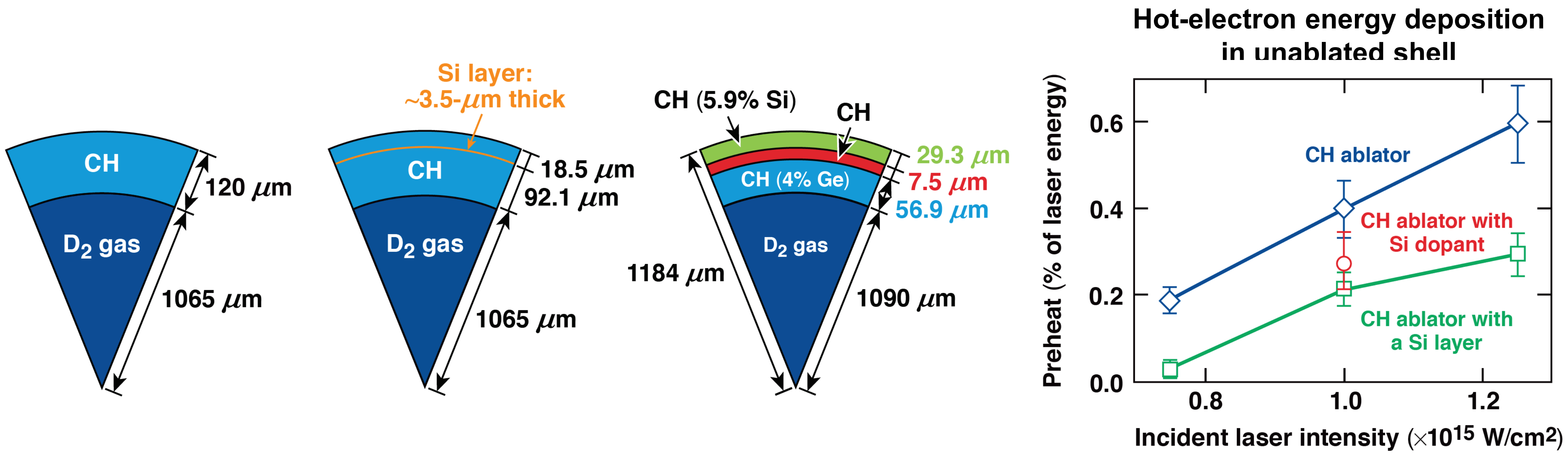
Hot-Electron Preheat and Mitigation in Polar-Direct-Drive Experiments at the National Ignition Facility



TC16117

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

- **Surrogate plastic implosion experiments were performed at the National Ignition Facility (NIF) to quantify preheat levels 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 (LPI's), suppressing preheat at the intensity of 7.5 $\times$ 10^{14} W/cm^2 and reducing by a factor of ~2 at higher intensities; hot-electron preheat is reduced by 30% using Si dopant at 10^{15} W/cm^2**

- **Shell convergence is found to significantly reduce hot-electron preheat late during the implosion**

Collaborators

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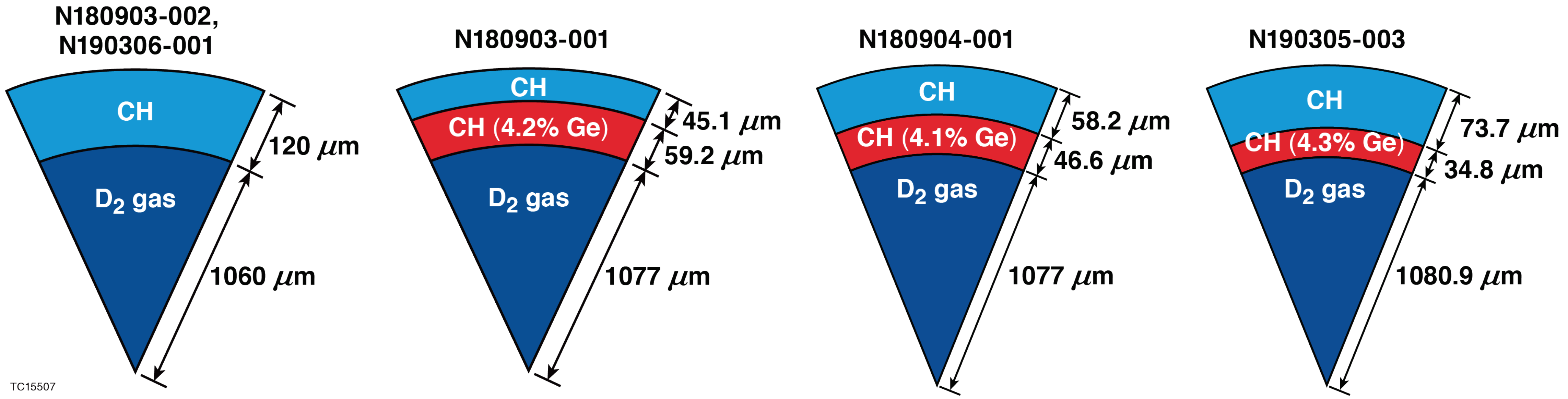
Hot-electron preheat in NIF polar-direct-drive (PDD) implosions was studied by comparing hard x-ray (HXR) emission between plastic and multilayered implosions*

