Use of PDV to measure the overdriven products equation of state in PBX 9502 and PBX 9501 and the EOS in shocked foams

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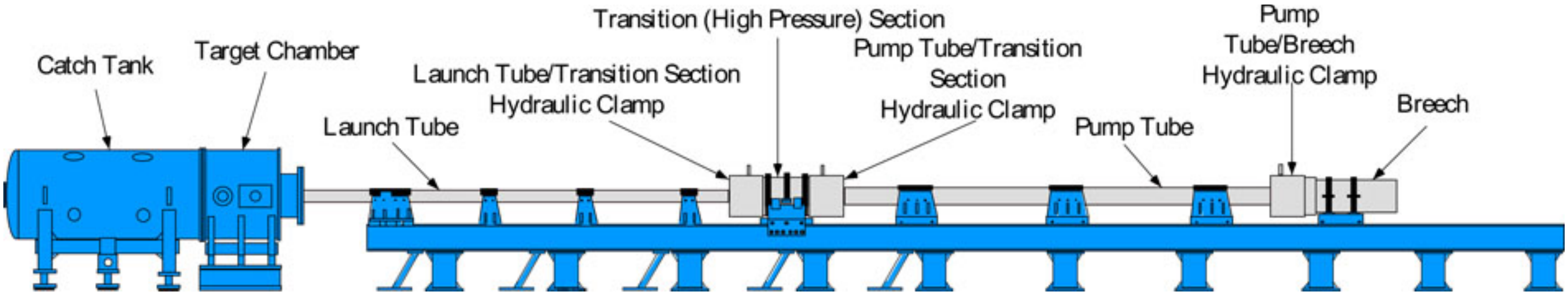
Unclassified
LA-UR-14-24531

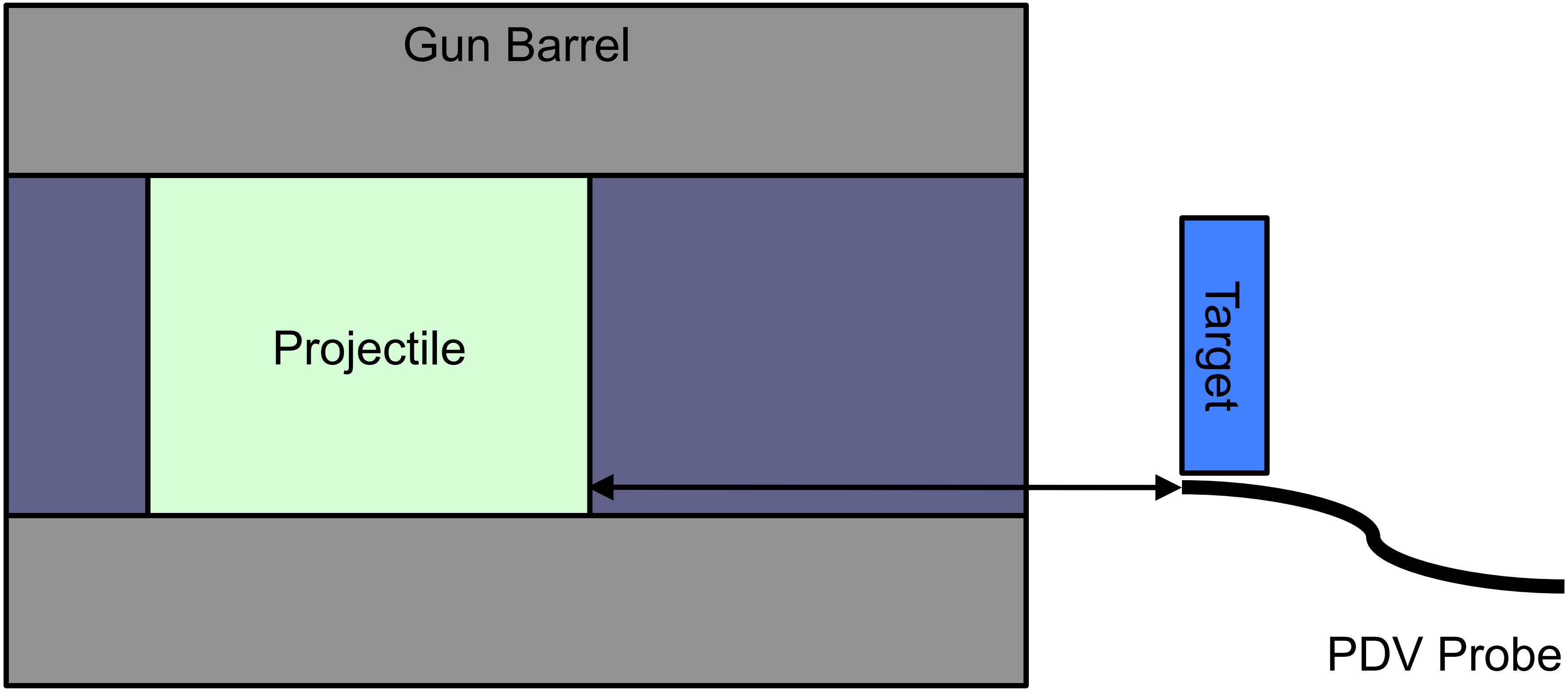
Gas Gun Experiments



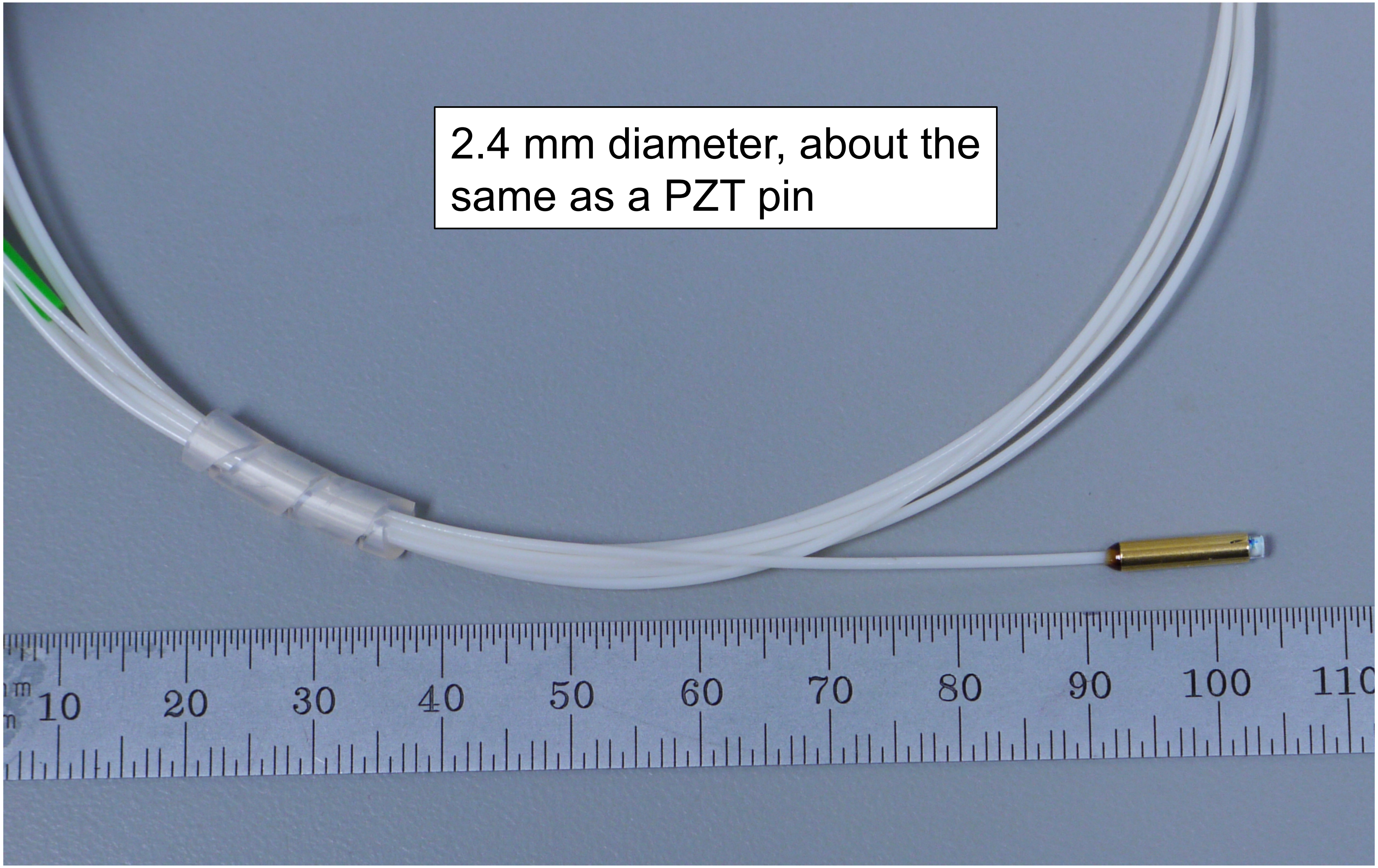
- **Purpose: Equation of State (EOS) & shock induced reactivity (shock initiation) studies**
- **pump tube: 4" (101.6 mm) φ by 25' (7.6 m) long**
- **launch tube: 2" (50.8 mm) φ by 25' (7.6 m) long**
- **First shot 5/94**
- **800 + shots to date**
- **Velocities up to 3.6 km/s**

- Gas breech - 15,000 psi
- Projectile velocities- <1 to 3.6 km/s
- Pump/Launch Tube - 100/50 mm dia.

Projectile velocity (1 probe)

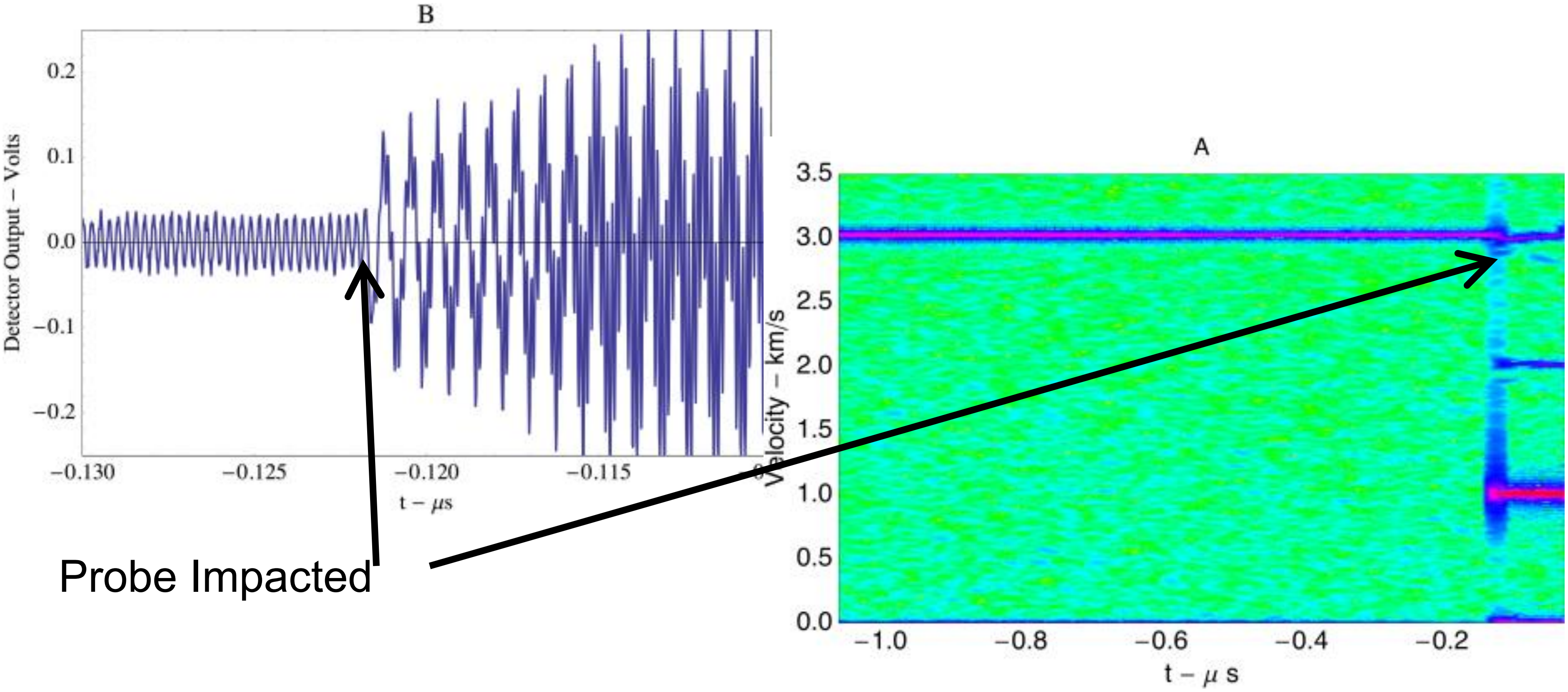


PDV Probe = AC Photonics 1CL15P020LCC01



2.4 mm diameter, about the same as a PZT pin

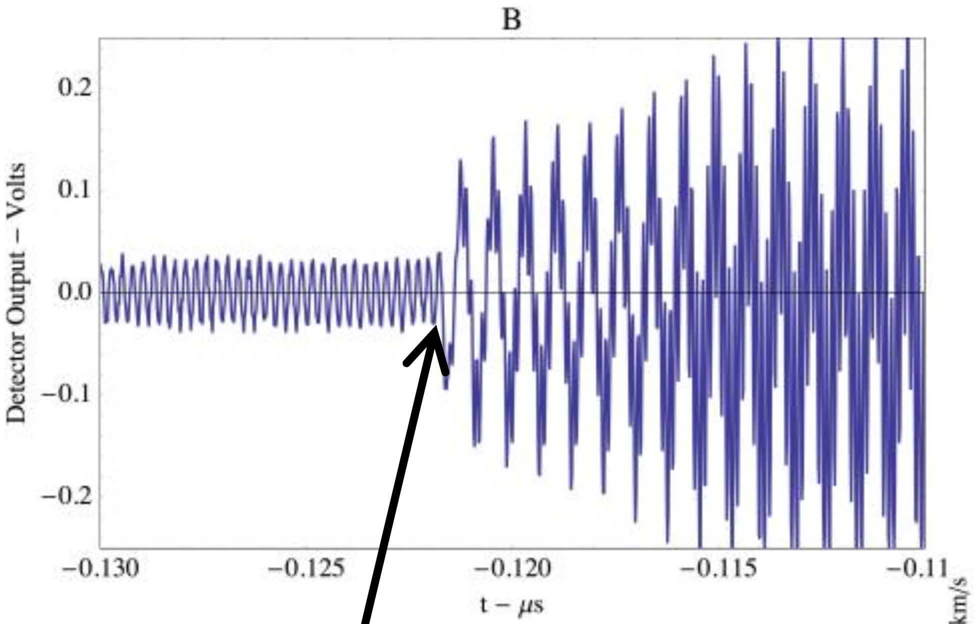
Projectile velocity PDV data (shot 2s-465)

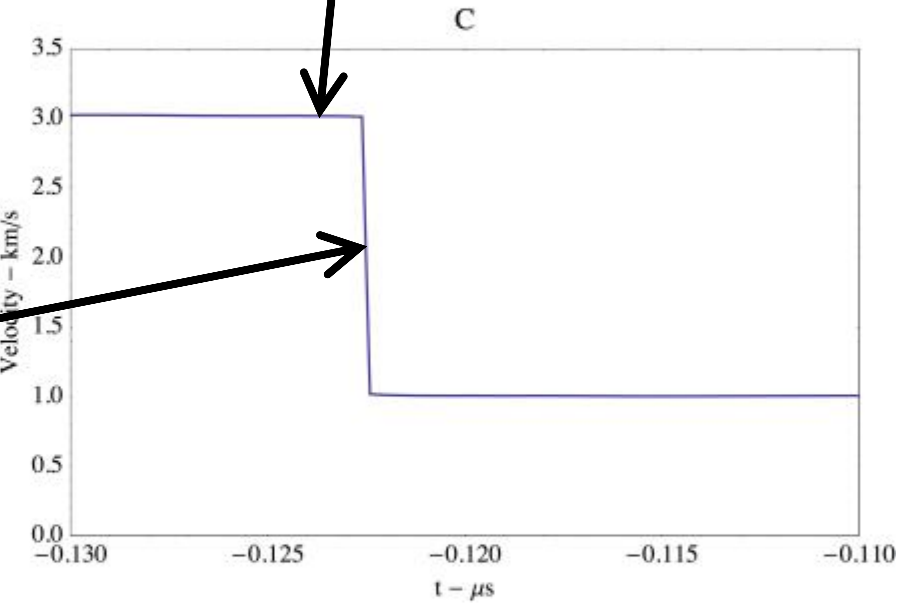


Probe Impacted

Projectile velocity PDV data (shot 2s-465)

PDV provides precise measure of projectile vel. & impact time!





