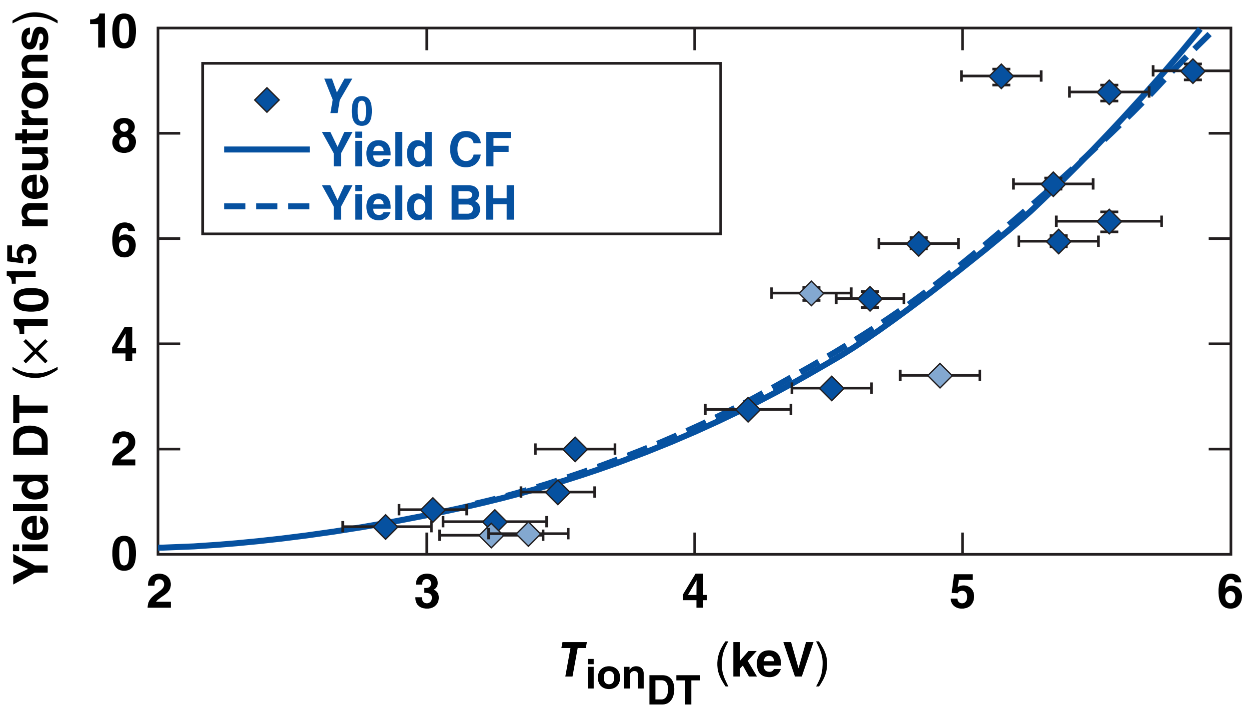
Ion-Temperature Measurements for Cryogenic, High-Foot, Inertial Confinement Fusion Implosions at the National Ignition Facility



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56th Annual Meeting of the American Physical Society Division of Plasma Physics
New Orleans, LA
27–31 October 2014

Summary

National Ignition Facility (NIF) ion-temperature scaling with implosion velocity implies α heating for some high-foot implosions

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NIF

- Ion-temperature measurements imply an isotropic neutron velocity distribution
  - reanalysis of DT data has reduced the spread from detector to detector
- Hot-spot temperature scales as a power law with respect to the implosion velocity*,**
- High-foot implosions separate into two classes
  - ion temperature < 4 keV—*PdV* heating
  - ion temperature > 4 keV—30% not caused by *PdV* work
    - isotropic fuel motion
    - alpha heating

*C. D. Zhou and R. Betti, Phys. Plasmas 14, 072703 (2007).
**C. D. Zhou and R. Betti, Phys. Plasmas 15, 102707 (2008).

