**Annual Conference of the Czech Aerosol Society**
**Nový Smokovec, SK, October 23-25, 2013**

# Real-world Particle Emissions from a Small Motorcycle Engine: Preliminary Experiences

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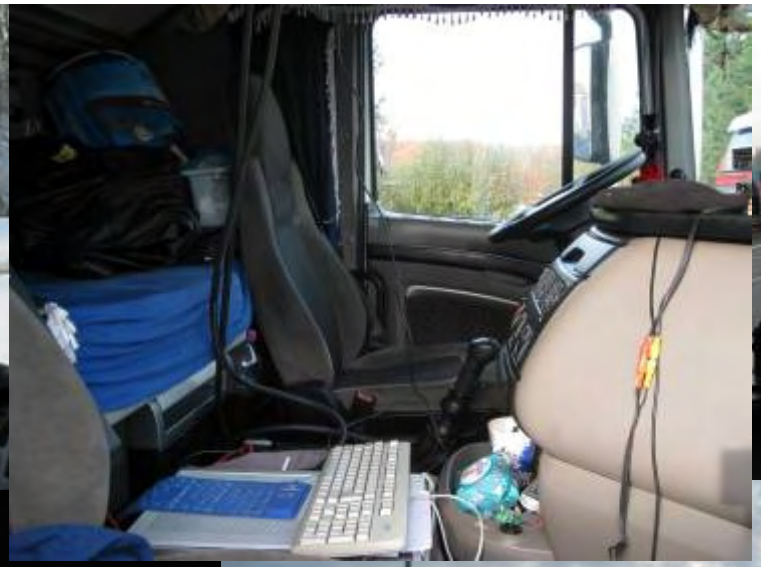
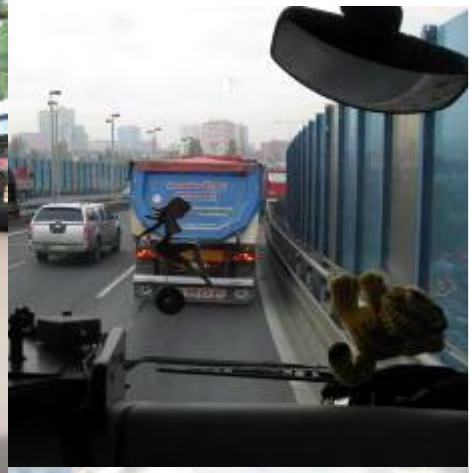
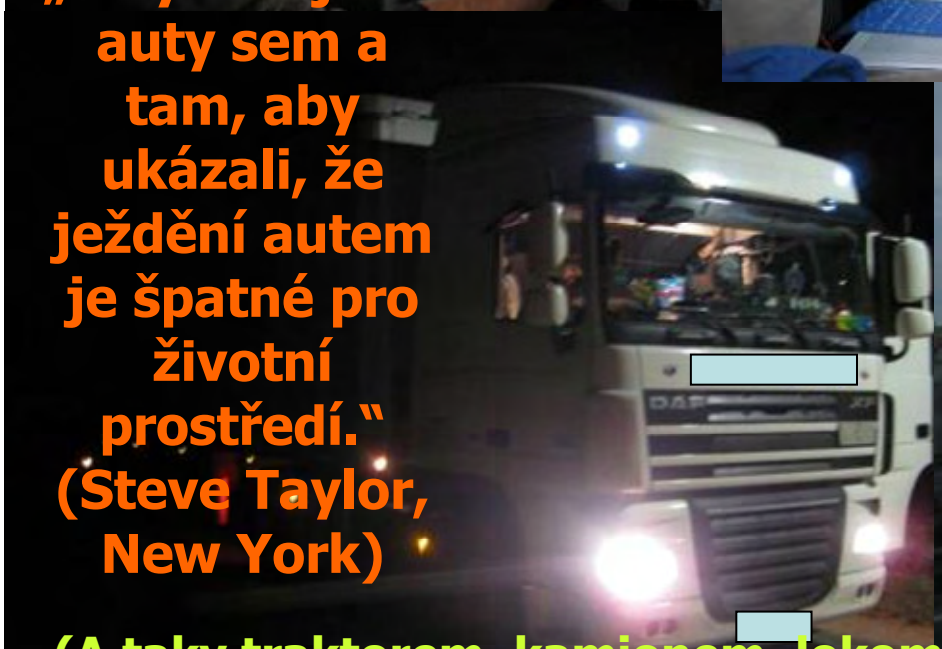
# Představení... Co děláme... Měření emisí za reálného provozu

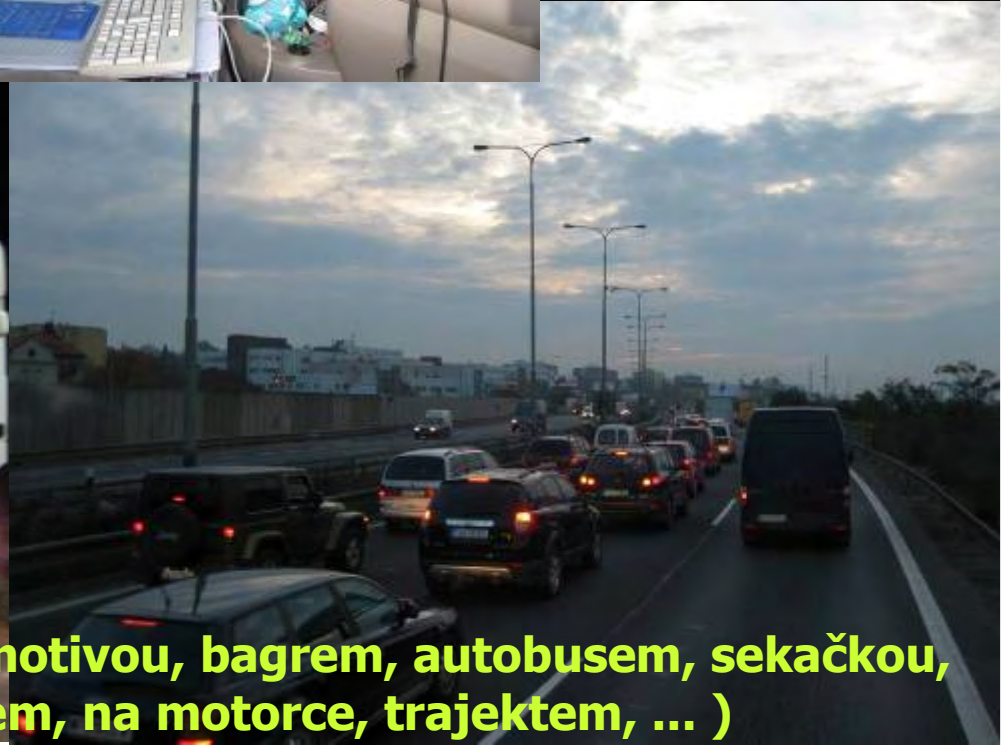
## ... měření nanočástic ve výfukových plynech a jejich vzorkování pro toxikologické analýzy





**„Celý den jezdí auty sem a tam, aby ukázali, že ježdění autem je špatné pro životní prostředí.“ (Steve Taylor, New York)**





**(A taky traktorem, kamionem, lokomotivou, bagrem, autobusem, sekačkou, nakladačem, malým letadlem, na motorce, trajektem, ... )**

California Environmental Protection Agency
AIR RESOURCES BOARD

AMERICAN LUNG ASSOCIATION of California

## Recent Research Findings:

### Health Effects of Particulate Matter and Ozone Air Pollution, January 2004

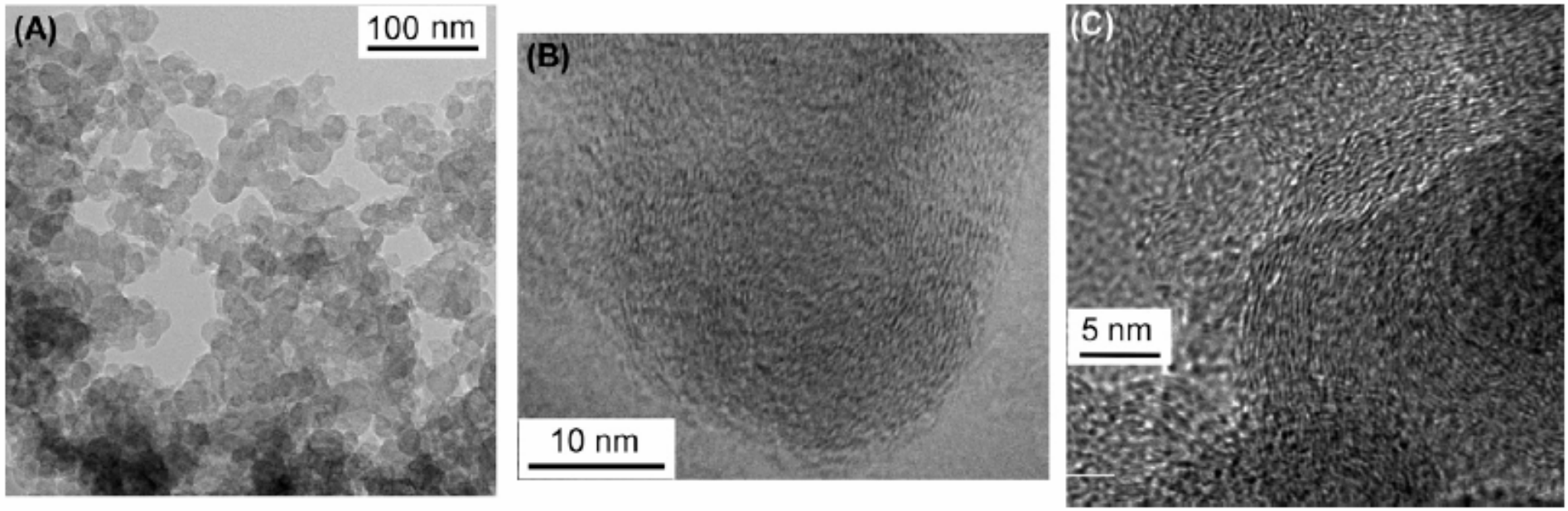
**Air Pollution Causes Premature Death**

Attaining the California PM standards would annually prevent about 6,500 premature deaths, or 3% of all deaths. These premature deaths shorten lives by an average of 14 years. This is roughly equivalent to the same number of deaths (4,200 - 7,400) linked to second-hand smoke in the year 2000. In comparison, motor vehicle crashes caused 3,200 deaths and homicides were responsible for 2,000 deaths (CARB 2002a, and CDHS 2000).

