Technical challenges with low level PM mass and number measurements

Rainer Vogt, Volker Scheer and Ulf Kirchner

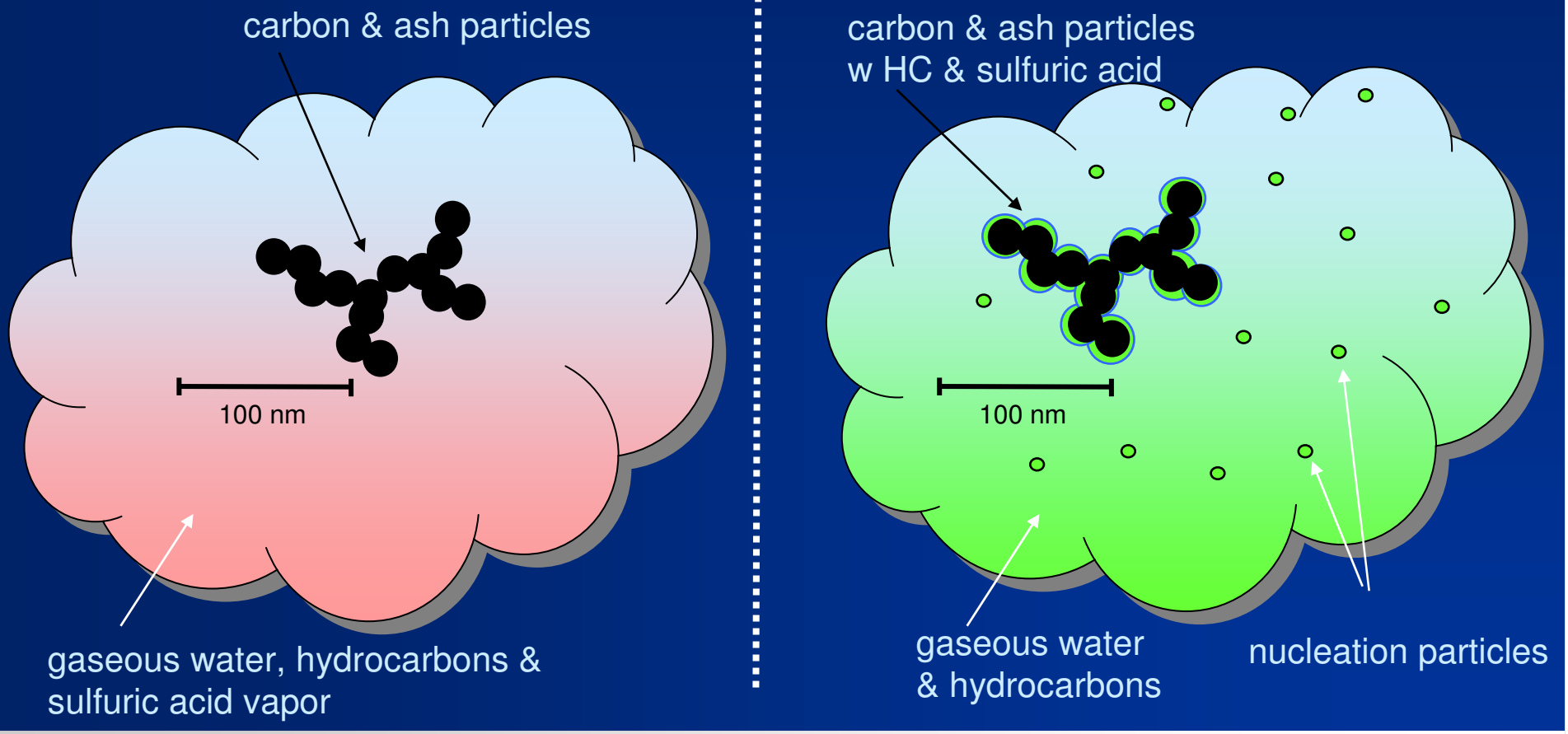
Ford Forschungszentrum Aachen GmbH

Outline

- Background
- Gravimetric PM measurement at EURO-5 level
- On-line PM mass measurement
- PM number count
- Conclusions

Diesel Particulate Matter

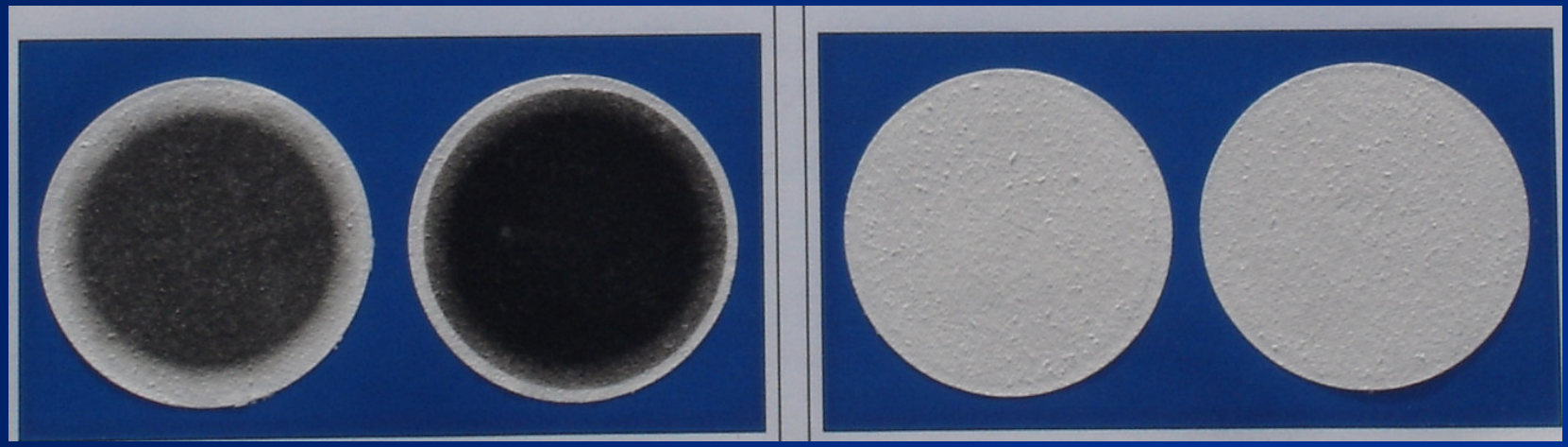
Engine-out ⋯⋯⋯⋯⋯⋯⋯⋯⋯⋯⋯⋯▸ Exhaust system / dilution & cooling



