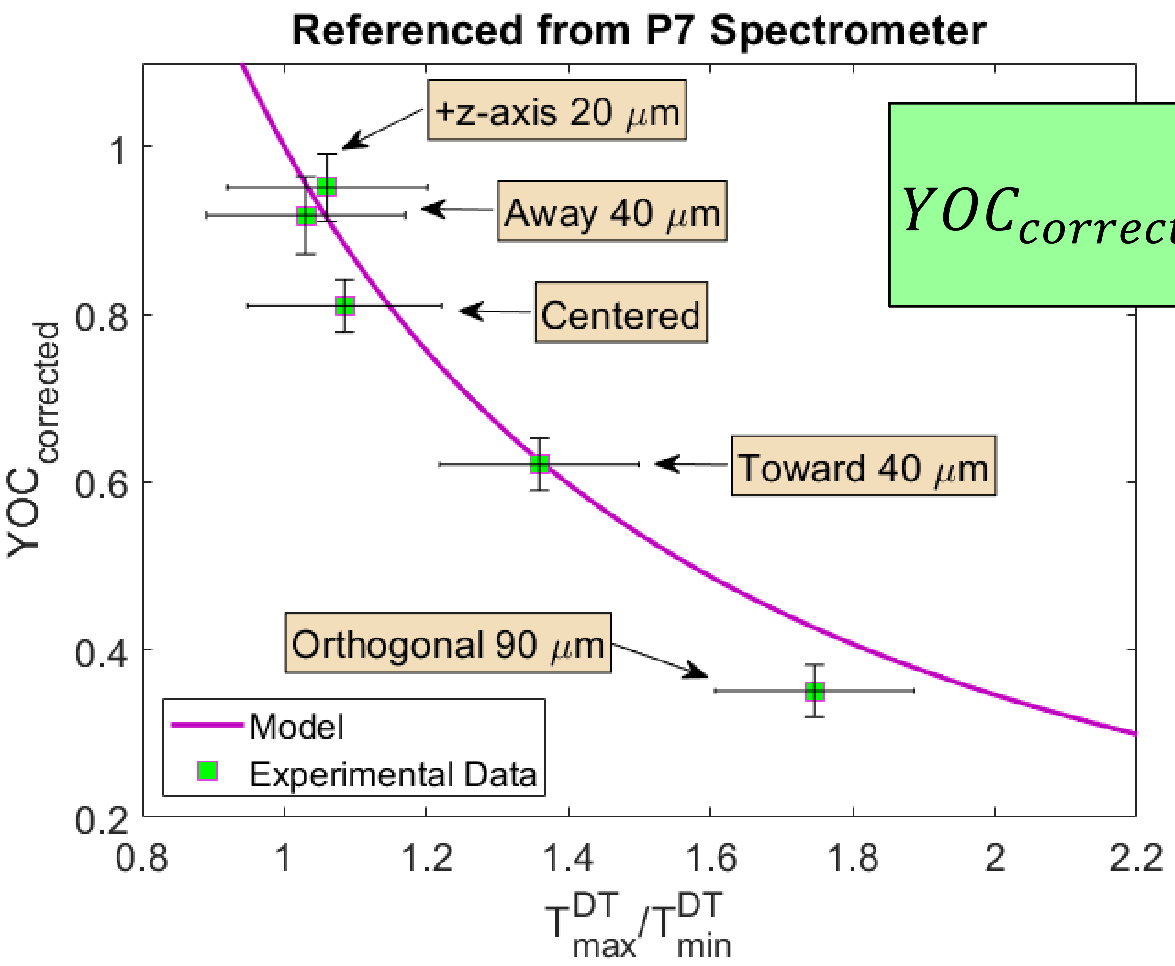
Inference of Isotropic and Anisotropic Flow in Laser Direct-Drive Cryogenic DT Implosions on OMEGA



$$YOC_{corrected} = \left(\frac{T^{DT}_{max}}{T^{DT}_{min}}\right)^{-1.53}_{l=1}$$

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Summary

A model to predict the yield degradation from anisotropic flow due to low-modes (l=1) shows good agreement with experimental data

- An isotropic and anisotropic flow can introduce additional broadening of the second moment on the energy distribution of fusion-produced neutrons.*
- An experimental campaign was designed to introduce low-mode variations in the fuel assembly with predefined target offsets.
- The anisotropic flow inferred from the second moment is consistent with a systematic low-mode in the laser system.

*K. Woo *et al*., Phys. Plasmas 27, 062702 (2020).

