Photonic Doppler Velocimetry Workshop IV

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Measuring Projectile Balloting in a Gas-gun Launcher Using 2-channel PDV

Scott Levinson and Sikhanda Satapathy

Institute for Advanced Technology
Austin, TX
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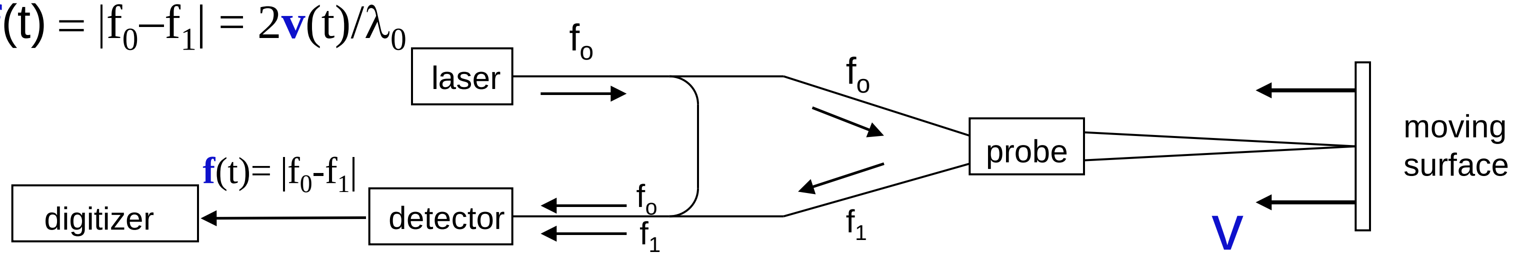
Quick Review of Photonic Doppler Velocimetry (PDV)

- PDV[1] developed recently for short range (~20 cm) high velocity shock experiments.
- PDV measures velocity by determining beat frequency **f** by "mixing" unshifted laser ($f_0 = c/\lambda_0$) with Doppler-shifted signal (f_1) that reflects off moving surface.

$$\mathbf{f}(t) = |f_0 - f_1| = 2\mathbf{v}(t)/\lambda_0$$



- ***Calculated Velocity* v*(t) is proportional to known or measured variables:* f *(t) or λ_0 having high precision & accuracy*.**
- Robust highly resolved & accurate alternative to VISAR & Fabry-Pérot.
- Has advantages w/o many liabilities of other techniques.

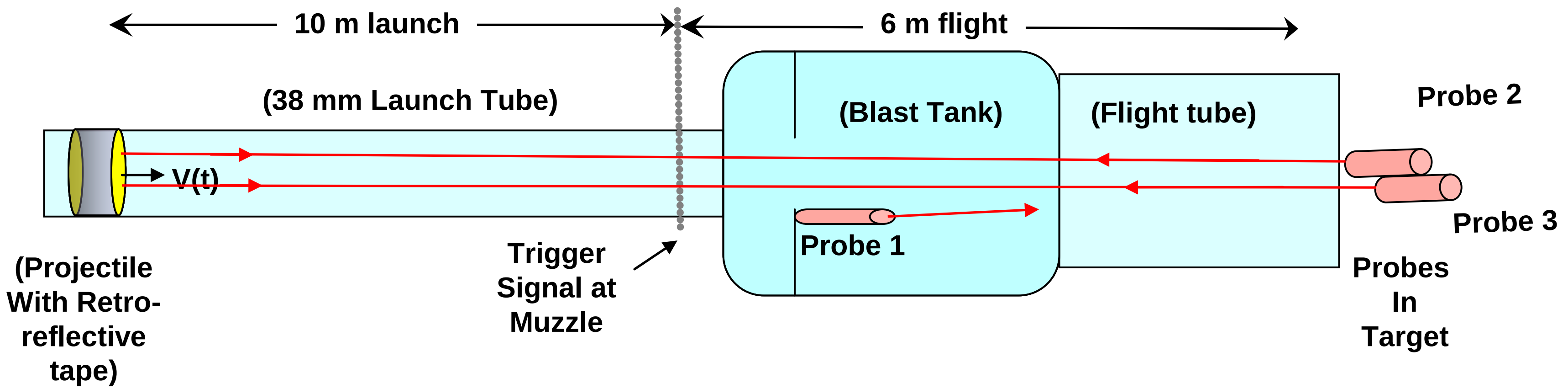
[1]**O. Strand**, D. Goosman, C.Martinez, and C. Whitworth, Rev. Sci. Inst. 77, 83108, 2006.

