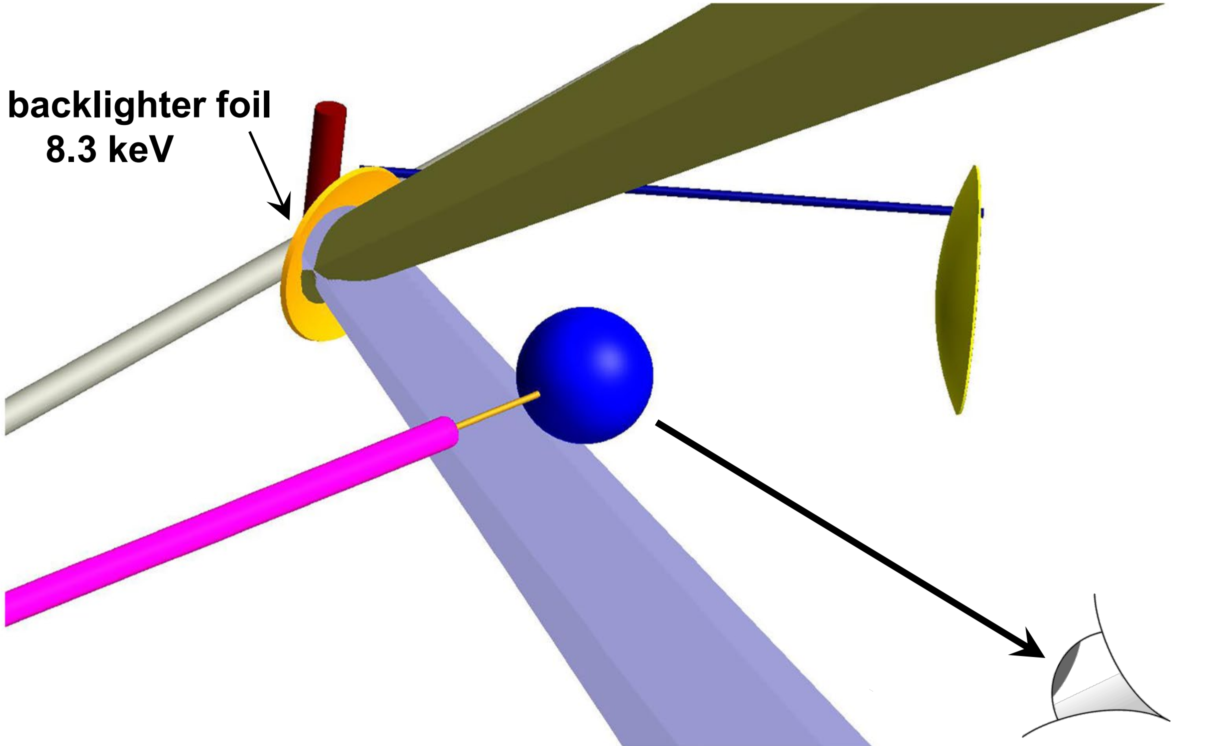
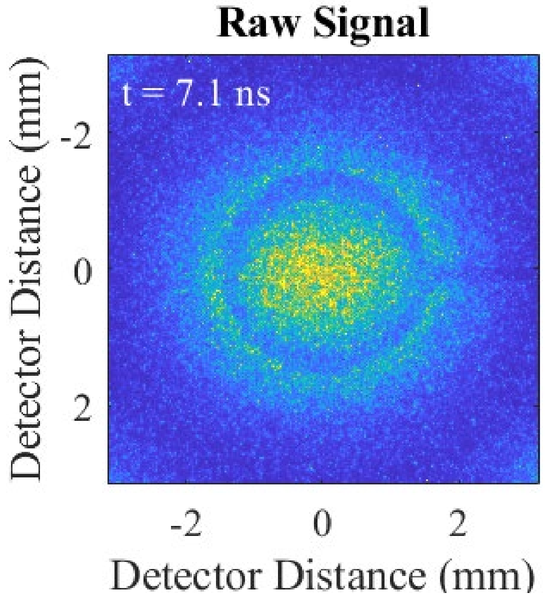
Diagnosing Polar-Direct-Drive Energy Coupling with Solid Spheres at the National Ignition Facility



Radiography camera



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Division of Plasma Physics
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Summary

Solid-sphere radiography is used to diagnose energy coupling at the National Ignition Facility (NIF) in polar-direct-drive experiments

- **Experimental shock- and ablation-front trajectories are inferred from time-resolved radiographic images and compared to 2-D *DRACO* radiation-hydrodynamic simulations**

- **A preliminary comparison between experiment and simulation reveals multiple discrepancies**
  - **Shock trajectories are overestimated at low intensities**
  - **Outer surface trajectories are systematically overestimated, but within preliminary error bars**

Collaborators

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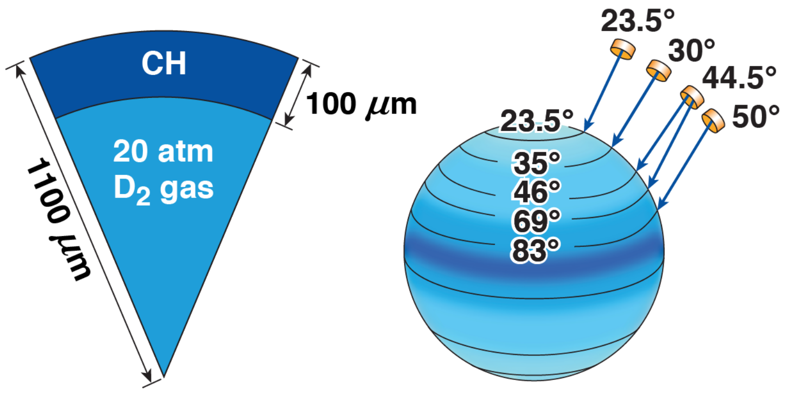
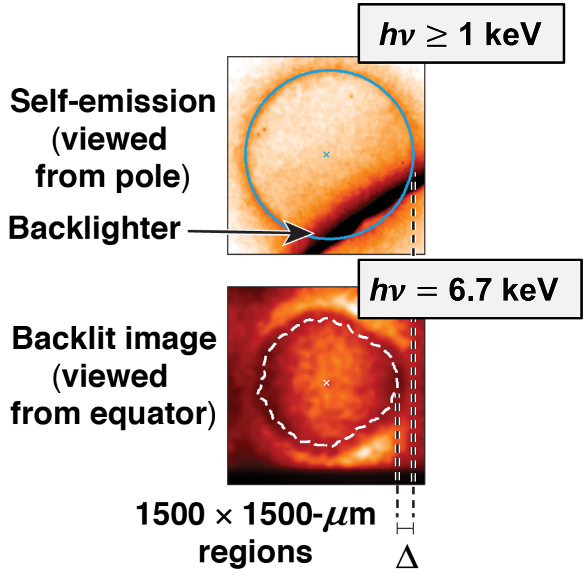
Motivation

Previous NIF polar-direct-drive shell-trajectory measurements

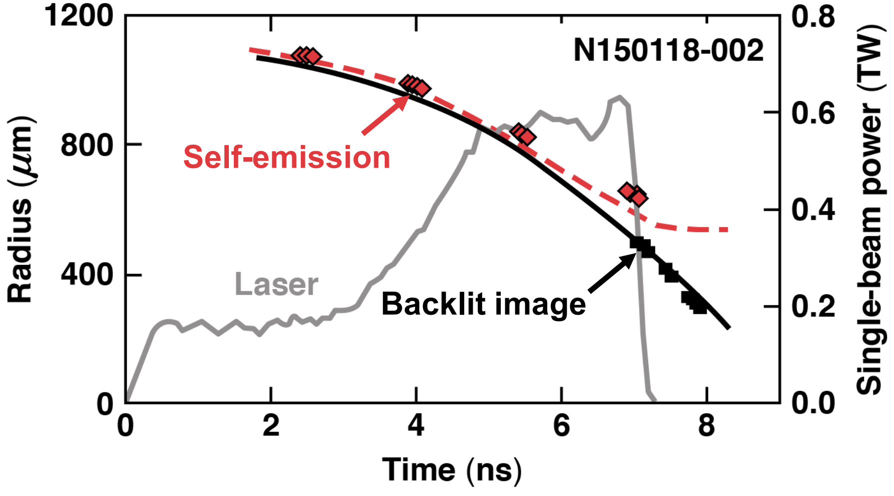
NIF PDD implosion
493 kJ
8×10^{14} W/cm^2



Measured gated x-ray images
(dx = 30 μm, dt = 100 ps)



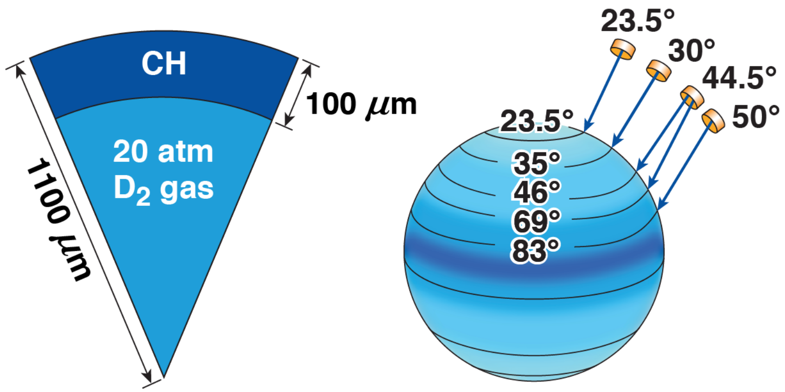
Shell trajectory



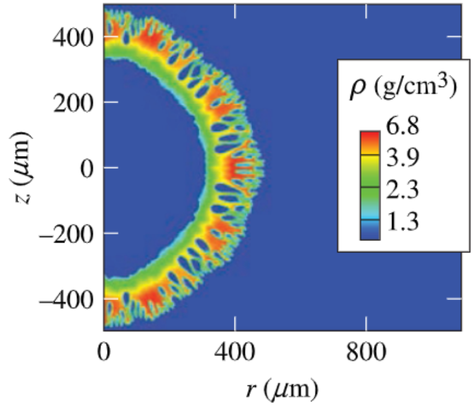
* P. B. Radha *et al.*, Phys. Plasmas 23, 056305 (2016).

