Harmonizing the measurement of ultrafine particles in atmospheric aerosol

CEN/TS 16976

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UNDERSTANDING, ACCELERATED

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Understanding Urban Air Pollution

+ Air Quality/Visibility Effects:
  - At high relative humidity water condensation enlarges UFPs to a size that is efficient at scattering light.
+ Increased Exposure to Ultrafine Particles
  - Recent studies show increased exposure near roadways, airports, tunnels, and schools.
+ Potential Health Effects:
  - Toxicological evidence points to UFPs as possible contributors to heart disease, lung disease, DNA damage, and translocation of UFPs to the brain.
+ Source Apportionment
  - Where is it coming from and how to reduce it

NABEL online CPC data

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Federal Office for the Environment FOEN

Topic Air

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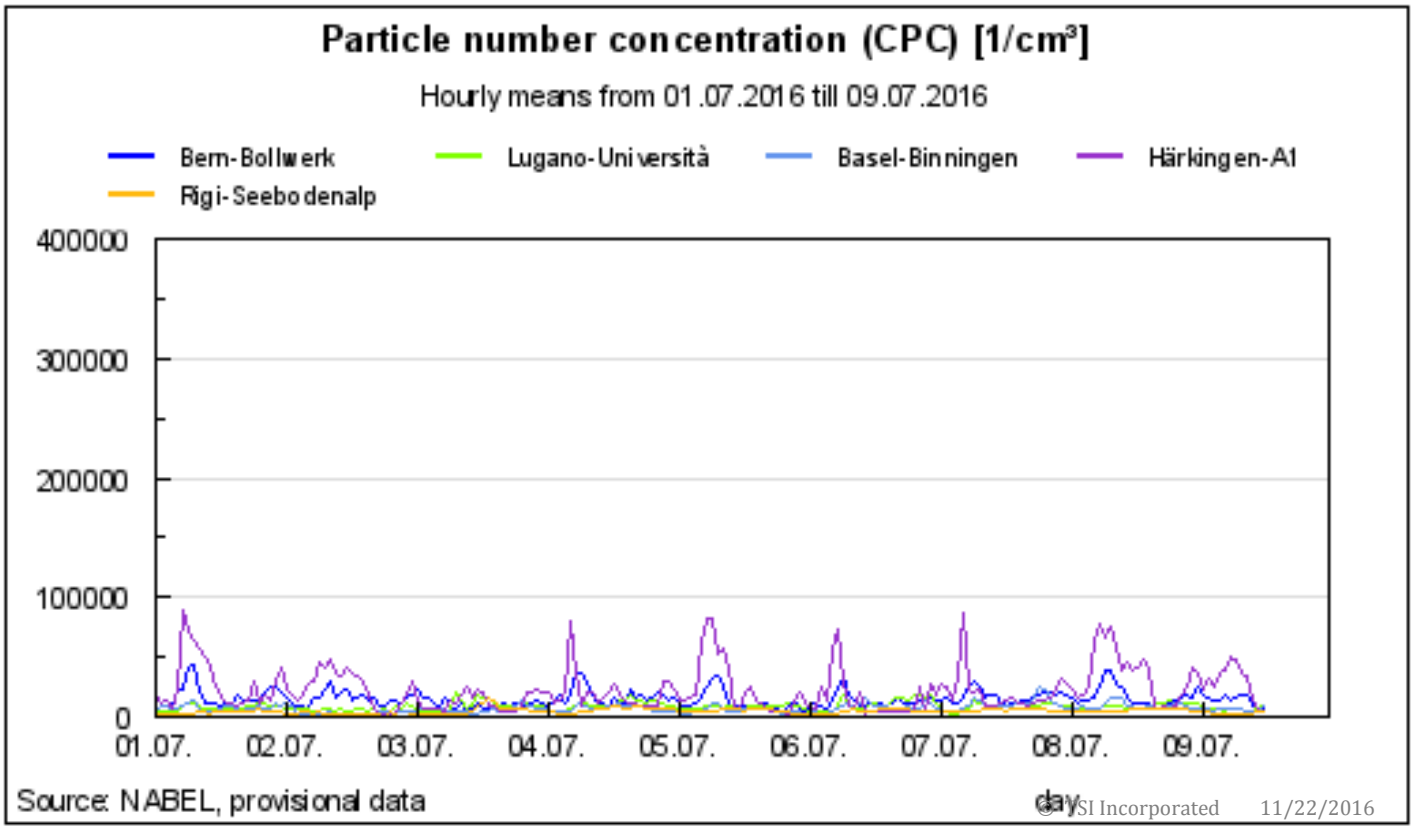
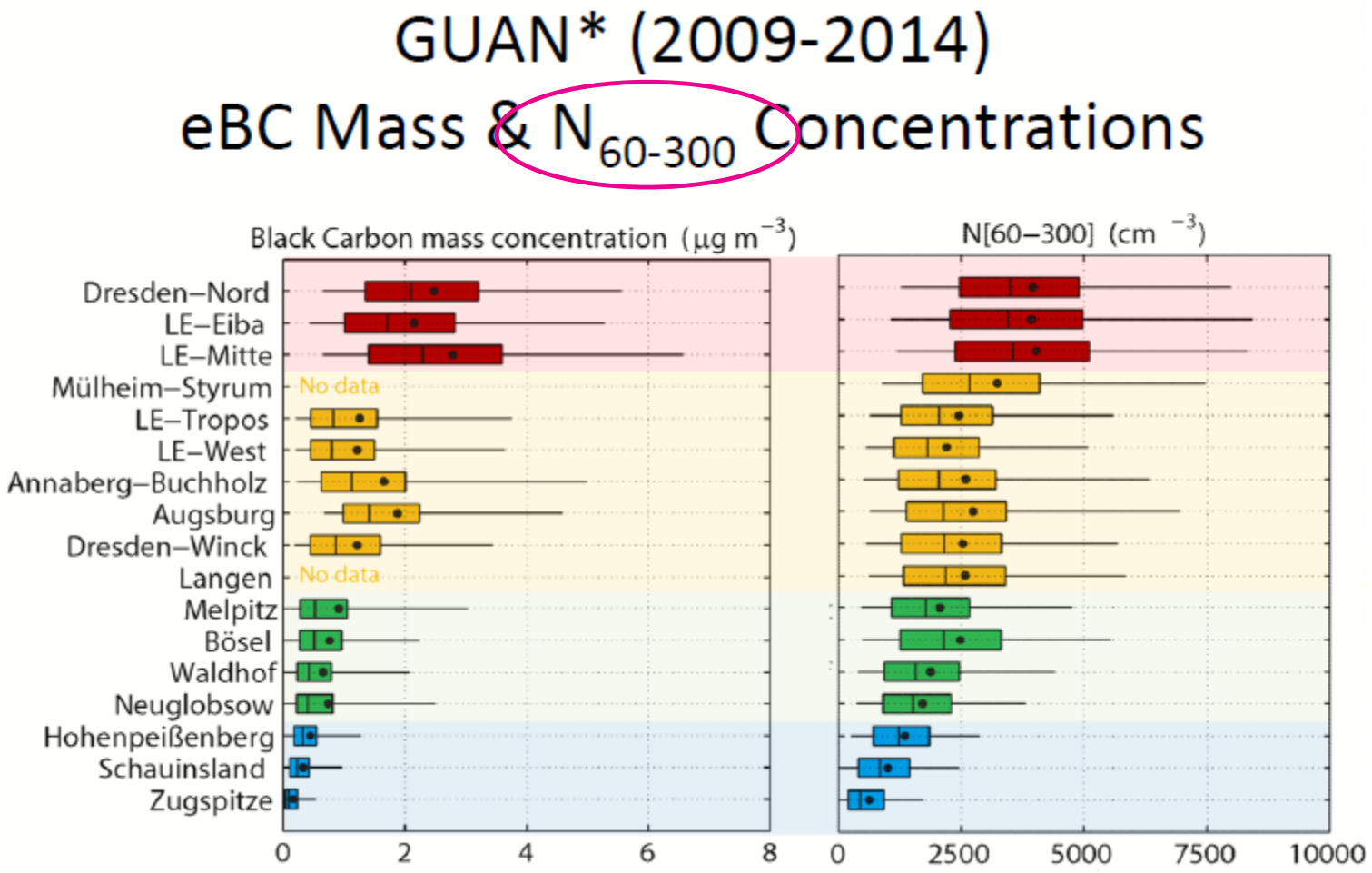
Data query NABEL



