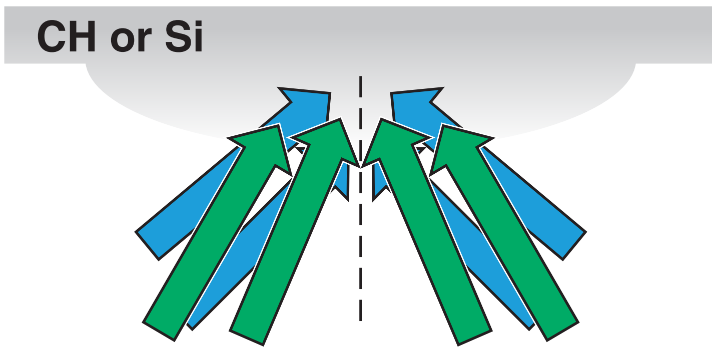
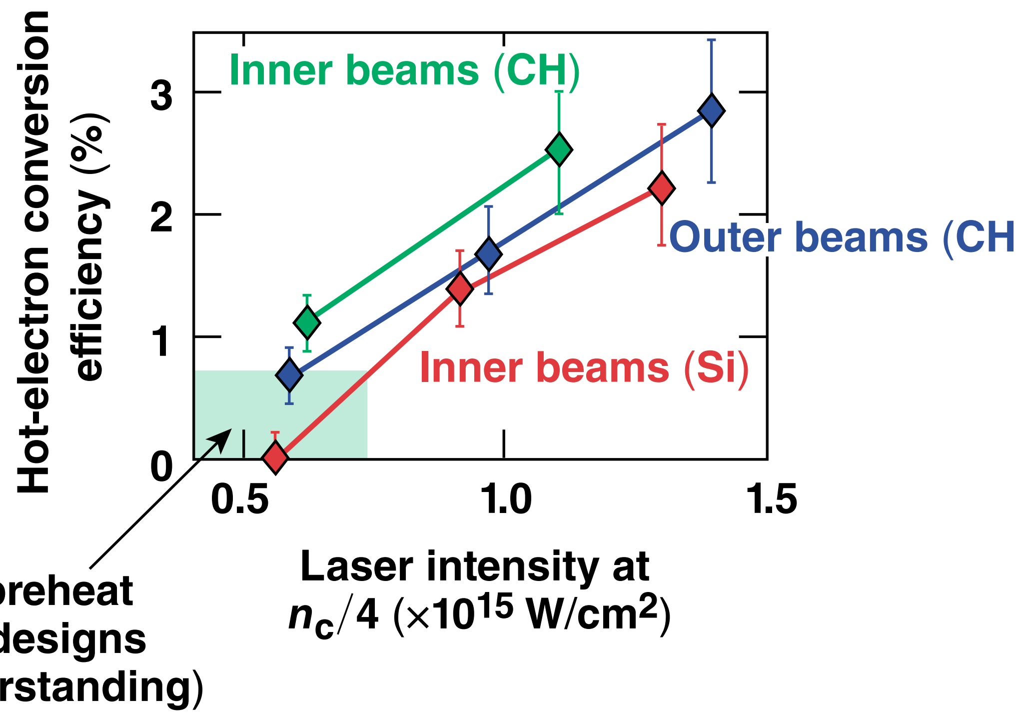
Hot-Electron Generation at Direct-Drive Ignition-Relevant Plasma Conditions at the National Ignition Facility

UR LLE



23° and 30° beams or
45° and 50° beams



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

47th Annual Anomalous Absorption Conference
Florence, OR
11–16 June 2017

Summary

A laser-energy conversion efficiency of ~1% to 3% into hot electrons with T_e ~ 45 to 60 keV was inferred

UR LLE

- Planar-target experiments at the National Ignition Facility (NIF) reproduce direct-drive (DD) ignition-relevant plasma conditions
- The properties of hot electrons were inferred using measured hard x-ray spectra and Monte Carlo simulations
- Hot-electron preheat levels suggest a need for mitigation
- Si ablators are found to increase the intensity threshold for hot-electron production and reduce the preheat by ~50%, compared to the relevant CH target shots

Maximum operating intensities at $n_c/4$:
~4.5 × 10^{14} W/cm^2 in CH and ~6.5 × 10^{14} W/cm^2 in Si

TC13426

Collaborators

M. J. Rosenberg, J. F. Myatt, W. Seka, R. Epstein, R. W. Short, S. P. Regan, D. H. Froula, P. B. Radha, and V. N. Goncharov

University of Rochester
Laboratory for Laser Energetics

J. W. Bates and A. J. Schmitt

Naval Research Laboratory

P. Michel, M. Hohenberger, T. Chapman, and J. D. Moody

Lawrence Livermore National Laboratory

Motivation

Hot-electron preheat can degrade fuel compression in DD ignition designs

- The ignition target performance is negatively affected if more than ~0.15% of the laser energy is coupled into the cold fuel in the form of hot electrons*
- If electron divergence is large, only ~25% of the hot electrons will intersect the cold fuel and result in preheat**
- Electrons with energy below ~50 keV will be stopped in the ablator and will not preheat the compressed fuel

Hot-electron preheat mitigation is needed if more than ~0.7% of the laser energy is converted to hot electrons at T_{hot} ~50 to 60 keV.