Previous NIF polar-direct-drive shell-trajectory measurements were limited by hydrodynamic instabilities*

NIF PDD implosion
493 kJ
8×10^{14} W/cm^2



TC11724d



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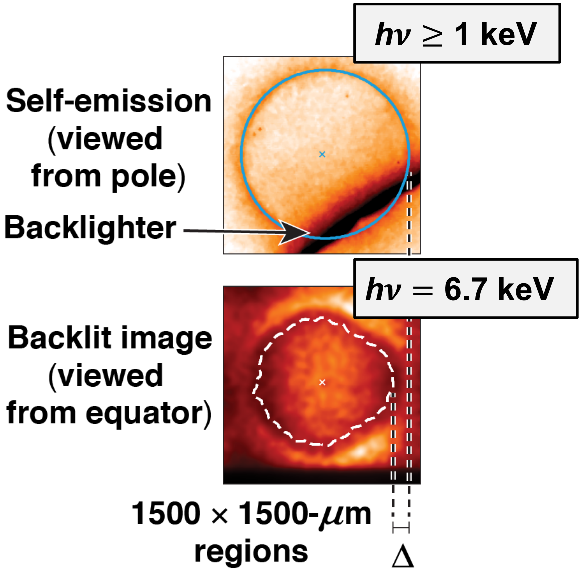
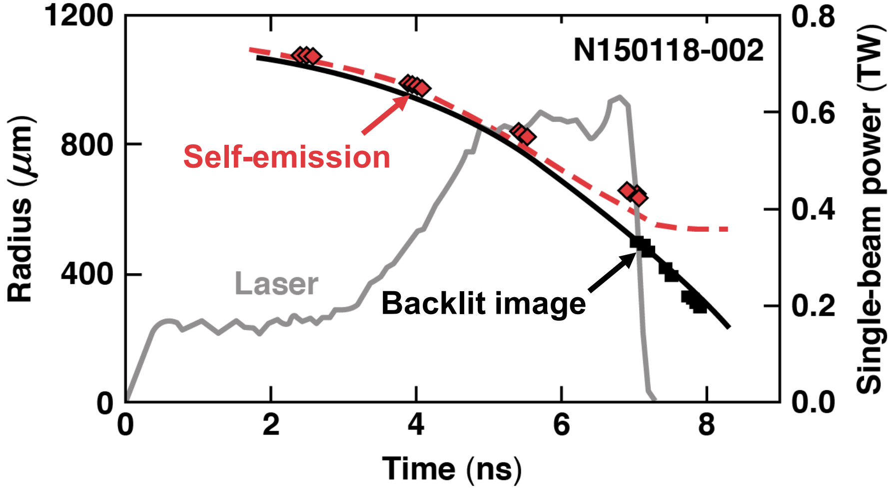


TC11725e

Shell trajectory



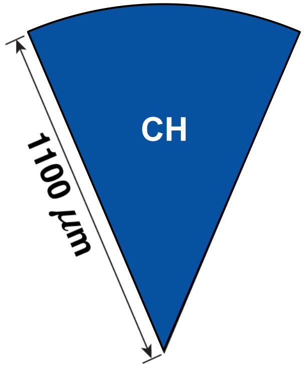
TC12730b

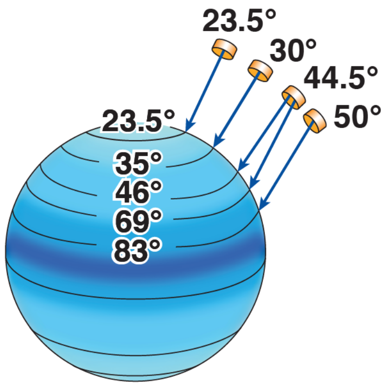
Backlit image: Modeled and measured v_{imp} match within 1%*
Self-emission: 9% overprediction of v_{imp} attributed to laser imprint and subsequent Rayleigh–Taylor growth*

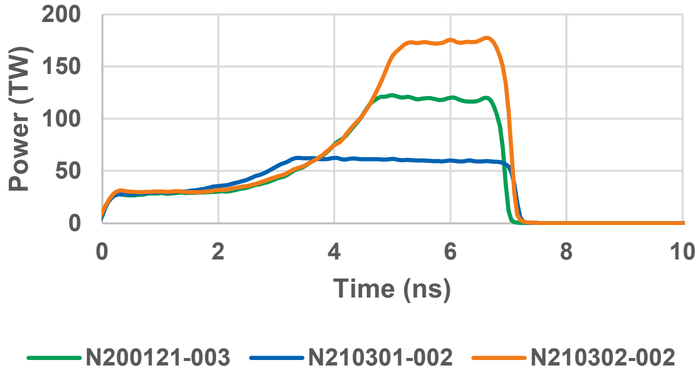
* P. B. Radha *et al.*, Phys. Plasmas 23, 056305 (2016).

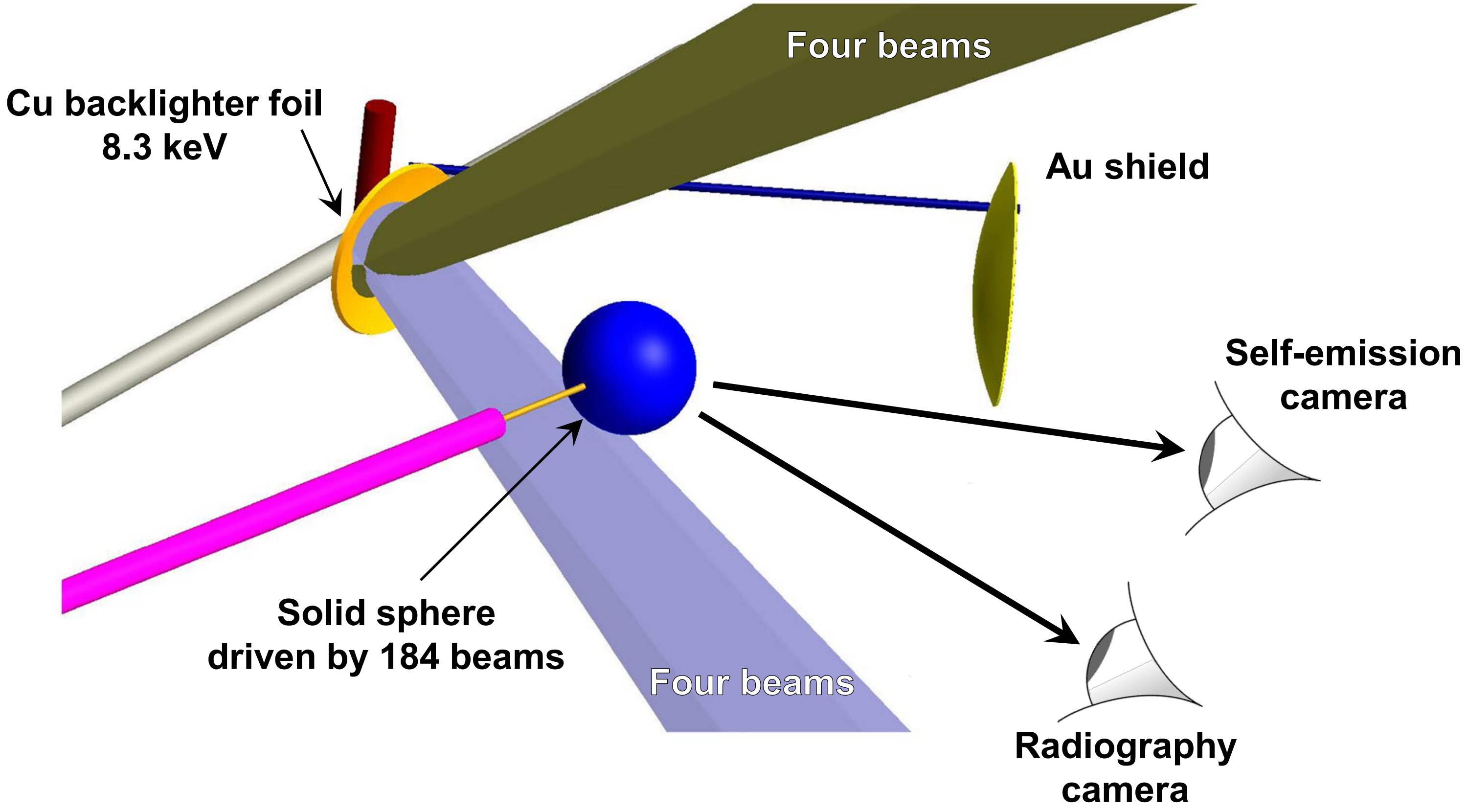
Solid, spherical, plastic targets are now used to drastically reduce the growth of hydrodynamic instabilities*

