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Fusion Neutron Energy Spectrum Measurements in Kinetic Plasmas

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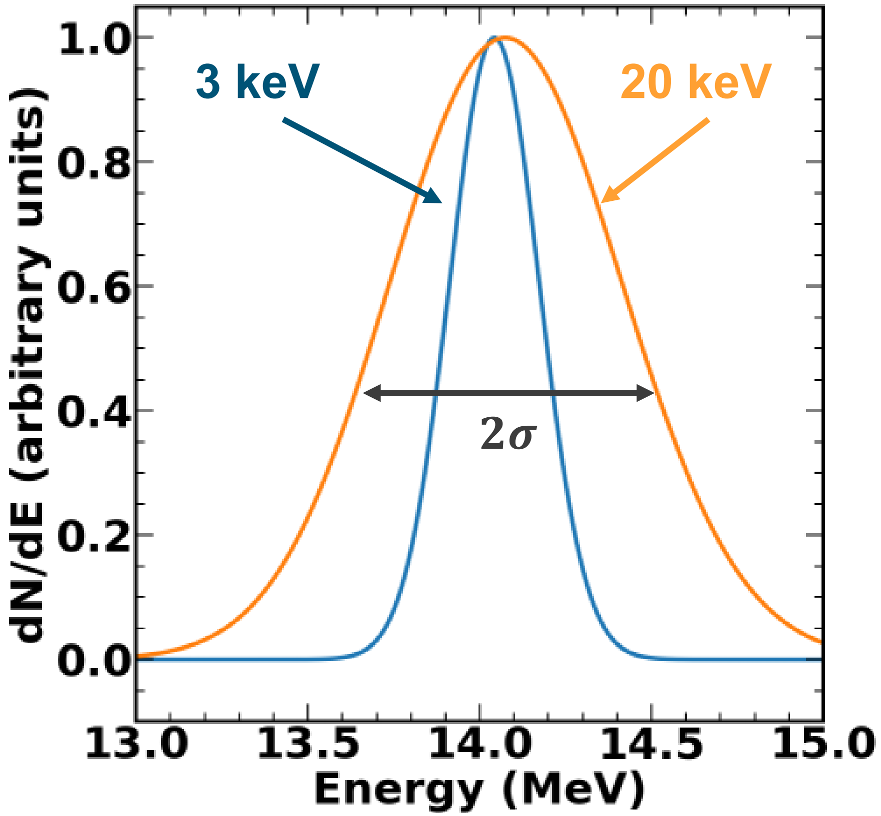
Measurements of the neutron energy spectrum emitted from high temperature shock driven implosions are inconsistent with a Maxwellian plasma model

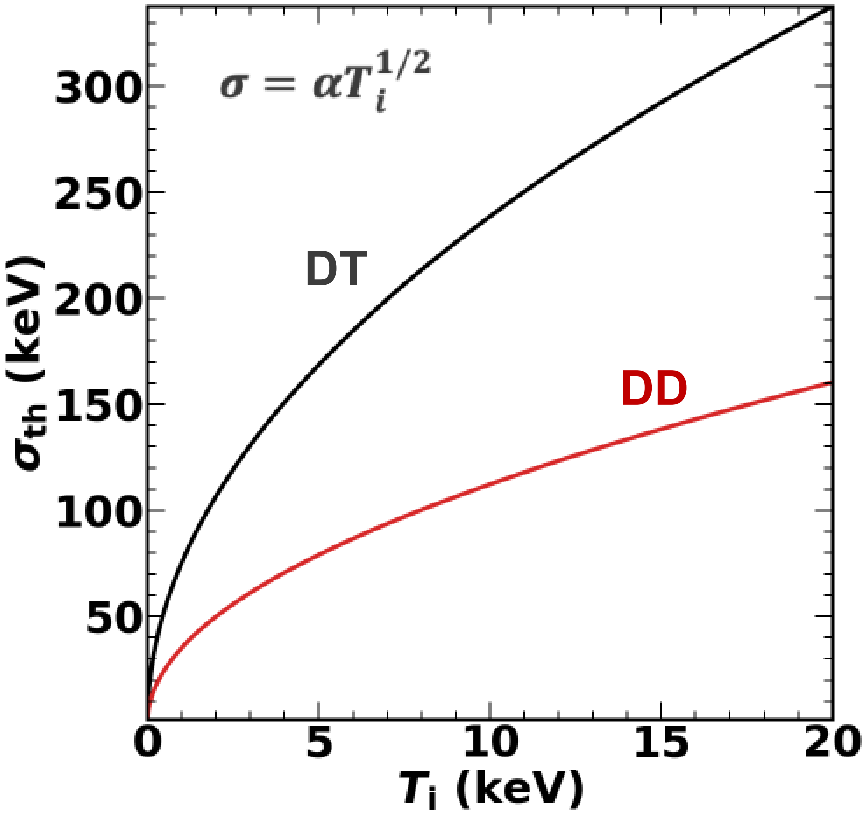
- The primary DT and DD neutron energy spectrum generated in laser direct drive inertial confinement fusion implosions were measured using a suite of neutron time of flight (nTOF) detectors on the OMEGA 60 laser
- Measurements of the primary DD neutron energy spectrum are inconsistent with a Maxwellian plasma model for the high-temperature, more-kinetic-like experiments
- Vlasov–Fokker–Planck (VFP) simulations reproduce the trend observed in the primary DD neutron energy spectrum measurements and suggest the presence of a bimodal ion velocity distribution in the high-temperature experiments

These results indicate that inferring a thermal plasma ion temperature from primary neutron energy spectrum measurements is not possible for kinetic plasmas

1. B. Appelbe, et al., GO07.00008, this conference

The neutron energy spectrum emitted from a single temperature Maxwellian plasma is well understood





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2. L. Ballabio, Nuclear Fusion 38 (11), (1998).

