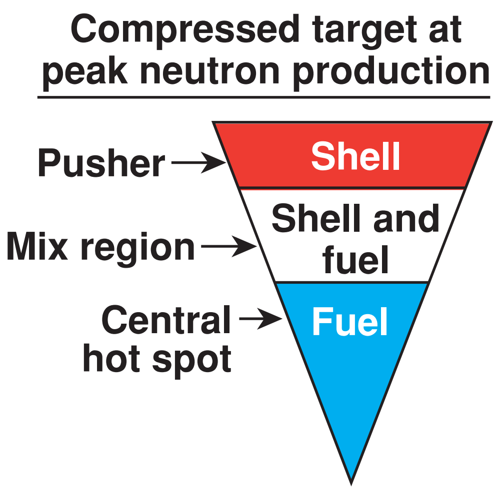
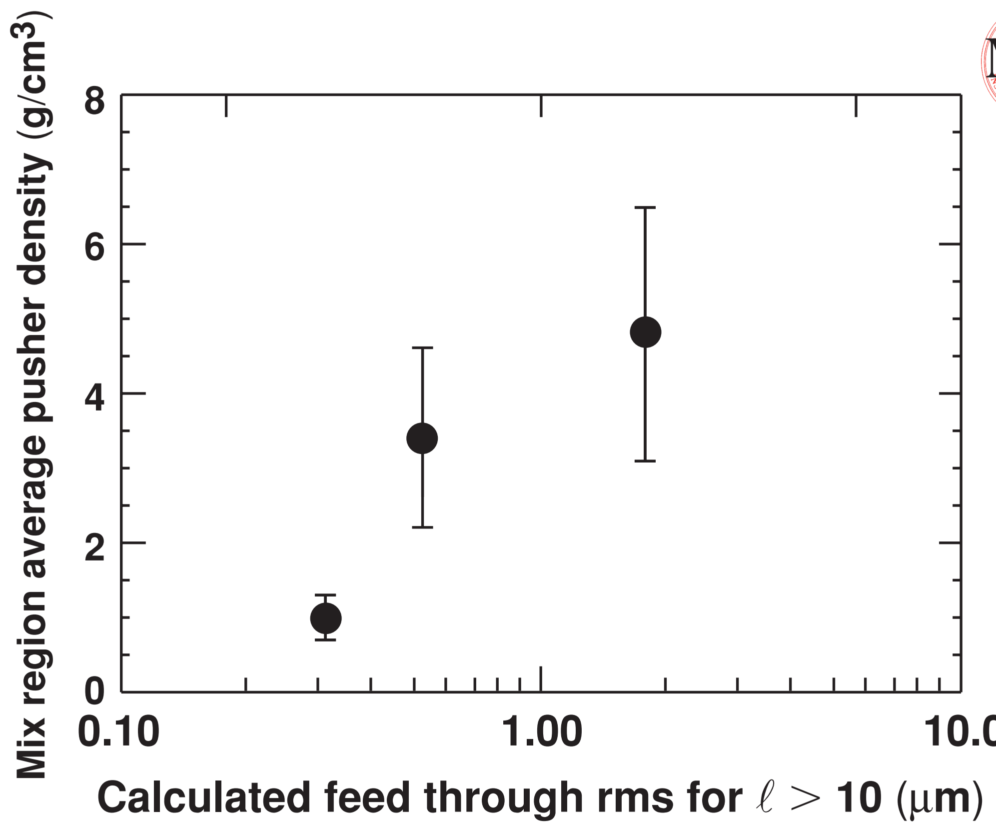
Experimental Investigation of Fuel–Pusher Mix in Direct-Drive Implosions on OMEGA





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Summary

The RT instability in its highly nonlinear, turbulent stage causes atomic-scale mixing of the shell material with the fuel in the compressed core of direct-drive ICF targets

- Fuel–pusher mix was diagnosed with x-ray spectroscopy, charged-particle spectroscopy, and core x-ray imaging.[1]
- Laser imprint and shell thickness were varied to change the feedthrough level of perturbations from the ablation surface to the inner surface of the shell.
- The mass density of plastic shell material (pusher) mixed with the hydrogen isotope fuel in the outer core is shown to depend on the calculated levels of feedthrough.

[1]S. P. Regan *et al.*, Phys. Rev. Lett. 89, 085003 (2002).