**In the EU: approximately 400 000 premature deaths annually due to transport emissions**

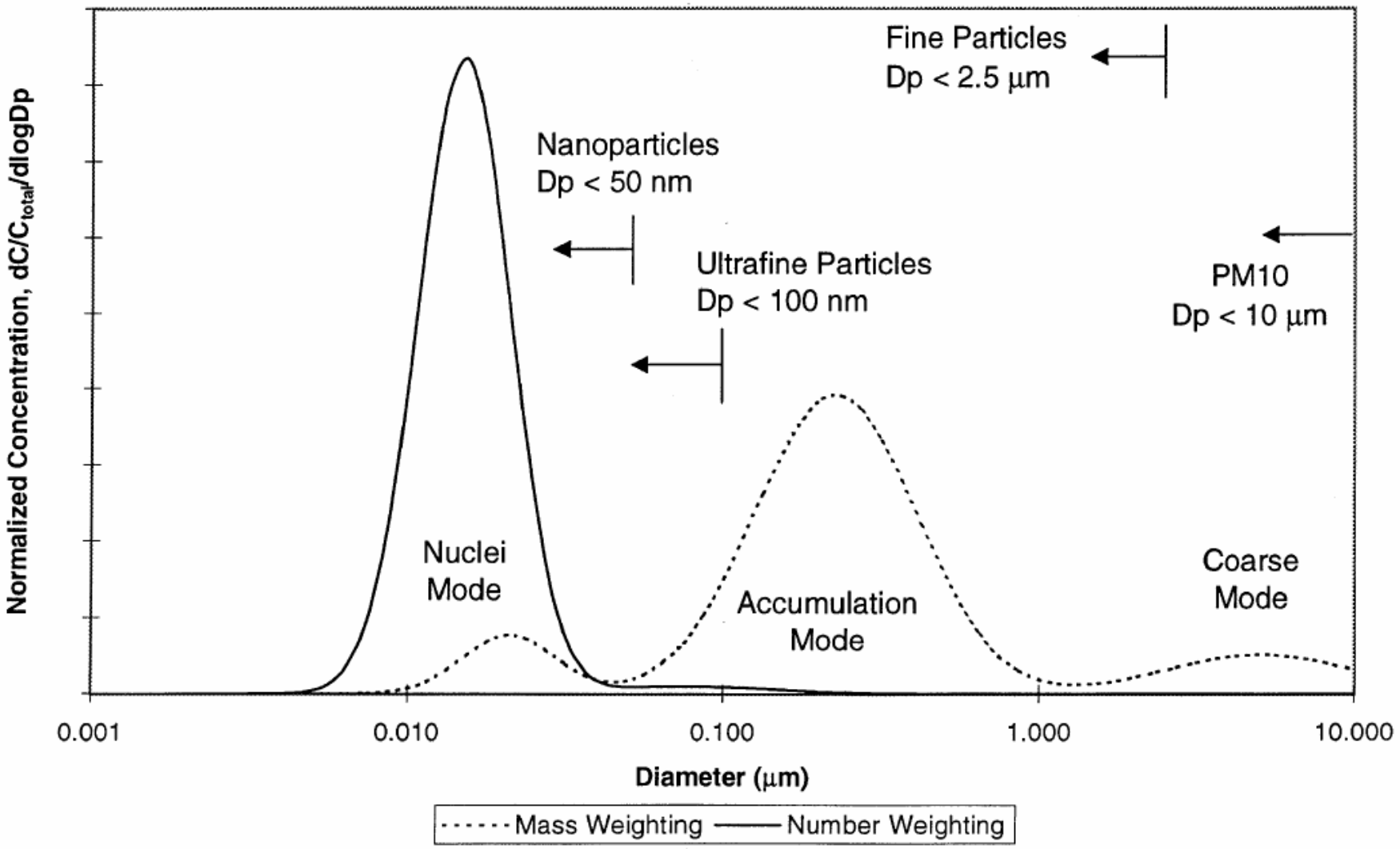
**This is one order of magnitude more than traffic accidents.**

# Diesel exhaust particulate matter



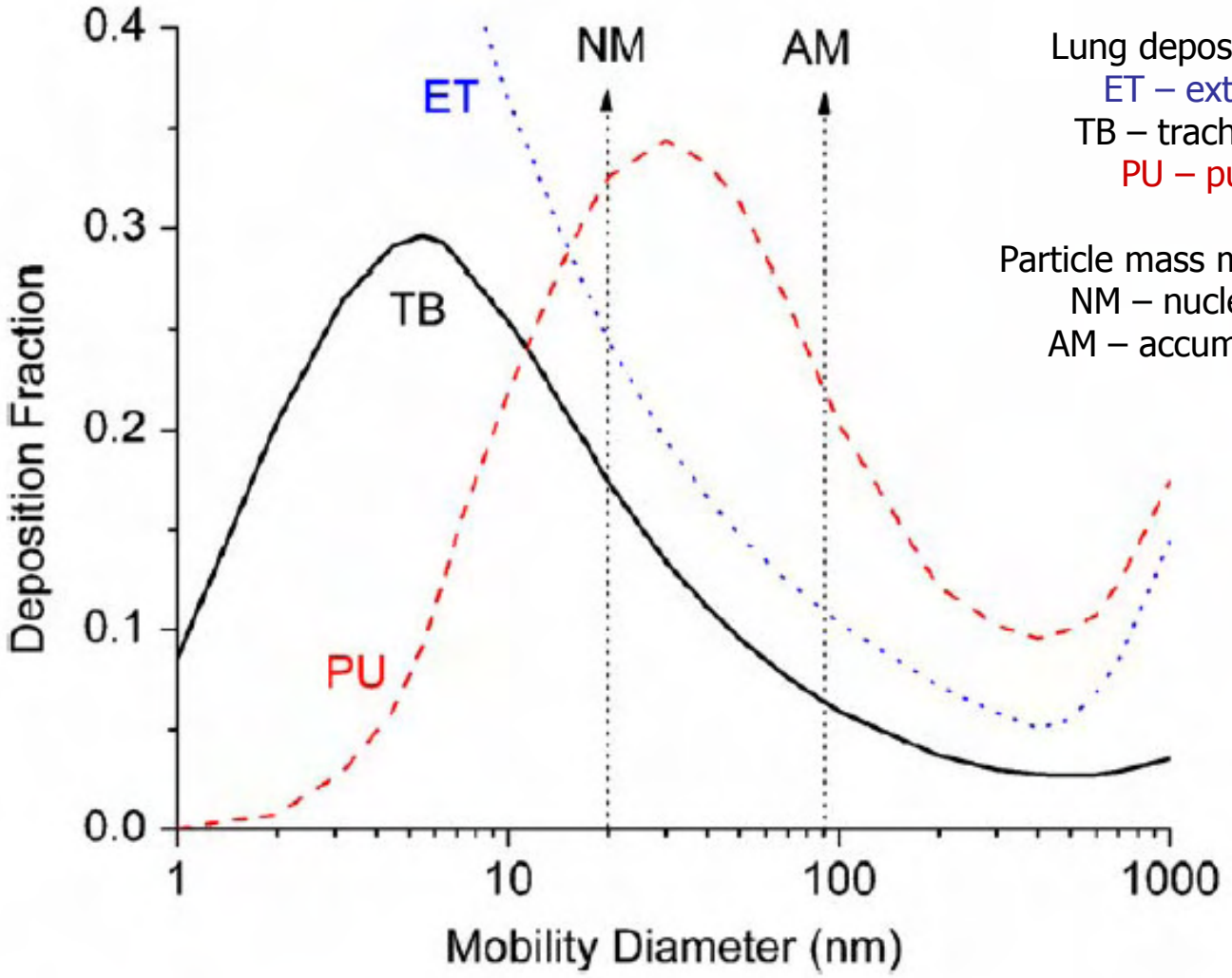

Liati A., Dimopoulos P.E., Combustion and Flame 157 (2010) 1658–1670.

# Typical diesel exhaust PM size distribution




Kittelson, *J. Aerosol Sci.* Vol. 29, No. 5/6, pp. 575-588, 1998

# Lung particle capture efficiency




Lung deposition fraction:
ET – extrathoracic
TB – tracheobronchial
PU – pulmonary

Particle mass median diameter:
NM – nucleation mode
AM – accumulation mode

**B. Alfoldy et al., Aerosol Science 40 (2009) 652—663.**

# Fractional Deposition of Inhaled Particles (Oberdörster)

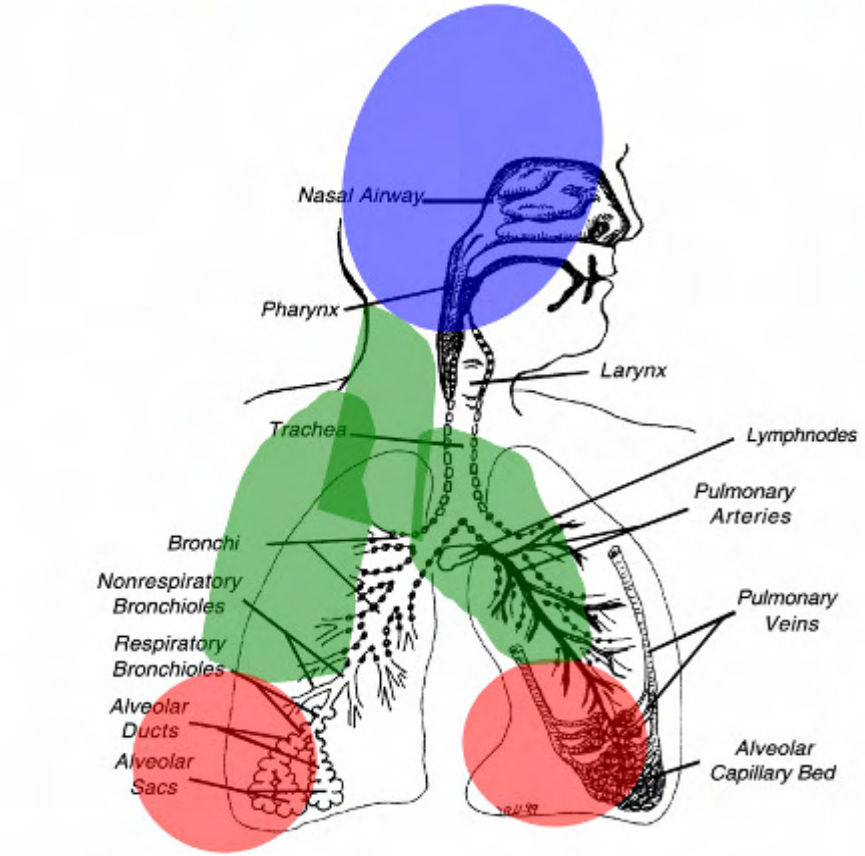
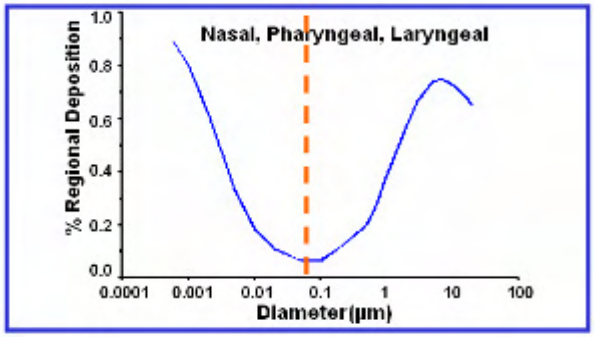
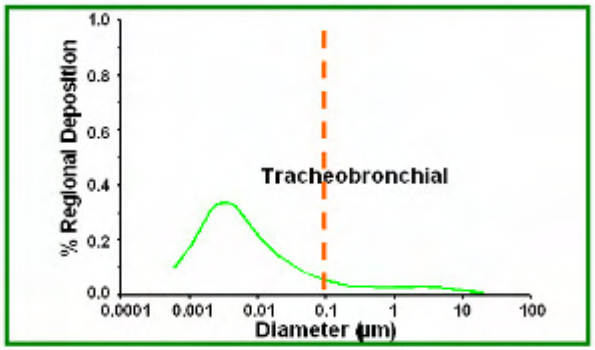
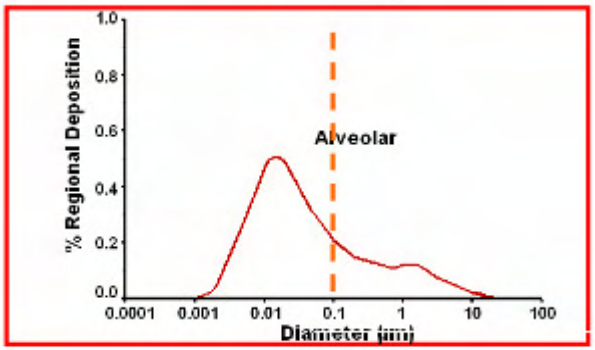



