2d-Laser Cantilever Anemometer

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Introduction

In the following, a new type of anemometer is presented. The so-called **2d-Laser Cantilever Anemometer (2d-LCA)** has been developed at the University of Oldenburg over the last 10years. It utilizes a sensitive measuring principle that was adopted from atomic force microscopy.

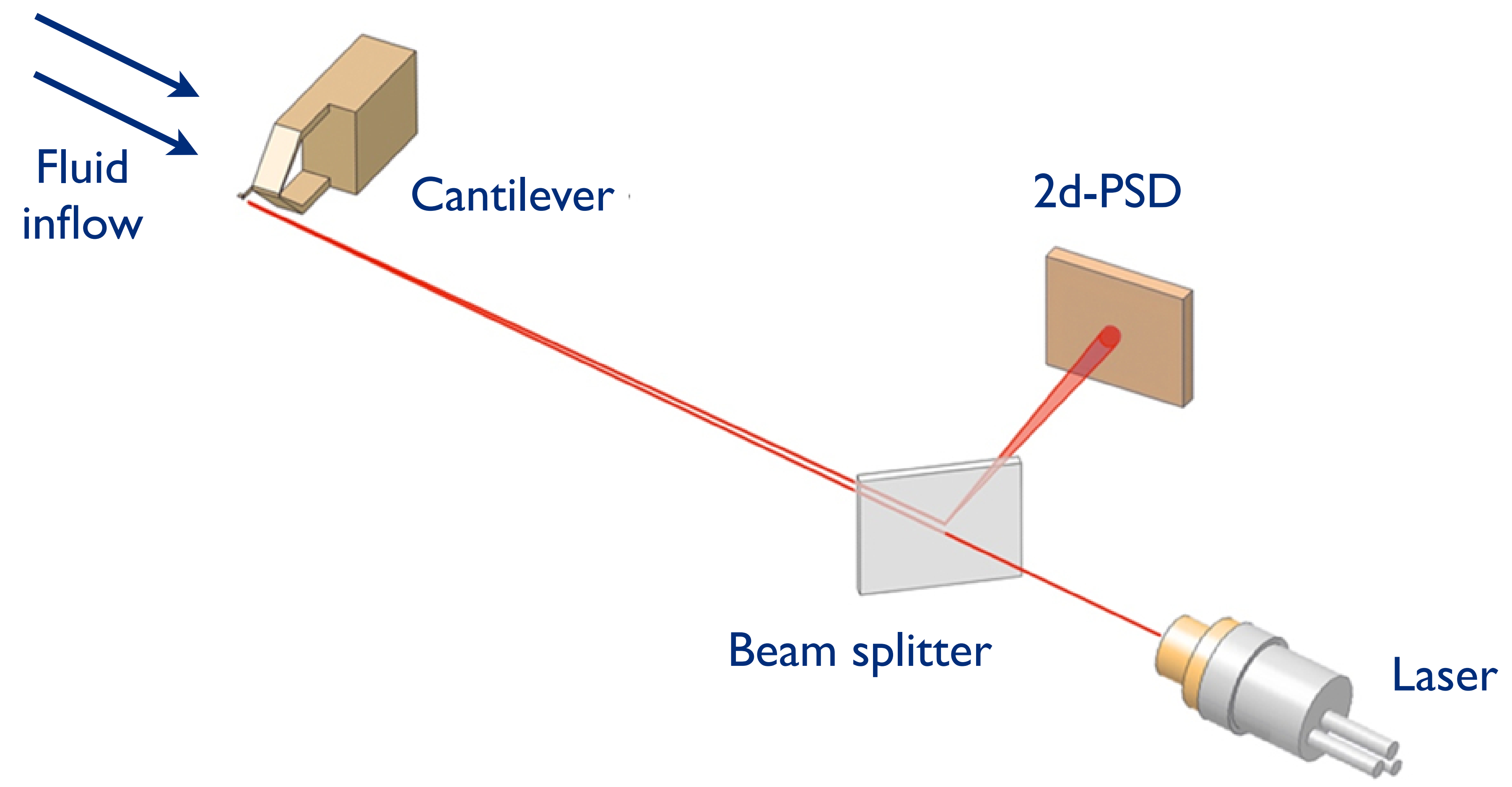
The main motivation for the development of the 2d-LCA was a lack of highly-resolving anemometers that are suitable for operation in a wide range of different flow conditions. These include **liquids, particle-laden flows** and **near-wall flows**.

Another important aspect is the demand for a robust and reliable **alternative for commercial standard x-wires**, which are commonly used for measurements of turbulent flows under laboratory conditions.

Measuring principle

A micro-structured cantilever is brought into the flow. The **drag force acting upon the cantilever causes a deformation**, which contains the information of the flow velocity and flow direction.

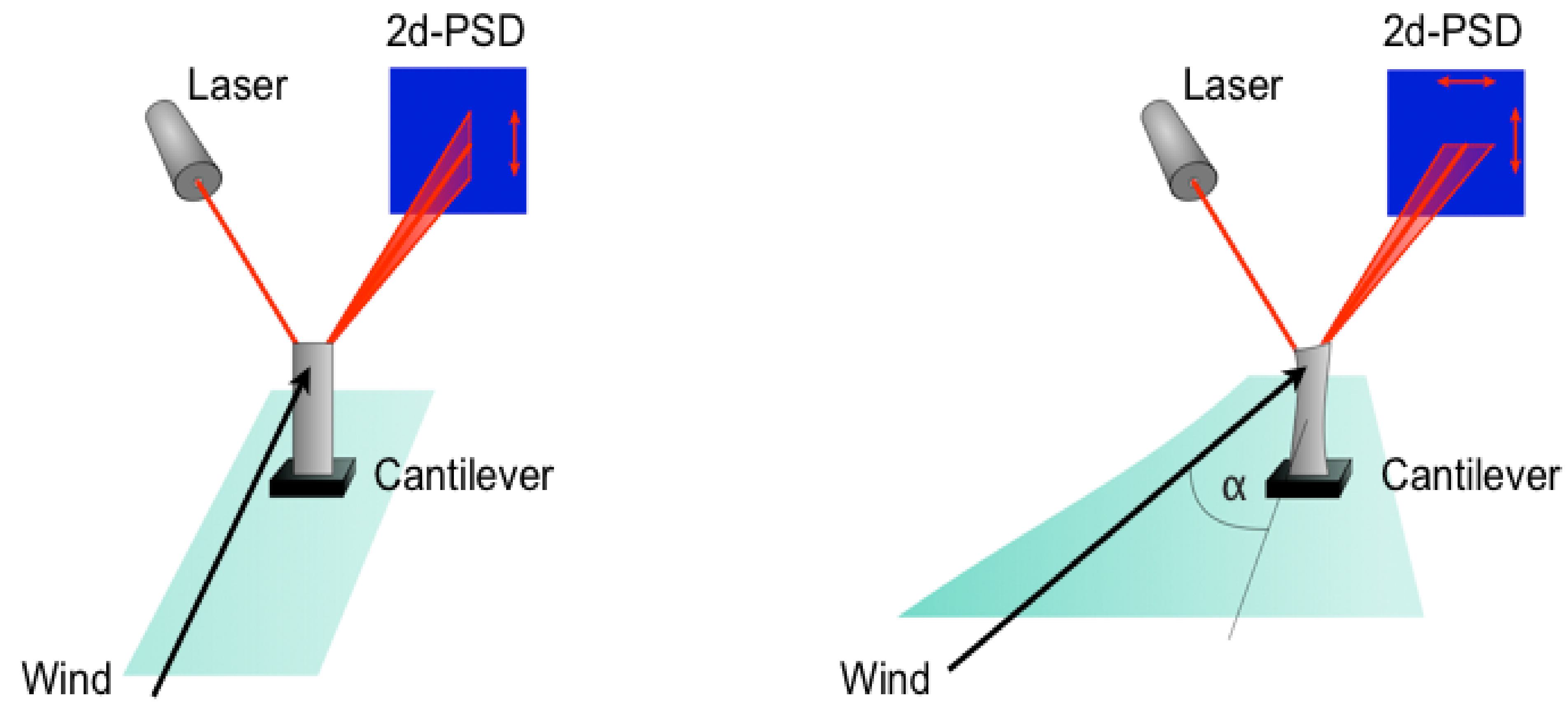
The deformation is gathered using the **laser leaver arm principle**. For this purpose a laser is directed onto the tip of the cantilever. The reflected light is tracked by means of a two-dimensional position sensitive detector (2d-PSD).



