HORIBA

Explore the future

Brake Dust Project

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Date: 2/10/15

Aim of the project

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Developing new particle measuring principle for analysis of Brake Dust pollutions

Outlook

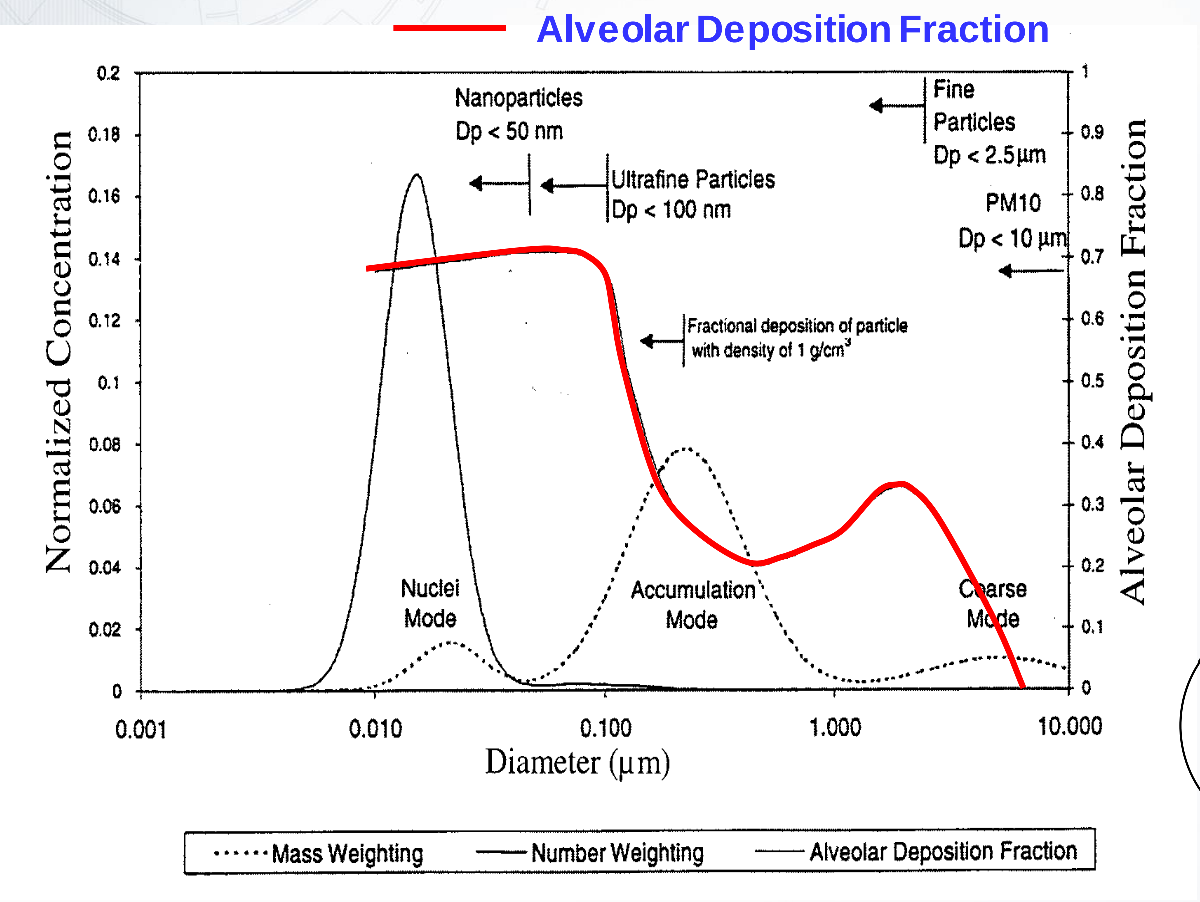
- Status of measurement procedure definition for brake particle emissions
- Emission behavior during brake event
- AK Bremsstaub and AK Master measurements
- Hose versus Sample box: Comparison of experimental results
- On-road measurements
- Results of first step
- Challenges and next steps

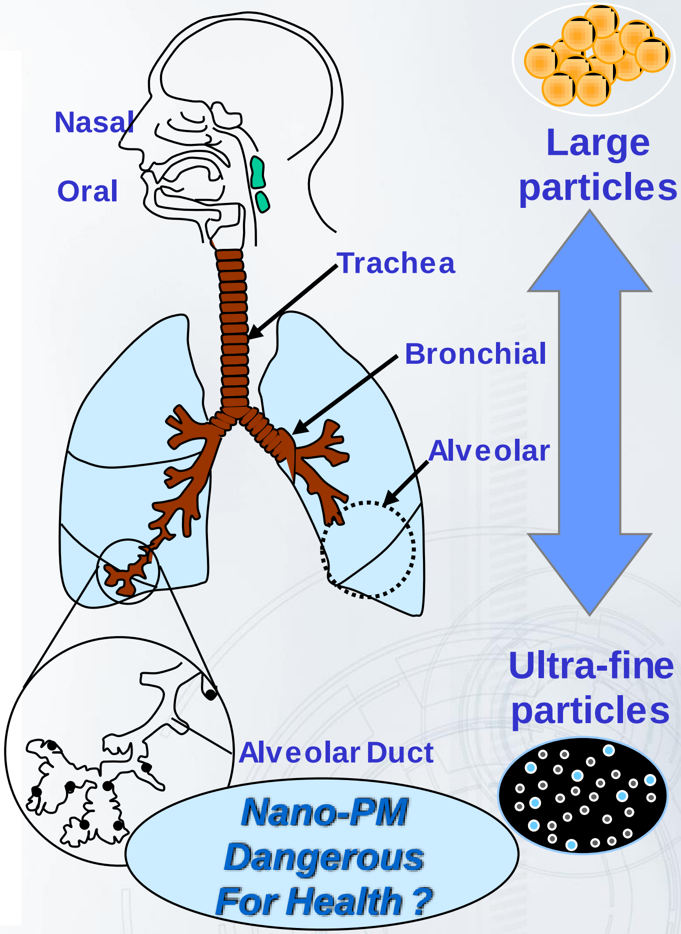
Status of measurement procedure definition for brake particle emissions

Background

■ Concern about Nano-particle

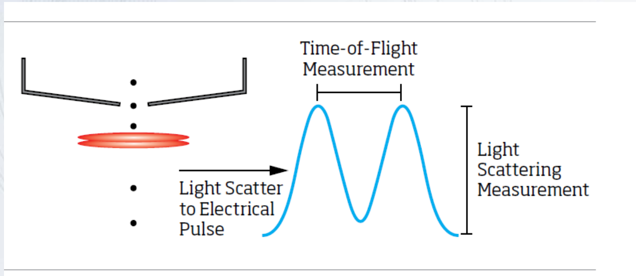
Fine particles (diameter < 2.5 μm) may reach deep into the lung.

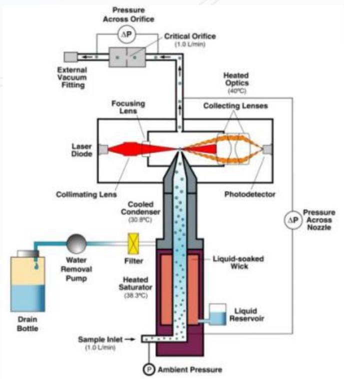


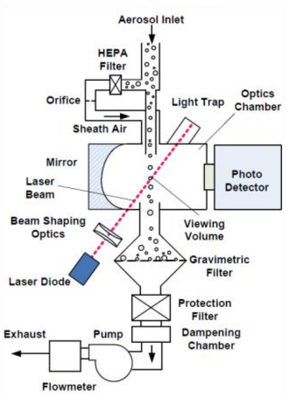


Source: Ishihara

Measuremetns 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

Measuremetns of particle size distribtuion

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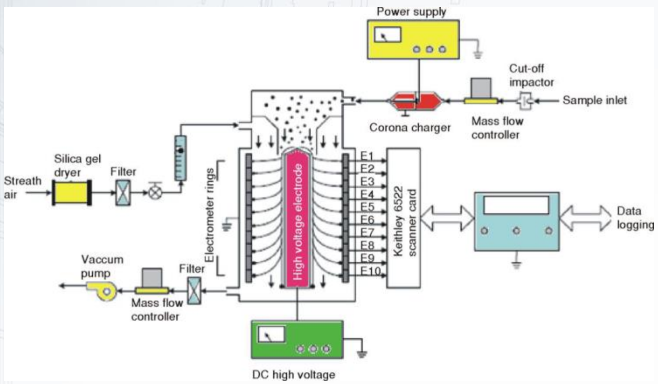
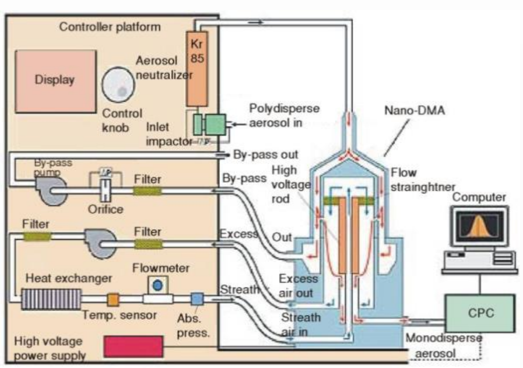
DMS



SMPS



DMS

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

SMPS

- In a Differential Mobility Analyzer (DMA) an electric field is created
- Airborne particles drift according to their electrical mobility.
- Particle size is then calculated from the mobility distribution

Brake dust, first approximation -PMP Protocol

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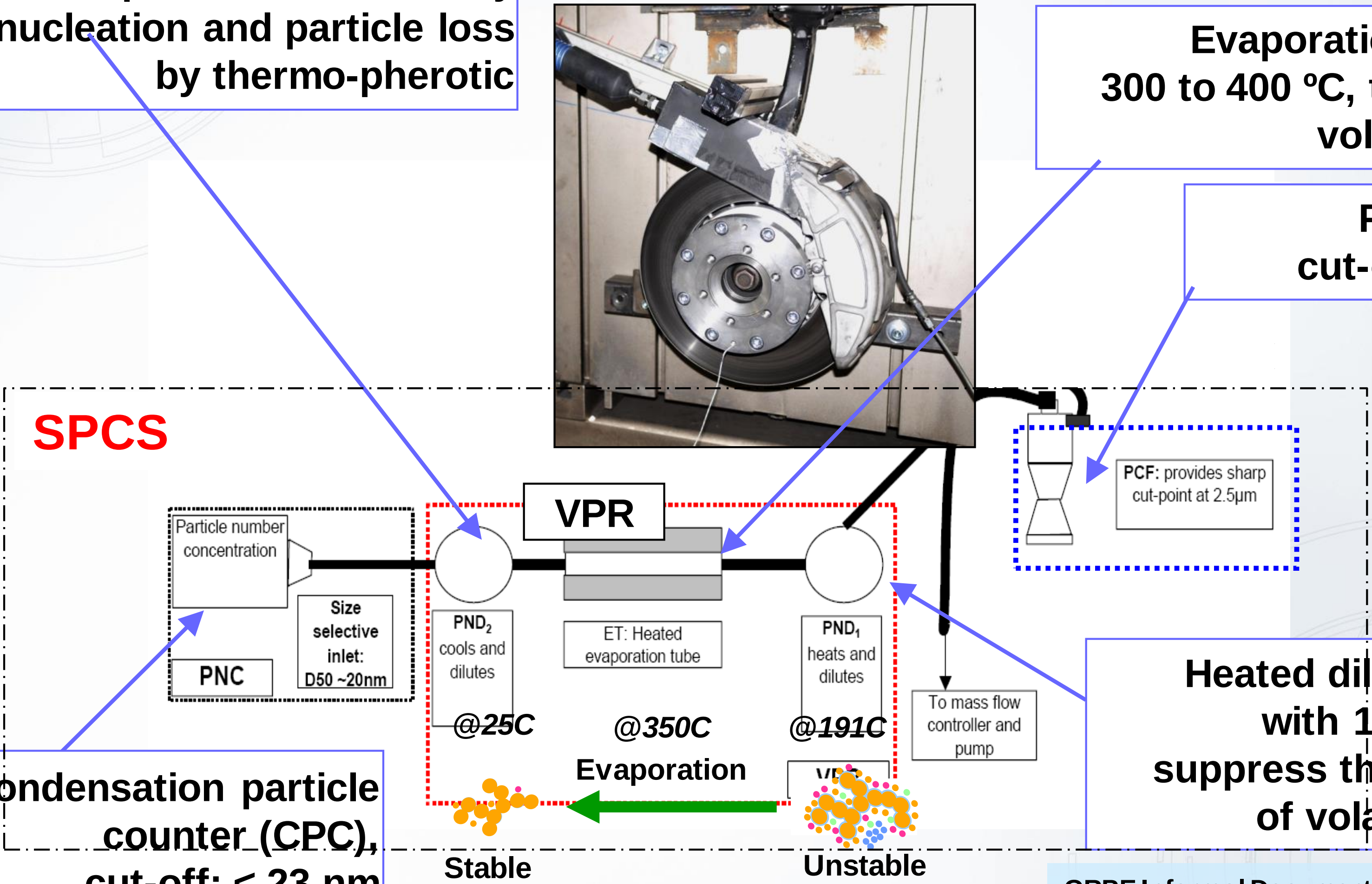
Cold diluter (PND2)
with room temperature air, to minimize particle formation by re-nucleation and particle loss by thermo-pherotic

Evaporation tube (ET)
300 to 400 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

Emission behavior during brake event

Emission behavior during brake event: Particle Image Velocimetry

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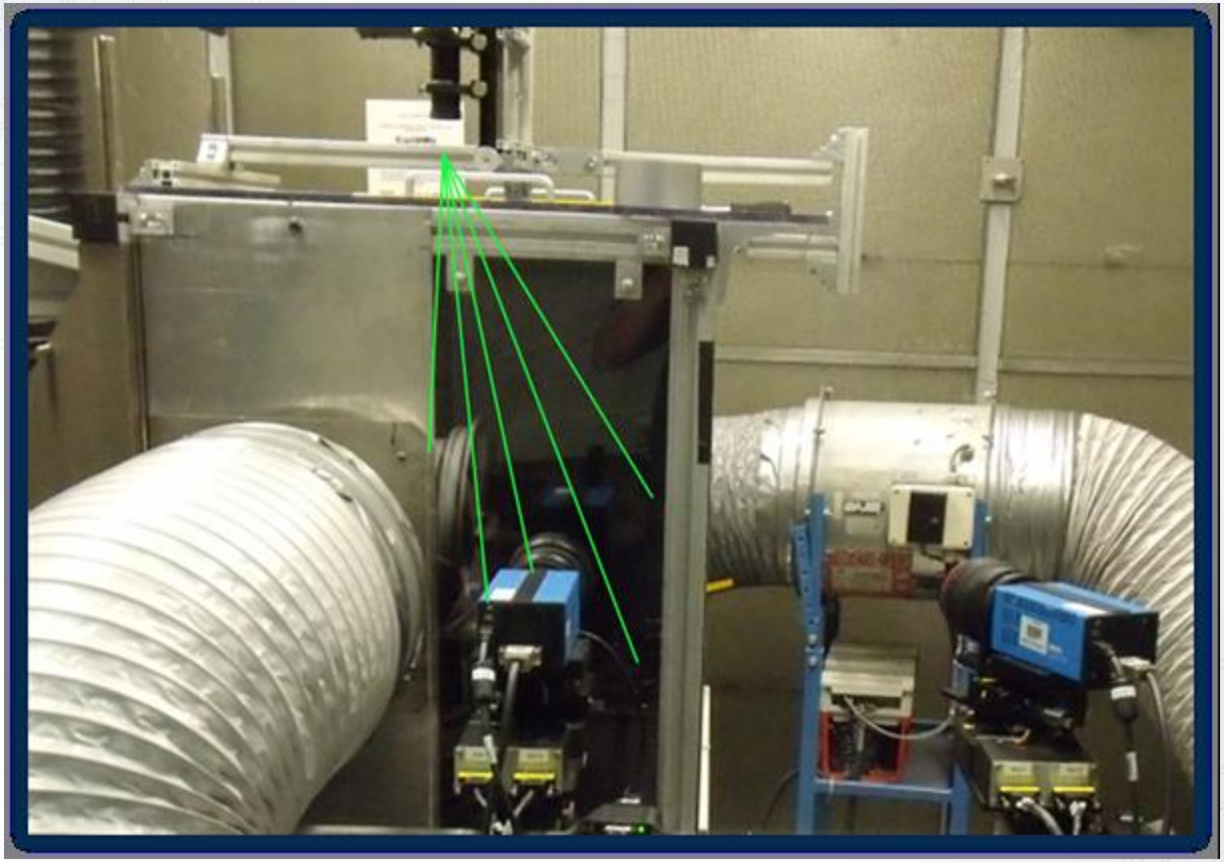
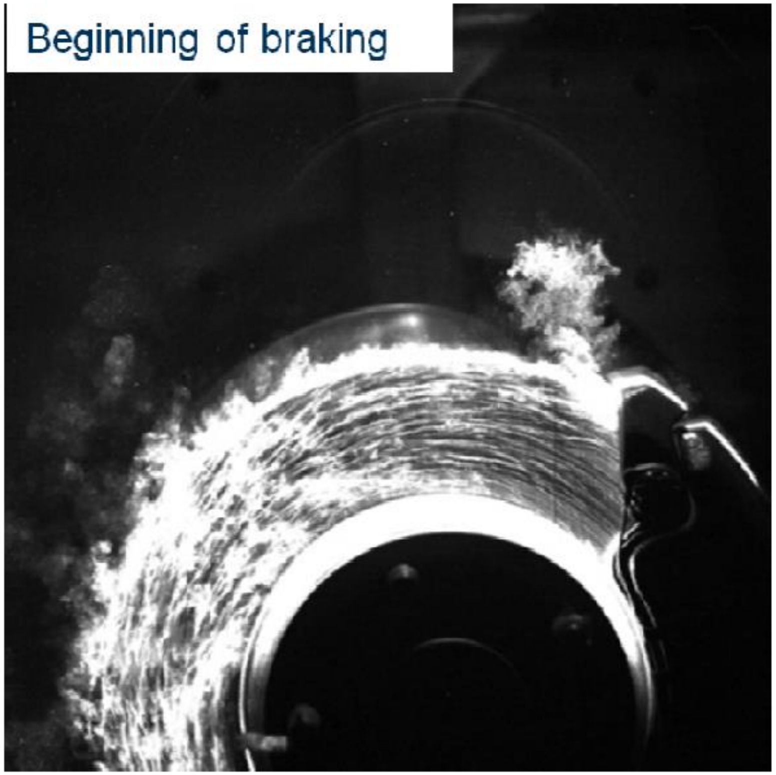
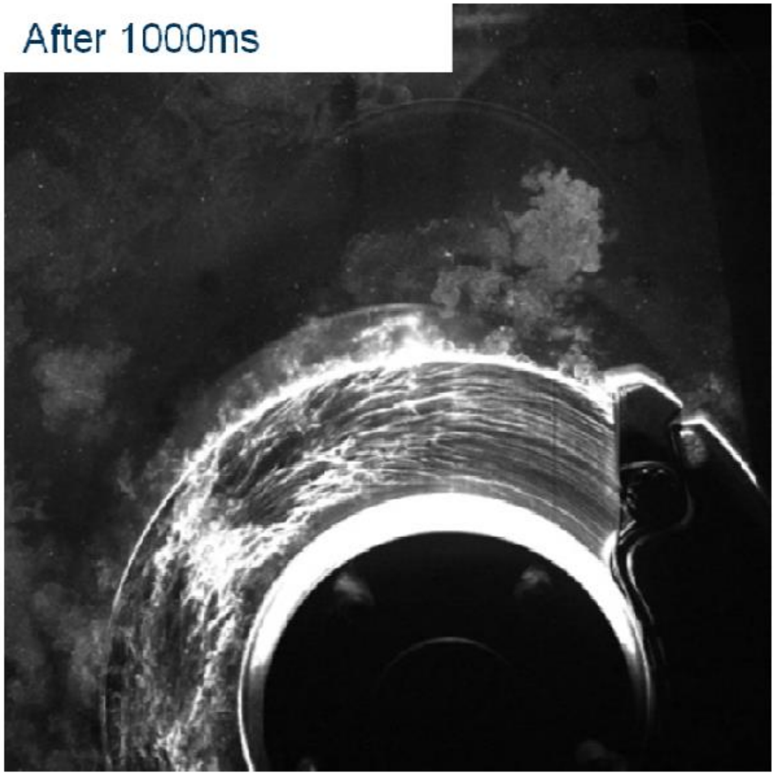


