Hearing on PFS and SCR in the Danish Parliament on Tuesday 21.11.2006

Ultrafine Particle Emissions of HDV Euro 4 and Euro 5 compared to Euro 3 with a VERT-Particle Filter

(Test on behalf of the Swiss EPA 2005)

A.Mayer/TTM

A.Mayer - TTM

Independent Consultant
on Emission Reduction of IC-Engines

TTM is responsible on behalf of Swiss EPA and SUVA for

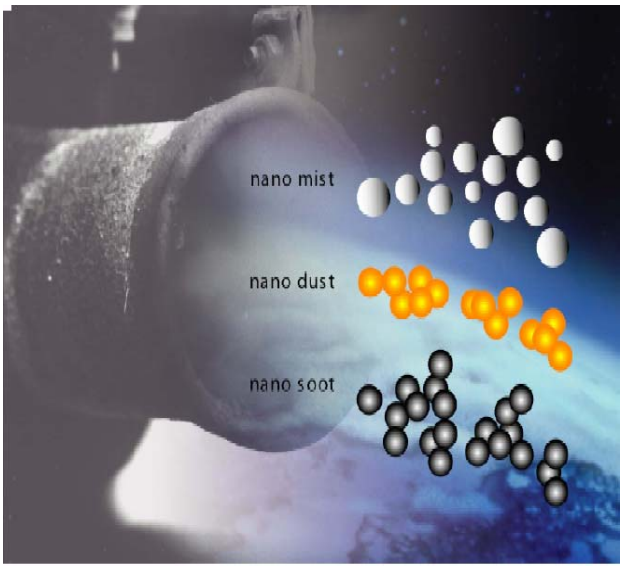
- **VERT Verification of Particle Filter Systems**
- **Quality Control of Filter Retrofits in Switzerland**

- **Research and Development in International Projects**
- **Implementation of Emission Reduction Measures (Germany, Austria, Poland, Italy, California, Canada, Ecuador, Chile, Korea, Japan ..),**
- **Organization of Seminars and Conferences**
- **Many SAE-papers and 2 books published 2004/5 on "elimination of combustions generated particles"**
- **SAE-fellowship 2004**
- **Award of Swiss Cancer Ligue 2006**

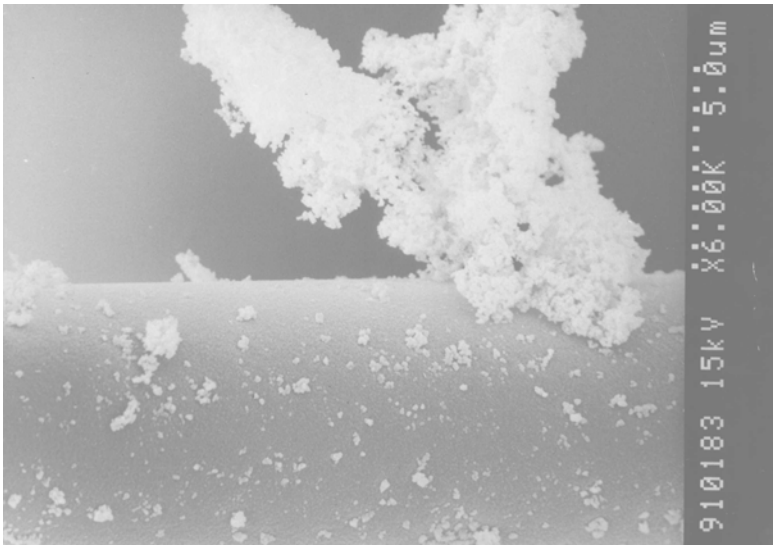
All IC-Combustion Engines are emitting very high numbers of solid particles

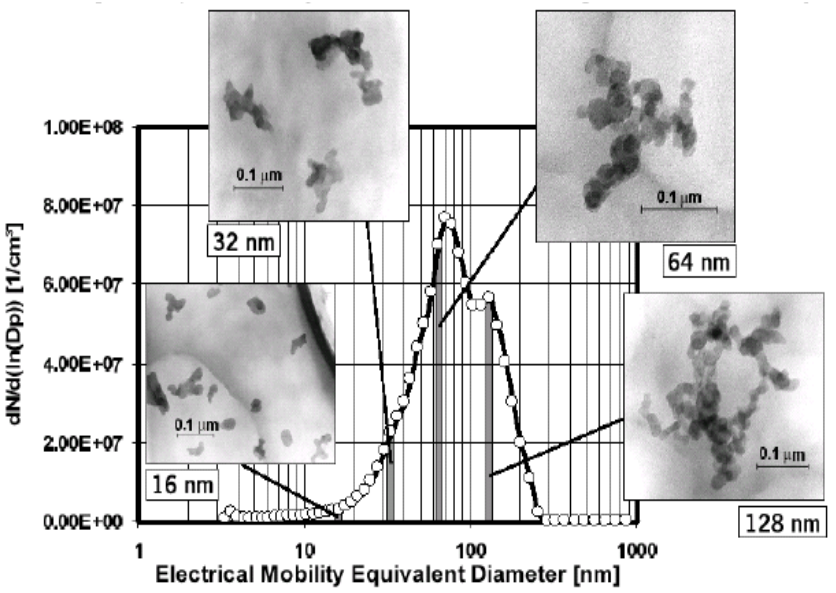
Size range 20-300 nm“

(Quelle:
M.Kasper/ ME)



