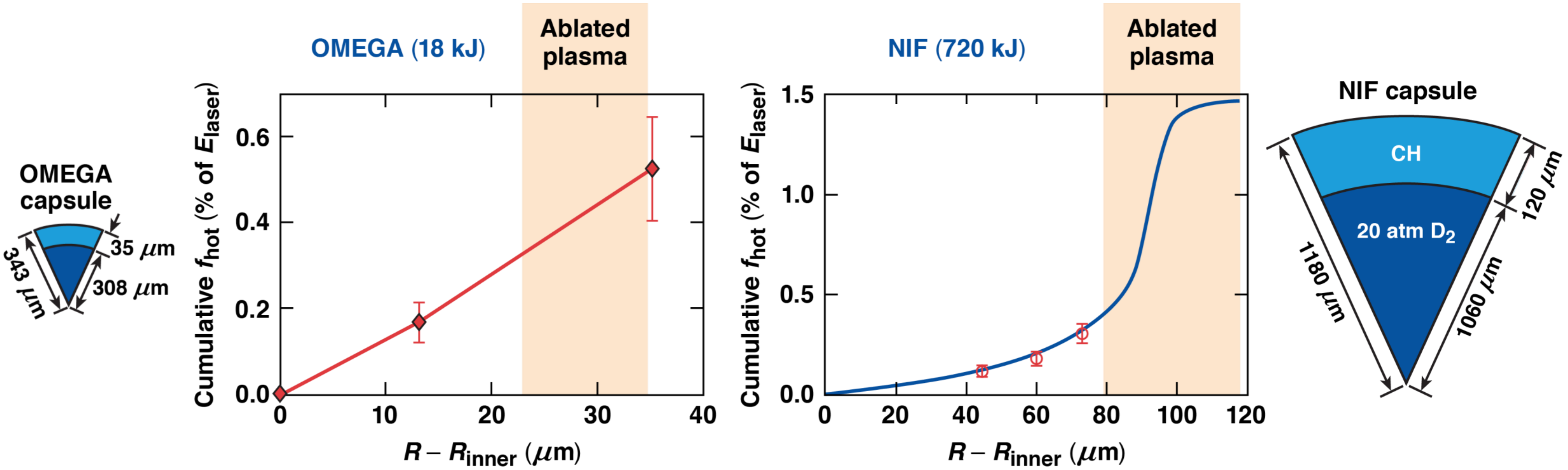
Hot-Electron Preheat in Hydrodynamically Scaled Direct-Drive Implosions at the National Ignition Facility and OMEGA



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Summary

Hot electron preheat has been diagnosed in hydrodynamically-scaled PDD implosions on NIF and OMEGA to assess direct-drive scalability

- **Hydrodynamic scaling underpins the extrapolation of direct-drive implosion performance from OMEGA to NIF, but not all aspects of physics scale (e.g. hot electron preheat)**

- **A platform using Ge-doped layers has been developed to diagnose hot electron preheat in hydro-scaled NIF and OMEGA implosions at 10^{15} W/cm^2 (720 kJ and 18 kJ, respectively)**

- **Both NIF and OMEGA experiments show ~0.2% of laser energy deposited as hot electron preheat in the inner ~80% of unablated shell, though NIF experiments show more hot electrons overall**

Collaborators

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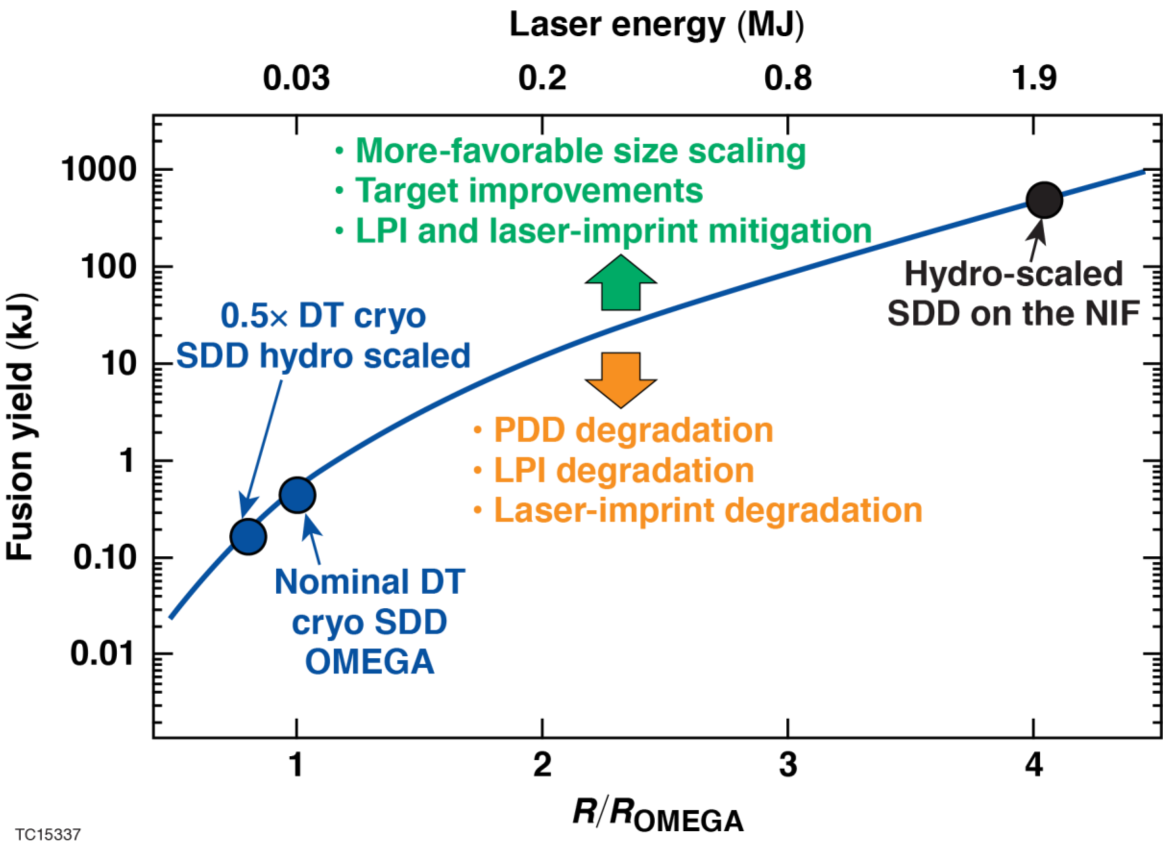
Motivation

