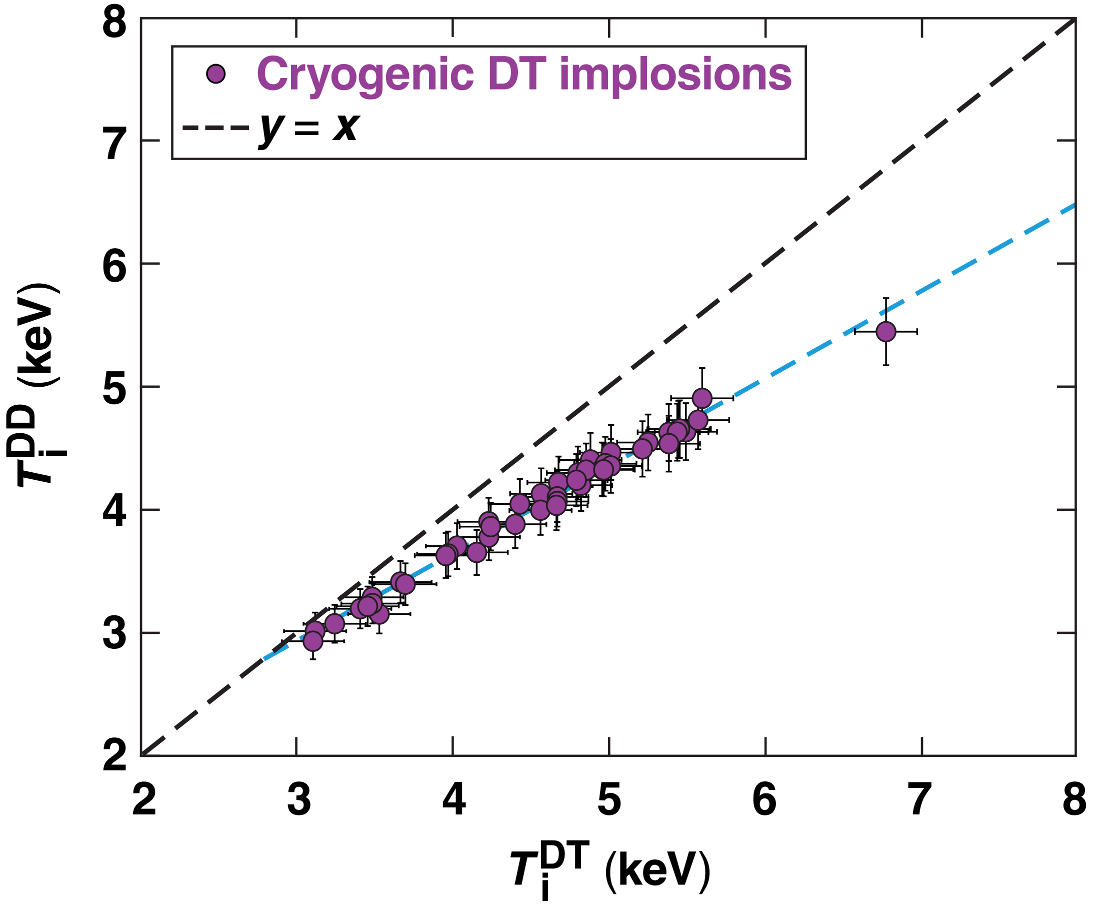
Evaluating the Residual Kinetic Energy in Direct-Drive Cryogenic Implosions on OMEGA



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Summary

Cryogenic direct-drive implosions show that the inferred DD ion temperatures are lower than the DT ion temperatures as plasma temperature increases

- Past theoretical work has shown that residual kinetic energy (RKE) will lead to the inferred DD ion temperature being lower than the DT inferred ion temperature*
- Relying only on RKE to explain the difference between DT and DD on OMEGA cryogenic implosions infers thermal temperatures that are inconsistent with measured yields on OMEGA
  - a similar trend with inconsistent thermal temperatures resulting from RKE has been observed in indirect-drive implosions at the National Ignition Facility (NIF)**

Variations in hot-spot profiles provide a possible important contribution to the observed discrepancy in inferred ion temperatures.

*T. J. Murphy, Phys. Plasmas 21, 072701 (2014).
**M. Gatu Johnson *et al.*, Phys. Rev E 94, 021202(R) (2016).

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Collaborators

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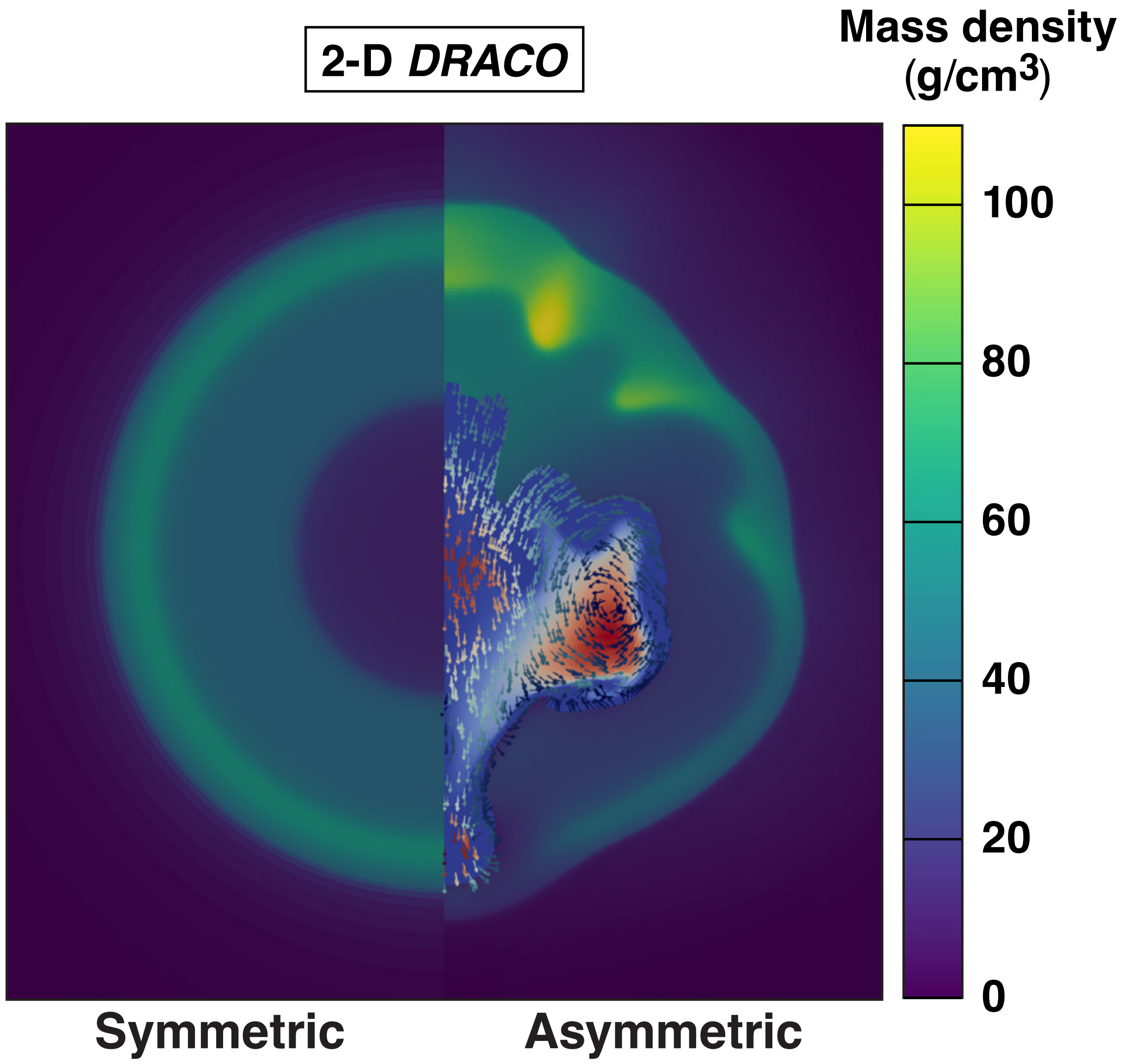
Fluid motion of the fuel assembly at peak compression will impart residual kinetic energy in the hot spot



