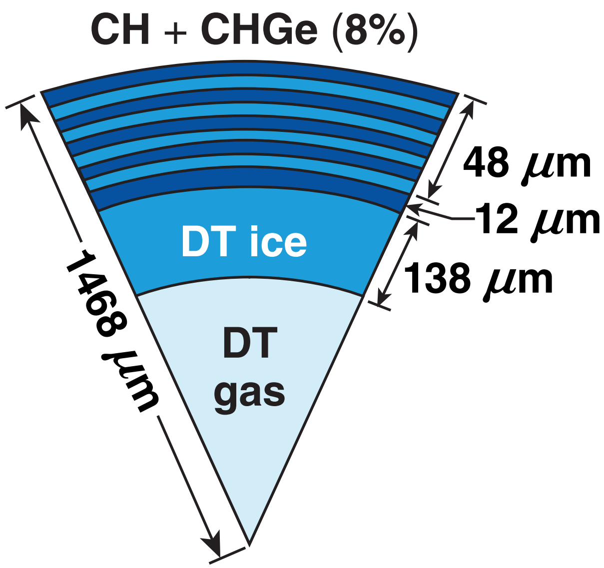
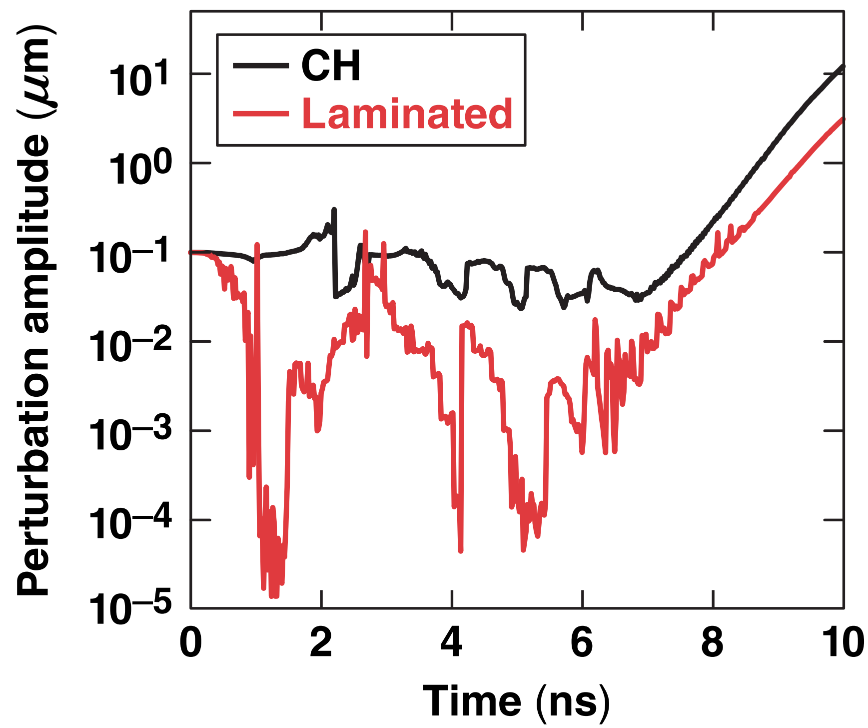
Benefits of Moderate-Z Ablators for Direct-Drive Inertial Confinement Fusion





M. Lafon
University of Rochester
Laboratory for Laser Energetics

56th Annual Meeting of the
American Physical Society
Division of Plasma Physics
New Orleans, LA
27–31 October 2014

