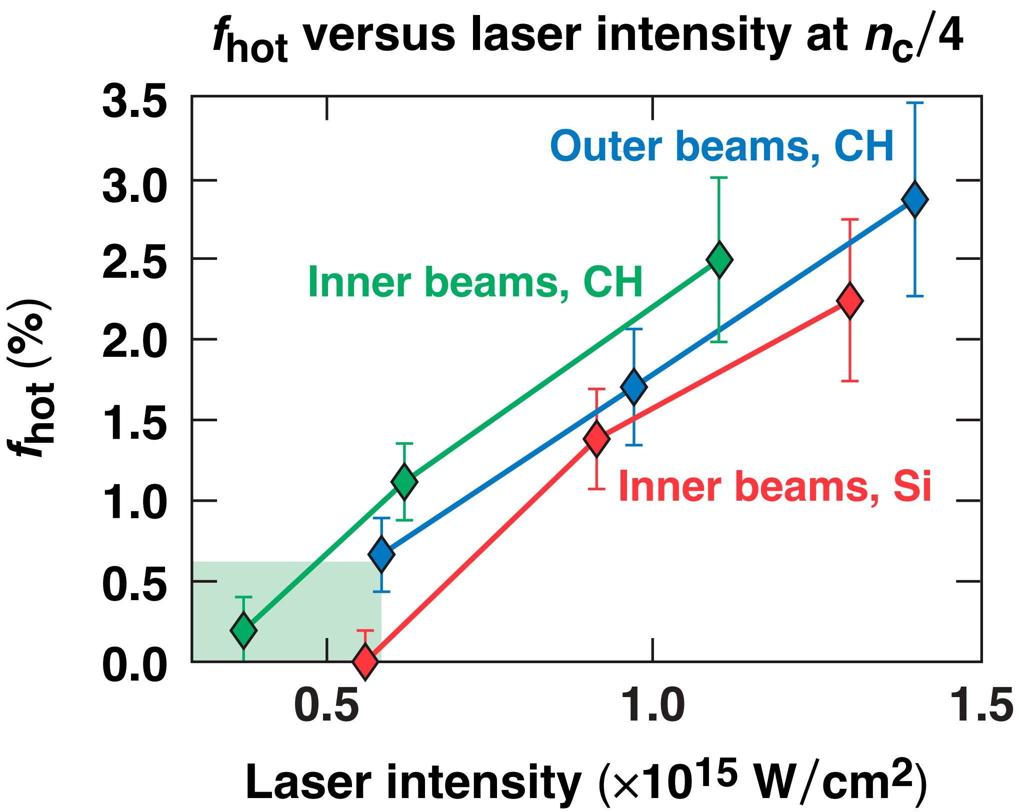
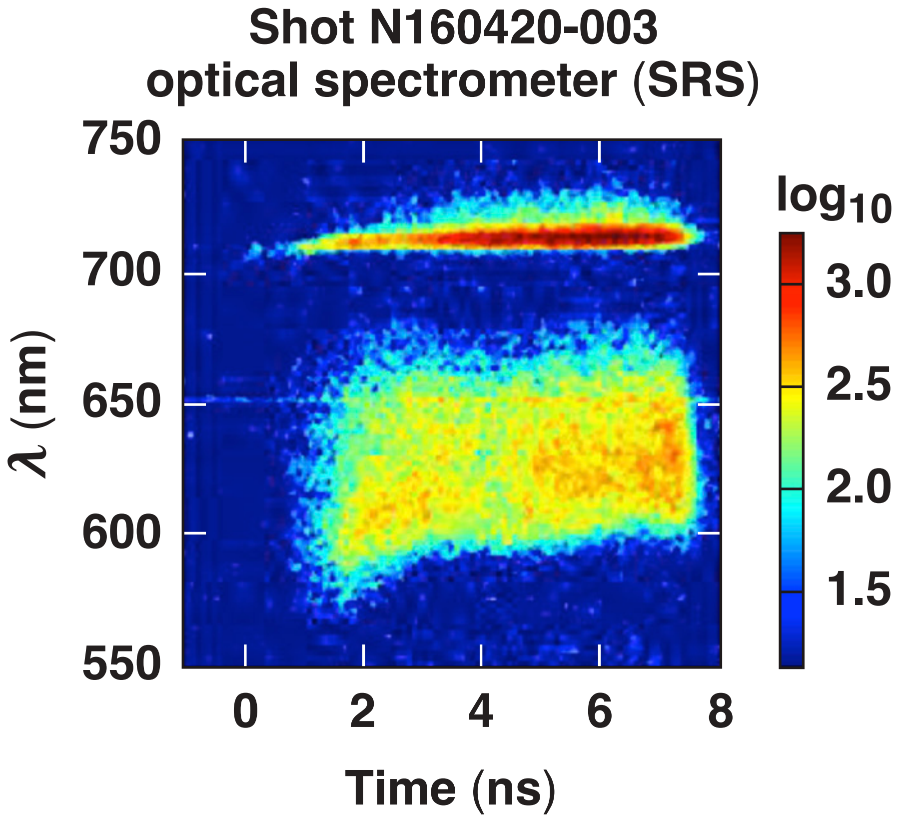
Laser–Plasma Interaction Experiments at Direct-Drive Ignition-Relevant Scale Lengths at the National Ignition Facility





M. J. Rosenberg
University of Rochester
Laboratory for Laser Energetics

60th Annual Meeting of the
American Physical Society
Division of Plasma Physics
Portland, OR
5–9 November 2018

Summary

Planar and spherical experiments at the National Ignition Facility (NIF) have investigated laser–plasma interaction (LPI) hot-electron production and coupling at direct-drive ignition-relevant coronal conditions

- Planar experiments achieve scale lengths of $L_n \sim 400$ to 700 μm, electron temperatures of $T_e \sim 3$ to 5 keV, and laser intensities of 0.5 to 1.5×10^{15} W/cm^2
- Hot-electron generation of the order of $f_{hot} \sim 0\%$ to 3% and $T_{hot} \sim 50$ keV has been observed
- Stimulated Raman scattering (SRS) is inferred to be the dominant LPI mechanism, although recent measurements ($3\omega/2$) have uncovered evidence of two-plasmon decay (TPD) as well
- Recent spherical experiments have diagnosed hot-electron coupling (preheat) to an implosion and estimate a wide angular divergence

Collaborators

A. A. Solodov, R. K. Follett, W. Seka, S. P. Regan, R. Epstein, A. R. Christopherson, R. Betti, A. V. Maximov, T. J. B. Collins, V. N. Goncharov, R. W. Short, D. P. Turnbull, D. H. Froula, and P. B. Radha

