

BRAKE DUST MEASUREMENTS-SELECTION OF THE MOST SUITABLE SAMPLING METHOD PMP43

05.05.2017, Dr. D.Lugovyy

HORIBA

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Agenda

1	Motivation
2	Comparison of existing sampling concepts
3	Horiba-AUDI concept
4	Selection of functional parameters
5	Findings
6	Outlook

Motivation

Motivation

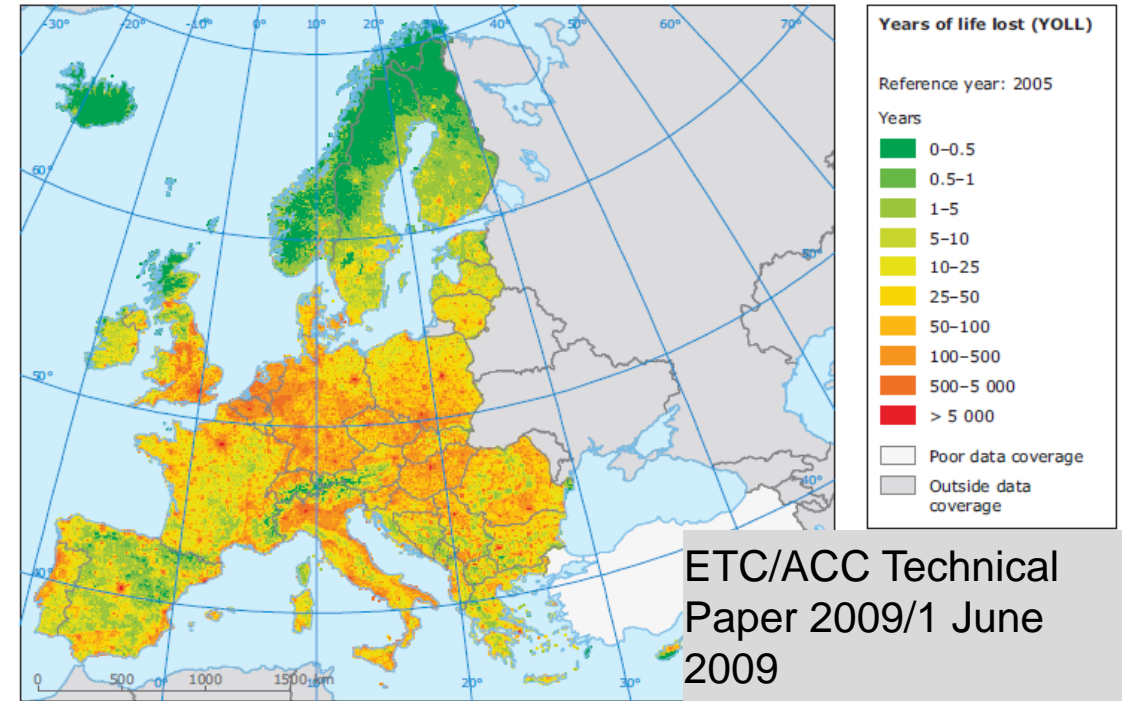
Two main drivers

- Health Effect
- Dirty Rims



Rim of my car

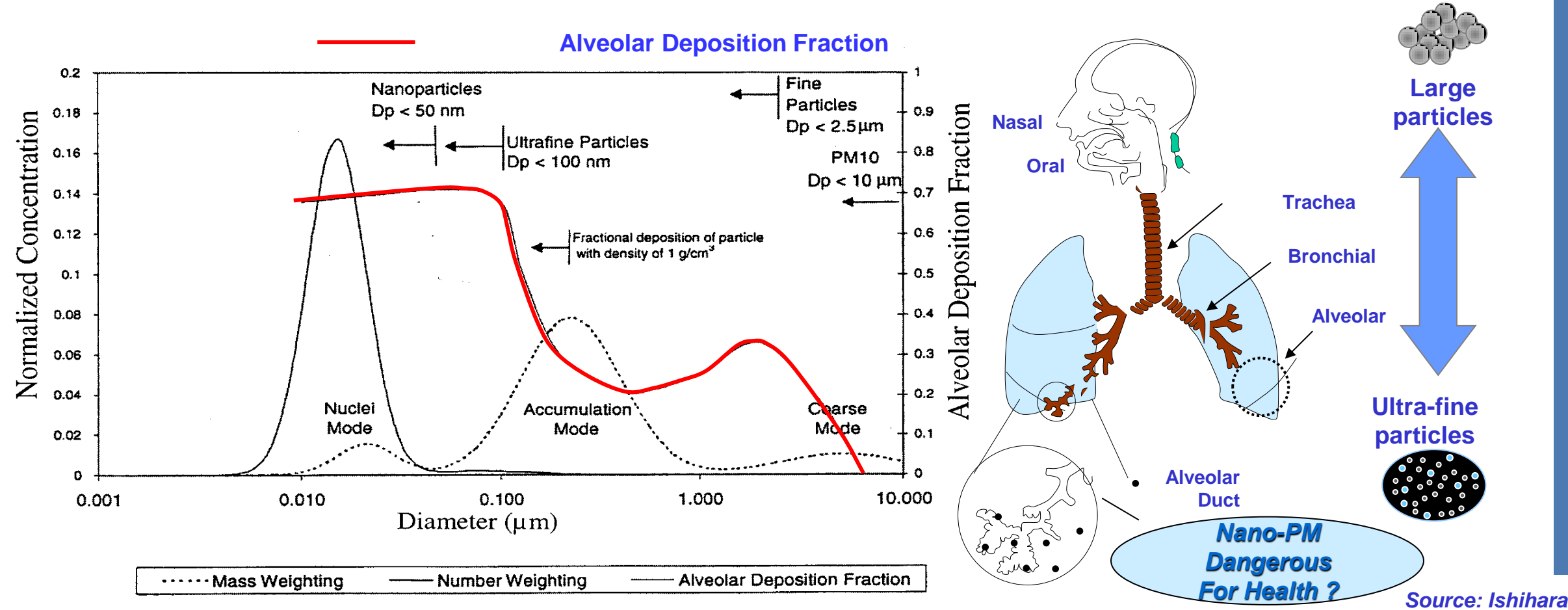
Map 2.1 Years of life lost (YOLL) in EEA countries due to PM_{2.5} pollution, 2005



Source: European Environment Agency 

Motivation: Concern about Nano-particle

Fine particles (diameter < 2.5 μm) may reach deep into the lung.



Activities in Europe

Goals of the project

1.	To demonstrate a novel and low environmental impact brake system that will reduce micro and nanoparticles emissions by at least 50%;
2.	To improve the measurement and understanding of micrometre-sized and ultrafine particles and their effects on health and the environment;
3.	Recommendations to policy makers.

LOW
BRA
SYS

Non-exhaust particle emissions – Key messages

Brake wear emissions:

- Industry (OEMs and instrument manufacturers) is actively working on the development of brake dyno rigs to assess particle emissions from brake systems
- It is likely that in the near future data and experience acquired in these activities may represent a good basis for the development, in case this is considered necessary, of a standardised measurement procedure based on the brake dyno concept
- Other technologies non directly related to brakes could be used to reduce particle generation, for example by reducing the number of braking events. A different approach than measuring particle emissions may be needed to take into account the benefits of these technologies.

REBRAKE goals:

1. At least 50% particulate matter (PM10) mass reduction from brake wear, in compliance with the EU2020 thematic strategy of 47% reduction of particulate matter by 2020;
2. Deeper comprehension of the physical and chemical phenomena underlying the brake wear process, including higher comprehension and analysis of characteristics coarse, fine and UFP particles.

Partners:



Brembo S.p.a –
Industrial partner



Kungliga Tekniska Högskolan
– Academic partner



Università degli Studi di
Trento – Academic partner

- **Project effort: 211 men-months, Total funding: € 2.061.716,43**
- **Project length: 48 months; starting March 2013, 1st**

WORKING ITEMS

Based on the GRPE decision (GRPE document 69-23, 06-2014), the PMP will have to prepare a more concrete and detailed working program on the following working items:

- ✓ Investigation of typical driving patterns and in particular of typical accelerations/decelerations
- ✓ Compilation and monitoring of on-going research projects
- ✓ Networking and exchange of information with experts in the field
- ✓ Development of a set of recommended measurement techniques and sampling procedures

Activities in Europe

Which activities are ongoing at HORIBA Europe?

HORIBA Europe R&D for Brake Emissions

First measurements done with MEXA 1000 SPCS in HORIBA Darmstadt in 2010. Joint project with University of Ilmenau

Since then, exchange with University of Ilmenau. They are using MEXA 2100 SPCS.

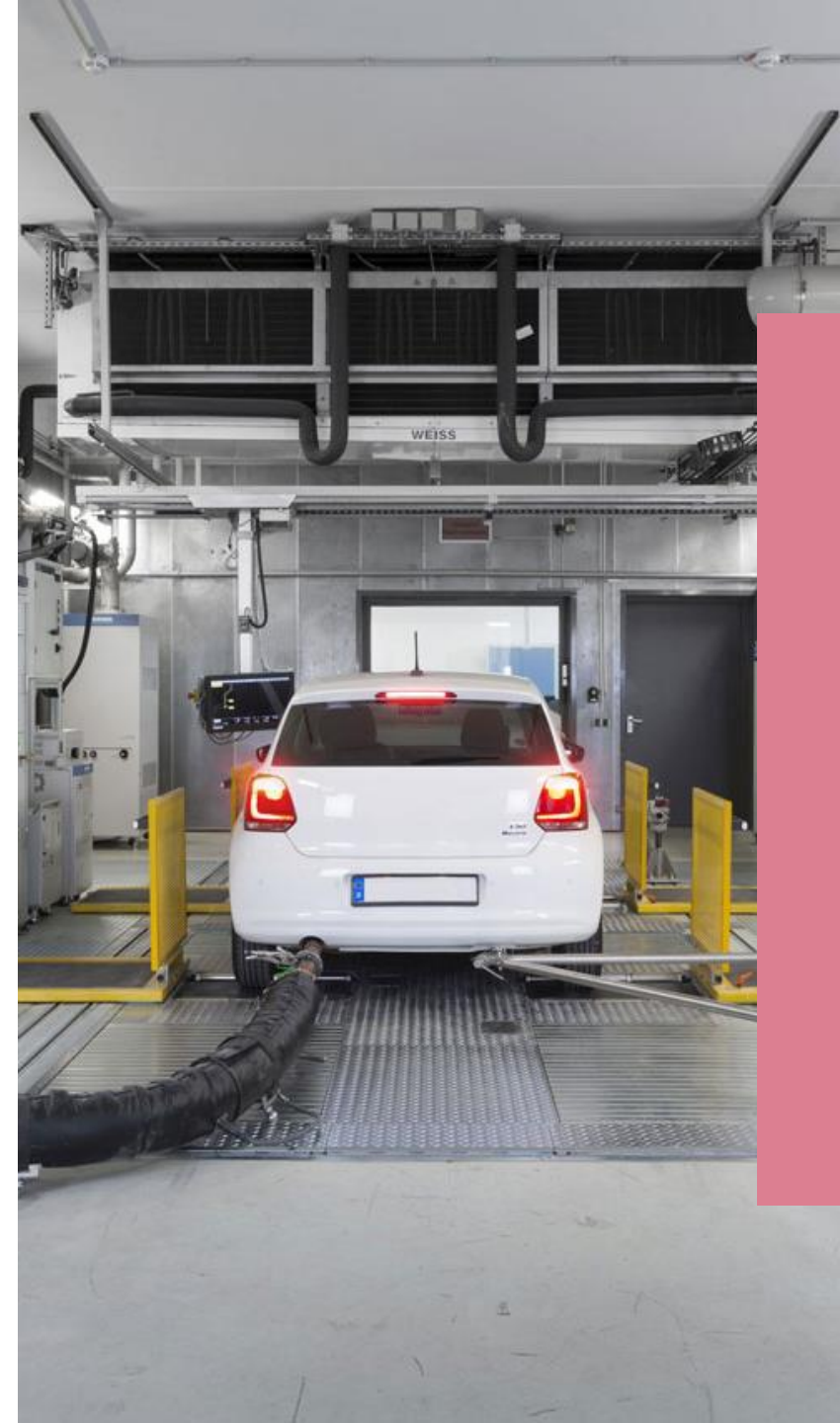
In 2014 HE hired two R&D Engineers for a Brake Dust Project.

In 2015 joint measurements with University of Ilmenau and HORIBA have been done -> Correlation between two test stands

In December HORIBA started the joint work with OEM for measuring particles from the Brake Test Stand Exhaust System using 10nm SPCS vs. PMP SPCS.

In 2016 joint work with TU Ilmenau and OEMs will be / is being progressed.

Since 2nd half of 2015 huge interest from OEMs and Tier 1 / Tier 2.



Activities in Europe

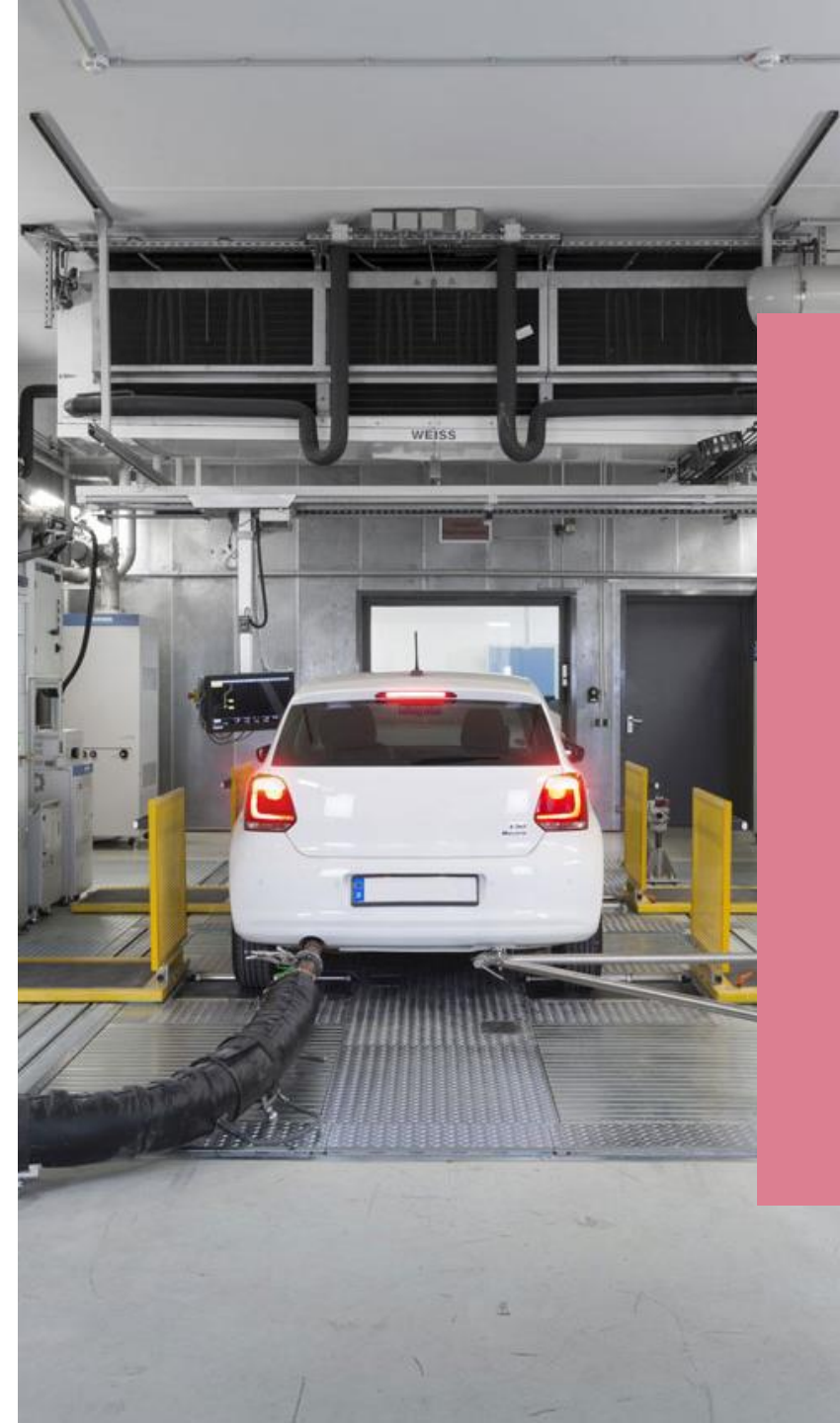
Deliverables

2015

- **Eurobrake:** *Inertia Brake Dynamometer Dust Particle Measurement*, Michael Wirth, Prof. Klaus Augsburg & Hannes Sachse (TU Ilmenau), Dmytro Lugovyy & Peter Lienerth (HORIBA Europe)
- **SAE Brake Colloquium:** *INERTIA BRAKE DYNAMOMETER DUST PARTICLE MEASUREMENT*, Michael Wirtz, Dmytro Lugovyy & Peter Lienerth (HORIBA Europe), Prof. Klaus Augsburg & Hannes Sachse (TU Ilmenau)

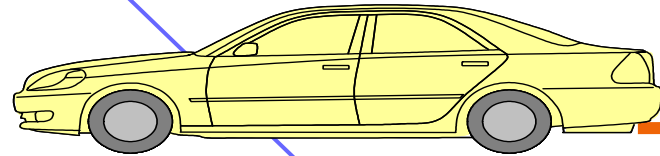
2016

- **Eurobrake:** *Sampling of Brake Dust Particles*, Hannes Sachse, Prof. Klaus Augsburg, David Hesse, Felix Wenzel (Technische Universität Ilmenau, Germany), Dmytro Lugovyy, Matthias Schröder (HORIBA Europe GmbH)
- **Brake Colloquium:** *BRAKE PARTICLE EMISSION MEASUREMENTS – A NEW DYNAMOMETER APPROACH*, Dr.-Ing. S. Gramstat, J. Münchhoff, AUDI AG, Dr.rer.nat. D. Lugovyy, M. Schröder, HORIBA Europe GmbH
- **Patent Application:** *Device for detecting and measuring brake dust*



