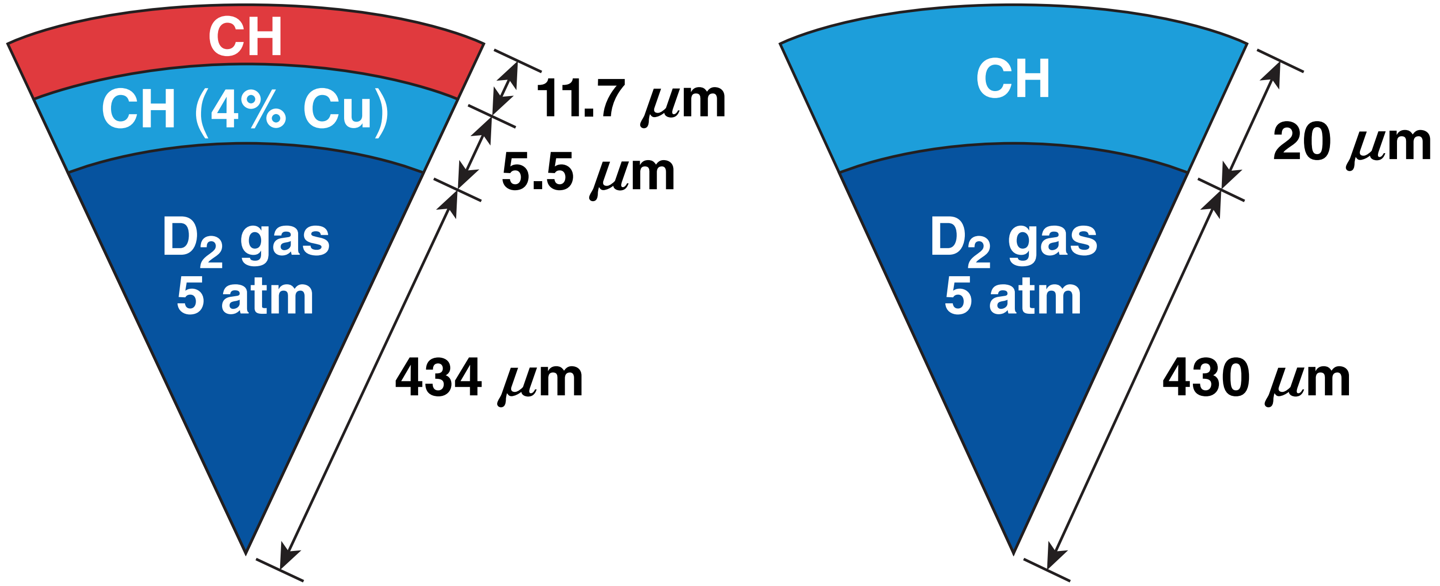
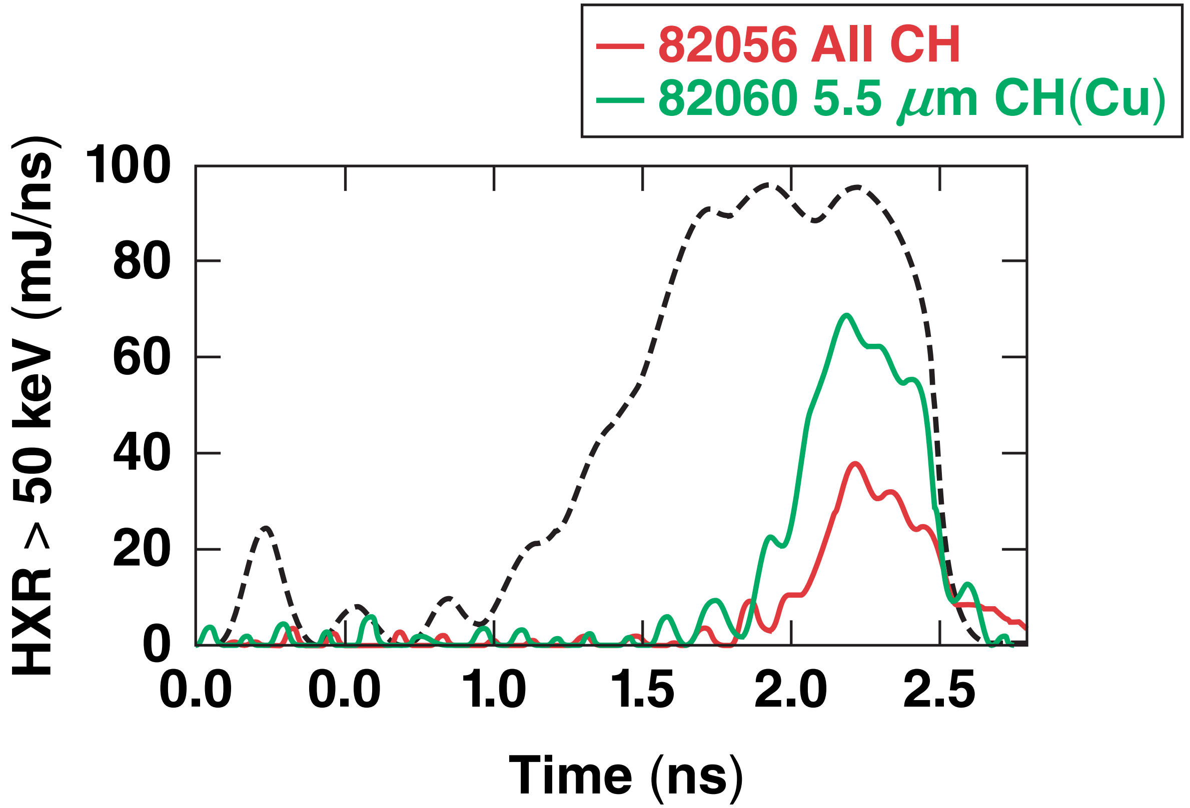
Direct Measurements of Hot-Electron Preheat in Inertial Confinement Fusion Implosions





