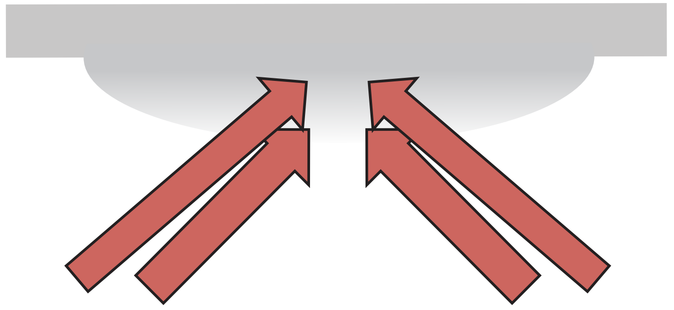
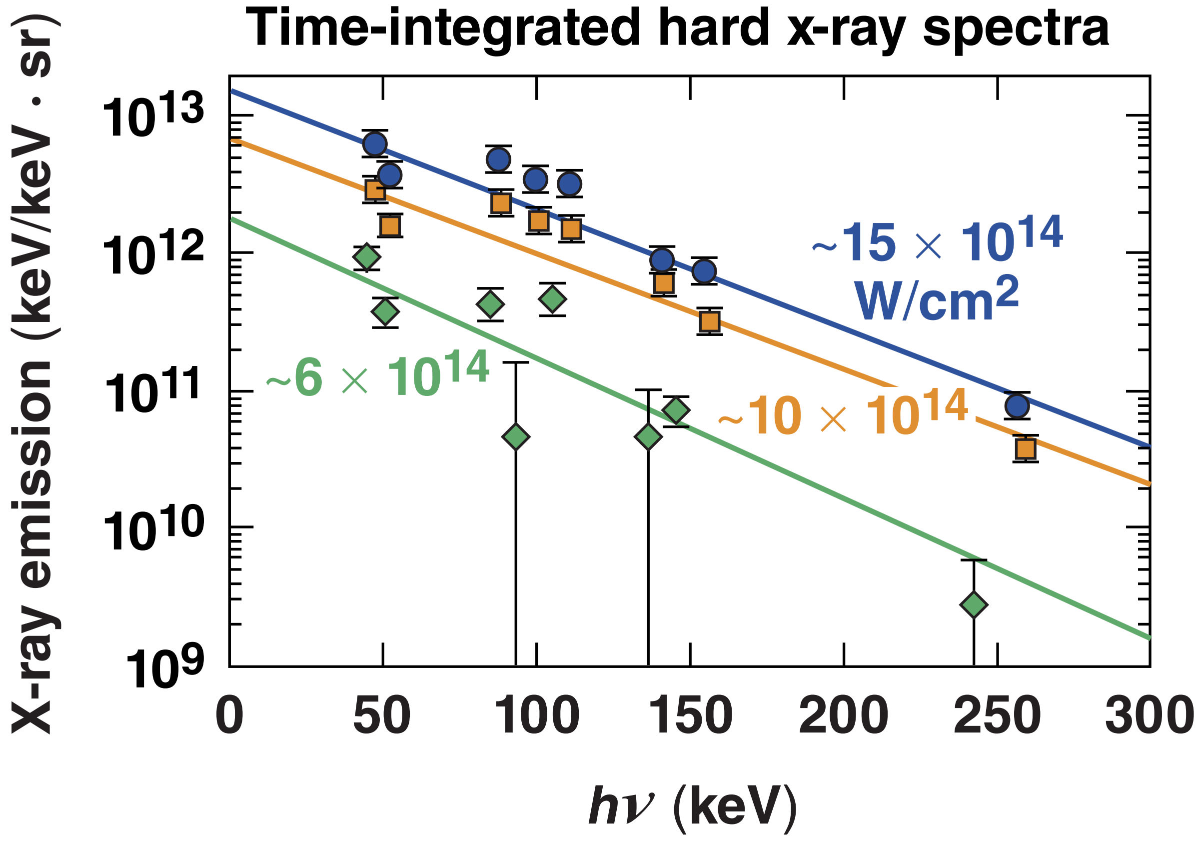
Planar Laser–Plasma Interaction Experiments at Direct-Drive Ignition-Relevant Scale Lengths at the National Ignition Facility





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Summary

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

- The fraction of laser energy converted to hot electrons increased with laser intensity from f_{hot} ~0.5% to 2.3%—from 6 to 15 × 10^{14} W/cm^2 — while T_{hot} was ~50 keV
- Stimulated Raman scattering (SRS), not two-plasmon decay (TPD), is the dominant hot-electron source at these conditions
- The use of Si ablators is being investigated for mitigating LPI hot electrons, and initial results indicate a reduction of the observed SRS, f_{hot}, and T_{hot} using small-angle beams

E25565

Collaborators

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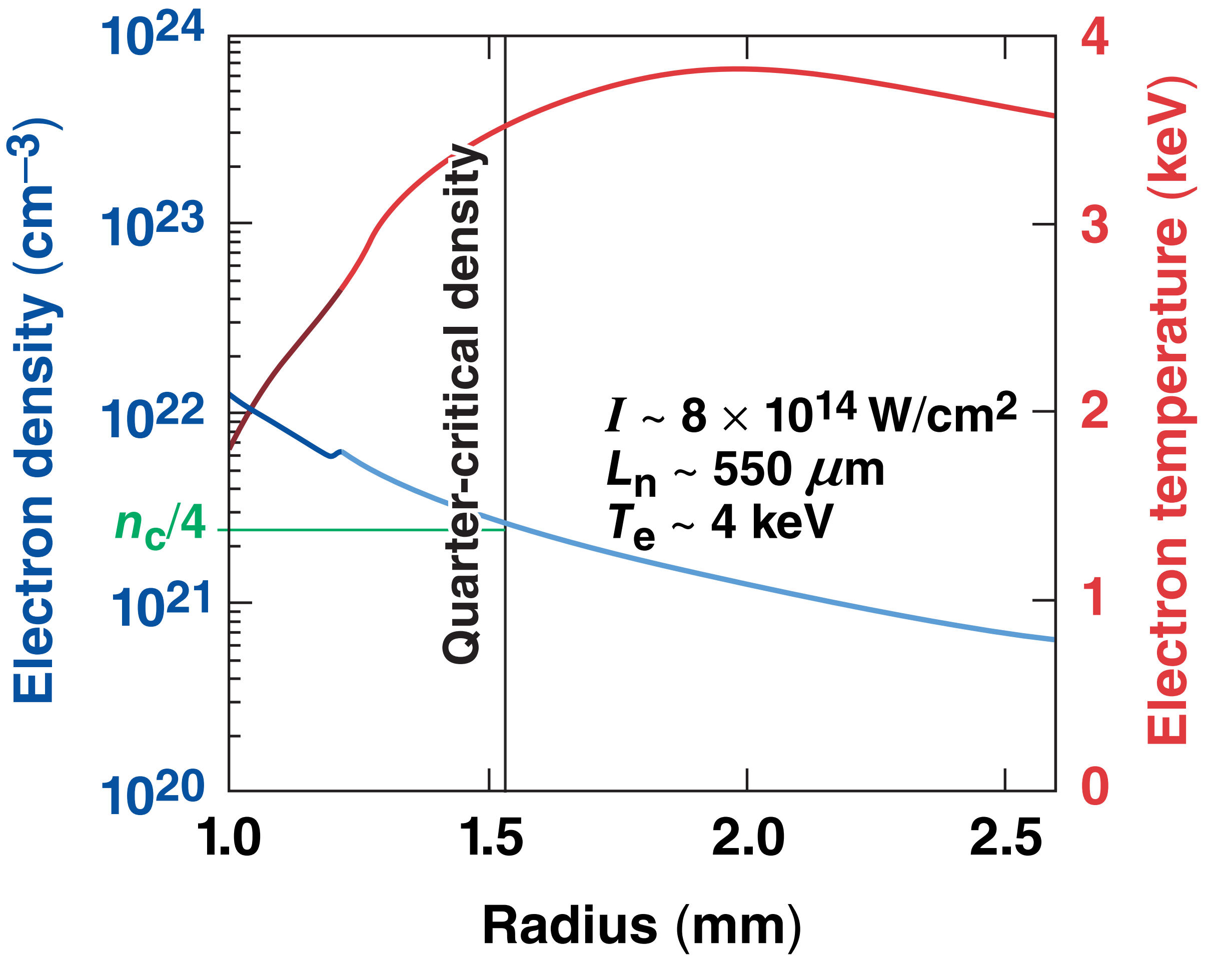
Motivation

