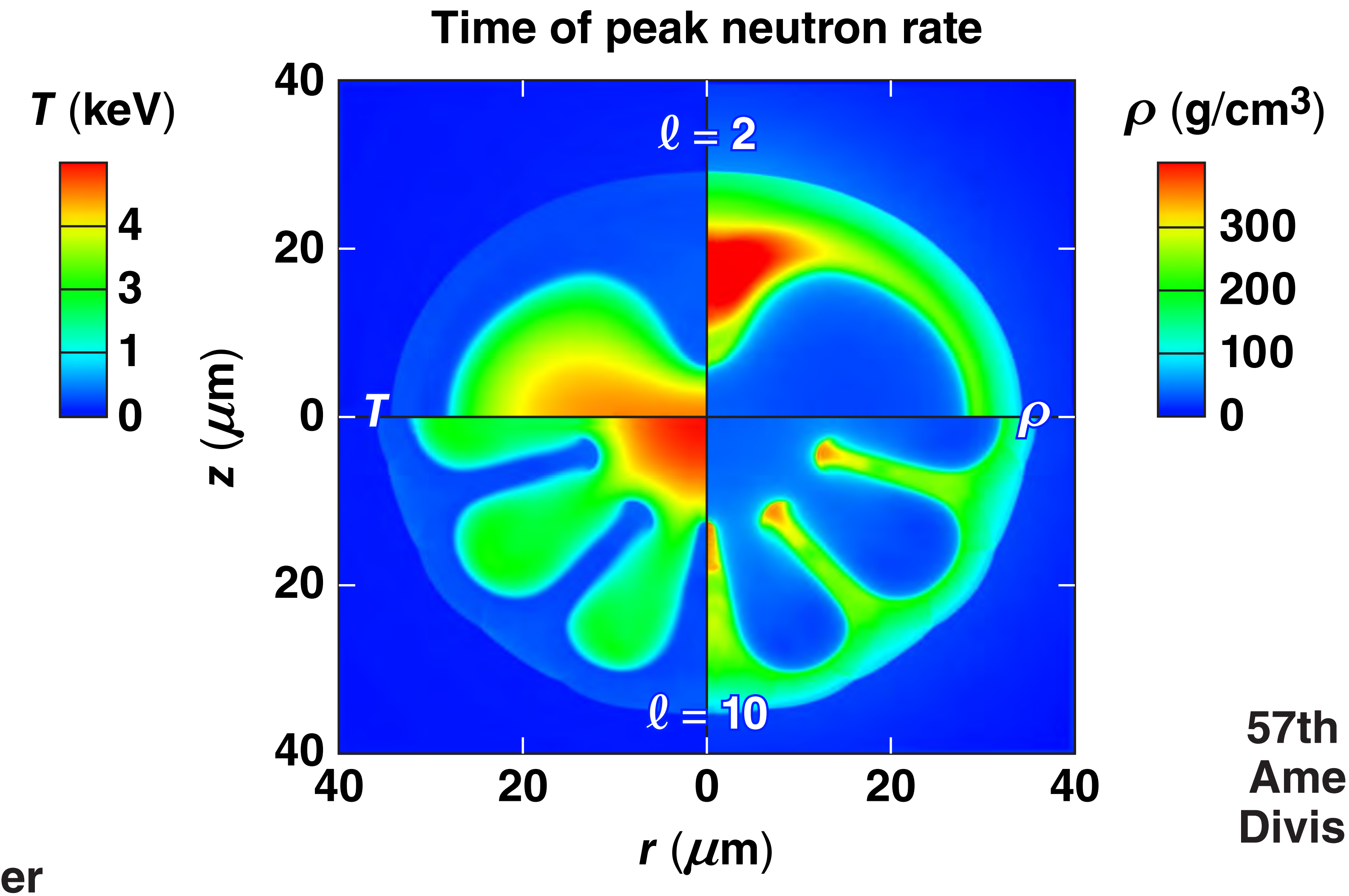
Effects of Long- and Intermediate-Wavelength Asymmetries on Hot-Spot Energetics



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Summary

Low- and intermediate-mode nonuniformities exhibit different degradation mechanisms of inertial confinement fusion (ICF) implosion performance

