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Numerical/Empirical Results of Converging and Colliding Shock Waves

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Outline

- Motivation
- Converging and diverging detonation
- Converging shock wave
- Shock wave collision

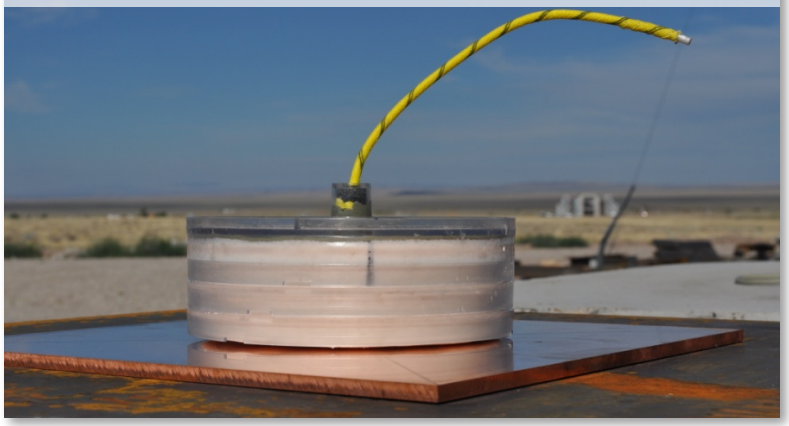
Motivation

- The Hydrocode Validation and Verification (V&V) team at Sandia National Laboratories requested a series of experiments be conducted to ensure shock interactions are being accurately predicted using their standard codes. To that end, experiments to achieve detonation wave convergence at a local level, and more global shock wave collisions within metal plates, were conducted with adequate diagnostics for detailed comparison to simulations. As will be shown, experiments and simulations agreed well allowing confidence in predicting the extreme pressures and temperatures typically obtained during these events.

Background

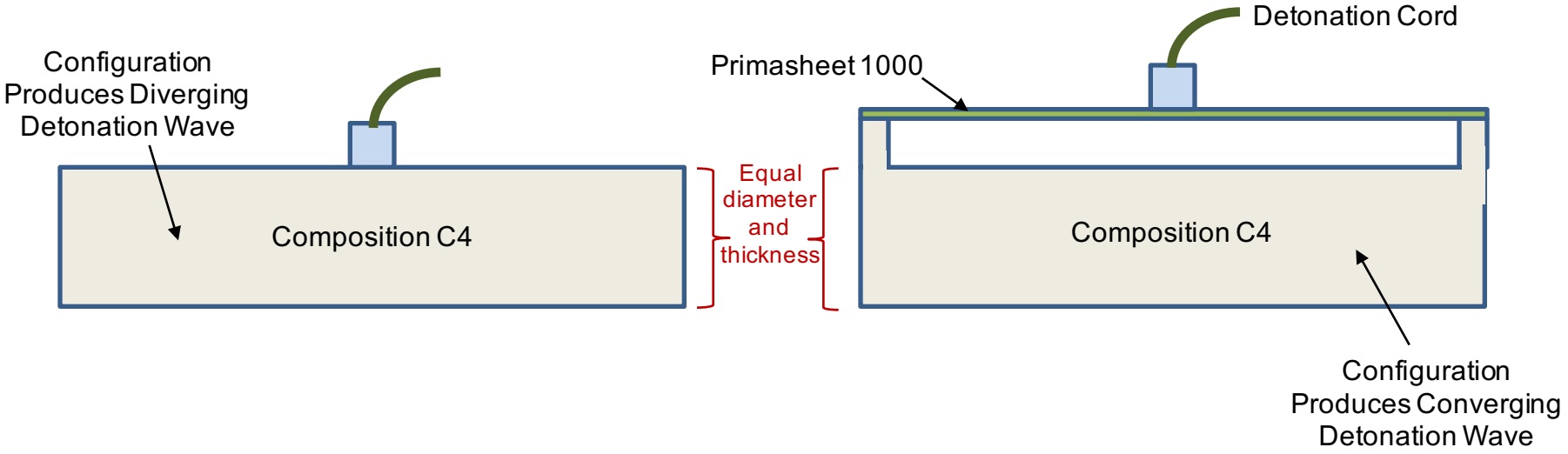
- This data set was compiled to illustrate how the wave speeds differ between the bulk charge and the cylindrical charge. The primary source of data came from the PDV system in which the probes were used to capture the time of arrival (TOA) of the shock wave through various copper plates. Accurately knowing the distance between probe locations, and measuring the TOA of the shock wave at each probe, it is easy to calculate the velocity between two points on the charge, and thus, across the entire charge (or target) surface. This is the method that was used to collect this data.

Cylindrical Charge on Copper



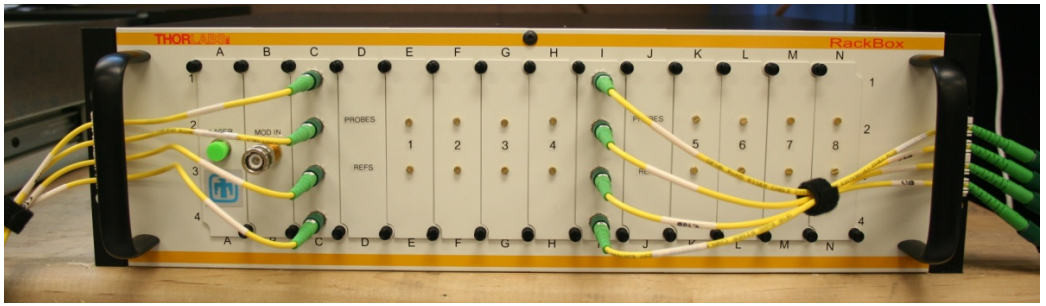
PDV Probes on back-side

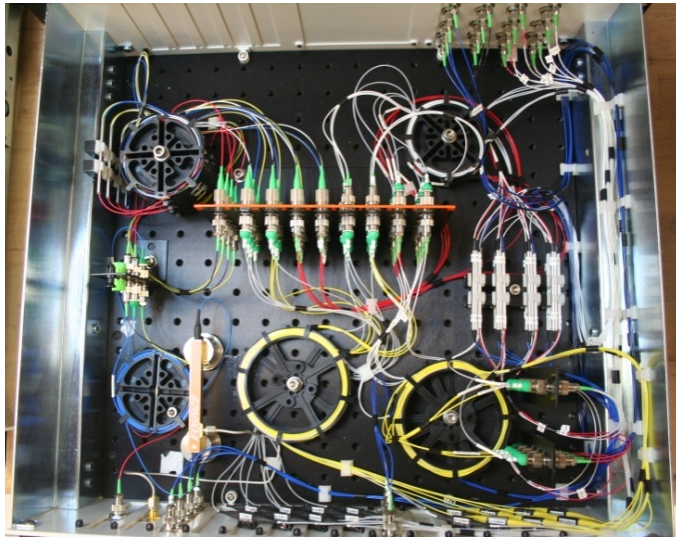
Cylindrical Charge Configuration



1-inch Cu Plate PDV System

- 8 Channels of PDV
- 6 GHz Bandwidth Digitizers
  - Allows us to measure velocities up to ≈ 4.6 km/sec

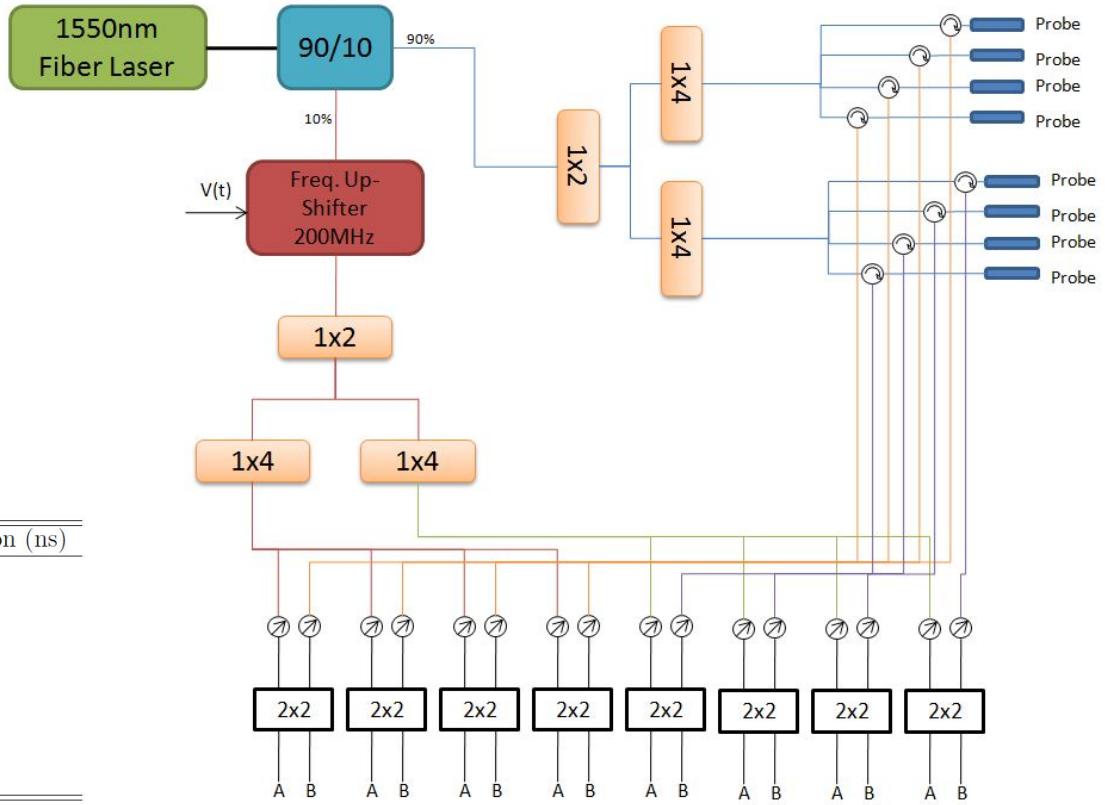




- Front Panel allows user to connect and adjust all 8 channels without having to open diagnostic.
- Offers independent adjustment of the probe returns and the reference levels.

1-inch Cu Plate PDV Test Configuration

- Reference light from the laser travels a separate path from the probe light.
- Doppler-shifted light returned from the probe(s) is mixed with the reference signals via the 2x2 couplers.
- The output of the 2x2 couplers are collected by high speed detectors on digitizers.

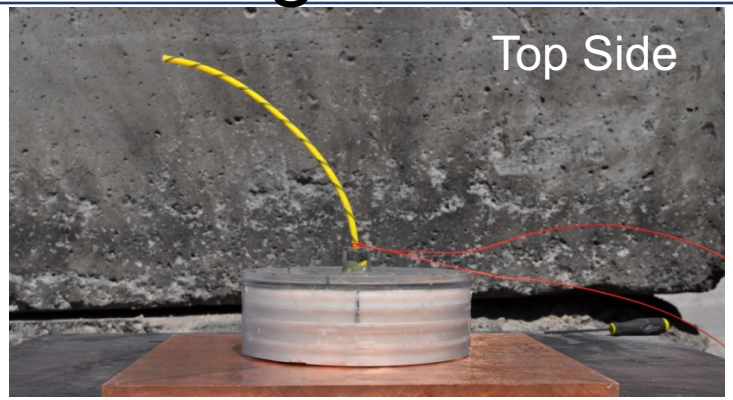


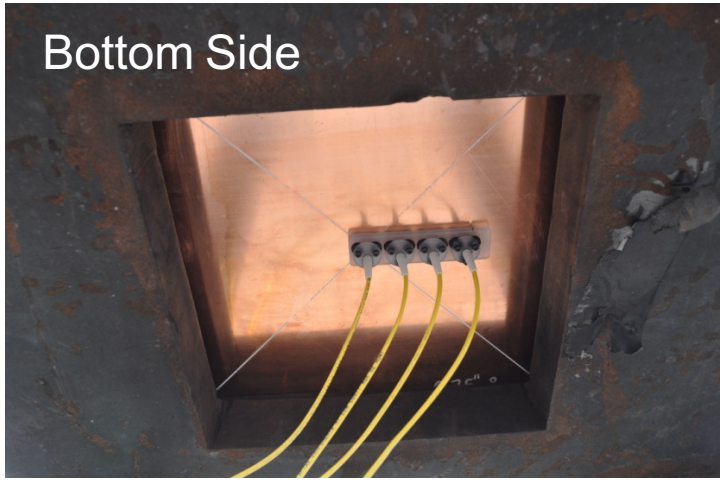
Velocity (m/s)	Beat frequency (GHz)	Time resolution (ns)
250	0.32	24.7
500	0.65	12.3
750	0.97	8.2
1000	1.29	6.2
1250	1.61	4.9
1500	1.94	4.1
1750	2.26	3.5
2000	2.58	3.1

Table above shows the beat frequency that the PDV system will generate for a given target velocity.