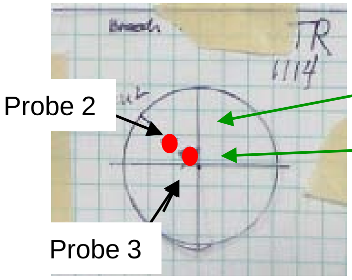
Objectives

- **Exploit the robust, precise qualities of PDV to quantify long-range axial gun-launch dynamics:**
  - **Velocity v(t)**
  - **Position x(t)**
  - **Acceleration a(t)**

- **And, using multi-channel PDV, we measure in-bore balloting angle profiles θ(t), dθ(t) /dt.**

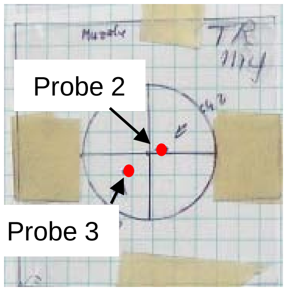
IAT's 2-Stage Light Gas Gun & PDV Layout



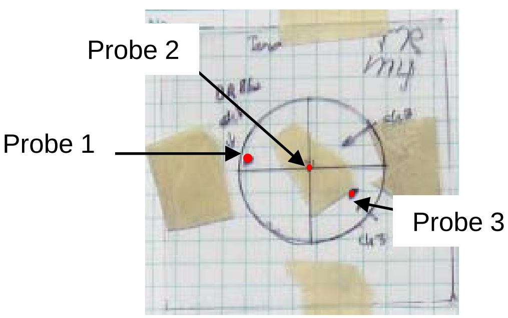


Beam Positions & Diameters at **Breech**

Measured Independent Beams & PDV Signals @ 16 m



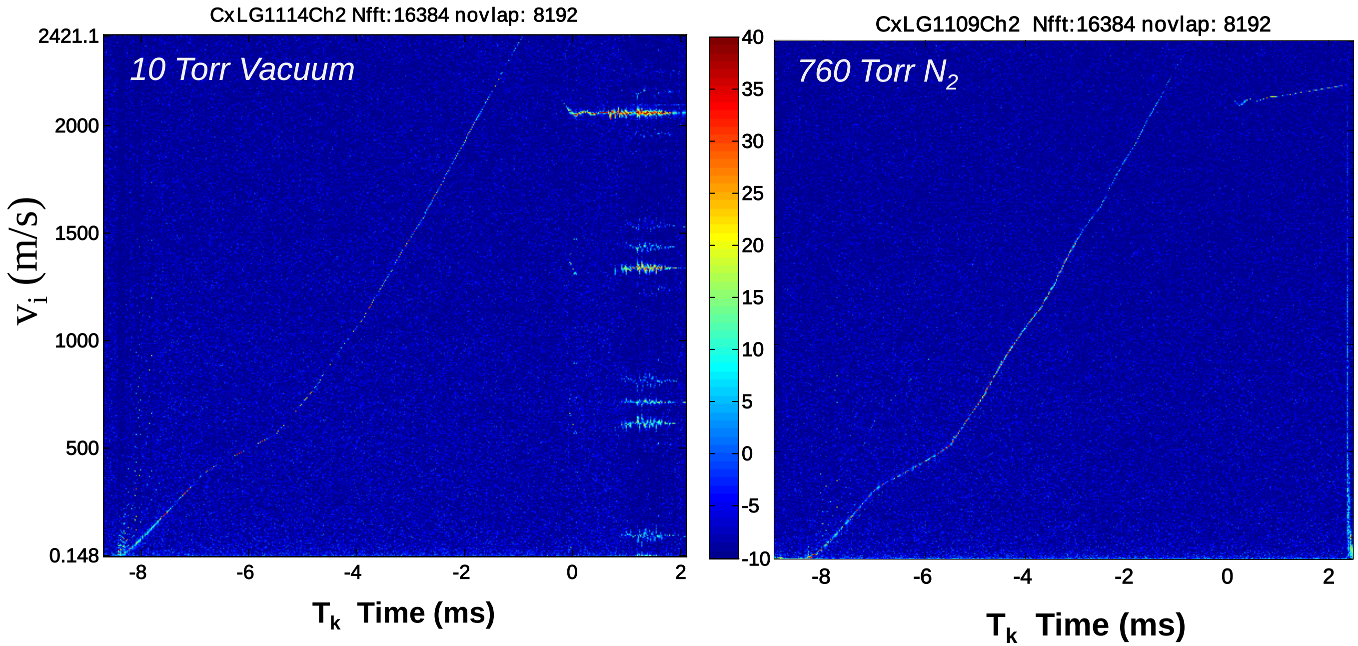
Beam Positions & Diameters at **Muzzle**



