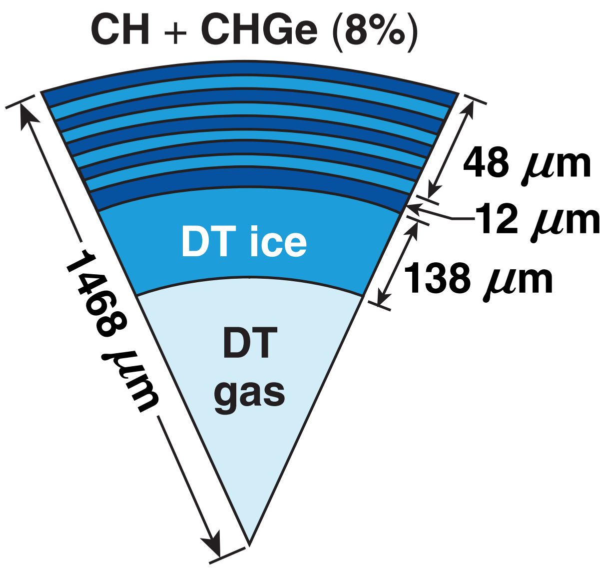
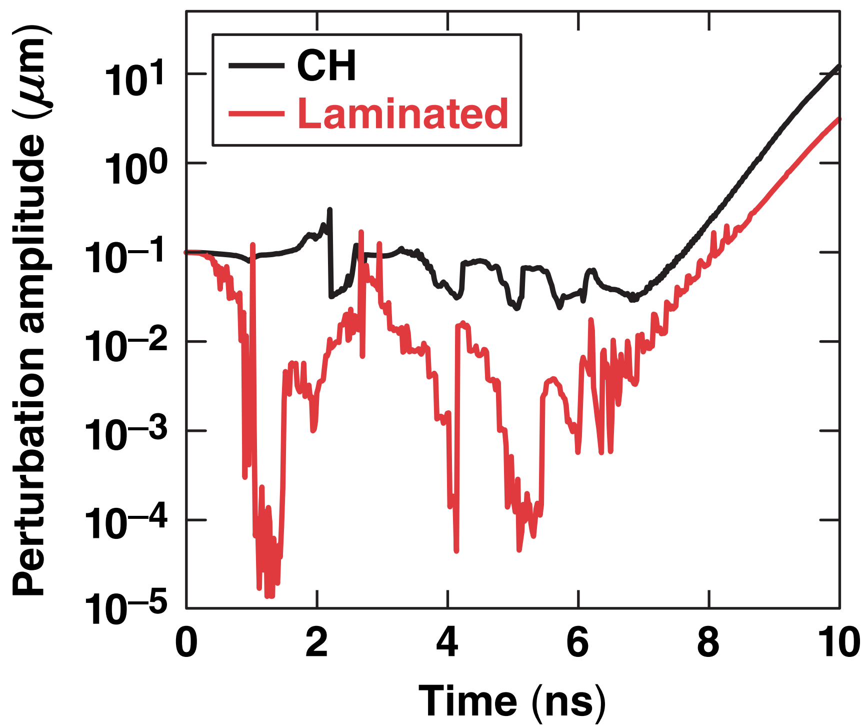
Benefits of Moderate-Z Ablators for Direct-Drive Inertial Confinement Fusion





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Summary

Alternative ablators using mid-*Z* materials are explored to improve the performance of direct-drive (ICF) targets

FSC

UR LLE

- Targets having a higher *Z* than plastic have demonstrated that less hot electrons are produced by the two-plasmon–decay (TPD) instability and also an improved hydrodynamic stability
- A laminated ablator represents an attractive trade-off between undoped and uniformly doped ablators for both laser–plasma instabilities and hydrodynamic stability
- An ignition design for direct drive using a laminated ablator is simulated in one and two dimensions and its performance is compared to a plastic ablator

Collaborators

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OMEGA experiments have demonstrated benefits from using mid-Z ablators

