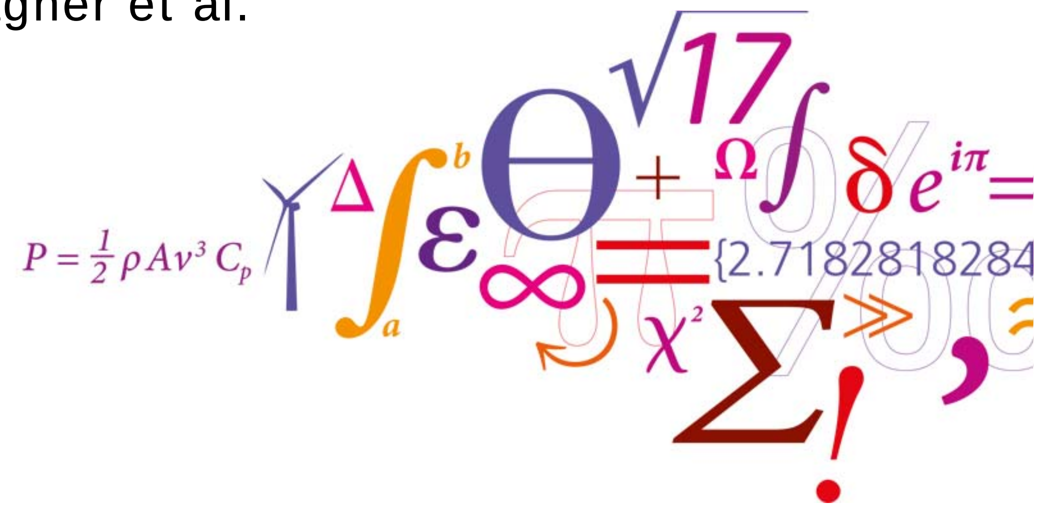
Lidar nacelle-based power curves -

can LiDaRs substitute conventional towers and instruments ?

Progress and status of the UniTTe project

Antoine Borraccino, Rozenn Wagner et al.

DTU Wind Energy



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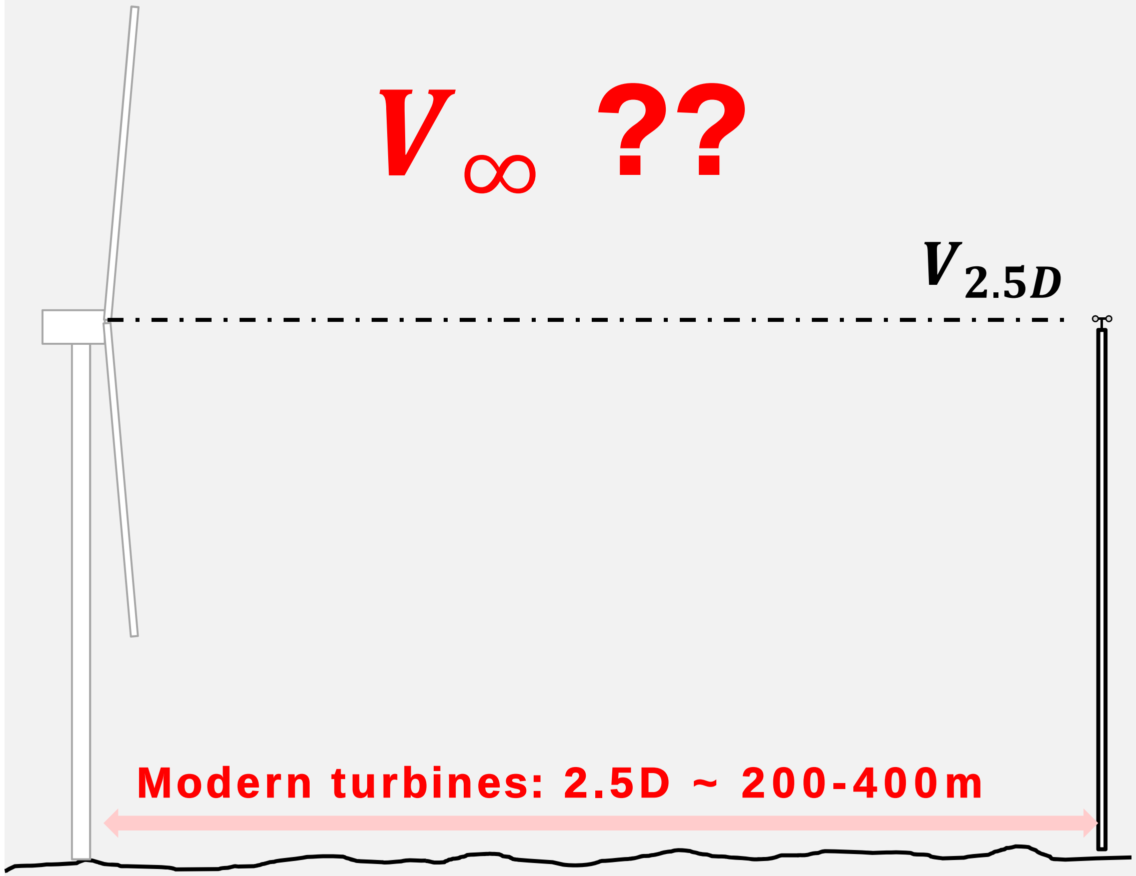
Turbine Testing

