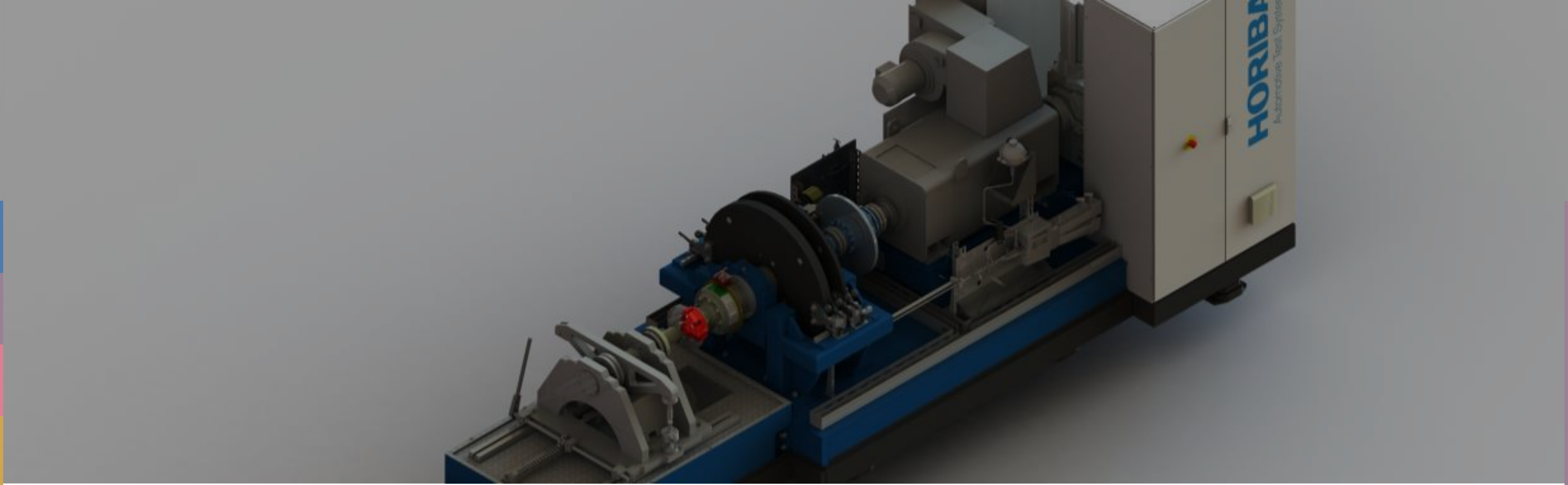

BRAKE DUST MEASUREMENTS-HORIBA APPROACH

TF2

05.10.2017, Dr. D.Lugovyy

Agenda

1	Project Definition
2	Comparison of exiting sampling concepts
3	Horiba-AUDI concept
4	Role of volatile content and comparison of measurements techniques
5	Findings
6	Outlook

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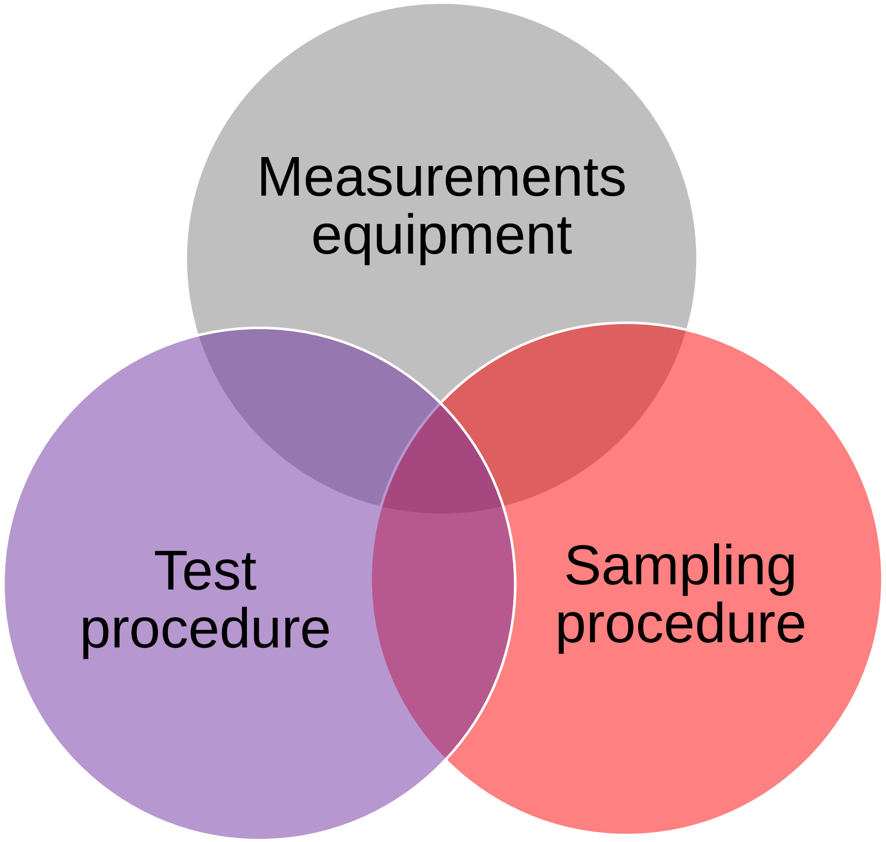
Project definition

To be solved



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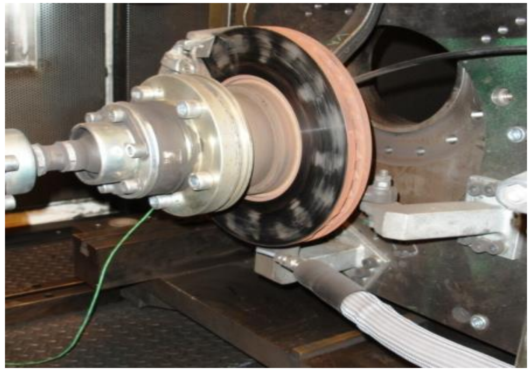
Aim of the project

Developing new particle measuring principle for analysis of Brake Dust pollutions

Comparison of exiting sampling systems

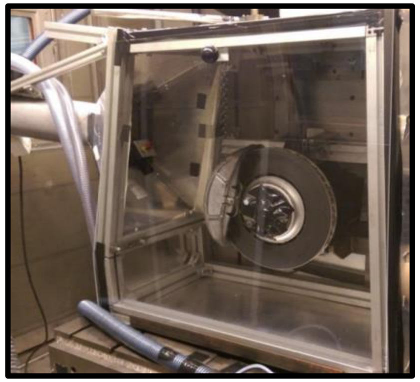
Sampling of Brake Dust- Biggest Challenge for Particulate Matter measurements

Hose

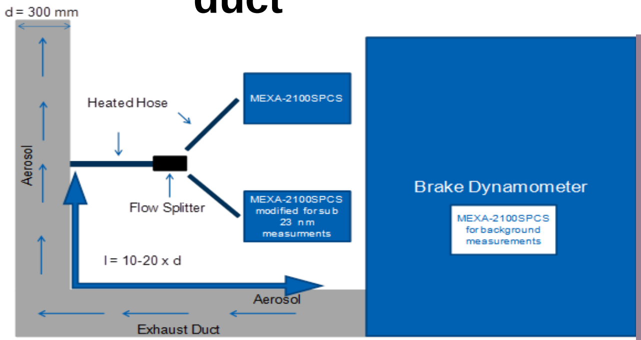


Sampling Box

Environmental chamber



Exhaust duct



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*

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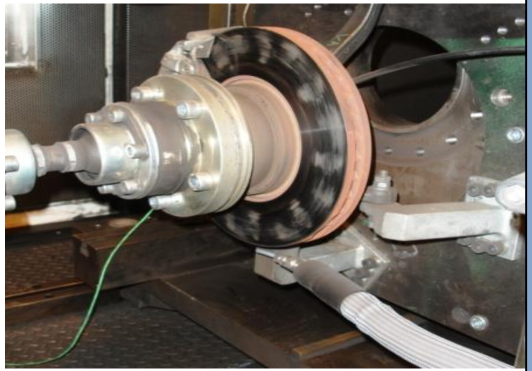
Sampling of Brake Dust