A. R. Christopherson
University of Rochester
Laboratory for Laser Energetics

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Summary

Hot-electron transport in direct-drive cryogenic implosions is studied by comparing hard x rays (HXR's) between all-plastic and multilayered implosions

- Differences in HXR signals between mass-equivalent all-CH and multilayered implosions can be used to infer hot-electron energy deposition into the payload
- Experiments utilizing Cu-doped payloads of varying thicknesses indicated that hot-electron deposition into the payload increases proportionally with the payload mass
- Post-shot analysis of these experiments predicted a 10% to 20% degradation in areal density caused by hot-electron preheat for an $\alpha = 4$ implosion irradiated at an intensity of 9×10^{14} W/cm^2

Collaborators

**R. Betti, W. Theobald, C. J. Forrest, E. M. Campbell,
J. Howard, J. A. Delettrez, C. Stoeckl, D. H. Edgell, W. Seka,
V. Yu. Glebov, A. K. Davis, A. Bose, and A. V. Maximov**

University of Rochester
Laboratory for Laser Energetics

M. S. Wei

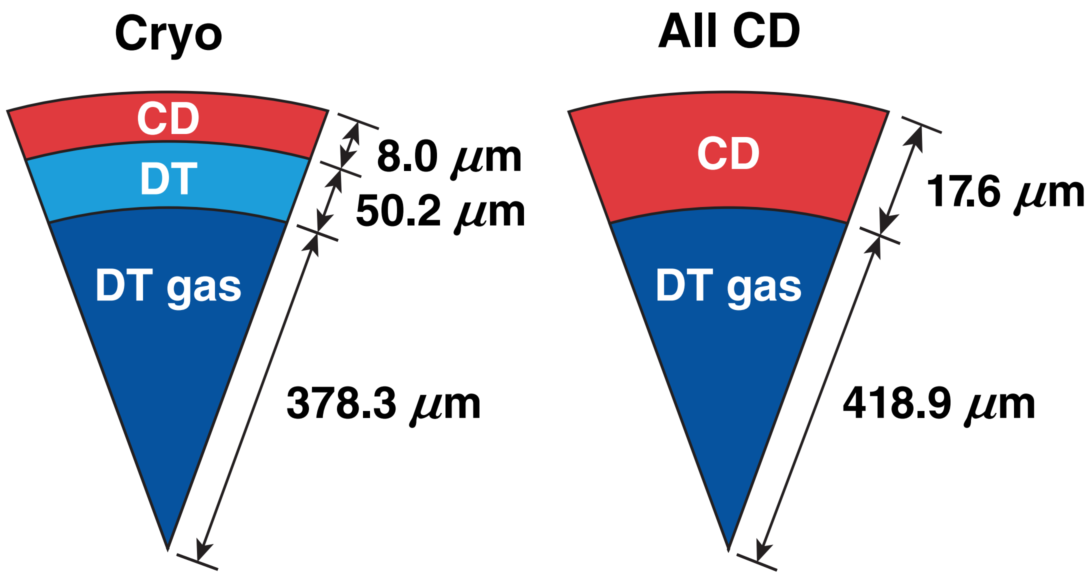
General Atomics

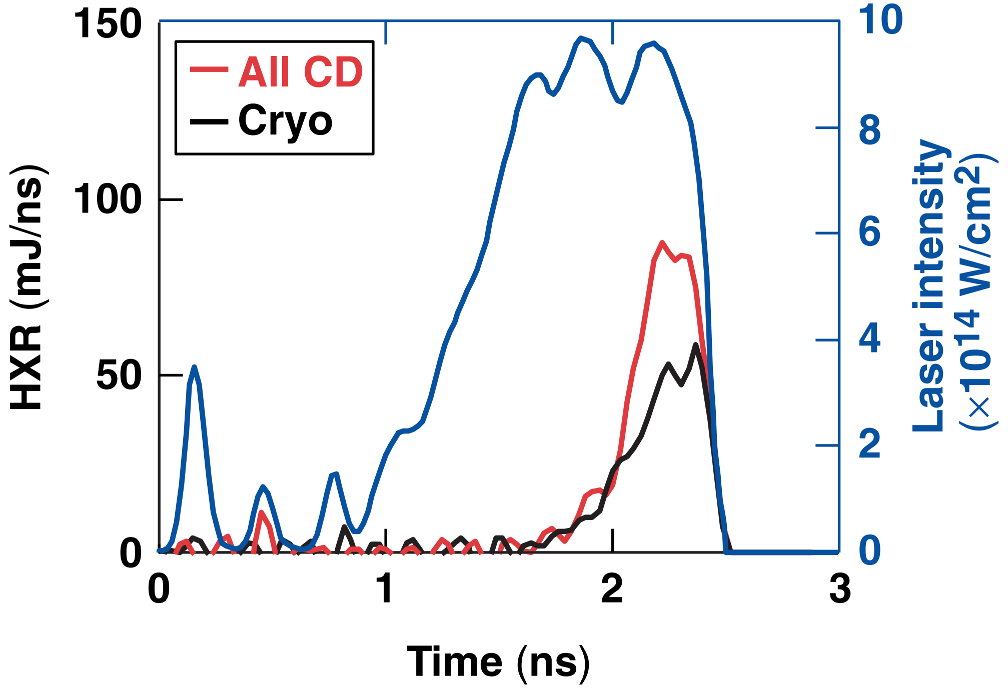
J. Peebles

Univeristy of California San Diego

The hot-electron energy deposited into the DT layer of cryo implosions is routinely inferred by comparing the cryo HXR* signal with the HXR signal of a mass-equivalent all-CD implosion

- Both implosions have the same pulse shape and are predicted to exhibit identical coronal conditions
  - this implies the source of hot electrons generated from two-plasmon decay (TPD) is the same in both implosions





This difference in the HXR signal implies some of the hot electrons slow down in DT!