Figure courtesy of J.Harkema



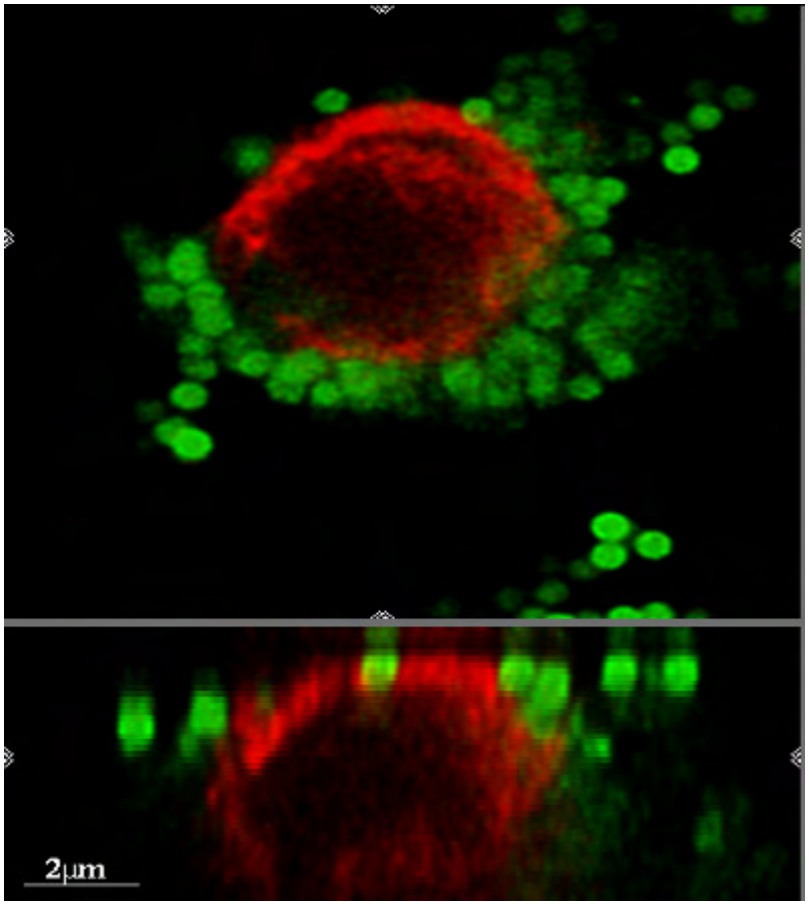



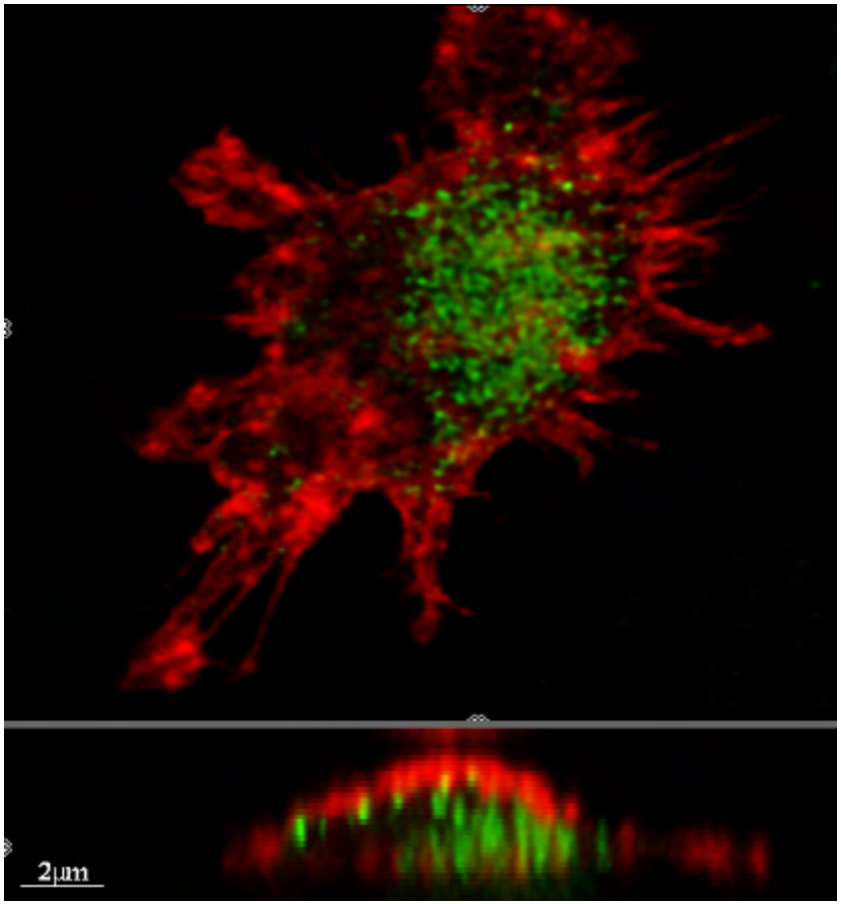

**A. Mayer, 12th ETH Conference on Combustion Generated Nanoparticles, Zurich, 2008**

# Penetration of nanoparticles through a cell barrier

- 1000 nm
  Polystyrene Particles

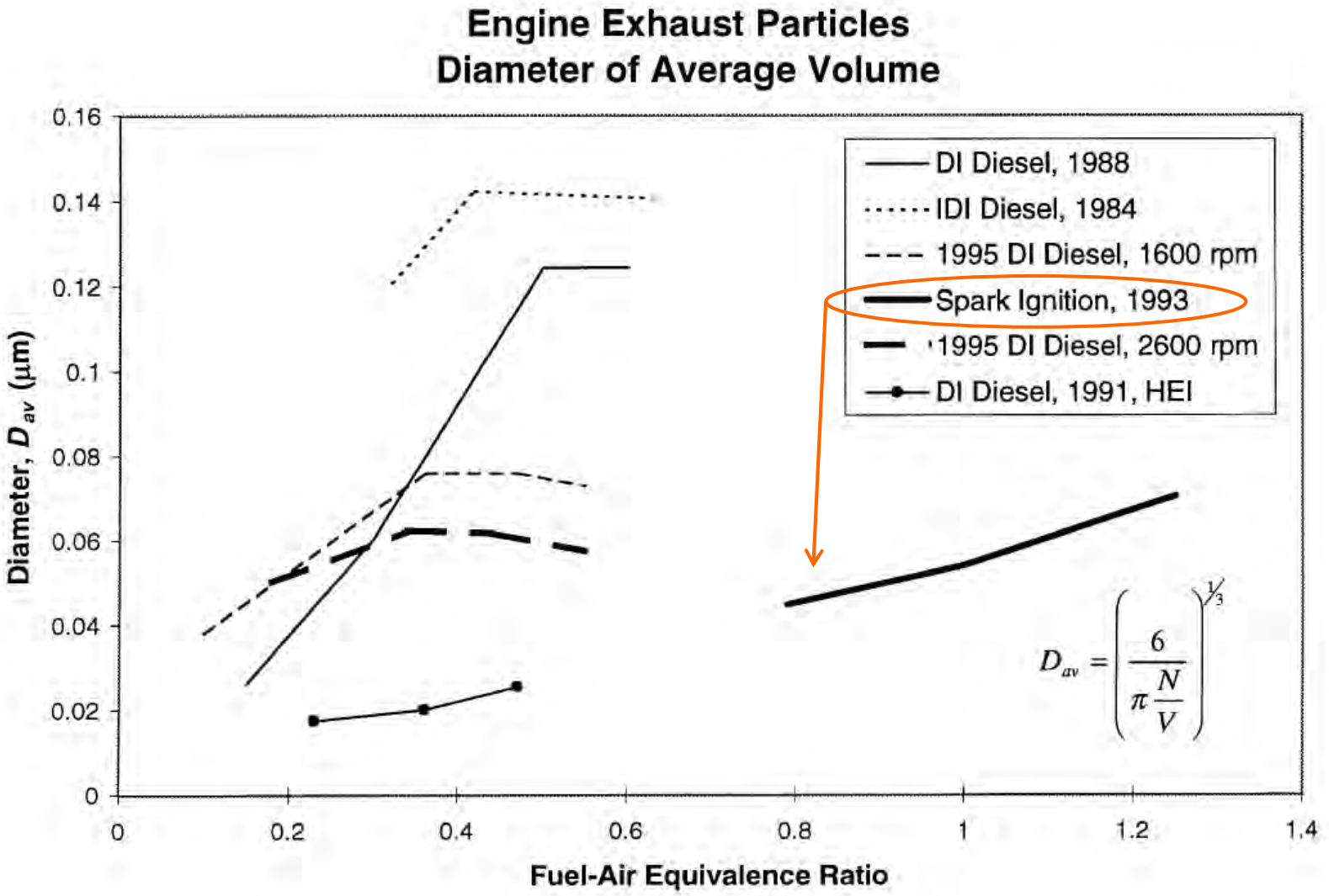



- 78 nm
  Polystyrene Particles




**Barbara Rothen-Rutishauer, as quoted by A. Mayer, 12th ETH Conference on Combustion Generated Nanoparticles**

# Particulate matter: Not just diesel engines.




Kittelson, *J. Aerosol Sci.* Vol. 29, No. 5/6, pp. 575-588, 1998

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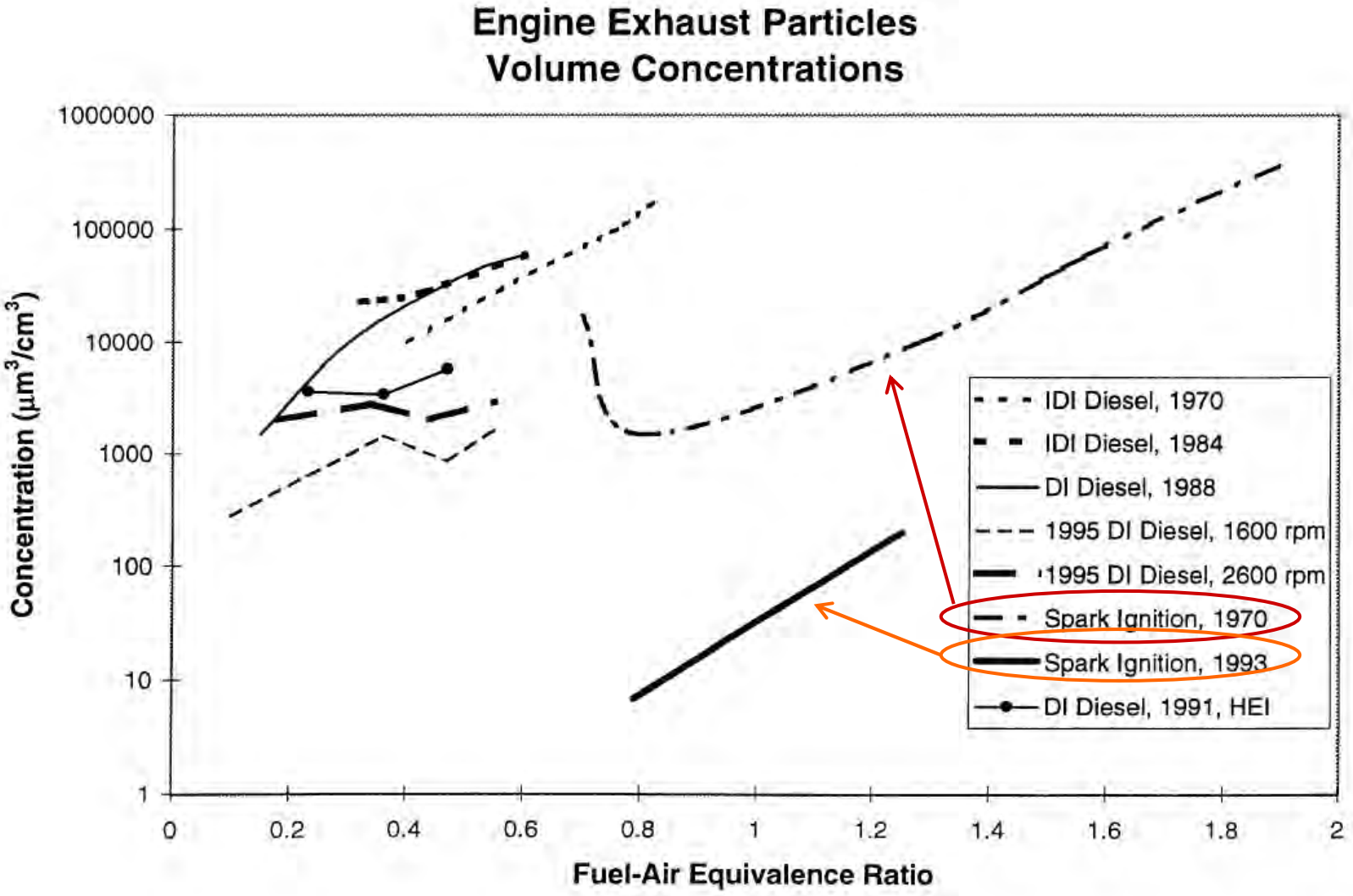



Kittelson, *J. Aerosol Sci.* Vol. 29, No. 5/6, pp. 575-588, 1998

## Engine exhaust toxicity project:

# MEDETOX

## Innovative Methods of Monitoring of Diesel Engine Exhaust Toxicity in Real Urban Traffic.

## EU LIFE+ program (LIFE10 ENV/CZ/651), 2011-2016

**Institute of Experimental Medicine, Academy of the Sciences of the Czech Republic – Jan Topinka, coordinator**

**Faculty of Mechanical Engineering, TU Liberec**

**Ministry of the Environment of the Czech Republic**

## Goal:

## Demonstrating innovative methods of monitoring toxicity

## on-board sampling system, focus on urban driving

## off-line toxicological assays on collected samples

**PEMS – Portable emissions monitoring system**

**-> PETS – Portable exhaust toxicity assessment system**

# Coindicence of problems in dense / congested urban areas

**High concentration of vehicles**

**-> high ambient concentrations**

**High population density**

**-> high number of people exposed**

**High frequency of problematic operating modes**

- **extended idling and creep**
