Stagnation in indirect drive implosions: an updated, updated picture

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LLNL ICF program
~~**June 21, 2016**~~
September 13, 2016

LLNL-PRES-663412-DRAFT
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

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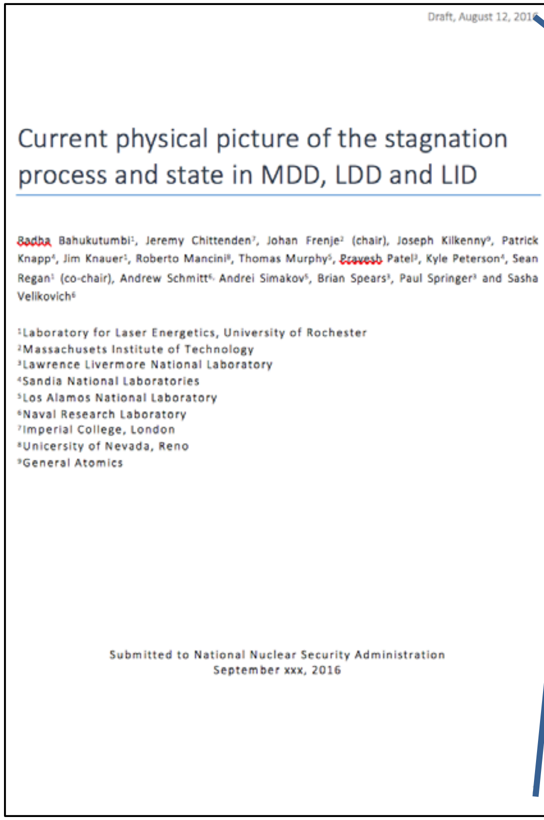
We’ll review the laser indirect drive (LID) stagnation picture, hypotheses, and actions


Draft, August 12, 2016

Current physical picture of the stagnation process and state in MDD, LDD and LID

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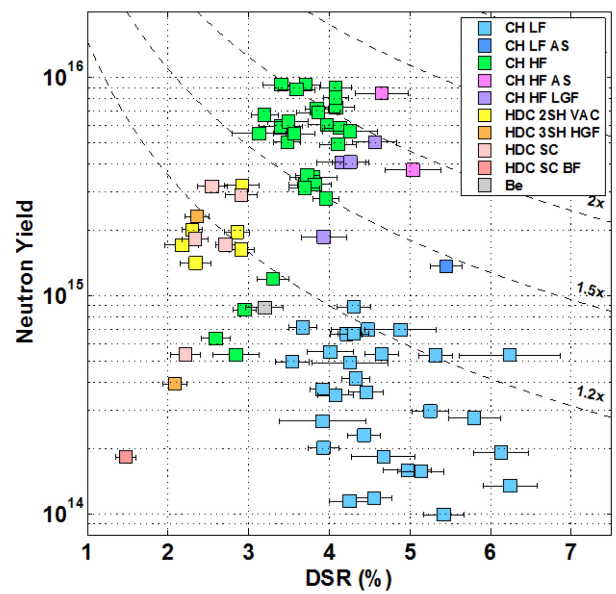
Submitted to National Nuclear Security Administration
September xxx, 2016

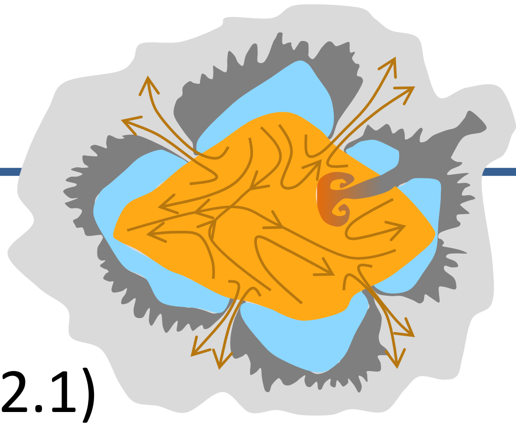
4. ‘Stagnation’ in Laser Indirect Drive (LID)

4.1 Introduction

Over seventy five cryogenic DT implosions have been performed at the NIF, spanning a number of capsule and hohlraum designs and laser pulse shapes (see Figure 4.1). This section focuses on the high-foot design [4.1], since it is the highest performing design to date, and the most studied. Most high-foot implosions (CH HF) were performed in a standard size Au or DU hohlraum with a high-gas-fill density (1.6 mg/cm³). Two experiments tested, an adiabat-shaped variant of the high-foot pulse (CH HF AS) in the same hohlraum, demonstrating higher fuel compression as predicted. More recent experiments have



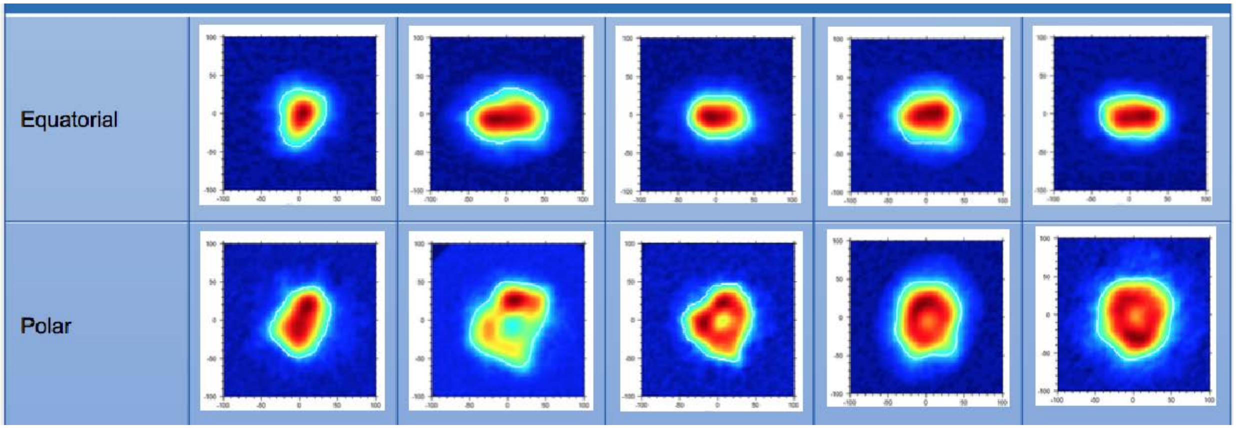
We have a picture of the stagnated implosion from experimental data compared to simulation

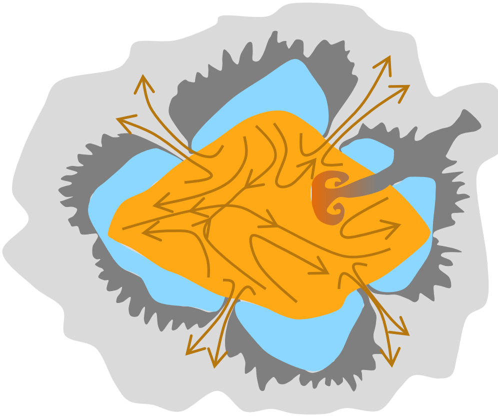


- Implosions in high-fill hohlraums are asymmetric (4.2.1)
- Engineering features are visible perturbations (4.2.1 b*)
- Hot spot ion temperatures are higher than expected, and DD/DT differential too large (4.2.2)
- We observe no mix in the high foot implosion platform (4.2.3)
- Burn width, both x-ray and nuclear, longer than simulation (4.2.4)
- Hot spot pressures are typically lower than simulations (4.2.5)
- DSR and fNADS measurements suggest the cold shell is perturbed and low rhoR (4.2.6*)

