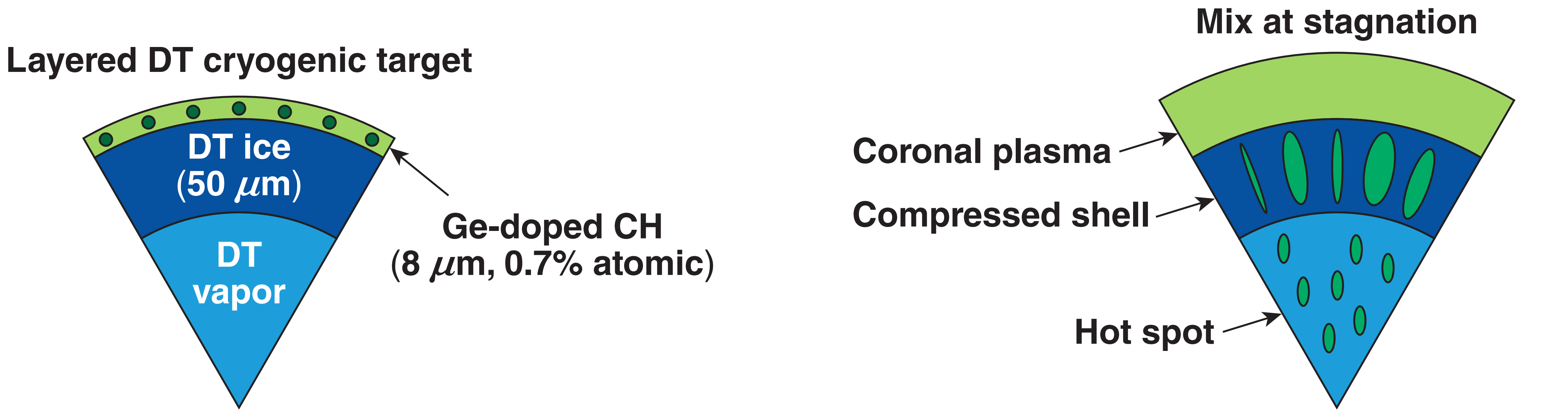
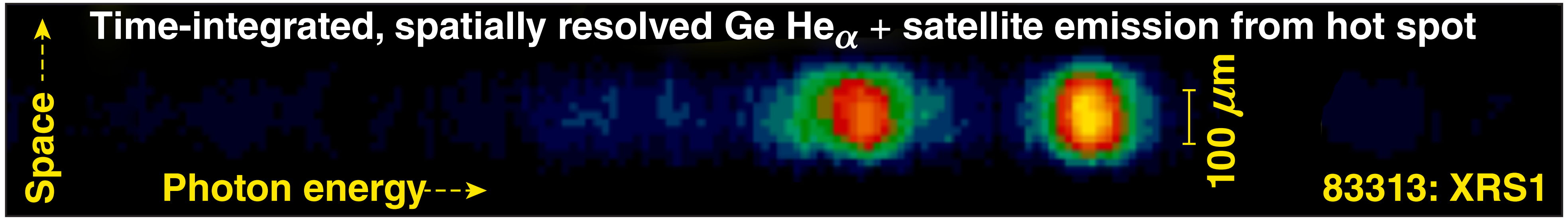
Hydrodynamic Mixing of Ablator Material into the Compressed Fuel and Hot Spot of Direct-Drive DT Cryogenic Implosions





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Summary

Mixing of ablator material into the hot spot of direct-drive DT cryogenic implosions is observed using x-ray spectroscopy*

- The ablation-front Rayleigh–Taylor hydrodynamic instability is seeded by laser imprint** and target-surface debris, and the mounting stalk mixes ablator material into the hot spot*,†
  - hot-spot mix increases radiative cooling of the hot spot*
- Trace amounts of Ge dopant in the CH ablator are used to track the hydrodynamic mixing
  - preliminary analysis shows the inferred hot-spot mix mass is below 100 ng

Future experiments will reduce the effects of radiative preheat from the high-Z dopant and identify the sources of hot-spot mix.

*B. A. Hammel *et al*., Phys. Plasmas 18, 056310 (2011);
S. P. Regan *et al*., Phys. Plasmas 19, 056307 (2012); S. P. Regan *et al*., Phys. Rev. Lett. 111, 045001 (2013).
**S. X. Hu *et al*., Phys. Plasmas 17, 102706 (2010).
†I. V. Igumenshchev *et al*., Phys. Plasmas 20, 082703 (2013).

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Collaborators

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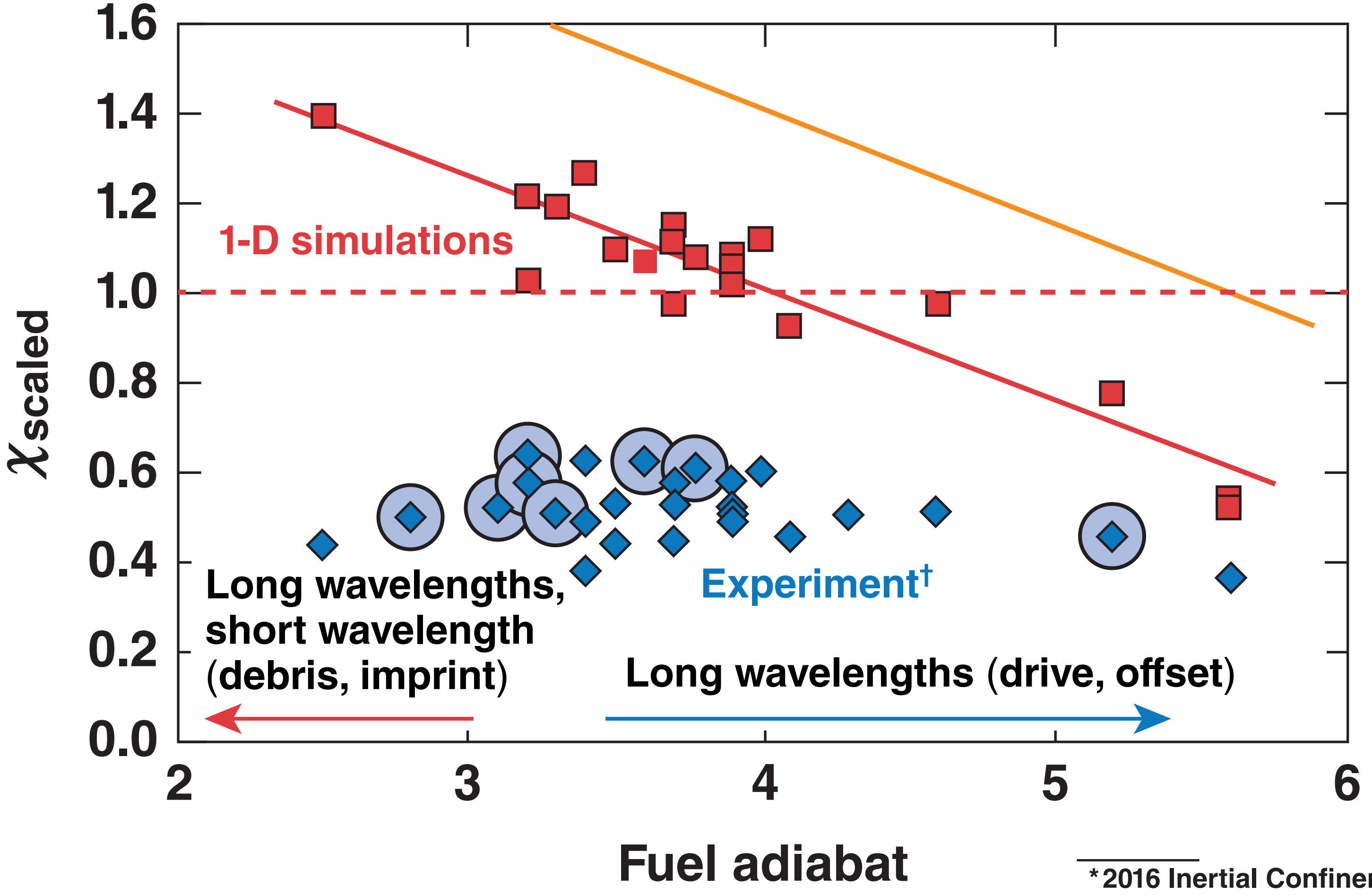
General Atomics

