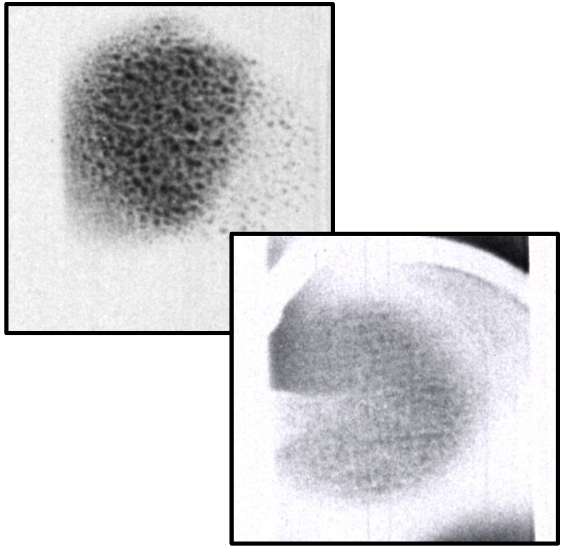
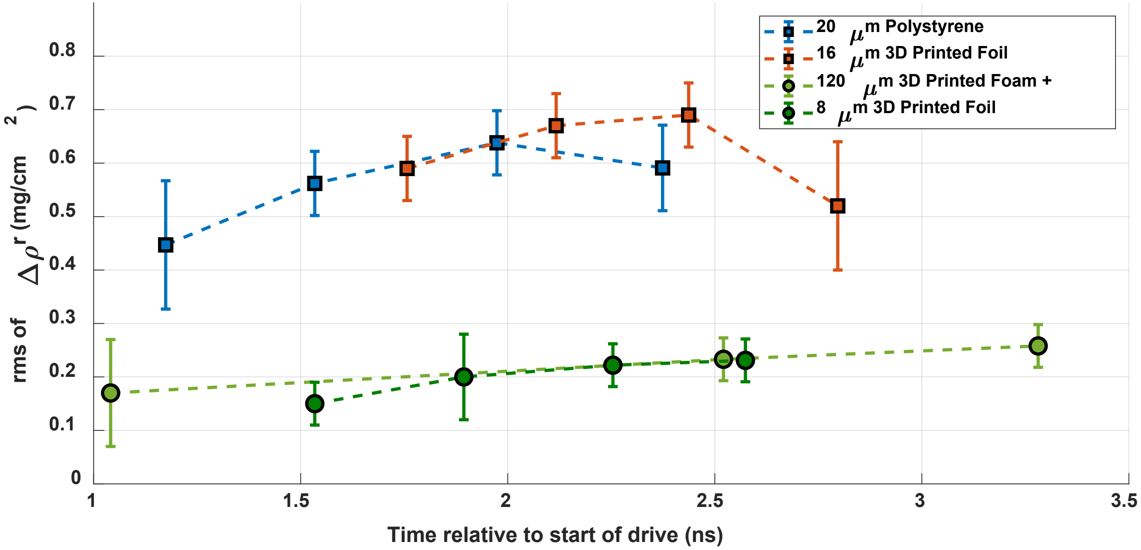
Measurements of Laser-Imprint Mitigation Using an Above-Critical-Density Foam Layer for Direct-Drive Inertial Confinement Fusion





J. L. Peebles
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APS-DPP 2022
Spokane, WA
October 20, 2021

Summary

The introduction of an over-dense foam layer fully mitigated laser imprint but introduced its own perturbations

- X-ray radiography of laser imprint seeded density modulations grown via the Rayleigh—Taylor instability demonstrate the effect of laser imprint which must be mitigated for improving laser direct drive implosions

- An above-critical-density foam layer can increase the scale length and ablation velocity, reducing the growth rate of the laser imprint modulations

- Experiments have tested and iterated on designs for 2PP printed planar foams, which eliminate laser imprint modes but introduce lower magnitude modes based on foam geometry

