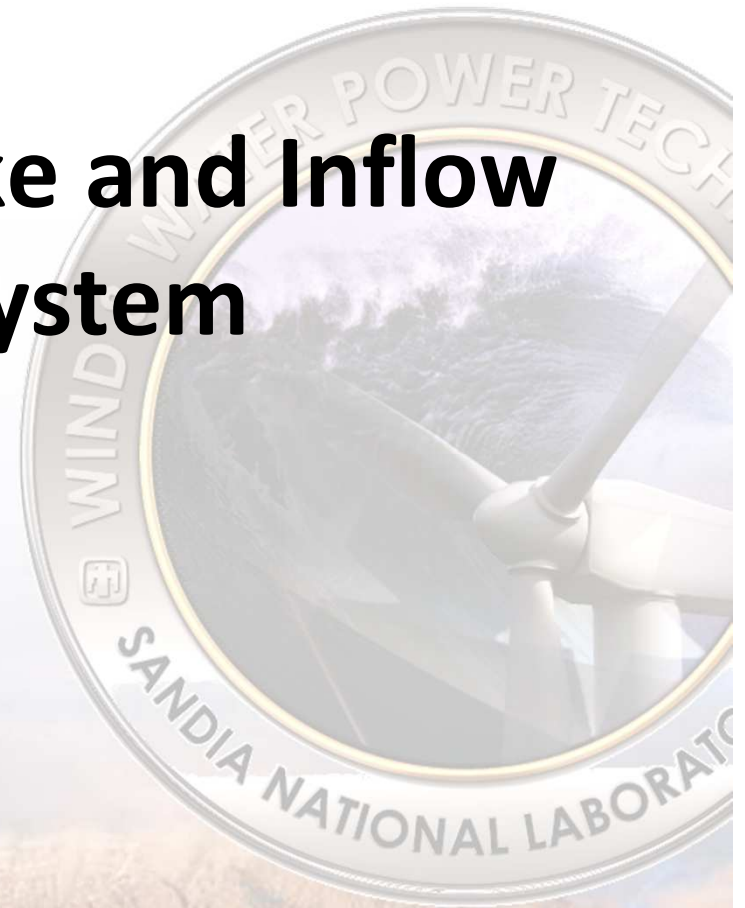


SNL Wind Turbine Wake and Inflow Laser Imaging System

March 1, 2013



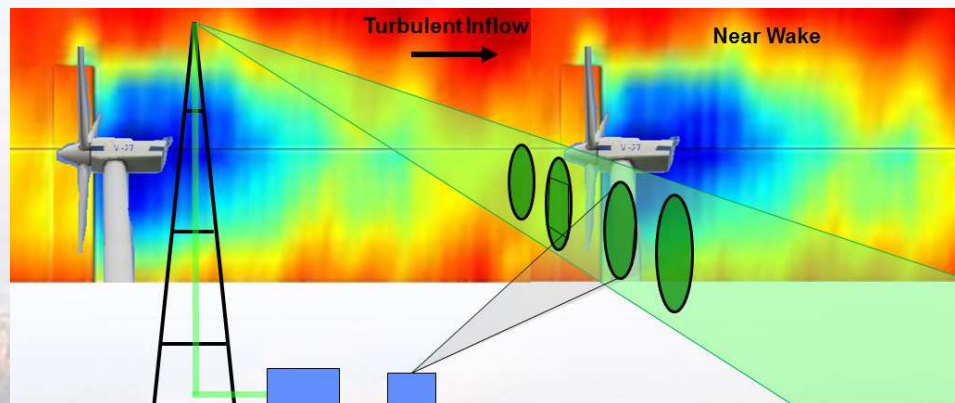
Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company,
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under contract DE-AC04-94AL85000.



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Wake and Inflow Measurement

- Capturing detailed flow structures is important to understanding the flow mechanisms that drive turbine-turbine interaction.
- Measurements will be used to create and improve high-fidelity and engineering level wind farm and turbine models.
- HSRIL system can image the inflow and wake at multiple locations from one illumination location.