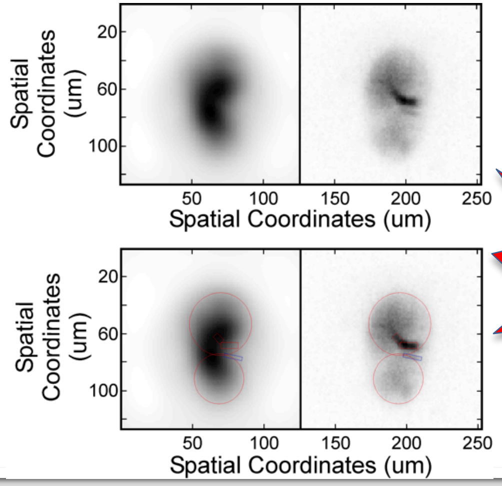
Implosions in high-fill hohlraums are asymmetric (4.2.1)

High foot hot spot x-ray images





Co-registered x-ray/neutron images

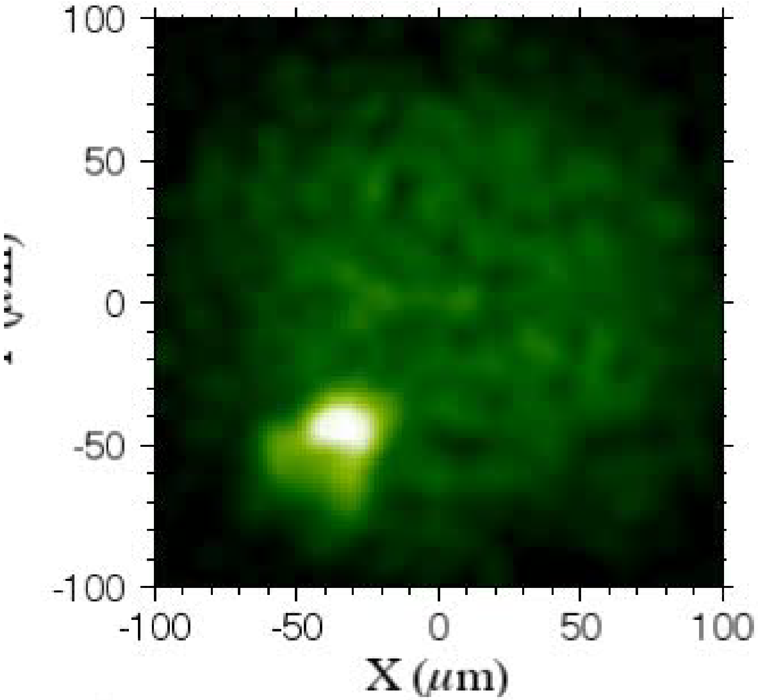


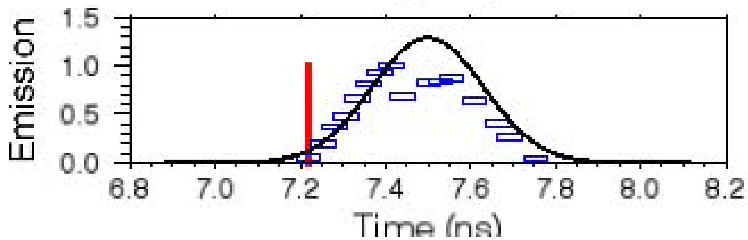
new

- X-ray shape is difficult to control in high-fill and vacuum hohlraums
- Asymmetric x-ray, neutron images
- Engineering features (tent, fill tube) may contribute

Engineering features are visible perturbations (4.2.1 b*)

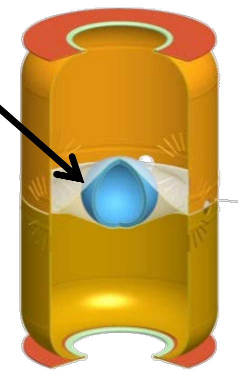
Filltube jet



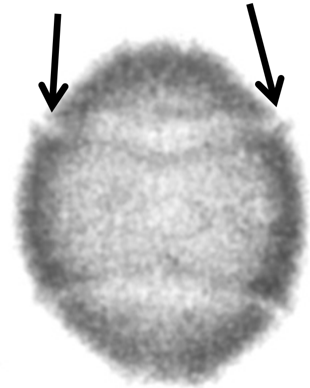


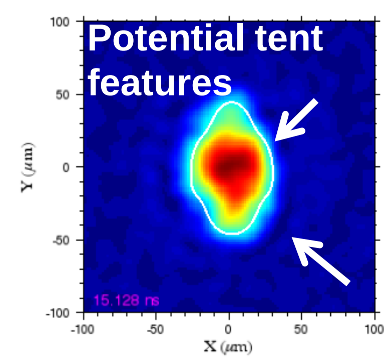
Tent scarring

support "tent"



