# PDV Measurements of Shock Wave - Particle Curtain Experiments in the LANL Horizontal Shock Tube: Mono- vs Poly-disperse Particle Curtains.

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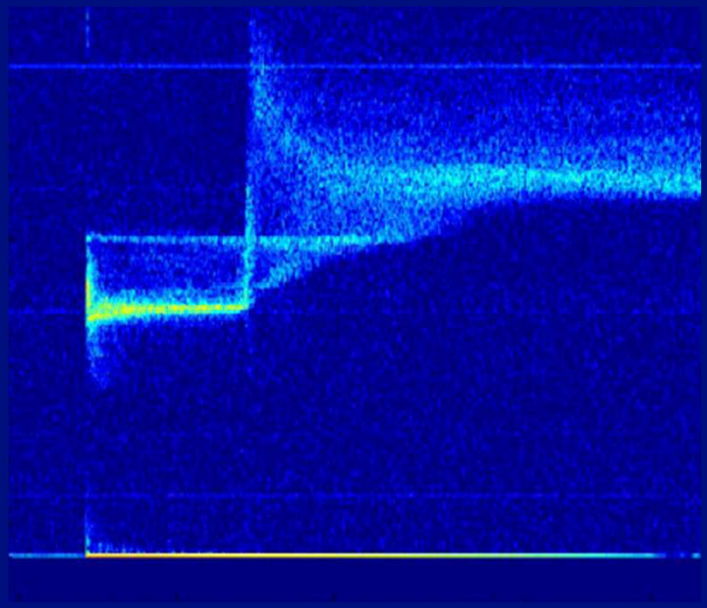
Physics Division – LANL

PDV Workshop – 2026/05/20

# Contents

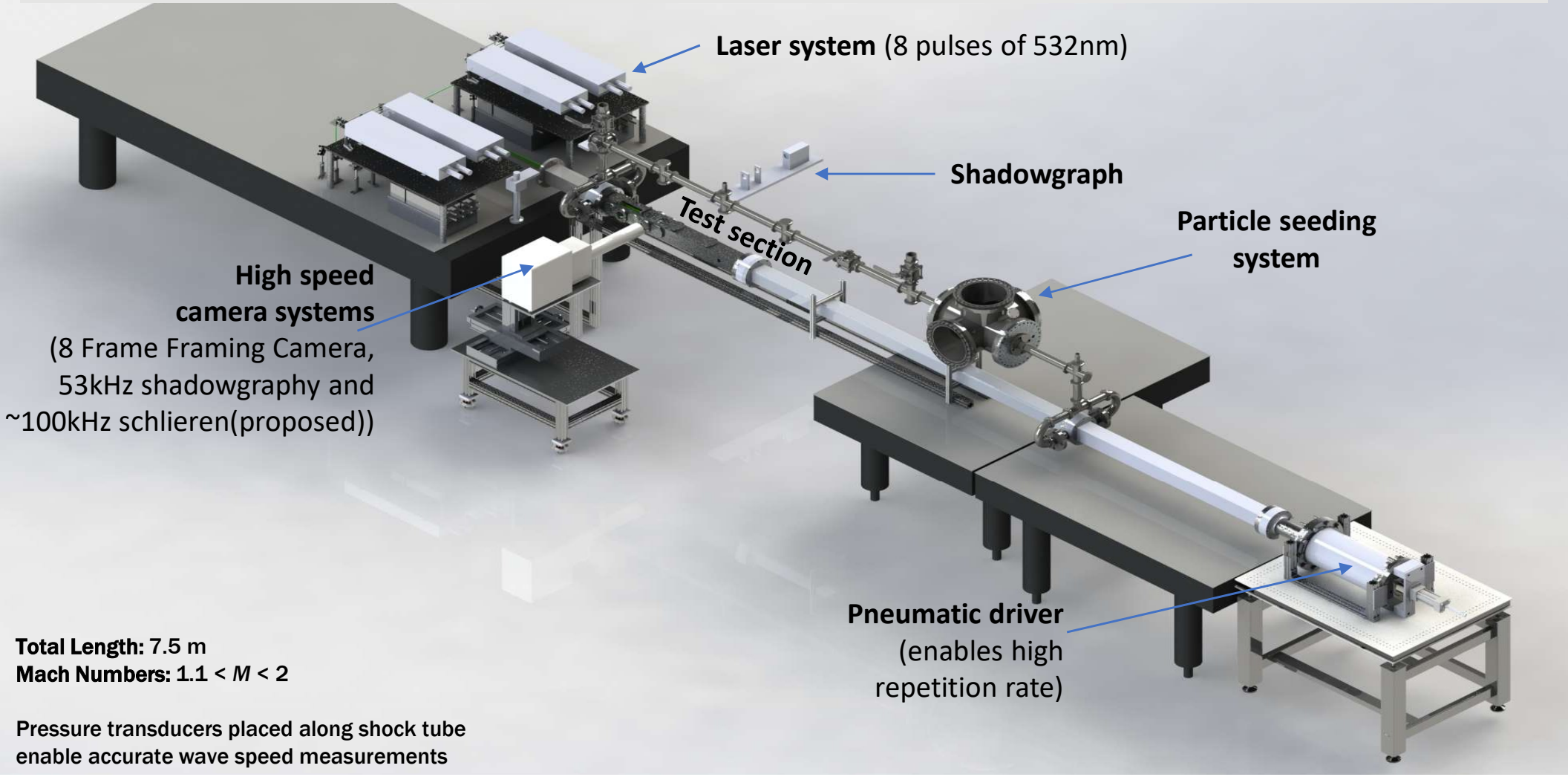
- Motivation: Measuring Particle Clouds /Measuring Through Particle Clouds
- Experiment Setup: The Horizontal Shock Tube
- Diagnostics
- Results
  - Mono-disperse
  - Poly-disperse
- Multiple Wavelength PDV

# Motivation

# Experiment Setup

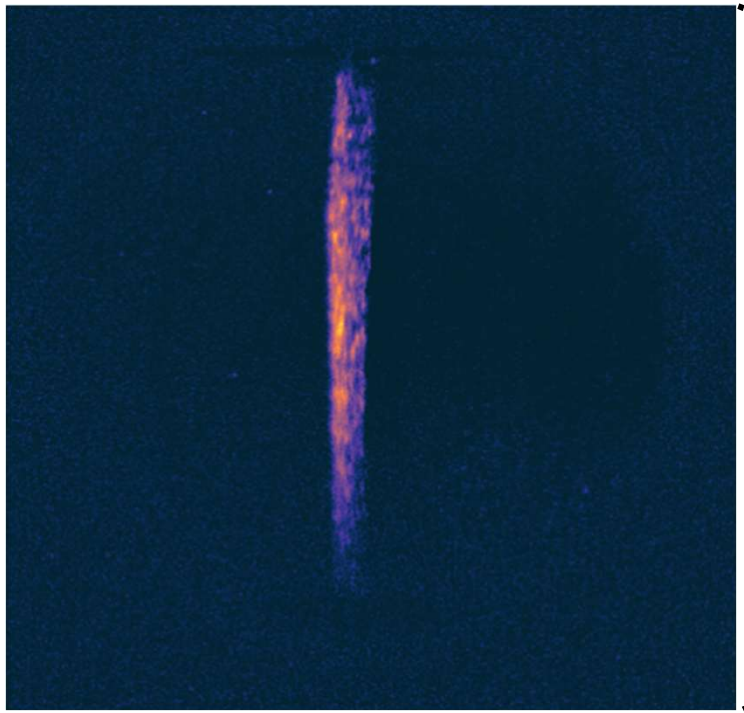
# The LANL Horizontal Shock Tube Was Modified to Enable Measurements of Single Particle Drag Due to Shock

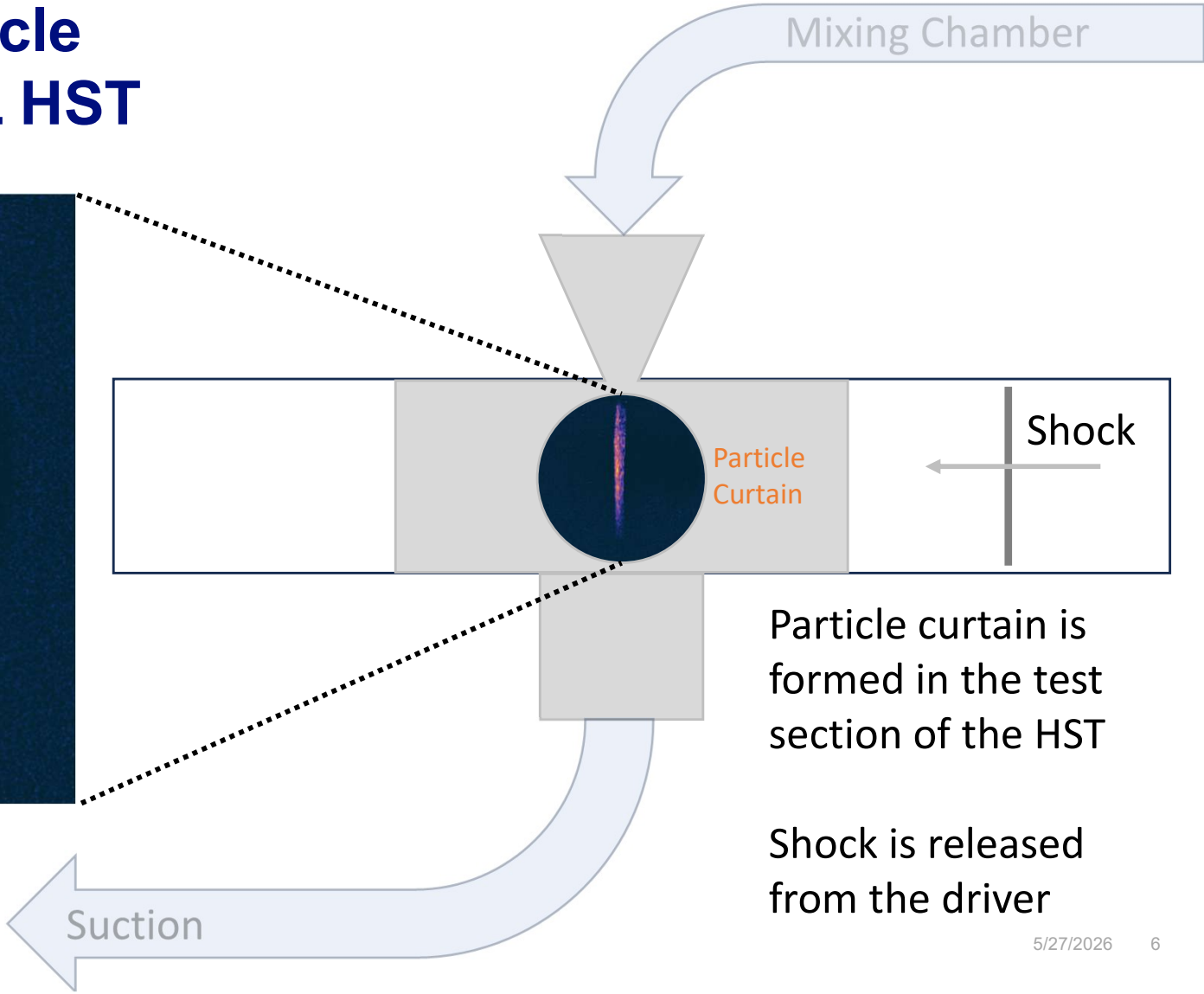



**Total Length:** 7.5 m
**Mach Numbers:** 1.1 < *M* < 2

Pressure transducers placed along shock tube enable accurate wave speed measurements

