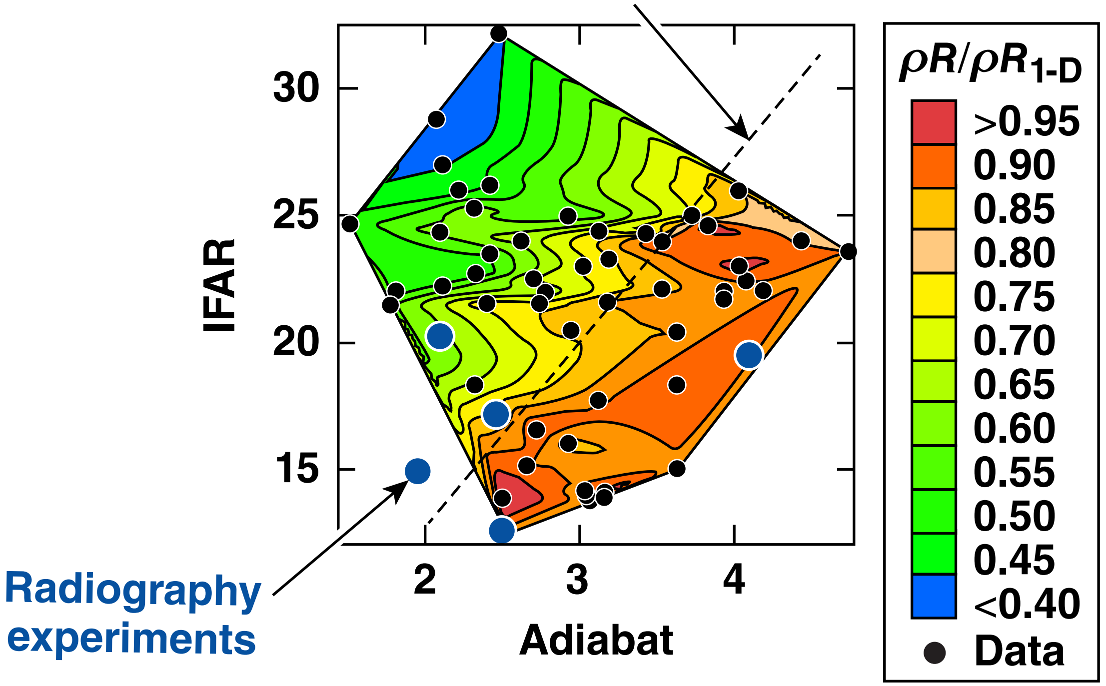
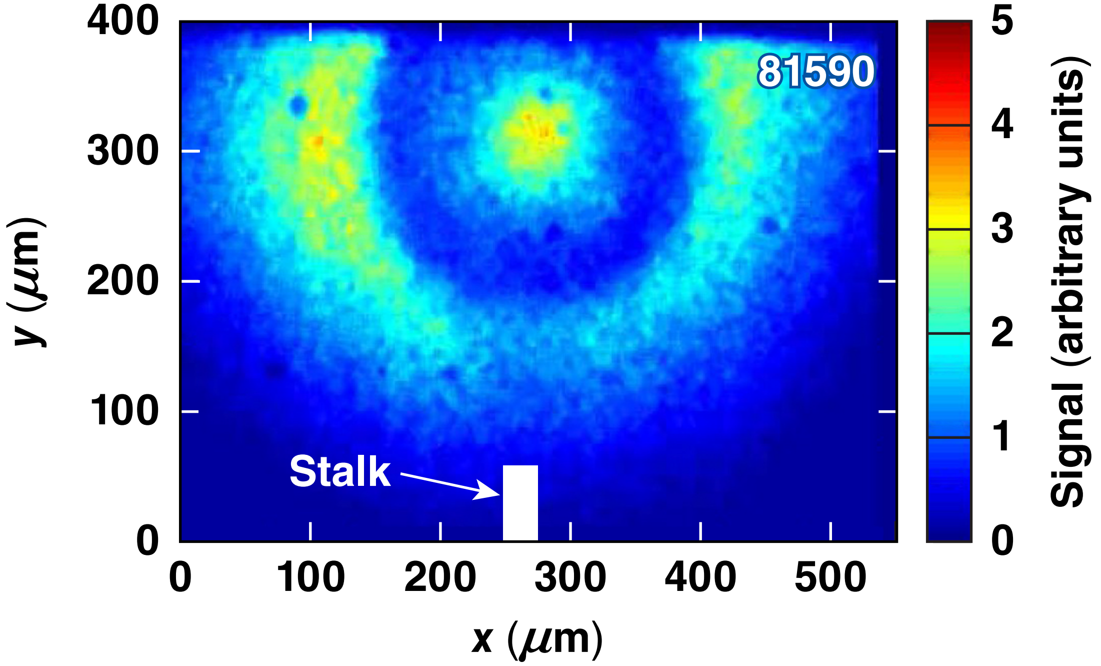
Investigating Small-Scale Mix in Direct-Drive Cryogenic DT Implosions with Radiography on OMEGA


Stability boundary $\mathrm{IFAR_s} = 20\ (\alpha/3)^{1.1}$


Experimental radiograph

ρR = areal density, IFAR = in-flight aspect ratio (shell radius/thickness)
Adiabat α = pressure/Fermi degenerate pressure

C. Stoeckl
University of Rochester
Laboratory for Laser Energetics

60th Annual Meeting of the
American Physical Society
Division of Plasma Physics
Portland, OR
5–9 November 2018

Summary

The onset of a mix signature in radiographs of DT cryo implosions is consistent with a stability boundary

- A stability boundary has been observed in cryogenic DT implosions, which can be parameterized by in-flight aspect ratio (IFAR) and adiabat α [$\text{IFAR}_\text{s} = 20\ (\alpha/3)^{1.1}$]*
- A crystal imager is used for short-pulse (20-ps), monochromatic x-ray radiography (1.865 keV) of 60-beam OMEGA DT cryogenic implosions**
- Mixing of carbon from the CH ablator material into the DT shell can be observed in the radiographs through increased absorption
- Mixing is observed in the radiographs only when the implosion design crosses the stability boundary

---

*V. N. Goncharov *et al.*, Phys. Plasmas 21, 056315 (2014).
**C. Stoeckl *et al.*, Rev. Sci. Instrum. 85, 11E501 (2014);
C. Stoeckl *et al.*, Phys. Plasmas 24, 056304 (2016).