Motivation: PMP Protocol for car engine

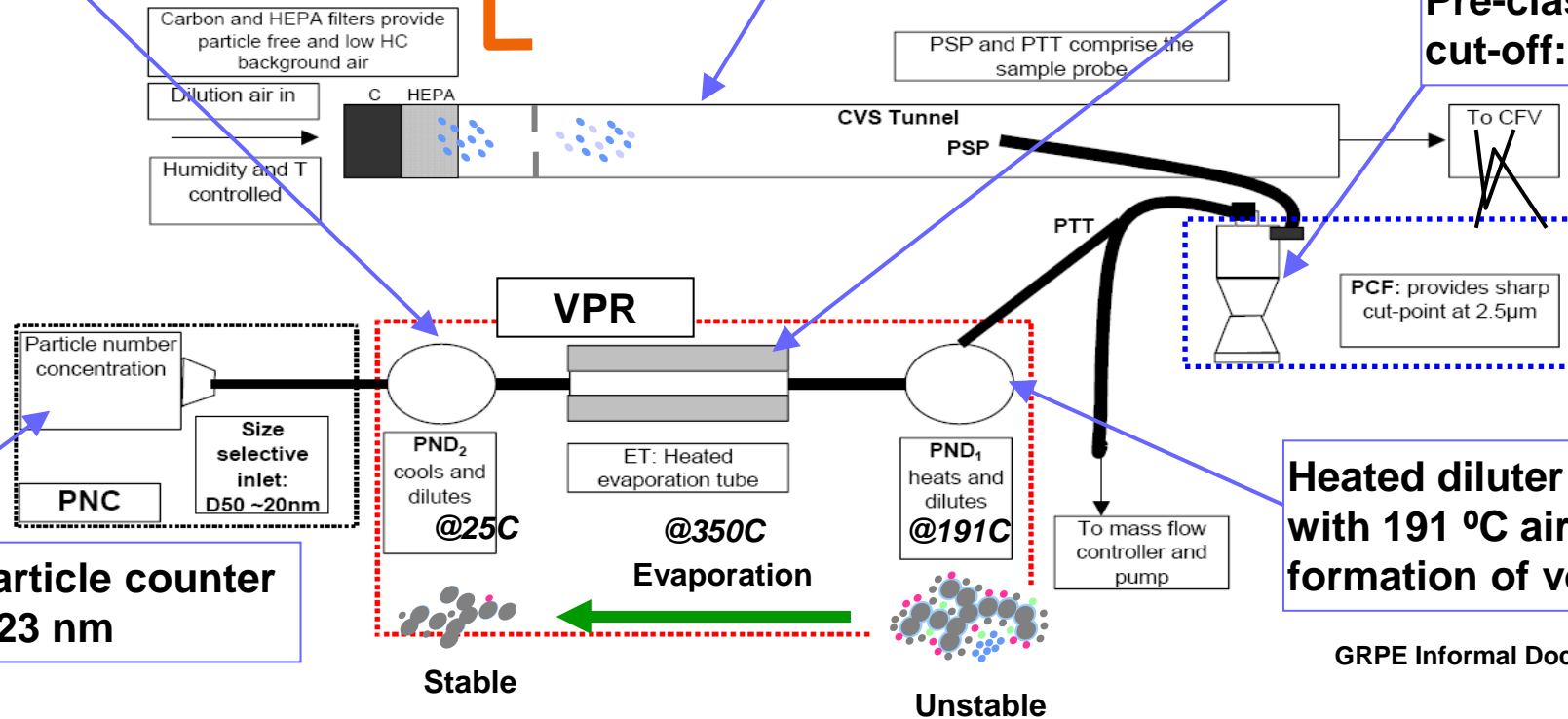
Cold diluter (PND2) with room temperature air, to minimize particle formation by re-nucleation and particle loss by thermo-pherotic



CVS tunnel, with carbon and HEPA filter

Evaporation tube (ET)
300 to 400 °C, to evaporate volatile particle

Pre-classifier
cut-off: > 2.5 μm



Heated diluter (PND1)
with 191 °C air, to suppress the
formation of volatile particle

GRPE Informal Document: GRPE-48-11-Rev.1

Motivation: Brake dust, first approximation -PMP Protocol

GRPE Informal Document: GRPE-48-11-Rev.1

Cold diluter (PND2)

with room temperature air, to minimize particle formation by re-nucleation and particle loss by thermo-pherotic



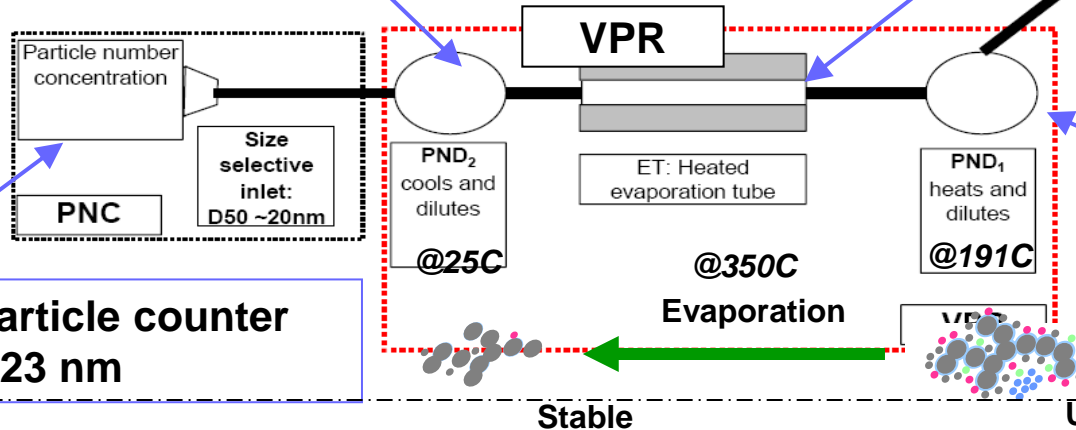
Evaporation tube (ET)
300 to 400 °C, to evaporate volatile particle

Pre-classifier
cut-off: > 2.5 μm

PCF: provides sharp cut-point at 2.5 μm

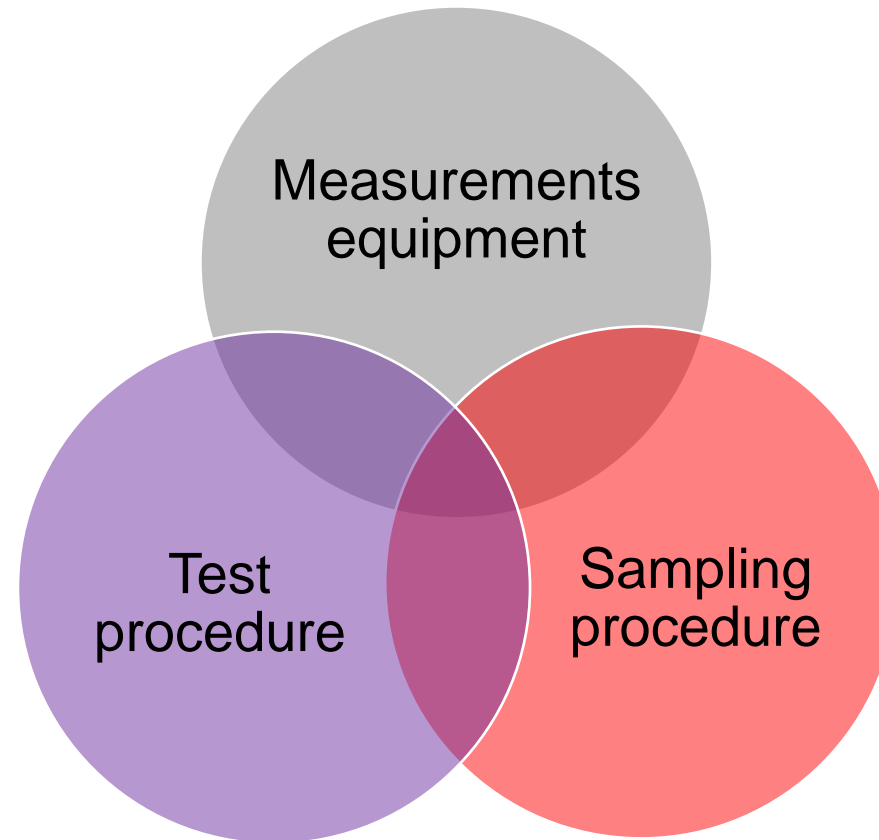
Heated diluter (PND1)
with 191 °C air, to suppress the formation of volatile particle

SPCS



Condensation particle counter (CPC), cut-off: < 23 nm

To be solved

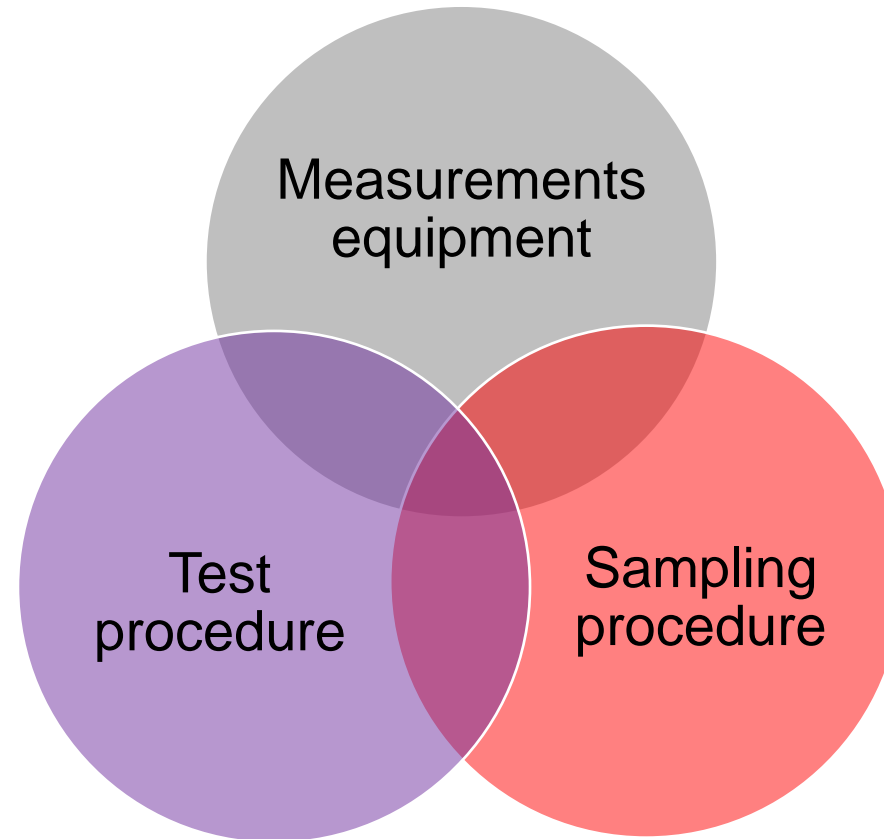


Aim of the project

Developing new particle measuring principle for analysis of Brake
Dust pollutions

To be solved by Brake Dust Project

- Building up new measurements set-up
- Investigation of chemical and physical properties of brake dust particles
- Definition of test procedure
- Role of test parameters and modification of sampling system



Selection of functional parameters: Measurement equipment

Measurement equipment

Definition of measurement range

- Measurement of particle size distribution.
- Modification existing and/ or developing of new equipment

Probe treatment

- Role of volatile content
- Dilution of the probe and sampling velocity

Physical and chemical properties of Brake Dust particles

- ✓ Investigation of morphology and chemical properties of Brake Dust particles
- ✓ Modification of measurement equipment

Measurement equipment

Definition of measurement range

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Probe treatment

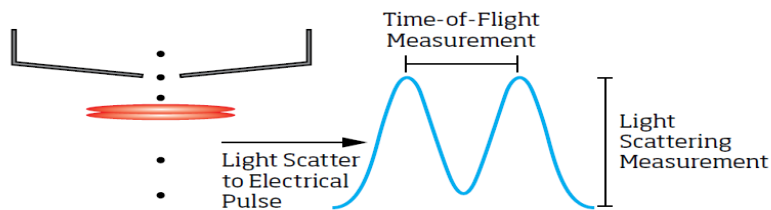
- Role of volatile content
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**Point of our
research**

Physical and chemical properties of Brake Dust particles

- ✓ Investigation of morphology and chemical properties of Brake Dust particles
- ✓ Modification of measurement equipment

Measurements of Particle Number



Aerodynamic Particle Sizer

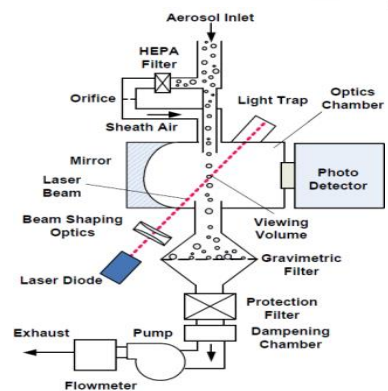
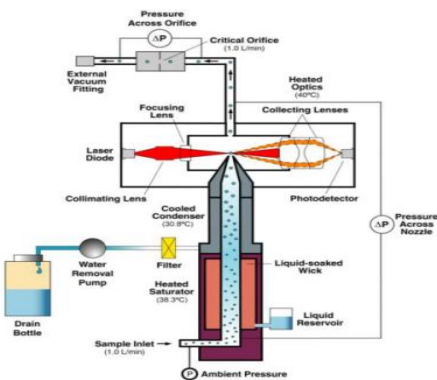
- Optical system with two partially overlapping laser beams to detect coincidence.
- One signal is generated with two crests
- Time between the crests provides aerodynamic particle-size information.
- Instrument does effectively limit the effect of coincidence on particle-size distributions.
- Lower detection limit 370nm

CPC

- The saturator provides saturated butanol vapor that mixes with particles in the condenser.
- Particle growth occurs in the condenser.
- The detector counts the electrical pulses generated from the light scattered by the particles .
- Lower detection limit 5-23nm

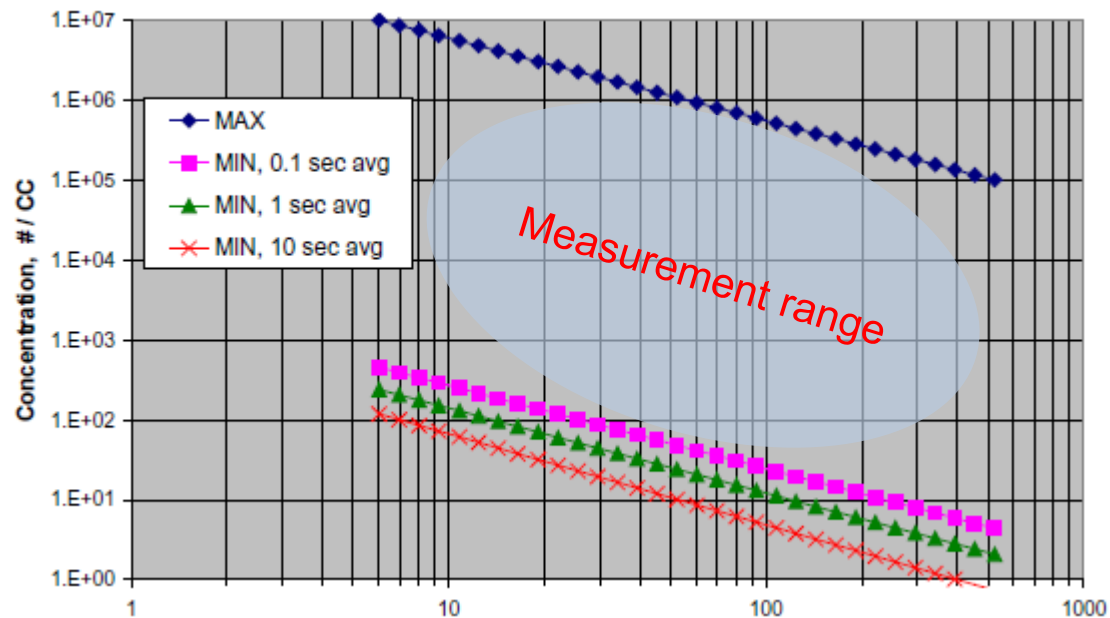
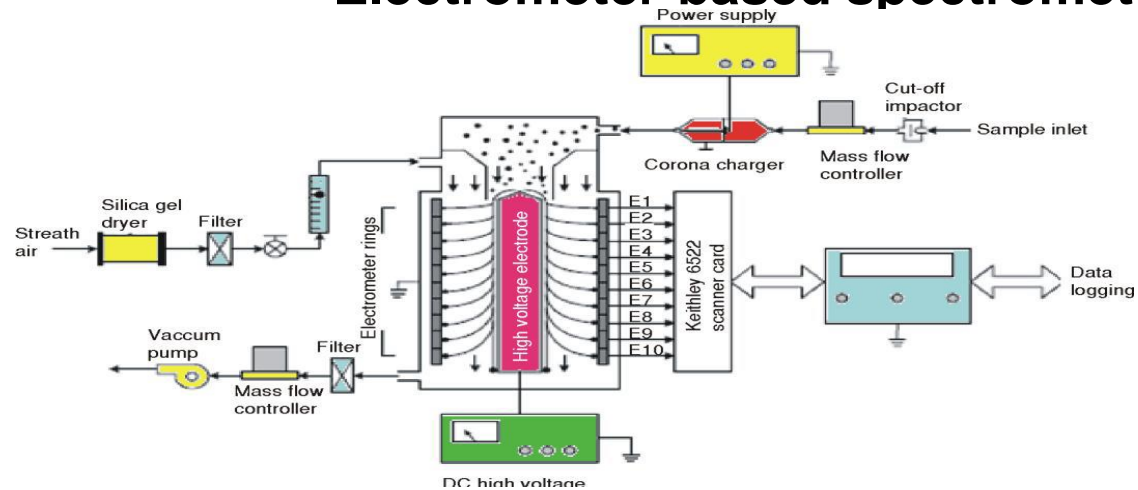
DustTruck

- Particle is illuminated by a sheet of laser light.
- Gold coated spherical mirror captures a significant fraction of the light scattered by the particles and focuses it on to a photo detector.
- The voltage across the photo detector is proportional to the mass concentration of the aerosol over a wide range of concentrations.
- Lower detection limit 100nm



Measurements of particle size distribution

Electrometer-based spectrometer



Features

- Unipolar corona discharge to place a prescribed charge on each particle proportional to its surface area.
- The charged aerosol is introduced into a strong radial electrical field inside a classifier column.
- Particles are drifted through a sheath flow to the electrometer detectors.
- Particles are detected at different distances down the column, depending upon their electrical mobility.

