A Revised Data Inversion Algorithm for the Dekati's Mass Monitor

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The operation principle of the Dekati's Mass Monitor has been presented by Niemelä et al. (2003) and it is based on the determination of effective particle density by comparing mobility and aerodynamic diameters (Ristimäki et al., 2002). The effective density is then combined with the number weighted particle size distribution to derive the total mass concentration of airborne particles in almost real-time.

Application of the instrument in the measurement of diesel exhaust aerosol resulted in systematic higher mass concentrations compared to the gravimetric procedure, by 20% (Lehmann et al., 2003) to 40% (Mamakos et al., 2006). The latter study provided evidence that the difference between the DMM and the filter-based PM cannot just originate from the different measurement principles but also from the actual implementation of the combined aerodynamic-mobility measurement in the DMM and the simplified calculation algorithm employed.

A new algorithm has been developed for the data inversion of the Dekati's Mass Monitor (DMM) which is based on the methodology described by Maricq et al. (2006) for the Electrical Low pressure Impactor. The inversion method takes into account the distinct and well documented characteristics of automotive exhaust aerosol. Specifically, it is assumed that the particles exhibit a fractal-like structure which implies a power-law dependence of the effective particle density on the particle mobility diameter (Maricq M., 2004). Additionally, following the study of Harris et al. (2001) suggesting a universal, signature vehicle exhaust size distribution, a fitting procedure is employed in which a lognormal size distribution having a fixed standard deviation at 1.75 is sought that best describes the measured DMM signal. The airborne particle mass can then be readily determined by combining the calculated mobility size distribution and the effective particle density profile assumed.

The performance of the revised algorithm was evaluated with five DMM units employed in the measurements of automotive exhaust under steady state and transient operation, conducted at three different laboratories. The vehicle/engine sample, spanning from Euro 2 to Euro 3 technologies, included two light duty diesel engines, four light duty diesel vehicles, one medium duty diesel vehicle, a conventional port fuel injection vehicle and a direct injection gasoline passenger car.

The calculated mass concentrations were found to be in good agreement with the filter-based particulate matter (PM). On an average the difference was within ±20% for both diesel and gasoline vehicles. The algorithm was also found to provide a good indication of the number concentrations. The recovered number concentrations agreed within ±16% to those measured with an SMPS or a CPC in the case of the diesel vehicles. In the case of the conventional gasoline vehicle, the algorithm tended to underestimate the number concentration by some 30%. This might be associated with deviations from the signature lognormal distribution and/or the predefined effective density profile employed in the inversion.

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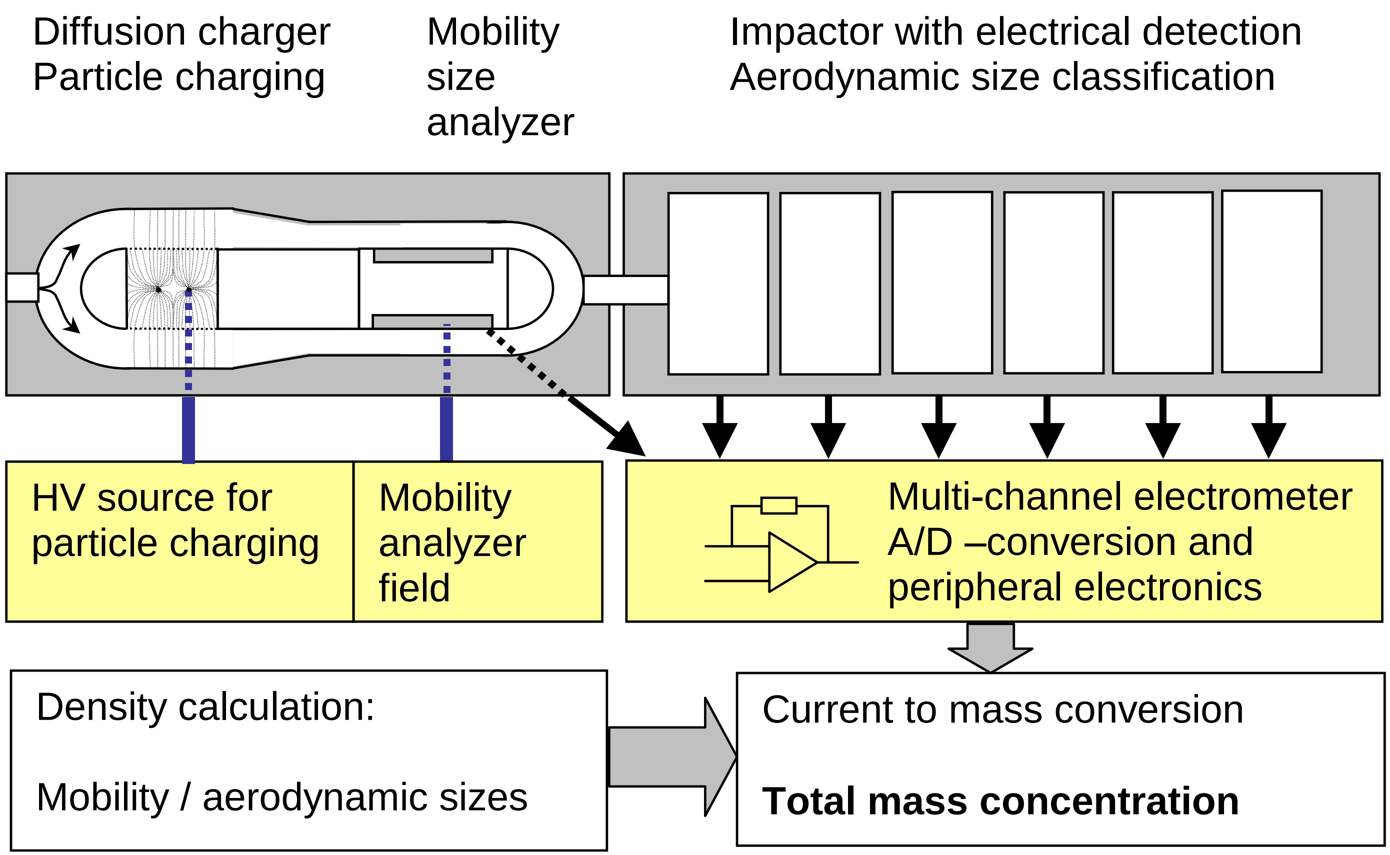
DMM configuration & operating principle

