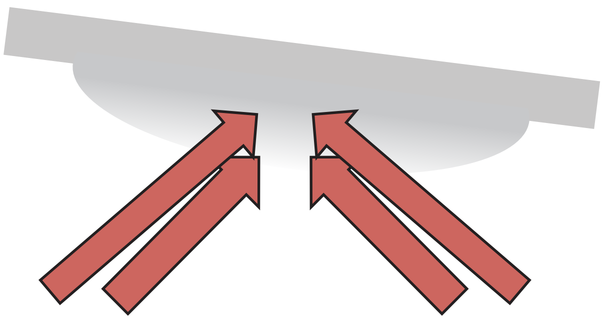
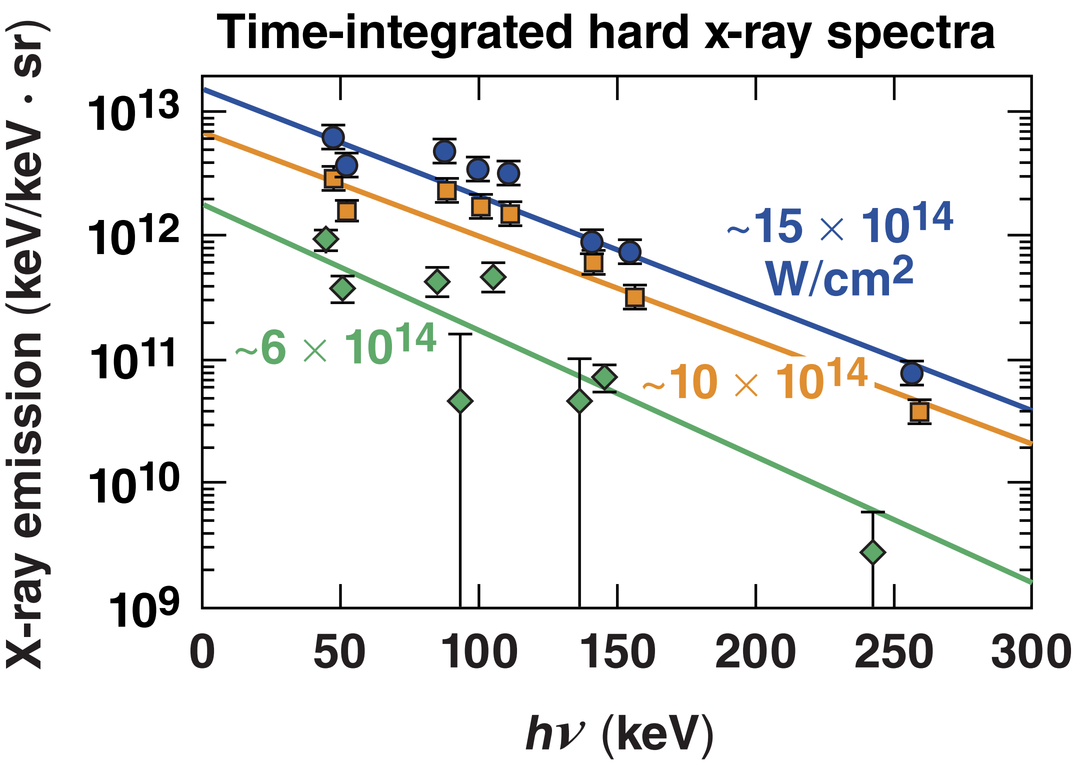
Planar Laser–Plasma Interaction Experiments at Direct-Drive Ignition-Relevant Scale Lengths at the National Ignition Facility



32 or 64 NIF beams
23° and 30°
or 45° and 50°



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46th Annual Anomalous Absorption Conference
Old Saybrook, CT
1–6 May 2016

Summary

A planar platform has been established at the National Ignition Facilty (NIF) to study laser–plasma interaction (LPI) hot-electron production at direct-drive ignition-relevant coronal conditions

- Planar-geometry experiments on the NIF with predicted scale lengths of ~600 μm and $T_e > 3$ keV were performed
- 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 $\times$ 10^{14} W/cm^2) while T_{hot} was ~50 keV
- The beam angle of incidence did not have a strong effect on f_{hot} or T_{hot}
- Ongoing experiments are resolving whether two-plasmon decay (TPD) or stimulated Raman scattering (SRS) is the dominant hot-electron source

E24809a

Collaborators

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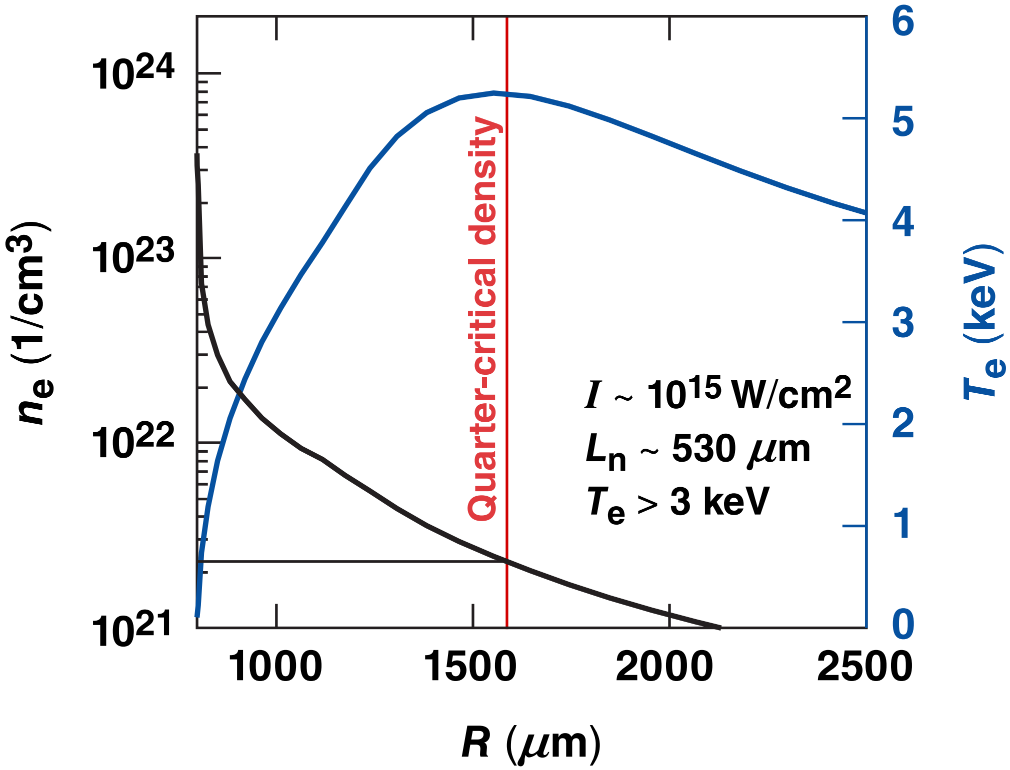
Naval Research Laboratory

Motivation

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

Two-dimensional simulated plasma conditions for igniting DD design*

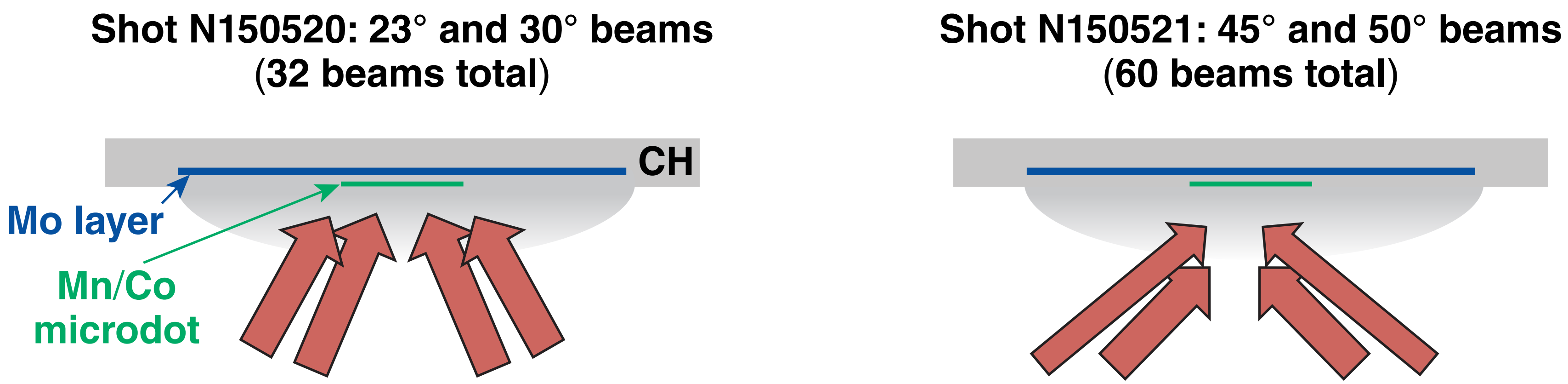


Currently, these coronal plasma conditions can be created only in NIF planar experiments.

