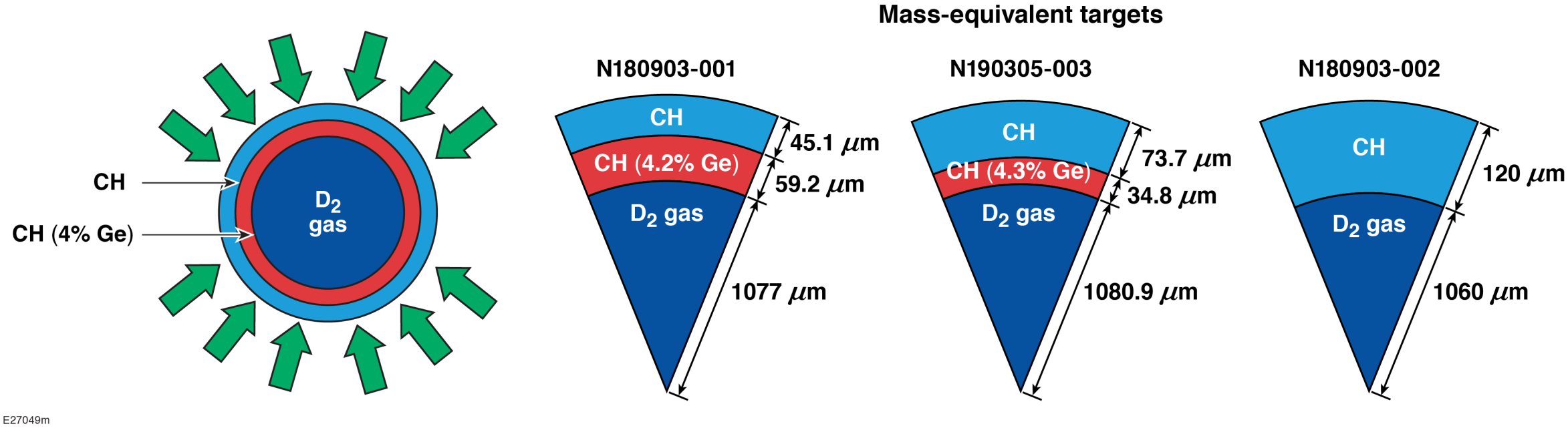
Hot-Electron Preheat and Energy Deposition in Direct-Drive Implosion Experiments at the National Ignition Facility



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A. A. Solodov *et al.*
University of Rochester
Laboratory for Laser Energetics

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Summary

Hot-electron preheat and energy deposition in the unablated shell have been measured in polar-direct-drive implosions on the NIF

- Hot-electron transport in NIF polar-direct-drive (PDD) implosions has been studied by comparing hard x-ray (HXR) production in all-plastic implosions with multilayered implosions
- The hot-electron deposition profile in the imploding shell has been diagnosed: 0.28% of laser energy is deposited in the unablated shell
  - 0.1% is deposited in the outer 20% portion
  - 0.18% is deposited in the inner 80% of the imploding shell

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).