# Setting Up The Particle Curtain in The LANL HST






Particle curtain is formed in the test section of the HST

Shock is released from the driver

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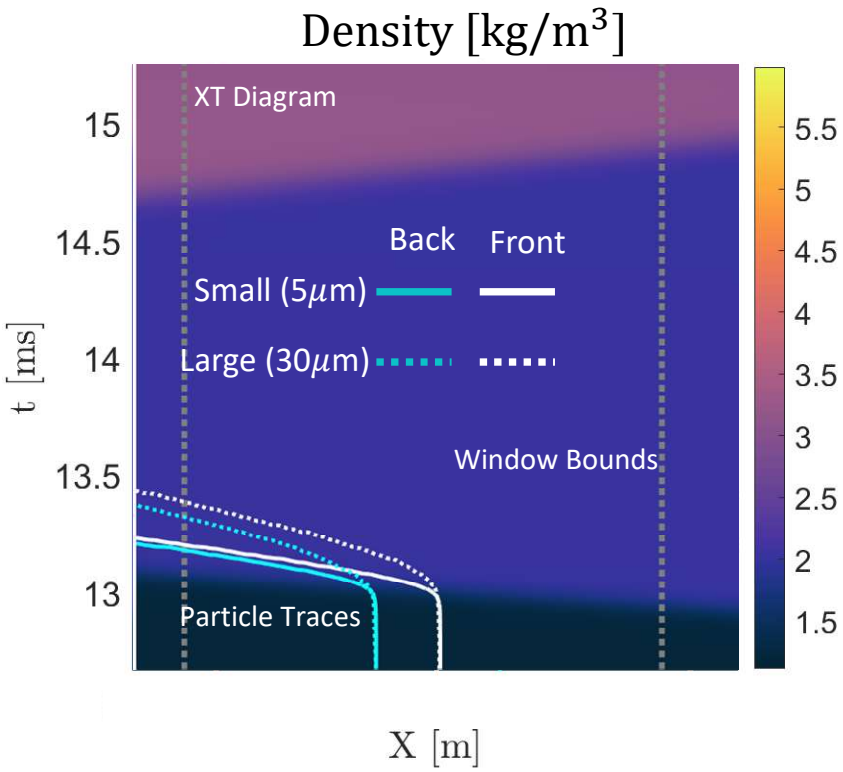


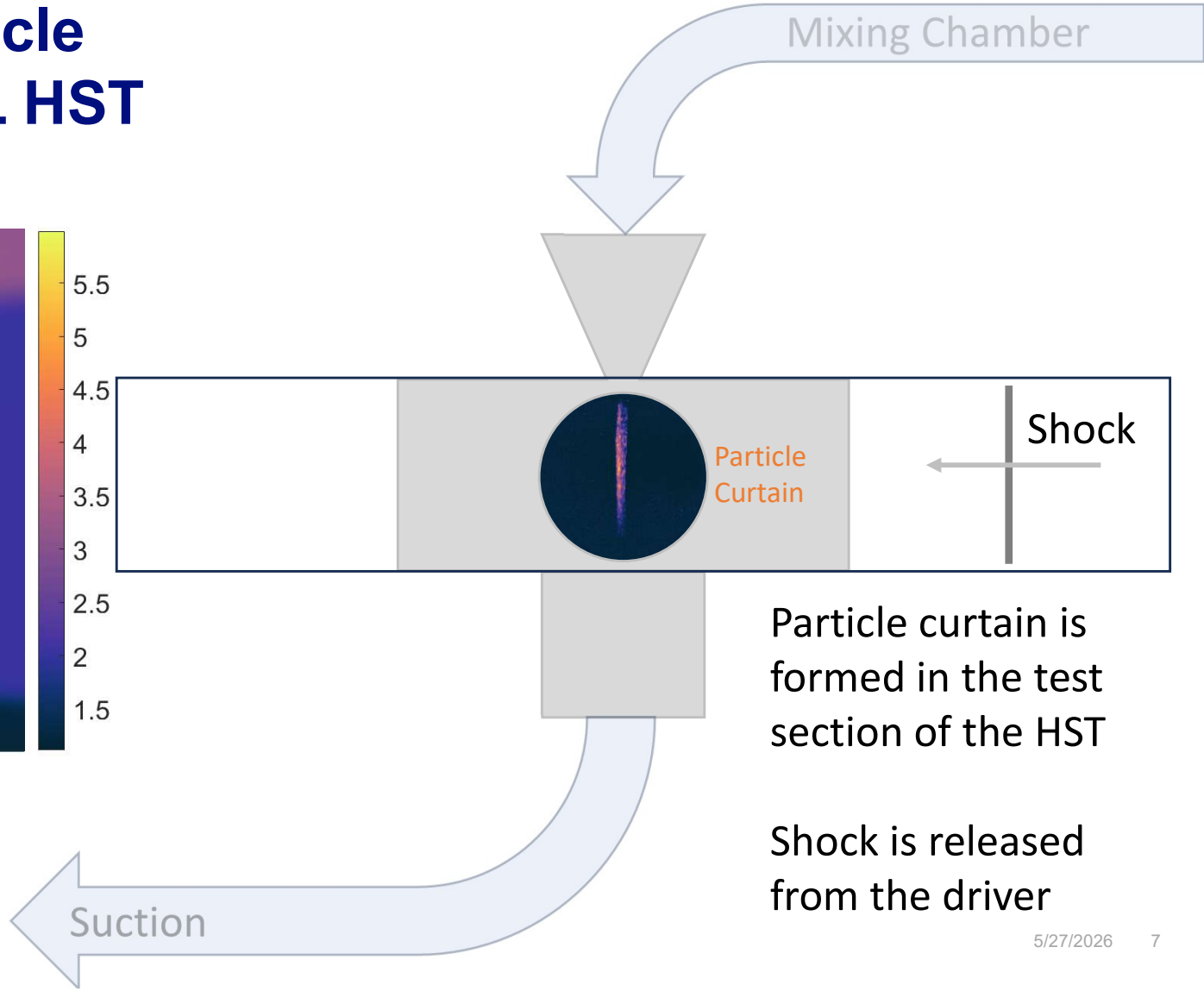


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# Diagnostics added to Help Validate PDV Measurements

- **Adjustable PDV Mount** – Can move laterally to place probes relative to the edge of the curtain
- **Laser Sheet** for Mie scattering to identify bulk curtain geometry measurements (potentially PIV /PTV)
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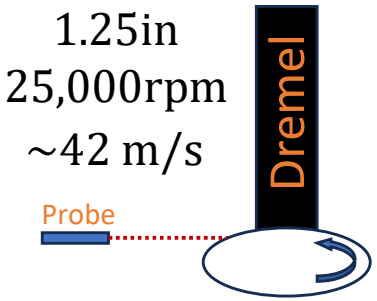
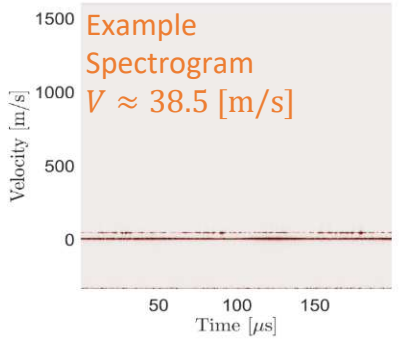
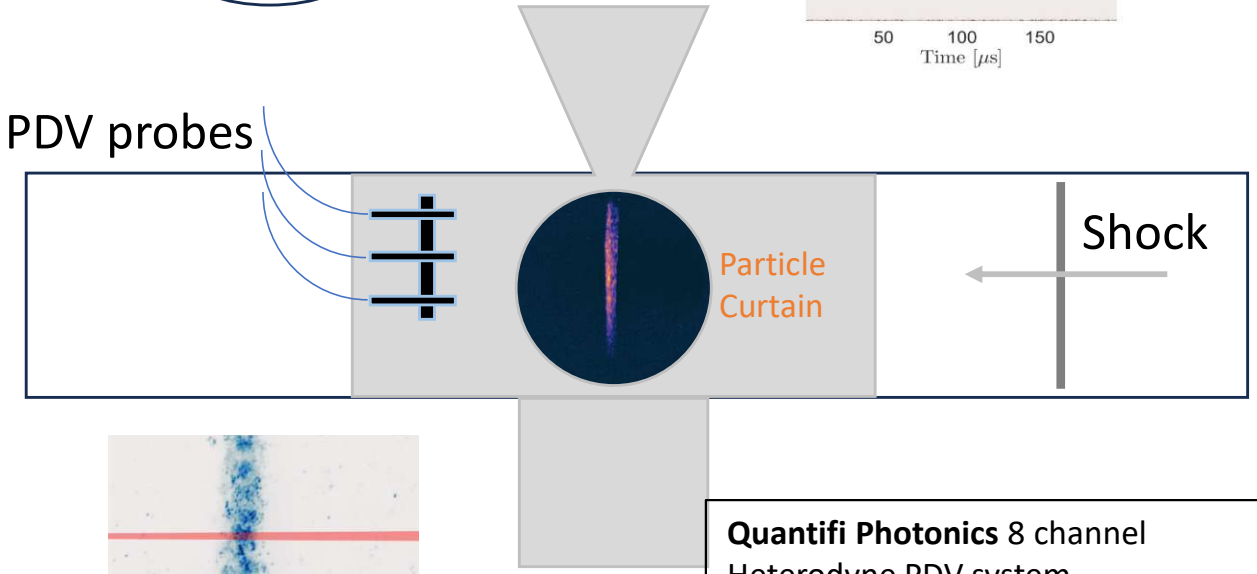
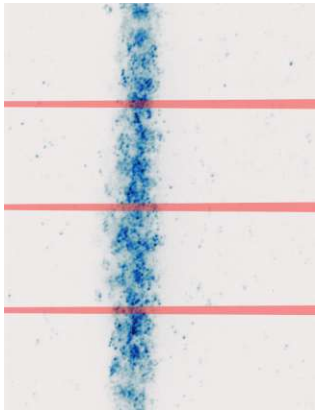



*Using rotating test setup (Mr Toothy)



Approximate lines of sight

**Quantifi Photonics** 8 channel Heterodyne PDV system.
**Target wavelength:** 1550 nm
**Reference wavelength:** 1550.004 nm