Hydrodynamic scaling is used to extrapolate performance of direct-drive cryogenic implosions from OMEGA to NIF energies



Hydro-scaling relations for how parameters vary with laser energy

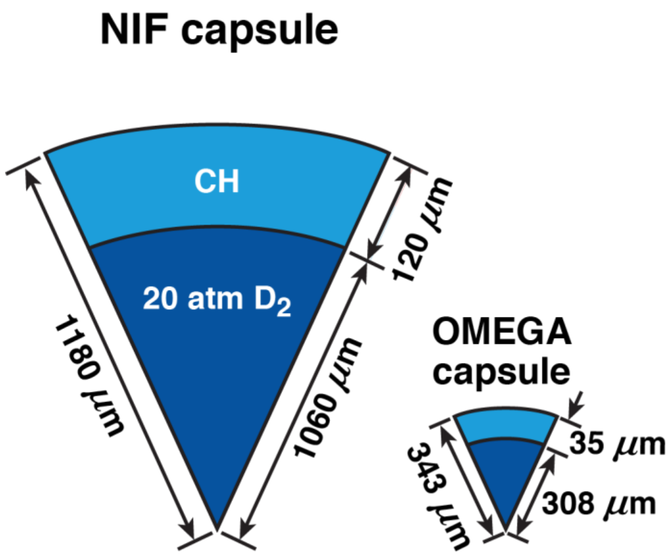
- All intrinsic properties (temperature, density, pressure, velocity) = fixed
- $M \propto E$
- $R \propto E^{1/3}$
- $t \propto E^{1/3}$
- $P \propto E^{2/3}$

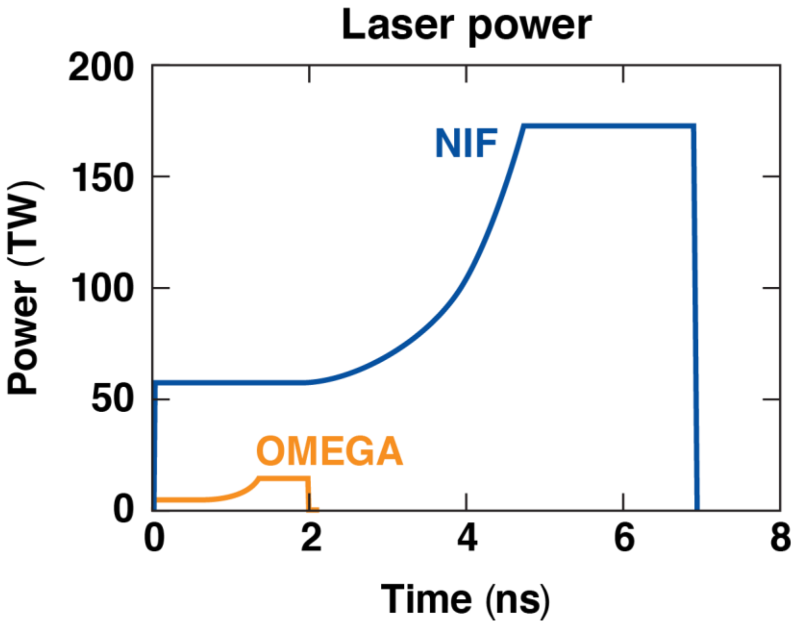
ICF observables

- Yield $\propto E^{4/3}$ (R^4)

Certain aspects of physics that affect performance, e.g. hot electron preheat, do not scale hydrodynamically and their scaling needs to be studied

To study preheat scaling, hydrodynamically equivalent polar direct drive (PDD) implosions were designed for NIF and OMEGA, spanning 40x in laser energy