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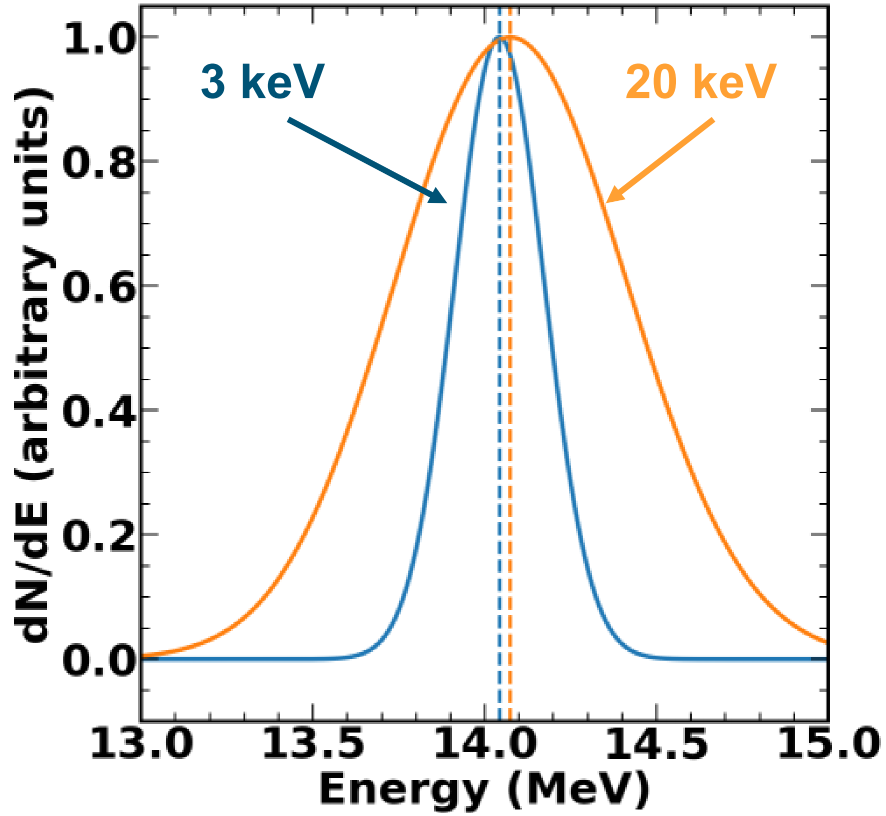

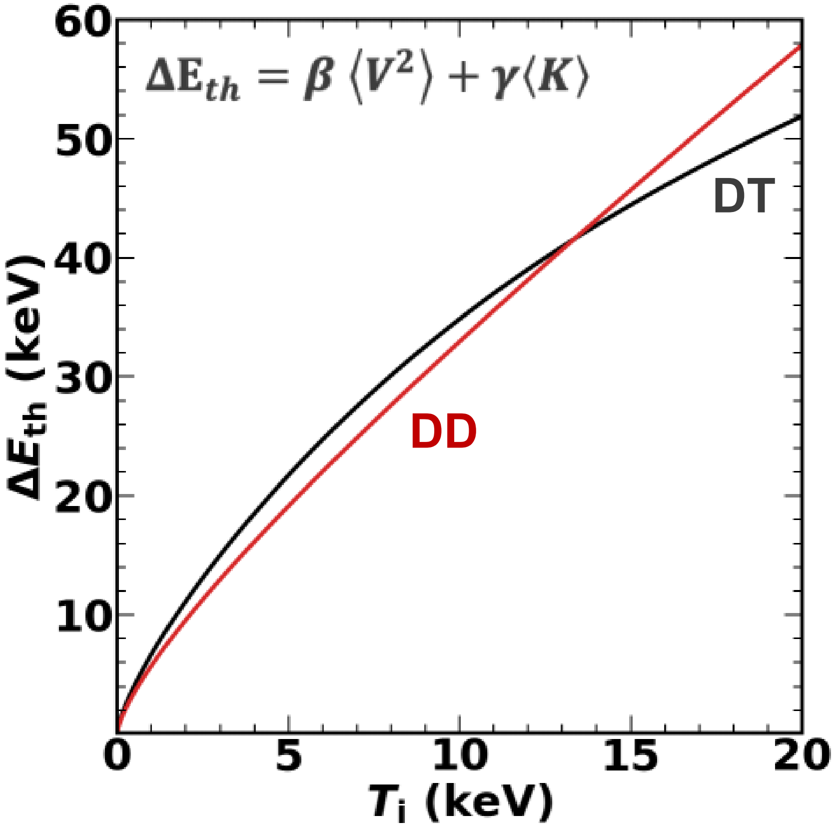

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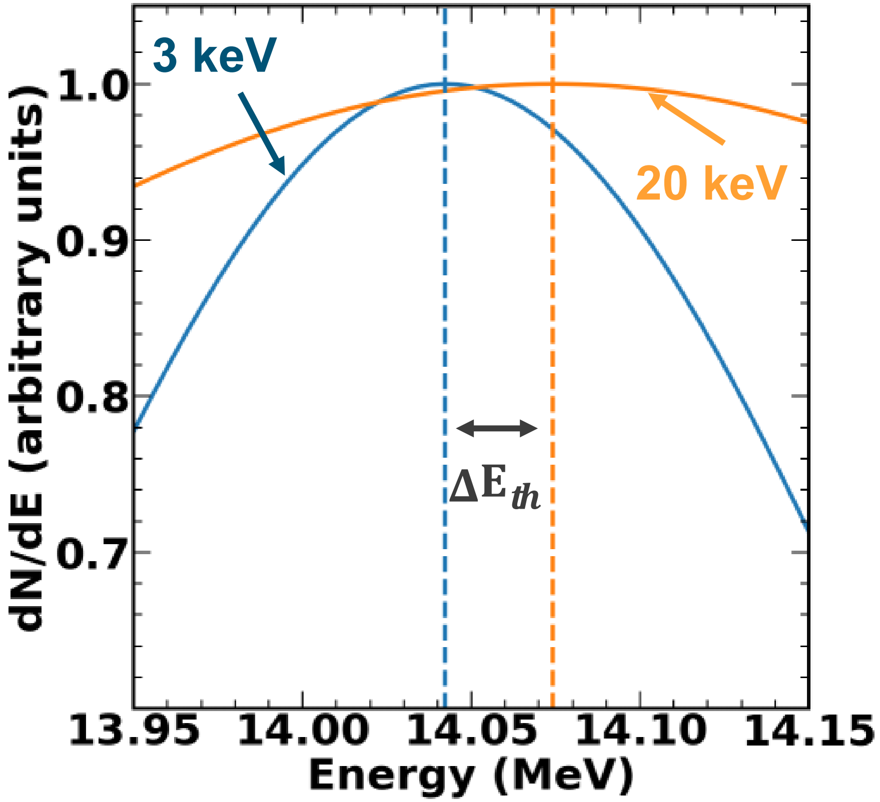

