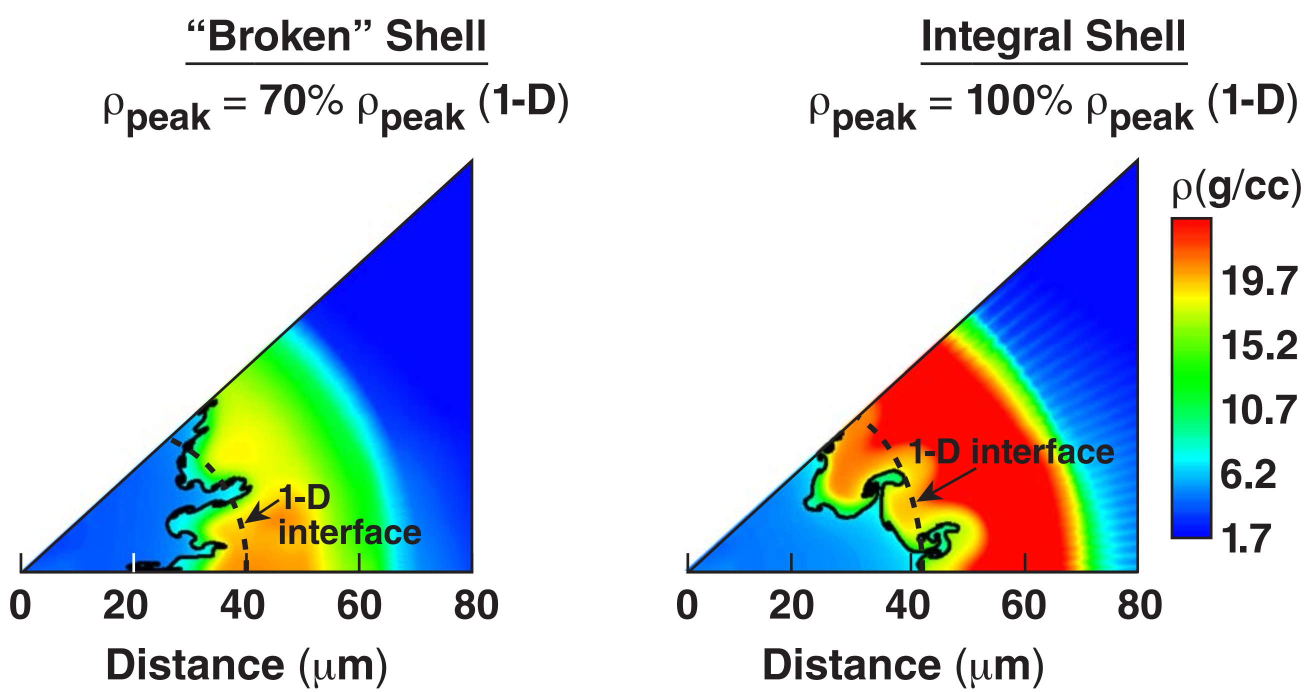
Multidimensional Analysis of Direct-Drive Plastic Shell Implosions on the OMEGA Laser



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Summary

2-D simulations of high-adiabat plastic shell implosions on OMEGA are in good agreement with experiment

- **Excellent agreement on laser energy absorption is obtained between experiment and simulation.**
- **Single-beam nonuniformity significantly influences fusion yields for “thin” (≤20 μm thick) shells through shell instability during acceleration, in contrast to the thicker (≥27 μm thick) shells.**
- **Good agreement with experimentally observed neutron production history, areal densities, and x-ray images of self-emission is obtained with 2-D simulations.**

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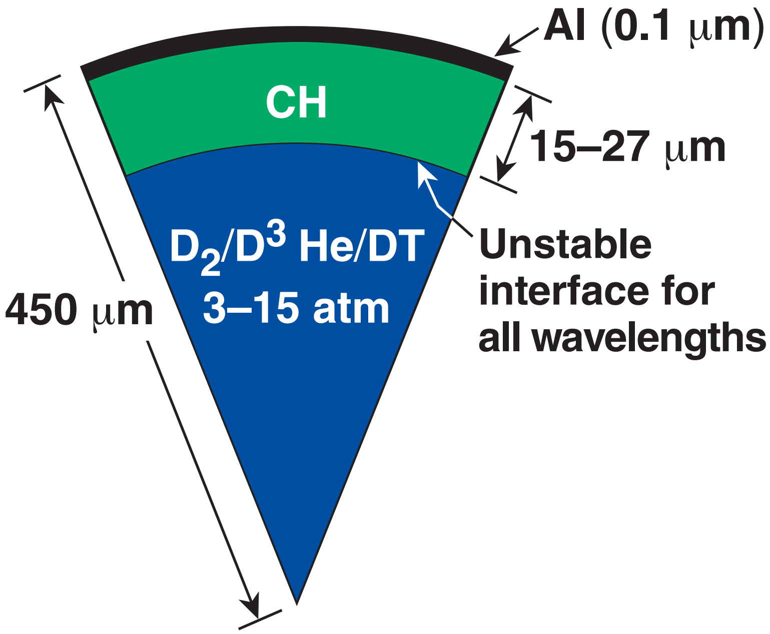
Outline

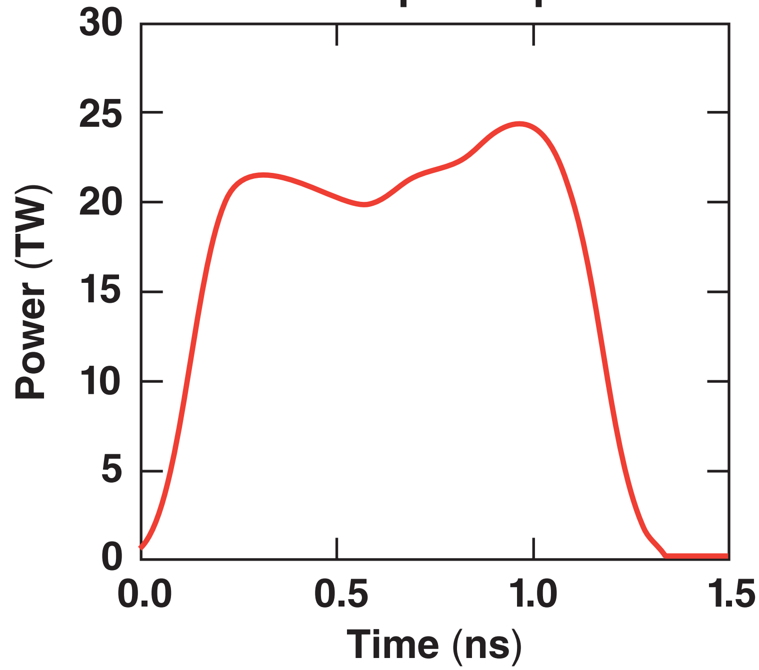
- Target, pulse shape, and experimental conditions
- Laser drive
- Nonuniformity seeds
- Effect of unstable growth on observables
- Comparison of 2-D simulations with experimental observables
  - neutron production rates
  - areal density
  - ion temperature
  - core x-ray images
- Estimates of turbulent mixing length

Targets, Experimental Conditions

A large number of warm plastic shells have been imploded on OMEGA



1-ns-square pulse with energy ~23 kJ 1-THZ 2-D SSD and polarization smoothing SG3/SG4 phase plates



- A variety of fills provides complementary information* on core conditions.