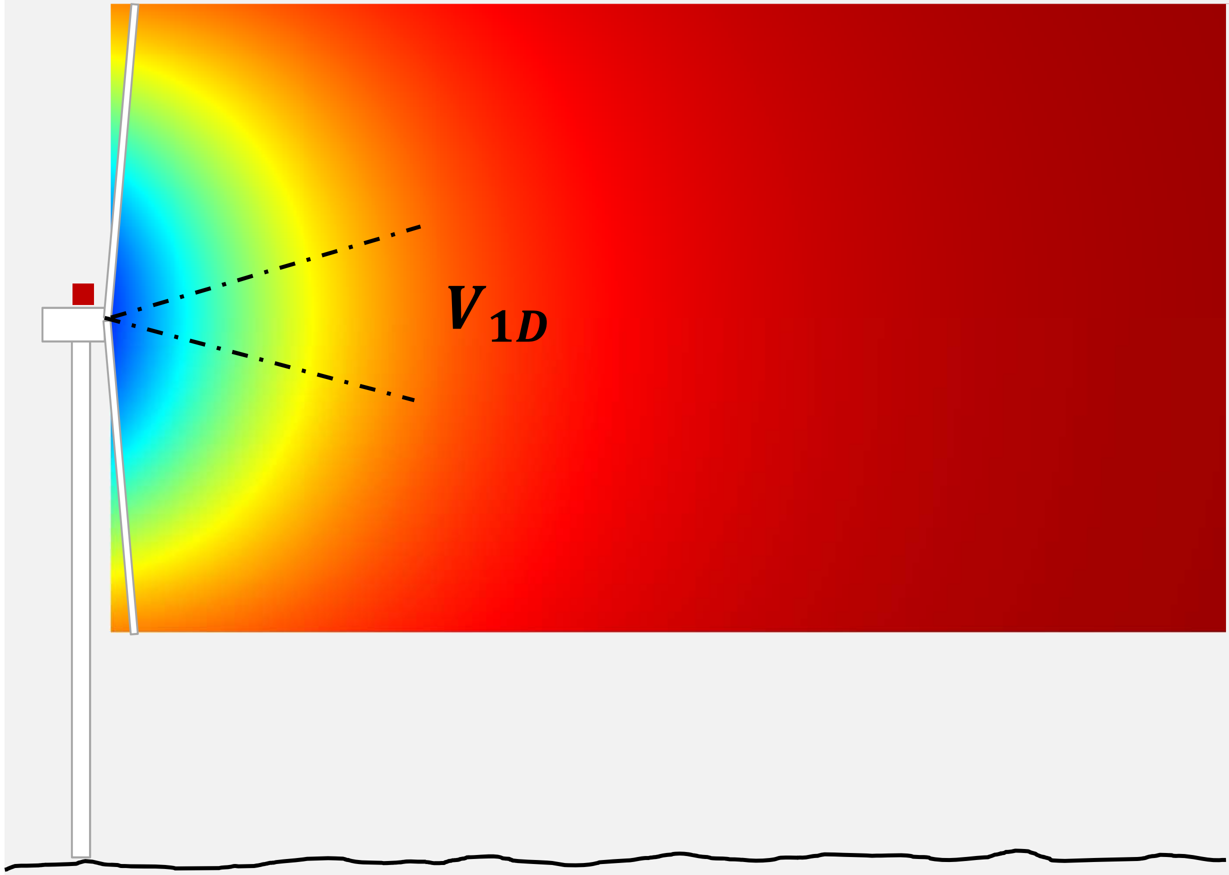
Are we doing it right?



Turbine testing requires to relate power and loads to “free wind speed”.

- How do we get the **free wind speed**?
- For very large turbines, is the wind speed at 2.5D still representative of the wind speed at the turbine location?
    - For very large turbine offshore?
    - In complex terrain?
- Nacelle lidars are interesting alternative to masts, but are they able to provide reliable measurements at those ranges?

UniTTe: Unified Turbine Testing

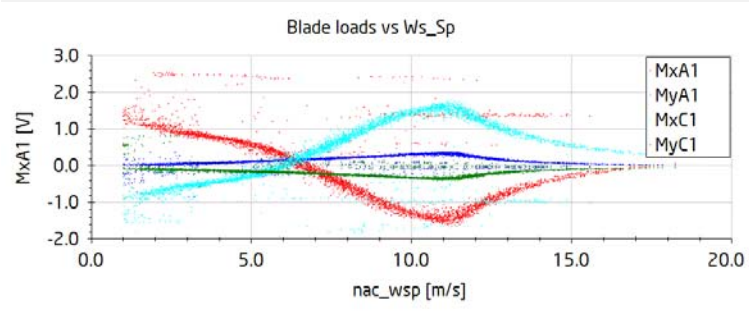


New methodology for power curve and loads assessment

- using profiling nacelle lidars
- based on near-flow measurement
- applicable in any type of terrain
- basis for the future standards (IEC, …)

