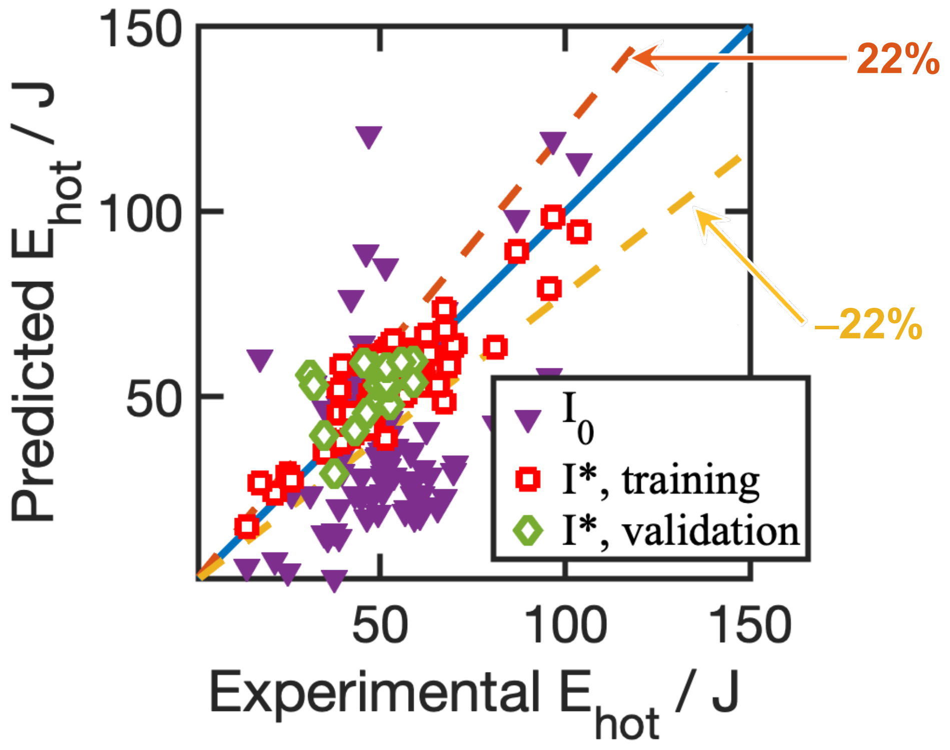
Predicting Hot-Electron Generation in Inertial Confinement Fusion with Particle-in-Cell Simulations

Predicted hot-electron energy



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Hot-electron generation in OMEGA implosions can be predicted by combining PIC simulations and experimental data

- A hot-electron scaling was obtained from PIC simulations as a function of laser-plasma conditions in the quarter-critical region
- Using this scaling and conditions from *LILAC* simulations, whole-pulse hot-electron generation can be predicted
- After taking potential inaccuracies in hydro and PIC simulations into account, our prediction agreed with the experimental hard X-ray data within experimental error bars

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We thank the UCLA-IST OSIRIS Consortium for the use of *OSIRIS*.

