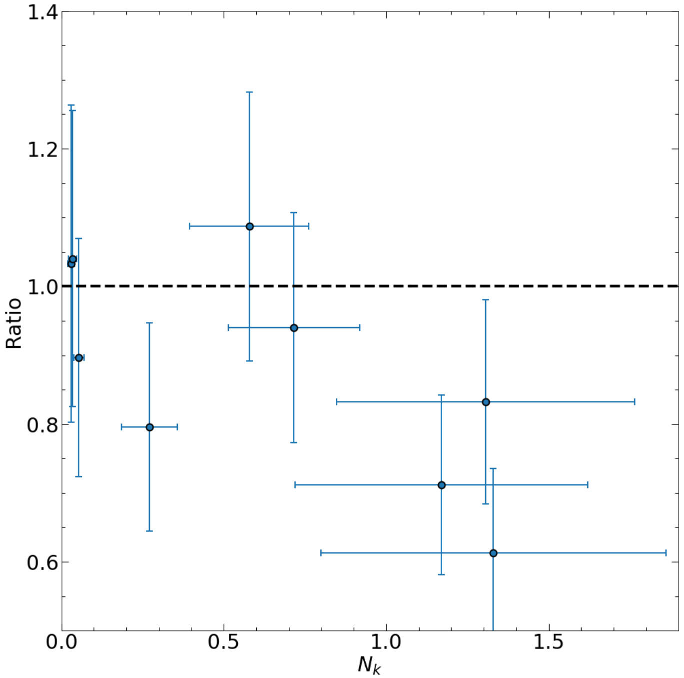
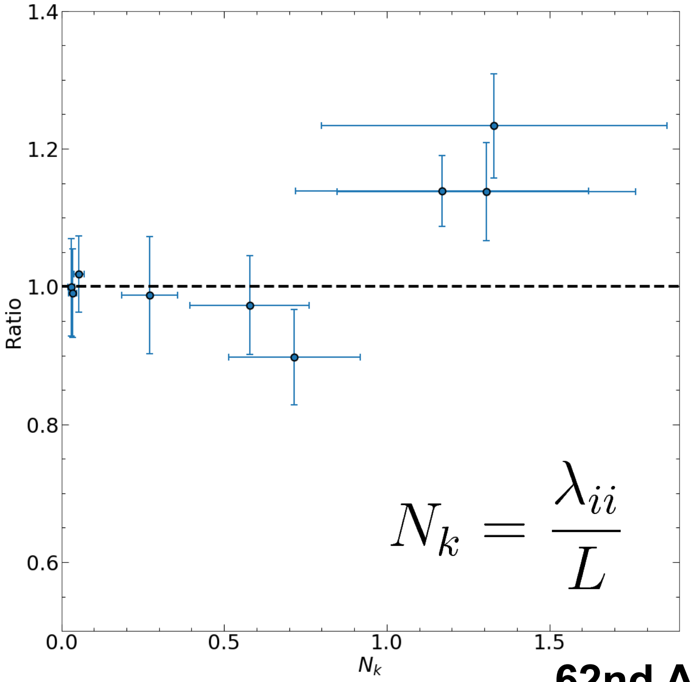
Measurements of the DT and DD neutron energy spectrum in high temperature fusing plasmas

Ratio of 1st and 2nd moment inferred DT ion Temperature



Ratio of 1st and 2nd moment inferred DD ion Temperature



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Laboratory for Laser Energetics

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9–13 November 2020

Summary

The DT and DD neutron energy spectrum emitted from DT plasmas with ion temperatures between 2-18 keV were measured

- High temperature DT plasmas were generated by illuminating DT filled spherical capsules with the OMEGA 60 laser
- The DT and DD neutron energy spectrum emitted from these plasmas were measured using a suite of neutron time of flight detectors
- The plasma temperature was inferred from the neutron energy spectrum using the Gamow velocity shift (1^{st} moment)[†] and the energy spectrum variance (2^{nd} moment)
- The ion temperature inferred from the 1^{st} moment and 2^{nd} moment are consistent for low Knudsen number plasmas

These results will be compared with Vlasov-Fokker Plank (VPF) calculations[*,] to investigate kinetic effects on the moments of the neutron energy spectrum**

* W.T. Taitano, Phys. Plasmas 25, 056310 (2018).
**B. Appelbe *et al.*, GO11.00001, this meeting
† A. Moore *et al.*, NO05:9, this meeting

