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Nanoparticles in ambient air of residential areas: sources and mitigation potential

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Outline

- **Motivation**

- **Sources of nanoparticle pollution** in a **residential area** over the course of an exploratory **field measurement** applying a **diffusion charge based UFP monitor**

- **Mitigation potential of nanoparticle emissions** in a **municipal biomass incineration plant** equipped with **gas-cleaning technology** (pulse-jet cleaned filters)

- **Summary and conclusions**

UFP (particles < 100 nm) as a “new pollutant“

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- **Currently: Ambient air** particle concentration and **particle emission limits** are typically **mass based gravimetrical concentrations**
- **Classification of UFP** as a **“new pollutant“** regarding the revision of the ambient air quality directive
- (Long-term) **measurement of ultrafine particles** is **only rarely performed** and **locally restricted** (examples include e.g. the German Ultrafine Aerosol Network)

→ **Spot measurements** can help to identify **local pollutant exposure** and concentration dynamics

→ Opportunity for **diffusion charge based measurement devices** (easier operation and maintenance compared to conventional SMPS systems)

- **Measurement** of the **nanoparticle emission in technical** (or industrial) **processes** is subject of research and requires **large measurement effort**

Scope of this presentation

Example limits of particle emissions from different sources and particulate matter concentrations in ambient air

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Immission

Ambient air quality limits for particulate matter

	Type of limit / recommendation	39. BImSchV (Germany)	WHO recommendation
$PM_{2.5}$	Yearly average	**25 µg/m³**	**5 µg/m³**
	Daily average	Not considered	**15 µg/m³** (approx. 3-4 exceedence days/year)
PM_{10}	Yearly average	**40 µg/m³**	**15 µg/m³**
	Daily average	**50 µg/m³** (limit may not be exceeded on more than 35 days/year)	**45 µg/m³** (approx. 3-4 exceedence days/year)

→ Gravimetrical (size resolved) limits; **no number based or UFP limits**

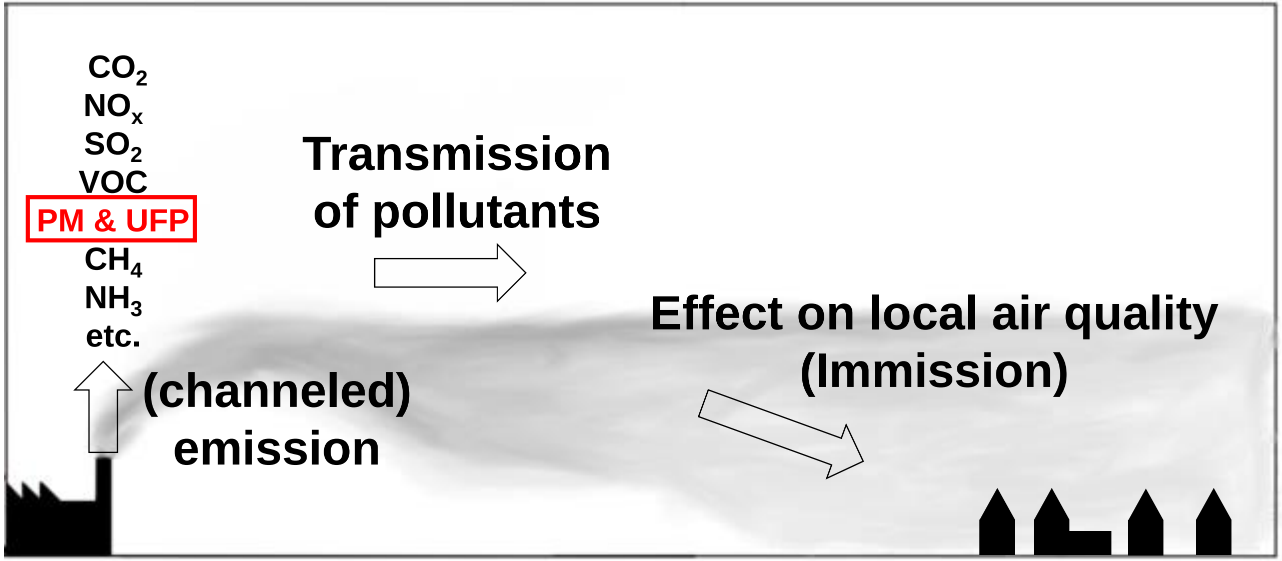
Emission

Limits for dust / particle emissions for several example processes

Total dust emissions in the **(chemical) industry**	WGC BREF	**1 - 5 mg/m³** (if pulse-jet cleaned filters are applicable and dust mass flow > 50 g/h)
	TA-Luft (Germany)	**20 mg/m³** (dust mass flow > 200 g/h) or **10 mg/m³** (dust mass flow > 400 g/h)
Engine exhausts of vehicles (Diesel car)	EURO VI	**4.5 mg/km** and **$6 \cdot 10^{11}$ #/km**
Wood-stove exhaust (installation after 12/31/2014)	1. BImSchV (Germany)	**40 mg/m³**

→ Mostly gravimetrical limits; rarely number based limits (e.g. engine exhaust)

Emission of pollutants and effect on air quality



Emission of pollutants (e.g. industry, traffic) and **emission monitoring**

Exposure to pollutants (e.g. in cities, residential areas, etc.) and **air quality monitoring**

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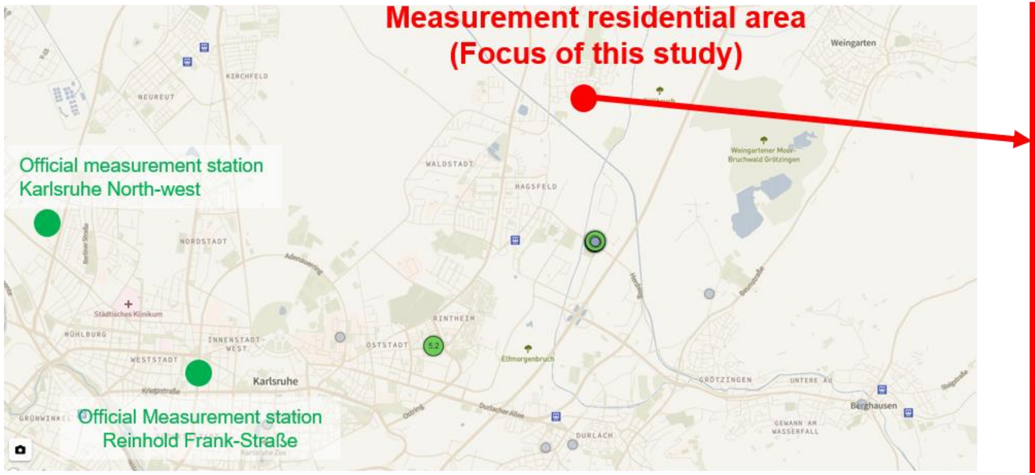
Measurements of nanoparticle concentrations in a residential area employing a charge based UFP monitor



- **Spot measurement** in a **residential area** near Karlsruhe (Germany) applying the **charge based UFP monitor** “AQ Guard Smart 2000“
- Measurement range: 1 000 – 10 000 000 #/cm³ and **sizes down to 10 nm**

Typical patterns of the daily particle concentration evolution in the residential area