NIF PDD implosion
350 – 625 kJ
0.4 – 1.2 × 10^{15} W/cm^2



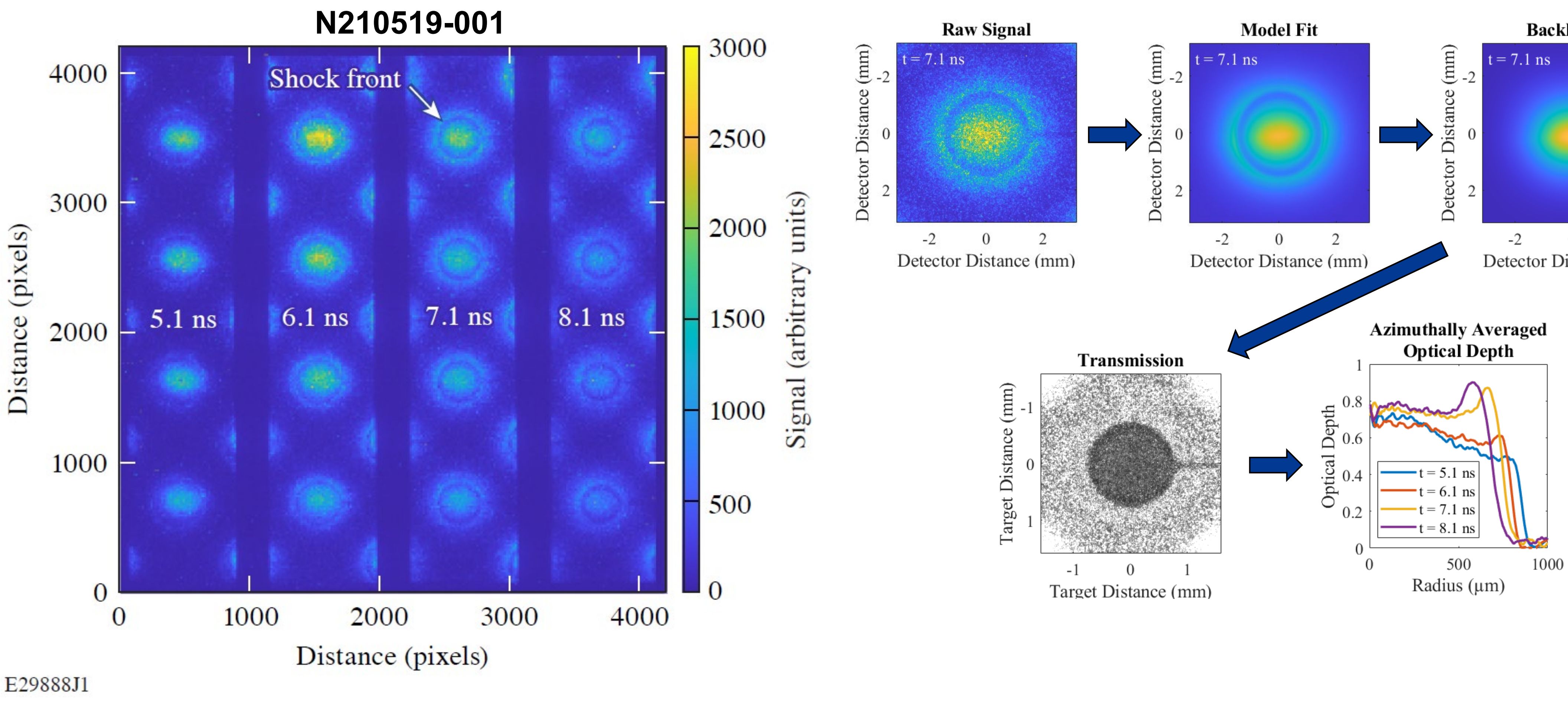






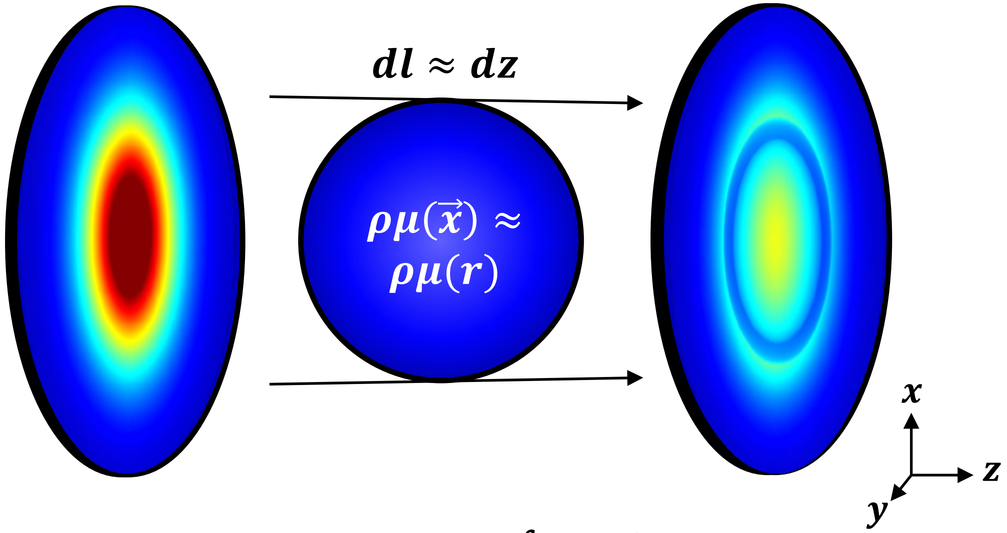
*S. P. Regan *et al.*, Bull. Am. Phys. Soc. 65, BO09.00011 (2020).

Radial optical depth profiles are extracted from raw radiographs by fitting entire strips simultaneously and azimuthally averaging the transmission images*



* L. Ceurvorst *et al*, Physics of Plasmas Accepted for Publication (2022).

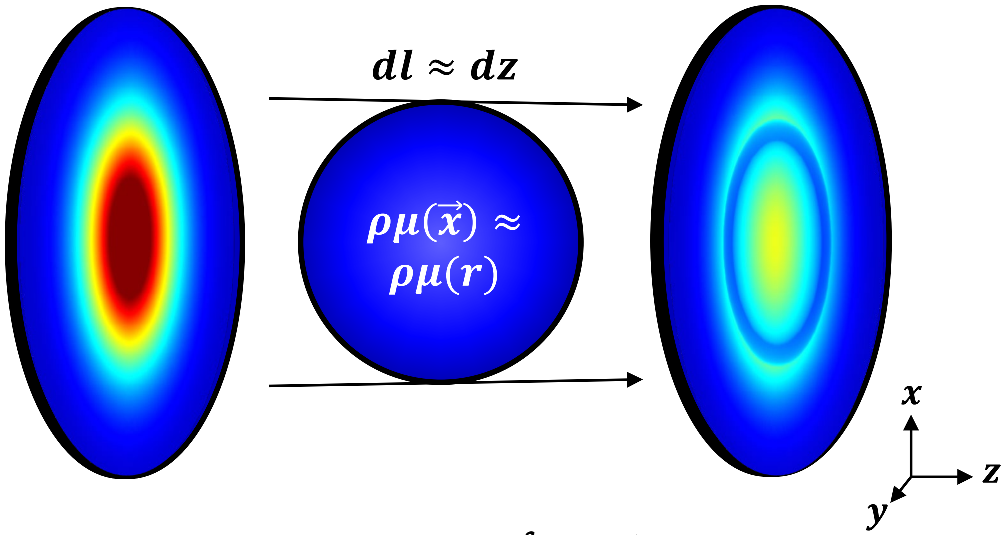
Optical depth profiles are roughly Abel transformations of the radial attenuation coefficient (density times opacity)



$$\text{Optical Depth} = \int \rho\mu(\vec{x})\, dl$$

$$\approx \text{Abel}\big(\rho\mu(r)\big)$$

Attenuation profiles are reconstructed by Abel inverting the optical depth profiles



