Real time measurement of the effective density and fractal dimension of diesel exhaust particles

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Motivation

- **Density and fractal dimension carry information:**
  - particle properties
  - origin of particles
  - structure of particles

- **Existing methods for density measurement**
  - DMA and Impactor in series (Kelly and McMurry, 1992)
  - DMA and APM in series (McMurry et al., 2002)
  - Accurate but slow (single mobility size at a time)

- **SMPS and ELPI used in several engine labs**
  - Parallel data in abundance

Effective density

- SMPS: distribution as a function of mobility diameter
- ELPI: classification according to aerodynamic diameter
- Mobility and aerodynamic diameter linked through effective density:

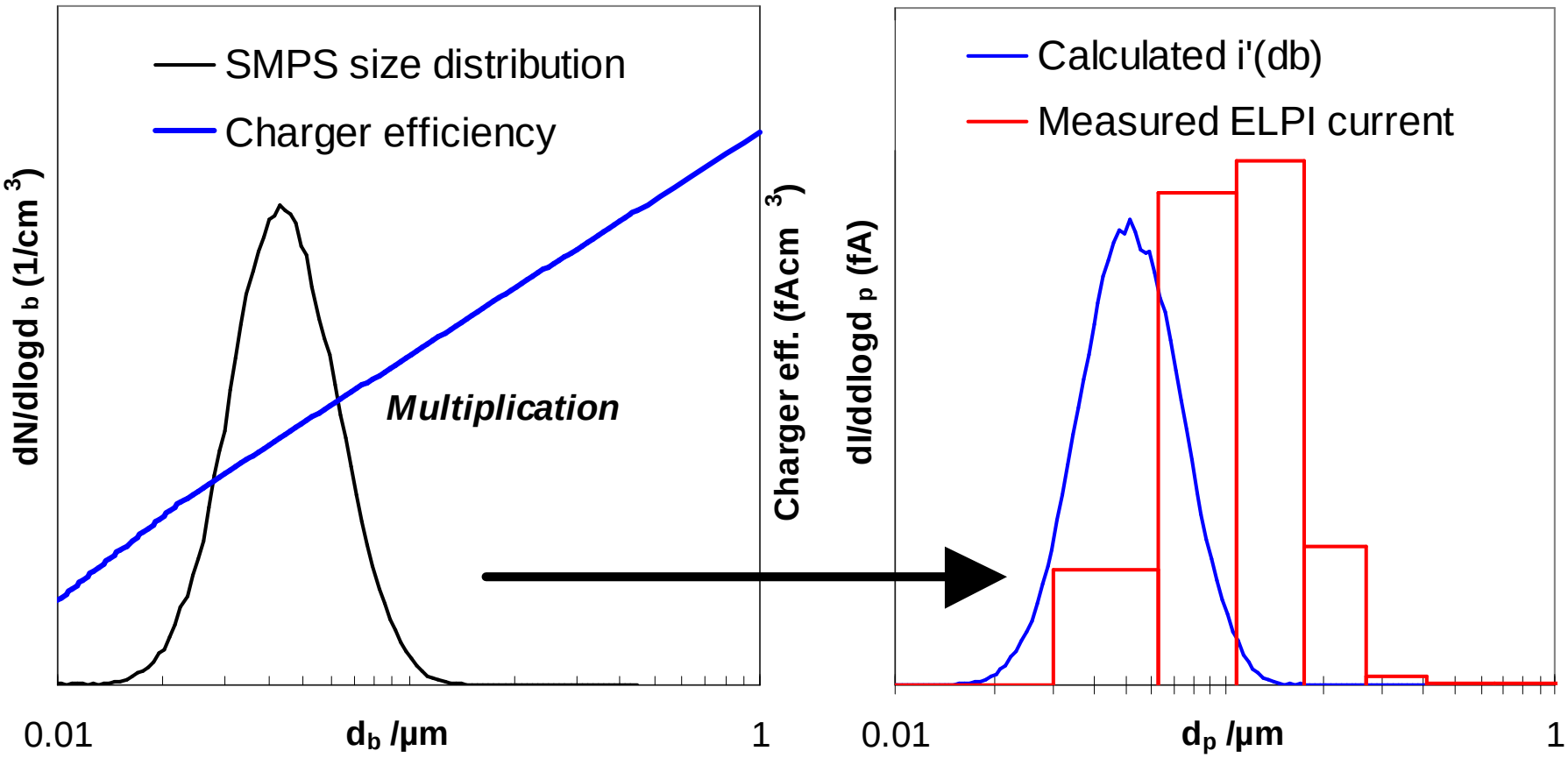
$$d_a^{\,2} C_c(d_a)\rho_0 = d_b^{\,2} C_c(d_b) \frac{[C_c(d_m)]^3 \rho_p}{[C_c(d_b)]^3 \chi^3} = d_b^{\,2} C_c(d_b)\rho_e$$

