Yield ratio observations in DT gas-filled implosions and their implications for single-ion fluid approximations

Kinetic Physics 2016 Workshop

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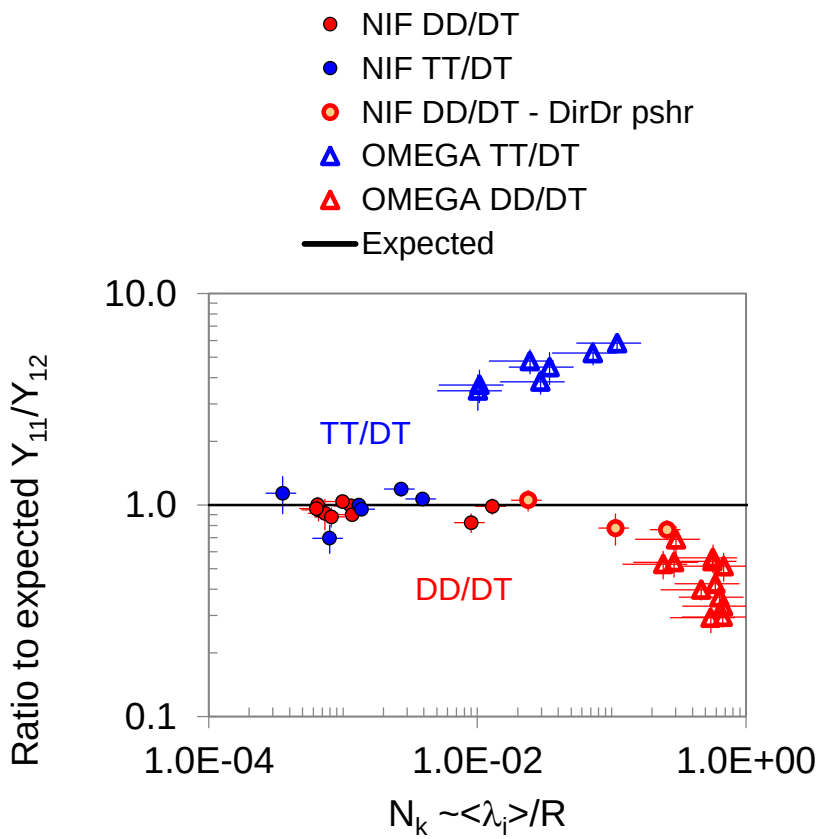
Yield ratio anomalies are observed in DT gas filled implosions at OMEGA but not in indirect drive at NIF

- At OMEGA the DD/DT and TT/DT yield ratios cannot be explained with single-fluid arguments and the anomalies increase with reduced collisionality [see other examples: **Kim, Herrmann, Frenje, Gatu-Johnson**]
- At NIF in indirect drive gas filled implosions, no anomalous behavior is observed
- These results suggest that the non-fluid issues observed at OMEGA are unimportant in the compression phase of DT NIF ignition experiments
- This data does not rule out the impact of possible early-time non-fluid issues on the initial-conditions of NIF ignition experiments



The yield ratio of two reactions with similar <σv> Ti dependence is independent of detailed Ti($\vec{r}$,t), ni($\vec{r}$,t) profiles, if we:

The yield of reaction 1+2 is: $$Y_{12} = \int \frac{f_1 f_2}{1+\delta_{12}} \frac{\rho(\vec{r},t)^2}{\bar{m}^2} \langle \sigma v \rangle_{12} \, d\vec{r} \, dt$$

1st, assume the ion fractions f_1 and f_2 are <u>fixed</u>

Then, the yield ratio is: $$\frac{Y_{11}}{Y_{12}} \cong \frac{1}{2} \frac{f_1 \int \frac{\rho^2}{\bar{m}^2} \langle \sigma v \rangle_{11} \, d\vec{r} \, dt}{f_2 \int \frac{\rho^2}{\bar{m}^2} \langle \sigma v \rangle_{12} \, d\vec{r} \, dt}$$

2nd, assume the ions are <u>Maxwellian</u> and have the same **Ti($\vec{r}$,t)** everywhere

Let's define: $$R = \frac{\langle \sigma v \rangle_{11}}{\langle \sigma v \rangle_{12}}$$

Then, expand: $$R \approx R_0 + \frac{\partial R}{\partial T}(T - \langle T \rangle)$$