The objective is to use the difference in the HXR signal to quantify hot-electron deposition into DT and the ρR degradation from preheat.

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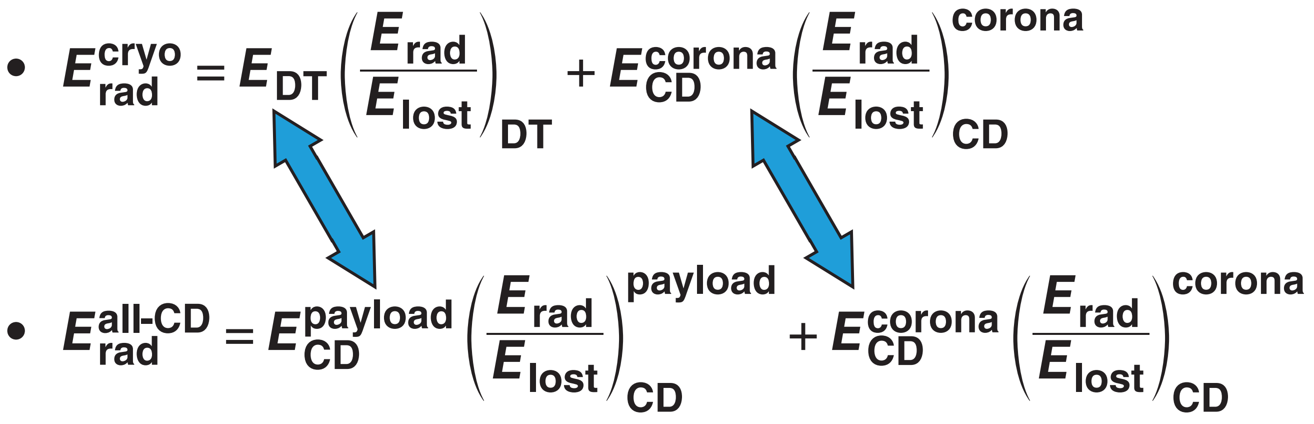
*HXR > 50 keV

If the hot-electron source is the same, the energy deposited into the DT can be inferred by subtracting the cryo HXR from the all-CD HXR

