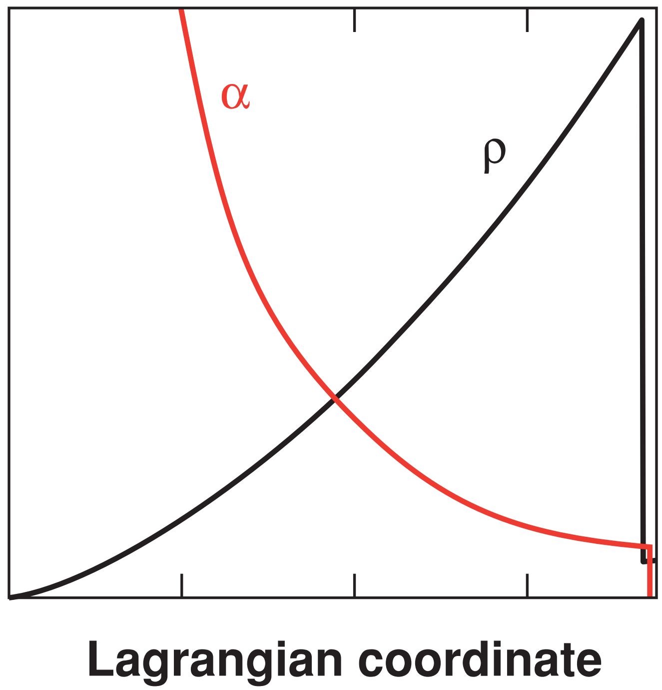
Adiabat Shaping of Direct-Drive OMEGA Capsules Using Ramped Pressure Profiles



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Motivation

- A shaped adiabat combines

  1. High capsule adiabat at the ablation front, resulting in high ablative stabilization of the Raleigh–Taylor (RT) instability:[1]

     $$\gamma_{RT} \approx 0.94\sqrt{kg} - 2.7\ kV_{abl},\ V_{abl} \sim \alpha^{3/5}$$

  2. Low fuel adiabat, giving high compression and high yield

- Shaping with a ramped pressure profile lends flexibility to adiabat shaping

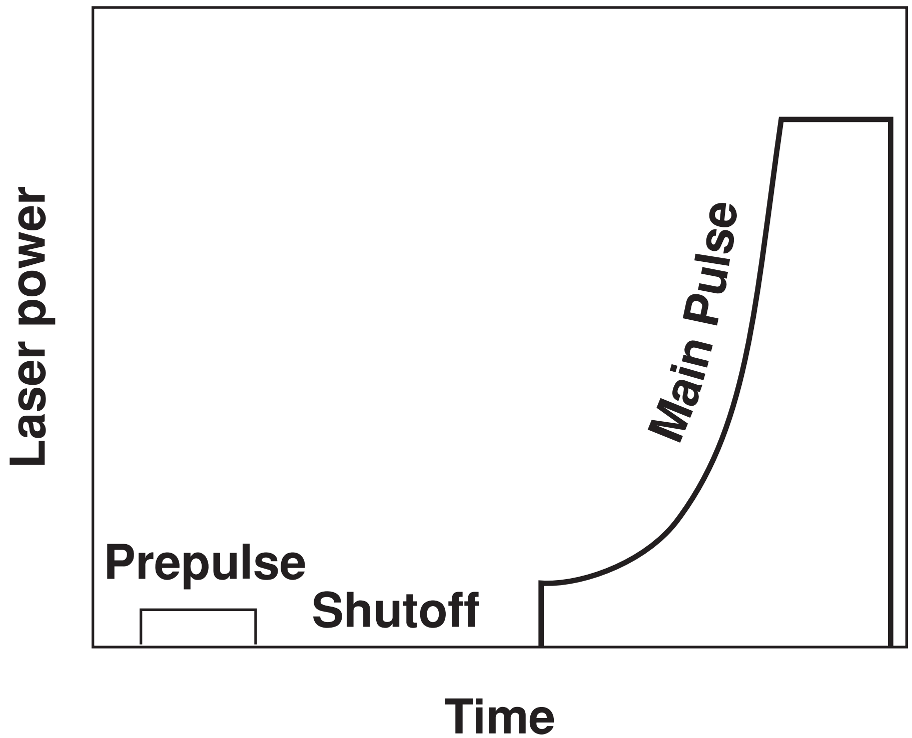
[1] R. Betti *et al.*, Phys. Plasmas 5, 5 (1998).