- A dominant $\ell = 1$ will have different effects of the measured neutron energy spectrum

  1. Collective motion establishes a shift in the neutron mean energy*

     $\langle E_n \rangle = E_0 + \Delta E_{th} + E_f$ (First moment)

  2. Variation in the flow enhances the broadening, leading to larger apparent ion temperature**

     $\sigma_n^2 = \sigma_{Brysk}^2 + \sigma_{KE}^2$ (Second moment)

*L. Ballabio, J. Källne, and G. Gorini, Nucl. Fusion 38, 1723 (1998).
**T. J. Murphy, Phys. Plasmas 21, 072701. (2014).

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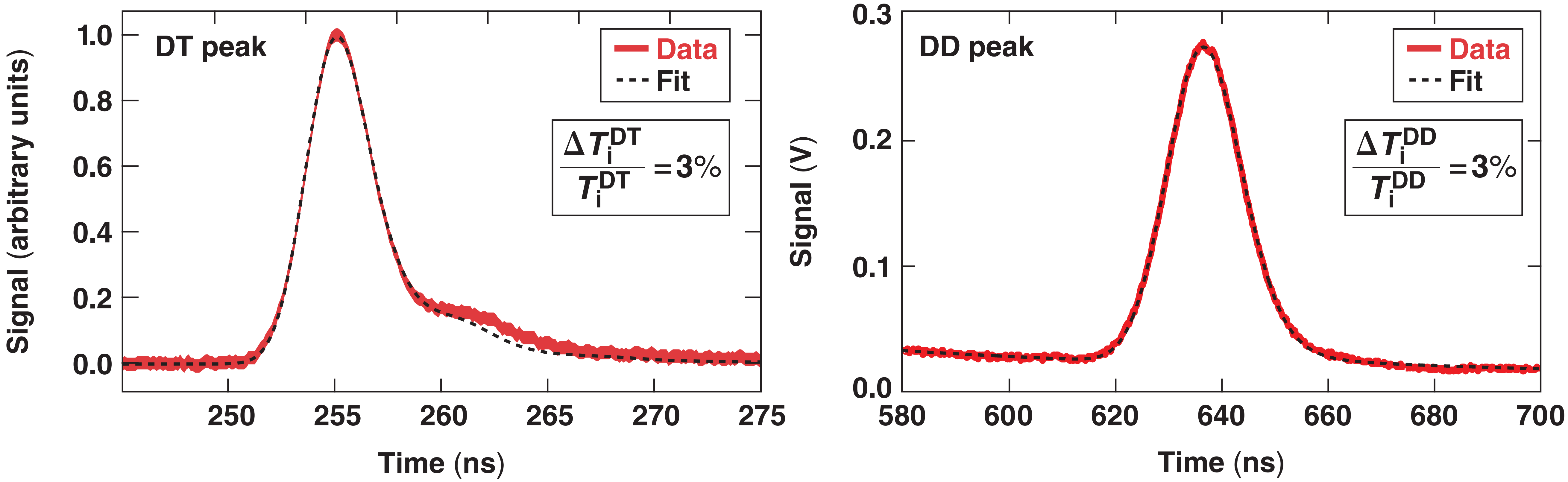
A forward-fit technique was used to infer the spectral moments of the peak distributions from a neutron-time-of-flight (nTOF) diagnostic

The nTOF diagnostics are located in a highly collimated line of sight to minimize background effects



C. J. Forrest *et al.*, Rev. Sci. Instrum. 87, 11D814 (2016).

The ratio of the apparent ion temperature can be used to infer the residual kinetic energy fraction (f_{RKE})

