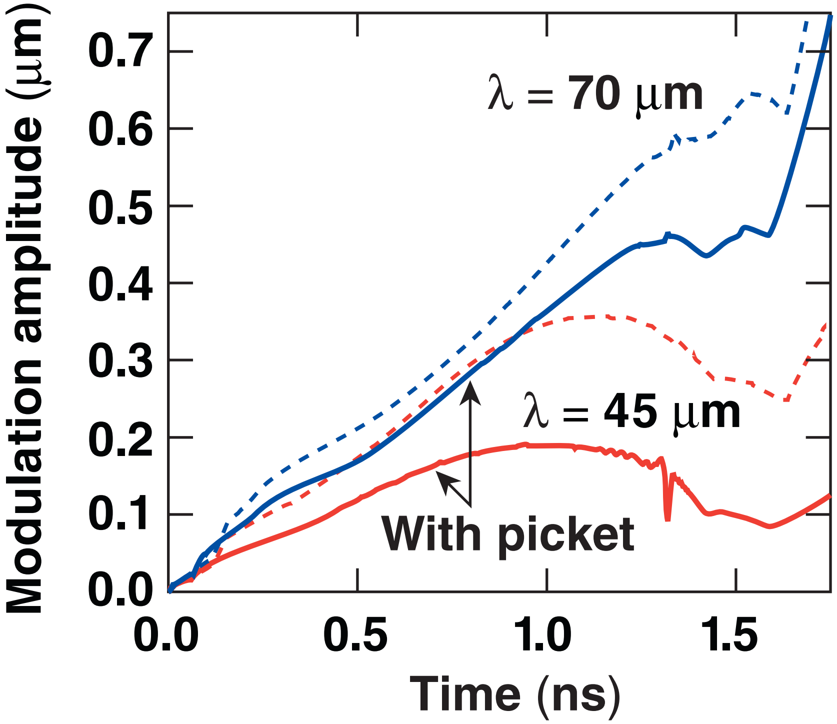
Pickets with an intensity of 100% of the drive pulse show reduced growth for both 30- and 20-μm perturbations



A brief high-intensity picket at the start of the foot pulse reduces imprint[1]

- Imprint reduction is greater for shorter wavelengths





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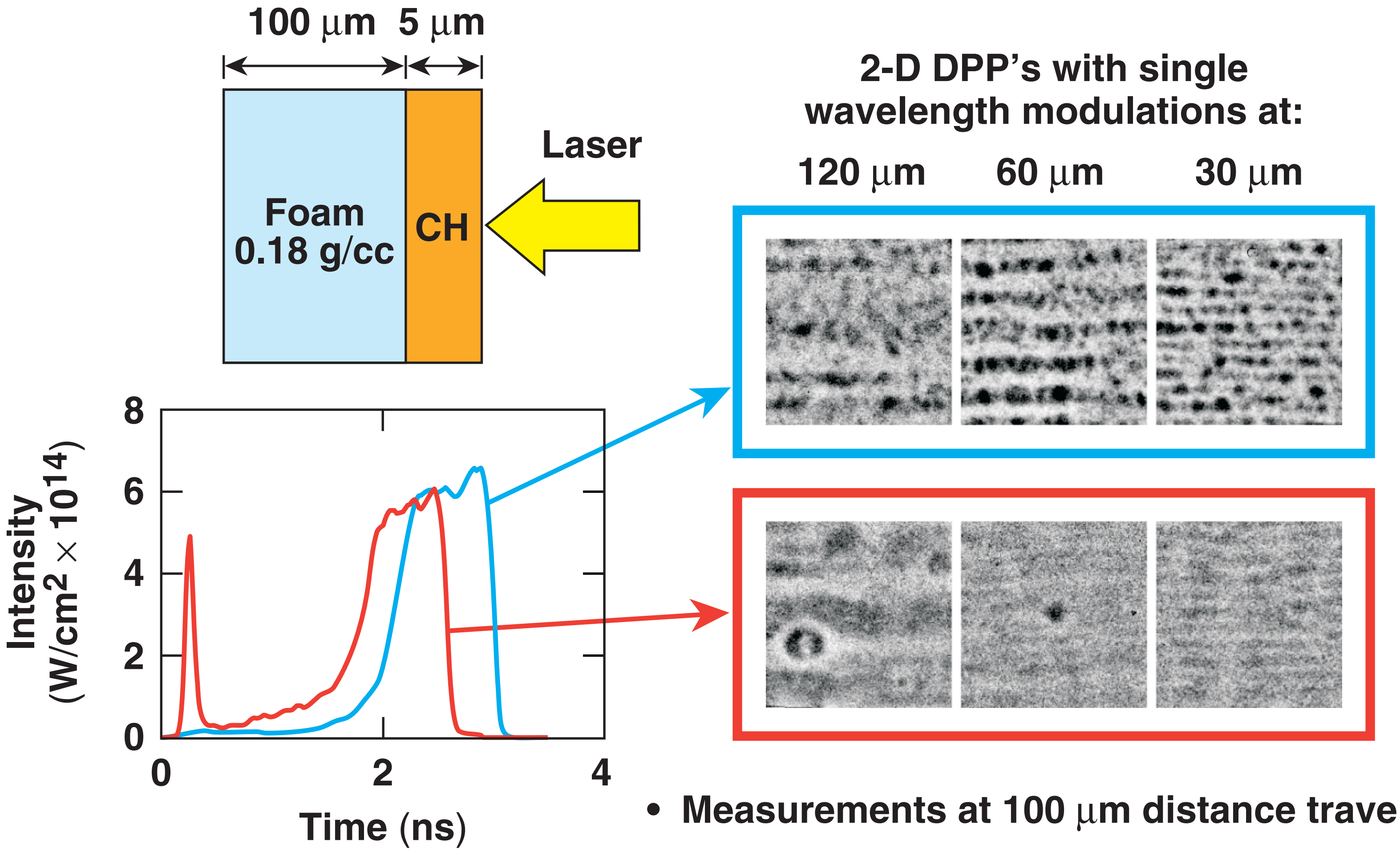
[1] T. J. B. Collins and S. Skupsky, Phys. Plasmas 9, 225 (2002).

TC5499a

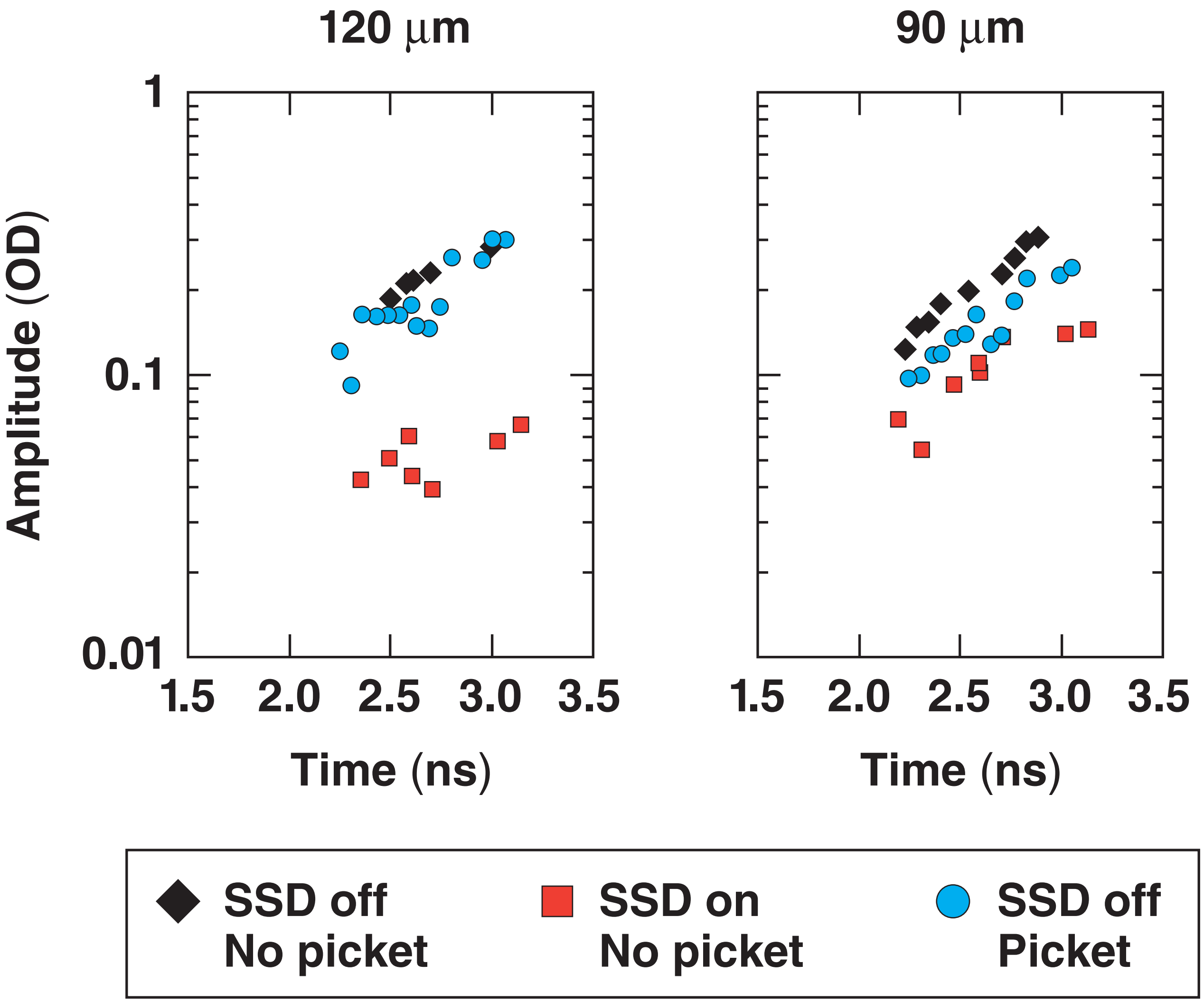
Measured radiographs show significant imprint reduction with picket pulses



- Measurements at 100 µm distance traveled.

