Direct-Drive, High-Convergence-Ratio Implosion Studies on the OMEGA Laser System

F. J. Marshall, J. A. Delettrez, R. Epstein, V. Yu. Glebov, D. D. Meyerhofer, R. D. Petrasso, P. B. Radha, V. A. Smalyuk, J. M. Soures, C. Stoekl, R. P. J. Town, and B. Yaakobi.

Laboratory for Laser Energetics, U. of Rochester

The effects of beam smoothing, pulse shaping, and target dimensions on the compressed core and shell performance of directly driven plastic capsules are studied on the 30-kJ, 60-beam OMEGA laser system. Experiments are performed on surrogate-cryogenic capsules where the main fuel layer is a polymer shell (either CH or CD + CH) and the hot spot is provided by the fill gas (D_2, DHe^3, DT, or H_2). The spatial evolution of the fuel and shell regions is recorded using both broadband and monochromatic time-resolved x-ray imaging techniques. Similar targets with inner Ti-doped layers provide additional spectral diagnostics of the shell and a source of monochromatic emission. Core conditions are diagnosed with measurements of the emergent x-ray, neutron, and particle spectra. For 1-ns-square drive pulses the calculated convergence ratios are in excess of 30, and the primary neutron yields are ≥20% of clean 1-D with shell areal densities >100 mg/cm^2. Shaped pulse implosions have higher convergence ratios. Compressed-target conditions measured include those of fuel and shell areal density, fuel ion temperature, shell electron temperature, and primary (DD) and secondary (DT) neutron yield. The effect of pulse shaping and the beneficial effects of beam smoothing on the final core conditions are seen in these measurements. Mixing, resulting from laser-irradiation nonuniformities and target imperfections that seed the Rayleigh–Taylor instability, are observed in the x-ray and neutron spectra and are seen to depend on both the level of beam smoothing and the pulse shape. Comparison of these results with 1- and 2-D hydrocode simulations (including models of fuel-shell mixing) is ongoing. This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under Cooperative Agreement No. DE-FC03-92SF19460, the University of Rochester, and the New York State Energy Research and Development Authority.

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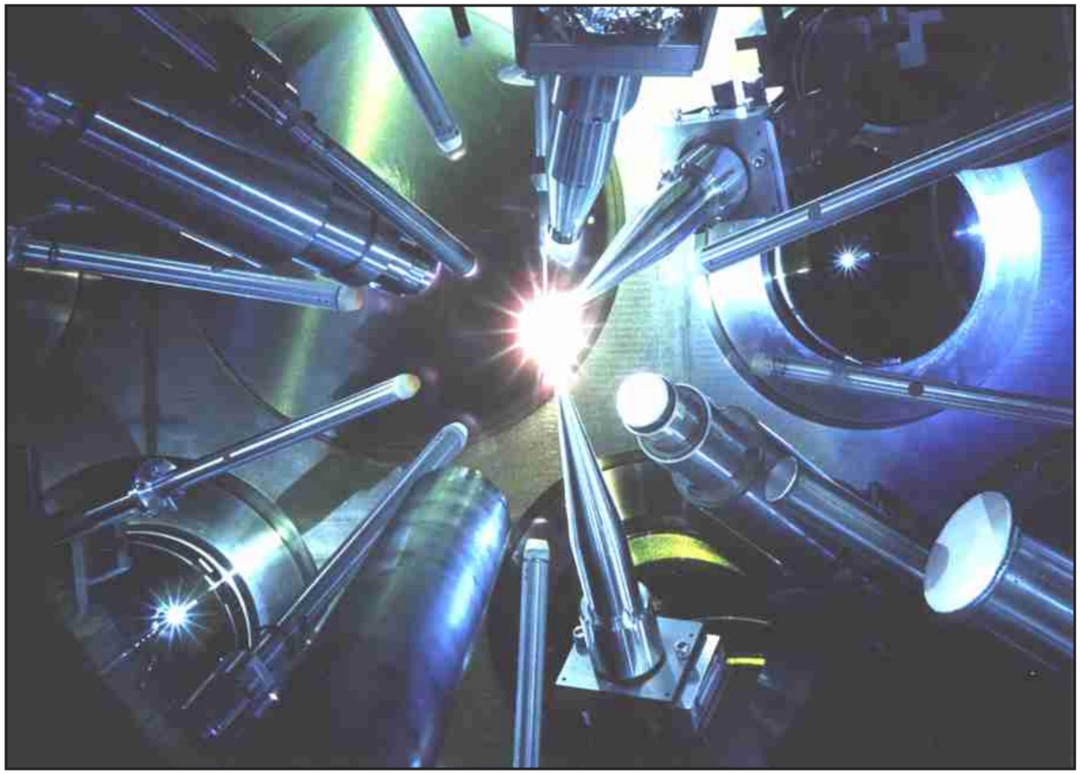

Frederic J. Marshall
University of Rochester
Laboratory for Laser Energetics

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Contributors

Experimental:
- Vladimir Glebov
- David Harding
- Richard Petrasso
- Wolf Seka
- Vladimir Smalyuk
- Christian Stoeckl
- David Meyerhofer
- Barukh Yaakobi
- John Soures

OMEGA Laser Operations:
- Jack Kelly
- Sam Morse
- Greg Pien
- Laser Operations Staff

Theory:
- Jacques Delettrez
- Richard Town
- Pat McKenty
- Reuben Epstein
- P. B. Radha

MIT:
- C. K. Li
- Damian Hicks
- Fredrick Séguin

LLE Staff:
- Many

Summary

We are investigating the effects of beam smoothing and pulse shape on target performance with OMEGA

- The core conditions of high-convergence-ratio targets have been diagnosed using x-ray, neutron, and particle spectroscopy:

  [ρR_{fuel}, ρR_{shell}, T_e, and T_i, Y_n(DD), Y_n(DT)].

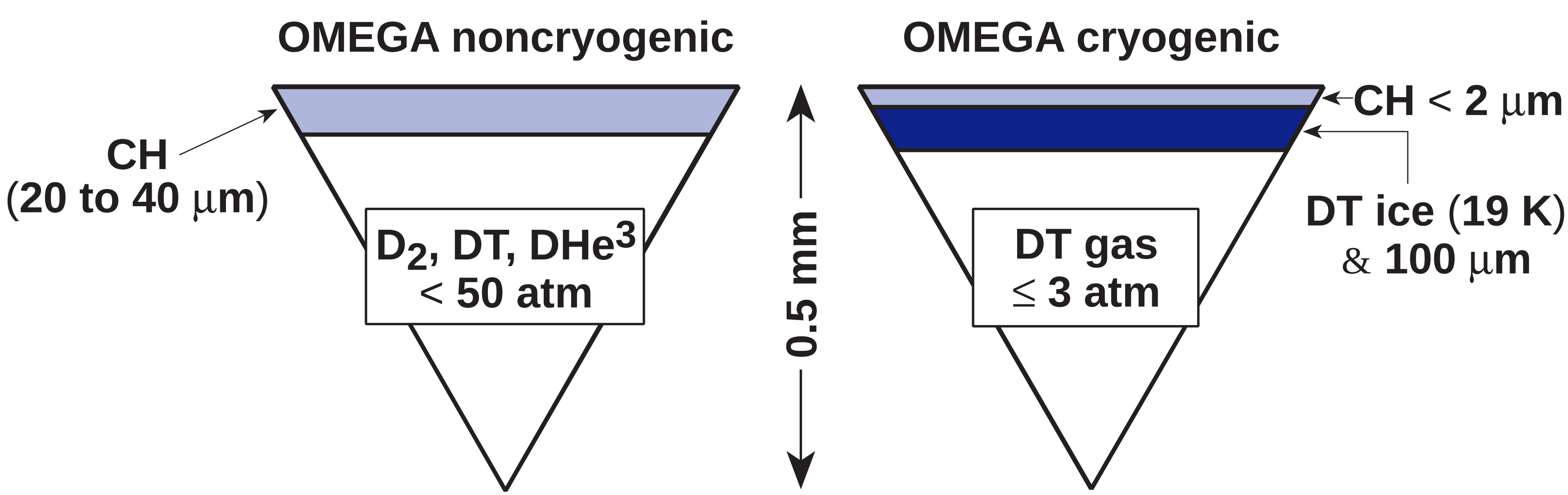
- Increased SSD bandwidth improves target performance.
  - The improvement is most evident for the least-stable conditions (i.e., longer, shaped pulses).