Short-wavelength perturbations from microscopic debris on target surface, the stalk, and laser imprint limit the performance of low-adiabat implosions*

Generalized Lawson criterion**

$$\chi_{\text{scaled}} = P\tau / P\tau_{\text{ign}} = (\rho R_{\text{no}\,\alpha})^{0.61} \left(0.12\, Y^{16}_{\text{no}\,\alpha} \big/ M^{\text{stag}}_{\text{DT}}\right)^{0.34} \left(E^{\text{NIF}}_{\text{laser}} \big/ E^{\text{OMEGA}}_{\text{laser}}\right)^{0.35}$$



Shot with inferred $P_{\text{hs}} > 50$ Gbar

Fuel adiabat
$\alpha = P/P_{\text{Fermi}}$

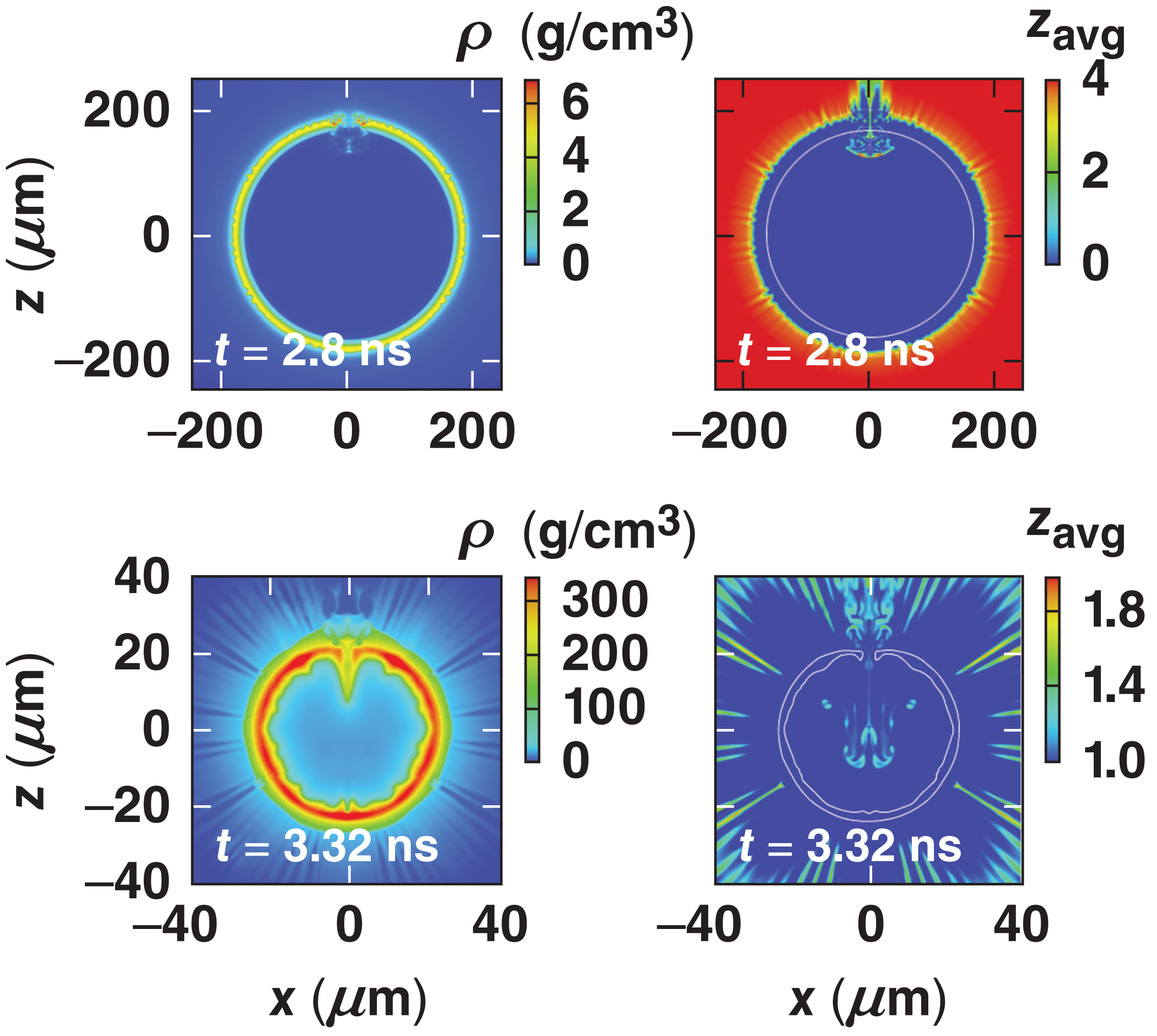
This work studies the mixing from short-wavelength perturbations for a range of fuel adiabats from 2.5 to 7.

