Determining Railgun Dynamics Using PDV

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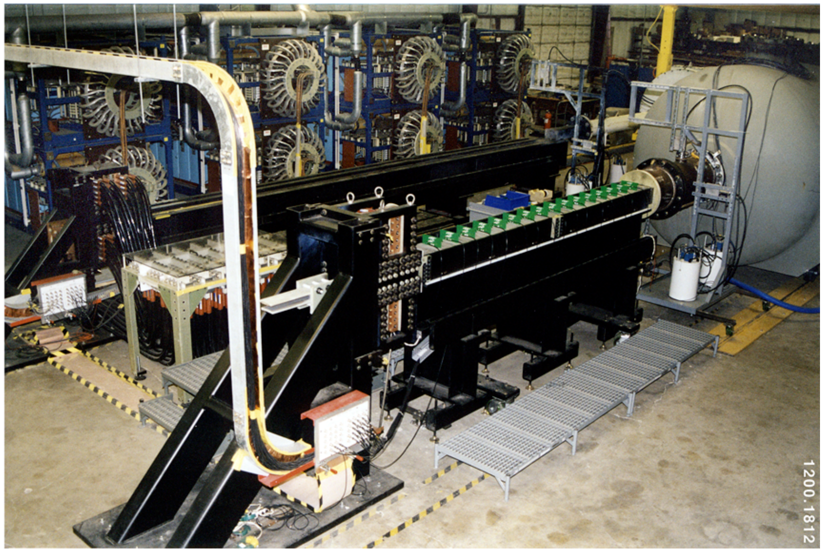
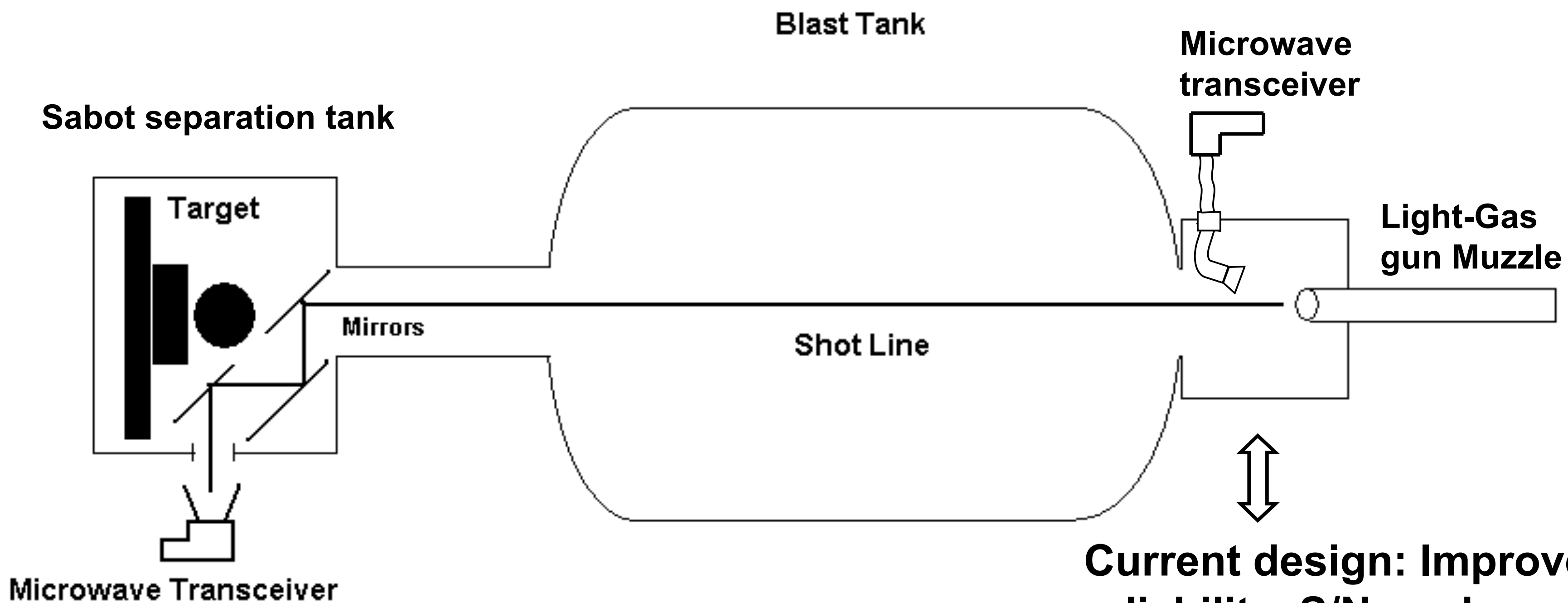
Outline

- Prior launcher experiments at IAT/UT
  - RADAR heterodyne
  - On-board optical



- Proposed heterodyne and photodetector velocimetry (PDV) concept on a railgun

Past Work With Radar Heterodyne Demonstrates Feasibility



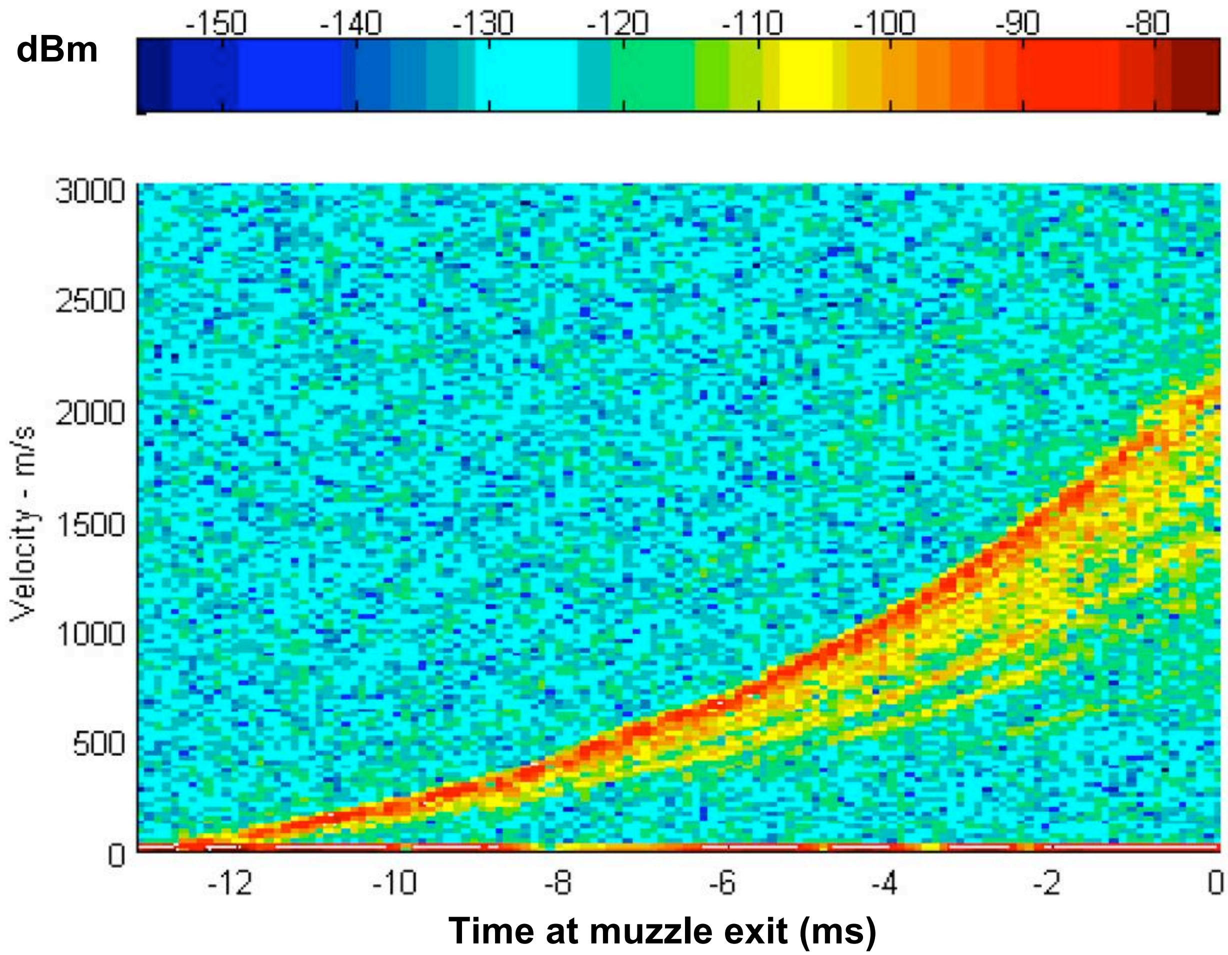
Current design: Improved reliability, S/N, and ease of setup make it a routine diagnostic on the LGG[2]

