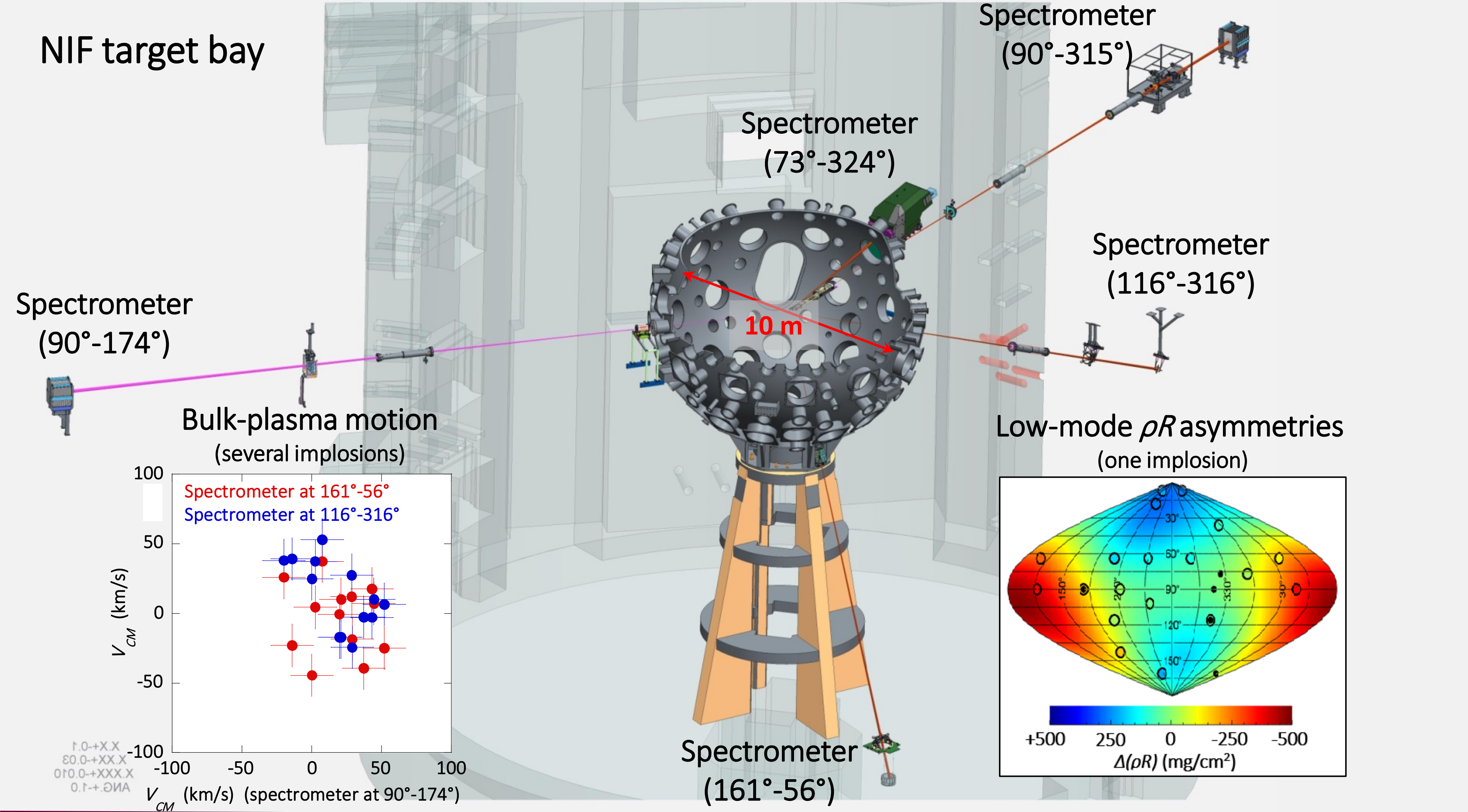
Observations of residual bulk-plasma motion and low-mode areal-density (ρR) asymmetries near peak convergence in NIF implosions



NIF target bay

Spectrometer (90°-315°)

Spectrometer (73°-324°)

Spectrometer (116°-316°)

Spectrometer (90°-174°)

Spectrometer (161°-56°)

Bulk-plasma motion (several implosions)

Low-mode ρR asymmetries (one implosion)

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Massachusetts Institute of Technology

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Collaborators and Sponsors

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Measured neutron spectra indicate substantial bulk-plasma motion and low-mode areal-density (*ρR*) asymmetries near peak convergence in NIF implosions

- Difference between the observed DT and DD apparent ion temperature ("T_i") increases with increasing implosion velocity and kinetic energy in the system.

- 2D simulations cannot describe the neutron data for implosion velocities > 340 km/s (when "T_i" is above 4 keV).

