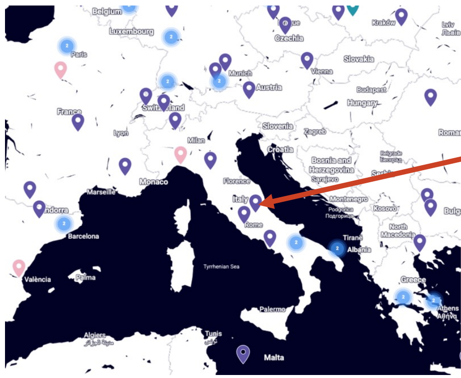
Laser disdrometer calibration. A light on standards in Europe PART I: theoretical framework

1) CETEMPS Center of Excellence
2) Università degli Studi dell'Aquila
3) DSFC Dipartimento di Scienze Fisiche e Chimiche
4) CNR ISAC
5) Università di Genova

ACTRIS
CCRES

Authors: Mario Montopoli [4,1] , Elisa Adirosi[4], Luca Baldini[4], Luca Lanza[5], Enrico Chinchella[5] Cauteruccio Arianna[5]
and vital support from AQ-NF team [1, 2, 3]



ACTRIS Cloud Remote Sensing Workshop June 2026 - D. Rossi, M. Montopoli and D. Cimini

Motivation

- **ACTRIS CCRES has recently established a laboratory procedure for laser disdrometer calibration (Kneifel et al., at LMU)**

- **Such procedure makes use of metal spheres as also suggested by the producers**

- **A recent publications from Chinchella et al. 2026 (**https://doi.org/10.1016/j.atmosres.2026.108865**)**
highlighted as water spheres behaves differently by metal ones in estimating the drop sizes.

- **European regulations complete the framework**

➢ **CEN(*) Regulations and Standardization (CEN/TS 17445)**

➢ **EN (**) 18097:2025 (Hydrometry — Non-Catching Rain Gauges — Calibration):**

➢ **CEN/TR 17993:2023 (Calibration and Accuracy of Non-Catching Precipitation Measurement Instruments)**

(*)CEN: European Committee for Standardization (CEN)
(**) EN: European / Norm Standard document

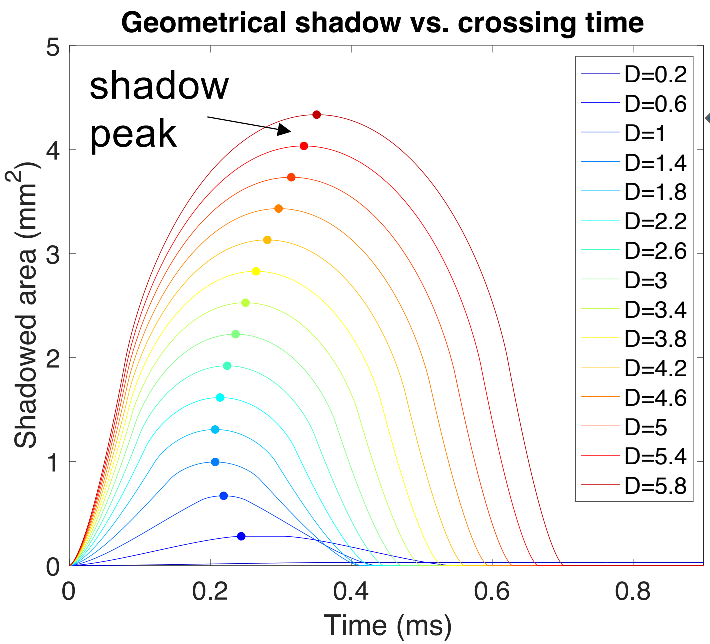
Outline

- **PART I: Why a metal sphere should produce a different “disdrometer signal” wrt. a water sphere?**

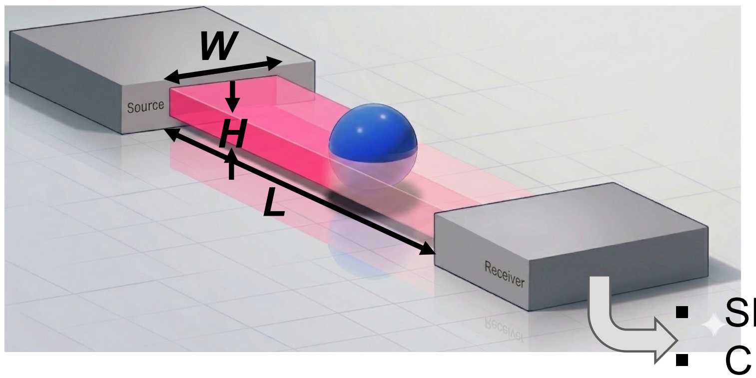
- PART II: How to conduct a laboratory calibration experiment in agreement with CEN regulations?

Disdrometer: principle of measure

- **Operating principle**: It works based on the extinction principle; as a particle passes through the light beam, it creates a shadow, which is measured by the receiver in terms of intensity and time duration.
- **Measurement range**: The sensor can measure particle diameters from 0.2 to 25 mm and fall velocities from 0.2 to 20 m/s.
- **Size retrieval:** from the shadow peaks, the sphere size can be retrieved (the target variable in this presentation)



Shadowed area vs. crossing time by a metal sphere of diameter *D* passing through a *H*=1 (mm) altitude of disdrometer laser beam.

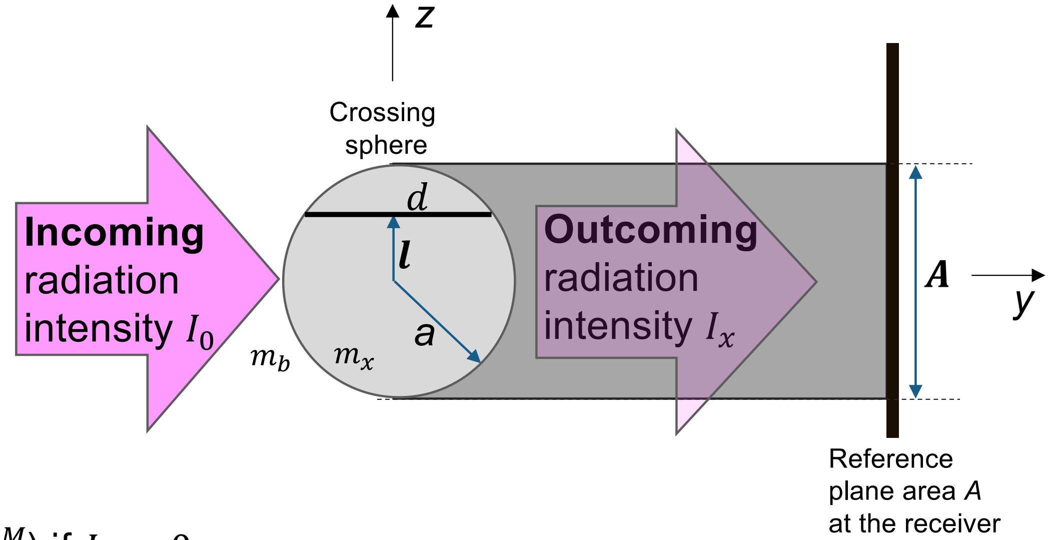


- Shadow
- Crossing time

	L (mm)	W (mm)	H (mm)	λ (nm)
Thies-LPM	228	20	0.75	786
Parsivel2	180	30	1.00	650

Shadow definition

•**Shadow** (S^x) can be defined as the area interested by a reduction of the radiation received (I_x) at the reference plane over the incoming one (I_0) :



$$S^x(t) = \int_A \left[1 - \frac{I_x(\boldsymbol{l},t)}{I_0}\right] d\boldsymbol{l} \begin{cases} = 0 \text{ (no shadow) if } I_x = I_0 \\ = A \text{ (geometrical shadow } S^M\text{) if } I_x = 0 \end{cases}$$

$\alpha_x = \frac{2\pi}{\lambda} Im\{m_x\}$	specific attenuation coefficient (m^{-1})
$m_x = n_x + jk_x$	complex refractive index of sphere of material *x*-th
$m_b = n_b + jk_b$	complex refractive index of the background

x is the sphere's material (x =*M* for metal, x=*W* for water)

I_x: refracted intensity (Lambert–Beer law)

Synthetic experiments

	Symbol	Units	LPM	PARSIVEL2
Laser beam height	H	(mm)	0.75	1.00
Laser beam wavelenght	λ	(nm)	786	650
Refractive index of water	m_W	-	1.328+j0	
Refractive index of metal	m_M	-	2.5+j3	
Sphere's diameters	D	(mm)	from 0.2 to 6	
Sphere's fall velocity	v_t	(ms^{-1})	Gunn and Kinzer 1949	

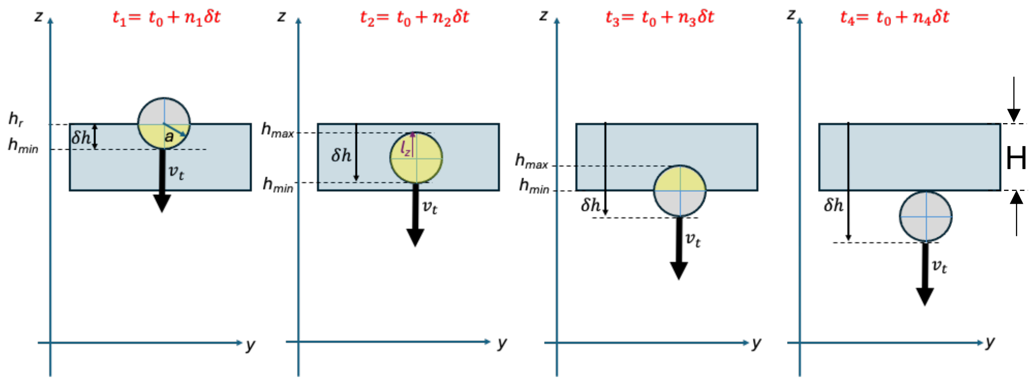
Table 1: Simulated experiment parameters.