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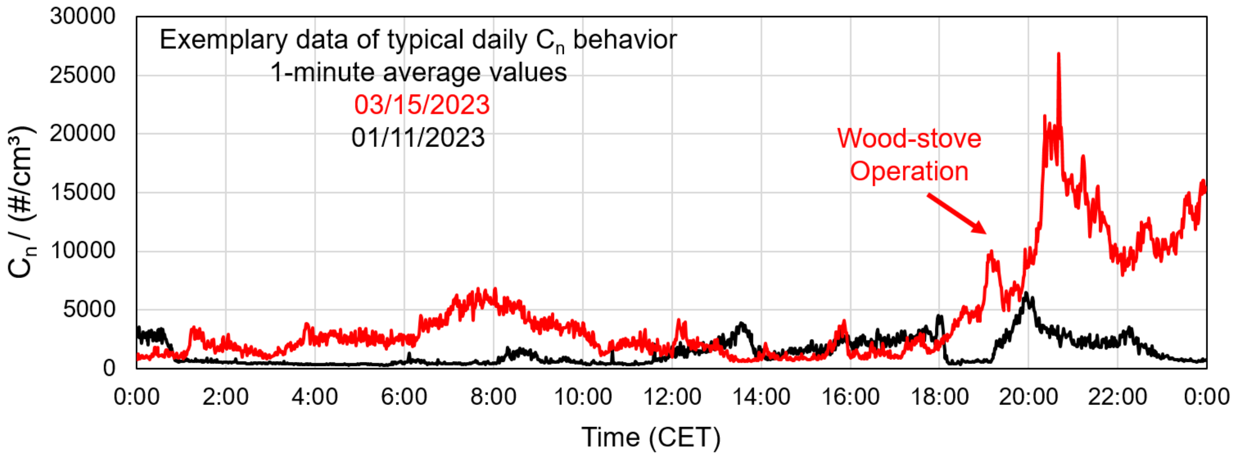


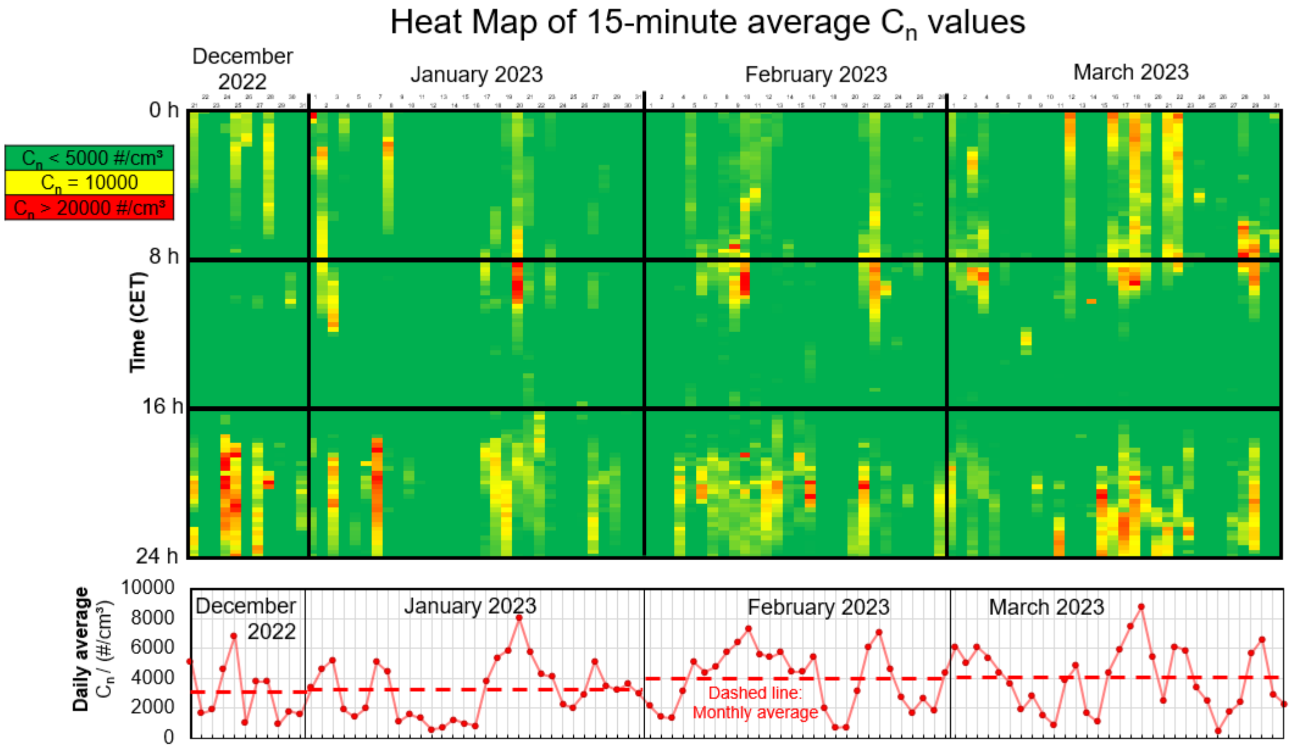
- **Two distinct patterns** commonly appear during the measurement period:
  - **Concentrations** close to the **typical background level** for rural areas (approx. 3000 #/cm³) and city background levels (approx. 5000 #/cm³) **throughout the day**
  - **Significant concentration increase during the evening hours** (here: starting at 18:00)

➡ **Source of air pollution: Wood-stove operation** in the surrounding neighbourhood

Overview of the 15-minute average particle concentrations during the measurement period

- On **53 out of 101 days (52%)** of measurements, the **particle concentration exceeded** the background level (above **6 000 #/cm³**) for **at least 1 hour in the evening (16 – 24 h)!**
- Increased **air pollution** in the evening hours is **not reflected** by daily or monthly **averages** (mostly **within typical** urban or rural **background levels**)

Wood-stove combustion is a major source of air pollution with UFP



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Location of the municipal biomass incineration plant

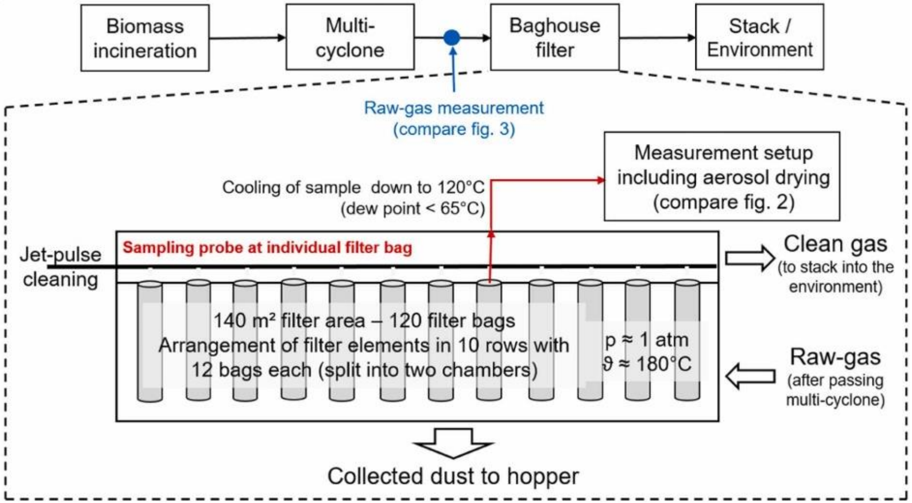
- **Field measurement** at a municipal biomass incineration plant in the german town "Günzburg" in cooperation with BWF Envirotec
- **District heating** with a power output of 0.85 MW
- Combustion of wood-chips and offcuts
- **Pulse-jet cleaned filters** as final waste-gas cleaning technology

