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Stochastic Shock Observations from Plate Impact of Porous Tantalum

Nathan W. Moore, Gary C. Chantler, Andrew W. Vackel, Jack L. Wise, Reeju Pokharel*, Donald Brown*

Sandia National Laboratories
*Los Alamos National Laboratory

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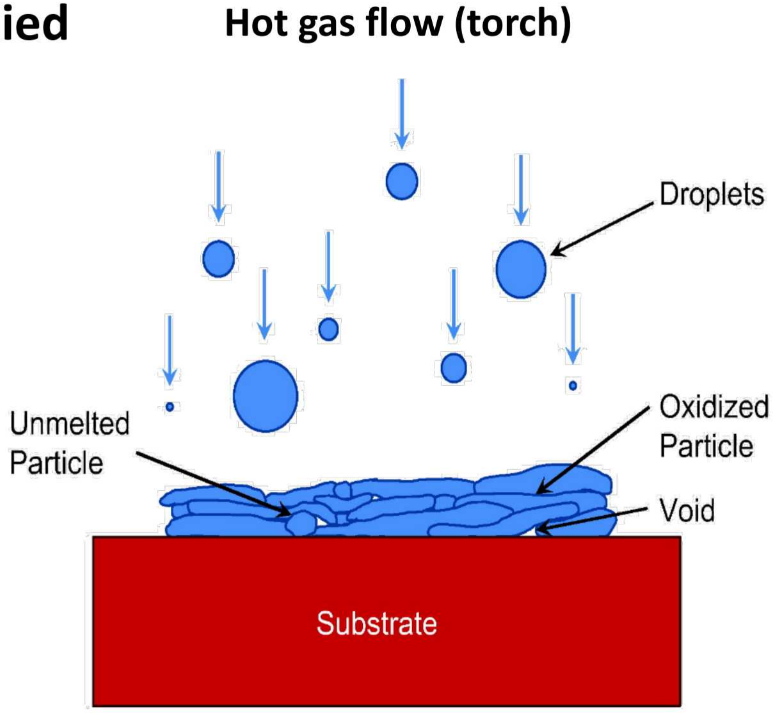
Porous Tantalum as a Stochastic Material

Shock in structured materials (e.g., additively-manufactured) is of increasing interest.

Stochastastic materials may present simpler test cases for multidimensional or reduce-order models

Porous Ta is appealing:

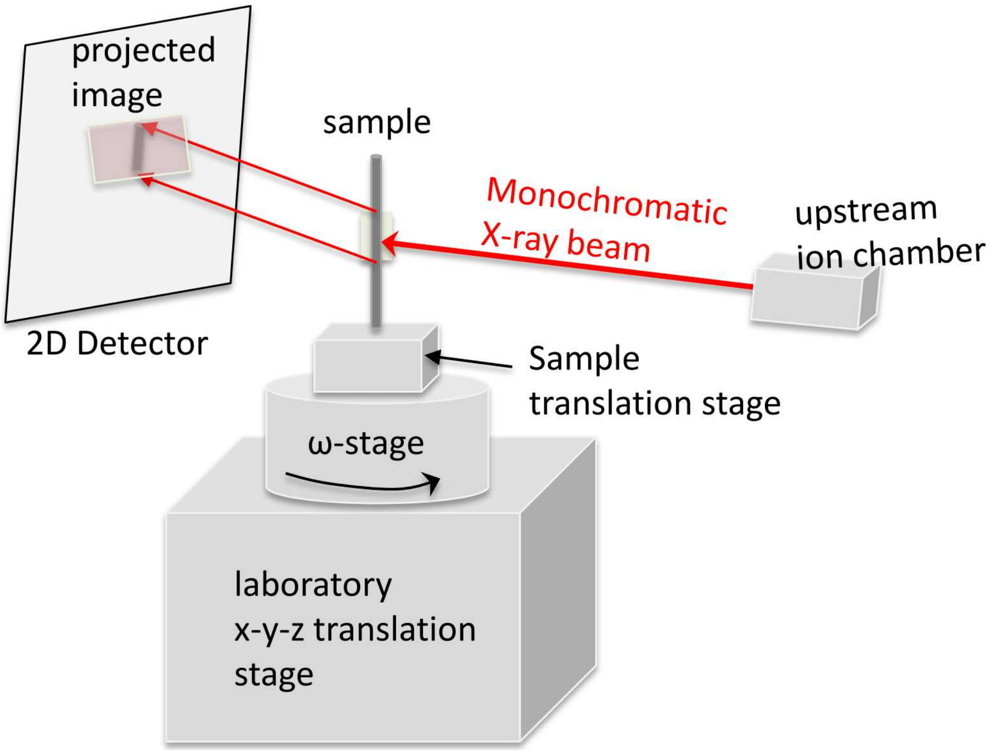
- **Shock behavior of solid Ta extensively studied**
- **Inexpensive, reproducible spray-forming**

