The DLR Project

WETTER & FLIEGEN

Final Colloquium, 14.03.2012

Simulated Lidar Signals for Wake-Vortex Detection ahead of the Aircraft

Markus Hirschberger, Institute PA, Lidar division

Deutsches Zentrum
für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Aircraft moves towards wake vortex.

Goal:

Evasive Action

or

Encounter with Gust Load Alleviation

Airborne Lidar measurements ahead of the Aircraft

- Wetter & Fliegen: Properties of on-board sensors
- Determination of full 3D wind vectors in clear air
- Feed-Forward-controller (active control)

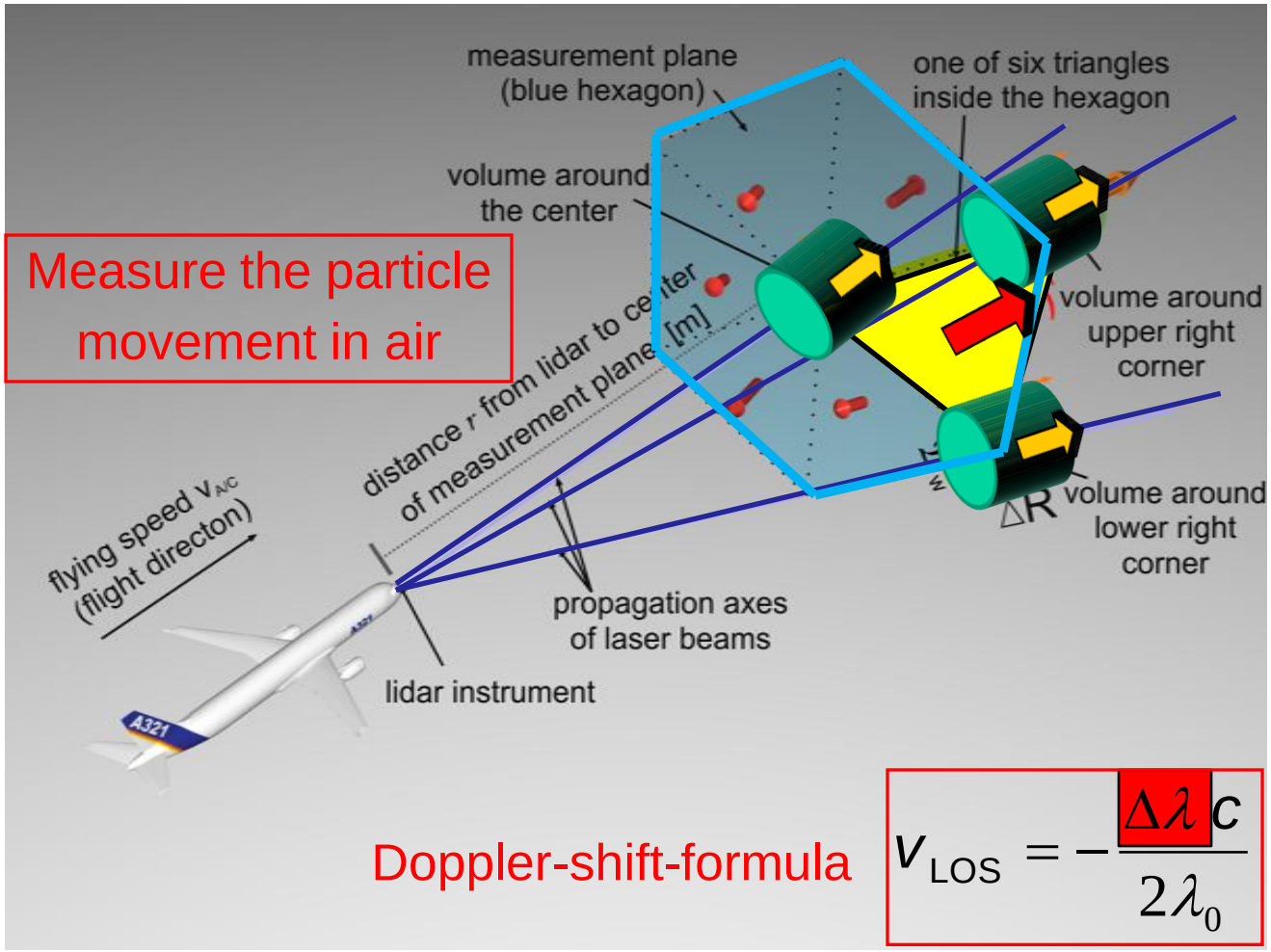
Requirements for feed-forward controller

Measurement property	landing approach
Range (distance)	30 – 150 m (120 – 600 m)
Measurement points (per slab)	min. 20 full 3D wind vectors
Error (standard deviation)	max. 2.5 m/s
Frequency (slabs per second)	min. 10 Hz
Volume (depth of each slab)	max. 3 – 15 m (12 – 60 m)

values for cruising speed in brackets!