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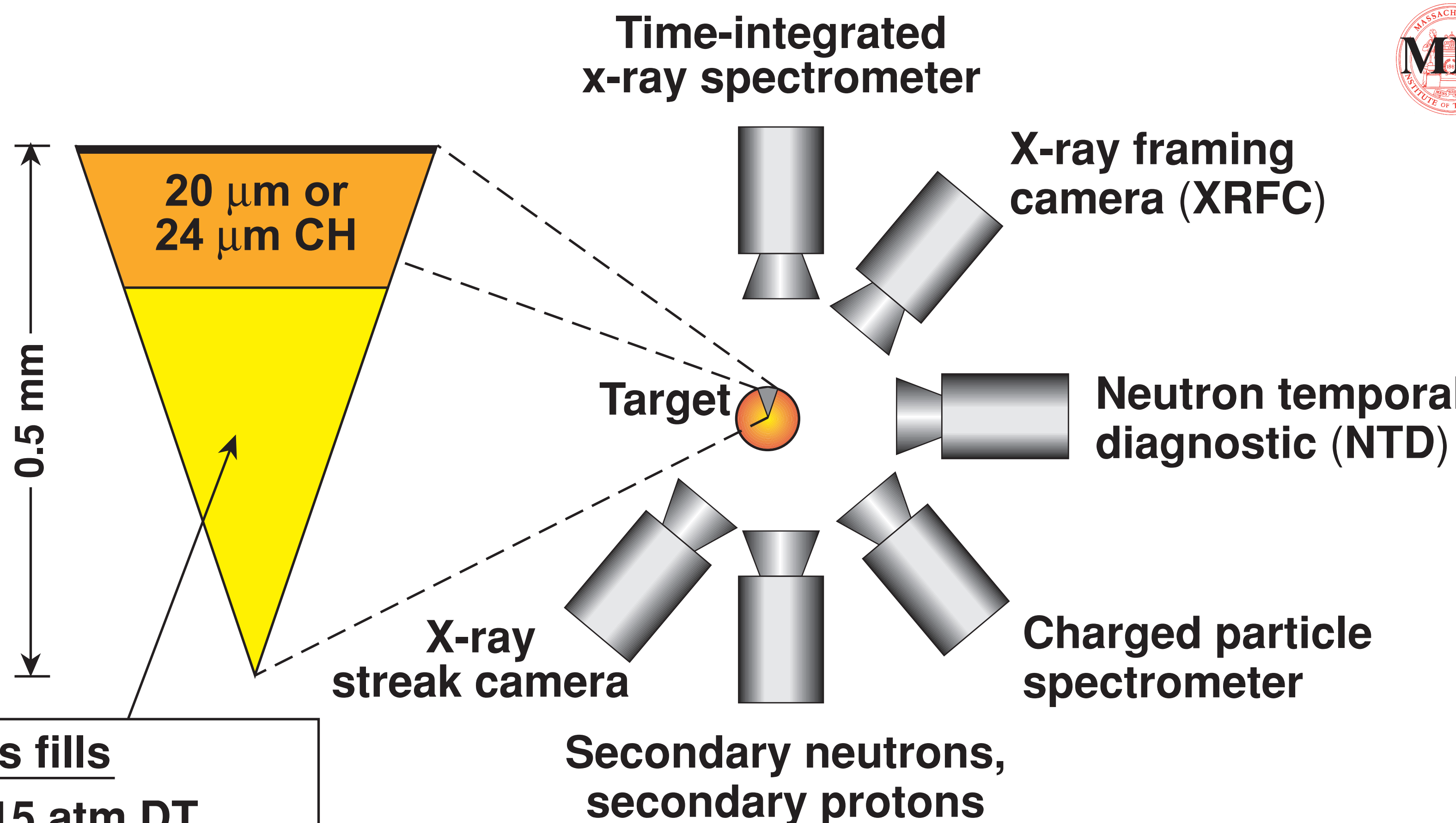
Spherical plastic shell targets were imploded with a 23-kJ, 1-ns square laser pulse



Gas fills

1. 15 atm DT
2. 15 atm DD
3. 15 atm DD and 0.054 atm Ar

- Predicted convergence ratios ranged from 13 to 15.
- Laser irradiation with 1-THz SSD, PS, and on-target beam-to-beam power imbalance < 5% rms.

