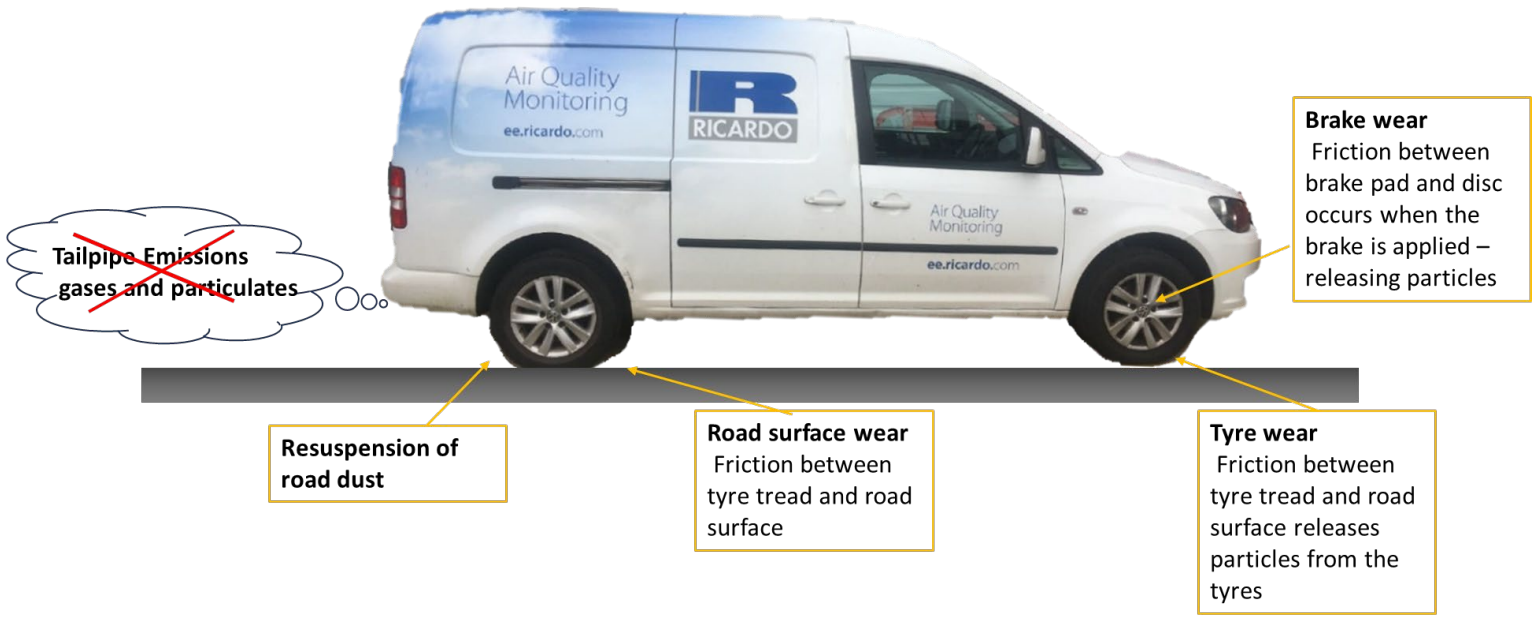
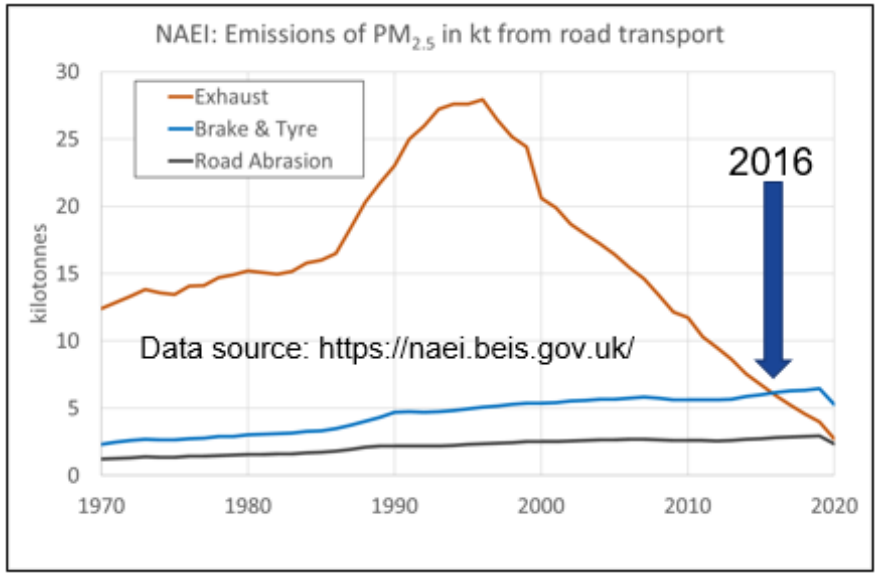
Development of a system to measure real world particle emissions from brake wear

Louisa Kramer, Jon Andersson, Michael Campbell, Ian Marshall, John Norris, Simon de Vries, Gary Waite, Jason Southgate and John Norris (Ricardo), Arup AECOM consortium, UK Department for Transport (DfT)

Non Exhaust Emissions (NEE)





International work on regulation

- UNECE is developing internationally recognised test procedures to measure brake and tyre particles

- Measuring **tyre and road** wear particles is technically very complex
  - As of February 2024, UNECE's World Forum for Harmonization of Vehicle Regulations have endorsed two methodologies for measuring tyre abrasion (UN Regulation No. 1172345).

- Work on measuring **brake** wear is more advanced
  - Global Technical Regulation (GTR 24) "Laboratory measurements of Brake Emissions for Light Duty Vehicles" was published in 2023.
  - EU has proposed limits on car (M1/N1) brake emissions within Euro 7, with initial limits set, during brake dynamometer testing, at 7 mg/km with ~50% higher limits for LCV.
  - Proposal for this limit to drop to 3 mg/km in 2035