NIF: National Ignition Facility

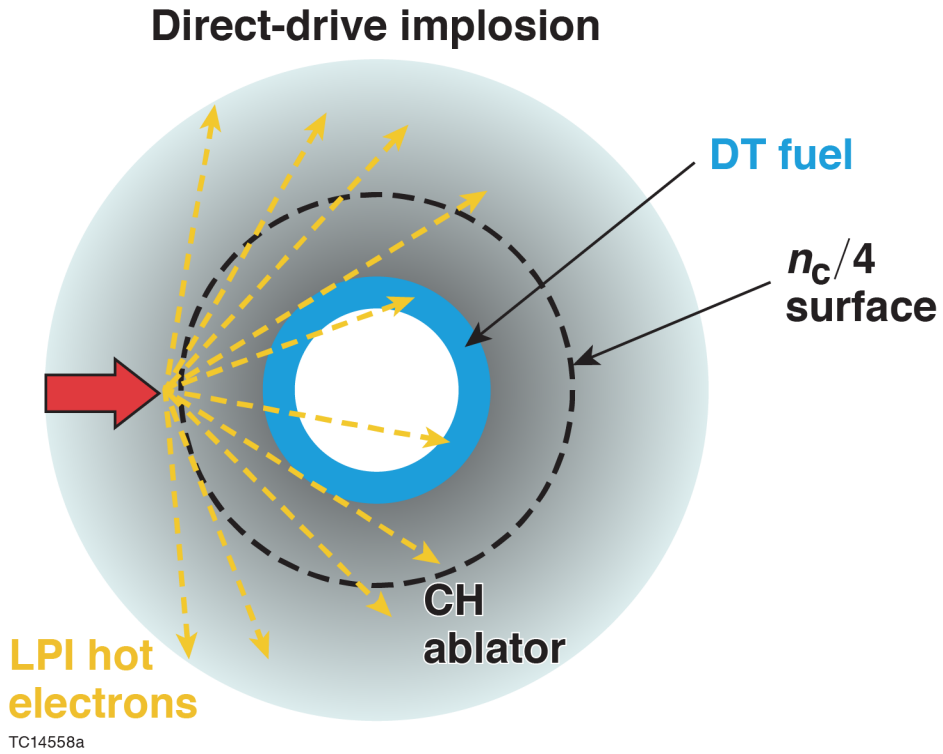
Collaborators

M. J. Rosenberg, A. R. Christopherson, R. Betti, M. Stoeckl, W. Seka, R. Epstein, R. K. Follett, P. B. Radha, S. P. Regan, D. H. Froula, J. P. Palastro, and V. N. Goncharov
University of Rochester
Laboratory for Laser Energetics

J. F. Myatt
University of Alberta

M. Hohenberger, B. Bachmann, and P. Michel
Lawrence Livermore National Laboratory

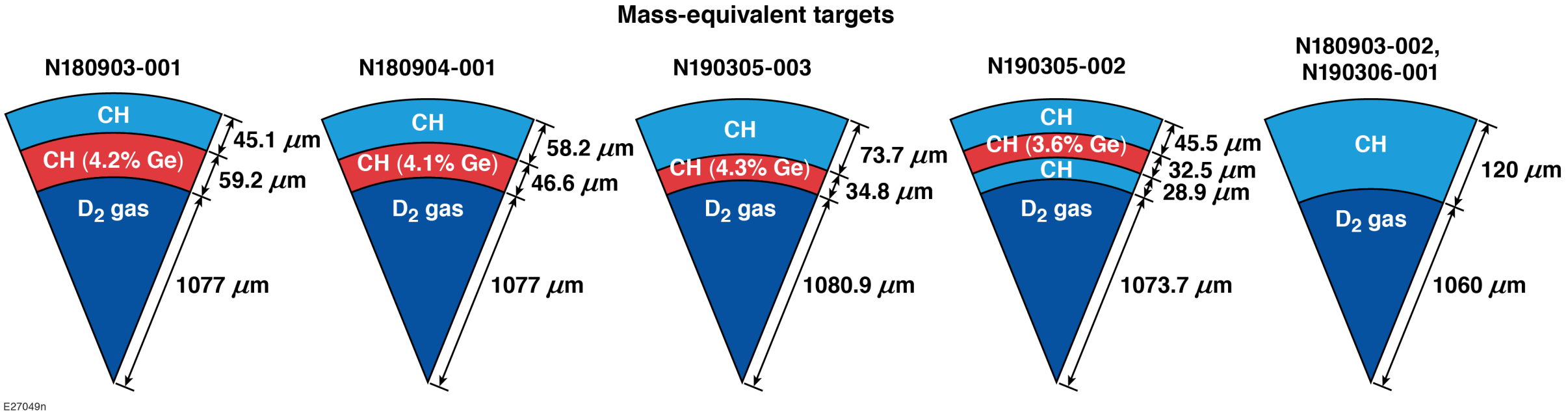
Hot-electron preheat can degrade fuel compression in direct-drive–ignition designs