Collaborators

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A. Mao, P. Fan, Y. Lu

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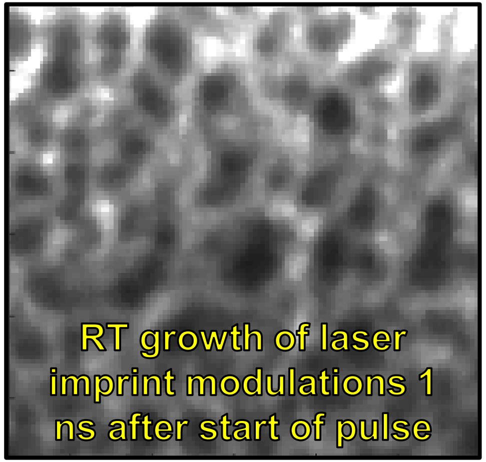
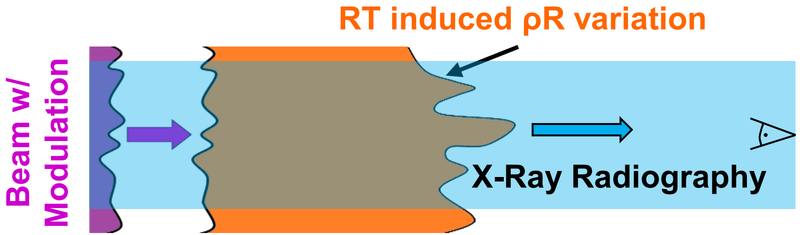
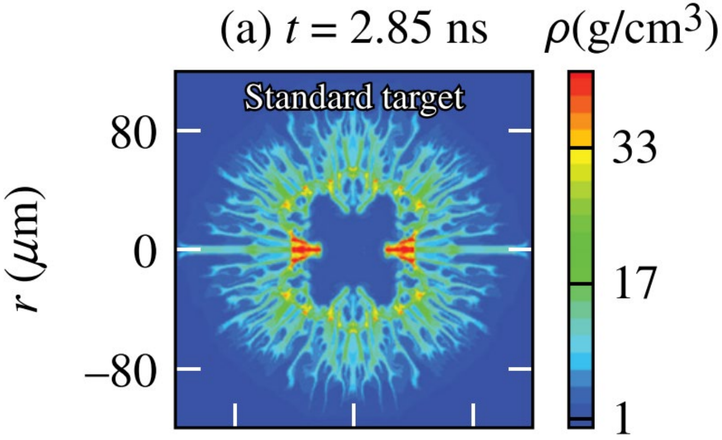
Laser imprint leads to shredding of the shell during direct drive implosions, potentially reducing performance







DRACO simulation:
Shredded shell from RT grown laser imprint
S. X. Hu *et al.*, Phys. Plasmas **25**, 082710 (2018)

For more information on laser imprint's effects on direct drive ICF performance see Wednesday's invited talk:

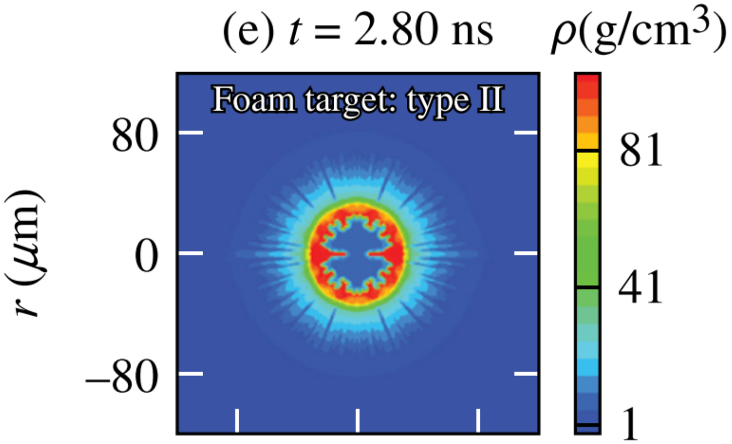
J. Knauer NI02.00002: A Systematic Study of Laser Imprint for Direct Drive—From Seeds to Integrated Implosions

Introduction of a foam layer can reduce Rayleigh-Taylor growth rate of laser imprint modulations

- Rayleigh-Taylor growth scales inverse to scale-length and ablation velocity
- The foam layer increases both parameters, reducing R-T growth