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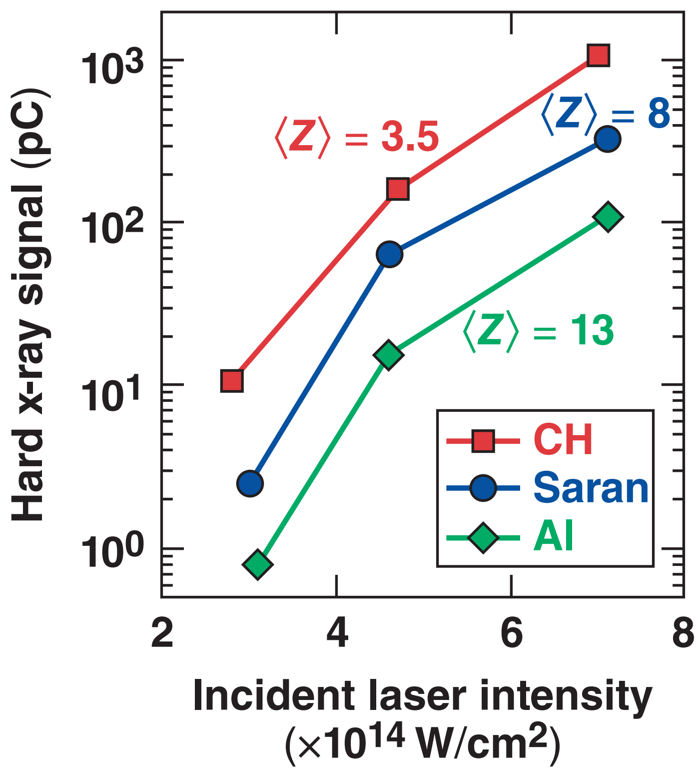
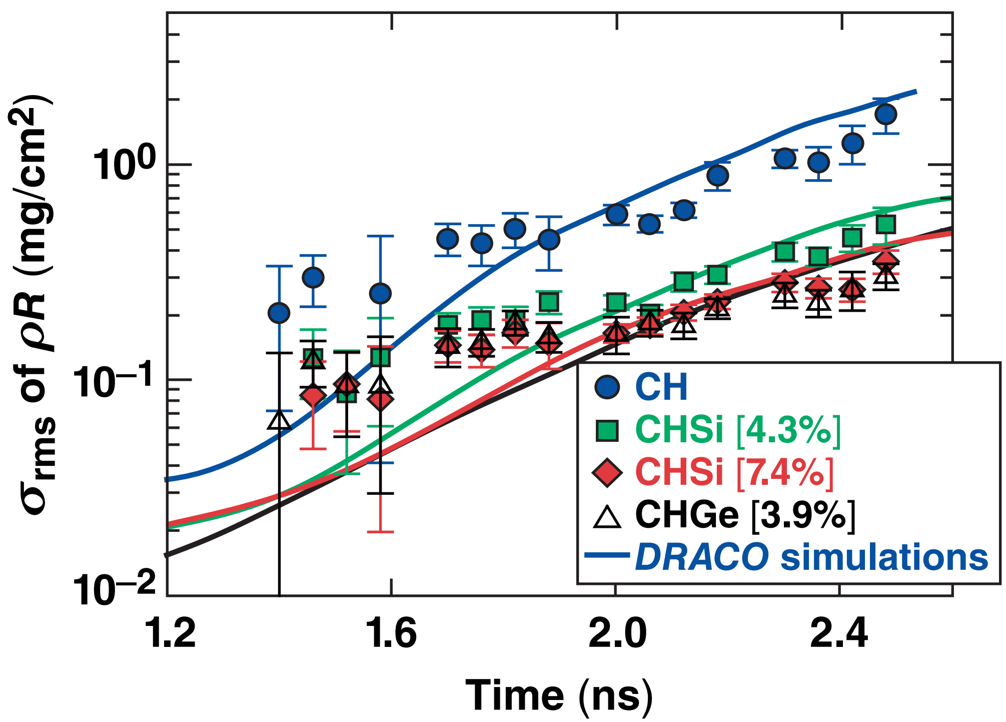
- Reduction of TPD-driven hot electrons has been observed in mid-*Z* materials



- Experimental results have shown significant mitigation of laser imprint and Rayleigh–Taylor (RT) instability growth rate



S. X. Hu *et al.*, Phys. Plasmas 20, 032704 (2013);
S. X. Hu *et al.*, Phys. Rev. Lett. 108, 195003 (2012);
G. Fiksel *et al.*, Phys. Plasmas 19, 062704 (2012).

