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Physical and chemical characterization of brake and tyre wear measured on a custom-build combined dynamometer

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Zentrum für Digitalisierungs- und Technologieforschung der Bundeswehr

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NextGenerationEU

Introduction

Brake and Tyre wear studies in the past have yielded vastly different results

Problem: Large difference in testing parameters

- Dynamometer designs (geometry, choice of materials)
- Vehicle simulation (weight, air resistance, inertia)
- Testing procedure (embedding, test cycles, cooling air flow rates/ temperatures)

When it is already difficult to compare studies on a single source – how can we compare brake & tyre wear?

Brake dynamometer

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- Custom-build brake dyno build in cooperation with AiP Automotive and HDC Blueprints
- Build to match the GTR requirements as close as possible, with only minor deviations
- Brake wear data on 2 pad types recently published

Neukirchen et al. 2025, *Journal of Hazardous Materials*

ELSEVIER

Journal of Hazardous Materials
Volume 482, 15 January 2025, 136609

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AiP
automotive

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Tyre module / combined dyno

- Add-on to existing infrastructure
- Roller from chassis dynamometer is pressed against tyre from the side
- Surface of roller consists of sintered metal, but can be exchanged in the future to mimic road interface more accuratly
- Second enclosure around roller to minimize background concentrations

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Tyre module / combined dyno

- Updated dynamometer is capable of single and simultaneous measurement of both sources

- Future measurements planned on ILS III brake wear components to correlate data to EURO 7 emission limits

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Test parameters

Emission source	Brake wear	Tyre wear
Simulated vehicle	SUV (1895 kg)	
Test cycle	WLTP Brake	Custom cycle
Duration	4.4 h	4.3 h
Total distance driven	192 km	350 km
Ø speed	43.7 km/h	80.8 km/h
Temperature	23 °C	12 °C
Test components	OEM LM Pad & Aftermarkt NAO Pad	All season + Winter tyres

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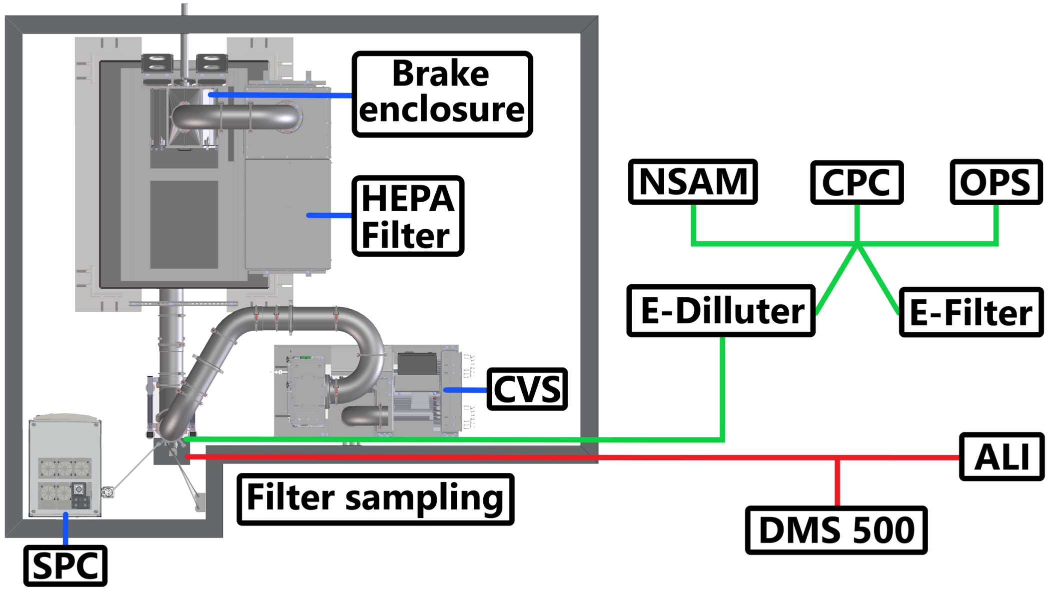
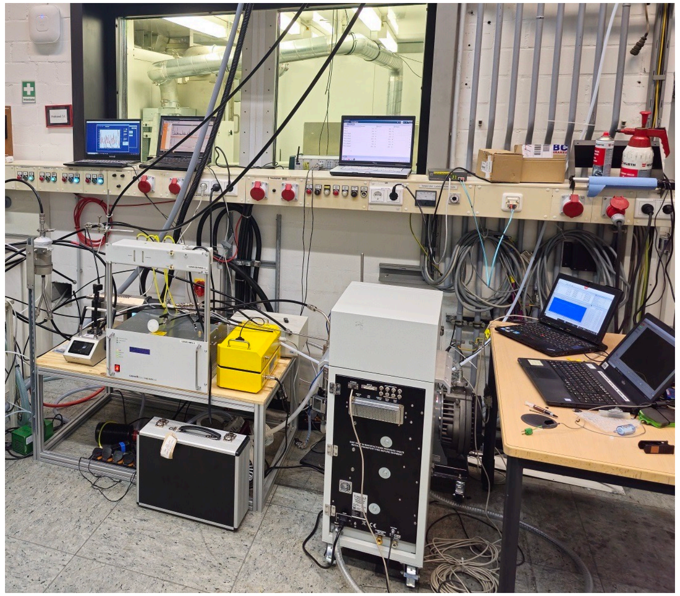
Online instrumentation