1-inch Cu Plate PDV Test Configuration

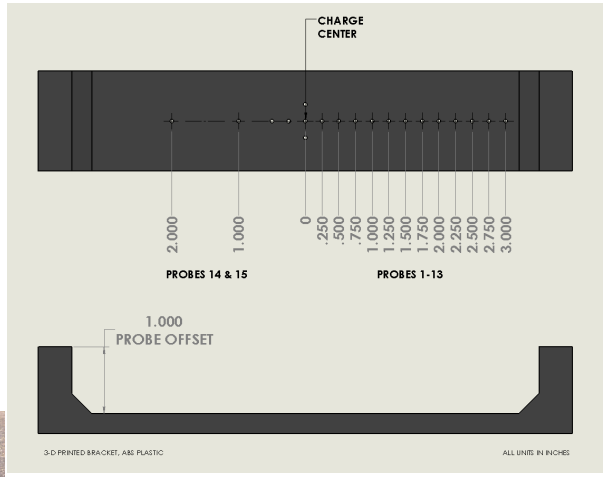
- Explosive charge is placed on top of copper target plate
- Copper target plate sits atop a steel stand with a square hole cut in it.



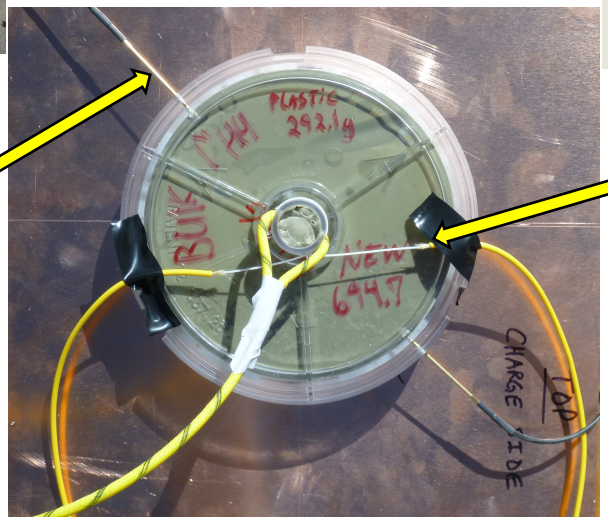


- Four collimated PDV optical probes are adhered to the bottom side of the copper plate.
- These probes will measure the free-surface velocity of the copper at different locations relating to the charge.

0.25-inch Cu Plate PDV Test Configuration



PZT pins for diagnostic trigger



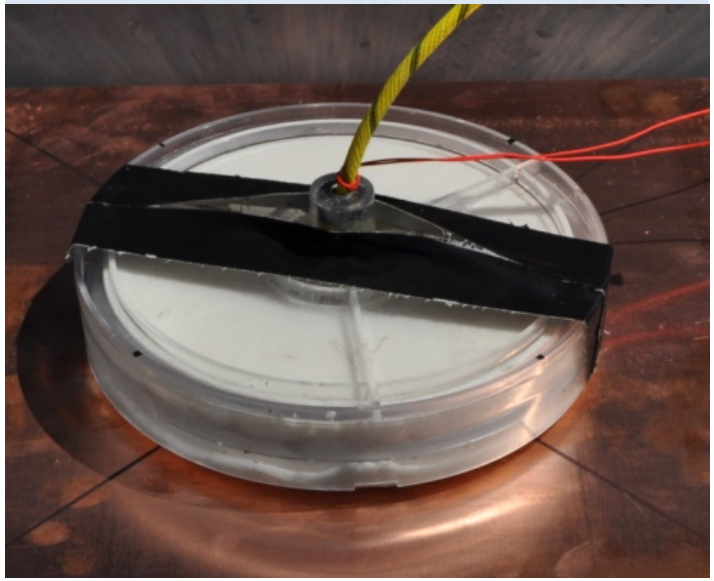
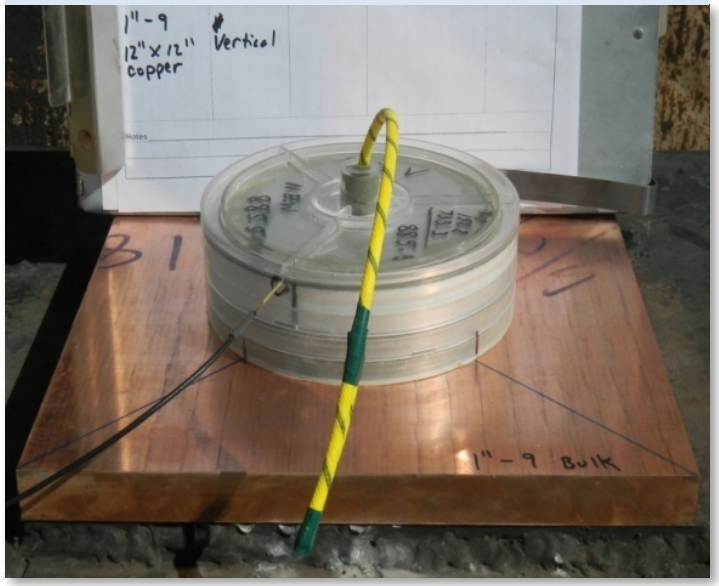
PDV break-fiber as timing reference for charge initiation

0.25-inch Cu Plate PDV Specifications

- 16 channel frequency-shifted photonic Doppler velocimetry (PDV) system
  - ~1550nm λ with tunable reference lasers (NKT Photonics)
  - 12.5GHz and 20GHz Miteq optical detectors
  - 8GHz / 40GS/s Keysight (Agilent) digitizers
  - AC Photonics collimating fiber probes, 9μm core
- Contact Devon Dalton for additional information
  - ddalton@sandia.gov

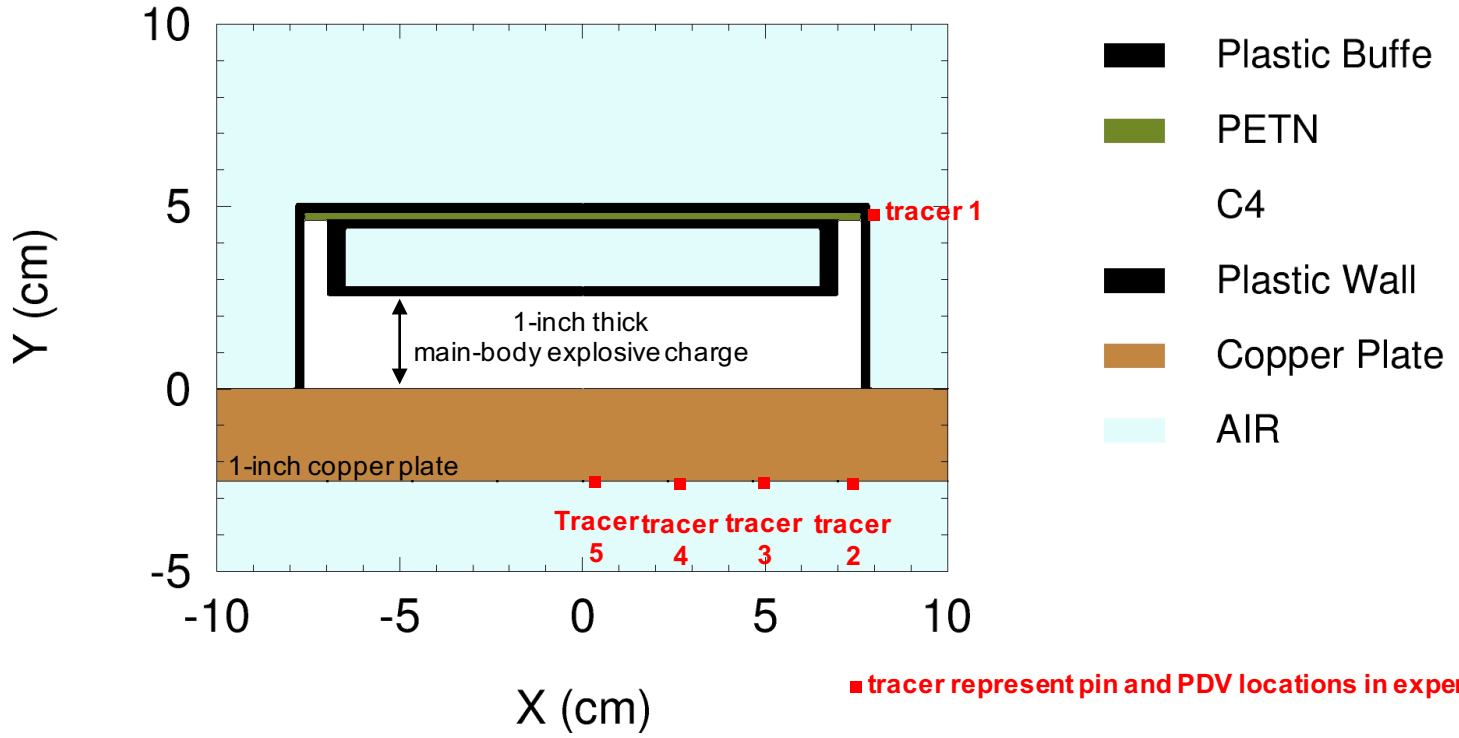
Cylindrical Convergence Test Configuration

