Nacelle lidar for power performance

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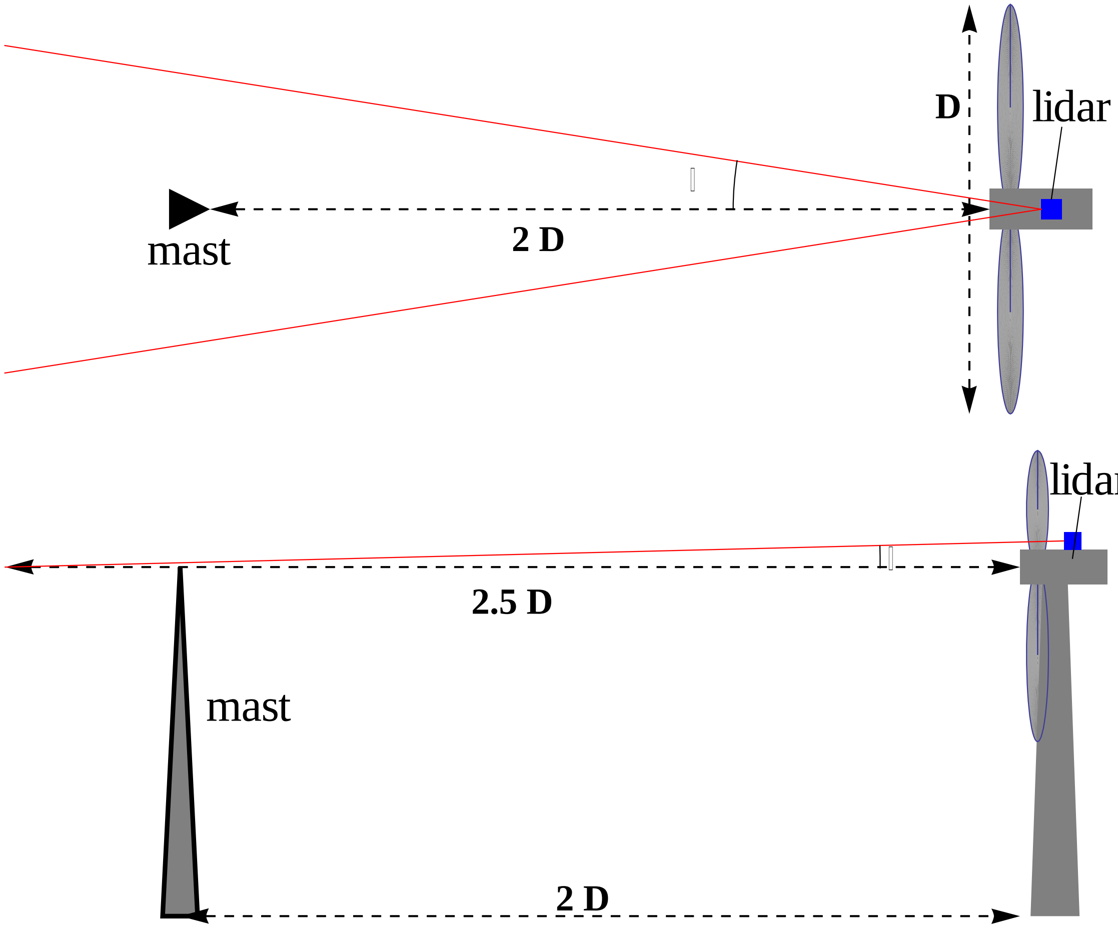
Project partners:
DTU; DONG Energy; Avent Lidar;
Siemens Wind power

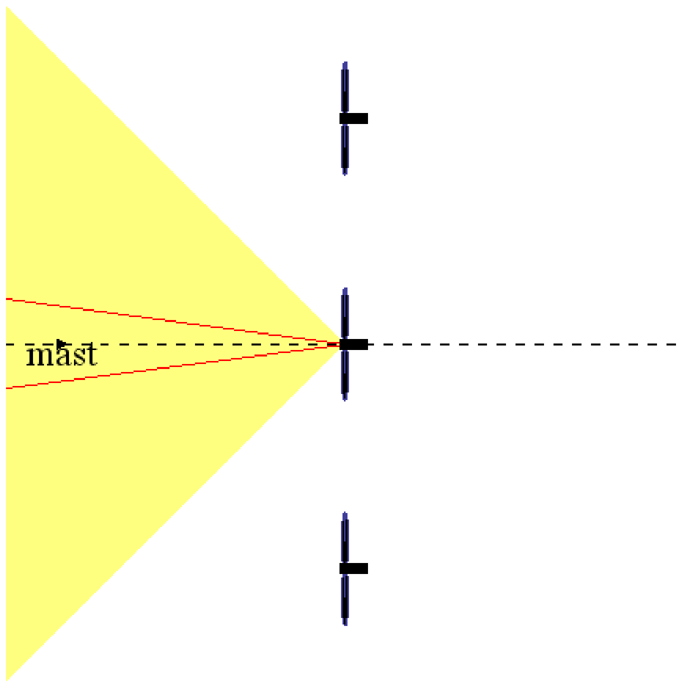
EWEA Technical Workshop
Lyon
2nd of June 2012