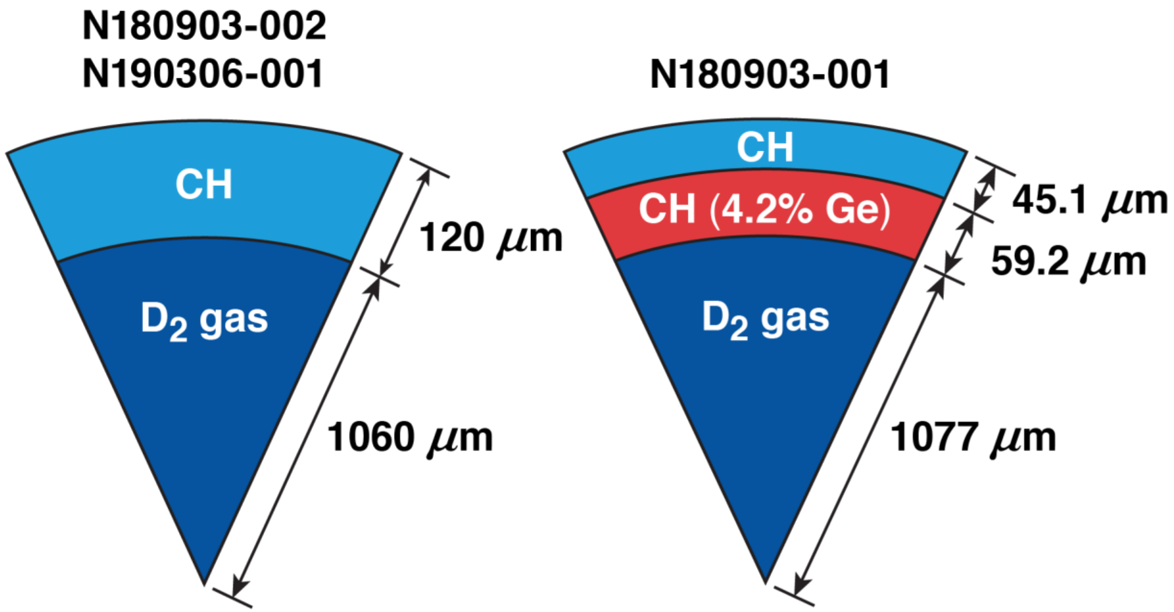


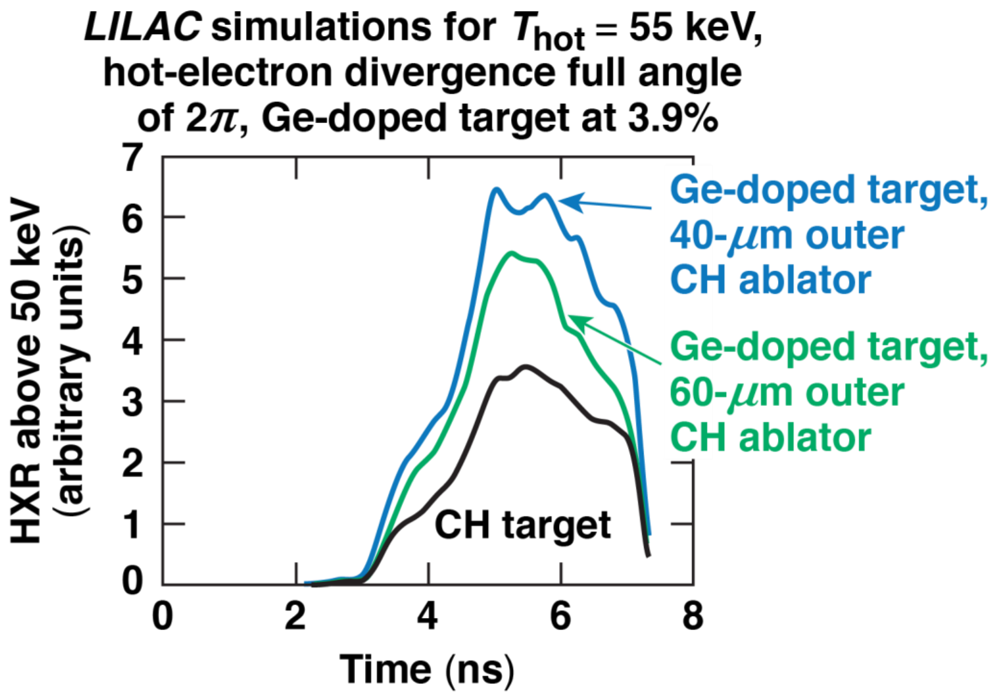
Parameter	NIF	OMEGA
E_L	720 kJ	18 kJ
P_L	172 TW	15 TW
$\langle I_L \rangle$ (W/cm^2)*	1.0x10^{15}	1.0x10^{15}
Pulse length	6.9 ns	2.0 ns
Capsule OD	2360 μm	690 μm
Shell thickness	120 μm	35 μm

*Average on-target laser intensity

A direct-drive implosion platform has been developed using Ge-doped layers