A new method to improve particle size selection in tandem DMA setup

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Size selection of airborne nanoparticles by differential mobility analyzers (DMA) is always hampered by the presence of larger particles carrying multiple charge downstream the mobility analyzer. Using two DMAs in series (tandem-DMA) improves monodispersity of the resulting aerosol, because most of the doubly charged larger particles exiting the first DMA will obtain single charge in the second neutralizer and therefore the fraction of larger particles downstream the second DMA is reduced. However, due to the low charging probability in bipolar chargers, usually this procedure yields too low particle concentrations to be useful.

In this work, we have tested a novel method to improve monodispersity of a size selected aerosol based on the tandem-DMA setup, according to Lüönd and Schlatter (2013). The key idea of the new method is that in the second DMA, an integer multiple of the mobility selected in the first DMA is selected, usually the double or triple mobility, instead of selecting the same mobility in both DMAs as in the conventional tandem-DMA setup. This is equivalent to selecting doubly or triply charged particles of the desired size. Larger particles penetrating the second DMA with the same mobility carry 4 or 6 unit charges, respectively. I.e. on the charge axis, they are separated from the desired particles by two or three units instead of one unit as in the standard DMA setup. As the charging probability of particles decreases with increasing charge level, selecting multiply charged particles in the second DMA decreases the fraction of larger particles carrying higher charge in the resulting aerosol as compared to a standard tandem-DMA setup. In order to obtain a sufficient fraction of doubly or triply charged particles upstream the second DMA, we replaced the first neutralizer of the tandem-DMA setup by a unipolar corona charger.

A schematic of the experimental setup to test the new charging and selection method is shown in Fig. 1. A TSI 3079 portable atomizer was used to generate a NaCl test aerosol with a mode diameter of 109 nm, a geometric standard deviation of 1.8, and a total number concentration around 10^7 cm^{-3}.

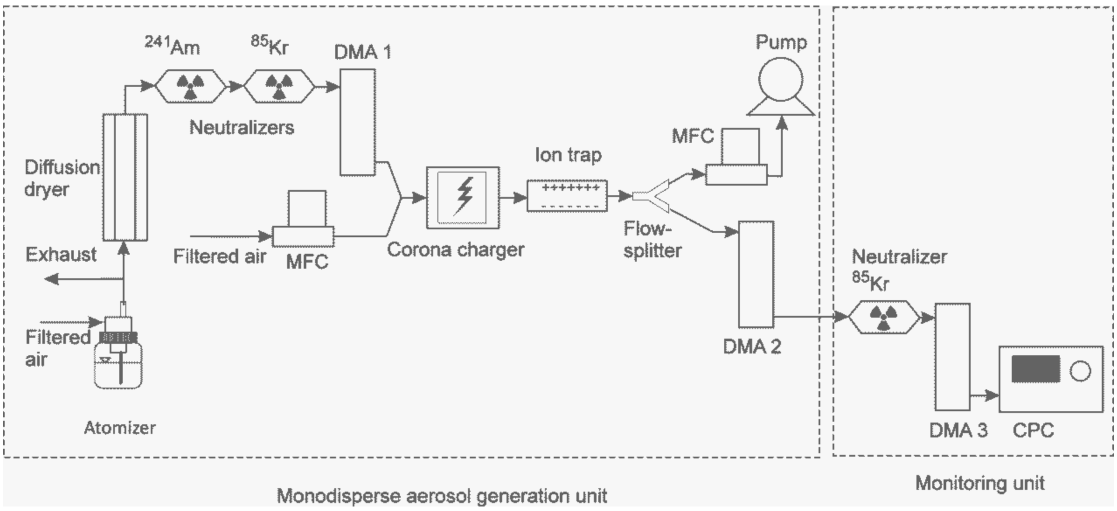

Figure 1: Experimental setup used to assess the new method to generate highly monodisperse aerosol particles (Lüönd and Schlatter, 2013)