E25536b

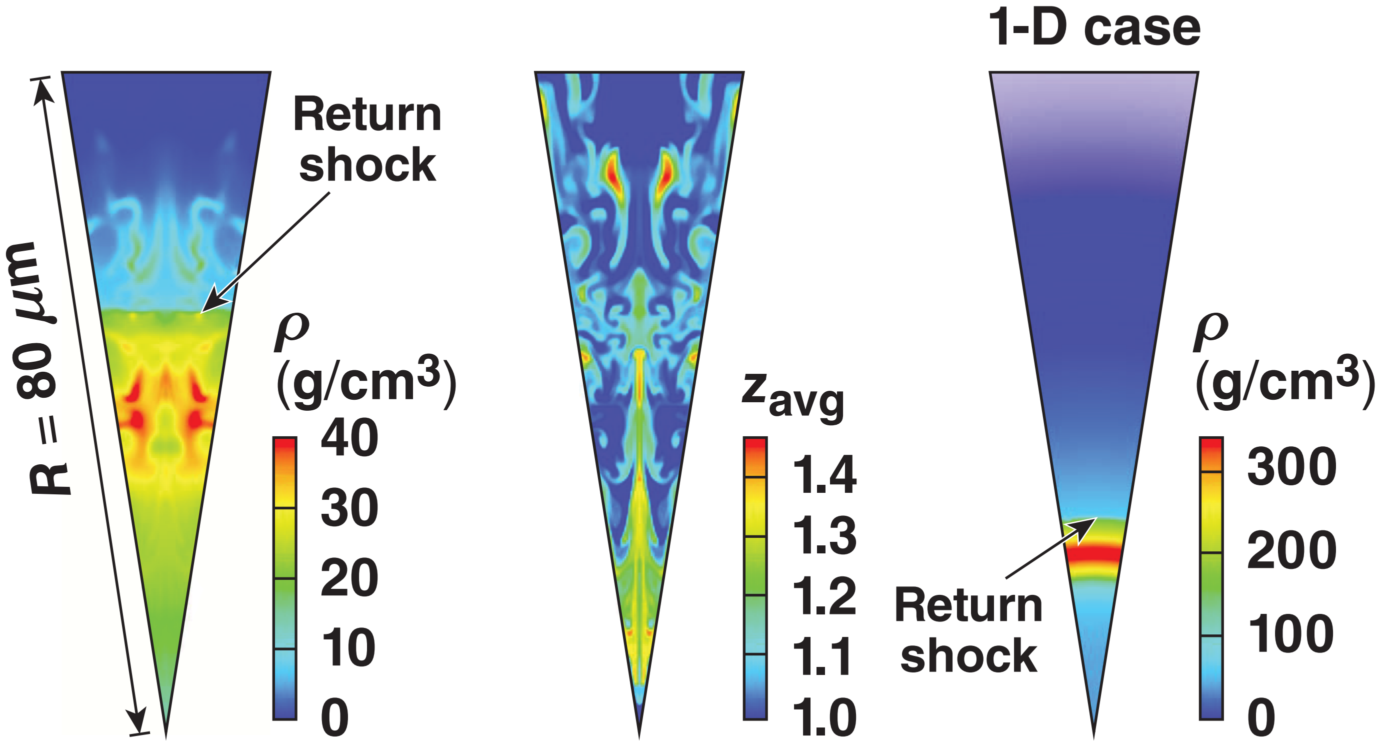
*2016 Inertial Confinement Fusion Program Framework, Office of Science and National Nuclear Security Administration, U.S. Department of Energy, Washington, DC, Report DOE/NA-0044 (2016).
**R. Betti *et al*., Phys. Rev. Lett. 114, 255003 (2015); A. Bose *et al*., Phys. Rev. Lett. E 94, 011201(R) (2016).
†S. P. Regan *et al*., Phys. Rev. Lett. 117, 025001 (2016).

Mix seeded by single or multiple surface defects have been simulated with 2-D *DRACO* hydrodynamics code*

Single-defect simulation



Multi-defect simulation



The ablation-front instability causes the ablator material to be mixed into the compressed fuel and hot spot.

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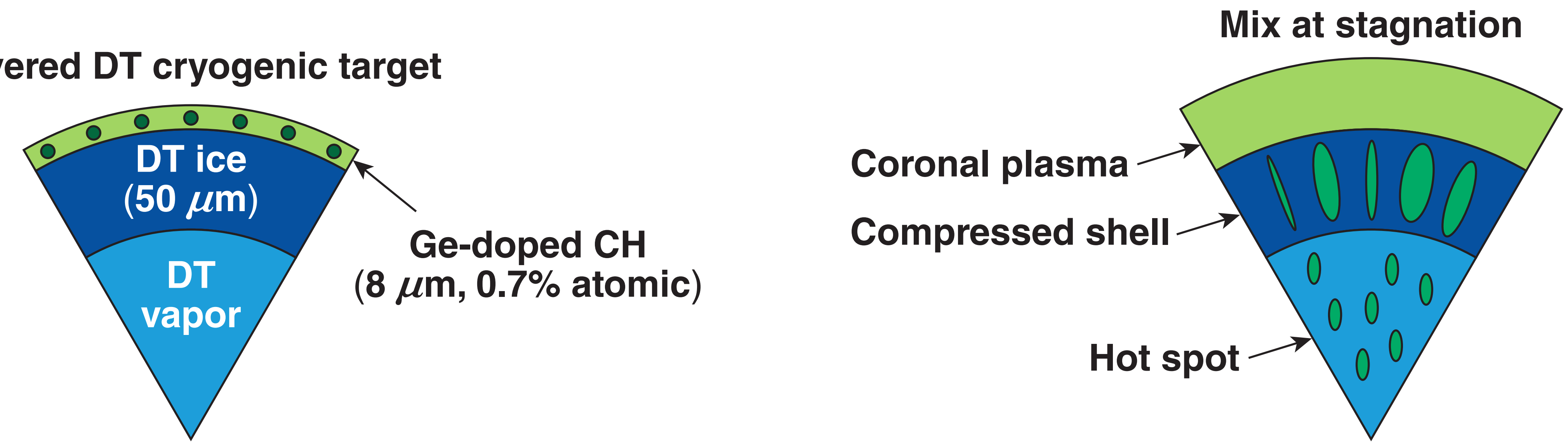
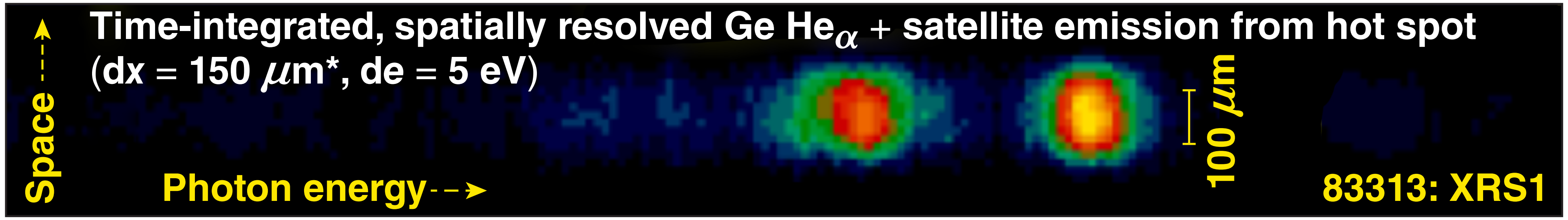
*I. V. Igumenshchev *et al.*, Phys. Plasmas 20, 082703 (2013).

Trace amounts of Ge in the plastic ablator were used to track the hydrodynamic mixing of the ablator to the compressed DT shell and the hot spot





If Ge reaches the hot spot, it will emit K-shell emission.