*J. A. Delettrez, T. J. B. Collins, and C. Ye, Bull. Am. Phys. Soc. 59, 150 (2014).
**B. Yaakobi *et al.*, Phys. Plasmas 20, 092706 (2013).
Hot-electron divergence will be investigated in Mo-ball experiments on the NIF.

Planar NIF experiments explore laser–plasma interaction (LPI) instabilities and hot-electron production in DD ignition-relevant plasma conditions

Coronal conditions predicted by *DRACO* radiation–hydrodynamic simulations

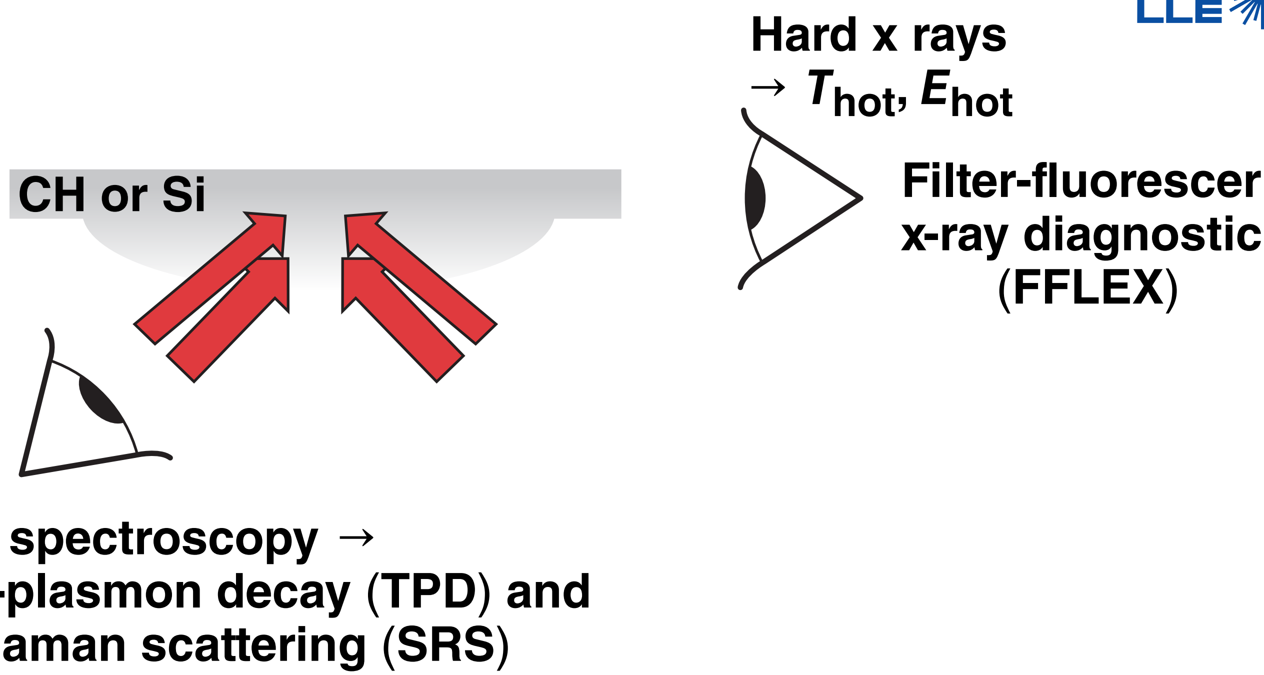
Parameters at $n_c/4$ surface	OMEGA*	Current NIF DD**	Ignition NIF DD†	Planar NIF
I_L (W/cm^2)	$<4 \times 10^{14}$	4.5×10^{14}	6 to 8×10^{14}	5 to 15×10^{14}
L_n (μm)	<350	350	600	500 to 700
T_e (keV)	<2.5	3.5	3.5 to 5	3 to 5

- Incident laser intensity is ~2× intensity at $n_c/4$ at ignition-relevant L_n and T_e

*S. X. Hu *et al.*, Phys. Plasmas 20, 032704 (2013).,
**M. Hohenberger *et al.*, Phys. Plasmas 22, 056308 (2015).,
†V. N. Goncharov *et al.*, Bull. Am. Phys. Soc. 61, BAPS.2016.DPP.TO5.3 (2016).