- Low-mode ($\ell \sim 2$) asymmetries result in a drop of hot-spot pressure and the burn volume is larger, while intermediate-mode ($\ell \sim 10$) asymmetries result in a smaller volume
- Measurable observables on OMEGA are reproduced by using a combination of low and intermediate modes
- Extrapolation of the OMEGA implosion with the highest Lawson parameter to a 1.9-MJ symmetric direct drive leads to 125 kJ of fusion yield

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Collaborators

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The effect of hydro instabilities is investigated by rewriting the yield-over-clean (YOC) in terms of the hot-spot properties

- **Yield:** $Y = \int dt \int dV \, \frac{n^2 \langle \sigma v \rangle}{4} \sim P^2 \frac{\langle \sigma v \rangle}{T^2} V\tau$

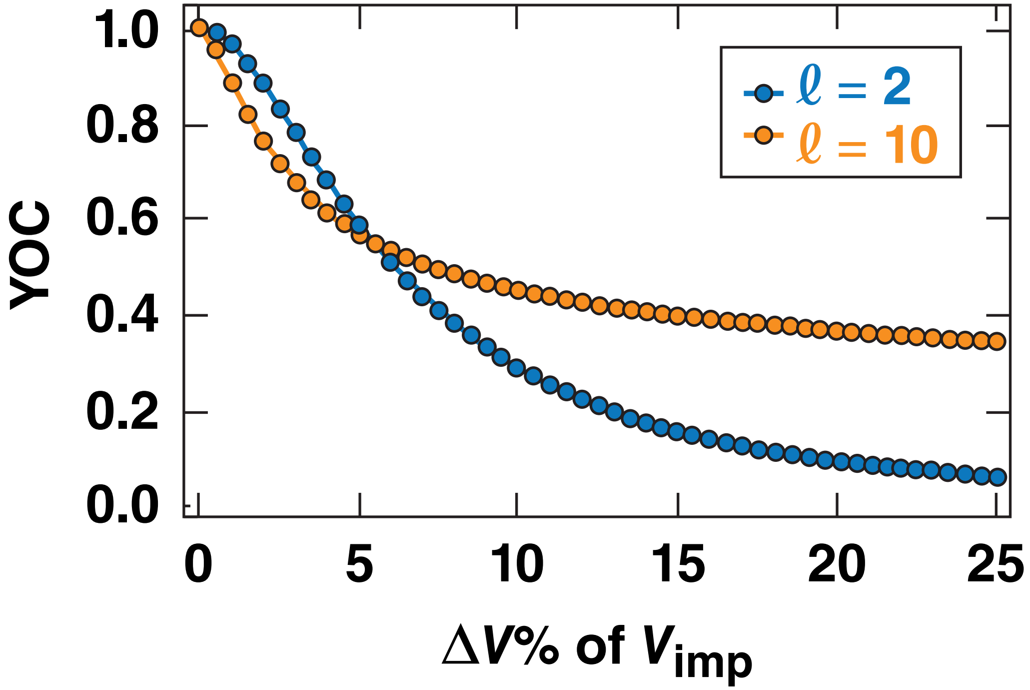
- **Fusion reactivity in** $2 < T < 7$ **keV:** $\langle \sigma v \rangle \sim T^{3.7}$

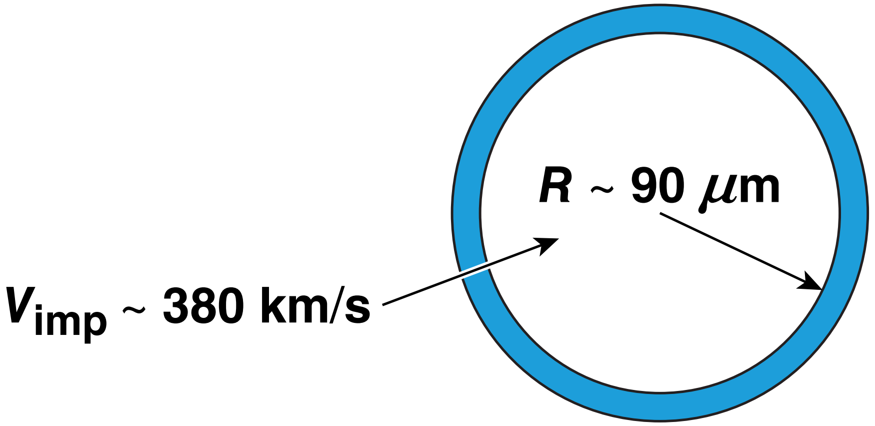
- **Burn volume:** $V = \frac{\int dt \left(\int dV \left\{ \frac{n^2 \langle \sigma v \rangle}{4} \right\}^{0.5} \right)^2}{Y} \approx V_{17}^{\text{x ray}}$

$$\boxed{\text{YOC} = \frac{Y}{Y_{\text{1-D}}} \simeq \left(\frac{P}{P_{\text{1-D}}} \right)^2 \left(\frac{V}{V_{\text{1-D}}} \right) \left(\frac{T}{T_{\text{1-D}}} \right)^{1.7} \left(\frac{\tau}{\tau_{\text{1-D}}} \right)}$$

