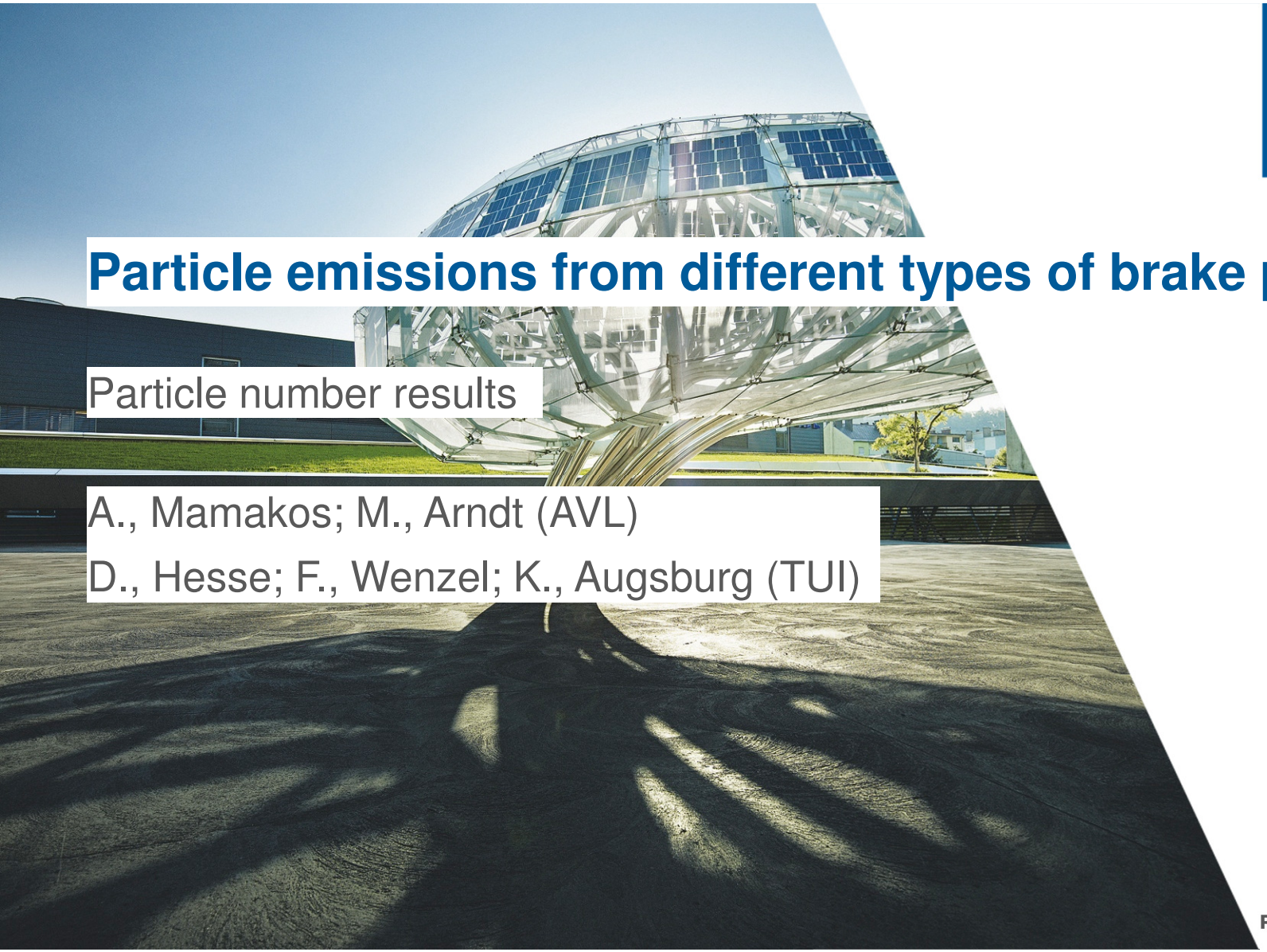


Particle emissions from different types of brake pads

Particle number results

A., Mamakos; M., Arndt (AVL)

D., Hesse; F., Wenzel; K., Augsburg (TUI)

Experimental - Setup

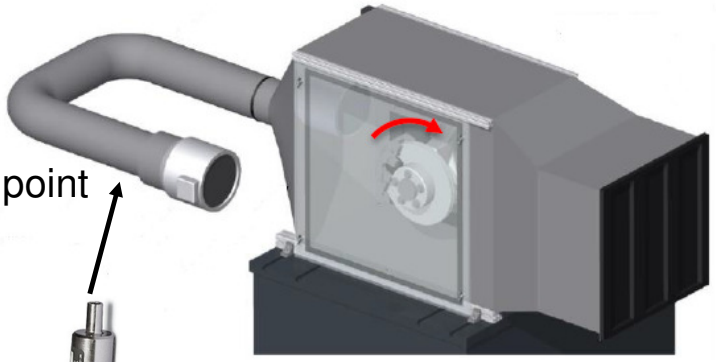
First phase campaign presented here focused on Particle Number (PN) emissions.