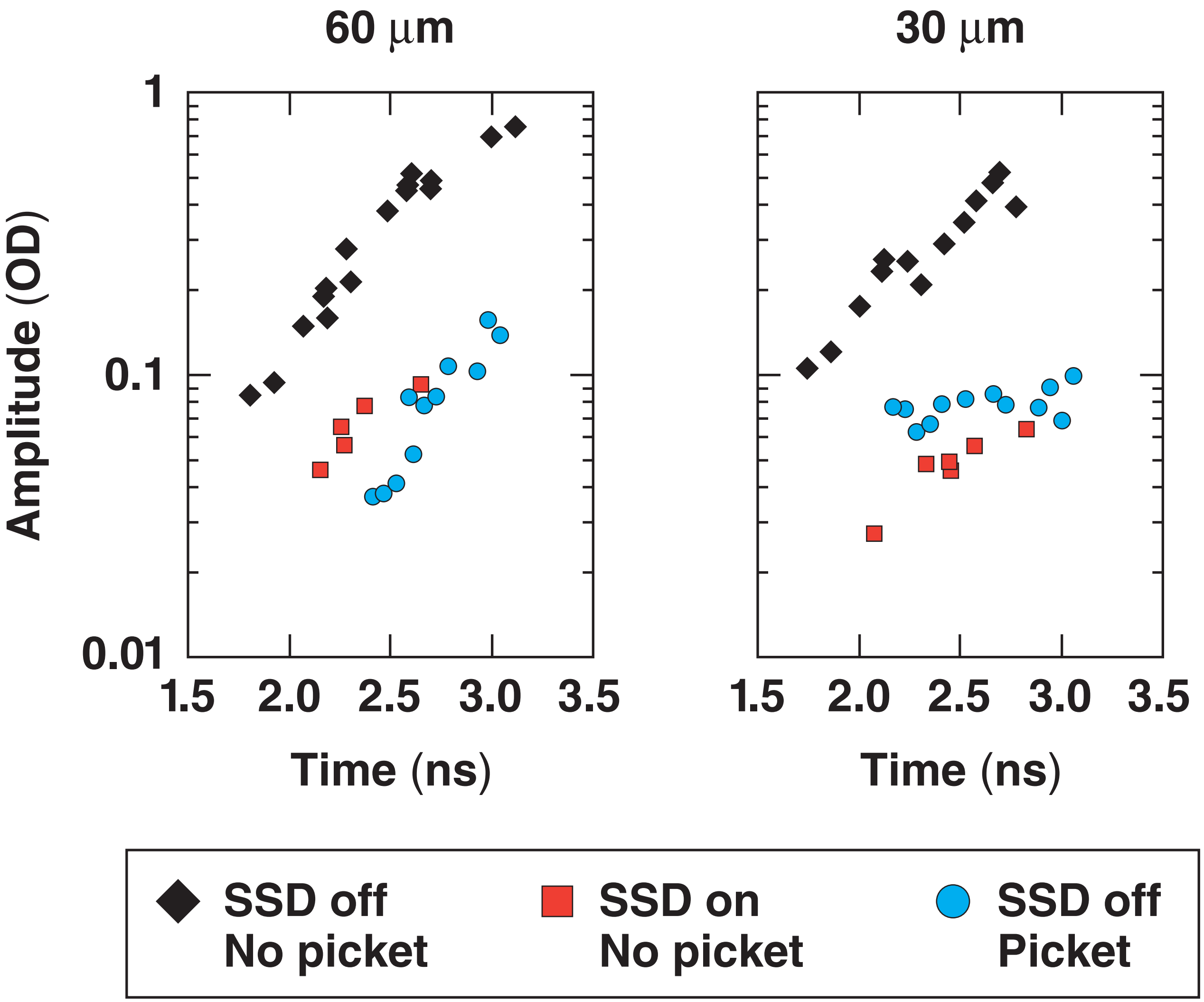
See V. Smalyuk JO1.005 this conference.

Little reduction in imprinting is seen for long-wavelength perturbations with a picket pulse



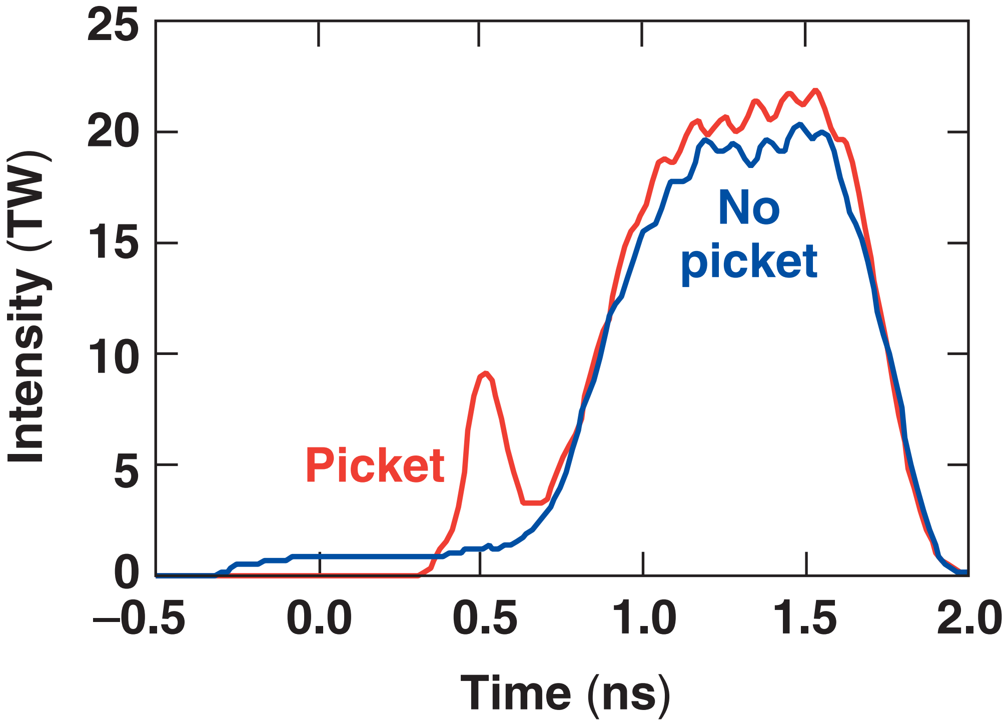
E13358

The picket is as effective as 1-D, 1.5-Å SSD at reducing the imprint for 60- and 30-μm wavelength perturbations