Hose



Pro

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

Contra

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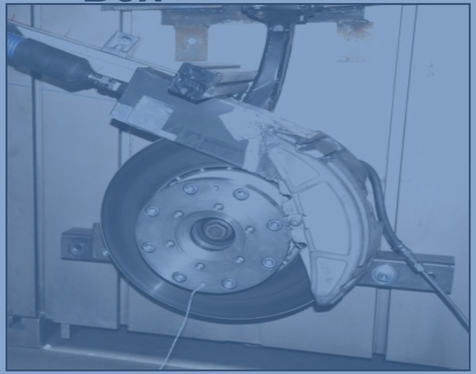
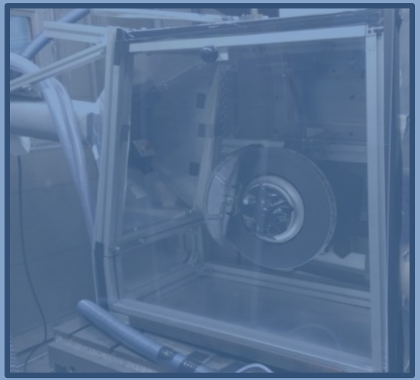
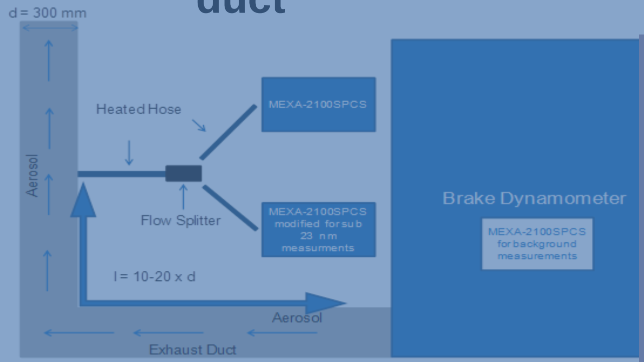
Sampling Box



Environmental chamber



Exhaust duct



Horiba focus

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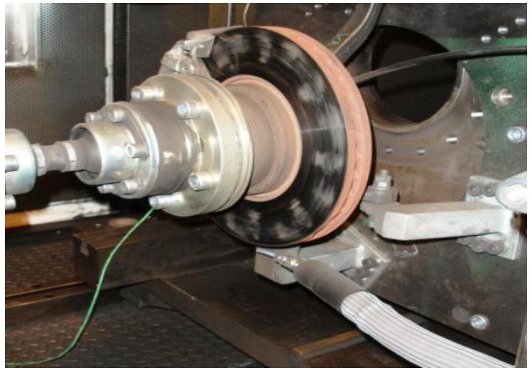
Sampling of Brake Dust

Hose



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

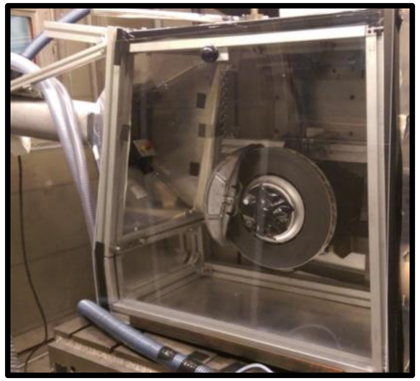
Contra
- ➢ Reproducibility of results
- ➢ Calculation PN per km
- ➢ High level of background particle concentration
- ➢ Probe homogeneity

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

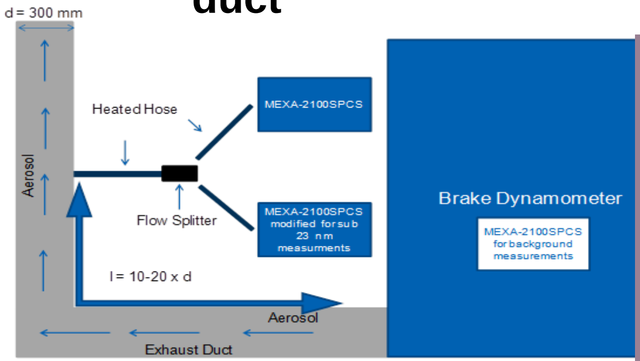
Environmental chamber



Pro
- ✓ Calculation PN per km
- ✓ Reproducibility of results
- ✓ Reduction of background particle concentration level

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

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For details please follow our presentation at PMP43

Horiba-AUDI concept

Motivation

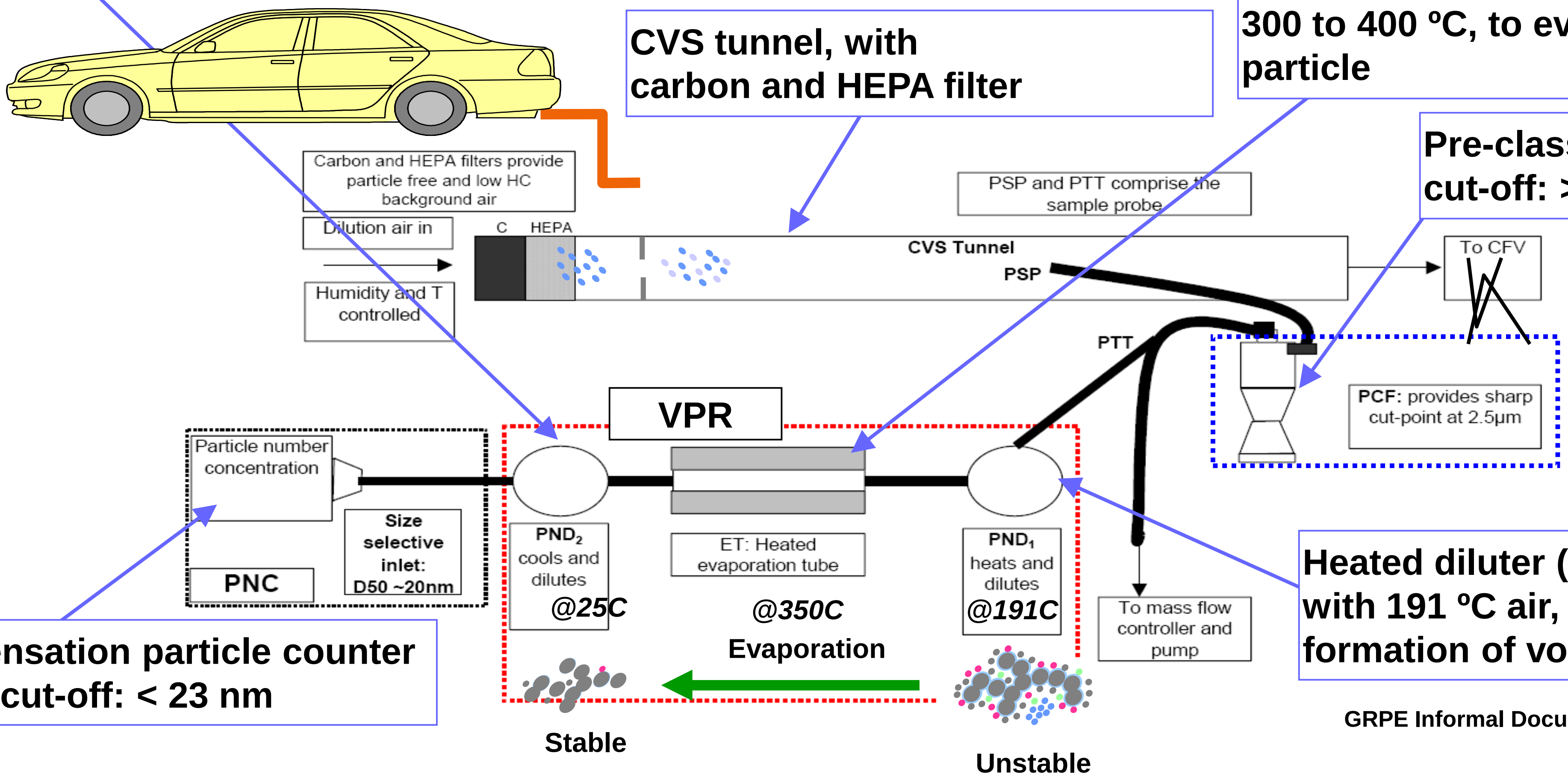
Motivation: PMP Protocol for car engine

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 ºC, to evaporate volatile particle

Pre-classifier cut-off: > 2.5 μm



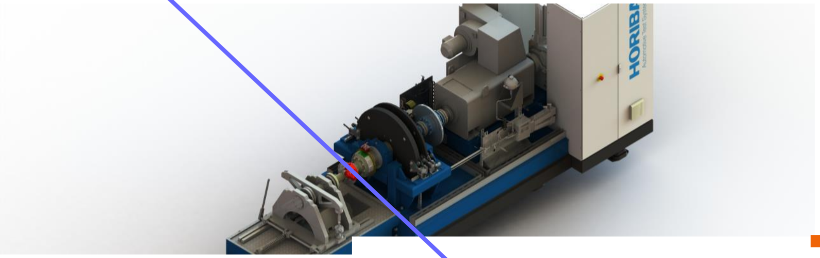
Heated diluter (PND1) with 191 ºC air, to suppress the formation of volatile particle

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

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

Brake dust, first approximation: PMP Protocol confined

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 ºC, to evaporate volatile particle

