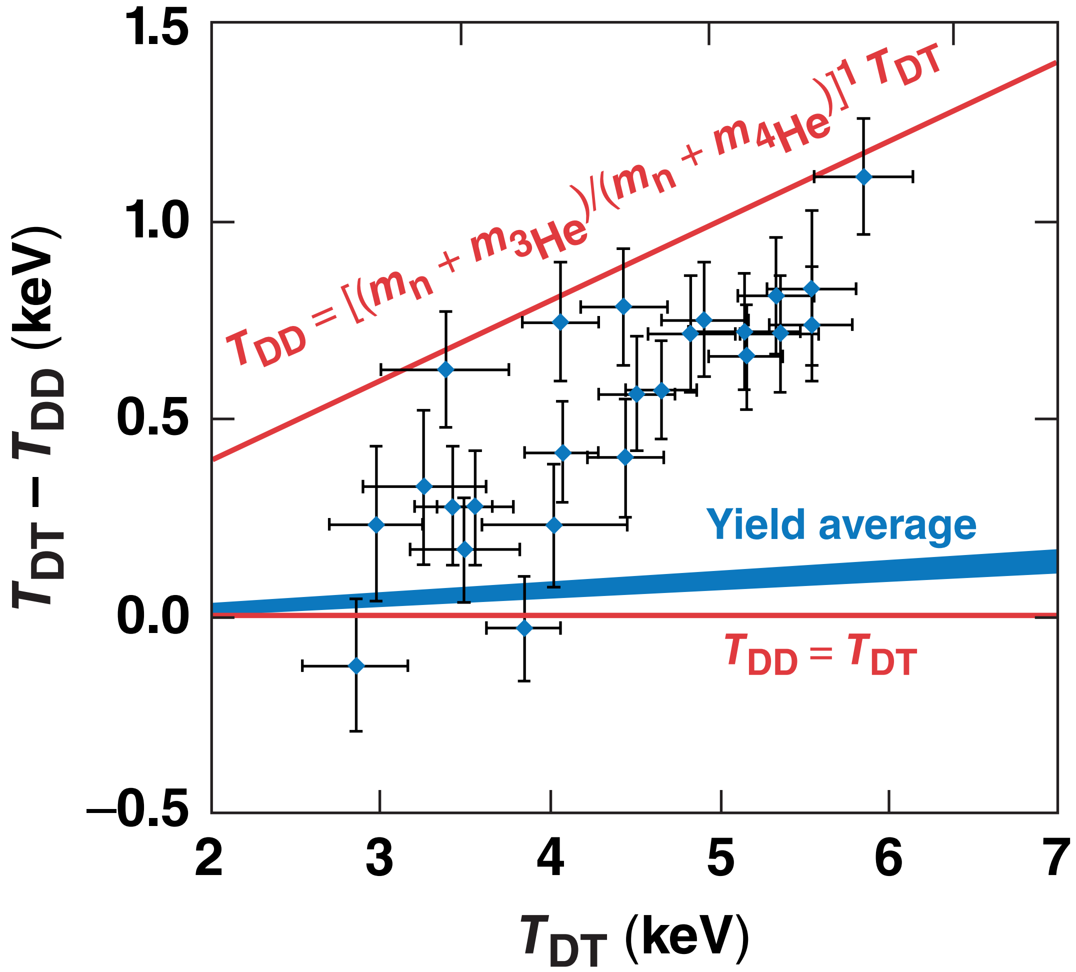
Neutron-Yield-Averaged Ion Temperature from DD and DT Fusion in National Ignition Facility High-Foot Implosions



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Summary

Ion temperature (T_i), as inferred from DD and DT data, implies that residual kinetic energy increases with temperature

- Differences in the value for T_i from the DD neutron peak and T_i from the DT neutron peak increase as temperature increases
- DD and DT reactivities were integrated in space and time over assumed profiles to better reflect implosion dynamics
- Reactivity integrals do not explain the measured differences

Collaborators

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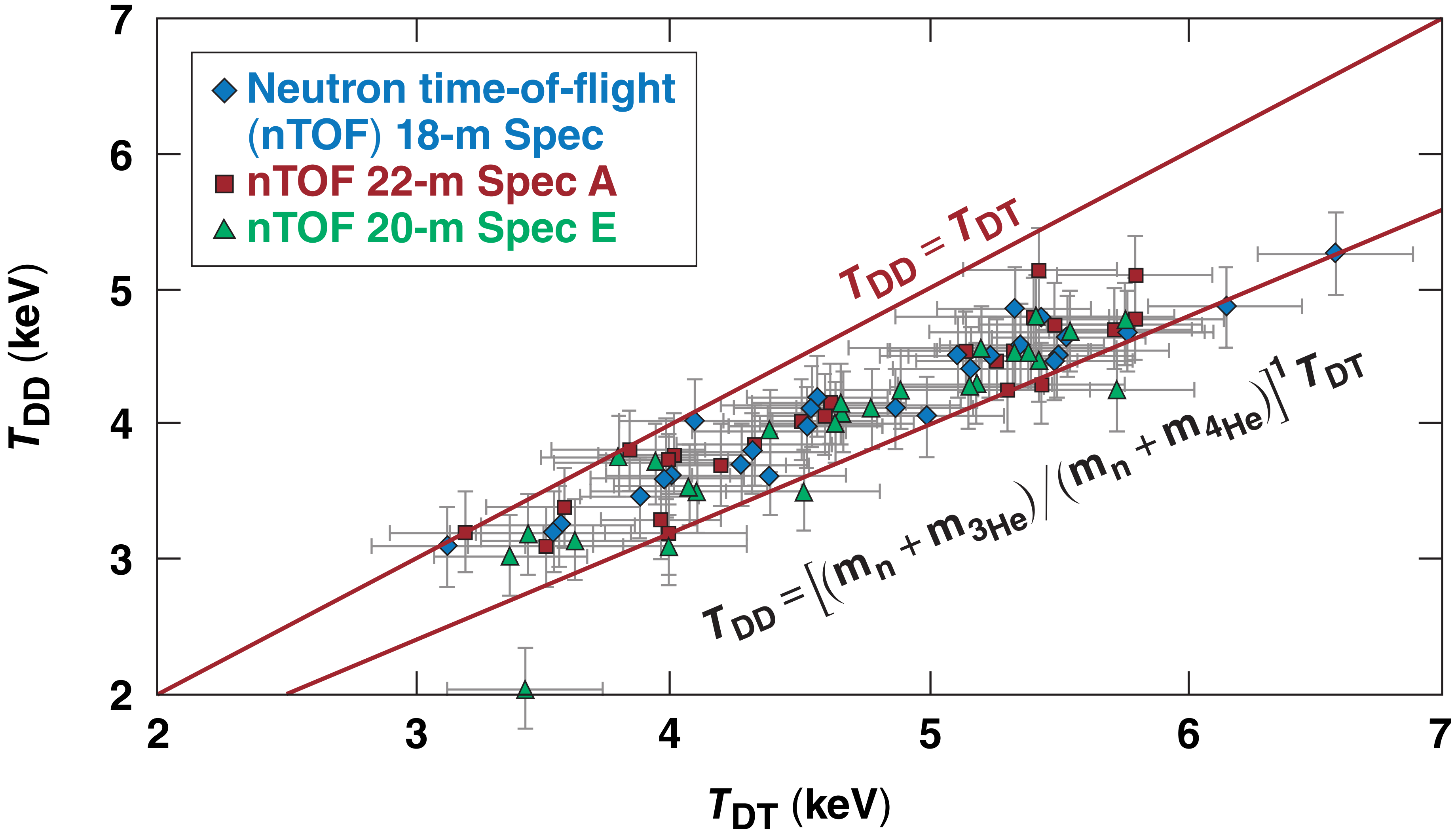
T_i from DD data and T_i from DT data differ more at higher temperatures



