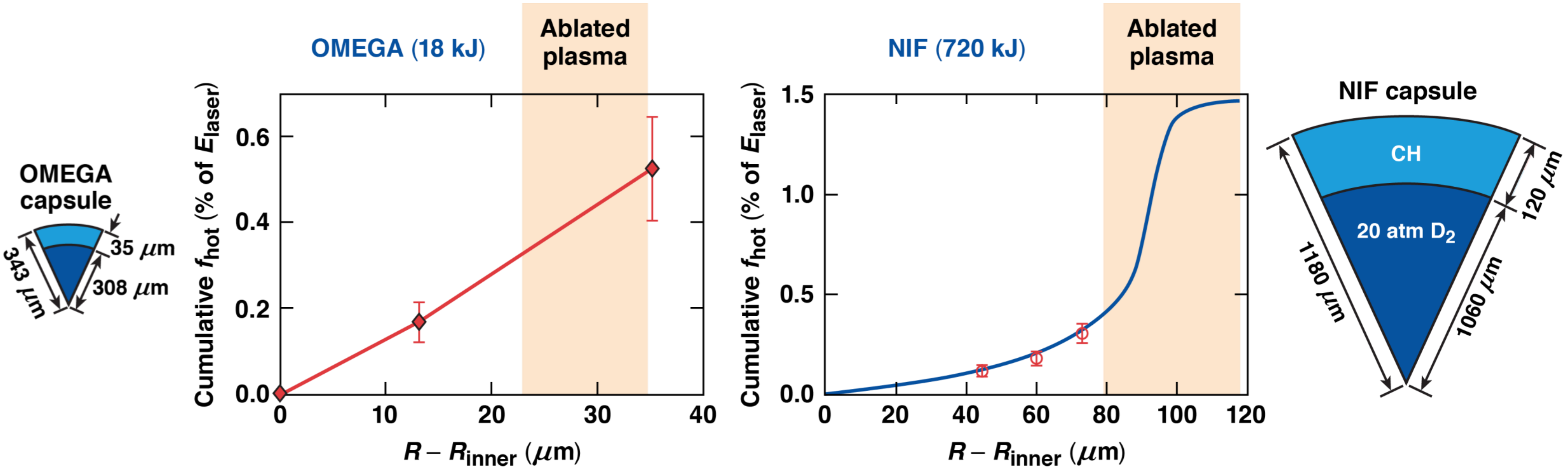
Hot-Electron Preheat in Hydrodynamically Scaled Direct-Drive Implosions at the National Ignition Facility and OMEGA



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Hot electron preheat in hydro-scaled PDD implosions on NIF and OMEGA is ~0.2% of laser energy at ignition-relevant intensities