TC12382d

Hot-electron production in CH targets and mitigation by the use of Si ablators was explored in NIF planar-target experiments

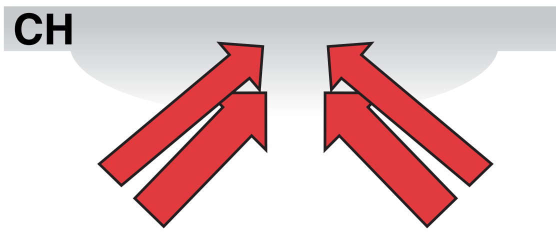


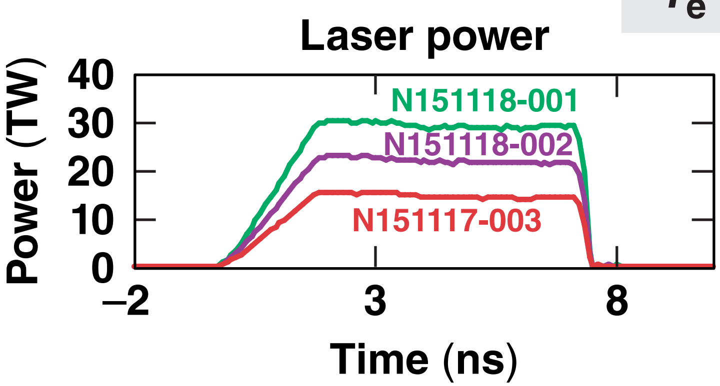
- CH and Si disks were irradiated by subsets of NIF beams from the south pole
- Principal measurements included hard x-ray bremsstrahlung to quantify hot-electron production and optical spectroscopy to explore the LPI mechanisms*

*W. Seka *et al.*, WeO-5, this conference;
P. A. Michel *et al.*, WeO-4, this conference.

TC13427

The scaling of hot-electron properties with laser intensity in CH targets was studied using large-angle beams





DRACO-simulated coronal conditions at $n_c/4$

	N151117-003	N151118-002	N151118-001
I (W/cm^2)	6×10^{14}	10.5×10^{14}	15×10^{14}
L_n (μm)	480	490	500
T_e (keV)	3.0	3.9	4.8

$$\eta_{SRS} = I_{14} L_{n,\,\mu m}^{4/3} / 2377 \sim 10 \text{ to } 25$$

$$\eta_{TPD} = I_{14} L_{n,\,\mu m} / (230\, T_{e,keV}) \sim 4 \text{ to } 7$$

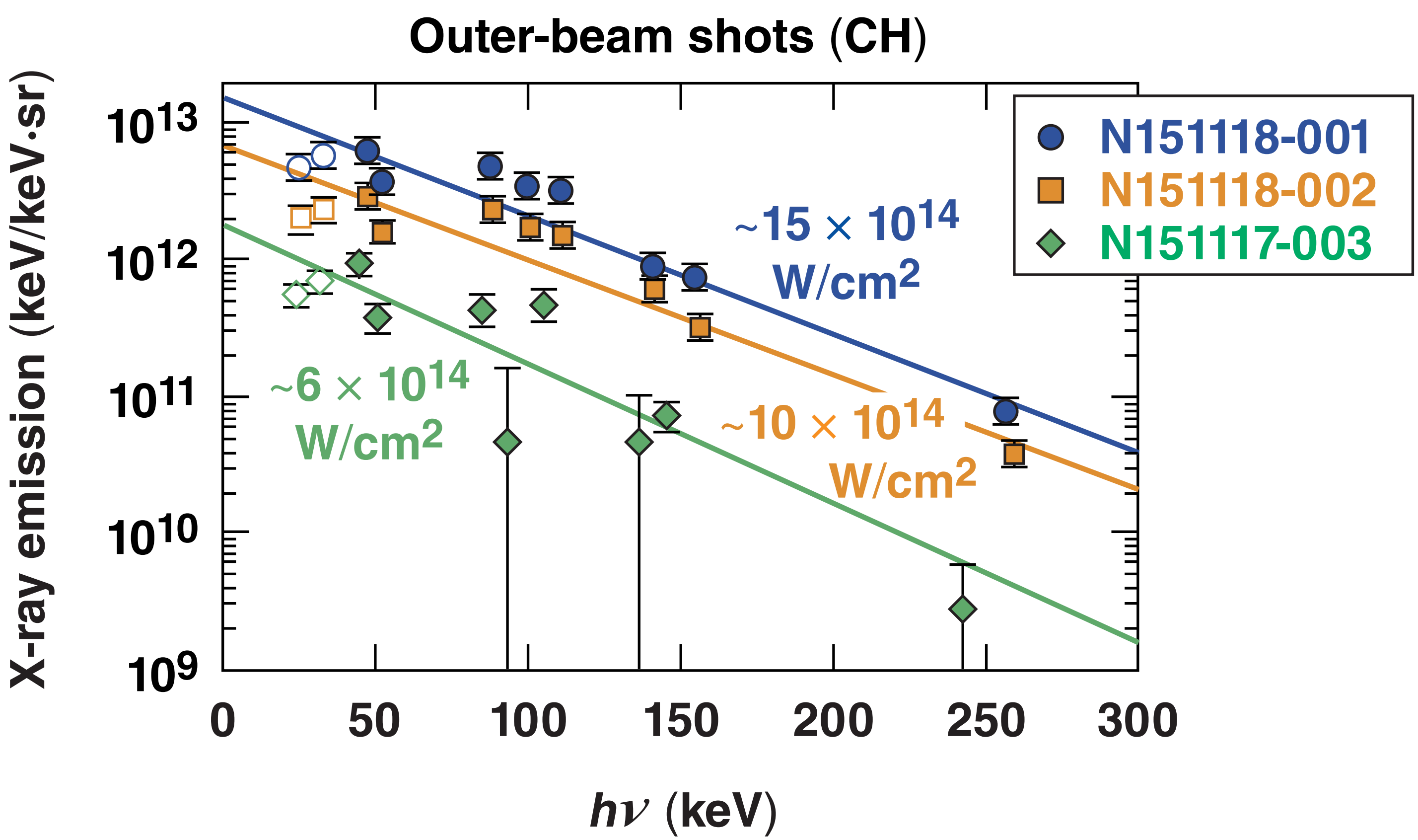
The SRS and TPD absolute-instability thresholds* are exceeded in this experimental design.