kA-band RADAR (λ=8.55) mm:

f_0 = 35.500000 GHz

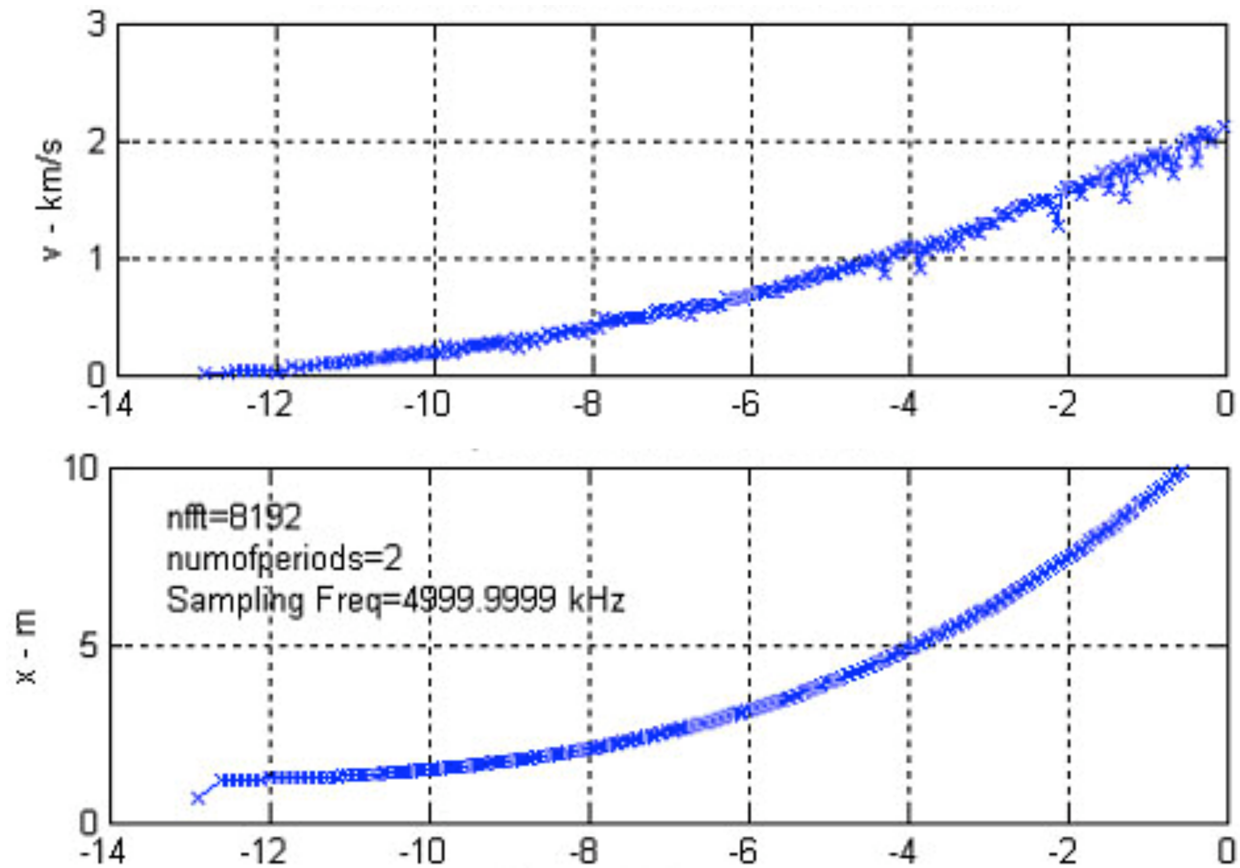
Proof-of-concept design: RADAR was successful after enduring 7 reflections and 24 m two-way travel[1]

Spectrogram of 35.5 GHz RADAR IF[2]



- Divide signal into short sub-records (length T_i) - velocity ~ constant in each
- FFT of each sub-record $\Rightarrow$ spectrogram
- Dominant signal at beat frequency $\Delta f_i = 2v_i/\lambda$

Position and Velocity from Spectrogram[2]