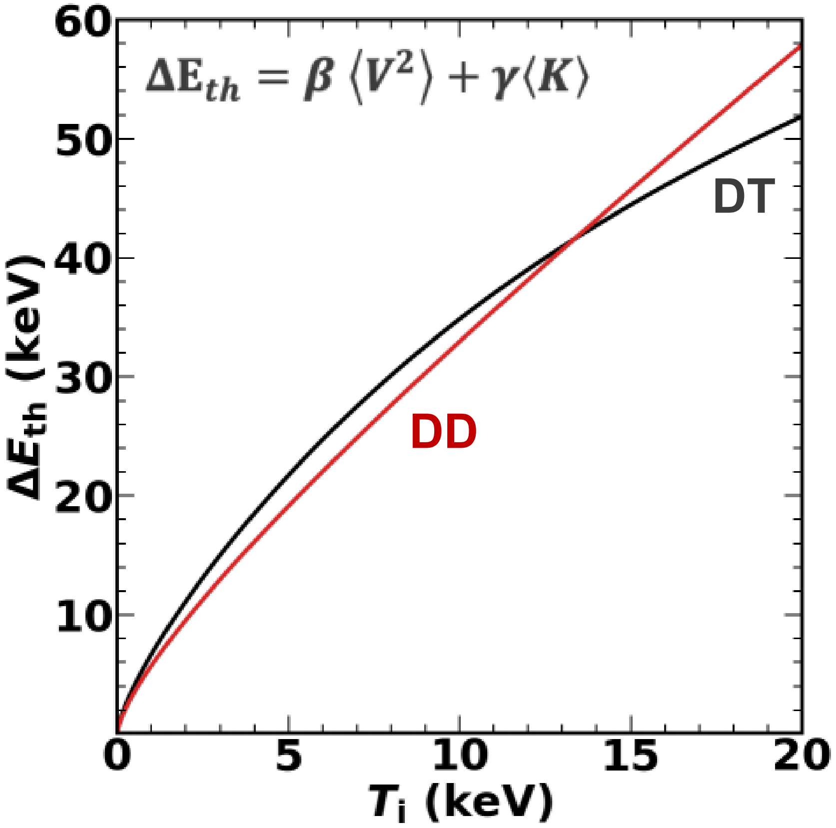

1. H. Brysk, Plasma Physics 15 (7), (1973).
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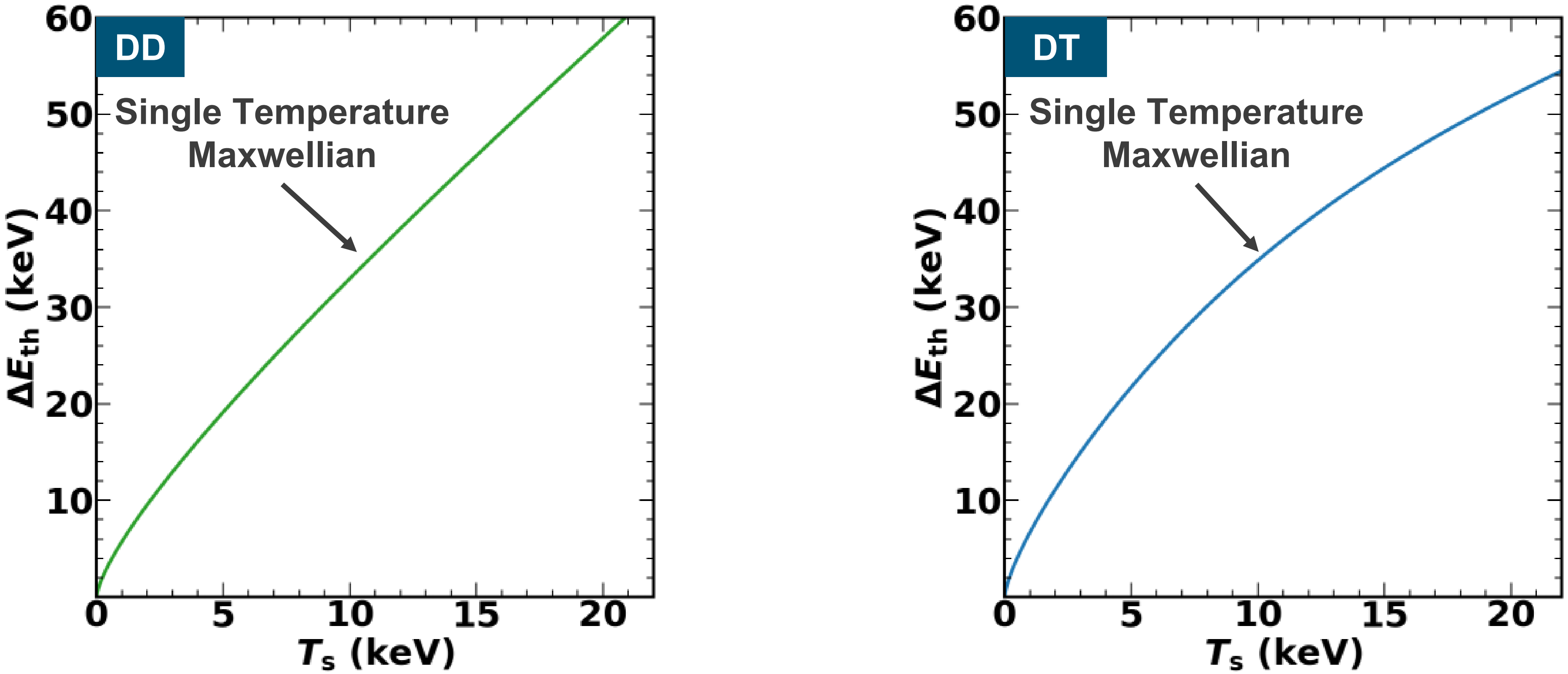
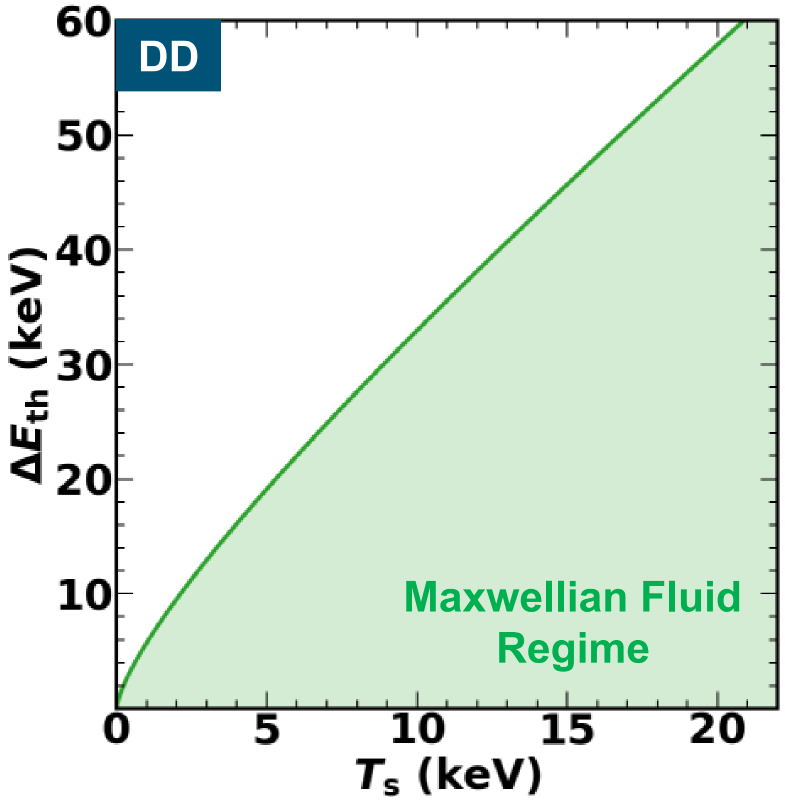
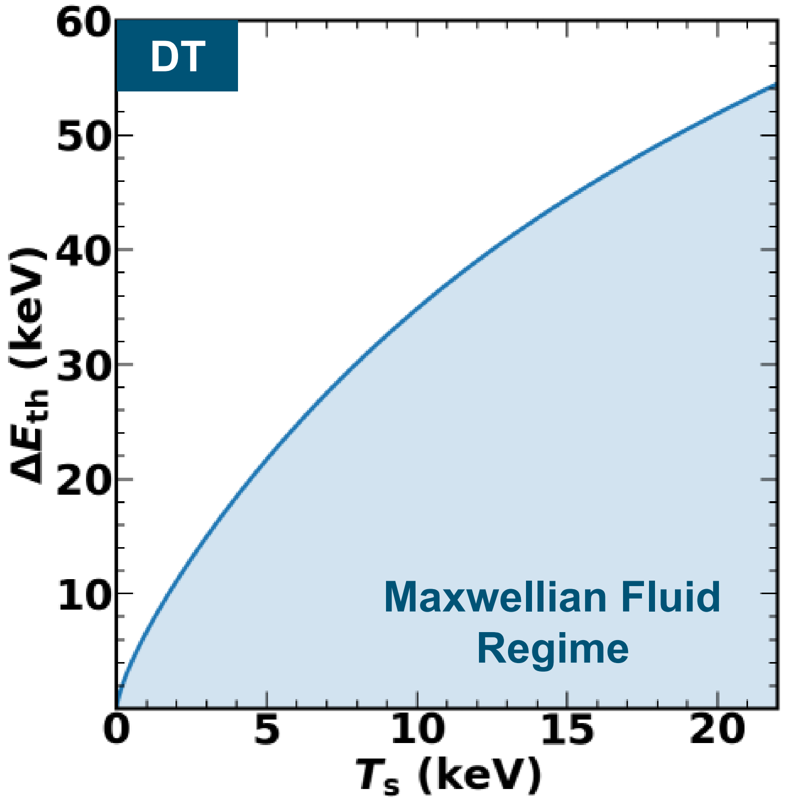
For a single temperature Maxwellian plasma a unique relationship exists between the Gamow energy shift and the plasma temperature