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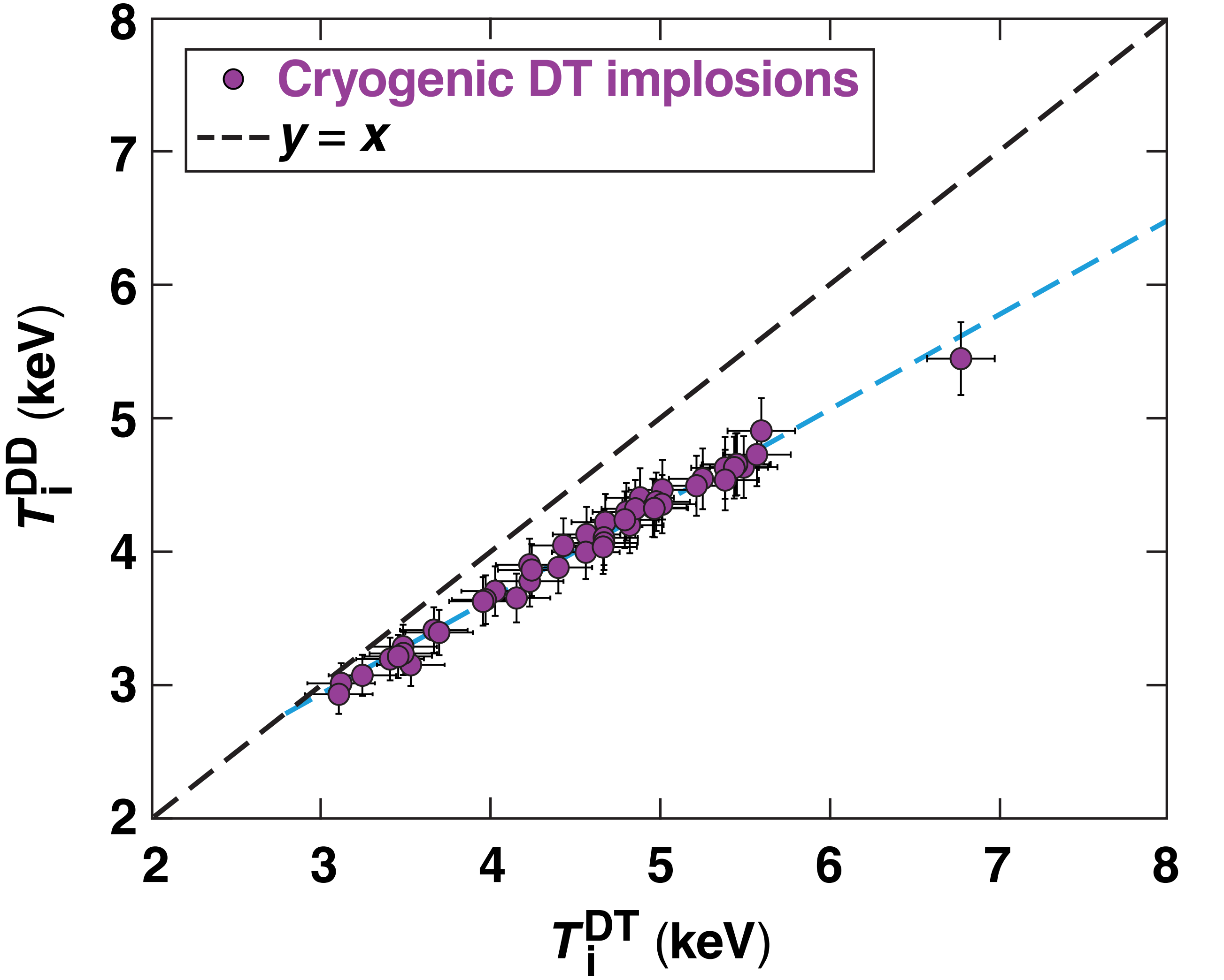

The f_{RKE}* can be defined as internal energy that did not contribute to the thermal energy of the hot spot

$$\frac{kT_{DT} = \frac{m_n V_n^2}{\langle E_n \rangle}(m_n + m_\alpha)\left[\frac{\langle A \rangle}{3(A_n + A_\alpha)}(1 - f_{RKE}) + \frac{2}{3} f_{RKE}\right]}{kT_{DD} = \frac{m_n V_n^2}{\langle E_n \rangle}(m_n + m_\alpha)\left[\frac{\langle A \rangle}{3(A_n + A_{^3He})}(1 - f_{RKE}) + \frac{2}{3} f_{RKE}\right]}$$

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

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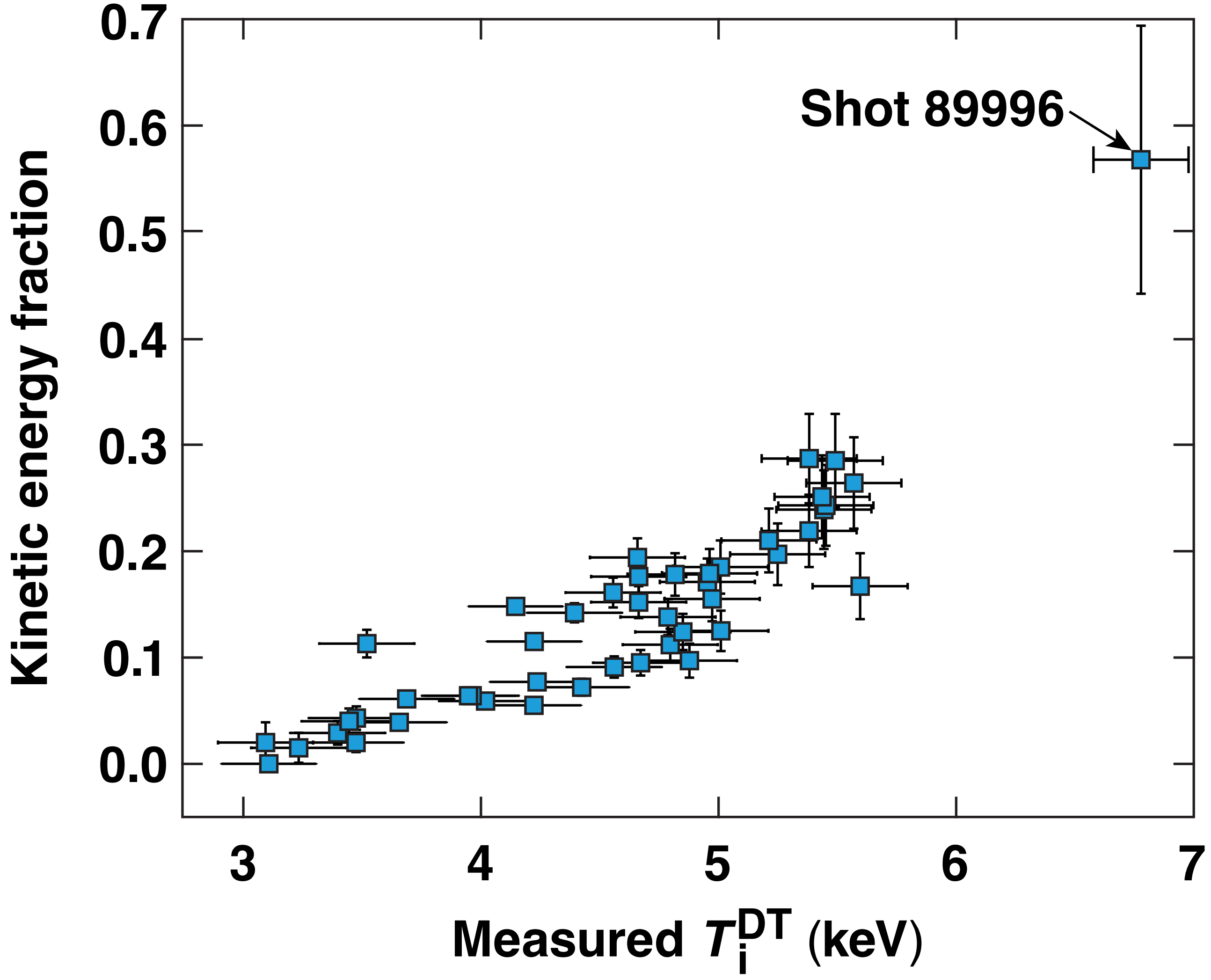
The kinetic energy fraction inferred from the ratio of the DT/DD ion temperature increases with the apparent temperature of the plasma



