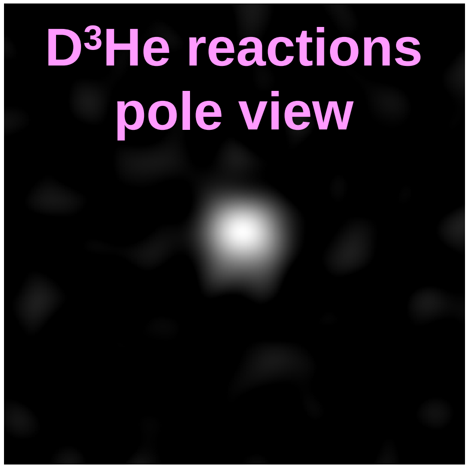
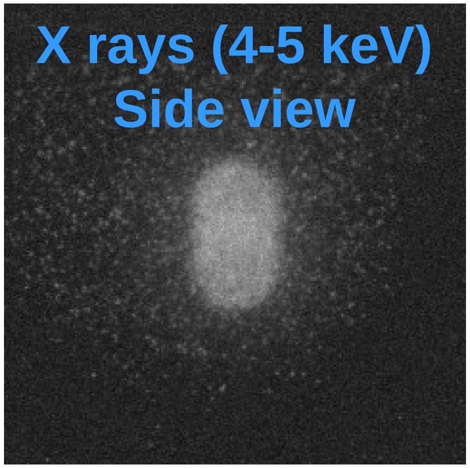
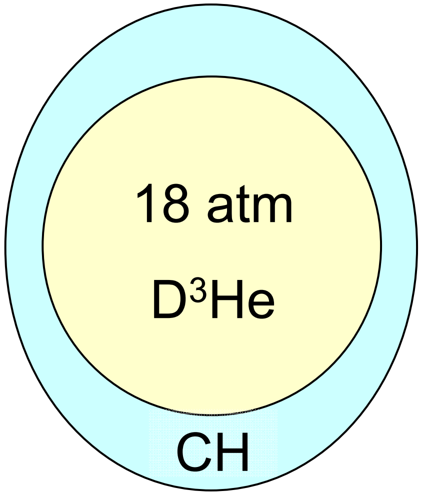
Controlling the symmetry of direct-drive implosions with target shimming