E13359

A picket pulse was added to a drive pulse that implodes a CH target

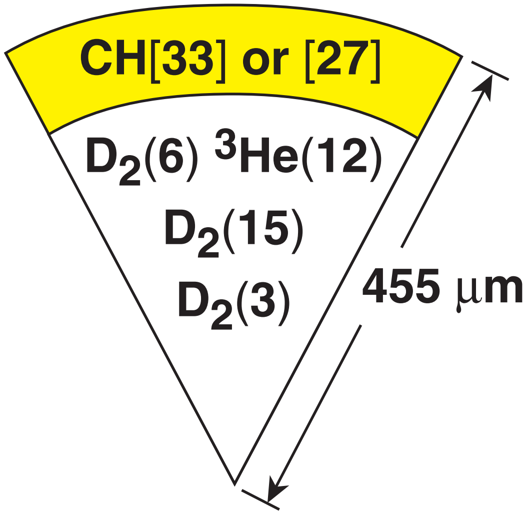


Picket pulse

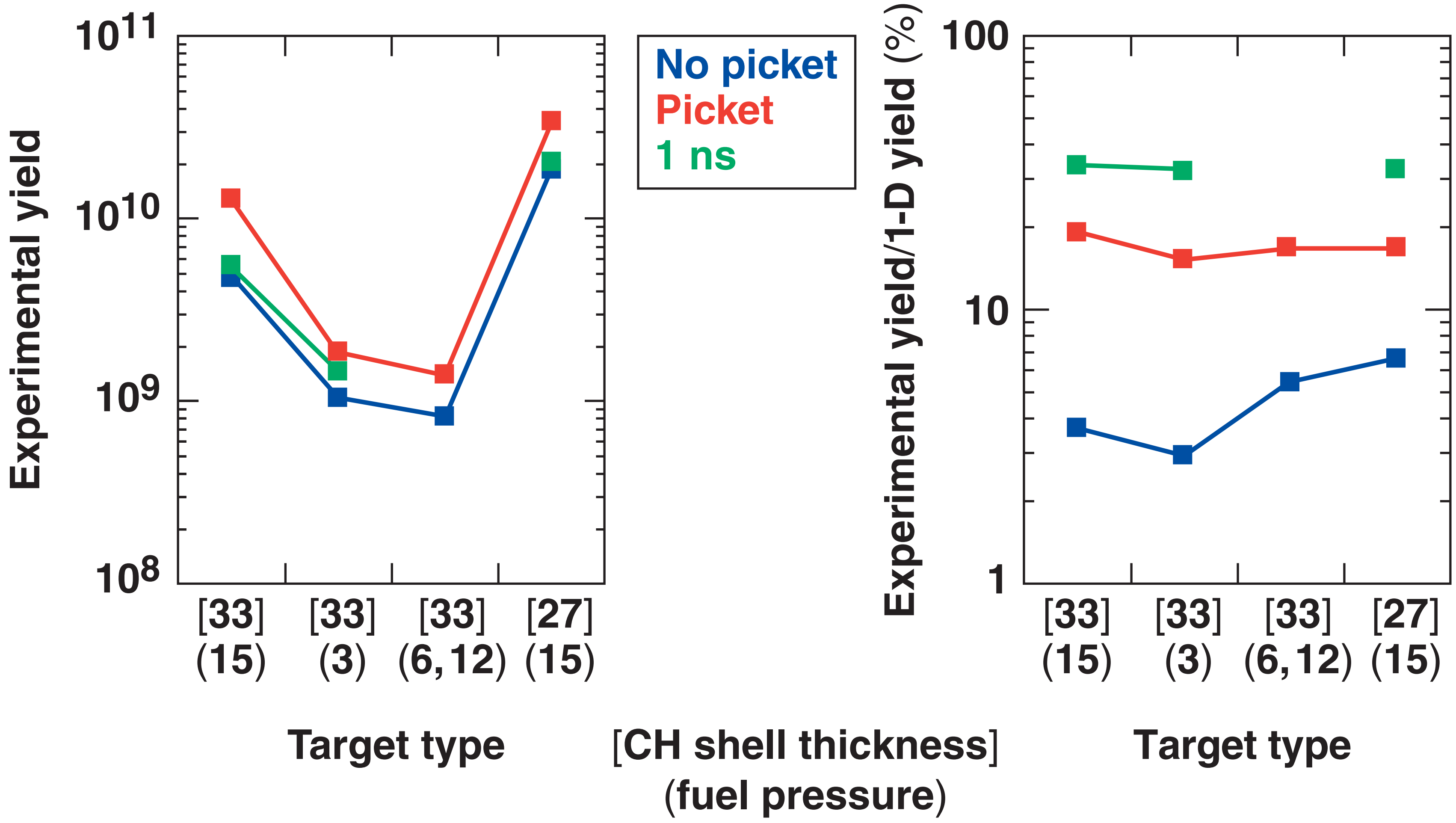
Width (FWHM) = 120 ps

Amplitude = 0.4 of drive

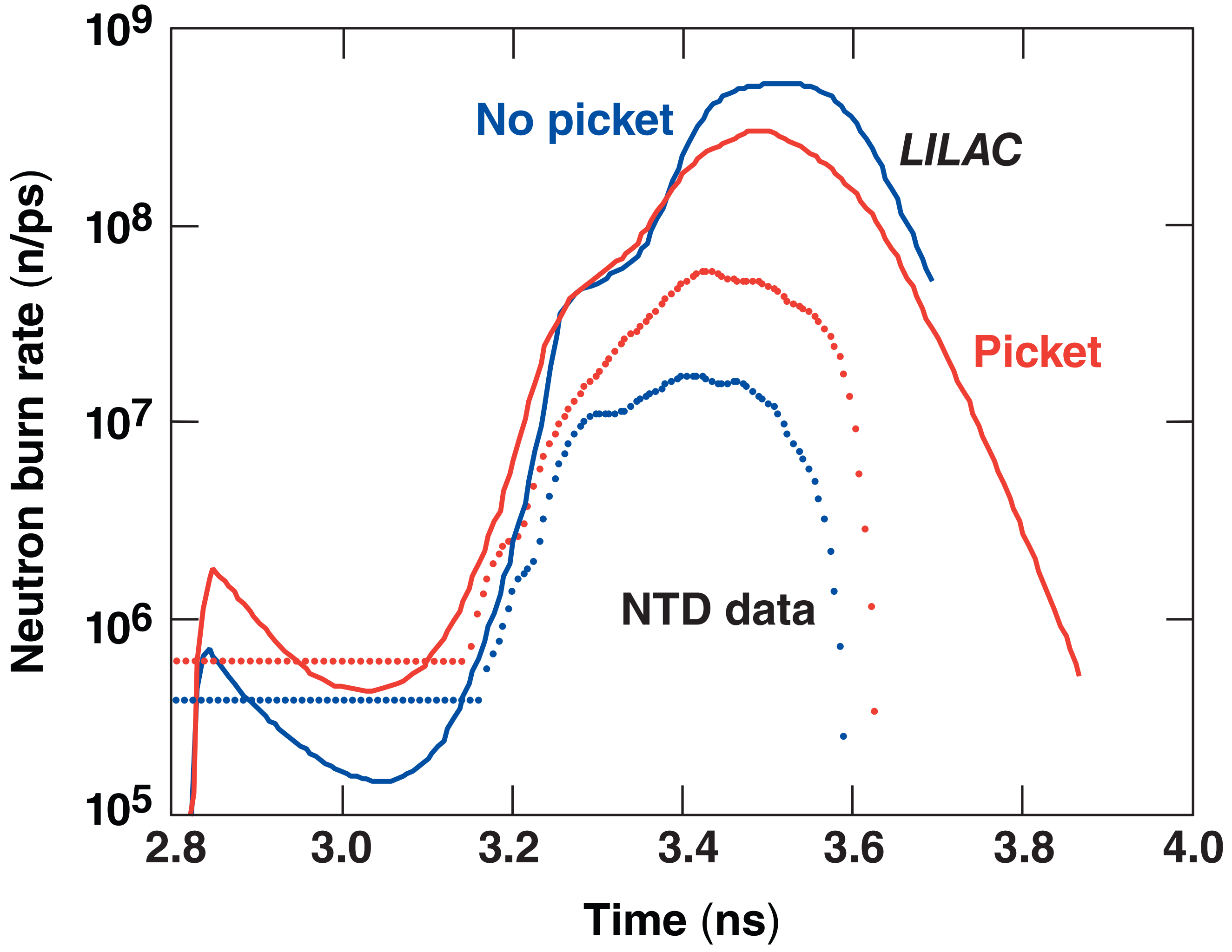
Position = 340 ps before drive



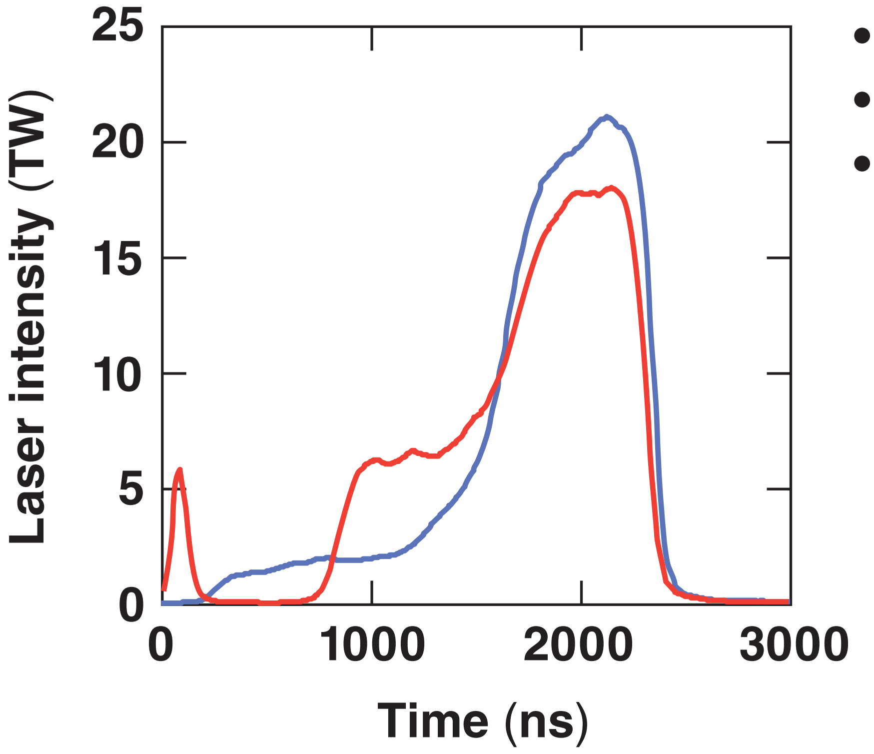
Both the experimental yield and the normalized yield increase when a picket pulse is used



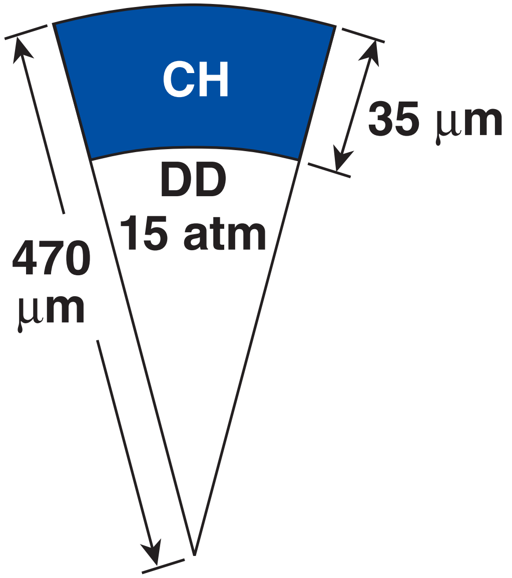
The neutron burn rate increases when a picket pulse is added to the drive pulse



A relaxation picket drive was designed for thick CH targets



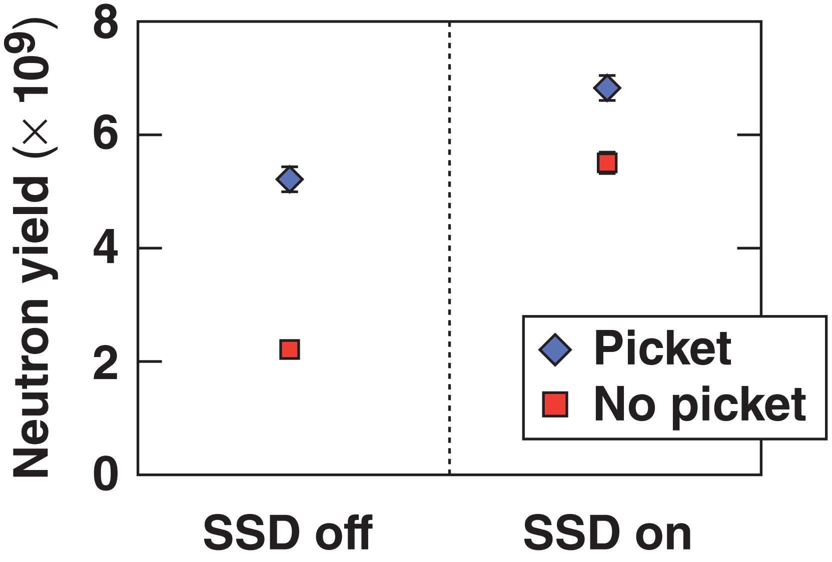
- Total laser energy: 18 kJ
- 6-TW, 60-ps Gaussian prepulse (RX)
- Contrast ratio of 2 in RX main pulse



See K. Anderson JO1.002 this conference.