UR LLE

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Collaborators

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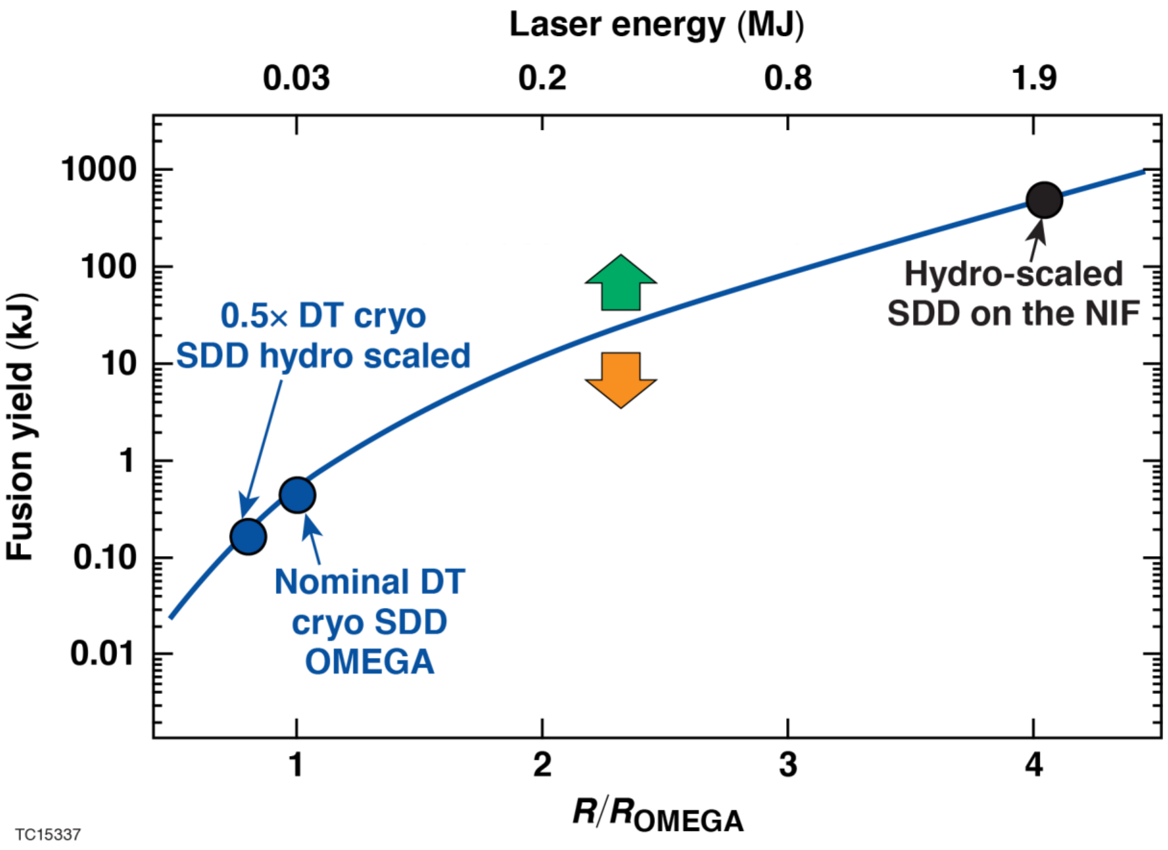
Hydrodynamic scaling is used to extrapolate performance of direct-drive cryogenic implosions from OMEGA to NIF energies



Hydro-scaling relations for how parameters vary with laser energy

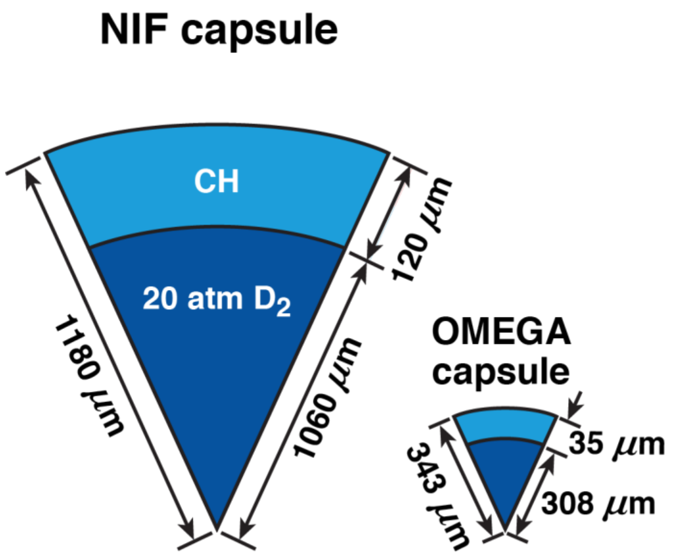
- All intrinsic properties (temperature, density, pressure, velocity) = fixed
- $M \propto E$
- $R \propto E^{1/3}$
- $t \propto E^{1/3}$
- $P \propto E^{2/3}$