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

TC13049a

Hot-electron properties were inferred using the measured hard x-ray spectra

Time-integrated hard x-ray spectra obtained using FFLEX*

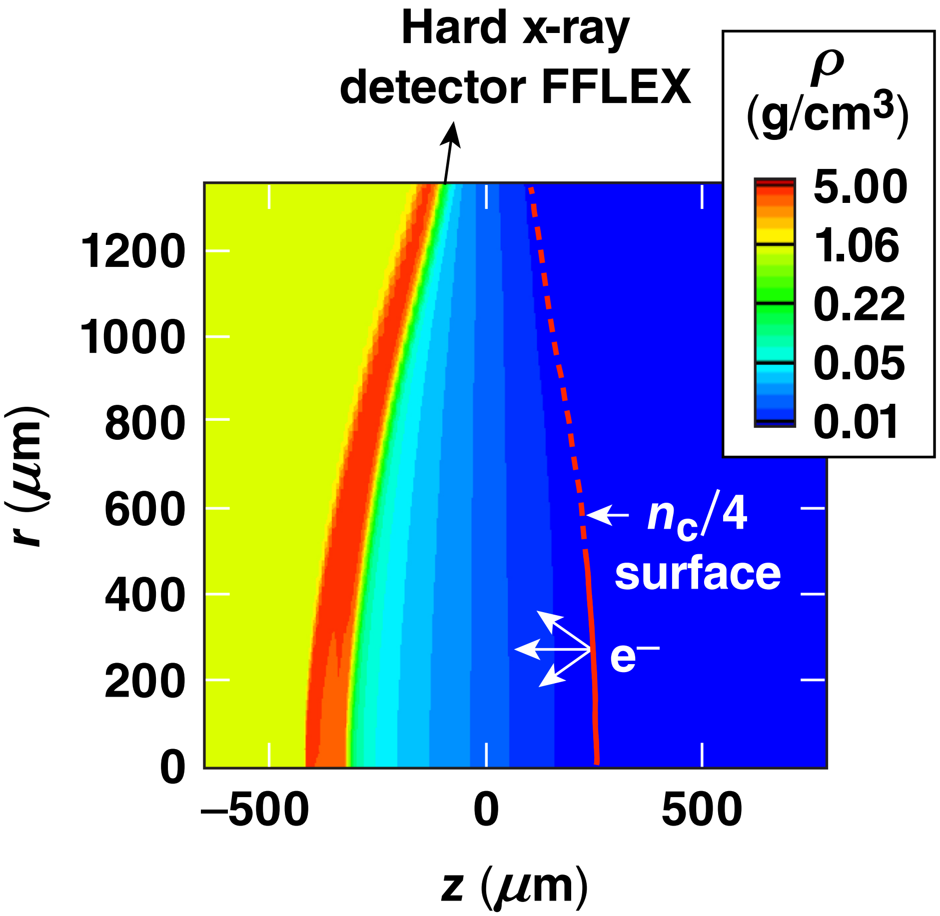


- Systematic uncertainties of FFLEX hard x-ray spectra are being investigated

TC13051a

*M. Hohenberger *et al.*, Rev. Sci. Instrum. 85, 11D501 (2014).

Hot-electron energy was inferred from comparison of the x-ray spectra and *EGSnrc** Monte Carlo simulations