Collaborators

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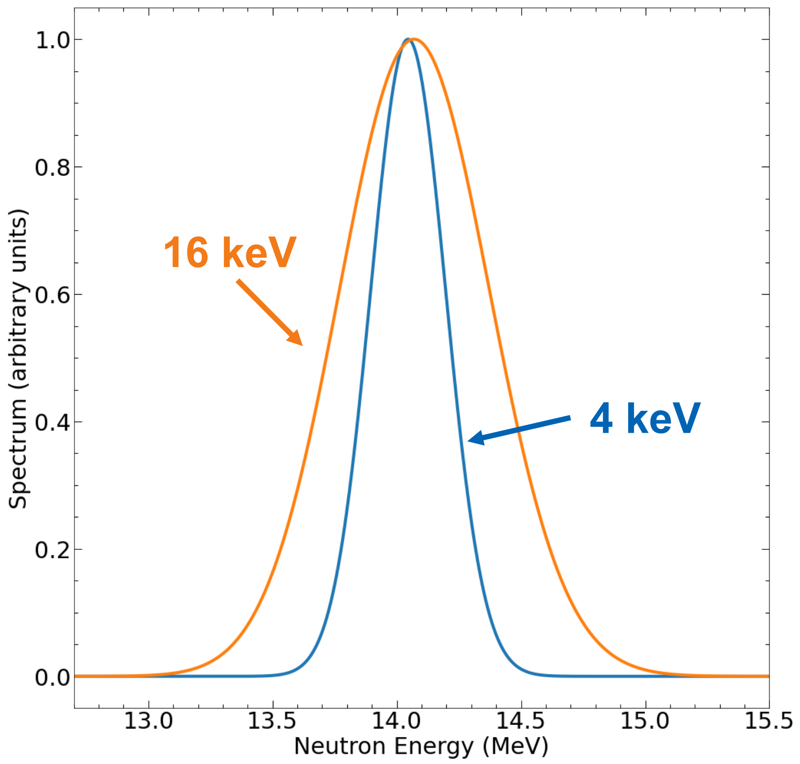
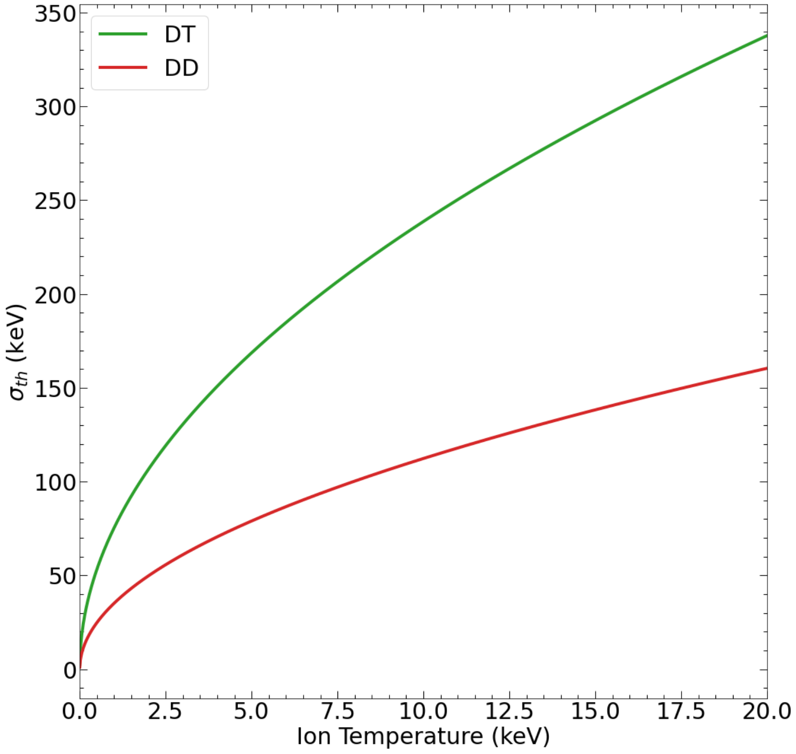
Massachusetts Institute of Technology

The neutron energy spectrum emitted from a fusing plasma contains important diagnostic information on the plasma conditions