University of Rochester
Laboratory for Laser Energetics

J. F. Myatt

University of Alberta
Department of Electrical and Computer Engineering

P. Michel, M. Hohenberger, L. Masse, G. Swadling, J. S. Ross, T. Chapman, and J. D. Moody

Lawrence Livermore National Laboratory

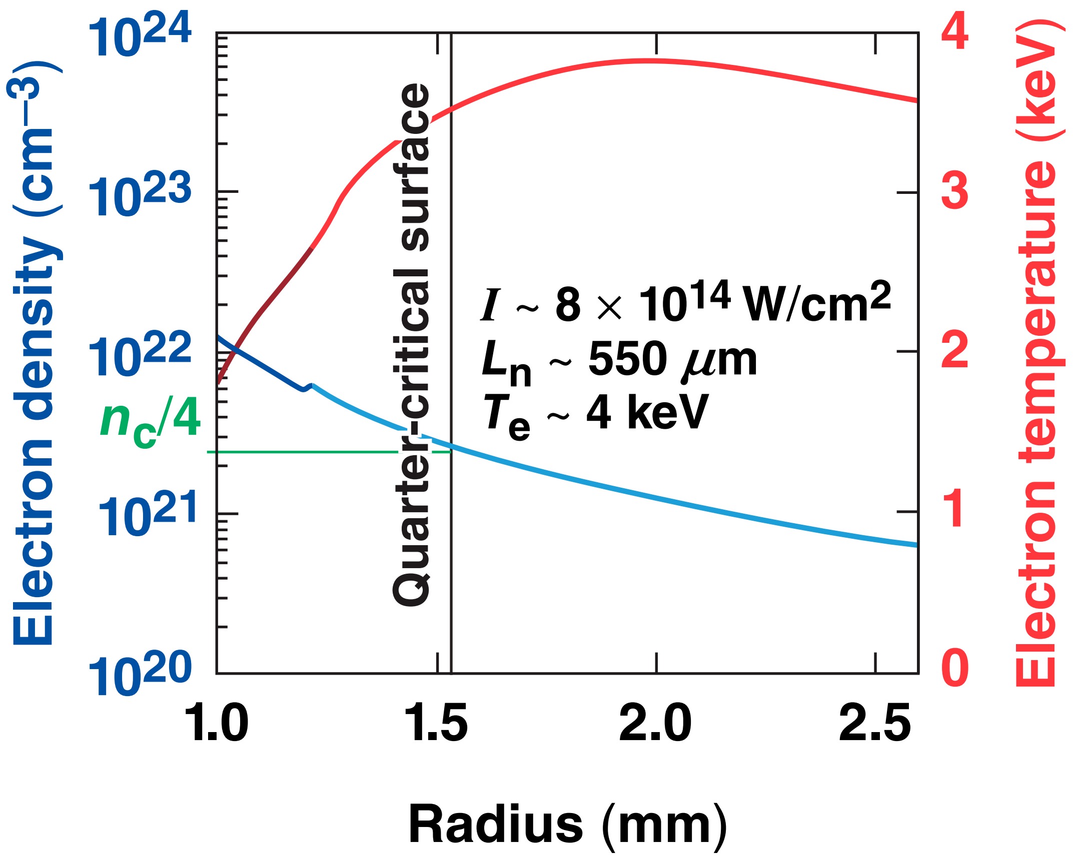
J. W. Bates and A. J. Schmitt

Naval Research Laboratory

Motivation

Direct-drive ignition designs predict long density scale lengths and high electron temperatures at which LPI may generate hot-electron preheat

1-D simulated plasma conditions for an igniting direct-drive design



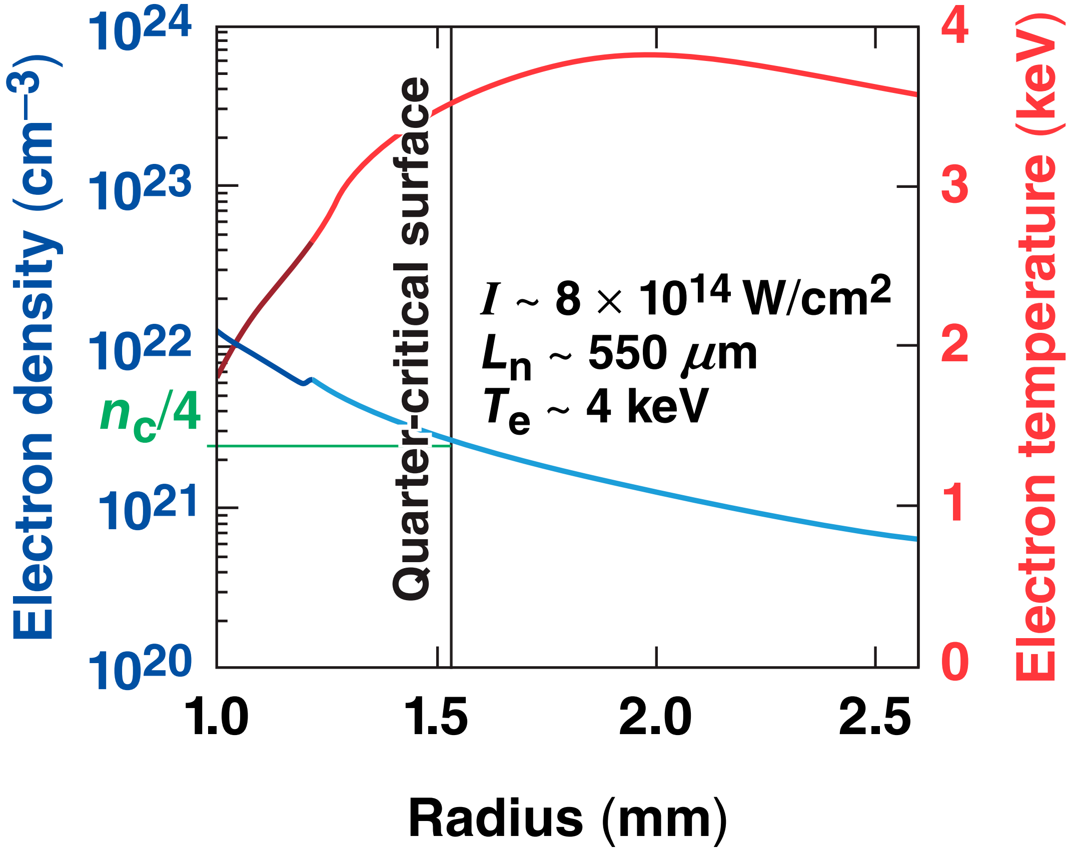
Experiments must be performed at these conditions to understand LPI at the NIF ignition scale.

E25732g

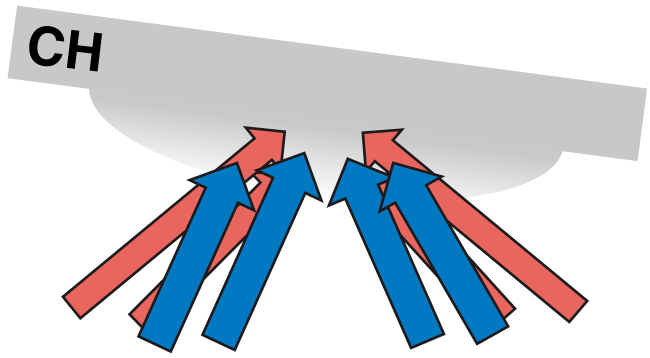
Motivation

Planar experiments on the NIF were designed to achieve plasma conditions comparable to direct-drive ignition designs

1-D simulated plasma conditions for an igniting direct-drive design



Planar platform



2-D *DRACO*-simulated plasma conditions at $n_c/4$

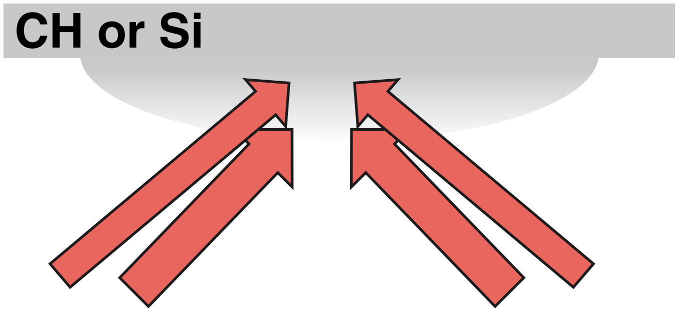
	NIF ignition scale	NIF planar experiments
L_n (μm)	500 to 600	400 to 700
T_e (keV)	3.5 to 5	3 to 5
I_L (W/cm^2)	(6 to 8) × 10^{14}	(4 to 15) × 10^{14}