- 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

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

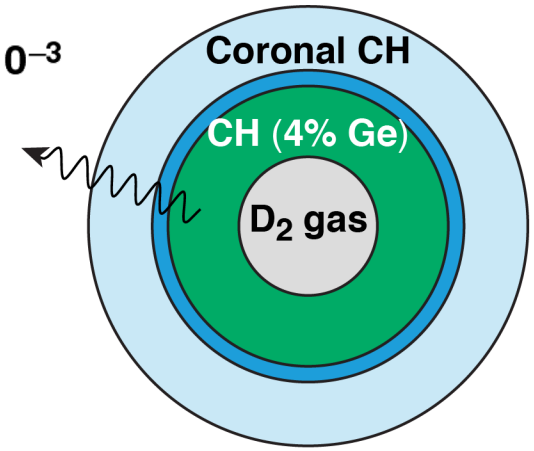
Hot-electron transport in NIF PDD implosions was studied by comparing HXR between all-plastic and multilayered implosions



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

The energy deposited into a payload can be inferred by subtracting the all-CH HXR from the HXR of a Ge-doped layered target

$$\left(\frac{E_{rad}}{E_{e,lost}}\right)^{payload}_{Ch\,(4\%\,Ge)} = 1.6\times10^{-3}$$



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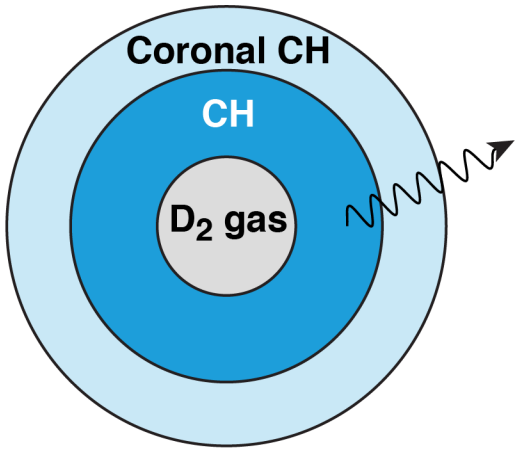


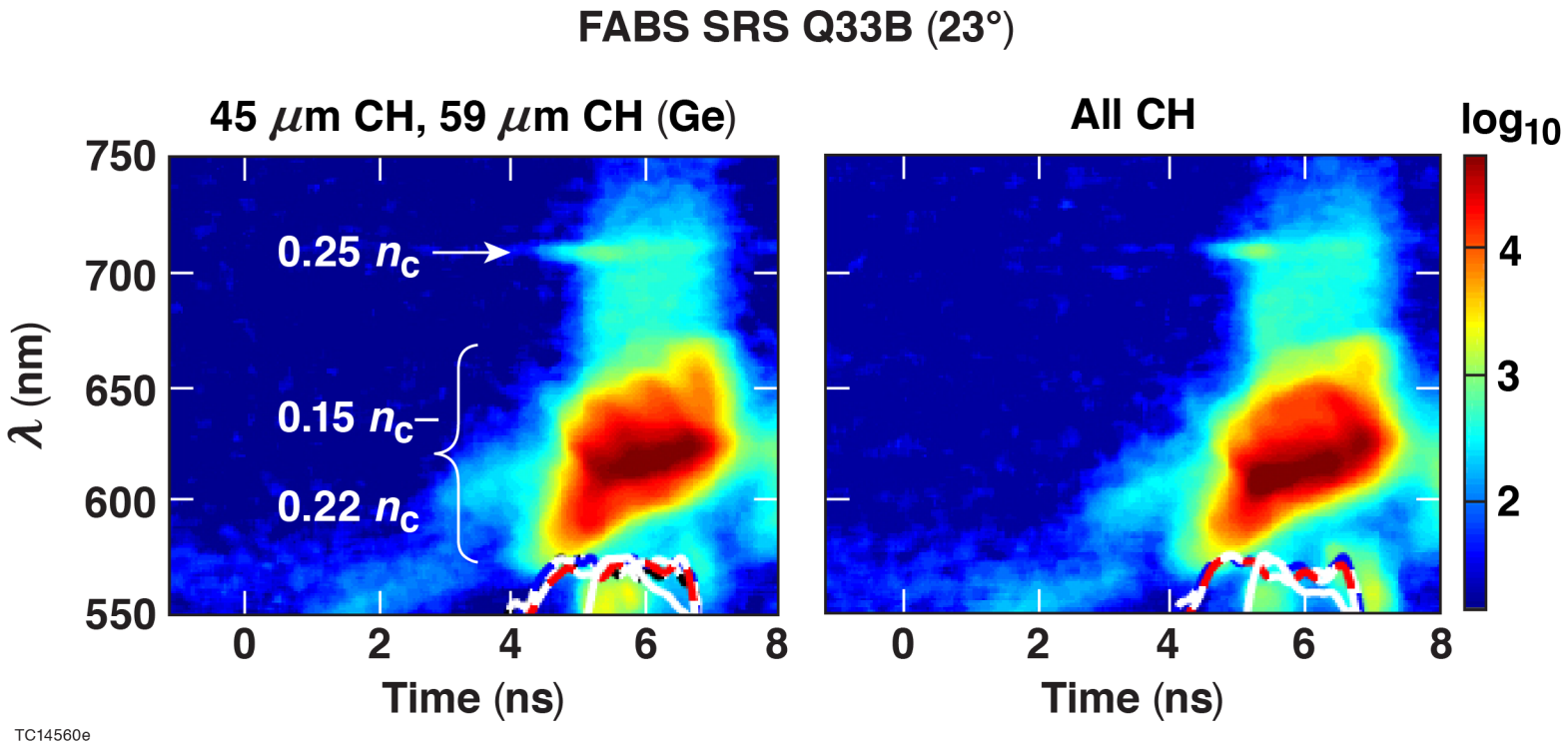
$$\left(\frac{E_{rad}}{E_{e,lost}}\right)_{CH} = 5\times10^{-4}$$