Source: google maps

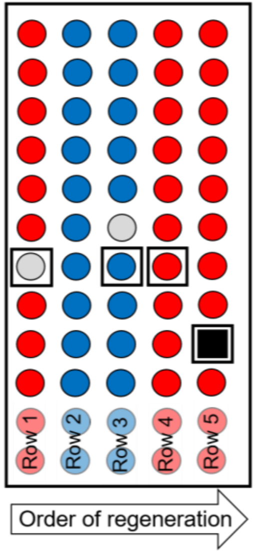
Setup of the baghouse filter and sample positions for particle emission measurement

Photograph of the baghouse filter exterior

Block flow diagram of gas purification of the biomass incineration plant



Schematic overview of measurement positions



Overview of filter media:

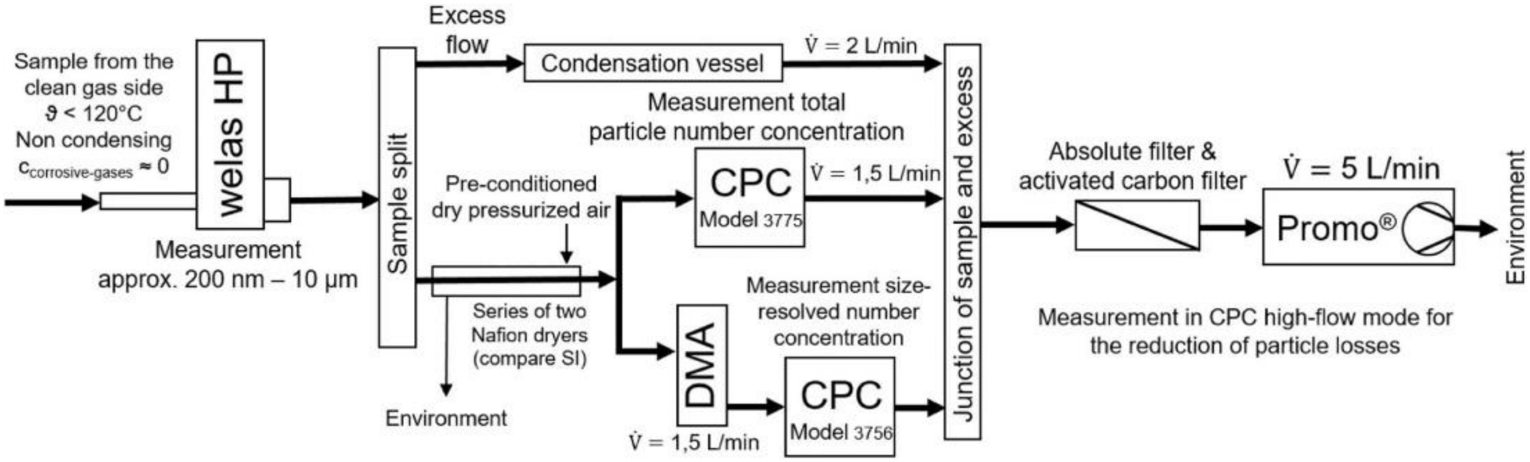
Aged needle-felt
Membrane filter medium
Newly-installed needle-felt
Raw-gas measurement

Black frame: measurement position relevant for this study

Regeneration of one individual row after a certain time interval (most commonly 8 minutes)

- **Process conditions** (e.g. water content of the exhaust gas, temperature, etc.) **require extensive aerosol conditioning** before entering the aerosol measurement devices (CPC & SMPS system)
- **Measurement** at **three different** positions (**filter bags** made from different filter media)

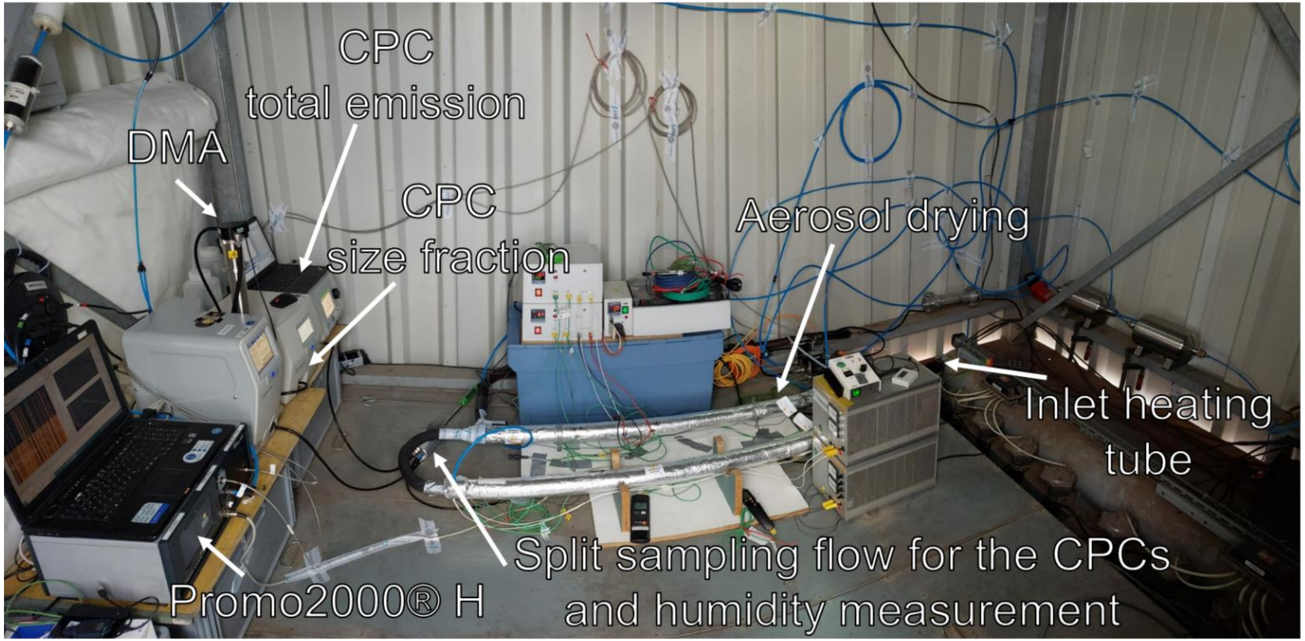
Aerosol conditioning and measurement setup



- Aerosol drying with Nafion dryers (to avoid condensation) and cooling
- **Simultaneous measurement** of **total particle number concentration** with CPC and **size-resolved particle number concentration** (e.g. scan of size distribution **down into the nanometer region**) with SMPS system

Photograph of the measurement setup

Photograph of the measurement setup (front view)



Top view of inlet

- High measurement effort (compared to ambient air measurement)