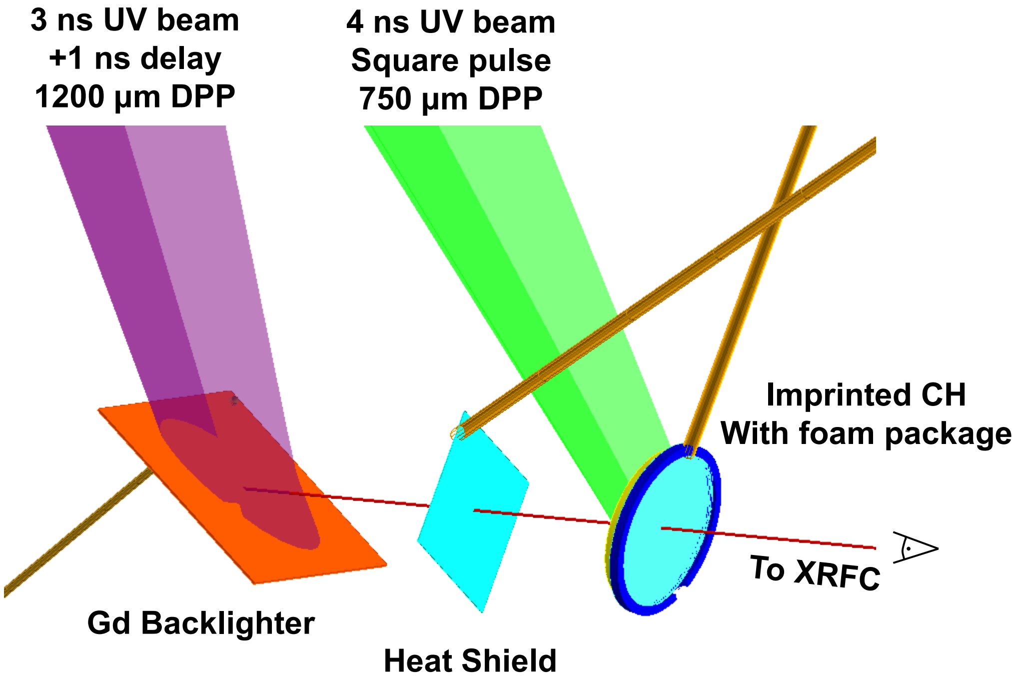
$$\gamma(k) = 0.94 \times \sqrt{\frac{ak}{1 + kL_n}} - 1.5 \times k v_{abl}$$

- Initial experiments with CRF foam indicated a shell with half the mass as foam would sufficiently suppress laser imprint

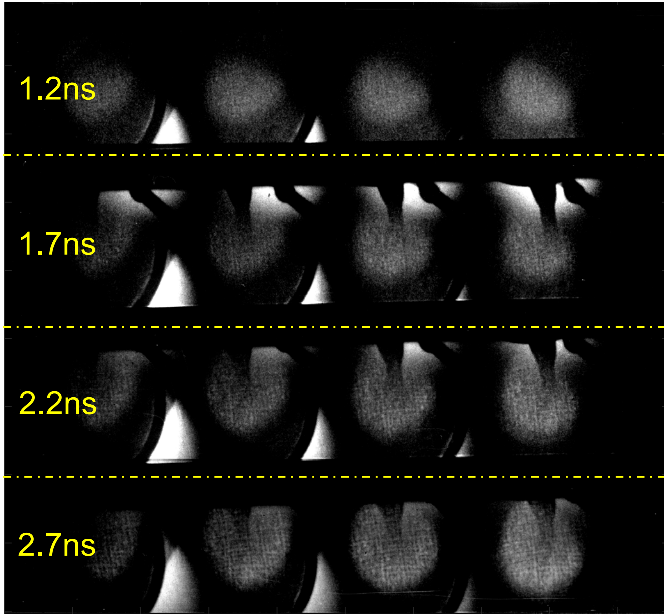


DRACO simulation:
Shell intact with added foam layer
S. X. Hu *et al.*, Phys. Plasmas **25**, 082710 (2018)

Face-on radiography experiments were performed on OMEGA EP to determine the effectiveness of AM foam as an imprint mitigator