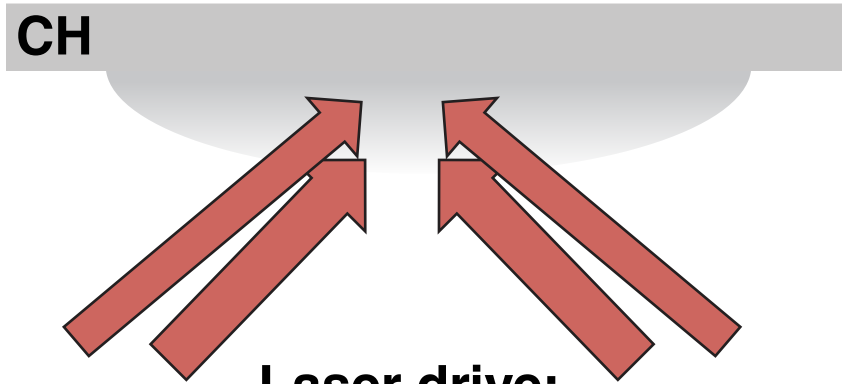
Direct-drive (DD)–ignition designs predict long density scale lengths and high electron temperatures under which LPI may occur

One-dimensional simulated plasma conditions for igniting direct-drive design

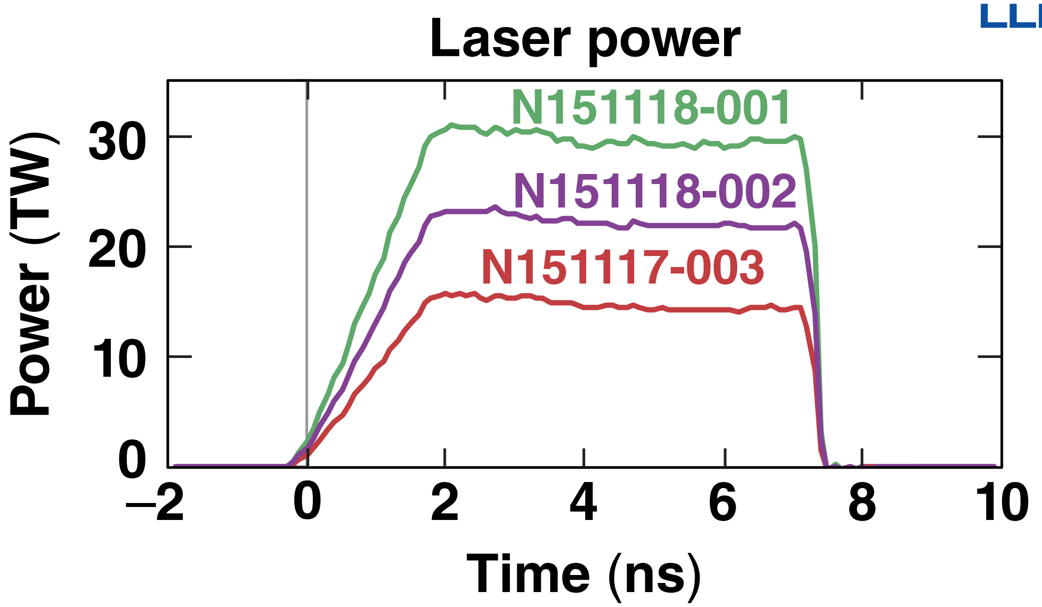


Currently, these coronal plasma conditions can be created only in NIF planar experiments.

Three experiments explored the scaling of hot-electron properties with laser intensity at ~500-μm scale lengths



Laser drive:
64 beams, 45° and 50°



$n_c/4$ parameter	DD ignition	Planar NIF*
I(W/cm^2)	6 to 8 × 10^{14}	6 to 15 × 10^{14}
T_e (eV)	4 keV	4 keV
L_n (μm)	550 μm	500 μm

Primary diagnostics
- Hard x ray → T_{hot}, E_{hot}/f_{hot}
- $\omega/2$ and SRS → LPI signatures

Considering overlapped laser intensities, these experiments are ~3 to 8× above the TPD threshold† and ~10 to 25× above the SRS threshold.‡

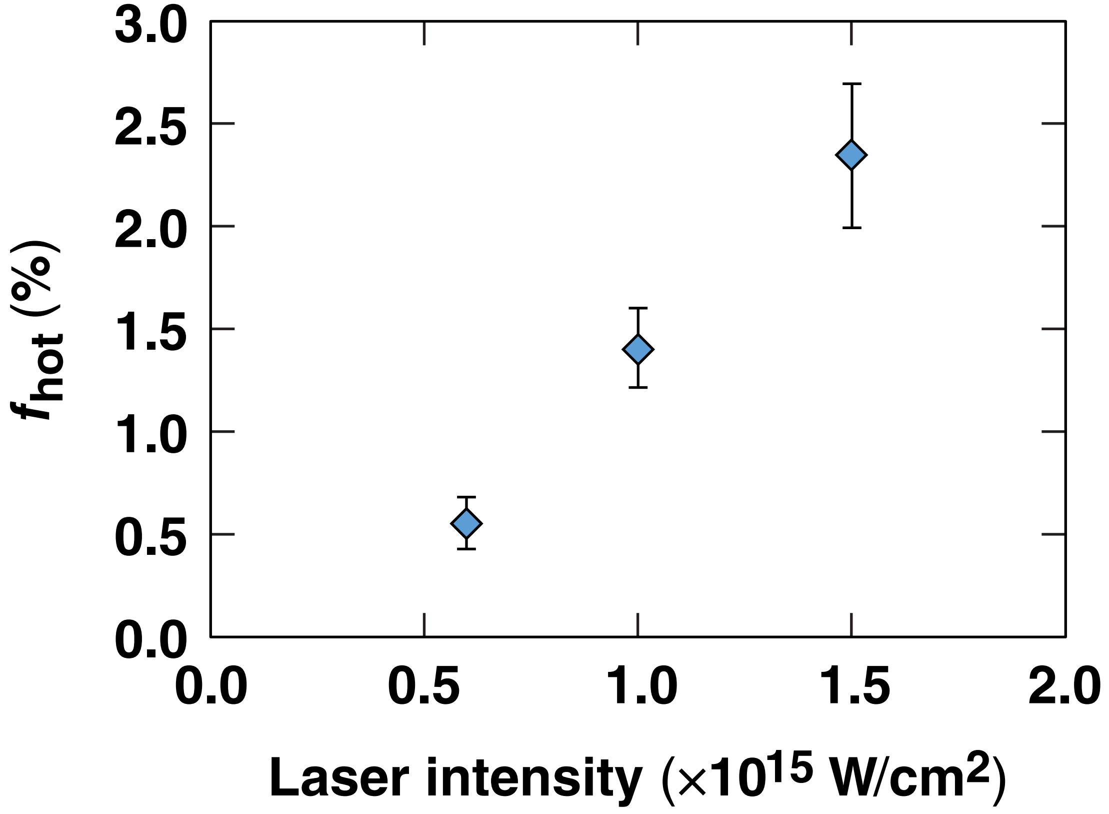
*A. A. Solodov *et al.*, UO9.00002, this conference.
†A. Simon *et al.*, Phys. Fluids 26, 3107 (1983).
‡C. S. Liu, M. N. Rosenbluth, and R. B. White, Phys. Fluids 17, 1211 (1974).

E24812d

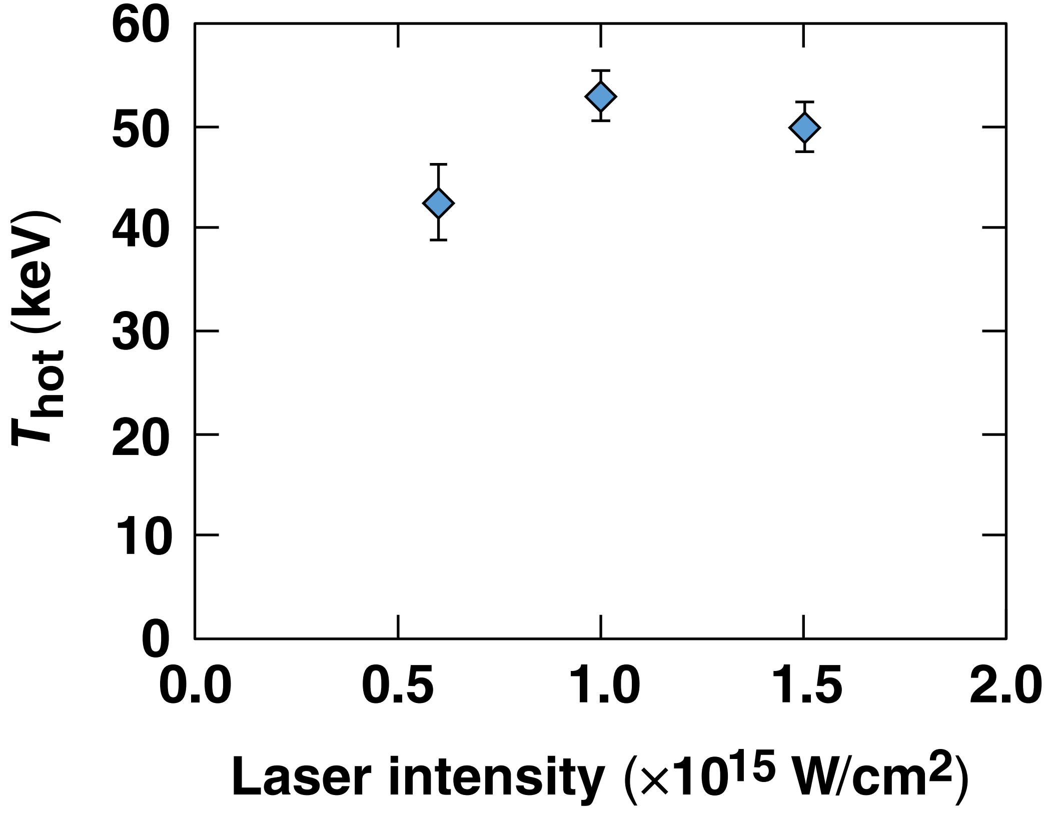
Time-integrated hard x-ray data show f_{hot} (E_{hot}/E_{laser}) increases with laser intensity, while T_{hot} is constant