Measuring principle

The total deformation of the cantilever is a superposition of **bending and twisting**. Bending arises from a straight inflow, i.e. angle of attack AOA=0°, whereas additional twisting is observed for AOA ≠ 0°.

In this manner **simultaneous measurements of two velocity components** are possible.

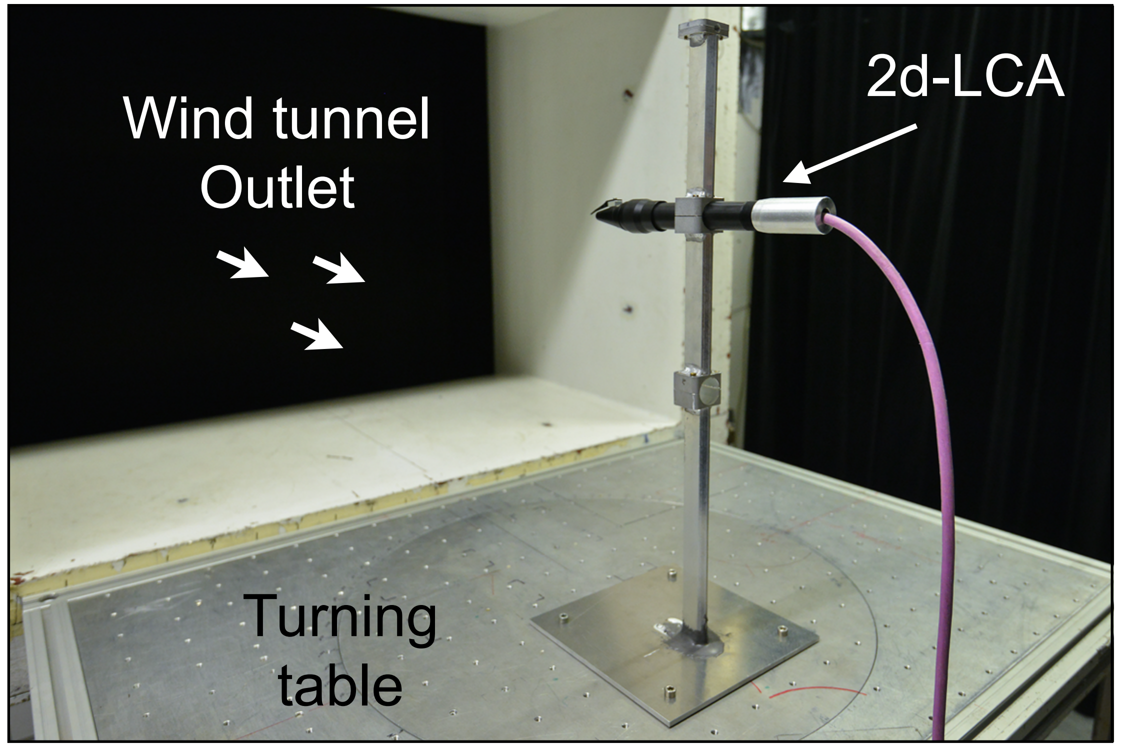


Calibration

The calibration is performed in a **wind tunnel or** in any other commercially available **calibration unit**.

During the calibration process the positions (x- and y-components) of the reflecting light spot along the 2d-PSD are recorded for different inflow velocities and angles of attack.

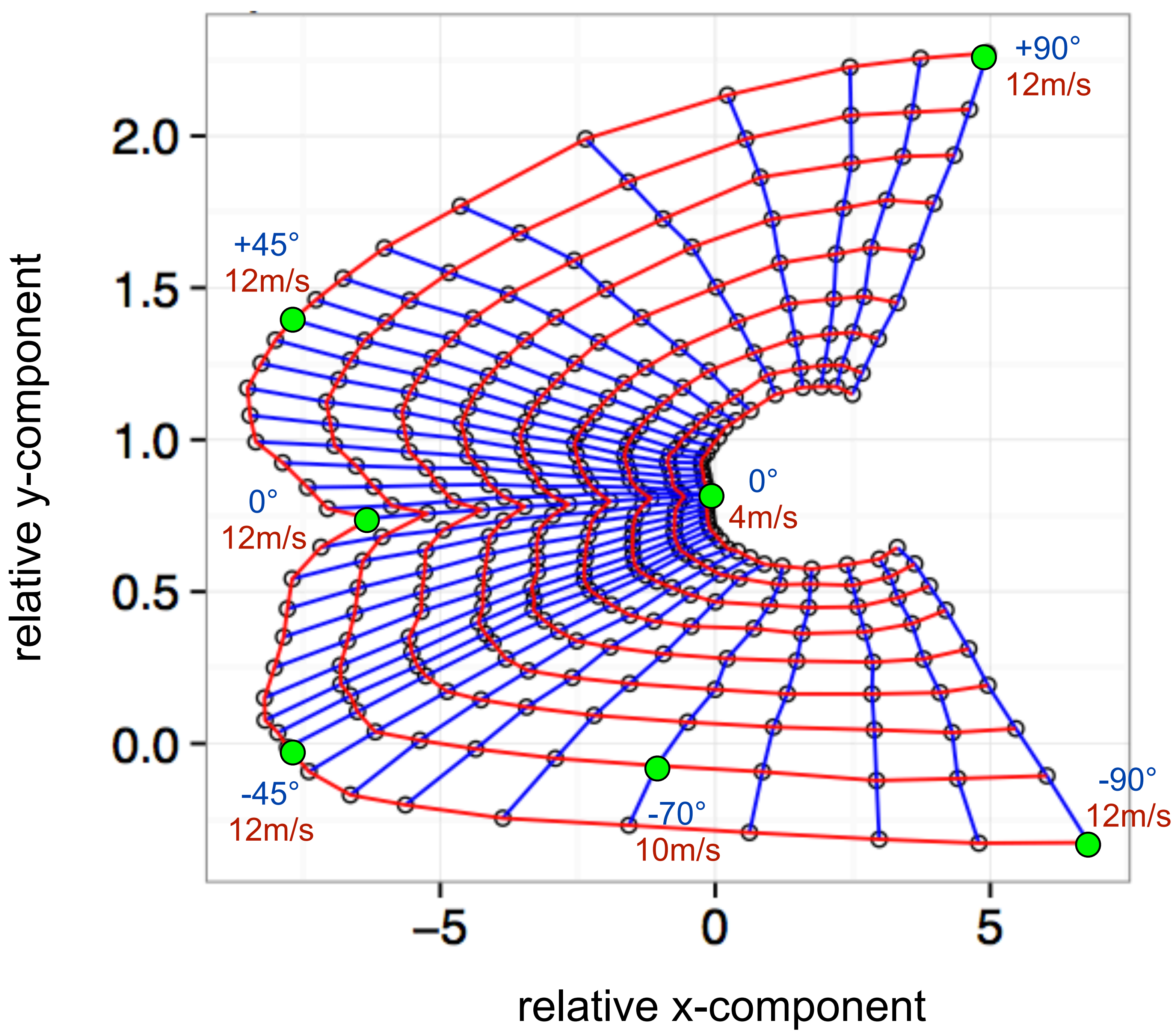
A calibration plane is obtained by plotting the recorded positions for each velocity and angle of attack.