Concentration

Low detection limit: from 10^3 - 10^2 #/cm³
Upper detection limit: $\leq 1 \times 10^7$ #/cm³

Size

Low detection limit: 5 nm
Upper detection limit : 1 μ m

Measuremetns of Particle Number-Horiba Solution for Exhaust Legislation

MEXA-2000SPCS series

Outlines

Models	MEXA-2000SPCS	MEXA-2100SPCS	MEXA-2200SPCS	MEXA-2300SPCS
Conformed standards	UN/ECE Regulation No. 83 (Rev. 3, Amend. 2) UN/ECE draft Regulation No. 49 ^{*1} (ECE/TRANS/WP. 29/GRPE/2010/7), to be updated	—	UN/ECE Regulation No. 83 (Rev. 3, Amend. 2) UN/ECE draft Regulation No. 49 (ECE/TRANS/WP. 29/GRPE/2010/7), to be updated	— ^{*2}
Measuring principle	Laser scattering condensation particle counting (CPC)			
Lower particle size limit	Counting efficiency of 23 nm particles: 50 % ±12 %, Counting efficiency of 41 nm particles: 90 % or more			
Measuring components and range	Number concentration of solid particles; 0 – 10000 up to 0 – 50000 particles/cm ³ (after internal dilution) ^{*3}			
Sample handling temperature	47 °C ± 5 °C (Dilute sampling)	Maximum permissive temperature (Direct sampling) 350 °C ^{*4}	47 °C ± 5 °C (Dilute sampling)	Maximum permissive temperature (Direct sampling) 350 °C ^{*4}
Diluted sample temperature	Primary diluter (PND1): 191 °C ± 10 °C Evaporation tube (ET): 350 °C ± 10 °C Secondary diluter (PND2): 35 °C or less	Pre-classifier: 47 °C ± 5 °C Primary diluter (PND1): 191 °C ± 10 °C Evaporation tube (ET): 350 °C ± 10 °C Secondary diluter (PND2): 35 °C or less	Primary diluter (PND1): 191 °C ± 10 °C Evaporation tube (ET): 350 °C ± 10 °C Secondary diluter (PND2): 35 °C or less	Pre-classifier: 47 °C ± 5 °C Primary diluter (PND1): 191 °C ± 10 °C Evaporation tube (ET): 350 °C ± 10 °C Secondary diluter (PND2): 35 °C or less
Dilution factors in diluters	Primary diluter (PND1): 10 to 200 ^{*3} Secondary diluter (PND2): 15	Diluter in DSU: 10 Primary diluter (PND1): 10 to 200 ^{*3} Secondary diluter (PND2): 15	Primary diluter (PND1): 10 to 200 ^{*3} Secondary diluter (PND2): 15	Diluter in DSU: 10 Primary diluter (PND1): 10 to 200 ^{*3} Secondary diluter (PND2): 15
PCRF	0.95 < fr(30 nm) / fr(100 nm) < 1.3, 0.95 < fr(50 nm) / fr(100 nm) < 1.2			
Volatile particle removal efficiency	99% or more, for C ₄₀ (30 nm of particle size, and 10000 particles/cm ³ or more)			
Accuracy of dilution factor	Within ± 10 % of nominal dilution factor setting (for VPR total dilution factor of 150 to 3000, gas based)			
Operating environment	Without CLU (standard): Ambient temperature: 5 °C to 30 °C, Ambient humidity: 80 % or less as relative humidity With CLU (optional): Ambient temperature: 5 °C to 45 °C, Ambient humidity: 80 % or less as relative humidity			
Power supply voltage and frequency	200/220/230/240 V AC (±10 %, max. 250 V), 50/60Hz (±1.0 Hz), single phase (to be specified at ordering)			
Power requirements	Main unit: Max. 2.3 kVA Main unit and all optional units: Max. 4.5 kVA	Main unit: Max. 2.5 kVA Main unit and all optional units: Max. 4.4 kVA	Main unit: Max. 2.4 kVA Main unit and all optional units: Max. 4.3 kVA	Main unit: Max. 2.6 kVA Main unit and all optional units: Max. 4.5 kVA
Dimensions (excluding any projections)/Mass				
Main unit (without transfer tube, control unit and optional units)	434(W)×731(D)×600(H) mm Approx. 115 kg	434(W)×845(D)×600(H) mm Approx. 120 kg	434(W)×910(D)×600(H) mm Approx. 140kg	434(W)×910(D)×600(H) mm Approx. 145 kg
Optional units ^{*5}	CYU: Approx. 290(W)×146(D)× 236(H) mm Approx. 4 kg SRU: Approx. 300(W)×550(D)× 450(H) mm Approx. 35 kg CLU: Approx. 570(W)×850(D)×1190(H) mm Approx. 80 kg (for CLU and optional cabinet) DFC: Approx. 464(W)×550(D)× 320(H) mm Approx. 38 kg LCU: Approx. 350(W)×690(D)× 670(H) mm Approx. 35 kg VGU: Approx. 550(W)×300(D)× 450(H) mm Approx. 20 kg			

^{*1}: Only for full flow tunnel.

^{*2}: MEXA-2300SPCS can be used in the measurement method according to the regulation. For detailed information, please contact HORIBA.

^{*3}: Dilution factor of the system should be determined so that the particle concentration after dilution fits into the measuring range.

^{*4}: Allowable range of gas temperature at sample probe inlet depends on the sampling condition, because it is limited as the temperature of diluter in DSU (350 °C or less). For detailed information, please contact HORIBA.

^{*5}: The dimensions depend on customers.

Concentration

Low detection limit up to: 0 #/cm³

Upper detection limit : 3x10⁸#/cm³

Size

Low detection limit : 10-23 nm

Upper detection limit : 2,5µm



Measurements of Particle Mass-Horiba Solution for Exhaust Legislation

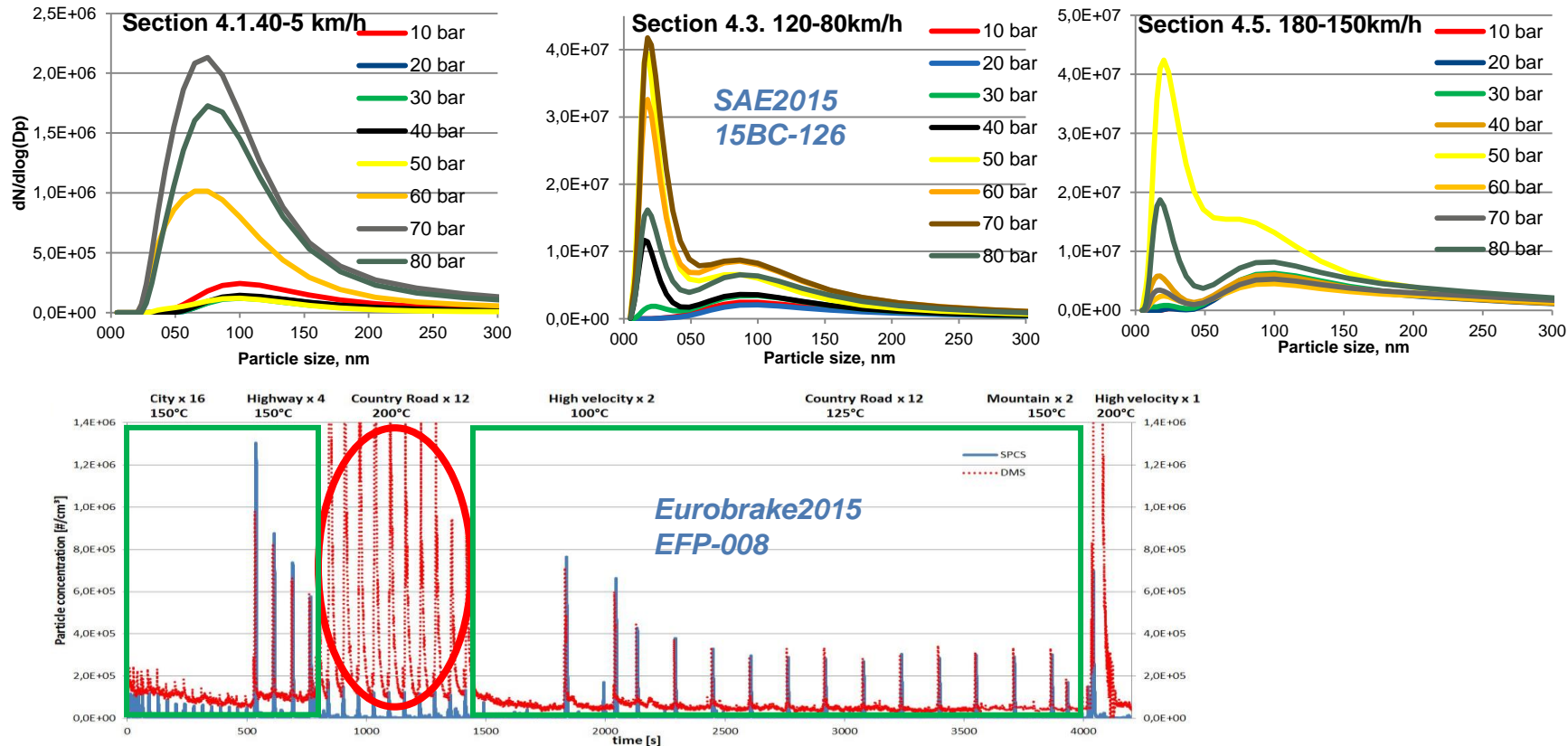
DLS-7000 PMP-conform

SPECIFICATIONS

Model:	DLS-7000
Dimensions:	570 (W) x 810 (D) x 1785 (H) mm
Mass:	Approx. 400 kg
Coating:	Munsell 5PB7/1 for the enclosure Munsell 5PB8/1 for the side plates
Power:	200 V to 230 V AC $\pm 10\%$, 50/60 Hz
Power consumption:	3 kVA
Ambient temperature:	5° C to 35° C
Ambient humidity:	less than 80% (relative humidity)
Sampling rate:	25 L/min to 50 L/min
Flow rate sensitivity:	$\pm 5\%$ of full scale
Suction power:	– 53.3 kPa at 50 L/min
Flow meter:	Venturi flow meter
Flow rate control:	PID control
Sample line:	4 lines changeable (Maximum)
Background line:	1 line (Option)



Definition of measurement range: Influence of sub-23 nm particle

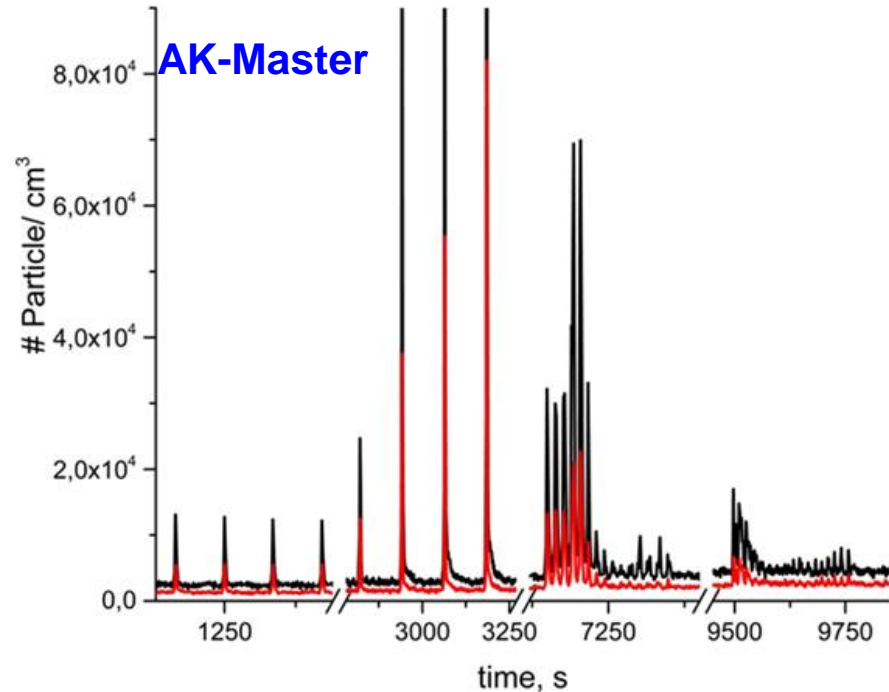


- Appearance of ultra-fine particle depends on wheel speed rather than on brake pressure or temperature
- Ultra-fine particles demonstrate first peak around 13 nm
- Disagreement between DMS and SPCS was observed

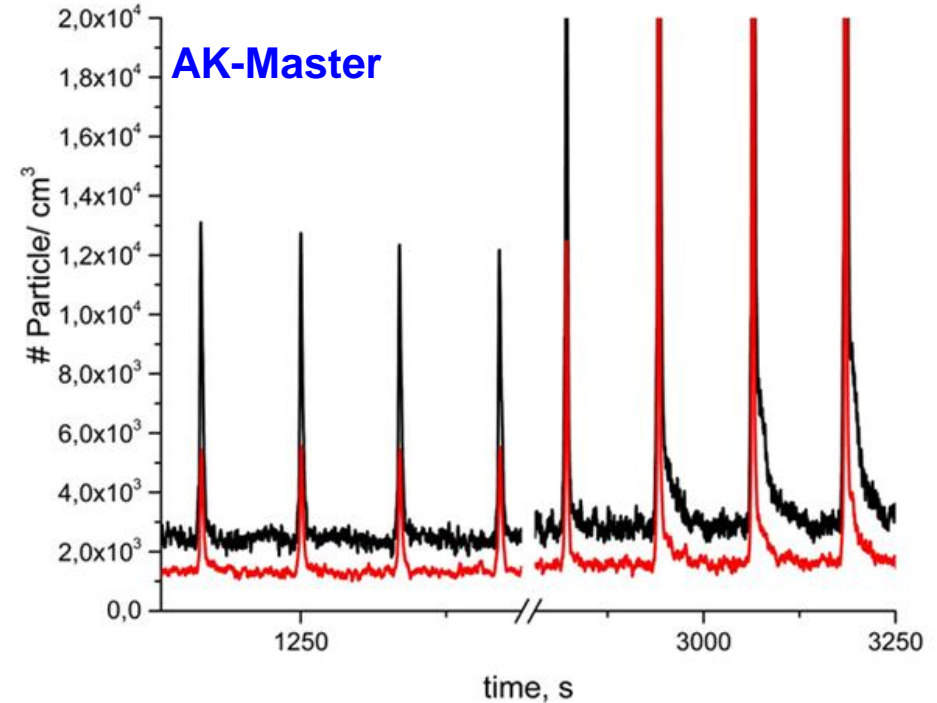
Definition of measurement range: Influence of sub-23 nm particle

Aerosol sample-splitter after the exhaust duct → standard SPCS (23 nm) versus prototype SPCS (10 nm)

Comparison of measured particle concentration using a standard SPCS 2000 (red line) and a sub-23 nm SPCS (black line).



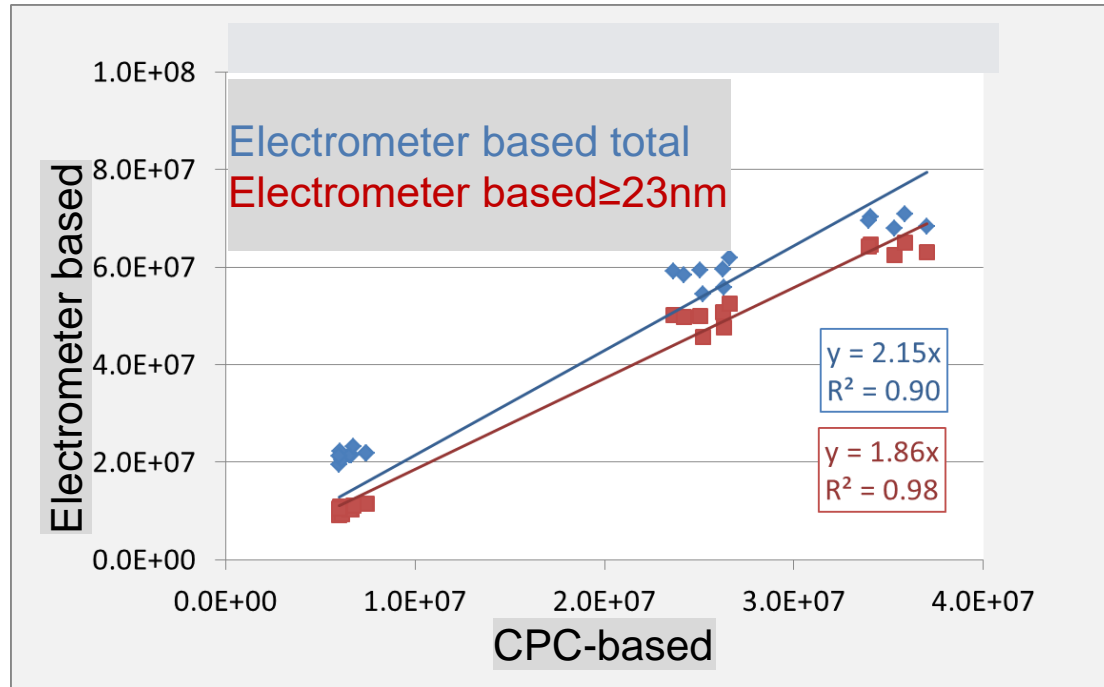
Zoomed time history of PN using a standard SPCS 2000 (red line) and a sub-23 nm SPCS (black line).