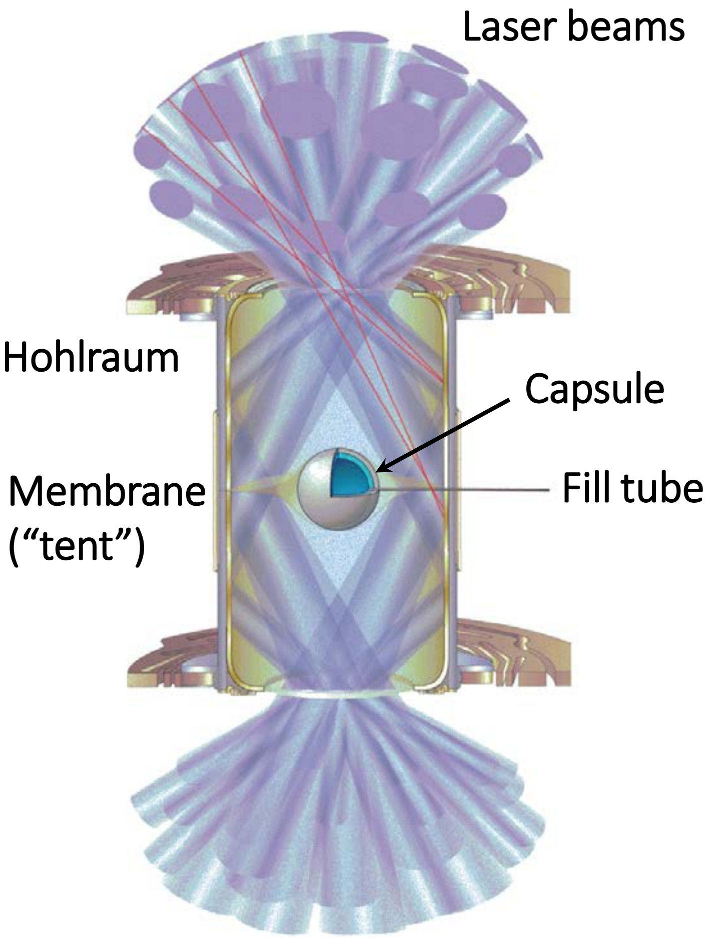
- Neutron data indicate substantial low-mode *ρR* asymmetries near peak convergence with regions of high *ρR* values at the poles or near the fill tube depending on experiment.

- 3D simulations indicate that these asymmetries prevent efficient conversion of implosion kinetic energy to thermal energy, resulting in substantial and bulk-plasma motion near peak convergence.

- Tent, fill tube and Hohlraum drive asymmetries are the largest performance degradation sources, which are being addressed by implementing new engineering solutions, more refined modeling and new diagnostics.

Data will be shown from two implosion campaigns, which used a wide range of experimental configurations[1-2]

Laser energy:	0.7–1.7 MJ
Laser power:	290–435 TW
Implosion velocity:	300–390 km/s
Capsule ablator:	165–195 um thick CH or HDC
Holhraum diameter:	5.75–6.72 mm



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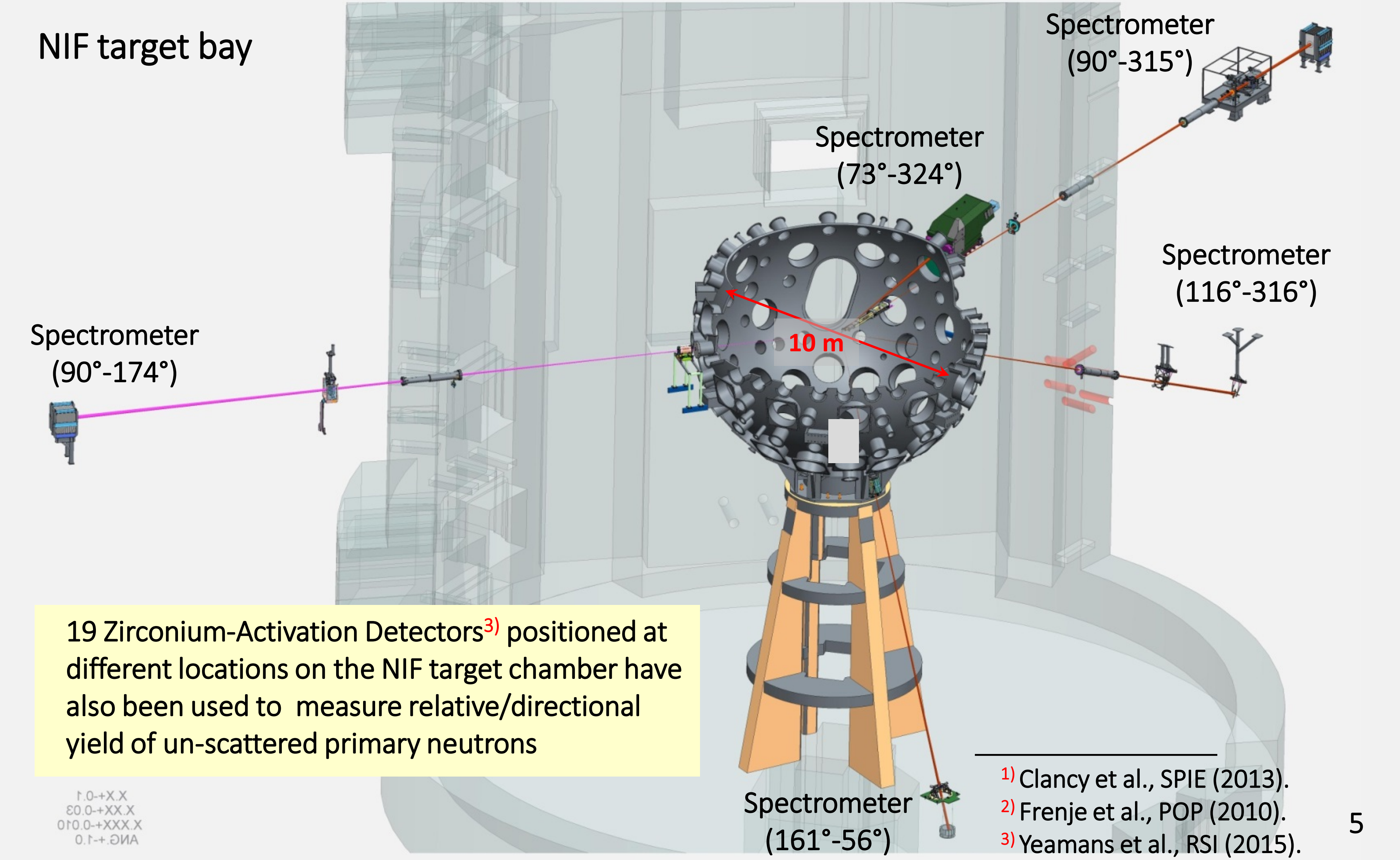
[1] Edwards et al., POP (2013).
[2] Hurricane et al., Nature Physics (2016).