Summary

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

- 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

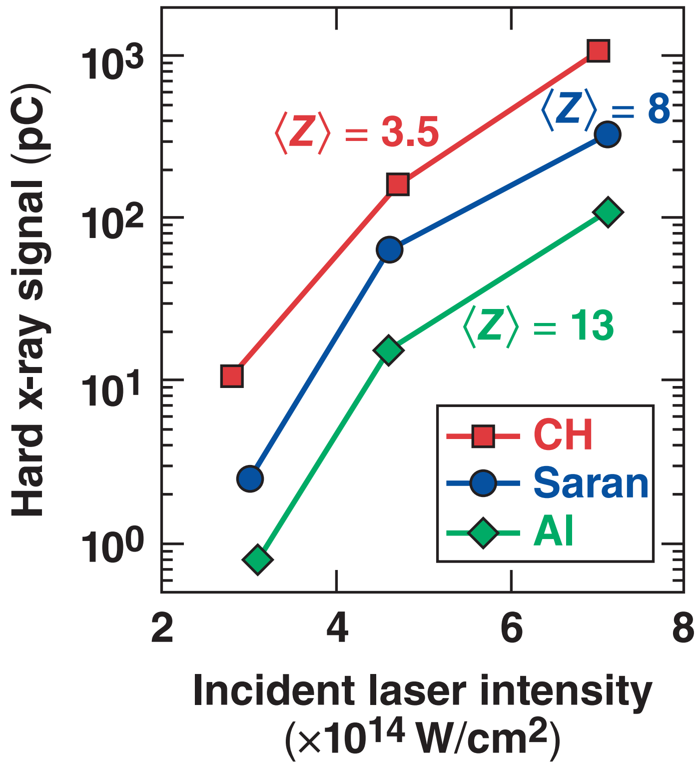
Collaborators

R. Betti,* K. S. Anderson, T. J. B. Collins, R. Epstein, S. X. Hu, P. W. McKenty, A. Shvydky, and S. Skupsky

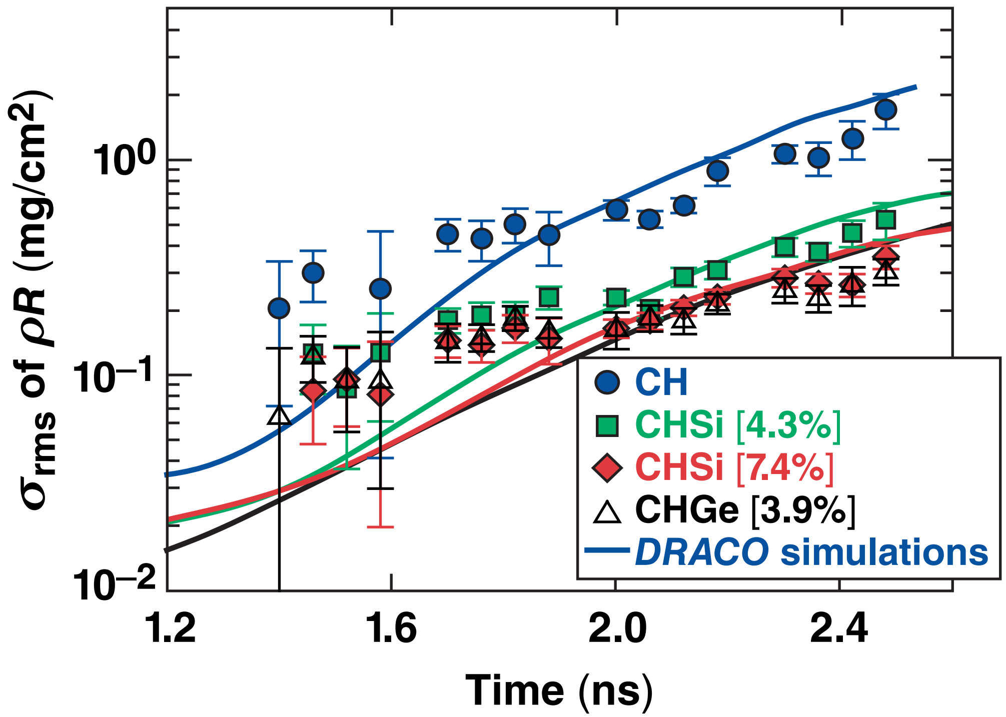
University of Rochester
Laboratory for Laser Energetics
*also Fusion Science Center