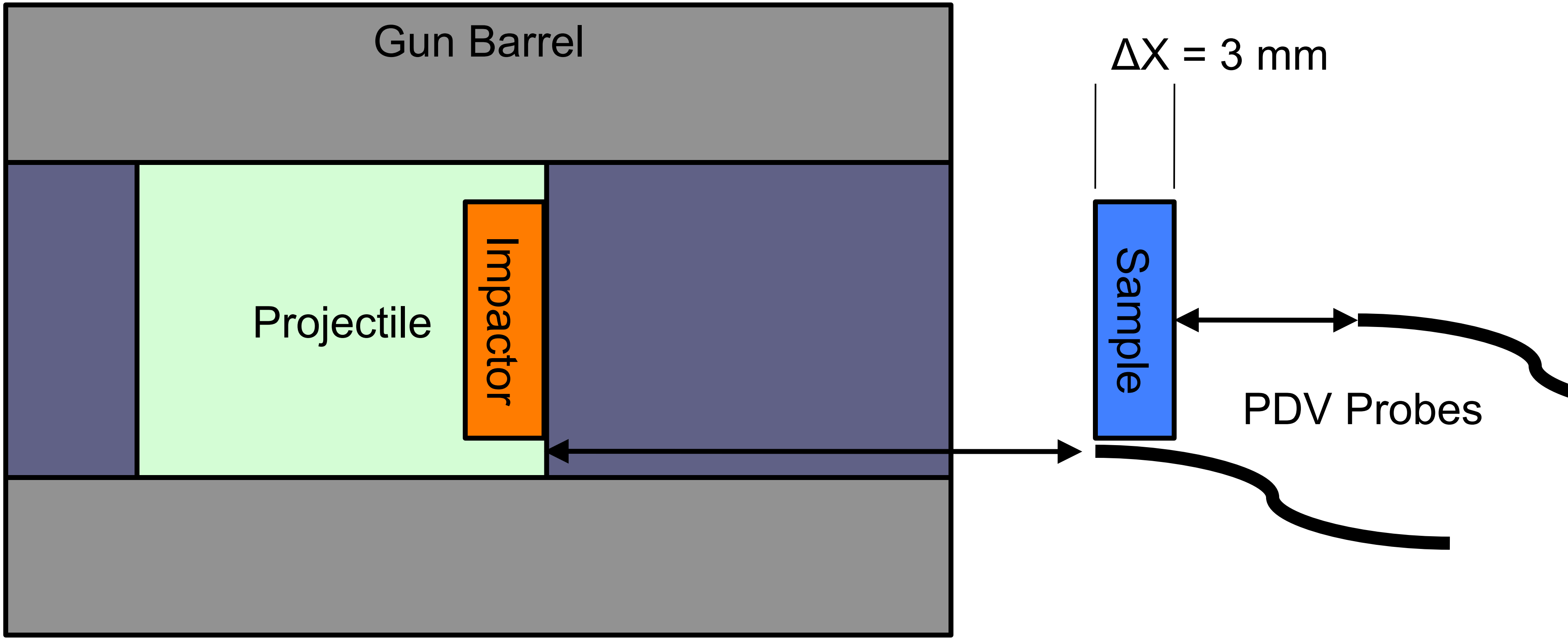
Vel. = 3.025 ± 0.002 km/s

Probe Impacted

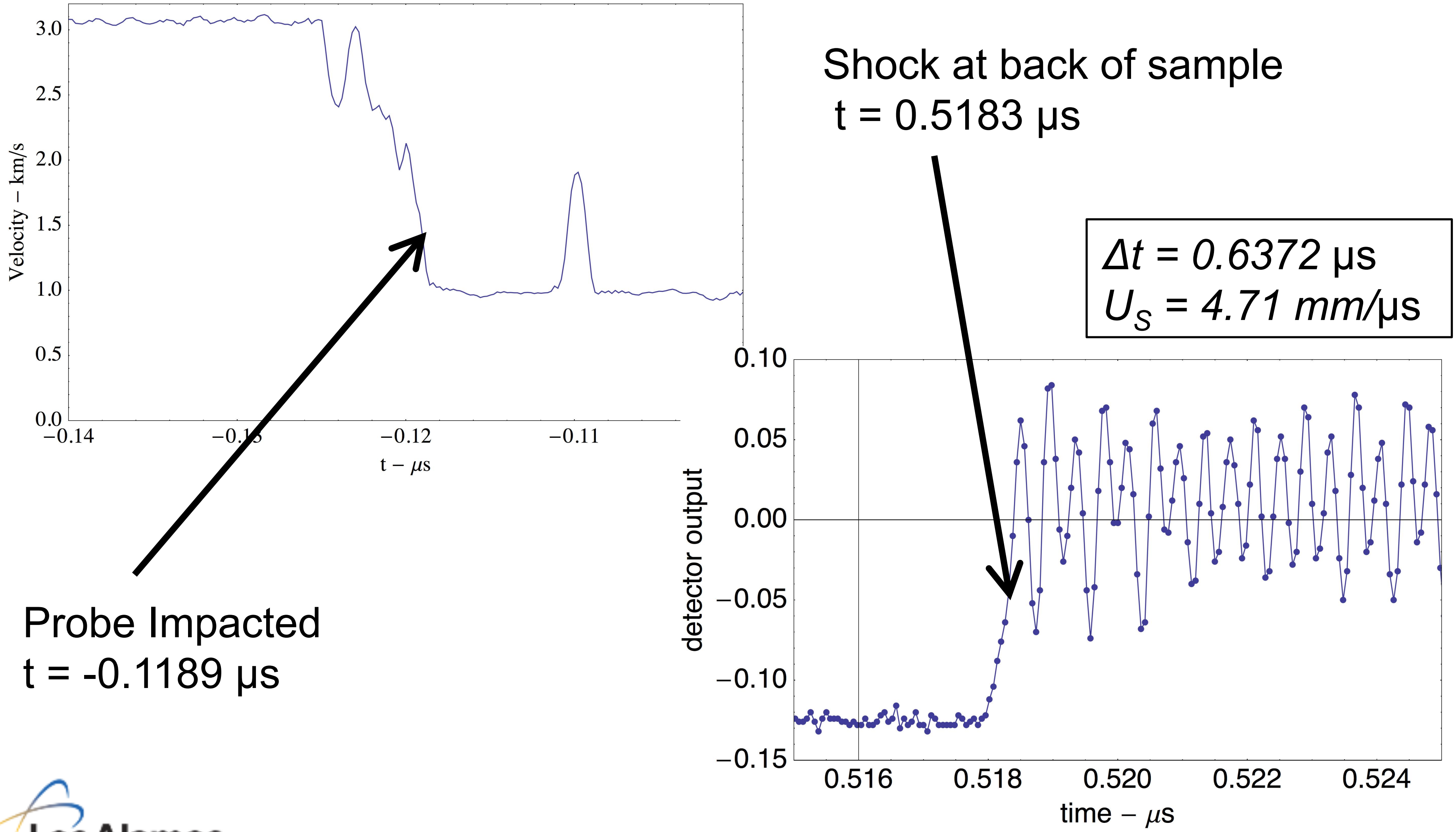
Impact time to 1 – 2 ns

Shock velocity (2 probes)

$\Delta x / \Delta t$



Shock Velocity *(Δt)*

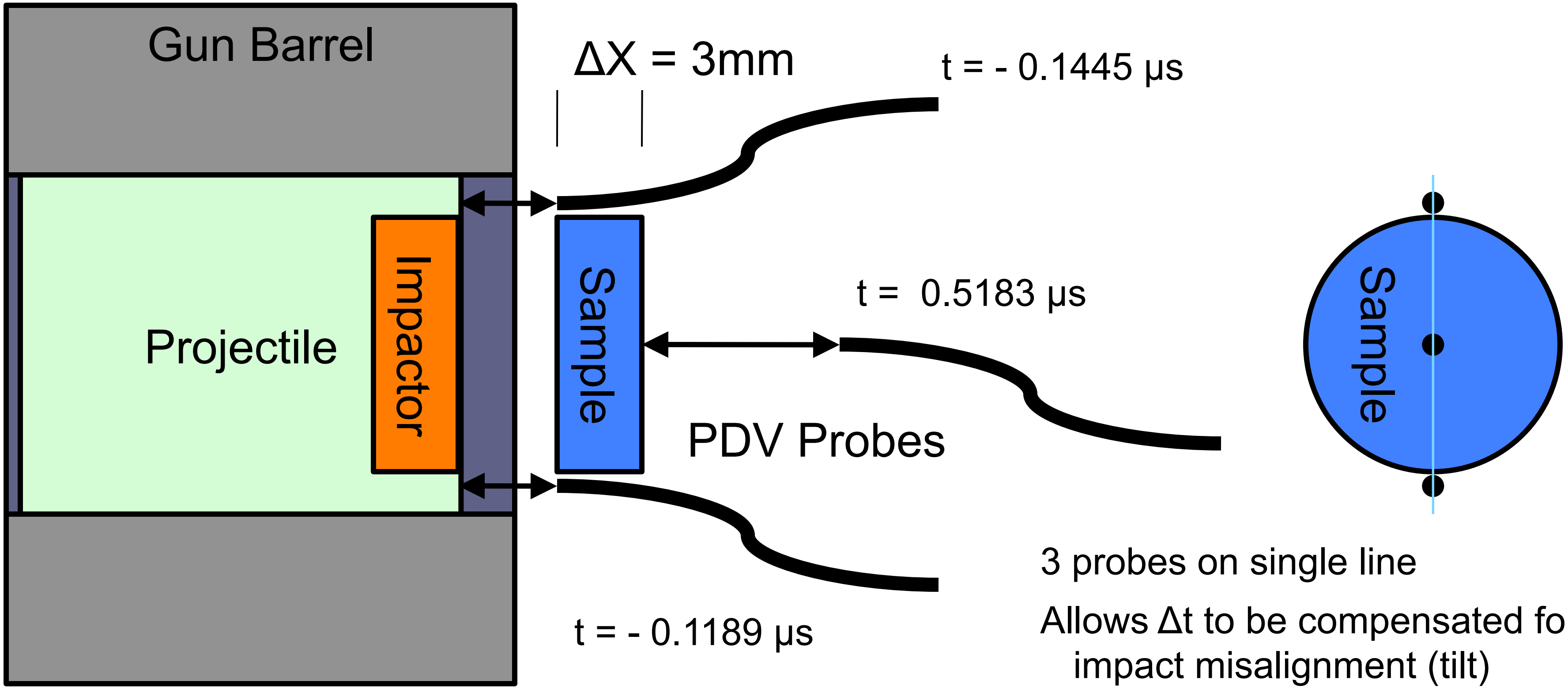


Shock at back of sample
t = 0.5183 μs

Δt = 0.6372 μs
*U_S = 4.71 mm/*μs

Probe Impacted
t = -0.1189 μs

More accurate shock velocity (3 or more probes)



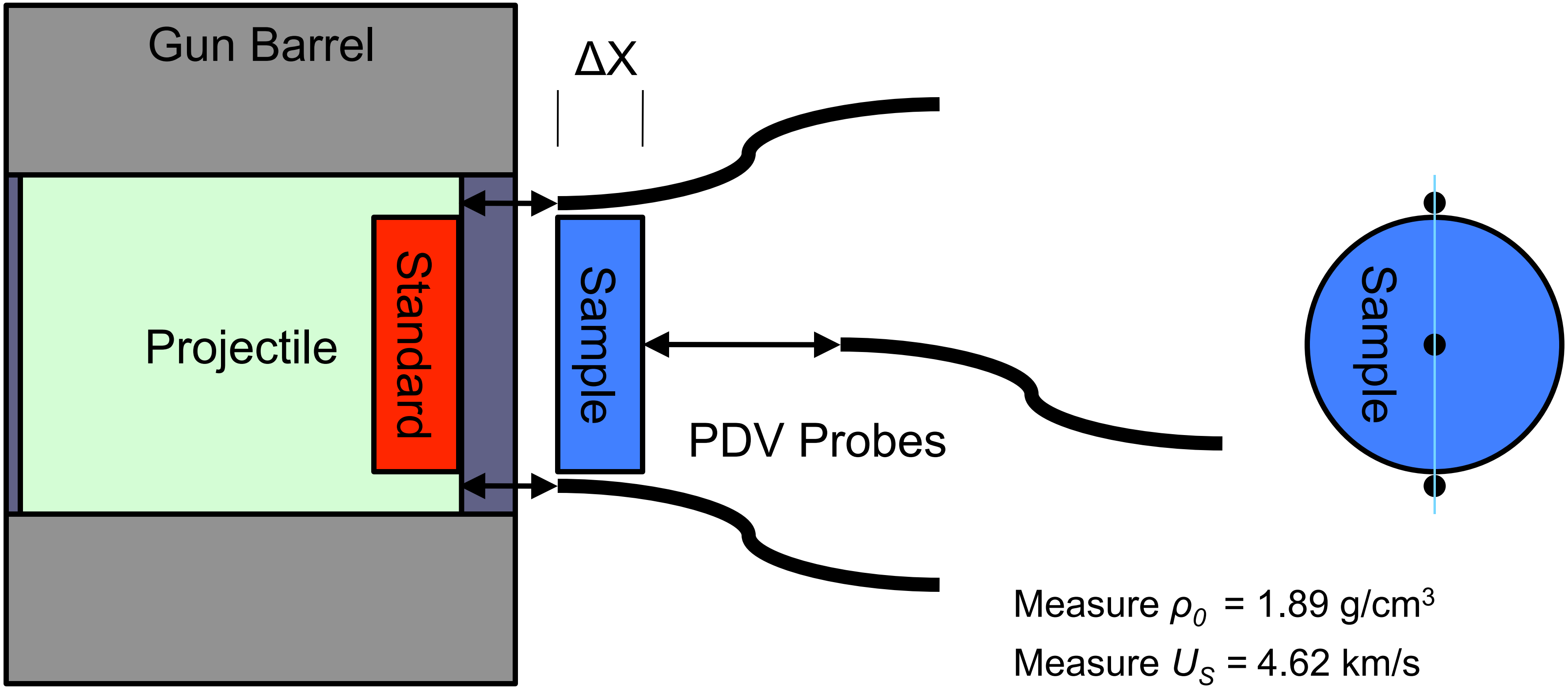
3 probes on single line

Allows Δt to be compensated for impact misalignment (tilt)

