Atmospheric Aerosol Physics, Measurements, and Sampling

Mobility Particle Size Spectrometer
& Aerodynamic Particle Size Spectrometer

São Paulo School of Advanced Science on Atmospheric Aerosols: properties, measurements, modeling, and effects on climate and health

Member of Leibniz Association

European Center for Aerosol Calibration

World Calibration Centre for Aerosol Physics

TROPOS
Leibniz Institute for Tropospheric Research

Types of Mobility Particle Size Spectrometers

Mobility Particle Size Spectrometer (MPSS)

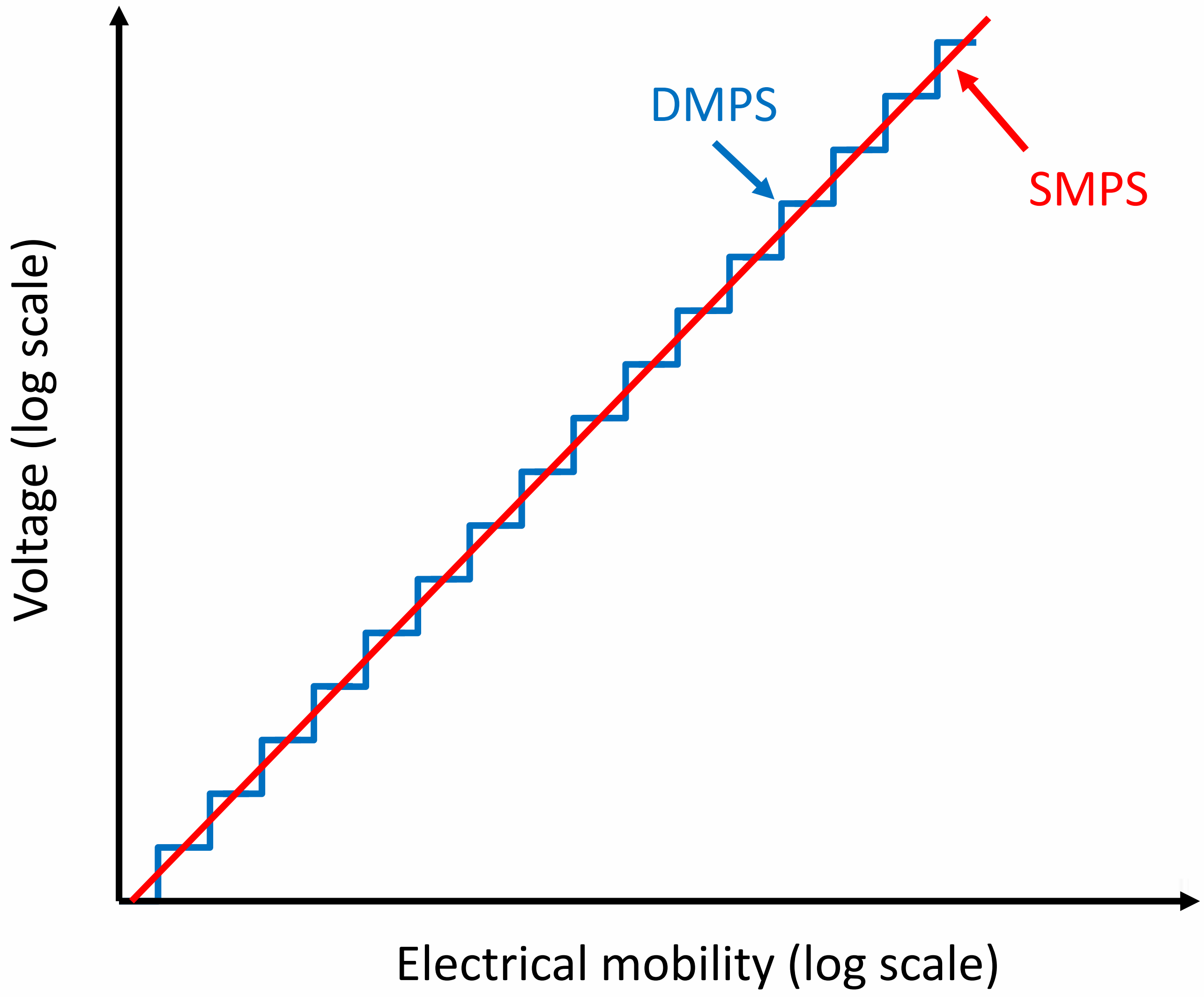
Main components

- Bipolar diffusion charger (old: neutralizer)
- Differential Mobility Analyzer (DMA)
- Condensation Particle Counter (CPC)

Different principles

- The voltage is increased stepwise (DMPS).
- The voltage is continuously increased (SMPS).

Voltage ramp



Length of the DMA

Mobility particle size spectrometers can measure a particle number size distribution only for a certain size range.

This particle size range depends on the DMA-geometry and the sheath air flow rate.

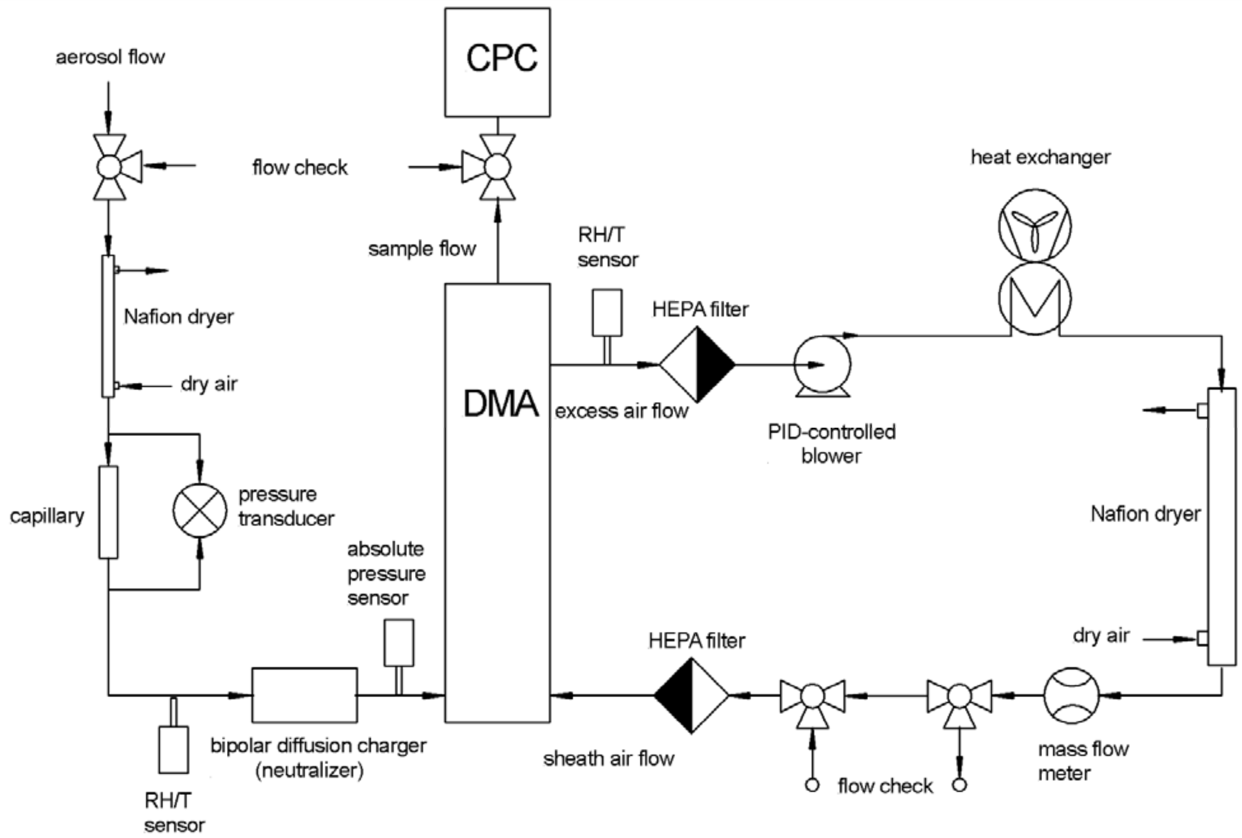
Long DMA

+ low sheath air flow rate — larger particle diameter
→ 10 to 800 nm

Short DMA

+ high sheath air flow rate — smaller particle diameter
→ 3 to 150 nm

MPSS – Recommended Setup in GAW and ACTRIS



Wiedensohler et al., 2012, Atmos. Meas. Tech., 5, 657–685.

Differential Mobility Particle Sizer (DMPS)

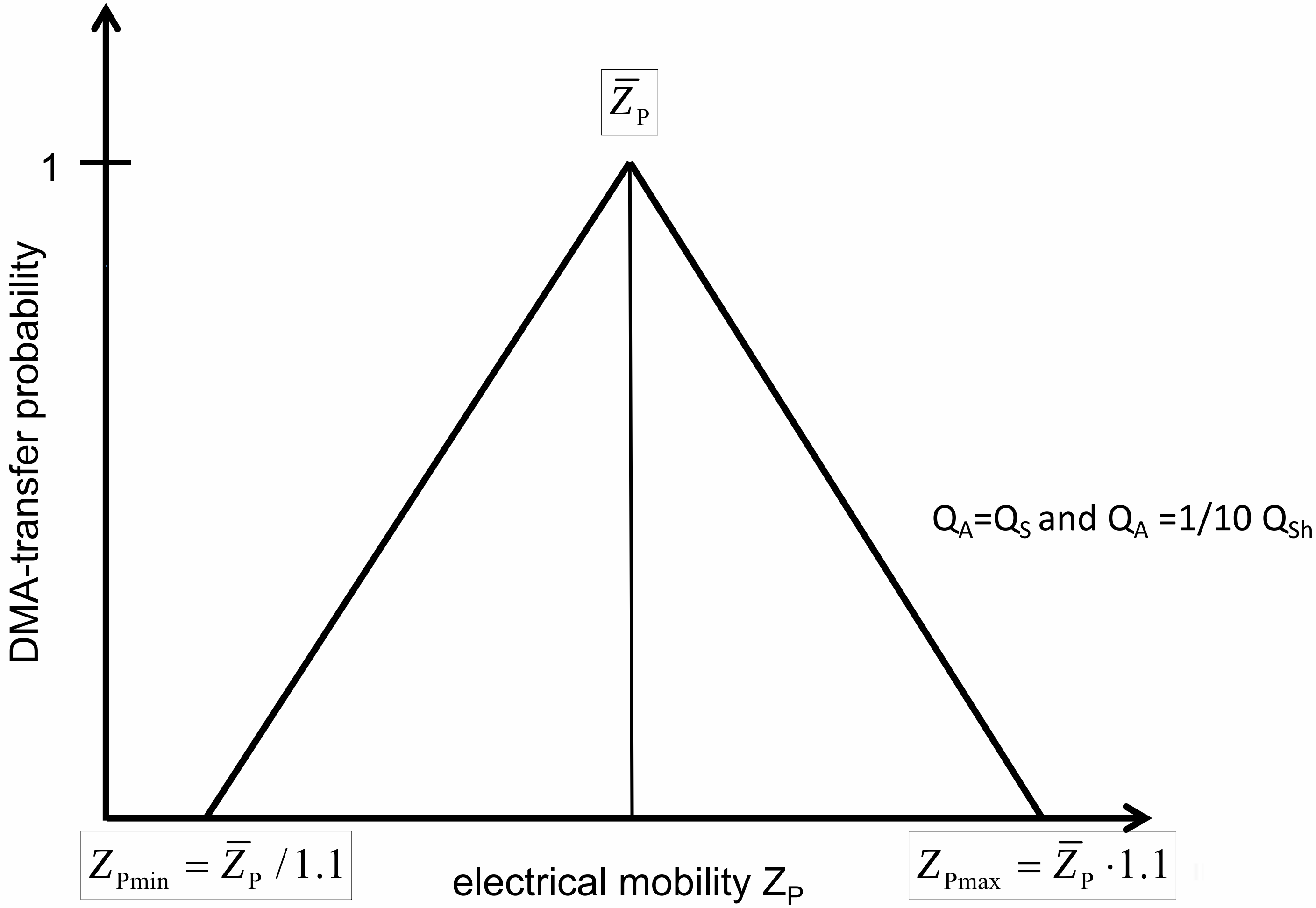
- The particles are brought in the bipolar charge equilibrium in the bipolar diffusion charger.
- A computer program sets stepwise the voltage for each selected mobility bin.
- After a certain waiting time, the CPC measures the number concentration for each mobility bin.
- The result is a electrical mobility distribution.
- The particle number size distribution can be calculated from the electrical mobility distribution by a computer inversion routine.
- A combination of two mobility particle size spectrometers allows to measure the particle number size distribution of the entire submicrometer size range.