- The main body explosive charge is 1-inch thick

Bulk Charge	Cylindrical Comp C4 Charge
	

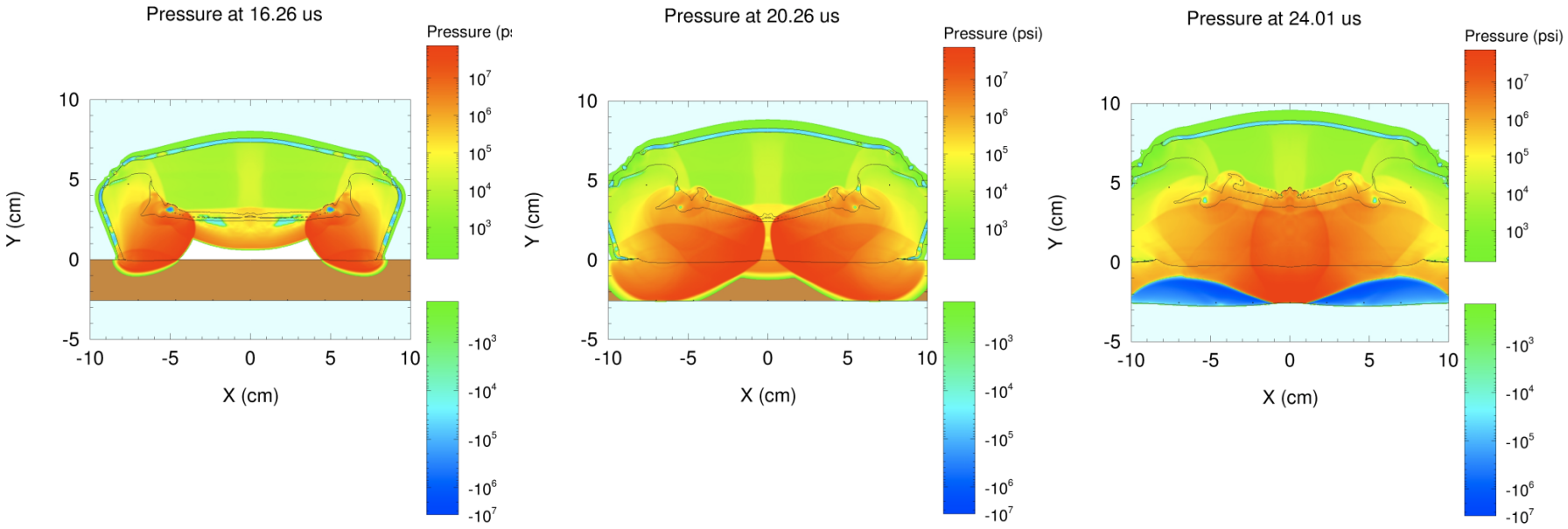
3D Simulation of Cylindrical Convergence

- Material plot at 0.00 us / 6-inch diameter by 1-inch height main body explosive charge

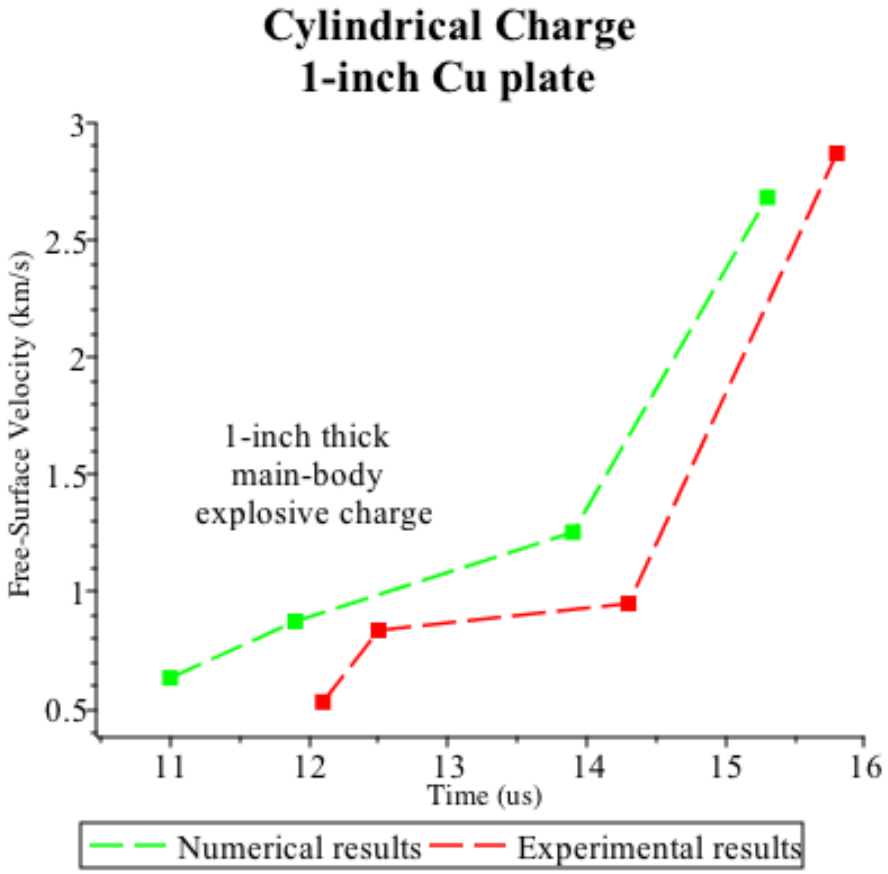


■ tracer represent pin and PDV locations in experiment

3D Computer Simulation



Numerical/Empirical Results



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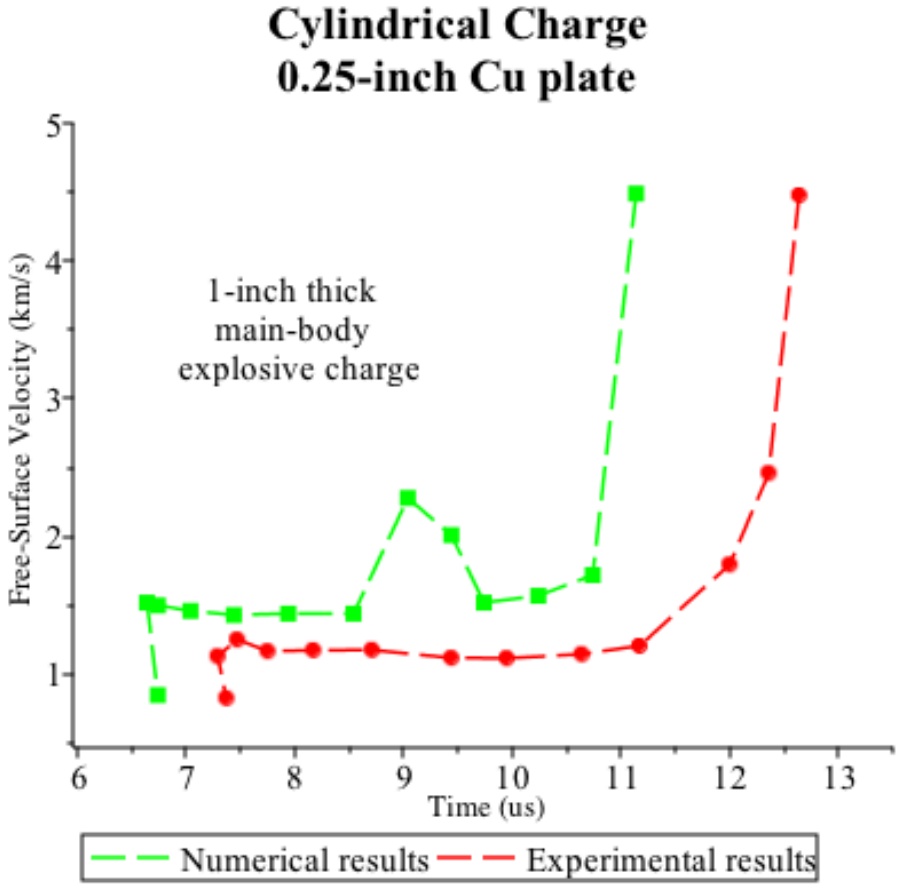

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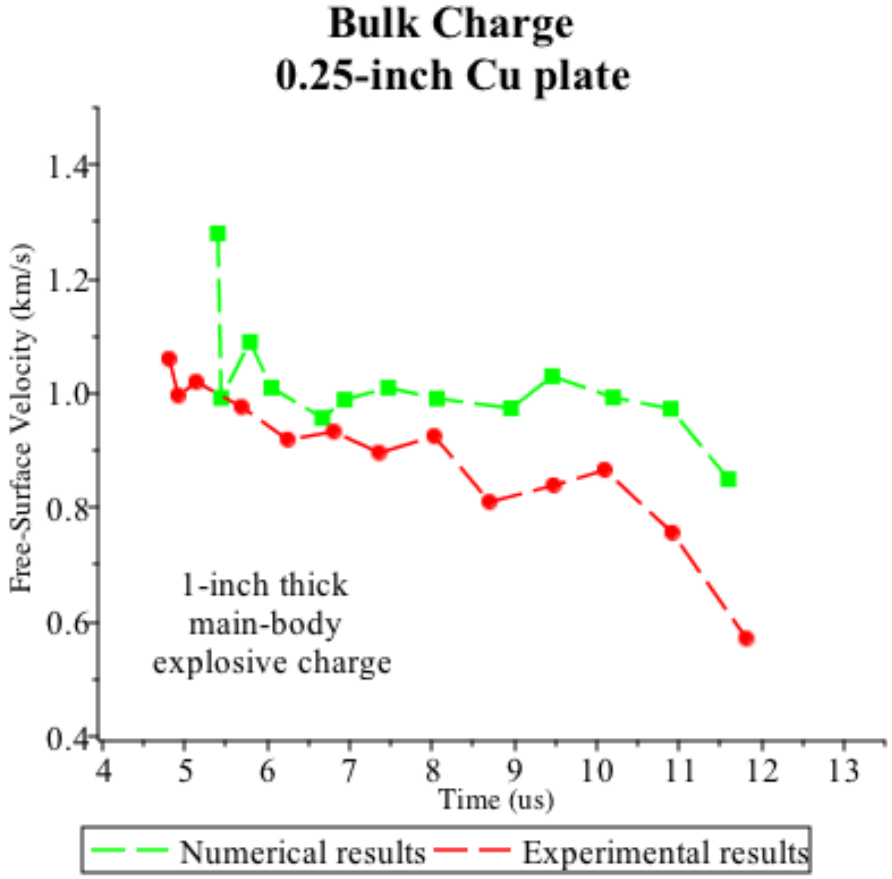
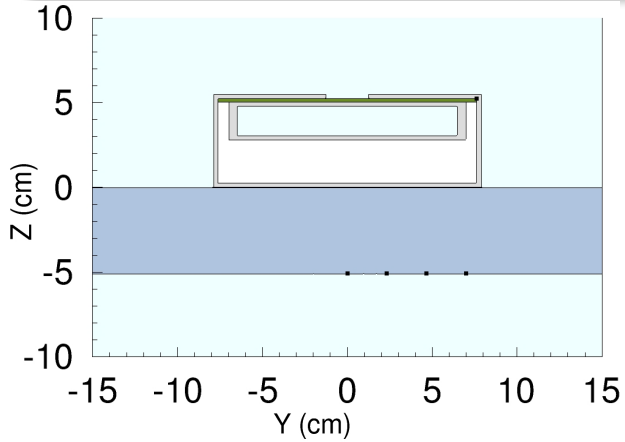
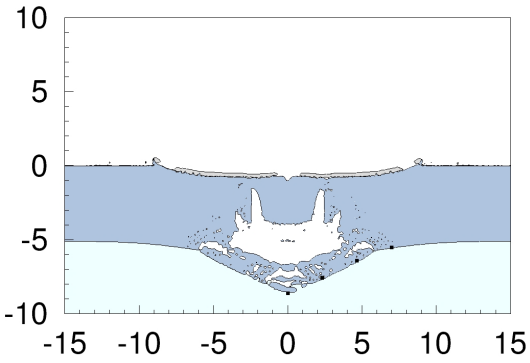
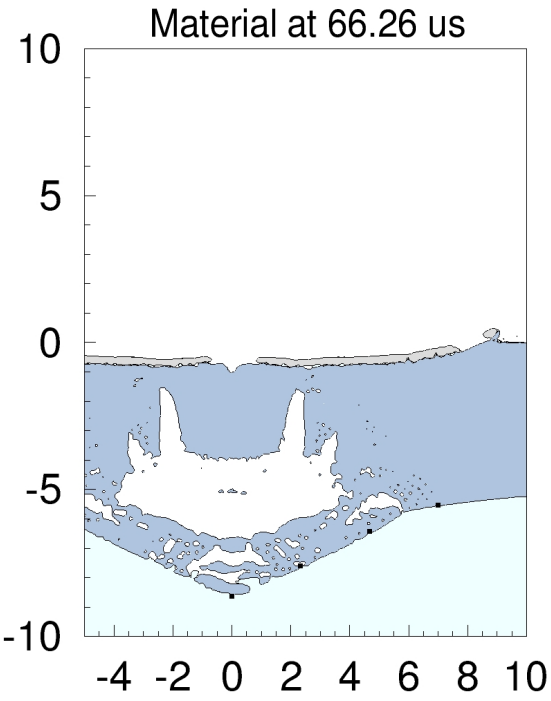


