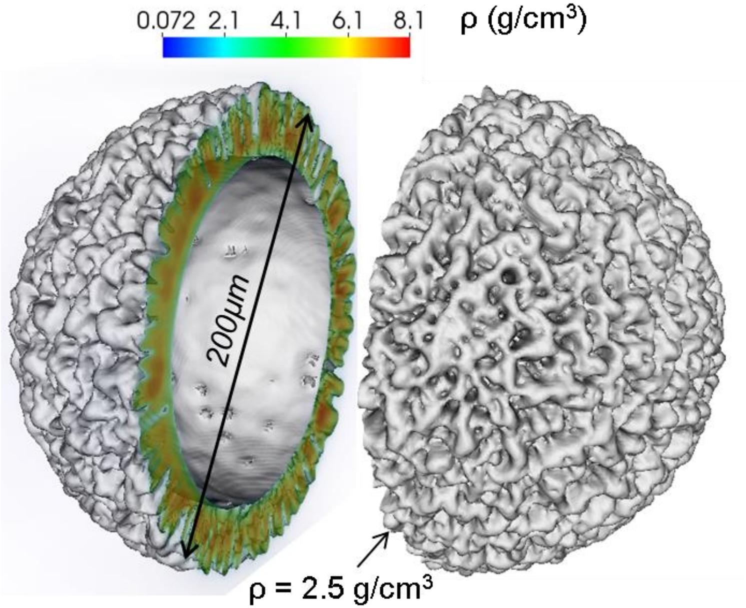
Three-dimensional hydrodynamic modeling of OMEGA direct-drive cryogenic implosions with the highest fusion yield

3-D *ASTER* simulations
of shot 90291 with imprint

End of acceleration
t=2.1 ns



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Known 3-D asymmetry effects can not be currently identified as dominant performance degradation mechanisms of high-yield OMEGA direct-drive implosions

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- These implosions are relatively stable with respect to laser imprinting, indicating that other performance-degradation mechanisms are present

- The role of low-mode perturbations (mostly mode $\ell = 1$) and surface defects in performance degradation can be significant, but it is uncertain because of uncertainties in initial conditions

[1] Igumenshchev *et al*., Phys. Plasmas **23**, 052702 (2016).

Collaborators

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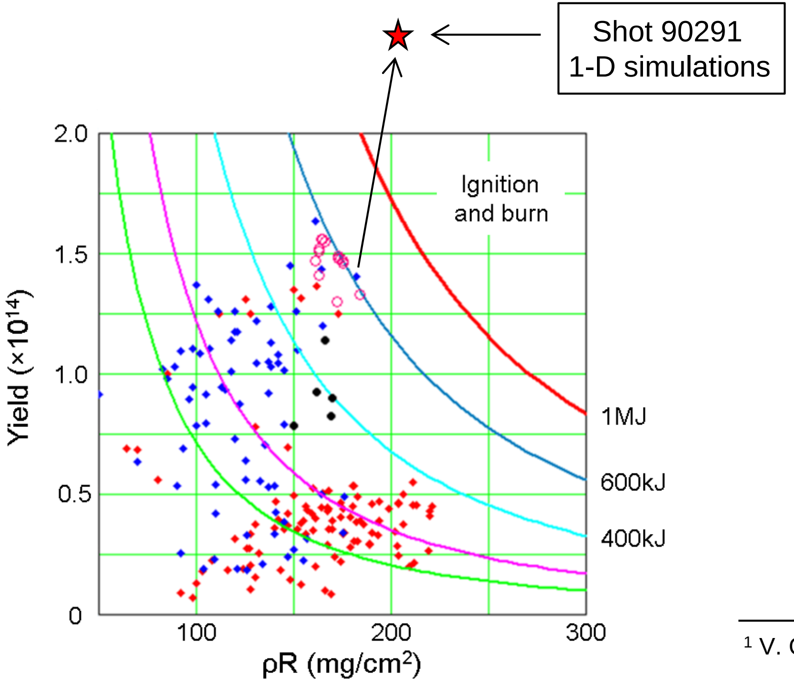
The Optimization Campaign[1] on OMEGA led to the highest neutron yield in cryogenic DT direct-drive implosions

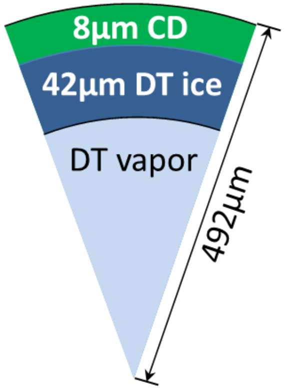
Extrapolated constant fusion yield curves for 1.9 MJ of laser energy