Description of the method

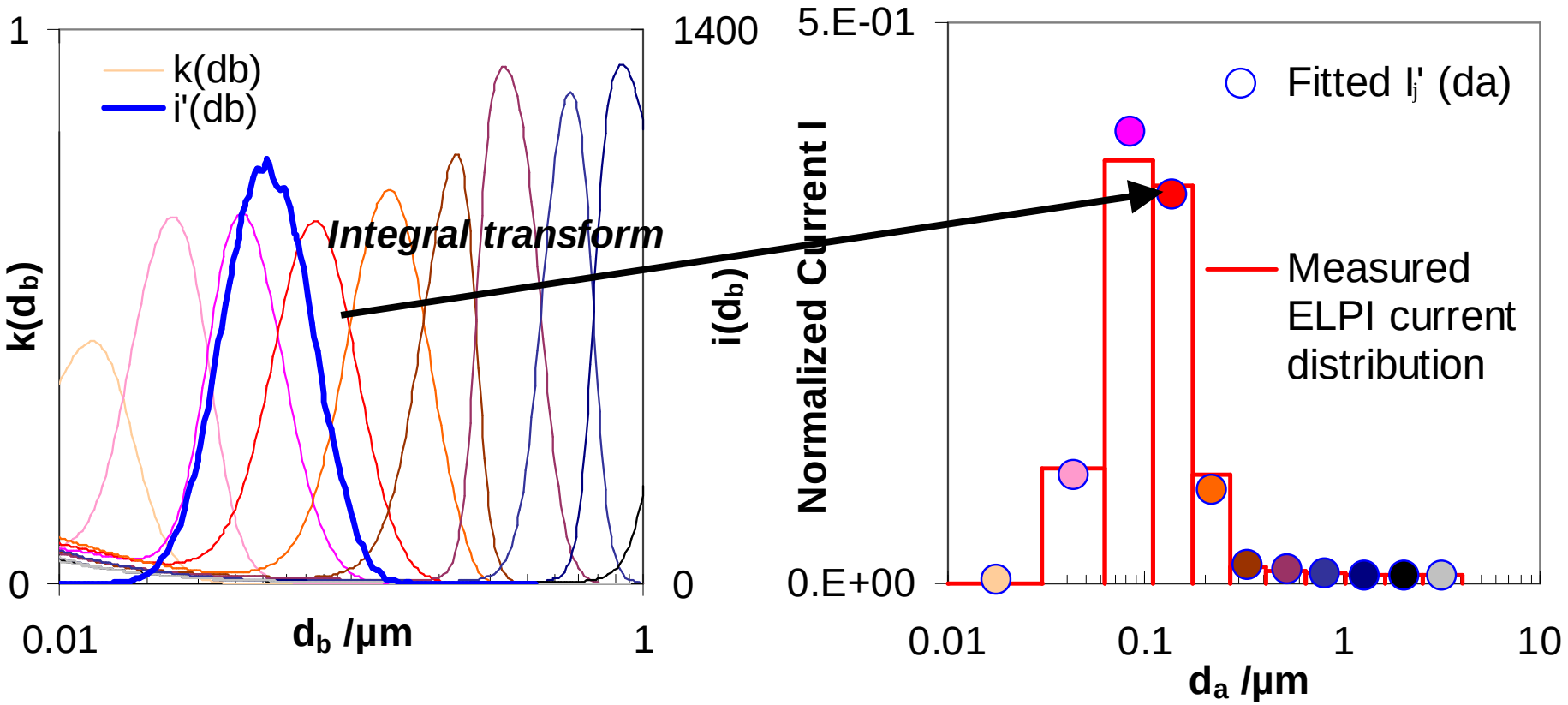
- **Simultanous measurement with SMPS and ELPI**
- **Number distribution measured by SMPS is converted to ELPI "current distribution"**
- **Calculated and measured ELPI current distributions compared**
  - Cost = difference between simulated and measured currents
- **Cost minimization**