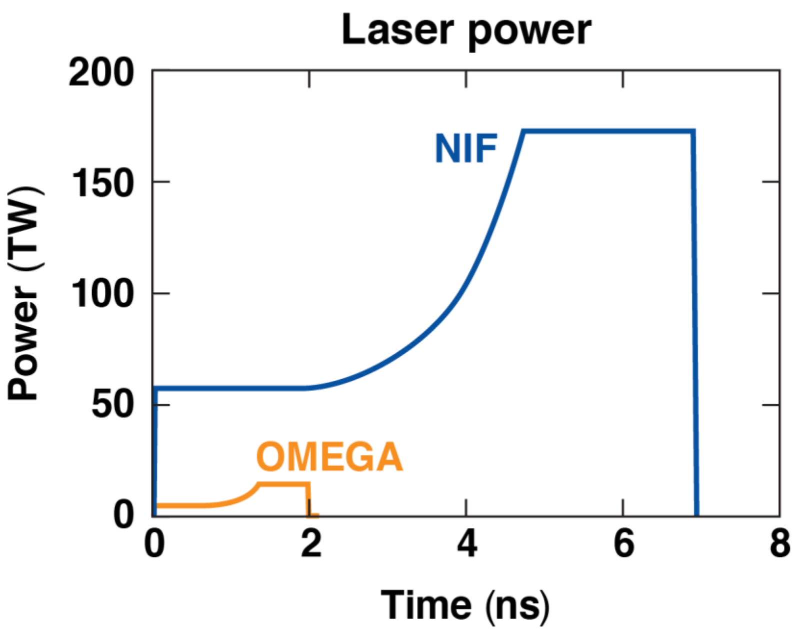
ICF observables

- 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



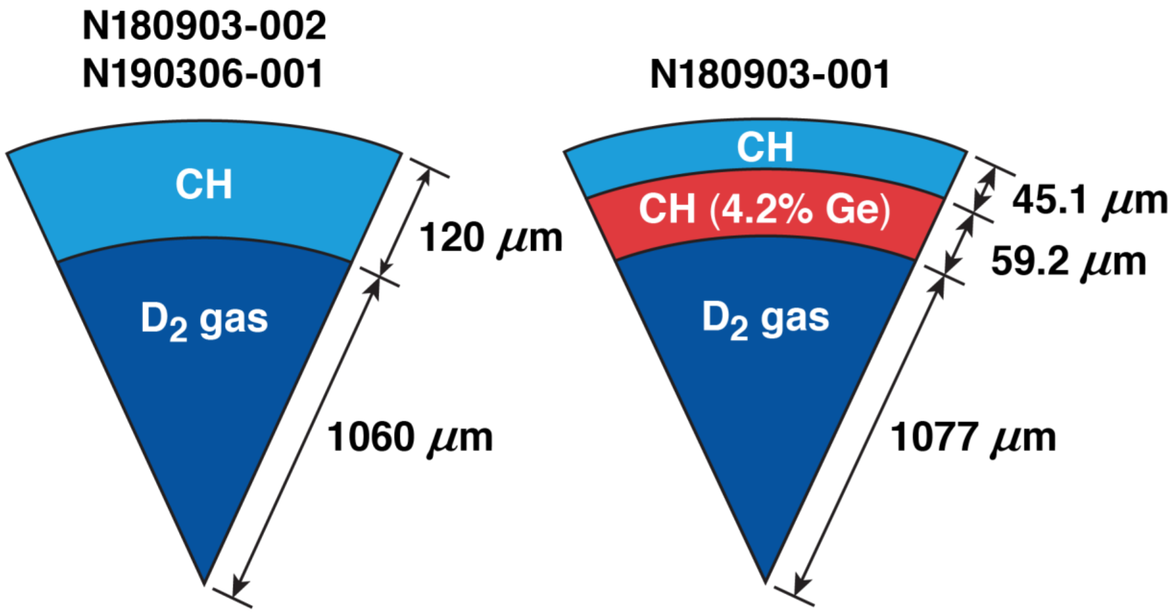


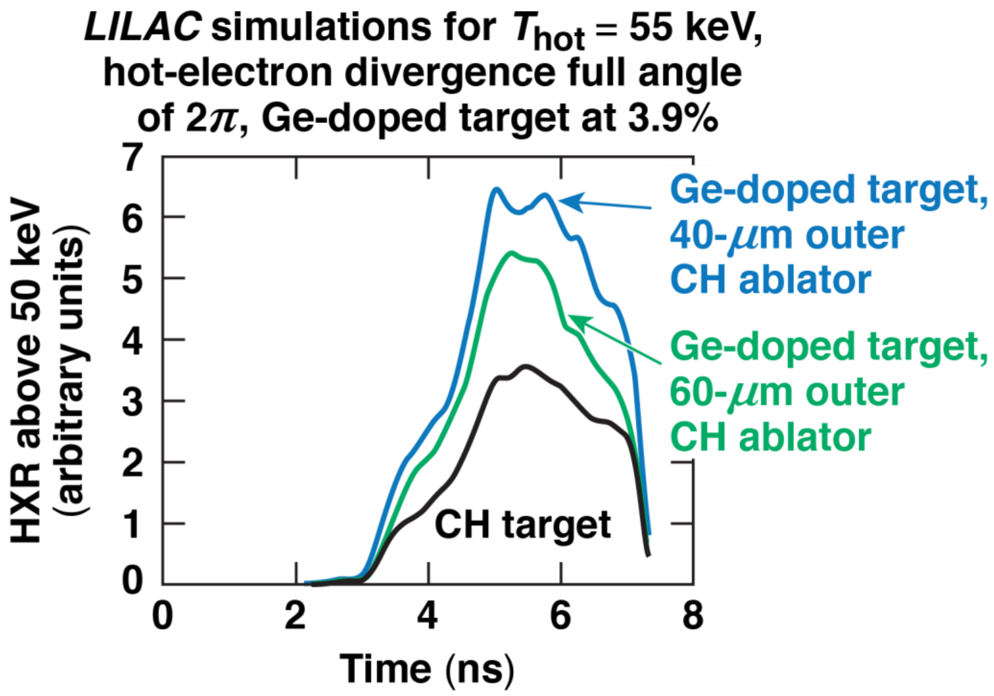
Parameter	NIF	OMEGA
E_L	720 kJ	18 kJ
P_L	172 TW	15 TW
$\langle I_L \rangle$ (W/cm^2)*	1.0x10^{15}	1.0x10^{15}
Pulse length	6.9 ns	2.0 ns
Capsule OD	2360 µm	690 µm
Shell thickness	120 µm	35 µm

*Average on-target laser intensity

Hot electron preheat deposited into the inner layer of the shell is diagnosed using implosions with or without a Ge-doped layer