E24131c

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

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



Primary diagnostics

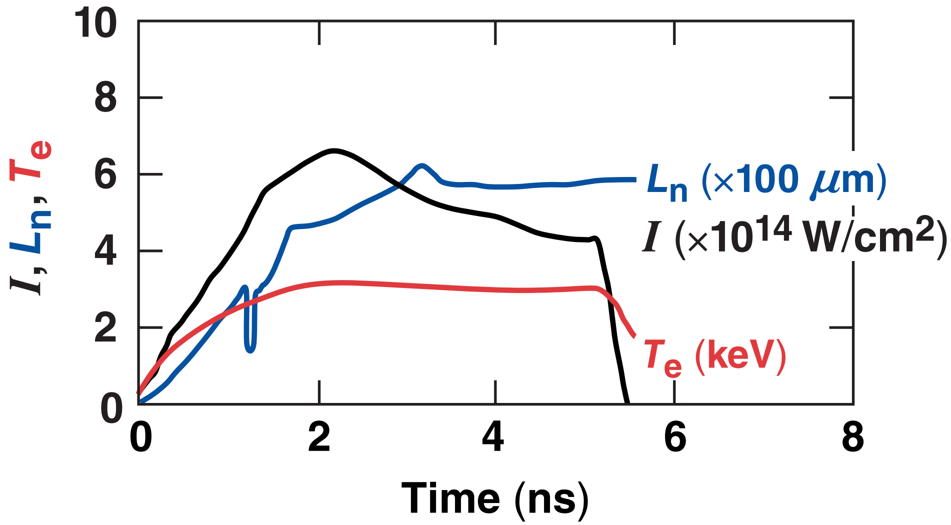
- Microdot spectroscopy → T_e
- $\omega/2$ and SRS → LPI signatures
- Hard x ray → T_{hot}, E_{hot}
- Mo K_α fluorescence → E_{hot}

E24713b

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; next talk

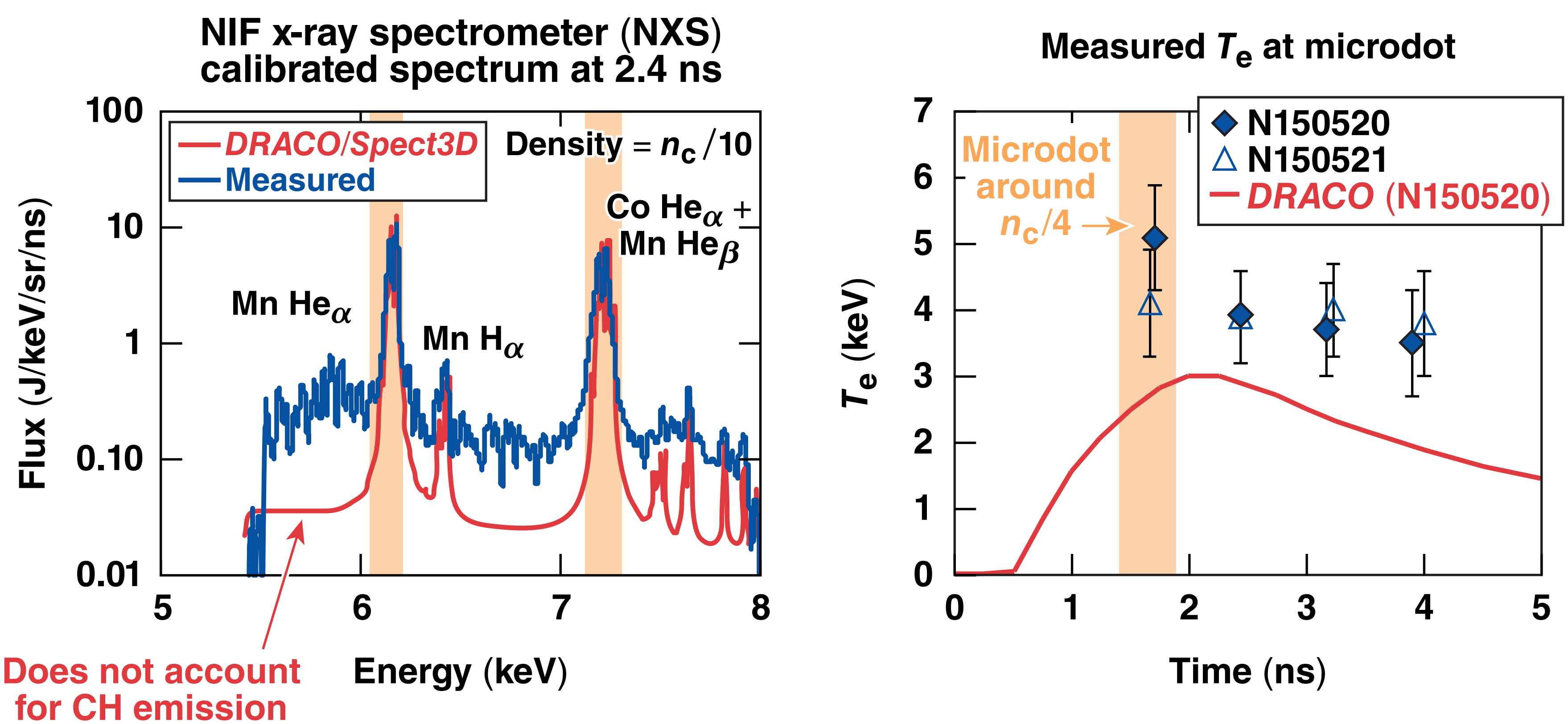
**A. Simon *et al*., Phys. Fluids 26, 3107 (1983).