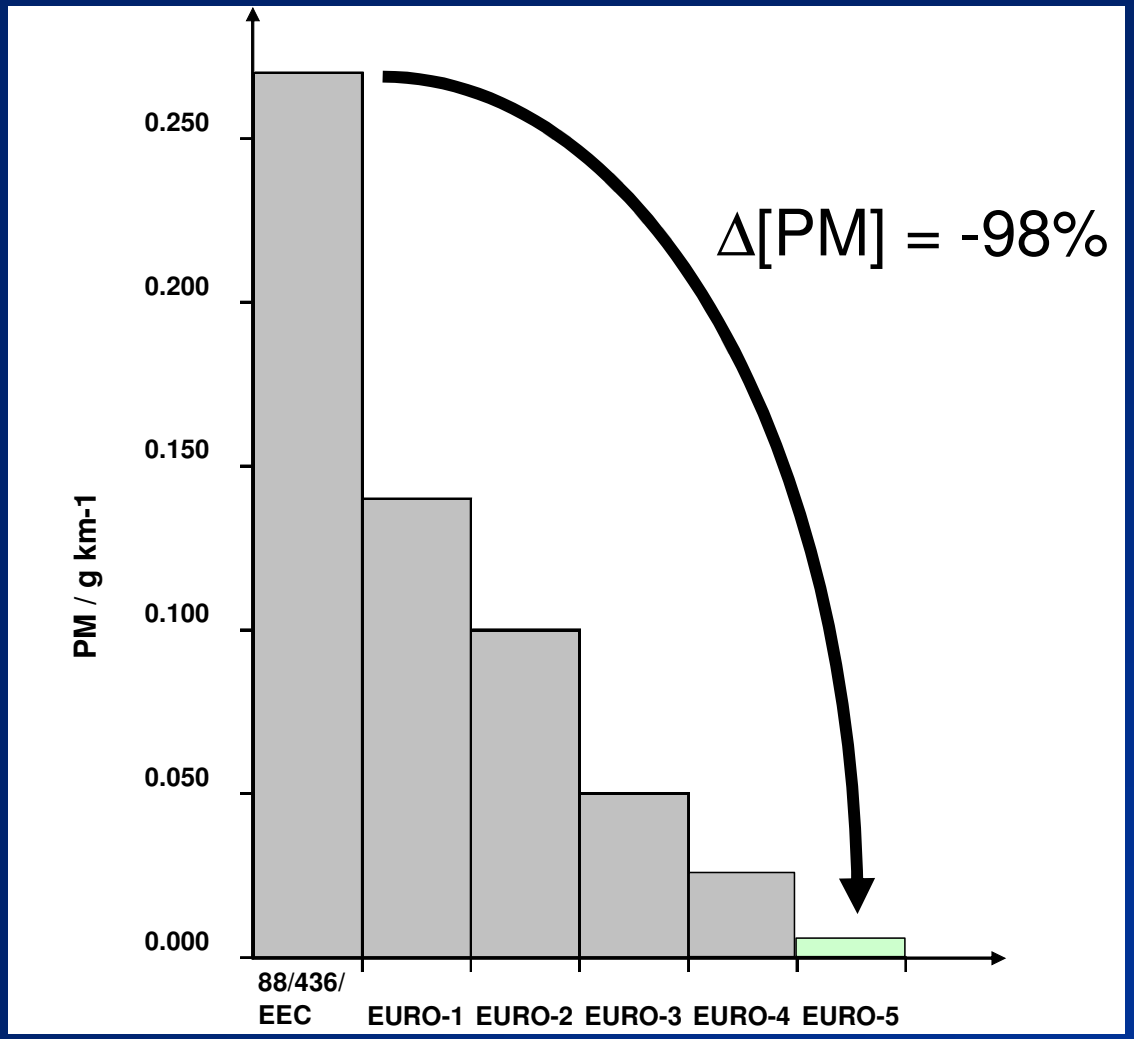
The Challenge: PM after Particle filter

w/o DPF (Euro-3)

w DPF



Development of PM limit values

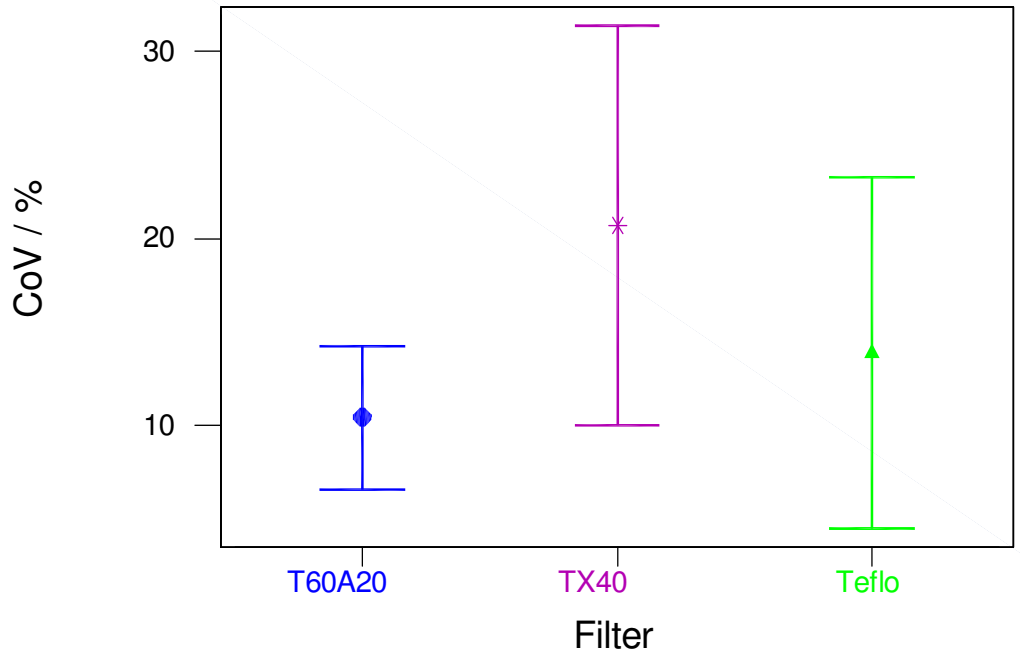


Investigation of PM filter sampling

- 3 types of filter material were investigated in terms of influence on PM emission results and variabilty: T60A20, TX40 and TEFLO
- Testing performed with a DPF equipped vehicle operated with EU reference fuel (S<10 ppm)
- Simultaneous sampling of up to five filter samples from CVS tunnel in parallel. Each filter sample consists of primary and secondary filter