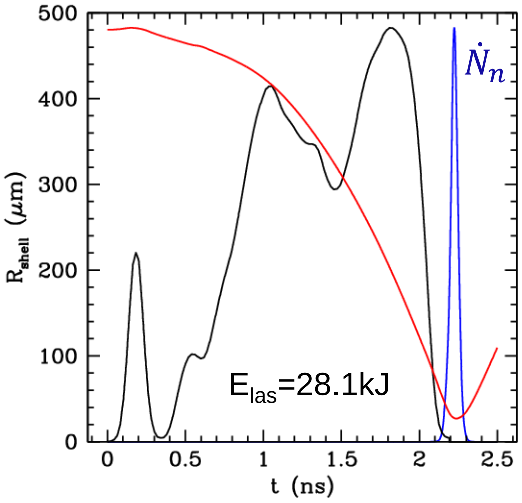
[1] V. Gopalaswamy *et al.*, Nature **565**, 581 (2019)

Measured directional variations of ρR and T_{ion} in shot 90291 indicate the presence of low-mode asymmetries

Target dimensions



Laser pulse and simulated shell trajectory and neutron history



Adiabat α ≈ 4.5

Measured and simulated performance of shot 90291

	N_n (10^{14})	P_{hs} (Gbar)	ρR (mg/cm²)	T_{ion} (keV)
Experiment	1.31±0.09	52±7	182±25 150±13	5.5±0.39 4.53±0.32
1-D sim.	2.83	99.6	202	4.20

Various hydrodynamic mechanisms reducing implosion performance were assessed using 3-D *ASTER* simulations

- Laser imprint → Development of small-scale perturbations
- Low-mode asymmetries → Directional (mode ℓ = 1) plasma flow in the hot spot[1]
- Surface defects → Injection of ablating materials inside the hot spot

Not included:

- Mount stalk → Jetting the cold fuel and possibly ablator materials into the hot spot

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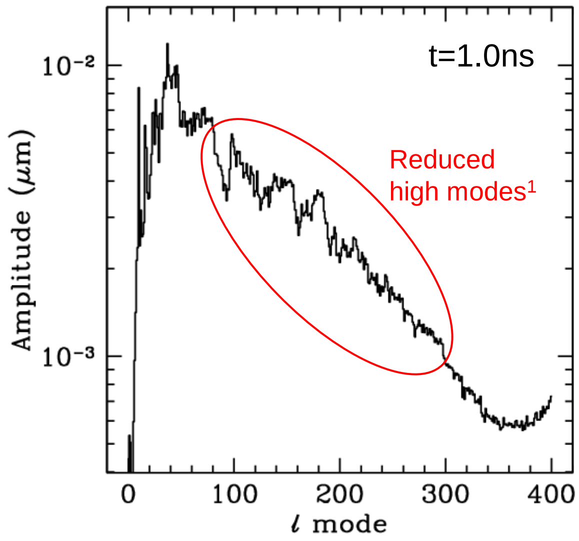
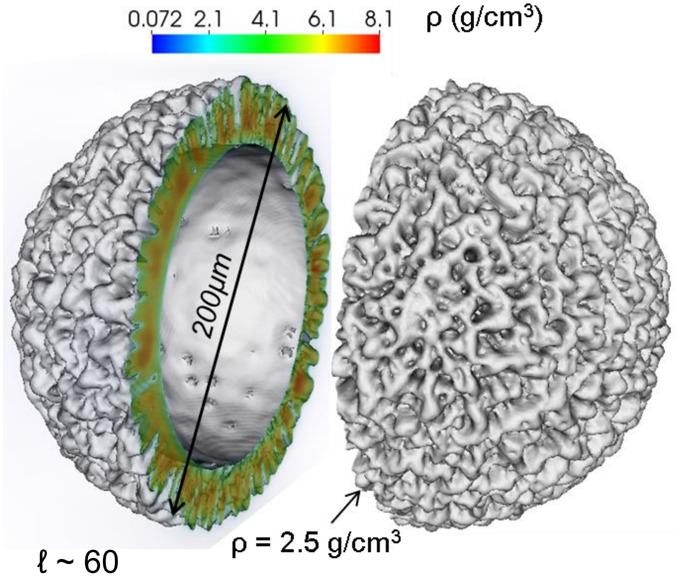
[1] R. Shah, YO5.00001, this meeting
S. Regan, YO5.00002, this meeting
O. Mannion, TO5.00002, this meeting
Z. Mohamed, YO5.00008, this meeting

3-D simulations suggest that imprint alone moderately affects the performance of shot 90291