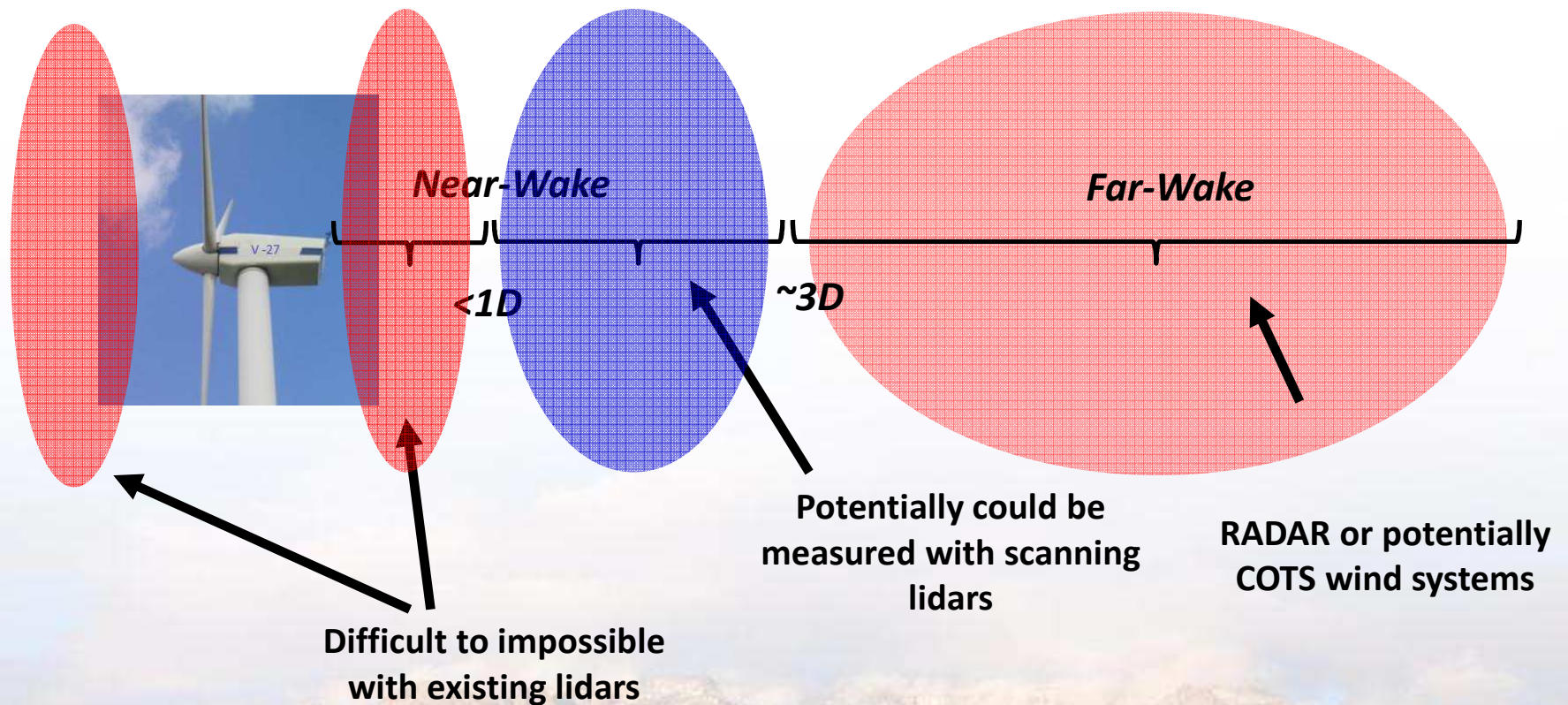
Wake Sensing Requirements

Vortices, turbulence, wake depression

Range resolution	10 cm – 1 m
Max Velocity	40 m/s
Measurement time	100ms – 1 s

Wake meandering, merging

Range resolution	1 - 10 m
Max Velocity	~10-20 m/s



Mobile Radar

Far-wake Region

Mobile Radar system can take measurements on the wind plant scale.