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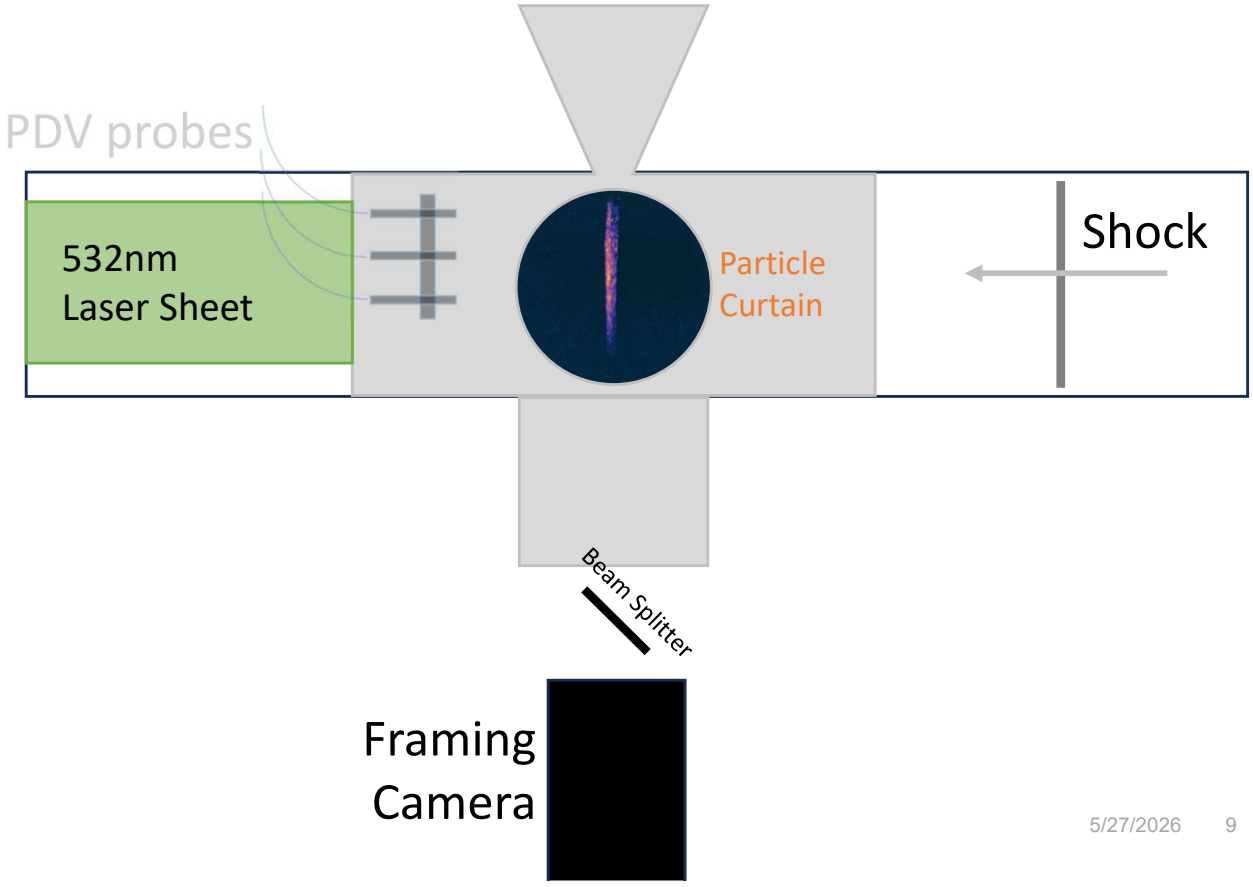

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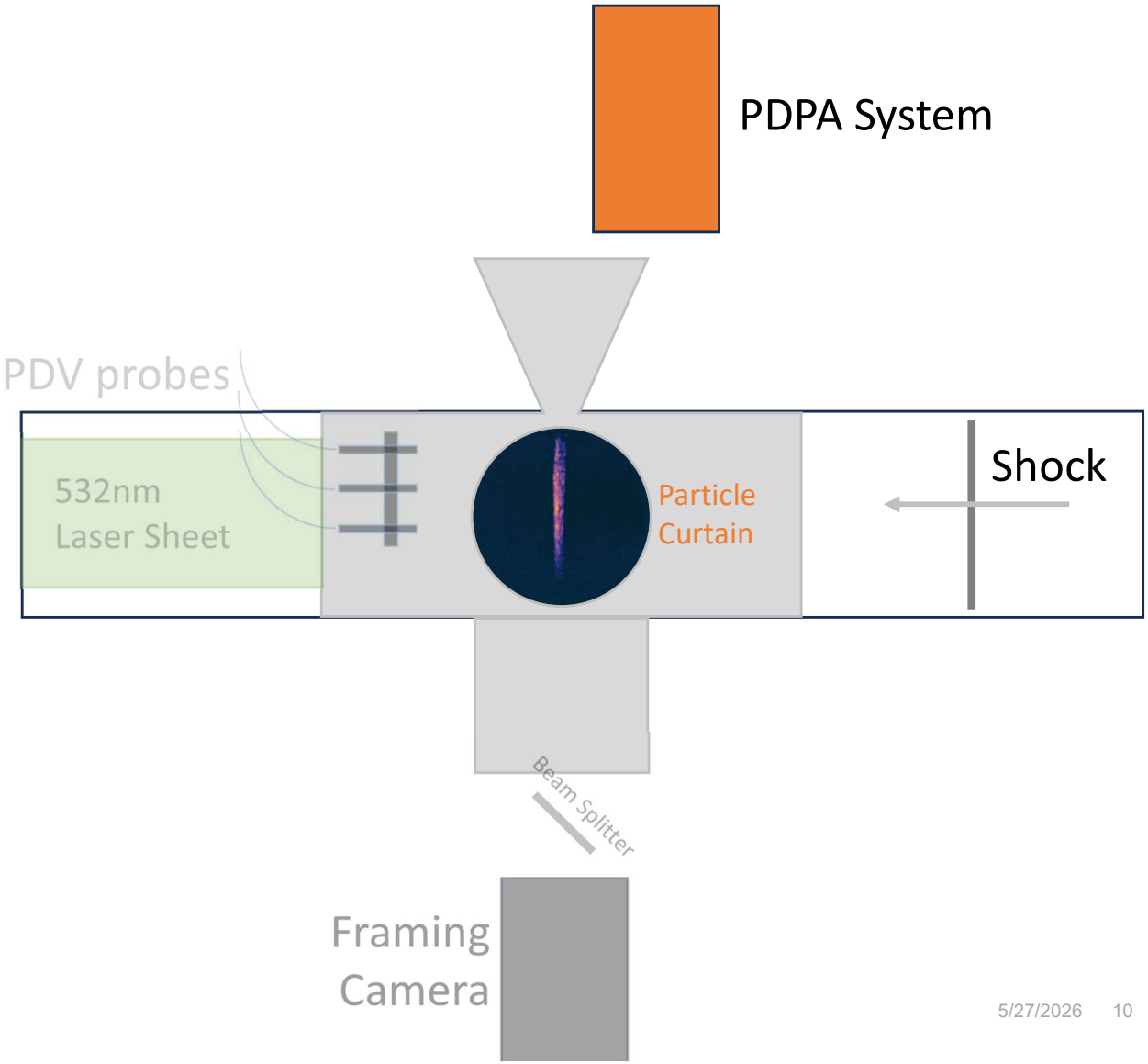

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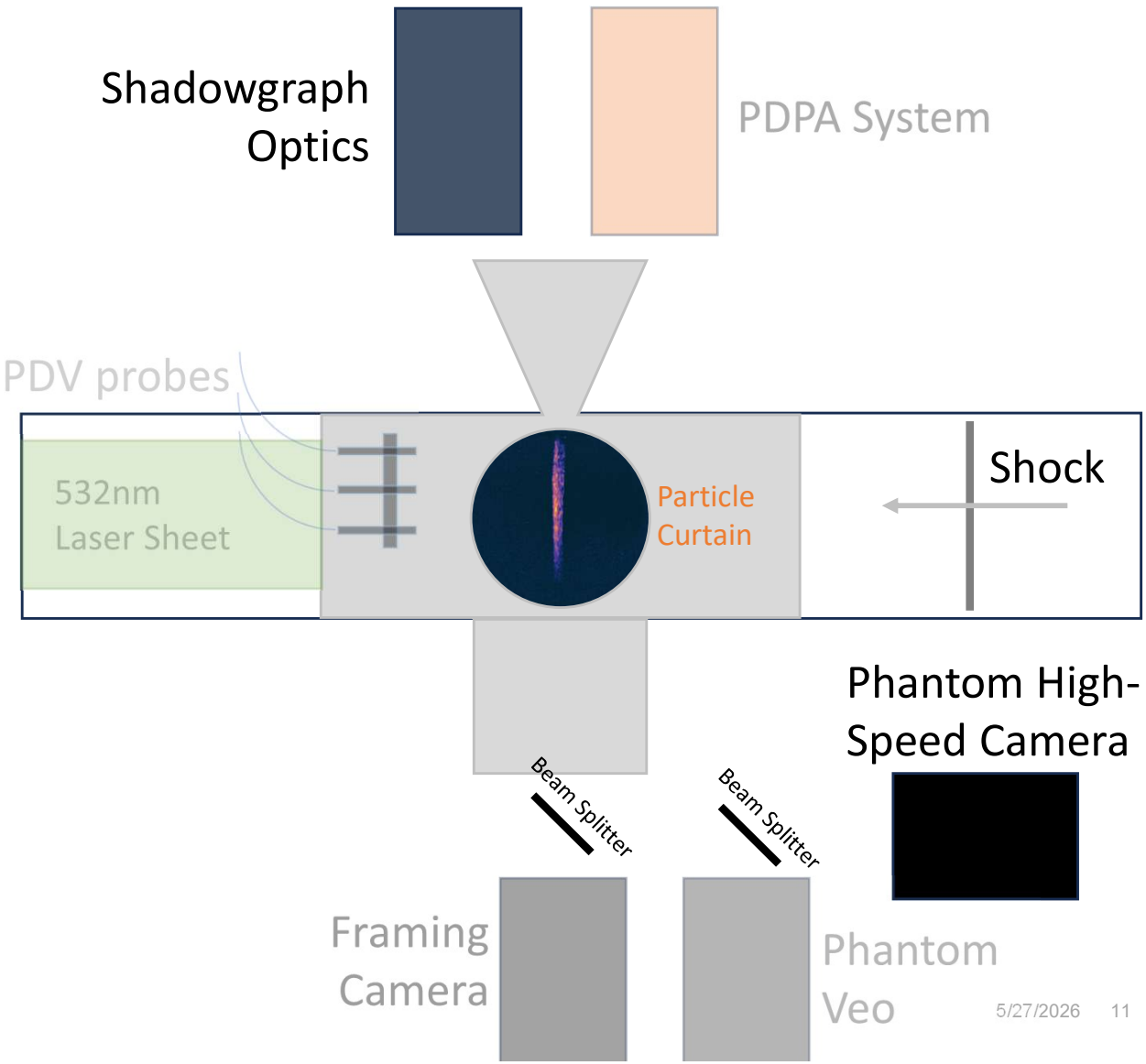