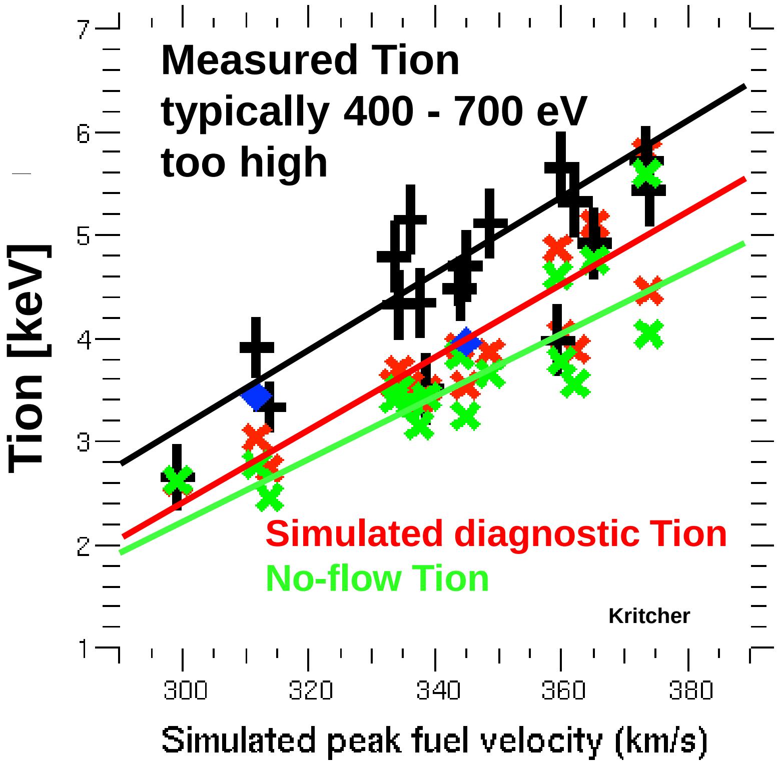
In-flight tent features



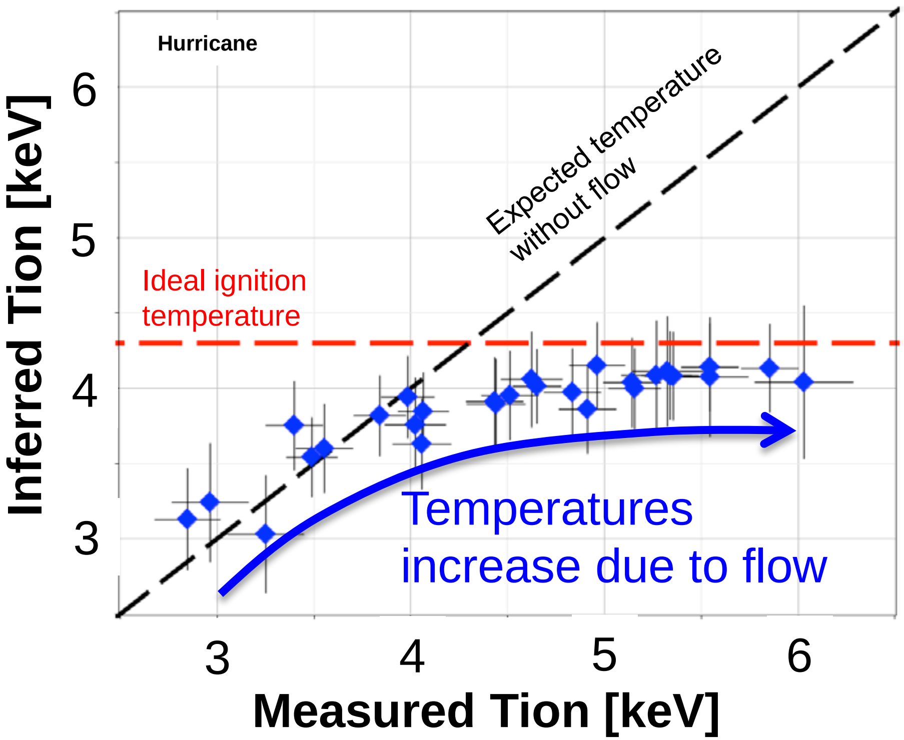


Hot spot ion temperatures are higher than expected, and DD/DT differential too large (4.2.2)

According to 2D simulations

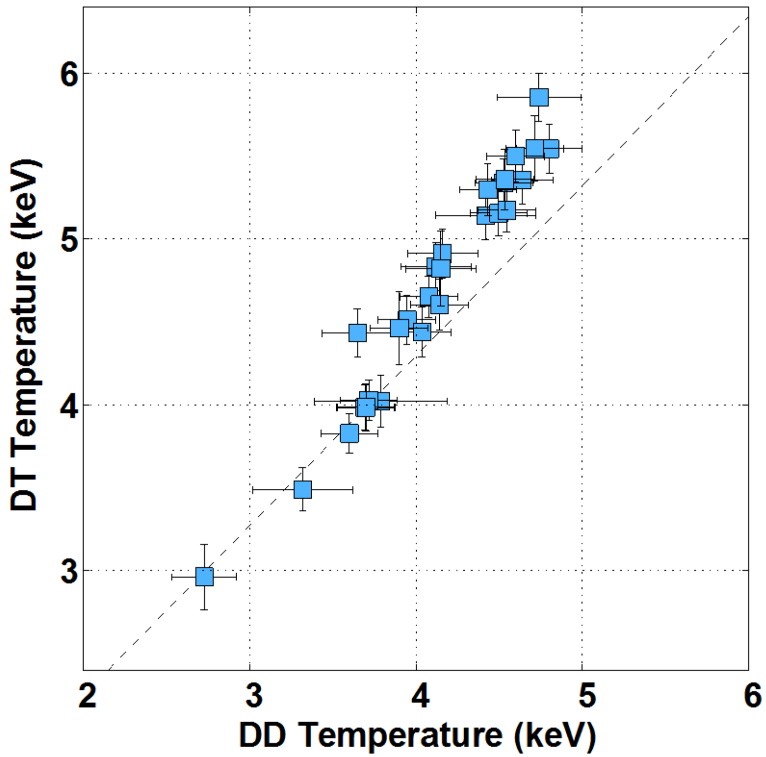


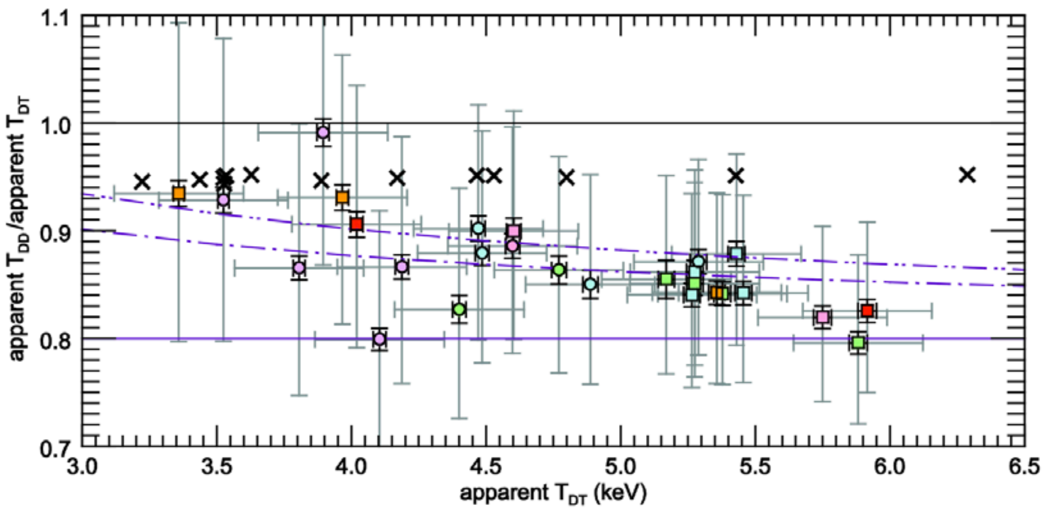
According to analysis



Hot spot ion temperatures are higher than expected, and DD/DT differential too large (4.2.2)

