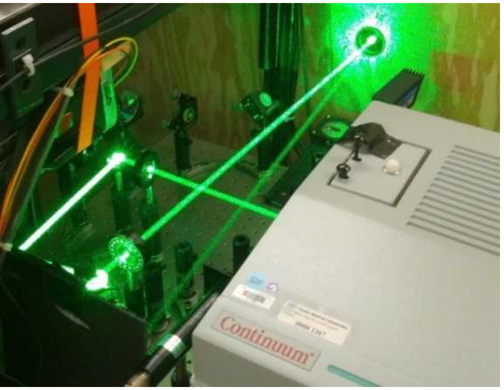
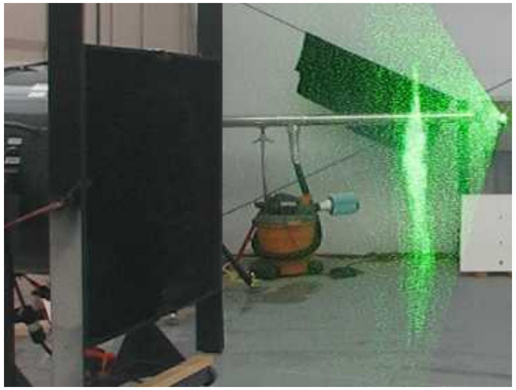
SAND2015-2953PE

Exceptional service in the national interest

Sandia National Laboratories





Overview of the Sandia Wake Imaging System

Wind Energy Technologies: Tommy Herges, David Maniaci, Brian Naughton
Laser Optics and Remote Sensing: Randy Schmitt, Mark Johnson
Optics and Sensor Engineering: David Bossert
Contraband Detection: Crystal Glen

Funded by DOE Wind and Water Power Technologies Office

4/15/2014

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

Outline

- Project Purpose and Objectives
- Velocity Diagnostic Implemented
- Simulation of SWIS Deployed at SWiFT facility
- Preliminary Field Test (Sprung Test)
  - Velocity Image Results
  - Noise Equivalent Velocity
- Implications for Deployment at SWiFT facility

Purpose & Objectives

Sandia Wake Imaging System (SWIS) Purpose: Capture instantaneous velocity images to resolve coherent turbulent structures in the wind turbine inflow and wake region

SWIS Impact:

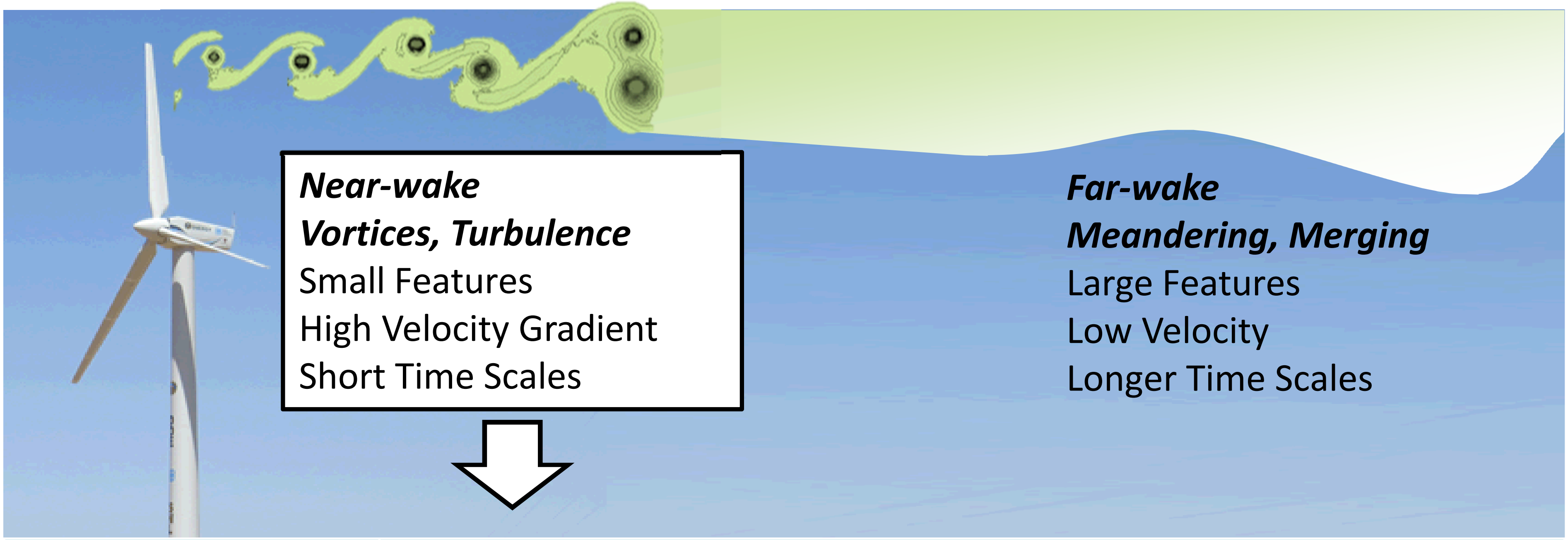
- Enable the validation of research codes and design tools used to optimize wind plant performance
- Complement existing measurement capabilities such as lidar and radar

Project Achievements:

- Implement Doppler Global Velocimetry (DGV) over large field of view
- Demonstrate successful velocity image measurement of surrogate flow field
- Developed SWIS modeling tool from calibrated radiometric model for system optimization and experimental planning at SWiFT facility

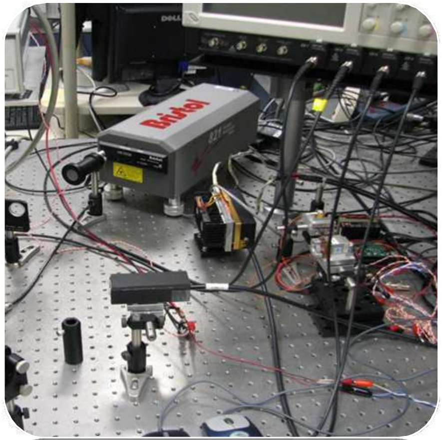
Velocity Diagnostic Selection

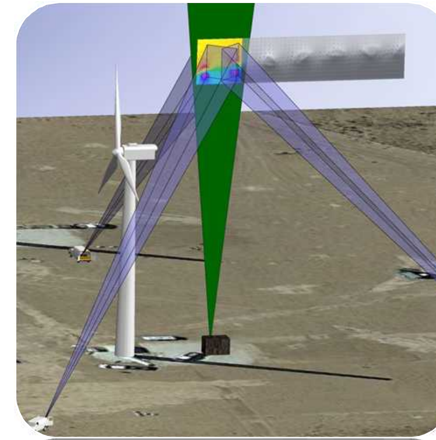
Sandia National Laboratories



Existing Systems	Challenges in Near-wake field testing
Particle Image Velocimetry (PIV)	**Small field of view** since individual particles need to be resolved by imaging device: • Requires extremely large tracer particles • Impractically short working distances
Scanning LIDAR	**Time and space resolution** of scanning point measurements is insufficient to capture coherent tip-vortex structures at SWiFT