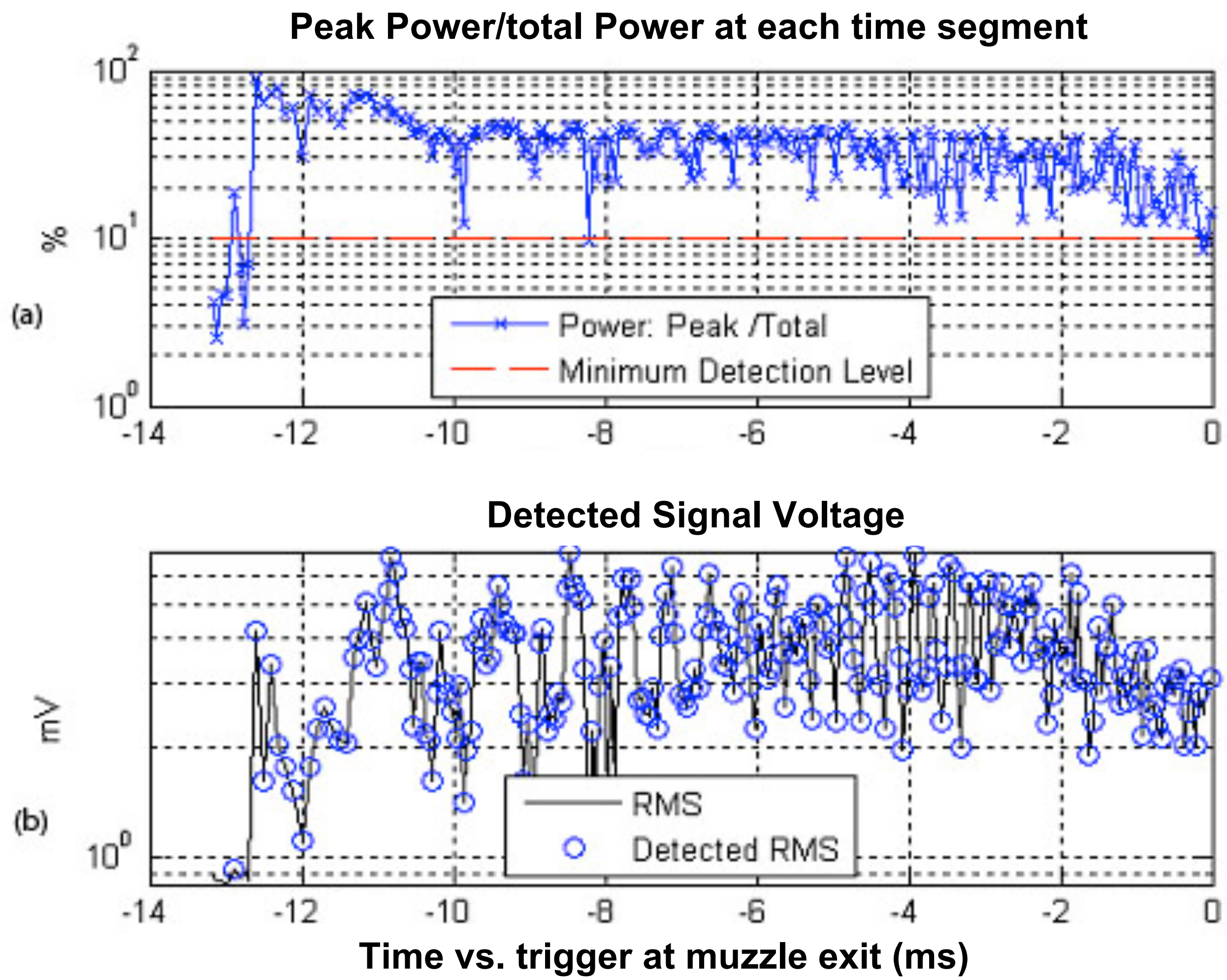


Time at muzzle exit (ms)

Spectral peak at each time T_i is the detected projectile velocity v_i

Position x_i is integrated projectile velocity

Quality of Radar Detection²



Past Experience Shows Difficulties of an Optical Data Link in a Railgun[3]

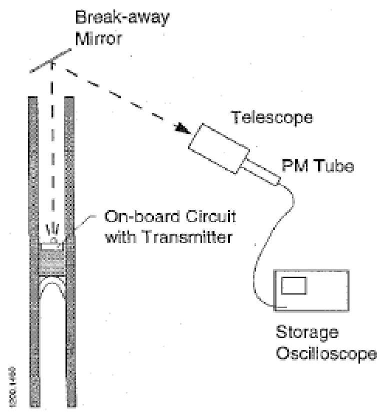


Fig. 1. System schematic showing in-bore transmitter, external mirror and method of data collection.

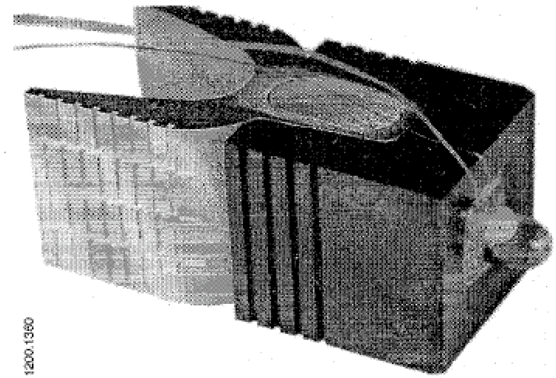


Fig. 2. Picture of launch package showing KJ-200 armature, black Lexan borerider with potted circuit in central cavity. The LED transmitter and energy storage capacitor are visible at the front.

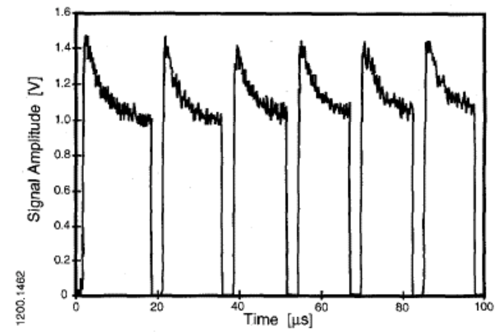


Fig. 4. Data stream received from in-bore transmitter during the first 100 μs of a test. The pulse frequency is approximately 60 kHz.

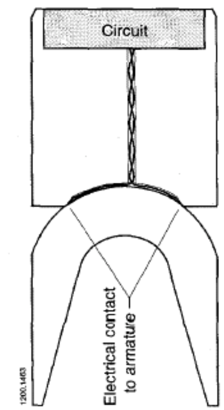


Fig. 5. Schematic showing connections for armature voltage measurement.

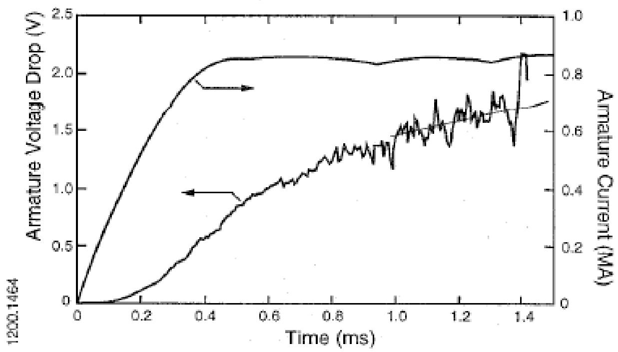


Fig. 6. Measured armature voltage and armature current versus time.