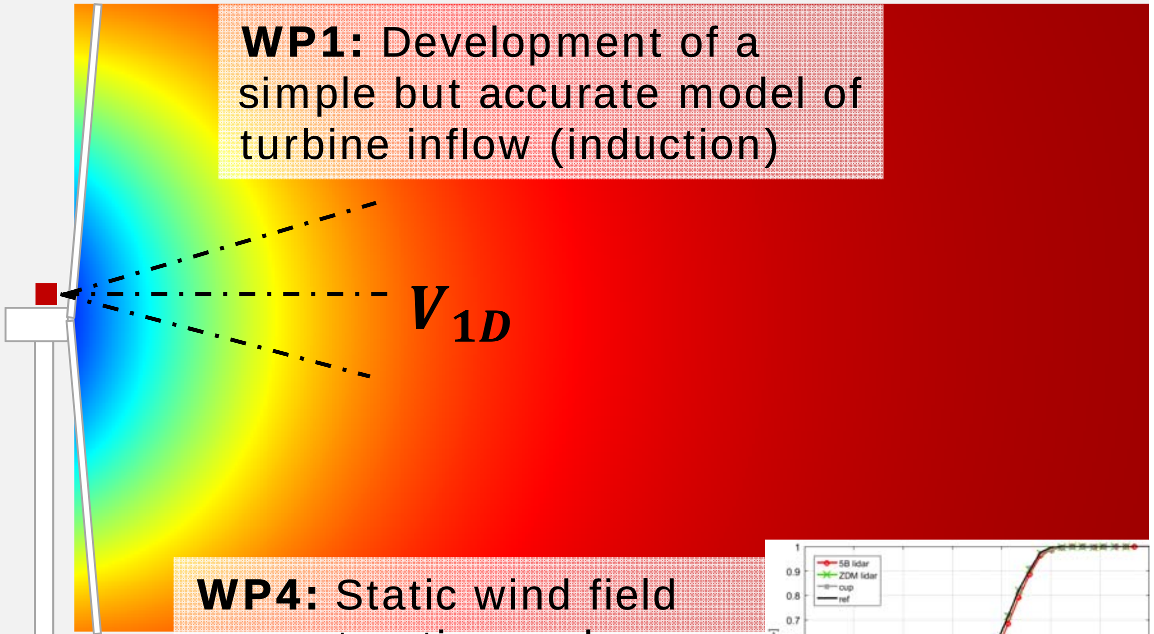
UniTTe: 5 work packages

WP5: Turbulence characterisation and loads assessment method

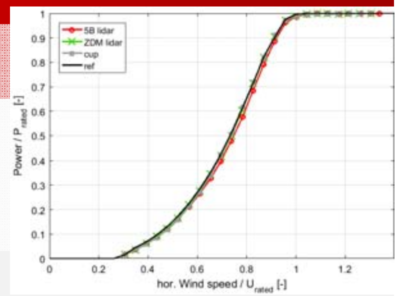


WP2: Calibration of nacelle lidars and measurement uncertainty estimation

WP1: Development of a simple but accurate model of turbine inflow (induction)



WP4: Static wind field reconstruction and power curve measurement method



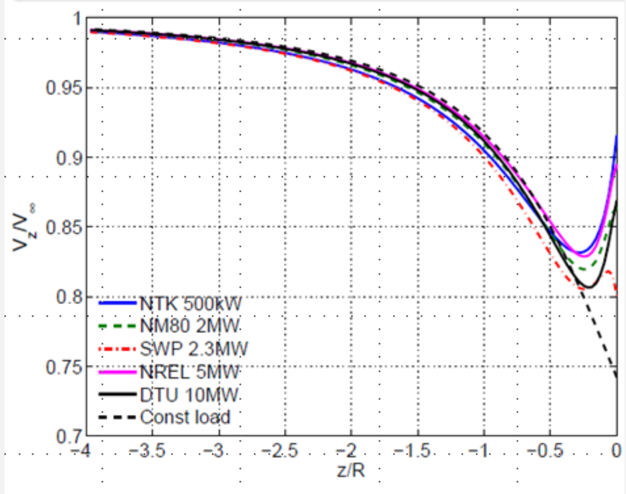
WP3: Full scale field measurement campaigns with nacelle lidars

WP1: Development of a simple induction model

1. Validation of CFD simulation against measurements (ShortRange WindScanner) of the inflow to 500kW Nordank turbine
2. CFD simulation of inflow to various turbines of various size from 500kW to 10MW

   → self similarity beyond 0.5 D upstream
3. Comparison of Vortex model (VM) to CFD