Raw-gas characterization

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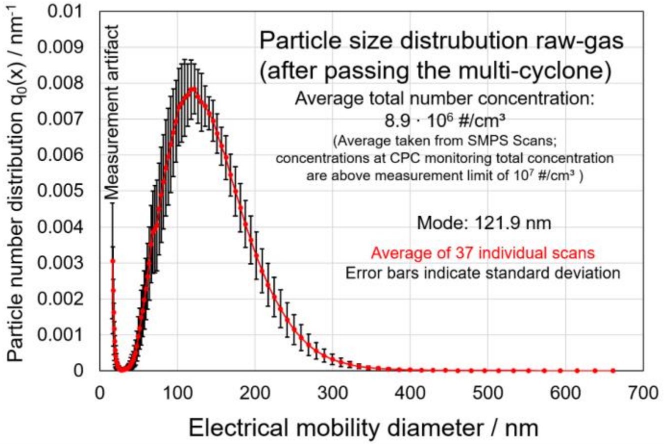
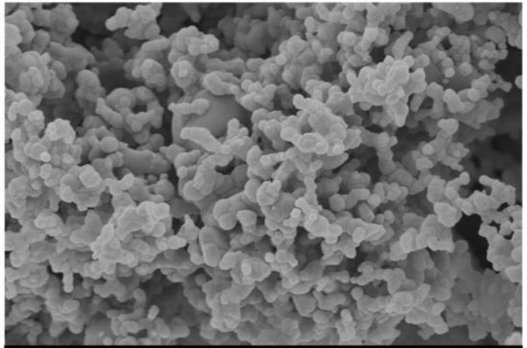
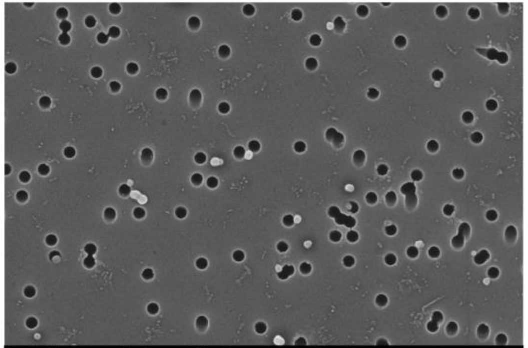




Particle agglomerates from gravimetric measurement (no drying & hot raw-gas)



Individual particles on Nucleopore® filter from raw-gas sample flow through measurement setup

- **Raw-gas** in the filterhouse (after passing a multicyclone) consists almost only of **submicron particles and UFP** below the detectable size range of scattered-light based optical particle counters
- **High particle number concentration** close to the **upper concentration limit of the used CPC** (despite particle losses through the measurement setup)
- **Gravimetrical raw-gas concentration ≈ 60 mg/m³**
- EDX analysis: Large fraction of potassium- (20%) and calciumoxides (16,5%), sulphur (7,5%) und carbon (21%)

Transient particle emission behavior of different filter bags made from different filter media

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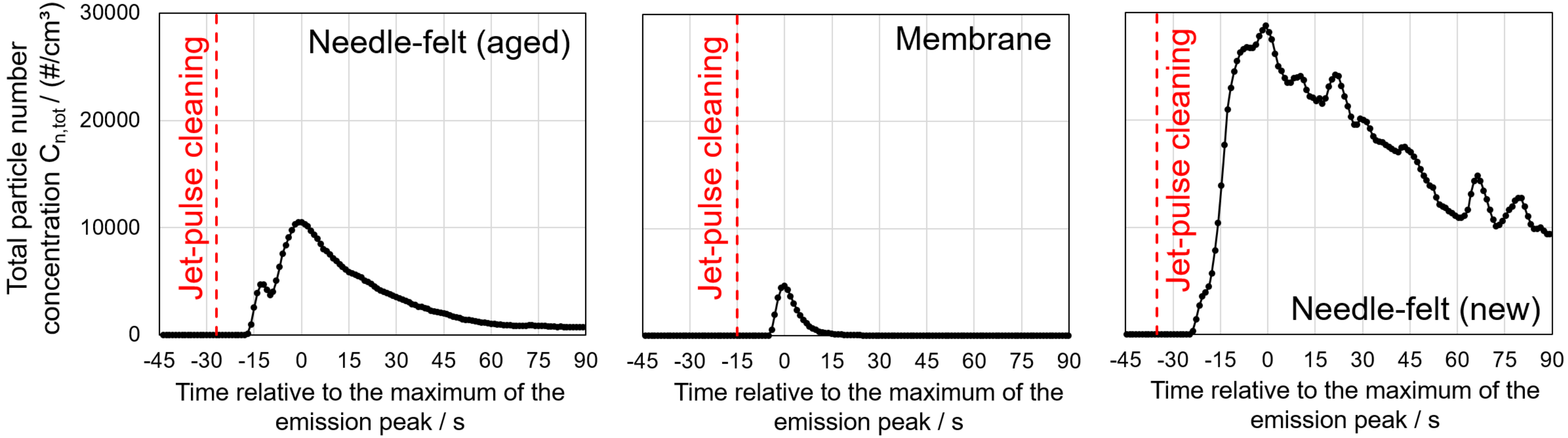
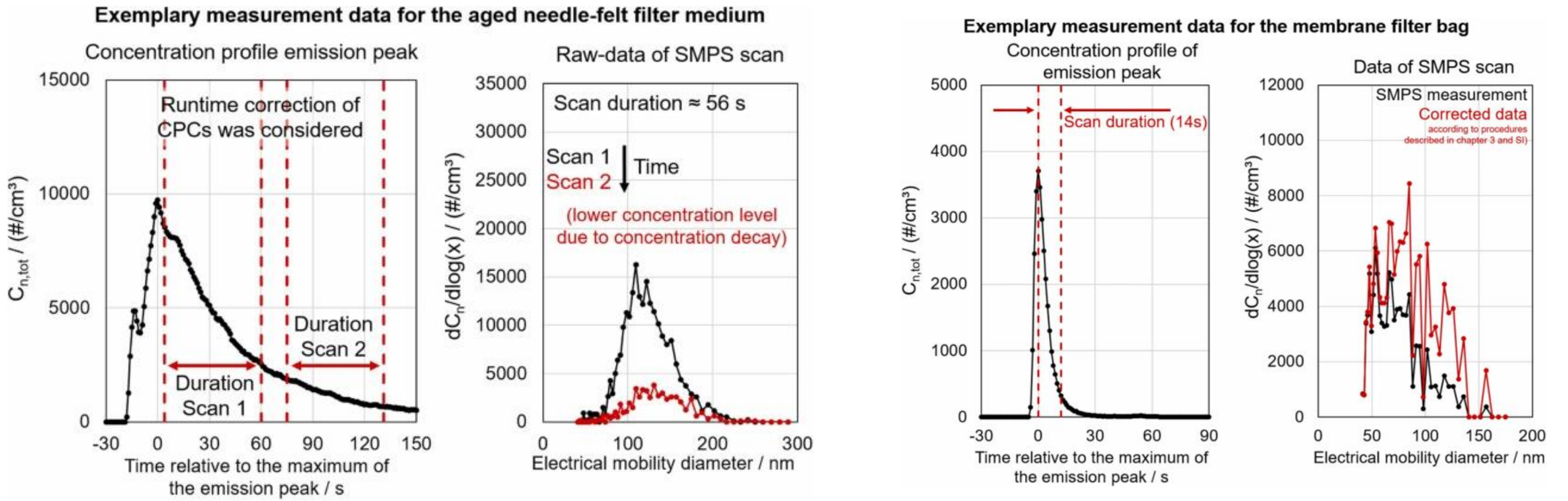
Exemplary data of emission peaks after regeneration of the corresponding row