Calibration

The **calibration plane of the 2d-LCA** is shown for velocities ranging from 4-12m/s and AOA of +/-90°.

The points indicate the collected data during calibration. Red and blue lines connect points that correspond to equal velocities and AOA, respectively. For reasons of clarity few points (highlighted in green) are labeled.

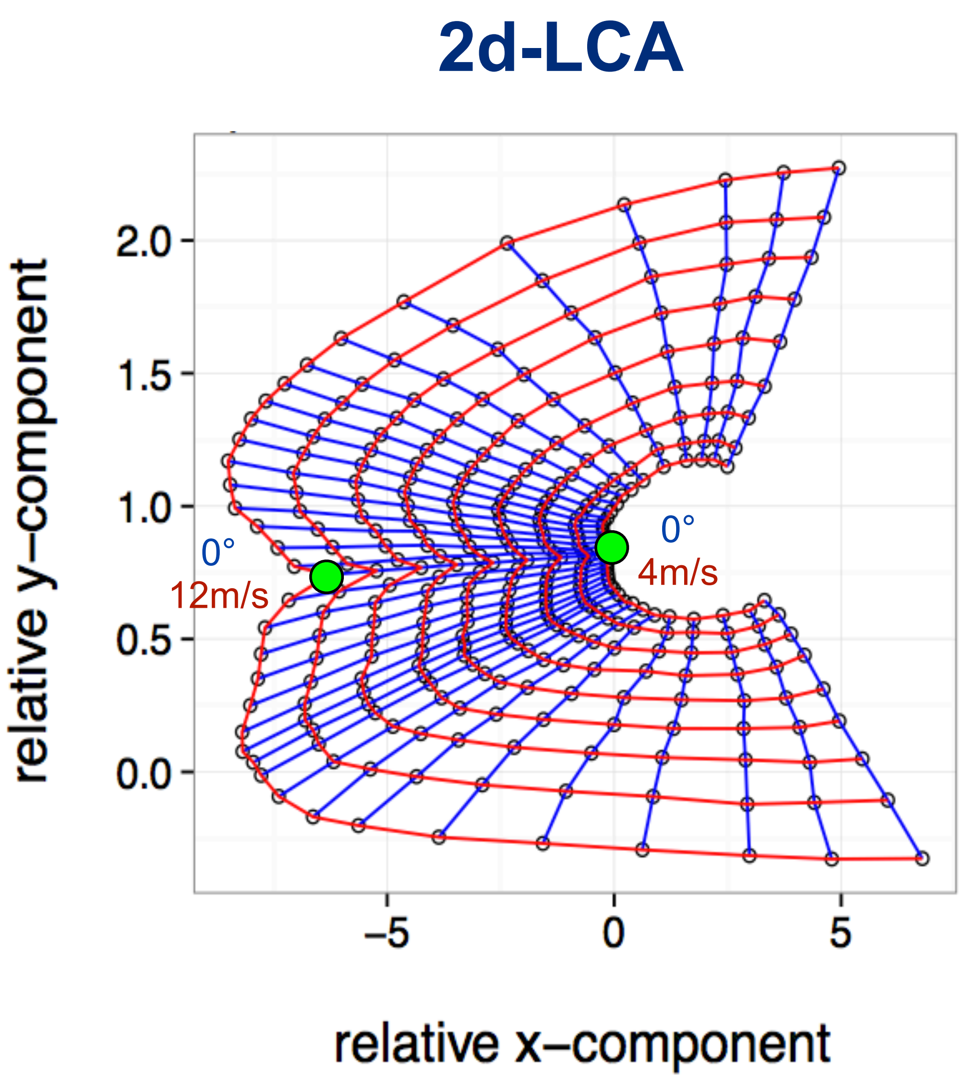


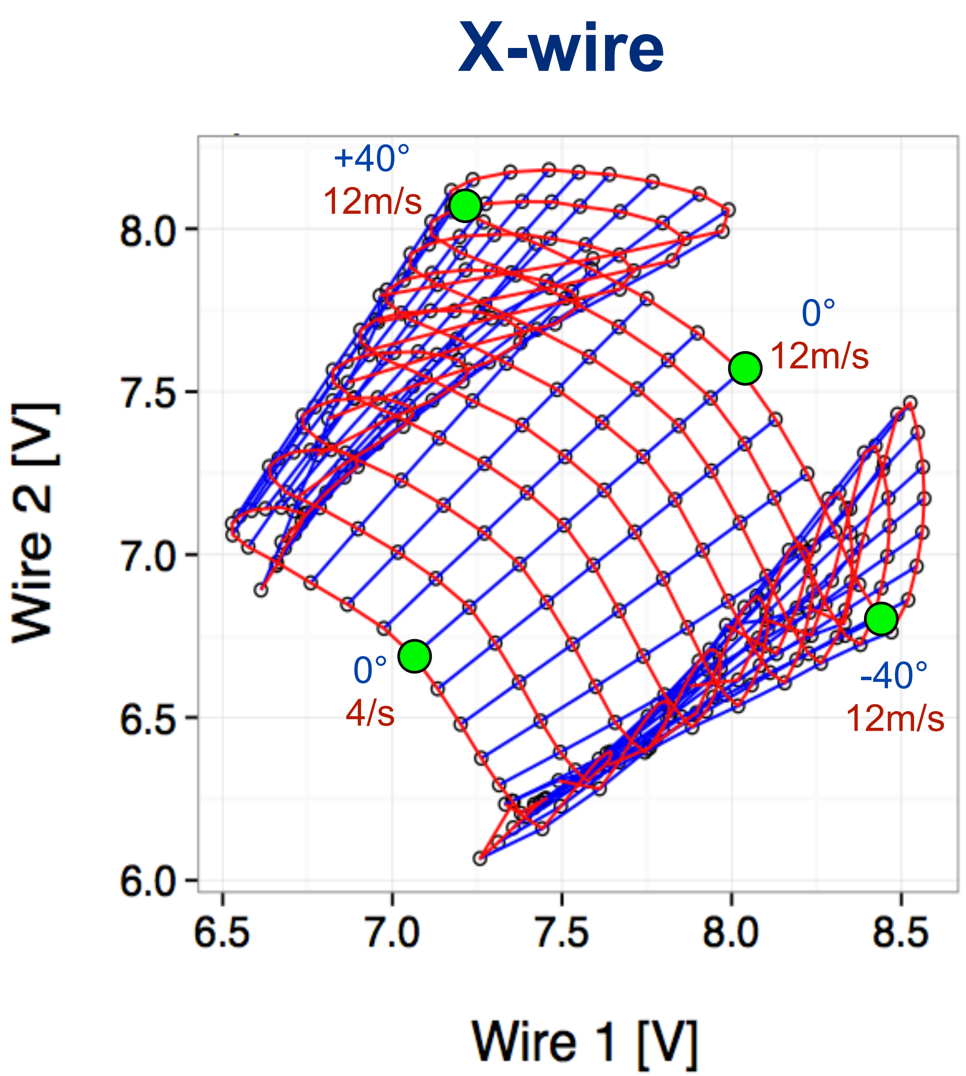
Calibration

In comparison to a calibration plane of a standard x-wire (type Dantec P51) the **2d-LCA calibration remains unique** for the entire angular range of +/-90°.