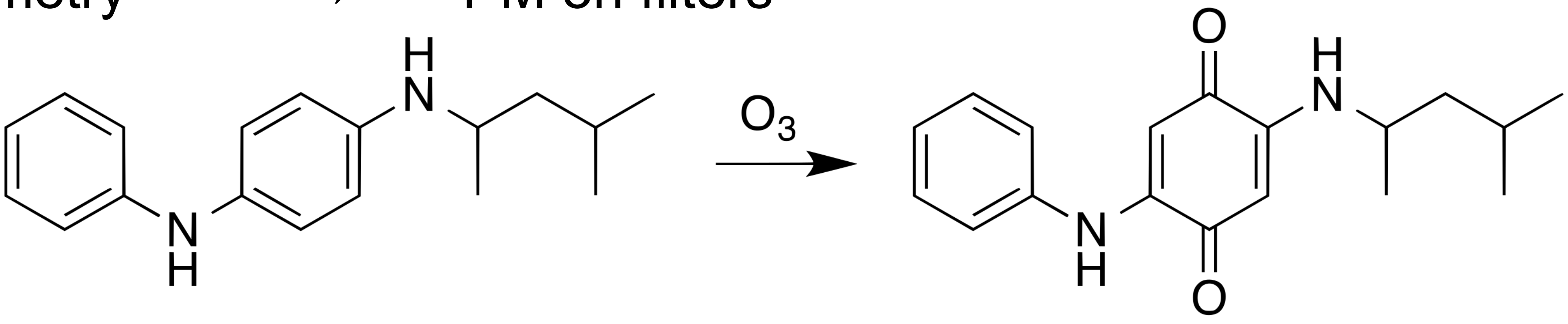
- CPC → PN
- SMPS & DMS → Size distribution (10 nm to 1000 nm)
- OPS → Size distribution (300 nm to 10 µm)
- Filter sampling → Offline analysis (PM_{10} & $PM_{2.5}$)





Offline instrumentation

- ICP-MS/MS → Metal content (Fe, Cu, Ba, Sb, …)
- SEM/EDX → Morphology & single particle elemental spectra
- LC-MS/MS → 20 Organic tyre marker molecules (6-PPD,…)
- Gravimetry → PM on filters



6-PPD   6-PPD Quinone

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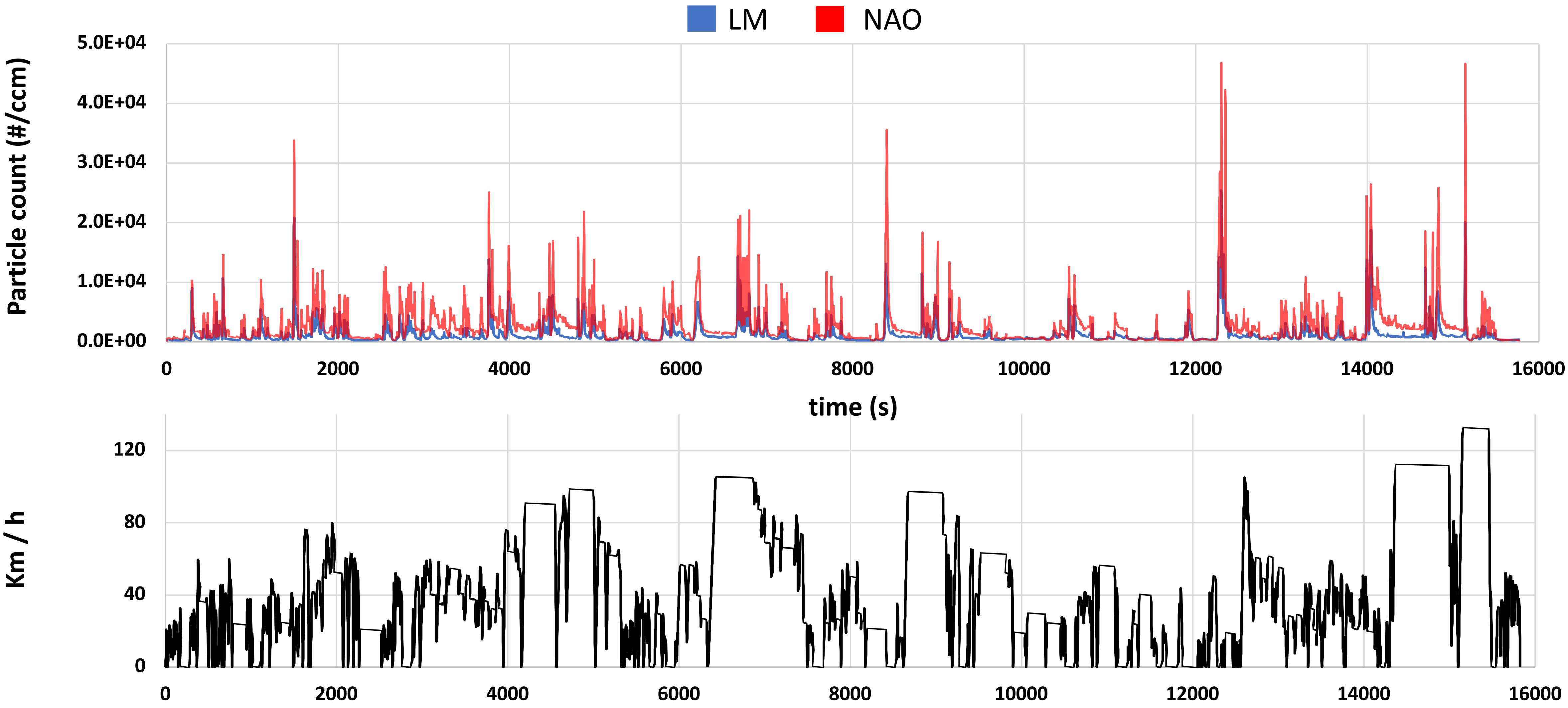
Brake wear - Overview