DMA 1 (Grimm 5.5-340 at 8 lpm sheath flow and 1.1 lpm aerosol flow) was set to select an electrical mobility Z1 corresponding to singly charged 50 nm particles. Selection was done in the upslope of the total size distribution on purpose: The resulting high fraction of multiply charged particles downstream DMA 1 allowed us to assess the potential of the new method in increasing the monodispersity of a size selected aerosol. Downstream DMA 1, a unipolar corona charger (Prototype by Matter Aerosol) with a product $N_i t$ of ion density and exposure time around $0.7 \cdot 10^{13}$ m^{-3} s was used to shift the charge distribution of the aerosol such, that a significant fraction of the particles entering DMA 2 (TSI 3085 at 3 lpm sheath flow and 0.3 lpm aerosol flow) carried 2 or 3 unit charges. Selecting an electrical mobility $Z_2 = 2 \cdot Z_1$ or $Z_2 = 3 \cdot Z_1$ with DMA 2 allowed those 50 nm particles which carried 2 or 3 unit charges to penetrate DMA 2, respectively. Downstream DMA 2, an SMPS (TSI DMA 3085 and CPC 3775) was used to determine the monodispersity of the resulting aerosol, i.e. the ratio $R_{c,2c}$ between particles of charge level c and larger particles at charge level 2c, where c = 2 or c = 3, respectively. Resulting size distributions are shown in Fig. 2 (blue curve for selection of triply charged particles at DMA 2 (c = 3), red curve for selection of doubly charged particles (c = 2)). For comparison, the green curve shows the size distribution obtained with a conventional tandem-DMA setup, i.e. using a neutralizer instead of the corona charger upstream DMA 2 and selecting $Z_2 = Z_1$ at DMA 2. The corresponding values for total number concentration and monodispersity are given in Tab. 1.

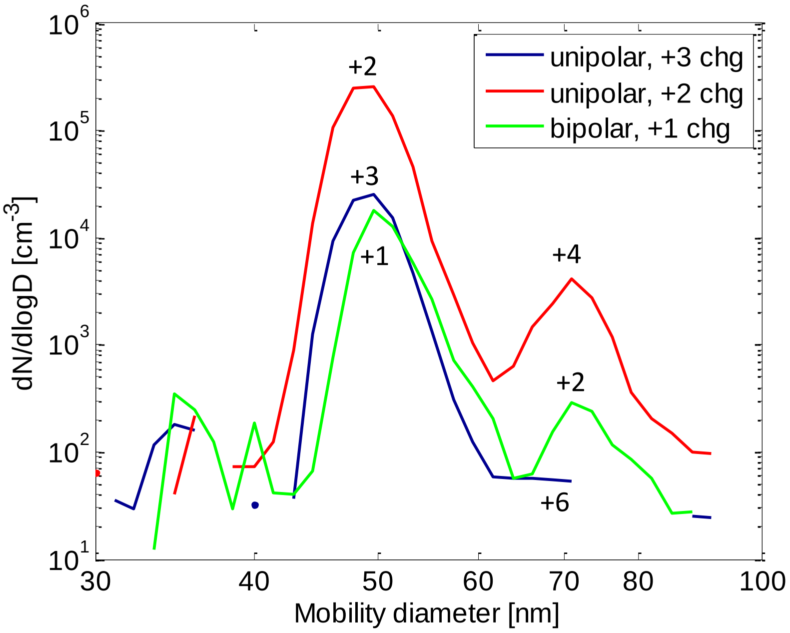

Figure 2: Size distribution measured with the monitoring unit downstream DMA 2 for the conventional tandem-DMA setup (green curve) as compared to the new method, selecting doubly (red curve) or triply (blue curve) charged particles at DMA 2. Note the logarithmic scale on the y-axis.

	Yield [cm^{-3}]	Monodispersity
bipol c = 1	936 ± 61	R1,2 = 42 ± 8
unipol c = 2	12’750 ± 110	R2,4 = 63 ± 5
unipol c = 3	1’255 ± 36	R3,6 = 295 ± 105

Table 1: Resulting particle number concentration and monodispersity downstream DMA 2 (adapted from Lüönd and Schlatter, 2013). Monodispersity is given in terms of the ratio Rc,2c of the concentrations of particles at charge level c and larger particles and the next, potentially penetrating charge level 2c.