- 2-D simulations of single-beam nonuniformity effects can account for the performance of the outer region of the shell.

- Low l-mode contributions due to beam balance appear to limit the performance of the most-stable, low-convergence-ratio targets.

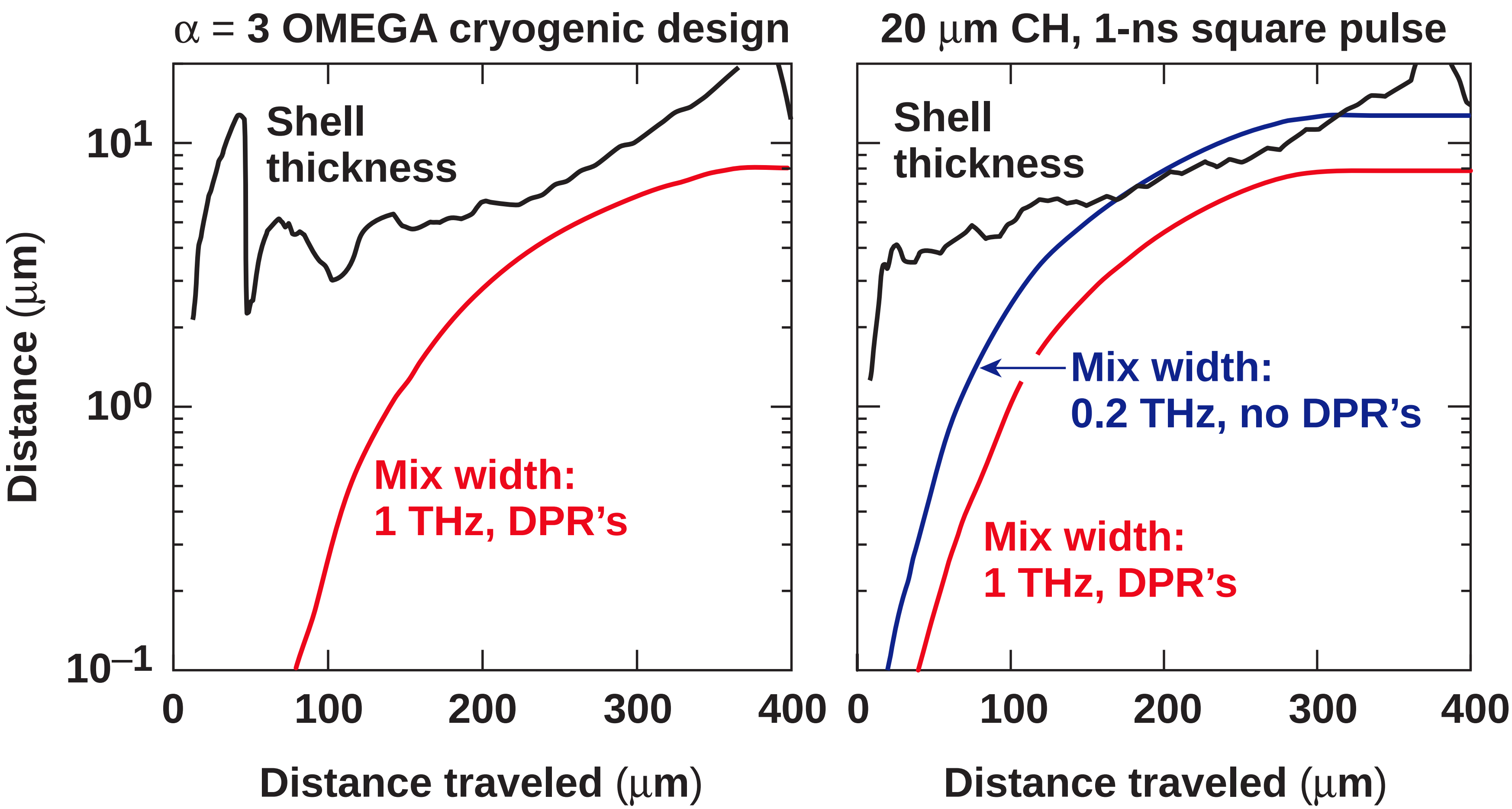
Current OMEGA experiments are preparatory to cryogenic implosions on OMEGA and NIF ignition

- OMEGA cryogenic implosions are energy scaled from NIF ignition target designs.
- Current noncryogenic implosions study hydrodynamics and stability issues.
- The CH shell corresponds to the main fuel layer (DT ice), and the fill gas corresponds to the hot-spot-forming central DT gas.



E10148

20-μm-thick plastic shells driven by 1-ns square pulses show similar stability to the OMEGA α = 3 cryo design



The mix width is calculated using an instability model with Takabe growth rates and Haan saturation.

TC5267

Outline

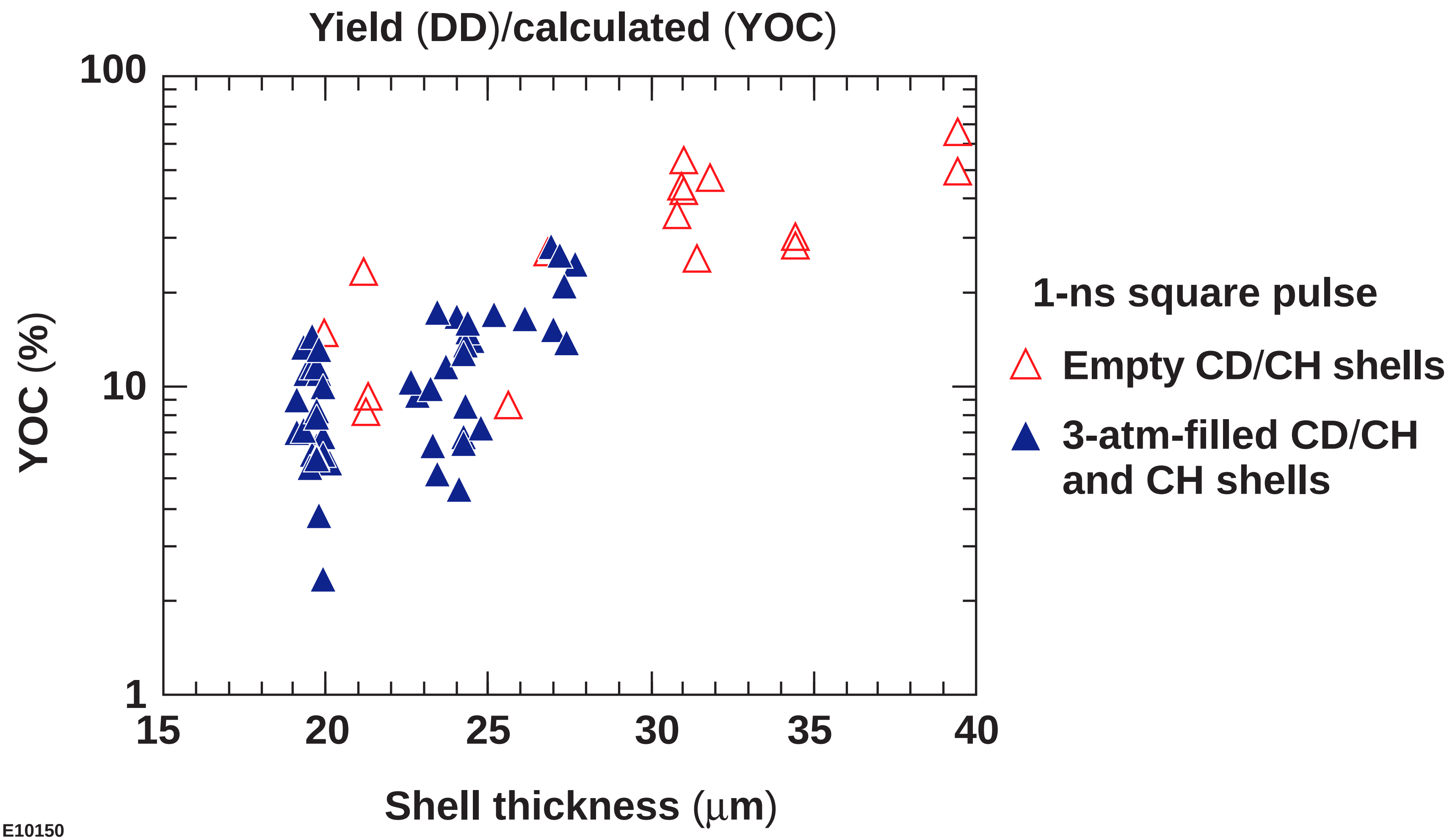
Direct-drive, high-convergence ratio implosion studies on the OMEGA laser system