***C. S. Liu, M. N. Rosenbluth, and R. B. White, Phys. Fluids 17, 1211 (1974).

E24714b

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

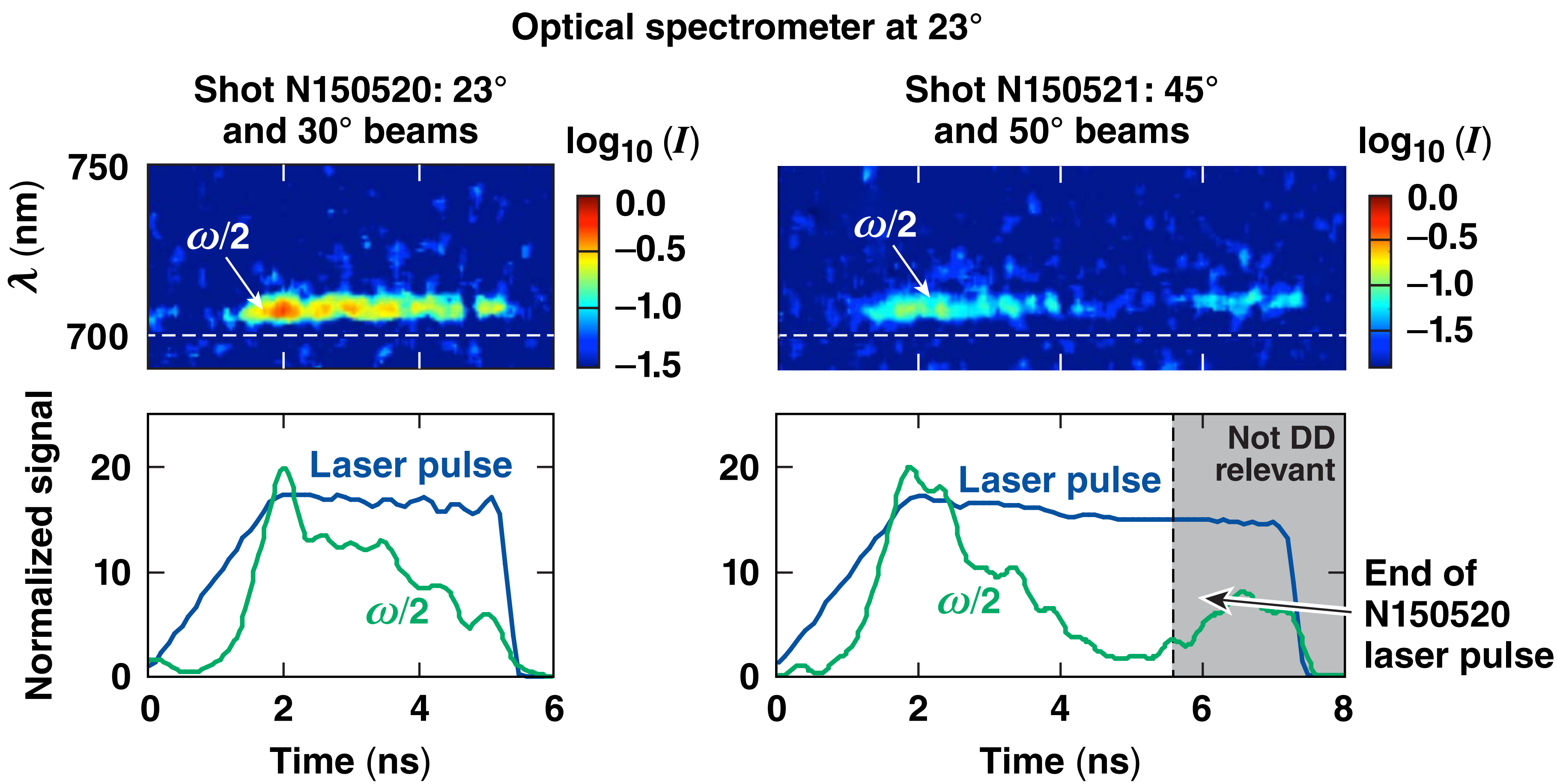
Shot N150520: 23° and 30° beams



TC12489b

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

ω/2 emission indicates that TPD is driven

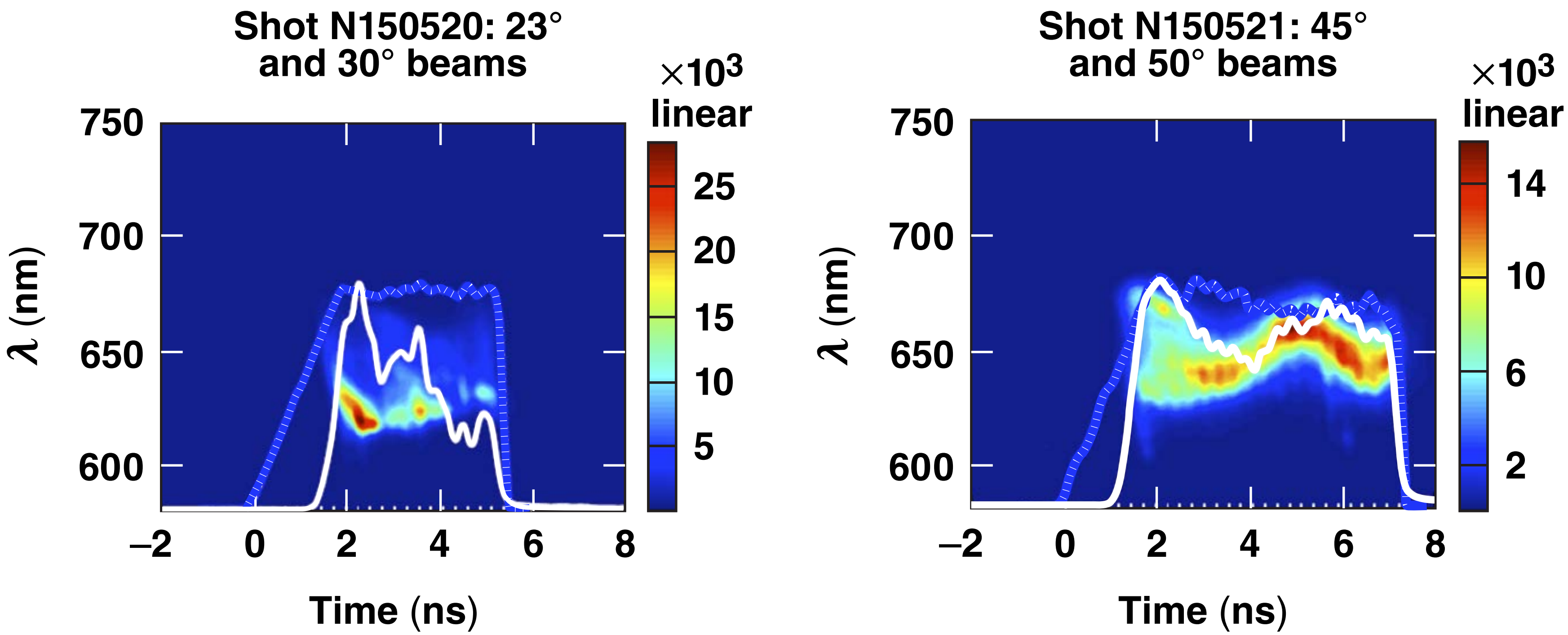


The ω/2 signal is weak because the viewing angle is far from the target normal.

E24127d

In addition to TPD, SRS is also observed

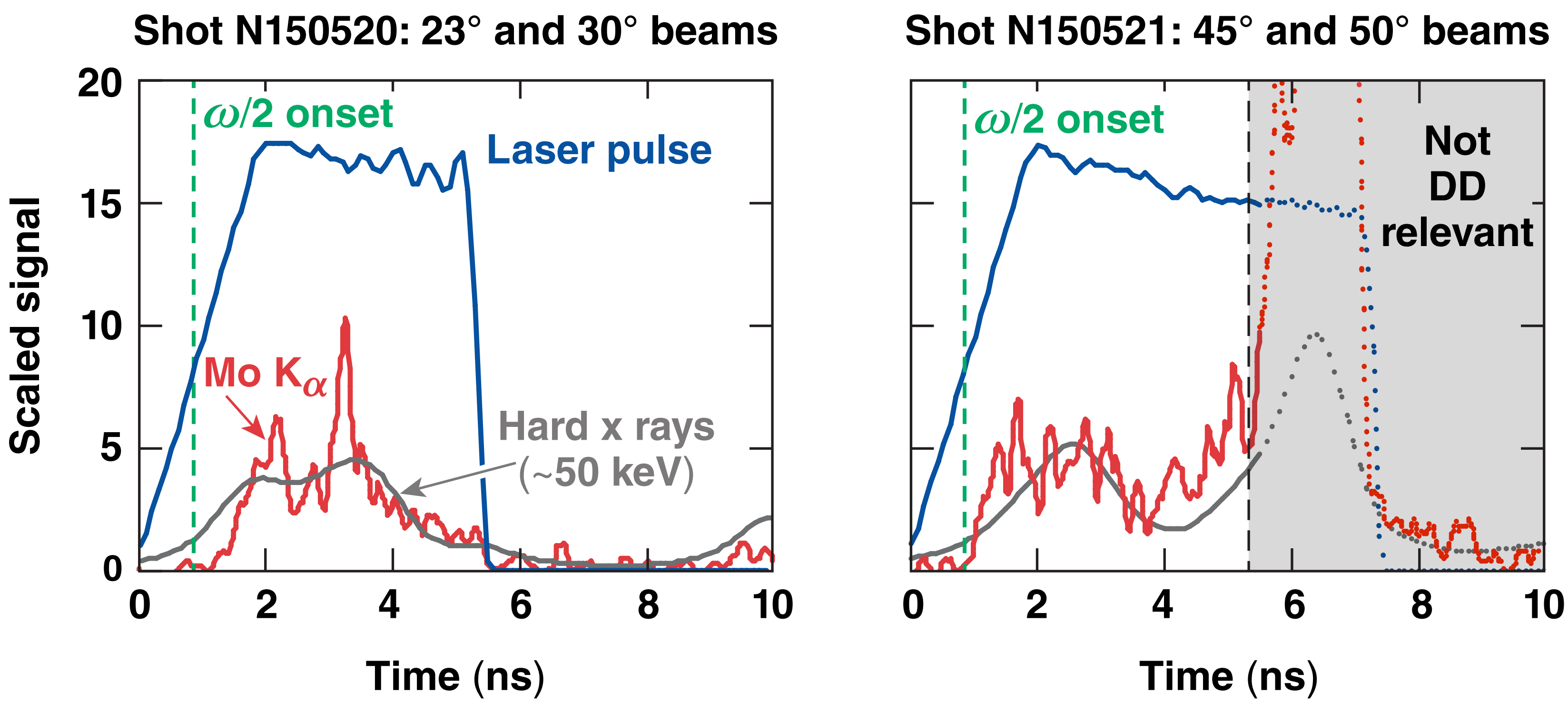
Optical spectrometer at 30°



Presently, it cannot be distinguished whether TPD or SRS is the dominant hot-electron source.