Project Development





Lab

- Laser
- Receiver
- Iodine Cell
- Image Processing
- 15 cm × 15 cm

Sprung

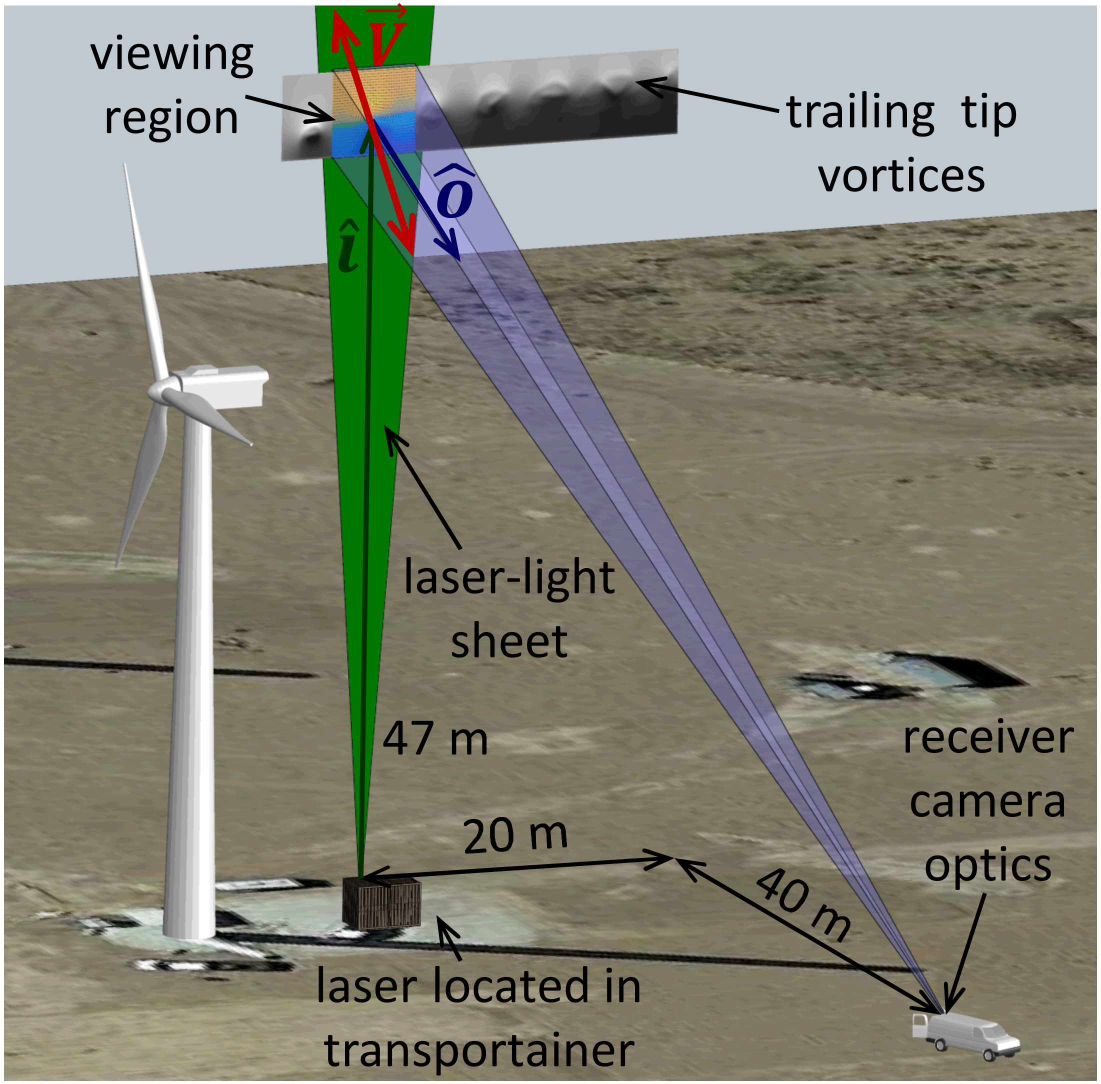
- Aerosol
- System Sensitivity
- Measurement Uncertainty
- 2 m × 2 m

SWiFT

- Outdoor Laser Use
- Field Deployable Aerosol System
- Additional Velocity Components
- 5 m × 5 m

- Sprung system sensitivity data calibrated radiometric model
- Provided capability to simulate experiments to improve validation and planning
- Currently finalizing safety procedures for outdoor laser operation
- Planned deployment of current system at SWiFT this summer to measure inflow

Notional SWIS Setup at SWiFT Facility

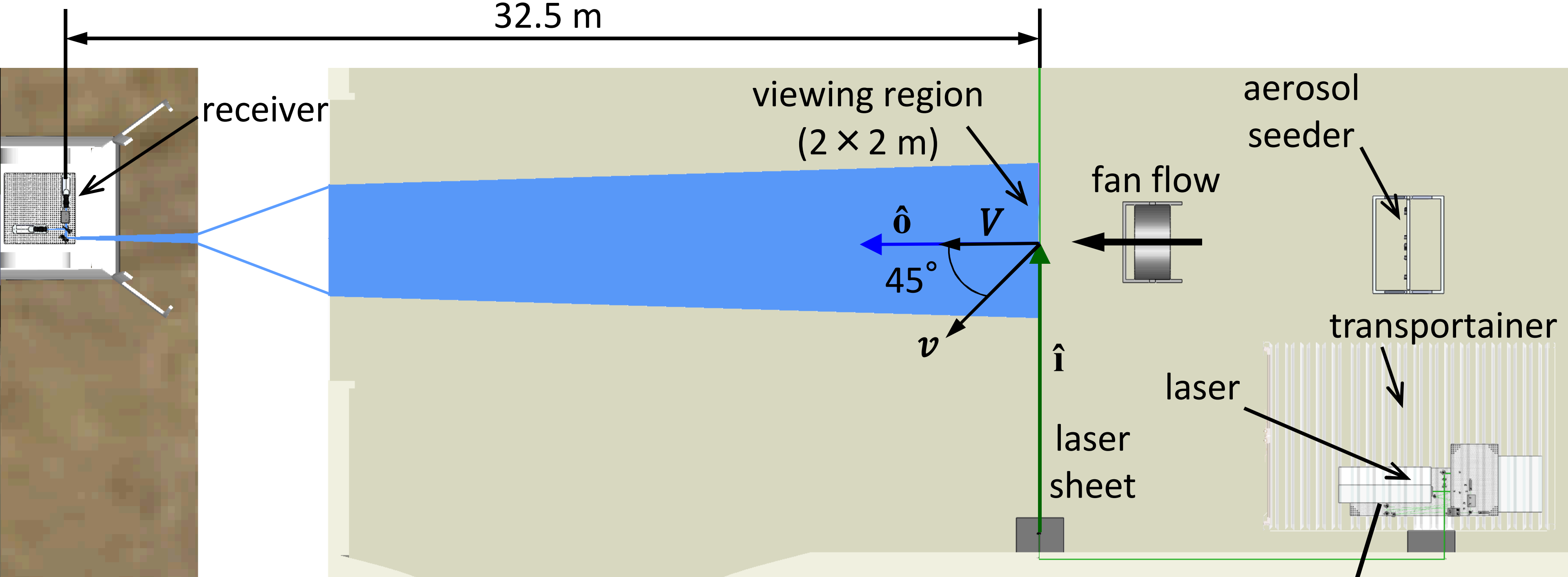


- Position of laser and camera dictates the measured velocity component
- Measure velocity component along bisector angle between observation and incident vectors, $(\hat{\boldsymbol{o}} - \hat{\boldsymbol{\imath}})$
- Additional velocity components measured with additional observation angles

Doppler frequency shift equation:

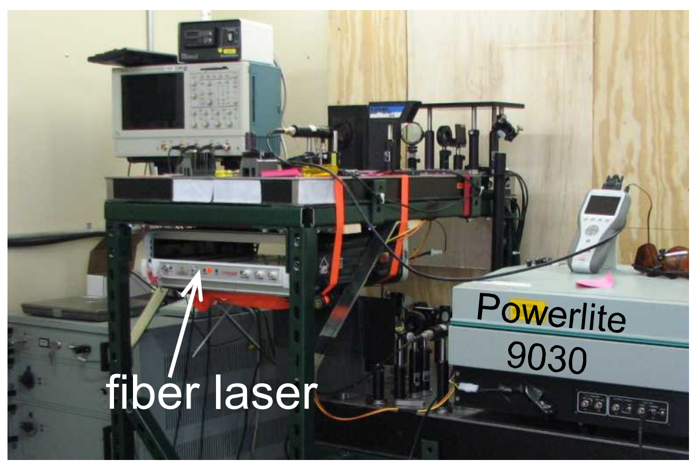
$$\Delta f_D = \frac{1}{\lambda}(\hat{\boldsymbol{o}} - \hat{\boldsymbol{\imath}}) \cdot \boldsymbol{V}$$

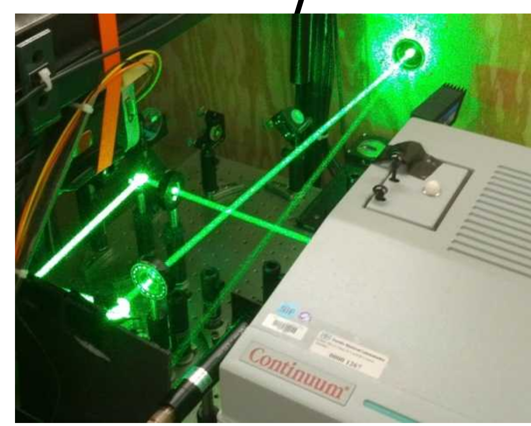
Doppler Global Velocimetry



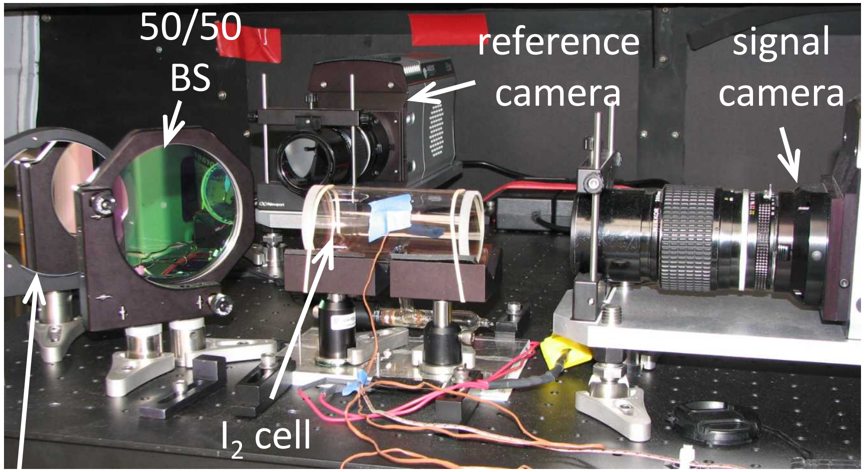
Doppler frequency shift equation:

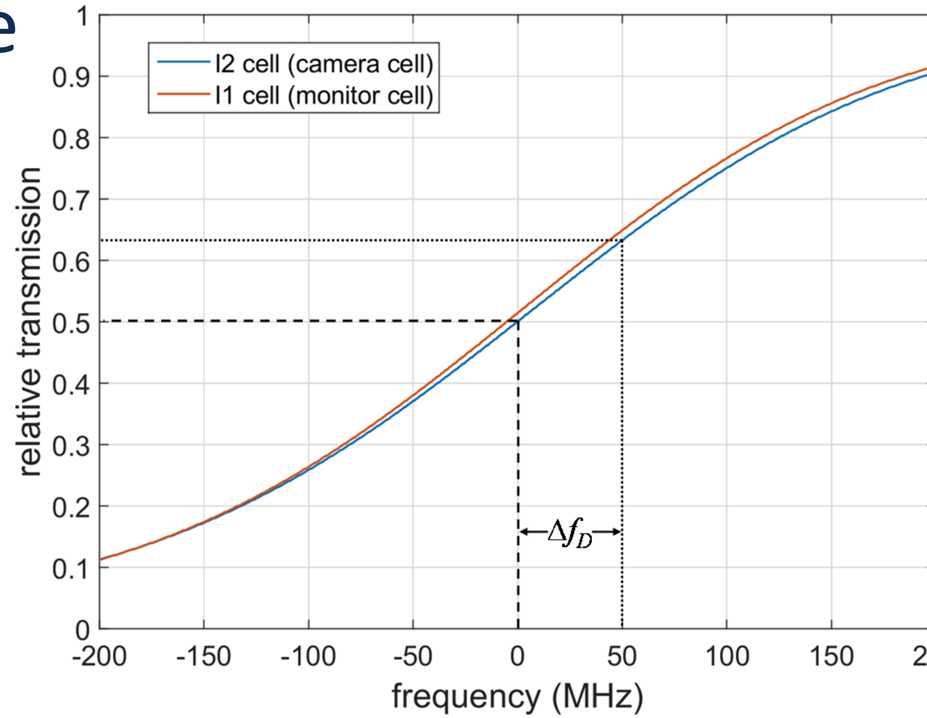
$$\Delta f_D = \frac{1}{\lambda}(\hat{\boldsymbol{o}} - \hat{\boldsymbol{\imath}}) \cdot \boldsymbol{V}$$