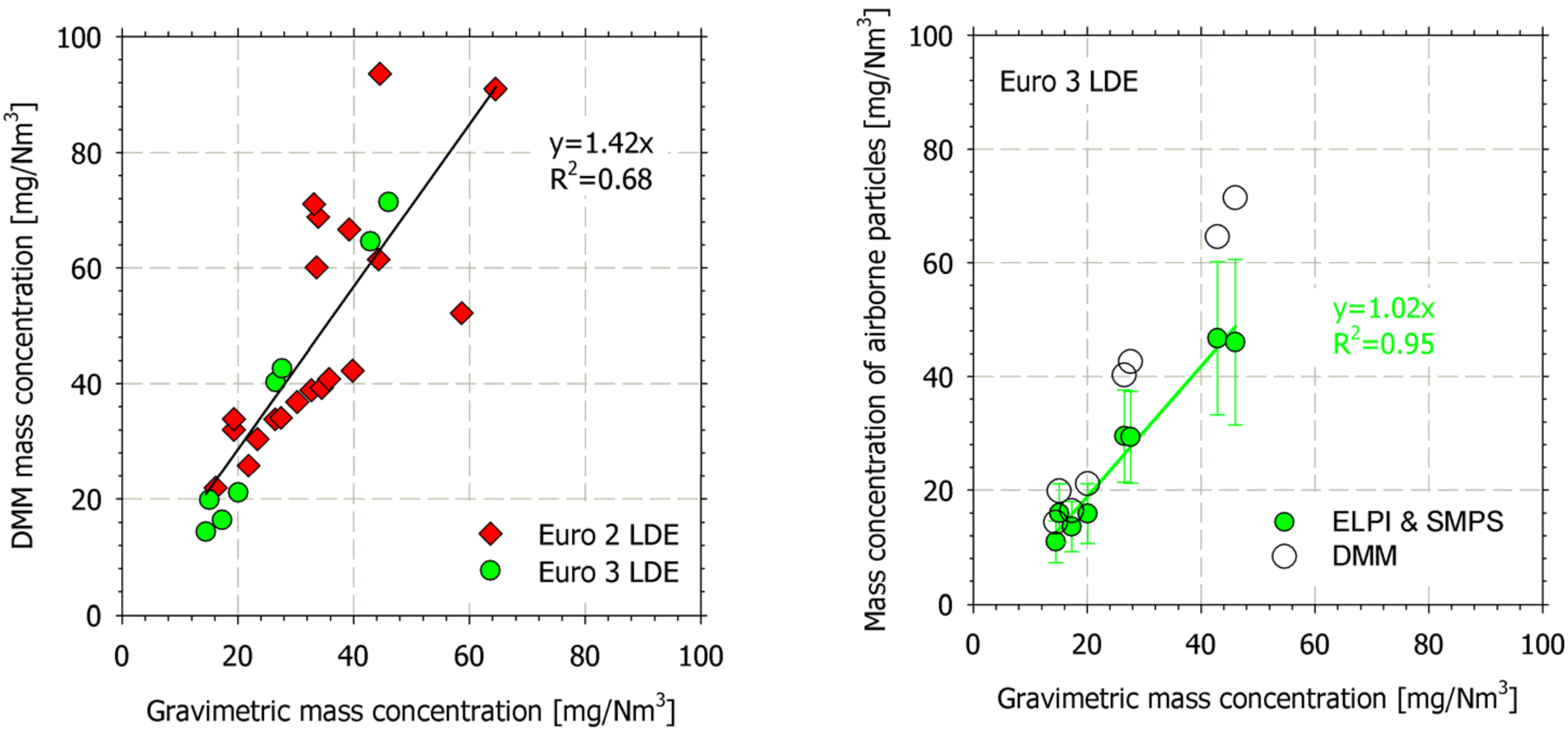


$$d_a^2 \cdot C_C(d_a) = d_B^2 \cdot C_C(d_B) \cdot \rho_{eff}(d_B)$$

$$m = \frac{\pi}{6} \int_{d_B=0}^{\infty} N(x) \cdot \rho_{eff}(x) \cdot x^3 \cdot dx$$

