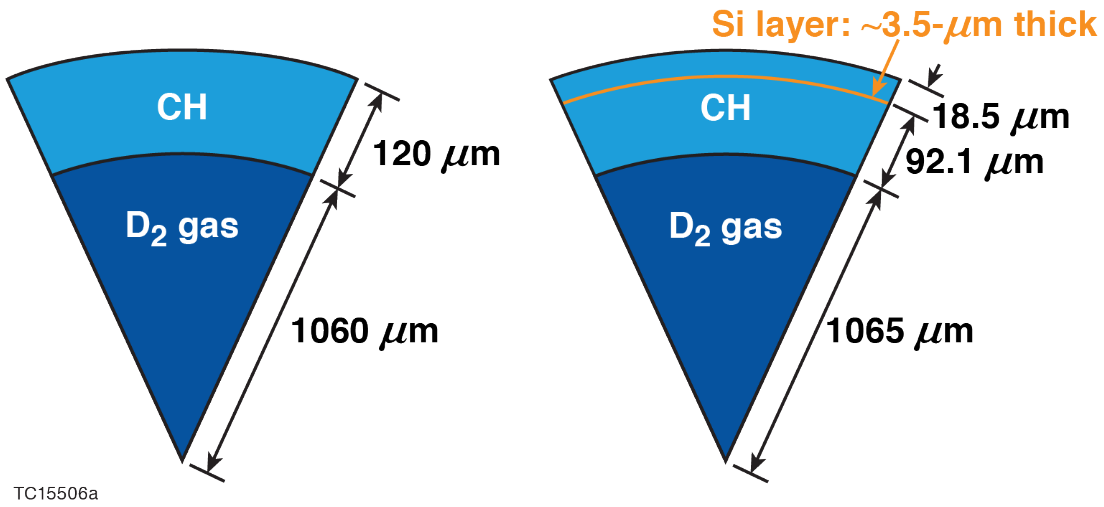
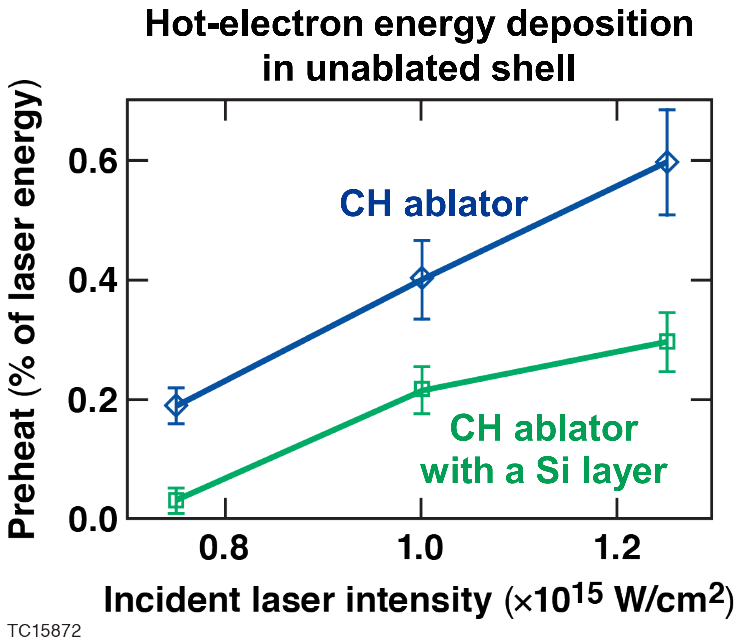
Hot-Electron Preheat and Mitigation in Polar-Direct-Drive Experiments at the National Ignition Facility





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Summary

Mid-Z Si layers provide a promising hot-electron preheat mitigation strategy for direct-drive ignition designs

- Surrogate plastic implosions were used to infer the hot-electron temperature and divergence, and directly measure the spatial hot-electron energy deposition profile inside the imploding shell
- Hot-electron coupling from 0.2% to 0.6% of the laser energy to the unablated shell is found for the incident laser intensity from (0.75 to 1.25) $\times$ 10^{15} W/cm^2, with half of the preheat coupled to the inner 80% of the unablated shell
- Si layers buried in the ablator mitigate the growth of laser–plasma instabilities and reduce preheat, providing a promising preheat mitigation strategy for ignition designs at an on-target intensity of about 10^{15} W/cm^2