  => Repeated with varying density until minimum difference between simulated and measured currents

Description of the method



Description of the method

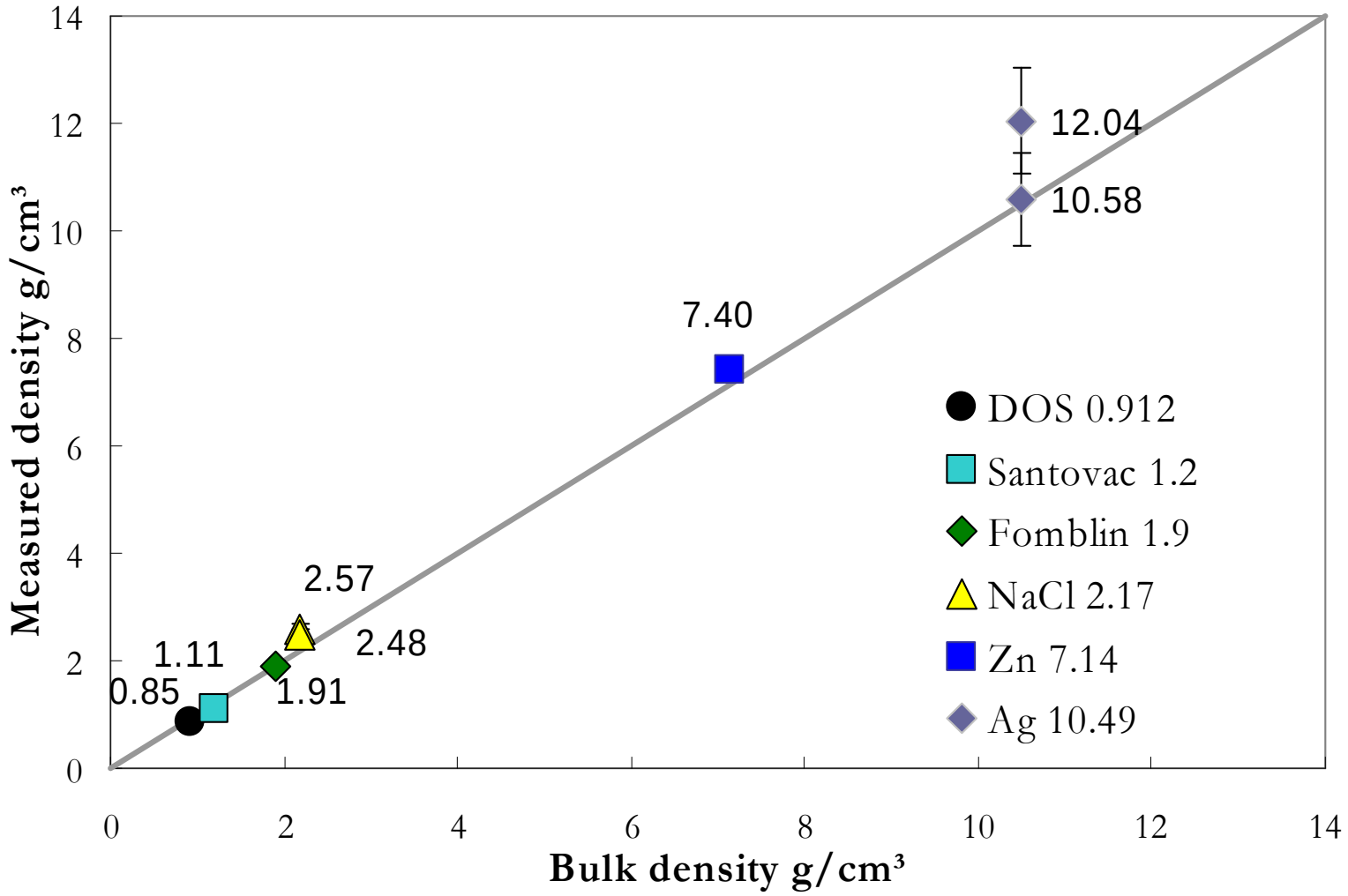


Constant density test particles

- **Liquid particles:**
  - density 0,912 (DOS) - 1,9 g/cm^3 (Fomblin)
- **Solid particles:**
  - density 2,17 (NaCl) - 10,49 g/cm^3 (Ag)