Collaborators

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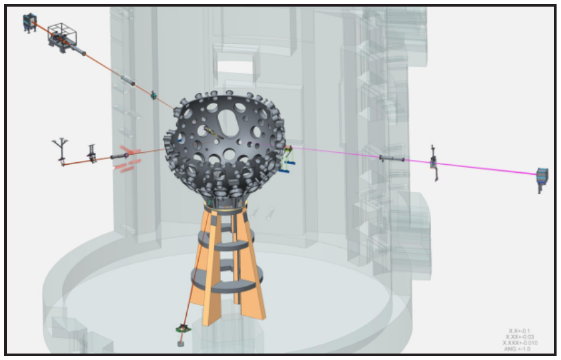
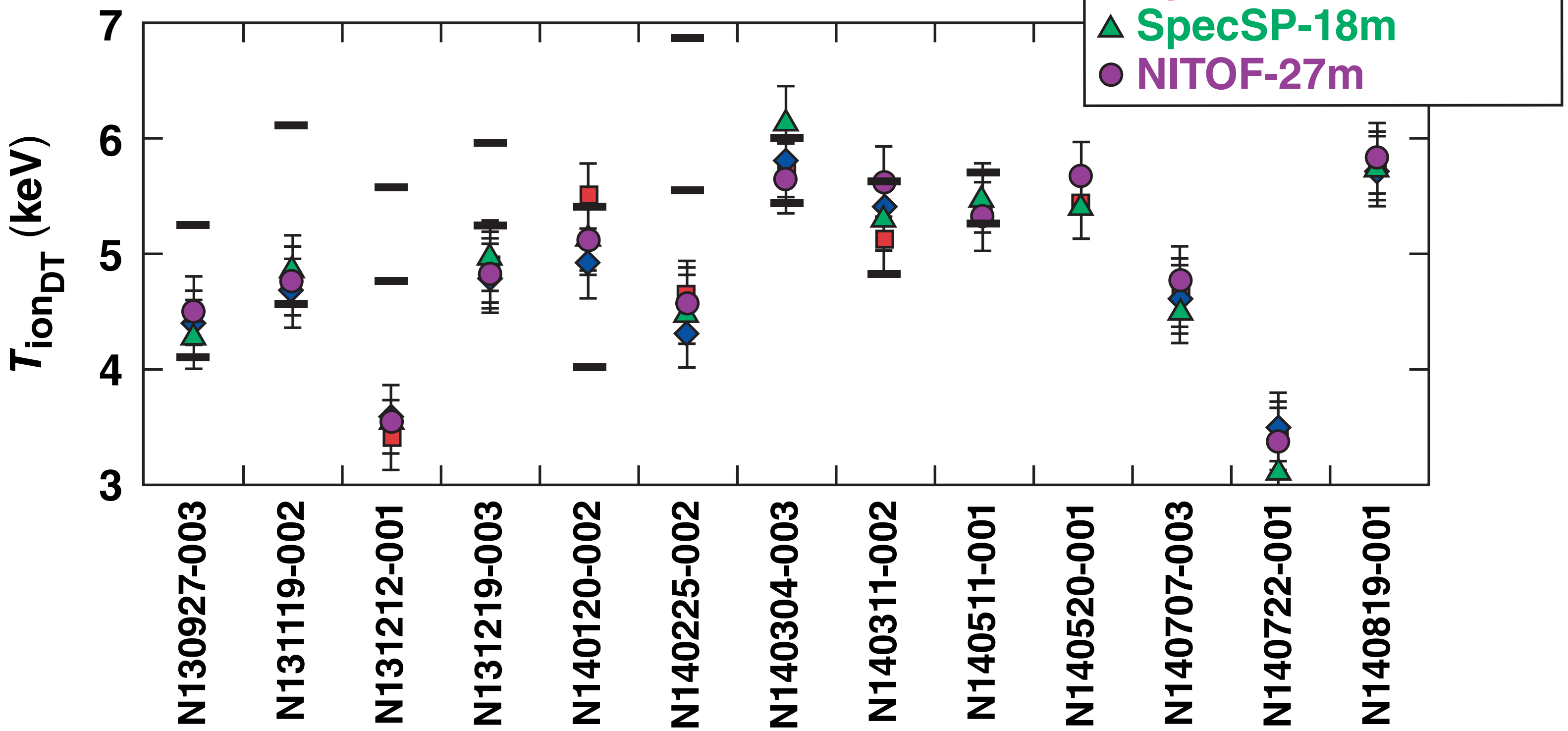
General Atomics