DTU Wind Energy
Department of Wind Energy

First measurement campaign
Prototype B2 - Onshore

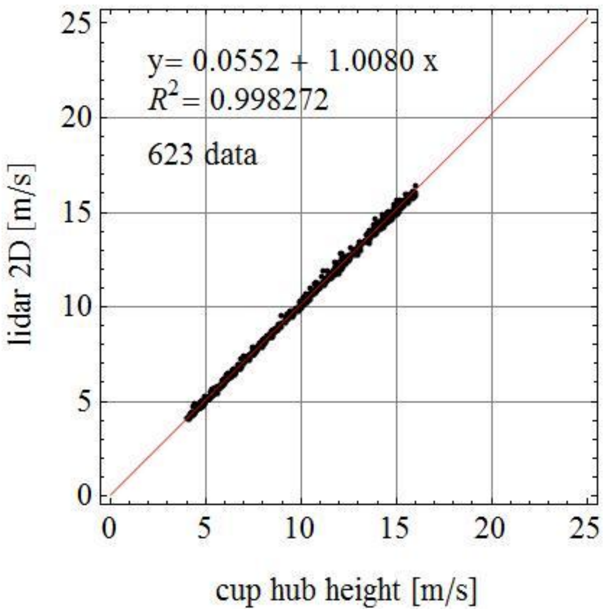


Power curve for westerly winds

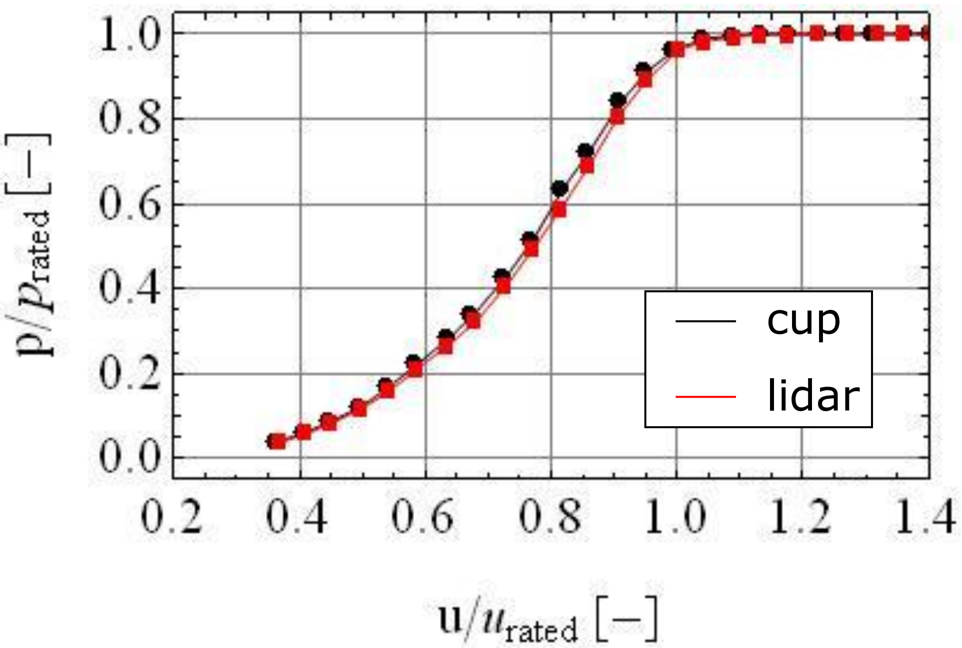


Power curve for westerly winds

Comparison lidar/cup anemometer



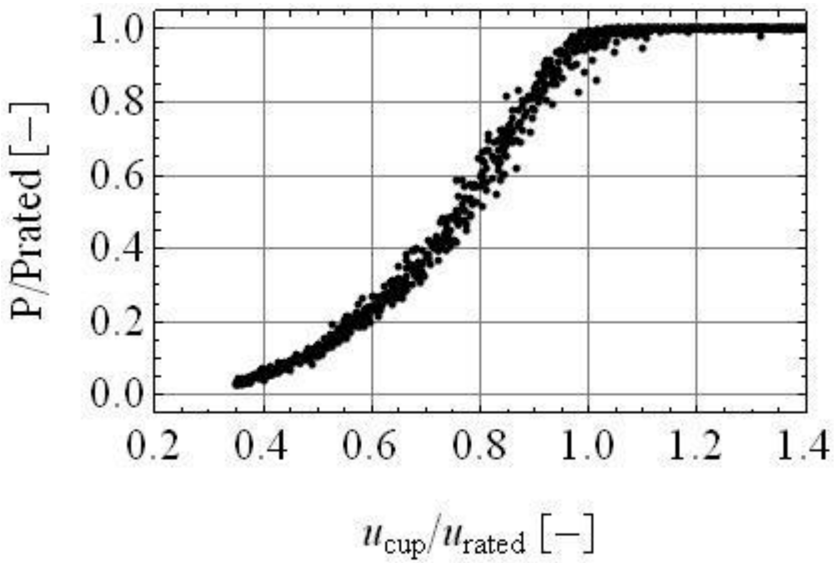
Bin-averaged power curves



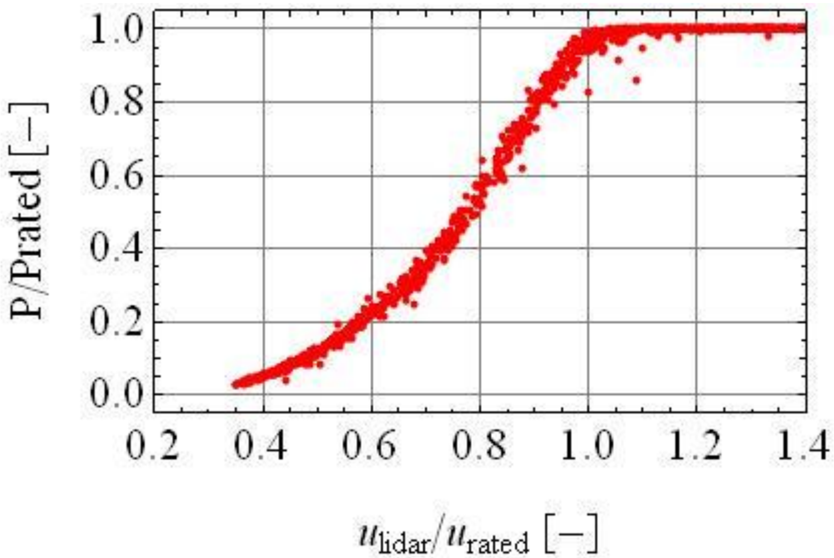
➔ Very close mean power curves

Power curve for westerly winds

Mast top mounted cup at hub height west from turbine

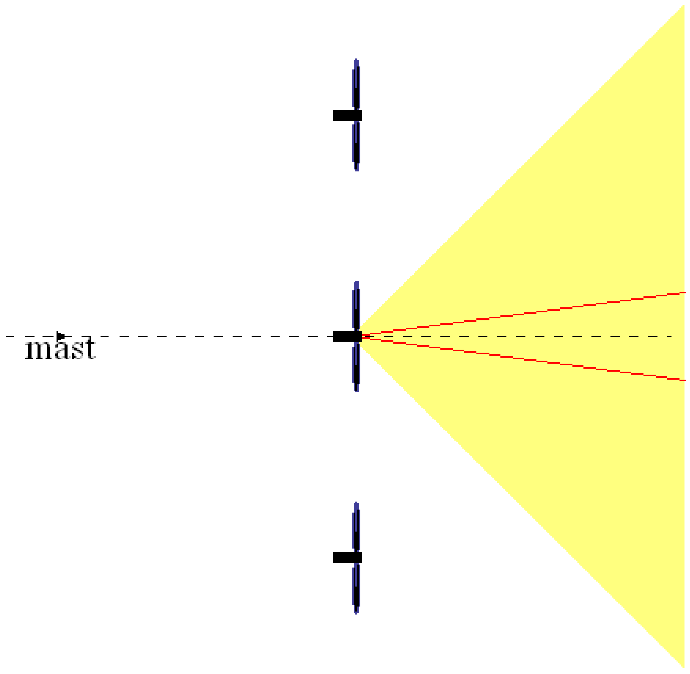