- Laser beam will be scattered over the optic system
- Camera will be used to take pictures

Emission behavior during brake event

Prof. Dr.-Ing. Klaus Augsburg, Dip.-Ing. Hannes Sachse, Rüdiger Horn, Sebastian Gramstat: Brake dust emission , 15th ETH-Conference on Combustion Generated Nanoparticles, June 26th – 29th 2011



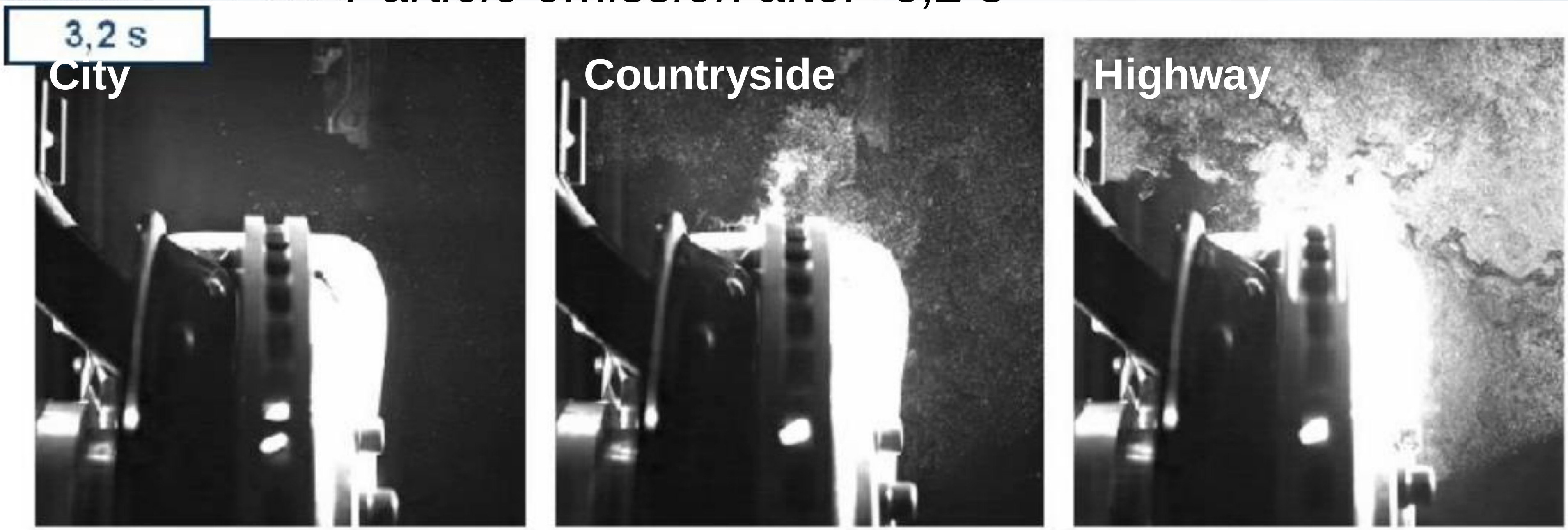


- Particle Image Velocimetry (PIV) is used
- Particle emission will be recorded during brake event

Role of sampling point: Evaluation of particle emission during AK Bremsstaub

Prof. Dr.-Ing. Klaus Augsburg, Hannes Sachse, Rüdiger Horn, Sebastian Gramstat: Brake dust emission, 15th ETH-Conference on Combustion Generated Nanoparticles, June 26th – 29th 2011

Particle emission after 3,2 s

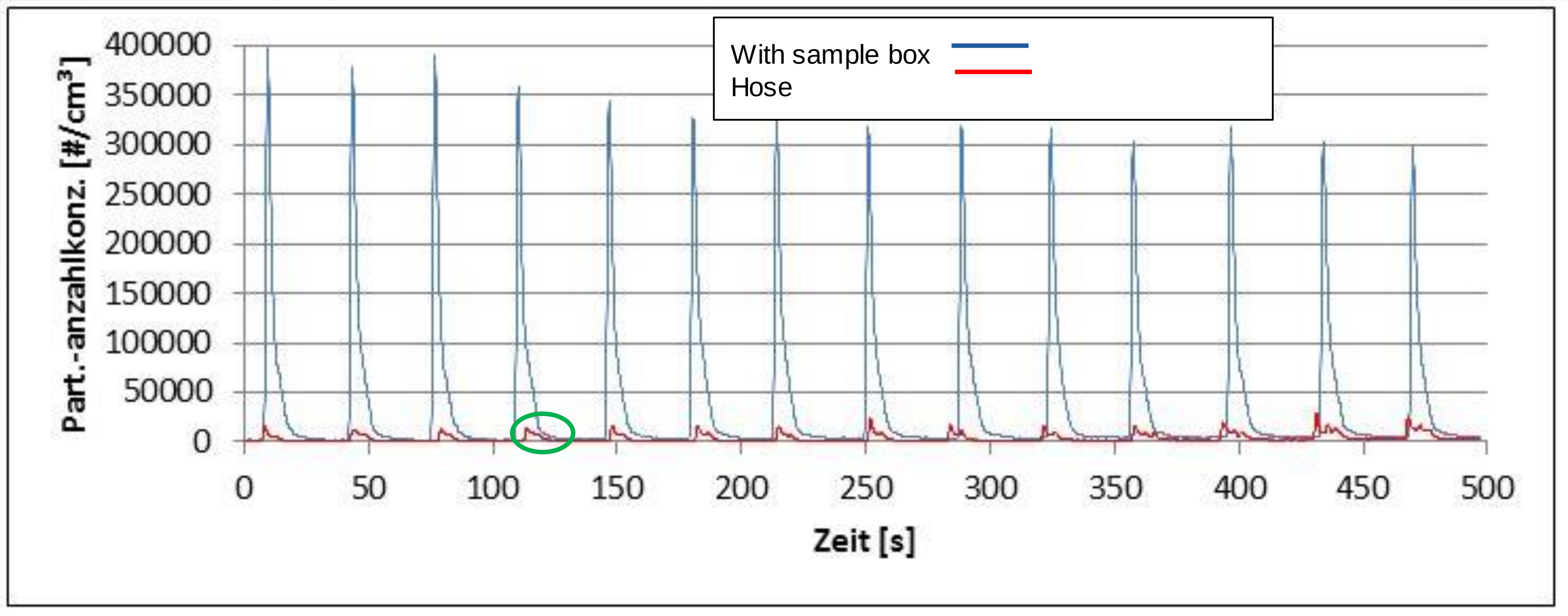


Evaluation of different braking scenarios with light-section method (PIV)

- Exponential growth of particle emissions with wheel velocity
- Area of emission plum increases with wheel velocity

Role of sampling point: Evaluation of particle emission during AK Bremsstaub

Prof. Dr.-Ing. Klaus Augsburg, Hannes Sachse, Frederic Egenhofer, TU Ilmenau 2014



Without ventilation

Role of sampling point: Evaluation of particle emission during AK Bremsstaub

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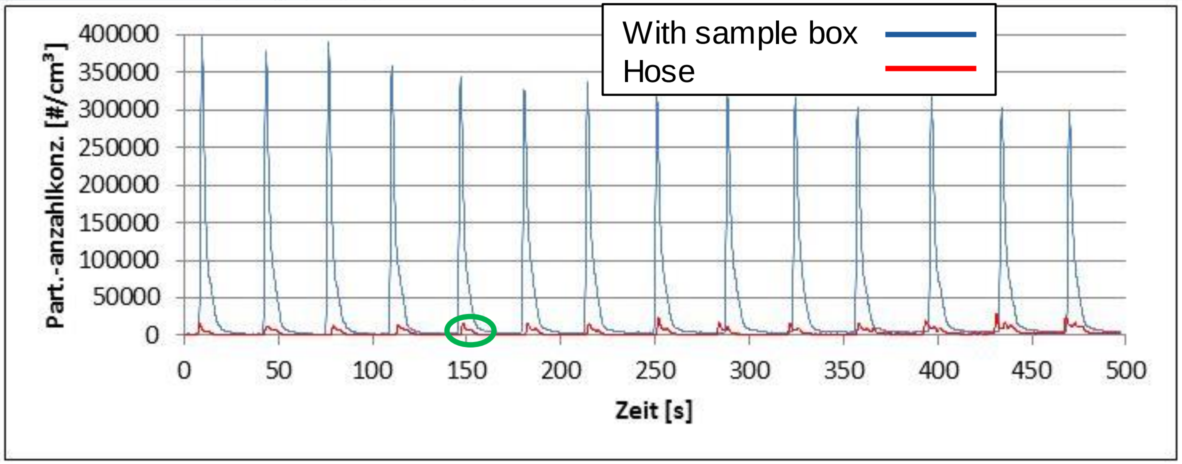
Prof. Dr.-Ing. Klaus Augsburg, Hannes Sachse, Frederic Egenhofer, TU Ilmenau 2014



AK-Bremstaub

City cycle

- ❑ 0-50 km/h
- ❑ 0.25 g
- ❑ 150° C
- ❑ 8 mm Hose
- ❑ Directly after brake caliper

Without ventilation

Sample box *versus* Hose AK-Bremsstaub

- ➢ **Application of sample box increase measured particle emission from 10^4 to 10^5 particle / cm^3**
- ➢ **Emission measured with Hose and Sample box follow same trend**

Role of sampling point: Evaluation of particle emission during AK Bremsstaub

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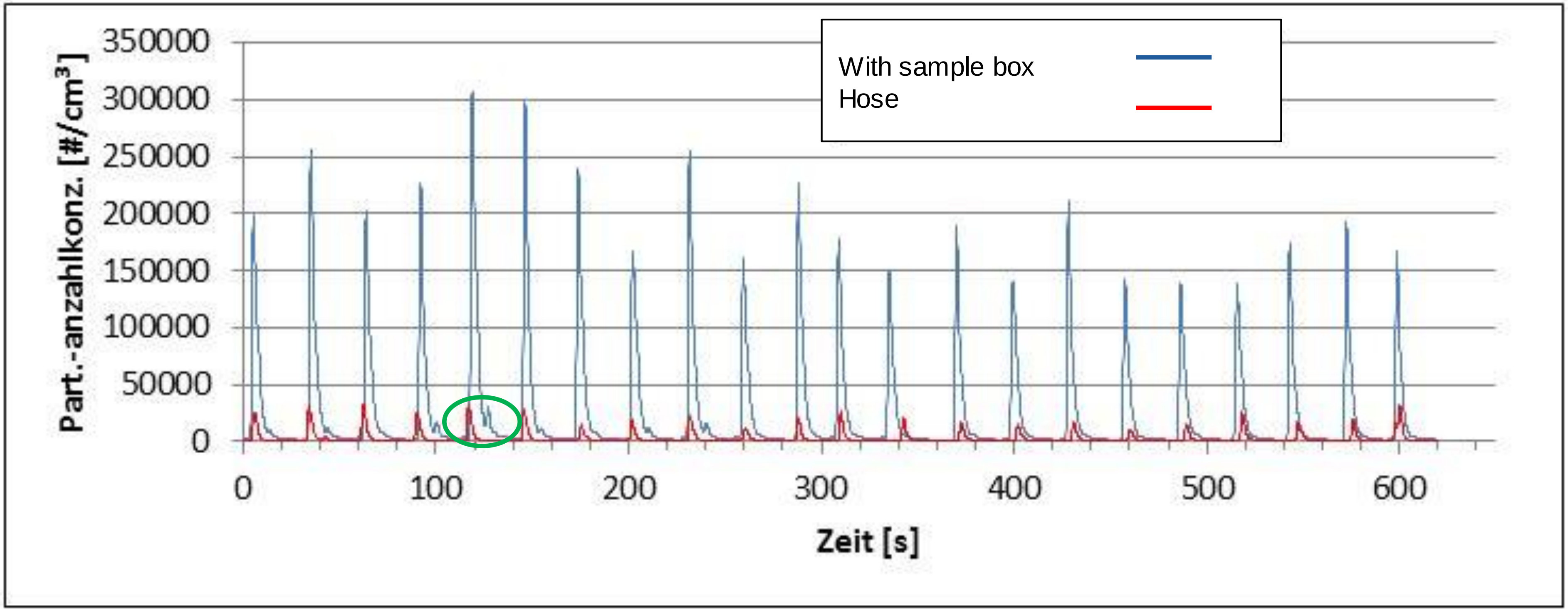

With ventilation

Role of sampling point: Evaluation of particle emission during AK Bremsstaub

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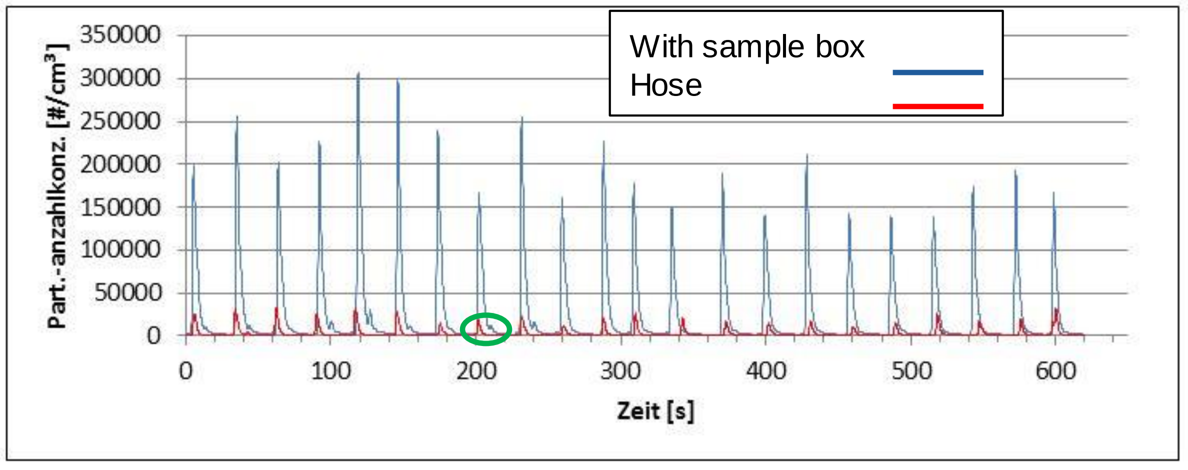

AK-Bremstaub

City cycle

- 0-50 km/h
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With ventilation

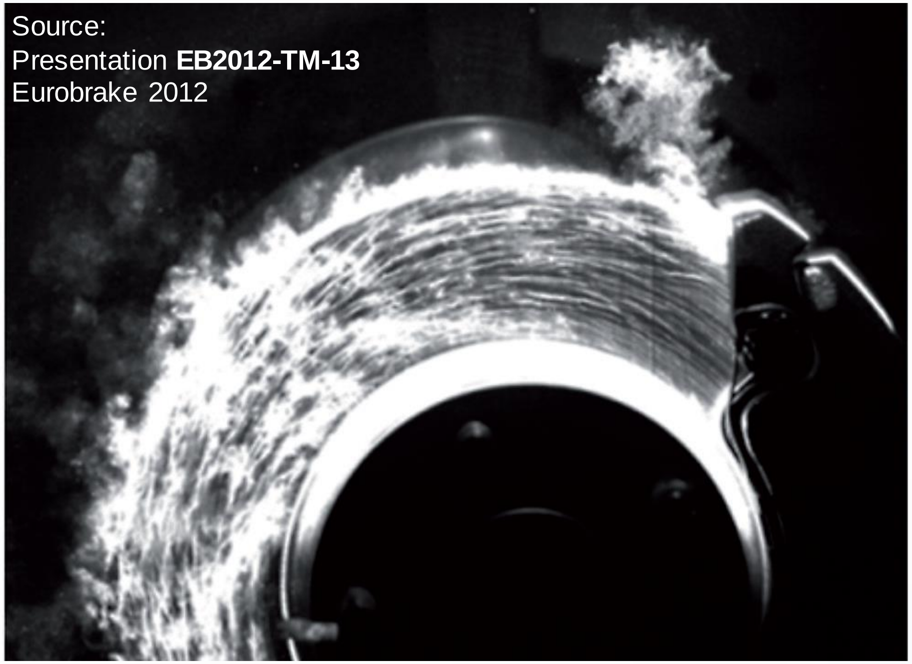
Sample box *versus* Hose AK-Bremsstaub

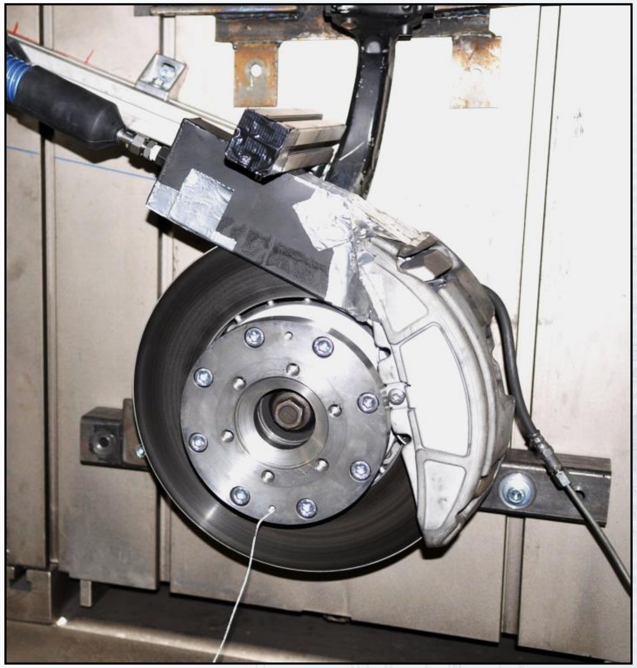
- **Application of sample box increase measured particle emission from 10^4 to 10^5 particle / cm^3**
- **Ventilation reduce particle concentration by factor 1,3 when sample box is applied.**
- **For measurements with Hose total particles amount is reduced after ventilation switched on**