- Review of recent OMEGA results
  - Gas-filled shells
  - Beam-smoothing effects (SSD bandwidth)
  - Pulse shaping
- Diagnostics
  - Neutron yield and spectroscopy
    [Y_n(DD), Y_n(DT), ρR_{fuel}, ρR_{shell}, T_i]
  - Charged-particle spectroscopy
    [Y_p(DHe^3), ρR_{total}, T_i]
  - X-ray continuum spectroscopy and imaging of Ti-doped shells
    (ρR_{shell}, Te)
- Conclusions
  - SSD smooths the high l-mode nonuniformities.
  - SSD benefits the least-stable implosions (shaped pulses) the most.

E10149

Fuel performance improves with increasing shell thickness

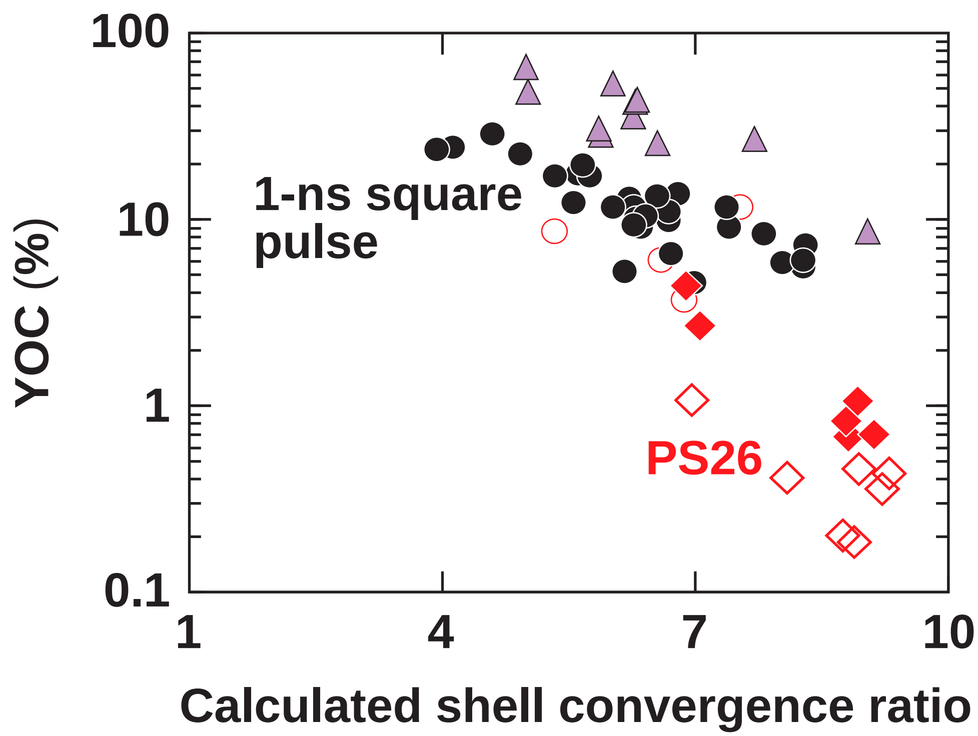
Gas convergence ratios $(r_{gas})_i / (r_{gas})_f$ range from 30 to 50.



E10150

Primary fusion yield (DD) from CH targets is a function of the shell stability

- **Shell convergence ratio (shell CR) is a measure of shell stability.**



△ Empty CD/CH (1 ns)

● 3- to 15-atm-filled CH (1 ns)

◆ 3- to 15-atm-filled CH (PS26)

SSD off = open symbols

$$\text{Shell CR} = \frac{(R_{shell})_i}{(R_{shell})_f},$$

$$(R_{shell})_f = \sqrt{\frac{3M_f}{4\pi\langle\rho R\rangle_f}}$$

The least-stable implosions show the most improvement with SSD.

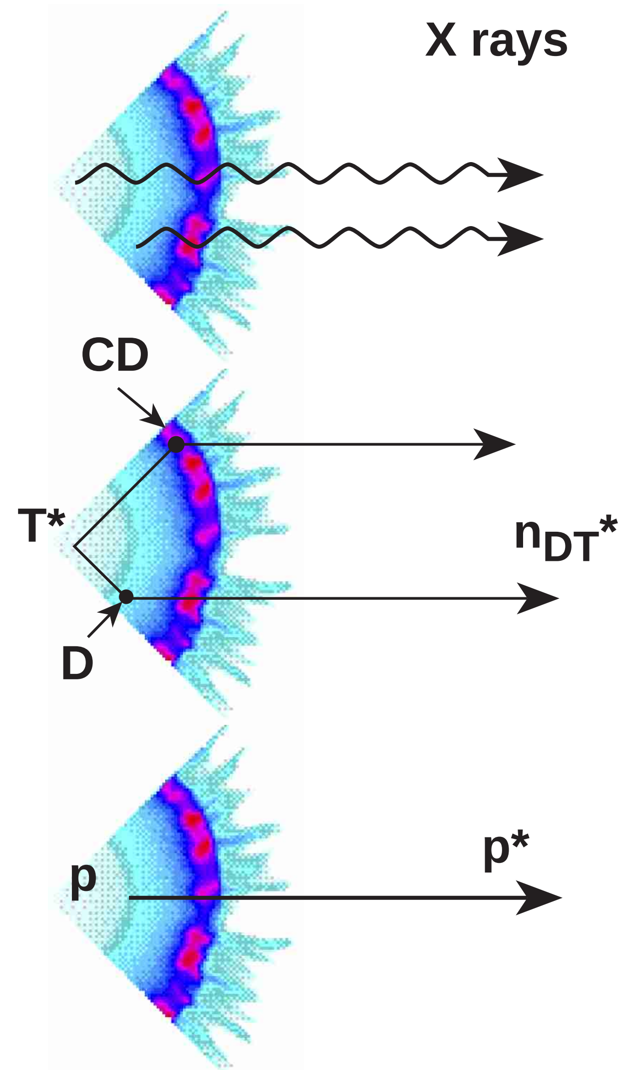
E10151

We are using three principal methods to determine ρR in compressed CH shells

- X-ray absorption: continuum or high-Z K-shell
  [ρR_{shell}, T_e]