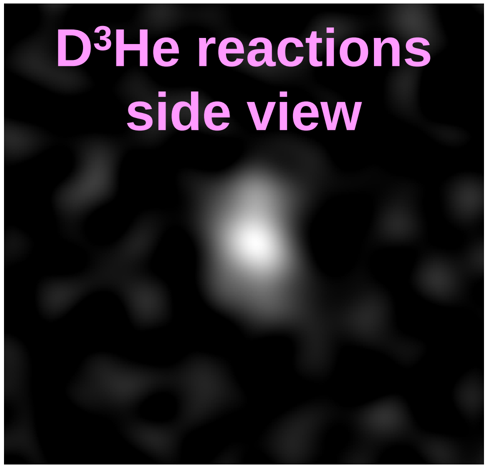


D^3He reactions pole view



X rays (4-5 keV) Side view





D^3He reactions side view

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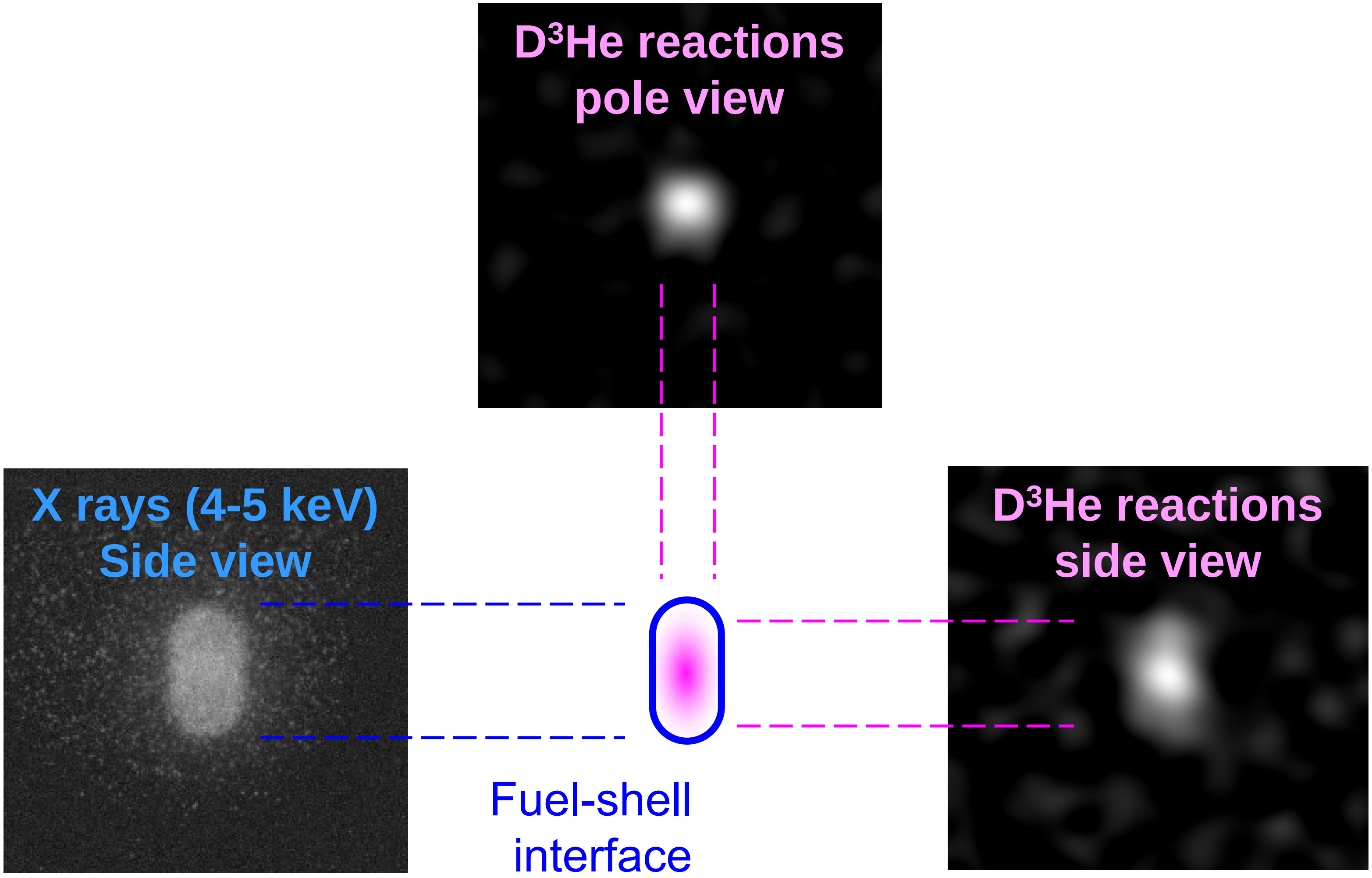
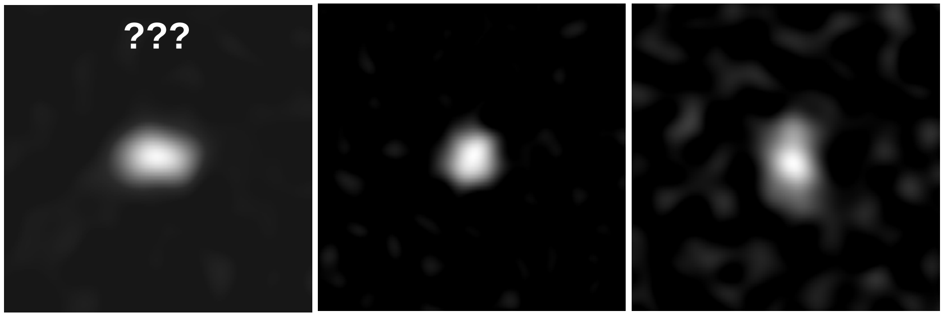
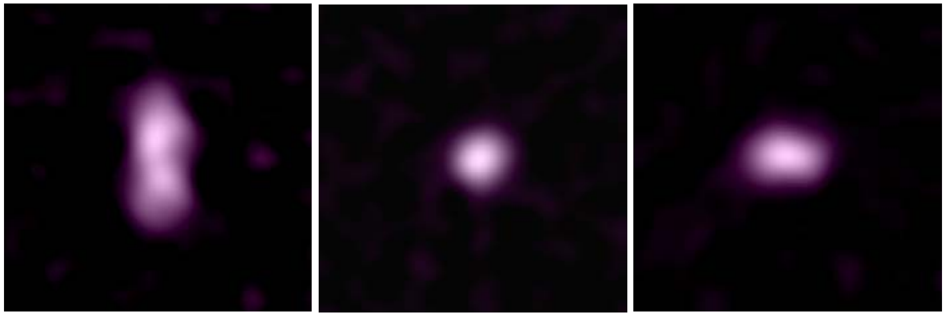


Summary

1) Target shimming changes
nuclear burn symmetry

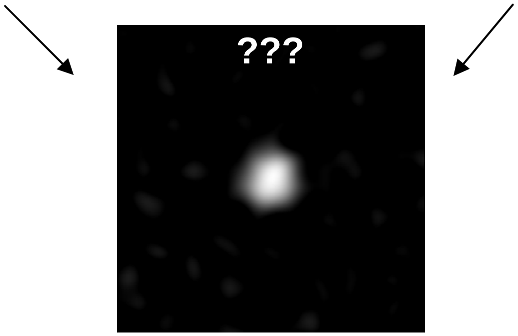


2) Drive asymmetry results in
burn asymmetry
and reduced performance



3) Shimming could counteract
drive asymmetry

- Polar Direct Drive
- Indirect Drive



4) A formula is proposed
for estimating
the amount of shimming necessary

Collaborators

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National Laboratory

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H.S. Park
H. Robey
R. Tipton