- AVL APC and AVL CPC were calibrated according to R83

Ongoing campaign focuses on Particulate Mass (PM) with different techniques:

- Photoacoustic/gravimetric (AVL PM PEMS)
- Electrical (ELPI plus, DMS500)
- Thermogravimetric

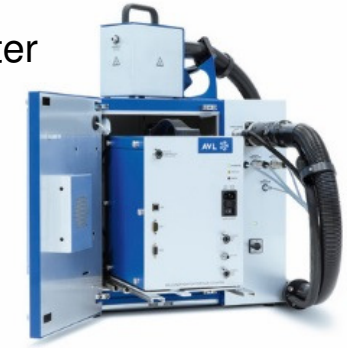
DMS 500
5 nm – 1 µm



Sample point

Dekati thermodenuder
in selected tests

TSI 3708
4-way splitter



Modified AVL APC
Catalytic stripper
Modified AVL CPC
10 nm cut-off

TSI 3776 CPC
2.5 nm cut-off

AVL CPC
23 nm cut-off

Experimental - Brake pads tested

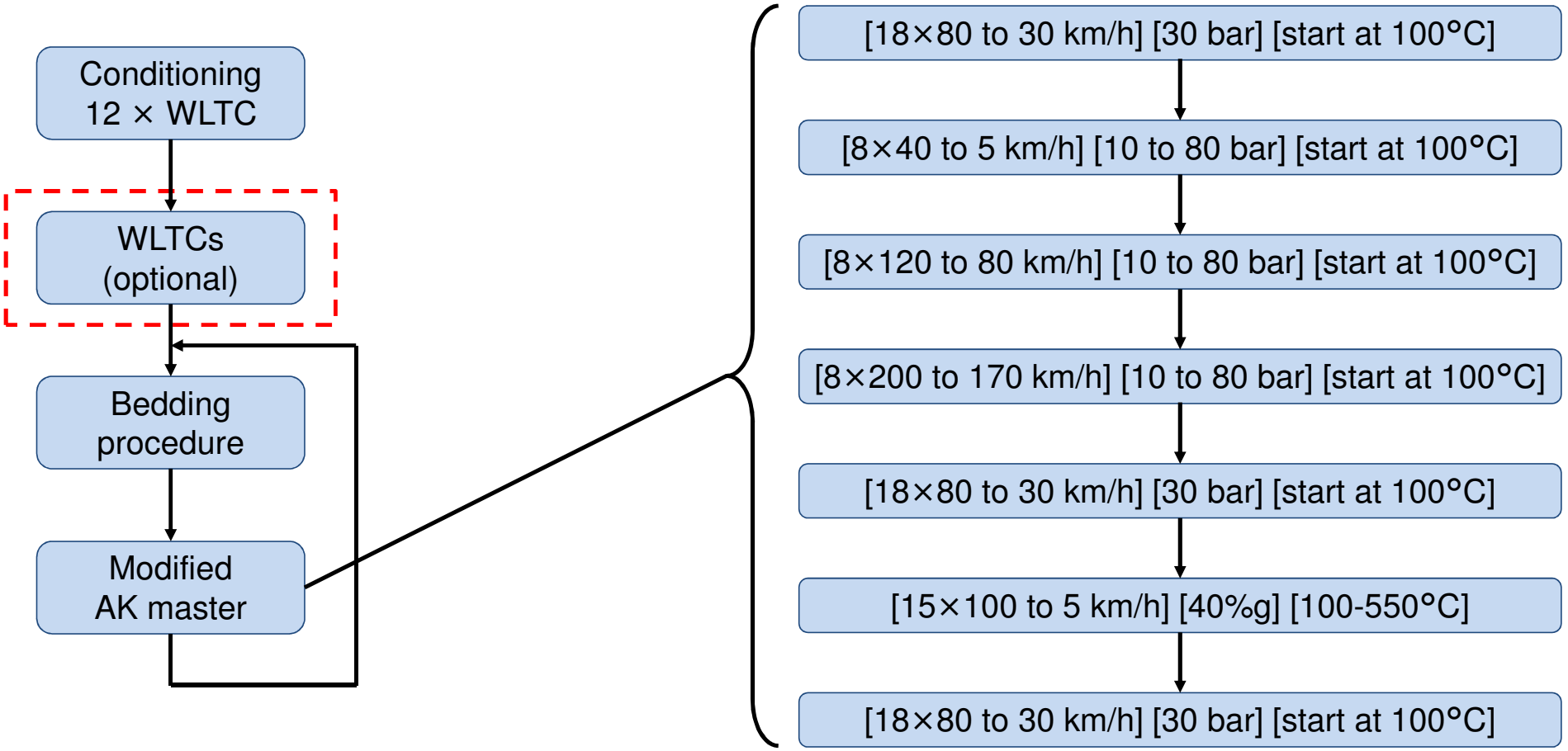
Four different types of commercial brake pads were tested. Two of them were series-production pads from European market (ECE) and two were of non-asbestos organic (NAO) type (US market). One pad from each category had no copper in their formulation. They will be abbreviated herewith as:

- NAO
- ECE
- NAO Cu-free
- ECE Cu-free

Dyno setting: Left front wheel of a entry-level luxury car

- Inertia: 60.4 kgm²
- effective radius: 126 mm
- rotor size: 278 mm

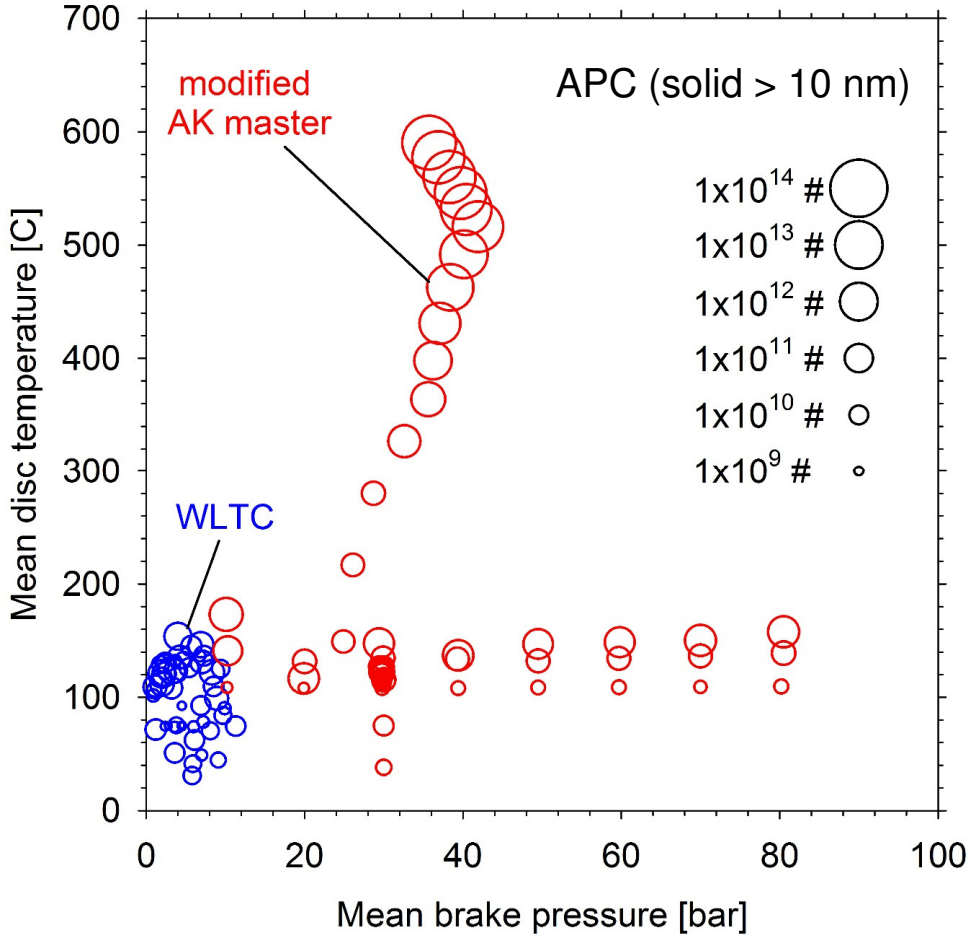
Experimental - Test procedure



WLTC vs modified AK master conditions

The braking events covered by the modified AK master procedure cover a much wider range of braking conditions.

Reported temperatures herewith correspond to mean temperature of the disc. Given the large thermal mass of the disc, its mean temperature may be a biased parameter especially considering that the braking duration also differs for different braking events.



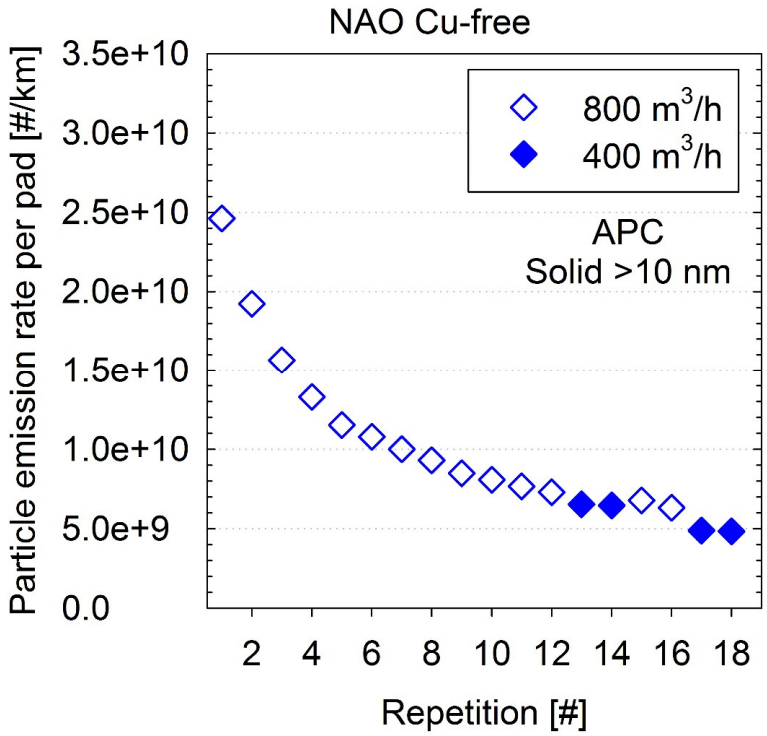
Effect of prehistory / tunnel flowrate

WLTCs were employed as a run-in procedure. Particle number emissions were continuously dropping even after 16 repetitions.

Operation of the tunnel at half the flowrate (400 m^3/h instead of 800 m^3/h) resulted in systematically lower solid particle number emission rates (5 to 30%).

Concentration levels (peak at 15000 $\#/cm^3$) were too low to attribute this to coagulation. Residence time inside the tunnel and APC ~4 seconds.

The results from the ongoing PM campaign are expected to provide some more insight.