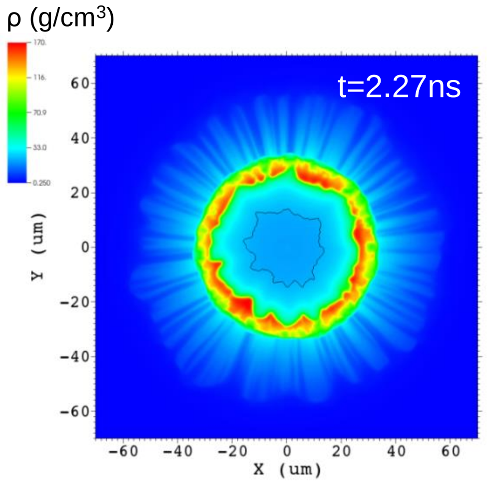
Spectrum of *ρR* modulations from imprint in beginning of acceleration



Target at end of acceleration, t=2.1 ns



Target at peak neutron production

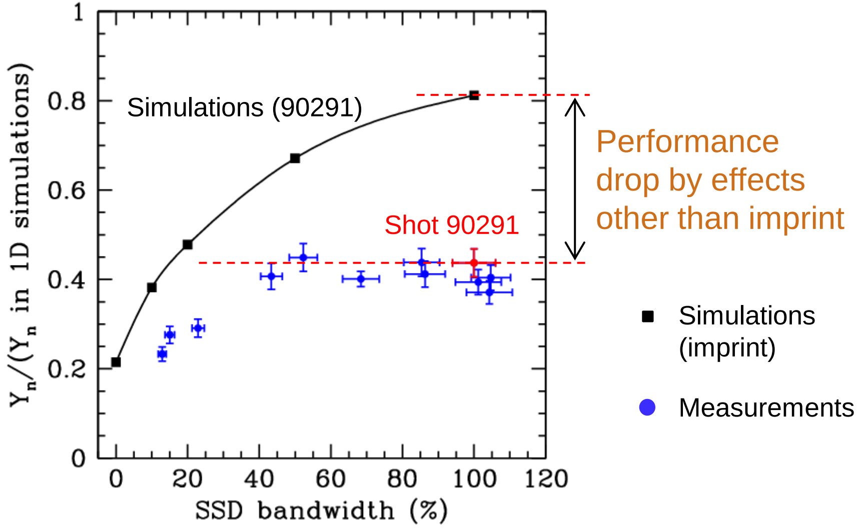


Relative neutron yield (3-D over 1-D) = 0.812

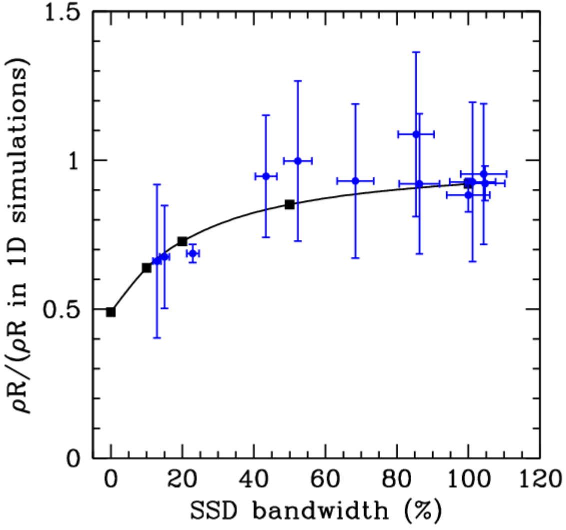
[1] Igumenshchev, Velikovich, Goncharov *et al*. PRL **123**, 065001 (2019)

Results of the experimental campaign[1] with varying laser smoothing (by SSD) also suggest that imprint is not the major factor reducing neutron yield

Measured and simulated neutron yield



Good agreements between measured and simulated areal densities

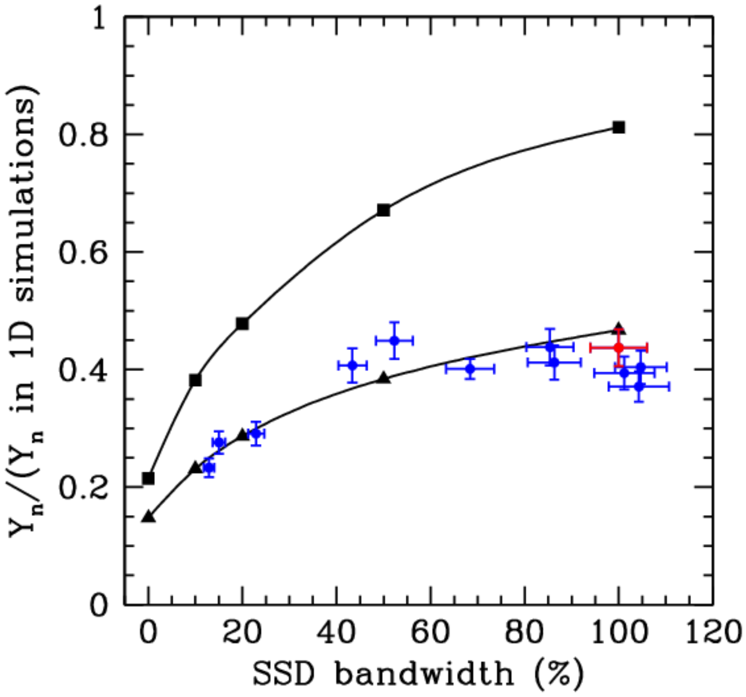


- Shown implosions have adiabat α ≈ 4.5

[1] J. Knauer, YO5.00004, this meeting

Simulations become closer to measurements if significant low-mode perturbations are included