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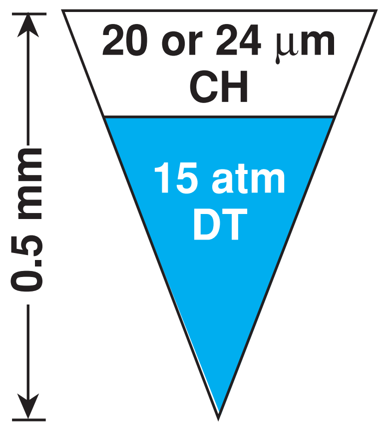
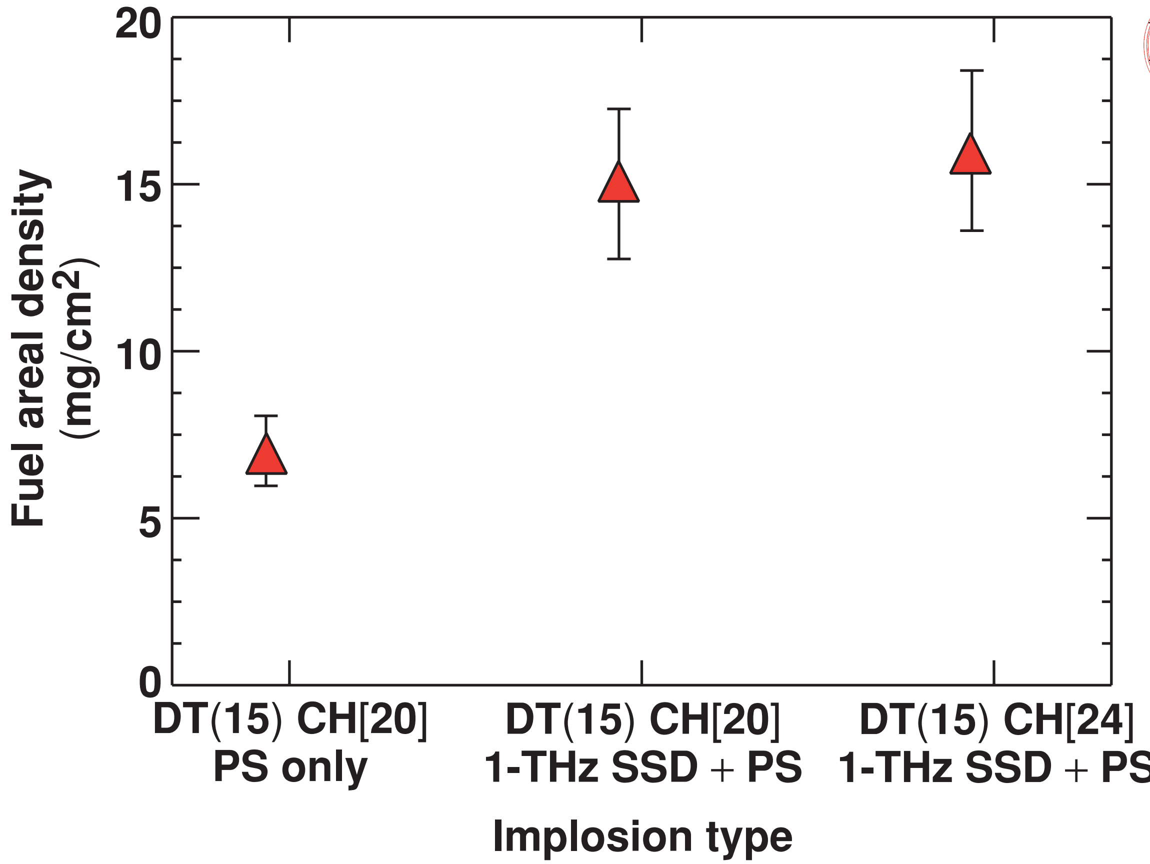
A charged-particle spectrometer is used to record the knock-on-deuteron spectrum for fuel-ρR measurements[1]





<u>Elastic scattering of primary DT neutrons with deuterons:</u>

$$n + D \rightarrow n' + D'$$

number of $D' \propto \langle \rho R \rangle Y_n$

E11839

[1]C. K. Li *et al.*, Phys. Plasmas <u>8</u>, 4902 (2001).

