INVESTIGATION OF NON-EXHAUST PARTICLE EMISSIONS UNDER REAL WORLD CONDITIONS FROM A LIGHT DUTY VEHICLE

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08.10.2015

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OUTLINE

- Introduction

- Potential occurrence of ultrafine particles from the tire/road interface
  Mathissen, Marcel, et al. "Investigation on the potential generation of ultrafine particles from the tire–road interface." Atmospheric Environment 45.34 (2011): 6172-6179.

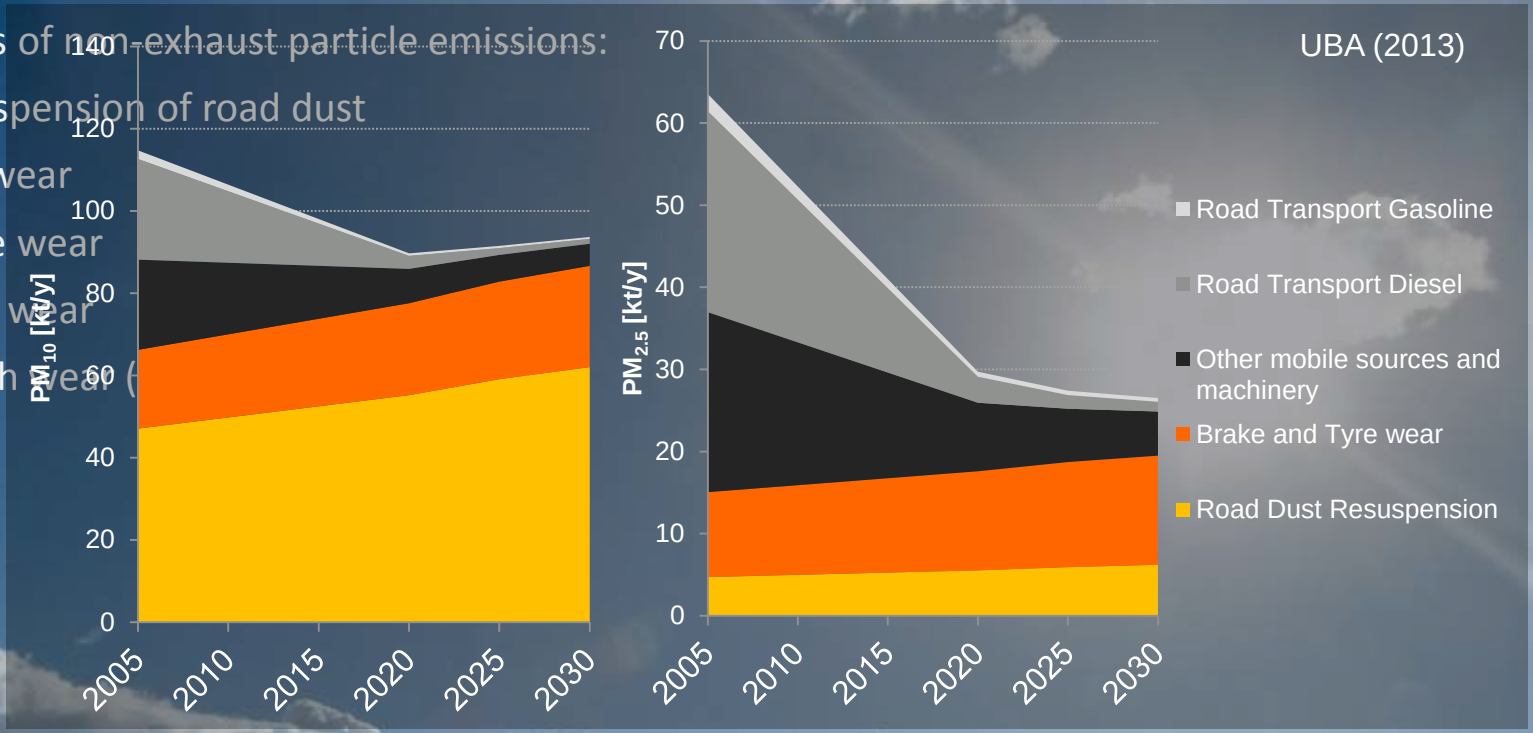
- Trailer based measurement method to estimate resuspended road dust emissions
  Mathissen, Marcel, et al. "Non-exhaust PM emission measurements of a light duty vehicle with a mobile trailer.“ Atmospheric Environment 59 (2012): 232-242.

- Summary

NON-EXHAUST PARTICLE EMISSIONS

Sources of non-exhaust particle emissions:

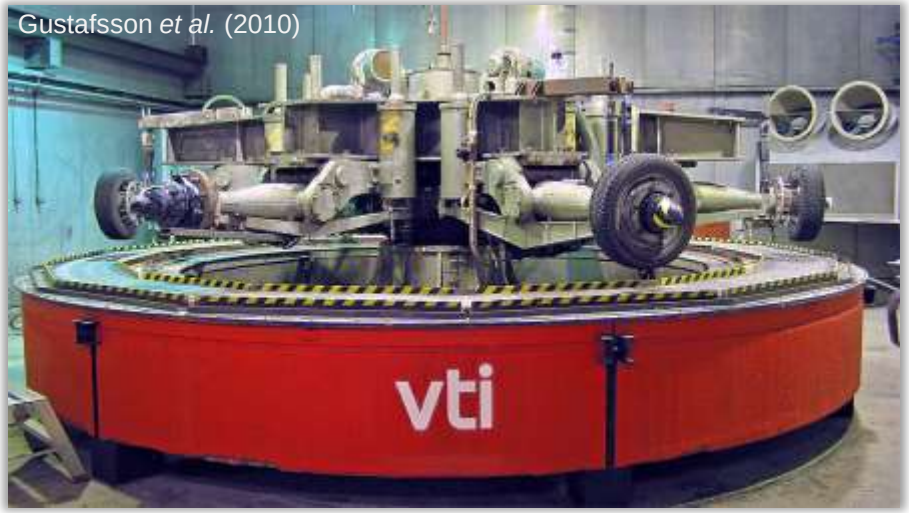
- Resuspension of road dust
- Tire wear
- Brake wear
- Road wear
- Clutch wear (

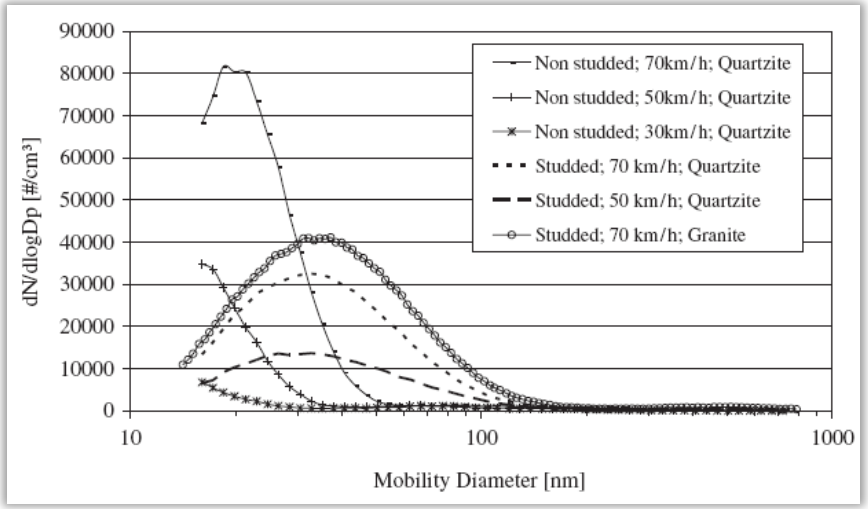


- The German Federal Environmental Agency expect an increasing share of PM10 non-exhaust emissions to the Transport sector for Germany from 58% to 93% (2005-2030). Similarly for PM2.5 from 24% to 74% (2005-2030).
- However, in case of Resuspension: Little knowledge for Central European conditions
- How can we quantify fugitive emission under real world conditions directly at the vehicle?

ULTRAFINE PARTICLES - MOTIVATION

- Dahl et al. (2006) studied particle emissions from the road-tire interface on a road simulator.
- Reported particle emission factors between $4x10^{11}$ – $3x10^{12}$ #/vkm at 50 and 70 km/h (comparable to exhaust particle number emissions post particulate Filter).
- Mean particle diameter between 15-50 nm depending on tire type.
- A newer study (Sjödin, 2010) found no ultrafine particles for unstudded tires.