http://www.bafu.admin.ch/luft/luftbelastung/blick_zurueck/datenabfrage/index.html?lang=en

http://wiki.tropos.de/index.php/GUAN

UFPs in Germany



From: Wiedensohler et al., Assessment of the Effectiveness of the Low Emission Zone Leipzig by Measurements of Soot and the Ultrafine Particle Number Concentration, talk at the 20th ETH-Conference, 2016

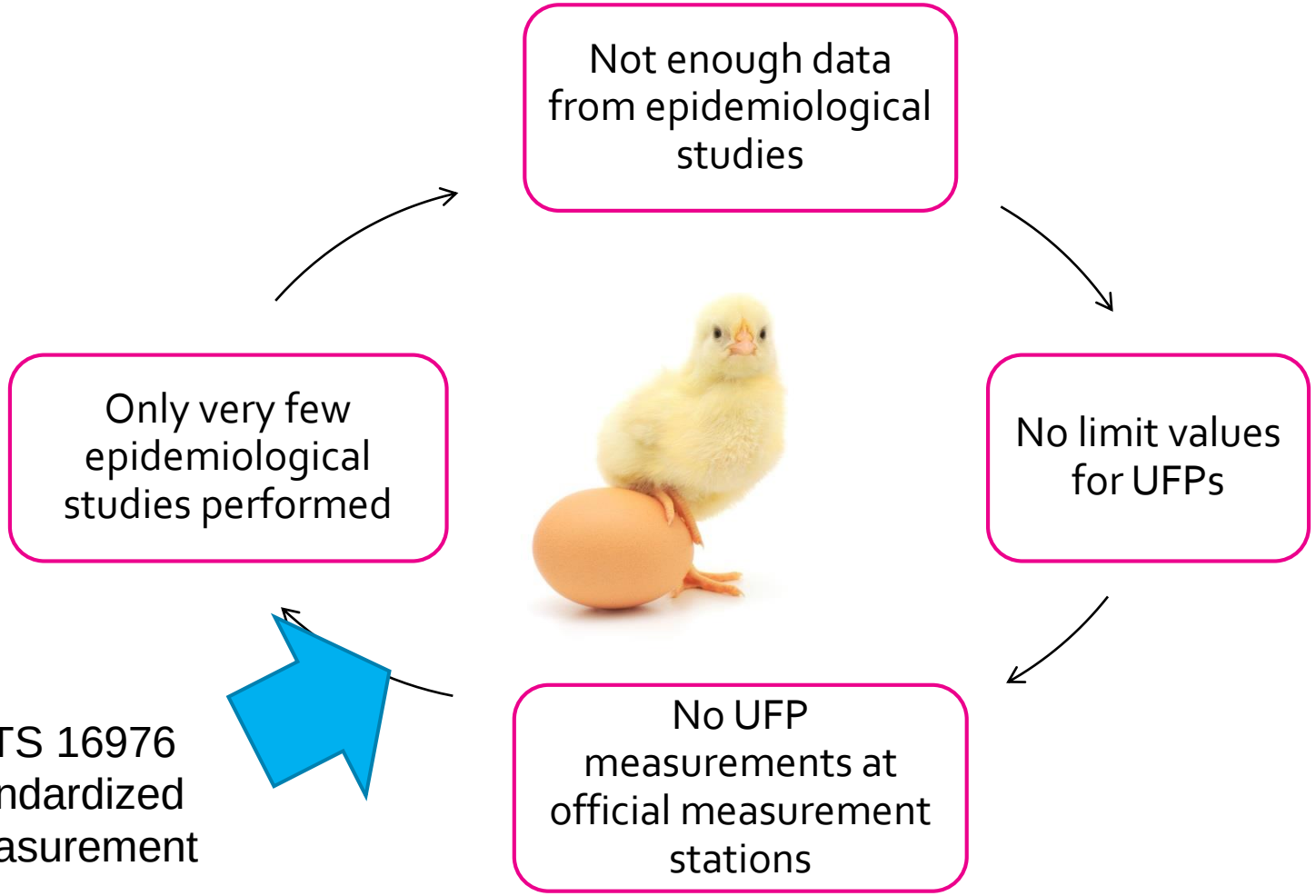
Use of CPCs in routine monitoring

TSI CPCs are used globally (e.g. in the Global Atmosphere Watch program) and in Europe for many years. This table shows select examples of CPCs used in continuous monitoring:

Country	Network	TSI CPC Used	Since
Switzerland	National Air Pollution Monitoring Network (NABEL) http://www.bafu.admin.ch/luft/00612/00625/index.html?lang=en	3775	2003
UK	Defra/DA "Particle Numbers and Concentrations Network" https://uk-air.defra.gov.uk/networks/network-info?view=particle	3022A	2000
Germany	German Ultrafine Aerosol Network (GUAN) https://www.tropos.de/en/research/atmospheric-aerosols/long-term-trends-and-process-analysis/long-term-studies-of-regional-importance-and-air-quality/guan-a-network-to-measure-ultrafine-particles/	3010, 3772	2008
Sweden	"Air Quality Network" http://slb.nu/slbanalys/luften-idag/	3775	2004
Netherlands	"Air Quality Network" www.luchtkwaliteit.amsterdam.nl	3022A, 3775	2006

However, when using different CPCs with different d_{50} cutpoints it is difficult to compare the data. In order to harmonize PN concentration measurements, a workgroup was formed to draft a set of requirements for the CPC and the sampling system -> **CEN/TS 16976**