DMS500 vs CPC-based techniques

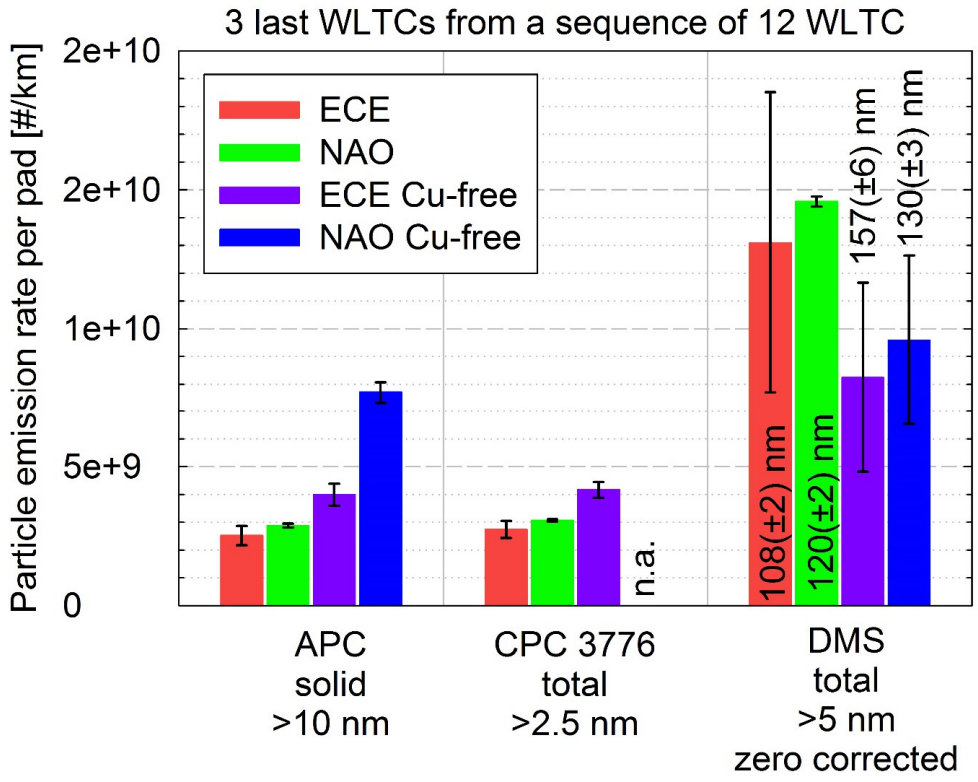
Particle number emission levels over the WLTC were well below the Euro 6 limit of 6×10^{11} #/km.

All particles emitted over the WLTC tests were larger than 10 nm with no evidence of volatile particles (APC similar to 2.5 nm CPC).

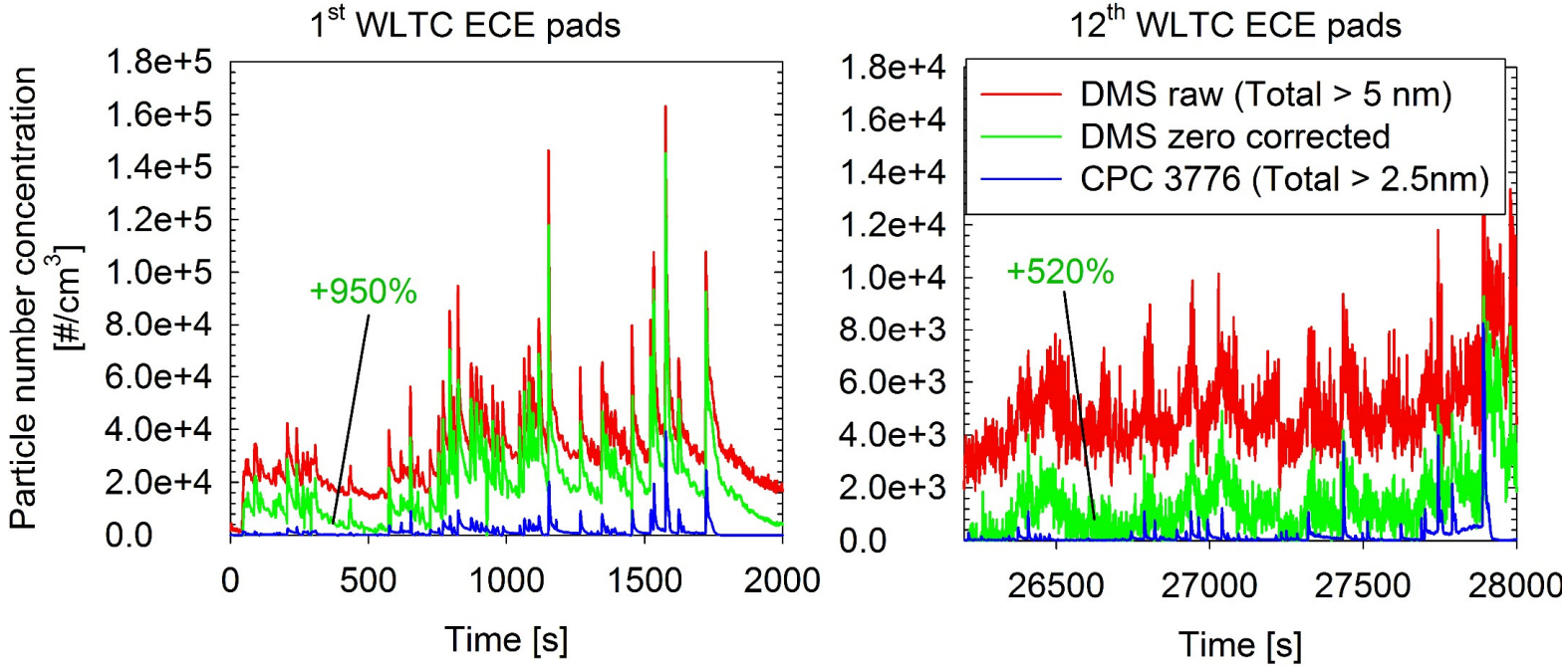
Measured mean mobility particle diameter was in the 110 to 160 nm range, over the WLTC.

DMS500 systematically overestimated true particle number emissions.

Over the WLTC, DMS measured ~400% higher number concentration for ECE and NAO and ~30-100% for the copper-free pads.



DMS500 overestimation



DMS500 overestimation was evident at all concentration levels and could not be related to background levels that were also varying ➔ Importance of transparent inversion algorithms and calibration.

Maintaining low background level is important for particle number measurements.

