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Copper spall experiments with recompression using HE (Copper Spall Soft Recovery Experiments)

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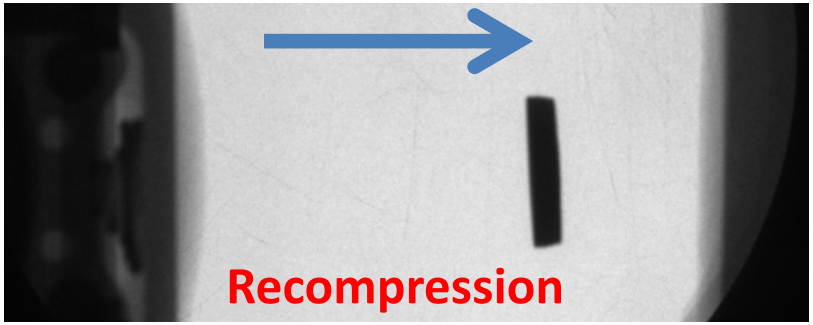
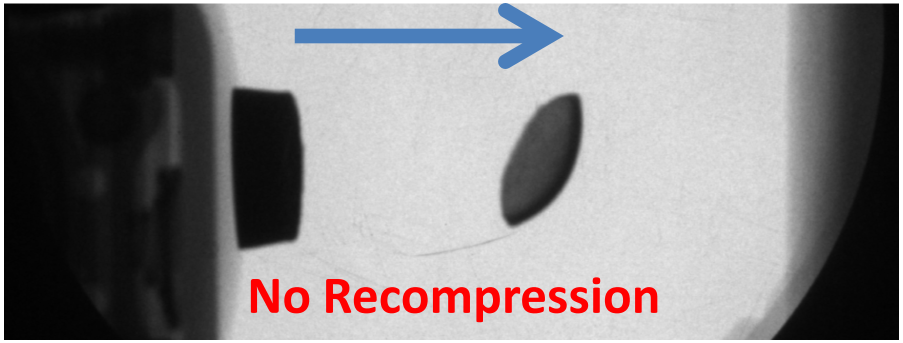
LANL: E. Ceretta, G. T. Gray, P. Rigg, D. Koller





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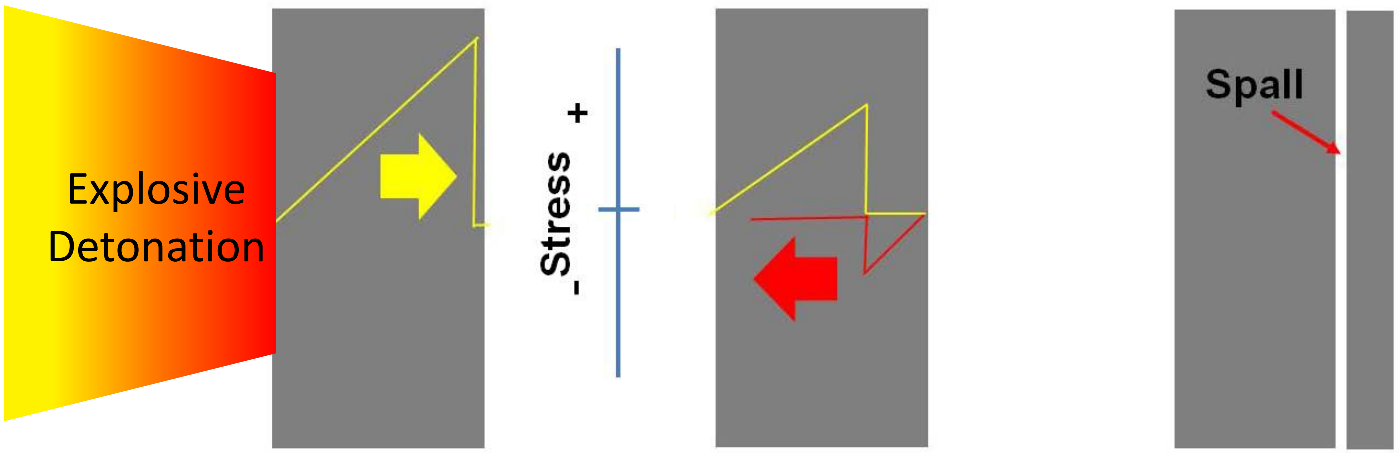
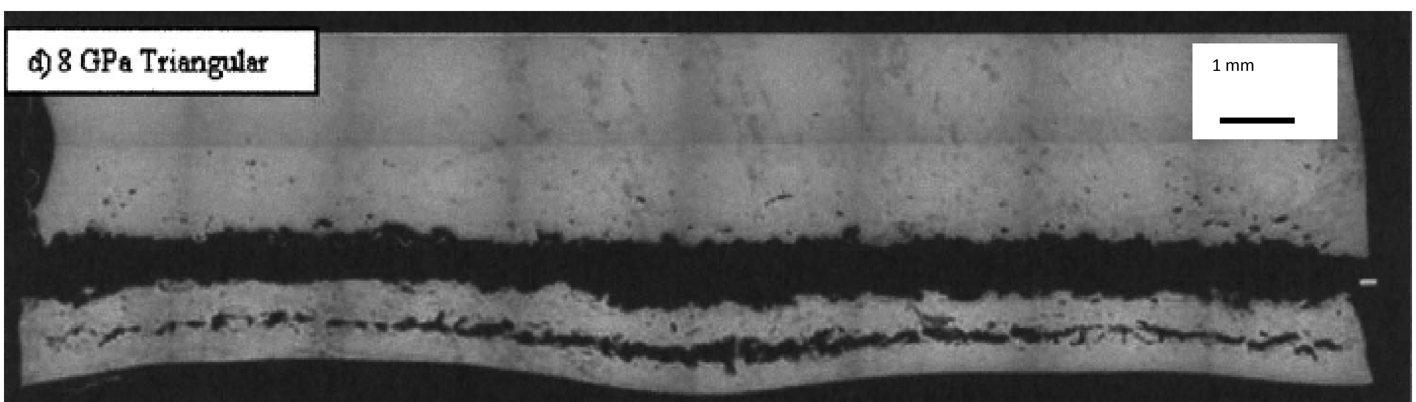
Metals in direct contact with explosives will spall