Collaborators

M. J. Rosenberg, M. Stoeckl, R. Betti, W. Seka, R. Epstein, C. Stoeckl, R. K. Follett, P. B. Radha, S. P. Regan, D. H. Froula, J. P. Palastro, and V. N. Goncharov

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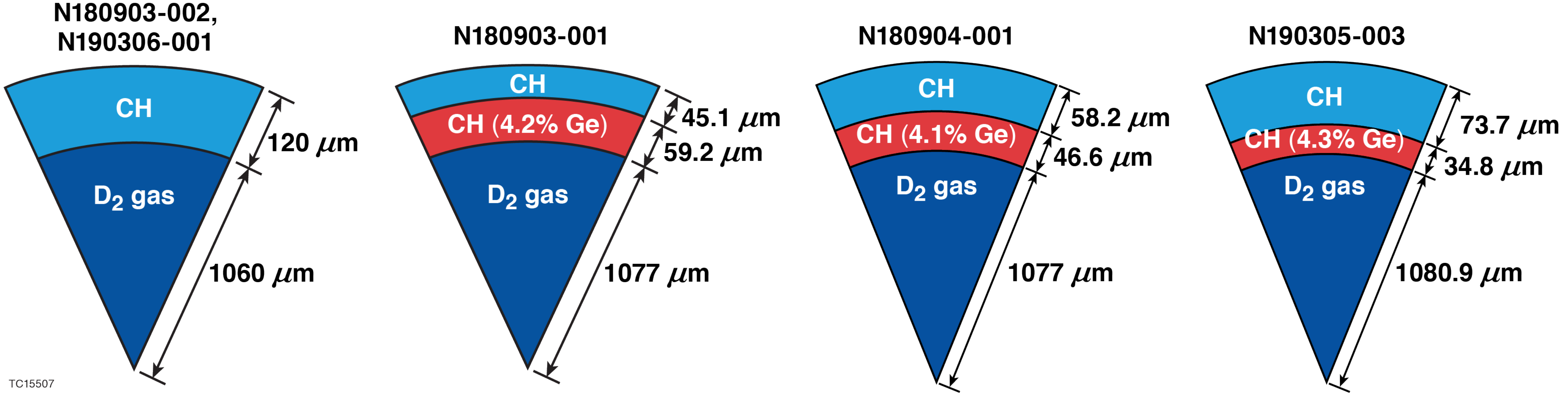
Hot-electron preheat in NIF PDD implosions was studied by comparing hard x-ray (HXR) emission between plastic and multilayered implosions*

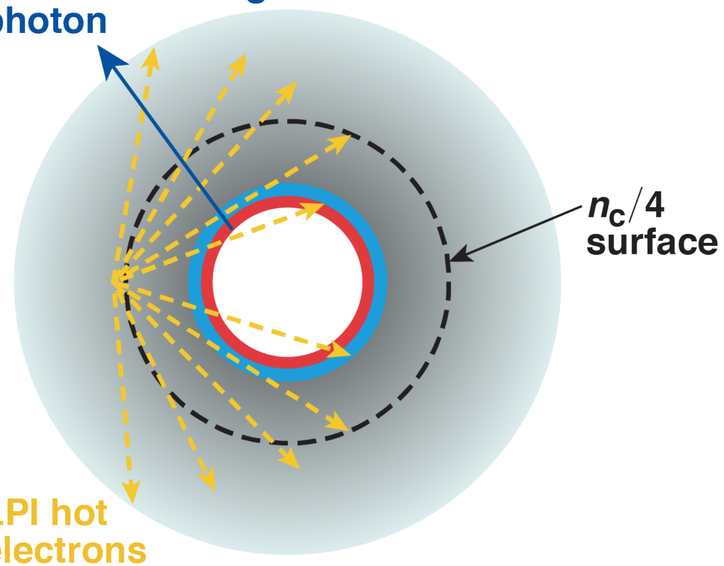
Mass-equivalent targets



Different thicknesses of the Ge-doped layer were examined to diagnose the hot-electron deposition profile in the imploding shell.