Measured experimental yields increase when a relaxation (RX) picket is used

Relaxation picket pulse



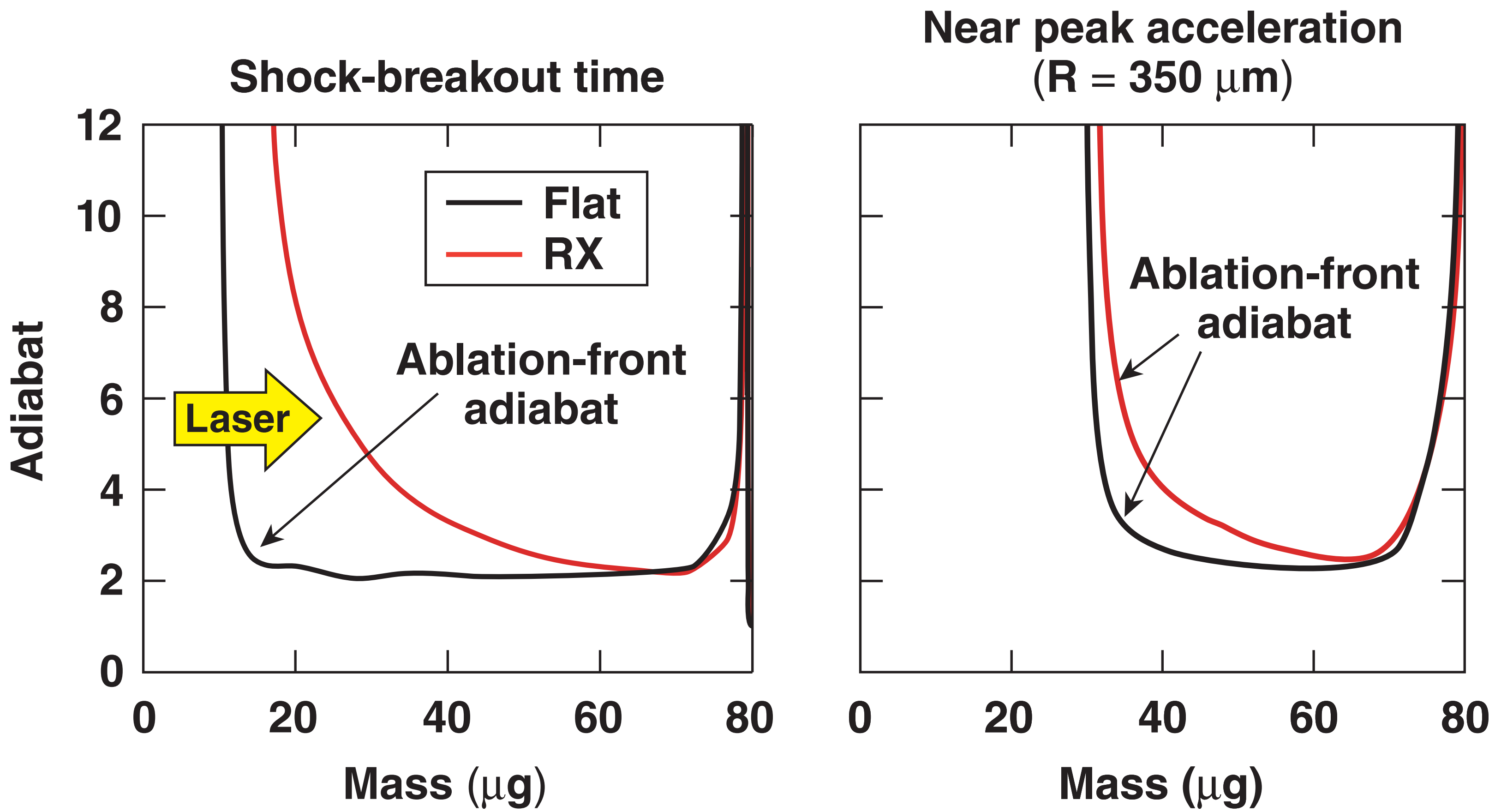
Laser energy very stable

E_{laser} = 17.3±0.2 kJ

	SSD off Yield (× 10^9)	SSD on Yield (× 10^9)
Picket	5.6±0.2	6.8±0.2
No picket	2.2±0.1	5.5±0.5

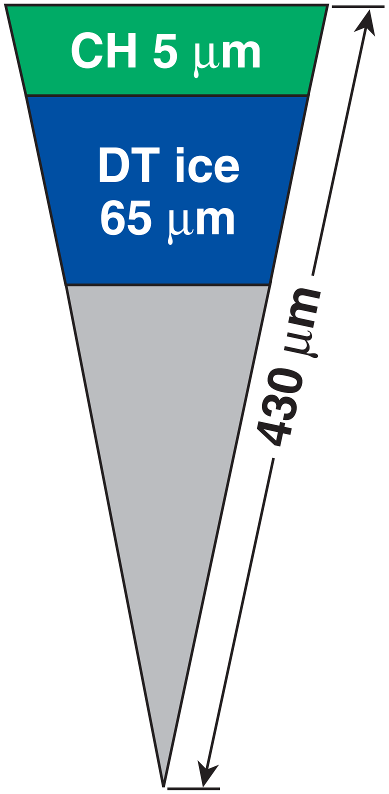
LILAC simulations indicate RX adiabat shaping is effective throughout the acceleration phase

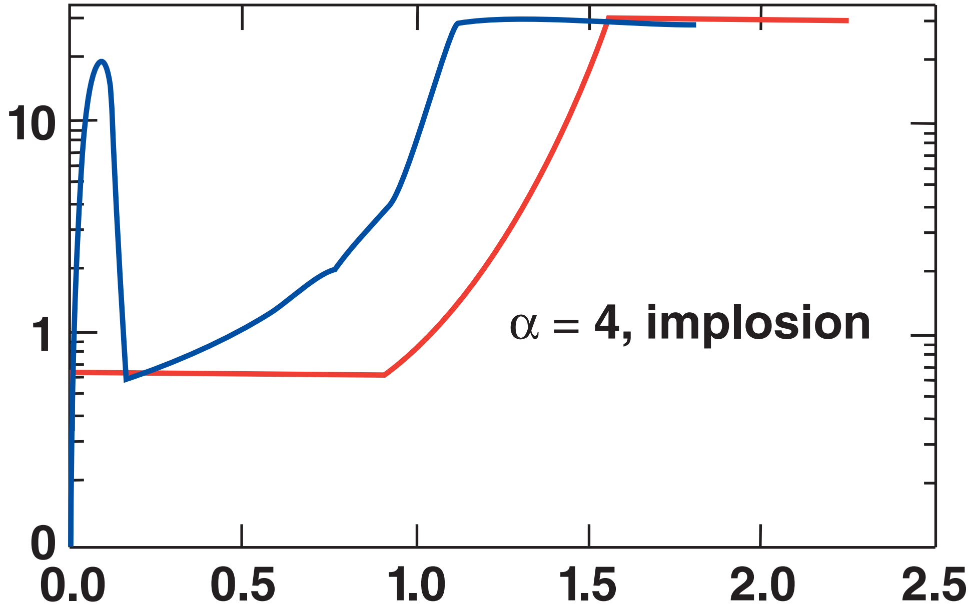
- RX shaping is significantly higher than "natural" radiative shaping.



TC6428a

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





1-D simulation	No picket	Picket
ρR (mg/cm^2)	330	305
Y ($\times 10^{14}$)	6.5	6
A_{bubble}/Th (%)[1]	>100	55

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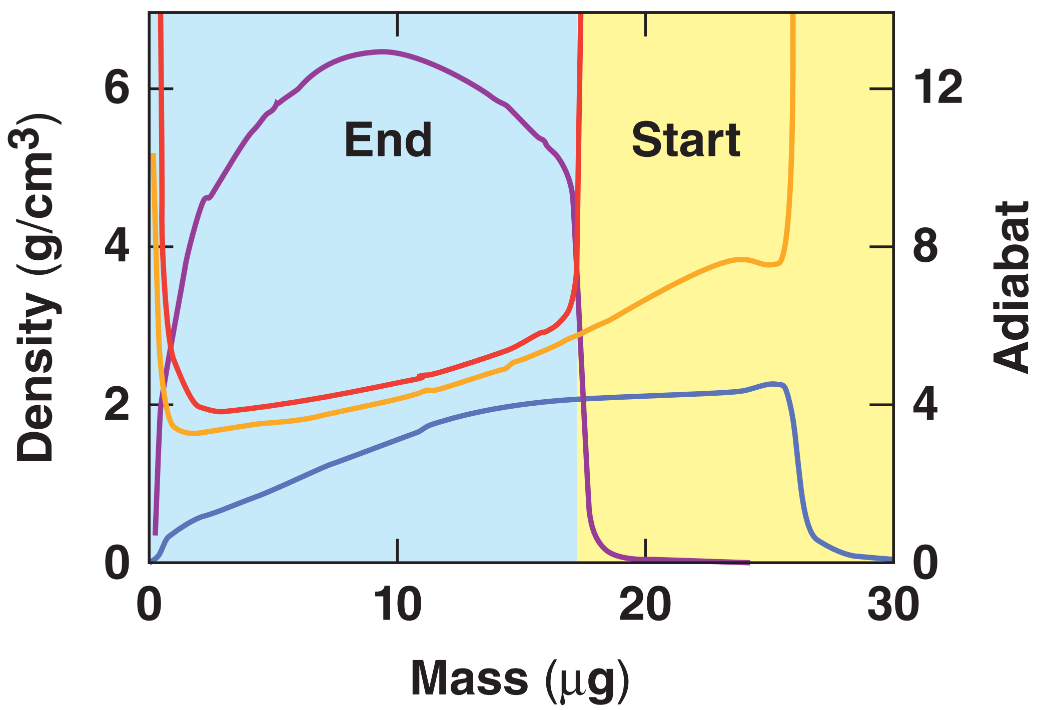
[1] V.N. Goncharov *et al.*, Phys. Plasmas 7, 5118 (2000).

A decaying shock wave picket shapes the shell adiabat at the start of acceleration

Decaying shock wave



Start of acceleration

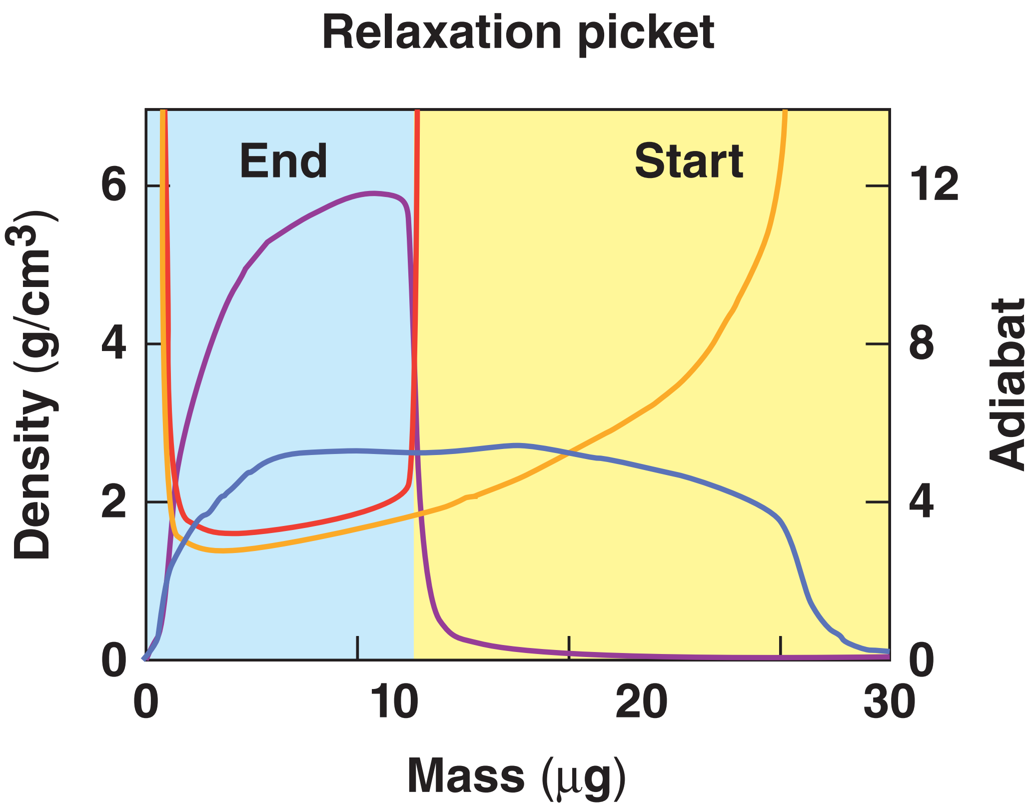
⟨Ablated⟩ adiabat = 8

⟨Inner⟩ adiabat = 5

End of acceleration

⟨Inner⟩ adiabat = 5

The relaxation picket shapes the adiabat of the shell at the onset of acceleration