E24811a

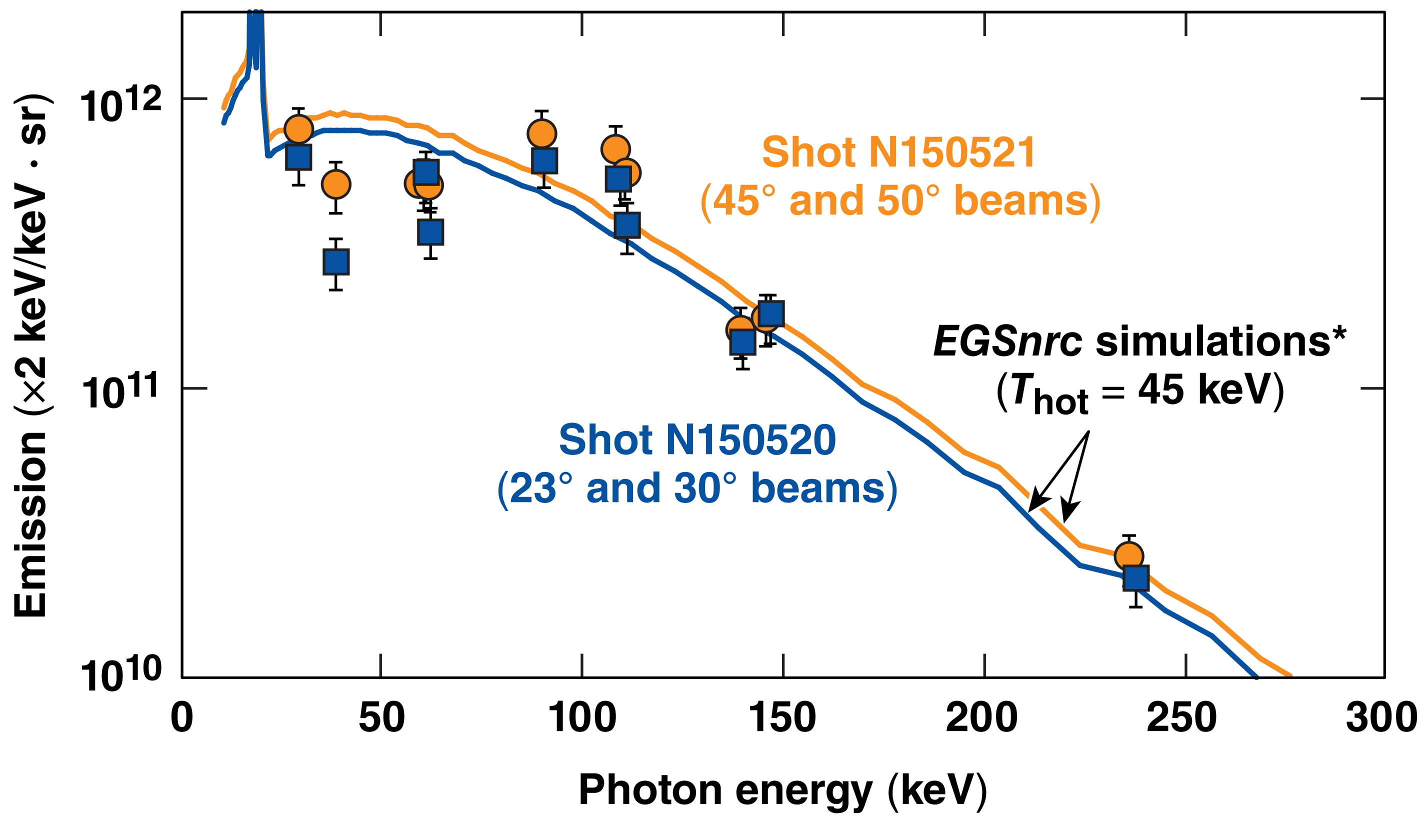
Hard x-ray and Mo K_α emission caused by LPI-generated hot electrons were observed



E24128e

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

Measured time-integrated hard x-ray spectrum
(N150521 data integrated over the duration of the N150520 laser pulse)

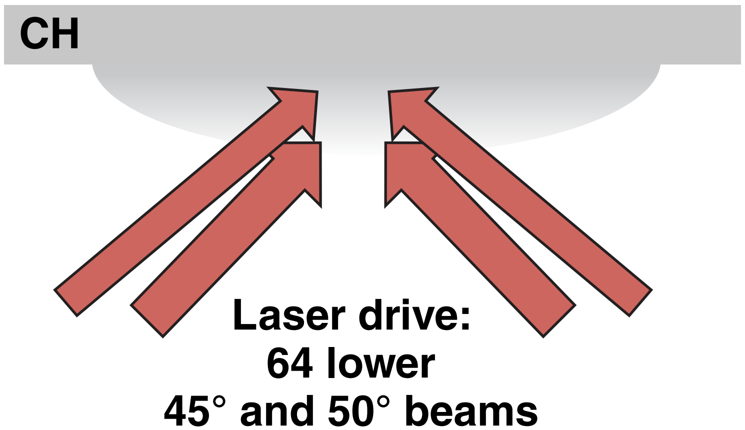


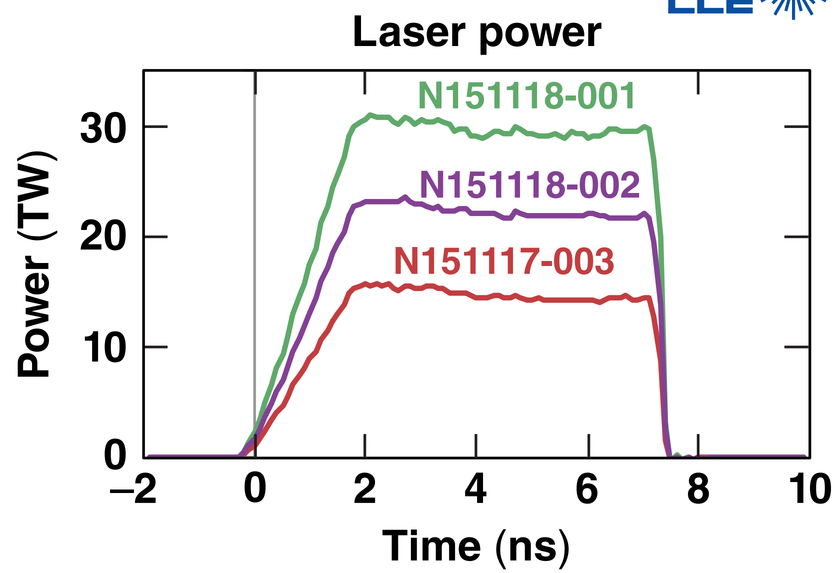
The beam angle-of-incidence did not have a strong effect on f_{hot} and T_{hot}.