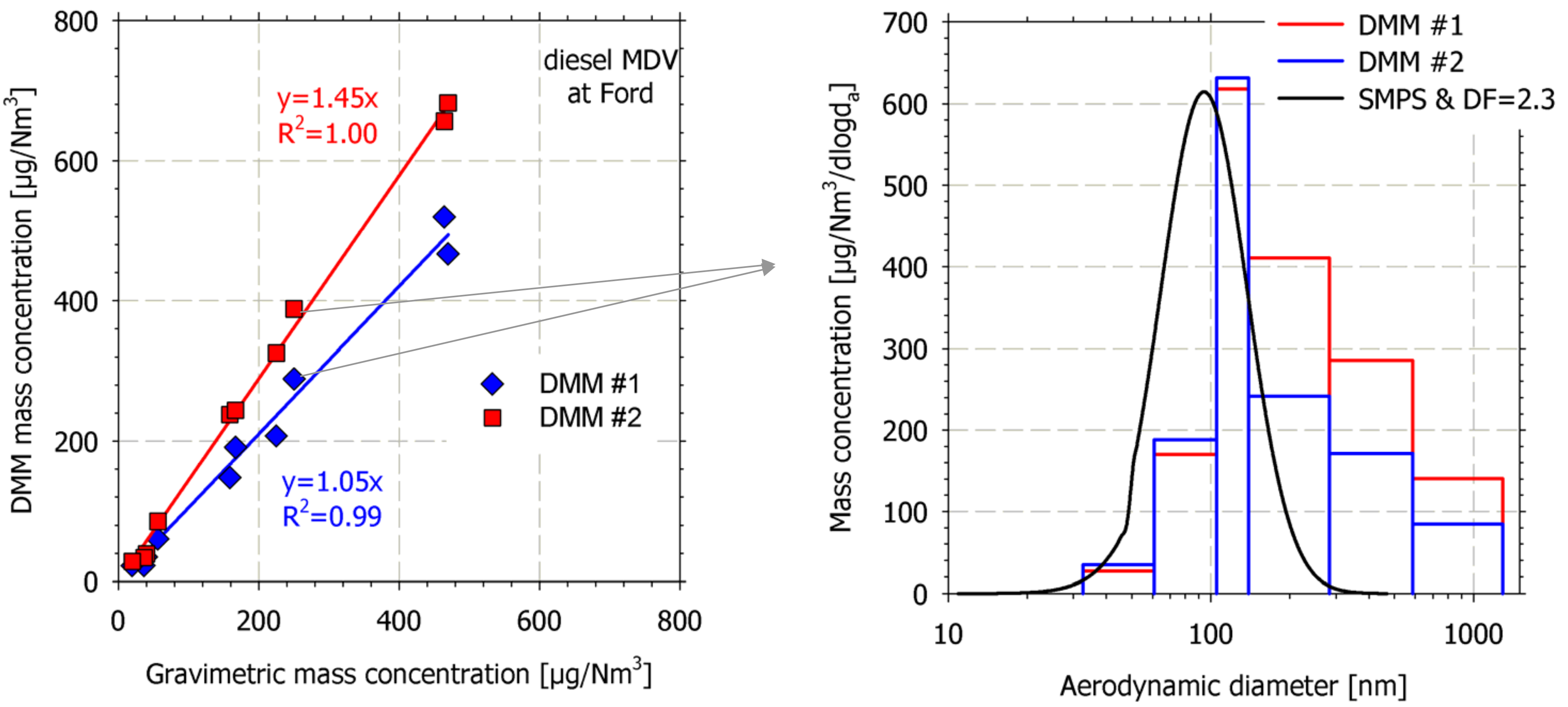
Source: V. Niemelä, J. Lilja, M. Moisio, H. Tuomenoja (2003),
Evaluation of DMM-230 Mass Monitor for Exhaust Emission Measurement, EAC 2003.

Drawbacks of the original data inversion method



Source: A. Mamakos, L. Ntziachristos, Z. Samaras (2006), Evaluation of the Dekati Mass Monitor for the Measurement of Exhaust Particle Mass Emissions. Environmental Science and Technology 40, 4739-4745

Origin of the problem



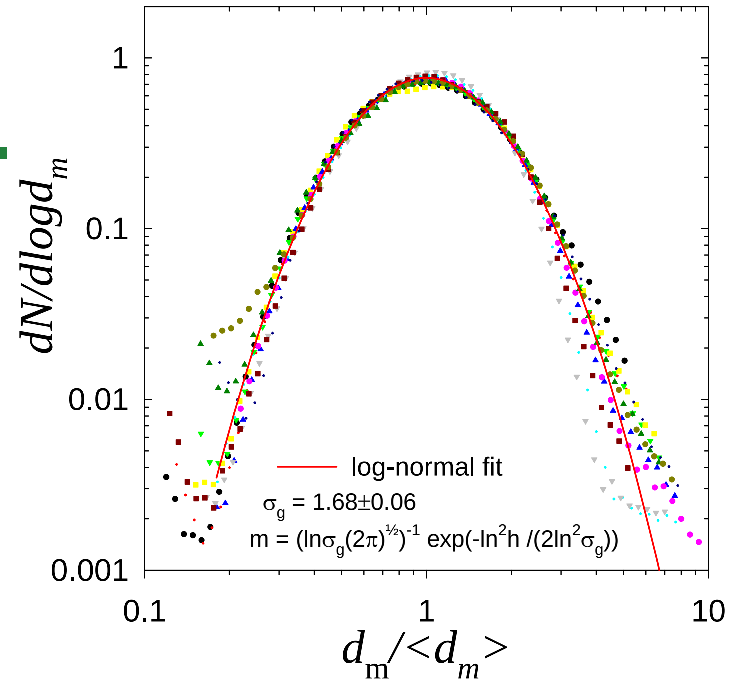
Revised inversion approach

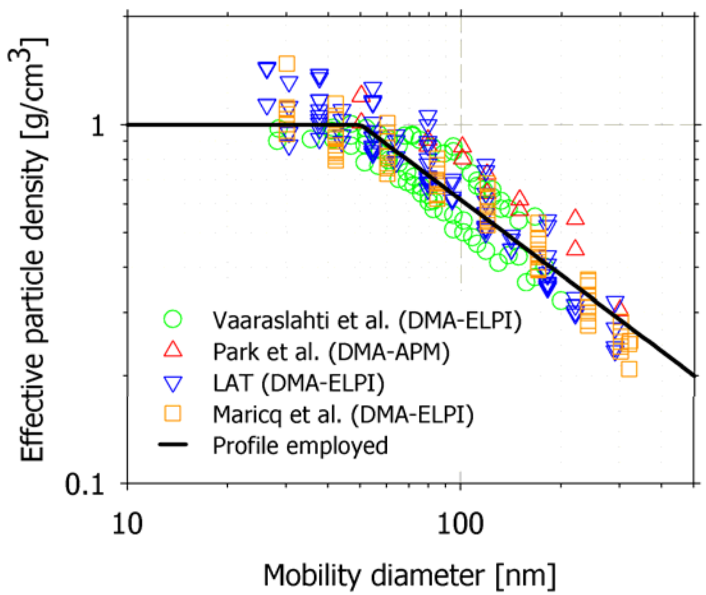
➢Assume lognormal distribution completely specified by N_{tot}, d_g & σ_g