Triangle Shock in Metal

Tension forms when shock reflects from free surface

Spall forms when tensile stress exceeds strength



Typical recovered sample showing spall layers

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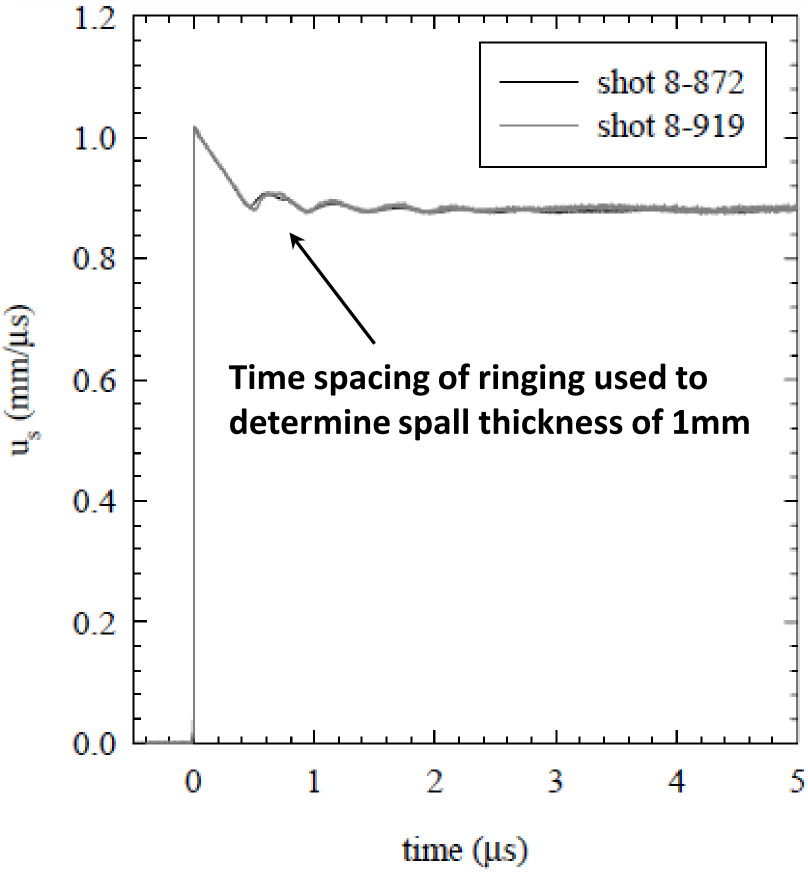
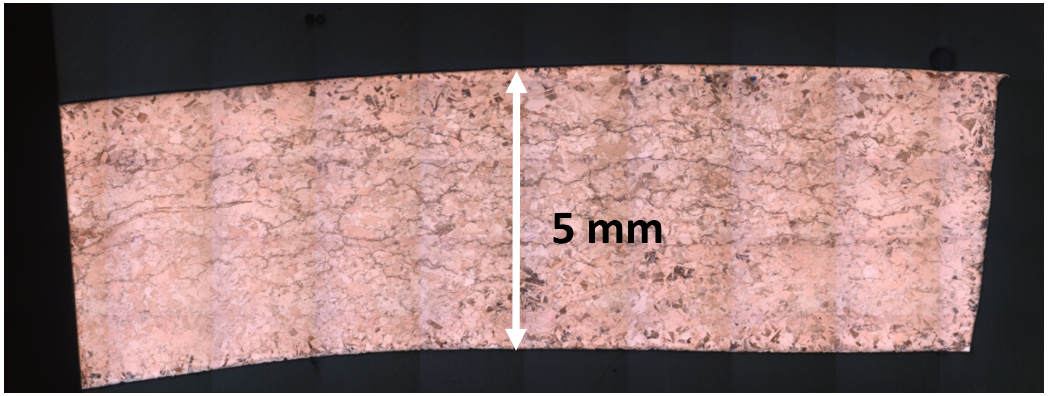
Anomalous results from previous LANL experiments*

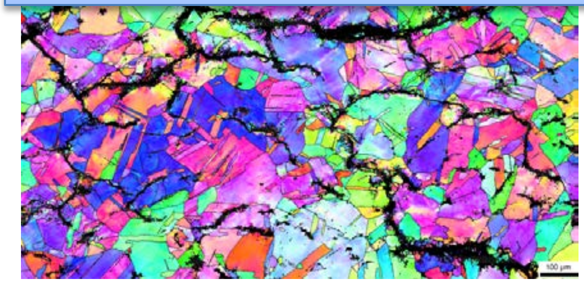
Surface velocity suggests a spall layer



but recovered samples do not!

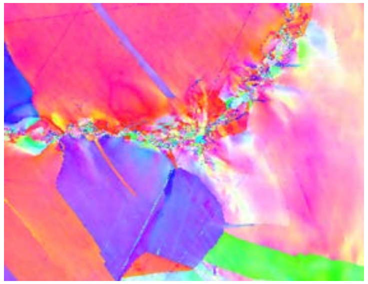


Zoomed in region viewed with orientation imaging microscopy (OIM)