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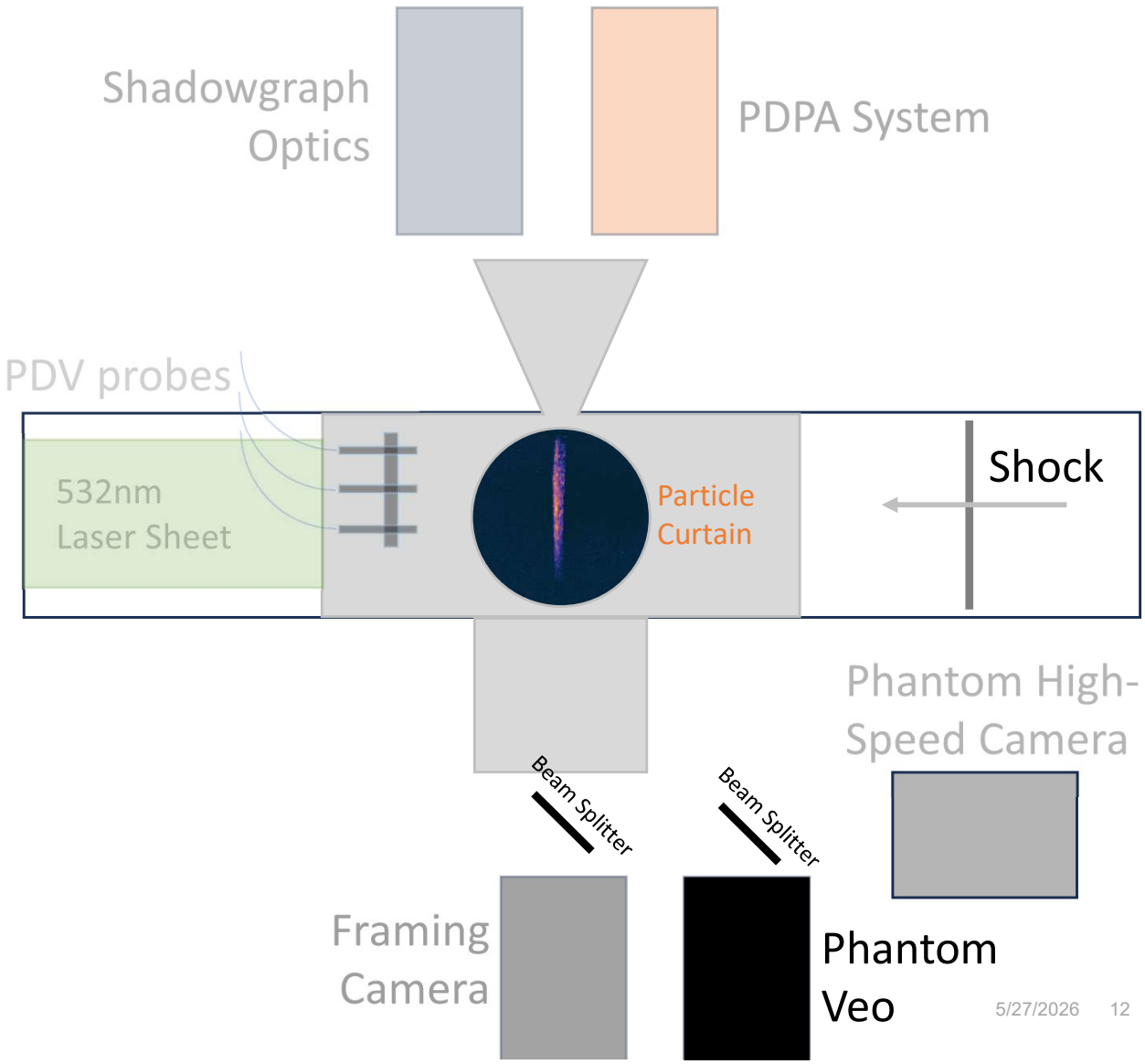

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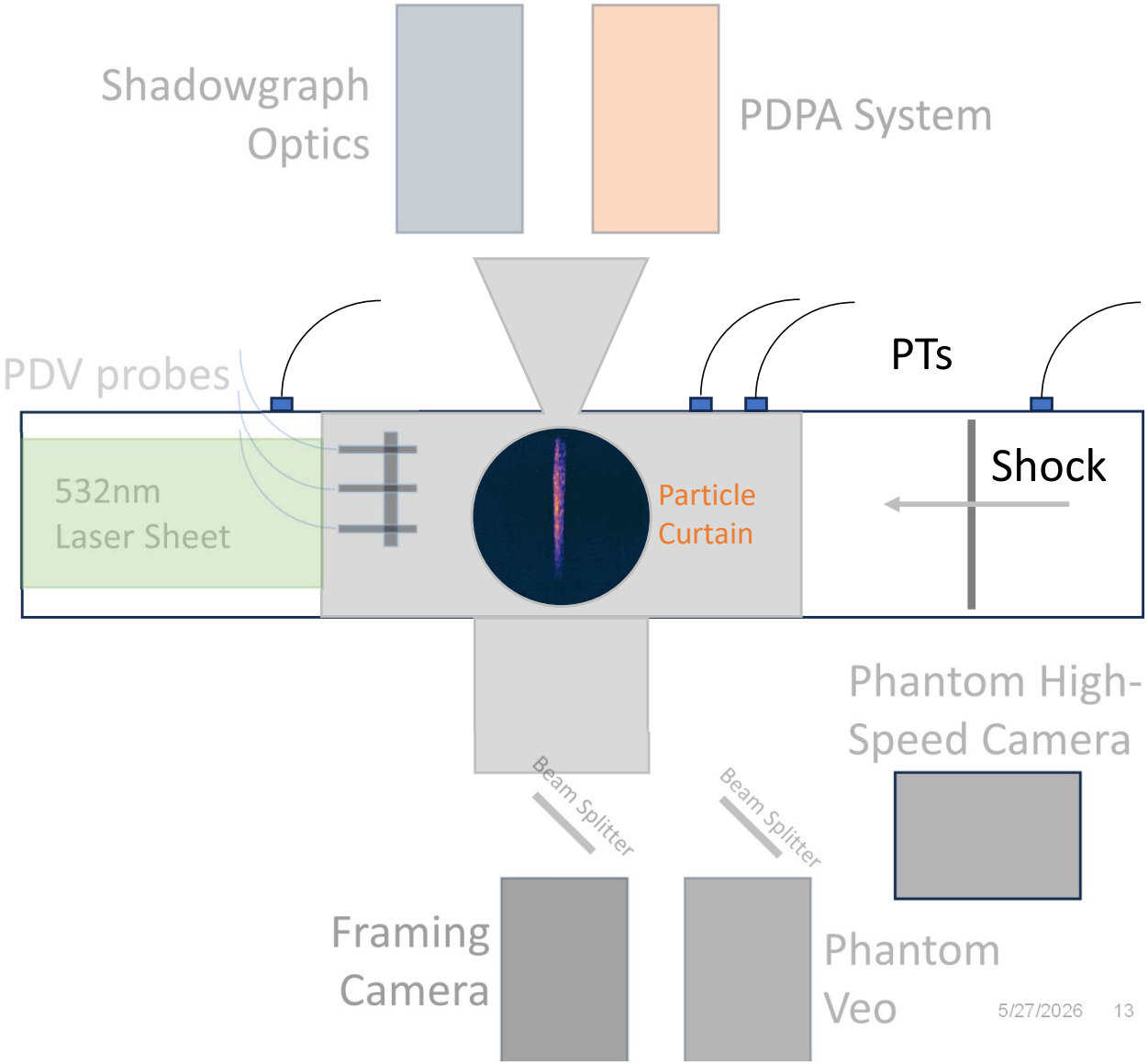
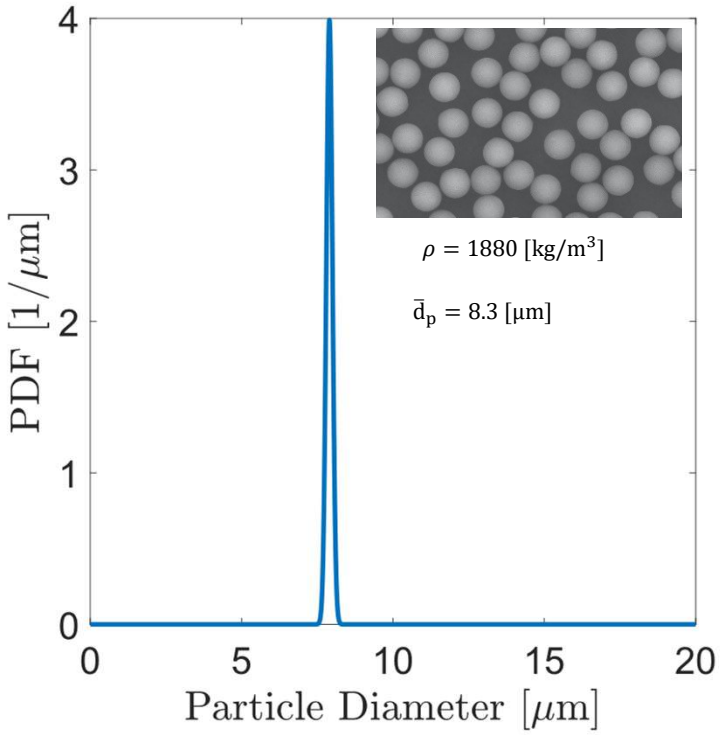
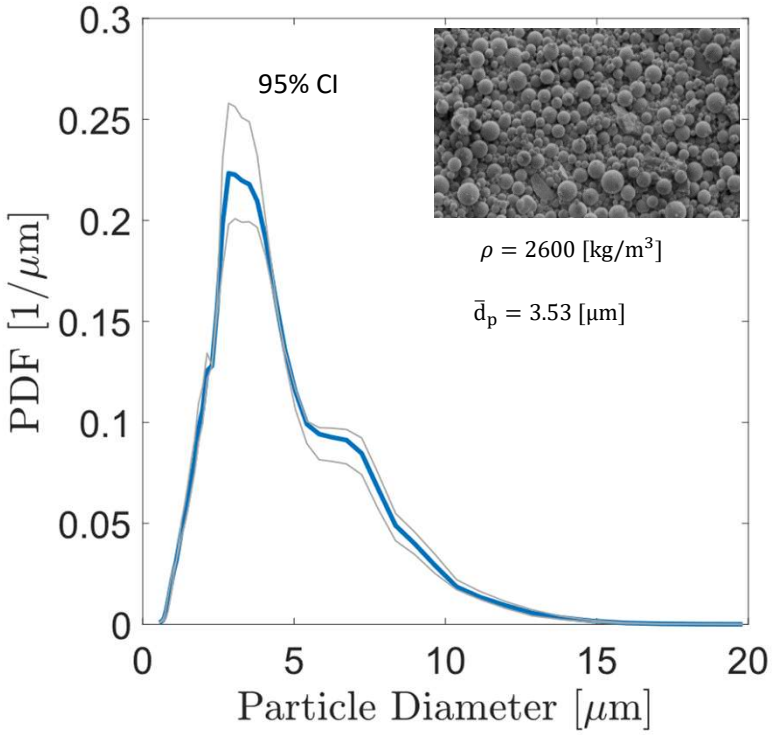