Other Colleagues doing related work

Neutron imaging of DT burn at OMEGA

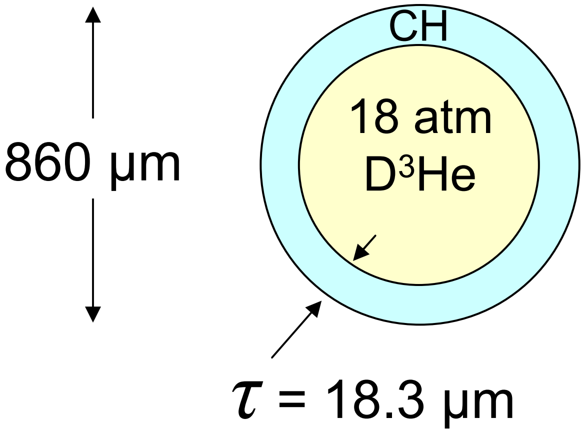
- L. Disdier *et al.*
- C. Christensen, G. Grim *et al.*

Study of P_4 shimming in indirect drive at the Sandia Z pinch

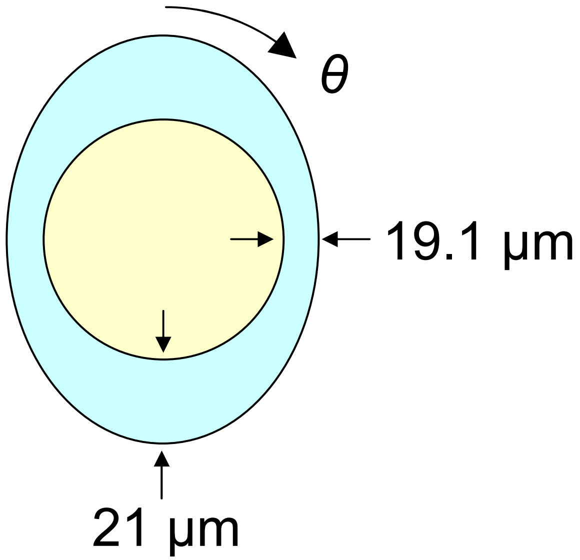
- D. Callahan, G. Bennet *et al.*

Two types of target were illuminated symmetrically by 22-kJ, 1-ns square laser pulses at OMEGA

1 Spherical target



2 Shimmed targets



$$\tau(\theta) = \sum_{\ell} A_\ell P_\ell(\cos\theta)$$

is dominated by P_0 and P_2,

$A_2 / A_0 = 0.07$

Orthogonal proton emission imaging cameras were used to study the spatial distribution of nuclear burn

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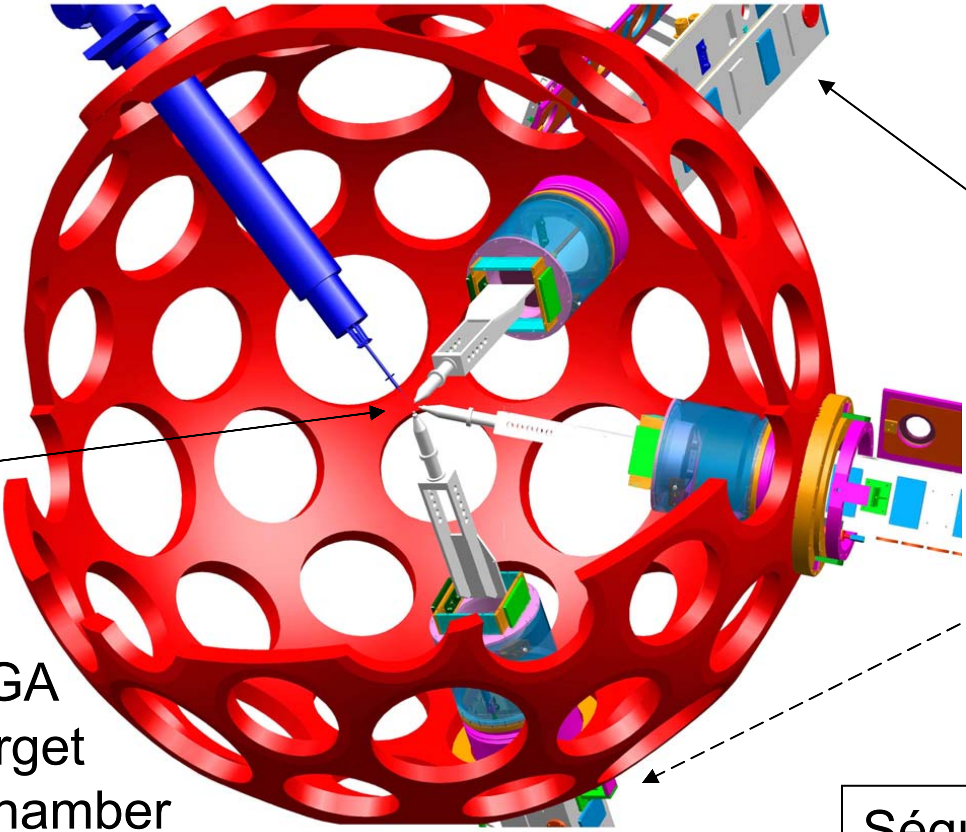


Target capsule

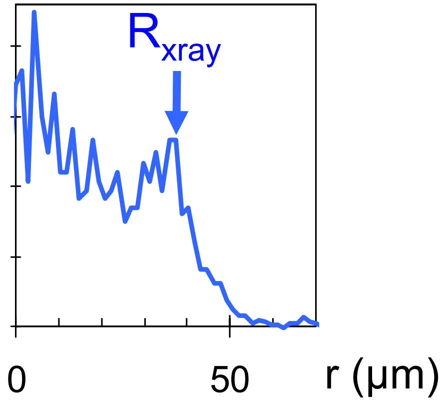
OMEGA target chamber

Cameras

Séguin *et al*., RSI 74, p. 975
DeCiantis *et al,* RSI, accepted
DeCiantis *et al,* PoP, submitted
Séguin *et al*., PoP, to be subm.