Dahl *et al.* - Atmospheric Environment 40 (2006) 1314–1323

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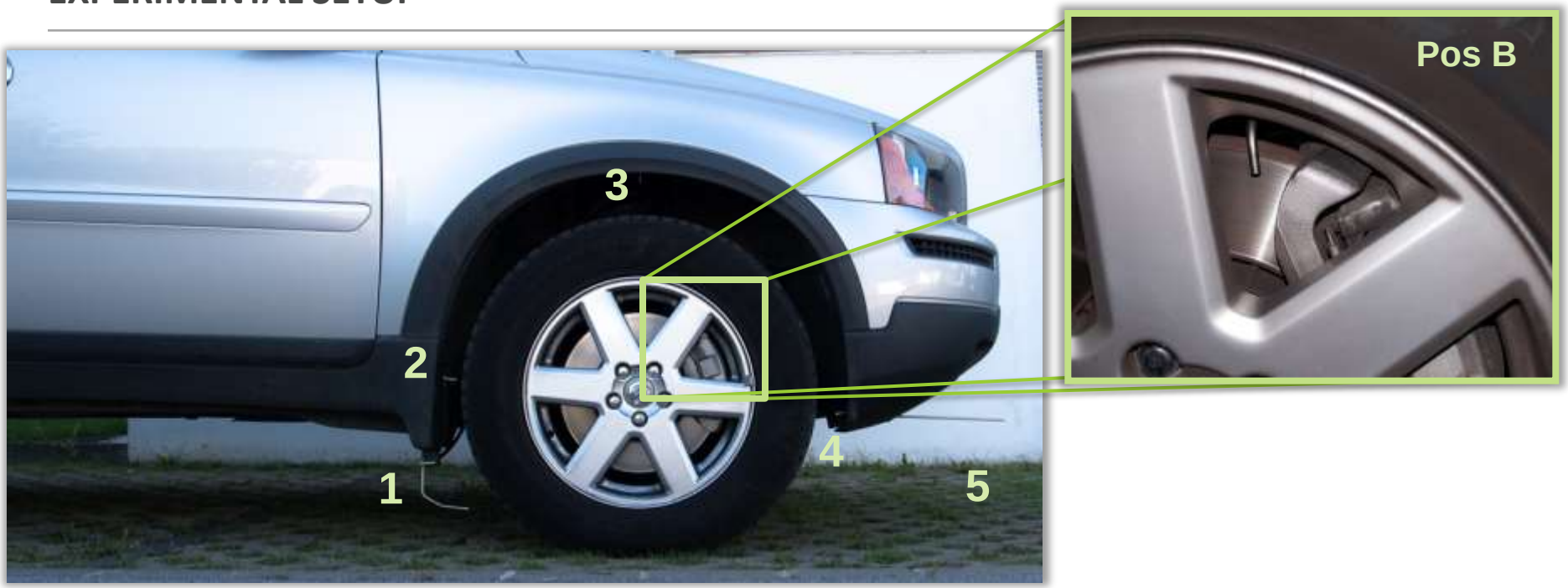
EXPERIMENTAL SETUP



- Measurement of particle size distribution with TSI EEPS (5.6 nm – 562.3 nm)
- NDIR CO_2-Measurement
- GPS data via Racelogic VBOX
- Up to 10 Hz Resolution

- 4 Measurement positions in wheel housing
- 1 Measurement position in driving direction in front of the car
- 1 Measurement position near brake disc + Pyrometer (IR-Temp)

TEST PROGRAM

Steady (straight) driving:

- for 4 different velocities: 50, 70, 100 & 120 km/h

Cornering (circle diameter ca. 48 m)

- at constant velocity: 30 km/h ($a_{lateral}$=2.9 ms^{-2}), 40 km/h ($a_{lateral}$=5.1 ms^{-2}))
- with increasing velocity until activation of stability control

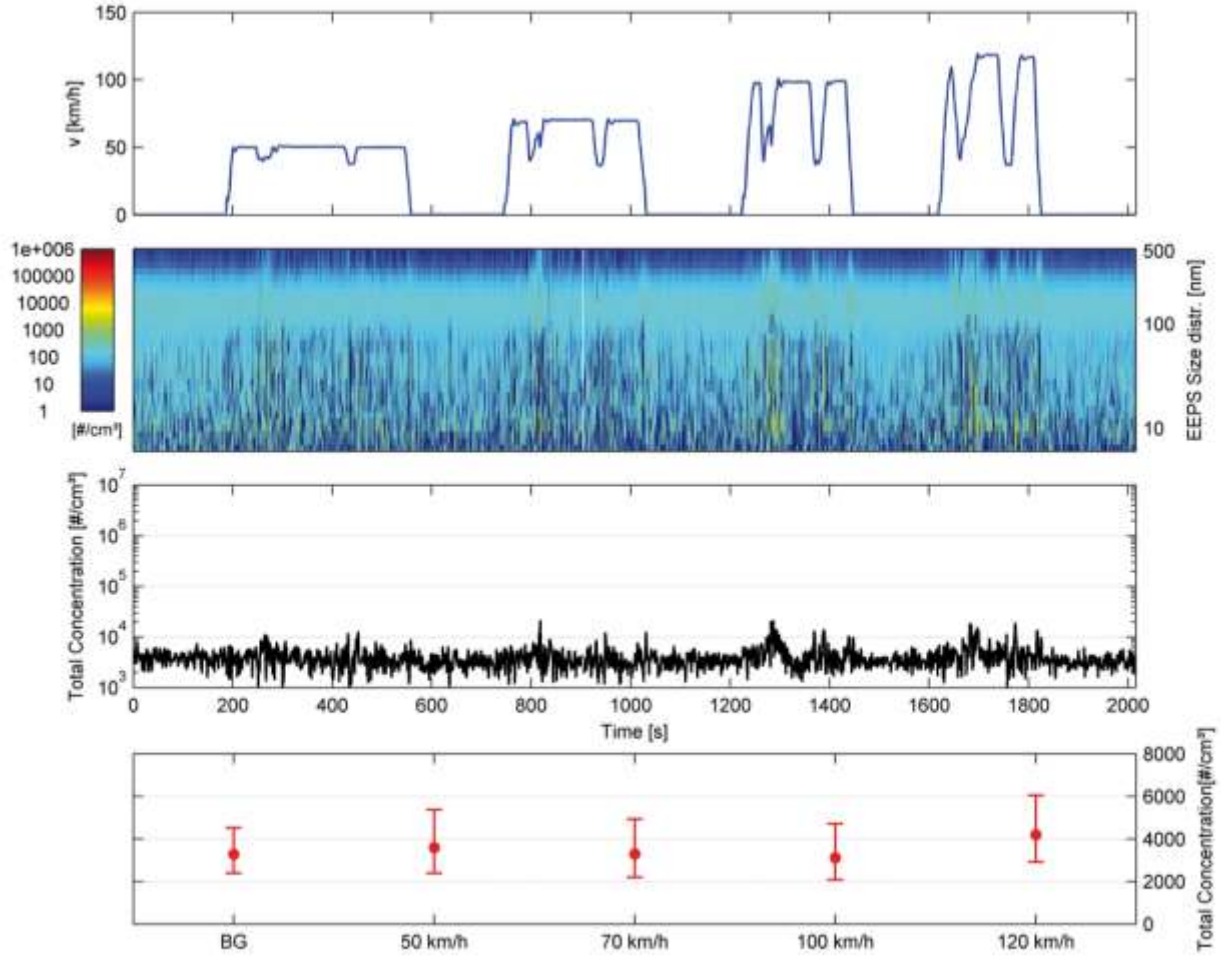
Acceleration

- Normal accelerations (up to 2.4 m/s^2)
- „Racing start“ (Activation of traction control)