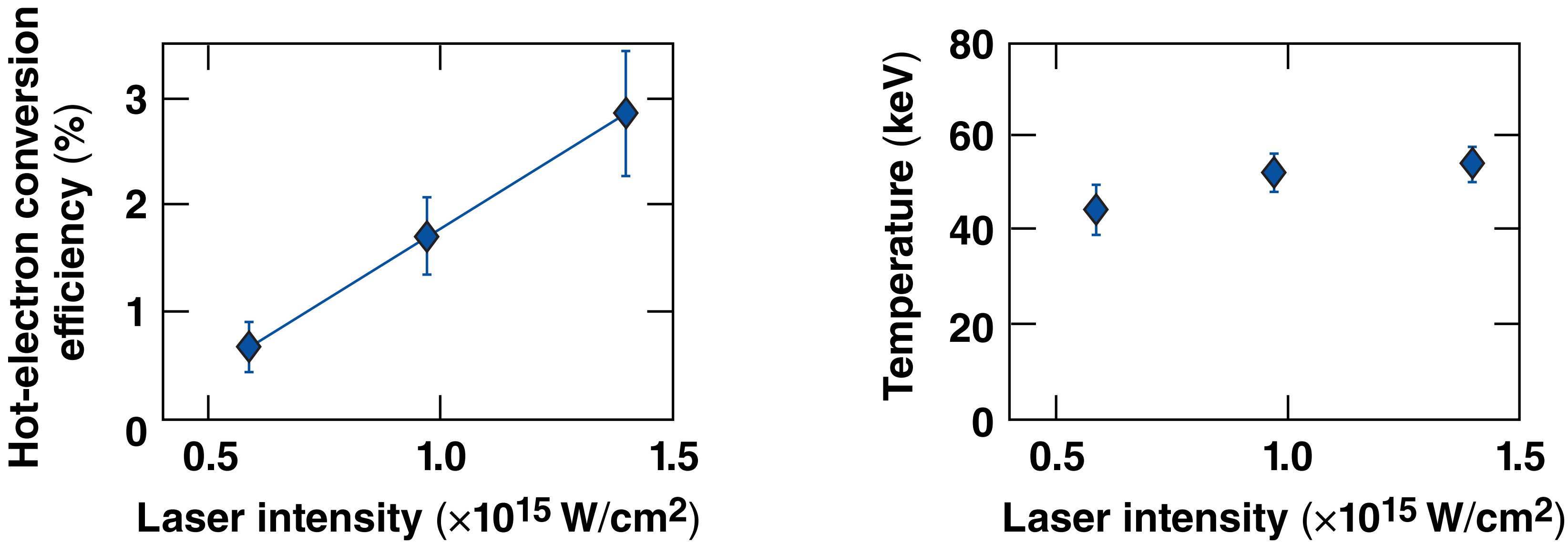
- Hot electrons are injected
  - at $n_c/4$ surface ($r < 500\ \mu$m)
  - isotropic in the forward 2π solid angle
  - temperature T_{hot} = 40 to 60 keV from the measured hard x-ray spectra

*I. Kawrakow et al., National Research Council Canada, Ottawa, Canada, NRCC Report PIRS-701 (May 2011).

TC13052a

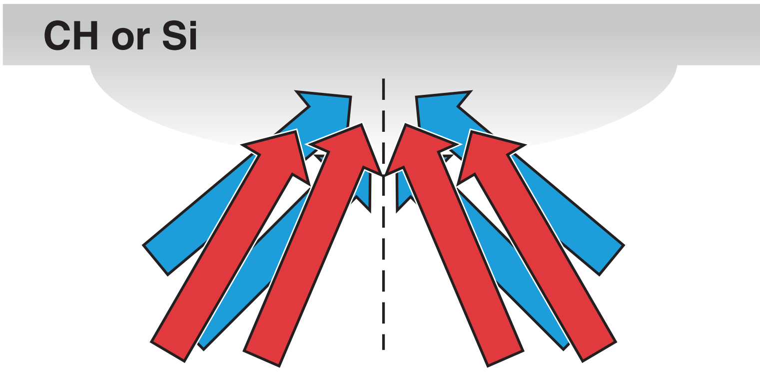
The inferred laser energy to hot-electron conversion efficiency increases from ~0.5% to 3% with the laser intensity

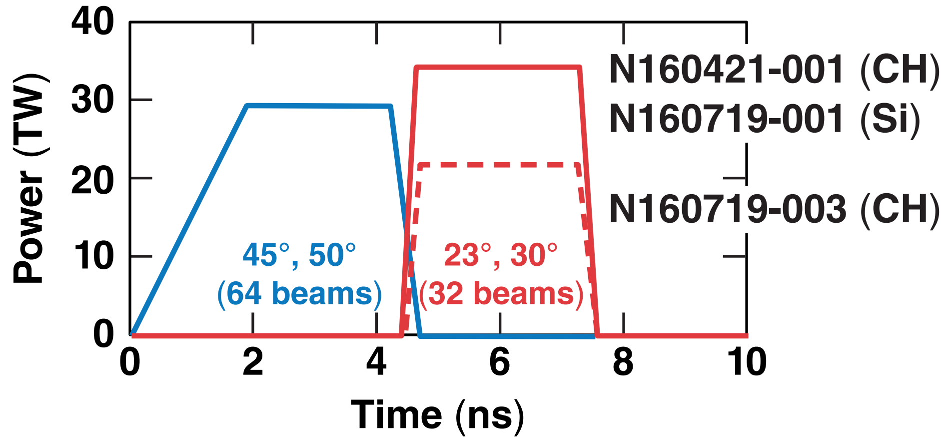
Hot-electron conversion efficiency and temperature (4.5 to 7.5 ns) versus laser intensity at $n_c/4$



TC13428

Hot-electron production in CH and Si targets was studied using small-angle beams





DRACO-simulated coronal conditions at $n_c/4$ (4.5 to 7.5 ns)