Start of acceleration

⟨Ablated⟩ adiabat = 12

⟨Inner⟩ adiabat = 3

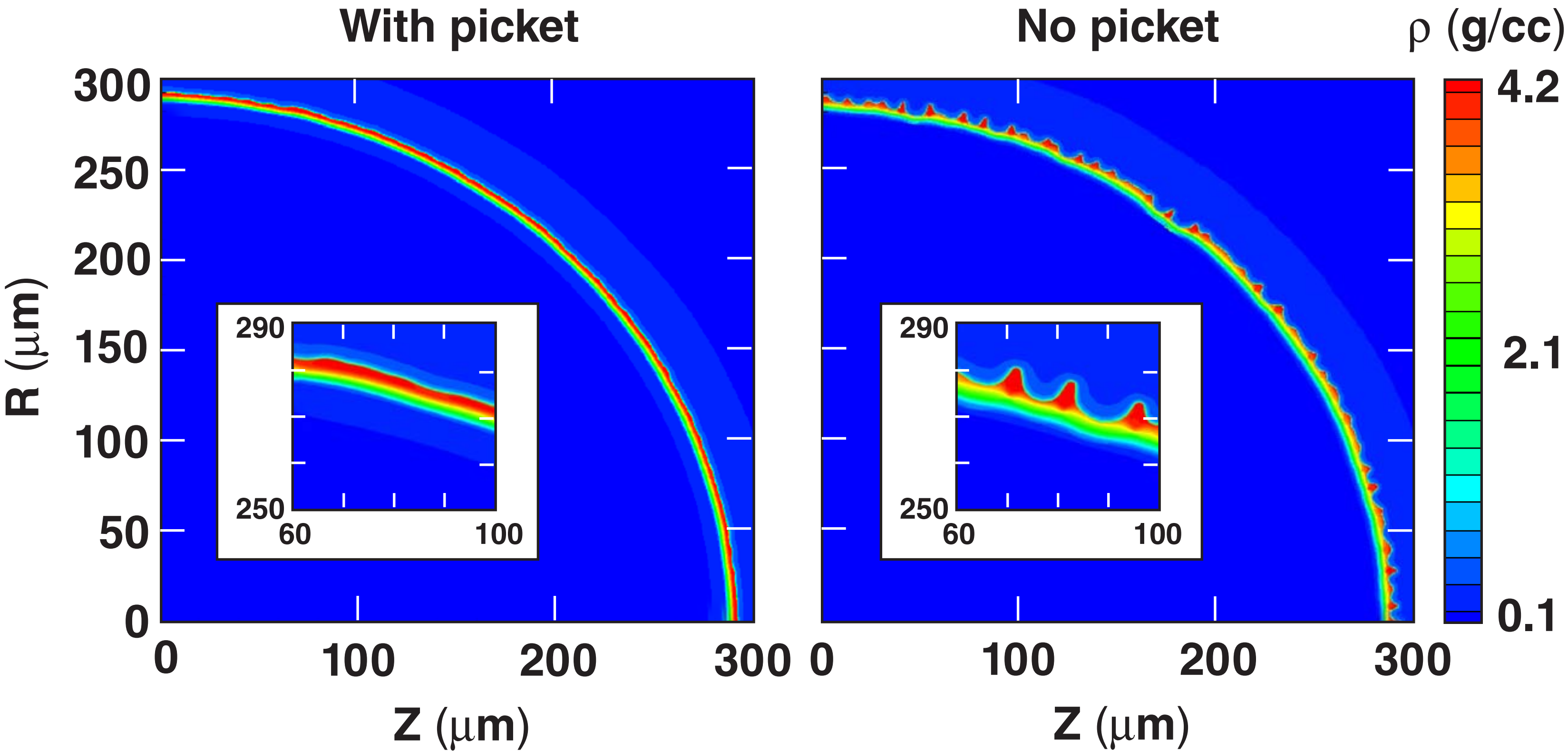
End of acceleration

⟨Inner⟩ adiabat = 4

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

Density contours at end of shell acceleration

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



Shell is significantly less distorted in the picket design.

TC5957

Summary/Conclusions

Pickets coupled to low-adiabat drive reduce both imprinting and perturbation growth

- Shell-adiabat shaping has the potential to improve target stability without significantly increasing the energy needed for compression.

- Planar experiments with pickets
  - Low-intensity picket reduces growth for 20-μm perturbations.
  - High-intensity picket stabilizes 20-μm perturbations.
  - Picket pulses were as effective as 1-D, 1.5-Å SSD at the reduction of short-wavelength imprinting.

- Spherical target experiments with pickets
  - A decaying shock-wave picket increases both absolute and normalized yields.
  - A relaxation picket increases experimental yield.

- Simulations show the performance of cryogenic implosions will improve with picket pulses.

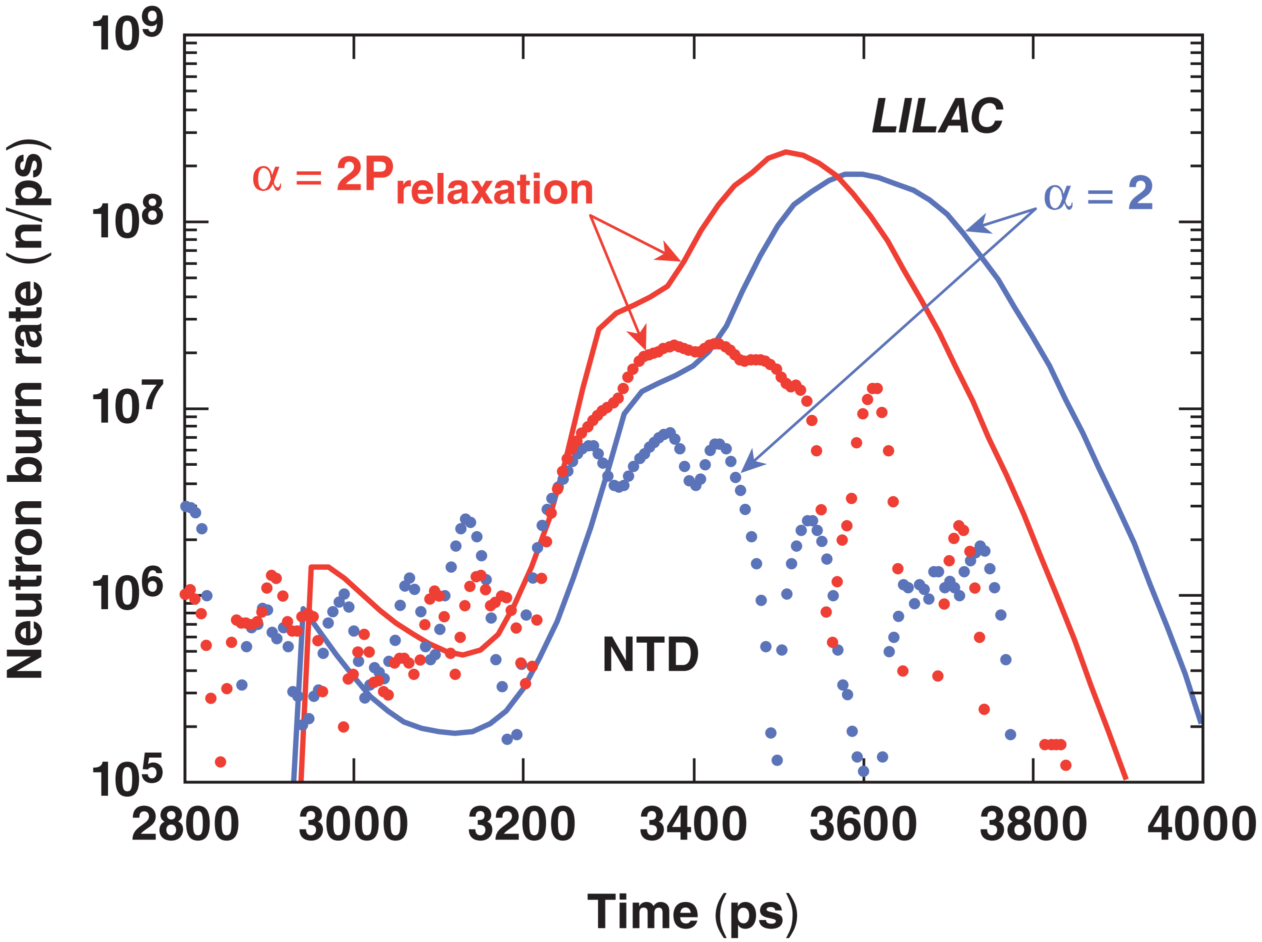
Picket-pulse shapes are not new to ICF, but LLE has studied the effect of a wide range of picket pulses

1975	J. D. Lindl and W. C. Mead: Improve target—performance improved when accelerated by a series of short laser pulses, "pickets". Attributed to impulsive acceleration
1980's	Work done at LLNL and LLE shows higher ablation front stability when a single picket is added to a low-adiabat drive pulse.
2003	T. J. B. Collins, *et al*.: Simulations demonstrate imprint reduction with a picket.
	V. N. Goncharov, *et al*.: Higher gain for NIF targets with "decaying shock wave" picket
	K. Anderson and R. Betti: Theory of "decaying shock wave" picket
2004	K. Anderson and R. Betti: Theory of "relaxation picket"

