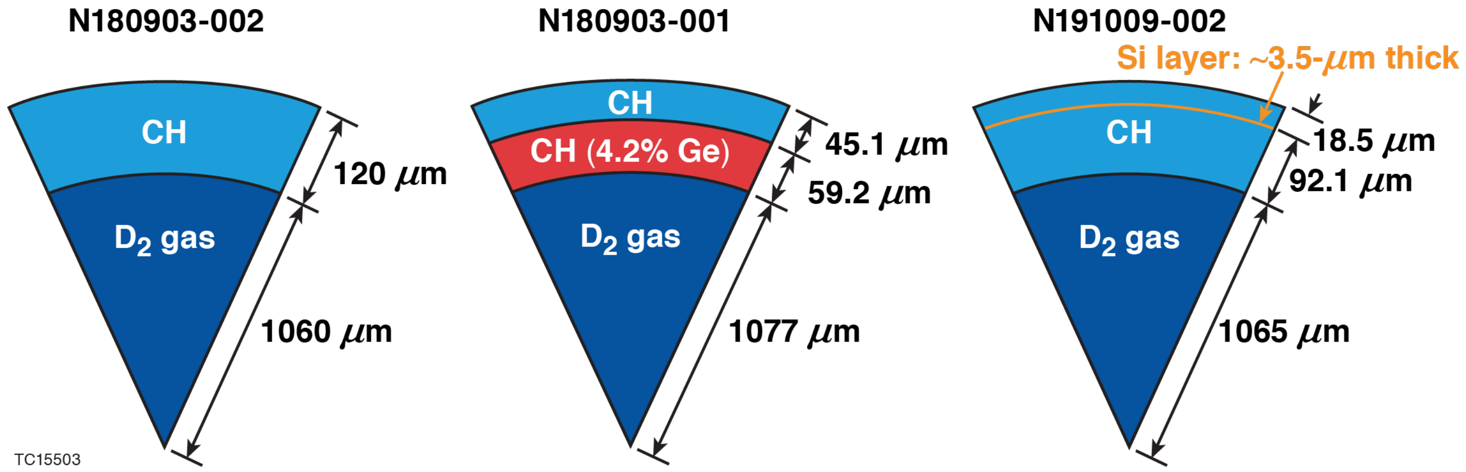
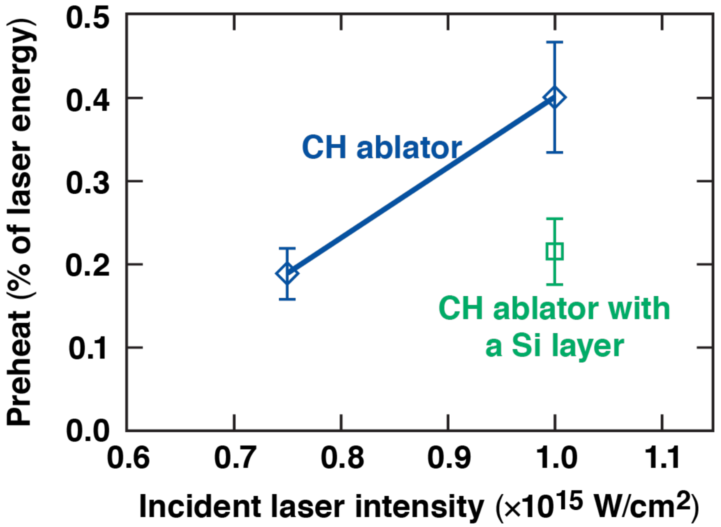
Scaling and Mitigation of Hot-Electron Preheat in Polar-Direct-Drive Experiments at the National Ignition Facility

Mass-equivalent targets



Hot-electron energy deposition in unablated shell



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Summary

Hot-electron energy deposition and preheat mitigation have been studied in polar-direct-drive (PDD) experiments at the National Ignition Facility

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- Hot-electron preheat has been measured by comparing hard x-ray (HXR) production in multilayered implosions on the NIF and analyzed using Monte Carlo simulations of hot-electron transport
- Hot-electron coupling from 0.2% to 0.4% of the laser energy to the unablated shell is found when the incident laser intensity increases from (0.75 to 1) $\times 10^{15}$ W/cm^2, with half of the preheat coupled to the inner 80% of the unablated shell
- Use of a thin Si layer in the ablator reduces the preheat by a factor of 2 at a laser intensity of 10^{15} W/cm^2

Mid-Z layers and laser frequency detuning/bandwidth* can reduce the hot-electron preheat.