The radiation–hydrodynamic code *DEC2D** is used to simulate the deceleration phase of implosions

- **Hydrodynamic profiles at the end of the acceleration phase (from the 1-D code *LILAC***) are used as the starting point, followed by a simulation of the deceleration phase in multidimension**
- ***Single- or multimode velocity perturbations are introduced to the inner surface of the shell***





In-flight target

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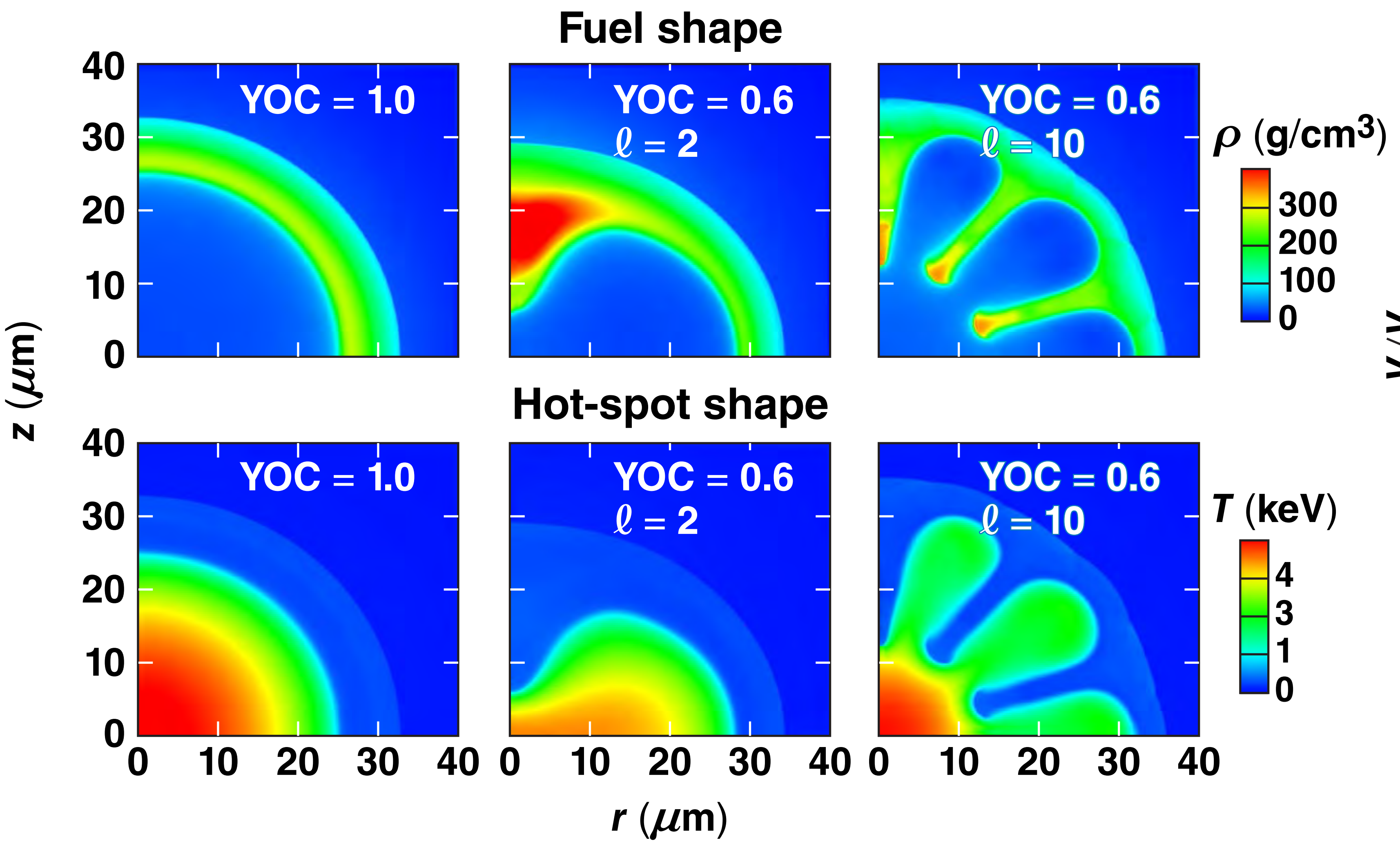
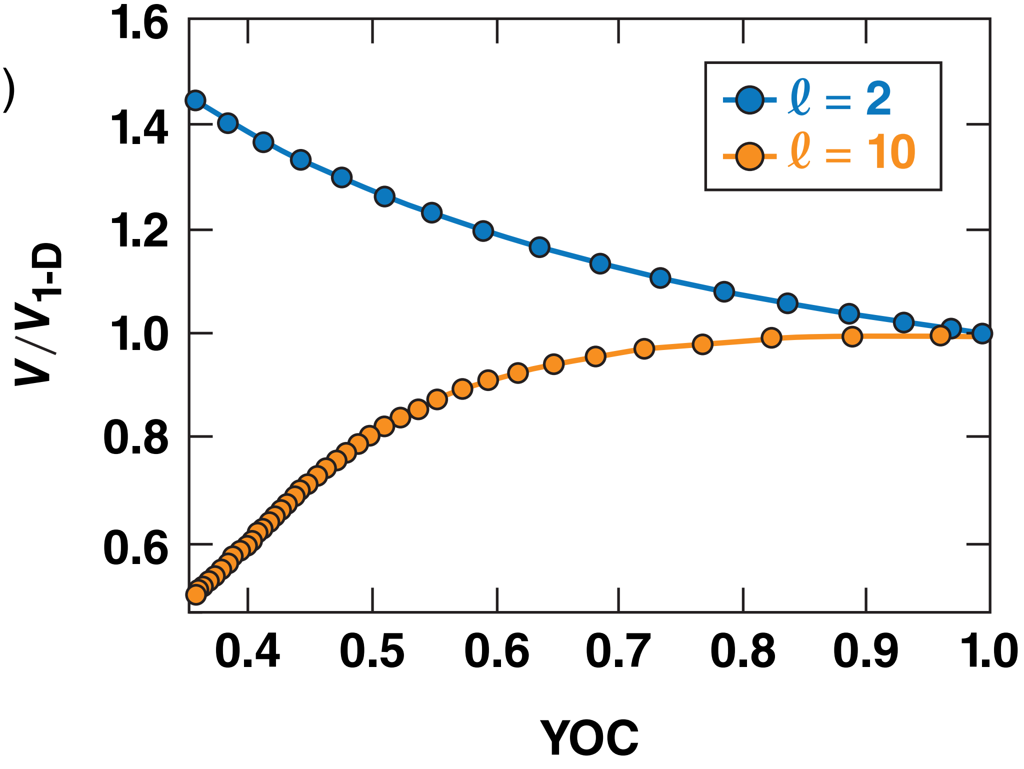
* K. M. Woo *et al*., GO5.00003, this conference;
K. Anderson, R. Betti, and T. A. Gardiner, Bull. Am. Phys. Soc. 46, 280 (2001);
A. Bose *et al*., Phys. Plasmas 22, 072702 (2015).