Rarefaction Shock Wave



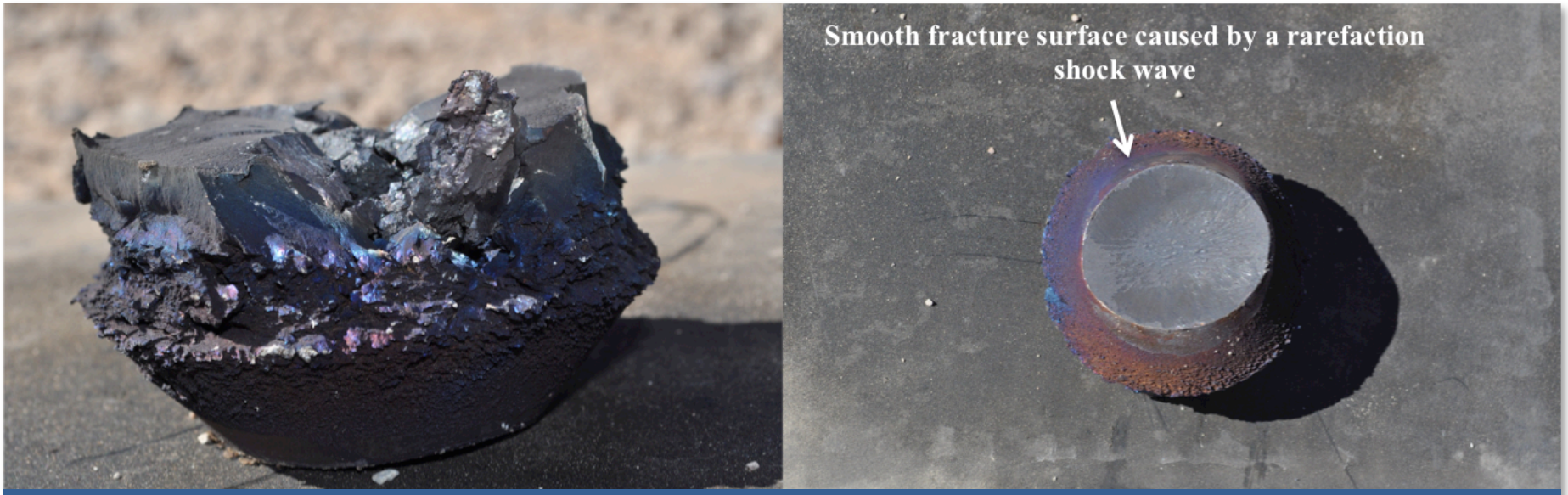




This pocket and smooth spall surface represents a rarefaction shock region based on an iron polymorphic transformation* from α – ε in iron and steel

Phase Change

- This pocked and smooth spall surface represents a rarefaction shock region based on an iron polymorphic transformation* from α – ε in iron and steel



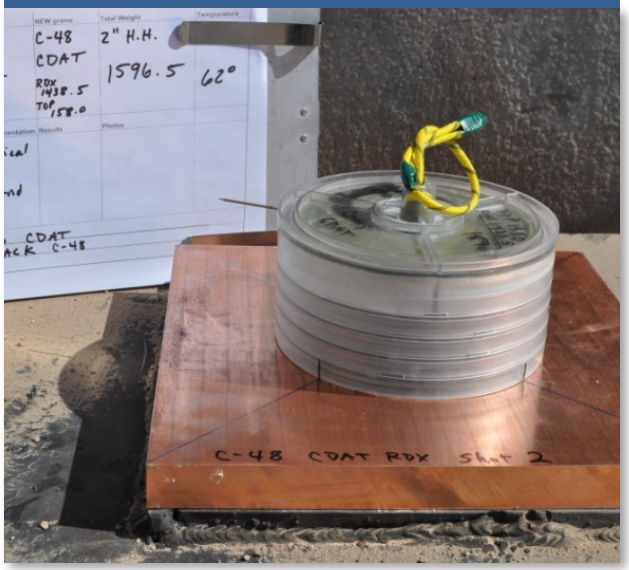
*A.G. Ivanov and S.A. Novikov, *Rarefaction Shock Waves in Iron from Explosive loading*, Combustion, Explosion and Shock Waves, Vol. 22, No. 3, pp 343-350, May-June 1986
*A.V. Bushman, G.I. Kanel', A.L. Ni, and V.E. Fortov, *Intense Dynamic Loading of Condensed Matter*, Taylor and Francis, Chap. 4 1993
*G.I. Kanel, S.V. Razorenov, and V. E. Fortov, *Shock-Wave Phenomena and the Properties of Condensed Matter*, Springer-Verlag, Chap. 6, 2004
*M.V. Zhernokletov and B.L. Glushak, Material Properties under Intensive Dynamic Loading, Springer-Verlag, Chap. 5, 2006

Pre-Experiment Photos

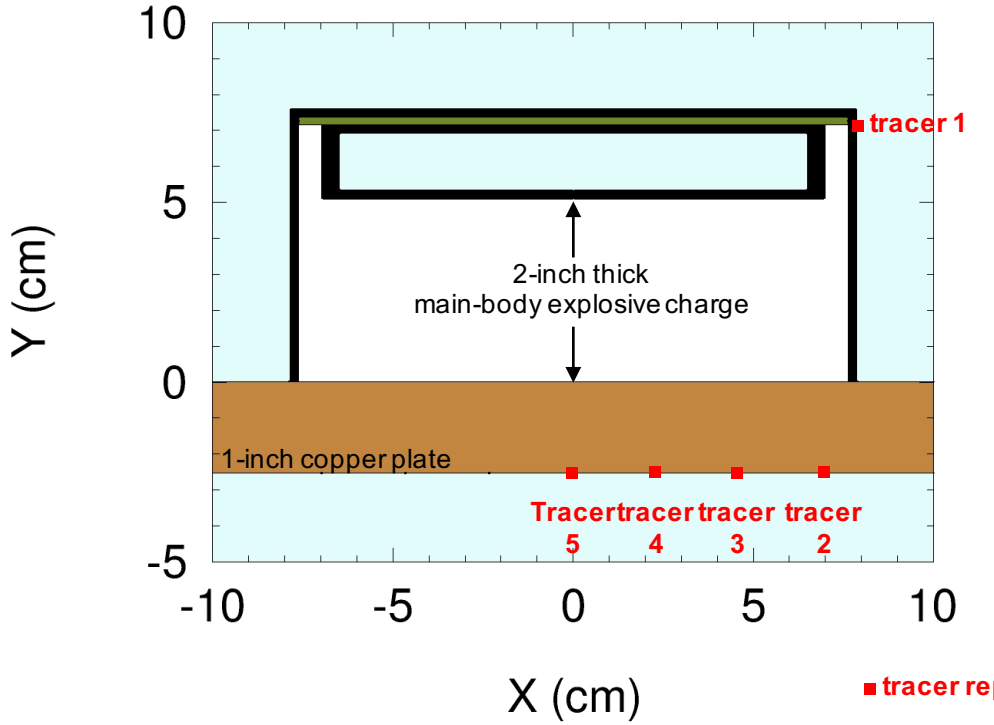
- 2-inch thick main-body explosive charge

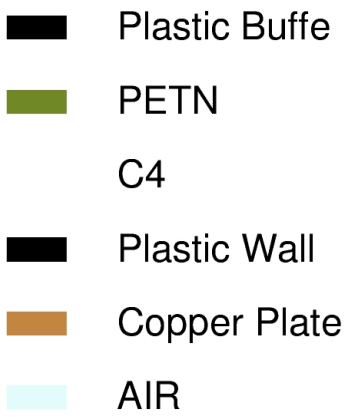
2-inch thick bulk charge

2-inch thick cylindrical charge



Simulation of Converging Detonation





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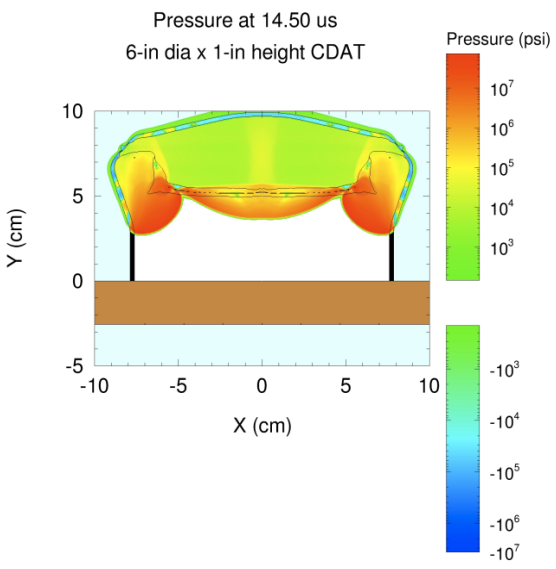
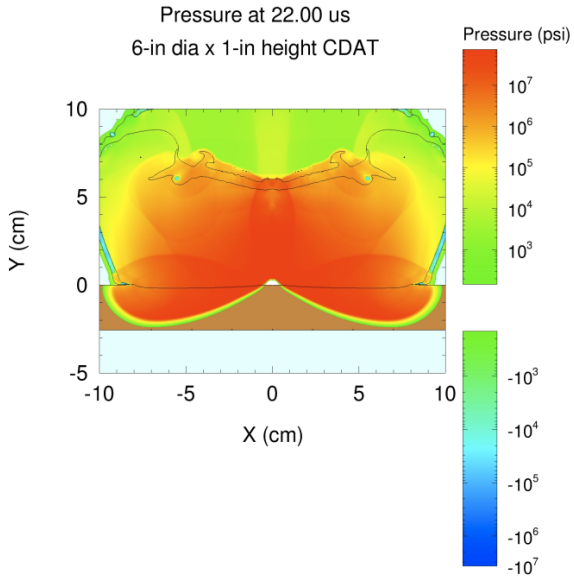
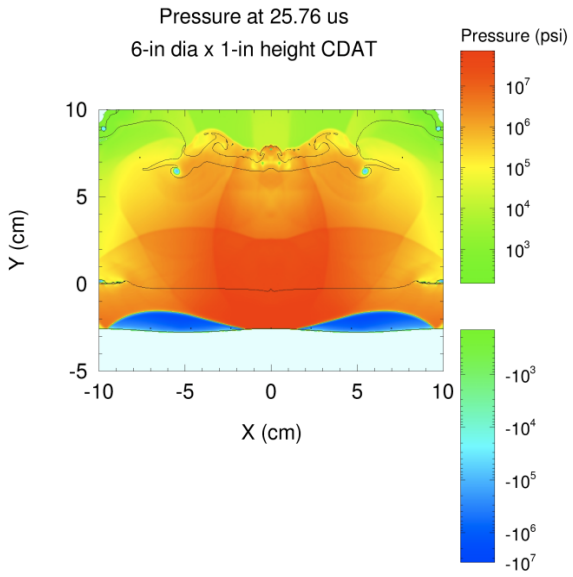
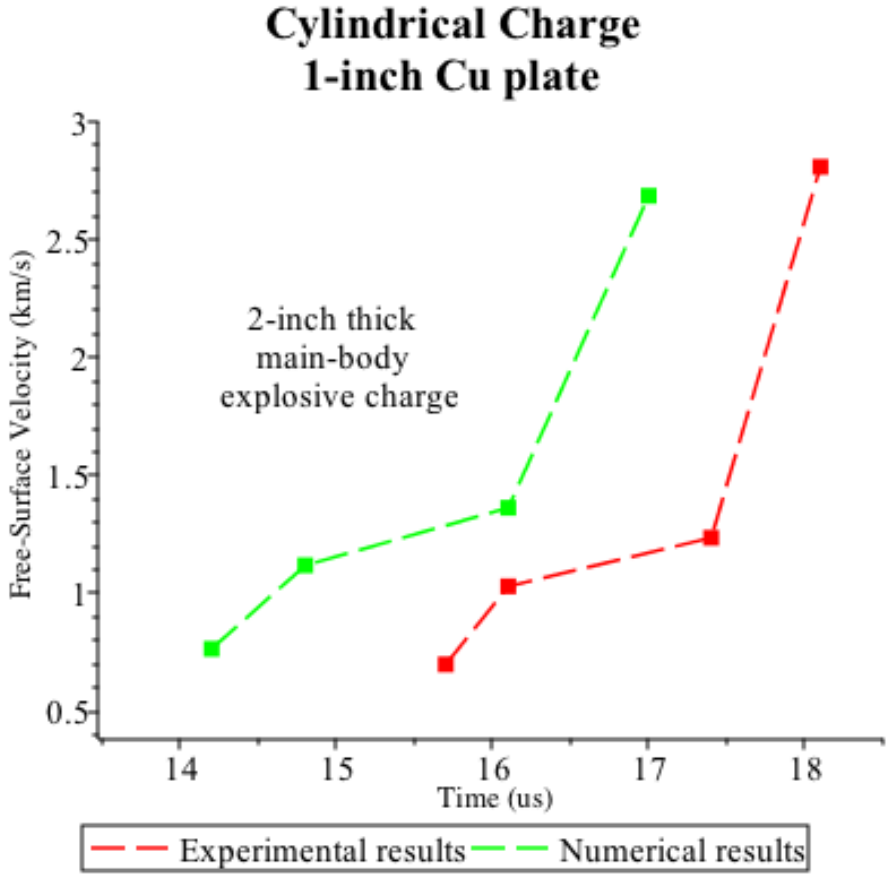