UNITED NATIONS
ECONOMIC COMMISSION
FOR EUROPE

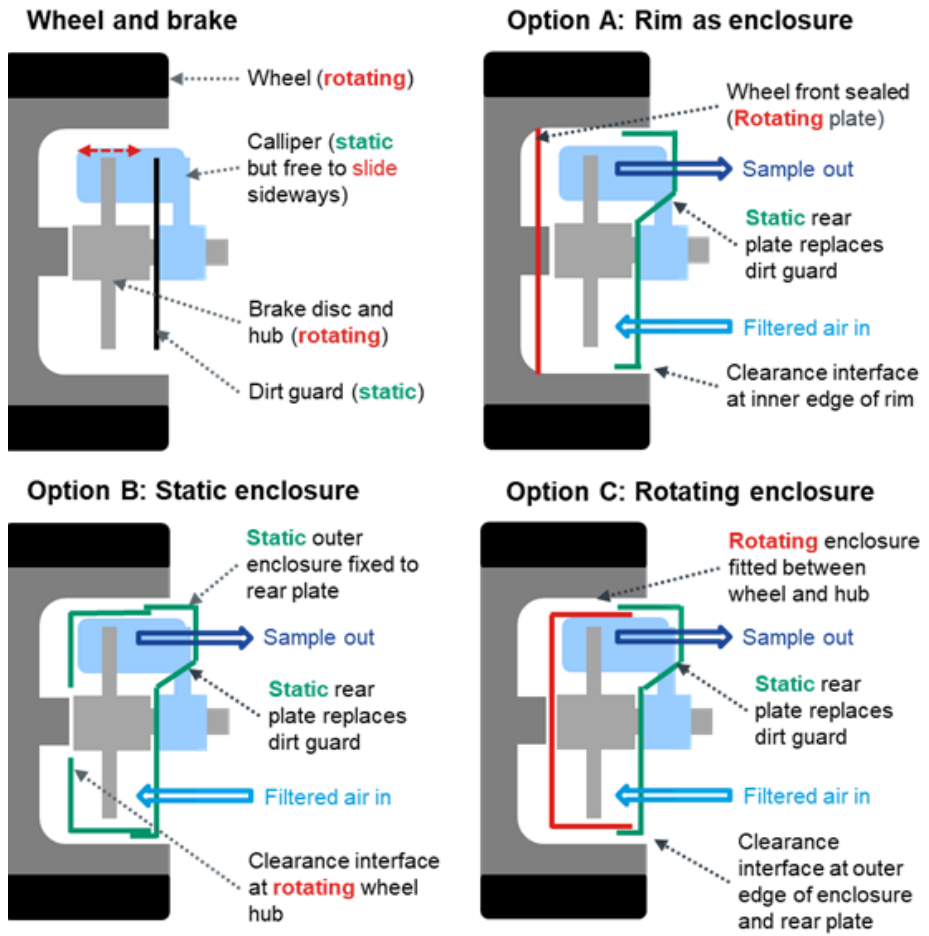
Measurement of Brake Wear

- Ricardo are supporting the Department for Transport in the UK to develop an effective system and methodology for measuring and characterising particles emitted from brake and tyre wear under **real driving** conditions

Primary aim is to develop emissions factors

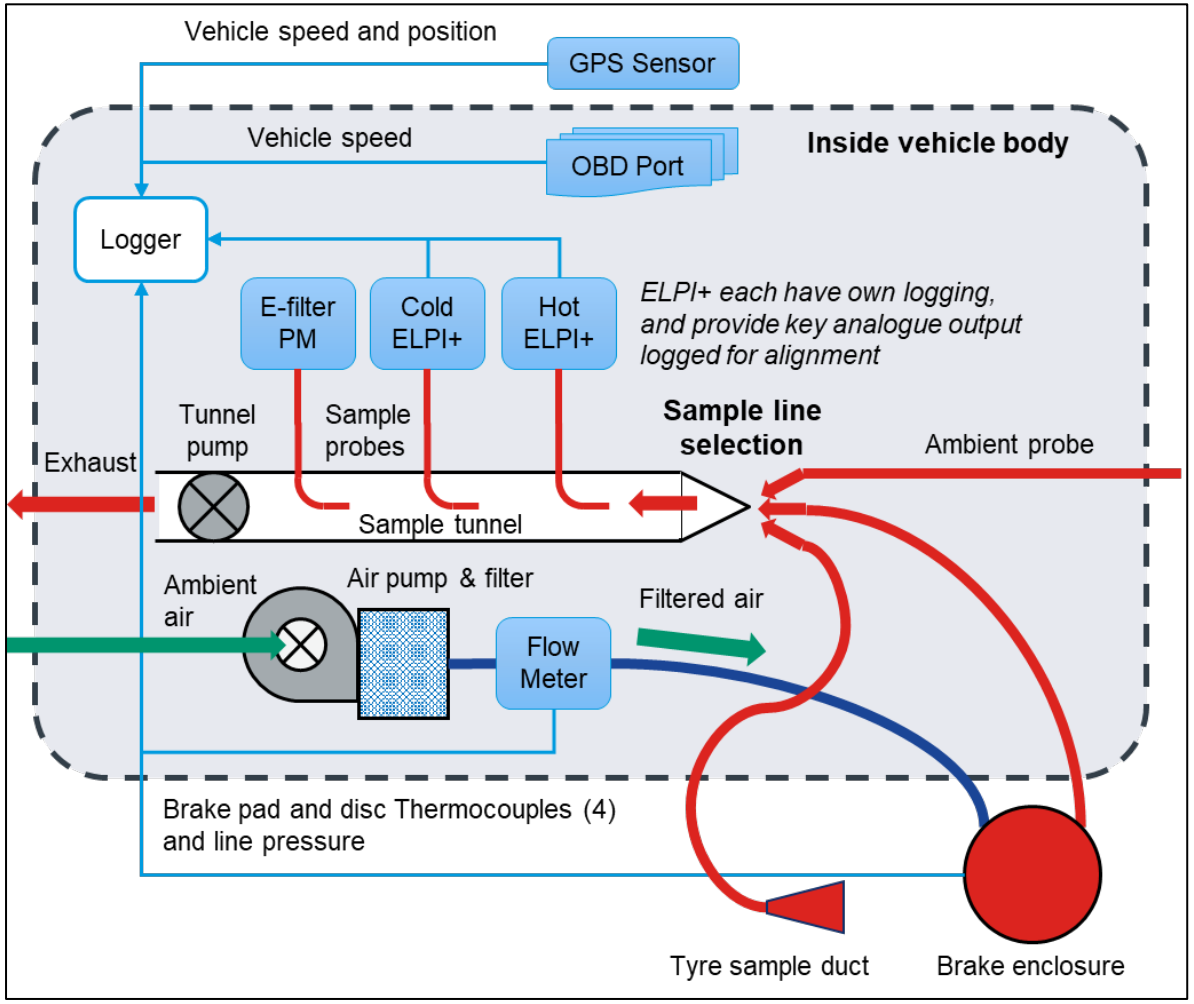
- In developing the system there was a need to consider:
  - A common sampling system and measurement equipment which can be used for both brake and tyre wear
  - Representative sample collection of particles
  - Repeatable and reproducible measurements
  - Careful consideration of background particles (i.e., re-suspension of road dust, tailpipe emissions)
  - Power and spatial demands of the system

System Design Example – Brake Wear Sampling



3 enclosure approaches used – to explore application to different braking system types