Shots N151117-18

f_{hot} versus laser intensity at $n_c/4$



T_{hot} versus laser intensity at $n_c/4$

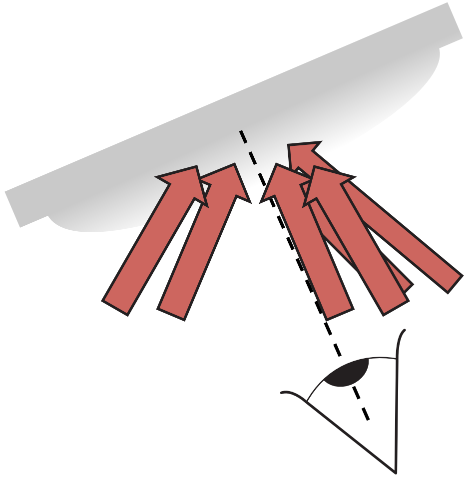


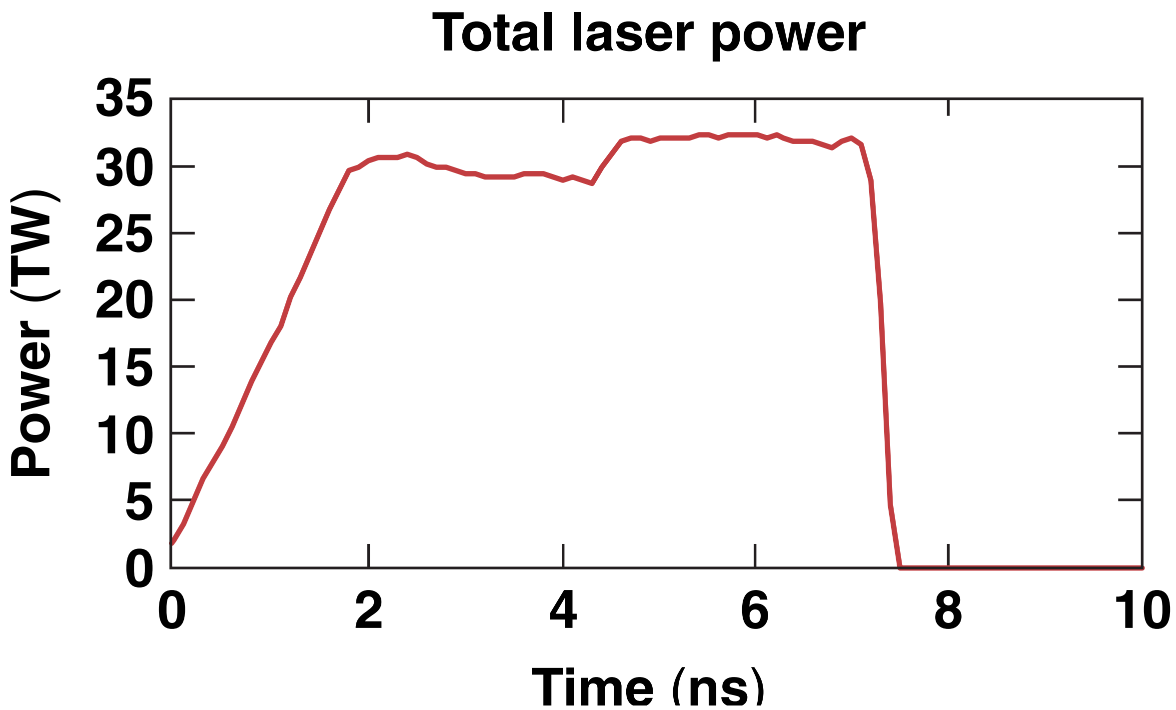
f_{hot} is close to levels tolerable in direct-drive–ignition designs; mitigation of hot electrons depends on understanding the LPI process that produces them.

E24813b

Subsequent experiments optimized the LPI measurement by orienting the target normal to the optical diagnostics

View along target normal is optimal for $\omega/2$, since most emission occurs within ~10° of normal*



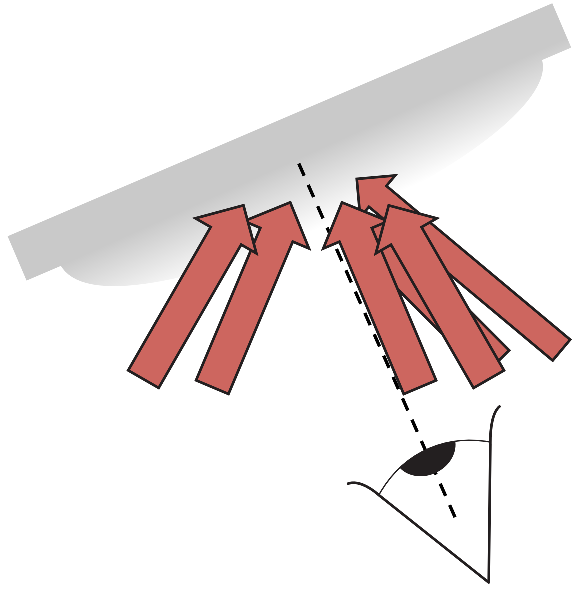


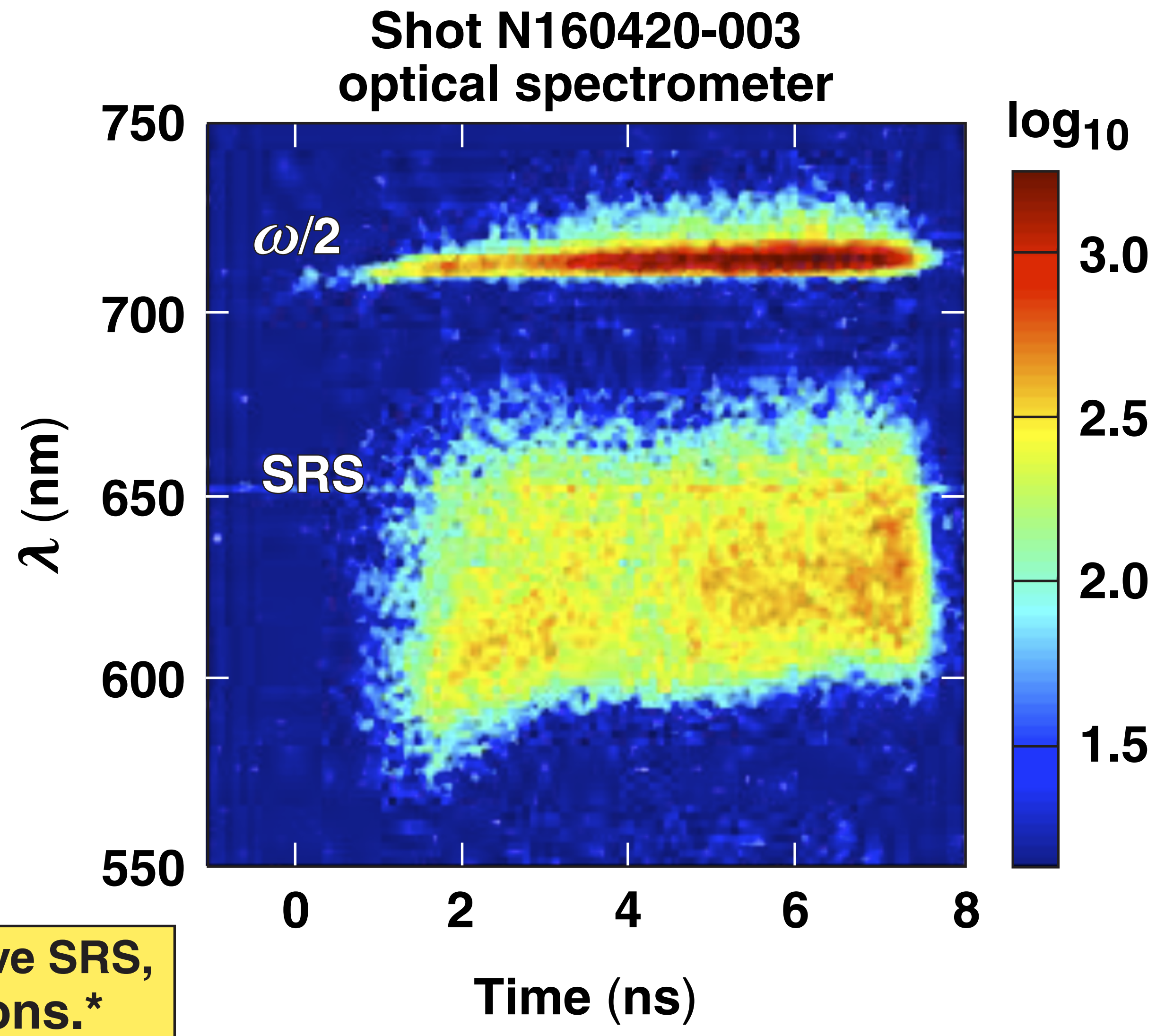
If TPD is dominant, expect to see broad spectral features at $\omega/2$, as have been observed previously on OMEGA.*

E25566

*W. Seka *et al.*, Phys. Rev. Lett. 112, 145001 (2014).