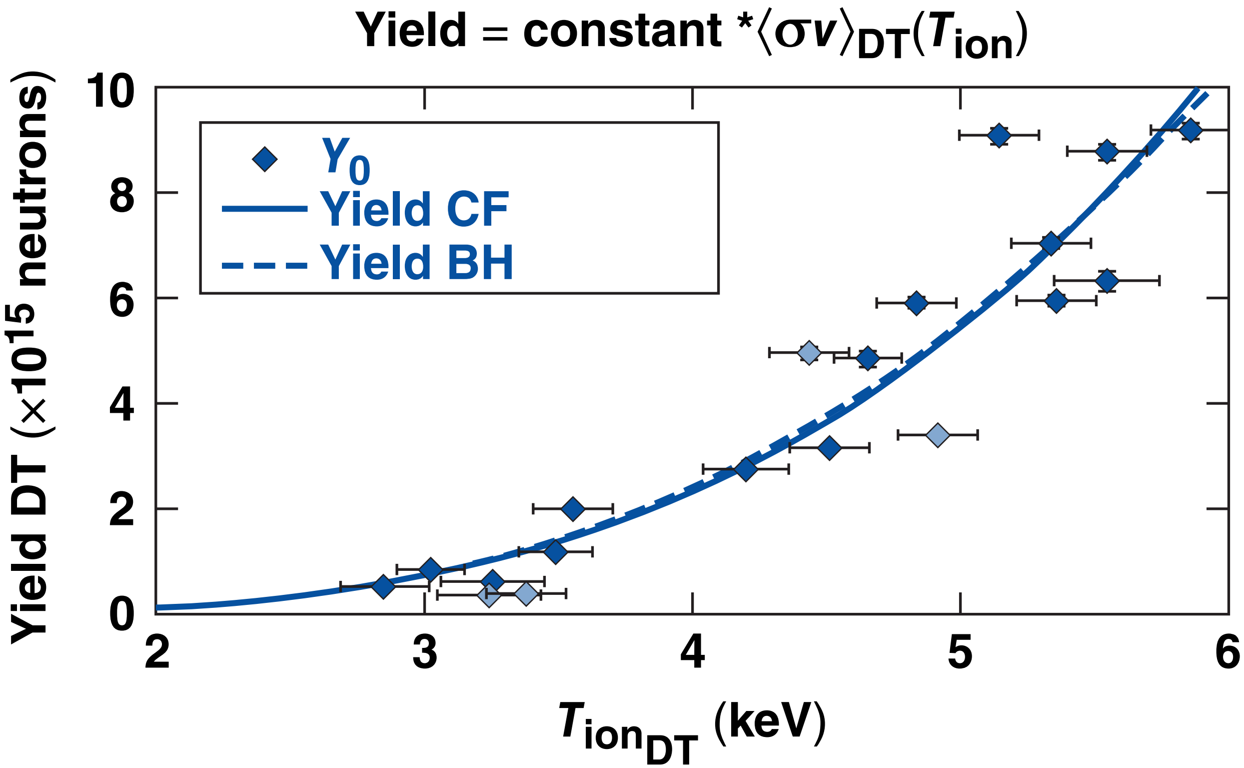
Reanalysis of DT ion temperature shows little variation between detectors





E23642

Measured DT yields for the high-foot campaign match the published DT reactivity



This would indicate that the temperature measurement has a large thermal component and that implosions have similar densities, burn volumes, and burn durations.

