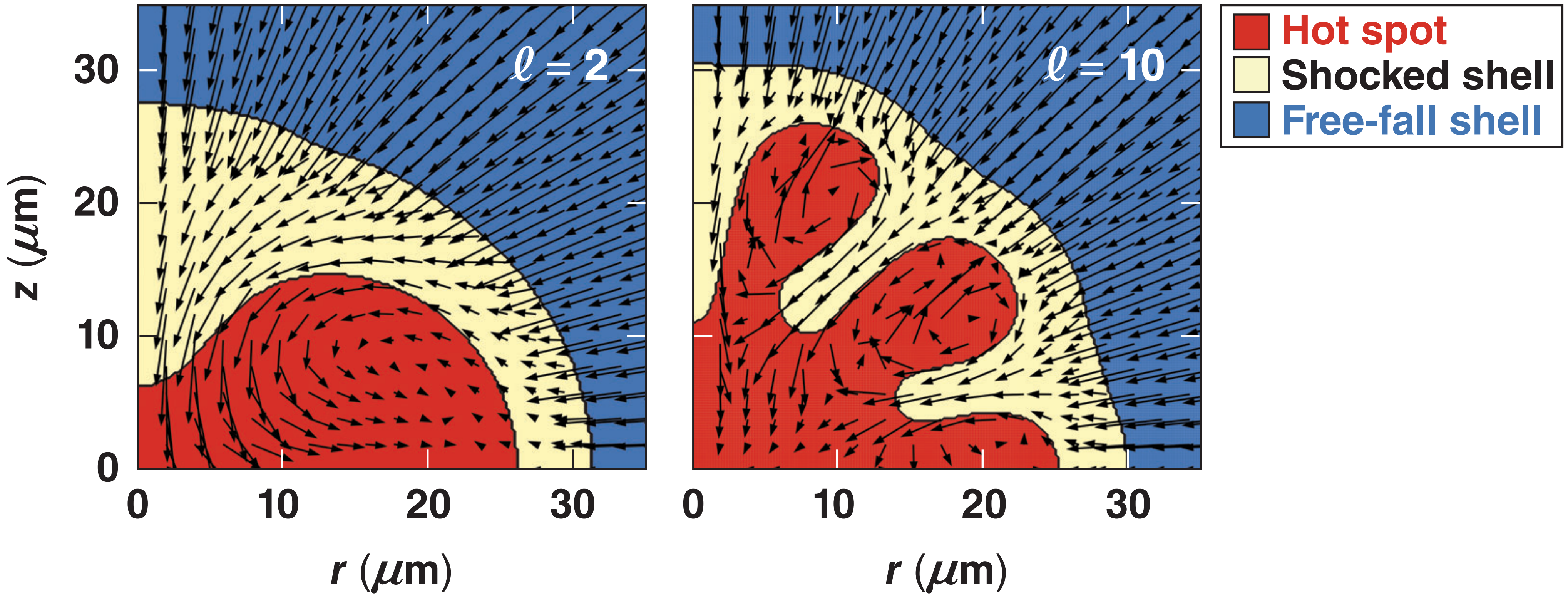
The Physics of Low- and Mid-Mode Asymmetries of the Hot Spot

Snapshot at bang time



A. Bose
University of Rochester
Laboratory for Laser Energetics and
University of Michigan, Ann Arbor

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Summary

The neutron-averaged observables can differ from the hot-spot volume-averaged quantities; the differences although small for low modes are more pronounced for mid-mode asymmetries

- The asymmetries are divided into low and mid modes by comparison of the mode wavelength with the hot-spot radius
- Low modes introduce nonradial motion, whereas mid modes involve cooling by thermal losses
- The energy distribution at stagnation is similar for both asymmetry types; however, the fusion reaction distribution is different
- A general expression is found relating the pressure degradation to the residual shell energy and the flow within the hot spot (i.e., the total residual energy)

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*A. Bose *et al.*, Phys. Plasmas 24, 102704 (2017).