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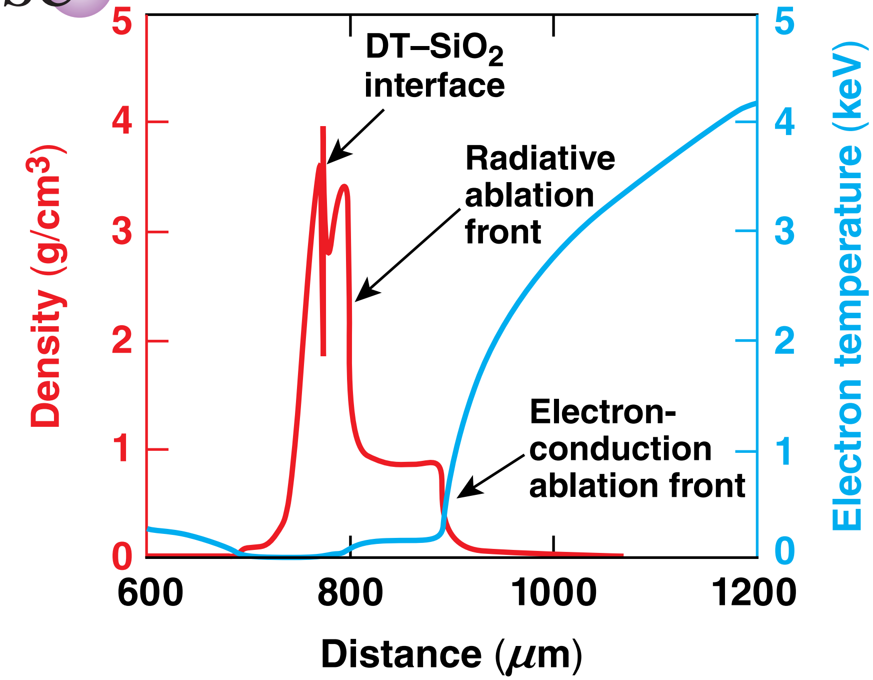
The hydrodynamics of mid-Z ablators is complicated by the presence of a double ablation front



- Modulations of density grow exponentially with a linear growth rate given by

$$\gamma_{RT} = \alpha \sqrt{\frac{A_T kg}{1 + A_T kL}} - \beta k V_a$$

with $A_T = \dfrac{\rho_{max} - \rho_{min}}{\rho_{max} + \rho_{min}}$

- Advantages
  - reduced TPD instability growth rate
  - similar RT instability growth factor*
- Drawbacks
  - reduced hydrodynamic efficiency
  - higher radiation losses
  - more radiative preheat of fuel