OMEGA experiments have demonstrated benefits from using mid-Z ablators

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



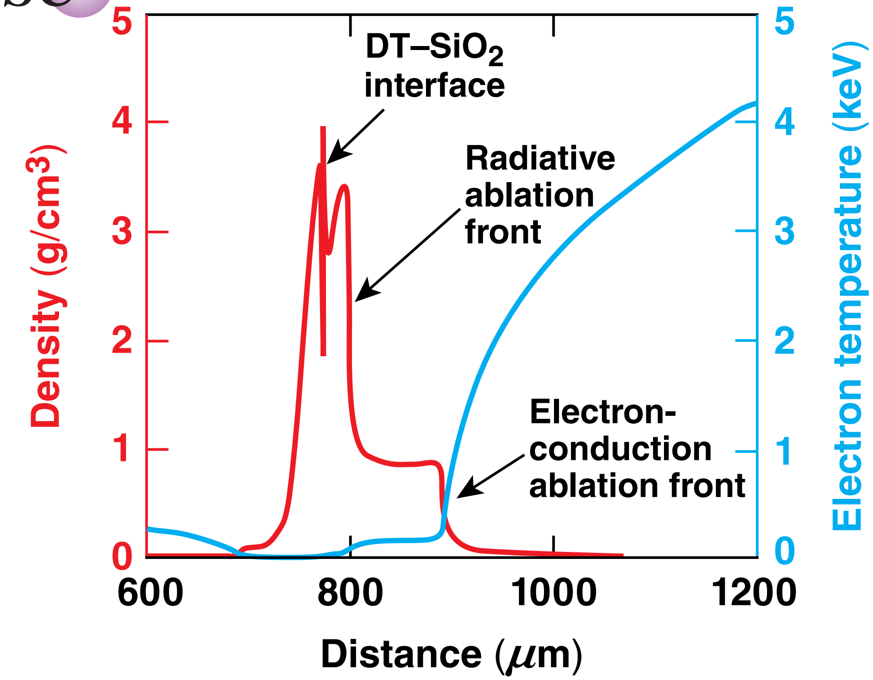
- Experimental results have shown significant mitigation of laser imprint and Rayleigh–Taylor (RT) instability growth rate



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).

UNIVERSITY of ROCHESTER

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

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

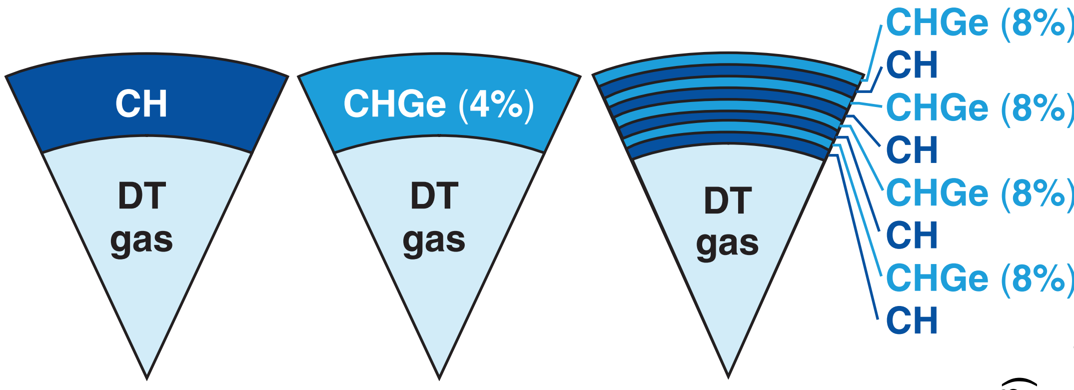
with $A_T = \frac{\rho_{max} - \rho_{min}}{\rho_{max} + \rho_{min}}$

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

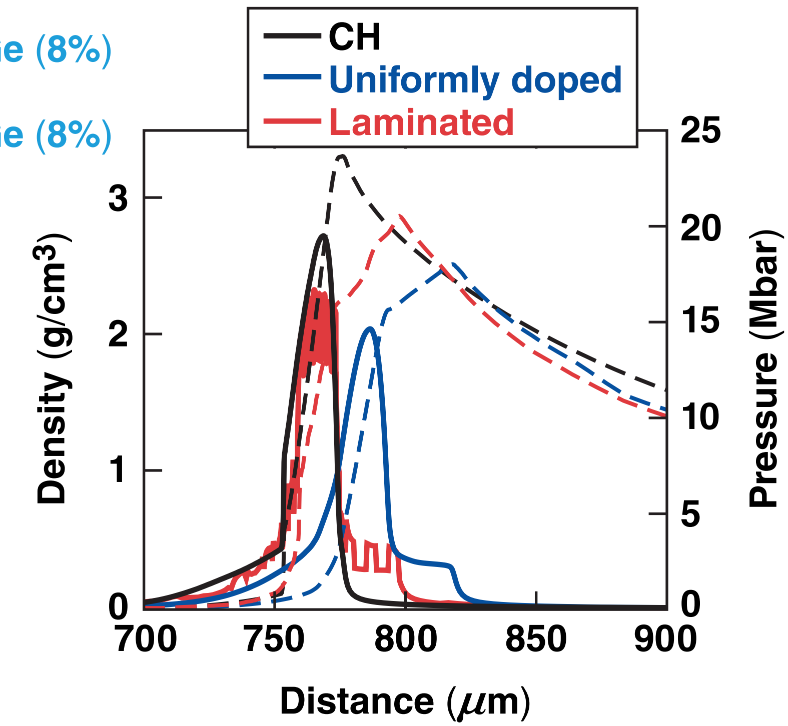
*M. Lafon *et al.*, "Direct-Drive-Ignition Designs with Mid-Z Ablators," to be submitted to Physics of Plasmas.