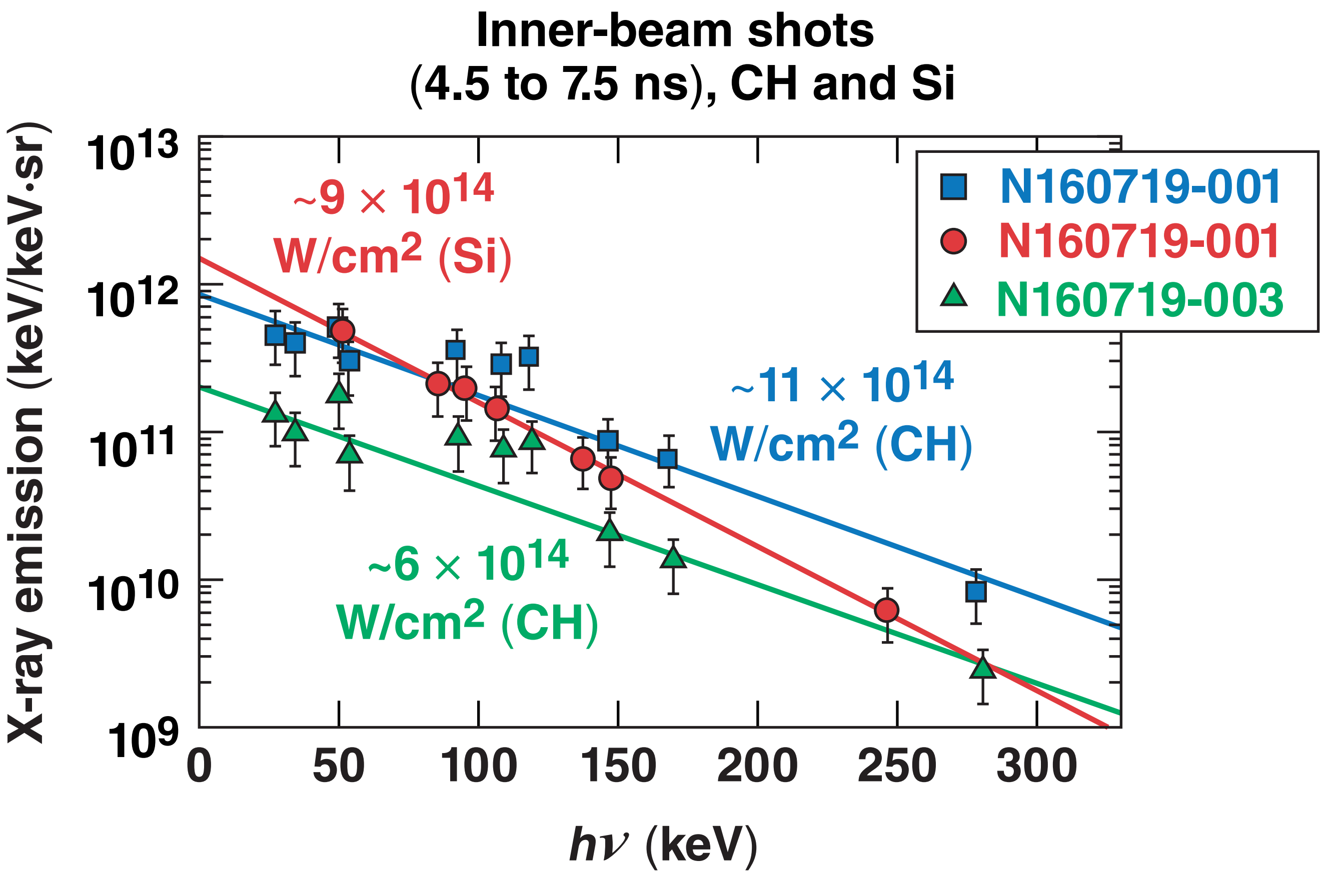
	N160719-003 (CH)	N160421-001 (CH)	N160719-001 (Si)
I (W/cm^2)	6×10^{14}	11×10^{14}	9×10^{14}
L_n (μm)	670	690	560
T_e (keV)	3.6	4.4	5.2

- Two more Si target shots (N161010-001 and N161010-002) explored higher and lower inner-beam intensities

TC13050a

Hot-electron properties were inferred using the measured hard x-ray spectra

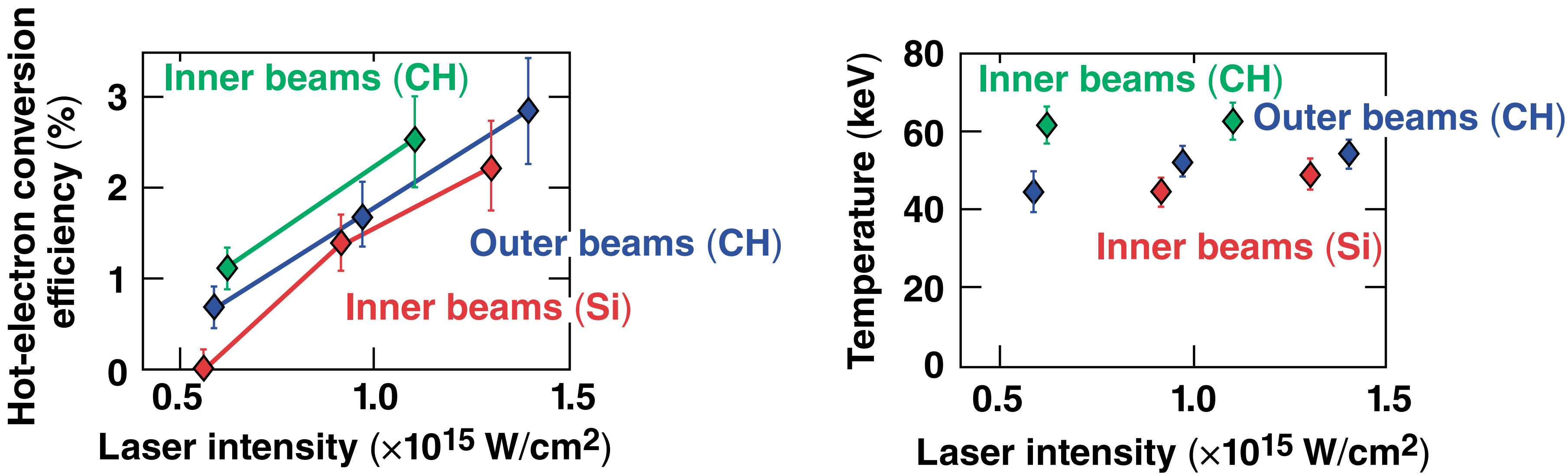
- Time-integrated hard x-ray spectra obtained using FFLEX