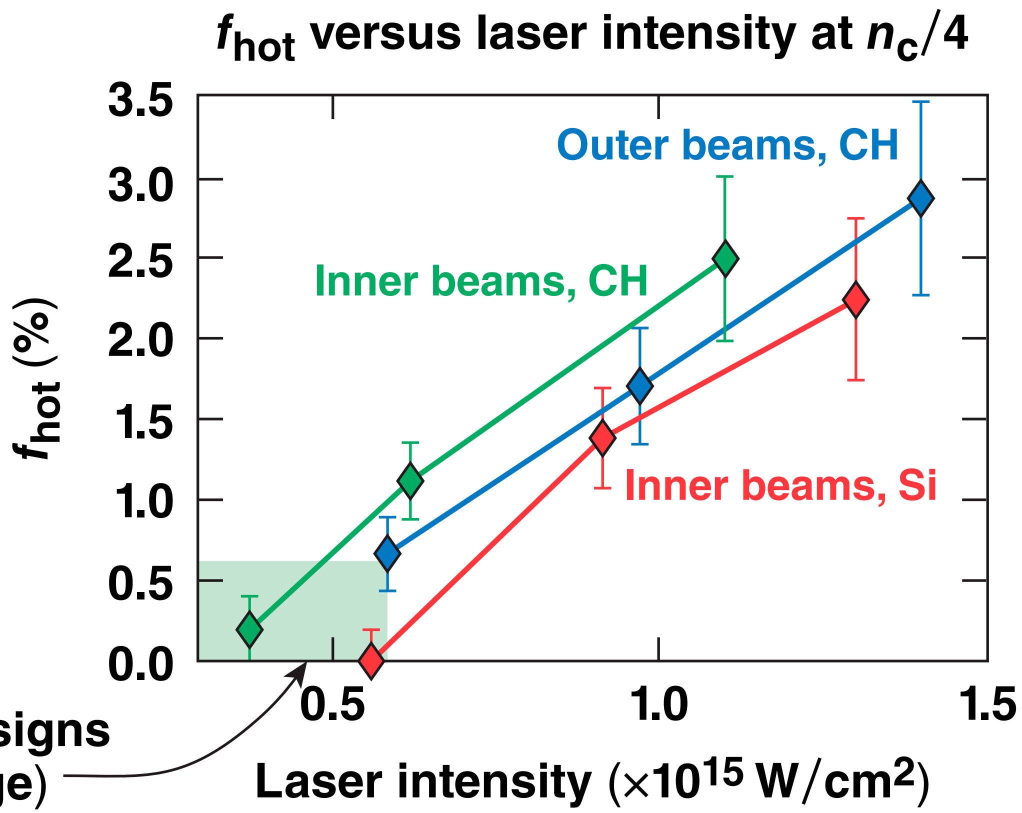
Experiments must be performed at these conditions to understand LPI at the NIF ignition scale.

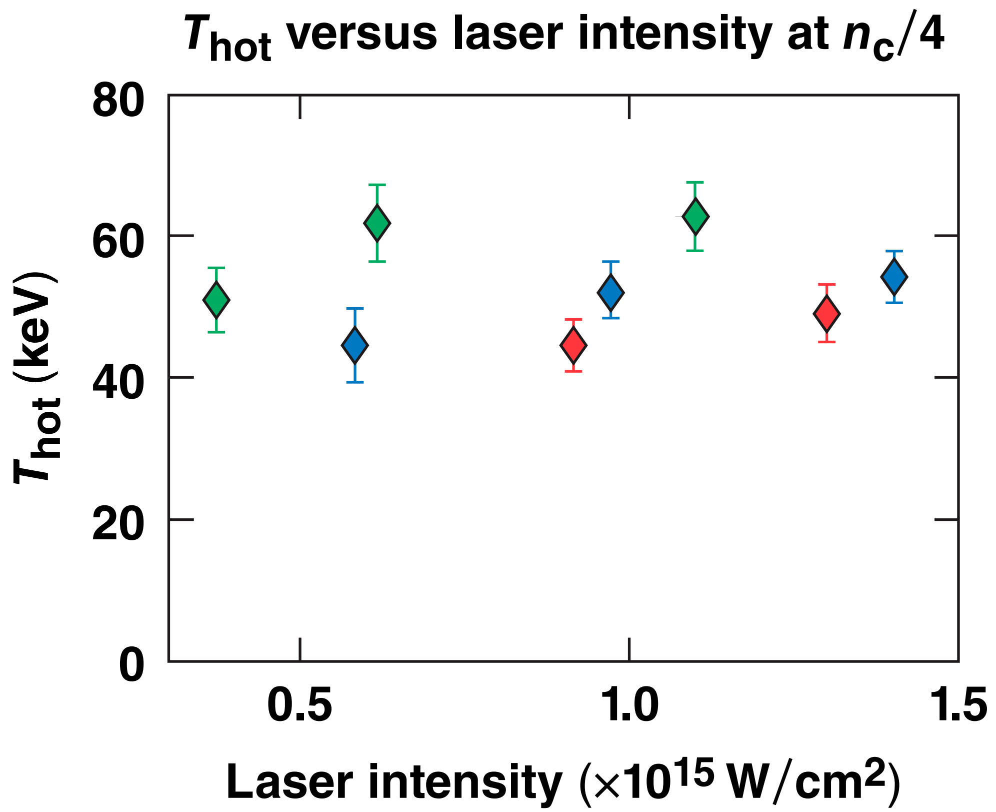
E25732f

A. A. Solodov *et al.*, J06.00010, this conference.

Hot-electron generation of f_{hot} up to 3% and T_{hot} of 40 to 60 keV has been inferred in planar CH and Si targets at intensities around 10^{15} W/cm^2







Intensity around 5 × 10^{14} W/cm^2 may be acceptable for preheat, but we need to understand: (1) LPI mechanisms (for mitigation), and (2) how hot electrons diverge or couple to an implosion.