Nacelle lidar measuring at the same height and the same distance as the cup



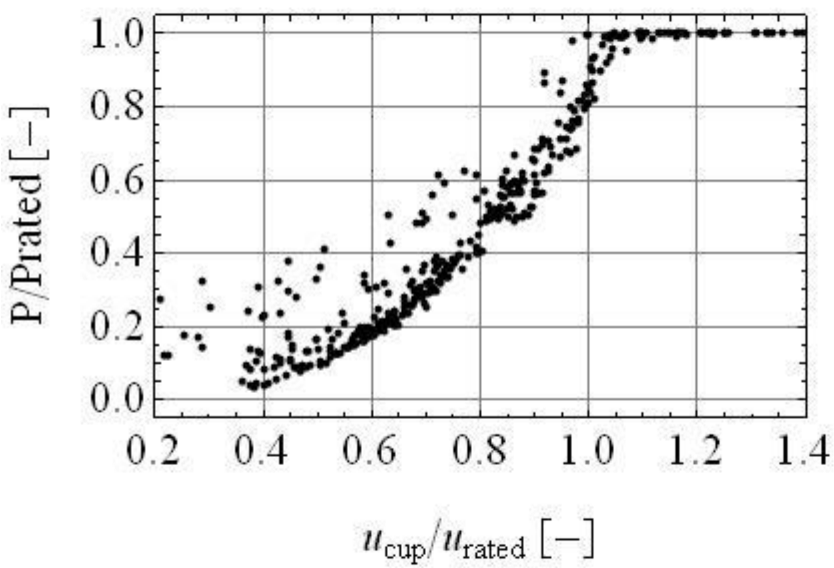
➔ Smaller scatter with the nacelle lidar than with the cup

Power curve for easterly winds

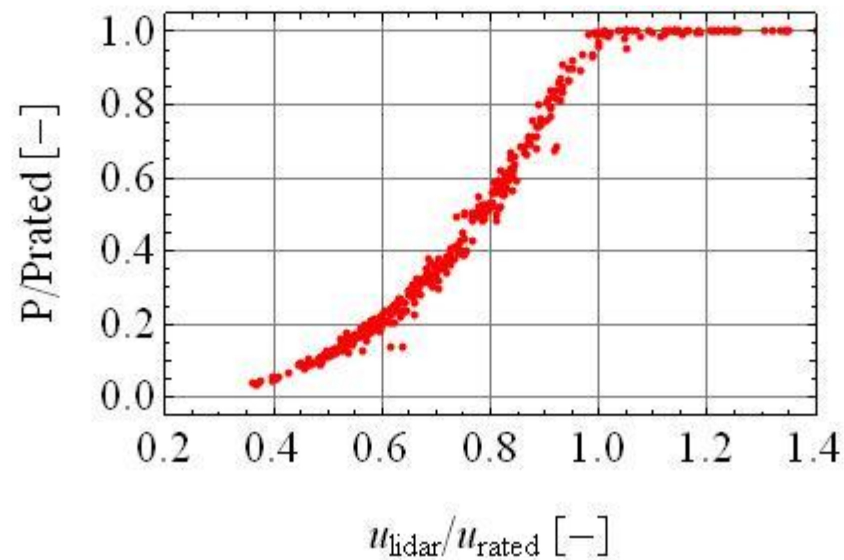


Power curve for easterly winds

Mast top mounted cup at hub height west from turbine (in wake of turbine)



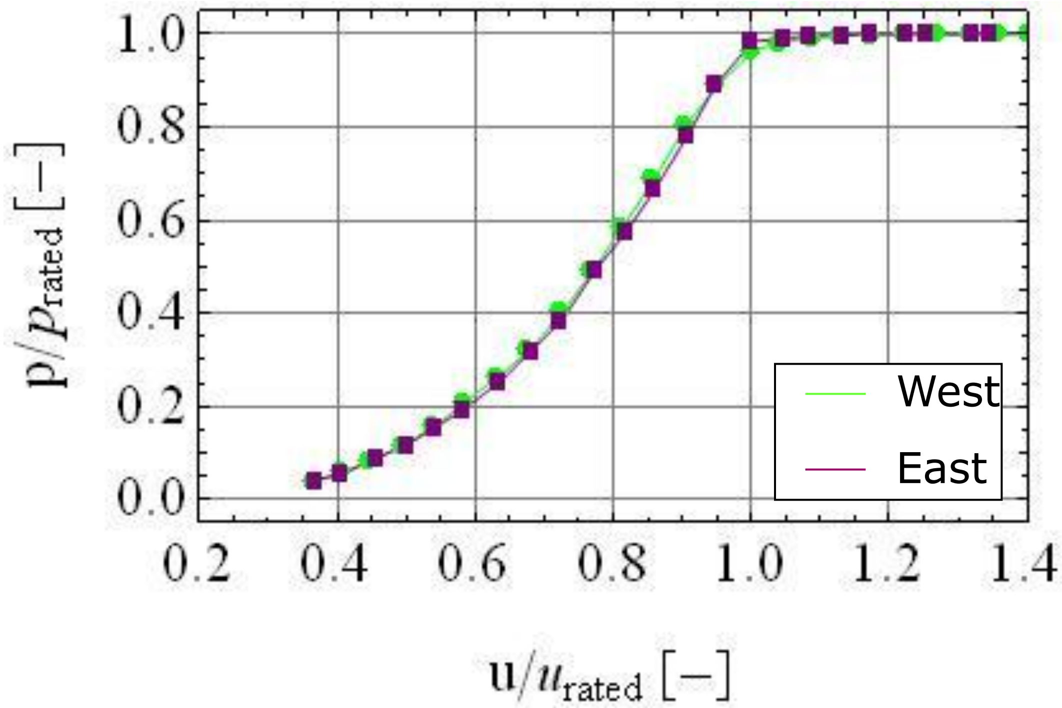
Nacelle lidar measuring on the east side (measuring forward, free wind)



→ The lidar is not disturbed by the turbine wake while the mast is.