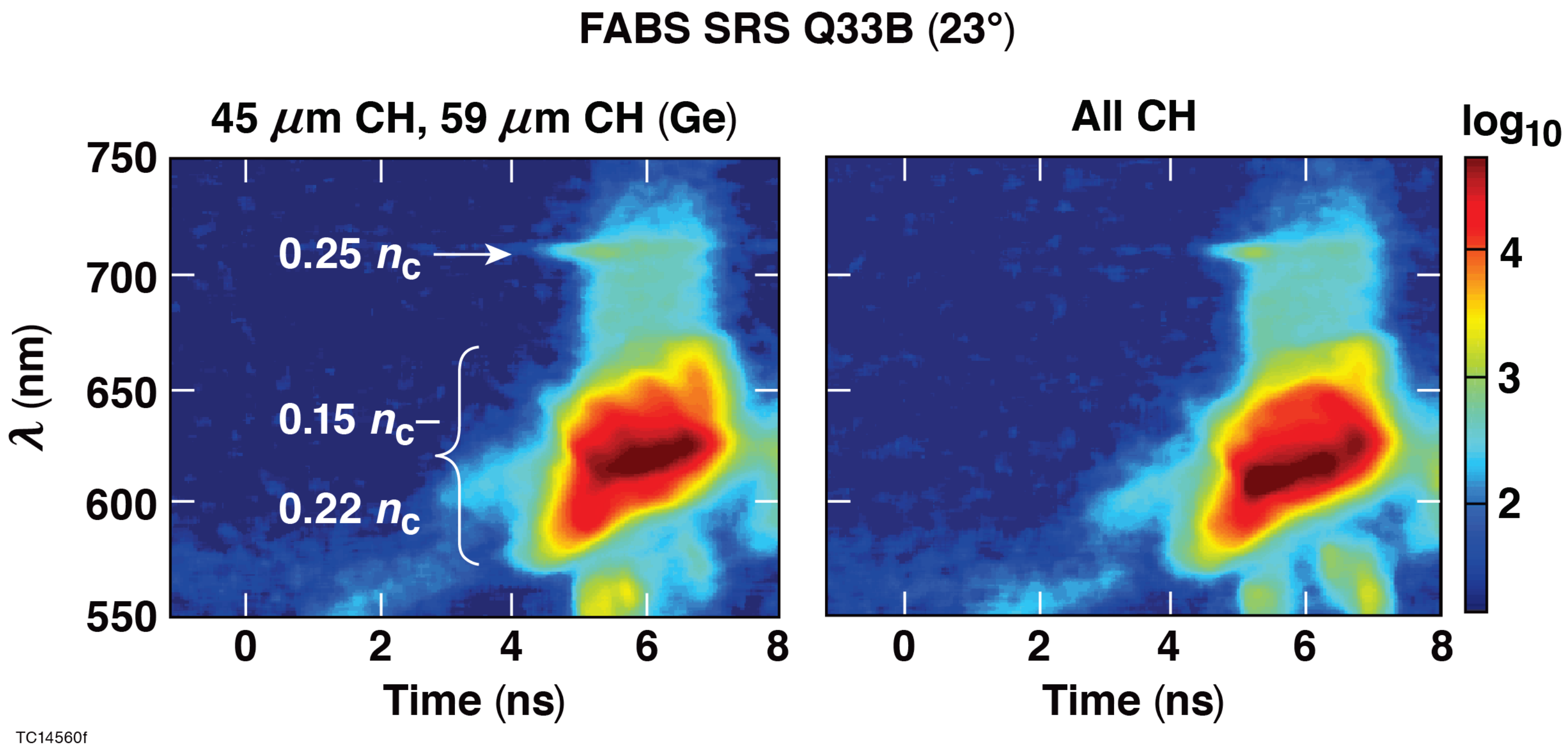
Mass-equivalent targets



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

* A. A. Solodov *et al.*, "Hot-Electron Preheat and Mitigation in Polar-Direct-Drive Experiments at the National Ignition Facility," submitted to Physical Review Letters.

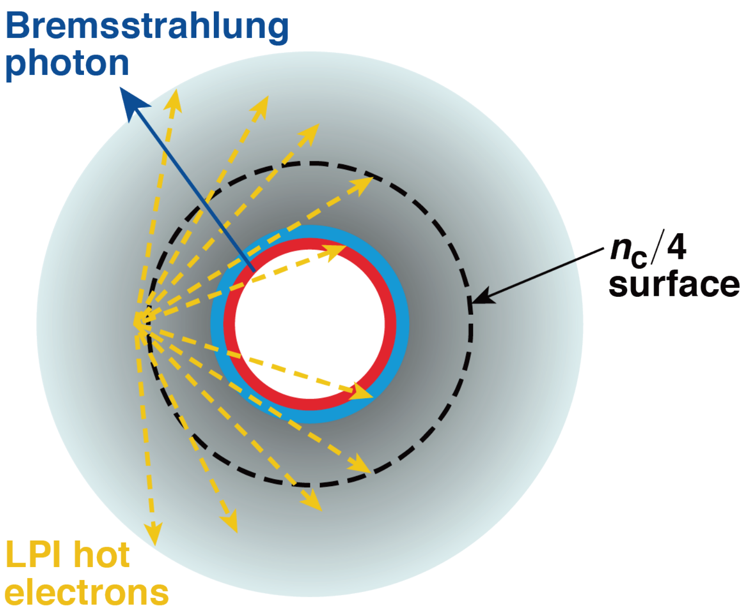
Time-resolved scattered-light spectra indicate that LPI is dominated by SRS and is similar between the all-CH and Ge-doped payload implosions



Similar LPI → similar hot-electron energy source

FABS: full-aperature backscatter station
SRS: stimulated Raman scattering
LPI: laser–plasma interaction