Note EP beams do not have SSD smoothing

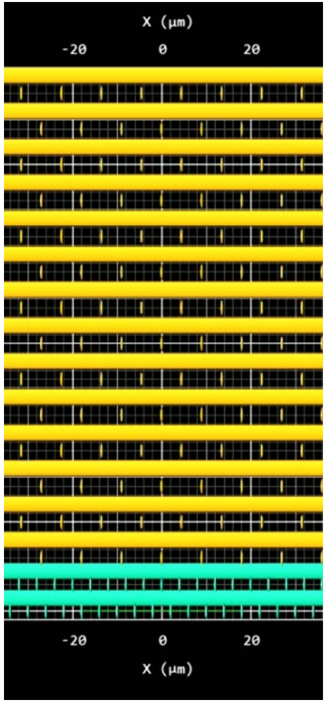


16 pinhole array XRFC
15 μm pinholes – 6x magnification

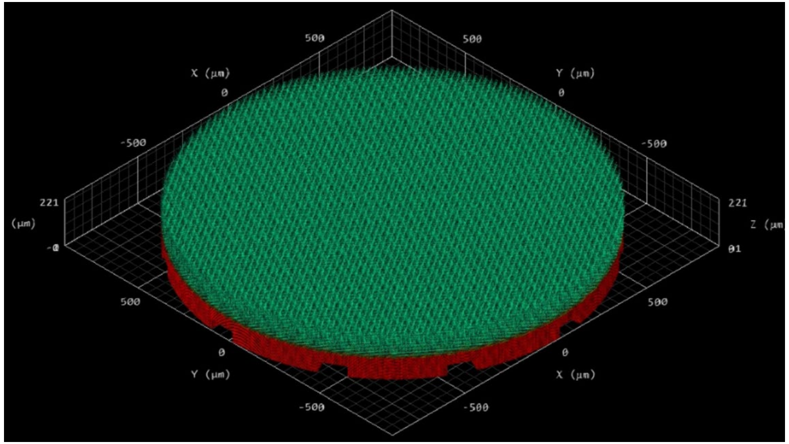
Foams are built using the 2PP process, also known as additive manufacturing or log pile structures

UR LLE

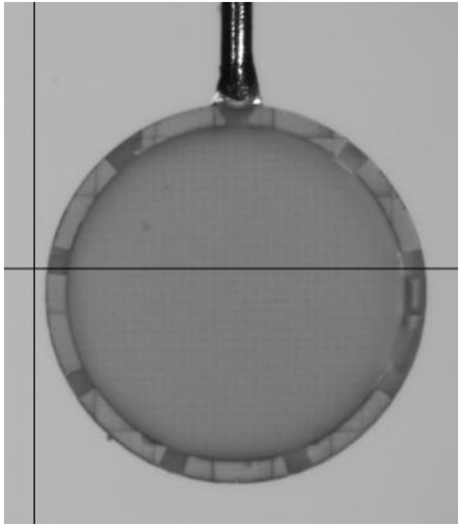
Filament thickness can be down to 500 nm



Foam cross section



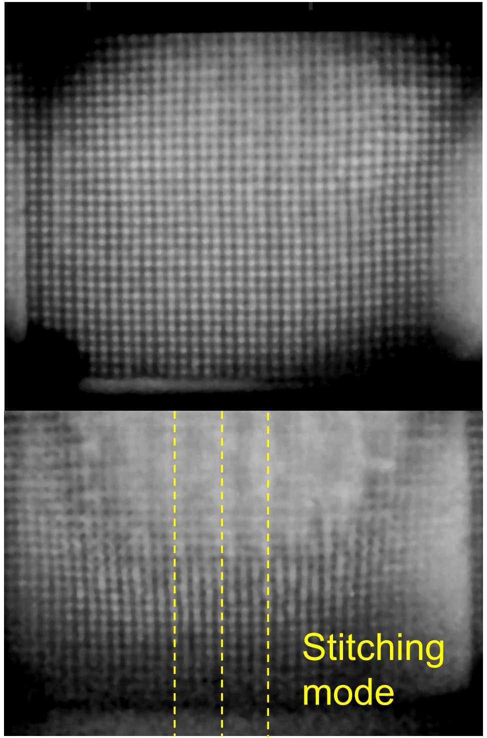
Cross section applied to target
Red is solid printed material (not foam)