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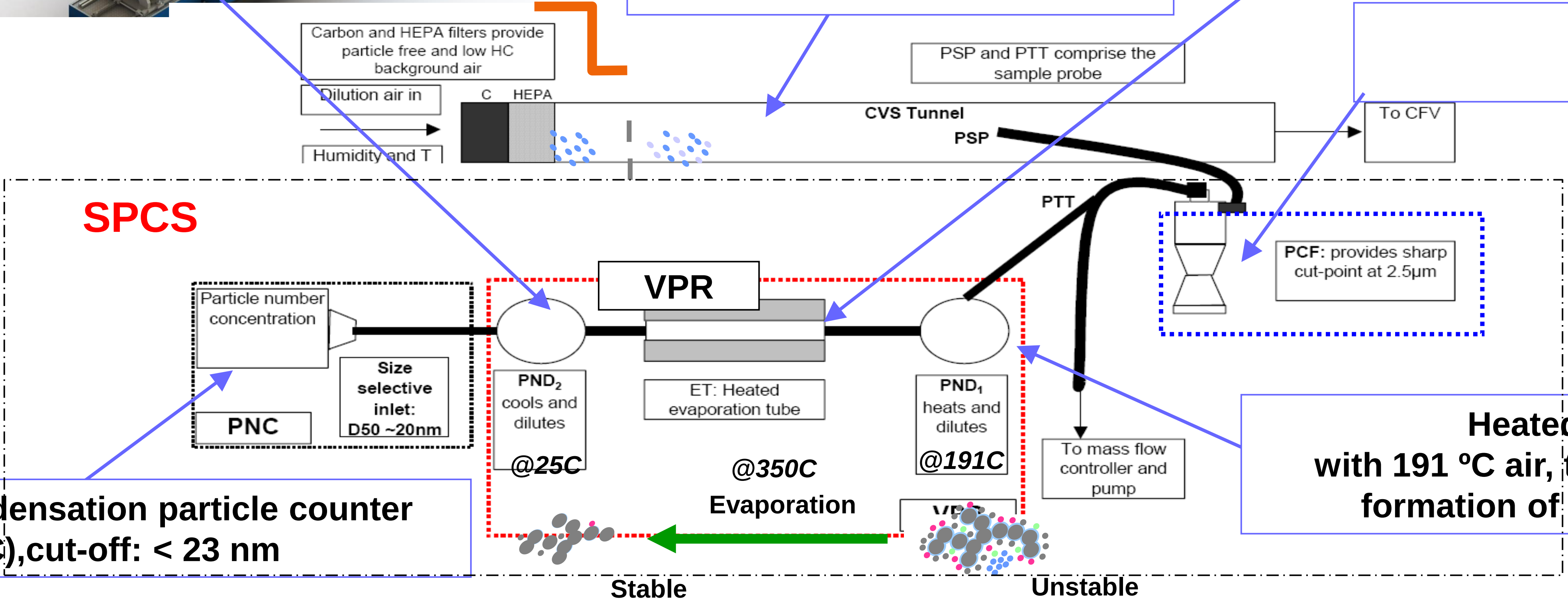

Heated diluter (PND1)
with 191 ºC air, to suppress the formation of volatile particle

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

Brake dust, first approximation: PMP Protocol confined

Advantages

- ➢ Homogeneous mixture of probe
- ➢ Good reproducibility and repeatability of results
- ➢ Direct comparison to results for engine emissions
- ➢ Volatile content of emission will be removed

Disadvantages

- ✓ Particle number is measured for PM2.5 only
- ✓ Emissions response is averaged over time and volume

Testing and validation of Horiba-AUDI concept

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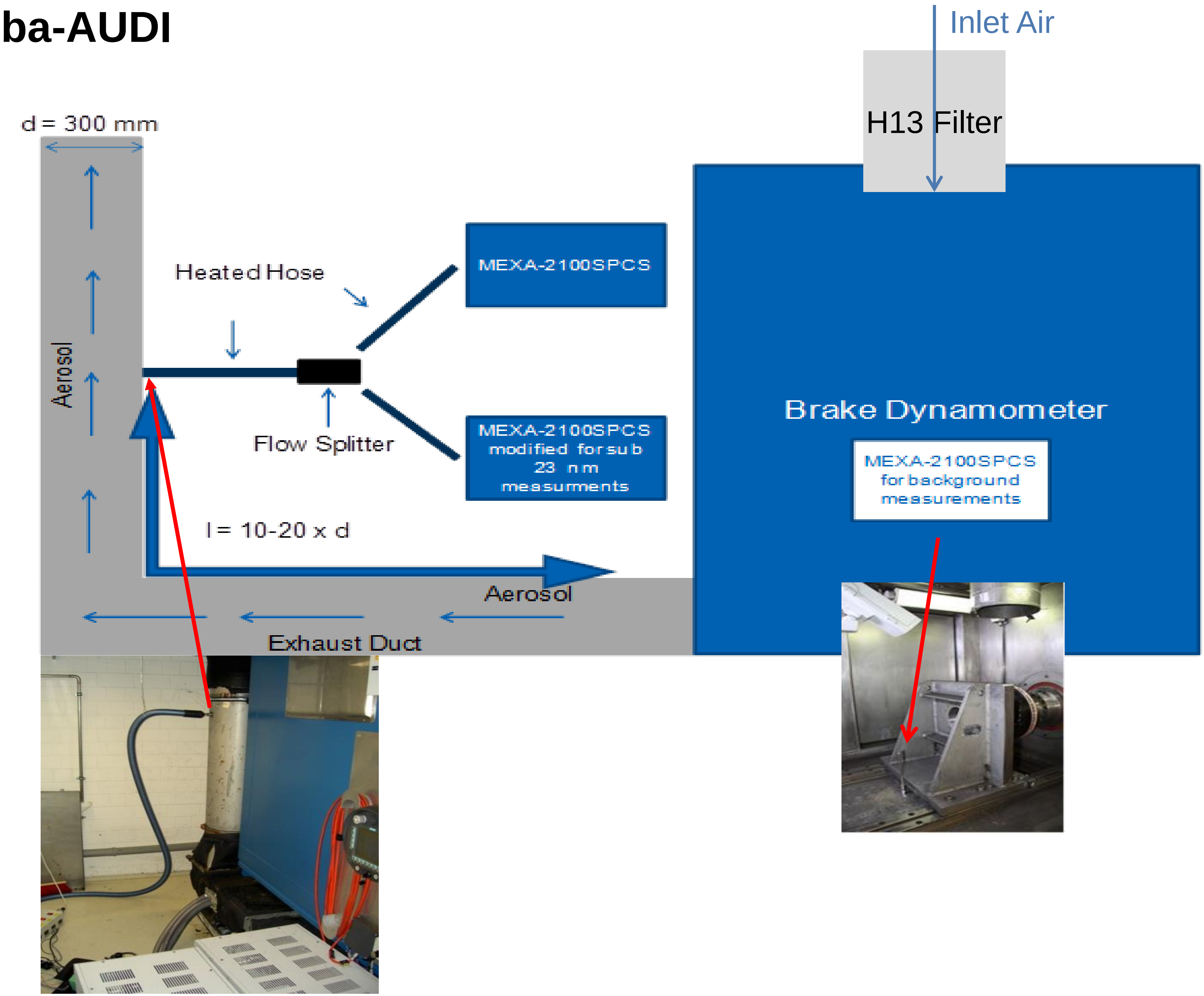
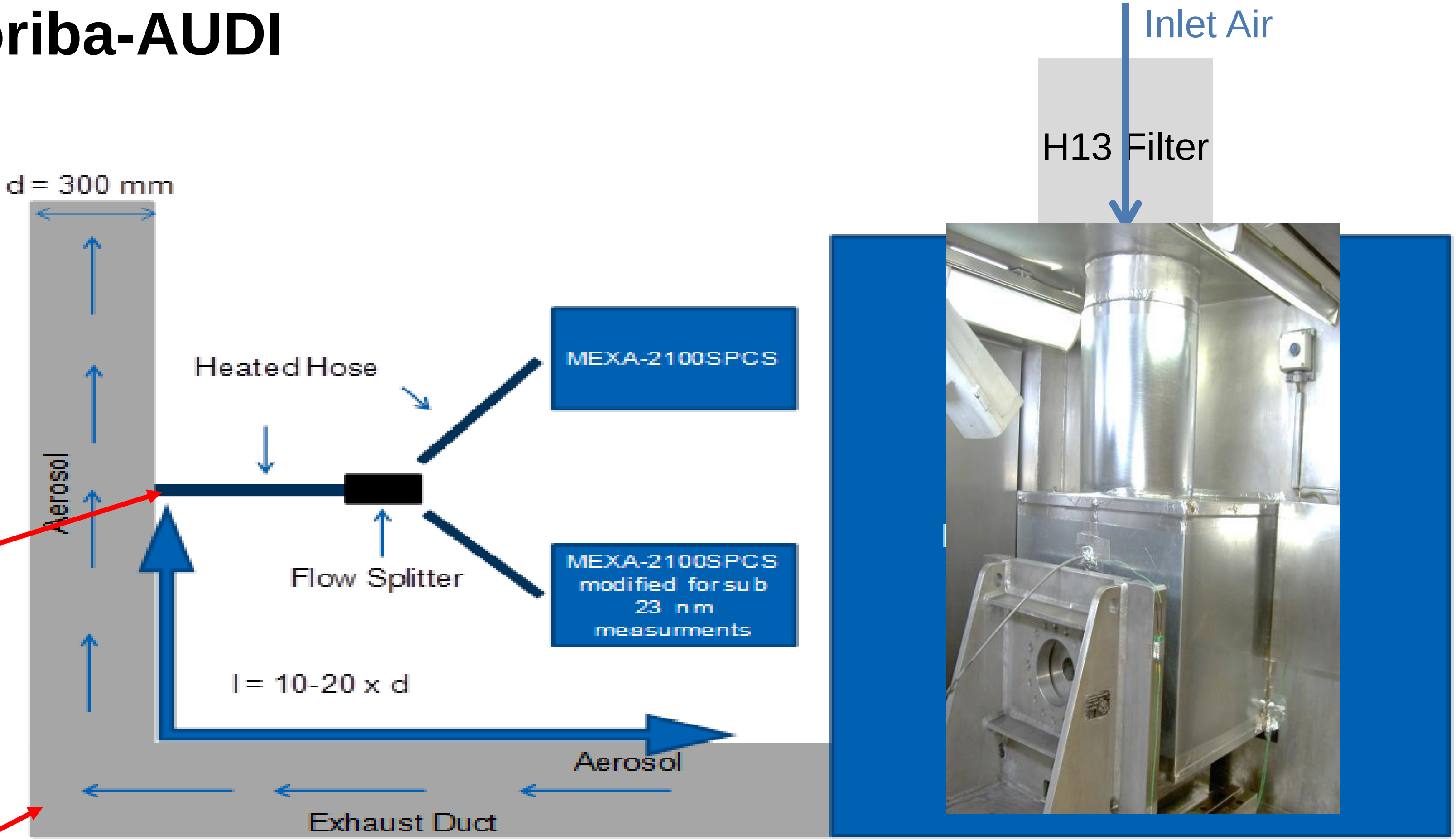
Experimental set-up Horiba-AUDI