Beam Positions & Diameters at **Target**

- **Accurate PDV measurements exploited for first time at long range**

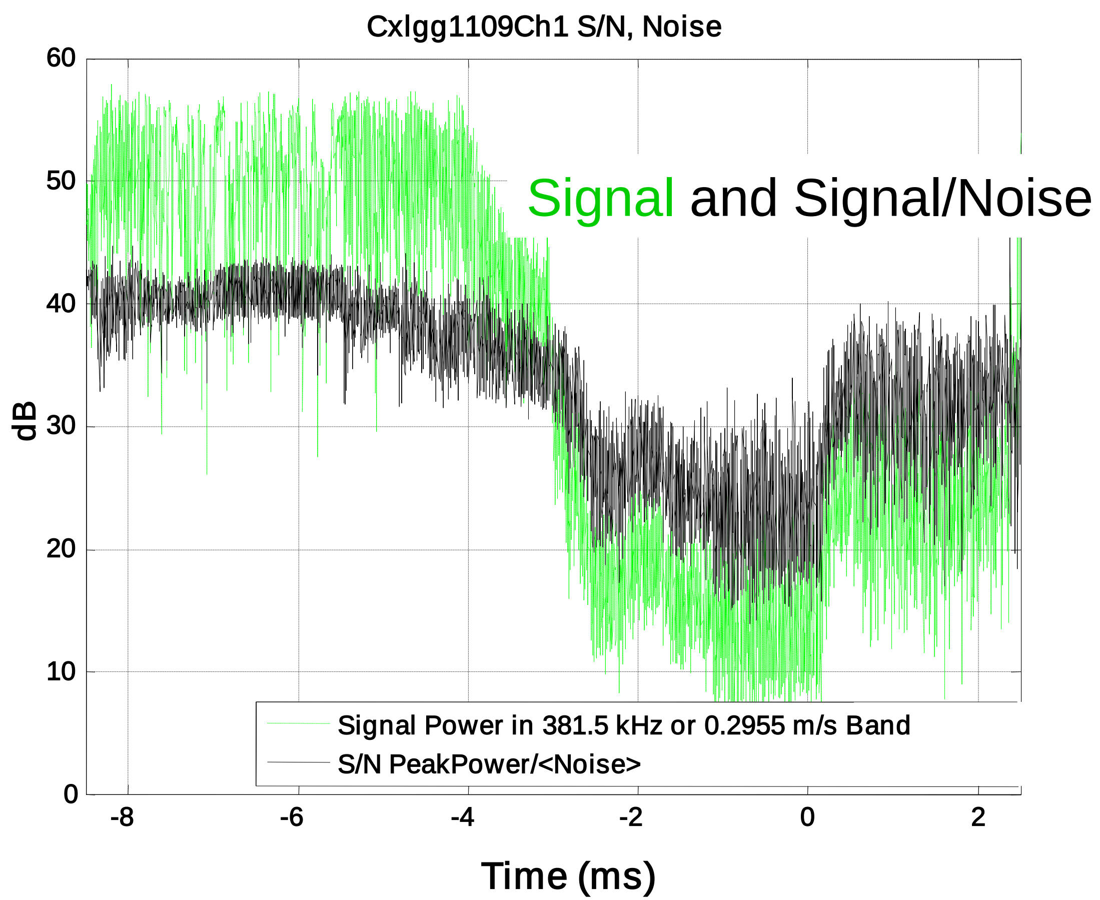
PDV Analyses of LGG in Vaccum & Full Atmosphere



- Digitally Sample "Mixed" PDV signal (Δt=.16 ns)
- Break record into (2^{14} sample $\leftrightarrow$2.6 μs) sub-records,
- FFT each sub-record k, noting $\mathbf{v}_i = \lambda_0/2 \times f_i$ = 0.77465 (m/s)/MHz $\times f_i$
- **Display signal amplitude $S_k(V_i)$ as 2-D Spectrogram** with axes: frequency f_i (velocity $\mathbf{v}_i$) & sub-record k (time T_k)

- **Narrow spectral signal $S_k(V_i)$ identifies velocity V_i at each time T_k**
- **Large (125 M-sample) data set required under-sampling. But aliasing will be corrected since a and v must be continuous**

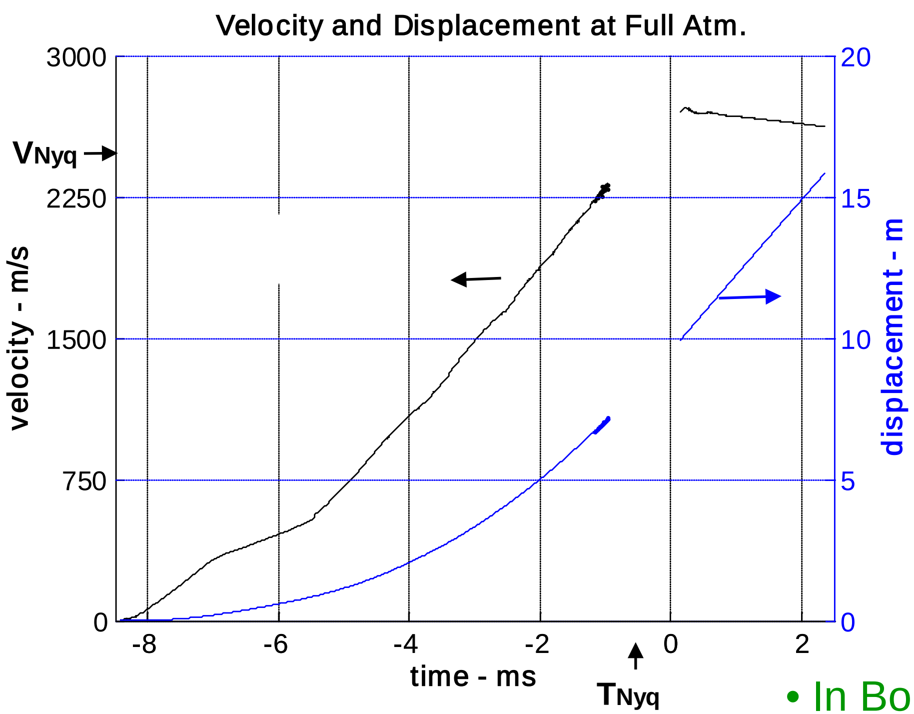
Figure of Merit of Test (Full Atmosphere)