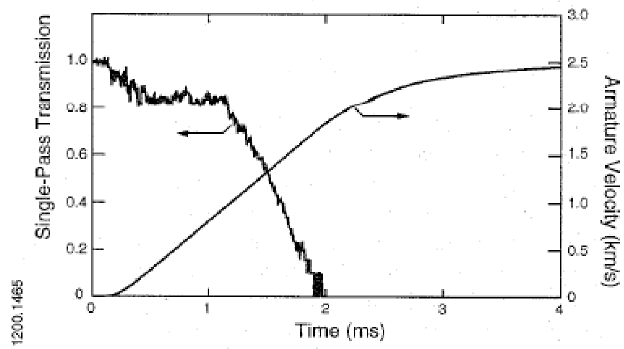
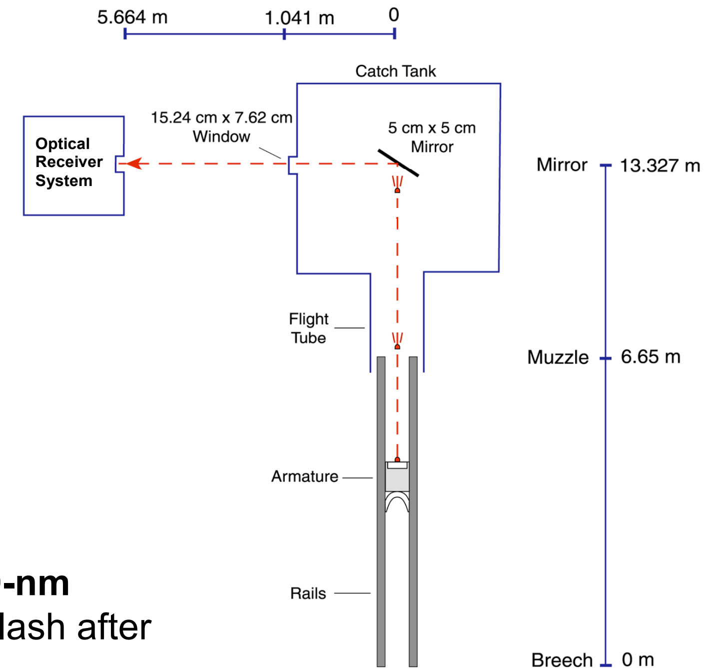


Fig. 7. Bore transmittance and launch package velocity versus time. For this test, the bore was filled with He.

Stationary Optical Signal in Presence of Dynamic MCL Railgun Muzzle Flash[4]

 Optical Emitter Attributes	AND190HAP LED	Honeywell VCSEL TO-46 Flat Window SV3637	Pill Pack Flat Window SV4637	Pill Pack Dome Lens SV2637	TO-46 Dome Lens SV5637
Mass	1019.5 mg	262.5 mg	33.1 mg	34.0 mg	310.1 mg
Beam Divergence è degrees:	6ú	10ú	10ú	4ú	2ú
$\Omega = 2\pi\{1\text{-Cos}(è/2)\}$ Steradians:	$8.6 \cdot 10^{-3}$	$24 \cdot 10^{-3}$	$24 \cdot 10^{-3}$	$3.8 \cdot 10^{-3}$	$0.96 \cdot 10^{-3}$
Typical Luminosity	0.13 mW (I_F = 20 mA)	1.5mW (I_F = 14 mA)			
Peak Emission Wavelength	612 nm	850 nm			
Bandwidth (FWHP)	15 nm	0.85 nm			
Modulation Bandwidth	0.1 GHz	10 GHz			
Maximum Power Dissipation P_D	125 mW	20 mW			
Maximum Forward Current I_F	50 mA	20 mA			

Compare LED with VCSEL

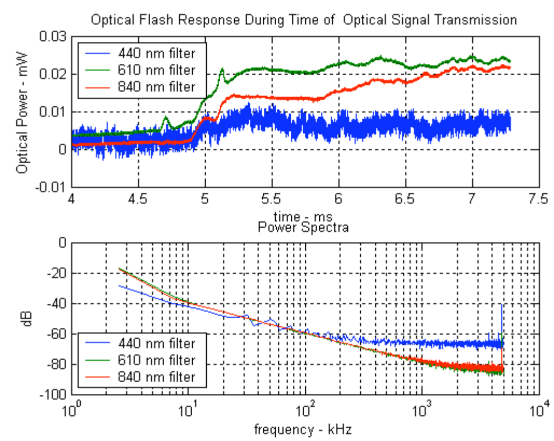


Optical signals from stationary **612 nm LED** and **850-nm VCSEL** (SV5637) were compared with MCL muzzle flash after armature exit.

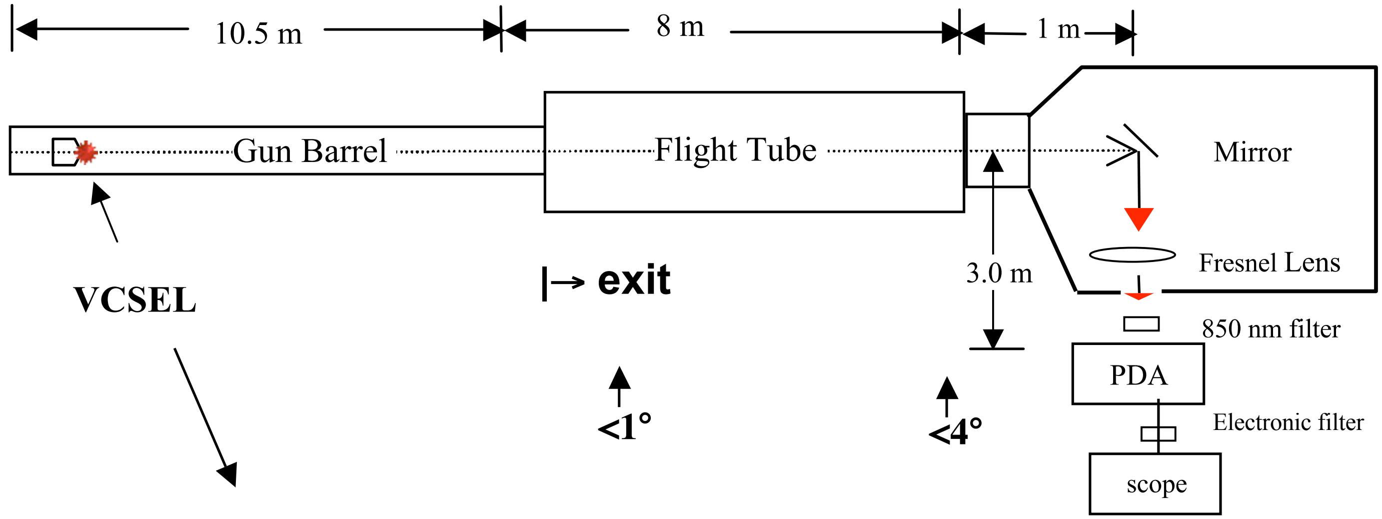
- **Muzzle flash overwhelmed** received optical signal from **612 nm LED** by a **factor of 20**—indicating such a device is unfeasible.
- **850-nm VCSEL—**was **about the same level** as the muzzle flash.