- $\frac{E_{rad}}{E_{e,lost}}$ is taken from theory; it is proportional to $\frac{\langle Z^2\rangle}{\langle Z\rangle}$, depends on T_{hot}, and logarithmically on plasma density

$$\text{Preheat formula:}^{*}\ E^{payload}_{CH\,(4\%\,Ge)} = \frac{E^{layered}_{rad} - E^{all\text{-}CH}_{rad}}{\left(\frac{E_{rad}}{E_{e,lost}}\right)^{payload}_{CH\,(4\%\,Ge)} - \left(\frac{E_{rad}}{E_{e,lost}}\right)_{CH}}$$

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



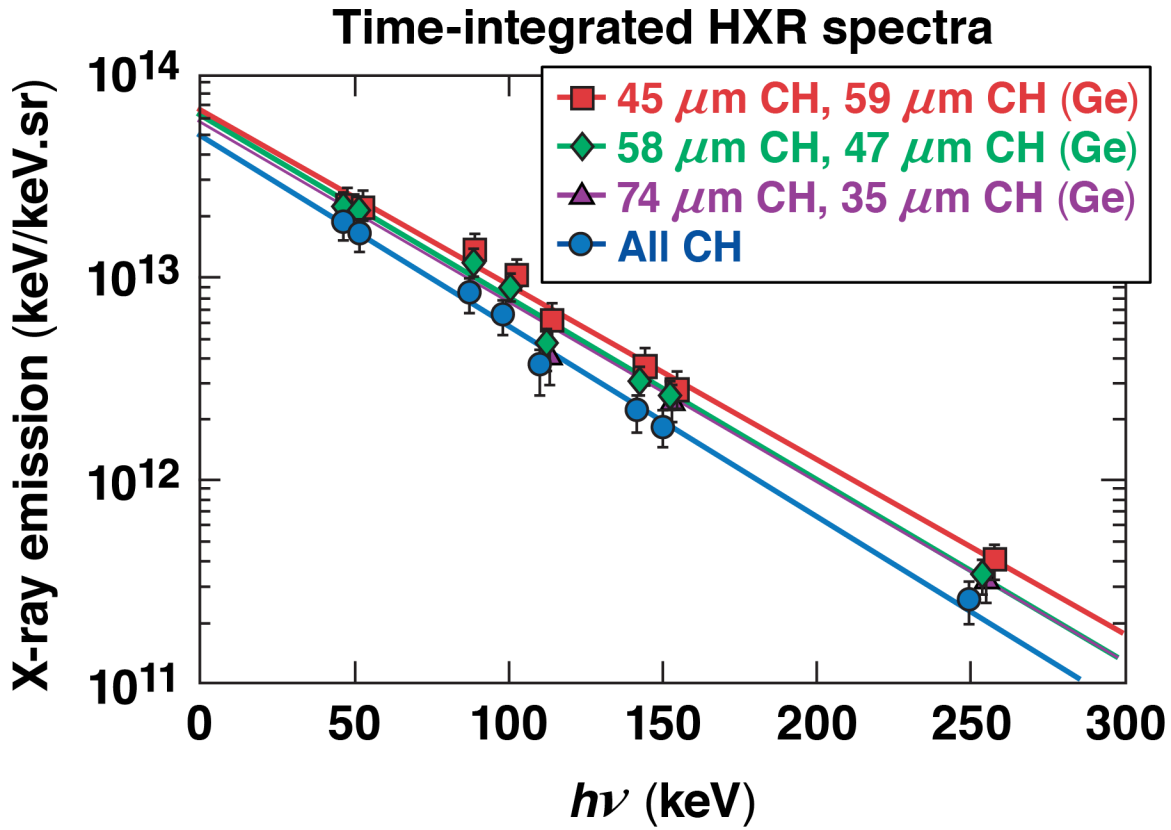
Simulated plasma conditions at $n_c/4$

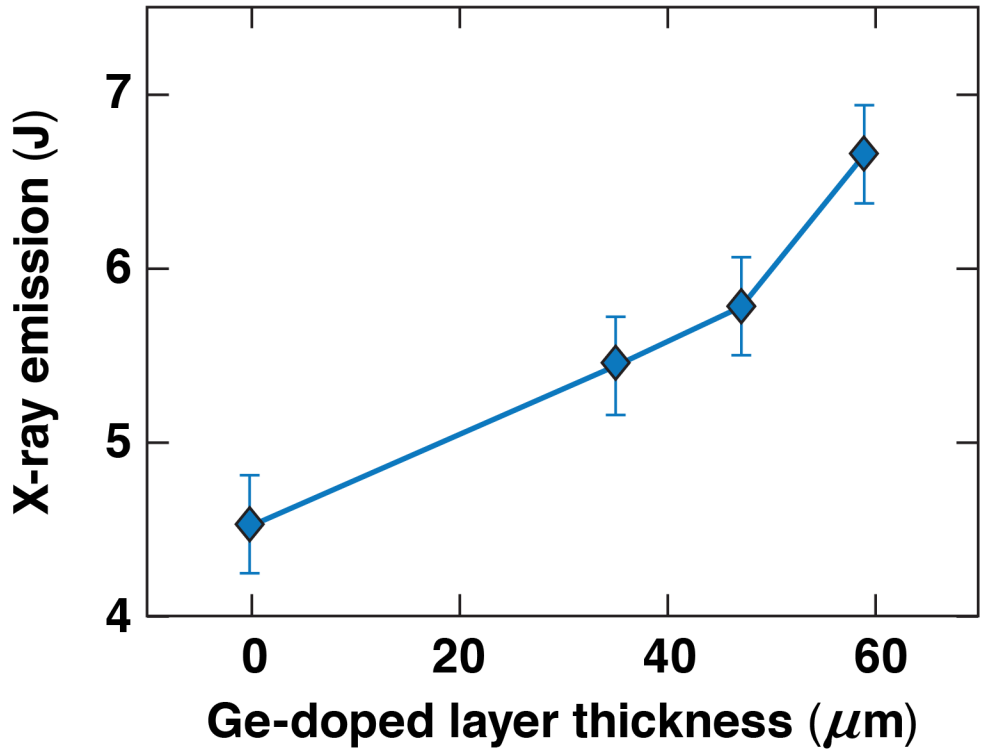
	NIF ignition scale	These experiments
L_n (μm)	600	400
T_e (keV)	3.5 to 5	3.2
I_L (W/cm^2)	(6 to 8) $\times$ 10^{14}	(4 to 8) $\times$ 10^{14}

Similar LPI → similar hot-electron source

FABS: full-aperture backscatter station
SRS: stimulated Raman scatter

The hard x-ray measurement recorded with the FFLEX* diagnostic shows enhanced HXR emission with the Ge dopant