E23643

Published hydrodynamic scaling formulae[1,2] are used to evaluate NIF cryogenic layer T_{ion} data

- Inferred data from O. L. Landen layer (private communication)
  - implosion velocity: scaled from convergent-ablator implosion data[3,4]
  - in-flight adiabat
    - calculated from entropy
    - entropy scaled from shock-merger data[5]
- Measured data
  - current values from the NIF database for the average DT yield and T_{ion}

[1]C. D. Zhou and R. Betti, Phys. Plasmas 14, 072703 (2007).
[2]C. D. Zhou and R. Betti, Phys. Plasmas 15, 102707 (2008).
[3]D. A. Callahan *et al*., Phys. Plasmas 19, 056305 (2012).
[4]N. B. Meezan *et al*., Phys. Plasmas 20, 056311 (2013).
[5]H. F. Robey *et al*., Phys. Plasmas 20, 052707 (2013).

The neutron-weighted scaling formula is used to relate ion temperature to implosion velocity

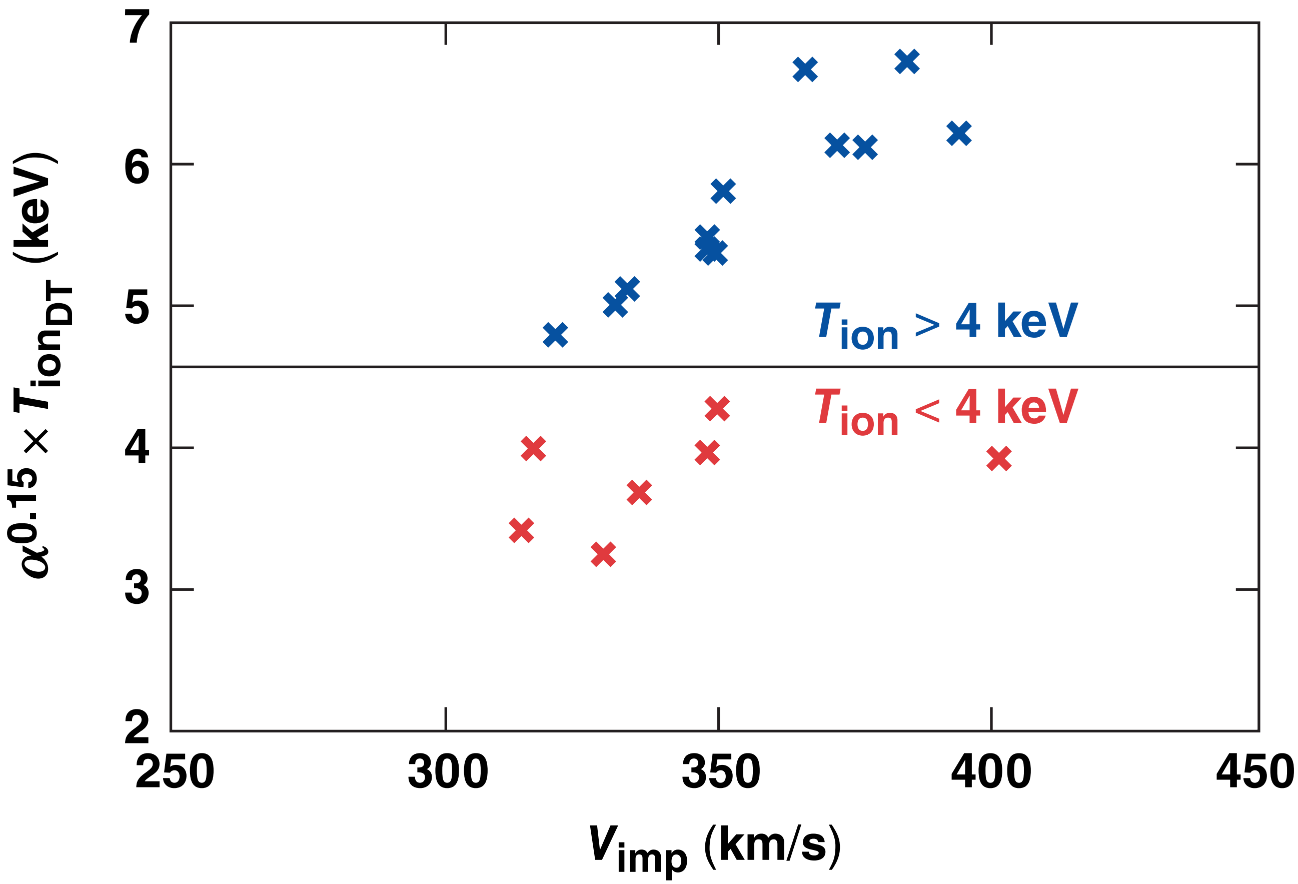
$$\left\langle T^{\text{no}\,\alpha} \right\rangle_{\text{n}} (E_{\text{L}}) = \frac{3.5}{\alpha_{\text{if}}^{0.15}} \left(\frac{V_{\text{i}}}{3 \times 10^{7}} \right)^{1.25} \left(\frac{E_{\text{L}}}{100} \right)^{0.07} \quad \text{(Ref. 1)}$$