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Collaborators

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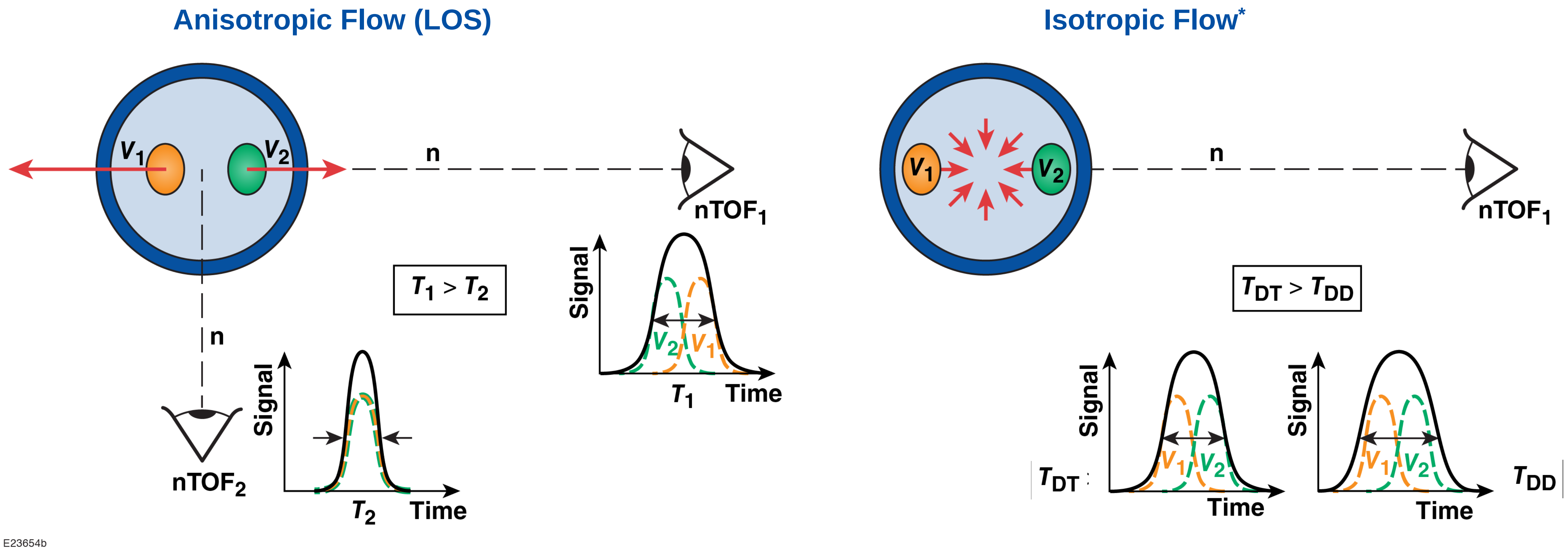
Two different mechanism can introduce broadening on the energy distribution of fusion-produced neutrons used to infer the temperature of the reactants



Anisotropic and isotropic flows is a signature of hot-spot residual kinetic energy (RKE) and can be determined since they have a different effect on the DT and DD ion temperatures.

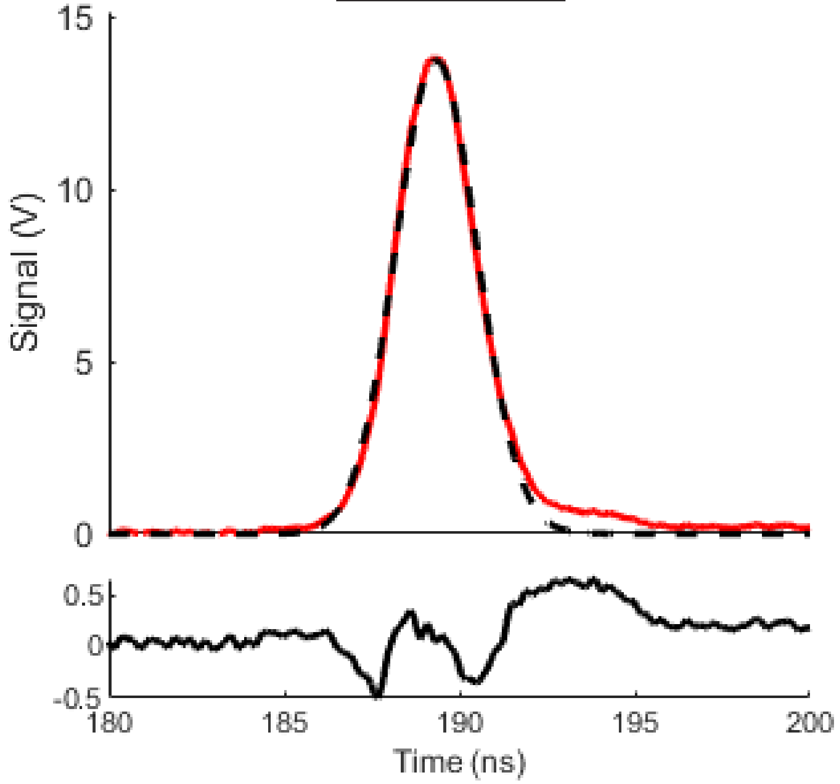
*Murphy *et al*., Rev. Sci. Instrum. 68, 614 (1997).