Scanning Mobility Particle Sizer (SMPS)

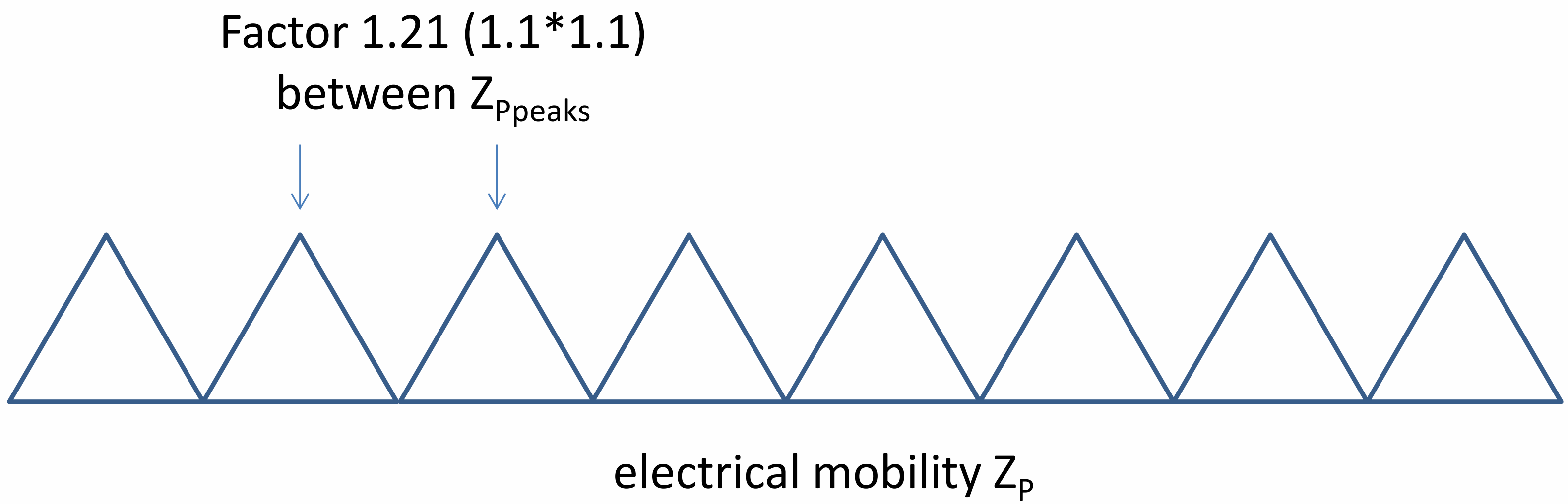
- The design of the system is identical to the DMPS.
- The difference lies in the measurement principle.
- The voltage is continuously increased.
- There is no waiting time any longer.
- The particle number concentration is measured as a function of time.
- The relationship between electrical mobility and time (time between DMA entrance and CPC detection) must be determined for each SMPS system.
- The result is again a electrical mobility distribution.
- The particle number size distribution must be calculated from the electrical mobility distribution by a computer inversion routine.

Principle of the Inversion Routine

Transfer Function



Stepping mode (DMPS)

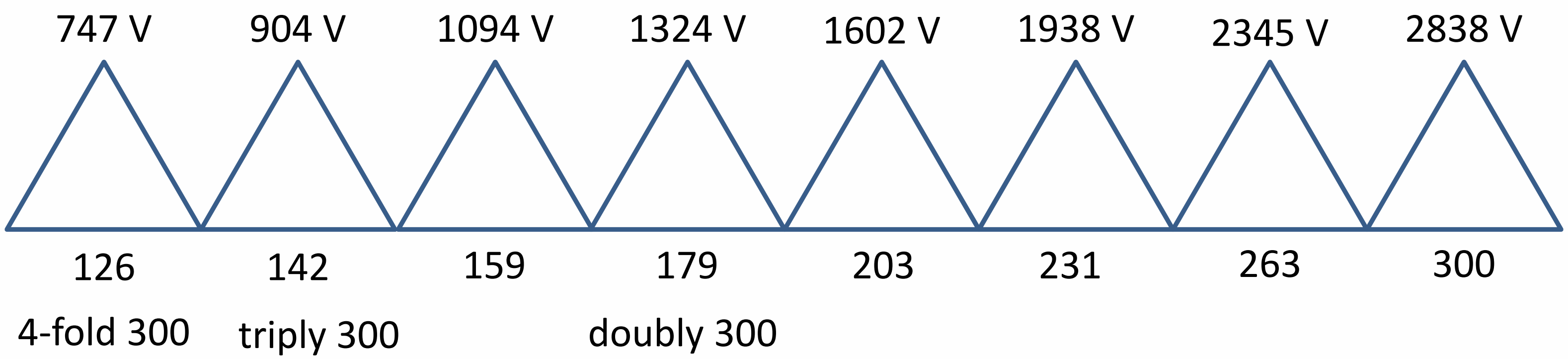


Example: Vienna-type DMA

R_i	25 mm
R_o	33.5 mm
L	280 mm
Q_{sh}	5 l/min
Q_a	0.5 l/min
Q_a / Q_{sh}	1/10

1.21^n	
1.0	
1.2	
1.5	
1.8	
2.1	~2
2.6	
3.1	~3
3.8	~4

Factor 1.21
between Z_{Ppeaks} or voltage



particle diameter D_P (nm) →

← electrical particle mobility Z_P

Voltage U (V) →

Bipolar Charge Distribution (for this example)

Dp (nm)	-4	-3	-2	-1	0	1	2	3	4
300	1,96%	6,48%	14,50%	22,98%	24,06%	17,83%	8,78%	2,91%	0,67%
263	1,37%	5,46%	13,92%	24,20%	25,83%	18,77%	8,40%	2,45%	0,47%
231	0,90%	4,45%	13,16%	25,32%	27,70%	19,61%	7,89%	2,00%	0,31%
203	0,56%	3,50%	12,23%	26,31%	29,67%	20,35%	7,26%	1,57%	0,19%
179	0,26%	2,38%	10,77%	27,35%	32,48%	21,11%	6,31%	1,07%	0,09%
159	0,18%	1,97%	10,10%	27,69%	33,73%	21,35%	5,88%	0,89%	0,06%
142	0,10%	1,42%	9,00%	28,06%	35,75%	21,59%	5,20%	0,64%	0,03%
126	0,05%	0,95%	7,82%	28,24%	37,99%	21,69%	4,48%	0,43%	0,02%

Main components

- Pre-Impactor
- Bipolar diffusion charger (old: neutralizer)
- Differential Mobility Analyzer (DMA)
- Condensation Particle Counter (CPC)

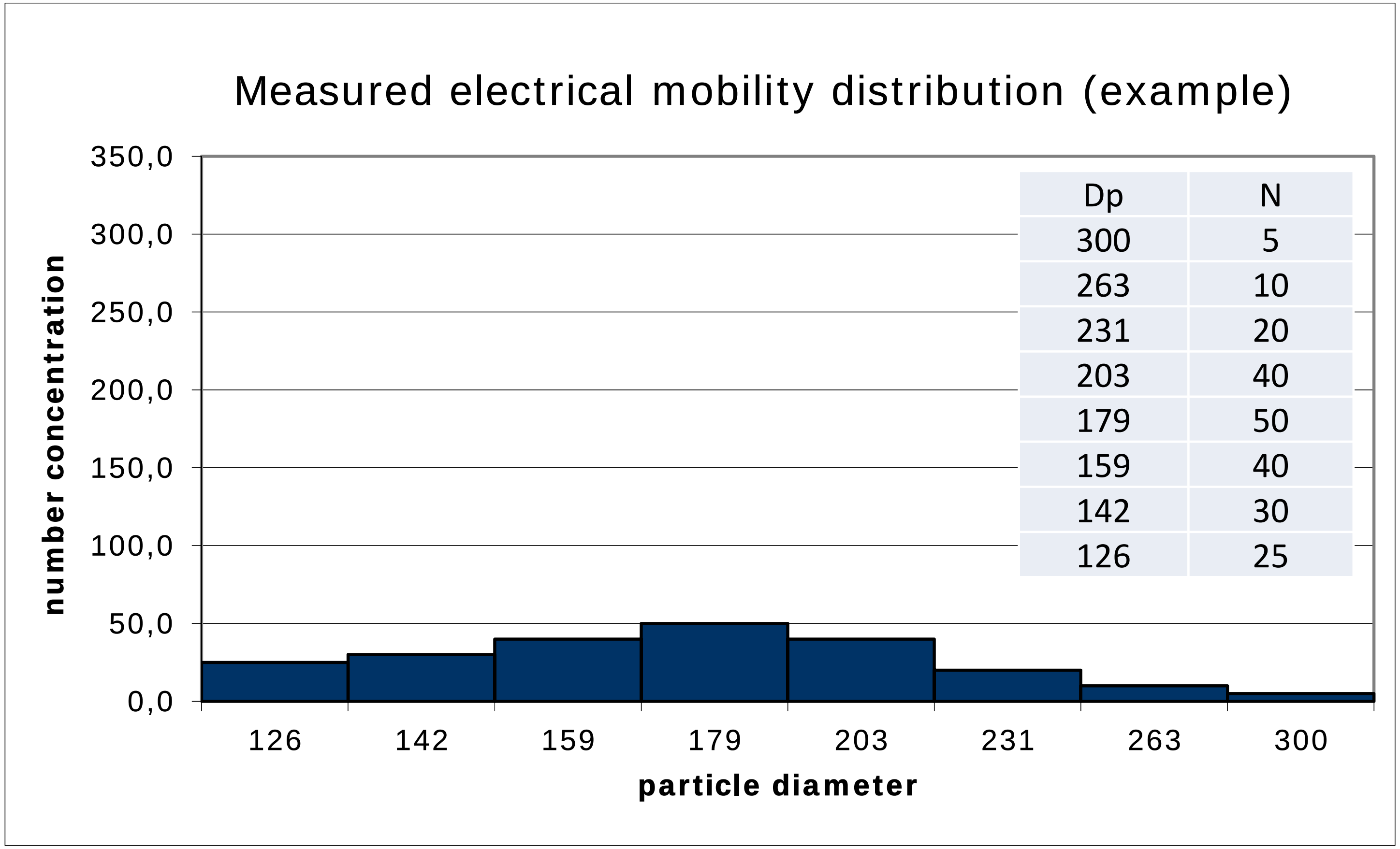
Pre-Impactor

- In a MPSS, an electrical mobility distributions is directly measured.
- The particle number size distribution is determined, knowing the bipolar charge distribution.
- A pre-impactor in front of the MPSS is needed:

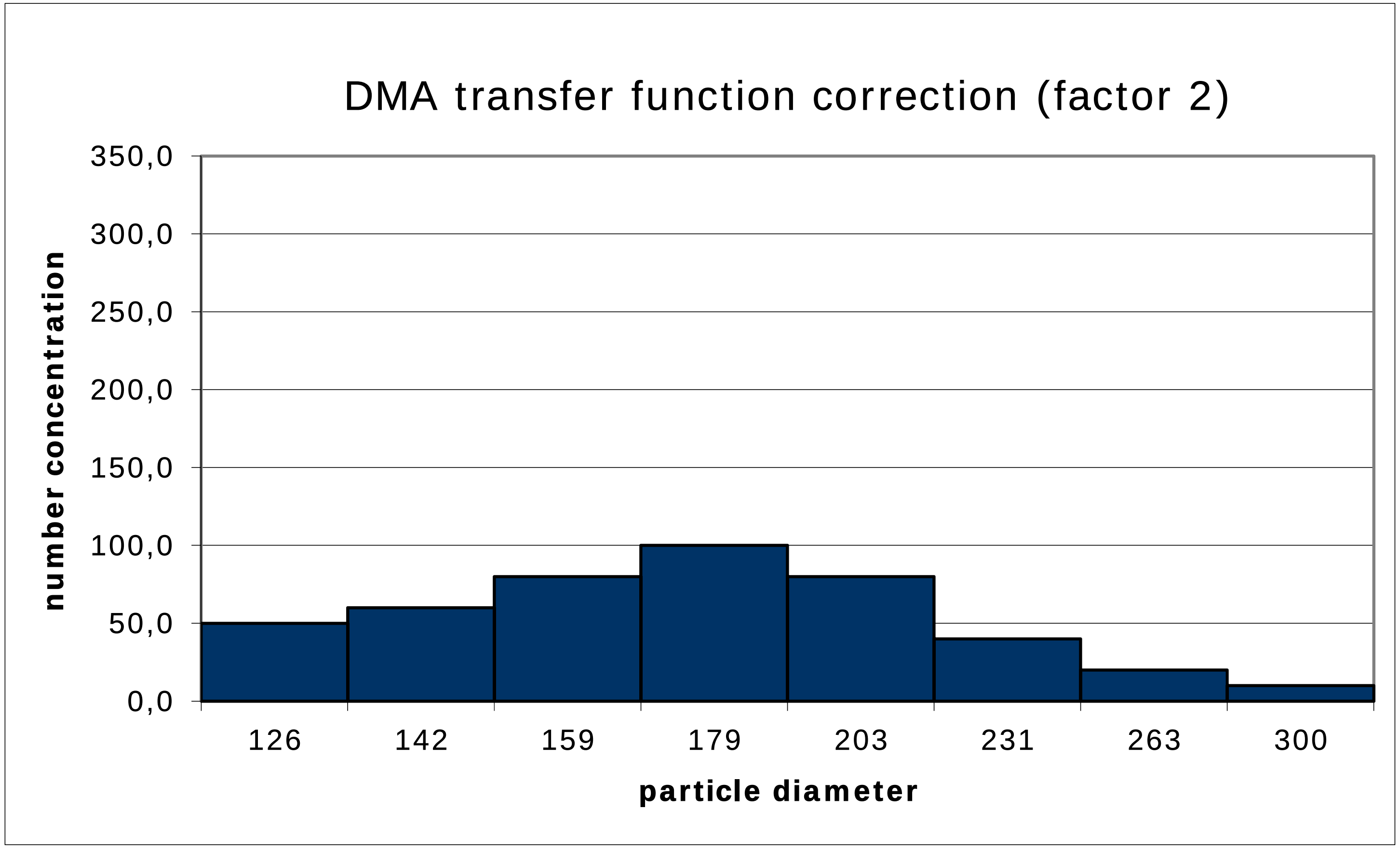
  → to eliminate the influence of multiple-charged particles larger than the nominal measured size range
- A pre-impactor in front of the MPSS might be not needed:

  → if the MPSS size range is up to 800 nm and if there is no significant course mode

Electrical Mobility Distribution



Correction Transfer Function (ideal triangle)



Bipolar Charge Distribution (for this example)

Dp (nm)	-4	-3	-2	-1	0	1	2	3	4
300	1,96%	6,48%	14,50%	22,98%	24,06%	17,83%	8,78%	2,91%	0,67%
263	1,37%	5,46%	13,92%	24,20%	25,83%	18,77%	8,40%	2,45%	0,47%
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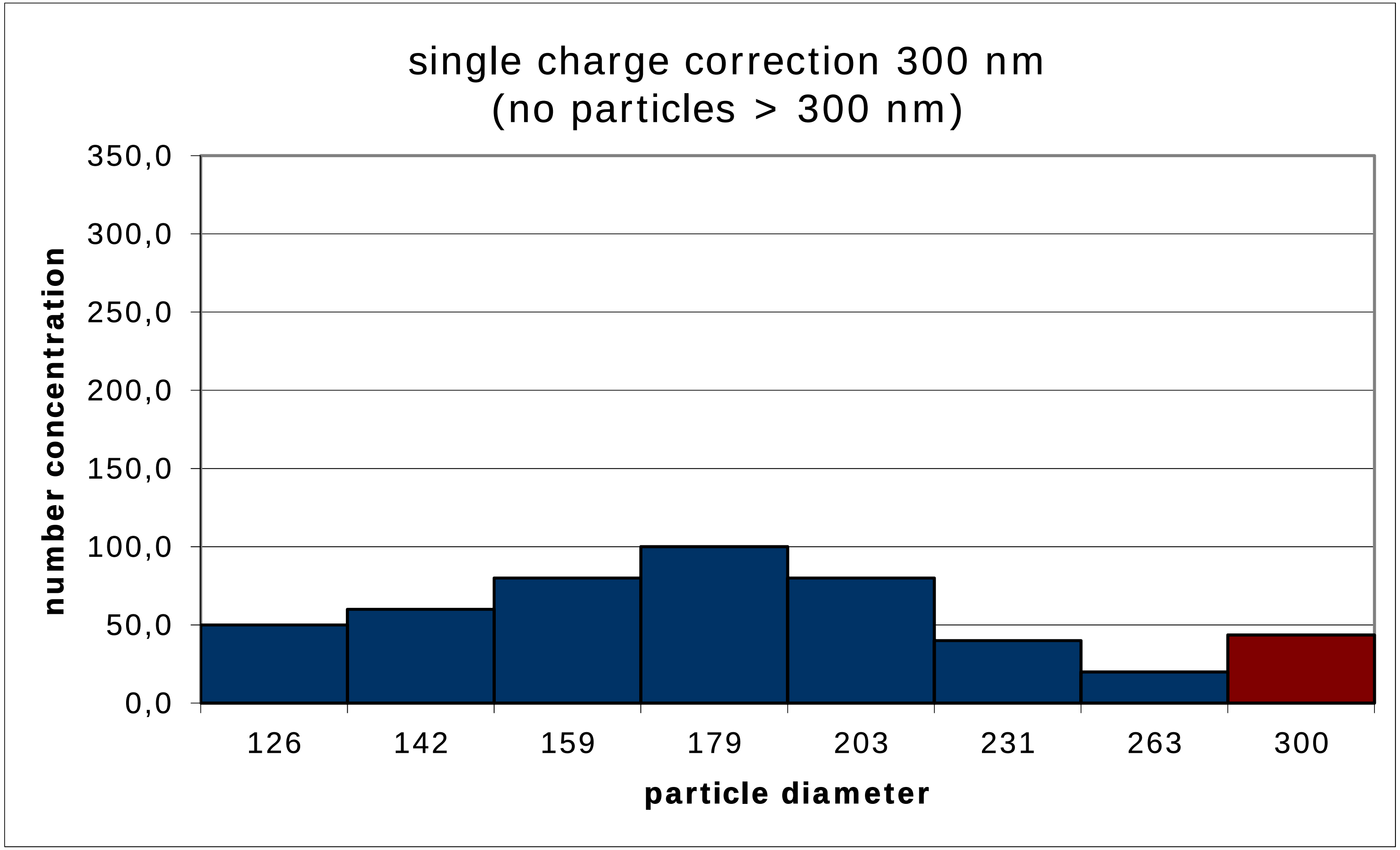
159	0,18%	1,97%	10,10%	27,69%	33,73%	21,35%	5,88%	0,89%	0,06%
142	0,10%	1,42%	9,00%	28,06%	35,75%	21,59%	5,20%	0,64%	0,03%
126	0,05%	0,95%	7,82%	28,24%	37,99%	21,69%	4,48%	0,43%	0,02%

Multiple Charge Correction: Step 1



Bipolar Charge Distribution (for this example)