Model DT Neutron Energy Spectrum**



Neutron energy spectrum variance as a function of ion temperature*,**



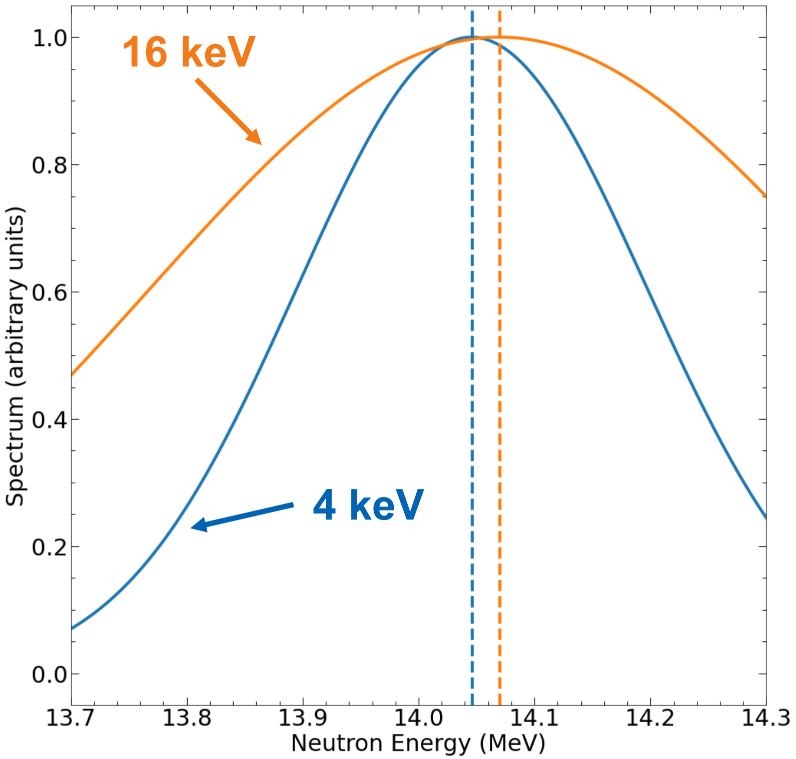
The second moment of the neutron energy spectrum can be used to infer the plasma ion temperature

* H. Brysk, Plasma Phys. 15, 611 (1973).

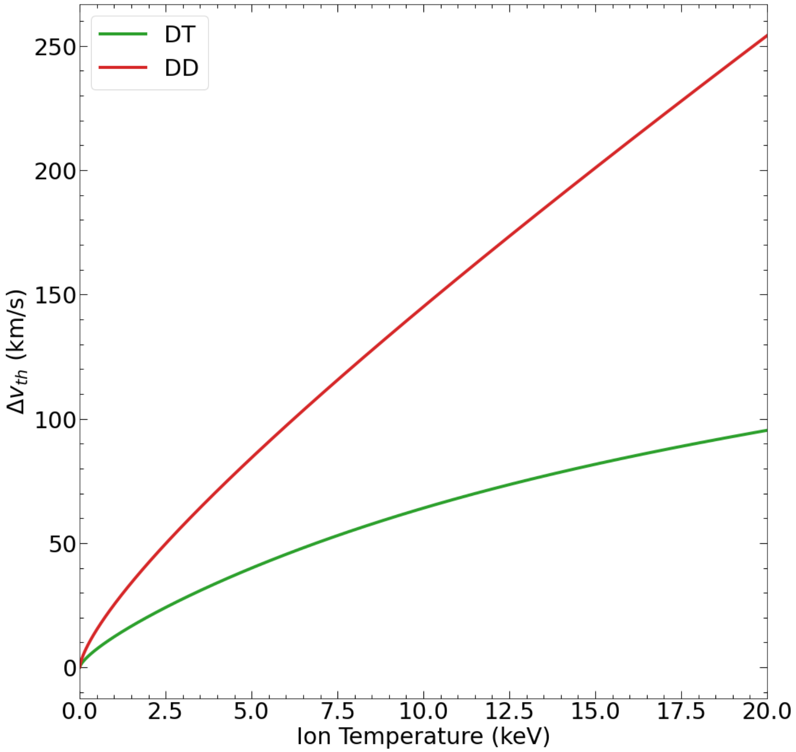
**L. Ballabio, J. Källne, and G. Gorini, Nucl. Fusion 38, (1998).

The neutron energy spectrum emitted from a fusing plasma contains important diagnostic information on the plasma conditions

Model DT Neutron Energy Spectrum**



Gamow velocity shift as a function of ion temperature*,**

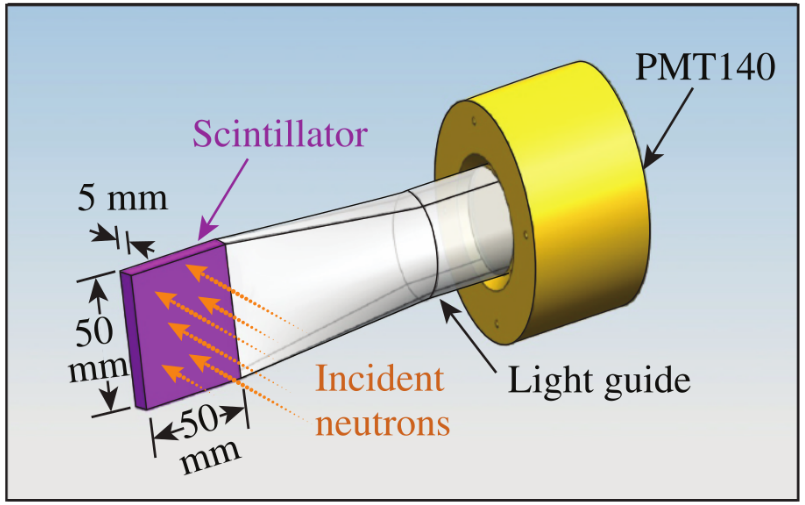


The first moment of the neutron energy spectrum can be used to infer the plasma ion temperature

* H. Brysk, Plasma Phys. 15, 611 (1973).
**L. Ballabio, J. Källne, and G. Gorini, Nucl. Fusion 38, (1998).