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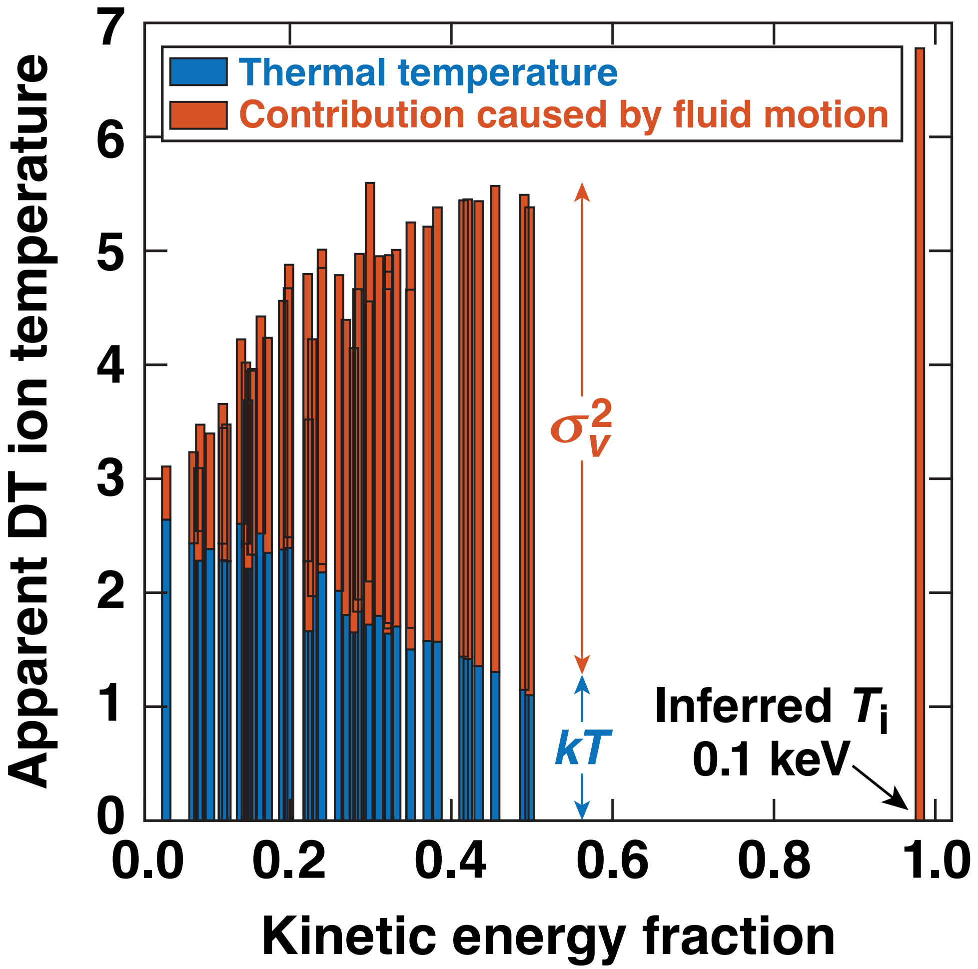
The residual kinetic energy inferred from cryogenic implosions underpredicts the thermal temperature of the fusing plasma



The apparent ion temperature of the fusing plasma can be expressed by the thermal temperature and variance caused by flow variations

$$\frac{kT_{DT} = kT + (m_n + m_\alpha)\sigma_v^2}{kT_{DD} = kT + (m_n + m_{^3He})\sigma_v^2}$$

σ_v^2 = is the contribution caused by the fluid motion for both the DT and DD reactants

An underprediction in the thermal temperature has also been observed from experimental data at the National Ignition Facility.