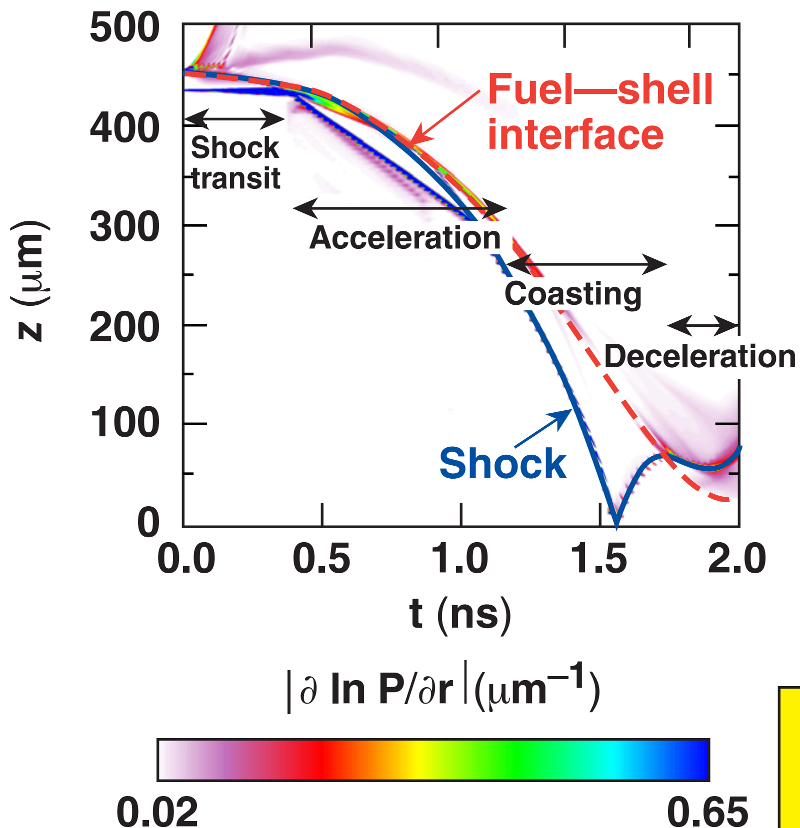
*Li *et al.*, Phys. Plasmas 10, 1919 (2003).
*Smalyuk *et al.*, Phys. Rev. Lett 90, 135002-1 (2003).
*Regan *et al.*, Phys. Rev. Lett. 92, 185002 (2004).

TC6669

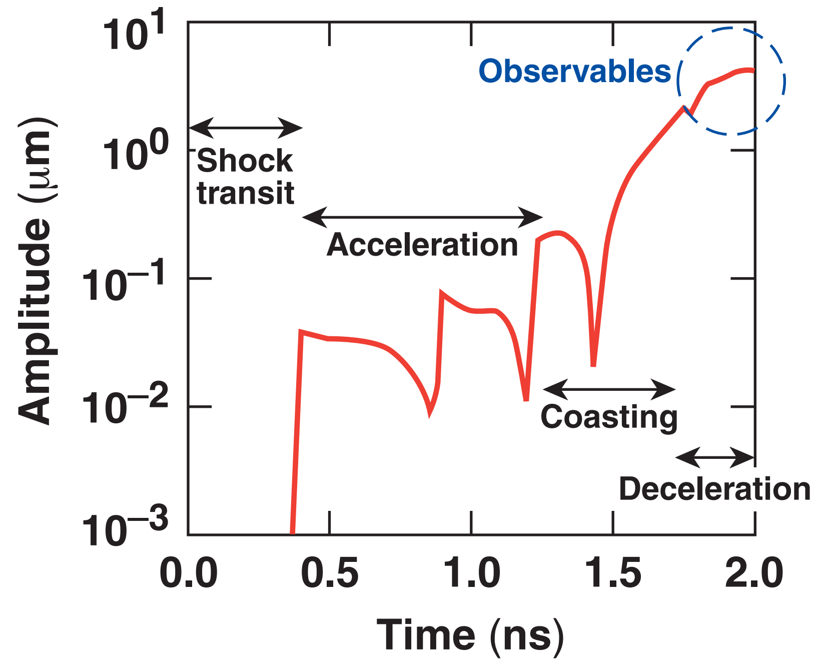
Most implosion observables occur during deceleration, after significant growth during all previous phases of the implosion

Simulation of 20-μm CH, 15 atm Shell

1-D dynamics



Growth of single mode (ℓ = 30) at fuel–shell interface



Plastic shell implosions provide a stringent test of laser drive modeling, nonuniformity sources, and implosion dynamics.

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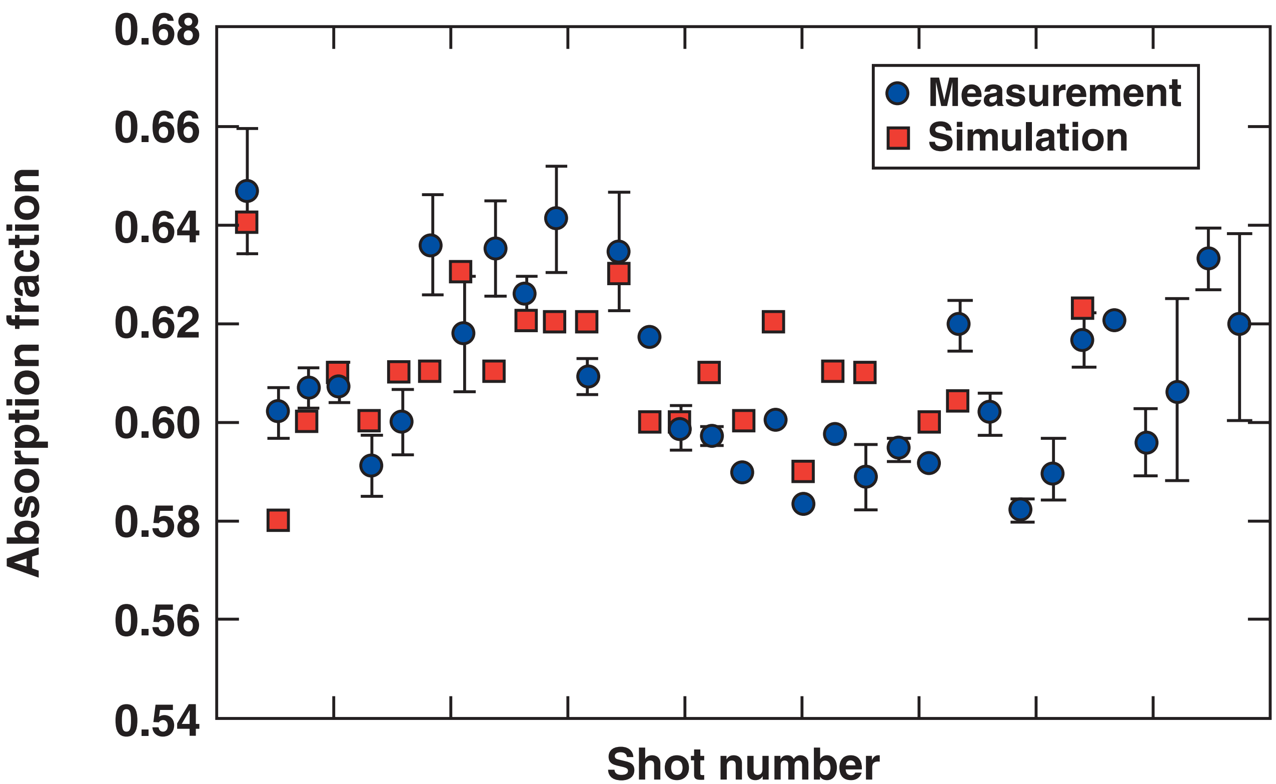
Laser Drive

The laser energy absorption model in hydrodynamic simulations agrees well with measurements*