- PM_{10} values of both pads more than 2 x higher than maximum value of EURO7
- NAO pad mass emissions higher than LM due to wrong labeling from manufacturer (13.9 % of Fe found via ICP-MS)

Brake pad	NAO	LM
geometric mean (nm)	143	123
TPN (#/km)	2.50×10^{10}	1.37×10^{10}
PM_{10} (mg/km)	16.3	15.1
$PM_{2.5}$ (mg/km)	7.2	5.4

Brake wear - PN



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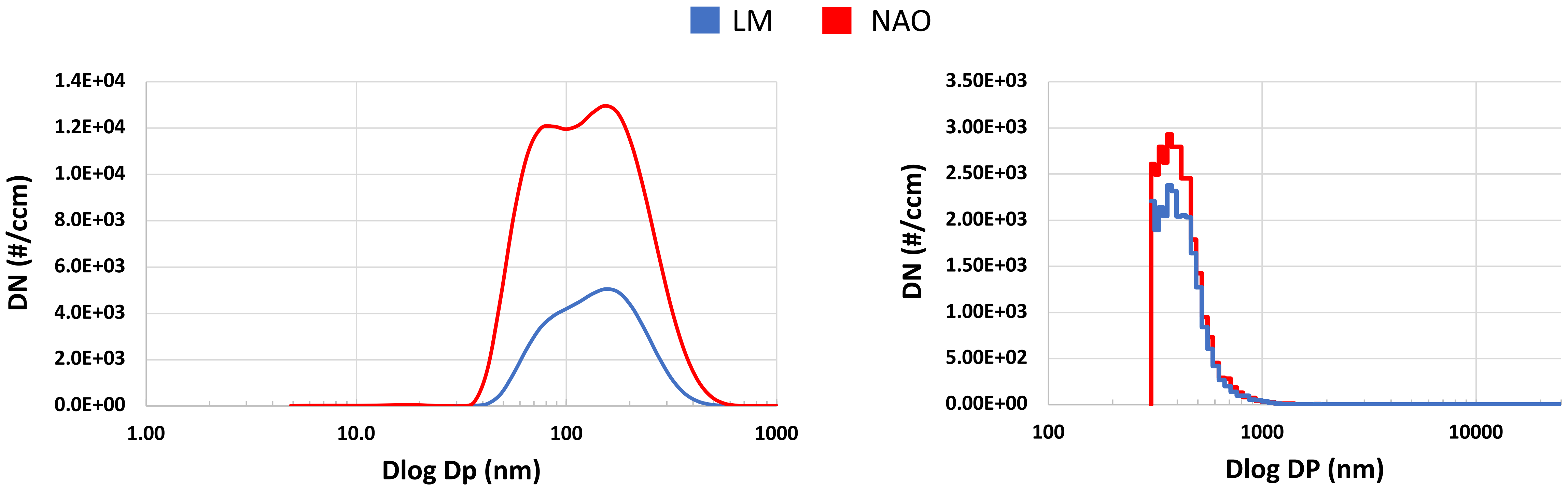
Brake wear – size

- Similar PN size distribution for both pads
- Considerable fraction of particles in the < 100 nm range