** J. Delettrez *et al*., Phys. Rev. A 36, 3926 (1987).

Intermediate-ℓ modes exhibit degradation in burn volume, whereas low-ℓ modes show an increase

OMEGA target at time of peak neutron rate





$$\mathrm{YOC} \simeq \left(\frac{P}{P_{\text{1-D}}}\right)^2 \left(\frac{V}{V_{\text{1-D}}}\right) \left(\frac{T}{T_{\text{1-D}}}\right)^{1.7} \left(\frac{\tau}{\tau_{\text{1-D}}}\right)$$

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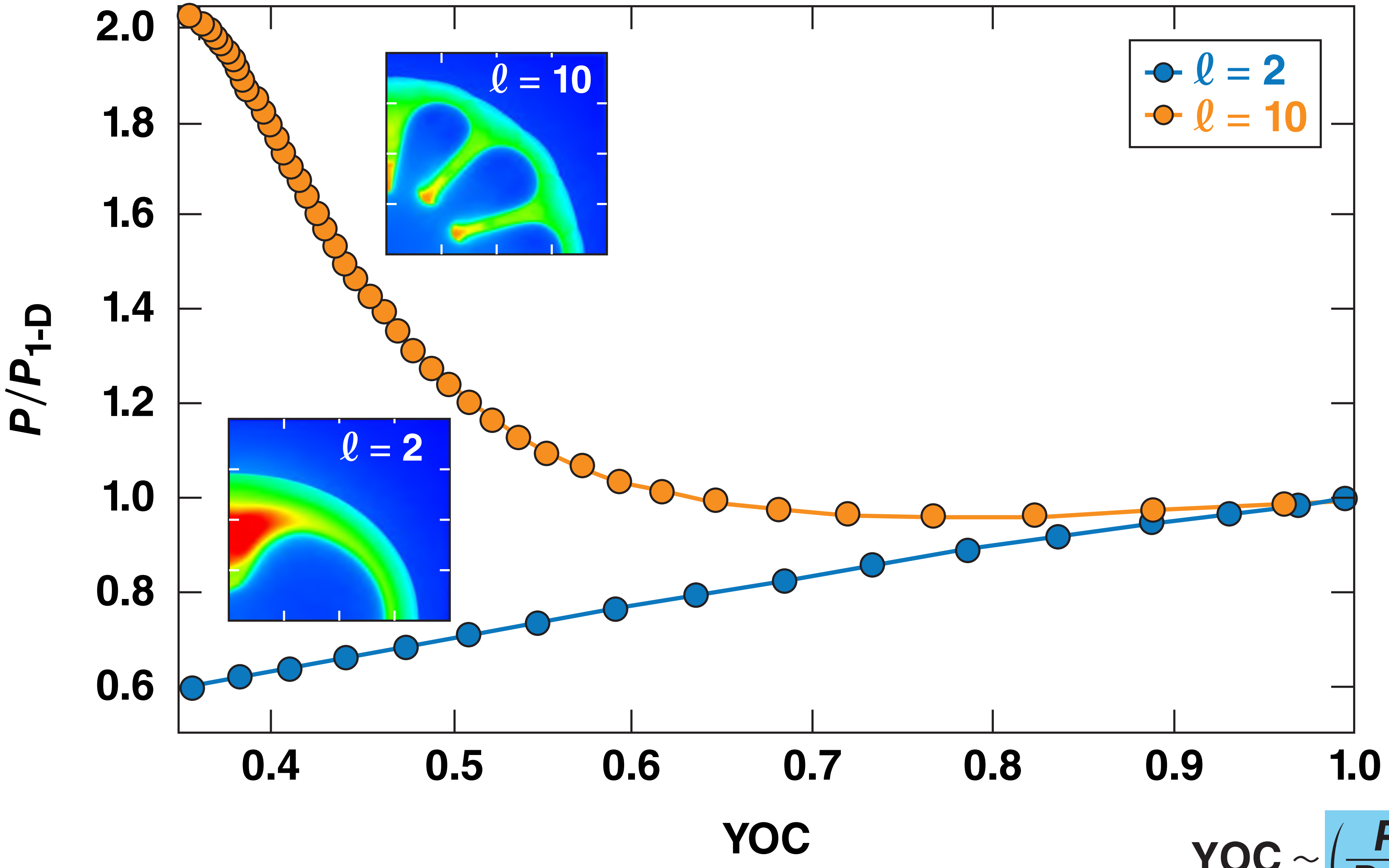
Yield degradation from low-ℓ modes results from a significant reduction in pressure compared to the 1-D values



$$\text{YOC} \simeq \boxed{\left(\frac{P}{P_{\text{1-D}}}\right)^2} \left(\frac{V}{V_{\text{1-D}}}\right) \left(\frac{T}{T_{\text{1-D}}}\right)^{1.7} \left(\frac{\tau}{\tau_{\text{1-D}}}\right)$$