- **dynamic / transient operation**
- **full-power accelerations**

**-> higher and/or more hazardous emissions**

**For toxicity evaluation, focus should be on realistic urban driving conditions.**

**Focus of this work: Small engines**

# Small engines

Abundant in scooters, small motorcycles and garden / yard equipment (chainsaws, weedeaters, lawnmowers, garden tractors, snowblowers)

Designed primarily for low cost and low weight, with less focus on durability, fuel economy or emissions

No periodic emission inspection or in-use compliance program

California: Average citizen produces more smog mowing the lawn than driving their car to work

Difficult to measure, especially during real-world operation

## Particles from multiple-attempt lawnmower engine start


# Goals

Real-world emissions measurement using a portable on-board monitoring system mounted on the tested equipment or on an accompanying cart or vehicle

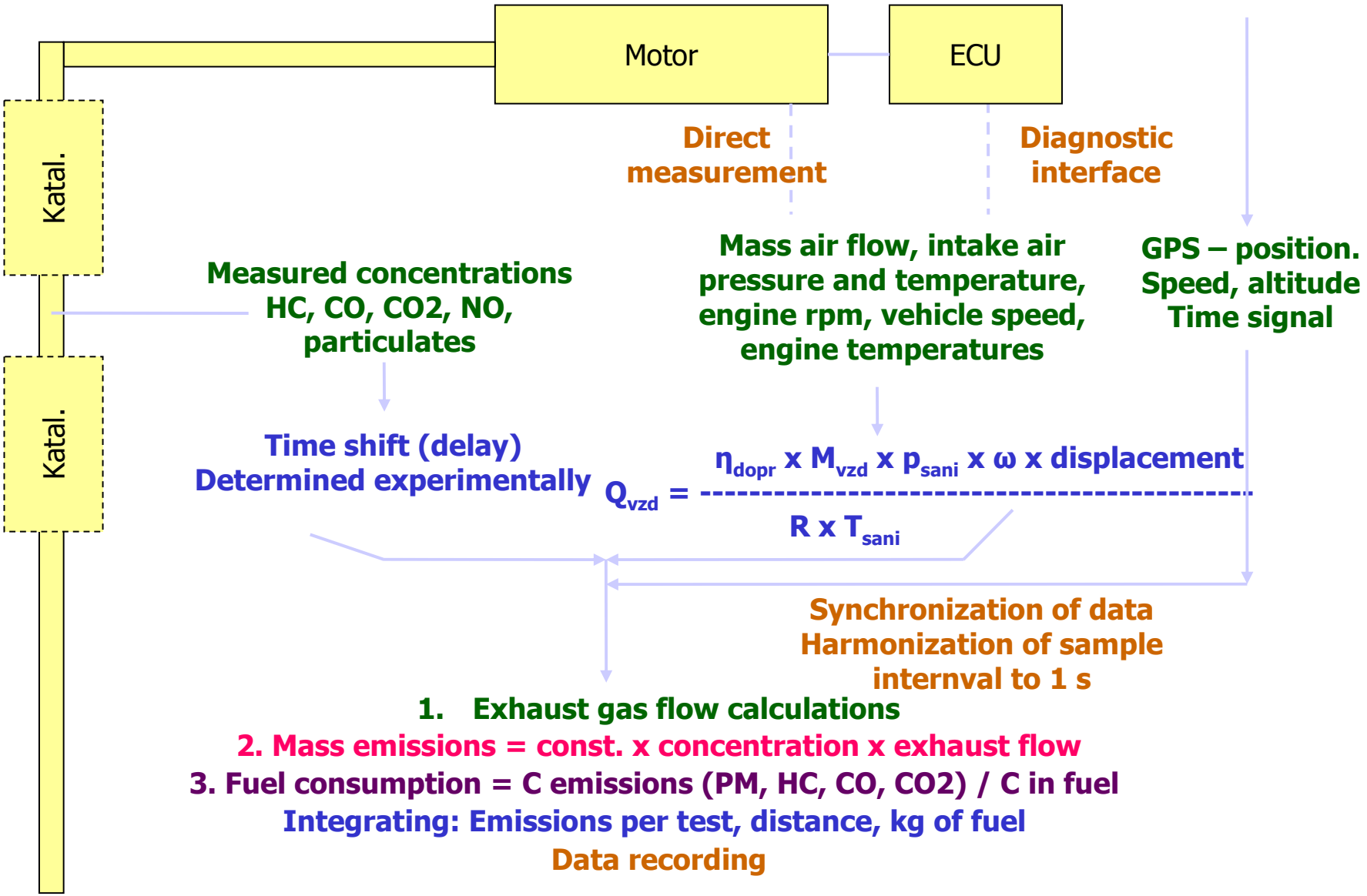
- development of test equipment
- development of test methodology
- assessment of emissions levels

Longer term: Collection of sample for toxicological assays

## Particles from multiple-attempt lawnmower engine start

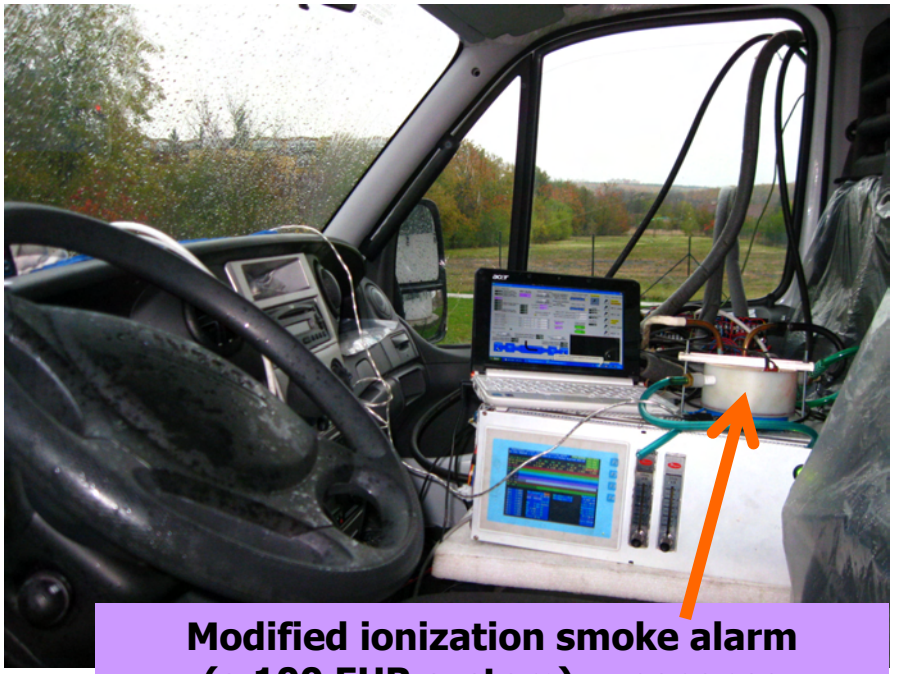

# Measurement of gases and PM with on-board system
## Sampling of PM with on-board proportional sampling system

# Monitoring system functional diagram



# On-board monitoring system - analytical part

**Response approximately proportional to PM mass concentrations for a given engine**



**Modified ionization smoke alarm (a 100 EUR system) - response proportional to total particle length (close to lung deposited surface area?)**