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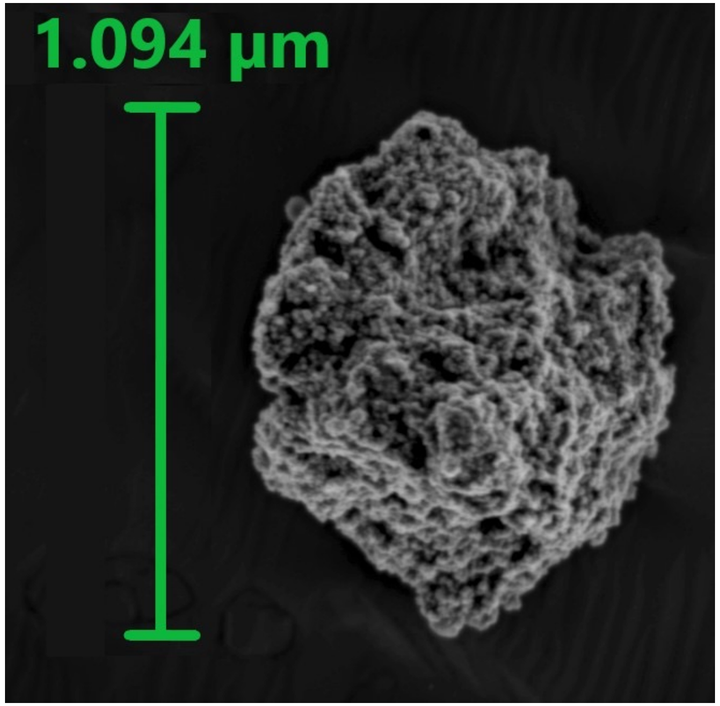
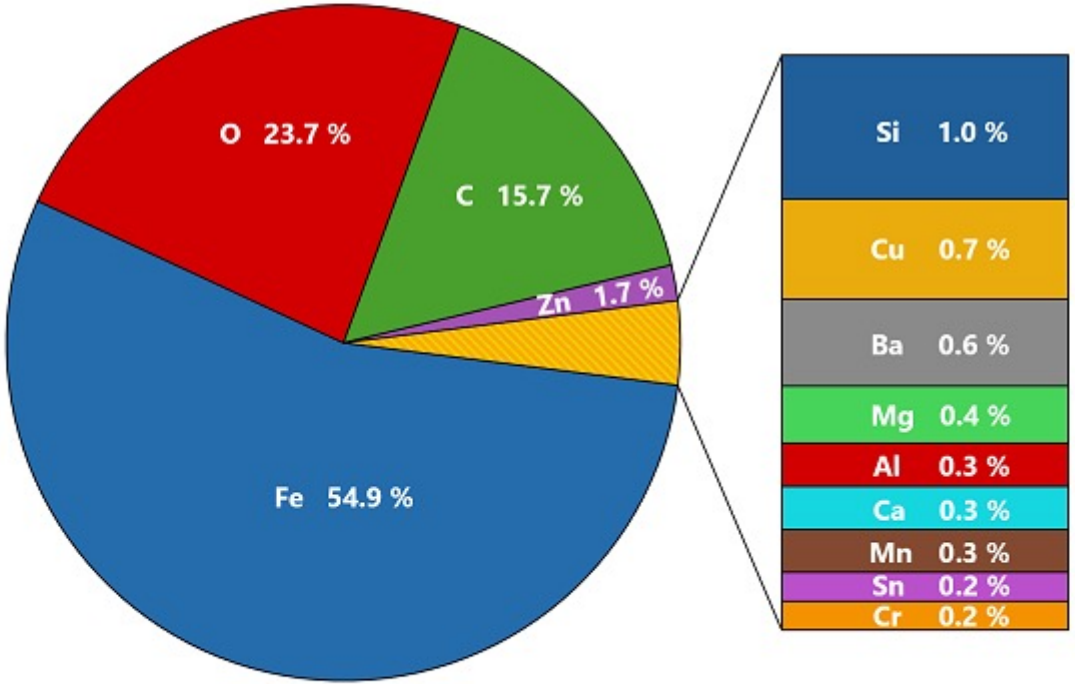
Brake wear - Morphology

- Sharp and rough edges typical for abrasion particles
- Diverse mixture of heavy metals found in particles