Scopes started with piezo-electric (PZT) or electrical shorting pin

Δt = 0.650 μs
U_S = 4.62 mm/μs

Measure a U_S - u_P Hugoniot point



Measure ρ_0 = 1.89 g/cm^3

Measure U_S = 4.62 km/s

Measure impact Vel. = 3.064 km/s

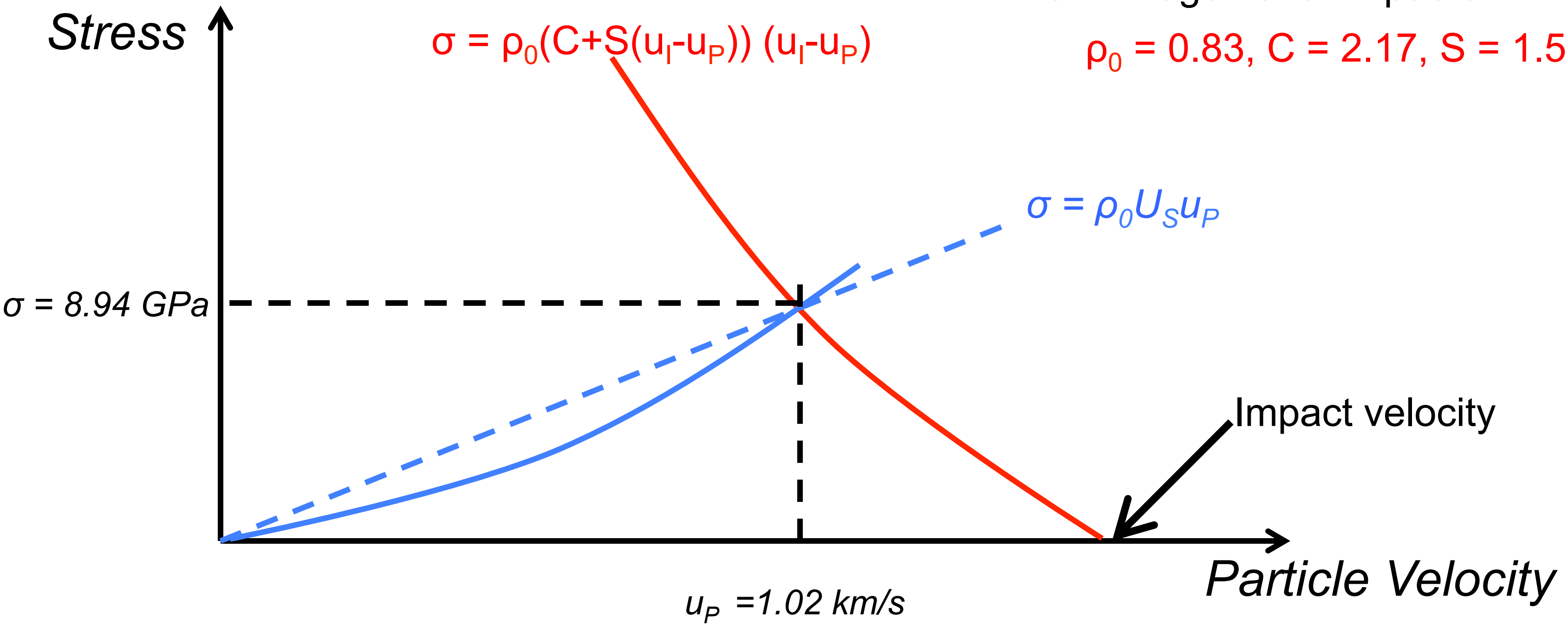
Measure a U_S - u_P Hugoniot point (cont.)

Measured U_S = *4.62*

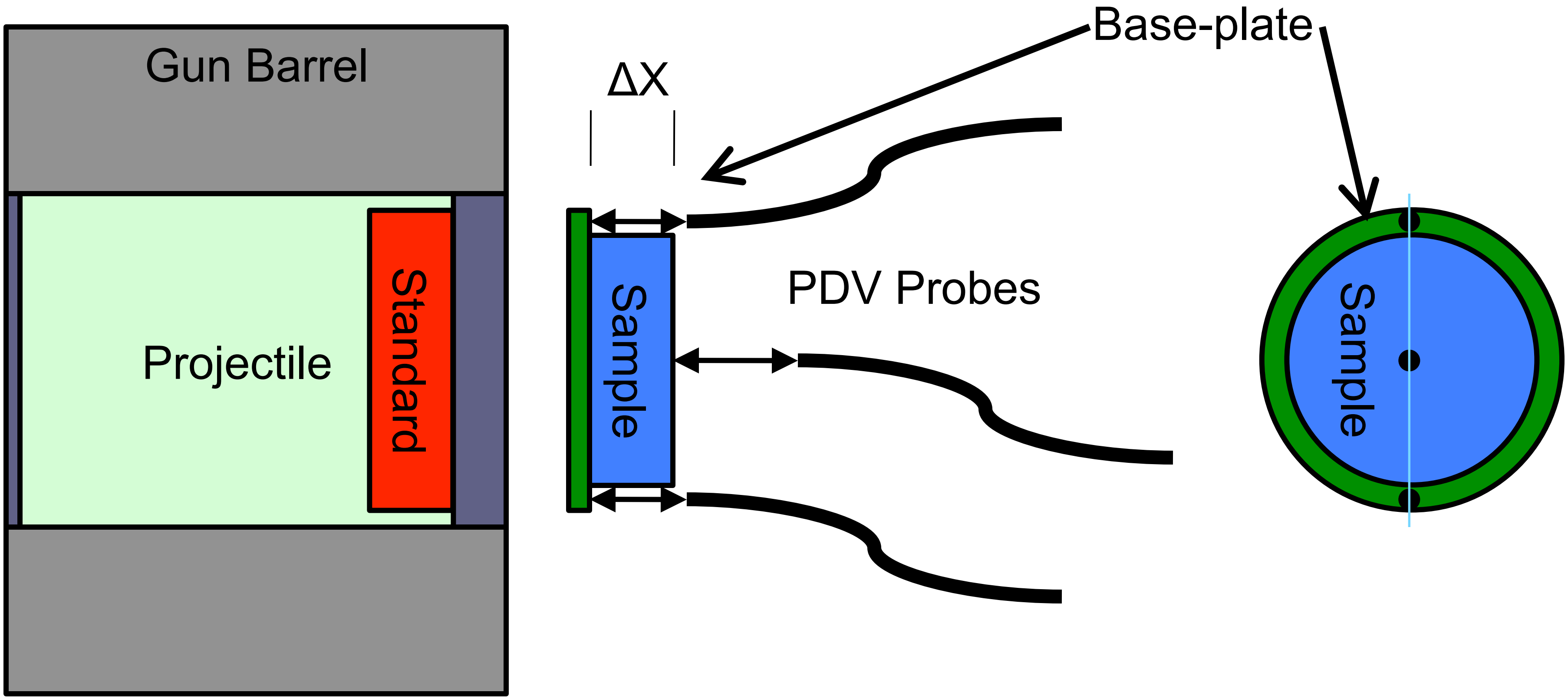
Measured impact Vel. = 3.064

Known Hugoniot of impactor

$\rho_0 = 0.83,\ C = 2.17,\ S = 1.53$



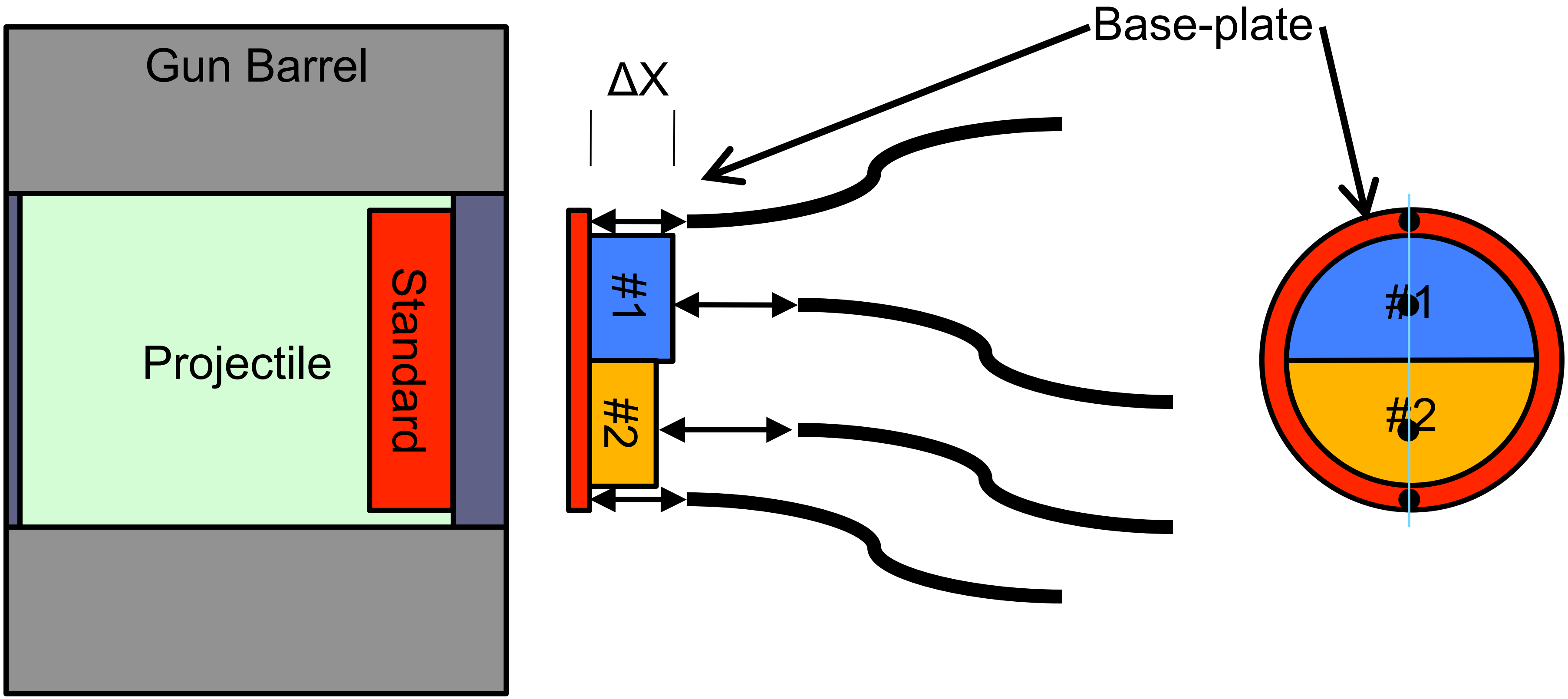
Base-Plate variant (projectile vel. not shown)



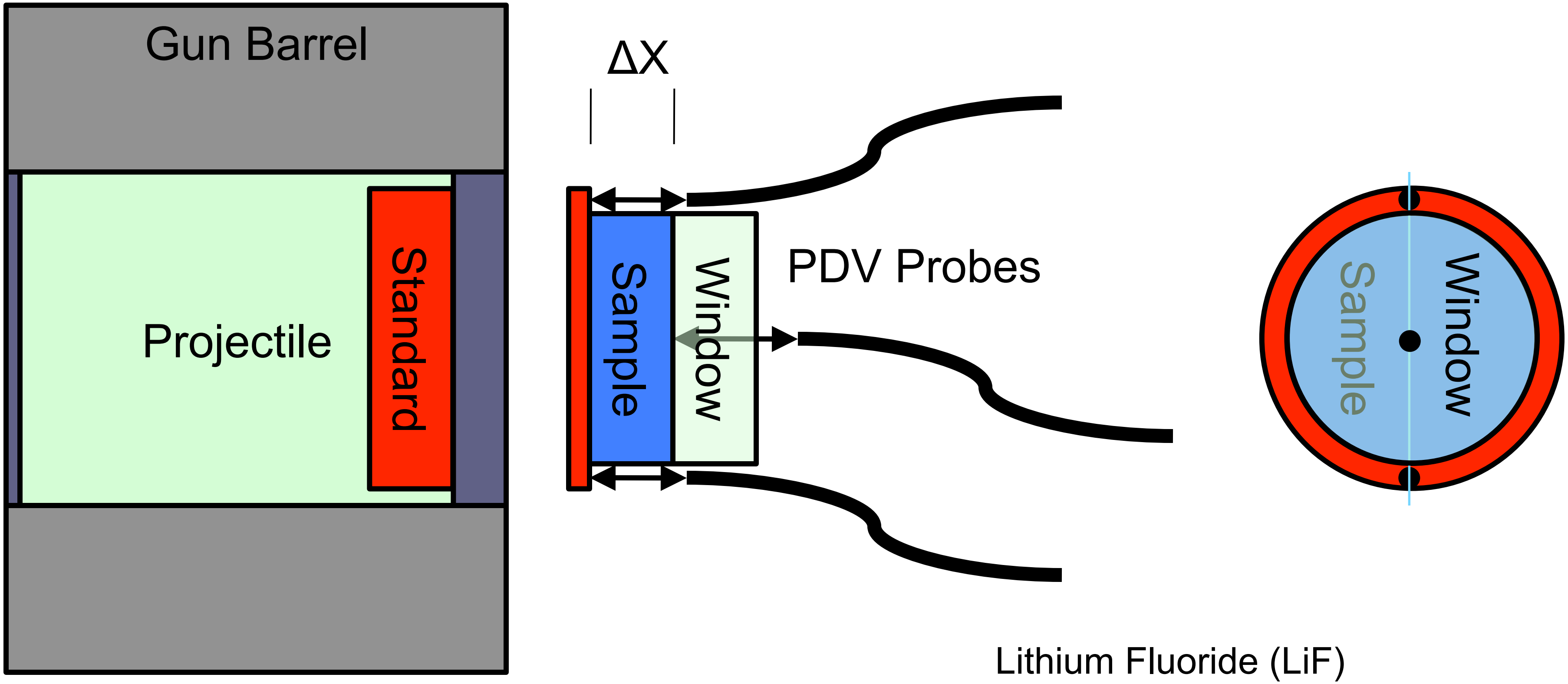
Good choices for base-plate material

- Same as standard
- Same as sample

Base-Plate variant – 2 (or more) samples



Add a window to maintain stress at back of sample (projectile vel. not shown)



Jensen, Holtkamp, Rigg, & Dolan, JAP,**101**,13523 (2007)

Lithium Fluoride (LiF)