➢Assume fractal-like structure implying a power law dependence of the effective density on particle size:

$$\rho_{eff} = min(\rho_{max}, \rho_{max}(d_m/d_0)^{(DF-3)})$$

➢σ_g=1.75, ρ_{max}=1 g/cm^3, DF=2.3, d_0=50 nm





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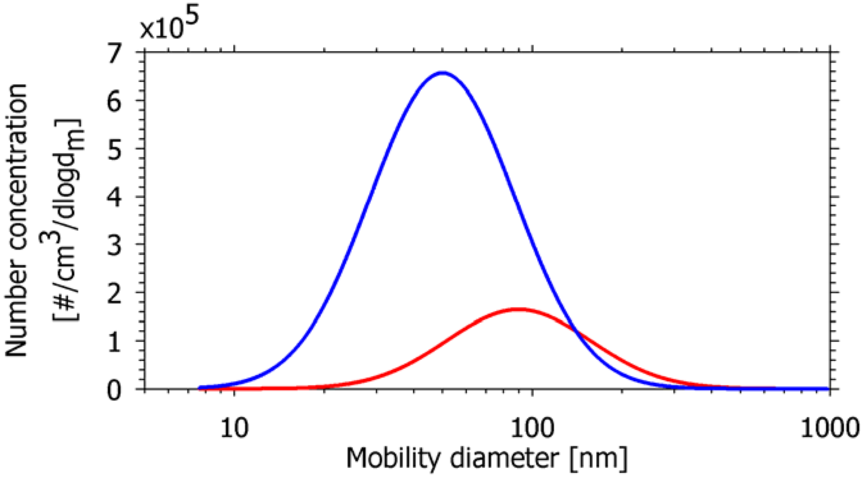
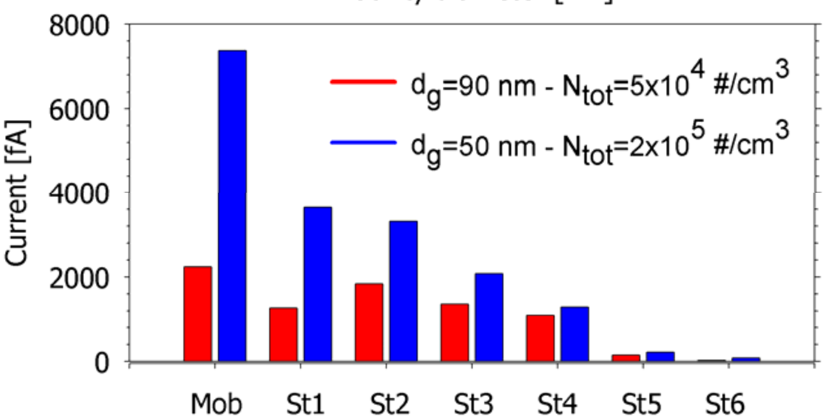
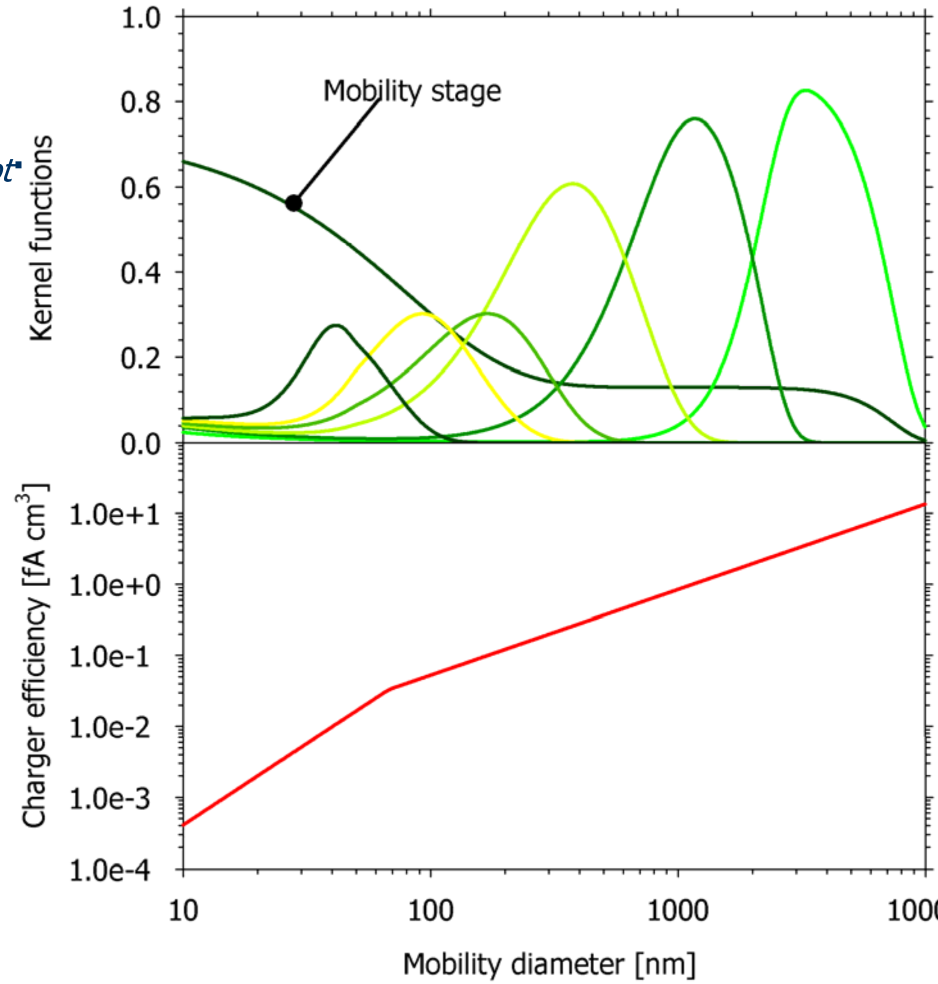
Implementation of the algorithm

➢Given the DMM kernel functions and the charger efficiency, it is possible to simulate the DMM responses for any pair of d_g and N_{tot}. The optimal pair minimizes the cost function:

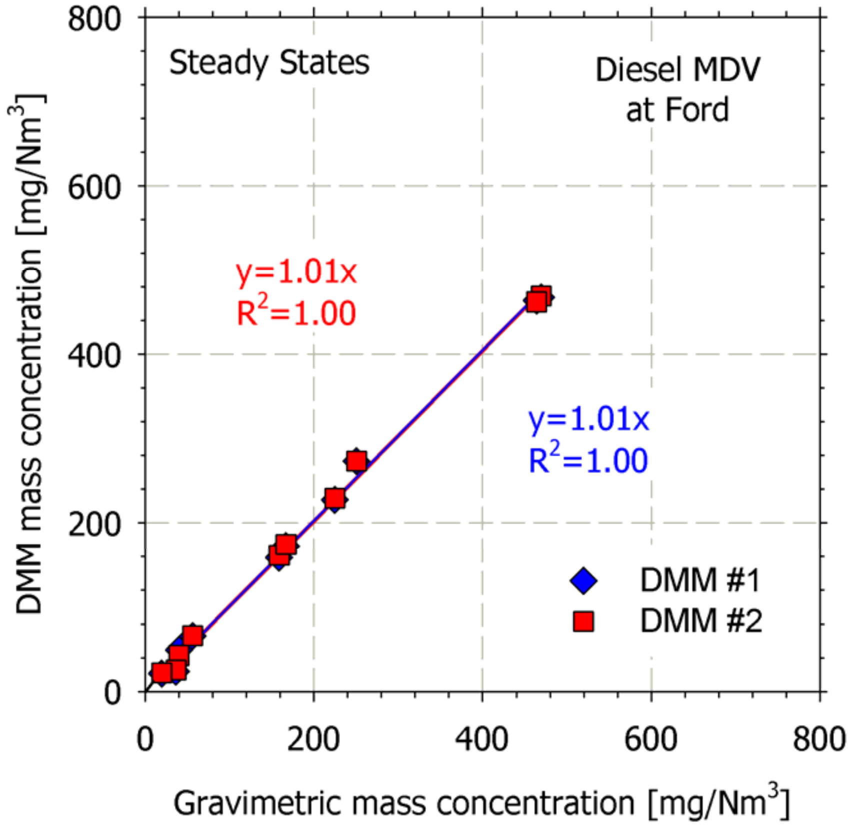
$$CF = \Sigma(I_{i,meas} - I_{i,sim})^2 \; , \; i = 0,\ldots,6$$

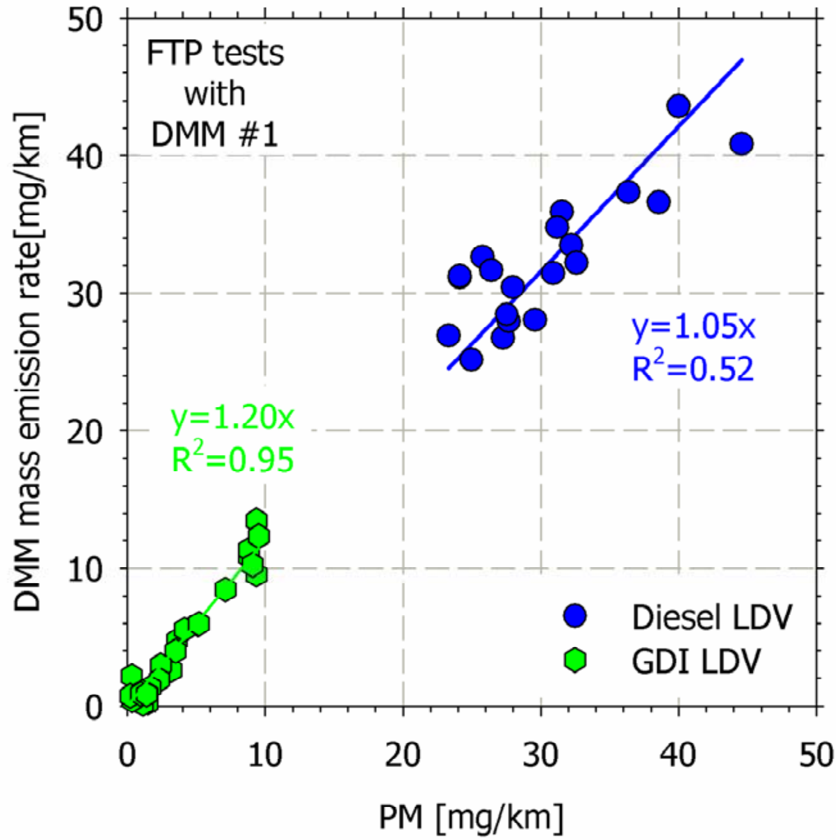






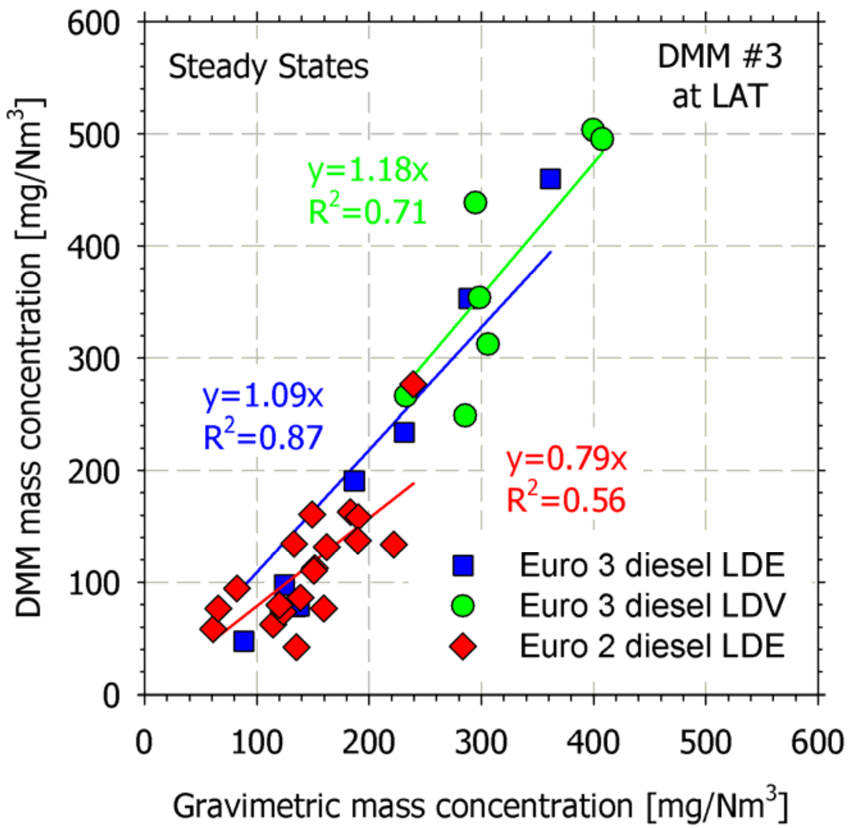
Application of the algorithm to experimental data collected at Ford