# Particle Curtain Material

**Monodisperse Particles**
(Plastic - PMMA)



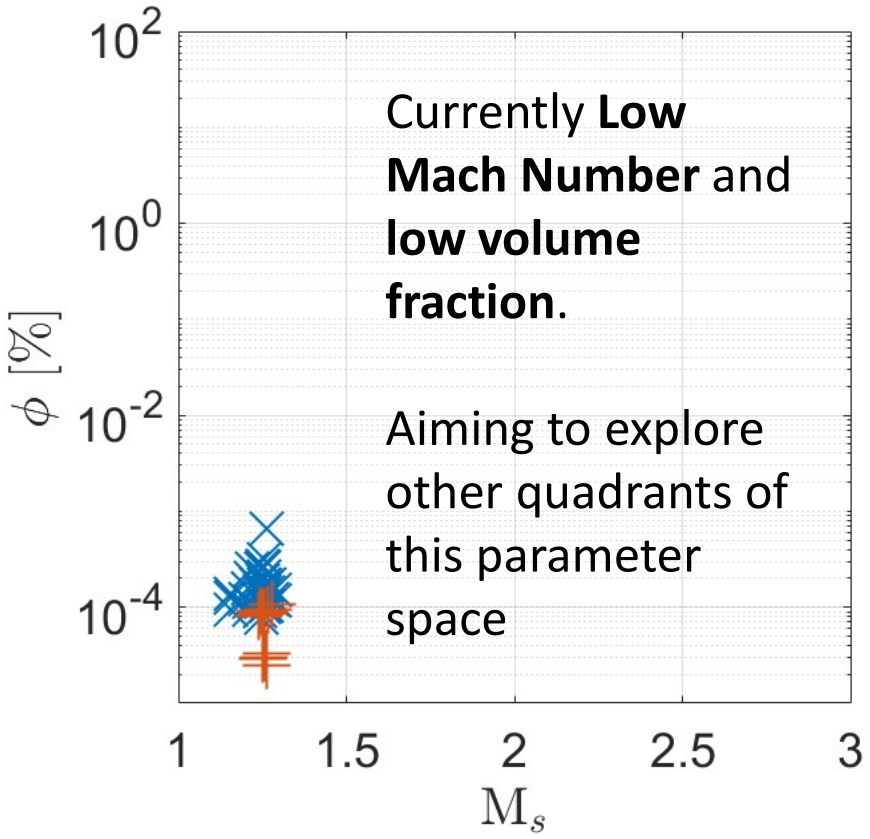

**Polydisperse Particles** (Glass - EMB10)



# Small Section of Parameter Space Currently Explored to Gain Confidence in Measurements

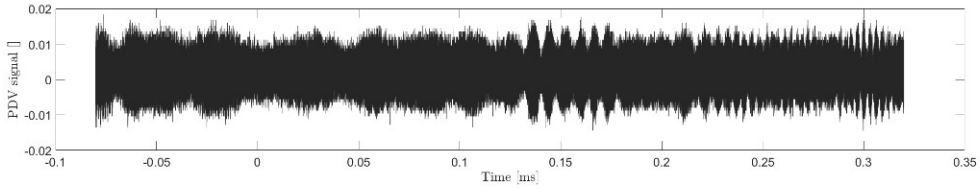
Monodisperse

Polydisperse

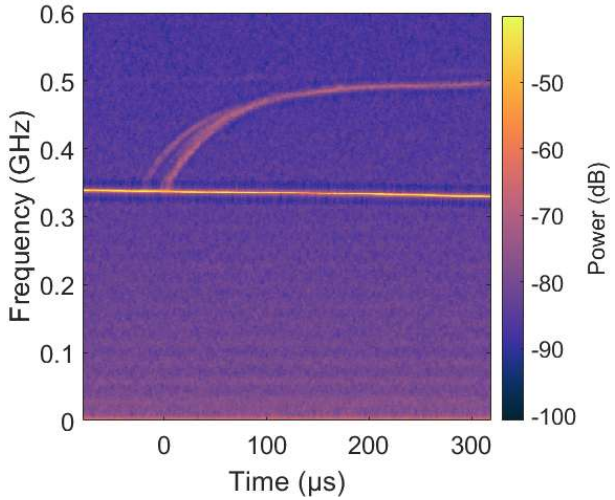


# Results

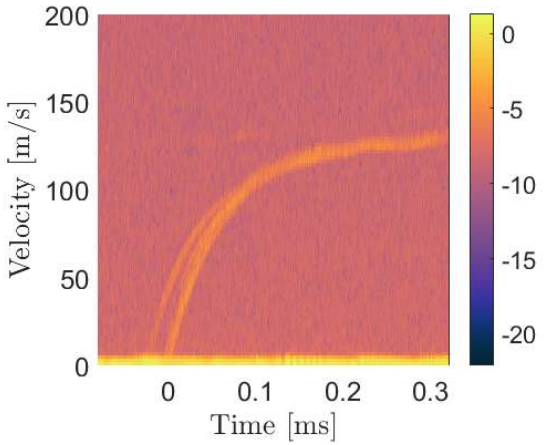
# PDV Measurement and analysis allowed extraction of curtain trajectories in the mono-disperse case



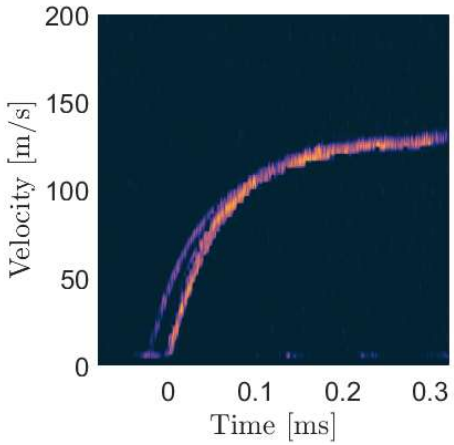

STFT




Coordinate transform to velocity accounting for slow drift




Signal extraction using KL divergence metric between noise and signal distributions

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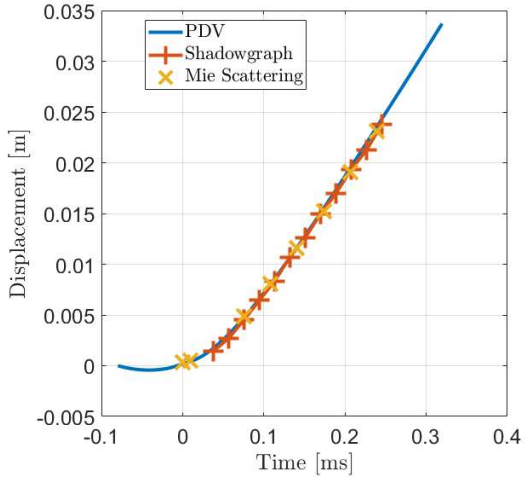
# PDV Measurement and analysis allowed extraction of curtain trajectories in the mono-disperse case




STFT




Velocity traces extracted and integrated. Particle trajectories validated with Mie scattering and shadowgraphy

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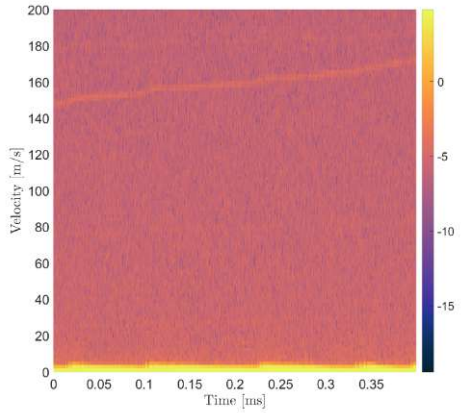
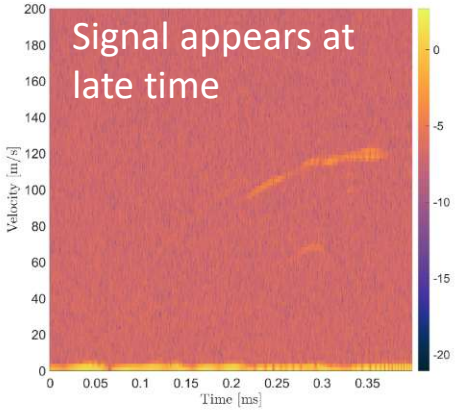
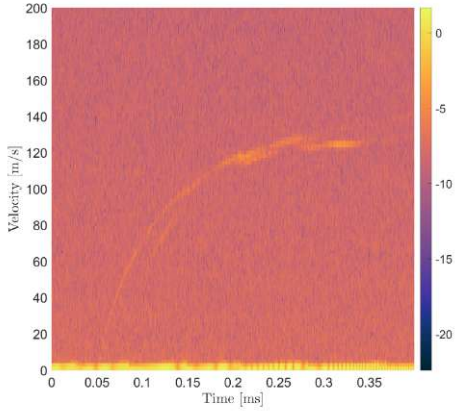
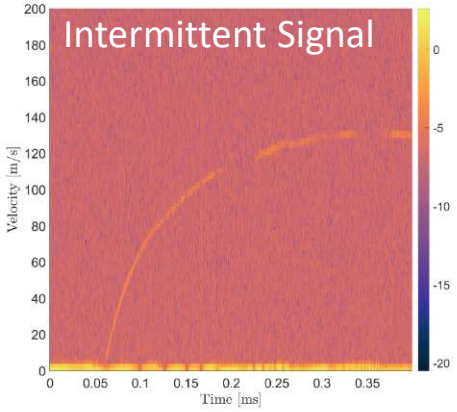
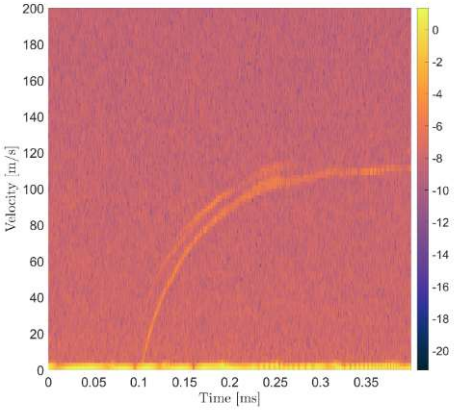
# PDV Measurements did show some interesting occurrences, any thoughts/suggestions welcome