For c = 2, the new method yielded a similar monodispersity as in the conventional tandem-DMA setup, but at a concentration one order of magnitude higher. For c = 3, the resulting concentration is similar as in the conventional setup, but due to the very low probability for particles around 73 nm to obtain +6 unit charges in the corona charger, the monodispersity of the aerosol downstream DMA 2 could be increased by a factor of 7. The choice of the charge level to be selected at DMA 2 therefore makes a decision between high obtainable number concentration and high monodispersity.

The new method has been shown to be promising for optimization of the size selection process in a tandem-DMA setup for cases where a sufficient input number concentration can be delivered by the aerosol generator.

Reference

- Lüönd, F., and Schlatter, J. (2013). Improved monodispersity of size selected aerosol particles with a new charging and selection scheme for tandem DMA setup. *Journal of Aerosol science* 62, p. 40 – 55

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Introduction

Size selection of aerosol particles by means of differential mobility analyzers (DMA) is always hampered by the fact that size and electrical mobility cannot be unambiguously related if different charging states exist among the particles. Larger, multiply charged particles can have the same electrical mobility as the singly charged particles of the desired size and therefore reduce monodispersity downstream the DMA.

In particle metrology, reliable sizing of particles is essential, e.g. for the measurement of the size-dependent counting efficiency of condensation particle counters (CPC). For vehicle homologation according to the UNECE regulations R49/ R83, CPCs have to meet strict specifications regarding the size-dependent counting efficiency.

In this work, we present a new method to optimize size selection in a tandem DMA setup. It is based on the selection of a defined, higher charge level in the second DMA which reduces the probability for penetration of unwanted larger particles.

Improving monodispersity

Improving monodispersity according to the method described by Lüönd and Schlatter (2013) relies on two key components:

- Selection of 2- or 3-fold mobility at DMA 2, i.e. selection of doubly or triply charged particles. Due to the low probability for 4- and 6-fold charge, penetration of larger particles is reduced.
- Use of a unipolar corona charger upstream DMA 2 instead of a neutralizer increases the probability for 2- and 3-fold charge and hence increases the yield of monodisperse aerosol.

A qualitative schematic of the mobility distribution downstream DMA 1 and upstream DMA 2 is shown in Fig. 1 for both the conventional and the new tandem DMA method.