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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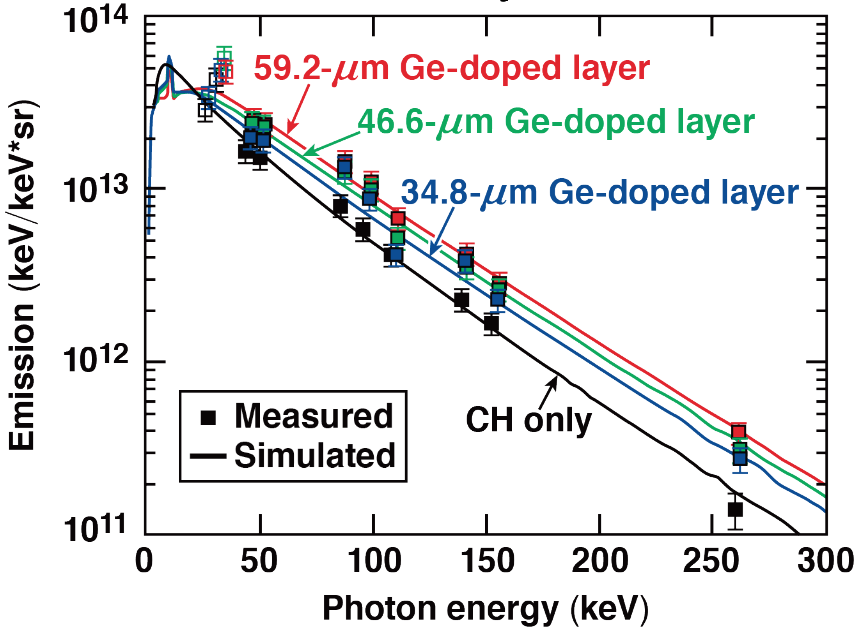


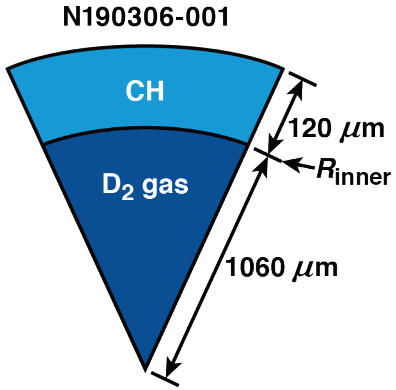
$T_{hot} \approx 55$ keV

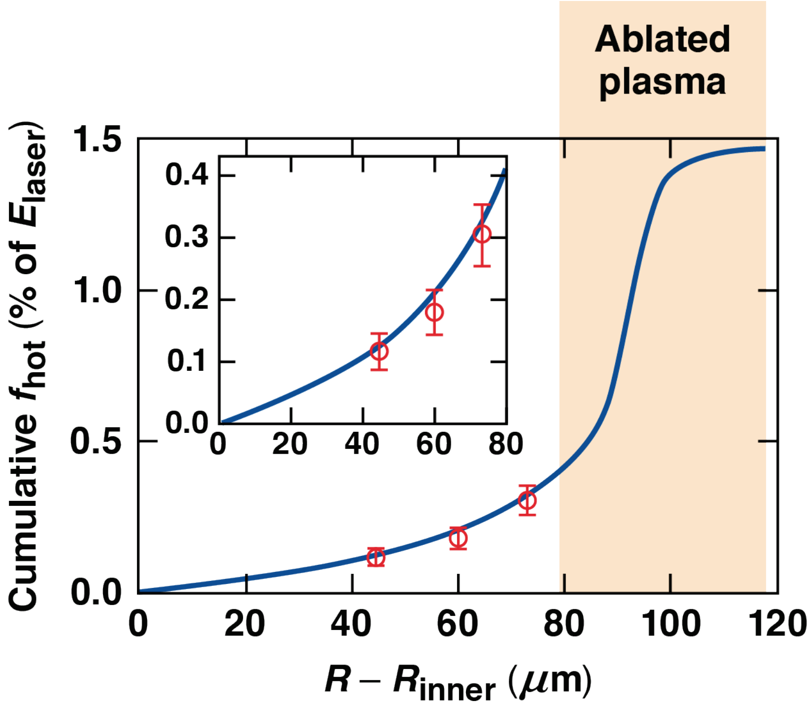
- Hot-electron temperature, total energy, divergence angle, and refluxing fraction were varied to reproduce the measured HXR spectra
- The hot-electron divergence half-angle is found to exceed 45°, the angular size of the cold shell from the $n_c/4$ surface

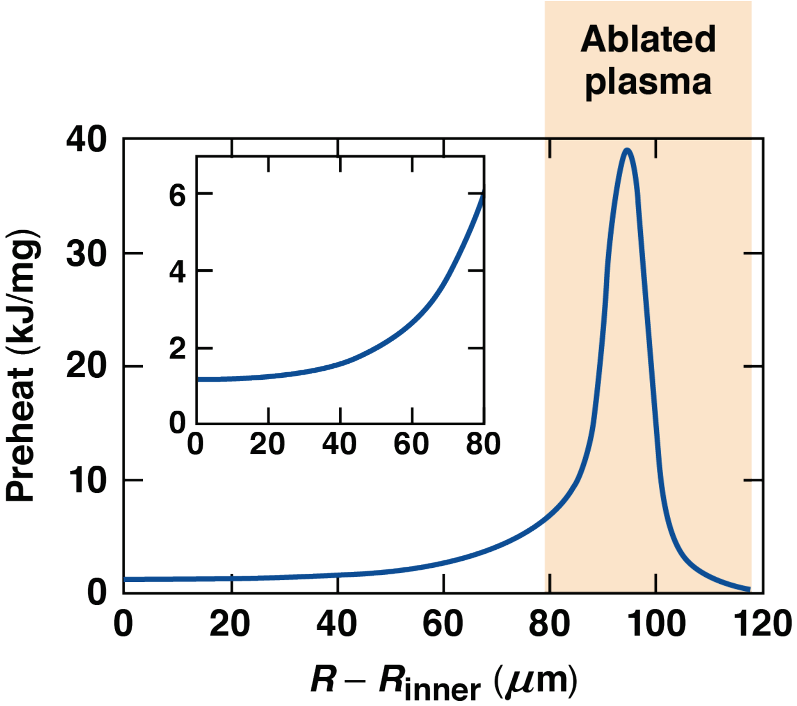
* J. Delettrez *et al.*, Phys. Rev. A 36, 3926 (1987).
** J. Allison *et al.*, Nucl. Instrum. Methods Phys. Res. A 835, 186 (2016).