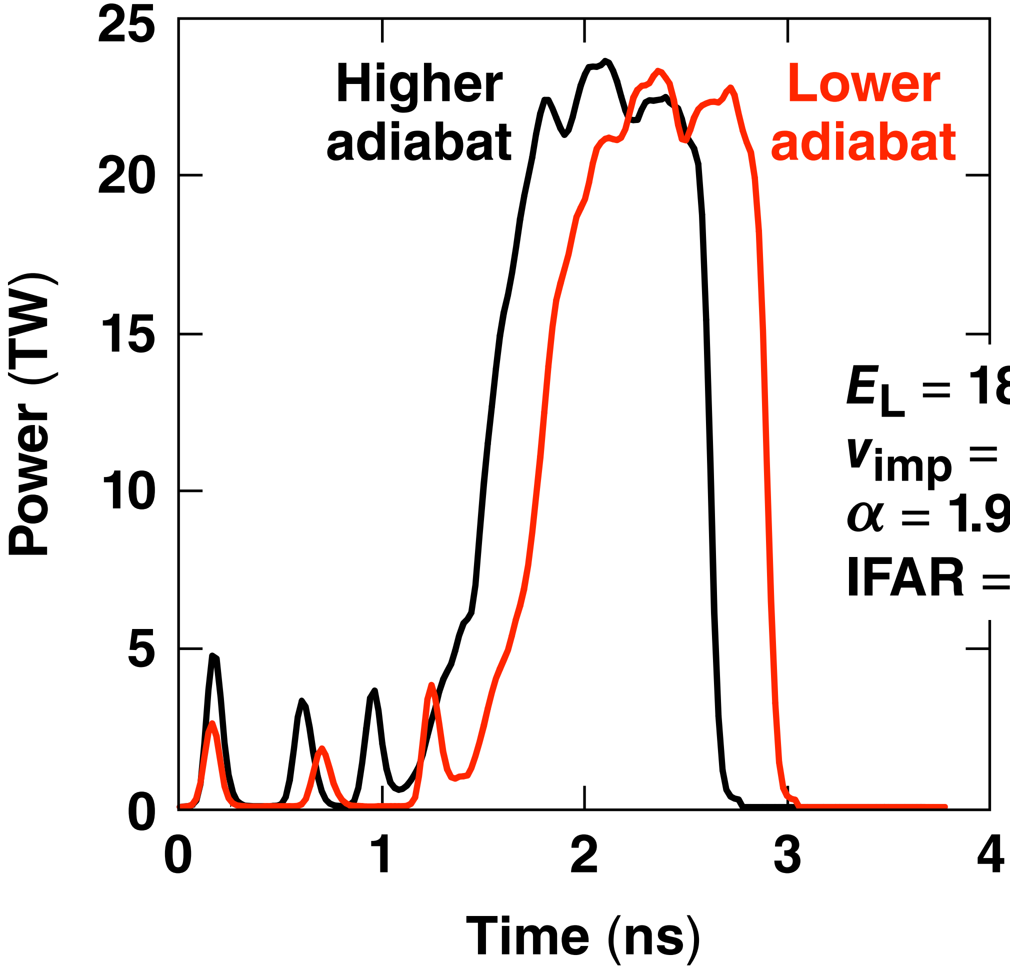
Collaborators

**T. J. B. Collins, R. Epstein, V. N. Goncharov, R. K. Jungquist, C. Mileham,
P. B. Radha, S. P. Regan, T. C. Sangster, and W. Theobald**

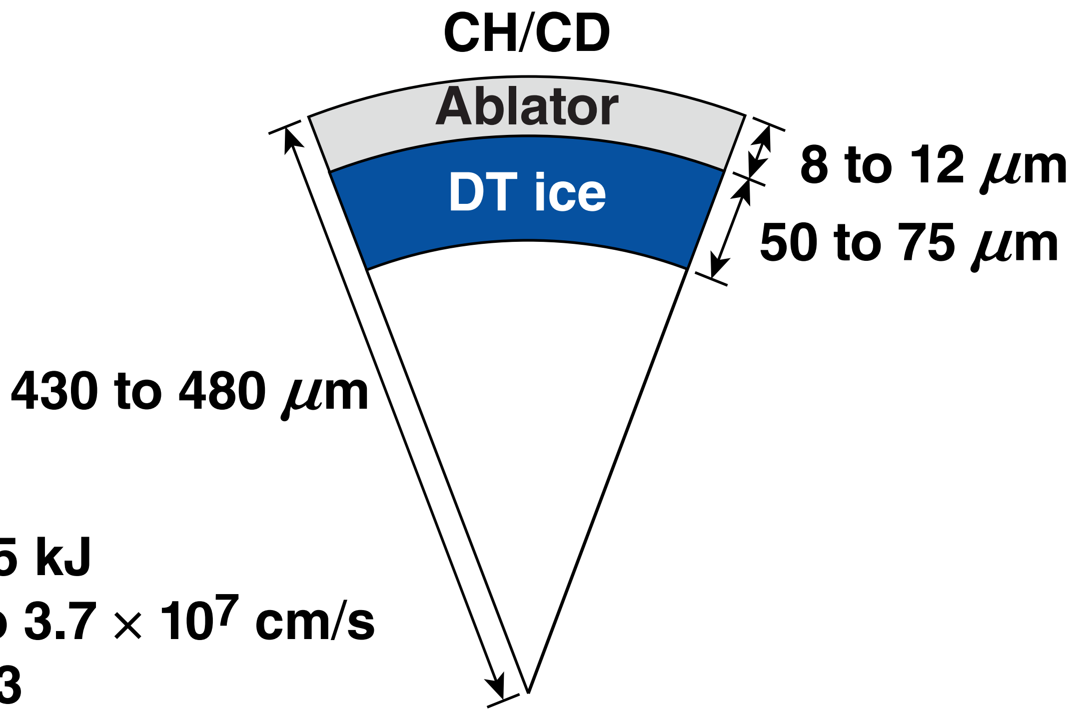
University of Rochester
Laboratory for Laser Energetics

The expected target performance is determined by the laser pulse shape and the target dimensions

Adiabat and IFAR are controlled by pulse shaping



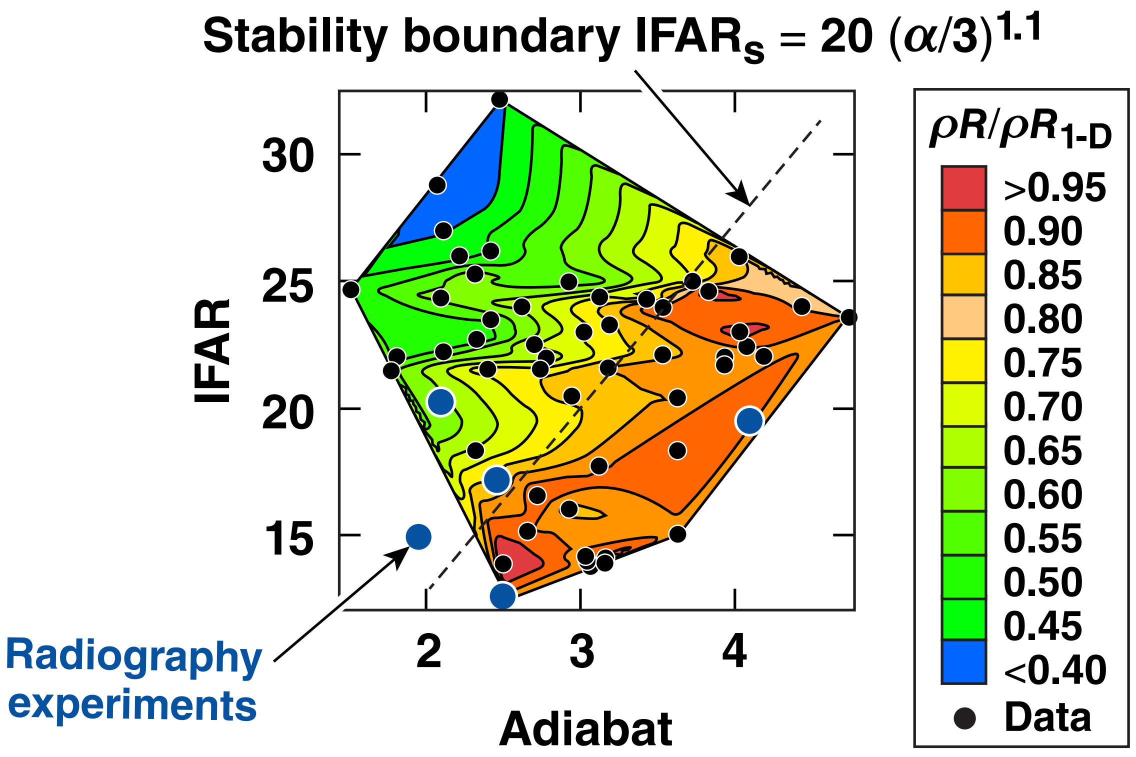
E_L = 18 to 25 kJ
v_{imp} = 2.4 to 3.7 × 10^7 cm/s
α = 1.9 to 4.3
IFAR = 10 to 20