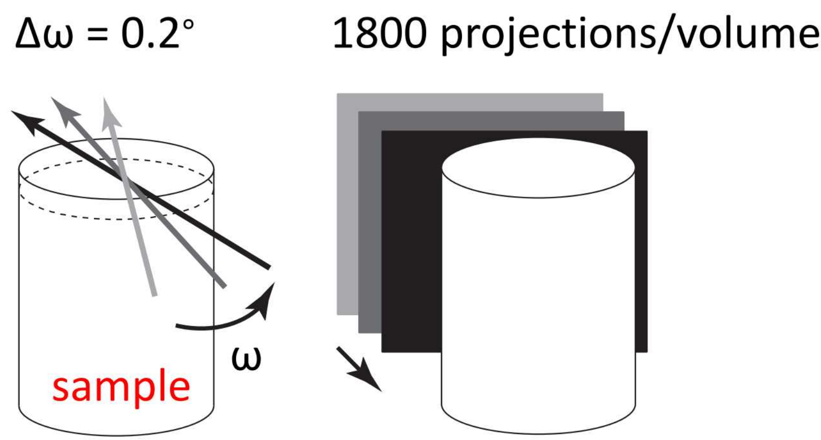


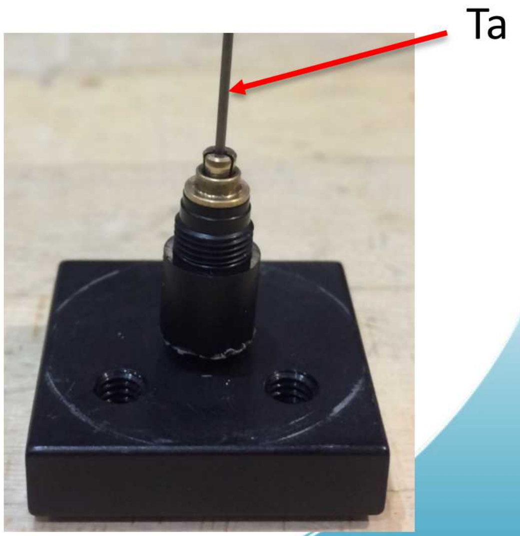
Successive coatings from molten-particle impact

Experimental setup at APS 1ID-E for x-ray tomography

Schematic of the instrument geometry





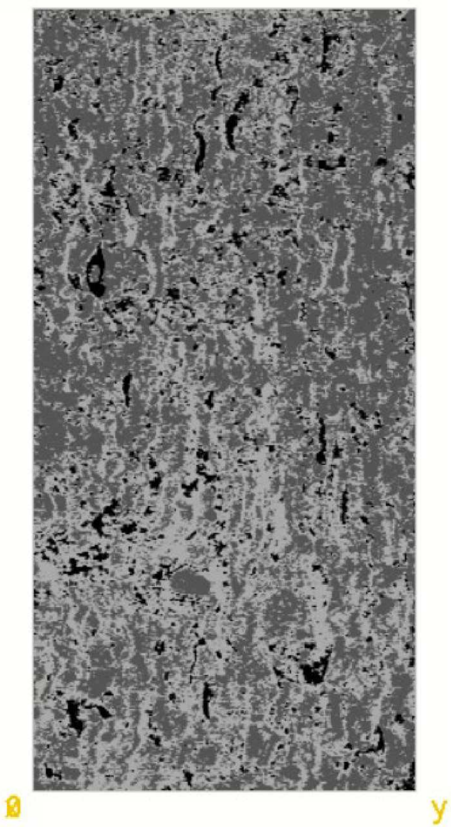


Energy = 67 keV

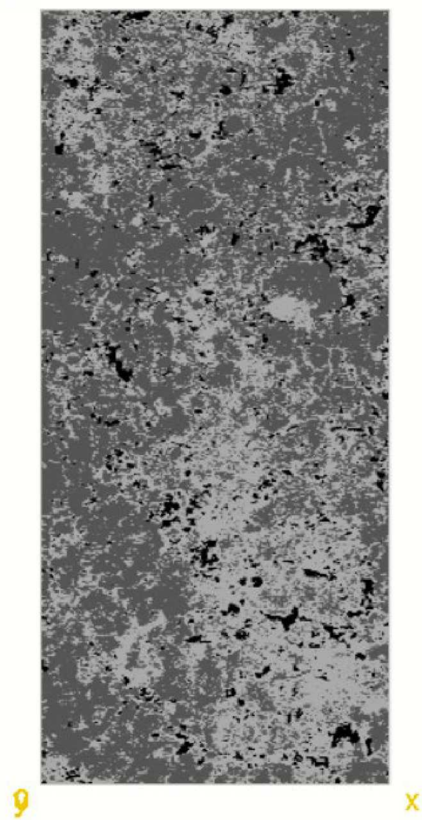
Pixel pitch = 781 nm (pre-shot) and 586 nm (post-shot)

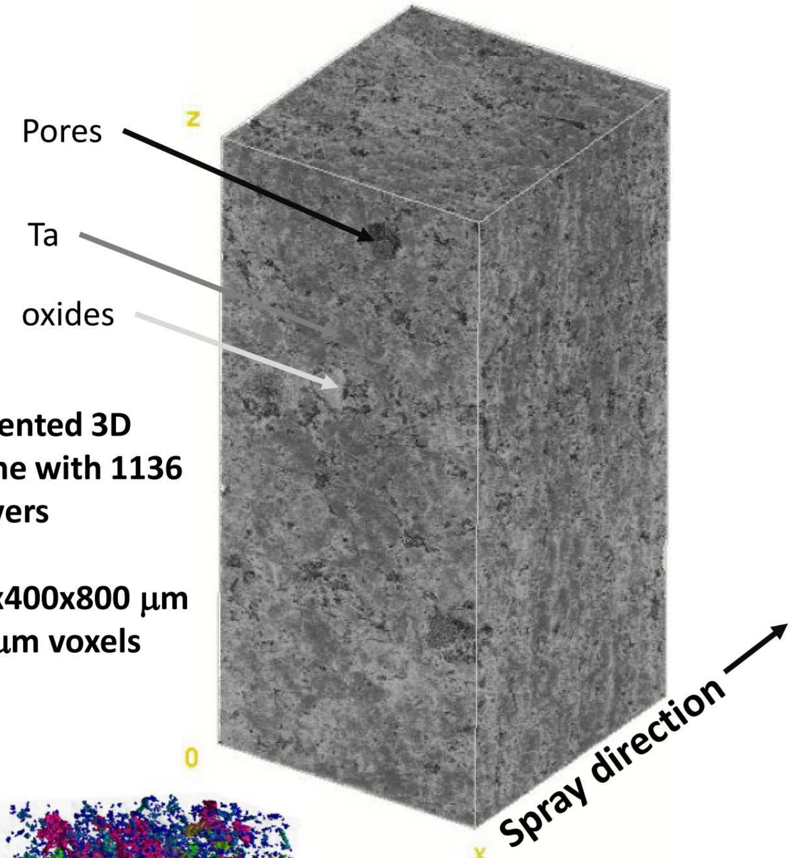
Lamellae, oxides and pores are sources of heterogeneity for shock response