AK Bremsstatub and AK Master measurements

Properties of the Measuring Chain

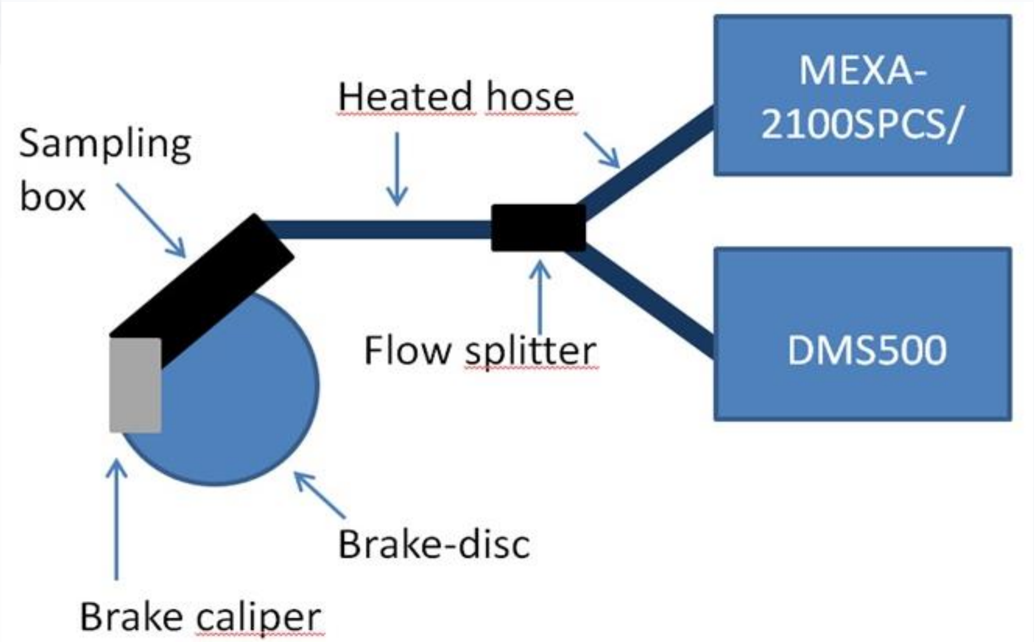
- Specialized sampling box to guarantee repeatability
- Strong reduction of particle distribution caused by moving air
- Traps the particles for a longer time
- High basic level for HORIBA MEXA particle counting system





Properties of the Measuring Chain

- SPCS: HORIBA MEXA particle counting system
- Well established for emission measurements!
- PMP conform equipment
- Particles from 23…2500nm measured with 10Hz
- DMS: particle size classification system from Cambustion
- Particles from 5…1000nm measured with 10Hz



Scope of Investigation

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- ❑ **AK-Master & AK-Bremsstaub performed at TU Ilmenau and at HORIBA in Darmstadt**
- ❑ **All test parameters were synchronized**
- ❑ **Air flow was calibrated in both locations**
- ❑ **ECE brake pads from same batch**

✓ **Can the test procedures deliver the same results when performed on different dynos?**

Dyno 1 TU Ilmenau	**Braking Torque**	**5.000Nm**
	Max. Speed	0…2.500 rpm
	Inertia Range	5…250kgm²

Dyno 2 HORIBA Darmstadt	**Braking Torque**	**6.000 Nm**
	Max. Speed	0…2.800 RPM
	Inertia Range	5…320 kgm²

Description of Test Schedule

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AK-Master

- ❑ Well-known friction level test for brake dynos
- ❑ Large practical experience
- Highest load and stress for friction material

AK-Bremsstaub

- ❑ Block-based cycle (one braking scenario repeated for 30 or 100 times in each block)
- Adaption effects of friction material which is not common in real driving
- Proven test cycle for comparing friction material with regard to wheel dust

Data Analysis – AK-Bremsstaub

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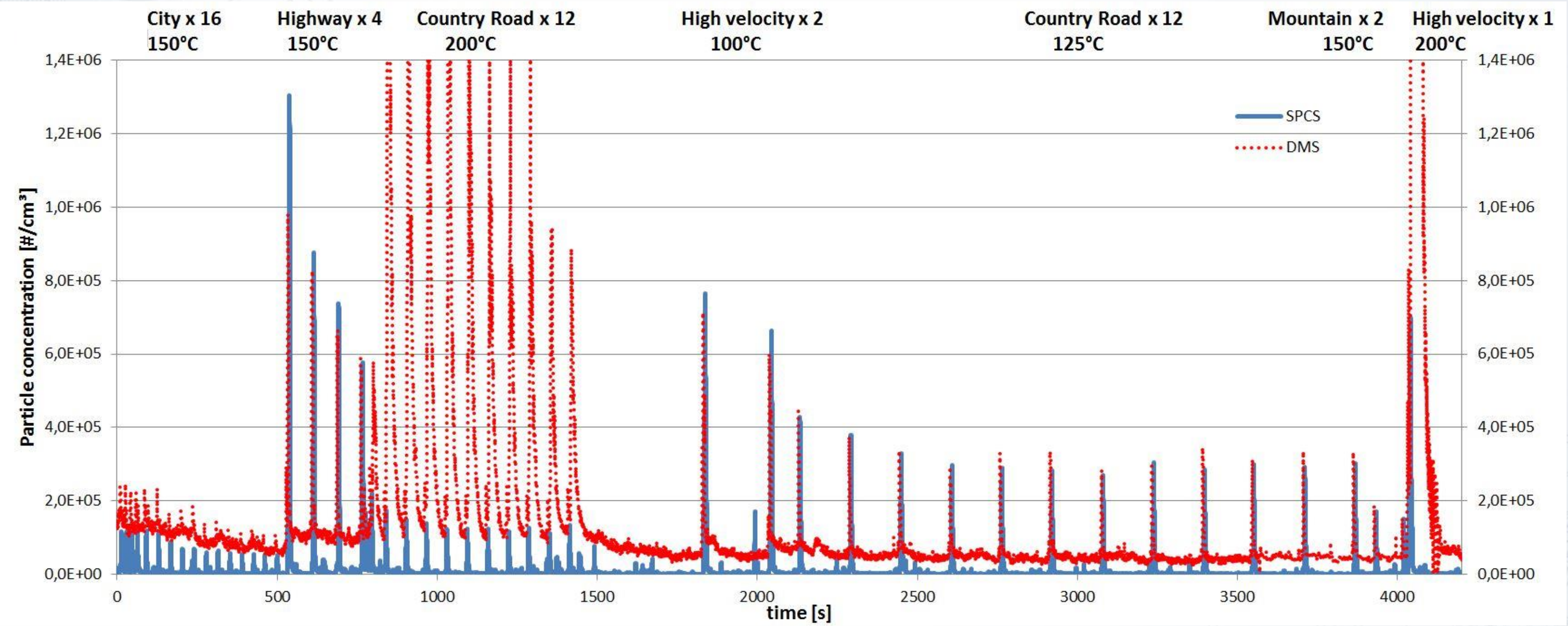
First repetition of the mixed cycle (different braking scenarios) with total particle concentrations



- **Concentrations measured during the braking events correspond to each other (for starting temp. <150˚ C)**

Data Analysis – AK-Bremsstaub

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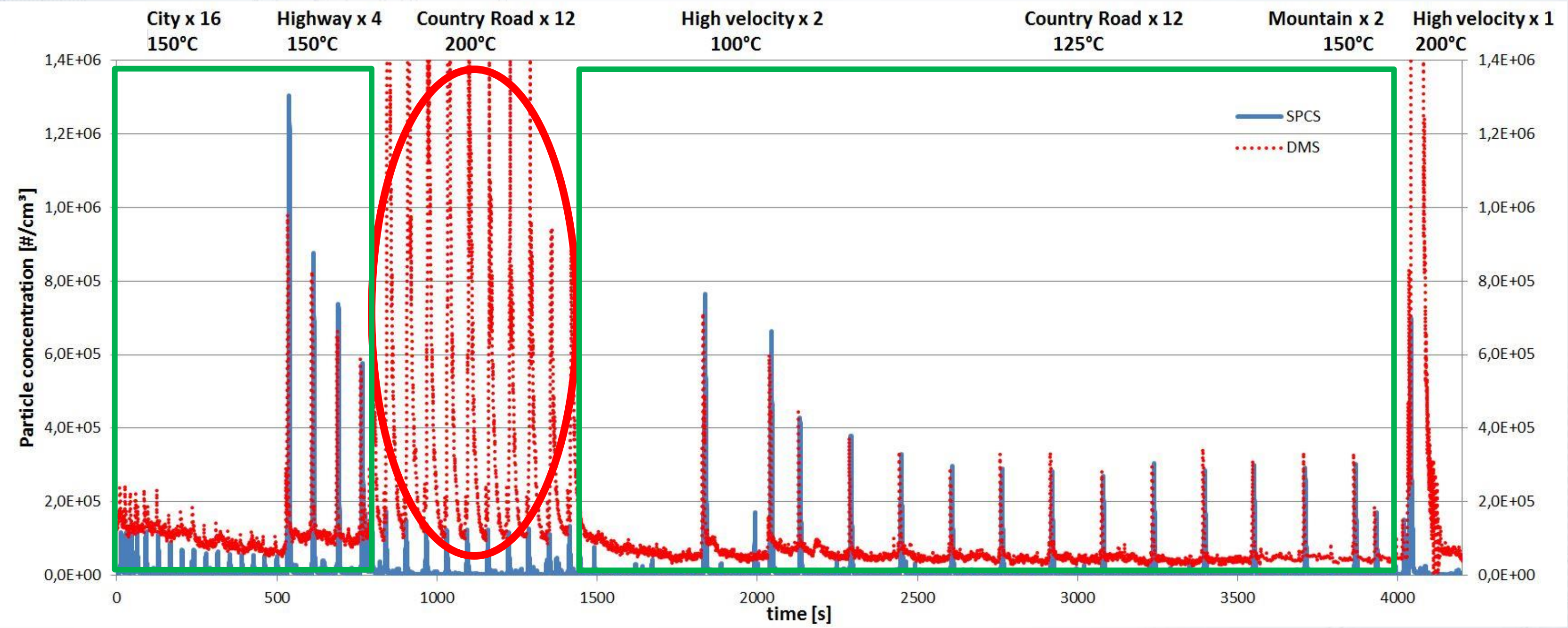

- **But differences for braking events with starting temp. of 200° C**

AK-Bremsstaub. Particle size distrubution

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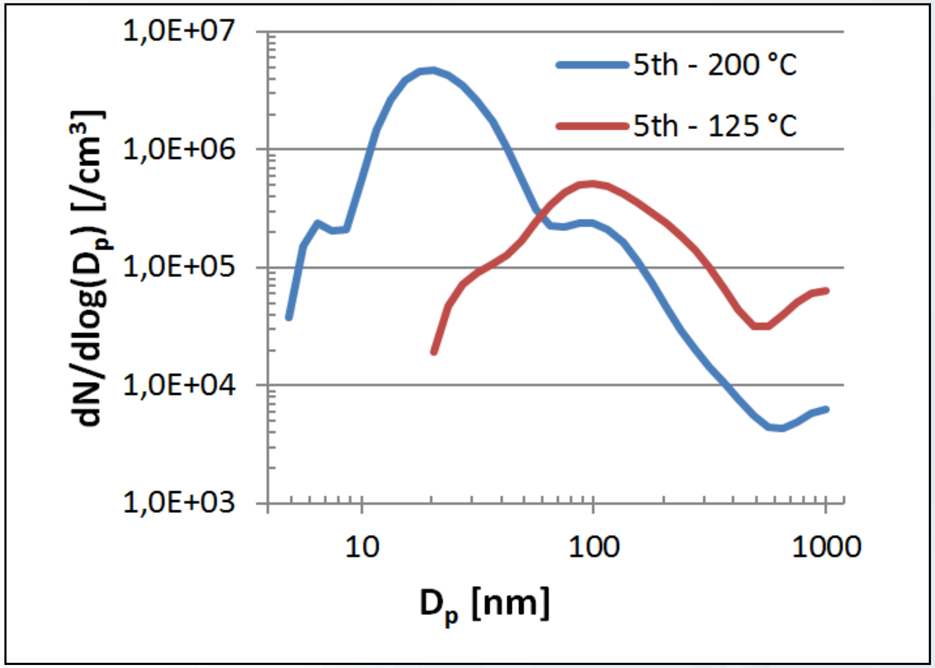
Wear debris as a function of the temperature

- **200° C => 20nm**
- **125° C => 100nm**

(ECE material used)



Conclusion

- **Amount and size distribution of wear debris differs significantly between both as a function of the temperature**
- **The particle distribution was measured by the DMS**
- **Origin of ultra-fine particle ≤ 20nm has to be defined**

Data Analysis – AK Master

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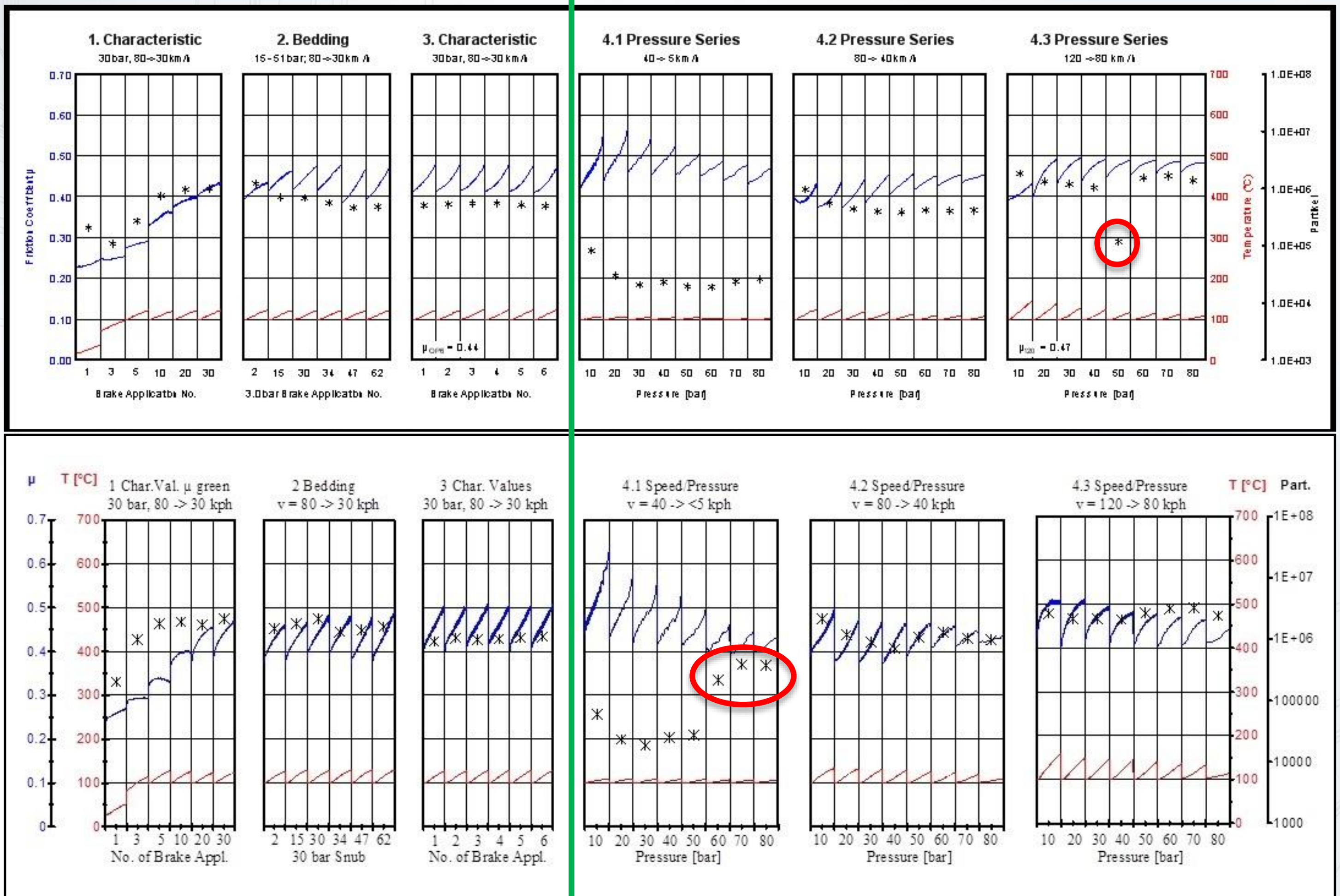
✳ Brake Dust Particles