Power curve for easterly winds

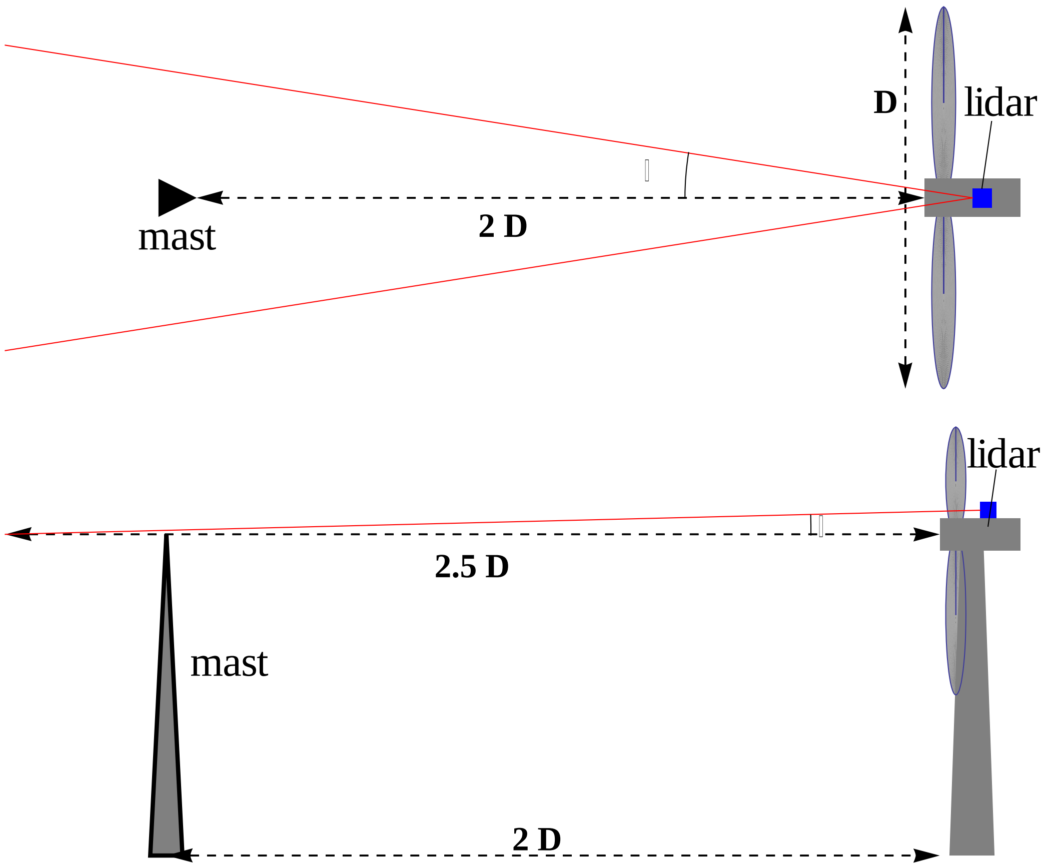
Nacelle lidar measurements from each sector

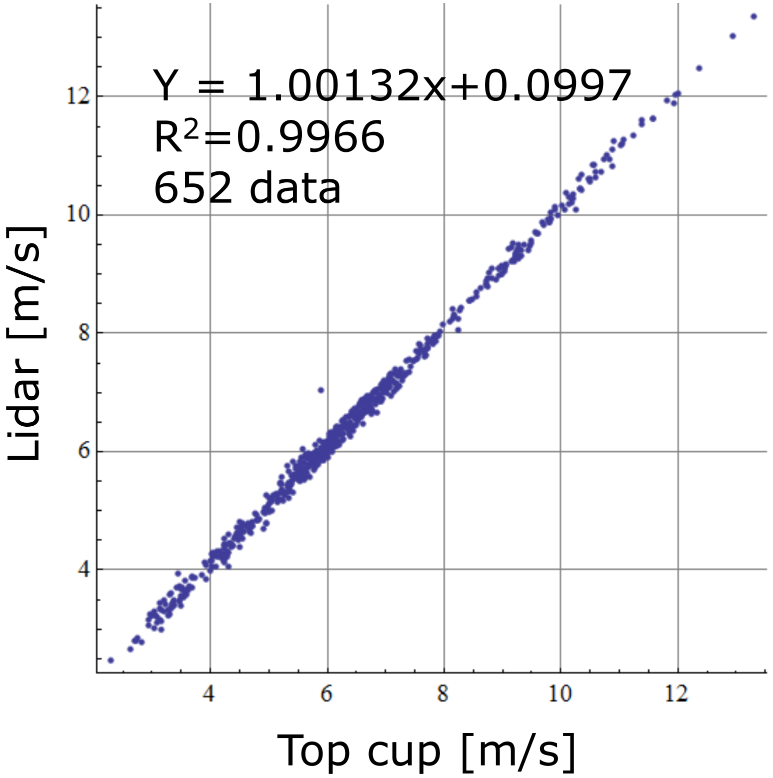


➔ Same power curve for easterly winds as for westerly winds!

Second measurement campaign (Ongoing)
Wind Iris- Offshore (coastal)

Second measurement campaign (Ongoing)
Set-up





Deviation 1: Measurement height

IEC 61400-12-1:
"Wind speed measurements shall be made at hub height [...] +/- 2.5%."