The seed of the deceleration-phase RT instability is calculated with a postprocessor to a 1-D hydrocode*

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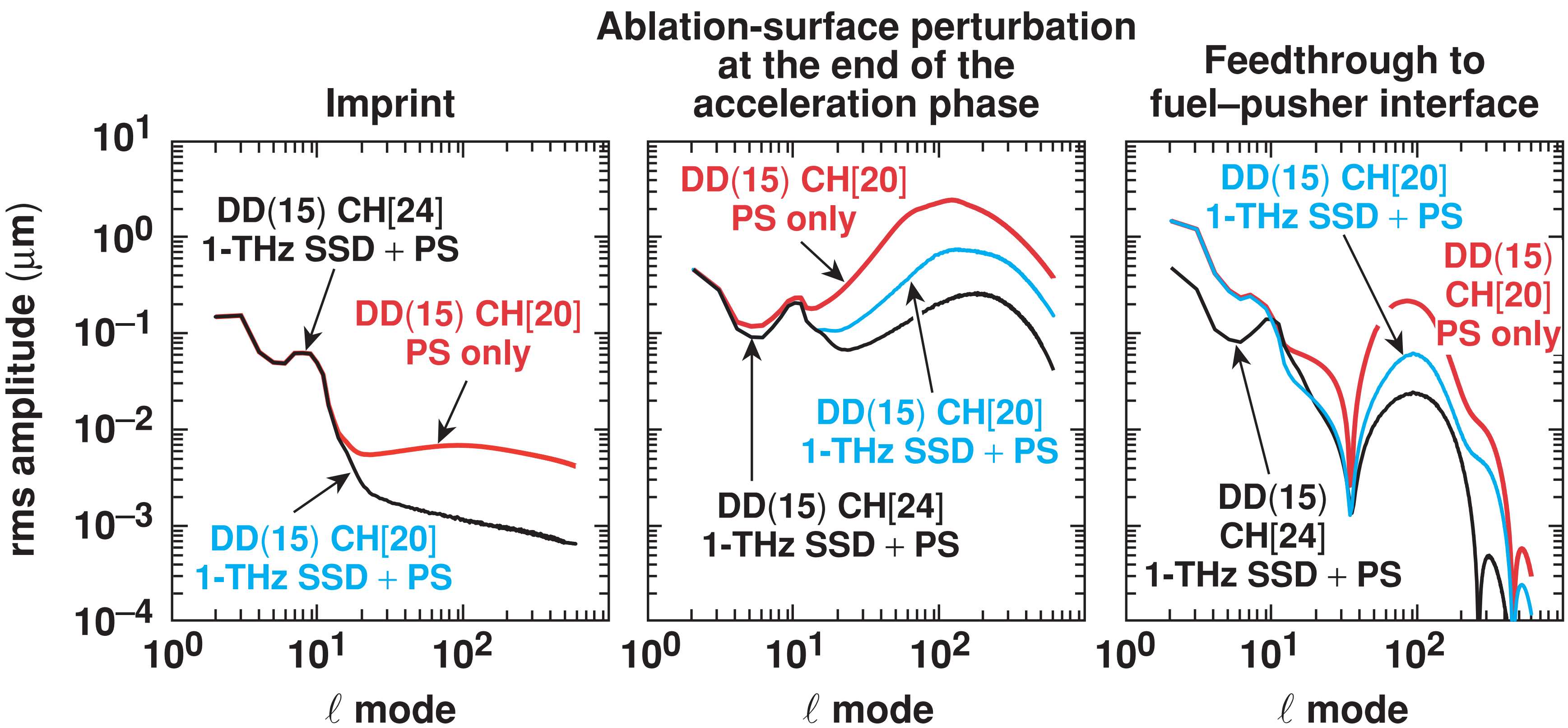

*V. N. Goncharov *et al.*, Phys. Plasmas 7, 5118 (2000).