- Secondary (DT) neutron yield from D in gas or shell (CD)
  [Y_n(DD),Y_n(DT), ρR_{fuel}, ρR_{shell}, T_i]

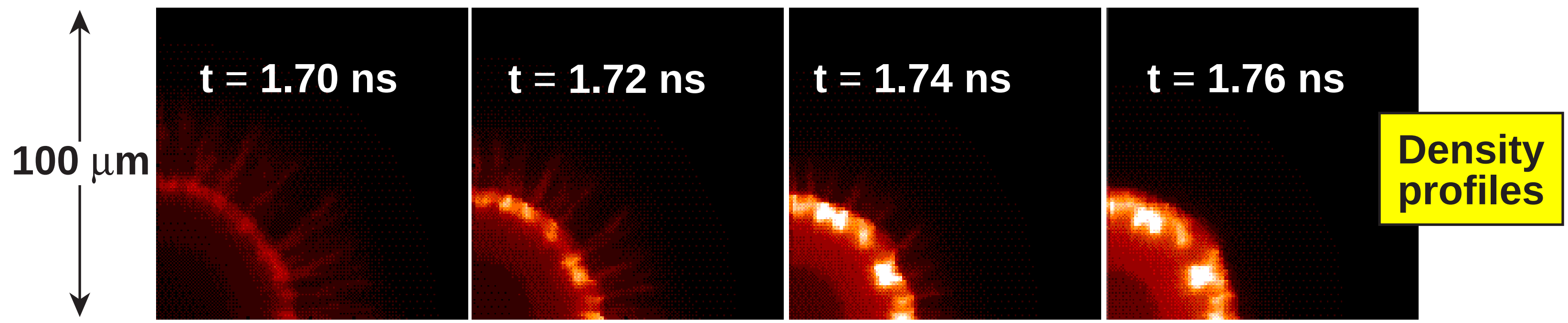
- Charged-particle energy loss of 14.7 MeV proton (D-He^3 reaction)
  [Y_p(DHe^3), ρR_{total}, T_i]



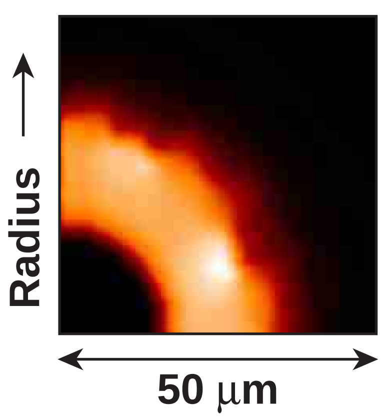
E10152

ORCHID simulations are used to estimate the effects of high-l-mode nonuniformities on measurements

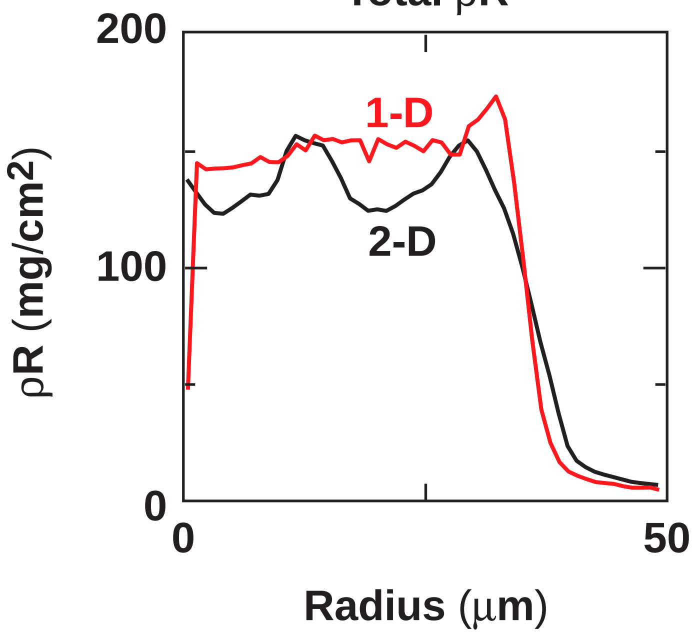
20-μm-thick, 3-atm-filled CH shell, 29 kJ, 1-ns square pulse