System Design – Instrumentation

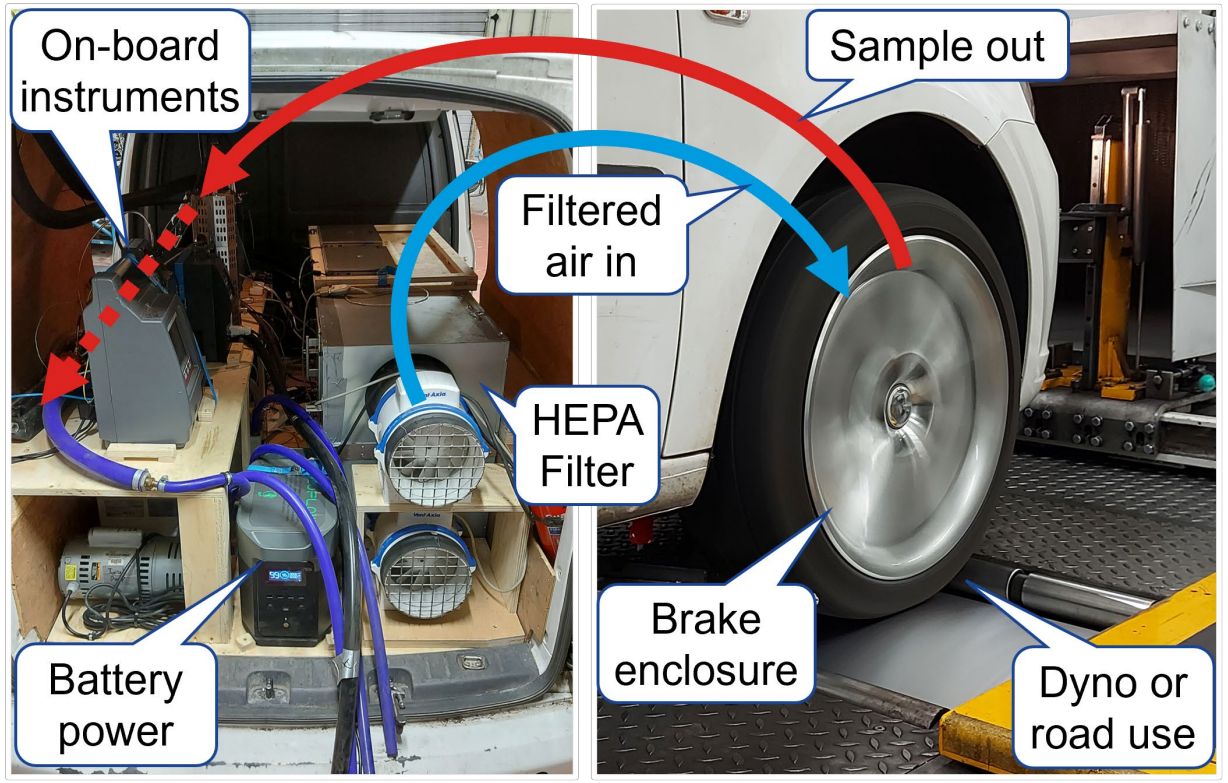


Sample analysis included:

- Combination of two Dekati® Electrical Low Pressure Impactors (ELPI+) for real-time particle size distribution and concentration (size range 6 nm – 10 µm)
  - "Cold" ELPI+ measures solid and volatile particles
  - "Hot" ELPI+ includes a 180°C heated inlet to remove the volatile component of the PM
- Dekati® eFilter for real-time PM mass concentration measurements – also includes a filter for reference gravimetric determination and analysis
- Horiba SPCS PN23 system (raw) used in parallel from tunnel for lab tests

VW Caddy vehicle

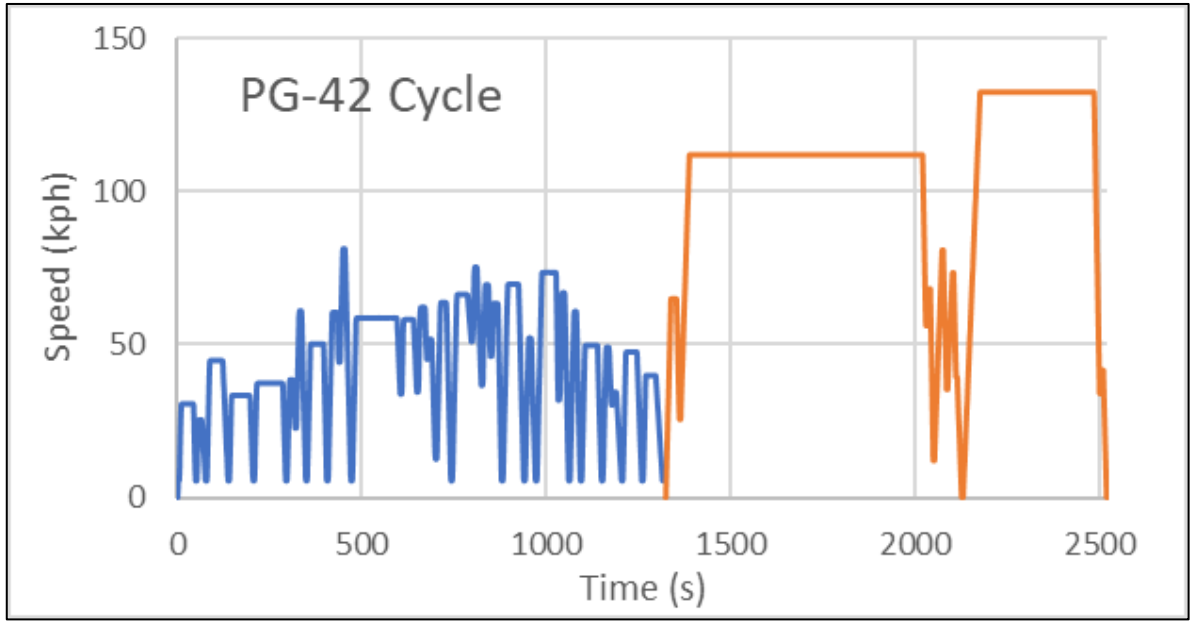
The entire system was installed to a small light duty van and measurements undertaken from the front wheel



Test Plan and Drive Cycles

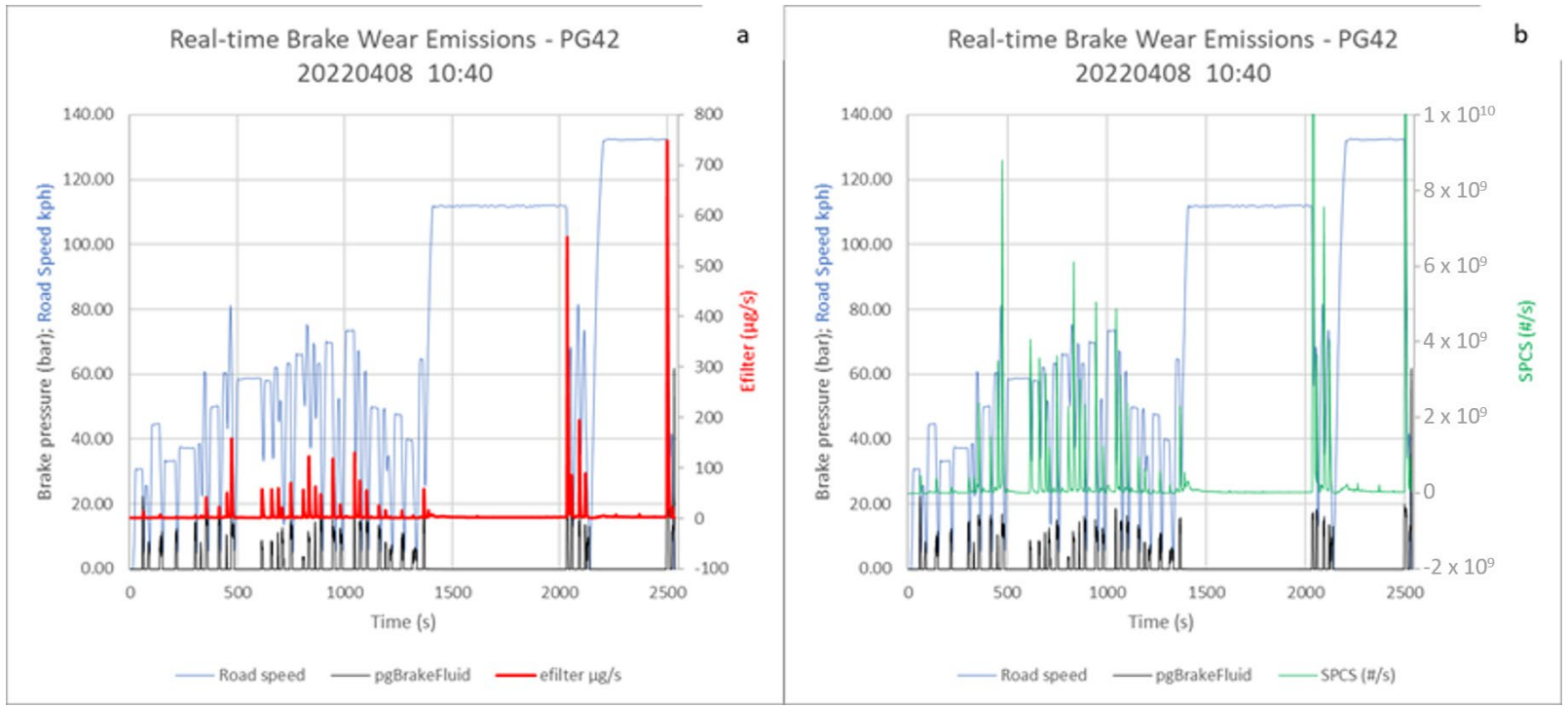
Tests	Details
Background sampling	Sampling background emissions from different inlets
Chassis Dyno	PG-42 cycles - sampling from brake and tyres
On-road/Track	Urban driving; track braking events of different magnitudes