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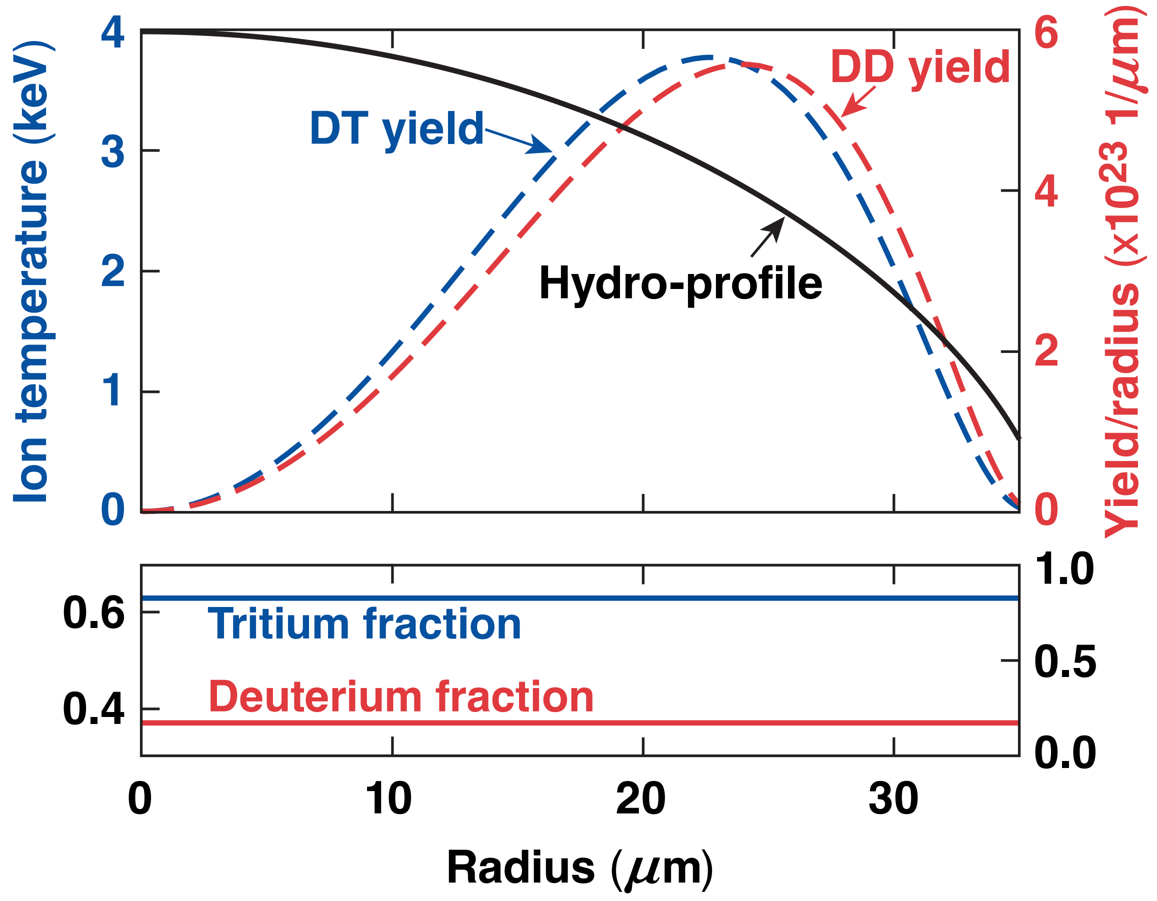
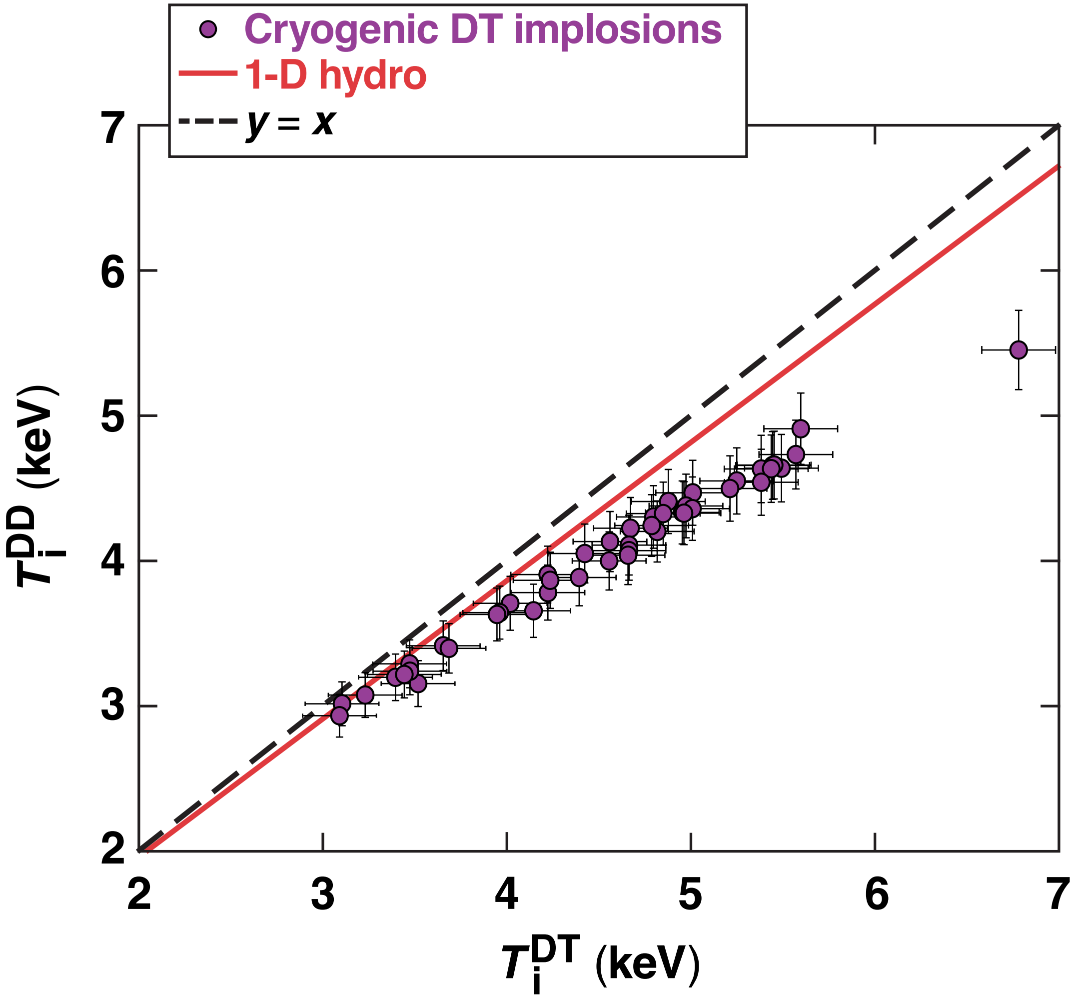
M. Gatu Johnson *et al.*, Phys. Rev E 94, 021202(R) (2016).

A 1-D model with a temperature profile from hydrodynamic simulations* can be used to calculate the DT and DD neutron-averaged ion temperature





- The DT and DD reactivities have different sensitivities with respect to the temperature profile of the hot spot