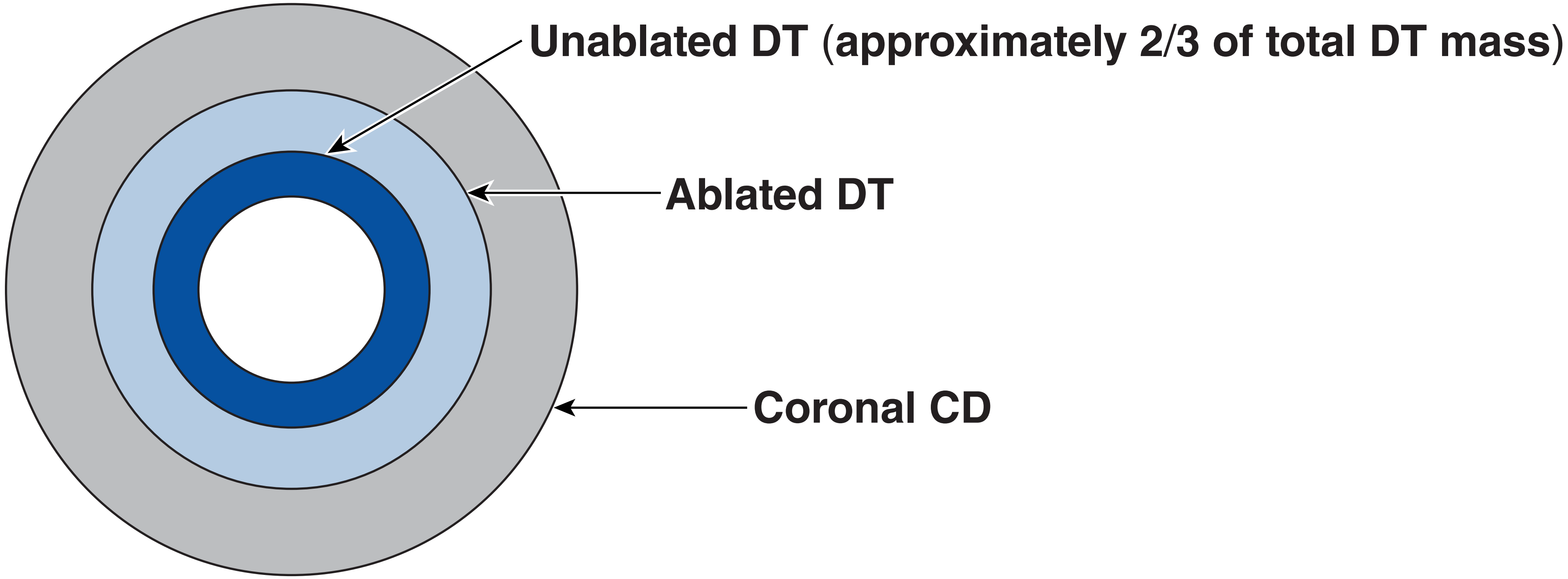


- $E_{\text{rad}}^{\text{cryo}} = E_{\text{DT}}\left(\frac{E_{\text{rad}}}{E_{\text{lost}}}\right)_{\text{DT}} + E_{\text{CD}}^{\text{corona}}\left(\frac{E_{\text{rad}}}{E_{\text{lost}}}\right)_{\text{CD}}^{\text{corona}}$
- $E_{\text{rad}}^{\text{all-CD}} = E_{\text{CD}}^{\text{payload}}\left(\frac{E_{\text{rad}}}{E_{\text{lost}}}\right)_{\text{CD}}^{\text{payload}} + E_{\text{CD}}^{\text{corona}}\left(\frac{E_{\text{rad}}}{E_{\text{lost}}}\right)_{\text{CD}}^{\text{corona}}$
- E_{DT} = energy deposited into the DT by the hot electrons
- $E_{\text{CD}}^{\text{payload}}$ = energy deposited into the CD payload by the hot electrons $\approx E_{\text{DT}}$
- $E_{\text{CD}}^{\text{corona}}$ = energy deposited into the CD corona by the hot electrons

DT preheat formula: $E_{\text{DT}} = \dfrac{E_{\text{rad}}^{\text{all-CD}} - E_{\text{rad}}^{\text{cryo}}}{\left(\frac{E_{\text{rad}}}{E_{\text{lost}}}\right)_{\text{CD}}^{\text{payload}} - \left(\frac{E_{\text{rad}}}{E_{\text{lost}}}\right)_{\text{DT}}}$

Although the preheat formula predicts electron energy into the total DT, the ρR degradation depends on electron energy into the unablated DT

- The difference in the HXR signal predicts electron energy into the total DT
- A fraction of DT mass is ablated during an OMEGA implosion