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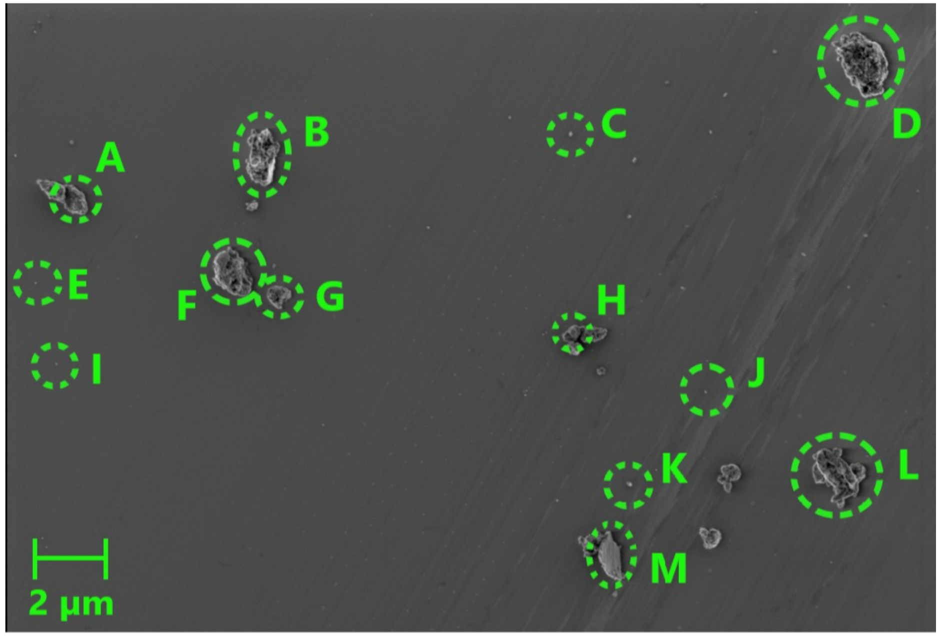
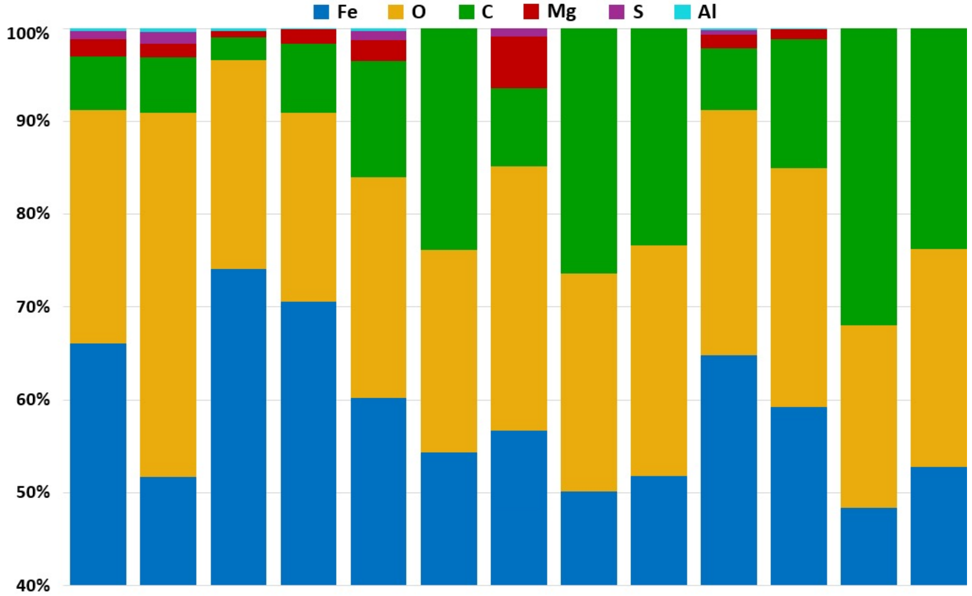
Brake wear – SEM/EDX

- High Fe contents in almost all particles
- Similar spectra over all size ranges and for both pads
- High metal concentrations also found in >100 nm particles





Particle	A	B	F	G	D	C	H	J	K	M	L	E	I
Size in nm	763	1530	1310	514	1760	86.6	629	61.7	143	1430	1470	33.4	56.4