YZ-slice



XZ-slice

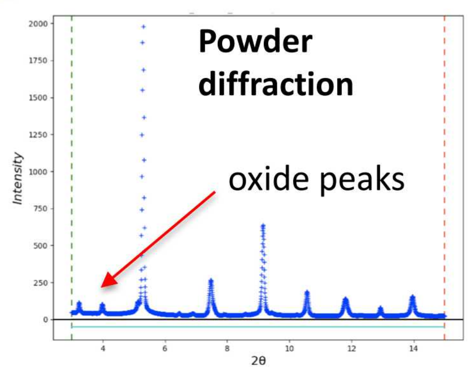


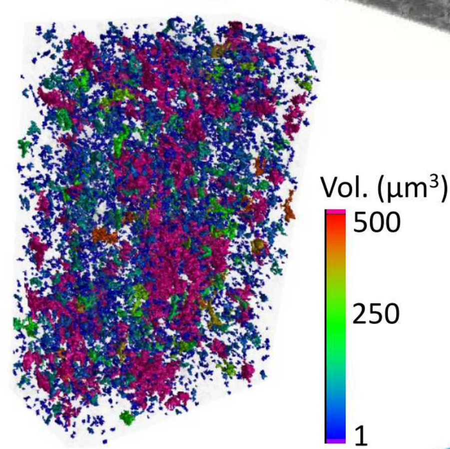


Segmented 3D volume with 1136 XY layers

~400x400x800 μm
~0.8-μm voxels

Lamella
~10-μm thick
~100-μm wide



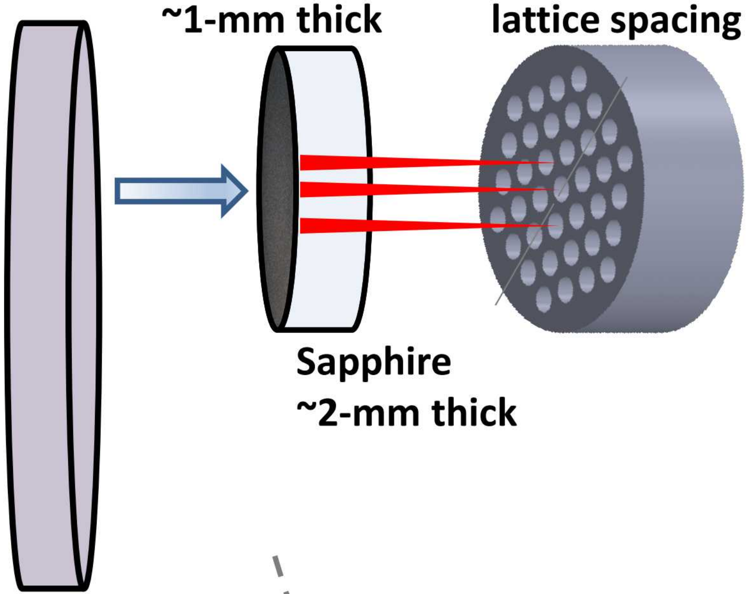


Optics Geometry

Porous Ta ~1-mm thick

2.5-mm hexagonal lattice spacing

Flyer (Al6061)

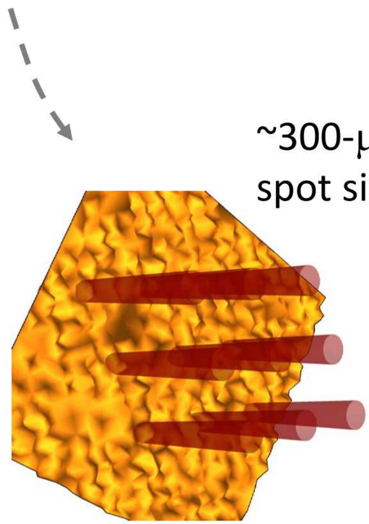


Sapphire ~2-mm thick

~300-μm spot size

Pseudo-random velocity field

Illustration, not to scale



Up to 13 probes per sample:

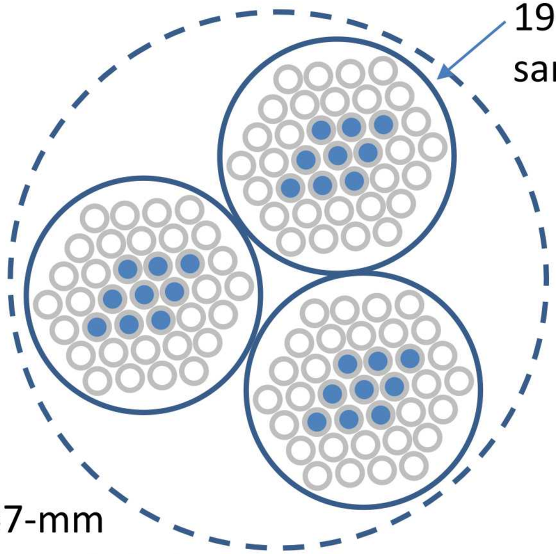
- Ascentta "triangle" probes
- 0° polished bare fiber
- Dual fiber send/receive configuration

Three interferometer types:

- Photonic Doppler Velocimetry (PDV)
- Photonic Displacement Interferometer (PDI)
- VISAR

Up to 3 samples per shot:

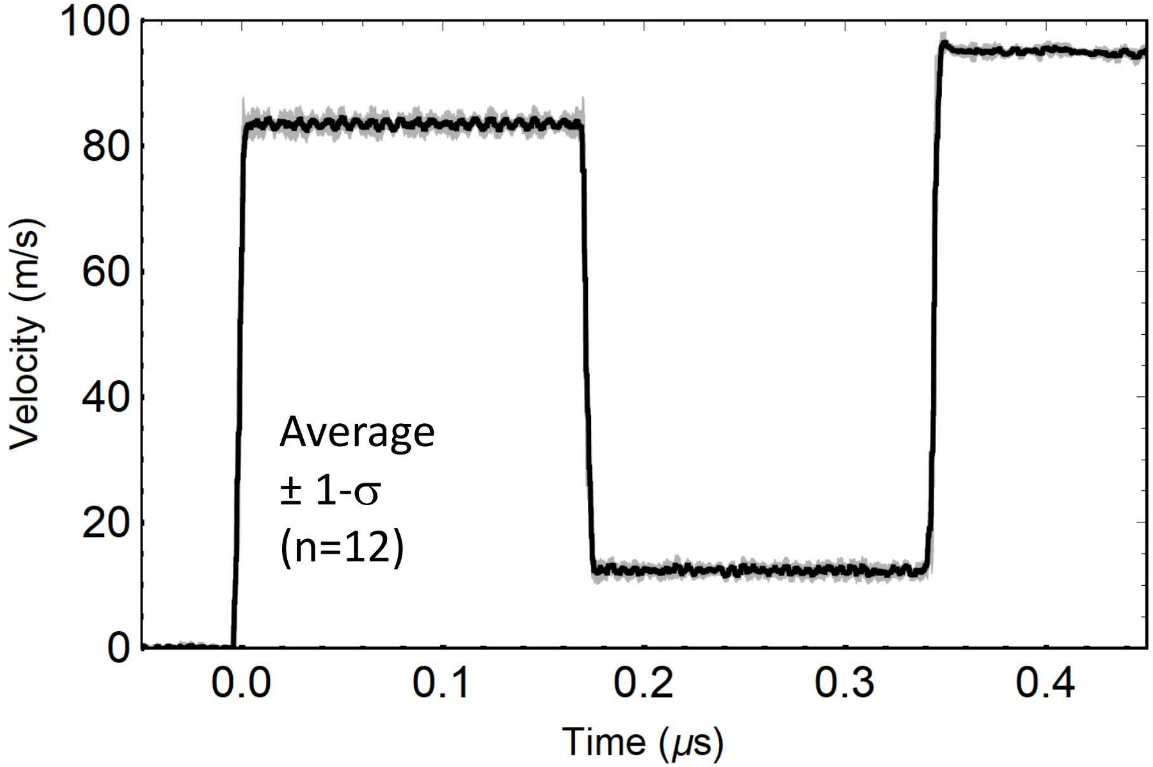
19-mm OD samples



57-mm impact circle

Lattice is removed for VISAR

Symmetric Sapphire-Sapphire Impact

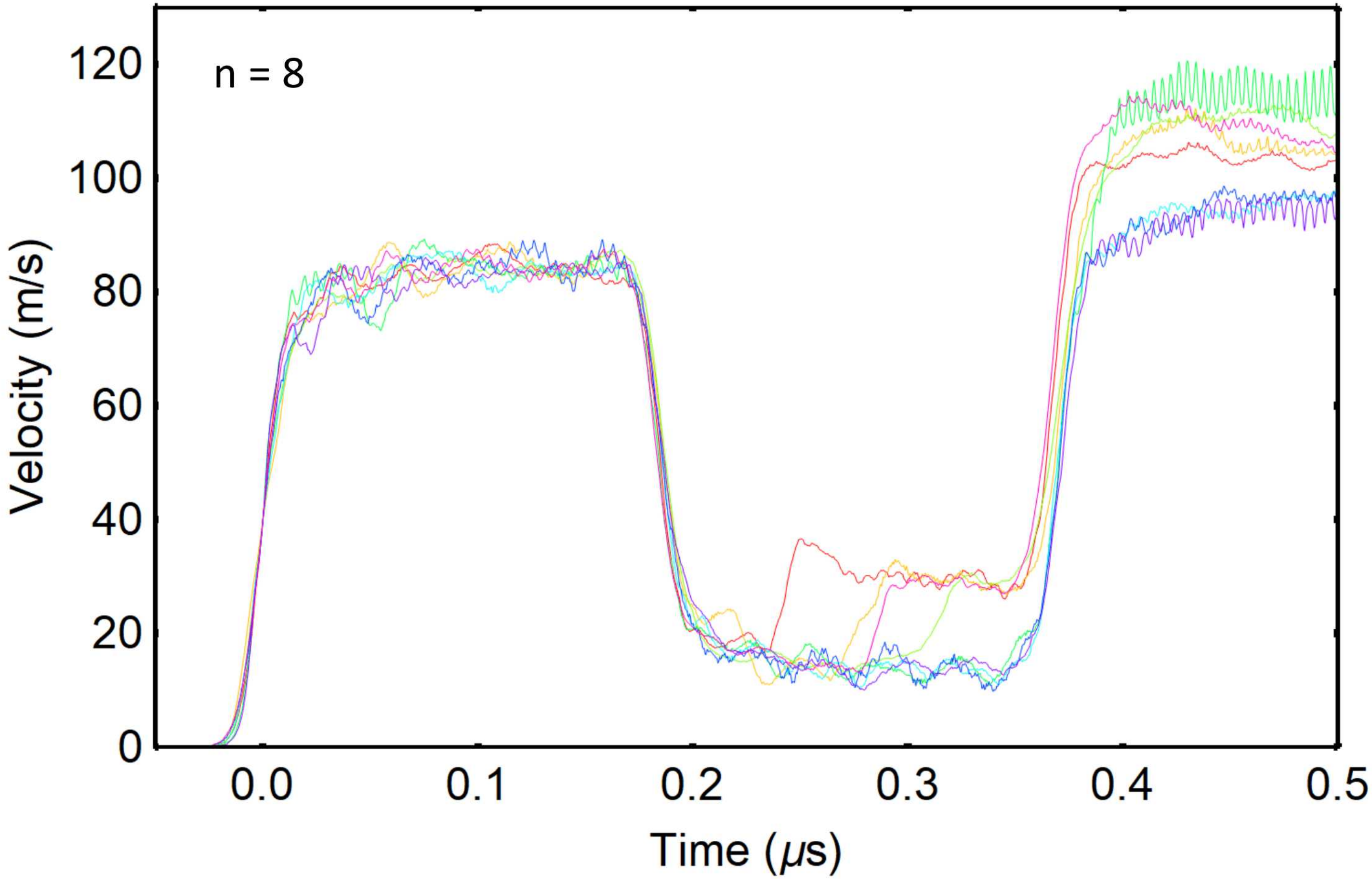


Average of PDI and PDV

3 other control shots produced comparable results

PDV, PDI, and VISAR (not shown) give same mean