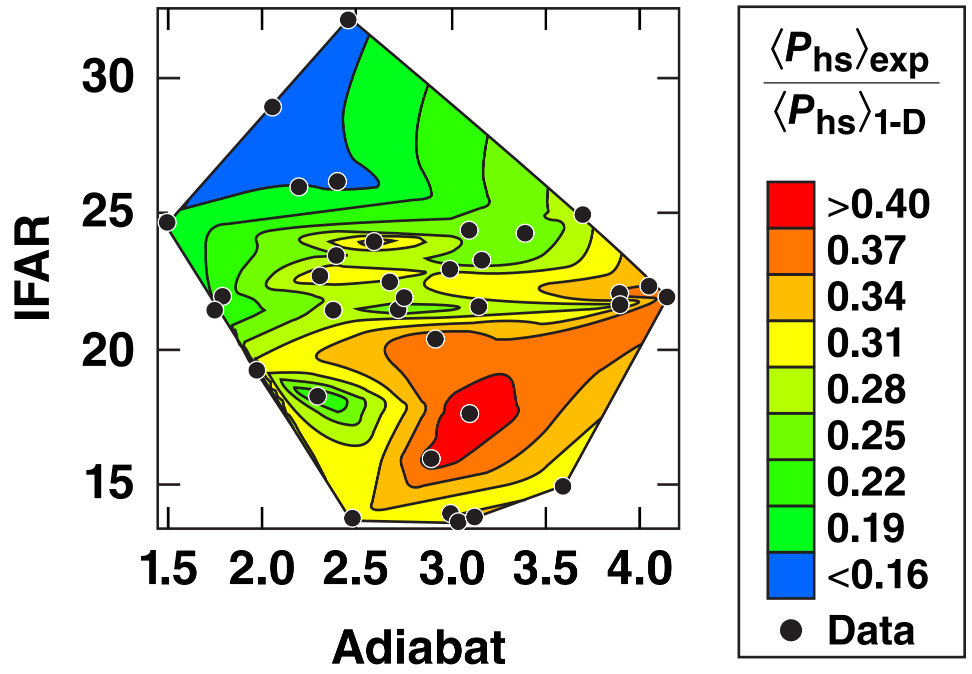
- Adiabat $\alpha = P/P_{\text{Fermi}}$
- v_{imp} = implosion velocity
- E_L = laser energy
- IFAR = shell radius/shell thickness

TC10248v

Experimental target performance is a strong function of adiabat and IFAR


Stability boundary $\text{IFAR}_s = 20\,(\alpha/3)^{1.1}$

Radiography experiments



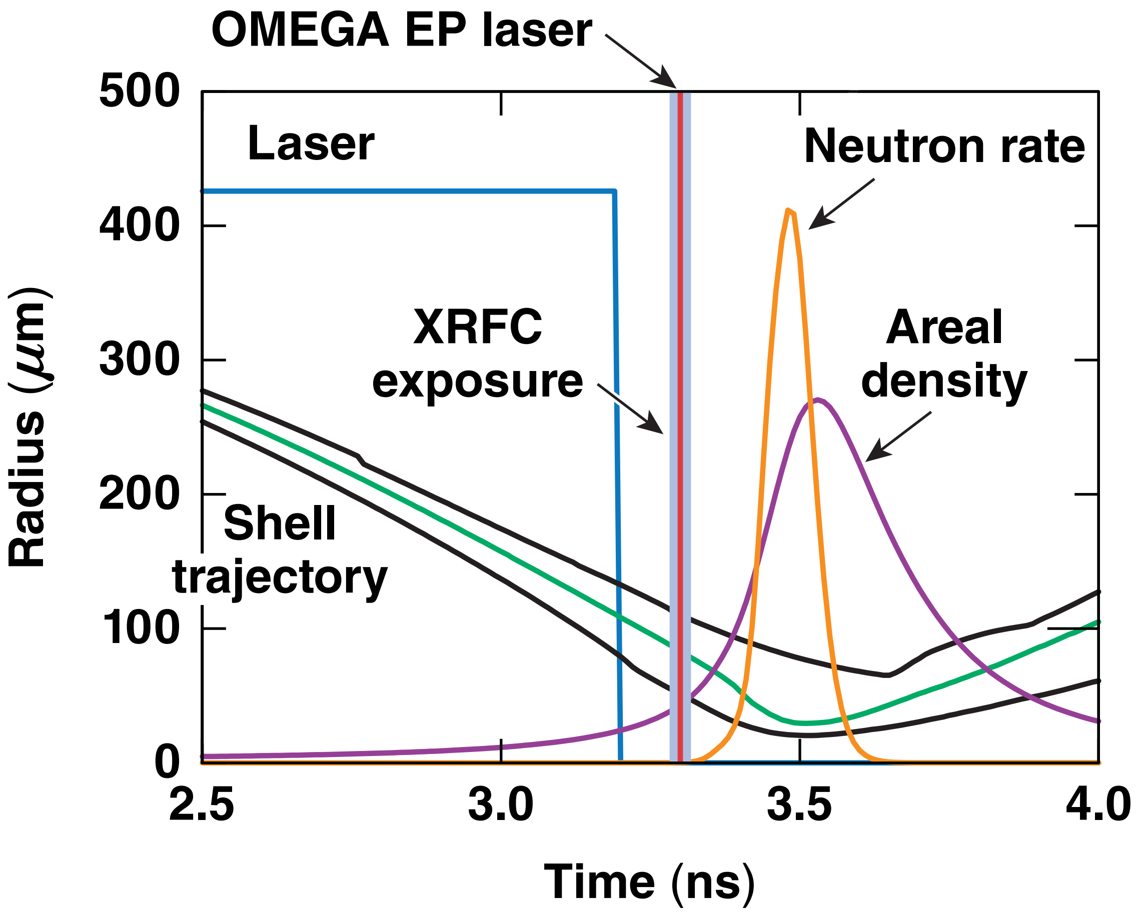
- The ratio of the measured areal density ρR and average hot-spot pressure $\langle P_{hs}\rangle$ over the 1-D simulated values are used as a performance metric