M. Rosenberg *et al.* Phys. Rev. Lett. 120, 055001 (2018).

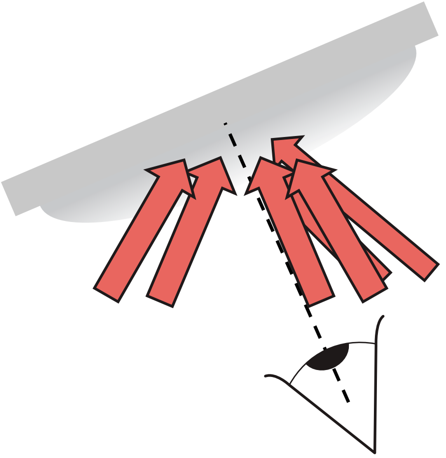
E27565a

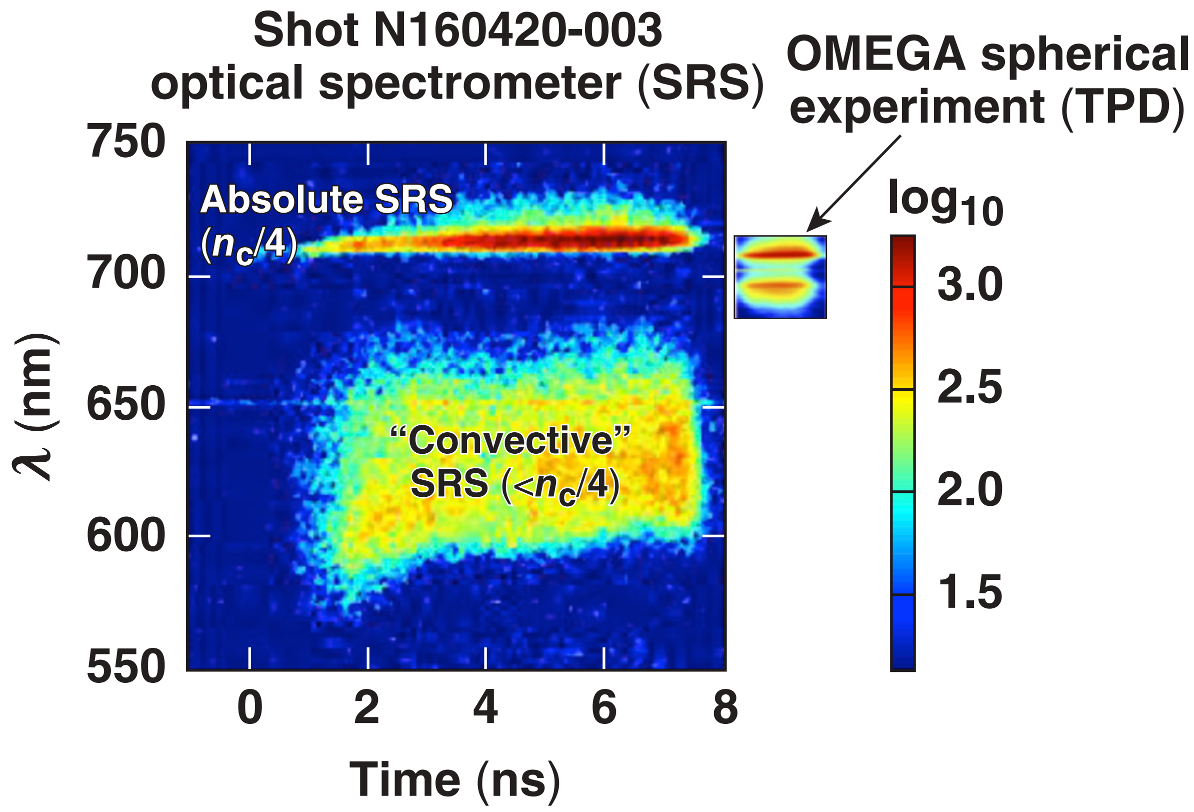
Optical data demonstrate different LPI physics on the NIF than on OMEGA—SRS dominates the scattered-light spectrum (both at and below $n_c/4$)

UR LLE

NIF: L_n = 525 μm
T_e = 4.5 keV

OMEGA:* L_n = 150 μm
T_e = 2.8 keV



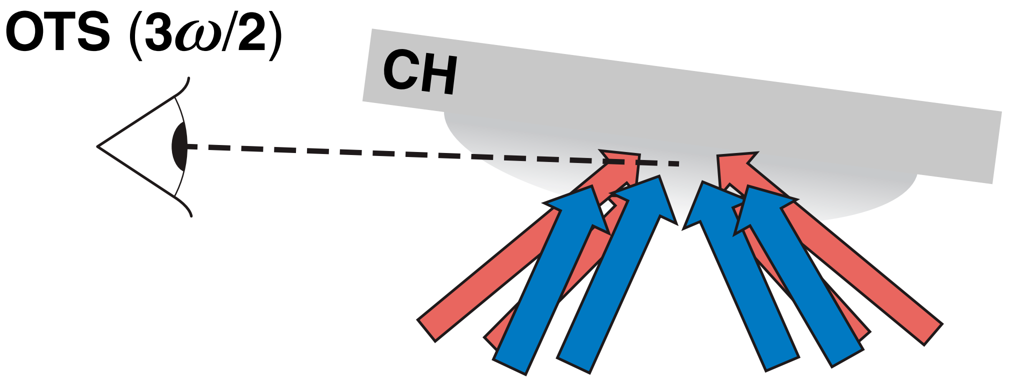


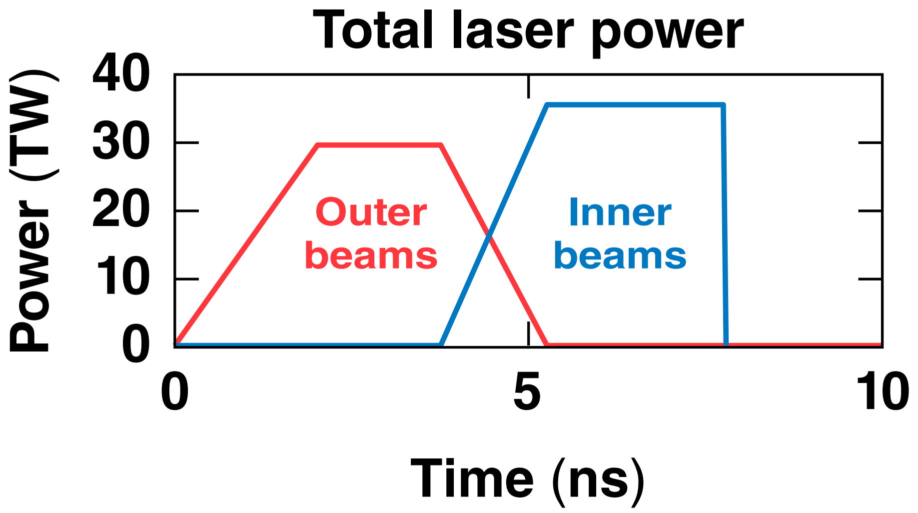
On the NIF, ~5% of laser energy is converted to SRS, consistent with the observed hot-electron fraction and suggestive of SRS being the dominant hot-electron source, although this does not rule out the presence of TPD.

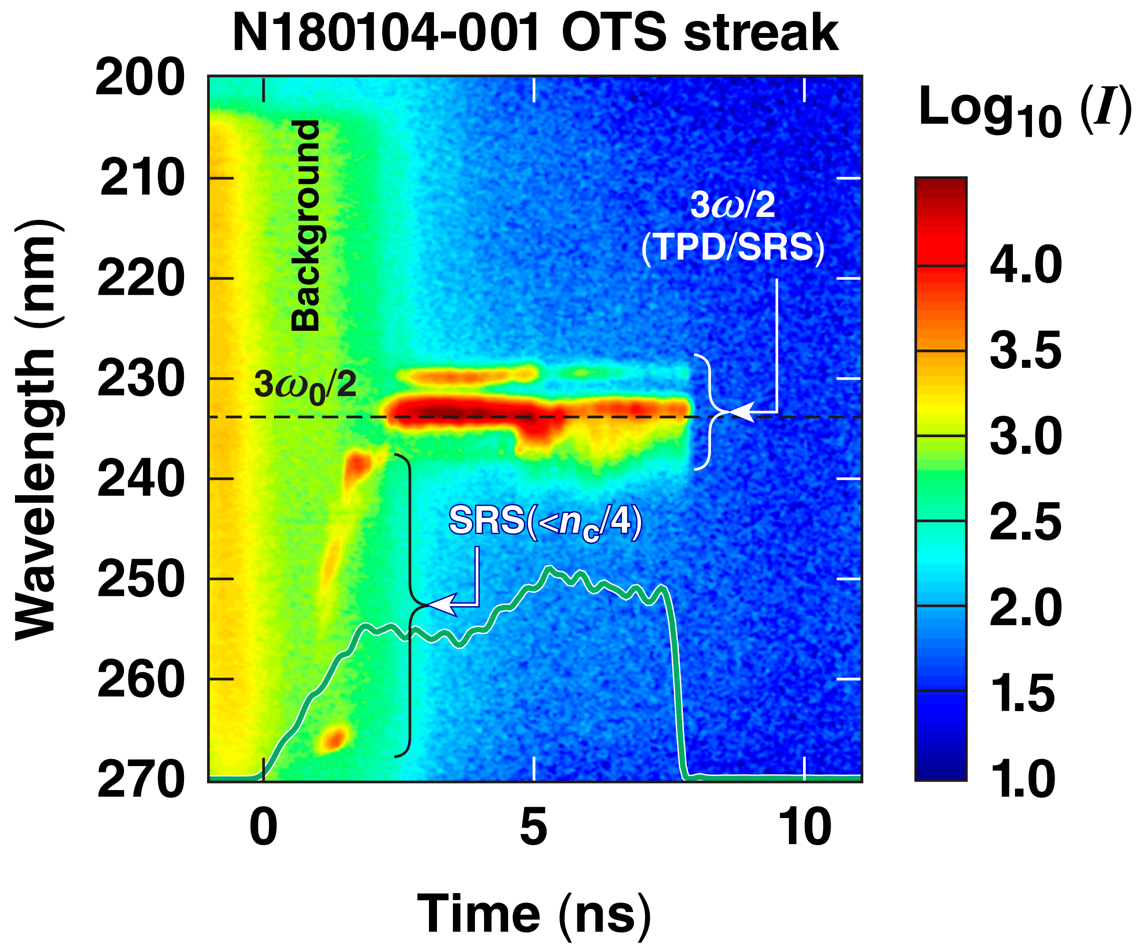
M. Rosenberg *et al.*, Phys. Rev. Lett. 120, 055001 (2018).
*W. Seka *et al.*, Phys. Plasmas 16, 052701 (2009).