*Similar spectrum recorded on same shot with dx = 40 μm and de = 5 eV

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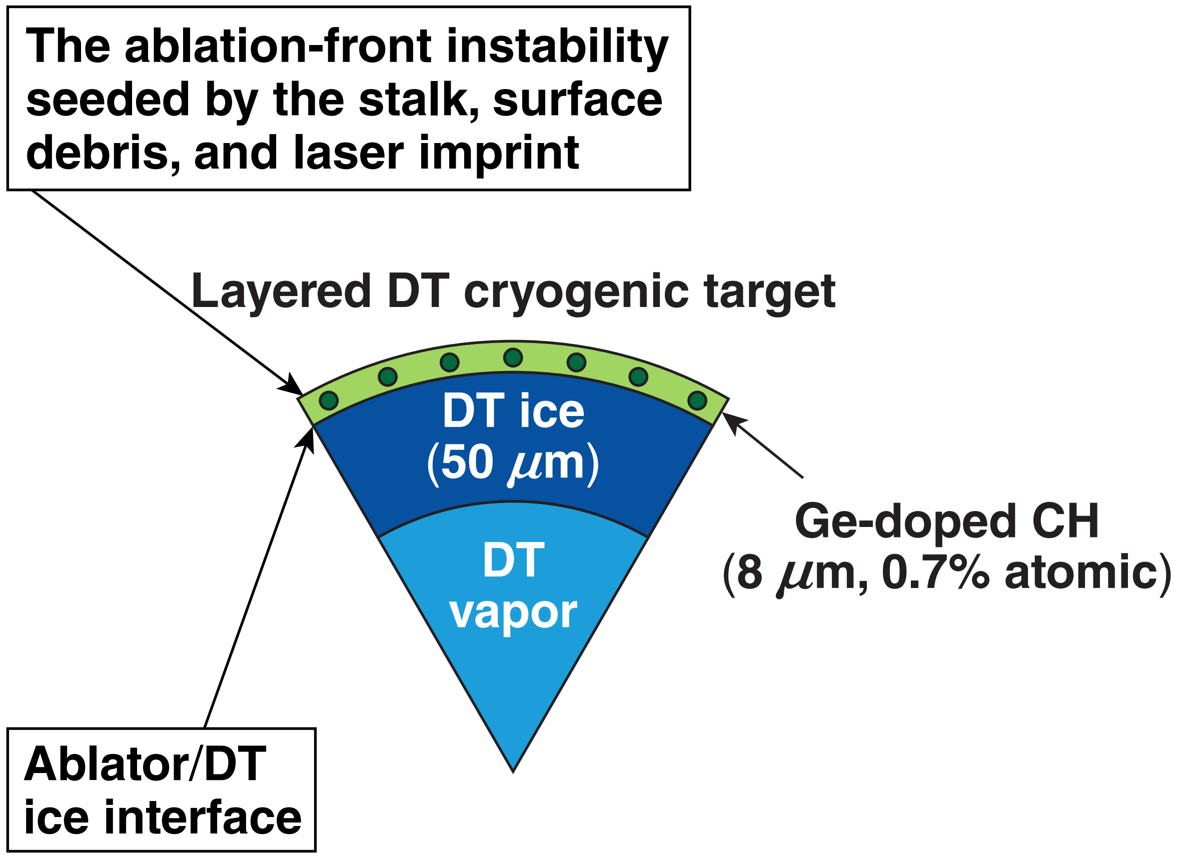
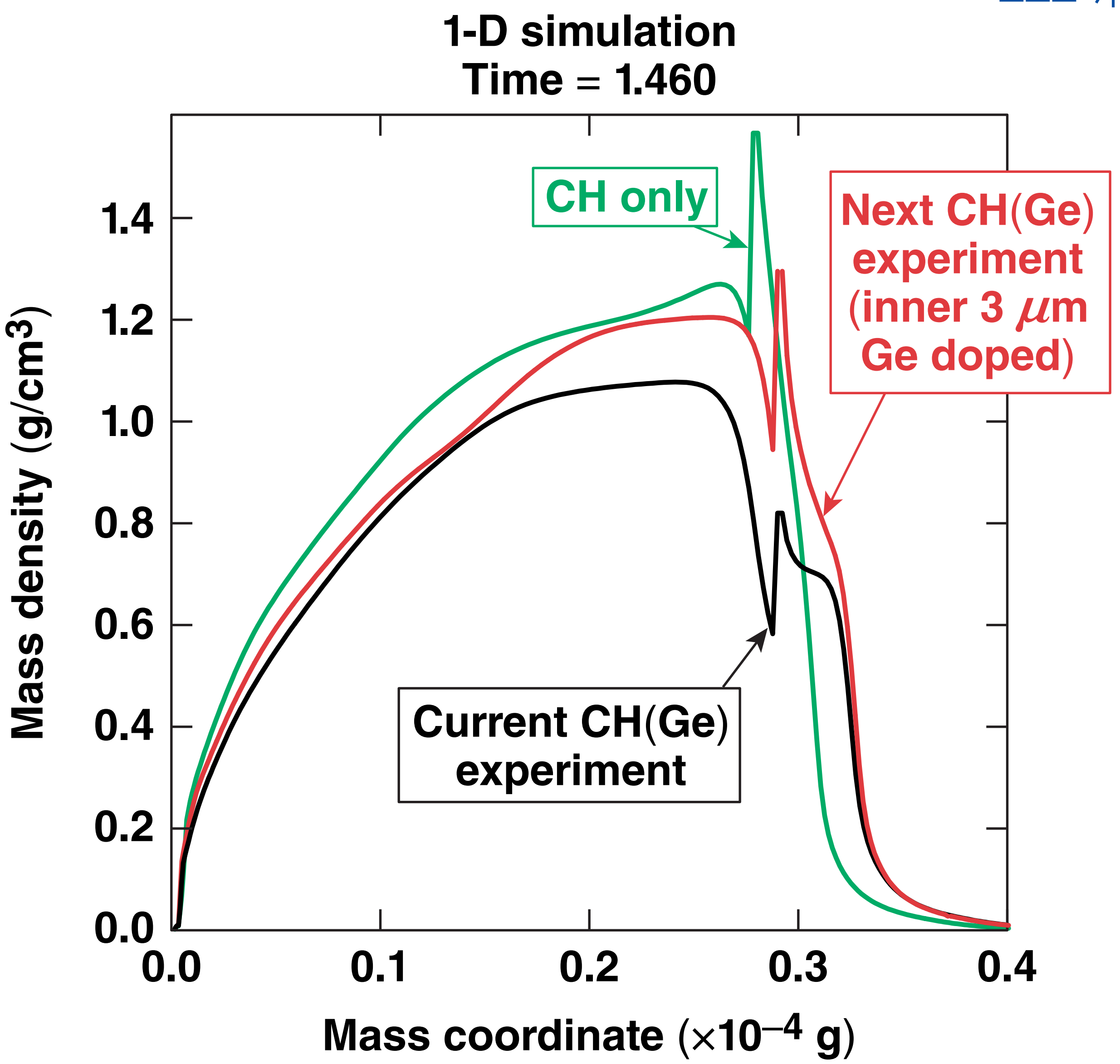
The ablator/DT ice interface could be stabilized by varying the radial distribution of the Ge-dopant in the CH ablator





The goal is to make the Ge-doped design a surrogate for the undoped one.