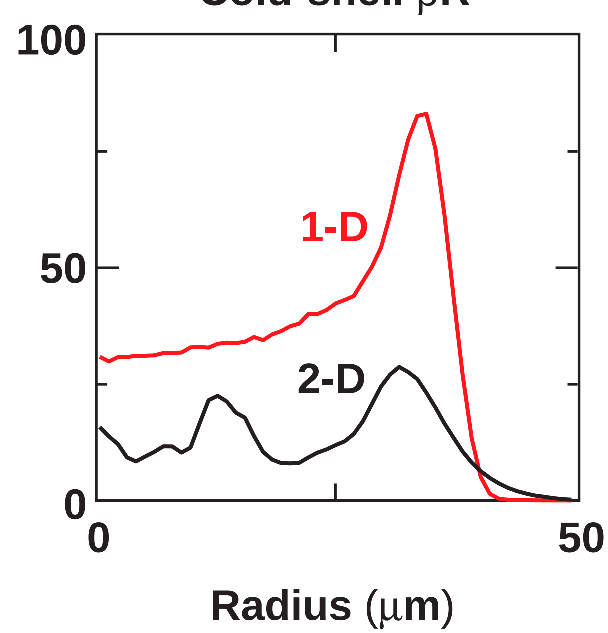
X-ray emissivity



Total ρR



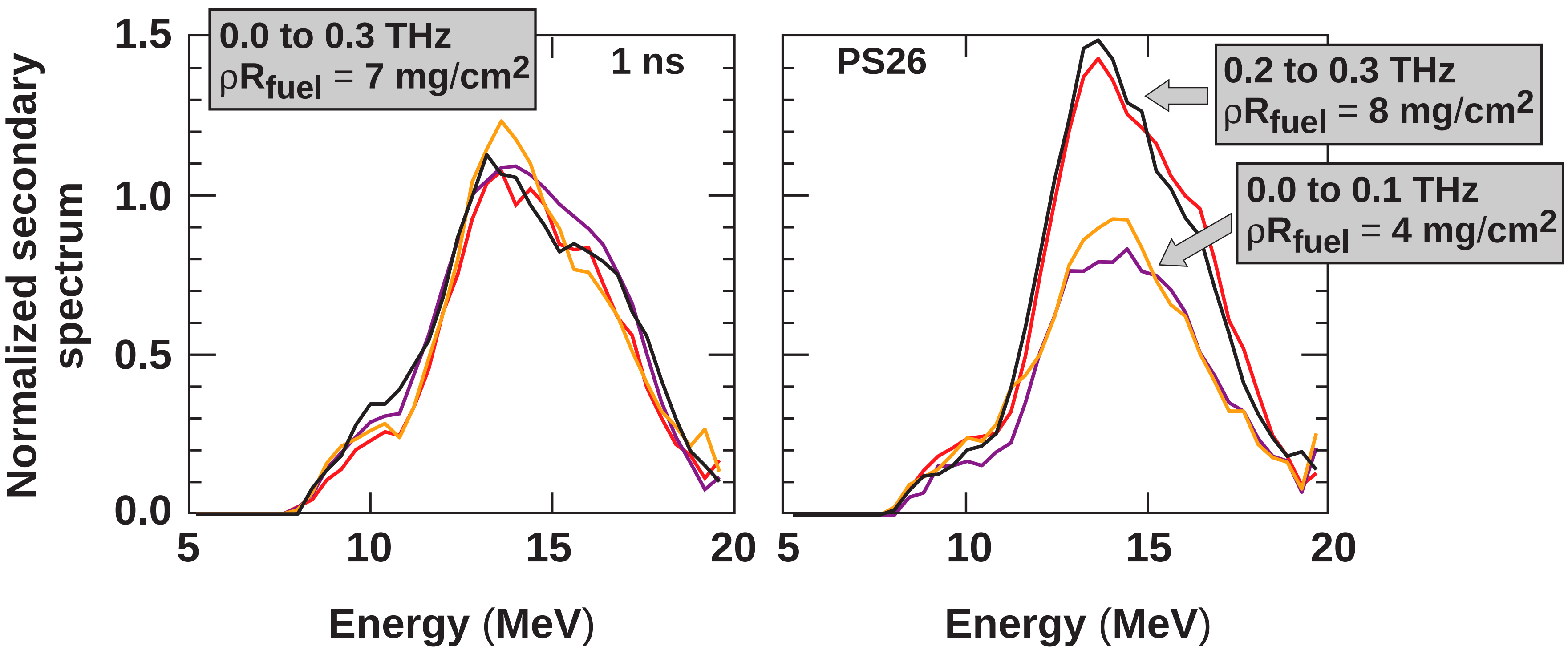
Cold-shell ρR



E10153

SSD increases the fuel ρR of shaped-pulse implosions

20-μm-thick, 3-atm-D_2-filled CH targets

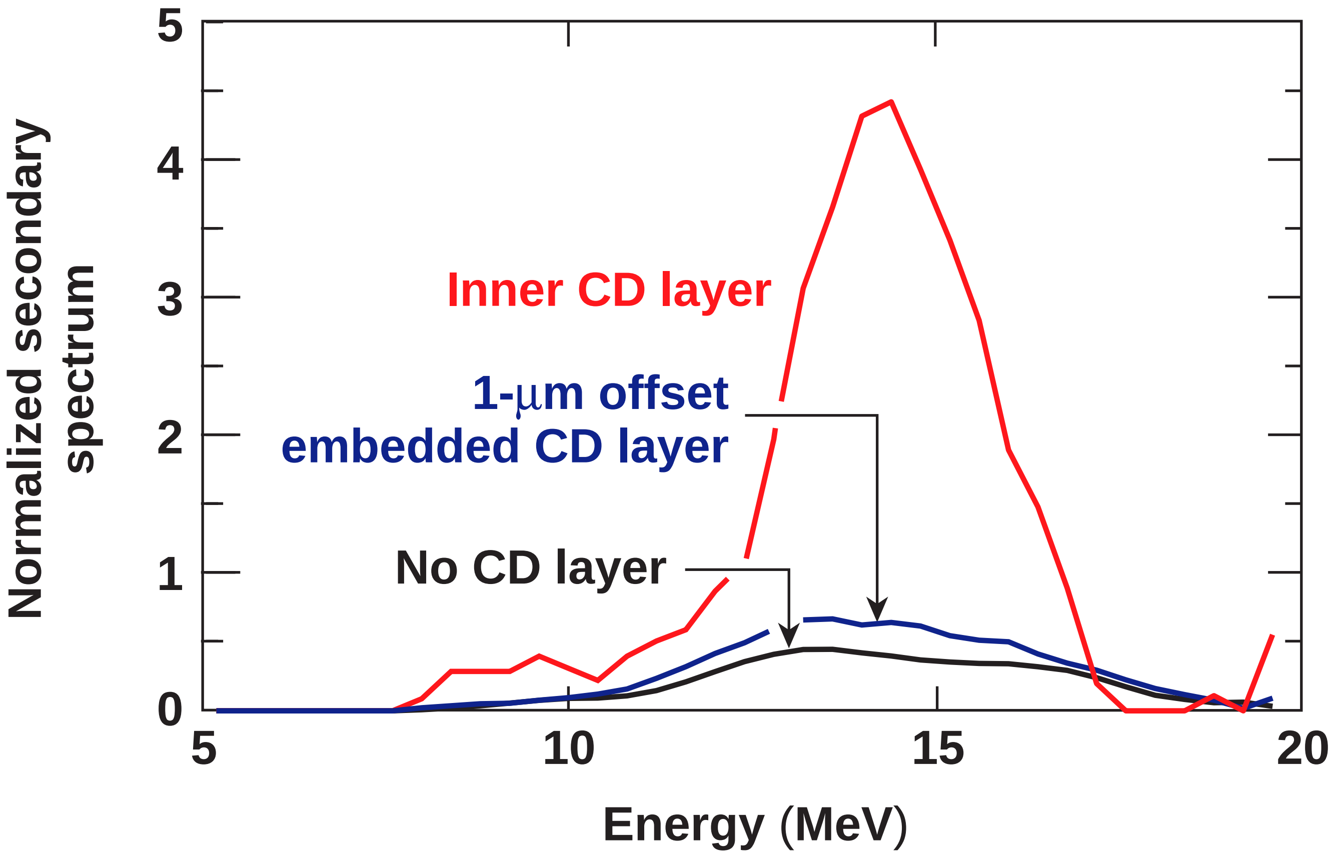


Secondary yields measured by MEDUSA

E10154

The experiments performed with and without CD layers put limits on the amount of mixing at stagnation

27-μm-thick, 3-atm D_2-filled CH targets, 1-ns square pulse.



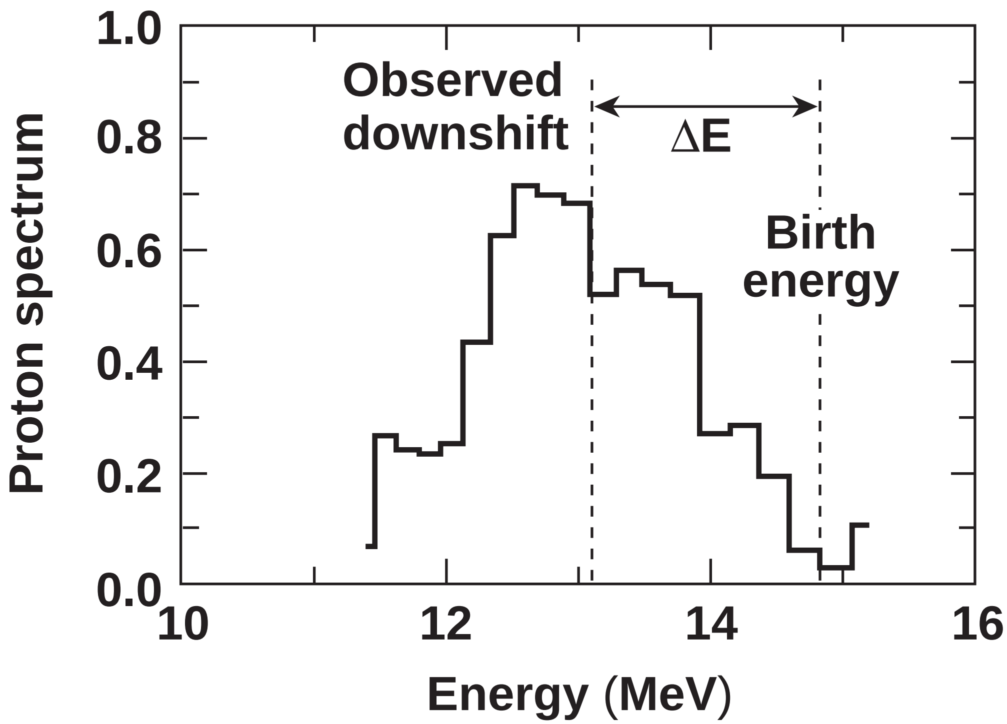
Minimal mixing within the inner 2-μm shell region is observed.