The spherical target imploded symmetrically

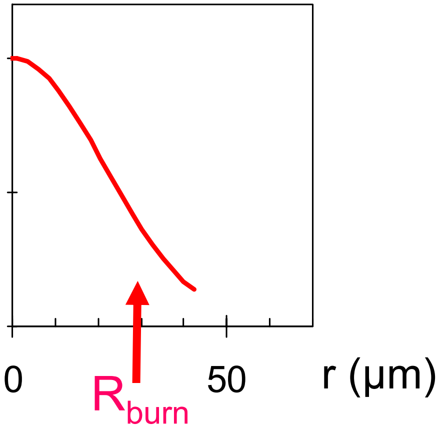
surface brightness



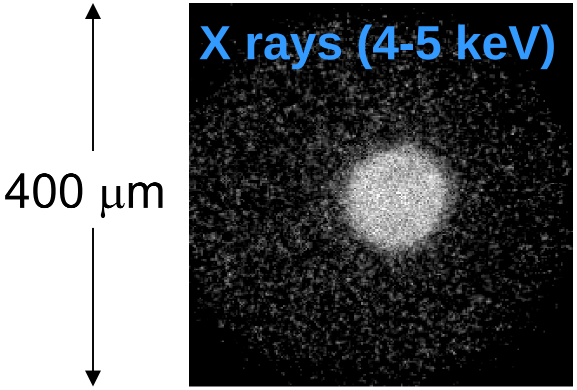
Shot 40534

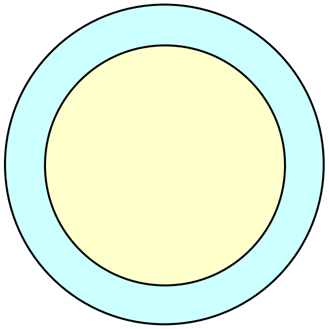
R_{burn} = 31 ± 2 µm

surface brightness

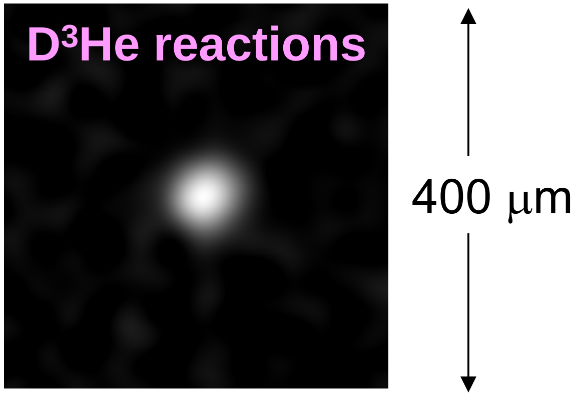


R_{xray} = 38 ± 5 µm





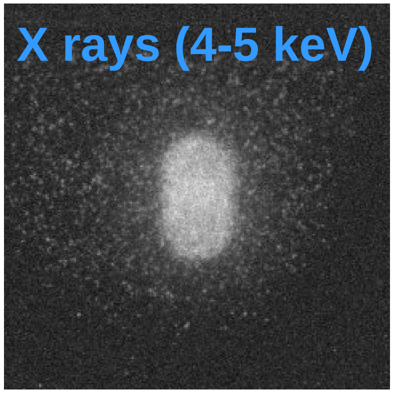
R_{burn} = 29 ± 2 µm

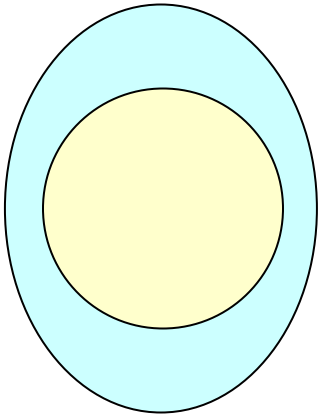