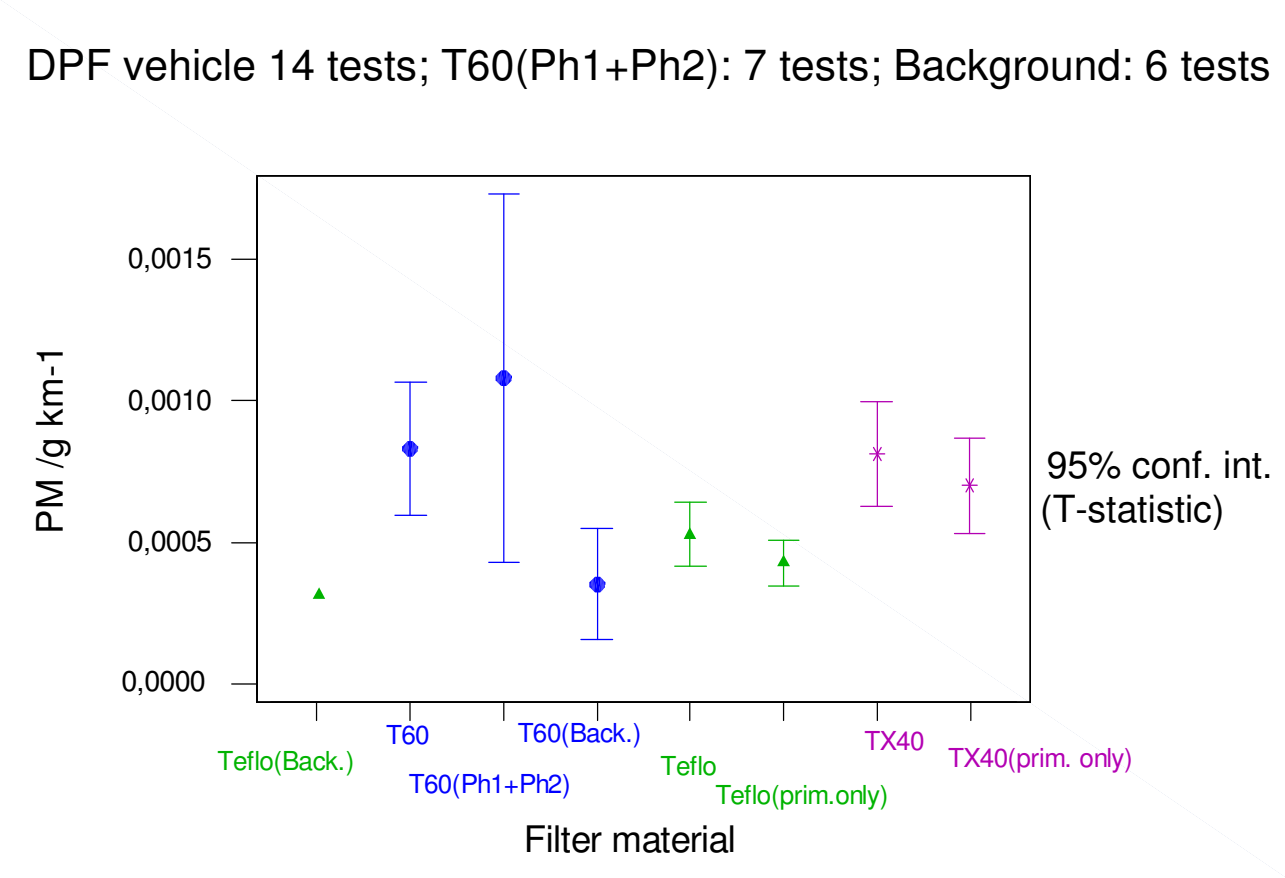
Variability from filter weighing

$$\text{CoV} = 100\% \times \sqrt{stdev(before)^2 + stdev(after)^2} \; / \; \Delta mass$$