- Repeated measurements were undertaken for all tests
- Results shown from instrumented **front** brake



PG-42: 42 minutes cycle based on high particle emitting sections of two well-known braking cycles: Worldwide Harmonized Light Vehicles Test Procedure (WLTP) and Los Angeles City Traffic (LACT) cycle

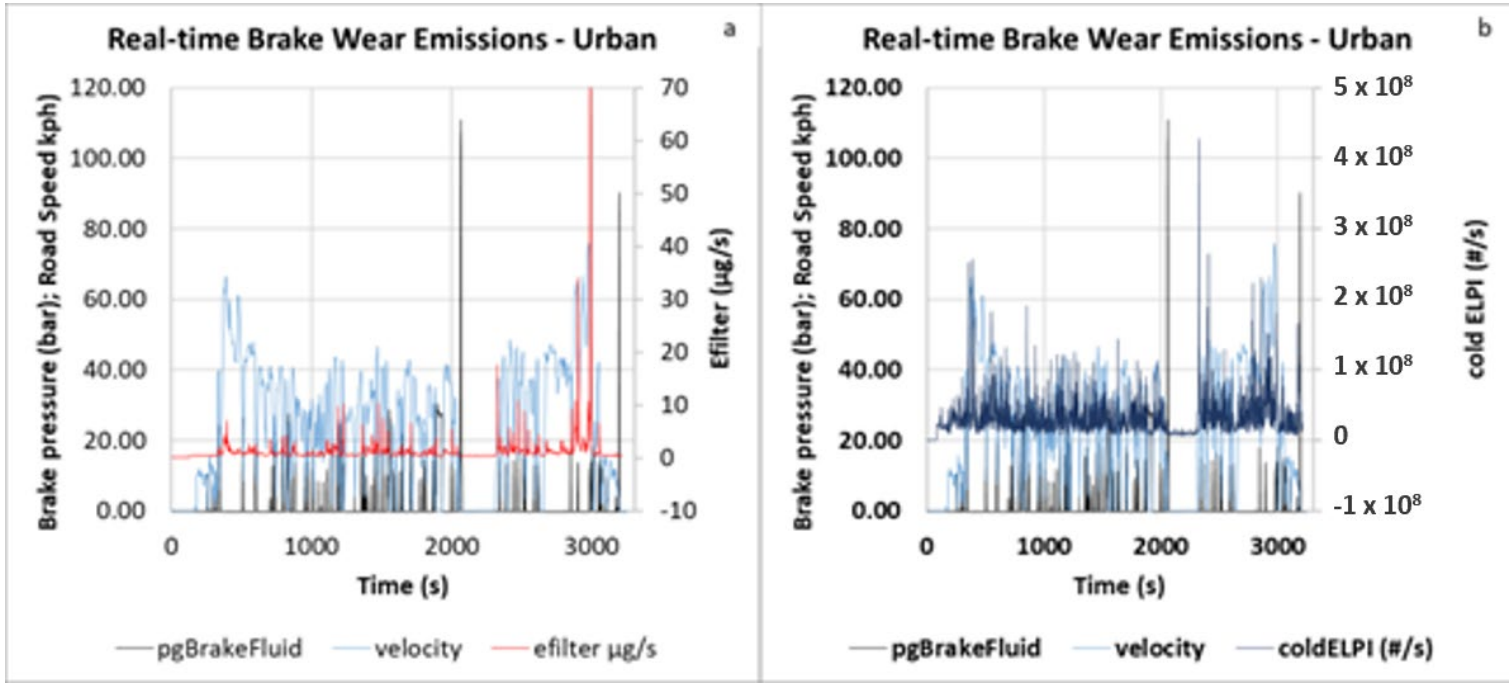
Real time brake emissions – Chassis Dynamometer



- Particle number and particle mass emissions from the hot ELPI, SPCS and eFilter coincided with increased braking pressure events on the chassis dynamometer
- Emissions from the cold ELPI were coincident, but more challenging to resolve

Baseline emissions between braking events return to very low levels (< 1% of emissions levels)

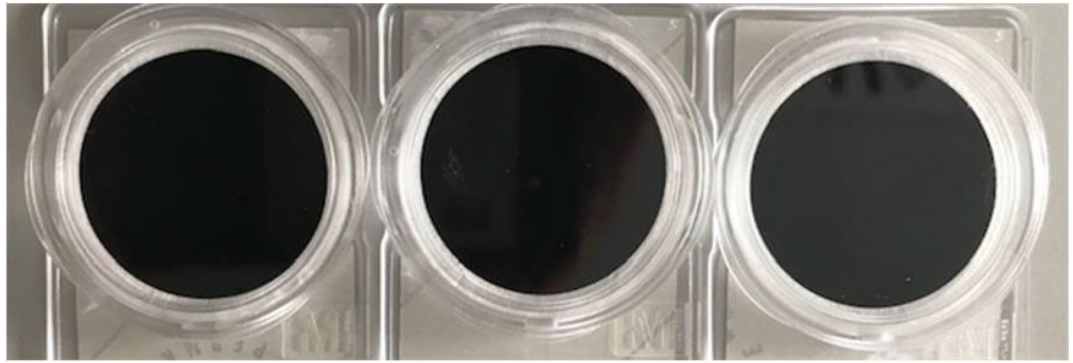
Real time brake emissions – Urban Road

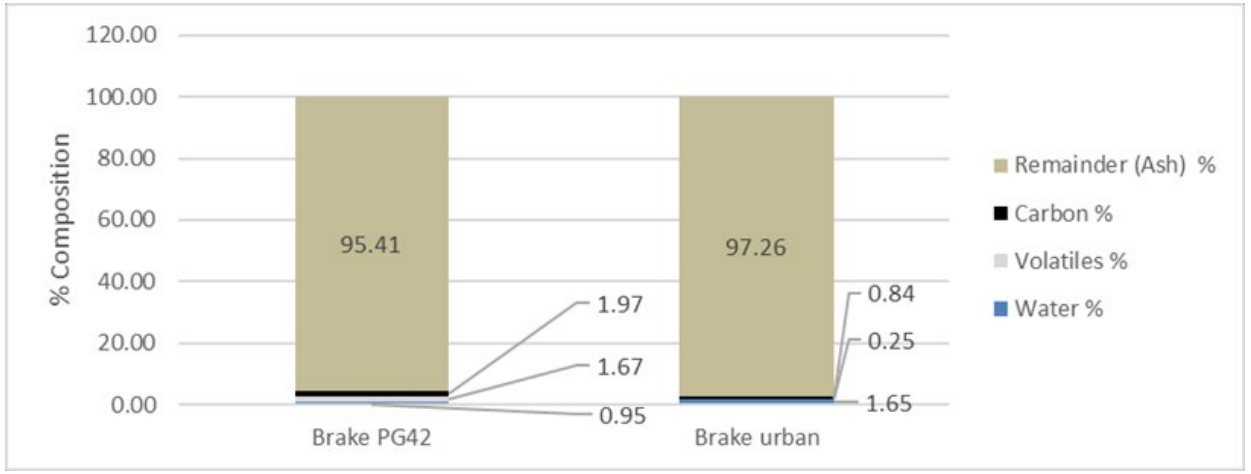


- Braking events on the urban road are representative of real-world driving
- Particle number and particle mass emissions events reported from braking overlay from the hot ELPI and eFilter
- Similar to the chassis dyno tests - emissions from the cold ELPI were more challenging to attribute to specific braking events