C-cut sapphire

Z-cut quartz

PMMA

Overdriven Products EOS in PBX 9502

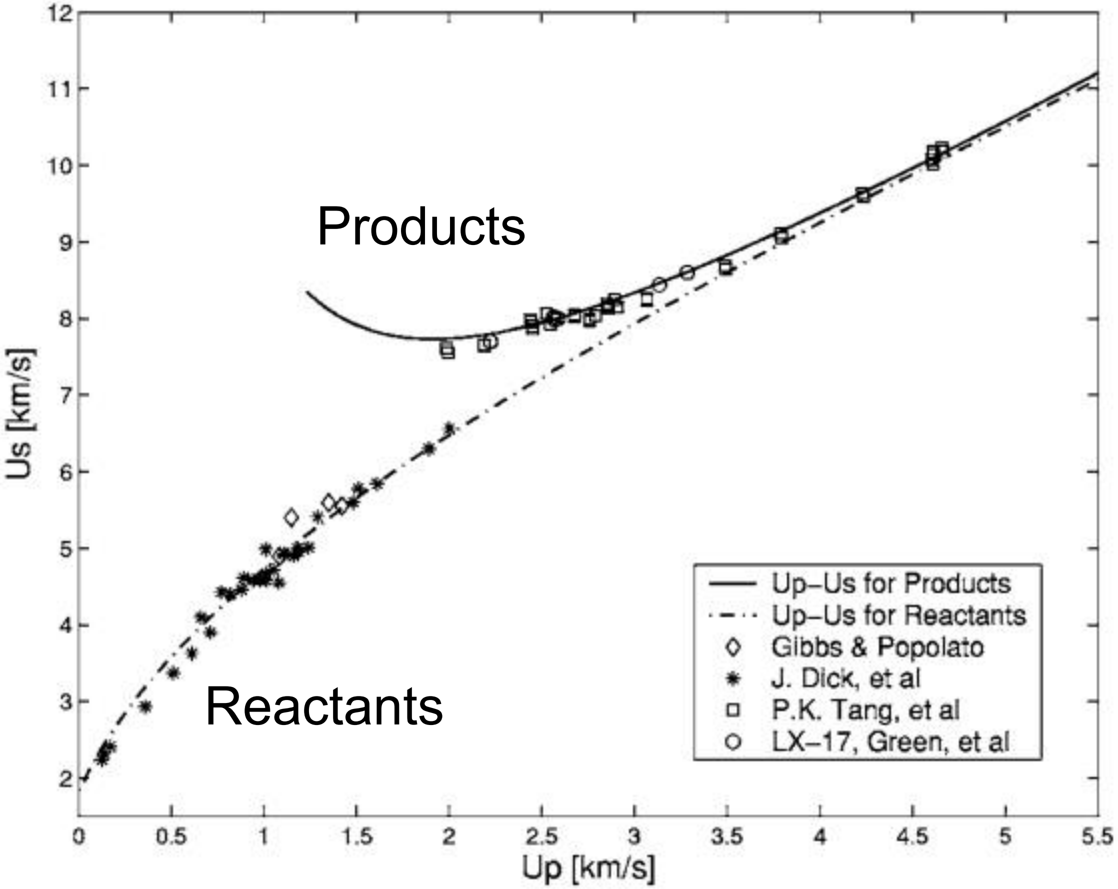
Background

- **PBX 9502 Composition**
  - 95% Tri-Amino-Tri-nitro-Benzene (TATB) by weight
  - 5 % Kel-F800 binder.
- **Overdriven definition: the explosive is driven with a piston such that**
  - $U_S > D_{CJ}$ (7.730 – 7.800 km/s)
  - $P > P_{CJ}$ (~ 28 GPa)

Outline

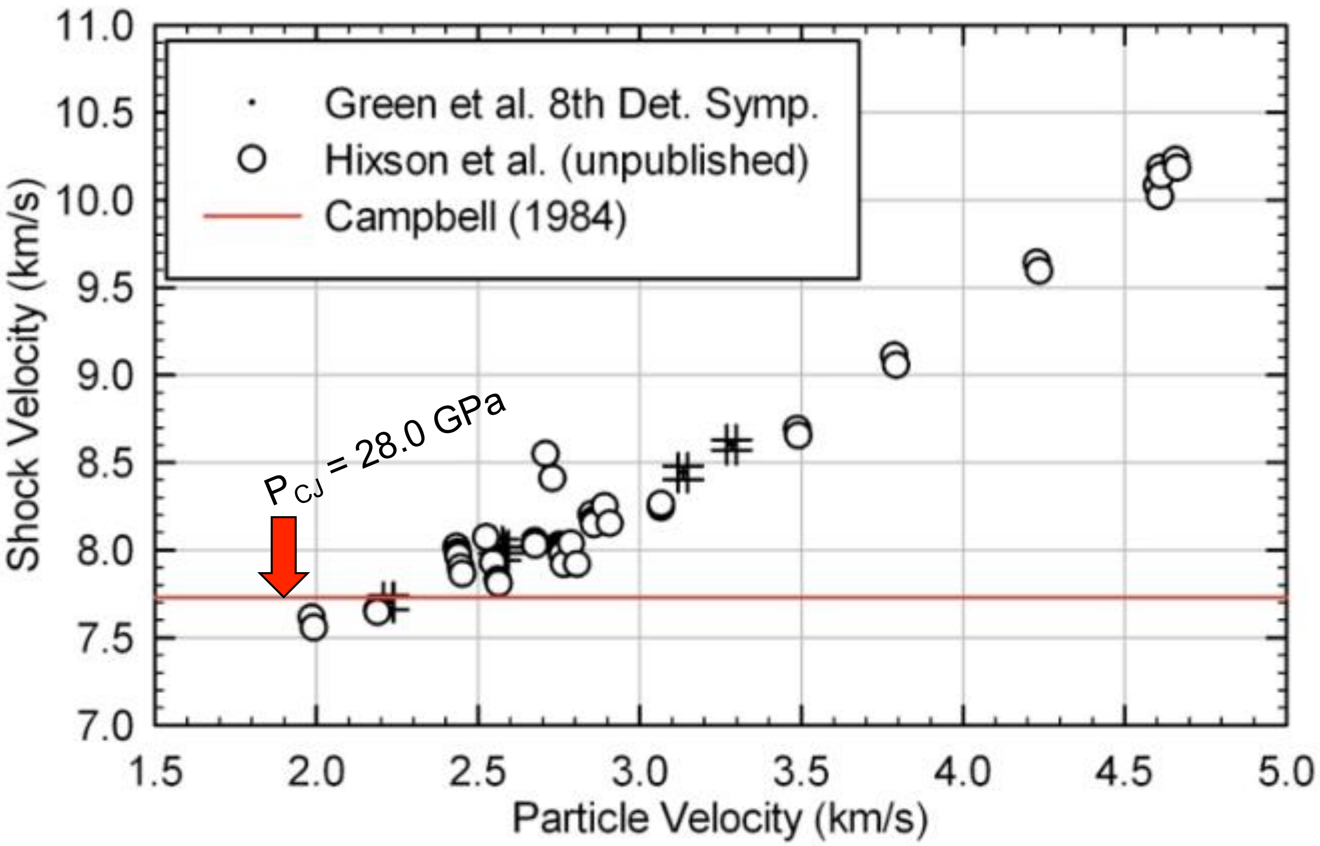
- **Data used in the Wescott, Stewart, Davis (WSD) reactive burn model for PBX 9502 products in the overdriven pressure range.**
- **Need for additional experiments near the CJ state.**
- **Our experiments and analysis.**
- **Comparison of experiments with simulations using using WSD.**

Equations of state for PBX 9502 used by Wescott, Stewart, & Davis



BL Wescott,DS Stewart, & WC Davis, “Equation of state and reaction rate for condensed phase explosives” J. Appl. Phys., 98, 053514 (2005)

Data set used by Wescott, Stewart, and Davis for PBX 9502 products EOS



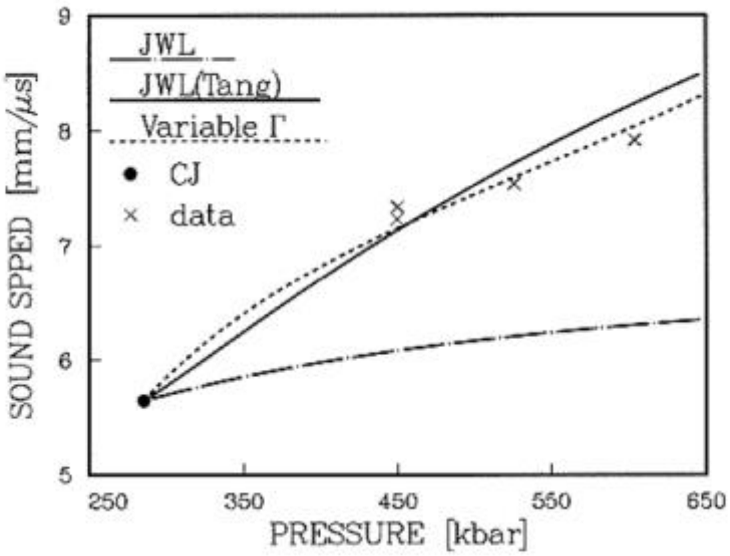
L Green, E Lee, A Mitchell & C Tarver “The supra-compression of LX-07, LX-17 …” 8th Det. Symp. 587 (1985)

PK Tang, WW Anderson, JN Fritz, RS Hixson, and JE Vorthman “A study of the overdriven behaviors …” 11th Det. Symp. 1058 (1998)

D_{CJ} = 7.729 km/s*
(108 mm ϕ charge)

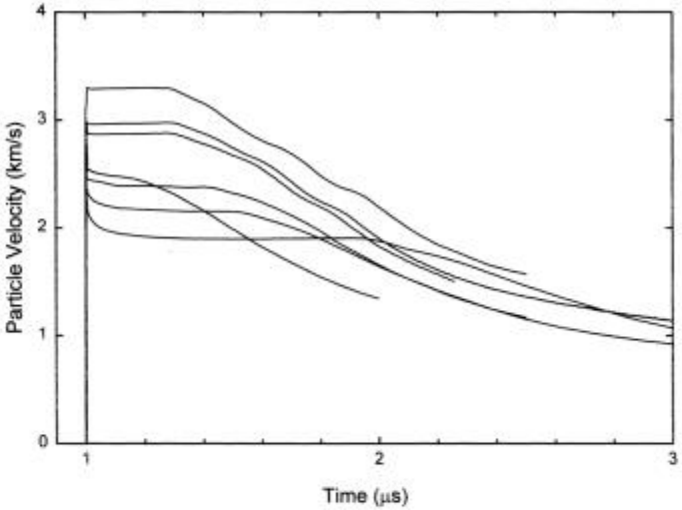
A. W. Campbell, Propellants Explosives Pyrotechnics, 9, 183 (1984)

Data not used by Wescott, Stewart, and Davis



Sound speed data

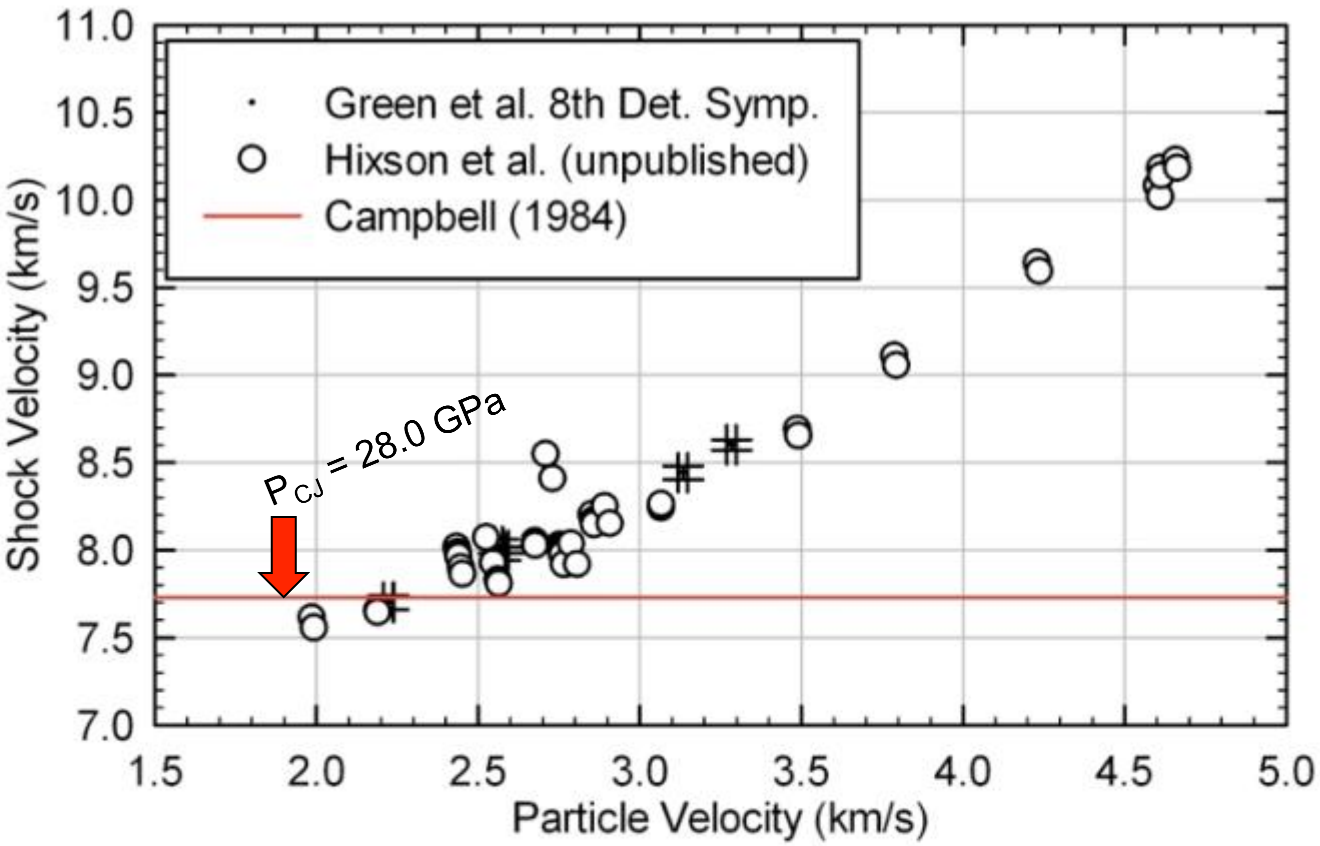
PK Tang et al. “A study of the overdriven behaviors …” 11th Det. Symp. 1058 (1998)



Release isentrope waveprofiles

JE Vorthman, RS Hixson, WW Anderson et al. “Release isentropes in overdriven PBX 9502 …” SCCM-1999,pg.223

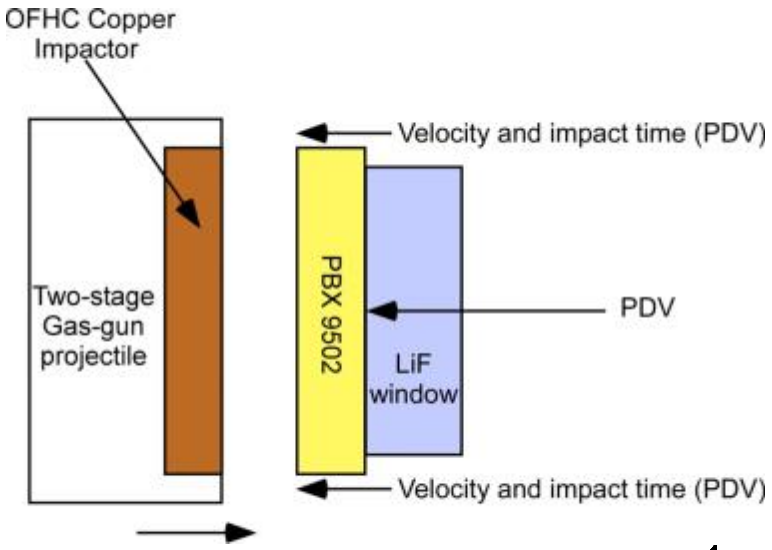
Can we make measurements near CJ with less scatter? Can we get around the non-steady wave problems?