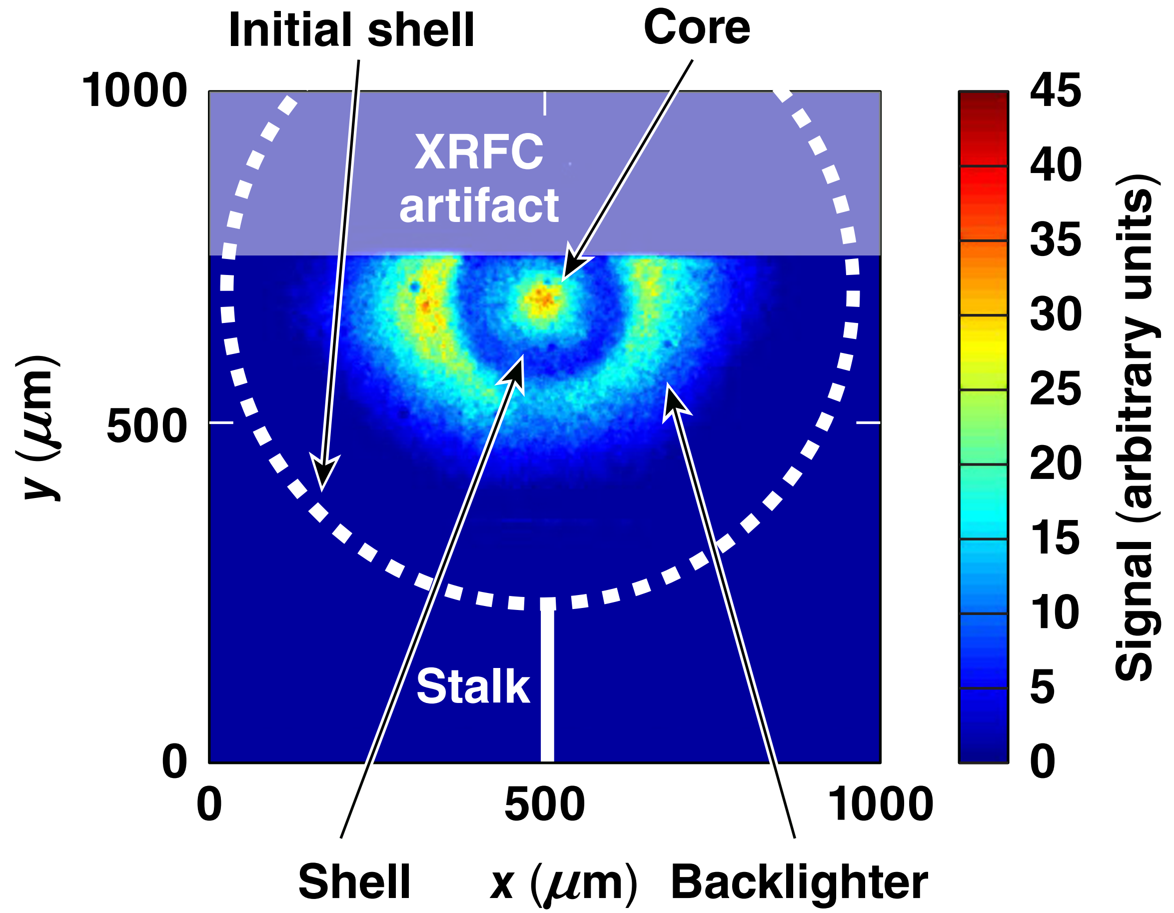
- The hot-spot pressure can be inferred from the observable quantities: neutron yield, ion temperature, and neutron rate

---

*V. N. Goncharov *et al.*, Phys. Plasmas 21, 056315 (2014).

Backlit images of the compressed DT shell were taken at a convergence of ~7 before peak neutron production

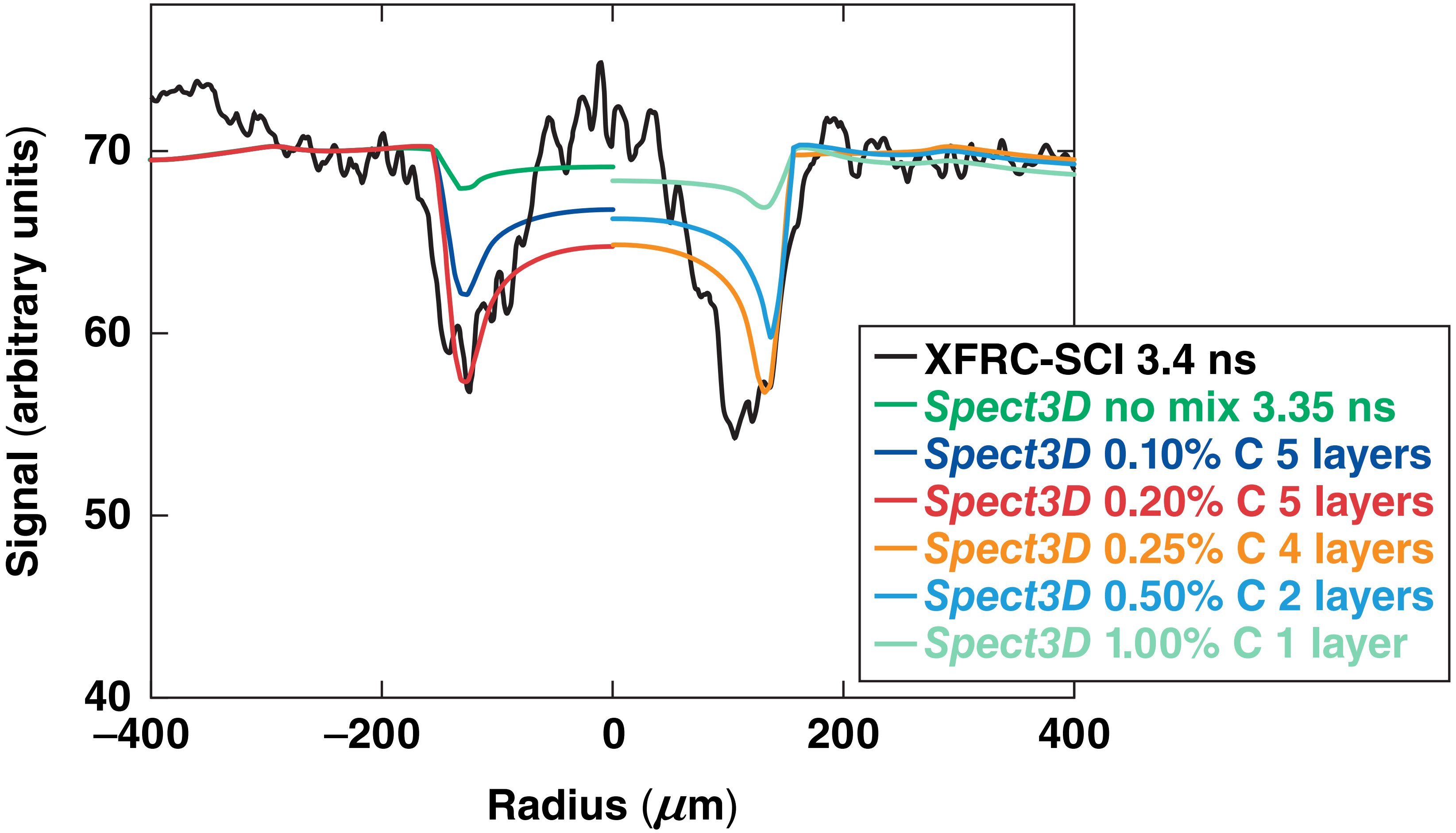




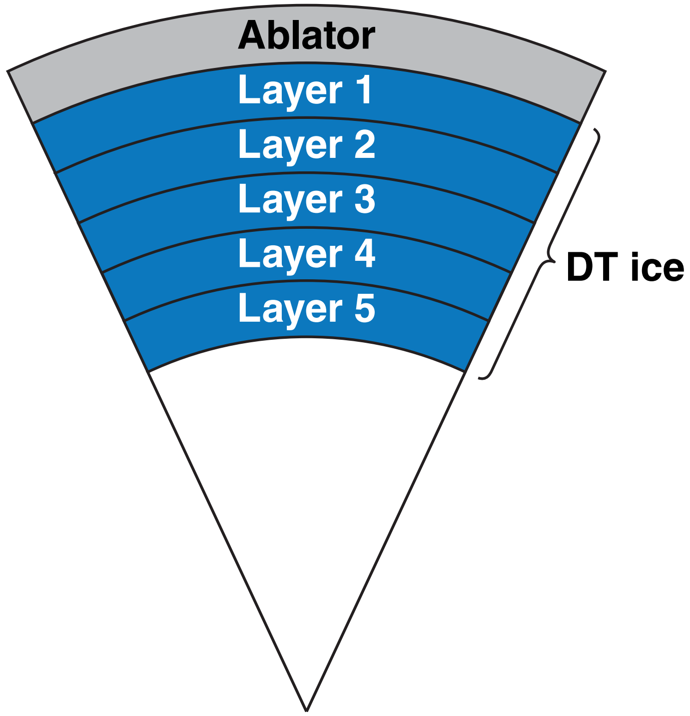
- **The effects of the deceleration Rayleigh–Taylor instability could distort the density profile of the shell closer to peak neutron production**