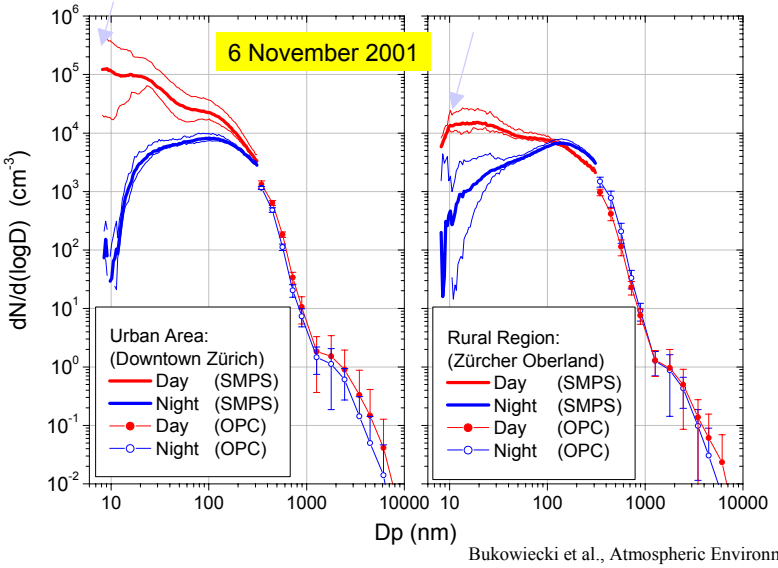
Soot Particles deposited on a 5 micron Filter Fibre





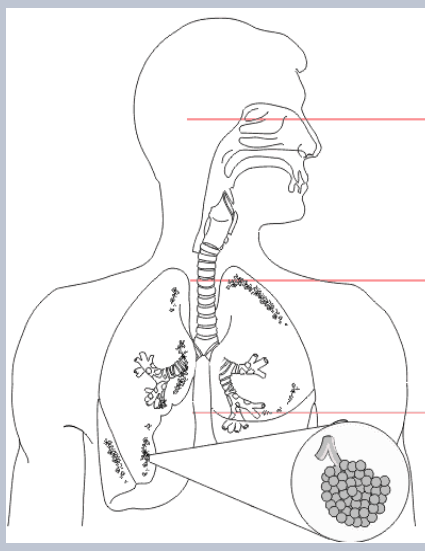
Source: METZ, BMW

Aerosol Number-Size distributions
in urban and rural areas mirror the emission profile



Bukowiecki et al., Atmospheric Environment, 2002

Deposition of Particles in the Airways depends strongly on Size



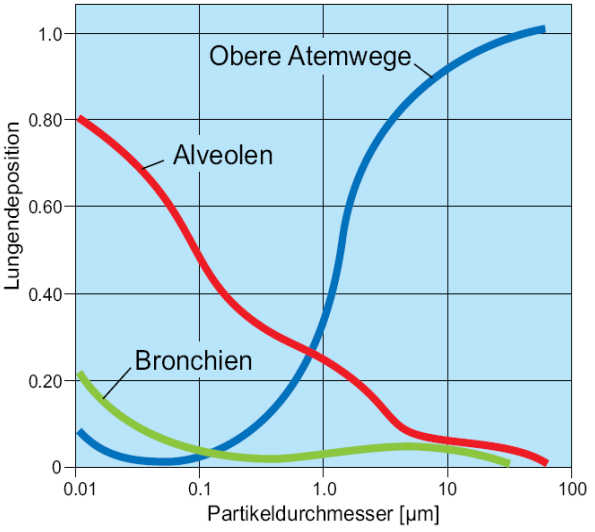
Angriffsorte	Luftschadstoffe
Nasen-Rachenraum	5-10 µm
Luftröhre	3-5 µm
Bronchien	2-3 µm
Bronchiolen	1-2 µm
Alveolen (Lungen-bläschen)	0.1-1 µm

Deposition

of particles in the airways depends mainly on particle size not mass

Nature takes care of particles > 1µm

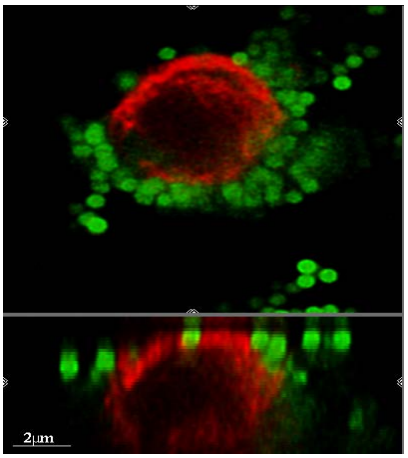
DPF must take care of particles < 1µm

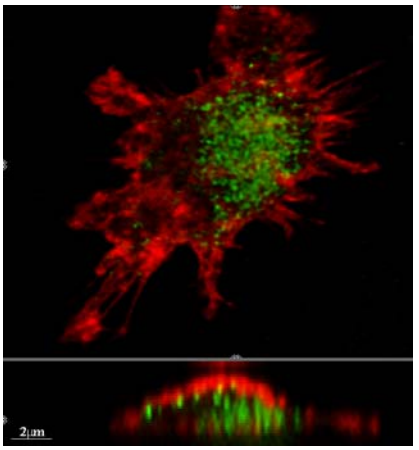


(Source: Hinds, 1982 Aerosoltechnology)

Macrophages *in vitro*

- 1000 nm Polystyrene Particles
- 78 nm Polystyrene Particles





B. Rothen-Rutishauser

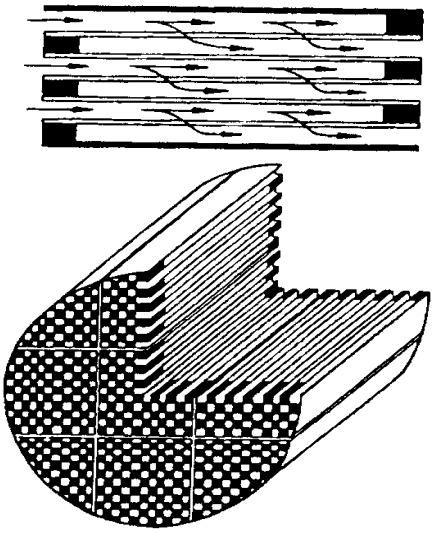
*w*hy are combustion generated ultrafine particles a health risk ?