Only a sharp, red-shifted $\omega/2$ feature is observed, suggesting a diminished presence of TPD relative to SRS



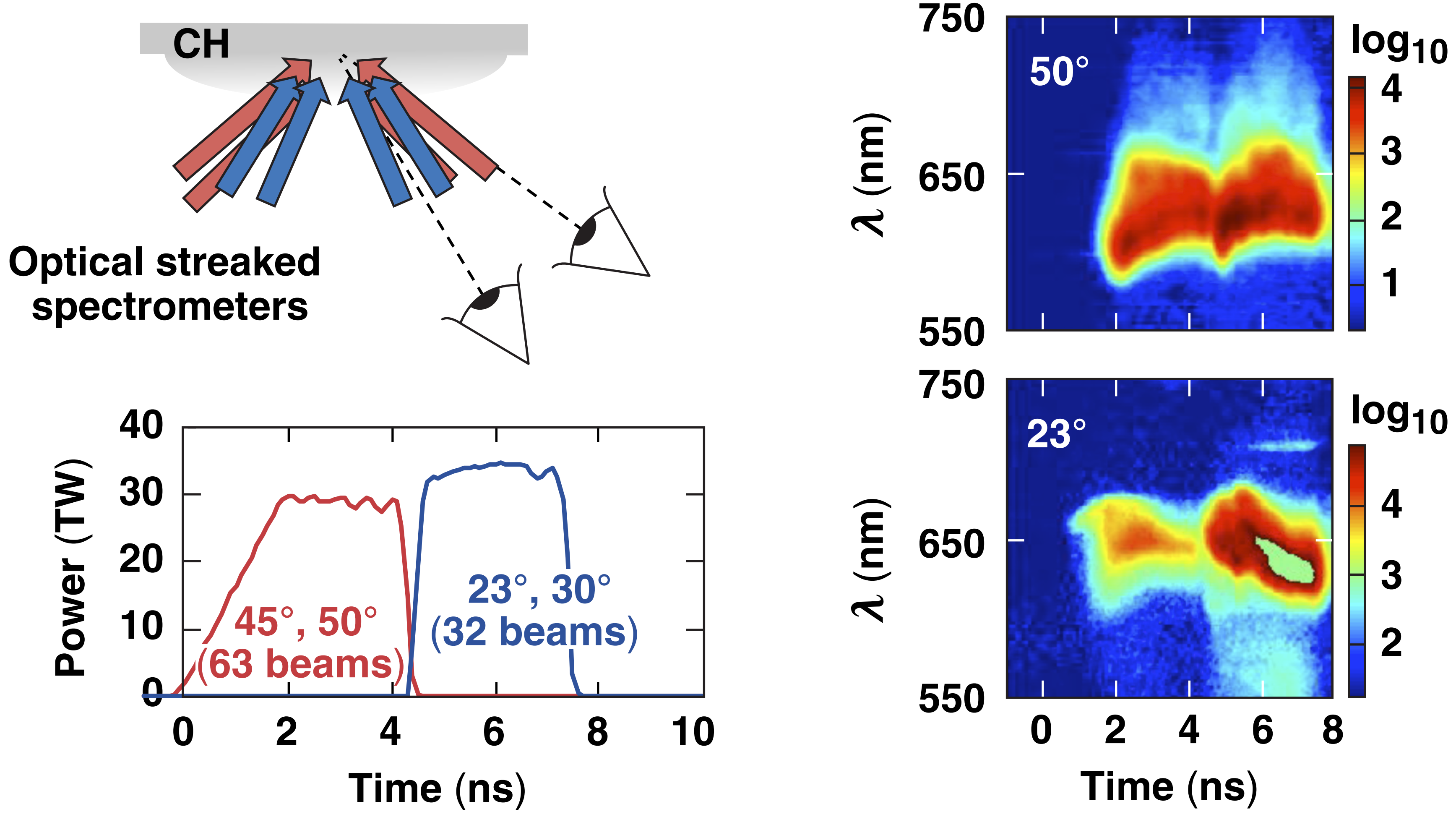


This spectrum indicates both absolute and convective SRS, at a level (≲5%) comparable to that of the hot electrons.*

*See W. Seka *et al.*, UO9.00003, this conference.

In related experiments, SRS is observed at many beam-angle positions, regardless of whether those beams are used

Shot N160421-001



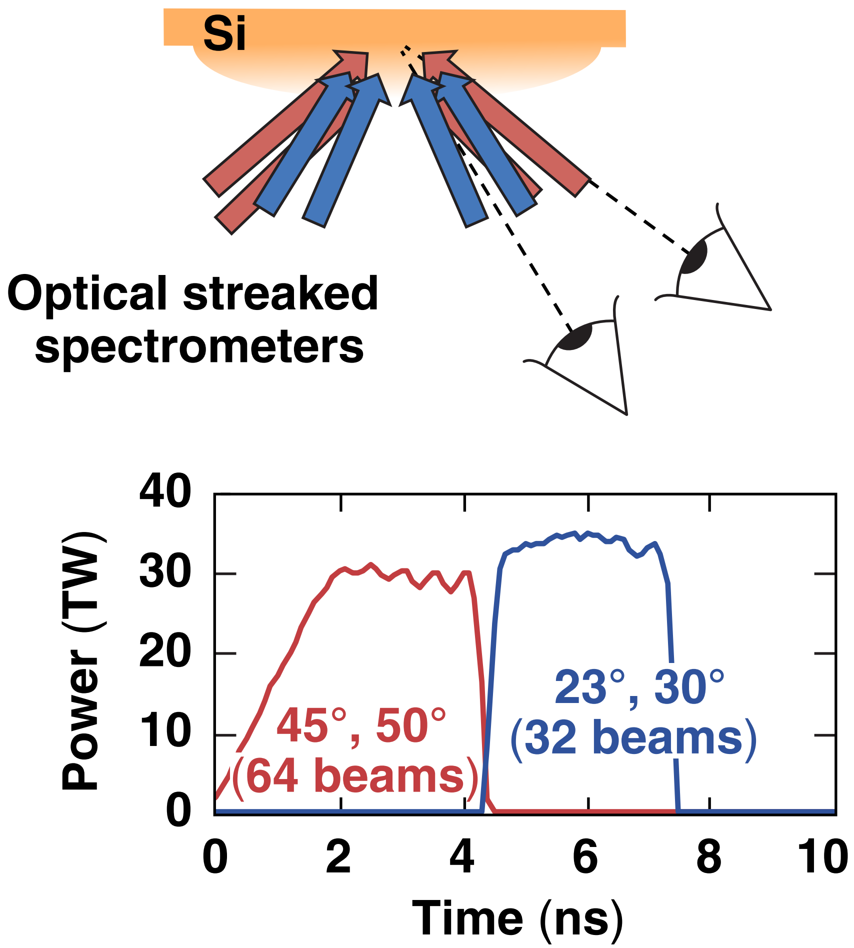
These data provide strong evidence of SRS sidescattering.*

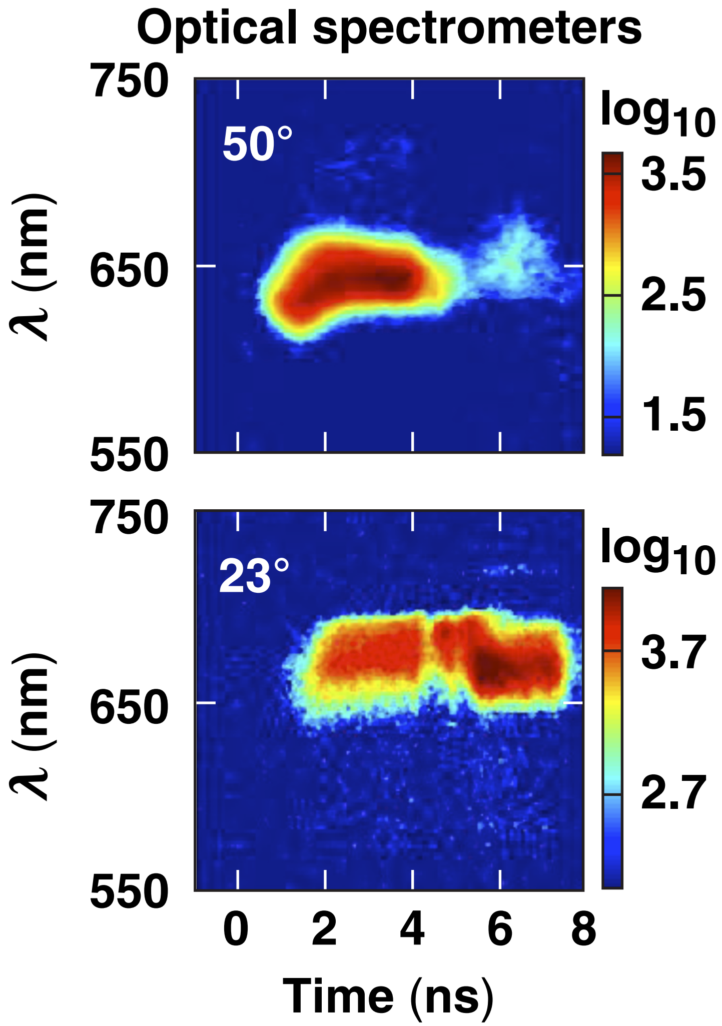
*P. Michel *et al.*, UO9.00004, this conference.