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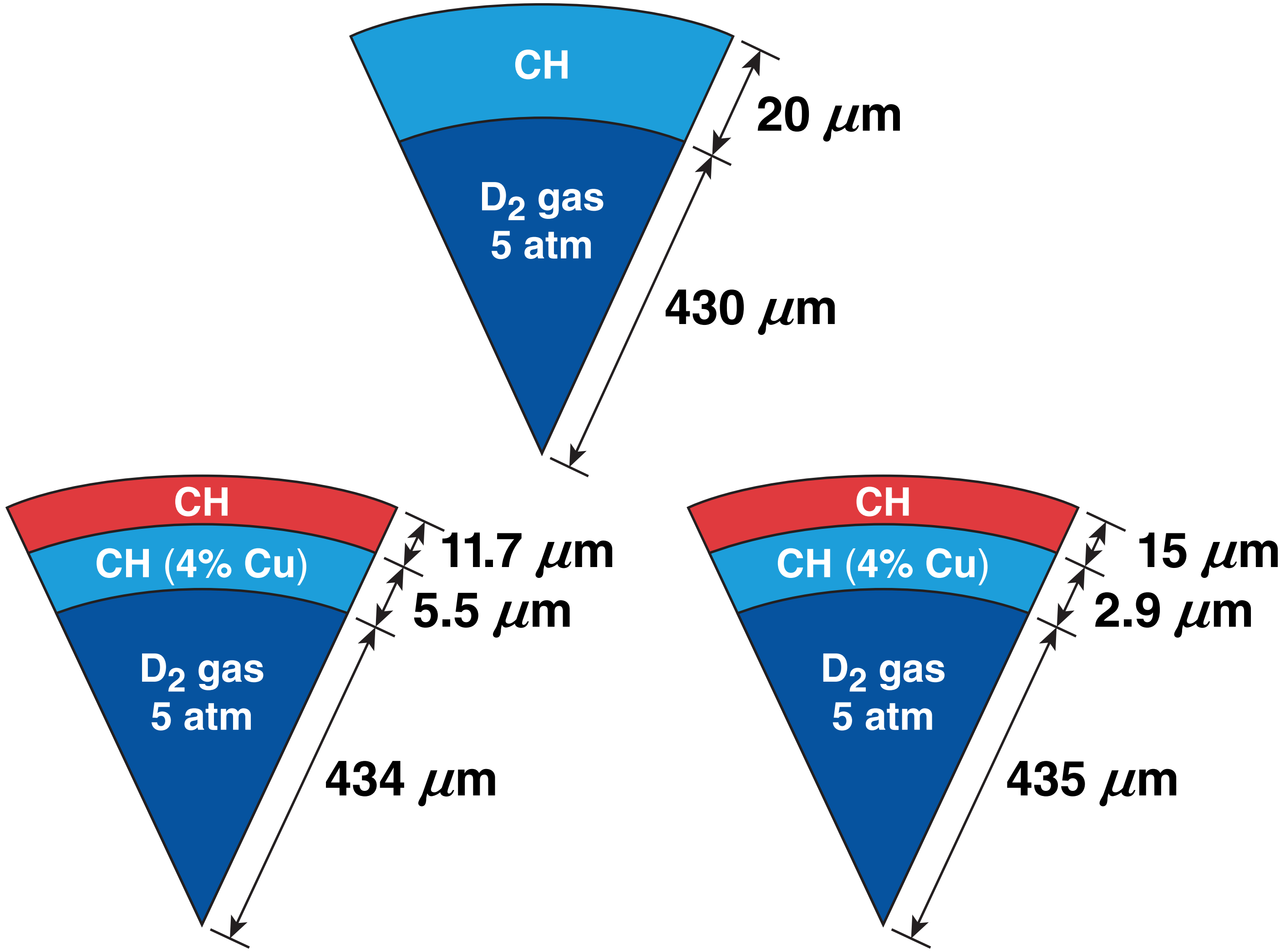
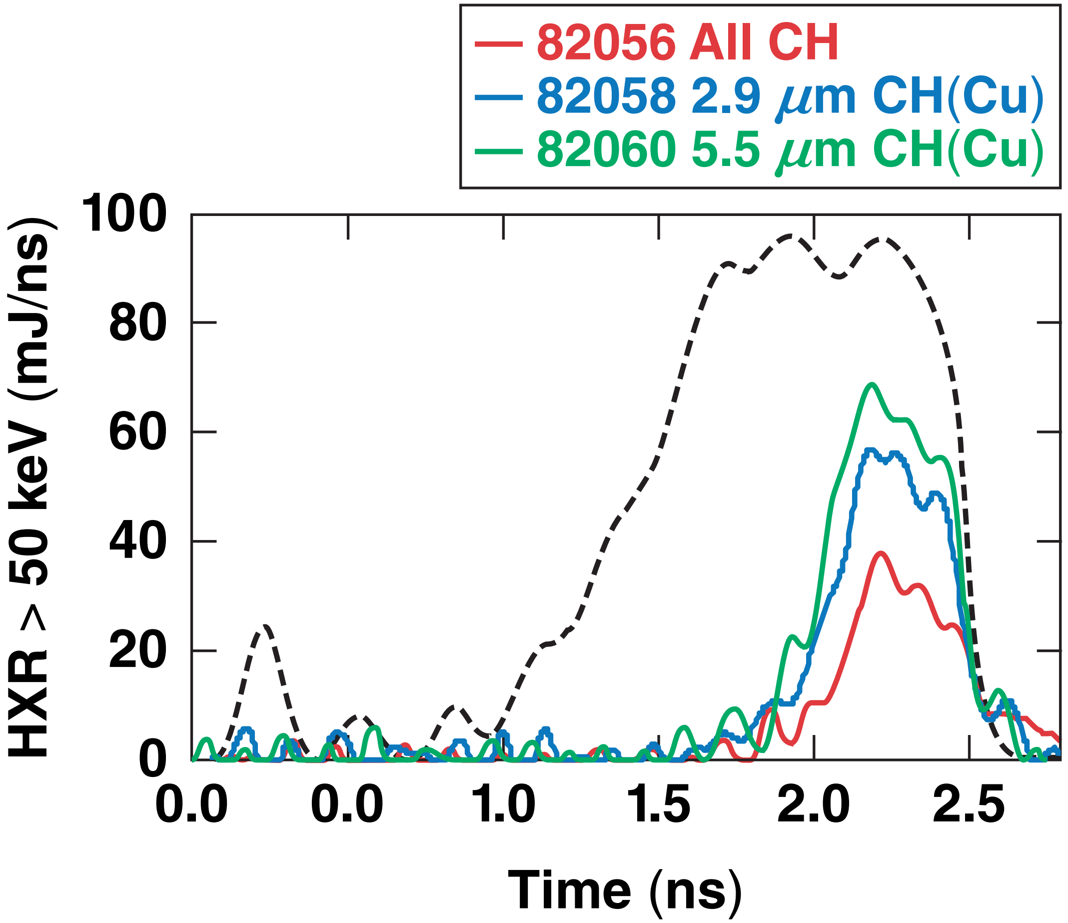
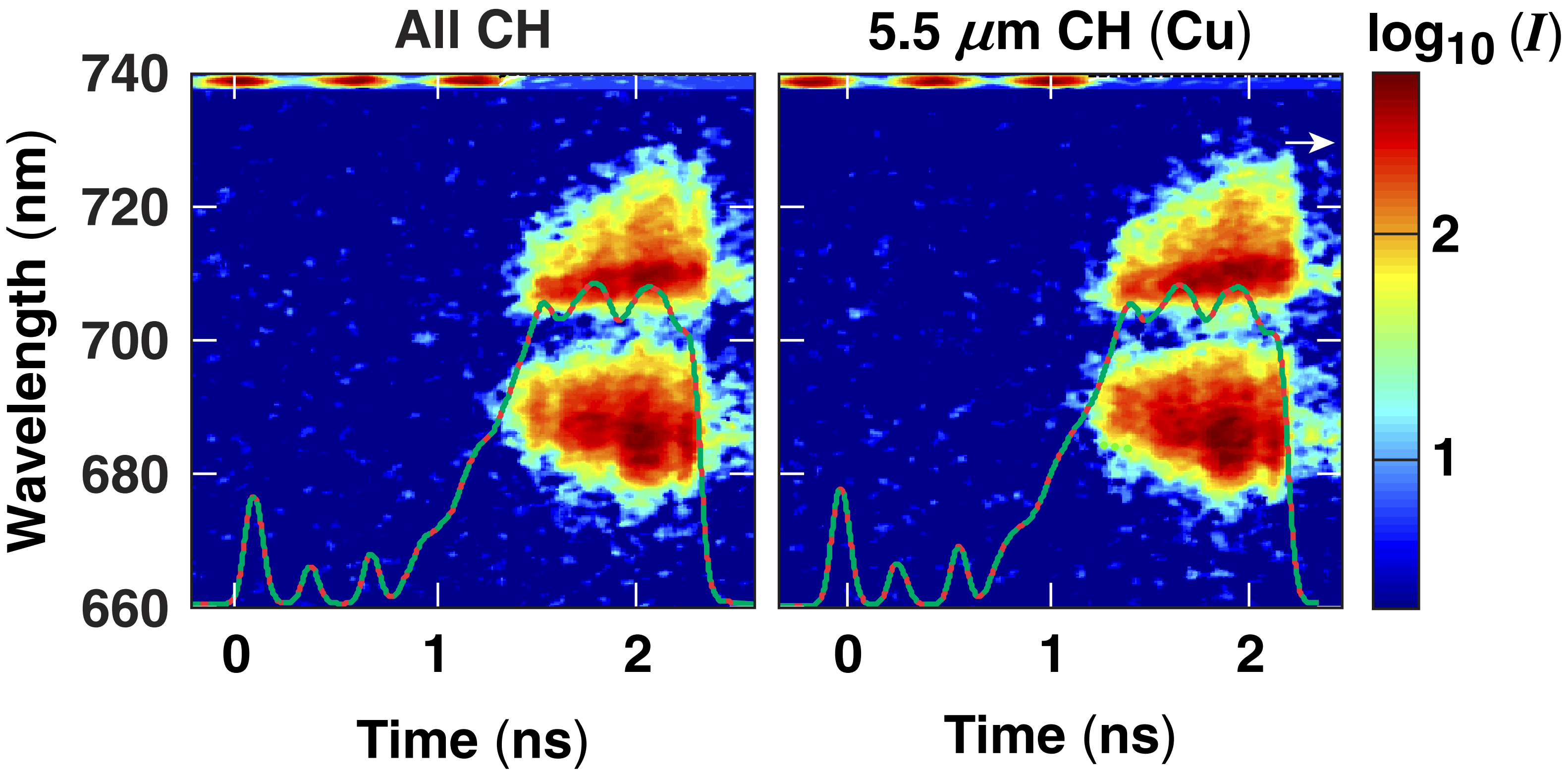
An experimental platform that utilized Cu-doped payloads of varying thicknesses was developed to measure where the hot electrons deposit their energy