Dp (nm)	-4	-3	-2	-1	0	1	2	3	4
300	1,96%	6,48%	14,50%	22,98%	24,06%	17,83%	8,78%	2,91%	0,67%
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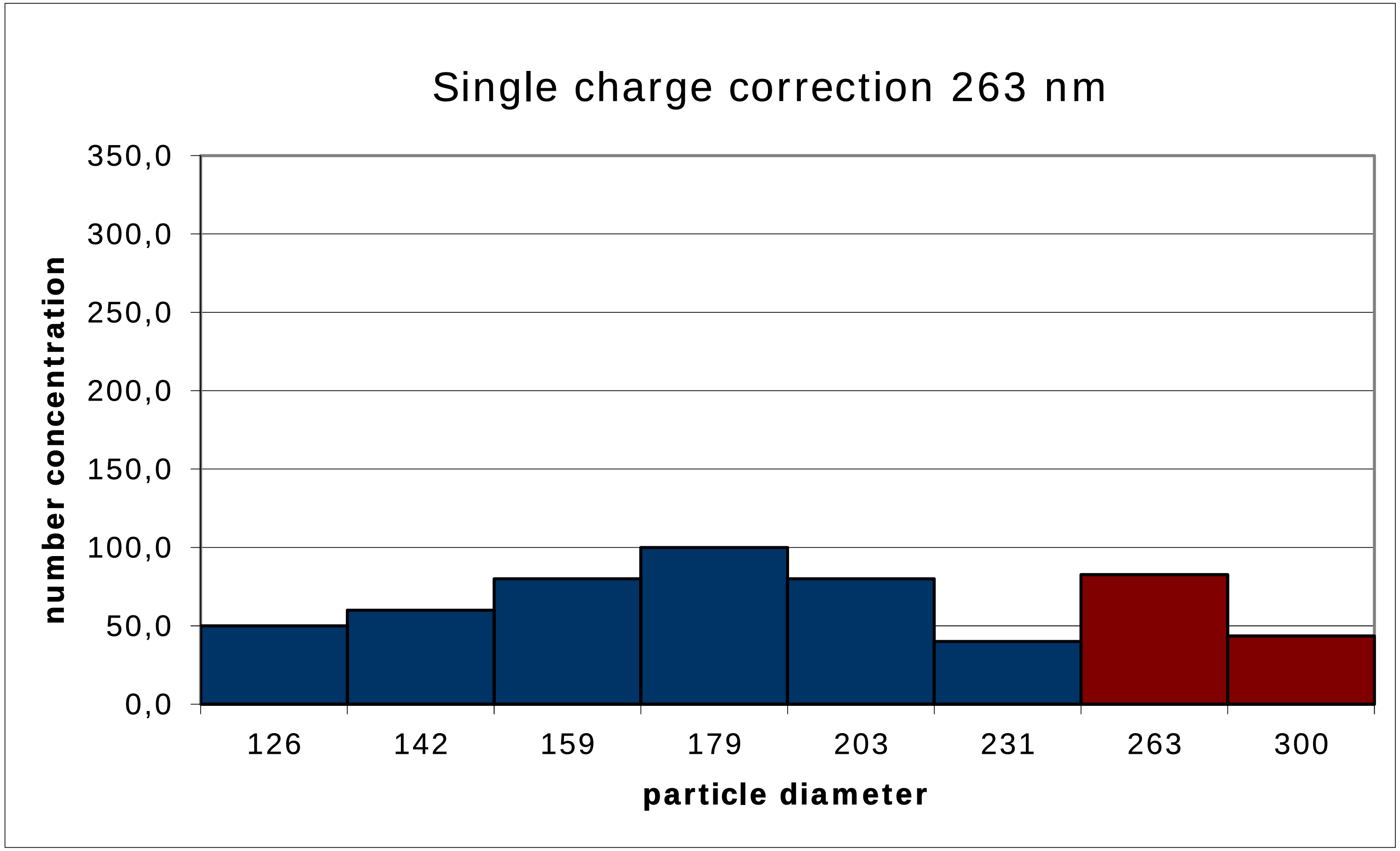
159	0,18%	1,97%	10,10%	27,69%	33,73%	21,35%	5,88%	0,89%	0,06%
142	0,10%	1,42%	9,00%	28,06%	35,75%	21,59%	5,20%	0,64%	0,03%
126	0,05%	0,95%	7,82%	28,24%	37,99%	21,69%	4,48%	0,43%	0,02%

Multiple Charge Correction: Step 2



Bipolar Charge Distribution (for this example)

Dp (nm)	-4	-3	-2	-1	0	1	2	3	4
300	1,96%	6,48%	14,50%	22,98%	24,06%	17,83%	8,78%	2,91%	0,67%
263	1,37%	5,46%	13,92%	24,20%	25,83%	18,77%	8,40%	2,45%	0,47%
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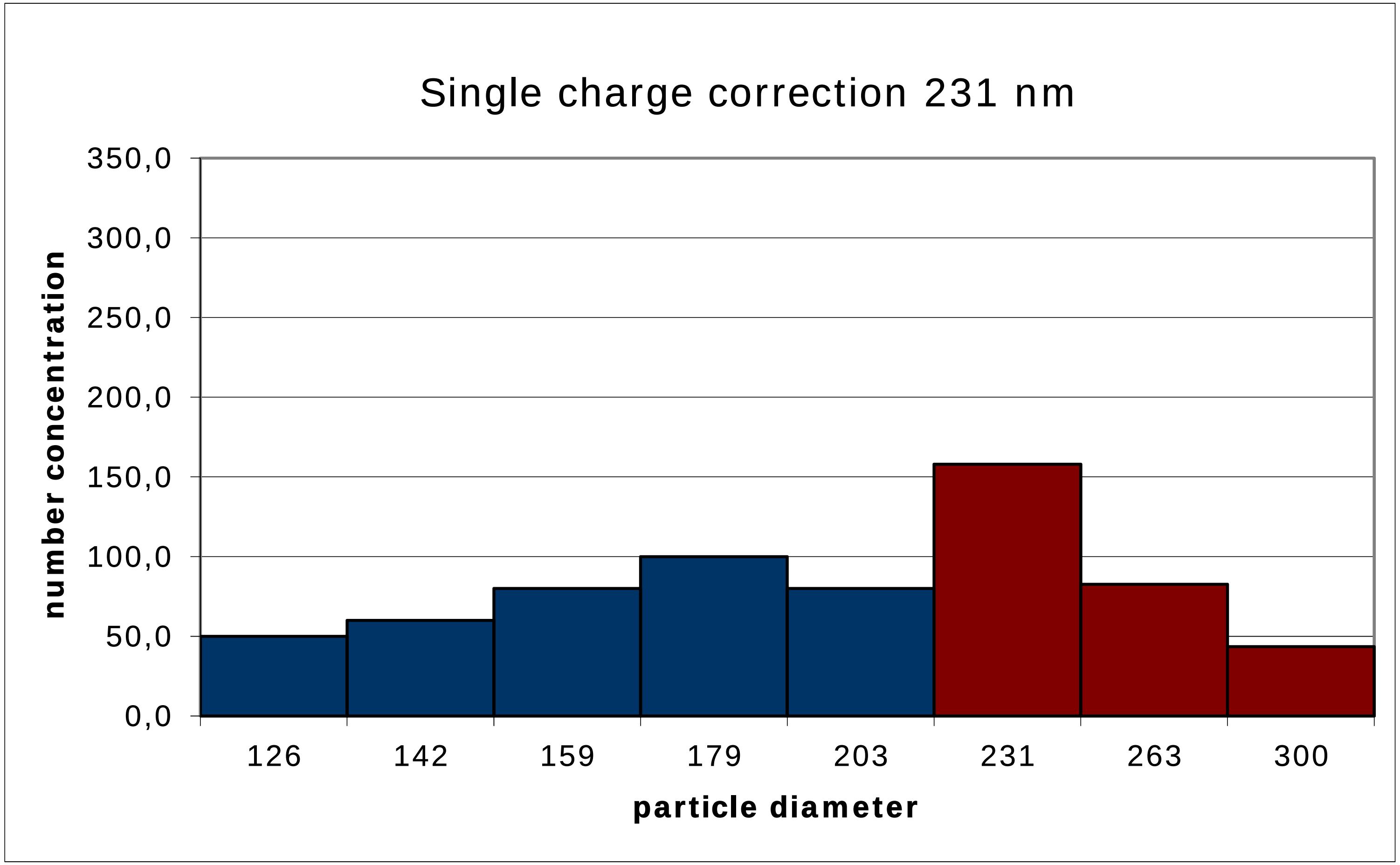
159	0,18%	1,97%	10,10%	27,69%	33,73%	21,35%	5,88%	0,89%	0,06%
142	0,10%	1,42%	9,00%	28,06%	35,75%	21,59%	5,20%	0,64%	0,03%
126	0,05%	0,95%	7,82%	28,24%	37,99%	21,69%	4,48%	0,43%	0,02%

Multiple Charge Correction: Step 3



Bipolar Charge Distribution (for this example)

Dp (nm)	-4	-3	-2	-1	0	1	2	3	4
300	1,96%	6,48%	14,50%	22,98%	24,06%	17,83%	8,78%	2,91%	0,67%
263	1,37%	5,46%	13,92%	24,20%	25,83%	18,77%	8,40%	2,45%	0,47%
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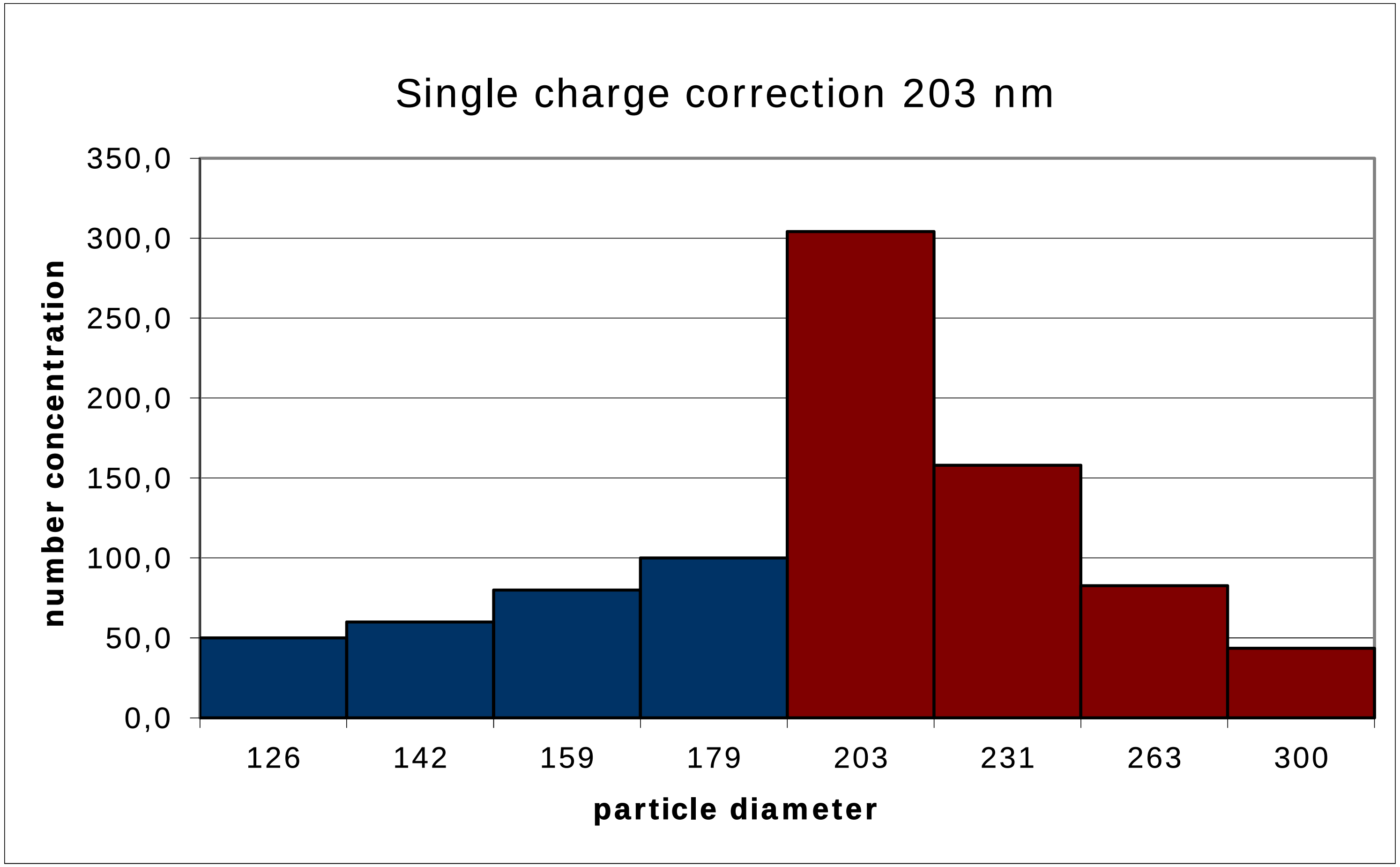
159	0,18%	1,97%	10,10%	27,69%	33,73%	21,35%	5,88%	0,89%	0,06%
142	0,10%	1,42%	9,00%	28,06%	35,75%	21,59%	5,20%	0,64%	0,03%
126	0,05%	0,95%	7,82%	28,24%	37,99%	21,69%	4,48%	0,43%	0,02%