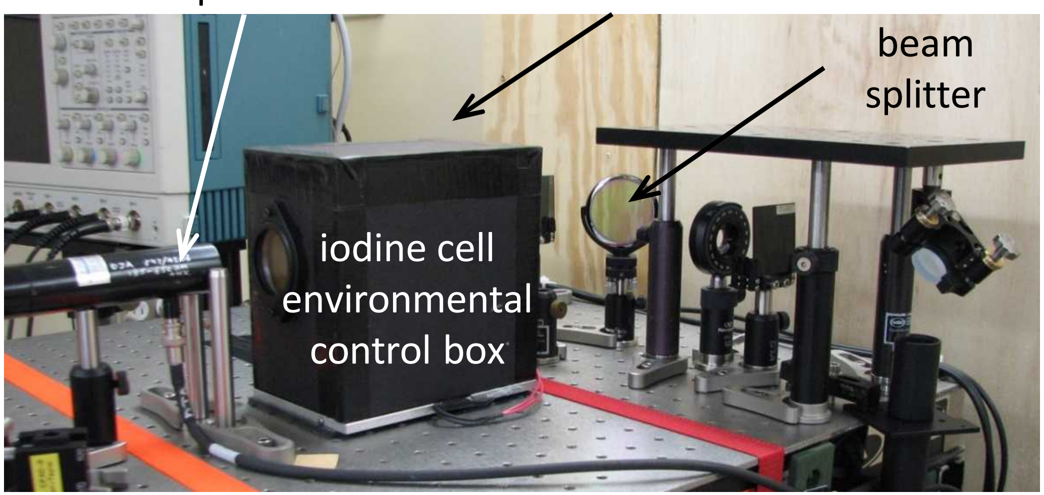


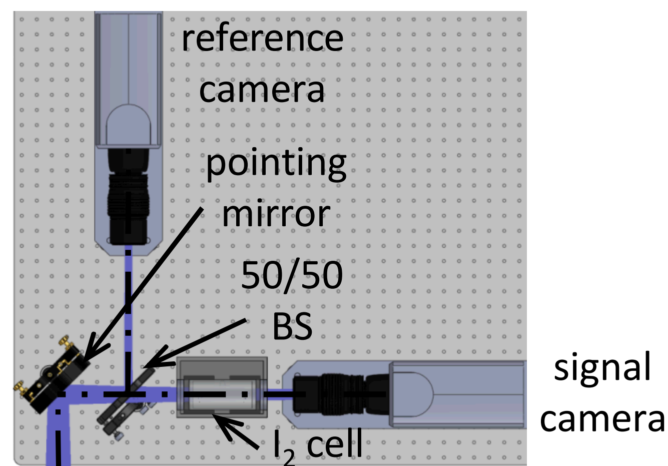


Iodine Absorption Profile Converts Frequency Shift into Intensity Change

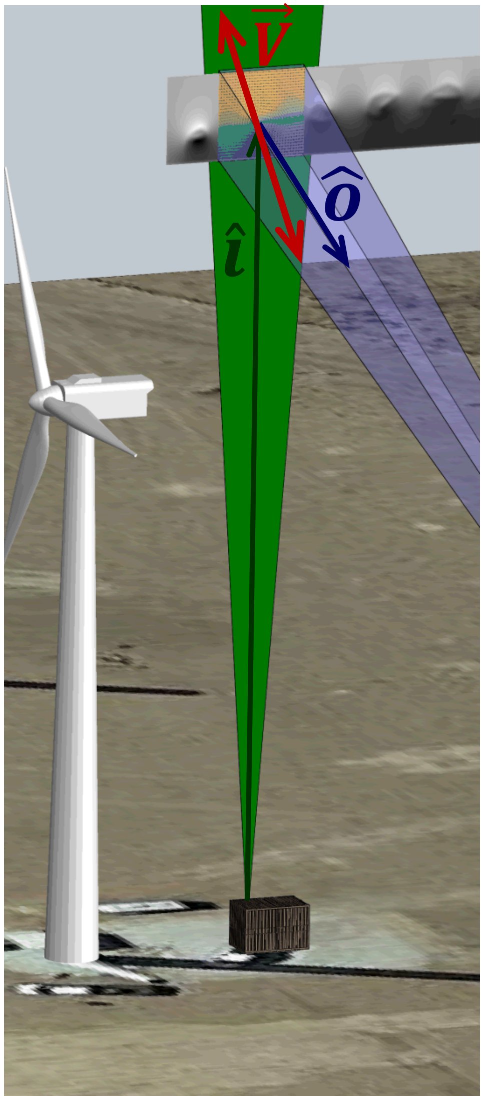


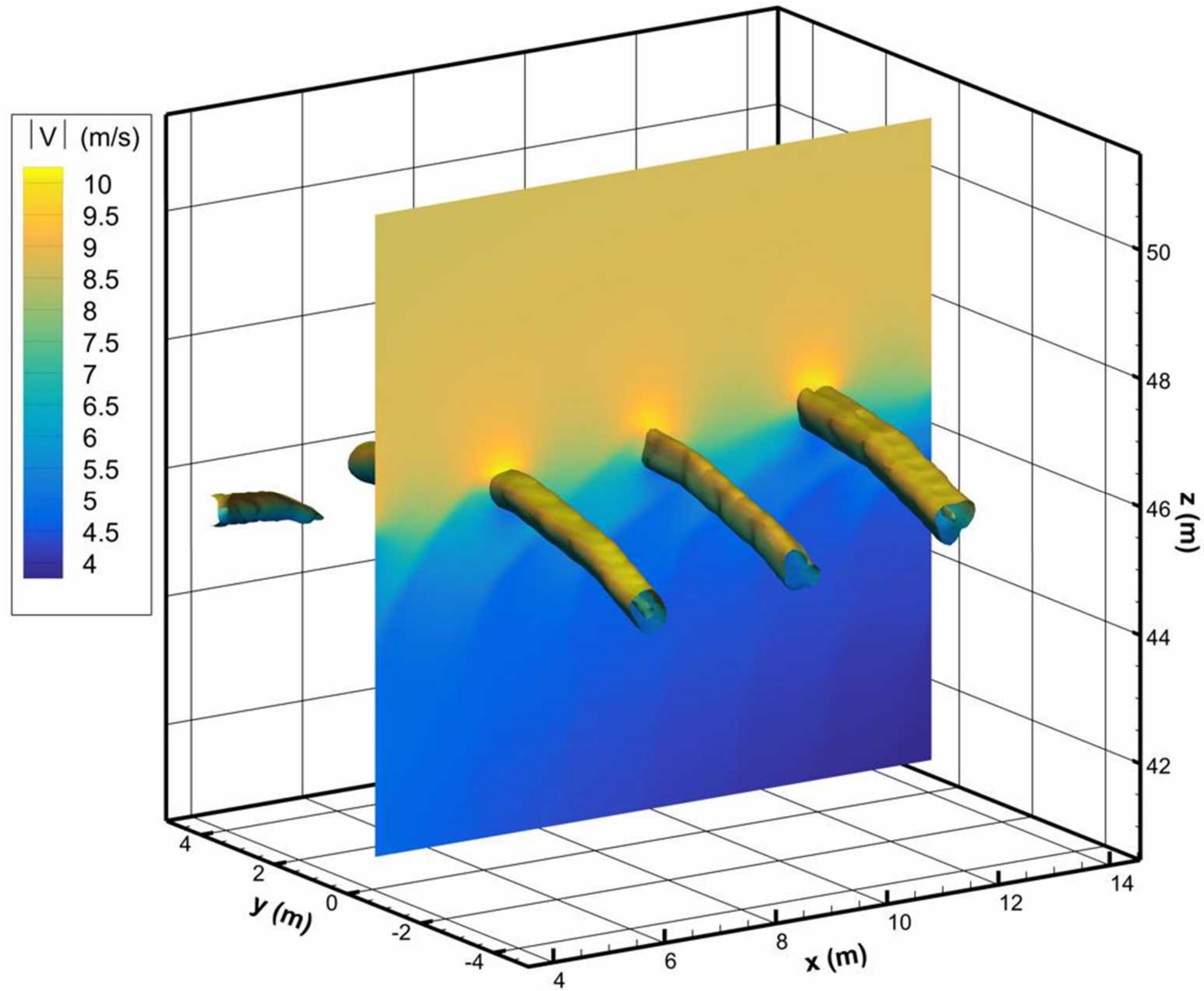






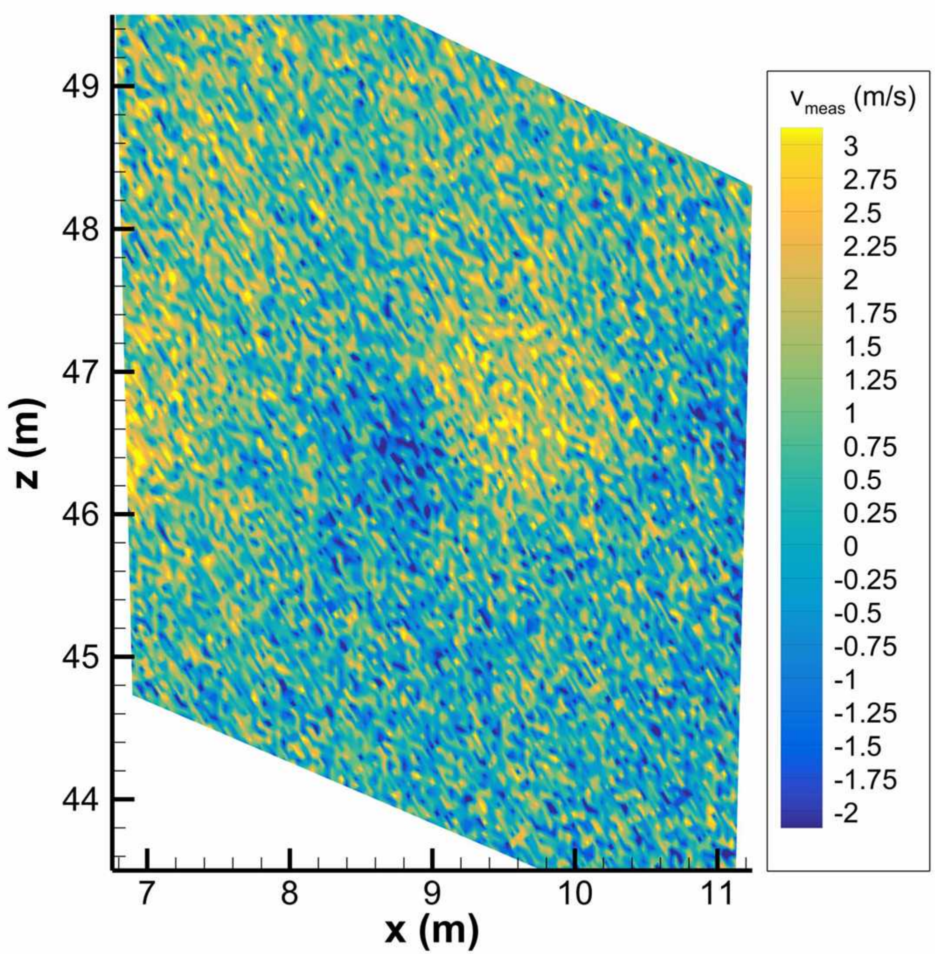
Simulated Measurements: Representative Flow