Five neutron spectrometers, positioned at various locations in the NIF target bay, have been used extensively to diagnose the implosions[1-2]



19 Zirconium-Activation Detectors[3] positioned at different locations on the NIF target chamber have also been used to measure relative/directional yield of un-scattered primary neutrons

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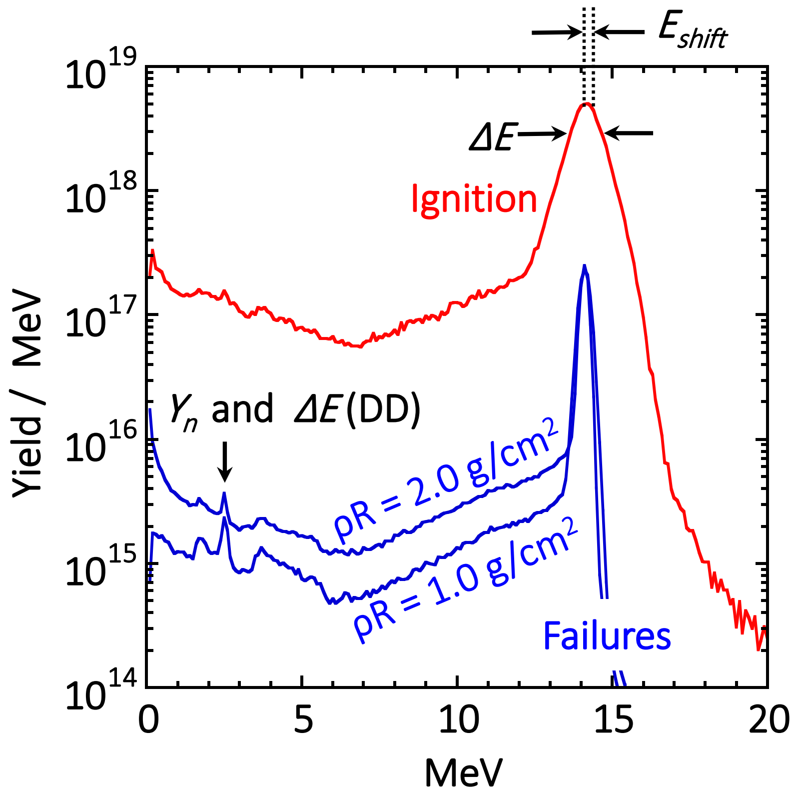
[1] Clancy et al., SPIE (2013).
[2] Frenje et al., POP (2010).
[3] Yeamans et al., RSI (2015).

From measured neutron spectra, yield (Y_n), apparent ion temperature ("T_i"), areal density (ρR), bulk-plasma flows, and their asymmetries are determined[1-3]



Y_n (DT) : From spectrum 13–15 MeV

Y_n (DD) : From spectrum 2.2–2.7 MeV

ρR : From $DSR = Y_n(10\text{–}12\ \text{MeV}) / Y_n(13\text{–}15\ \text{MeV})$

Flows : From E_{shift} (beyond T_i-induced shift)

"T_i" : From ΔE

ΔE is affected by:
1. Plasma flows
2. Thermal temperature

$$"T_i" \approx \overbrace{\left(\frac{m_D + m_T}{k}\right)\sigma_v^2}^{\text{Variance in bulk-plasma velocity}^{4\text{-}5)}} + T_{thermal}$$