**Nephelometer (laser scattering)**

Filtered dilution air

10-12 lpm raw exhaust

Before or after DOC, DPF, …

Sample cool & reheat

Condensate and large particle removal

CAT

**Charge meter**

F-FC-P

F-FC-P

F-FC-P

**NDIR-HC,CO,CO2**

**chem.cell NO**

F-FC-P

**NDIR-HC,CO,CO2**

**chem.cell NO**

F-FC-P

Filter, flow control, pump

Engine

outflow

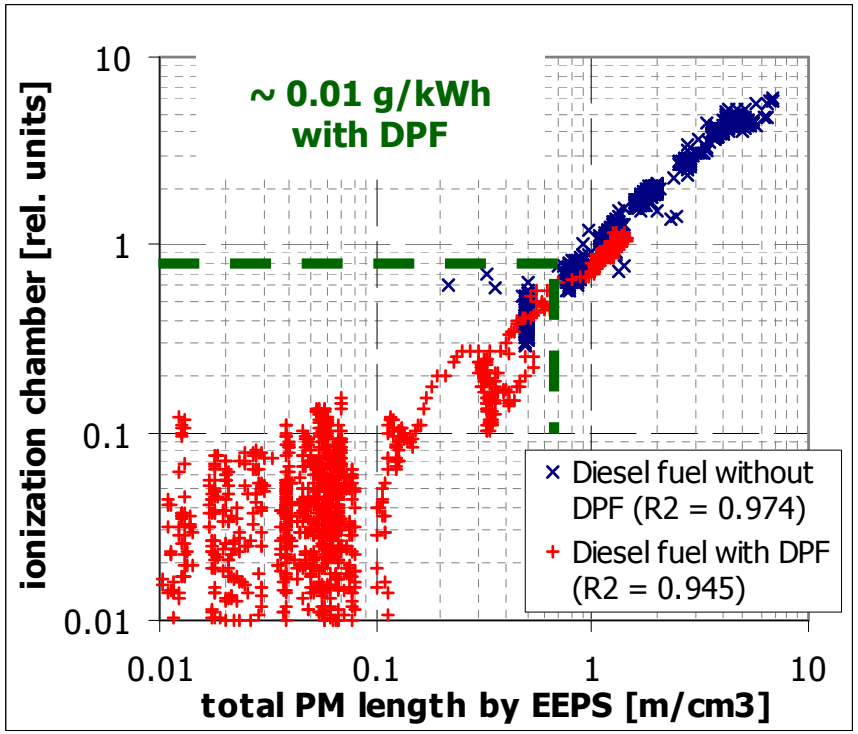
# PEMS PM measurement comparison
## – Zetor 1505 engine, steady-state tests, 2008-2010

### Measuring ionization chamber - total particle length

[Vojtíšek, Journal of the Air & Waste Management Association, 61, 2011, 126-134]

**comparison with electrostatic classifier**

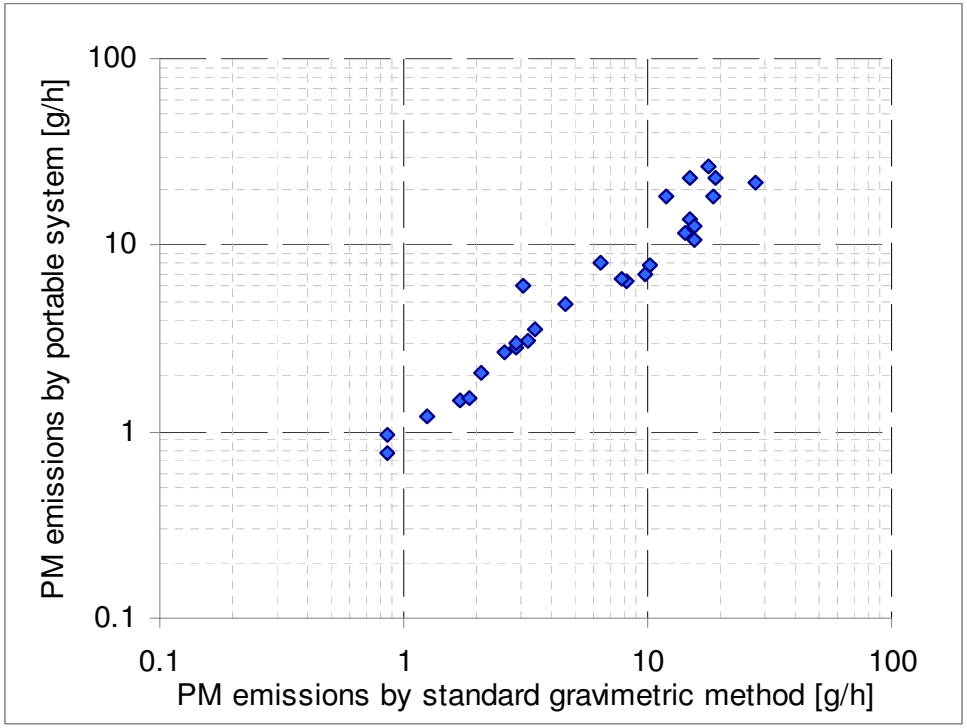
(Engine Exhaust Particulate Sizer, TSI, St. Paul, MN, USA)




### Light scattering device (semi-condensating integrating nephelometer) – approximation of total particle mass

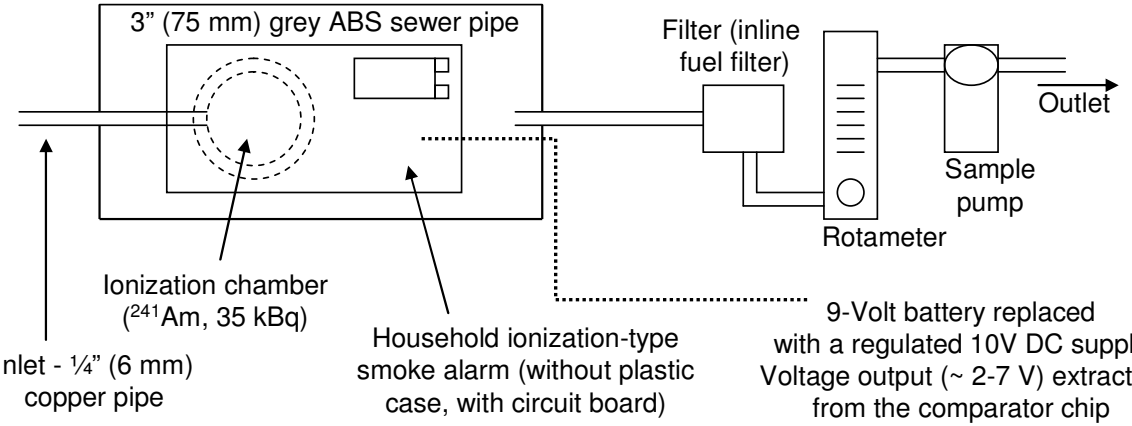
[Vojtíšek, Society of Automotive Engineers Technical Paper Series, 2001-01-3641 (2001) a 2009-24-0148 (2009)]

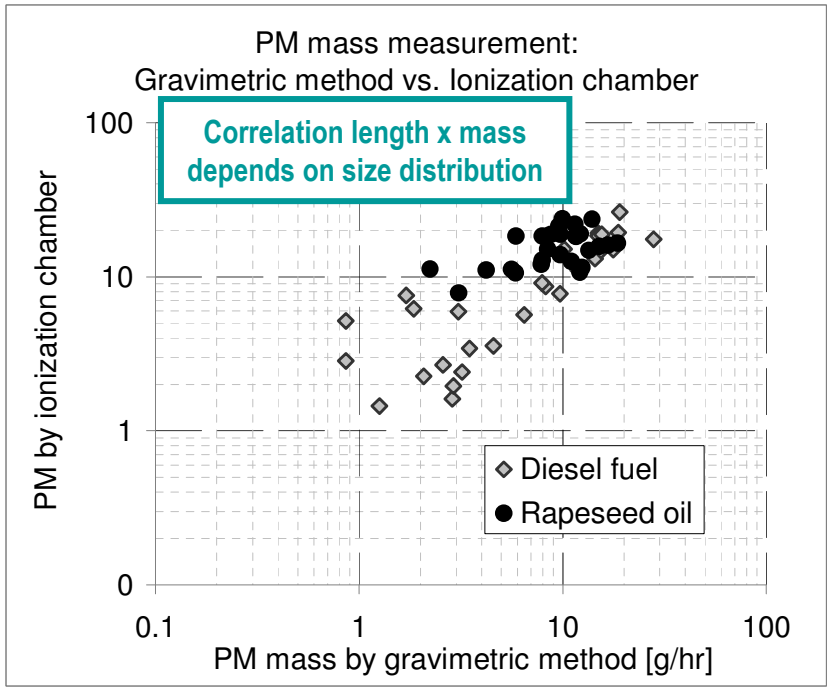
**comparison with gravimetric measurement**

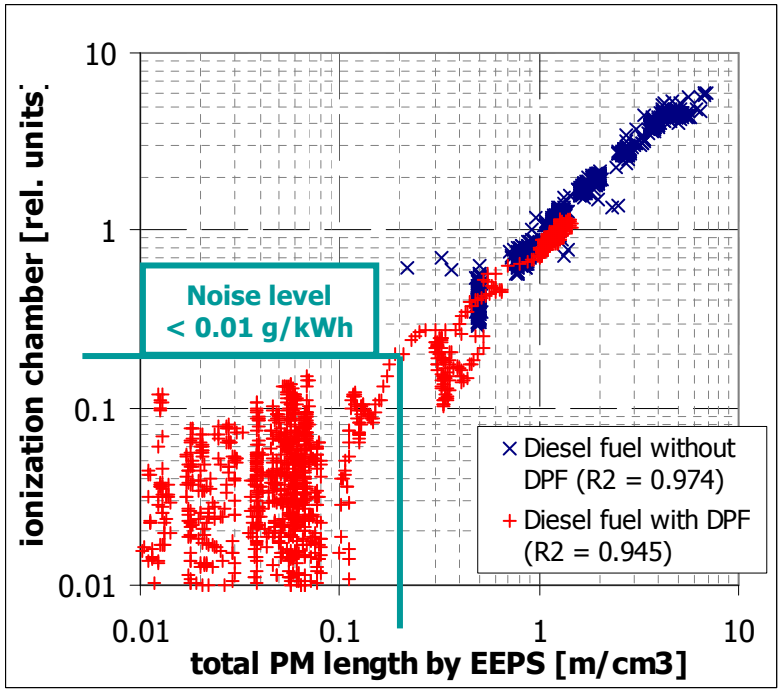


# Low-cost PM length measurement

- Inexpensive device made out of a household smoke alarm
- Measurements correlate with total PM length
- Comparison measurements during steady-state operation