Numerical/Empirical Results



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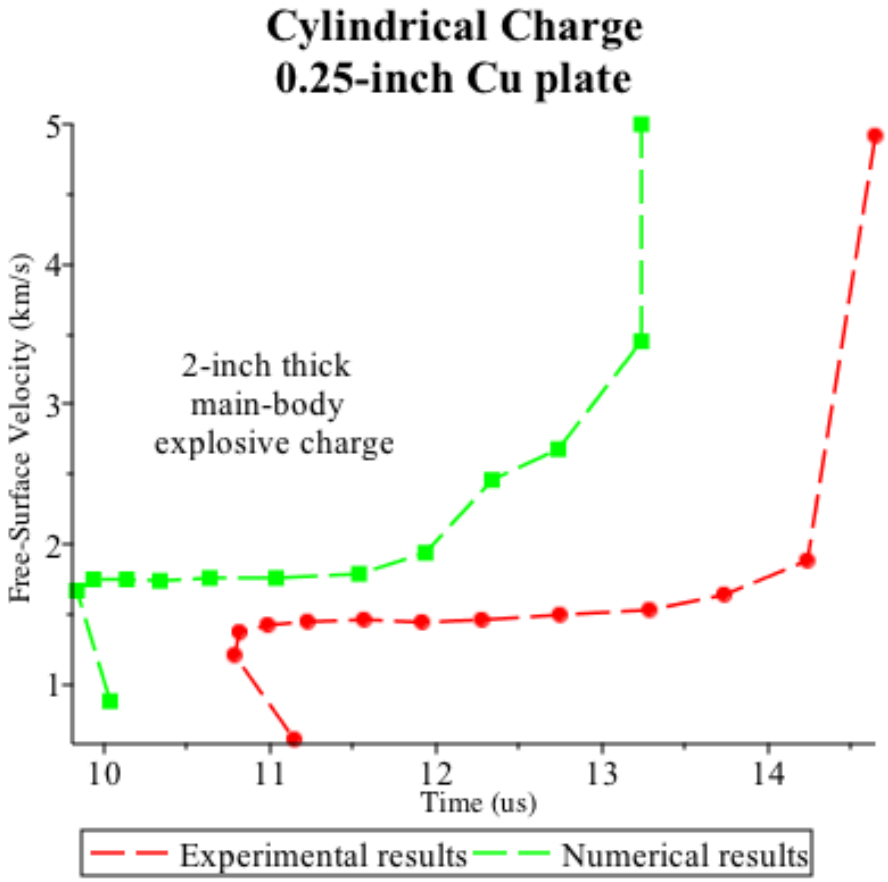

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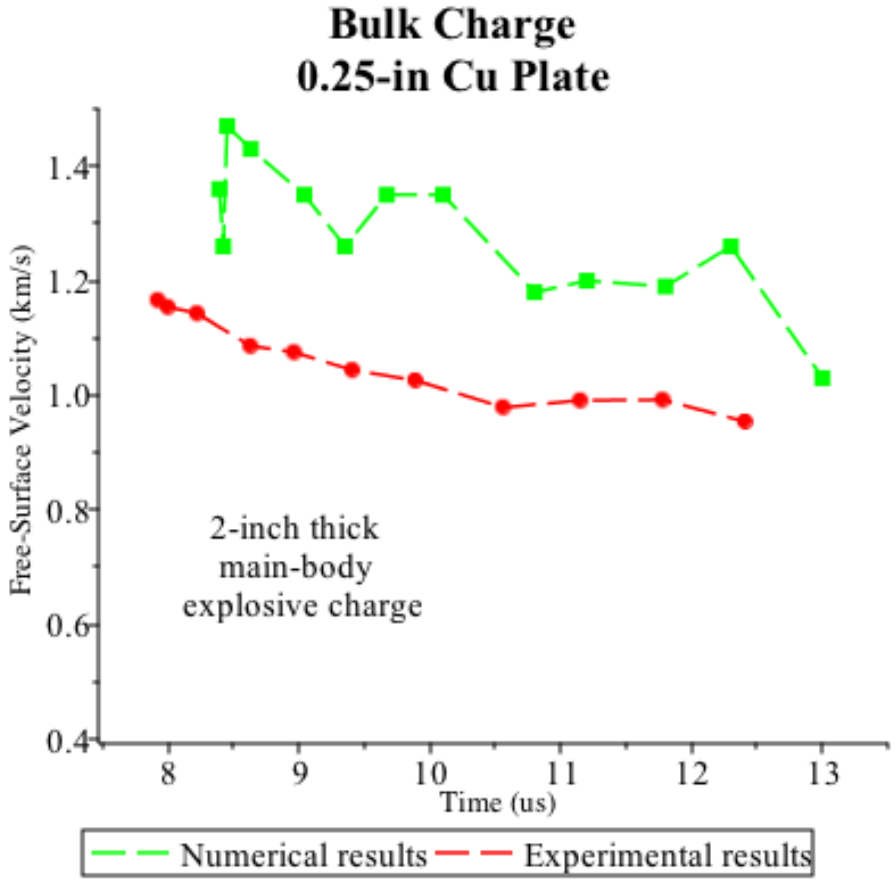
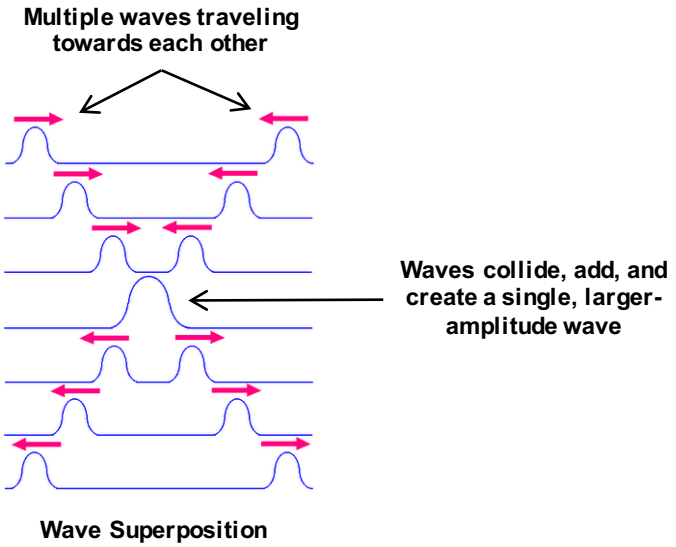
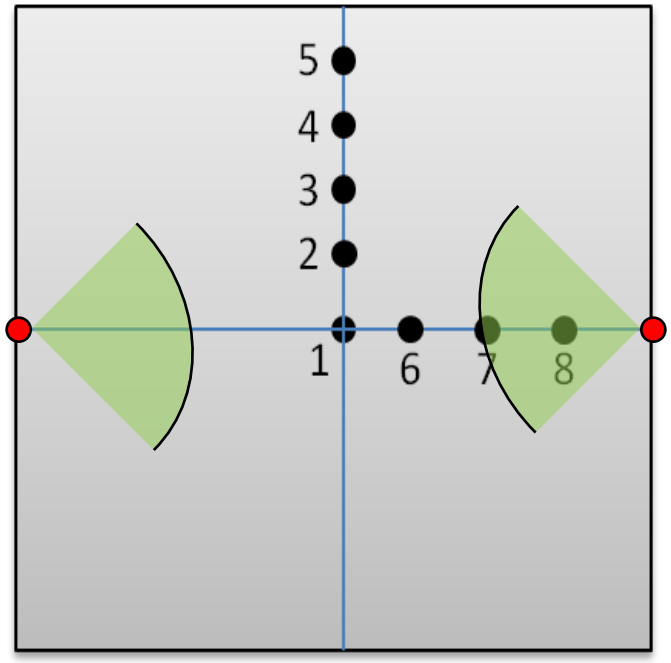