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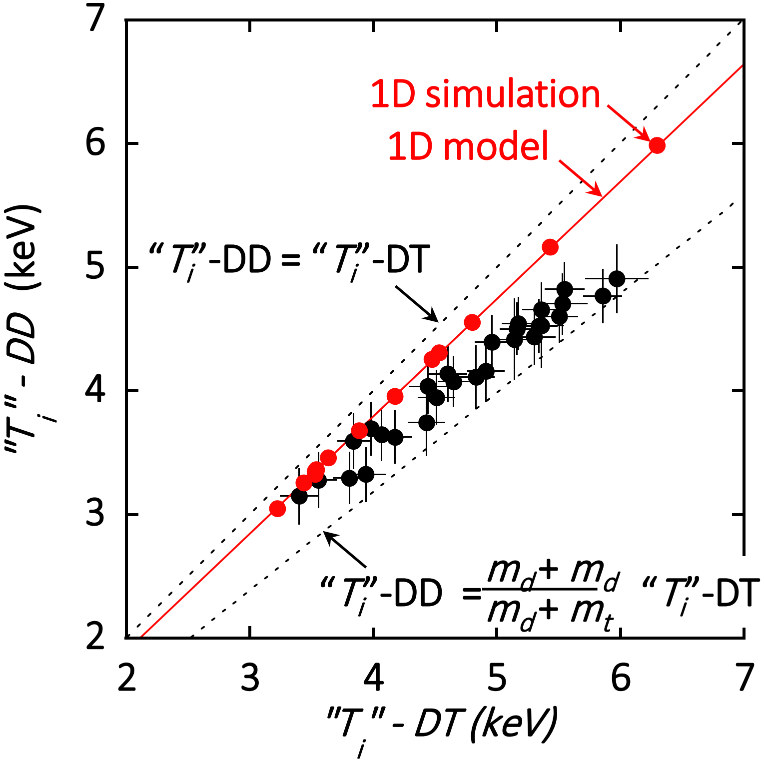
[1] Frenje et al., NF (2013).
[2] Gatu Johnson et al., PRE (2016).
[3] Spears et al., POP (2016).
[4] Murphy et al., POP (2015).
[5] Munro et al., NF (2016).

The difference between measured DT and DD “T_i” (ΔT_i) increases with increasing implosion velocity[1-2]

“T_i” data for several implosions



Increasing implosion velocity ⇨

- The DD reactivity emphasizes cooler regions more than the DT reactivity.
- The DT reaction kinematics emphasize plasma flows more than DD.
- If ΔT_i is due to plasma flows, a $T_{thermal}$ of ~2 keV is inferred, which is too low to reproduce measured Y_n unless fuel density is much higher than measured.

Substantial 3D effects combined with bulk-plasma flows must be invoked in the interpretation of the data

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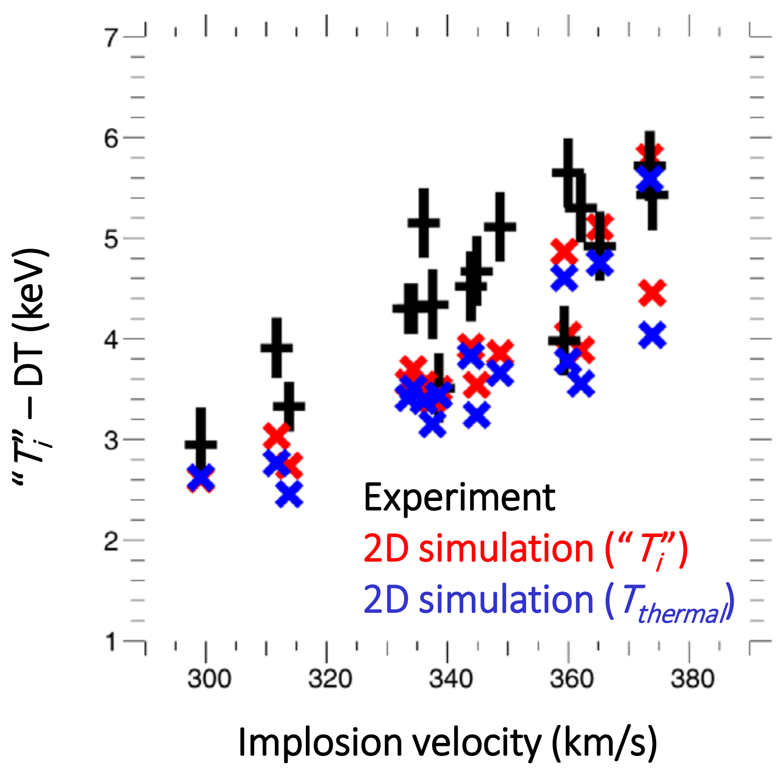
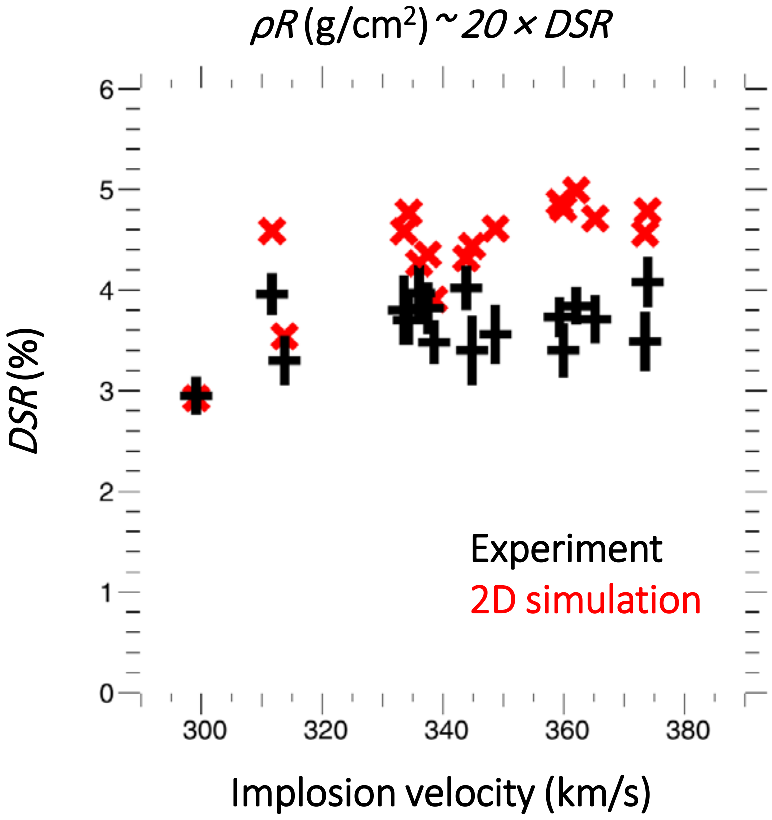
[1] Gatu Johnson et al., PRE (2016).