to diagnose hot electron preheat deposited into the inner layer of the shell

NIF target designs





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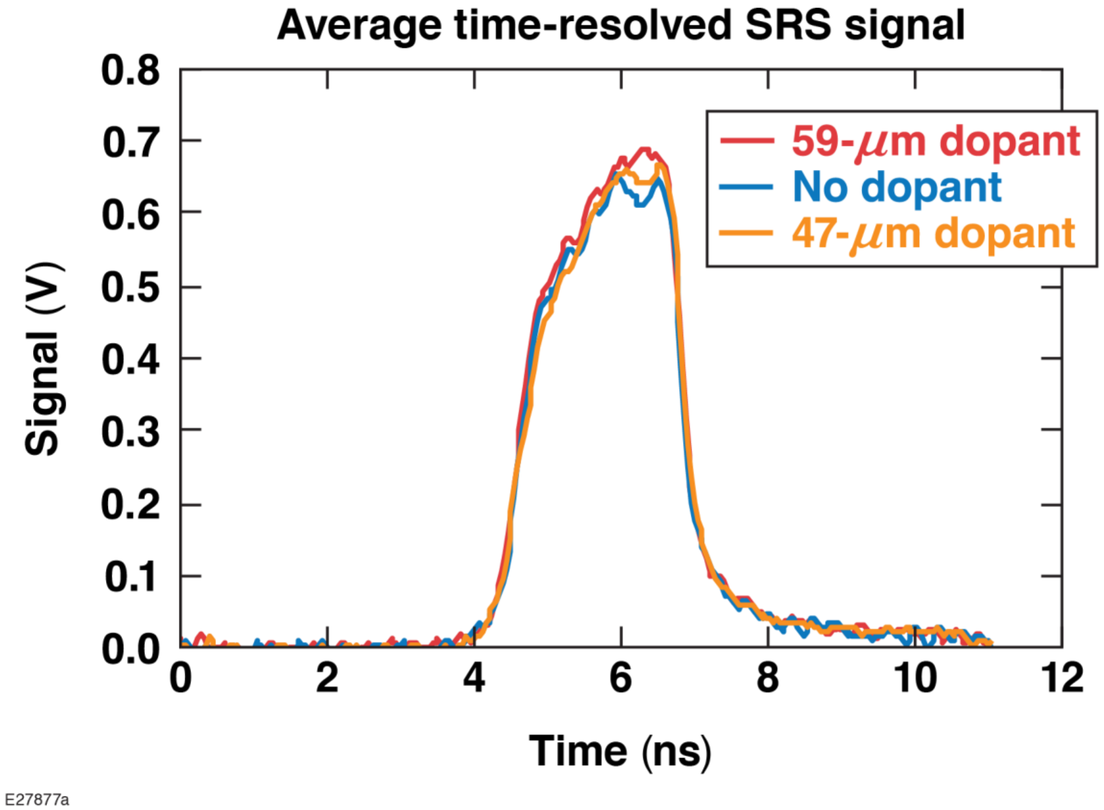
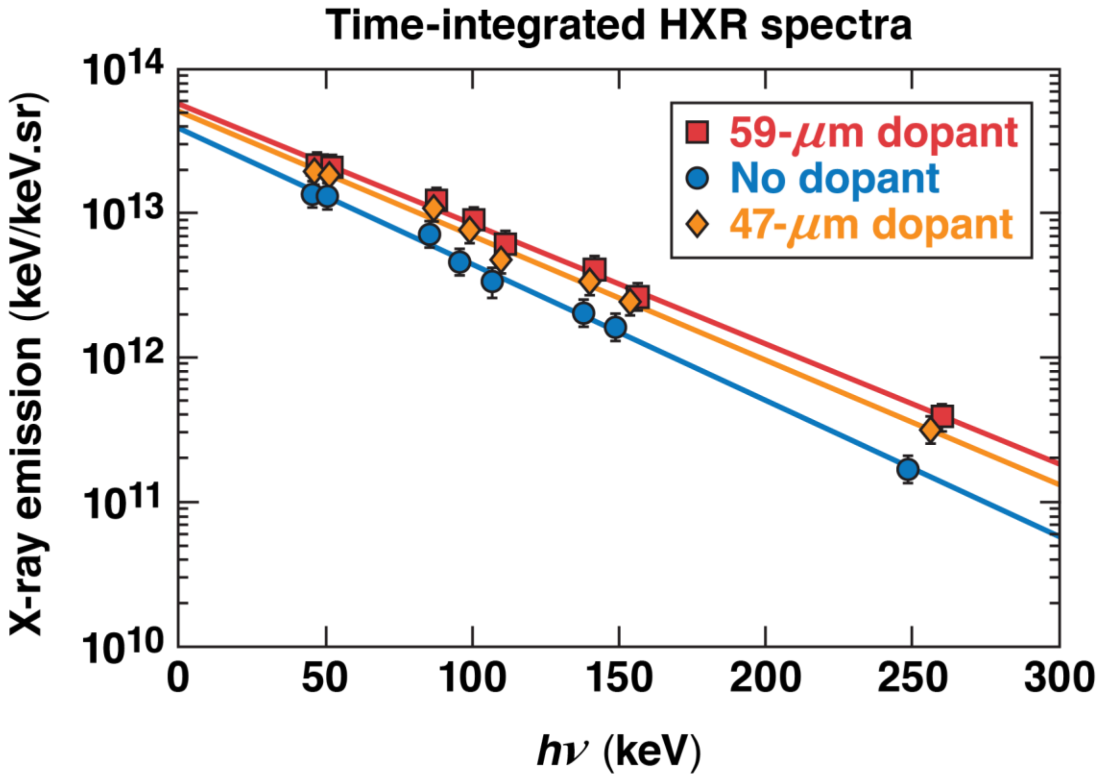
For an identical laser drive and identical hot electron source, the difference in hard x-rays ∝ hot electron energy deposited in Ge-doped layer