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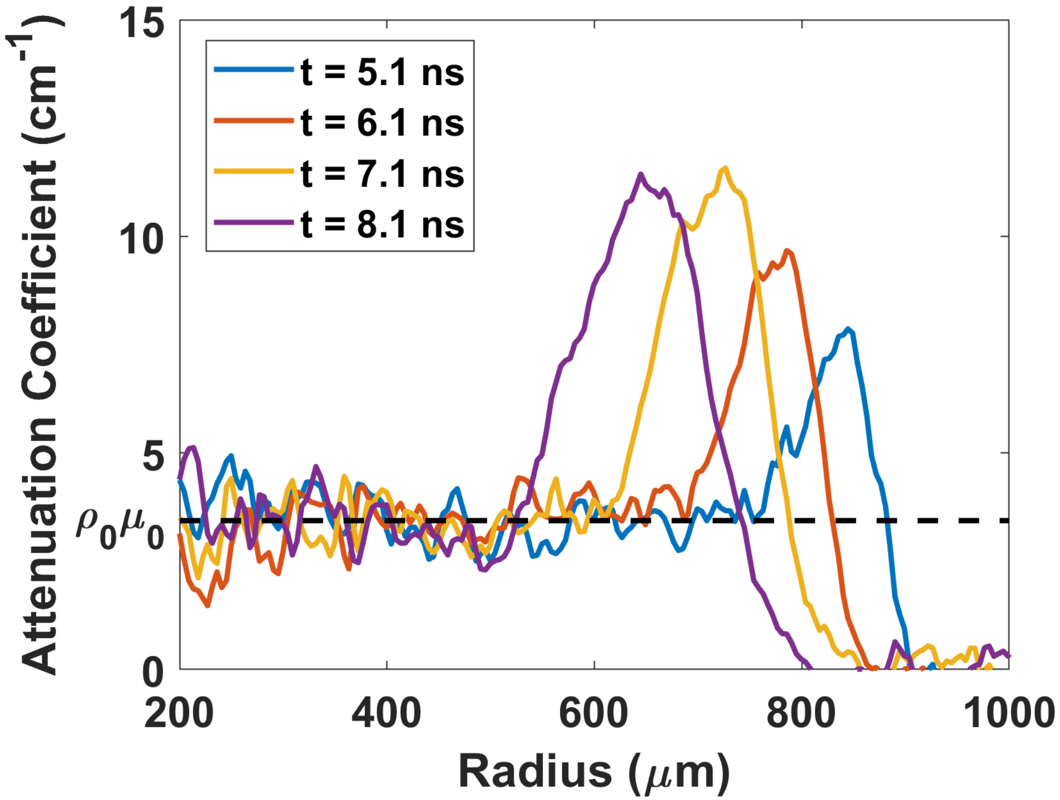
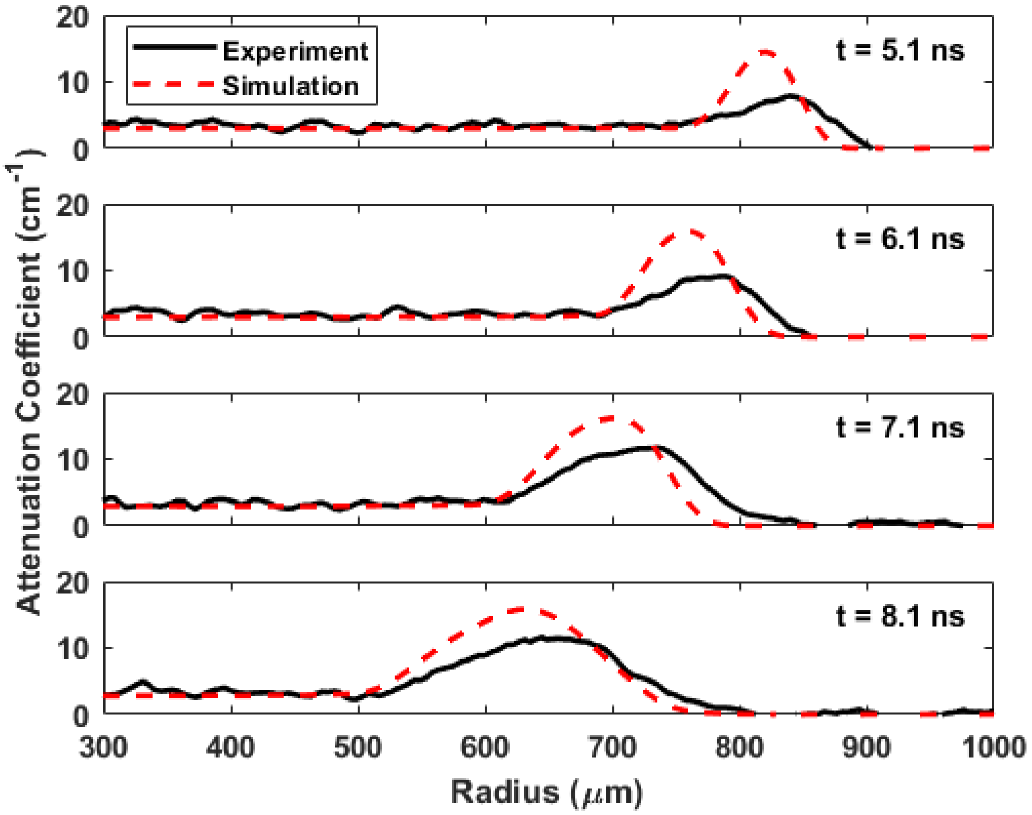


Attenuation profiles converge to $\rho_0\mu_0$ in the unshocked region as expected

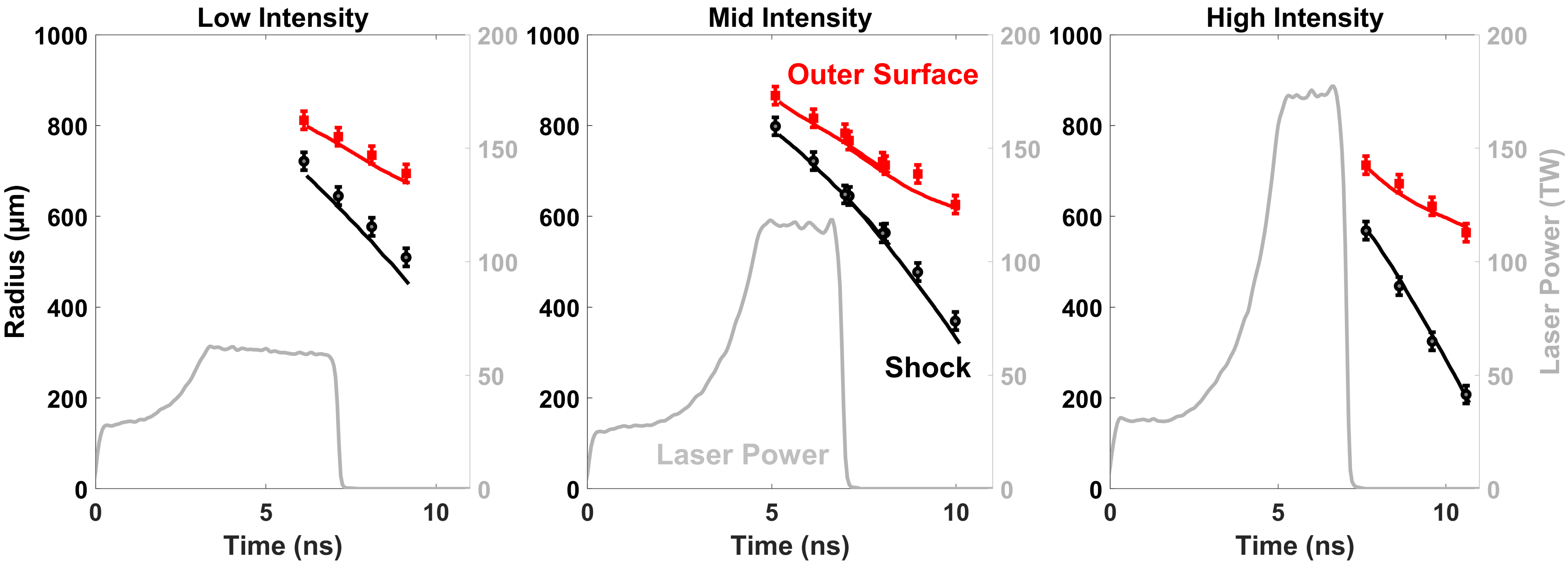
The same analysis applied to post-processed* *DRACO*** simulations shows significant differences in ablation trajectory and overall attenuation



The width of the shocked region is underpredicted by simulations and cannot be due to hydrodynamic instabilities

* J. J. MacFarlane *et al.*, High Energy Density Phys. 3, 181 (2007).
** P. B. Radha et al., Physics of Plasmas 12, 032702 (2005).

Tracking the 50% rise and fall surfaces of the attenuation profiles shows significant discrepancies, particularly at lower intensities



Shock velocities are overestimated at low intensities by ~11%

* Scattered light analysis: S. Kostick CO04.00009

Summary

Solid-sphere radiography is used to diagnose energy coupling on the National Ignition Facility (NIF) in polar-direct-drive experiments

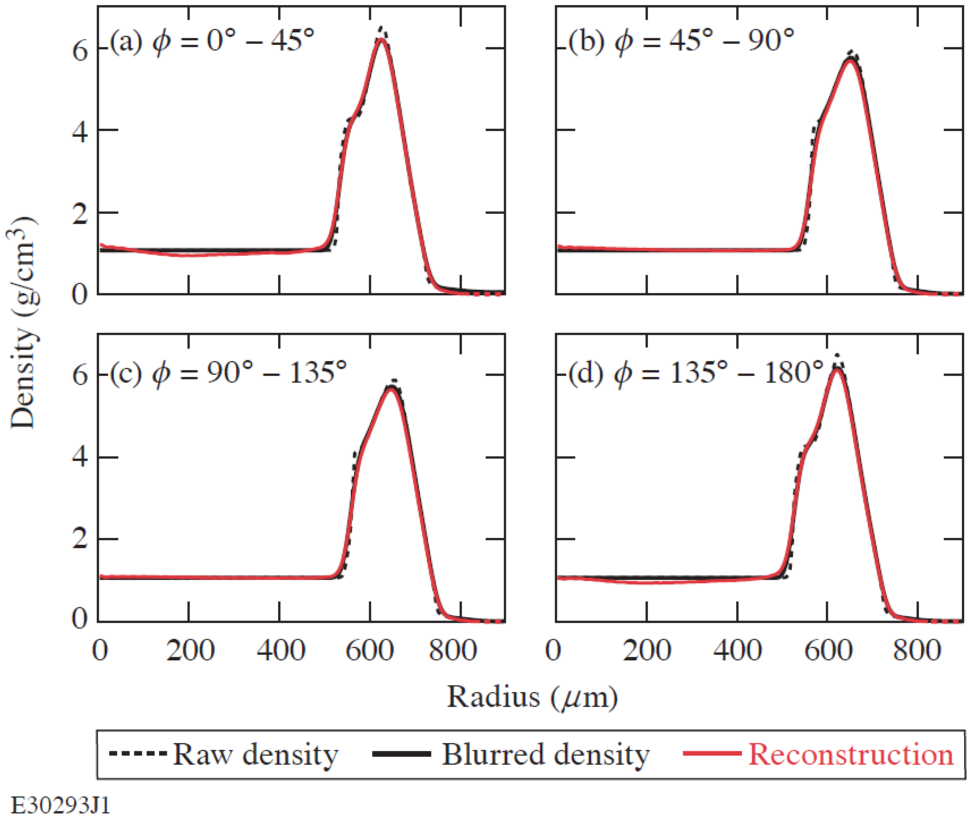
- **Experimental shock- and ablation-front trajectories are inferred from time-resolved radiographic images and compared to 2-D *DRACO* radiation-hydrodynamic simulations**