E10155

The OMEGA charged-particle spectrometers (CPS) measure the total ρR

20-μm-thick, 3-atm DHe^3-filled CH targets, 1-ns square pulse

D-He^3 reaction proton spectrum



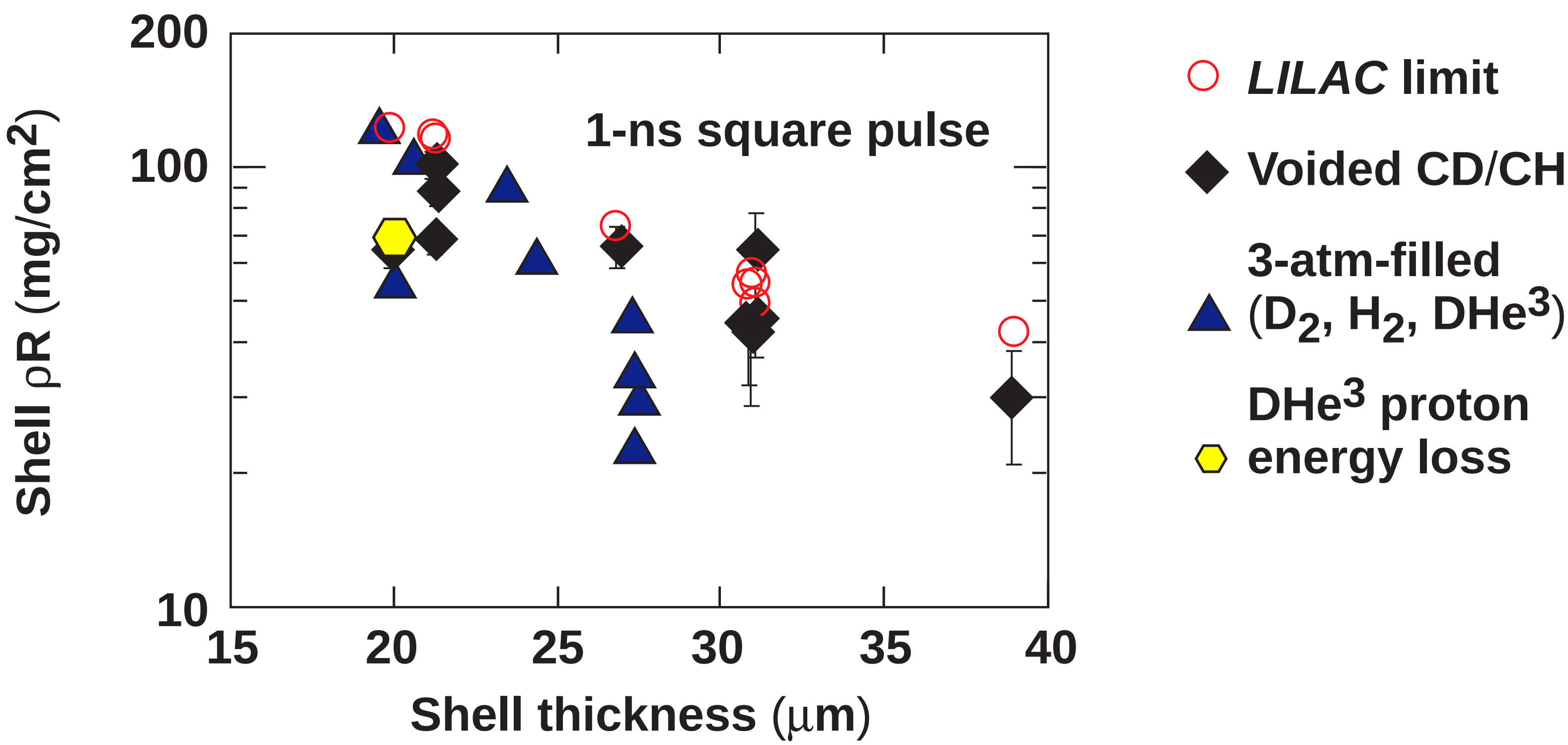
Energy loss
$\Delta E = 1.63 \pm 0.04$ MeV

Implied areal density
$\rho R_{total} = 70 \pm 5$ mg/cm^2

Averaged over three shots

The shell ρR is determined from the secondary neutron yield and from the 14.7-MeV proton energy loss

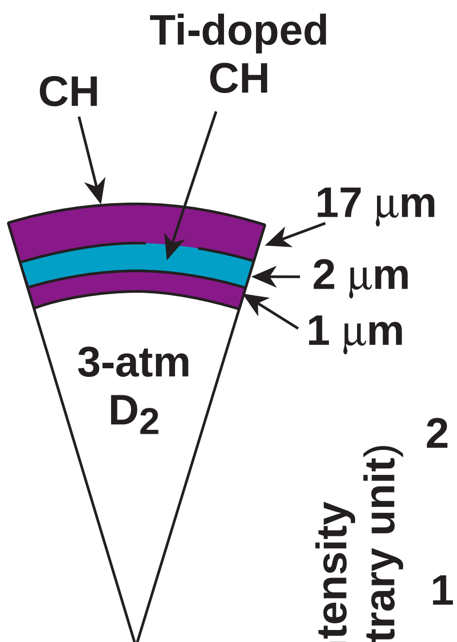
The methods give consistent values for the shell ρR (the yield ratio determined values are lower limits).

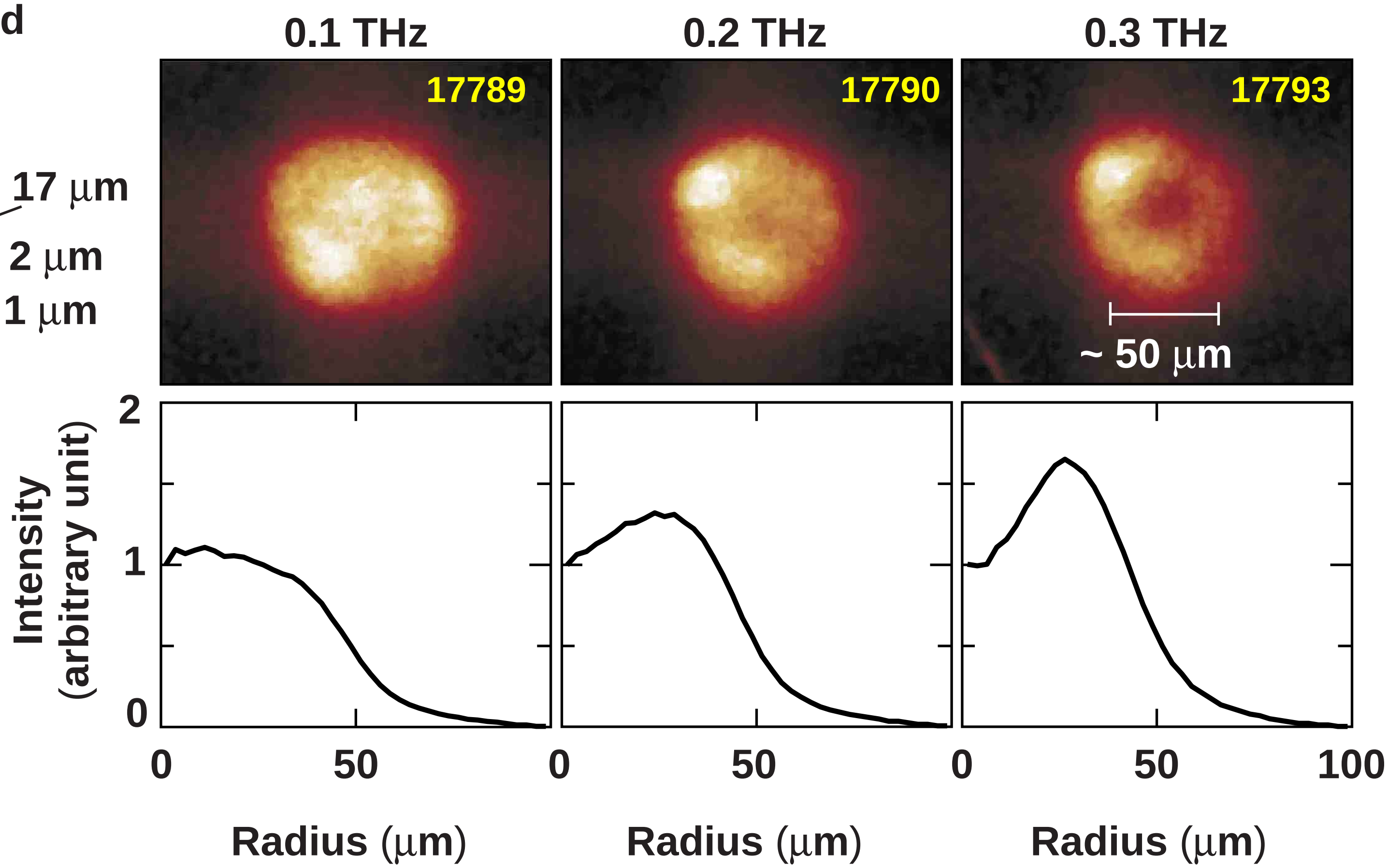


E10157

The 5- to 7-keV x-ray images show a more-compact and integral stagnation region with increased SSD bandwidth