Thermogravimetric analysis of filters

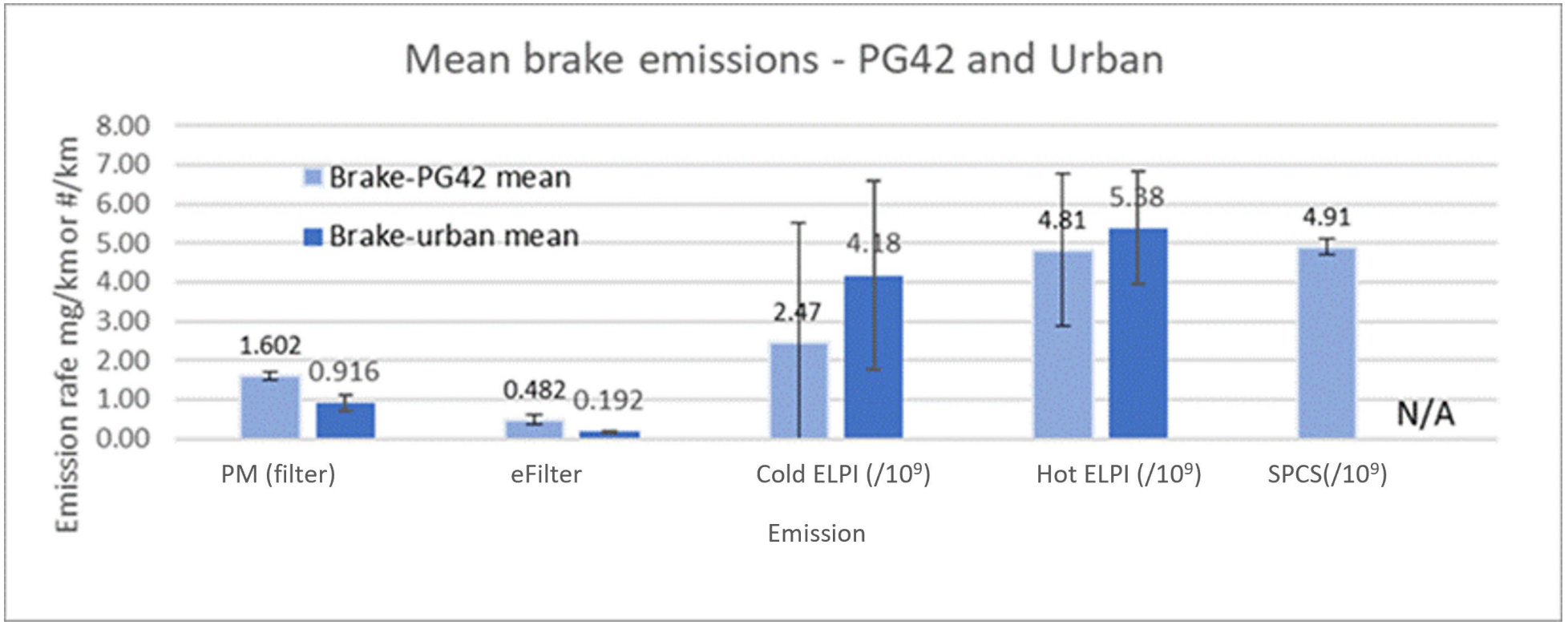
3 repeat PM filters from PG-42 brake testing



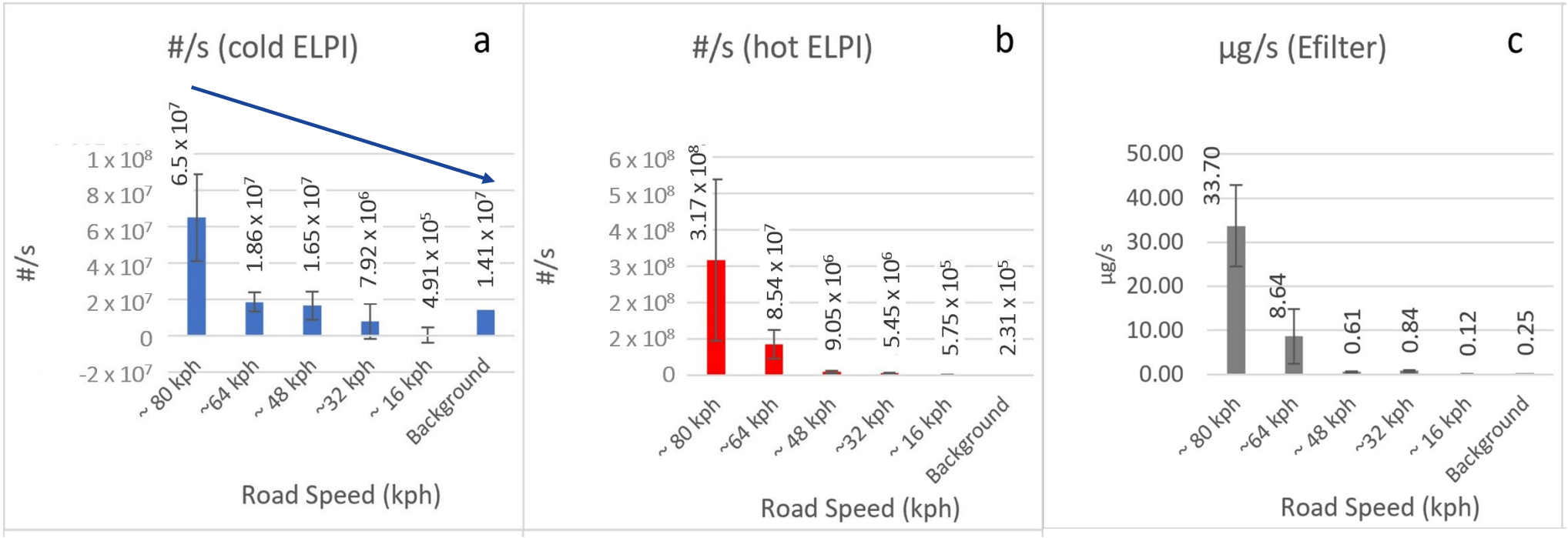


Thermogravimetric analysis of filters indicated > 95% non-volatile and non-oxidizable material