- Shadows are calculated for each particle type
(*x*= Metal and *x*=Water spheres) and at each crossing time.

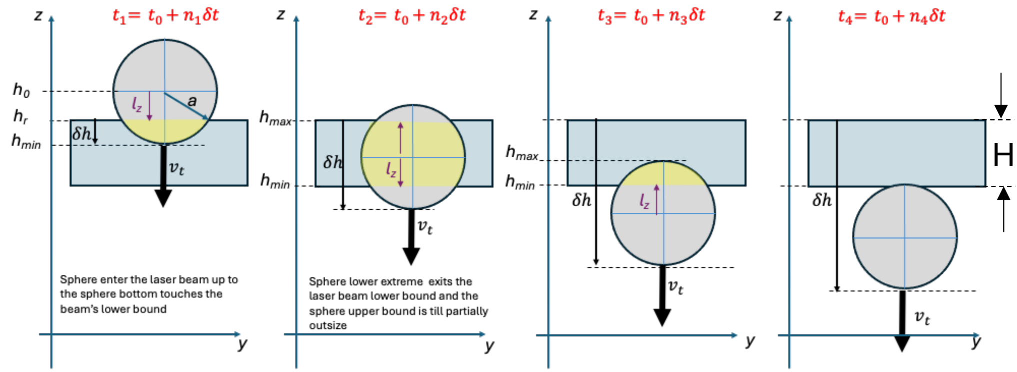
- No sampling issue are considered.

Falling spheres through a laser beam (side view)

Sphere diameter lower than beam heigh



Sphere diameter larger than beam heigh

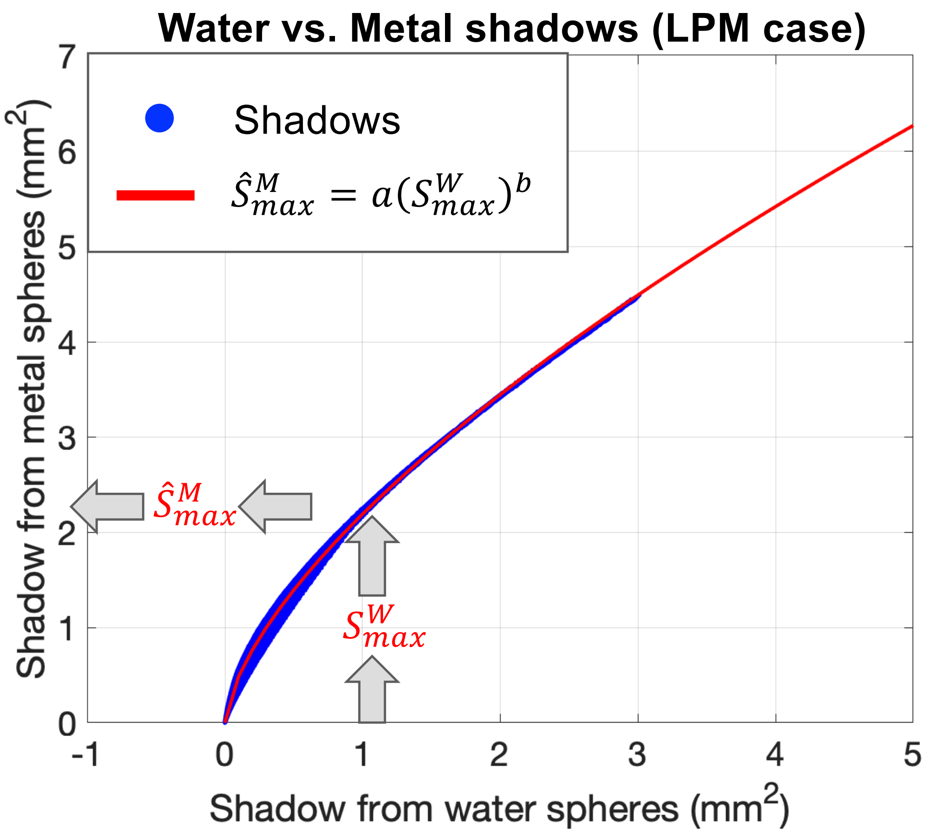


Shaded geometrical area

Shadowed area: geometrical vs. refraction-guided

- **Metal and water sphere shadows are highly correlated to each other**

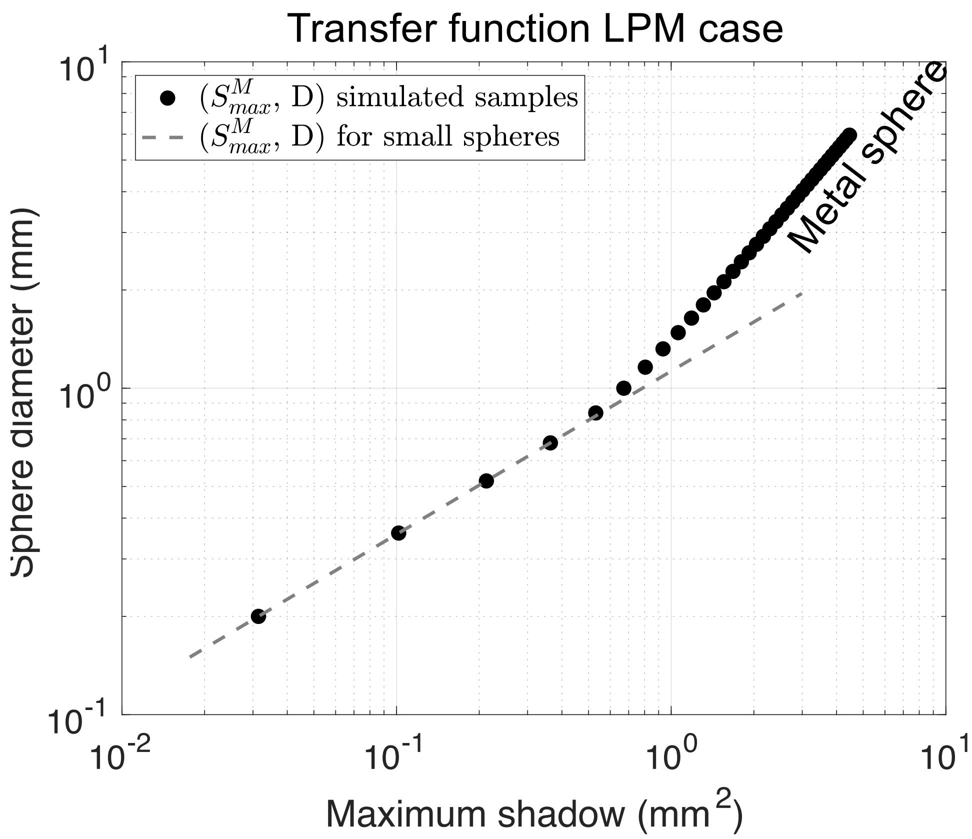
- **Shadow from water speres** (S^{W}_{max}) **can be transformed into that from metal sphere** $(\hat{S}^{M}_{max})$ **using regression coeff.** *a* and *b*



The blue dots dispersion in the figure is due to the shadows over time while the sphere is crossing the laser beam.