~ 1 mm

Hi-Mag OIM shows small crystals in damage features



~ 50 µm

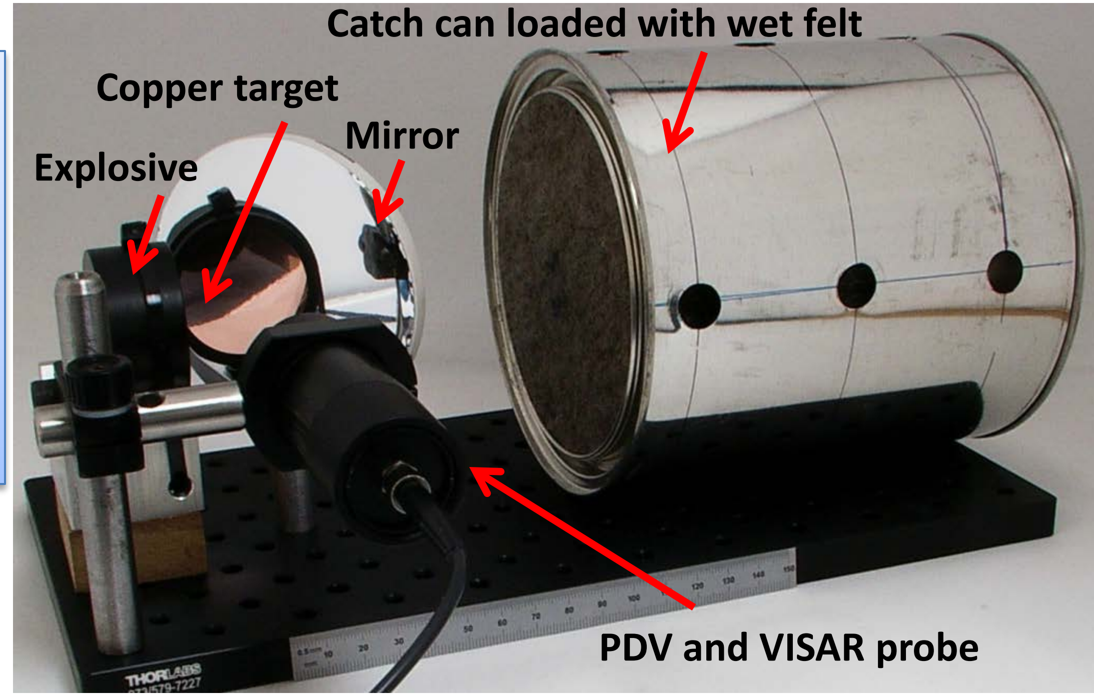
*Baratol plane wave generator experiment, SCCM 2005, Koller, et. al.

Soft recovery experiments were performed to reproduce anomaly

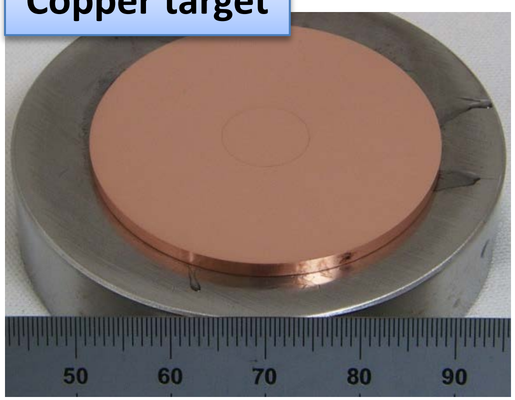
Combined PDV, VISAR, Radiography, and 2D simulation

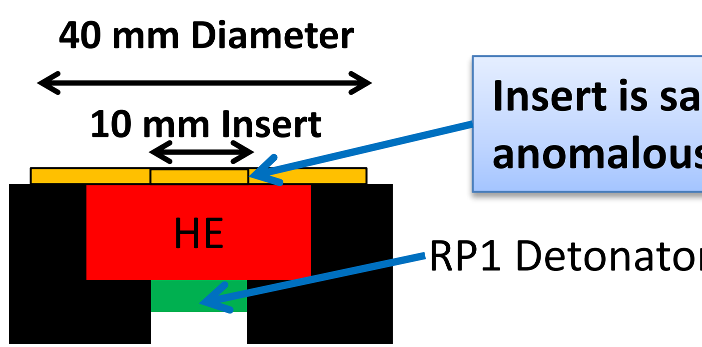
Explore late time dynamics with long record length PDV and radiography