* R. K. Follett *et al.*, Phys. Rev. Lett. 116, 155002 (2016);
R. K. Follett *et al.*, Phys. Plasmas 26, 062111 (2019);
D. Turnbull *et al.*, "Impact of Spatiotemporal Smoothing on the Two-Plasmon–Decay Instability," to be published in Physics of Plasmas.

Collaborators

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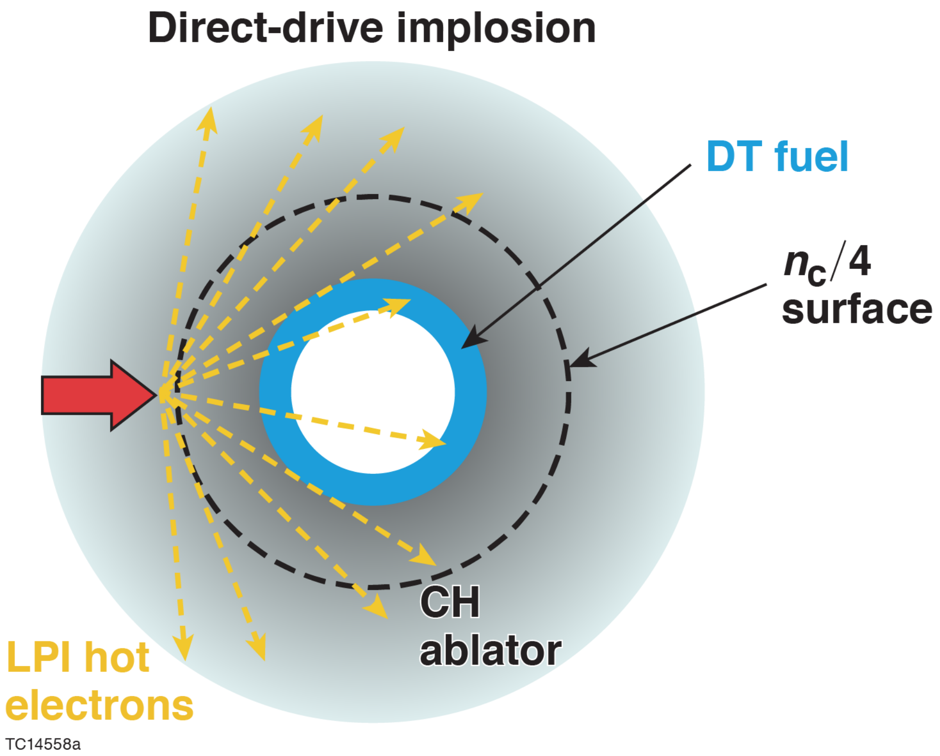
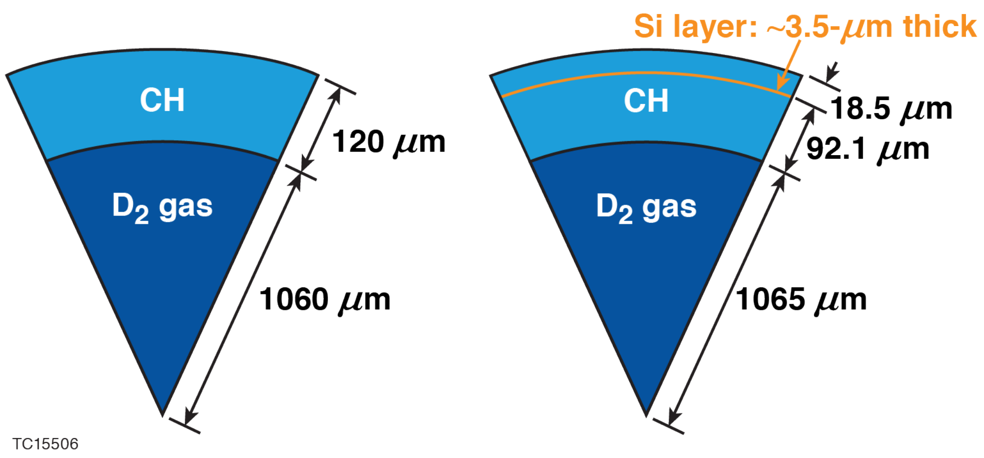
Hot-electron preheat can degrade fuel compression in direct-drive–ignition designs