   → derivation of simple 2D induction model



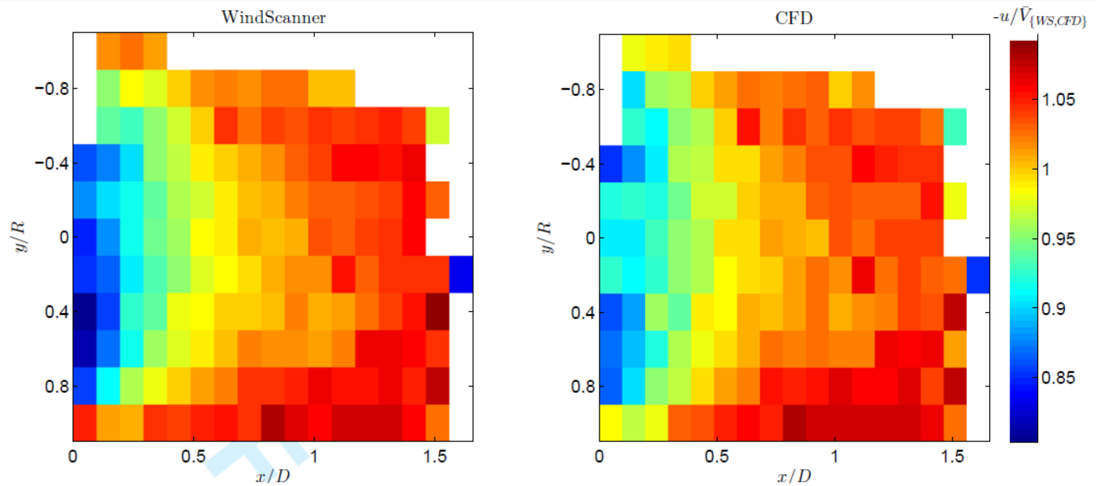
$$\frac{U(x)}{U_\infty} = 1 - a_0\left(1 + \frac{\xi}{\sqrt{1+\xi^2}}\right) f(\rho)$$

$$a_0 = \frac{1}{2}\left(1 - \sqrt{1 - \gamma C_t}\right)$$

is the axial induction factor at the rotor plane

$$\xi = \frac{x}{R};\ \rho = \frac{r}{R}$$

γ cst, account for cst loading assumption in VM



ARM Forsting et al. *Validation of a CFD model with a lidar based wind scanner upstream of wind turbine*. Submitted to Wind Energy

N Troldborg and ARM Forsting. *Characterisation of the induction upstream of wind turbines in uniform inflow*. Submitted to Wind Energy in October 2016.

WP2: Nacelle lidars calibration and measurement uncertainty

Why shall we calibrate?

- ❑ to ensure measurement traceability
- ❑ to establish the measurement uncertainty
- ❑ to provide a correction, if needed

Conclusions

- ➢ V_los uncertainties ~2-3% with 95% confidence
- ➢ Major contribution of cup anemometer uncertainties to the combined V_los uncertainties
- ➢ Need for better cup calibration procedures!

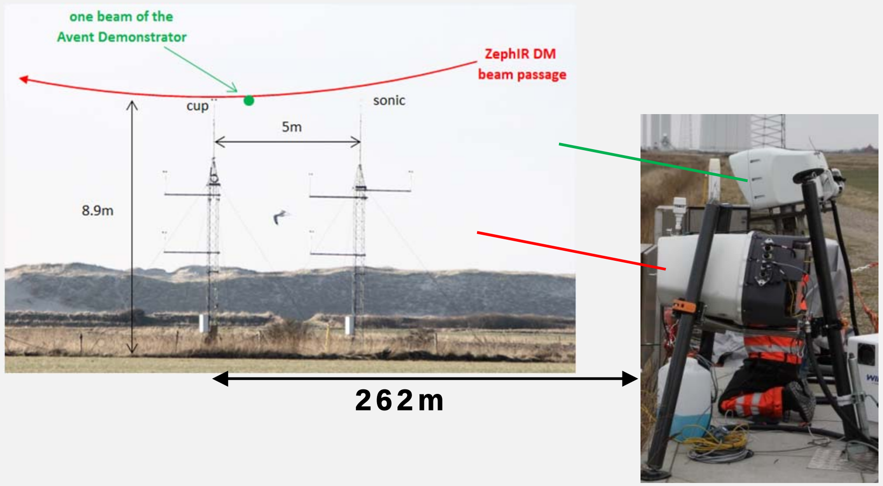
A Borraccino, M Courtney and R Wagner. *Generic methodology for calibrating profiling nacelle lidars*. DTU Wind Energy E-0086.

A Borraccino and M Courtney. *Calibration report for Avent 5-beam Demonstrator lidar*. DTU Wind Energy E-0087.

A Borraccino and M Courtney. *Calibration report for ZephIR Dual-Mode lidar (unit 351)*. DTU Wind Energy E-0088.

Method: the white box approach

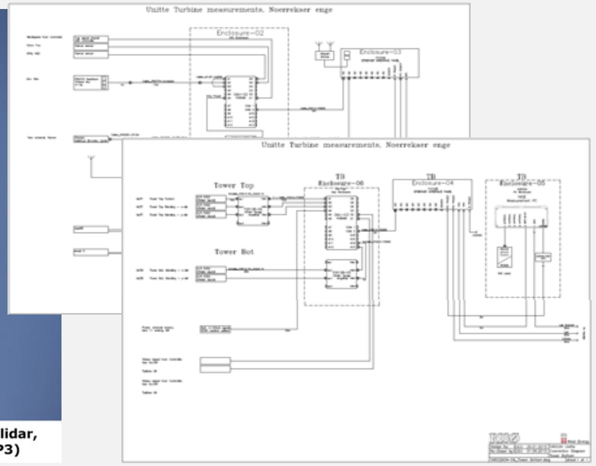
1. Calibrate inclinometers and beam angles
2. Calibrate and derive the uncertainty of the LOS velocity measurement
3. Combine and derive the uncertainty of the reconstructed wind parameters (e.g. horizontal wind speed)