1. Simulations of Doppler Wind Lidar (DWL)

Principle of wind velocity and direction measurement by onboard-DWL

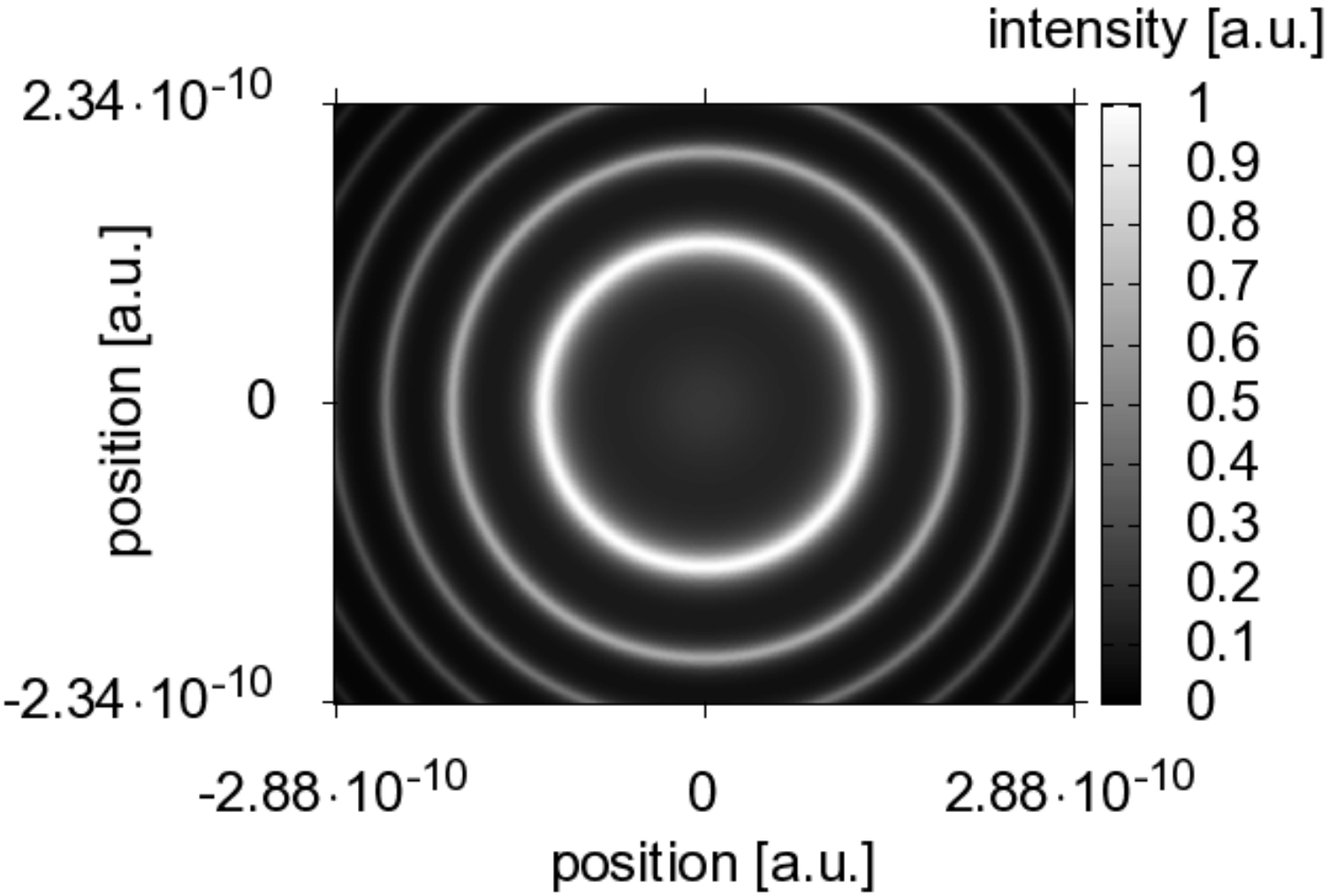


Measure the particle movement in air

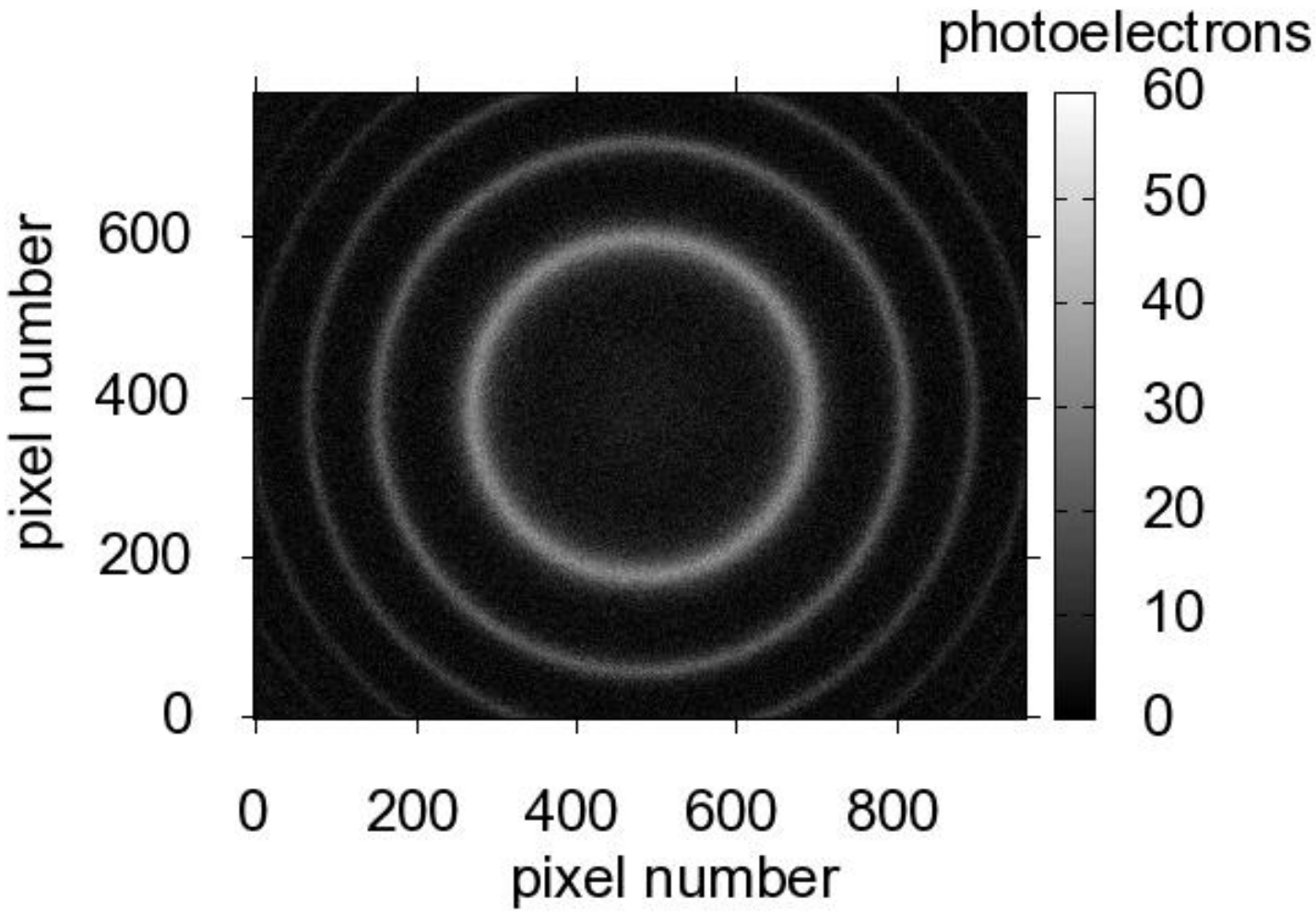
Doppler-shift-formula

$$v_{\mathrm{LOS}} = -\frac{\Delta\lambda\, c}{2\lambda_0}$$

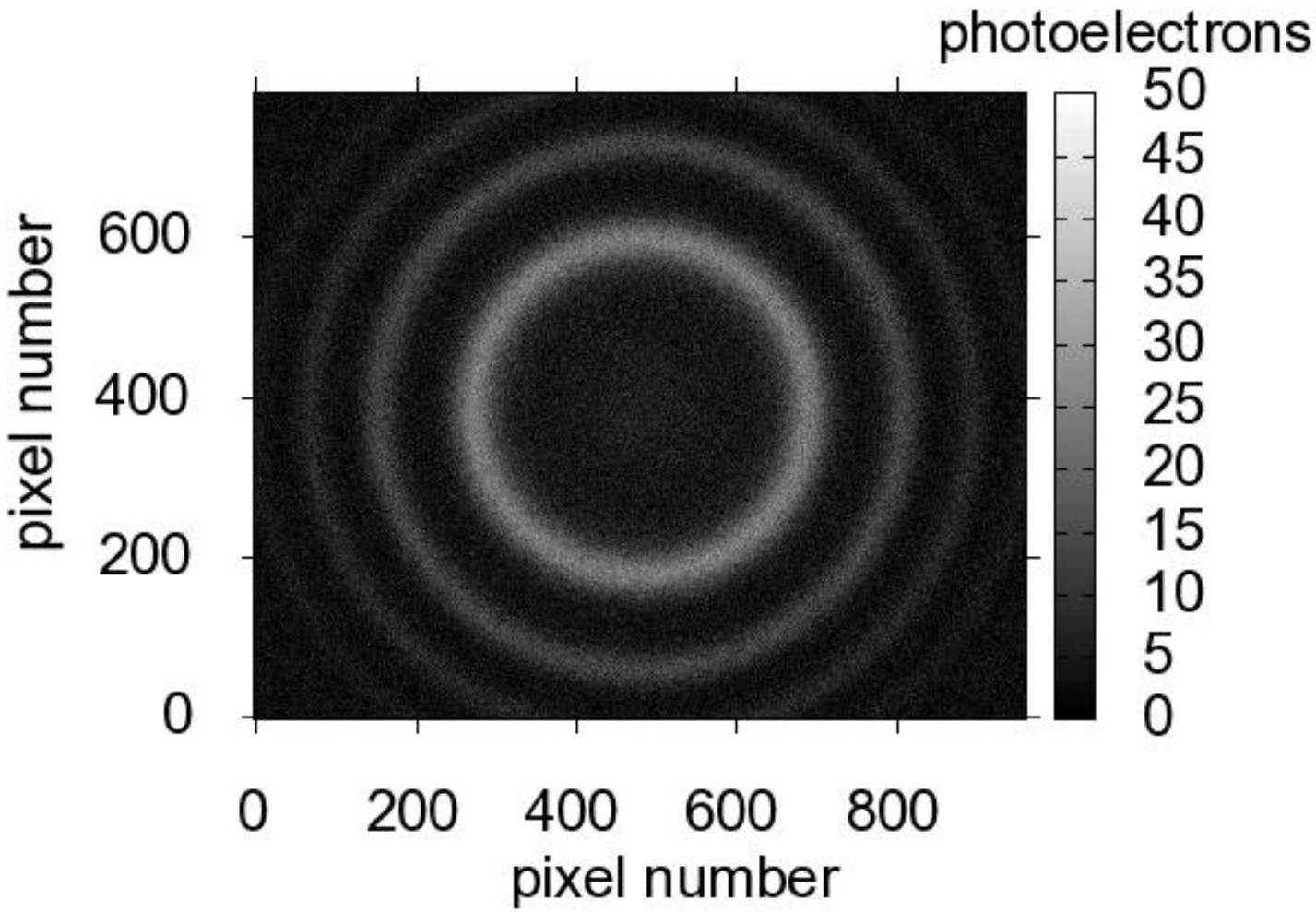
Forward simulation: Simulated FPI-diagrams of a Fringe-Imaging DWL



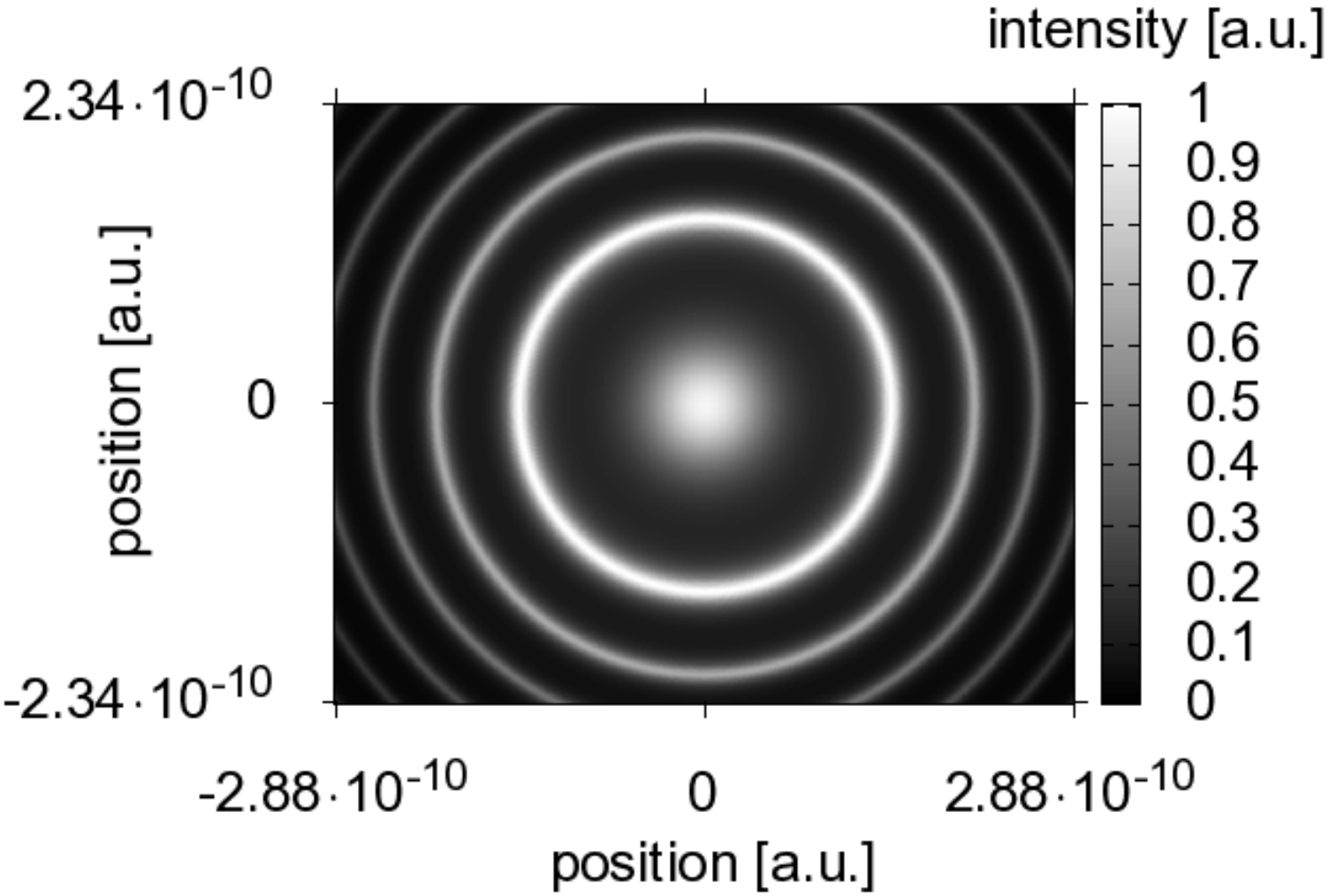
Forward simulation: Simulated FPI-diagrams of a Fringe-Imaging DWL