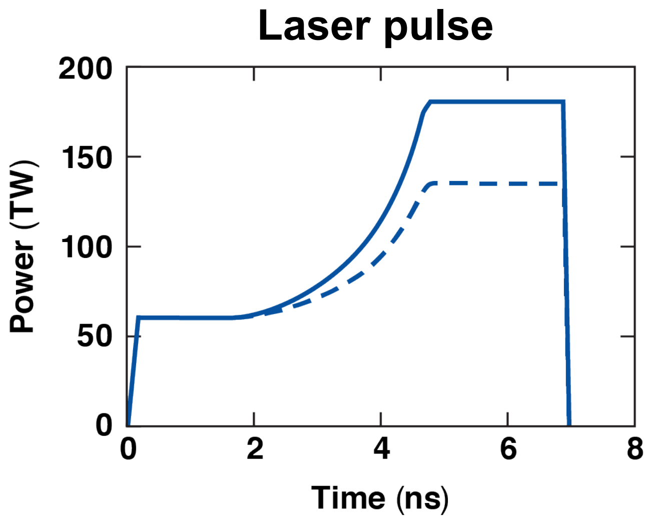


- Fuel compression is negatively affected if more than ~0.15% of laser energy is coupled into fuel preheat*
- If electron divergence is large, only ~25% of electrons intersect the cold fuel**
- Electrons below ~50 keV are stopped in the ablator

LPI: laser–plasma interaction
* J. A. Delettrez, T. J. B. Collins, and C. Ye, Phys. Plasmas 26, 062705 (2019).
** B. Yaakobi *et al.*, Phys. Plasmas 20, 092706 (2013).

Hot-electron preheat and preheat mitigation using a thin Si layer in the ablator have been studied in room-temperature plastic implosions on the NIF





Simulated plasma conditions at 0.17 $n_c < n < 0.25\, n_c$, where stimulated Raman scattering (SRS) is active

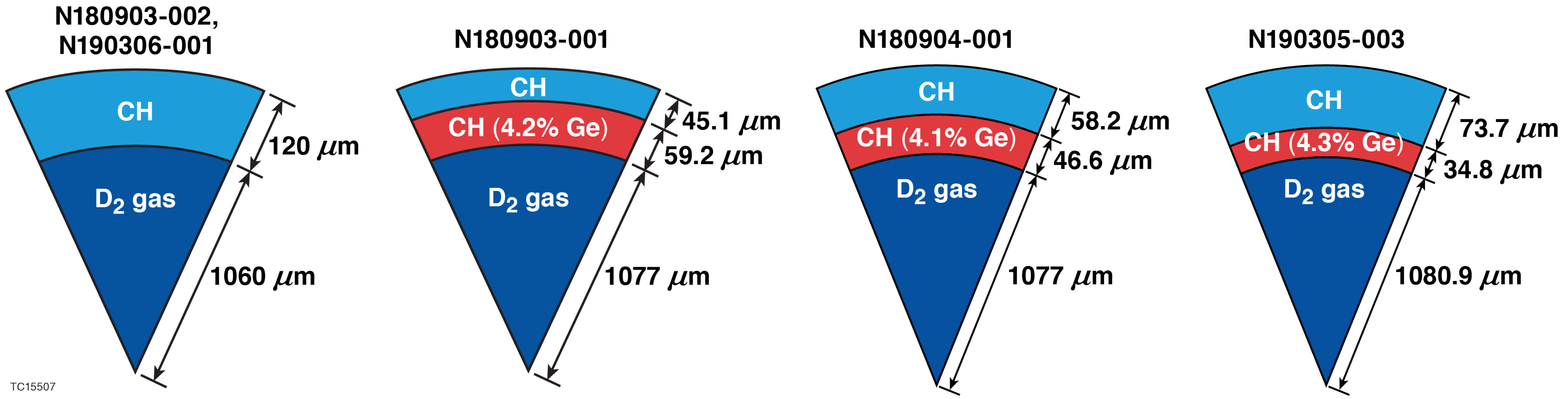
Ablator material	Incident intensity ($\times 10^{15}$ W/cm^2)	I_L ($\times 10^{14}$ W/cm^2)	L_n (μm)	T_e (keV)
CH	1	2.7 to 6	420	3.2
CH	0.75	2.3 to 4.5	420	3.0
CH+Si	1	2.8 to 6	340	3.9
CH+DT, ignition design*	1.2 to 2	6 to 10	600	3.5 to 5