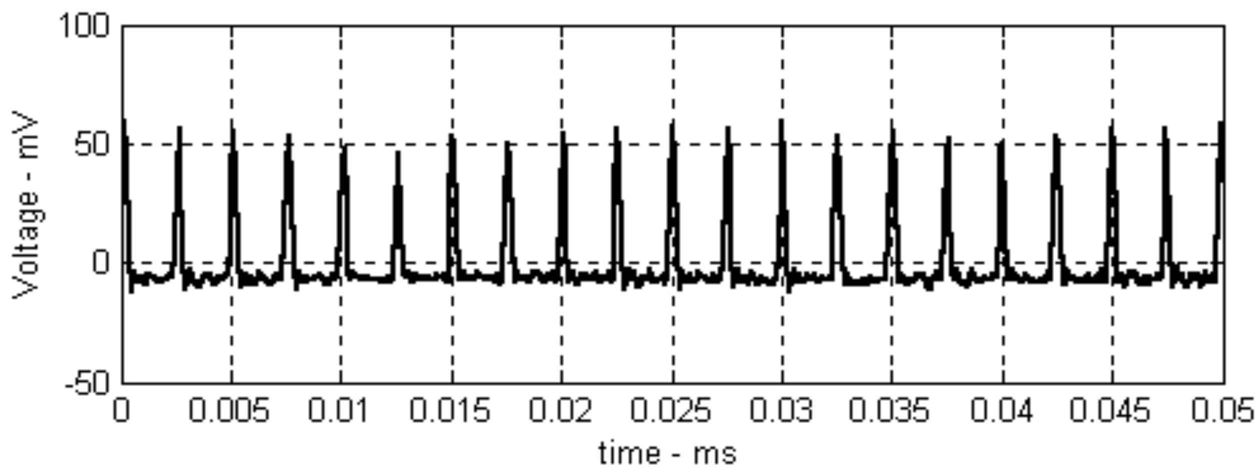
➢ **low-frequency spectral content of the optically filtered muzzle flash and the narrow optical beam of the VCSEL indicate several tens of decibels improvement in S/N**

➢ **Gun-launched modulated optical transmission appeared feasible.[6]**



Two-stage Light-gas Gun Range Configuration for Optical Signal Experiments[5]

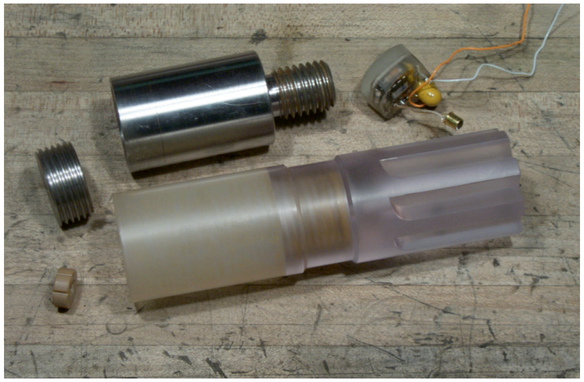


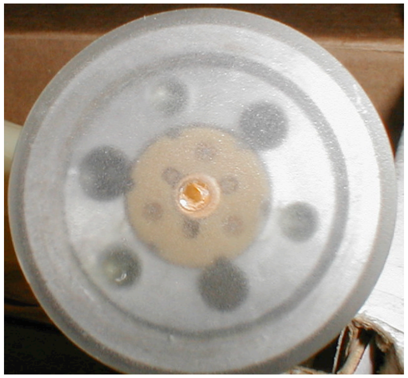


pulse-width: 400-ns
period: **2.55-µs**

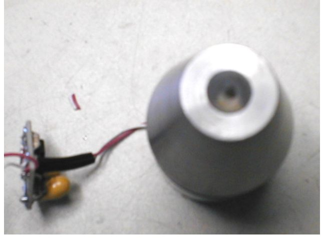
Projectiles,VCSEL & Electronics[5]