PIC: particle-in-cell

Collaborators

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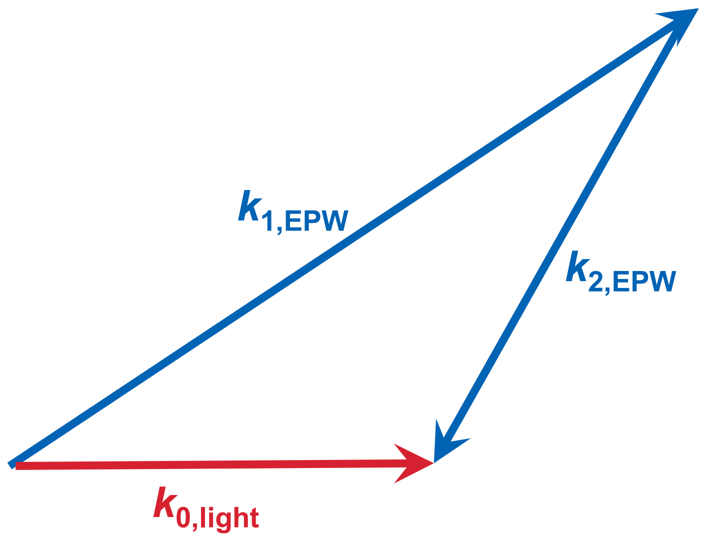
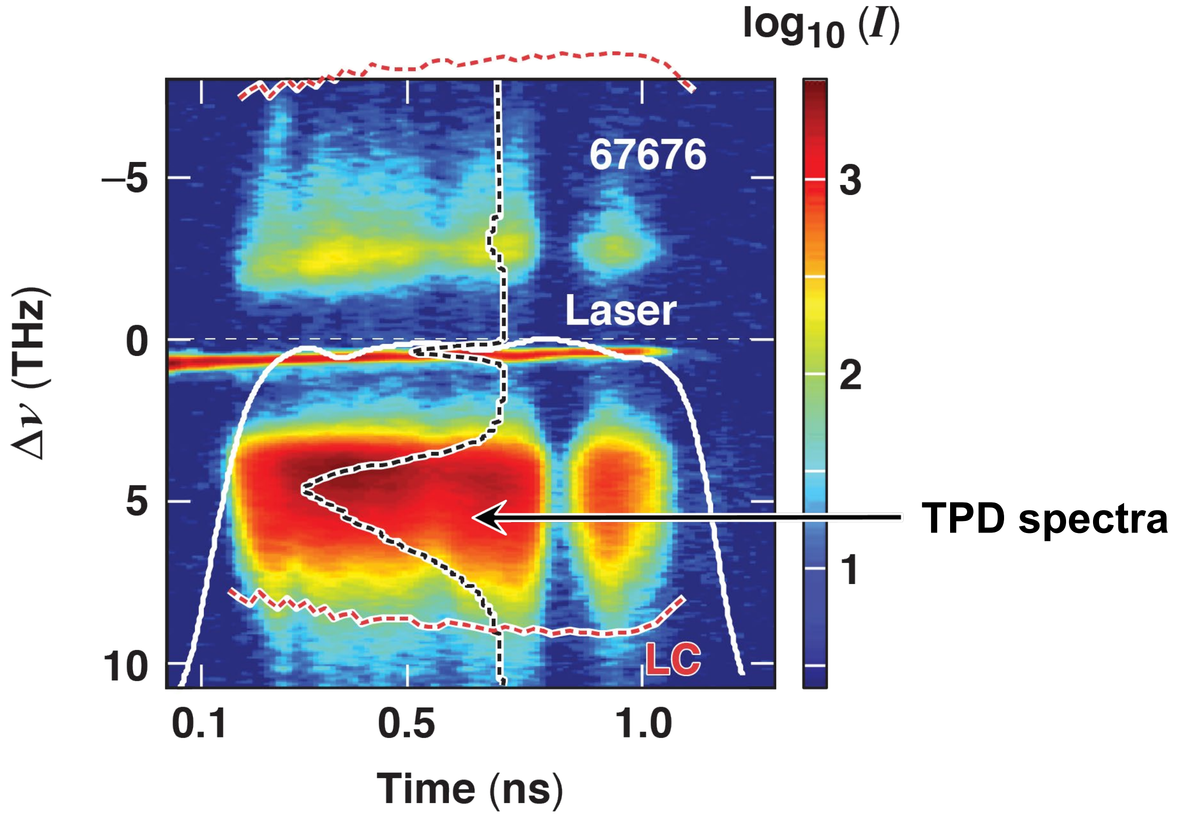
Laser-plasma instabilities in the OMEGA experiments were shown to be dominated by two-plasmon decay (TPD)*