- penetrate alveoli membranes into the organism
  → size matters
- very in high concentrations of invisible aerosol
  → number matters
- toxic, create cancer
  → substance matters

Epidemiology associates ultrafine particles with mortality due to lung deseases, heart desease and cancer

→ Law requires to minimize emission of carcinogenic substances not to a fixed limit only but as low as possible acc. to **best available technology BAT**

Technology is available
CORNING 1982

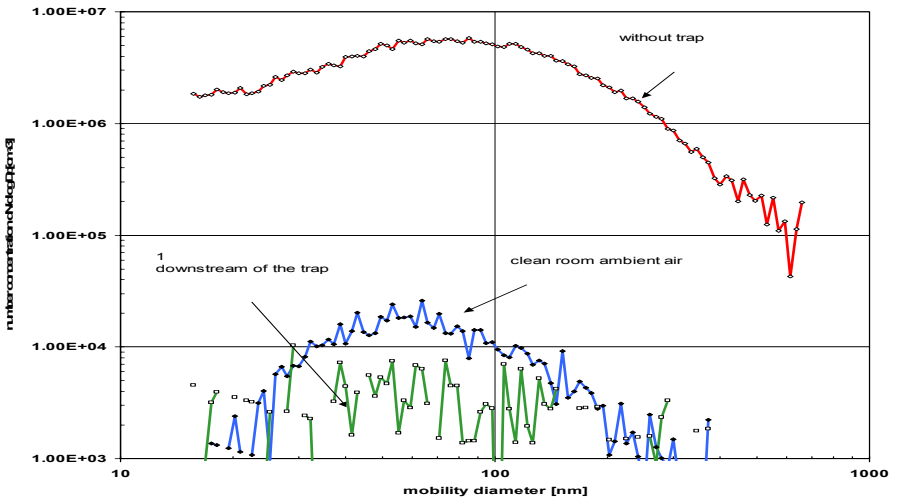


some VERT-tested PFS after 2000 op.hrs

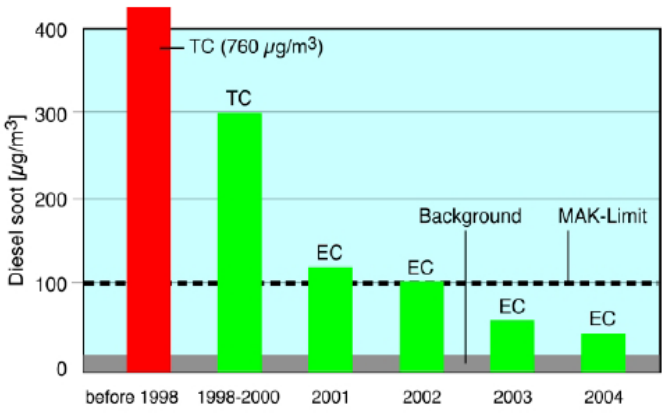
VERT= Swiss Filter Quality Standard

Manufacturer	Regeneration		PZAG [%]
ADASTRA	FBC		99.351
AIRMEEX	FBC		99.973
ARVINMERITOR	Full Flow Burner		99.854
ATH	Stand Still Burner		99.998
COMELA	Heat Storage with twin Filter Set		98.310
DCL	Electric External		99.999
DINEX	Catalyzed		99.906
ECS (UNIKAT)	On Board Electric		99.999
ECS (UNIKAT)	Catalyzed		99.955

Exhaust Gas downstream Filter is cleaner than Ambient Air !



SUVA:Tunnel-Luftqualität 1998-2004



and air will become as clean as in Swiss Tunneling Sites by Filter Technology

Key Question:

Is Euro 4 and Euro 5

best available technology and minimizes health risk from Ultrafine Particle Emissions of HD-Diesel engines ?

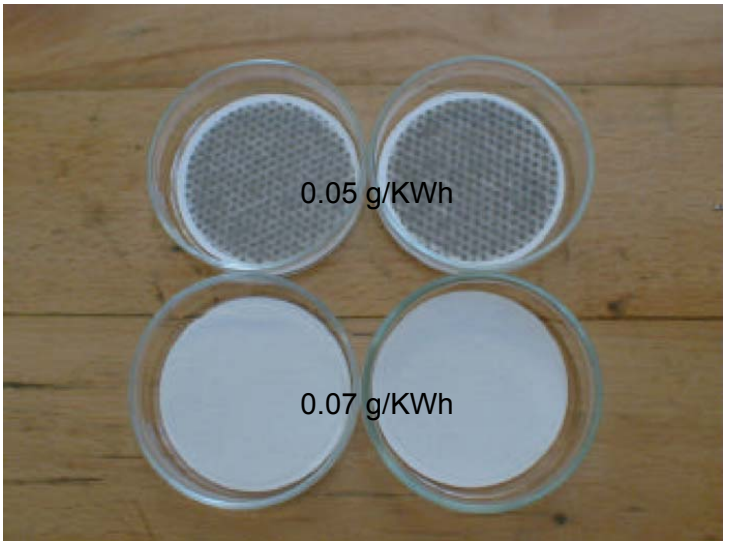
→EU-homologation can not give the answer since it limits only total mass and disregards the toxicity parameters: size, number and substance

Euro 4 and Euro 5 seem very clean - but what about Ultrafines ?