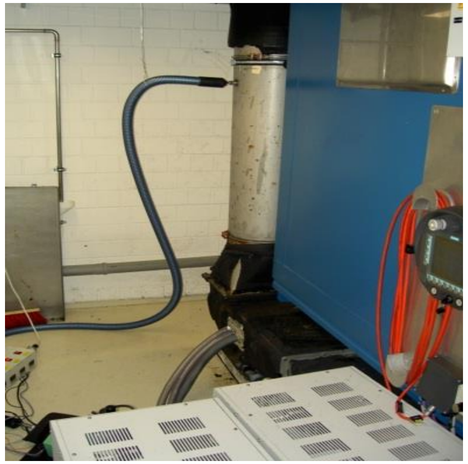
- Housing for 100% collection of brake emission
- Position of sampling defined according to GRPE-48-11-Rev.1
- Parallel Particle Number and Particle Size Distribution measurements-DMS
- 10 nm Horiba SPCS for PN measurements
- AK Master



Experimental set-up Horiba-AUDI

- Housing for 100% collection of brake emission
- 2 sampling points
  - Inside testing chamber
  - Exhaust duct





Optional sampling point for isokinetik particle mass measurements

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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/cm³ (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/cm³ 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 : $3x10^8$#/cm³

Size
Low detection limit : 10-23 nm
Upper detection limit : 2,5μm

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Measuremetns 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 ±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:	±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)