Used 25 x 10 mm Detasheet explosive (similar to Baratol). Single point initiated



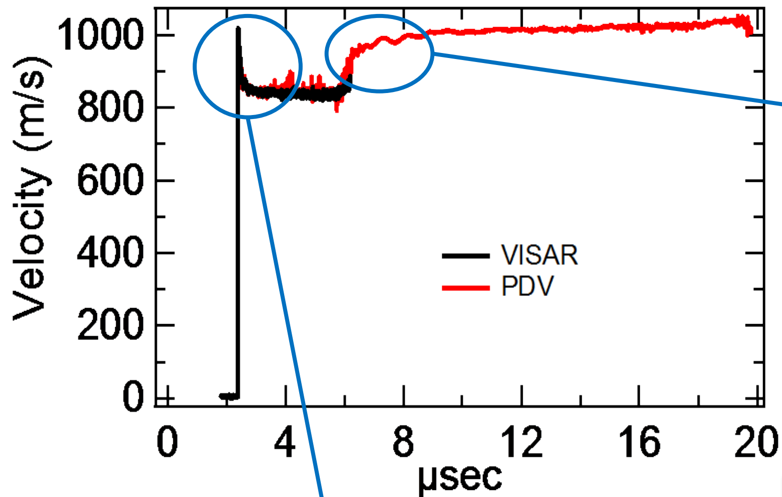
Copper target

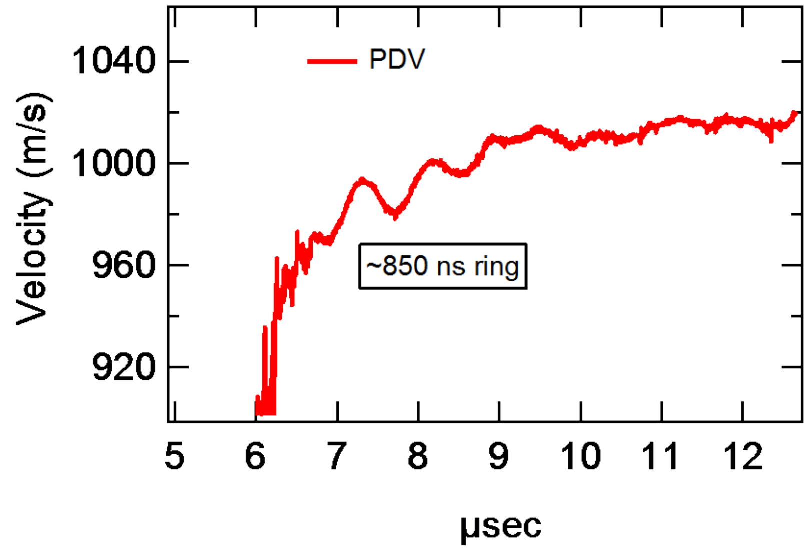


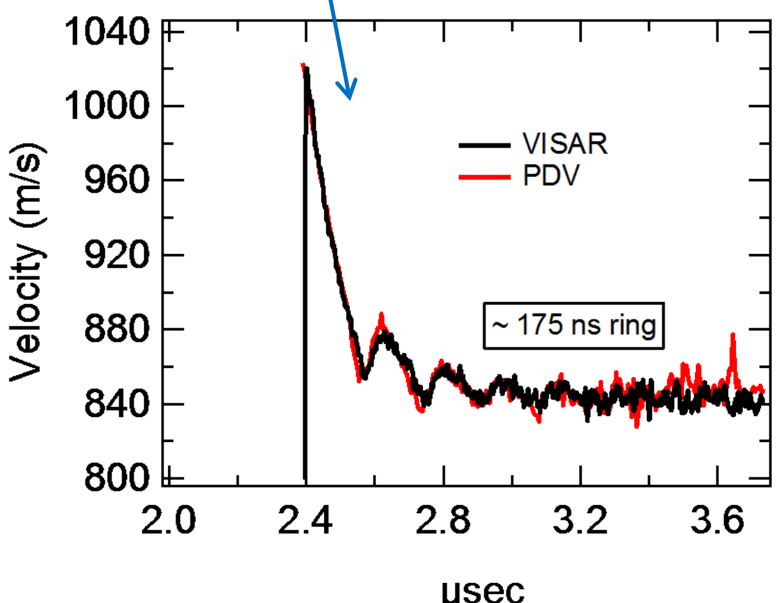


Insert is same material from anomalous LANL experiments

Free surface velocity records indicate spall and a recompression bump







Early part of record indicates spall with a scab thickness of 400 µm.

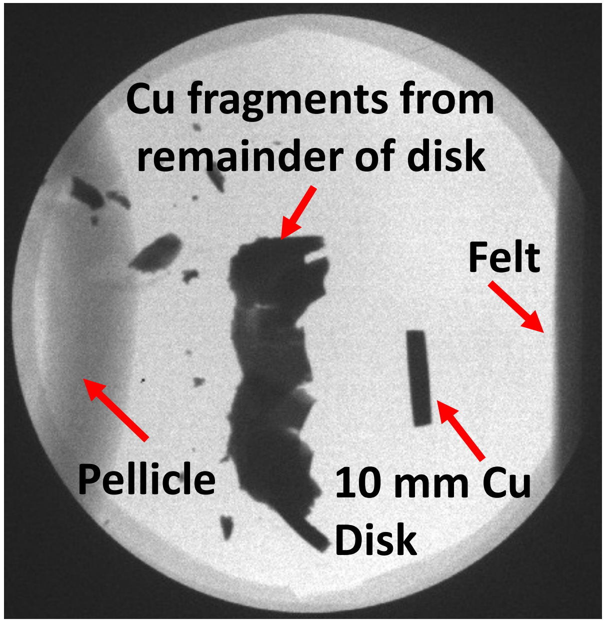
Late time velocity increase caused by bulk copper re-impacting spall layer (recompression).

Ringing after recompression indicates a thickness (2 mm) similar to that of the undamaged sample and could close voids*

***Becker, et. al, JAP 102, 093512 (2007)**

Radiography and soft recovery shows shocked sample is in reasonably good shape

Radiograph 100 μs after detonation

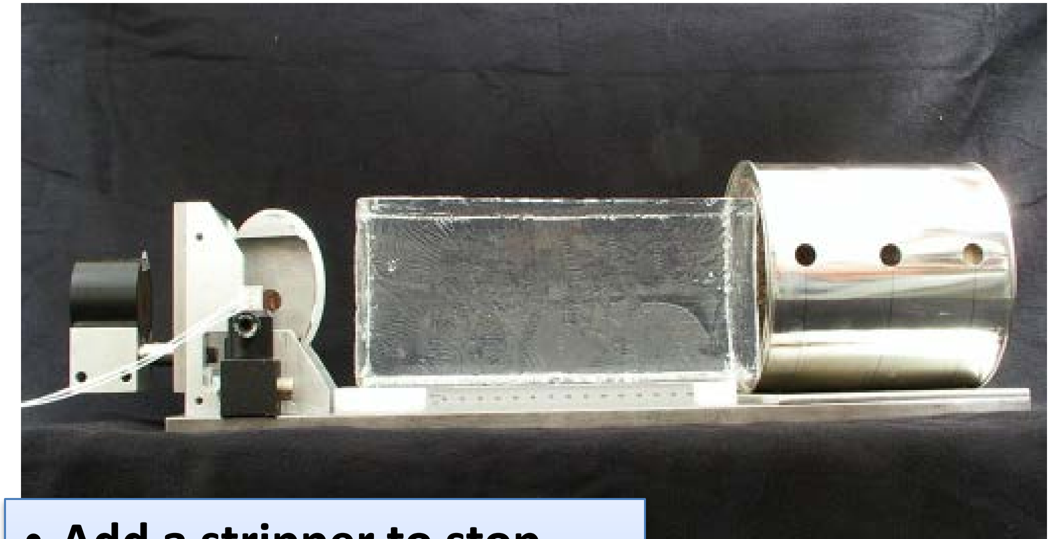


Recovered Sample

X-ray shows center disk intact 100 μs after SBO and remainder of 40 mm sample is highly fragmented: good momentum trapping

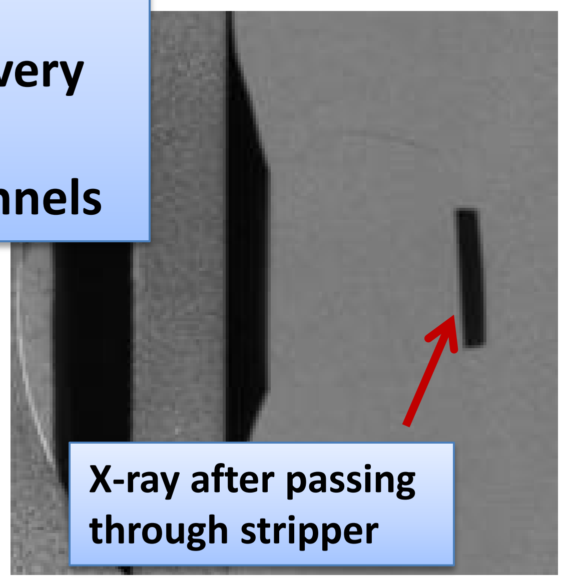
10 mm disk is recovered in ok shape, but improvements to soft recovery were needed (requested)