D_{CJ} = 7.729 km/s*

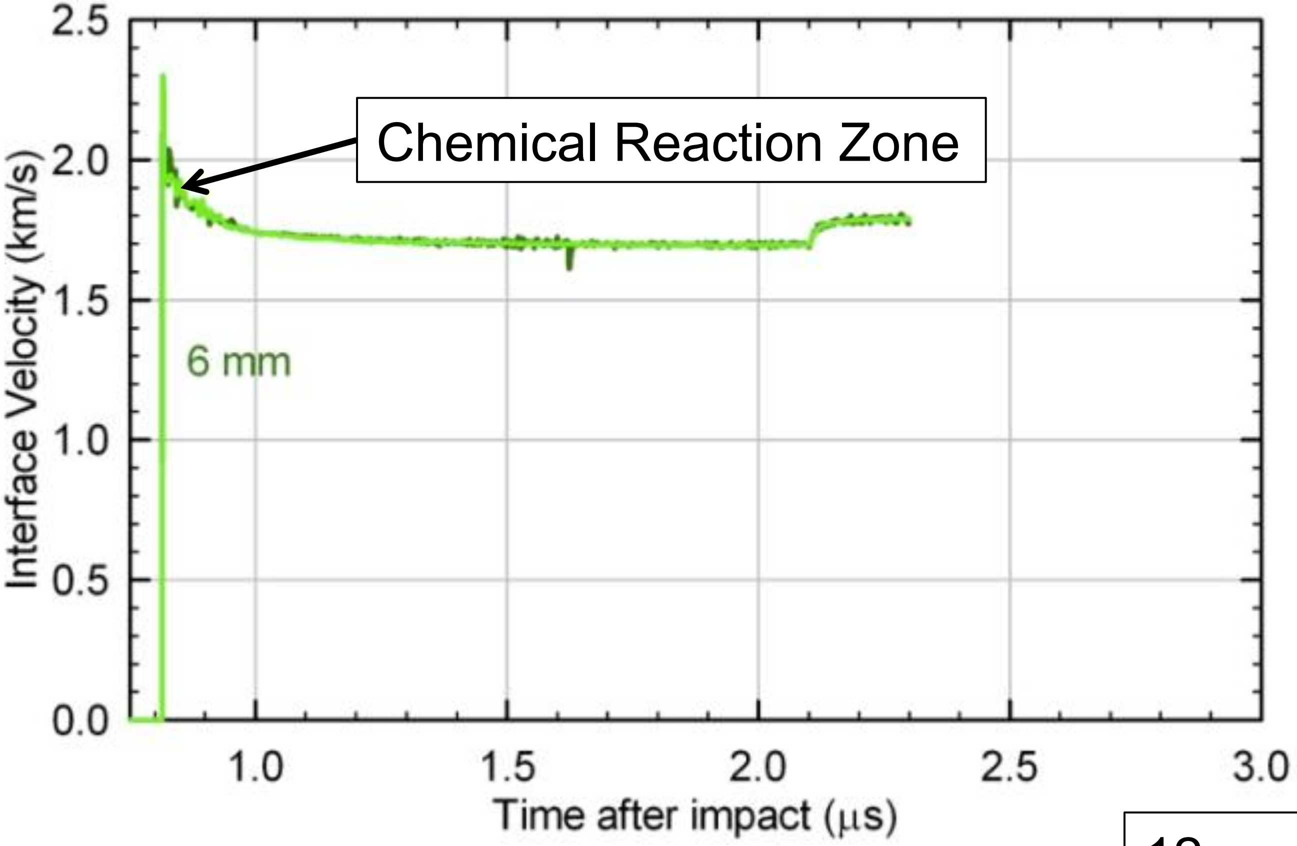
(108 mm ϕ charge)

Our attempt to refine the data near CJ.



1. Gas Gun Experiments
2. Thick wide samples: 6,9,12 mm. 43.2 mm diameter.
3. Thick impactors: ~ 7 mm thick.
4. Repeat experiment – same projectile velocity & different PBX 9502 thickness.
5. Wave profiles for comparison with reactive burn models and Direct Numerical Simulations

≈ 2.6 km/s projectile velocity, 6 mm thick sample



$u_{flyer} = 2.594 \pm 0.004$

$\Delta x = 6.006 \pm 0.007$

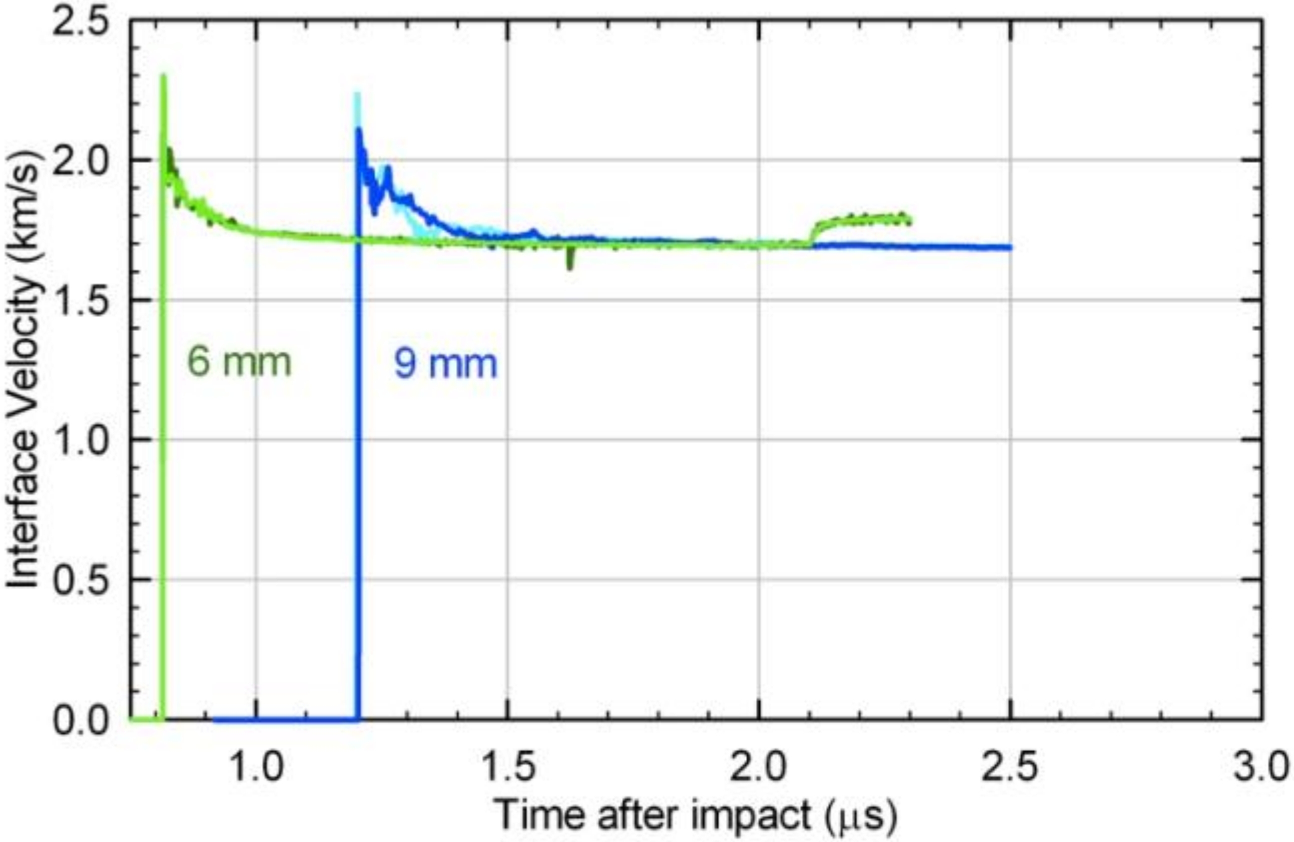
$\Delta t = 0.813 \pm 0.012$

$U_S = 7.39 \pm 0.11$

$u_P = 1.963 \pm 0.008$

12 ns uncertainty in Δt due to assumed flyer plate "bow"

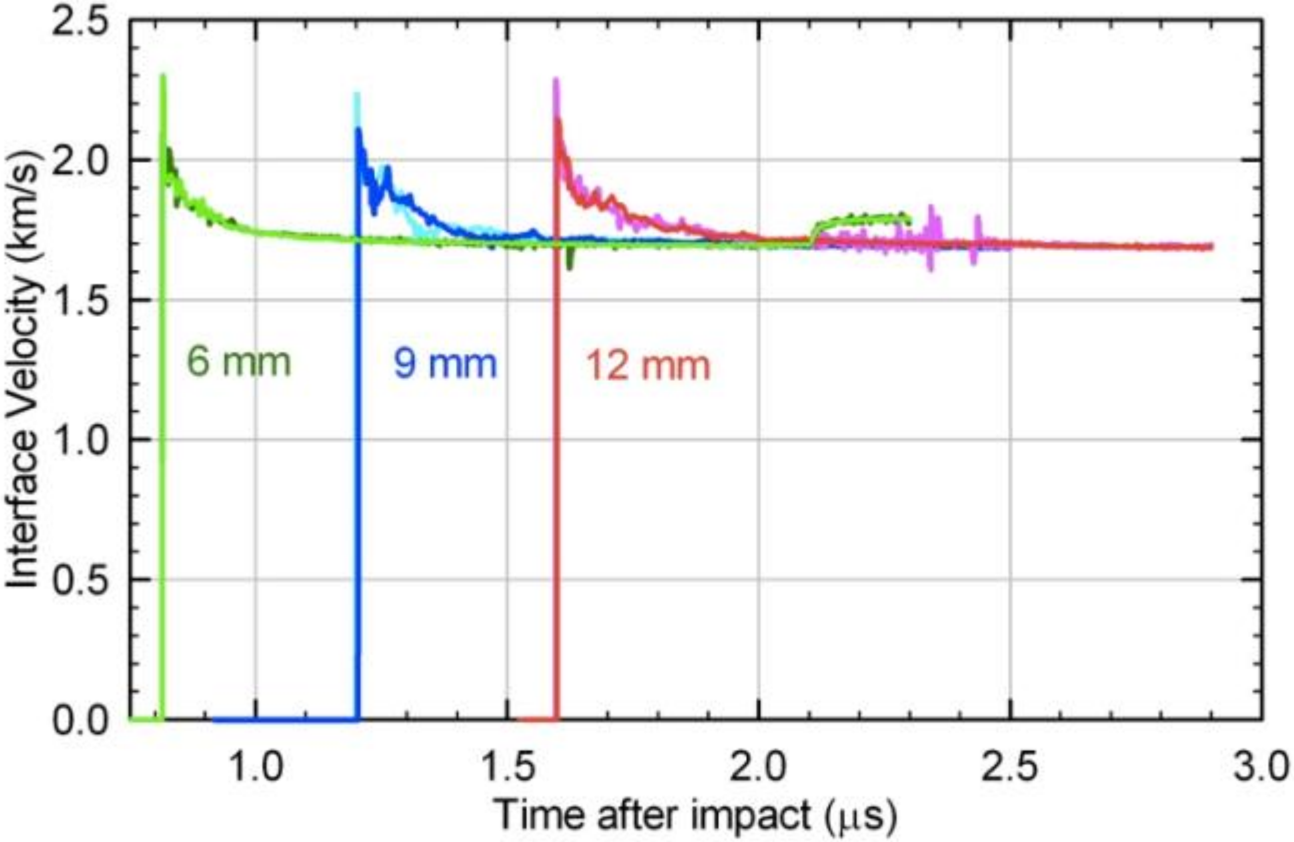
≈ 2.6 km/s projectile velocity, 6 & 9 mm thick sample



u_{flyer} = 2.594 ± 0.004
Δx = 6.006 ± 0.007
Δt = 0.813 ± 0.012
U_S = 7.39 ± 0.11
u_P = 1.963 ± 0.008

u_{flyer} = 2.575 ± 0.005
Δx = 9.001 ± 0.016
Δt = 1.202 ± 0.012
U_S = 7.49 ± 0.08
u_P = 1.942 ± 0.007

≈ 2.6 km/s projectile velocity, 6, 9, & 12 mm thick sample



u_{flyer} = 2.594 ± 0.004
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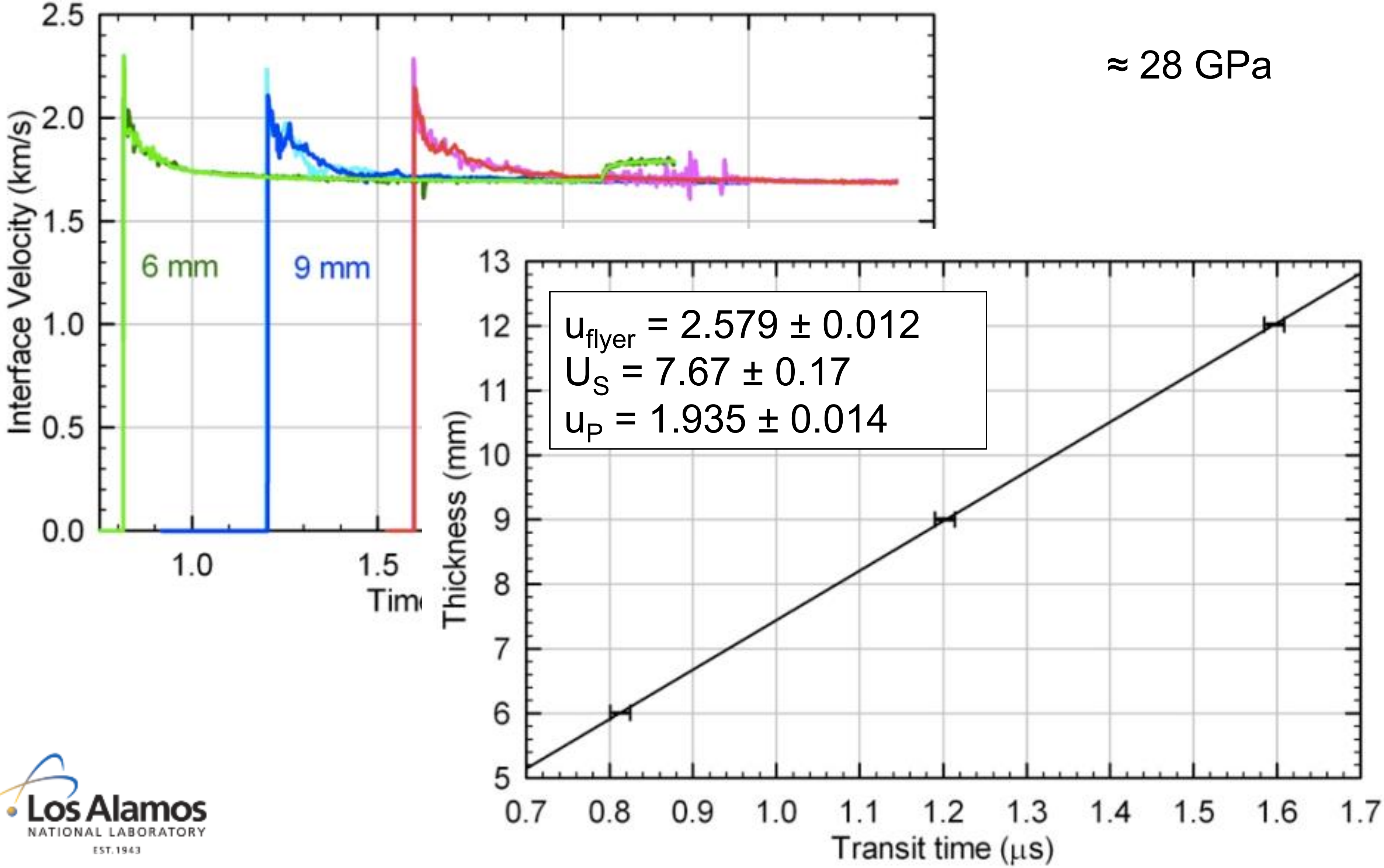
u_{flyer} = 2.575 ± 0.005
Δx = 9.001 ± 0.016
Δt = 1.202 ± 0.012
U_S = 7.49 ± 0.08
u_P = 1.942 ± 0.007

u_{flyer} = 2.569 ± 0.005
Δx = 12.021 ± 0.017
Δt = 1.597 ± 0.012
U_S = 7.53 ± 0.06
u_P = 1.935 ± 0.007