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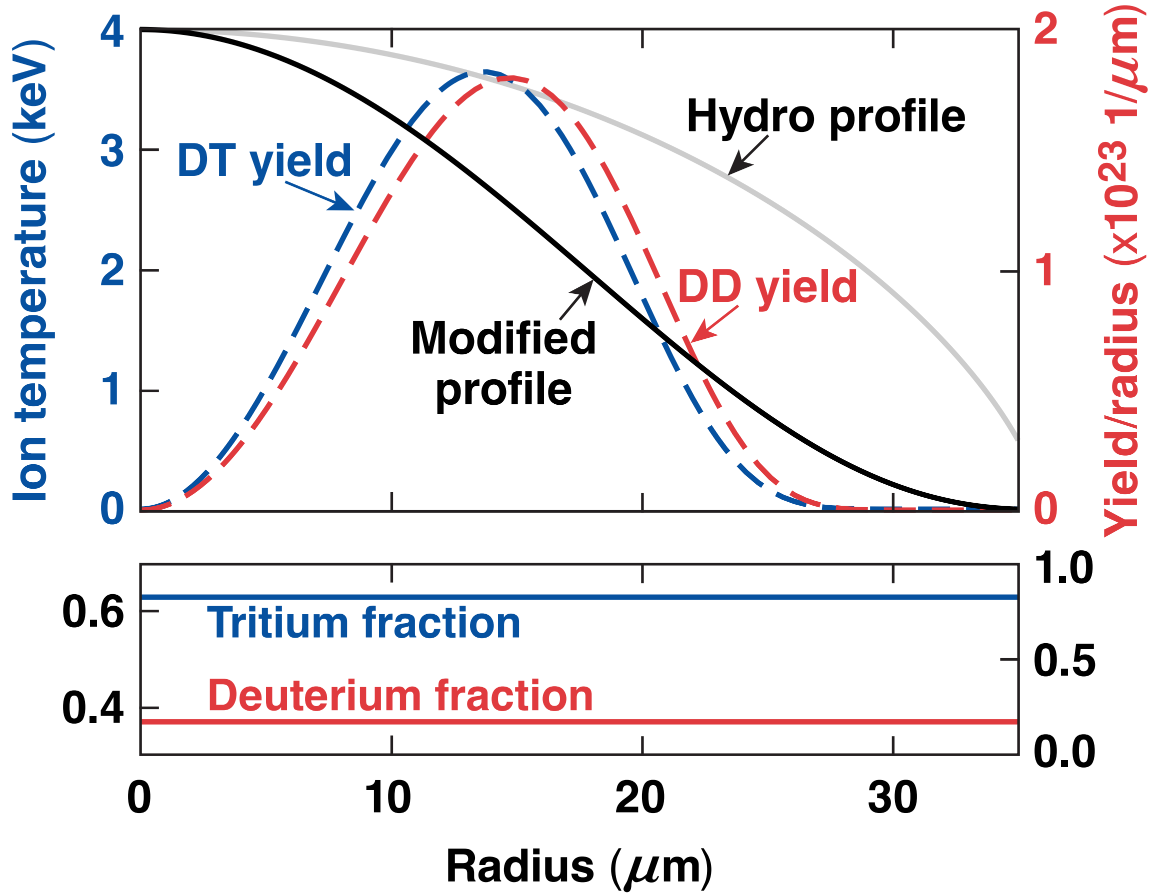
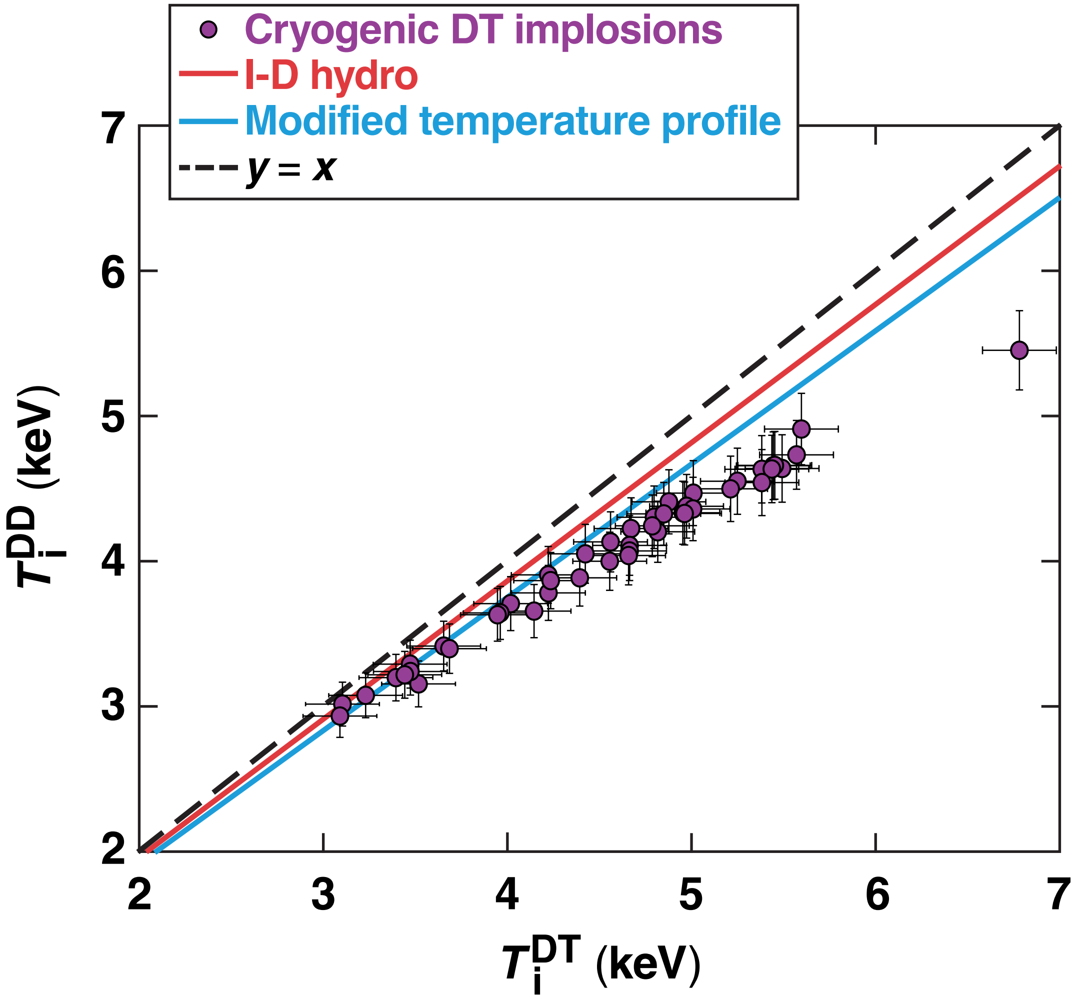
*S.P. Regan *et al.*, Phys. Rev. Lett. 117, 025001 (2016).