Results: transfer function (from shadow to size)

- **The transfer function (TF) varies as a function of the shadow definition considered.**



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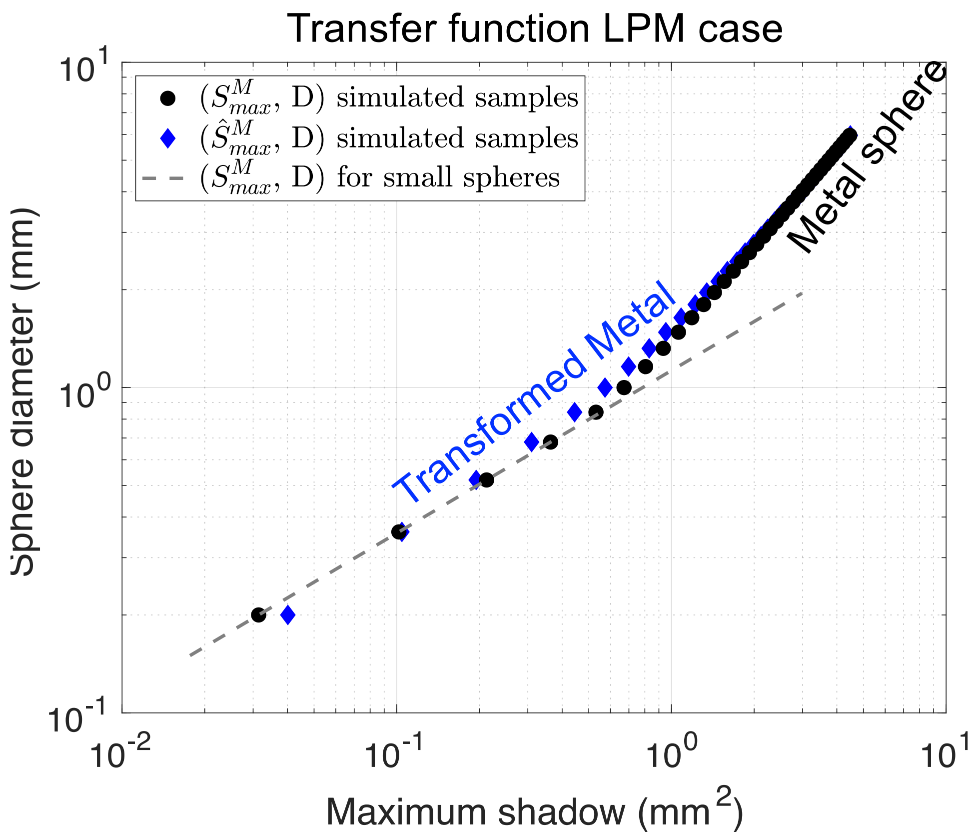
- **TF of transformed metal sphere ≠ TF of metal sphere**



Results: transfer function (from shadow to size)

- **The transfer function (TF) varies as a function of the shadow definition considered.**

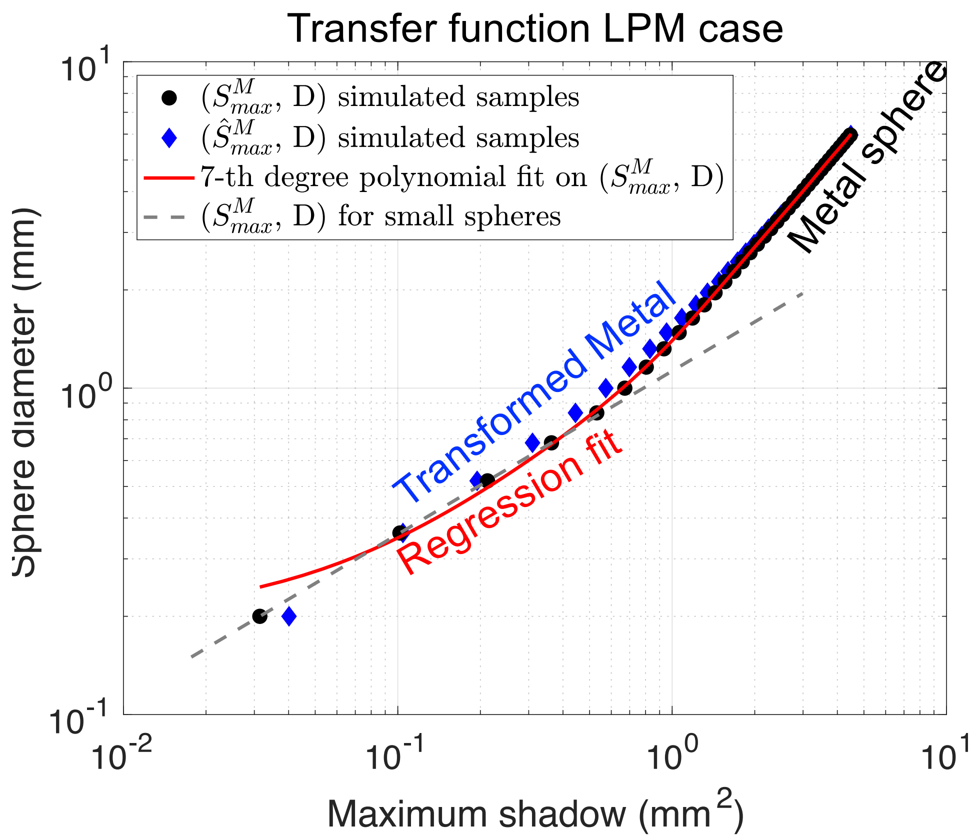
- **TF of transformed metal sphere ≠ TF of metal sphere**

- **Differences are further amplified if considering a polynomial regression:**

$$\widehat{D}^x = \sum_{k=1}^{N+1} p_k^M \, [S_{max}^x]^{(N-k+1)} \quad with \; N = 7$$

x = M for metal sphere; x = W for water sphere

- **Reasonably, disdrometers might assume the transfer function associated to the geometrical shadow of metal spheres (solid red curve and p_k^M coeff.)**



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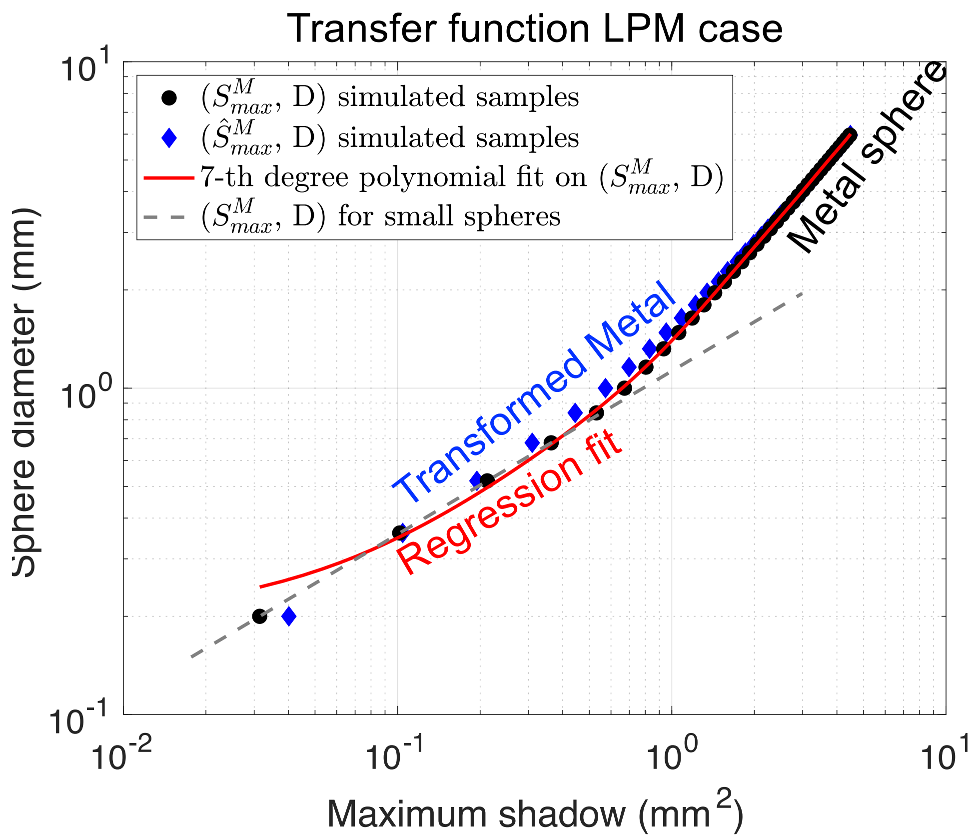

- **It is therefore clear that calibration using metal spheres can produce calibration curves that differ from those obtained using water spheres, that is, the hydrometeor whose dimensions we wish to determine.**

Diameter estimation errors: comparison with laboratory experiments

- Assumed disdrometer size-estimation-formula (tuned on metal spheres)

$$\widehat{D}^{x} = \sum_{k=1}^{N+1} p_k^M \, [S_{max}^{x}]^{(N-k+1)} \text{ with } N \text{ in } [3, 11]$$

- Relative error metric

$$e_D^x \, (\%) = \frac{\widehat{D}^{x} - D}{D} \, 100$$

x =*M* for metal sphere;
x =*W* for water sphere

D= true diameter
p_k^M= estimation coefficients tuned on metal spheres
S_{max}^x= maximum shadow registered by the disdrometer in response to particle x