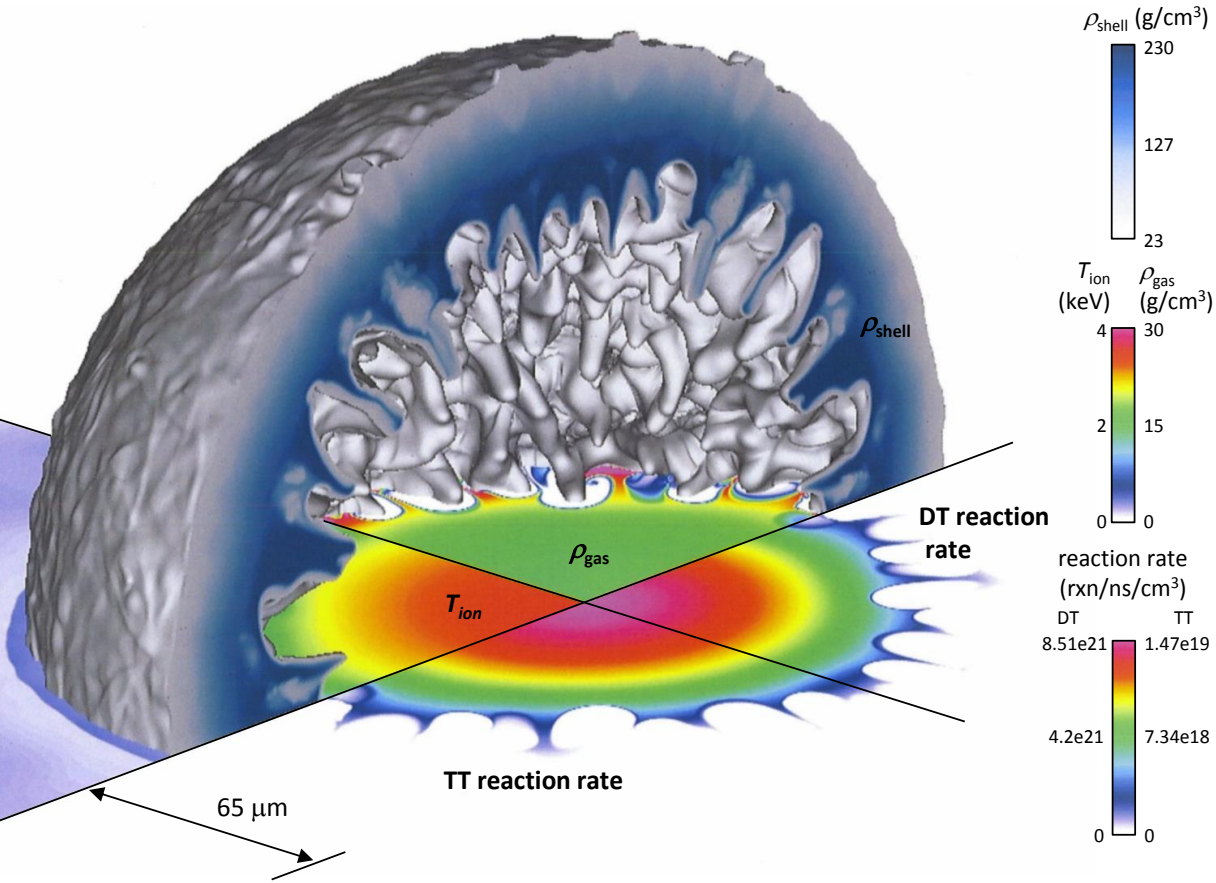
Neglecting 2nd order and higher

$$\langle T \rangle - \langle T \rangle = 0$$

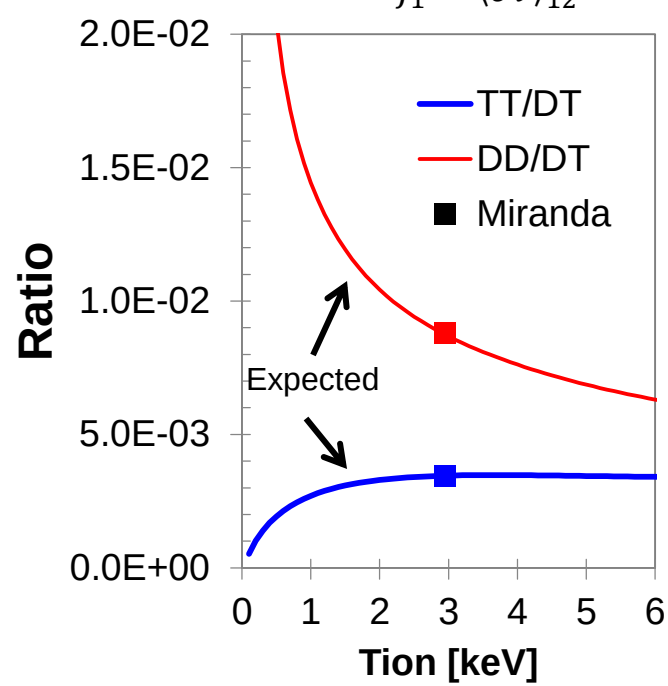
$$\frac{Y_{11}}{Y_{12}} = \frac{1}{2} \frac{f_1}{f_2} R_0 \left[1 + \frac{\frac{1}{R_0} \frac{\partial R}{\partial T} \int \rho(\vec{r},t)^2 \, (T - \langle T \rangle) \, \langle \sigma v \rangle_{12} \, d\vec{r} \, dt}{\int \rho(\vec{r},t)^2 \langle \sigma v \rangle_{12} \, d\vec{r} \, dt} \right]$$

The yield ratio we expect is now simply: $$\boxed{Y_{11}/Y_{12} \cong \frac{1}{2} \frac{f_1}{f_2} \frac{\langle \sigma v \rangle_{11}}{\langle \sigma v \rangle_{12}}}$$

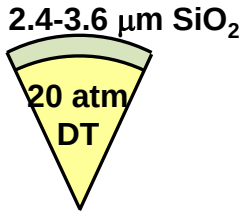
Detailed Miranda simulations by Chris Weber confirm this analytical logic for gas-filled NIF implosions

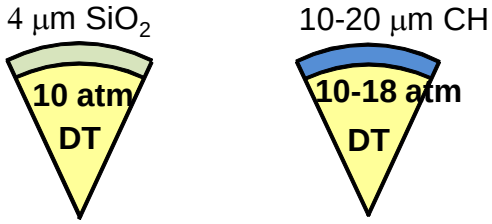


$$2\,Y_{11}/Y_{12}\,\frac{f_2}{f_1} \cong \frac{\langle\sigma v\rangle_{11}}{\langle\sigma v\rangle_{12}}$$

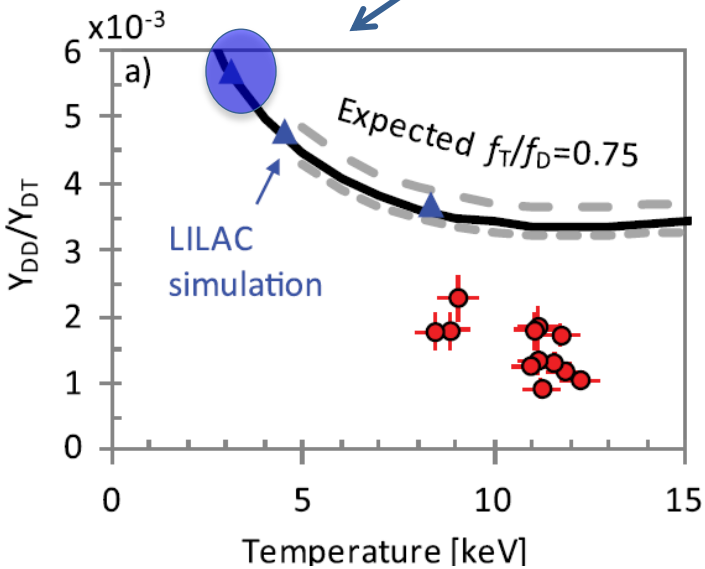


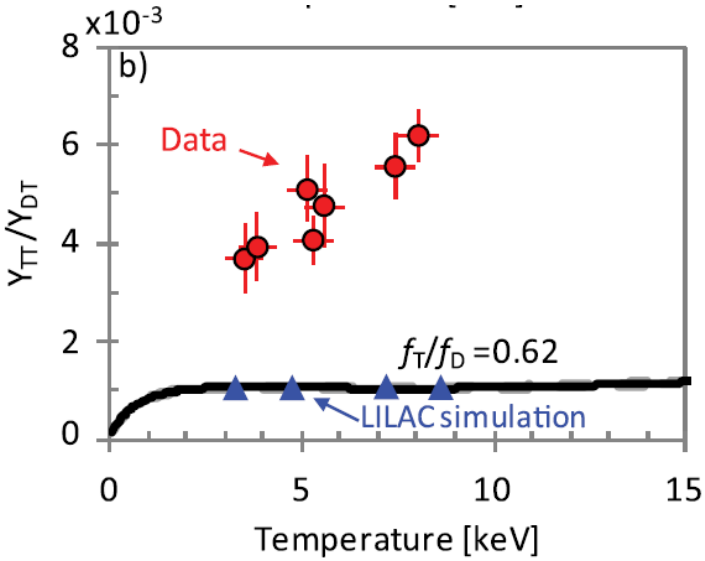
A variety of gas-filled OMEGA implosions have shown yield ratios that are anomalous and trending with temperature