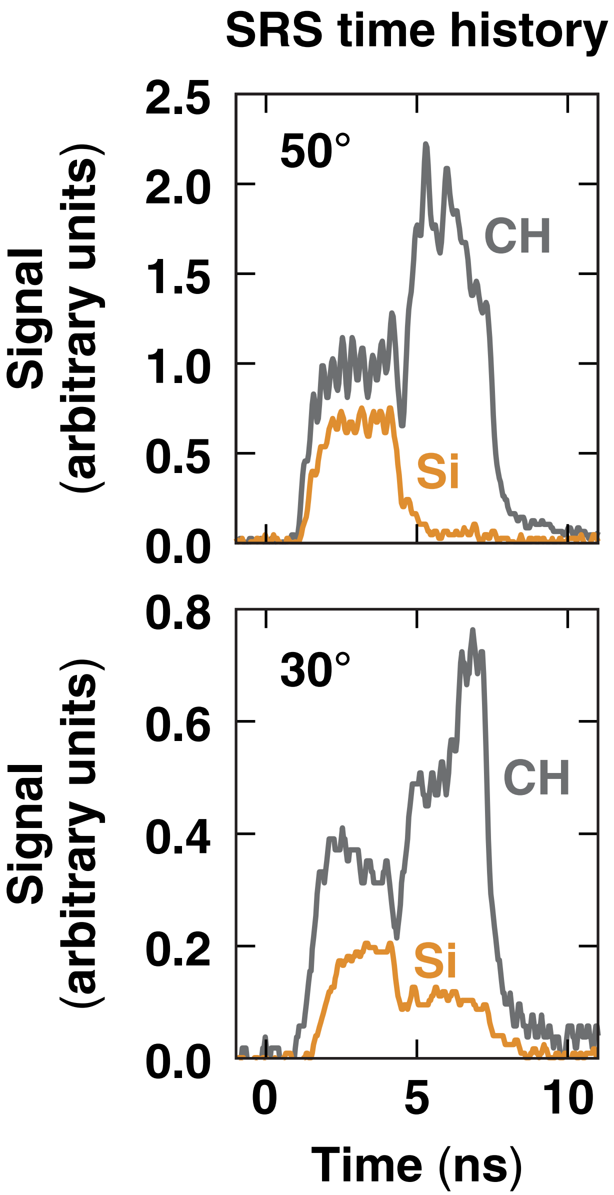
E25568

Use of an Si ablator—part of a proposed LPI mitigation strategy—causes a reduction in observed SRS driven by small-angle beams, relative to CH

Shot N160719-001

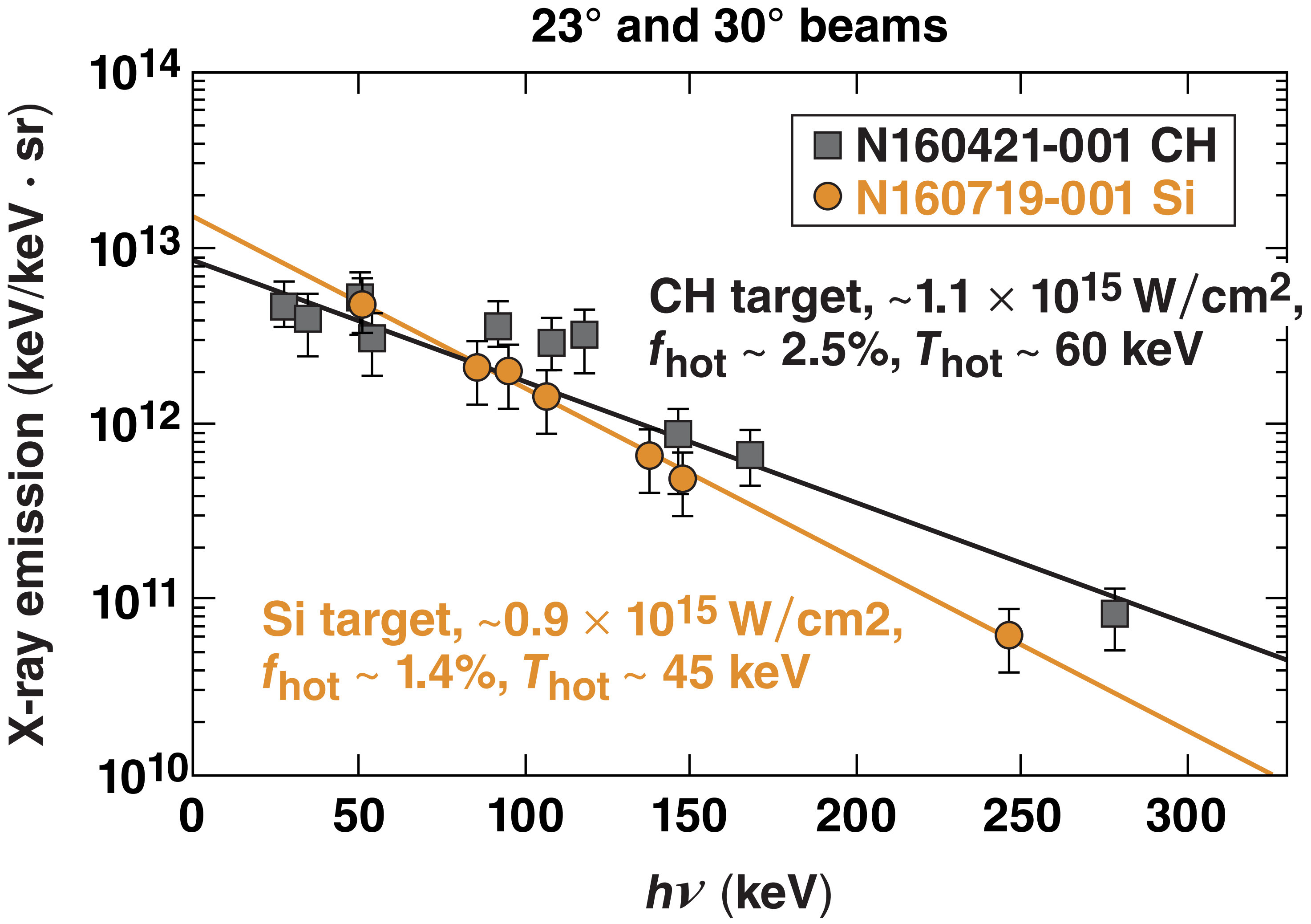






E25569

Compared to the CH target, the Si target produced an ~40% lower f_{hot} and an ~15-keV lower T_{hot} for small-angle-beam drive



*A. A. Solodov *et al*., UO9.00002, this conference.