Measured and simulated neutron yield



Simulations:

■ Imprint

▲ Imprint and 20-µm offset (resulting in $V_{\text{hot spot}} \approx 50$ km/s†)

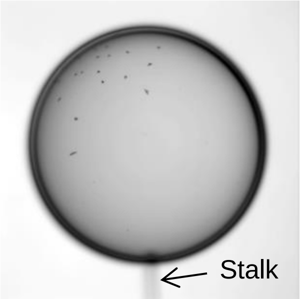
- Recent experiments indicate that the OMEGA laser can unintentionally introduce a mode $\ell = 1$ asymmetry equivalent to about 20 to 50 µm target offset (under investigation)‡

† O. Mannion, TO5.00002, this meeting

‡ S. Regan, YO5.00002, this meeting

Surface defects and their distributions can contribute to the observed implosion asymmetry and performance degradation of shot 90291

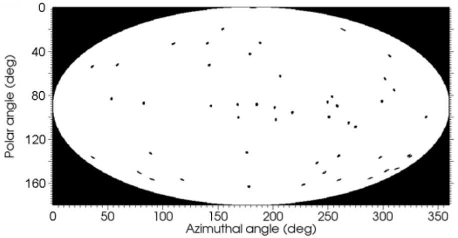
Several tens of surface defects are typically observed in pre-shot target images

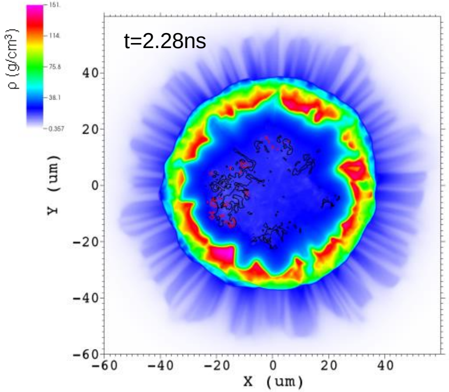


Highly asymmetric distributions in some cases

50 surface defects (2-µm dip and 10-µm diam) assumed in *ASTER* simulations

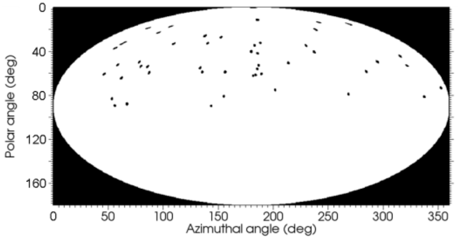
Symmetric

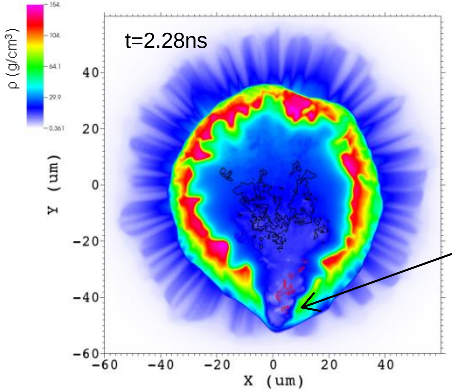




YOU* = 0.61

Asymmetric





Jet

YOU = 0.54

* YOU is the neutron yield over the yield in uniform (1-D) simulations

Various hydrodynamic mechanisms reducing implosion performance were assessed using 3-D *ASTER* simulations

- Laser imprint → Development of small-scale perturbations — **The effect is small**
- Low-mode asymmetries → Directional (mode $\ell = 1$) plasma flow in the hot spot — **May be important**
- Surface defects → Injection of ablating materials inside the hot spot — **May be important**

Not included:

- Mount stalk → Jetting the cold fuel and possibly ablator materials into the hot spot — **The effect is small in 2-D*
Is it important in 3-D?**

* Igumenshchev *et al*., Phys. Plasmas **16**, 082701 (2009).

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UR LLE

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More work is needed to identify the dominant performance degradation mechanism

* Igumenshchev *et al*., Phys. Plasmas **16**, 082701 (2009).

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New diagnostics are being developed for better target characterization and resolving the problem of the mode-1 asymmetry

[1] Igumenshchev *et al*., Phys. Plasmas **23**, 052702 (2016).