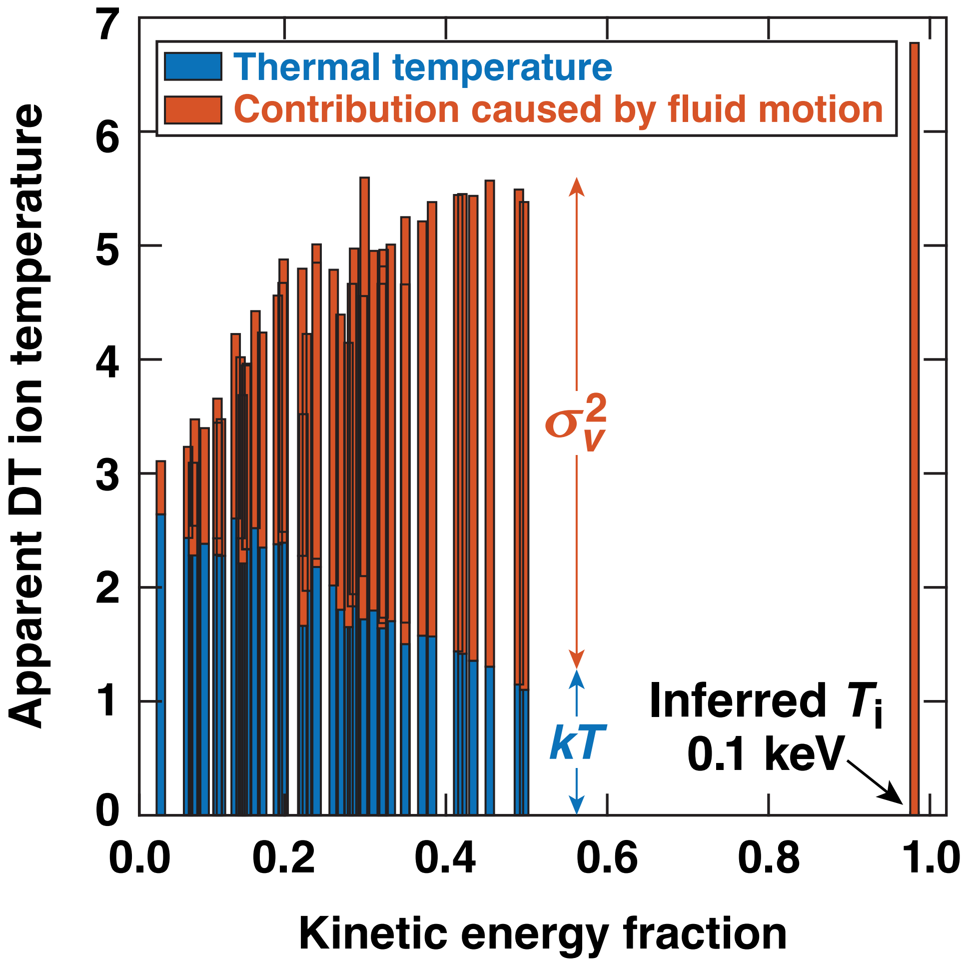
The DT and DD neutron-averaged ion temperatures are highly sensitive to the profile of temperature

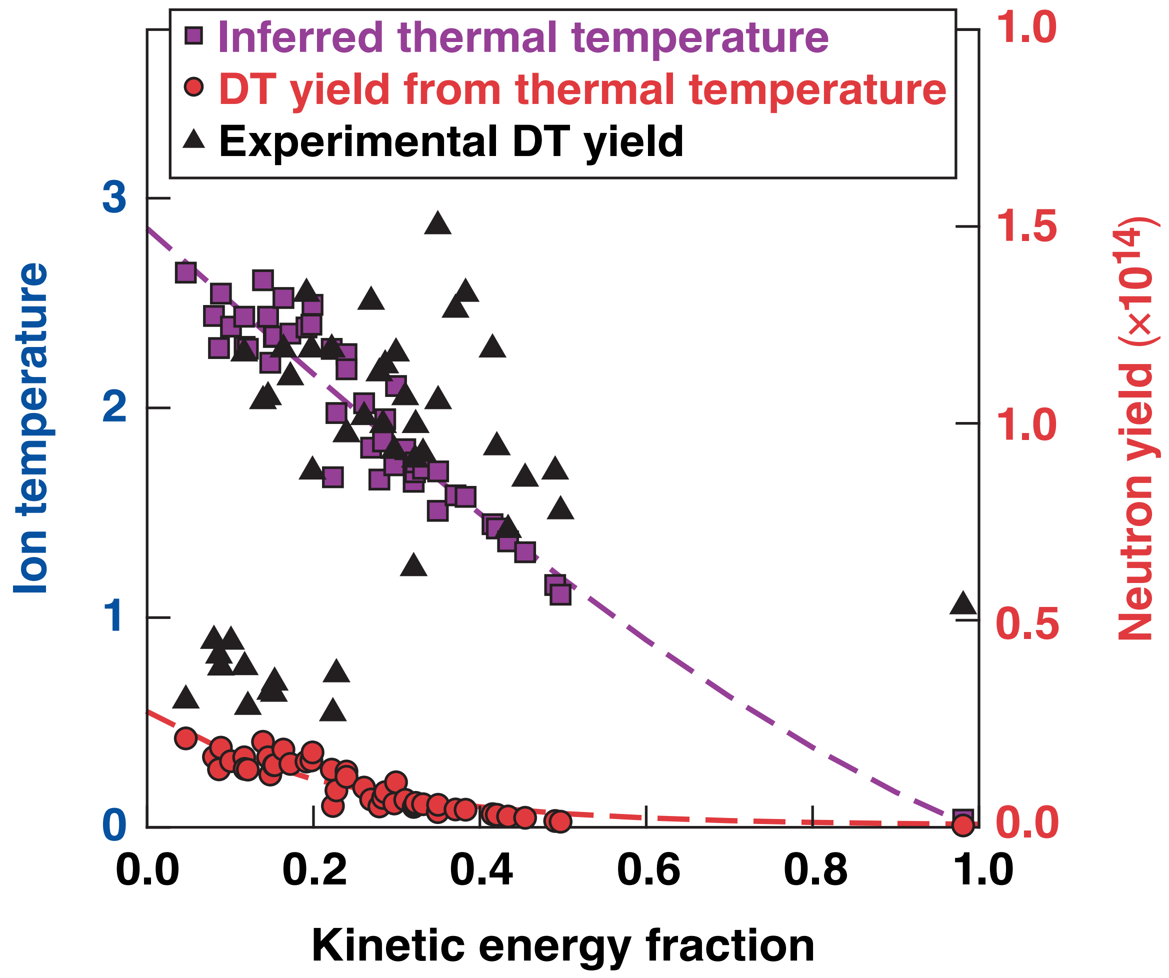




- Mixing of the cold-fuel layer with the hot-spot is one possibility that will modified the shape of the temperature profile

An estimate of the DT yield from the inferred thermal temperature of the hot spot is not consistent with the experimental yield





- The experimental yield does not show a decrease with an increase in the inferred kinetic energy fraction

