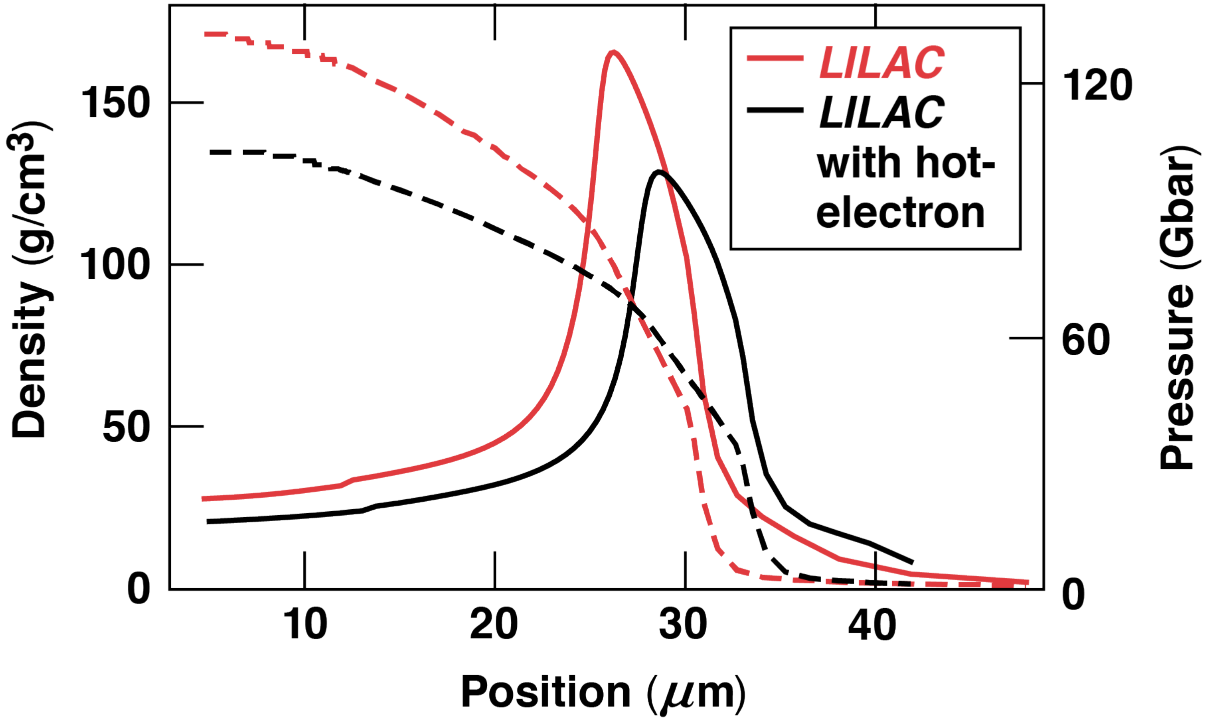
Analysis of Hot-Electron Preheat for High-Performance OMEGA Cryogenic Implosions

Simulated profiles at stagnation



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Summary

The impact of fast-electron preheat was studied for high-performing cryogenic implosions using the 1-D radiation-hydrodynamic code *LILAC*

- The preheat in unablated DT fuel is inferred by subtracting hard x-ray signals of cryogenic implosions from the hard x-ray signal of a mass-equivalent warm implosion with a similar pulse shape*
- The 1-D radiation-hydrodynamic code *LILAC*** was used to uniformly deposit the experimentally inferred fast-electron energy into unablated DT
- Simulations suggest reduction in neutron-averaged areal densities of ~20% from hot-electron preheat in high-performance implosions

* A. R. Christopherson *et al.*, Phys. Rev. Lett. 127, 055001 (2021).
** J. Delettrez et al., Phys. Rev. A 36, 3926 (1987).