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*T. J. Murphy, Phys. Plasmas 21, 072701 (2014).

T_i analysis for static, homogeneous hot spots must be generalized for more-realistic conditions

- Calculate yield-weighted temperatures by integrating over spatial and temporal profiles
- Use Bosch and Hale DD and DT fusion reactivities
- Hot-spot scaling*
- Calculation conditions
  - isobaric hot spot
  - ideal gas equation of state (EOS) (relates density and temperature)
  - temperature spatial profile given by models of Betti and Patel
  - temperature temporal profile is a Gaussian
  - radius temporal profile is a hyperbola
    - hyperbola determined by implosion velocity and stagnation radius
- Measured data from the National Ignition Facility (NIF) database

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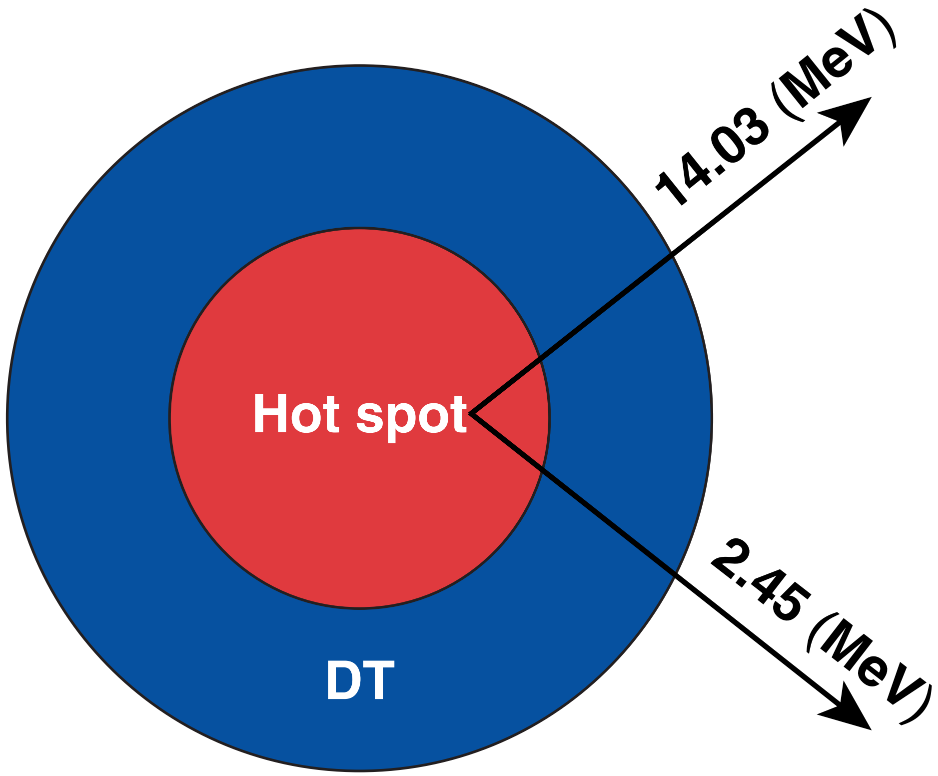
*C. D. Zhou and R. Betti, Phys. Plasmas 14, 072703 (2007).

Yield-averaged temperatures for the DT and DD fusion reactions are calculated from the reactivity integrals



$$\langle kT_{\mathrm{DT}}\rangle = \frac{\int_0^\infty \tau_{14}(t)\int_0^{R_{\mathrm{hs}}(t)} kT(r,t)\,\frac{\mathrm{d}}{\mathrm{d}t}\,\frac{\mathrm{d}Y_{\mathrm{DT}}(r,t)}{\mathrm{d}r}\,\mathrm{d}r\mathrm{d}t}{\int_0^\infty \tau_{14}(t)\int_0^{R_{\mathrm{hs}}(t)} \frac{\mathrm{d}}{\mathrm{d}t}\,\frac{\mathrm{d}Y_{\mathrm{DT}}(r,t)}{\mathrm{d}r}\,\mathrm{d}r\mathrm{d}t}$$

$$\langle kT_{\mathrm{DD}}\rangle = \frac{\int_0^\infty \tau_{2.5}(t)\int_0^{R_{\mathrm{hs}}(t)} kT(r,t)\,\frac{\mathrm{d}}{\mathrm{d}t}\,\frac{\mathrm{d}Y_{\mathrm{DD}}(r,t)}{\mathrm{d}r}\,\mathrm{d}r\mathrm{d}t}{\int_0^\infty \tau_{2.5}(t)\int_0^{R_{\mathrm{hs}}(t)} \frac{\mathrm{d}}{\mathrm{d}t}\,\frac{\mathrm{d}Y_{\mathrm{DD}}(r,t)}{\mathrm{d}r}\,\mathrm{d}r\mathrm{d}t}$$