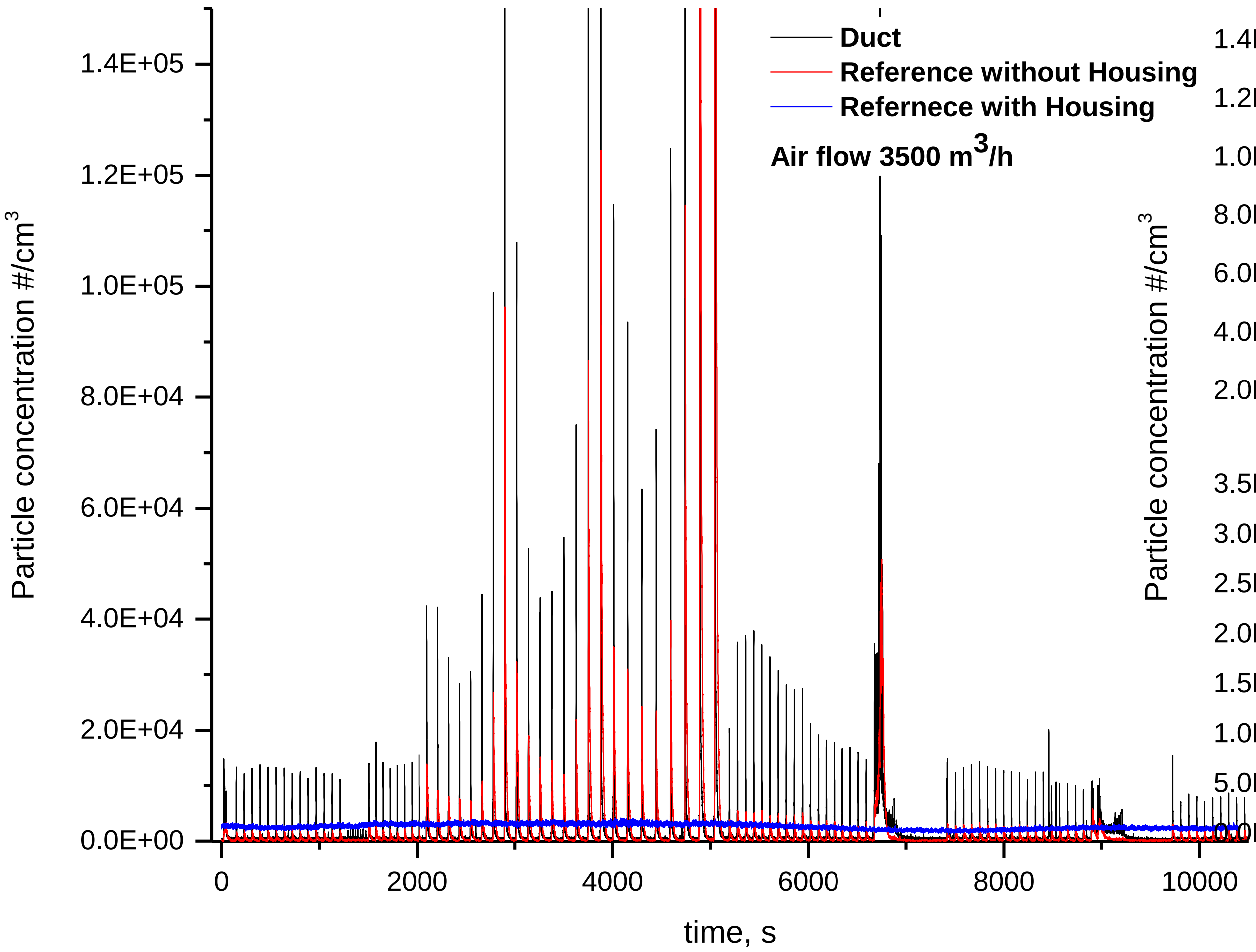
Results – Housing Concept

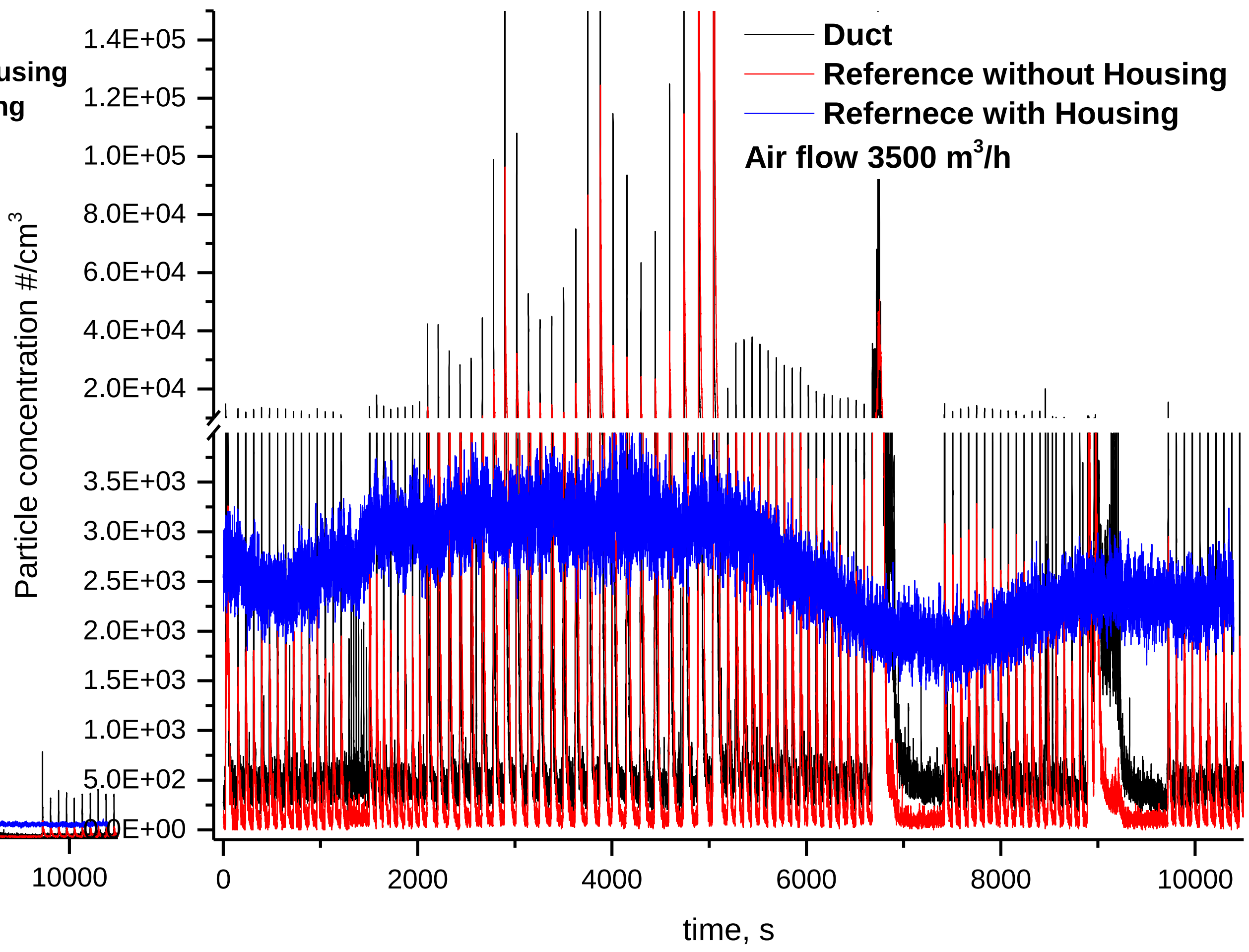
Objective: avoid the dissipation of emitted particles inside the dynamometer test chamber

housing is sealed carefully
→ direct air flow leads almost all ultra-fine particles to the exhaust duct

Results – Housing Concept

reference sampling point





Without housing: particle losses, single brake applications can be observed
With housing: low and stable particle concentration (NO H13-filter!)

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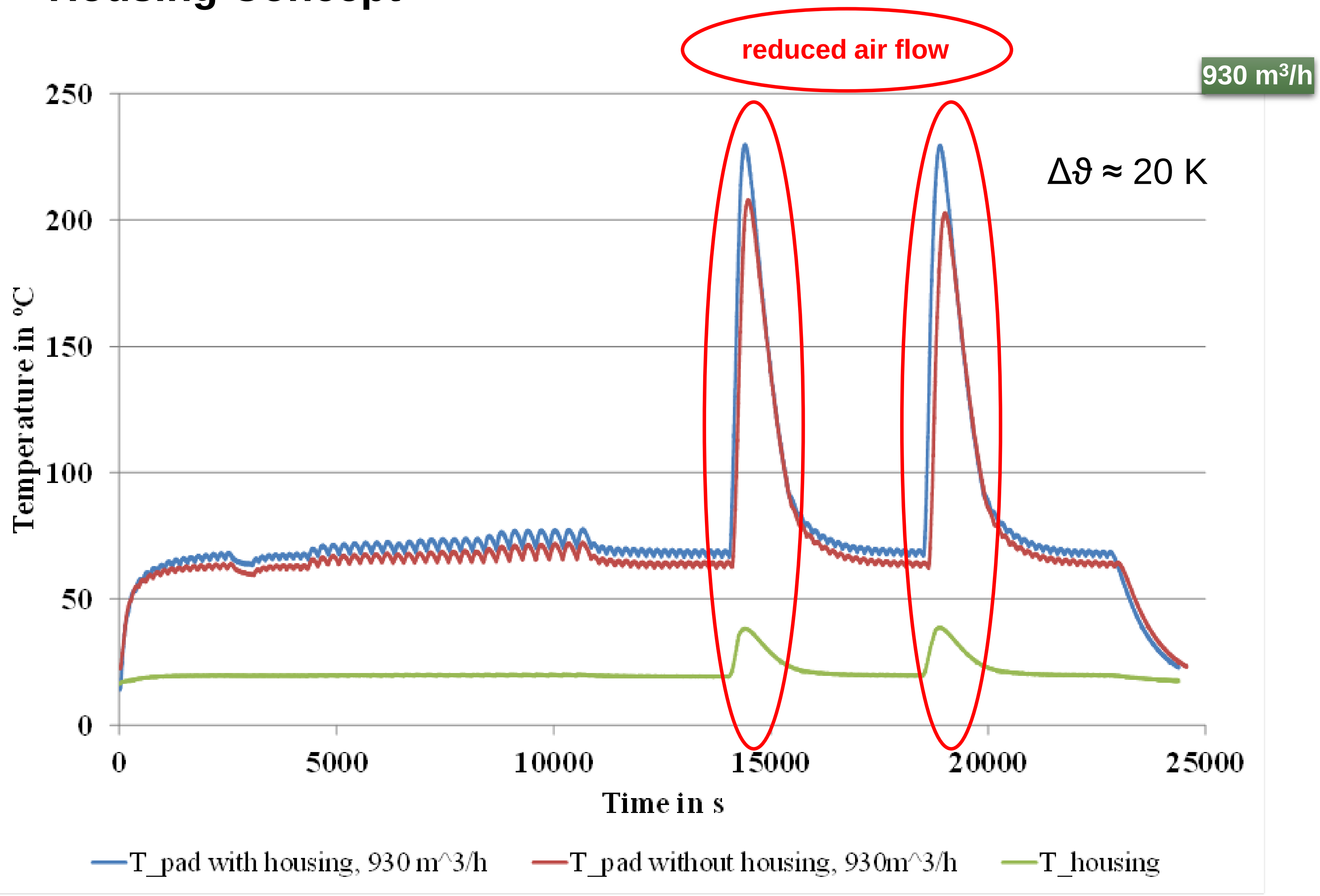
Question: thermal condition of the brake?