Multiple Charge Correction: Step 4



Bipolar Charge Distribution (for this example)

Dp (nm)	-4	-3	-2	-1	0	1	2	3	4
300	1,96%	6,48%	14,50%	22,98%	24,06%	17,83%	8,78%	2,91%	0,67%
263	1,37%	5,46%	13,92%	24,20%	25,83%	18,77%	8,40%	2,45%	0,47%
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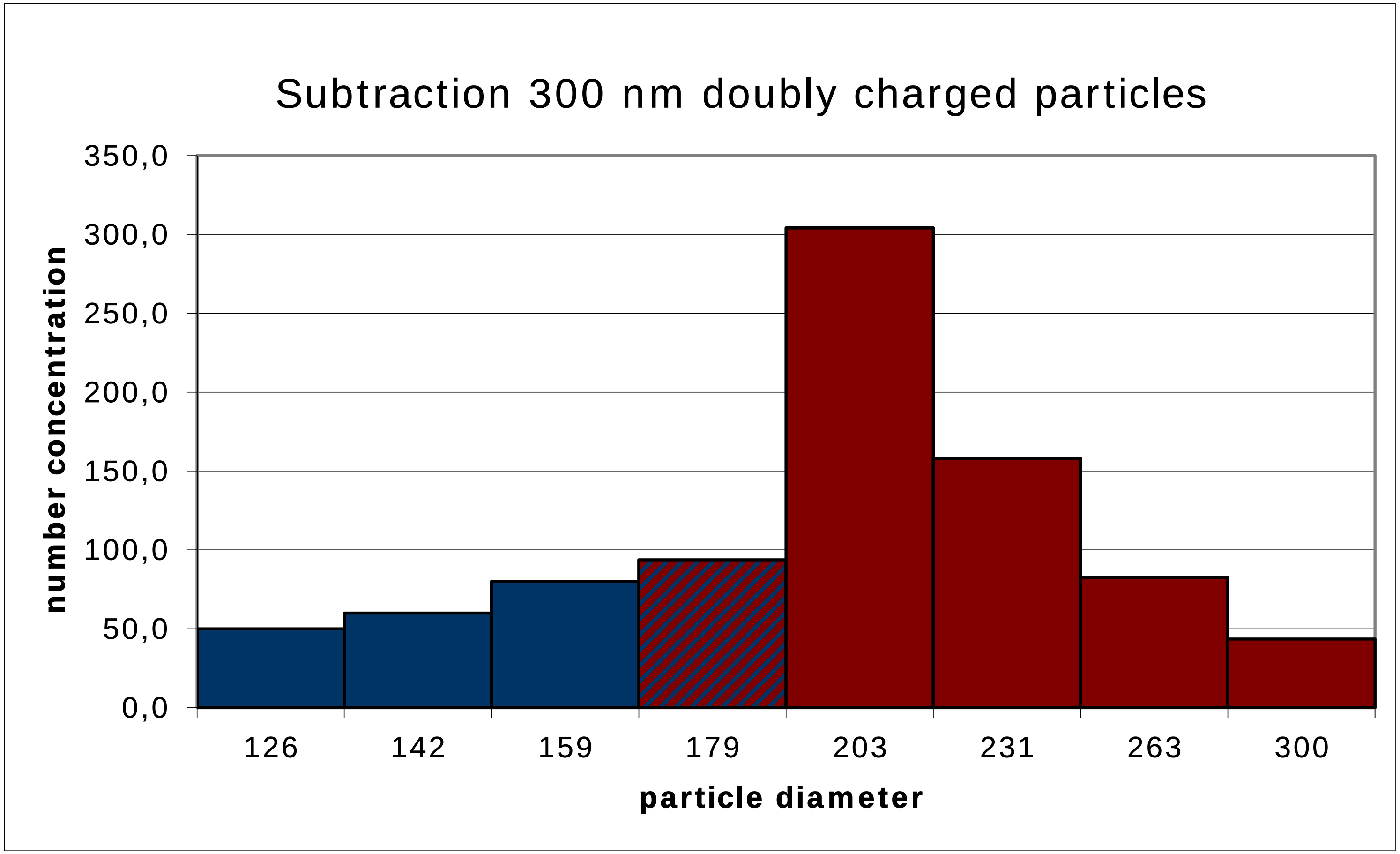
159	0,18%	1,97%	10,10%	27,69%	33,73%	21,35%	5,88%	0,89%	0,06%
142	0,10%	1,42%	9,00%	28,06%	35,75%	21,59%	5,20%	0,64%	0,03%
126	0,05%	0,95%	7,82%	28,24%	37,99%	21,69%	4,48%	0,43%	0,02%

Multiple Charge Correction: Step 5



Bipolar Charge Distribution (for this example)

Dp (nm)	-4	-3	-2	-1	0	1	2	3	4
300	1,96%	6,48%	14,50%	22,98%	24,06%	17,83%	8,78%	2,91%	0,67%
263	1,37%	5,46%	13,92%	24,20%	25,83%	18,77%	8,40%	2,45%	0,47%
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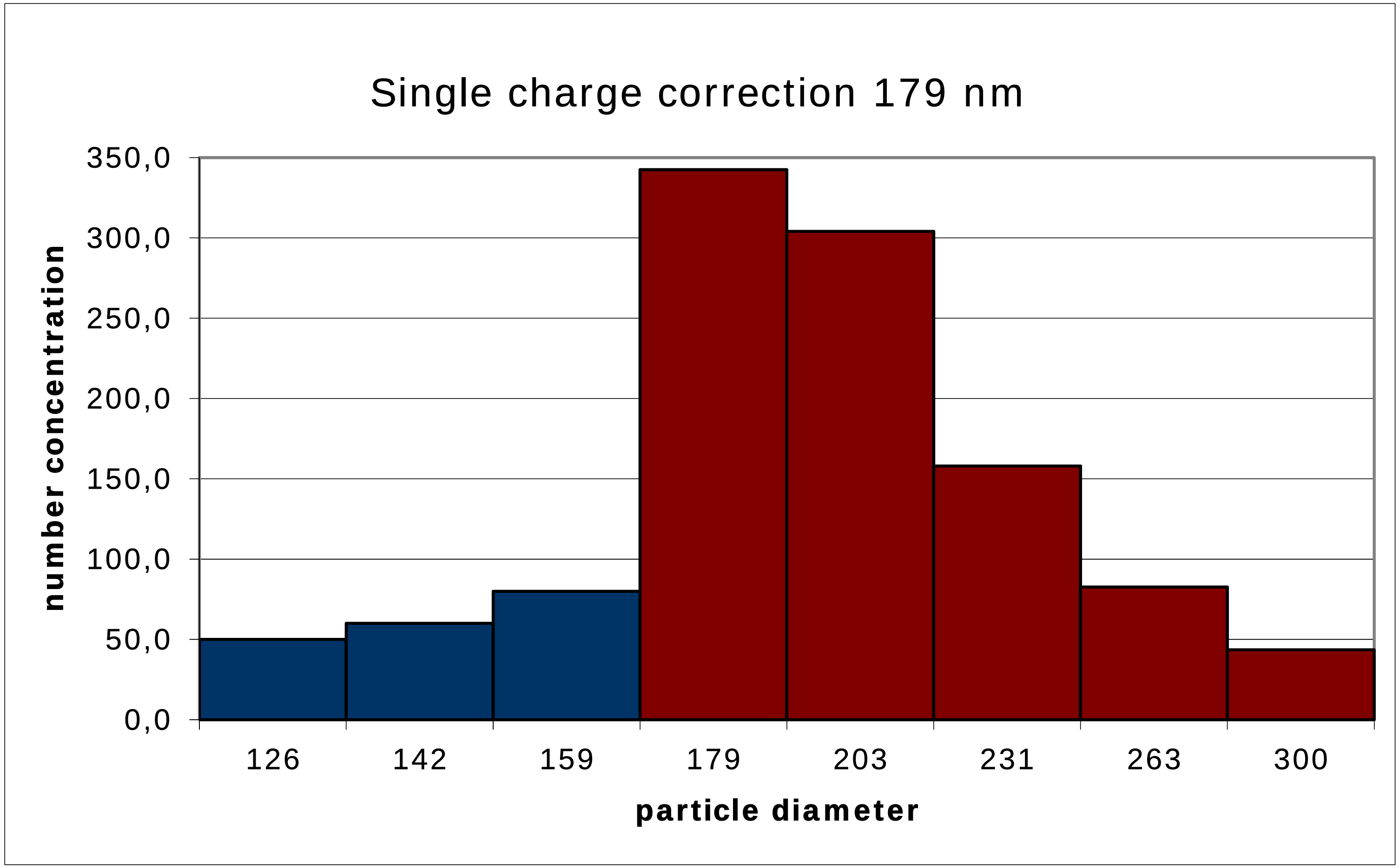
142	0,10%	1,42%	9,00%	28,06%	35,75%	21,59%	5,20%	0,64%	0,03%
126	0,05%	0,95%	7,82%	28,24%	37,99%	21,69%	4,48%	0,43%	0,02%

Multiple Charge Correction: Step 6



Bipolar Charge Distribution (for this example)