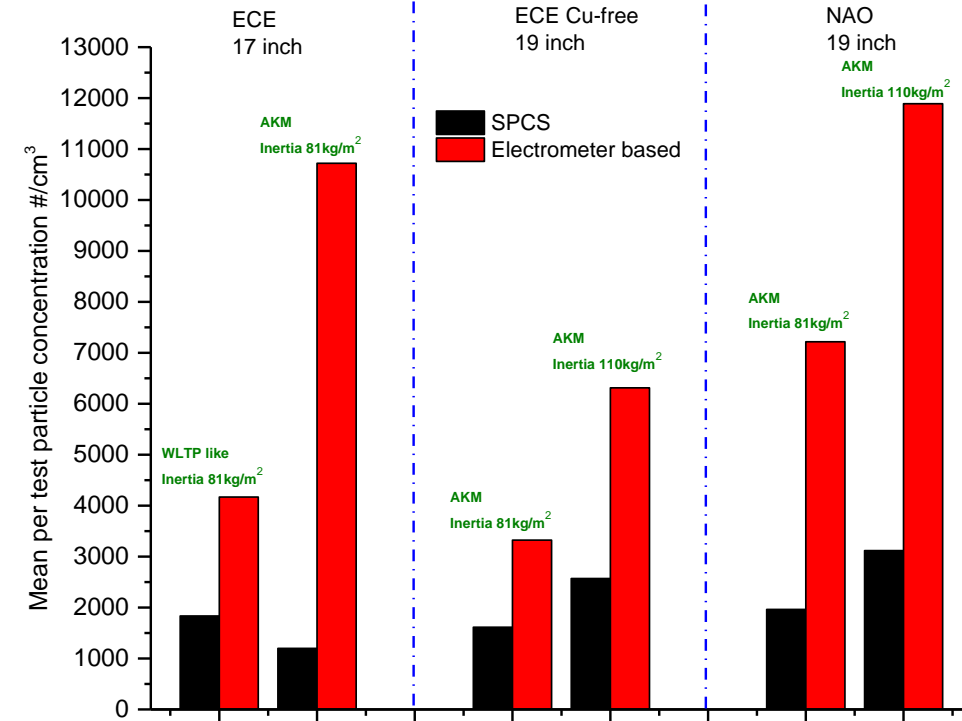
- ❖ No significant variations of qualitative time history
- ❖ Difference: same order of magnitude but factor varies between 2 and 6
- ❖ Ratio $PN_{\text{sub23}}/PN_{\text{standard}}$ between single brake events is almost stable (around 1,5)
- ❖ Prototype with cut-off D_{50} at 10 nm is used in our research

Definition of measurement range: Influence of sub-23 nm particle

Comparison of measured particle concentration using Palas particle generator



Comparison of particle concentration measured during brake tests

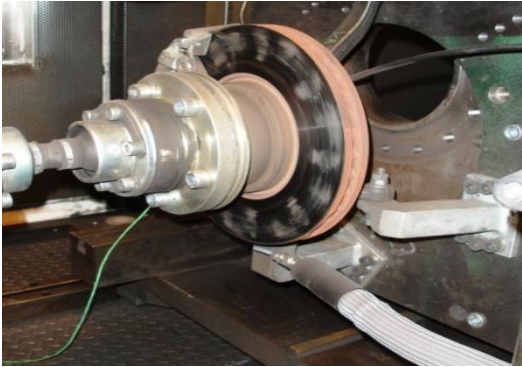


- ❖ Different factors can affect results of measurements for electrometer based instruments
- ❖ Only CPC based instruments fulfilled exhaust legislation requirements
- ❖ Electrometer-based techniques can be used for indicative measurements only

Comparison of exiting sampling systems

Sampling of Brake Dust

Hose



Pro

- ✓ Easy to install
- ✓ Different sampling points are possible

Contra

- Reproducibility of results
- Calculation PN per km
- High level of background particle concentration
- Probe homogeneity

Sampling Box



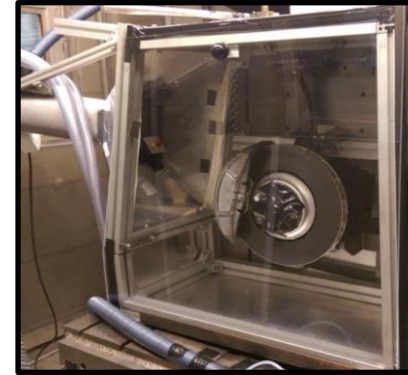
Pro

- ✓ Easy to install
- ✓ Reproducibility of results
- ✓ Fast response on emissions events
- ✓ Reduction of background particle concentration level
- ✓ Possibility to use for RDE

Contra

- Probe homogeneity
- Calculation PN per km
- Limited number of applications

Environmental chamber



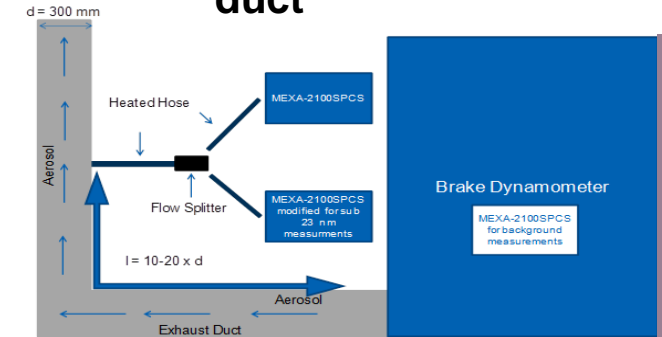
Pro

- ✓ Calculation PN per km
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Contra

- Complicated installation
- Limited number of applications
- Probe homogeneity
- Emissions response is averaged over time and volume

Exhaust duct



Pro

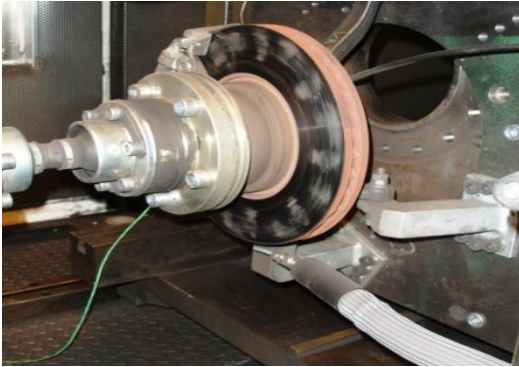
- ✓ Calculation PN per km
- ✓ Reproducibility of results
- ✓ No modification of brake dyno is required
- ✓ Probe homogeneity
- ✓ Reduction of background particle concentration level
- ✓ Probe homogeneity

Contra

- Special requirements to air ventilations system
- Emissions response is averaged over time and volume

Sampling of Brake Dust

Hose



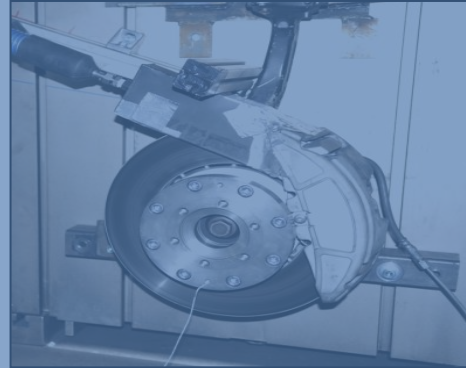
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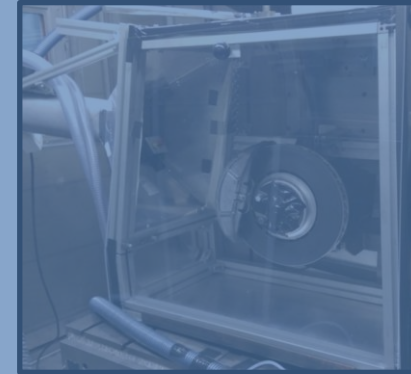
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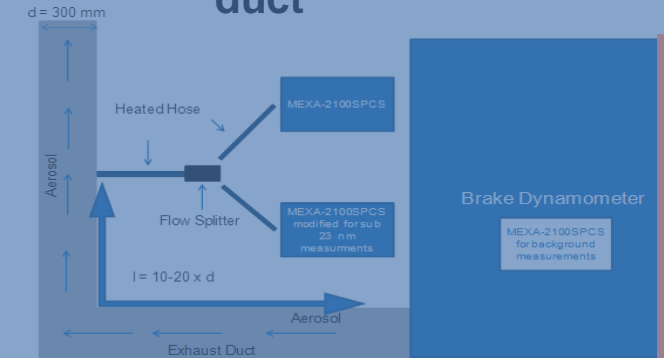
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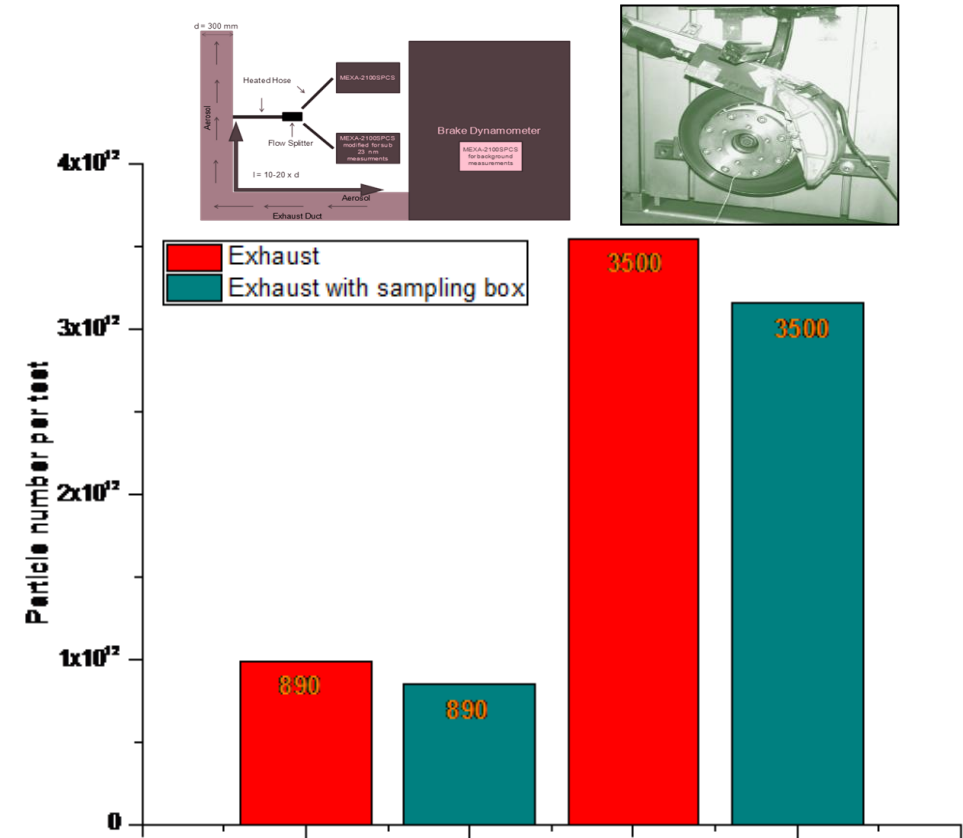
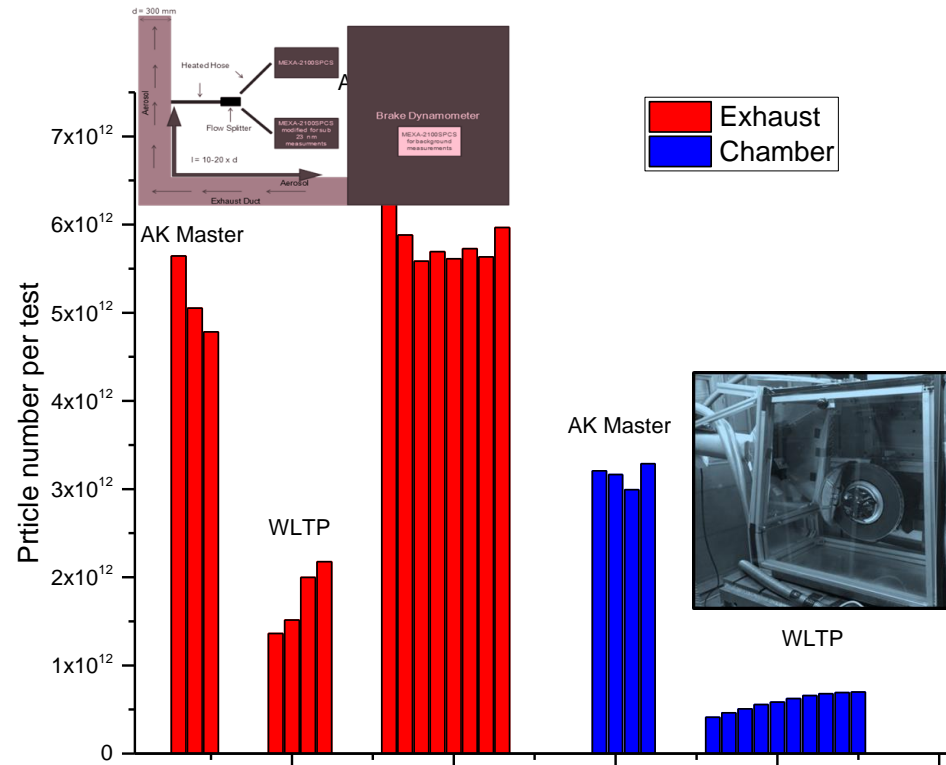
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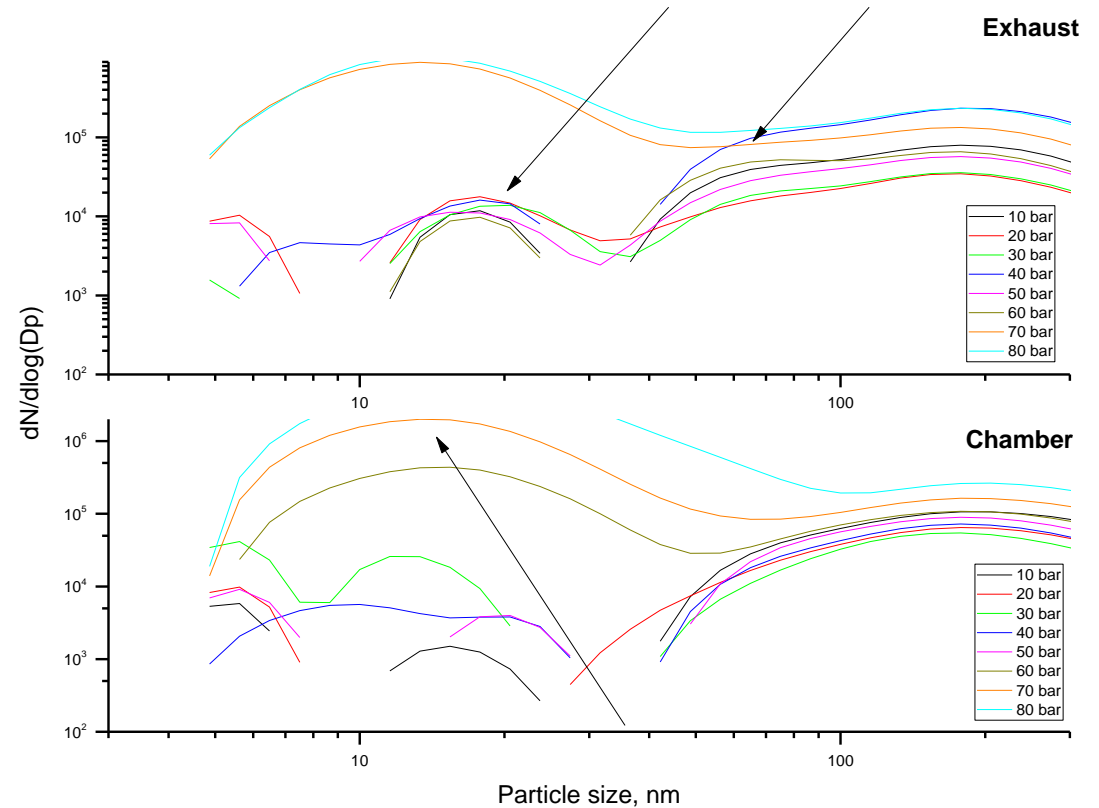
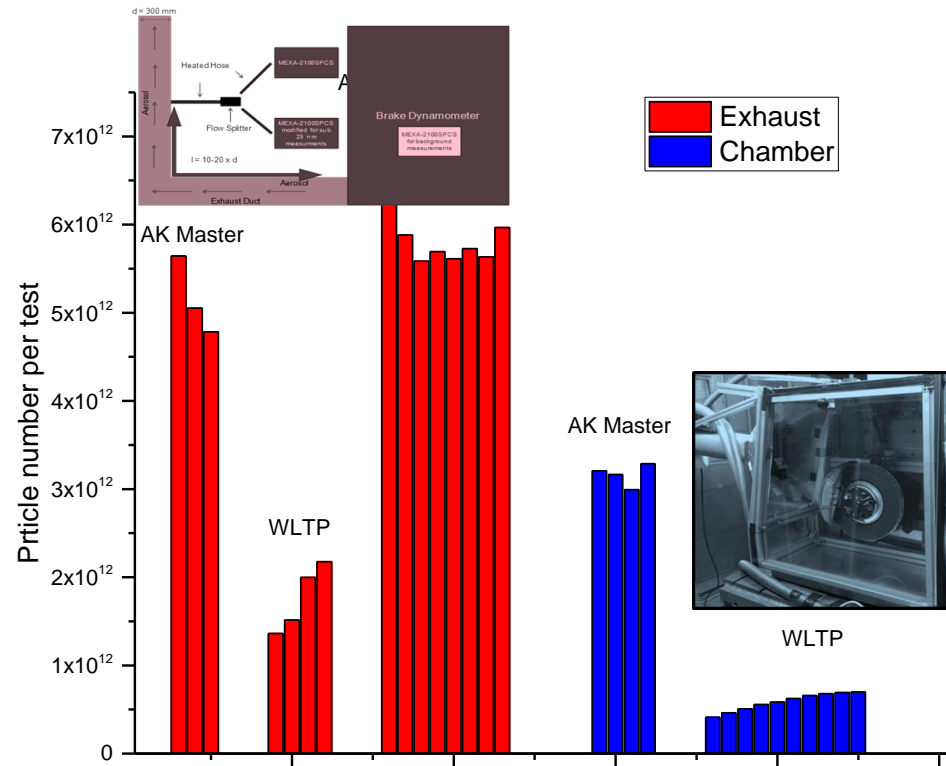
Horiba focus

Sampling concepts: Comparison



- PN measured using *Environmental chamber* much lower to measured in exhaust duct
- Measurements with *Sampling box* is not representative
- Strong particle coagulation is expected for *Environmental chamber* and *Sampling box*

Sampling concepts: Comparison



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Sampling concepts: Comparison