TC6027

Outline

- Explanation of adiabat-shaping physics using ramped pressure profiles
- Analysis of shock-timing constraints
- Comparison of adiabat shapes from various prepulses

Shaping the adiabat with pressure relaxation requires a weak prepulse followed by a power shutoff and the main laser pulse



The main pulse sets the adiabat by launching a strong shock through a relaxed pressure profile.

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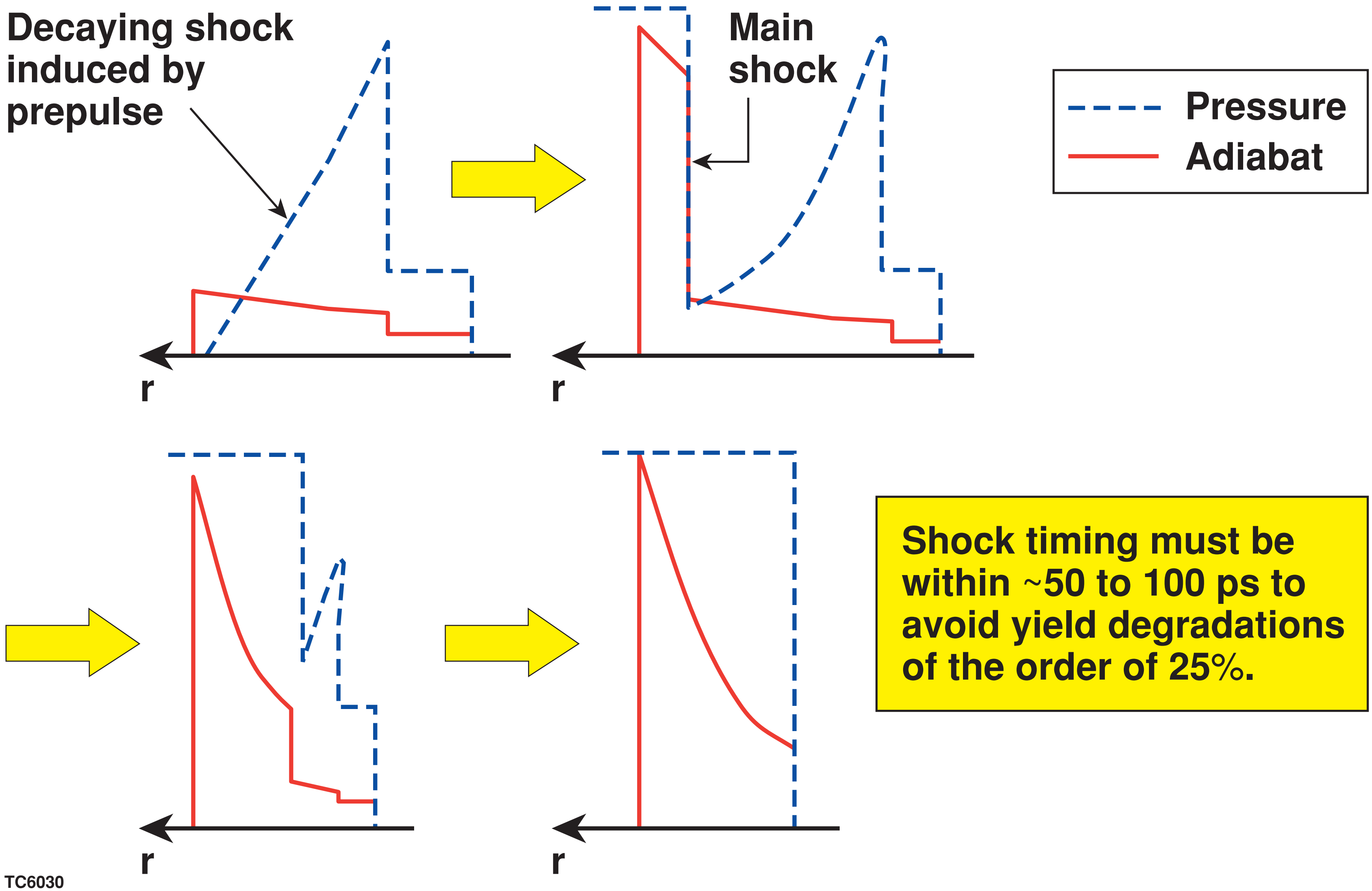
The shock from the main pulse shapes the shell adiabat as it travels up the relaxed density and pressure profile



Shock timing must be within ~50 to 100 ps to avoid yield degradations of the order of 25%.