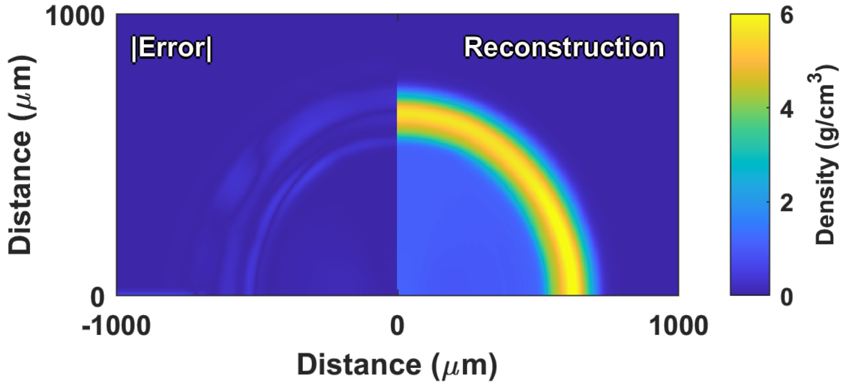
- **A preliminary comparison between experiment and simulation reveals multiple discrepancies**
  - **Shock trajectories are overestimated at low intensities**
  - **Outer surface trajectories are systematically overestimated, but within preliminary error bars**

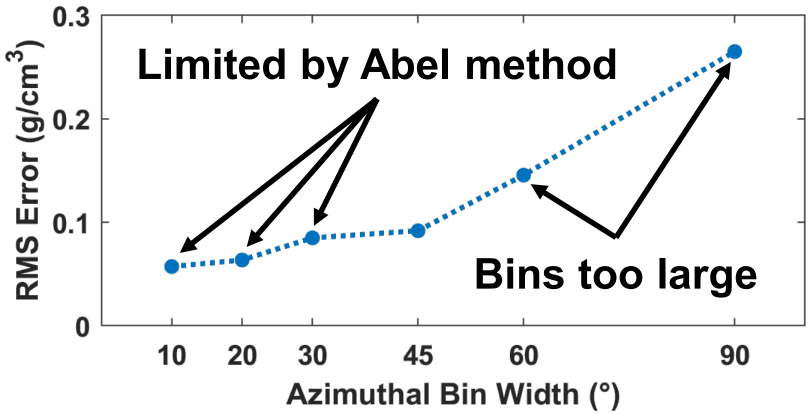
Upcoming experiments with new pulse shapes will help to distinguish between cross-beam energy transfer, preheat, and heat transport discrepancies

Backup Slides

Without noise, this reconstruction method has less than 0.06 g/cm³ RMSE when applied to *DRACO* simulations







RMSE: Root-mean-square error $\left[\sum_i^n (X_i - Y_i)^2/n\right]^{1/2}$

The same analysis applied to post-processed *DRACO* simulations shows significant differences in ablation trajectory and overall attenuation

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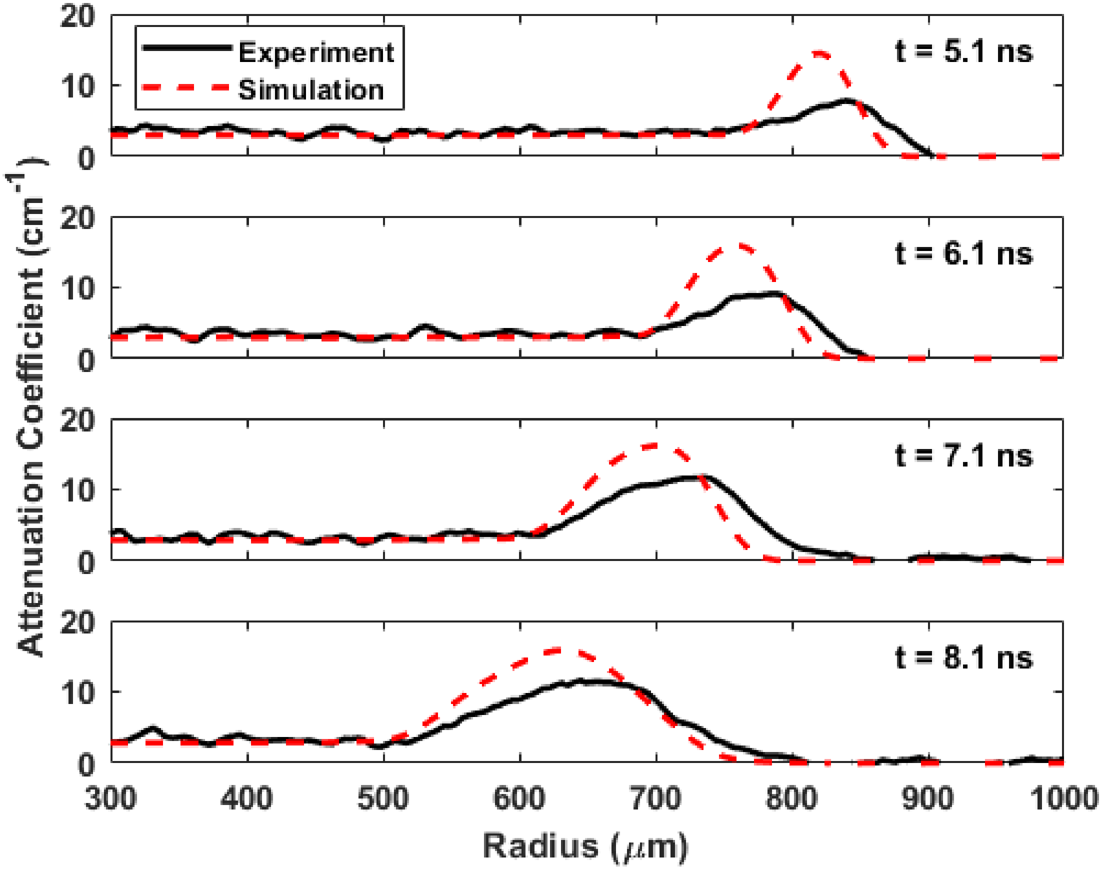

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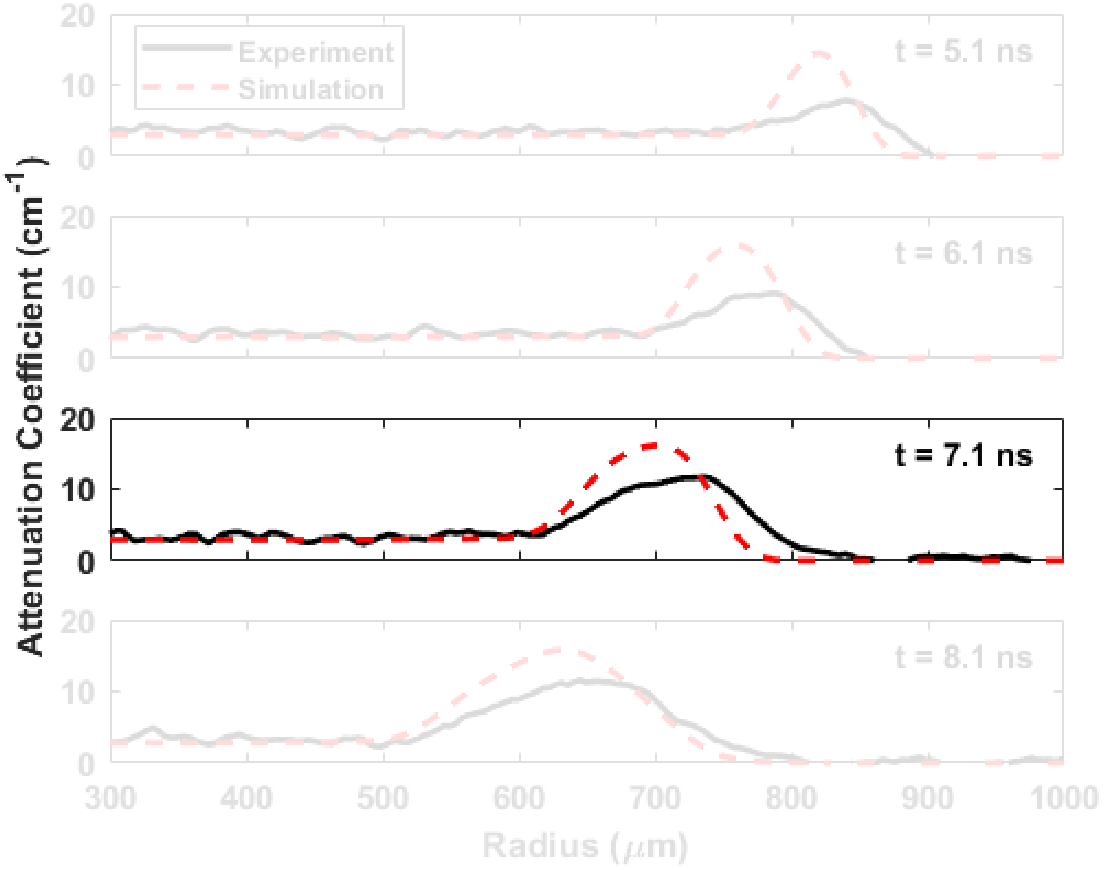
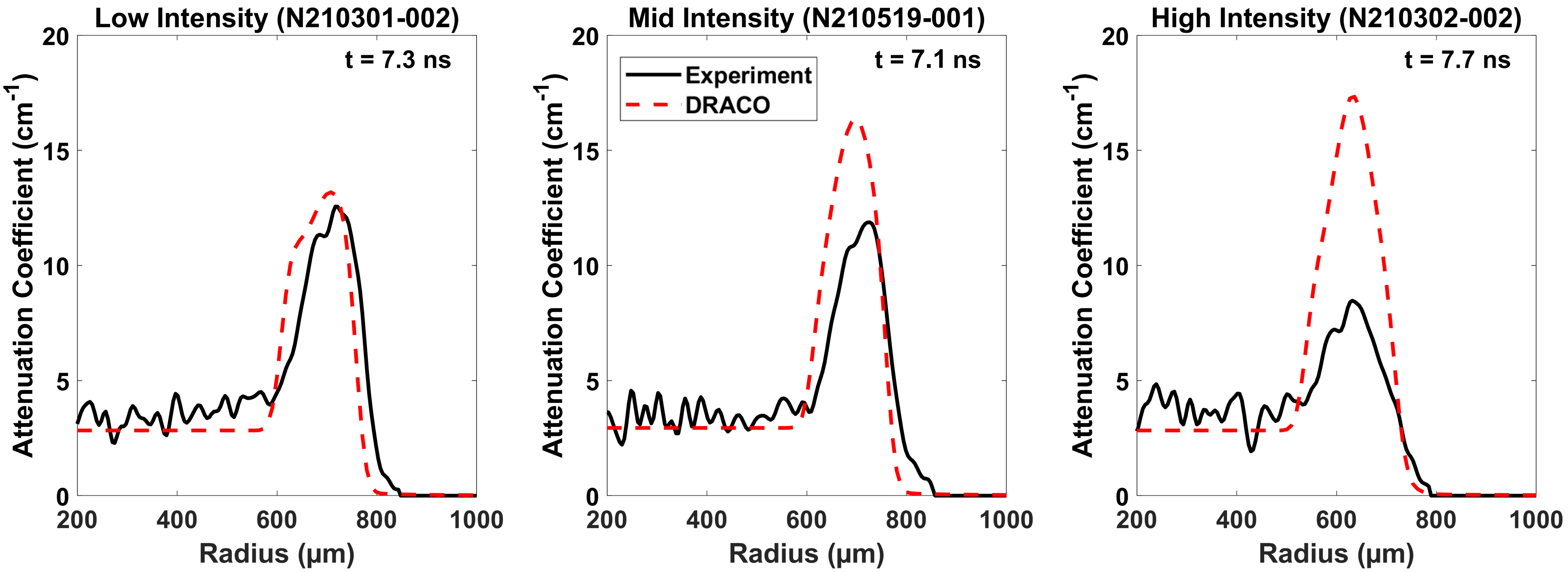
The same analysis applied to post-processed *DRACO* simulations shows significant differences in ablation trajectory and overall attenuation