Platform based on A. Christopherson, et al. (submitted to Physical Review Letters).

Hard x-ray (HXR) emission on NIF shows the expected variation with Ge-doped layer thickness, with identical LPI



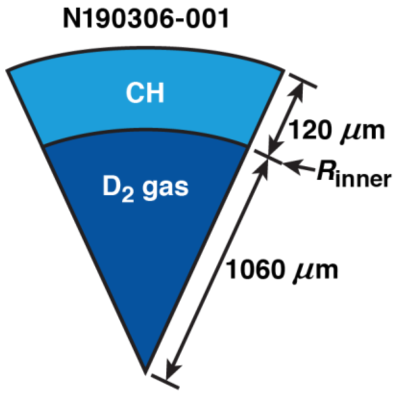


Identical LPI/hot e⁻ source

Different HXR emission due to <Z>

See also A. A. Solodov *et al.* BO09.00015 (this session)

Hot electron preheat in NIF implosions is inferred to be ~0.2% of laser energy (or ~2 kJ/mg of shell mass) over the inner ~80% of unablated shell



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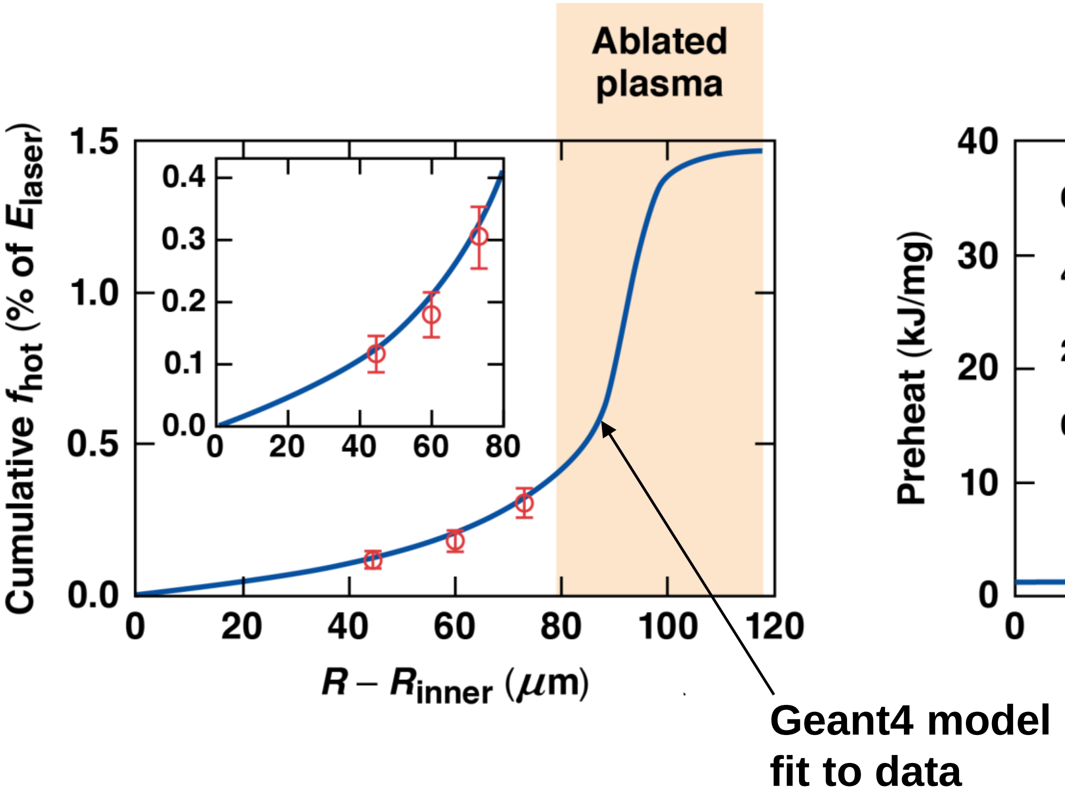
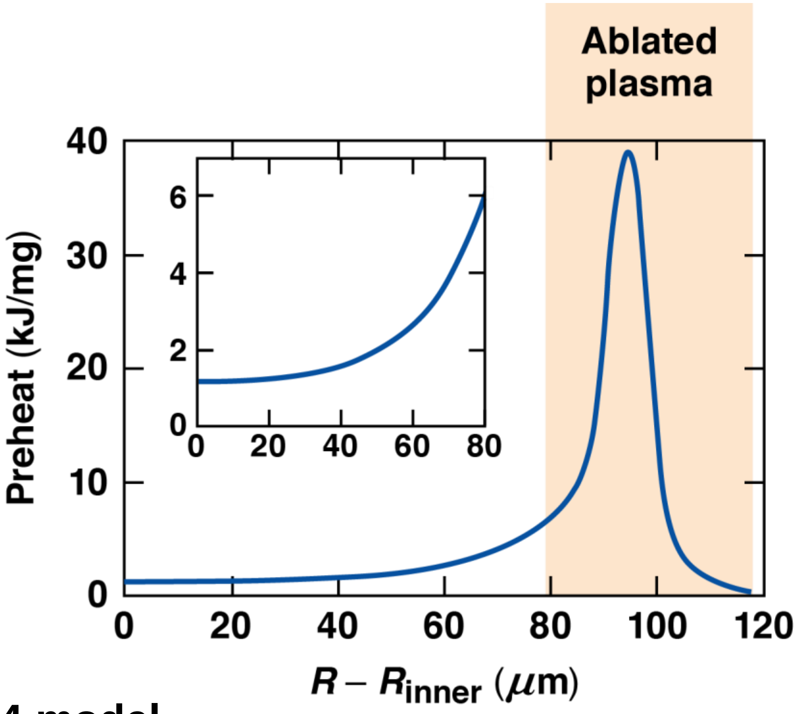
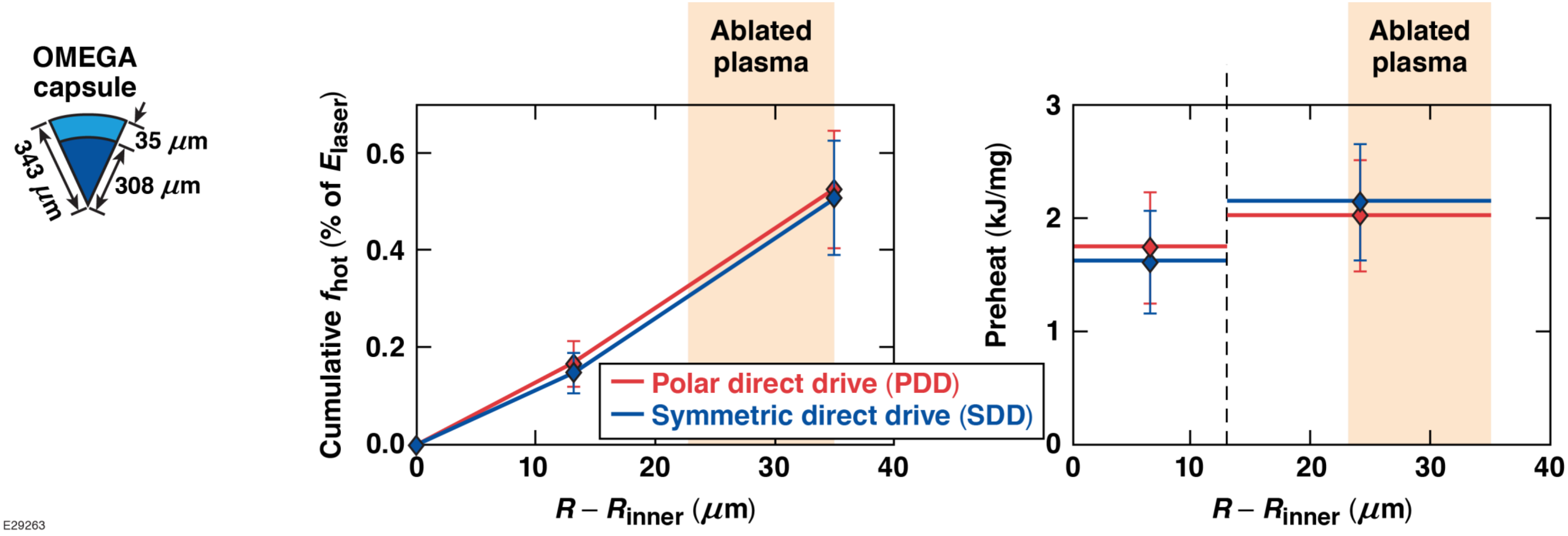




This level of preheat is close to ~0.15% limit for direct-drive ignition designs; Si layers have been found to reduce preheat by ~2x

See also A. A. Solodov *et al.* BO09.00015 (this session)