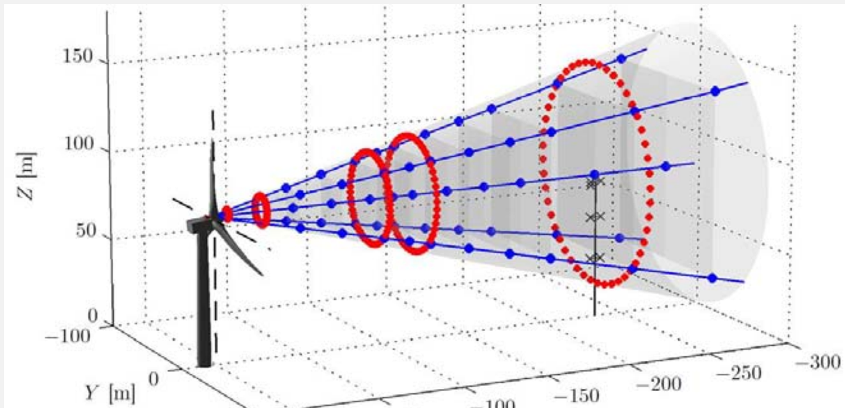
WP3: Full scale measurements

- WTG 4 in Nørrekær Enge
- Hub height met mast (top cup, vane, sonic, low tip cup)
- Strain gauges on turbine (edge/flapwise blade moments, top and bottom tower bending moments)
- Two nacelle lidars (Avent 5 Beam Demonstrator and ZephIR Dual Mode)
- 7 months measurements (25% free wind sector)

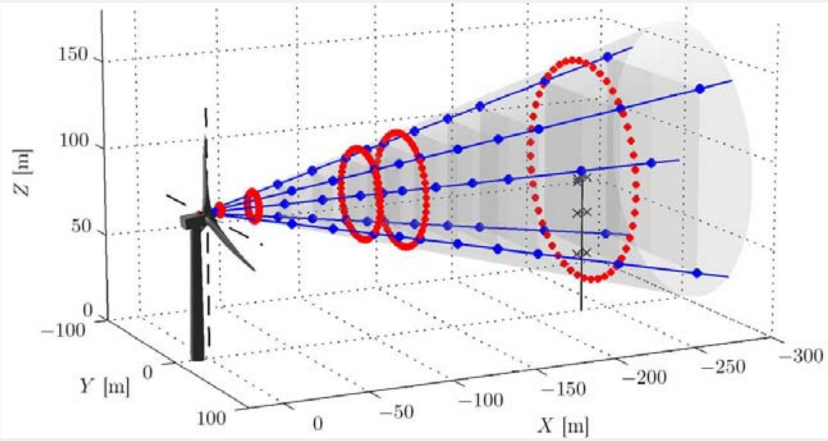
Fully instrumented turbine 04 in Nørrekær Enge, DK: ZephIR Dual-Mode lidar, 5-beam Avent lidar, spinner anemometer, full loads sensors (MC2, WP3)



Lidars view from the nacelle of turbine 04, Nørrekær Enge, DK (MC2, WP3)



WP4: Static Wind field Reconstruction & Power Curve



Developed in UniTTe:

- Combined wind model with induction model (from WP1)
- Can fit measurements taken close to the rotor and retrieve free wind speed, and wind characteristics “anywhere”
- Application to power curve measurement

Wind Field Reconstruction Approach:

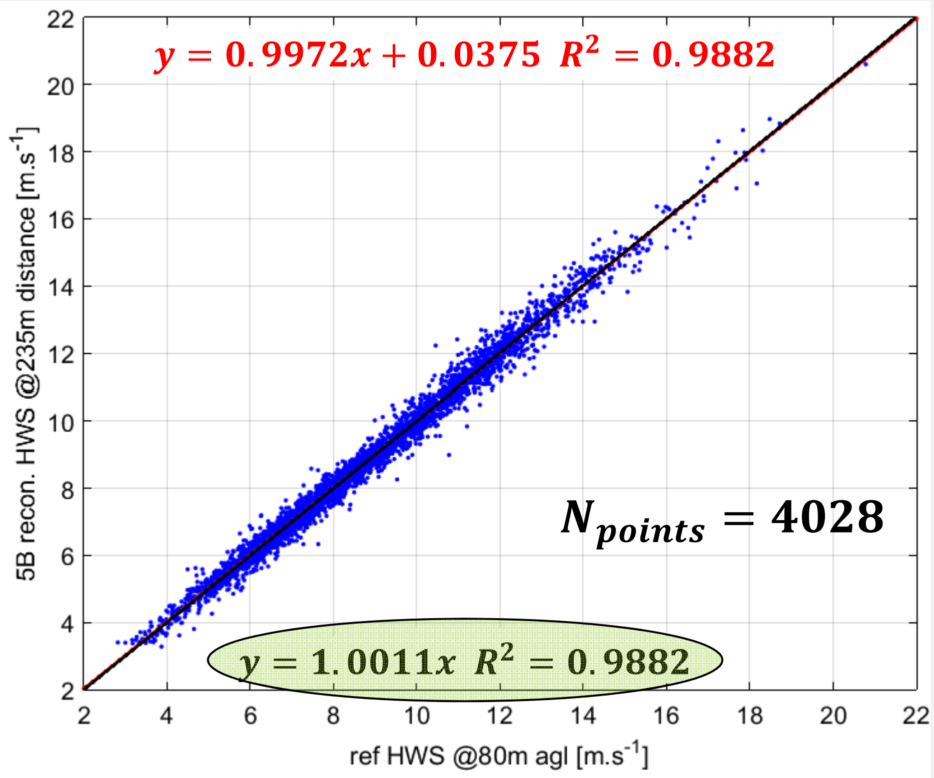
1. Fit the lidar LOS velocity measurement to a wind model (yaw misalignment, shear, veer, …) – iterative process minimising difference between simulated and measured V_los
2. Output wind field characteristics: free wind speed at hub height, yaw misalignment, shear, veer, induction factor …
3. Estimate wind vectors (wind speed, direction,…) at any wanted location