E25733

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

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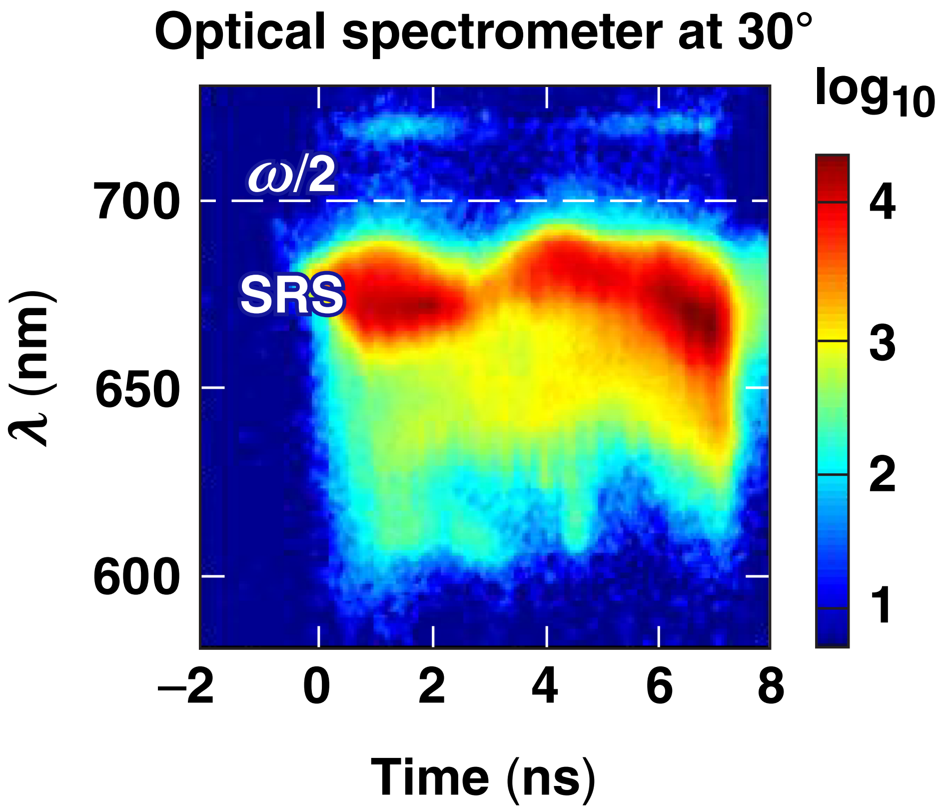
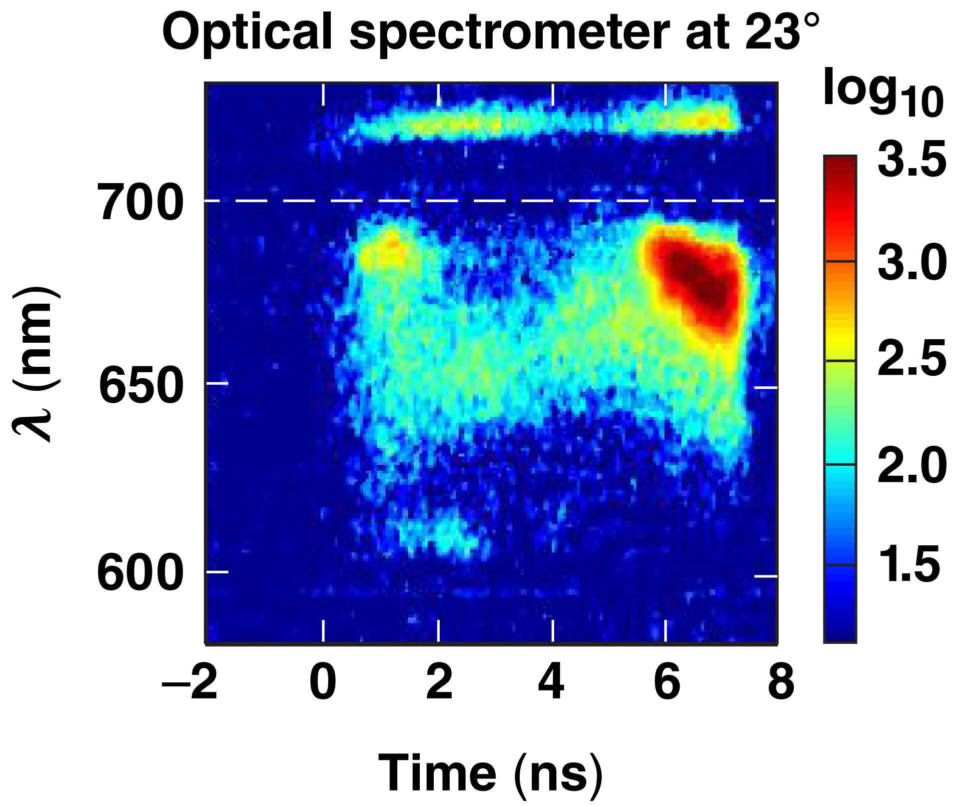
Appendix

Emission both at $\omega/2$ and associated with SRS is observed

15×10^{14} W/cm^2



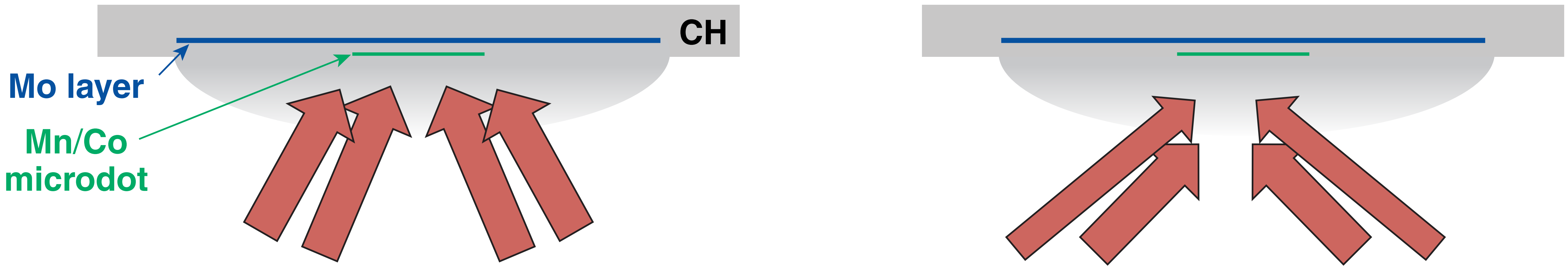


Further experiments were needed to determine whether TPD or SRS is the dominant hot-electron source.

E24815b

Two planar experiments were performed on the NIF to constrain plasma conditions and to study the beam angle-of-incidence dependence of LPI

Pole	Equator
Shot N150520: 23° and 30° beams (32 beams total)	Shot N150521: 45° and 50° beams (60 beams total)



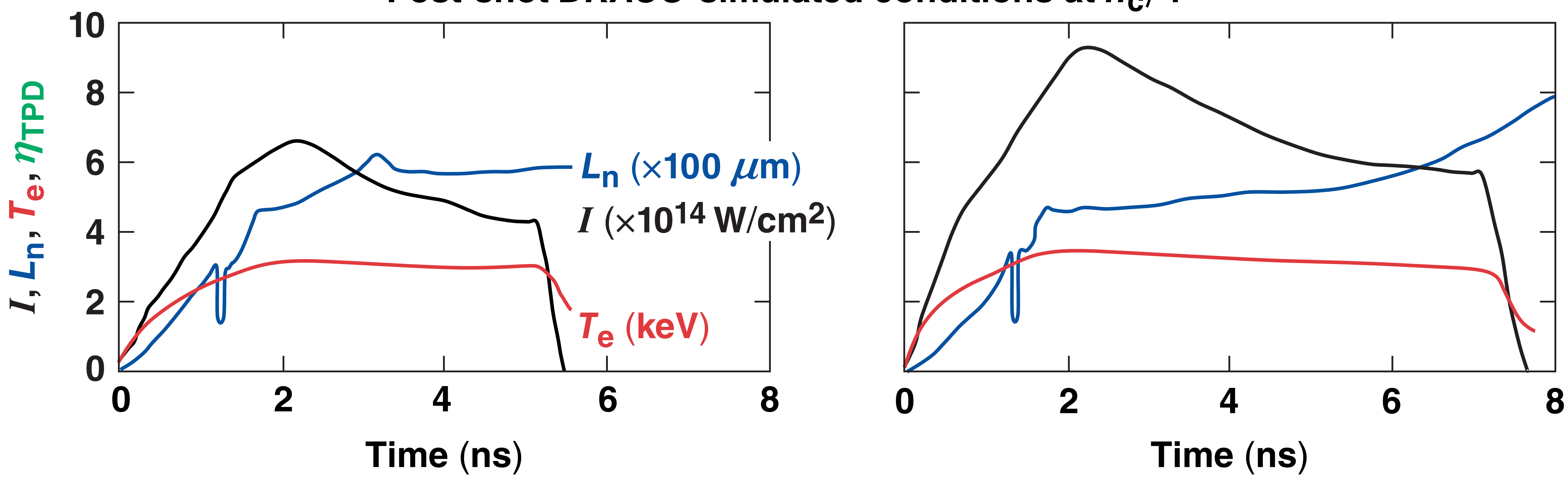
Primary diagnostics
- Microdot microscopy → T_e
- $\omega/2$ and SRS → LPI signatures
- Hard x ray → T_{hot}, E_{hot}
- Mo–K_α fluorescence → E_{hot}

E24713c

Long-scale-length (>500-μm), high-temperature (>3-keV) coronal plasma conditions are predicted by 2-D *DRACO* simulations

Shot N150520: 23° and 30° beams | Shot N150521: 45° and 50° beams

Post-shot *DRACO*-simulated conditions at $n_c/4$*



The empirical TPD and theoretical SRS thresholds are exceeded in this experimental design: $\eta_{TPD} = I_{14}\, L_{n,\mu m}/(230\, T_{e,keV})$ ~ 4 to 5, $\eta_{SRS} = I_{14}\, L_{n,\mu m}^{4/3}/2377$ ~ 10 to 13.**