The shimmed targets imploded with prolate asymmetry

Shot 40532

Shot 40533



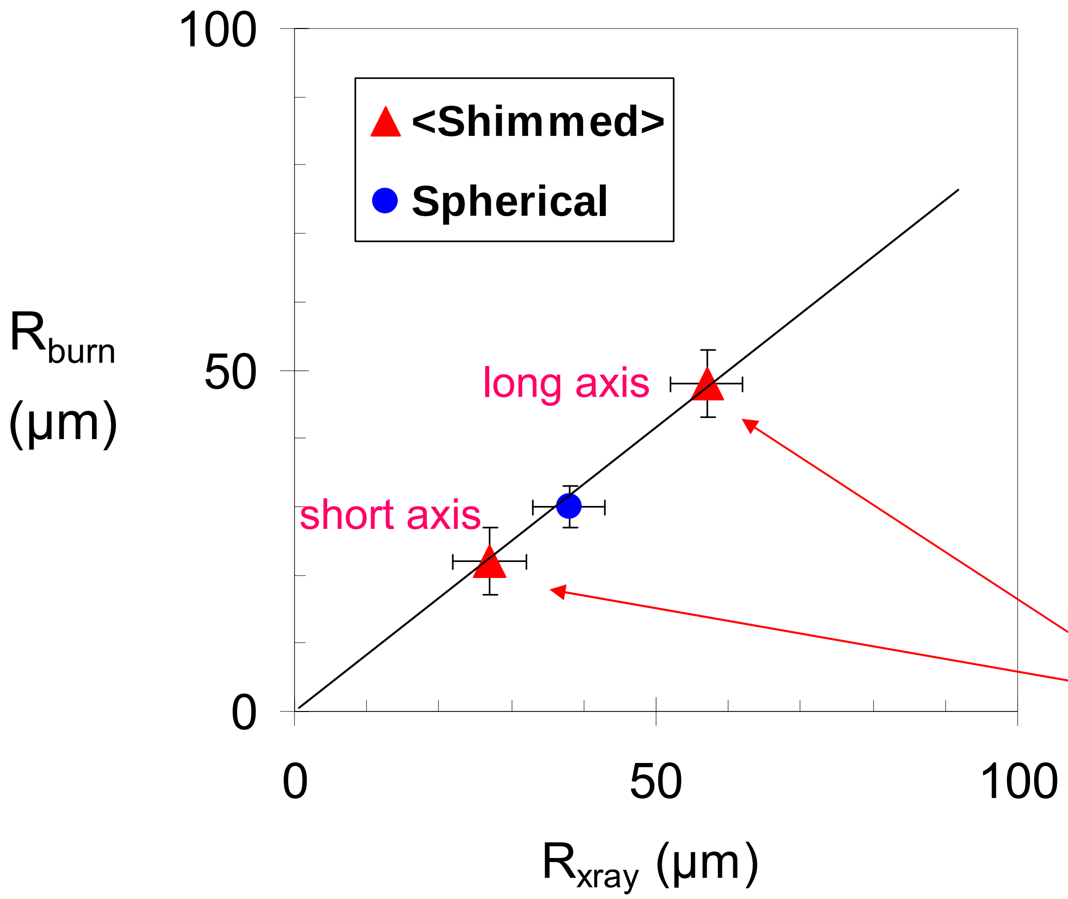


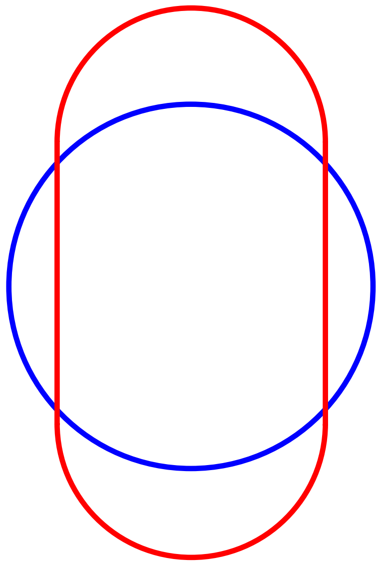
Shot 40532

Shot 40533

Each image is now characterized by two different radii
(for the long and short axes), as plotted on the next page

Burn measurements and x-ray measurements show similar distortion in core and shell due to shimming