UNIVERSITY of ROCHESTER

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.

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

FSC

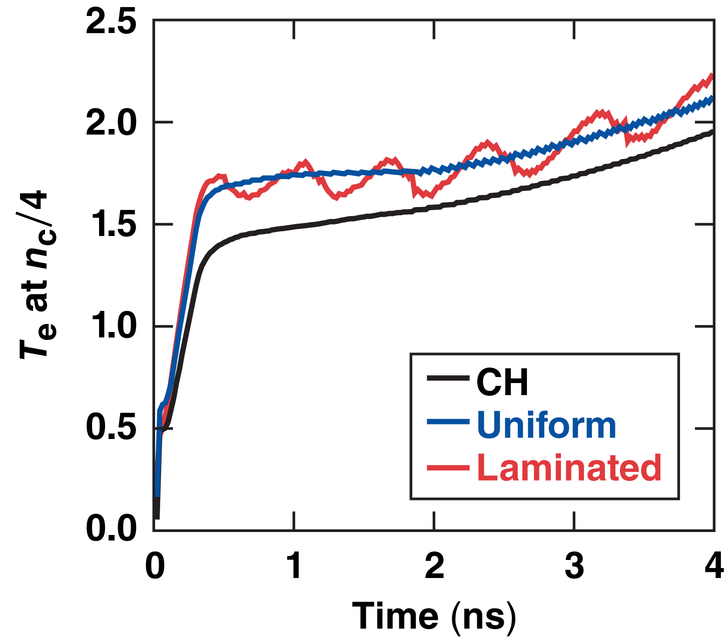
UR LLE

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

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

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

- 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

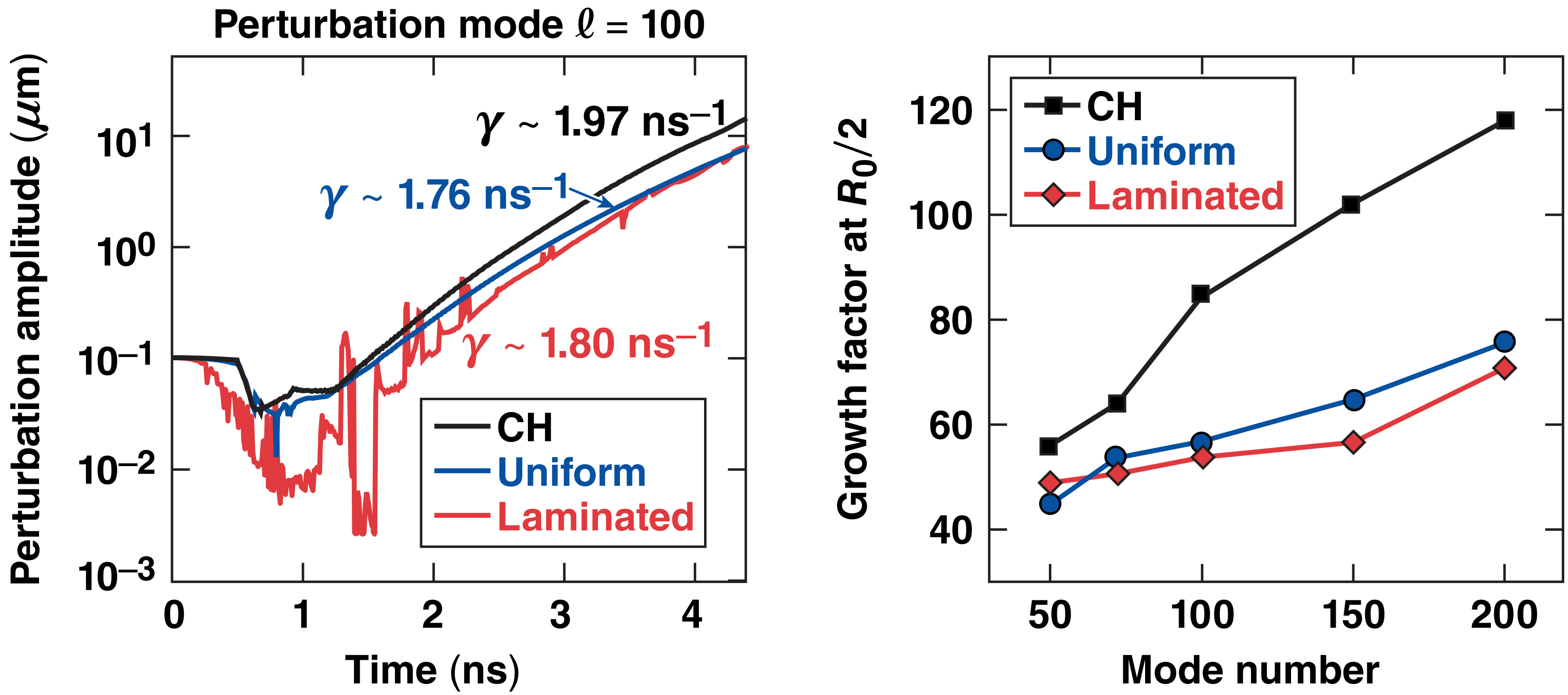
*I. V. Igumenshchev *et al.*, Phys. Rev. Lett. 110,145001 (2013).