HORIBA Darmstadt

TU Ilemenau

similar behaviour

good reproducibility

Data Analysis – AK Master

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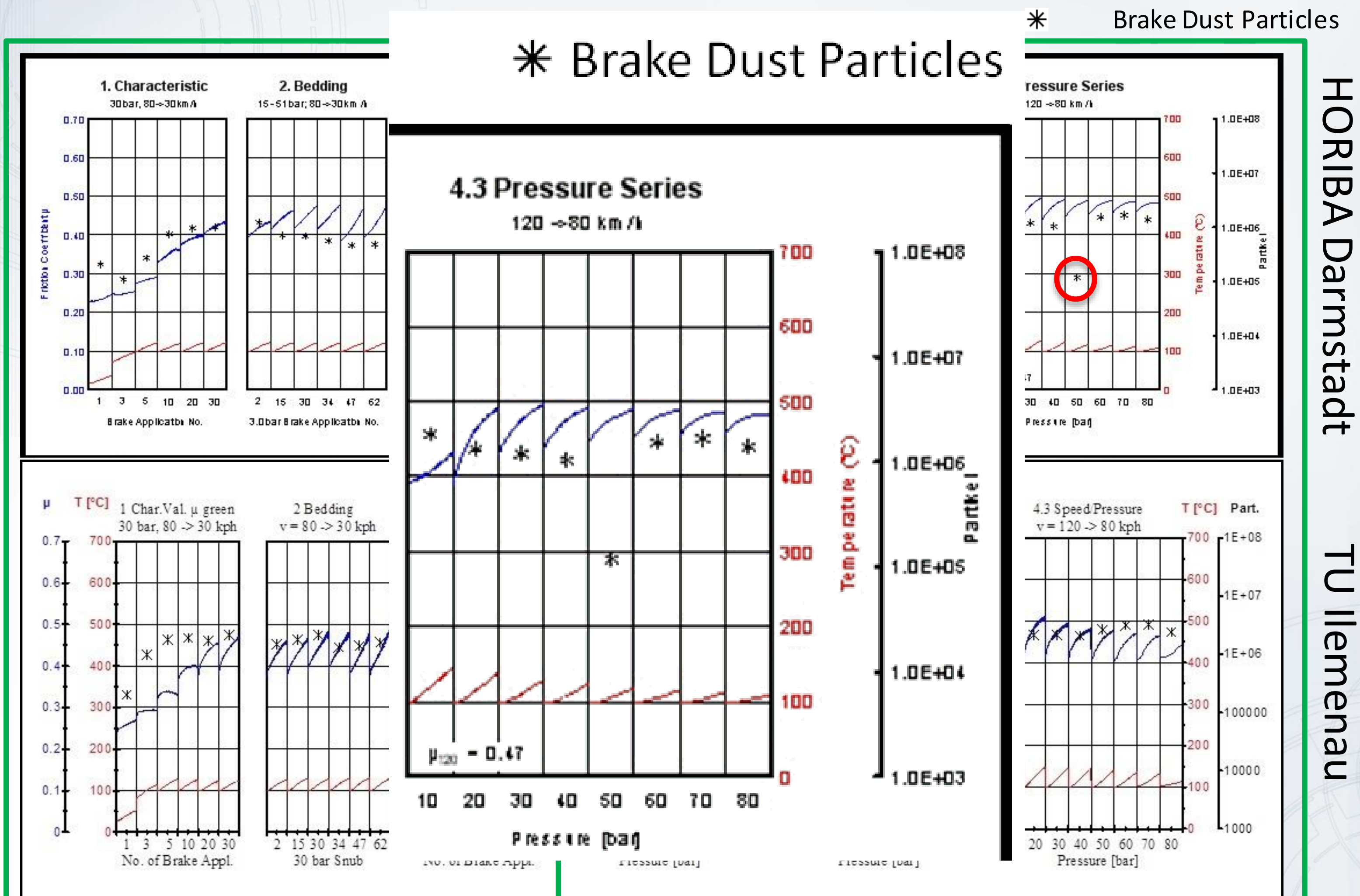

similar behaviour

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Data Anaysis – AK Master

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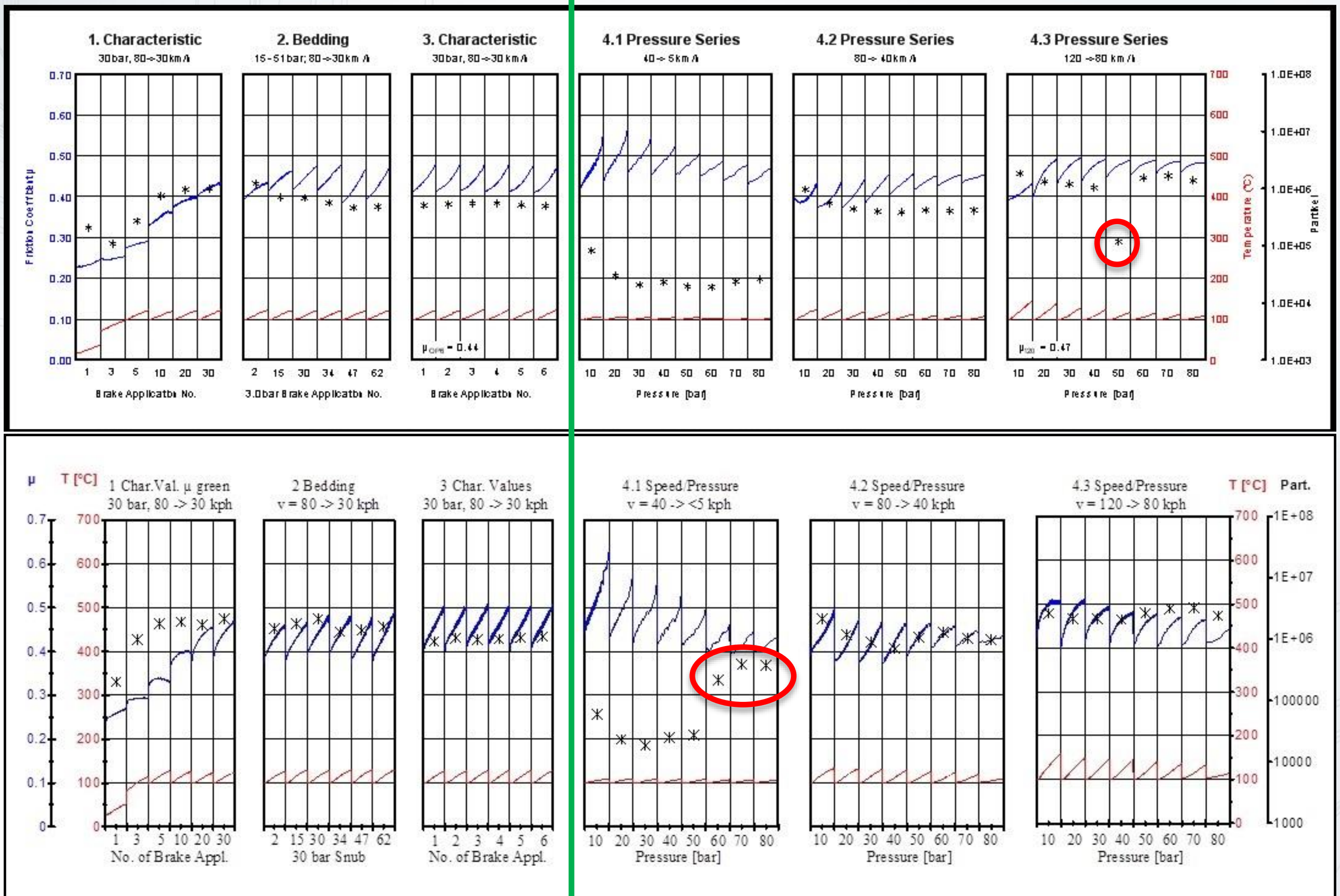
✳ Brake Dust Particles



HORIBA Darmstadt

TU Ilemenau

similar behaviour **good reproducibility**

Data Analysis – AK Master

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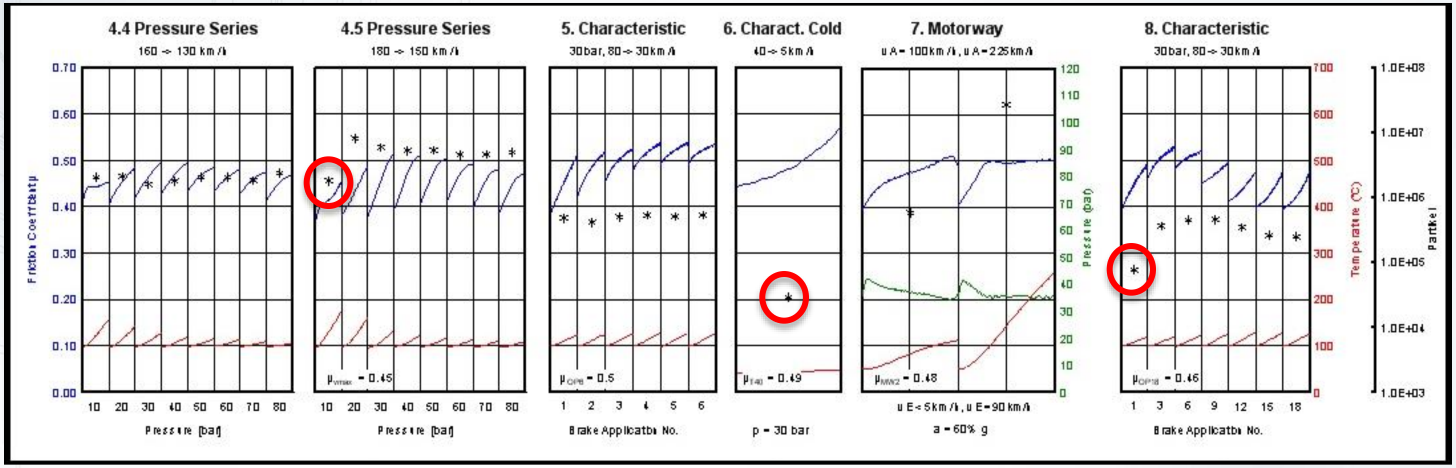
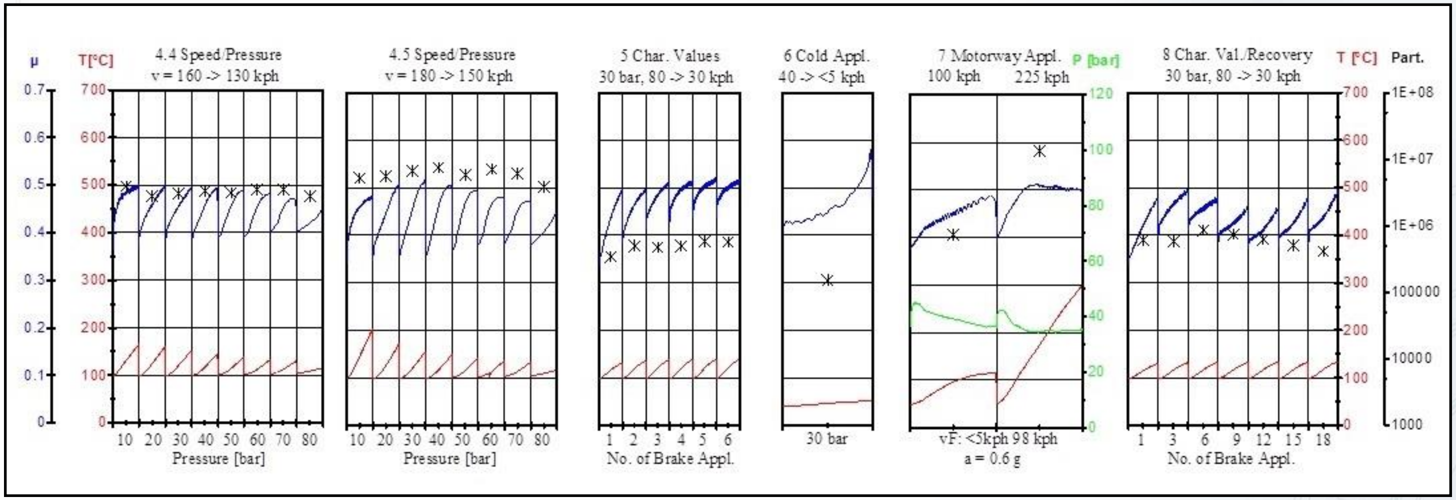
✳ Brake Dust Particles



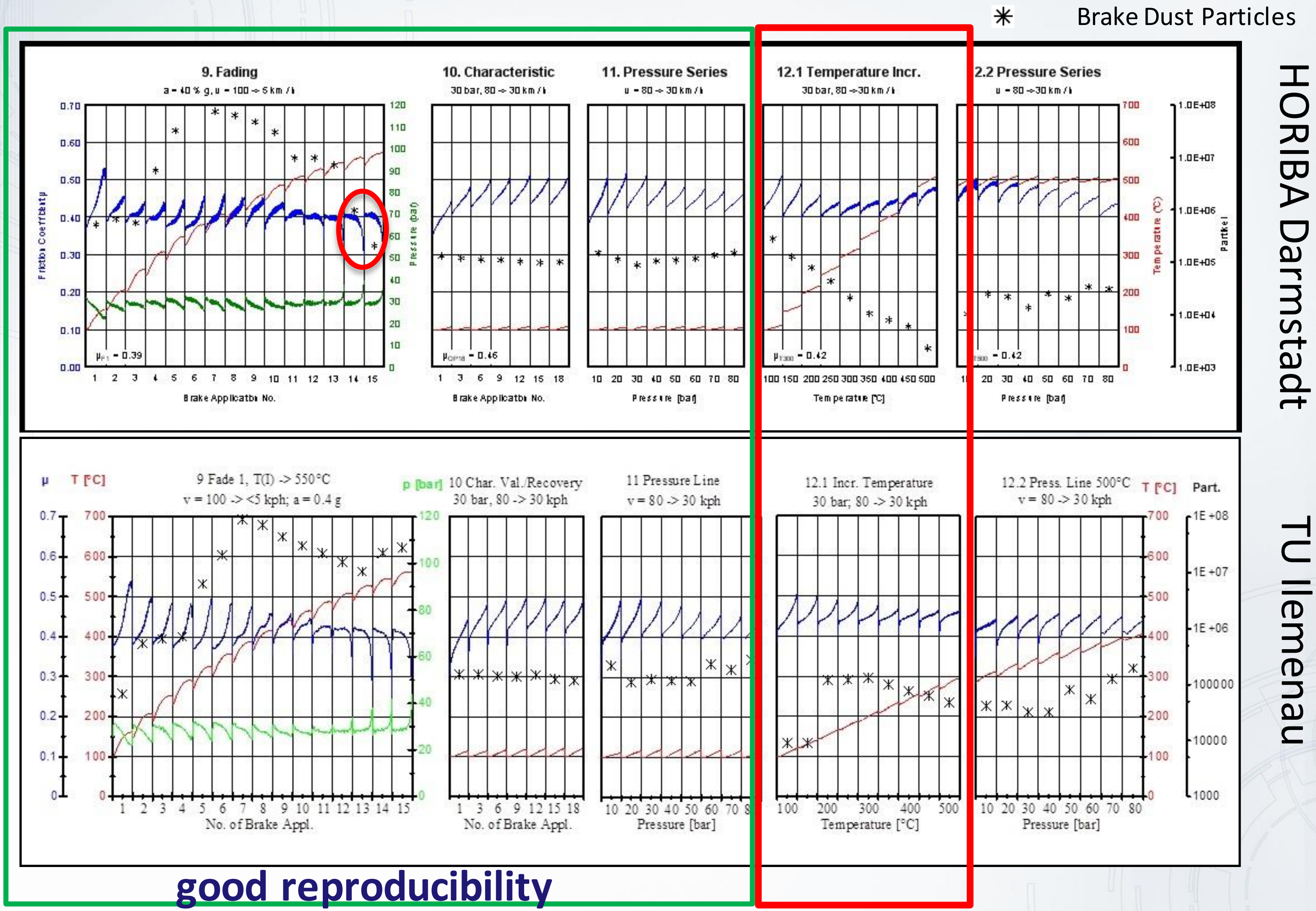
HORIBA Darmstadt



TU Ilemenau

good reproducibility

Data Analysis – AK Master



Data Analysis – AK Master

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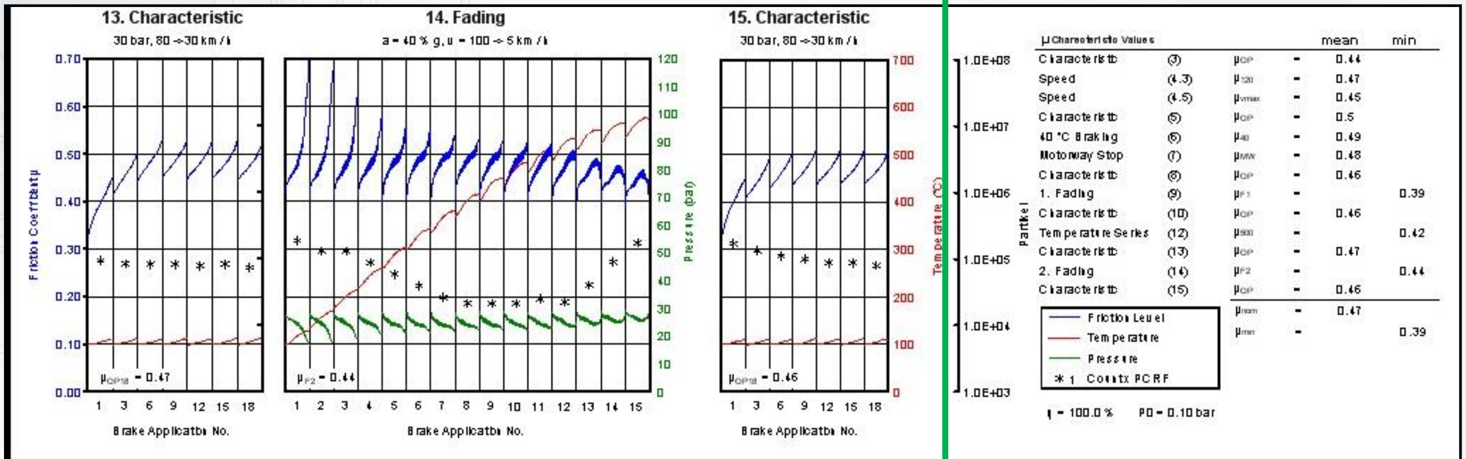
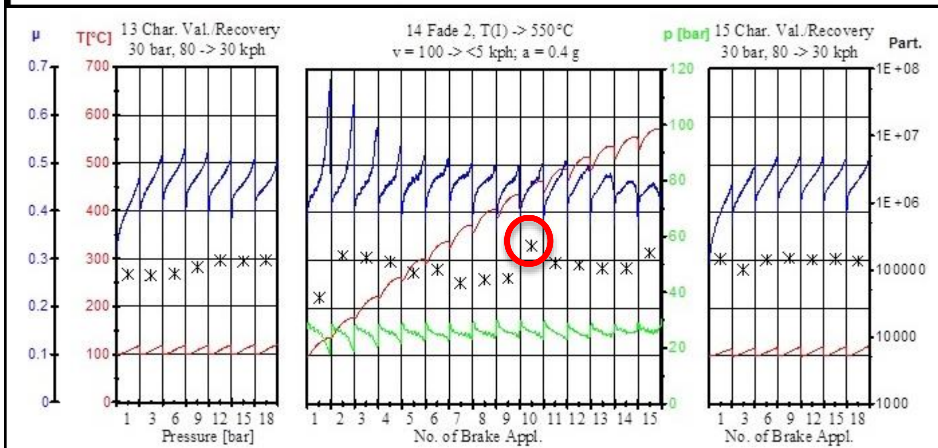
✳ Brake Dust Particles