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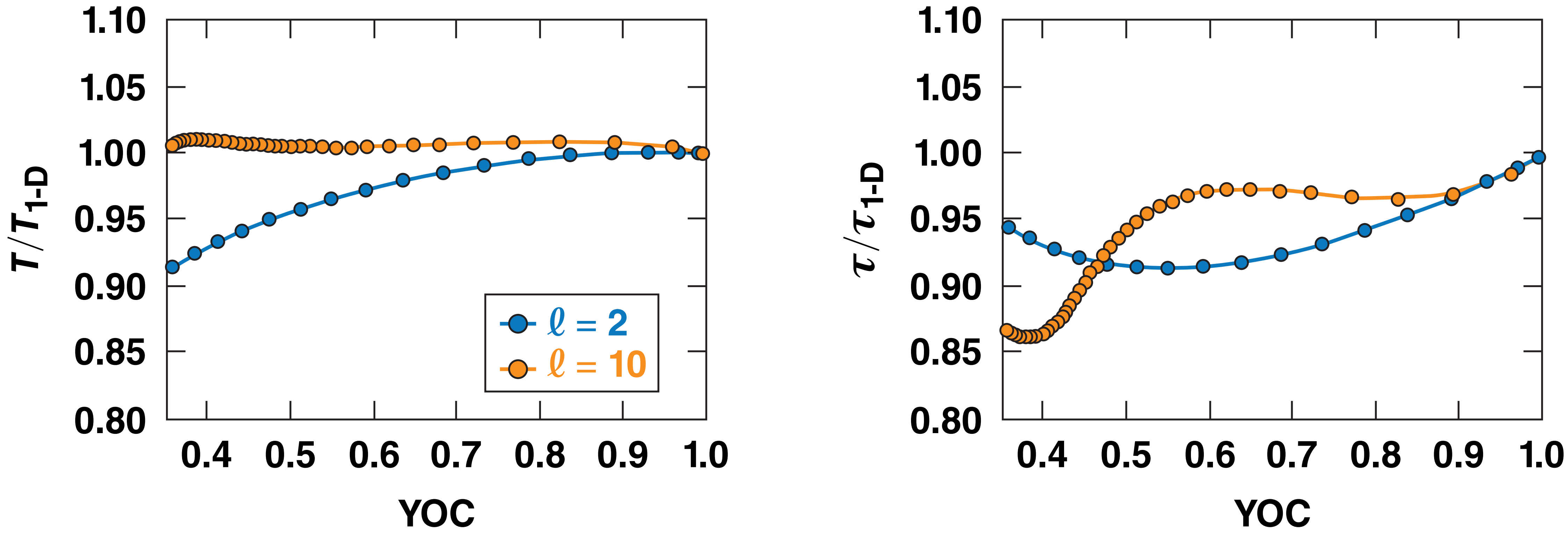
Ion temperatures and burnwidths are little affected by nonuniformities



$$\text{YOC} \simeq \left(\frac{P}{P_{1\text{-D}}}\right)^2 \left(\frac{V}{V_{1\text{-D}}}\right) \left(\frac{T}{T_{1\text{-D}}}\right)^{1.7} \left(\frac{\tau}{\tau_{1\text{-D}}}\right)$$

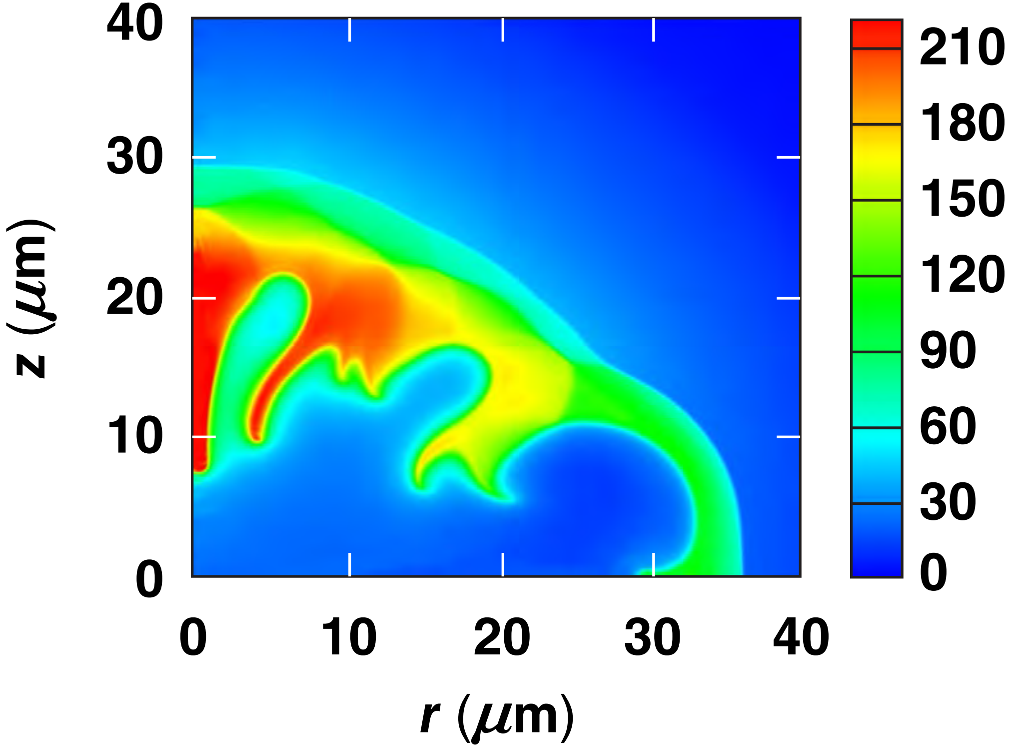
Measurable observables on OMEGA are reproduced by using a combination of low and intermediate modes