* Platform based on A. Christopherson *et al.*, *Phys. Rev. Lett.* 127, 055001 (2021).

Hot-electron preheat was inferred from comparison of the measured HXR spectra to simulations using the hydrocode *LILAC** and the Monte Carlo code Geant4**



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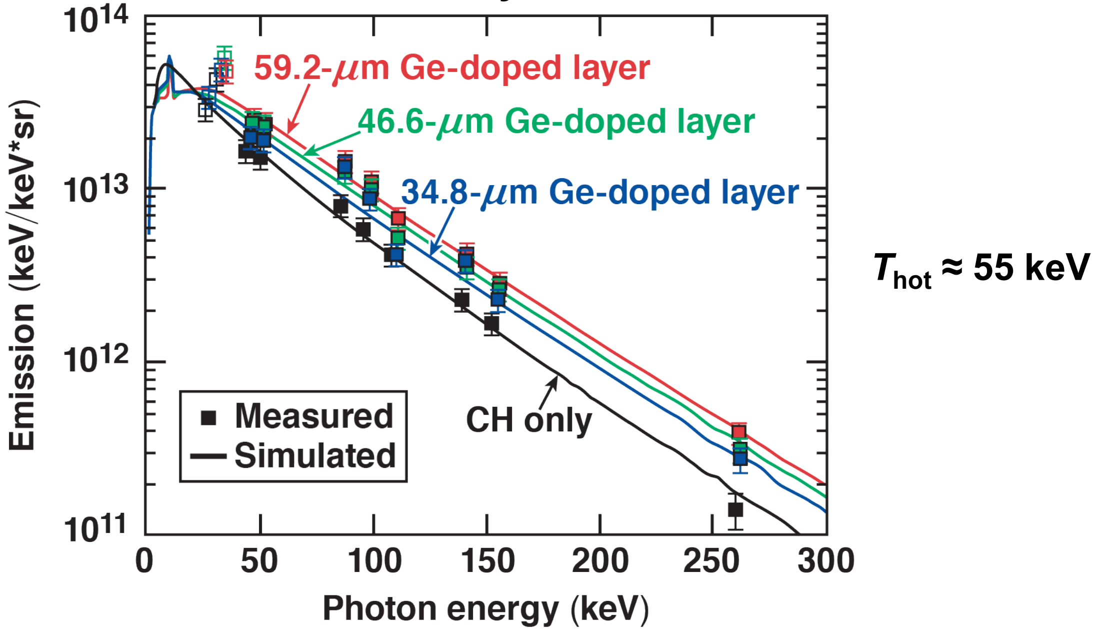


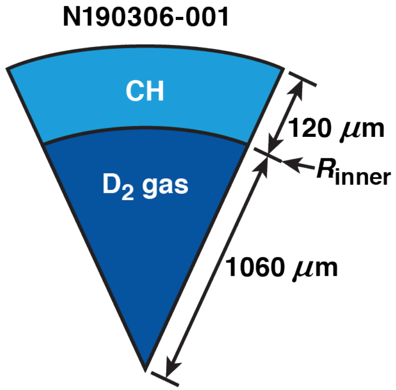
- Hot-electron temperature, total energy, divergence angle, and refluxing fraction were varied to reproduce the measured HXR spectra
- The hot-electron divergence half-angle is found to exceed 45°, the angular size of the cold shell from the $n_c/4$ surface