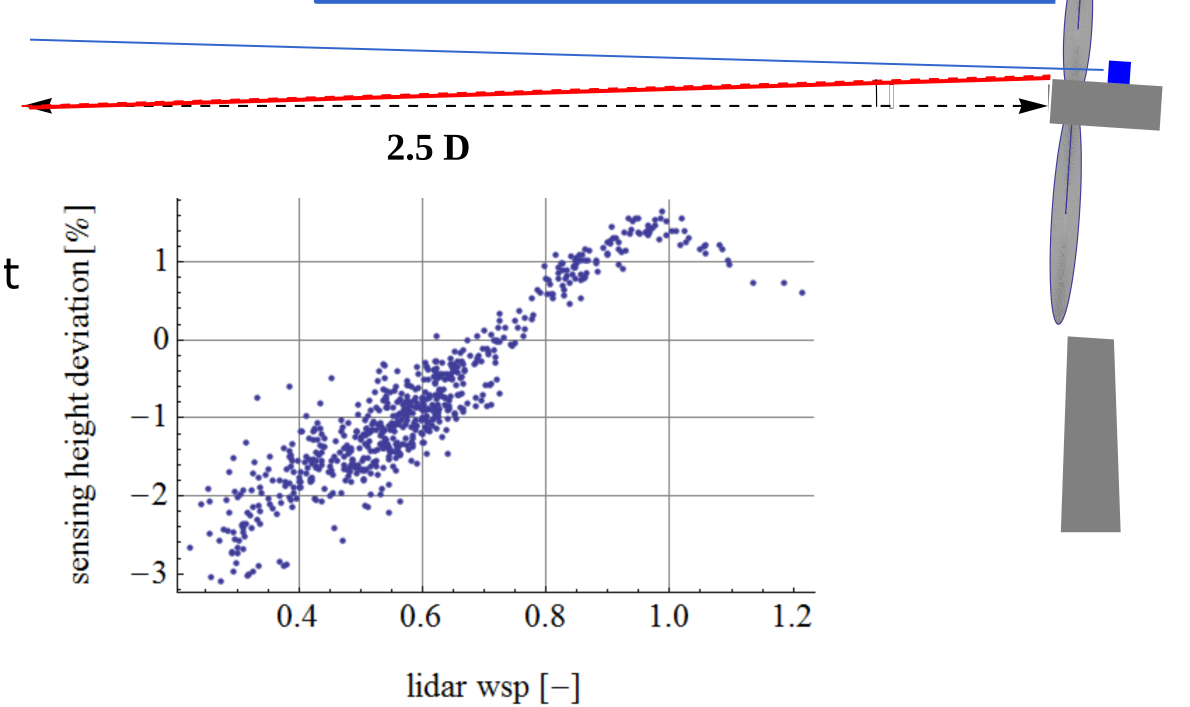
Nacelle tilt variations

↓

Variation in the line-of-sight direction

↓

Variation in measurement height



→Almost within +/- 2.5% of hub height
→Need accurate measurement of the lidar inclination (inclinometers)
→The deviation will depend on the turbine tower flexibility.

Deviation 2: Accuracy of wind speed measurements

IEC 61400-12-1:
”The anemometer shall be calibrated […].”

Comparison with mast at 2D in front of turbine is not ideal:

- The lidar measures above the cup anemometer

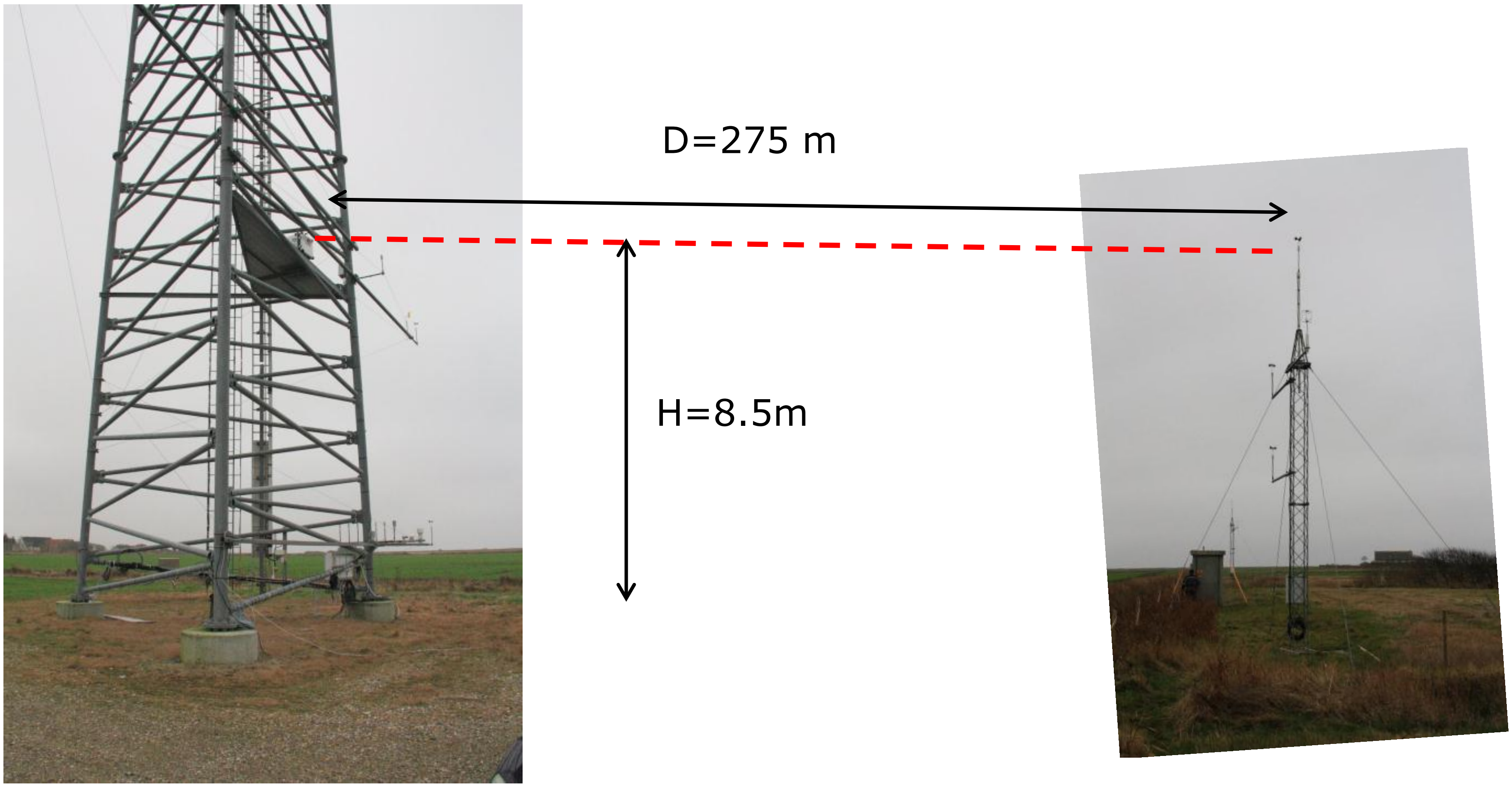
- The lidar tilts and rolls with the nacelle

- The inflow may be inhomogeneous in the probe length due to the induction effect in front of the rotor