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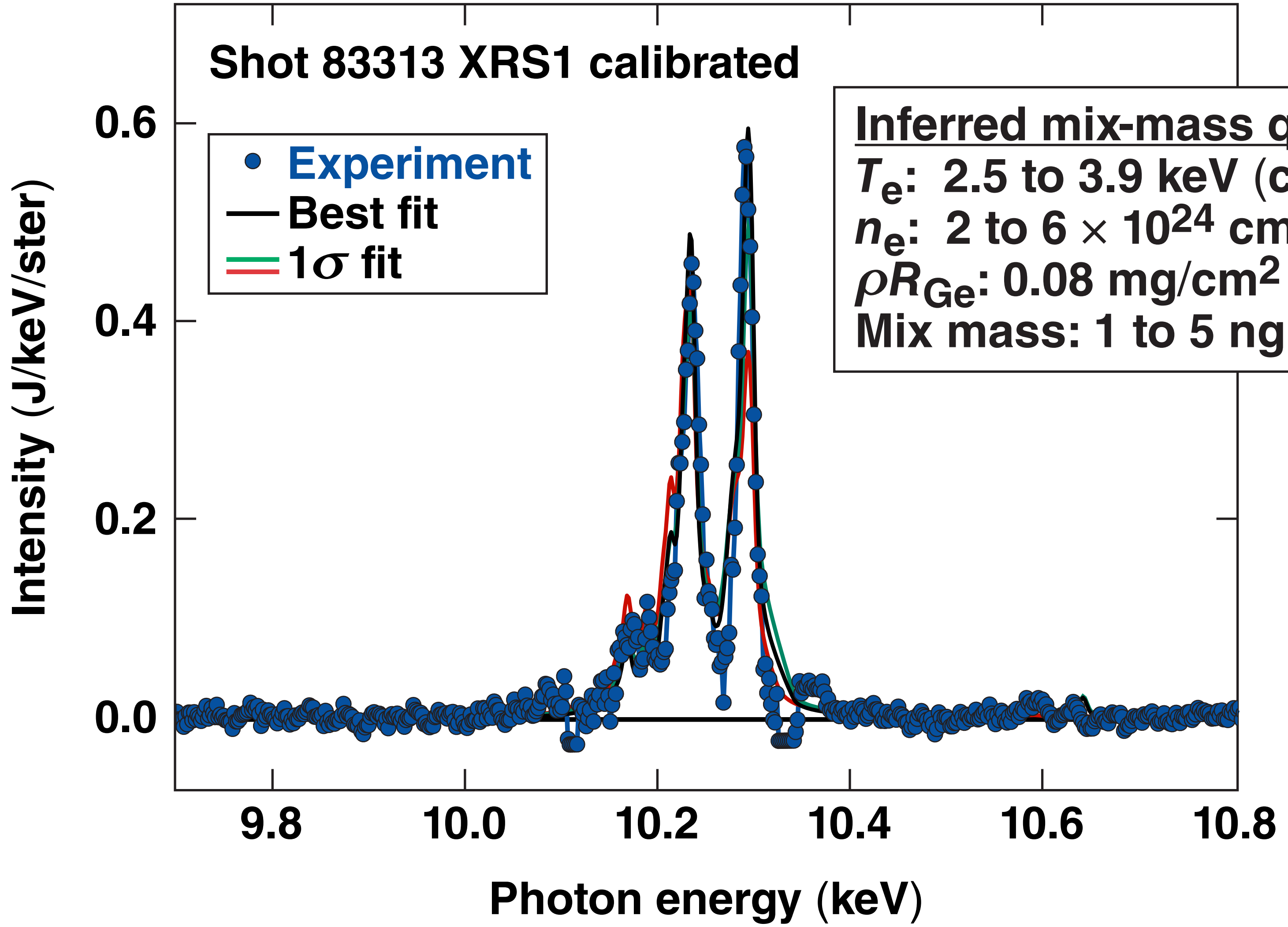
The hot-spot Ge K-shell emission is analyzed with an atomic physics code assuming uniform plasma conditions to diagnose the hot-spot mix mass*



Inferred mix-mass quantities
T_e: 2.5 to 3.9 keV (comparable to T_i)
n_e: 2 to 6 × 10^{24} cm^{-3}
ρR_{Ge}: 0.08 mg/cm^2
Mix mass: 1 to 5 ng

The brightness of the Ge K-shell emission depends on n_e, T_e, and ρR_{Ge}.