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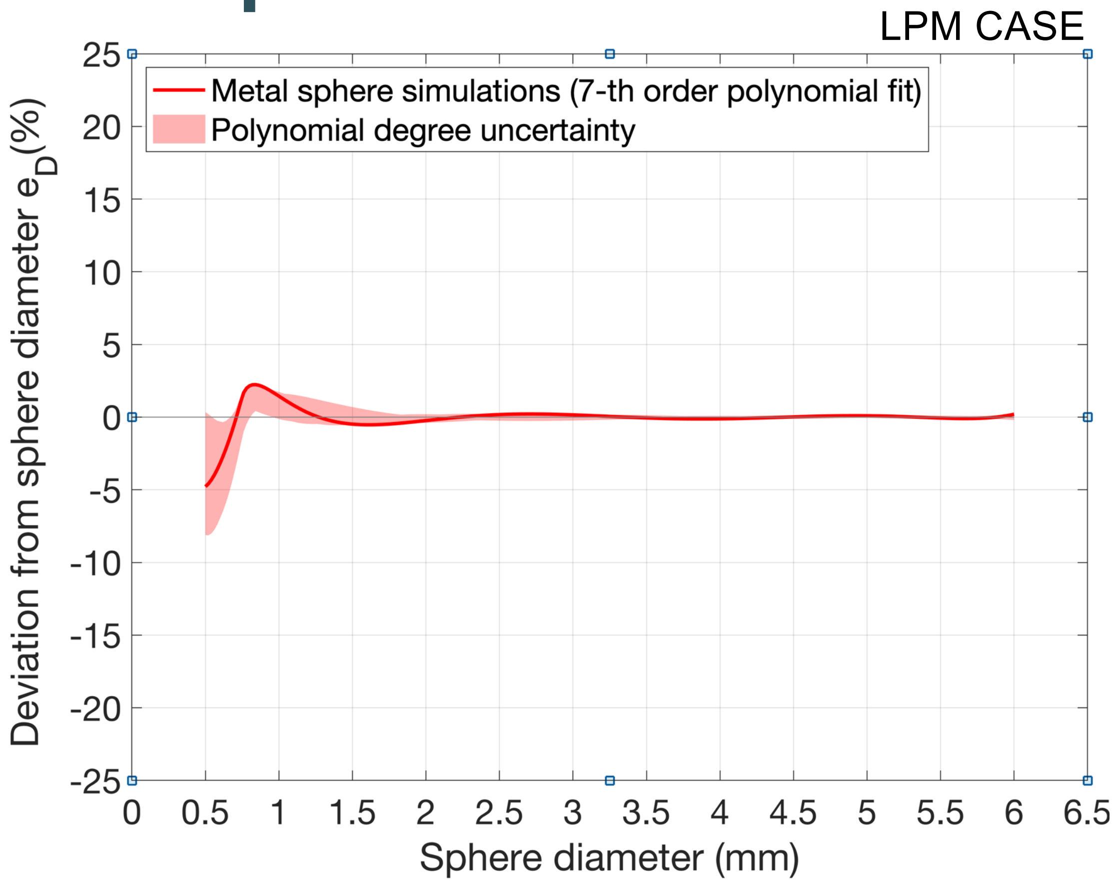

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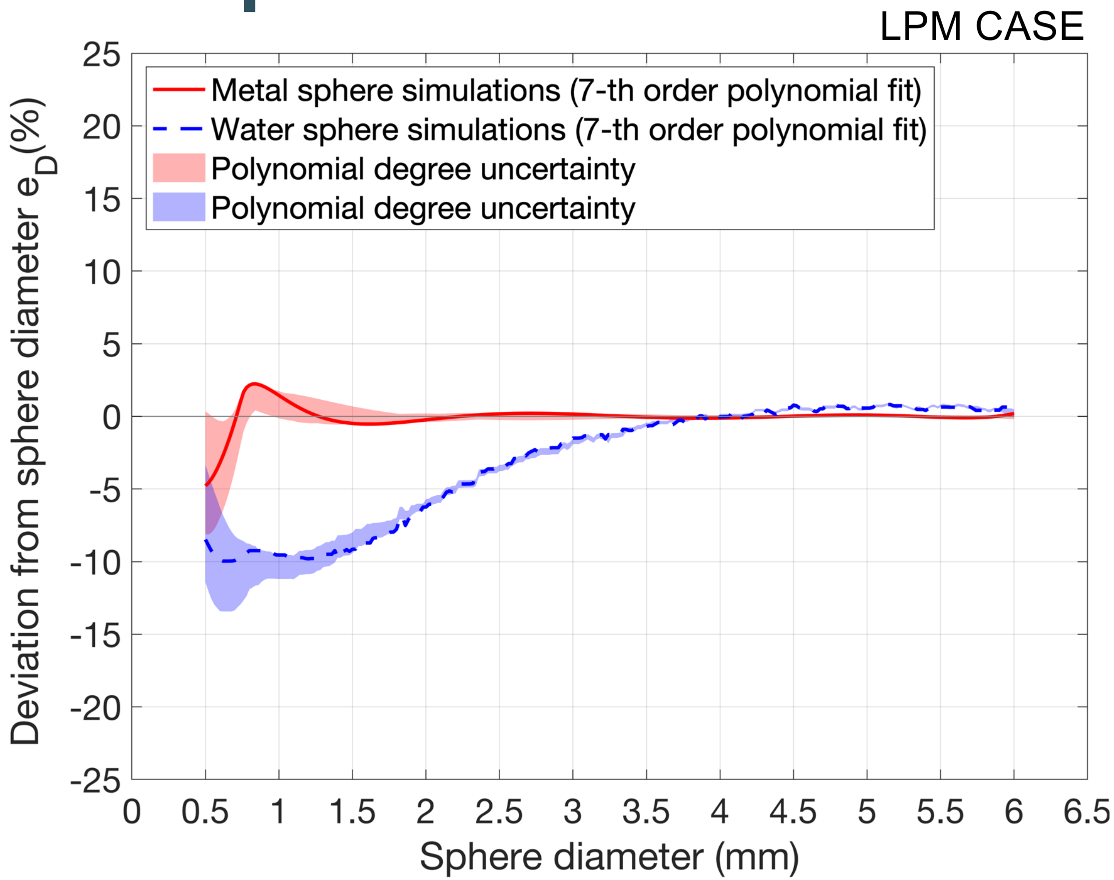

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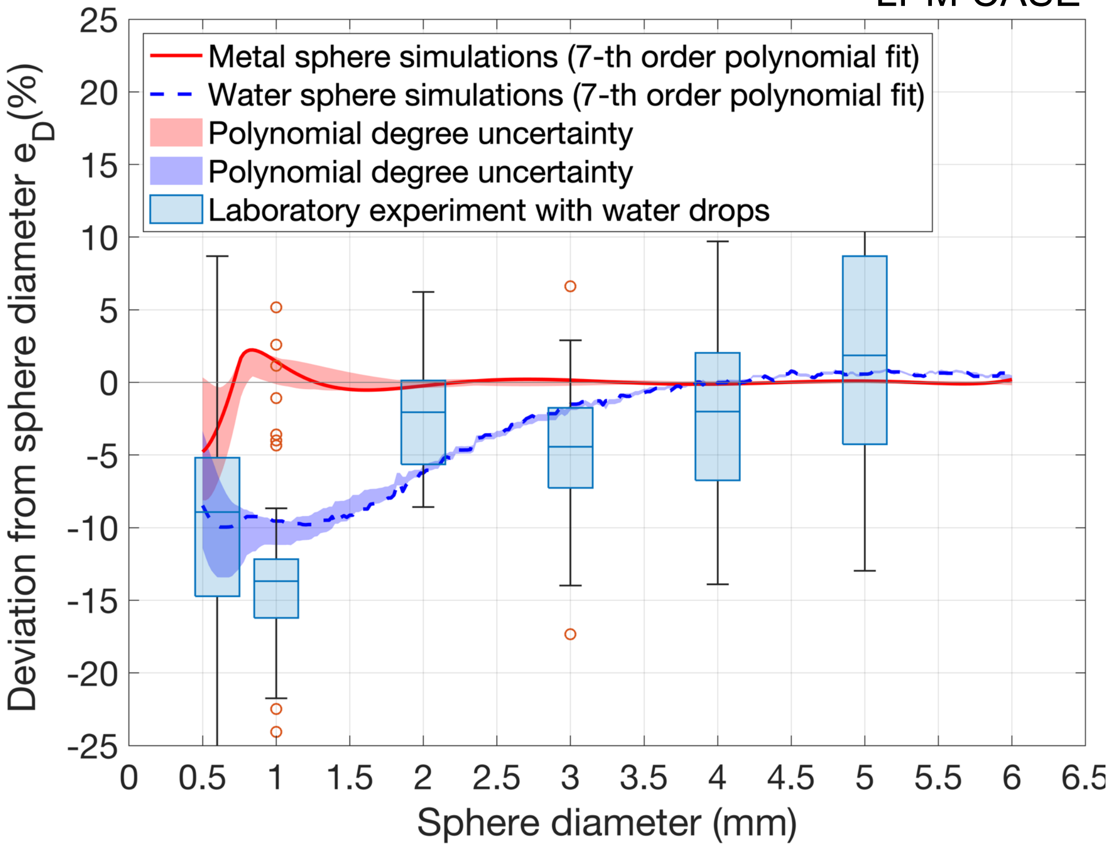
Similar results are obtained for Parsivel2.