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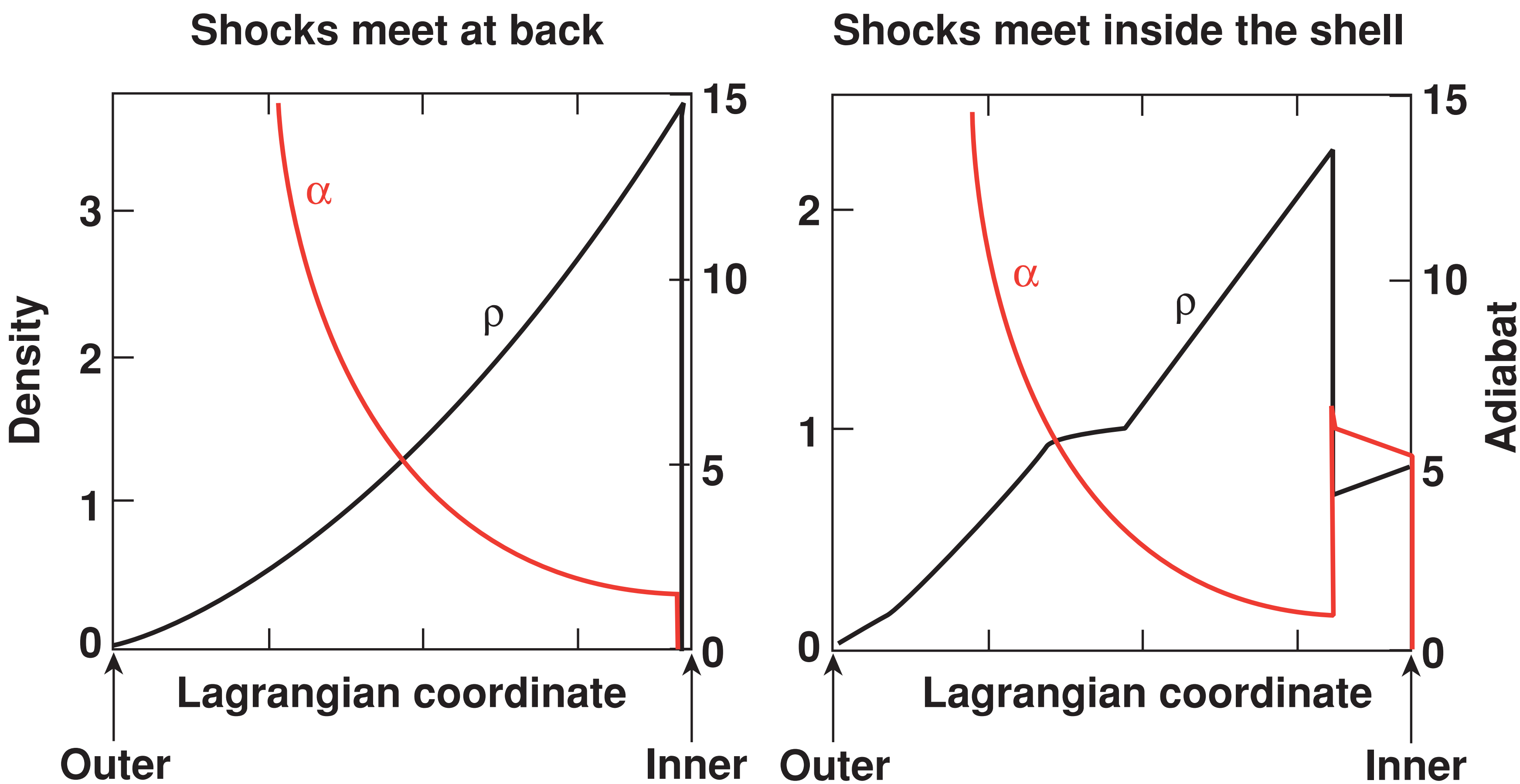
If the main pulse starts too soon, the shocks meet inside the shell, setting the rear surface on a high adiabat