Results – Housing Concept



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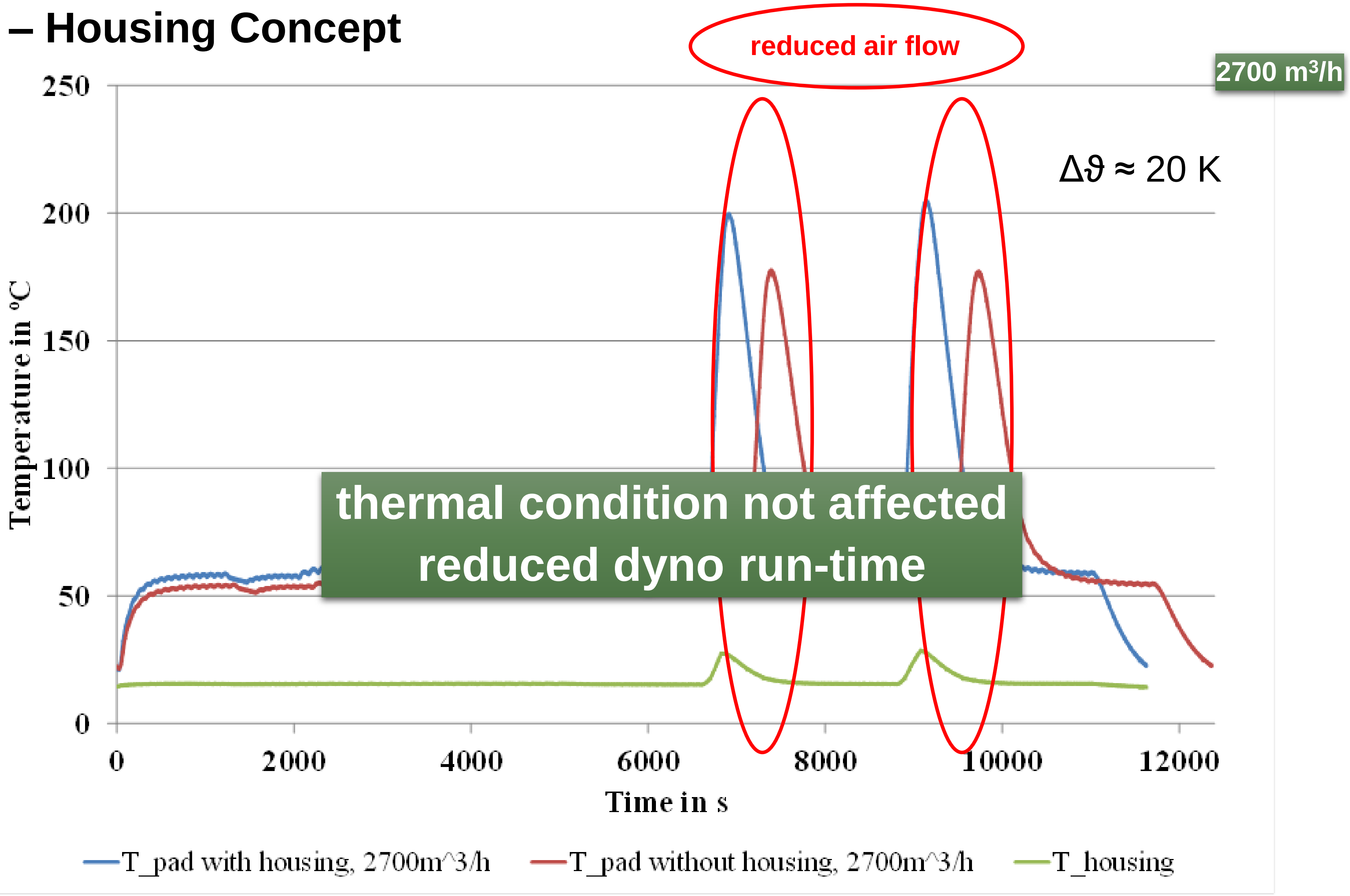
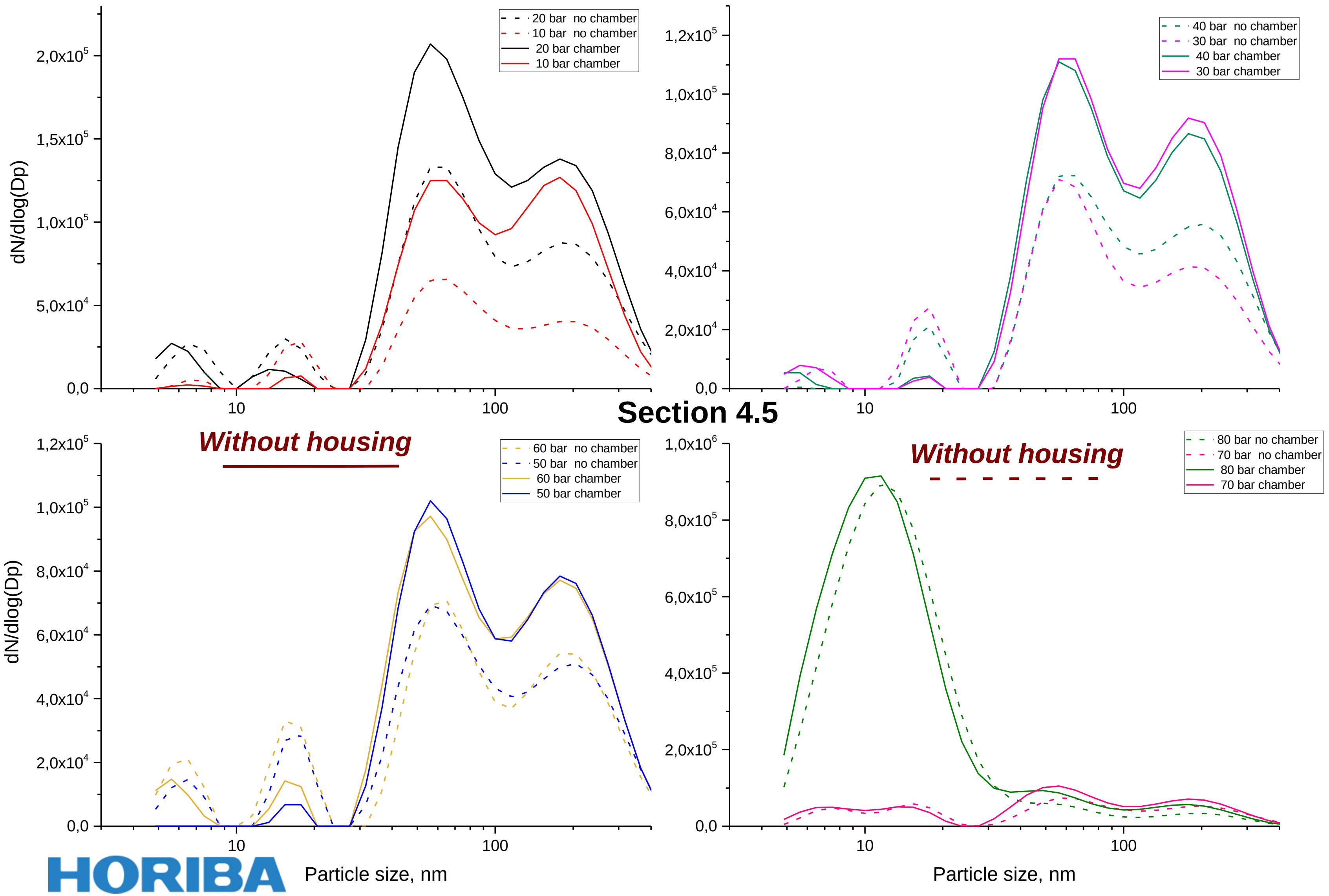
Results – Housing Concept



Verification of sampling concept: Particle size distribution



Implementation of the housing to sampling chain:

- ❖ Allow to collect all emitted particulates
- ❖ Does not change particle size distribution
- ❖ Increase the number of collected particles for all particle sizes

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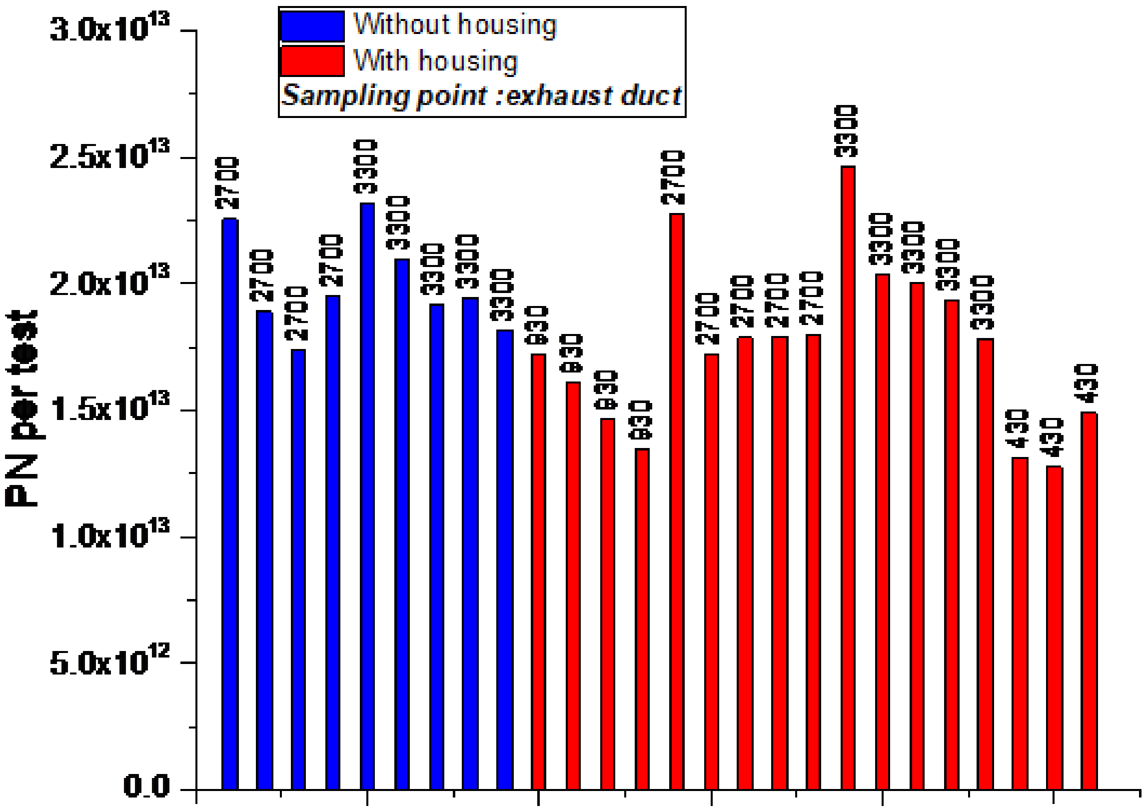
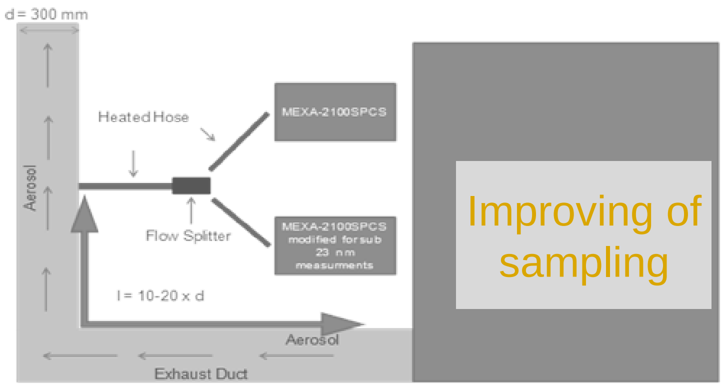
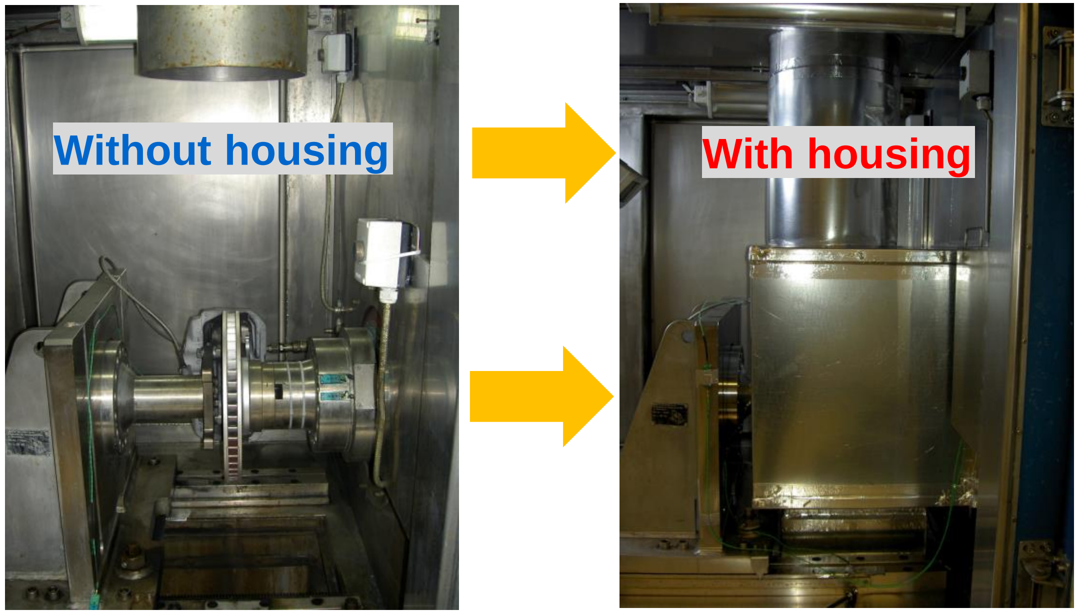
Testing and Validation of Horiba-AUDI concept