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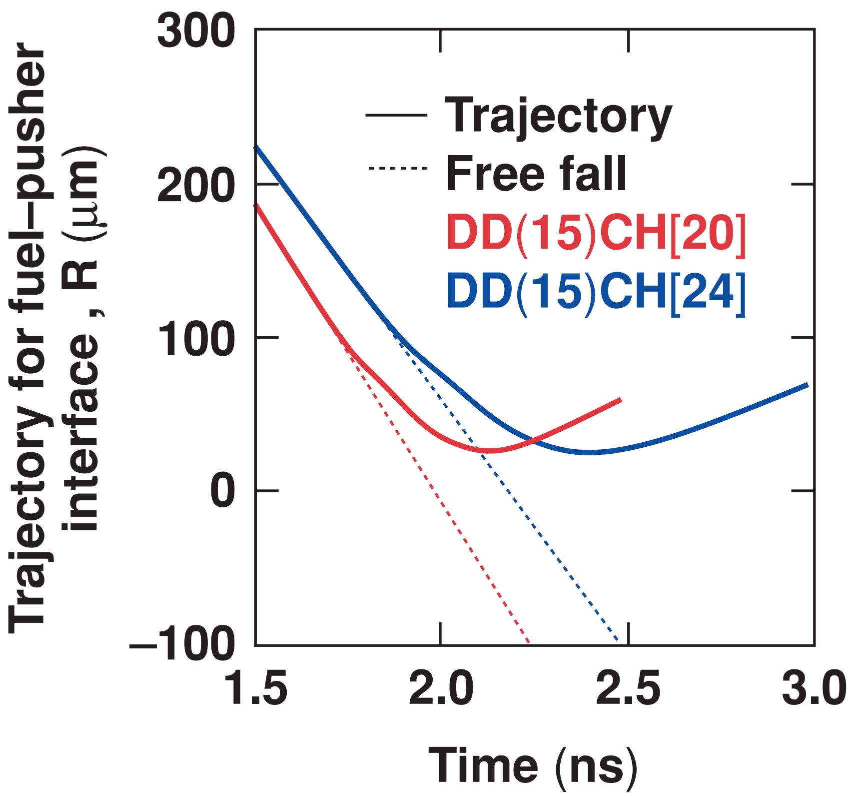
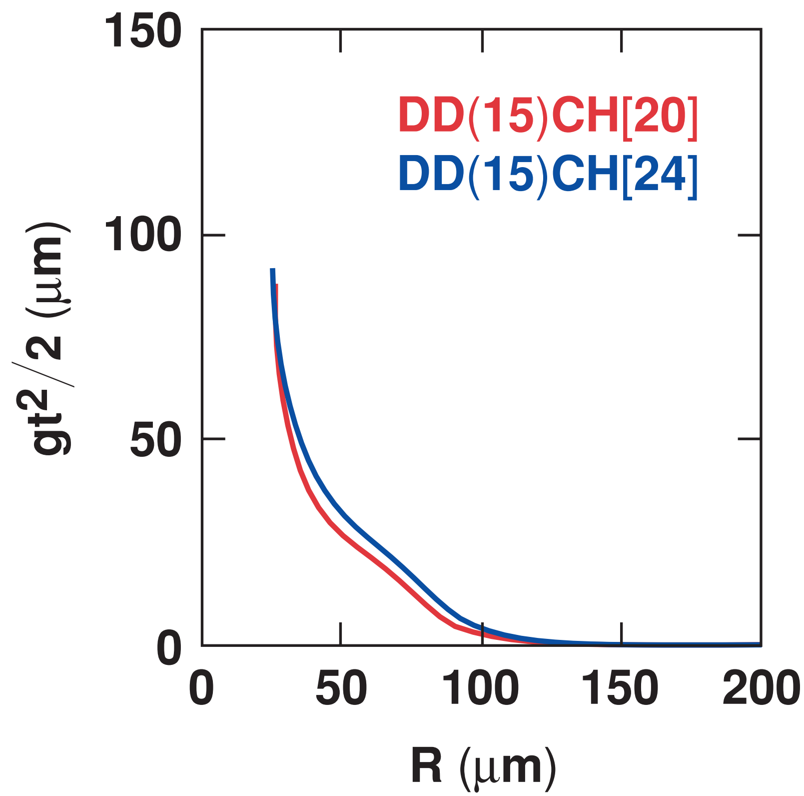
Growth factor of RT instability during deceleration phase is predicted to be comparable for 20- and 24-μm shells





Rayleigh–Taylor growth:

$$GF = e^{\gamma t}, \text{ where } \gamma t = \sqrt{\frac{A_T 2\ell}{R}\,\frac{gt^2}{2}}$$