- **Particle emission peak after filter regeneration** (typical for pulse-jet cleaned filters) that **decays to** a **zero** concentration level with growing filter cake on the filter bag
- **Transient** particle emission **behavior requires corresponding experimental methodology** and **correction of SMPS scans** (concentration decay during the scan of a size distribution); especially for the membrane filter medium (measurement duration of only several seconds)

Transient particle emission behavior of different filter bags made from different filter media



- **Particle emission peak after filter regeneration** (typical for pulse-jet cleaned filters) that **decays to** a **zero** concentration level with growing filter cake on the filter bag
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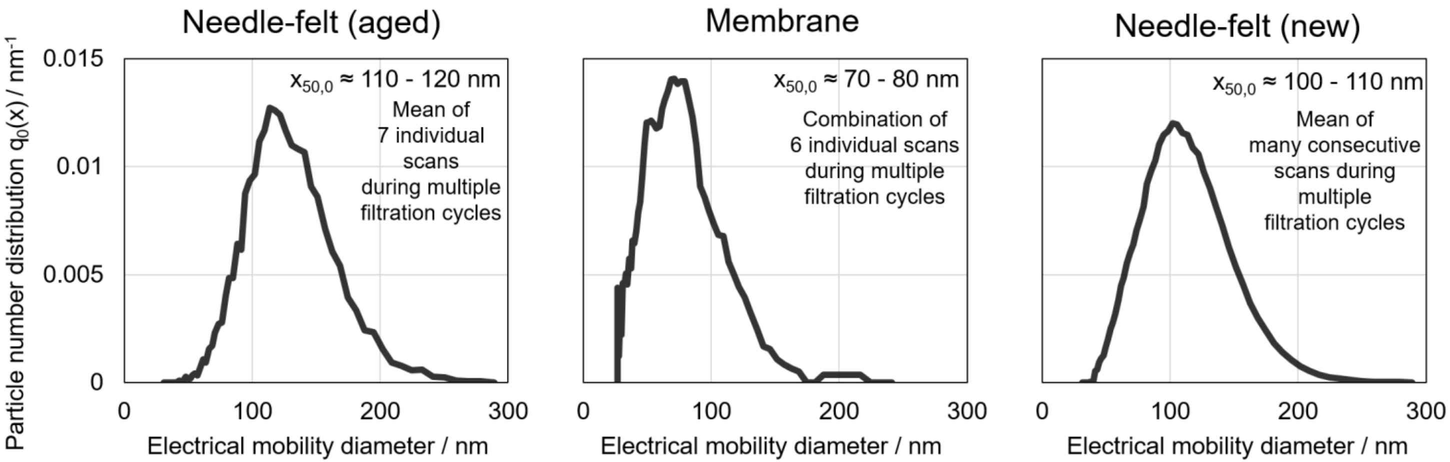
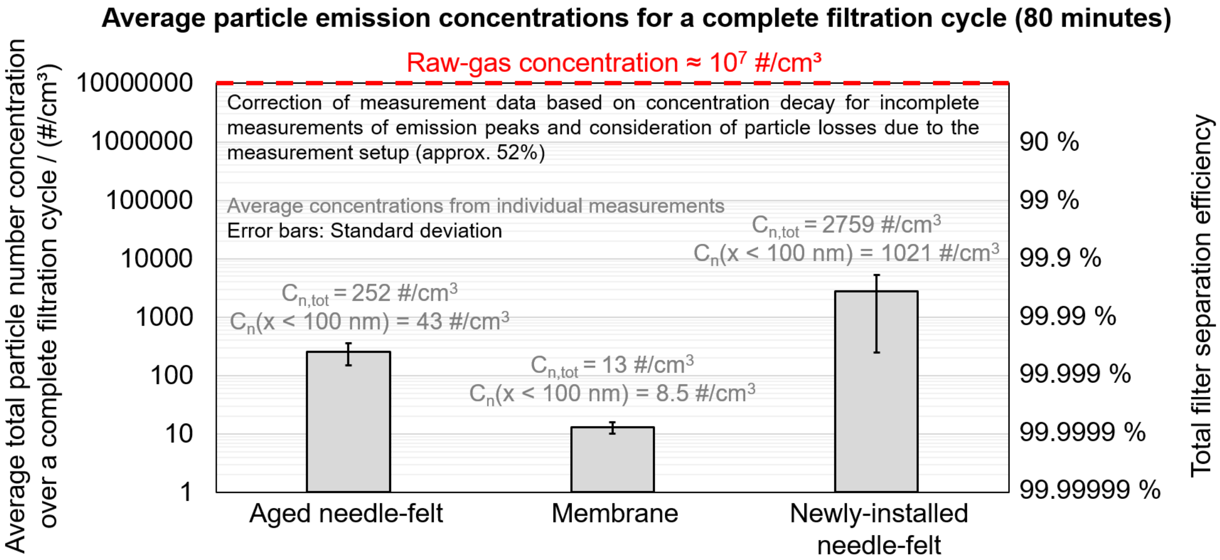
Particle size distribution of the emission penetrating the individual filter bags



- **Varying complexity for the determination of the corresponding size distributions**
  - **Different number of scans necessary** to obtain a comprehensive distribution (e.g. due to **corrections based on concentration decay** or **combination of distributions** in case of the membrane filter bag)
- **Differences of the particle size distribution** for the **corresponding filter bags** all ranging into the **nanometer region**
- Lowest mean particle diameter $x_{50,0}$ for the membrane filter bag at 70-80 nm

Average particle number concentration of the particle emission penetrating the different filter bags



Controlling Measurement of chimney sweep: $C_m = 0$

Classification as small and medium firing installation according to the 1st federal emission control ordinance **(1. BImSchV);**

Combustion of wood-chips / offcuts → limit: 100 mg/m³

- **Significant emission reduction by application of pulse-jet cleaned filters**
- **Filter separation efficiency > 99.9 %** and concentrations similar to (or even below) typical background concentrations for rural areas)

→ **Mass based limits** and measurements **do not** properly reflect the actual **(nano-) particle emission**

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- **Summary and conclusions**

Summary and conclusions

- **Wood-stove combustion** in individual homes can **cause severe air pollution** and **impact the local particle concentration dynamics** in residential areas

- **Increased concentrations above the background** level for **52%** of the measurement **period**

- (Municipal) **incineration plants** equipped with **proper waste-gas cleaning technology <u>do not</u>** significantly **contribute to air pollution** compared to wood-stove combustion in residential homes

- **UFP measurements** are **required** for a **complete evaluation** of particle **emissions** and **ambient air quality**

- “Todays air quality limits are tomorrows emission limits“
  → Size resolved particle number limits in the future?

Thank you for your attention!

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Are there questions, comments, remarks?