[g/kWh]	CO	HC	NOx	PM	EC	PZ	NO_2
EURO 3 w/o DPF	< 2.1	< 0.7	< 5.0	< 0.1	?	?	?
Limits	*2.1*	*0.7*	*5.0*	*0.1*			
EURO 4 - PM-Kat	0.1	0.01	3.02	0.014	?	?	?
Limits	1.5	*0.5*	*3.5*	*0.02*			
EURO 5 – SCR	0.27	0.01	1.56	0.013	?	?	?
Limits	*1.5*	*0.5*	*2.0*	*0.02*			

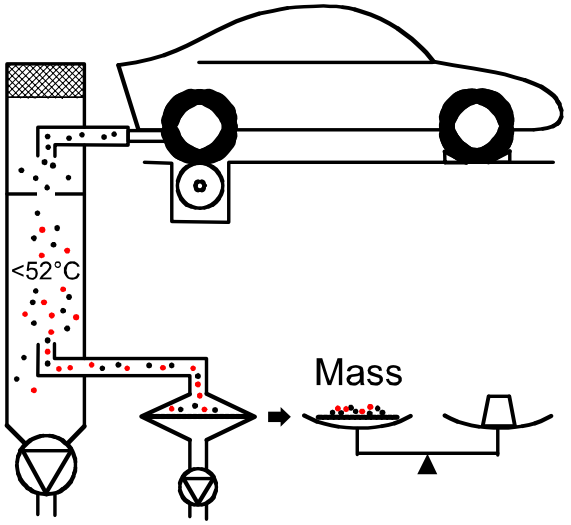
Particulate Mass Samples upstream and downstream of a Particle Filter in a Bus

(Odense 2003)

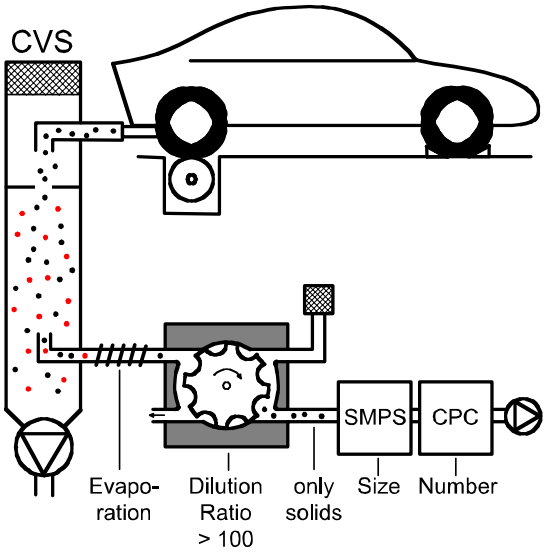


Hansen, Jensen, Ezerman (2001) Report 270-1-0019, Engine Technique Aarhus

How do we measure Particle Mass PM according to the legal procedure



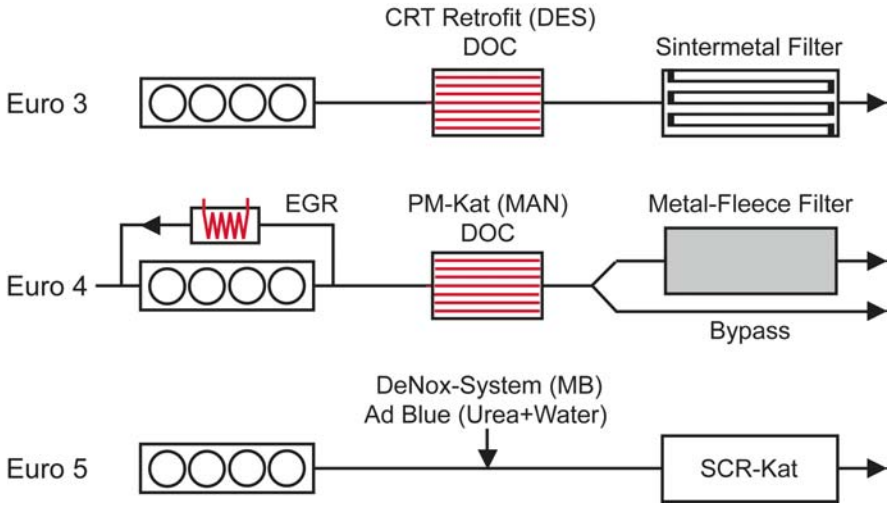
How do we measure solid Particle Number and Size acc. to EU-PMP