Combine results from all ≈ 2.6 km/s projectile velocity experiments



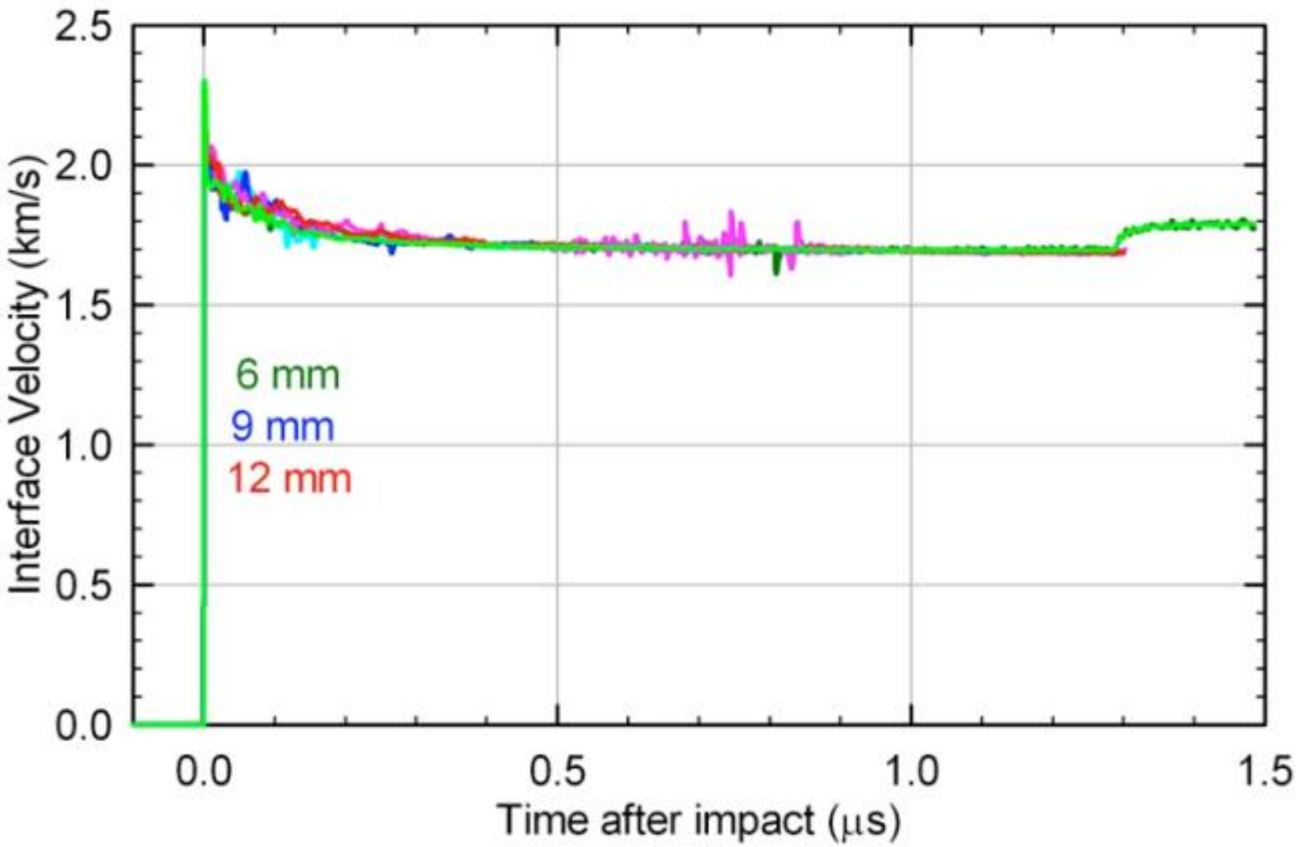
$u_{flyer} = 2.579 \pm 0.012$

$U_S = 7.67 \pm 0.17$

$u_P = 1.935 \pm 0.014$

≈ 28 GPa

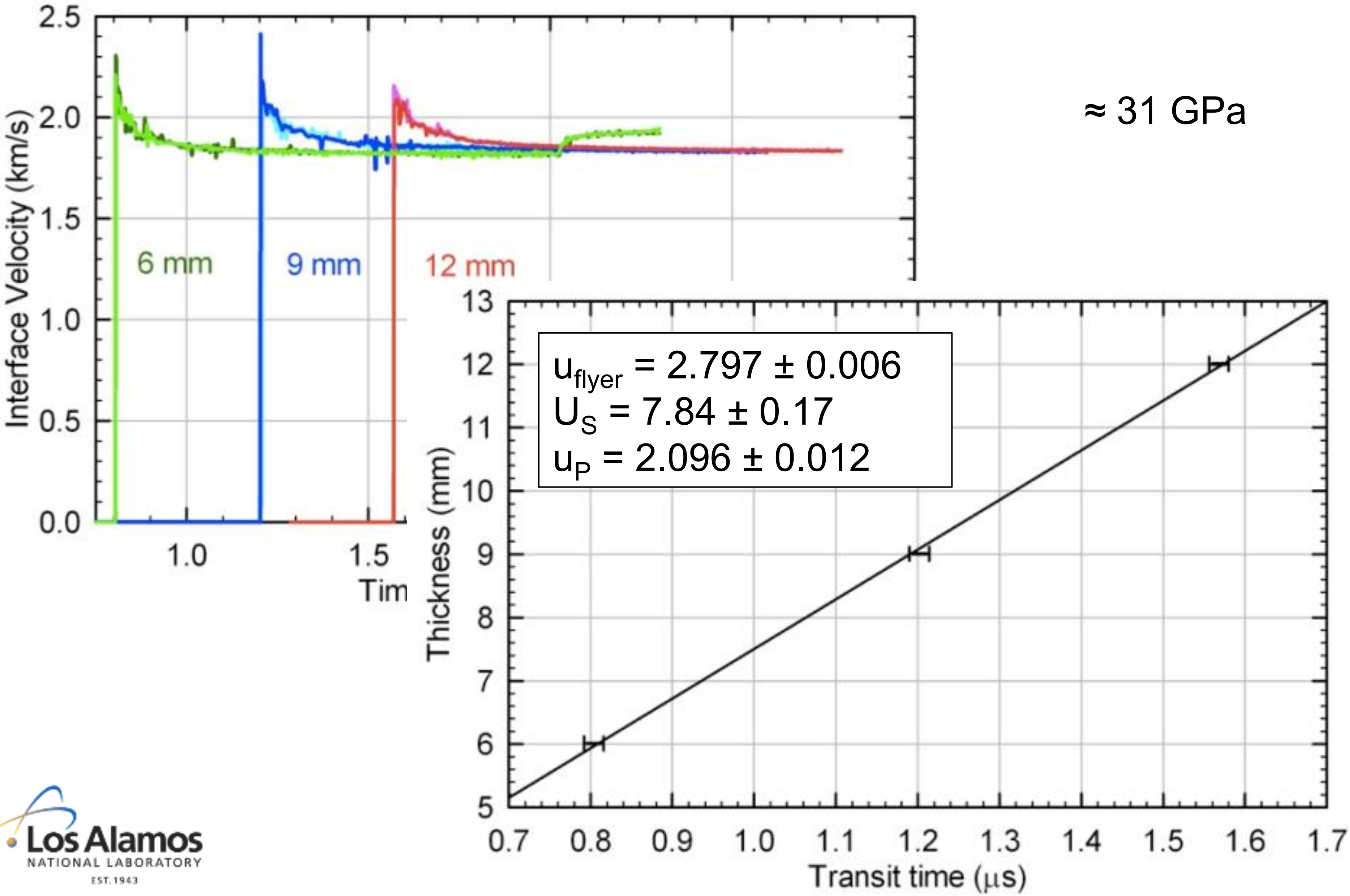
Is the wave structure steady?



≈ 2.6 km/s impact vel.
≈ 28 GPa

- close to steady (not definitive)
- small differences in “reaction zone.”

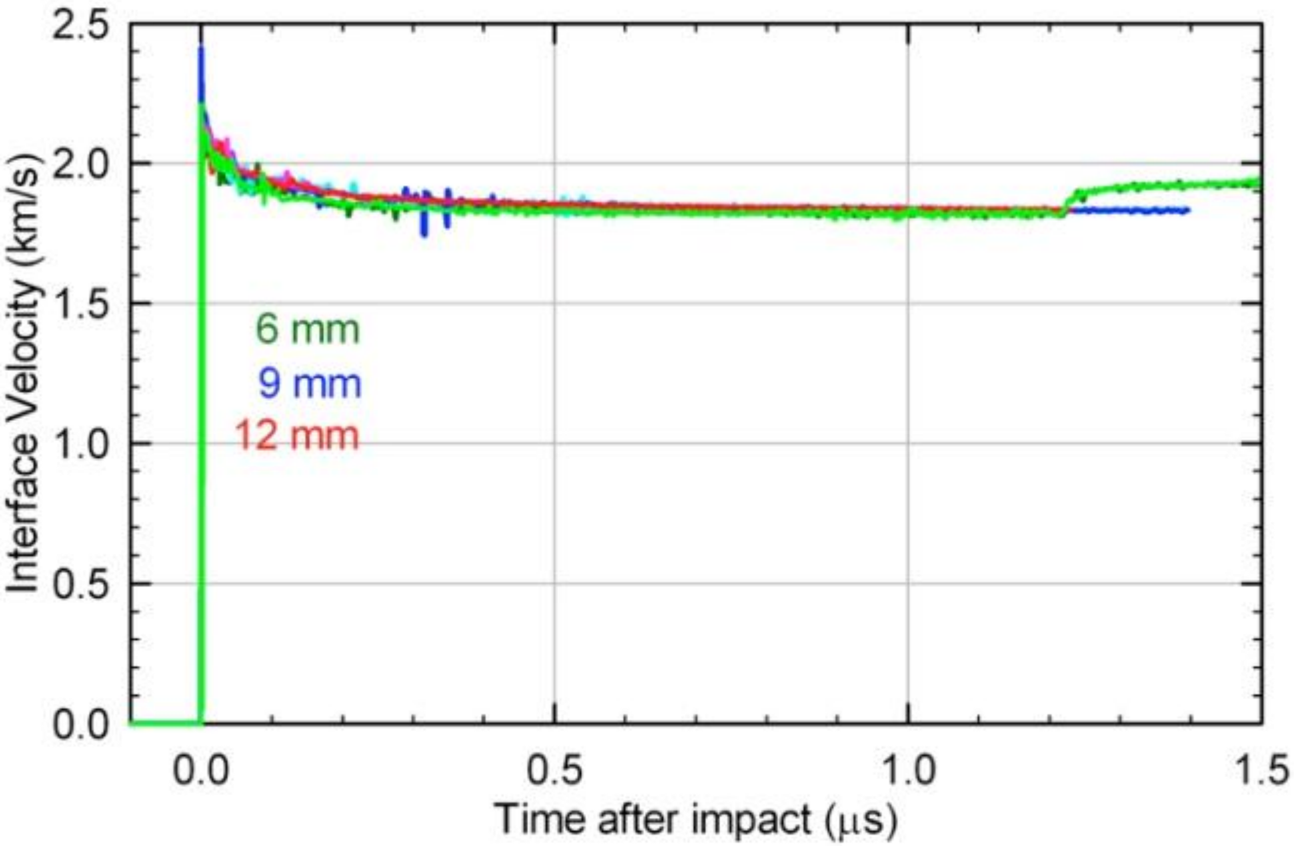
Combine results from all ≈ 2.8 km/s projectile velocity experiments



u_{flyer} = 2.797 ± 0.006
U_S = 7.84 ± 0.17
u_P = 2.096 ± 0.012

≈ 31 GPa

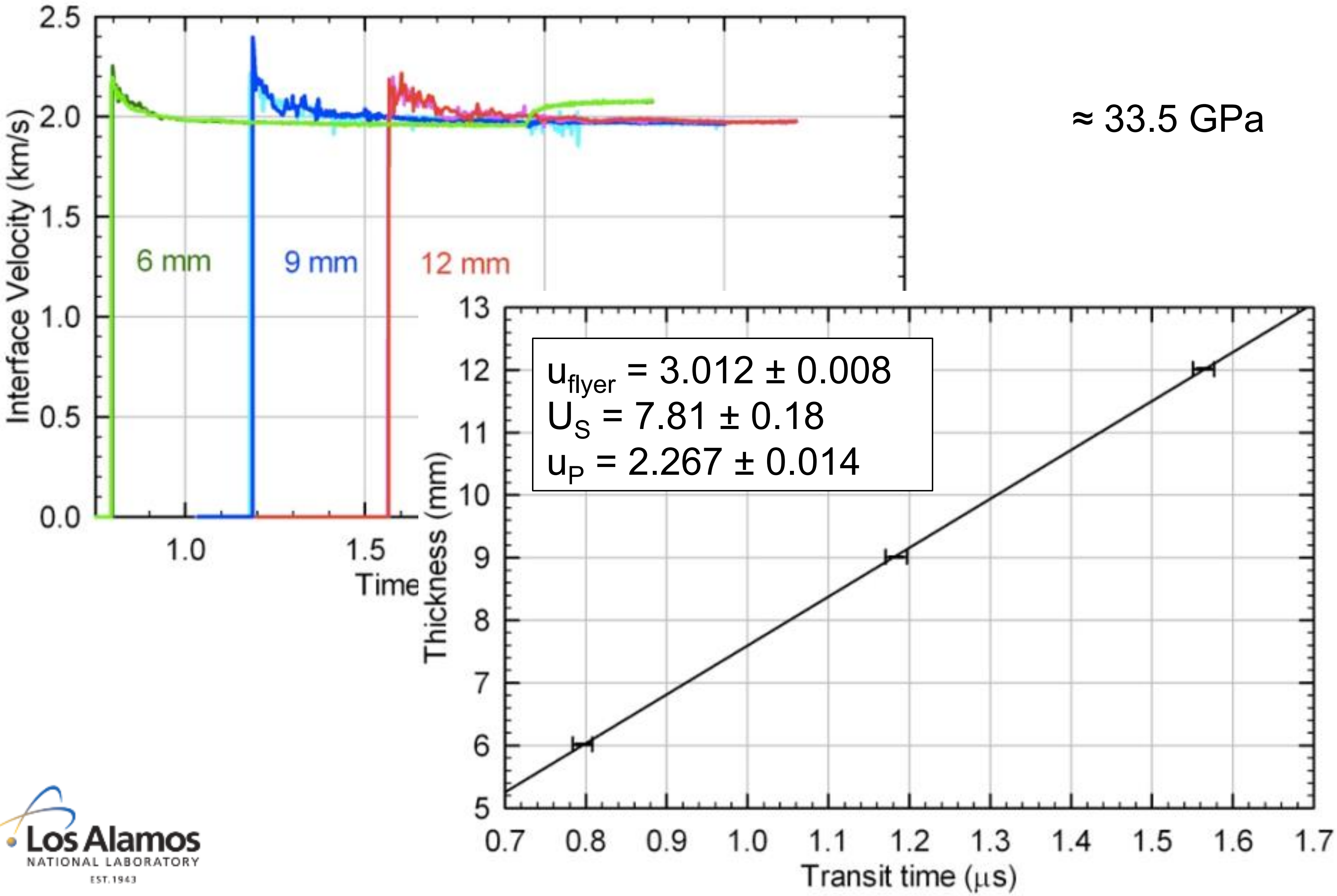
Is the wave structure steady?