NIF target designs



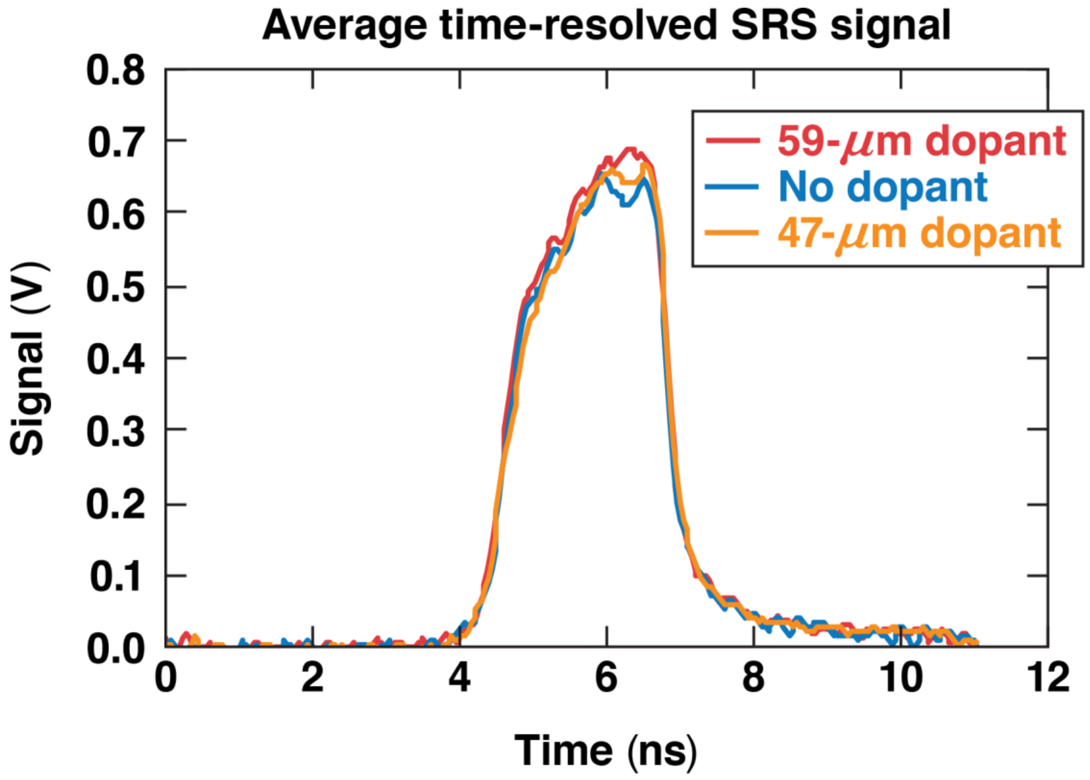


E29257

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. *Phys. Rev. Lett.* 127, 055001 (2021)