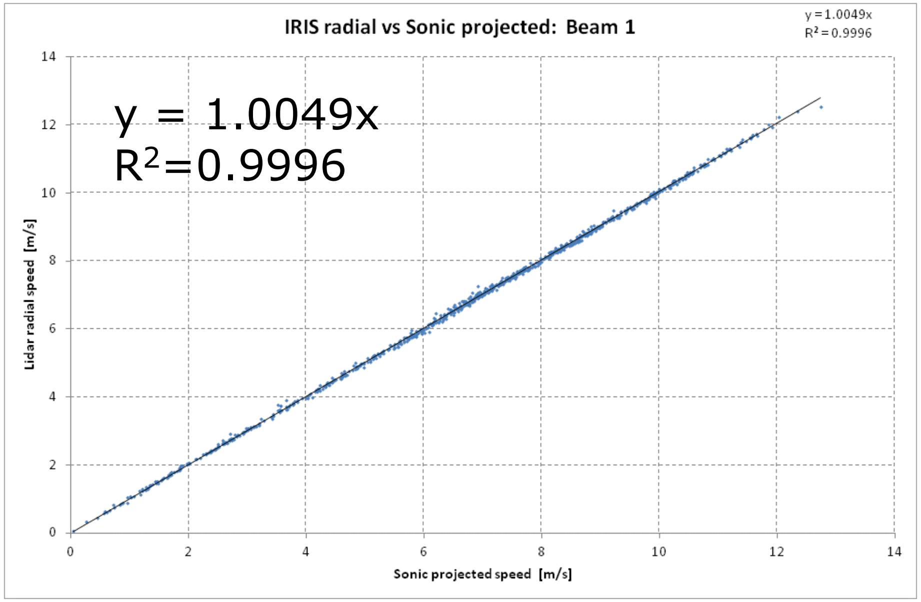
- Aim: use the lidar without mast

→ DTU has been developping a method to calibrate a nacelle lidar

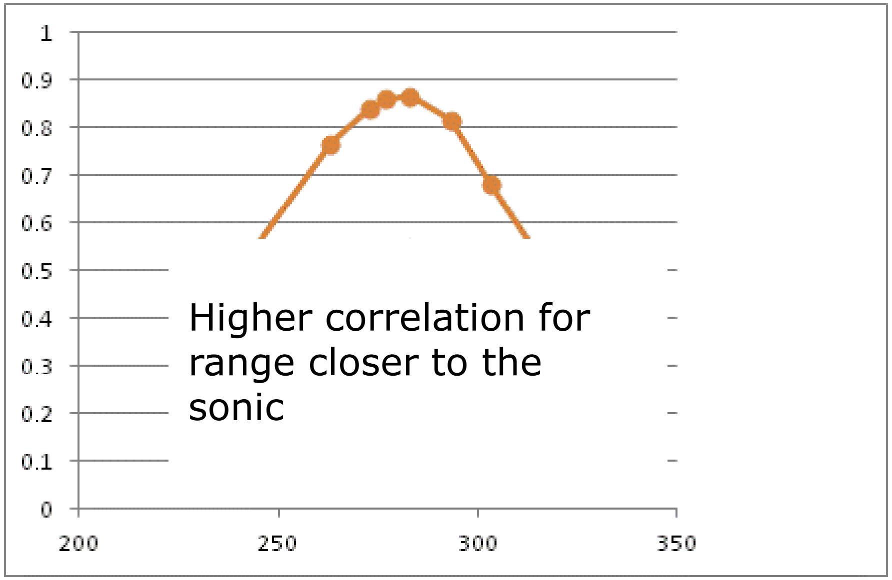
Calibration set up



Calibration:
LOS wind speed and measurement range



Comparison lidar radial speed to sonic speed projected onto LOS direction



Correlation at various ranges between the lidar radial speed and the sonic projected speed

Deviation 3: Wind direction measurement

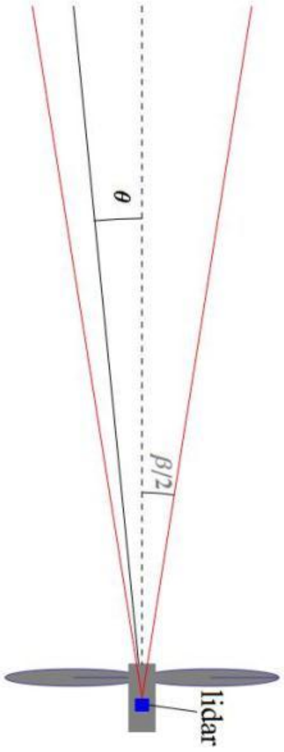
IEC 61400-12-1:
”The […] uncertainty of the wind direction measurement should be less than 5°.”

The nacelle lidar gives the angles between the wind direction and the lidar orientation.

Wind direction = turbine yaw + yaw error

→ The lidar must be perfectly aligned with the turbine.

→ The nacelle lidar cannot detect the difference between a yaw error and a horizontal shear.

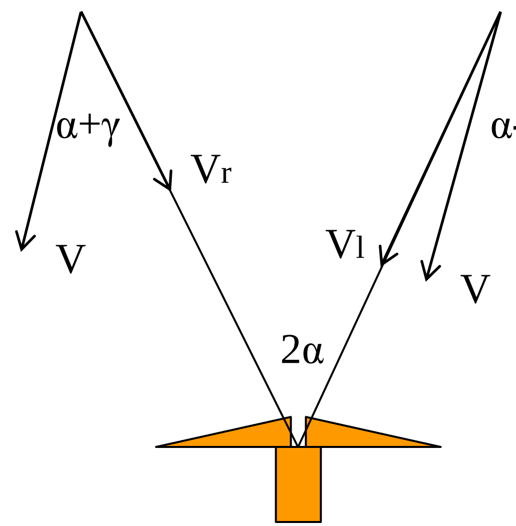


"Apparent Yaw Error"