Further information in the corresponding peer-reviewed articles:

Bächler, P., Weis, F., Kohler, S., Dittler, A., (2024). ***Exploratory measurements of ambient air quality in a residential area applying diffusion charge based UFP monitor***. Gefahrstoffe – Reinhaltung der Luft, 84 (1-2), 15-22, https://doi.org/10.37544/0949-8036-2024-01-02-17

Bächler, P., Meyer, J., Ligotski, R., Krug, P., Dittler, A., (2024). ***Measurement of transient nanoparticle emissions of a municipal biomass incineration plant equipped with pulse-jet cleaned filters***. Process Safety and Environmental Protection, 184, 601-614, https://doi.org/10.1016/j.psep.2024.02.013

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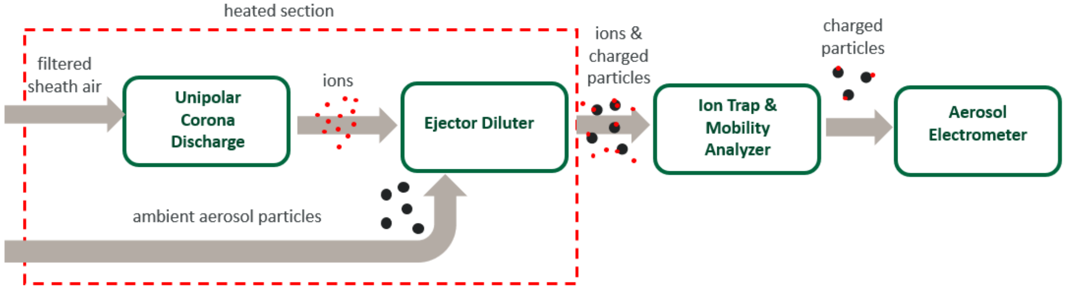
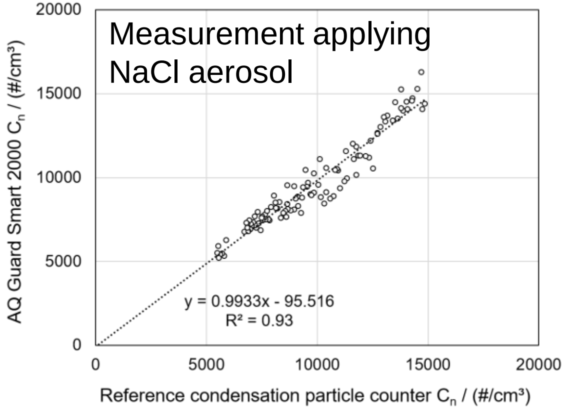
Working principle of AQ-guard Smart 2000 and comparison to CPC measurements