- **Shorter L_n and higher T_e reduce** SRS and two-plasmon decay in Si**

* T. J. B. Collins *et al.*, Phys. Plasmas 19, 056308 (2012).
** R. K. Follett *et al.*, Phys. Rev. Lett. 116, 155002 (2016); C. S. Liu, M. N. Rosenbluth, and R. B. White, Phys. Fluids 17, 1211 (1974).

Hot-electron transport in NIF PDD implosions was studied by comparing HXR between plastic and multilayered implosions*

Mass-equivalent targets

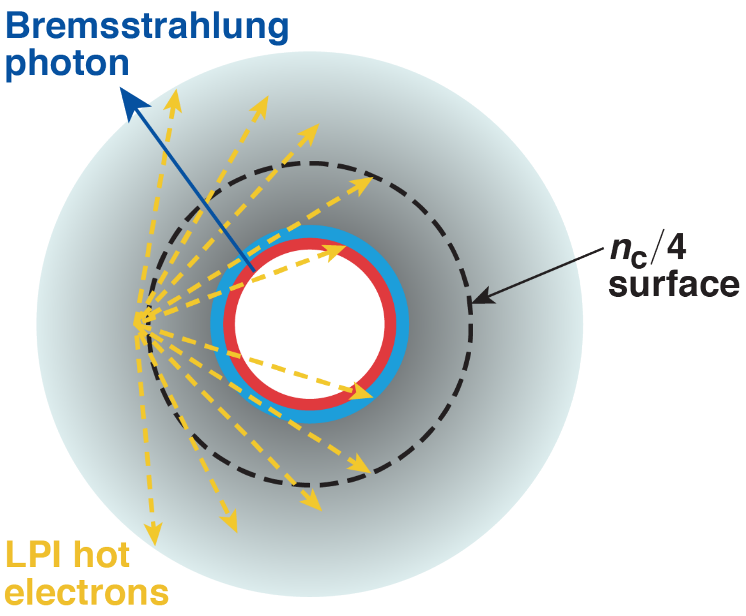


TC15507

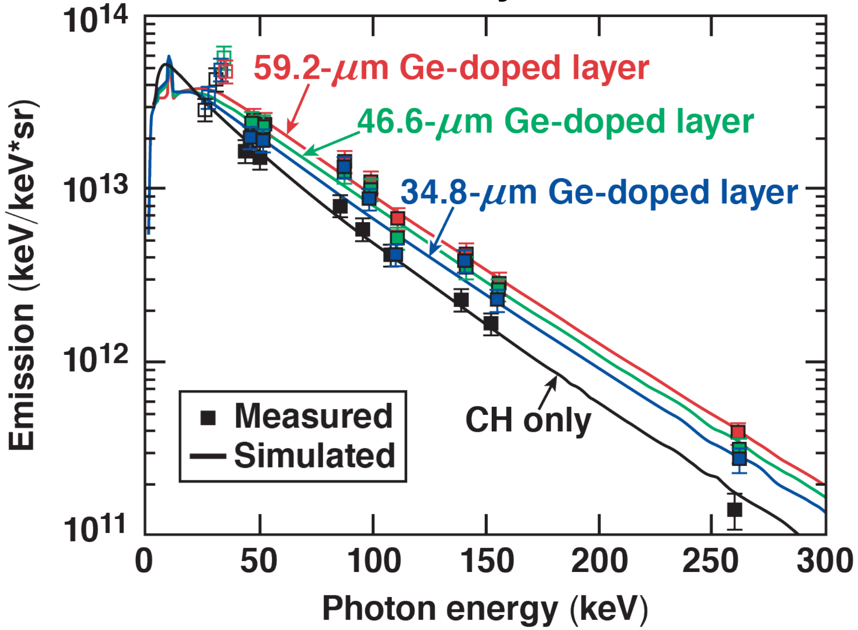