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



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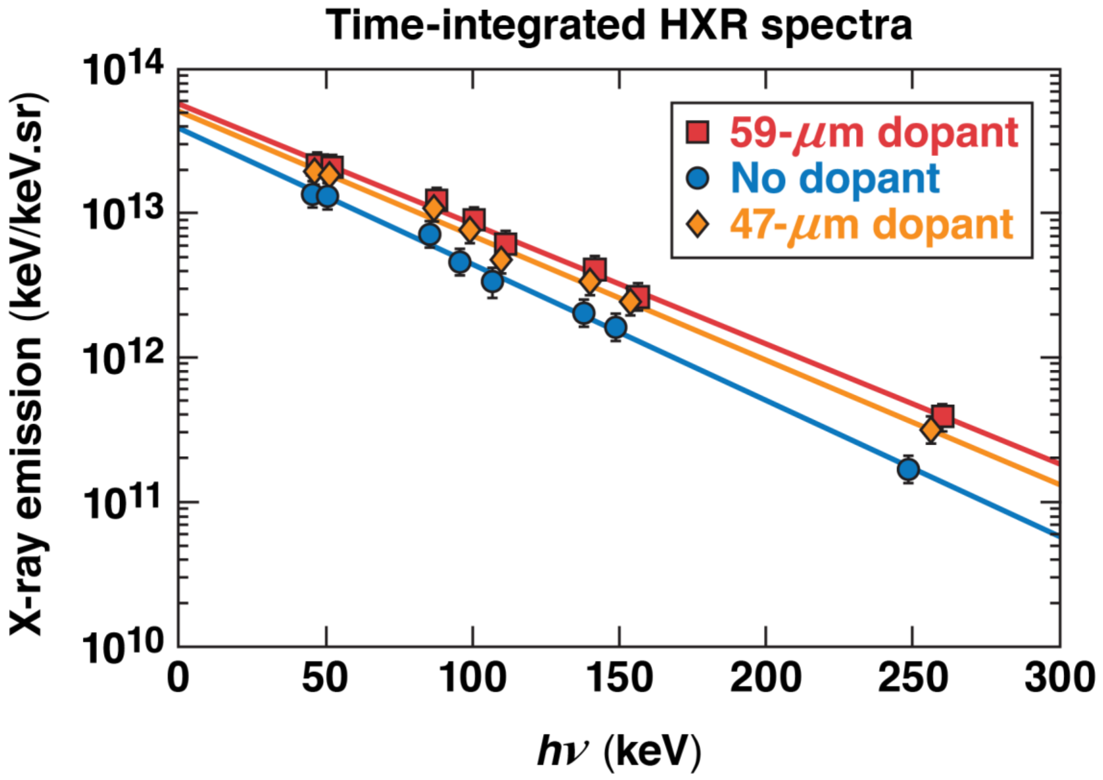
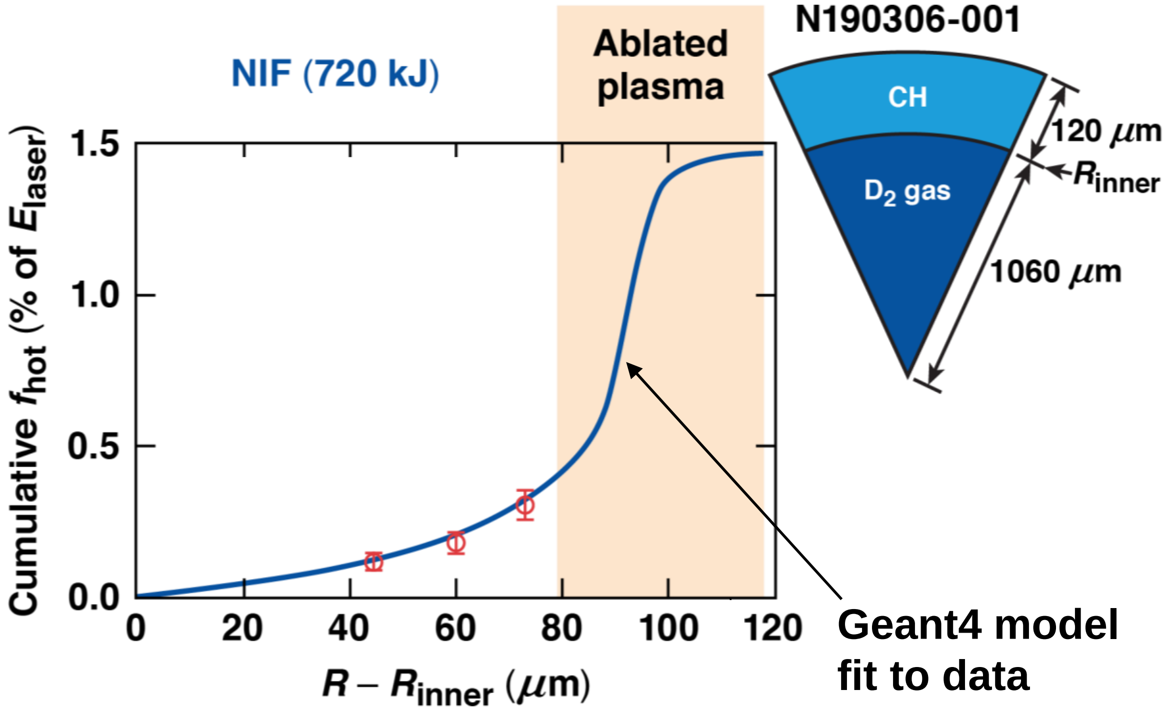