Collaborators

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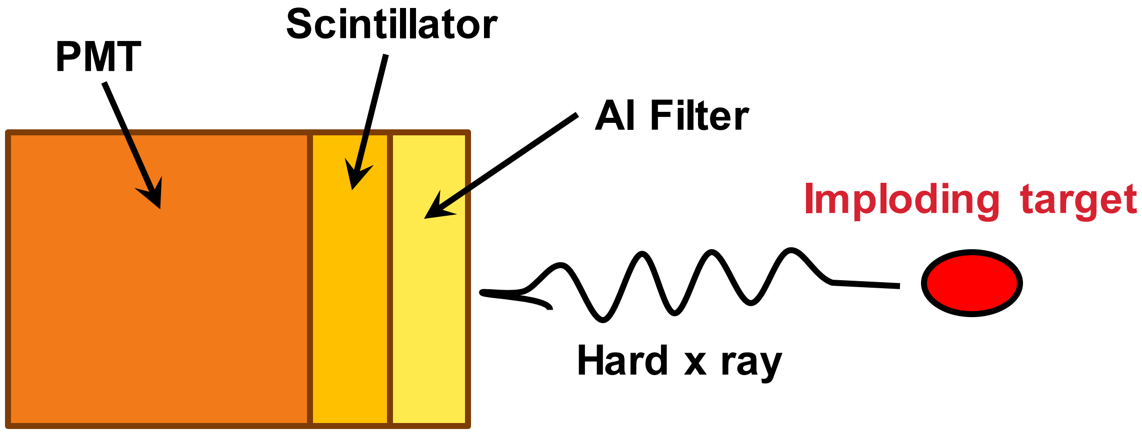
A time-resolved, four-channel hard x-ray detector is used to measure hard x rays generated when fast electrons slow down in the target*



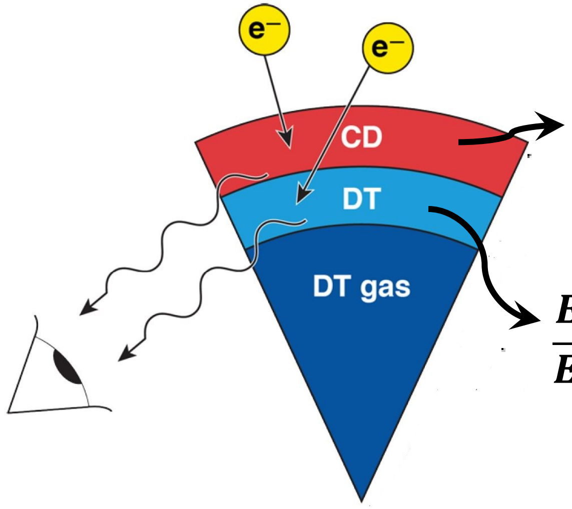
HXRD channel

Channel 1	> 20 keV
Channel 2	> 40 keV
Channel 3	> 60 keV
Channel 4	> 80 keV

- The hard x-ray signal for the 40-keV channel is used to measure the fraction of energy deposited into fast electrons
- Multiple channels with differing energies allow calculation of $T_{\text{hot-e}}$ (assuming Maxwellian distribution)

* C. Stoeckl *et al.*, Rev. Sci. Instrum. 72, 1197 (2001).
PMT: photomultiplier tube
HXRD: hard x-ray detector

Fast-electron energy deposited into the DT layer is inferred from the difference in hard x-ray signals between cryogenic and mass-equivalent warm implosions*



$$\frac{E_{\mathrm{rad}}}{E_{\mathrm{dep}}} = 5.9 * 10^{-4}$$

$$\frac{E_{\mathrm{rad}}}{E_{\mathrm{dep}}} = 1.1 * 10^{-4}$$

$$E_{\mathrm{hot,DT}} = \frac{\mathrm{HXR}_{\mathrm{all\ CD}} - \mathrm{HXR}_{\mathrm{cryo}}}{\left(\frac{E_{\mathrm{rad}}}{E_{\mathrm{dep}}}\right)_{\mathrm{CD}} - \left(\frac{E_{\mathrm{rad}}}{E_{\mathrm{dep}}}\right)_{\mathrm{DT}}}$$

Radiative power $\frac{E_{\mathrm{rad}}}{E_{\mathrm{dep}}} \propto \frac{\langle Z^2 \rangle}{\langle Z \rangle}$

- $\mathrm{HXR}_{\mathrm{all\ CD}}$ is the hard x-ray signal from an all-CD implosion with identical pulse shape, target outer radius, and mass as a cryogenic implosion i.e., same fast-electron source

Inferring fast-electron preheat for a cryogenic implosion requires a mass-equivalent warm implosion with identical pulse shapes.