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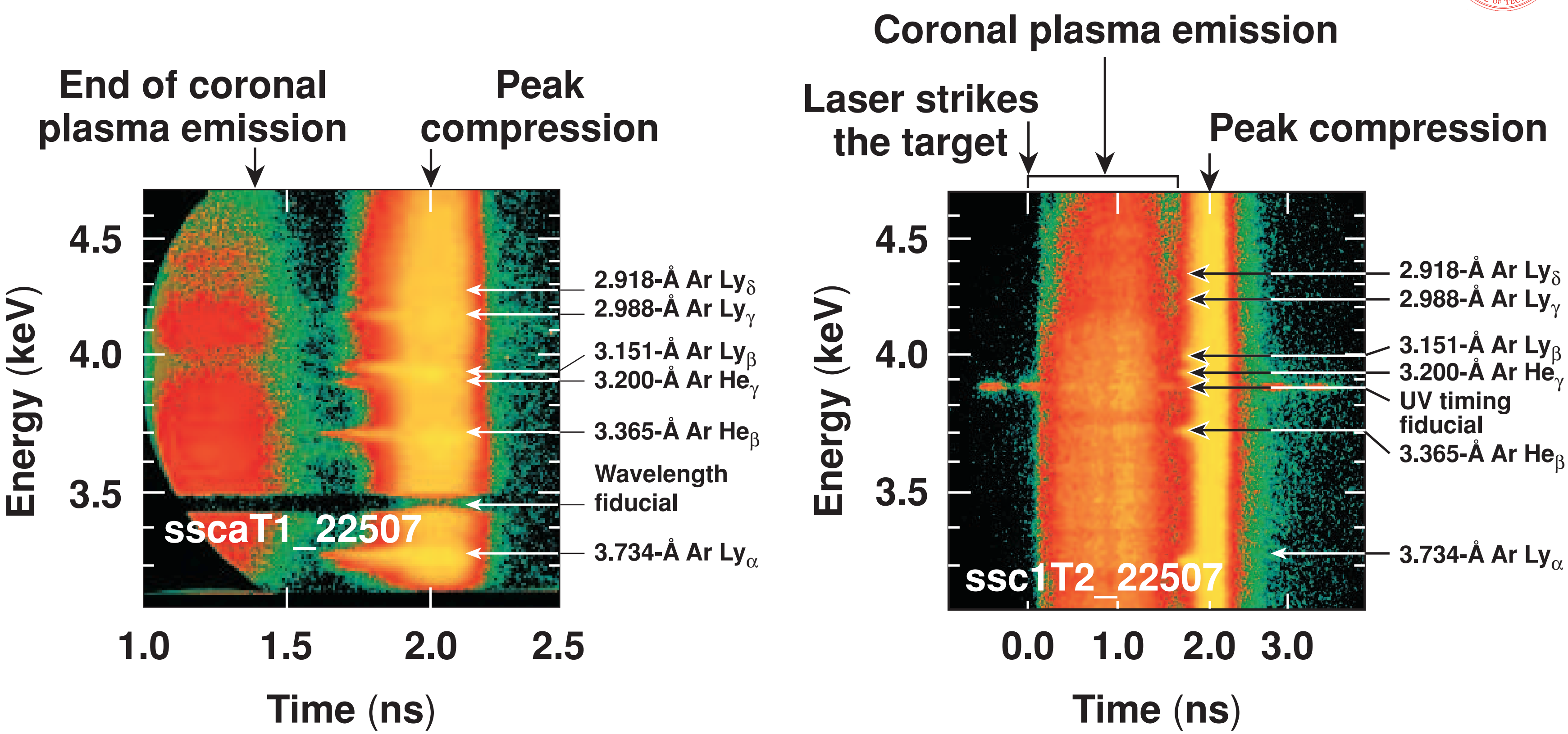
Streaked x-ray spectroscopy is used to measure time-dependent Ar K-shell spectral line shapes



- **Absolute timing of peak x-ray signal is established with a slower streak camera.**

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Time history of emissivity-averaged core n_e and T_e is inferred from the Ar *K*-shell spectroscopy