Brake emissions: Chassis Dyno and On-road

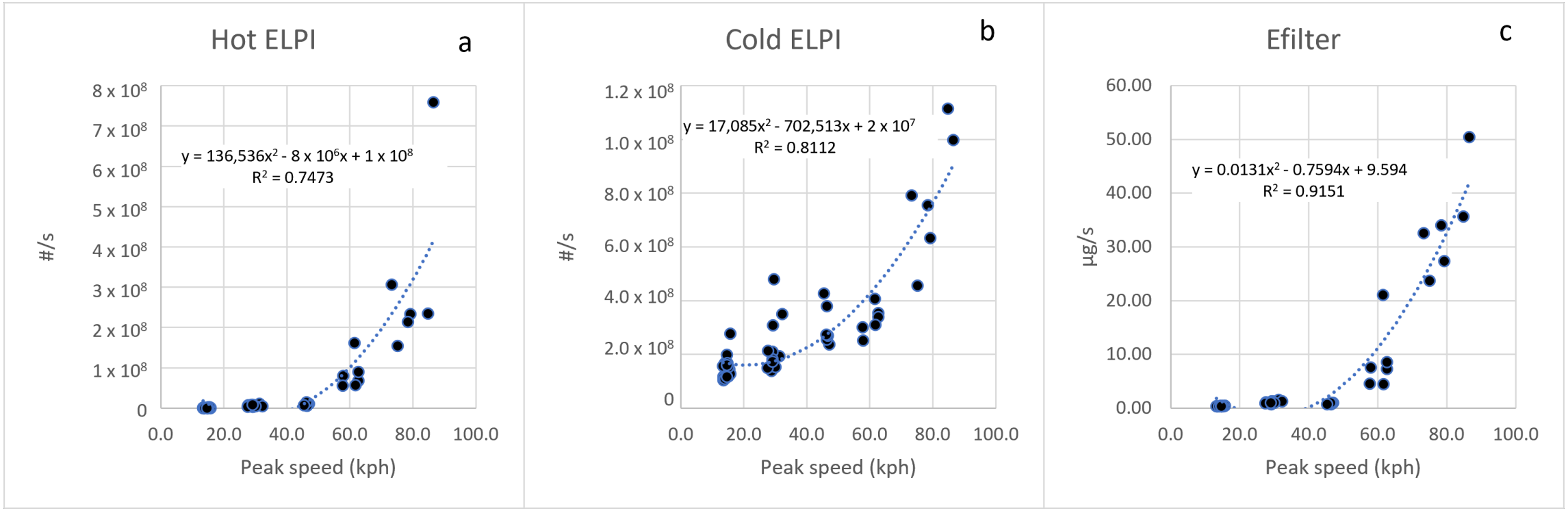


Brake emissions: Moderate braking



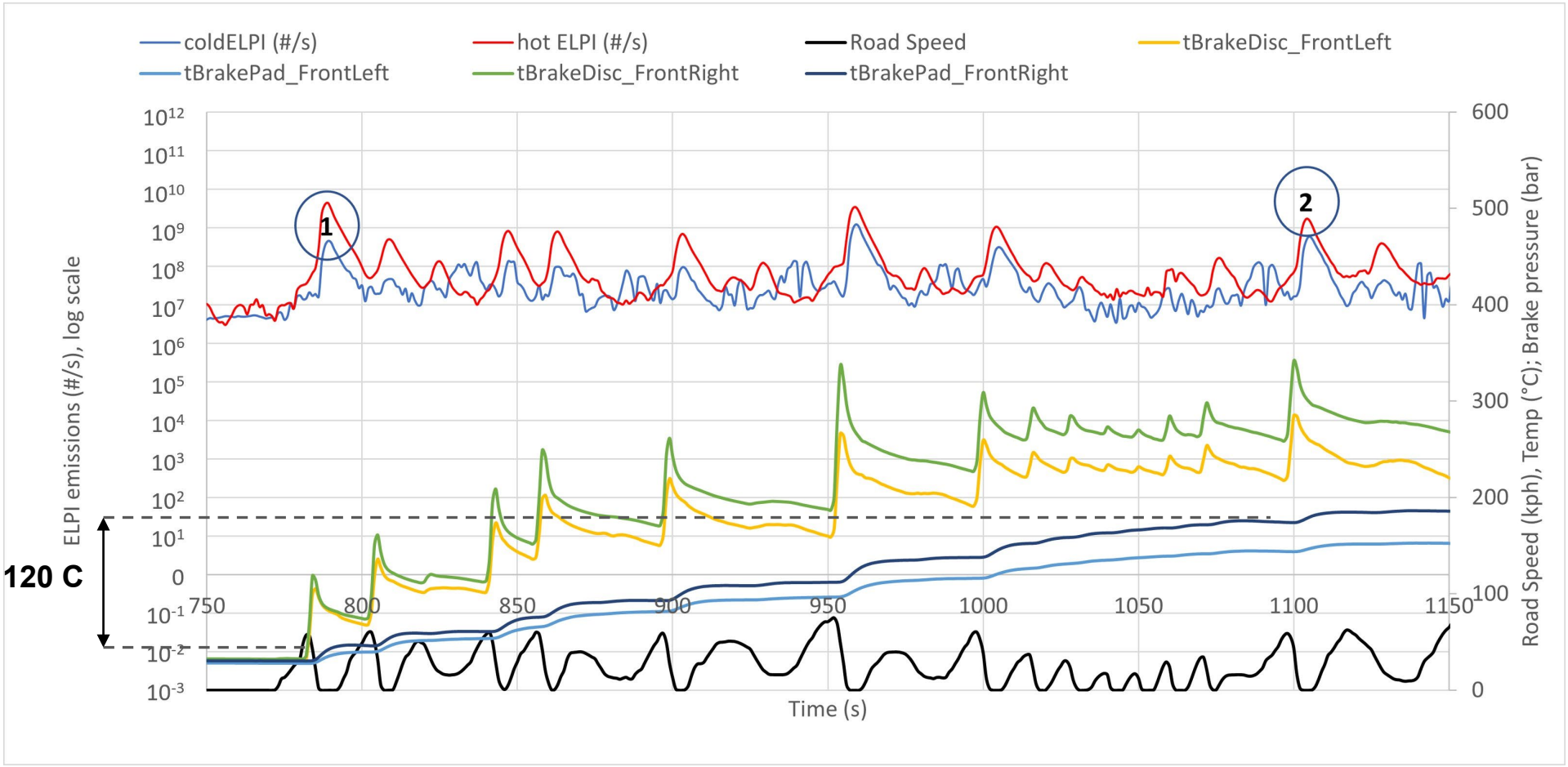
Brake emissions decreased when the initial speed at which braking was initiated was reduced.

Relationship between emissions and vehicle speed



PN and particle mass increase with peak speed following a quadratic relationship (i.e. proportional to kinetic energy).