Identical LPI/hot e$^-$ source

Different HXR emission due to <Z>

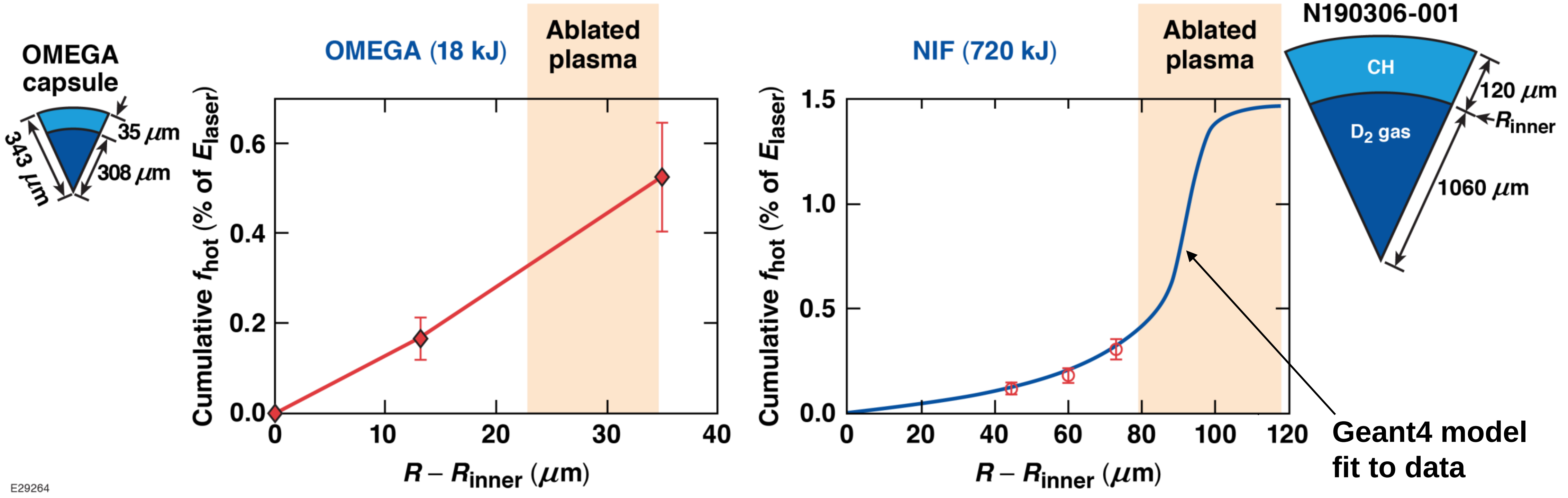
See also A. A. Solodov *et al.* UO04.00005 (this session)