The yield from the fusion of A and B nuclei is determined by the reactivity and hot-spot conditions

$$\frac{d}{dt}\left(\frac{d}{dV}Y_{AB}\right)=\frac{1}{1+\delta(A,B)}\cdot n_A(V,t)\,n_B(V,t)\cdot\sigma v_{AB}\left[kT_{AB}(V,t)\right]$$

- With spherical symmetry

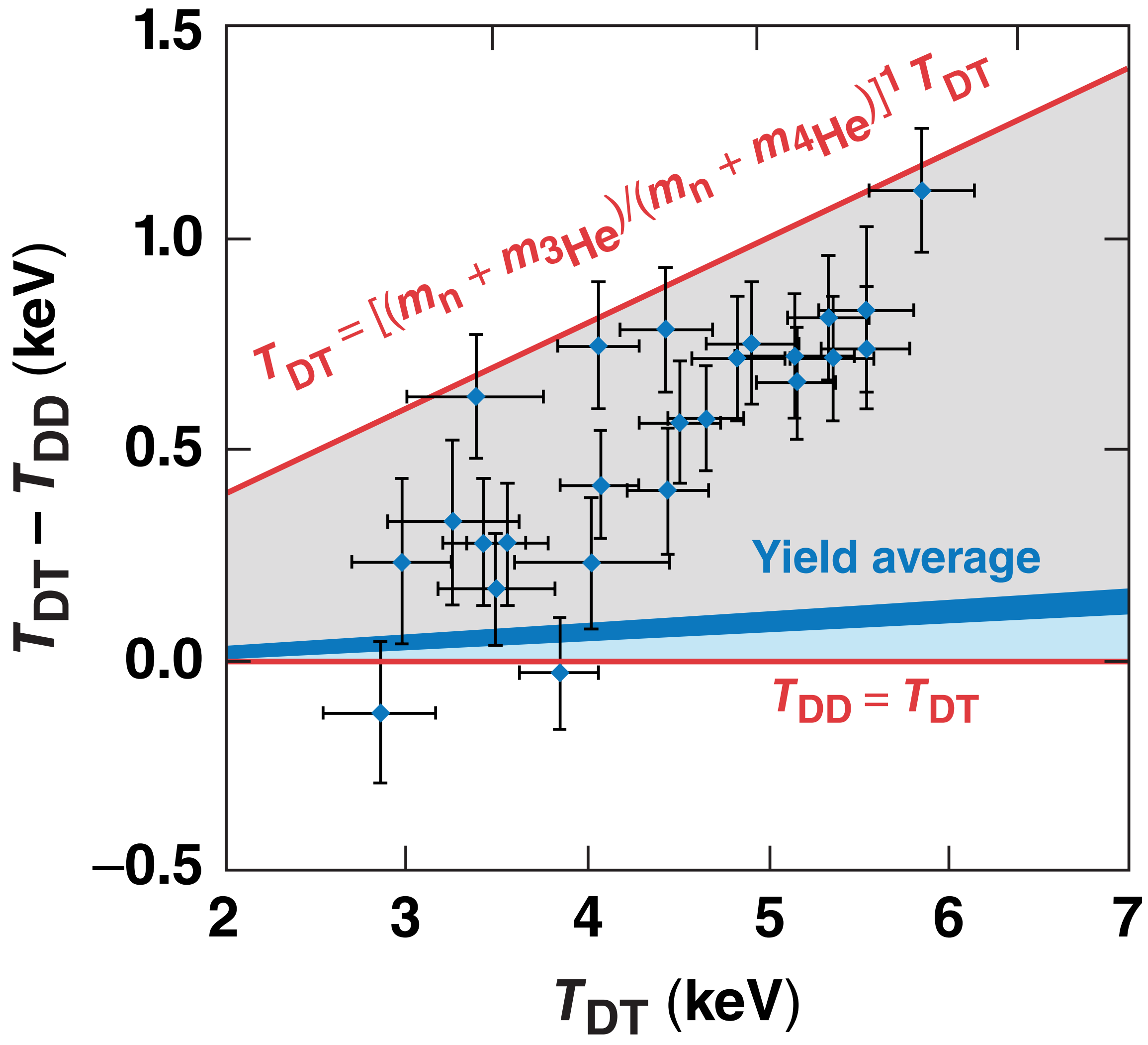
$$\frac{d}{dt}\left(\frac{d}{dr}Y_{AB}\right)=\frac{\left[4\cdot\pi\cdot r(t)^2\right]}{1+\delta(A,B)}\cdot n_A(r,t)\,n_B(r,t)\cdot\sigma v_{AB}\left[kT_{AB}(r,t)\right]$$

- With an isobaric hot spot and ideal gas EOS, the yield becomes

Initial and final boundary conditions were taken from the experimental data

- Implosion velocity from 2-D ConA experiments = 320 km/s min; 390 km/s max
  - stagnation radius (P_0) = 25.7 μm min; 45.1 μm max
  - maximum ρR (21* DSR) = 0.44 g/cm^2 min; 1.1 g/cm^2 max
  - burnwidth = 140 ps min; 220 ps max
- High areal densities must account for the transmission differences between the 14.03- and 2.45-MeV neutrons

Detector-averaged T_i can be used to study the differences between DD data and DT data