Forward simulation: Simulated FPI-diagrams of a Fringe-Imaging DWL



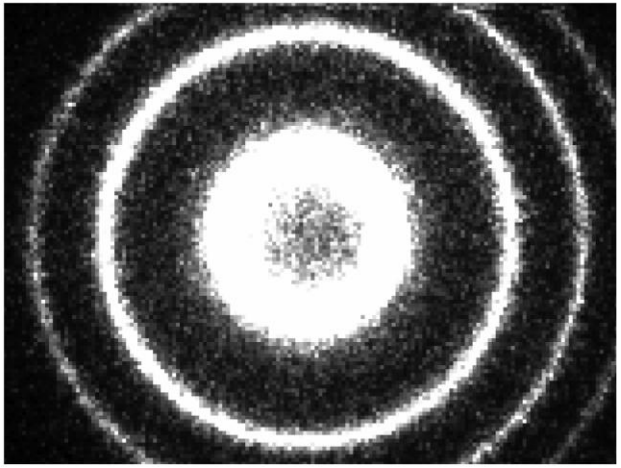
Forward simulation: Simulated FPI-diagrams of a Fringe-Imaging DWL



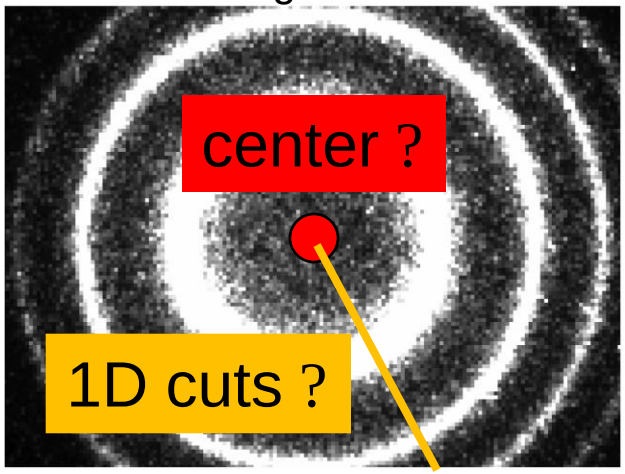
Interferograms (ICCD) of Onboard-measurements: AWIATOR, Nov./Dez. 2006

reference signal

image 1



backscattering in dense clouds



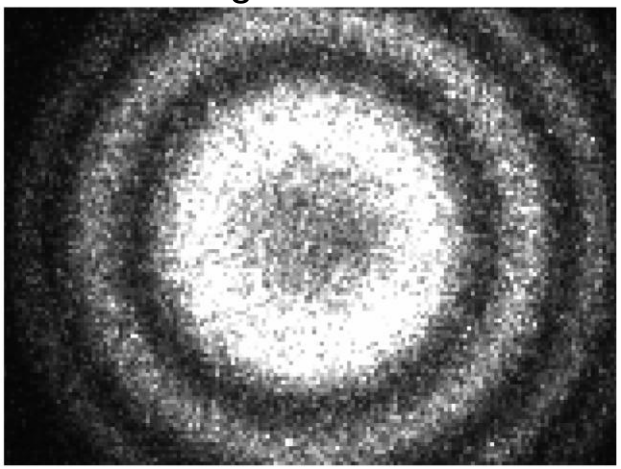
mainly Mie

image 2

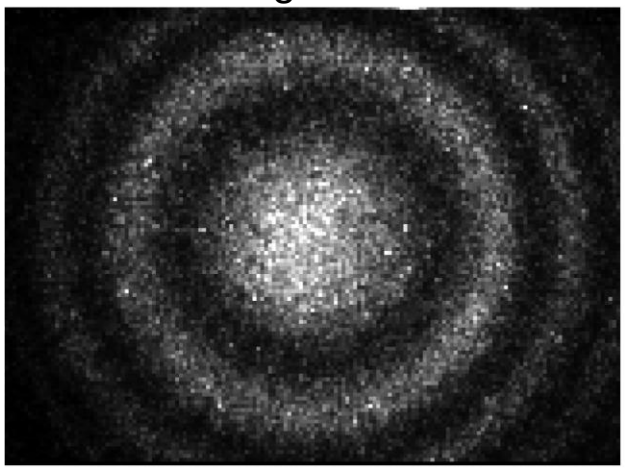
backscattering in 3600 m altitude

mixture of Mie and Rayleigh

image 3



backscattering in 11900 m altitude

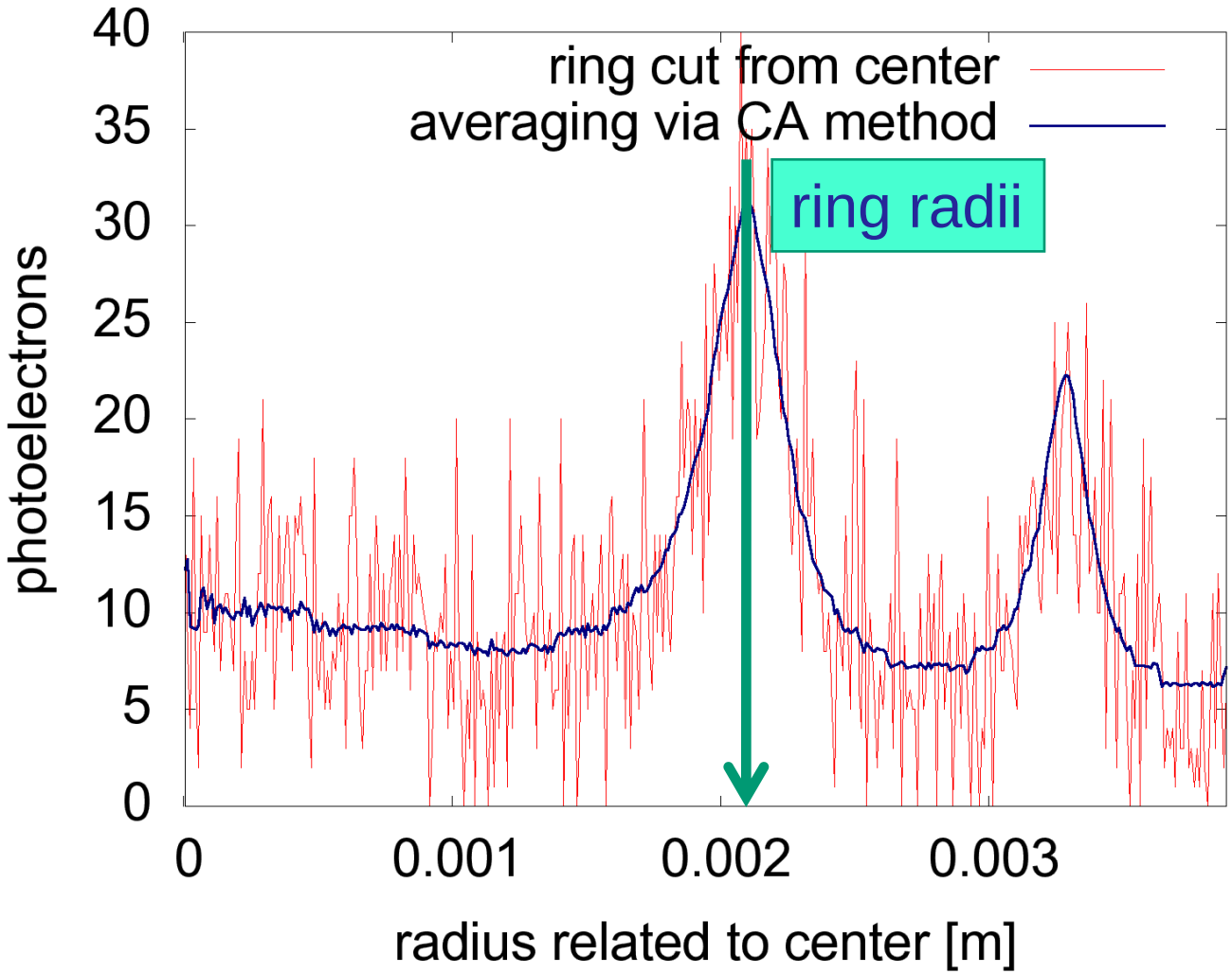


better visible Rayleigh-scattering

image 4

Jenaro Rabadan et al., Journal of Aircraft (2010)