plateau velocity within ~1 m/s (standard deviation)

Forward Ballistic Impact of Porous Tantalum

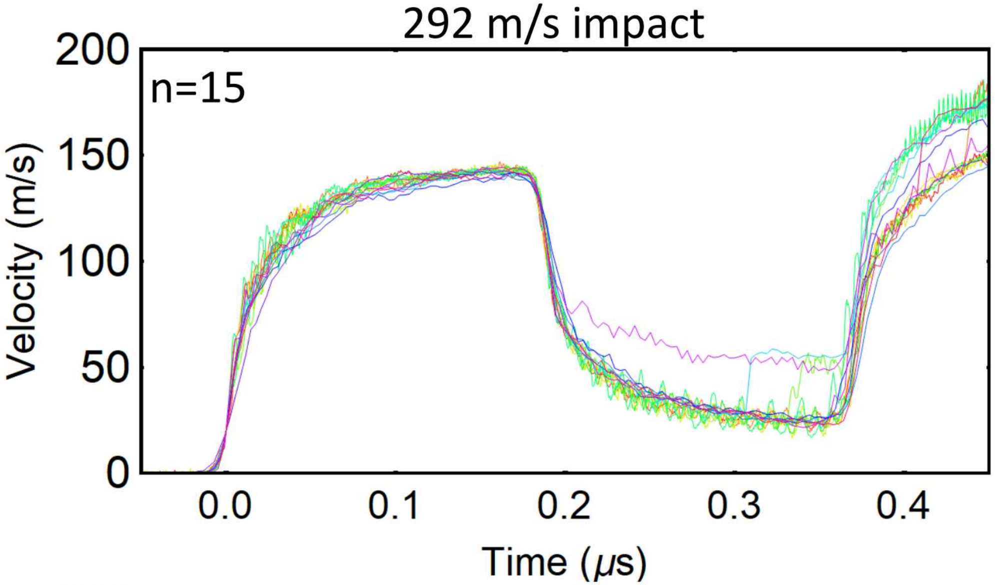


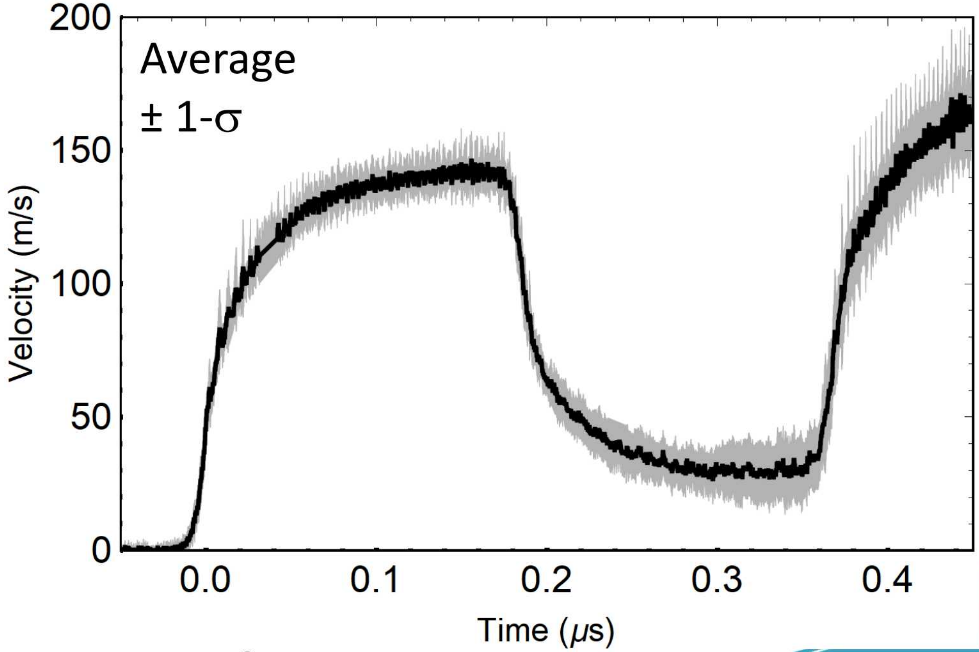
Time axes aligned at 40 m/s.

169 m/s

Forward Ballistic Impact of Porous Tantalum

Superposition for two samples on the same shot.