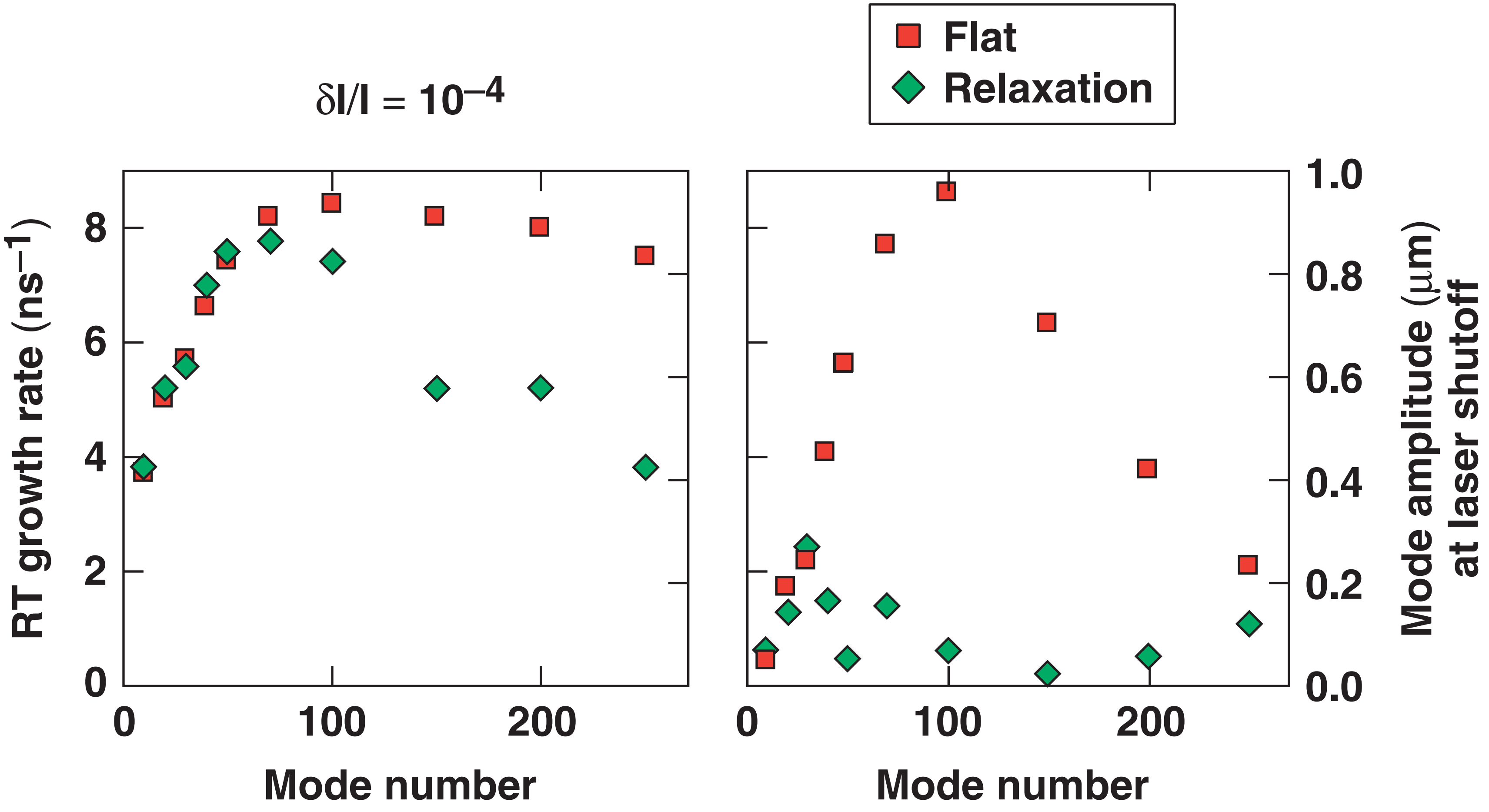
The first published work on adiabat shaping in the open literature used low-energy x ray absorption

1980’s	Work done at LLNL shows adiabat shaping in spherical targets
1991	J. H. Gardner, *et al*.: First published mention of adiabat shaping by absorption of low energy x rays
1999	L. Phillips, *et al*.: X-ray adiabat shaping target design with W-doped CH and wetted foam
2000	S. E. Bodner, *et al*.: X-ray adiabat shaping target design with thin Au layer and wetted foam
2003	V. N. Goncharov, *et al*.: Higher gain for NIF target due to adiabat shaping K. Anderson and R. Betti: Theory of “decaying shock wave” adiabat shaping
2004	K. Anderson and R. Betti: Theory of “relaxation picket” adiabat shaping

The neutron burn rate increased when the RX picket drive was used with SSD off



Single-mode 2-D simulations of imprint in DT cryo targets show reduced growth rates and lower perturbation mode amplitudes for RX designs

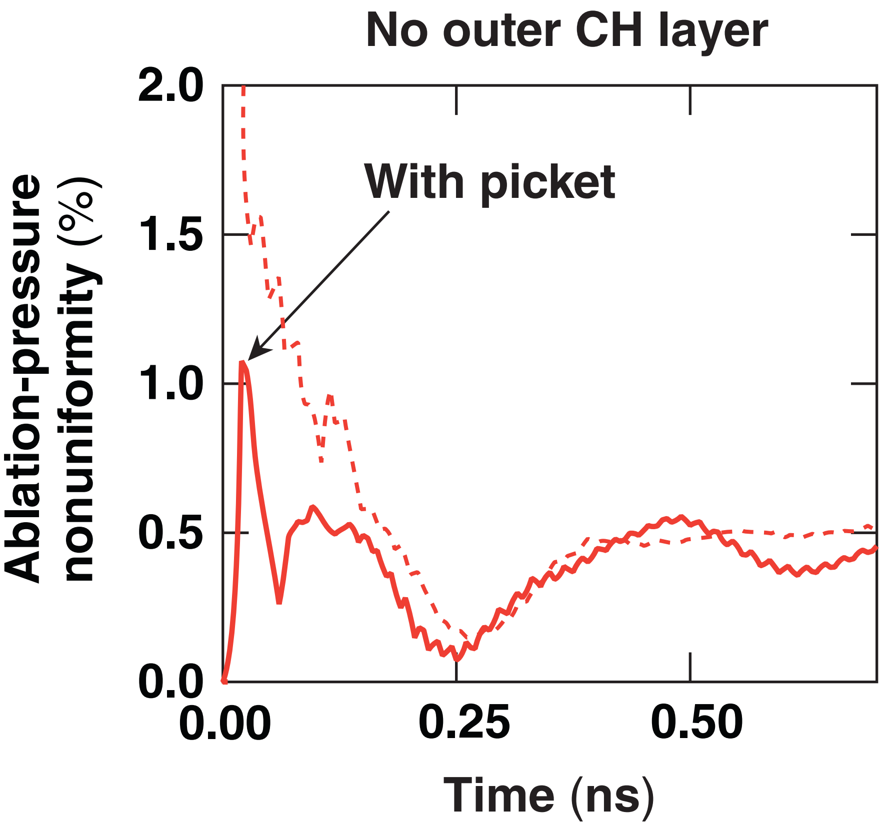


The intensity spike reduces the effects of CH layer

- The intensity spike
  - launches a stronger shock,
  - which reaches the CH/DT interface sooner,
  - and results in a greater post-shock sound speed;
  - the width of the compressed CH is less,
  - so the rarefaction waves returns sooner
  - and is shorter in duration.
- The spike reduces the early Rayleigh–Taylor growth.
- Rayleigh–Taylor growth starts at a lower amplitude.

The intensity picket reduces ablation pressure nonuniformity

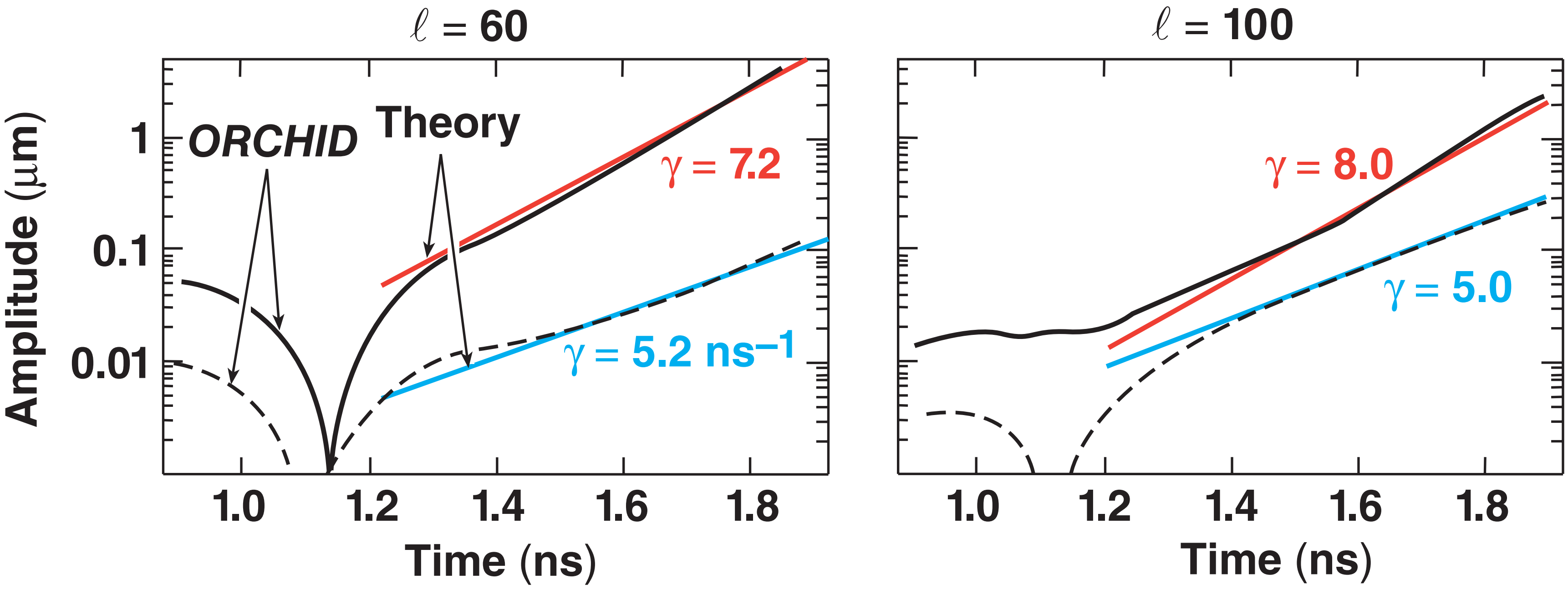
- Smoothing distance d_c between critical and ablation surfaces increases with laser intensity.
- Pressure nonuniformity decreases exponentially with smoothing distance.
- Thermal smoothing contributes to imprint reduction.