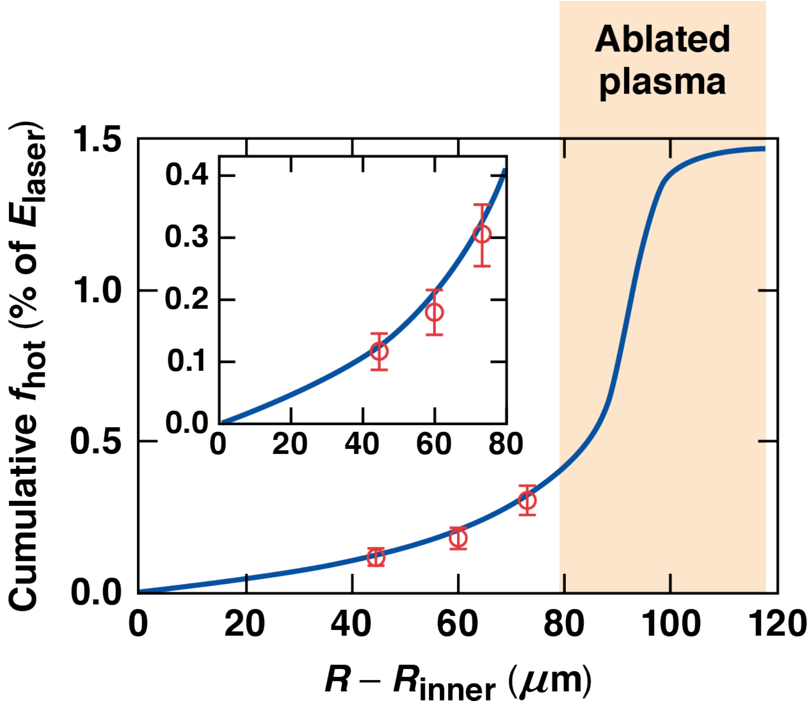
* J. Delettrez *et al.*, Phys. Rev. A 36, 3926 (1987).
** J. Allison *et al.*, Nucl. Instrum. Methods Phys. Res. A 835, 186 (2016).

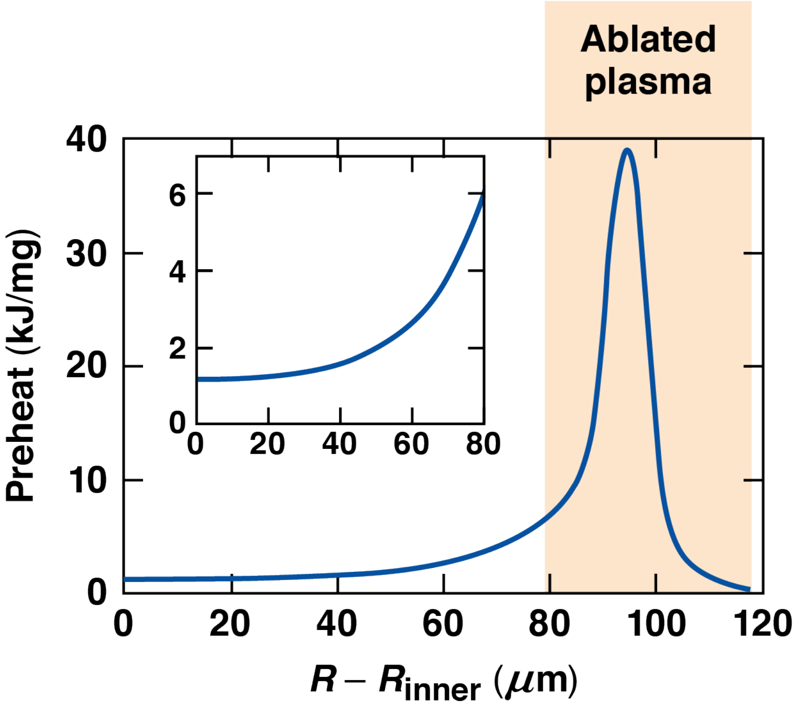
LPI: laser–plasma interaction

The hot-electron energy deposition profile was inferred from Geant4 Monte Carlo simulations