Implementation of Housing: Air Flow effect





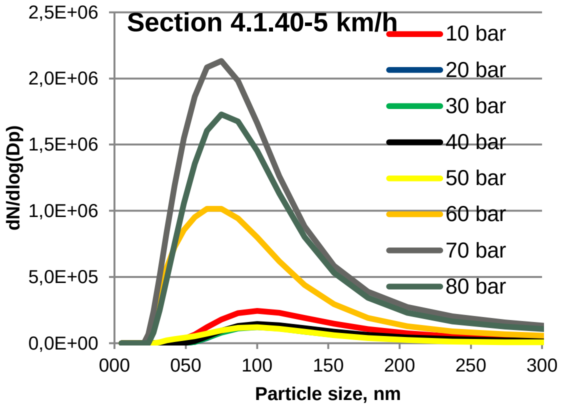


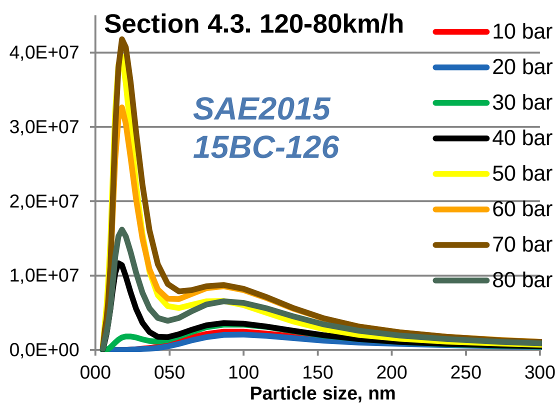
- Horiba-AUDI concept is validated for PN measurements!
- Application of housing is strongly improved reproducibility±15% of test results
- Particle emission depends on air flow velocity and sequence

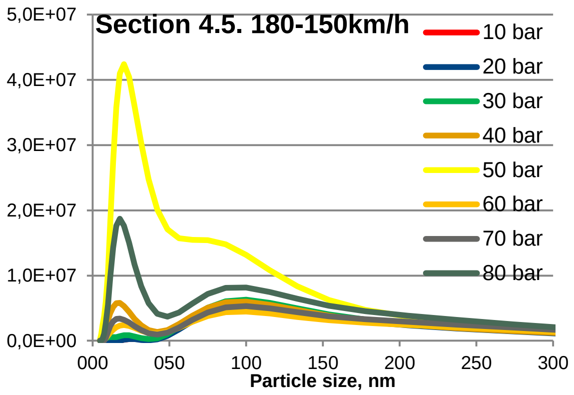
Definition of measurement range

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

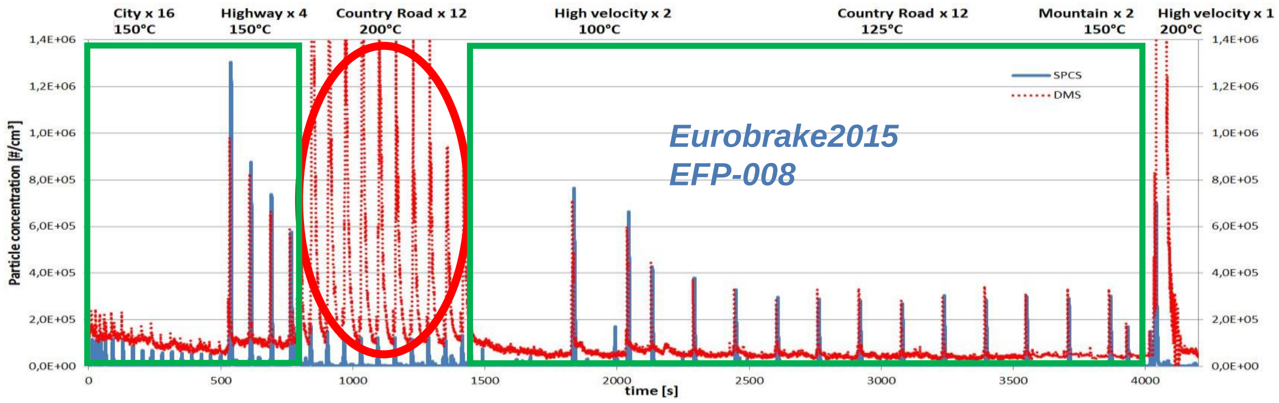
AK Master







AK Bremsstaub

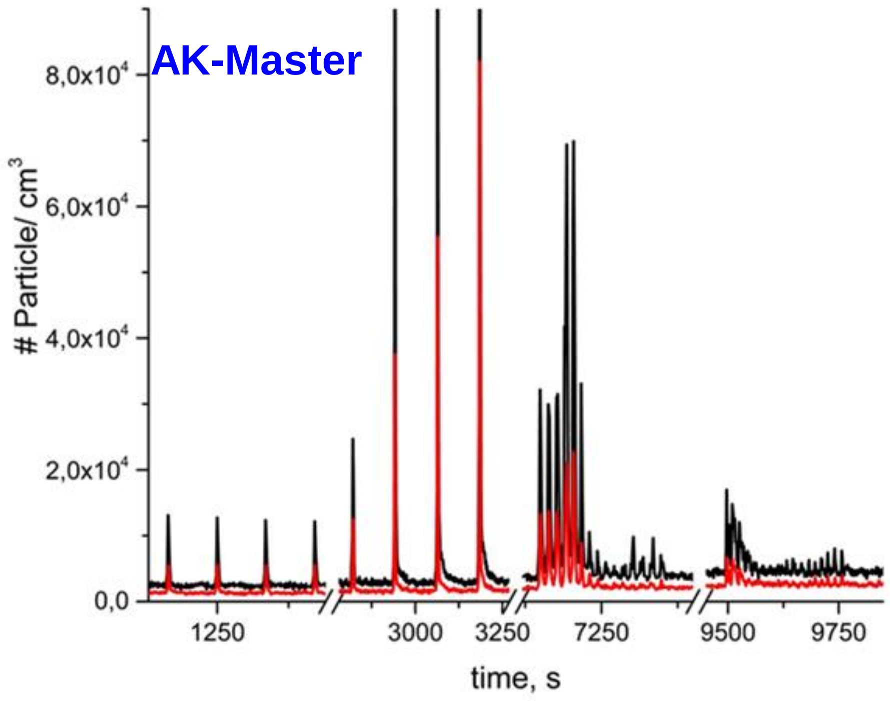


- ➢ **Appearance of ultra-fine particle depends on wheel speed rather than on brake pressure or temperature**
- ➢ **Ultra-fine particles demonstrate first peak around 13 nm**
- ➢ **Disagreement between DMS and SPCS was observed**