Collaborators

R. Betti and K. M. Woo

University of Rochester
Laboratory for Laser Energetics

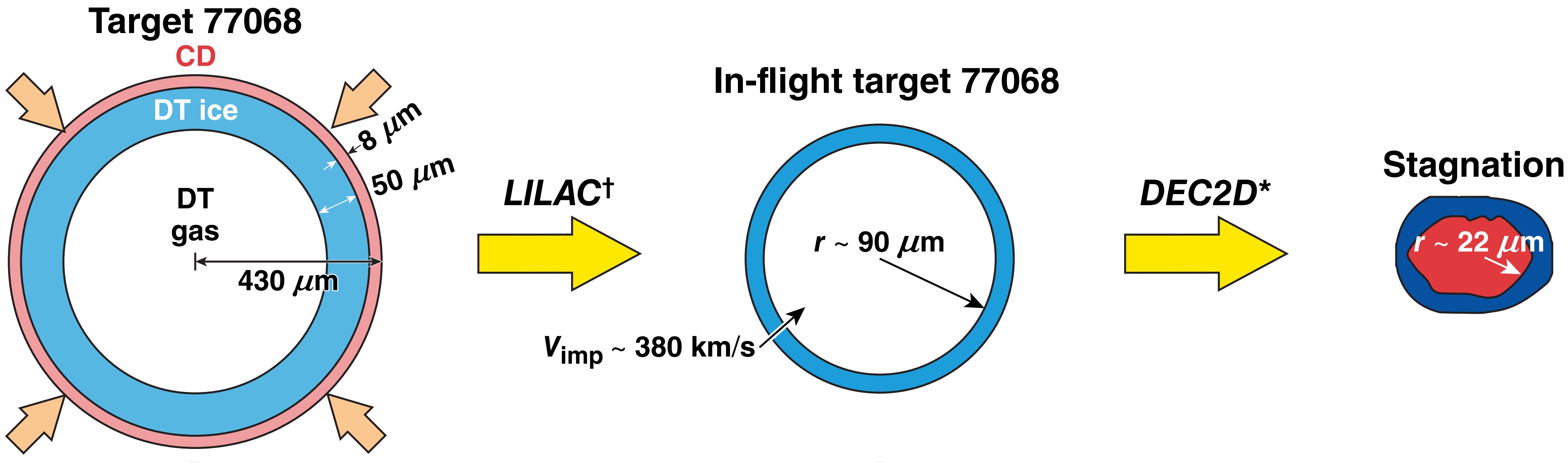
D. Shvarts

Negev Nuclear Research Center
Ben-Gurion University of the Negev

**D. S. Clark, S. W. Haan, A. L. Kritcher, O. L. Landen,
J. D. Lindl, J. H. Nuckolls, and M. D. Rosen**

Lawrence Livermore National Laboratory

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



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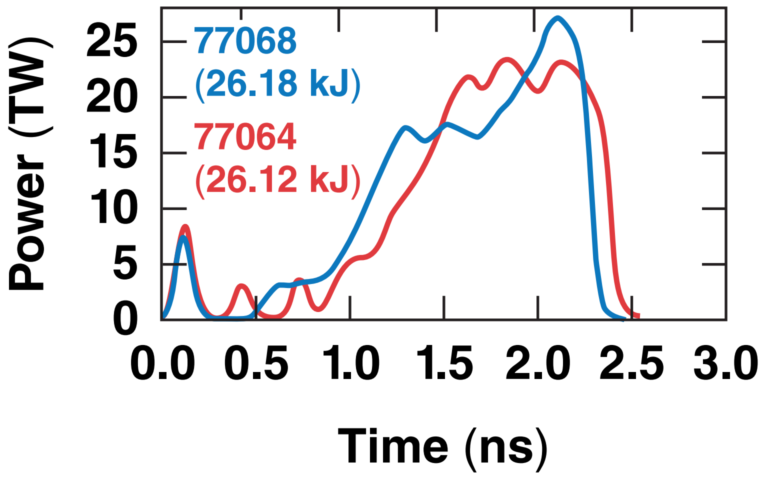
Pulse shape



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Velocity perturbation

$\Delta V / V_{\text{imp}}$

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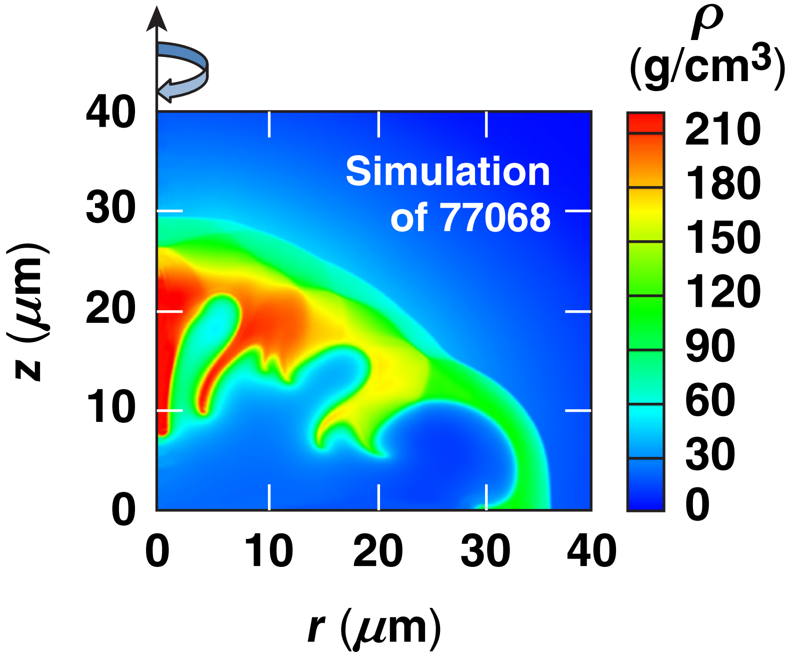
* K. M. Woo *et al.*, Bull. Am. Phys. Soc. 59, 354 (2014); A. Bose *et al.*, Phys. Plasmas 22, 072702 (2015).