HORIBA Darmstadt



TU Ilmenau



Characteristic Values μ			Avg.	Min.
Char. Value	(3)	μOP6	0,46	
Speed/ Pressure	(4.3)	μv120	0,46	
Speed/ Pressure	(4.5)	μvmax	0,44	
Char. Value	(5)	μOP6	0,48	
40°C Brake Appl.	(6)	μT40	0,46	
Motorway Appl. 2	(7)	μMW2	0,47	
Char. Value	(8)	μOP18	0,44	
Fade 1	(9)	μF1		0,39
Char. Value	(10)	μOP18	0,44	
Temperature	(12)	μT500		0,42
Char. Value	(13)	μOP18	0,46	
Fade 2	(14)	μF2		0,44
Char. Value	(15)	μOP18	0,46	
		μnom:	0,46	
		μmin:		0,39

good reproducibility

AK Master. Particle size distribution. Section 4.3

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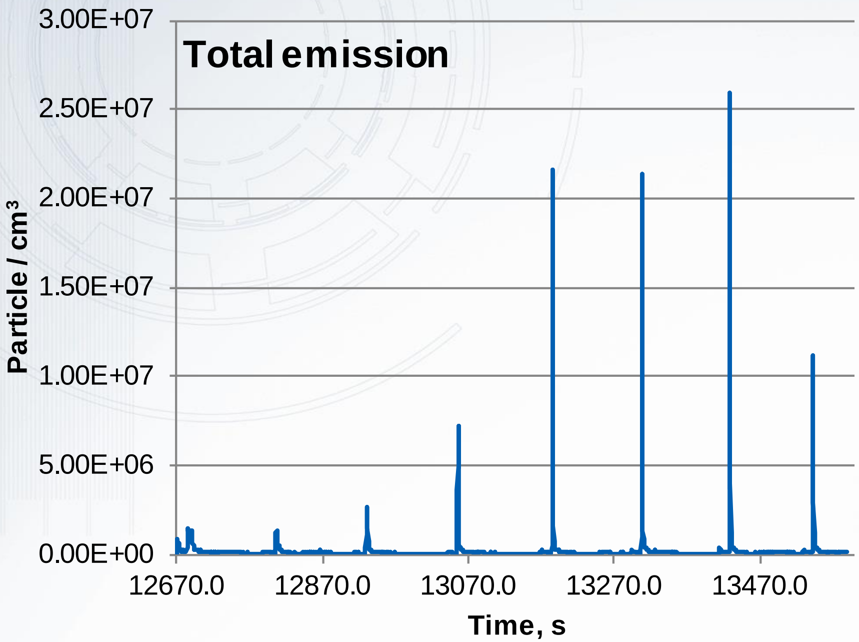

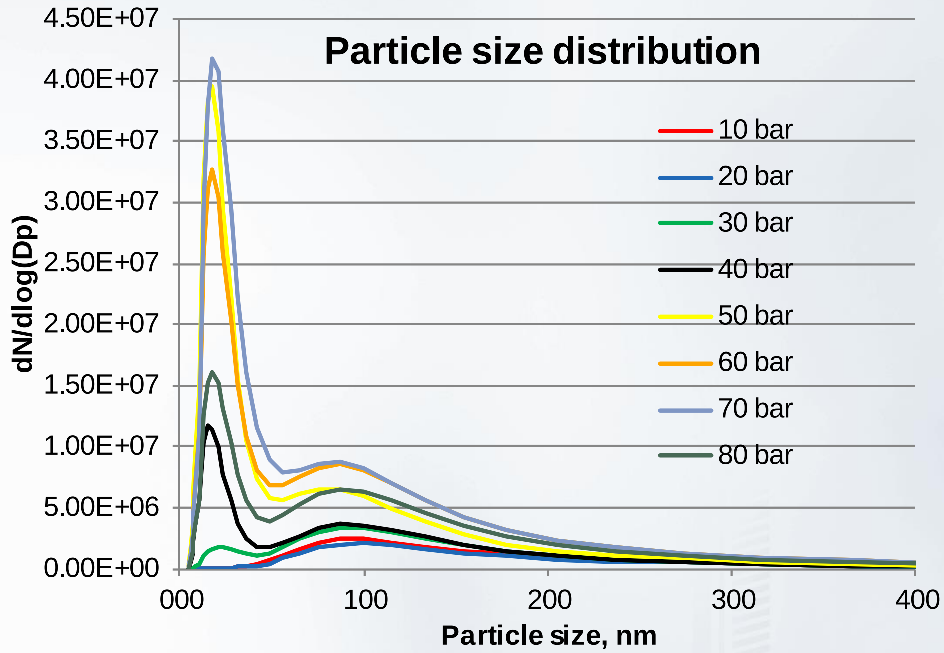

- **Total emission changes with increasing pressure**
- **Particle size distribution changes with increasing pressure**

AK Master. Particle size distribution. Section 4.3

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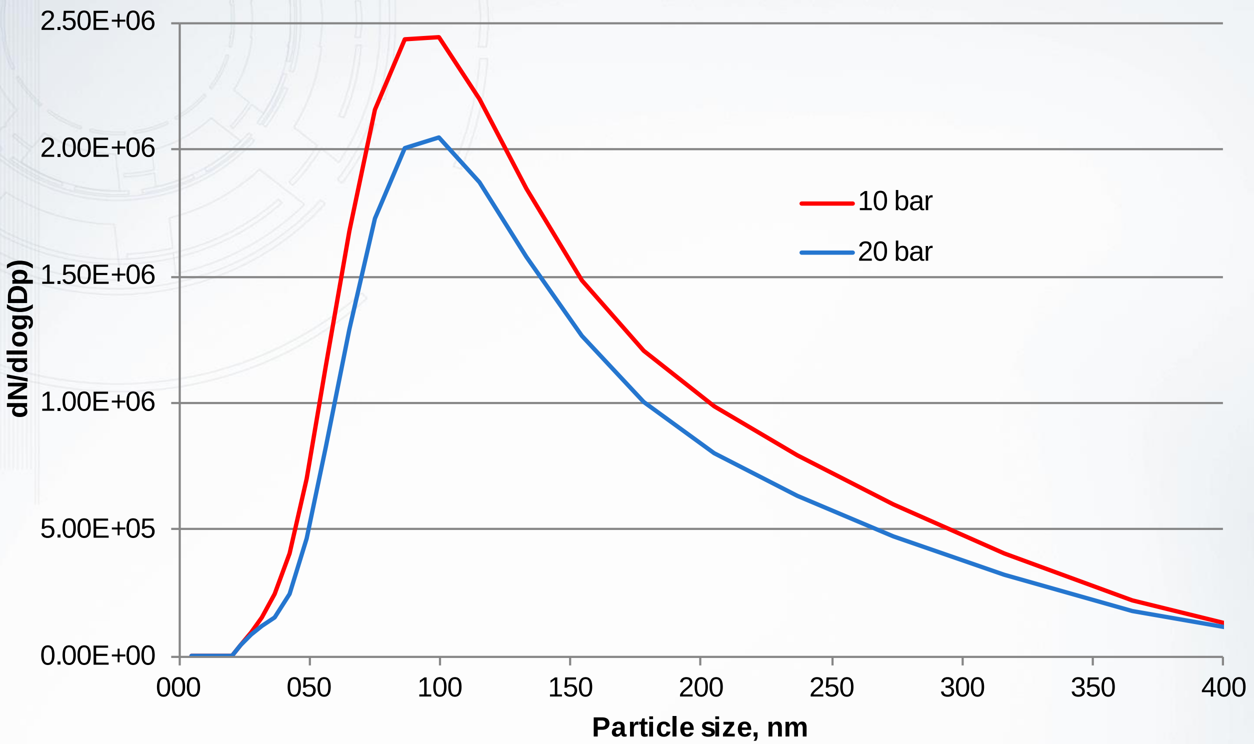

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AK Master. Particle size distribution. Section 4.3

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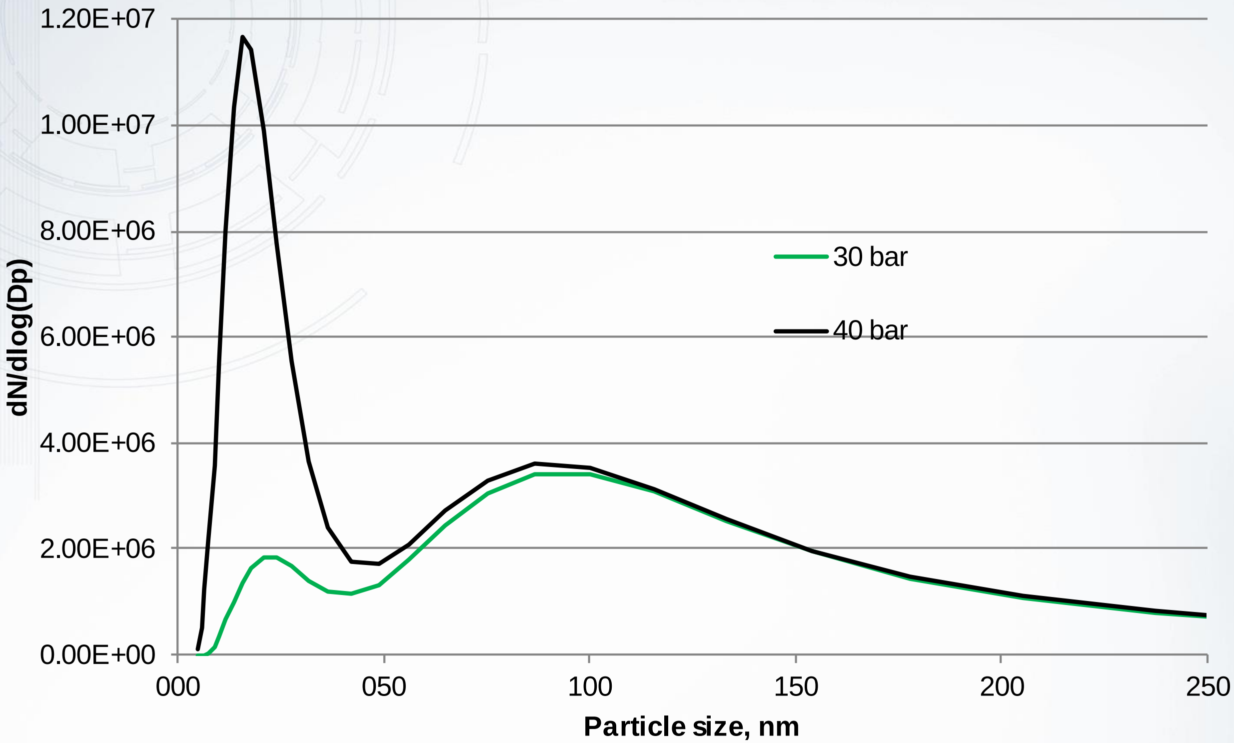
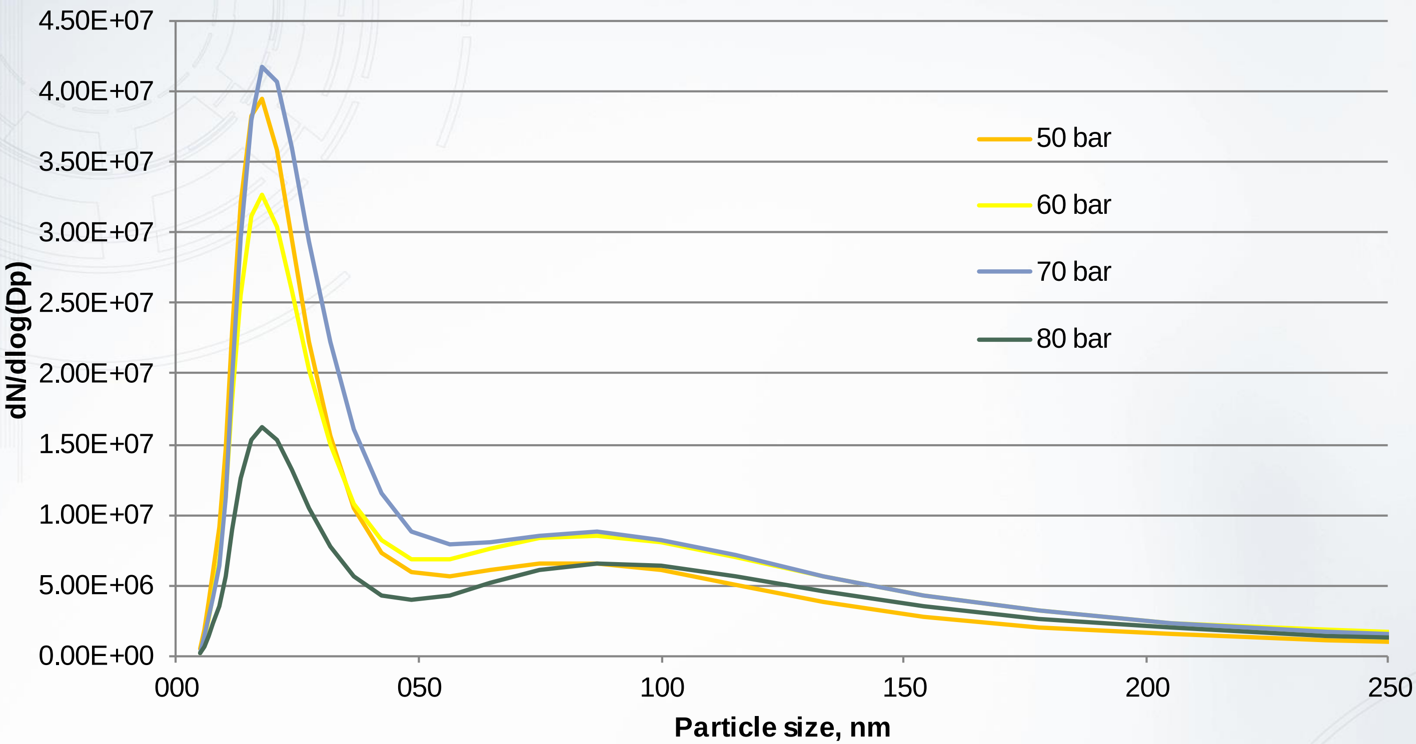


- **Formation of ultrafine particles ≤ 20nm is observed**
- **Amount of ultrafine particles ≤ 20nm exceed the amount of 100nm particles**

AK Master. Particle size distribution. Section 4.3



- ➢ **Size distribution is dominated by ultrafine particles ≤ 20nm**

AK Master. Particle size distribution. Section 4.3

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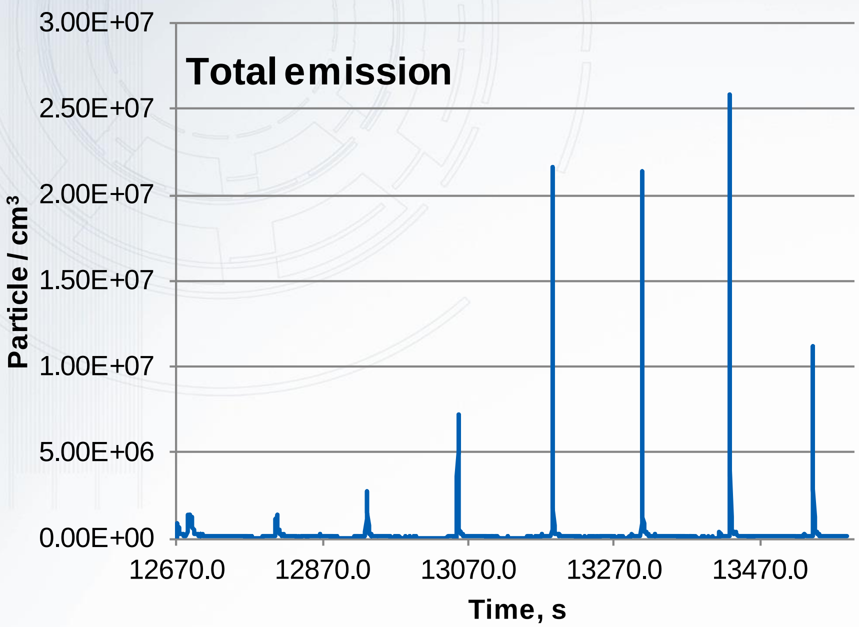
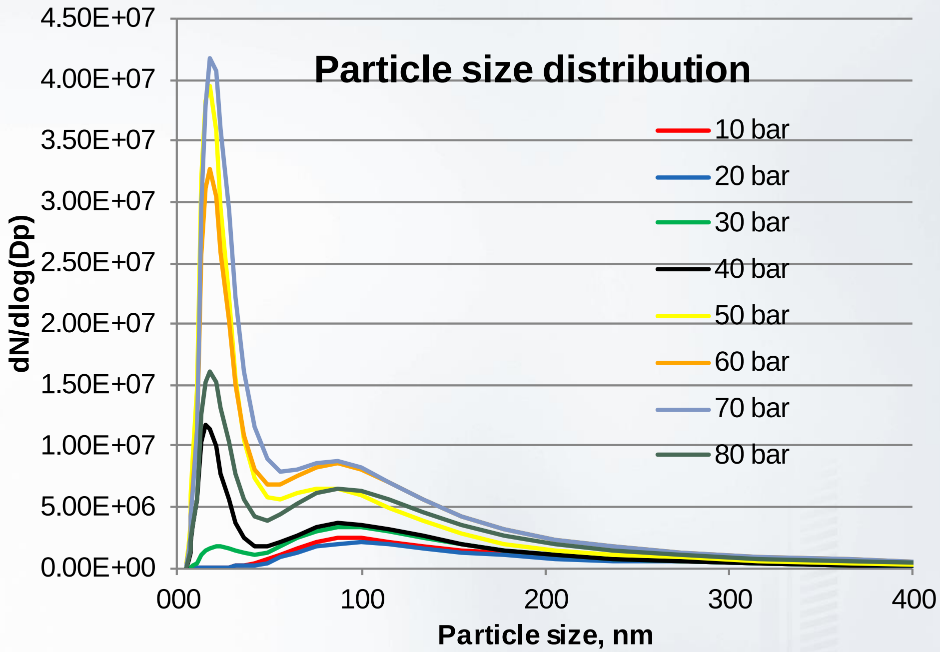
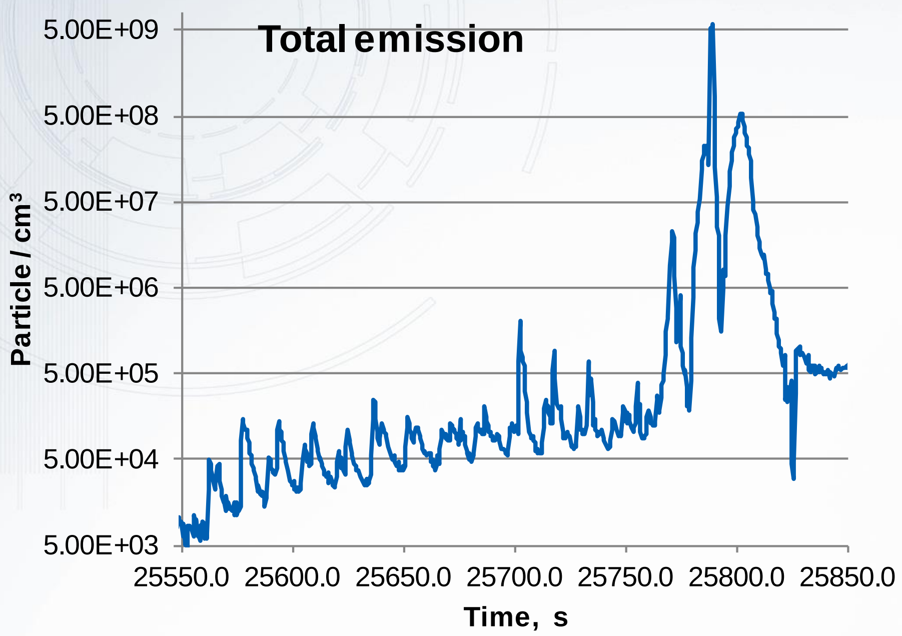
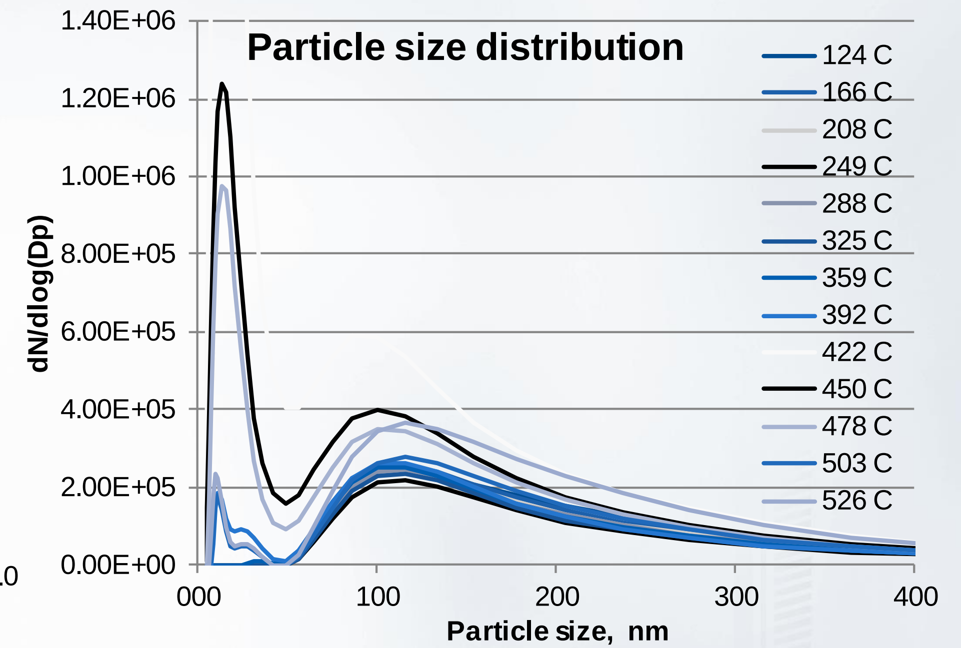