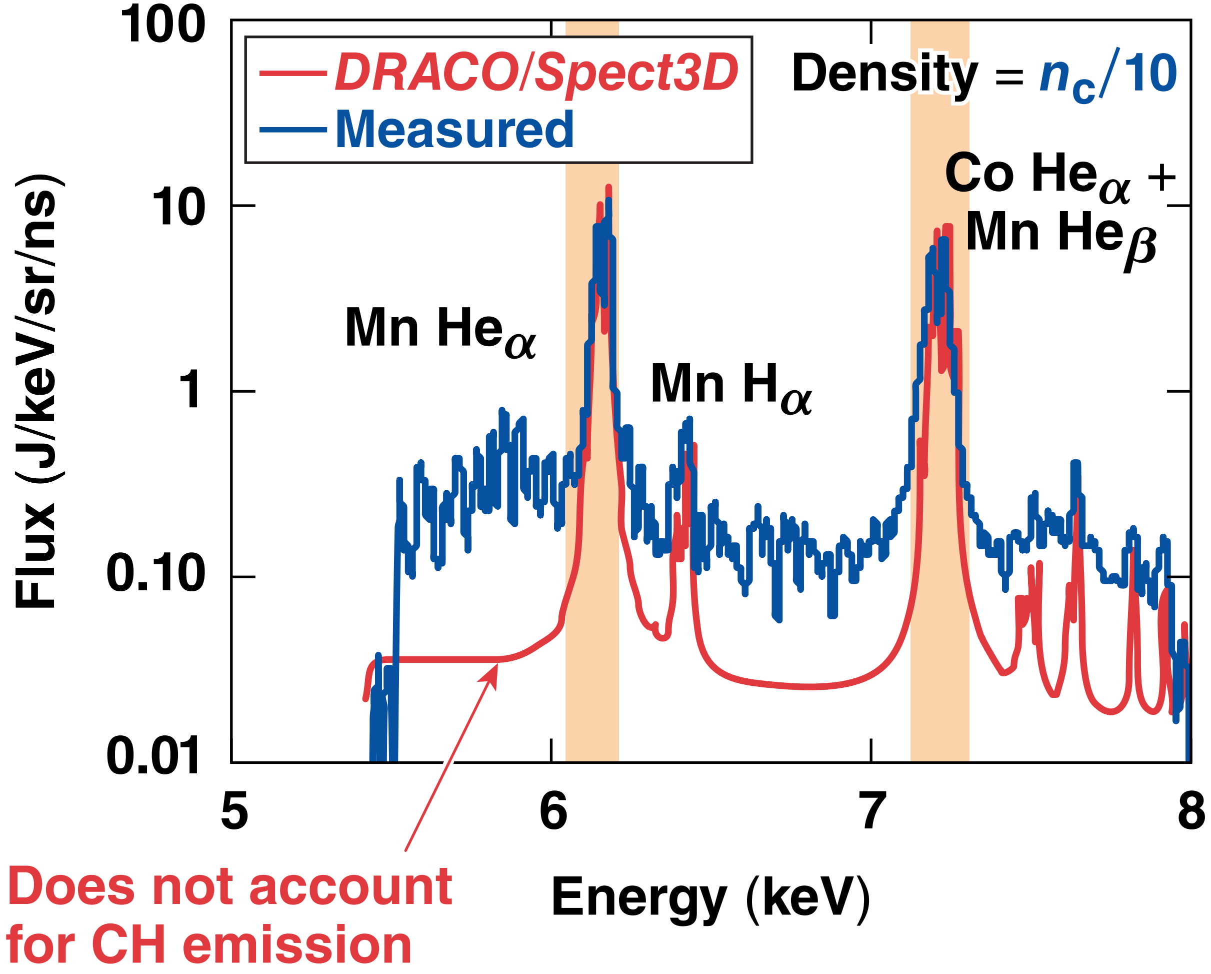
*A. A. Solodov *et al.*, presented at the Ninth International Conference on Inertial Fusion Sciences and Applications (IFSA 2015), Seattle, WA, 20–25 September 2015

**A. Simon *et al.*, Phys. Fluids 26, 3107 (1983).
C. S. Liu, M. N. Rosenbluth, and R. B. White, Phys. Fluids 17, 1211 (1974).

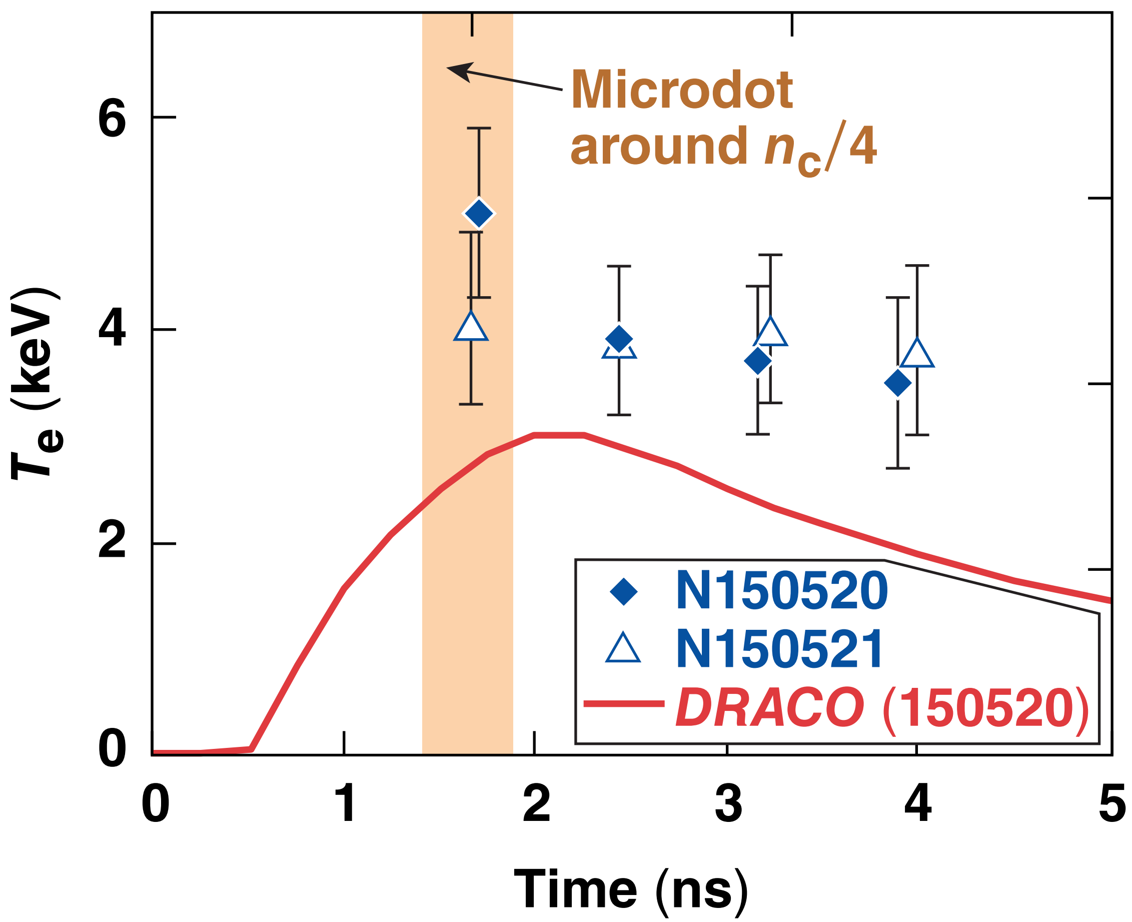
E24714c

The isoelectronic ratio* of the Mn/Co K-shell emission lines is used to infer $T_e = 4.6 \pm 1.1$ keV at $n_c/4$