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

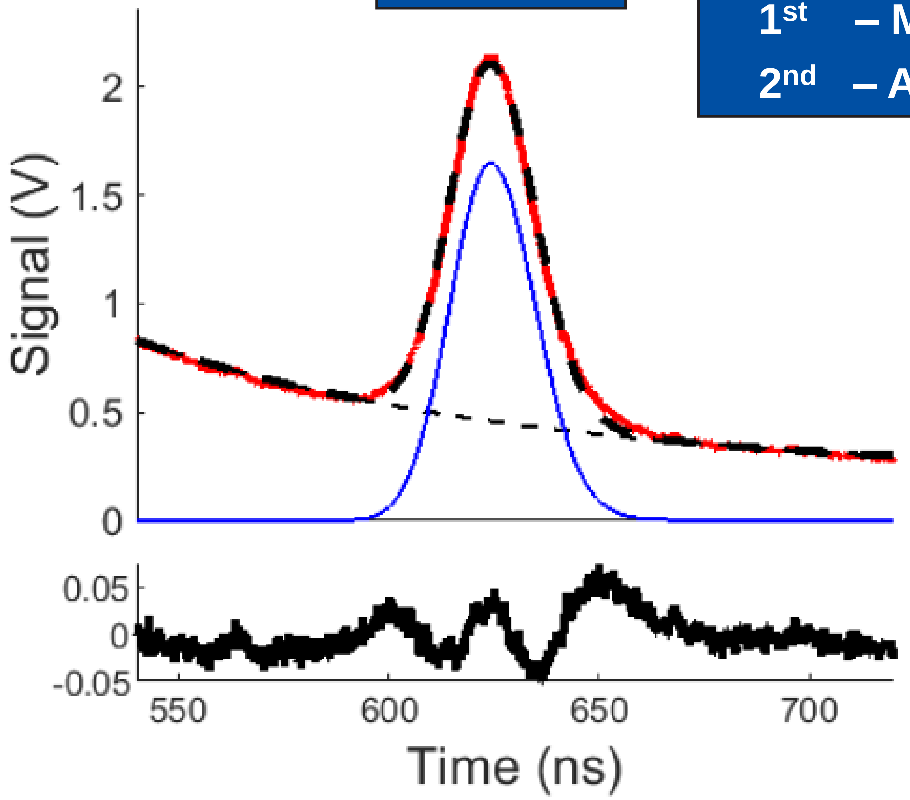
$$I(t) = c\left[S(E)_{los} S(E)_{nlo} \frac{dN}{dE}\frac{dE}{dt}\right] \otimes R(E,t)^{**}$$

Moment
- 0^{th} – Neutron Yield
- 1^{st} – Mean Energy Shift
- 2^{nd} – Apparent Ion Temperature

DT Peak



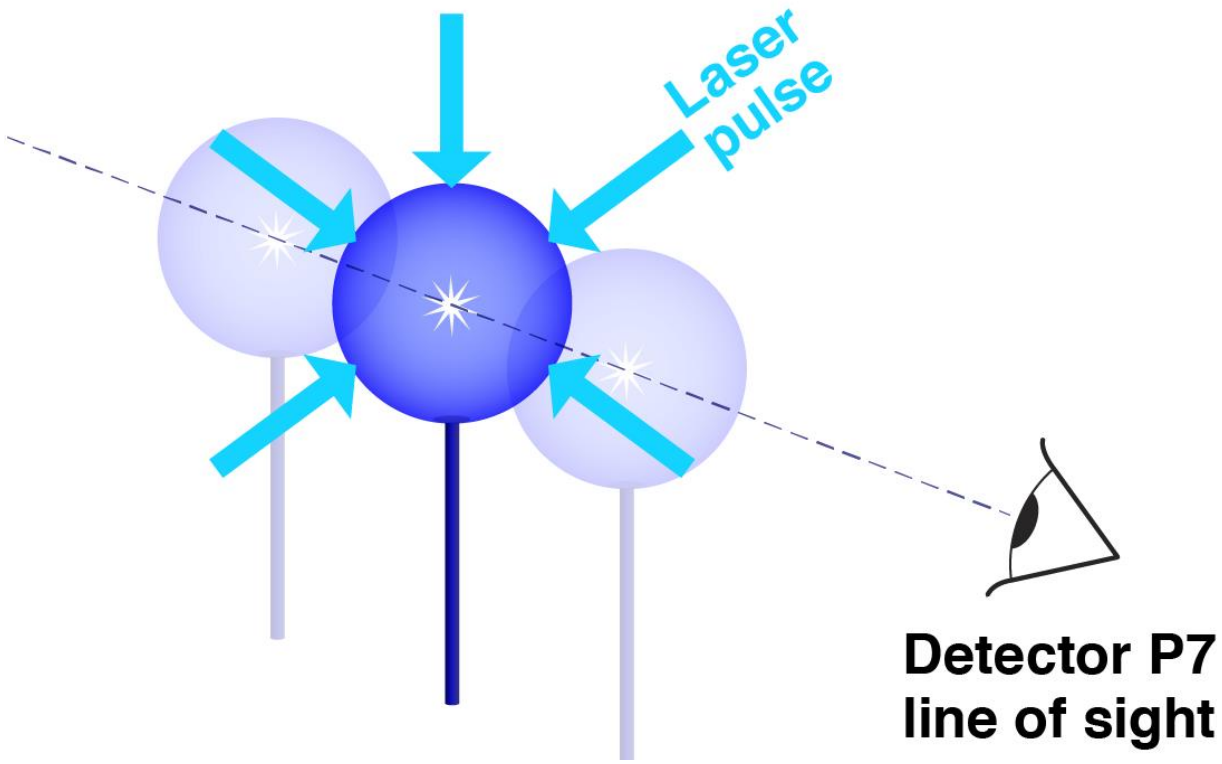
DD Peak



The line-of-sight $S(E)_{los}$ attenuation, non-linear light output $S(E)_{nlo}$, and $R(E,t)$ were modeled using a neutron transport code (MCNP).

*L. Ballabio, J. Källne, and G. Gorini, Nucl. Fusion 38, 1723 (1998).
**Mohamed et al., Submitted to Journal of Applied Physics. (2020).

An experimental campaign was designed to introduce low-mode variations in the fuel assembly with predefined target offsets



The target was positioned with 5 different offsets to the detectors line-of-sight (i.e. P7).