E25567h

In addition to optical measurements, recent NIF experiments diagnosed $3\omega/2$ emission, which revealed evidence of TPD







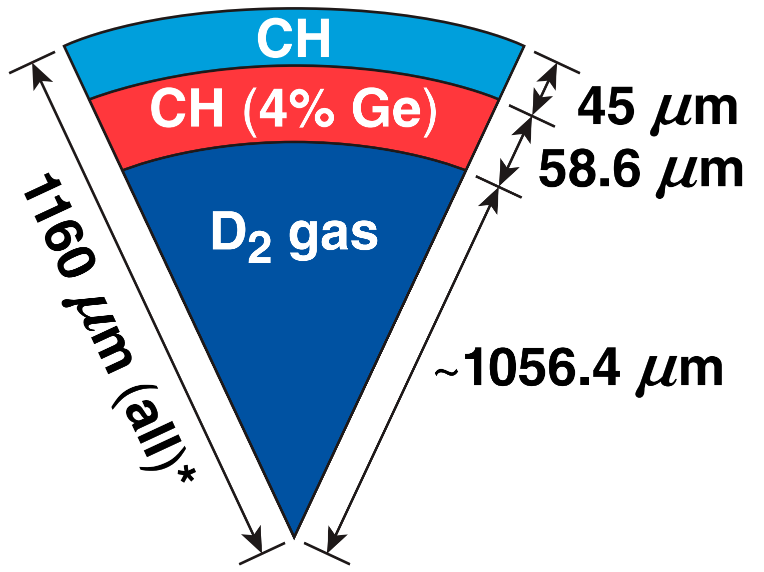
The $3\omega/2$ doublet is suggestive of some TPD activity, although this is consistent with a SRS-dominated regime.

E27532a

OTS: optical Thomson scattering

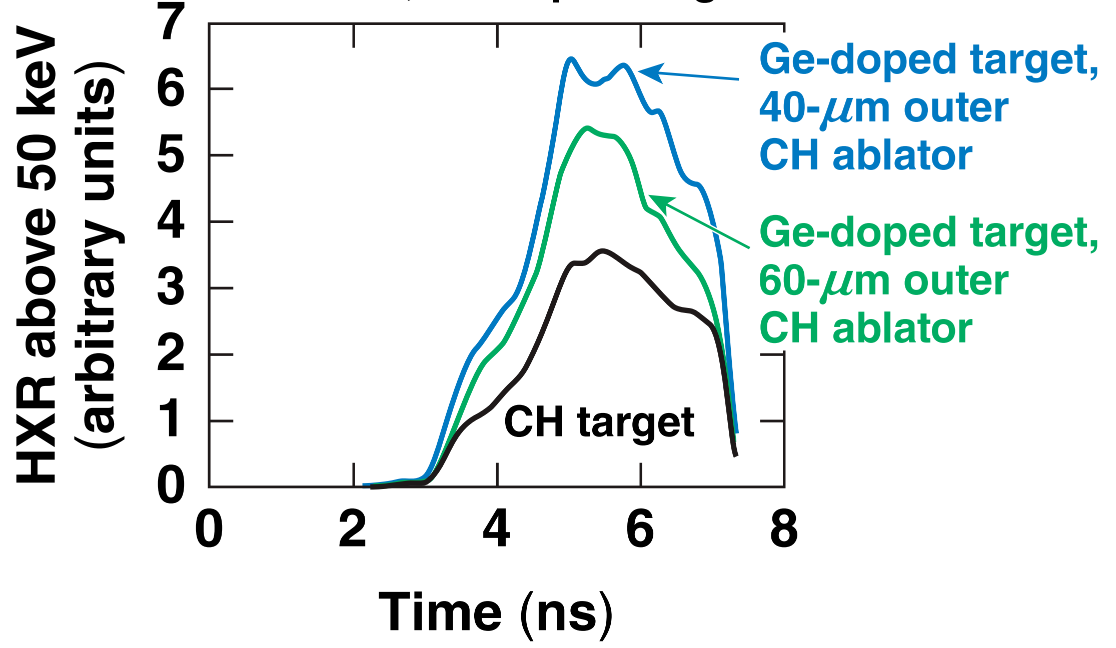
A spherical-geometry platform has been implemented on the NIF to diagnose the coupling of hot electrons to an imploding shell

Target designs*



Predicted NIF hard x-ray (HXR) data

LILAC simulations for T_{hot} = 55 keV, hot-electron divergence full angle of 2π, Ge-doped target at 3.9%