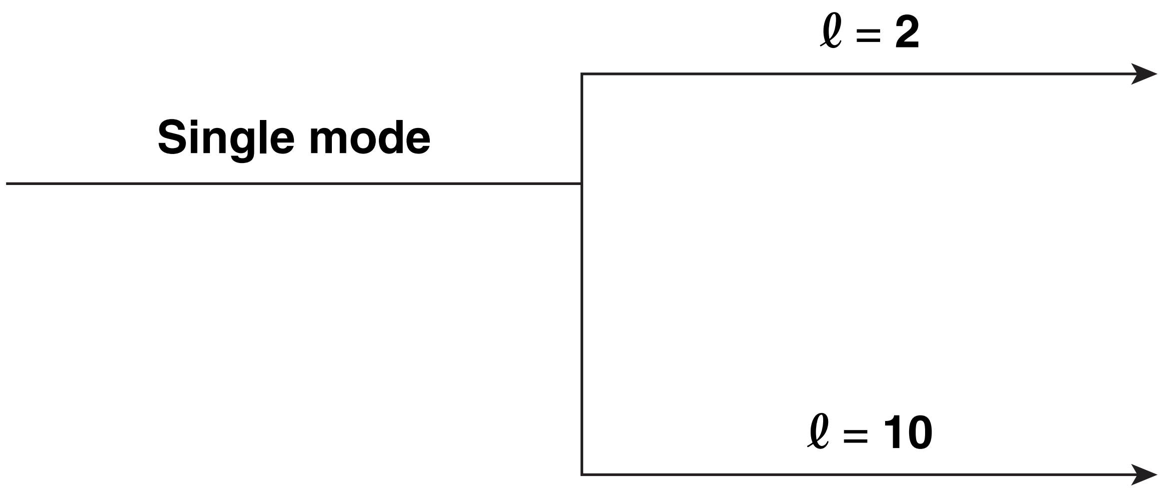
† Nonlocal + cross-beam energy transfer model: I. V. Igumenshchev *et al.*, Phys. Plasmas 17, 122708 (2010).

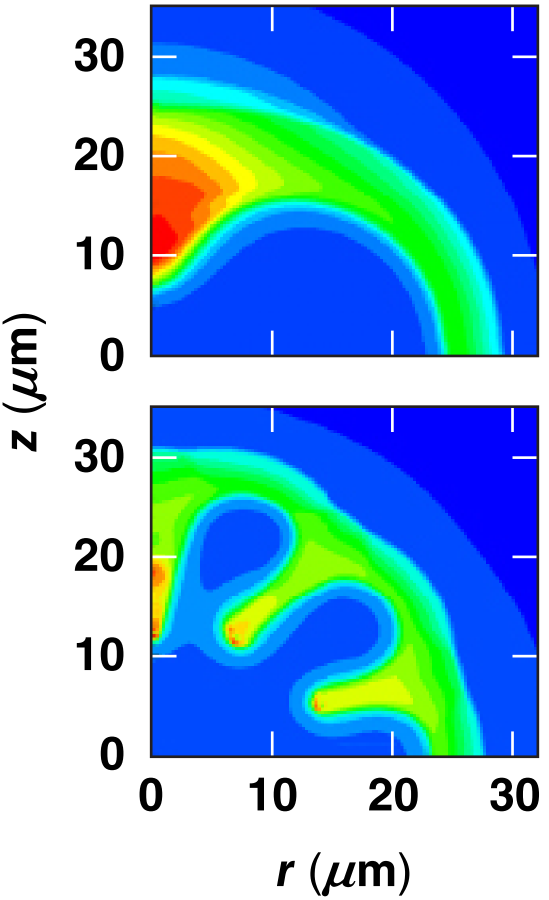
Motivation

The observables for cryogenic implosions on OMEGA* can be reproduced using a combination of low and mid modes**