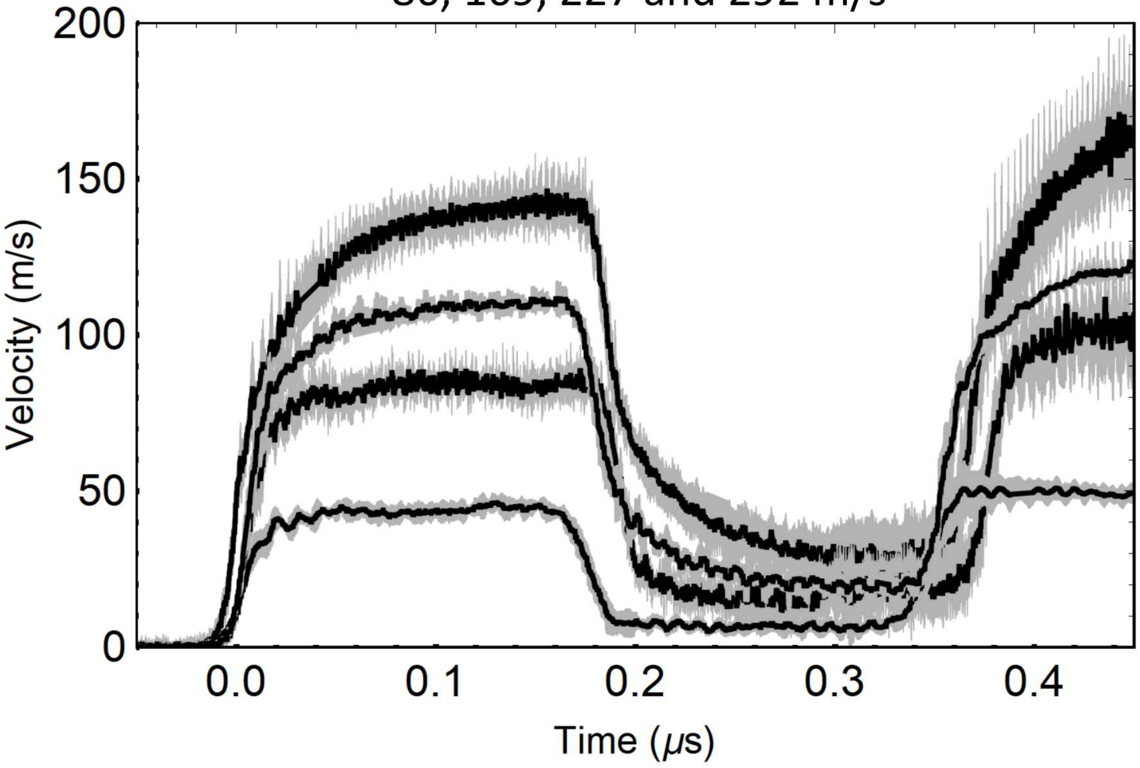


Forward-Ballistic Impact of Porous Tantalum: Multiple impact velocities

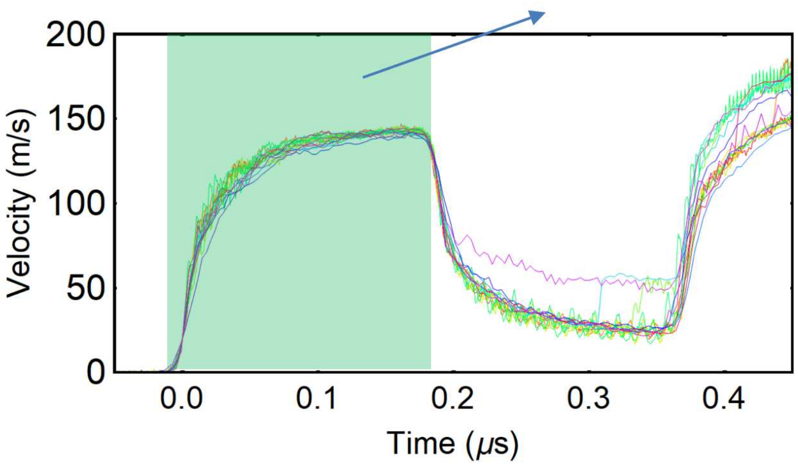
Reproducible features: rounding of stress wave