The (Chicken – Egg) Problem



CEN/TS 16976
-> standardized measurement

Thanks to Dr. Josef Cyrys for this slide

CEN/TS 16976:2016

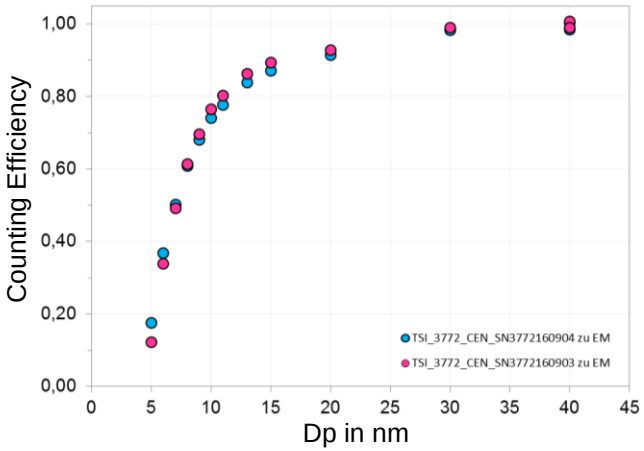
+ CEN = European Committee for Standardization.
  - officially recognized by the EU and the European Free Trade Association
  - brings together the National Standardization Bodies of 33 European countries.
+ The CEN/TS 16976 (published 24. August 2016)
  - *"**describes a standard method** for determining the particle number concentration in ambient air […]. The standard method is based on a Condensation Particle Counter (CPC) operated in the counting mode and an appropriate dilution system for concentrations exceeding the counting mode range […]. The lower and upper sizes considered within this document are **7 nm and a few micrometres**, respectively."*
+ The CEN/TS 16976
  - contains general information about the properties of the aerosol and the method
  - defines performance criteria and test procedures for **suitable CPCs**
  - defines performance criteria and test procedures for the **sampling system**
  - lists requirements for the installation, initial checks and calibrations, and operation of a CPC and sampling system at a monitoring site
  - suggests a standardized data reporting format
  - describes Quality Assurance and Quality Control procedures

CEN/TS 16976
CPC performance criteria

Performance characteristic	**Criteria**
Actual flow rate	≤ 5 % difference to the nominal flow rate ≤ 2 % difference to the factory-certified flow rate
Number concentration measurement range Lower limit Upper limit Dynamic range	 ≤ 100 cm^{-3} (based on at least 1500 particle counts) ≥ 10 000 cm^{-3} (including coincidence correction) at least 3 orders of magnitude
Concentration response	
Slope Linearity	1 ± 0,05 all residuals < 4 % of the measured value
Detection efficiency at low particle size	D_{50} = 7 nm ± 0,7 nm D_{90} < 14 nm
Detection efficiency (at intermediate particle sizes)	> 95 % at (50 ± 10) nm
Upper particle size detection limit	> 90 % detection efficiency at 1000 nm ± 100 nm
Zero count rate	< 1 min^{-1}
Response time	t_{rise} < 5 s t_{fall} < 5 s $\left\lvert\frac{t_{rise}-t_{fall}}{t_{rise}}\right\rvert$ < 10 % or < 0,5 s

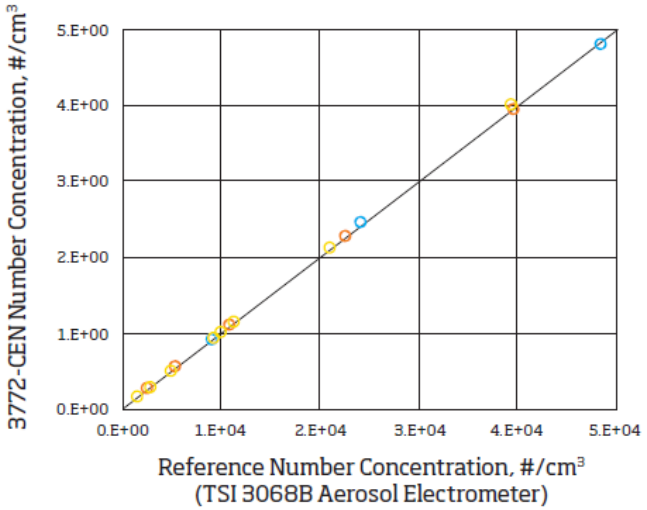
Excerpt from CEN/TS 16976 Table 1 – CPC performance criteria

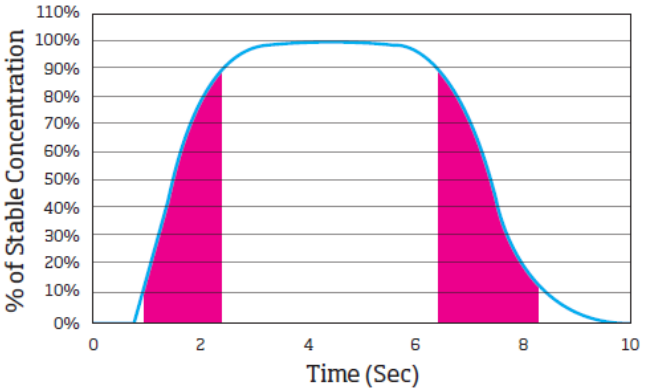
TSI 3772-CEN CPC Performance



Counting efficiency for silver particles that are generated with the evaporation/ condensation method measured by the World Calibration Centre for Aerosol Physics (WCCAP)