The **x-wire calibration collapses** for AOA exceeding the range of about +/-40°.

It should be noted that the velocity resolution (distances between red lines) increases for the 2d-LCA and decreases for the x-wire with increasing inflow velocity.



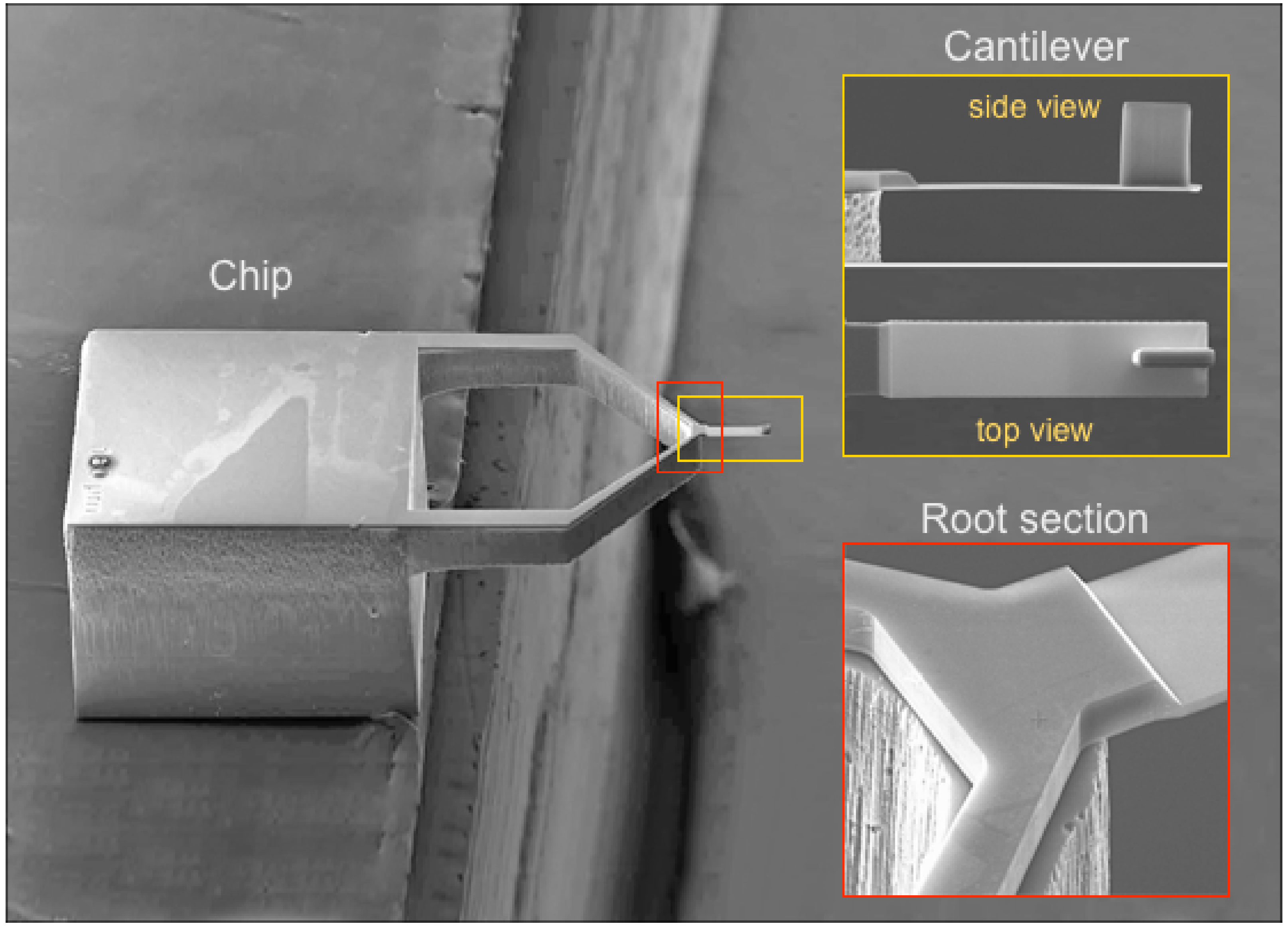


Cantilever design

The cantilever chip is **micro-structured using lithography** techniques. It is attached to the front face of a triangular-shaped structure.

The **cantilever is made of silicon (Si)** and features a vane, which is made of SU8. The vane increases the sensitivity towards cross-winds, i.e. amplifies the amount of twisting due to lateral forces.