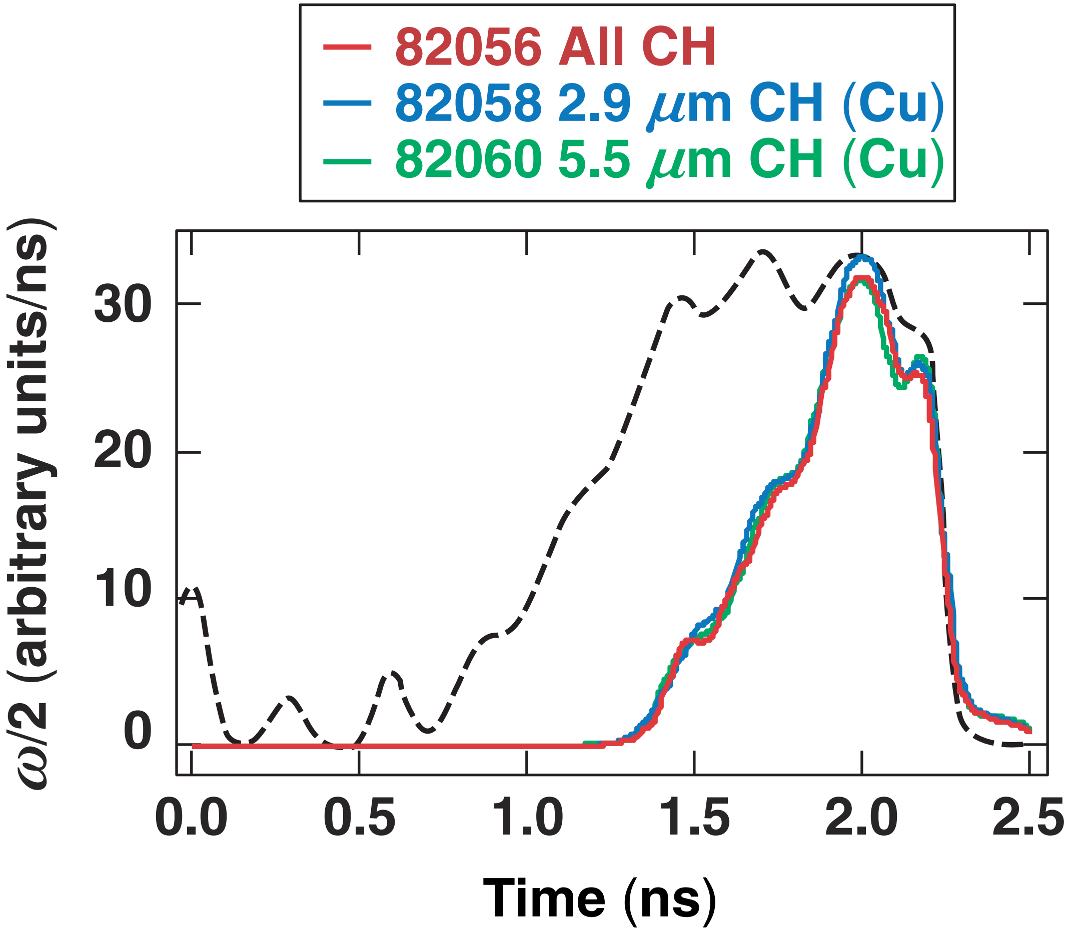




The HXR increases in Cu-doped targets.

Half of OMEGA images indicate that the TPD activity in the corona is identical between the all-CH and CH(Cu) payload implosions