Results from Glebov APS2011 – show no anomaly



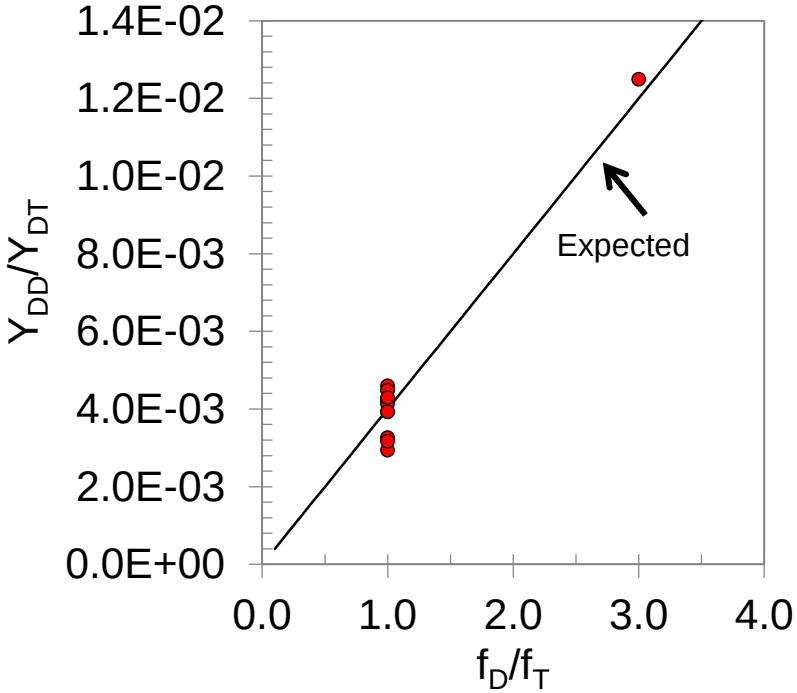


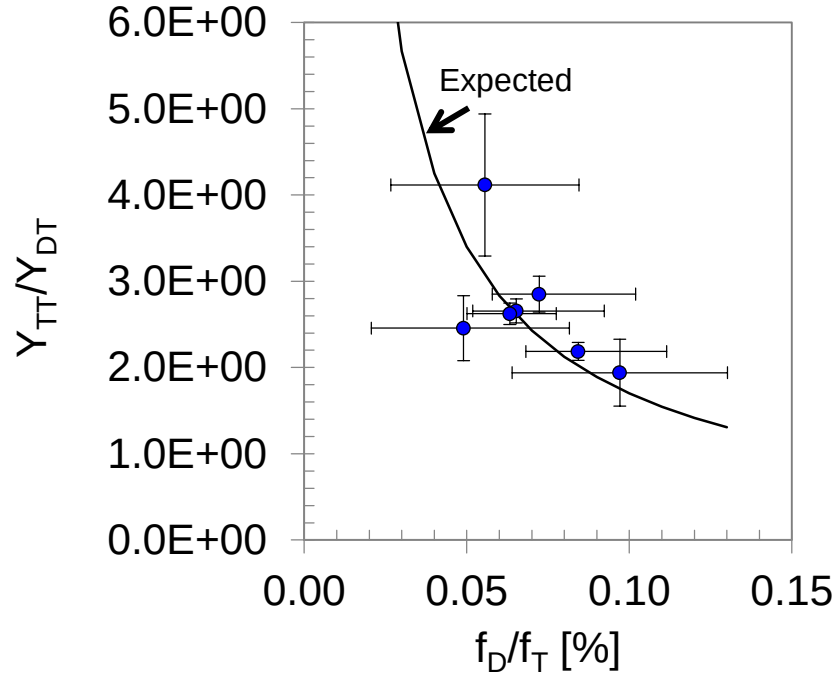
$$Y_{DD}/Y_{DT} \cong \frac{1}{2}\frac{f_D}{f_T}\frac{\langle\sigma v\rangle_{\mathrm{DD}}}{\langle\sigma v\rangle_{\mathrm{DT}}}$$

$$Y_{TT-rx}/Y_{DT} \cong \frac{1}{2}\frac{f_T}{f_D}\frac{\langle\sigma v\rangle_{\mathrm{TT}}}{\langle\sigma v\rangle_{\mathrm{DT}}}$$

Exact cause is still not known, both species separation and kinetic effects have been proposed

NIF DT gas-filled symcap and indirect drive exploding pusher implosions have been fired at a range of different fuel mixtures





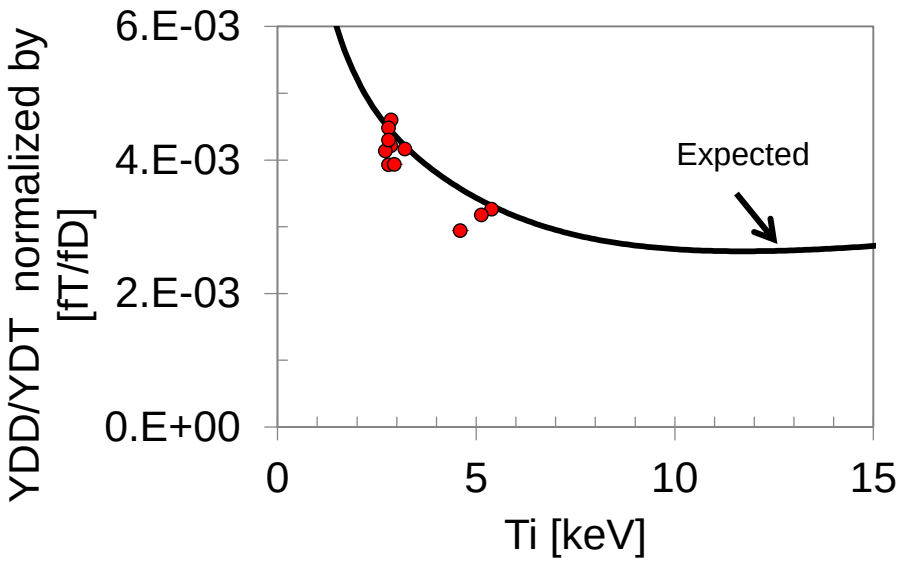
$$Y_{TT-rx}/Y_{DT} \cong \frac{1}{2}\frac{f_T}{f_D}\frac{\langle\sigma v\rangle_{\mathrm{TT}}}{\langle\sigma v\rangle_{\mathrm{DT}}}$$

To make it easier to compare different platforms, let's normalize out the initial fuel fractions:

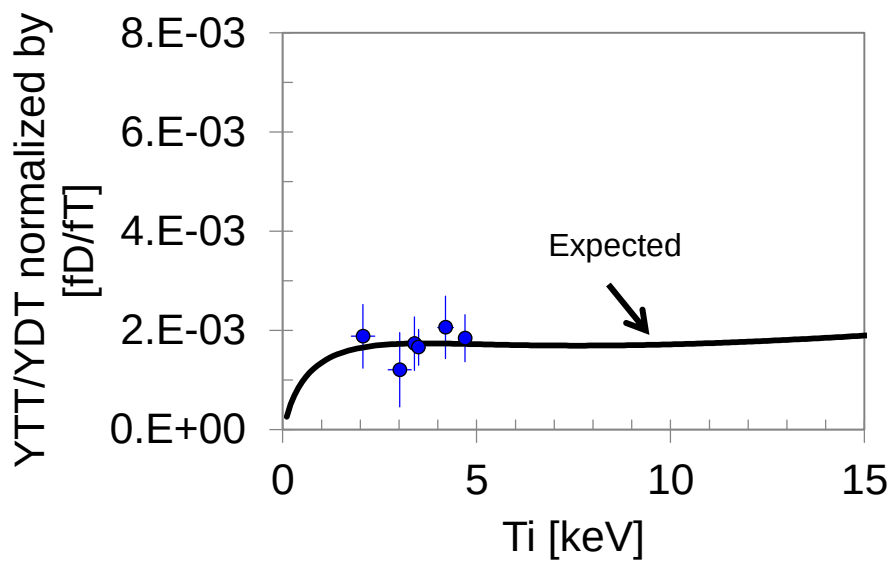
$$Y_{11}/Y_{12}\frac{f_2}{f_1} \cong \frac{1}{2}\frac{\langle\sigma v\rangle_{11}}{\langle\sigma v\rangle_{12}}$$

If we normalize out the initial fill, these gas-filled NIF indirect drive implosions show no apparent anomaly