Lidar measurements @ multi-dist (near flow)

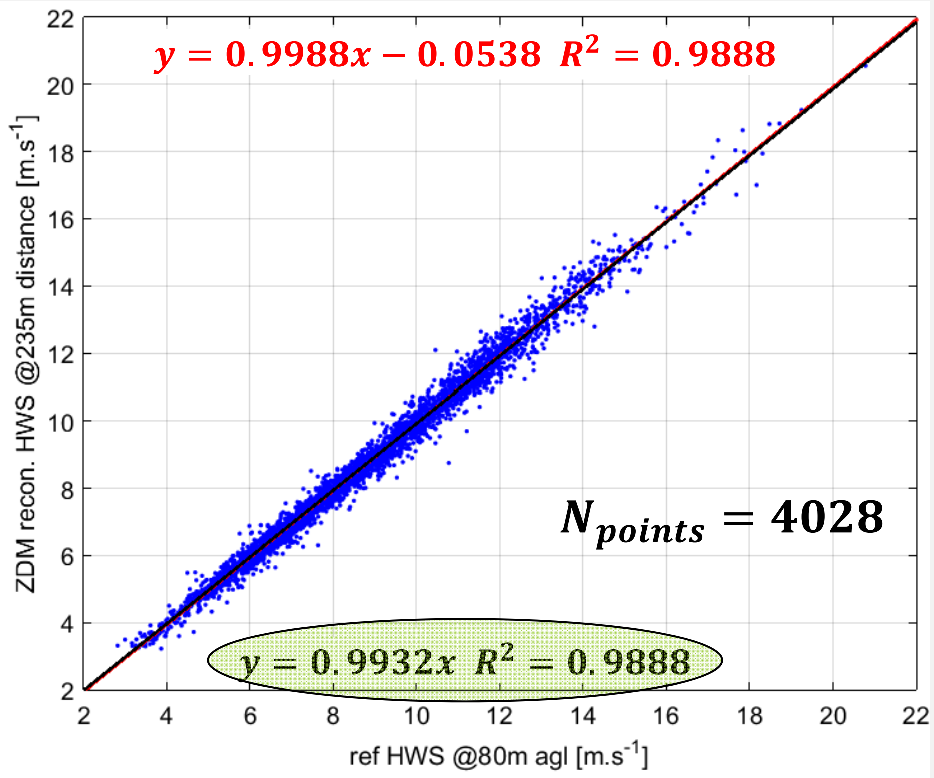
Mast comparison

HWS estimated @hub height and @2.5D distance
(main filters: free wind sector + LOS availability)