TC11748

UNIVERSITY of ROCHESTER

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*

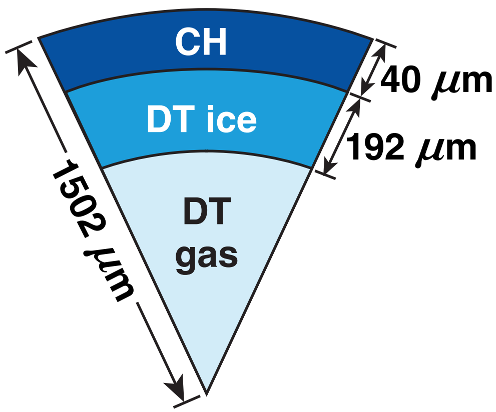


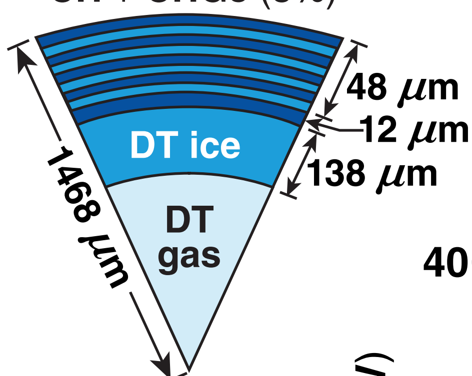
- The RT growth is mitigated by finite density gradients generated by successive layers of doped and undoped plastic

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

TC11749

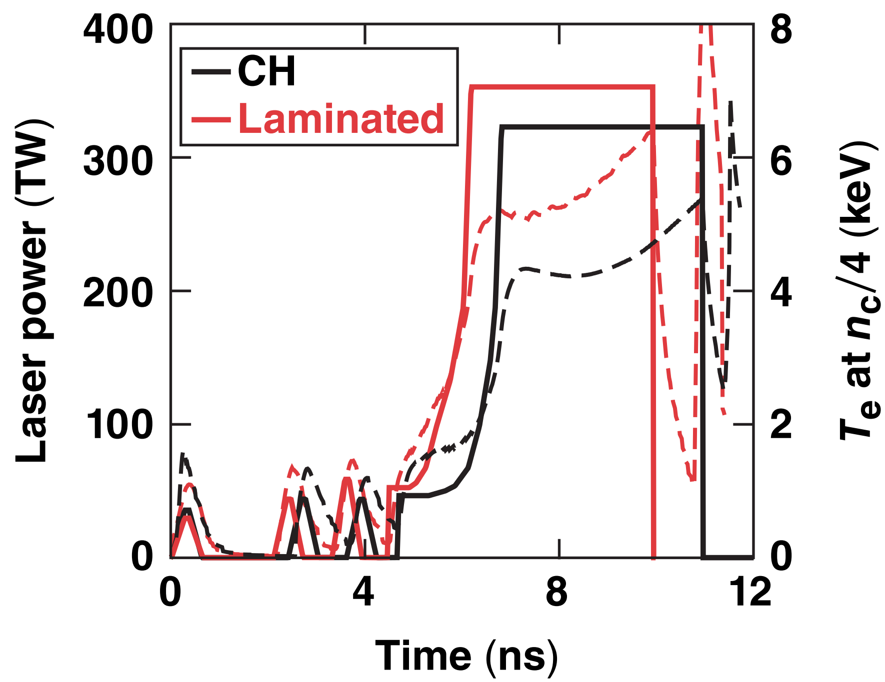
An ignition target using a laminated ablator has been designed and compared with a plastic ablator