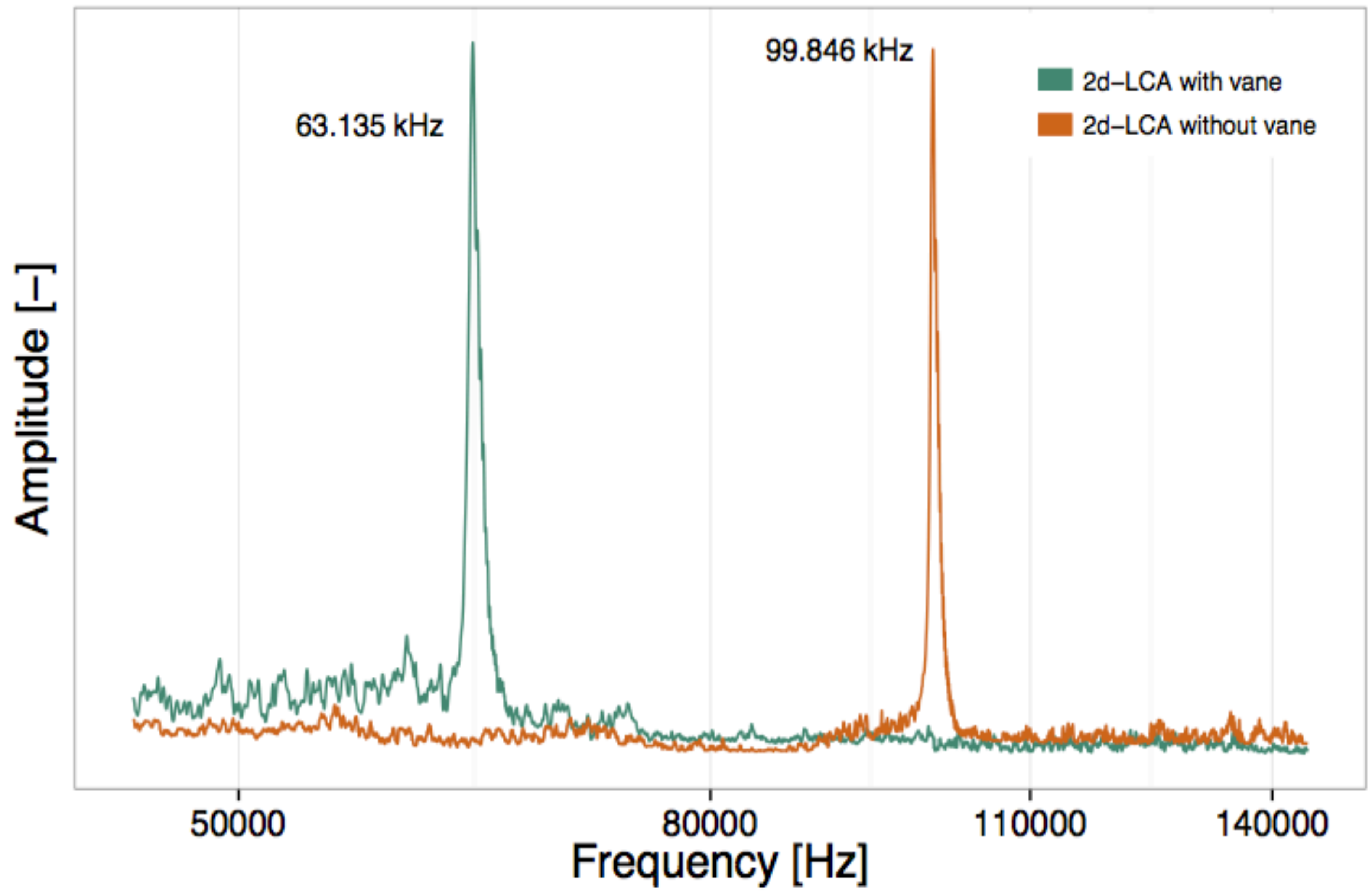
The dimensions of the cantilever are (140-180)µm x 40µm x 1.2µm (L x W x T).



Resolution

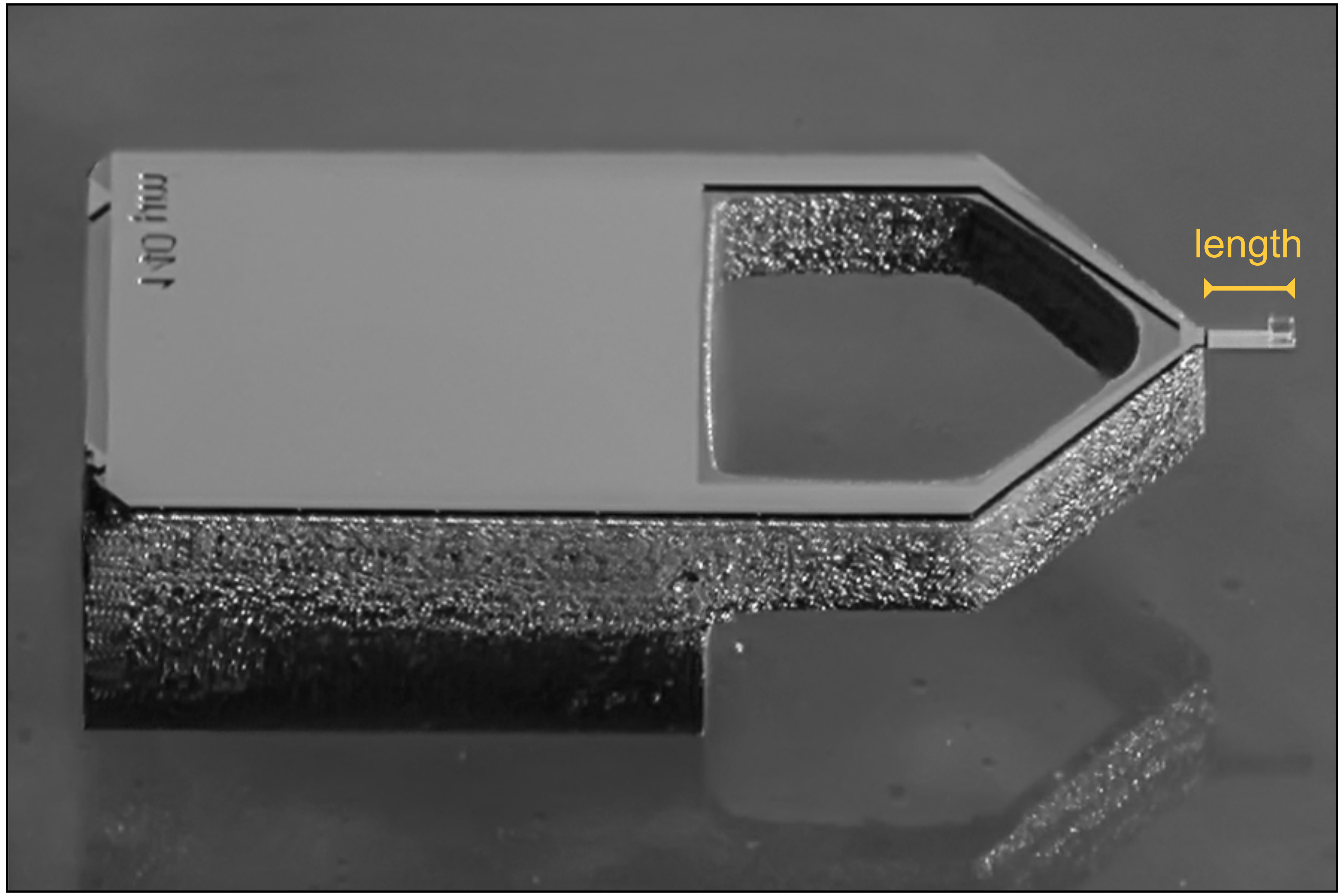
The **temporal resolution** of the 2d-LCA is **limited by the first resonant mode** of the cantilever.