- **Size range 40-280nm (peak diameter)**

Constant density test results

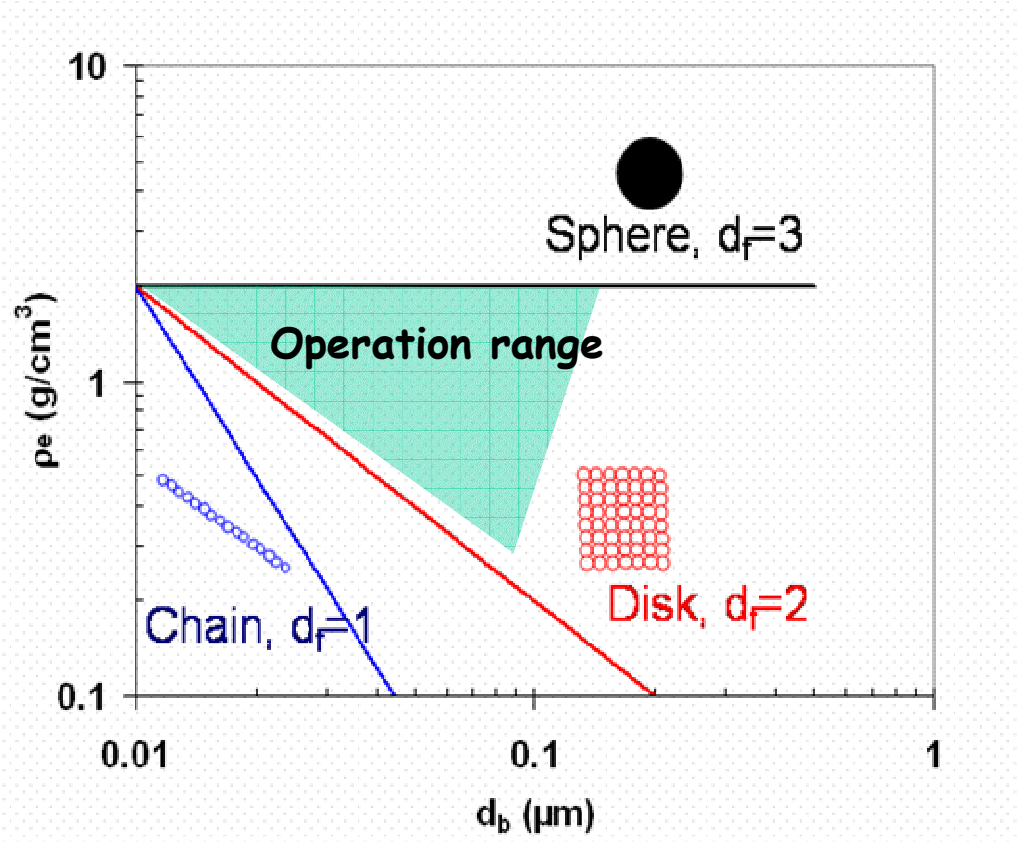


Constant density results

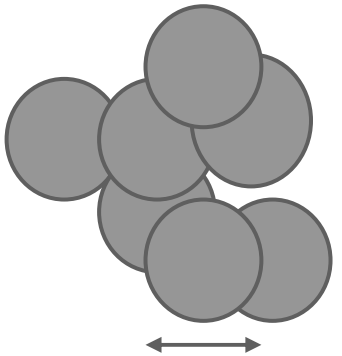
ρ (fitted)	DOS	Santovac	Fomblin	NaCl	Zn	Ag
Number of scans	22	5	7	4	3	3
Standard dev.	0.05	0.07	0.09	0.10 / 0.06	0.01	0.93 / 0.86
Standard dev. %	5.4 %	6.0 %	4.5 %	3.97 / 2.28	0.2 %	7.74 / 8.14
min	0.72	1.06	1.71	2.42 / 2.42	7.39	11.33 / 9.81
max	0.90	1.23	1.84	2.67 / 2.54	7.42	13.09 / 11.51
Average	**0.85**	**1.11**	**1.91**	**2.57 / 2.48**	**7.40**	**12.04 / 10.58**
Bulk value	**0.912**	**1.2**	**1.9**	**2.17**	**7.14**	**10.49**
error %	**-6.5 %**	**-7.2 %**	**0.4 %**	**18.2 / 14.5**	**3.7 %**	**14.7 / 0.9**