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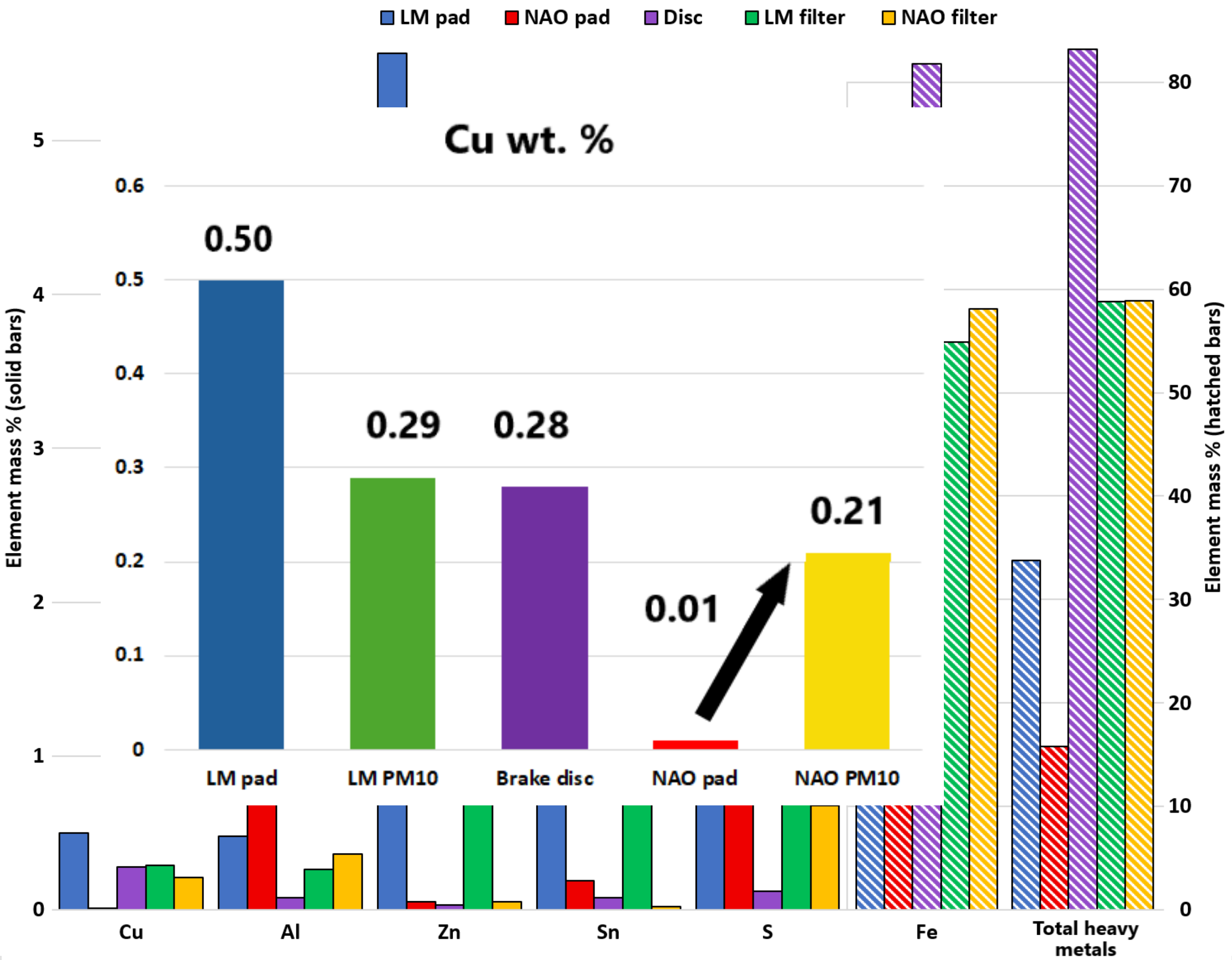
Brake wear – Brake disc influence



- Large influence of wear from the brake disc observable
- Particles from NAO pad increased from 0.01 to 0.21% of Cu in filter samples

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Tyre wear - Nanoparticles

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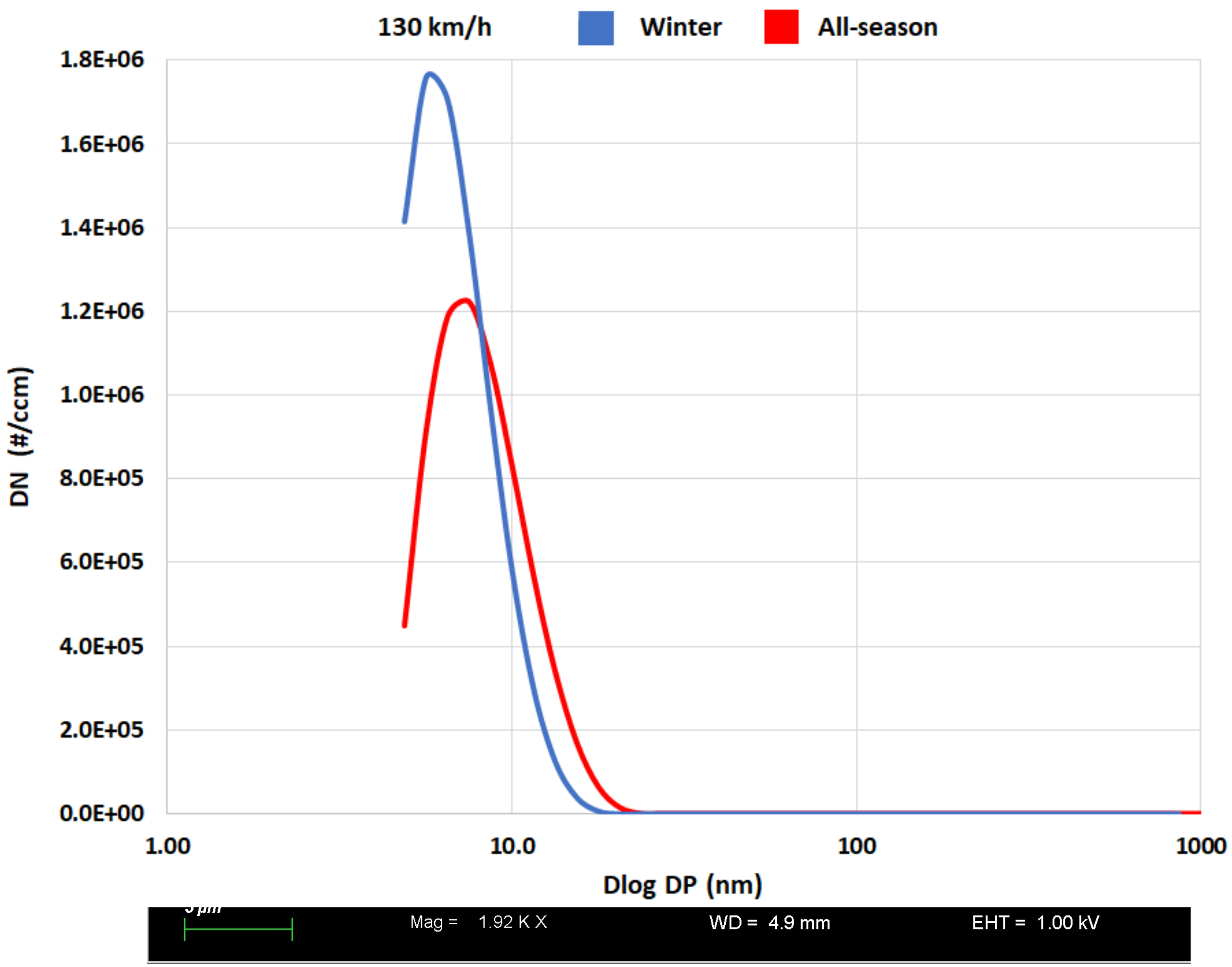
- Tyre wear commonly associated with large particles >10 µm
- While true for PM, recent studies indicate that high numbers of volatile/ semi-volatile NPs are also generated
- For lower speeds also PN modes at 50 nm & 110 nm visible