Different thicknesses of the Ge-doped layer are examined to diagnose the hot-electron deposition profile in the imploding shell.

* A. R. Christopherson *et al.*, "Direct Measurements of DT Fuel Preheat from Hot Electrons in Direct-Drive Inertial Confinement Fusion," submitted to Physical Review Letters.

NIF implosions were simulated using the hydrocode *LILAC*,* hot-electron transport, and energy deposition in the imploded shells using the Monte Carlo code Geant4**



TC15508

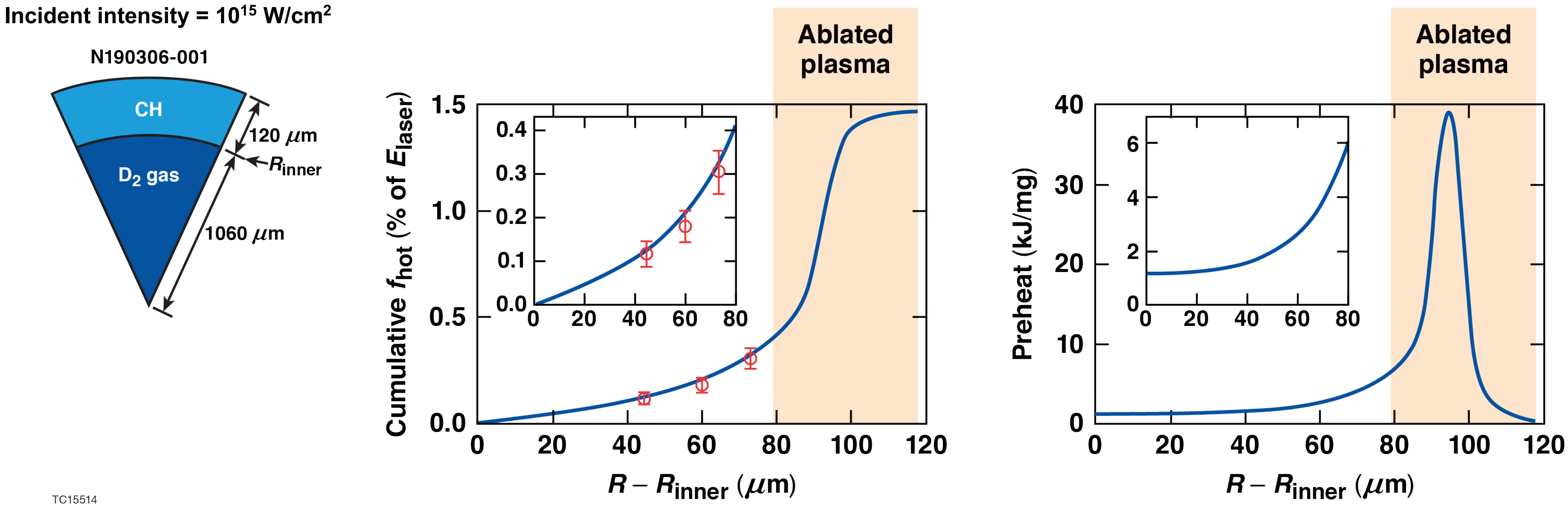


$T_{hot} \approx 55$ keV

- 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).