Incident intensity = 10^{15} W/cm^2







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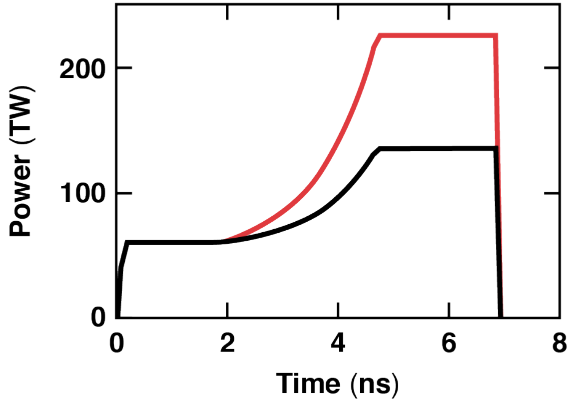
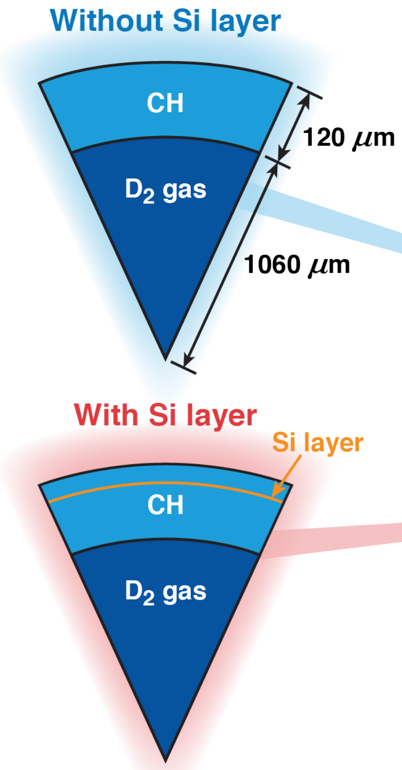
- Red circles: energy deposition in the Ge-doped layer in multilayered targets

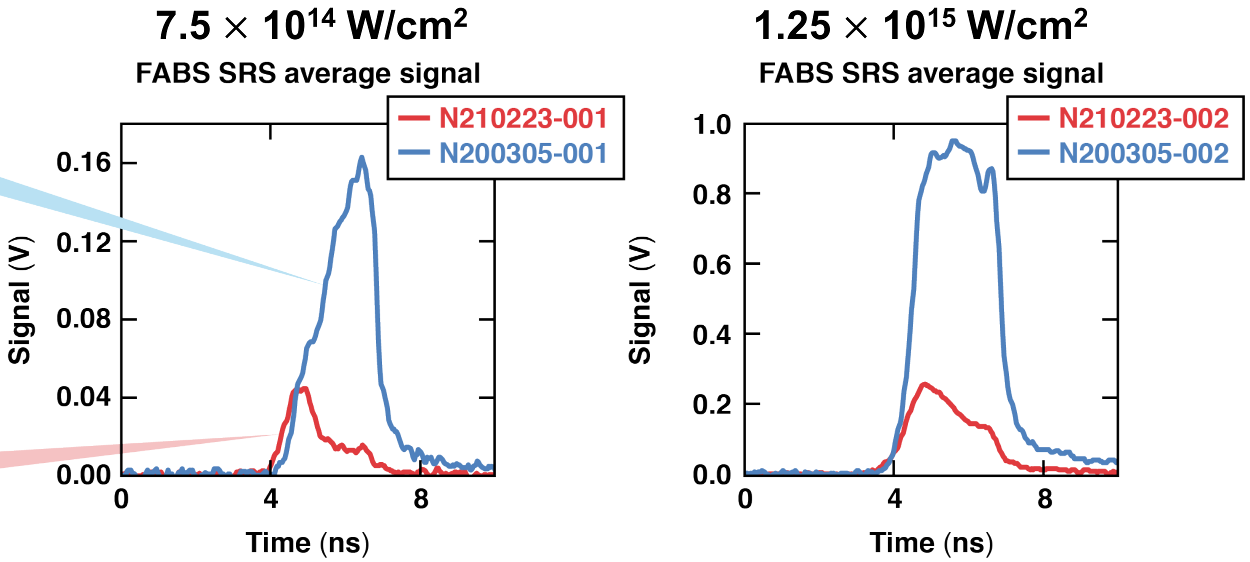
About half of the preheat (~0.2% of E_{laser}) is deposited in the inner 80% of the unablated shell.