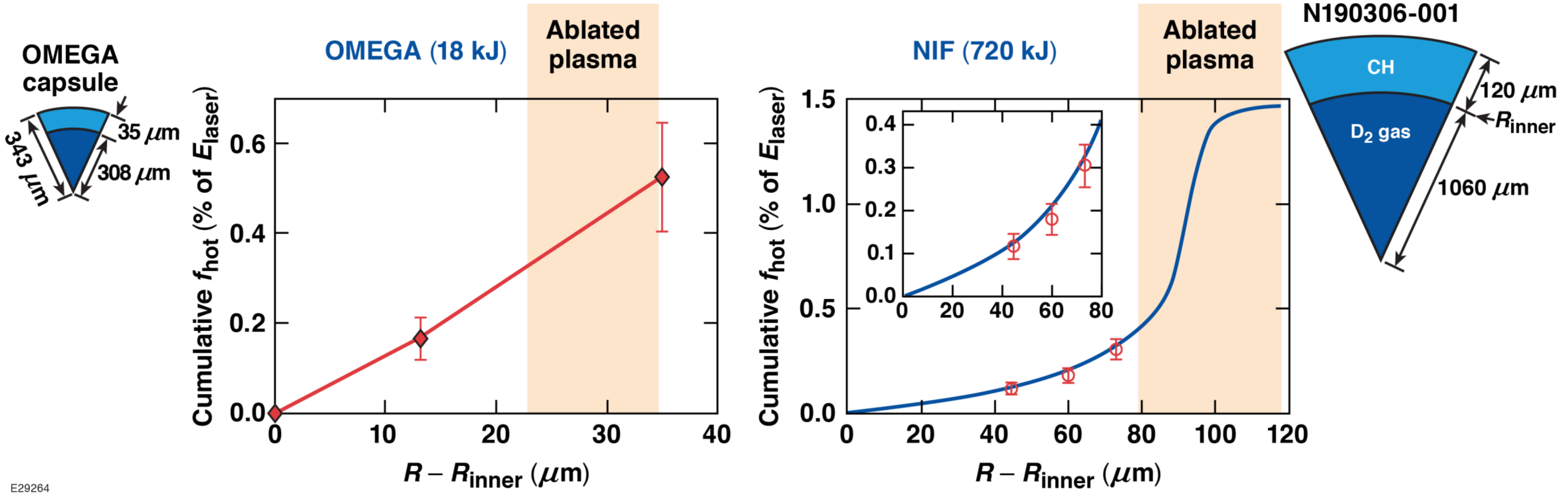
Hydrodynamically-scaled versions of these experiments on OMEGA show preheat ~0.15% of laser energy deposited to the inner 60% of unablated shell



Caveat: SDD experiments at ~10% higher laser power

Preheat is not strongly sensitive to polar drive (PDD) vs. symmetric drive (SDD) illumination

NIF and OMEGA experiments show a similar fraction of hot electron energy deposited to the inner shell layer, despite more hot e⁻ generation on NIF



Hypothesis: higher ablated-plasma ρL and SRS hot electrons on NIF generated at larger radius than TPD on OMEGA

These results support validity of hydro-scaling in warm implosions, though hot electron attenuation in the outer ablator is important and will have to be accounted for in cryogenic implosions with ablated DT

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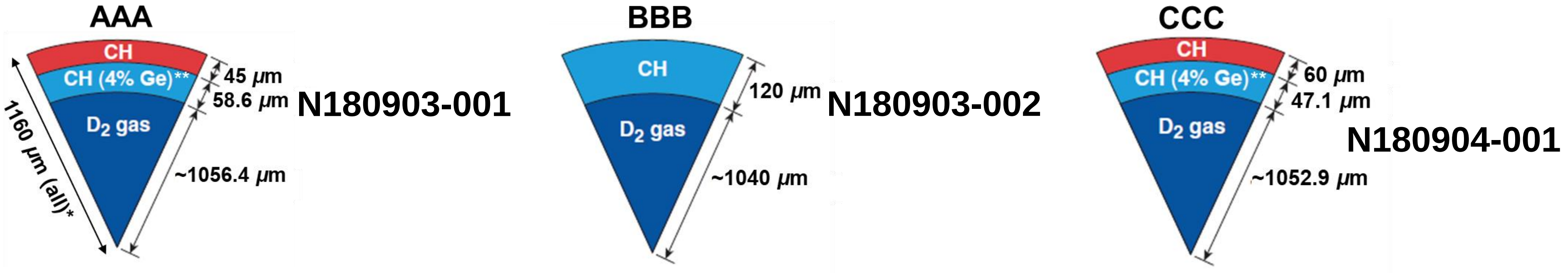
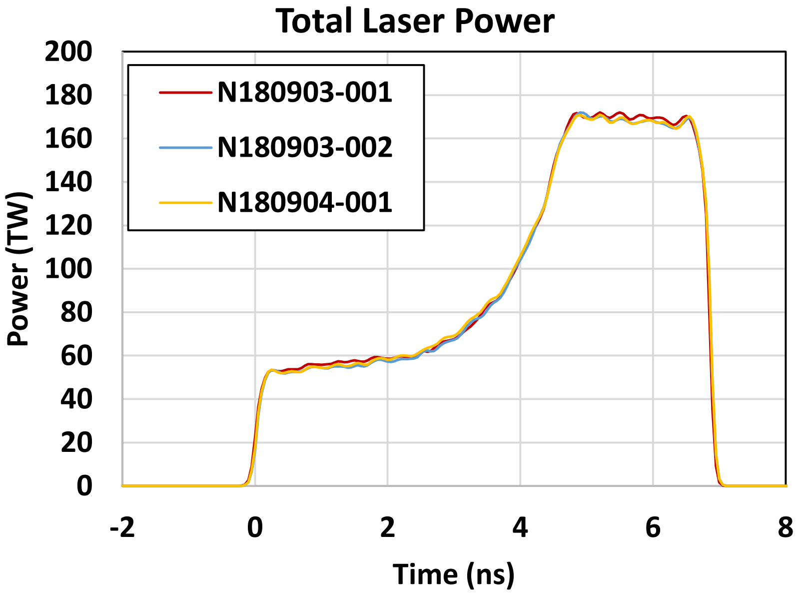
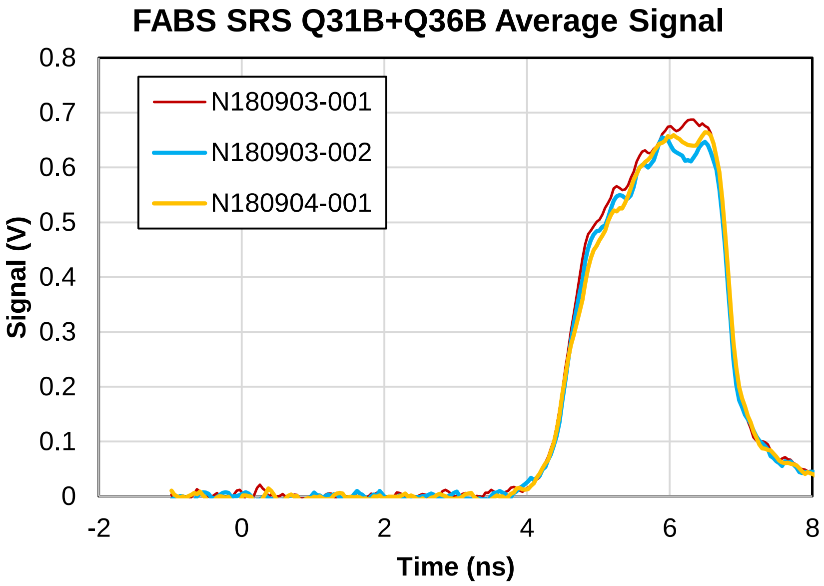
These result suggest similar preheat at NIF and OMEGA scales in warm implosions, though cryogenic implosions will have less shielding by outer ablator and will have to be accounted for on NIF