≈ 2.8 km/s impact vel.
≈ 31 GPa

- close to steady (not definitive)
- small differences in "reaction zone."

Combine results from all ≈ 3.0 km/s projectile velocity experiments



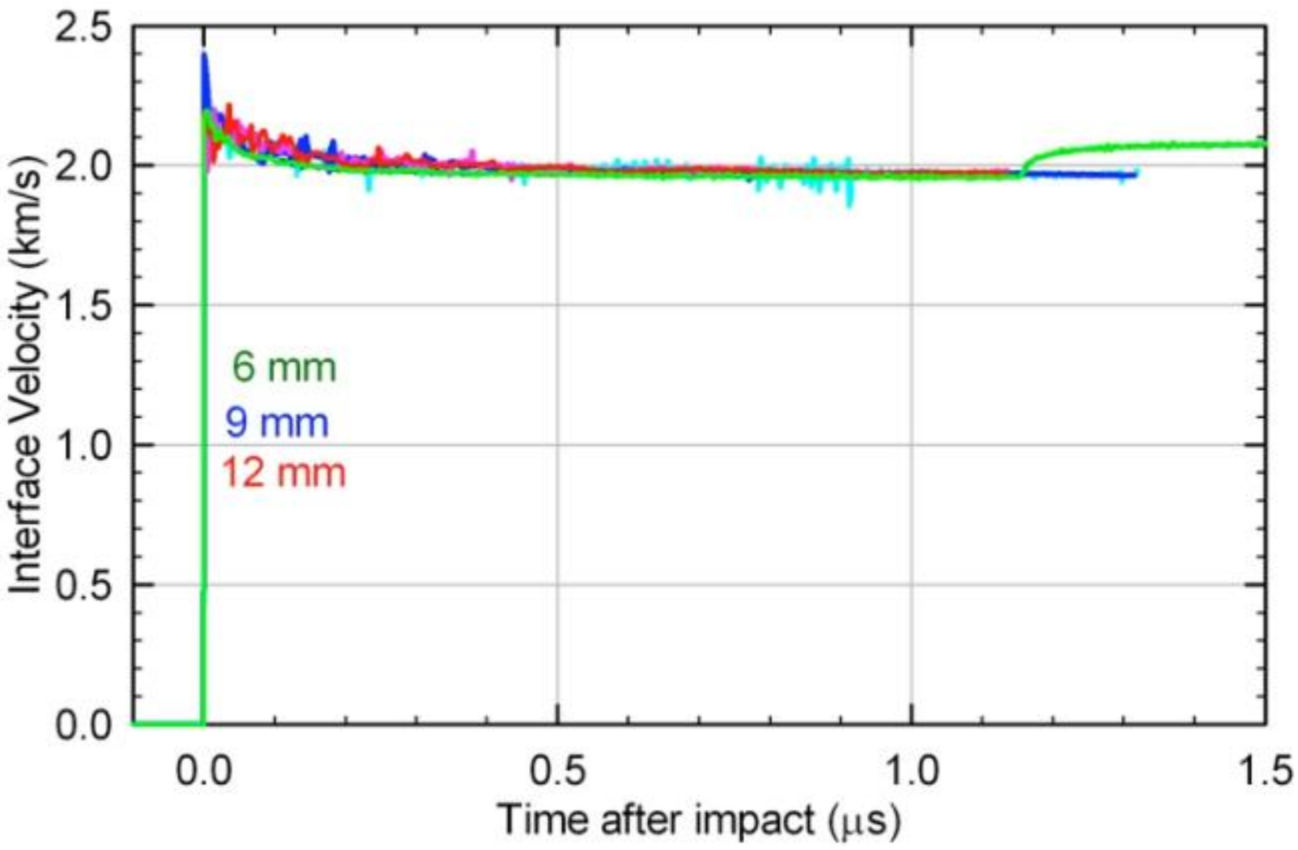
$u_{flyer} = 3.012 \pm 0.008$

$U_S = 7.81 \pm 0.18$

$u_P = 2.267 \pm 0.014$

≈ 33.5 GPa

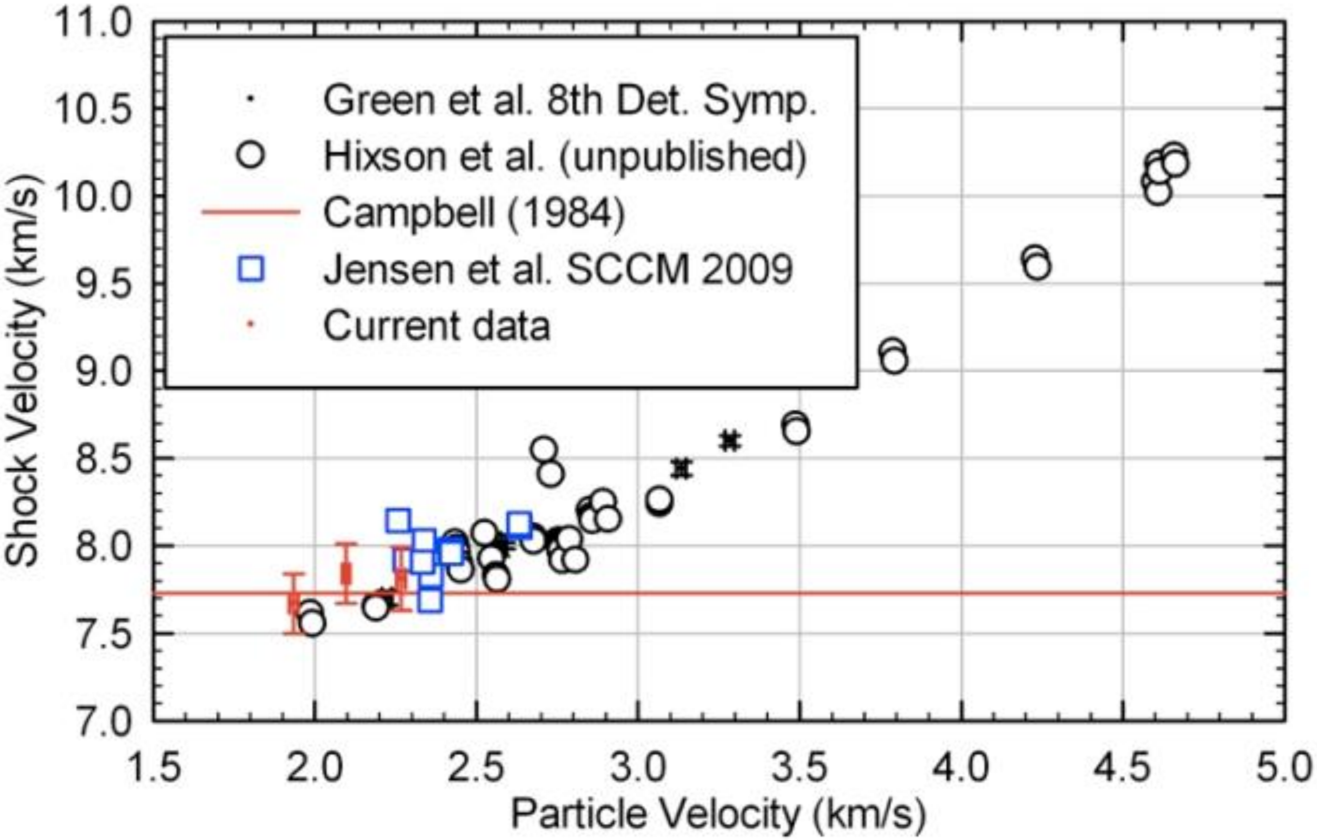
Is the wave structure steady?



≈ 3.0 km/s impact vel.
≈ 33.5 GPa

- close to steady (not definitive)
- small differences in “reaction zone.”

Addition of our data to the other data sets.

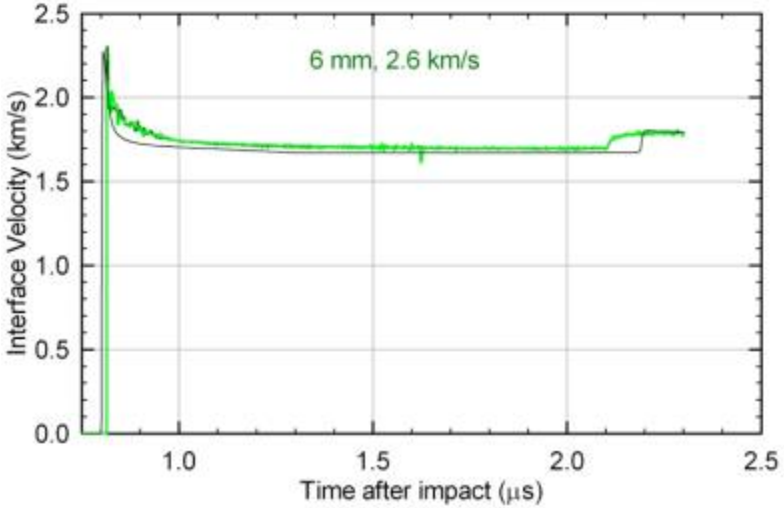


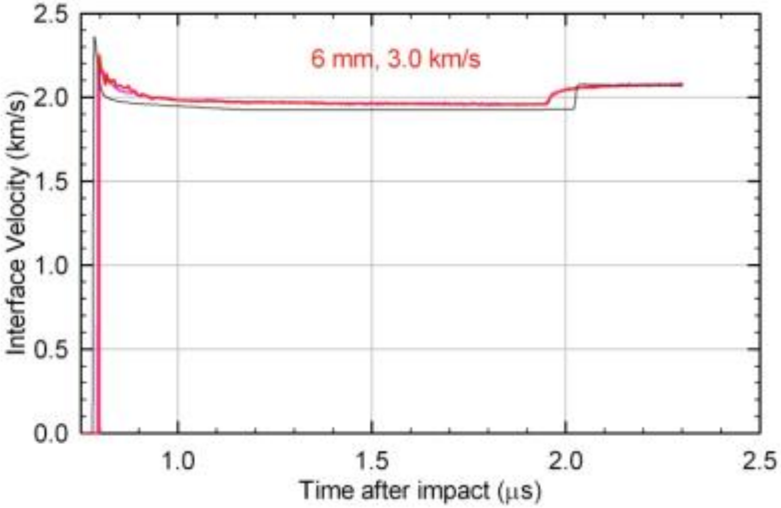
Still lots of scatter.
Error bars ~ 2.3% in U_S.

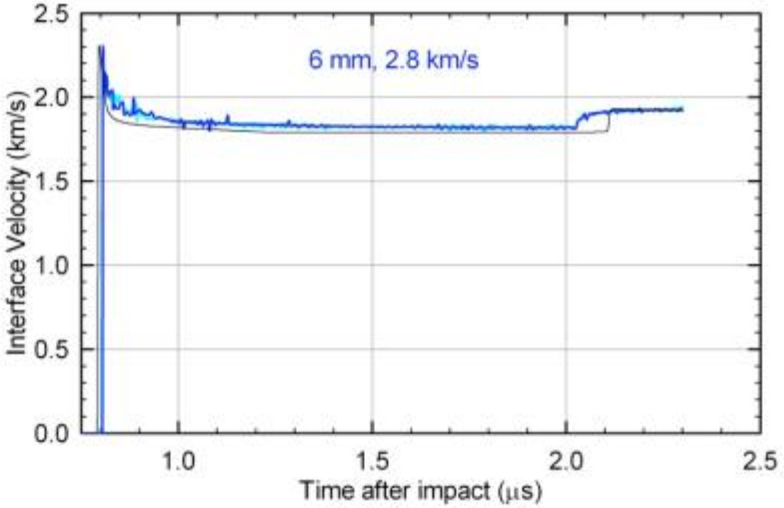
It takes a lot of effort to measure shock velocity with small error bars.

Unsteady waves contribute to scatter.

How well does WSD model the profiles?





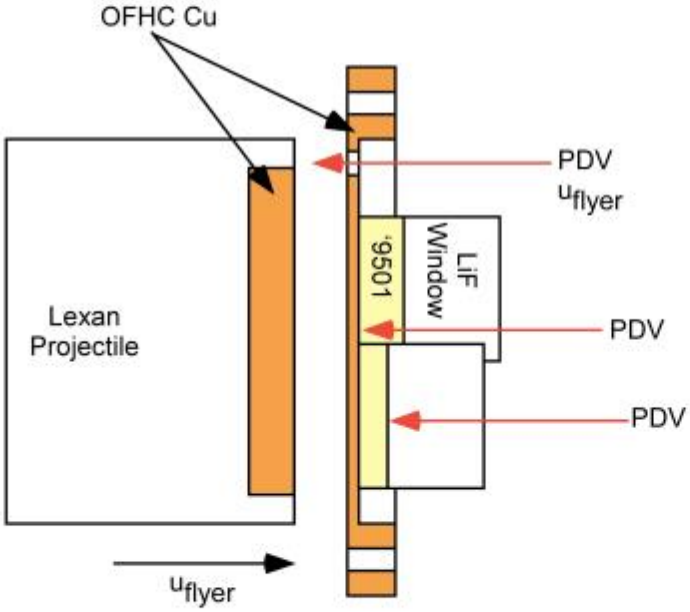


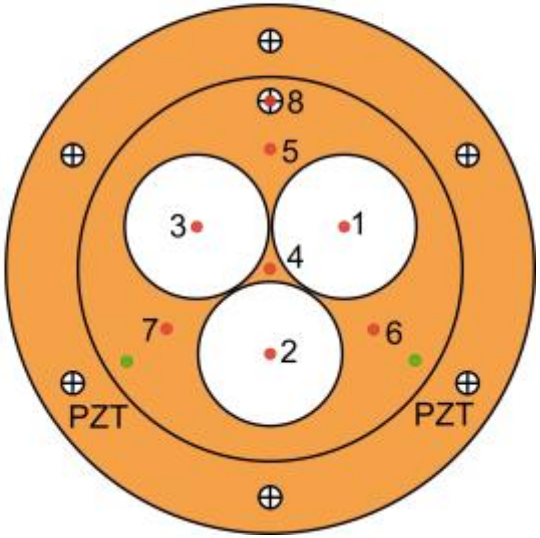
- U_S high (~ 1%)
- plateau low (1-2%)
- “reaction zone” short.
- Sound speed too low.

PBX 9502 Summary/Conclusions

- We have measured U_S, u_P and interface velocity waveprofiles in PBX 9502 in the pressure range 28 – 33.5 GPa. This is very near the CJ pressure of ~ 28 Gpa.
- Waves are judged to be “close to steady” but <u>not definitively steady</u> after 6 – 12 mm of propagation.
- Error bars for U_S are ~ 2.3%.
- Error bars for u_P are ~ 0.7%.
- The Wescott, Stewart, Davis reactive burn model reproduces measured shock arrival times and measured interfaces velocities to 1 – 2%. Calculated sound speeds in products are low.