*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; next talk

E24130b

Three additional experiments explored the scaling of hot-electron properties with laser intensity





Primary diagnostics

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

$I \sim 15 \times 10^{14}$ W/cm^2 at $n_c/4$

$I \sim 10 \times 10^{14}$ W/cm^2 at $n_c/4$

$I \sim 6 \times 10^{14}$ W/cm^2 at $n_c/4$

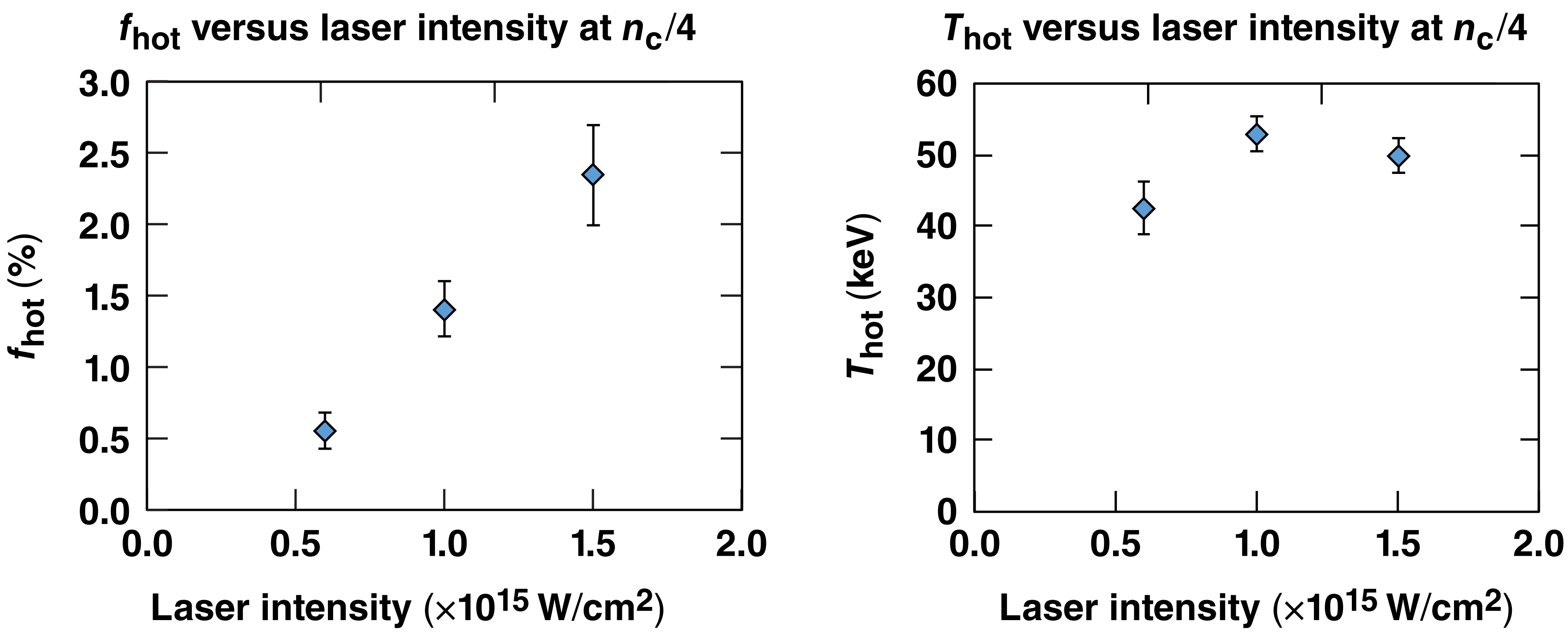
All three: $L_n \sim 500$ to 600 μm at $n_c/4$

Note: direct-drive–ignition designs* have laser intensities ~8 to 10 $\times$ 10^{14} W/cm^2, $L_n \sim 500$ to 600 μm

E24812a

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

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

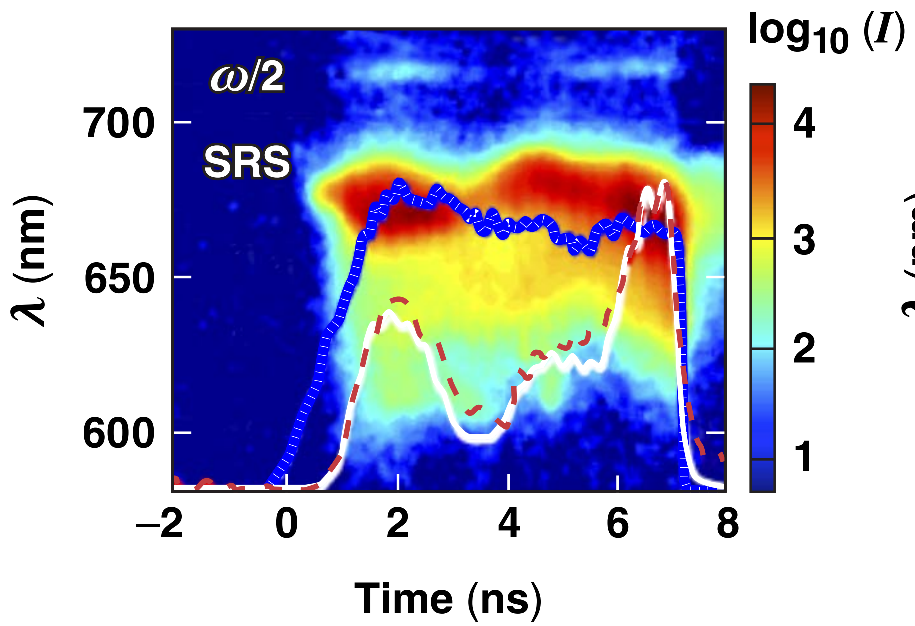


E24813a

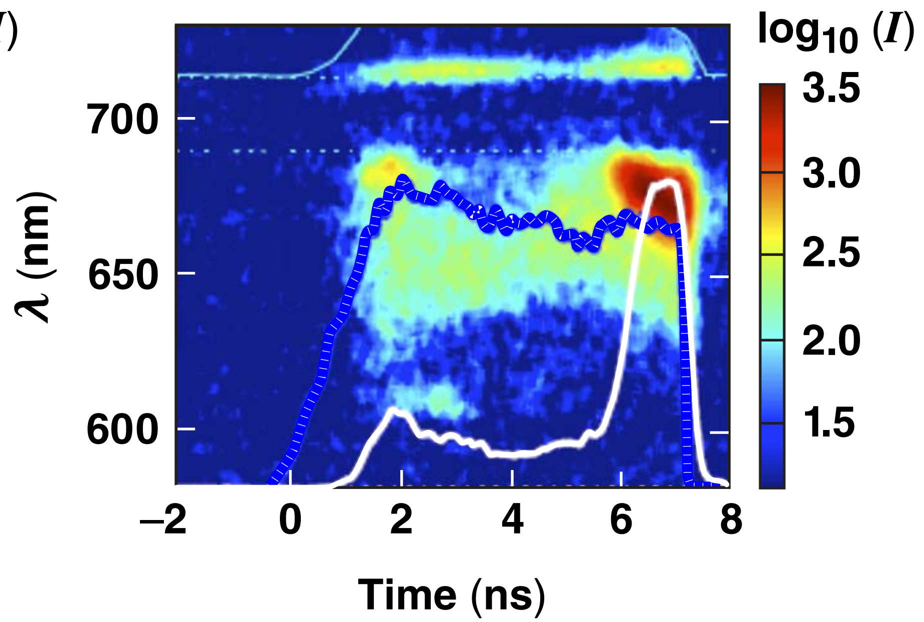
Evidence of $\omega/2$ and SRS is again observed

15×10^{14} W/cm^2

Optical spectrometer at 30°



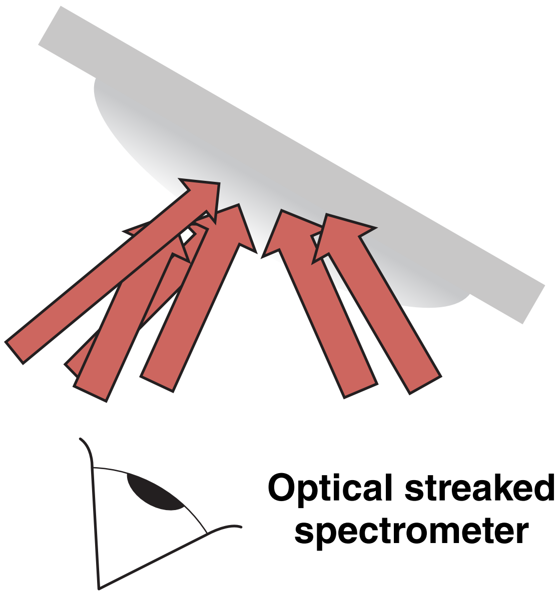
Optical spectrometer at 23°



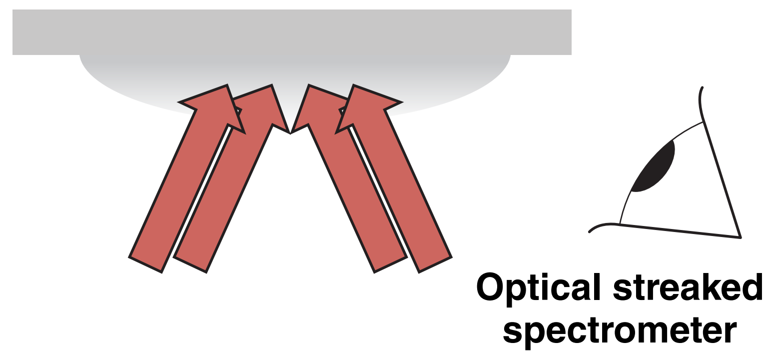
It is inconclusive whether SRS, TPD, or both is the dominant hot-electron source.