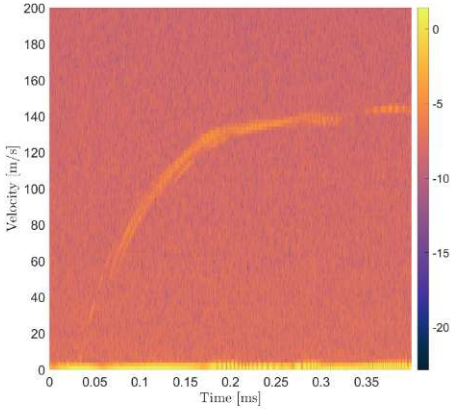


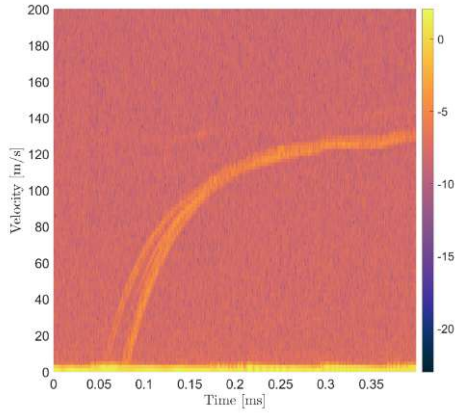



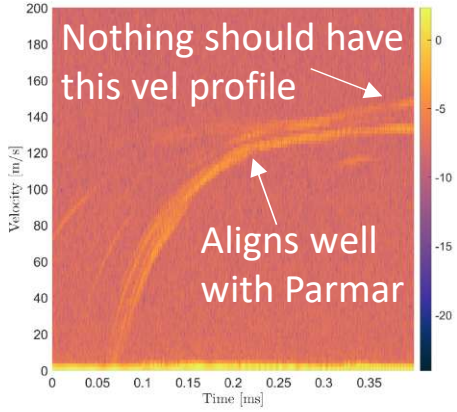



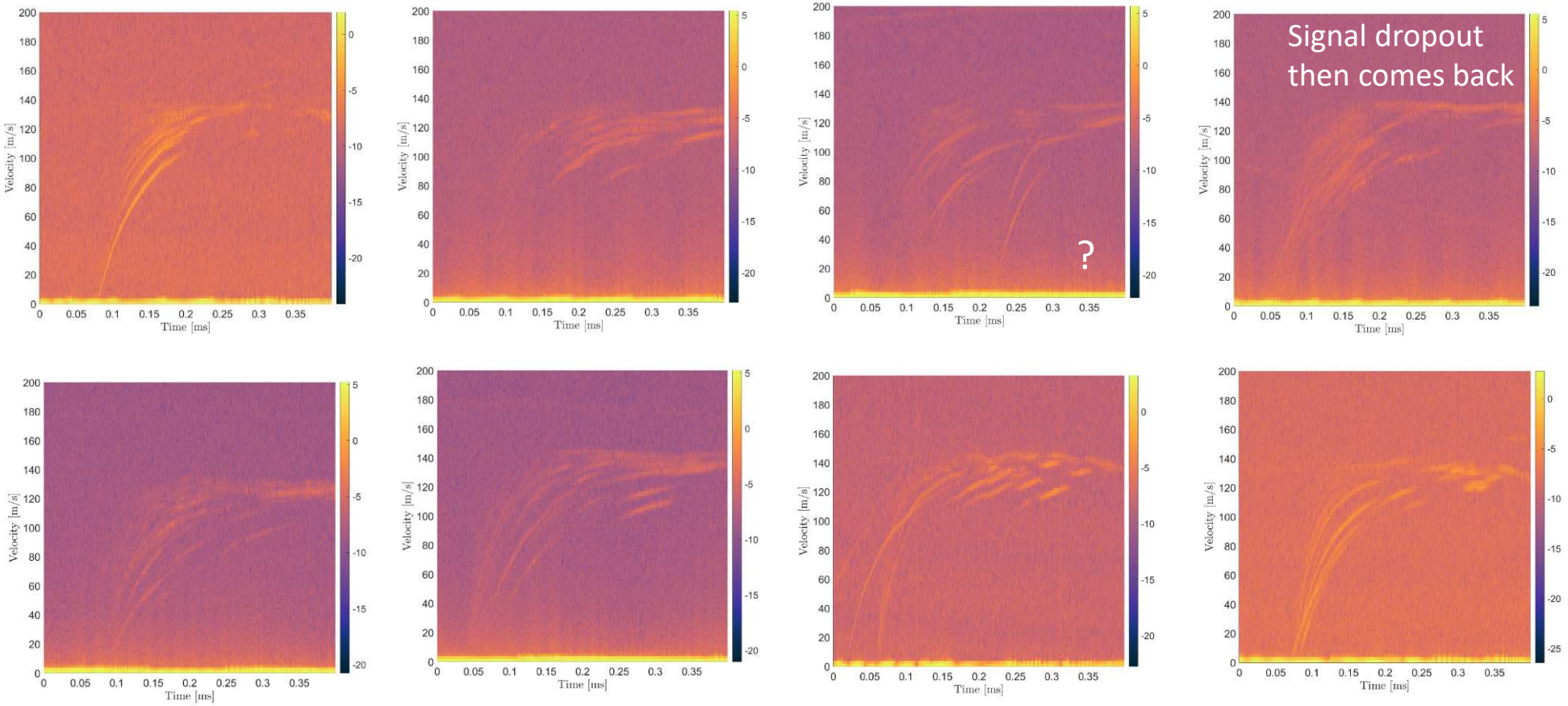



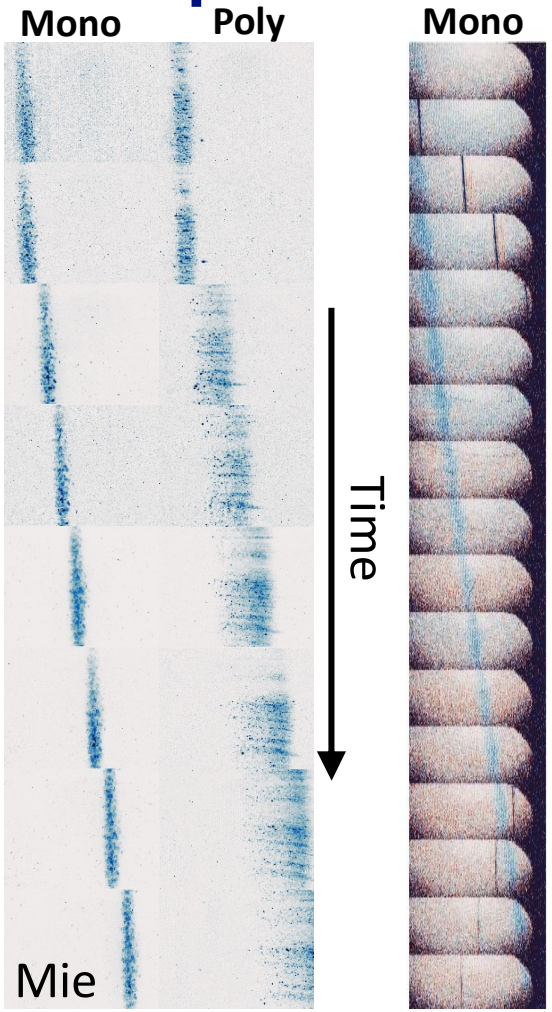

**Monodisperse Examples**

# PDV Measurements did show some interesting occurrences, any thoughts/suggestions welcome




**Polydisperse Examples**

# Example results

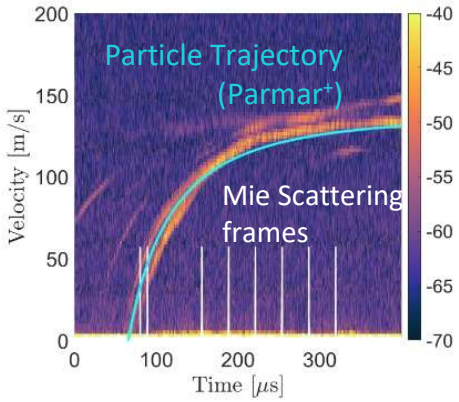


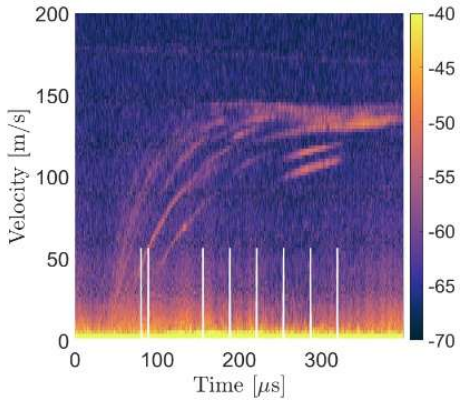

+ Parmar, M., et. al. *Shock Waves* **19**, 317–329 (2009)

## Monodisperse Particles (PMMA)

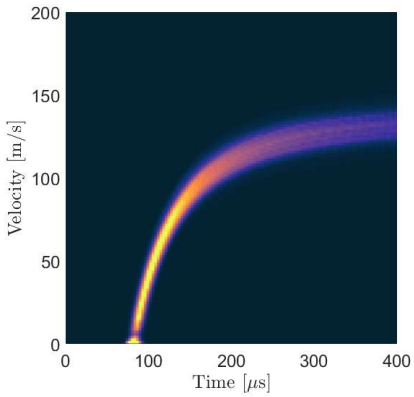
## Polydisperse Particles (EMB10)

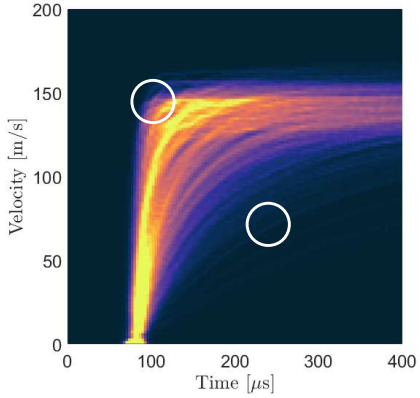
**PDV Spectrogram**




**MC – sampled PDF of particle trajectories (Parmar)**




Not seeing the fastest and slowest particles

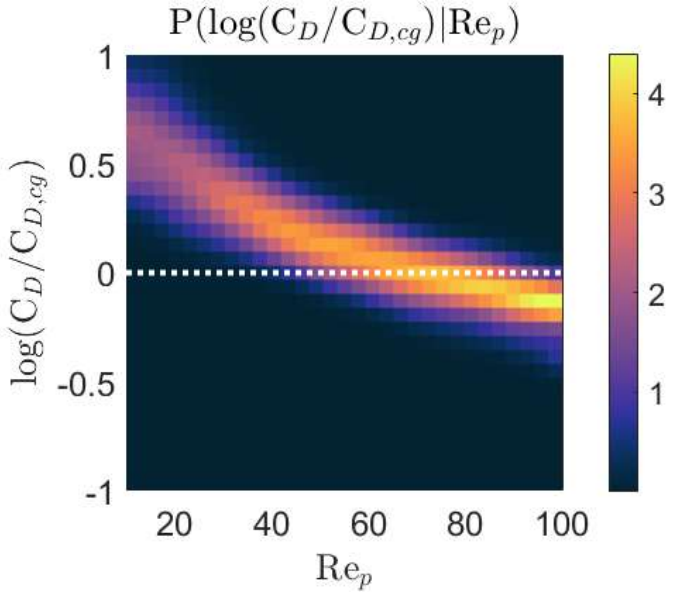
## With Confidence in Particle Trajectory Measurements, Particle Drag Can Be Estimated.

$C_{D,cg}$ - Clift Gauvin quasi-steady drag

Drag $$C_D = \frac{F}{\frac{1}{2}\rho V^2 A}$$

Empirical Drag $$C_D = \frac{4}{3}\frac{\rho_p}{\rho_g} d_p \frac{\ddot{x}_p}{\left(u_g - \dot{x}_p\right)^2}$$

Reynolds Number $$Re_p = \frac{\rho_g \, d_p \left|u_g - \dot{x}_p\right|}{\mu_g}$$




Measured drag is consistent with previous single particle drag measurements that deviate from standard drag predictions.

Note: at these shock strengths, initial particle velocity deposited after shock passage is negligible.

# Summary

## Current Work

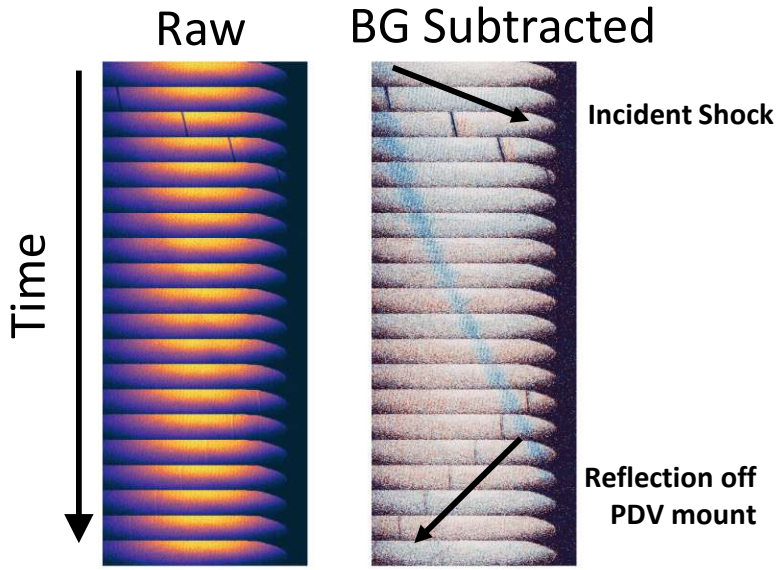
- The LANL HST has been modified to generate particle curtains to act as a test bed for diagnostic validation and development
- Initial low volume fraction curtains have been generated
- PDV measurements have been performed and simultaneous planar Mie scattering and Shadowgraphy validate measurements in the monodisperse case

## Future Work

- A method of generating higher volume fraction curtains is being tested
- Work towards implementation and testing of multi-wavelength PDV for inference of particle cloud properties has begun