APPENDIX

SRS signal confirms an identical hot electron source in doped and un-doped NIF experiments







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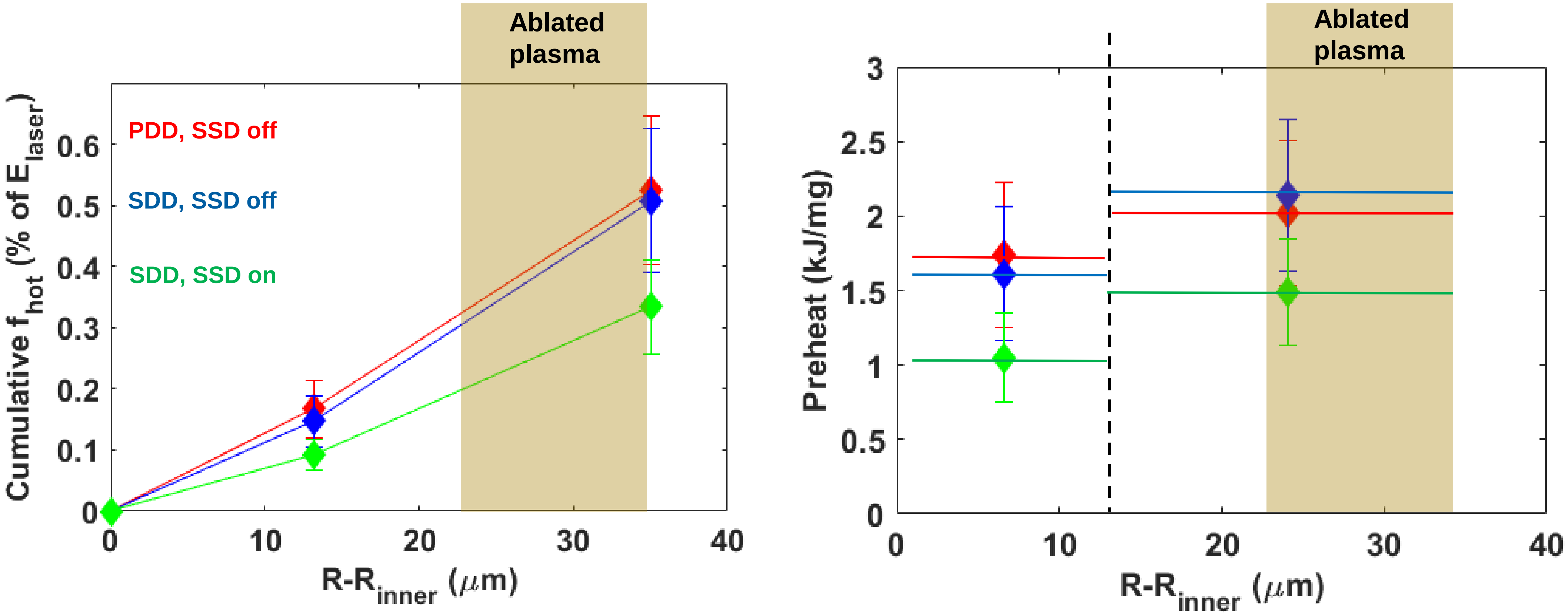
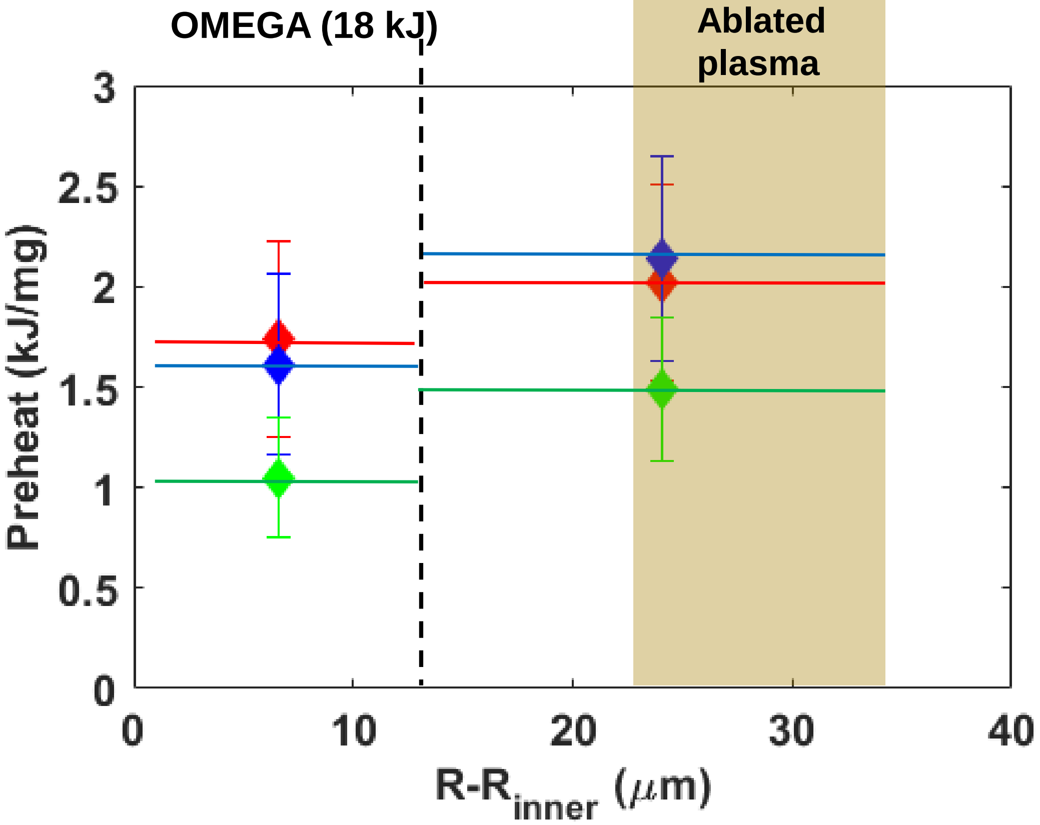
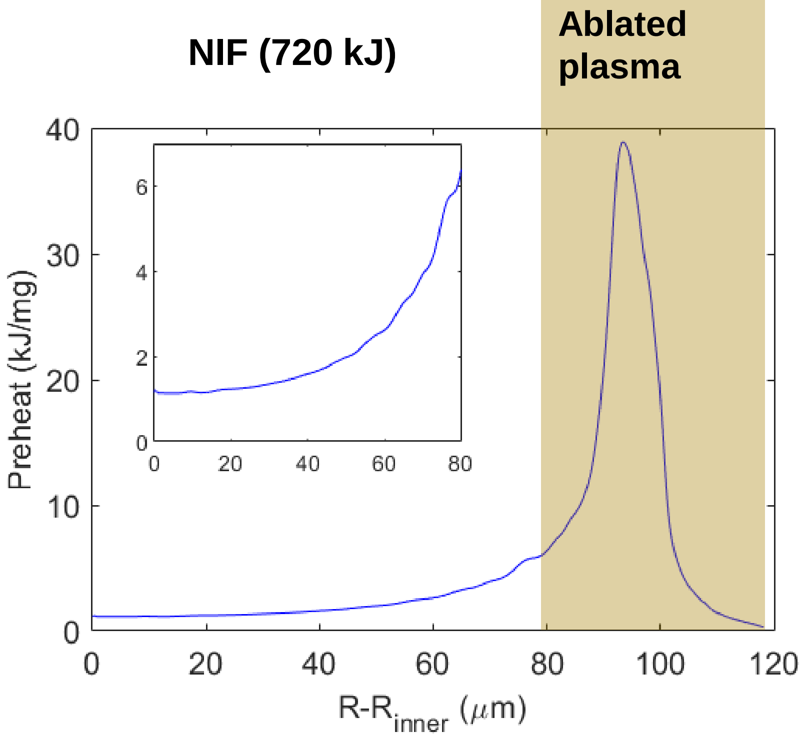