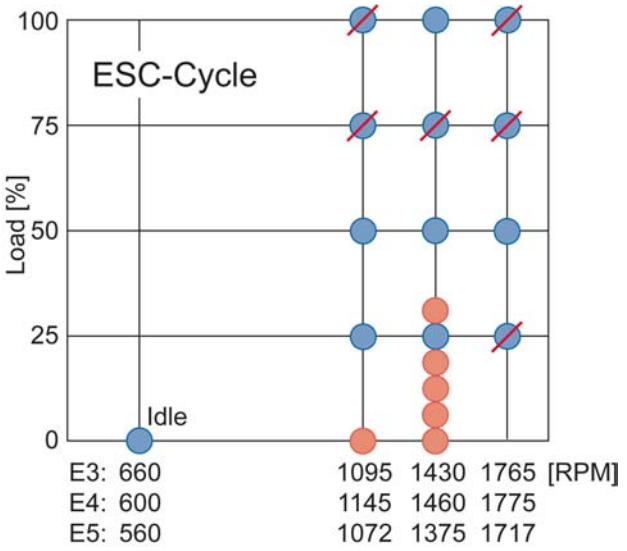
Test Vehicles for Swiss-EPA-Test

- **EURO 4 – PM-Kat**
  - MAN: TGA 18.430
  - 316 kW/1900 rpm - 31'196 km
- **EURO 5 – SCR**
  - Mercedes Benz 1896-LS Euro 5
  - 348 kW / 1796 - 2'863 km
- **EURO 3 - DPF**
  - Mercedes Benz 1846-LS EURO 3
  - 355 kW / 1695 rpm - 49'051 km
  - DPF: HJS sintermetal wall flow , regeneration CRT, retrofit

Exhaust Aftertreatment Concepts



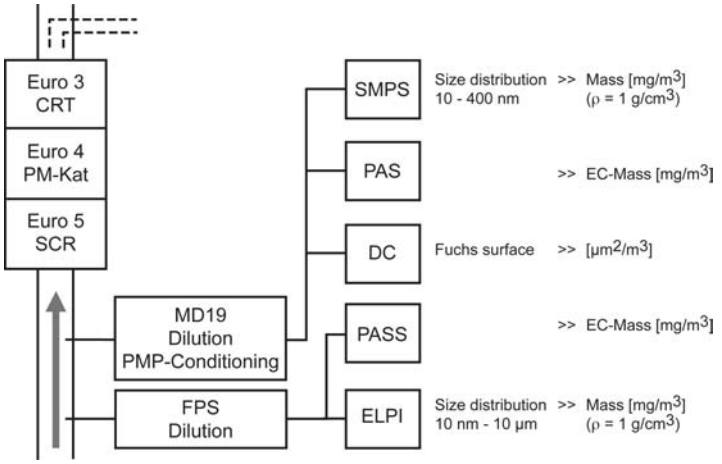
Selected Operating Points



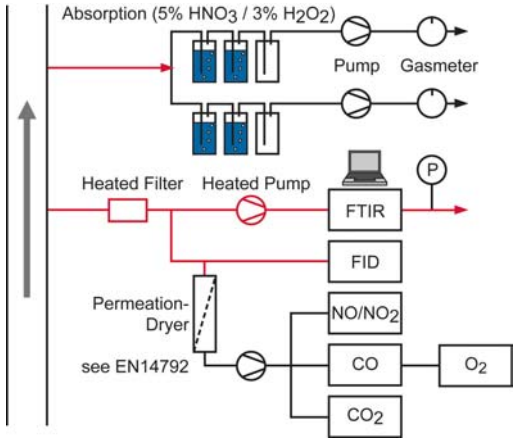
Instruments for Particle Analysis

	Product	Measurement Principle	Size Range	Result
SMPS	TSI	electric mobily sizing and CNC-counting	10-400 nm 60 classes	count per class → volume, mass
PAS	ME PAS 2000	photoelectric charging comb.aerosol surface	< 1000 nm	electric charge → EC-mass
DC	ME LQ1-DC	diffusion charging Fuchs-surface-meas.	< 1000 nm	electric charge → Fuchs-surface
PASS	AVL	Photoacustic measurement of EC	< 10'000 nm	Pressure signal → EC-mass
ELPI	DEKATI	Aerodynamic sizing online counting	< 10'000 nm 12 classes	counts per class → volume, mass