A suite of neutron time of flight (nToF) detectors*,† are used to measurement the 1st and 2nd moment of the neutron energy spectrum

nToF Detector Design**



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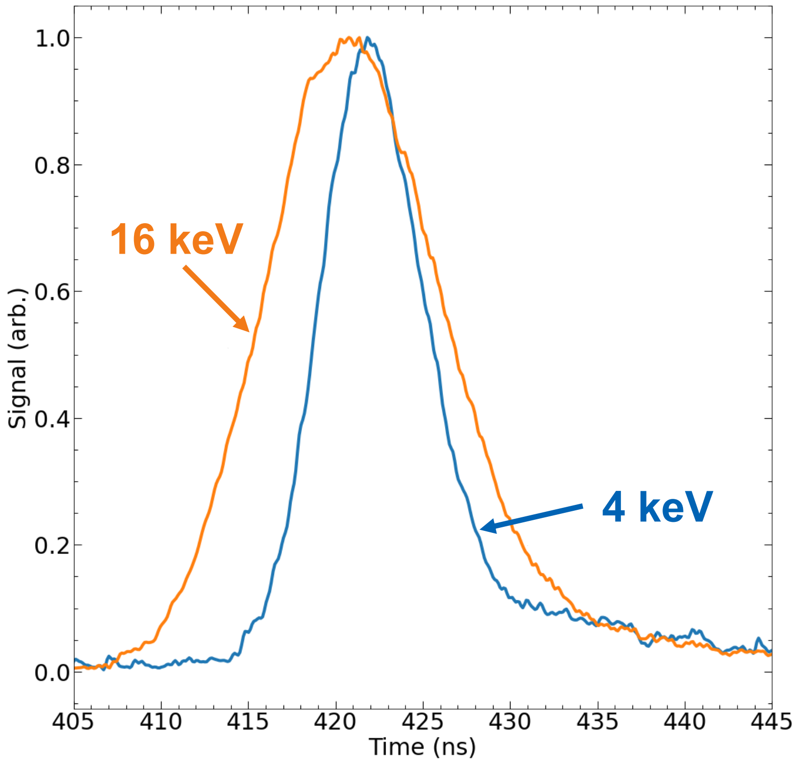
Example DT nToF data

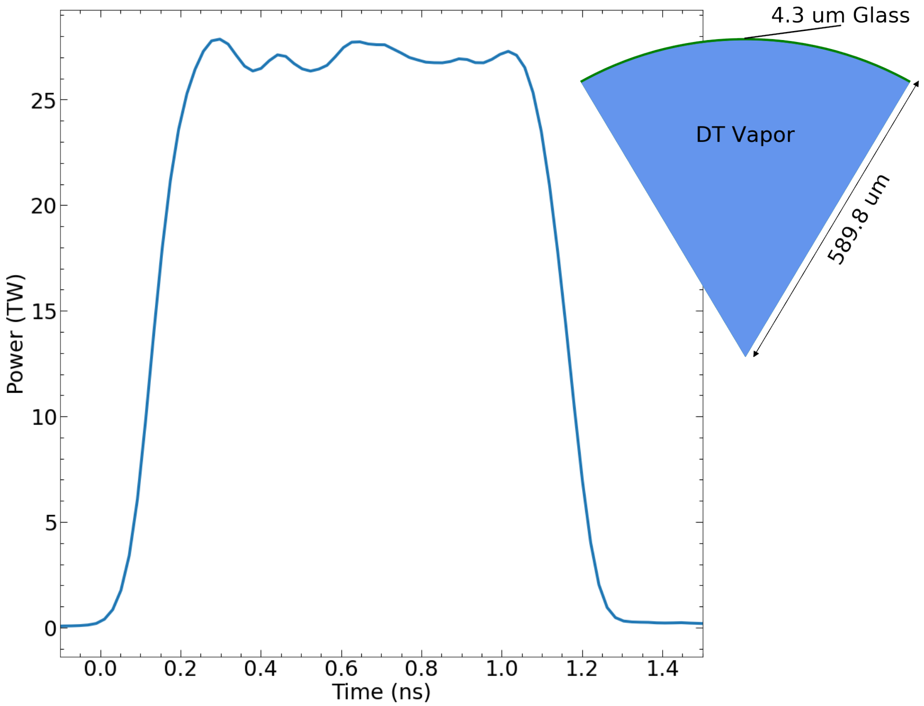


The DT neutron energy spectrum is measured along 5 lines of sight (LOS) and the DD neutron energy spectrum is measured along 2 LOS