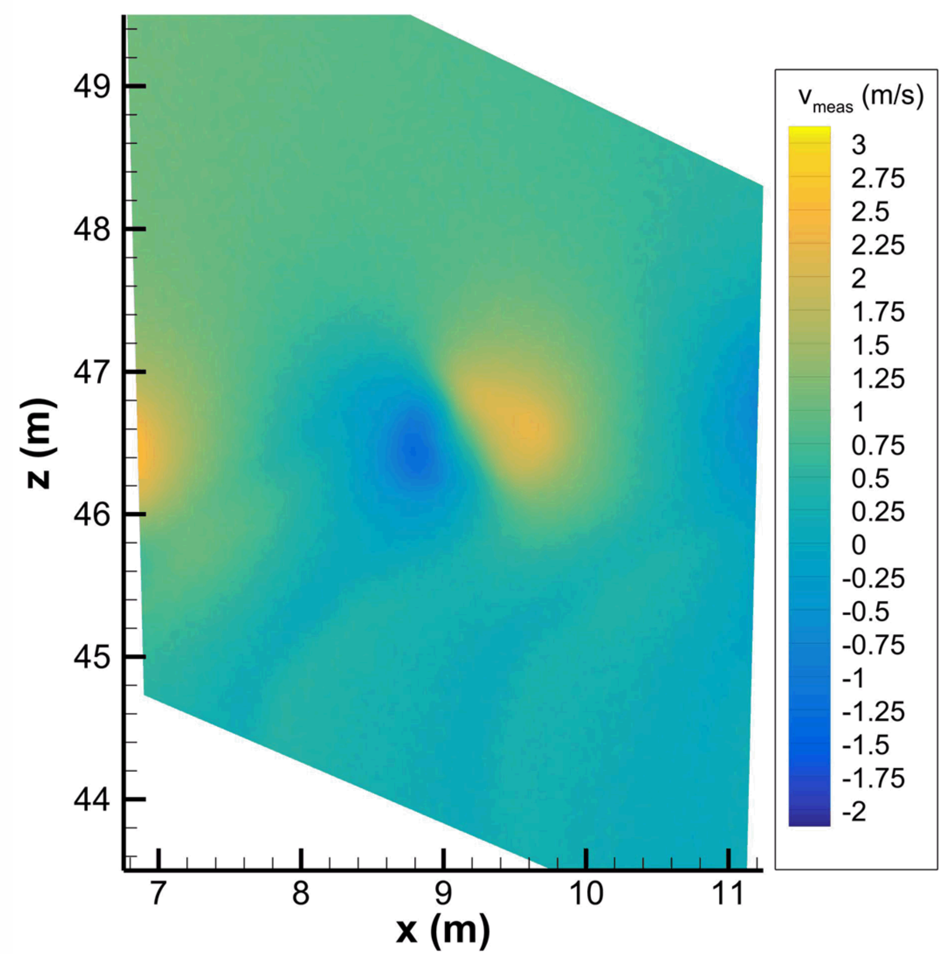


Simulated Measurements

Current System

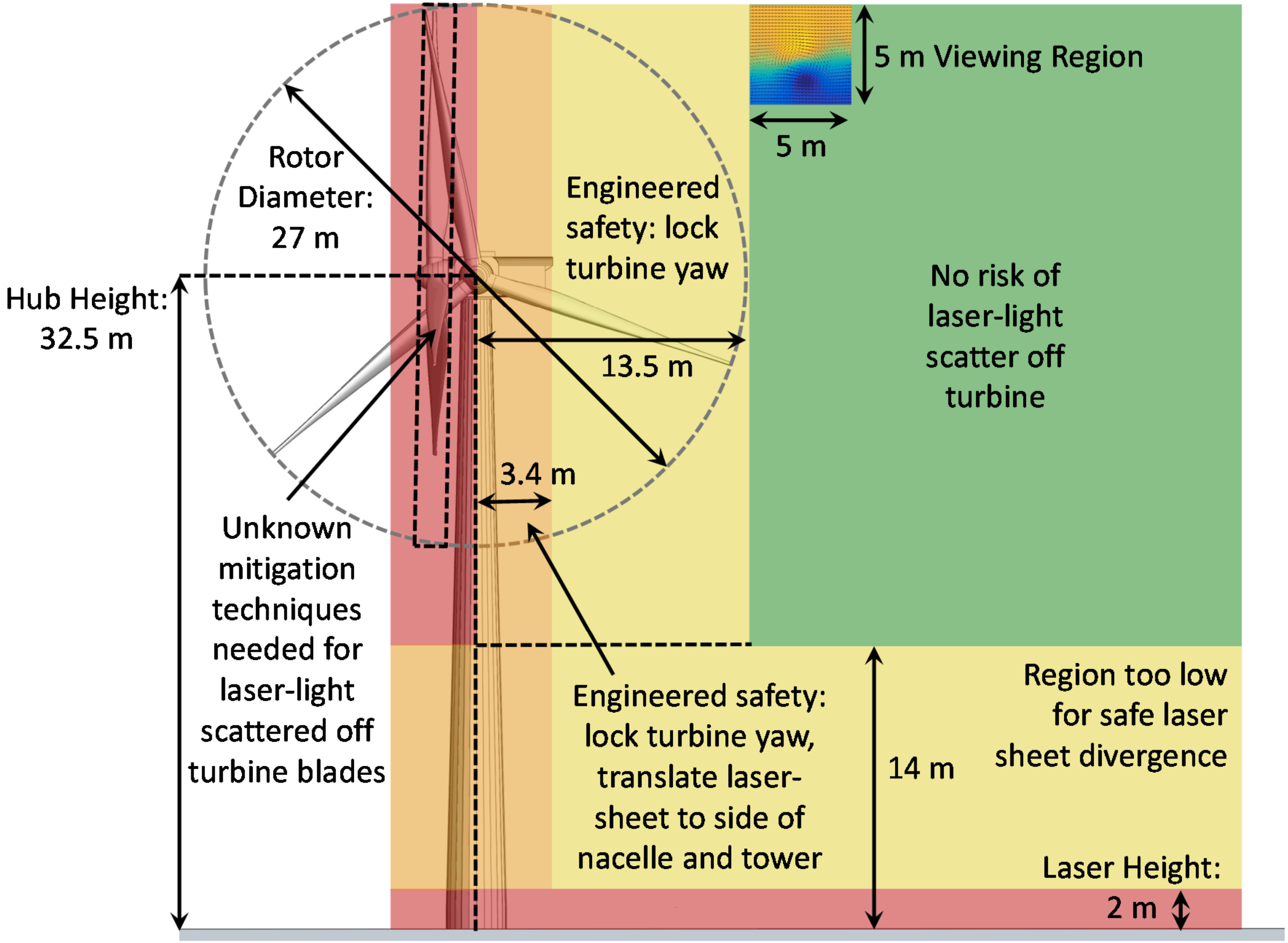


Fully Upgraded System

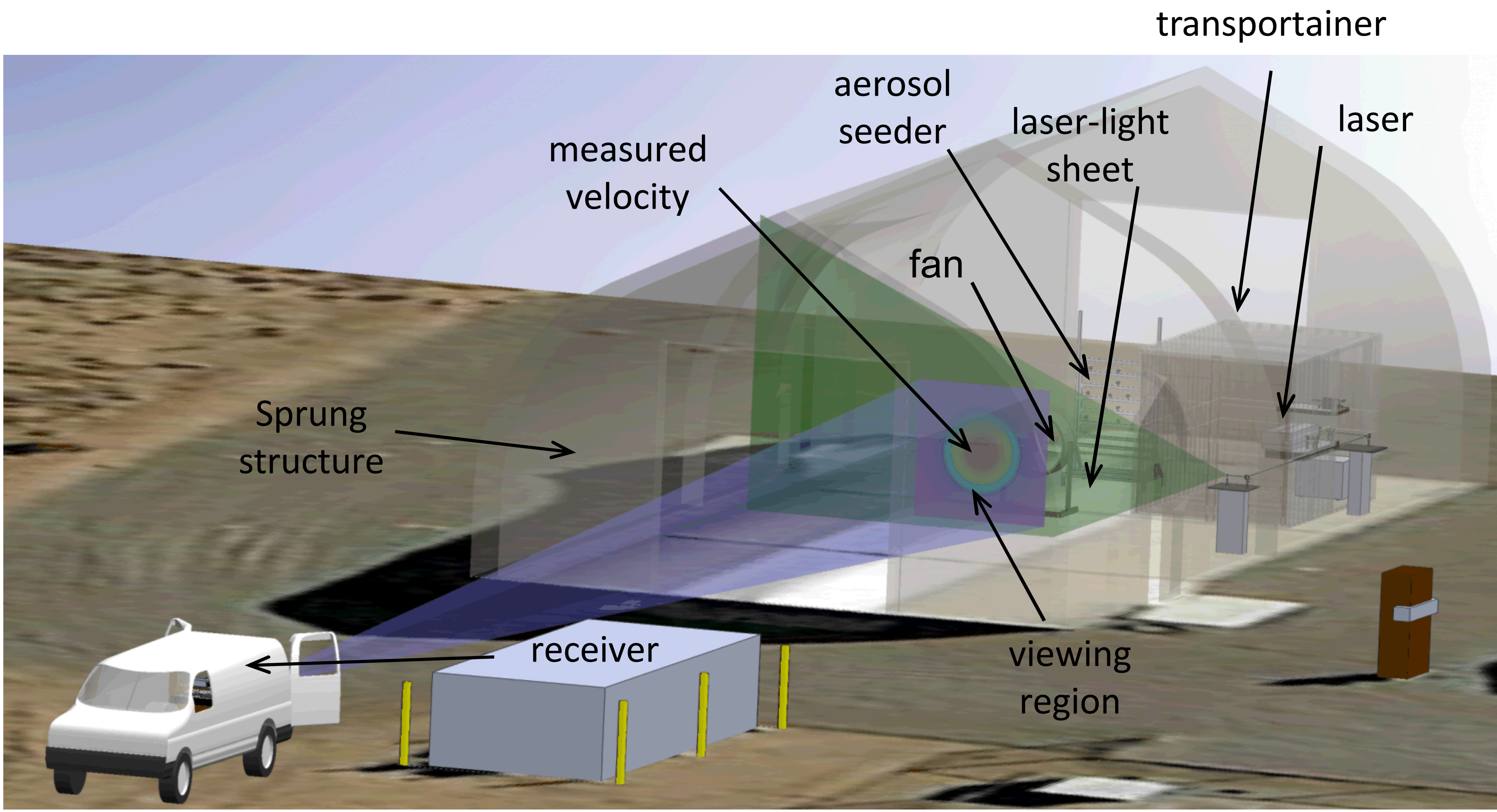


$v_{neq} = 1.43\ m/s$ $\quad v = \langle .17 \quad .93 \quad .33 \rangle$ $\quad v_{neq} = 0.03\ m/s$

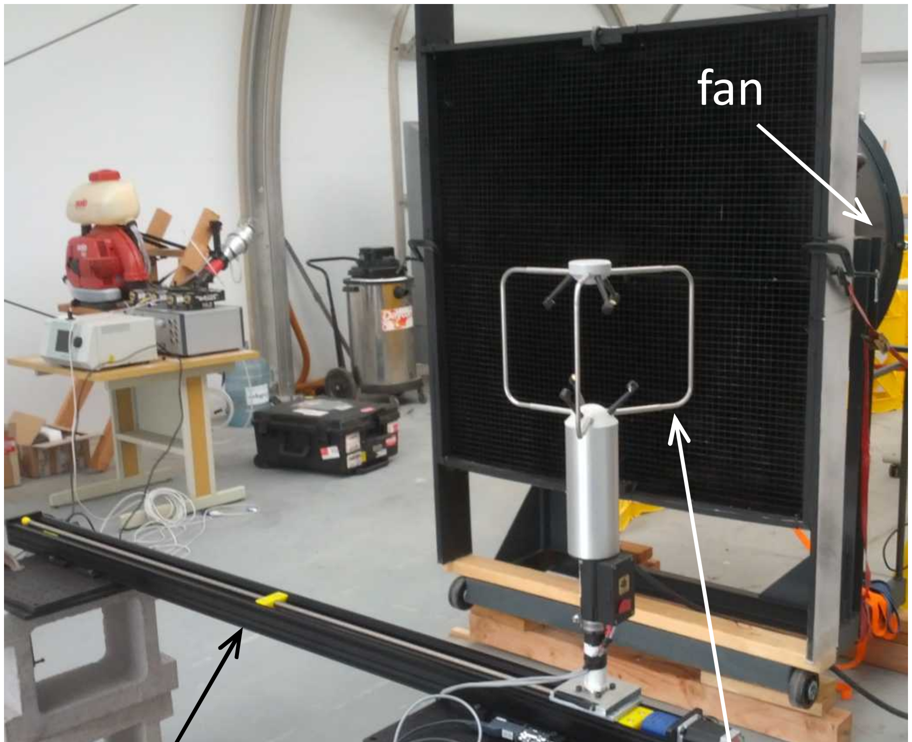
Laser safety considerations vs measurement location