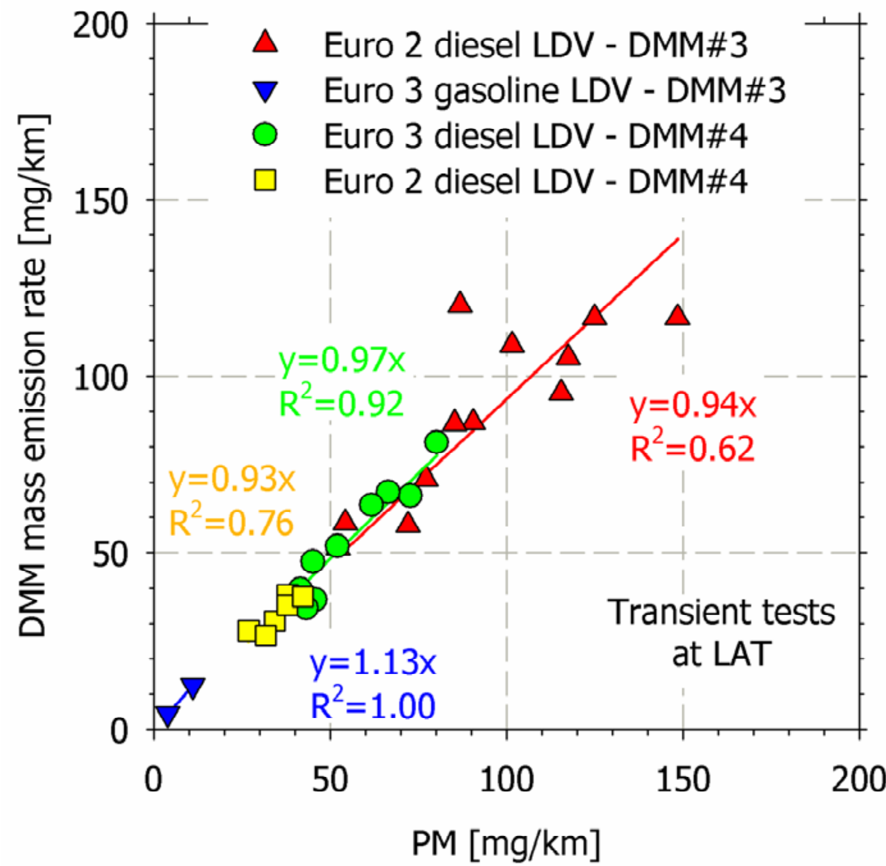




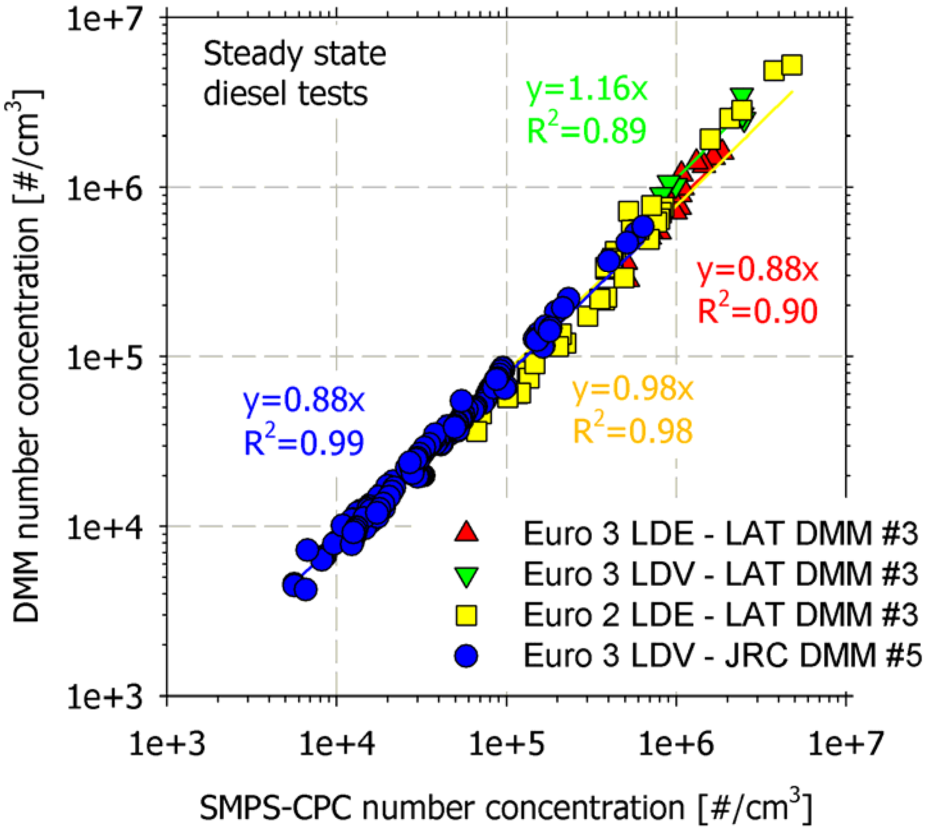
The revised algorithm is less sensitive to uncertainties associated with the diffusion losses and the electrometer drifts