Ignoring E_{L} and using km/s for velocity and keV for T_{h}

$$\alpha_{\text{if}}^{0.15} T_{\text{h}} = 3.5 \frac{V_{\text{imp}}^{1.25}}{300}$$

[1] C. D. Zhou and R. Betti, Phys. Plasmas 15, 102707 (2008).

High-foot NIF data separate into two regions: T_{ion} < 4 keV and T_{ion} > 4 keV



E23646

Small amounts of alpha heating will modify the multiplier and not the exponent

$$T_h \sim \frac{P_h}{\rho_h} \sim \frac{P_h R_h}{\rho R_h} \quad \text{(Ref. 1)}$$

$$T_h^{\text{Meas}} = T_h^{\text{Thermal}} + T_h^V$$

$$T_h^{\text{Meas}} \sim \frac{P_h R_h}{\rho R_h} + \theta_\alpha \varepsilon_\alpha Y_{DT} + T_h^V$$

θ_α = fraction of alpha energy coupled to hot spot
ε_α = alpha energy (3.5 MeV)

$$T_h^{\text{Meas}} = \frac{1}{1-f_h} \frac{P_h R_h}{\rho R_h}$$

f_h = fraction of T_h not caused by *PdV* work

[1]C. D. Zhou and R. Betti, Phys. Plasmas 14, 072703 (2007).