- **Velocity detected throughout bore - even with low S/N**
- **Signal is lost for 1 ms before muzzle, but recovers outside of bore**

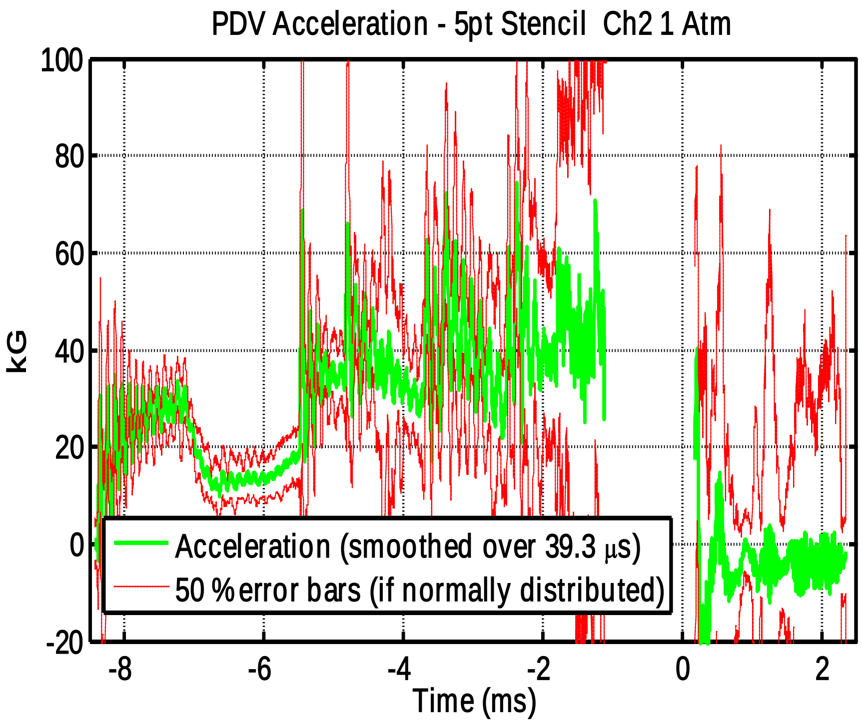
Detected Displacement, Velocity and Acceleration Profiles at Full Atmosphere

Velocity & Displacement
Peaks at Full Atmosphere



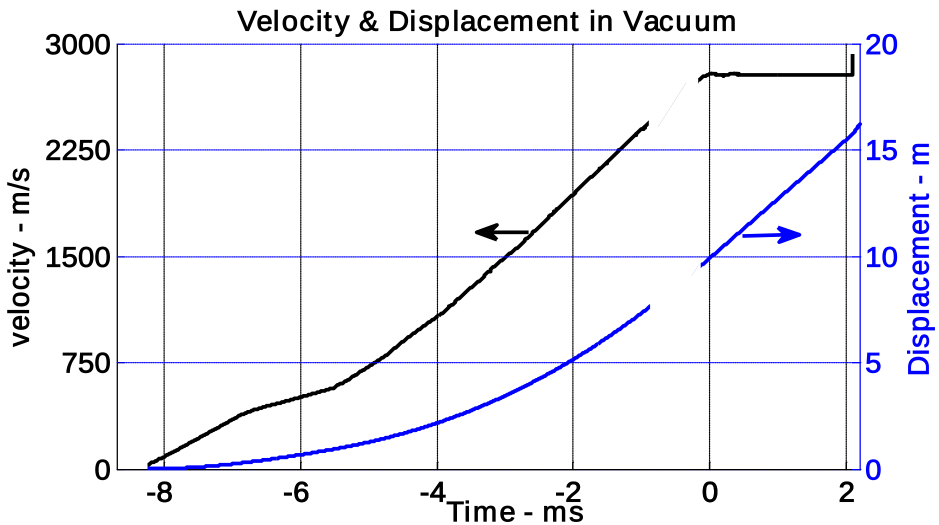
Alias correction when $T>T_{Nyq}$:
$V= 2*V_{Nyq} - V$ for $V > V_{Nyq}$

Acceleration and Error bars

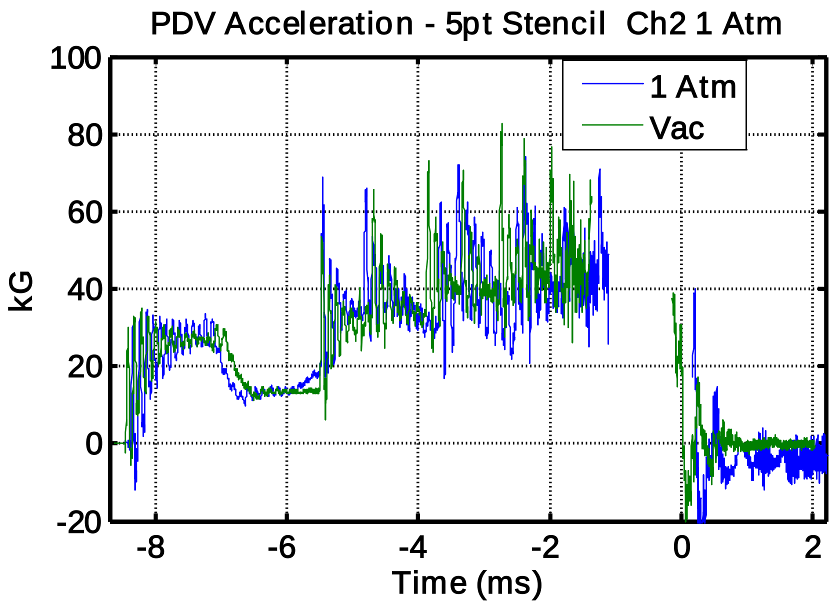


- In Bore:
  - 2 distinct acceleration stages
  - Evidence of projectile ringing early in shot
- in free flight: ~ 4 kgee deceleration which corresponds to in full atmosphere