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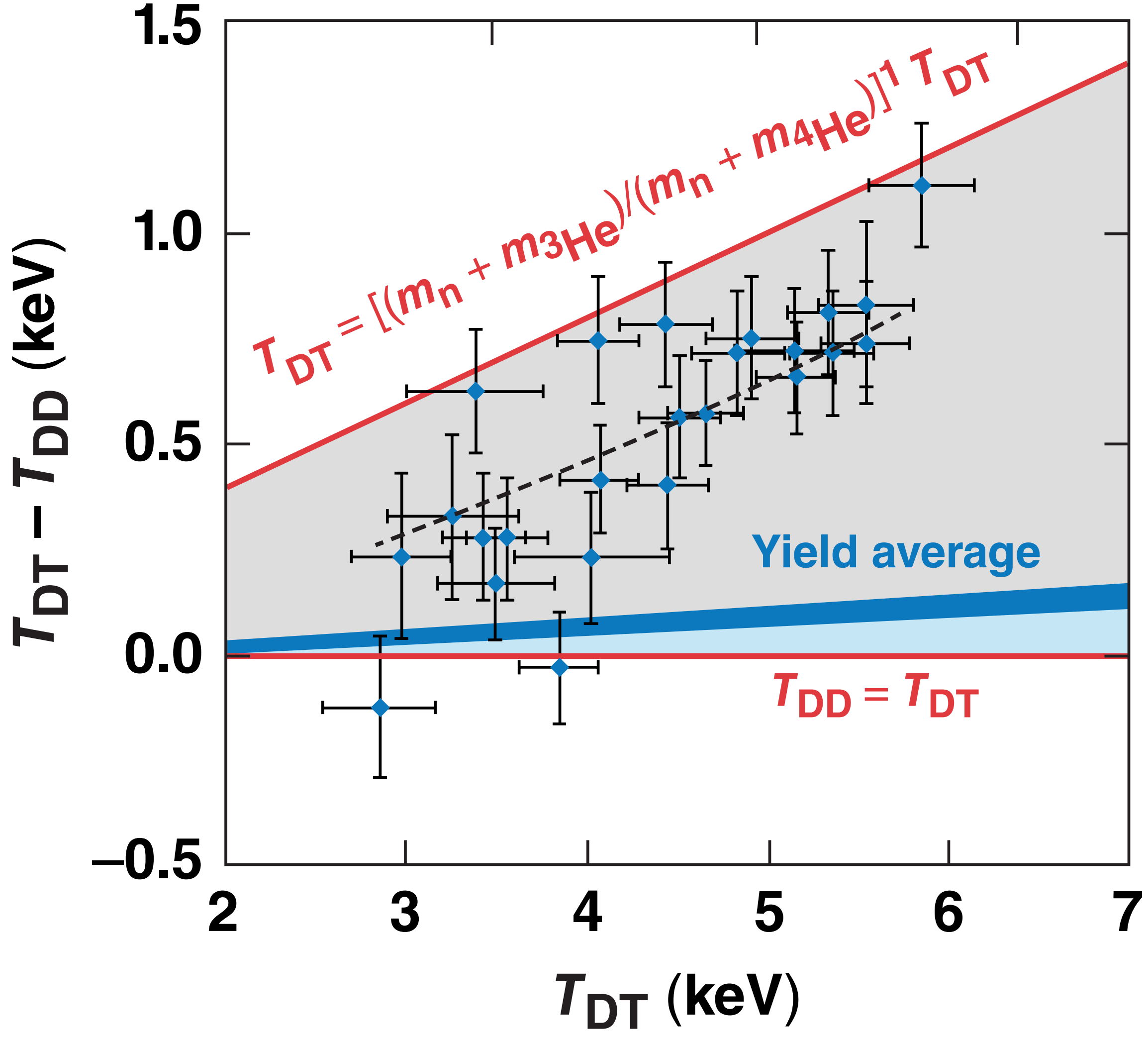
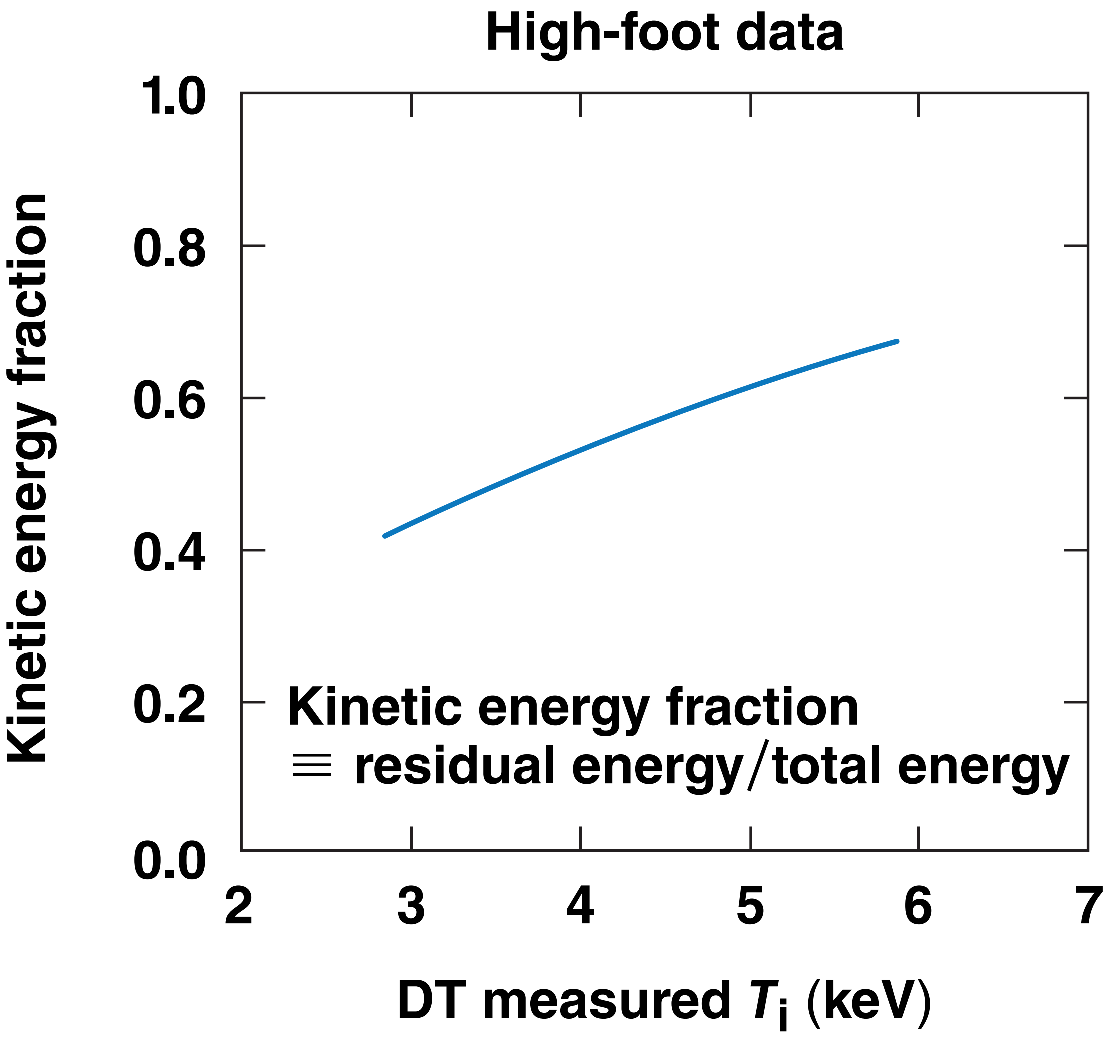