1 scale and 0.8 scale DT symcaps, DT IDEPS



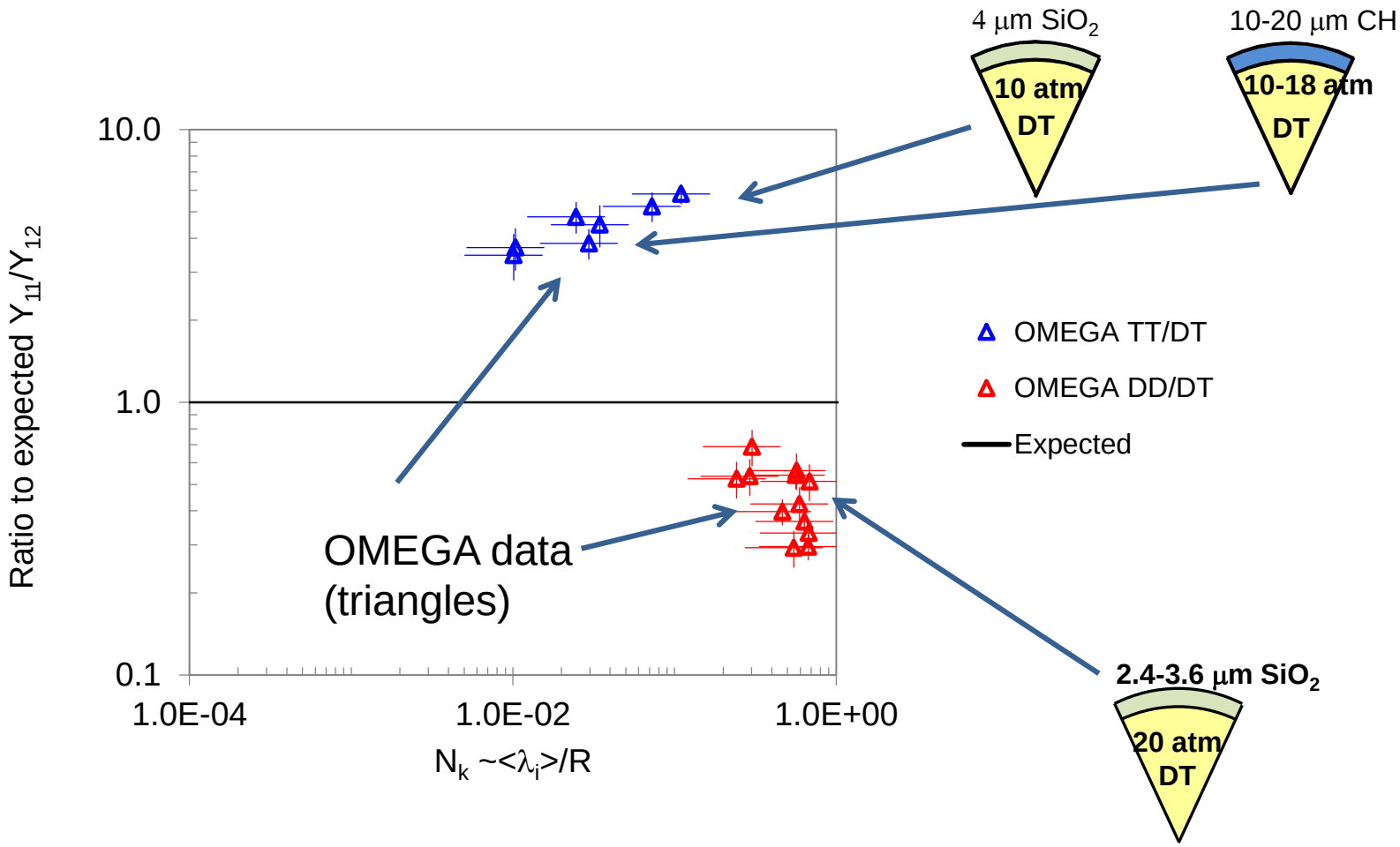
1 scale and 0.8 scale TT and HT symcaps



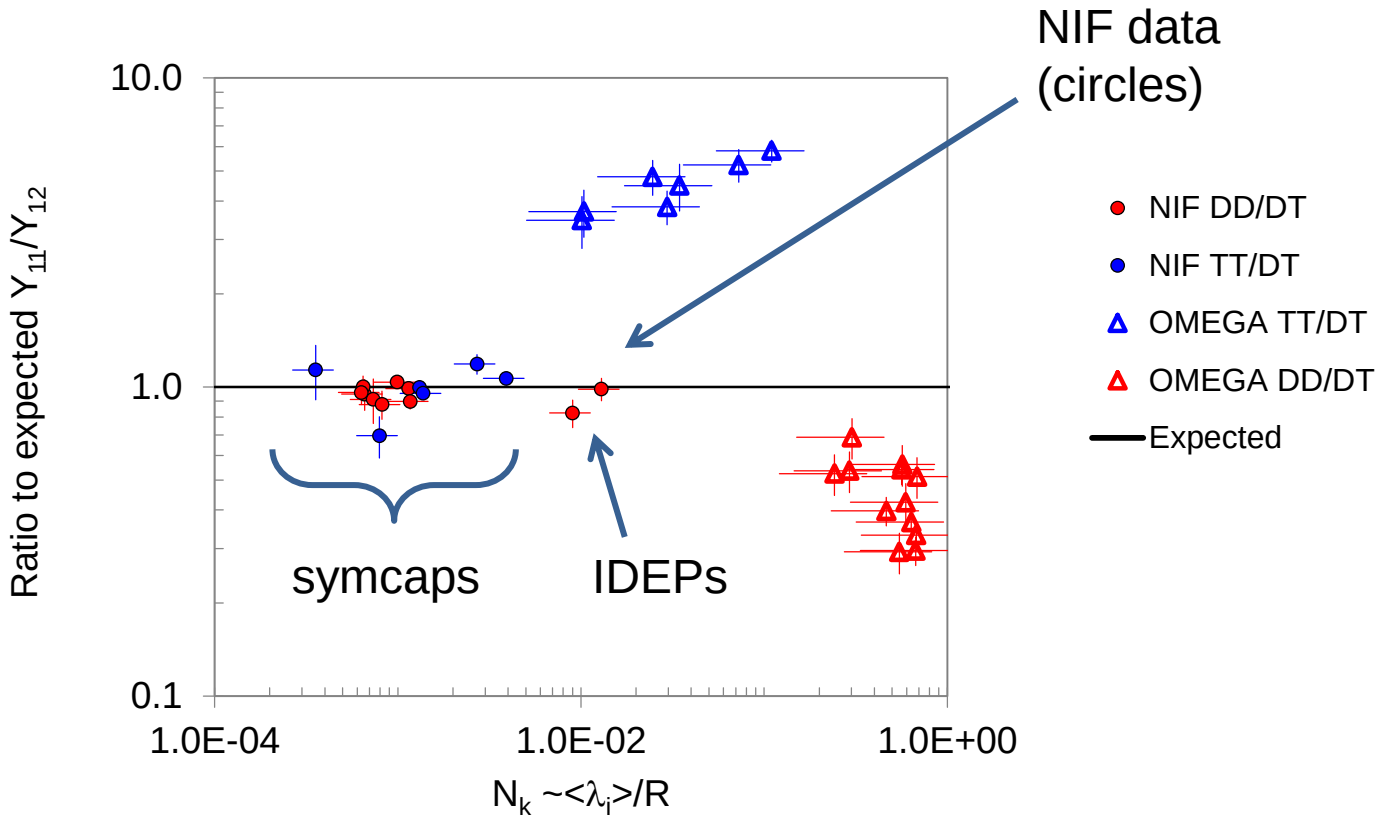
$$Y_{DD}/Y_{DT} \cong \frac{1}{2}\frac{f_D}{f_T}\frac{\langle\sigma v\rangle_{\mathrm{DD}}}{\langle\sigma v\rangle_{\mathrm{DT}}}$$

$$Y_{TT-rx}/Y_{DT} \cong \frac{1}{2}\frac{f_T}{f_D}\frac{\langle\sigma v\rangle_{\mathrm{TT}}}{\langle\sigma v\rangle_{\mathrm{DT}}}$$