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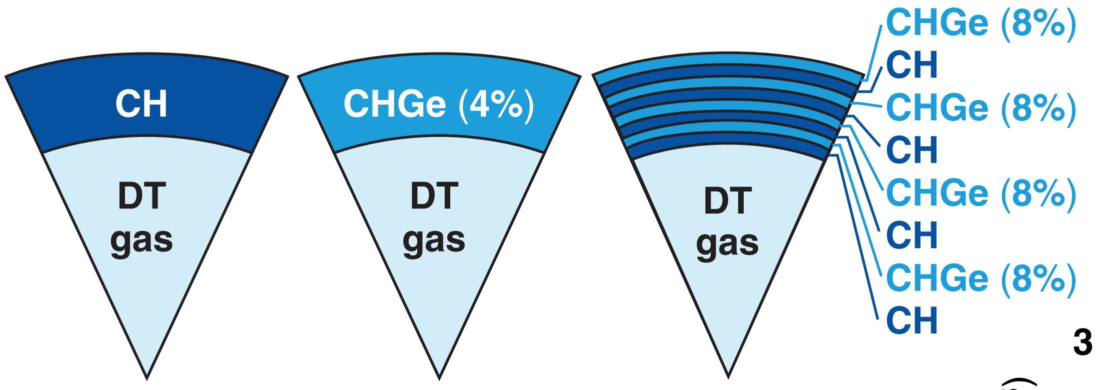
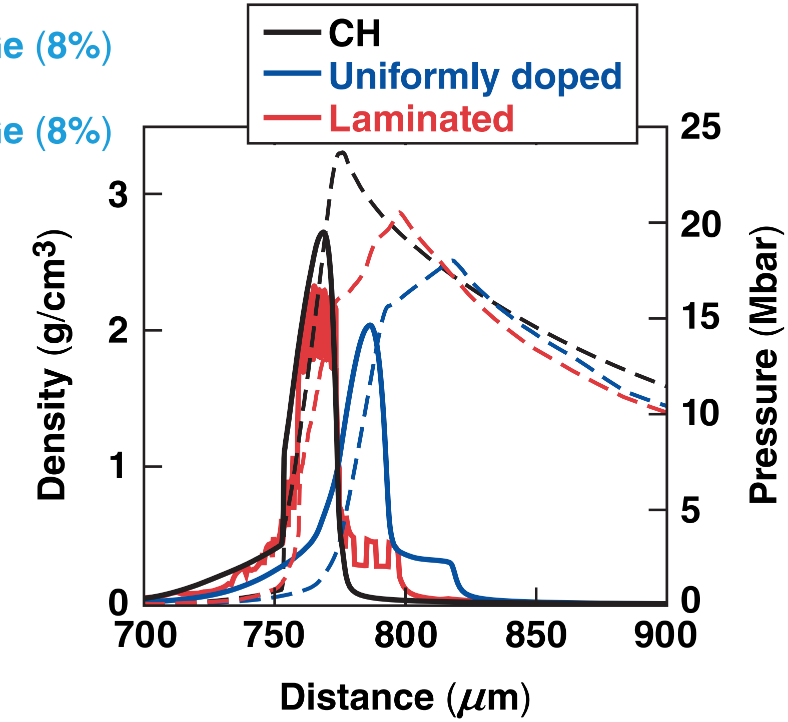
*M. Lafon *et al*., "Direct-Drive-Ignition Designs with Mid-Z Ablators," to be submitted to Physics of Plasmas.

Using a laminated ablator as a trade-off between pure plastic and mid-Z material is investigated



I_L (W/cm^2)	~2.5×10^{14}
E_L (kJ)	~100
R_{ext} (μm)	930
$\Delta R_{ablator}$	42 to 50
Number of layers (laminated ablator)	21 × (1 μm CH + 1 μm CHGe)



The hydrodynamic efficiency is improved in laminated ablators while exhibiting a similar coronal temperature than uniformly doped ablators.

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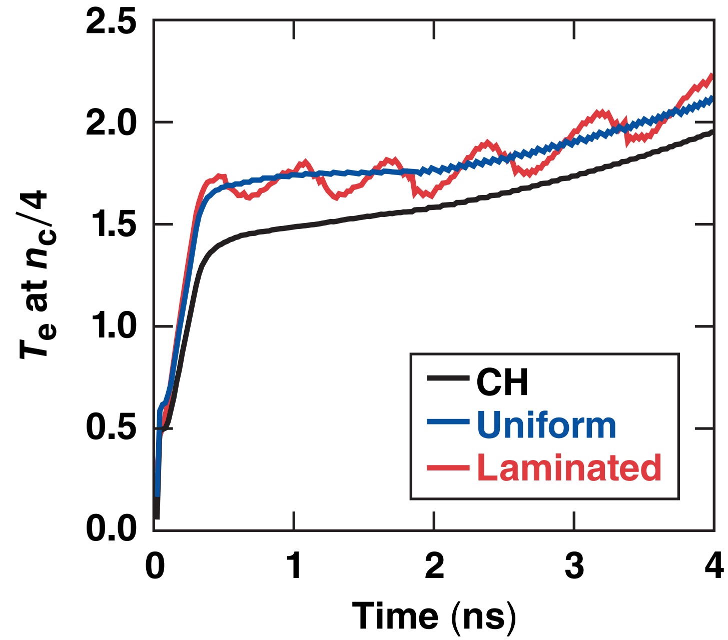
Reduced laser–plasma instabilities are expected from laminated ablators in comparison with plastic