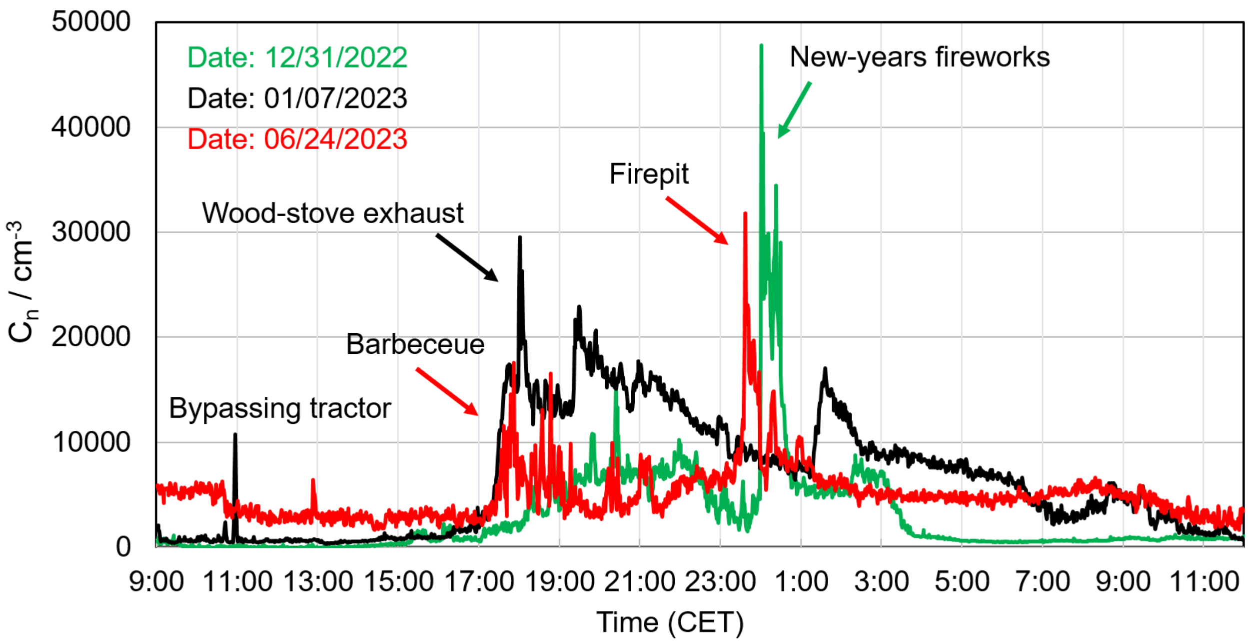
Measurement principle

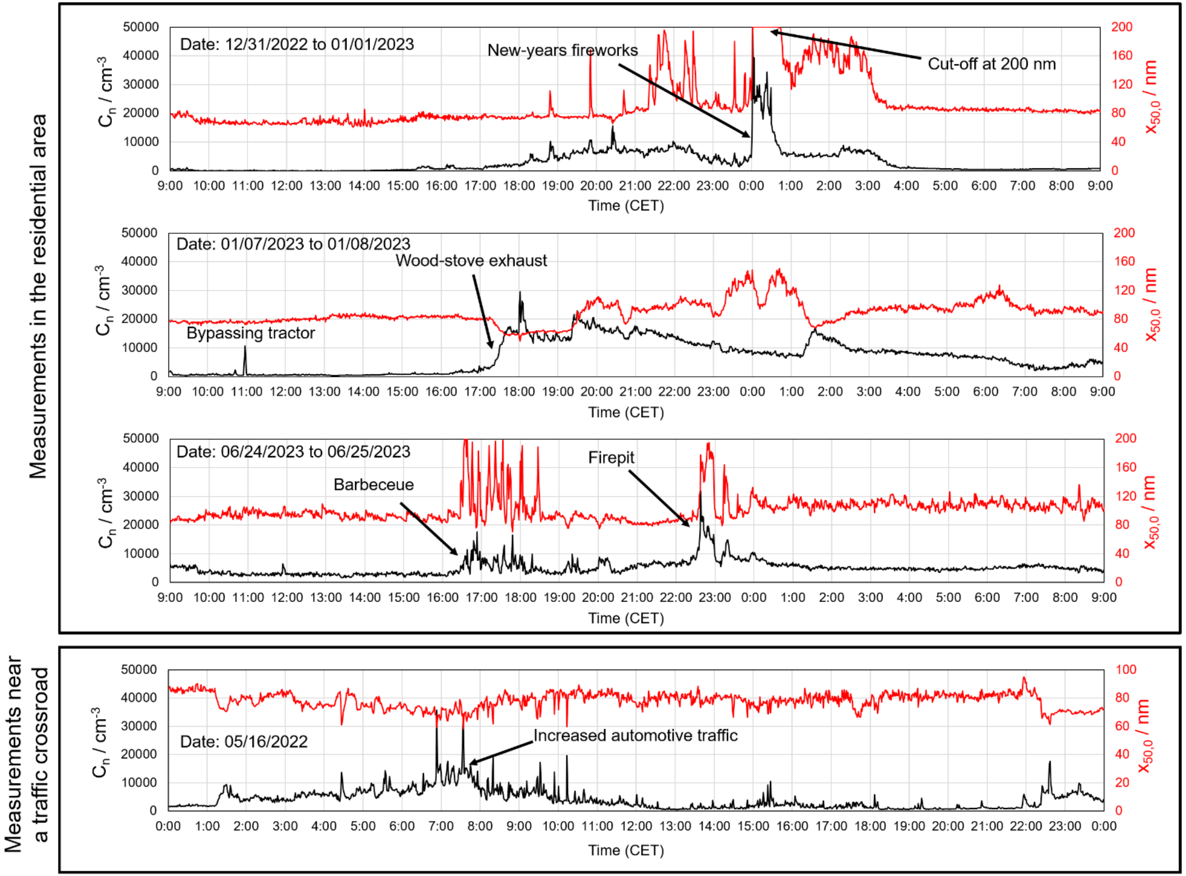


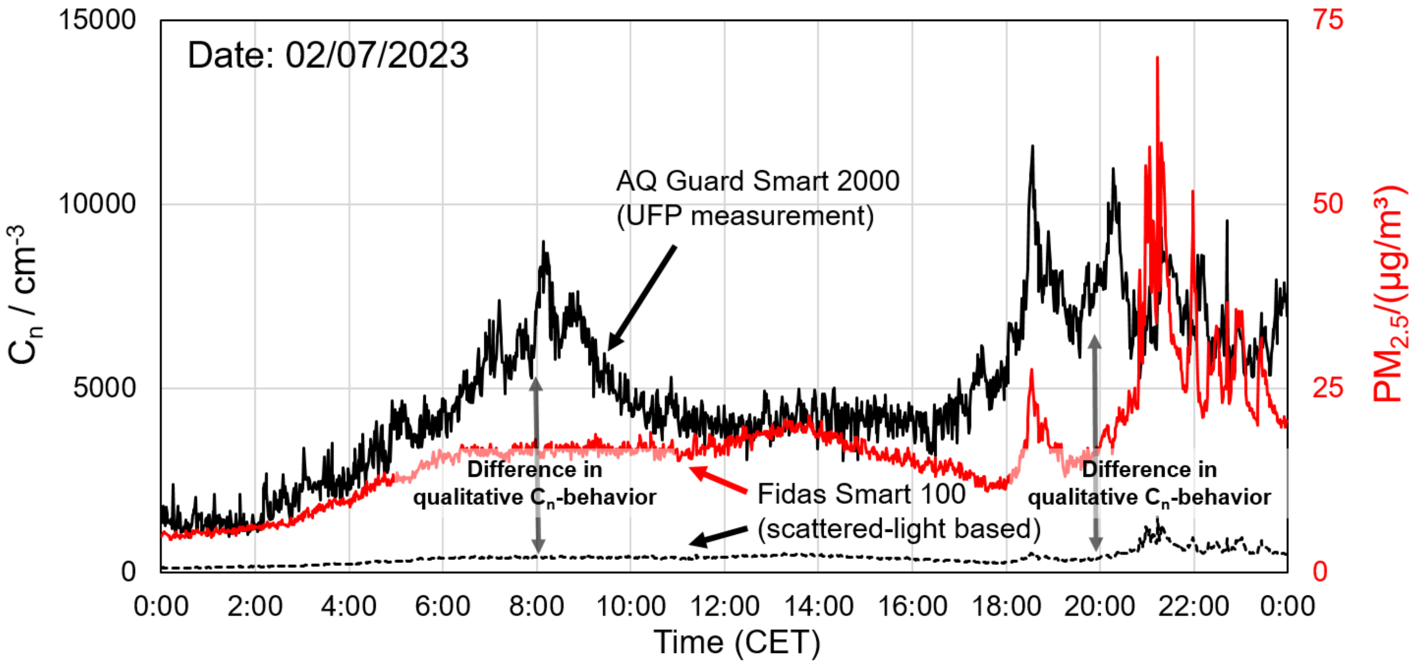


- Measurement principle based on **unipolar diffusion charging** of the **aerosol** and subsequent **measurement of an electrical current**
- Good **correlation** between **CPC measurement** (minimum size 10 nm) and the charge based **UFP monitor for increased concentrations** (here > 5000 #/cm³)
- Drawback: High **signal noise** for **lower concentrations** (below 3000 #/cm³)

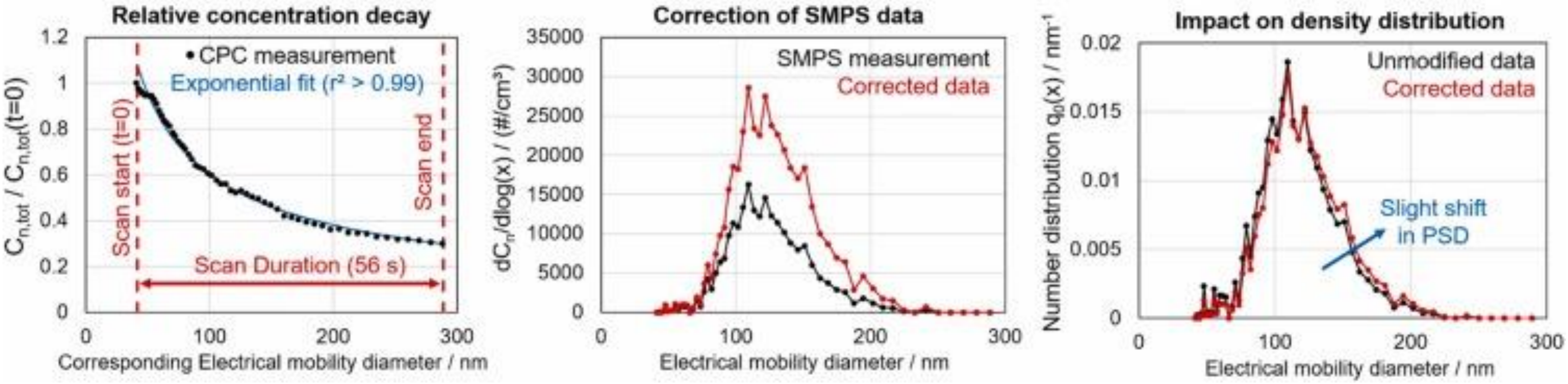
➡ **Suitable device** for the identification and **quantification of UFP hotspots**