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

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



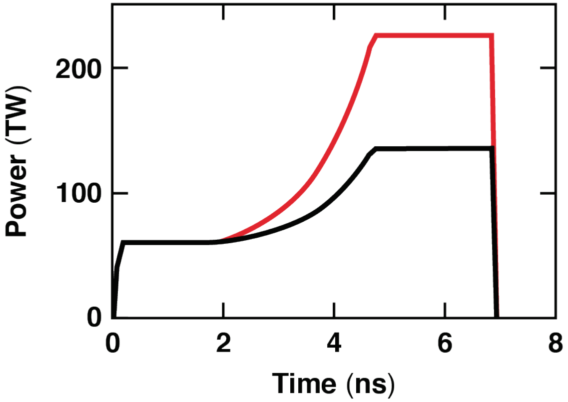


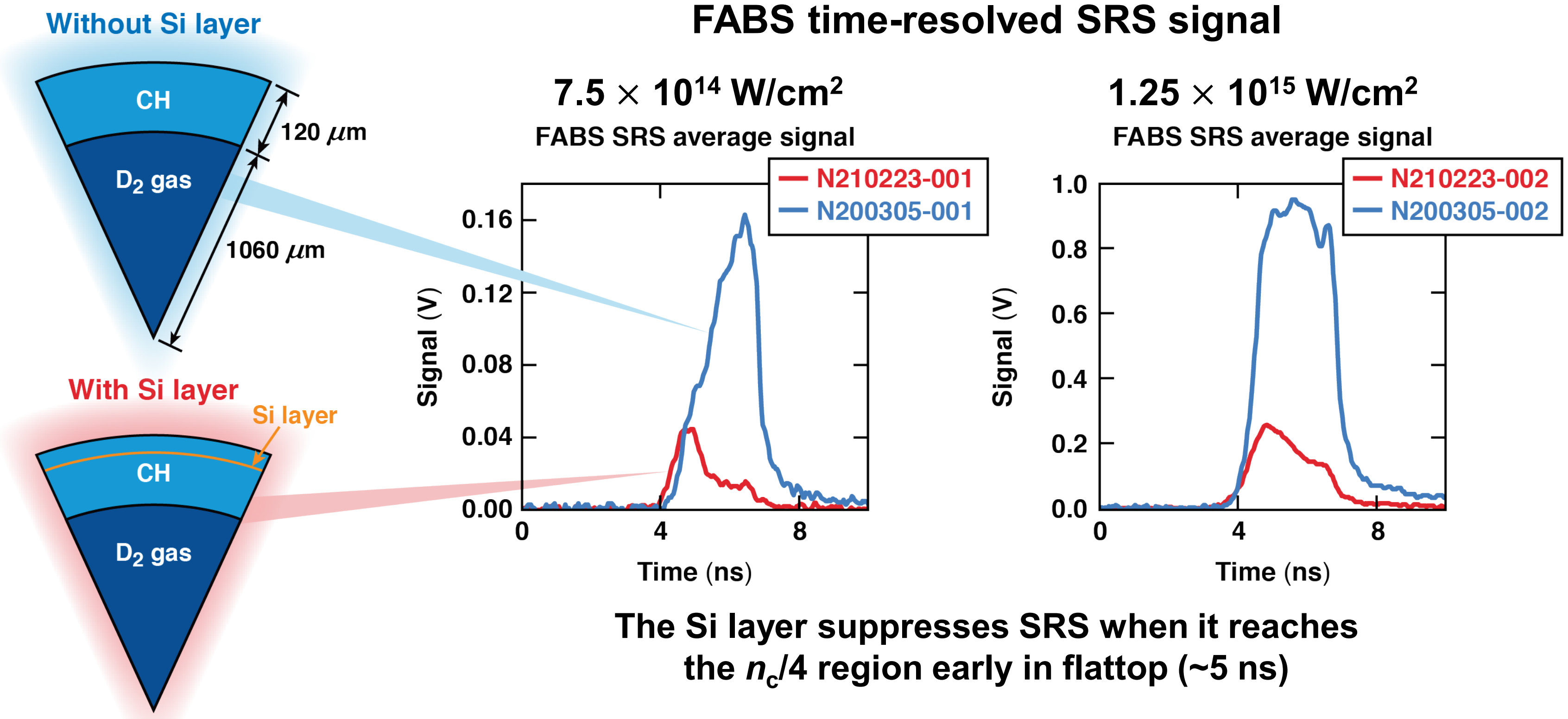


- **Red circles: energy deposition in the Ge-doped layer in multilayered targets**