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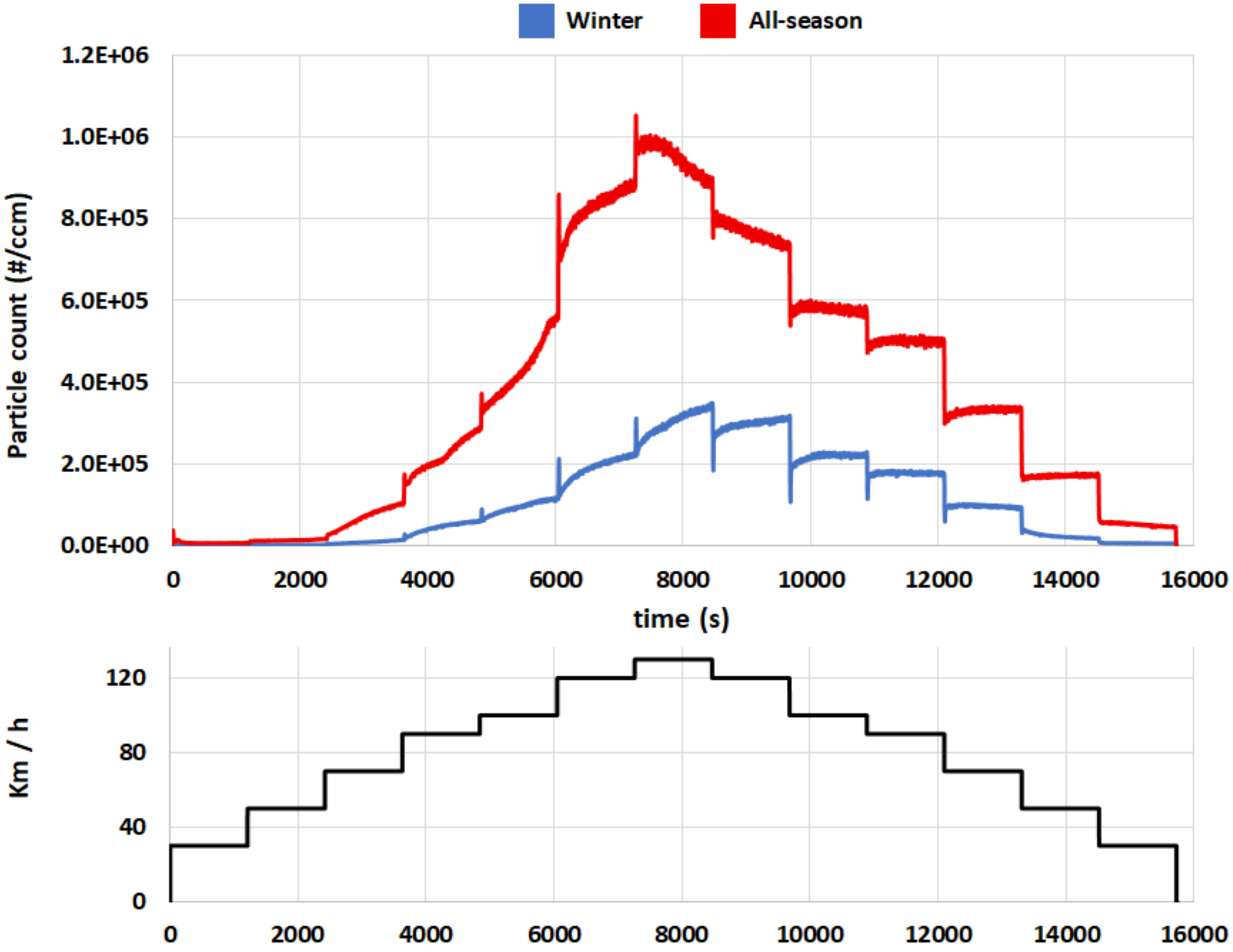
Tyre wear - PN