Braking

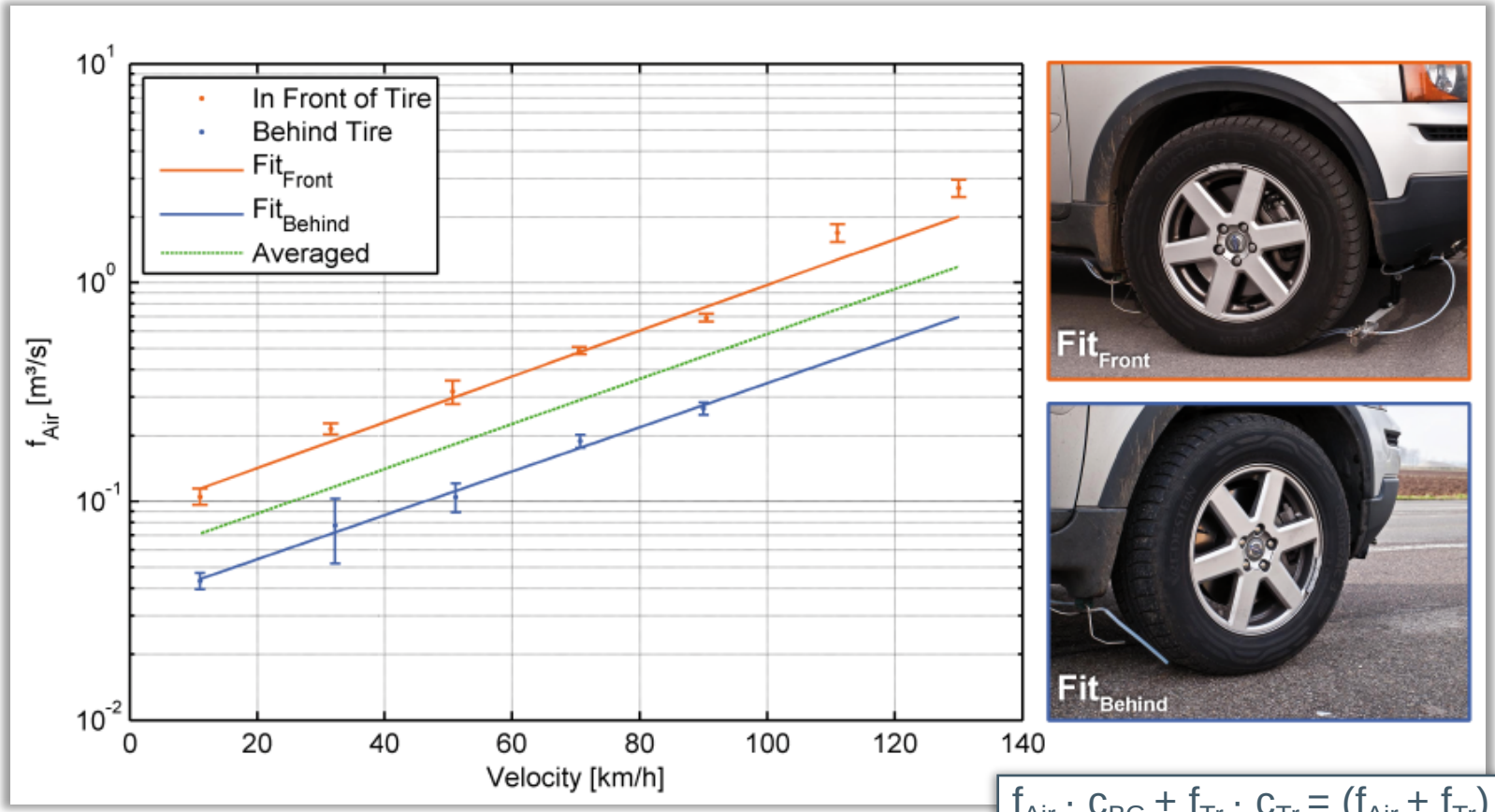
- Normal Braking
- Full Stop Braking for different starting velocities → Activation of ABS (a_{Brake}= 9 ms^{-2})

RESULTS – STEADY (STRAIGHT) DRIVING



- **Particle concentration in the order of 3 - 5 x 10^3 #/cm^3 (background-level)**
- **No particle concentration enhancement measurable while driving**

RESULTS – TRACER GAS EXPERIMENT



$$f_{Air} \cdot c_{BG} + f_{Tr} \cdot c_{Tr} = (f_{Air} + f_{Tr})\, c_{Meas}$$

- Tracer (10% NO in N_2) released in Front of / behind the Tire
- Estimated EF is based on the average of these measurements

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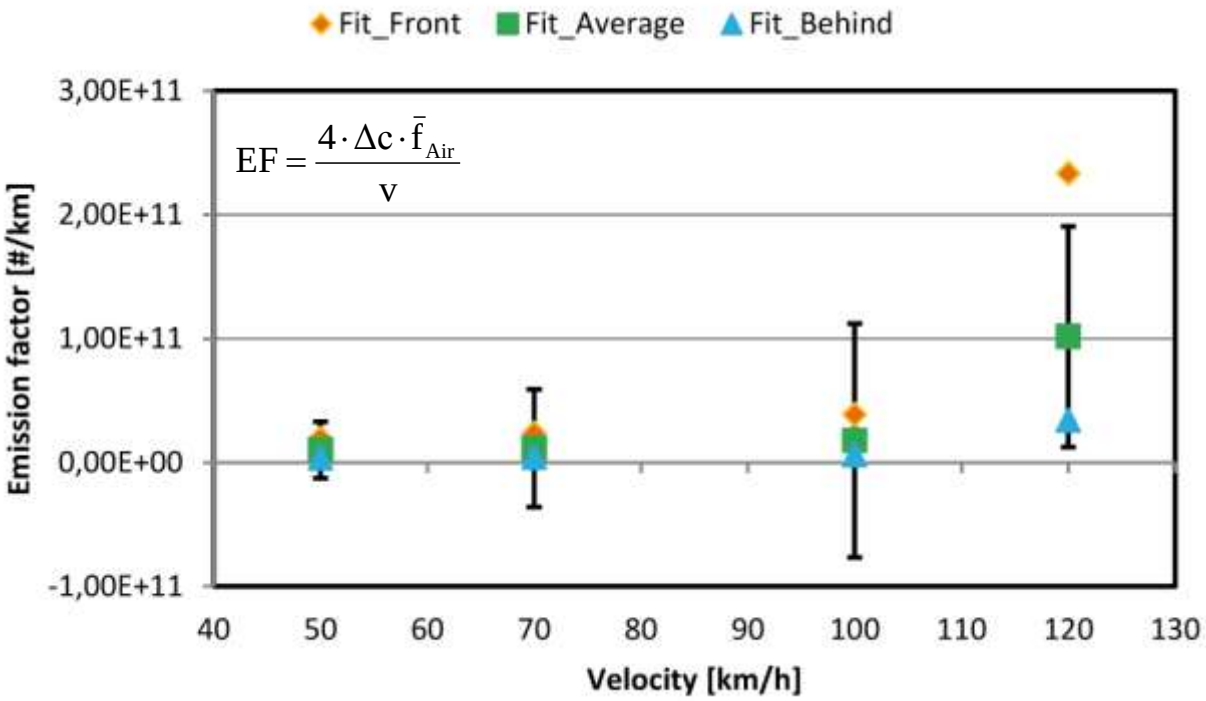
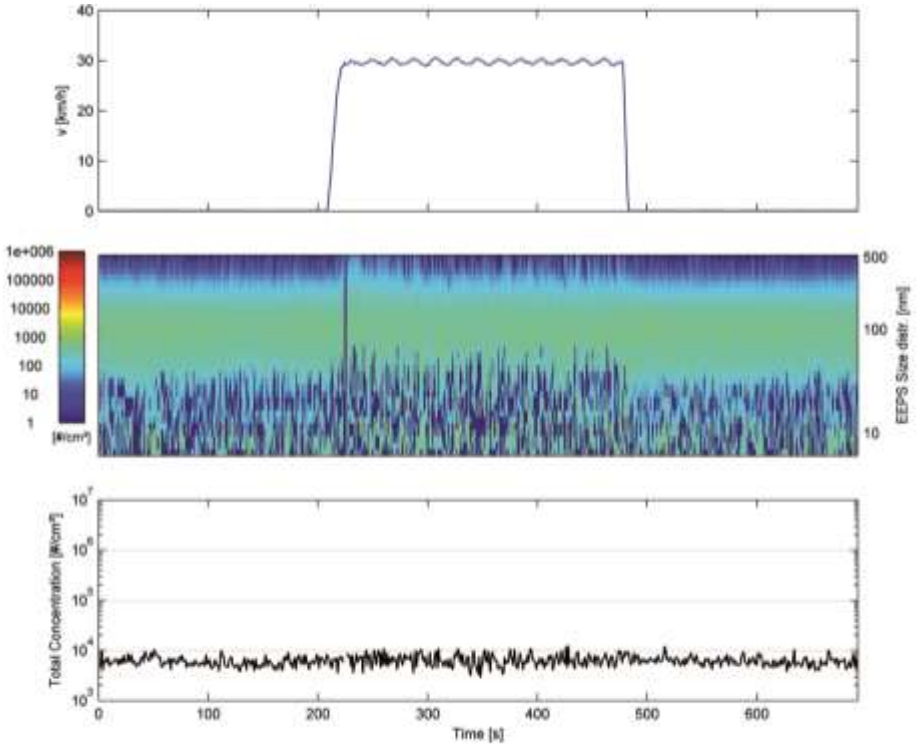
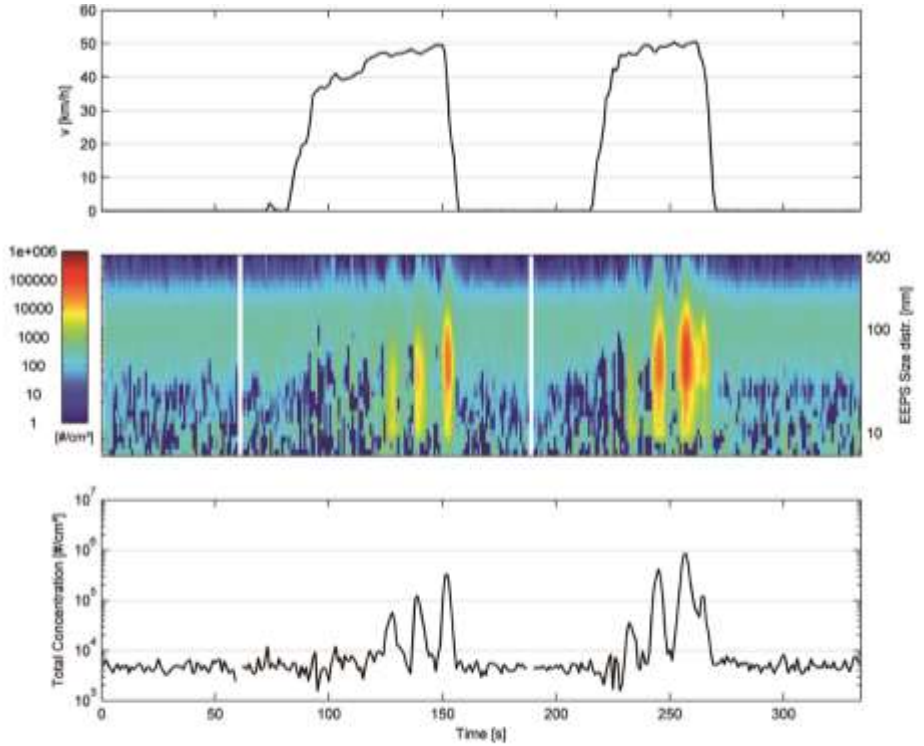
EMISSION FACTOR STEADY STRAIGHT DRIVING