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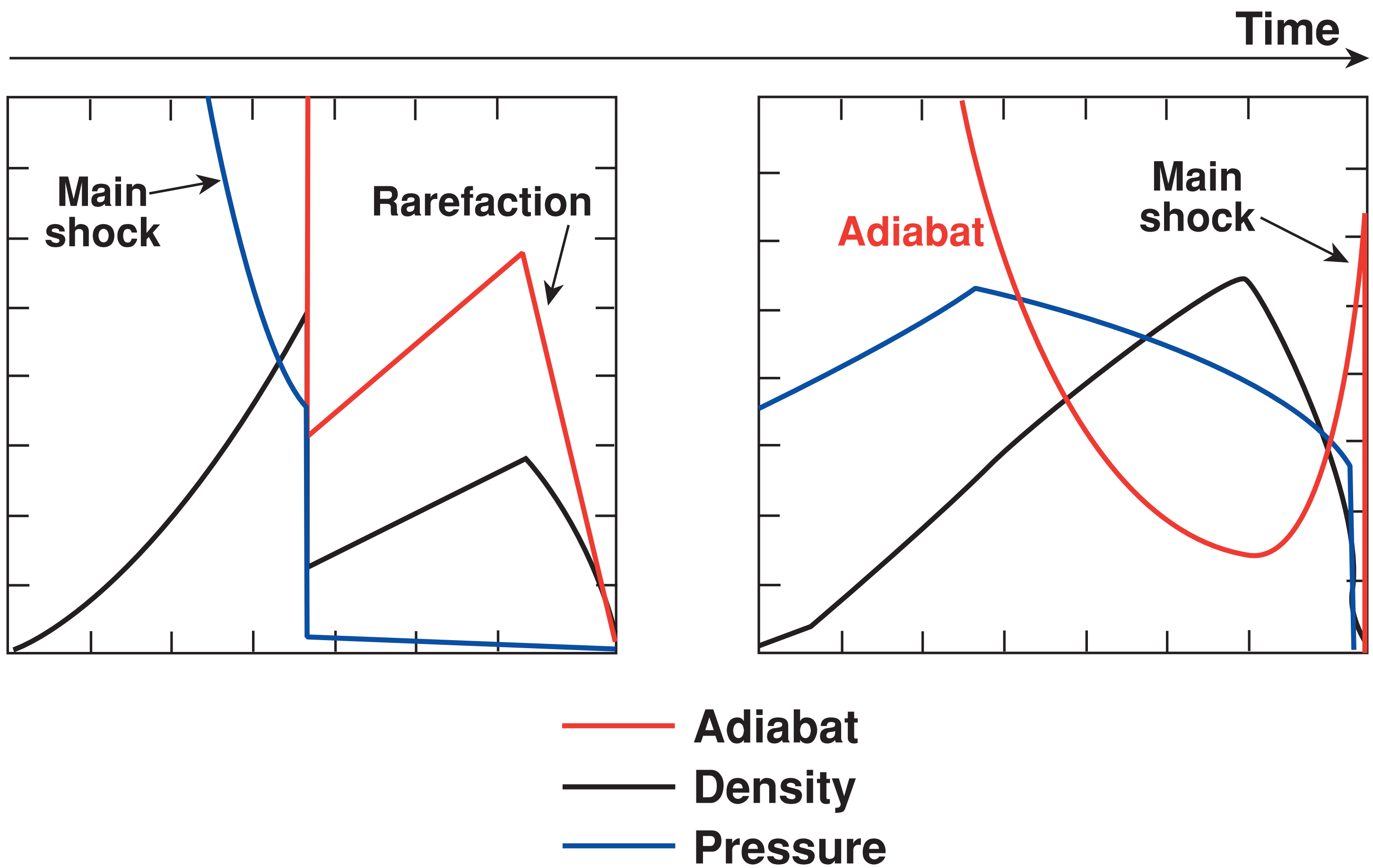
If the main pulse is delayed too much with respect to the prepulse, the back of the shell is set on a high adiabat



Late main pulse → The inner shell surface is set on a high adiabat .