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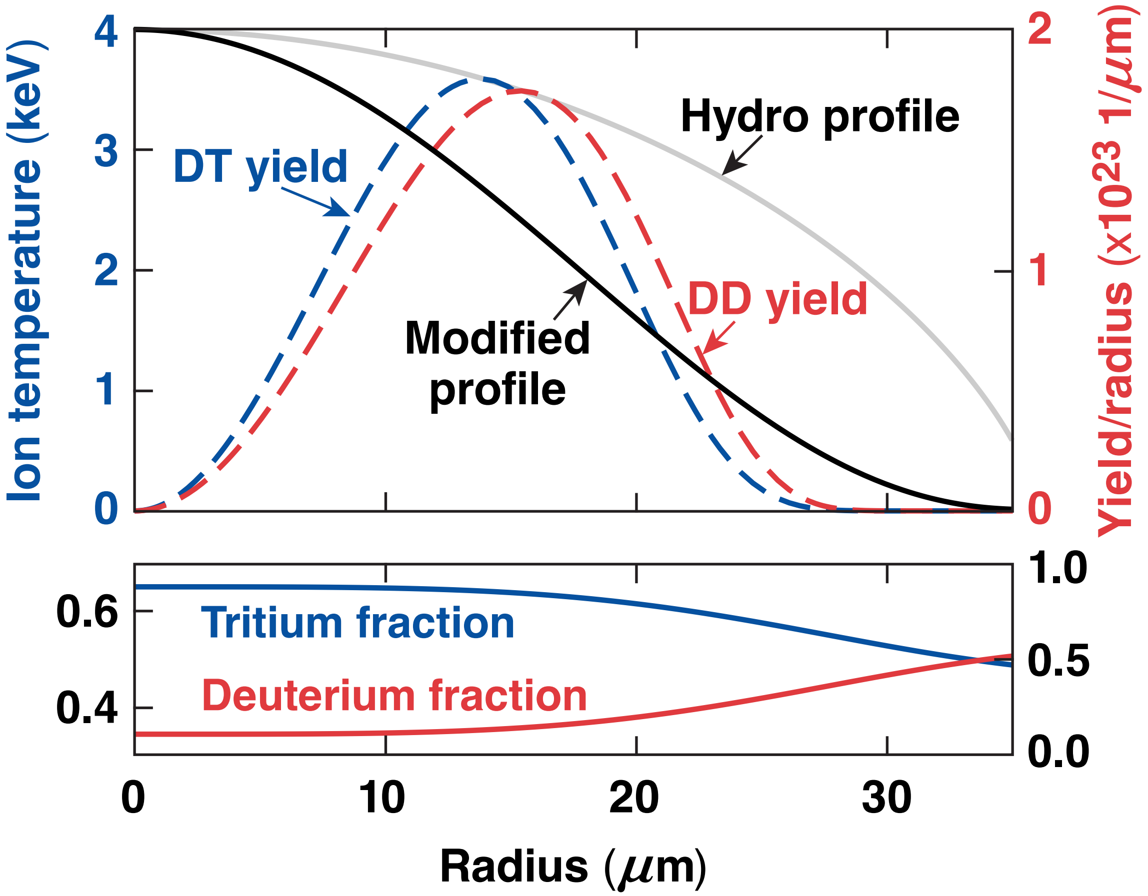
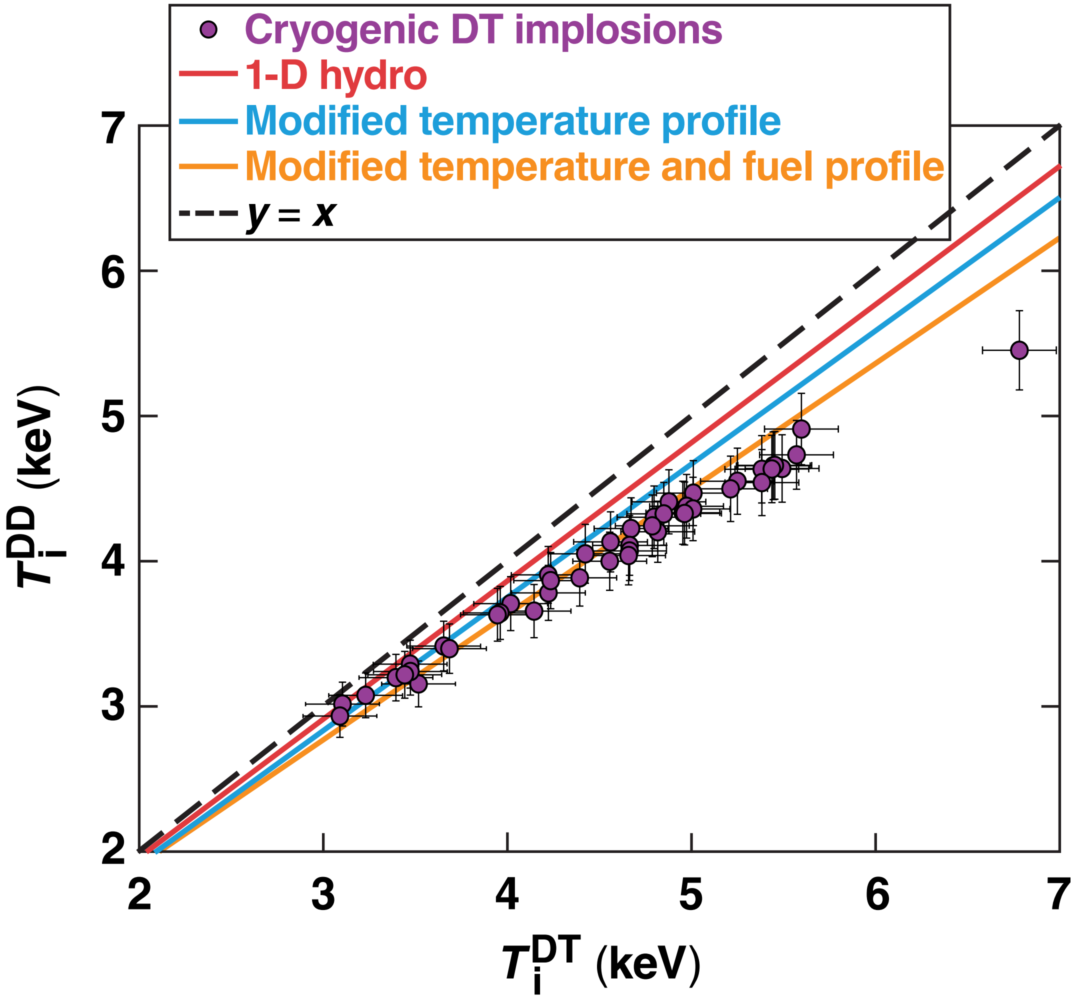
The DT and DD neutron-averaged ion temperature ratio is affected from different profiles of fuel fractions over the radius of the hot spot





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