Hot-spot shape at bang time





E_L 26.18 kJ	Experiment	2-D simulation
Yield	5.3×10^{13} (±5%)	5.3×10^{13}
P (Gbar)	56 (±7)	56
T_i (keV)	3.6 (±0.3)	3.7
R_{hs} (μm)	22 (±1)	22
τ (ps)	66 (±10)	54
ρ*R* (g/cm^2)	0.196 (±0.018)	0.194

- For indirect-drive implosions on the NIF, low modes are considered to be the main cause of degradation†

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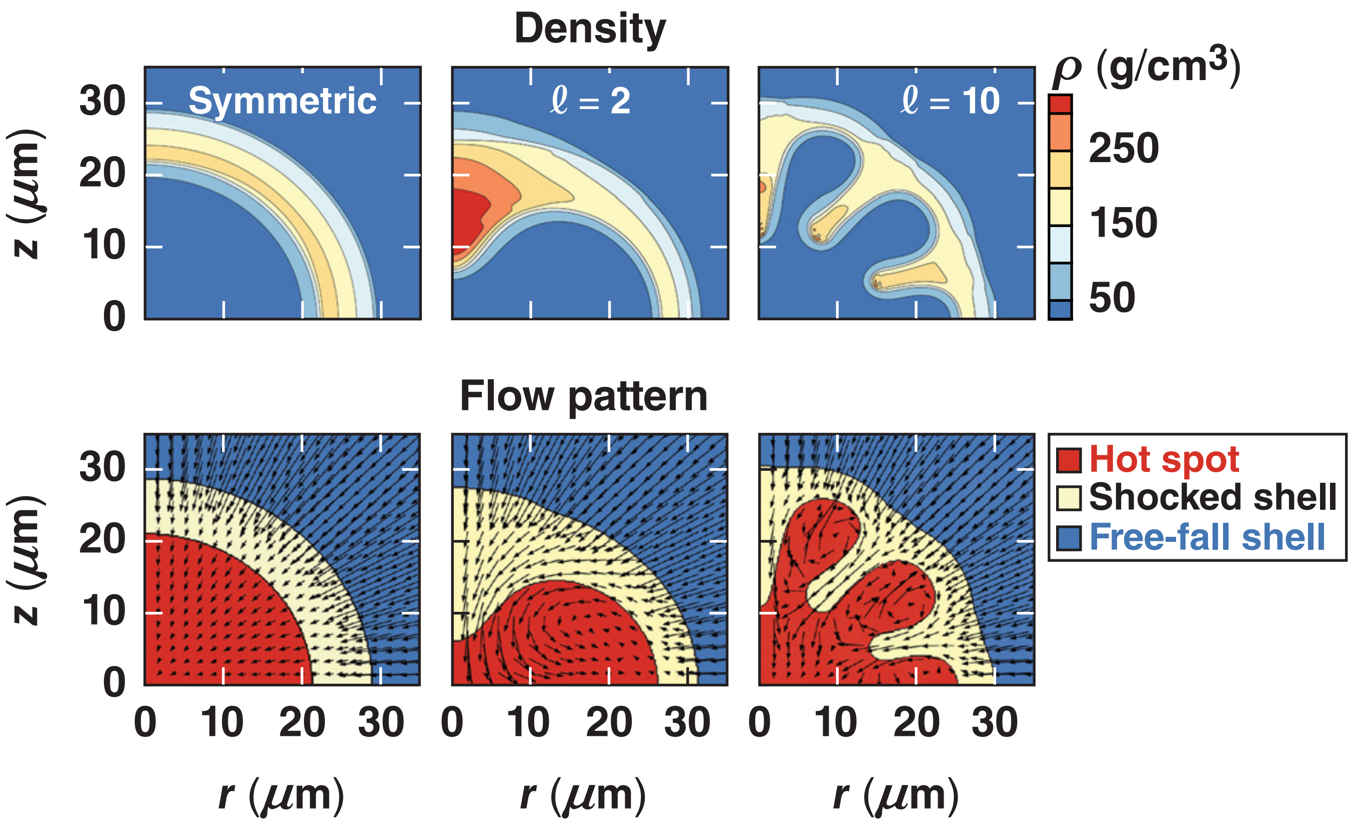
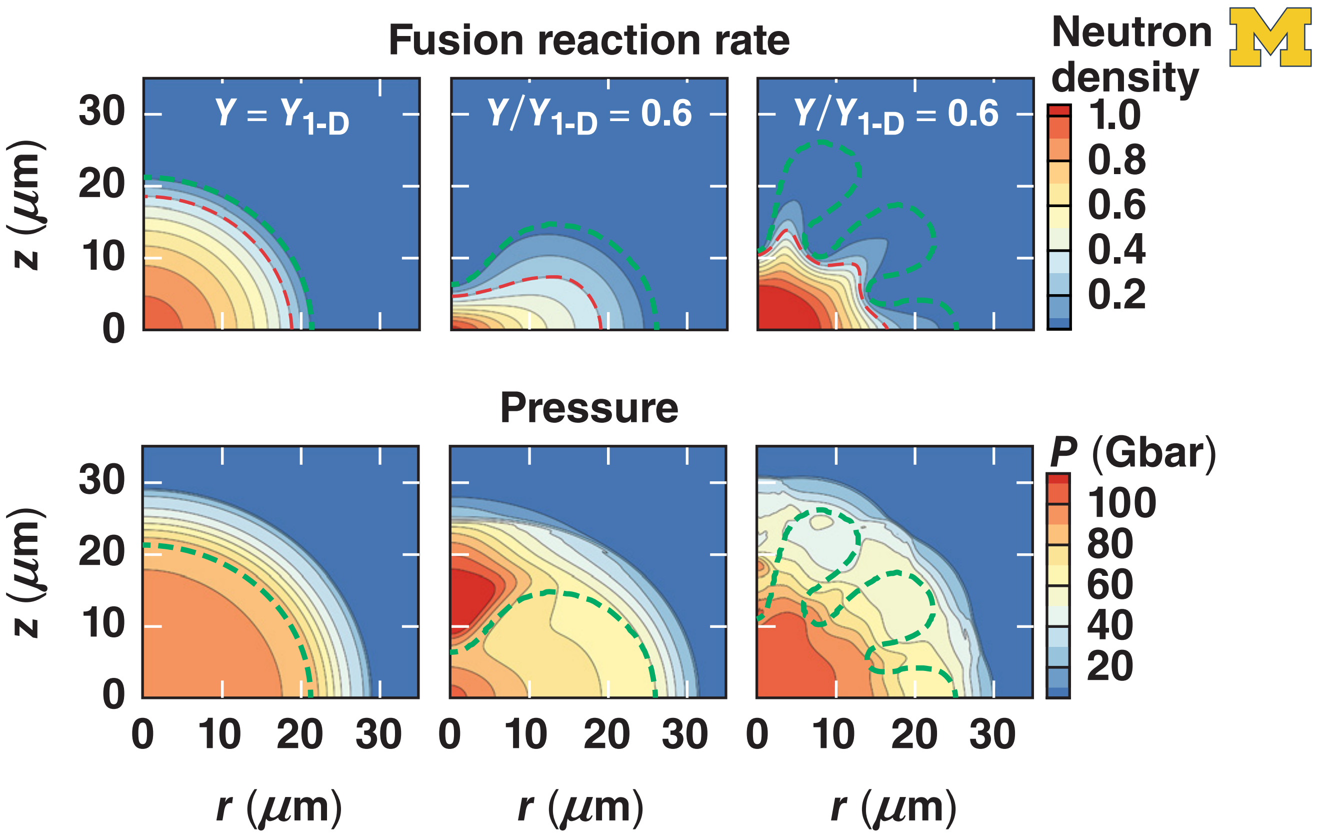
* S. P. Regan *et al.*, Phys. Rev. Lett. 117, 025001 (2016); 117, 059903(E) (2016).
** A. Bose *et al.*, Phys. Rev. E 94, 011201(R) (2016).
† J. D. Lindl, Phys. Plasmas 2, 3933 (1995).
NIF: National Ignition Facility