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



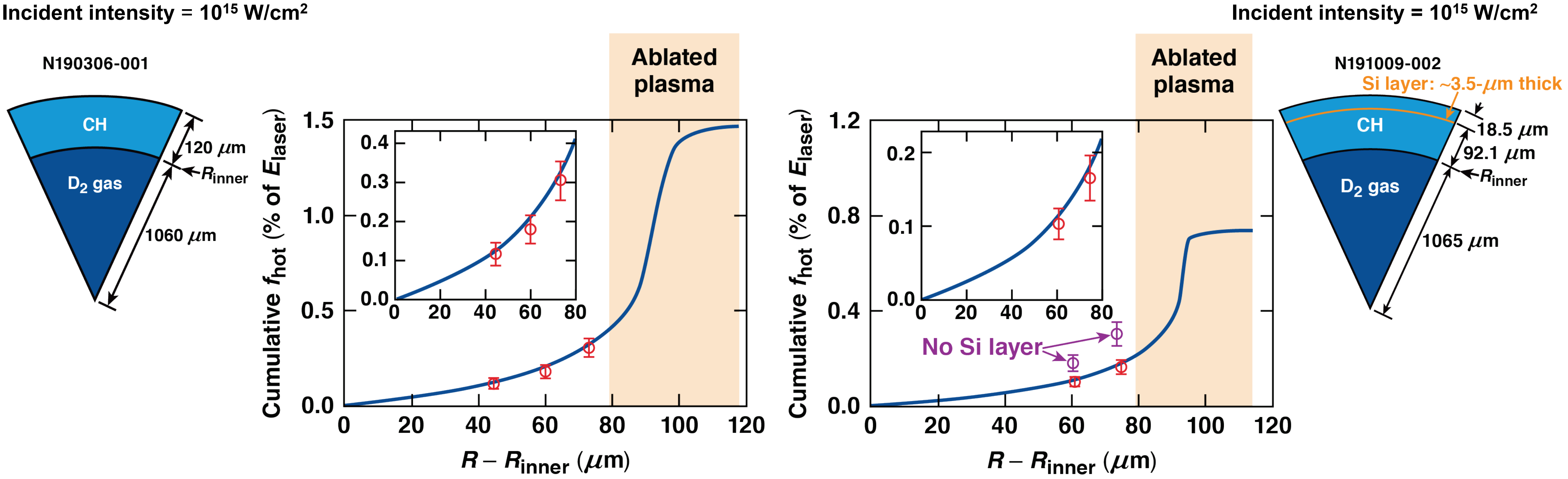


The Si layer suppresses SRS when it reaches the $n_c/4$ region early in flattop (~5 ns)

- **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) (1985); 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/cm^2



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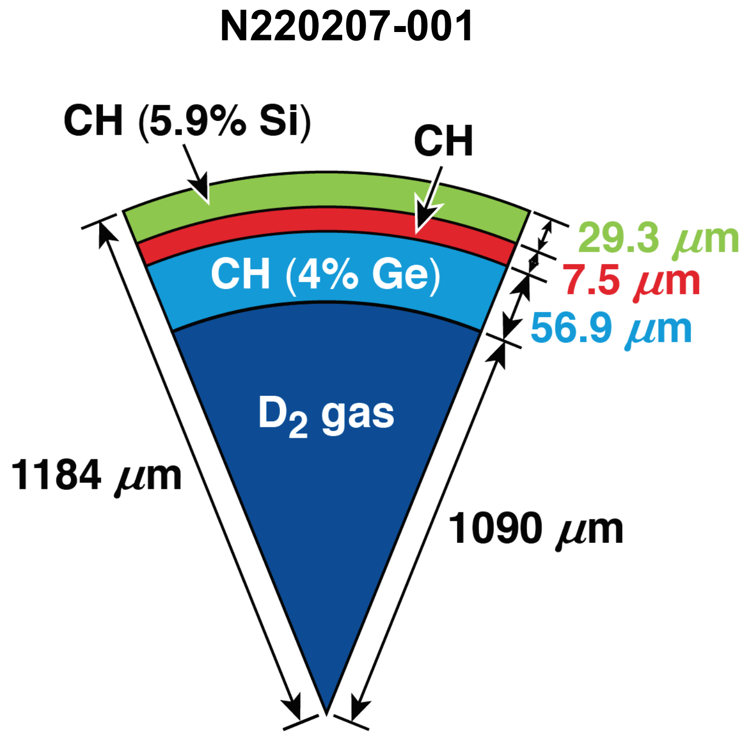
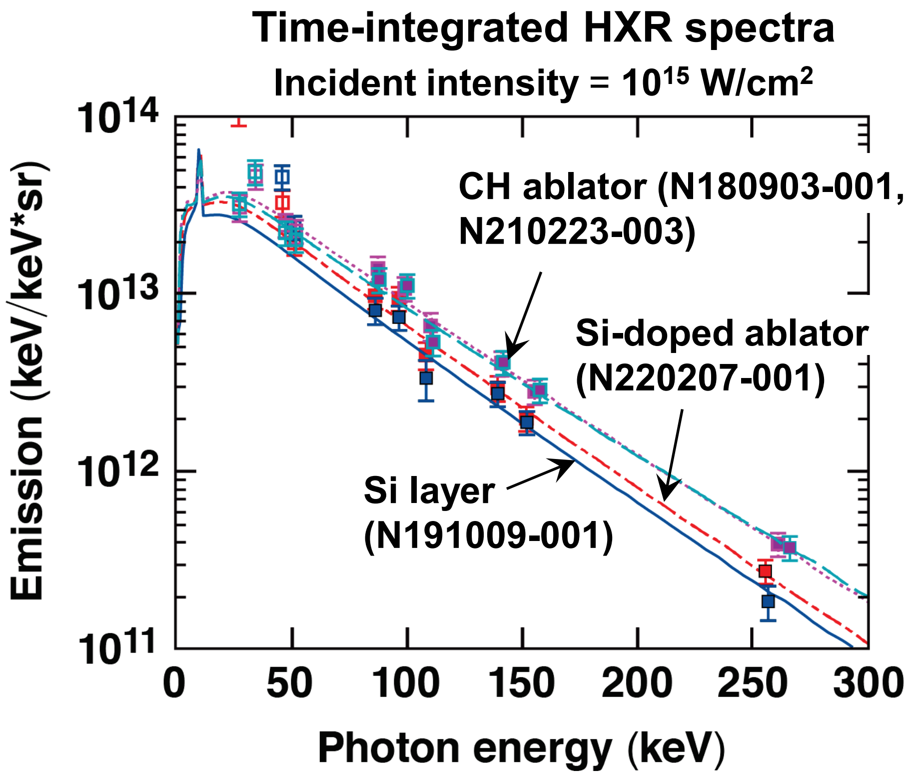
About half of the preheat is deposited in the inner 80% of the unablated shell.