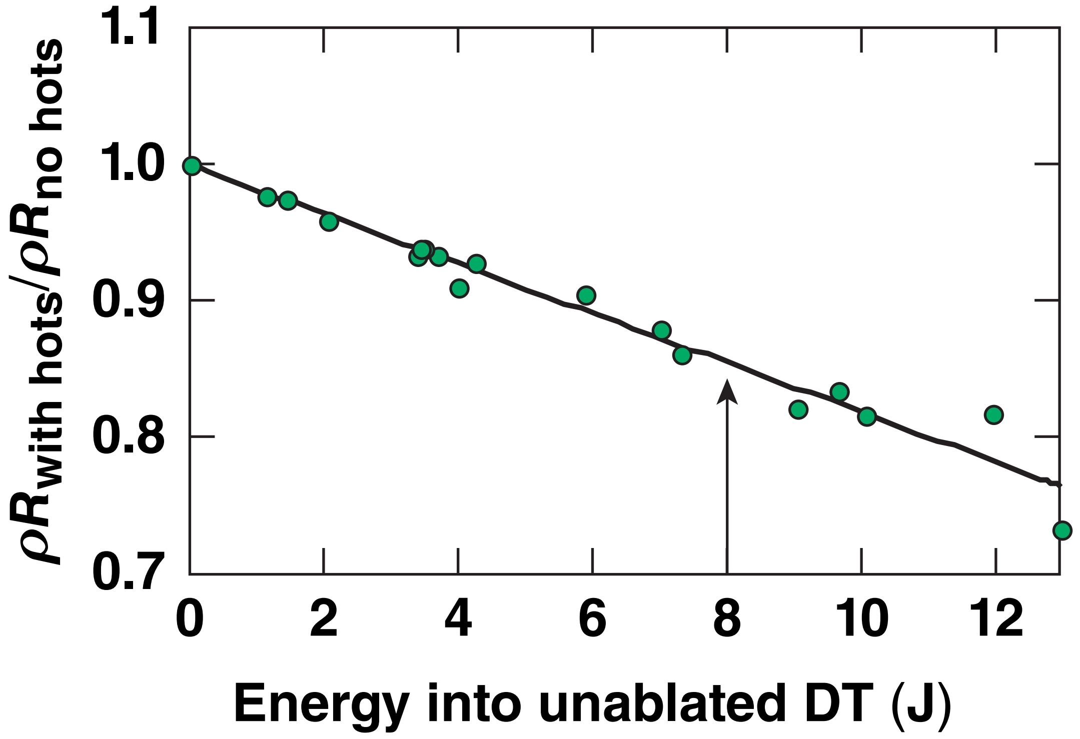
This data supports the assumption that the hot-electron source between the all-CH and multilayered implosions is the same.

The fraction of hot electrons coupled into the payload increases proportionally with payload thickness

	82058 [2.9 μm CH(Cu)]	82060 [5.5 μm CH(Cu)]	77064 (50 μm DT)
Total energy into hot electrons (J)	30±15 J	28±11 J	28±12 J
Energy into payload (J)	6±3 J	13±5 J	12±5 J

- Large uncertainties are caused by hot-electron temperature (~50%) and hard x-ray diagnostic (HXRD) calibration (~20%)
- Since the unablated mass is 2/3 of total DT mass, we expect 8±3 J (out of 12±5 J) is coupled into the unablated DT for 77064

Hot-electron preheat and areal-density degradation are determined from 1-D *LILAC* simulations that include hot-electron transport*



1-D ρR = 224 mg/cm^2
8 J into unablated DT: ρR = 192 mg/cm^2
Experiment: ρR = 195±15 mg/cm^2

The 8±3 J deposited into the unablated DT leads to a 10% to 20% degradation in areal density.

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* J. A. Delettrez *et al.*, UO9.00015, this conference.

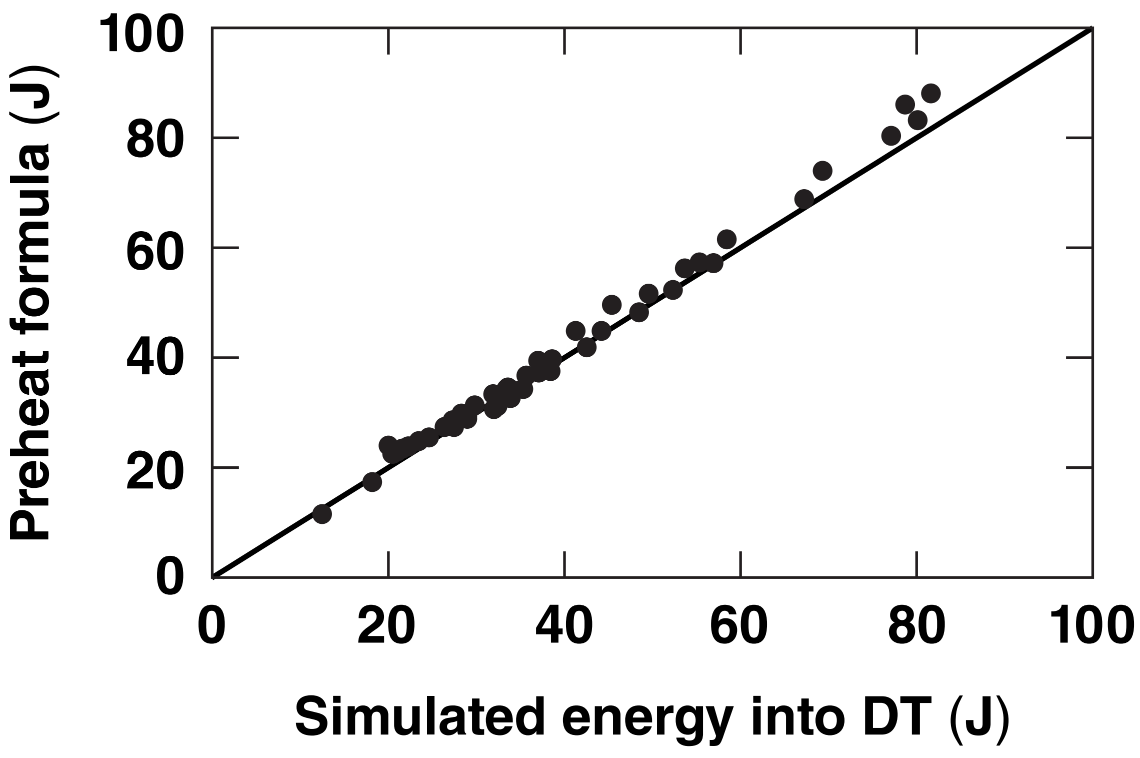
TC13190

Hot-electron transport in direct-drive cryogenic implosions is studied by comparing hard x rays (HXR's) between all-plastic and multilayered implosions