- **Assumption: Equal emissions for all four tires**
- **Estimated maximal EF: < 1x10^{11} #/vkm (30 times smaller than reported by Dahl *et al.*)**

NORMAL CORNERING / EXTREME CORNERING





- No enhanced concentrations for normal cornering
- Extreme cornering: Screeching tires and activation of stability control.
- Tire slip results in enhanced particle concentrations up to 3.5×10^6 #/cm³.

- No enhanced particle concentrations for normal accelerations
- Enhanced particle concentrations measurable for racing start maneuvers

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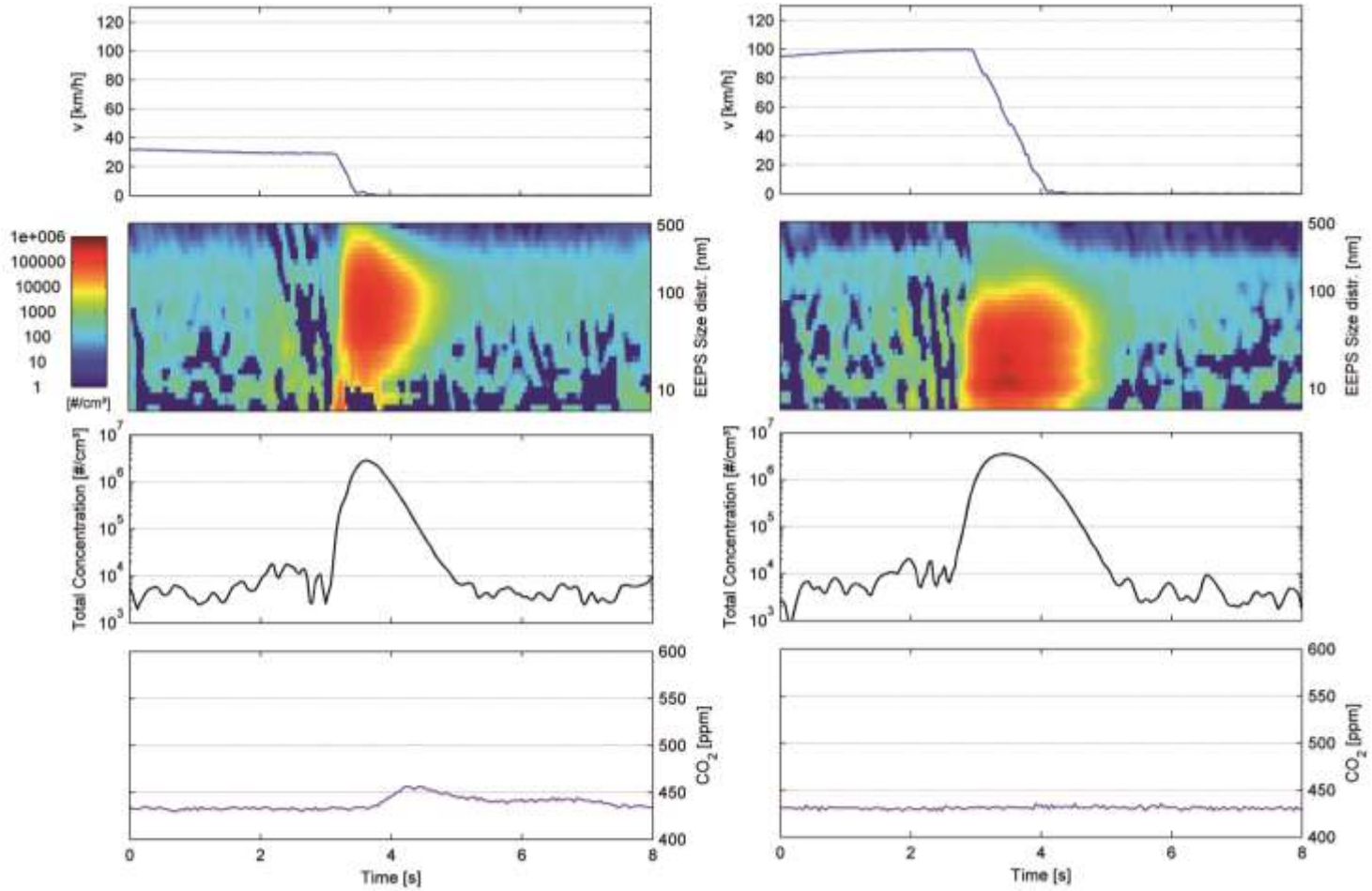
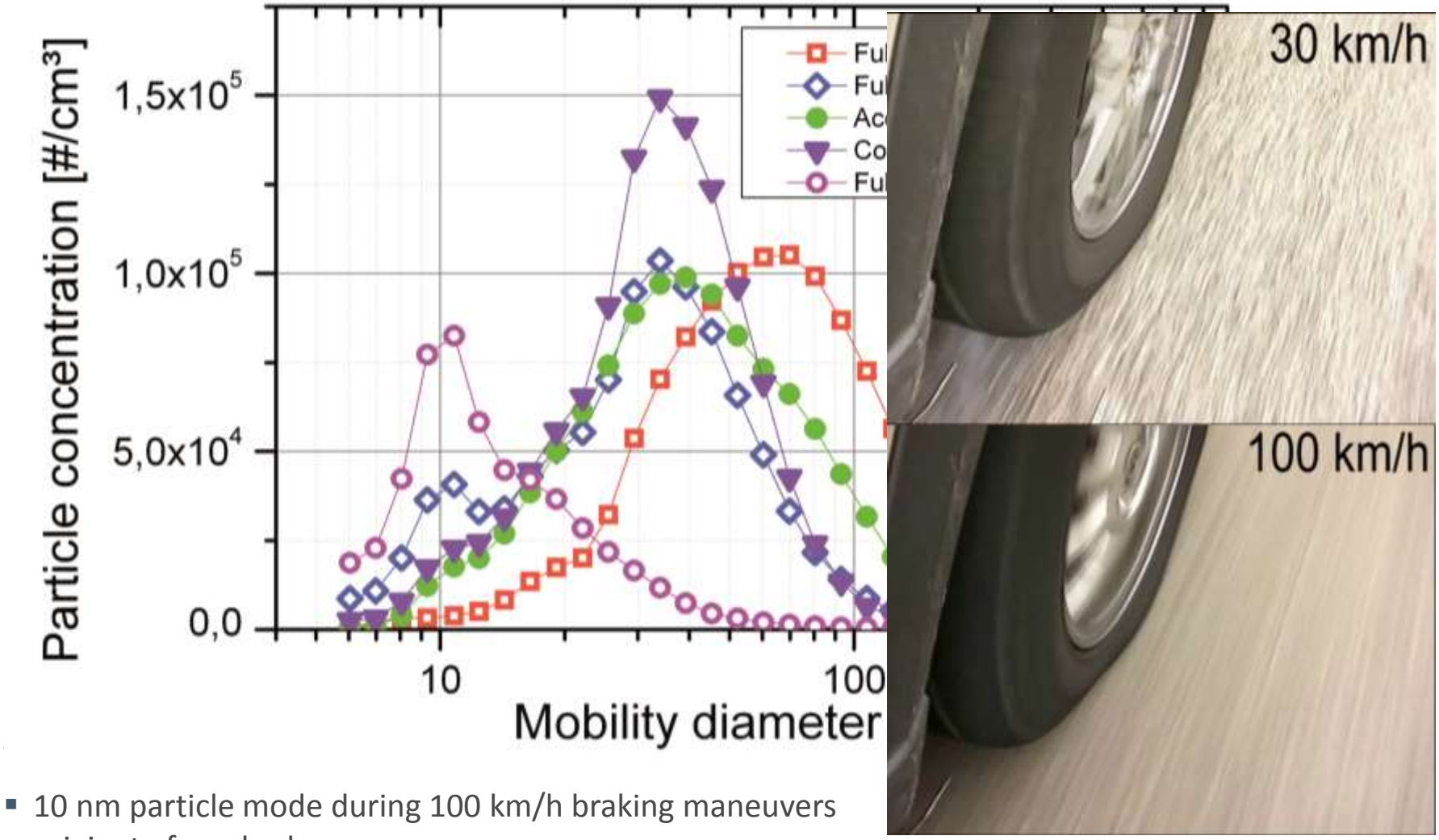
NORMAL BRAKING / FULL STOP BRAKING