# END

# Estimating Volume Fraction (low volume fraction cases)




**Mie Theory**

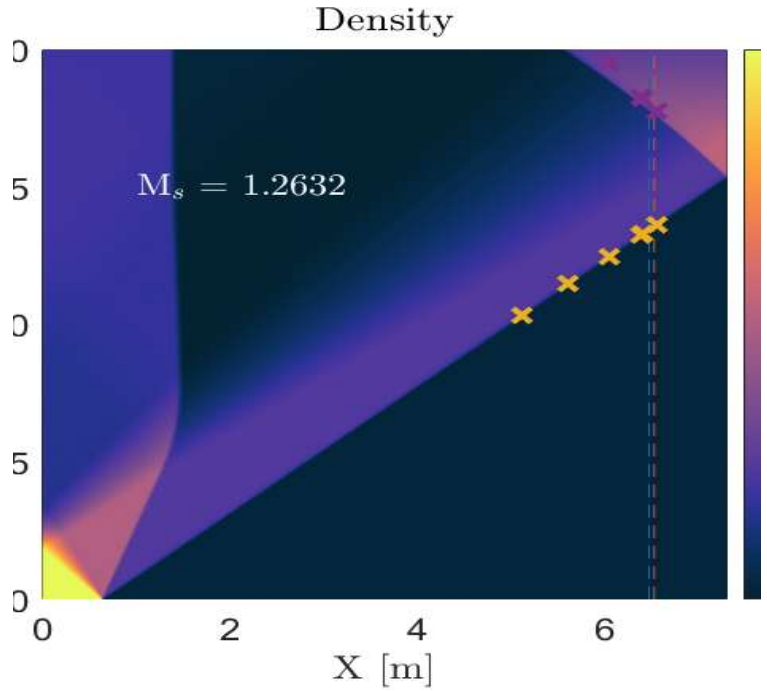
$I$ - Background subtracted signal
$I_0$ - Background signal
$\boldsymbol{\rho}$ **– Number density**
$\sigma_{sca}$ - scattering cross-section
$x$ – Distance light travelled through medium

$$\frac{I}{I_0} = \exp(-\boldsymbol{\rho}\sigma_{sca}x)$$

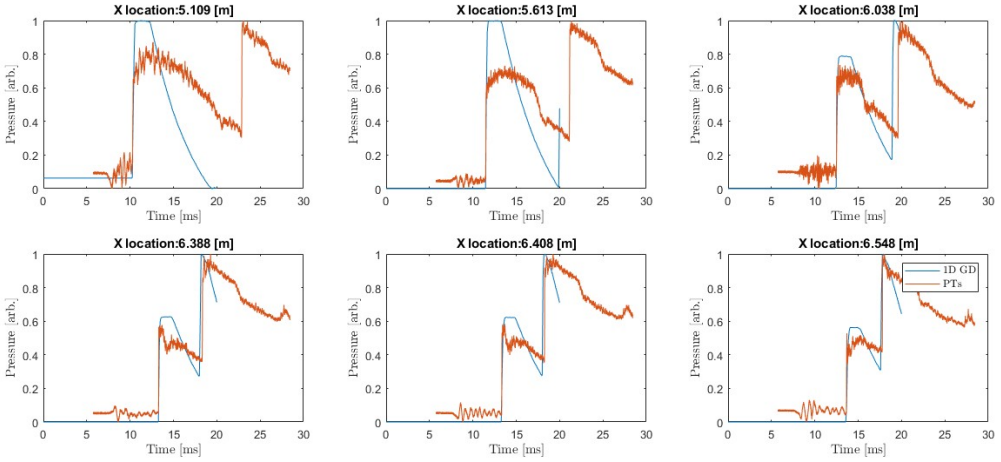
# Estimating Bulk Gas State (allows confidence in estimate of gas velocity the curtain experiences)

1D GD Simulation
PT measurements

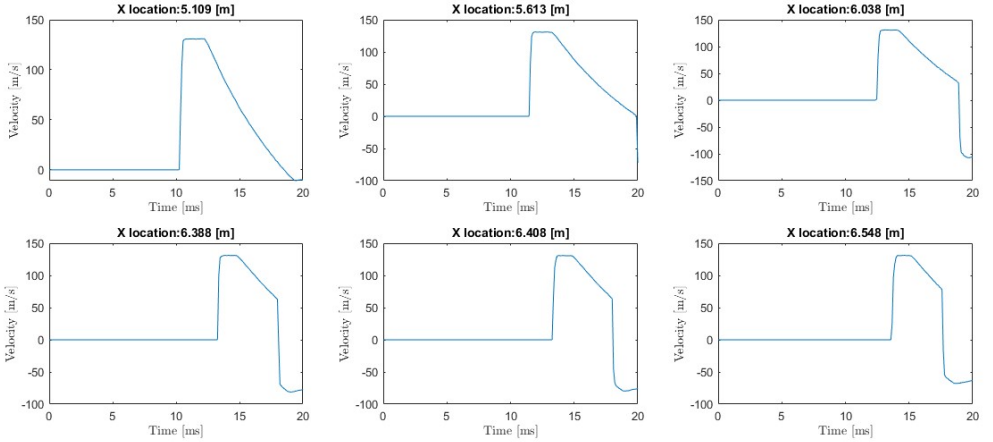
Estimate wavespeeds from PT measurements.




**Pressure traces at PT locations**




**Bulk velocity at PT locations**

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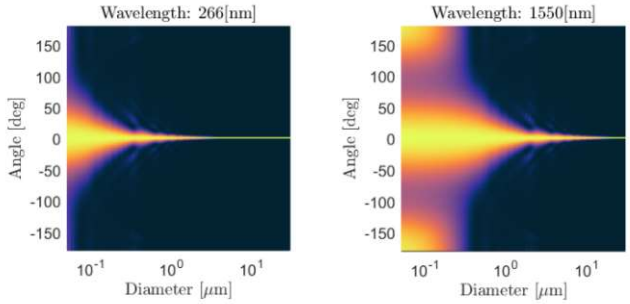
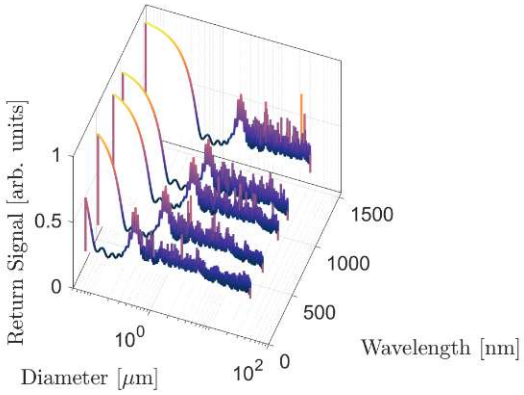
# Potential Multi-Wavelength Methodology

# PDV Probes Using Different Wavelengths Might Enable Inference of Particle Cloud Properties

Mie Theory




Return Signal (±180°)

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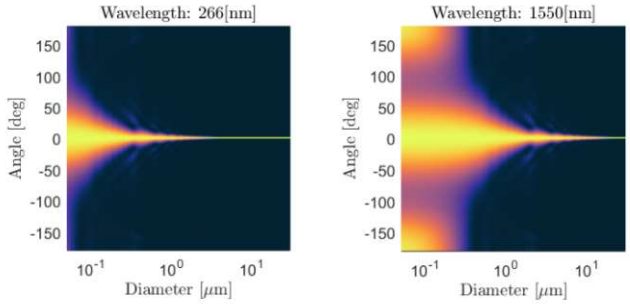
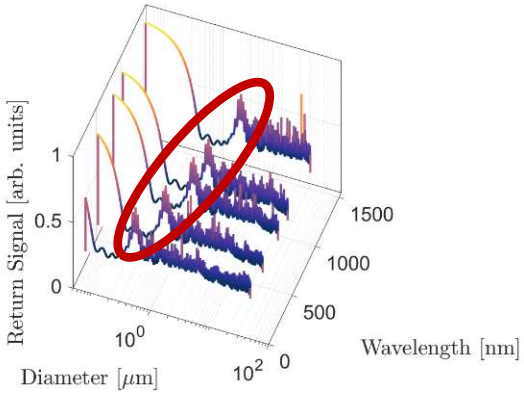



Return Signal (±180°)

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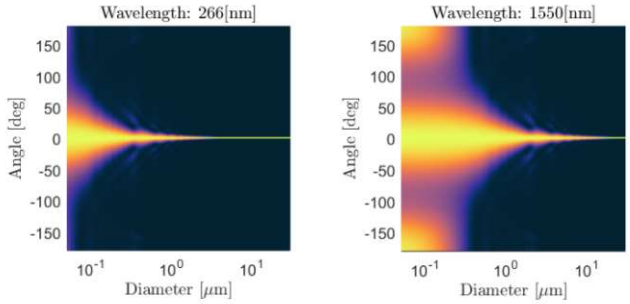
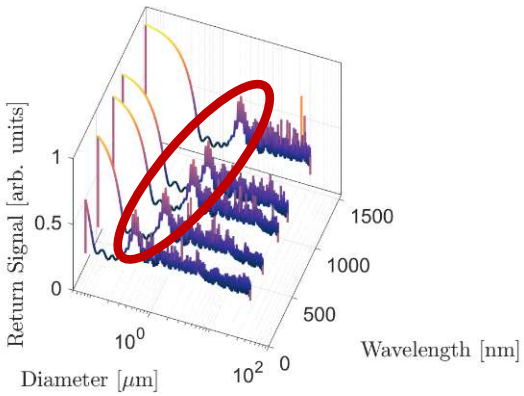
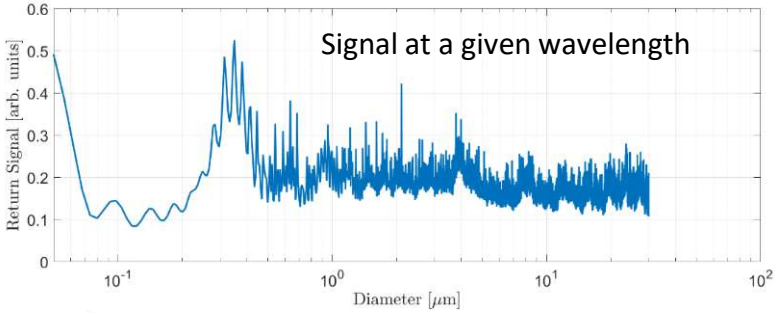
# PDV Probes Using Different Wavelengths Might Enable Inference of Particle Cloud Properties

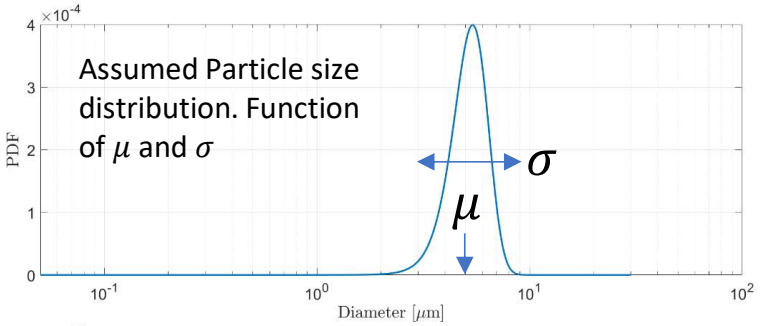
Mie Theory

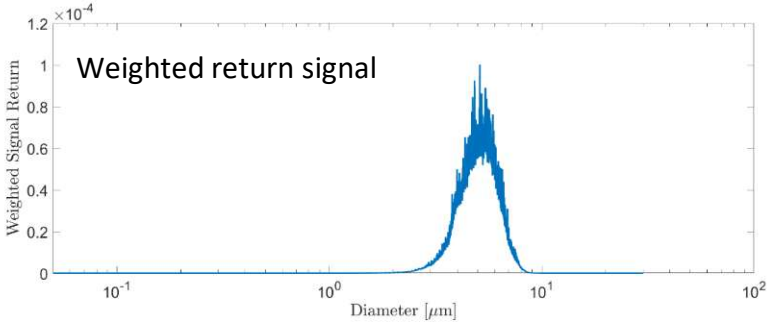



Return Signal (±180°)