no significant difference for filter media

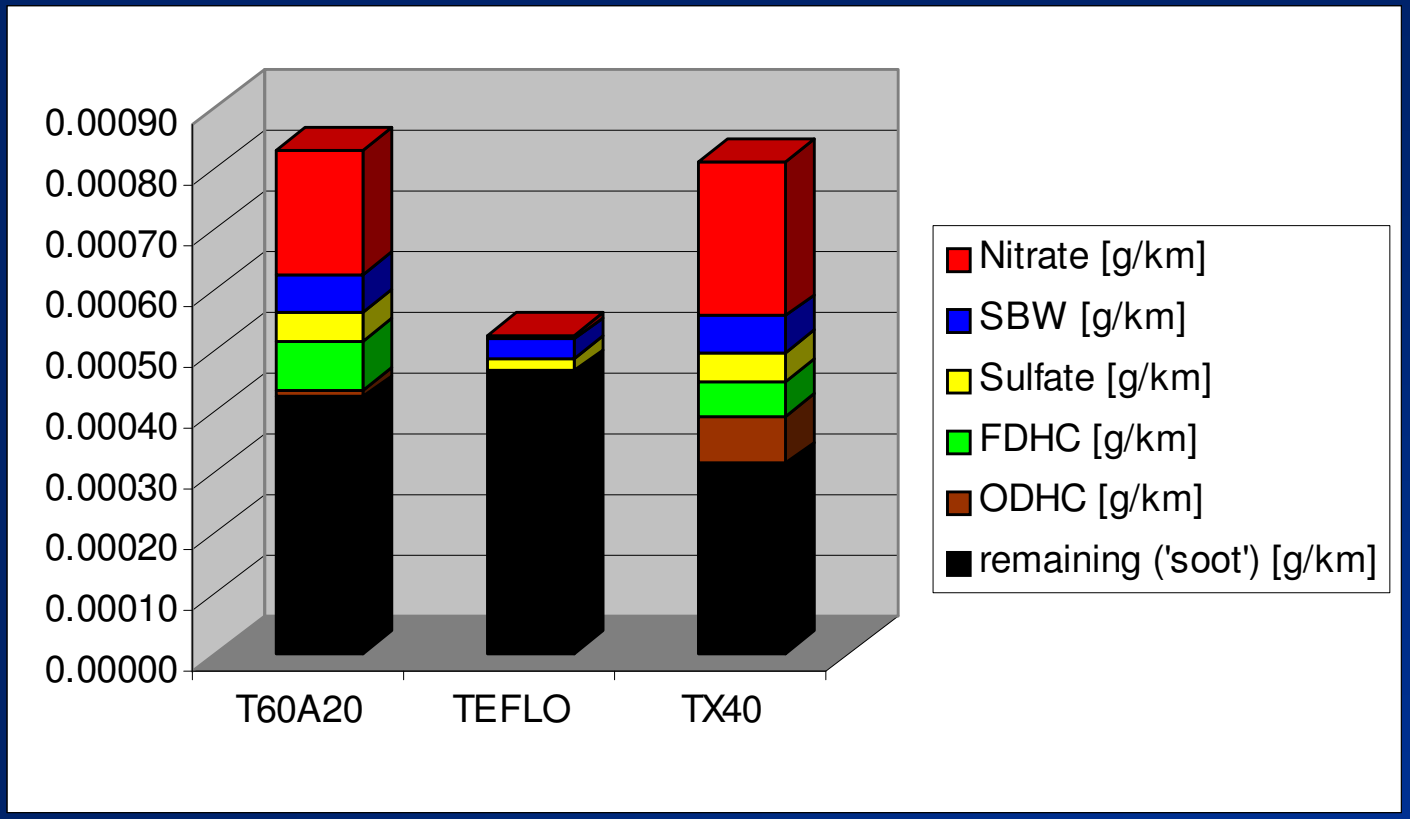
Filter material and variability



CoV(T60)=50%
CoV(Teflo)=33%

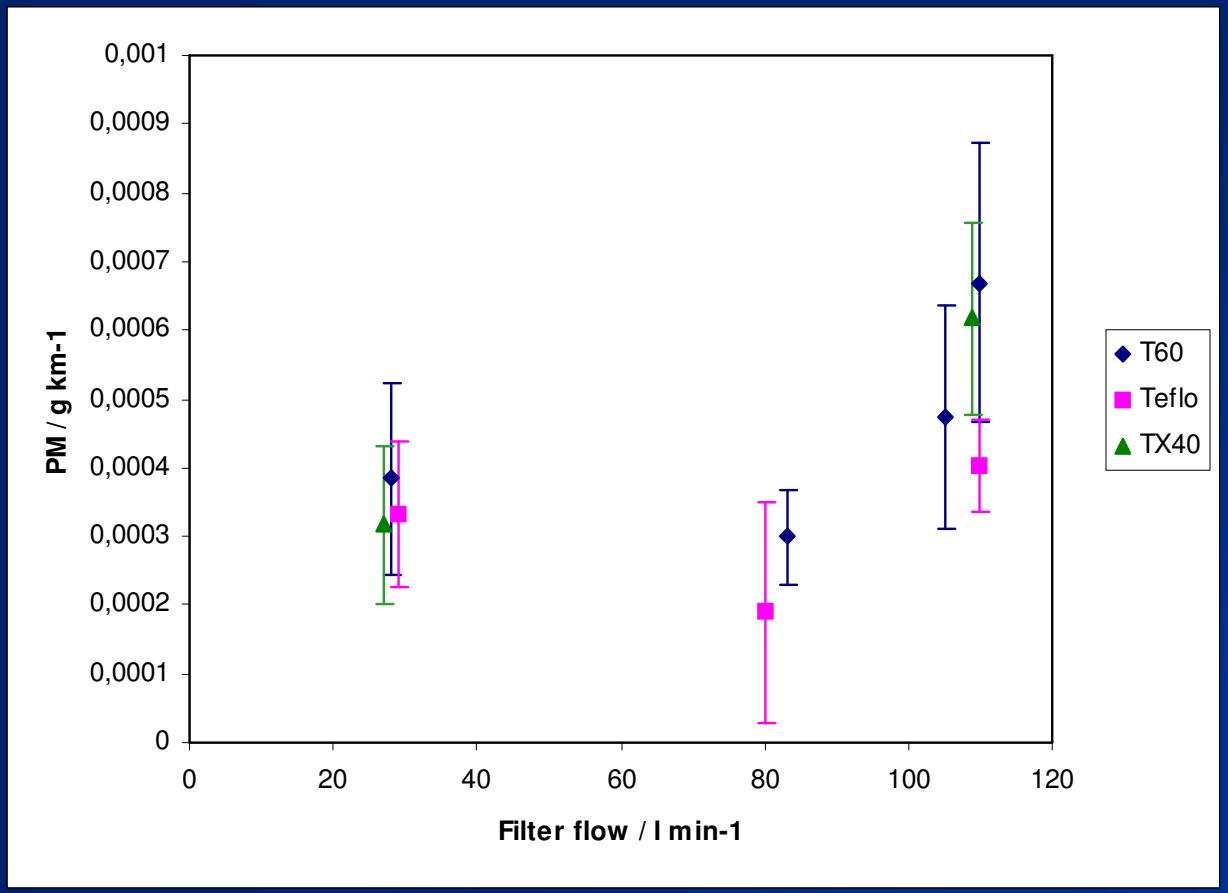
=> Sum and variability of T60 Phase 1&2 is larger than the sum filter
=> Use of Teflo filter (Prim.only) versus T60A20 (Prim&Sec.) reduces standard deviation by 66% (0.41 mg km-1 to 0.14 mg km-1); TX40(Prim.only)=0.29 mg km-1)
=> Also, the PM emission is lower by 49% (0.83 mg km-1 versus 0.43 mg km-1)

PM composition



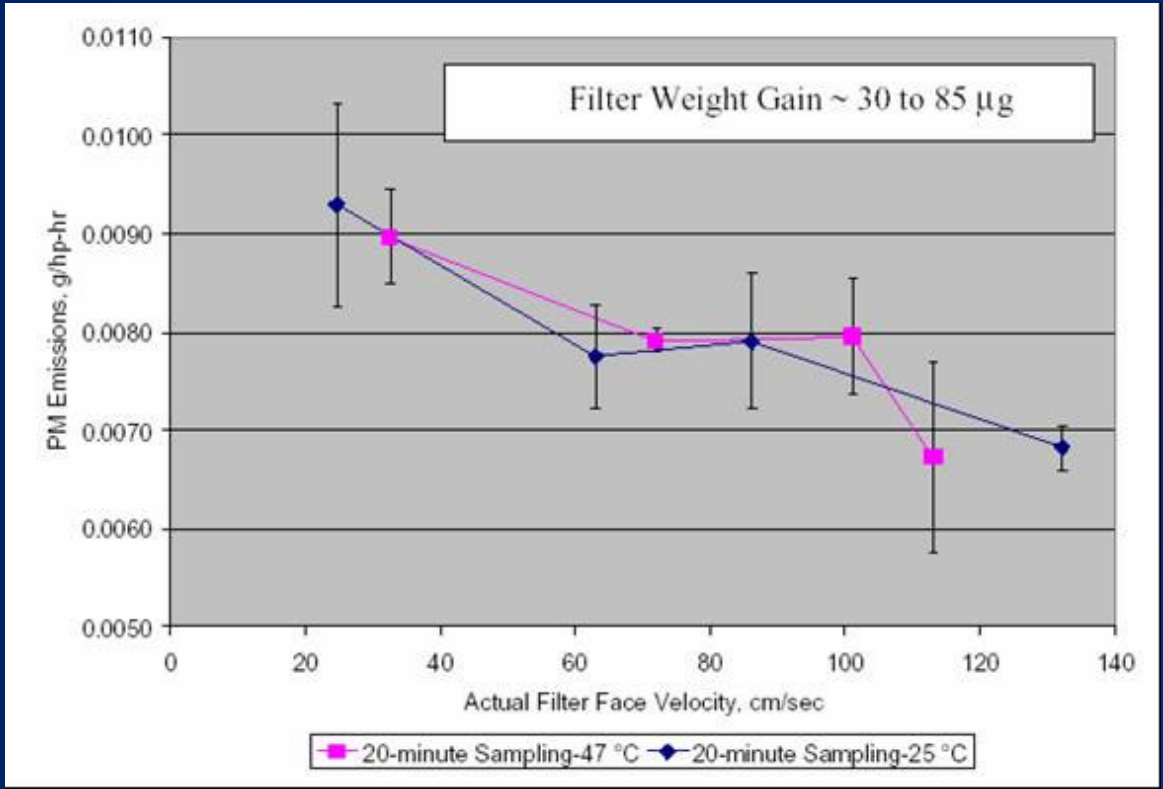
- TEFLO filters have low nitrate and low HC content
- Volatiles responsible for higher PM emission values on T60A20 and TX40 filters

PM filter sampling flow influence



- DPF vehicle
- 4-21 repeat tests
- primary filter only
- one filter for Ph1&2
- 95% confidence (T-statistic)

Influence of Filter Temperature?



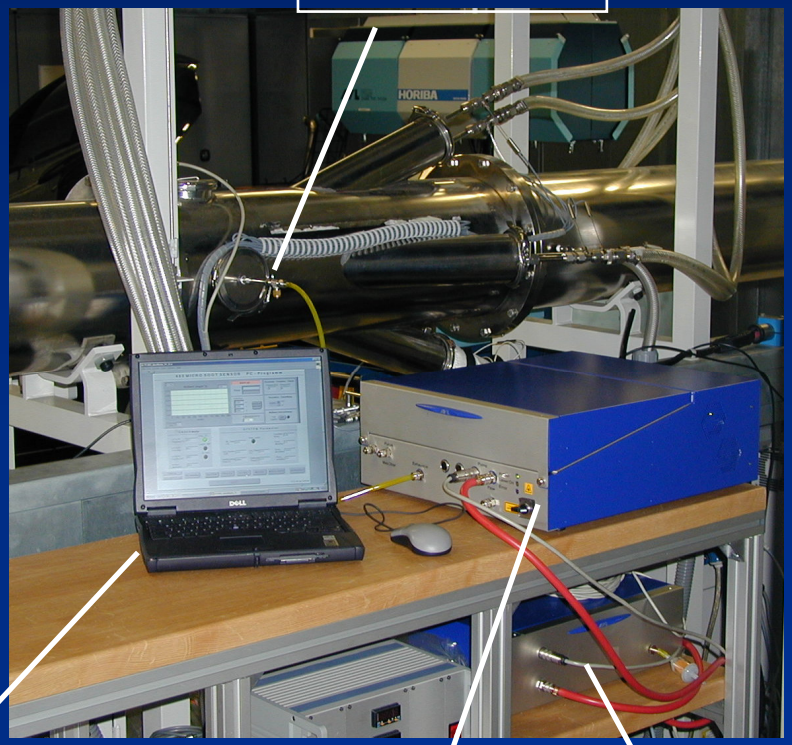
- 20 minutes sampling
- Heavy duty diesel engine DPF equipped, w small bypass
- Ref: CRC E-66 Phase 1 report.