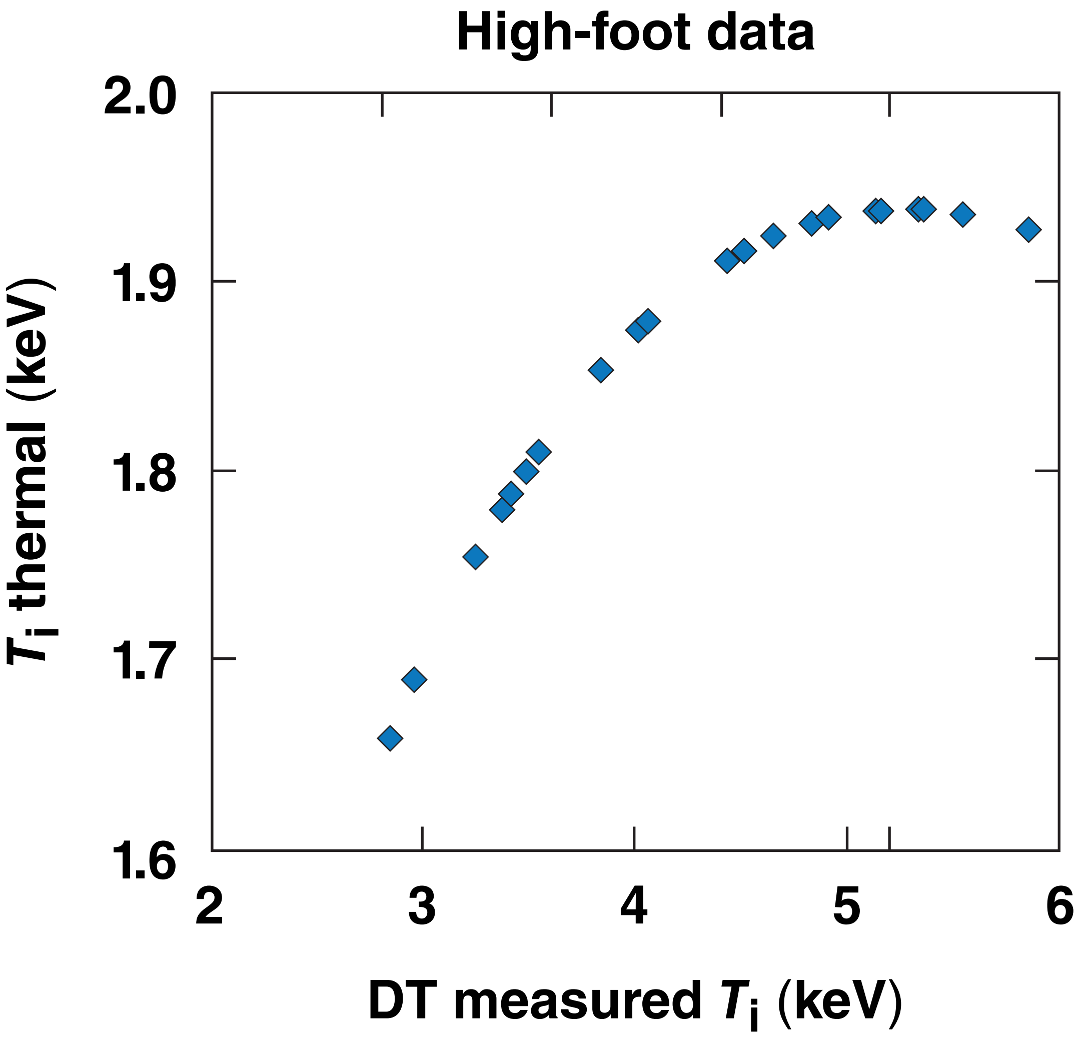
Detector-averaged T_i can be used to study the differences between DD data and DT data