E24815a

Ongoing experimental work is aimed at identifying the source of hot electrons



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.

E24812b

Summary/Conclusions

A planar platform has been established at the National Ignition Facilty (NIF) to study laser–plasma interaction (LPI) hot-electron production at direct-drive ignition-relevant coronal conditions

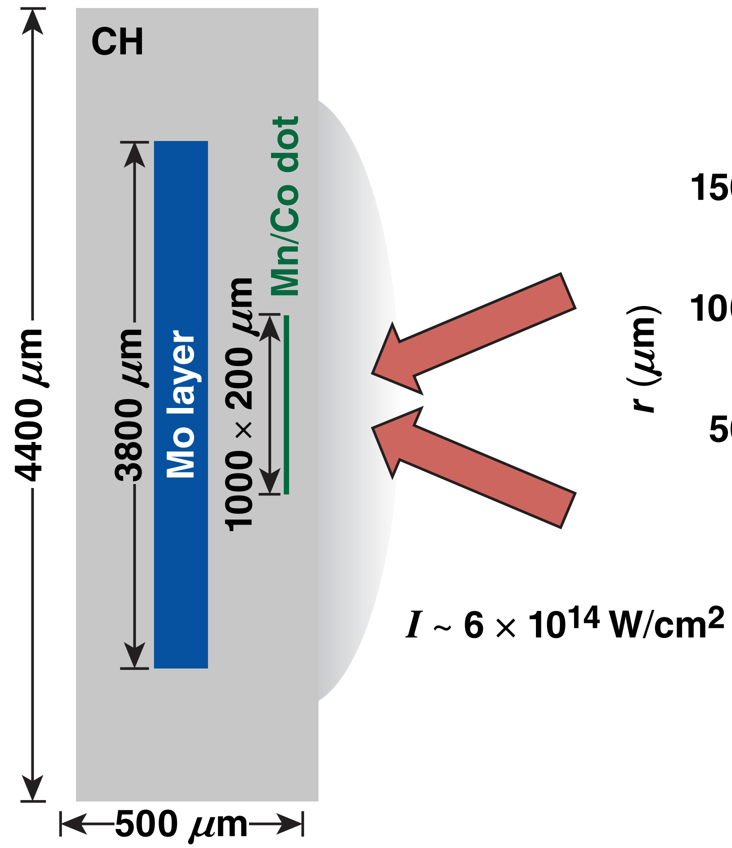
- Planar-geometry experiments on the NIF with predicted scale lengths of ~600 μm and $T_e > 3$ keV were performed
- The fraction of laser energy converted to hot electrons increased with laser intensity from f_{hot} ~ 0.5% to 2.3% (from 6 to 15 $\times 10^{14}$ W/cm^2) while T_{hot} was ~50 keV
- The beam angle of incidence did not have a strong effect on f_{hot} or T_{hot}
- Ongoing experiments are resolving whether two-plasmon decay (TPD) or stimulated Raman scattering (SRS) is the dominant hot-electron source

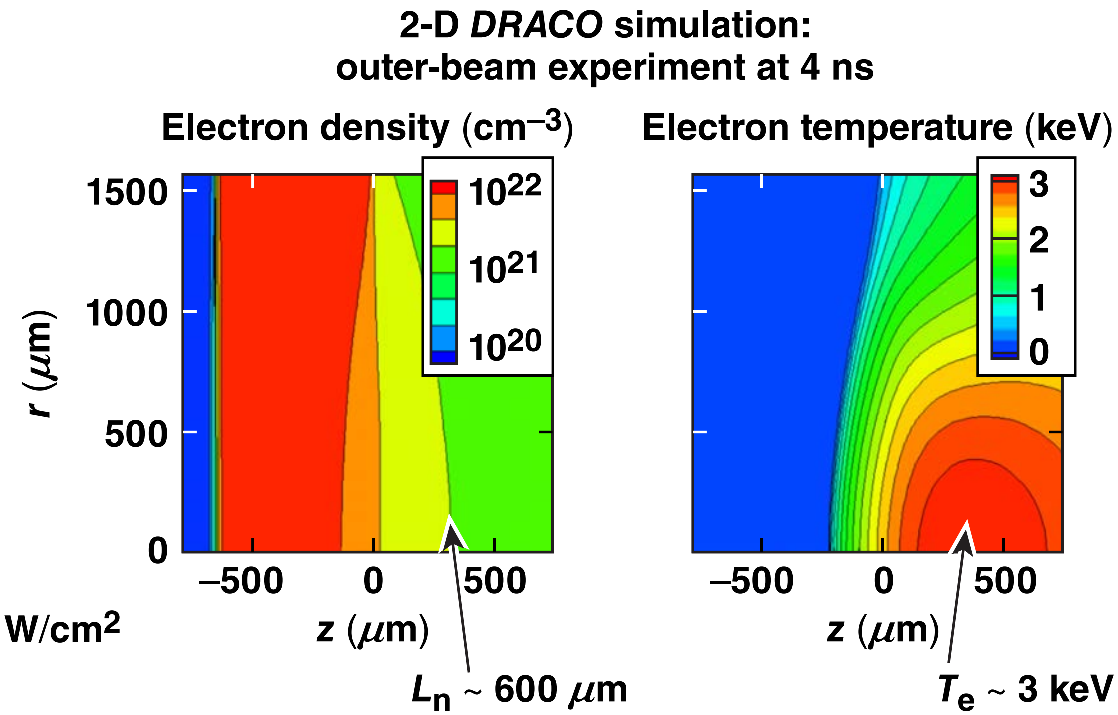
E24809a

Appendix

E25043

Planar-target TPD experiments on the NIF were designed using *DRACO*

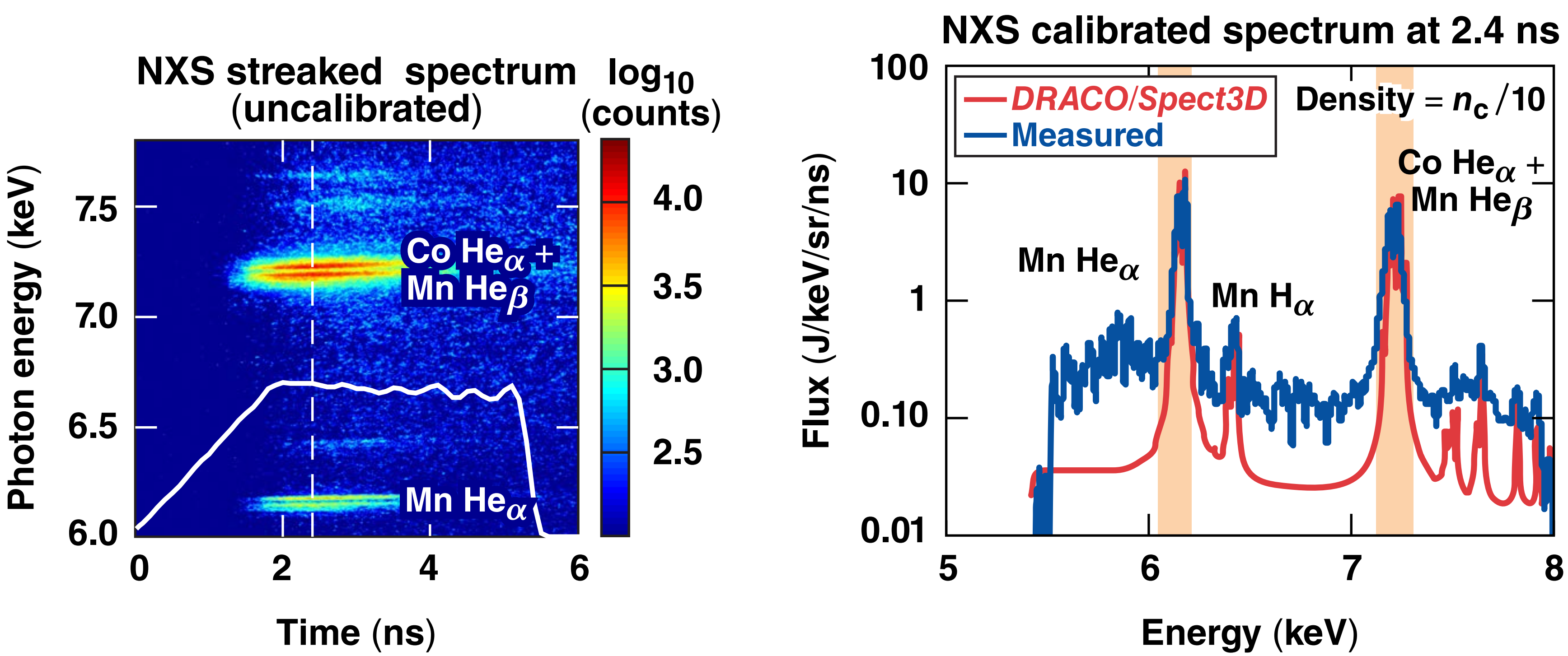




E24122c

The electron temperature (T_e) is inferred from the isoelectronic ratio* of the Mn/Co K-shell emission lines