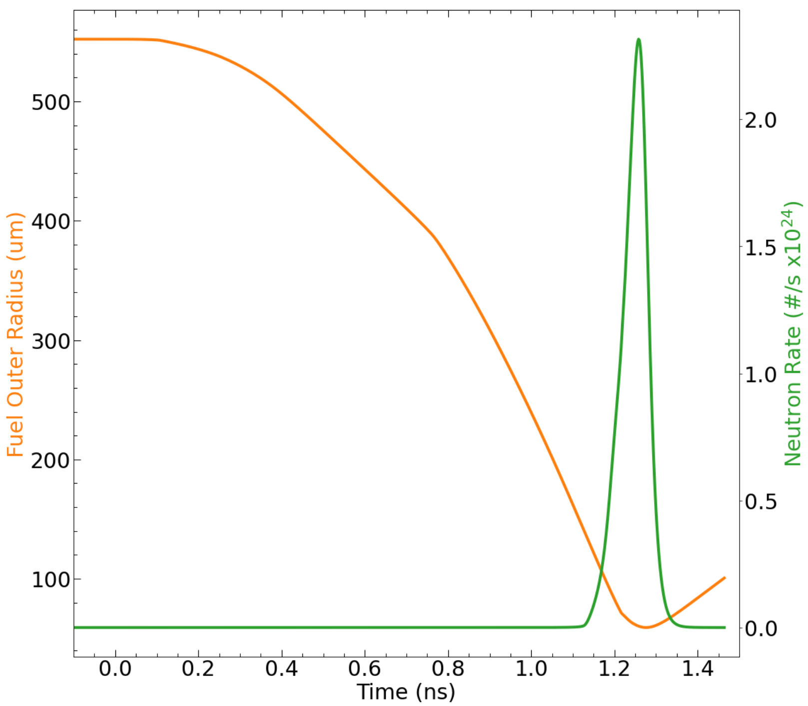
*O. M. Mannion et al., Nucl. Instrum. Methods Phys. Res. Sect. A 964, 163774 (2020).
** O.M. Mannion, et al., Rev. Sci. Instrum. 89, 10I131 (2018).
†R. Hatarik, Rev. Sci. Instrum. 89, 10I138 (2018).

A set of experiments were performed to generate plasmas from 2-18 keV and a comparison was made between the 1st and 2nd moment ion temperatures

Laser pulse and target design



Implosion and neutron production time history



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

The ion temperature inferred from the 1st moment and 2nd moment are consistent for low Knudsen number plasmas

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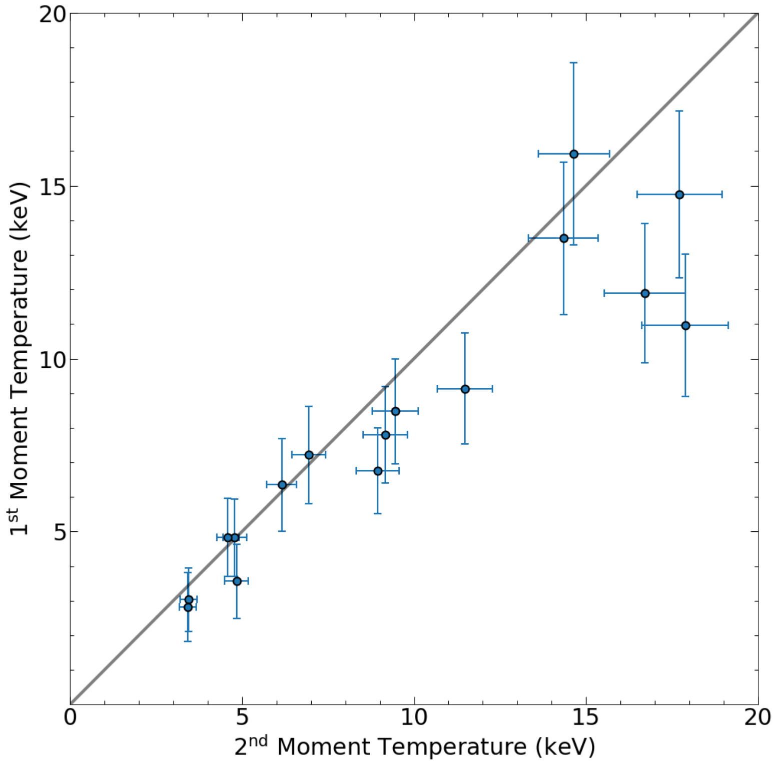
Temperature inferred from DT fusion neutron spectrum