- **Increasing brake pressure enhance formation of ultra-fine particles**
- **No clear dependence of brake pressure on particle emission as well as size distribution was found.**

AK Master. Particle size distribution. Section 14





- Total emission increases with a rising temperature
- Particle size distribution changes with a rising temperature

AK Master. Particle size distribution. Section 14

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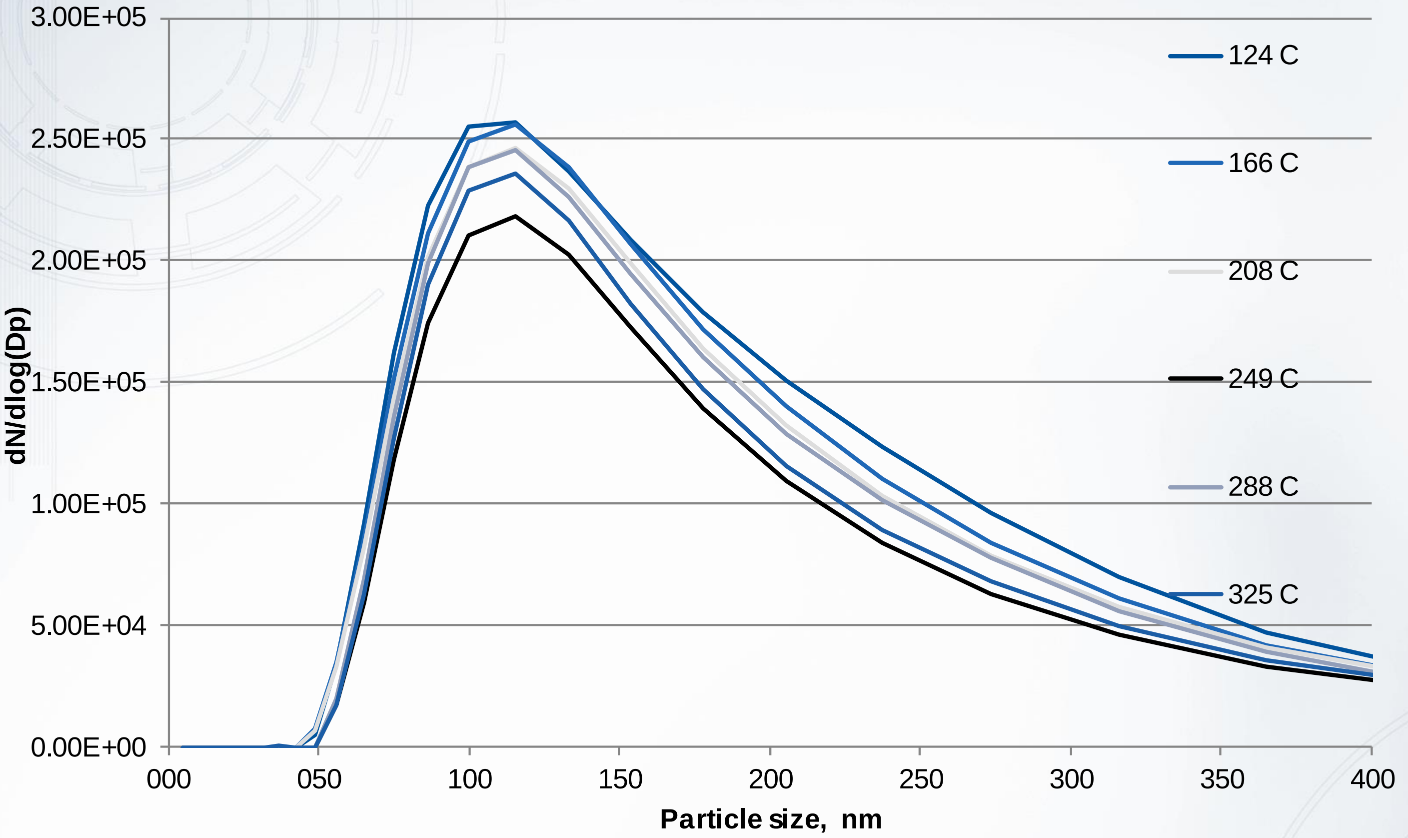

- **Size distribution is dominated by 100nm and 200nm particles**

AK Master. Particle size distribution. Section 14

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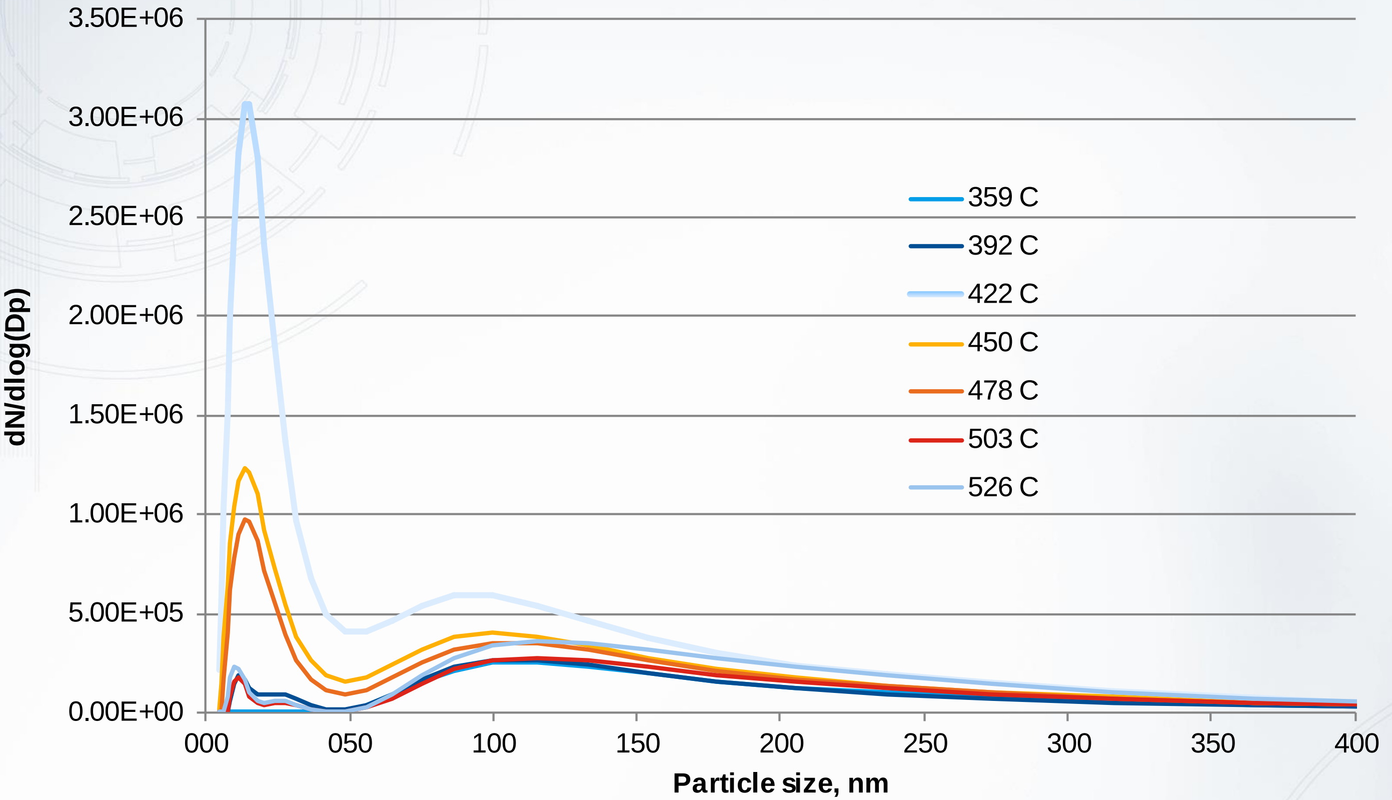

- Formation of ultrafine particles ≤ 20nm is observed
- Ultrafine particles ≤ 20nm exceed the amount of 100nm particles

AK Master. Particle size distribution. Section 14

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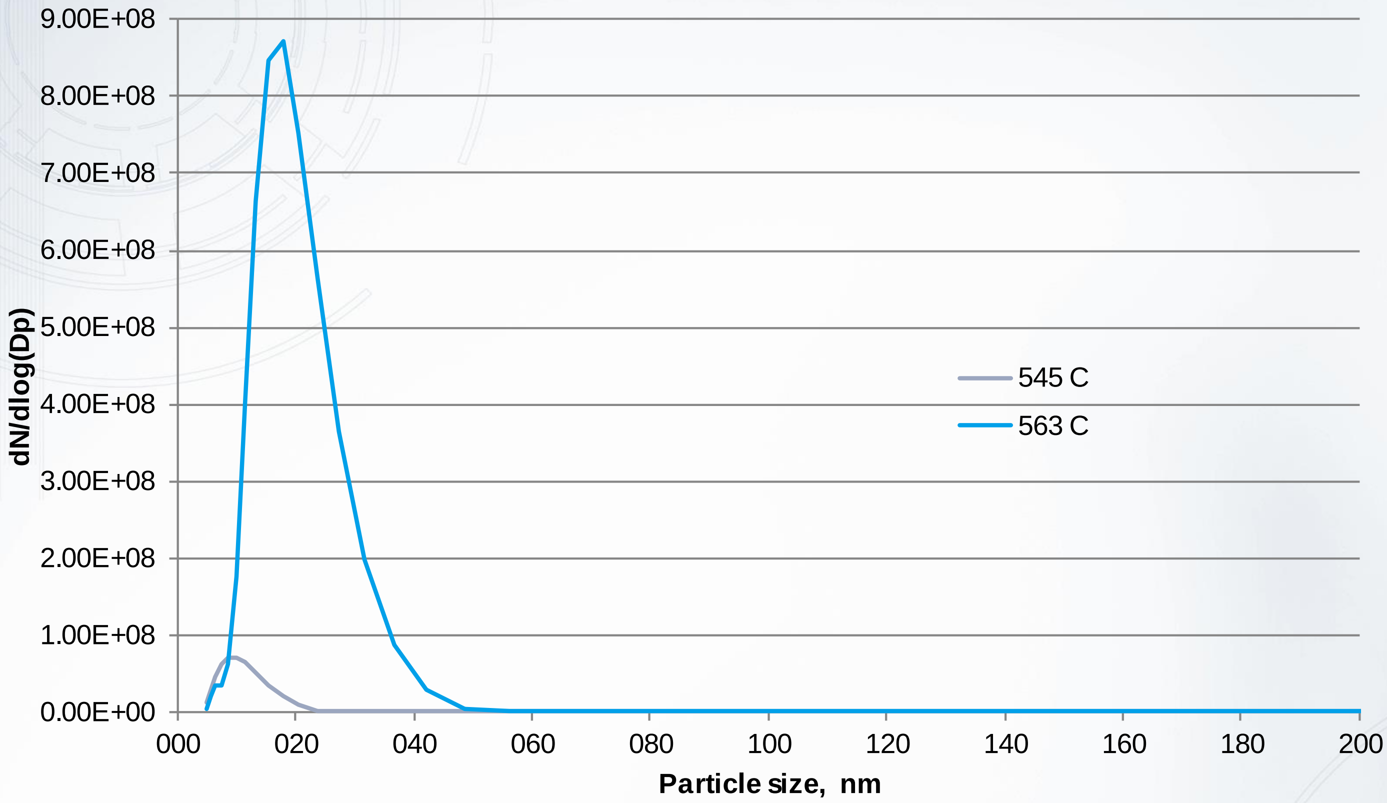

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AK Master. Particle size distribution. Section 14

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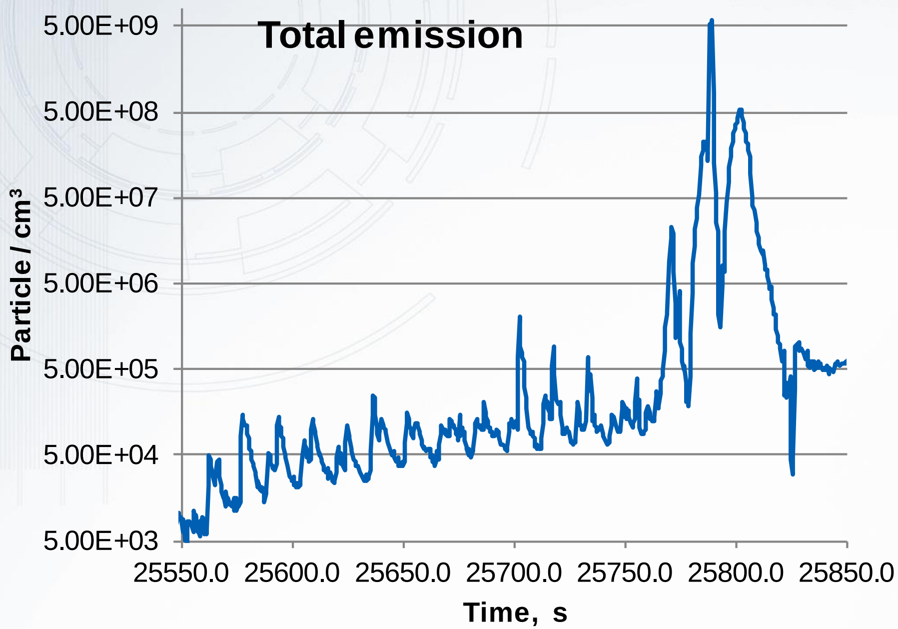
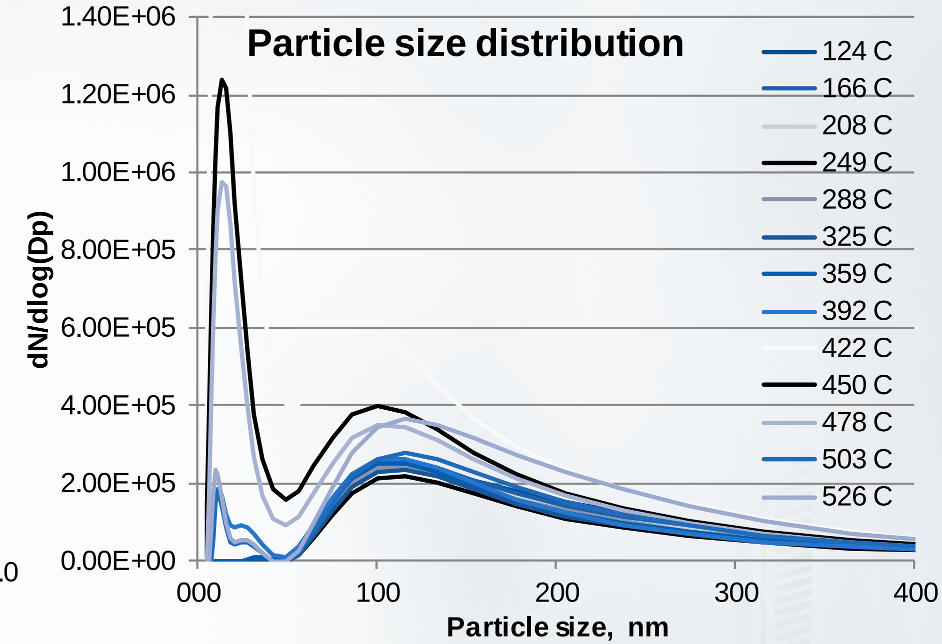
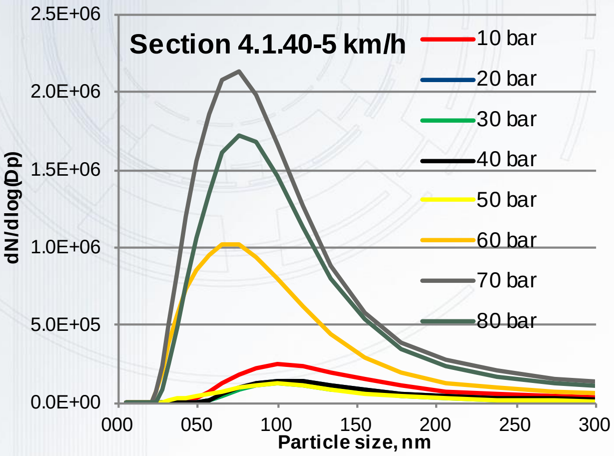
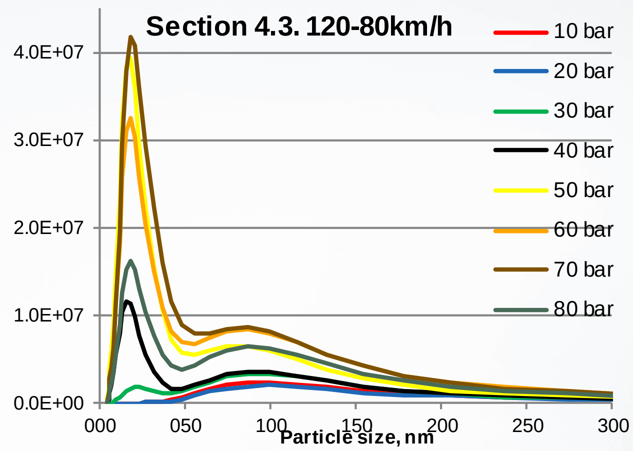