Shot N15020: 23° and 30° beams
NXS calibrated spectrum at 2.4 ns



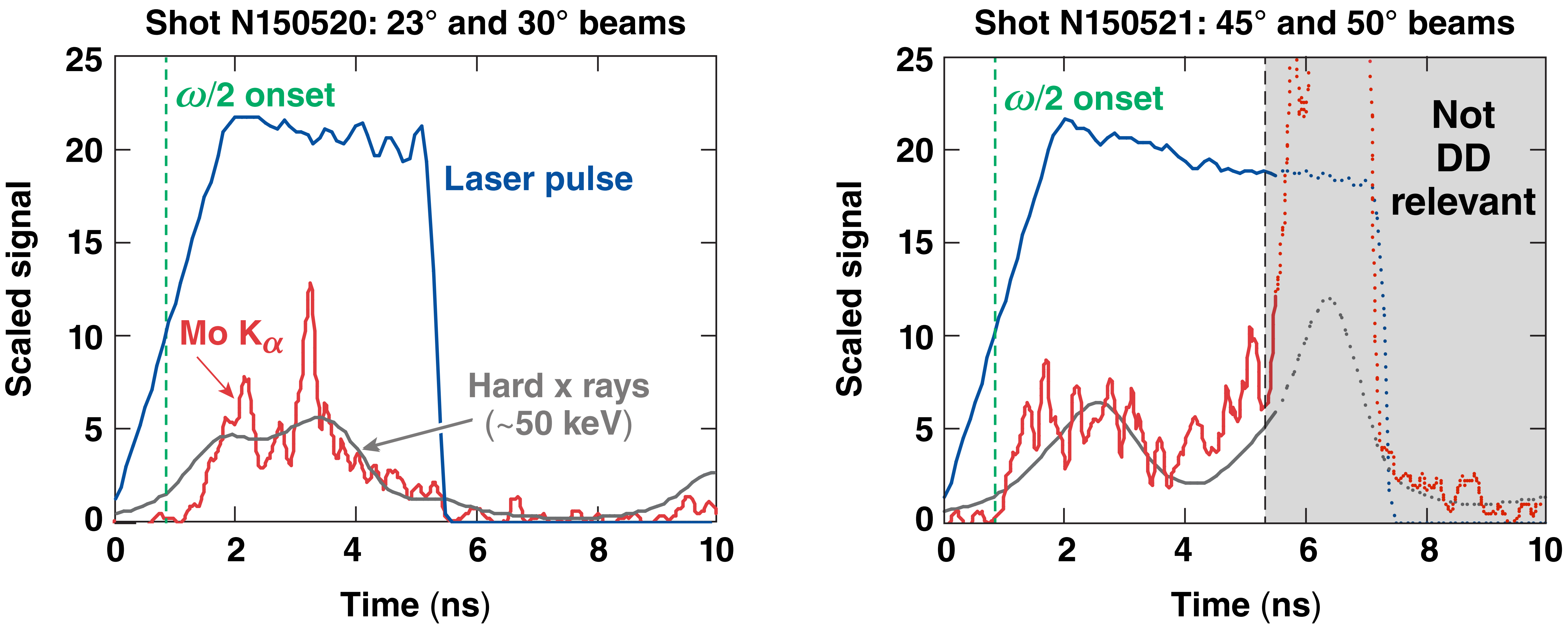
Measured T_e at micodot



TC12489

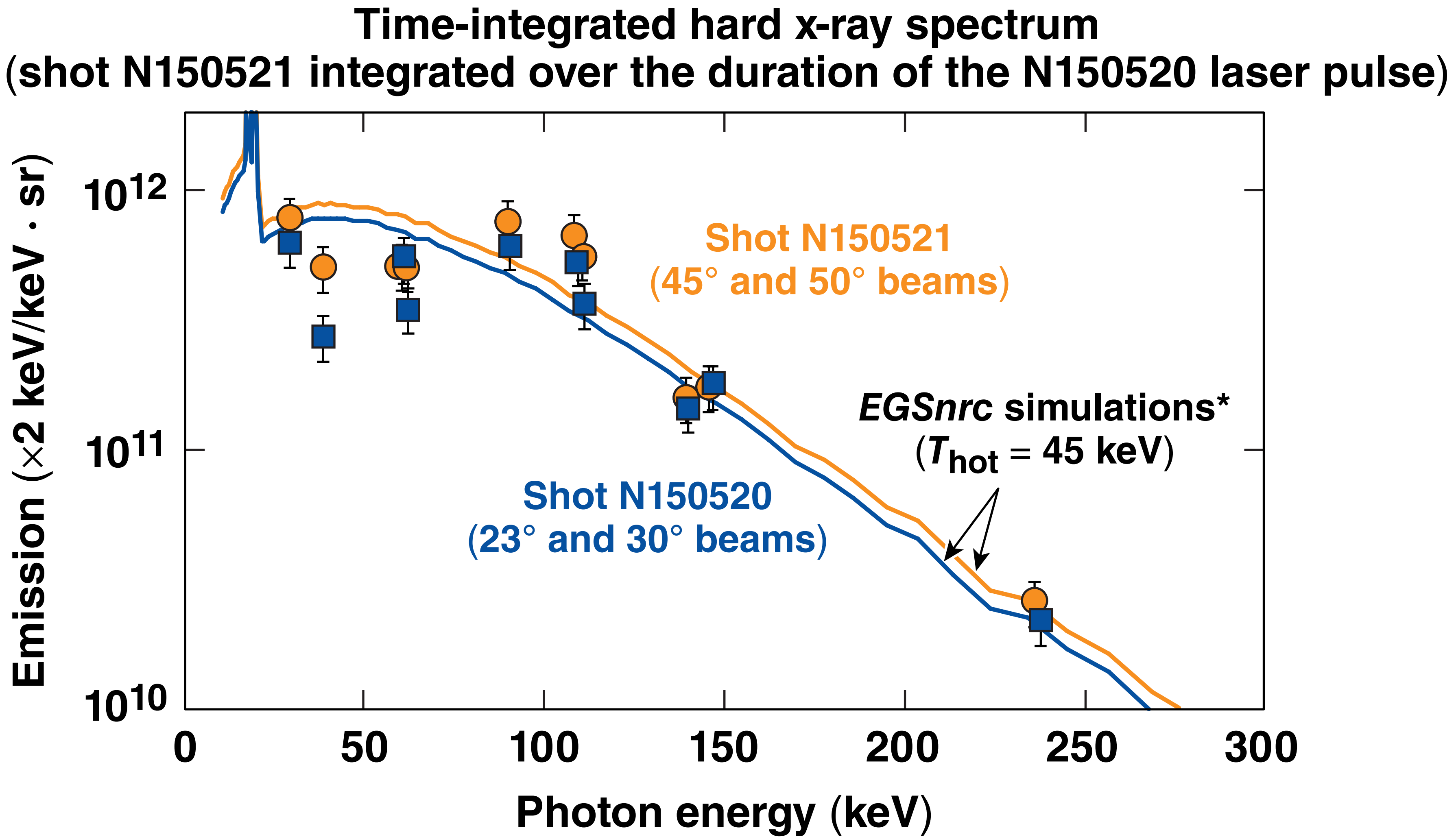
*R. Marjoribanks *et al.*, Phys. Rev. A 46, R1747 (1992).

Hard x-ray and Mo–K_α emission caused by LPI-generated hot electrons were observed



E24128f

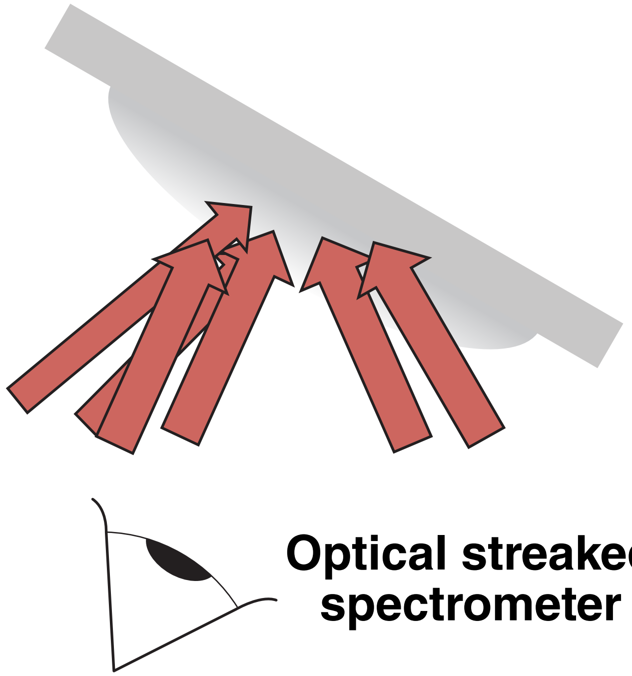
Time-integrated hard x-ray spectra indicate T_{hot} ~ 45±5 keV, f_{hot} ~1% for both experiments



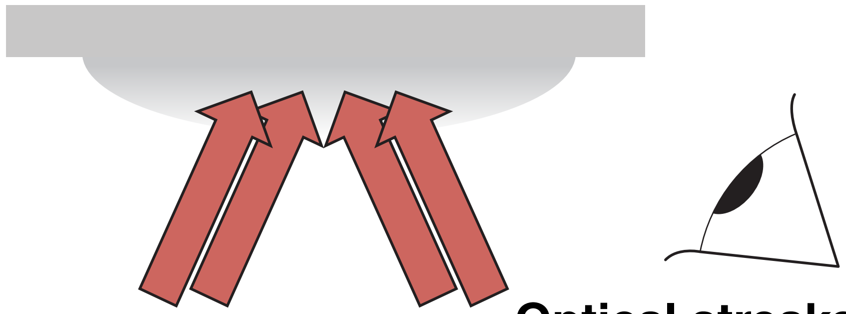
The beam angle-of-incidence did not have a strong effect on f_{hot} and T_{hot}.

*A. A. Solodov *et al.*, presented at the Ninth International Conference on Inertial Fusion Sciences and Applications (IFSA 2015), Seattle, WA, 20–25 September 2015.

Subsequent experiments optimized the $\omega/2$ measurement by orienting the target normal to the optical diagnostics



View along target normal is optimal for $\omega/2$ and for complete SRS spectrum and energy measurements



Oblique view for SRS spectrometer in 23°/30° beam experiment may provide evidence of multibeam SRS sidescatter

If SRS is dominant, expect that $E_{SRS} \sim E_{hot}$.
If TPD is dominant, expect to see broad spectral features at $\omega/2$.
LPI mitigation using a buried mid-Z layer depends on the hot-electron source.

E24812e