Shot N150520: 23° and 30° beams

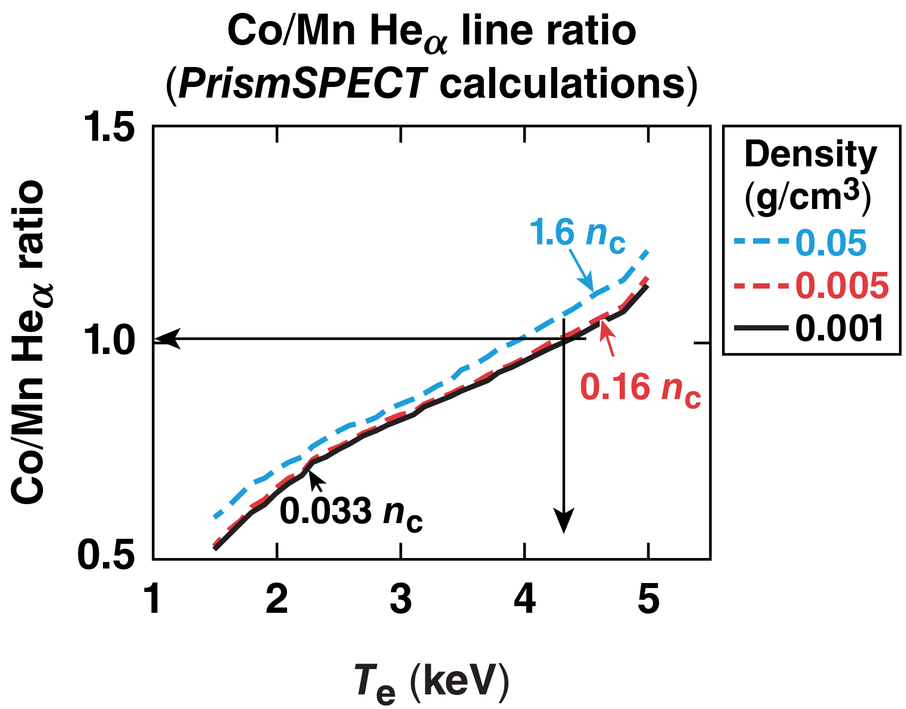


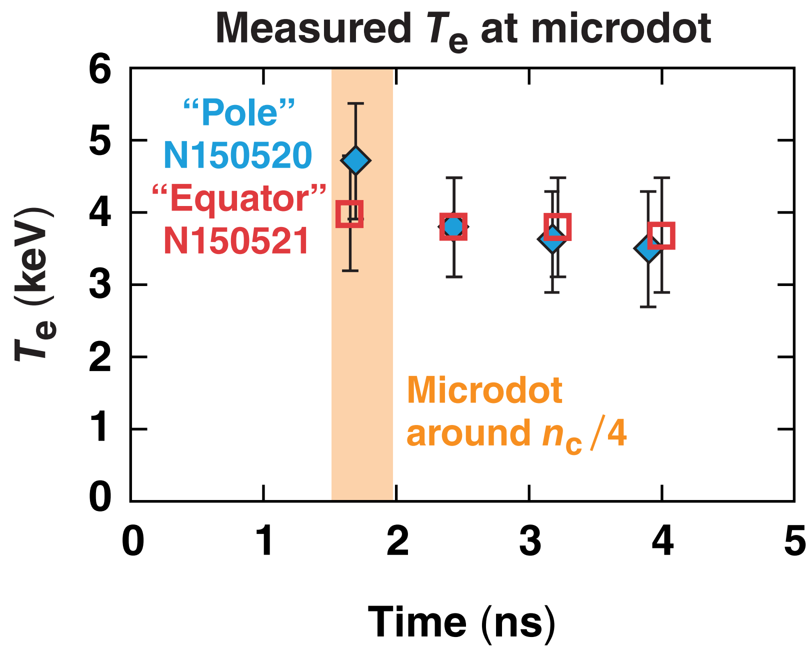
***DRACO* predicts that the microdot is at the $n_c/4$ surface at t = 1.5 to 2.0 ns.**

TC12489c

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

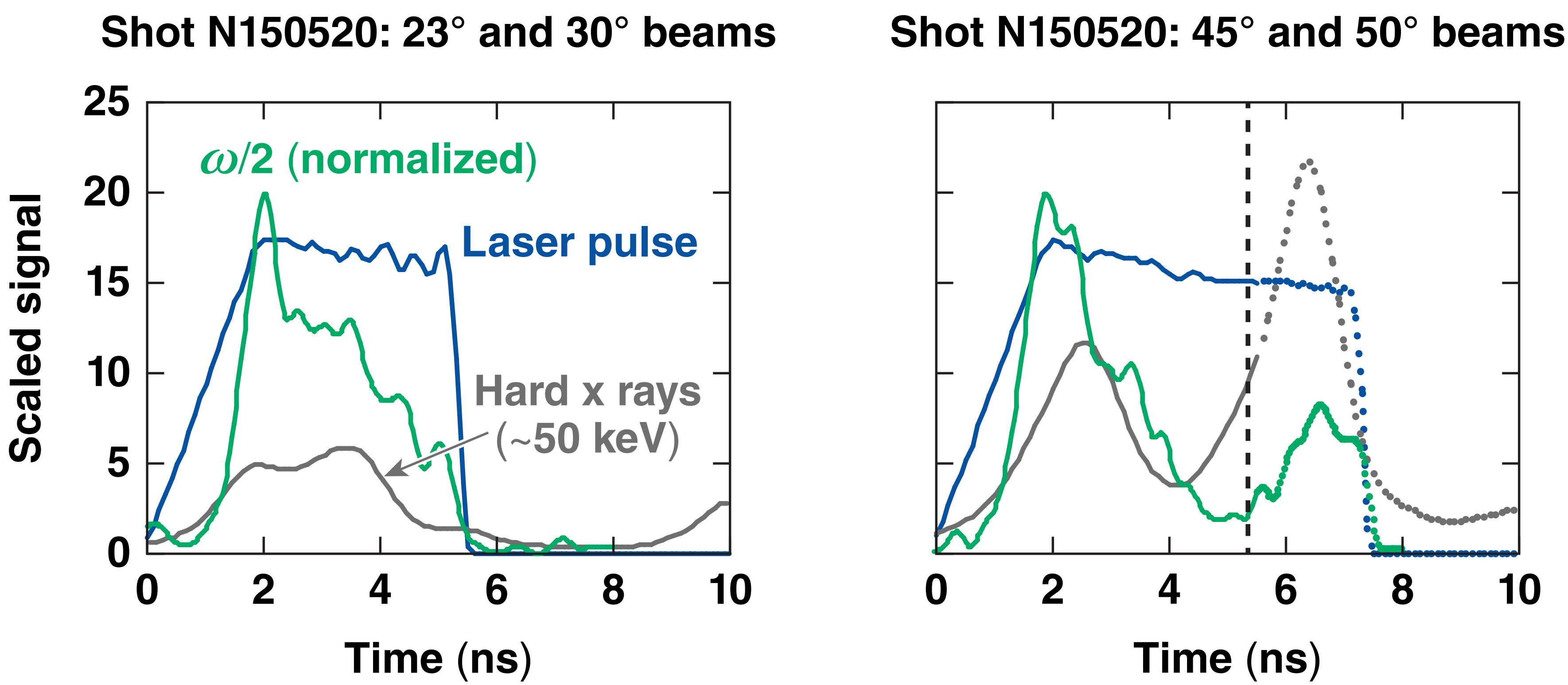
The measured Co/Mn He$_\alpha$ line ratio indicates T_e = 4.3±1.1 keV at $n_c/4$