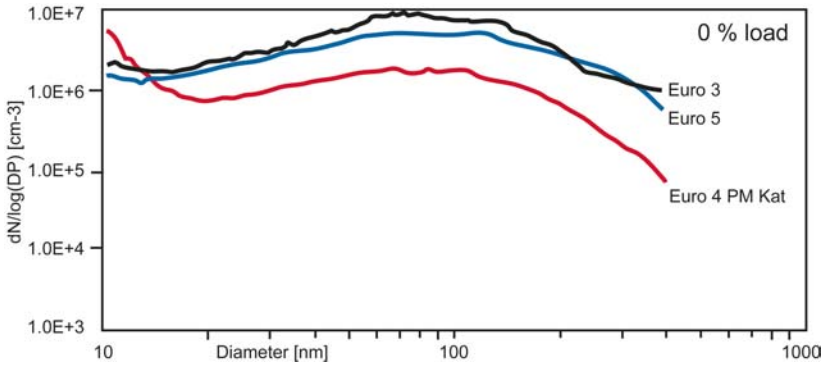
Sampling and Instrumentation



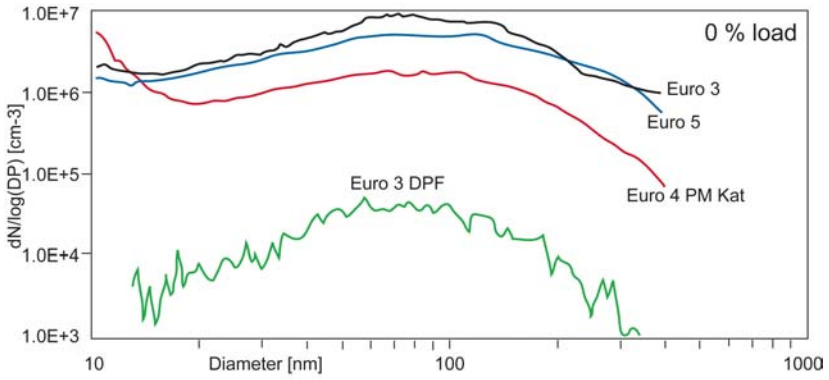
Gas Analysis and Metal Sampling



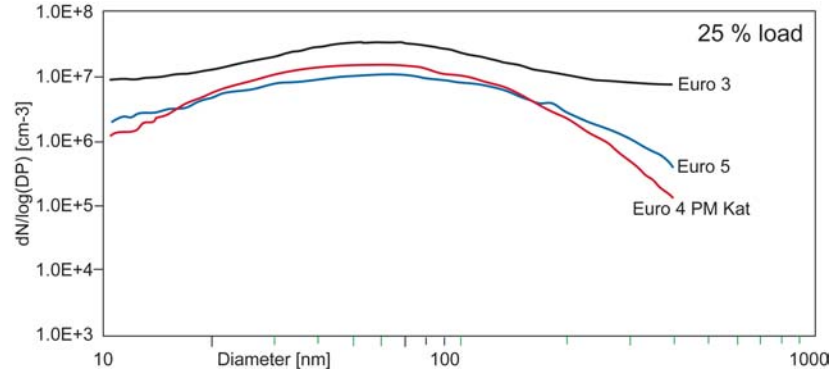
Size Distribution (SMPS) at Low Idle



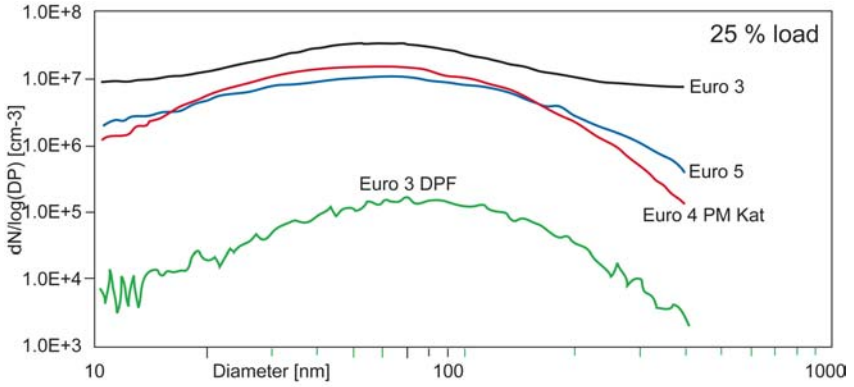
Size Distribution (SMPS) at Low Idle



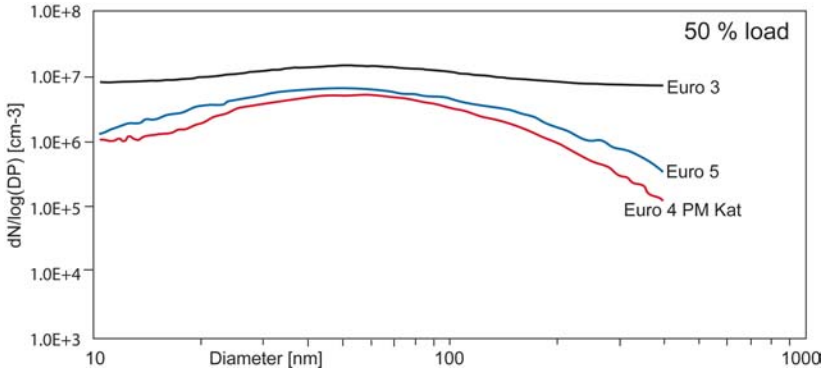
Size Distribution at 1400 rpm 25% Load



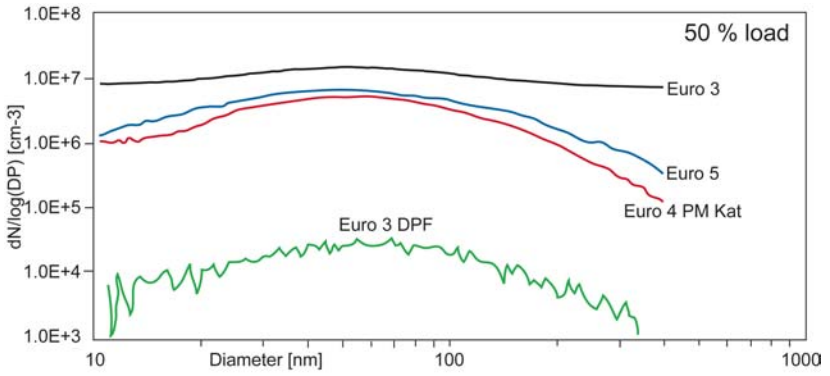
Size Distribution at 1400 rpm 25% Load



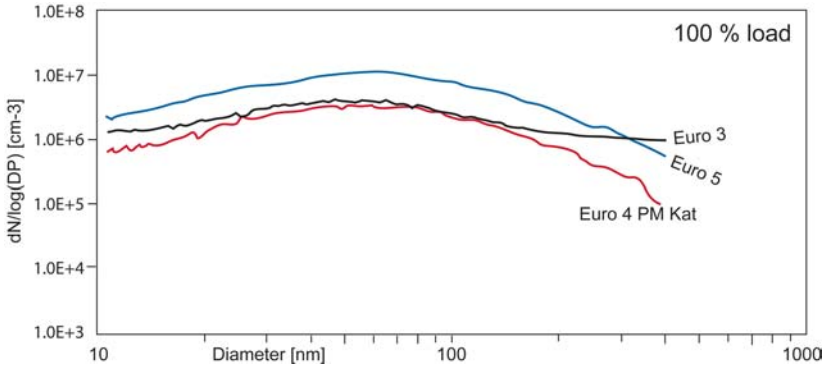
Size Distribution at 1400 rpm 50% Load



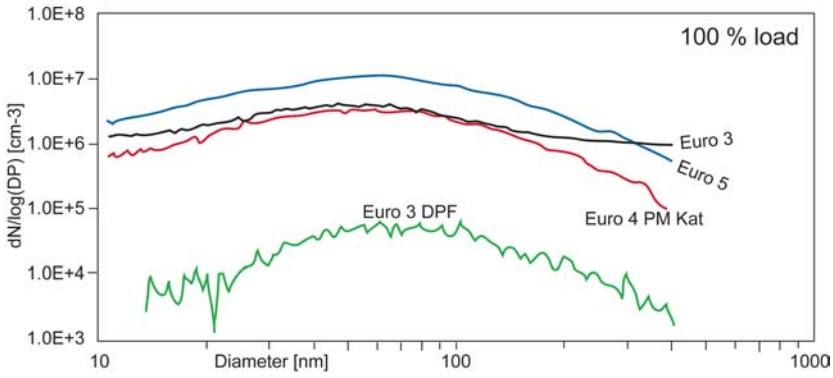
Size Distribution at 1400 rpm 50% Load



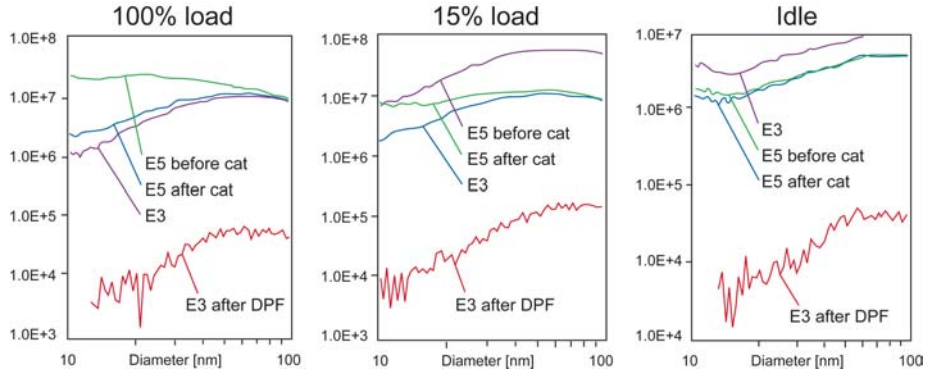
Size Distribution at 1400 rpm Full Load



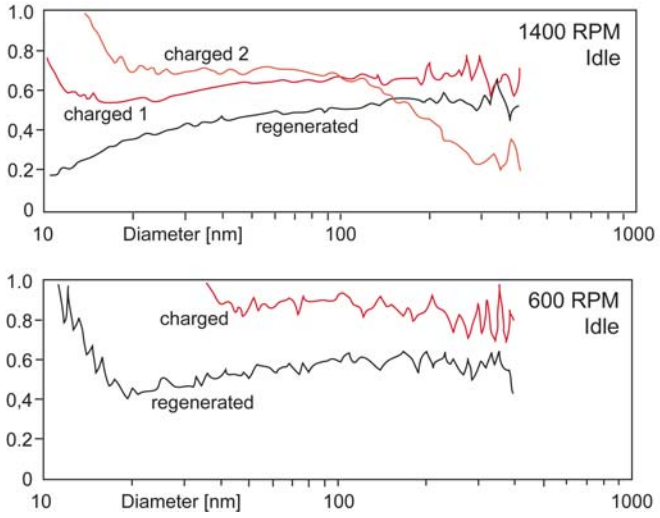