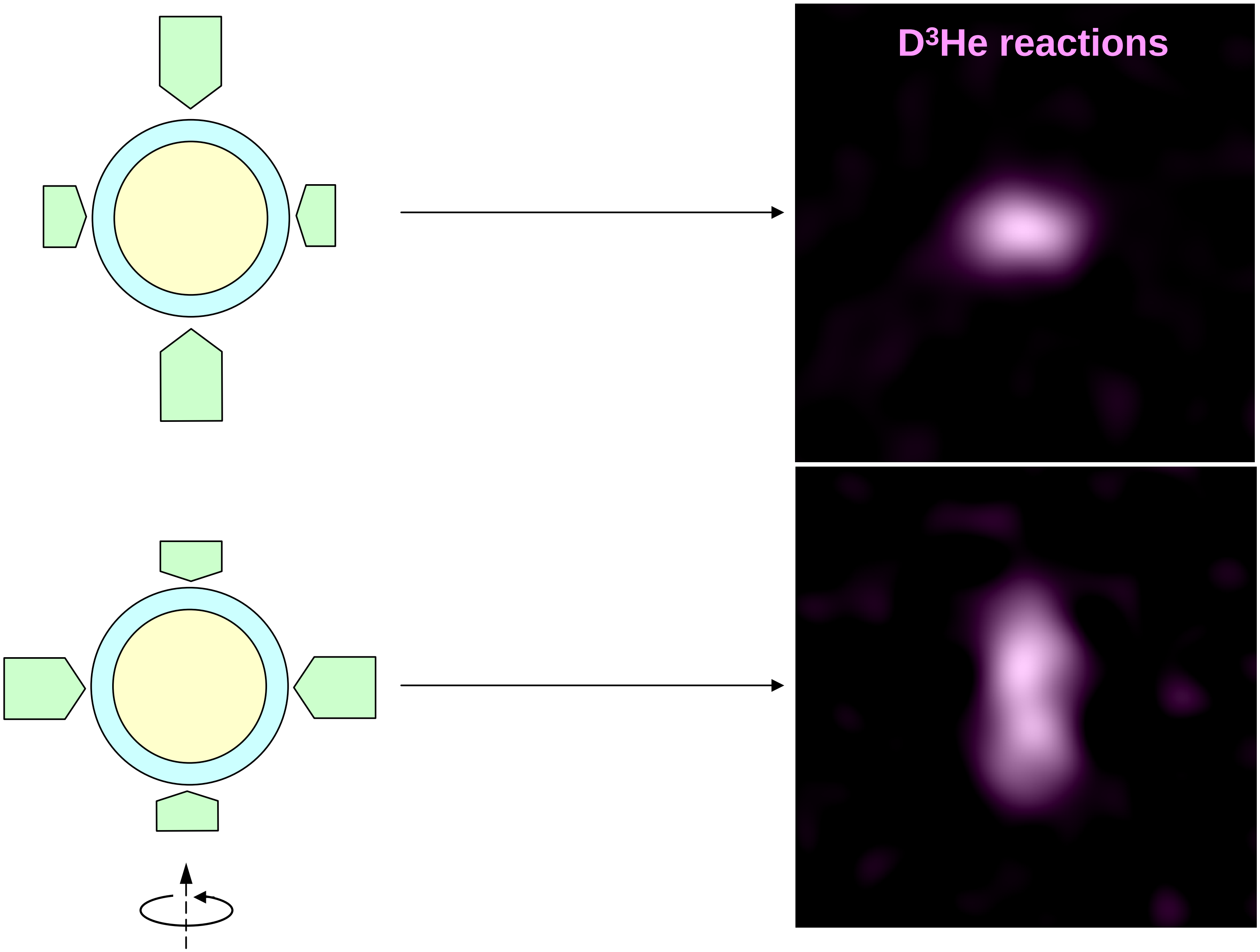


$R_{long} / R_{short} \approx 2.1$

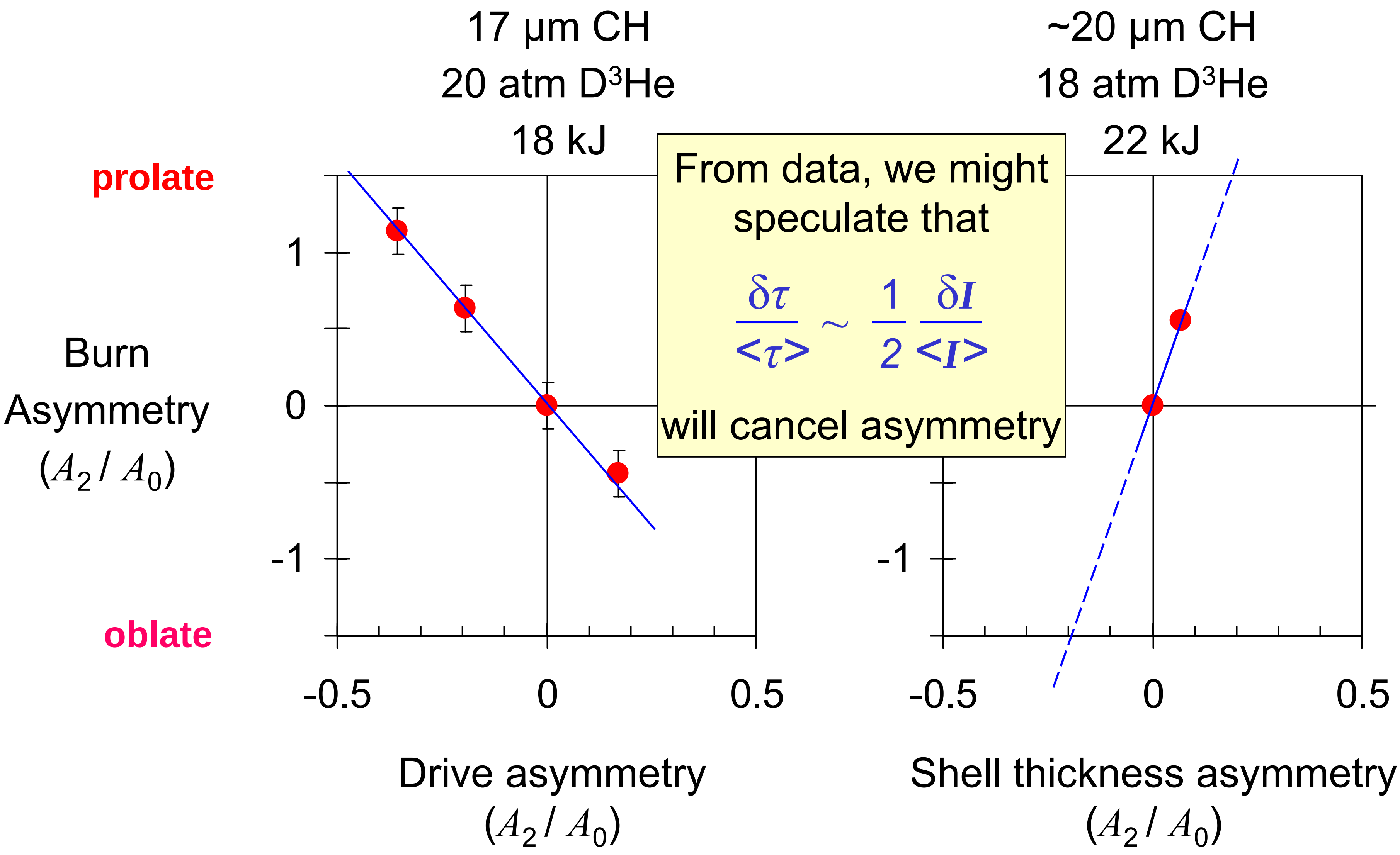
$A_2 / A_0 \approx 0.55$

for the shimmed target

Asymmetric drive leads to asymmetric burn and reduced yield



There are systematic connections between burn asymmetry and each of its causes