Absorption Fraction for 1ns-Square Pulse on CH Shells



*W. Seka, HO1.009

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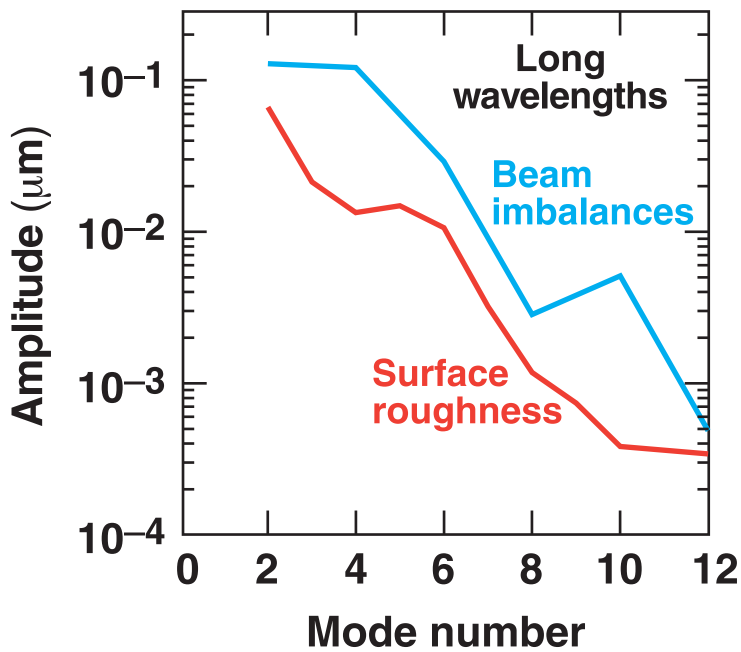
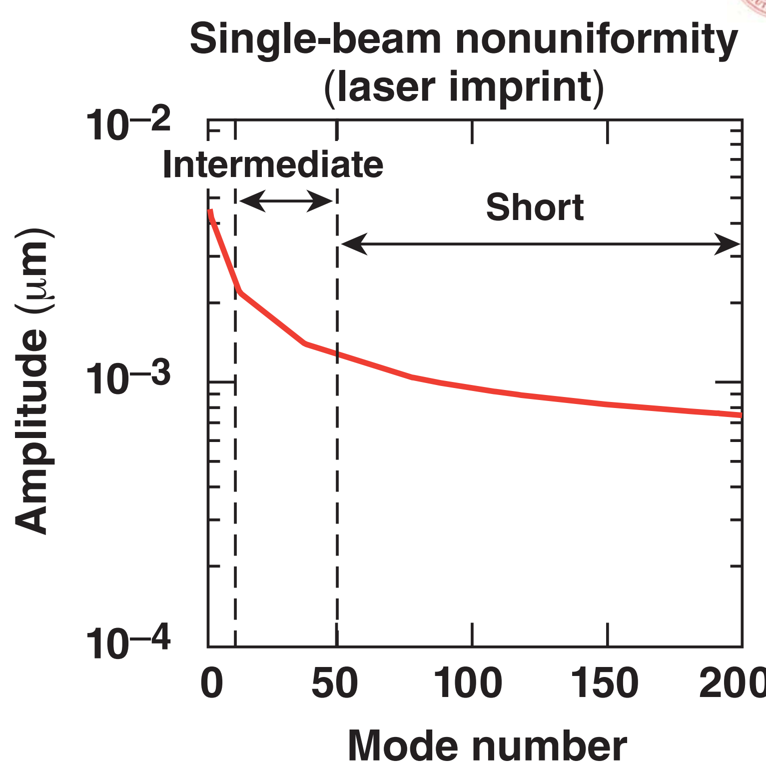
Nonuniformity Seeds

Irradiation and target nonuniformities are seeds for unstable growth in ICF implosions

Ablation Surface Amplitudes at the Start of the Acceleration Phase





- Beam mispointing, mistiming, asymmetries in spot shapes, and energy imbalance manifest in low-order (long wavelength) modes.
- Phase plate speckle results in intermediate and short wavelength nonuniformity seeds.

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Two extremes of shell stability are probed on OMEGA by varying the shell thickness

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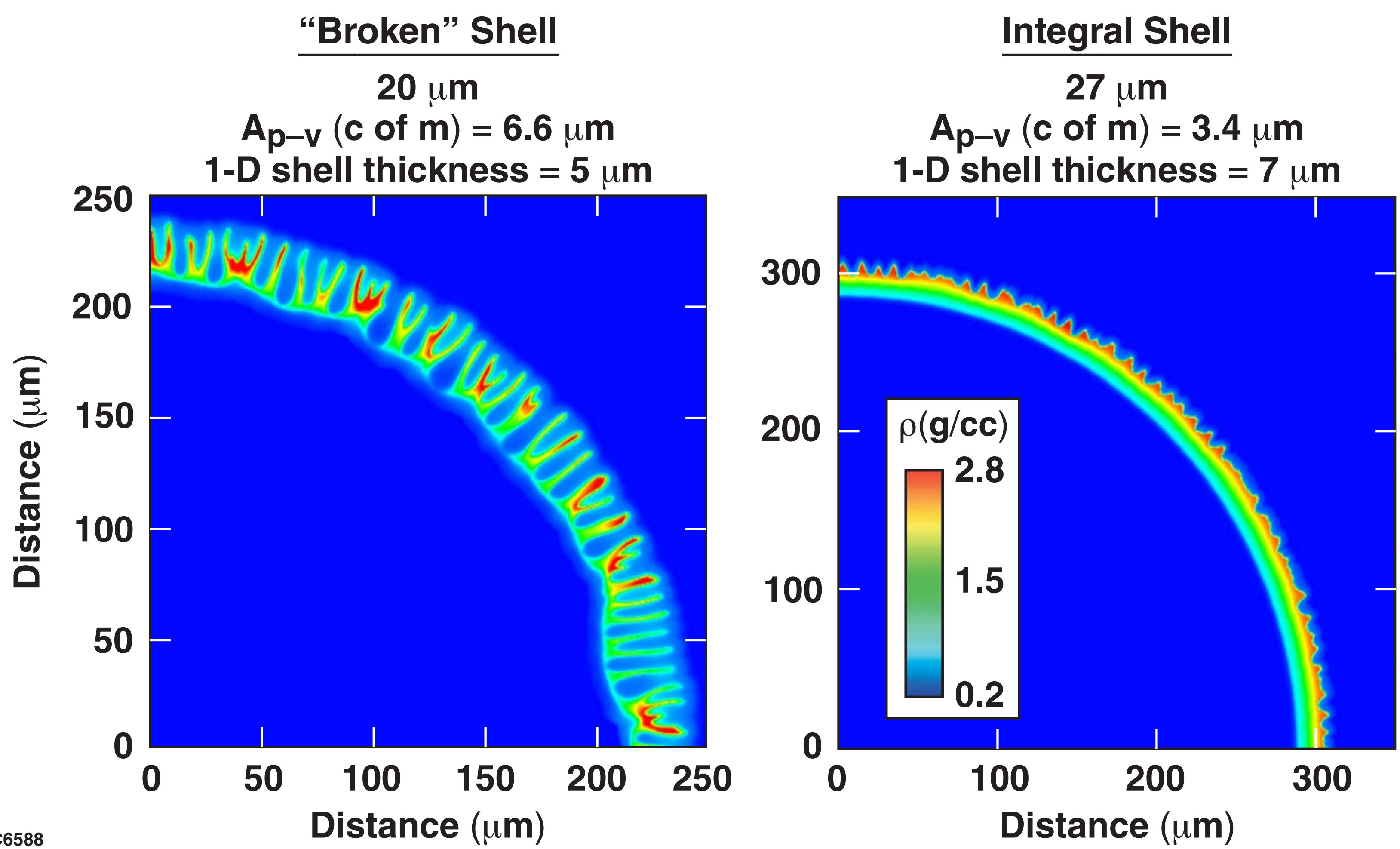
Multimode simulation of laser imprinting; modes 2–200 at end of acceleration phase