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

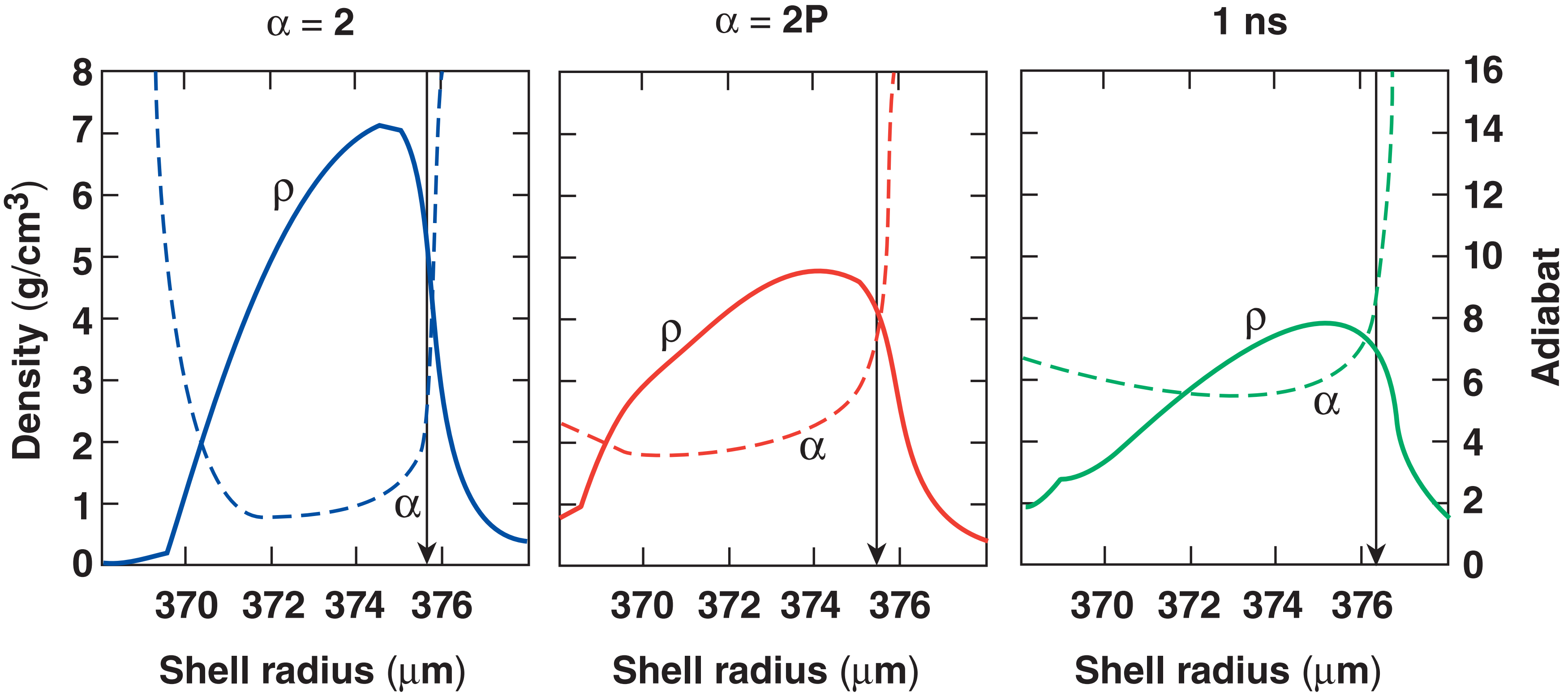


For DT foils:[2] $\gamma = 0.94\sqrt{kg} - 2.6\ kV_a$

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

TC5955

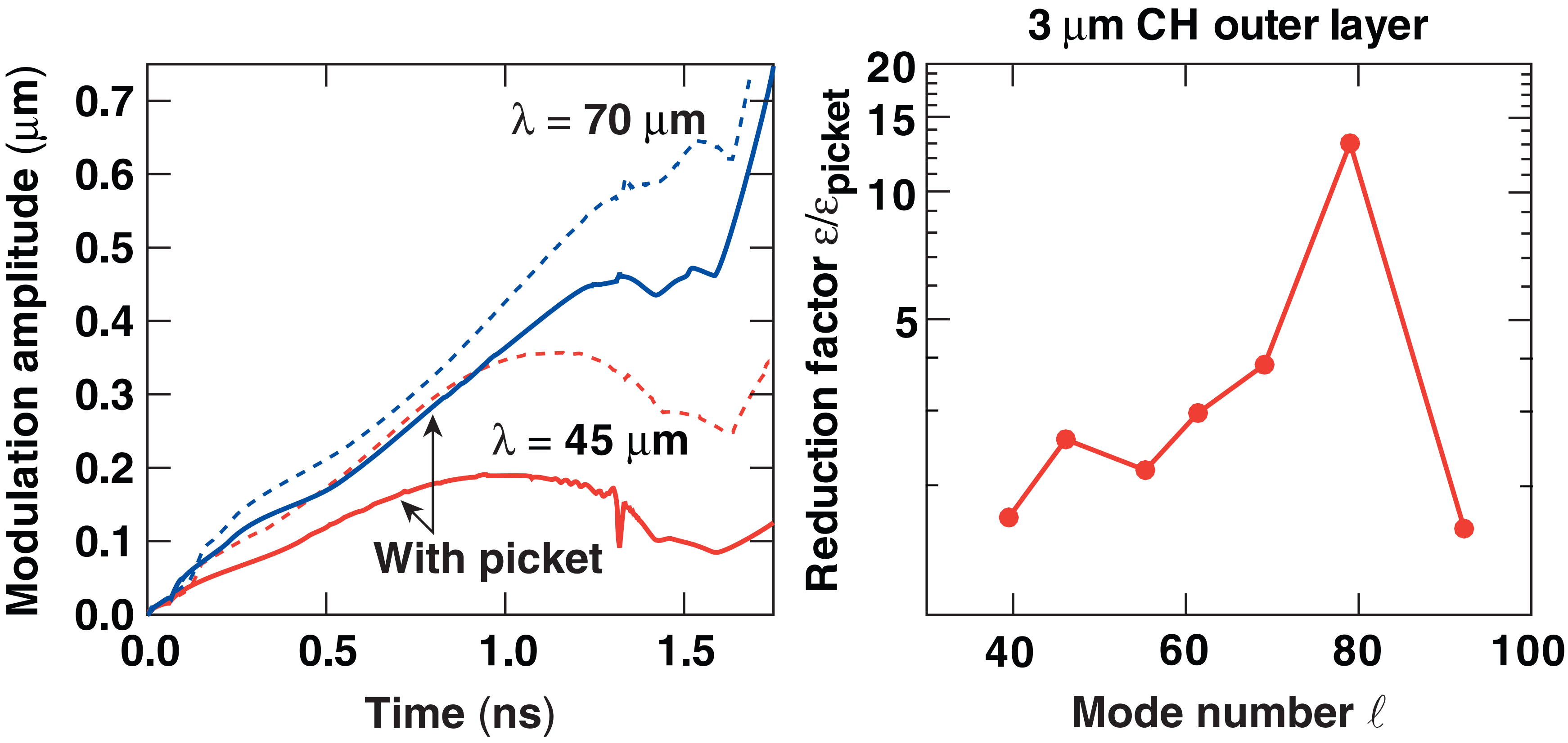
The adiabat at the ablation interface increases from 4 to 7 when a picket is added



E11908a

Imprint reduction is greater for shorter wavelengths

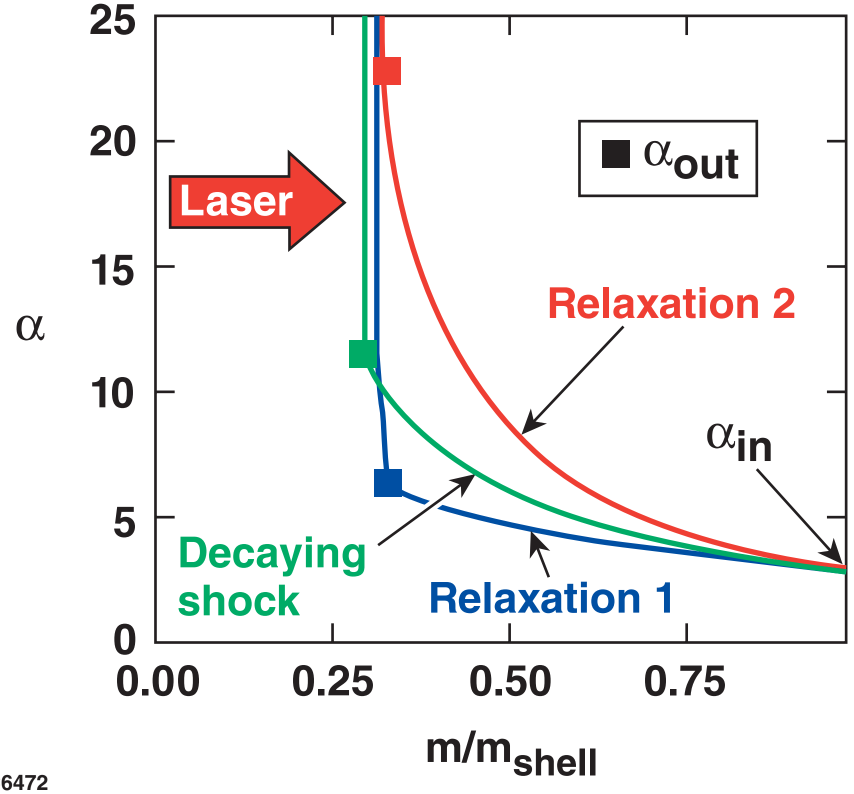
- Early-time growth is less for greater wavelengths.