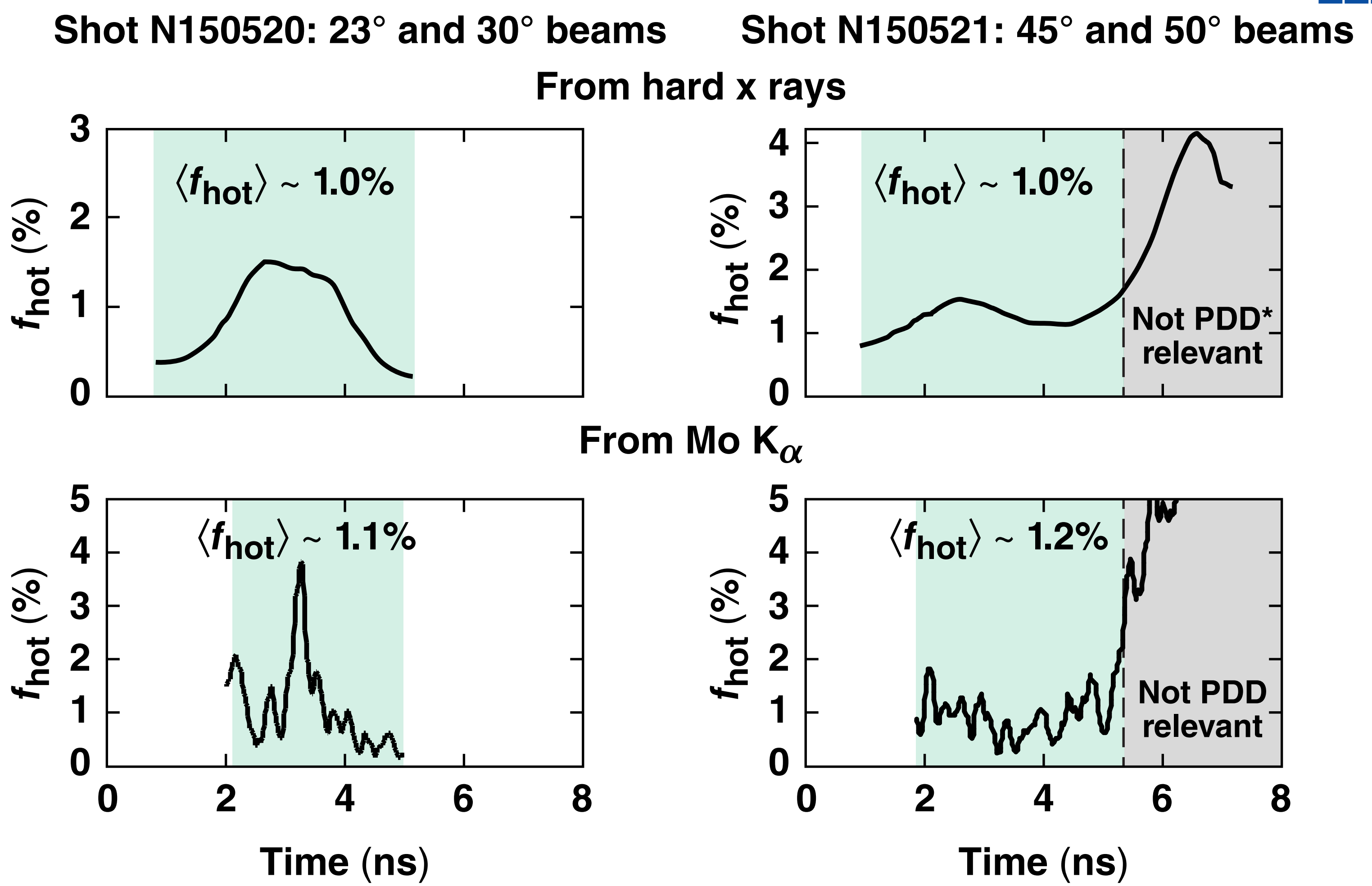
TC12491b

The hard x-ray and $\omega/2$ signals have similar temporal histories



E25044

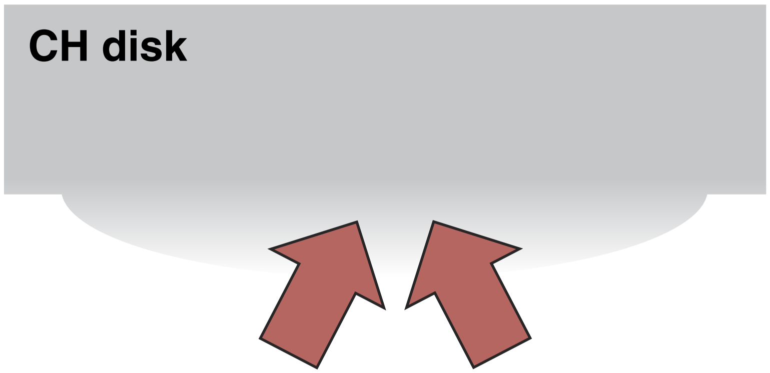
Absolute hard x-ray and Mo K_α emission levels indicate f_{hot} (E_{hot}/E_{laser}) ~ 1% in both experiments

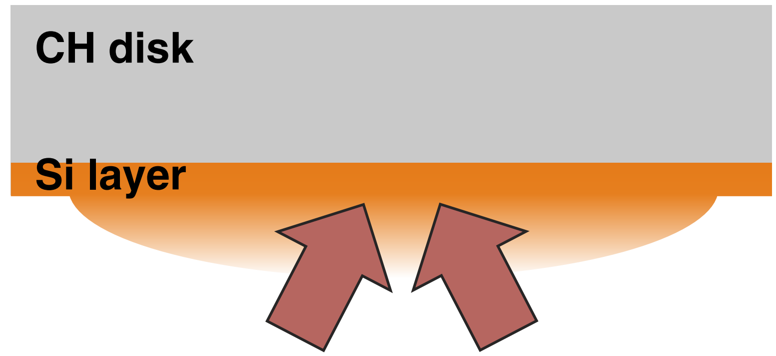


The beam angle of incidence did not have a strong effect on f_{hot} and T_{hot}.

PDD: polar direct drive

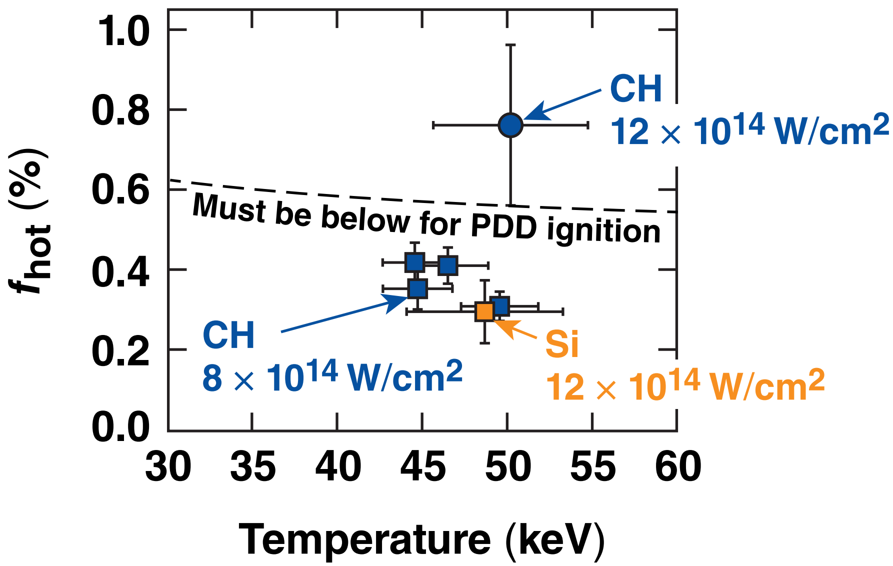
Future work will determine the source of hot electrons and the use of mid-*Z* ablators to mitigate LPI in the $\eta > 1$ regime





Test LPI mitigation
by mid-*Z* ablator

Si ablator reduces
hot electrons
in NIF PDD implosions



E24816a