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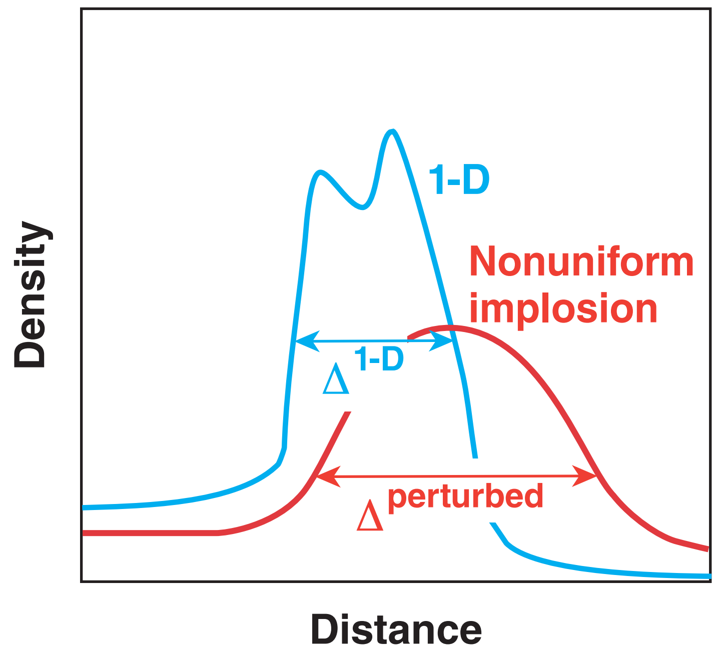
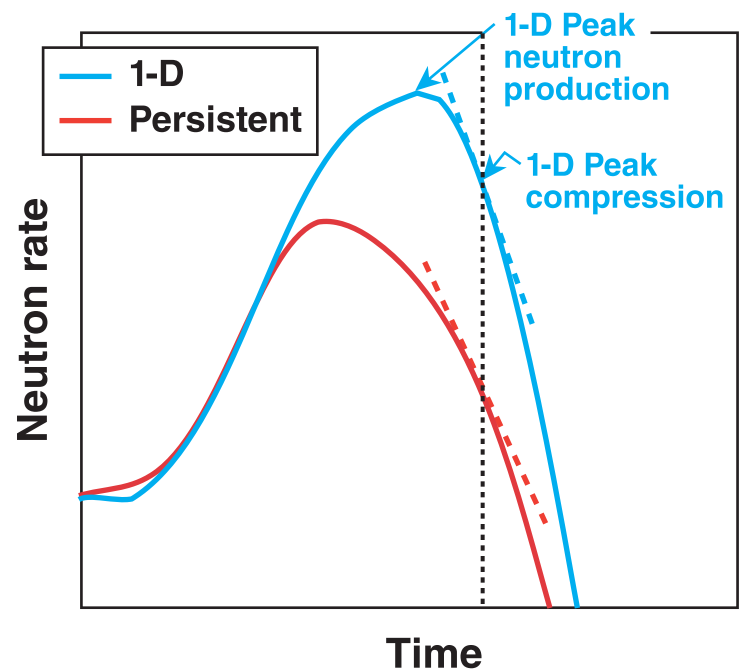
"Broken" shells show a persistence of neutron production due to undercompression

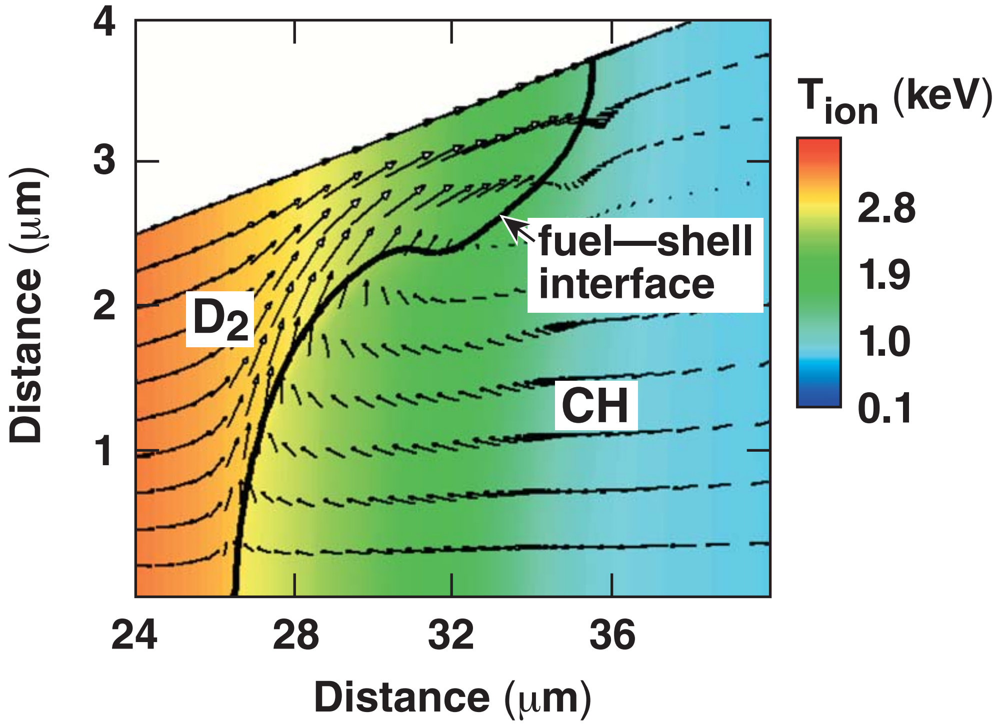




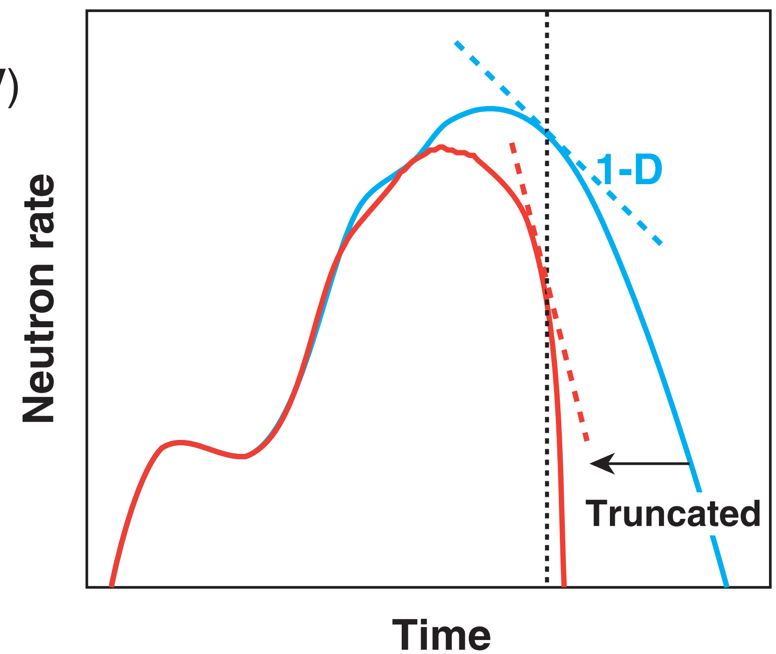
- Time for shock to transit shell = $\Delta / U_{\text{shock}} \sim \Delta$; $\Delta^{\text{perturbed}} > \Delta^{\text{1-D}}$
- Disassembly is delayed.

Integral shells result in burn truncation due to unstable fluid flow at the interface

Single-mode simulation showing fluid flow at interface



Schematic of neutron rates



- Mass flow into the bubbles is an important burn truncation mechanism.