OMEGA shot 77068

E_L 26.18 kJ	Experiment	1-D simulation	2-D simulation
Yield	5.3×10^{13} (±10%)	1.7×10^{14}	5.3×10^{13}
P^* (Gbar)	56 (±7)	97	57
T_i (keV)	3.6 (±0.3)	3.82	3.7
R_{hs} (μm)	22 (±1)	22	22
τ (ps)	66 (±10)	61	54
ρR (g/cm^2)	0.196 (±0.018)	0.211	0.194

Combination of $\ell = 2$ with 5% ΔV
and 2% ΔV for $\ell < 20$ with $22 < \ell^{-2} < 100$ spectrum
V_{imp} = 380 μm/ns

Density at peak neutron rate from simulation of 77068 using hydrocode *DEC2D*



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*C. Cerjan, P. T. Springer, and S. M. Sepke, Phys. Plasmas 20, 056319 (2013).

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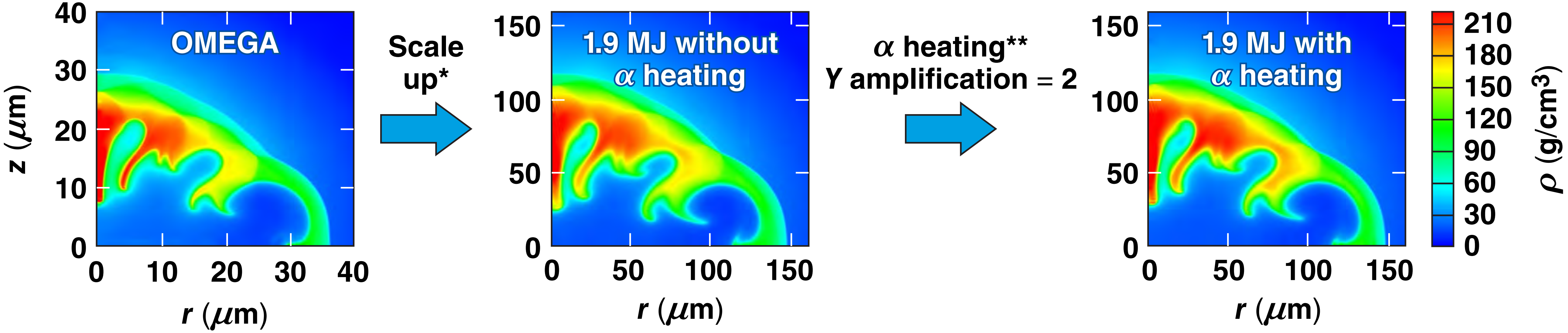
Extrapolating OMEGA results to hydro-equivalent targets driven by 1.9-MJ symmetric illumination leads to 125 kJ of fusion yield

Densities at peak neutron rate



Scale up*

α heating**
Y amplification = 2

Shot 77068	OMEGA 26.18 kJ	1.9 MJ without α heating	1.9 MJ with α heating
Yield	5.3×10^{13}	2.25×10^{16}	4.45×10^{16}
P^* (Gbar)	57	57	79
T_i (keV)	3.7	4.7	5.1
R_{hs} (μm)	22	92.3	92.5
τ (ps)	54	215	193
ρR (g/cm^2)	0.194	0.83	0.81

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*R. Nora *et al.*, Phys. Plasmas 21, 056316 (2014); A. Bose *et al.*, Phys. Plasmas 22, 072702 (2015).
**R. Betti *et al.*, Phys. Rev. Lett. 114, 255003 (2015).

Summary/Conclusions

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