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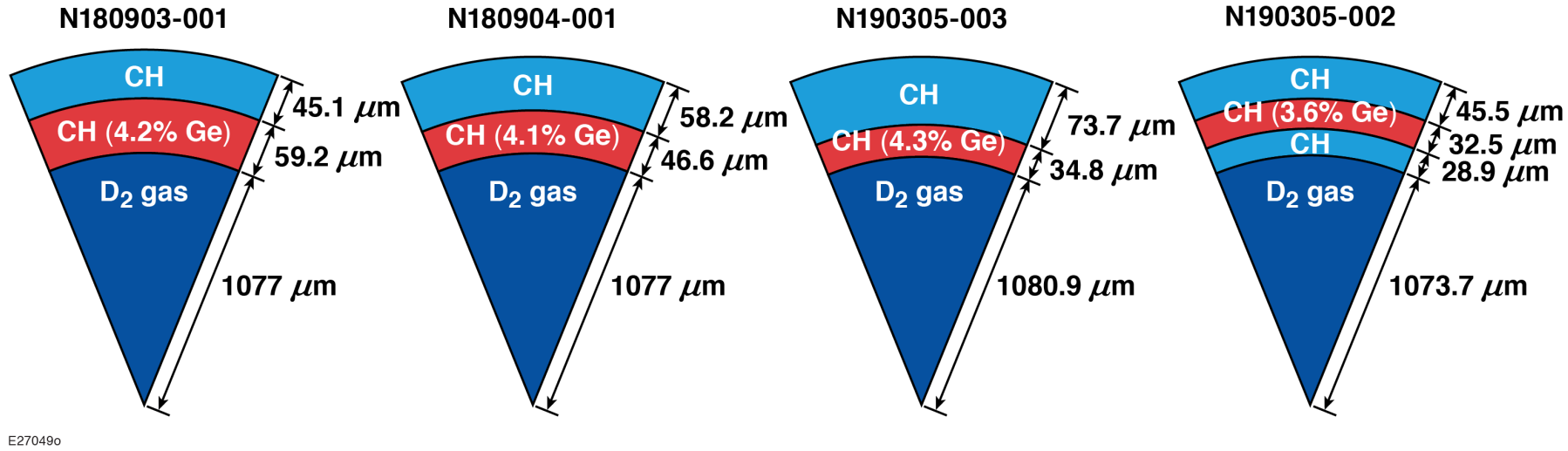
$T_{HXR} = T_{hot} \approx 50$ keV

* M. Hohenberger *et al.*, Rev. Sci. Instrum. 85, 11D501 (2014).
FFLEX: filter-fluorescer x-ray diagnostic

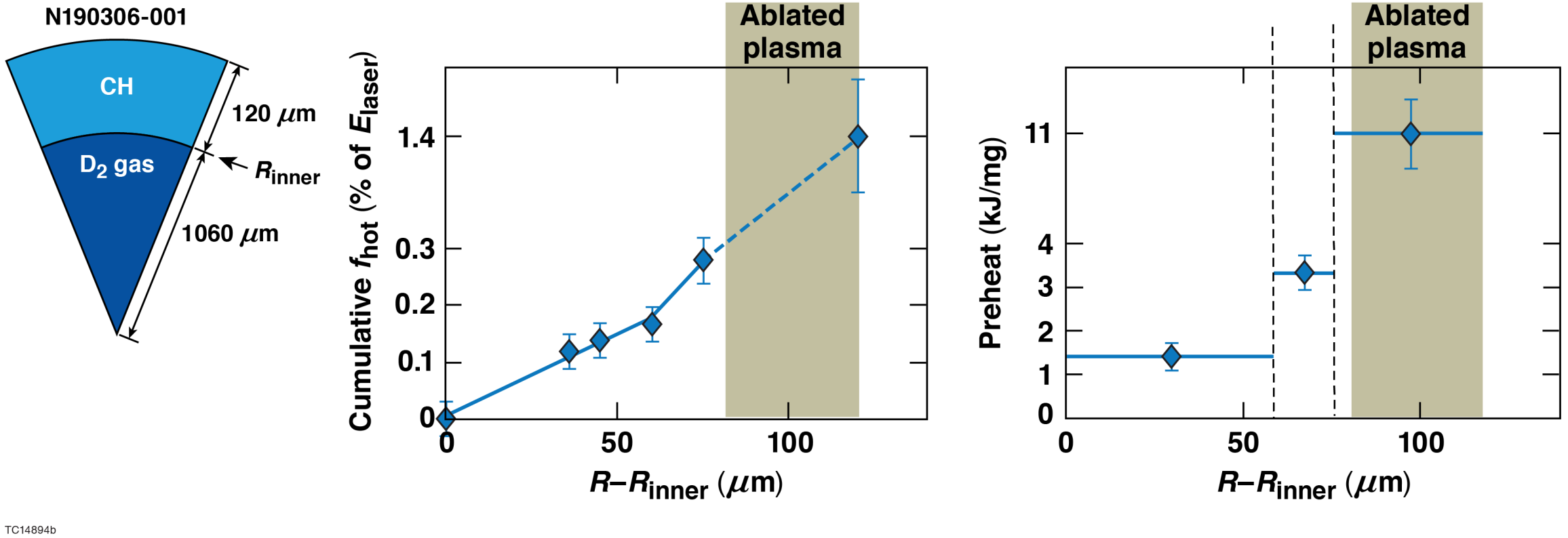
The energy deposition in different parts of the imploding shell has been found