Dp (nm)	-4	-3	-2	-1	0	1	2	3	4
300	1,96%	6,48%	14,50%	22,98%	24,06%	17,83%	8,78%	2,91%	0,67%
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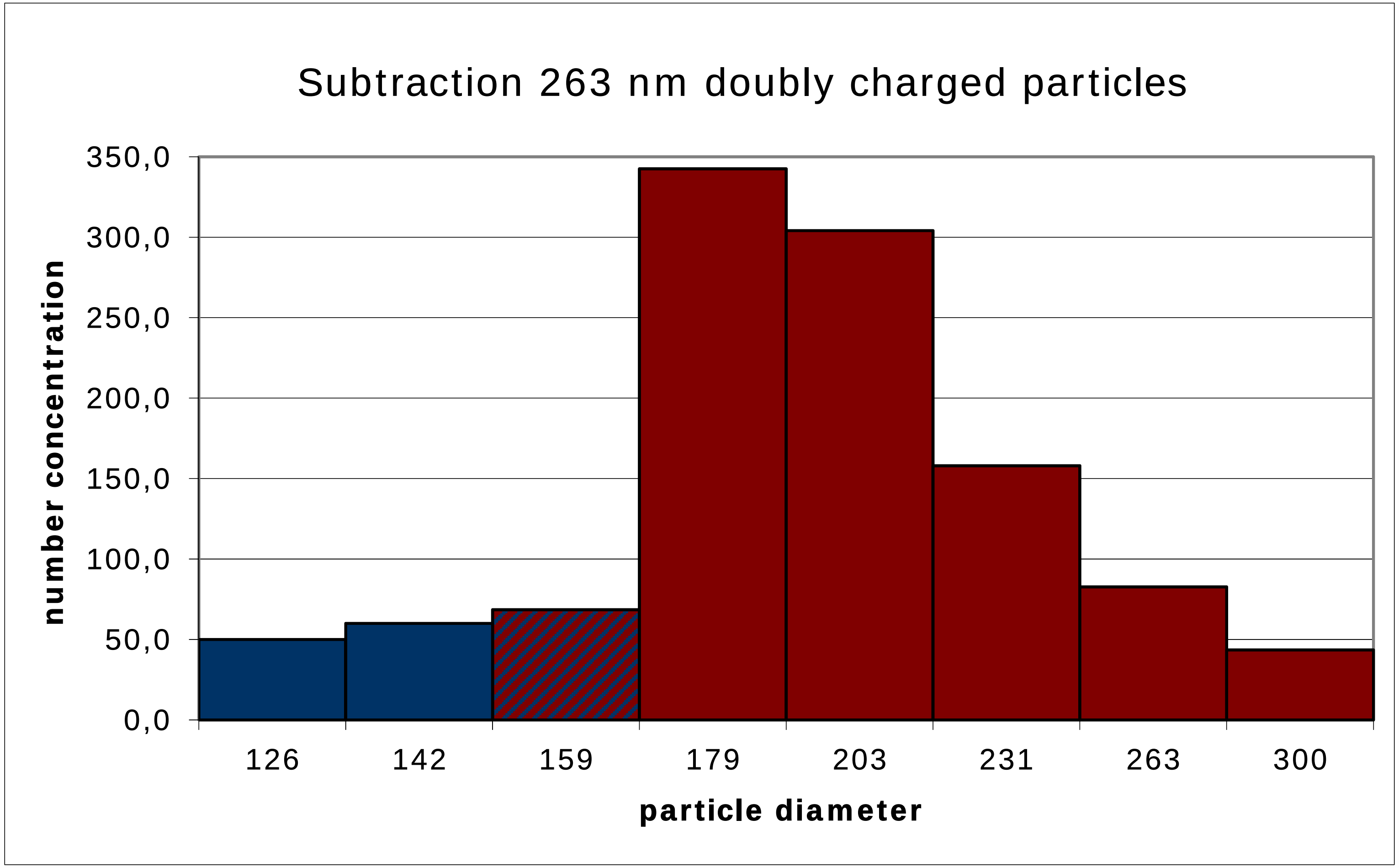
142	0,10%	1,42%	9,00%	28,06%	35,75%	21,59%	5,20%	0,64%	0,03%
126	0,05%	0,95%	7,82%	28,24%	37,99%	21,69%	4,48%	0,43%	0,02%

Multiple Charge Correction: Step 7



Bipolar Charge Distribution (for this example)

Dp (nm)	-4	-3	-2	-1	0	1	2	3	4
300	1,96%	6,48%	14,50%	22,98%	24,06%	17,83%	8,78%	2,91%	0,67%
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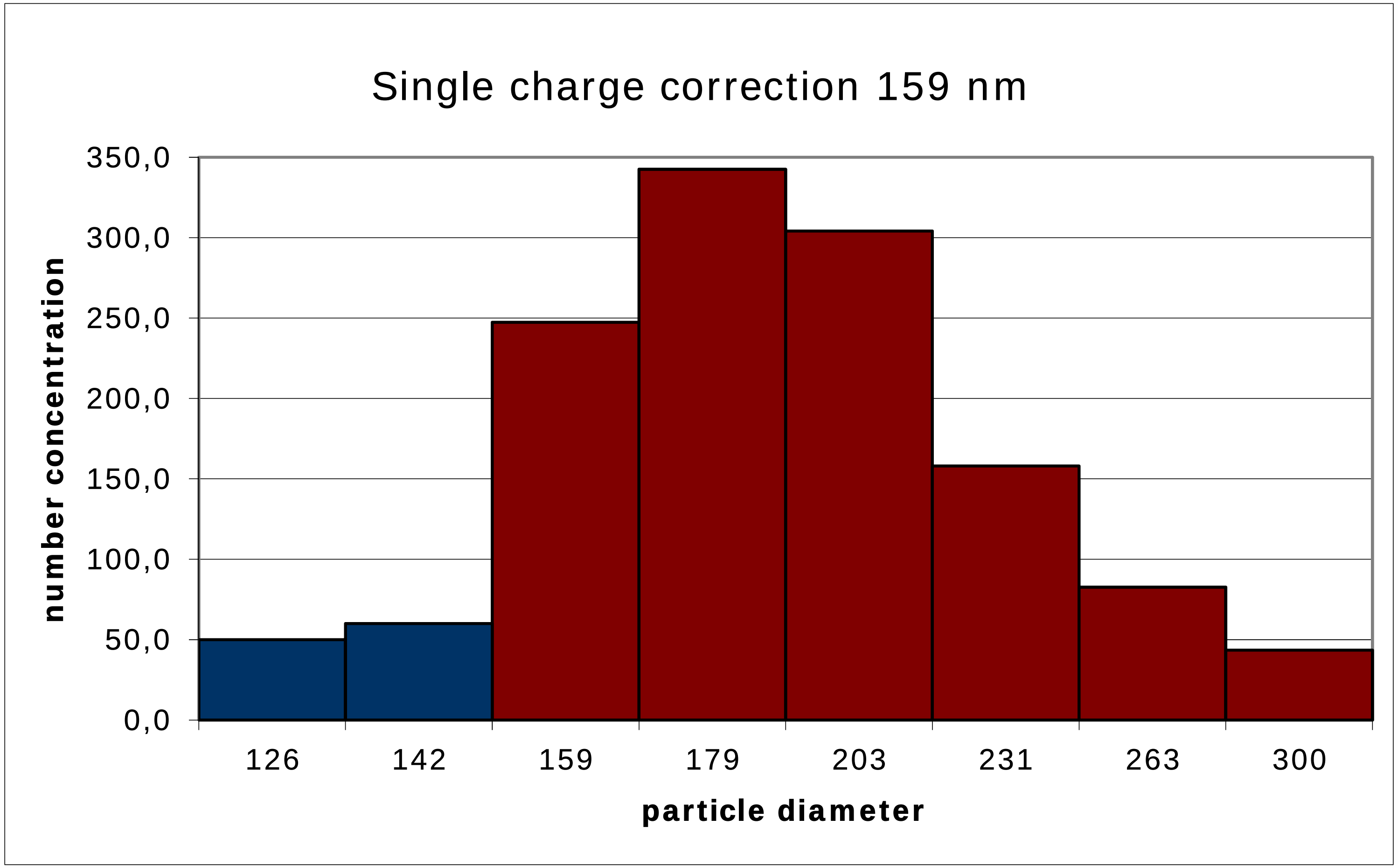
126	0,05%	0,95%	7,82%	28,24%	37,99%	21,69%	4,48%	0,43%	0,02%

Multiple Charge Correction: Step 8



Bipolar Charge Distribution (for this example)

Dp (nm)	-4	-3	-2	-1	0	1	2	3	4
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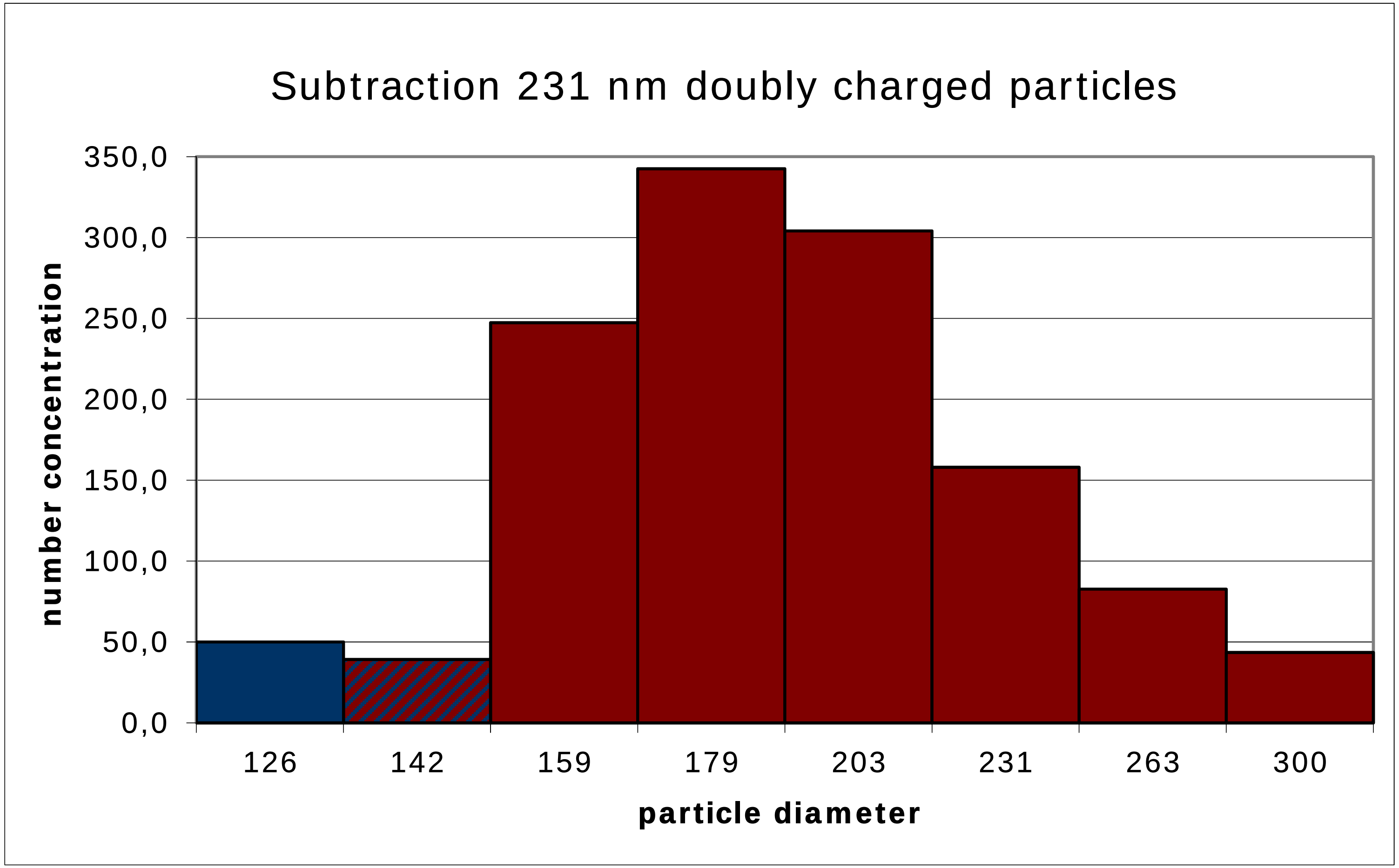
142	0,10%	1,42%	9,00%	28,06%	35,75%	21,59%	5,20%	0,64%	0,03%
126	0,05%	0,95%	7,82%	28,24%	37,99%	21,69%	4,48%	0,43%	0,02%

Multiple Charge Correction: Step 9



Bipolar Charge Distribution (for this example)