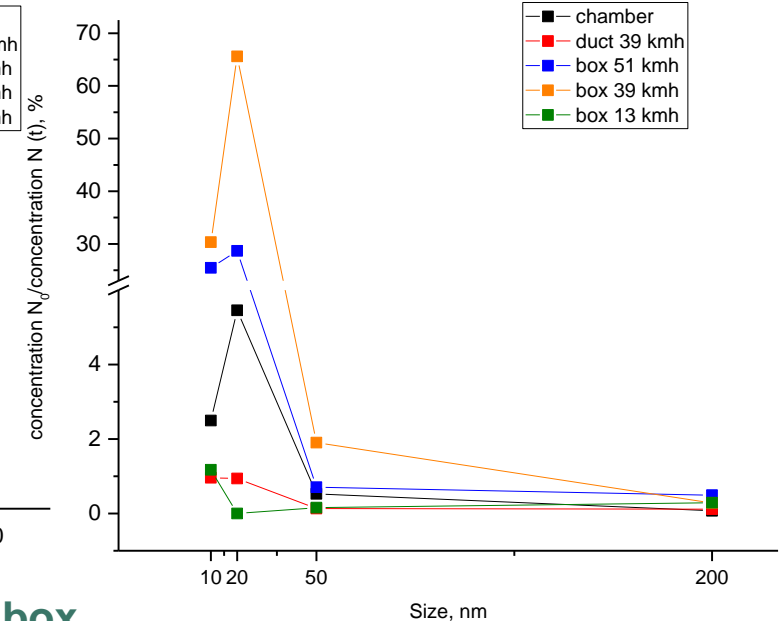
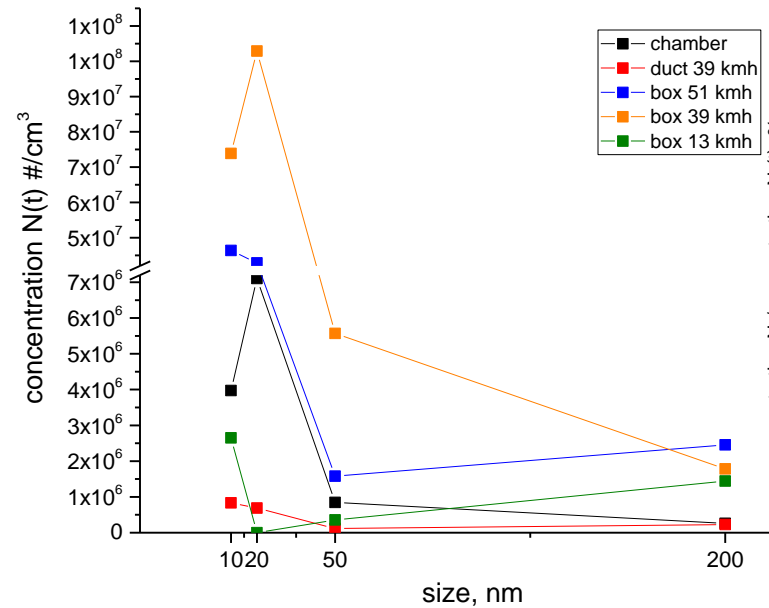
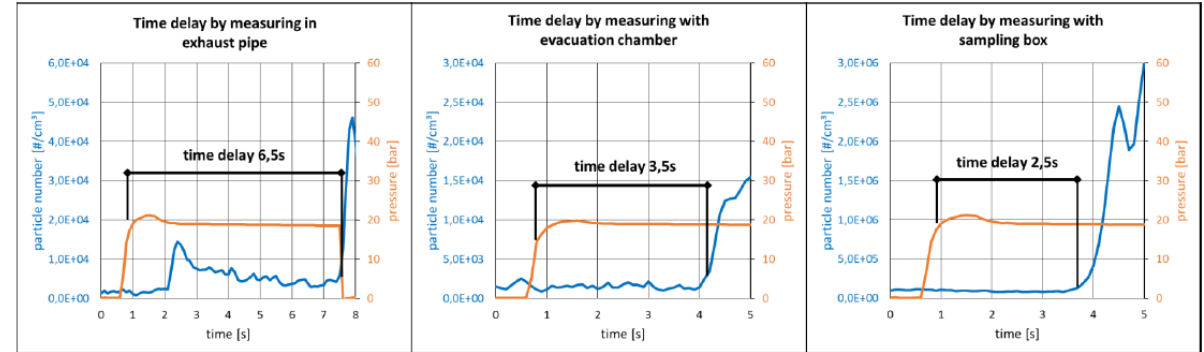
Polydisperse coagulation

$$N(t) = \frac{N_0}{1 + tN_0K_0}$$

where N_0 is original particle concentration
 t is time,
 K_0 is coagulation coefficient, calculated as

$$K_0 = \frac{4kTC_c}{3\eta}$$

Geometric standard deviation (GSD) ≤ 2.5 .

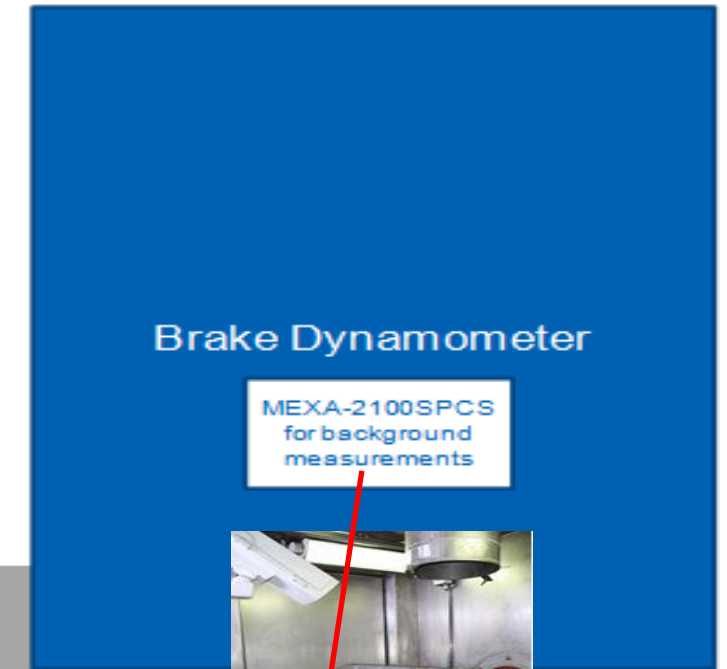
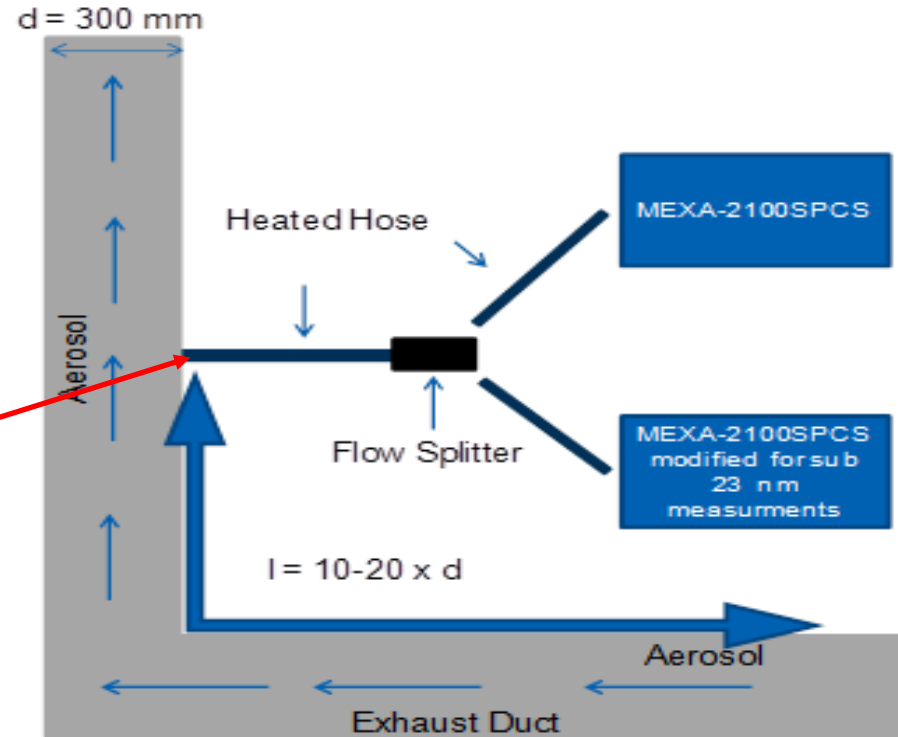
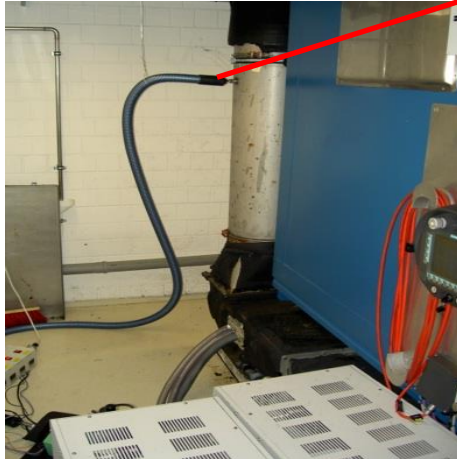


- ❖ Strong coagulation is calculated for **Environmental chamber** and **Sampling box**
- ❖ **Exhaust duct is** validated as sampling point!

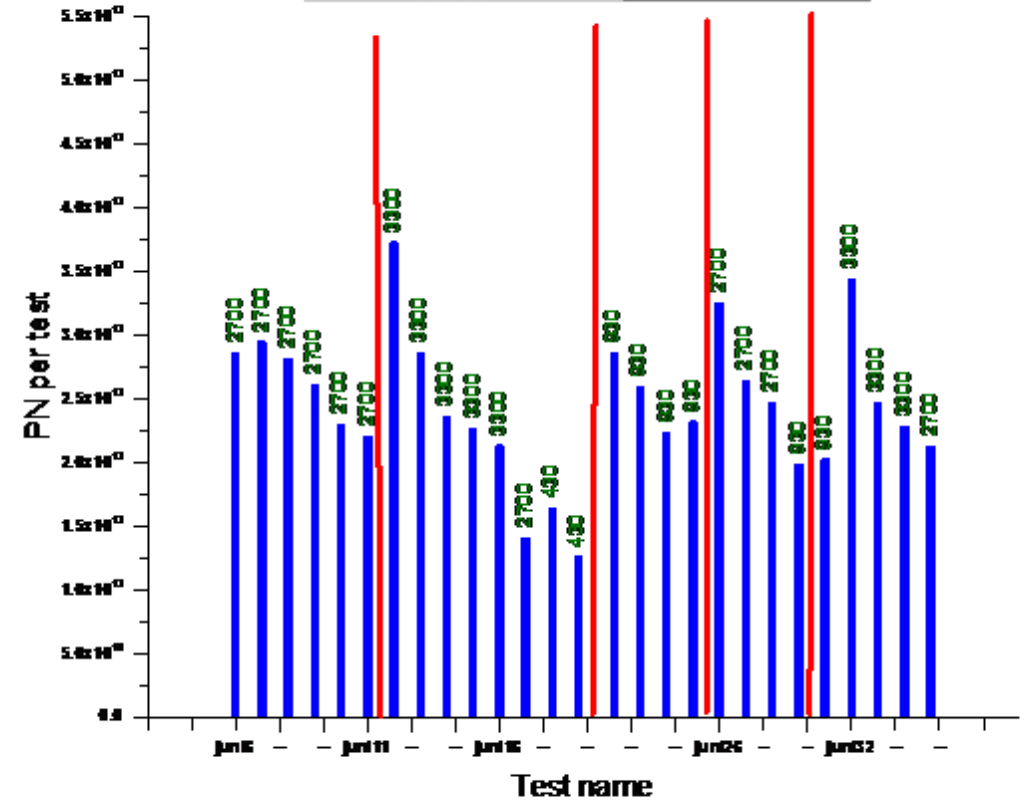
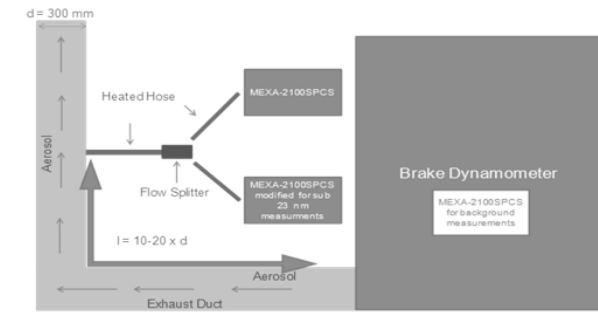
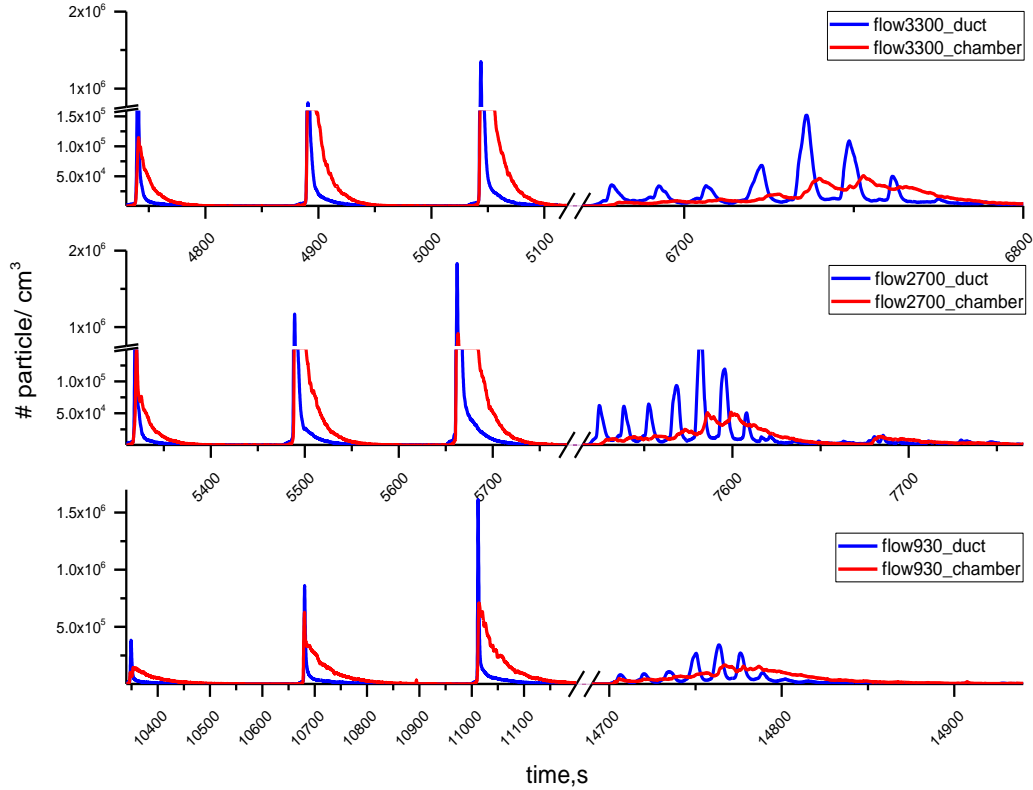
Testing and validation of Horiba-AUDI concept

Experimental set-up AUDI-Horiba

- 17" 2 piston frame-design caliper, low steel (ECE) brake pads (AUDI A8)
- 2 sampling points
 - Inside testing chamber
 - Exhaust duct



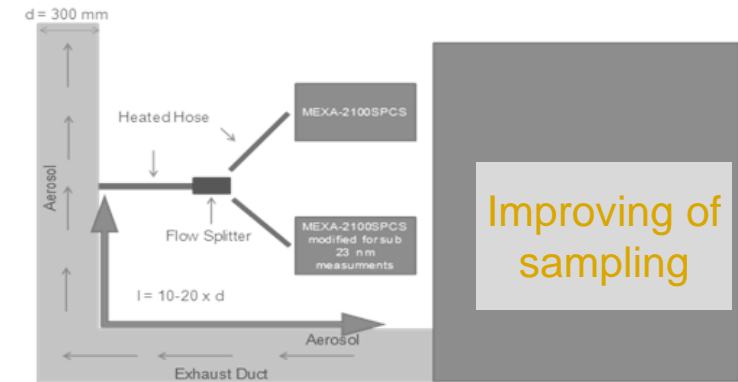
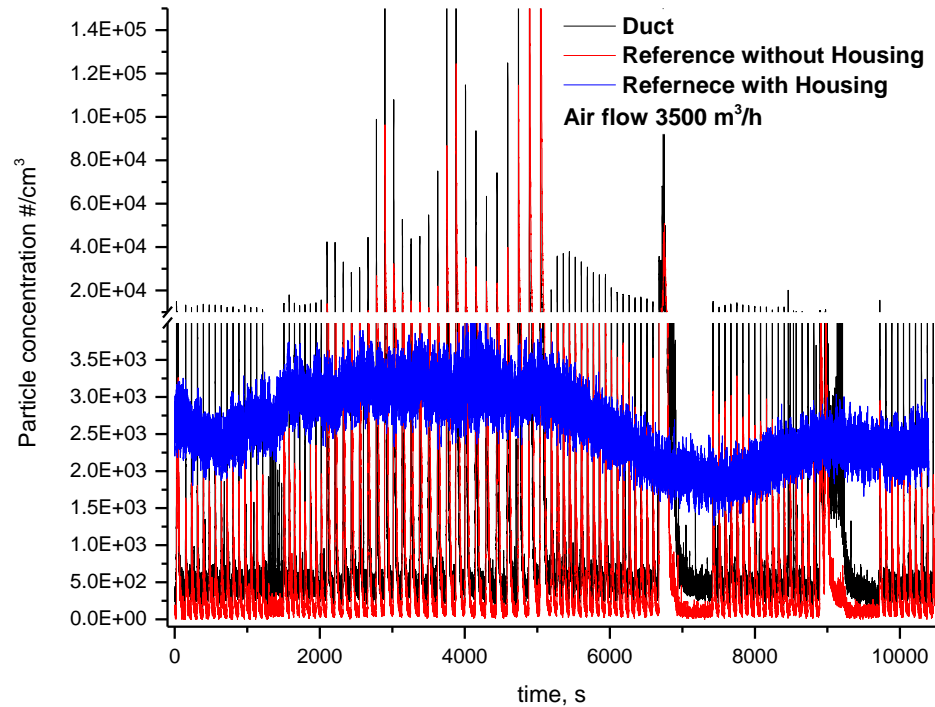
Testing procedure: Air Flow effect



- ❖ Particle emission depends on air flow sequence
- ❖ Increasing air flow leads to reduction of residuals in brake dynamometer cabin

Testing and Validation of Horiba-AUDI concept

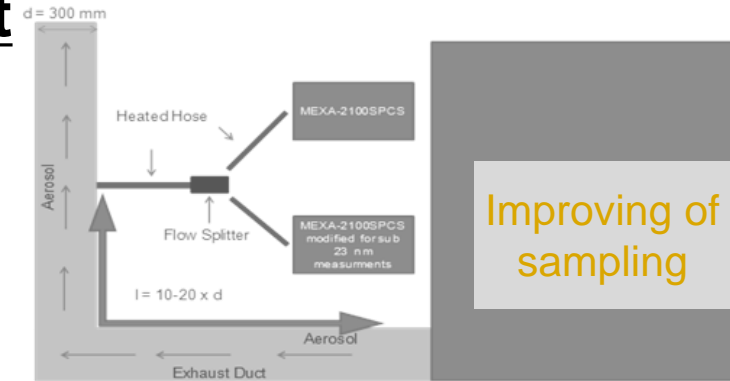
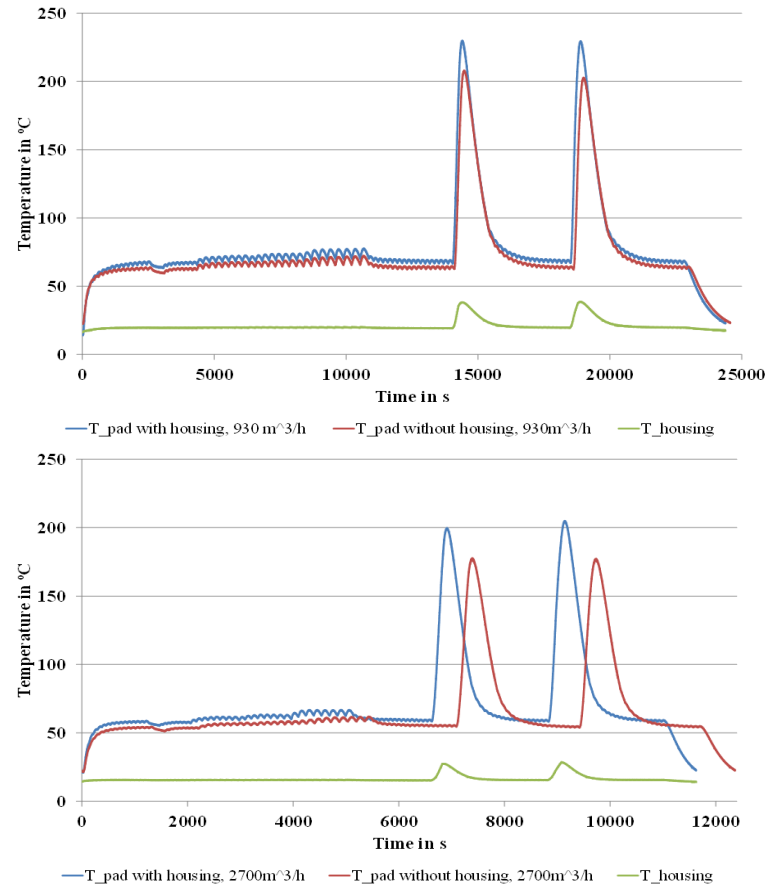
Implementation of housing : Airborne collection



- ❖ Application of housing allow to collect 100% Brake Dust Airborne
- ❖ Horiba-AUDI concept is validated for PN measurements!