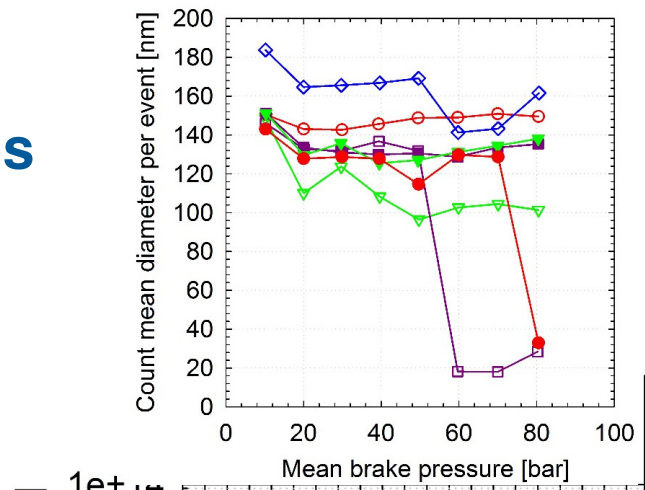
120 to 80 km/h decelerations

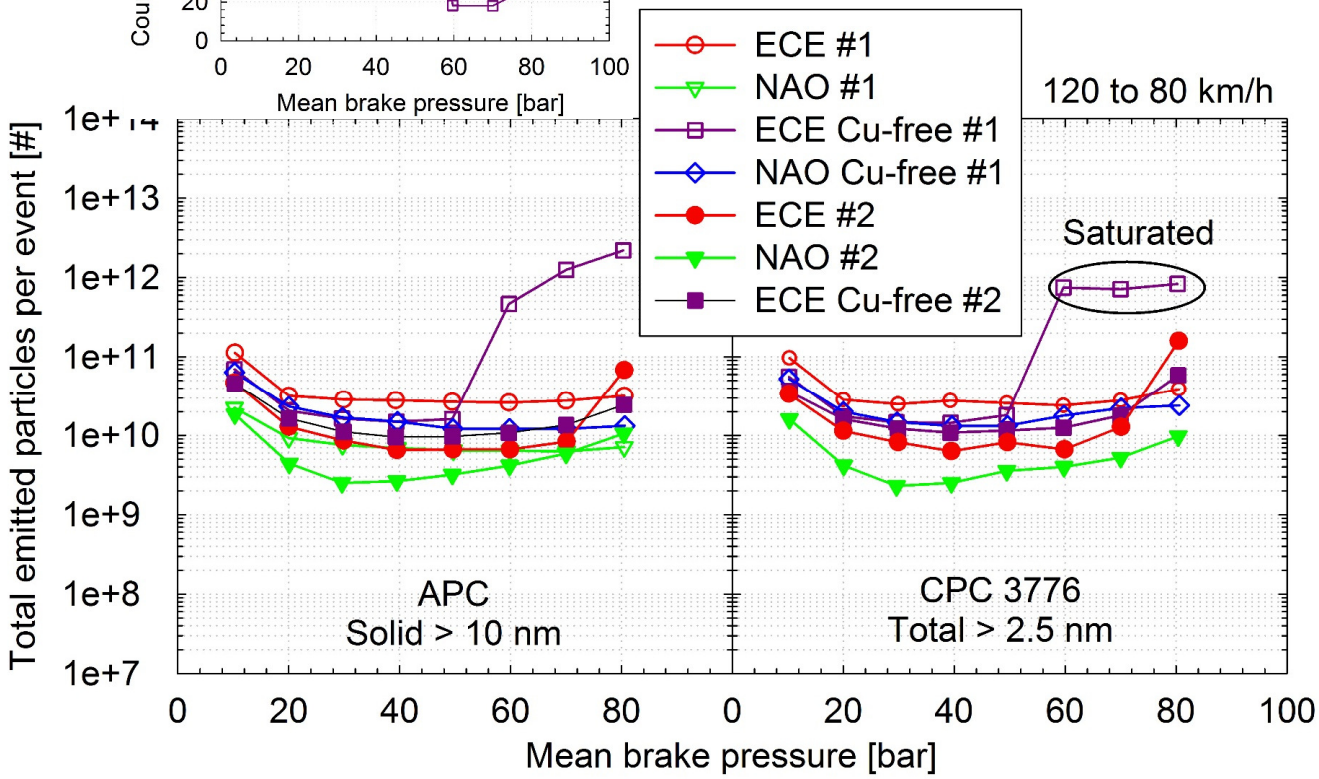
Distinct nucleation mode appeared at high mean braking pressures with ECE (80 bar) and especially ECE copper-free (60 to 80 bar).

A large fraction of that is measured by the APC so it is solid in nature

Bimodal distribution during these events with the combined count mean diameter reaching 20-30 nm.