Mode structure of TPD



$$\eta \equiv \frac{L_{\mu m} I_{14}}{233\, T_{e,\mathrm{keV}}} \quad *$$

Time-resolved $\omega/2$ spectra**

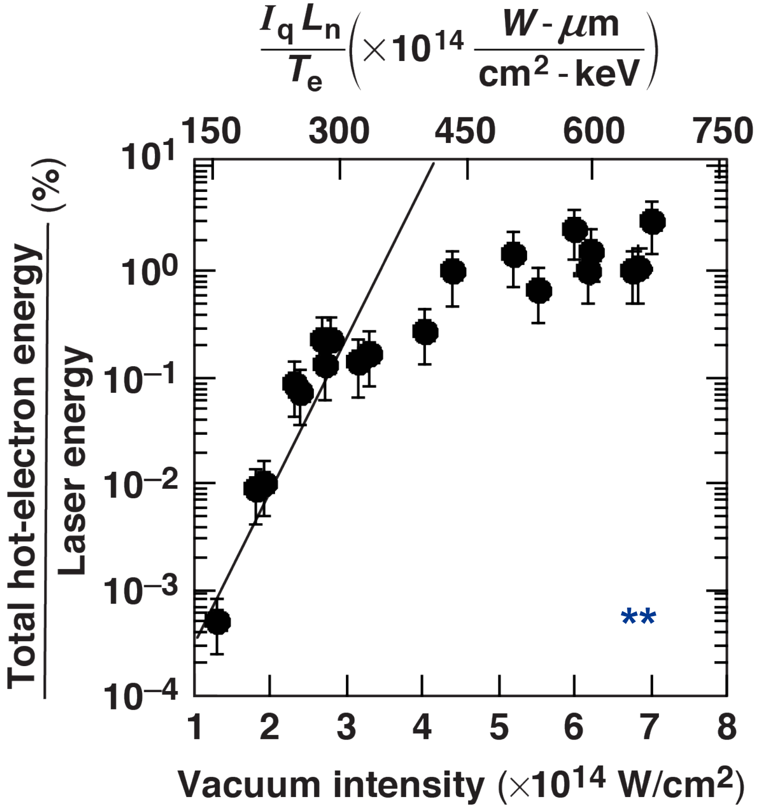


A predictive hot-electron capability is required for direct-drive inertial confinement fusion design.

* A. Simon *et al.*, Phys. Fluids 26, 3107 (1983).
** W. Seka *et al.*, Phys. Rev. Lett. 112, 145001 (2014).

Previous efforts for hot-electron scaling focused on the dependency of η *,**,†

Experimental f_{hot}



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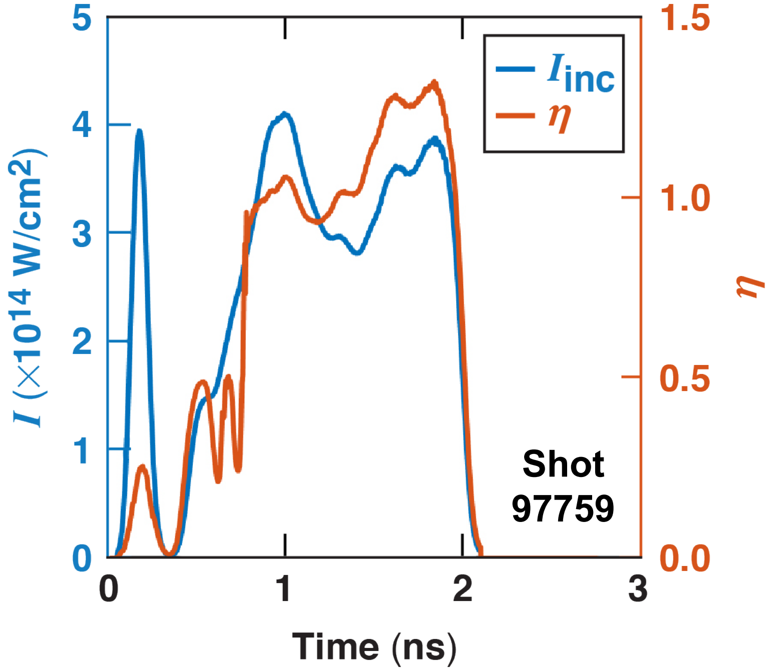
Plasma conditions from *LILAC* ‡



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f_{hot} should be a combination of Te and η

* C. Stoeckl *et al.*, Phys. Rev. Lett. 90, 235002 (2003).
** D. H. Froula *et al.*, Phys. Rev. Lett. 108, 165003 (2012).
† D. Turnbull *et al.*, Phys. Plasmas 27, 102710 (2020).
‡ J. Delettrez *et al.*, Phys. Rev. A 36, 3926 (1987).

We used 2-D *OSIRIS* simulations* to study hot-electron scaling

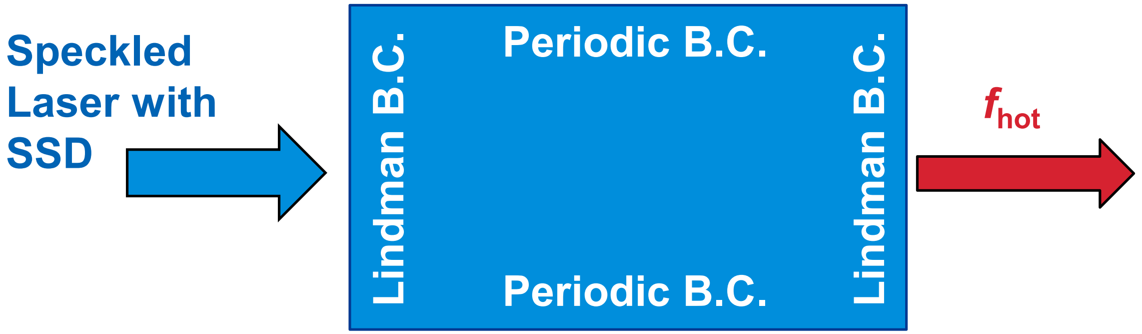
86 simulations to scan
laser-plasma conditions