TC5501a

Including the effects of finite shock strength and finite ablation leads to somewhat shallower adiabat profiles

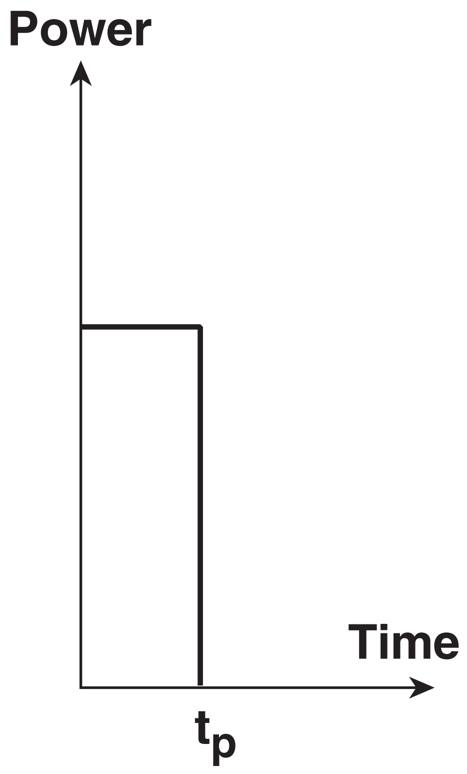
Decaying shock	Relaxation (1st kind)	Relaxation (2nd kind)
$\alpha \sim \dfrac{1}{m^{1.1-1.2}}$	$\alpha \sim \dfrac{1}{m^{0.8-1.0}}$	$\alpha \sim \dfrac{1}{m^{1.6-1.8}}$



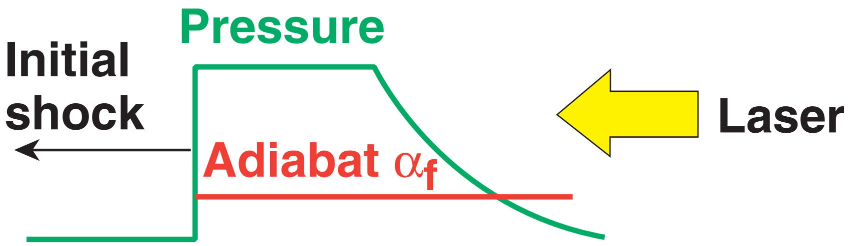
Steepest adiabat and largest ablation velocity

TC6472

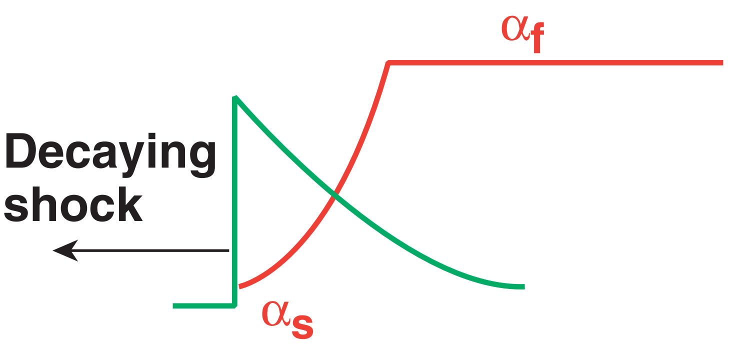
Adiabat shaping is done using an intensity picket



- $t = 0$ 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

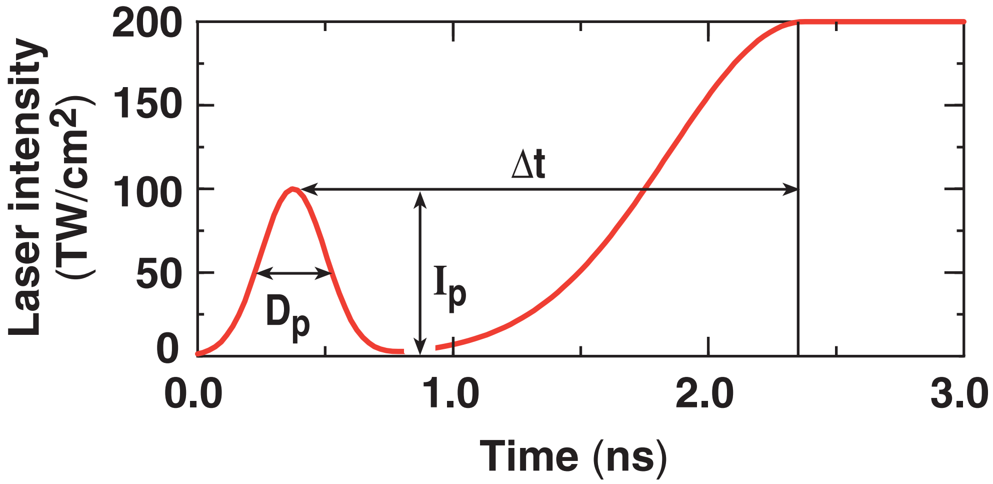


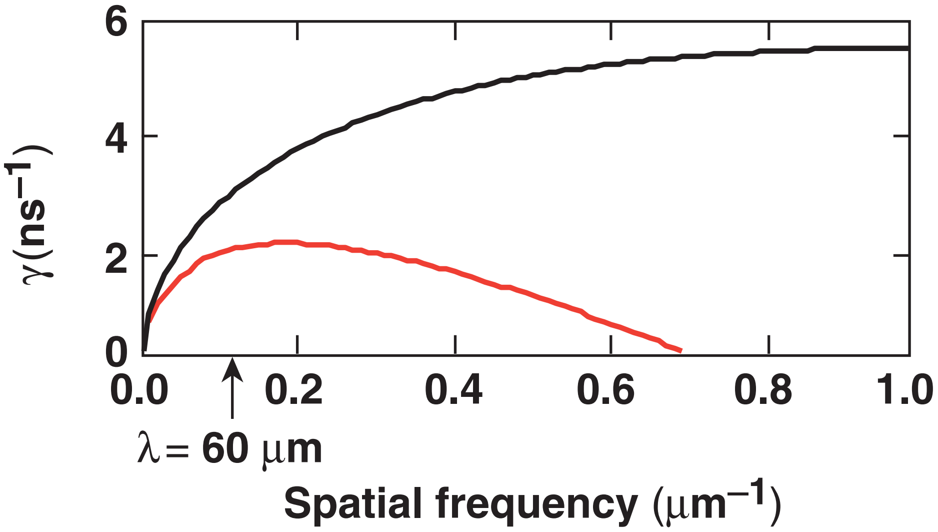
Calculations show

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

valid for $\gamma > 1.2$.

The Betti dispersion formula with 1-D hydrodynamic simulations were used to design the laser pulse shape





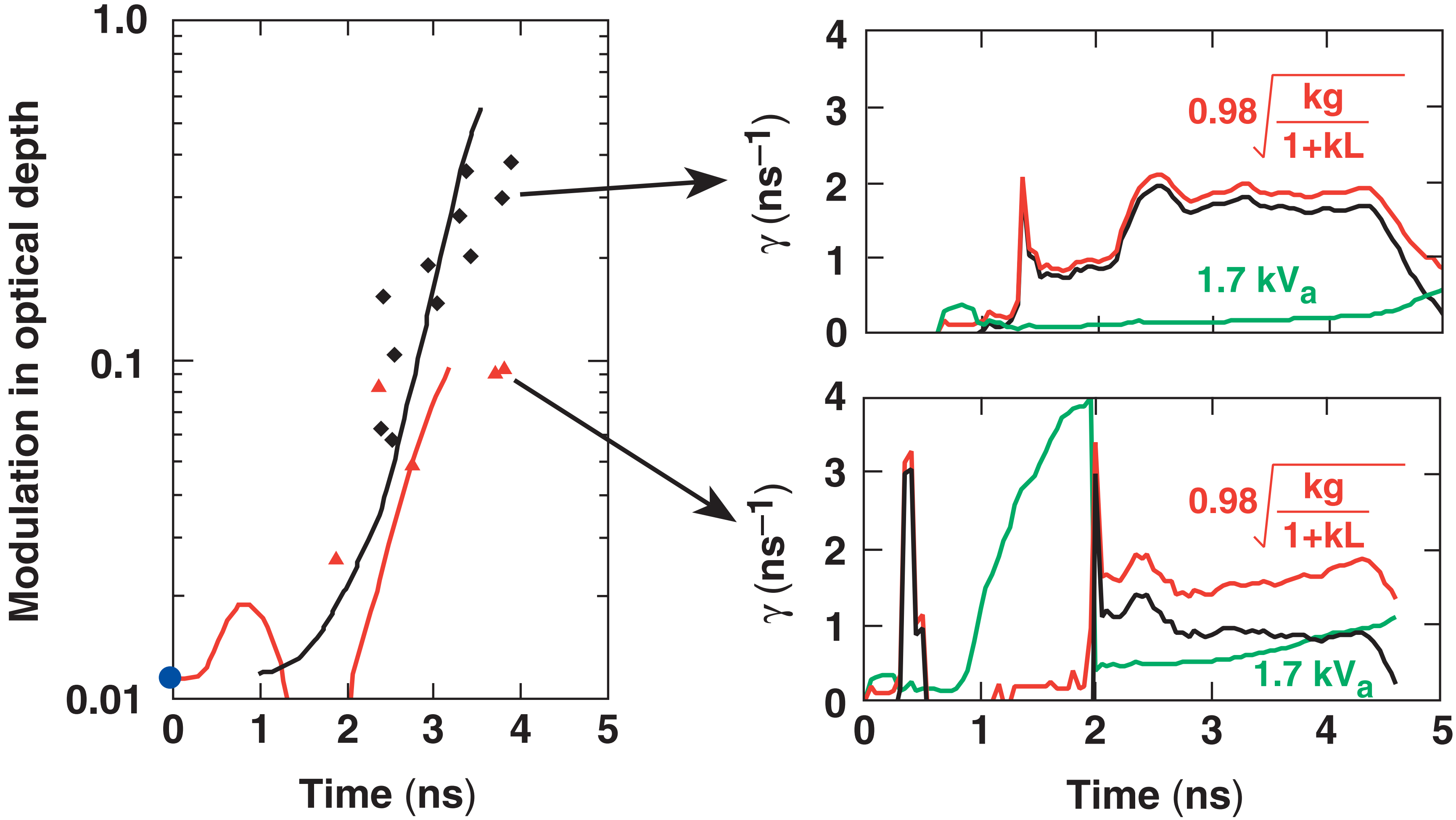
- The laser pulse consists of a picket pulse followed by a drive pulse.
- We characterize the picket shape by three quantities.
- The standard drive pulse is a 750-ps rise to a 200 TW/cm^2 flattop.

$$\gamma = 0.98\sqrt{\frac{kg}{1+kL}} - 1.7\ kV_a$$

$$V_a \alpha\ \frac{\dot{m}}{\langle\rho\rangle}$$

- Picket pulse reduces $\langle\rho\rangle$, thereby increasing V_a.

Growth of the 60-μm perturbation at the ablation interface is reduced when a picket-fence pulse is used



E10684

Little growth is measured for the 20-μm perturbation with the picket-fence pulse