Experimental results missing center and end points. Probes were bad

Two Point Convergence

- Diagram of PDV locations

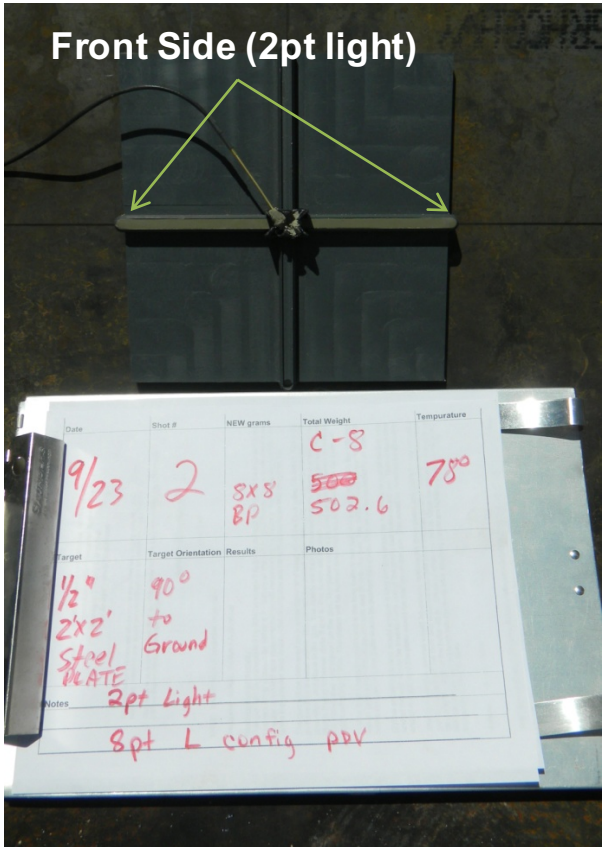




Two-point Light

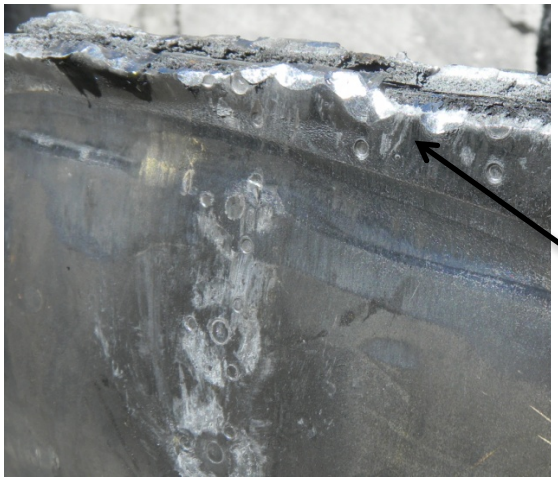
Two Point Convergence

8 External PDV Probes



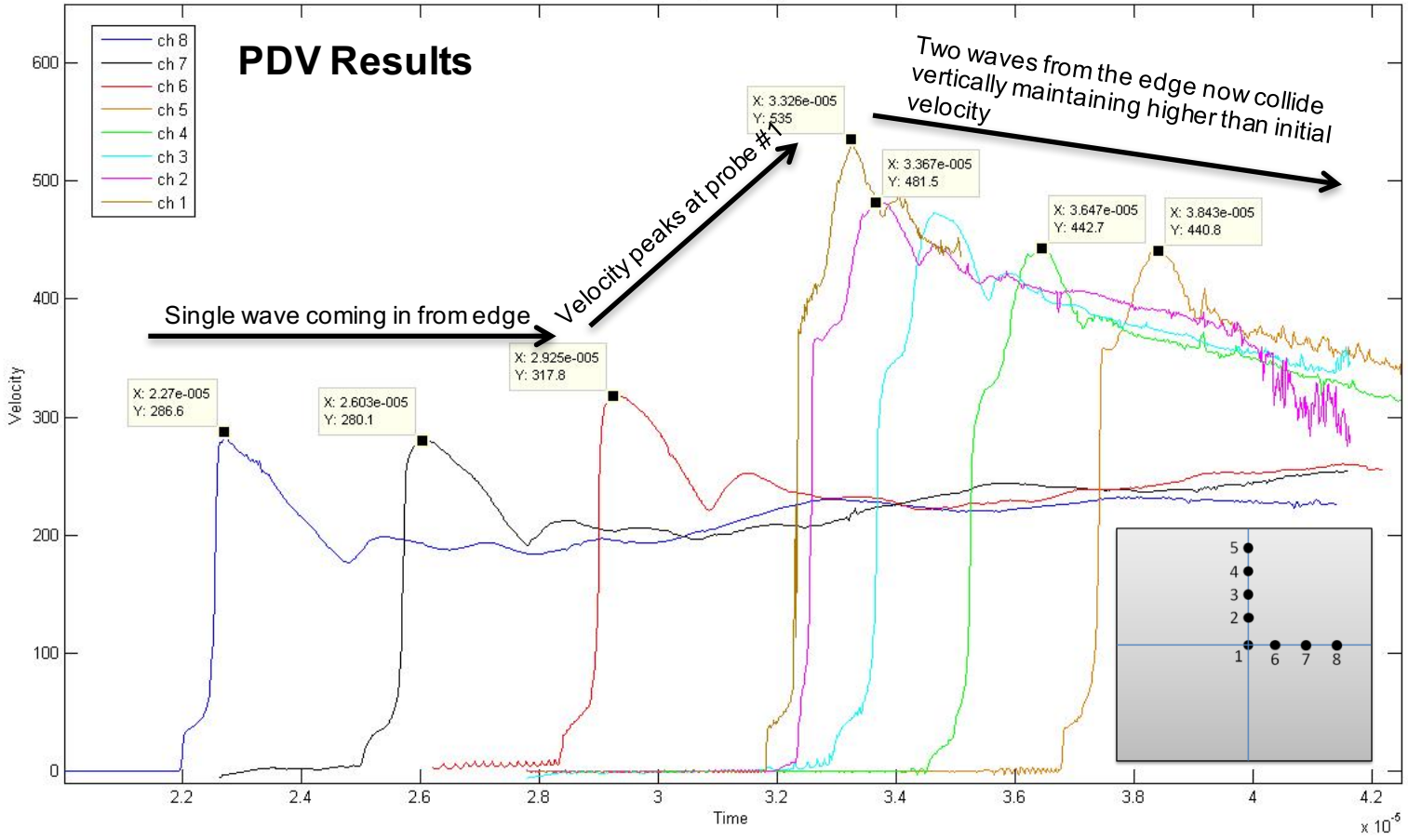
Two Point Convergence

Post Shot Photos



Again, post shot “prints” left on the tear location indicates precise PDV probe location(s).

Two Point Convergence



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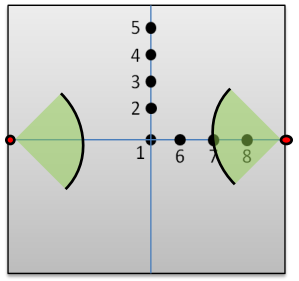
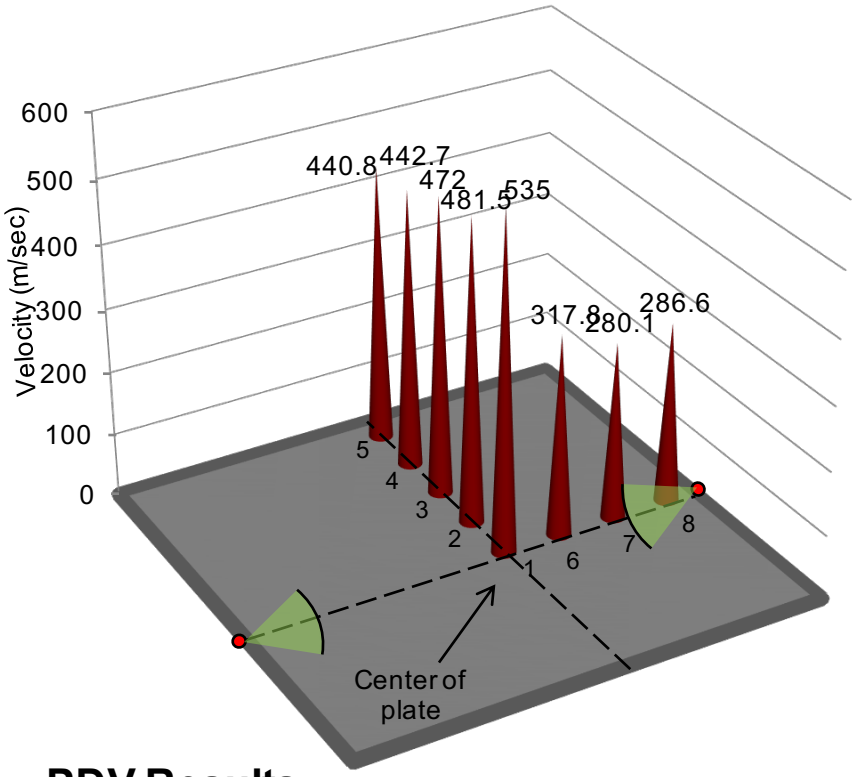
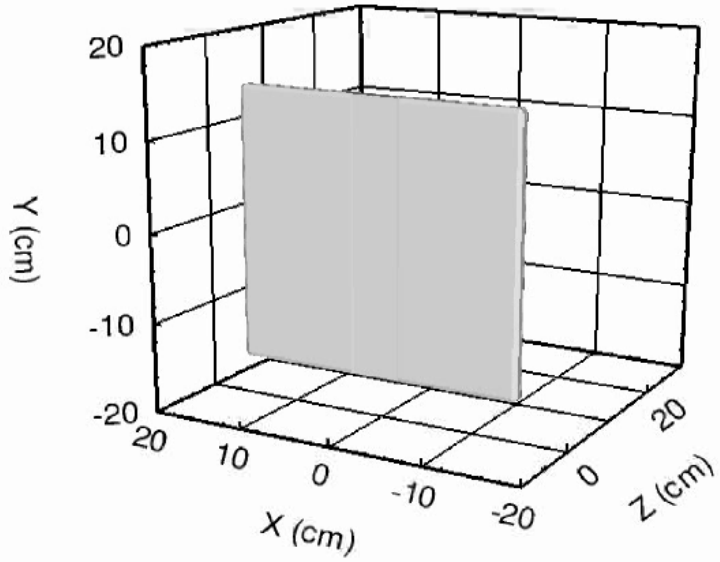