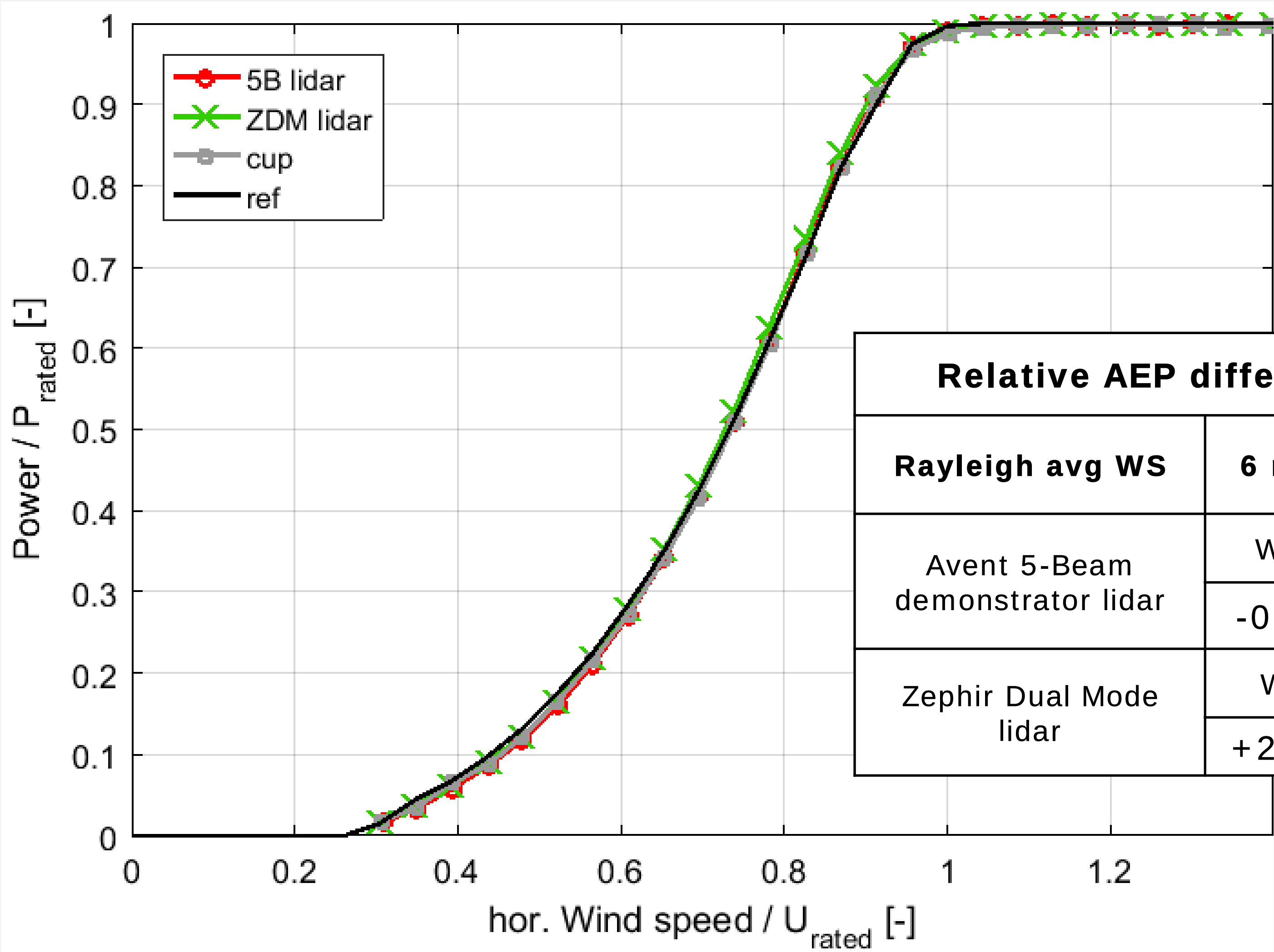
5B-Demo: use the 5 pts @[0.5 0.75 1.0 1.15] D



ZDM: use 10 pts @[0.3 1.0 1.25] D



Power curves with lidar measurements @ multi-dist (near flow)



Relative AEP difference to IEC-mast			
Rayleigh avg WS	**6 m/s**	**8 m/s**	**10 m/s**
Avent 5-Beam demonstrator lidar	Wspeed difference: +0.1%		
	-0.4%	-0.1%	+0.0%
Zephir Dual Mode lidar	Wspeed difference: -0.7%		
	+2.0%	+1.3%	+0.9%

Conclusions

Achievement so far (or very soon):

- Measurement uncertainty estimate – established method (technical reports published in 2015)

  → ***LOS velocity uncertainty = 2-3%***

  → ***Calibration of nacelle lidars at DTU WE***

- Simple and robust induction model in flat terrain (published by end of 2016)
- Wind field reconstruction method from short range nacelle lidar measurement in flat terrain (published by end of 2016)

  → ***No longer need to measure at 2.5D***

- Assessment of turbulence measurement with commercial nacelle lidars (published by end of 2016)

  → ***Can retrieve the u-variance but not other parameters***

Coming next

- Adaptation of WFR method to measurements in **complex terrain** and demonstration campaign — *November 2016 to April 2017*
- **Proposal** for including nacelle-based lidar measurements for power curve measurement to **IEC standard** (61400-12-1) — *Beginning 2017*
- **Turbulence characterisation** from nacelle lidar measurements (flat terrain) — *October to December 2016*
- **Loads assessment** using nacelle lidar instead of met. mast measurements (flat terrain) — *Beginning 2017*

Thank you for your attention

Want to know more?

- **WebSite**: www.UniTTe.dk
- **Contacts**:
  - Speaker (PhD student in UniTTe): Antoine Borraccino borr@dtu.dk
  - Project manager: Rozenn Wagner rozn@dtu.dk