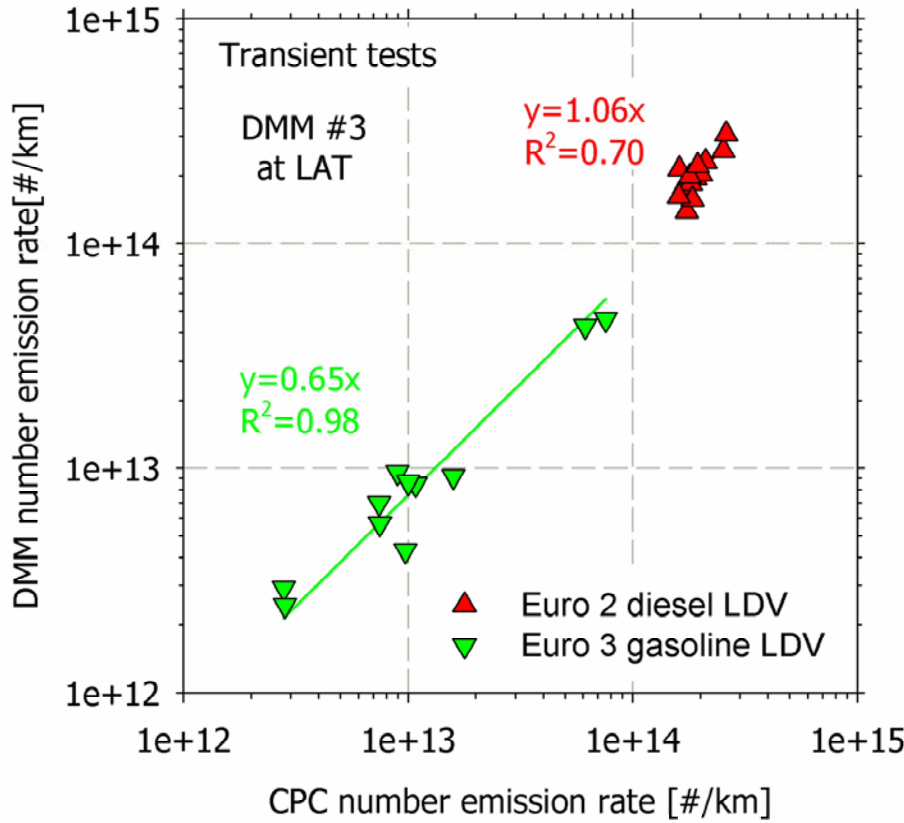
Application of the algorithm to experimental data collected at LAT





Possibility to infer number concentration





Conclusions

- A revised data inversion algorithm has been developed for the Dekati's Mass Monitor.

- The algorithm was validated with experimental data collected at three laboratories. Five different DMM units were employed for the particle characterization of 7 diesel vehicles/engines and 2 gasoline vehicles (one MPI and one GDI).
  - In the case of diesel exhaust aerosols, the calculated DMM mass concentrations agreed with the filter-based PM within ±20% on an average.
  - A good agreement with PM was also established in the case of the conventional and direct injection gasoline vehicles with the relative differences being on average 13 and 20%, respectively.

- The algorithm was found to provide also a very good estimate of the particle number concentrations, especially in the case of diesel exhaust were the differences from the reference measurement techniques (CPC and SMPS) were on average less than ± 15%.

Thank you very much for your attention!

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M. Maricq	Ford
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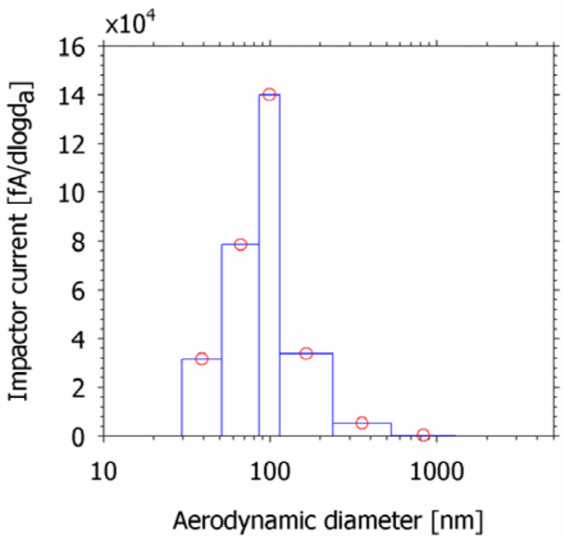
Z. Samaras	LAT
J. Tikannen	Dekati

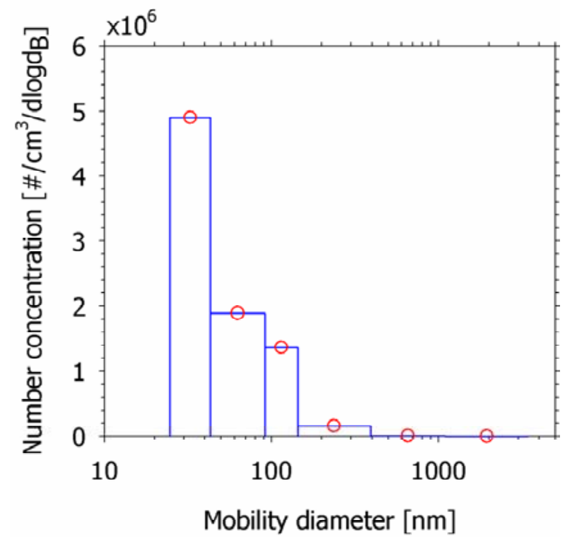
Description of the original inversion method