XRFC: x-ray framing camera

Simulations assuming the mixing of carbon into the DT shell can reproduce the measured absorption



- Exposure time of 200 ps, CR = 4
- DT (60 μm) CH (8 μm), 860-μm diam, offset ~25 μm
- α ~ 2.5, IFAR ~ 17; YOC = 7%, ρR/clean = 78%

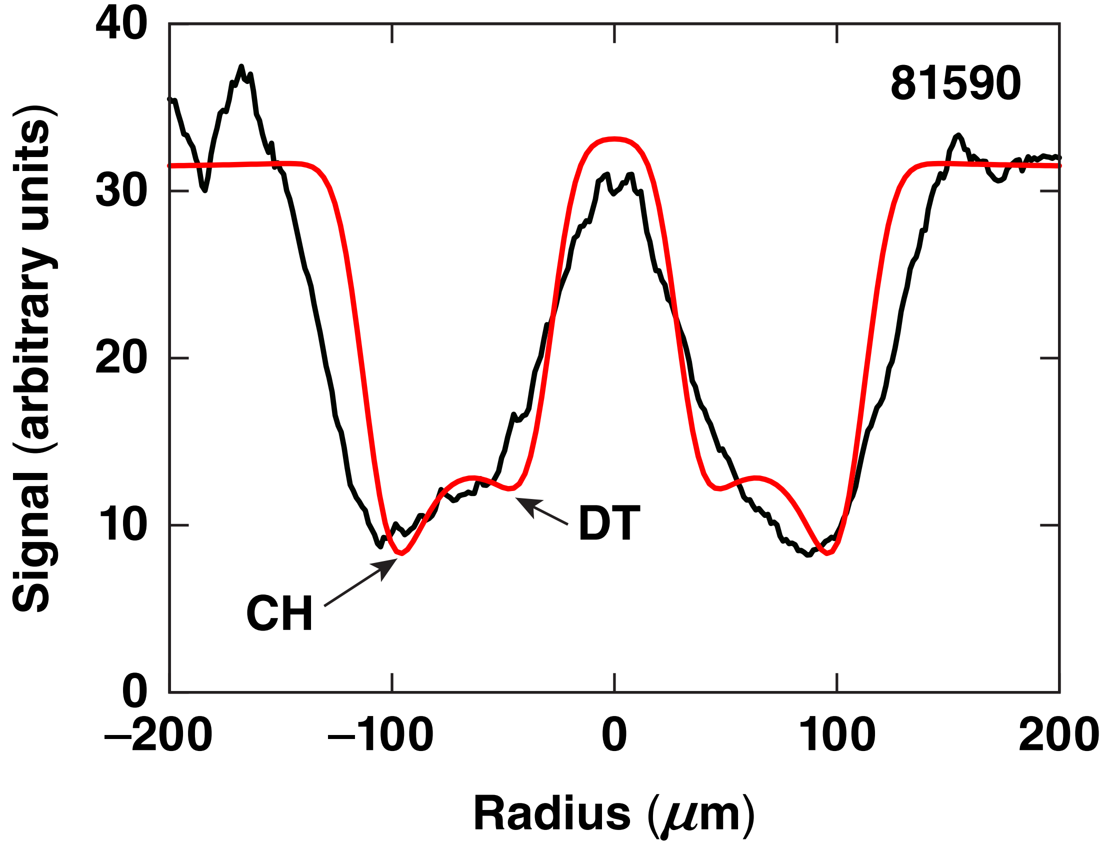


The depth of the mixing can be inferred by separating the DT ice into layers in the *LILAC* simulations

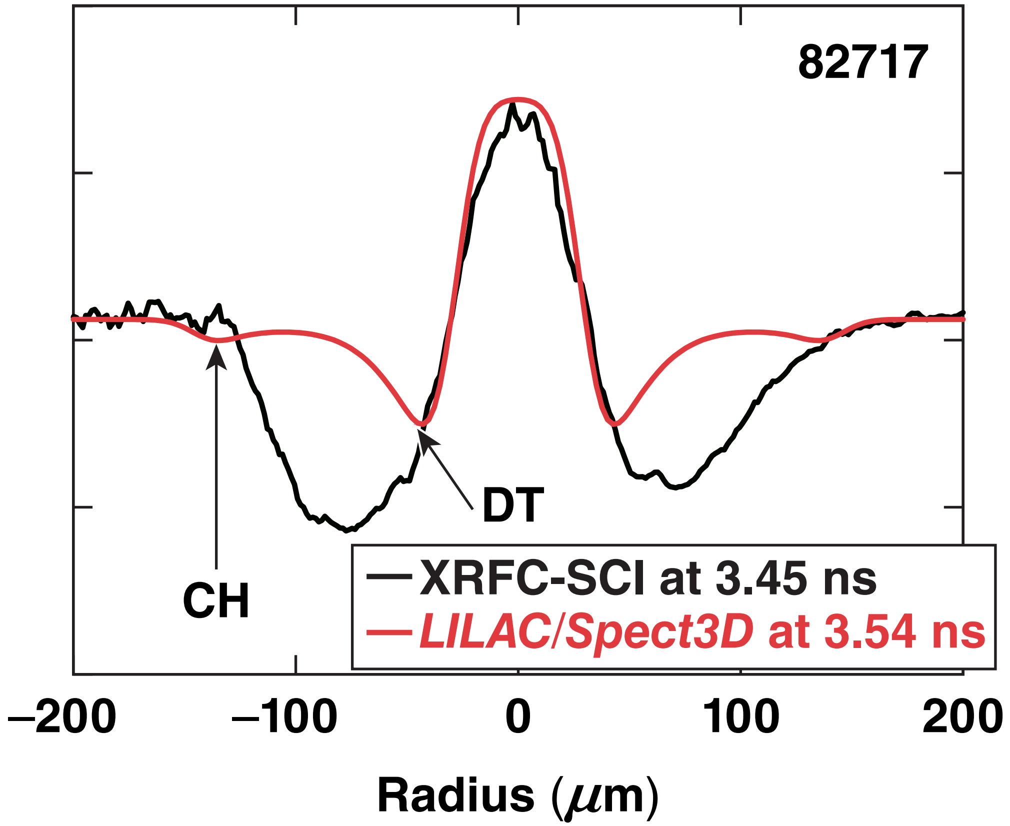
---

CR: convergence ratio

Small changes in the implosion design can lead to significant differences in the mix signature



- DT (60 μm) CH (12 μm) 888-μm diam
- $\alpha \sim 2.5$, IFAR ~ 10; YOC = 20%, ρR/clean = 78%
- $\text{IFAR}_s = 16$