$f_{ICF} = 1 - e^{-\alpha T_{DT}}$

The kinetic energy fraction ranges from 0.4 to 0.7 for the NIF high-foot implosions





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Summary/Conclusions

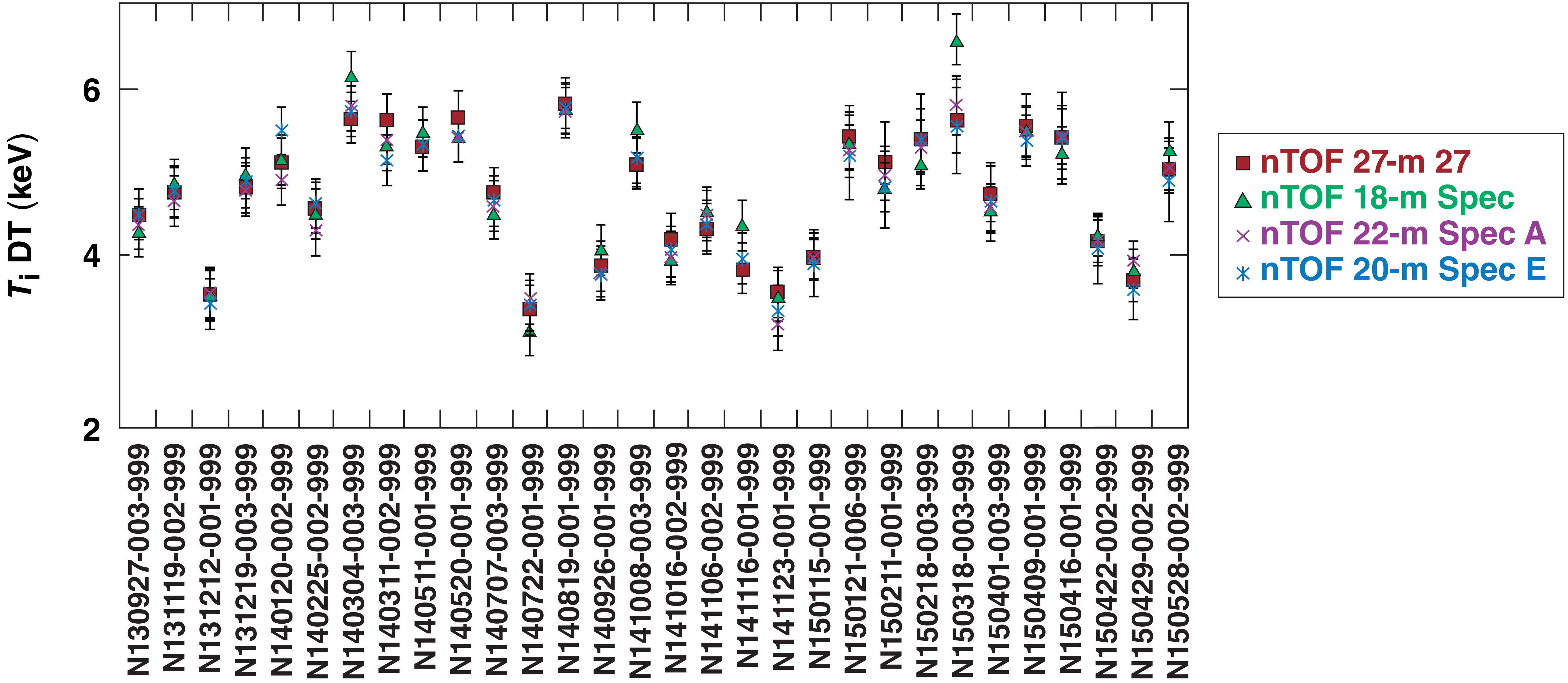
Ion temperature (T_i), as inferred from DD and DT data, implies that residual kinetic energy increases with temperature

- Differences in the value for T_i from the DD neutron peak and T_i from the DT neutron peak increase as temperature increases
- DD and DT reactivities were integrated in space and time over assumed profiles to better reflect implosion dynamics
- Reactivity integrals do not explain the measured differences

Temporal and spatial profiles are now needed to compute yield-averaged temperatures

- Time profiles for
  - $r_{hs}(t)$ – hot-spot radius
    - hyperbola used
    - asymptotic slope determined by implosion velocity
    - minimum radius from stagnation radius
  - $kT(0,t)$ – $r = 0$ hot-spot temperature
  - Gaussian with width determined by the measured burnwidth
  - $P_{hs}(t)$—hot-spot pressure
    - ideal gas EOS used to scale with temperature and volume
    - maximum pressure given by stagnation pressure
- Radial profile for temperature

The ion temperature from the DT peak shows little variation between detectors over the high-foot campaign



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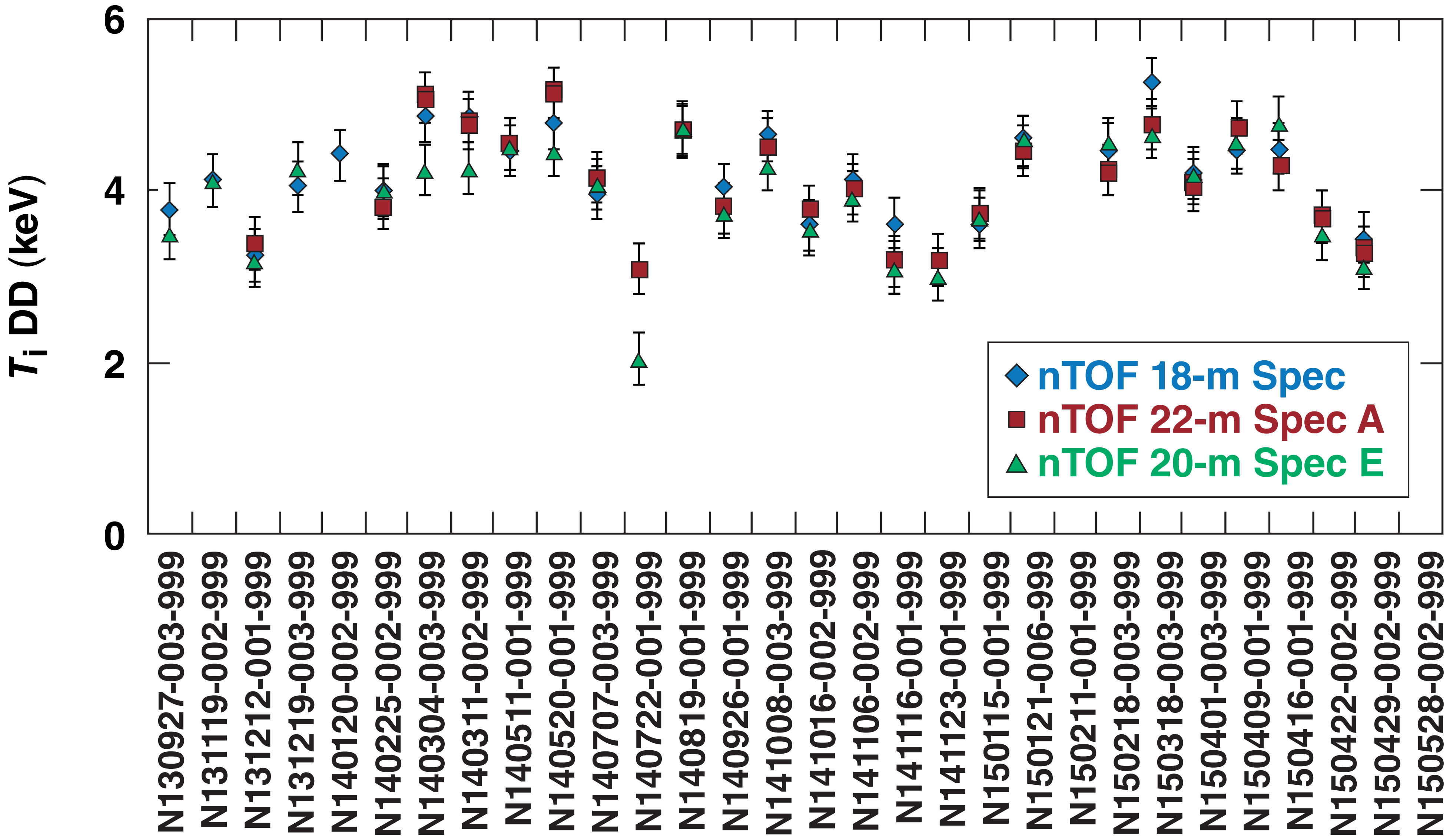
The ion temperature from the DD peak shows little variation between detectors over the high-foot campaign