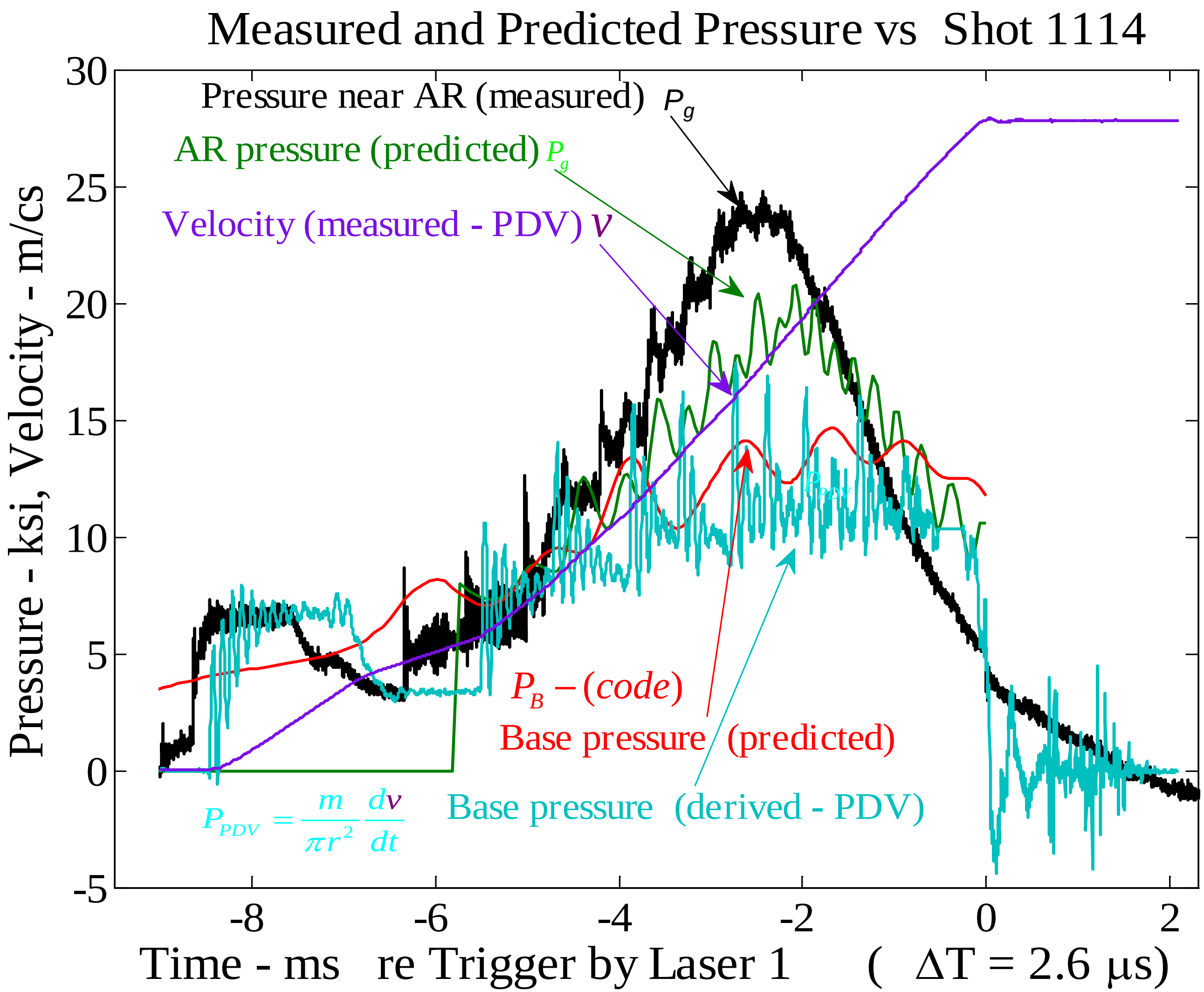
Axial X(t), V(t) and dV/dt profiles in Vacuum



- Velocity detected throughout bore, reaching 2782 m/s
- Signal is lost for less than 0.40 ms near muzzle
- No drag is observed in Vacuum, confirming 37 km/s^2 drag is caused by air