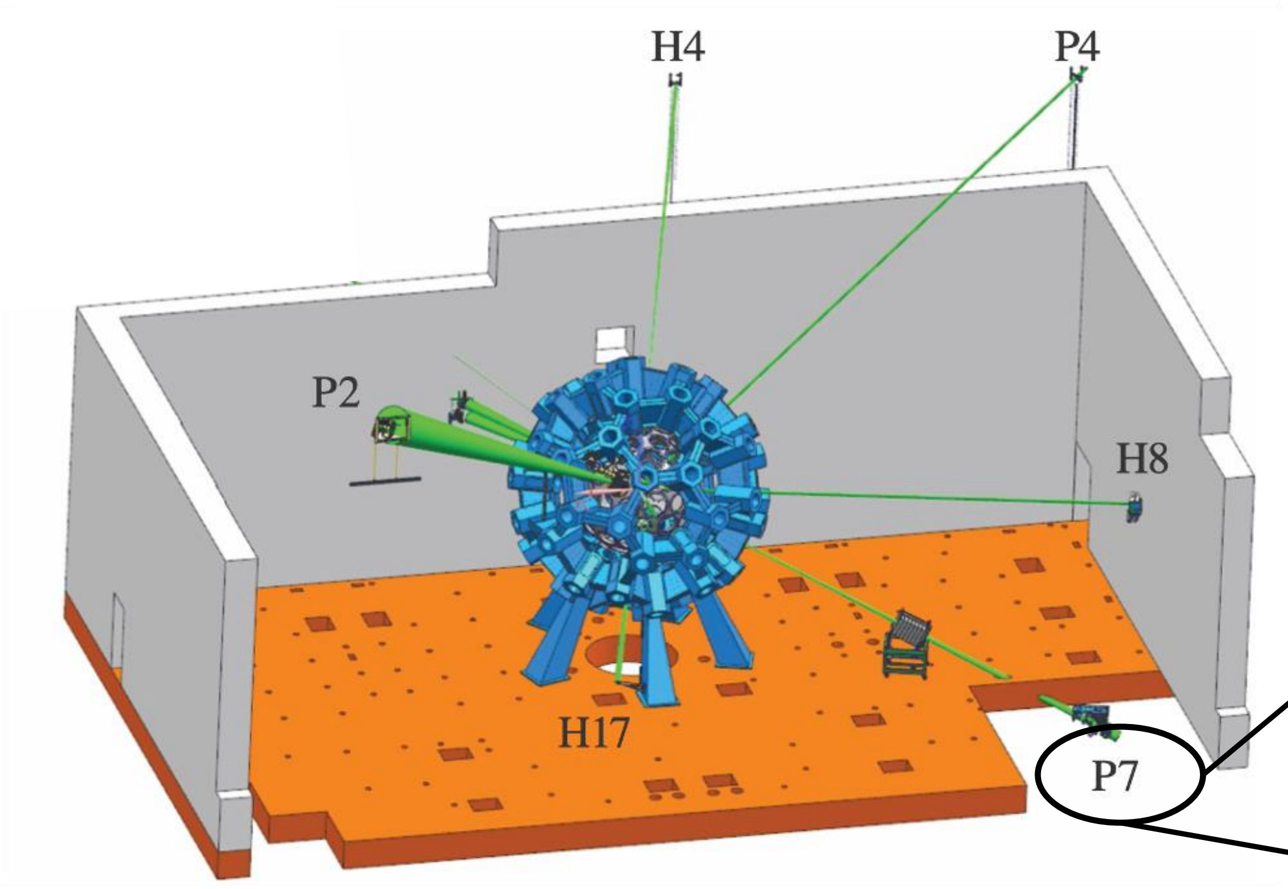
1. Target chamber center (TCC)
2. Away from detector (40 μm)
3. Toward detector (40 μm)
4. Orthogonal to detector (90 μm) [not shown]
5. Along the positive z-axis (20 μm) [not shown]

Laser parameters remained constant in this direct-drive cryogenic DT experimental campaign.

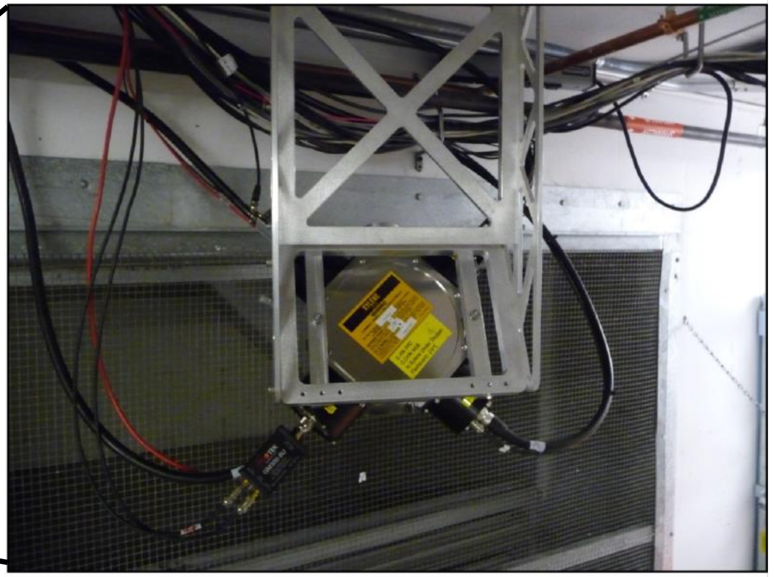
The goal for this campaign was to see if variations in the experimental parameters including residual kinetic energy (RKE) can be inferred.