The width of the shocked region is underpredicted by simulations and cannot be due to hydrodynamic instabilities

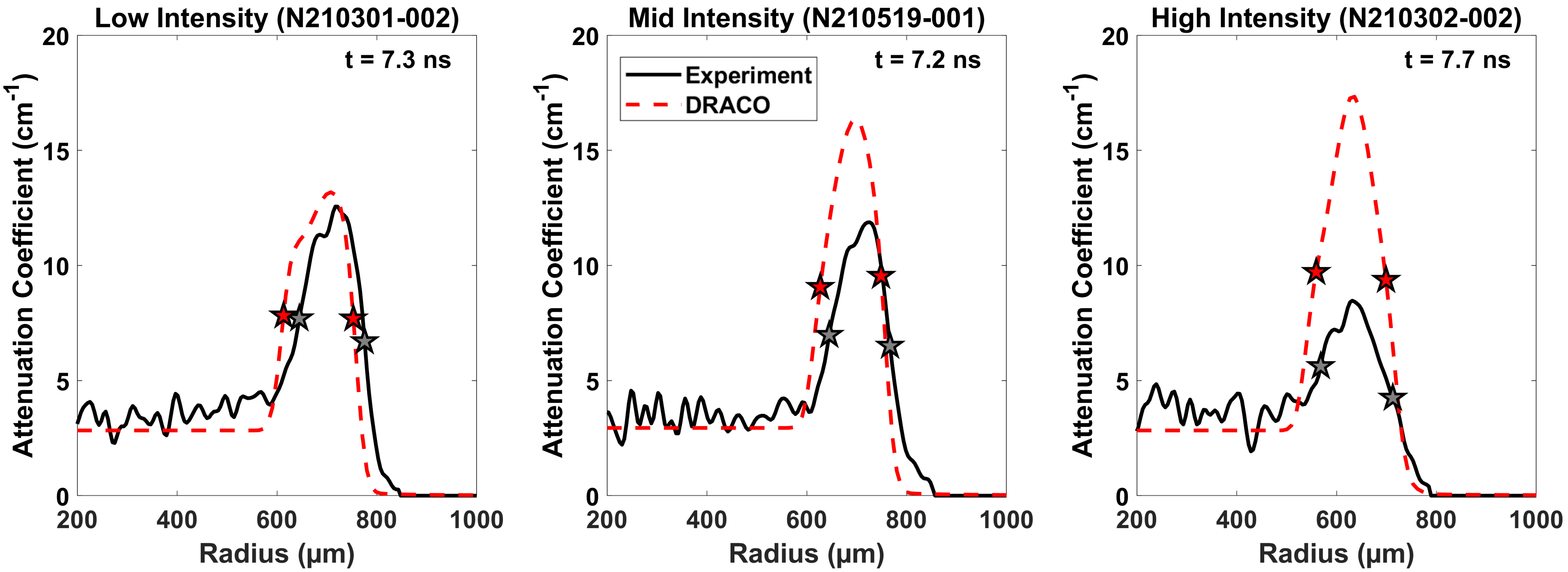
Profile shapes become more discrepant between experiment and simulations at lower intensities



Ionization in shocked region lowers opacity in experiment, but shape discrepancies are still under investigation*

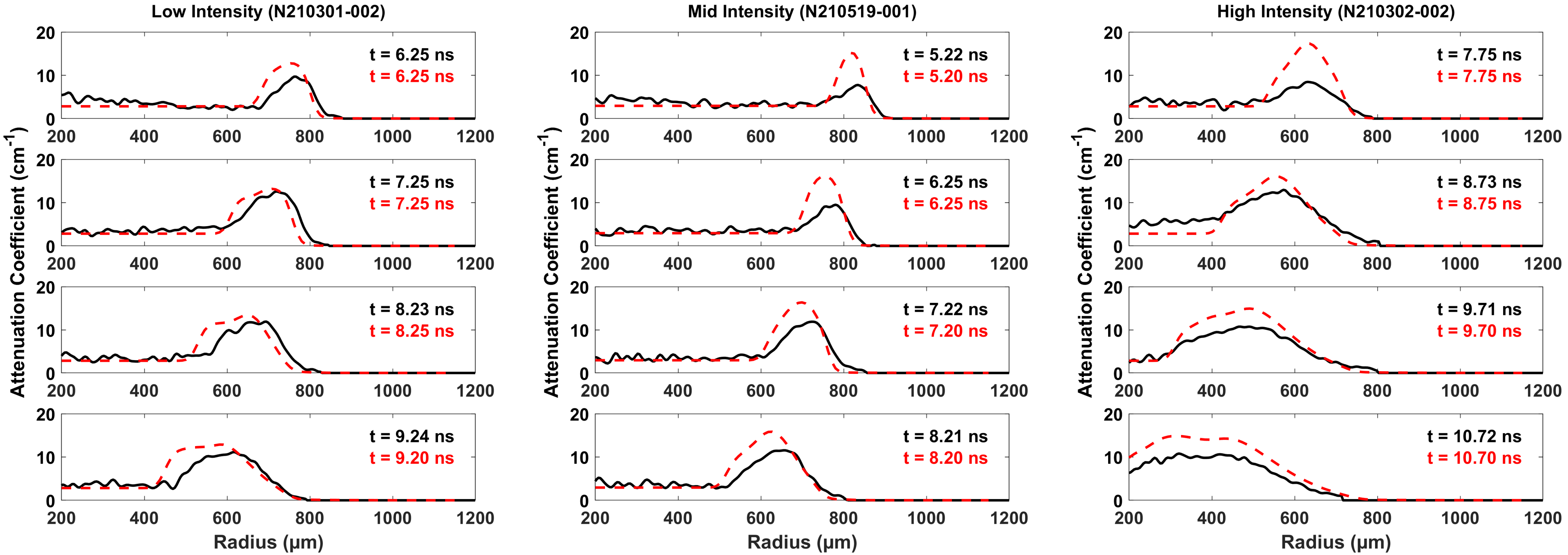
* Backscatter analysis: S. Kostick CO04.00009

The same analysis applied to post-processed *DRACO* simulations shows significant differences, particularly at lower intensities