=> no influence of filter temperature at 47°C

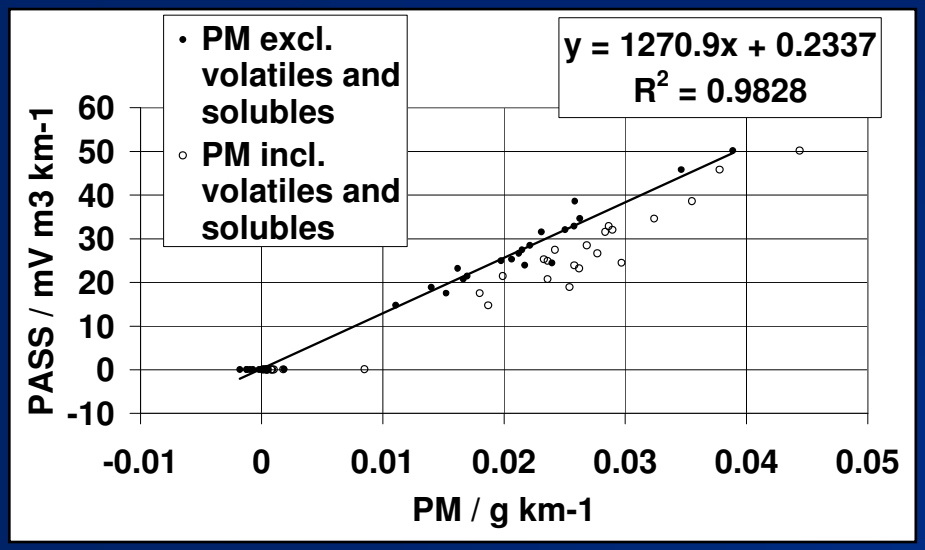
On-line PM mass measurement: Photoacoustic Soot Sensor (PASS)

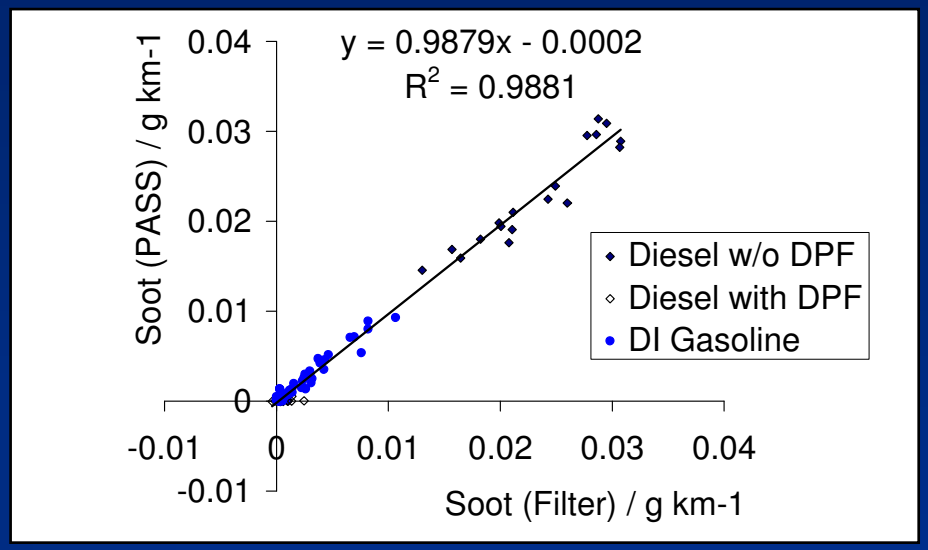
- AVL483 micro soot sensor
- Detection range

  <0.01 mg/m^3 - >100 mg/m^3
- Time resolution < 1 s
- Max. operation temperature is 50°C, therefore dilution is required