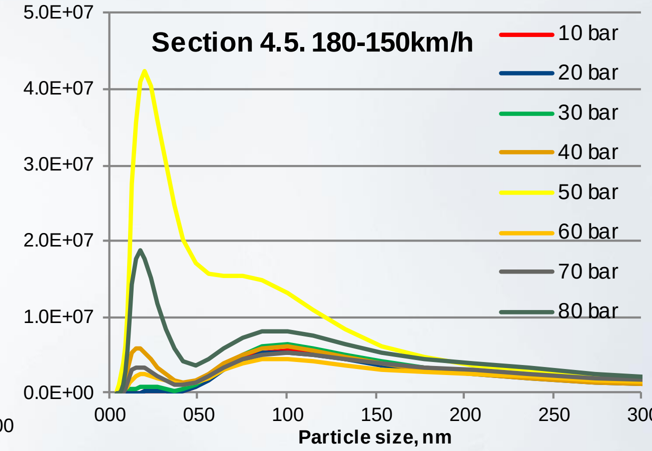


- **Total emission increases with rising temperatures**
- **Rising temperatures enhance formation of ultra-fine particles**
- **At temperatures ≥ 478° C size distribution is dominated by ultrafine particles ≤ 20nm**

AK-Master. Particle size distribution. Wheel speed







- **Appearance of ultra-fine particle depends on wheel speed rather than on brake pressure**
- **Increasing wheel speed enhances formation of ultra-fine particles at lower brake pressure**
- **Total particle emission increases with increasing wheel speeds**

Results – AK Master

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- The highest fault coefficient is 1.7 when the dynamometers are working equally.
- A comparison of particle measurements performed on two different dynamometers is possible!
- Increasing brake pressure enhance formation of ultra-fine particles.
- Total emission increases with increasing temperature.
- At temperatures higher ≥ 478° C size distribution is dominated by ultrafine particles ≤ 20nm.
- Increasing wheel speed enhance formation of ultra-fine particles at lower brake pressure.

Hose versus Sample box: Comparison of experimental results

Role of sampling point: Evaluation of particle emission during AK Bremsstaub

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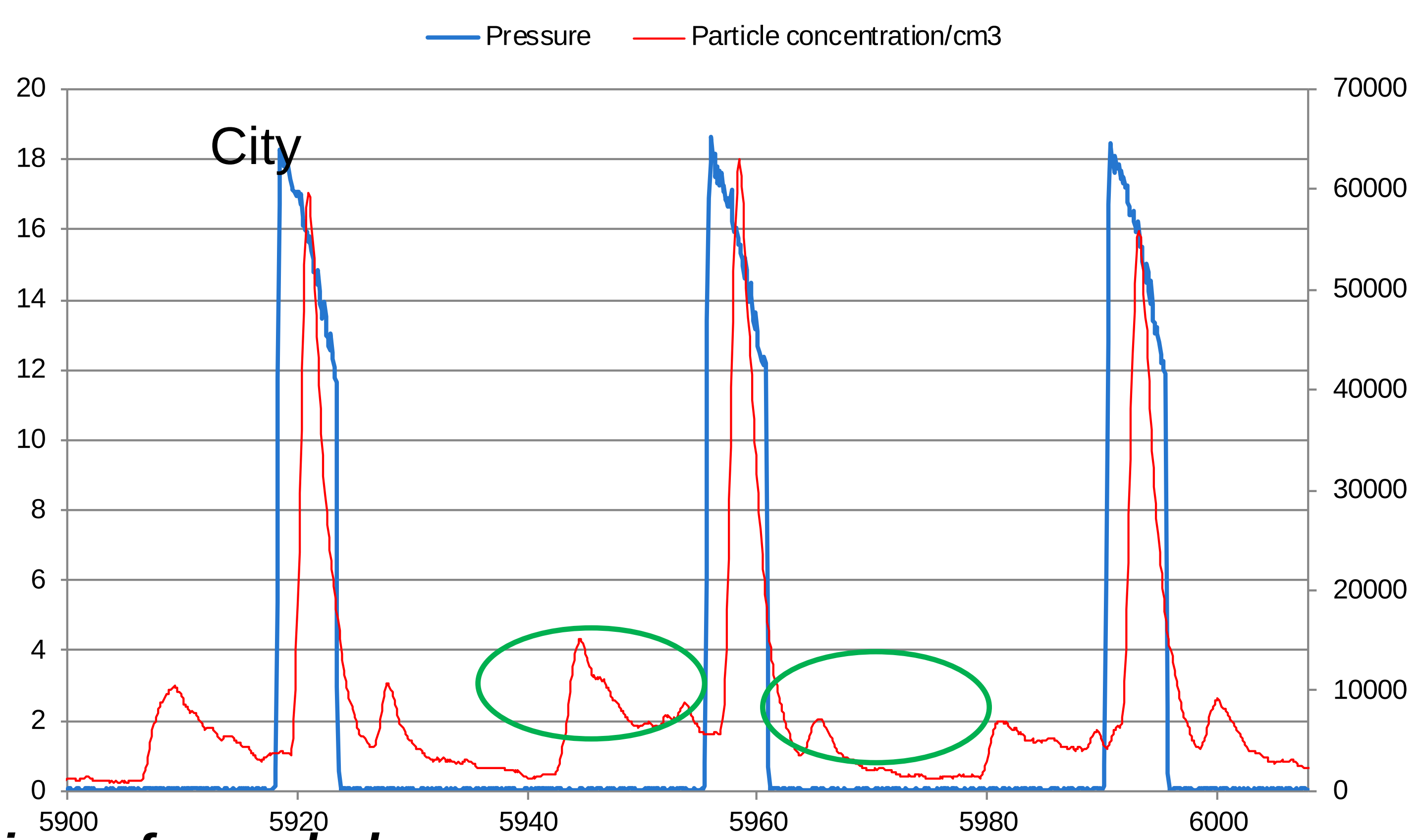
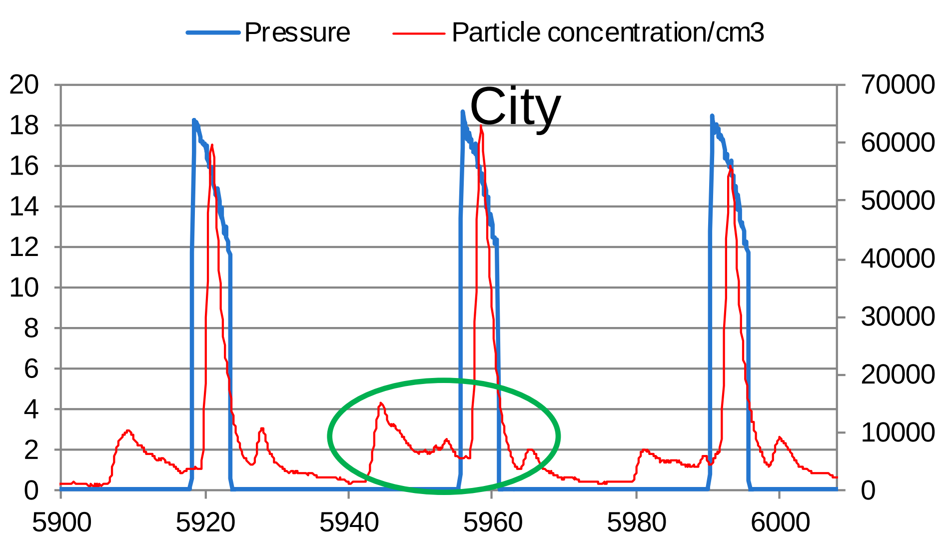
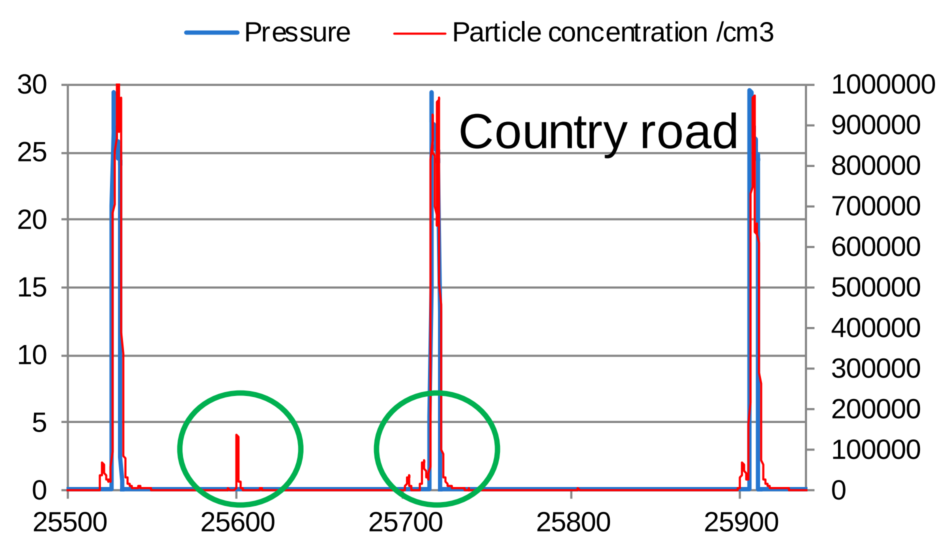


Application of sample box

- Course of brake event can be analyzed
- Allow to see fine off-brake emission peaks

Role of sampling point: Evaluation of particle emission during AK Bremsstaub

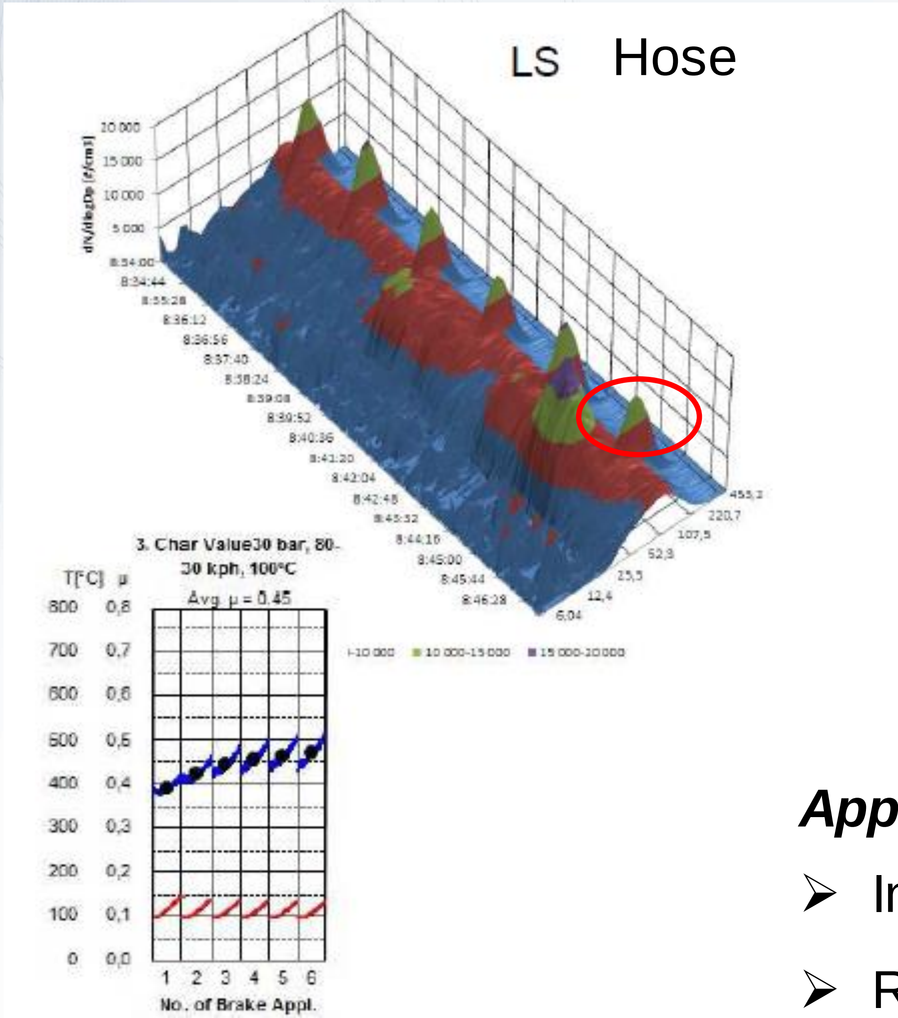


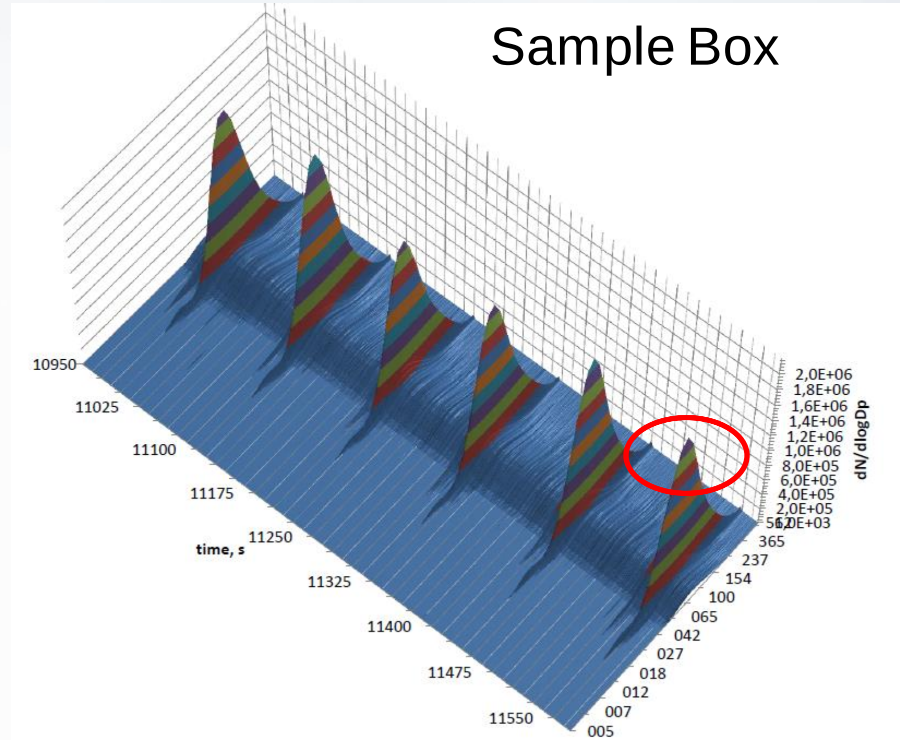


Application of sample box

- Course of brake event can be analyzed
- Allow to see fine off-brake emission peaks

AK-Master. Particle size distribution. Hose *versus* sample box





Application of sample box

- Increase measured particle concentration
- Reduce background
- Allow to see fine emission peaks

PMP35

AK-Master. Particle size distribution. Hose *versus* sample box

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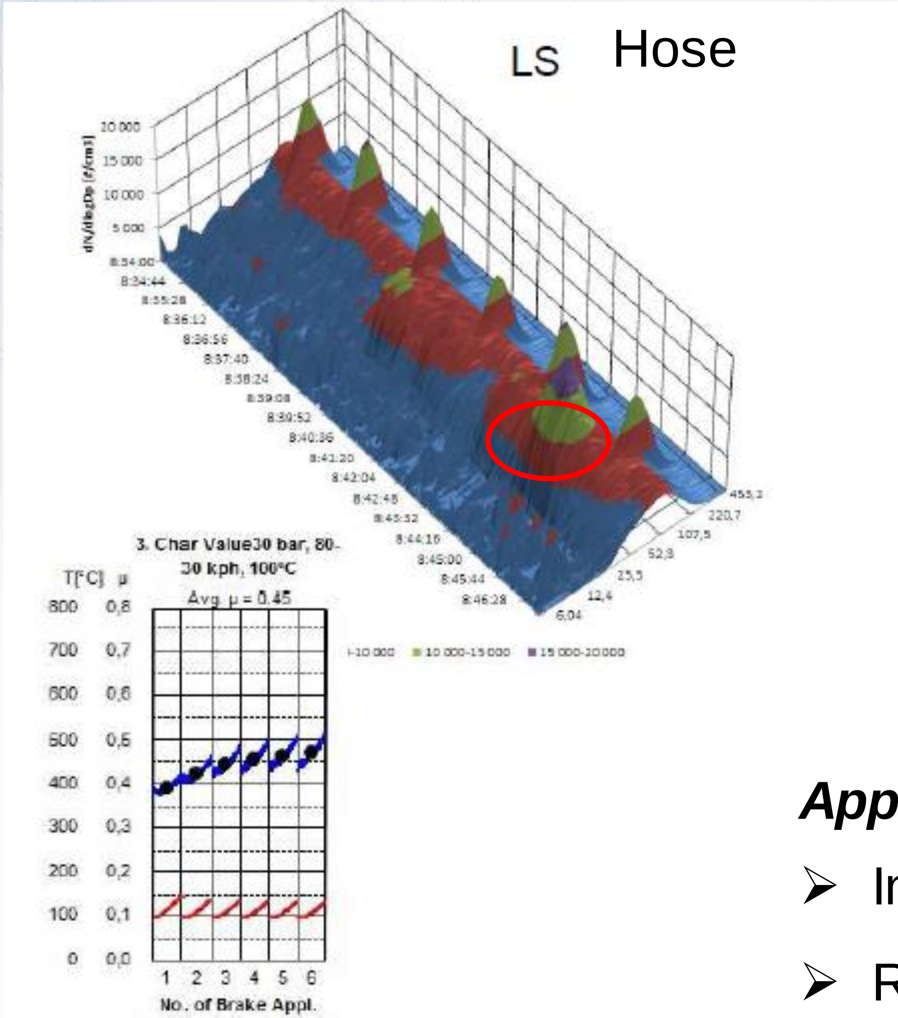