[2] Kritcher et al., POP (2016).

Significant discrepancies between data and 2D simulations are observed for implosion velocities > 340 km/s (when "T_i" is above 4 keV)





Tent and fill tube are NOT considered in these 2D simulations, and an another indication that engineering features and 3D effects are becoming increasingly important with increasing implosion velocity

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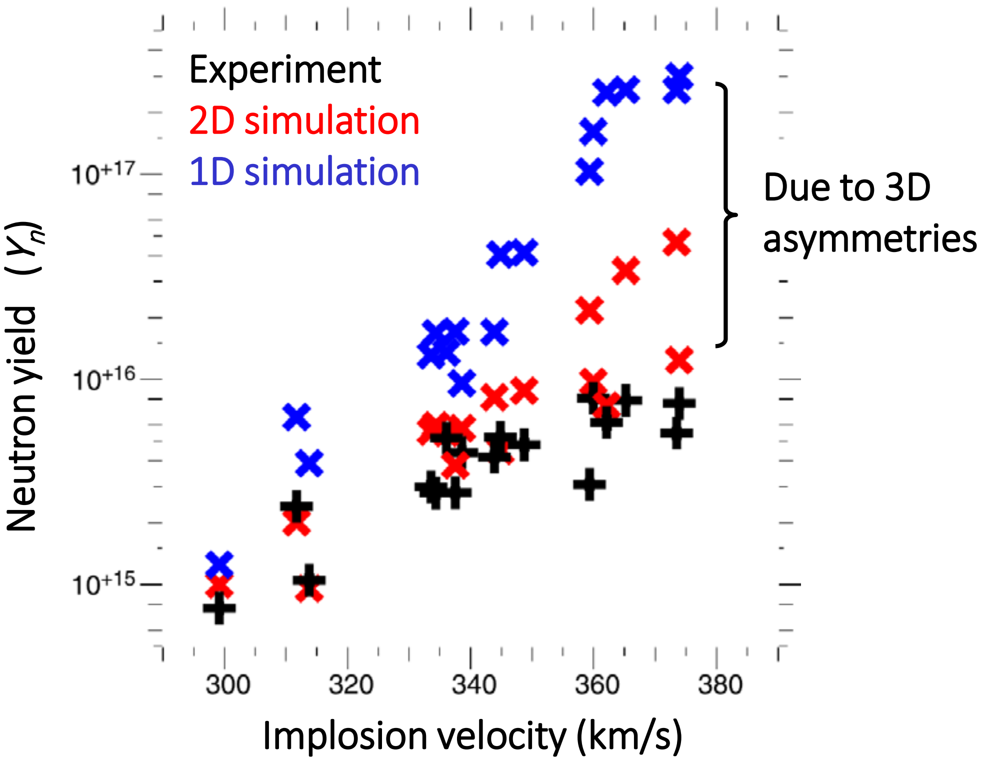
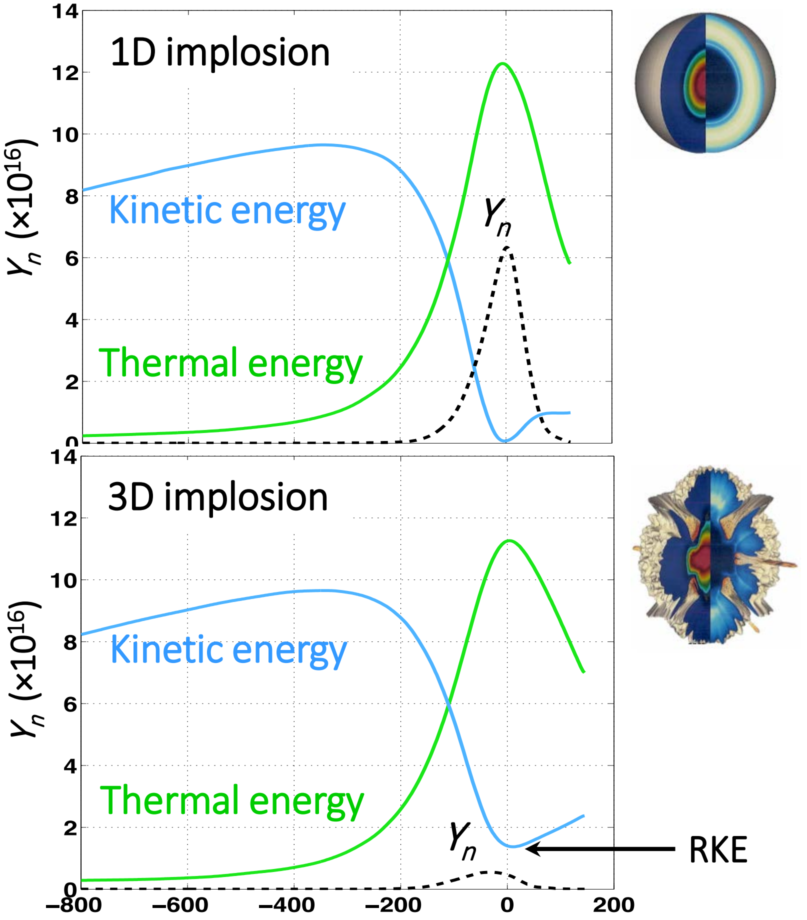
[1] Kritcher et al., POP (2016).