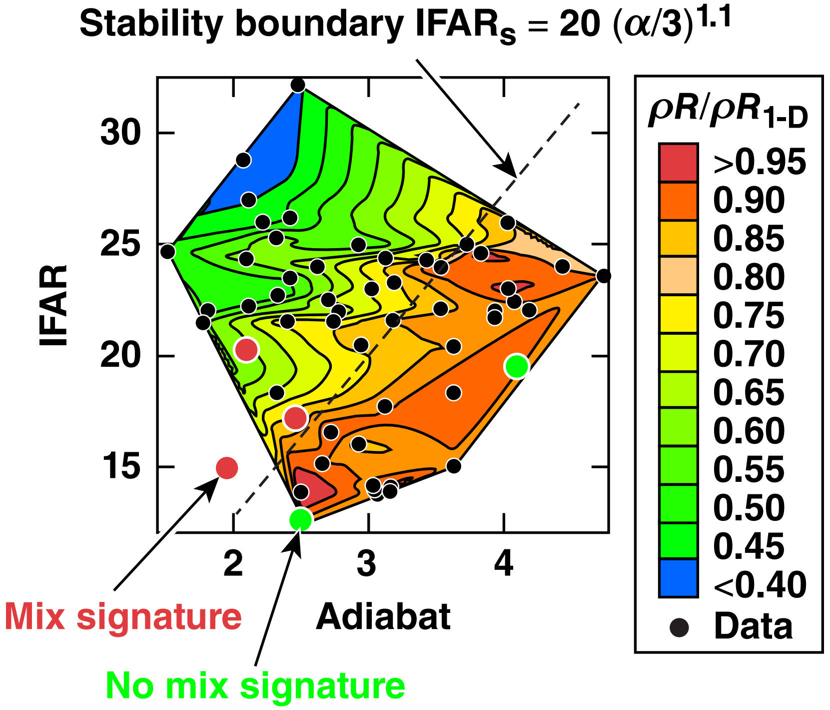


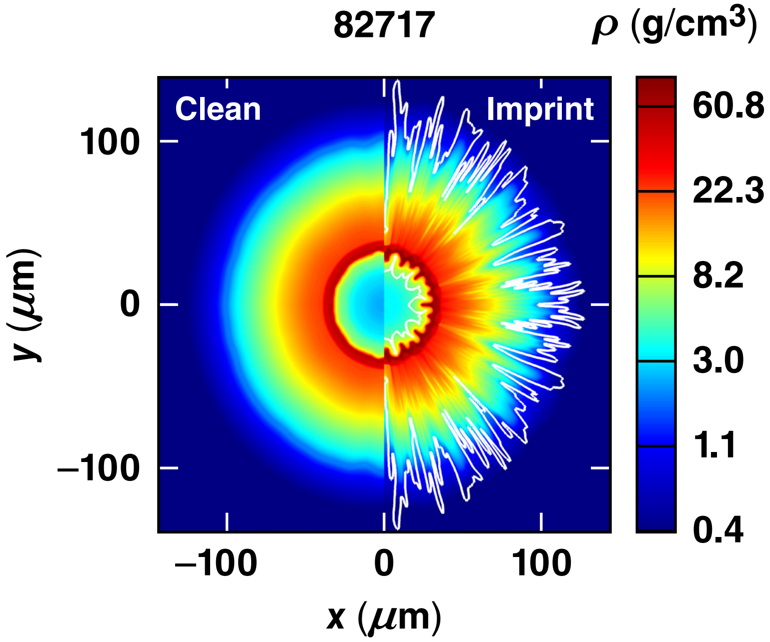
- DT (60 μm) CH (11 μm) 960-μm diam
- $\alpha \sim 2$, IFAR ~ 15; YOC = 8%, ρR/clean = 41%
- $\text{IFAR}_s = 13$

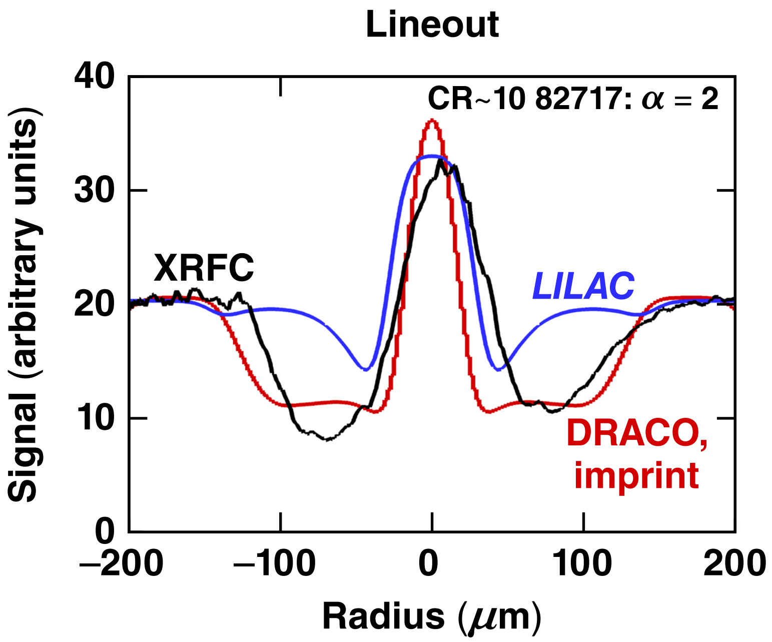
SCI: spherical crystal imager
YOC: yield over clean

E27873

A trend for mixing consistent with the empirical scaling with IFAR and adiabat can be seen the experimental data







- Multidimensional simulations* indicate that the mix is caused by laser imprint
- Experiments with varying levels of laser smoothing are planned to validate the code

---

*T. J. B. Collins *et al.*, U04.00014, this conference.

Summary/Conclusions

The onset of a mix signature in radiographs of DT cryo implosions is consistent with a stability boundary

- A stability boundary has been observed in cryogenic DT implosions, which can be parameterized by in-flight aspect ratio (IFAR) and adiabat α [$\text{IFAR}_\text{s} = 20\ (\alpha/3)^{1.1}$]*
- A crystal imager is used for short-pulse (20-ps), monochromatic x-ray radiography (1.865 keV) of 60-beam OMEGA DT cryogenic implosions**
- Mixing of carbon from the CH ablator material into the DT shell can be observed in the radiographs through increased absorption
- Mixing is observed in the radiographs only when the implosion design crosses the stability boundary

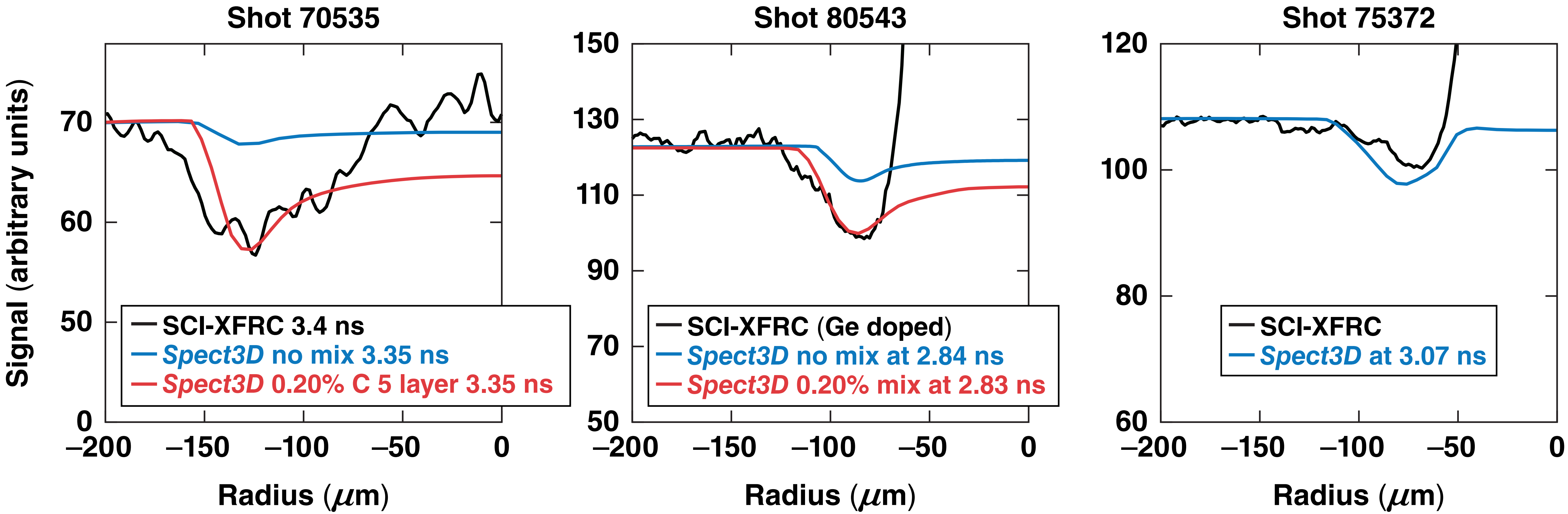
Significant improvements to the radiography setup are in progress. The backlighter brightness has been increased by more than 5× and a path to improve the spatial resolution has been identified.