Backward simulation: Calculation of radii

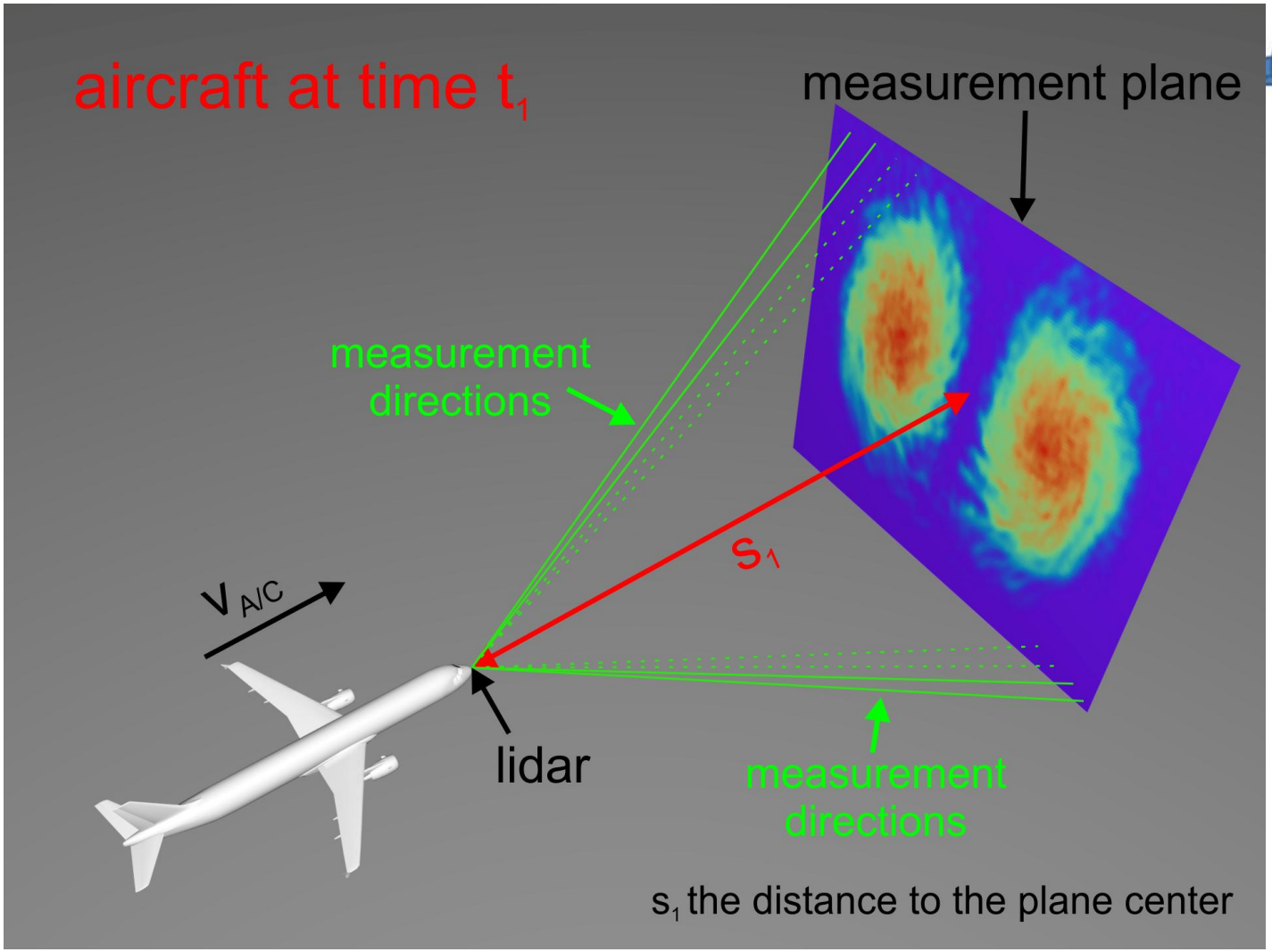


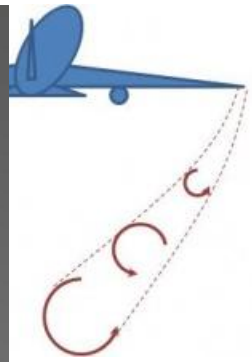
Results of DWL studies

- Error of peak radius or ring center of only 1/40 of a pixel with side length of 10 µm means already an error of 1 m/s at a wavelength of 355 nm !
- for exactly known FP ring center at a distance of 56 m and depth of 10 m 20 ring diagrams are sufficient for a bias and standard deviation < 2 m/s of v_{LOS}
- for determination of center at the same conditions as above bias of 7 m/s and a standard deviation of 3 m/s for v_{LOS}
- Evaluation needs too much time

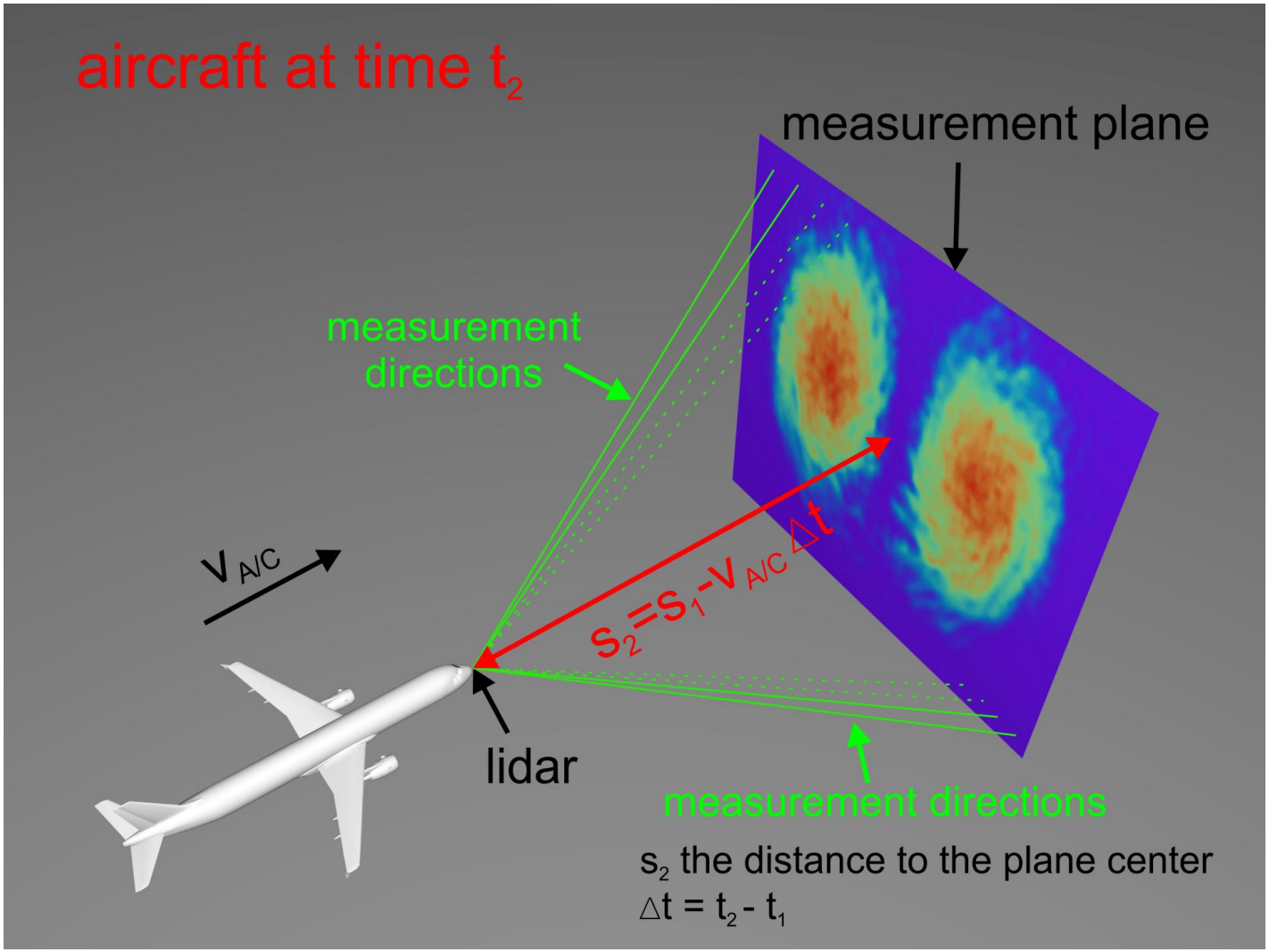
M.C. Hirschberger and G. Ehret, „Simulation and high-precision wavelength determination of noisy 2D Fabry-Pérot interferometric rings for direct-detection Doppler lidar and laser spectroscopy“, **Applied Physics B – Lasers and Optics 103, pp. 207-222 (2011).**