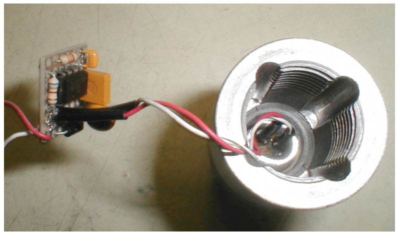
Slugs used in Shots 643 and 653

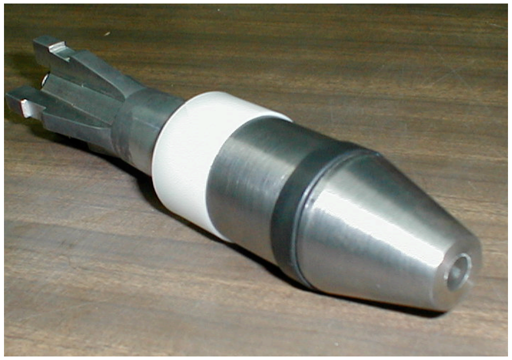




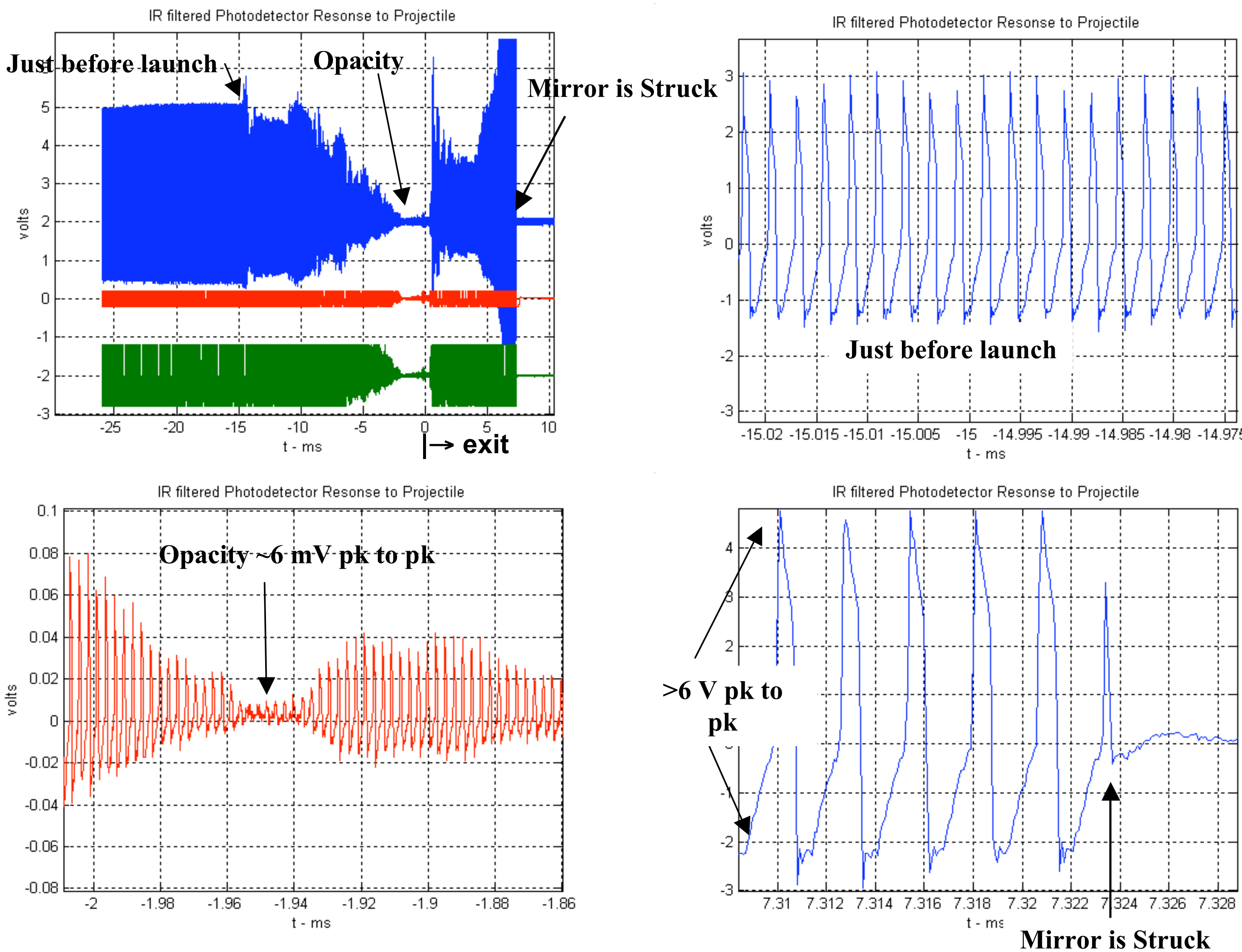
Refined projectile used in Shot 683







Received IR Signal Projectile at 760 Torr with Refined Projectile[5]

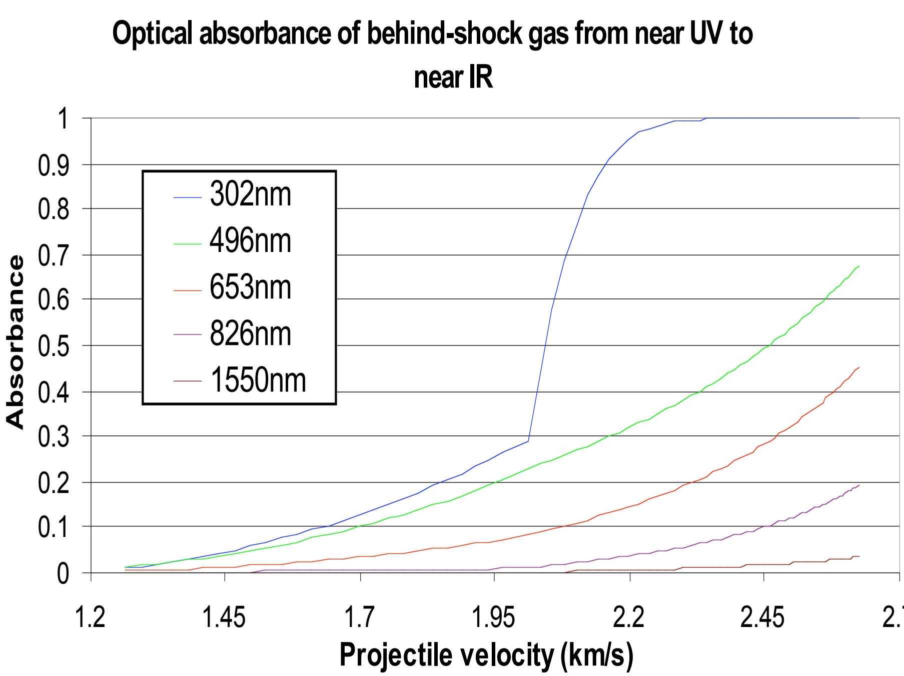


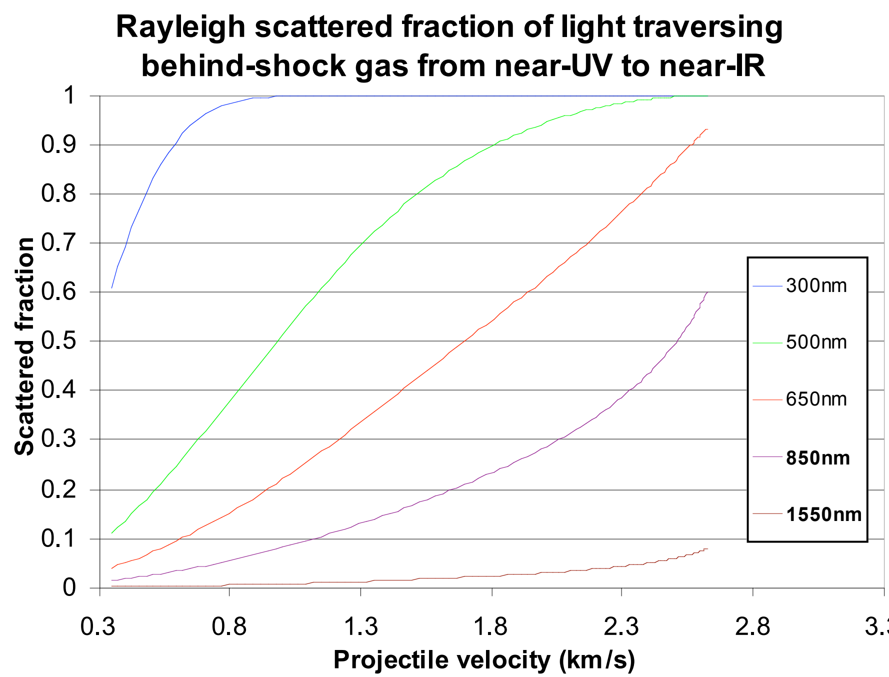
Absorbance and Rayleigh Scattering of Behind-shock Gas: The Importance of Wavelength[6]

• **Optical absorbance is an attenuation/energy dissipative effect[7]**

• **Rayleigh scattering is a dispersive but energy conserving effect—but combined with absorbance it will cause signal reduction[8].**

➢**1550 nm significantly better than 850 nm (VCSEL) and visible**





Gun-launched Optical Transmitter Using a 1.5-mW VCSEL[5]