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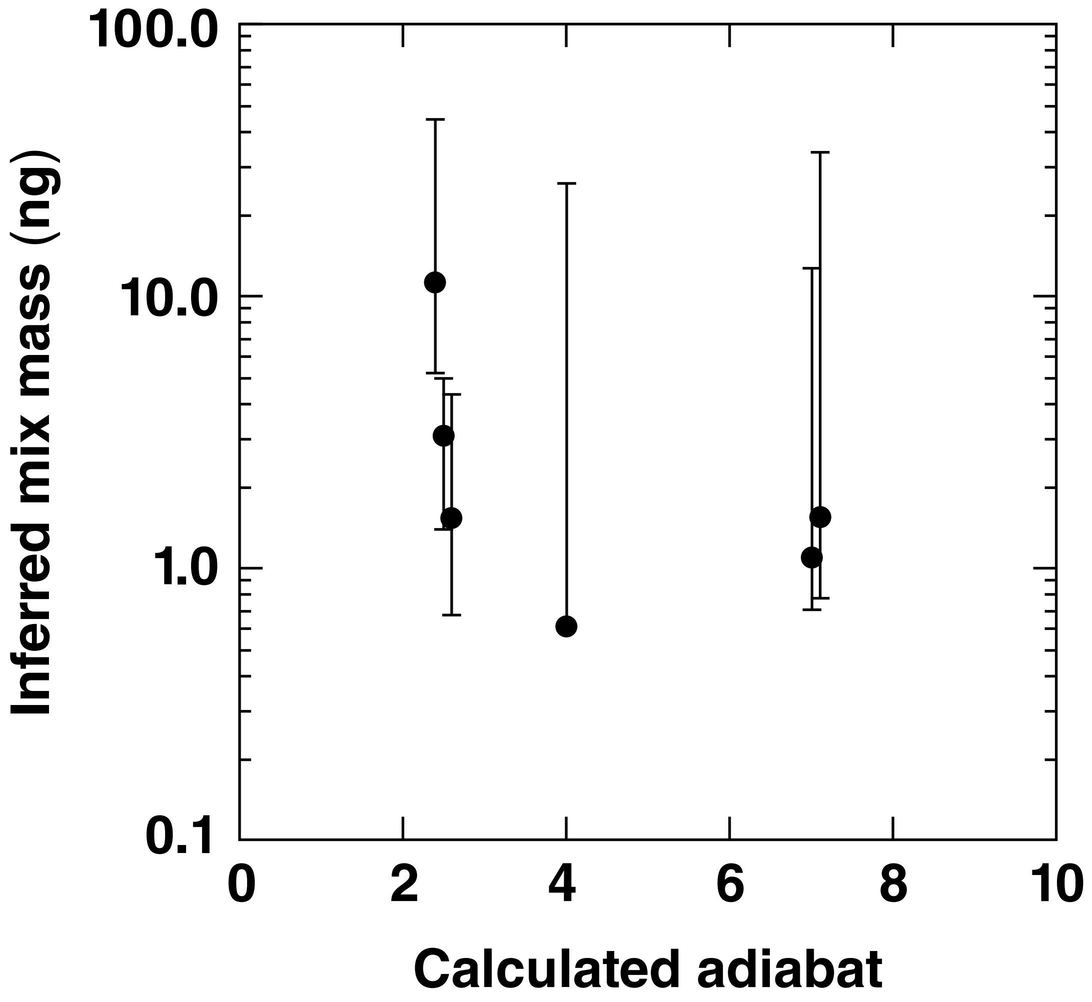
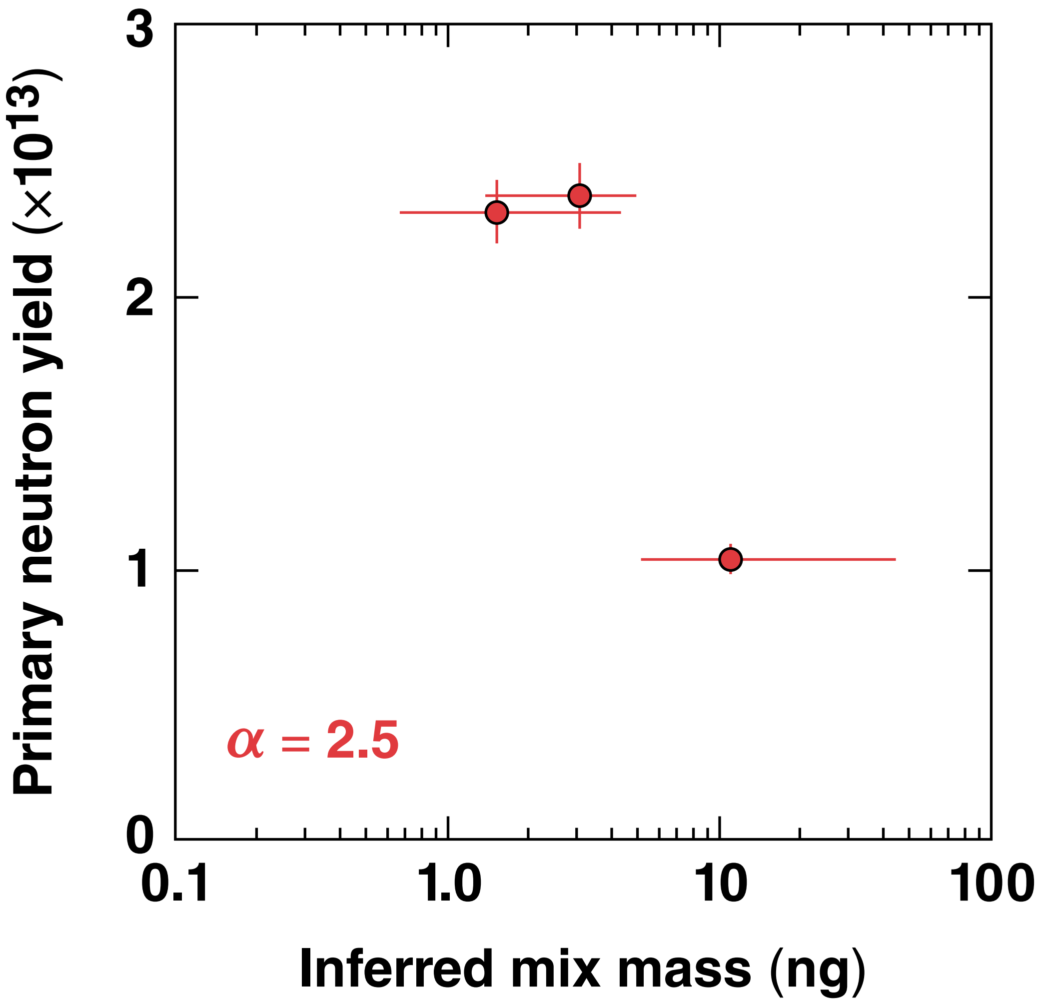
*S. P. Regan *et al.*, Phys. Rev. Lett. 111, 045001 (2013).

Preliminary analysis shows the hot-spot mix mass is below 100 ng for a range of fuel adiabats between 2.5 and 7





Lower neutron yield is observed with a higher amount of hot-spot mix mass.

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Future work will identify the sources of hot-spot mix mass

- Optimize the Ge-doped design to reduce radiative preheat
  - minimize the Atwood number of the ablator/DT interface
  - vary the initial radial distribution of the dopant
  - reduce the *Z* of the dopant

- Identify the sources of hot-spot mix
  - stalk: record Si K-shell emission from stalk and S K-shell emission from stalk glue
  - laser imprint: study effects of laser-beam smoothing
  - microsopic debris: use ablators with smoother surfaces and less debris than the glow-discharge polymerization (GDP) plastic (e.g., polystyrene)

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Summary/Conclusions

Mixing of ablator material into the hot spot of direct-drive DT cryogenic implosions is observed using x-ray spectroscopy*