2. Simulations of a Backscatter Lidar for wind measurements

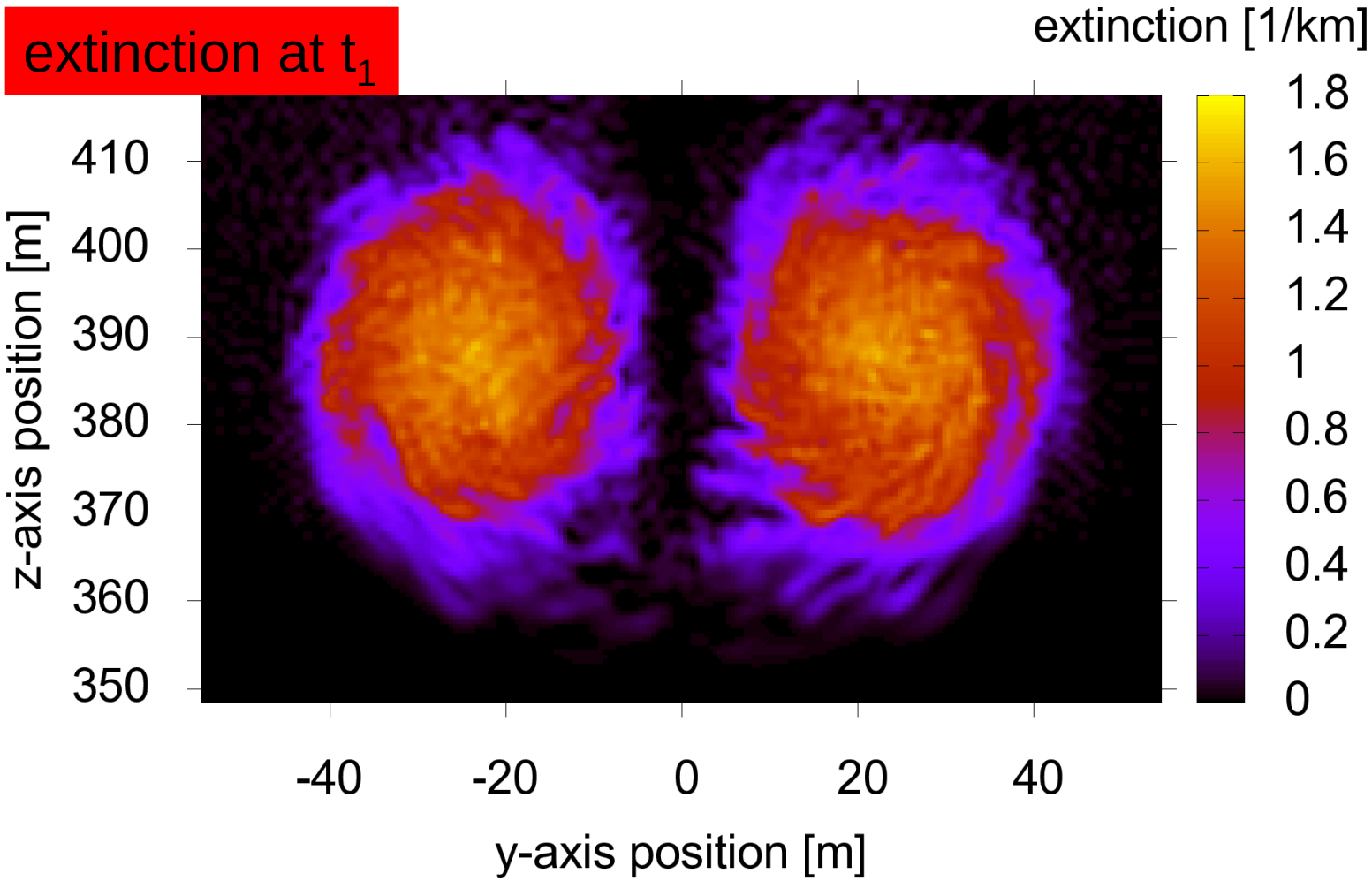




2. Simulations of a Backscatter Lidar for wind measurements

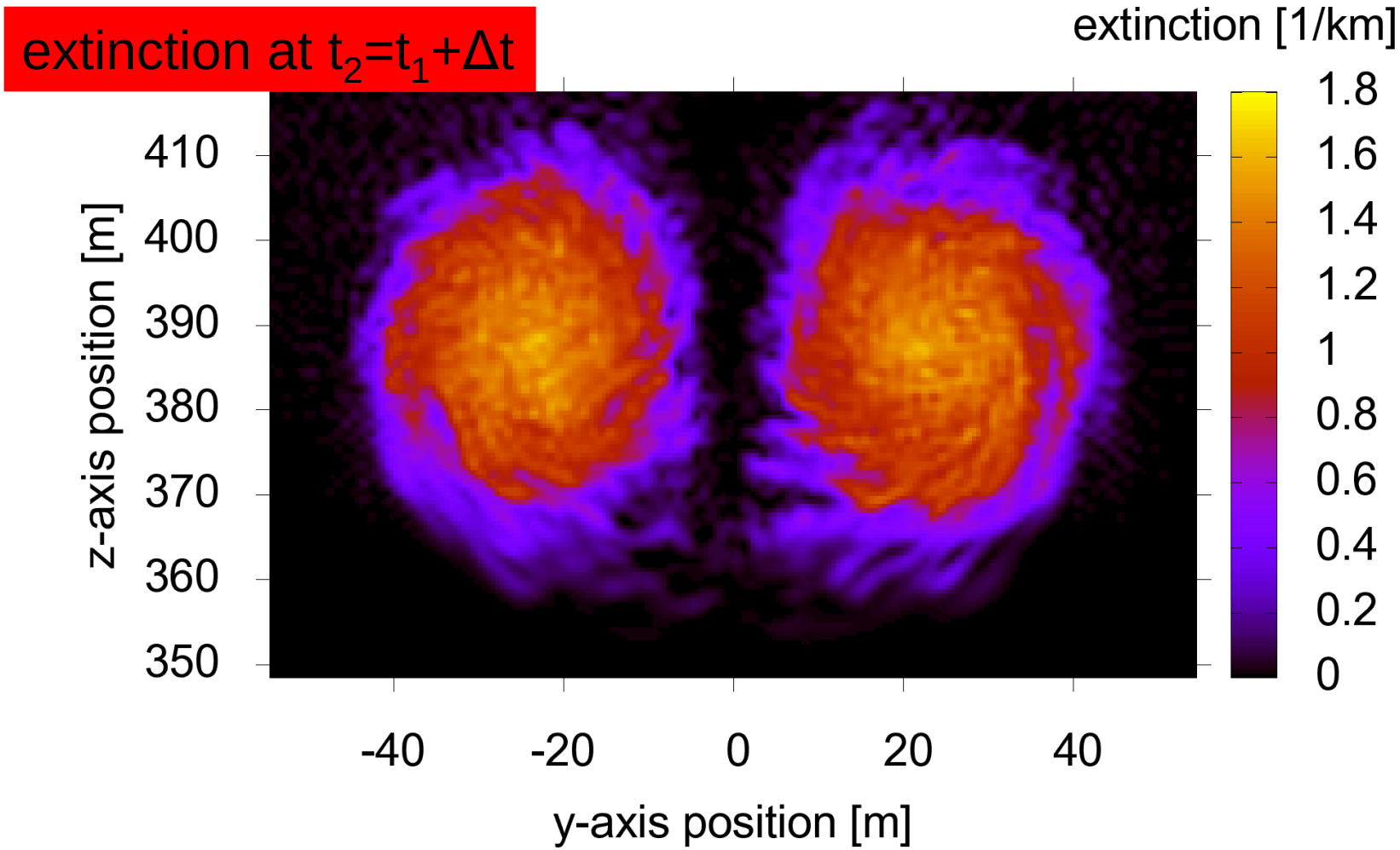


Wake Vortex Extinction profiles from Large Eddy Simulations



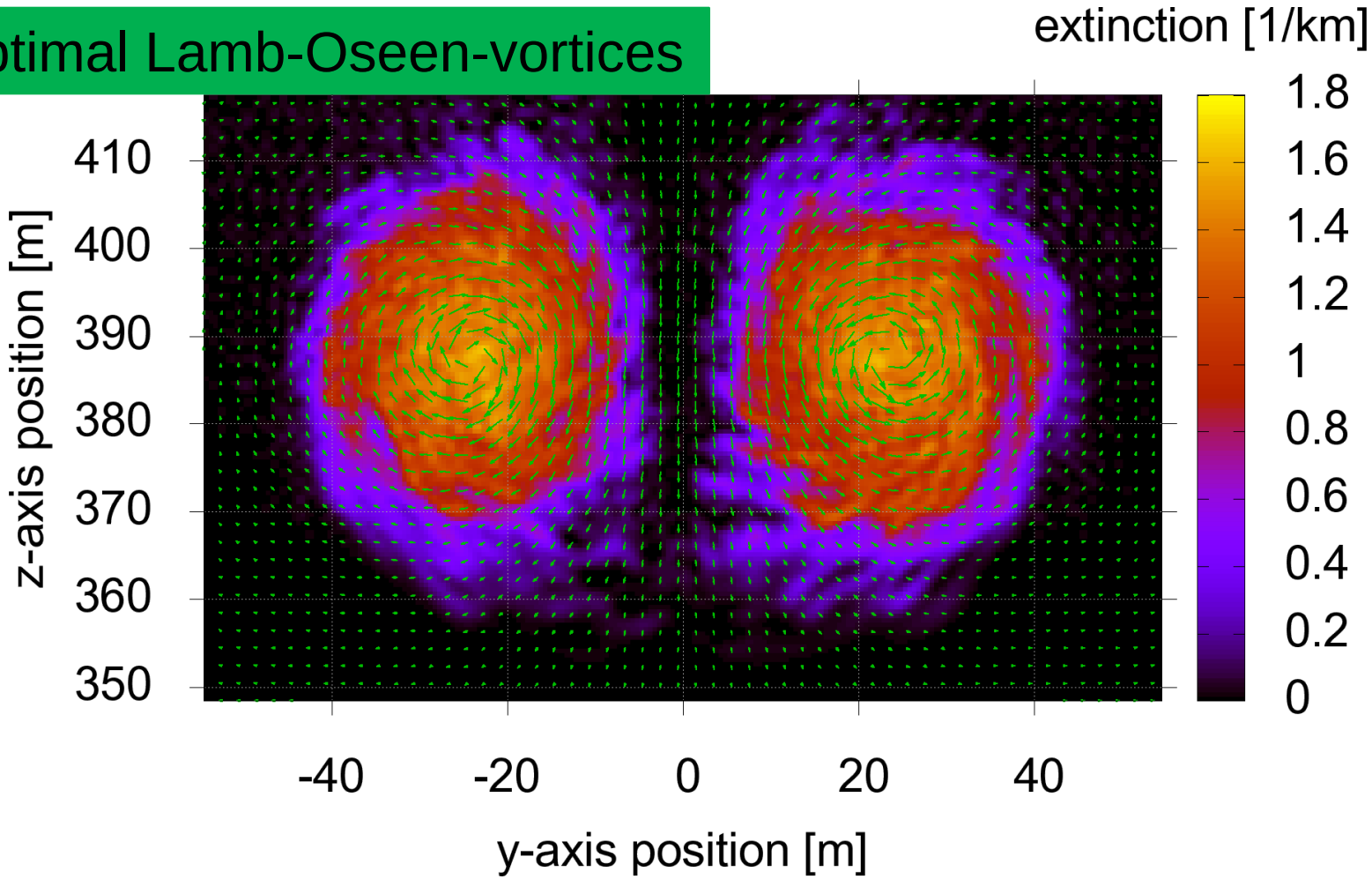
- extinction slab for A340 generated wake vortices, t*=40 s, ε*=0.01, N*=0.35