Linearity: Data points show data for 4 units, black line shows y=x





Response time: Shown are

t_{rise} < 2 s and t_{fall} < 2 s for the 3772-CEN CPC

CEN/TS 16976 further Requirements vs. TSI solution: 3772-CEN CPC

CEN/TS 16976 General requirements of the CPC	TSI: 3772-CEN CPC
The CPC shall have no internal flow splitting	**YES**, full flow CPC
The working fluid shall be n-butanol	**YES**, butanol CPC
Single particle counting up to 10,000 particles/cm^3	**YES**, up to 50,000 particles/cm^3
1 second sampling, 1 minute reporting interval	**YES**
The instrument shall record a number of parameters, including warnings & error flags, e.g. signal quality out of tolerance, butanol level too low	**YES**, proven* pulse height monitor to ensure data accuracy [monitors wick health, supersaturation stage & status]
The detection efficiency shall be measured according to ISO 27891, using silver particles produced by the evaporation/condensation method	**YES**, D_{50} = 7 nm with silver particles calibrated by the World Calibration Centre (TROPOS)
Recommendation to record data in the EBAS format (Annex C)	**YES**, CEN data record

CEN/TS 16976
Sampling system requirements

Performance characteristic	Criterion
Diffusion losses for smallest relevant particle size of 7 nm	< 30 %
Relative humidity of primary flow at CPC inlet	< 40 %, accuracy ±3 %

Excerpt from CEN/TS 16976 Table 2 – Sampling system performance criteria

Sampling system general requirements:

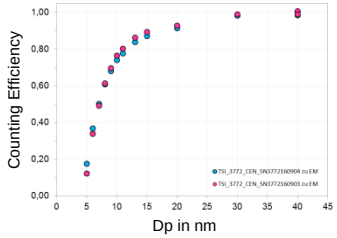
CEN/TS 16976 General requirements of the Sampling System	TSI: 3772200 Sampling System
Measure and record relative humidity, temperature and absolute pressure at CPC inlet	**YES**, rH/T/p are measured and recorded via analog-in by the 3772-CEN CPC
Drying (yes/no)	**YES**, drying via single-tube Nafion Dryer
Dilution (yes/no)	**YES**, standard 3:1 dilution (others can be requested) to increase concentration limit to 150,000 particles/cm^3 Accuracy ± 5%, stable in time

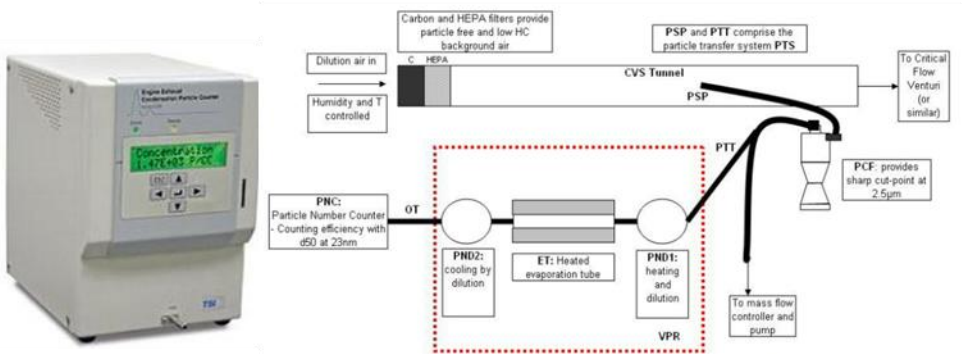
The sampling system

- PM-10 inlet with 16.67 L/min flow (low particle losses at 7nm)
- 36“ long, efficient dryer (Permapure single-tube Nafion dryer)
- Built-in 3:1 dilution
- Continuous measurement of rH/T/p and recording in 3772-CEN CPC

Summary:
3772-CEN CPC & Sampling System

Recently, TSI released a new CEN/TS 16976 compliant CPC with a dedicated sampling system which is calibrated and characterized by WCCAP/TROPOS (Prof. Wiedensohler).





Regulation No. 83 (UNECE)

CEN/TS 16976

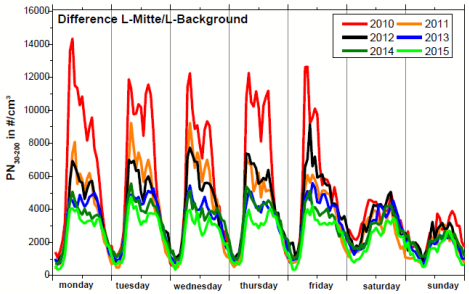
The model 3772-CEN CPC brings the same technology and accuracy to atmospheric monitoring that the EECPCs used in type approval testing according to Euro 5b/6 legislations rely on.