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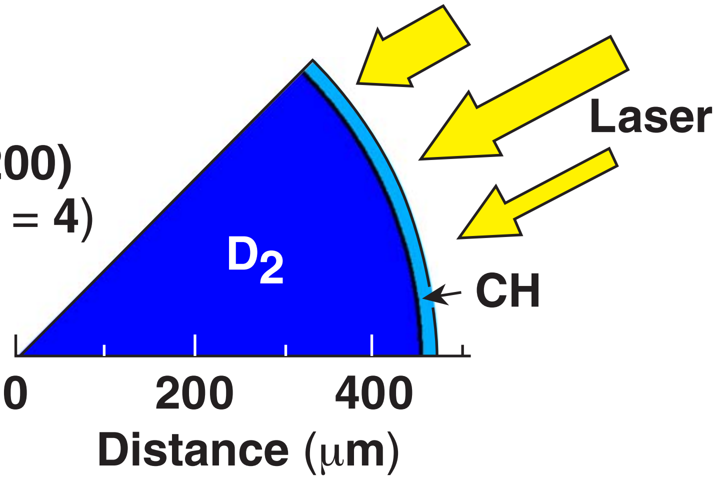
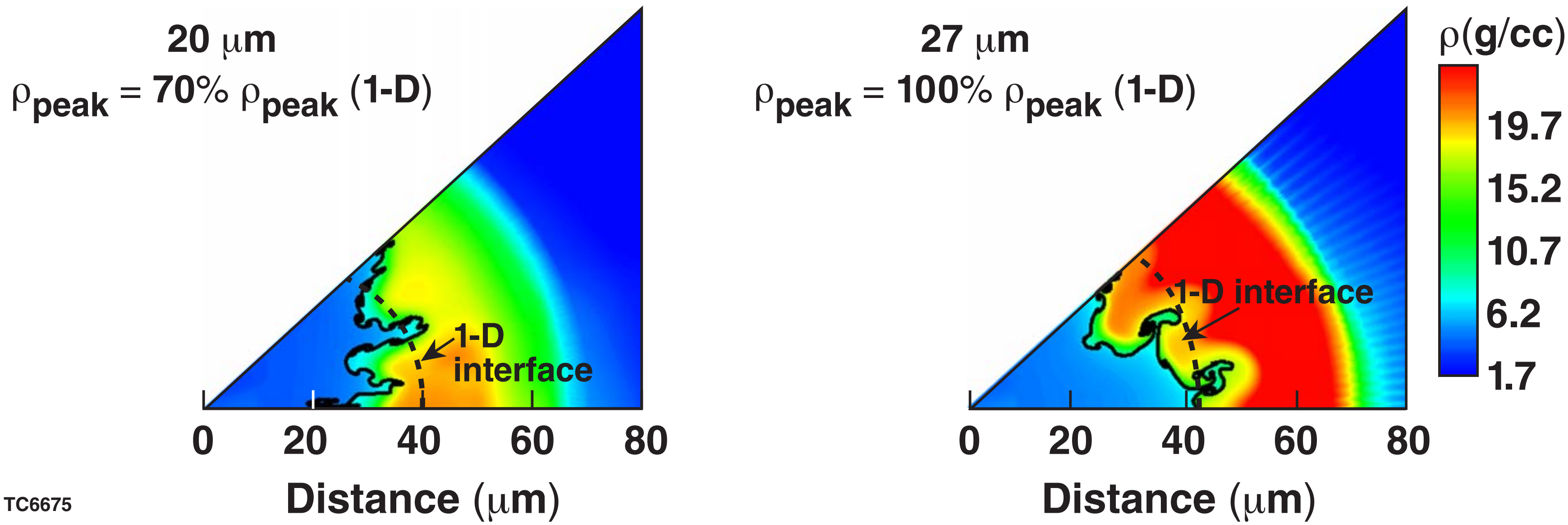
Undercompression is evident in broken shells modeled in two-dimensions using *DRACO*

Nonuniformity seeds:
Laser imprint (ℓ = 20 and 200)
Beam-beam imbalances (ℓ = 4)



Peak Neutron Production



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Neutron production rates persist in the "thin" shell simulations and truncate in the "thick" shell simulations

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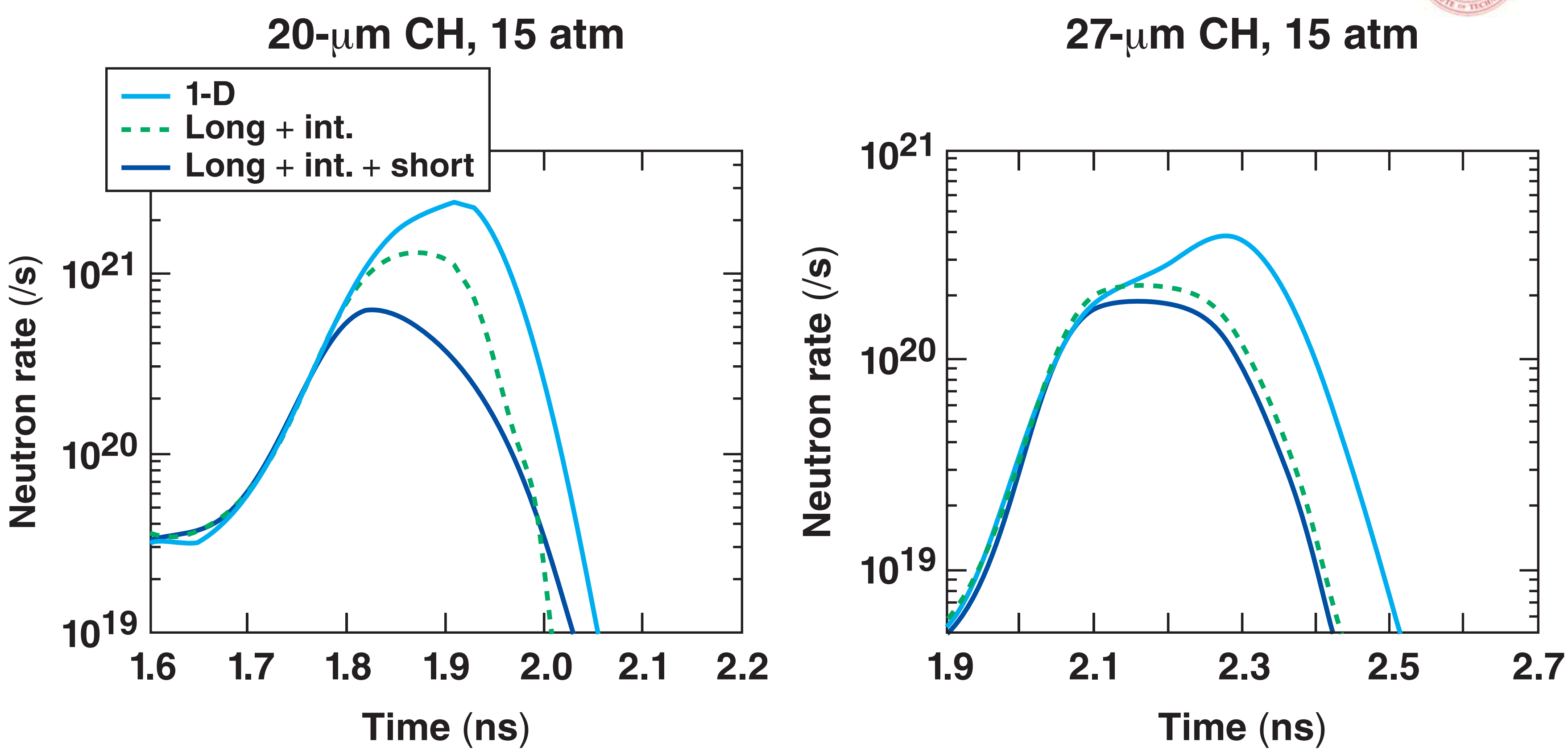

- Short wavelengths significantly influence the temporal evolution of the neutron rate for unstable shell, in contrast to the stable shell

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Similar trends in neutron production rates are observed experimentally

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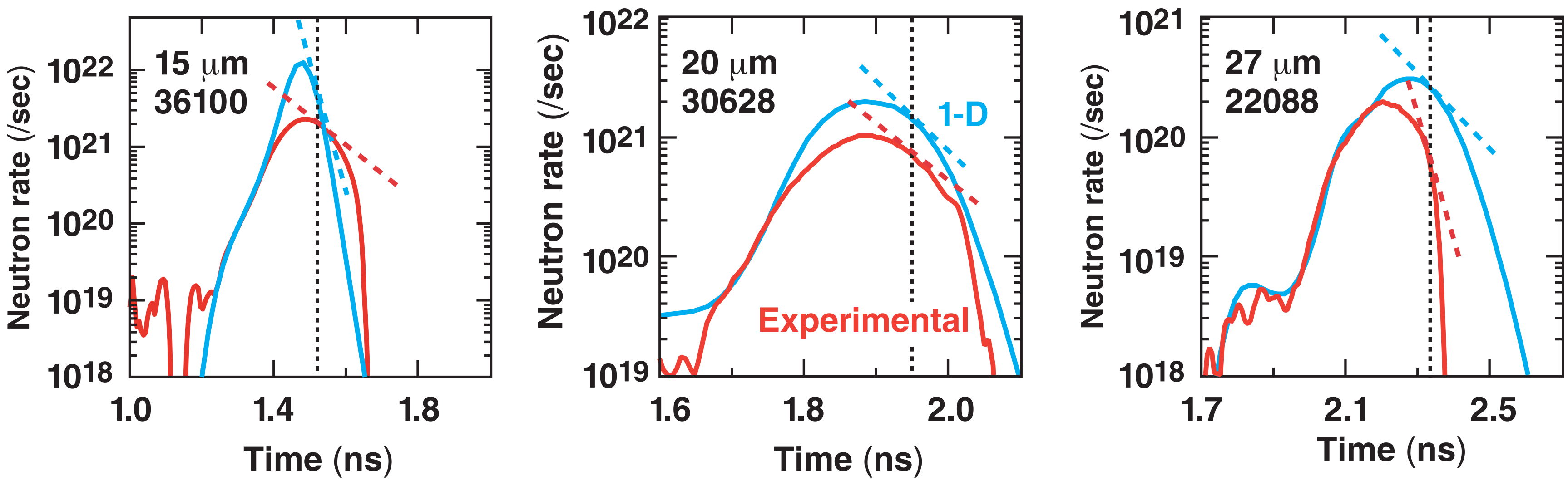
Less stable, persistent neutron rate ← → More stable, truncated neutron rate