Neutron time-of-flight diagnostics are positioned strategically around the OMEGA target chamber to provide a set of 3D measurements

OMEGA Target Chamber



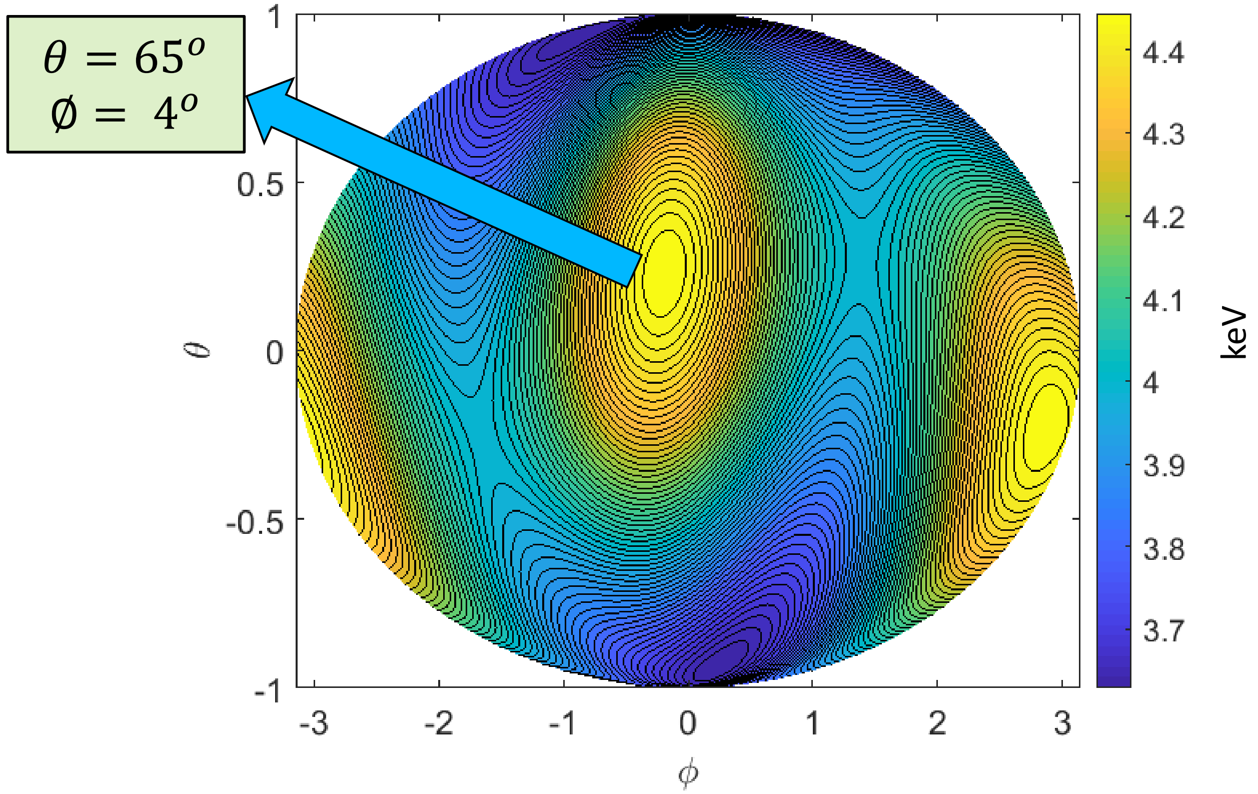
The 2nd moment of the neutron distribution is used to interpret the apparent temperature of the reactants from several lines-of-sight.