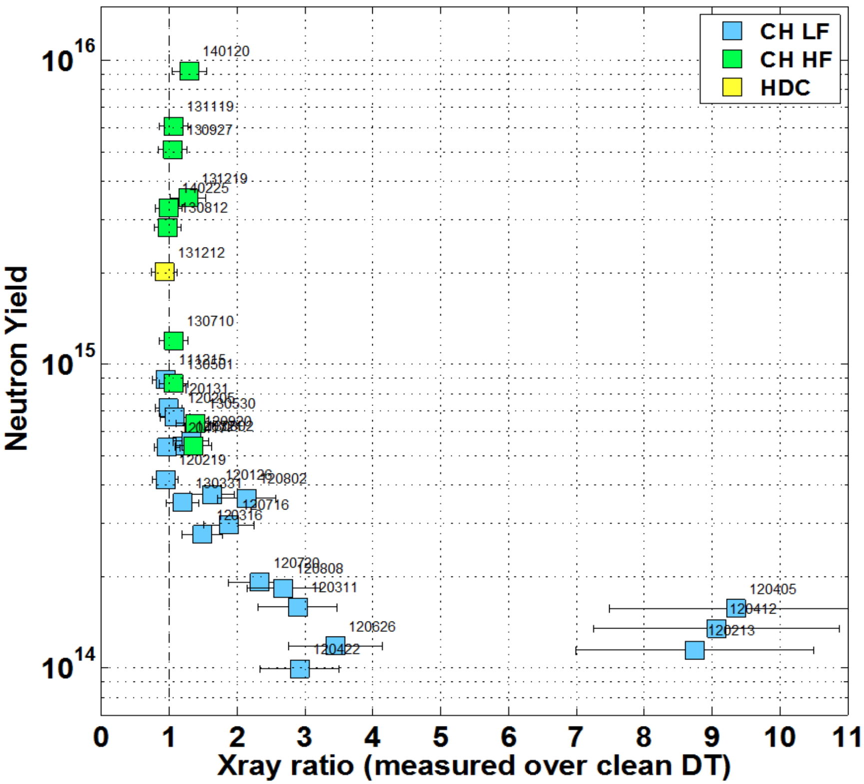
Gap between DD and DT temperatures is larger than predicted by simple theories or modestly perturbed simulations





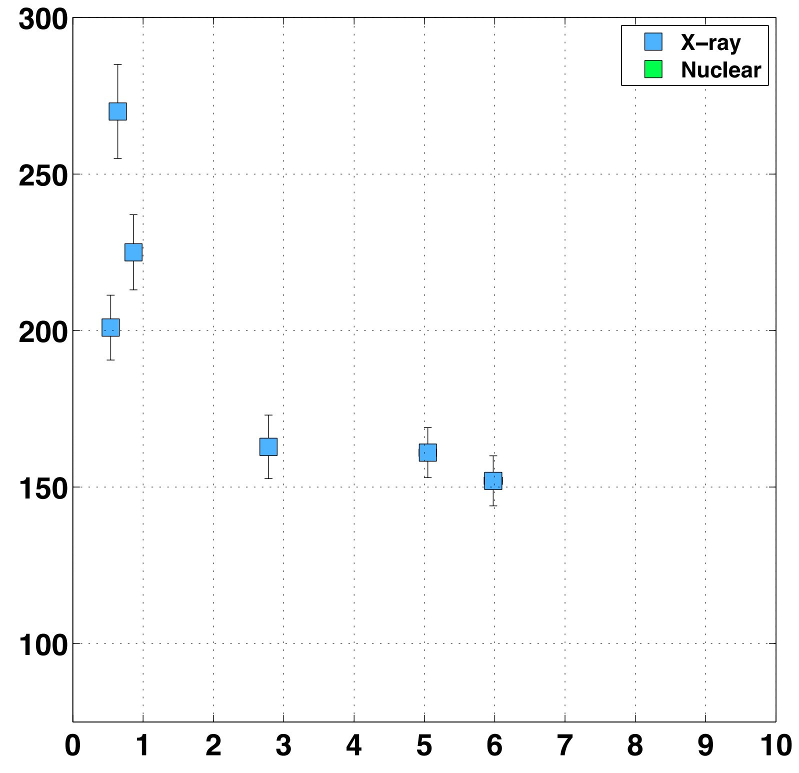
We observe no mix in the high foot implosion platform (4.2.3)

- Mix increases the x-ray production for fixed neutron production
- Observed in low foot experiments
- Not detected in high foot experiments



Burn width, both x-ray and nuclear, are longer than simulation (4.2.4)

- X-ray and nuclear burn widths trend similarly
- Both widths longer than simulations by 10s ps
- 3D asymmetries in increase widths in simulations.
- X-ray/nuclear delta (~ 25 ps) slightly larger than in simulations (~ 10 ps)
- Crucial for pressure estimates



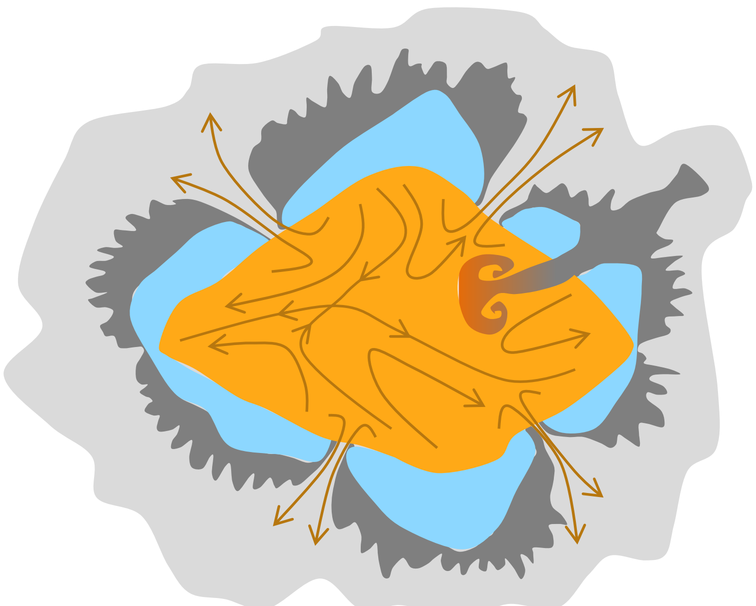
Hot spot pressures are typically lower than simulations (4.2.5)

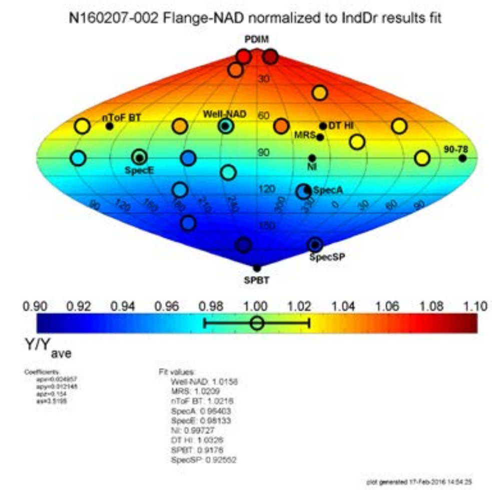
- burn-averaged hot-spot pressure from 1D isobaric model
  - Y_n, T_i, x-ray and neutron emission radii, and burn width
- Pressure increases with reduced coast time, increased velocity
- Falls for most strongly driven implosions -- cliff

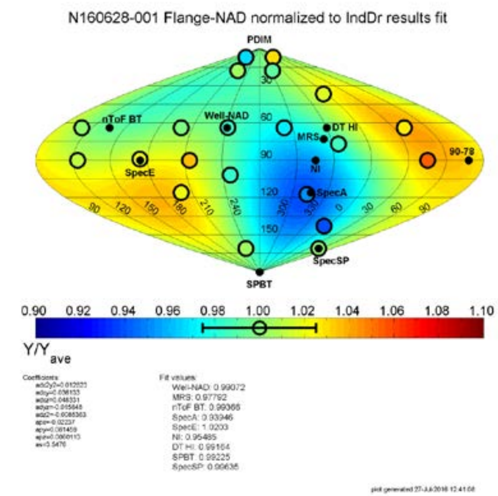
Omitted figure

DSR and fNADS measurements suggest the cold shell is perturbed and low ρR (4.2.6*)