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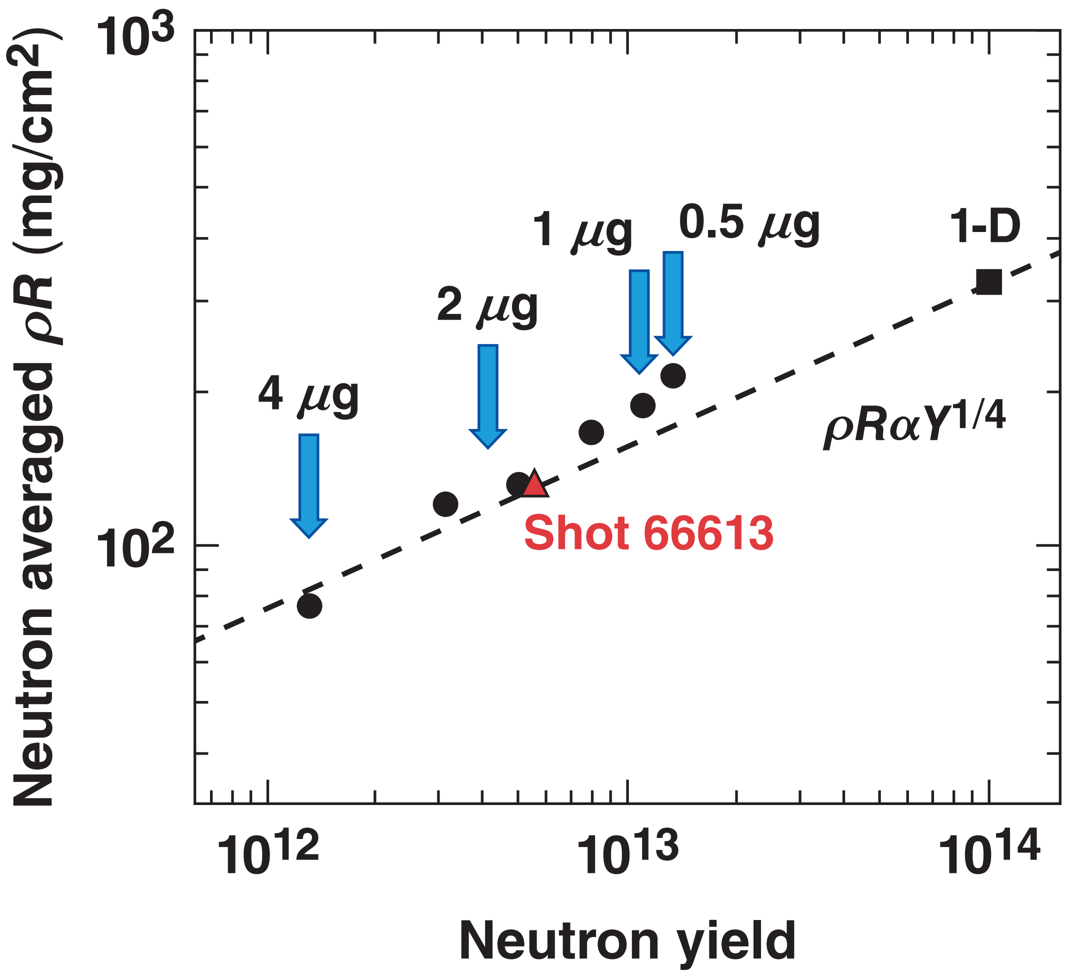
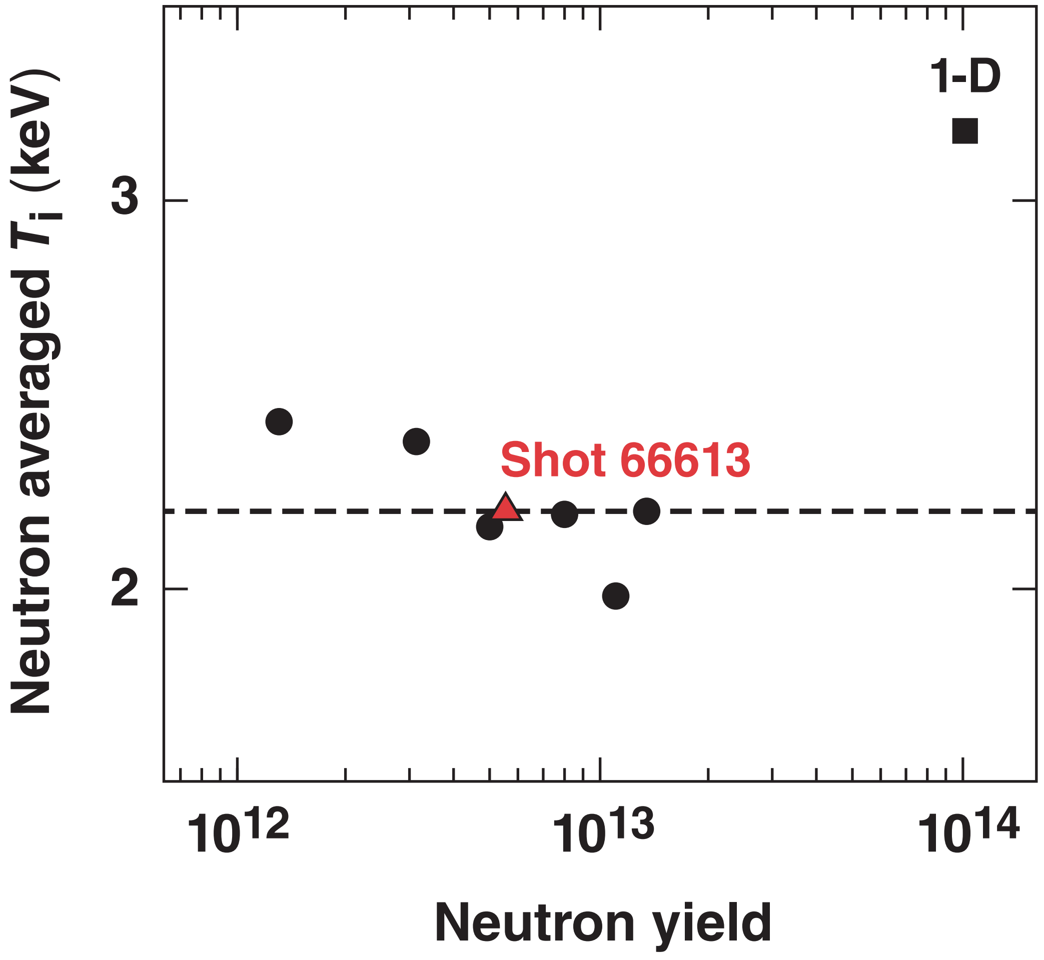
The ablation-front instability seeded by ~150 debris particles is predicted to cause ~1 to 2 μg of hot-spot mix*





The mixing of ablator mass into the hot spot reduces target performance.

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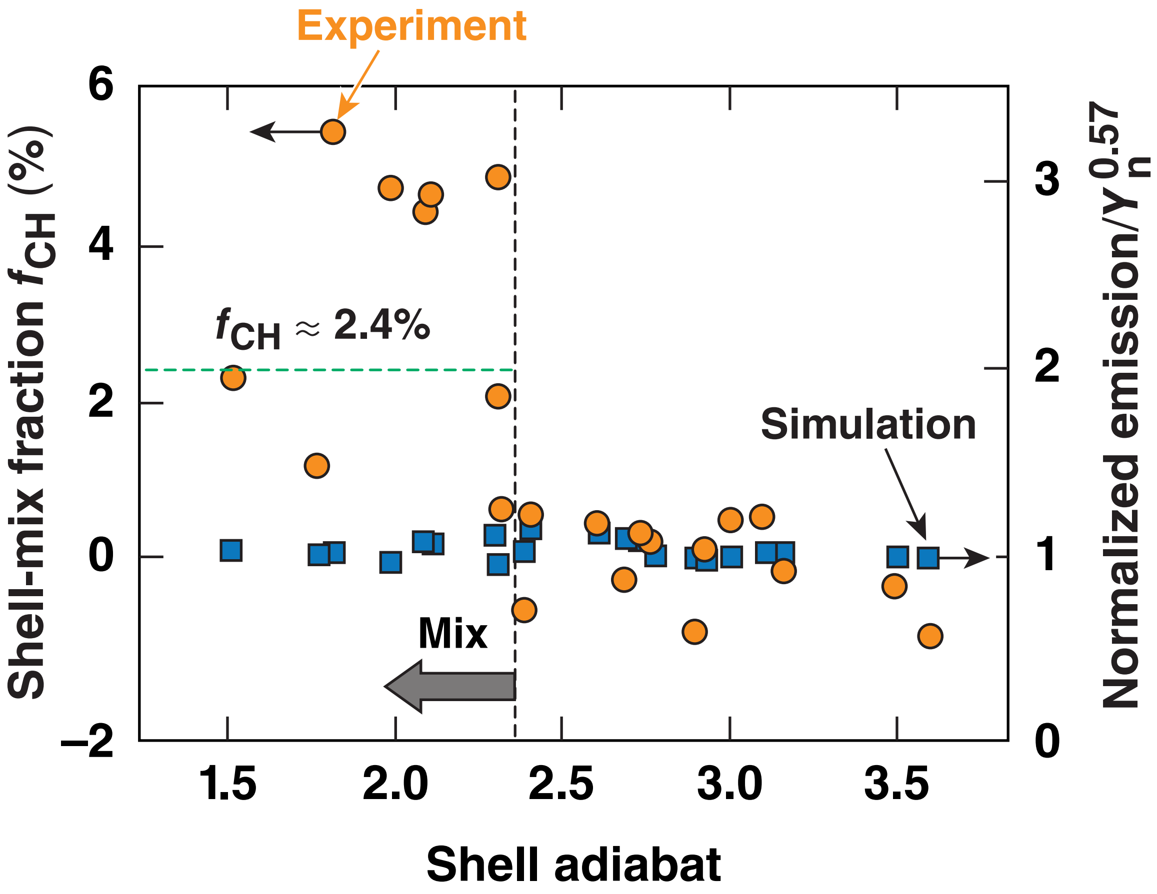
*I. V. Igumenshchev *et al*., Phys. Plasmas 20, 082703 (2013).