Final target build

Early iterations of foam targets had a few challenges

- First foams had “stitching” which greatly increases print speed but introduces significant density modulations
  - Stitching was removed on subsequent targets
- Attaching foams to pre-existing polystyrene foil lead to inconsistent results
  - Print a solid target with foam on top
- Large pore size lead to target driven modulations
  - Data indicated that bottom interface layers coupled the most so pore size was decreased for these layers



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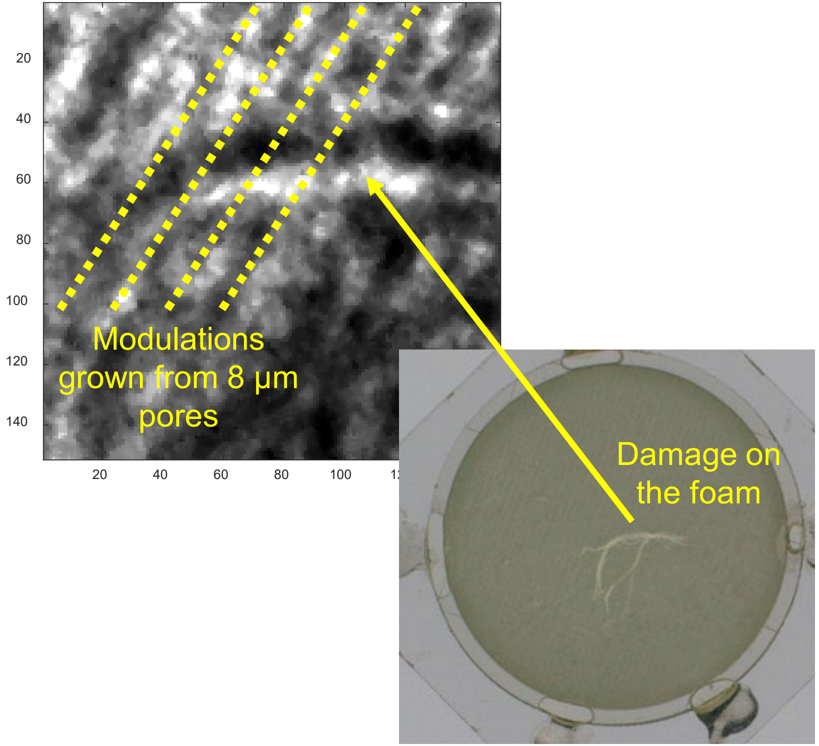
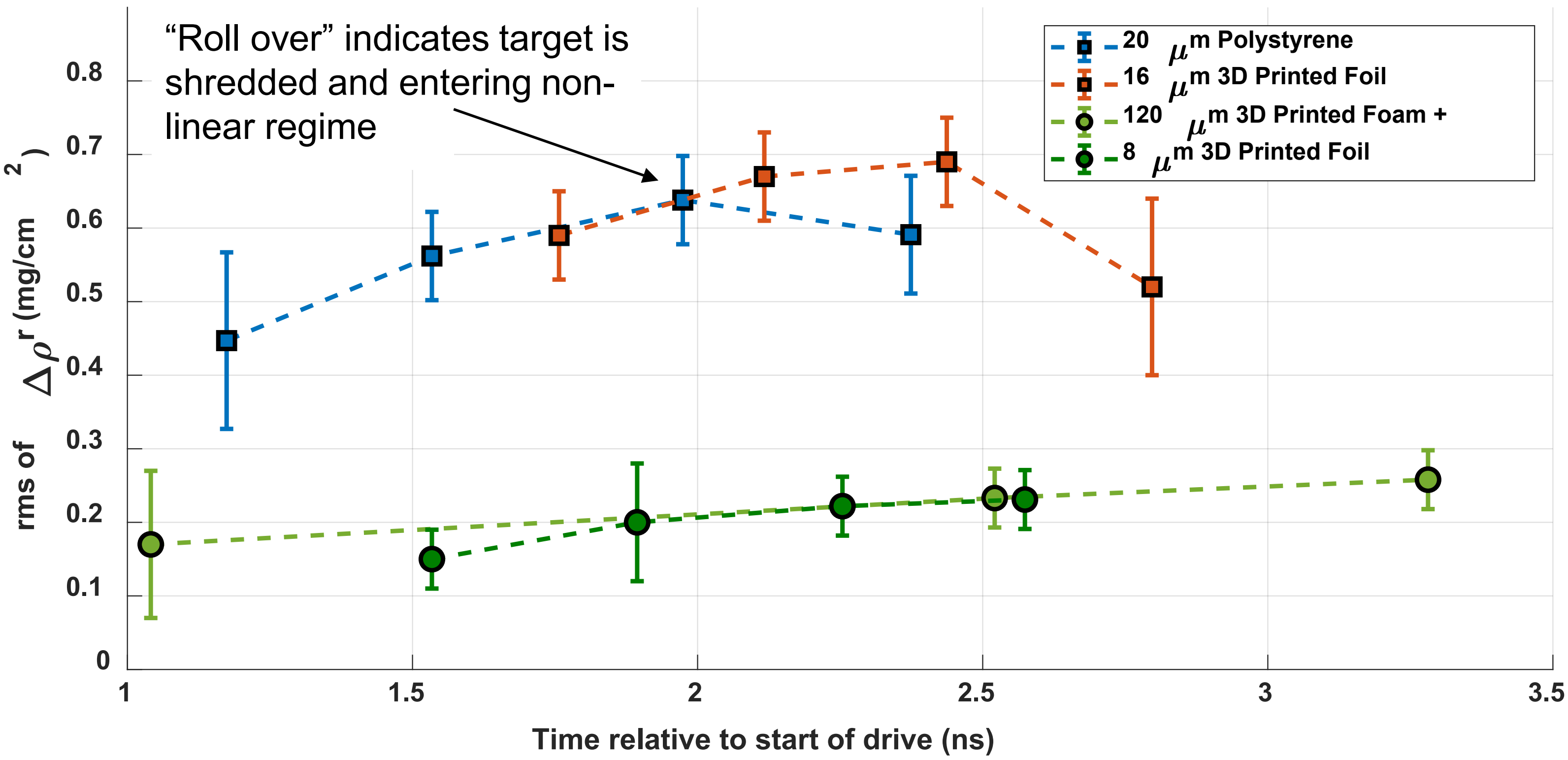
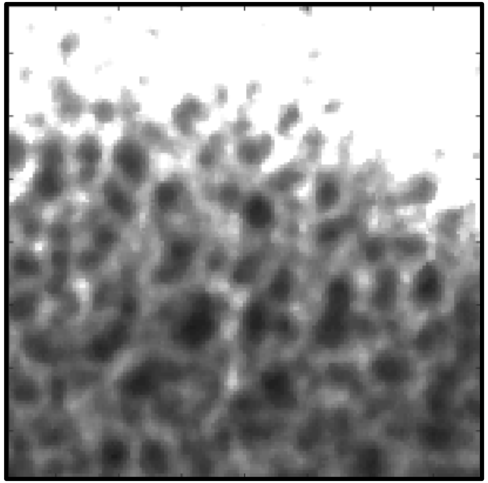