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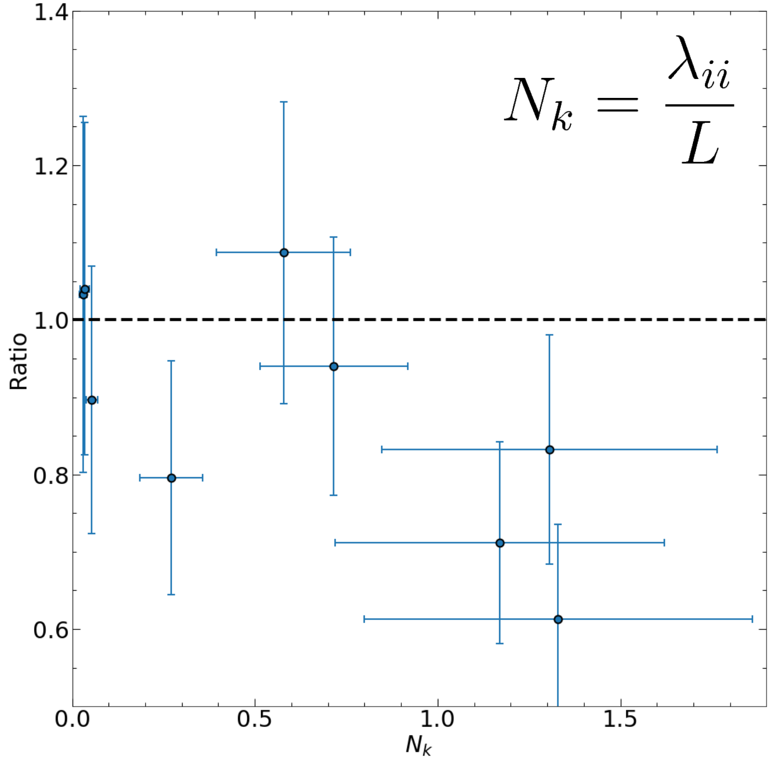
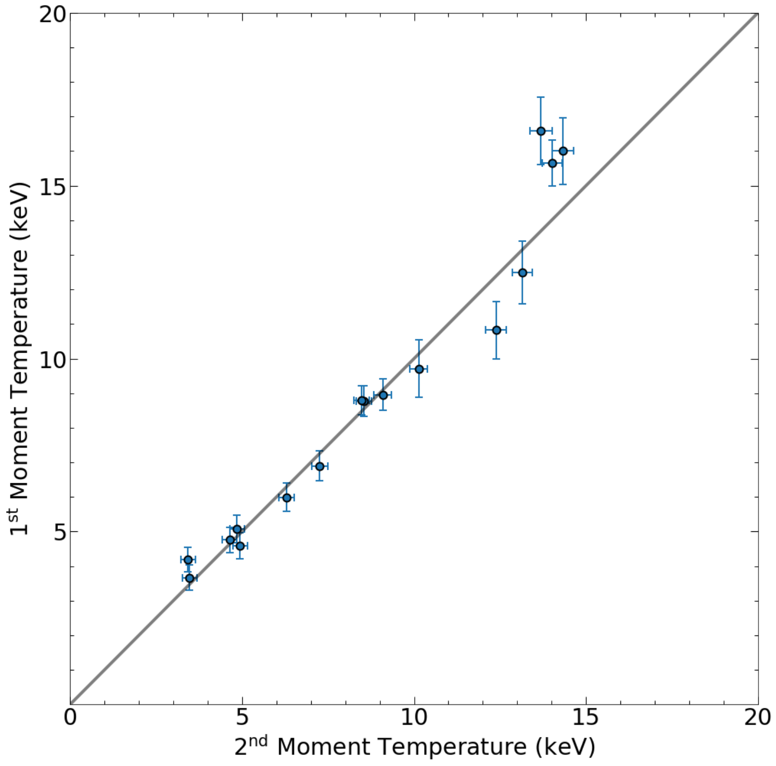
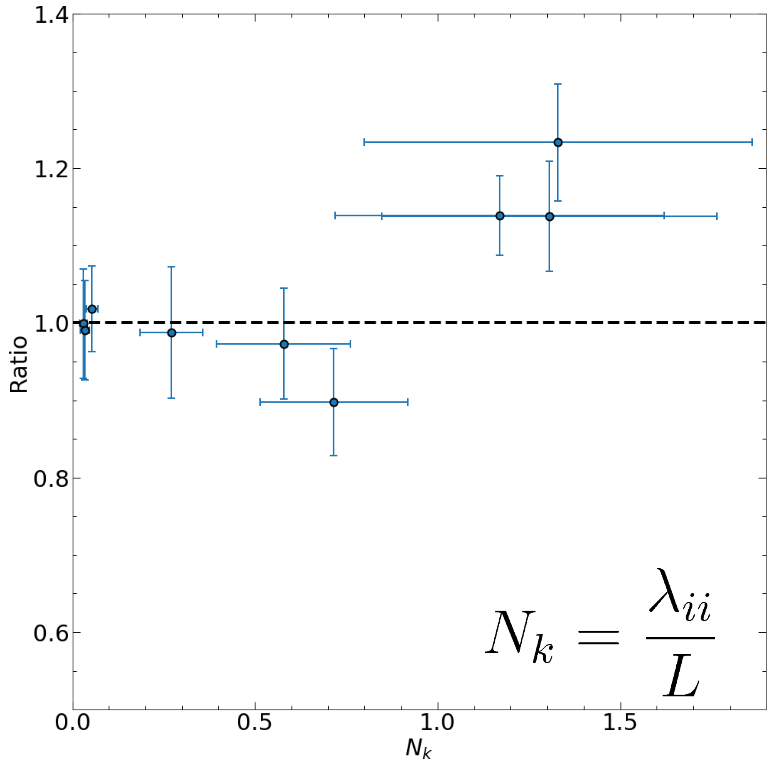