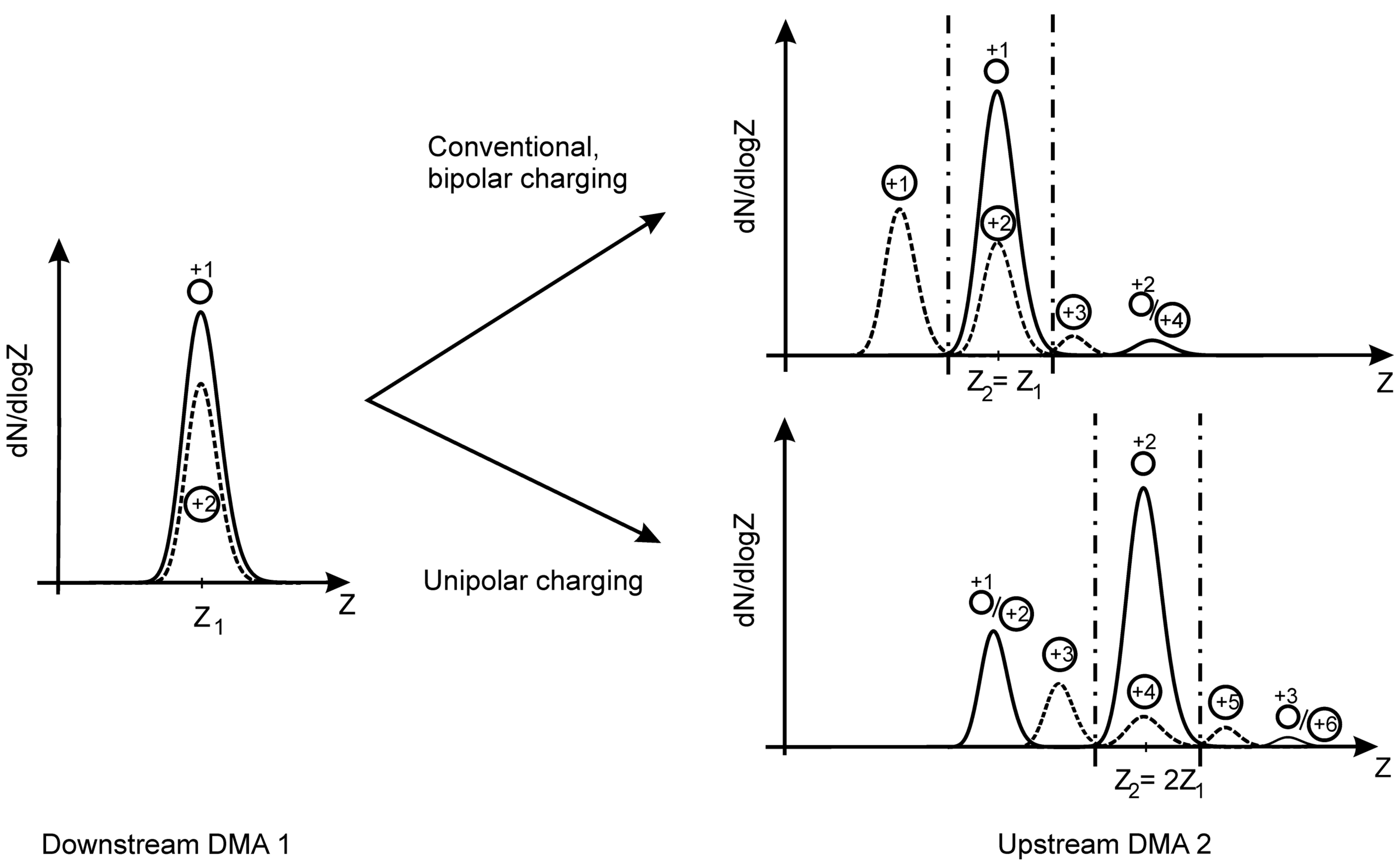

Figure 1: Qualitative schematic of the mobility distributions in the charging and selection process according to Lüönd and Schlatter (2013, lower panel) as compared to the conventional tandem DMA scheme (upper panel). Note that peak amplitudes of higher charge levels are exaggerated for visibility.

The experimental setup to assess the new charging and selection method is shown in Fig. 2 for NaCl particles. Upstream DMA 2, a unipolar positive corona charger is used to obtain significant probability for 2- and 3-fold charged particles. Downstream DMA 2, concentration and monodispersity are controlled by an SMPS.