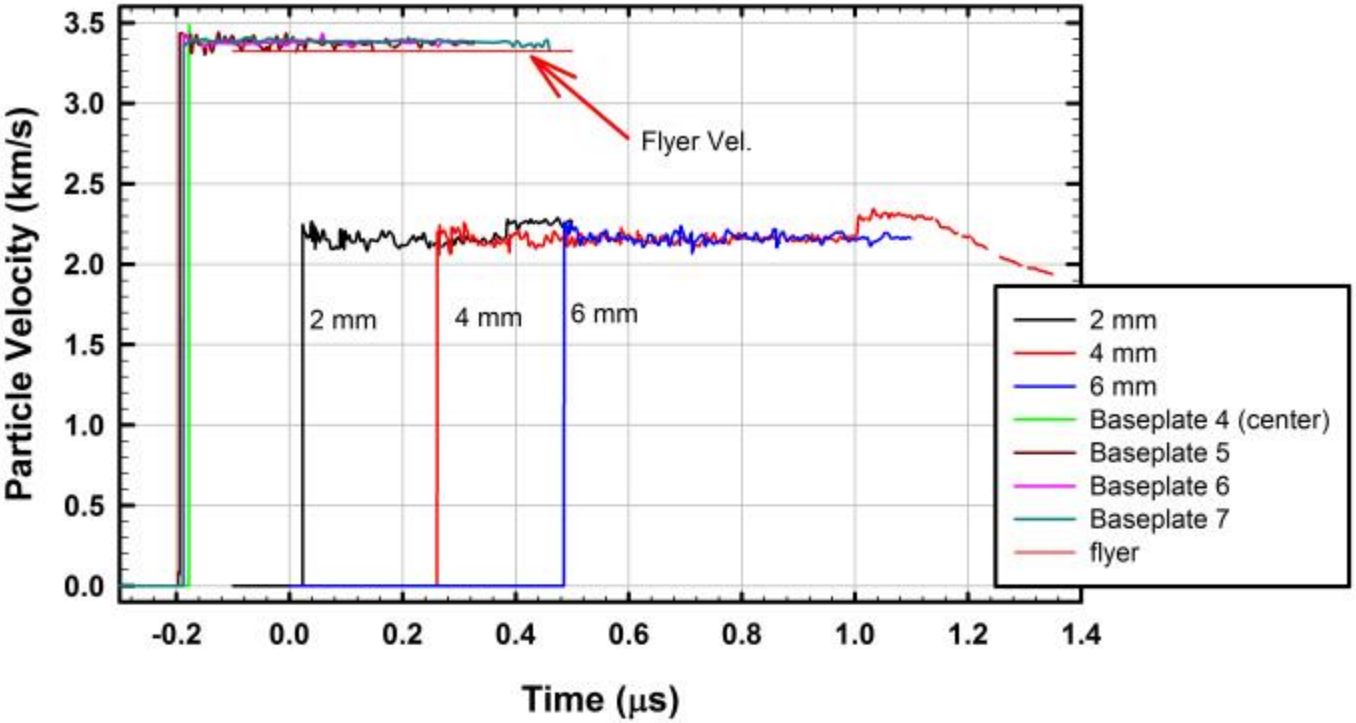
Overdriven PBX 9501/Experiment





- 8 PDV probes
- Velocity
- 3 on sample
- Plate jump off
    - Tilt and flyer bow (no statistics)

Overdriven PBX 9501@ 40.8 GPa/Experiment - uncorrected



- Baseplate jump off times vary by 19 ns (tilt and bow)
- Tilt = 1.25 mrads (10 mrads typical)
- Bow = 24 ns (extrapolated to edge of flyer)
  - Center of flyer hits first
- Flyer = 3.322 km/s – Baseplate = 3.381 km/s
- No reaction zone in ‘9501

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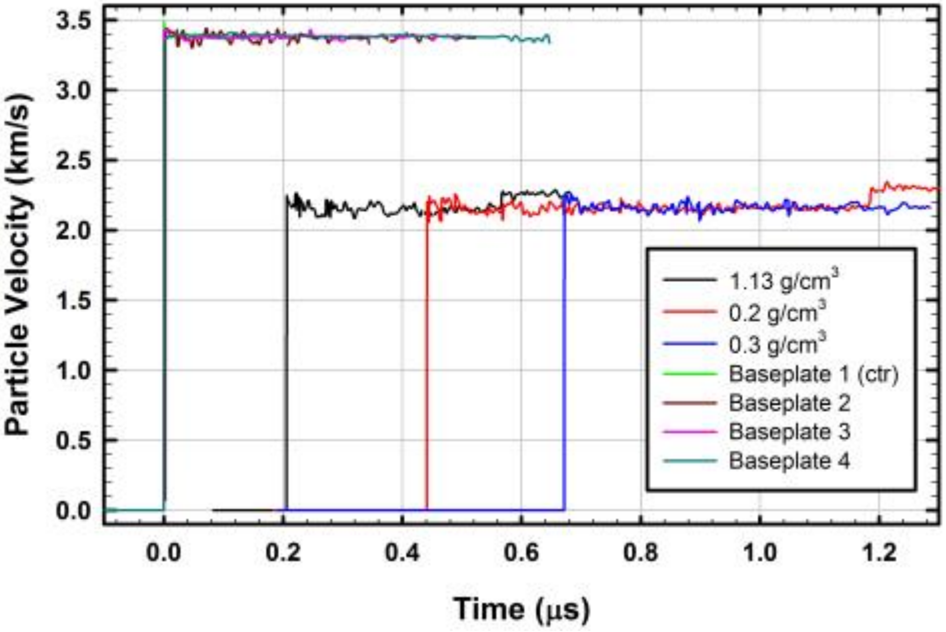
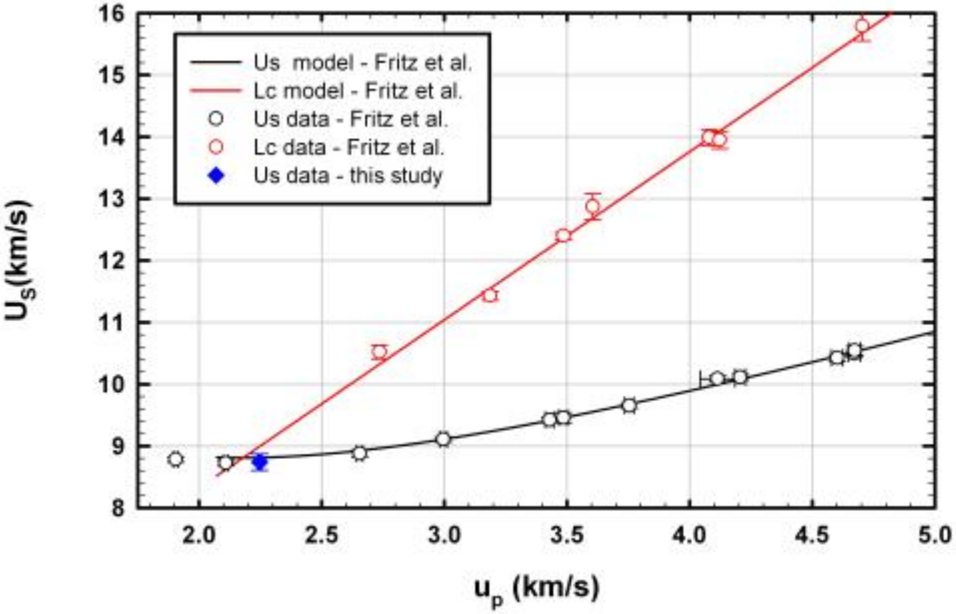
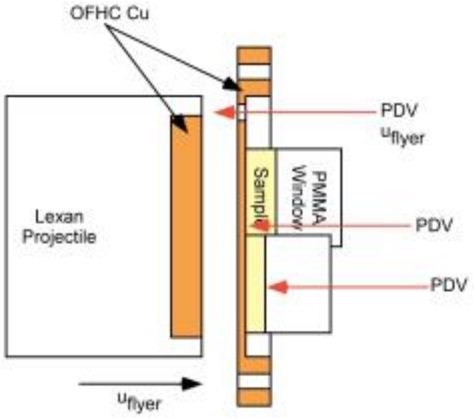
Overdriven PBX 9501@ 40.8 GPa/Experiment - corrected

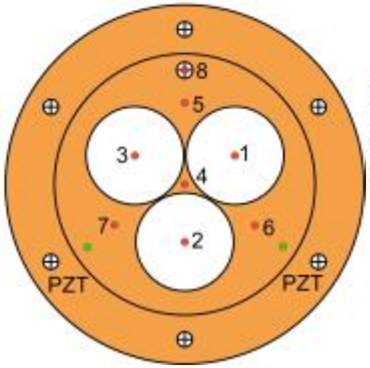


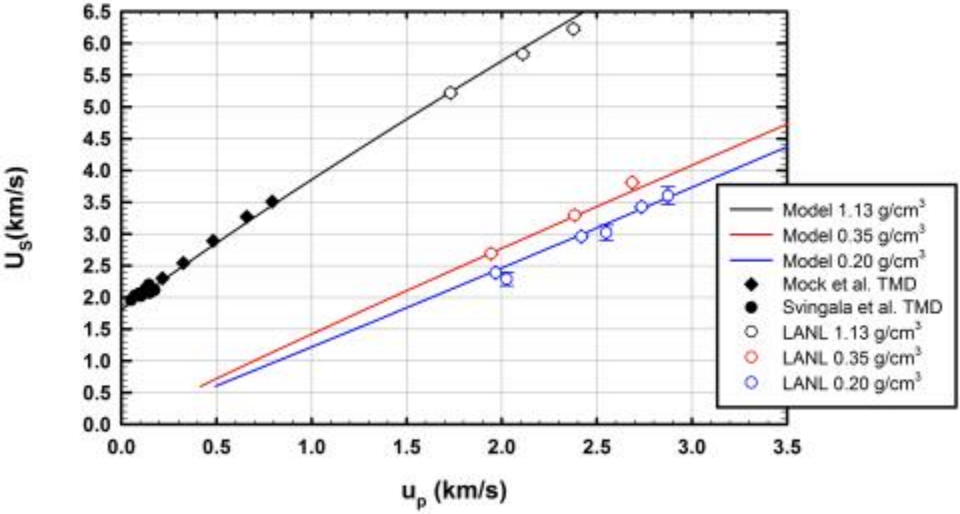
- Acceptable Hugoniot data with this method.



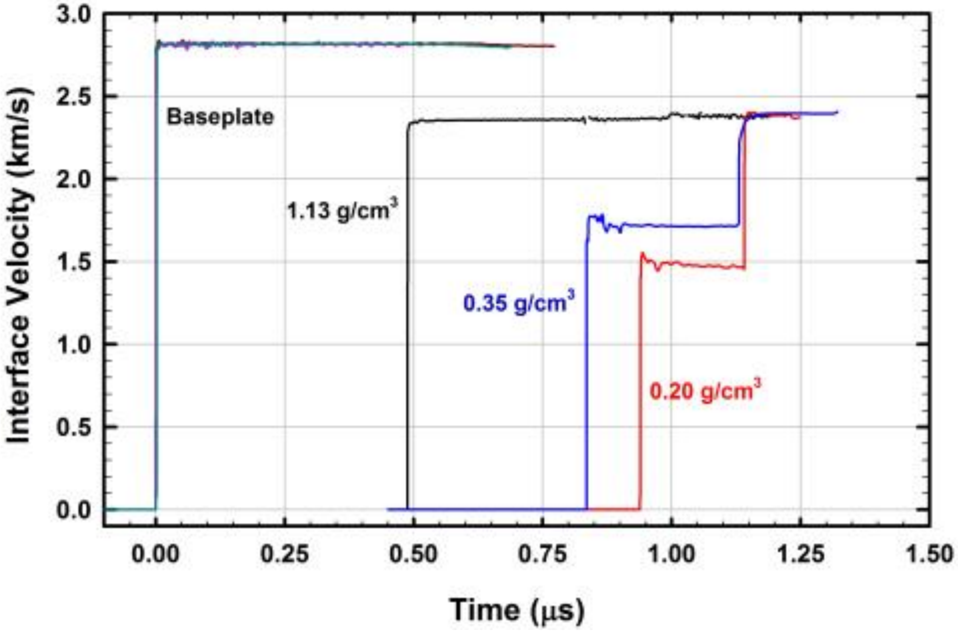
PolyUrea Aerogel Foam Experiments

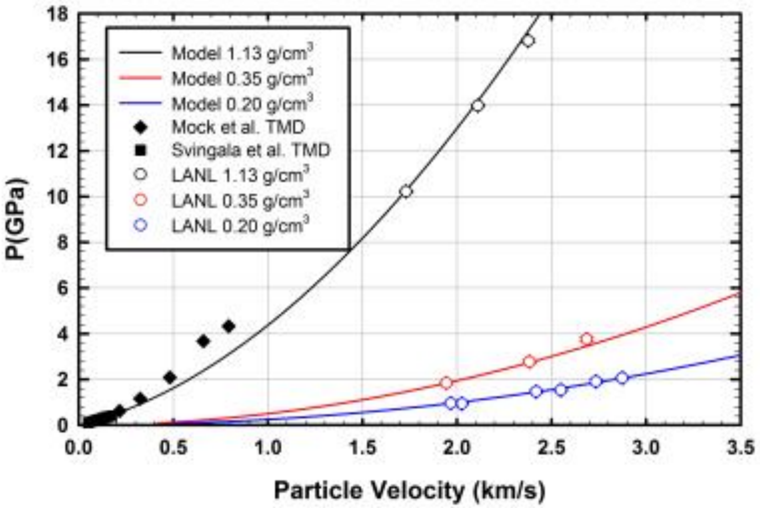






- 3 samples, same “drive”





Summary, Conclusions, and Questions

- **Most Shock Physics experiments formerly done with pins can be done at least as well with PDV.**
- **8 channels is minimum. ~14 channels would be ideal (Mitchell & Nellis, pins.)**
- **Tilt and Bow are vital corrections.**
- **For low impedance materials, shock transit time method gives more accurate results than front surface impact method.**
- **Wave profiles are (usually) not as beautiful as those from VISAR. Why?**

Extra slide (Numerical Details for WSD simulations on ‘9502)

Numerical Details:

It uses the 2nd Order Total Variation Diminishing Lagrangian Method in conjunction with a linearized Riemann Solver that allows for arbitrary EOSs as mentioned in our 2011 TPX paper.

The initial Lagrangian spacing is 10 microns.

Model Details:

WSD is the standard one presented in their 2005 paper (and for this problem exactly the same as the desensitization model from the 2006 Det Symp).

The inerts are modeled with the following:

c Lexan (Keane based Mie-Gruneisen)

rho0 = 1.193d0
bulk modulus = 4.44d0
derivative of bulk modulus at p=0 = 11.d0
derivative of bulk modulus at p=infinity = 4.10d0
Gamma_0 = 0.6d0
rho*Gamma = constant

c Cu (Linear Us-Up Mie Gruneisen)

rho0 = 8.924d0
eospar(3,2) = 3.91d0
eospar(3,3) = 1.51d0
Gamma_0 = 2.00d0
rho*Gamma = constant

c LiF (Linear Us-Up Mie Gruneisen)

rho0 = 2.638d0
c0 = 5.15d0
s = 1.35d0
Gamma_0 = 1.5d0
rho*Gamma = constant

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