- The laser-intensity thresholds for excitation of stimulated Raman scattering (SRS) and TPD instabilities are respectively

$$I_{SRS}\,(10^{14}\,\mathrm{W/cm^2}) \approx 1000\,\frac{T_e\,(\mathrm{keV})}{L^{4/3}\,(\mu\mathrm{m})}$$

$$I_{TPD}\,(10^{14}\,\mathrm{W/cm^2}) \approx 230\,\frac{T_e\,(\mathrm{keV})}{L(\mu\mathrm{m})}$$

- The effect of cross-beam energy transfer (CBET) is reduced with higher coronal temperature*



V_{imp} (km/s)	without CBET	with CBET
CH	189	171
Uniformly doped	168	161
Laminated	185	174

*I. V. Igumenshchev *et al.*, Phys. Rev. Lett. 110,145001 (2013).

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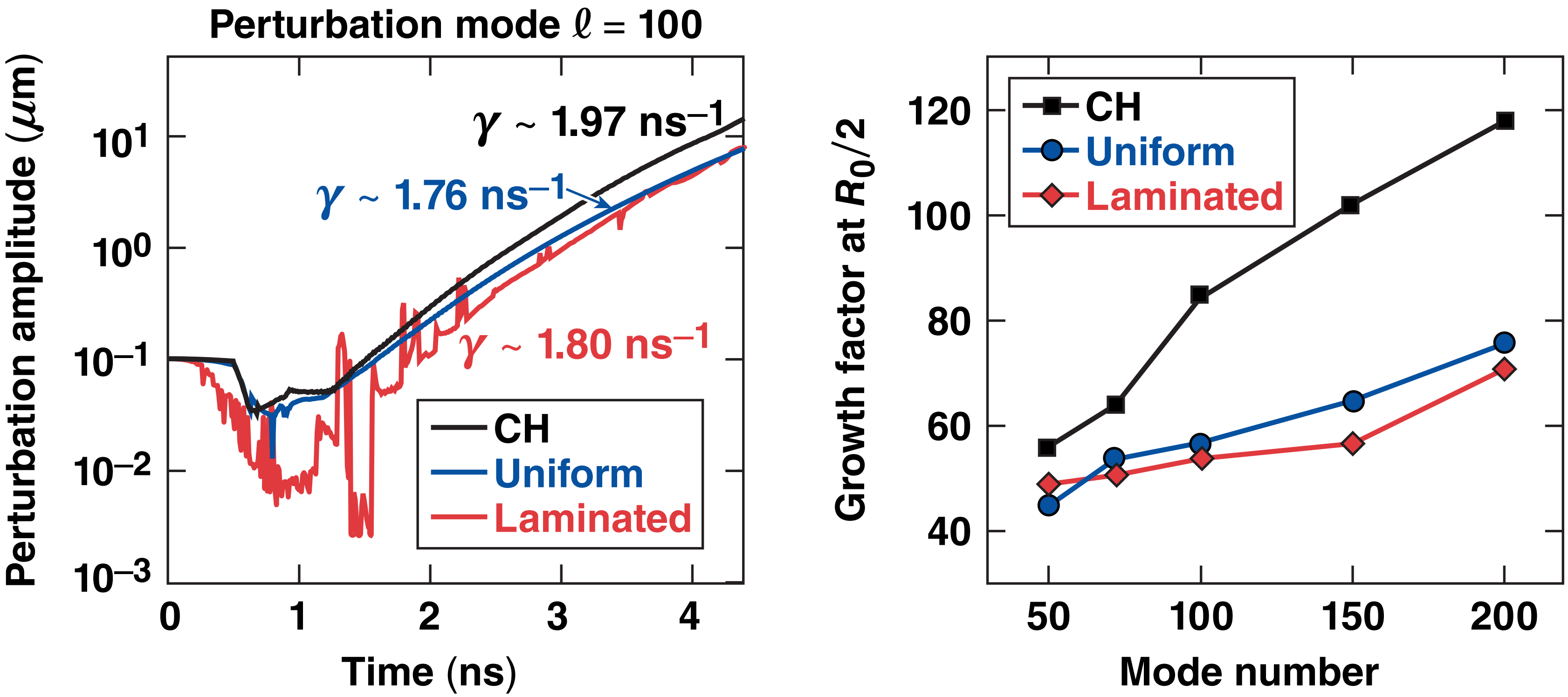
Single-mode simulations show that laminated ablators reduce the perturbation growth and stabilize high modes