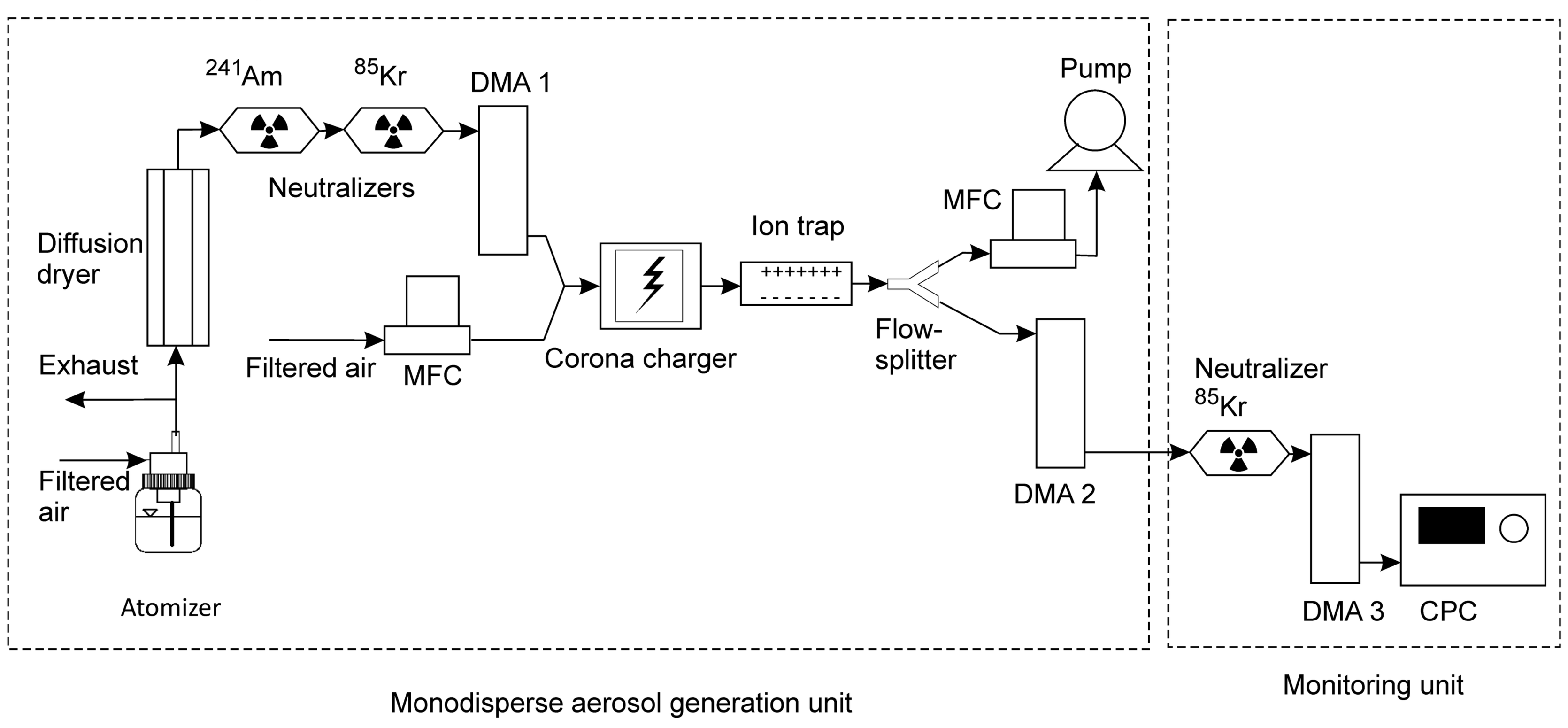

Figure 2: Experimental setup to generate highly monodisperse NaCl aerosol and control the resulting yield and monodispersity (Lüönd and Schlatter, 2013).

Instrumentation: DMA 1: Grimm 5.5-340 at 8 lpm sheath air, 1.2 lpm sample Corona charger: Prototype by Matter Aerosol, $N_i t \approx 0.7 \cdot 10^{13}$ m^{-3} s. DMA 2: TSI 3085 at 3 lpm sheath flow, 0.3 lpm sample. Monitoring unit: SMPS with TSI 3085 DMA and TSI 3775 CPC, 3 lpm sheath flow, 0.3 lpm sample.

Results

Selection of 50 nm NaCl particles from a total size distribution with mode diameter 109 nm, GSD 1.8 according to the new method as compared to the conventional case (Fig. 3 and Tab. 1):

- Unipolar charging upstream DMA 2 and selection of 2-fold charged particles yields a similar monodispersity (ratio between singly charged 50 nm and larger particles at higher charge levels) as the conventional method, but an order of magnitude higher concentration.
- Unipolar charging and selection of 3-fold charged particles yields a similar concentration as the conventional method, but a better monodispersity by a factor 7.