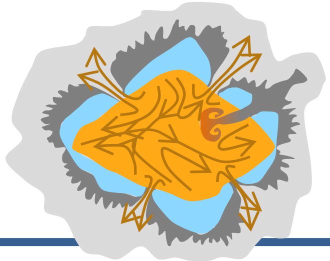
- DSR provides an average measure of fuel rhoR – typically 20% below simulated
- fNADS shows structure – sometimes correlated with the filltube







We have developed hypotheses based on our stagnation picture (observations and theory)



- Radiation drive asymmetry is a major degradation mechanism
- The capsule support tent is a significant degradation mechanism
- The fill tube is damaging the hot spot and the cold shell
- Hot spot flows are elevating the ion temperature (insight here)
- The D:T ratio in the fuel is closer to 60:40 (insight here)

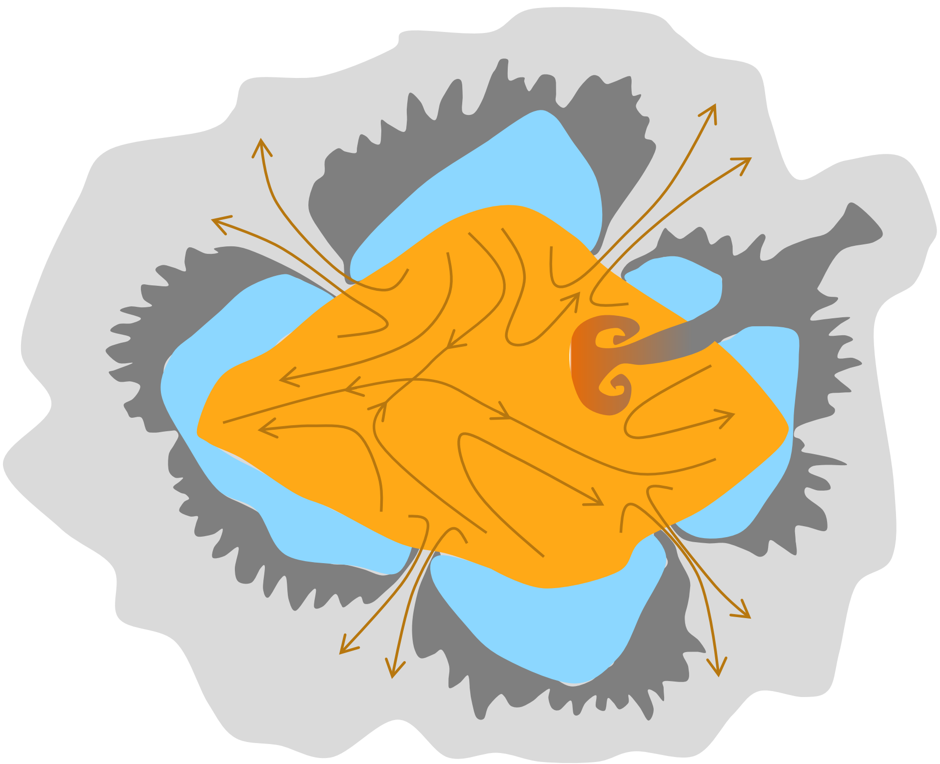
new

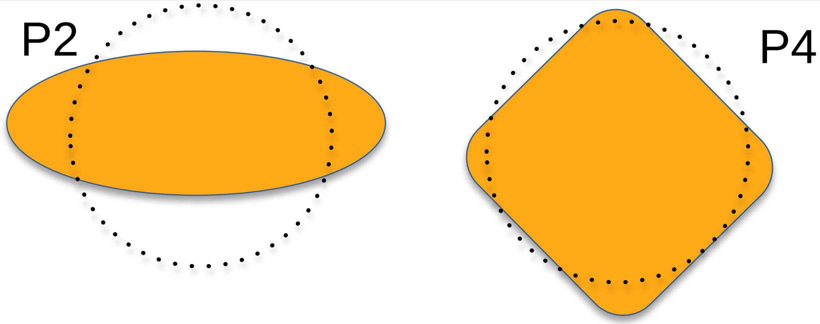
- Lower-than-predicted conductivity increases the ion temperature
- Kinetic effects (species separation, ion equilibration) are affecting yields and temperatures

- Oxygen non-uniformities may seed instability growth
- Hot electron preheat is lowering DSR

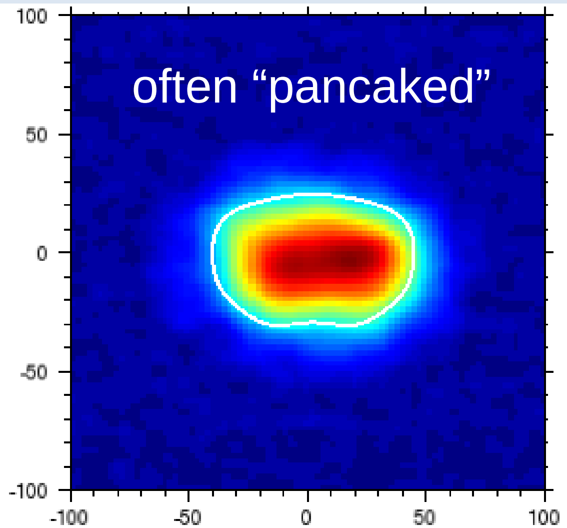
Hypothesis 1: Radiation drive asymmetry is a major degradation mechanism