We improved our soft recovery experiments

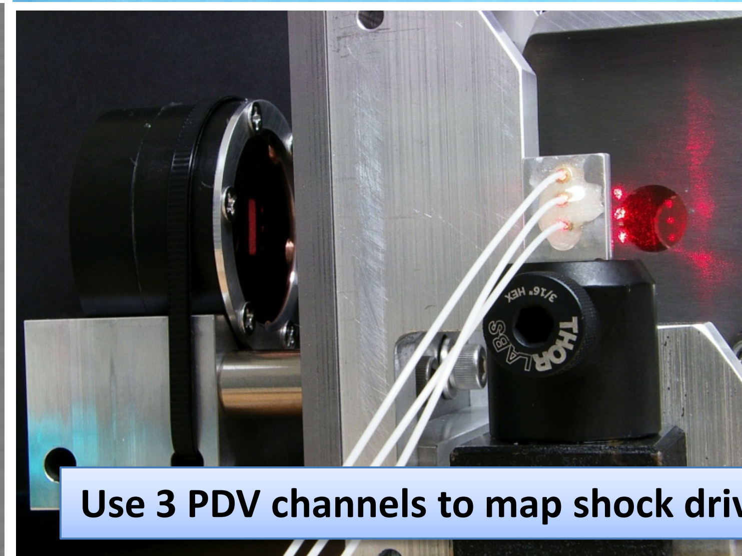


- Add a stripper to stop debris
- More "gentle" recovery in ballistics gel
- Added velocity channels