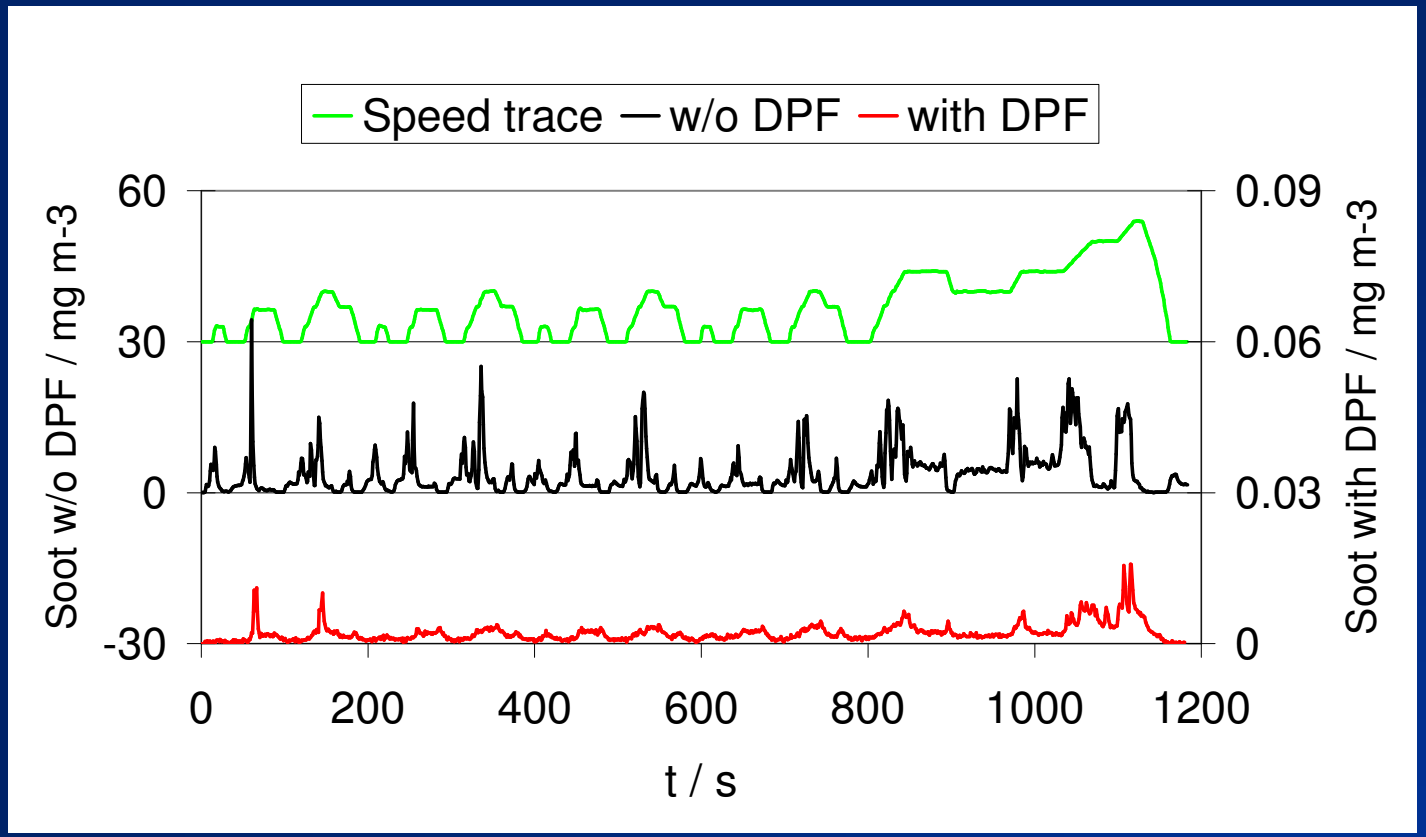
PASS: Correlation with filter samples





- PASS detects soot only
- PASS data compare well with soot measurements by filter samples independent on engine technology

PASS: NEDC with and w/o DPF



- Average soot emission with DPF = 0.03 mg/km
- PASS LOD=0.01 mg/m3 => ~0.2mg/km

Particle number count

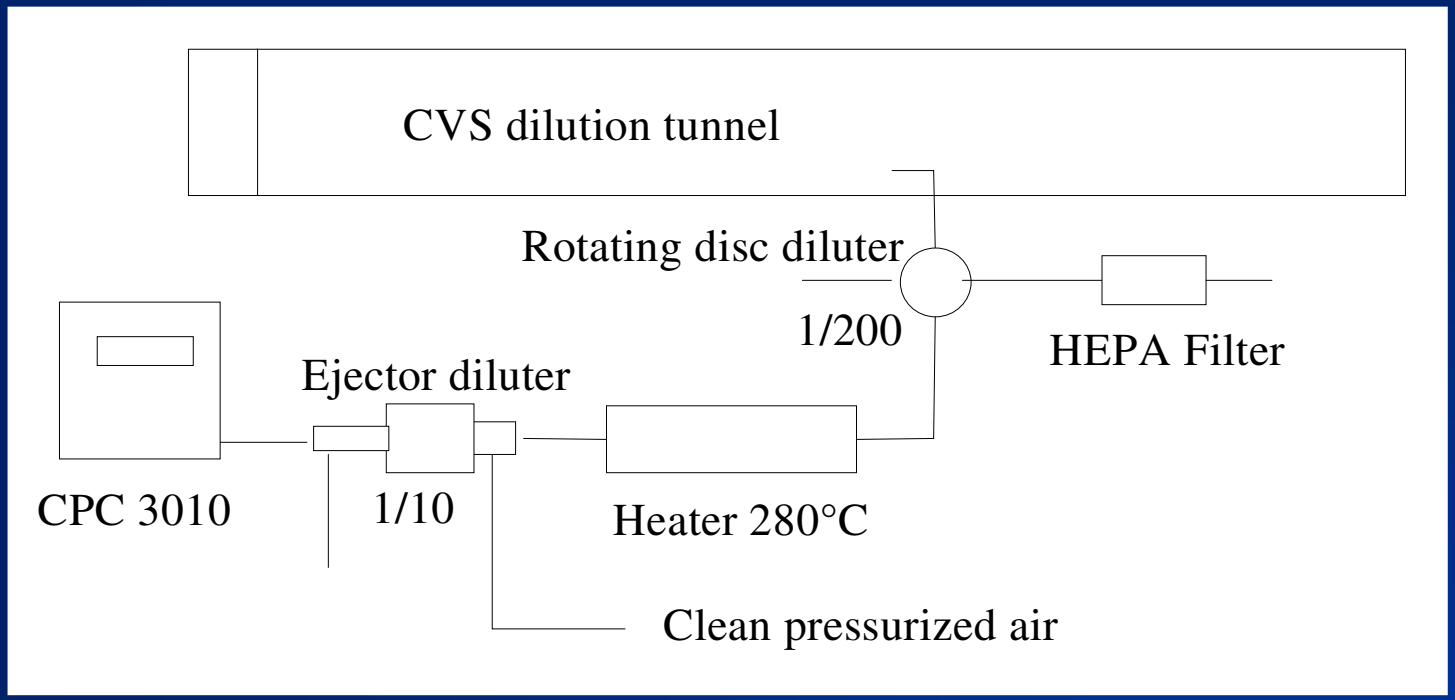
Particulate Measurement Program (GRPE-PMP)

- to measure total ‘solid’ particle number emission (>20nm)
- Condensation particle counter (CPC) with themo-conditioning

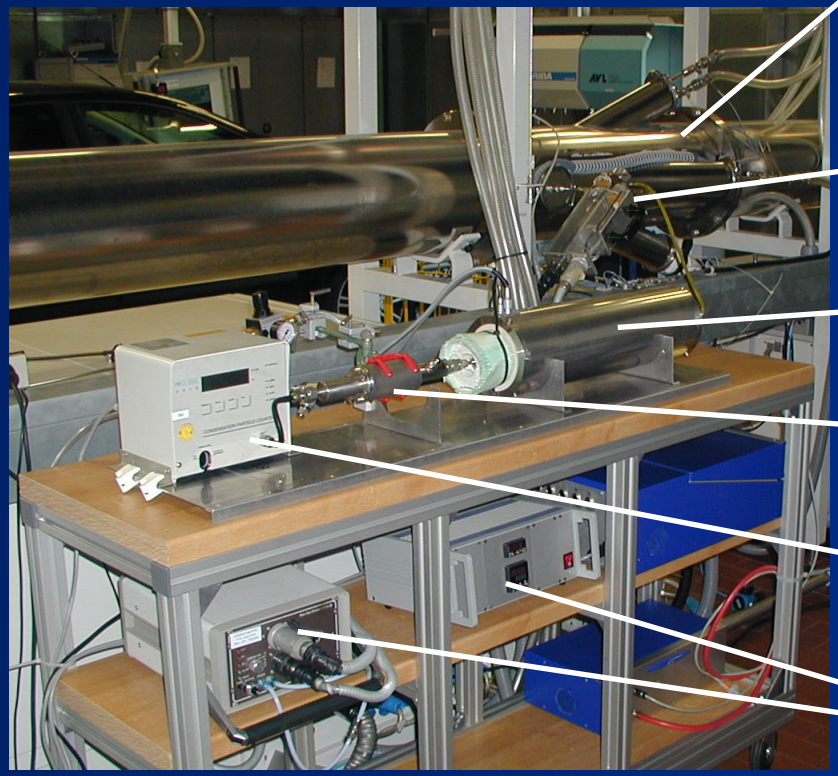
Details

- Sampling from CVS plus secondary/tertiary dilution; primary dilution air shall be HEPA filtered
- Background subtraction not permitted for certification testing; allowed for COP / In-Use
- CPC with defined lower cut; operating in ‘count mode’ only
- CPC provides time resolved total particle number
- Combination with thermodenuder or hot dilution ['thermodilution‘; 1.) 150℃ dilution, 2.) 350℃ evapotation 3.) dilution] in order to suppress formation of nucleation particles
- Calibration: with calibrated electrometer; currently no calibration standard available, although governments believe in potential of CAST certified by Swiss METAS