Atmospheric researchers can now expect the same accuracy and very tight tolerances.

Summary:
3772-CEN CPC & Sampling System

The CEN/TS 16976 harmonizes the continuous measurement of particle number concentration in the atmosphere by defining

- a set of requirements for the CPC,
- a set of requirements for its sampling system,
- the measurement procedure and
- the reporting of measurement results.



This standard method facilitates data comparison & use

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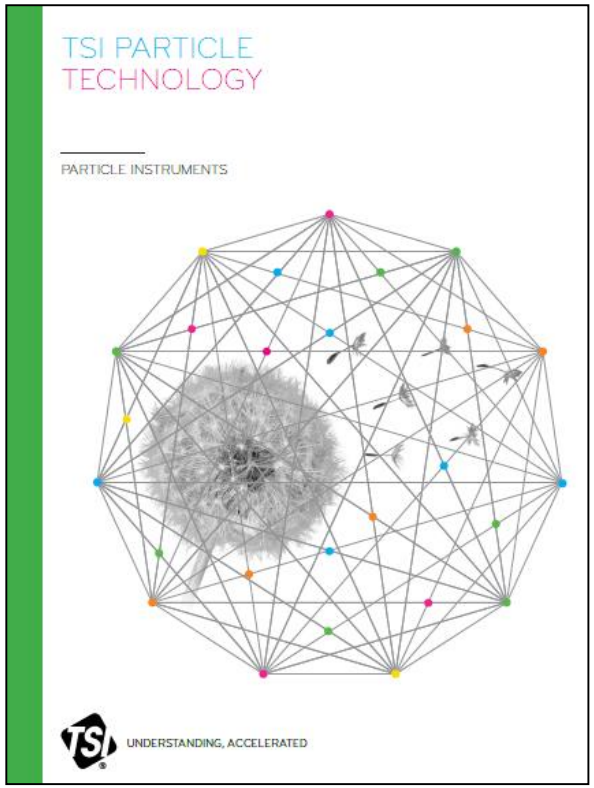
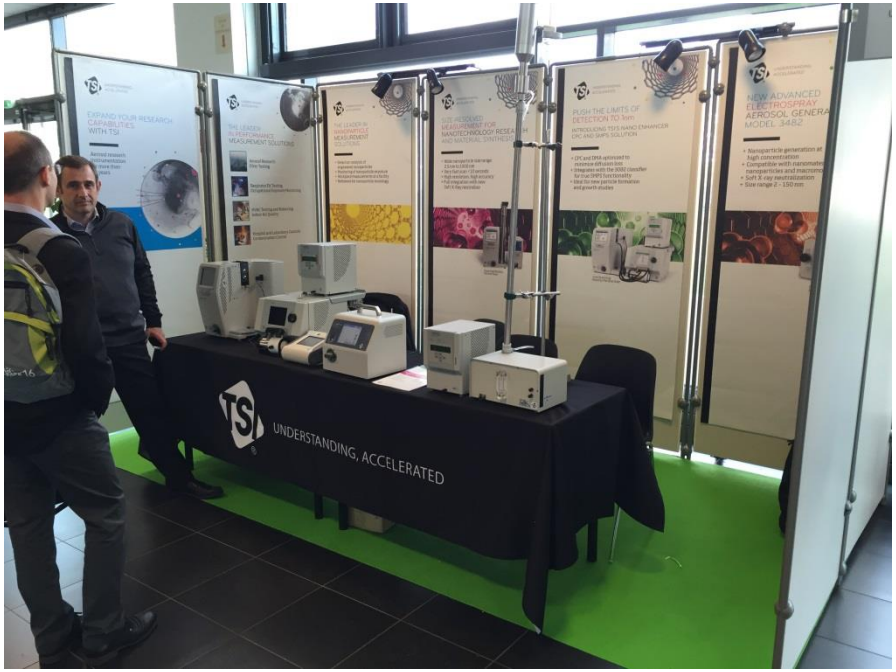
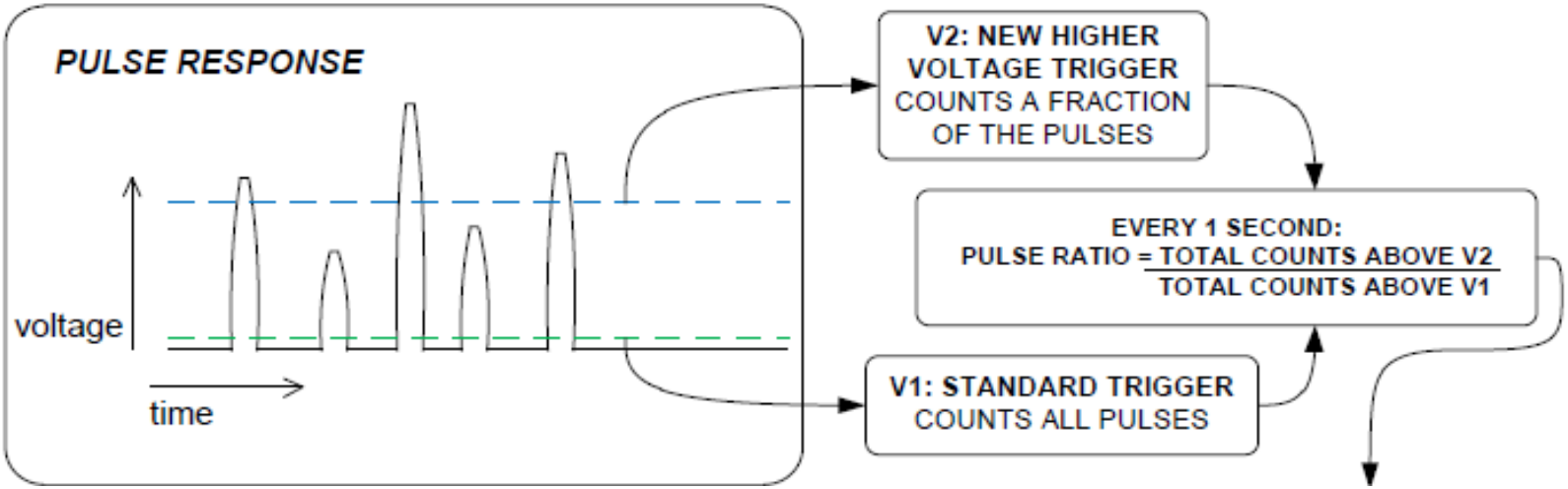
Thank you very much for your attention!