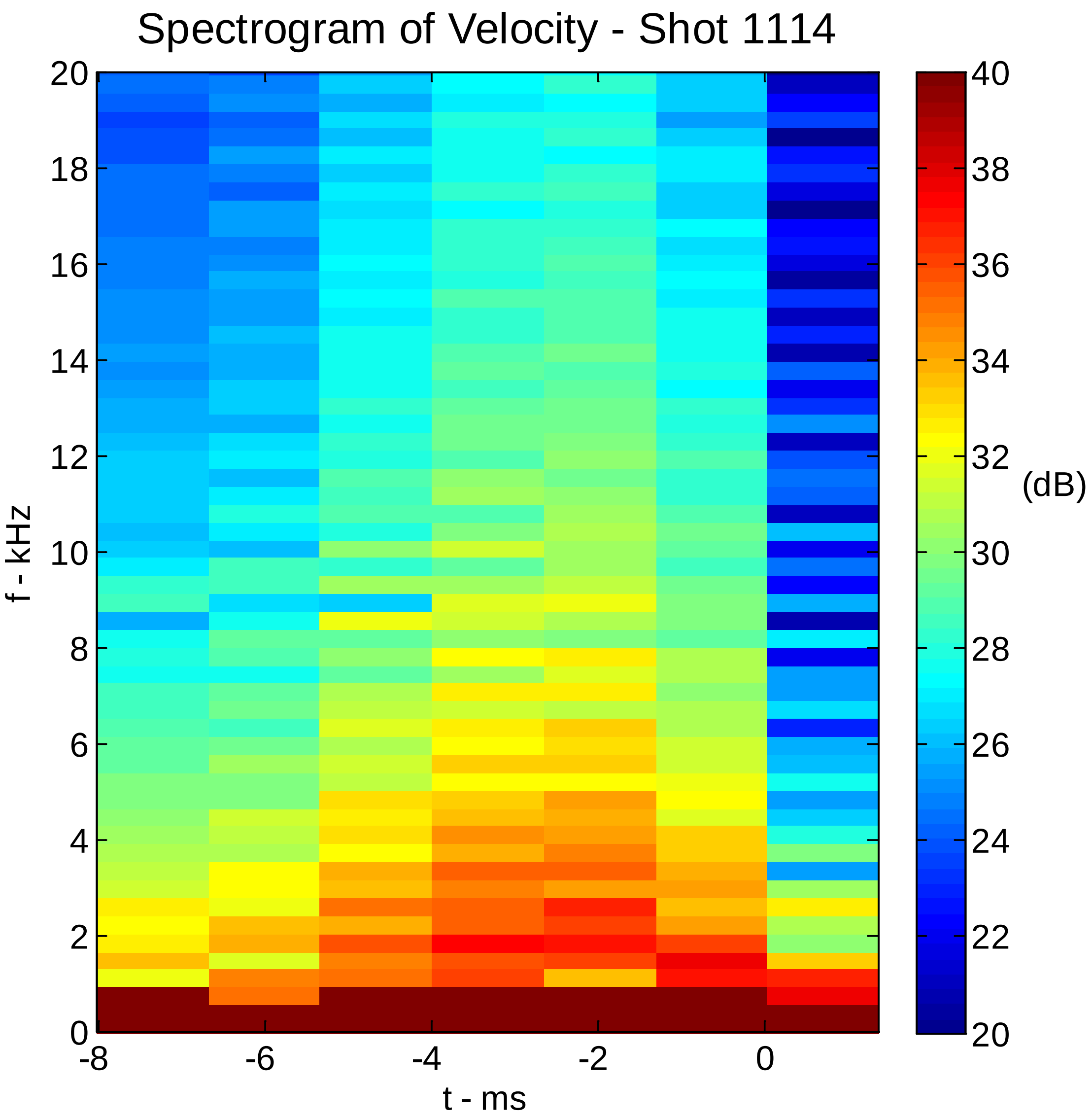
Pressures Estimates



P_B and P_{PDV} in reasonable agreement <1 kHz (code predictions not valid at higher freq)

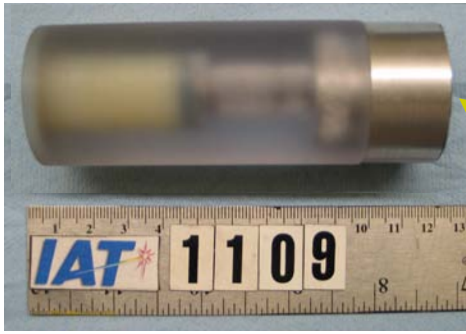
P_B and P_{PDV} exhibit spiky *behavior - likely due to reflections of the shock structure in the hydrogen gas*