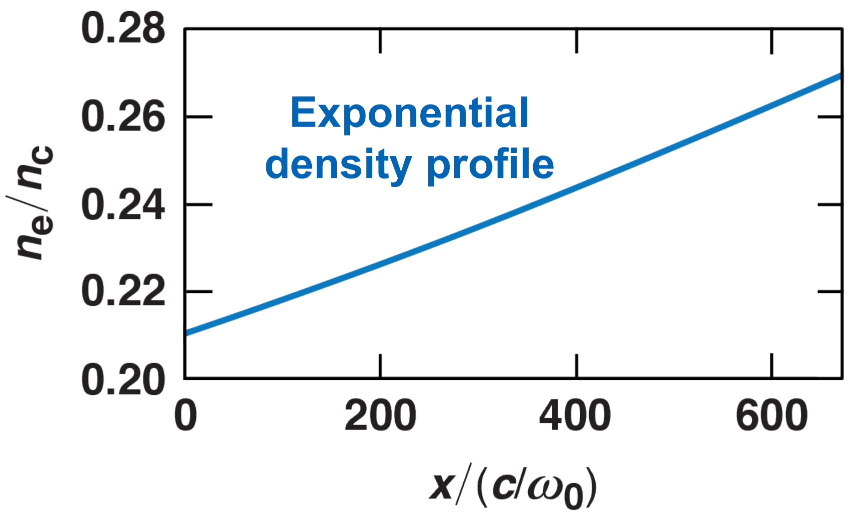
$100 < L_{\mu m} < 200$

$1.5 < T_{e,keV} < 2.5$

$0.8 < T_{i,keV} < 1.2$

$1.5 \times 10^{14} < I_{W/cm^2} < 3.0 \times 10^{15}$





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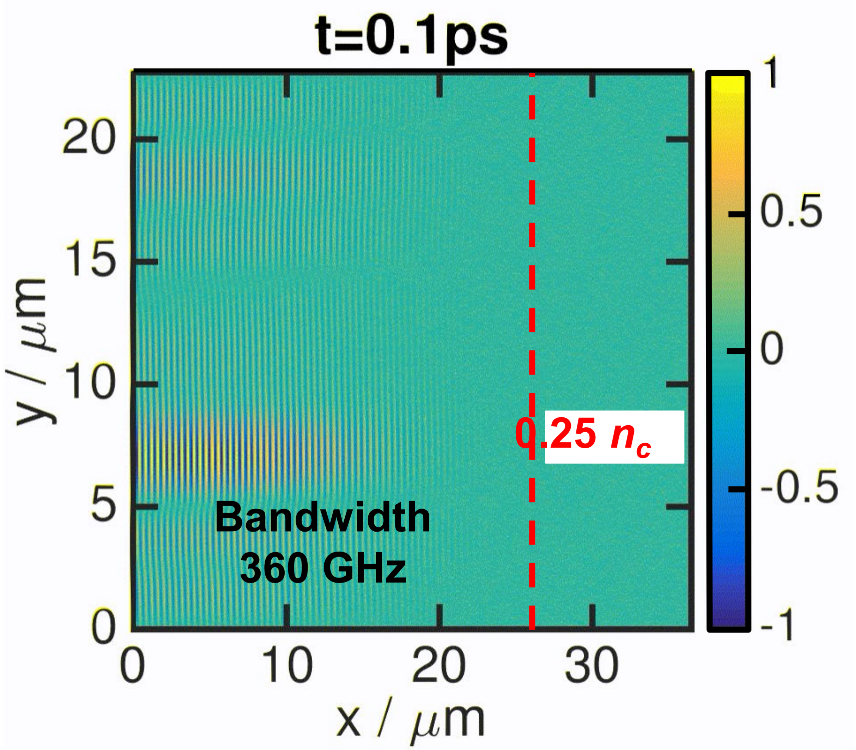
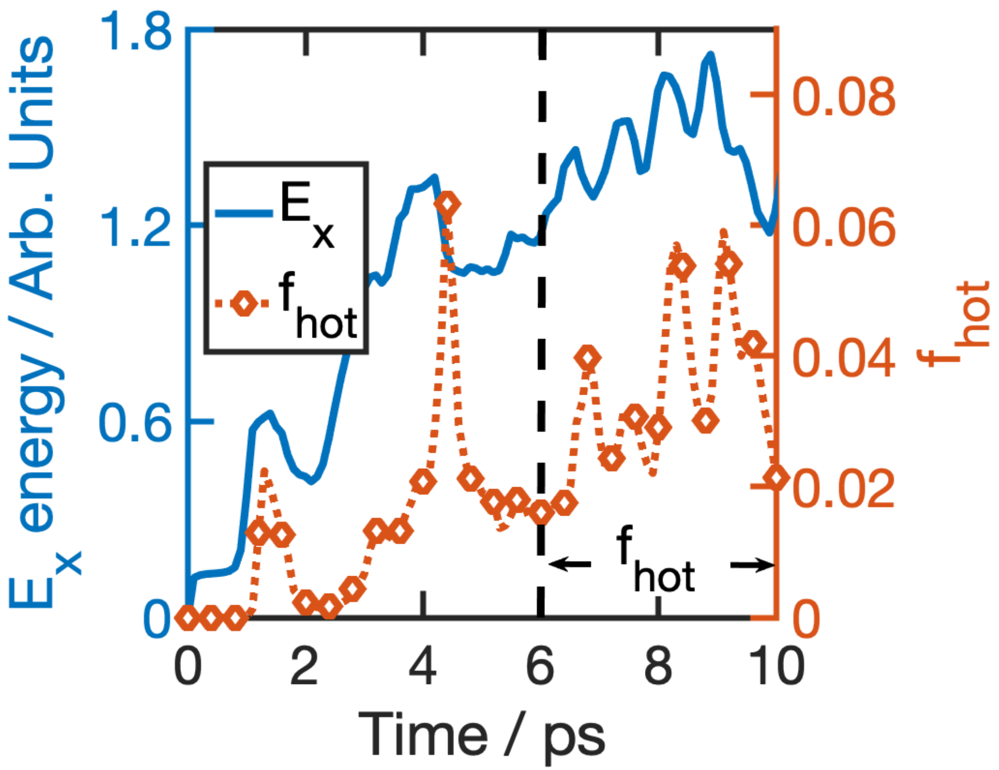
*R. A. Fonseca *et al.*, in Computational Science – ICCS 2002, edited by P. M. A. Sloot *et al.*, Lecture Notes in Computer Science, Vol. 2331 (Springer, Berlin, 2002), p. 342.
B.C.: boundary condition