Sample captured in ballistics gel

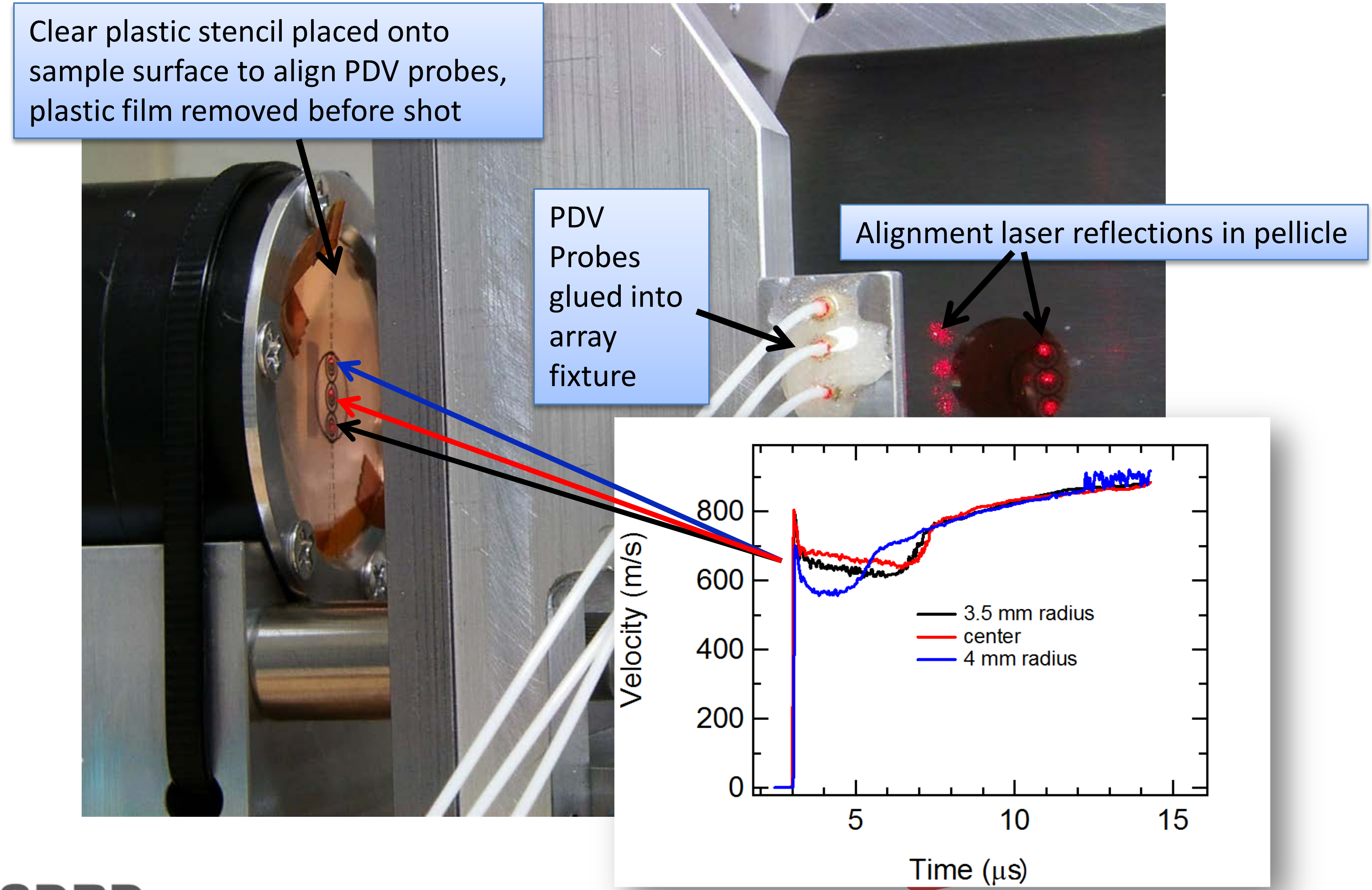


X-ray after passing through stripper



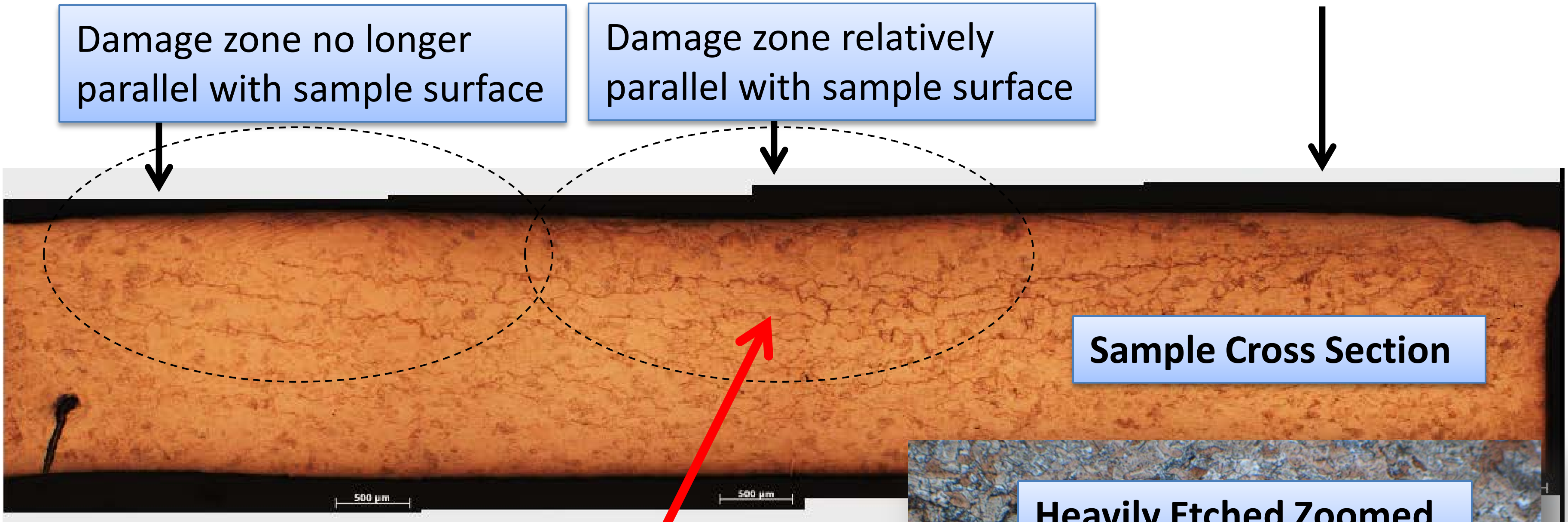
Use 3 PDV channels to map shock drive

Velocity data suggests radial position is important because of drive curvature



Metallography also suggests radial position is important

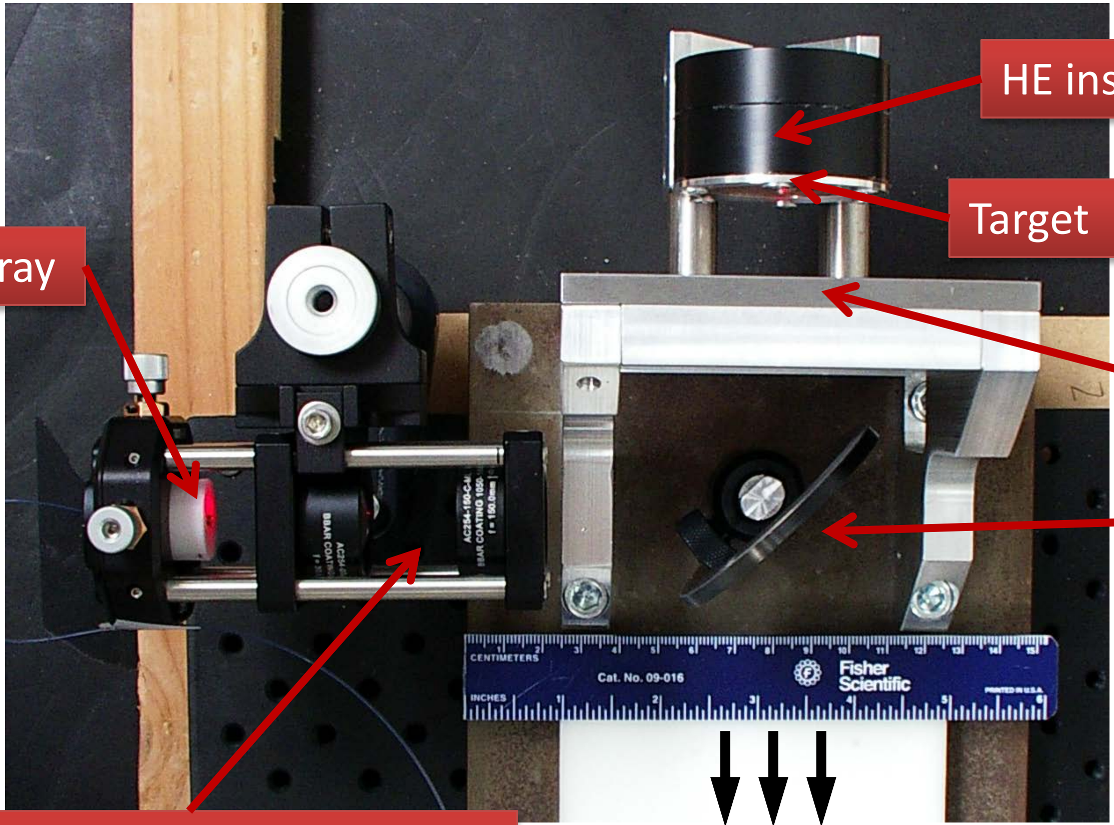
(Arrows mark nominal position of PDV probe)



Damage features consistent with anomalous LANL Baratol experiments

These damage features may be opened and closed voids, heat generated may have caused localized melting. This explains the apparent recrystallization in damage features

MPDV system used to obtain 12 velocity points across line to examine the radial position dependence



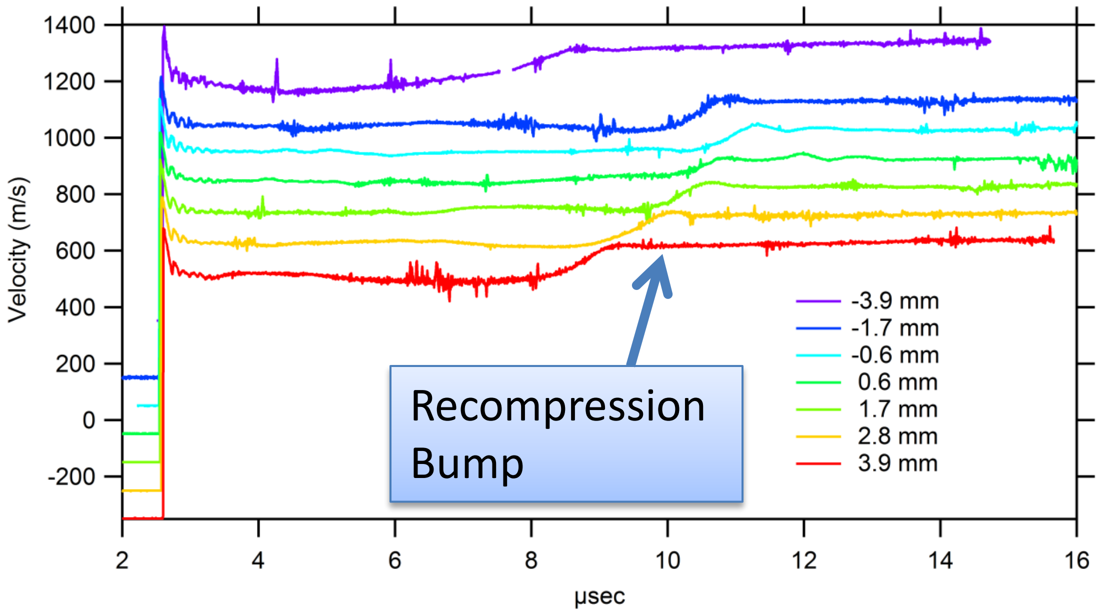
Imaging optics Mag = 4.5 with 1.1 mm spacing on target