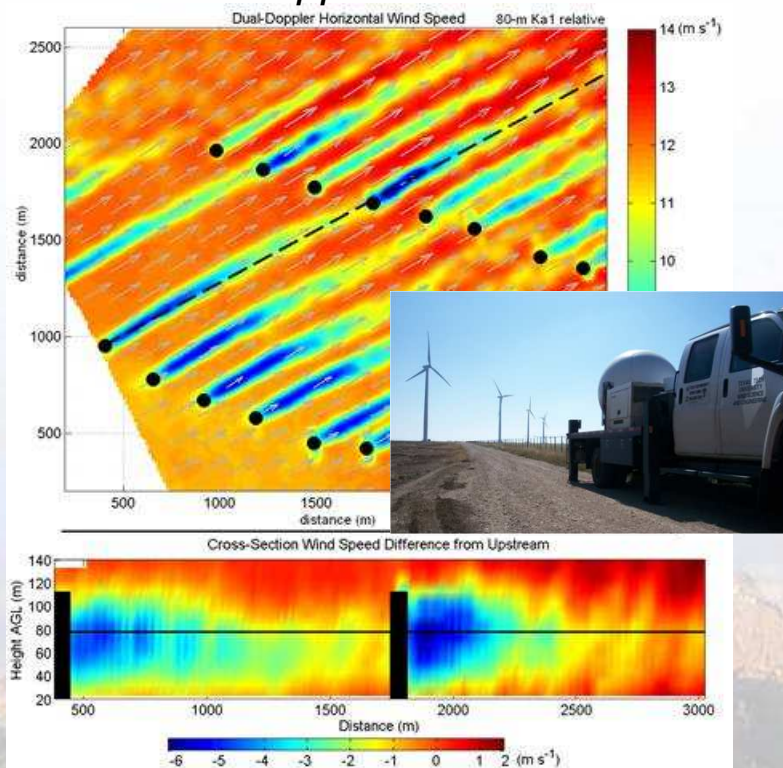
MET towers provide measurements at a limited number of locations.



TEXAS TECH
UNIVERSITY

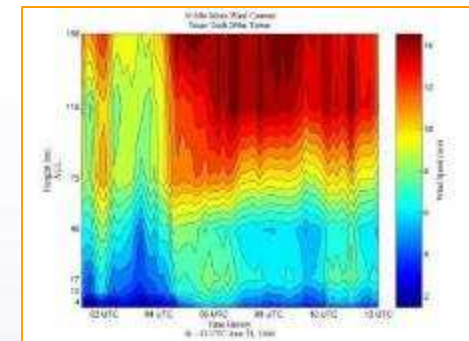
Distributed Wind Resource Assessment

2x mobile Doppler research radars



Large-scale Test Infrastructure

200 meter anemometer tower



MW Wind Turbines



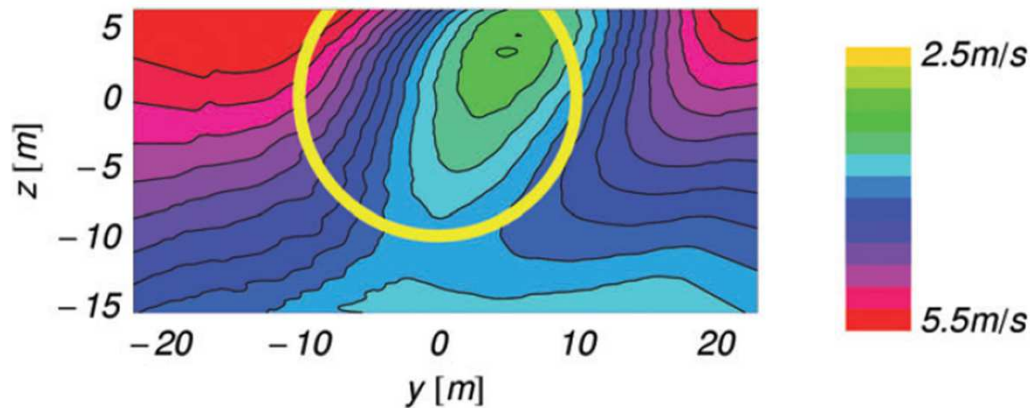
Scanning Wind Lidars

Middle Region

Scanning lidar systems potentially could measure wake deficit, meandering and wake merging

- Custom or modified OTS systems
- Mono or multi-static coherent and direct detection lidars
- Challenging measurement timeline over large volume
- Meter-scale range resolution