Wake Vortex Extinction profiles from Large Eddy Simulations



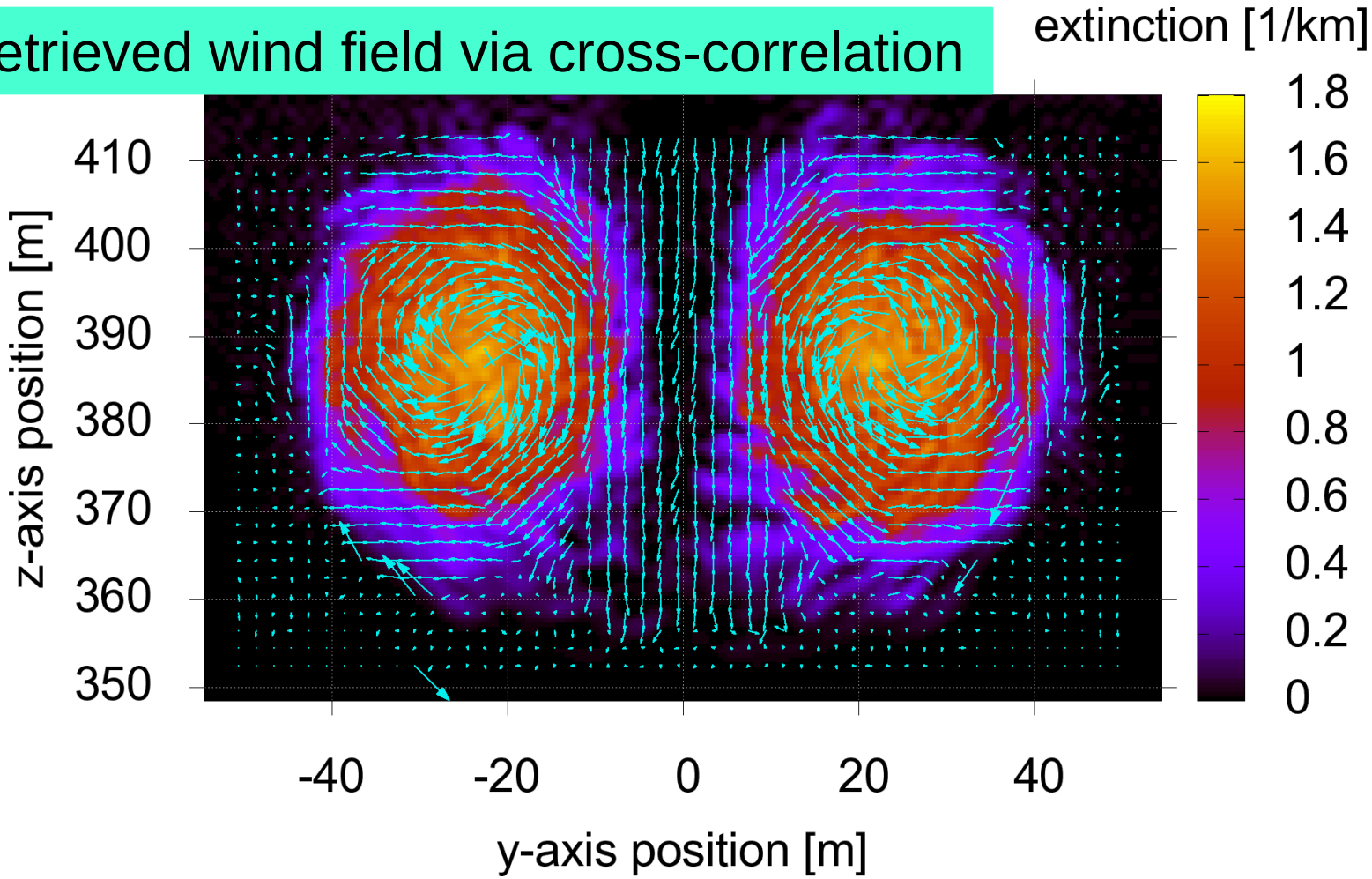
Wake Vortex Extinction profiles from Large Eddy Simulations