- No enhanced ultrafine particle concentrations for normal braking
- Harsh braking maneuvers result in particle formation
- Different particle size distribution for 100 km/h and 30 km/h full stop braking.

SIZE DISTRIBUTIONS



- 10 nm particle mode during 100 km/h braking maneuvers originate from brakes

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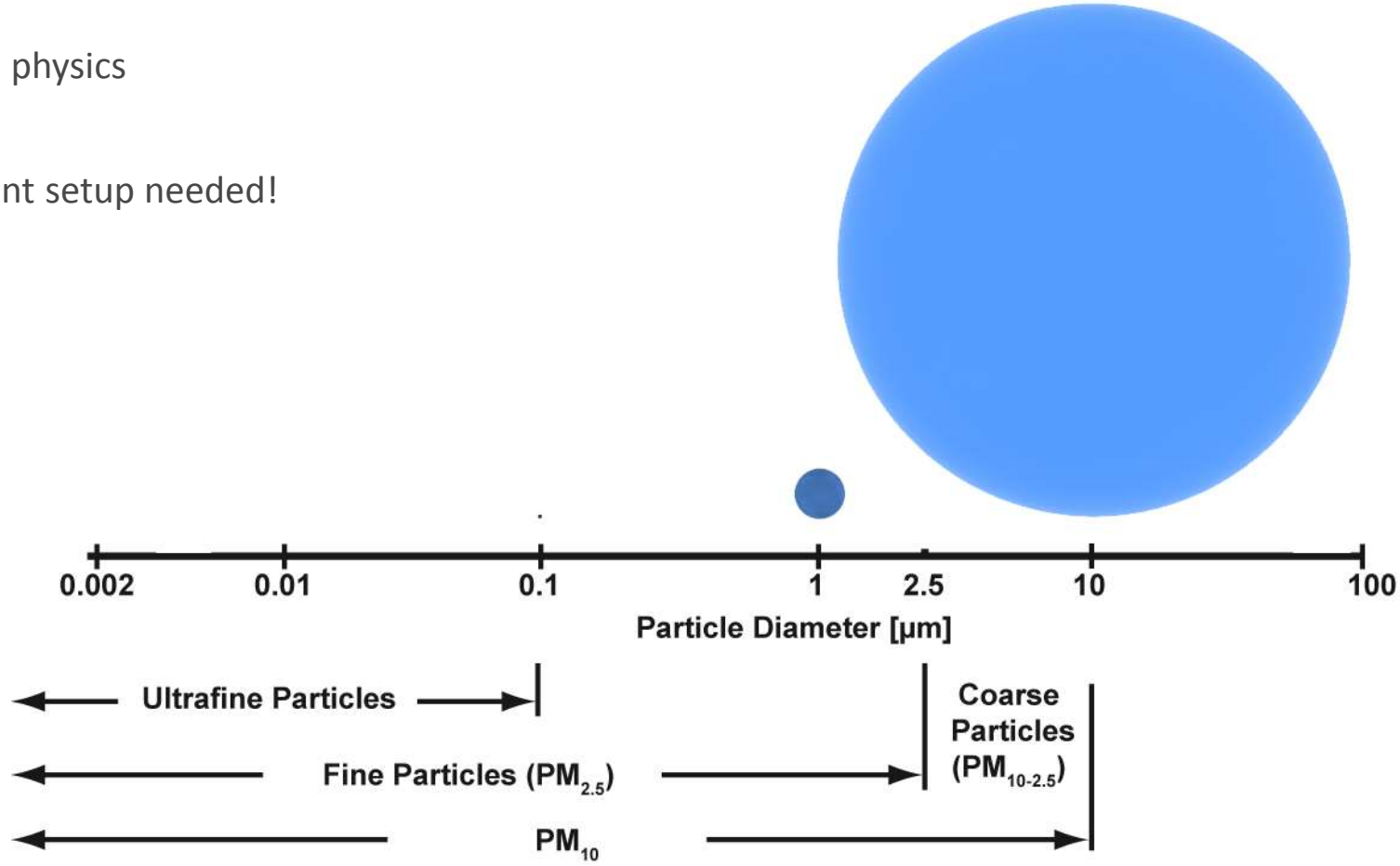
FROM THE SMALL TO THE LARGE

- Particles due to resuspension are generally found in the coarse mode
- Different particle physics
- New measurement setup needed!



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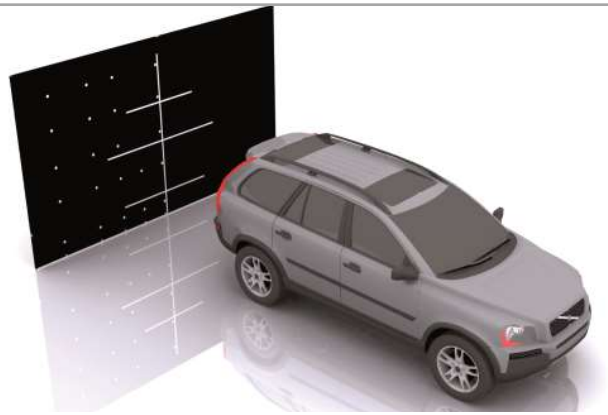
MEASUREMENT SETUP

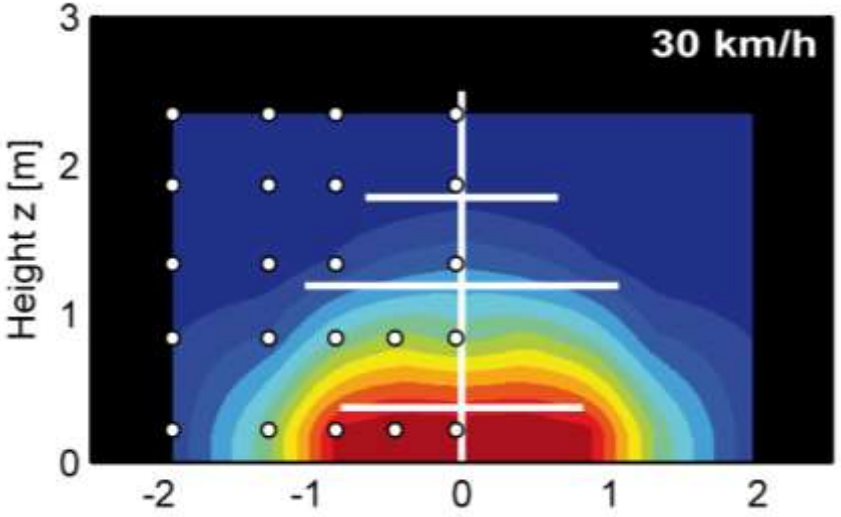
- **Estimation of total non-exhaust emissions:**