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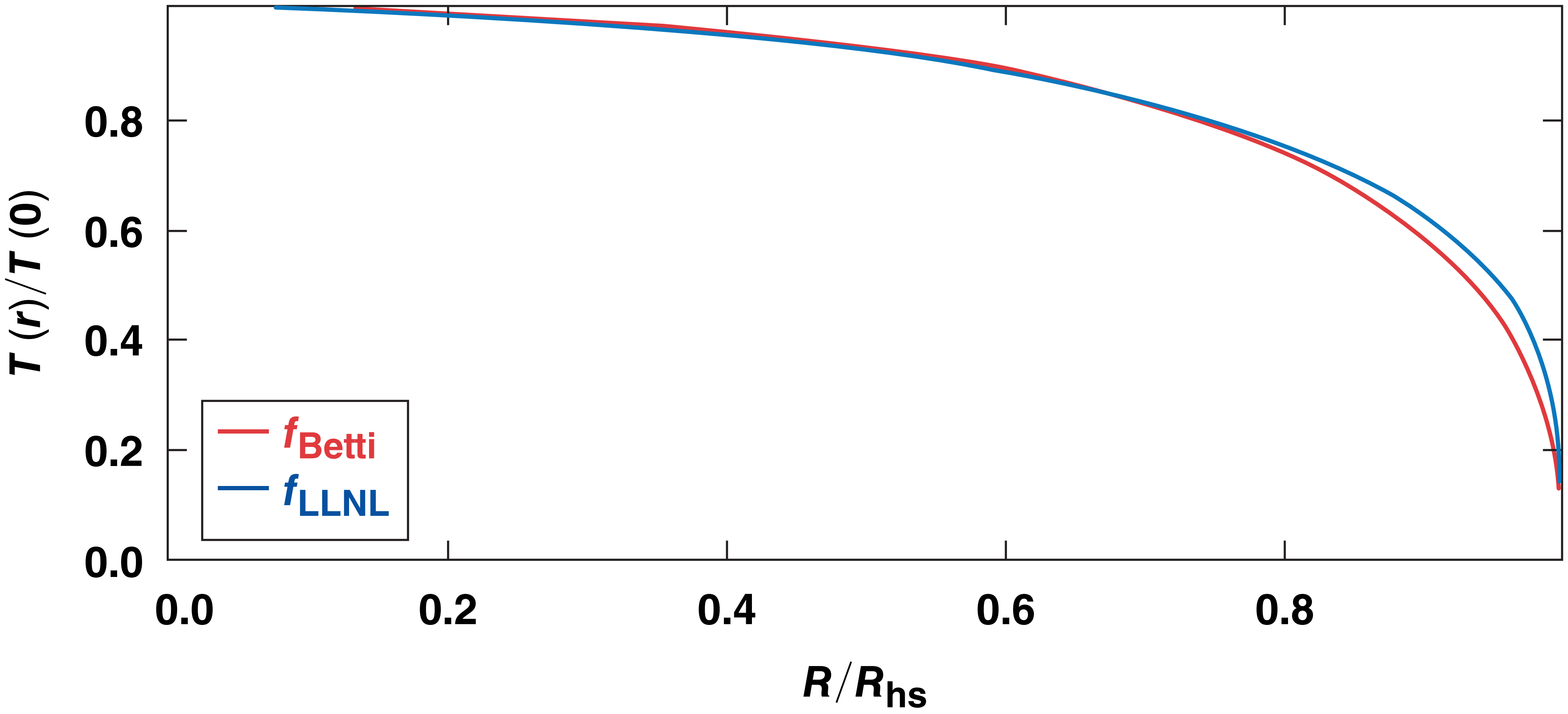
Two different spatial profiles for the temperature were studied with little difference observed