1. H. Brysk, Plasma Physics 15 (7), (1973).
2. L. Ballabio, Nuclear Fusion 38 (11), (1998).

A Maxwellian plasma with a distribution of ion temperatures in space and time can reduce the Gamow shift for a given spectral temperature

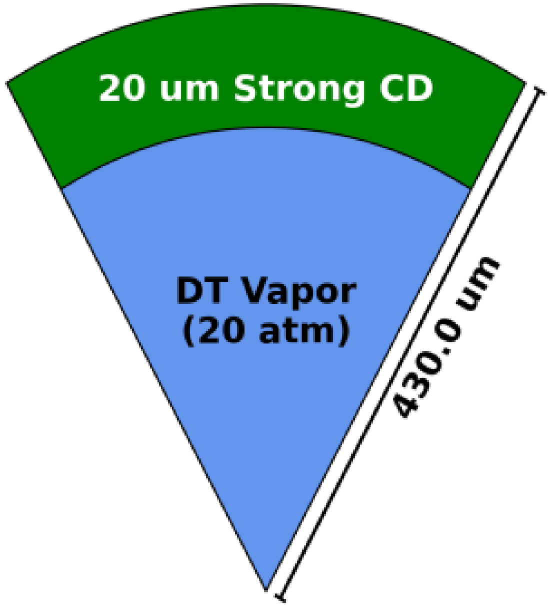




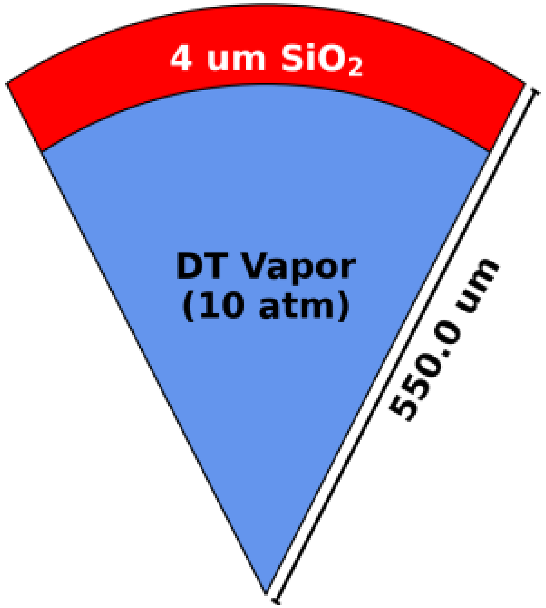
Measurements that fall outside of the Maxwellian fluid regime would provide direct evidence of a non-Maxwellian distribution