TSI booth at Minatec

Pulse height analyzer



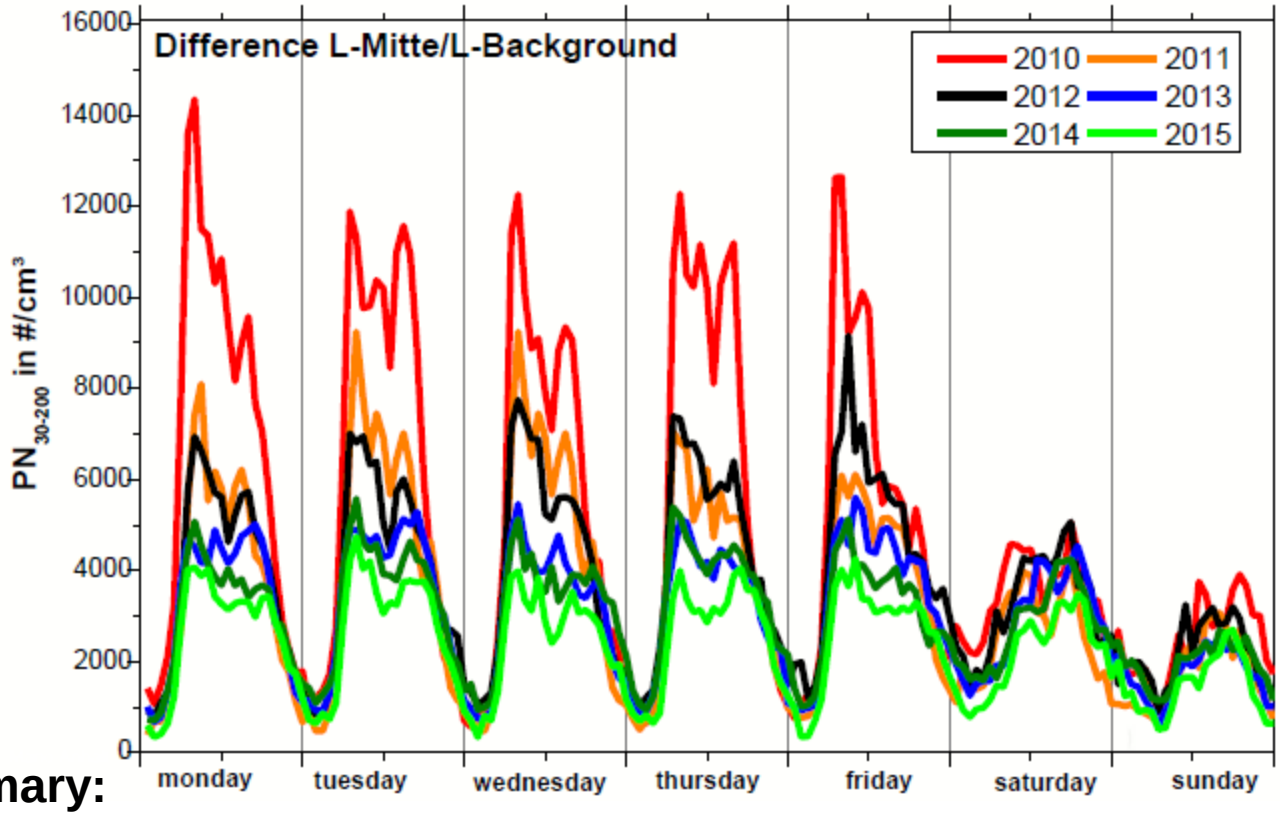
Pulse Response

Each particle passing through the optics generates an electric pulse, and the height of the pulse can be correlated to the size of the grown droplet.

Pulse Height Error

Under certain conditions, particles do not grow to this droplet size, and as a result, the pulse height is decreased. Both Model 3772-CEN CPC and 3783 includes an error which is triggered when pulse height decreases enough to indicate a problem with the measurement.

Leipzig Low Emission Zone



Summary:

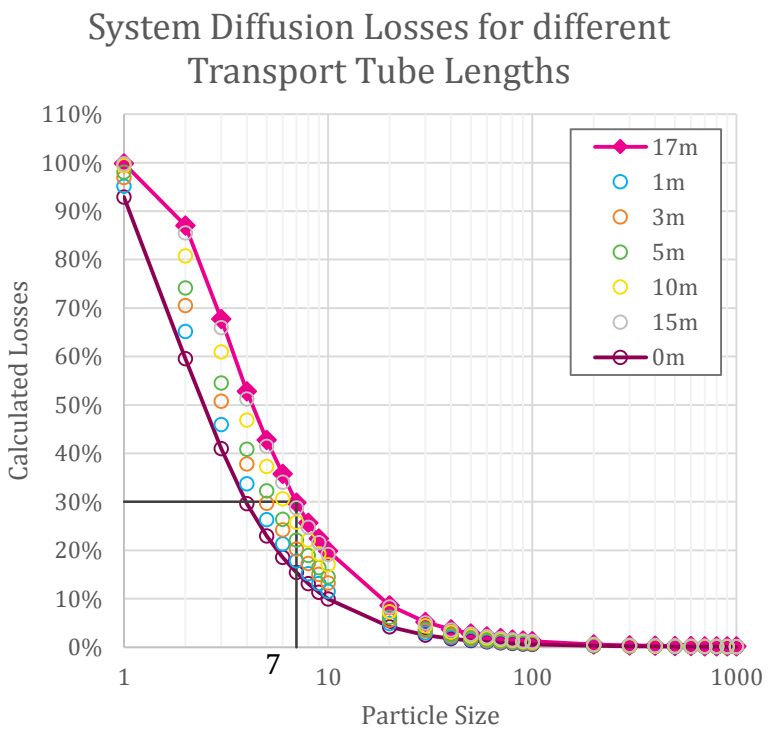
- The LEZ Leipzig (at the street site) was successful in terms of:
  - Black carbon mass concentration reduction ~ 50%
  - Ultrafine particles ($N_{30\text{-}200}$) **reduction > 50%**

From: Wiedensohler et al., Assessment of the Effectiveness of the Low Emission Zone Leipzig by Measurements of Soot and the Ultrafine Particle Number Concentration, talk at the 20th ETH-Conference, 2016

Backup slide: Diffusion Losses < 30% at 7 nm

+ Calculated straight-tube diffusion losses for major components of the aerosol flow system

System Component	7nm losses
36” Nafion Dryer @ 5 L/min	8%
12” Internal tubing @ 1 L/min	8%
1m transport tubing @ 16.67 L/min	3%
3m “ “ “ “ “	6%
5m “ “ “ “ “	8%
10m “ “ “ “ “	12%
15m “ “ “ “ “	16%
Max transport tubing length = 17m	



PN vs PM measurements

Why are people looking more and more at particle number concentration (PN) instead of PM (particulate matter expressed in mass)?

> 2.3.3.1 PM **number concentration.** As previously discussed, PM emitted through the combustion process occurs primarily in the ultrafine size range (i.e. less than 0.1 μm in diameter); thus, the **impact on PM mass may be negligible.** However, emissions of these small particles occur in **extremely large quantities**; therefore, PM number concentration measurements often provide a good **indication of primary PM exhaust emissions** from motor vehicles. In addition, several health studies suggest that ultrafine particles **may lead to adverse health effects** identified in the near-road literature

How do you quantify UFPs?

Problem: Detection of light scattering "peters out" for particles less than 0.1 µm

Solution: Condensation Particle Counters (CPCs): 3-Step process to make particles BIGGER