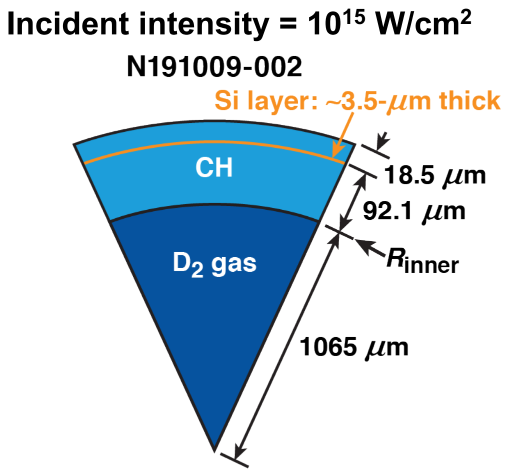
The hot-electron energy deposition profile was inferred from Geant4 Monte Carlo simulations

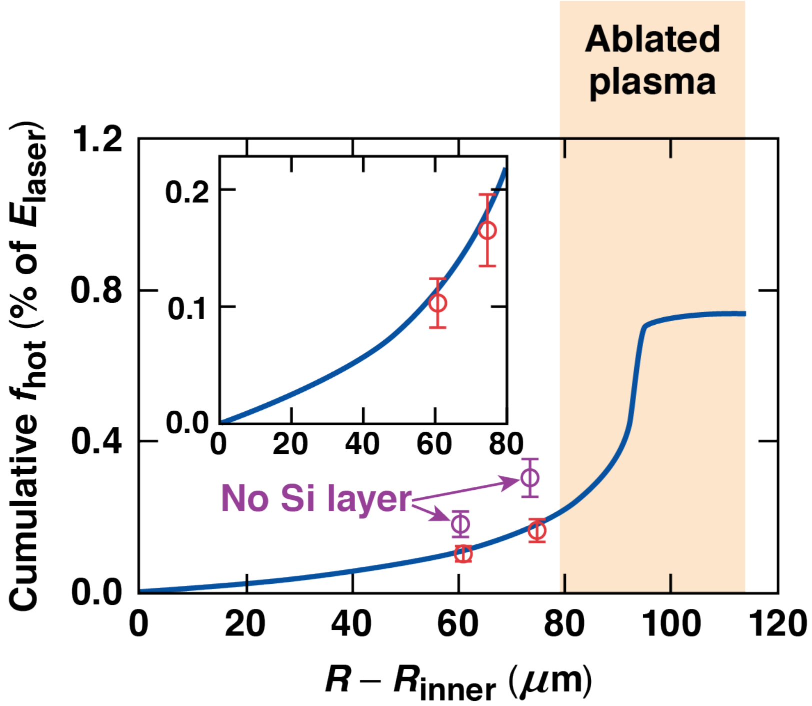


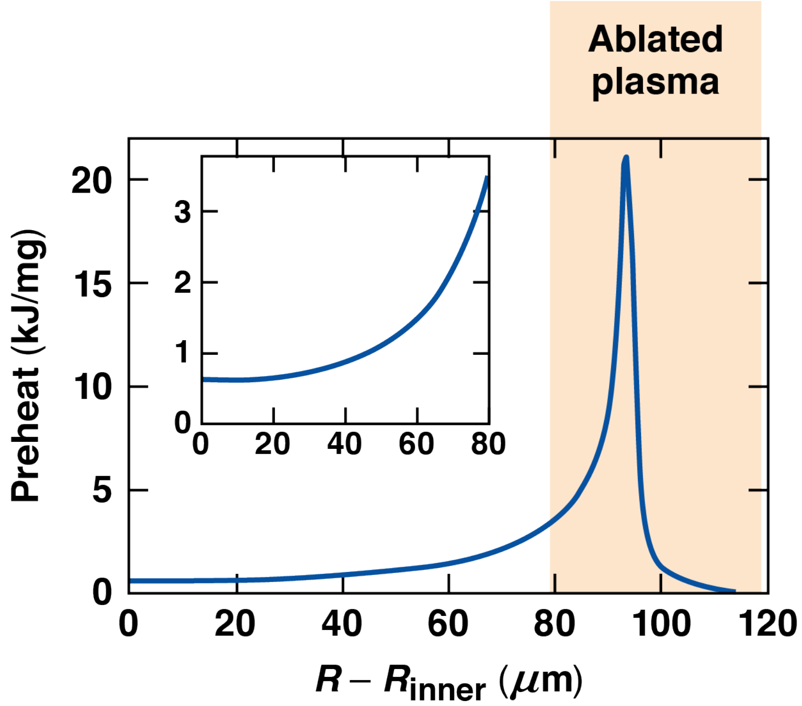
- Red circles: energy deposition in the Ge-doped layer in multilayered targets

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

Hot-electron preheat is reduced by ~2× in implosions with a Si layer in the ablator







TC15515

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

About half of the preheat (~0.1% of E_{laser}) is deposited in the inner 80% of the unablated shell.

NIF experiments demonstrate preheat scaling with the incident laser intensity and preheat mitigation using a thin mid-*Z* Si layer in the ablator