The first resonant modes for two cantilevers (with vane and without vane) of equal lengths of 140µm were identified experimentally to be 63kHz and 100kHz. For this purpose, both cantilevers were driven using electrostatic excitation at continuous sweeping frequencies up to 140kHz. The amplitudes of the cantilevers were monitored using interferometry.



Resolution

The **spatial resolution** of the 2d-LCA **corresponds to the largest dimension of the cantilever**, which is the length of 120µm, 140µm or 160µm (depending on the design of the cantilever)

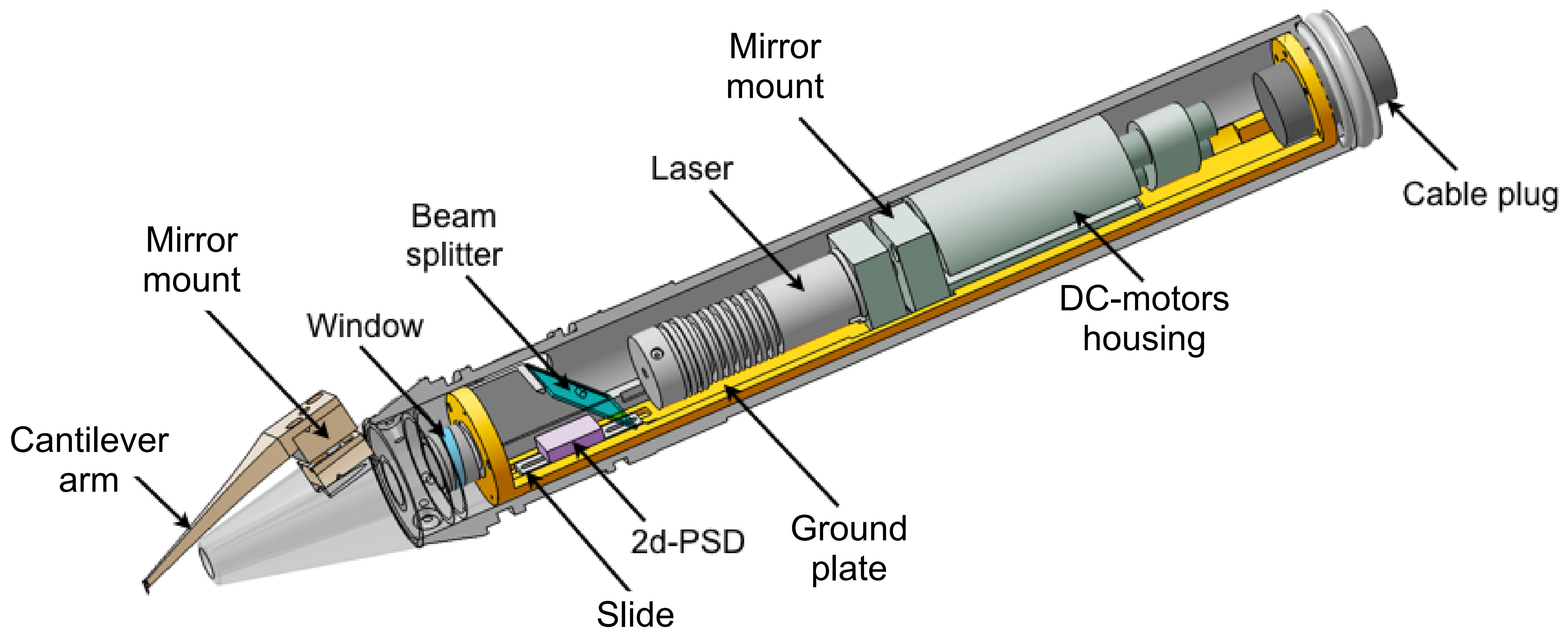


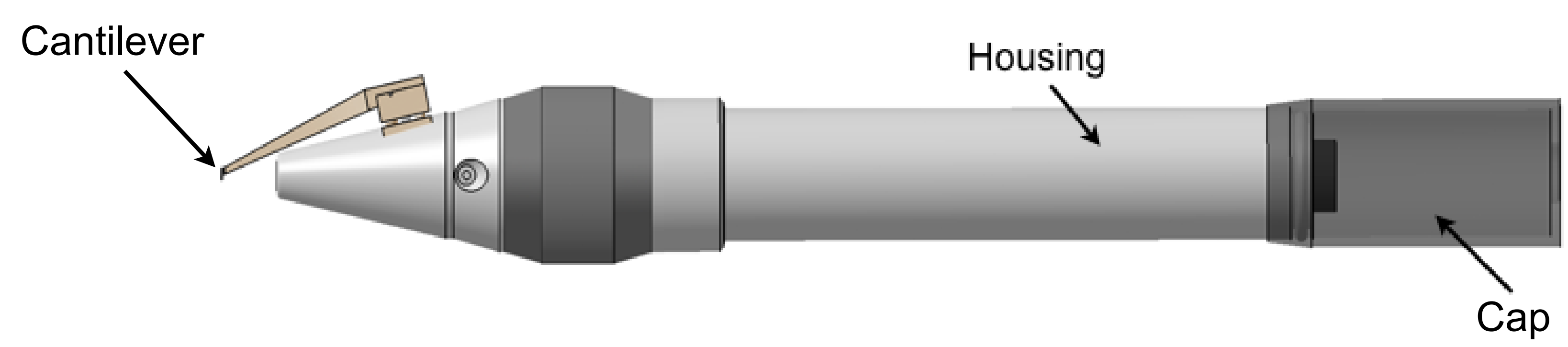
Anemometer design

The housing of the 2d-LCA is made of aluminum and measures about 22cm in length.

The anemometer is equipped with two DC-motors and various adjustable mechanisms that are used for alignment of the laser and the cantilever.

The cantilever is attached to the tip of the cantilever arm.





Anemometer design

The whole measuring technique is housed in one small box. This box includes an amplifier, low-pass filters, controls for the laser adjustment and an fast A/D-converter (6ch., 16bit, max. 150kHz/ch.). The output signal is transmitted via USB to a computer (software for LabView is included).

4 input channels are available for additional sensors, thus providing an easy way for simultaneous measurements.

The system is very compact, lightweight and can also be operated with batteries. In combination with a notebook it is highly portable.

By contrast to hot-wire anemometry no costly signal conditioning is needed for the 2d-LCA. This is mainly due to the optical isolation of the sensing element (hot-wires are active components of the electronics and transfer external noise to the signal processing unit).