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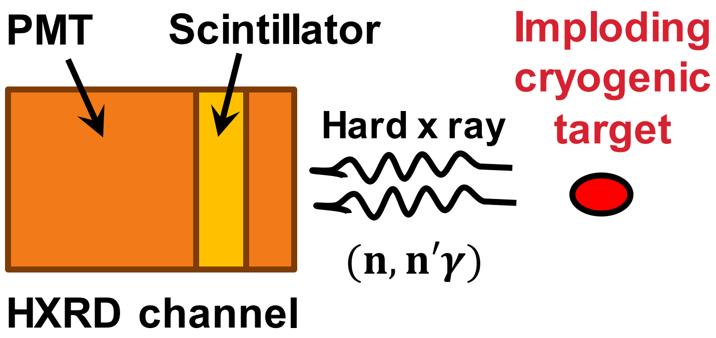
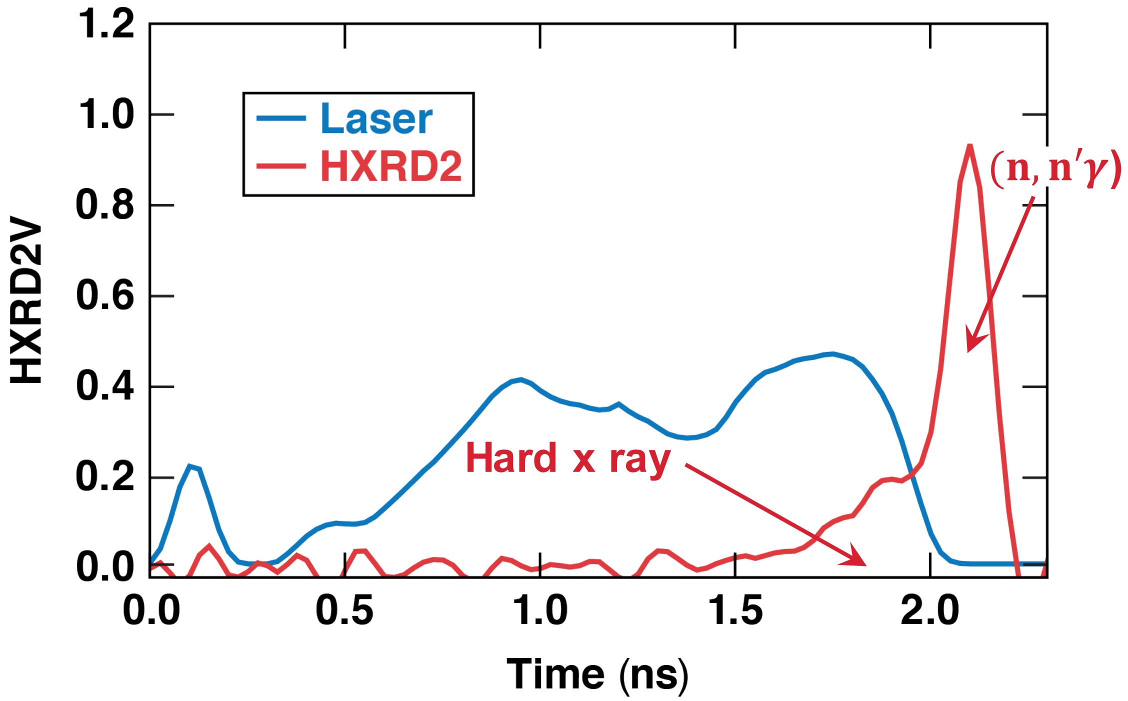
Hard x-ray signals for high-yield cryogenic implosions are corrupted by the $(n, n'\gamma)$ signal