Foam targets showed substantial smoothing, new modulations from the target grew in time, but did not saturate

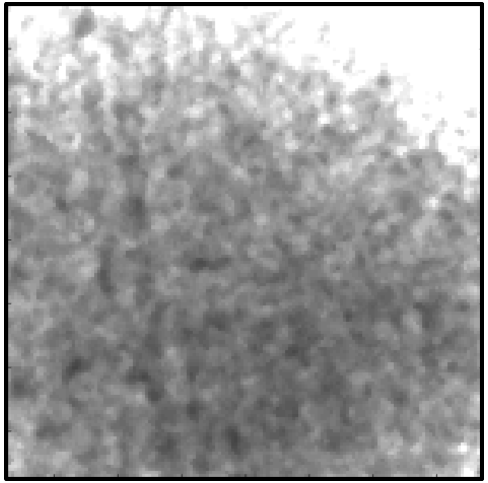


Late time growth is observed in target modes, initial conditions are determined by pore size

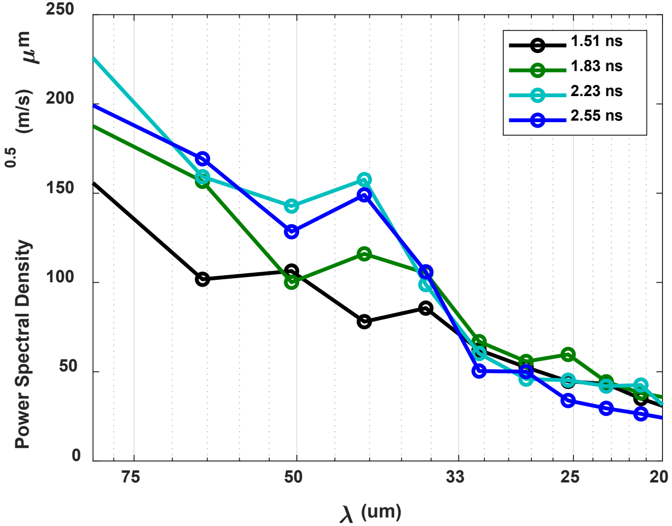
3D Printed Foil



3D Printed Foil + Foam

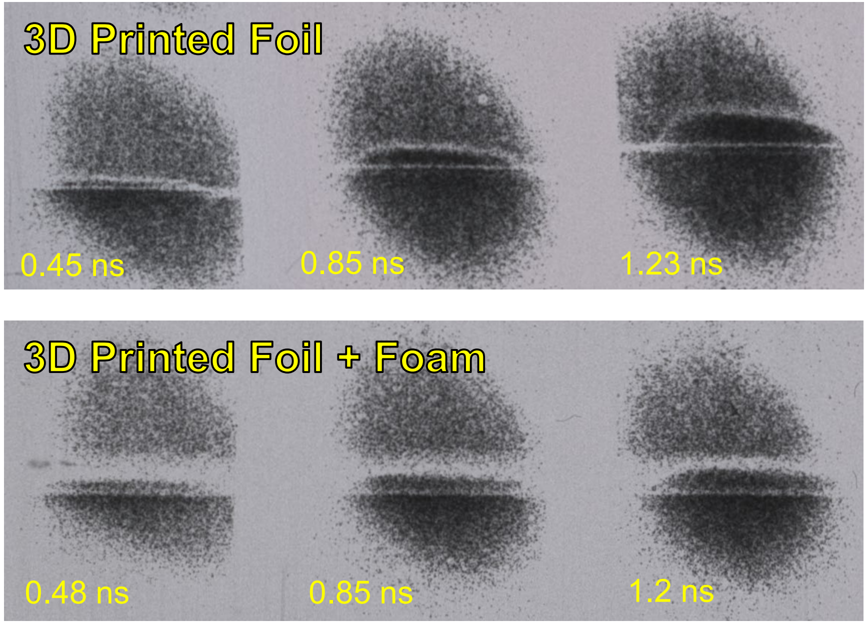


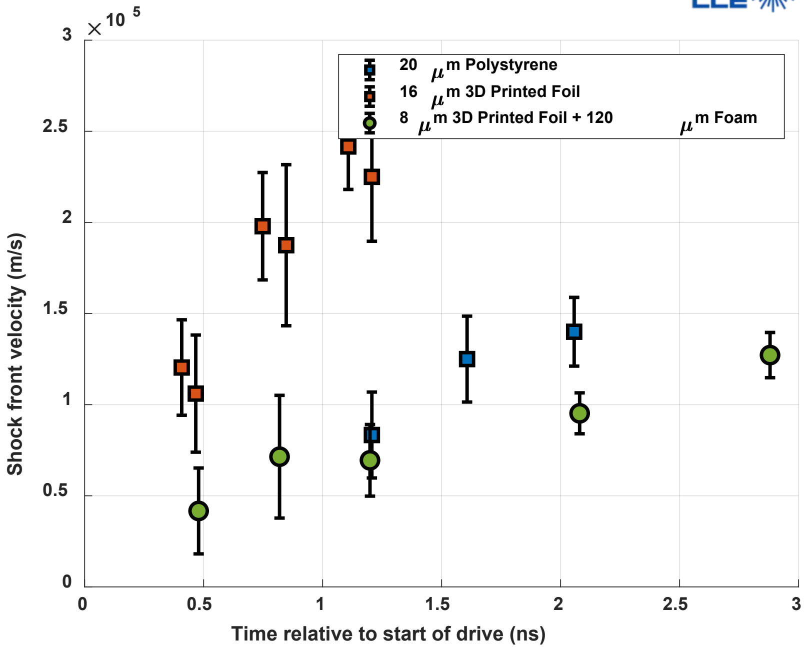
Spectral evolution for foam targets



- Initial pores grow in mode size and amplitude over time
- Initial growth can be controlled and reduced by printing finer resolution pores or by pre-expanding the coating with a low intensity pulse