1. B. Appelbe, et al., GO07.00008, this conference
2. A. Crilly, et al., in preparation

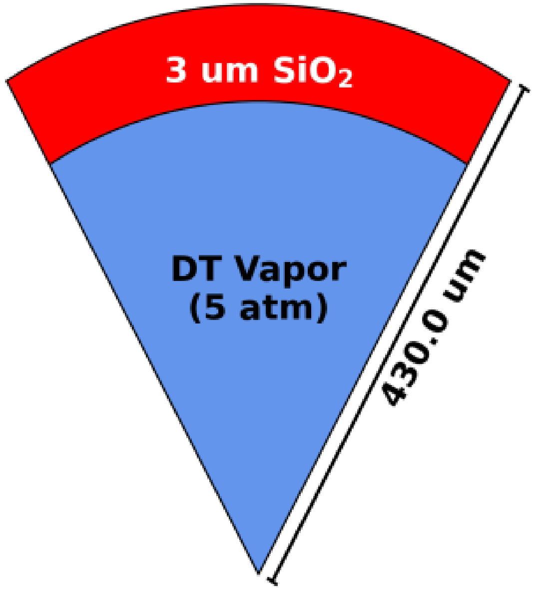
A set of experiments were performed to test the Maxwellian plasma neutron energy spectrum model



$T_i < 6$ keV
$N_k < 1$



$T_i \sim 10$ keV
$N_k \sim 1$

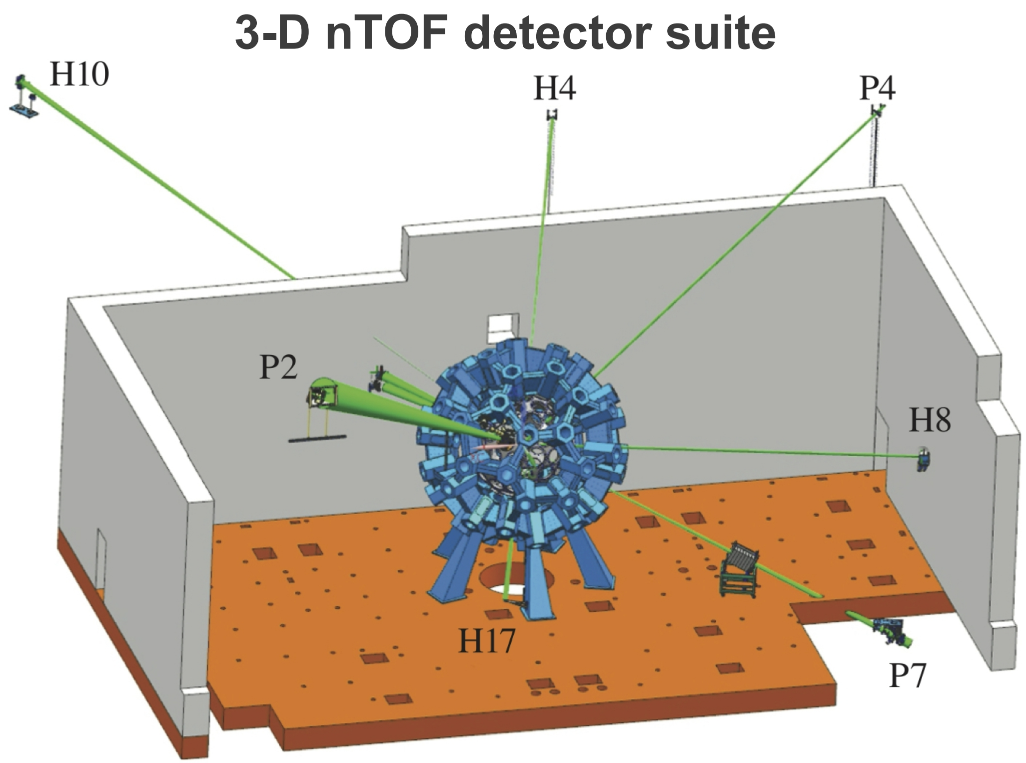


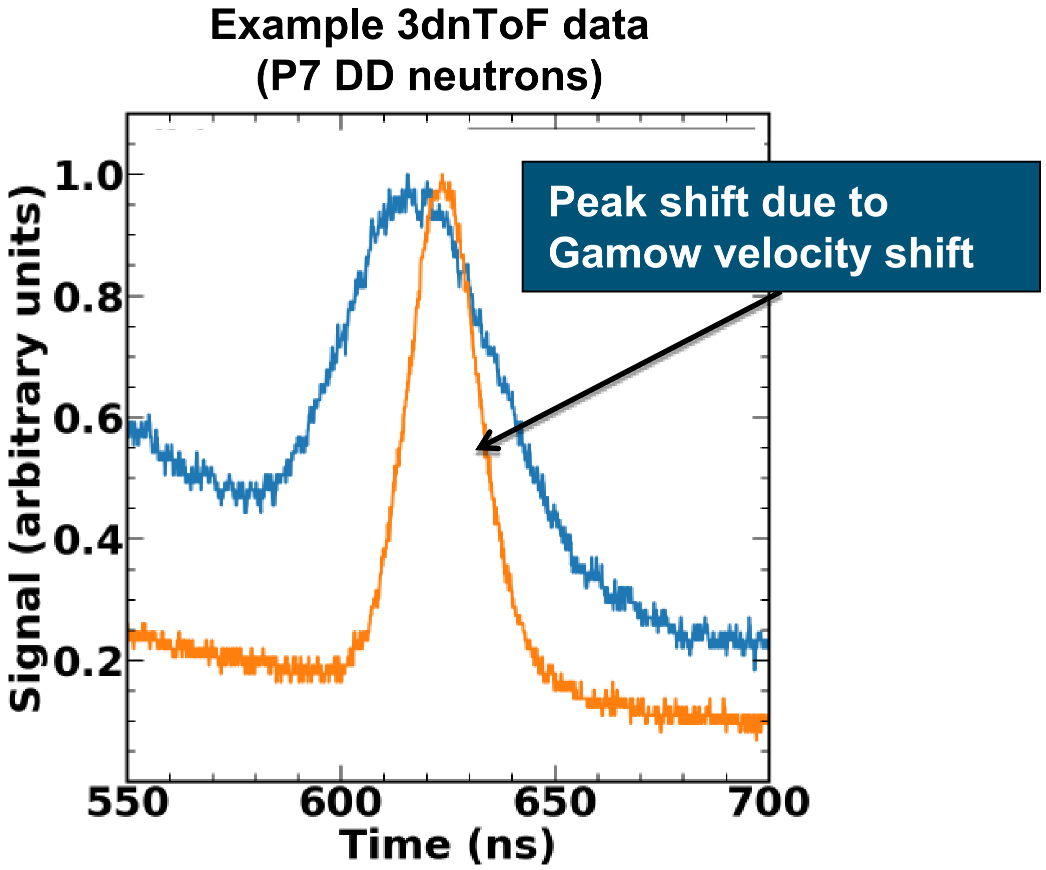
$T_i > 15$ keV
$N_k > 1$

The laser power, shell thickness, and gas pressure were varied to achieve different conditions