- For a high-yield implosion, DT primary neutrons emit γ rays by inelastic scattering $(n, n'\gamma)$
- The γ-ray signal must be removed to obtain an accurate hard x-ray only signal and reliable preheat inference



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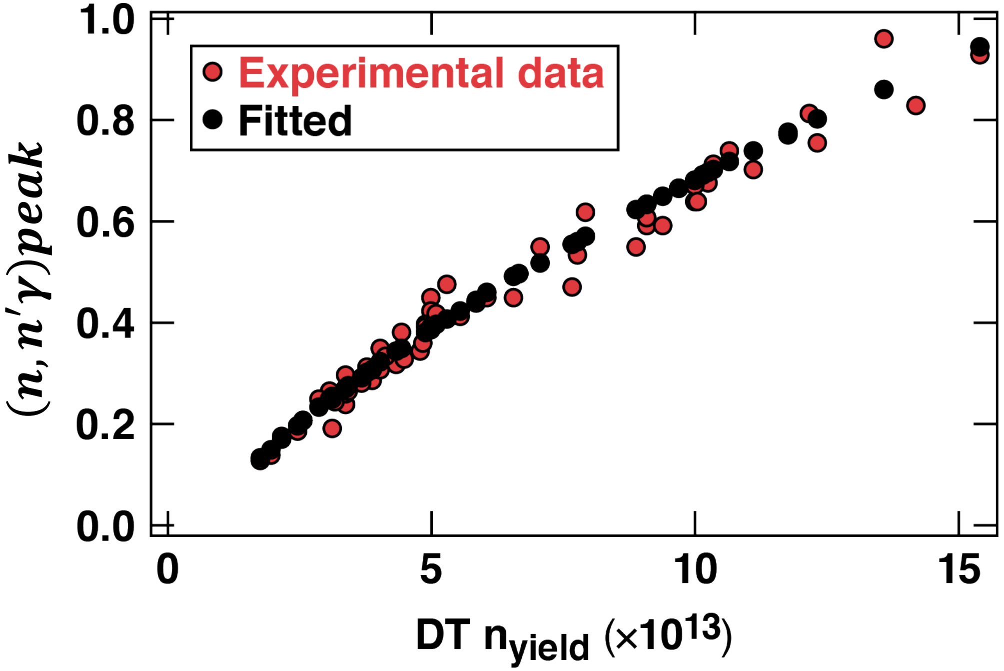
Shot 90288 $DT_n = 1.51 \times 10^{14}$

The $(n, n'\gamma)$ signal is well correlated with the neutron yield enabling development of an algorithm to remove the $(n, n'\gamma)$ signal from the HXR signal



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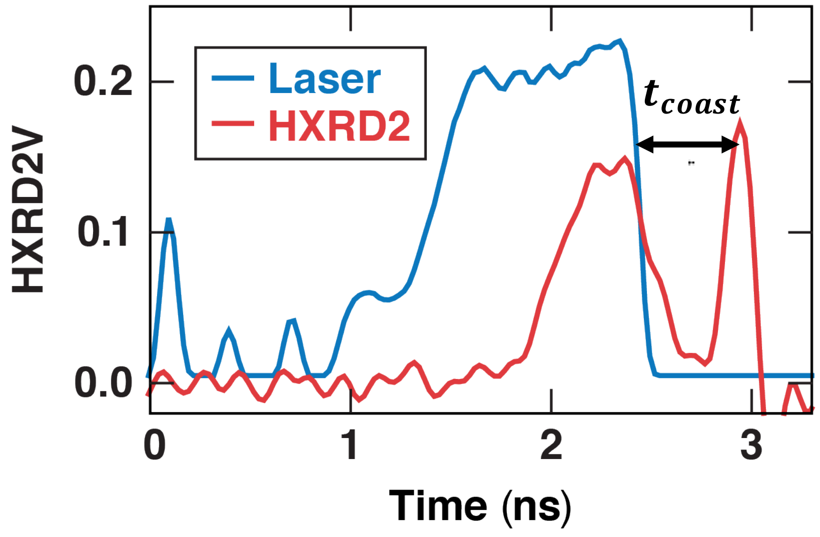
- The $(n, n'\gamma)$ signal is found to be well correlated with the primary DT neutron yield
- To reduce the effect of the hard x-ray signal on the fit, data from a higher filtered (>60-keV) channel are used