X-ray and nuclear diagnostics were used to monitor the enhanced-radiative losses of the hot spot caused by the mix*



X-ray spectroscopy experiments were conducted on OMEGA to diagnose the hot-spot mix.

*Sangster *et al.*, Phys. Plasmas 20, 056317 (2013);
R. Epstein *et al.*, Phys. Plasmas 22, 022707 (2015). [Similar to T. Ma *et al.*, Phys. Rev. Lett. 111, 085004 (2013).]

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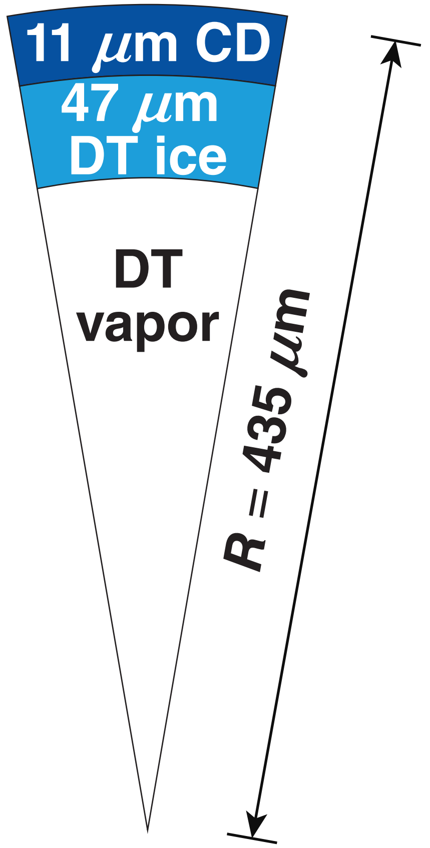
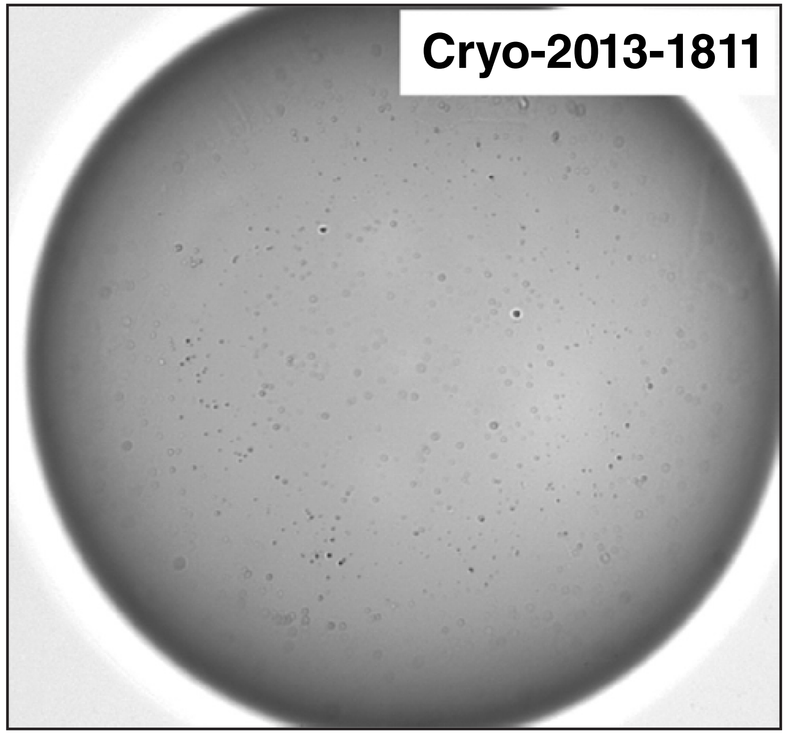
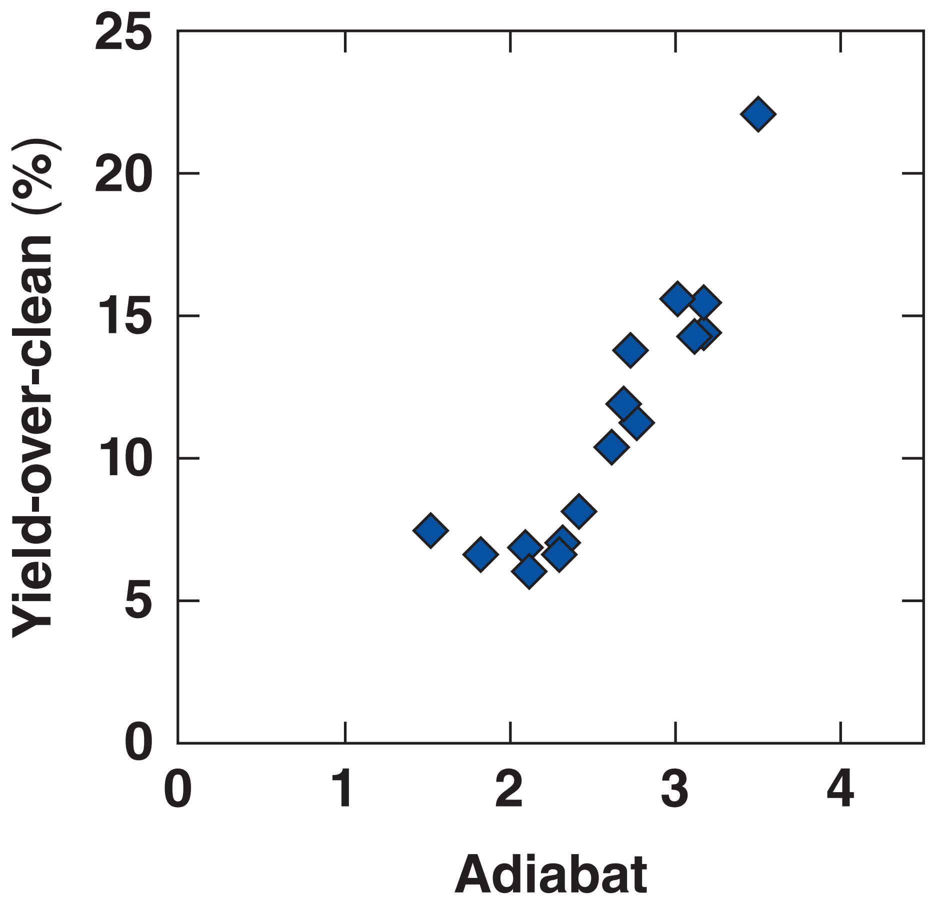
The experimental signatures of mix seeded by surface debris were investigated with 2-D *DRACO* simulations



Measured optical shadowgraph showing surface debris





The 2-D simulations predict a degradation in target performance caused by mixing the ablator into the hot spot.

*I. V. Igumenshchev *et al*., Phys. Plasmas 20, 082703 (2013).