$N_k = \frac{\lambda_{ii}}{} \propto \frac{T_i^2}{}$

The 3dnToF detector suite was used to measure the primary DT and DD neutron energy spectrum along multiple lines of sight

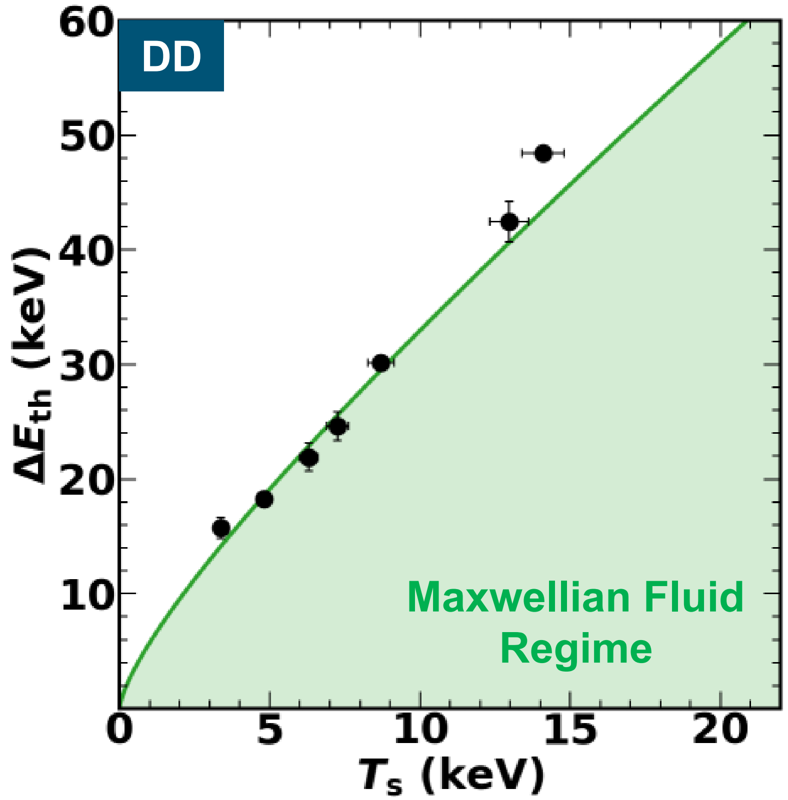


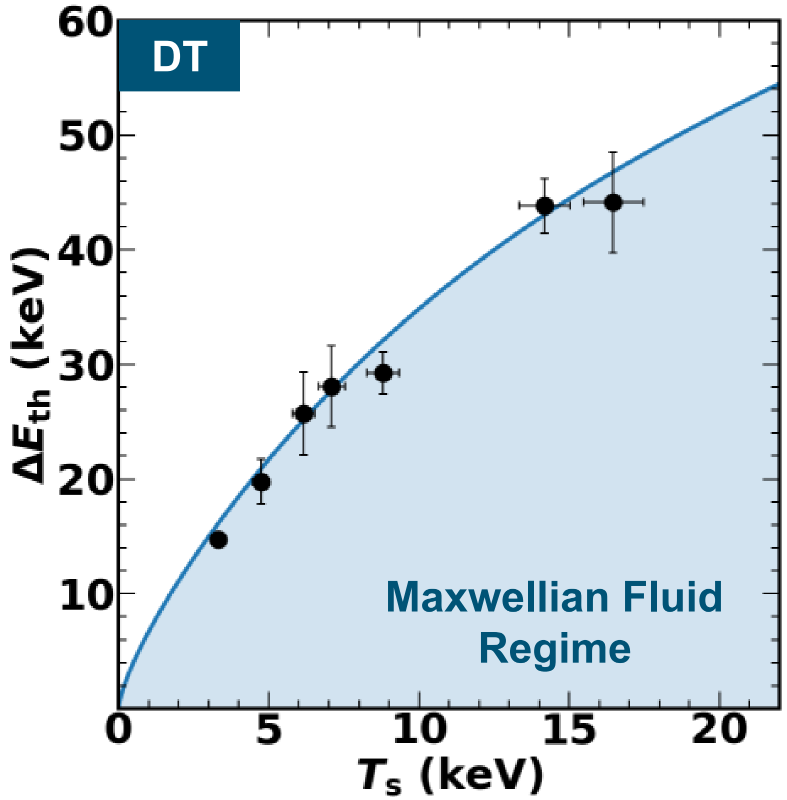


The plasma apparent ion temperature, bulk velocity, and Gamow shift was inferred from these measurements

1. O. M. Mannion et al., Nucl. Instrum. Methods Phys. Res., Sect. A 964, 163774 (2020).

Measurements of the Gamow shift agree with the Maxwellian fluid theory for low temperature implosions but show discrepancies for high temperature implosions