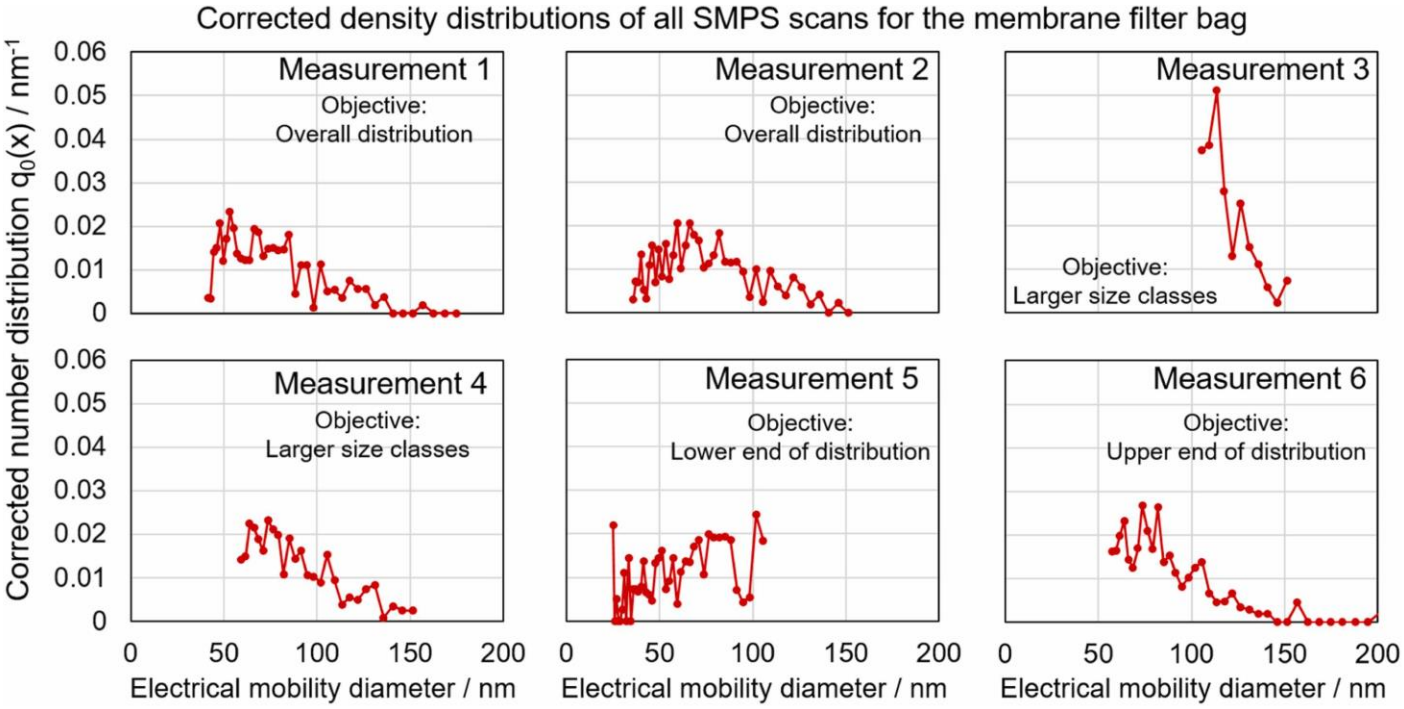

50000
40000
30000
20000
10000
0
C_n / cm^{-3}
Date: 12/31/2022
Date: 01/07/2023
Date: 06/24/2023
New-years fireworks
Firepit
Wood-stove exhaust
Barbeceue
Bypassing tractor
9:00
11:00
13:00
15:00
17:00
19:00
21:00
23:00
1:00
3:00
5:00
7:00
9:00
11:00
Time (CET)

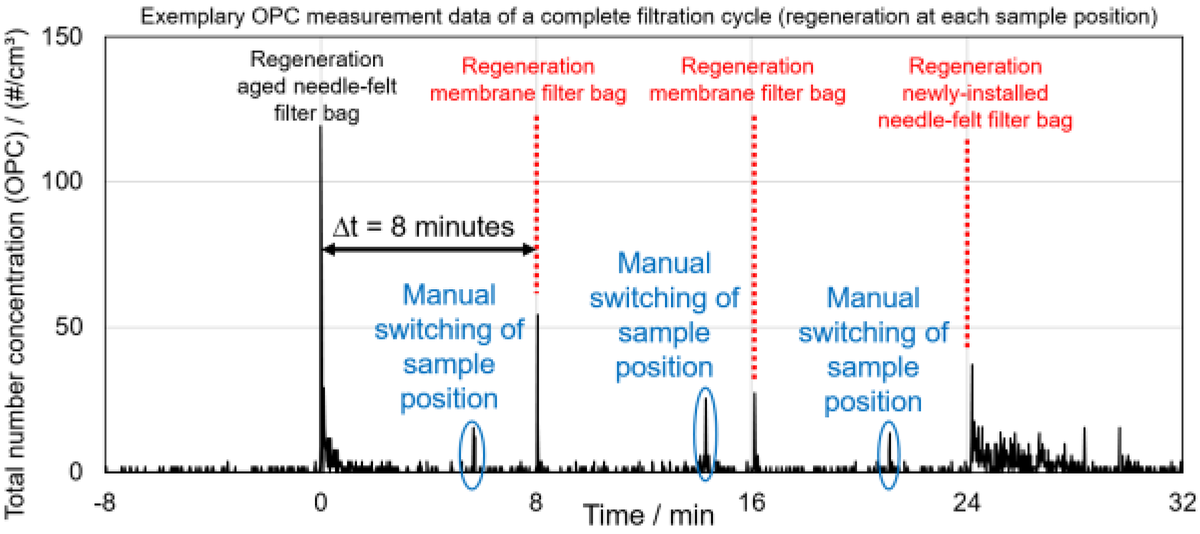

Measurements in the residential area
Date: 12/31/2022 to 01/01/2023
New-years fireworks
Cut-off at 200 nm
Date: 01/07/2023 to 01/08/2023
Wood-stove exhaust
Bypassing tractor
Date: 06/24/2023 to 06/25/2023
Barbeceue
Firepit
Measurements near a traffic crossroad
Date: 05/16/2022
Increased automotive traffic
C_n / cm^{-3}
$x_{50,0}$ / nm
Time (CET)


Date: 02/07/2023
AQ Guard Smart 2000
(UFP measurement)
Difference in
qualitative C_n-behavior
Fidas Smart 100
(scattered-light based)
Difference in
qualitative C_n-behavior
C_n / cm^{-3}
$PM_{2.5}$/(µg/m³)
15000
10000
5000
0
75
50
25
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time (CET)

Description of the correction procedure based on the example shown in figure 6




Corrected density distributions of all SMPS scans for the membrane filter bag
Corrected number distribution $q_0(x)$ / nm^{-1}
Measurement 1
Objective:
Overall distribution
Measurement 2
Objective:
Overall distribution
Measurement 3
Objective:
Larger size classes
Measurement 4
Objective:
Larger size classes
Measurement 5
Objective:
Lower end of distribution
Measurement 6
Objective:
Upper end of distribution
Electrical mobility diameter / nm


Exemplary OPC measurement data of a complete filtration cycle (regeneration at each sample position)
Total number concentration (OPC) / (#/cm³)
150
100
50
0
-8
0
8
16
24
32
Time / min
Regeneration aged needle-felt filter bag
Regeneration membrane filter bag
Regeneration membrane filter bag
Regeneration newly-installed needle-felt filter bag
Δt = 8 minutes
Manual switching of sample position
Manual switching of sample position
Manual switching of sample position