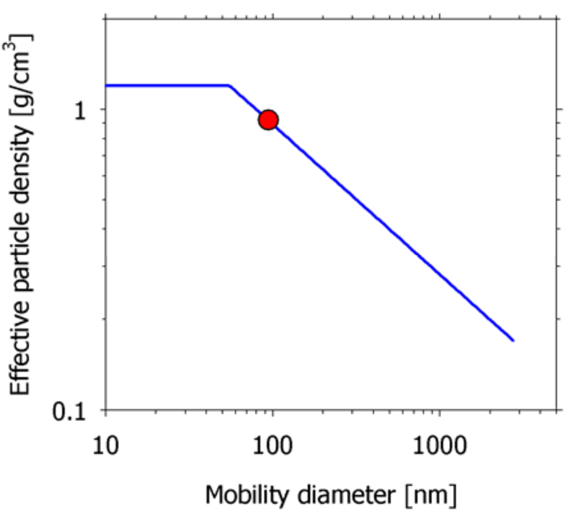


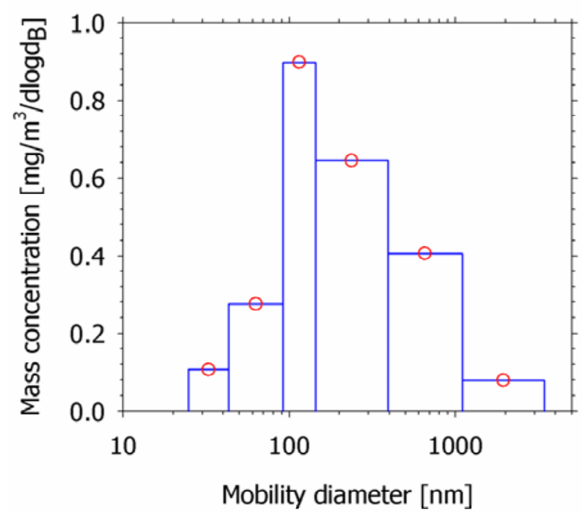
$$d_{gI,a} = \exp\left(\frac{\sum_{i=1}^{6} I_i \ln\left(d_{mid,i}\right)}{\sum_{i=1}^{6} I_i}\right)$$

$$d_{gI,m} = f\left(I_{mob}/I_{stages}\right)$$

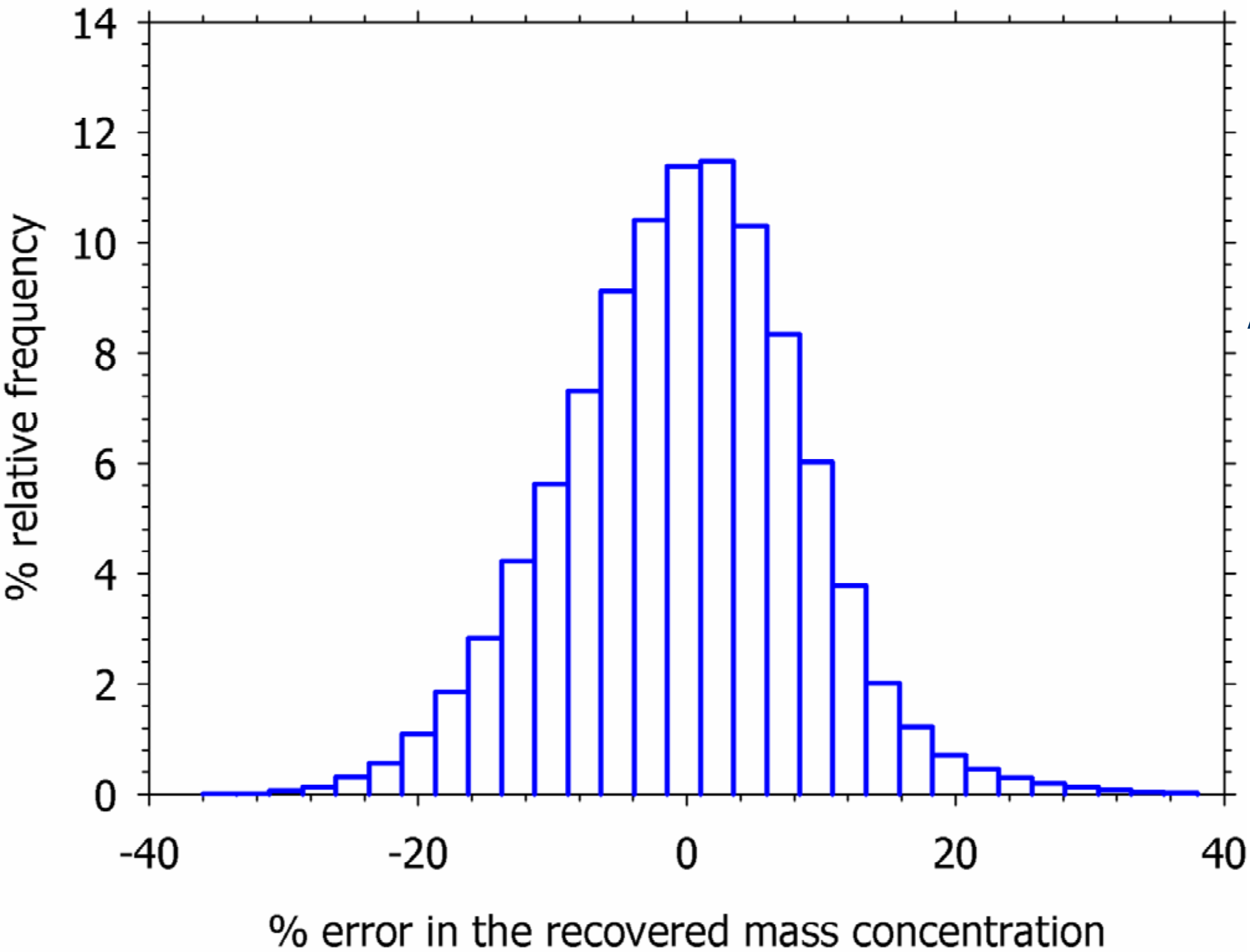
$$\rho_{eff}\left(d_{gI,m}\right) = \frac{C_c\left(d_{gI,a}\right)\cdot d_{gI,a}{}^{2}}{C_c\left(d_{gI,m}\right)\cdot d_{gI,m}{}^{2}}$$







Estimated errors associated with the assumptions employed for the data inversion



Monte Carlo simulations:

d_g=40-120 nm

DF=2-2.5

σ_g=1.65-1.85

ρ_{max}=0.8-1.4 g/cm^3

d_{B0}=30-70 nm

Nucleation Mode Effect