$$E = \sum_{t} c_{Av} \cdot A \cdot v_{vehicle}$$

- **Characterization of particle dispersion in vehicle wake needed**

VEHICLE WAKE CHARACTERIZATION



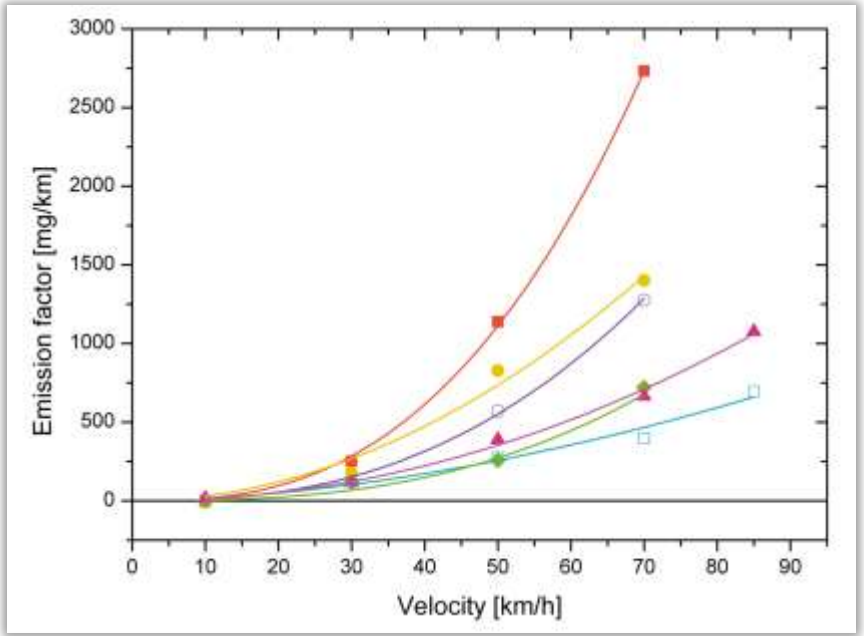


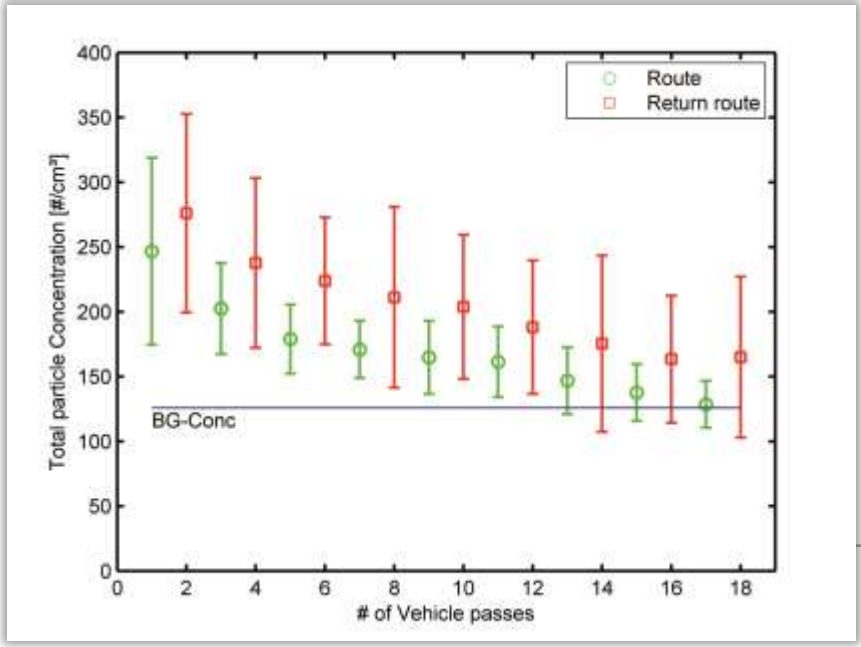
- Isoaxial alignment of measurement device
- Investigations on optimal measurement position in vehicle wake
- Tracer gas experiment for emission factor estimation

UNPAVED ROADS

- **Average emission factor at 30 km/h: 24000 mg/vkm ± 19000 mg/vkm PM_{10}**
- **Emission factor clearly velocity dependent**
- **No further investigations after DustTrak contamination**

AGRICULTURAL PAVED ROADS





- Average emission factor for 30 km/h (PM_{10}): 155 mg/vkm $\pm$ 53 mg/vkm
- Each measurement will change the emission potential of a road

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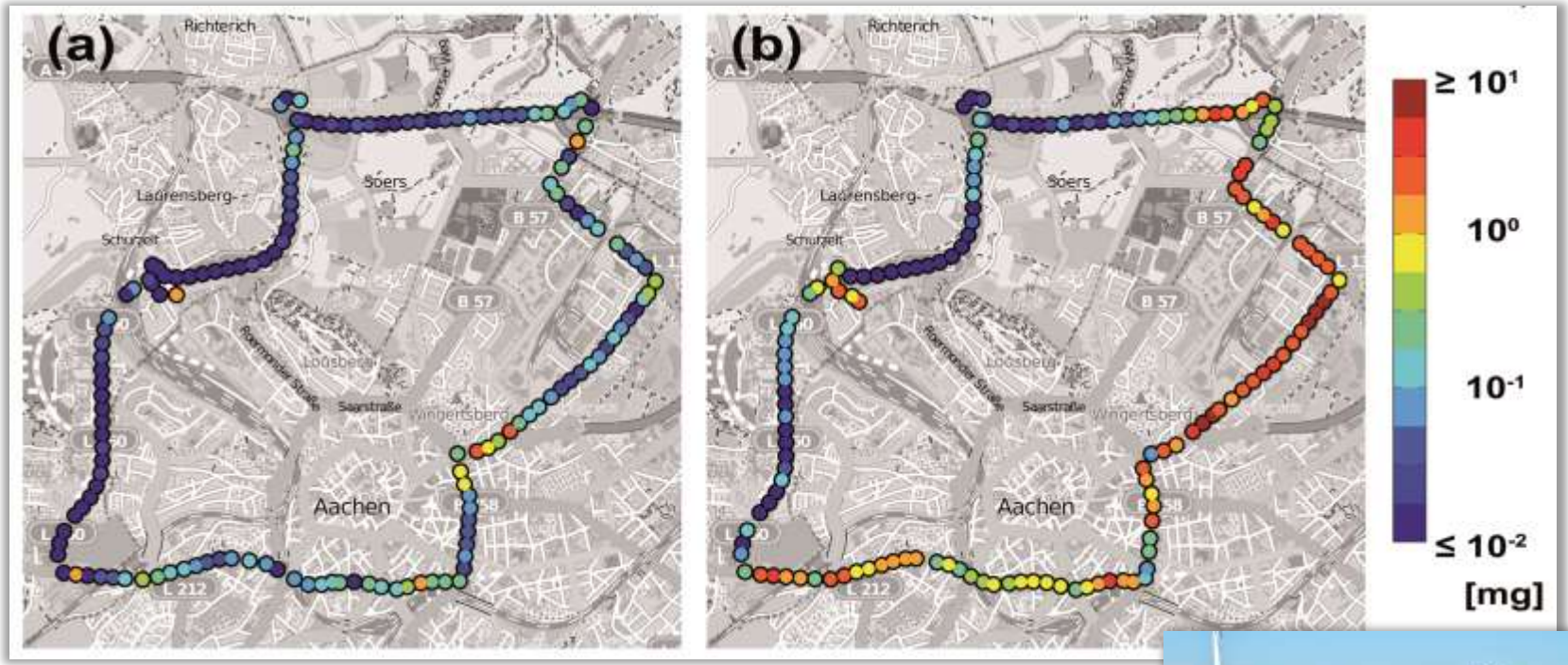
PAVED ROADS – SPATIALLY RESOLVED EMISSIONS