We can attempt to compare all the data by plotting the ratio to expected verse the ion mean free path

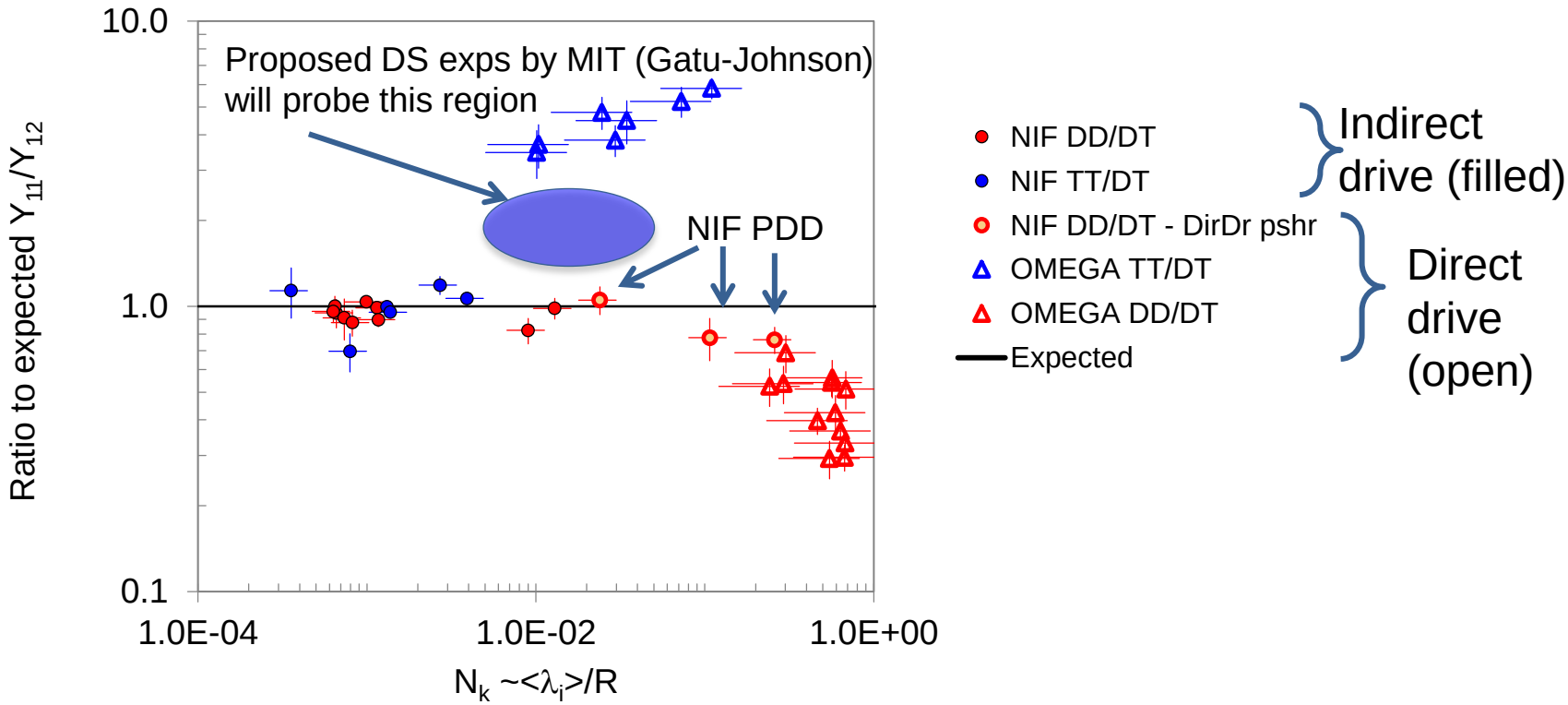


The global result is consistent with problems with low collisionality not present in NIF symcaps and IDEPs, and presumably not layers



This data does not rule out the impact of possible early-time non-fluid issues on the initial-conditions of NIF ignition experiments

Direct drive exploding pushers on the NIF may show a weak anomaly consistent with Ω trends – we should look at more data…



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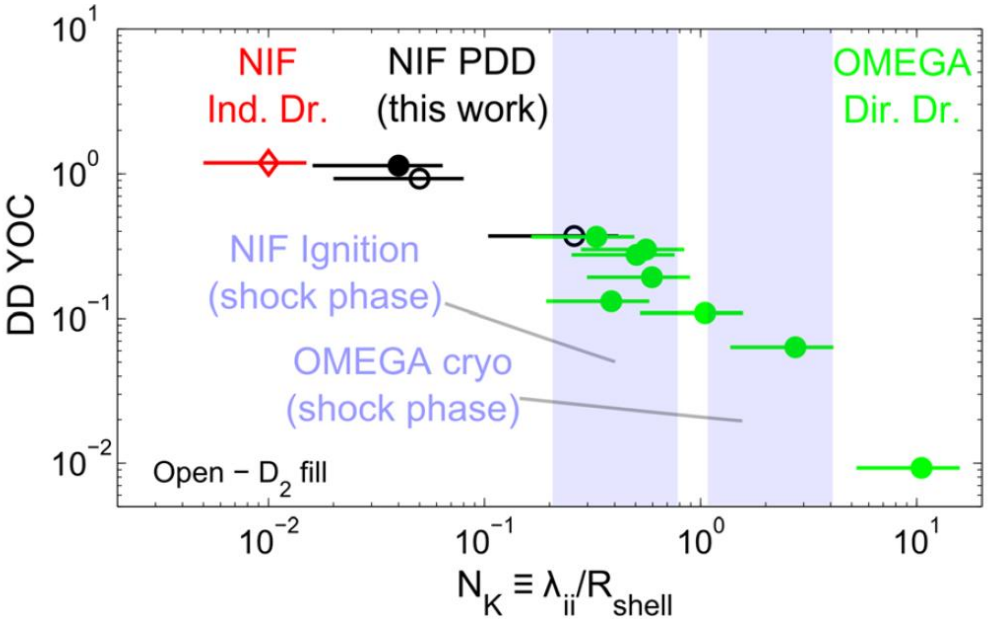
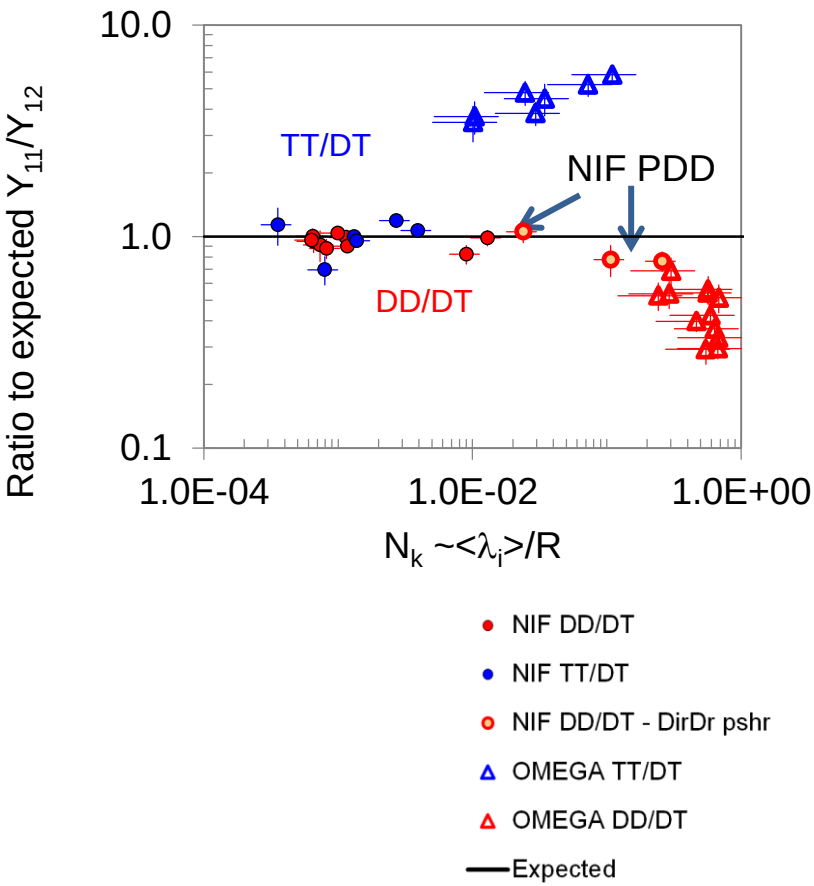
These results seem consistent with the findings of Rosenberg et al. for D^3He and DD implosions