Smoothing by spectral dispersion (SSD)* induces intermittent speckles on a time scale of 3 ps

Laser E_y with SSD



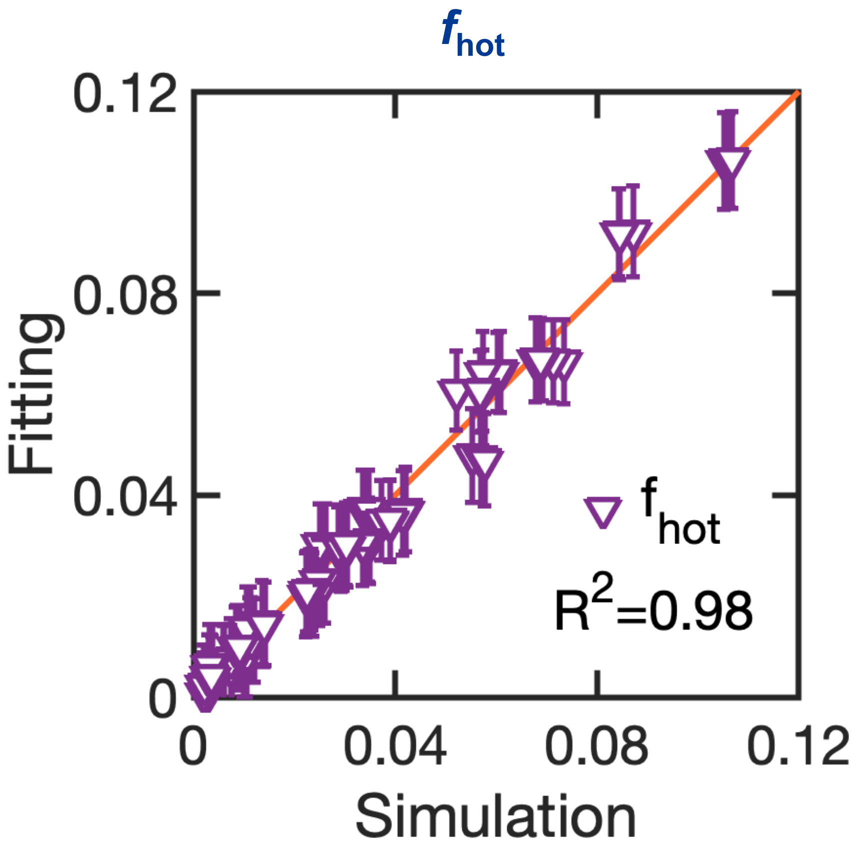
E_x energy and f_{hot}



L = 150 μm, I = 2.0 $\times$ 10^{14} W/cm^2
T_e = 2.5 keV, T_i = 1.5 keV

*S. Skupsky *et al.*, J. Appl. Phys. 66, 3456 (1989).