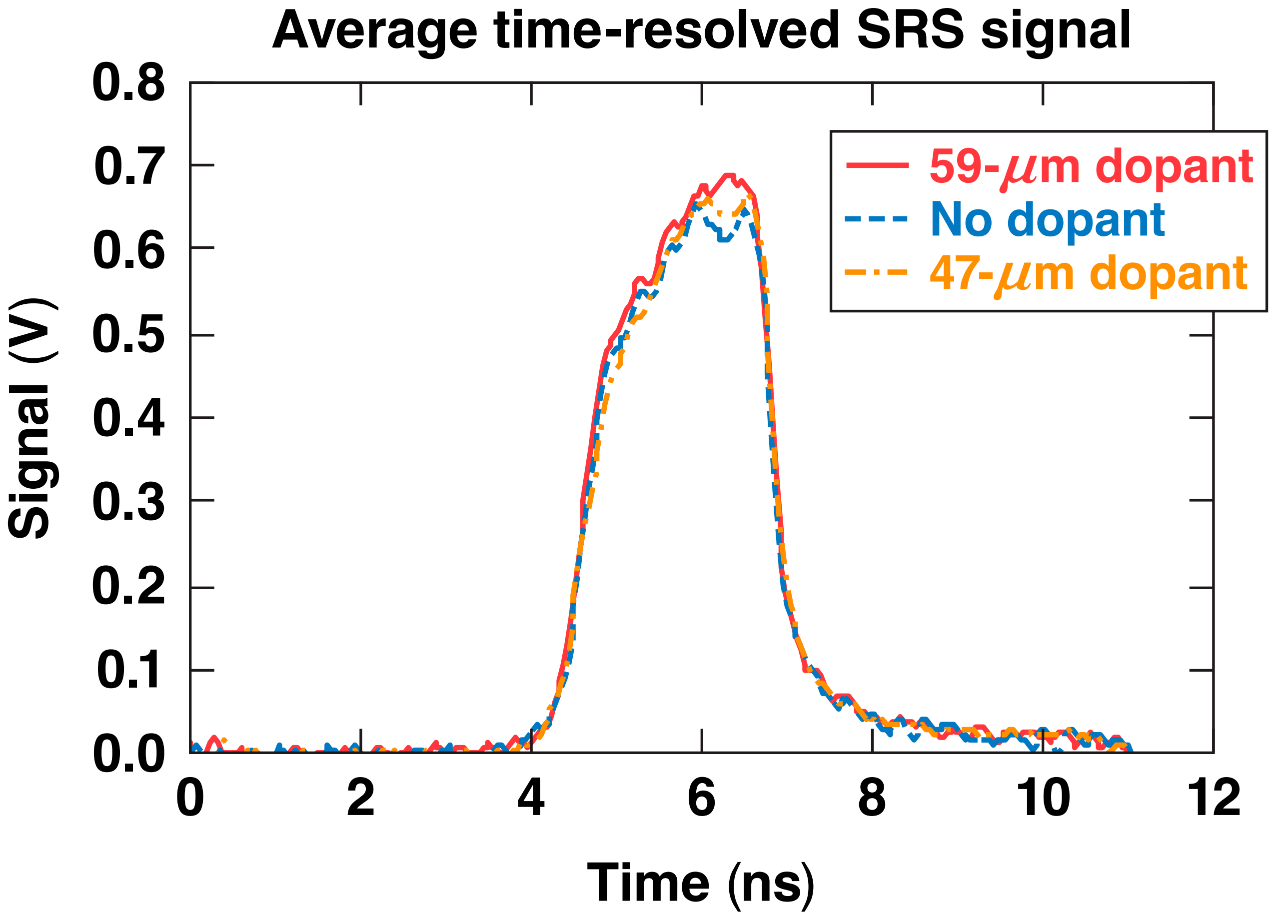


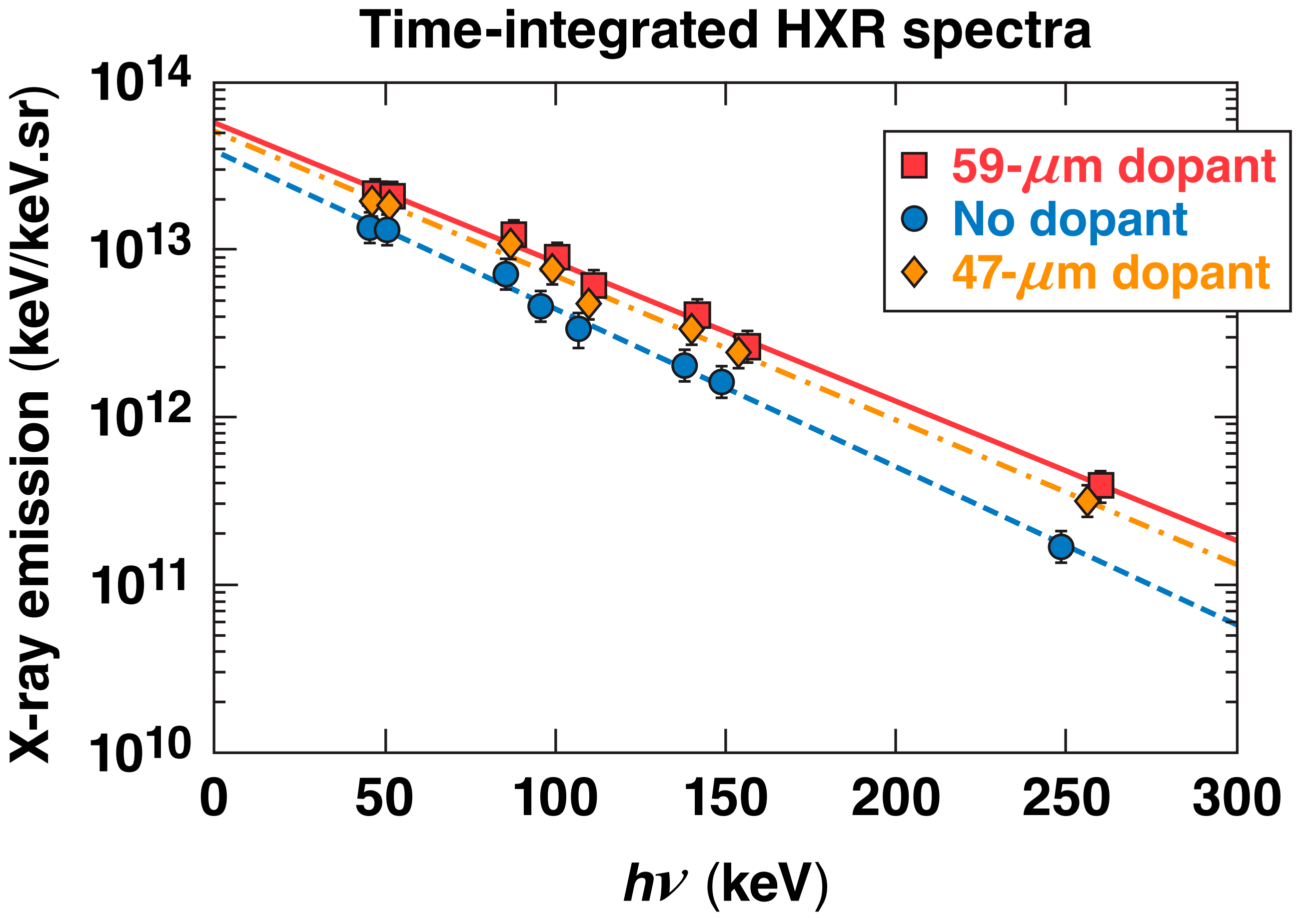
Difference in hard x-ray signals between mass-equivalent CH and multilayered implosions → hot-electron energy deposited in the inner shell layer.

*Platform adapted from OMEGA: A. R. Christopherson *et al.*, Bull. Am. Phys. Soc. 61, BAPS.2016.DPP.NO5.7 (2016). A. A. Solodov *et al.*, J06.00010, this conference.

E27049e

Experiments demonstrate an identical SRS/hot-electron source and an ~2× enhancement of HXR signal in the doped targets





Hard x-ray enhancement is consistent with a wide angular divergence and a small fraction of hot-electron energy coupled to the inner shell layer.