*Vojtíšek, M.: Total Diesel Exhaust Particulate Length Measurements Using a Modified Household Smoke Alarm Ionization Chamber. Journal of the Air and Waste Management Association, ISSN 1047-3289, 61, 2011, 126-134.*

# PM length measurement – comparison

## 0.1 g/kWh PM engine, various fuels and modes, EC 1%-79%
## reference: EEPS sampling from dilution tunnel

**heated ionization "fire detector"**

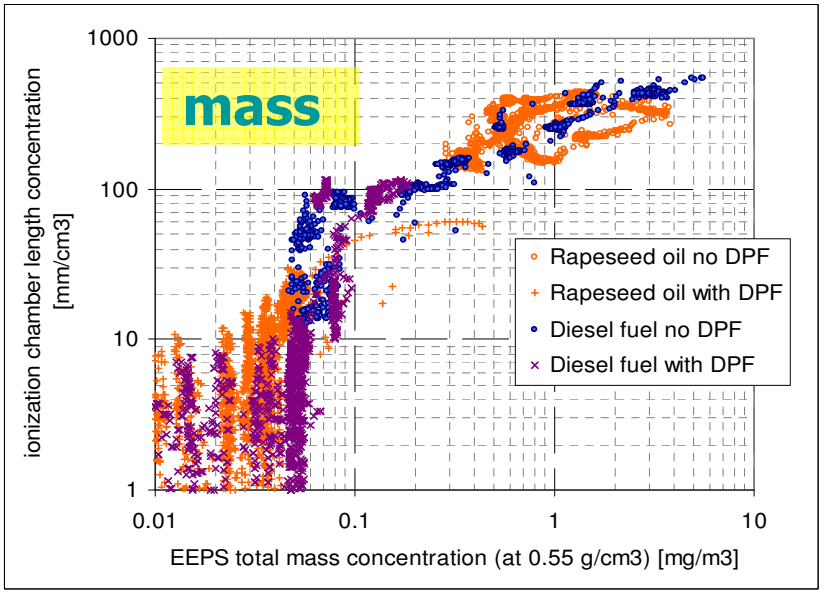
**undiluted raw exhaust**

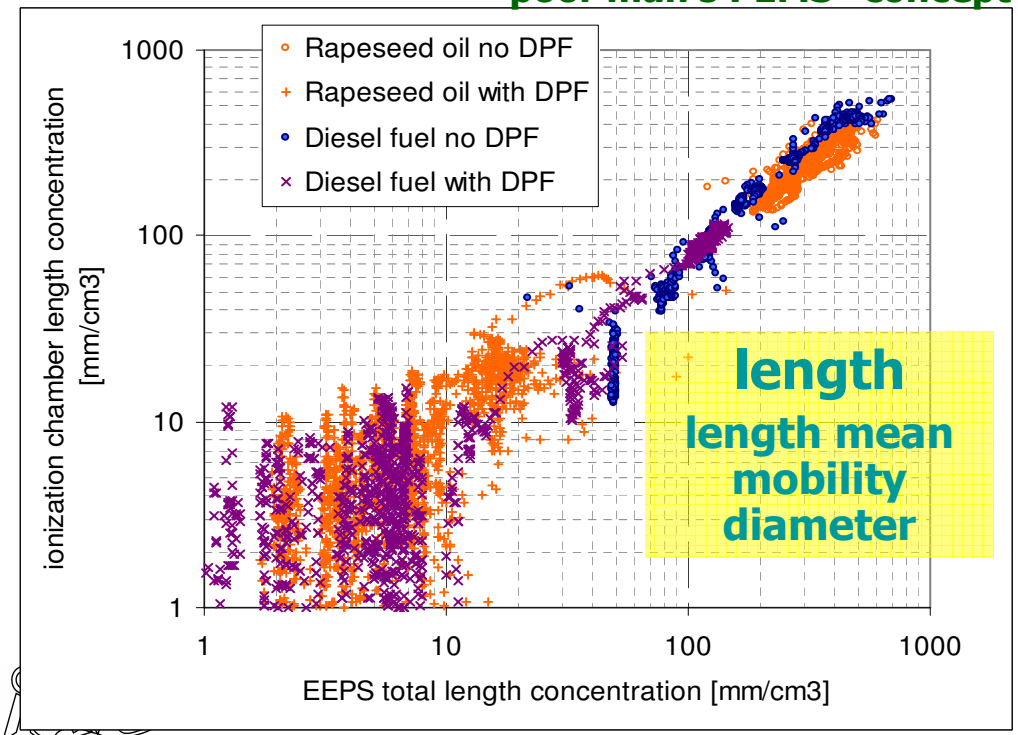
(multiplied by intake air flow for comparison measurements)

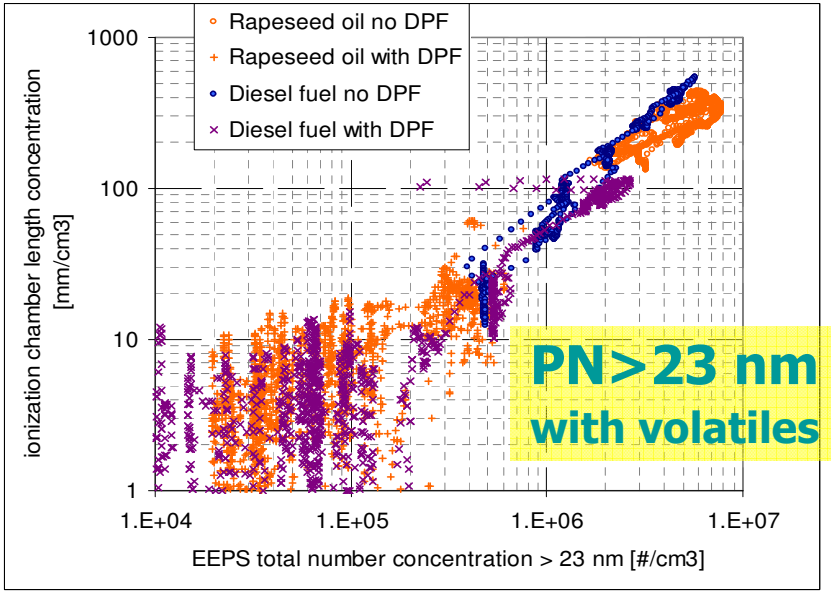
**~ 0.1 mg/m3 sensitivity**

**cheap (100 EUR)**

**"poor man's PEMS" concept**



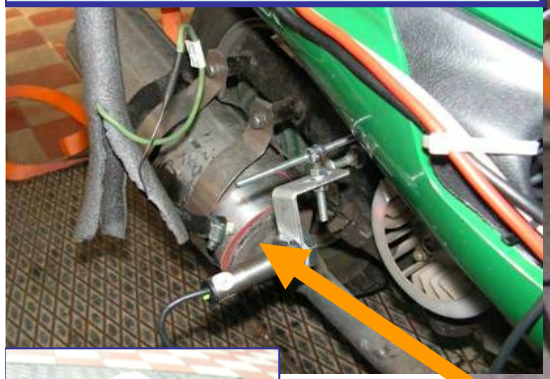



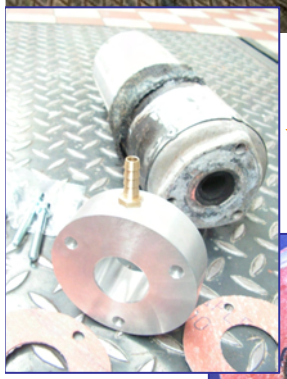



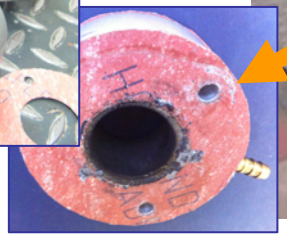
# Test vehicle: 2009 Coliber Fartt RHON LH50QT-6 scooter

**Engine: 0.049-liter, 2 kW, air-cooled, four-stroke carbureted engine**

139QMB, Qingqi Group Ningbo Rhon Motorcycle Co., Ltd.







5 Hz GPS receiver Speed, position, altitude

Battery

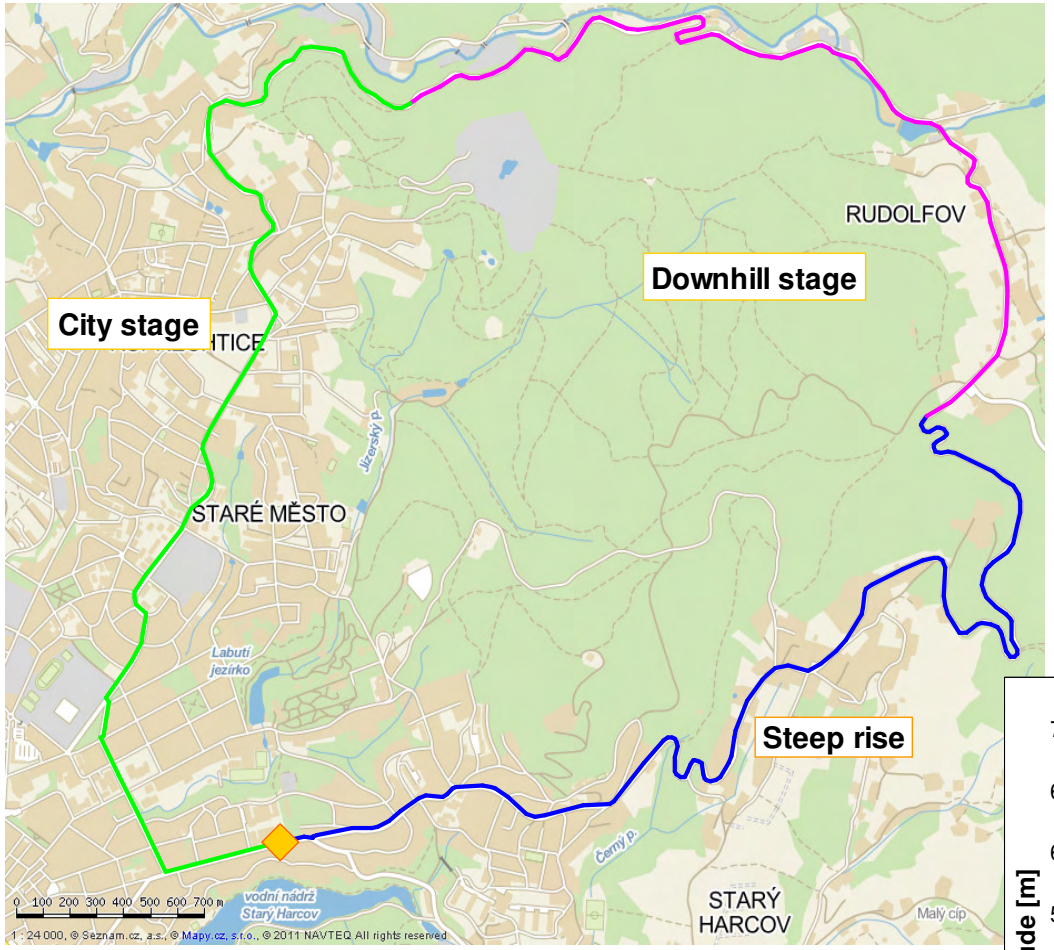
Engine speed measured with optical tachometer