Experiment Configuration



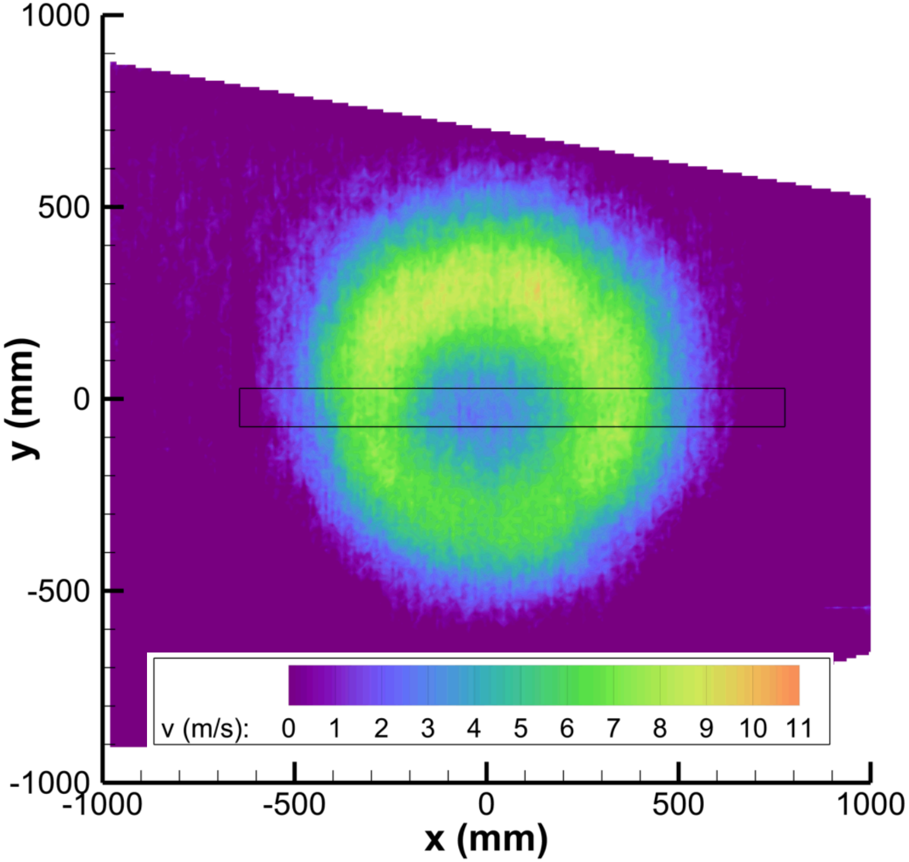
Representative Flowfield

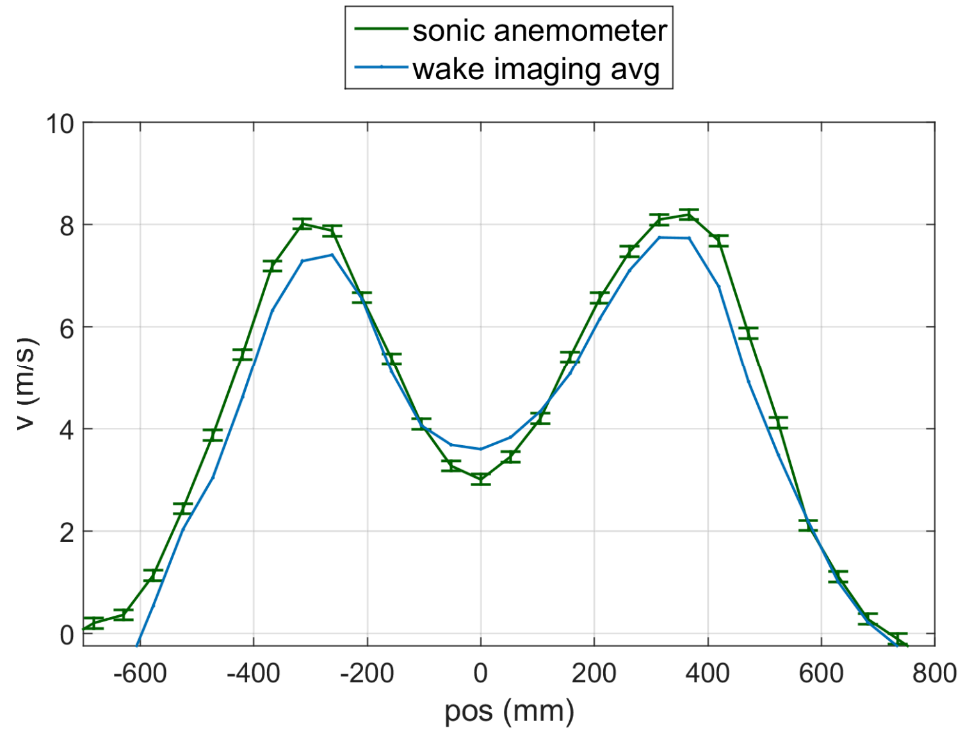


traverse

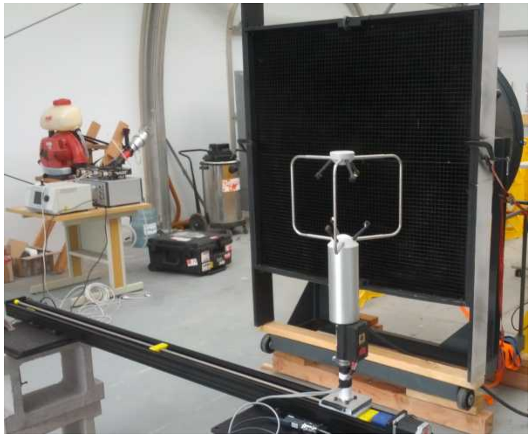
sonic anemometer

Velocity Measurement Comparison



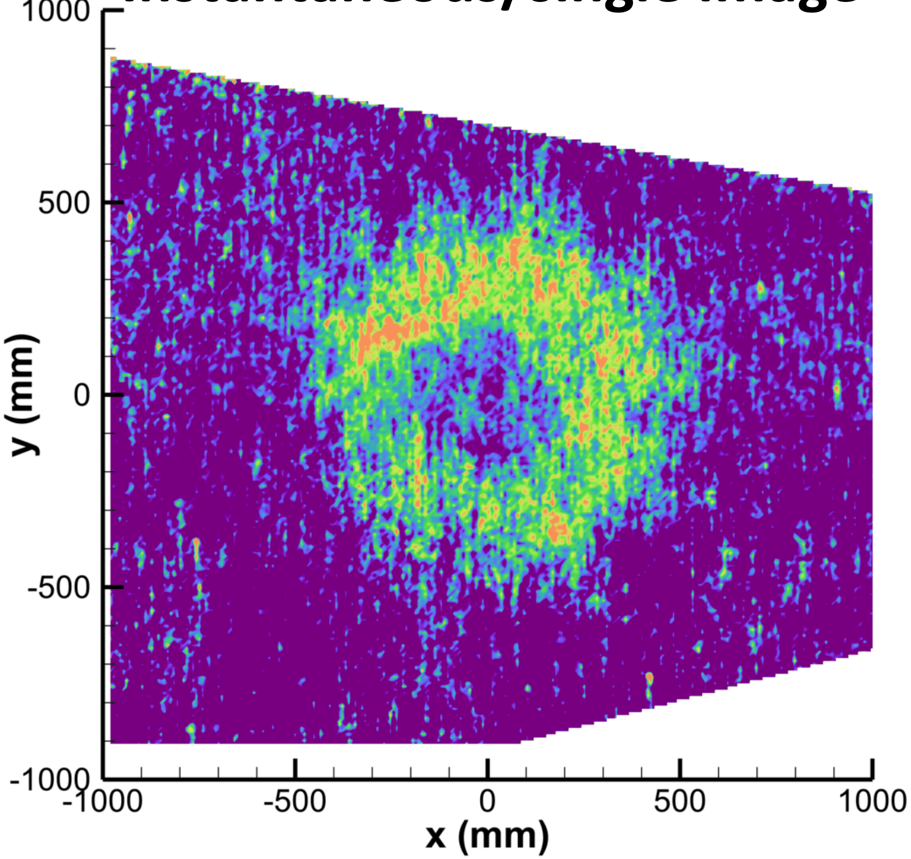


- Independent sonic anemometer data compares well
- Velocity image processed to match sonic anemometer spatial resolution
- Velocity bias exists between different SWIS data sets