- Differences in HXR signals between mass-equivalent all-CH and multilayered implosions can be used to infer hot-electron energy deposition into the payload
- Experiments utilizing Cu-doped payloads of varying thicknesses indicated that hot-electron deposition into the payload increases proportionally with the payload mass
- Post-shot analysis of these experiments predicted a 10% to 20% degradation in areal density caused by hot-electron preheat for an $\alpha = 4$ implosion irradiated at an intensity of 9×10^{14} W/cm^2

The preheat formula correctly predicts the energy deposited into DT regardless of the hot-electron temperature, source divergence, and transport model

$$E_{\mathrm{DT}} = \frac{E_{\mathrm{rad}}^{\mathrm{all\text{-}CD}} - E_{\mathrm{rad}}^{\mathrm{cryo}}}{\left(\dfrac{E_{\mathrm{rad}}}{E_{\mathrm{lost}}}\right)_{\mathrm{CD}}^{\mathrm{payload}} - \left(\dfrac{E_{\mathrm{rad}}}{E_{\mathrm{lost}}}\right)_{\mathrm{DT}}}$$



- The hot-electron temperature varies from 40 to 80 keV
- The divergence angle varies from 0π to 4π
- All three transport models were used here

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Hot-electron preheat and areal-density degradation are determined from 1-D *LILAC* simulations that include hot-electron transport*

- The 1-D code *LILAC* uses a straight-line model, where electrons lose energy according to a slowing-down formula**
- The radiation emitted by hot electrons is calculated from National Institute of Standards and Technology tables
- The hot-electron source is Maxwellian with the measured temperature
- Electrons are born at the quarter-critical surface
- The fraction of laser energy into suprathermals and the source divergence angle are constrained by the two measured HXR signals
- Electrons at the edge of the simulation are reflected back into the target at a random angle

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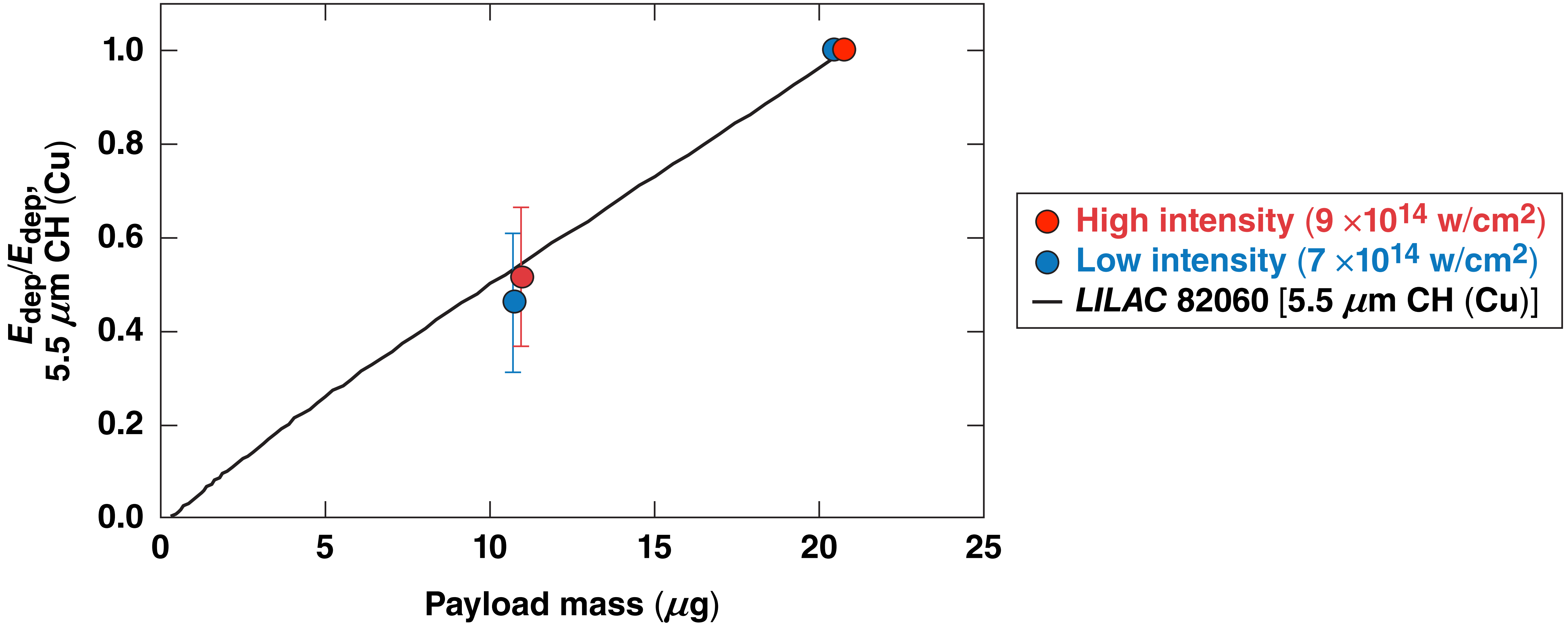
*J. A. Delettrez *et al.*, UO9.00015, this conference.

**A. A. Solodov and R. Betti, Phys. Plasmas 15, 042707 (2008).

TC12370a

The hot-electron energy deposition per unit mass is approximately constant in *LILAC* simulations* that include hot-electron transport



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* J. A. Delettrez *et al.*, UO9.00015, this conference.

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