University of Denmark, 2010

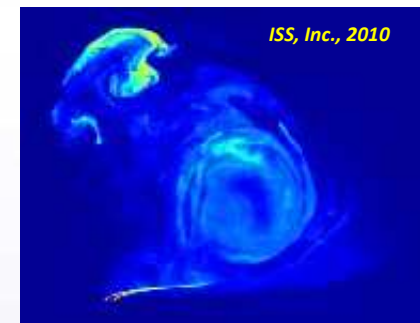
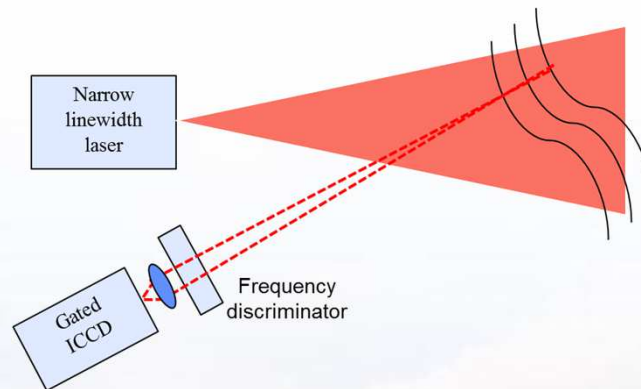


High Spectral Resolution Imaging Lidar

Near-Rotor Region

- An imaging lidar is similar to conventional direct-detection lidars

- A pulsed, narrow linewidth laser is used to flood illuminate the scene
- A time-gated focal plane array is used to obtain range resolution and to truly provide a 3-D image of the scene
- Velocity is determined for each pixel from Doppler shifts measured with a single edge spectral absorption filter



- Imaged-based lidar measures the velocity distribution of a **large area in parallel – non-scanning, fast!**
- **High spatial resolution** afforded by pulsed transmitter together with gated, imaging ICCD
- 3-D image of the velocity distribution with high spatial resolution **enables direct comparison with flow modeling**
- Similar techniques have been demonstrated on a smaller scale in wind tunnels