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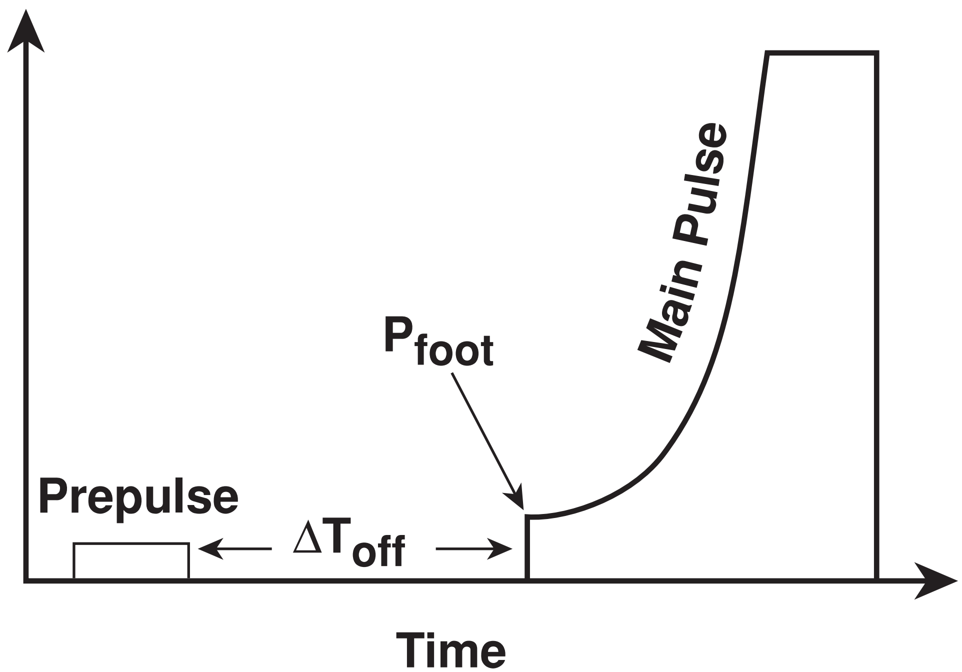
Two constraints on the main pulse: (1) the main and prepulse shocks must meet at the shell's rear surface and (2) the rear-surface adiabat is an assigned design parameter



For a given prepulse ($P_{prepulse}$, $\Delta T_{prepulse}$) and rear adiabat, the laser shutoff time ΔT_{off} and main-pulse foot power P_{foot} are determined by these two constraints.

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Dimensional analysis provides simple approximate formulas for the shutoff time and foot power

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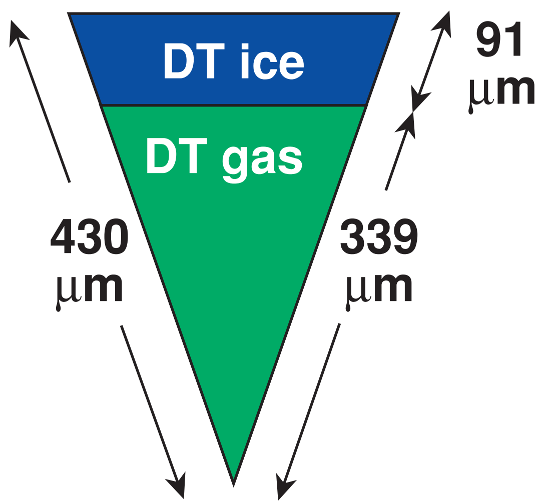
$$\frac{\Delta T_{off}}{\Delta T_{prepulse}} \approx const \bullet \left(\frac{m^*}{M_{shell}}\right)^{\mu} \left(\frac{P_{back}}{P_{prepulse}}\right)^{\varpi}, \quad \frac{P_{foot}}{P_{prepulse}} \approx const \bullet \left(\frac{m^*}{M_{shell}}\right)^{\nu} \left(\frac{P_{back}}{P_{prepulse}}\right)^{\varphi}$$

$$\Delta T_{off}(ns) \approx 1.6 \left[\frac{0.1}{\Delta T_{prep}(ns)}\right]^{0.9} \left[\frac{\Delta_{shell}(\mu m)}{90}\right]^{1.9} \left[\frac{10}{P_{prep}(Mb)}\right]^{1.12} \left[\frac{\rho_0\left(g/cm^3\right)}{0.25}\right]^{1.23} \alpha_{back}^{0.17}$$