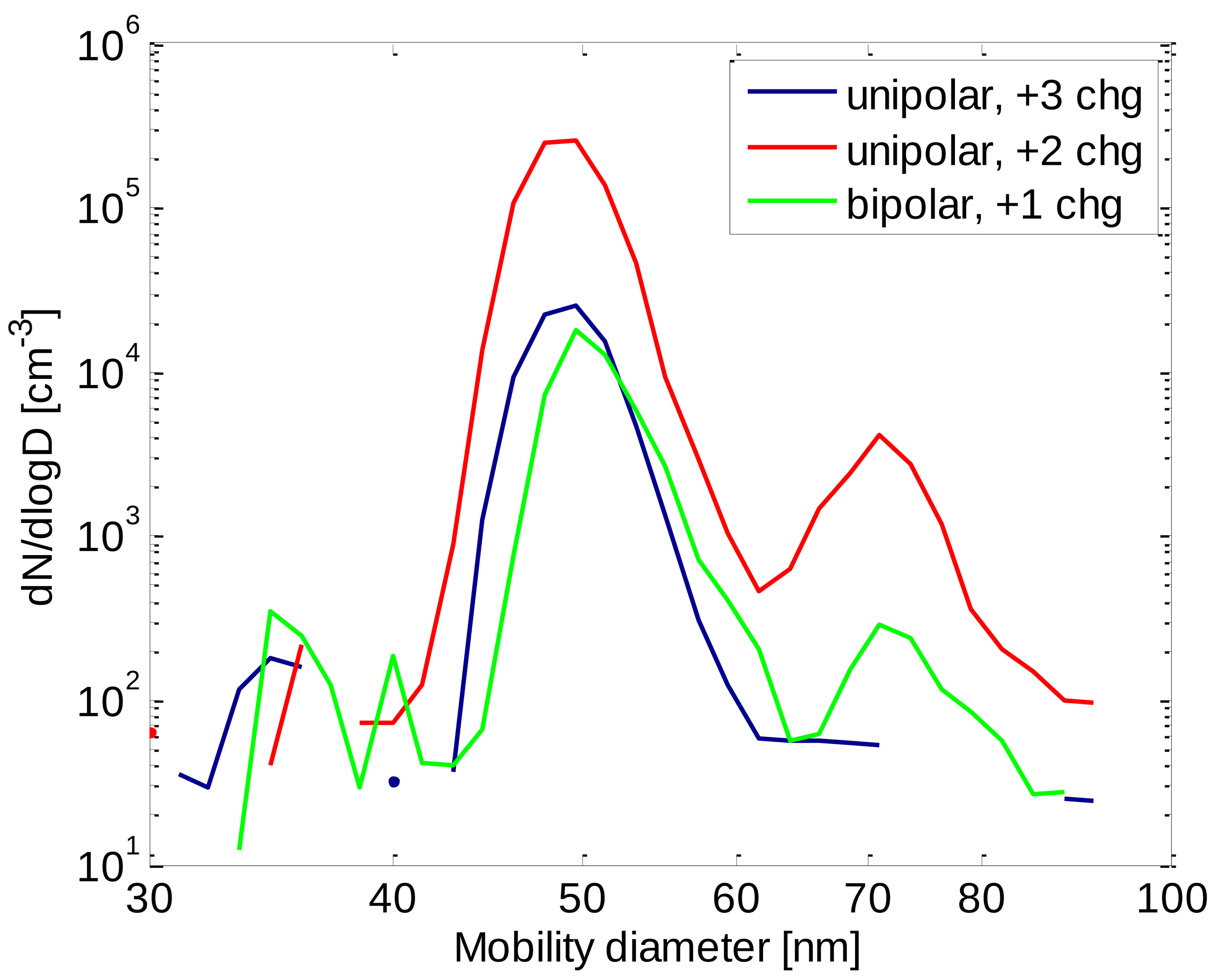

Figure 3: Resulting size distribution downstream DMA 2 for the conventional case (green curve) and for the new method optimized for high concentration (red curve, 2-fold charged particles selected) and for high monodispersity (blue curve, 3-fold charged particles selected)

	Yield [cm-3]	Monodispersity
bipol c = 1	936 ± 61	$R_{1,2}$ = 42 ± 8
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Table 1: Resulting particle number concentration and monodispersity downstream DMA 2 (adapted from Lüönd and Schlatter, 2013). Monodispersity is given in terms of the ratio $R_{c,2c}$ of the concentrations of particles at charge level c and larger particles and the next, potentially penetrating charge level 2c. c=1 refers to the conventional case, c=2 and c=3 to selection of 2-fold and 3-fold charged particles at DMA 2, according to the new method.

Conclusions

- The performance of a tandem DMA setup can be enhanced by selecting a defined higher charge level (c = 2 or c = 3) at DMA 2 and using a unipolar charger upstream DMA 2.
- The new method is promising for cases with high total number concentration (around 10^7 cm^{-3}) where the selected particle diameter is not in the far downslope of the polydisperse size distribution.
- Further optimization is possible with the use of a charger with adjustable $N_i t$ product.

Reference

- Lüönd, F., and Schlatter, J. (2013). Improved monodispersity of size selected aerosol particles with a new charging and selection scheme for tandem DMA setup. *Journal of Aerosol science 62*, p. 40 – 55

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