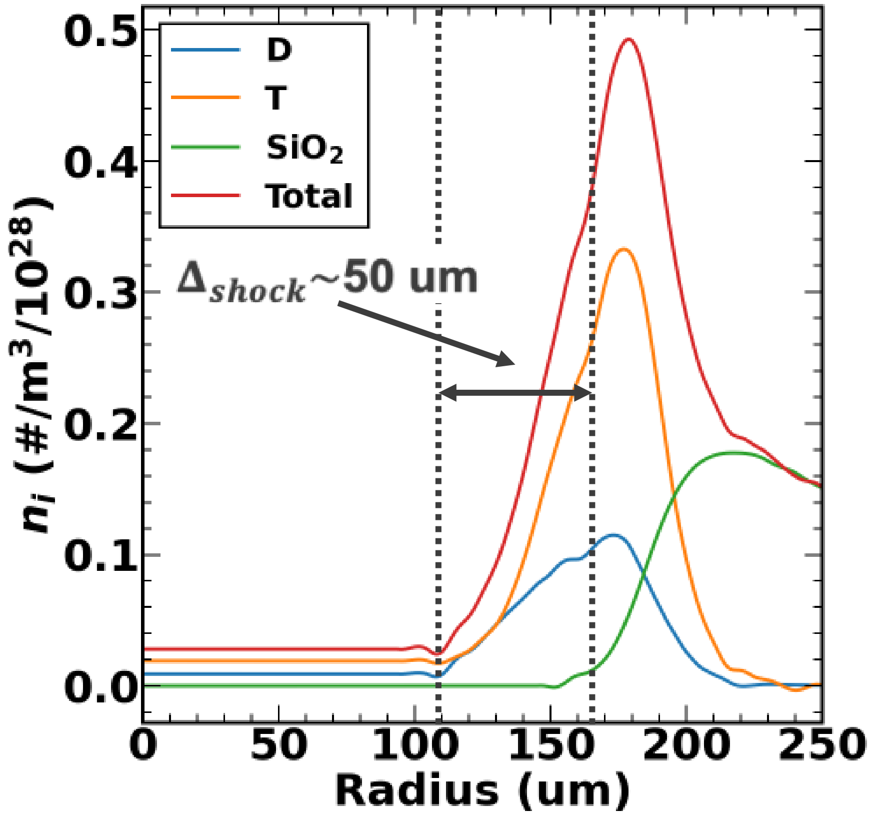




The anomalous DD data points suggest the presence of a non-Maxwellian ion velocity distribution in these kinetic implosions

The multi-ion Vlasov-Fokker-Planck (VFP) code iFP[1] was used to study the anomalous high temperature implosion results

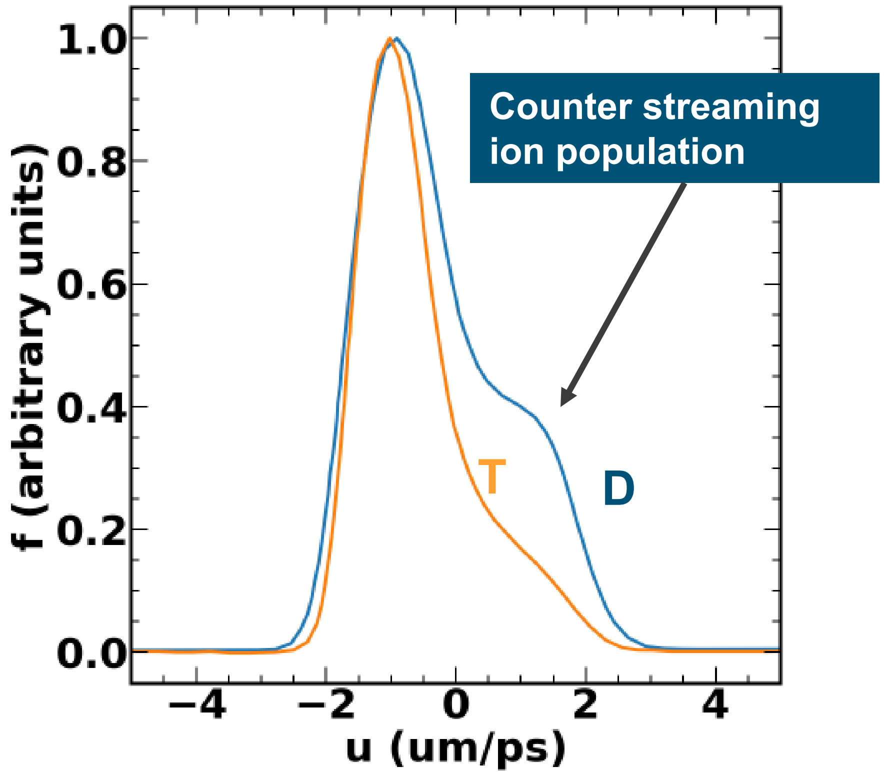
- iFP calculations were initiated half way through the laser pulse using the hydrodynamic profiles from a radiation hydrodynamic simulation
- The ion velocity distribution of each ion species was calculated by solving the VFP equations on a discrete velocity grid

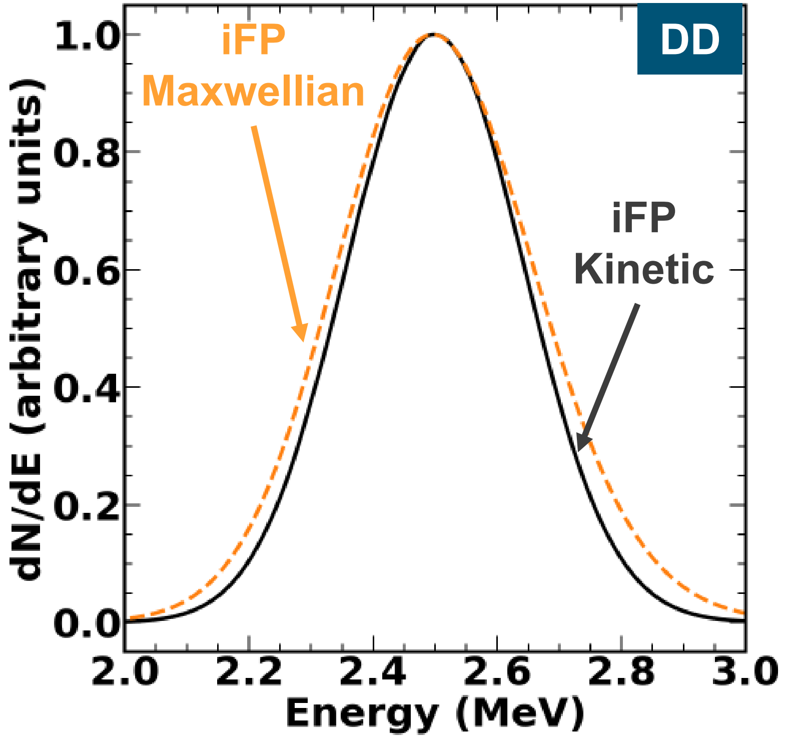


The long mean free paths leads to a smoothing out of the implosions shock front

1. W. T. Taitano, Physics of Plasmas 25 (5) (2018).

The diffuse shock front leads to a bimodal ion velocity distribution at peak neutron production in the iFP simulations