E23647

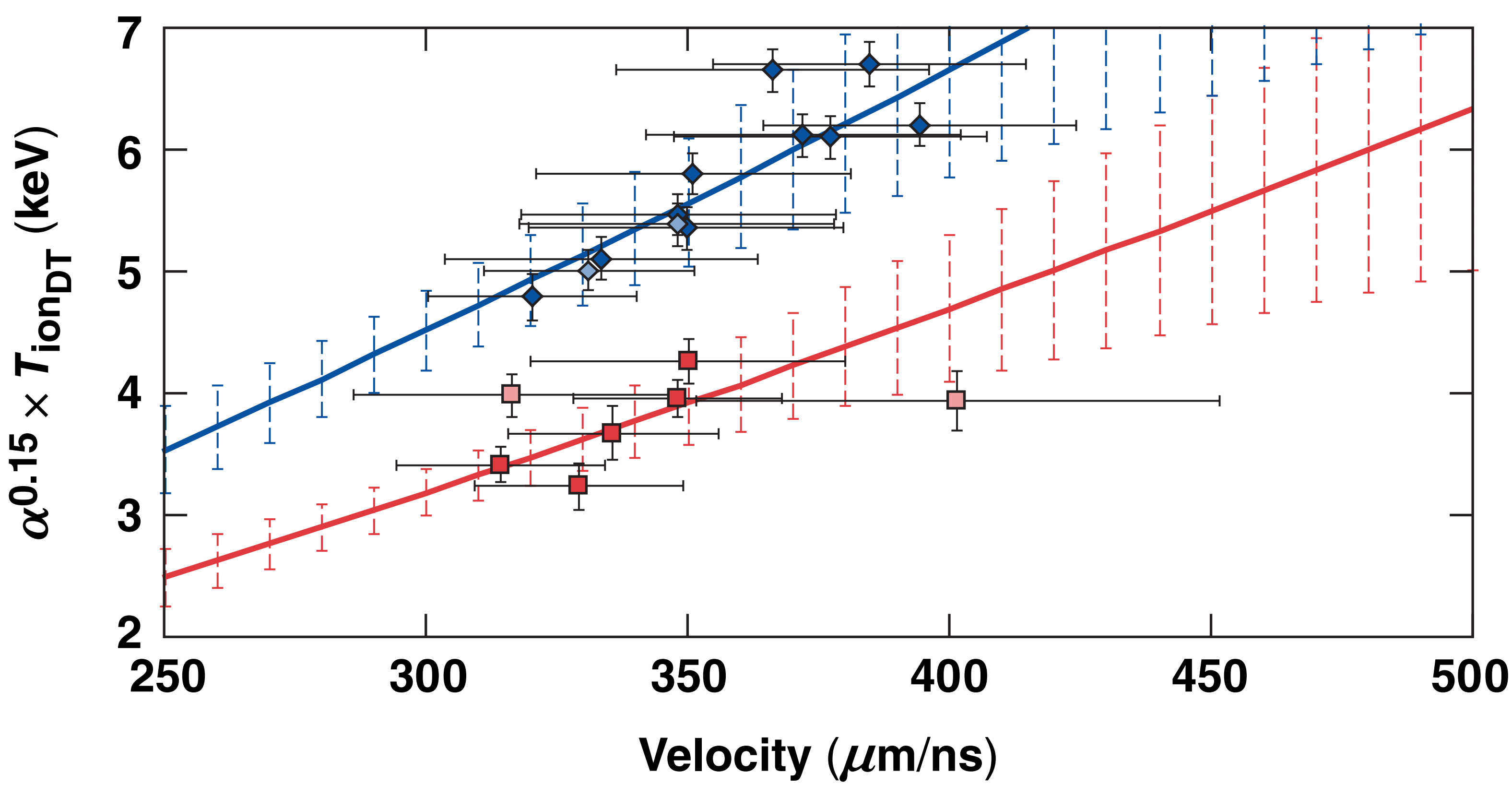
Hot-spot temperature scales as a power law for no-alpha heating and small-alpha heating

$$\alpha_{\mathrm{if}}^{0.15} T_{\mathrm{h}} = 3.5 \left(\frac{V_{\mathrm{imp}}}{300} \right)^{1.25}$$

$$\alpha_{\mathrm{if}}^{0.15} T_{\mathrm{h}} = \frac{3.5}{1 - f_{\mathrm{h}}} \left(\frac{V_{\mathrm{imp}}}{300} \right)^{1.25}$$

E23648

Data are fit with the same exponent for V_{imp} but with different multipliers



E23649

Fit values for the exponent and multiplier compare well with neutron-weighted scaling values

$$\alpha^{0.15}\, T_{\text{ion}} = A_{\text{fit}}\, (V_{\text{imp}}/V_{\text{norm}})^{a_{\text{fit}}}$$

Minimum χ^2 fit

V_{norm}	300 (km/s)
a_{fit}	1.4±0.4
$A(<4\ \text{keV})_{\text{fit}}$	3.2±0.2
$A(>4\ \text{keV})_{\text{fit}}$	4.5±0.3
a_{Zhou}	1.25
A_{Zhou}	3.5

$$f_{\text{h}} = 1 - \frac{3.2 \pm 0.2}{4.5 \pm 0.3} = 0.29 \pm 0.03$$

E23650

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