Raw exhaust sampling point (no dilution)

Special adapter fabricated and inserted before muffler (outside air penetrates well into tailpipe)

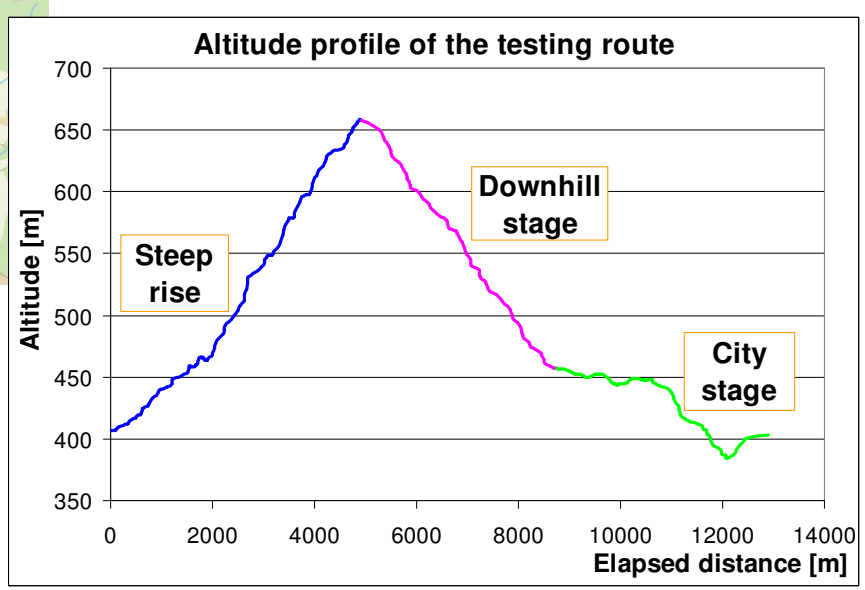
Intake air manifold absolute pressure

# Experimental – Test route




- Route length: approx. 13 km
- Start point altitude: 410 m
- Peak altitude: 660 m
- Lowest point altitude: 380 m

- Engine already running & warm (no cold start)



# Summary results

| Route | HC [g/km] | CO [g/km] | $NO_x$ [g/km] | PM laser [mg/km] | PM ion1 [km/km] | PM ion2 [km/km] | $CO_2$ [g/km] |
|---|---|---|---|---|---|---|---|
| Urban | 2.72 | 11.2 | 0.50 | 3.3 | 406 | 386 | 53 |
| Rural | 1.30 | 8.4 | 0.41 | 2.7 | 320 | 255 | 39 |

**Limits in g/km during prescribed driving cycles**

**EU Euro 3** (since 1.1.2007, 2002/51/EC), <150 cc, ECE R47 test cycle
**HC 0.80 CO 2.0 NOx 0.15**

**California** (2008 and subsequent model years, Title 13, CCR §1958), <280cc
**HC+NOx 0.8 CO 12**

**US EPA** (MY 2006 and later)
**HC 1.0 (or HC+NOx 1.4) CO 12**

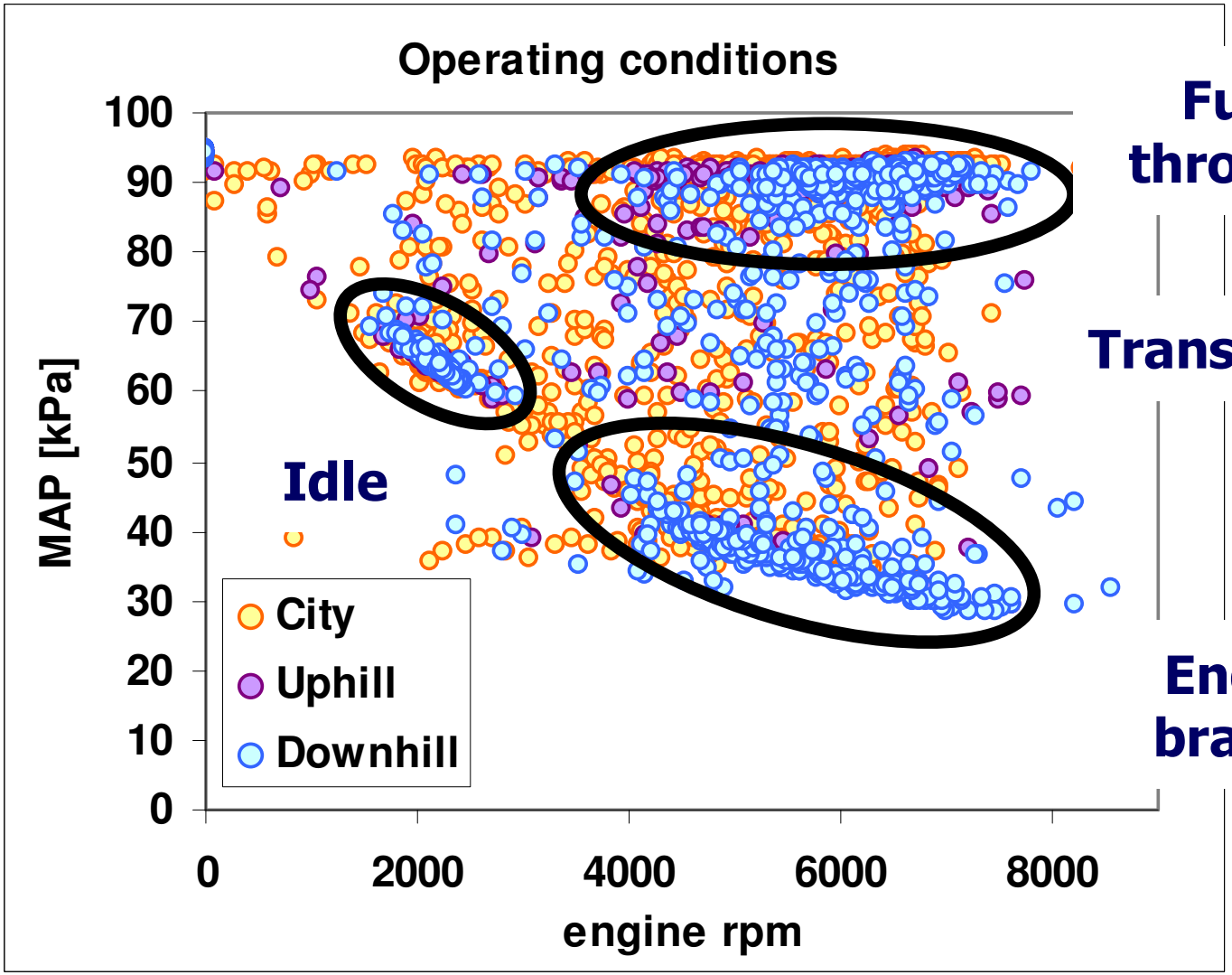
**Canada** (MY 2006 and later)
**HC 1.0 (or HC+NOx 1.4) CO 12**

**China** (2008 and subsequent model years), mopeds <50cc, ECE R47 test)
**HC+NOx 1.2 CO 1.0 fuel cons. 2 l/100 km (~48 g CO2/km)**

**India** (2005-2010, Bharat II standard)
**HC+NOx 1.5 CO 1.5**

# How a scooter is driven

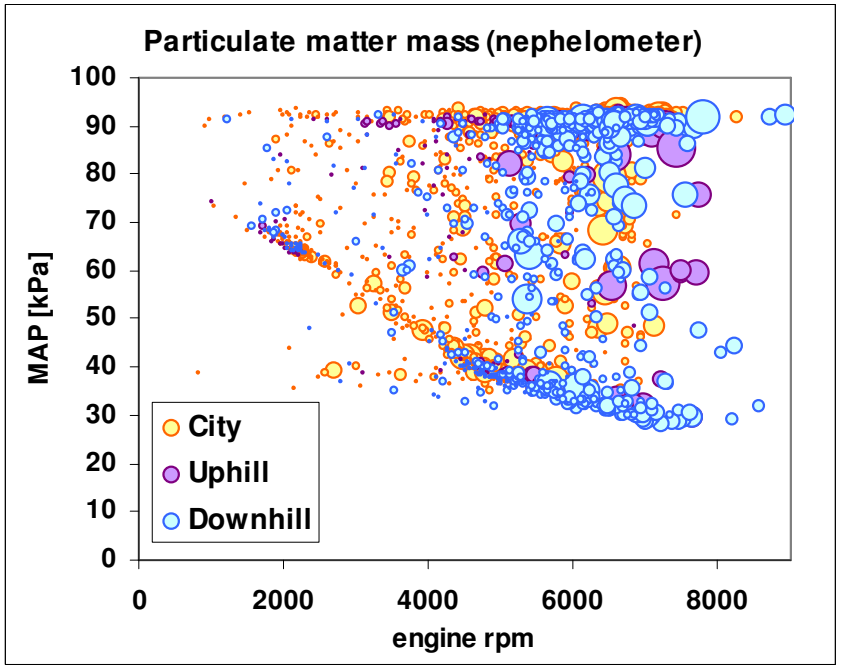
## Mostly "full power or nothing", pulse-width modulation
## Example: Liberec region, each point = 1 second of operation
## Distinct regions: idle, full-power, engine braking, transitions