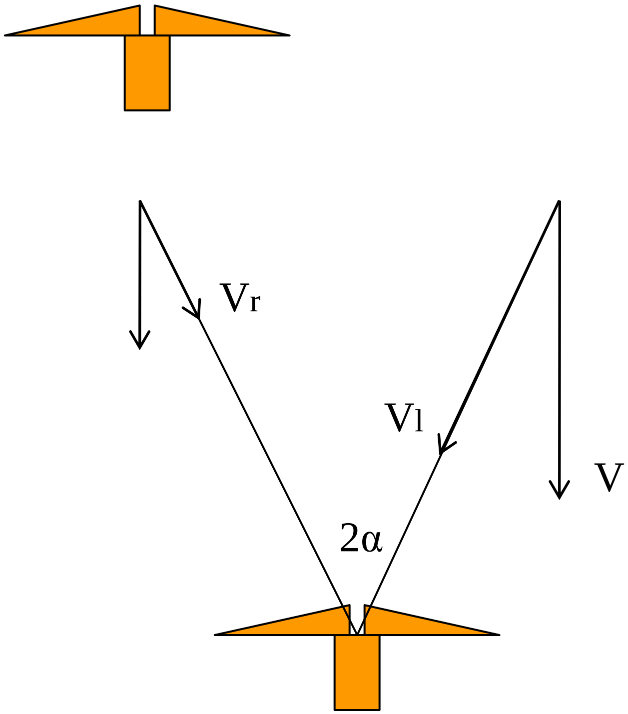
Such a lidar cannot distinguish between horizontal shear and yaw error.

$$V_r = V\cos(\alpha+\gamma)$$
$$V_l = V\cos(\alpha-\gamma)$$

$$f = V_l / V_r$$
$$\gamma = A\tan\left(\frac{f-1}{\tan\alpha(f+1)}\right)$$



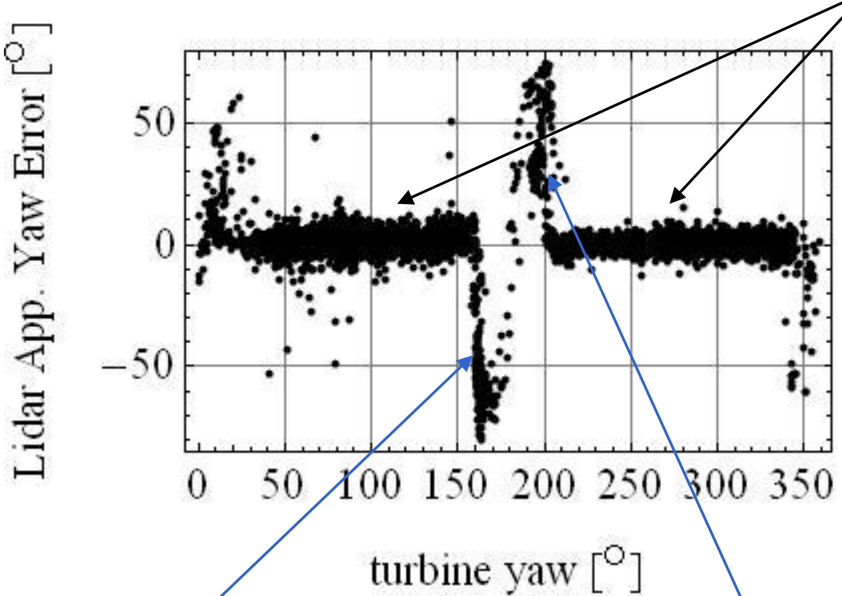
No horizontal shear and yaw error γ



No yaw error but horizontal shear in wake of another wind turbine

"Apparent Yaw Error"

Both beams in free wind



1st beam in the wake, 2nd beam in free wind

2nd beam in the wake, 1st beam in free wind

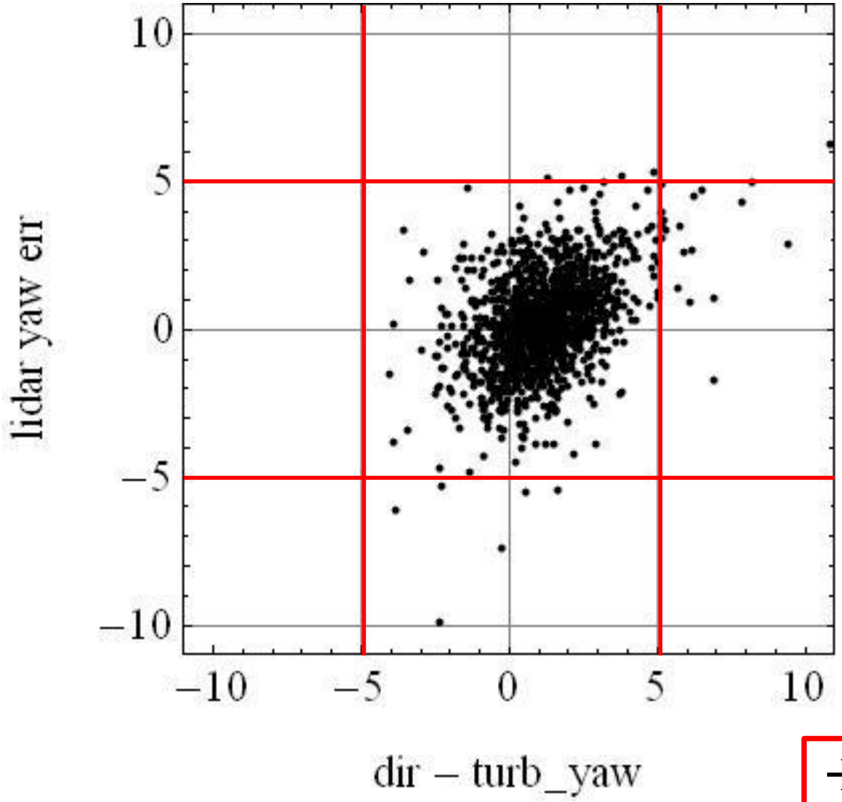
Appear like huge yaw error

Can detect when the beam is in the wake

Deviation 3: Wind direction measurement

IEC 61400-12-1:
”The […] uncertainty of the wind direction measurement should be less than 5°.”

“Apparent Yaw Error” vs true yaw error



Turbine in normal operation, outside wake of neighboring turbines:

→The lidar gives a yaw error within the same range as the vane,

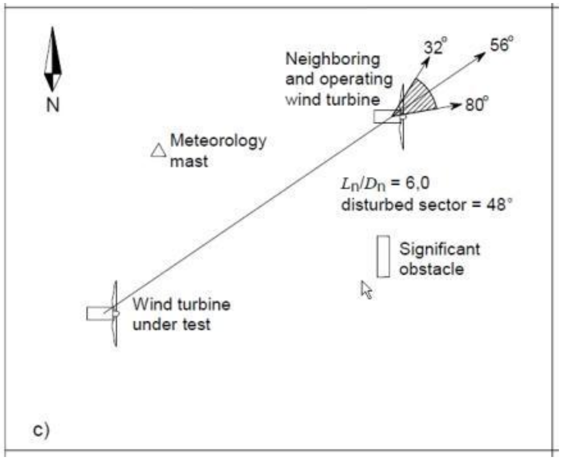
→but with a poor correlation.