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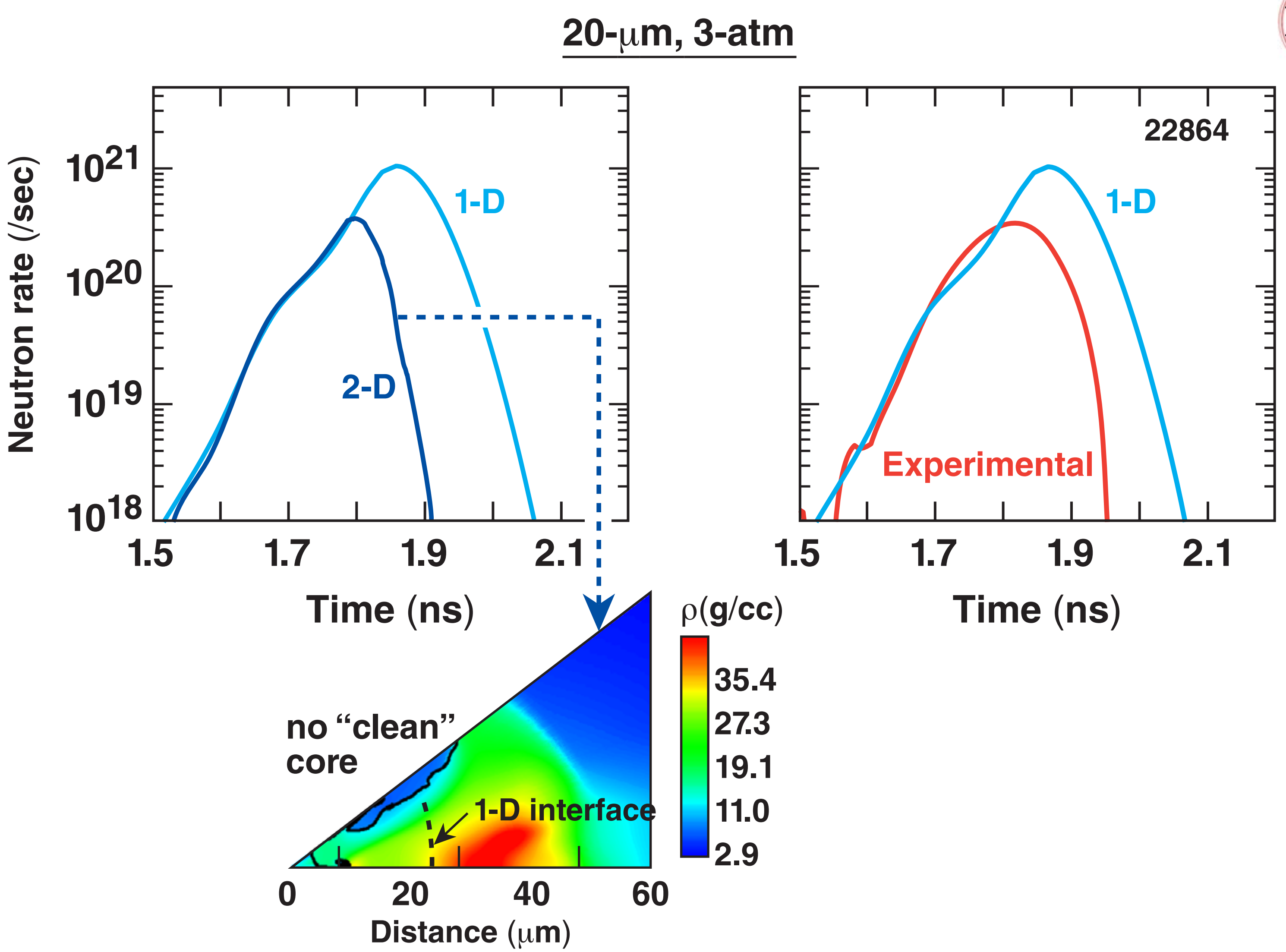
The lower fill pressure for the broken shell does not show a widening of the neutron production rate



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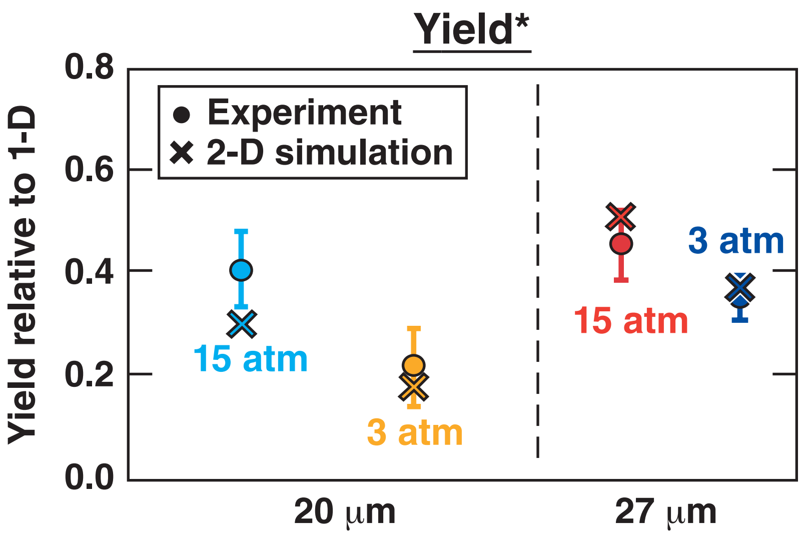
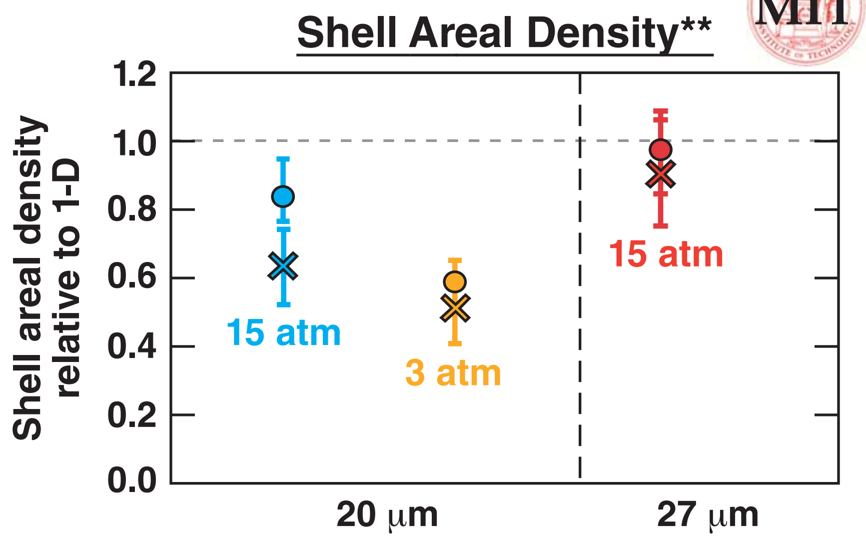
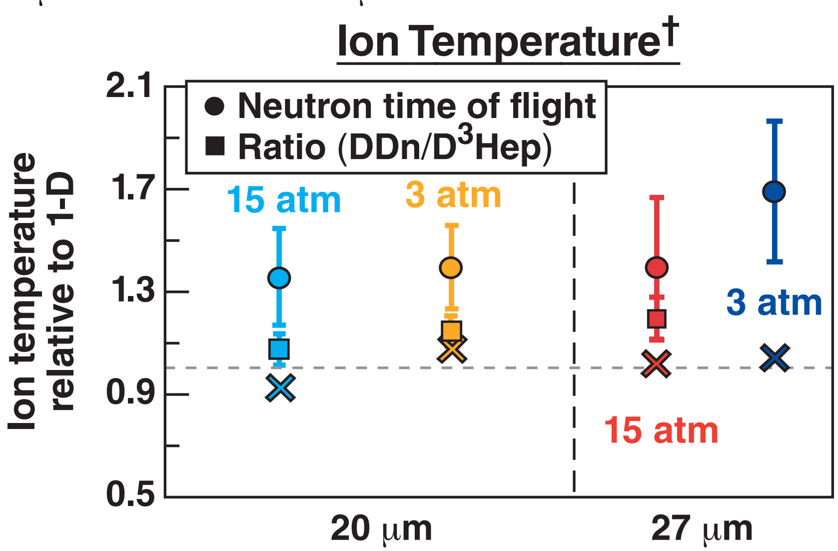
Yields and areal densities from simulation show good agreement with observations