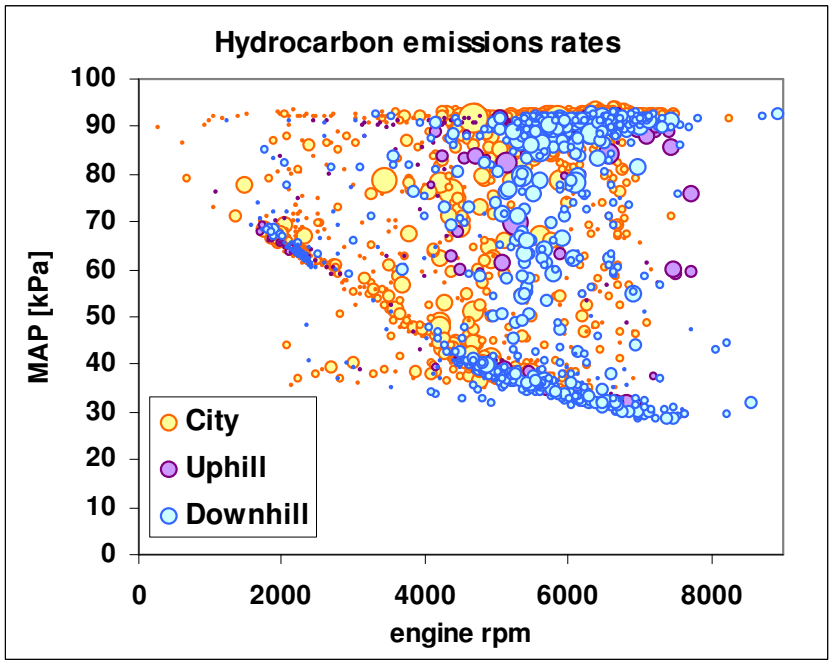


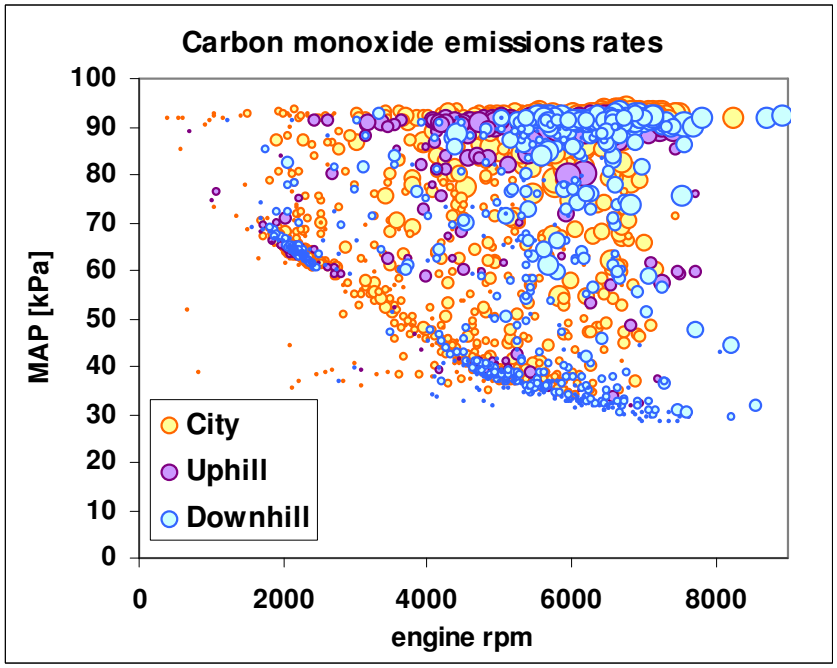
# Emissions patterns

**Larger particles (detected by light scattering) and hydrocarbons dominated by transitions**

**CO high during transitions and at full power**



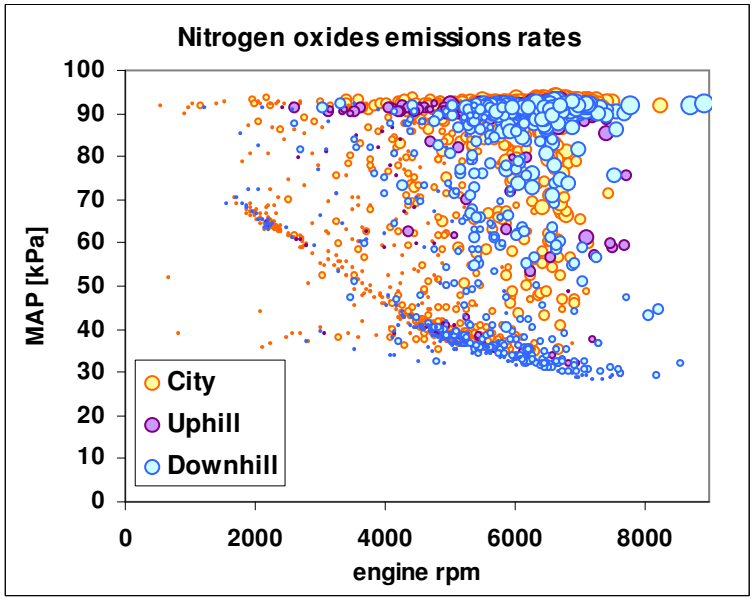



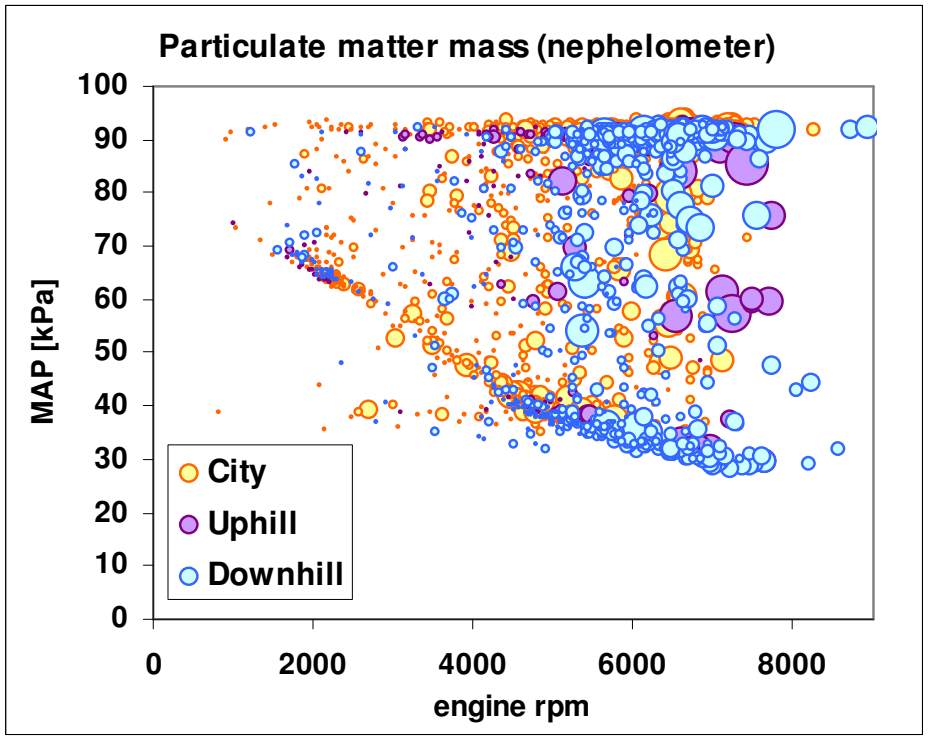
# Emissions patterns

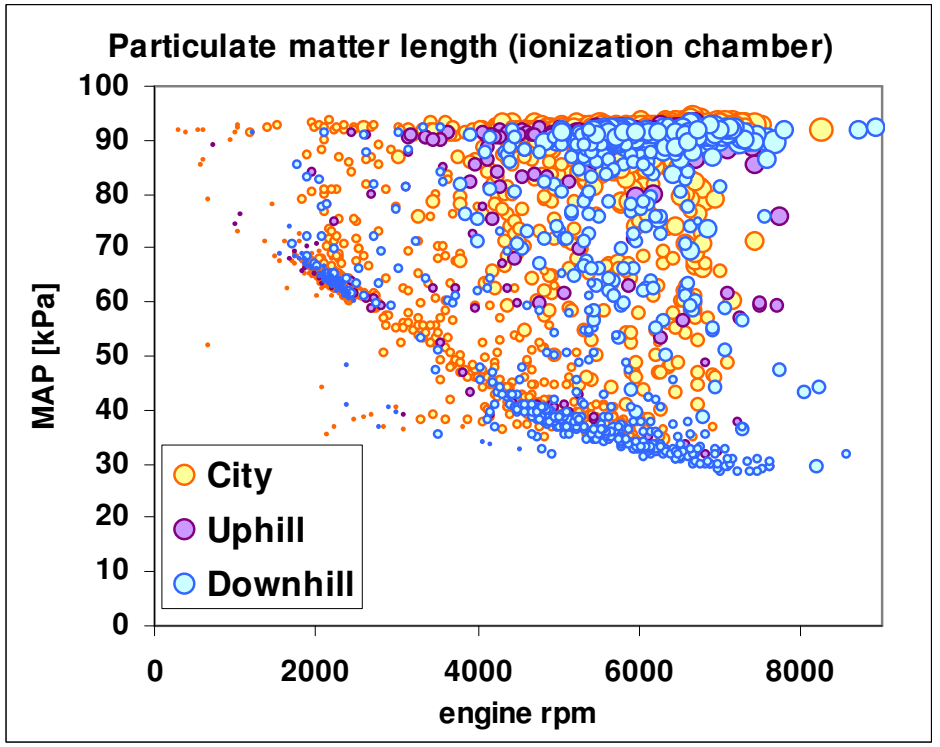
**Larger particles (detected by light scattering) and hydrocarbons dominated by transitions**

**Small particles (detected by ionization chamber) emitted throughout the operating range**

**NOx highest at full power**



# 2009 scooter vs. 1996 Škoda Felicia (SAE 2013-24-0102)

| Route | HC [g/km] | CO [g/km] | $NO_x$ [g/km] | PM laser [mg/km] | PM ion1 [km/km] | PM ion2 [km/km] | $CO_2$ [g/km] |
|---|---|---|---|---|---|---|---|
| Urban | 2.72 | 11.2 | 0.50 | 3.3 | 406 | 386 | 53 |
| Rural | 1.30 | 8.4 | 0.41 | 2.7 | 320 | 255 | 39 |

| | HC [g/km] | CO [g/km] | NOx [g/km] | CO2 [g/km] | PM [mg/km] | PM length [km/km] |
|---|---|---|---|---|---|---|
| Gasoline | 0.128 ± 0.004 | 2.299 ± 0.004 | 0.283 ± 0.009 | 159 ± 3 | 3.56 ± 0.07 | 613 ± 23 |
| E85 | 0.113 ± 0.01 | 0.829 ± 0.19 | 0.661 ± 0.028 | 148 ± 2 | 3.17 ± 0.04 | 422 ± 16 |
| E85 vs. gasoline | -11% | -64% | +134% | -7% | -11% | -31% |
| p-value | 0.952 | 0.200 | 0.010 | 0.493 | 0.684 | 0.860 |
| Gasoline | 0.145 ± 0.004 | 2.444 ± 0.147 | 0.202 ± 0.003 | 163 ± 3 | 1.48 ± 0.1 | 394 ± 98 |
| Butanol 85% | 0.168 ± 0.016 | 2.22 ± 0.22 | 0.482 ± 0.09 | 167 ± 4 | 2.18 ± 0.17 | 320 ± 13 |
| Bu85 vs. gasoline | +16% | -9% | +139% | +2% | +47% | -19% |
| p-value | 0.131 | 0.268 | 0.032 | 0.331 | 0.011 | 0.477 |

# Conclusions

A typical scooter equipped with a miniature portable on-board monitoring system (PEMS)

Emissions successfully measured during real-world operation on local test routes – measurement is possible

Operating pattern is "all or nothing", plus idle and transitions

PM emissions comparable to an older passenger car

HC, CO, NOx higher than from an older passenger car

Preliminary tests conducted on other types of engines

**PM emissions of small engines are not insignificant and deserve future attention**

## Acknowledgments


# MEDETOX

**Innovative Methods of Monitoring of Diesel Engine Exhaust Toxicity in Real Urban Traffic.**

**EU LIFE+ program (LIFE10 ENV/CZ/651), 2011-2016**


**Goal:**

**Demonstrating innovative methods of monitoring toxicity**
**on-board sampling system, focus on urban driving**
**off-line toxicological assays on collected samples**

**PEMS – Portable emissions monitoring system**
**-> PETS – Portable exhaust toxicity assessment system**


**Czech Science Foundation – BIOTOX project (13-01438S)**
**Mechanisms of toxicity of biofuel particulate emissions**