20-μm CH shells, 1-ns square pulse, 25 kJ, Ti-doped embedded layers





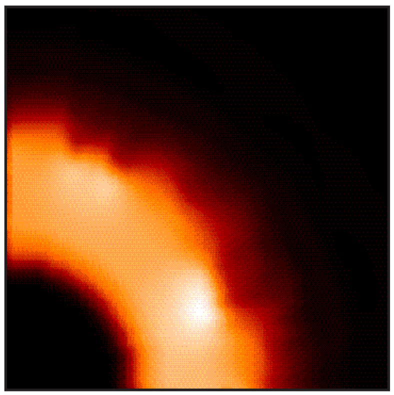
E10158

ORCHID is used to simulate the effect of shell nonuniformities on x-ray images

UR LLE

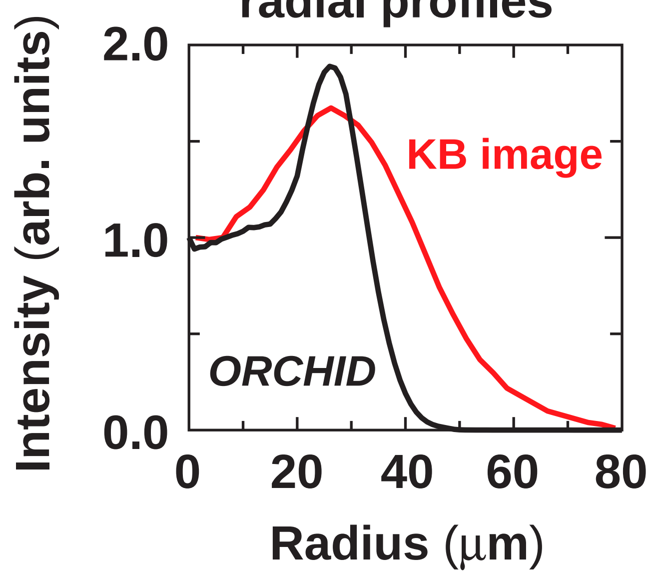
3-atm-filled, Ti-doped, 20-μm CH shells, 1-ns square pulse

ORCHID
simulated x-ray emissivity

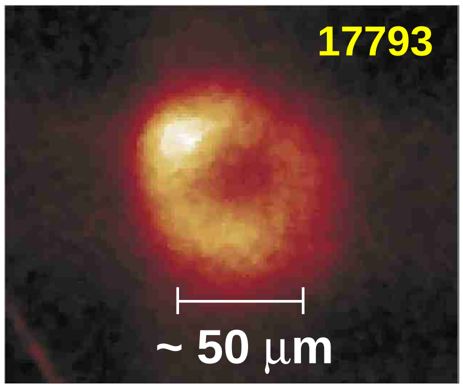


← 50 μm →

Comparison of radial profiles



OMEGA shot 17793



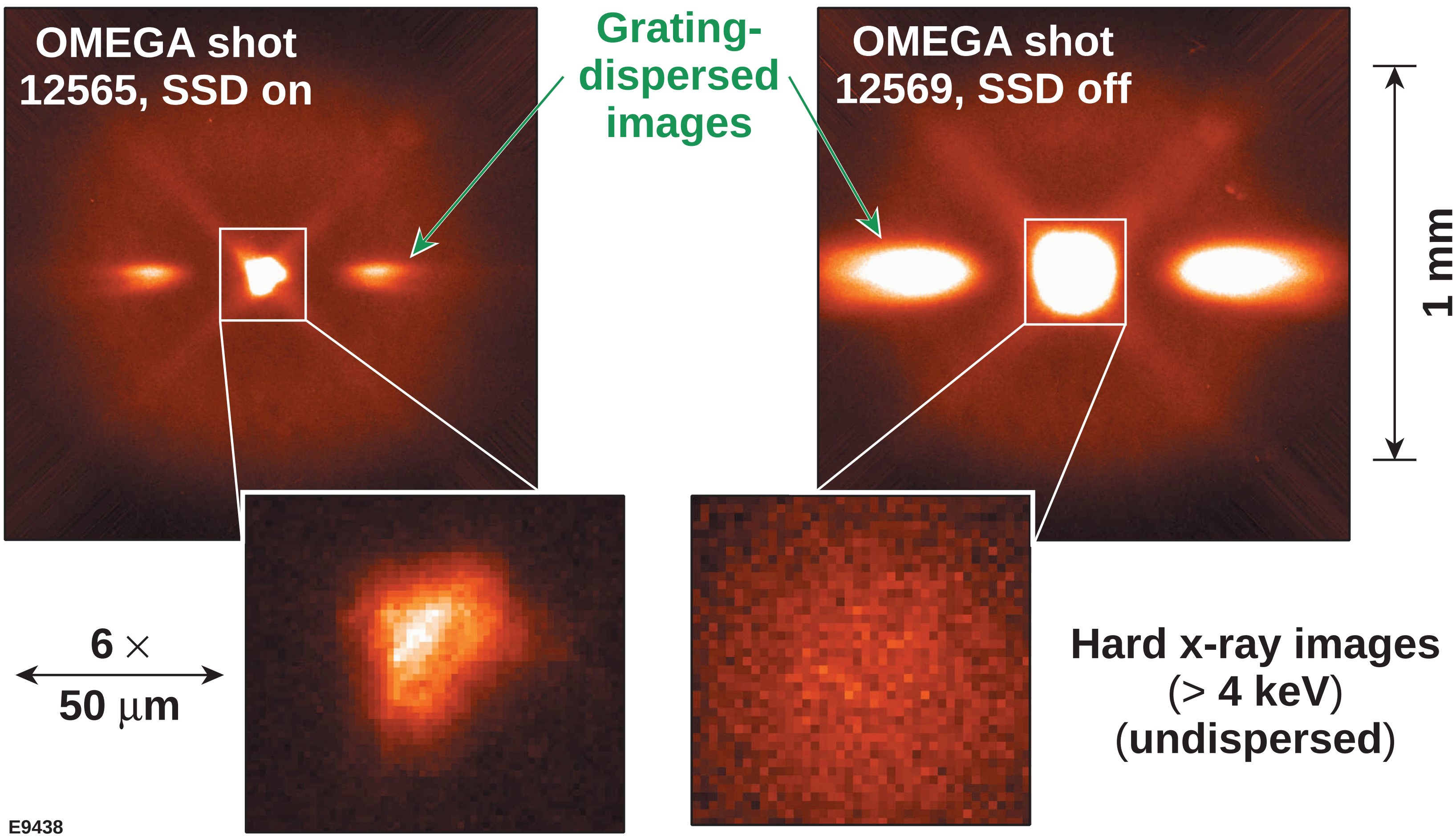
KB microscope x-ray images

2-D *ORCHID* x-ray emission profile shows a similar size but different width than seen in the KB microscope image.