Dp (nm)	-4	-3	-2	-1	0	1	2	3	4
300	1,96%	6,48%	14,50%	22,98%	24,06%	17,83%	8,78%	2,91%	0,67%
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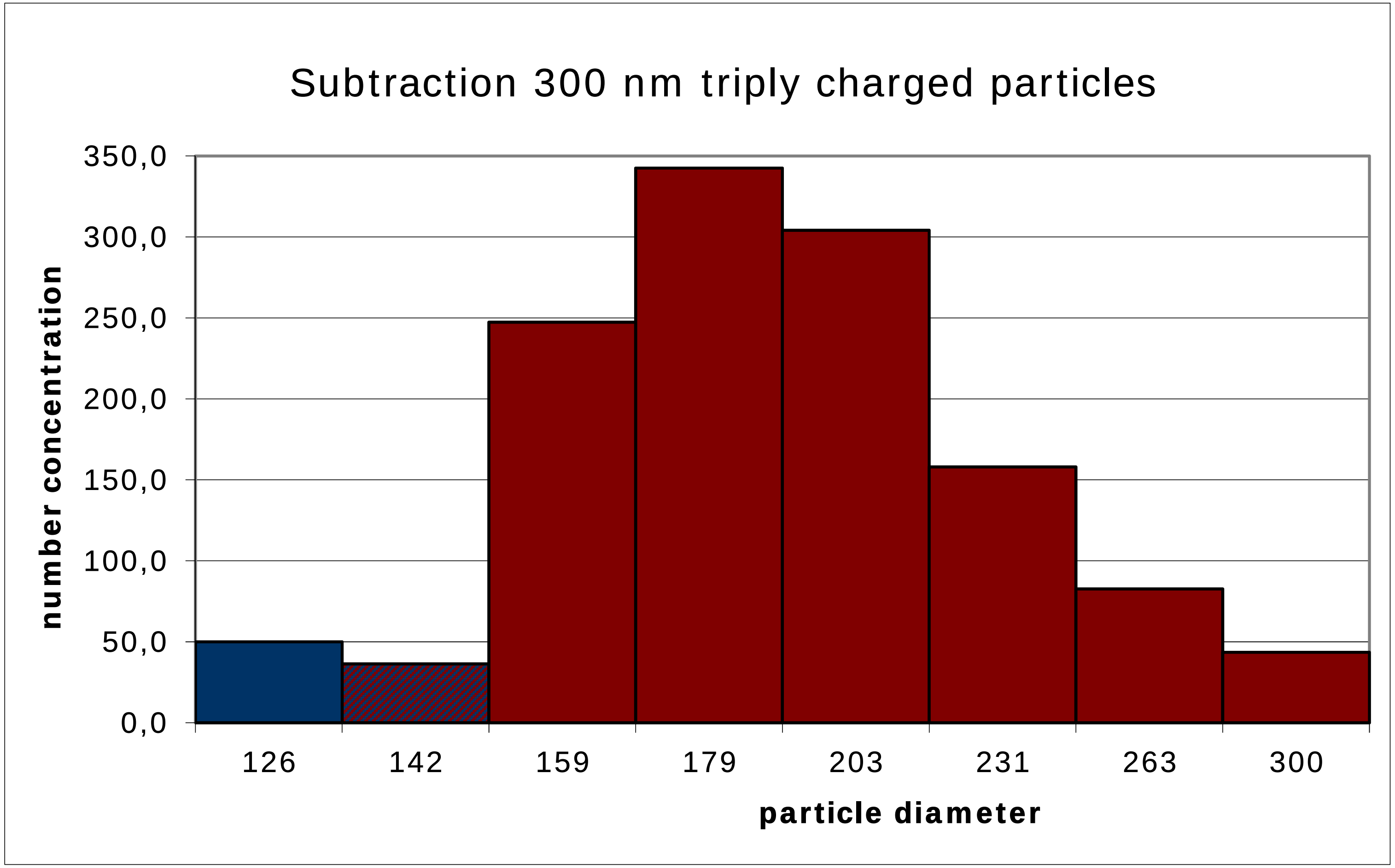
126	0,05%	0,95%	7,82%	28,24%	37,99%	21,69%	4,48%	0,43%	0,02%

Multiple Charge Correction: Step 10



Bipolar Charge Distribution (for this example)

Dp (nm)	-4	-3	-2	-1	0	1	2	3	4
300	1,96%	6,48%	14,50%	22,98%	24,06%	17,83%	8,78%	2,91%	0,67%
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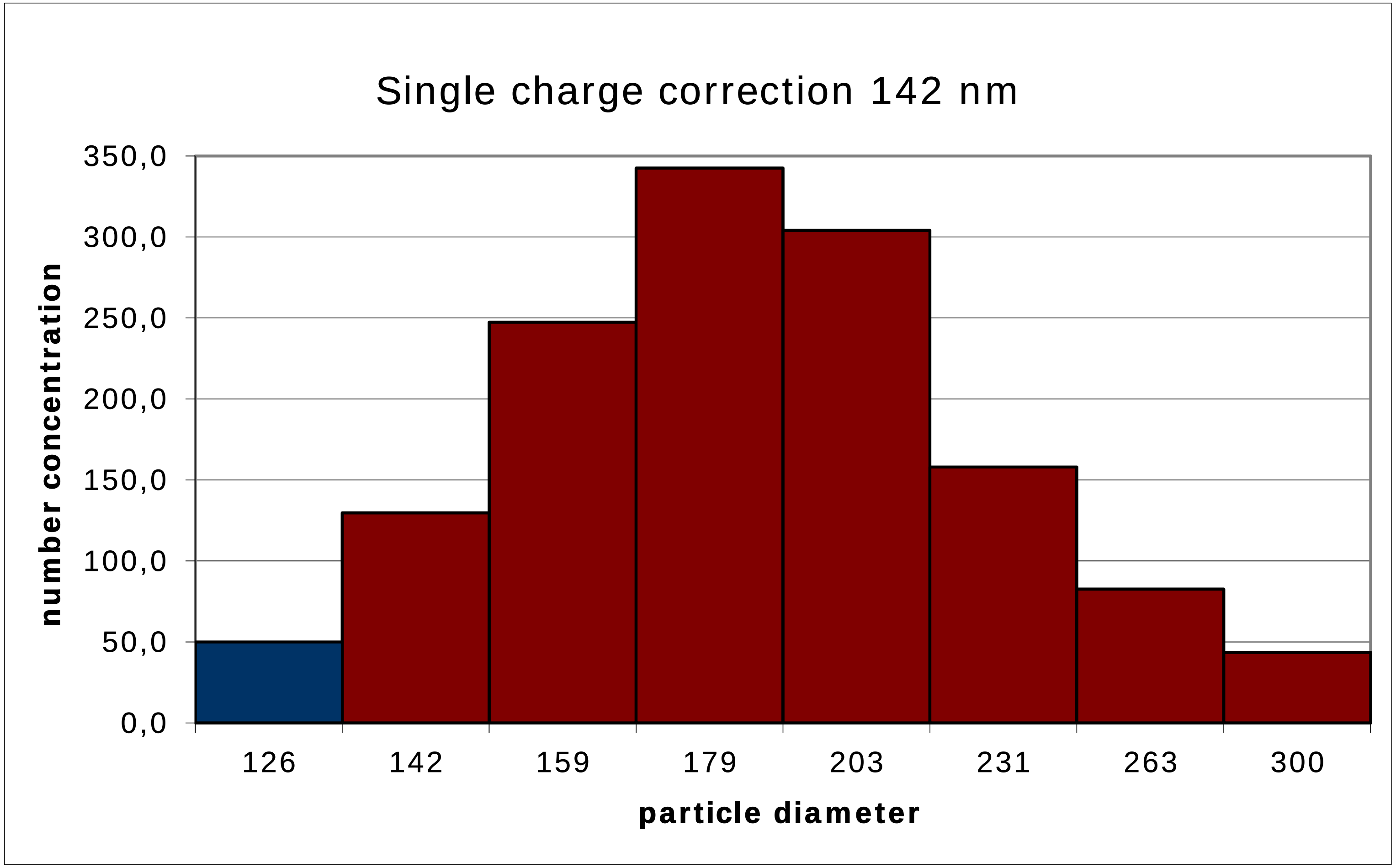
159	0,18%	1,97%	10,10%	27,69%	33,73%	21,35%	5,88%	0,89%	0,06%
142	0,10%	1,42%	9,00%	28,06%	35,75%	21,59%	5,20%	0,64%	0,03%
126	0,05%	0,95%	7,82%	28,24%	37,99%	21,69%	4,48%	0,43%	0,02%

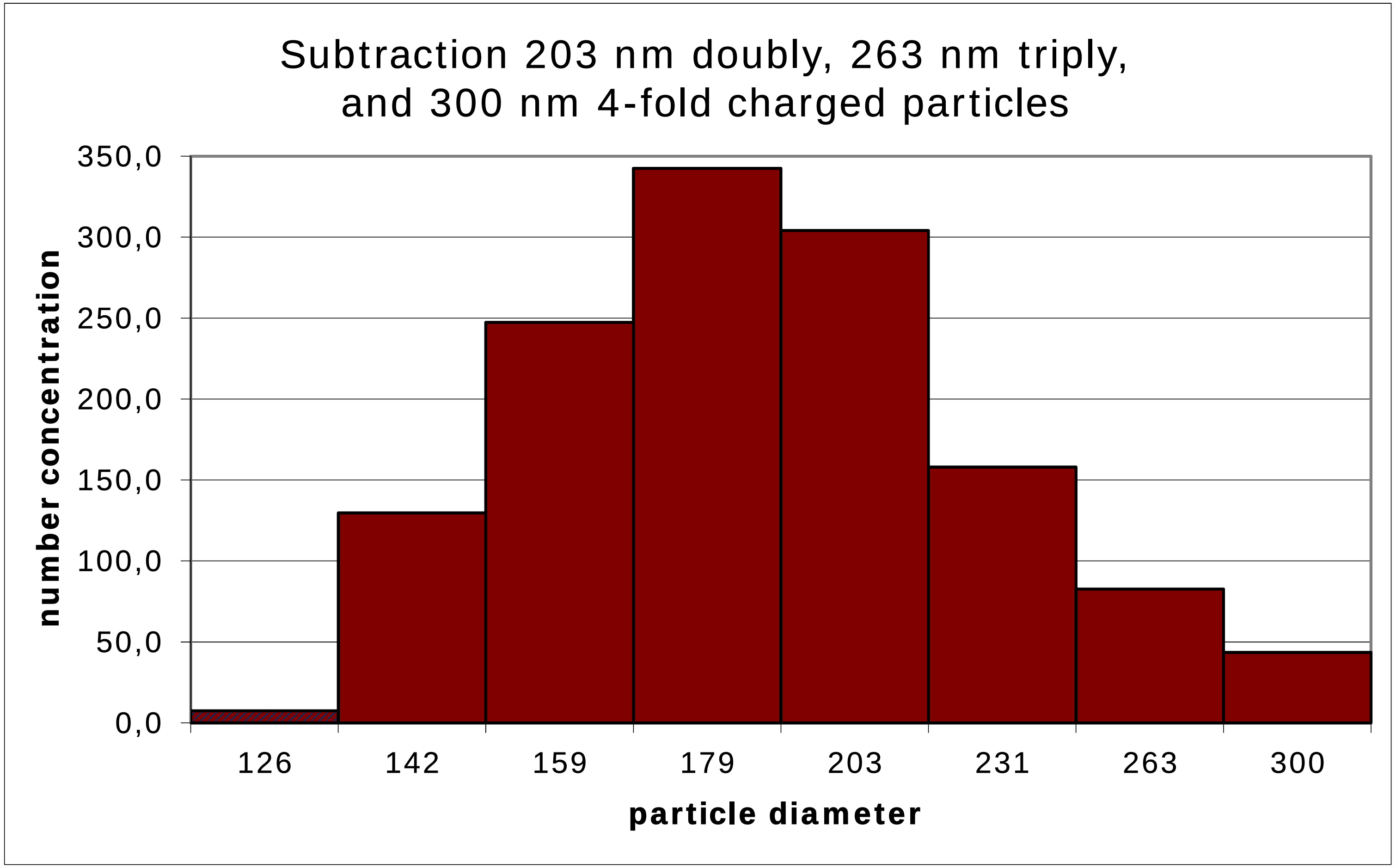
Multiple Charge Correction: Step 11



Bipolar Charge Distribution (for this example)