TC13429

The inferred laser energy to hot-electron conversion efficiency increases from ~0.5% to 3% with the laser intensity

Hot-electron conversion efficiency and temperature (4.5 to 7.5 ns) versus laser intensity at $n_c/4$

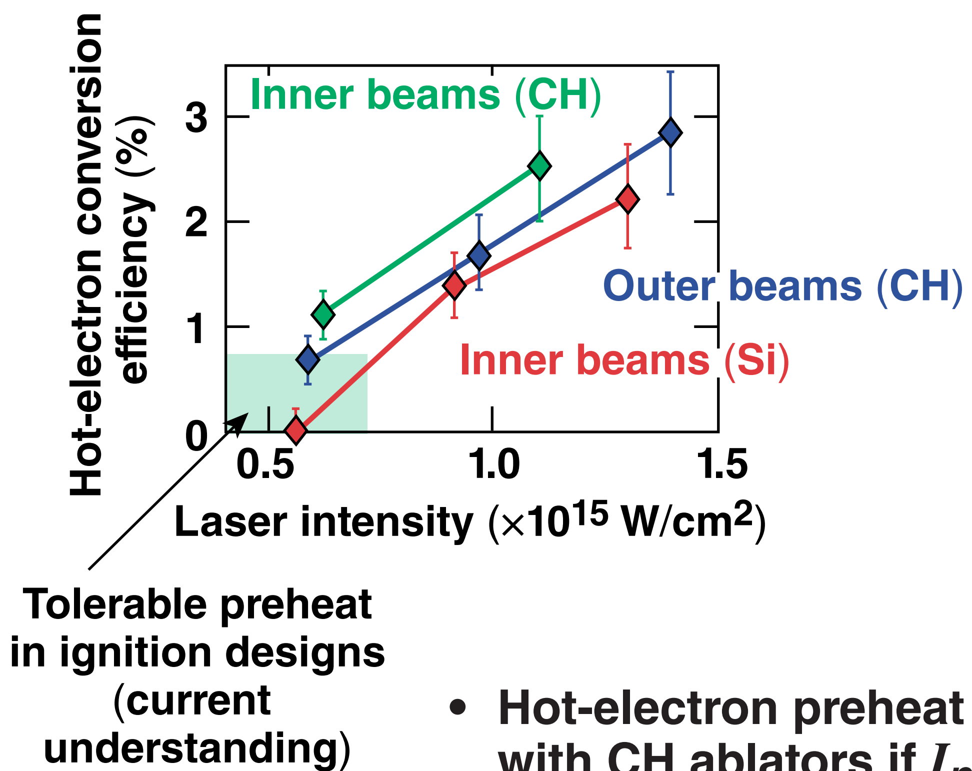


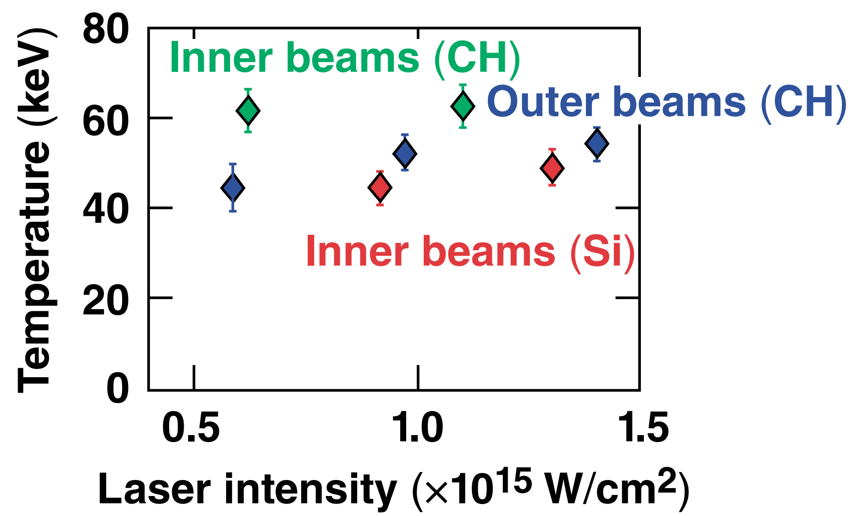
- The use of a Si ablator reduces the energy of hot electrons above ~50 keV (relevant to preheat) by ~50%, compared to the relevant CH shots, and increases the hot-electron–generation intensity threshold