E10159

SSD has a dramatic effect on the final stagnation of direct-drive ICF capsules

20 kJ, PS26 pulse shape, with DPP's, 0.95-mm diameter
3 atm H_2-filled, 27-μm-thick shells

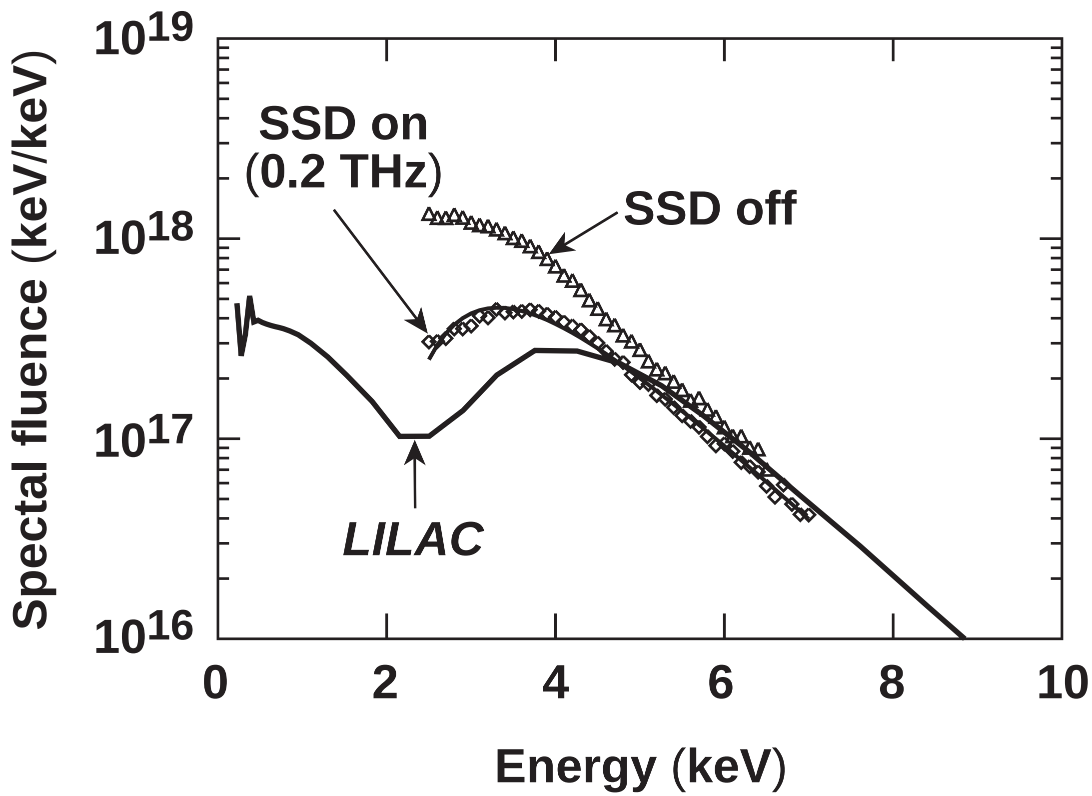


E9438

X-ray spectral measurements have confirmed the beneficial effects of SSD on direct-drive implosions

UR LLE

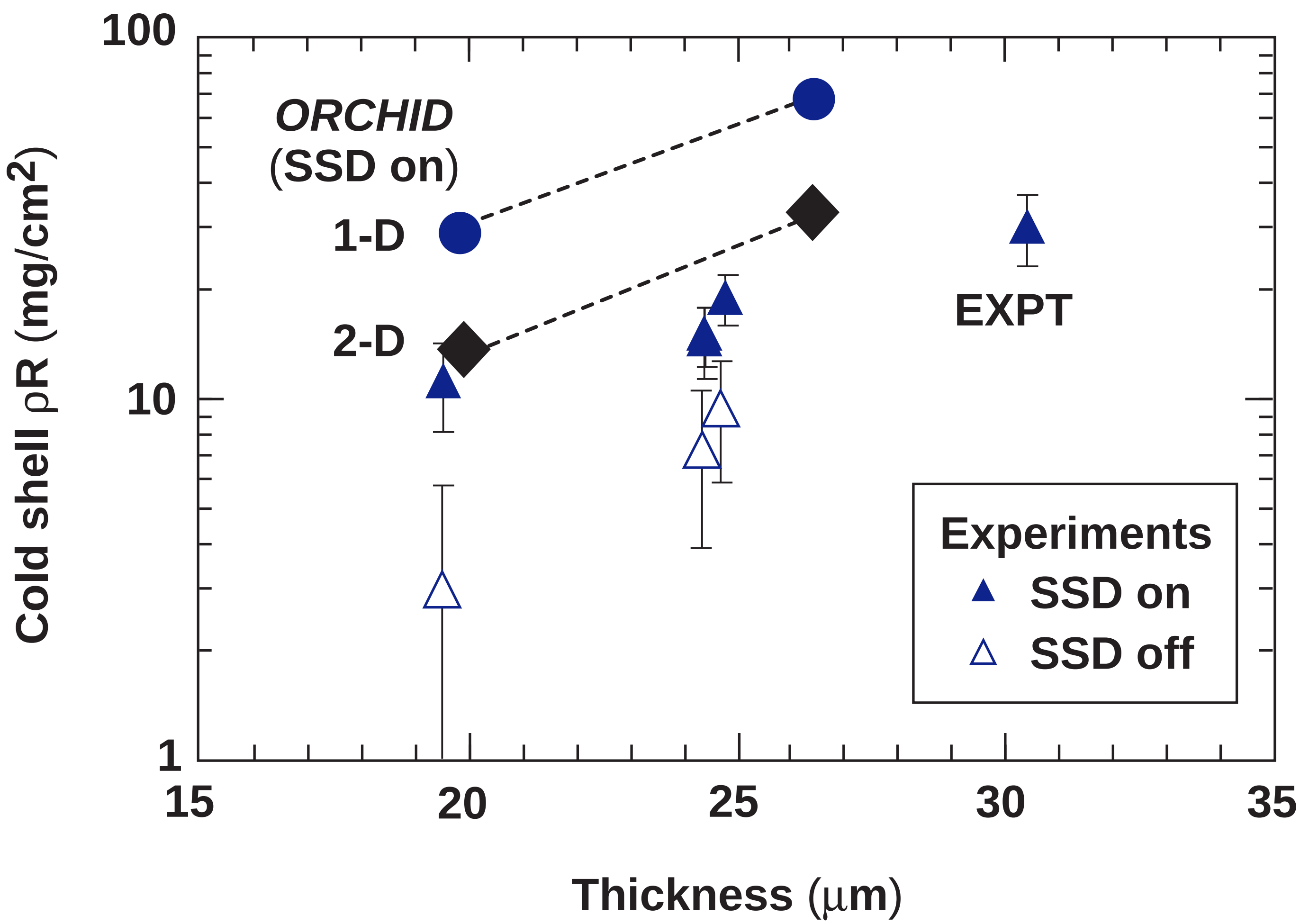
OMEGA shots 12531 and 12534
3-atm-DHe^3–filled, 25-μm-thick CH targets
25-kJ, 1-ns square pulse



E9436

2-D *ORCHID* simulations qualitatively agree with experimental measurements of cold shell ρR

Cold shell ρR versus shell thickness
3-atm-filled CH shells, 1-ns square pulse



E10167

Summary/Conclusions

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- **2-D simulations of single-beam nonuniformity effects can account for the performance of the outer region of the shell.**

- **Low l-mode contributions due to beam balance appear to limit the performance of the most-stable, low-convergence-ratio targets.**