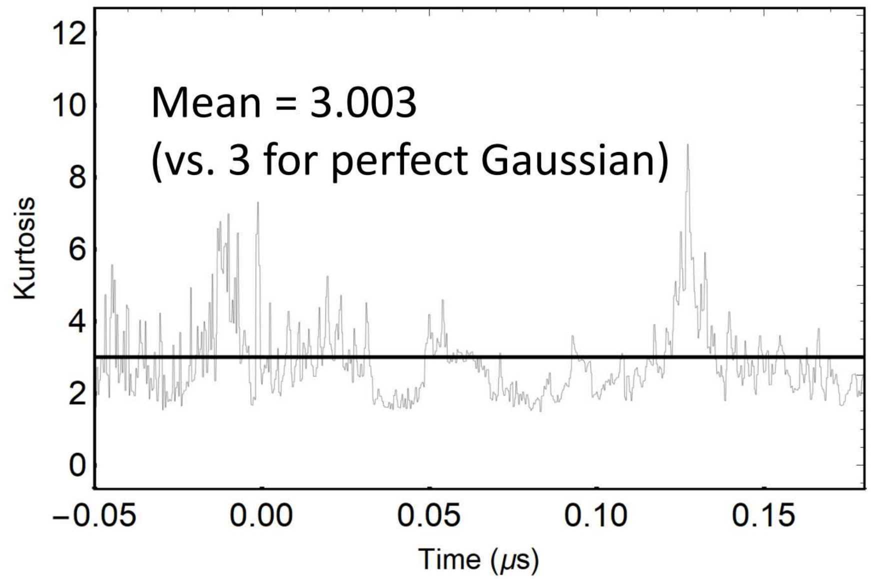
Min. of 5–10% s.d. depending on ROI

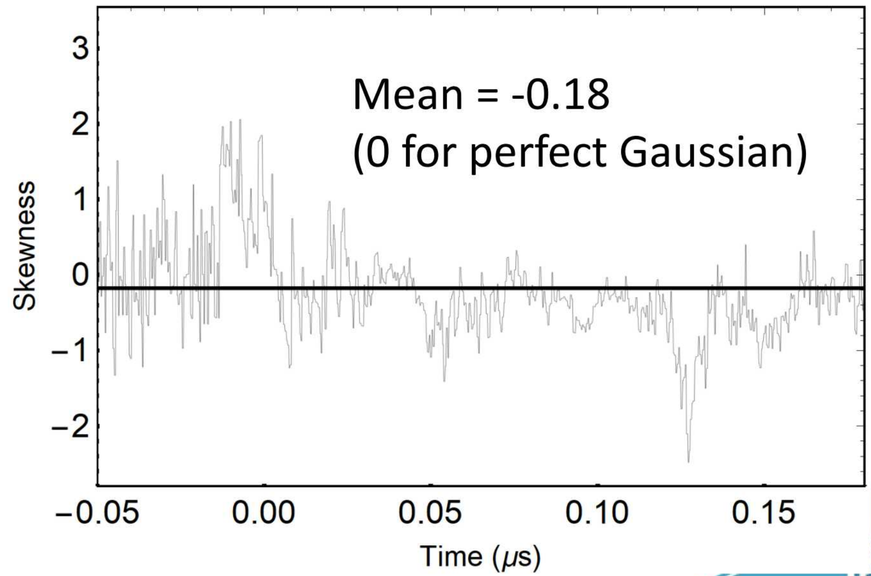
86, 169, 227 and 292 m/s



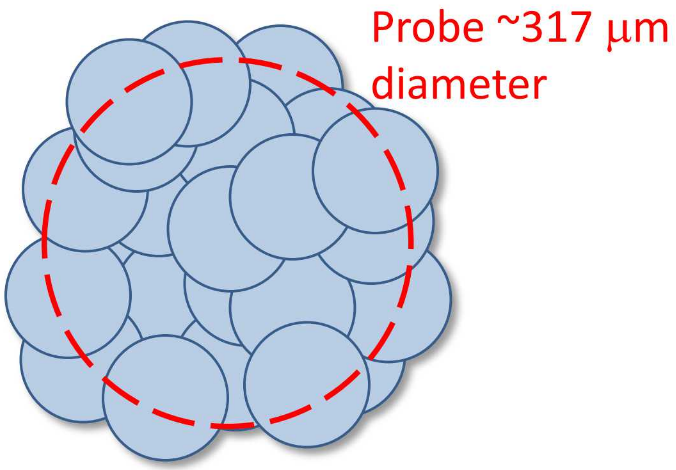
Spatial Velocity Distribution is approximately Gaussian