Wake and Inflow Imaging

Remote
Steering Mirror

Turbulent Inflow

Near Wake

Illuminator
Laser

Receiver

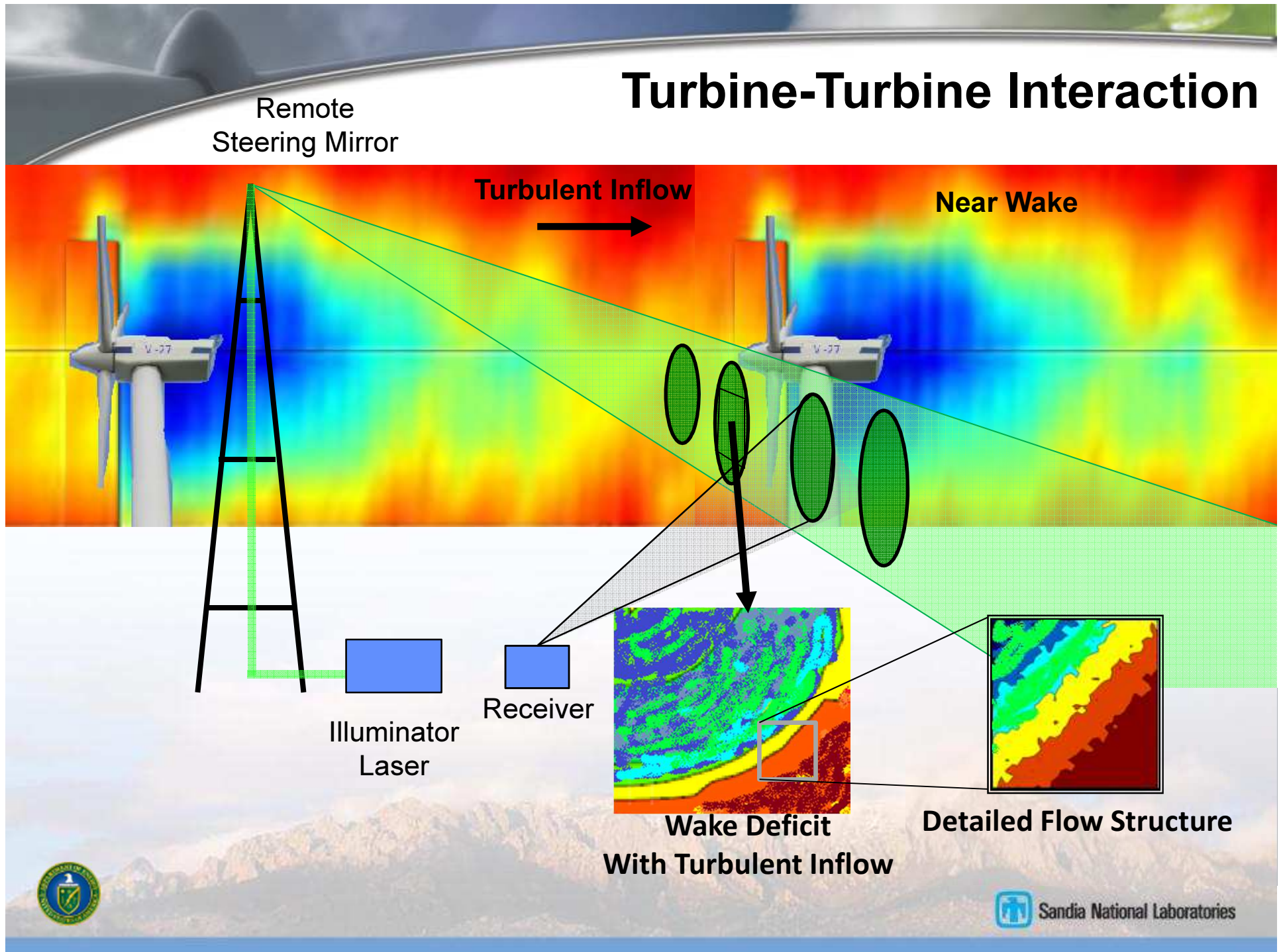
Wake Deficit
With Turbulent Inflow

Detailed Flow Structure



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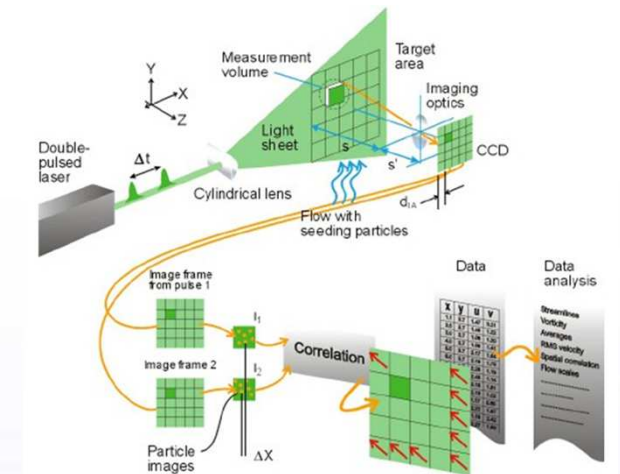
Turbine-Turbine Interaction



Particle Imaging Velocimetry

■ How does HSRI Lidar compare to Particle Imaging Velocimetry?

- Both are image-based techniques
- Both measure an entire 2-D cross section of the flow field simultaneously
- Both require a Class-IV laser system and high speed gated camera
- HSRI Lidar measures the velocity along the line of sight, while PIV measures transverse velocities –*complimentary data*
- Use of multiple HSRI lidar receivers provides 3D maps



• HSRI Lidar:

- It is *not necessary to track individual particles* to obtain velocity
- Scattering is obtained from aerosol particles so there is *no need to seed the flow*
- Allows measurements at *large standoff and wide fields of view*



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Lidar Comparison

Parameter	HSRIL	ZephIR	Windcube
Range	10-100 meters	10-200 meters	40-200 meters
Range Resolution	2 meter	17 meters*	30 meters
Velocity Range	1-100 m/s	1-70 m/s	0-60 m/s
Velocity Precision	<0.5 m/s**	0.1 m/s	0.1 m/s
Sample Rate	20 Hz	50 Hz	***
Resolution Elements per Sample	10,000	1	1
Eyesafe	No	Yes	Yes

Commercial lidar specs (for ZephIR and WindCube) obtained from internet sites and T. Mikkelsen, et al., "Wind scanner: a full scale laser facility for wind and turbulence measurements around large wind turbines", Riso National Lab report.

* At 100m range. Range resolution varies quadratically with range.

** Dependent on laser power, aerosol density, optics, and field of view.

*** Unknown – should be similar to ZephIR.

Program Plan

- Currently, a demonstrator HSRIL lidar is being built and characterized against laboratory targets
- Field testing of the demonstrator lidar at SNL is planned for March 2013
- Design of a full-scale, field deployable lidar will commence upon successful field testing