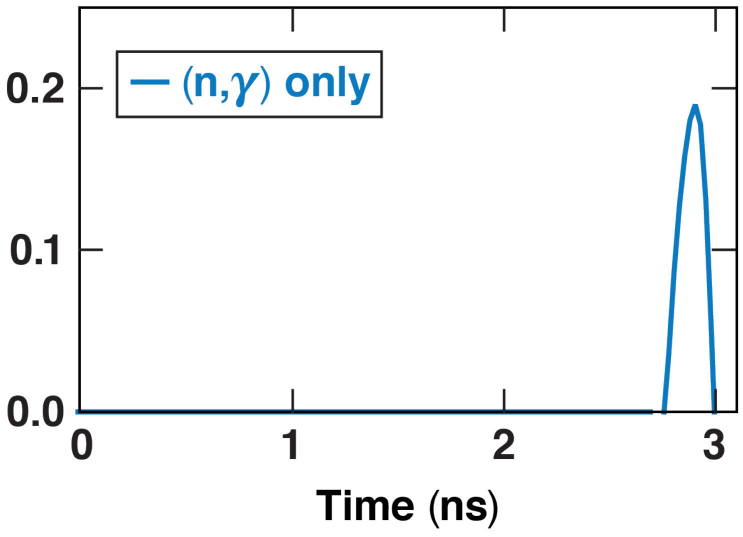
$$(n, n'\gamma)_{\mathrm{Peak}} \propto \mathrm{DT}_{\mathrm{n}}^{0.64}$$

There is a High degree of correlation between $(n, n'\gamma)$ signal and DT yield, which allows its subtraction if a reference $(n, n'\gamma)$ only signal is available.

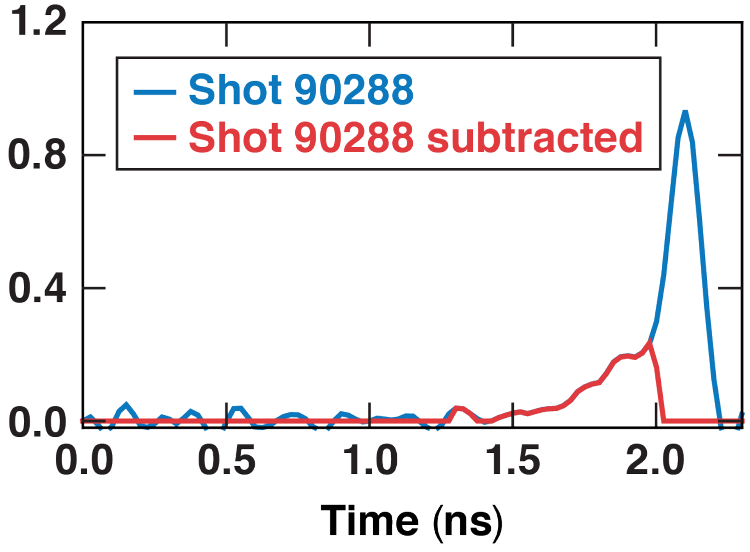
A reference $(n,n'\gamma)$-only signal is constructed from the hard x-ray signal of a long coasting time implosion

- Overlap of the $(n,n'\gamma)$ signal and hard x-ray signal is caused by proximity of laser pulse and bang time
- Shots with high coasting phase have well-separated hard x-ray and $(n,n'\gamma)$ signals