Si layers strategically placed in the ablator were found to mitigate LPI and hot-electron preheat





FABS time-resolved SRS signal



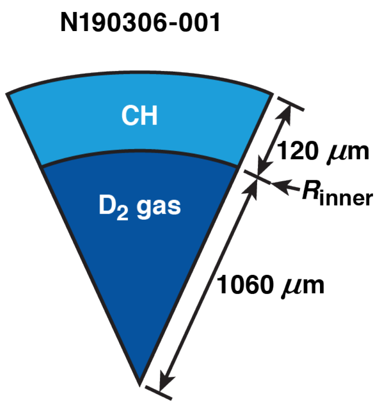
The Si layer suppresses SRS when it reaches the $n_c/4$ region early in flattop (~5 ns)

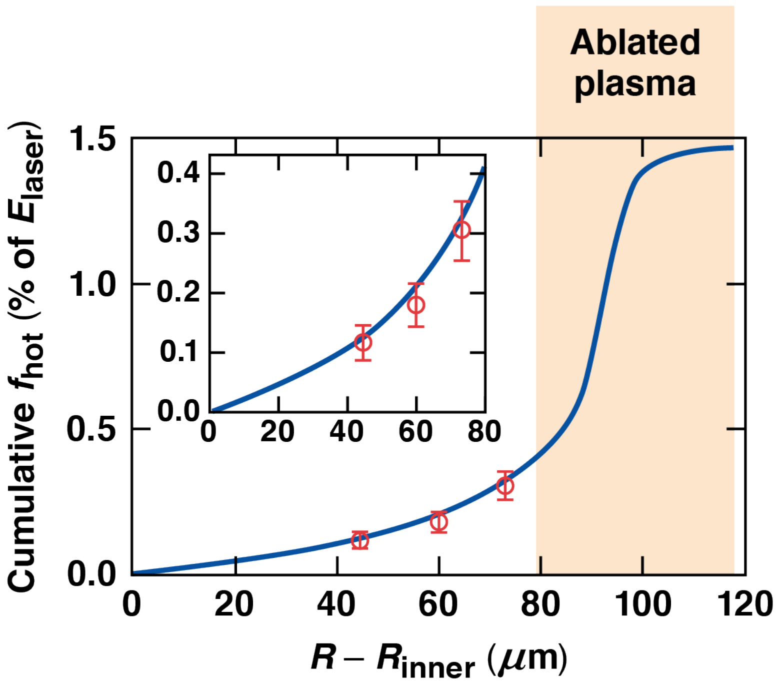
- **SRS is mitigated* in Si by**
  - **shortening the density scale length at $n_c/4$ from ~420 μm to ~340 μm according to hydro simulations**
  - **increasing the electron–ion collisionality $\nu_{ei} \propto Z_{eff} = \langle Z^2 \rangle / \langle Z \rangle$, which enhances absorption of the incident and scattered light and damps electron plasma waves**

* C. S. Liu, M. N. Rosenbluth, and R. B. White, Phys. Fluids 17, 1211 (1974); R. E. Turner *et al.*, Phys. Rev. Lett. 54, 189 (1985); 1878(E); J. R. Fein *et al.*, Phys. Plasmas 24, 032707 (2017); J. F. Myatt *et al.*, Phys. Plasmas 20, 052705 (2013).

Hot-electron preheat is reduced by ~2× with a Si layer at an incident intensity of 10^{15} W/cm²

Incident intensity = 10^{15} W/cm²





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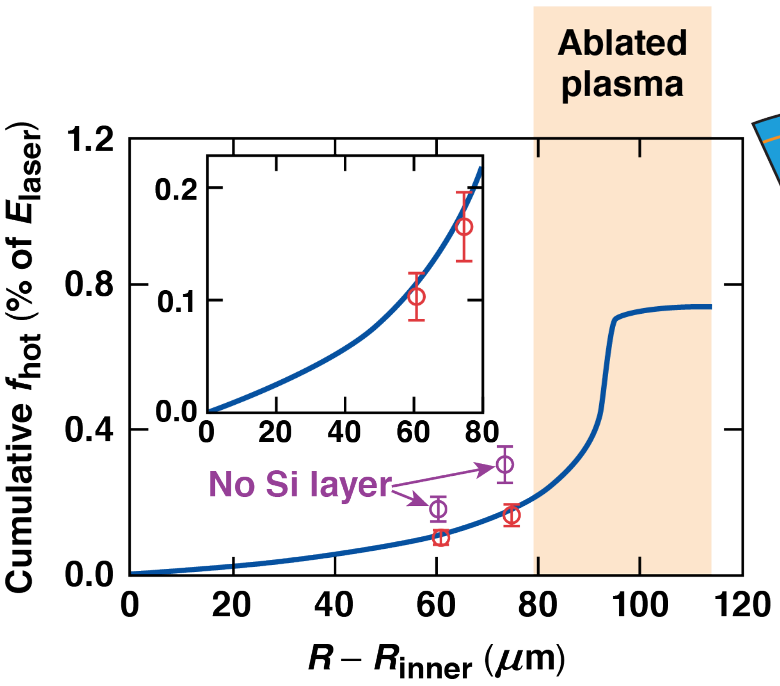