- Significant stabilization of the ablation front has been experimentally observed for laminated ablators in an indirect-drive configuration*



- The RT growth is mitigated by finite density gradients generated by successive layers of doped and undoped plastic

*L. Masse *et al.*, Phys. Rev. Lett. 98, 245001(R) (2007);
L. Masse *et al.*, Phys. Rev. E. 83, 055401 (2011).

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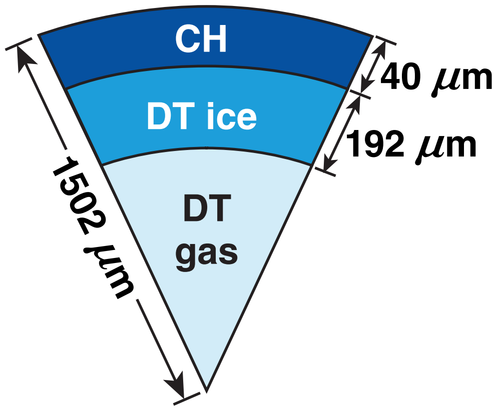
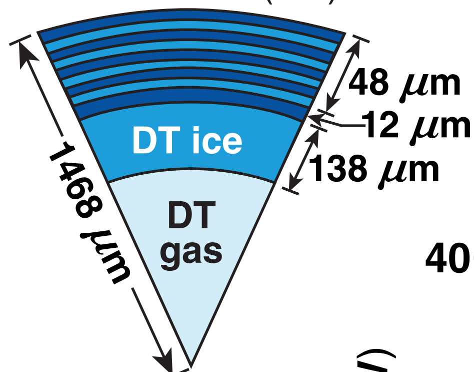
An ignition target using a laminated ablator has been designed and compared with a plastic ablator



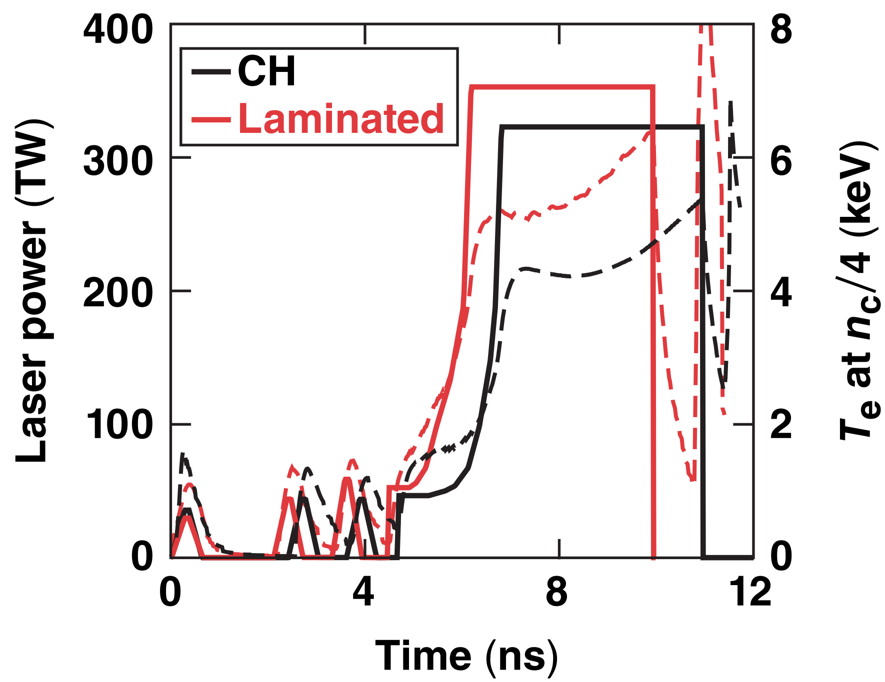
G = 61



G = 48

Flux limiter *f* = 0.06, without CBET

V_{imp} (km/s)	~360
E_L (MJ)	~1.6
Adiabat	~2.0
I_L (W/cm^2)	~1.2 × 10^{15}
ITF*$_{1\text{-D}}$	~3.4