Testing and Validation of Horiba-AUDI concept

Implementation of Housing: Set-up temperature



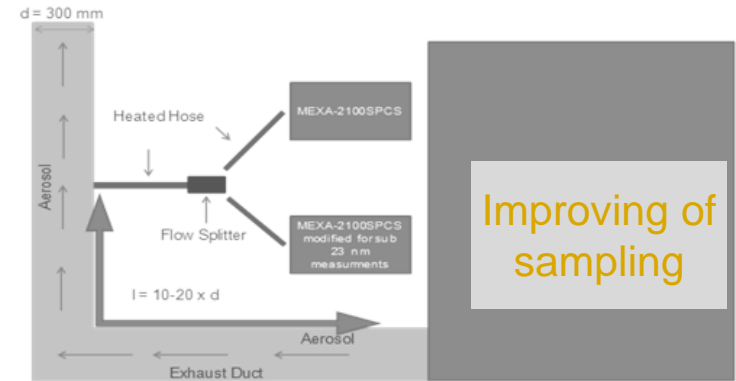
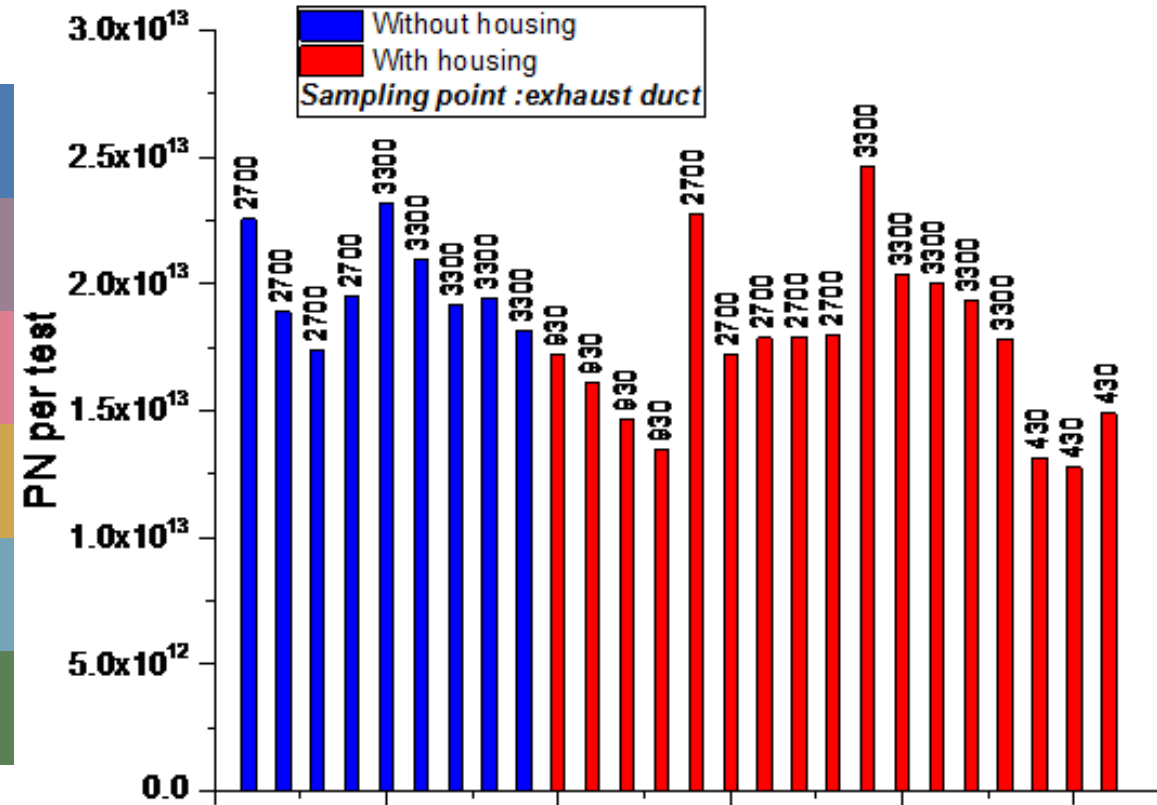
Improving of sampling



- ❖ Application of housing does not change set-up temperature
- ❖ Temperature of Brake Pads stay $\leq 220^\circ\text{C}$ even if rotor temperature is $\geq 500^\circ\text{C}$

Testing and Validation of Horiba-AUDI concept

Implementation of Housing: Air Flow effect



- ❖ Horiba-AUDI concept is validated for PN measurements!
- ❖ Application of housing is strongly improved reproducibility of test results
- ❖ Particle emission depends on air flow sequence

Selection of functional parameters: Testing procedure

Testing procedure

Testing conditions

- Air velocity and air quality.
- Position brake in car
- Vehicle load and environmental conditions

Test cycle

- Conditioning of brake pad and brake disk
- Developing of new cycle based on driving conditions
- Modification of existing cycle

Object of Investigations

- Particle Number per test(PN)
- Particle Mass(PM): gravimetical and/or on-line

Testing procedure

Testing conditions

- Air velocity and air quality.
- Position brake in car
- Loading of the car and environmental conditions

Test cycle

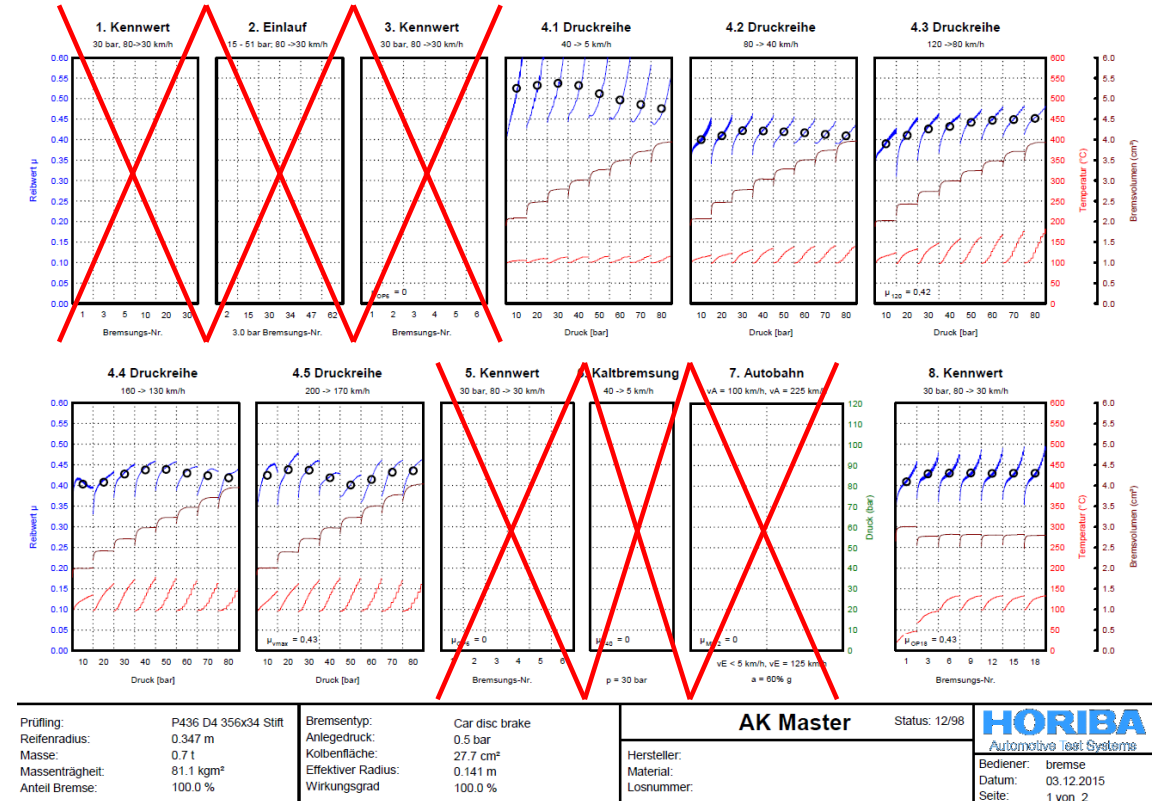
- Conditioning of brake pad and brake disk
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Object of Investigations

- ✓ Particle Number per test(PN)
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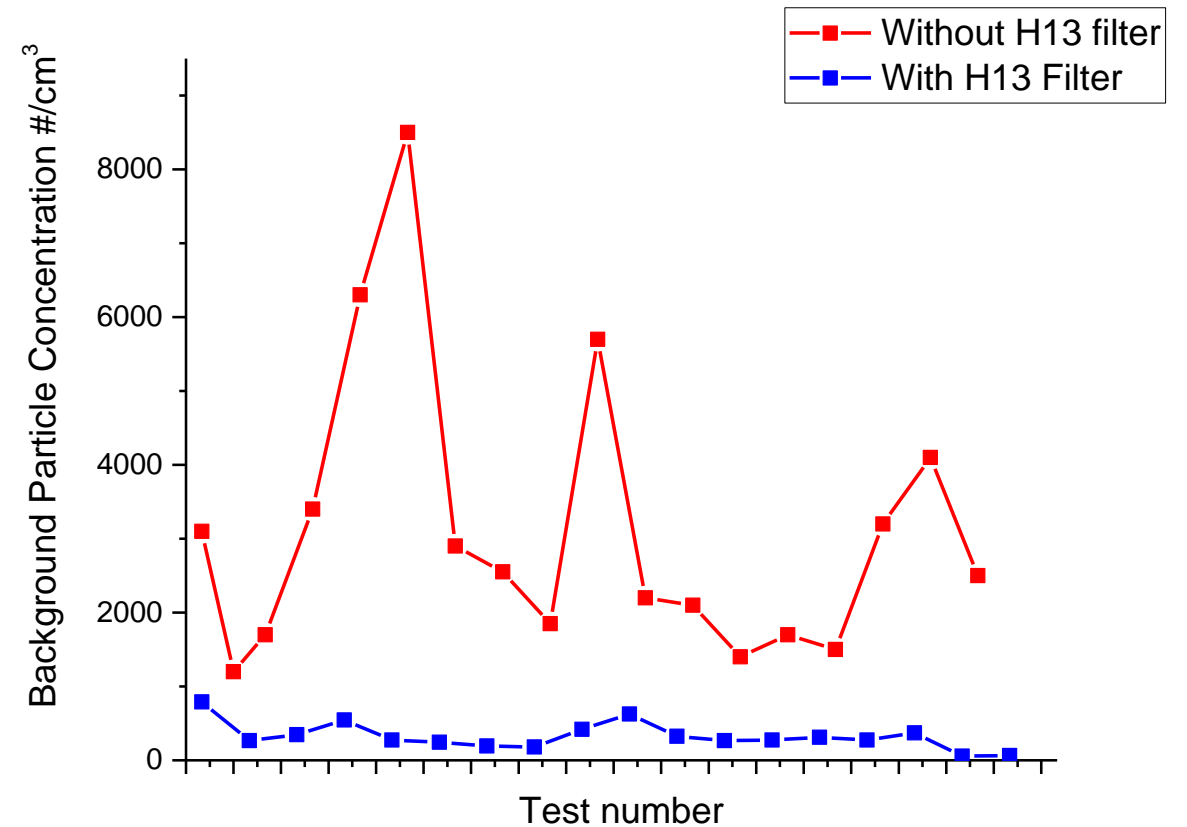
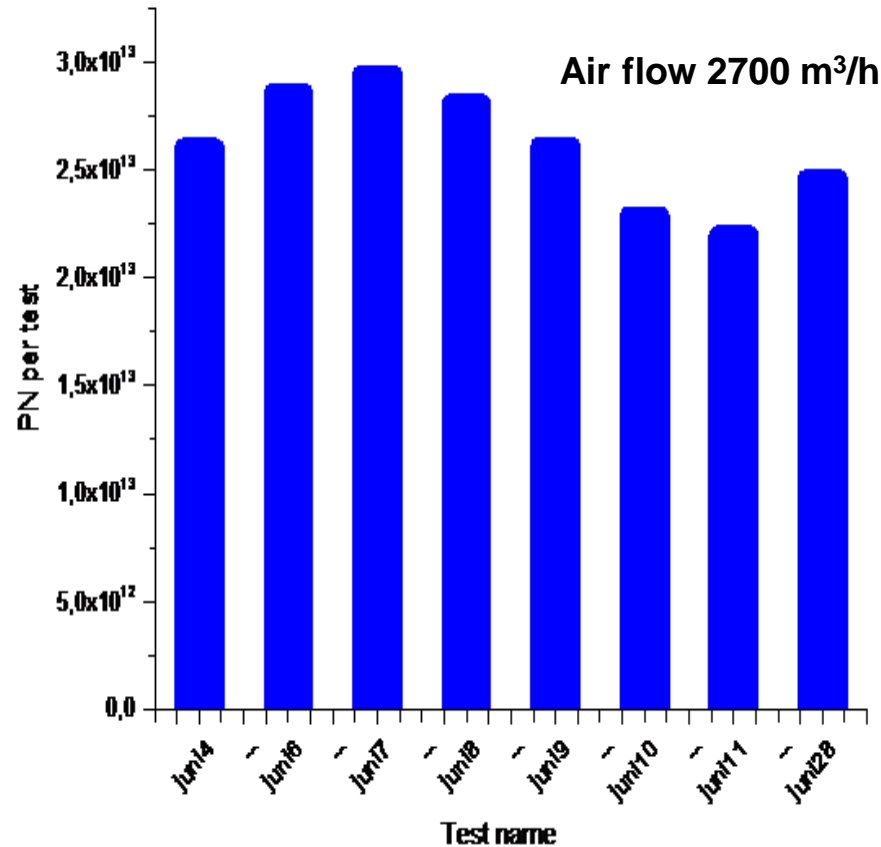
**Point of our
research**

Testing procedure: New Bedding cycle



- ❖ AK Master without sections 1-3, 5-7, 11 and 14-15
- ❖ Air flow: 430, 930, 2700 and 3450 m³/h
- ❖ No RDE cycle intended yet!