- 3 orders of magnitude increase in PN from 30 – 130 km/h
- PN emissions unstable until thermal equilibrium is reached
- All-season tyre showed ~ 3 times higher PN



Tyre wear - Overview

- At higher speeds both tyres formed large amounts of volatile NPs
- PM_{10} one order of magnitude lower than brake wear
- All-season tyre PN emissions higher, however Winter tyre emitted more PM

Tyre type	All - season	Winter
geometric mean (nm)	7.8	8.1
TPN (#/km)	6.73×10^{10}	2.07×10^{10}
PM_{10} (mg/km)	0.43	1.56
$PM_{2.5}$ (mg/km)	0.31	0.80

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Summary

- Both sources, although beeing abrasion derived, generated considerable amounts of nanoparticles
- Brake wear measurements revealed a high contribution of the brake disc
- Tyre wear produced high numbers of volatile particles
- Although emitting more PN, tyre wear PM levels were 1 order of magnitude lower than brake wear

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ULTRHAS
ULtrafine particles from TRansportation - Health Assessment of Sources

Thank you for your attention!

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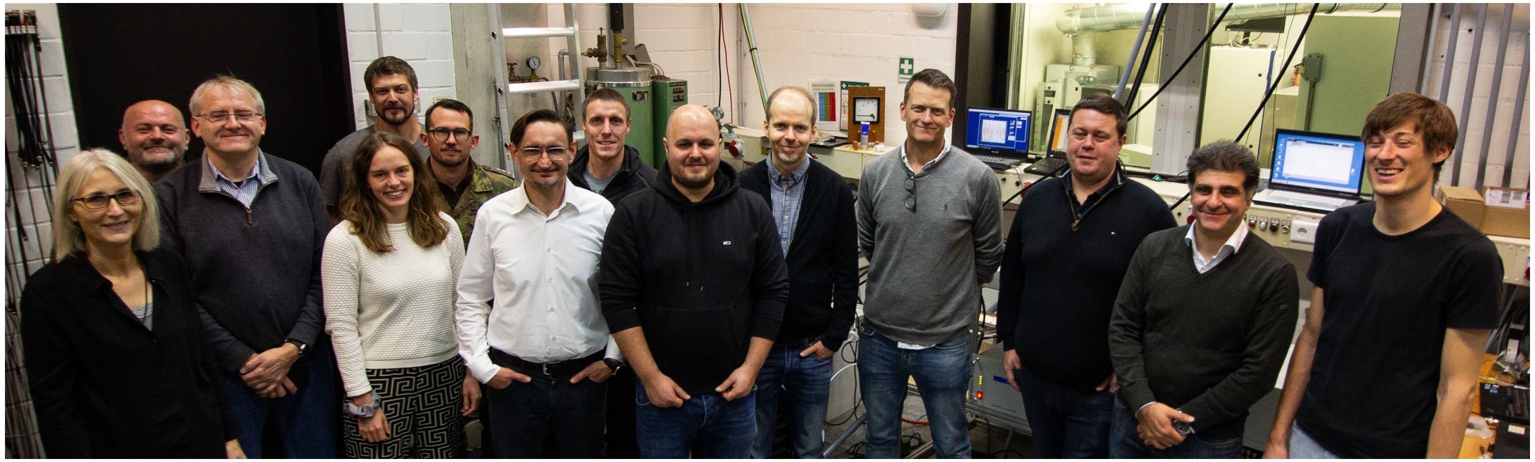

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NIPH Norwegian Institute of Public Health

HelmholtzZentrum münchen German Research Center for Environmental Health

UNI FR Université de Fribourg Universität Freiburg

Universität der Bundeswehr München

University of Eastern Finland

Universität Rostock Traditio et Innovatio

Finnish institute for health and welfare

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Results (ICP-MS bulk material)

- High Fe concentration in NAO pad
- Typical Brake markers visible in varying concentrations

Element %	LM Pad	NAO Pad	Brake disc
Fe	27.63	13.90	85.91
Cu	0.54	0.01	0.26
Cr	0.28	0.03	0.19
Mn	0.11	0.08	0.54
Al	0.65	1.94	0.16
Zn	6.75	0.11	0.04
Ba	2.01	0.02	0.00
Heavy metals	35.34	14.23	87.09

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Results (ICP-MS particles)

- Particles from NAO pad contained more Fe than LM pad
- Typical Brake markers visible in varying concentrations

Element %	LM Pad		NAO Pad	
	% of PM10	% of PM2.5	% of PM10	% of PM2.5
Fe	54.85	54.46	58.13	57.19
Cu	0.29	0.28	0.21	0.20
Cr	0.61	0.60	0.13	0.13
Mn	0.29	0.29	0.31	0.31
Al	0.26	0.24	0.36	0.28
Zn	1.46	1.45	0.05	0.01
Ba	0.41	0.40	0.01	0.00

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