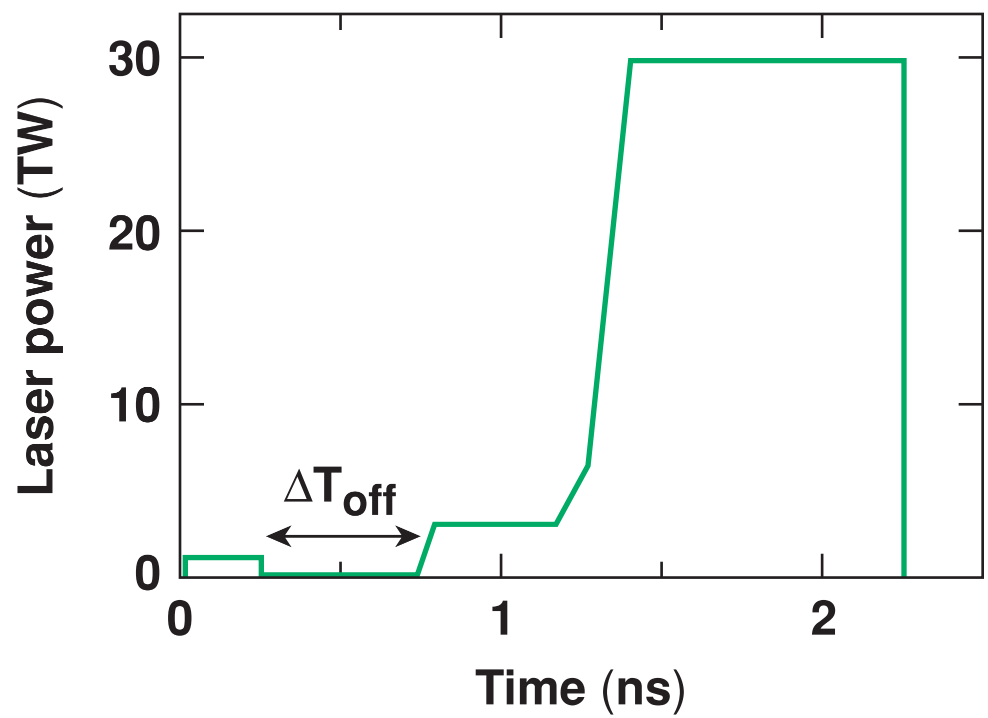
$$P_{foot}(Mb) \approx 9 \left[\frac{\Delta T_{prep}(ns)}{0.1}\right]^{0.28} \left[\frac{90}{\Delta_{shell}(\mu m)}\right]^{0.28} \left[\frac{P_{prep}(Mb)}{10}\right]^{0.19} \left[\frac{\rho_0\left(g/cm^3\right)}{0.25}\right]^{1.44} \alpha_{back}^{0.95}$$

Cryogenic DT OMEGA capsule design and sample laser pulse shape

Typical 1-D yields ~ 10^{15}



Pulse shape: 250 ps, 1.2 TW prepulse



- ΔT_{off} varies with prepulse pressure and duration and with capsule parameters.

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Varying the intensity of the prepulse changes the steepness of the adiabat profile

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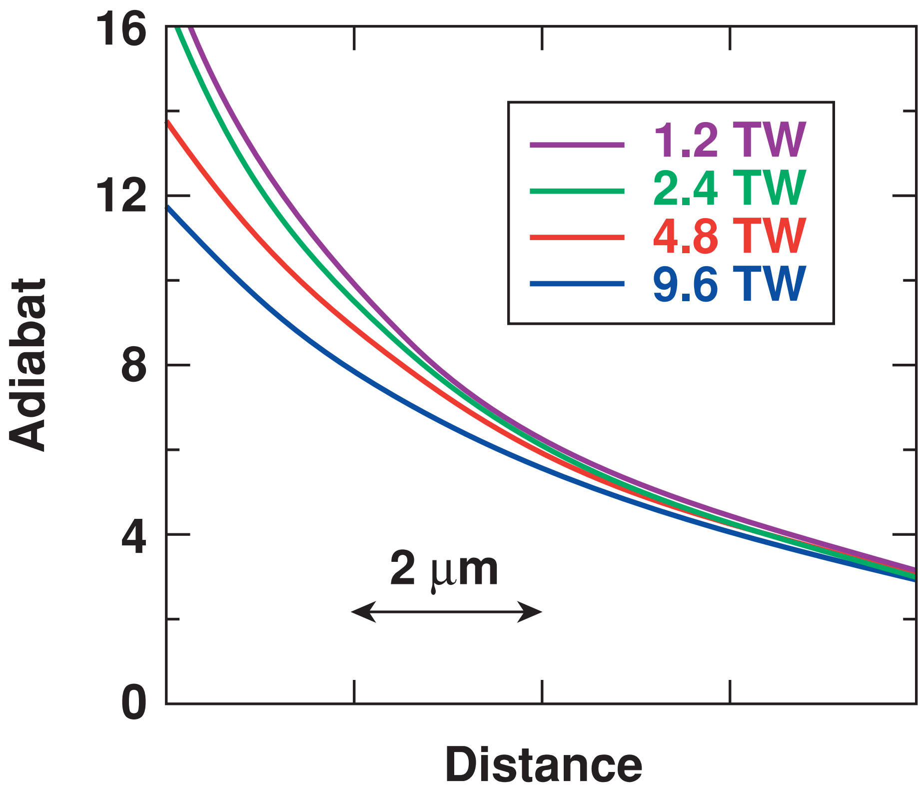
Results of varying the intensity of 50-ps square prepulses