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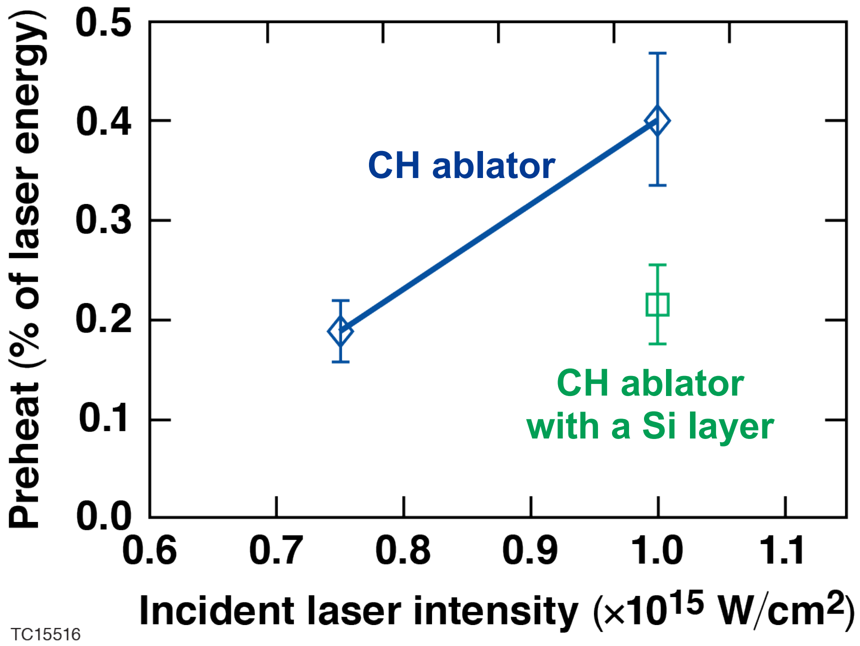
Hot-electron energy deposited in the unablated shell



About half of the preheat energy is deposited in the inner 80% of the unablated shell, which is comparable or less than 0.15% of E_{laser}, tolerable to preheat

We investigate how these results extrapolate to NIF ignition-scale cryogenic DT implosions*

- longer density scale lengths and reduced hot-electron attenuation in ablated DD increase the preheat
- larger shell convergence ratio (~3 to 3.5 instead of ~2 in these experiments) reduces the preheat by ~60%

* T. J. B. Collins *et al*., Phys. Plasmas 19, 056308 (2012);
T. J. B. Collins *et al*., Phys. Plasmas 25, 072706 (2018).

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