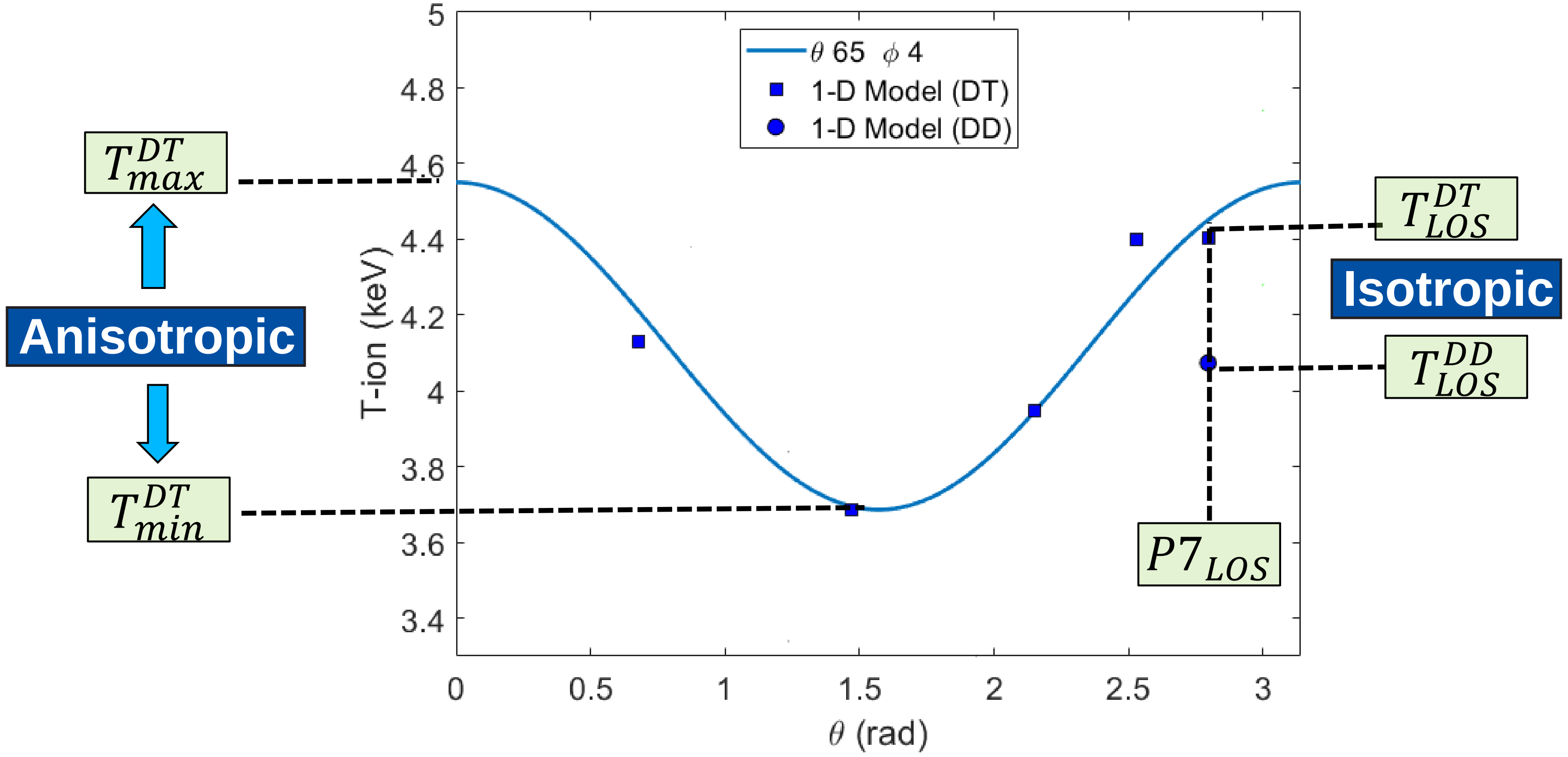


T^{DT}_{los} = 5 lines-of-sight (H2,P4,H8,H4,P7)

T^{DD}_{los} = 1 lines-of-sight (P7)

A variation in the apparent ion temperatures can be well represented with a cosine-square variation along the measured hot-spot flow axis





The hot-spot flow is directed away from the P7 line-of-sight as expected with the presence of a l=1 mode

$$T^{DT} = T^{th} + M_{DT}\sigma^2_{iso} + M_{DT}\sigma^2_{aniso}cos^2(\theta)$$

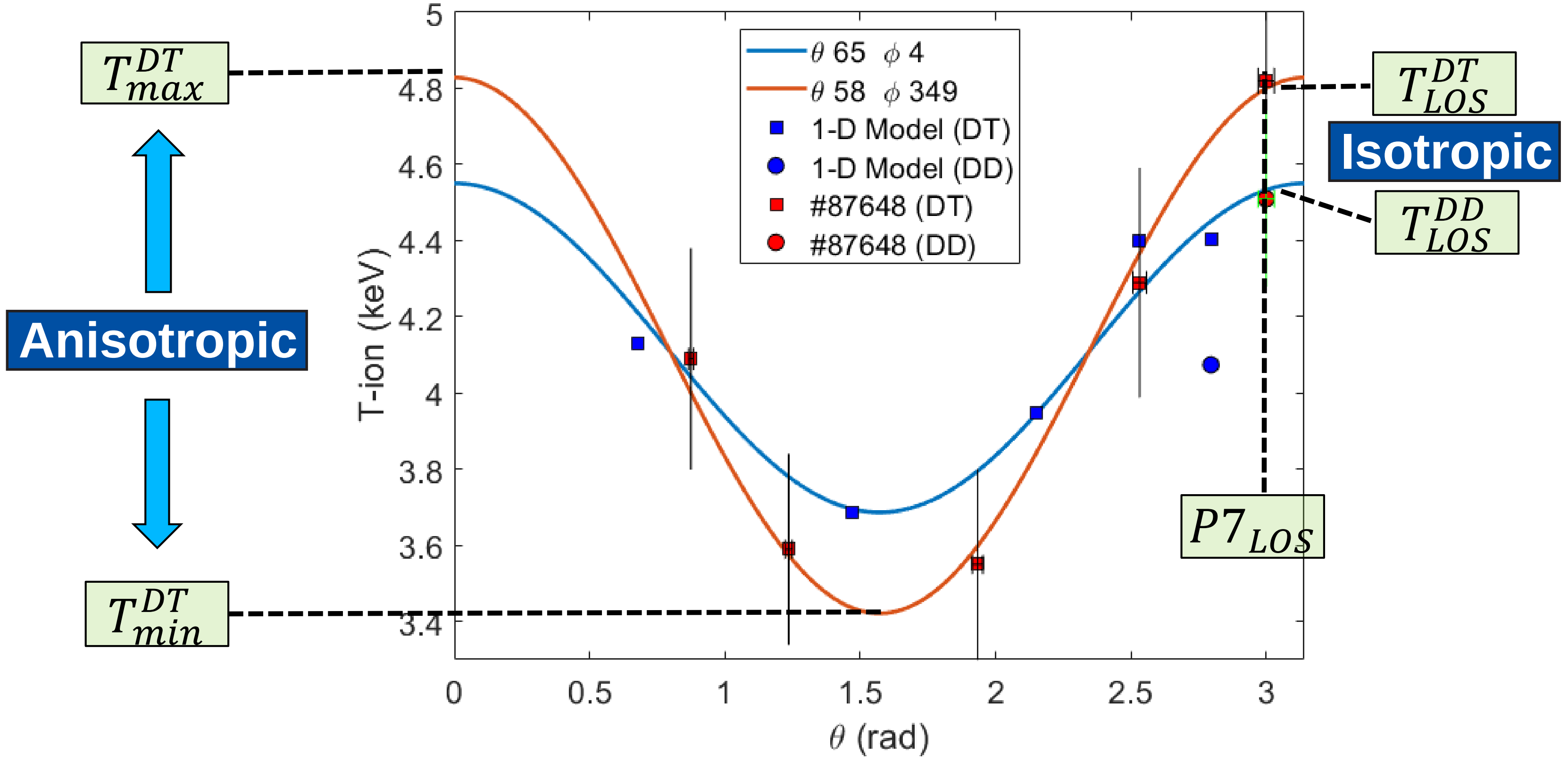
A semi-empirical model of the ion temperature variation shows good agreement with the experimental data with the -40 um target offset