Two-point Light



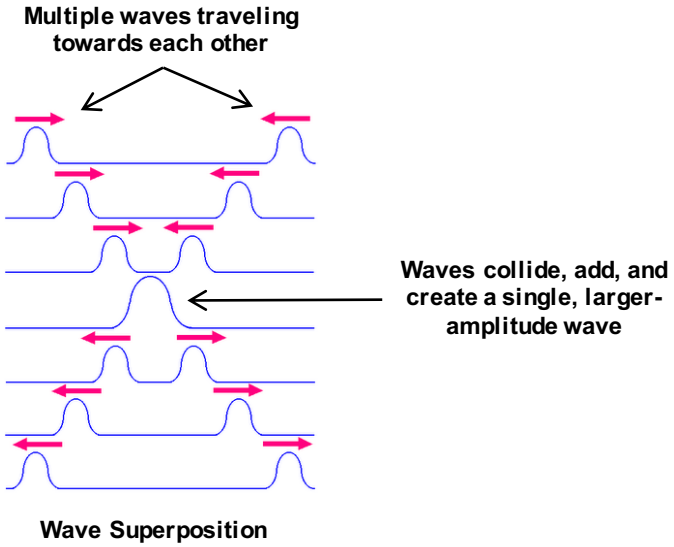
PDV Results

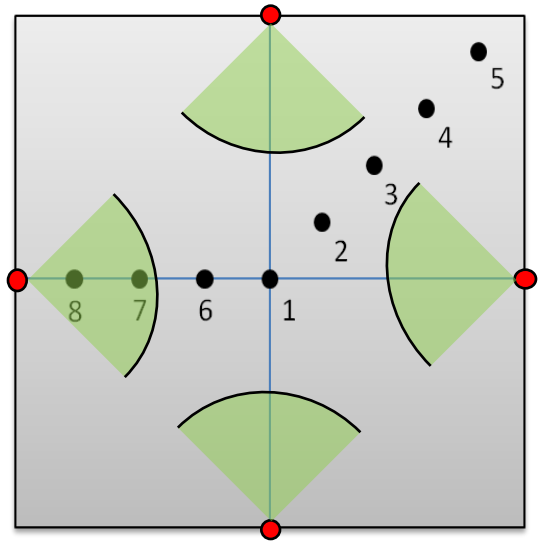
Two Point Convergence



Time = 0.00 us

Four Point PDV Placement

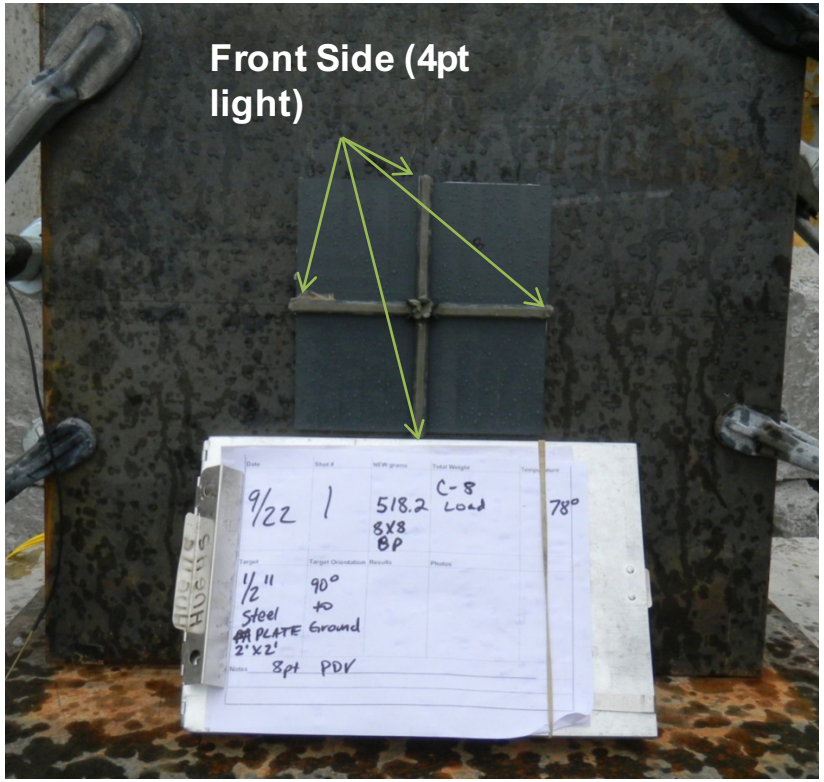


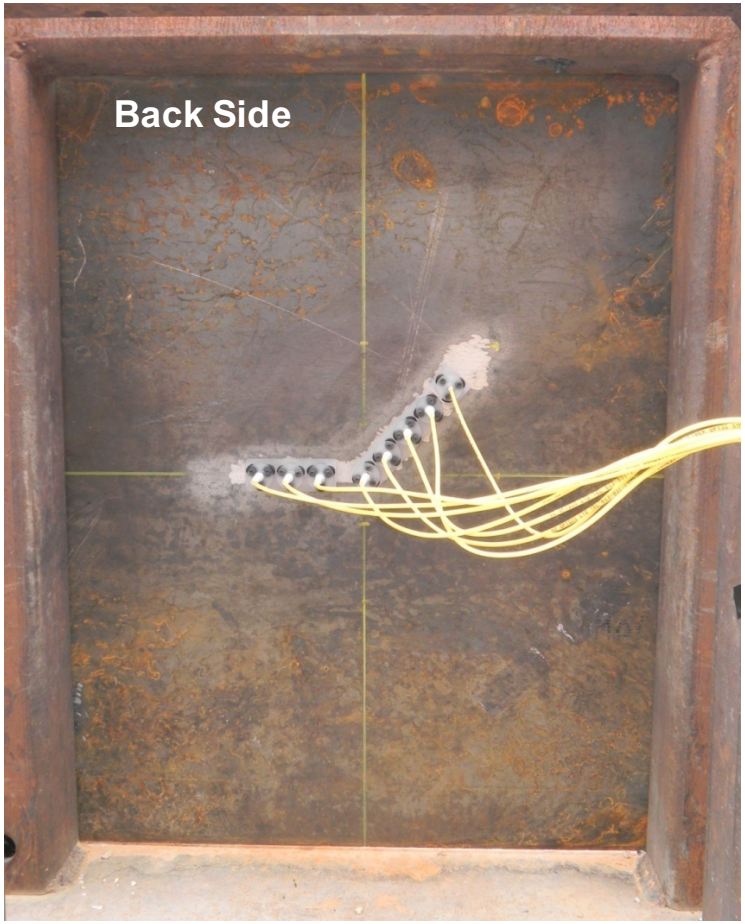


Four-point Light

Four Points of Convergence

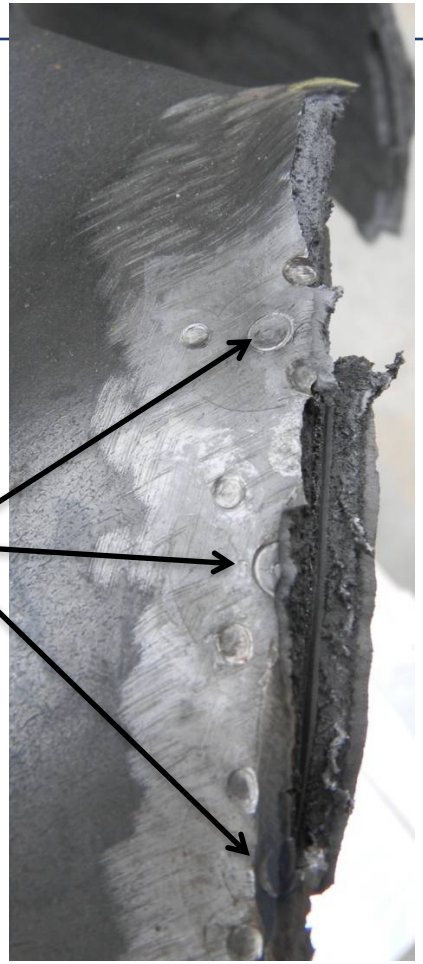
8 External PDV Probes



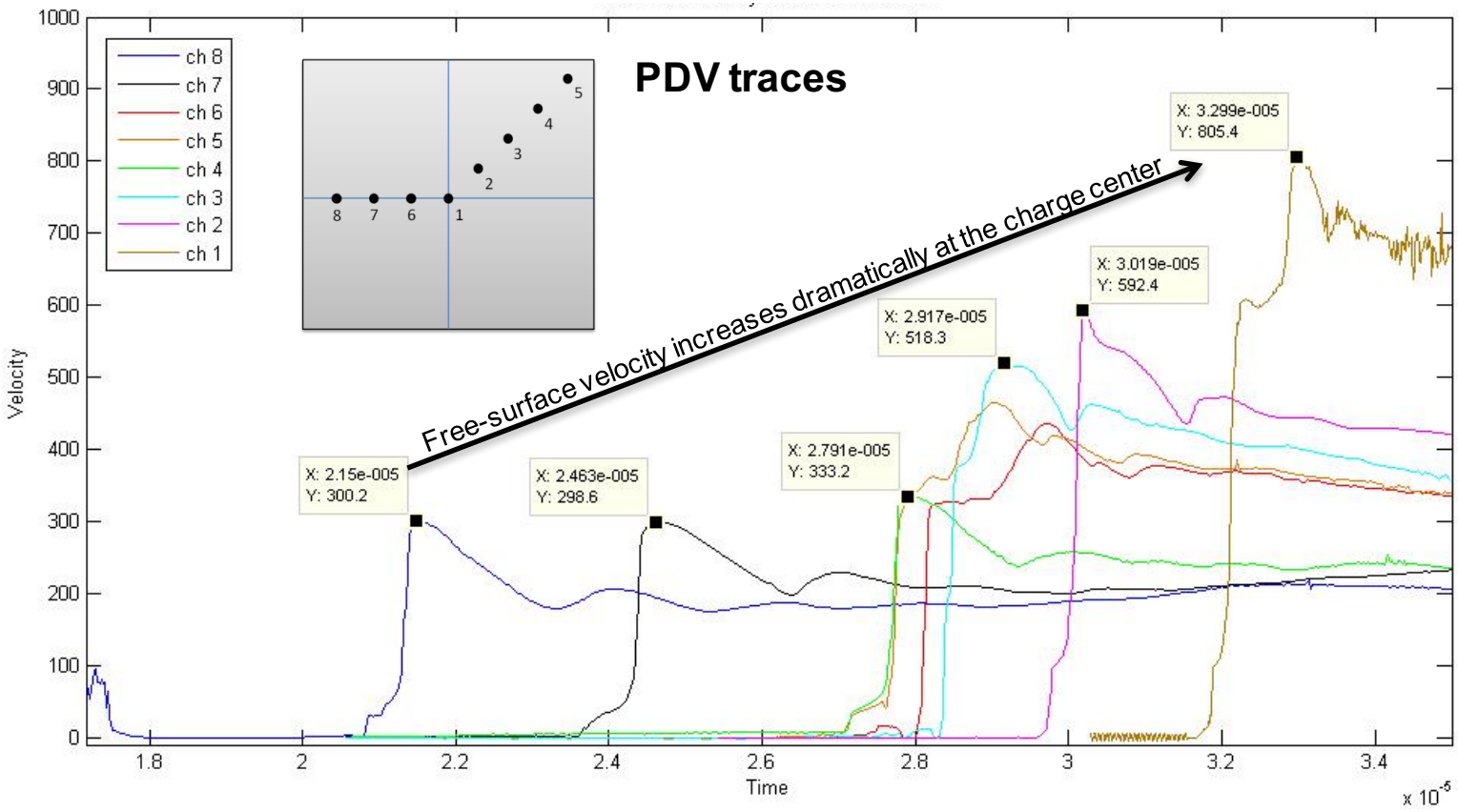


Post Shot Photos

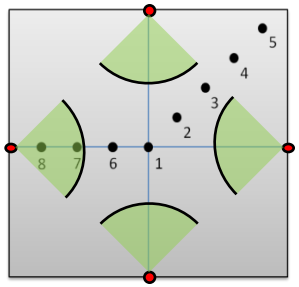
Post shot "prints" left on the tear location indicates excellent PDV probe placement.