- **High local variability of emission potential:**

  10 % of a real world measurement is responsible for 63 % of the total emissions

- **Repeatability (covariance): 10-30 %**

$$Cov = \frac{\sigma}{\mu} \cdot 100\%$$

- **Lowest emission on the autobahn**

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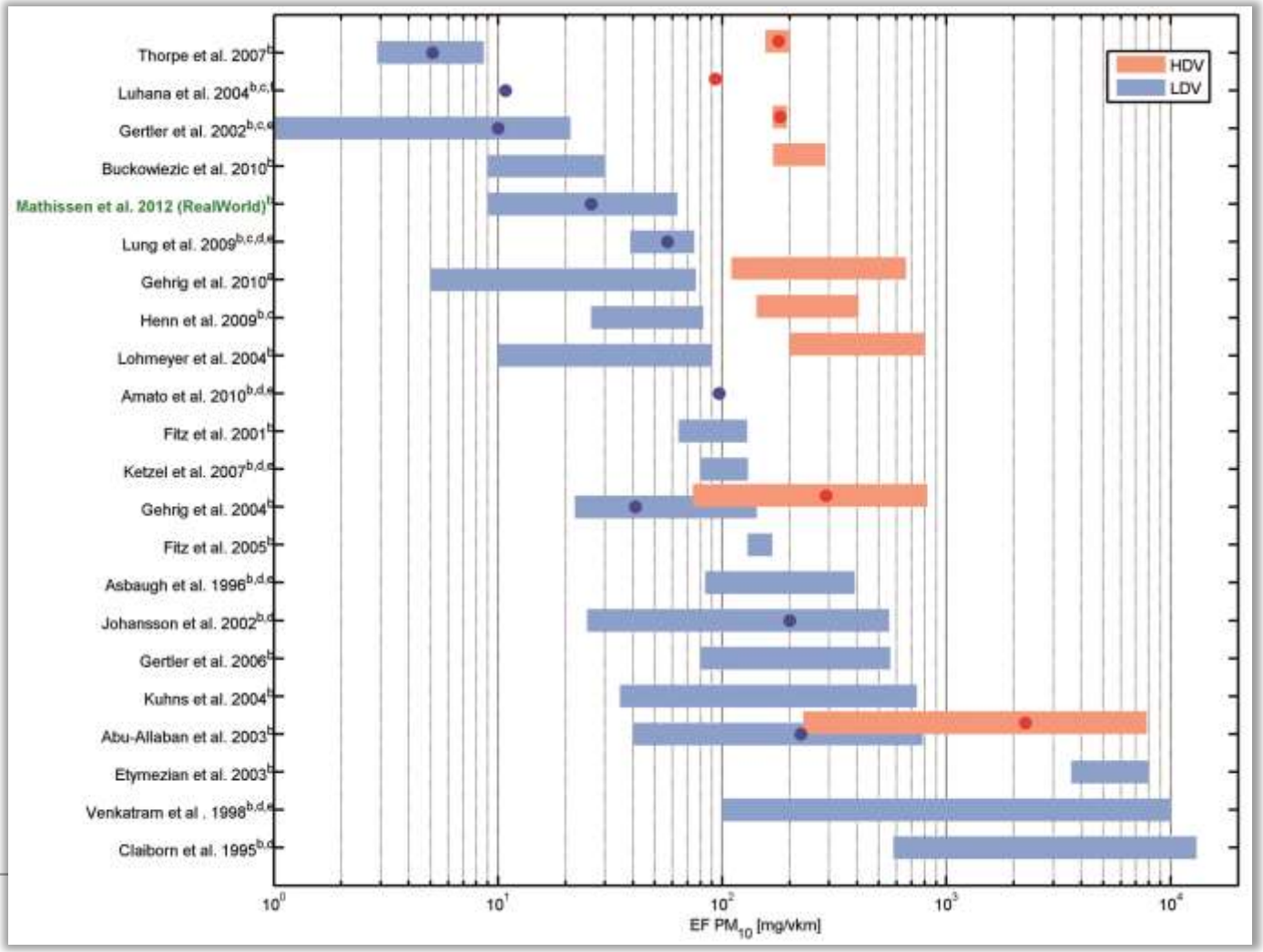
PAVED ROADS – EMISSION FACTOR

- Average PM_{10} emission factor: 26 mg/vkm $\pm$ 18 mg/vkm
- Euro 5 PM_{10} limit for diesel cars: 4.5 mg/km



SUMMARY

- Experimental setup capable of measuring non-exhaust particle emissions under real world conditions.
- Estimation of emission factors based on tracer gas dispersion measurements

UF particles from the Tire/road interface:

- Under normal driving conditions no substantial ultrafine particle concentration enhancement measurable.
- Upper limit of emission factor for steady straight driving estimated to be < $1x10^{11}$ #/km
- Under extreme conditions only (full stop braking, extreme cornering, racing start) ultrafine particles measurable with mean particle sizes between 30 nm - 80 nm.
- Particle formation related to significant tire slip.

Resuspension of road dust:

- Diffuser inlet to sample isokinetically; Characterization of vehicle wake
- Estimated emission factors:
  - Unpaved roads (30km/h): 24000 mg /vkm ± 19000 mg/vkm
  - Agricultural paved roads (30km/h): 155 mg/vkm ± 53 mg/vkm
  - Real world roads: 26 mg/vkm ± 18 mg/vkm
- High local variability of emission potential.

THE END

Thank you for you kind attention!

- Investigation on the potential generation of ultrafine particles from the tire–road interface.
  Atmospheric Environment Vol. 45, 2011, pp. 6172–6179
- Non-exhaust PM emission measurements of a light duty vehicle with a mobile trailer.
  Atmospheric Environment Vol. 59, 2012, pp. 232–242

VEHICLE BASED DIRECT MEASUREMENTS

TRAKER
Kuhns *et al.* (2001),
Etyemezian *et al.* (2003)

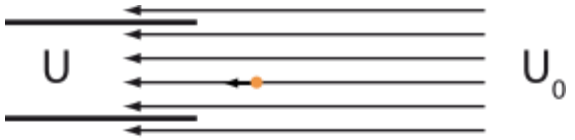
SNIFFER
Pirjola *et al.* (2009)

SCAMPER
Fitz *et al.* (2002)

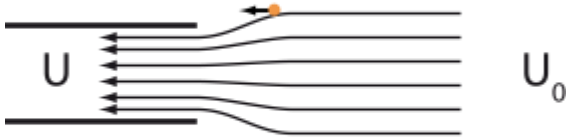
SCAMPER
Fitz *et al.* (2005)

ISOKINETIC SAMPLING

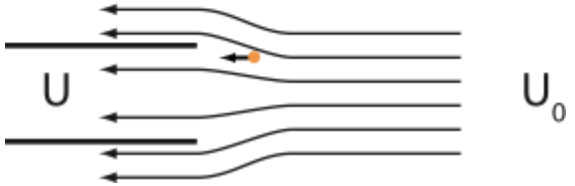
Isokinetic sampling ($U=U_0$)



Super-isokinetic sampling ($U>U_0$)



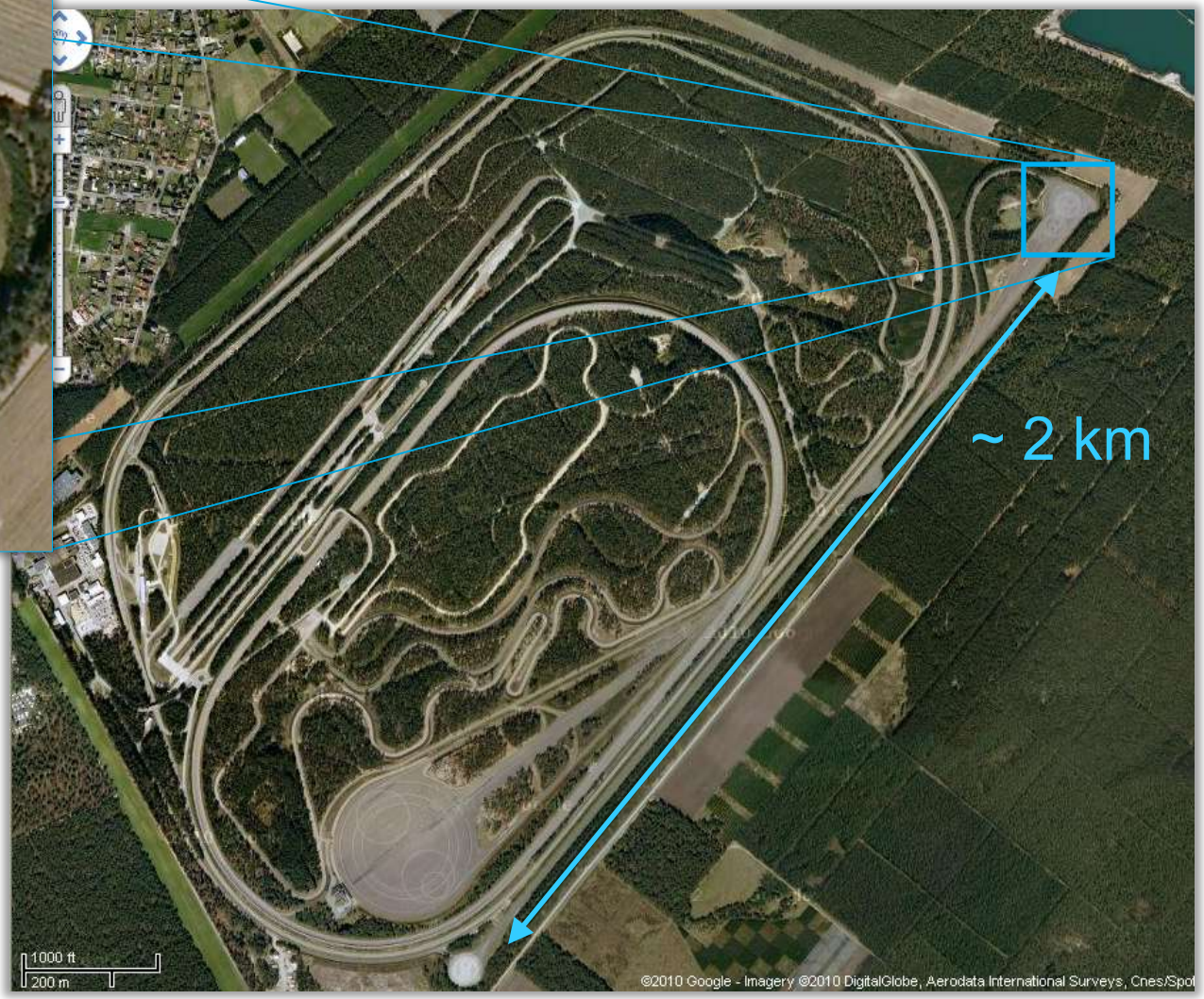
Sub-isokinetic sampling ($U<U_0$)