M. J. Rosenberg et al., Physics of Plasmas 21, 122712 (2014)

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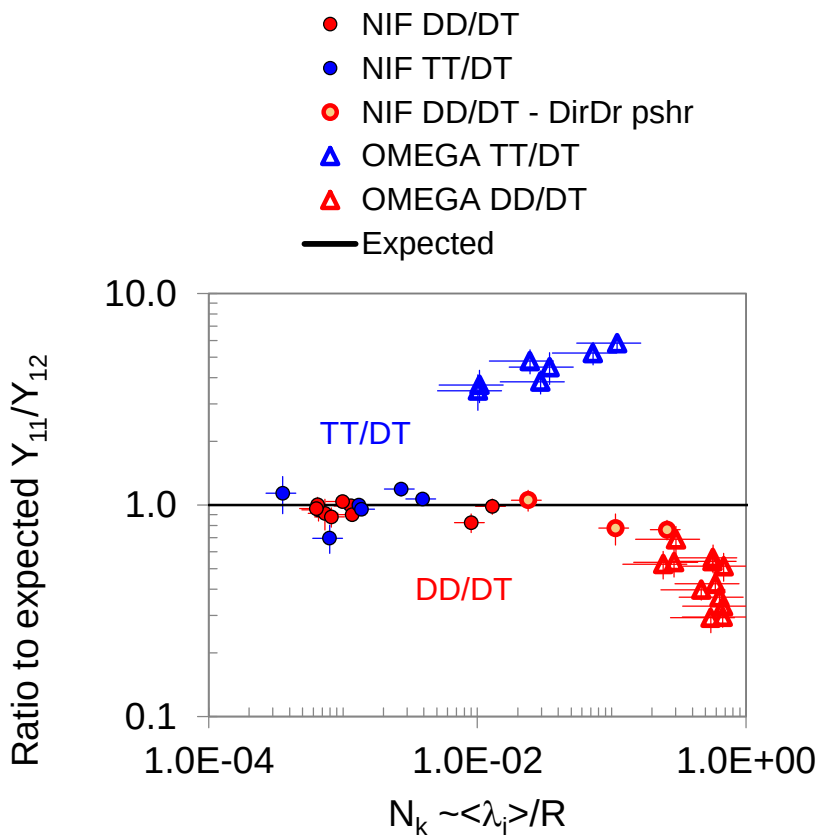

EXTRA SLIDES

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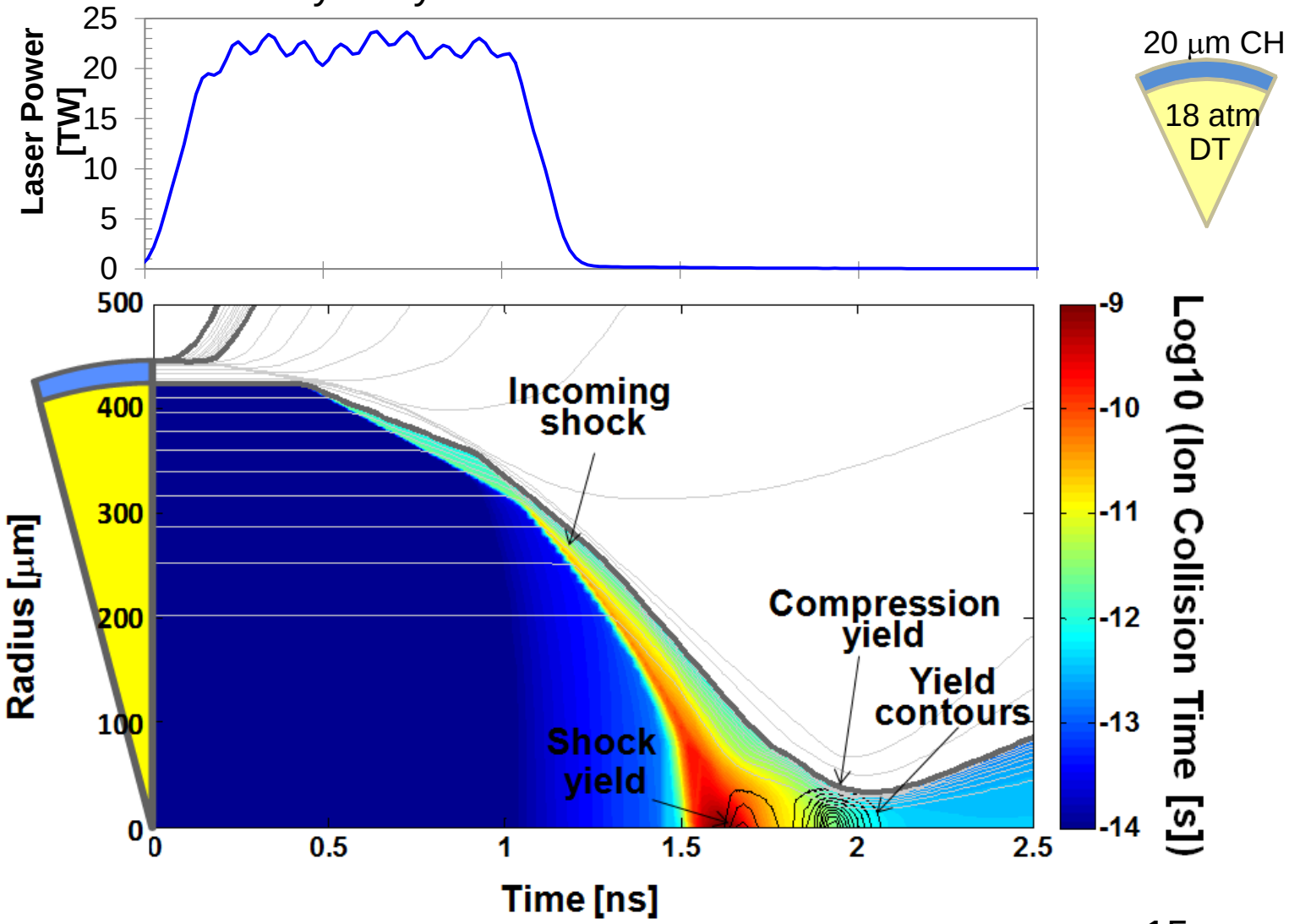
The ion collision time is dynamic between compression and shock burn in OMEGA implosions, starting kinetic and becoming collisional in high compression