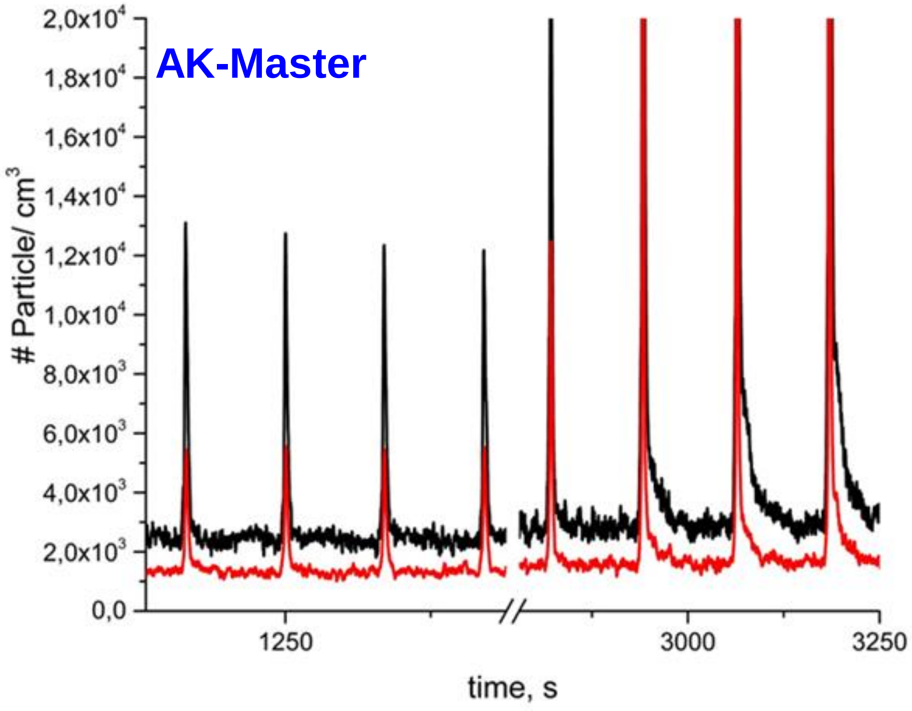
Definition of measurement range: Influence of sub-23 nm particle

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 $PN_{sub23}/PN_{standard}$ between single brake events is almost stable (around 1,5)**
- **Prototype with cut-off D_{50} at 10 nm is used in our research**

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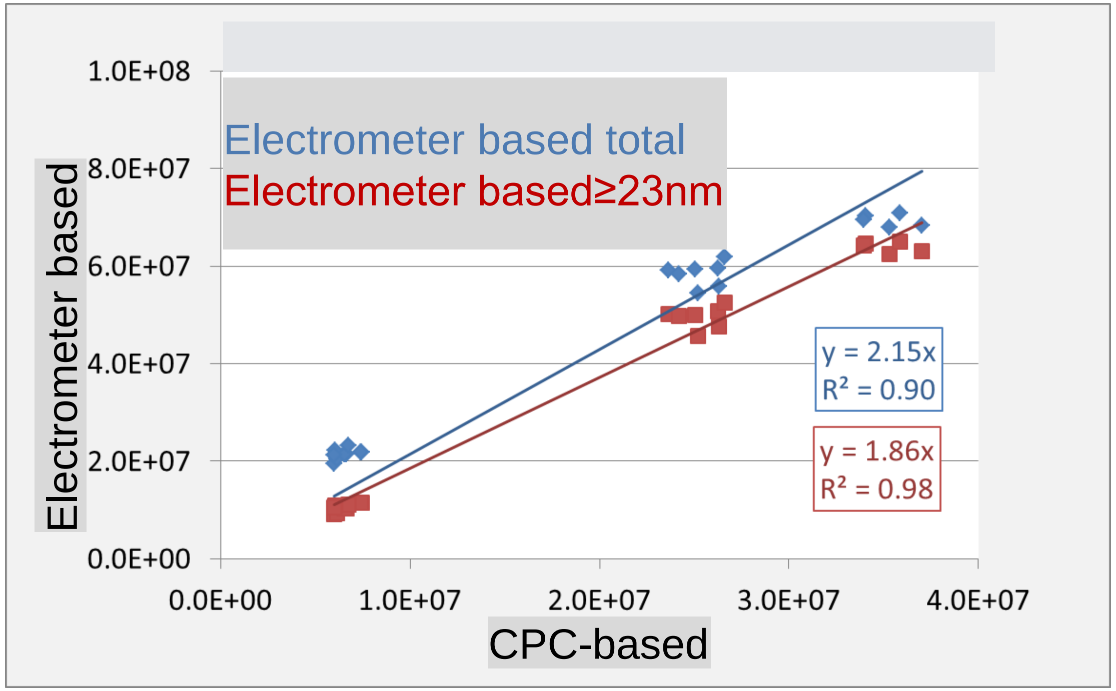
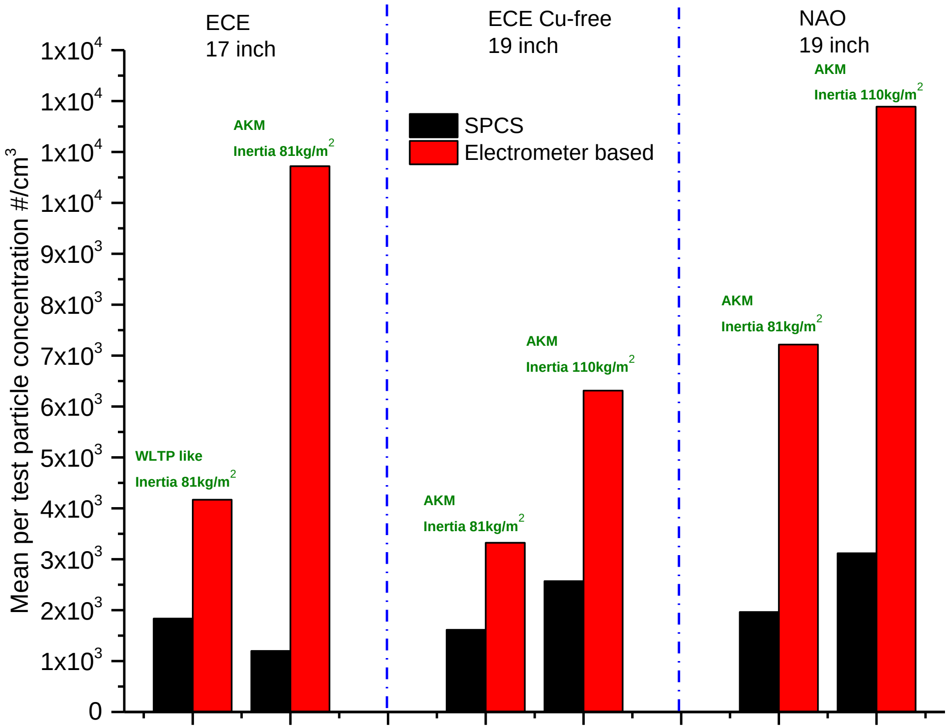
Particle Number measurements: Electrometer *versus* CPC-based devises

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**

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Finding's

- Most suitable sampling point for PN was defined
- Results can be directly compared to data obtained for exhaust measurements
- Horiba-AUDI set-up provide 100% sampling of Brake Dust Airborne
- Testing parameters such as air flow, air quality, etc. can affect results of PN measurements
- By variation of air flow velocity different dilution ration can be applied
- Particle emission was measured in range $1x10^5$-10^6 particle/cm^3
- SPCS particle counter was modified to 10 nm cut-off according special requirements for Brake Dust Emission measurements
- Reproducibility of results can be achieved only by removing of volatile content
- 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 reponcible for mechanical stability of brakes as well as NVH effects-material research on this topic will siginificantly extend markt capacity from certification to material R&D

Thank you

Cảm ơn

감사합니다

ありがとうございました

Dziękuję

धन्यवाद

Grazie

Merci

谢谢

நன்றி

ขอบคุณครับ

Gracias

Obrigado

Σας ευχαριστούμε

Děkuji

Teşekkürler

شكرا

Tack ska ni ha

Danke

Большое спасибо