Si-doped plastic ablators have advantageous hydrodynamic properties* and are promising to mitigate hot-electron preheat

Benefits of Si-doped plastic ablators:

- increase laser inverse bremsstrahlung absorption
- reduce cross-beam energy transfer
- reduce imprint
- better hydrodynamic stability than a Si layer



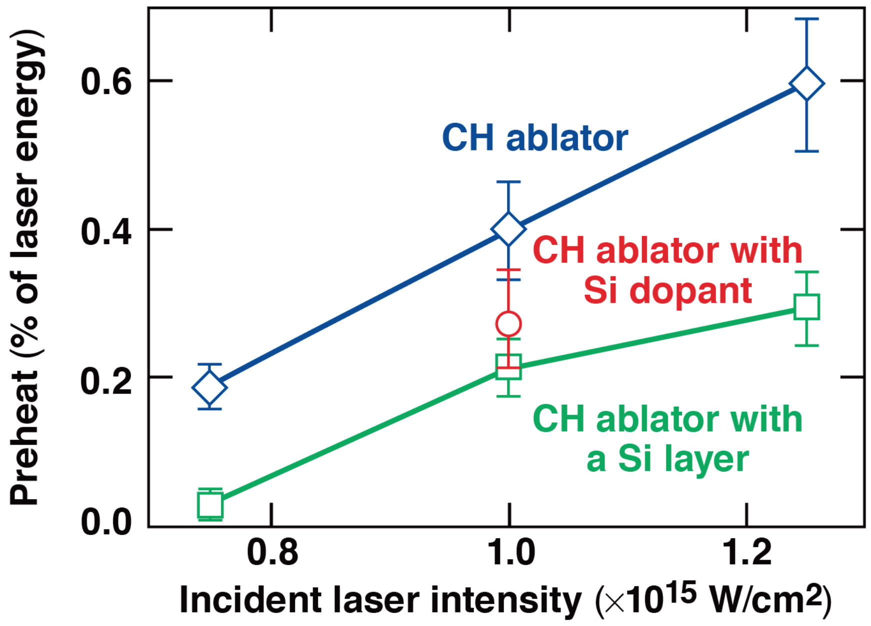


~30% preheat reduction using Si dopant, compared to plastic ablators

*V. N. Goncharov *et al.*, Phys. Plasmas 21, 056315 (2014) and references therein.

Hot-electron preheat scaling with the incident laser intensity has been obtained with and without mitigation using Si layer or dopant

Hot-electron energy deposition in an unablated shell



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

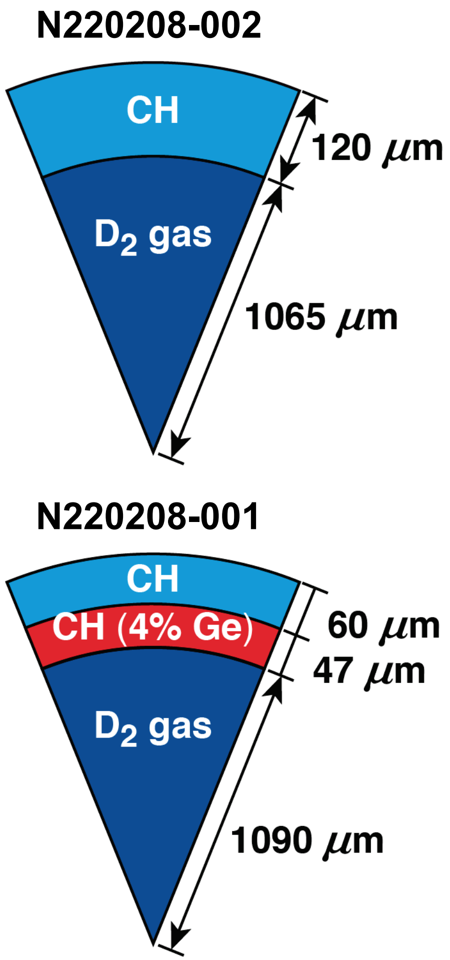
- 0.1% to 0.15% of E_L at I ~ (1 to 1.25) × 10^{15} W/cm^2 with a Si layer
- 0.14% of E_L at $I = 10^{15}$ W/cm^2 with Si dopant

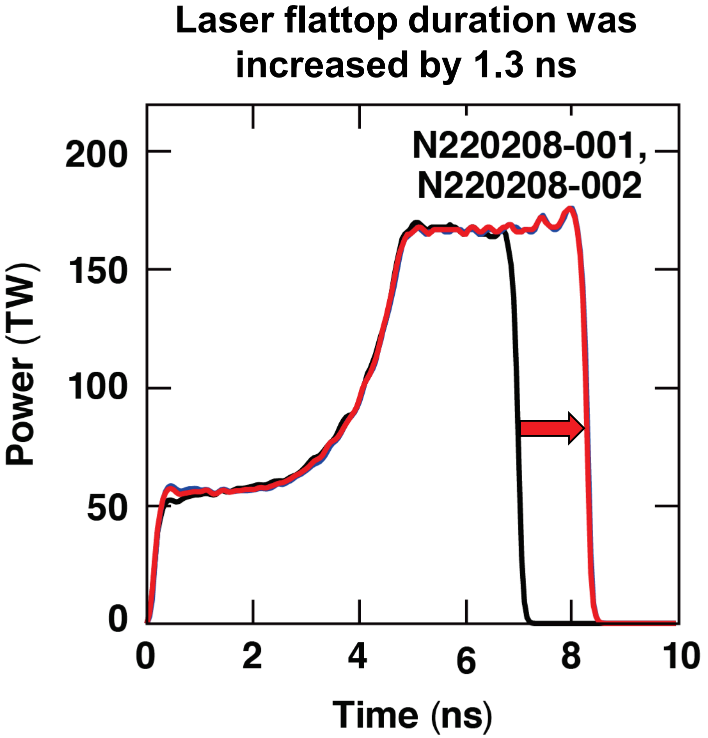
~0.15% of the laser energy is an acceptable preheat fraction for high-gain ignition designs*