Mean disc temperature <150 C



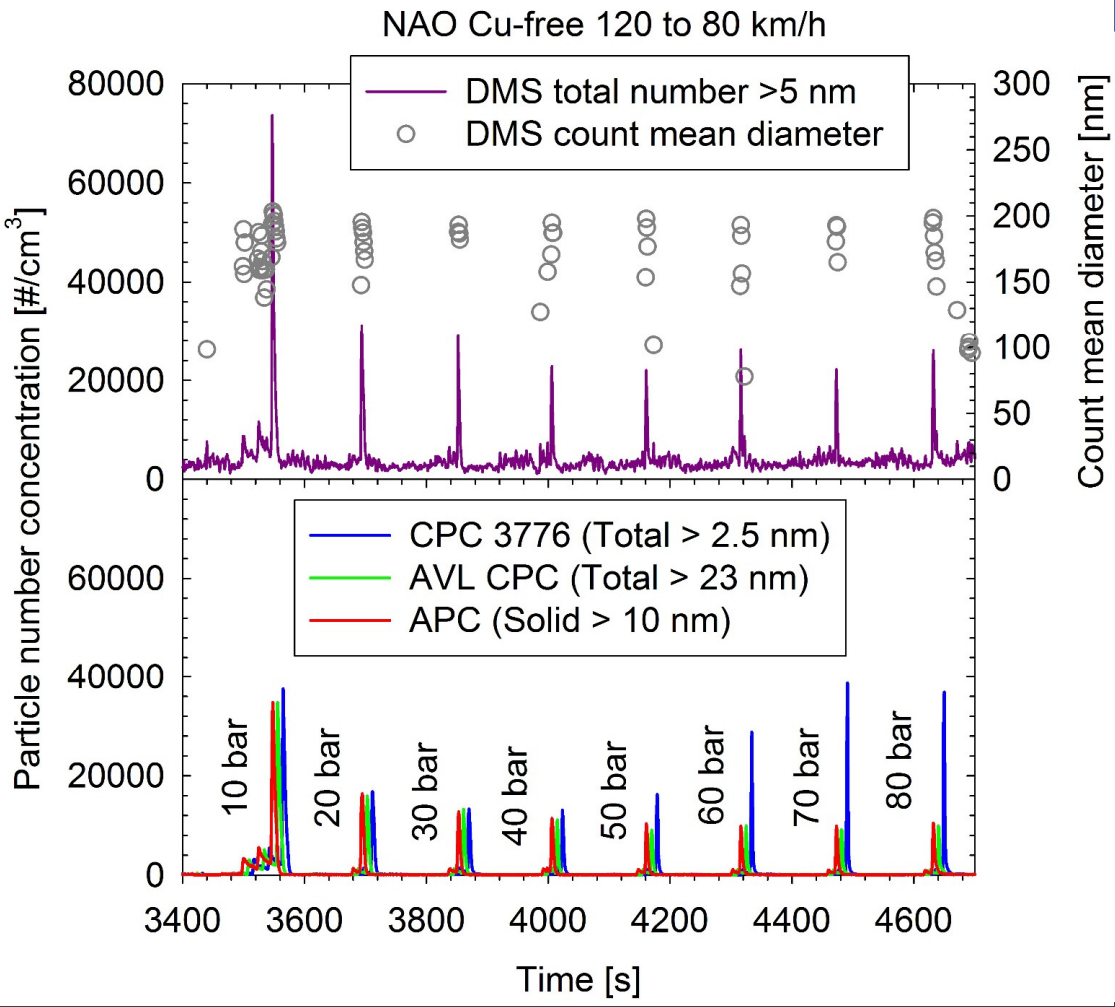


Sub-10 nm particles

During some events, the 2.5 nm CPC recorded higher concentrations than the 23 nm CPC and the 10 nm APC.

No evidence of such particles in the DMS size distributions (>5 nm).

Sub 5 nm particles may be produced during some braking events and due to the low concentrations they can remain at this size (will not grow by coagulation)