- Lower-intensity prepulses give stronger shaping, shorter entropy-gradient scale length L_S.
- Convective instabilities are driven by entropy gradients with growth rates:

$$\gamma_{conv} \sim \frac{1}{\sqrt{L_S}}$$

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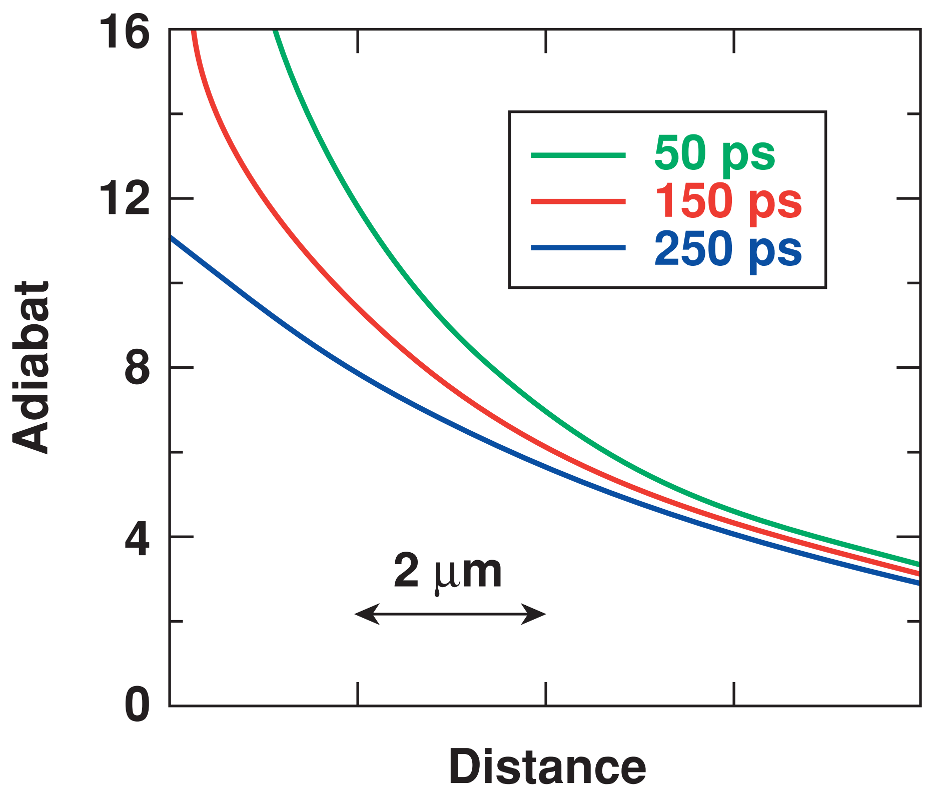
A study of 1.2-TW square prepulses shows that varying the length of the prepulse also affects the steepness of the adiabat profile



Shorter prepulses give stronger shaping and shorter entropy-gradient scale length L_S.

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Conclusion

- Adiabat shaping combines high fuel compression with high ablative Rayleigh–Taylor stabilization.
- Adiabat shaping can be done using a short prepulse followed by a period of laser shutoff and the main drive pulse.
- 1-D simulations have verified adiabat shaping for various prepulses.
- This method of adiabat shaping allows flexibility in setting adiabat shapes.
- Ongoing research:
  - 2-D simulations to evaluate capsule stability for various adiabat shapes.
  - Effects of both Rayleigh–Taylor stabilization and convective instability will be studied.