E27877

A. A. Solodov *et al.*, J06.00010, this conference.

Summary/Conclusions

Planar and spherical experiments at the National Ignition Facility (NIF) have investigated laser–plasma interaction (LPI) hot-electron production and coupling at direct-drive ignition-relevant coronal conditions

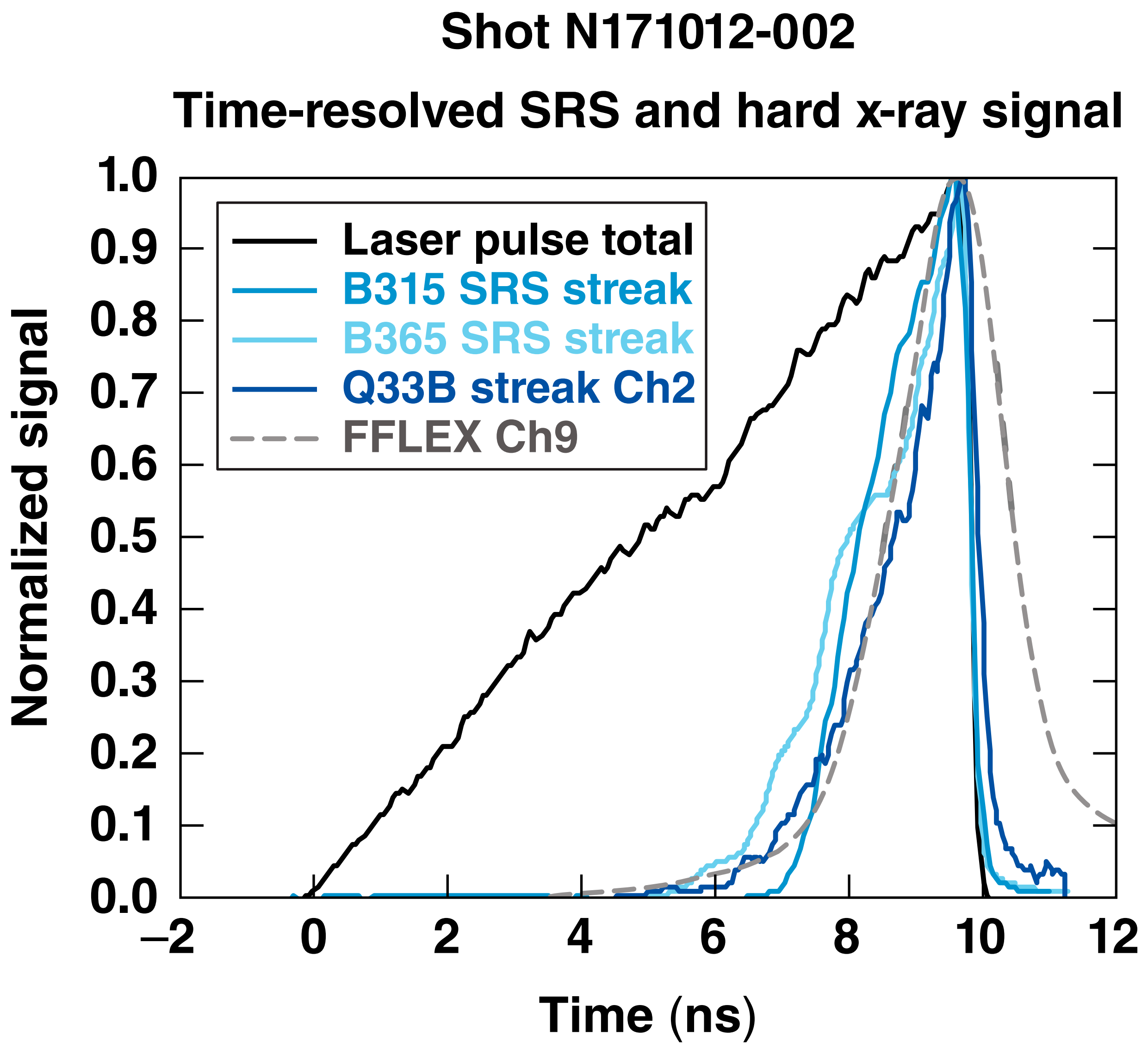
- Planar experiments achieve scale lengths of $L_n \sim 400$ to $700\ \mu$m, electron temperatures of $T_e \sim 3$ to 5 keV, and laser intensities of 0.5 to 1.5×10^{15} W/cm^2
- Hot-electron generation of the order of $f_{hot} \sim 0\%$ to 3% and $T_{hot} \sim 50$ keV has been observed
- Stimulated Raman scattering (SRS) is inferred to be the dominant LPI mechanism, although recent measurements ($3\omega/2$) have uncovered evidence of two-plasmon decay (TPD) as well
- Recent spherical experiments have diagnosed hot-electron coupling (preheat) to an implosion and estimate a wide angular divergence

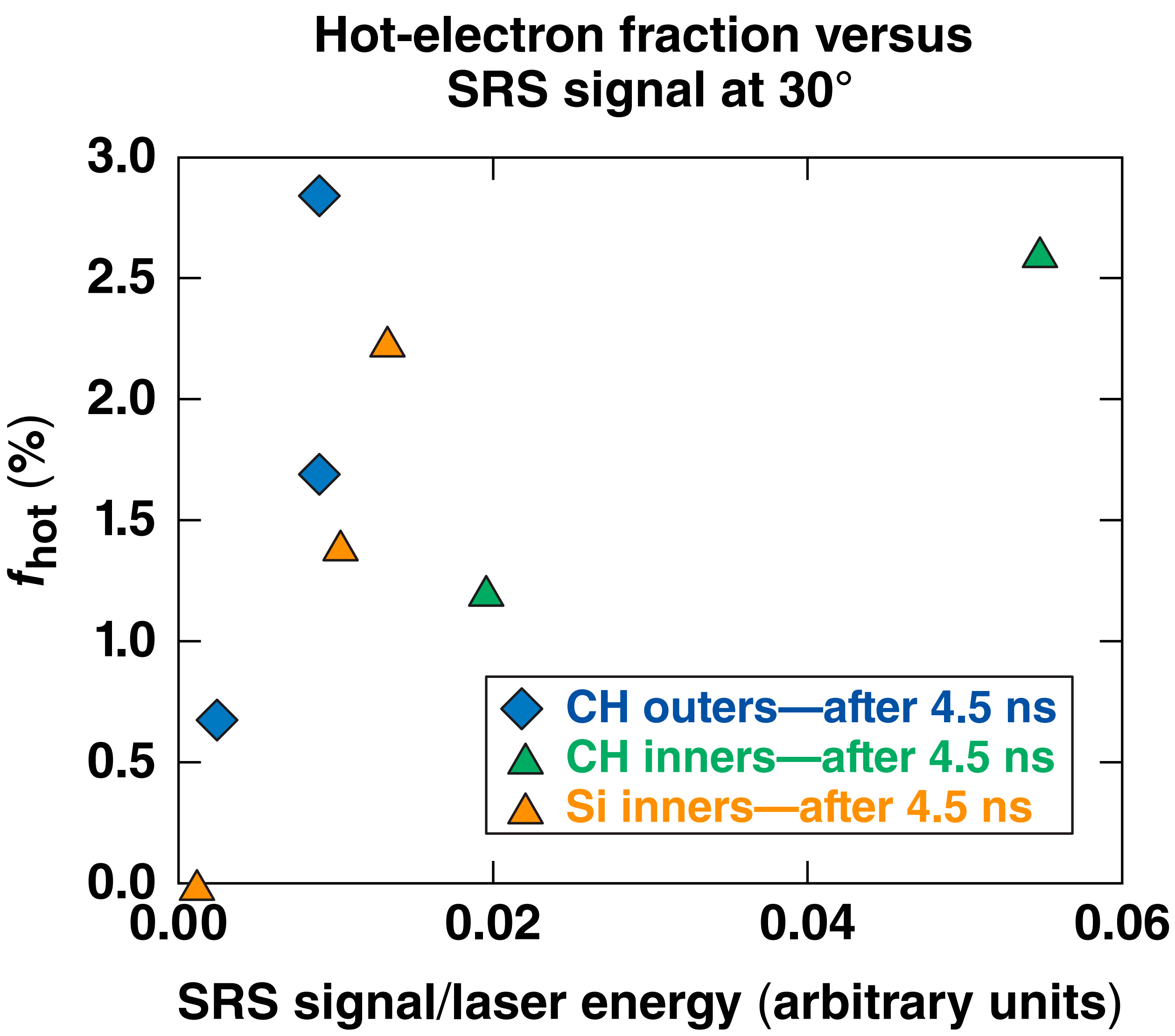
These results indicate a viable ignition-design space for direct drive.