Solid PM number-setup at Ford R&A



´PMP-setup´ for particle number measurement



Dilution tunnel (Primary dilution ~1/10)

Rotating disc diluter (Secondary dilution 1/200)

Heater (280°C)

Ejector diluter (Tertiary dilution 1/10)

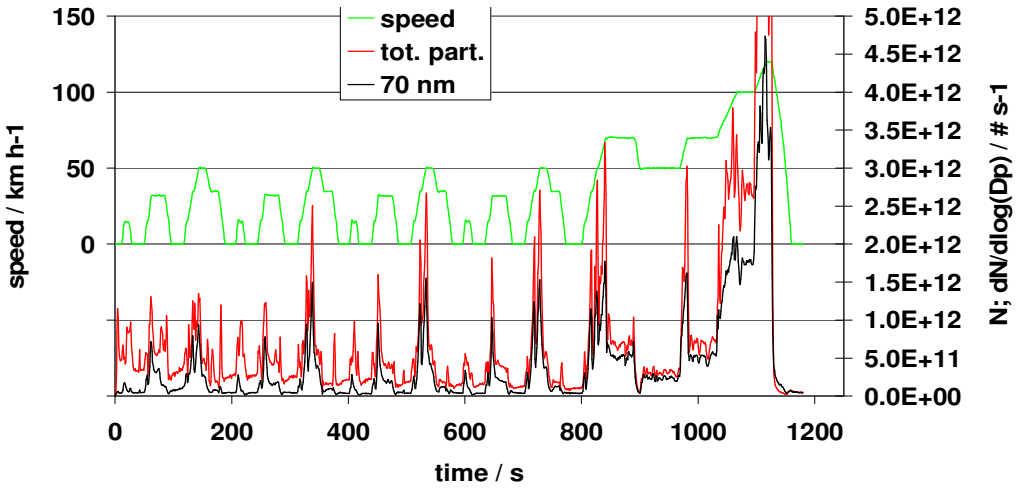
CPC (Particle counting)

Control units

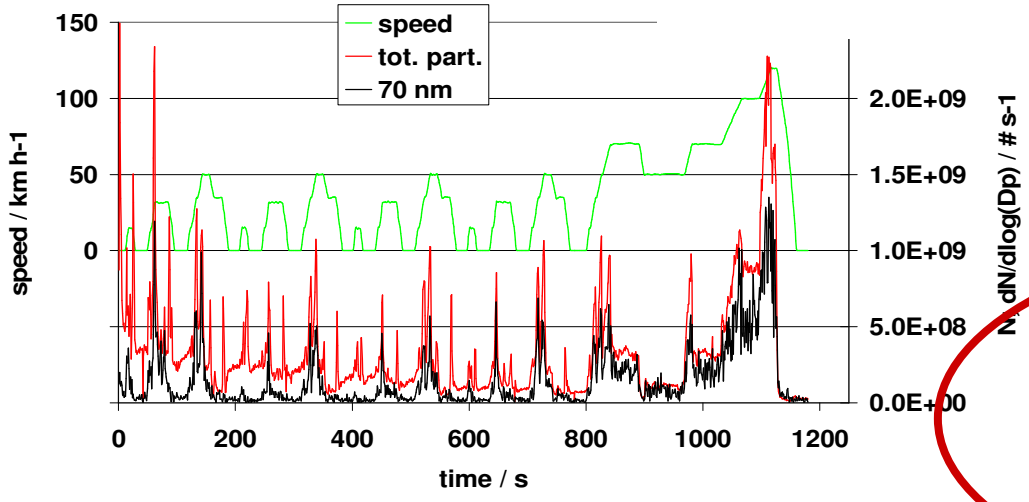
Diesel particle filter efficiency

Euro-3 Diesel:
w and w/o DPF

without DPF



with DPF

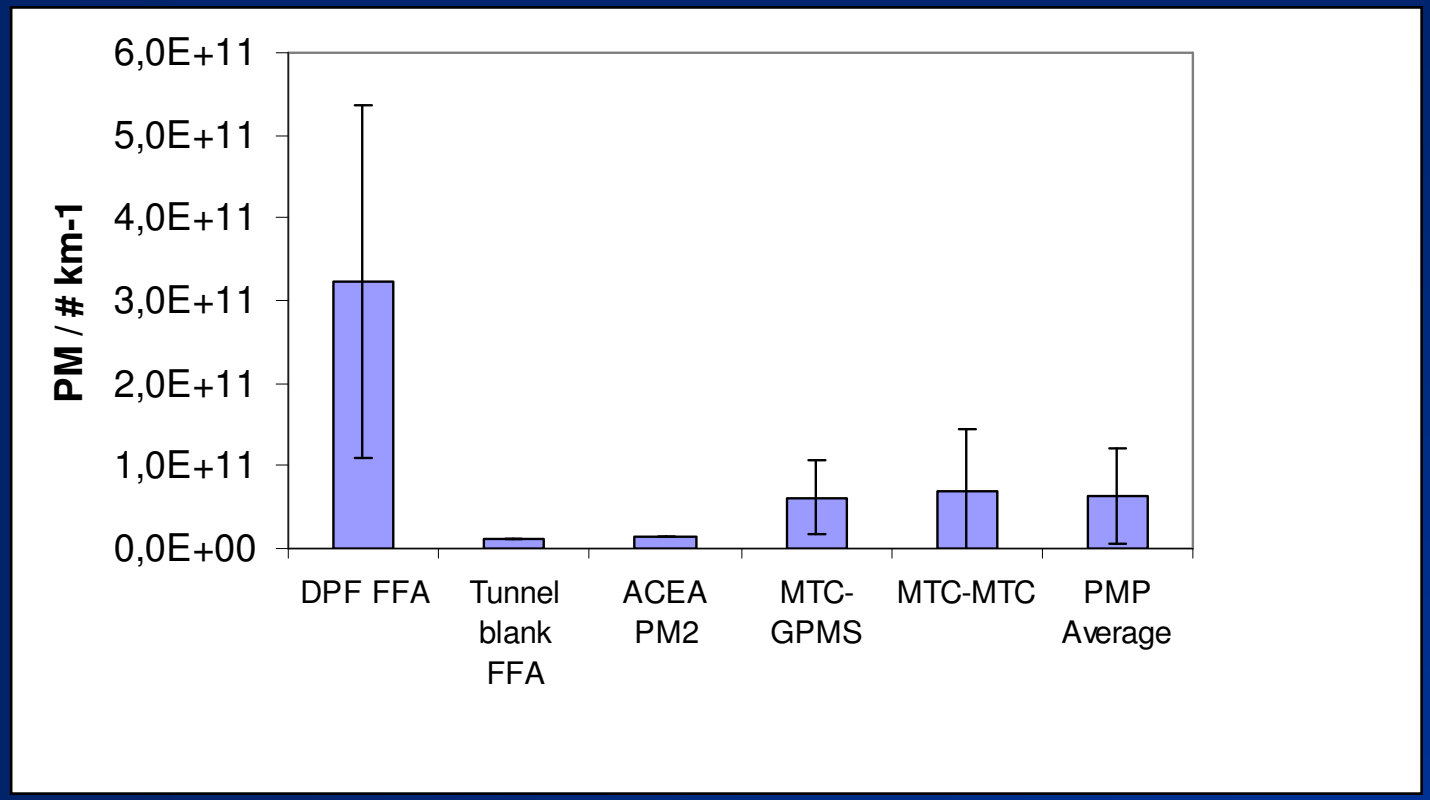


larger PM number reduction (total: 9.2×10^{13} -> 3.1×10^{10} **Eff. = 99.97%**)

than PM mass (26.6 -> 1.2 mg/km **Eff. = 95%**)