Hot electron preheat in NIF implosions is inferred to be ~0.2% of laser energy over the inner ~80% of unablated shell



See also A. A. Solodov *et al.* UO04.00005 (this session)

NIF and OMEGA experiments show 0.2% 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

Results show that hot electron preheat does not invalidate hydrodynamic scaling between OMEGA and NIF warm implosions

See also A. A. Solodov *et al.* UO04.00005 (this session)

These results contribute to extrapolation of preheat in ignition-scale cryogenic direct drive implosions of around 0.15% of laser energy

	Multiplier	Preheat (% of laser)
Preheat into inner 80% of unablated shell in warm subscale NIF implosion		~0.2%
Increase scale length to full scale	~1.5-2	
Increase convergence ratio at end of pulse	~0.4-0.8	
DT shell and some DT in ablator	~1-1.8	
Improve beam smoothing	~0.8	
Si layer*	~0.5	
Total	**~0.5-1**	**~0.1-0.2%**

Subscale NIF warm implosion

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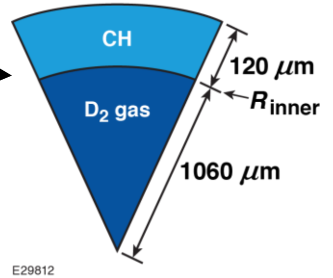
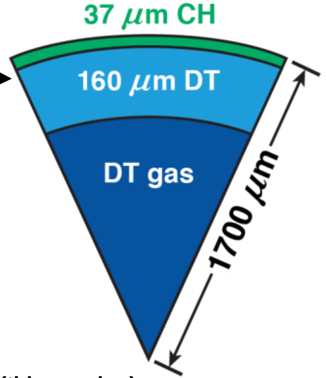


Notional NIF ignition design



~0.15% is acceptable preheat fraction for ignition designs**
→ Intensities around 10^{15} W/cm^2 produce acceptable preheat for ignition designs

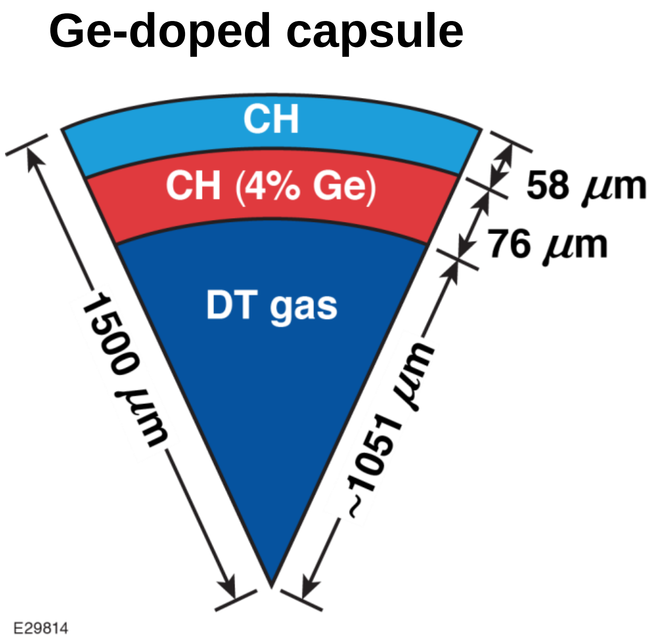
Note: current preheat results are near-"worst case scenario" given poor beam smoothing on NIF