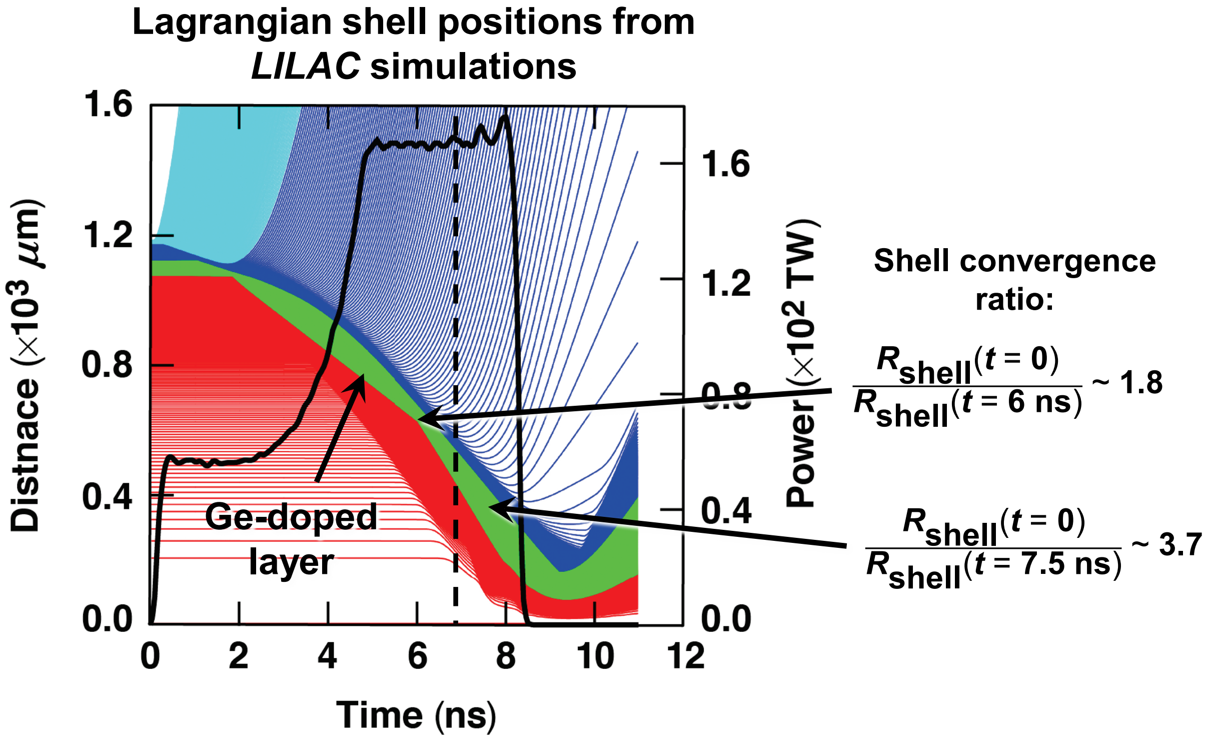
Si layers and dopants provide a promising preheat mitigation strategy for ignition designs at an on-target intensity of about 10^{15} W/cm^2.

*J. A. Delettrez, T. J. B. Collins, and C. Ye, Phys. Plasmas 26, 062705 (2019).

Recent experiments studied the effect of shell convergence during the implosion on preheat







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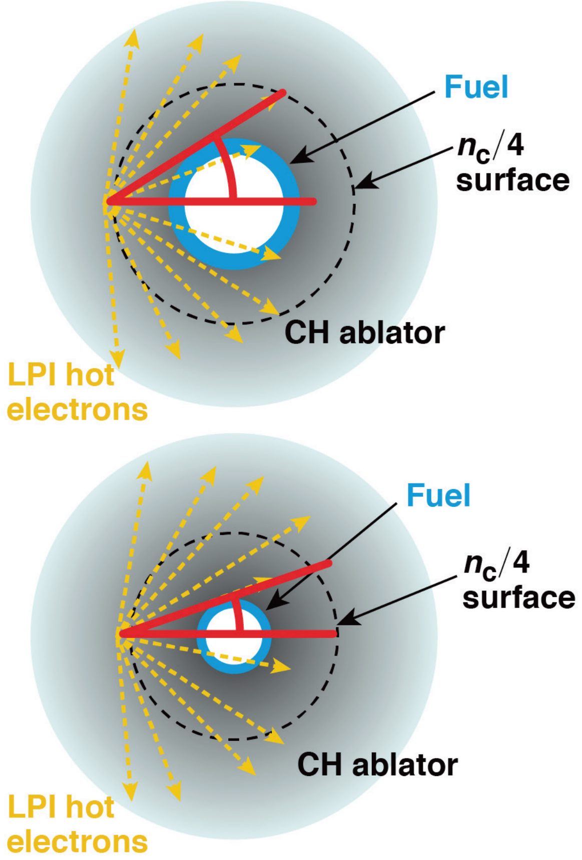
Hot-electron preheat decreases as the shell converges



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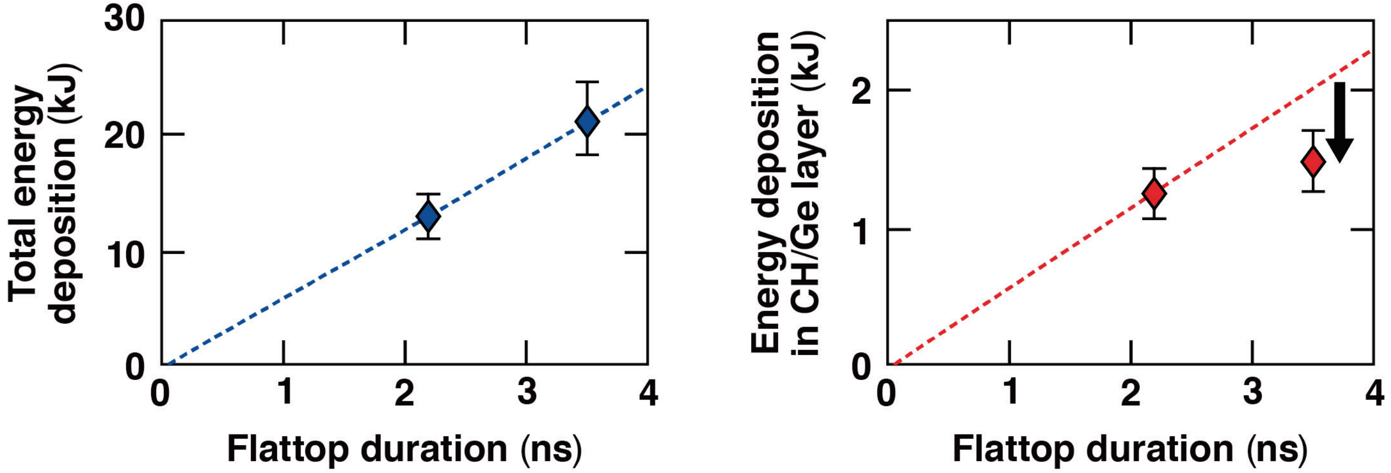
Inferred hot-electron energy deposition:
total and in the Ge-doped layer for two flattop durations