For low-mode asymmetries the bubbles are hot and sustain fusion reactions, while for mid modes they are cooled by thermal losses





- Low mode ($\lambda_{RT} > R_h$)
  - – bubbles are hot and sustain fusion
  - – hot spot is isobaric (approximately)
  - – nonradial flow motion in the shocked shell and hot spot

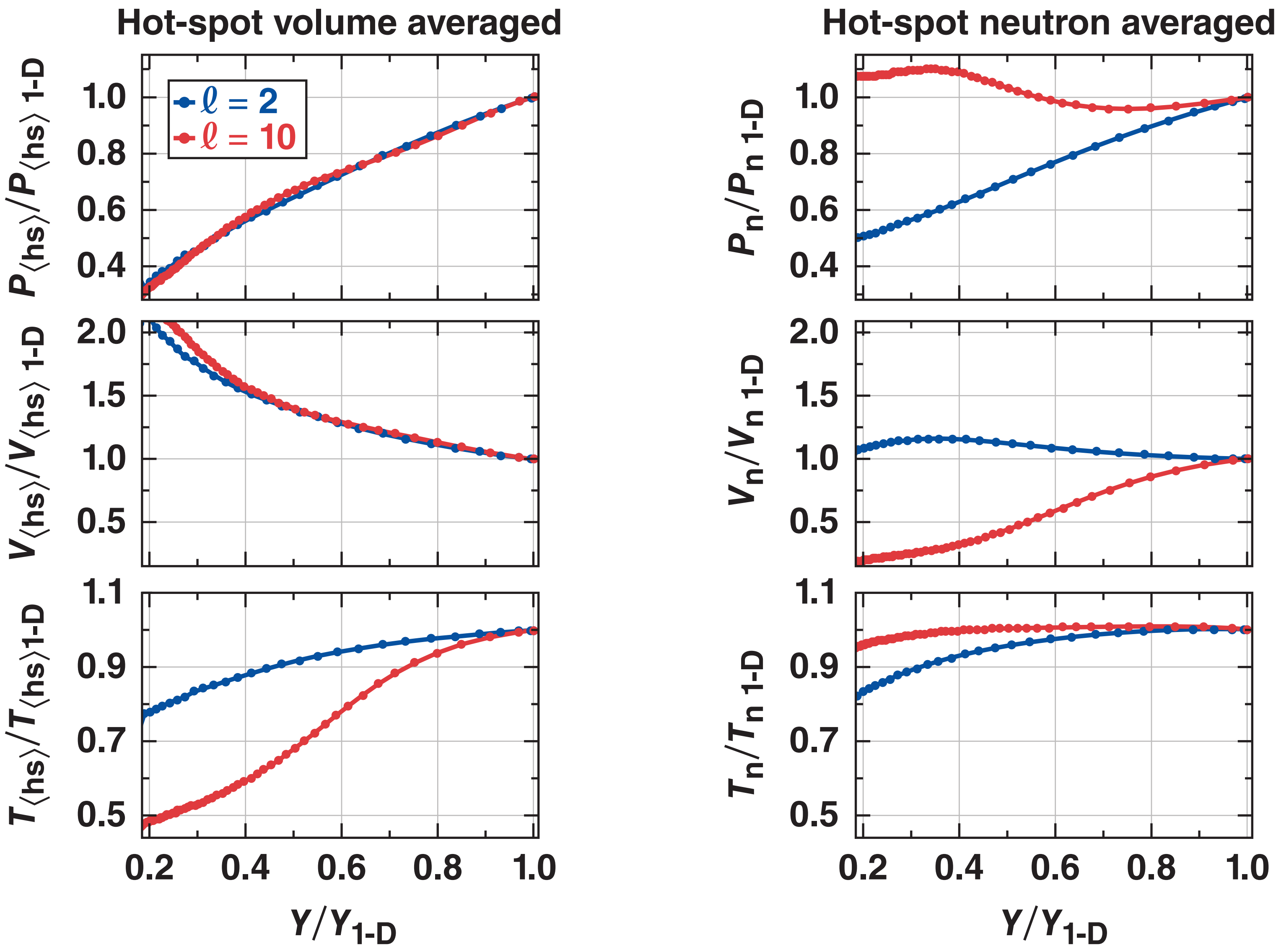
- Mid mode ($\lambda_{RT} < R_h$)
  - – bubbles are cold and do not produce fusion
  - – hot spot is not isobaric $\nabla P \sim \text{Mach}^2$
  - – radially inward and outward motion

RT: Rayleigh–Taylor

For implosions with asymmetries, the neutron-averaged and the volume-averaged quantities are different, but the differences are less for low modes and more pronounced for mid modes

Hot-spot boundary

$\rho_h(t) < 1/e \times \rho_{\text{max 1-D}}(t)$


Hot-spot volume averaged

Hot-spot neutron averaged

neutron-averaged quantities

$$Q_n = \frac{\int dt \int dV n_D n_T \langle \sigma v \rangle Q}{\int dt \int dV n_D n_T \langle \sigma v \rangle}$$

The yield degradation results primarily from a reduction in the hot-spot pressure for low modes and from a reduction in burn volume for mid modes.