Results are insensitive to polar drive (PDD) vs. symmetric drive (SDD) illumination, but are affected by laser beam smoothing (SSD)

NIF and OMEGA experiments show a similar fraction of hot electron energy deposited to the inner shell layer, despite more hot e generation on NIF





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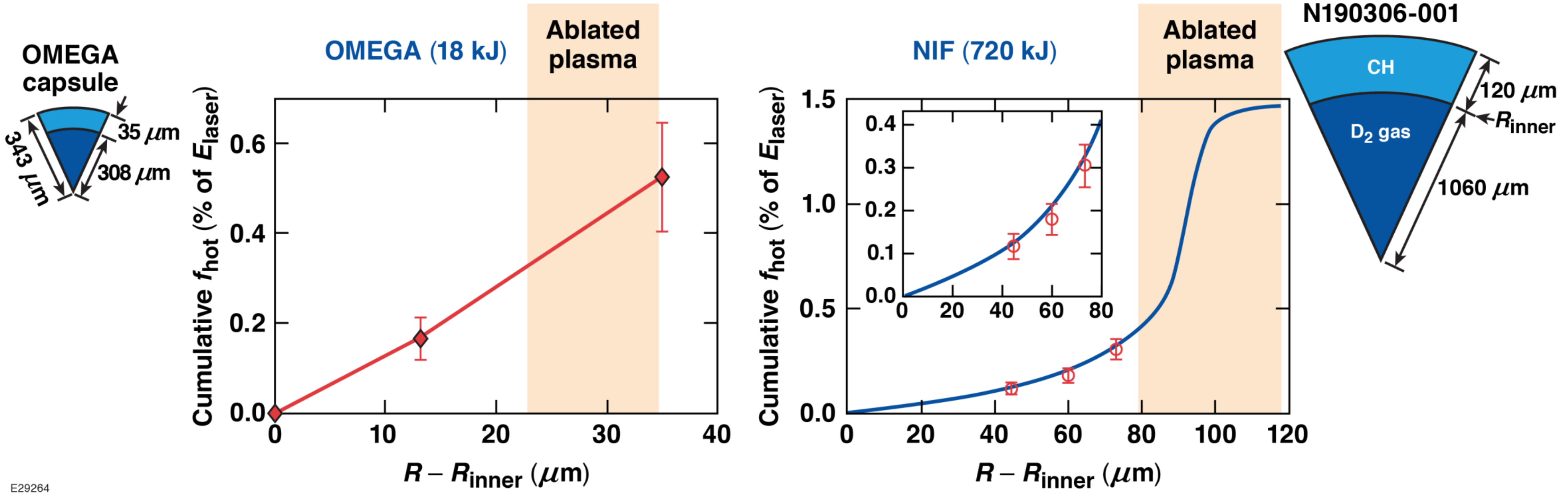

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[would be nice if Andrey can do simulations to show how much hots energy would get into DT payload on NIF in a cryo design]