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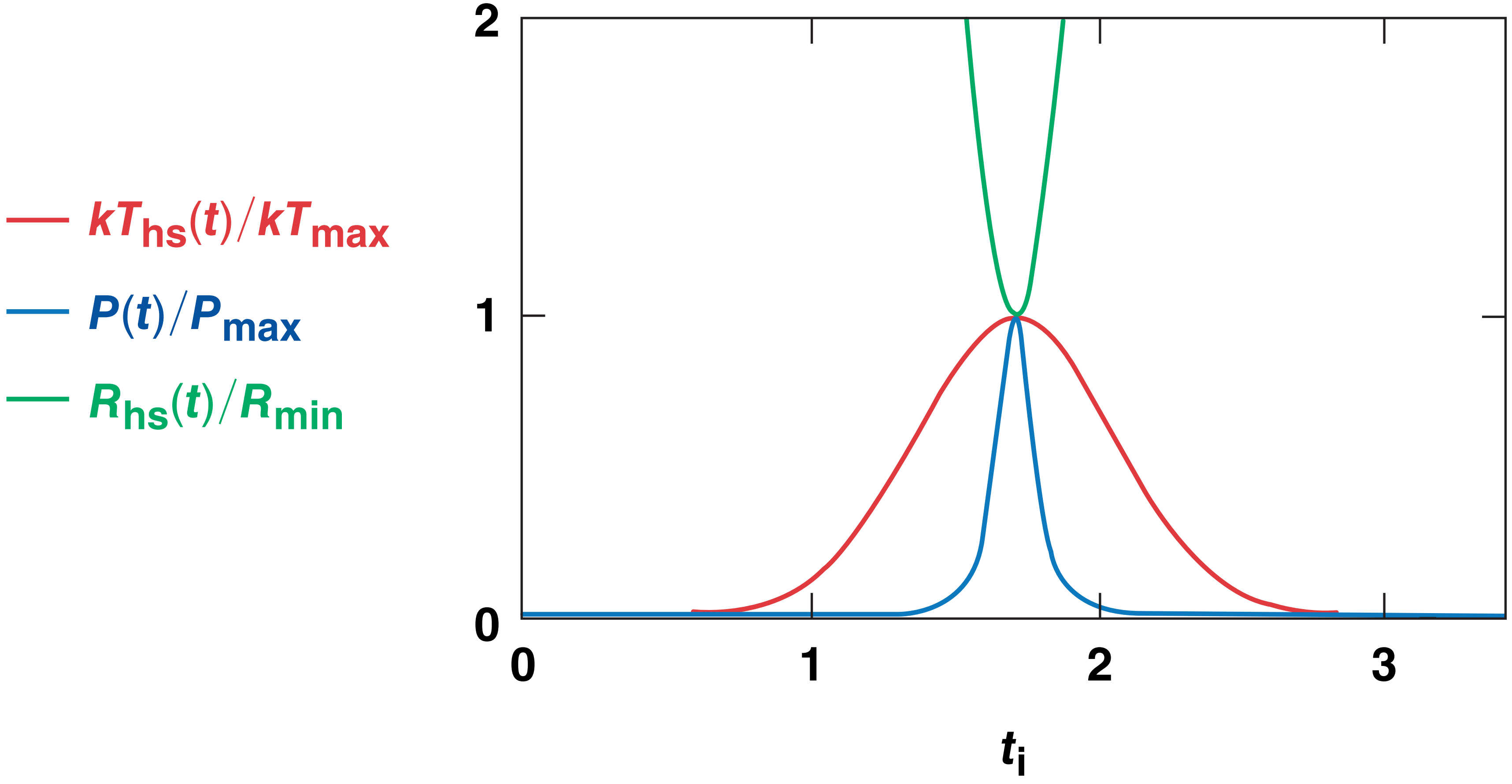
Temporal profiles are scaled to final hot-spot conditions

Temperature, pressure, and radius versus time



- Final hot-spot conditions scaled from no-alpha heating models*

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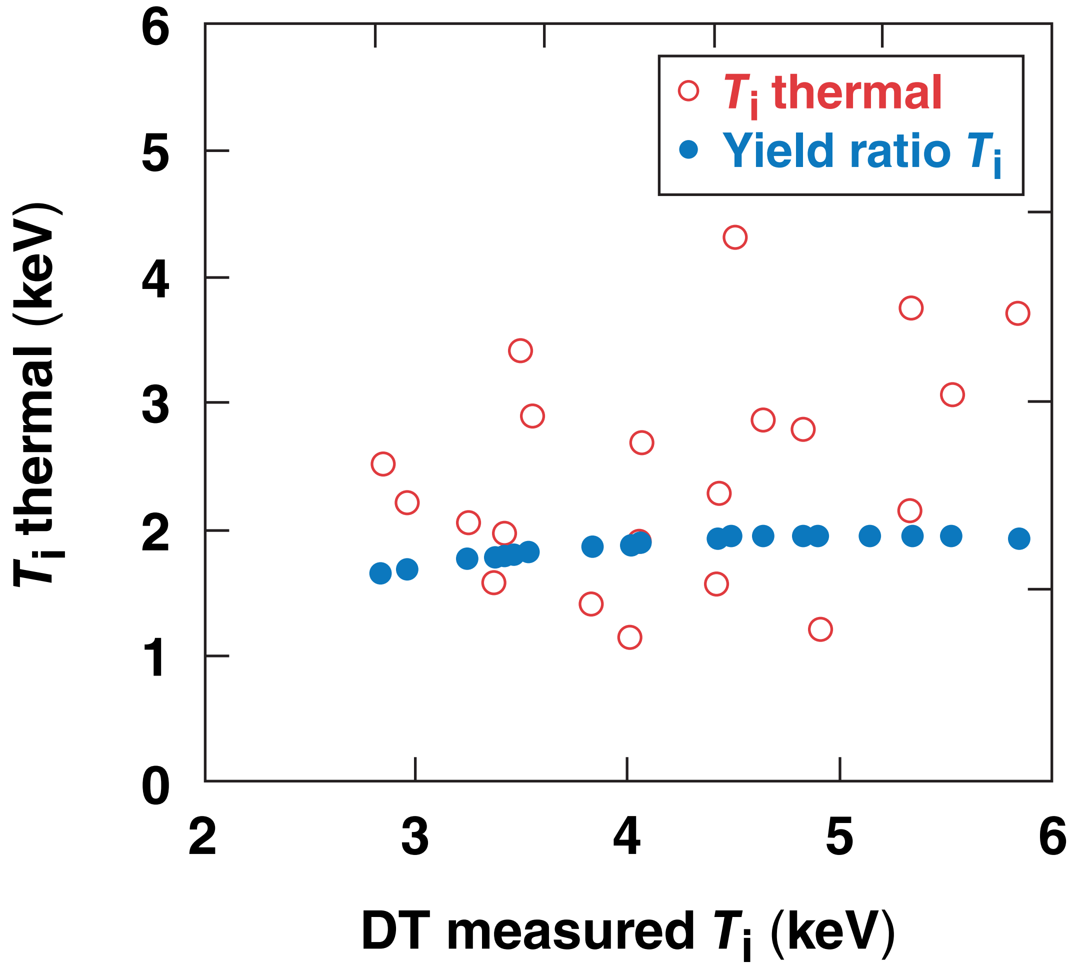
*C. D. Zhou and R. Betti, Phys. Plasmas 14, 072703 (2007).

T_i calculated from Y_{DT}/Y_{DD} is consistent with T_i thermal



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