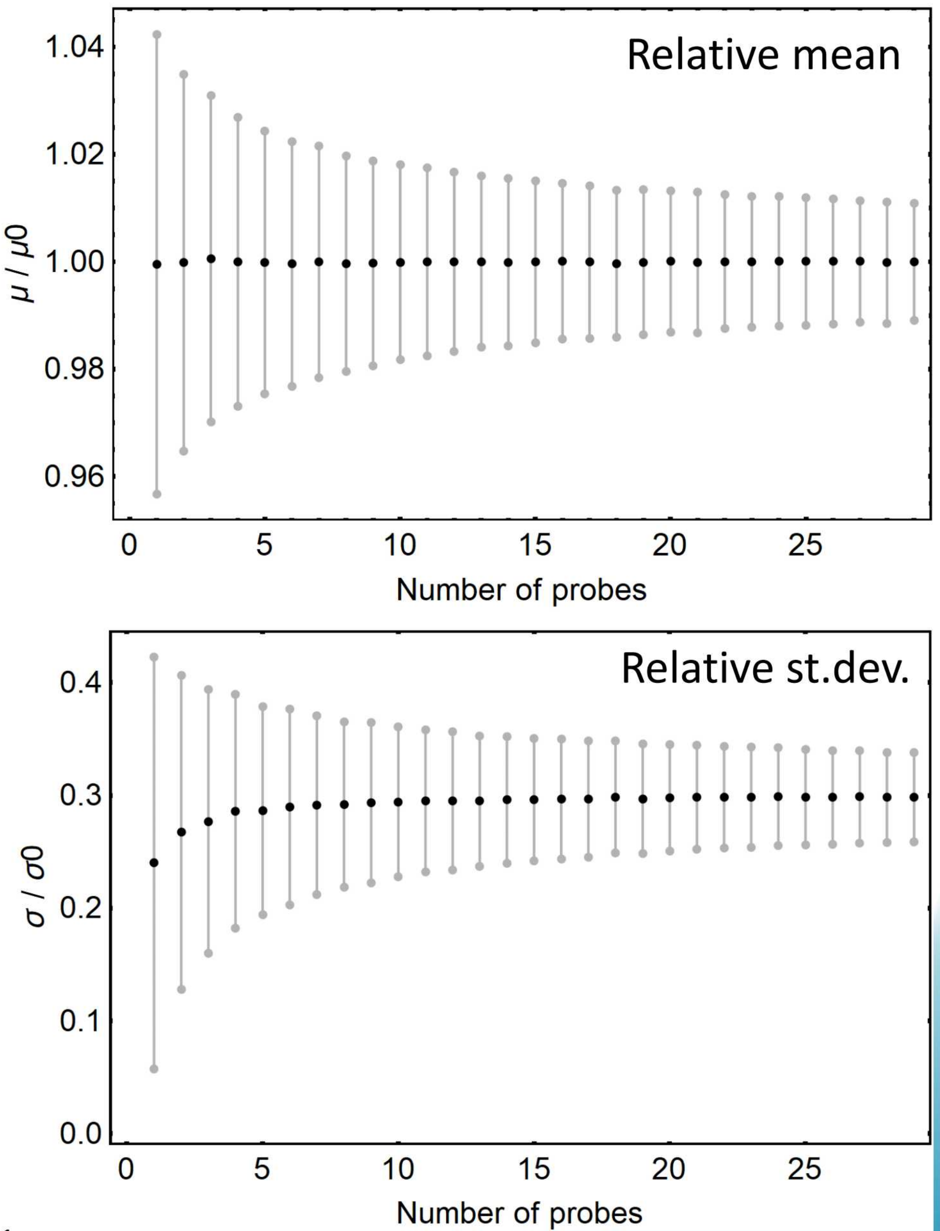




Effect of Finite Probe Size



Spats ~100 μm diameter



Monte Carlo simulations assuming:

- Response uniform within a splat
- Gaussian distr. of splat responses
- Uniform sampling by probe
- Avg/s.d. of *N* probes

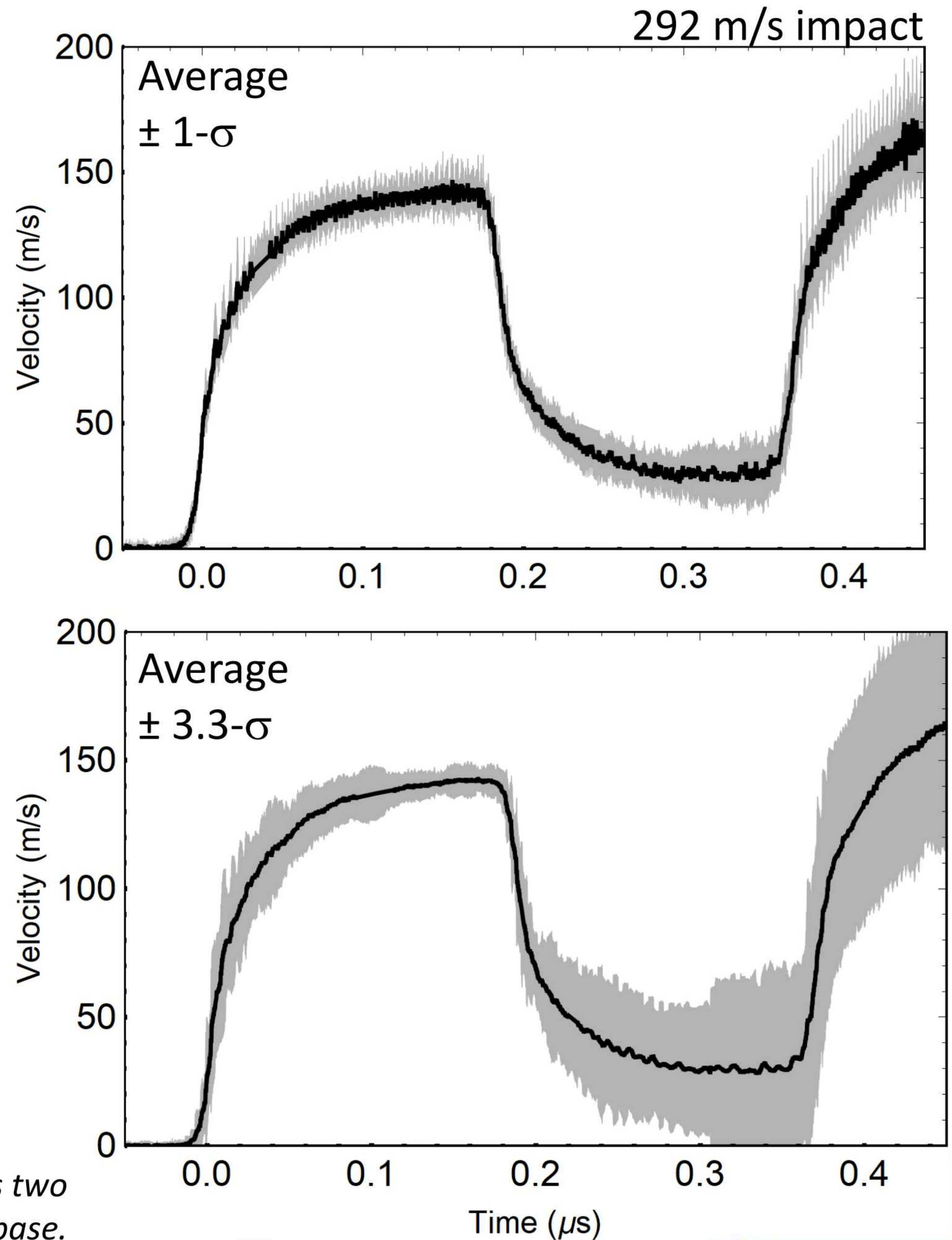
~5-10 probes convergence to mean

~317 μm probes underestimates distribution width by ~1/0.3 = 3.3×

Distributions with Finite Probe Size Correction

As measured

Projected based on probe/feature size ratio



Top result was one sample. Bottom result is two samples with PDI & PDV put onto same time base.

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Conclusions

Multipoint velocimetry control experiments:

- Up to 26 measurements per shot demonstrated
- PDI, PDV and VISAR give same mean response within probe-to-probe variation of ~1 m/s

Porous Tantalum has stochastic structure and stochastic (Gaussian) shock response during plate impact loading:

- Spatial velocity distribution is ~Gaussian commensurate with stochastic particle deposition
- Velocity distribution standard deviation was ~5-10% of mean
- Represents lower bound to variation, owing to optic dimensions
- Consistent rounding of wave stress profile indicative of dissipation (e.g., pore collapse)