Low mode asymmetry



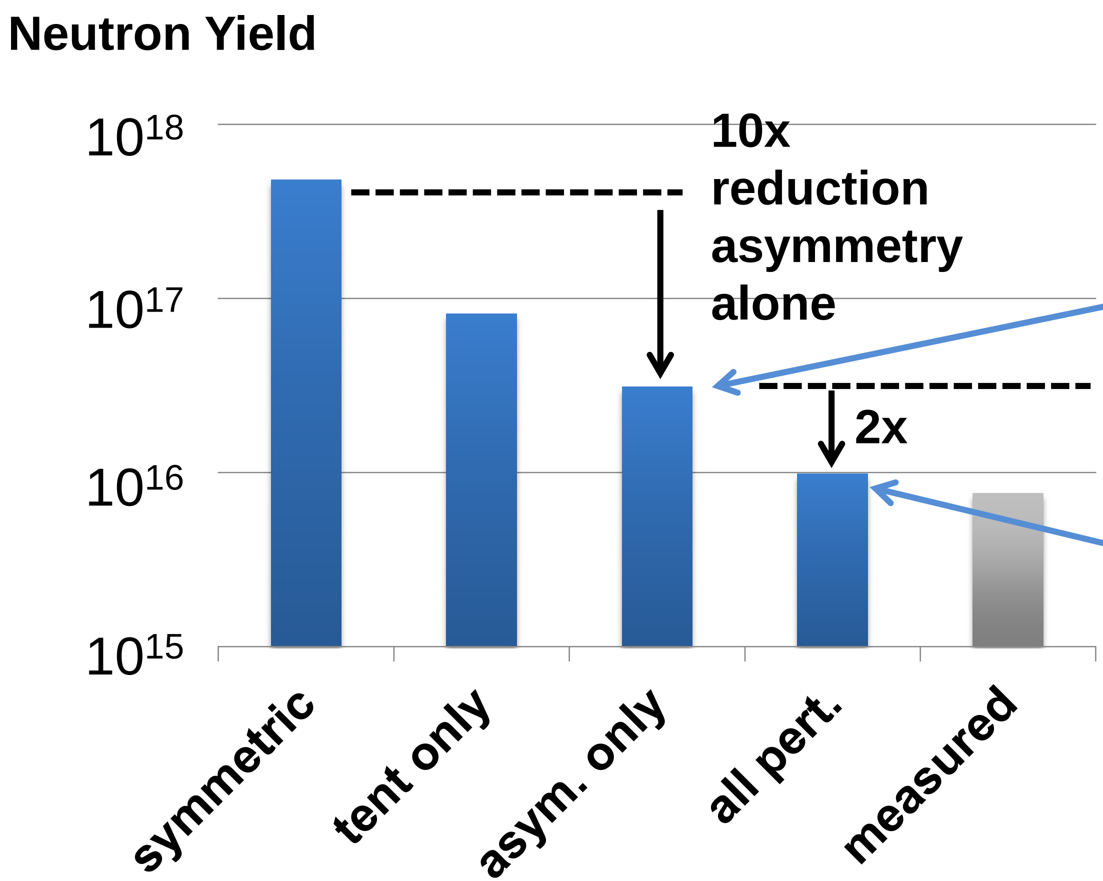


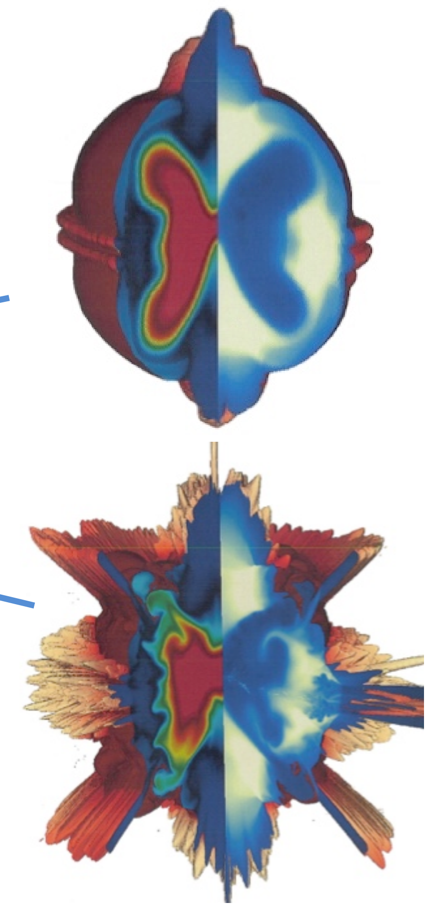
Stagnation X-ray emission



To produce a hot spot like this, the surrounding implosion must be quite distorted.

Time dependent asymmetry is hypothesized to be the limiting factor in current performance



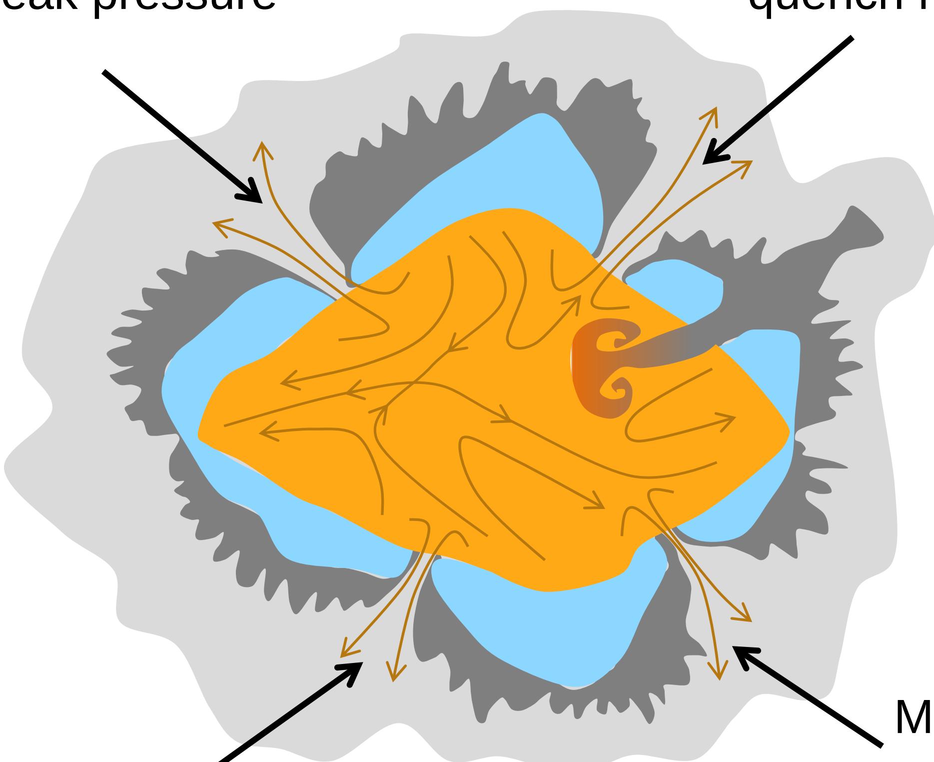


from high-foot implosion N140520 (D. Clark)

Hypothesis 2: The capsule support tent is a significant degradation mechanism

Tent features leak pressure

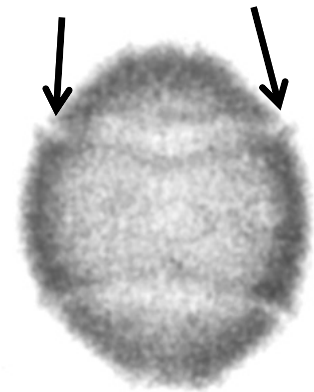
Tent features quench hot spot

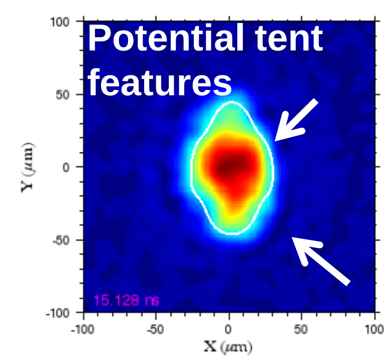


May confound P2, P4 diagnosis

support “tent”