Diesel soot: fractal like agglomerates

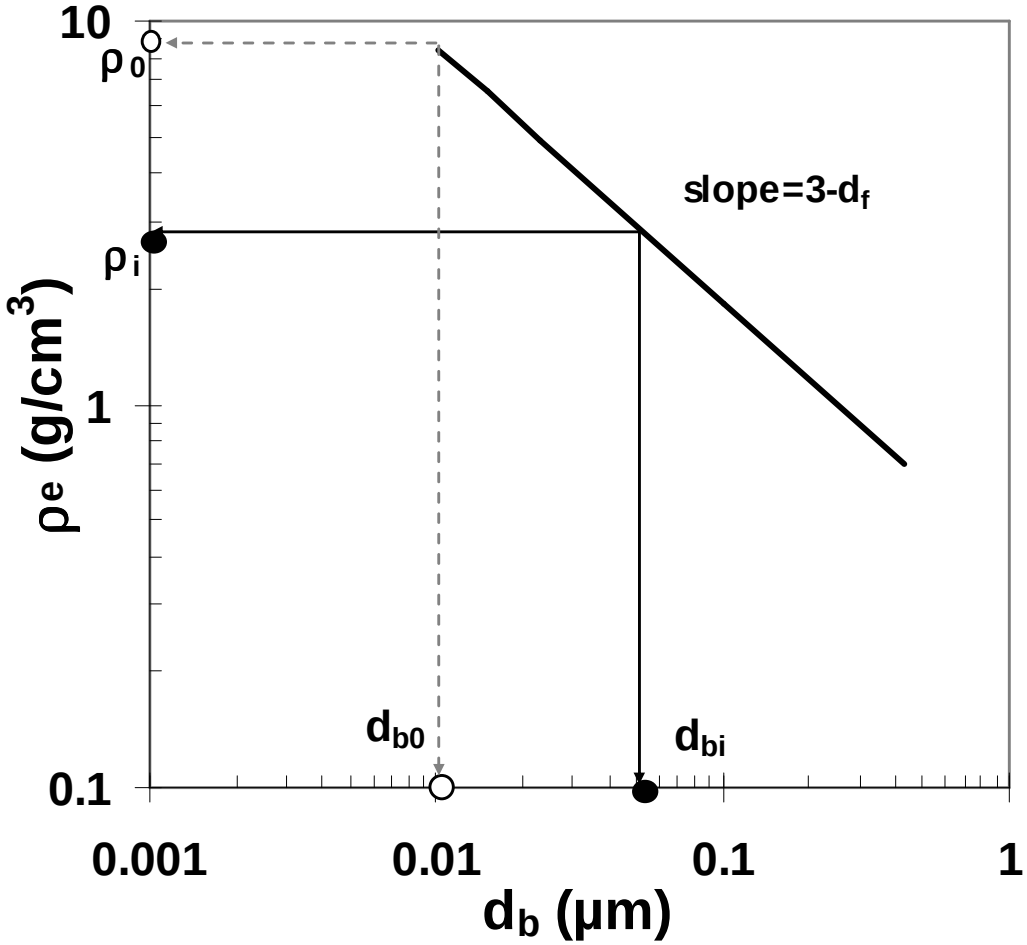
- Fractal dimension d_f defines the scaling of ρ_e and d_b:



$$\rho_e \propto d_b^{\,d_{fm}-3}$$

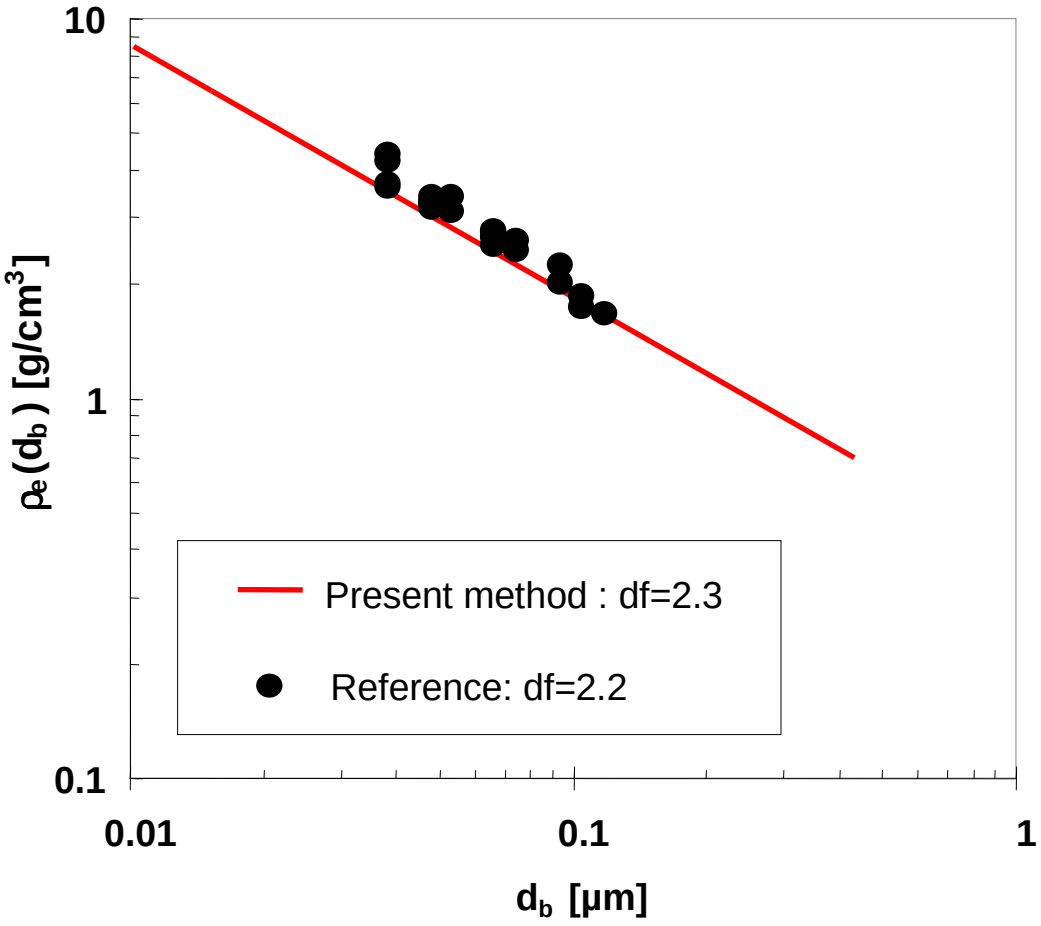


Agglomerates: density vs d_b



Agglomerates: silver particles

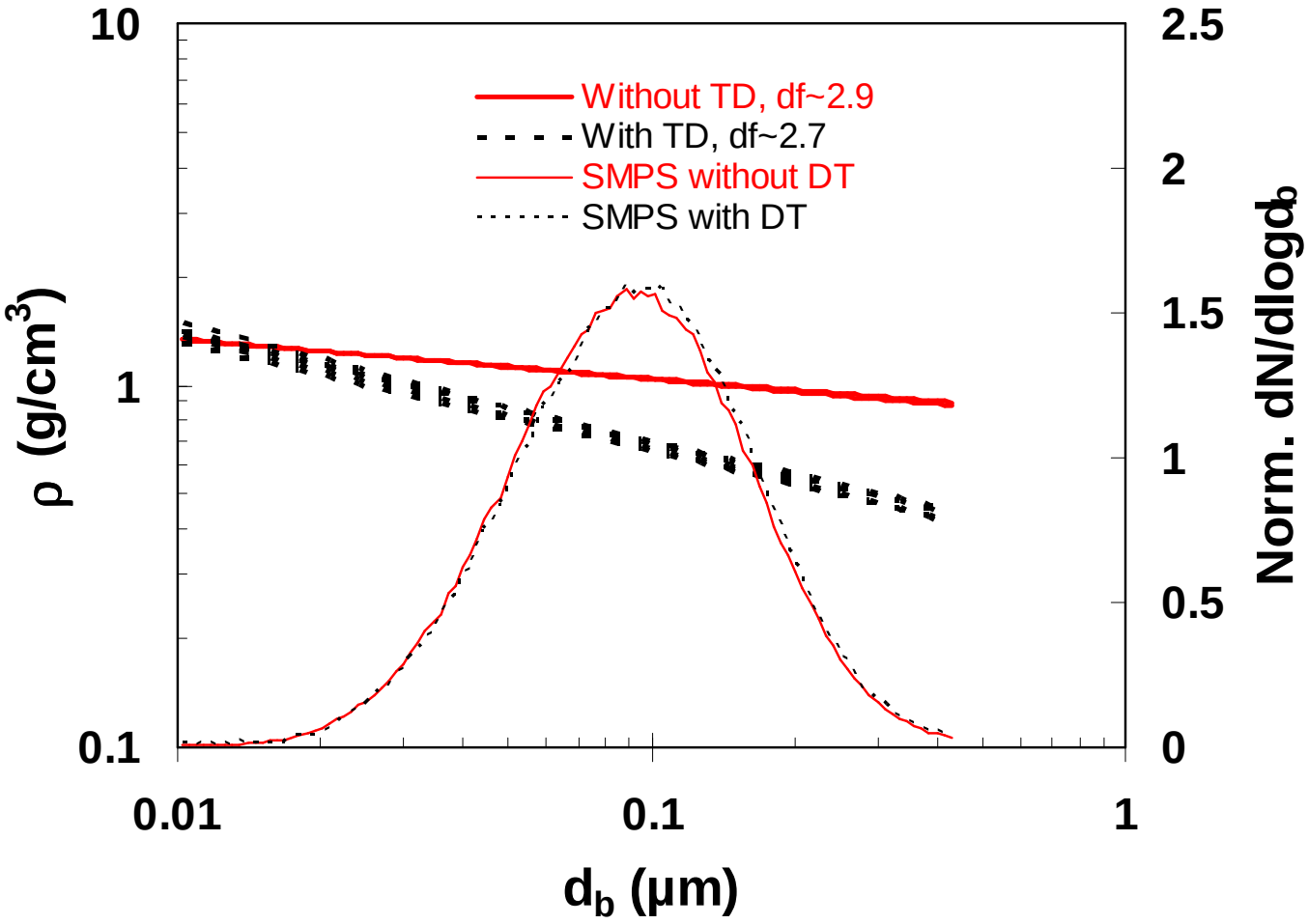
- reference method: DMA (monodisperse particles) + impactor



Diesel vehicle tests

- **Audi A4 1.9 TDI (Euro II)**
  - Direct injection
  - EGR + oxidation catalyst
- **Euro II fuel (EN590)**
- **Steady state tests on chassis dyno**
- **Dilution methods**
  - Porous tube diluter (+ thermo denuder)
  - 2 stage ejector diluter: 1st at 180°C, 2nd at room temperature

Example results



Discussion 1: soot particles

- **Effective density: 0.4 – 1.3 g/cm^3 (soot)**
  - Comparable to other methods.

- **Fractal dimension: 2.6-3**
  - Higher than most other studies
  - We obtain average over the size distribution
    - Higher d_f for small particles (monomer-cluster agglomeration)
    - Lower d_f for larger particles (cluster- cluster)

Discussion 2: method

- **Positive**
  - Simple, no time loss from distribution measurement
  - Fast enough for on-line operation
  - Old data can be re-evaluated
- **Negative**
  - Less accurate than serial methods
  - Inaccuracy increases for low fractal dimension values
- **Further development**
  - Search method development
  - Multi-mode distributions

Presentation based on:

Ristimäki J., Virtanen A., Marjamäki M., Rostedt A., Keskinen J. (2002) *J. Aerosol Sci.* **33**, 1541

Virtanen, A., Ristimäki, J., Marjamäki, M., Vaaraslahti, K., Keskinen, J., and Lappi, M. (2002) Effective density of diesel exhaust particles as a function of size. *SAE 2002-01-0056.*

Virtanen, A., Ristimäki J., Keskinen, J. (2003) Method for measuring effective density and fractal dimension of aerosol agglomerates. Submitted to *AST.*