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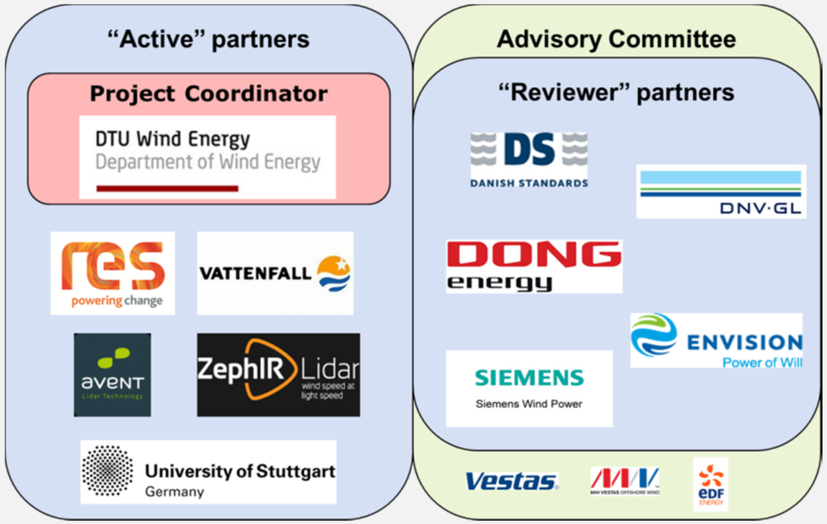
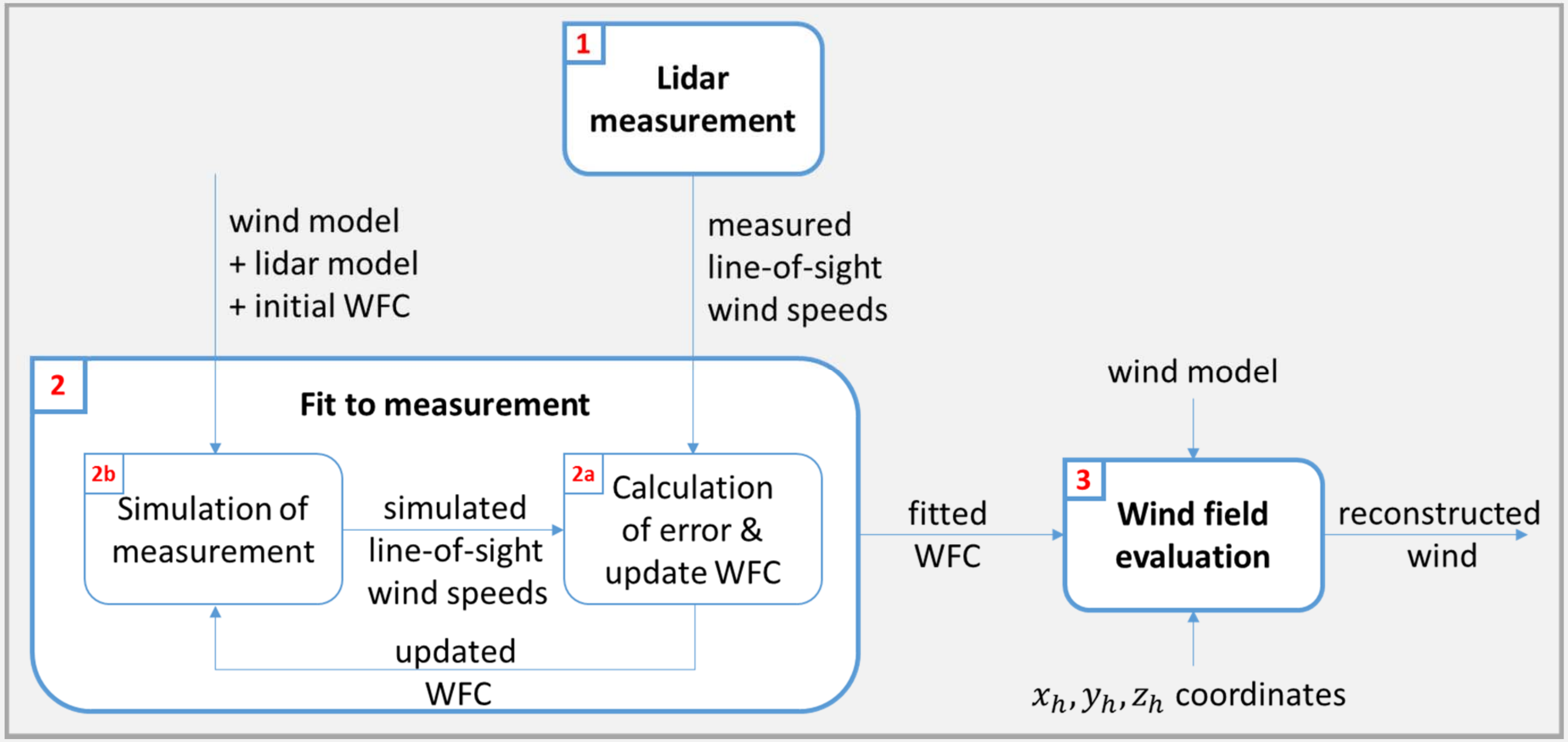


Wind Field Reconstruction: whatizit? how?

- **Doppler Wind LidaRs** do not …

… measure wind speed, wind direction, shear, …

- **They:**
  - only measure LOS velocities
  - estimate/reconstruct wind field characteristics (WFC)



Power performance verification: nacelle-mounted lidars, the future?

- Several possibilities for lidar measurements:

1) <u>2.5D distance</u>
   fitting wind speed + direction + shear to lidar-measured LOS velocities

2) <u>Multiple distances close to rotor</u>
   induction integrated in wind field reconstruction

$$\frac{U(x)}{U_\infty} = 1 - a\left(1 + \frac{\xi}{\sqrt{1+\xi^2}}\right)$$

$$a = \frac{1}{2}\left(1 - \sqrt{1 - C_t}\right)$$