TC13430

The inferred laser energy to hot-electron conversion efficiency increases from ~0.5% to 3% with the laser intensity

Hot-electron conversion efficiency and temperature (4.5 to 7.5 ns) versus laser intensity at $n_c/4$

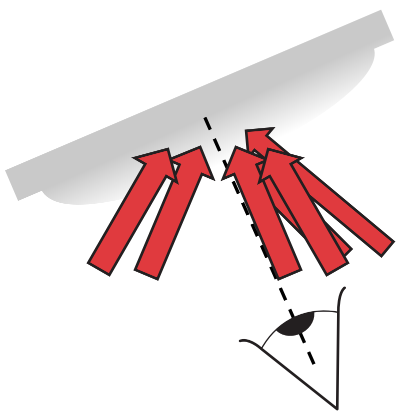




- Hot-electron preheat is tolerable in DD ignition designs with CH ablators if $I_{n_c/4} < 4.5 \times 10^{14}$ W/cm^2; with Si ablators if $I_{n_c/4} < 6.5 \times 10^{14}$ W/cm^2

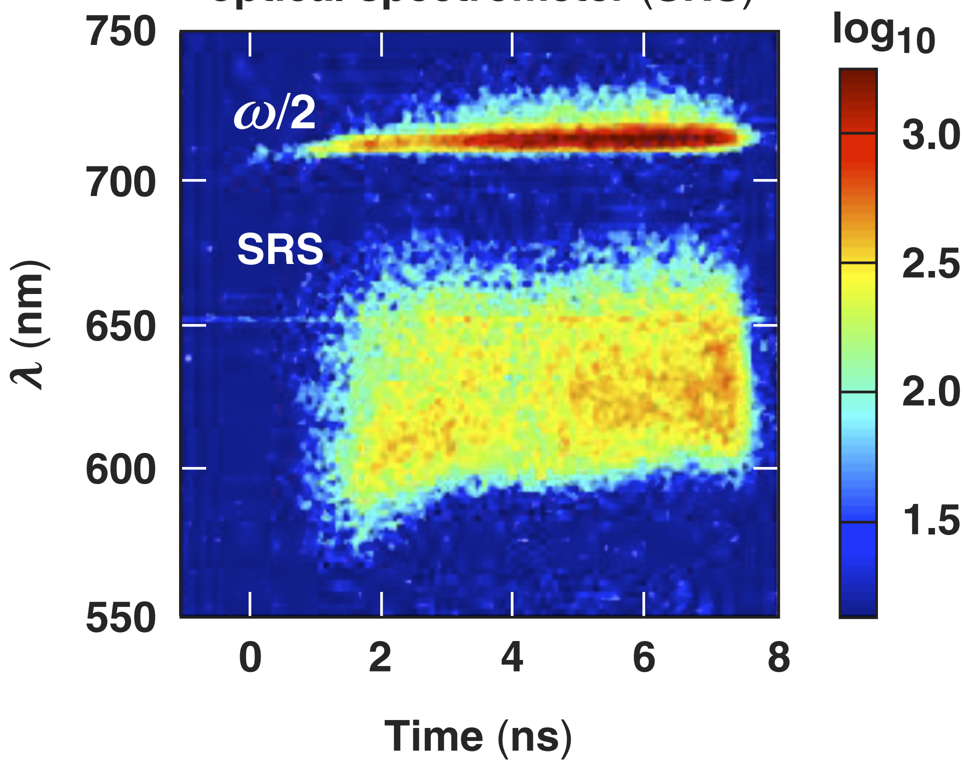
TC13432

Hot-electron production is attributed to stimulated Raman scattering, which dominates LPI in these experiments*



Optical streaked spectrometer
[Near backscatter imager (NBI) Q33B]

Shot N160420-003
optical spectrometer (SRS)



- SRS is excited at a level (≤5%) comparable to that of the hot electrons

*M. J. Rosenberg *et al.*, WeI-2, this conference;
W. Seka *et al.*, WeO-5, this conference;
P. A. Michel *et al.*, WeO-4, this conference.

TC13431

Summary/Conclusions

A laser-energy conversion efficiency of ~1% to 3% into hot electrons with T_e ~ 45 to 60 keV was inferred

UR LLE

- Planar-target experiments at the National Ignition Facility (NIF) reproduce direct-drive (DD) ignition-relevant plasma conditions
- The properties of hot electrons were inferred using measured hard x-ray spectra and Monte Carlo simulations
- Hot-electron preheat levels suggest a need for mitigation
- Si ablators are found to increase the intensity threshold for hot-electron production and reduce the preheat by ~50%, compared to the relevant CH target shots

Maximum operating intensities at $n_c/4$:
~4.5×10^{14} W/cm^2 in CH and ~6.5×10^{14} W/cm^2 in Si

TC13426