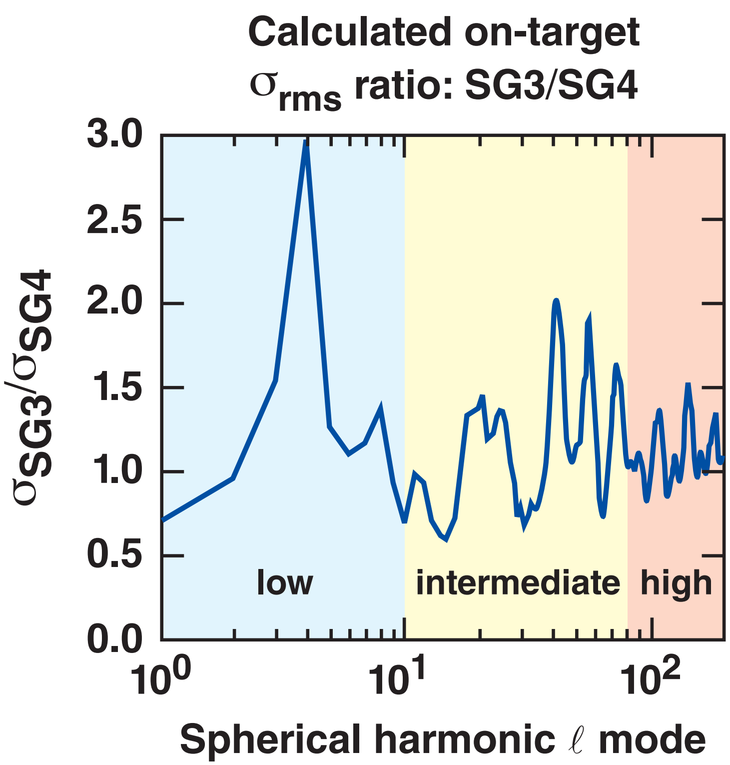


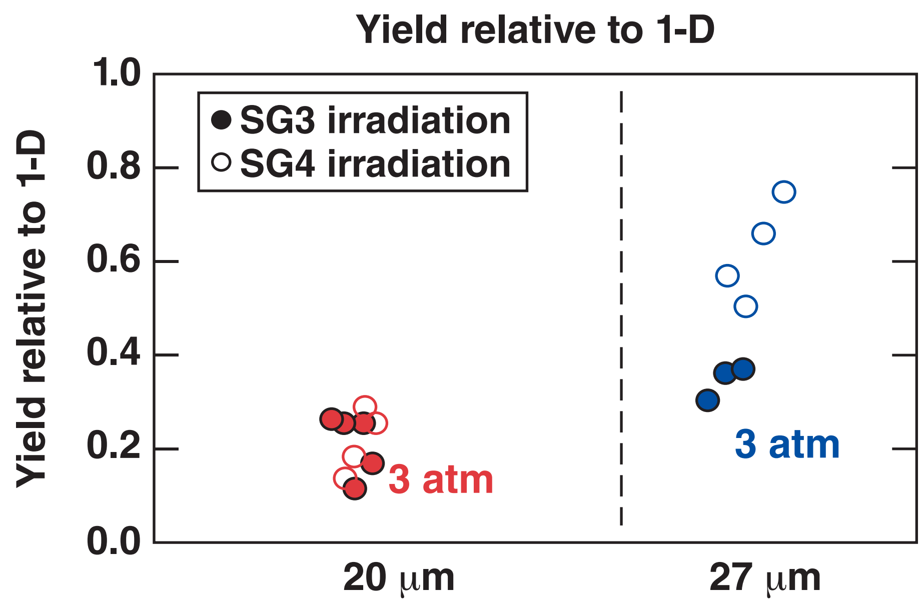
*S. P. Regan, CO1.004
**Li et al., Phys Plasmas 7, 2578 (2000).
†J. Frenje, CO1.009

TC6679

The marginal effect of long and intermediate wavelengths for thin shells is consistent with observations* using new phase plates

- **Far field intensity envelope:** $I(r) \propto \exp\left[-\left(\frac{r}{\delta}\right)^n\right]$
- **New SG4:** $n = 4.1$, $\delta = 360$ μm
- **Old SG3:** $n = 2.2$, $\delta = 308$ μm





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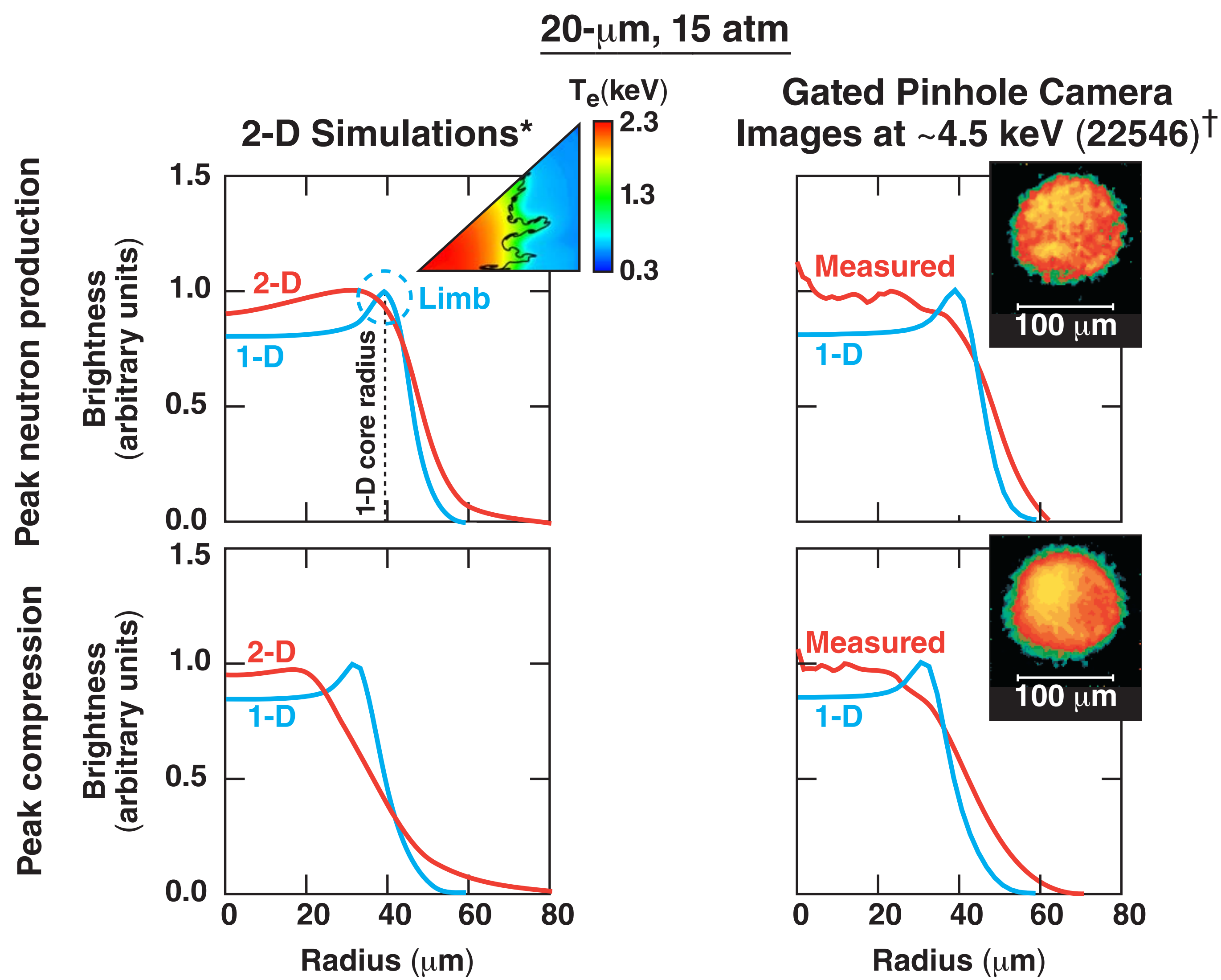
*S. P. Regan, CO1.004