3D asymmetries prevent efficient conversion of implosion kinetic energy to thermal energy, resulting in Residual Kinetic Energy (RKE) and reduced Y_n[1)]



Qualitative picture[2)]



This indicates that RKE also becomes more significant with increasing implosion velocity

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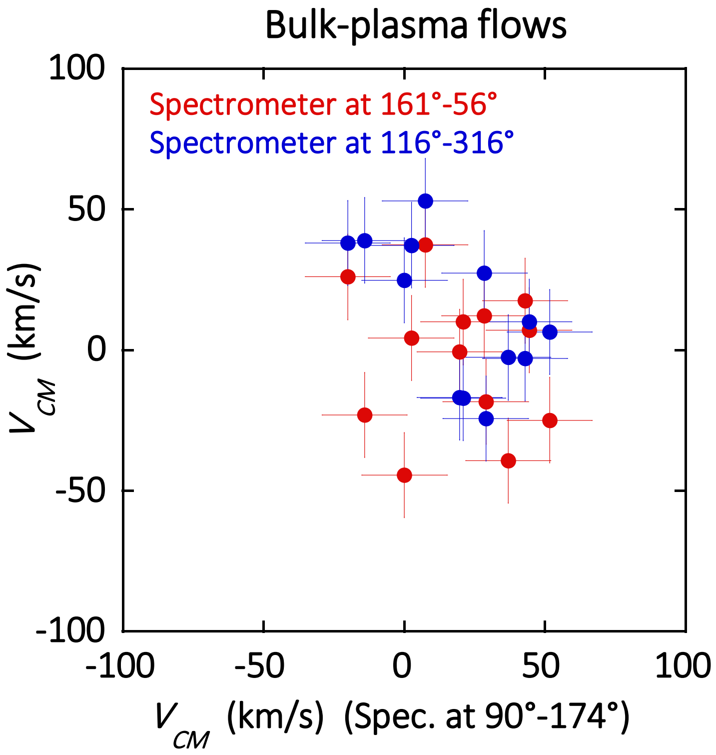
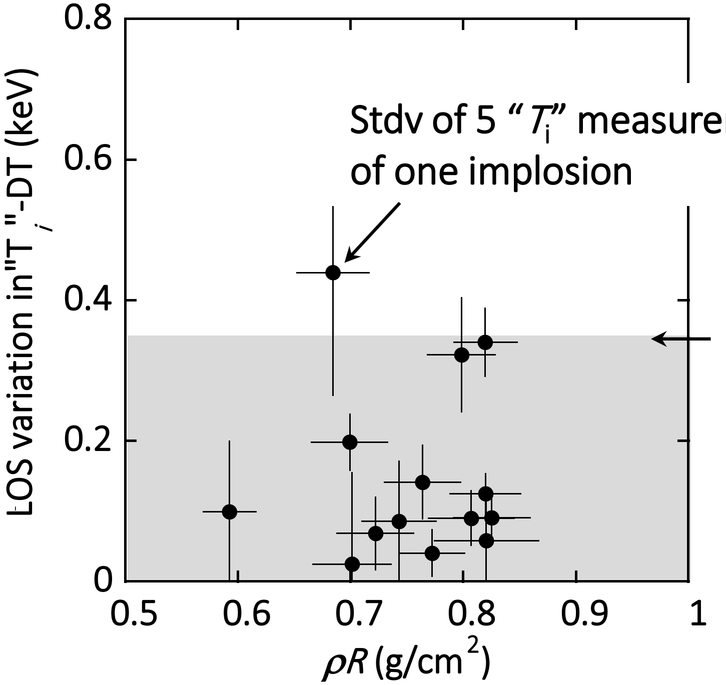
[1)] Kritcher et al., POP (2016).