Evaluation of the isotropic term.

A ~200 eV difference in the apparent DT and DD temperature from this campaign infers an indeterminate isotropic contribution.

Evaluation of the anisotropic term.

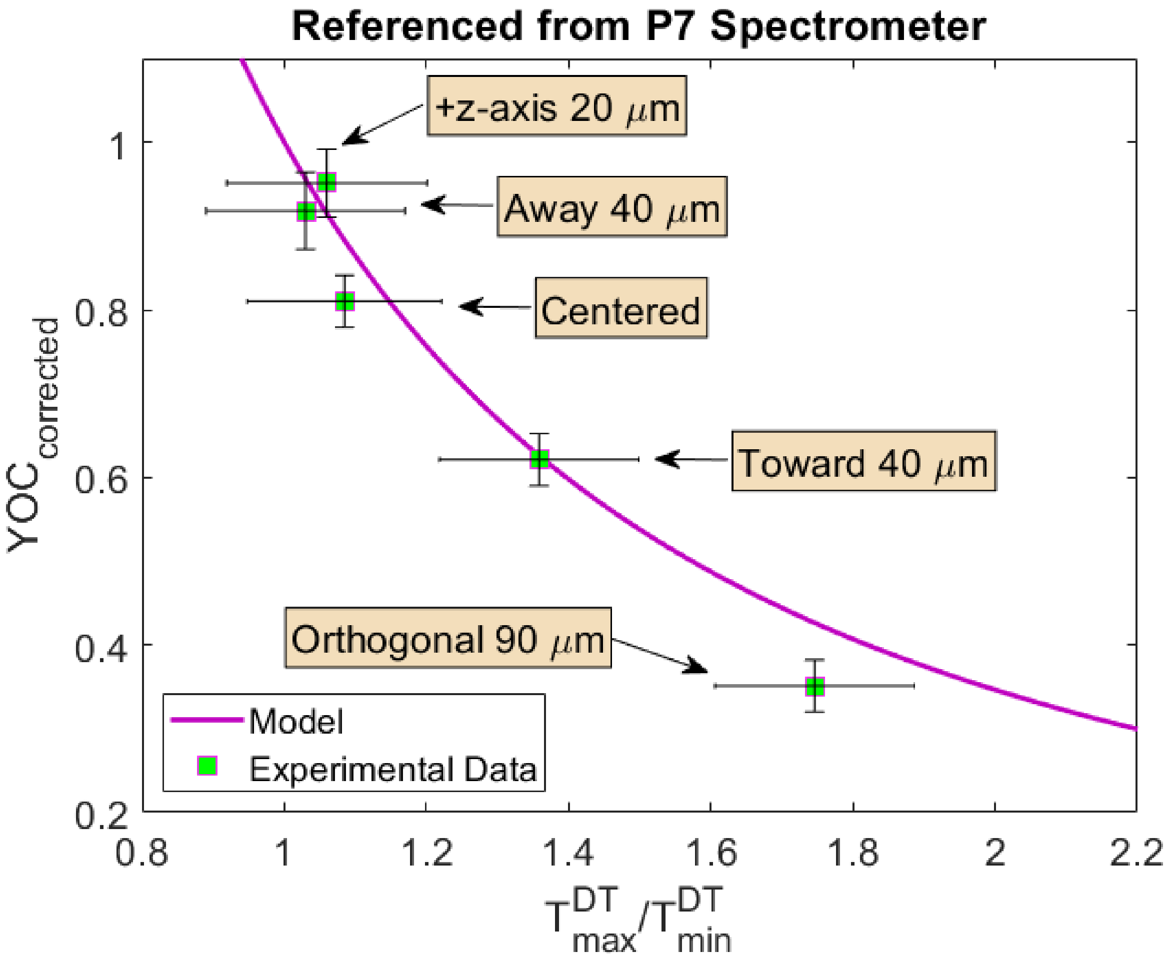
In the presence of large anisotropic flows the ion temperature asymmetry can explain yield degradations.*,**



$$YOC_{corrected} = (1 - RKE)^u = \left(\frac{T_{max}^{DT}}{T_{min}^{DT}}\right)_{l=1}^{-1.53}$$

*K. Woo *et al.*, Phys. Plasmas 27, 062702 (2020).
**A.Lees *et al.*, Phys. Rev. Lett. 127, 105001 (2021)

A model to predict the yield degradation from anisotropic flow due to low-modes shows good agreement with experimental data



$$YOC_{corrected} = \left(\frac{T^{DT}_{max}}{T^{DT}_{min}}\right)^{-1.53}_{l=1}$$

A disagreement with the yield degradation is observed in the example with the target moved away from the P7 line-of-sight.