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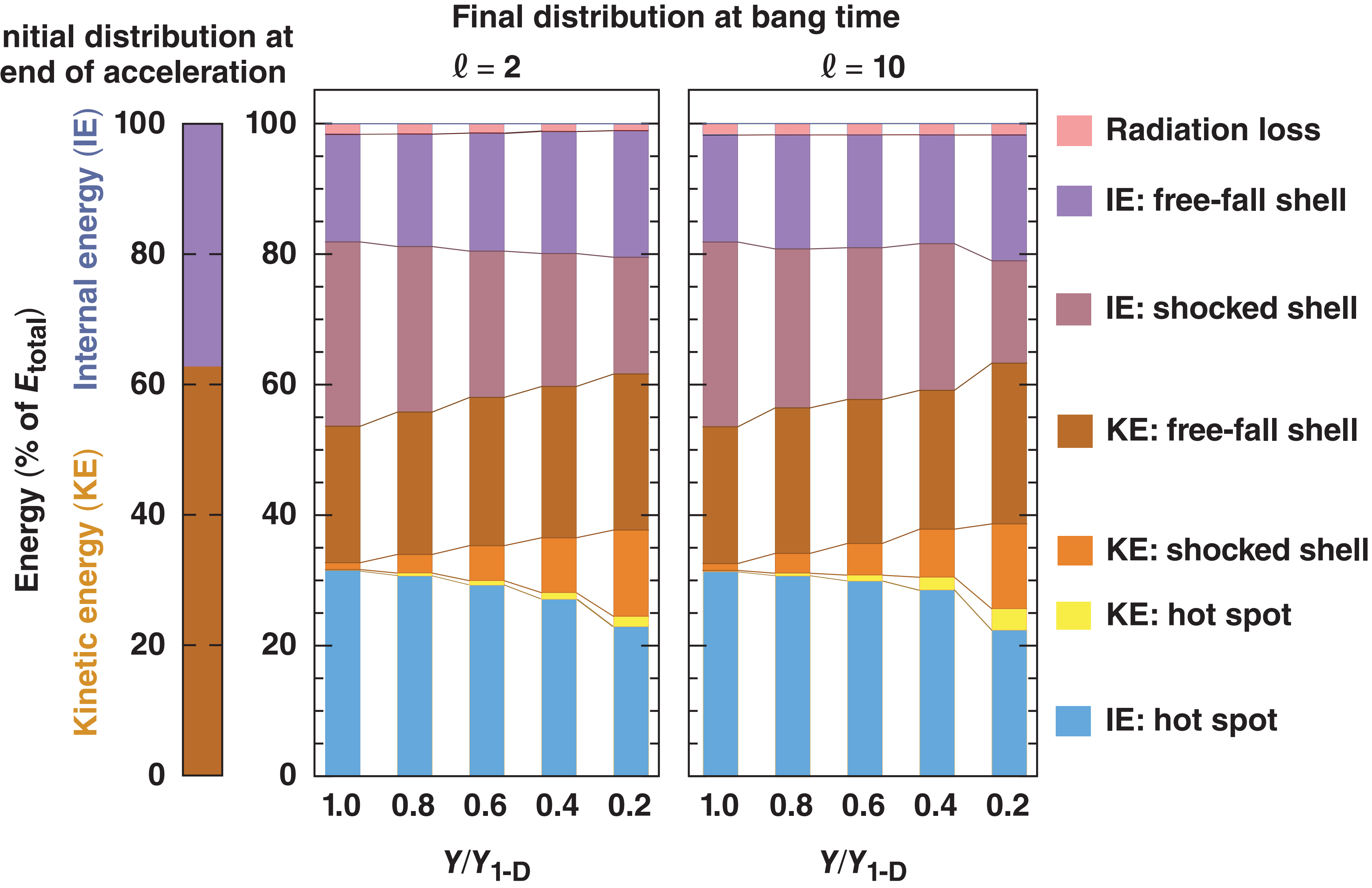
The energy distribution in different regions of an implosion is similar for low and mid modes



$\text{TotResE} = \text{IE}_{h\ 1\text{-D}} - \text{IE}_h$

TC13541

A general expression is found relating the pressure degradation to the total residual energy and the flow within the hot spot