[2)] Weber et al., POP (2015).

The neutron-spectral data also indicate substantial RKE and bulk-plasma flows, but insignificant Lines-Of-Sight (LOS) variation in "T_i"-DT





Stdv of 5 "T_i" measurements of one implosion

Systematic unc

-> Quasi-isotropic bulk-plasma flows[1], or time-dependent drive asymmetries that could potentially retain significant plasma motion while producing time-integrated neutron spectra in which the combined effects appear isotropic[2]

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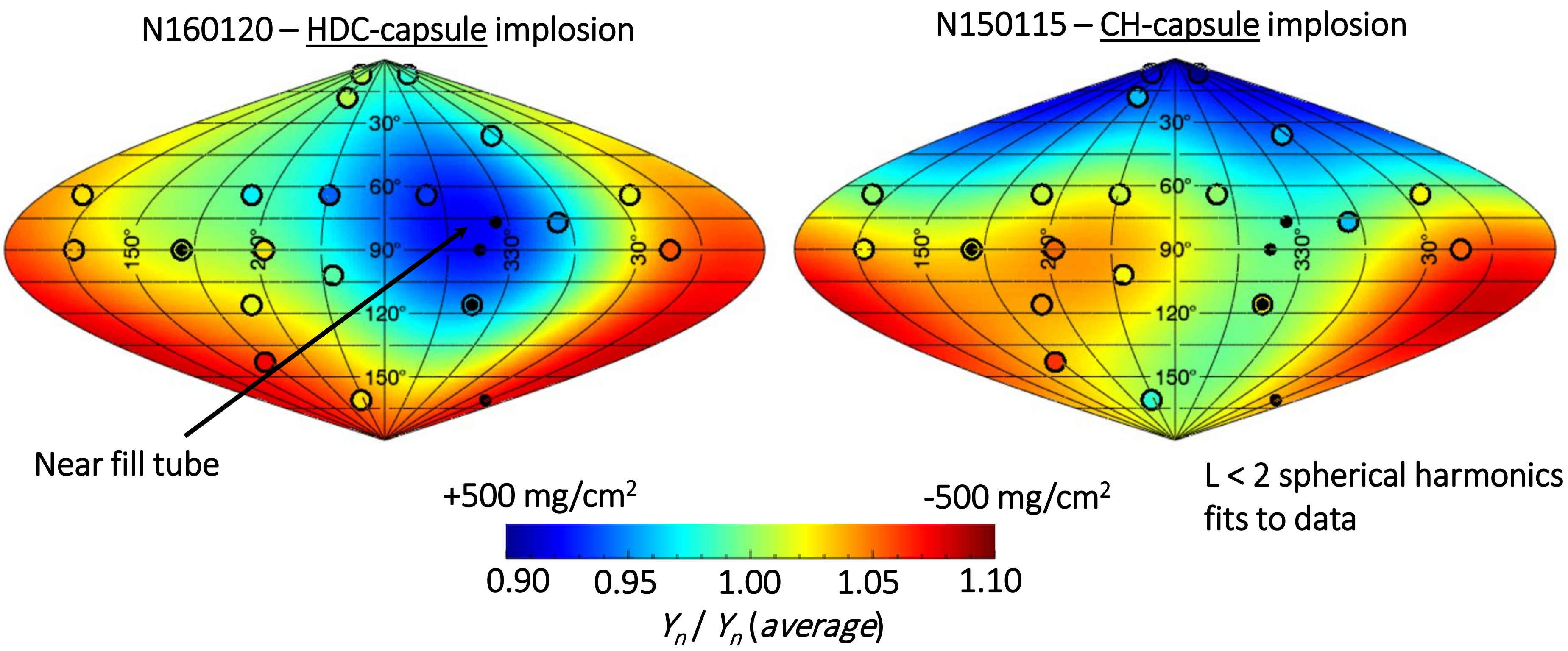
[1] Gatu Johnson et al., PRE (2016).

[2] Chittenden et al., POP (2016).

The Zirconium-activation detectors[1] often show low-mode *ρR* asymmetries with high *ρR* values near the fill tube or the poles depending on experiment



N160120 – <u>HDC-capsule</u> implosion

N150115 – <u>CH-capsule</u> implosion

Near fill tube

L < 2 spherical harmonics fits to data

HDC implosions are generally more symmetrically driven than CH implosions (larger Hohlraum-to-capsule ratio, lower Hohlraum-gas fill, shorter pulses), which is why we predominantly see the fill-tube-induced high-*ρR* feature rather than high-*ρR* polar features in the CH implosions