---

*V. N. Goncharov *et al.*, Phys. Plasmas 21, 056315 (2014).
**C. Stoeckl *et al.*, Rev. Sci. Instrum. 85, 11E501 (2014);
C. Stoeckl *et al.*, Phys. Plasmas 24, 056304 (2016).
†T. J. Collins *et al.*, UO4.00014, this conference

Backup

A trend for mixing can be seen in the experimental data that is consistent with the empirical scaling with IFAR and the adiabat



- $\alpha \sim 2.5$, IFAR = 17
- YOC = 7%, ρR/clean = 92%
- $\text{IFAR}_\text{s} = 16$

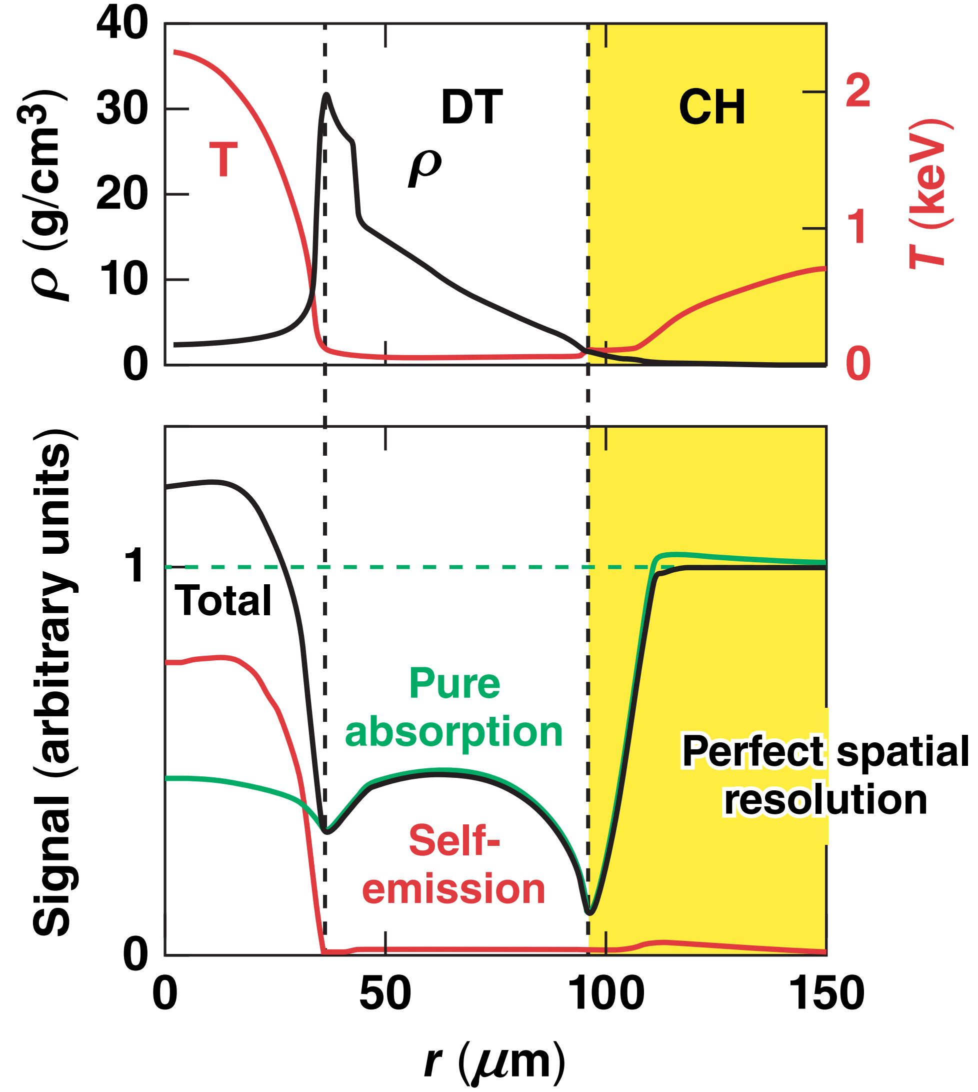
- $\alpha \sim 2.0$, IFAR = 20
- YOC = 9%, ρR/clean = 54%
- $\text{IFAR}_\text{s} = 14$

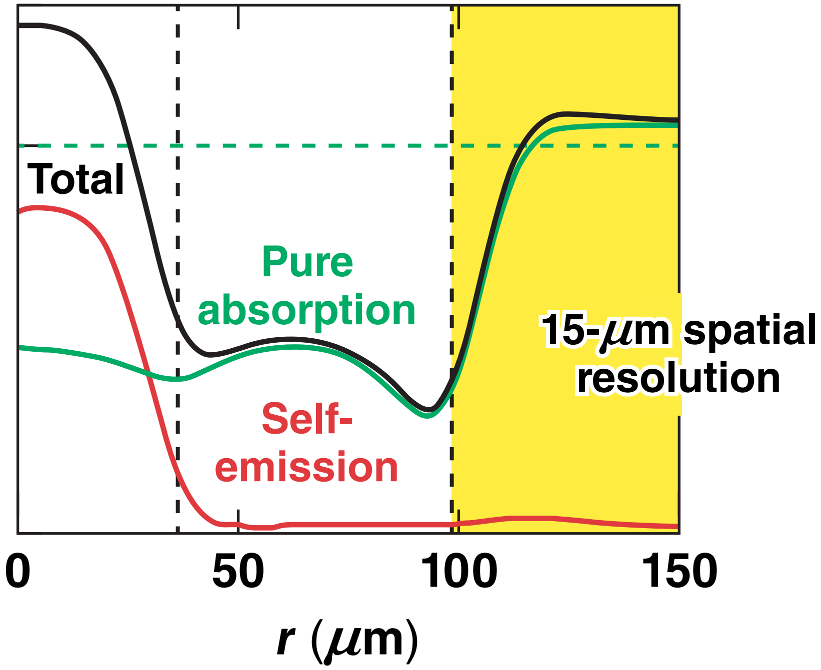
- $\alpha \sim 4.0$, IFAR = 20
- YOC = 18%, ρR/clean = 90%
- $\text{IFAR}_\text{s} = 27$

E25631b

Simulations show that a small amount of carbon causes significant absorption in the images

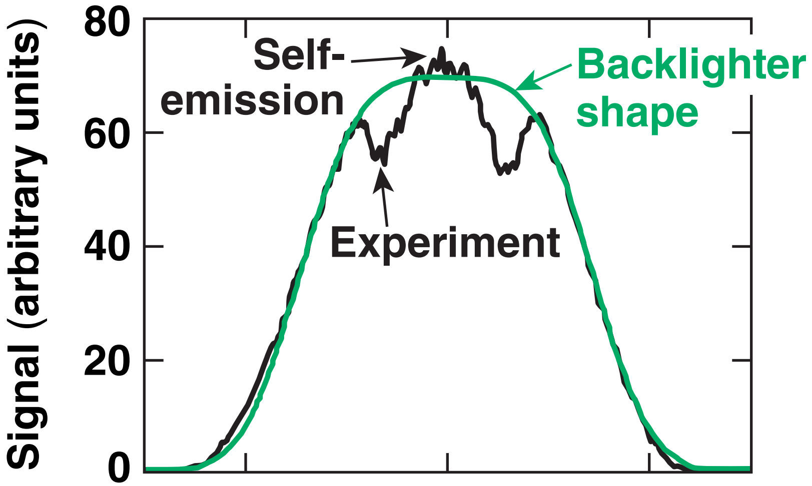
LILAC/*Spect3D* profile and image at CR = 13