Performance

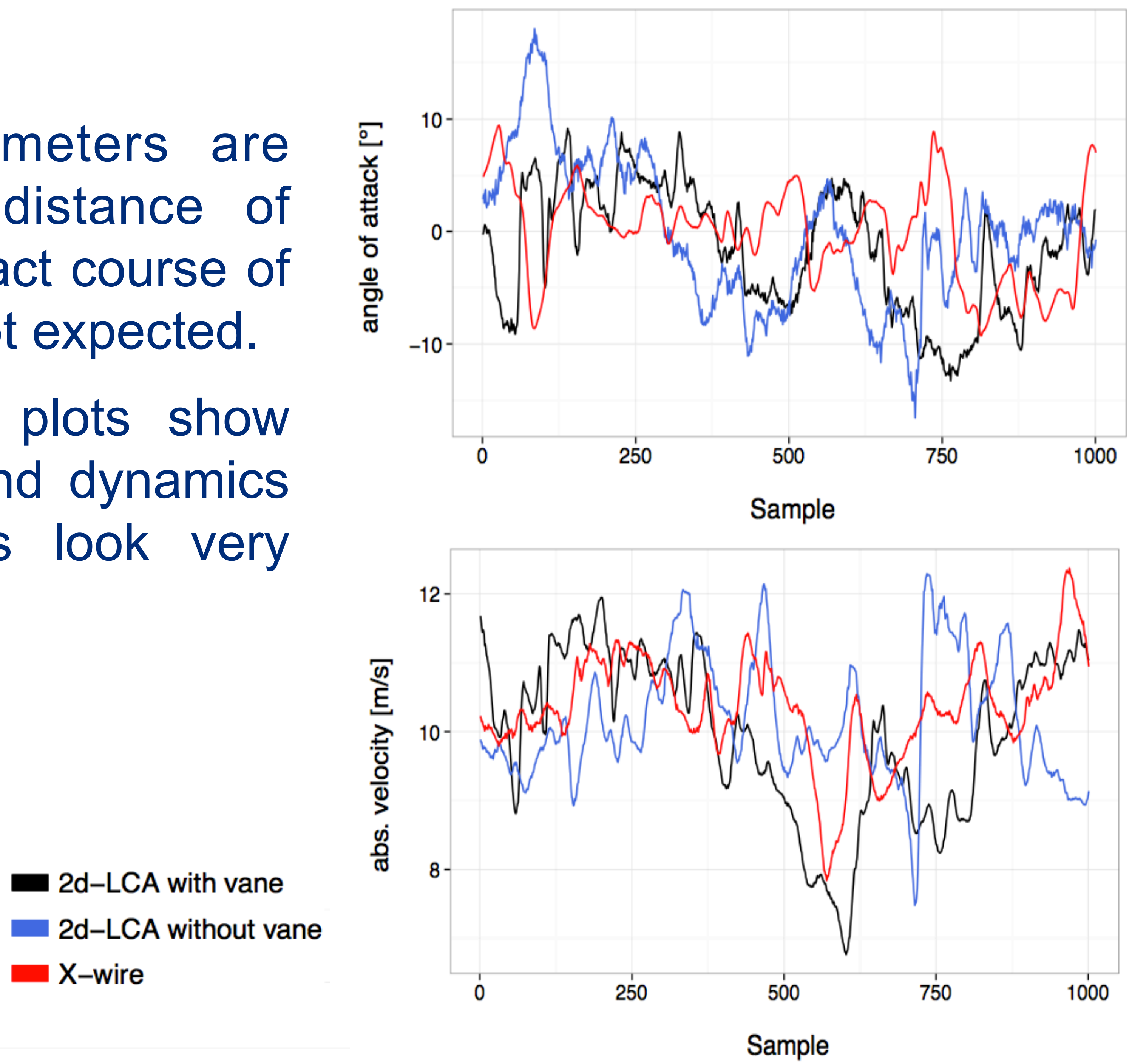
Some measurements in turbulent flow with two 2d-LCAs (with vane and without vane) and a standard x-wire (Dantec type P51) were performed.

The measurements were conducted in a wind tunnel at a velocity of 12m/s. A cylinder has been used to generate turbulent flow (Re ≈ 15800).

The time series of the angle of attack and the absolute value of velocity are used for a quick comparison.

Since all anemometers are separated by a distance of about 20cm an exact course of all trajectories is not expected.

Nevertheless, the plots show that the shapes and dynamics of all time series look very similar.