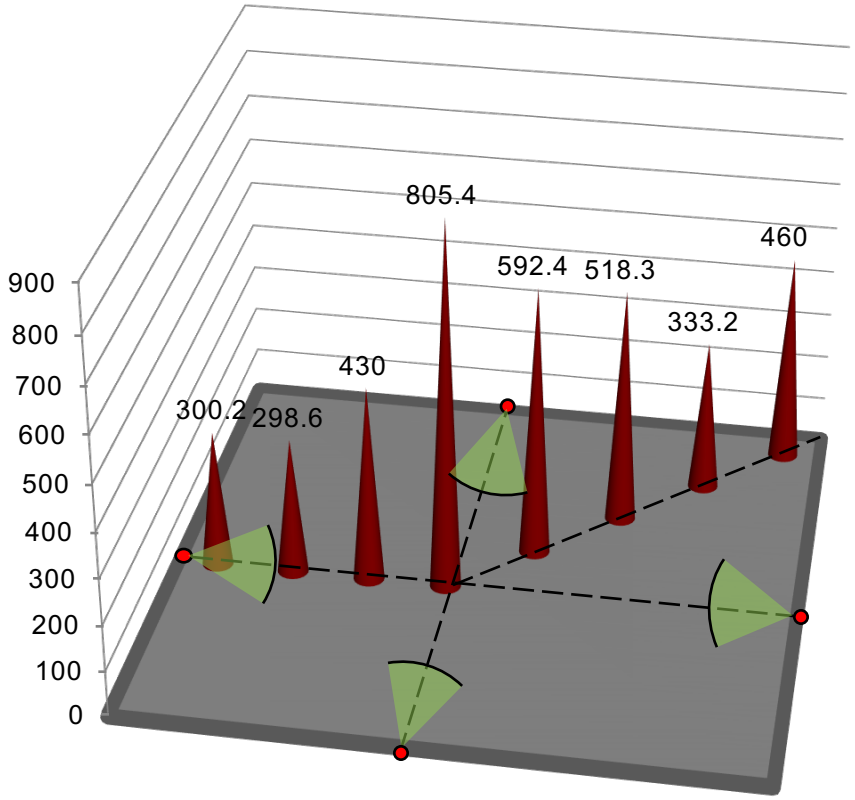
Four Points of Convergence



Four Points of Convergence

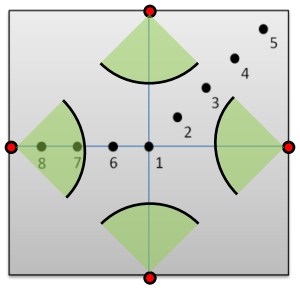


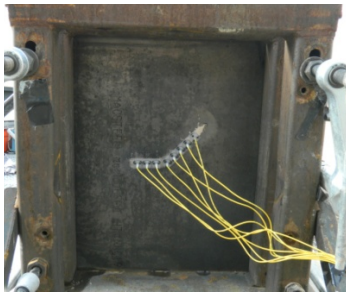
Four-point Light



PDV Results Test #1

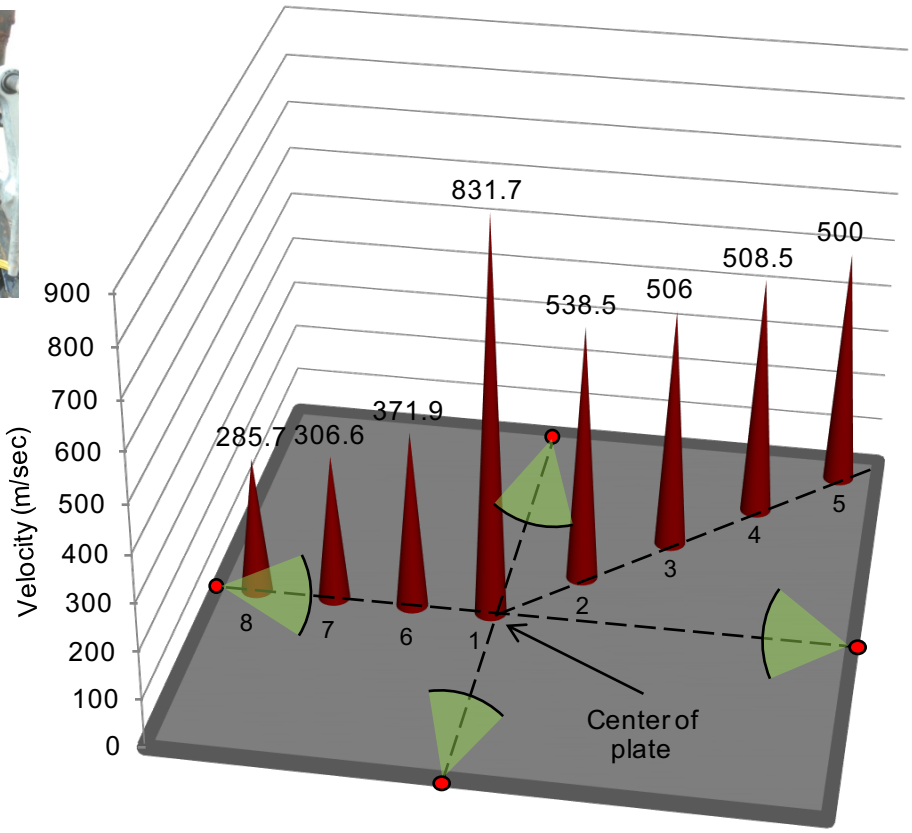
Four Points of Convergence





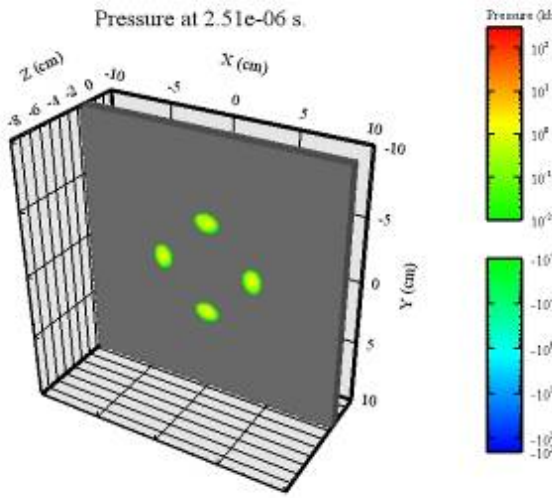
Four-point Light

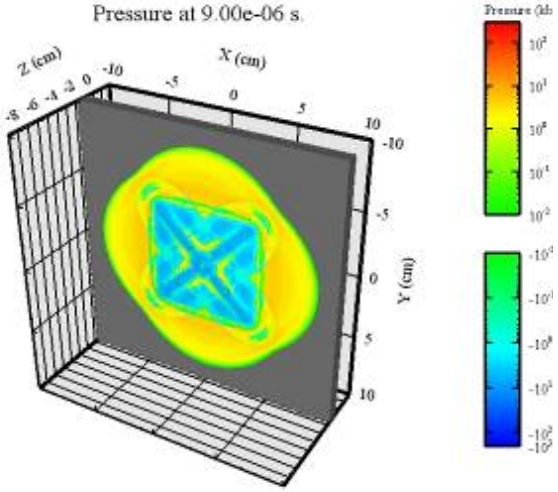
Experimental Results

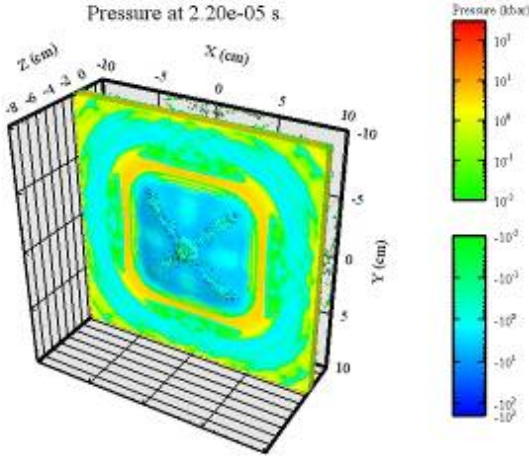


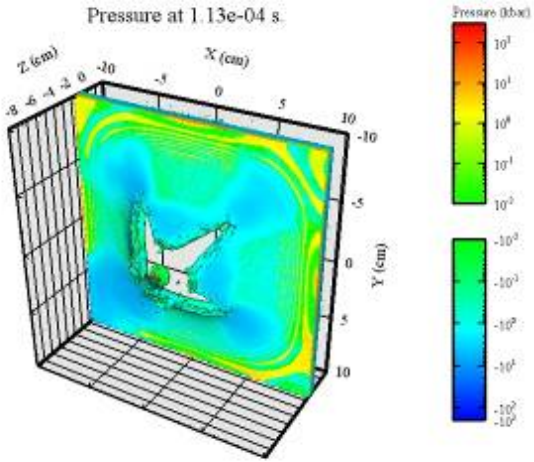
PDV Results Test #2

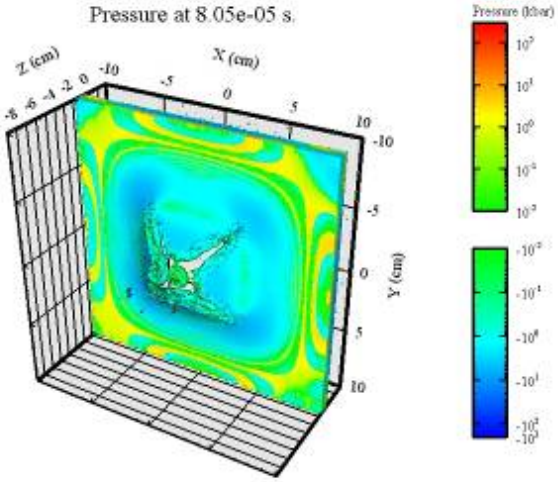

Sandia
National
Laboratories
DETS

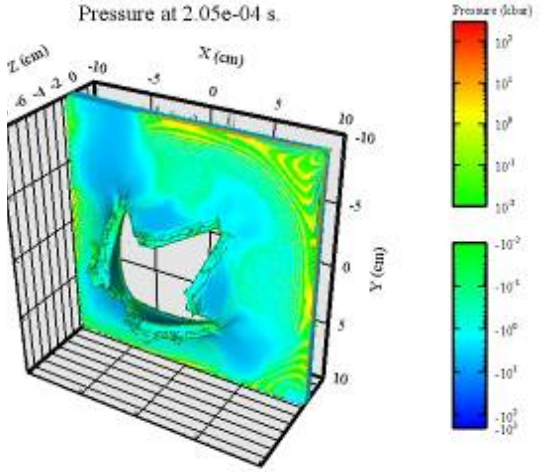

Pressure at 2.51e-06 s.
Z (cm)
X (cm)
Y (cm)


Pressure at 9.00e-06 s.
Z (cm)
X (cm)
Y (cm)

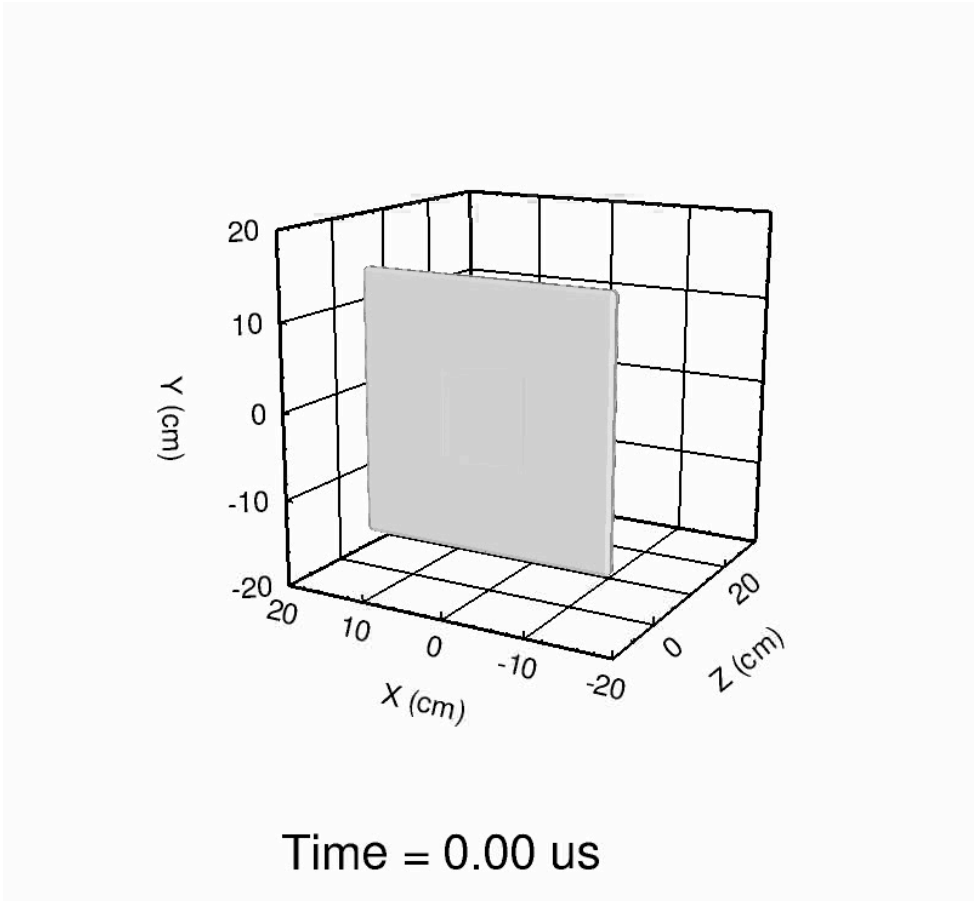

Pressure at 2.20e-05 s.
Z (cm)
X (cm)
Y (cm)


Pressure at 1.13e-04 s.
Z (cm)
X (cm)
Y (cm)


Pressure at 8.05e-05 s.
Z (cm)
X (cm)
Y (cm)


Pressure at 2.05e-04 s.
Z (cm)
X (cm)
Y (cm)

Four Points of Convergence



Four Points of Convergence

Questions