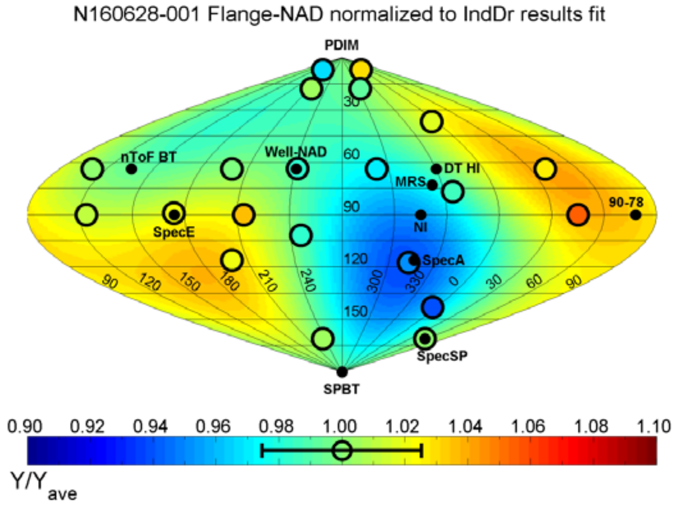
In-flight tent features

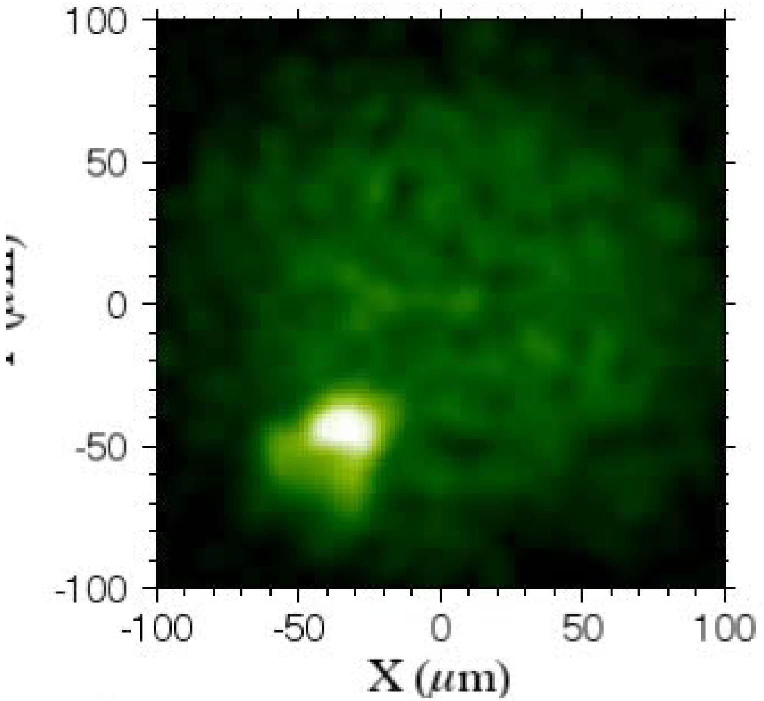


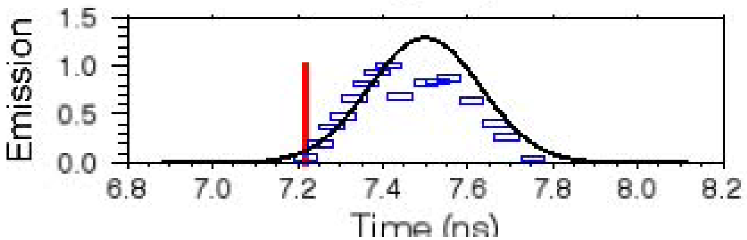


Hypothesis 3: The fill tube is damaging the hot spot and the cold shell

- Emitting jets originate from fill tube direction – looks harmful
- FNADS perturbations localized near fill tube

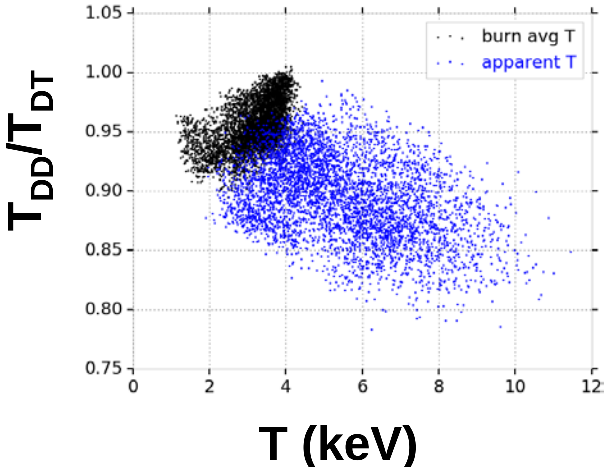




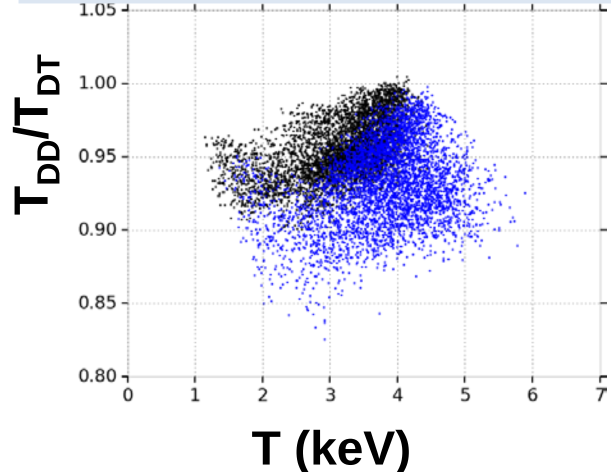


Hypothesis 6: Hot spot flows are elevating the ion temperature

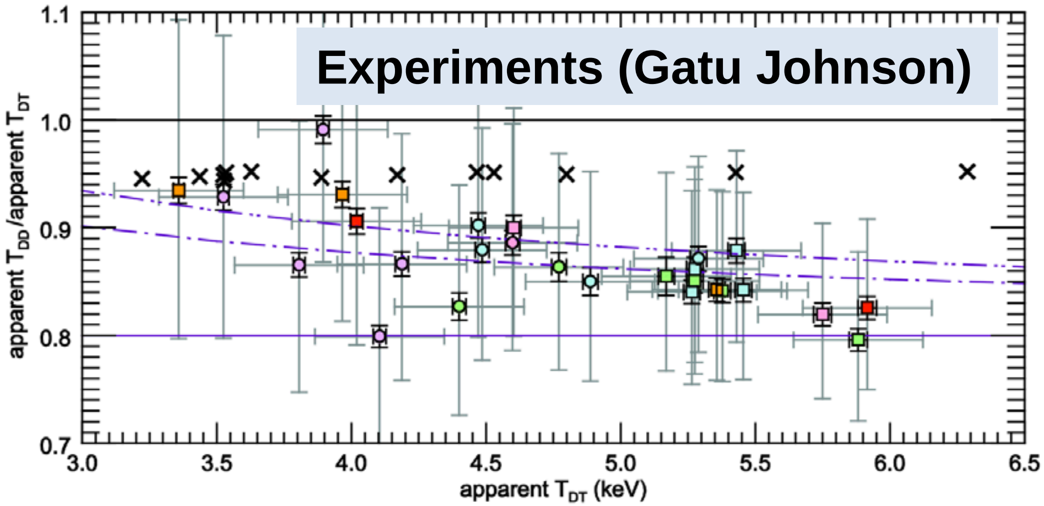
Simulated polar Tion



Simulated equatorial Tion



Experiments (Gatu Johnson)