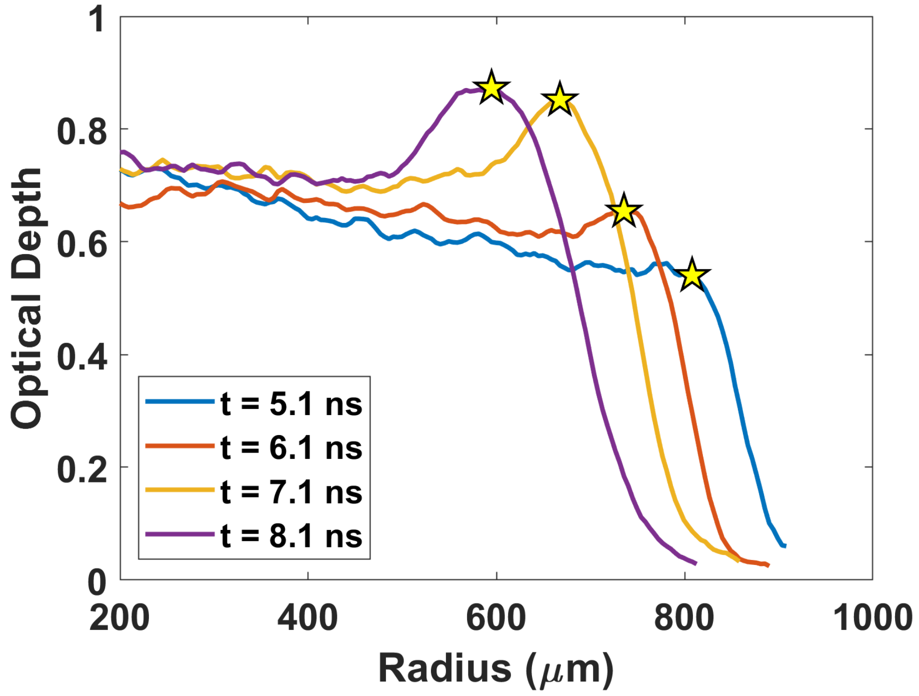
Plot the 50% rise and fall surfaces

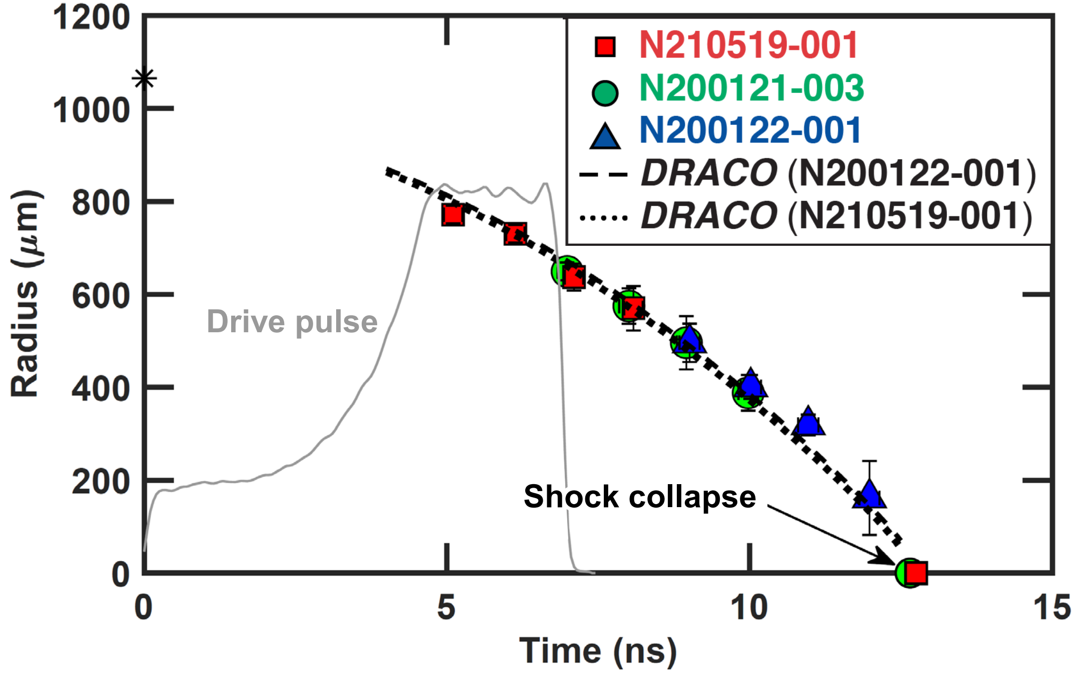
The same analysis applied to post-processed *DRACO* simulations shows significant differences in ablation trajectory and overall attenuation



The width of the shocked region is underpredicted by simulations and cannot be due to hydrodynamic instabilities

Shock trajectories were previously calculated by tracking the maximum optical depth in each line out*, showing good agreement with 2D *DRACO* simulations**

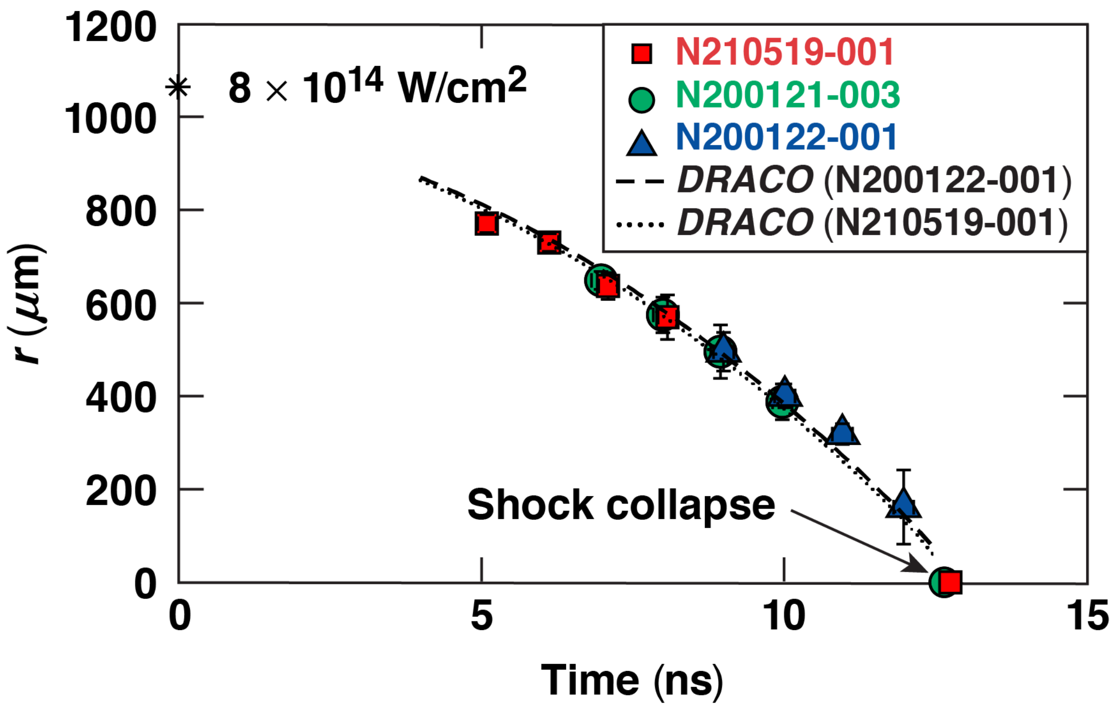




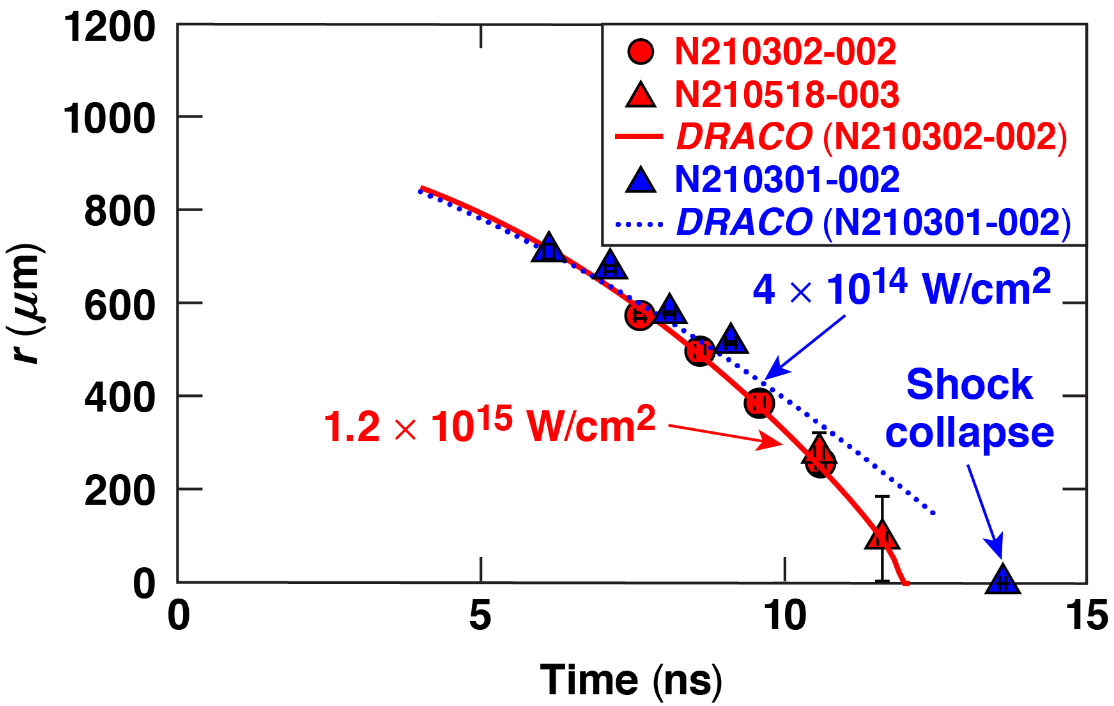
The simulations were post-processed with *Spect3D*† and take the instrument response function into account

* Trajectory analysis performed by Wolfgang Theobald
** P. B. Radha et al., Physics of Plasmas 12, 032702 (2005).
† J. J. MacFarlane *et al.*, High Energy Density Phys. 3, 181 (2007).