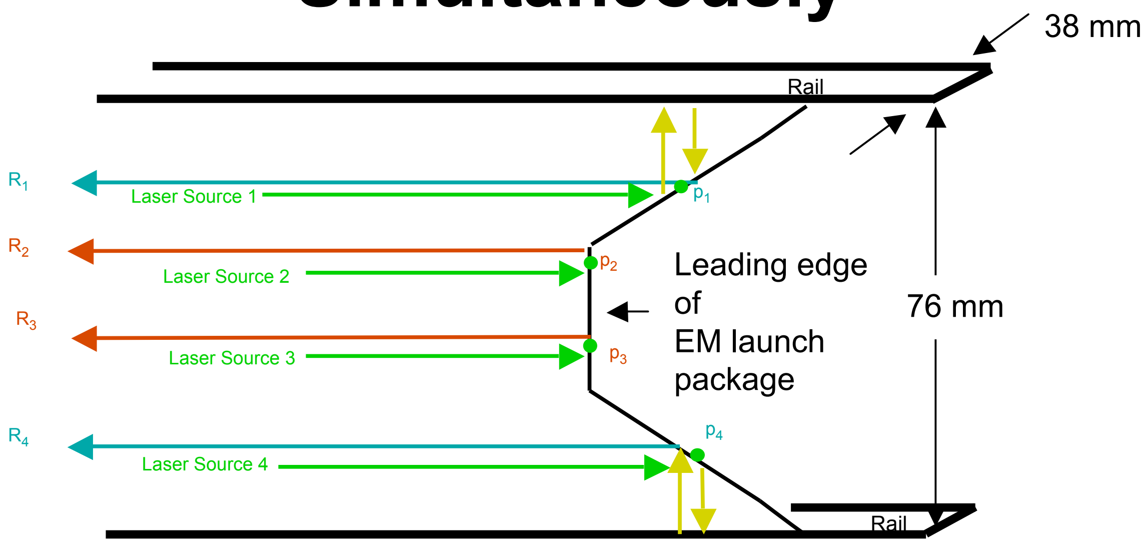
Hypervelocity gun-launched optical experiments at full atmosphere were successful.

- Projectiles transporting a VCSEL and transmitter electronics were launched to 21 kG, 1.55 km/s at 1.0 atmosphere
- Narrower band VCSEL allows higher gains due to optical filtering and higher frequency electronic filtering of the signal.
- Signal @ λ=850 nm was continuously stable and detectable from launch-beginning to impact.
- Optical bore opacity increased significantly (up to **1000×**), **but recovered** in flight.
- **Modern, commercial off-the-shelf (COTS) optics @ λ=1550 nm should offer substantial improvement[6].**

Problem

- Measure axial and transverse (balloting) motion of a projectile in a railgun

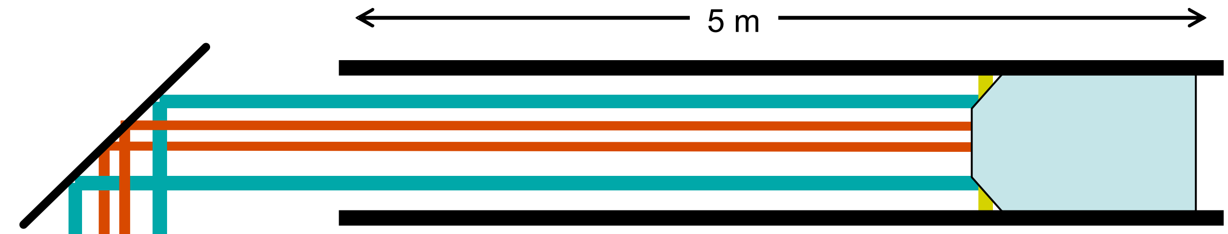
Principles for Measuring Axial and Transverse Velocity Components Simultaneously[9]

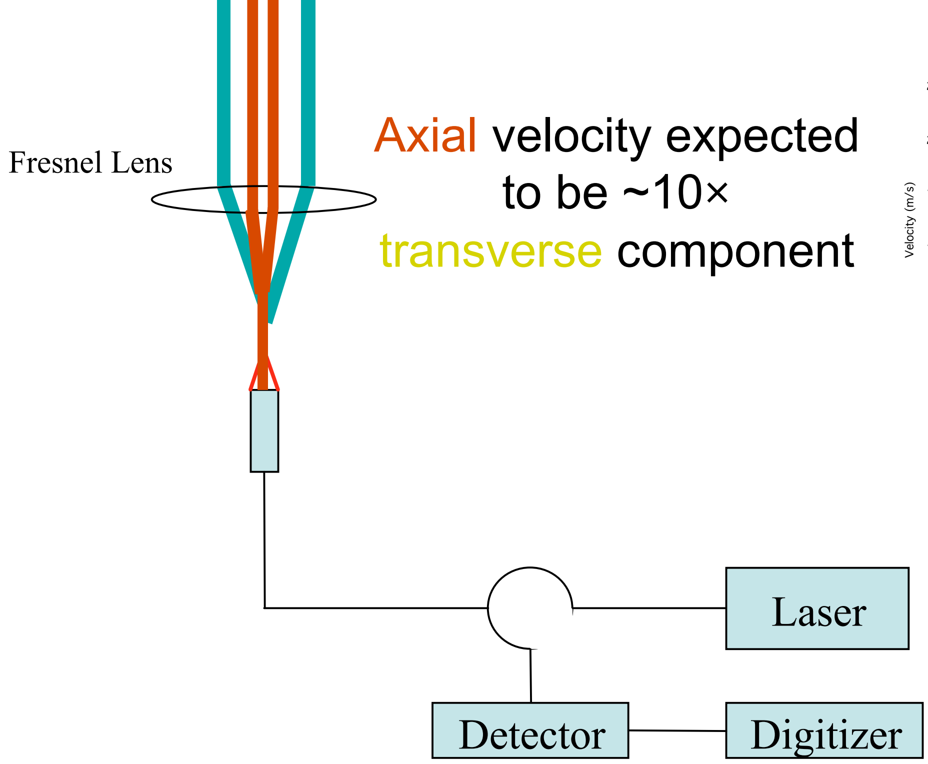


1. Split laser signal (λ_0 = 1550 nm) into four oscillator signals at frequency f_0=193414.49 GHz
2. Determine beat frequencies Δf_i of each received signal R_i, which is proportional to the rate of optical path length change: $\Delta f_i = f_d - f_0 = 2(v_i/c)f_0 = 2v_i/\lambda_0$:

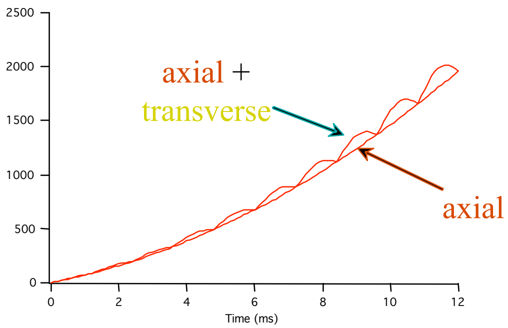
- Δf_2 & Δf_3 are proportional to |axial| launch-package velocity components (only): v_2 & v_3 at p_2 & p_3
- Δf_1 & Δf_4 are proportional to algebraic sum: |axial| + |transverse| components: v_1 & v_4 at p_1 & p_4

Implementation With a Single Probe Using PDV[9]