The ion temperature inferred from the 1st moment and 2nd moment are consistent for low Knudsen number plasmas

Temperature inferred from DD fusion neutron spectrum*



Ratio of 1st and 2nd moment inferred DD ion Temperature



The source of the increasing discrepancy in these two measurements at large Knudsen number is being studied

*A systematic error of 20 km/s in the DD Gamow shift measurement has been removed from the data

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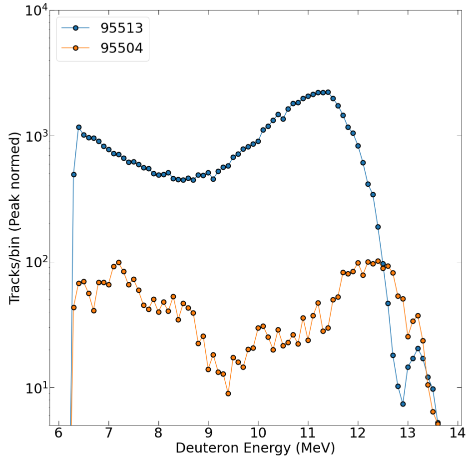
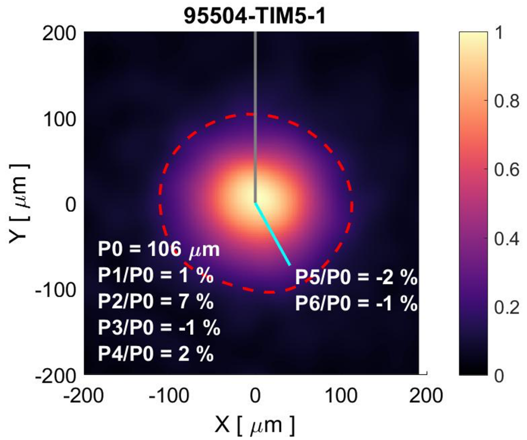
Backup Slides

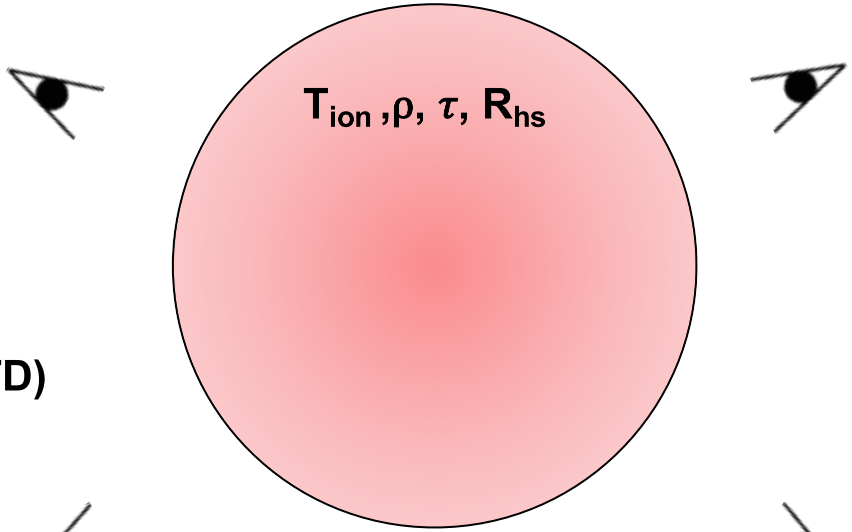
The conditions of the fusing plasmas at peak compression were measured using x-ray and nuclear diagnostics