The obtained scaling law depends on η as well as T_e



$$f_{hot} \sim \{6.7 - 3.1(\frac{L_n}{150})^{0.012}(\frac{T_e}{2})^{0.17}(\frac{T_i}{T_e})^{-0.0054}\eta^{-0.17}$$
$$-3.3(\frac{L_n}{150})^{0.034}(\frac{T_e}{2})^{-0.30}(\frac{T_i}{T_e})^{0.0053}\eta^{0.060}\}^{2.3}.$$

Hot-electron energy and the measured charge can be predicted with T_{hot}

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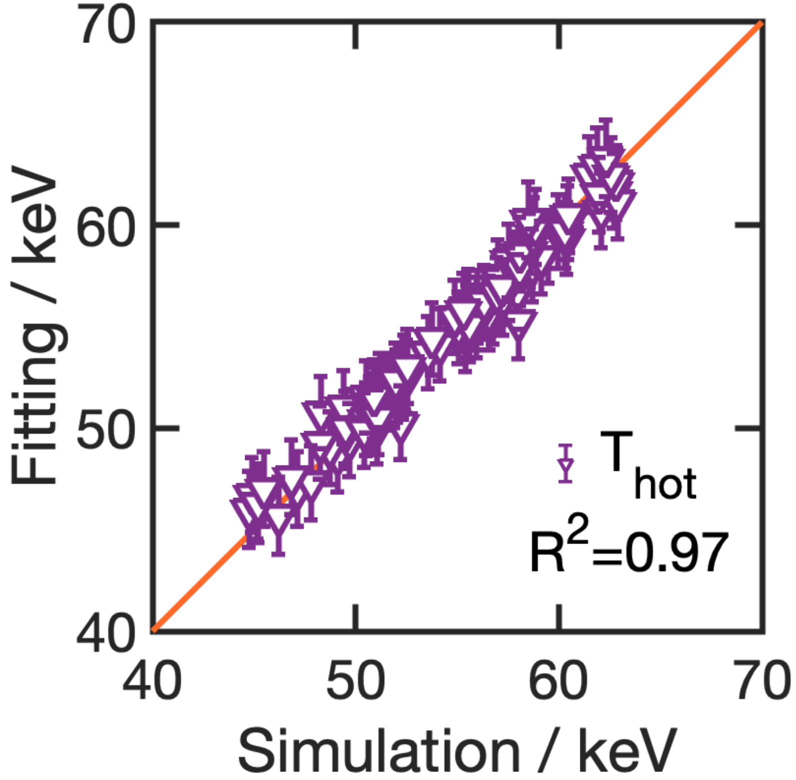
Hot-electron temperature scaling



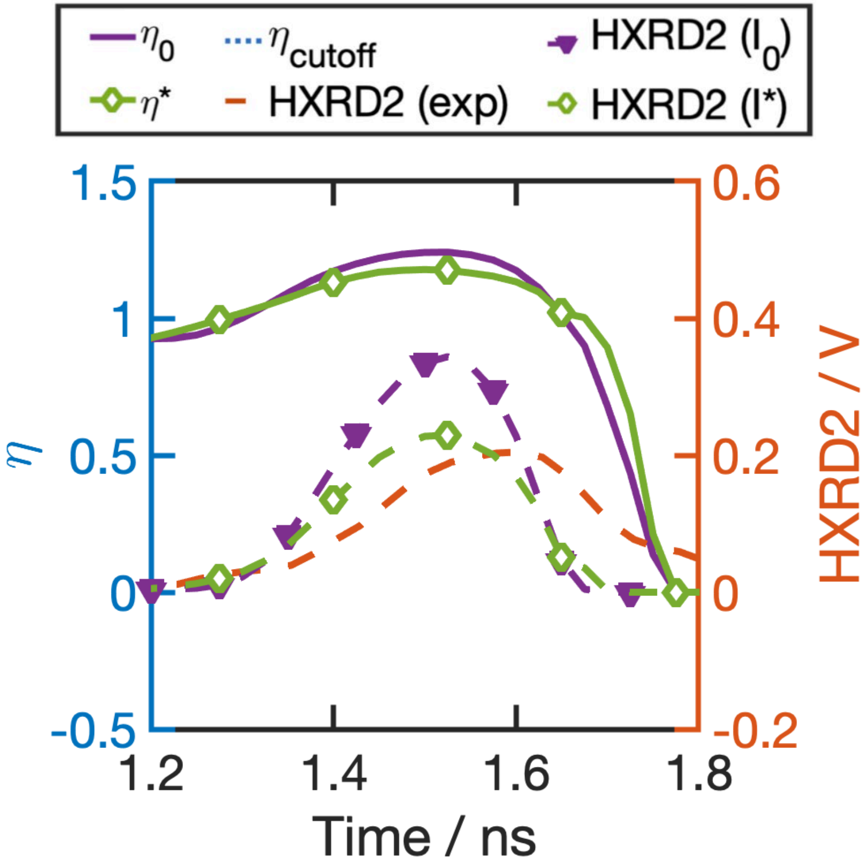
$$\mathrm{d}E_{\mathrm{hot}}/\mathrm{d}t = 4\pi R(t)^2 I_0(t) F_{\mathrm{hot}}(t),$$