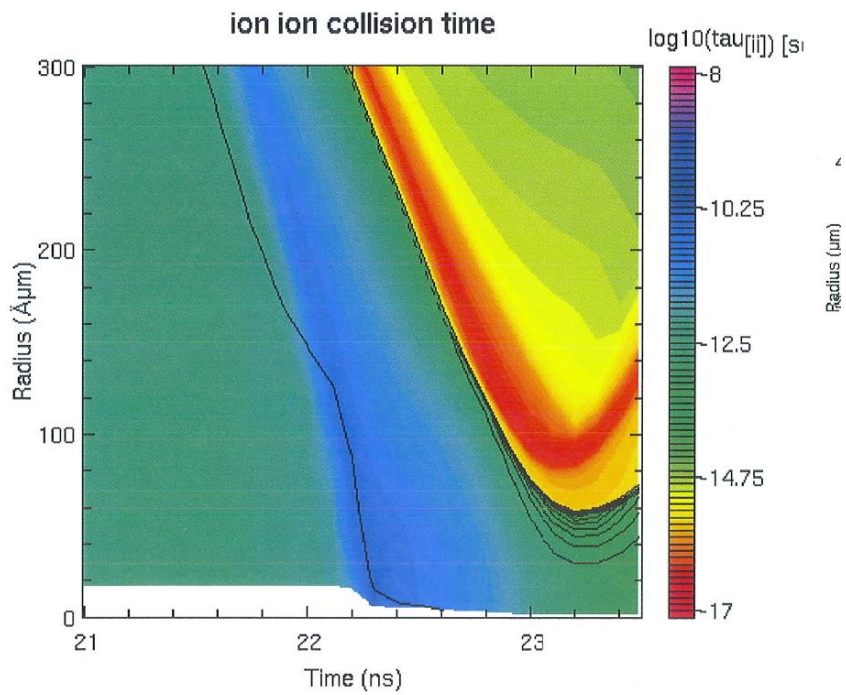
LILAC Hydrodynamic Simulation of shot 55983



In contrast NIF implosions are very collisional near bangtime

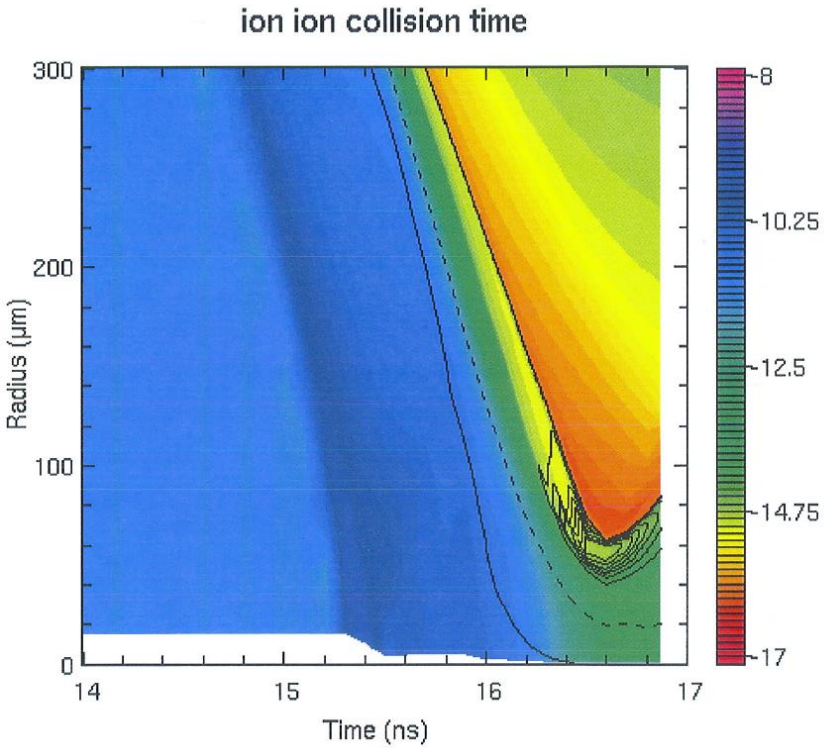
LF symcap

HYDRA simulation



HYDRA simulation

HF layer



The yield ratio of two reactions with similar <σv> Ti dependence is independent of detailed Ti($\vec{r}$,t), ni($\vec{r}$,t) profiles

$$Y_{12} = \int \frac{f_1 f_2}{1+\delta_{12}} \frac{\rho(\vec{r},t)^2}{\bar{m}^2} \langle\sigma v\rangle_{12}\, d\vec{r}\, dt$$

Assume f_1 and f_2 are <u>fixed</u>

$$\frac{Y_{11}}{Y_{12}} \cong \frac{1}{2} \frac{f_1 \int \frac{\rho^2}{\bar{m}^2} \langle\sigma v\rangle_{11}\, d\vec{r}\, dt}{f_2 \int \frac{\rho^2}{\bar{m}^2} \langle\sigma v\rangle_{12}\, d\vec{r}\, dt}$$

Define:

$$R = \frac{\langle\sigma v\rangle_{11}}{\langle\sigma v\rangle_{12}}$$

Expand:

$$R \approx R_0 + \frac{\partial R}{\partial T}(T - \langle T\rangle)$$

This requires that: $\frac{\partial^2 R}{\partial T^2} \sigma_T{}^2 \sim 0$

Using S-factor parameterization:

$$\frac{\partial^2 R}{\partial T^2} = R \frac{K}{9} \left[\frac{4}{T^{7/3}} + \frac{K}{T^{8/3}} \right]$$

Where:

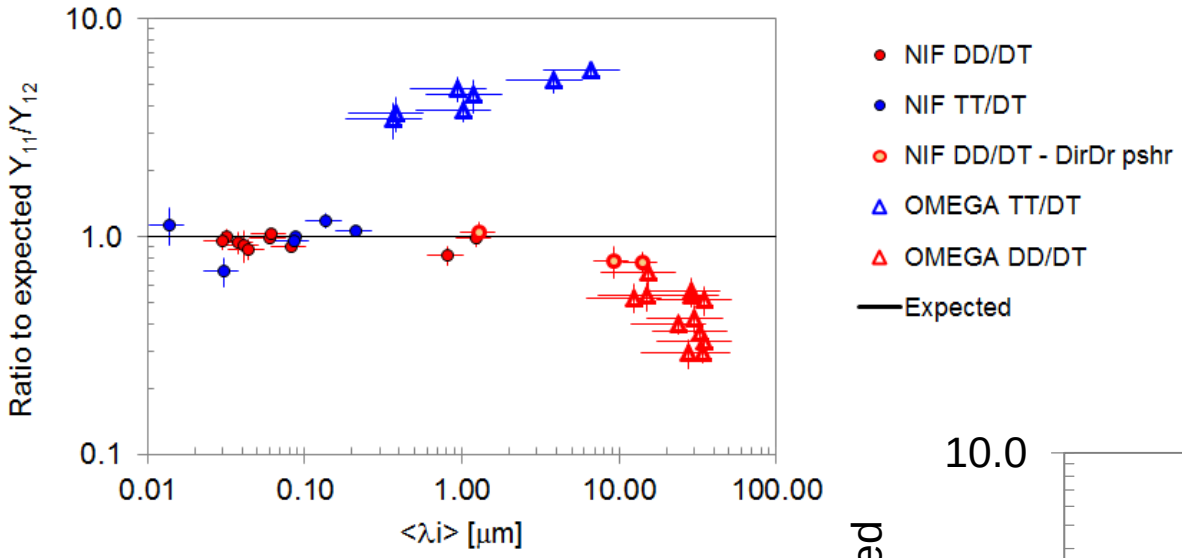
$$K = \frac{-3\left(c\,\pi\,\alpha_f\right)^{2/3}}{2^{7/6}\,(m_1 + m_1)^{1/3}} \left[(Z_1 m_1)^{2/3} - (Z_1 Z_2 m_1 m_2)^{1/3} \right]$$

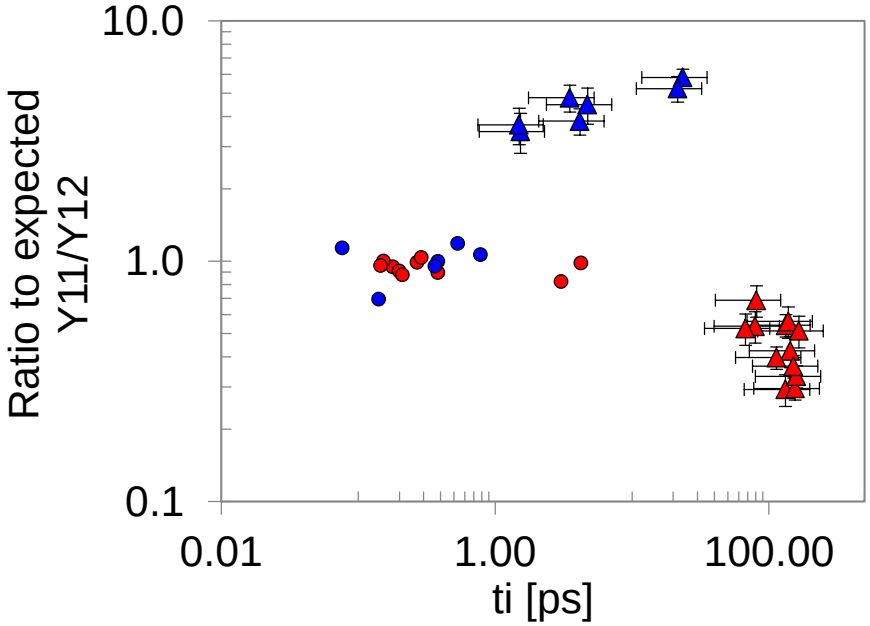
Indeed, it is small for DD/DT and TT/DT

$\langle T\rangle - \langle T\rangle = 0$

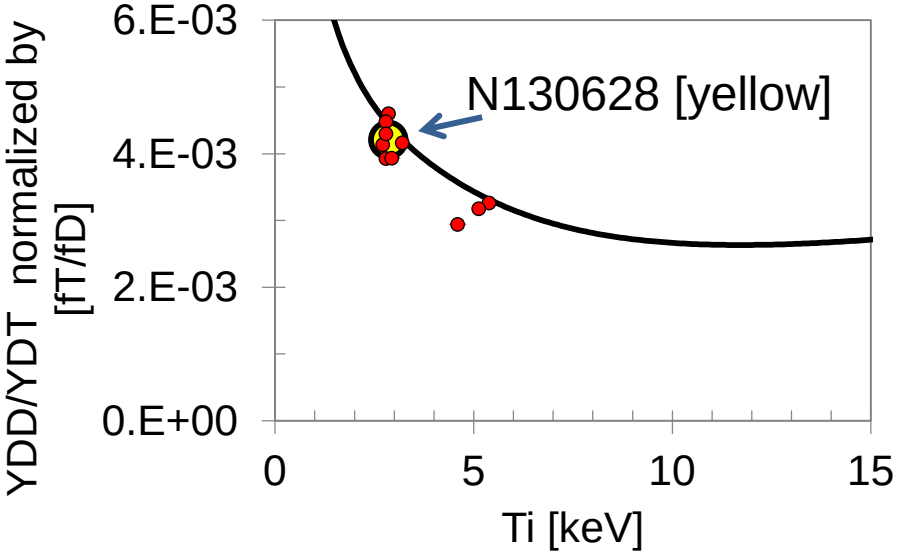
$$\frac{Y_{11}}{Y_{12}} = \frac{1}{2}\frac{f_1}{f_2} R_0 \left[1 + \frac{\frac{1}{R_0}\frac{\partial R}{\partial T} \int \rho(\vec{r},t)^2\, (T - \langle T\rangle)\, \langle\sigma v\rangle_{12}\, d\vec{r}\, dt}{\int \rho(\vec{r},t)^2 \langle\sigma v\rangle_{12}\, d\vec{r}\, dt} \right] = \boxed{Y_{11}/Y_{12} \cong \frac{1}{2}\frac{f_1}{f_2}\frac{\langle\sigma v\rangle_{11}}{\langle\sigma v\rangle_{12}}}$$

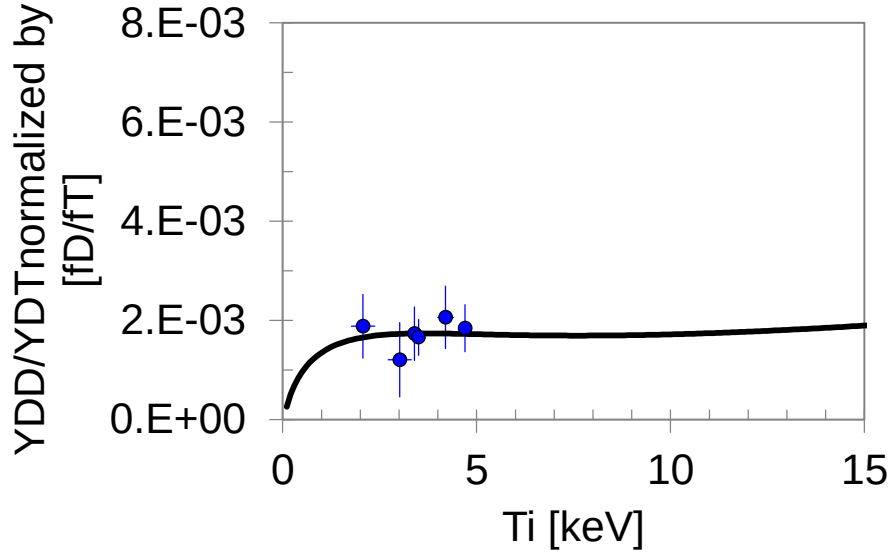
Other metrics to plot the data against:





HDC symcap N130628 callout - ref Darwin Ho's talk





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