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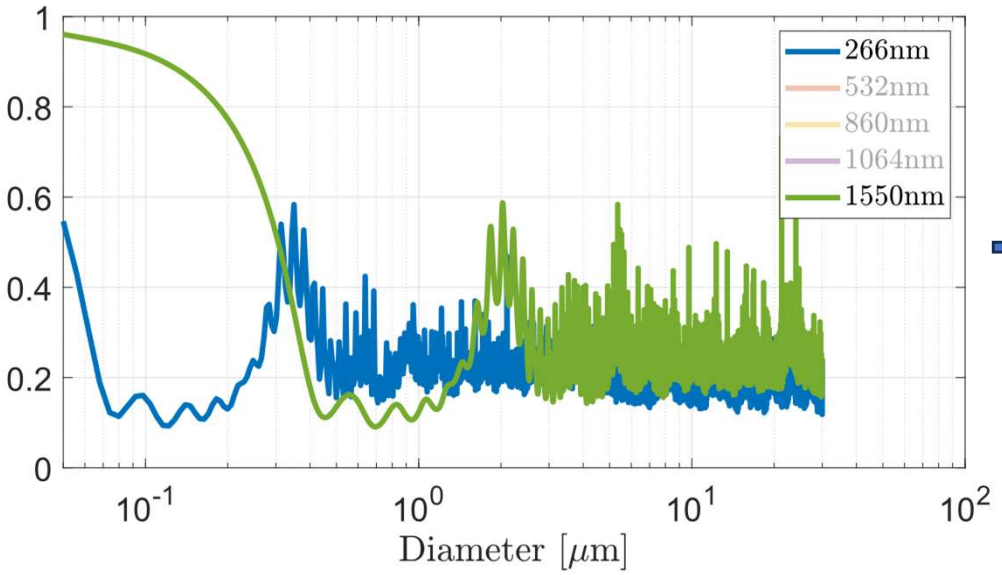
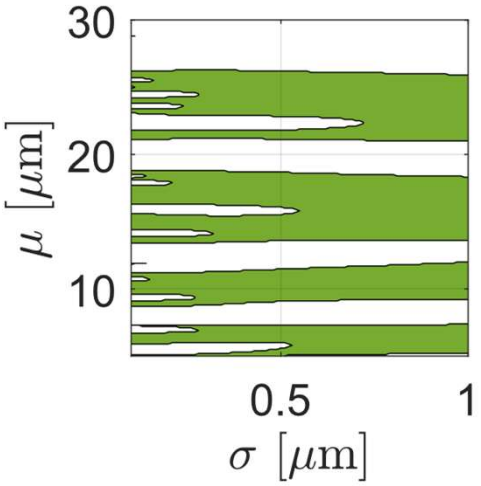
# PDV Probes Using Different Wavelengths Might Enable Inference of Particle Cloud Properties



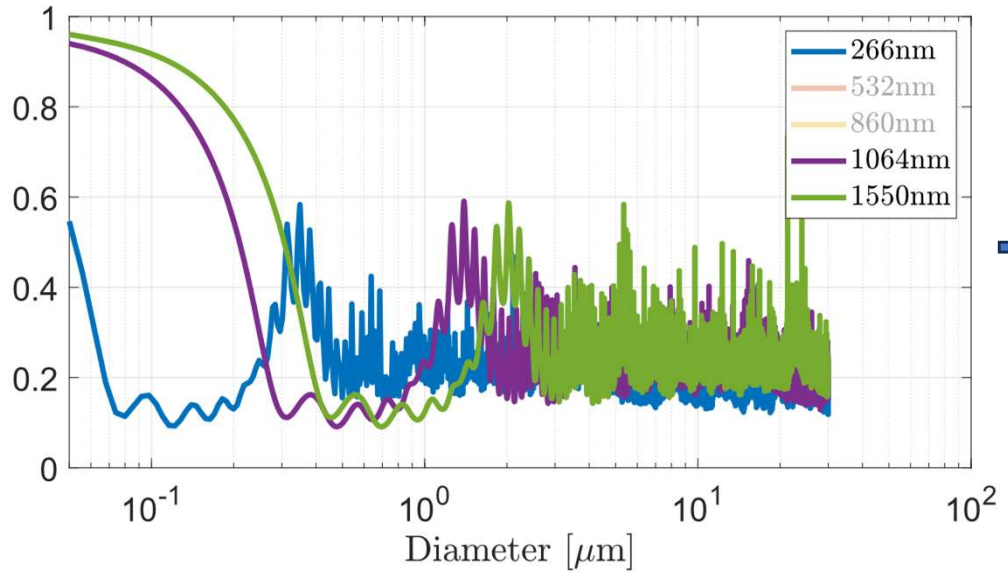

Particle size distribution parameter space



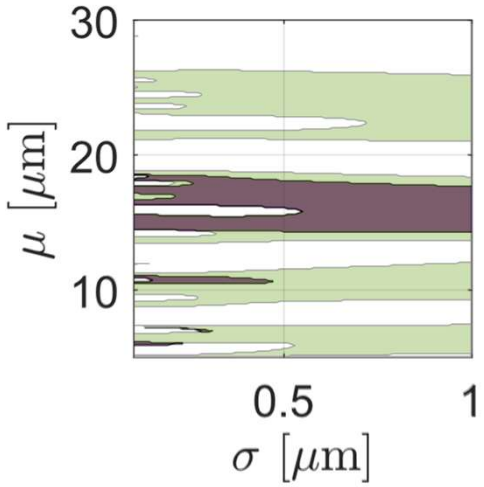

Parameters consistent with measured signals at different wavelengths

Two probes with two different wavelengths don't strongly constrain the particle size distribution

# PDV Probes Using Different Wavelengths Might Enable Inference of Particle Cloud Properties



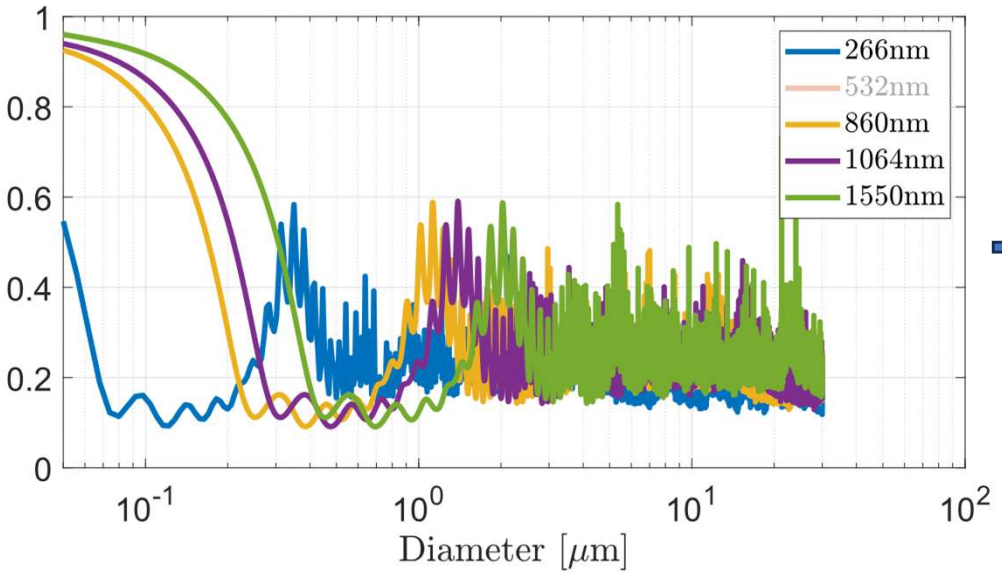

Particle size distribution parameter space



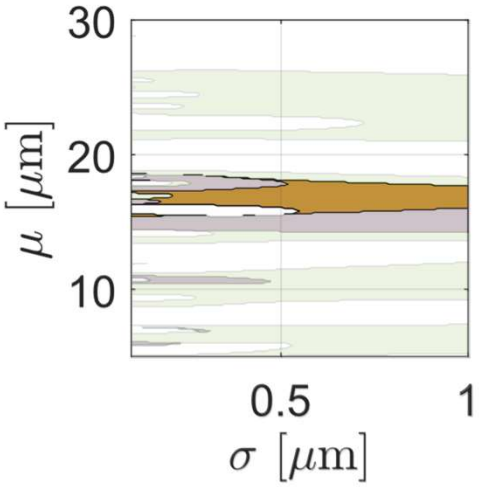

Parameters consistent with measured signals at different wavelengths

Adding more probes with more wavelengths further constrains the particle size distribution

# PDV Probes Using Different Wavelengths Might Enable Inference of Particle Cloud Properties




Particle size distribution parameter space




Parameters consistent with measured signals at different wavelengths

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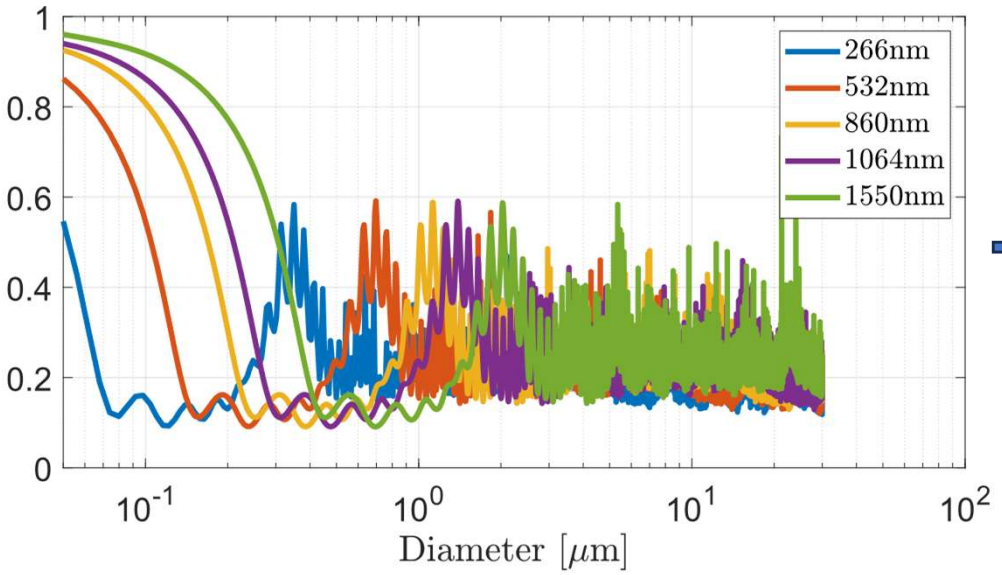
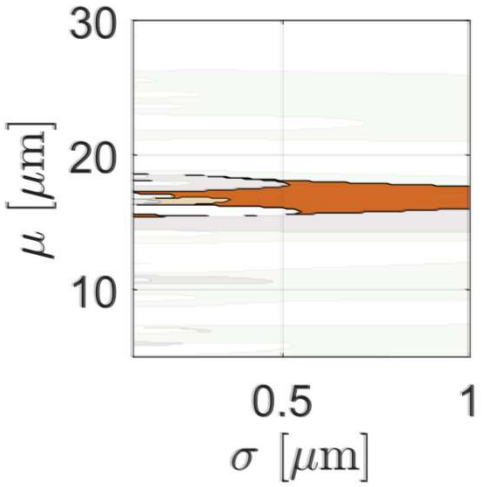
# PDV Probes Using Different Wavelengths Might Enable Inference of Particle Cloud Properties




Particle size distribution parameter space




Parameters consistent with measured signals at different wavelengths

Adding more probes with more wavelengths further constrains the particle size distribution