The radius of minimum transmission, corresponding roughly to the shock front position, is in good agreement between the experiment and simulations



E29885

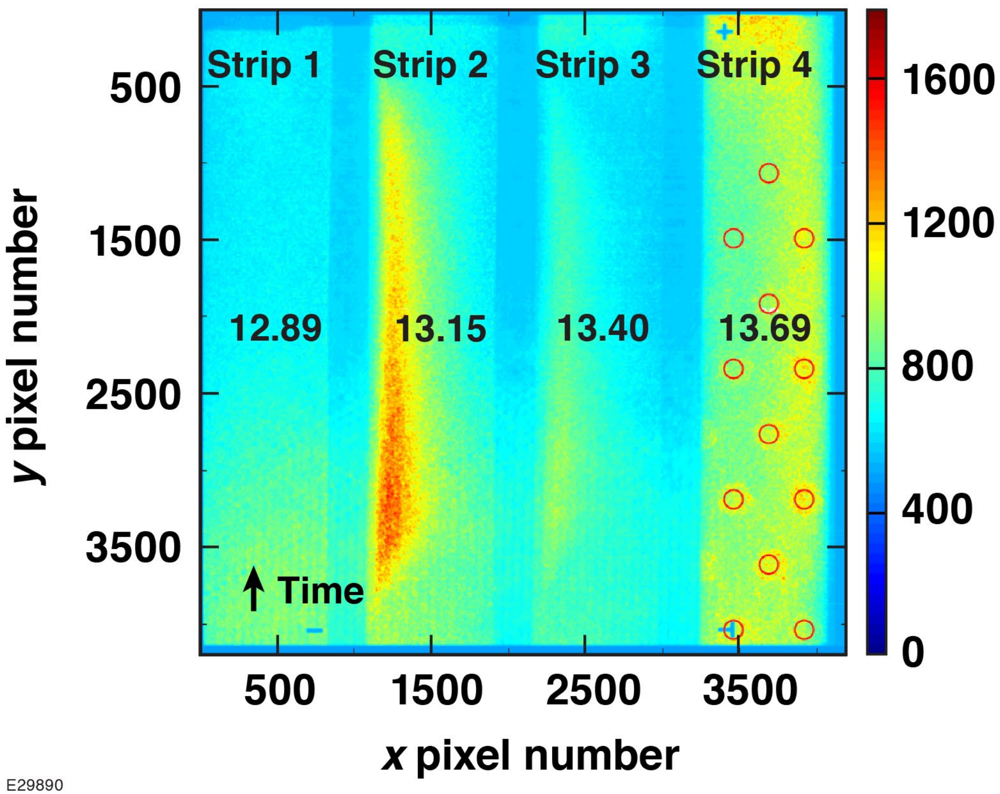


E29889

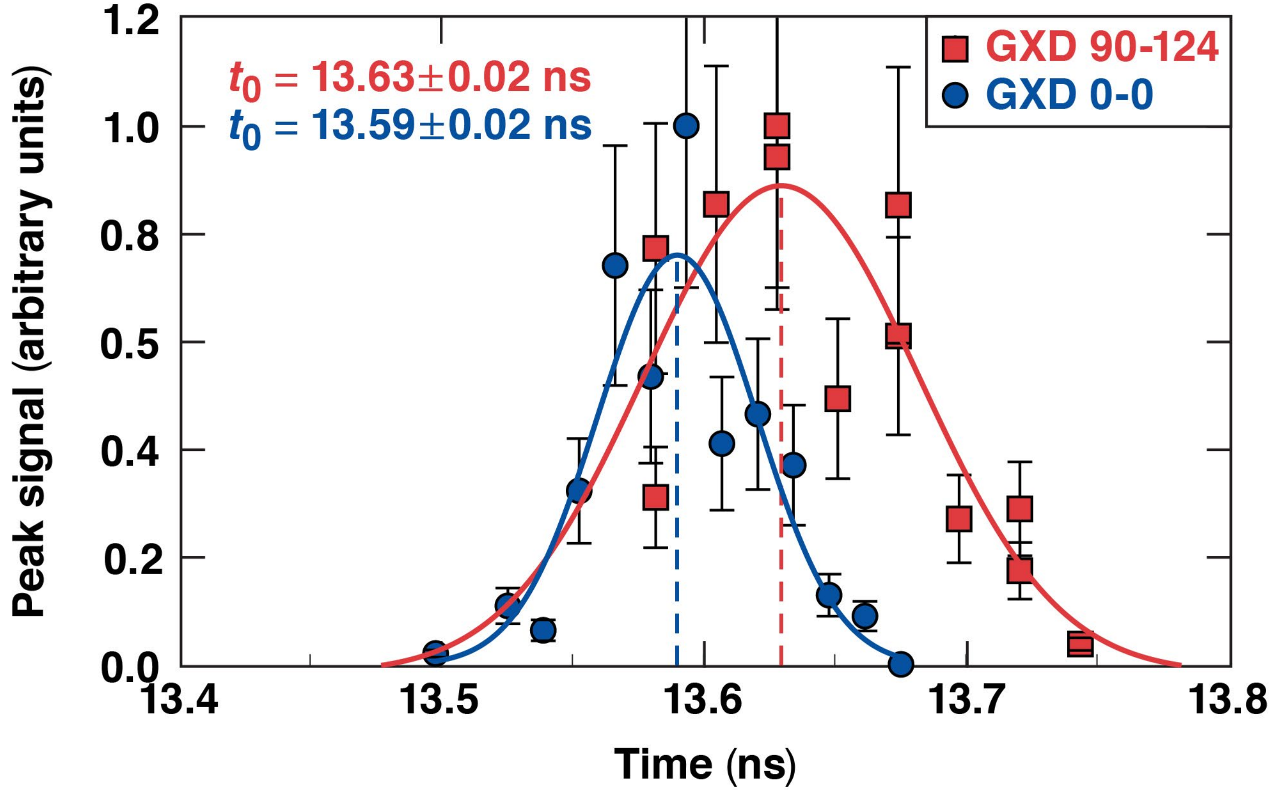
Using this method, the shock velocity is inferred to be approximately 4 ± 3% lower in experiment, requiring additional accuracy in future measurements.

The arrival time of the shock in the center of the sphere was measured at 4×10^{14} W/cm^2 from the x-ray flash created by the shock collapse

Raw image GXD 0-0: N210301-002



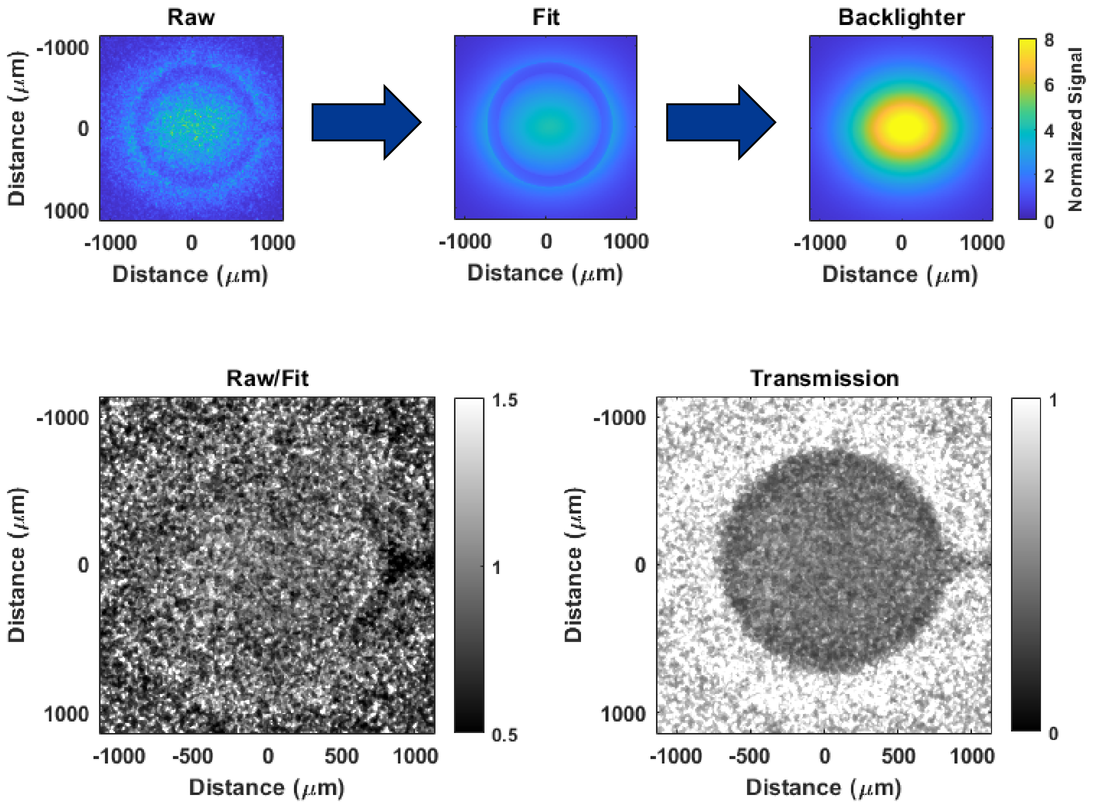
Flash time: N210301-002



E29890

The x-ray flash time from both diagnostics is in agreement, providing an average value of 13.61±0.05 ns, which will be compared to radiation-hydrodynamic simulations.

Backlighter profiles are inferred from fits and used to produce transmission profiles in each strip



Backlighter
Two elliptical, rotatable super-Gaussians

Transmission
<u>Forward Abel transform of:</u> Unshocked sphere $(\rho_0\mu_0)$ Linear Rise Shocked shell $(\rho_h\mu_h)$ Linear Fall

$$\rho_0 = 1.07\ \mathrm{g/cm^3}$$
$$\mu_0 = 3.2\ \mathrm{cm^2/g}$$