Energy into Ge-doped layer (kJ)	2.0±0.4 kJ	1.1±0.3 kJ	1.0±0.3 kJ	1.2±0.3 kJ
Laser energy (%)	0.28±0.05%	0.17±0.03%	0.14±0.03%	0.16±0.03%

- All targets show 1.4±0.3% of total laser energy transferred to hot electrons

The energy-deposition profile in the imploding shell has been inferred



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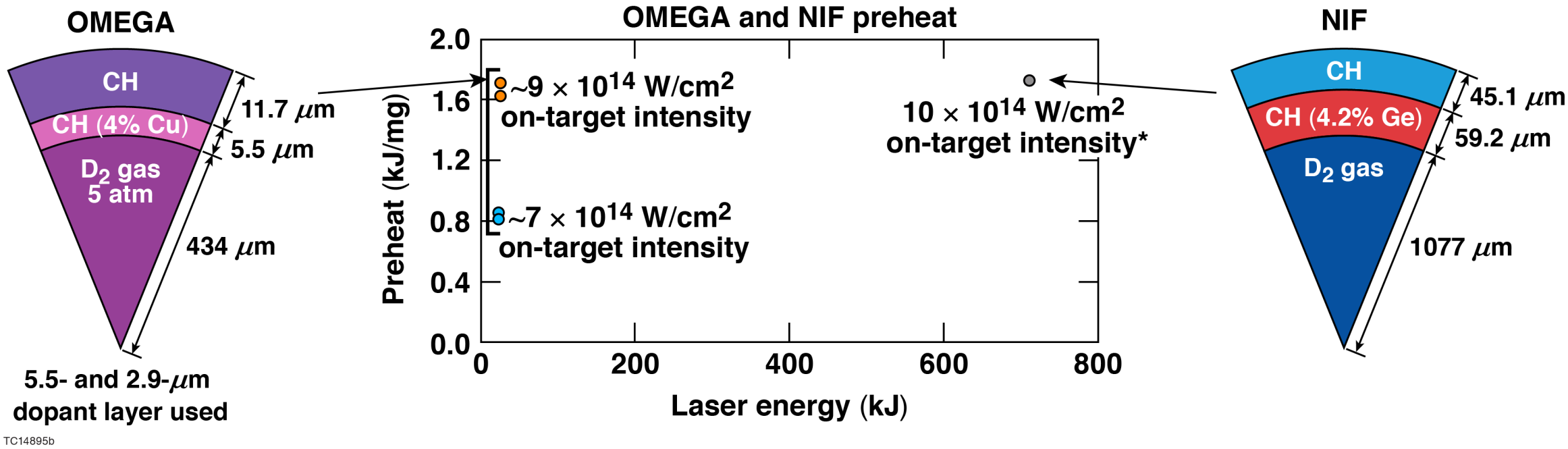
- About a quarter of total hot-electron energy coupled to the implosion is coupled to the unablated shell, indicating a wide angular divergence of hot electrons

OMEGA and NIF experiments show roughly similar preheat per mass, even though implosion conditions are different (not hydro-equivalent)



OMEGA experiments hydro-equivalent to the NIF design are proposed for FY20.

* $n_c/4$ intensity is lower, especially for the NIF (long scale lengths)

Summary/Conclusions

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