- Isokinetic (isoaxial) sampling
  - Representative sampling

- Diffuser inlet for isokinetic sampling

MEASURING LOCATION - LOMMEL PROVING GROUND



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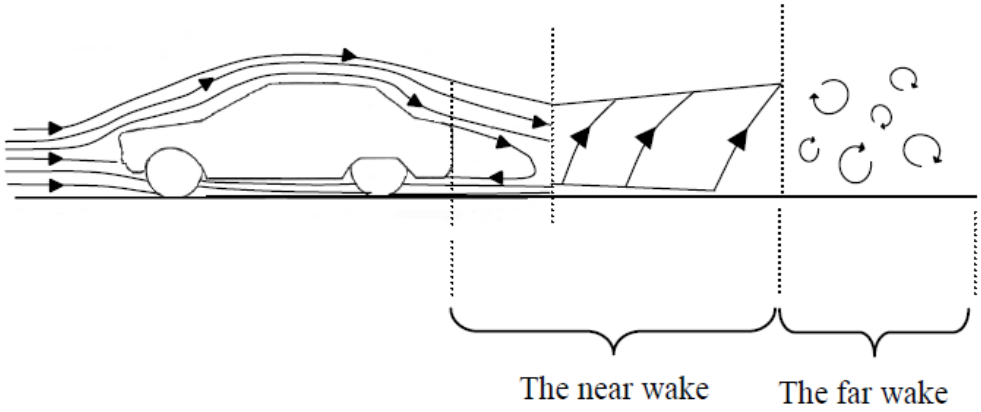
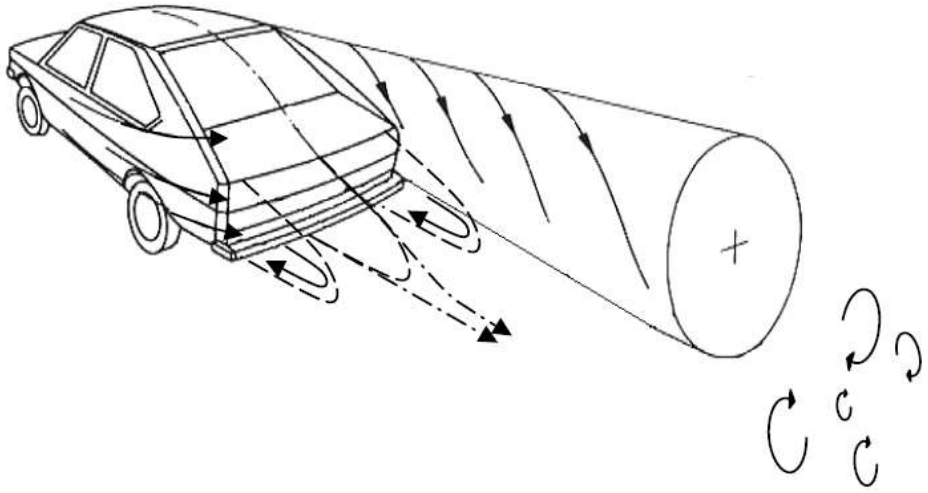
WIND TUNNEL TEST – VEHICLE WAKE

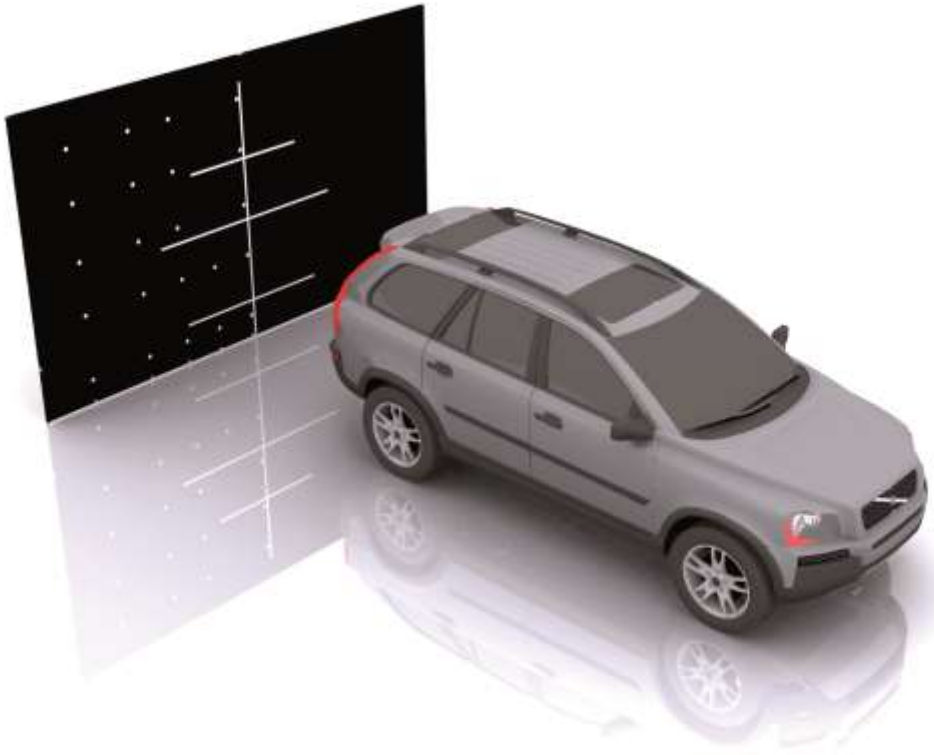
K.Richards (2002)





- Isoaxial alignment of measurement device
- Investigations on optimal measurement position in vehicle wake

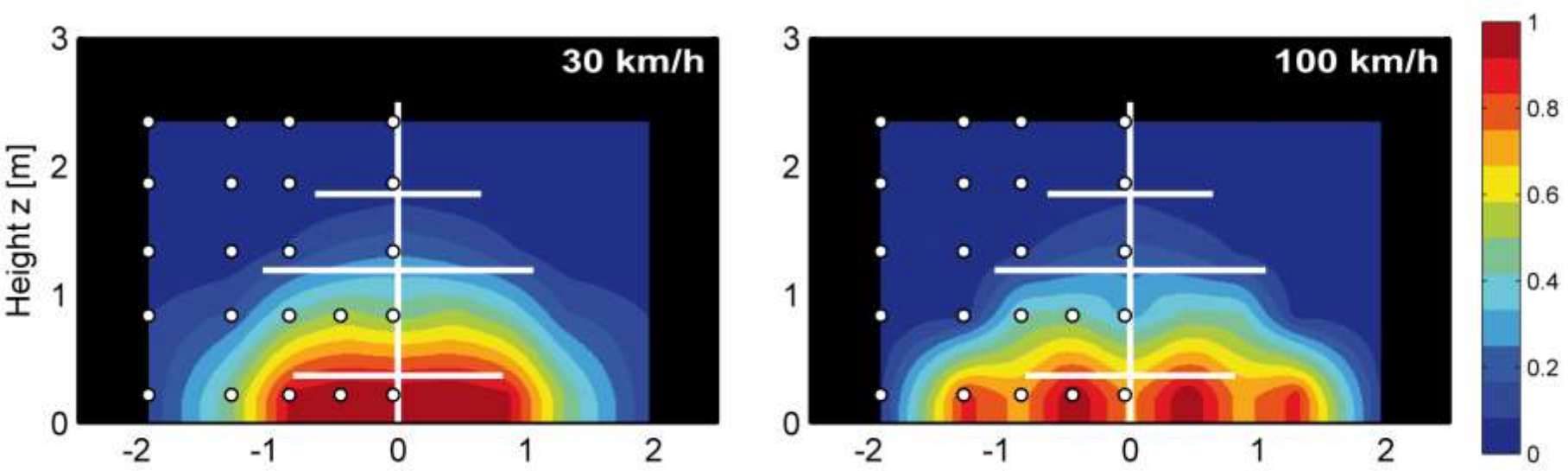
TRACER GAS EXPERIMENT



Wake characterization:

- Release of tracer gas (10% NO in N_2) at 6 different probes
- Assumption: Particles and tracer gas are dispersed equally

TRACER GAS EXPERIMENT - RESULT



- 2 Velocities (30 km/h, 100 km/h)
- 3 Repetitons
- 6 different tracer gas release points
- 22 measurement points
- + partial wake characterization for longer vehicle-trailer distance

- Further characterization: Local wind speed