Foam targets have different trajectories from foil targets, which may cause delayed growth of modulations

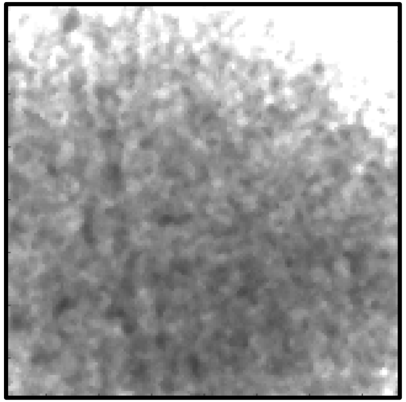


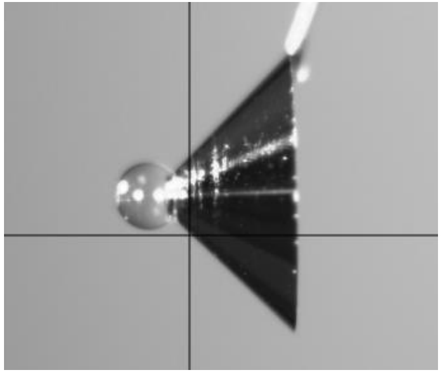


- Foam targets reached comparable velocities as polystyrene, but are delayed in time
- 3D printed foils appeared more responsive, foam interface appears to cause slower shock speed

Further mitigation of target modes and moving forward with spherical targets

- While target modes are lower magnitude than laser imprint modes, they still require more mitigation for use in Laser Direct Drive
  - The foam layer provides a good location to apply a high Z coating, which can be used to pre-expand the foam (similar to “Hybrid” targets)
- Fully spherical targets have a few engineering challenges
  - How well does 3D printed material hold fuel?
  - The printer resolution (500 nm) means spheres are approximated with steps, which could introduce modes
  - First spherical tests are underway – Q2FY23





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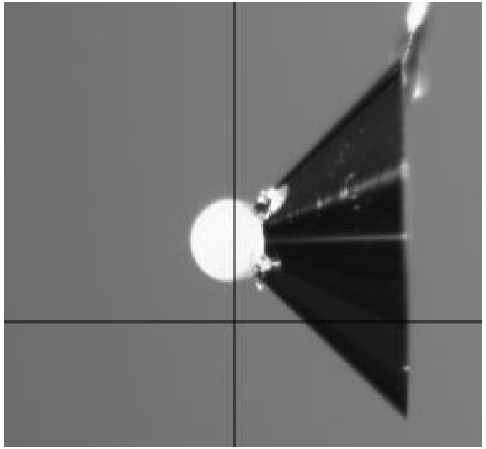
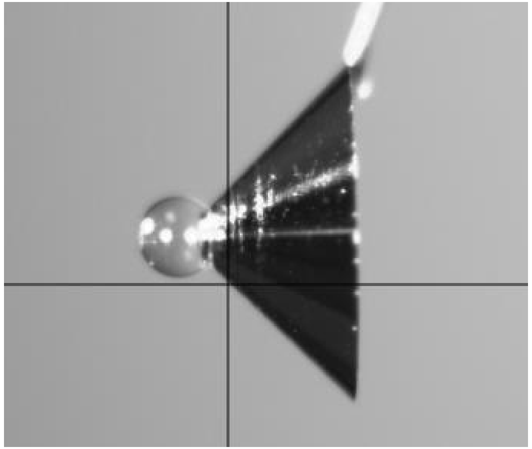
Extras

Moving forward with spherical targets

Initial cone in shell shot day examined feasibility of building foams and solid material in a sphere





Engineering challenges for spheres:

- Inner shell has roughness of printer resolution
- Removing resin requires a larger hole than typical targets
- Resolution and total print size are related when printing targets without stitching

Full spherical test coming in FY23
Primary goal is to verify gas retention or leaking in printed targets