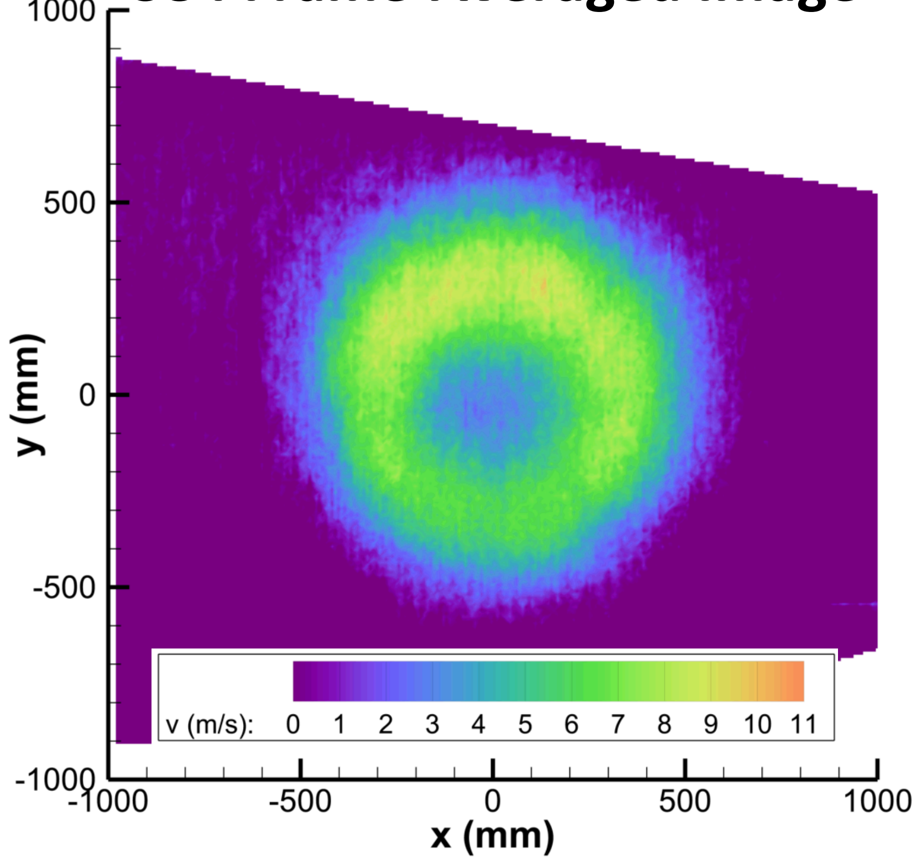


Velocity Images

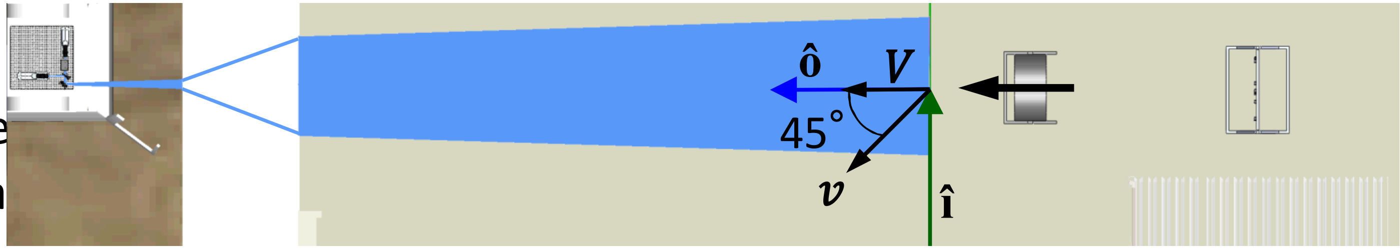
Instantaneous/single Image



384 Frame-Averaged Image



- 2 m
- Incre
- Insta

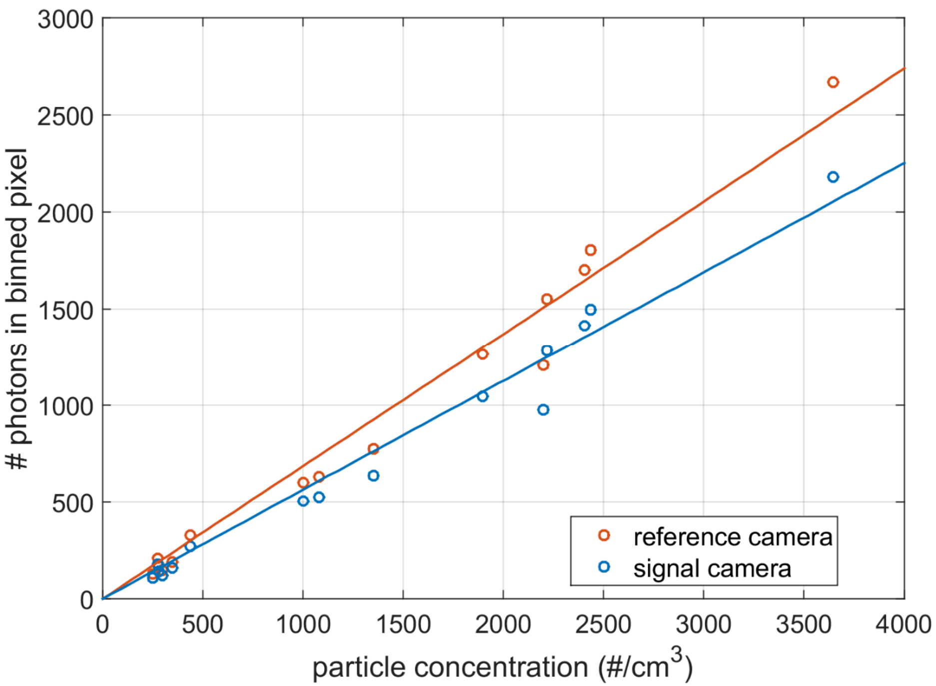


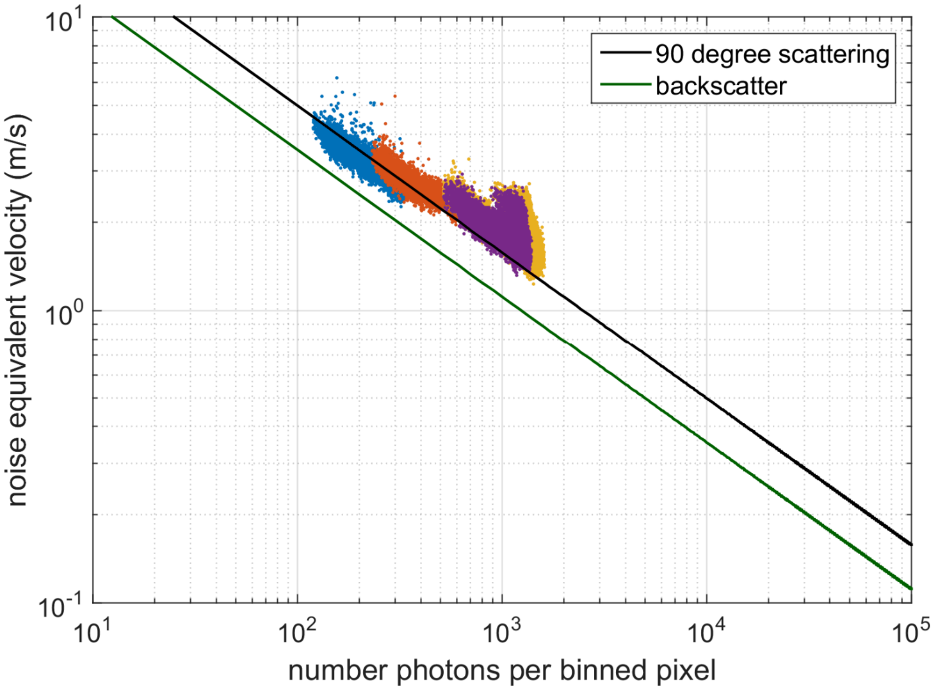
Sensitivity Results and Implications

- Noise equivalent velocity represents the minimum resolvable velocity variation
- Shot noise equals the square root of the number of photoelectrons collected per binned pixel:

$$\sigma = \sqrt{N} \qquad NSR = \frac{\sigma}{N} = \frac{\sqrt{N}}{N} = \frac{1}{\sqrt{N}}$$

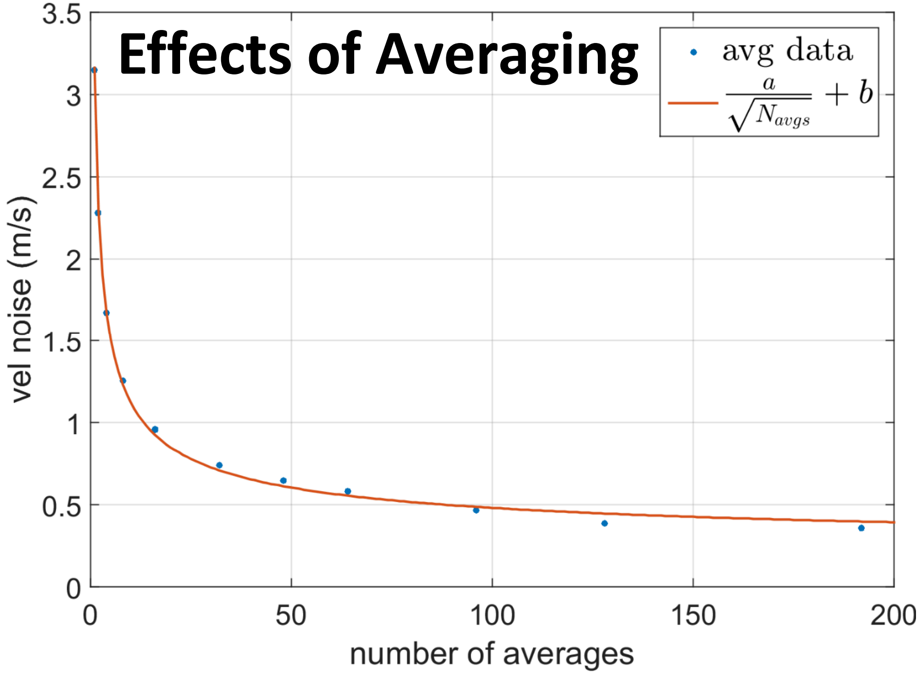
- Noise equivalent velocity likely shot-noise limited and depends inversely on number of photoelectrons