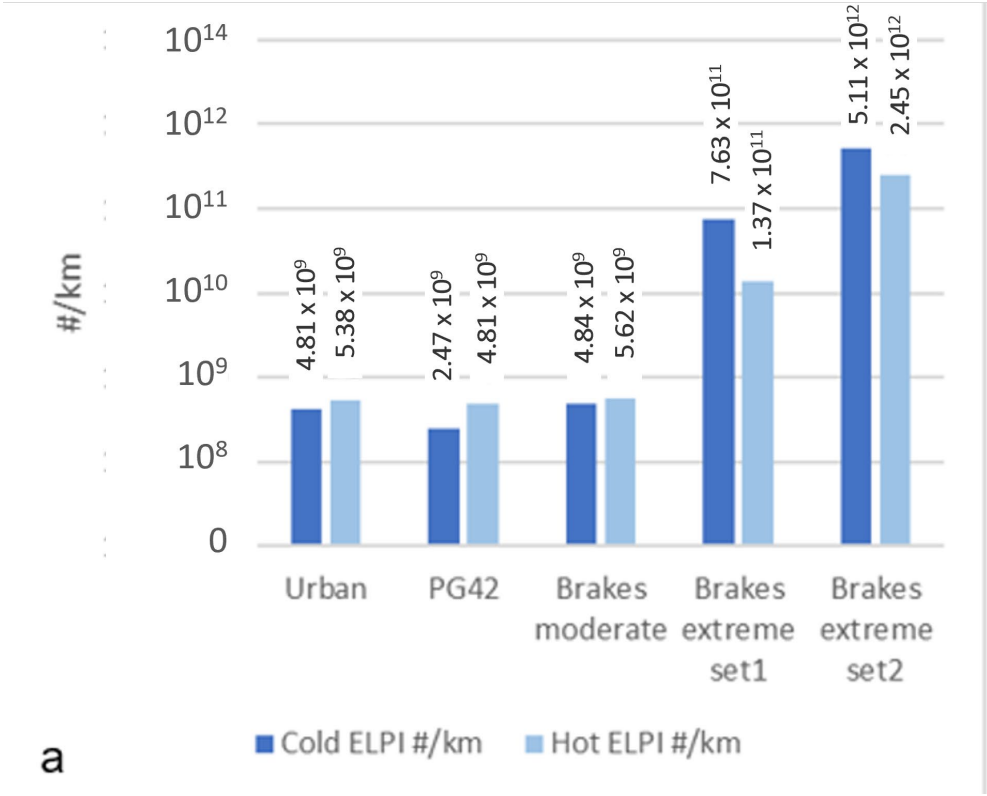
Effective of temperature on brake particle emissions

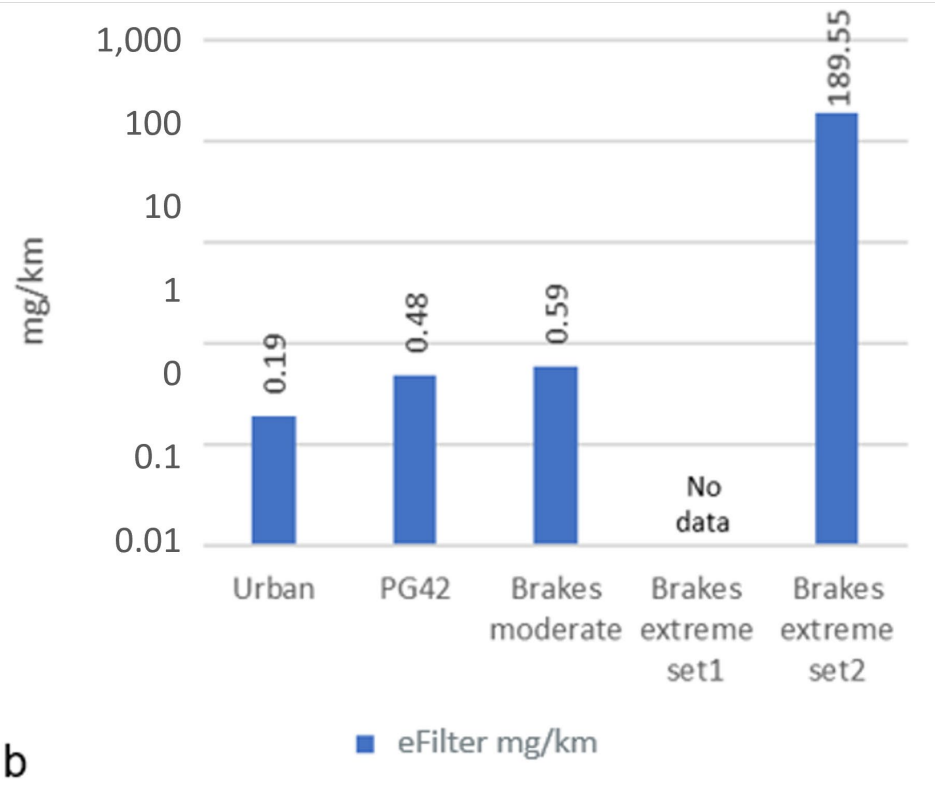


At T_{pad} < ~180 ◦C & T_{disc} < 350 ◦C temperature does not appear to have a large impact on PN emissions