*Ignition threshold factor

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DRACO simulations show a reduced perturbation growth for an ignition target using a laminated ablator

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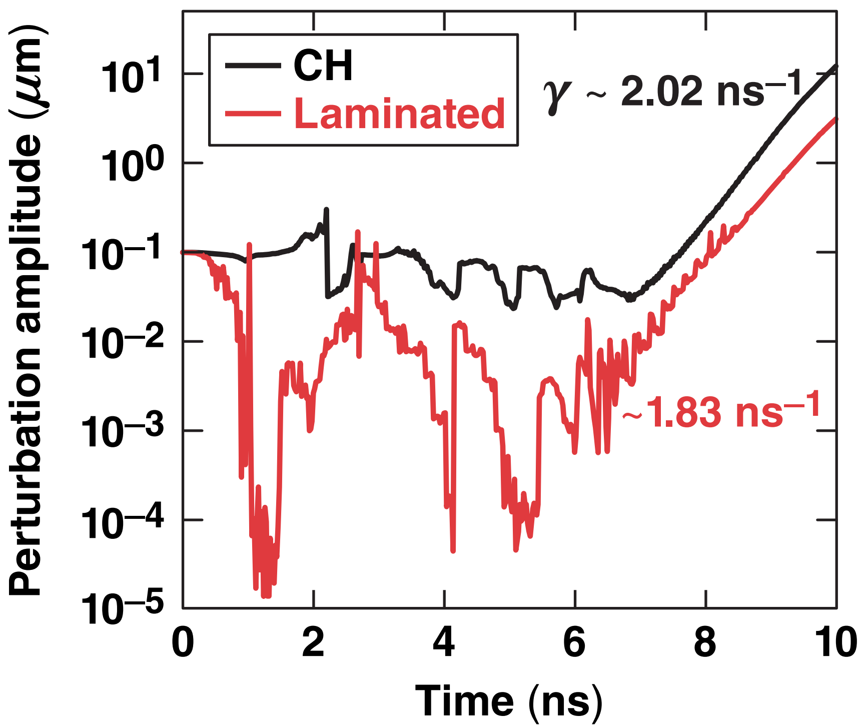
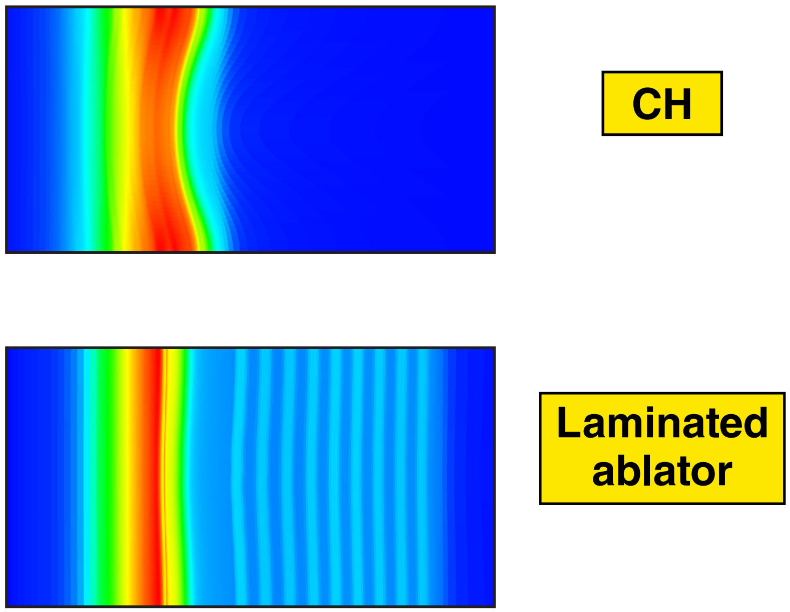
Perturbation mode $\ell = 100$



Density profiles at $R_0/2$ for mode $\ell = 100$



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Summary/Conclusions

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