LPM CASE



•**Lab. experiment from Chinchella et al. 2026 (https://doi.org/10.1016/j.atmosres.2026.108865)**

Conclusions

- Geometrical shadow produced by metal spheres differs from that produced by water spheres (due to refraction)
- If shadow is defined as that produced by a metal sphere (i.e. purely geometrical shadow), but water drops are tested, some systematic size estimation errors can arise.
- Such size systematic errors underestimate smaller drops as -10% and converge toward zero for larger ones.
- These results seems to be confirmed by laboratory experiments.

Suggestions for the future

- Try checking with the disdrometer producer how really disdrometer transfer function is defined.
- Try defining an "universal" correction factor curve to adapt the metal sphere calibration into that of water
- Test the impact of size errors on *Z* and *R* in light rain regimes

Laser disdrometer calibration: a light on standards in Europe (PART 2)

The European norm and laboratory calibration using water drops vs. metallic spheres

Chinchella, E., Cauteruccio, A. and L.G. Lanza
University of Genoa, Italy
WMO Measurement Lead Centre "B. Castelli" on precipitation intensity
luca.lanza@unige.it

LC-PrIn B. Castelli

DICCA WMO

Normative process at European scale

TC 318 Hydrometry

WG 12 "*Measurement of Rainfall Intensity*"

EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

through STAIR 2017 to EURAMET

EMPIR EURAMET

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

WMO **CIMO**

CHIEF STAKEHOLDER

INCIPIT

Metrology for non-catching rain instruments

WG12

2021

Pre-normative
EMPIR Project 18NRM03:
2019 - 2022

CALIBRATION AND ACCURACY OF NON-CATCHING INSTRUMENTS TO MEASURE LIQUID/SOLID ATMOSPHERIC PRECIPITATION

NWI to develop a European standard on non-catching precipitation measurement instruments (including disdrometers)

from pre-normative research to …

2022

Preparatory technical document
Technical Report
TR 17993:2023
"Calibration and accuracy of non-catching precipitation measurement instruments"

Approved by member states in September **2023**

Final normative document
European Norm
EN 18097:2025
"Metrological requirements and test methods for non-catching type rain gauges"

Approved by member states in September **2025**

In force !!

Research results on calibration procedures

EMPIR

EURAMET

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

INCIPIT

Metrology for non-catching rain instruments

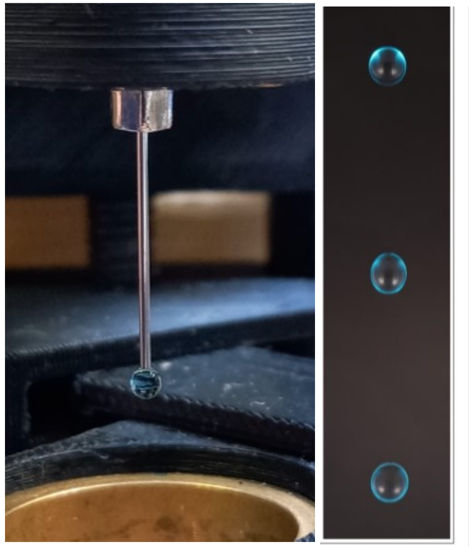
Meteorological Applications
Science and Technology for Weather and Climate
Open Access
RMetS
REVIEW ARTICLE | Open Access

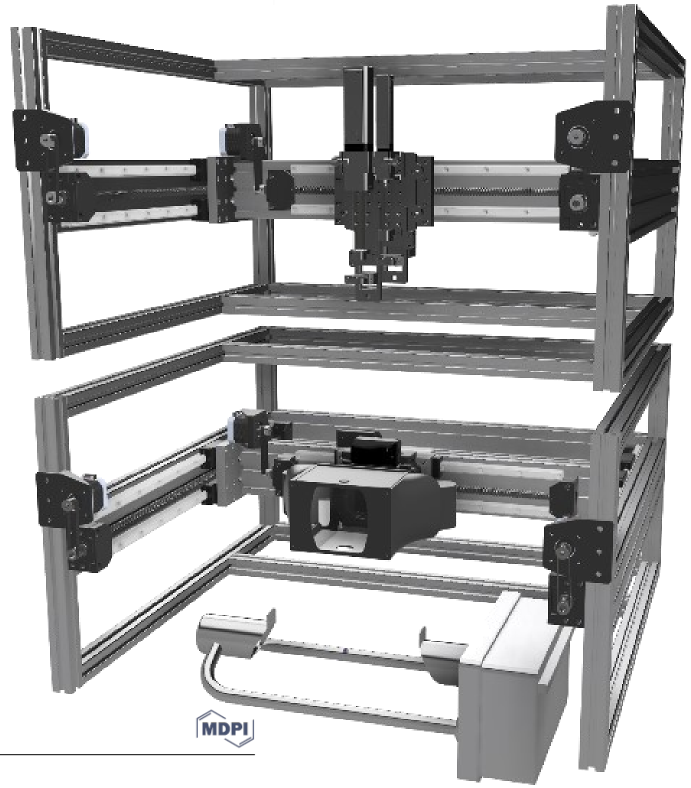
Calibration of non-catching precipitation measurement instruments: A review

L. G. Lanza, A. Merlone, A. Cauteruccio, E. Chinchella, M. Stagnaro, M. Dobre, M. C. Garcia Izquierdo, J. Nielsen, H. Kjeldsen, Y. A. Roulet, G. Coppa, C. Musacchio, C. Bordianu, M. Parrondo

First published: 25 May 2021 | https://doi.org/10.1002/met.2002

A rain drop generator using a reference photogrammetric system





Laboratory and field tests

sensors
MDPI
Article

Calibration Uncertainty of Non-Catching Precipitation Gauges

Quentin Baire [1,*], Miruna Dobre [1], Anne-Sophie Piette [1], Luca Lanza [2,3], Arianna Cauteruccio [2,3], Enrico Chinchella [2,3], Andrea Merlone [4], Henrik Kjeldsen [5], Jan Nielsen [5], Peter Friis Østergaard [5], Marina Parrondo [6] and Carmen Garcia Izquierdo [6]

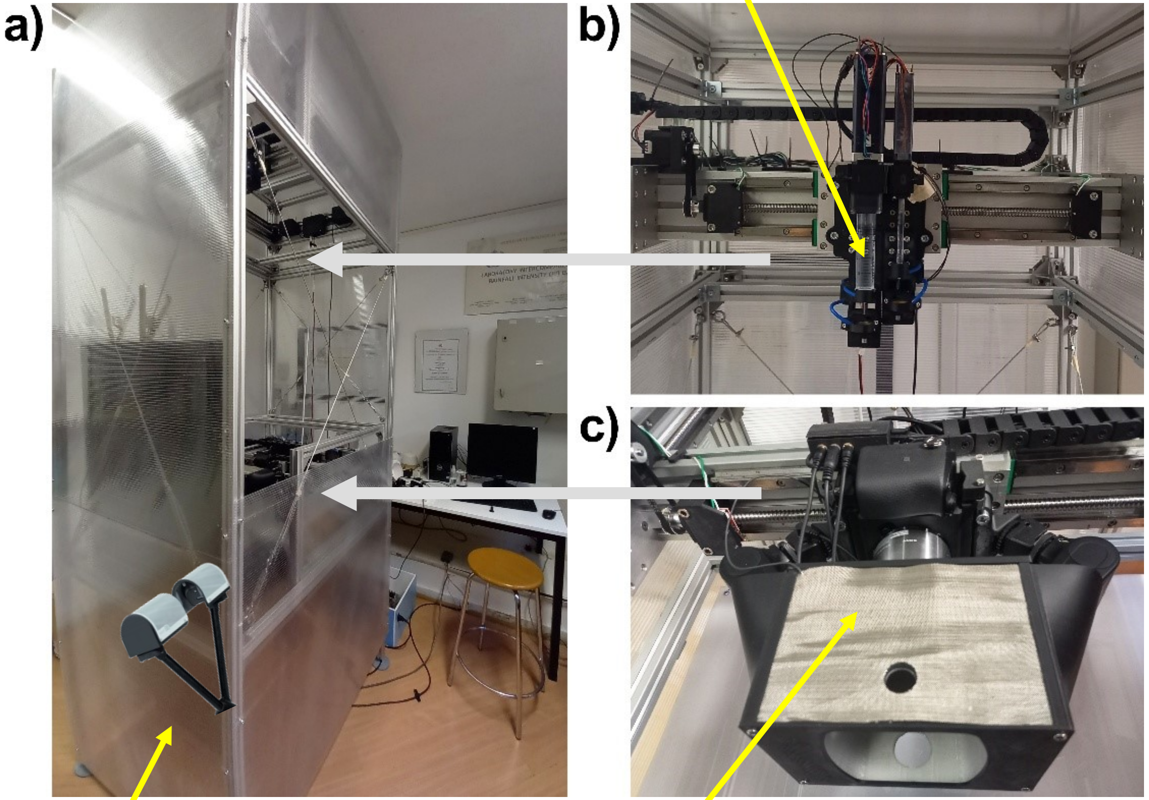
A laboratory calibration procedure using generated water drops