- **Adiabatic compression:**

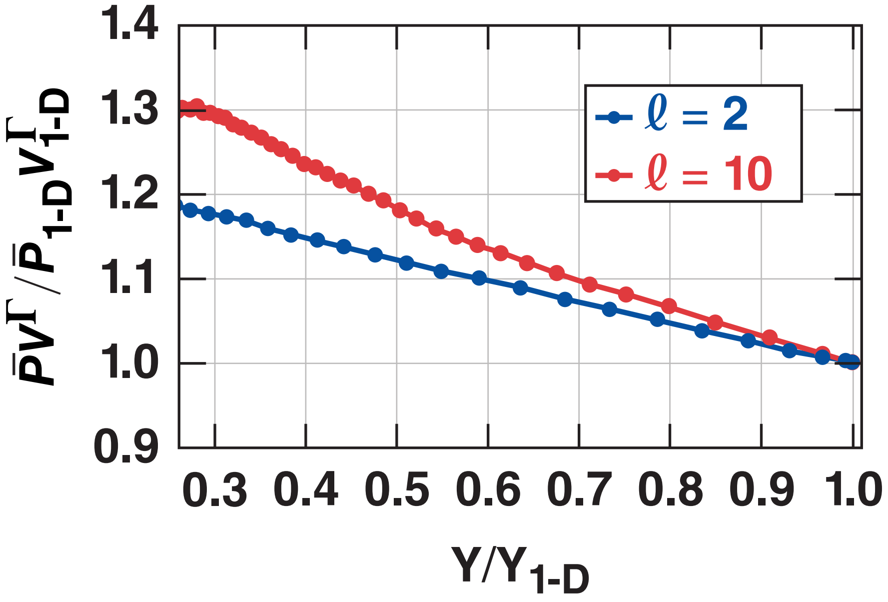
$$\frac{\bar{P}V^{\Gamma}}{\bar{P}_{1\text{-D}}\,V_{1\text{-D}}^{\Gamma}} = e^{\Delta_{\text{flow}}}$$

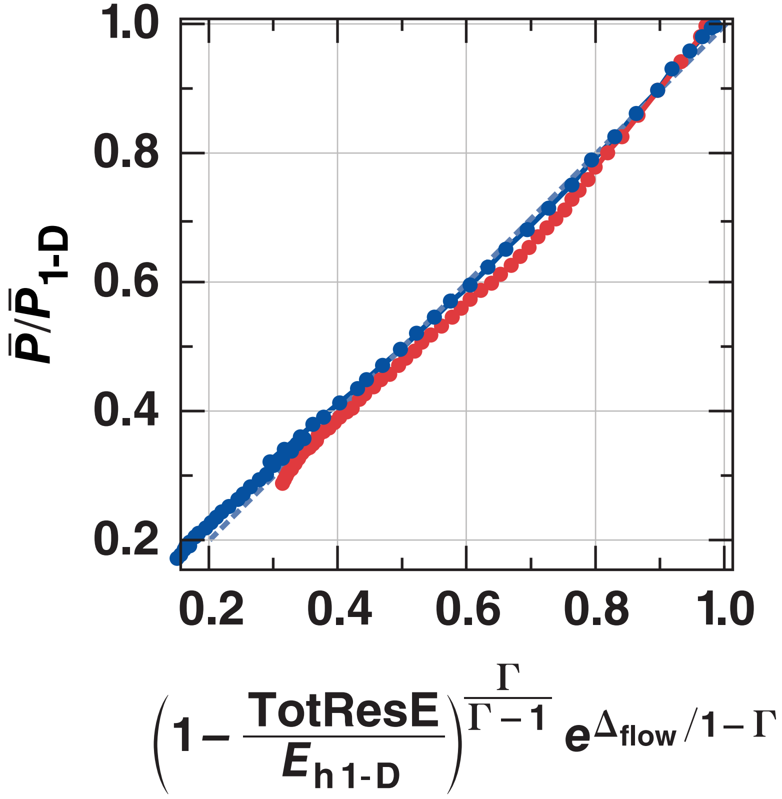
- **Energy conservation:**

$$\frac{E_{\text{h}}}{E_{\text{h}\,1\text{-D}}} = \frac{\bar{P}V}{\bar{P}_{1\text{-D}}\,V_{1\text{-D}}} + \frac{\text{KE}_{\text{h}}}{E_{\text{h}\,1\text{-}D}}$$

- **Hot-spot volume-averaged pressure scaling with total residual energy:**

$$\frac{\bar{P}}{\bar{P}_{1\text{-D}}} = \left(1 - \frac{\text{TotResE}}{E_{\text{h}\,1\text{-D}}}\right)^{\frac{\Gamma}{\Gamma-1}} e^{\Delta_{\text{flow}}/1-\Gamma}$$





TC13253

Summary/Conclusions

The neutron-averaged observables can differ from the hot-spot volume-averaged quantities; the differences although small for low modes are more pronounced for mid-mode asymmetries

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TC13891

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*A. Bose *et al.*, Phys. Plasmas 24, 102704 (2017).