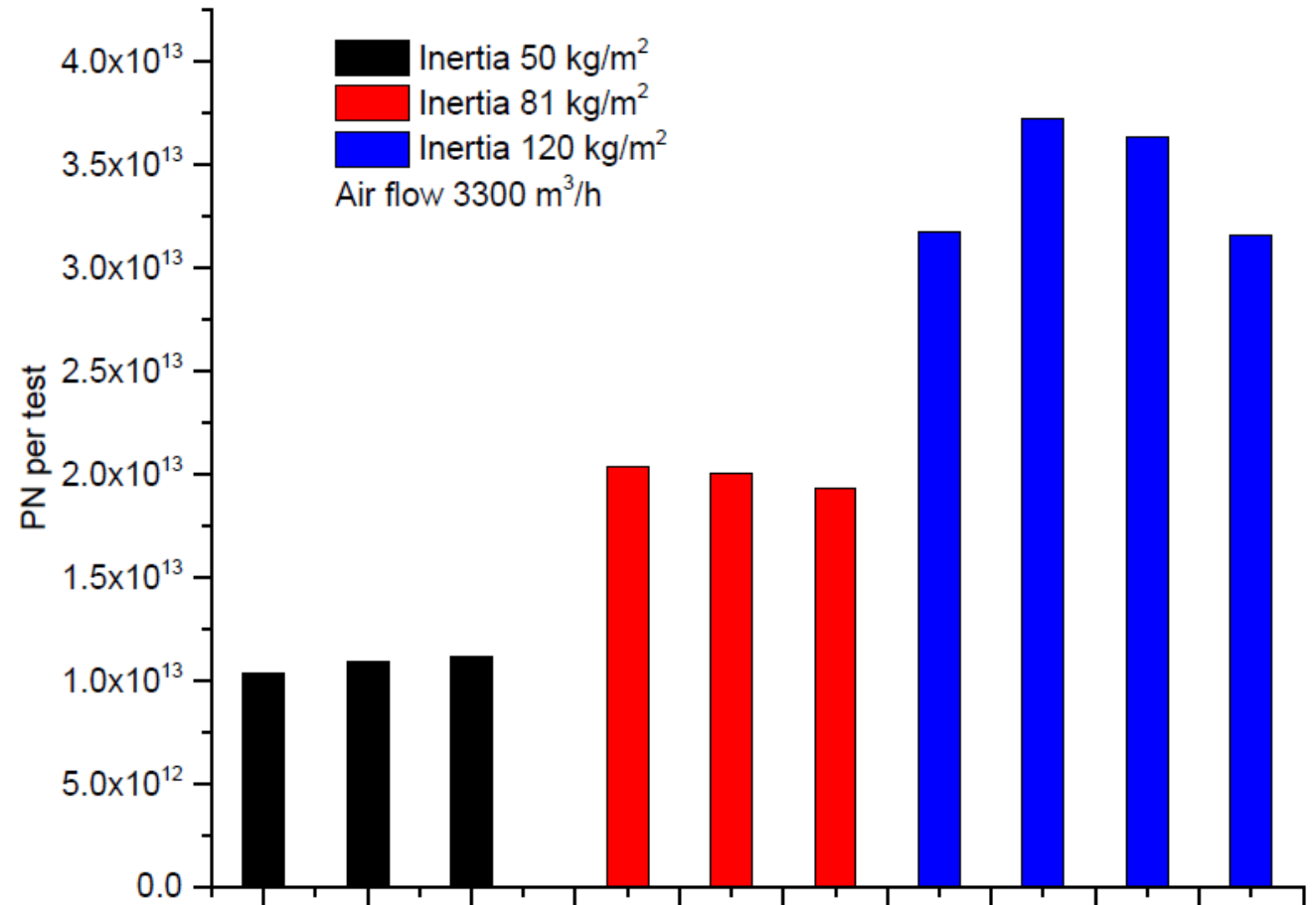
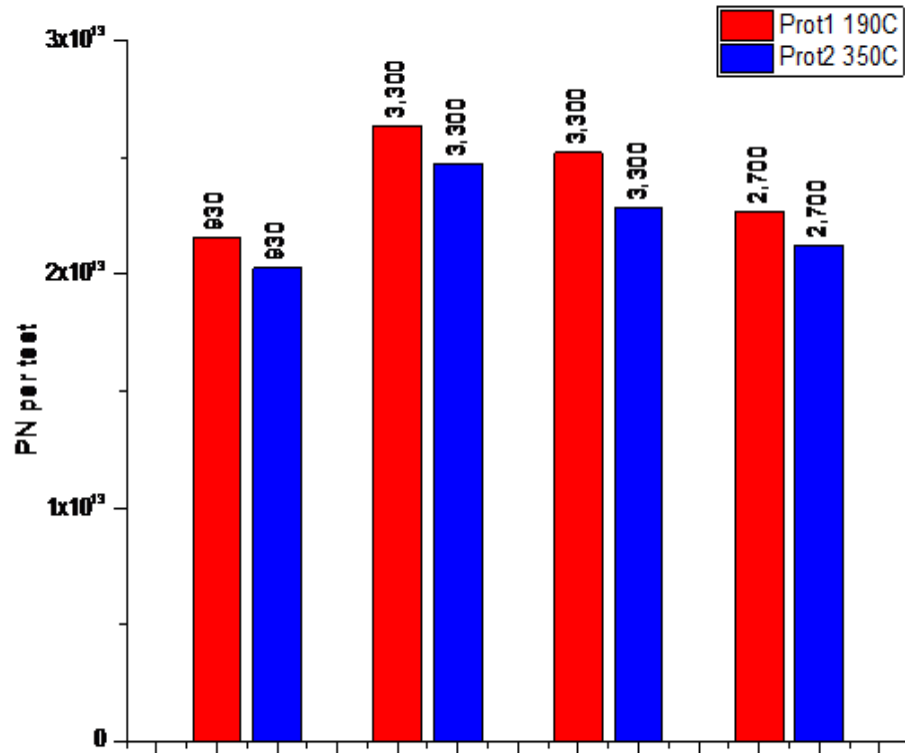
Testing procedure: Inlet Air quality and Stabilization of Particle Emission



- ❖ Application of H13 filter leads to strong reduction of particle background concentration as well as stabilization of background level
- ❖ Particle emission was stabilizing by third repetition.
- ❖ For tests measured with inlet air velocity 2700 m³/h variation of PN is not higher as $\pm 20\%$.

Testing procedure:

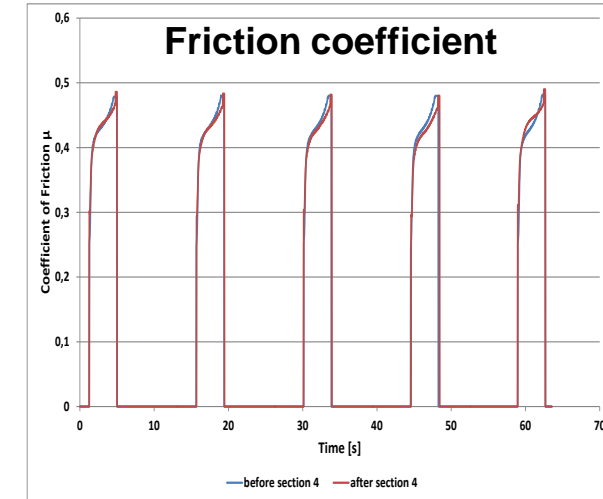
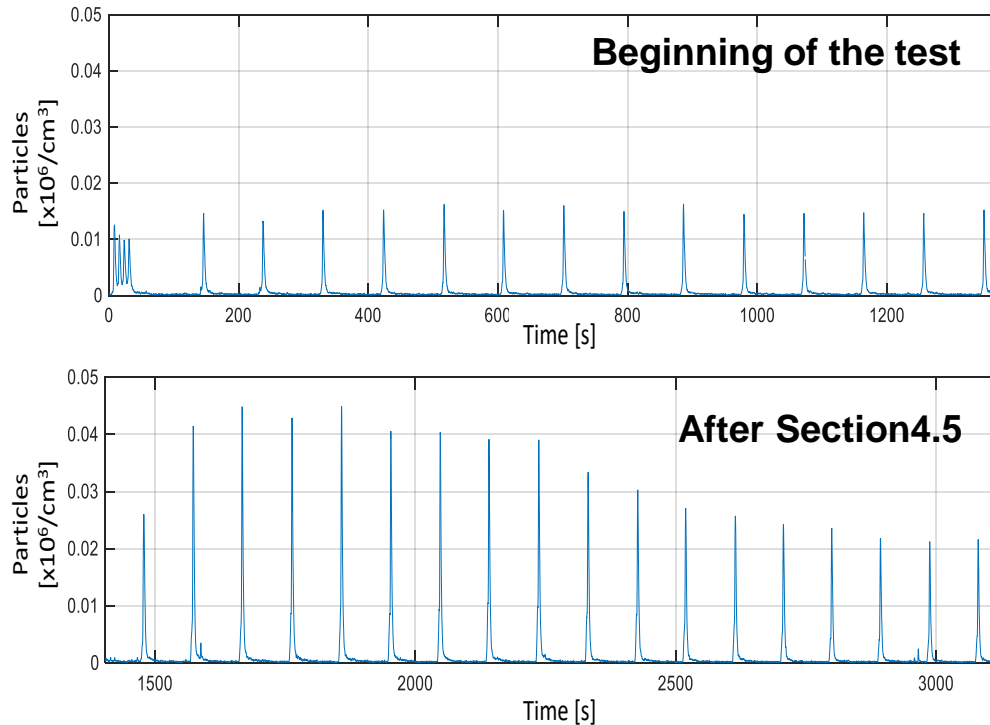
Volatile content and role of inertia



- ❖ Measurements equipment demonstrate reproducibility within $\pm 5\%$.
- ❖ Increasing of inertia strongly increases particle emission
- ❖ No volatile content with $T \geq 190^\circ \text{C}$ was observed in emission from ECE pads

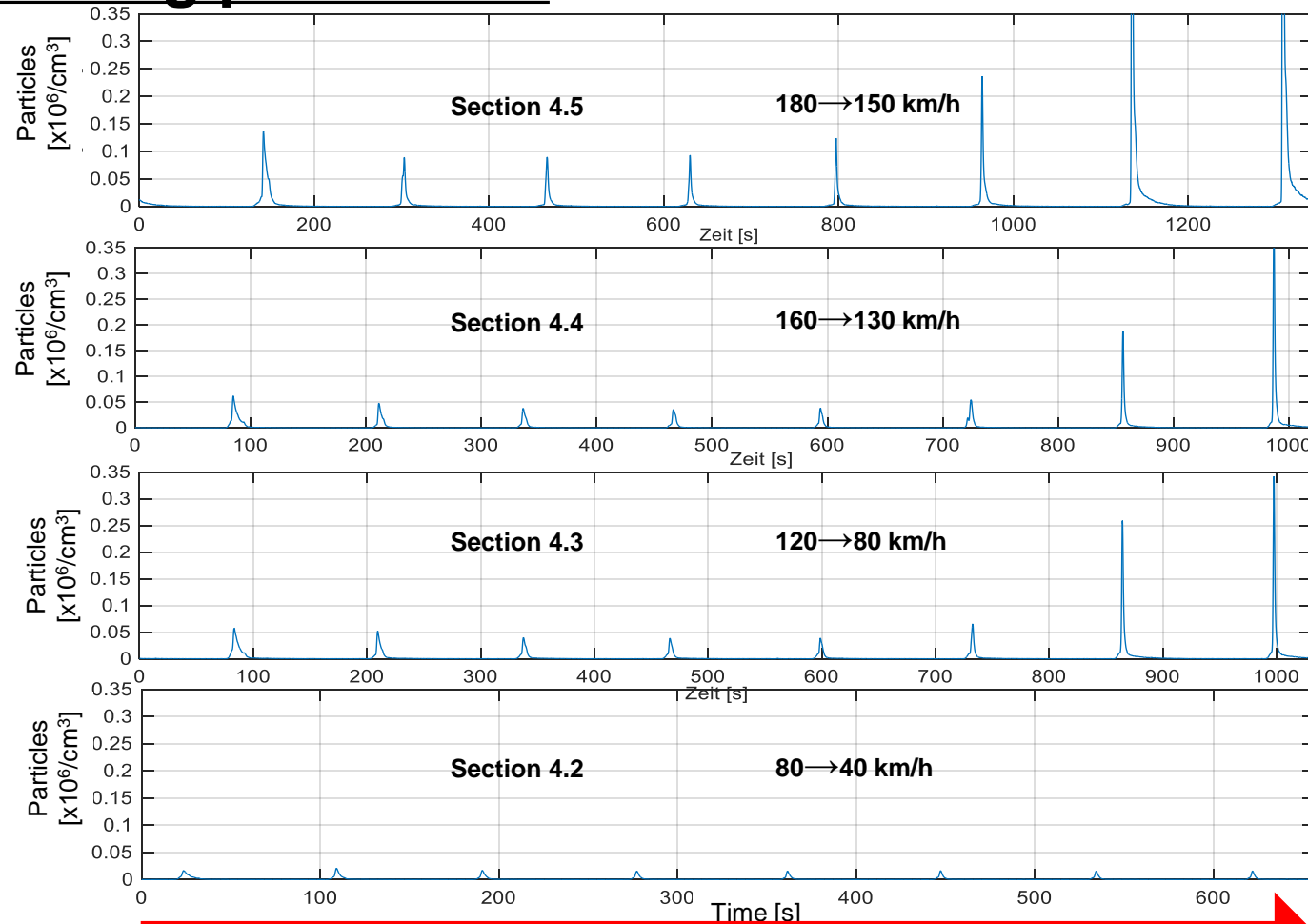
Testing procedure:

Section 8 and “Memory” effect



- ❖ Particle concentration changes drastically for same brake conditions
- ❖ Friction coefficient does not change
- ❖ Effect is reproducible and observed at 4 different air velocities

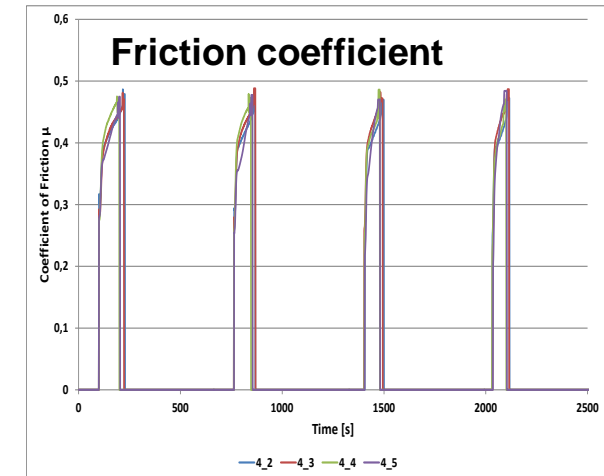
Testing procedure:



Disk speed

Brake pressure

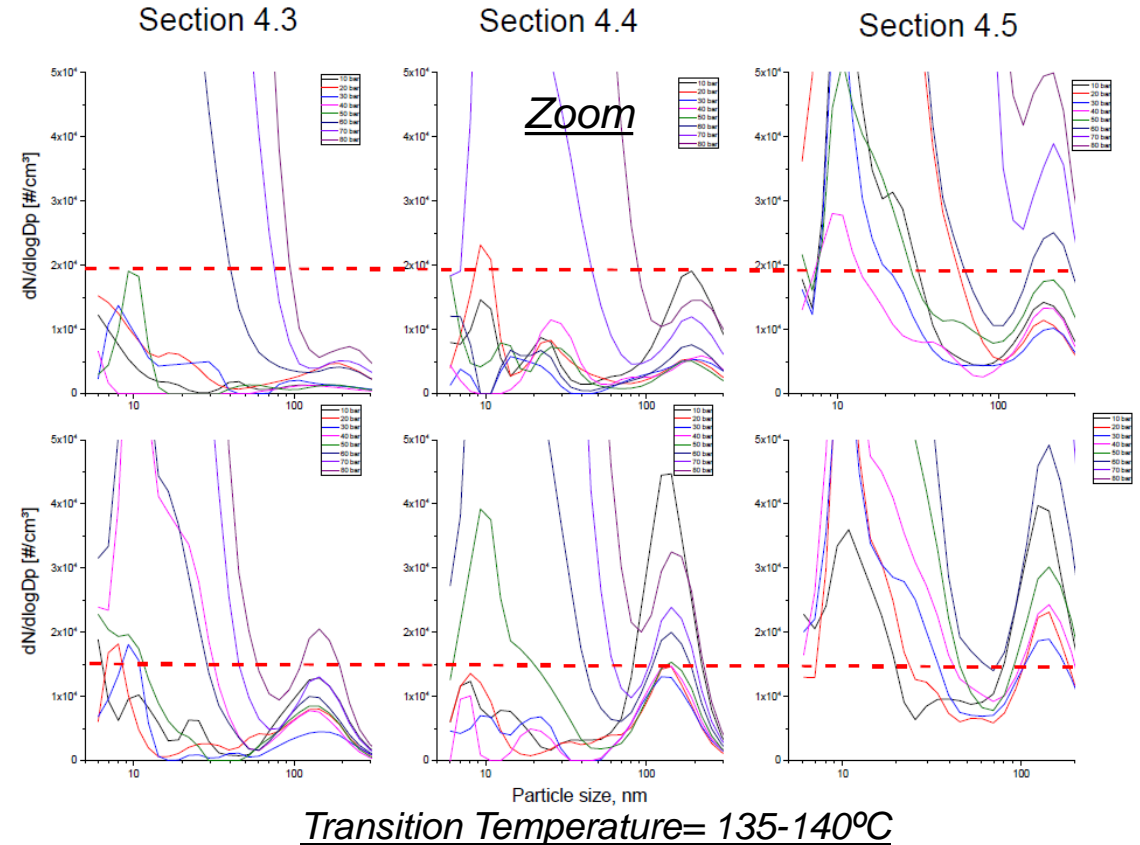
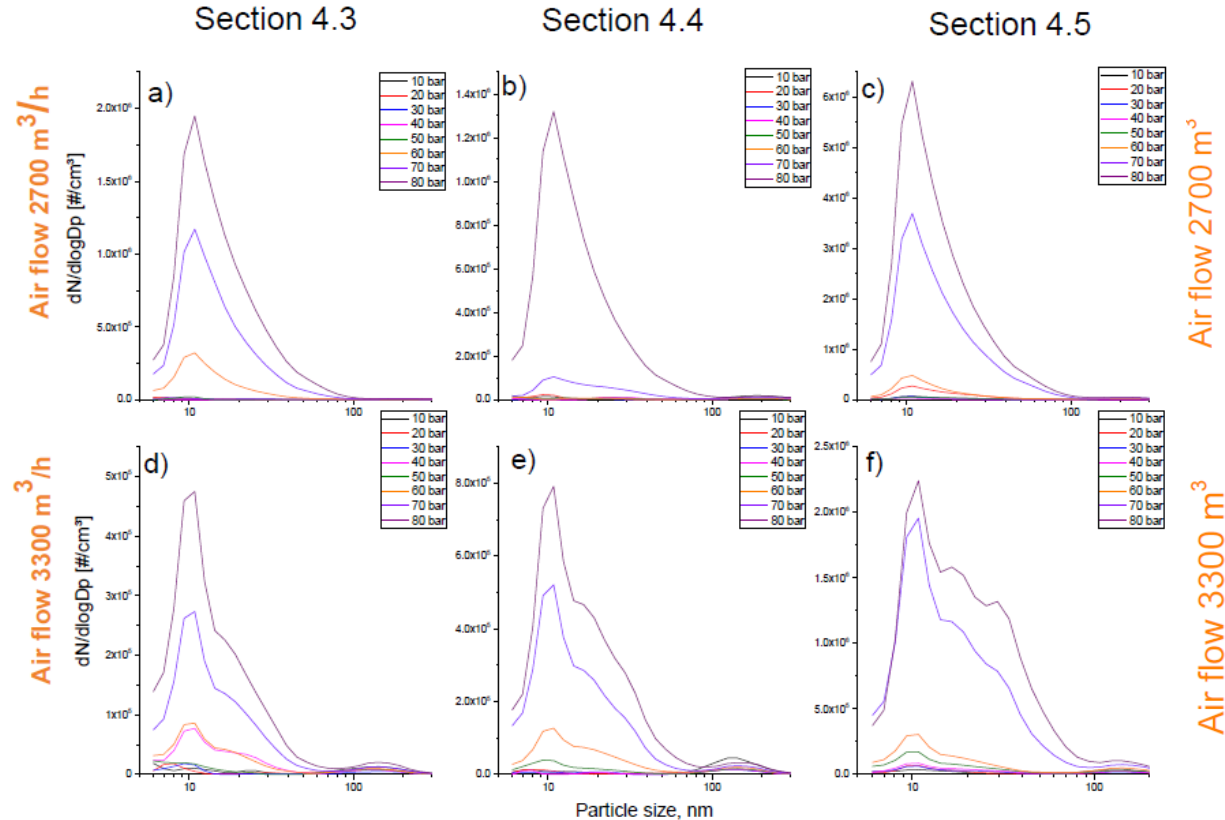
Pressure and disk speed effect