optimal Lamb-Oseen-vortices

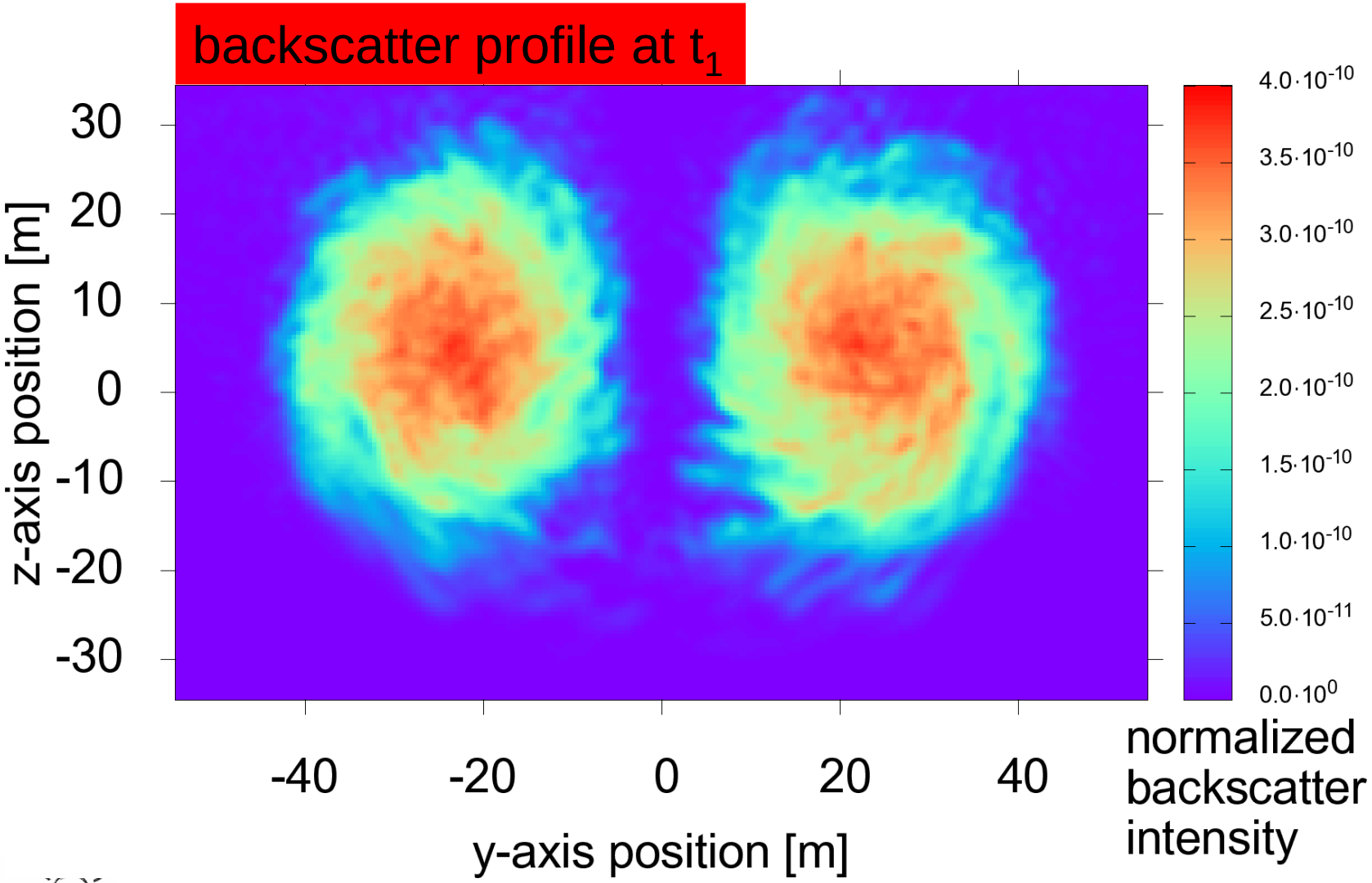


Wake Vortex Extinction profiles from Large Eddy Simulations

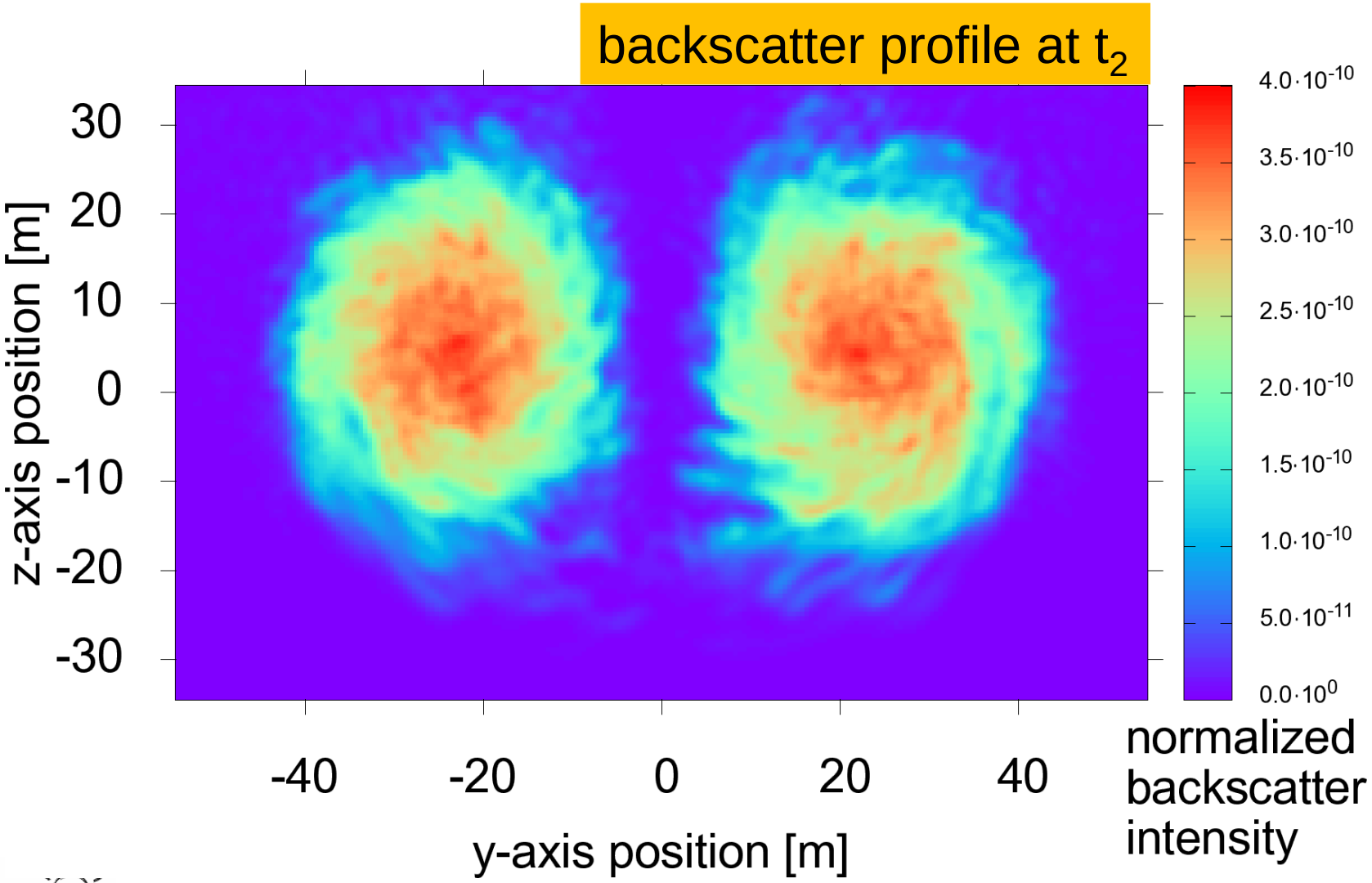
retrieved wind field via cross-correlation



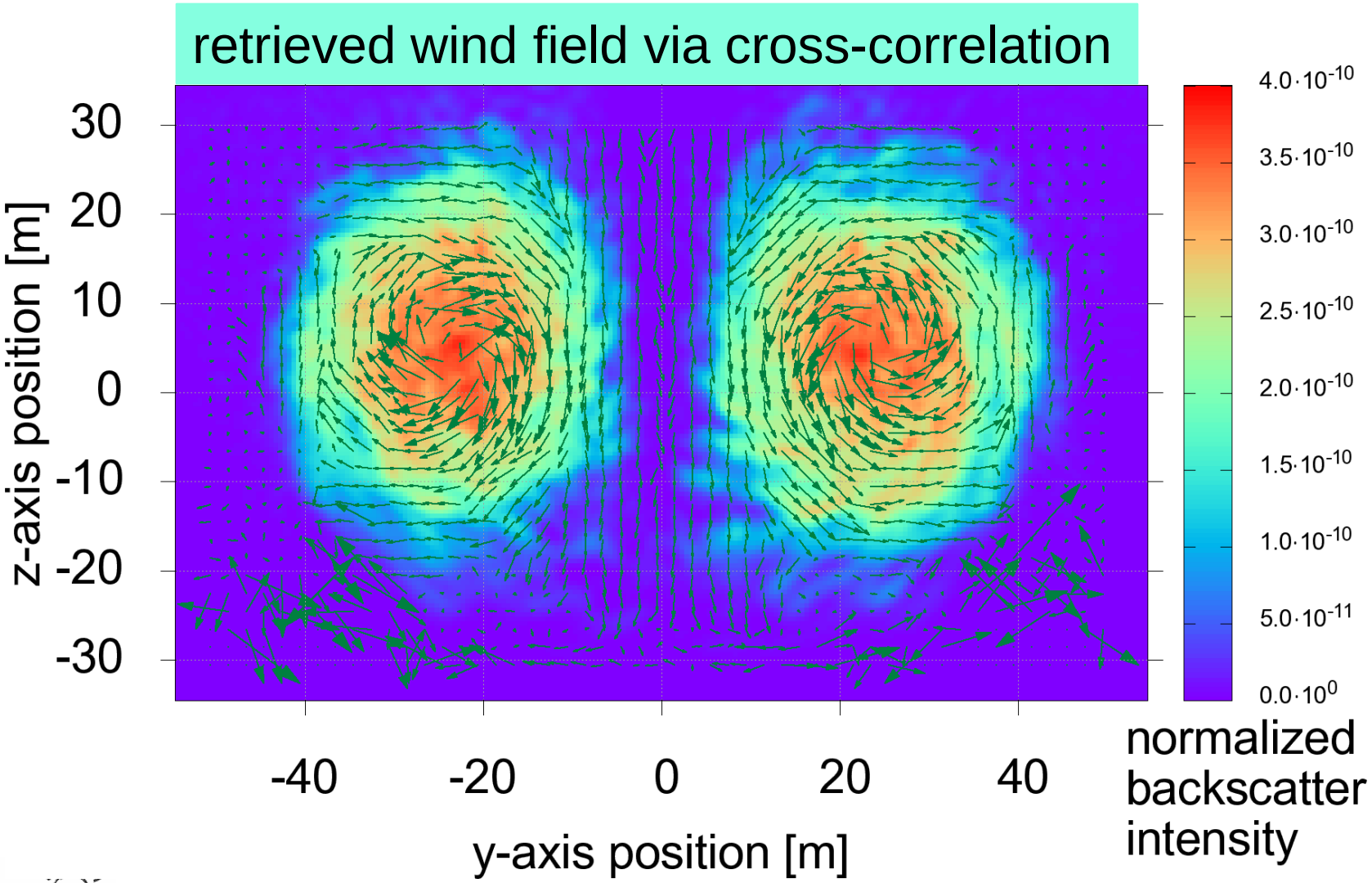
Backscatter profiles of Monte-Carlo simulations



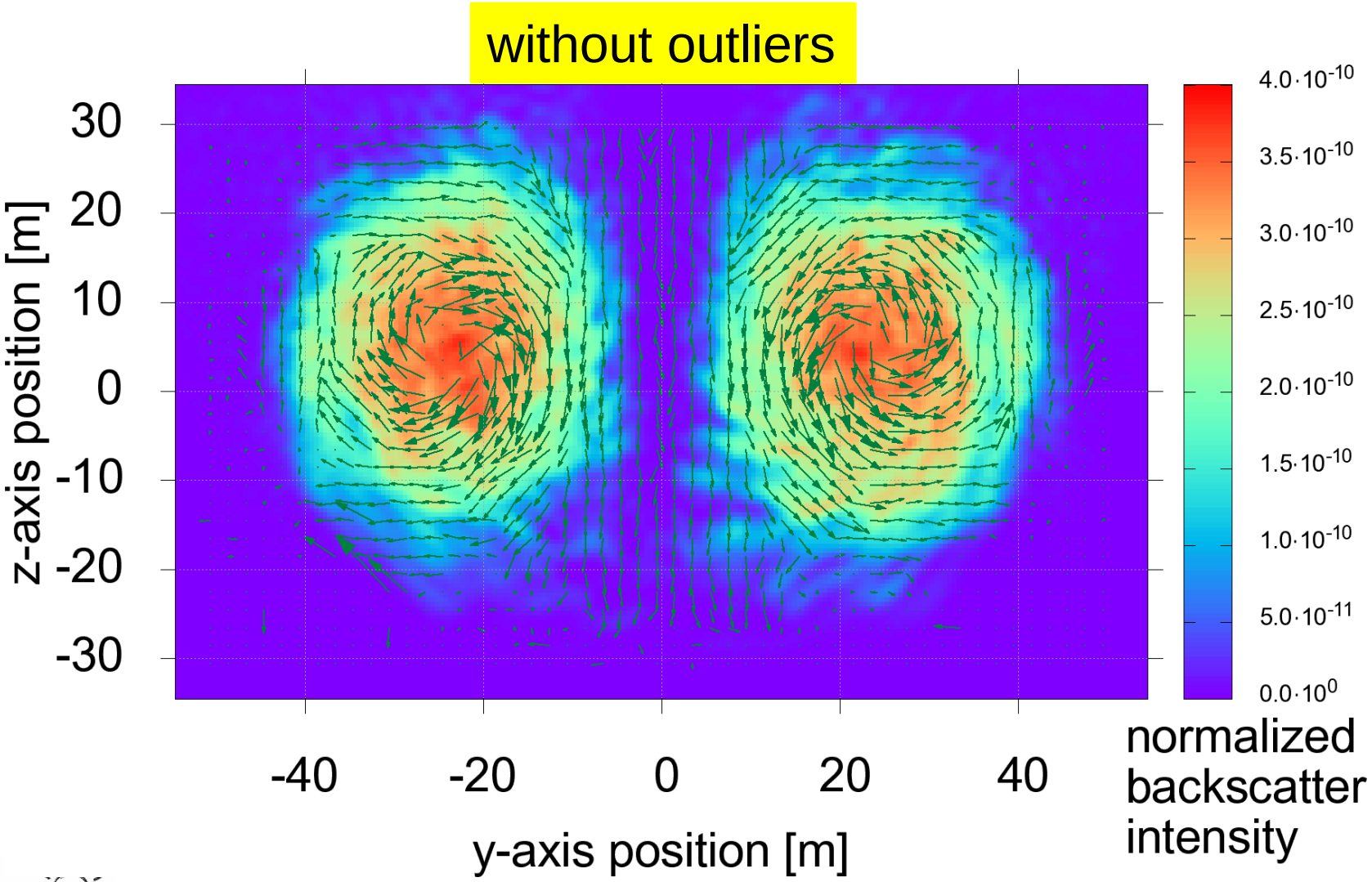
Backscatter profiles of Monte-Carlo simulations