Disdrometer calibration device using water drops

developed at the University of Genoa

Two main components:

- on demand generation of water drops



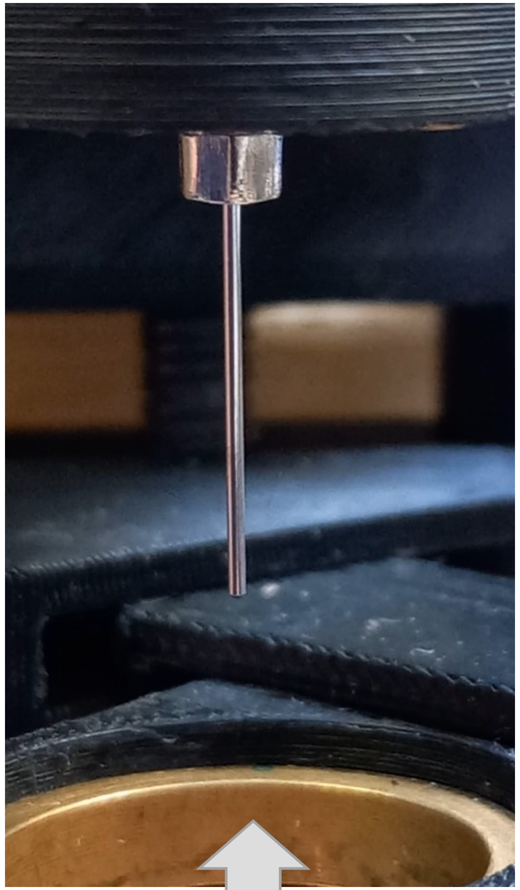
Two precision volumetric pumps

Total volume **small pump: 1 ml**

- Piston displacement resolution: **0.0010 mm**
- Volume increment resolution: **0.023 μl**

Total volume **large pump: 20 ml**

- Piston displacement resolution: **0.0013 mm**
- Volume increment resolution: **0.35 μl**



Instrument under test

- photogrammetric system to provide the reference diameter and fall velocity of released water drops

Drops are released 'on demand' by generating a voltage difference of **5000V** between the nozzle and a metal ring below

The photogrammetric reference system

APS-C sensor

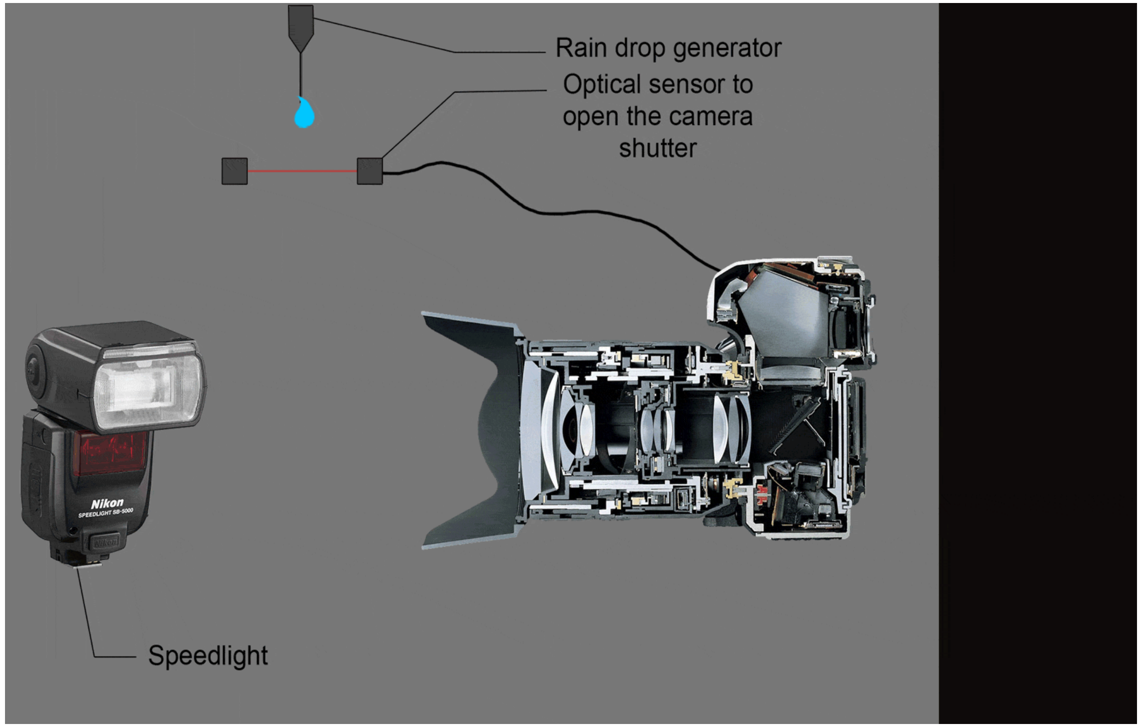
23.5 x 15.6 mm

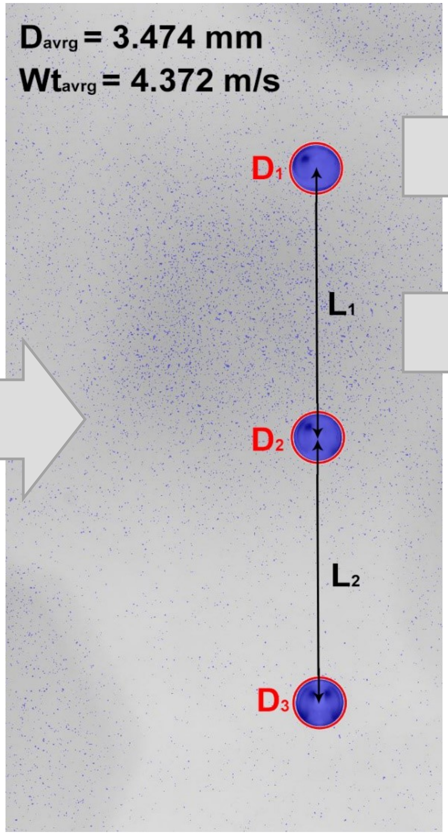
24.2 M pixels

3.89 μm pixel

Each falling drop is captured 3 to 5 times in the same picture against a black background thanks to a high-speed flash activated sequentially

Images are then processed by applying greyscale filtering and contour detection algorithms to retrieve the contour of the drop in all positions and obtain:





- **the reference drop diameter, D_{ref}**

- **the reference drop fall velocity, V_{ref}**

(calculated based on the timing of the flashes, set at 2,5 ms, and measuring the drop fall path from the image)

Laboratory calibration of optical disdrometers

according to EN 18097:2025

Disdrometers tested:

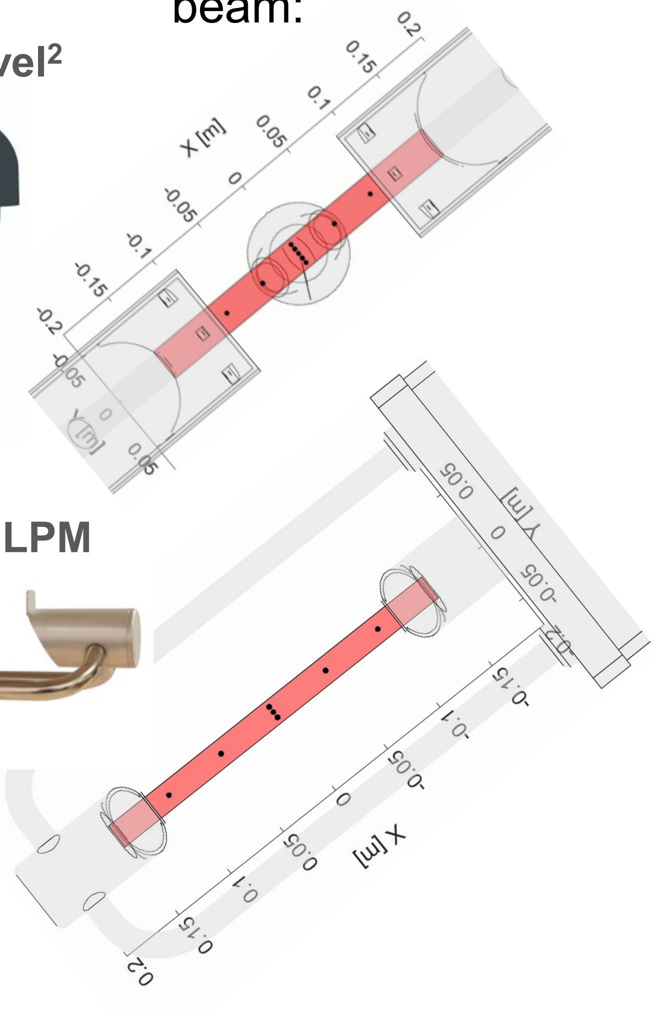
OTT Parsivel²

Raw data only

Thies Clima LPM

Raw data and PSVD matrix

Five positions tested along and across the laser beam:



Test programme for comparison:

Reference water drops
nominal diameter from **0.6** to **5 mm**. Released from 1.2 m above the laser beam

Calibrated metallic spheres
nominal diameter from **1** to **5 mm** (as suggested by the manufacturer).