Velocity Fluctuations

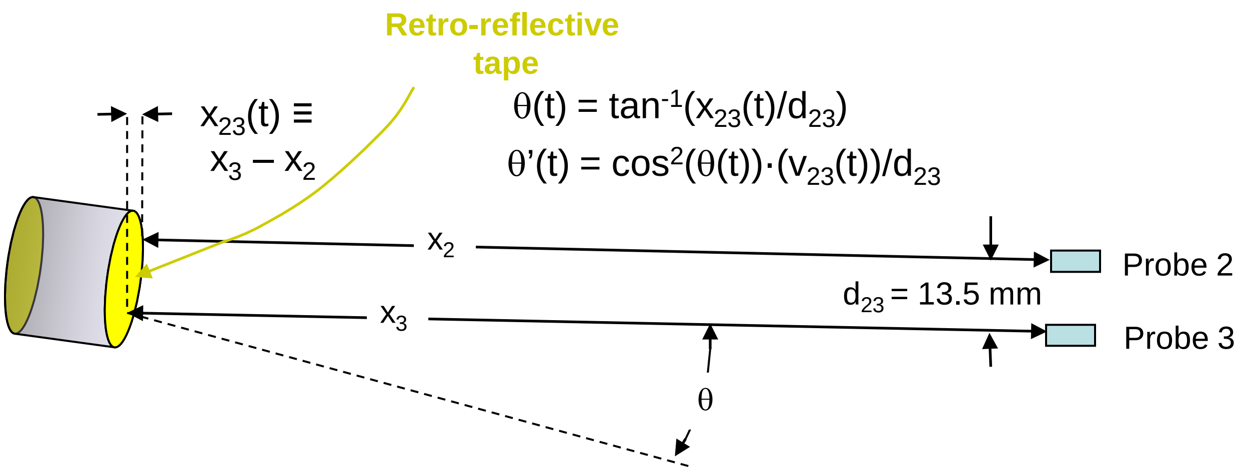


(Spectrogram of Spectrogram)

Balloting Angle From Multiple High-Resolution Axial PDV Measurements



0.75- in Aluminum leading edge on Lexan slug has ~0.5 mm smaller diameter

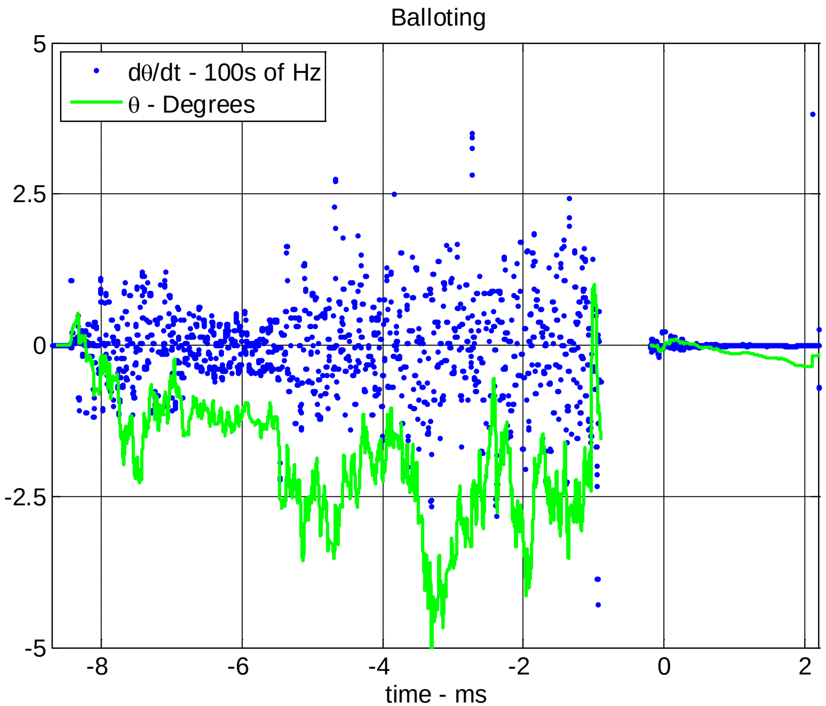


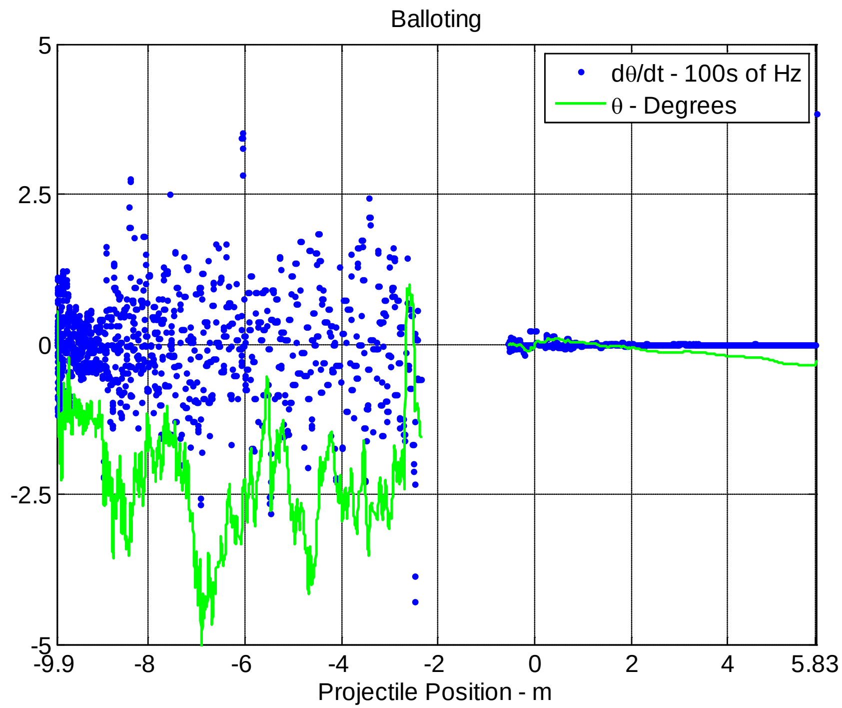
$$\theta(t) = \tan^{-1}(x_{23}(t)/d_{23})$$

$$\theta'(t) = \cos^2(\theta(t))\cdot(v_{23}(t))/d_{23}$$

- Tests prior to launch at 16 m established > 20 dB isolation between Probe 2 & Probe 3
- Precision & accuracy of balloting angle θ(t) is controlled by precision & accuracy probe separation d_{23}, velocity measurement technique and numerical integration method.