E27876

Appendix

SRS observations correlate with hard x-ray measurements





FFLEX: filter-fluorescer x-ray diagnostic

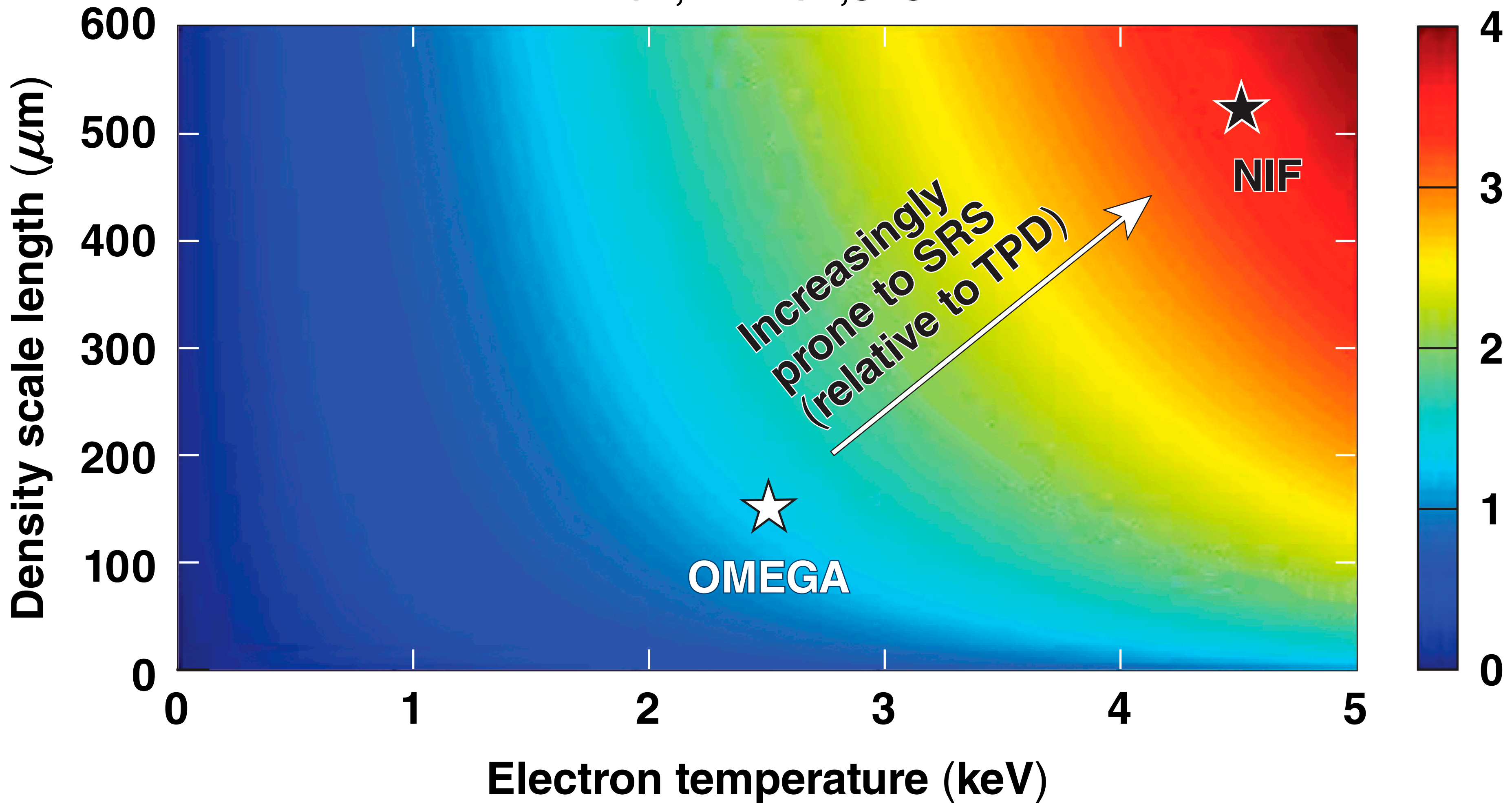
E27531

The dominance of SRS at the NIF scale may be partially explained by evaluating the absolute thresholds of SRS versus TPD

UR LLE

Ratio of absolute TPD and SRS thresholds

$(I_{\text{thr,TPD}}/I_{\text{thr,SRS}})$



E26298b

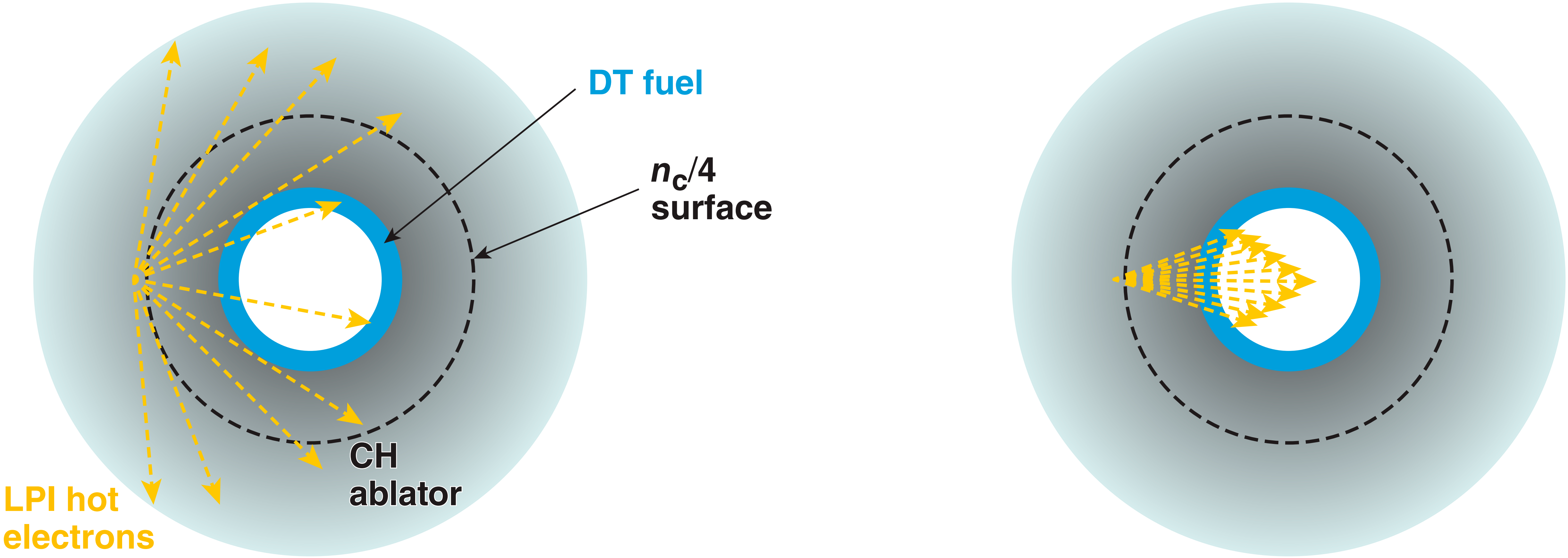
M. Rosenberg *et al.* Phys. Rev. Lett. 120, 055001 (2018).

The tolerable fraction of hot electrons generated (f_{hot}) depends on how the electrons couple to an implosion

UR LLE

Direct-drive implosion

Wide angular divergence* | **Narrow angular divergence**



Tolerable f_{hot} ~0.7%

Tolerable f_{hot} ~0.2%

*OMEGA experiments described in B. Yaakobi *et al.*, Phys. Plasmas 20, 092706 (2013).

E27569a