Effective of extreme braking

Averaged cumulative emissions for all cycles



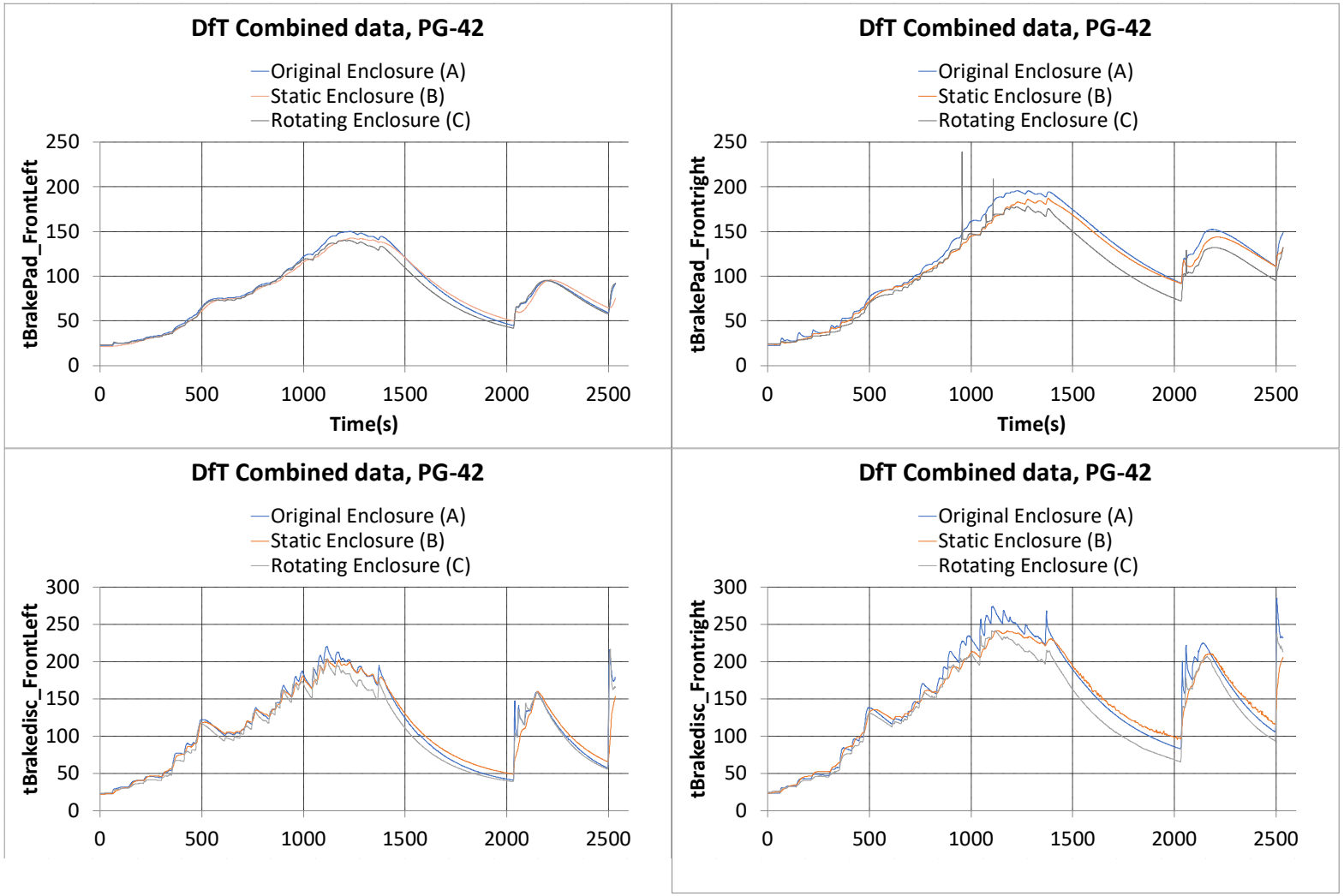


T_{pad} reached ~ 350 C during extreme braking events

PN 1-3 orders of magnitude higher

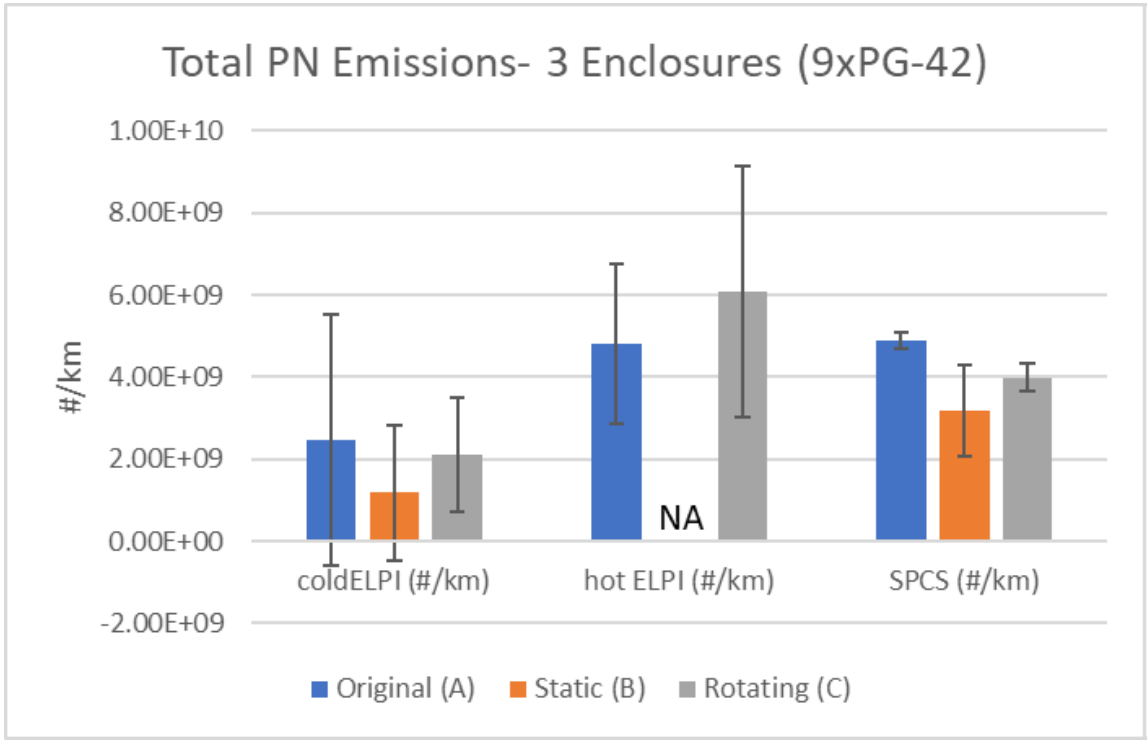
Mass emissions up to 190 mg/km

Comparison between 3 brake enclosure designs - Temperature

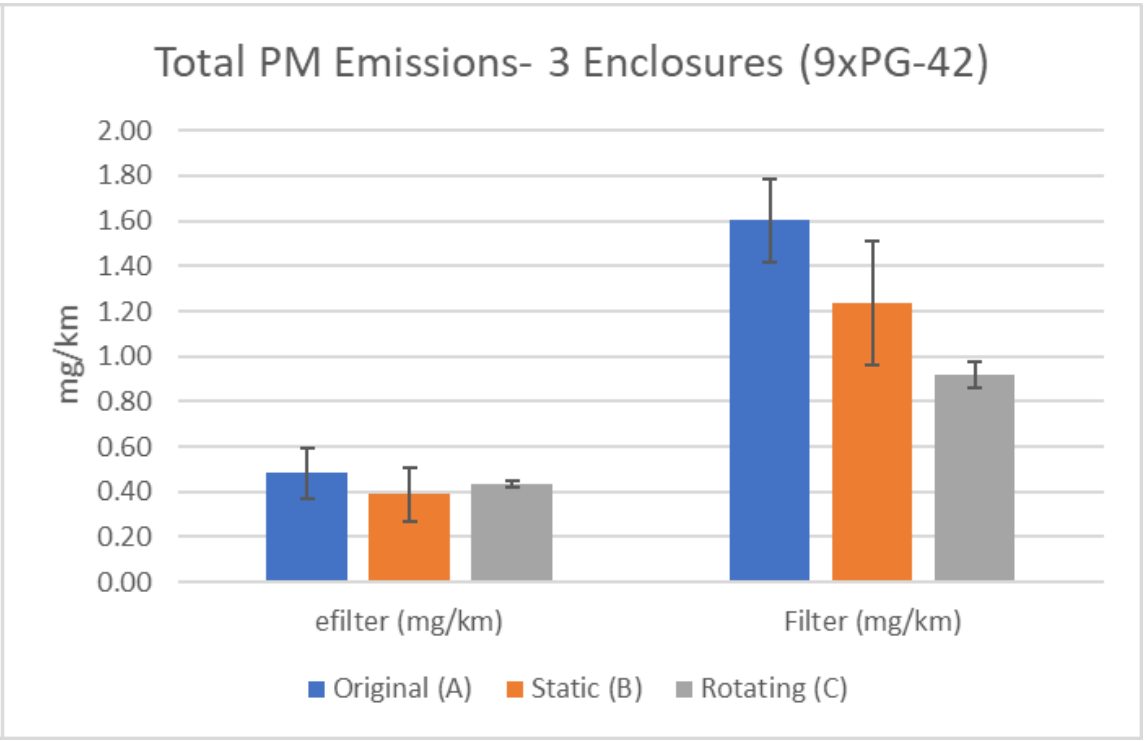


Comparison between 3 brake enclosure designs - Emissions

Particle Number



Particle Mass



Summary

- An on-road system for measuring brake and tyre wear was developed and installed to a small light duty van
- Testing was successfully undertaken in a chassis dynamometer facility; on a nearby test-track; and on-road in an urban environment
- Three different approaches to enclosing the brake were tested and shown to be generally similar
- Real-time non/low volatility particle number emissions corresponded to real-time braking events, with emissions around 2 - 5 x 10^9#/km/brake, lowest emissions were seen at lowest speeds
- Real-time particle mass emissions responses also aligned with braking events, and mass emissions (~$PM_{2.5}$) were around 1mg/brake/km

Future Work

Test power of the measurement system to discriminate between brake types etc

- Study specific influences on brake particle emissions on chassis dyno, test track and road
- E.g., disc and pad compositions, driving dynamics

Further information:
Contact: Louisa Kramer (louisa.kramer@ricardo.com)

Phase 1 Report: https://www.gov.uk/government/publications/measurement-of-emissions-from-brake-and-tyre-wear

Andersson, J., Kramer, L.J., Campbell, M., Marshall, I., Norris, J., Southgate, J., de Vries, S. and Waite, G., 2024. A Practical Approach for On-Road Measurements of Brake Wear Particles from a Light-Duty Vehicle. *Atmosphere*, *15*(2), p.224. https://www.mdpi.com/2073-4433/15/2/224