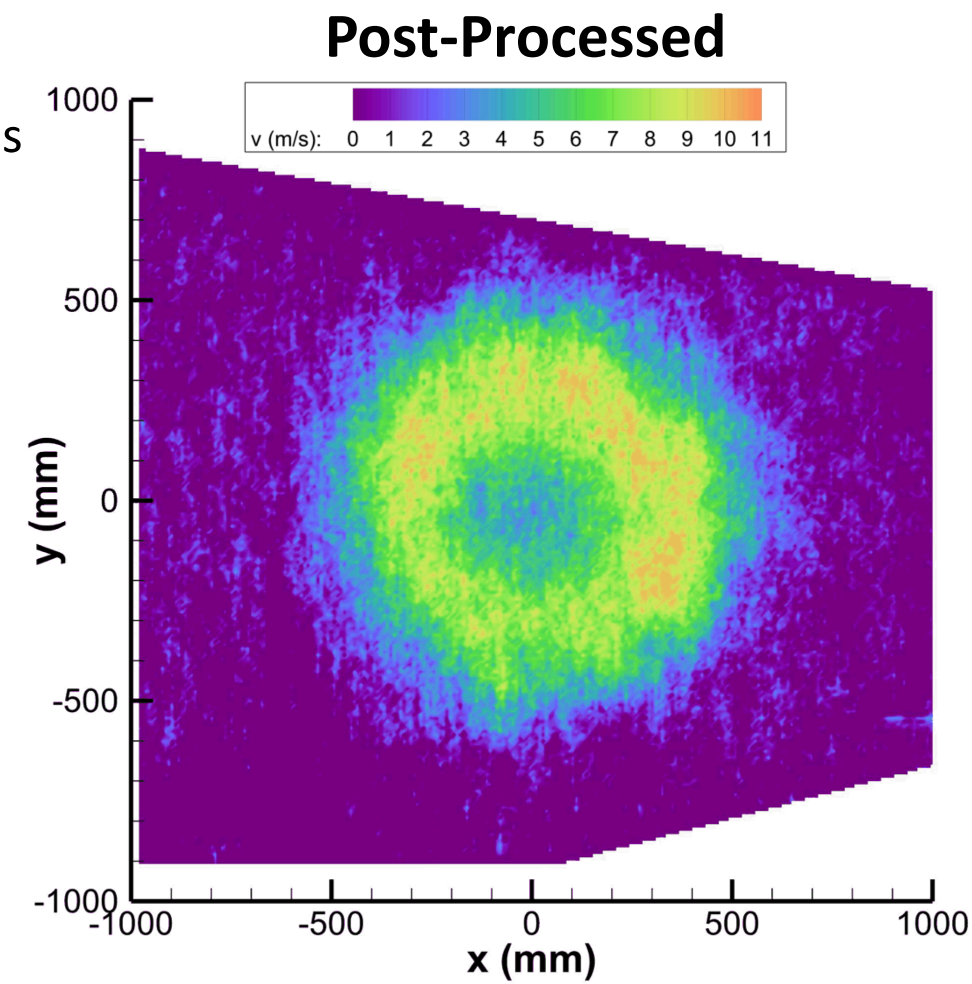




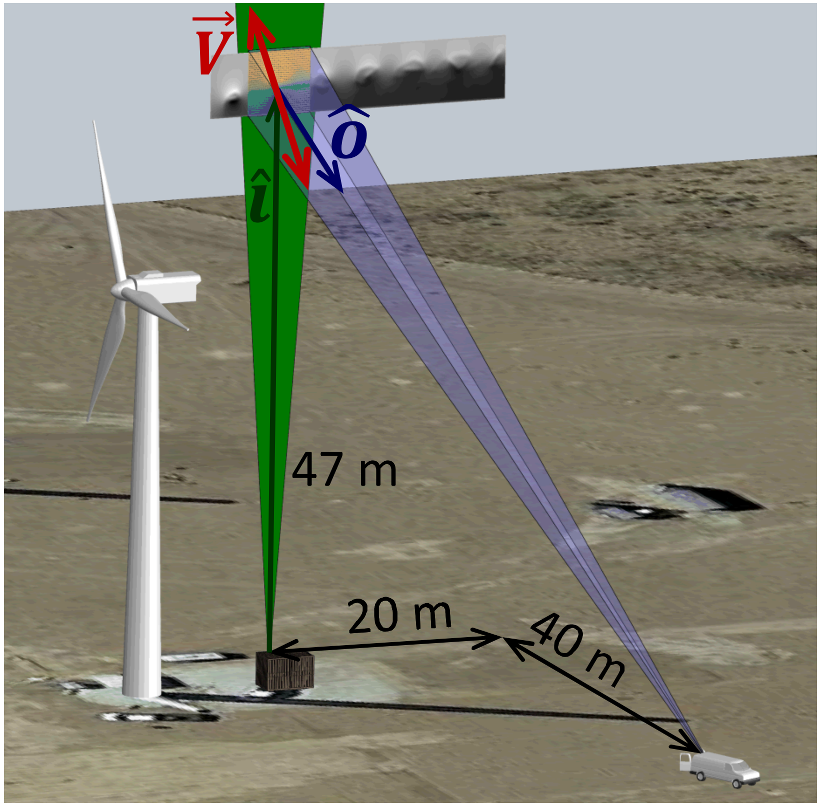
Reducing Noise for SWiFT Deployment

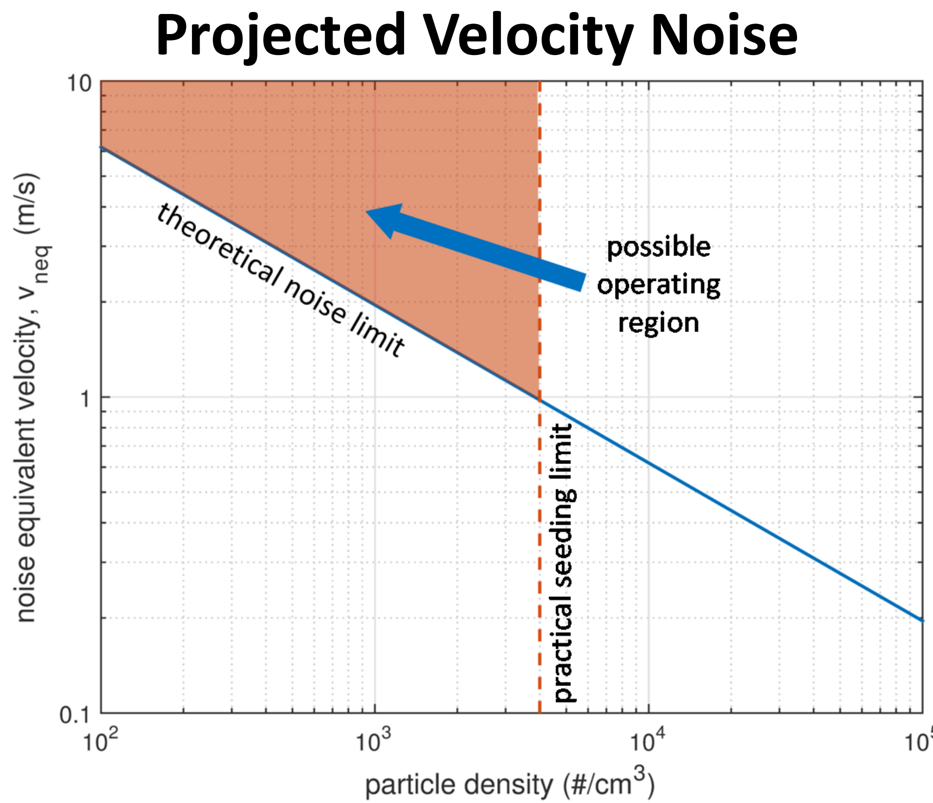
- Increase energy per laser pulse
- Receiver binning (increased signal with reduced spatial resolution)
- Higher particulate concentration
- Larger receiver aperture
- Improved post-processing techniques
  - Averaging
  - Filtering





Current SWIS Status





- Determining quantity of interest for validation of wind plant simulations
- Optimize SWIS configuration to meet validation requirements
- Theoretical noise limit can be adjusted by the configuration and equipment
- Preparing for initial measurement campaign at SWiFT