Hot spot areal density (KO-D)

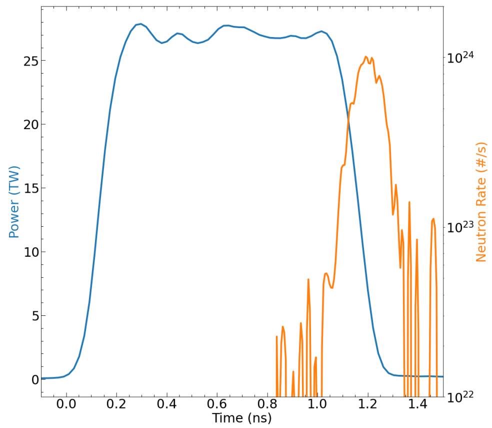


Hot spot size (PCIS)

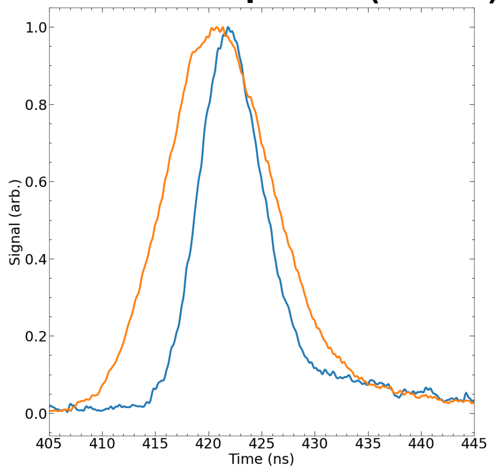




Neutron production rate (NTD)



Neutron Spectra (nToFs)



The plasma Knudsen number has been estimated from the hot spot radius, areal density, and ion temperature

- The Knudsen number is given by*

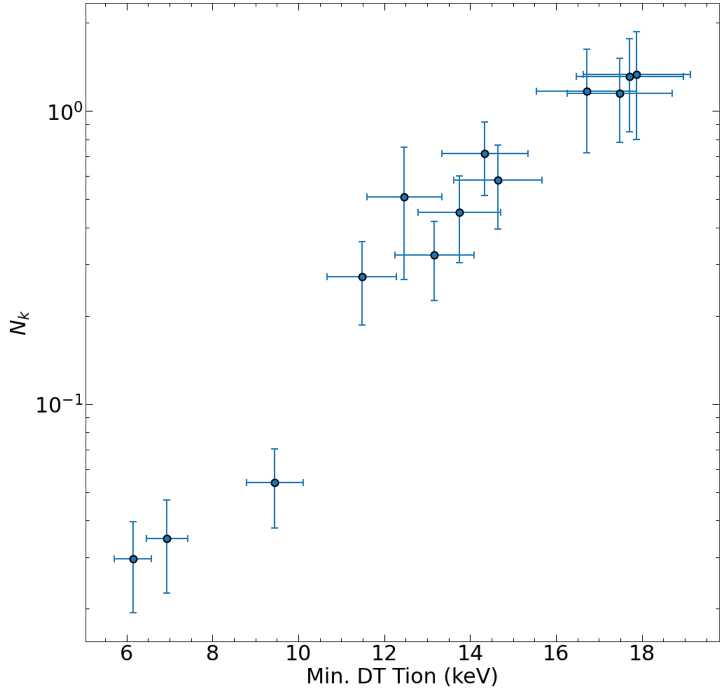
$$N_K = \frac{\lambda_i}{L} \approx 0.092 \frac{\langle A \rangle}{2.5} \frac{4}{\ln \Lambda} \frac{T_i^2}{\rho L}$$

- The Coulomb Log is calculated the NRL** expression or with the approximation assuming a single temperature plasma

$$\lambda_{ii'} = \lambda_{i'i} = 23 - \ln\left[\frac{ZZ'(\mu+\mu')}{\mu T_{i'} + \mu' T_i}\left(\frac{n_i Z^2}{T_i} + \frac{n_{i'} Z'^2}{T_{i'}}\right)^{1/2}\right].$$

- Using the areal density from KO-D ρR and hot spot radius from x-ray images we can calculate the hot spot density

Inferred Knudsen number vs DT ion temperature



*K. Molvig et. al., Phys. Rev. Lett. 109, 1 (2012).
**J. D. Huba, NRL Plasma Formulary (2009)

* First reference
** Second reference
† Third reference
‡ Fourth reference