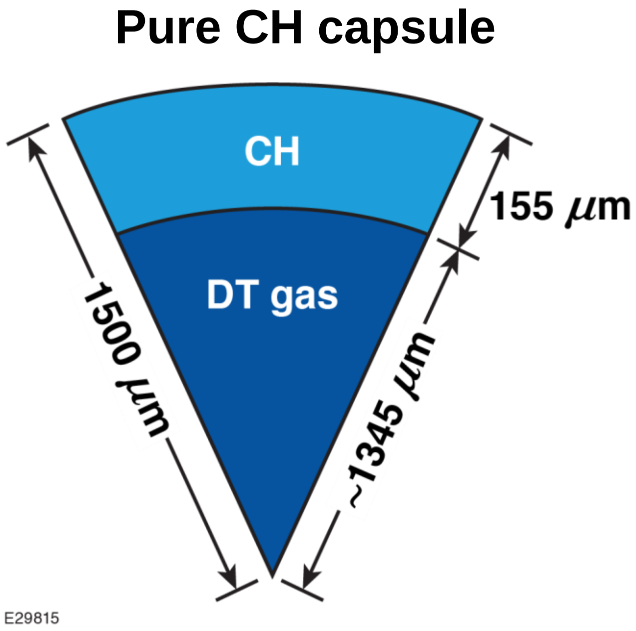
* See A. A. Solodov *et al.* UO04.00005 (this session)
** J. Delettrez *et al. Phys. Plasmas* 26, 062705 (2019)

Upcoming experiments will explore scaling of preheat within NIF scale, between 2.3 mm (720 kJ) and 3.0 mm (1.5 MJ) capsule diameter (laser energy)

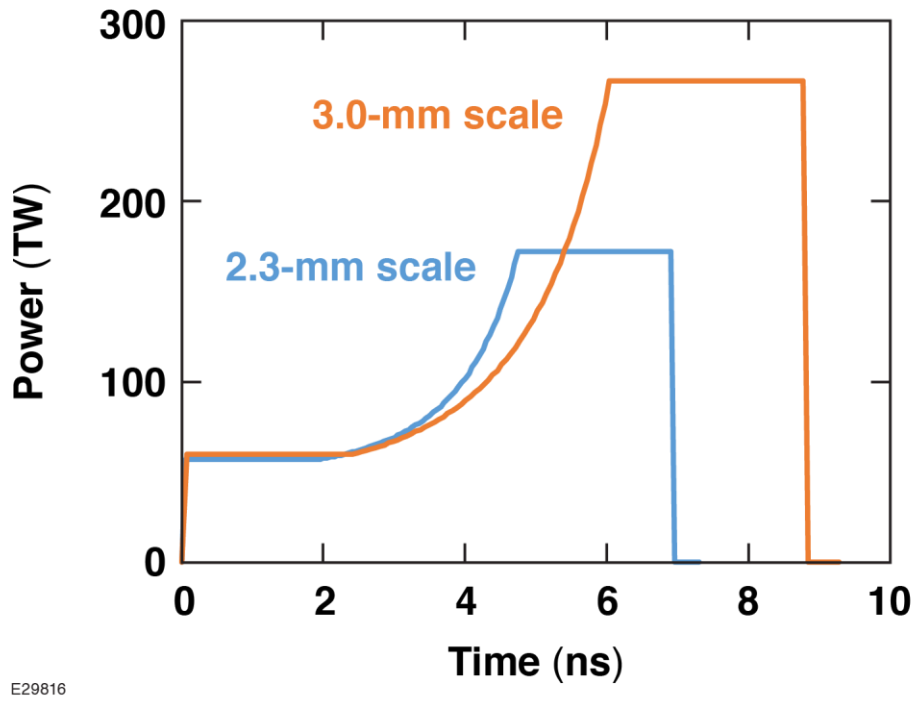
$P \sim R^2$
$t \sim R$

Mass-equivalent 3-mm capsules





Notional laser pulse



Data will help set intensity limits for direct-drive ignition designs

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Future experiments will directly diagnose preheat at 1.5 MJ scale to constrain the extrapolation