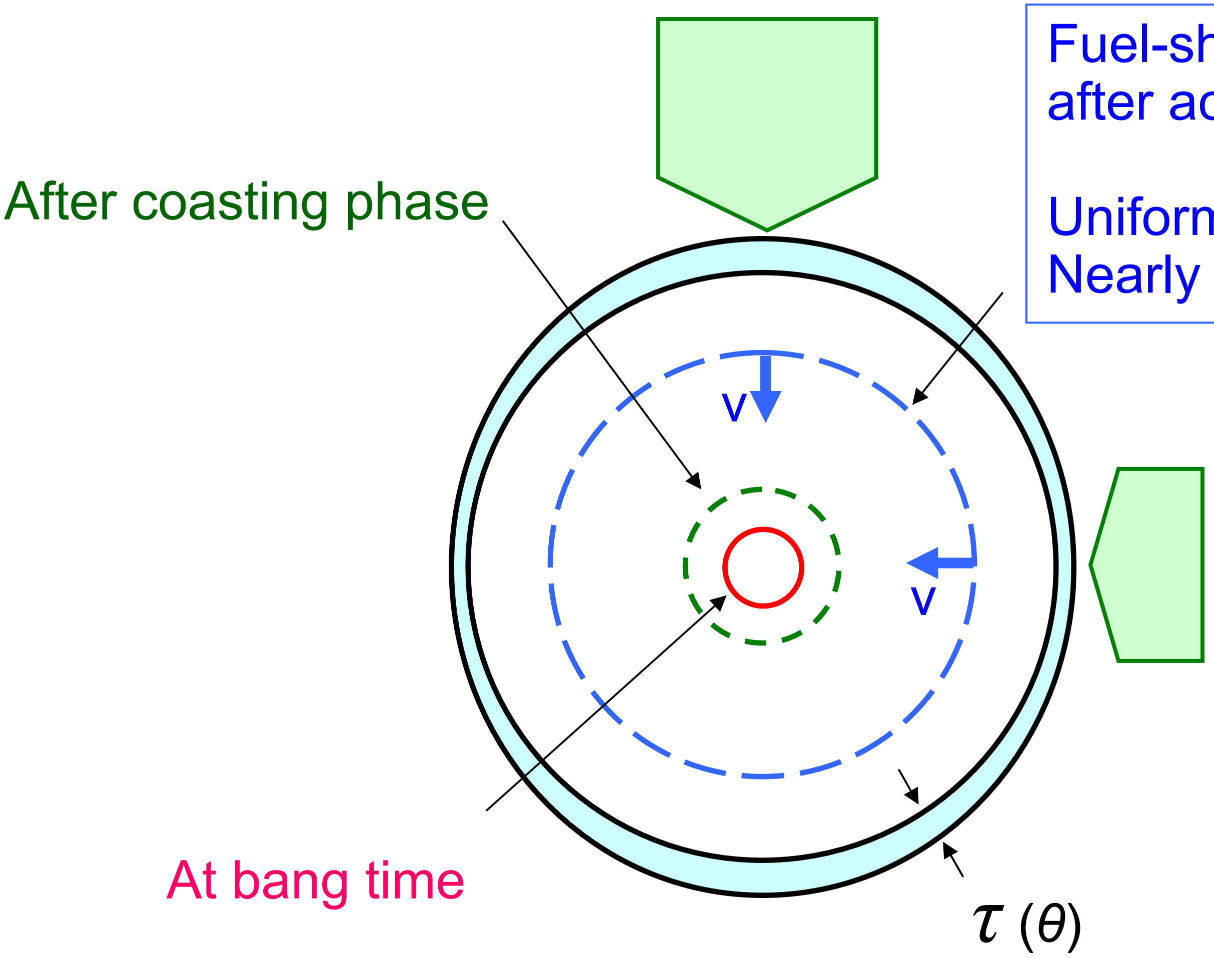


From data, we might speculate that

$$\frac{\delta\tau}{\langle\tau\rangle} \sim \frac{1}{2}\,\frac{\delta I}{\langle I\rangle}$$

will cancel asymmetry

Let’s vary the shell thickness to get uniform implosion velocity and radius after the acceleration phase