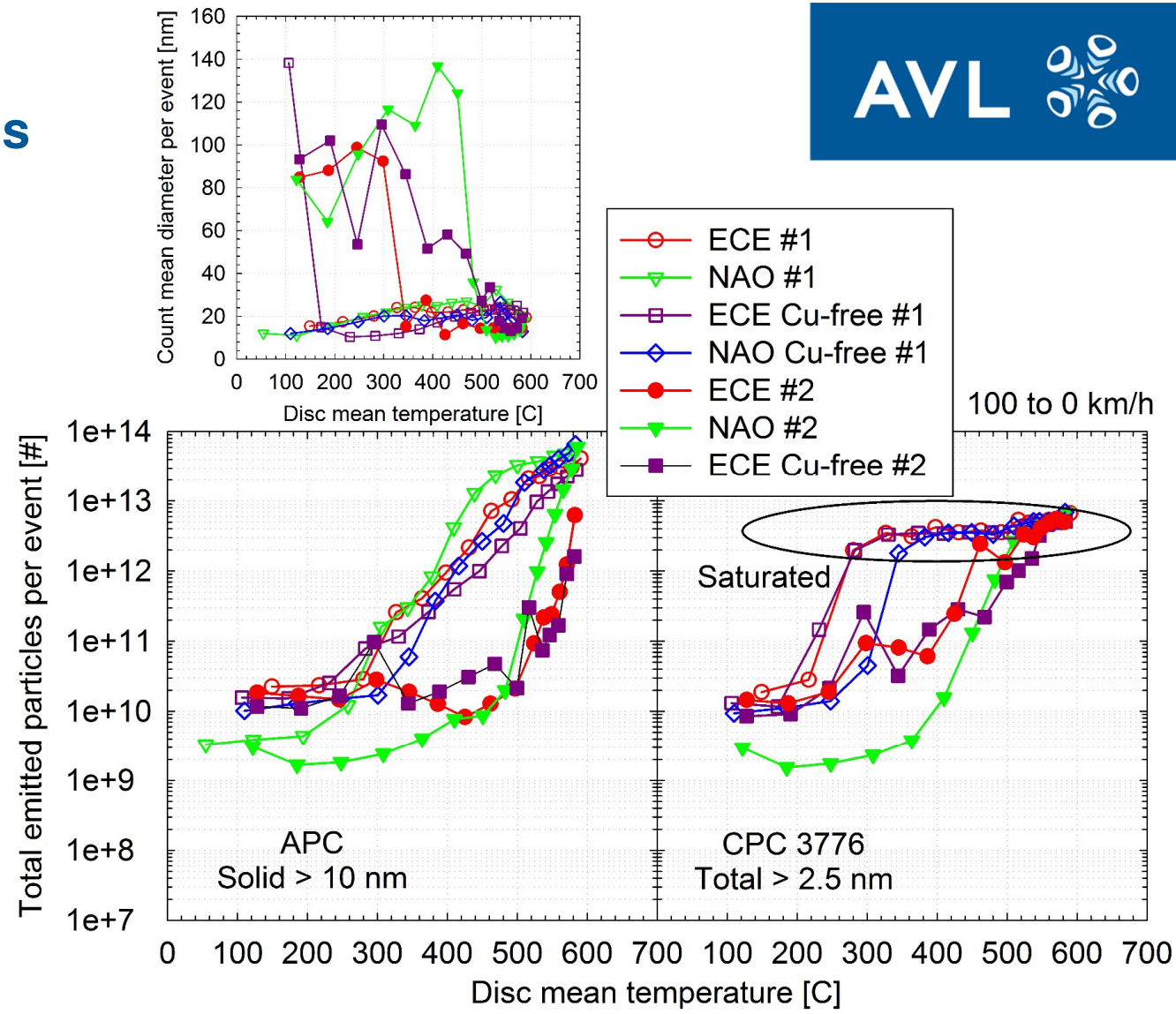


100 to 0 km/h decelerations

Fade event: Consecutive brakes from 100km/h to full stop in an attempt to raise the temperature:

- Distinct nucleation mode forms for all particles.
- Number concentrations increases by 4 orders of magnitude
- 2.5 nm CPC registered more particles (up to the point it got saturated) ➔ smaller than 10nm and/or volatile particles are present.

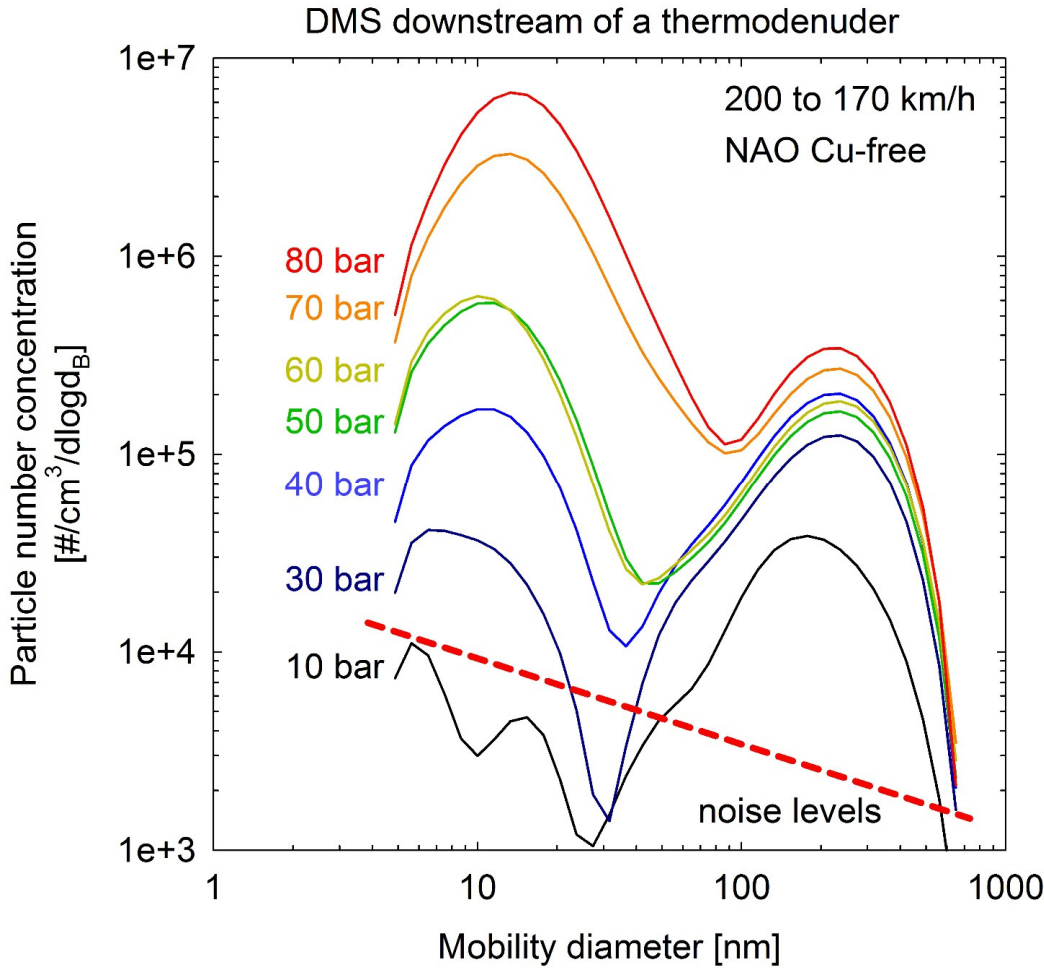
The particle emissions were reduced and the onset of nucleation mode particle formation was delayed in the second repetition



Volatility of nucleation mode particles

Dedicated tests with the DMS sampling through a thermodenuder verified that the nucleation mode particles are not volatile in the sense that they survive thermal treatment at 300 C.

No correction for particle losses was applied.