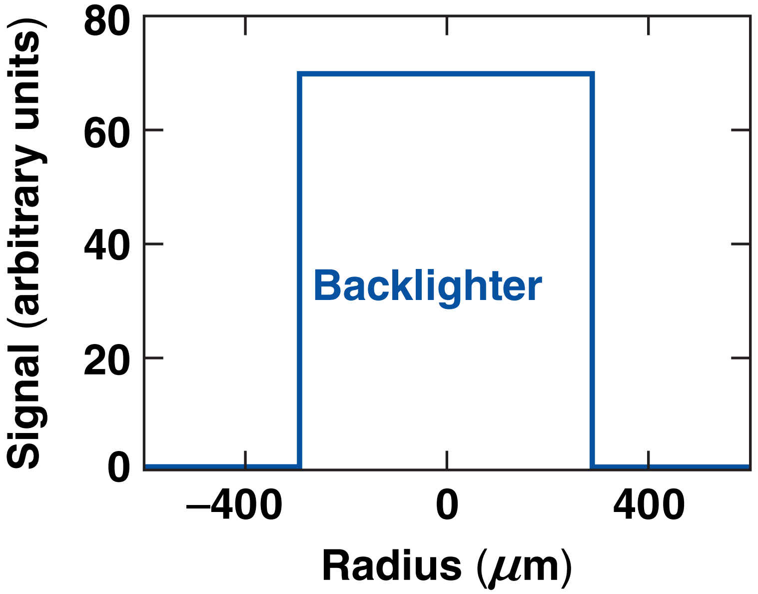


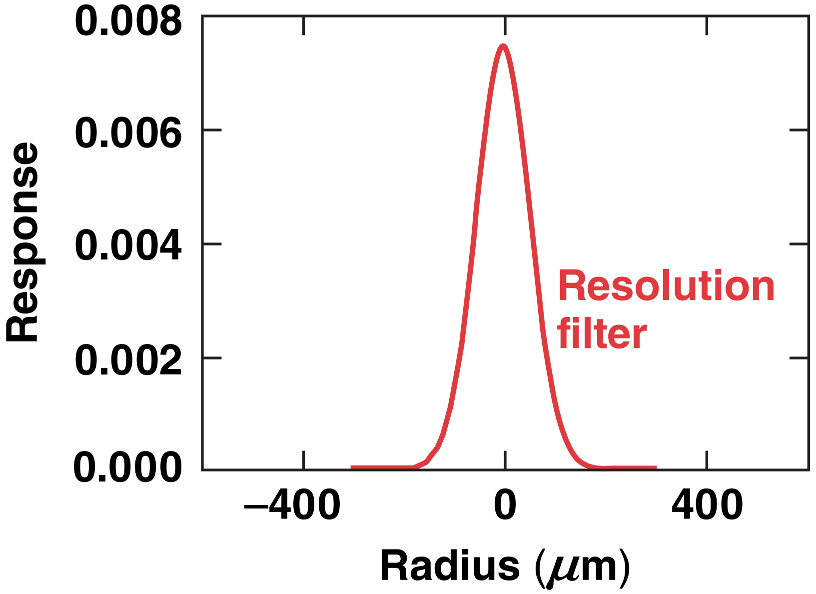
- 25-kJ low-adiabat pulses
- 20-ps exposure, 20-ps backlighter
- ~200-eV blackbody-equivalent backlighter brightness

The lineouts of the backlit images from the crystal imager must be corrected for the backlighter shape

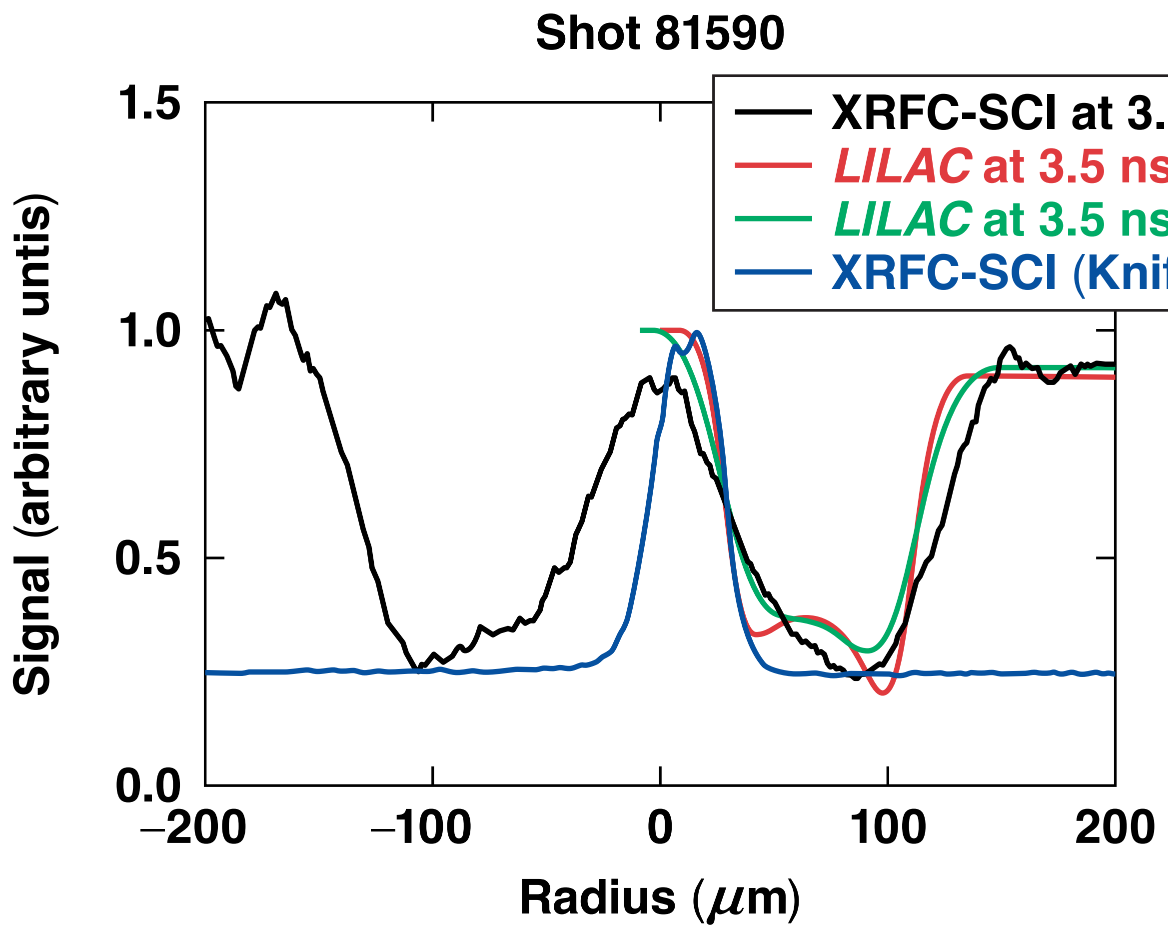


- The backlighter is assumed to be uniform
- It is convolved with a Gaussian representing the geometric resolution of the imager
- The width and amplitude of the backlighter is adjusted to match the signal





The spatial resolution of the imager is taken into account in the post-processing with *Spect3D*



- The resolution measured with a knife-edge target on OMEGA is consistent with the ~15 μm used in *Spect3D*