Results are expressed in terms of the percentage relative bias:

$$e_X[\%] = \frac{X_{meas} - X_{ref}}{X_{ref}} \cdot 100$$

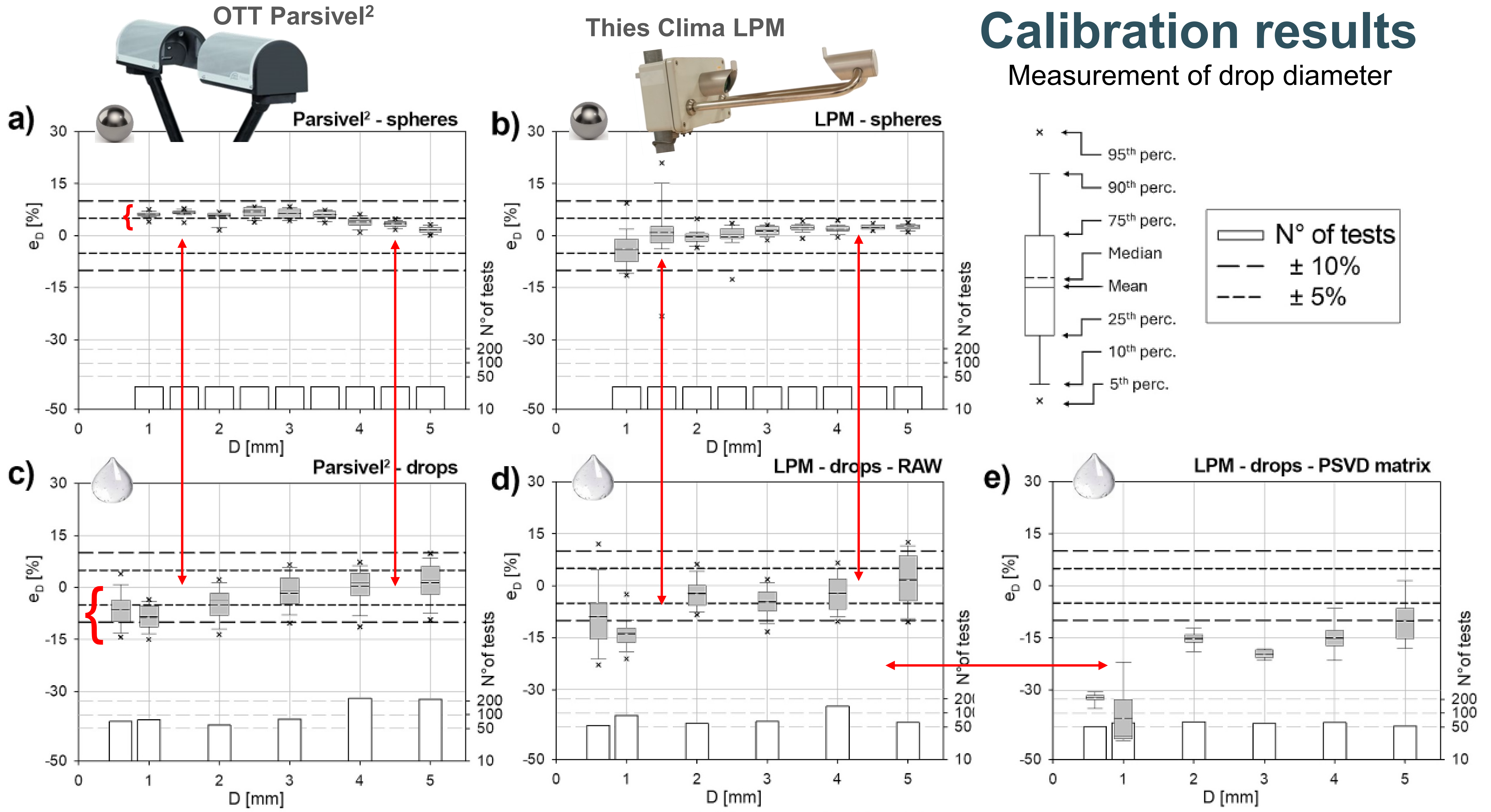
Calculated for the diameter (*D*), fall velocity (v), and derived quantities including rainfall intensity (RI) and radar reflectivity (Z)

$$RI = \int_{D_{min}}^{D_{max}} N(D)\,V(D)\,v(D)\,dD \qquad Z = \int_{D_{min}}^{D_{max}} N(D)\,D^6 dD$$

with N(D) the numerosity of drops of a given size according to DSD assumed in the calculation.