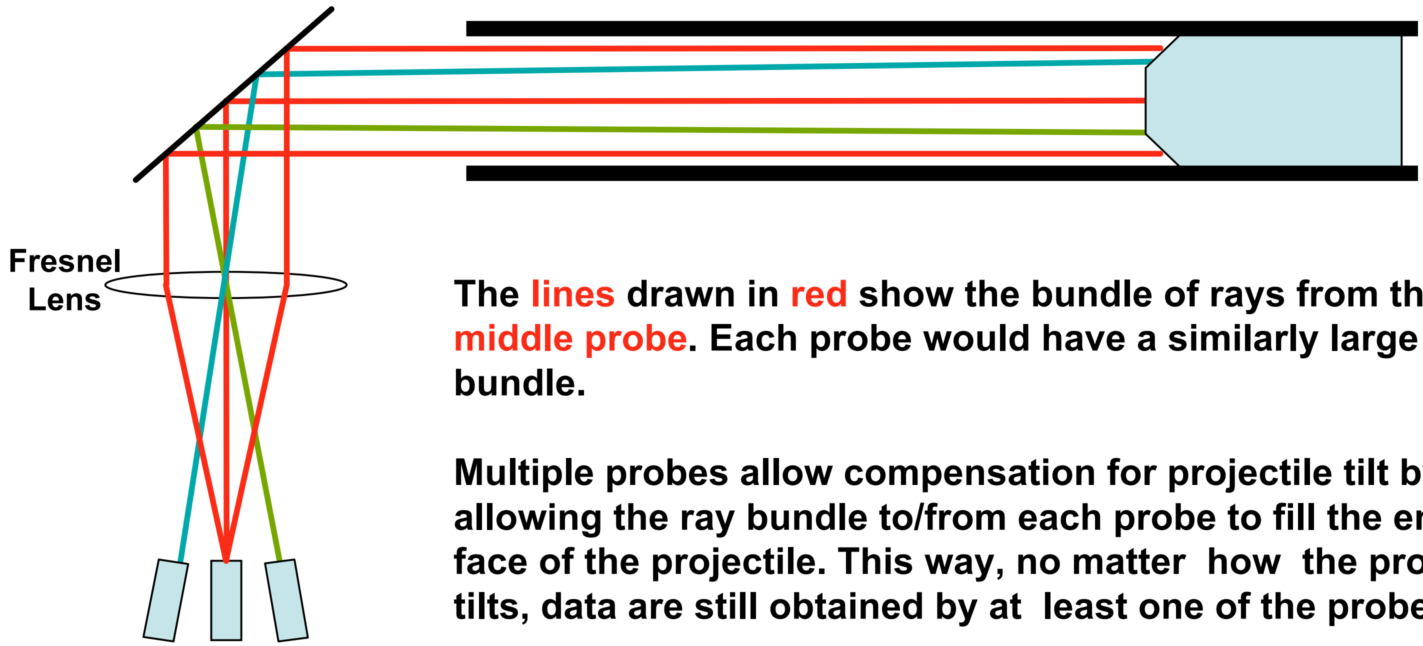


Axial velocity expected to be ~10× transverse component



The spectrogram would show both axial and transverse components at one time.

Multi-probe System Can Increase Tolerance to Projectile Balloting[9]

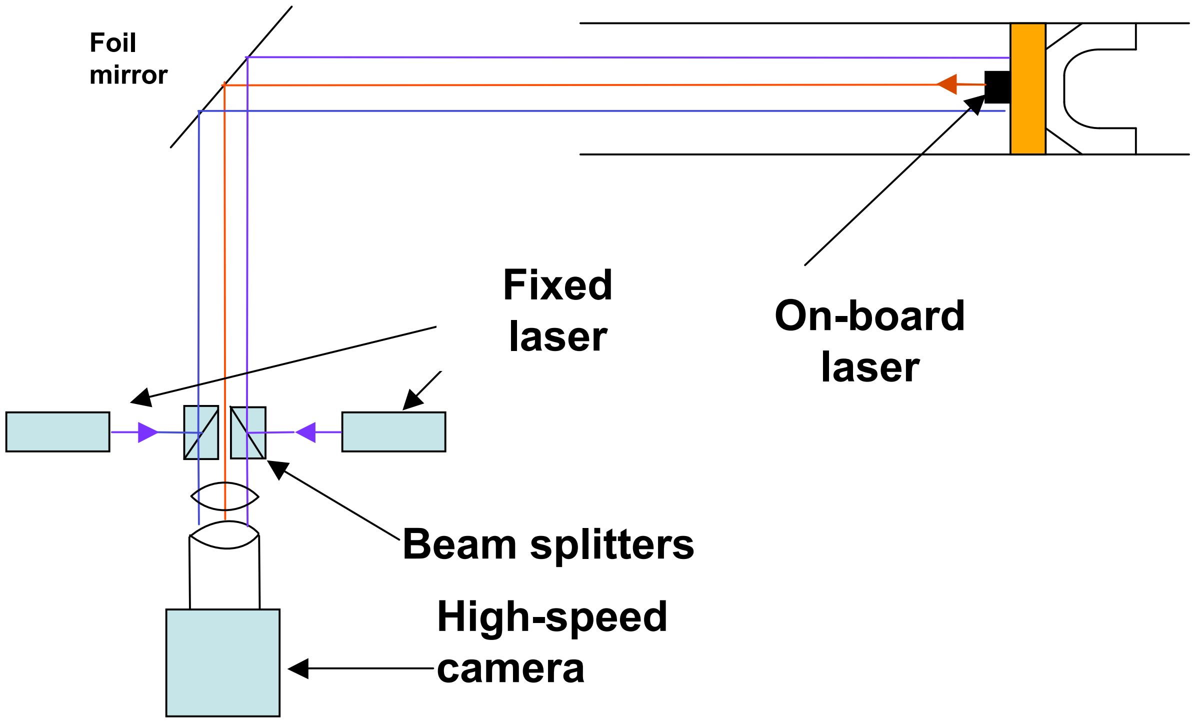


The lines drawn in red show the bundle of rays from the middle probe. Each probe would have a similarly large bundle.

Multiple probes allow compensation for projectile tilt by allowing the ray bundle to/from each probe to fill the entire face of the projectile. This way, no matter how the projectile tilts, data are still obtained by at least one of the probes.

Note that each probe will record both axial and transverse components.

Camera Recording for 2-D Balloting, Angle of Attack (AoA) and Axial Velocimetry in Railguns



- Use two fixed and one on-board laser to distinguish 2-D balloting and AoA
- High-speed camera detects and records 32 × 64 *x-y* beam coordinates at 100 kiloframes per second and 12-bit amplitude resolution (BW).
- Additional PDV photonics (not shown) provide faster axial component

Summary

- **Optical Devices can be compatible with railgun launcher.**
- **Heterodyning can be used to measure in-bore axial velocity.**
- **PDV shows promise in solving major problems in railgun diagnostics.**

Challenges

- Optical infrastructure
- Balance need for performance and cost effectiveness with latest COTS technology
- Find financial support (e.g., DURIP 2007).

References

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