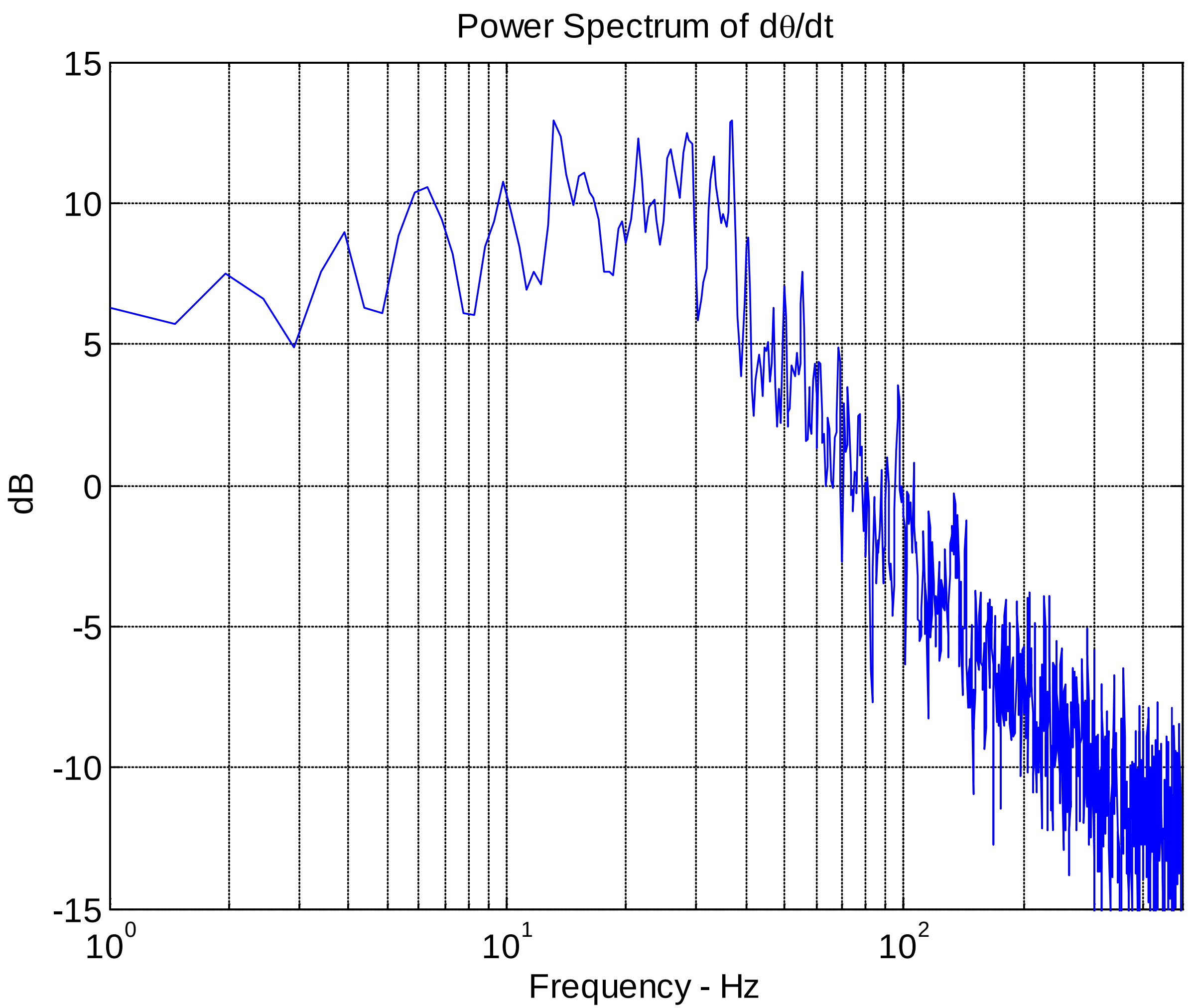
Balloting Angle





- **Balloting is quiescent before launch (t <-8.5 ms) and in free flight (-0.54 m < x > 5.83 m): θ < 0.2° .**
- **θ(t) correlates with axial a(t) changes, reaching peak of nearly θ=-5° .**
- **balloting angle profile measurements appear feasible, even in high G environments**

Power Spectrum of Balloting Angle



- *Balloting angle has broad, low frequency spectrum that peaks < 40 Hz*

Conclusions

- PDV analysis was successfully applied on launches over 16 m distances ~ 2-orders larger than used previously.
- Position, velocity, acceleration & Drag profiles were resolved
- New Non- disturbing, High-G measurements are now feasible with PDV
  - High frequency, Base-Pressure measurements
  - Multiple PDV signals: measurement of high-G balloting angle profile now f.