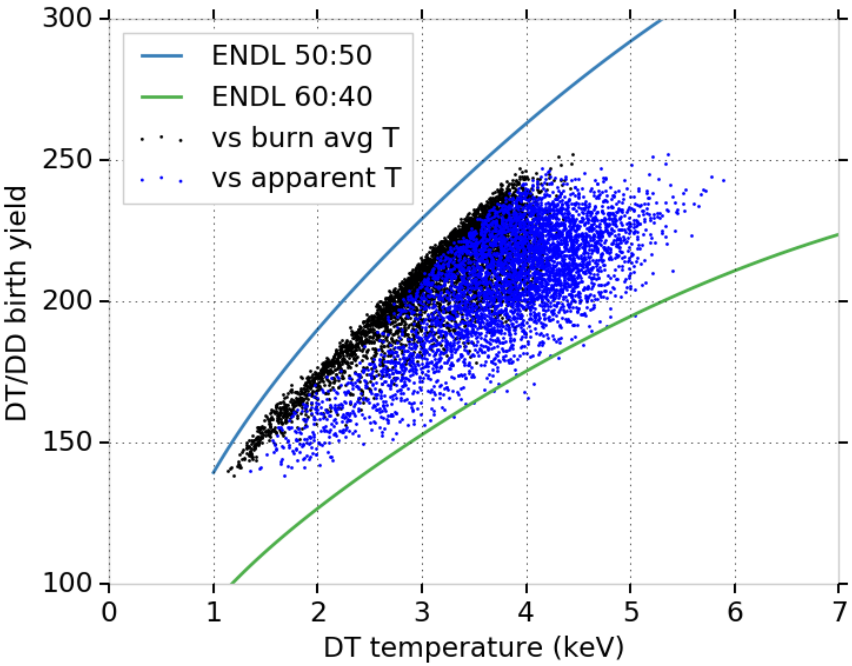


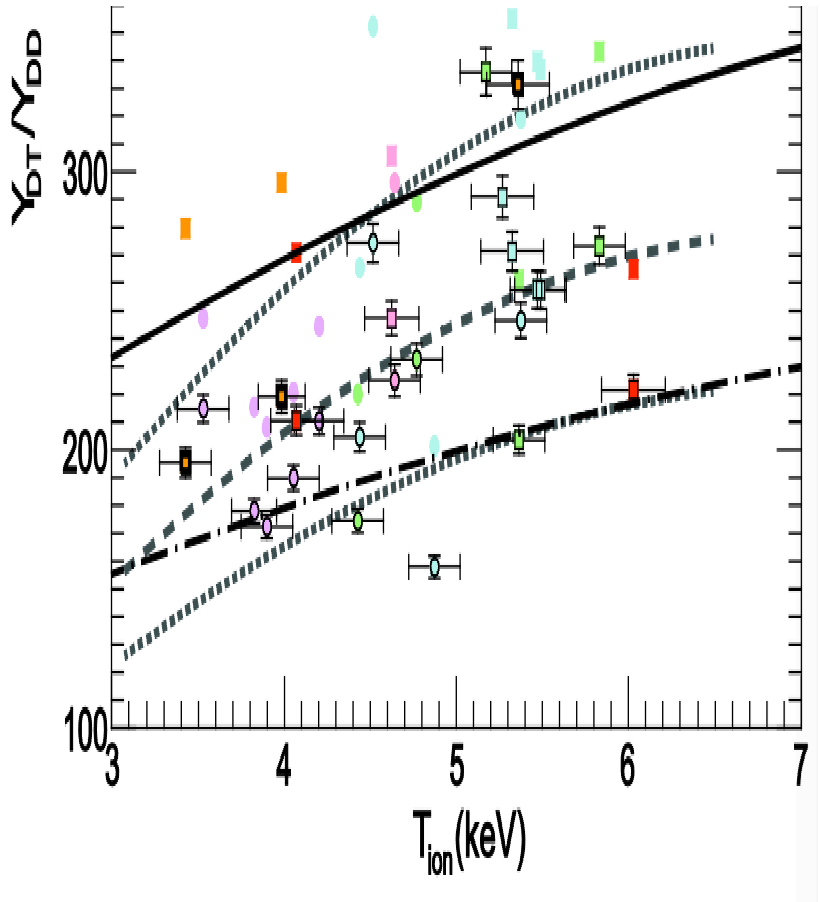
Simulation database of asymmetric implosions

- **black is thermal T**
- **Blue is apparent T**

- **"3D-ish" pole shows trend similar to experiment**
- **Large temperature shifts from non-P1 flows (P2)**
- **But experiments show more isotropy – multiple jets (10s)**

Hypothesis 8: The D:T ratio in the fuel is closer to 60:40





DT temperature in blue is apparent temperature on equatorial LOS (often lowest apparent temperature)

- 1D models with 60:40 fuel explain yield ratios
- Asymmetric implosions with 50:50 explain yield ratios AND Tion trends

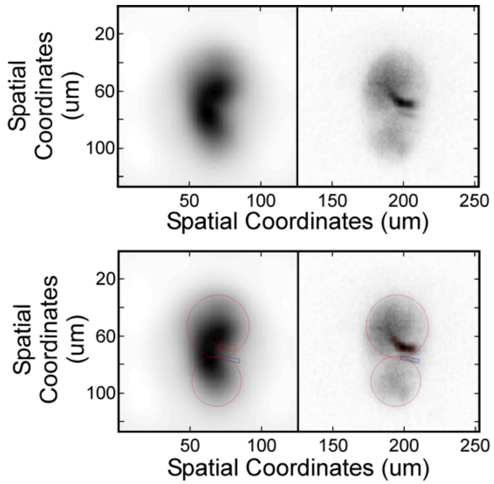
We're full of hypotheses

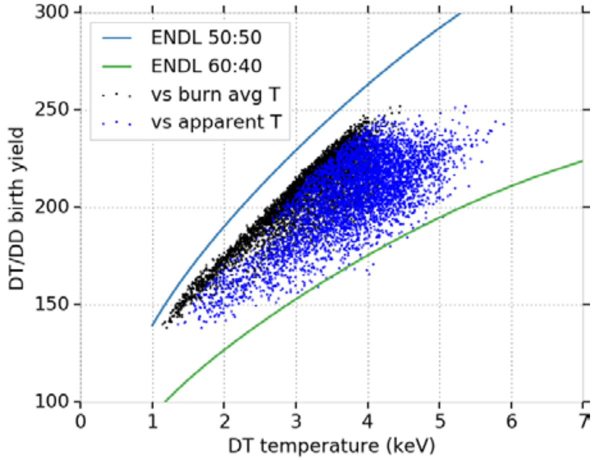
- Hypothesis 7: Reduced thermal conductivity (relative to simulation) increases the ion temperature
- Hypothesis 9: Kinetic effects (species separation, ion equilibration) are affecting yields and temperatures

- Can be explained without appealing to enhanced or modified physics (vanilla code)

We are making progress on developing our stagnation picture and hypotheses

- New measurements are adding to our observables





- New simulations and thinking are helping us to evaluate hypotheses – especially in combination

- Measurements, simulations, and experiments are planned to test our hypotheses – more from Prav, next.

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