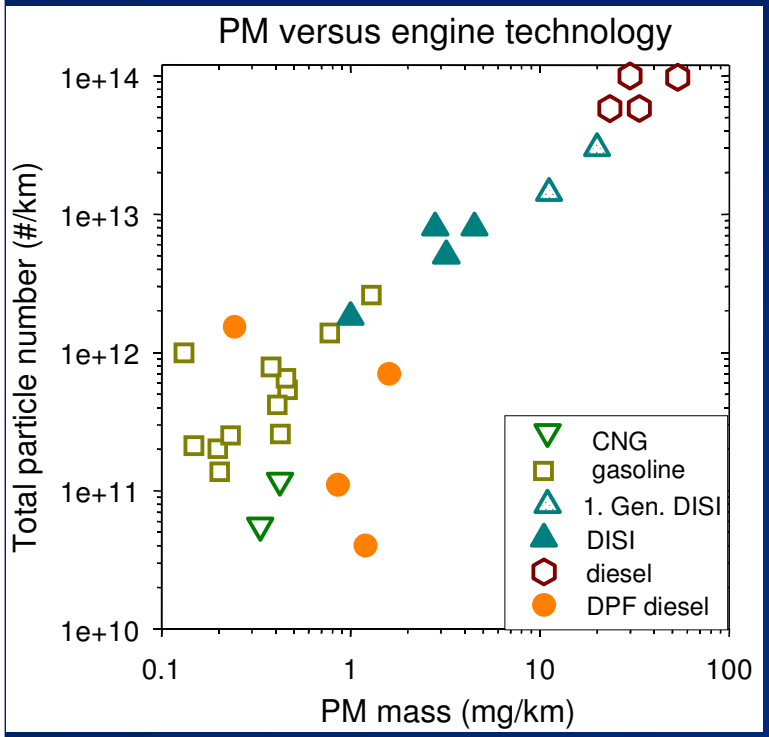
PM number of DPF vehicles

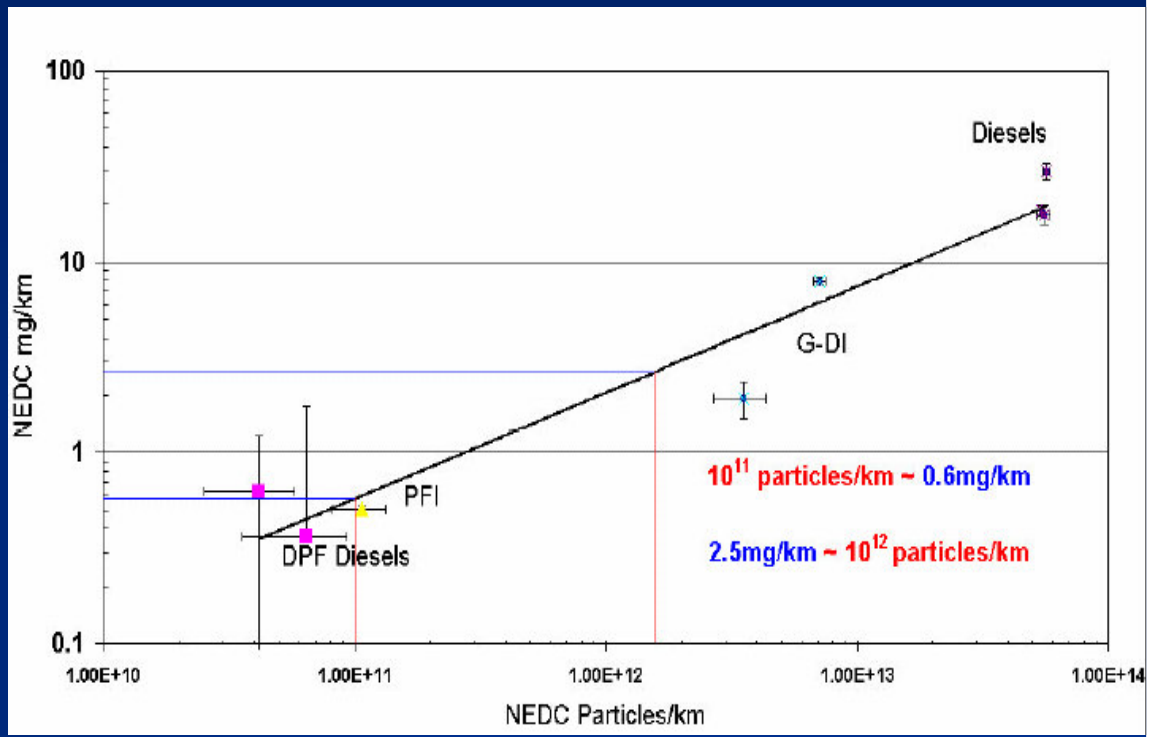
- all data with PM number count for solid particles (95% C.I.)



=> large variability (CoV=27%-73%); PM number level is depending on individual laboratory setup (and vehicle)

PM number / PM mass relationship [20]





R.Vogt / M.Maricq (Ford Motor Comp.), AVL Forum 2004

J. Andersson, (Ricardo Inc.) ETH 2005

=> PM mass and PM number show correlation

=> 10^{11} part. km^{-1} ≈ 0.1 mg/km (assuming D_p = 80 nm) solid PM, remainder is gaseous adsorption artefact

=> coefficient of variance is similar for PM mass and number at Euro-5 level

Summary (1)

- GRPE PMP program and revision of R-83 are moving forward. The revised R-83 has two elements: 'enhanced gravimetry' and 'total solid particle count‘
- PM from vehicle with DPF (Diesel Particulate Filter) can be overwhelmed by hydrocarbons, sulfate (and nitrate)
- microbalances are pressed to their limit: the 10 - 50 µg PM collected is much less than 1/1000 of the filter mass; the balance is affected by temperature, drafts, static electricity, RH, barometric pressure
- Vehicle tests with DPF show lowest variability for single TEFLO filters
- Sampling flow has impact on PM emission result and needs careful investigation
- Effect of filter temperature (47℃) is not evident

Summary (2)

- PASS shows suitable sensitivity for time resolved soot measurements over range of Euro-3 to post-DPF level
- Diesel particle filters remove very efficiently soot particles at all sizes (>99% by number), but only 95% by mass, due to gaseous adsoprtion artefact
- PM mass and PM number show correlation for range of engine technologies
- Coefficient of variance (CoV) is similar for PM mass and number measurement at Euro-5 level; tunnel background is significant. The purpose of a PM number regulation remains questionable
- Measurement at the Euro-5 level is very complicated and difficult and remains a technical challenge, especially in the routine test laboratory