To Ballistics Gel

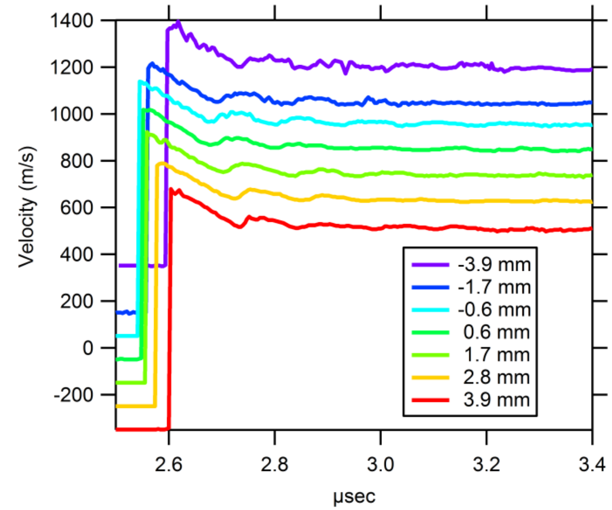
We also varied Cu sample thickness to change recompression amplitude

Velocity on 2 mm thick copper sample with Detasheet HE

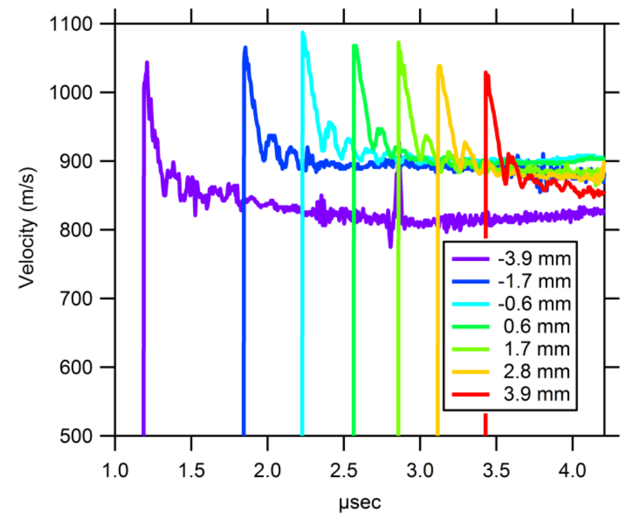
Staggered Velocity Plot



Staggered Velocity Plot (Zoom)



Staggered Time Plot (Zoom)



2 mm sample shows recompression bump. Drive curvature from single point detonation is clearly evident.

- Shock break out at r = 4 mm is 60 ns
- Center vel = 1090 m/s, r = 4 mm is 1030 m/s

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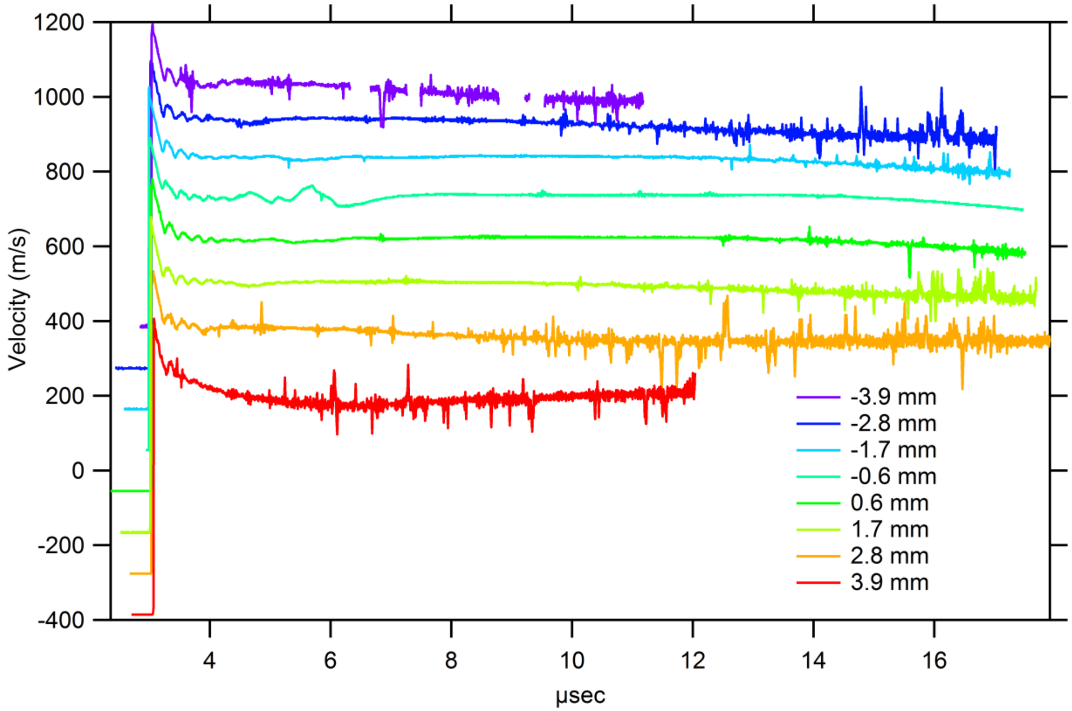
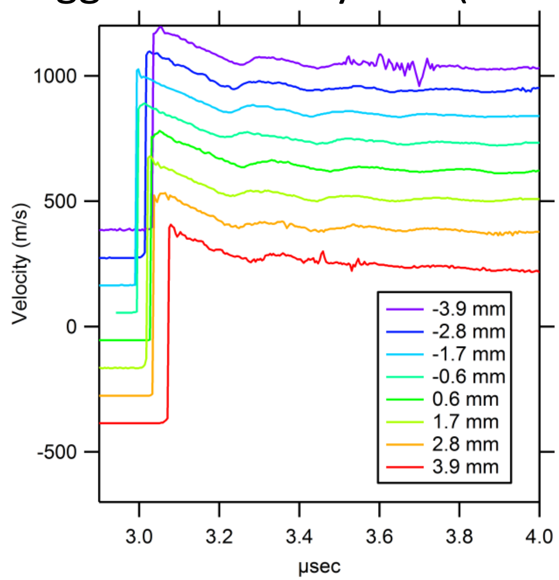
Velocity on 4 mm thick copper sample with Detasheet HE