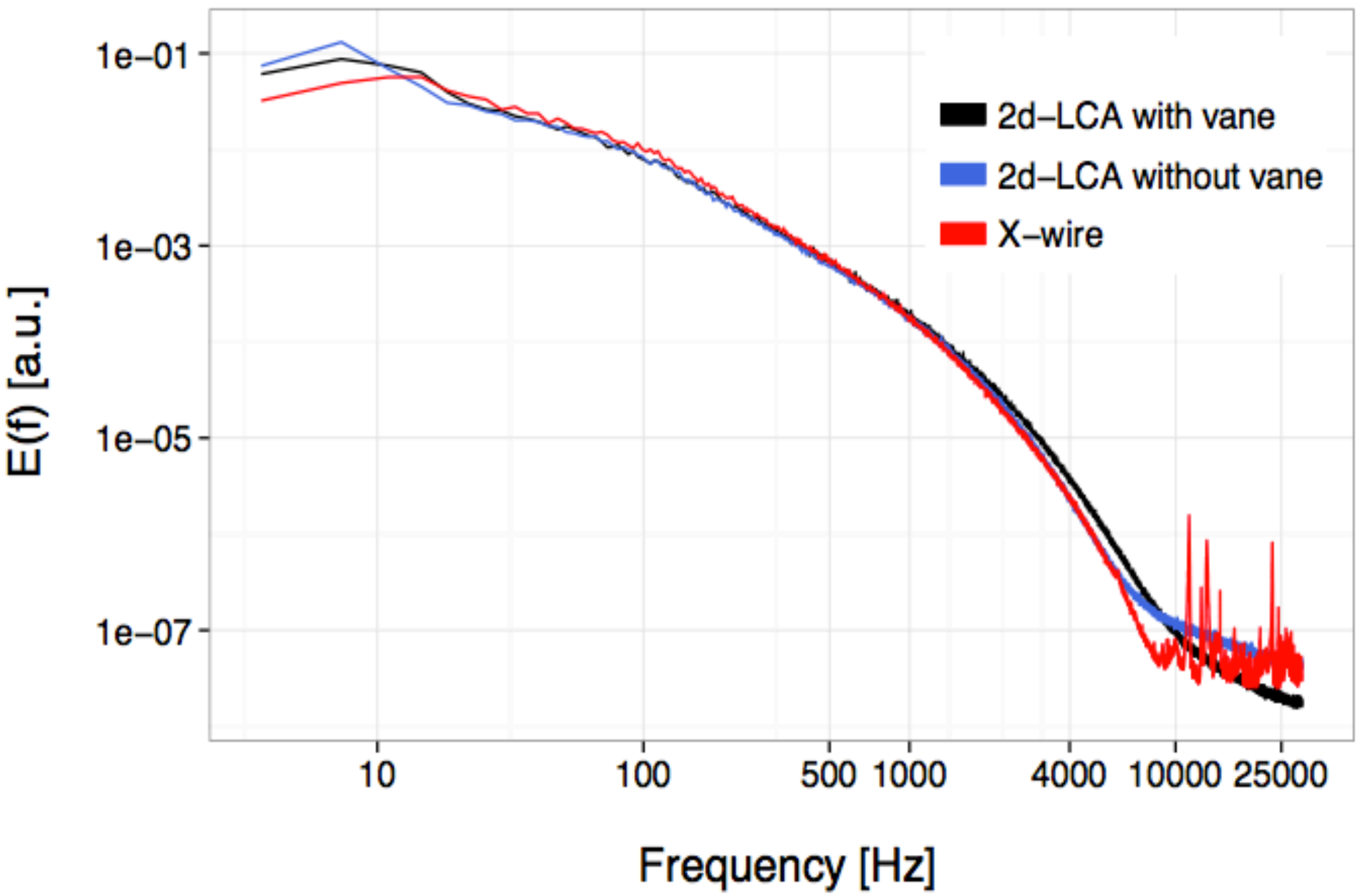


Performance

The power spectra of the longitudinal velocity component show good agreement within the inertial range.

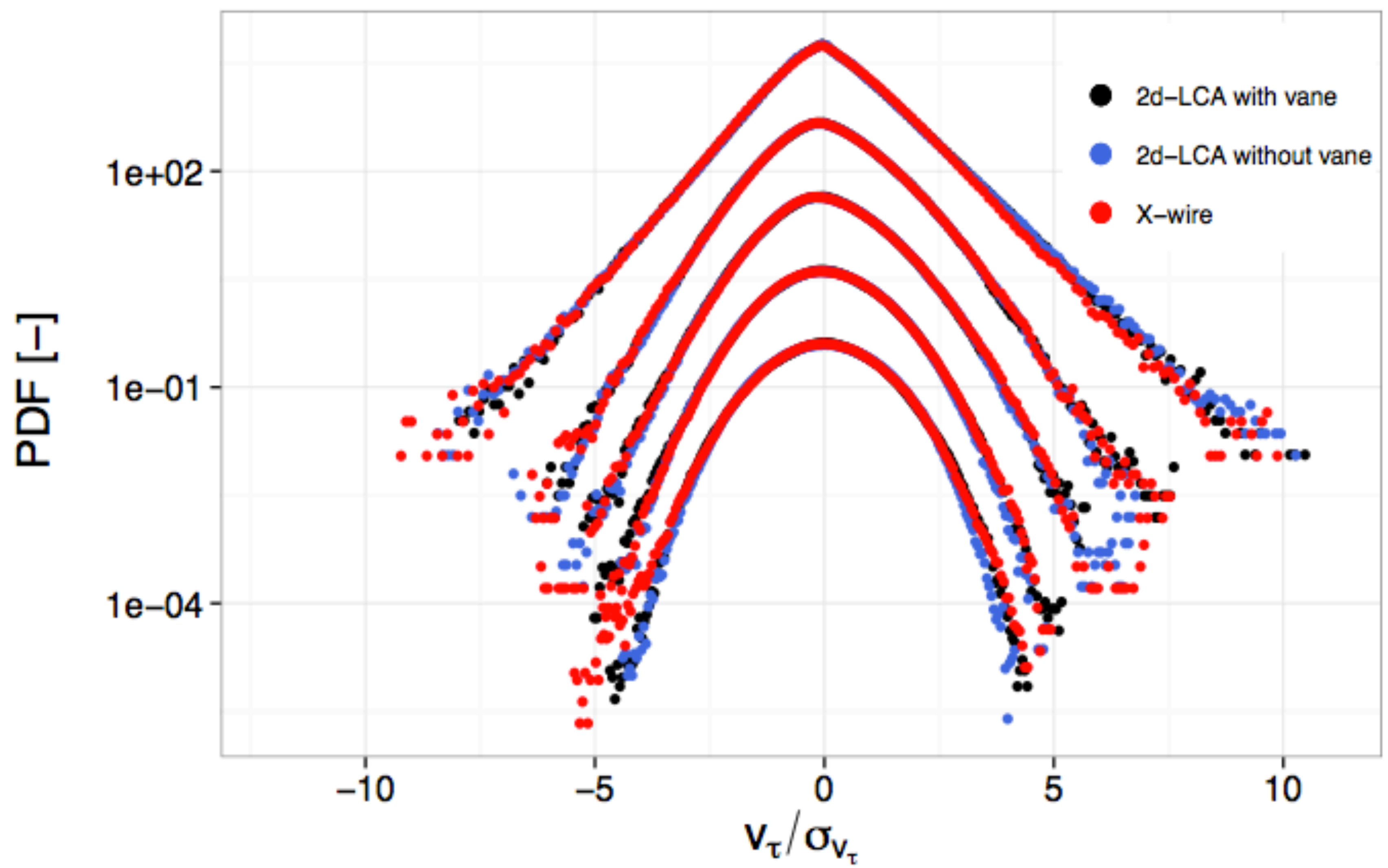
All spectra have a comparable dynamic range although the slope within the dissipation range slightly differs.

Both 2d-LCA spectra do not show any noise in the high frequency region.



Performance

The probability density functions (PDFs) of velocity increments are shown for time steps τ_1=3s, τ_2=0.33s, τ_3=1.7ms, τ_4=0.34ms and τ_5=0.17ms (bottom to top). Again, a good agreement between all three anemometers is observed.



Summary of features of the 2d-LCA and a standard x-wire

	2d-LCA	X-wire
temporal resolution	~ 60-100kHz	~ 40-100kHz
spatial resolution	140-180µm	~1250µm (for instance Dantec p51)
range of velocities	from ~ 1m/s	~ 0.5-150m/s
range of angles of attack	+/- 90° (relative to sensor)	~ +/- 45° (relative to sensor)
accuracy	sensor signal is proportional to v^2, therefore the accuracy increases for higher velocities	sensor signal follows King's law and loses accuracy towards higher velocities
cost	low cost because no complex electronics needed Price upon request	~ USD 50.000 (including Dantec Streamline and CTAs)

2d-LCA for atmospheric use (2d-ALCA)

The measuring principle of the 2d-ALCA is exactly the same as for the 2d-LCA. However, a more robust cantilever made of stainless steel (with gold coating) is used to allow for measurements in rough atmospheric environments.

The larger size of the cantilever (about 1mm in length) provides a higher stability at the expense of temporal resolution (~10kHz).

Two prototypes of the 2d-ALCA were successfully tested in the field and during a measuring campaign at the off-shore met mast FINO3.