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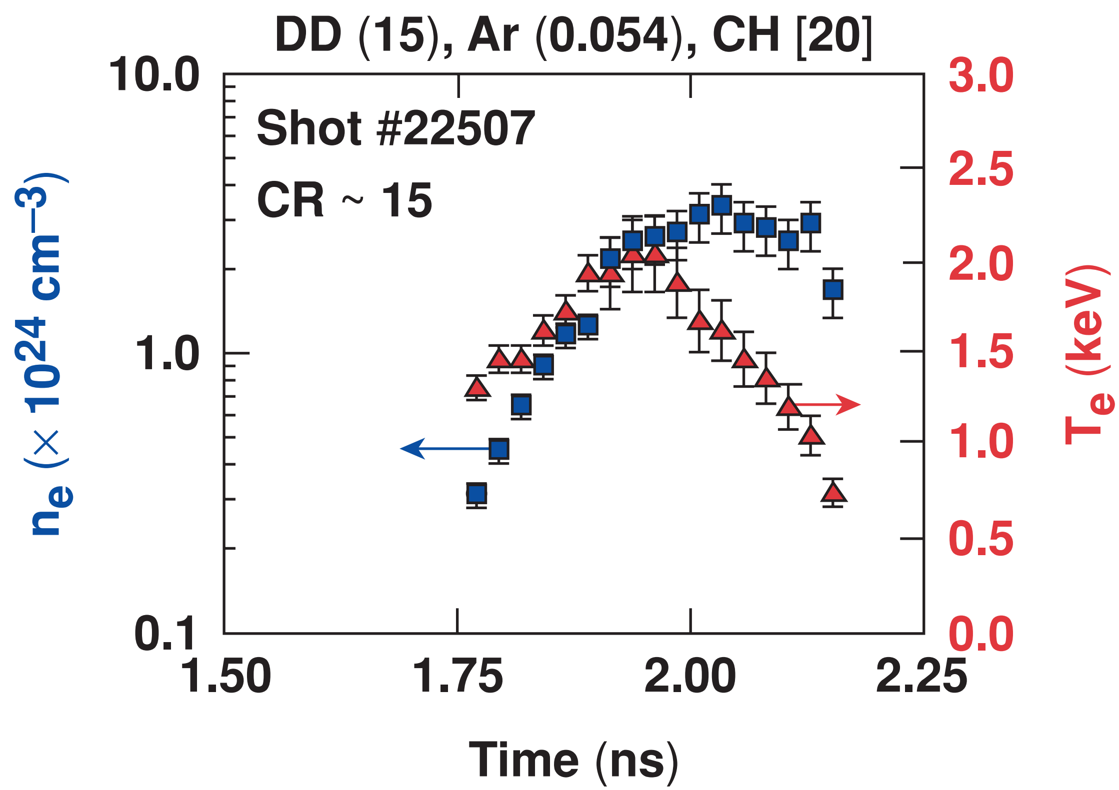

- Significant changes in the Ar *K*-shell emission spectrum occur during the implosion.
- Peak neutron production is measured ~170 ps±100 ps before peak x-ray production.
- *LILAC* simulations indicate that peak neutron production occurs at the same time as peak emissivity-averaged T_e.

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Spectroscopic results are compared with nuclear measurements of $\rho_f R$ and x-ray core images to estimate the amount of fuel-pusher mix

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- The $\rho_f R$ measurement is obtained from knock-on deuteron spectra recorded on similar implosions with a DT fill gas.

$$\rho_f R \text{ (knock-ons)} = 15 \text{ mg/cm}^2$$

- The radius of the imploding core at peak neutron production estimated from $M_f = 4/3\ \pi\ (\rho_f R)\ R^2$ is consistent with the radius estimated from gated x-ray images ($R_{x\text{-ray}} = 38 \pm 5\ \mu m$)

$$R = 42\ \mu m$$

- $\rho_f = 3.6\ (\pm\ 1)\ g/cm^3$

Time-resolved x-ray spectroscopy

$$n_e = n_e(D) + n_e(Ar) + n_e(CH)$$

$\rho_f R$ and core x-ray images

ρ_{CH}

E10984

DD(15)CH[20] implosion with full-beam-smoothing has an estimated core mass composition in the mix region of ~1/2 deuterium and ~1/2 CH

DD(15), Ar(0.054), CH[20]

$n_e(CH) = n_e - n_e(D) - n_e(Ar)$

n_e	2.2×10^{24} cm^{-3} (averaged over 170-ps neutron burnwidth)
T_e	1.9 keV (averaged over 170-ps neutron burn width)
$n_e(D)$	1.1×10^{24} cm^{-3}
$n_e(Ar)$	3.3×10^{22} cm^{-3}
$n_e(CH)$	1.1×10^{24} cm^{-3}
ρ_{CH}	3.4 (±1.2) g/cm^3
ρ_f	3.6 (±1.0) g/cm^3

- Pressure (electron + ion) ~ 11 Gbars
- Because the diagnostic spectral lines are sensitive only to the n_e within approximately a Debye length of the Ar radiator, the shell material must mix with the Ar-doped fuel on the atomic scale.