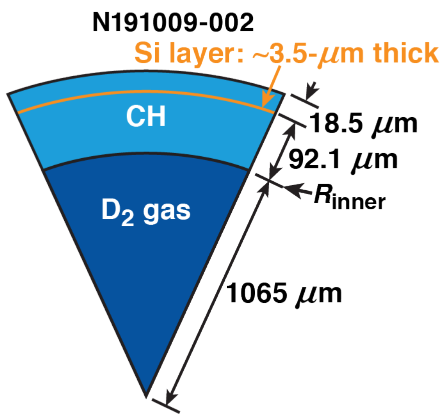

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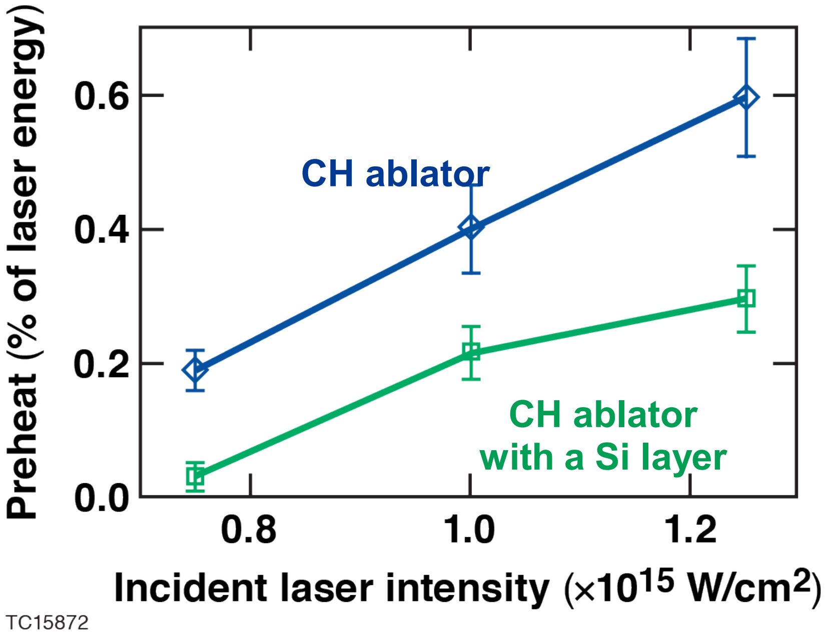
About half of the preheat is deposited in the inner 80% of the unablated shell.

Hot-electron preheat scaling with the incident laser intensity has been obtained with and without a Si layer

Hot-electron energy deposition in an unablated shell



About half of the preheat is deposited in the inner 80% of the unablated shell: 0.1 to 0.15% of E_l at $I \sim (1 \text{ to } 1.25) \times 10^{15}$ W/cm^2 with a Si layer

~0.15% of the laser energy is an acceptable preheat fraction for high-gain ignition designs*

Si layers provide a promising preheat mitigation strategy for ignition designs at an on-target intensity of about 10^{15} W/cm^2.

Si layers should be kept thin to maximize the drive (ablation) pressure and reduce radiation preheat**

* J. A. Delettrez, T. J. B. Collins, and C. Ye, Phys. Plasmas 26, 062705 (2019), see also M. R. Rosenberg *et al.* UO04.00004 (this session).
** V. N. Goncharov *et al.*, Phys. Plasmas 21, 056315 (2014).

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