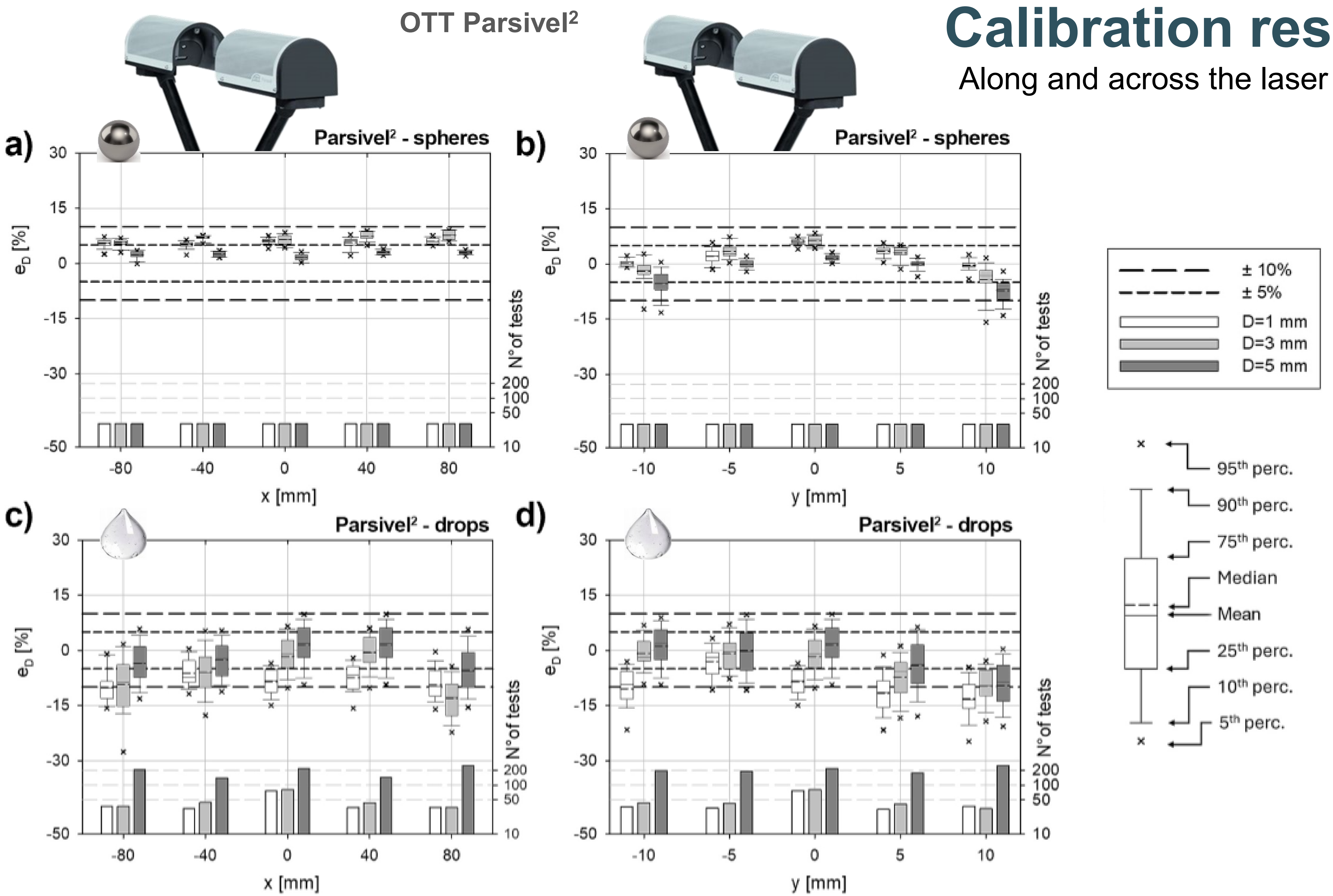
Calibration results

Measurement of drop diameter



Calibration results

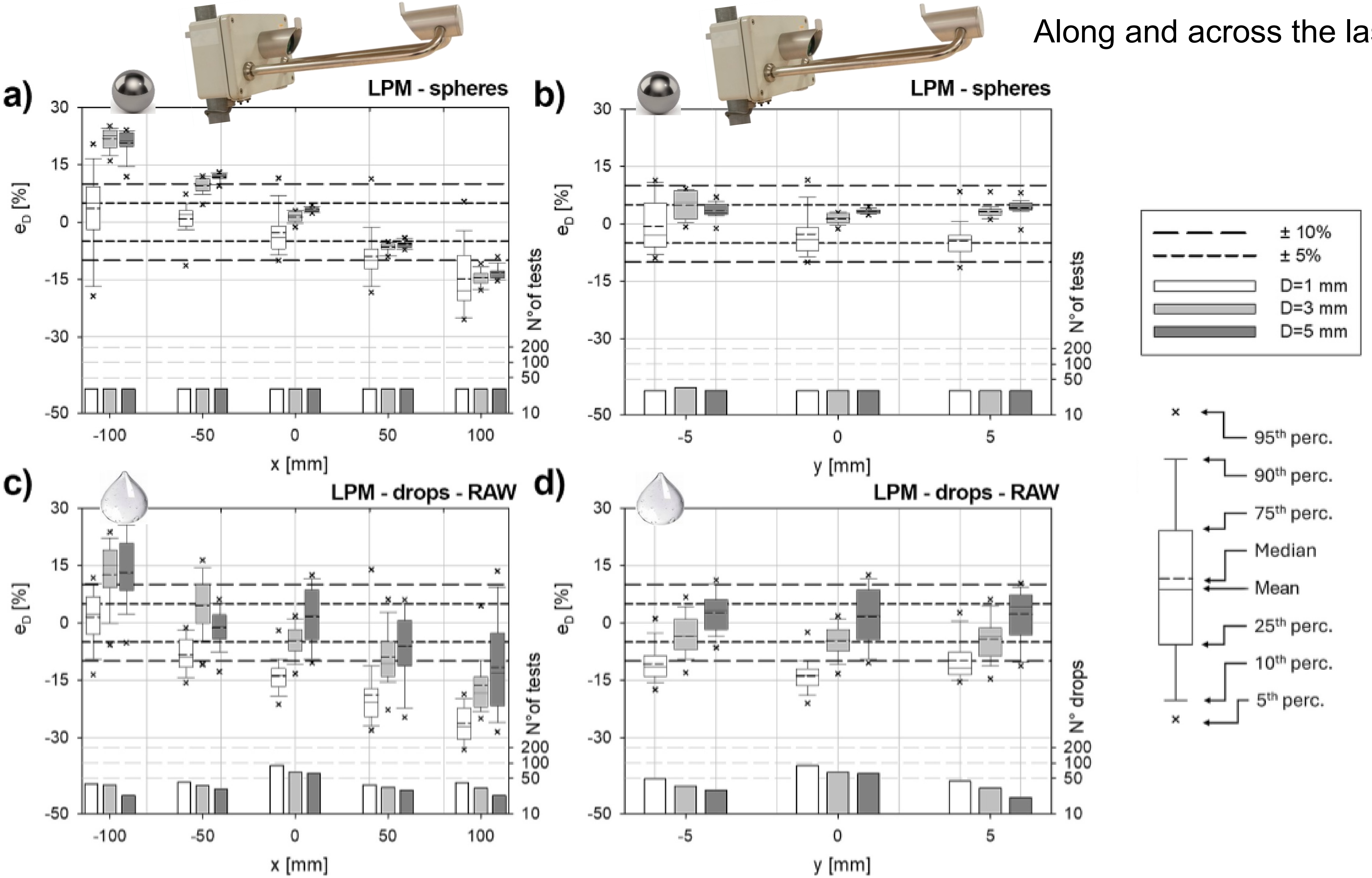
Along and across the laser beam



Calibration results

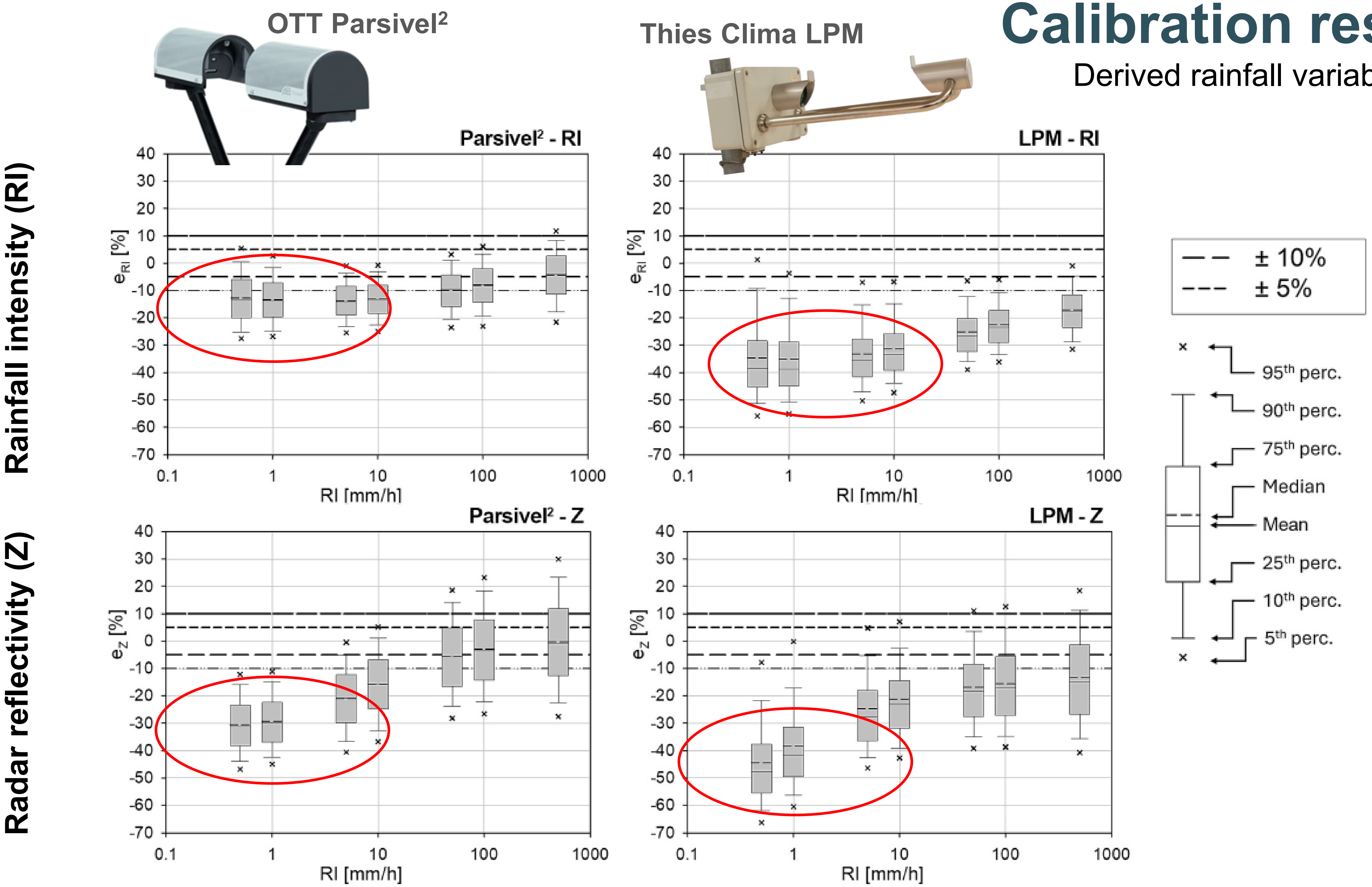
Along and across the laser beam

Thies Clima LPM



Calibration results

Derived rainfall variables



Conclusions

- For the disdrometers tested, the measurement biases for drop size and fall velocity reach, in the worst configurations, 30% of the reference value;
- The bias propagates in the calculation of integral variables such as RI (-35% to -8%) and Z (-25% to -2%).
- Calibration using metallic spheres show significantly different results than using water drops, therefore **they cannot be used according to EN 18097:2025**.

References

Chinchella, E., Cauteruccio, A. and L.G. Lanza (2026). On the accuracy of optical disdrometer measurements. *Atmospheric Research*, **336**, 108865, https://doi.org/10.1016/j.atmosres.2026.108865

Baire, Q., Dobre, M., Piette, A.S., Lanza, L.G., Cauteruccio, A., Chinchella, E., Merlone, A., Kjeldsen, H., Nielsen, J., Friis Østergaard, P., Parrondo, M., Garcia Izquierdo, C. (2022). Calibration uncertainty of non-catching precipitation gauges. *Sensors*, **22**(17), 6413. https://doi.org/10.3390/s22176413

Lanza, L. G., Merlone, A., Cauteruccio, A., Chinchella, E., Stagnaro, M., Dobre, M., Garcia Izquierdo, M. C., Nielsen, J., Kjeldsen, H., Roulet, Y. A., Coppa, G., Musacchio, C., Bordianu, C., and Parrondo, M. (2021). Calibration of non-catching precipitation measurement instruments: A review. *Meteorological Applications*, **28**(3), e2002. https://doi.org/10.1002/met.2002