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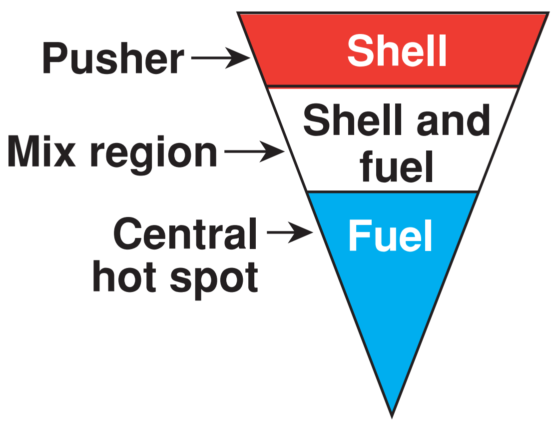
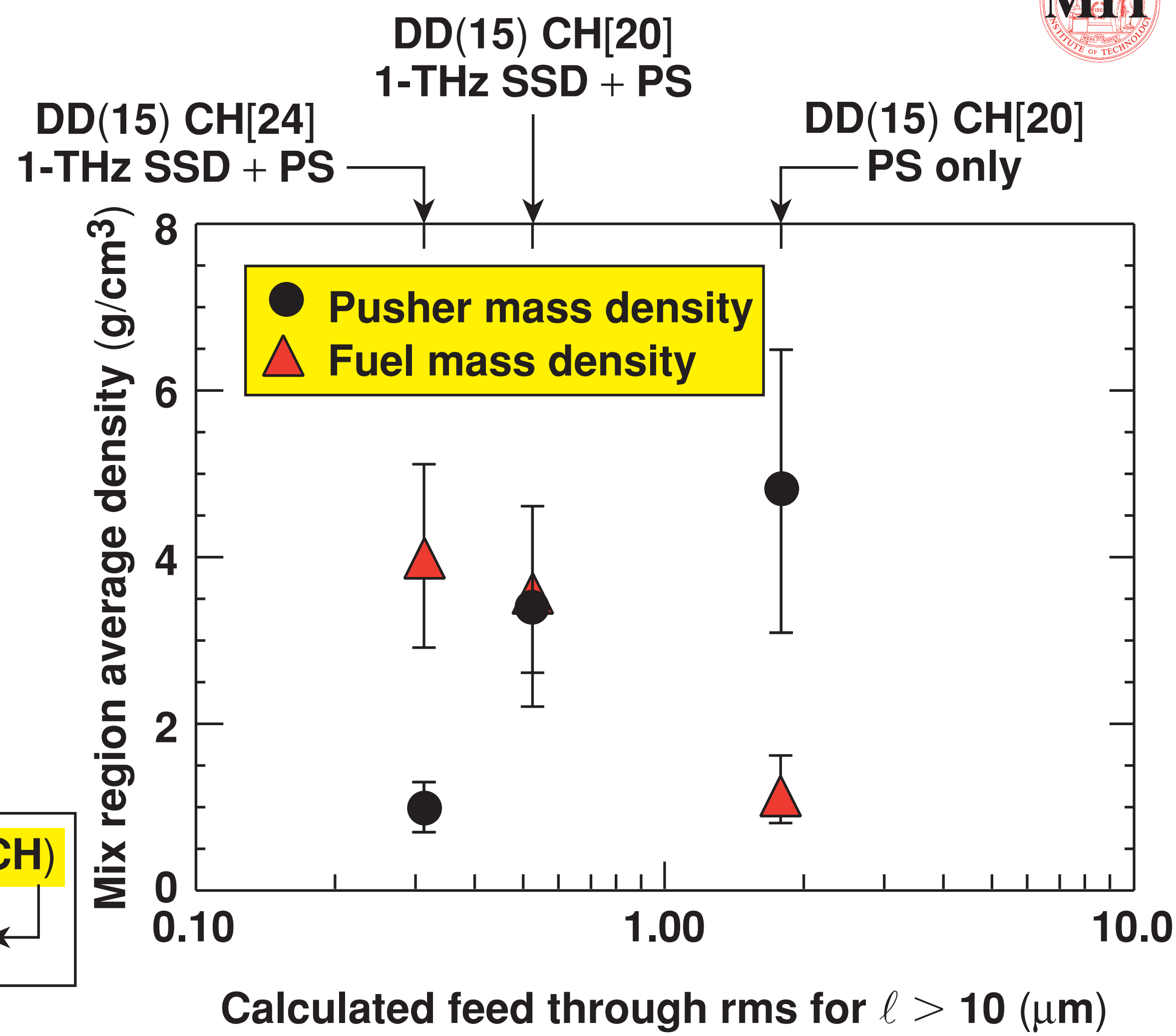
Fuel–pusher mix depends on hydrodynamic stability of implosion

Compressed target at peak neutron production



$n_e = n_e\,(D) + n_e\,(Ar) + n_e\,(CH)$

ρ_{CH} in mix region



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Summary/Conclusion

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