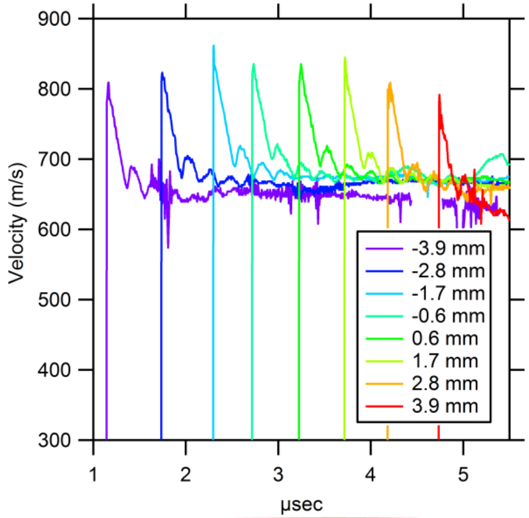
Staggered Velocity Plot



Staggered Velocity Plot (Zoom)



Staggered Time Plot (Zoom)



4 mm sample doesn't have recompression.
Drive curvature slightly less than 2 mm exp.

- Shock break out at r = 4 mm is 50 ns
- Center vel = 830 m/s, r = 4 mm is 780 m/s

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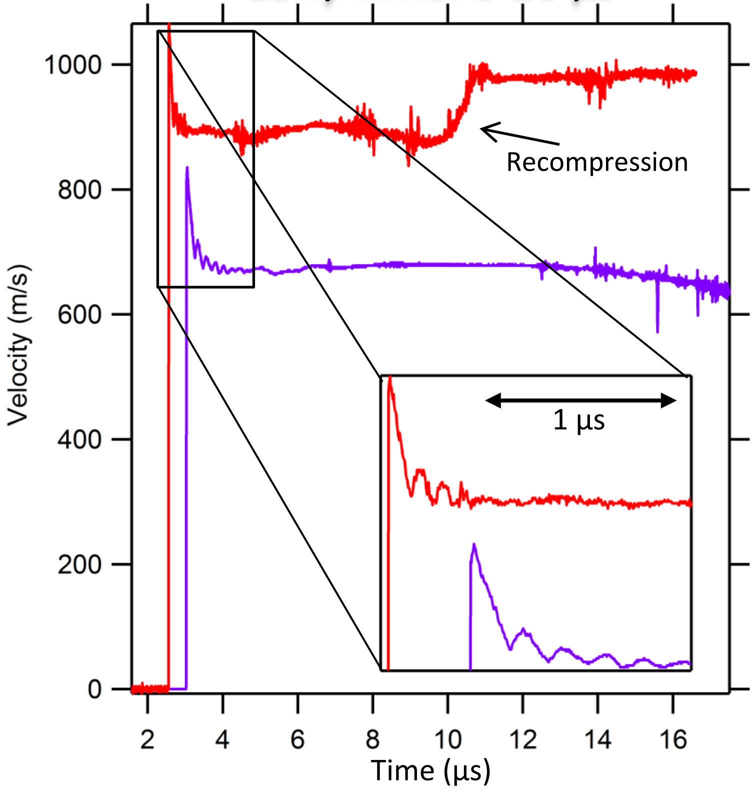
Recompression after spall welds spall scab onto bulk sample

Early Time: 0-20 µs

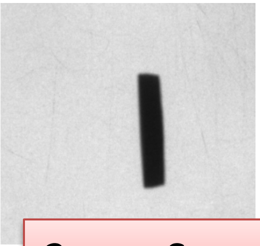


Recompression

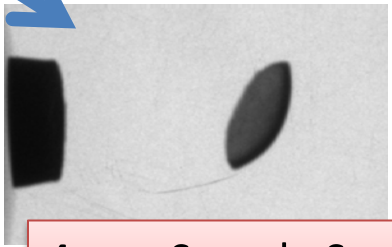
No Recompression

Intermediate Time ~ 100 µs

Late Time > 1 s



2 mm Sample Intact



4 mm Sample Spall Scab Separation

Thin (1.9 mm) sample spalls and recompresses, stays intact.
Thick (4.0 mm) sample spalls and does not recompress, spall scab separates.
Peak stress and release rate lower for thick sample with spall scab separation, inconsistent with previous release rate hypothesis.*

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Peak stress and release rates are similar to the anomalous LANL experiments (Final Slide)

Release Rate, Spall Strength, Peak Stress and Spall Thickness for Damage Experiments

Experiment	Δu_{fs} (m/s)	Release rate (m/s^2)	Spall strength (GPa)	Peak Stress (GPa)	Estimated spall thickness (mm)	Time spacing in 1st spall ring (ns)
Detasheet (2 mm Cu)	160	13.3E+08	3.1	21	0.29	120
Detasheet (4 mm Cu)	135	6.8E+08	2.6	17	0.52[a]	220
Baratol (Darcie)	139	6.7E+08	2.7	22.2	1.04	439

12 point MPDV used to investigate spall and recompression phenomena.

Recompression after spall can close voids ("heal" damage).

Recompression caused by explosive gasses accelerating bulk sample until it impacts spall scab.

Thick samples never catch up to spall scab

More experiments with varied sample thickness in progress

[a]Recovered Spall Scab Thickness From Mass Measurement = 0.50 mm