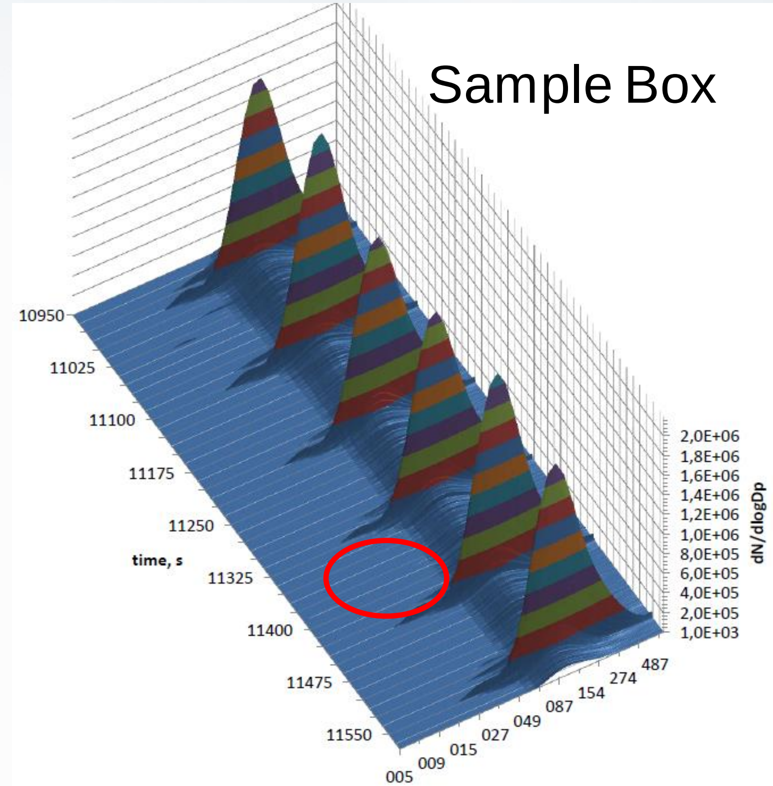

PMP35

Application of sample box

- Increase measured particle concentration
- Reduce background
- Allow to see fine emission peaks

AK-Master. Particle size distribution. Hose *versus* sample box

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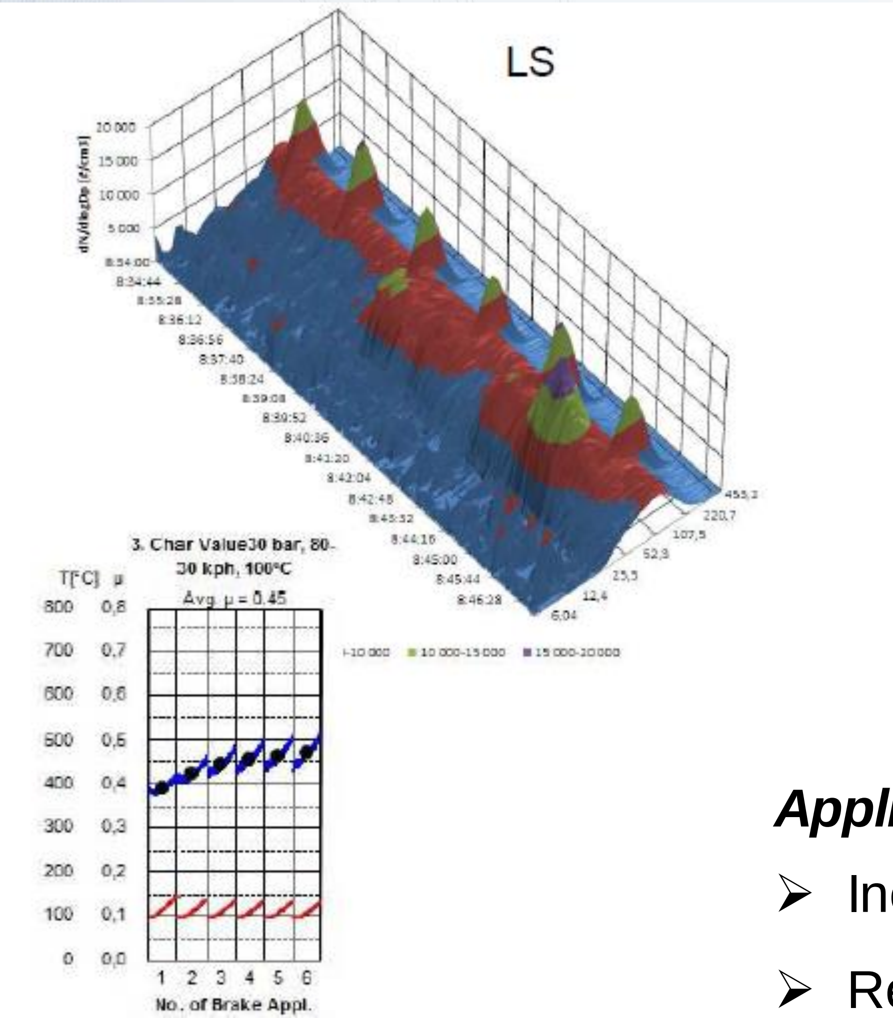

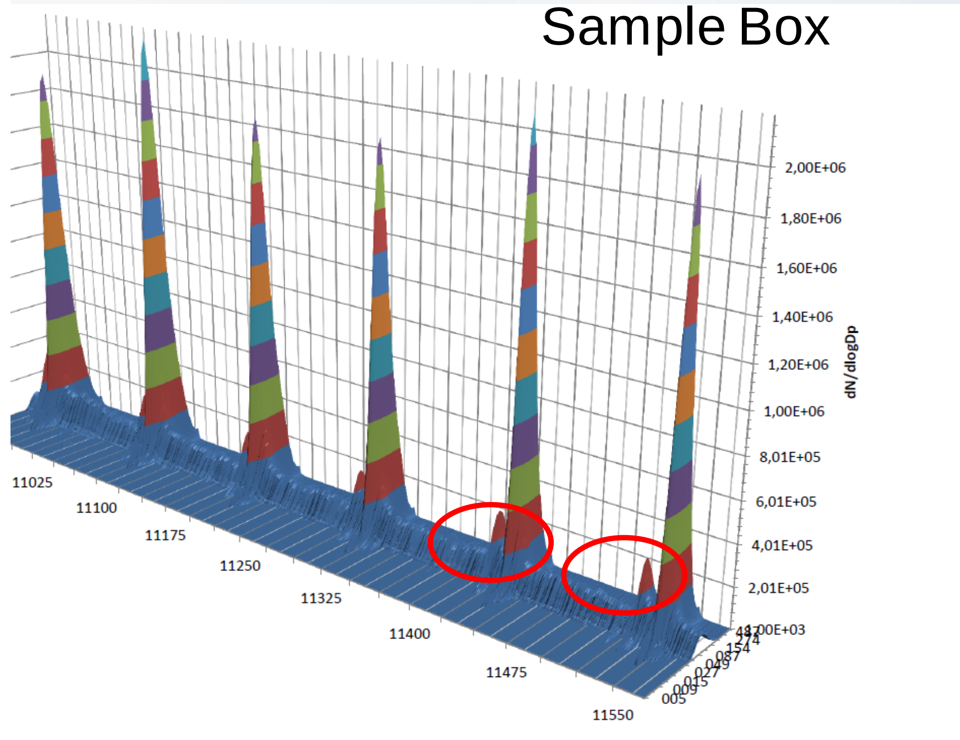

Application of sample box

- Increase measured particle concentration
- Reduce background
- Allow to see fine off-brake emission peaks

PMP35

Conclusions

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- Particle emission values were found in the same range with a deviation coefficient of 1.7 for AK Master for same tests at two different dynos.
- No clear dependence brake pressure on particle emission as well as size distribution was found
- Increasing temperature enhance formation of ultra-fine particles
- Appearance of ultra-fine particle depends on wheel speed rather than on brake pressure

On-road-brake-events

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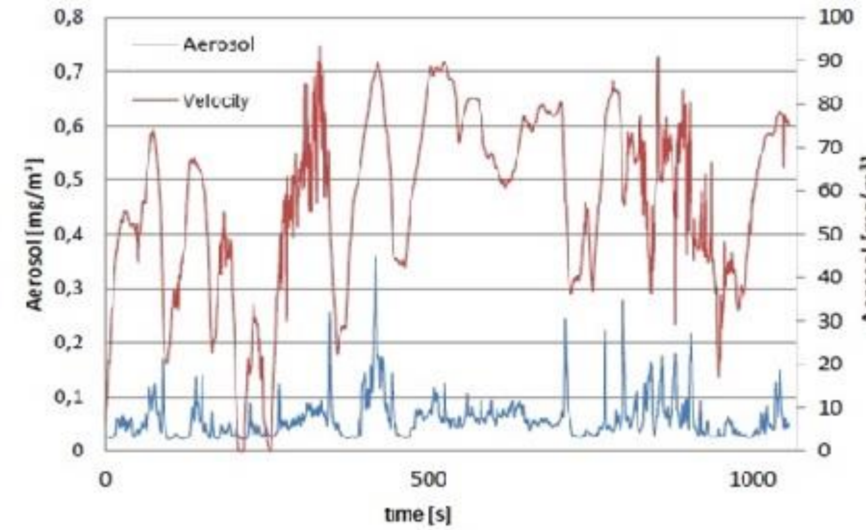
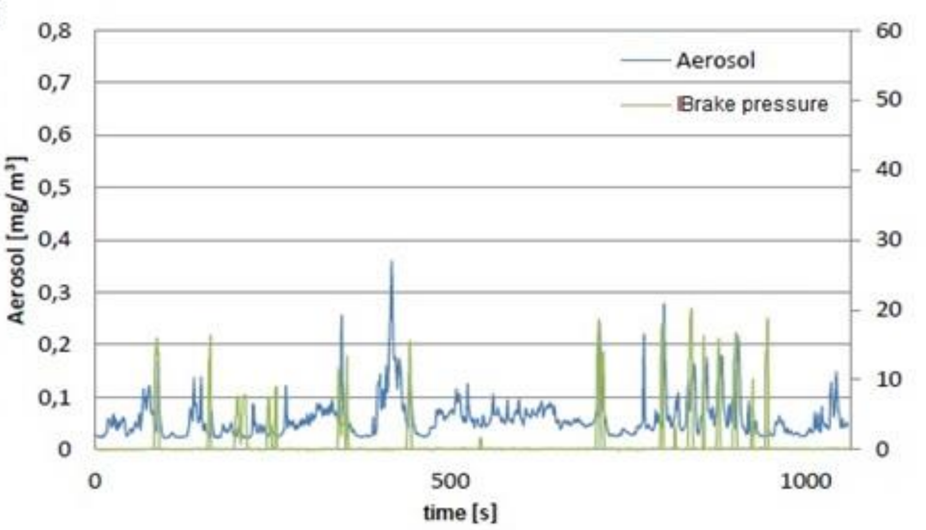




- **TSI Dusttrak system installed on a light duty vehicle**
- **Sampling point behind the brake calliper to minimize effects from other particle sources**
- **A pressure sensor in the brake hydraulic is necessary**
- **Only from 750 seconds on, there is a verified correlation between particle emission and brake events.**

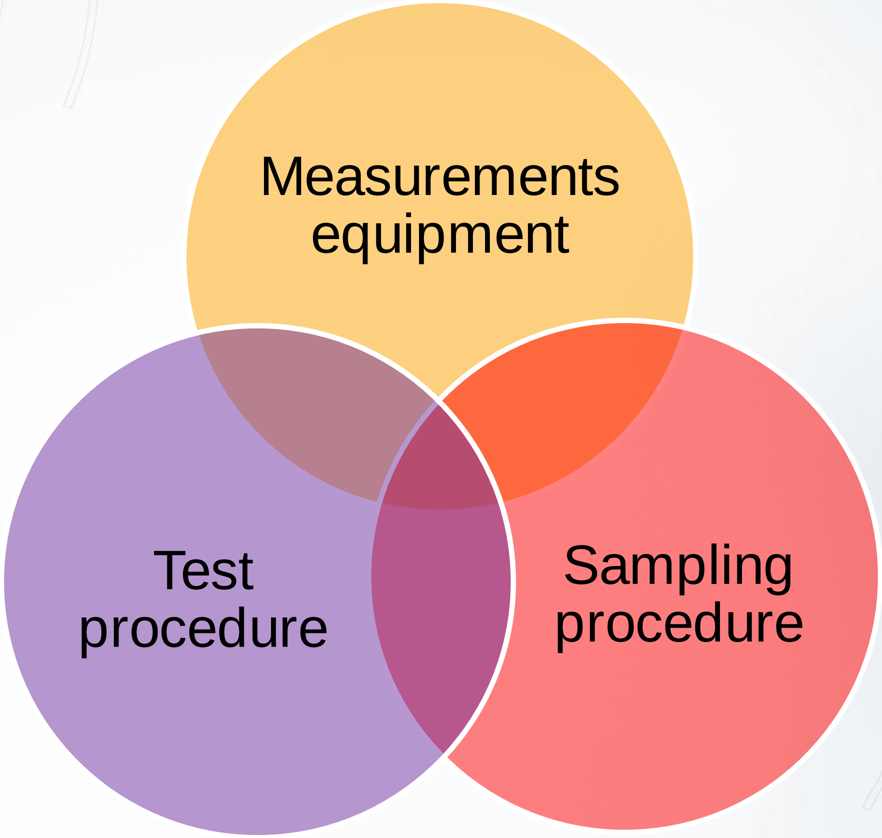
Results of first step

- Exiting sampling set-up provide good reproducibility for particle emission measurements
- Exiting sampling set-up can be installed at every brake dynamometer without their modification
- Splitter provide homogeneous distribution of aerosol flow for 2 used instruments and can be used in future
- Particle emission was measured in range $1x10^5$-10^8 particle/cm^3
- Particle emission depends on disk temperature, wheel velocity and less on applied pressure
- Particle emission recorded during one single brake event demonstrate a few characteristic peaks at different time points
- Application of sample box allow to investigate course of single brake event
- Particle size distribution depends on disk temperature
- For high disk temperature T≥180° C big amount of ultrafine particles 5-20 nm was recorded with DMS
- Results of real drive emission tests are affected by many sources of particles

Challenges

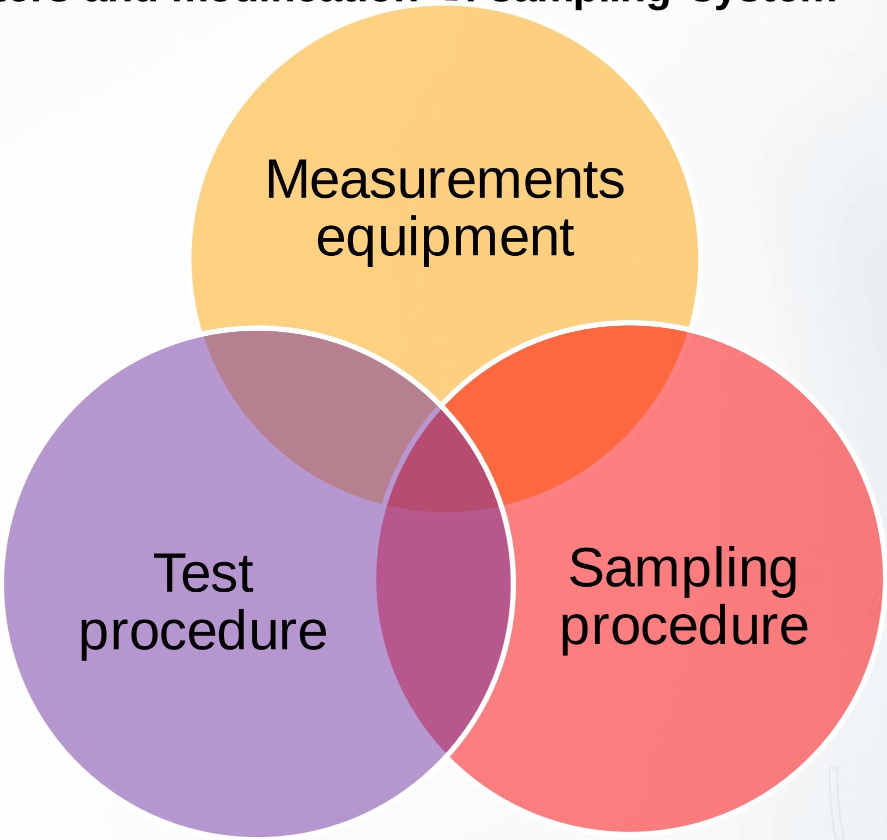
- Disagreement in total concentration measured with SPCS and DMS for some test sections
- Big amount of ultrafine 5-20nm can not be measured with SPCS
- Data evaluation for particle emission measurement required synchronization and additional data evaluation from brake dynamometer
- Improving of sampling system
- Test procedure not defined yet
- Role of test parameters

To be solved


Measurements equipment
Test procedure
Sampling procedure

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



Thank you

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Thank you

ありがとうございました

Cảm ơn

ขอบคุณครับ

谢谢

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Gracias

Grazie

Σας ευχαριστούμε

धन्यवाद

நன்றி

Tacka dig

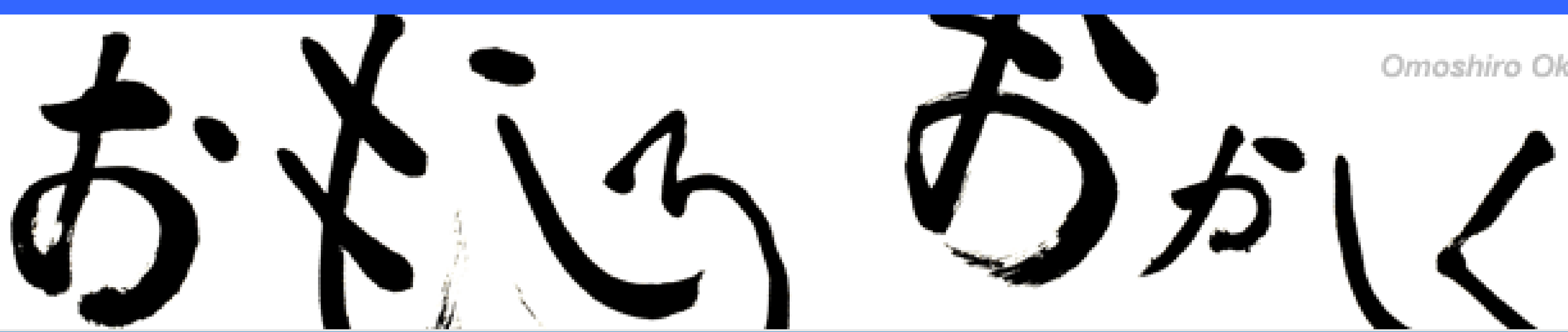
Danke

Merci

Obrigado

감사합니다

Большое спасибо



Omoshiro Okashiku