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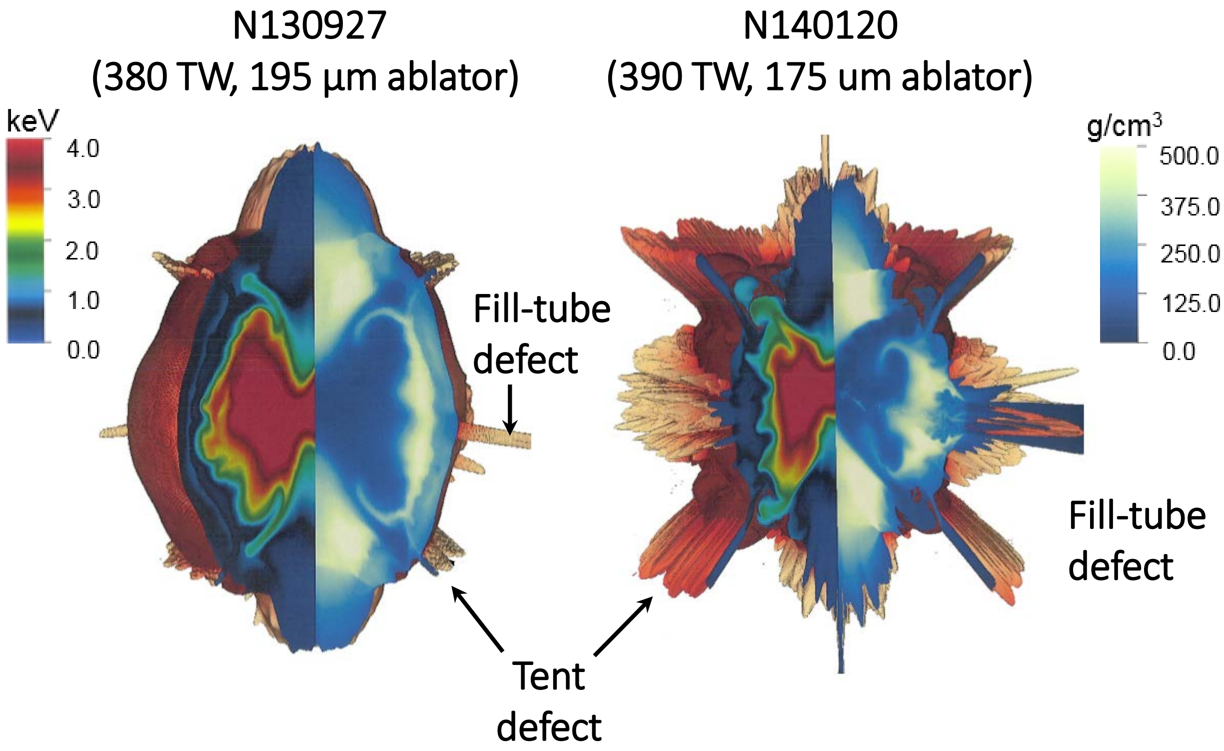
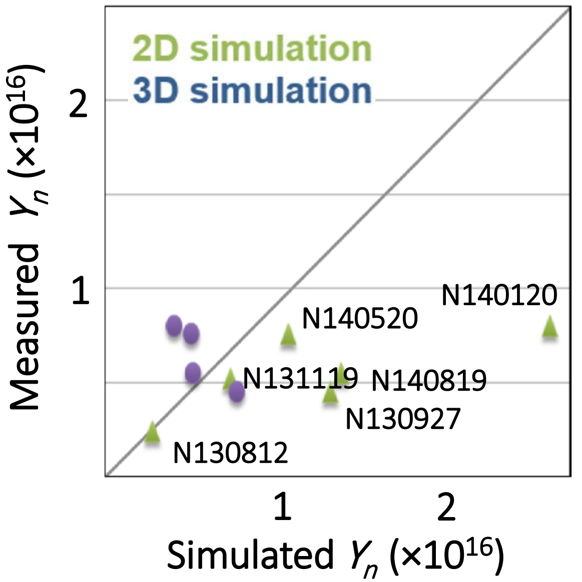
[1] Yeamans et al., RSI (2012).

3D simulations provide a fair representation of the implosions but do not capture all experimental trends[1]





- 3D simulations are still low in "T_i" and high in ρR.
- The hypothesis is that the tent, fill tube and time-dependent Hohlraum drive asymmetries are the largest performance degradation sources.

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[1] Clark et al., POP(2016).

The performance degradation issue is being addressed by implementing new engineering solutions, more refined modeling, and new diagnostics

Some new diagnostics:

- 30 additional Zirconium-activation detectors will resolve the fuel *ρR* distribution up to mode L=4[1)], compared to the current limit of L=2.

- The Magnet Recoil Spectrometer (MRSt) for time-resolved measurements of neutron spectrum from which $Y_n(t)$, "$T_i(t)$", $\rho R(t)$, and $V_{CM}(t)$[2)].

- Antipodal neutron-Time-Of-Flight spectrometers for high-precision measurements of V_{CM}[3)].

- A Ross-pair spectrometer for measurements of the x-ray continuum slope from which an emissivity-weighted T_e can be determined and contrasted to the apparent T_i[4)].

- Time-resolved Compton radiography to measure shape, *ρR* distribution, and RKE of the surrounding layer of dense fuel[5)].

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1) Yeamans, private communication (2016).

2) Frenje et al., RSI (2016).

3) Kilkenny et al., BAPS DPP (2014).

4) Jarrot et al., RSI (2016).

5) Hall et al., RSI (2016).

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