$$E_{\mathrm{hot}} = Q/(-1.12 + 0.66 T_{\mathrm{hot}} + 0.00097 T_{\mathrm{hot}}^2),*$$

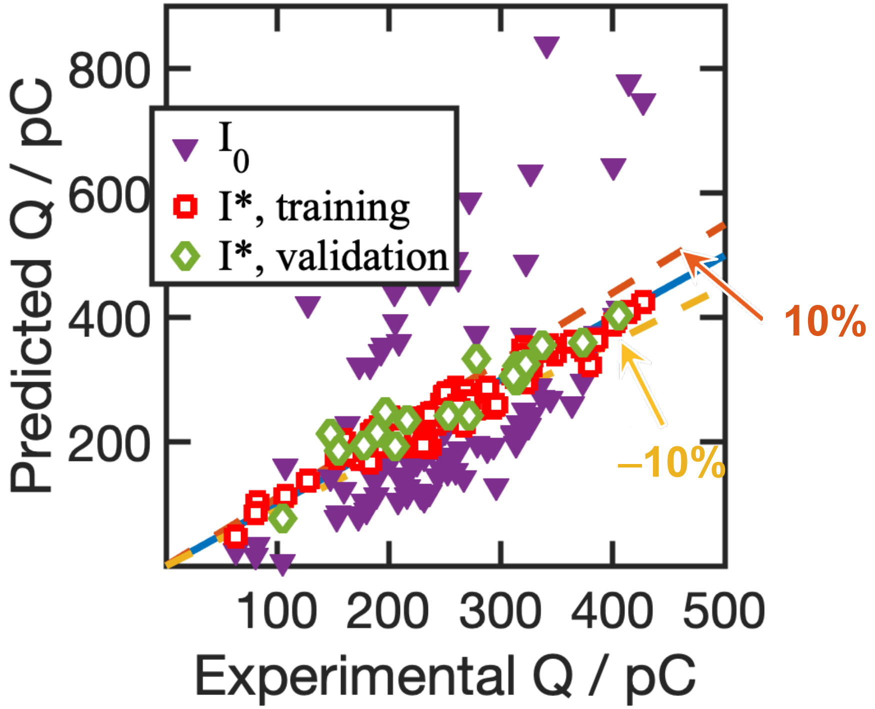
$$T_{hot} \sim \{2.5 + 55(\frac{L_n}{150})^{0.092}(\frac{T_e}{2})^{0.47}(\frac{T_i}{T_e})^{0.033}\eta^{0.073}\} keV.$$

* D. Turnbull *et al.*, Phys. Plasmas 27, 102710 (2020);
A. Christopherson, Ph.D thesis, University of Rochester, 2020.

LILAC laser intensity was modified by minimizing the relative error of the measured charge