Other experimental campaigns around this time period did observe unexpected results that were indicating that there was an inherent low-mode:

- **Beam-pointing**
- **Beam-energy imbalance**

The anisotropic flow inferred from the second moment is consistent with a systematic low-mode (l=1) that leads to a yield degradation.

A model to predict the yield degradation from anisotropic flow due to low-modes (l=1) shows good agreement with experimental data

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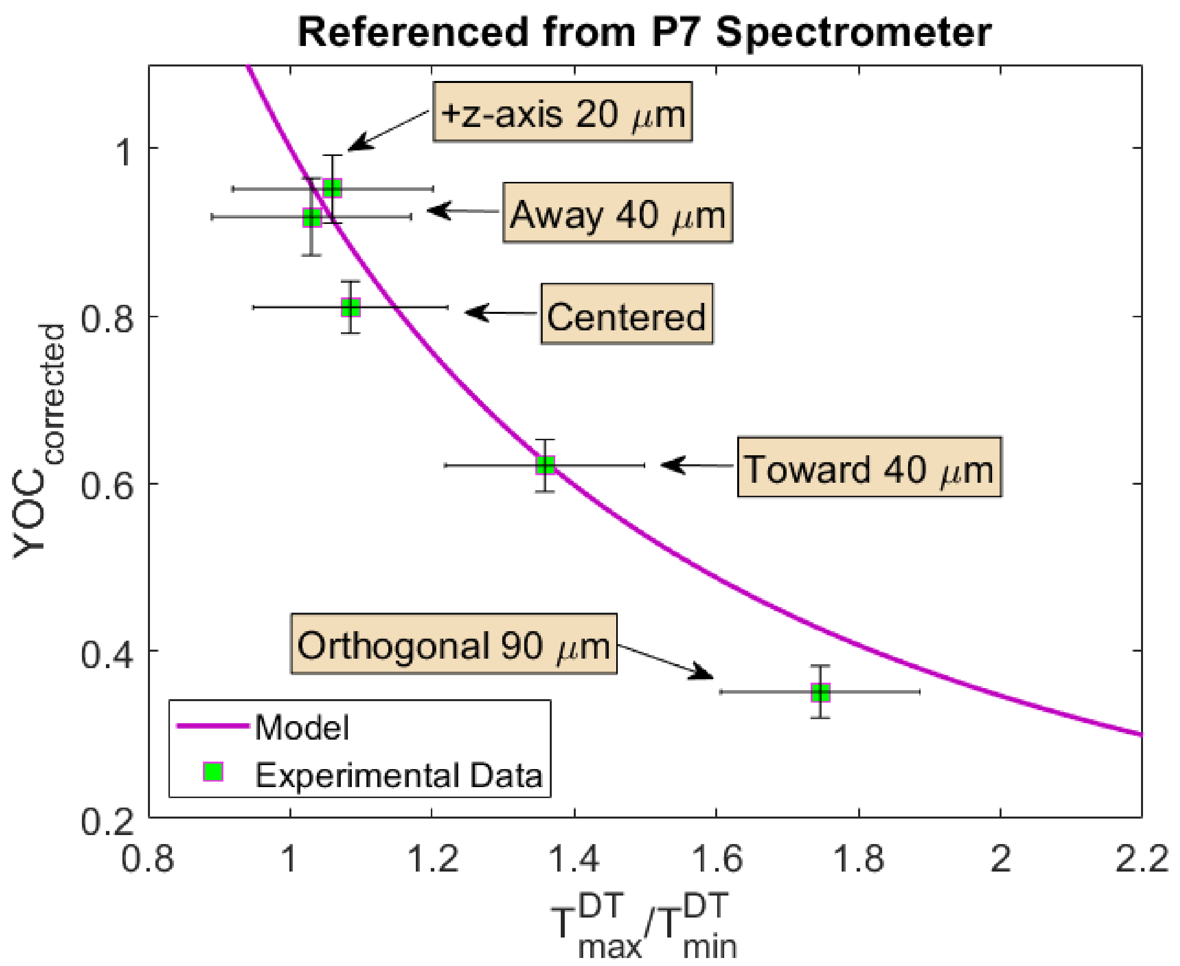

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Shot #	Primary DT Neutron Yield	Anisotropic Flow (km/s)^2	Offset
87638	1.81e13	3.60e4	Orthogonal (90-um)
87644	4.51e13	3.85e3	Z-axis (-20-um)
87648	2.71e13	2.45e4	Away (-40-um)
87651	4.55e13	2.10e3	Centered
87653	4.12e13	5.39e3	Toward (+40-um)

The anisotropic flow inferred from the second moment is consistent with a systematic low-mode.