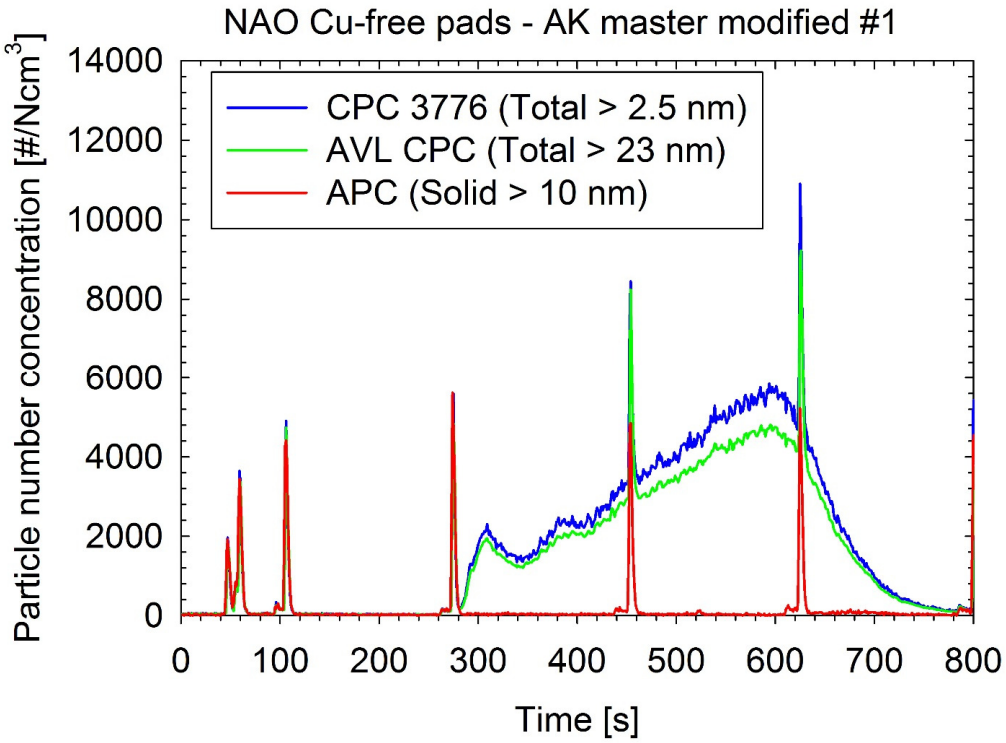


Volatile “artefacts”

In some occasions, emission events of volatile particles were registered by the instrumentation sampling thermally untreated particles.

Such events occurred typically at the beginning of the tests and considering the low temperatures they cannot be associated with oil leaks from bearing.

Perhaps related with handling of pads or tunnel during installation, but origin is unclear ➔ Importance of handling the pads and conditioning of sample (dilution air and/or thermal treatment)



Conclusions

- Real time size distribution measurement instrumentation can give valuable insights on the nature of emitted particles. However, care needs to be taken when interpreting the reported number concentrations.
- Transparency of the calculation procedure as well as definition of appropriate calibration approach is important.
- Depending on the test conditions, particle number concentrations can be low (i.e. <10000 #/cm^3 for WLTC). Dilution concepts with low background levels and instrumentation with low detection levels are required for proper quantification of particle number emissions.
- The braking events over WLTC produce solid particles peaking above ~100 nm.
- Under more aggressive braking events, a distinct nonvolatile nucleation mode is observed sometimes even peaking below 5 nm.
- Concentrations of this nucleation mode exceeded the range of both full flow and partial flow CPCs. For a precise concentration measurement a dilution system will be necessary to cover the wide range of possible particle concentrations.
- The prehistory of pads can have a significant effect on the particle number emissions from brake events.
- Conditioning of tunnel and pads needs to be carefully considered to avoid/control artefacts.

Outlook / PM measurements

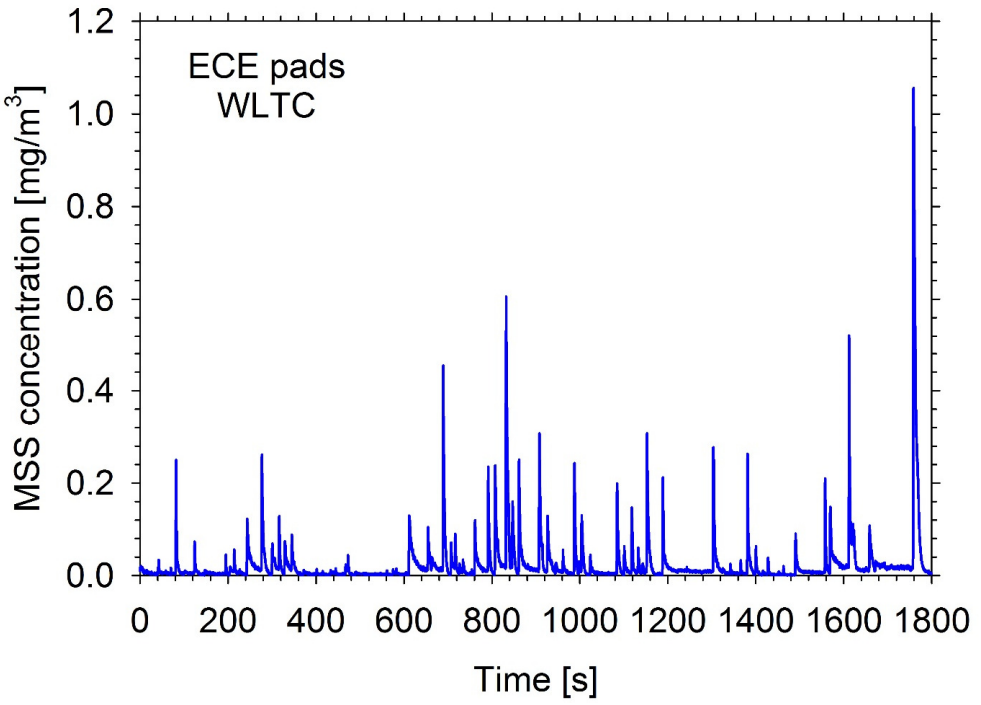
Mass concentrations measured by the MSS only represents the contribution of black carbon and perhaps some other IR light absorbing materials.

Gravimetric samples suggested that light absorbing matter only constitutes ~10% of the total PM being emitted.

For this specific conditioned ECE pad, the total PM and solid PN emission rates for a single pad over a WLTC were:

~5 mg/km > Euro 6 standard (4.5 mg/km)

5×10^9 #/km ~ 1% of Euro 6 standard (6×10^{11} #/km)

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