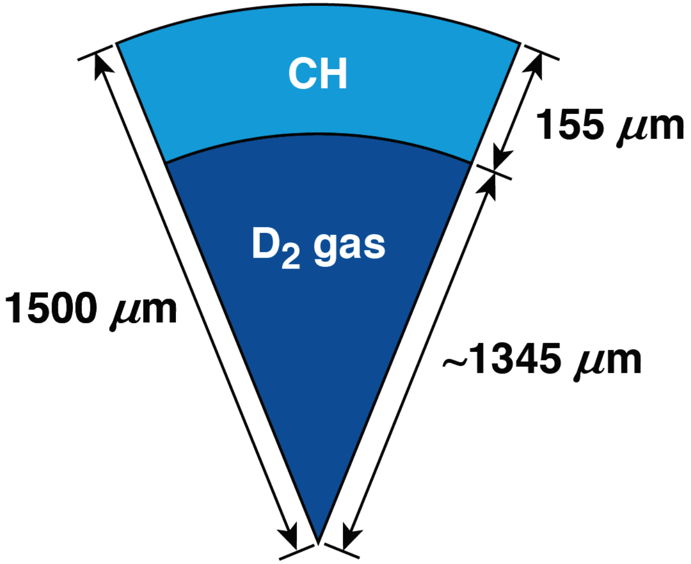


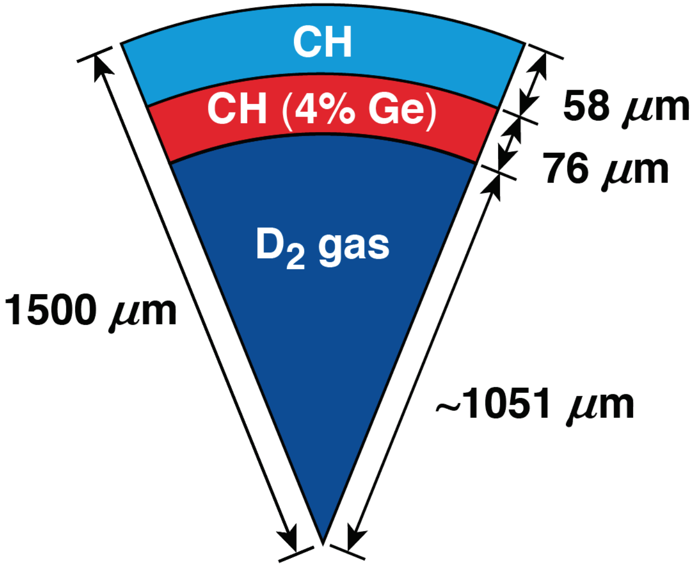
- **Energy deposition in the Ge-doped layer decreases as the solid angle of the dense shell from the $n_c/4$ surface: by a factor of ~4 during the last 1.3 ns of the 3.5-ns flattop pulse**

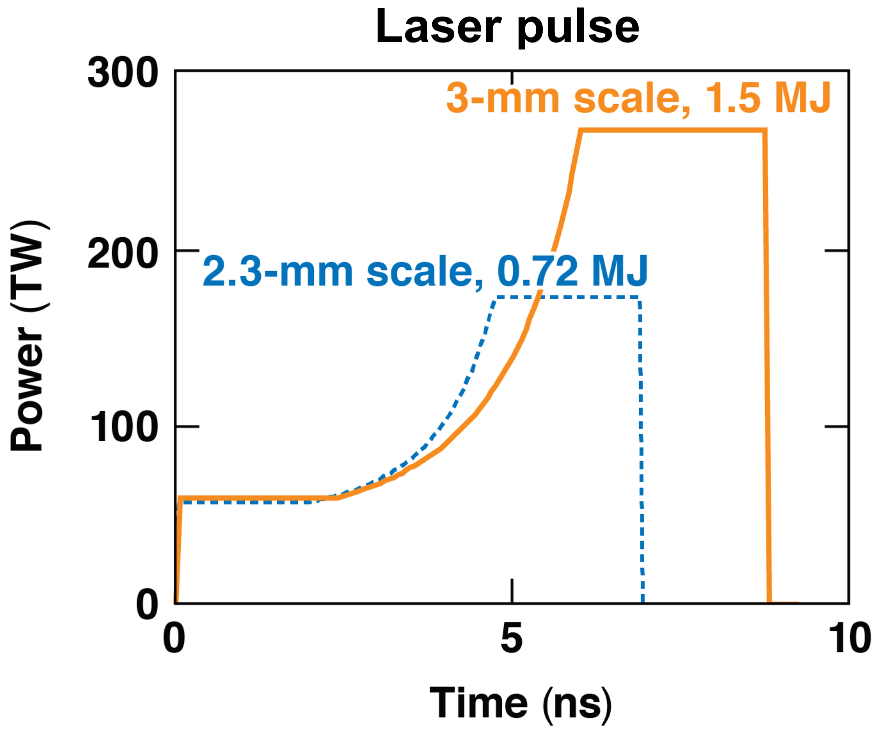
Shell convergence can decrease preheat in high-gain ignition cryo designs,* in which convergence of 1.5 to 4 at peak hot-electron production is expected.

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

NIF experiments in September 2022 will measure preheat in ~30% larger ignition-scale implosions







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

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