Size Distribution at 1400 rpm Full Load



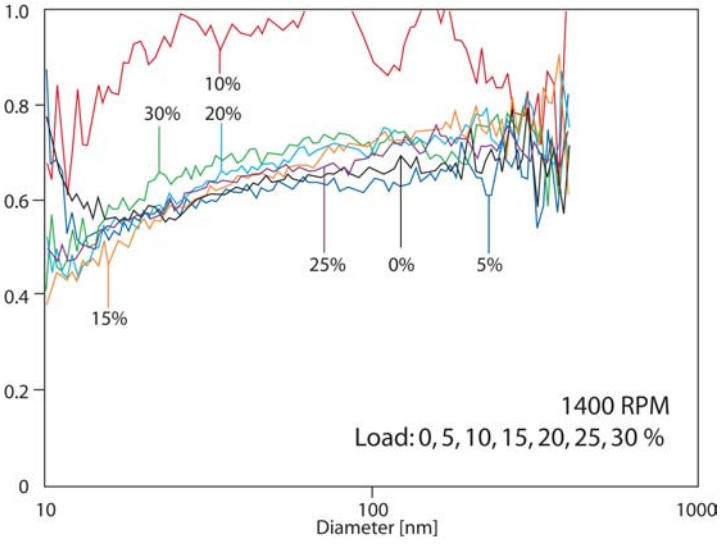
Nanoparticle Emissions with SCR



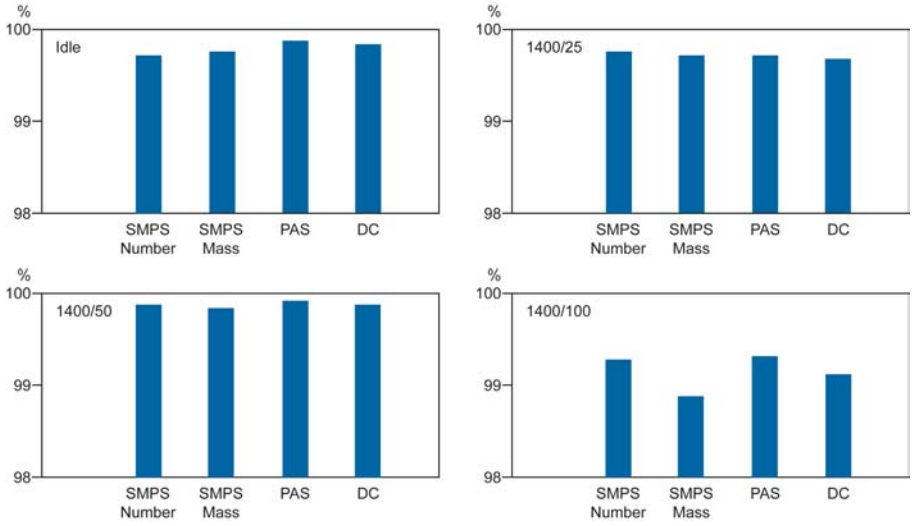
Euro 4 PM-Kat when soot charged



Euro 4 PM-Kat : Penetration-Instability

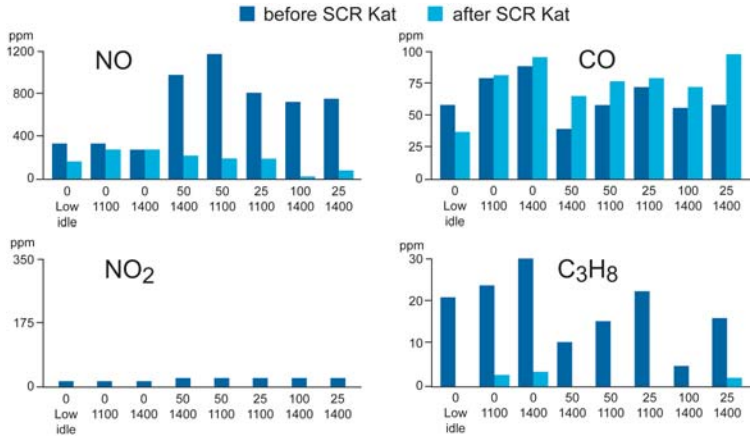


Euro 3 DPF-Efficiency, all Instruments



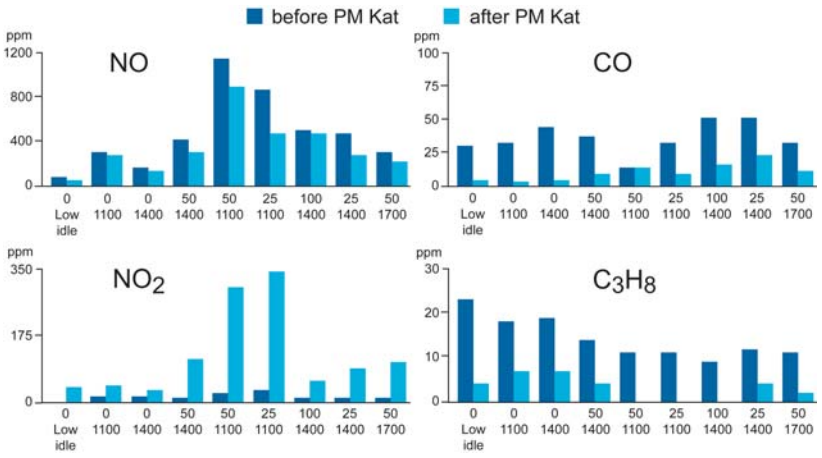
Gas Emissions Euro 5 [ppm]

→ no DeNOx-Effect at light load



Gas Emissions Euro 4 [ppm]

→ very high NO2-emission



Summary and Conclusions

- Particle Filter PFS eliminate ultrafine solid particles (soot and metal oxides) = BAT – efficiency > 99.0 % acc. to VERT
- Euro 4/Euro 5 HDV without DPF emit up to 1000 times more ultrafine carcinogenic particles than Euro 3 with VERT-filter. The same with older HDV and all LDV-Diesels
- PM-Kat ("open filter") is an low efficiency unstable bypass and his Pt-Oxidation catalyst is worsening the situation (like all DOC) by emitting high concentrations of NO_2

→ PFS is absolutely required for Euro 4 and 5

→ PFS is also required for all older HDV and all LDV-Diesels

→ PFS are available and proven for all applications

→ DOC increases the toxicity of Diesel exhaust gas

Further Information

- ETH-Konferenz “combustion generated nanoparticles”
  CD mit Proceedings www.nanoparticles.ethz.ch
- Minimierung der Partikelemissionen
  Expert-Verlag 2004; ISBN 3-8169-2430-1
- BUWAL-Homepage: www.umwelt-schweiz.ch/buwal
- AKPF-Homepage: www.akpf.org
- DieselNet: www.dieselnet.com
- Nanopartikelmesstechnik: www.matter-engineering.com
- Partikelfilteranwendung: ttm.a.mayer@bluewin.ch