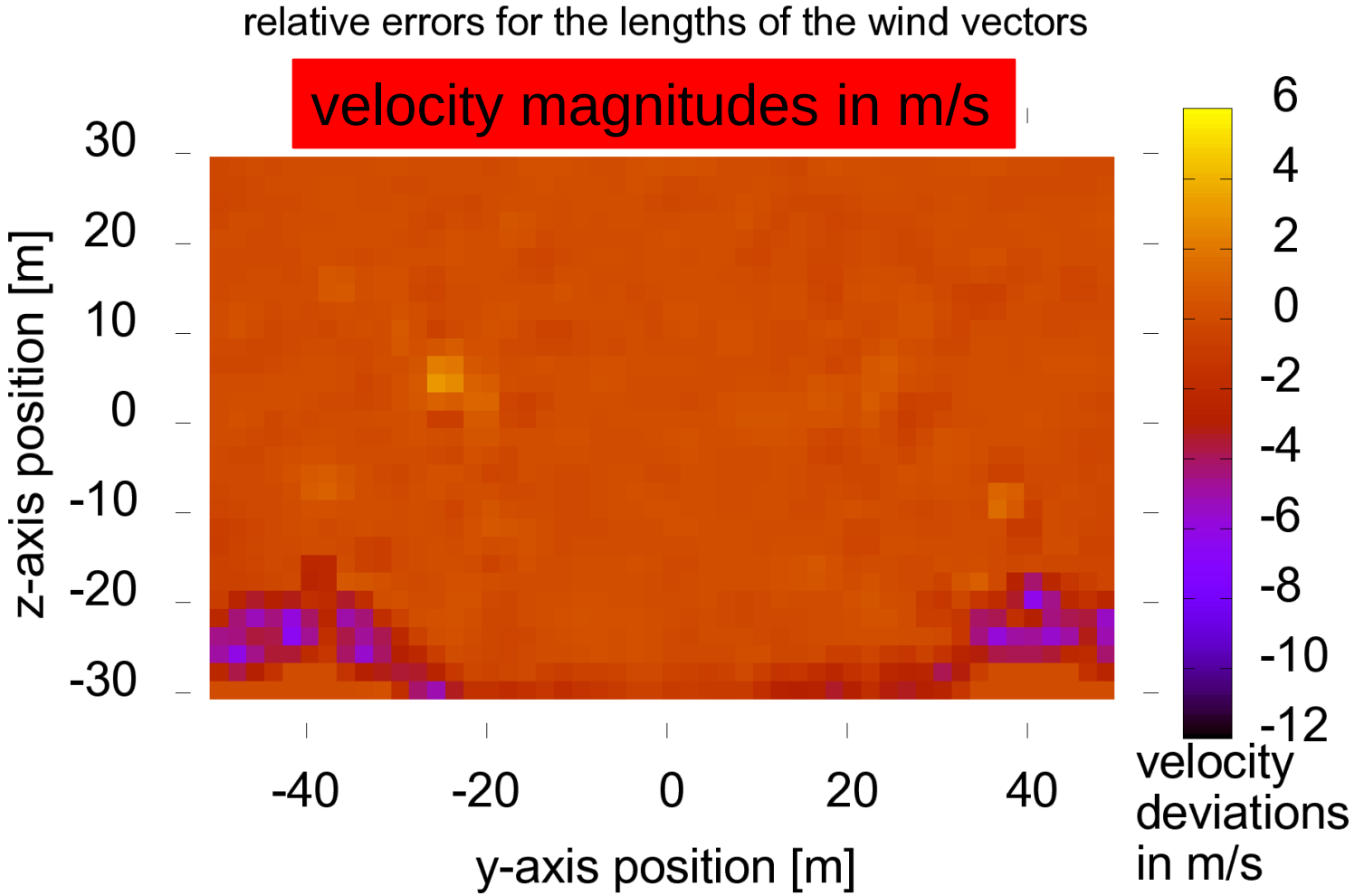
Backscatter profiles of Monte-Carlo simulations



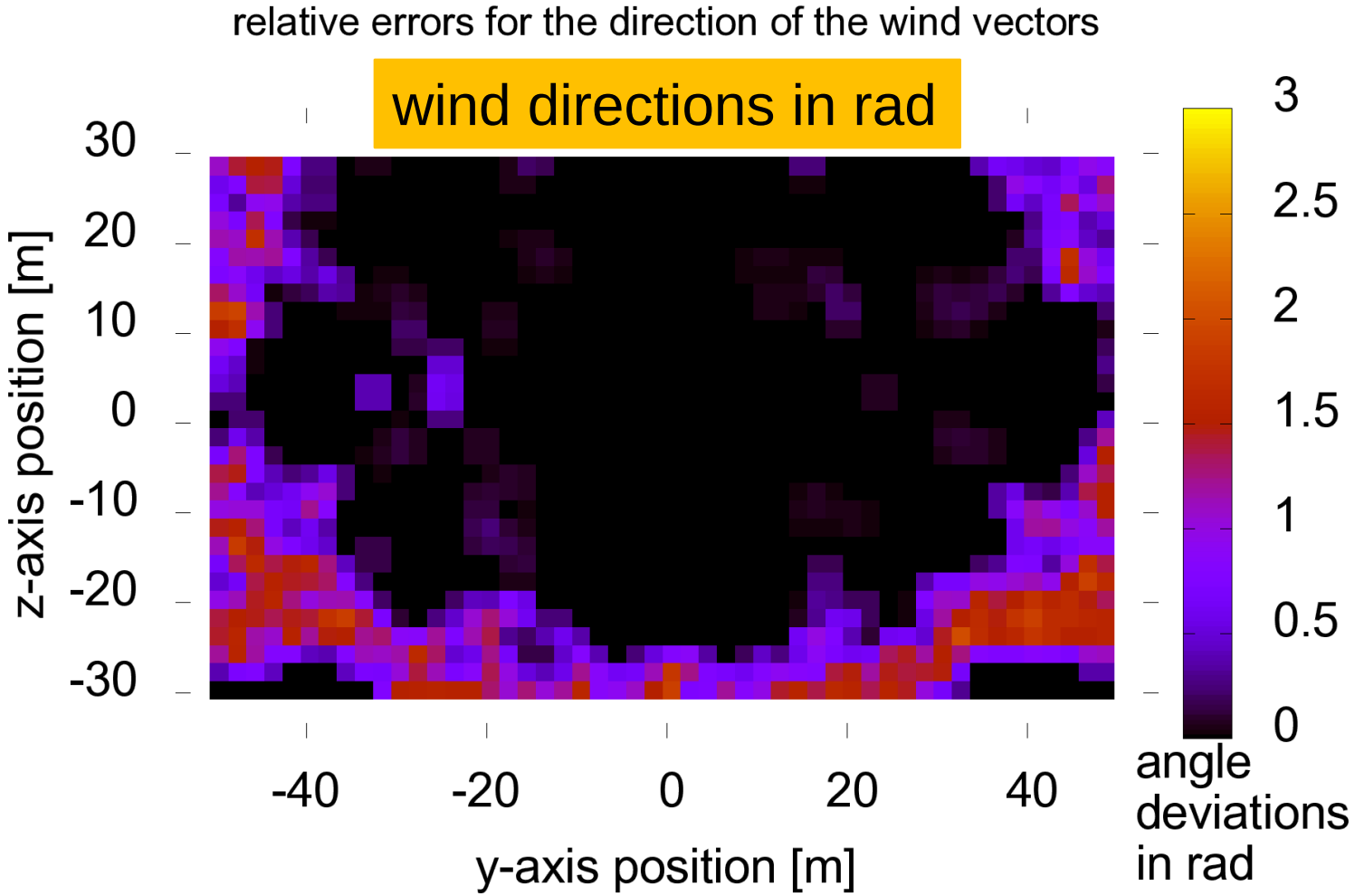
Backscatter profiles of Monte-Carlo simulations



Relative deviations between wind field of extinction profiles and wind field of backscatter profiles via cross-correlation



Relative deviations between wind field of extinction profiles and wind field of backscatter profiles via cross-correlation



Benefits and results of the simulated BL

- feasibility of detecting rotational features of vortices shown
- sufficient number of v- and w-components of wind vectors per slab and more slabs per second
- relatively low errors for wind velocities and directions, i.e. more precision for y- and z-components (transversal to aircraft‘s propagation axis x ; crucial to flight stability) => very erroneous for DWL !
- much faster signal processing

Conclusion from the simulations

- From the DWL and BL simulations it turns out to be advisable to combine a FI-DWL for the x- with a BL for the y- and z-wind components
- BL may be sufficient for flight control

M.C. Hirschberger, T. Misaka, F. Holzäpfel, C. Horn , „Simulated Lidar Signals for Wake Vortex Detection ahead of the Aircraft“, **this project‘s final report, pp.130-143.**

Outlook

- Principle of BL also useful to measure wakes behind wind power stations or to optimize their orientation to the wind direction
- further BL simulations useful (angles of encounter and vortex ages, wavelength)

Challenges for building a BL device for wind measurements:

- distribution of thousands of pulses (or split parts of pulses) at the same moment of time
- adaption of measurement angles according to flight speed
- BL must be able to detect the backscattered photons from different directions at the same time plus to distinguish between the directions of backscattered photons
- design and build a working lidar instrument for flight control

Thank you for your attention !