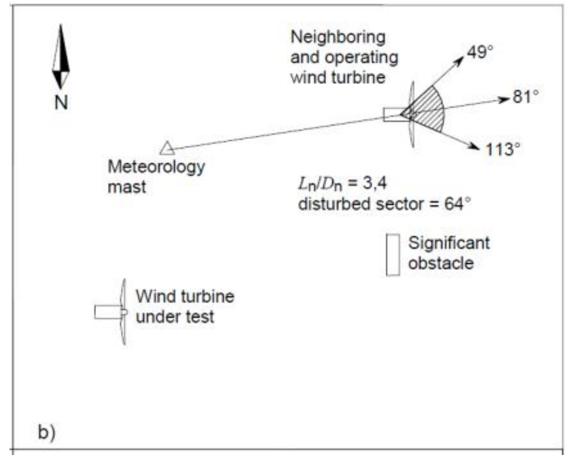
→Small yaw error, within the vane measurement uncertainty range (5°)

→ Indication that the lidar is able to conform to the 5° requirement
→ But needs to be formally investigated

Deviation 4: wind sector definition

IEC 61400-12-1:





The wind turbine is in the wake of the neighboring turbine.

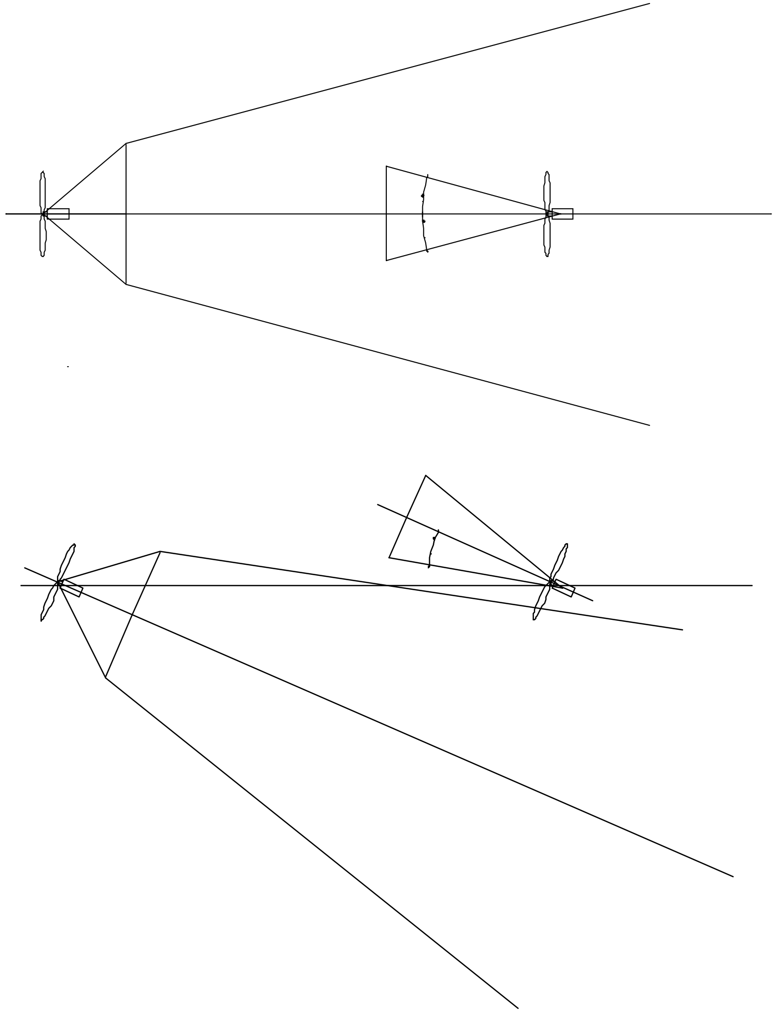
The mast is in the wake of the neighboring turbine.

Sectors to be exculded:

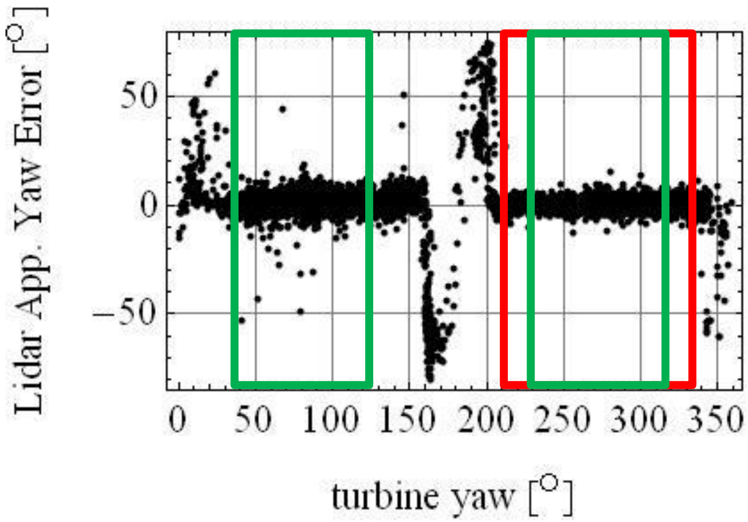
- Centered on the direction from the neighboring turbine and the turbine under test/mast
- The width is given by: $\alpha = 1.3 \arctan\left(2.5 \frac{D_n}{L_n} + 0.15\right) + 0.10$

Deviation 4:
wind sector definition

Test turbine in wake of neighbouring turbine(beam angle 30deg)



$$\alpha = 1.3Atan\left(2.5\frac{D_n}{L_n - L_b} + 0.15\right) + 10$$



Beam outside the wake as long as:

- Wind direction within new sector
- and the full beam angle $\beta < \alpha$

Conclusions

•Variations in measurement height almost within 2.5%
→ need to measure tilt

•Method to calibrate nacelle lidar under development

•Nacelle lidar measures the relative wind direction
→ need to combine to yaw signal

•Different definition of valid wind sector for power curve

•Other deviation : sampling frequency (to be investigated)

•Taking proper account of all these deviations, the nacelle lidar can be successfully used for standard power curve measurement.

•Nacelle lidar measures upwind → better correlation with wind at the rotor

•Nacelle lidar can measure in larger sector than mast → faster power curve

Thank you for your attention

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