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

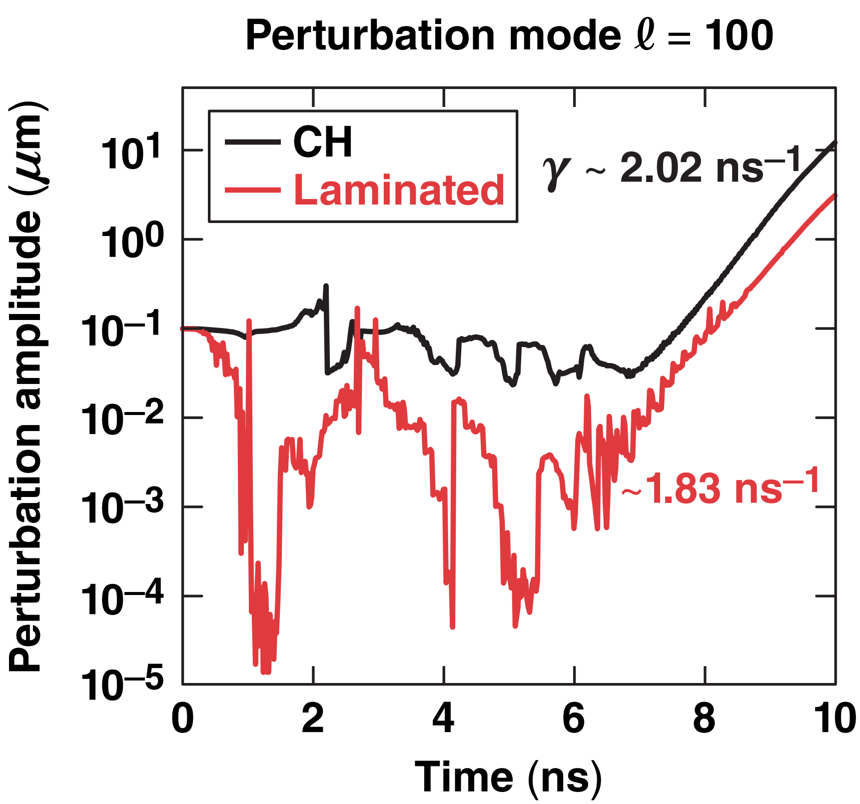


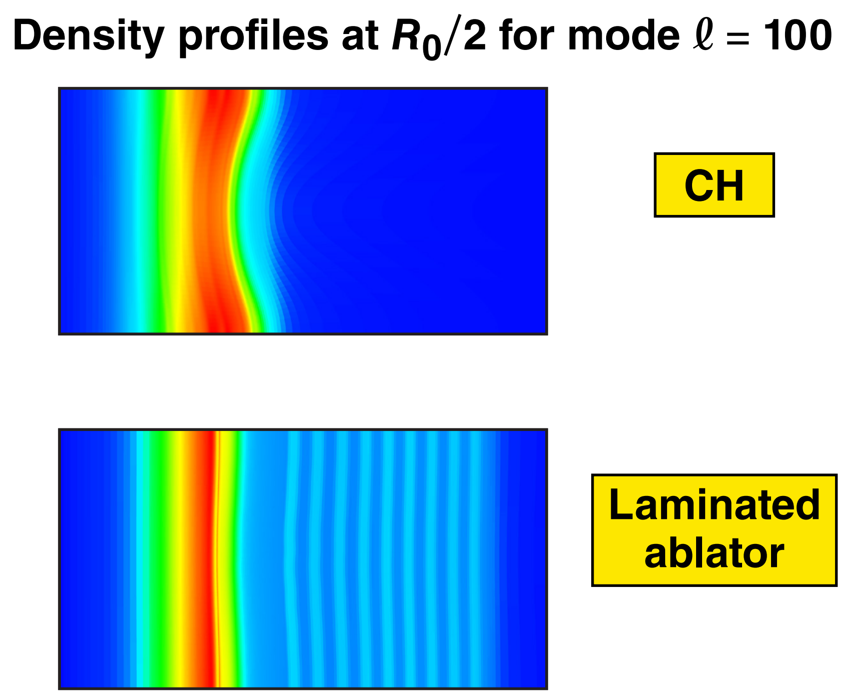
*Ignition threshold factor

TC11750

UNIVERSITY of ROCHESTER

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





TC11751

Summary/Conclusions

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

- 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

UNIVERSITY of ROCHESTER