- ❖ Particle concentration increases rather with increasing disk speed than brake pressure.
- ❖ Friction coefficient does not change
- ❖ Effect is reproducible and observed at 4 different air velocities

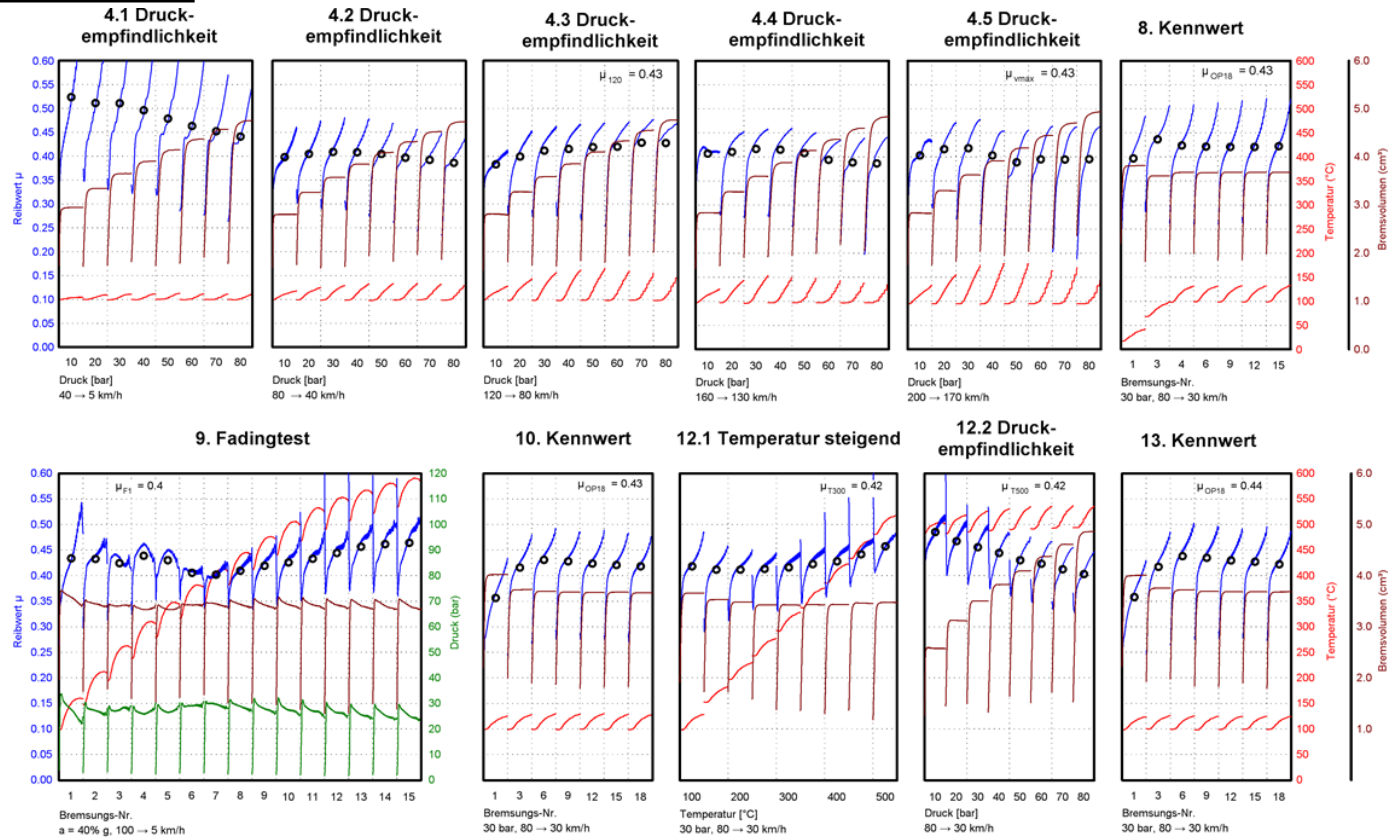
Testing Procedure:

Pressure and disk speed effect - Particle size distribution



- ❖ Bi-modal particle size distribution observed for ECE brake pads
- ❖ Concentration of nano-particles increases drastically after brake pressure reach 40 bar, Transition temperature~140°C
- ❖ Air flow can affect particle emission

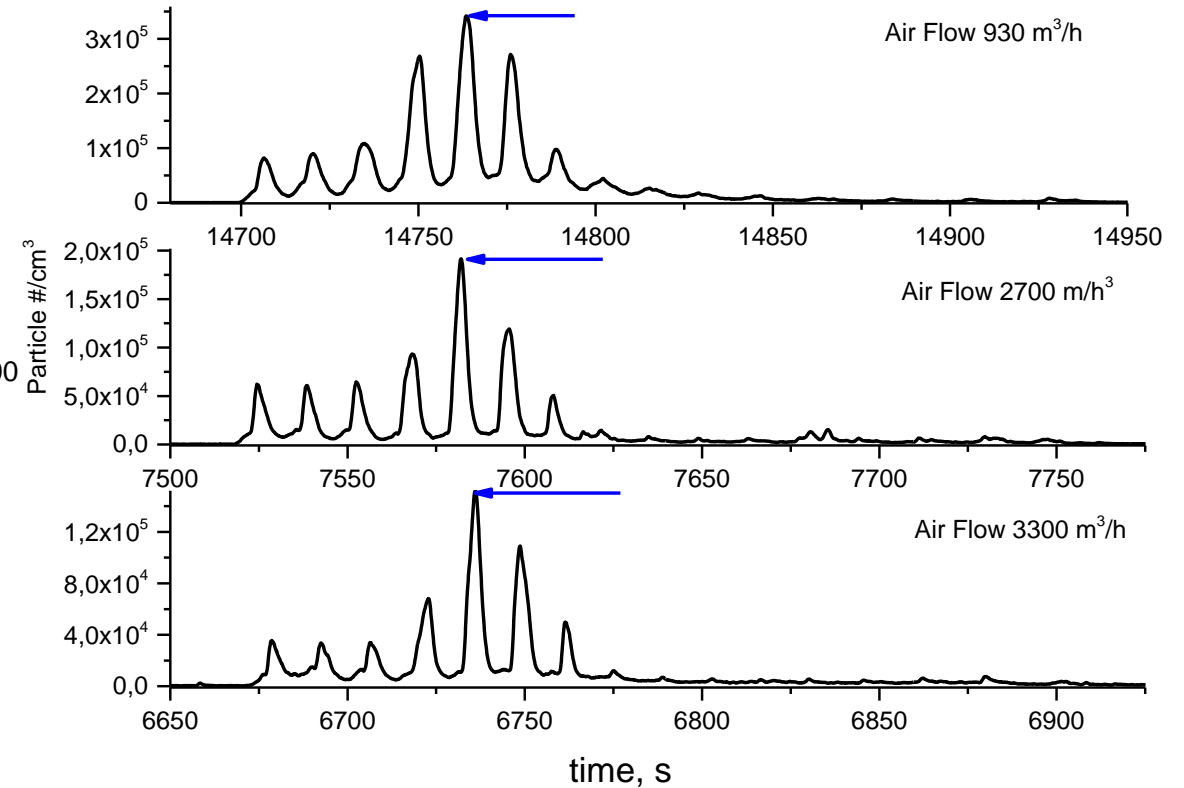
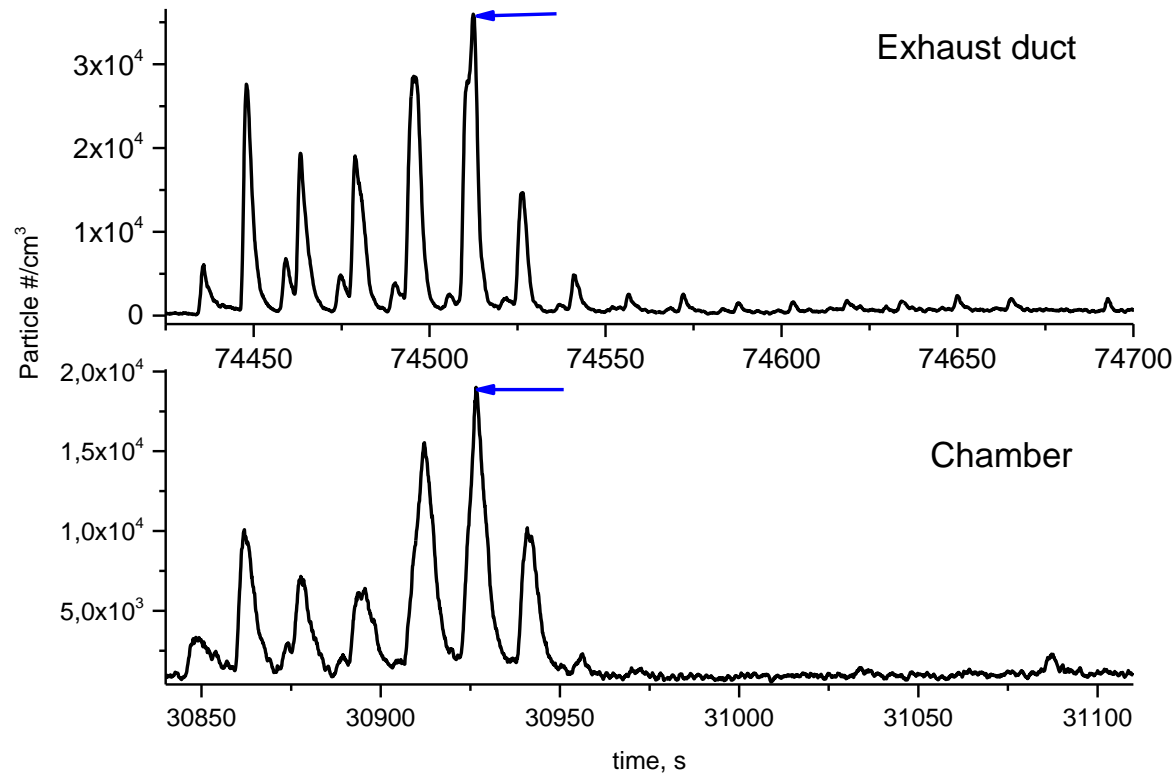
Testing Procedure



- ❖ Friction coefficient does not differ between bedding and brake pressure section
- ❖ Particle emission changes drastically at the same time
- ❖ Global parameters can not be used for characterization of BPE
- ❖ Effect is reproducible and observed at 4 different air velocities

Testing Procedure:

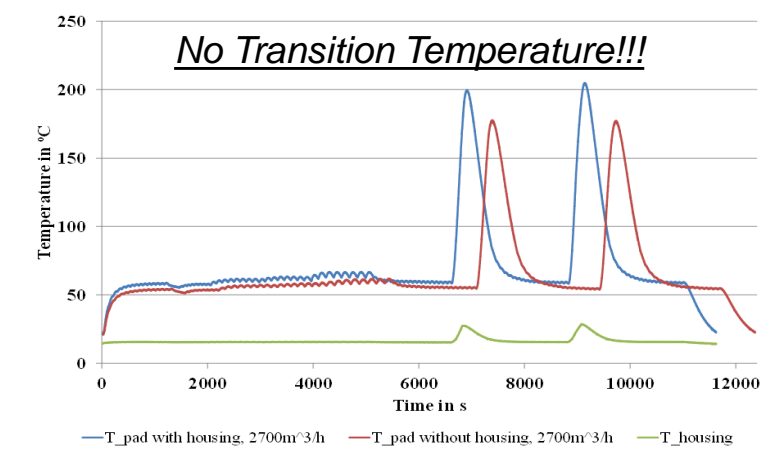
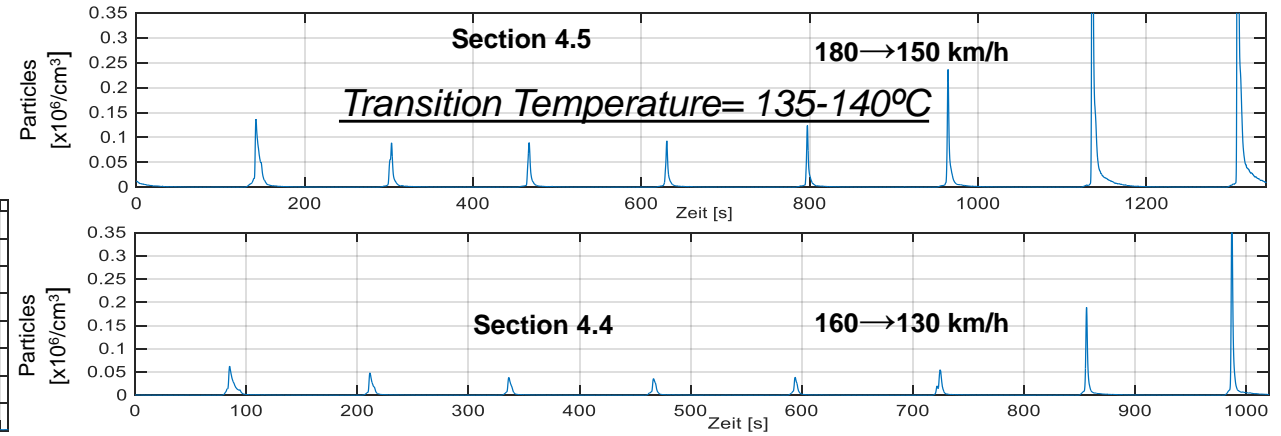
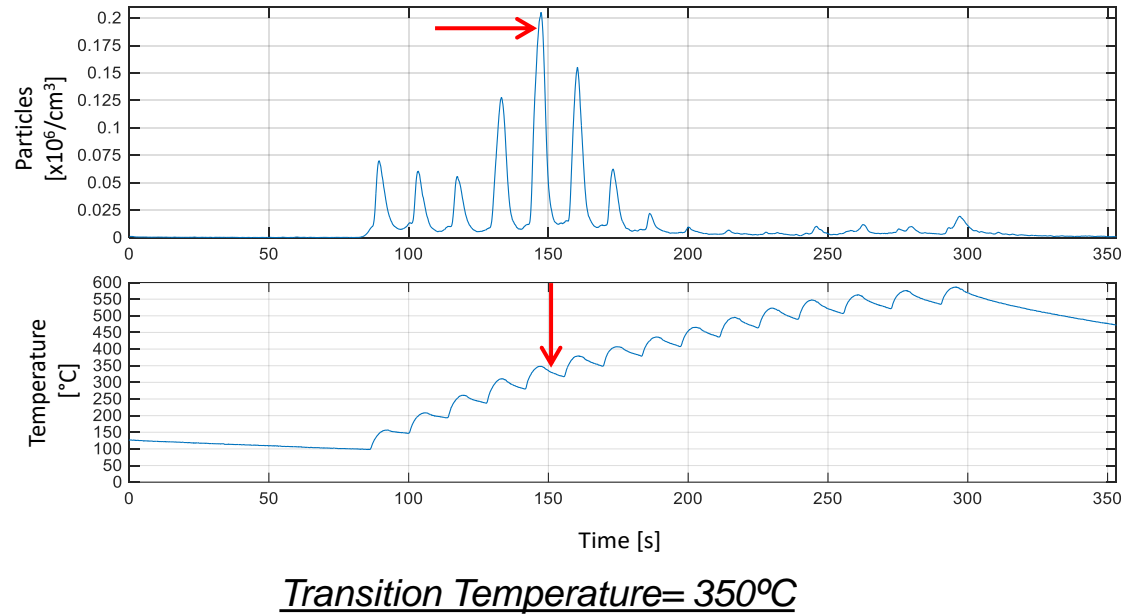
Section 9 and Temperature effect



- ❖ Strong reduction of BPE for disk temperature $T \geq 350^\circ \text{ C}$.
- ❖ Effect is reproducible and observed at 4 different air velocities
- ❖ Effect is reproducible and observed at 3 different sampling points by 2 different brake dynos

Testing procedure

Role of disk and brake pads temperature



- ❖ Disk transition temperature depends rather on applied loading then on conventional heating
- ❖ No transition temperature for brake pads is observed

Finding's

- ❑ Most suitable sampling point for PN was defined
- ❑ Horiba-AUDI set-up provide 100% sampling of Brake Dust Airborne
- ❑ Testing parameters(air flow, air quality, etc.) can affect results of PN measurements
- ❑ SPCS particle counter was modified according special requirements for Brake Dust Emission measurements and provide fast response, high accuracy and reproducibility for measurements of Brake Dust Emission
- ❑ The comparison of particle measurements performed on two different dynamometers is possible
- ❑ Particle emission from set of new brake pads and disk can be stabilized during short time.
- ❑ Particle emission was measured in range 1×10^5 - 10^8 particle/cm³
- ❑ Particle emission depends on inertia, disk temperature, wheel velocity and less on applied pressure
- ❑ Horiba-AUDI set-up provide good reproducibility for particle emission measurements
- ❑ Horiba-AUDI set-up can be used for R&D research on material of brake pads and disks as well as for brake certification
- ❑ Horiba-AUDI set-up can be installed nearly at every brake dynamometer without big modification

Outlook

- ❑ Continue research on definition of sampling point and Evaluation role of probe dilution and sampling velocity
- ❑ Evaluation role of non-brake parameters- velocity of air flow, direction of flow, humidity etc.
- ❑ Comparison of brake pads produced of different materials- ECE, NAO, Ceramic
- ❑ Investigations on composition of brake dust emissions
- ❑ Robin Round at 2-3 Labs
- ❑ Test feasibility of PM for brake airborne measurements
- ❑ Break Wear was reported to be reponsible for mechanical stability of brakes as well as NVH effects-material research on this topic will significantly extend markt capacity from certification to material R&D

Omoshiro-okashiku
Joy and Fun

おもしろおかしく

眞峰



Thank you

Cảm ơn

감사합니다

ありがとうございました

Dziękuję

धन्यवाद

Grazie

Merci

谢谢

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நன்றி

Gracias

Obrigado

Σας ευχαριστούμε

Děkuji

Teşekkürler

شكرا

Tack ska ni ha

Danke

Большое спасибо