Fuel-shell interface
after acceleration phase:

Uniform radial velocity
Nearly spherical

The shell thickness variation required to keep the implosion velocity symmetric can be estimated from the ablation-driven rocket equations

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For direct drive
(from J.D. Lindl, PoP **2**, p. 3933):

$$\boxed{\dot{m} = \alpha\, I^{1/3}; \qquad v_{imp} = \beta\, I^{1/3} \ln\left(\frac{m_0}{m}\right)}$$

To lowest order, the angular thickness distribution that gives uniform implosion velocity after acceleration is

$$\boxed{\frac{\delta\,\tau(\theta)}{\langle\tau\rangle} \approx \frac{2}{3}\left[1 - \frac{1}{4}\frac{\langle d\tau\rangle_{ablation}}{\langle\tau\rangle}\right]\frac{\delta\, I(\theta)}{\langle I\rangle}}$$

We can estimate what this means for typical OMEGA shots

$$22\,\text{kJ} \Rightarrow \langle d\tau \rangle_{ablation} \approx 10\text{ - }12\,\mu\text{m} \quad \Rightarrow \quad \boxed{\frac{\delta\tau(\theta)}{\langle\tau\rangle} \approx \frac{2}{3}\left[1 - \frac{3\,\mu\text{m}}{\langle\tau\rangle}\right]\frac{\delta I(\theta)}{\langle I\rangle}}$$

$$\langle\tau\rangle = 20\,\mu\text{m} \Rightarrow \quad \boxed{\frac{\delta\tau(\theta)}{\langle\tau\rangle} \approx 0.6\,\frac{\delta I(\theta)}{\langle I\rangle}}$$

From data, we speculated

$$\frac{\delta\tau}{\langle\tau\rangle} \sim \frac{1}{2}\frac{\delta I}{\langle I\rangle}$$

The shell thickness variation required
to counterbalance a 10% intensity variation is

$\delta\tau \approx 1.2\ \mu\text{m}$

Summary

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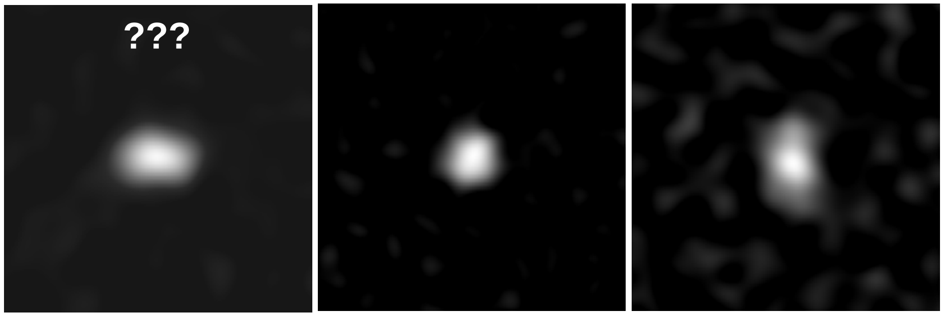

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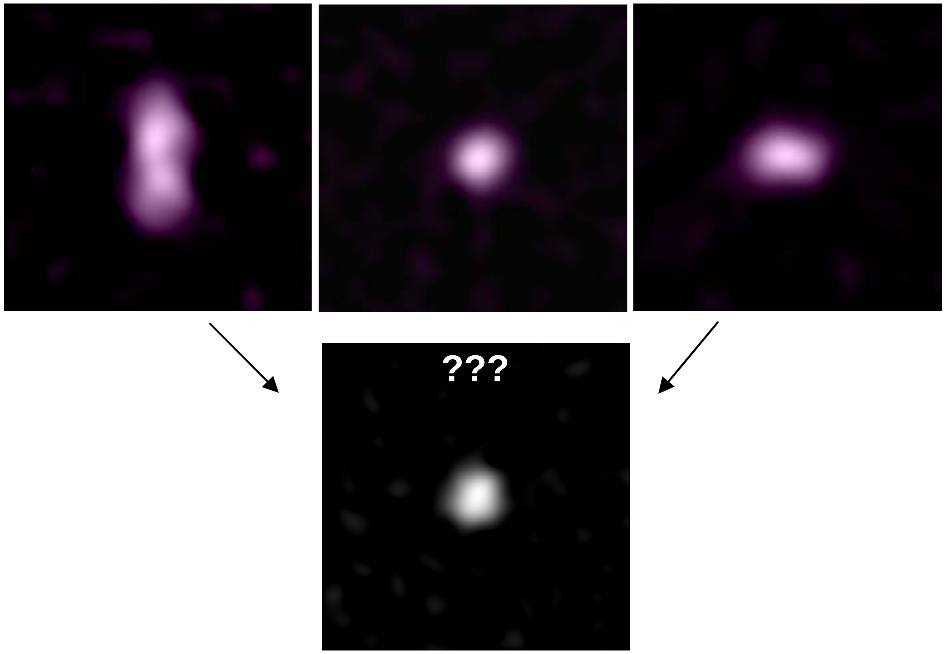

3) Shimming could counteract drive asymmetry

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4) A formula is proposed for estimating the amount of shimming necessary