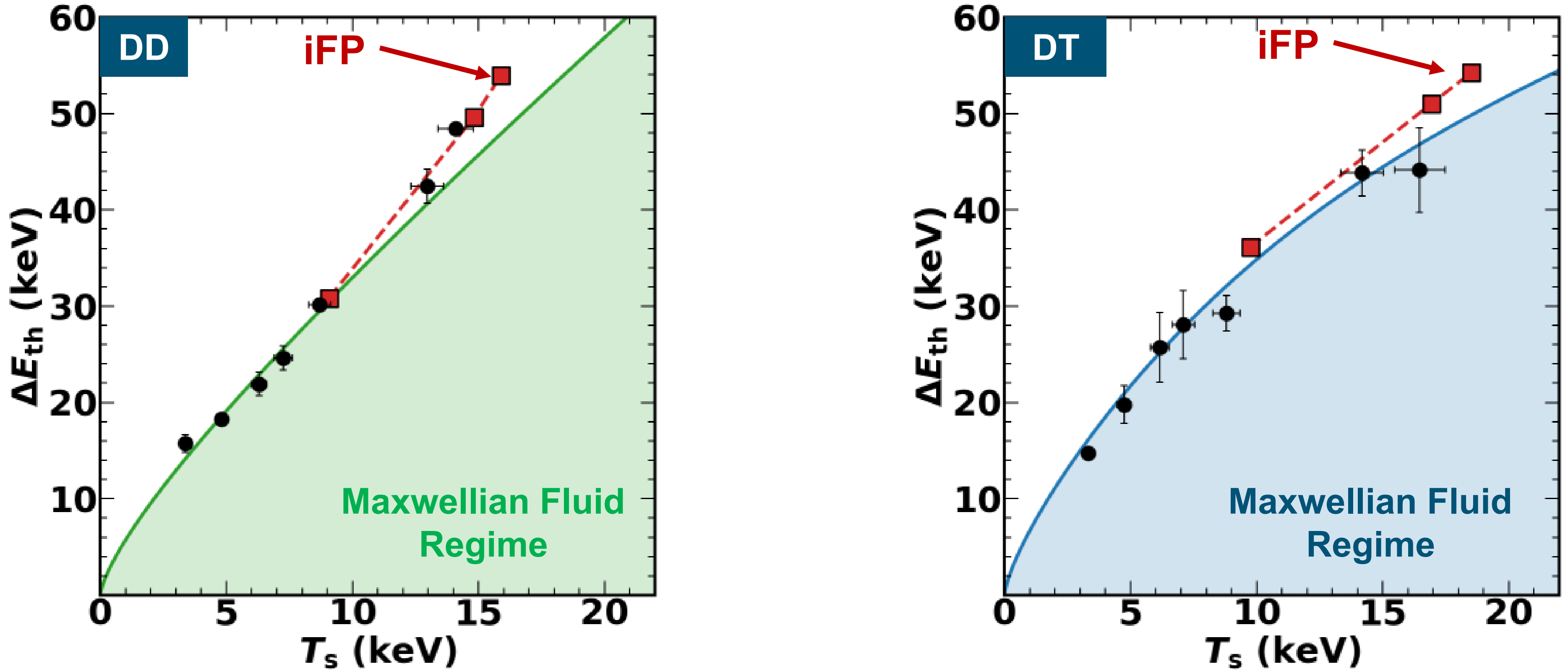




The bimodal ion velocity distribution produces a narrower neutron energy spectrum

1. B. Appelbe, et al., GO07.00008, this conference

The iFP simulations reproduce the trend observed in the high temperature DD primary neutron spectra data



The iFP bimodal ion velocity distribution predictions are consistent with the high temperature DD measurements

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Funding source

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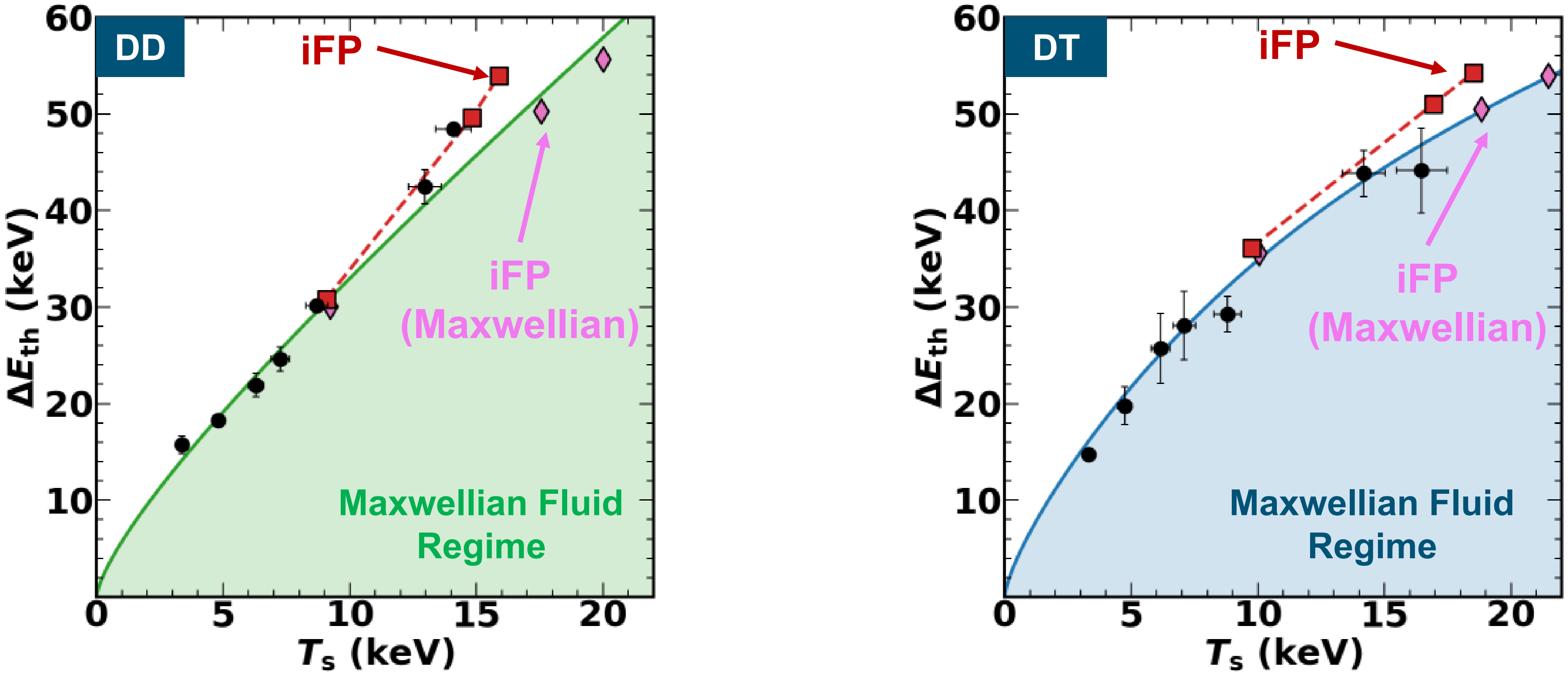

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