Predicted charge from hot electrons

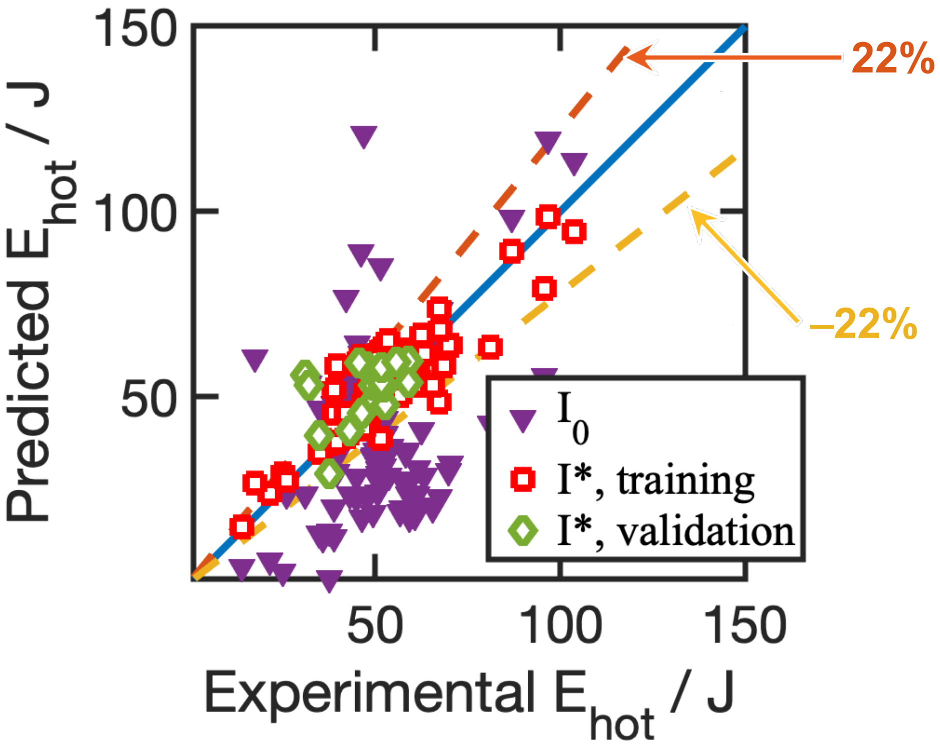


$$I* = I_0 \cdot \left(a_0 + \sum_{i=1}^{2} a_i \cdot L^{b_i} \cdot T_e^{c_i} \cdot T_i^{d_i} \cdot \eta^{e_i} \cdot r^{f_i} \right) \cdot \left[1.0 - \tanh\left(g_0 + \frac{dr}{dt} / h_0 \right) \right] / 2.0$$

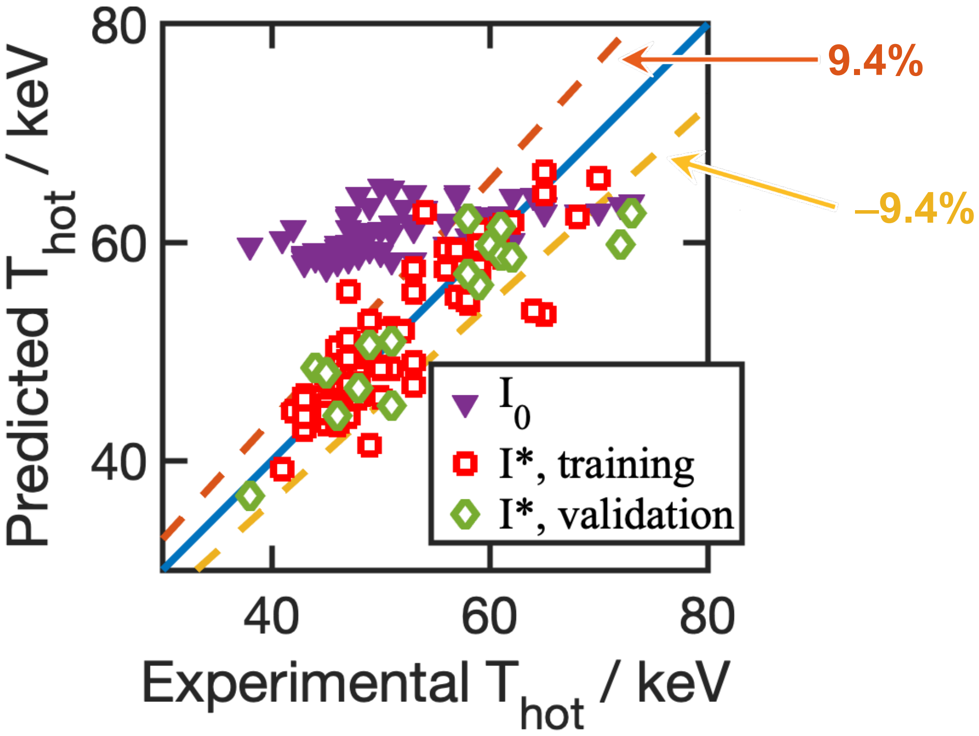
, I_0 is laser intensity from *LILAC*.

The modified predictions of Ehot and Thot matched the data

Predicted hot-electron energy



Predicted hot-electron temperature



Hot-electron generation in direct drive can be predicted by PIC simulations

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