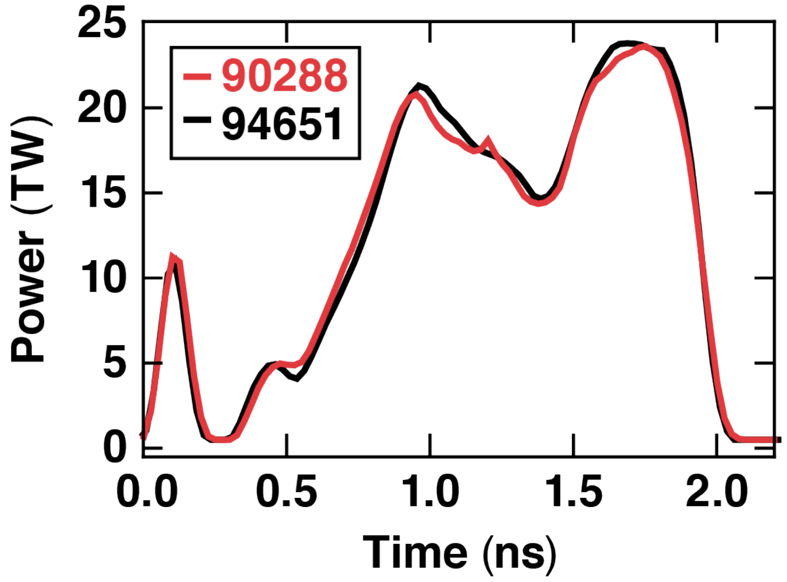
Shot 76362 $(\mathrm{DT_n} = 2.5 * 10^{13})$



Shot 90288 subtraction

The reference $(n,n'\gamma)$-only signal and the $(n,n'\gamma)$ to neutron yield scaling is used to subtract the $(n,n'\gamma)$ signal from cryogenic implosions.

Fast-electron preheat was inferred for high-performing OMEGA implosion shot 90288



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	90288	94651 (all CD)
OD (μm)	958	984
Mass (μg)	52	54

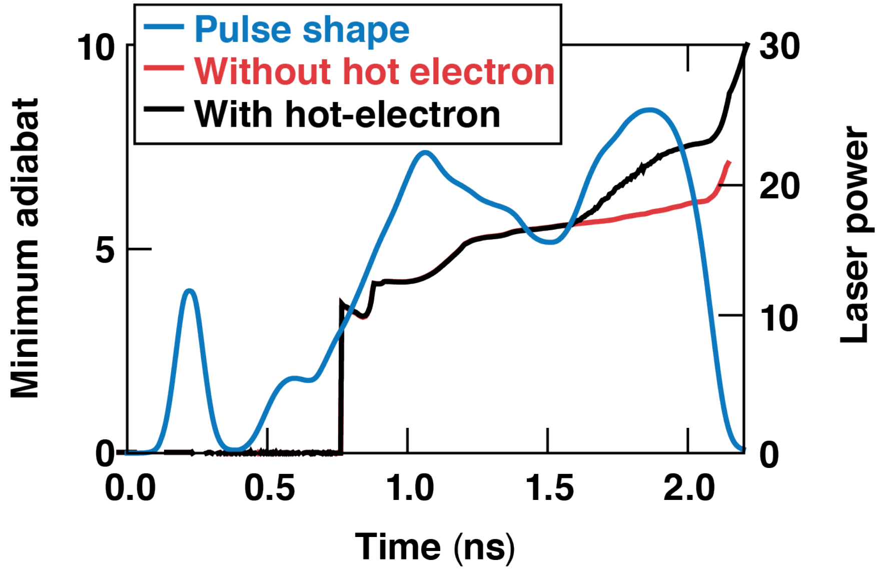
90288 preheat summary	
All-CD HXR	213±21 pC
Cryo HXR	106±11 pC
T_{hot}	55±6 keV
Total *E* into fast electrons	42.62±16.39 J
Total preheat in DT	22.46±8.51 J
Preheat unablated DT*	8.68±3.69 J

Preheat analysis of a repeat of 90288 (96806) reproduce the energy deposited in unablated DT