Limb brightening is significantly reduced in 2-D simulations, consistent with observations



TC6681

*Post processed with Spect3D, PRISM Computational Sciences, Madison, WI
†S. P. Regan *et. al.*, Phys. Plasmas 9, 1357 (2002).

Amplitude of short wavelengths are consistent with estimates from turbulent mixing

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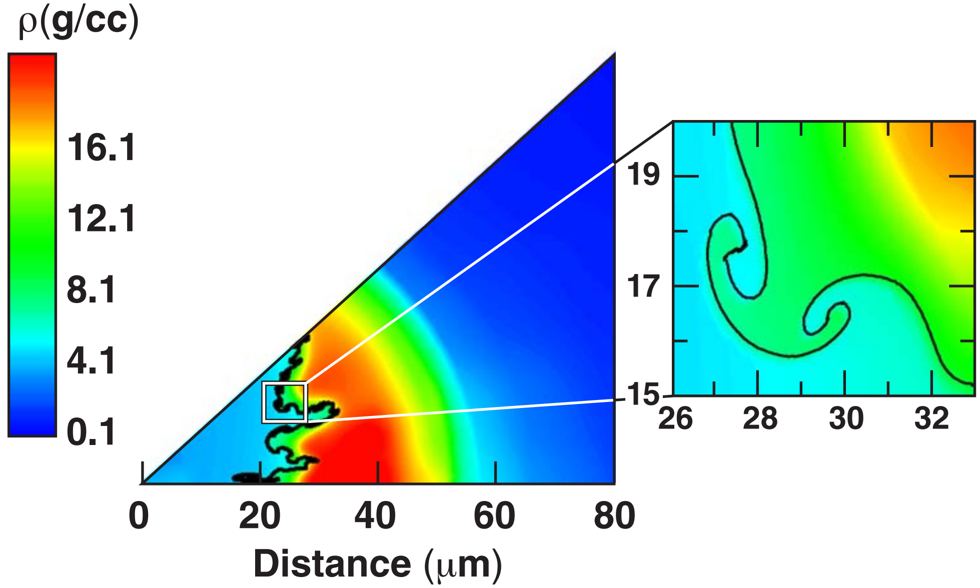
Peak neutron production, 20μm–15atm



Turbulent mixing length

$h \sim \alpha A_T g t^2$

$\alpha \sim 0.05$*, $A_T = 0.18$, $gt^2 = 120\ \mu m$

$h \sim 1\ \mu m \sim$ amplitude of short wavelength in simulation

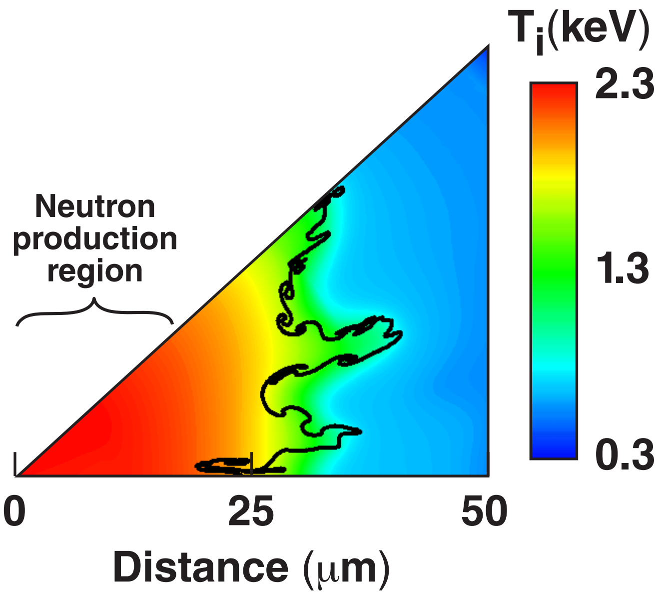
*D. L. Youngs, Physica 12D, 32 (1984); U. Alan *et al.*, Phys. Rev. Lett. 72, 2867 (1994); G. Dimonte, Phys. Plasmas 6, 2009 (1999).

TC6680

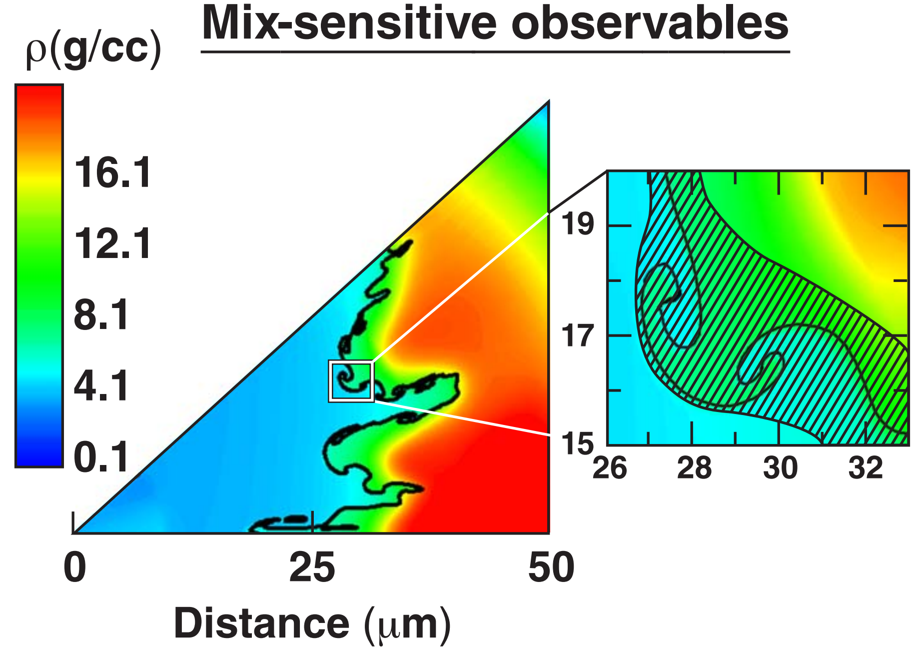
Primary neutron yields are not influenced by the turbulently mixed region

- Secondary neutron rates*, Ar-K shell** spectra, and D^3He proton yields* from CD shells are sensitive to small-scale mix.

Primary Neutrons



Mix-sensitive observables



*Li *et al.*, Phys. Rev. Lett. 89, 165002 (2002); P. B. Radha *et al.*, Phys. Plasmas 9, 2208 (2002).

**S. P. Regan *et al.*, Phys. Plasmas 9, 1357 (2002).

†D. Wilson *et al.*, Phys. Plasmas 11, 2723 (2004).

TC6729

Summary/Conclusions

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TC6667