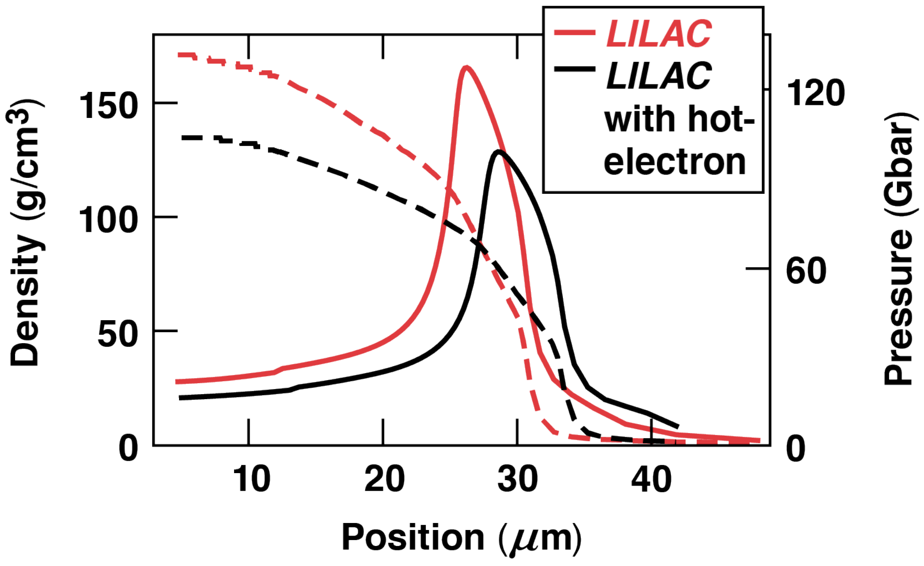
* Assuming energy deposited per unit mass in DT (ablated or unablated) is constant

LILAC simulation with experimentally measured preheat can explain lower measured areal density compared to nominal *LILAC*

Time evolution of shell adiabat



Simulated profiles at stagnation



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	LILAC + hot electron	Experiment	*LILAC*
Minimum adiabat	7.5	N/A	5.3
$\langle \rho R \rangle$ (mg/cm^2)	154	160±21	182
Peak burn-averaged pressure (Gbar)	99.1	60	125

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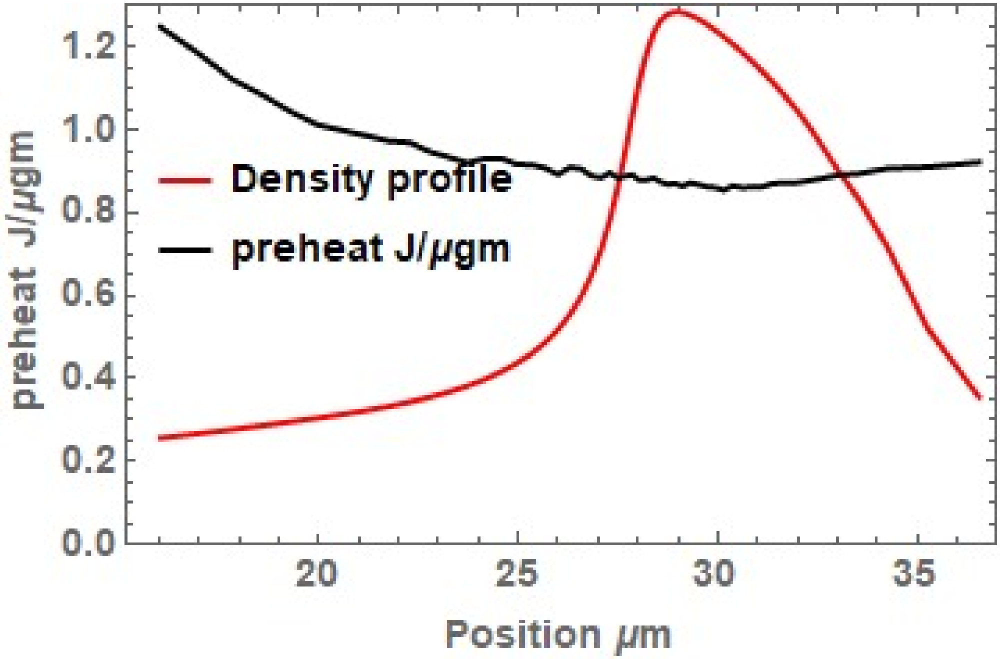
Hot-electron energy deposition profile



* First reference
** Second reference
† Third reference
‡ Fourth reference