Dp (nm)	-4	-3	-2	-1	0	1	2	3	4
300	1,96%	6,48%	14,50%	22,98%	24,06%	17,83%	8,78%	2,91%	0,67%
263	1,37%	5,46%	13,92%	24,20%	25,83%	18,77%	8,40%	2,45%	0,47%
231	0,90%	4,45%	13,16%	25,32%	27,70%	19,61%	7,89%	2,00%	0,31%
203	0,56%	3,50%	12,23%	26,31%	29,67%	20,35%	7,26%	1,57%	0,19%
179	0,26%	2,38%	10,77%	27,35%	32,48%	21,11%	6,31%	1,07%	0,09%
159	0,18%	1,97%	10,10%	27,69%	33,73%	21,35%	5,88%	0,89%	0,06%
142	0,10%	1,42%	9,00%	28,06%	35,75%	21,59%	5,20%	0,64%	0,03%
126	0,05%	0,95%	7,82%	28,24%	37,99%	21,69%	4,48%	0,43%	0,02%

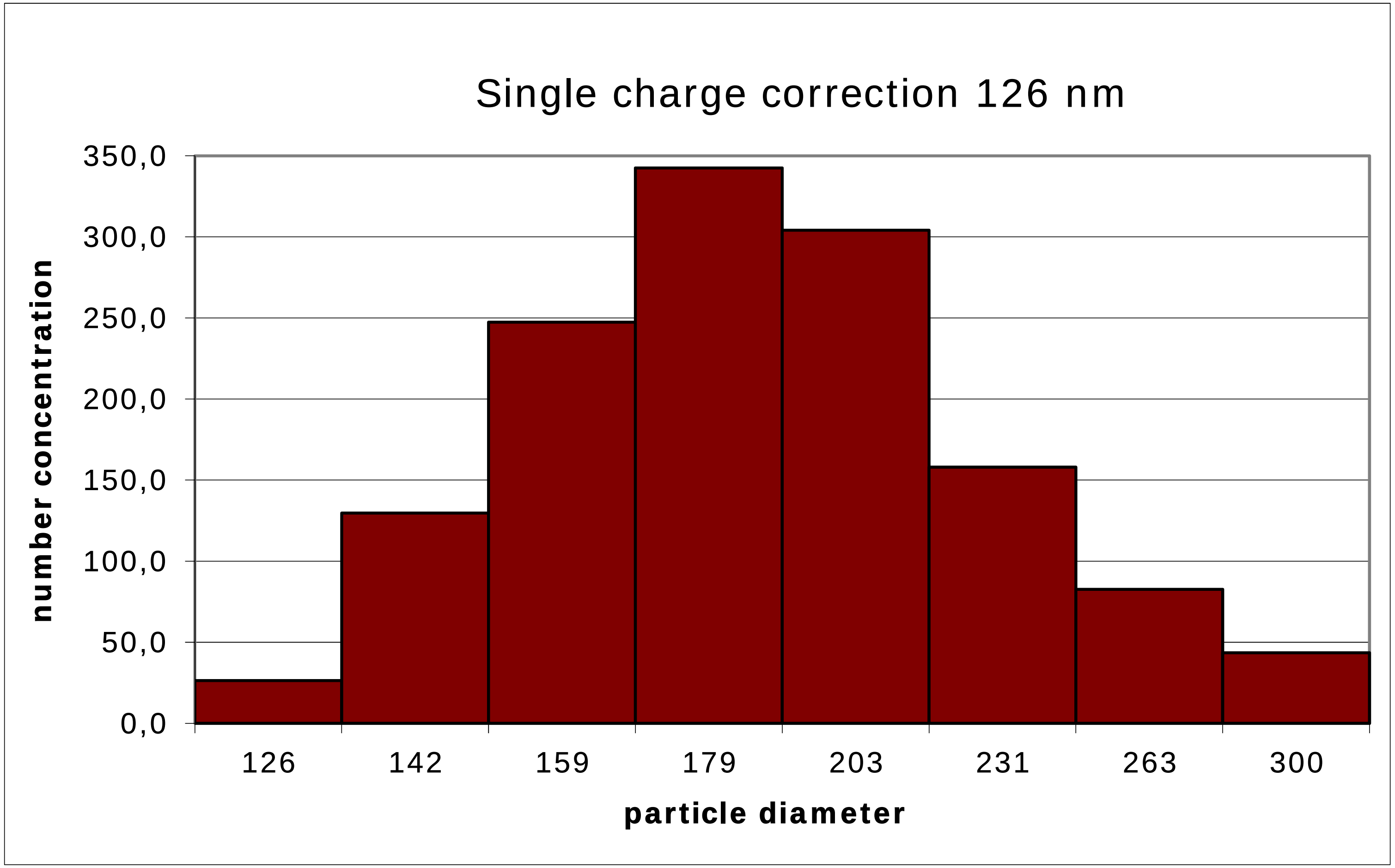
Multiple Charge Correction: Step 12



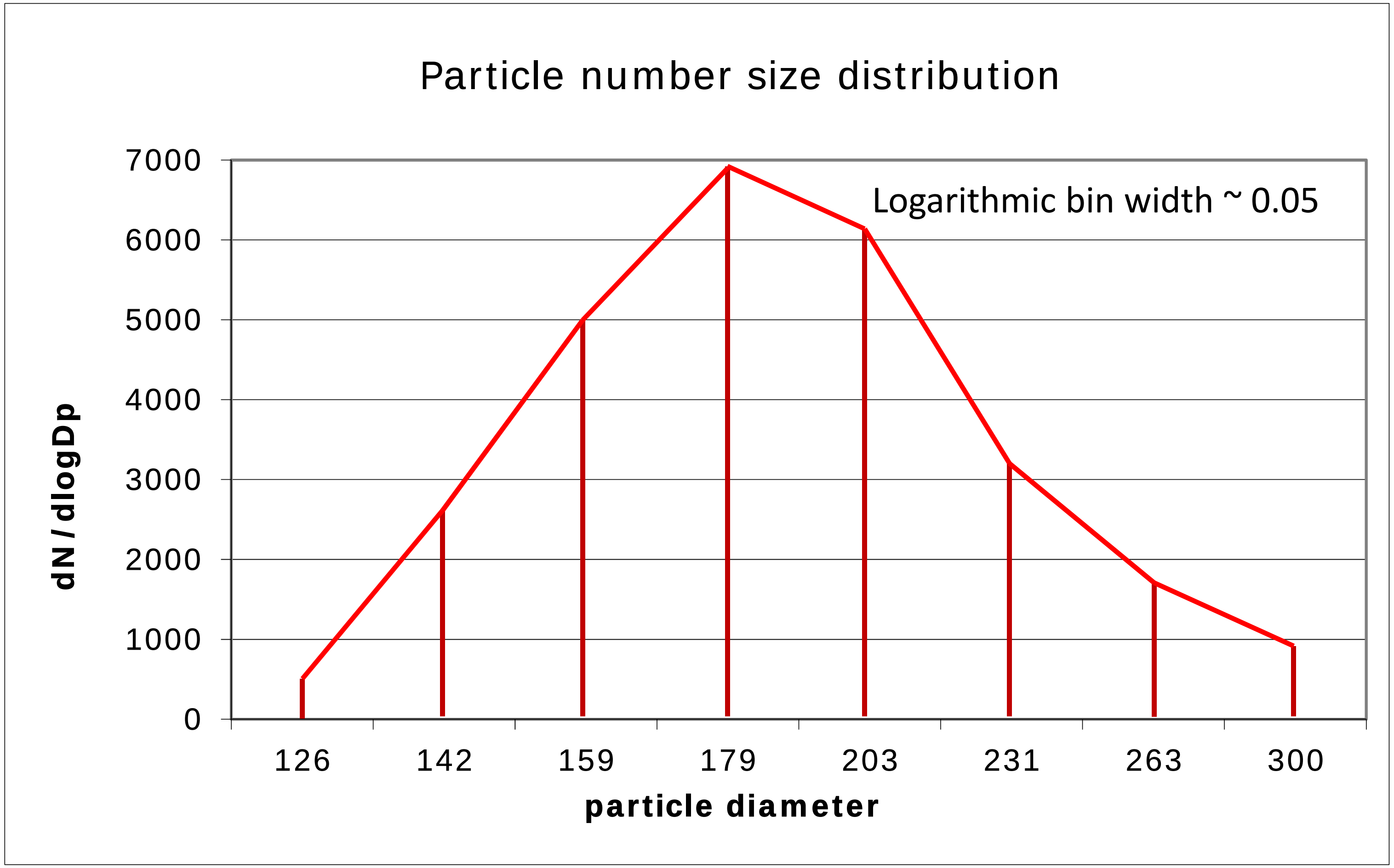
Bipolar Charge Distribution (for this example)

Dp (nm)	-4	-3	-2	-1	0	1	2	3	4
300	1,96%	6,48%	14,50%	22,98%	24,06%	17,83%	8,78%	2,91%	0,67%
263	1,37%	5,46%	13,92%	24,20%	25,83%	18,77%	8,40%	2,45%	0,47%
231	0,90%	4,45%	13,16%	25,32%	27,70%	19,61%	7,89%	2,00%	0,31%
203	0,56%	3,50%	12,23%	26,31%	29,67%	20,35%	7,26%	1,57%	0,19%
179	0,26%	2,38%	10,77%	27,35%	32,48%	21,11%	6,31%	1,07%	0,09%
159	0,18%	1,97%	10,10%	27,69%	33,73%	21,35%	5,88%	0,89%	0,06%
142	0,10%	1,42%	9,00%	28,06%	35,75%	21,59%	5,20%	0,64%	0,03%
126	0,05%	0,95%	7,82%	28,24%	37,99%	21,69%	4,48%	0,43%	0,02%

Multiple Charge Correction: Step 12



Normalization to logarithmic bin width



Mobility Particle Size Spectrometer

Data Handling

MPSS - Data Correction

After the multiple charge correction, the calculated particle number size distribution has to be corrected for:

- The CPC counting efficiency curve
- Internal losses due to particle diffusion
- Losses due to diffusion in the inlet and sampling tubes

The internal losses can be calculated by the method of the “equivalent pipe length”.

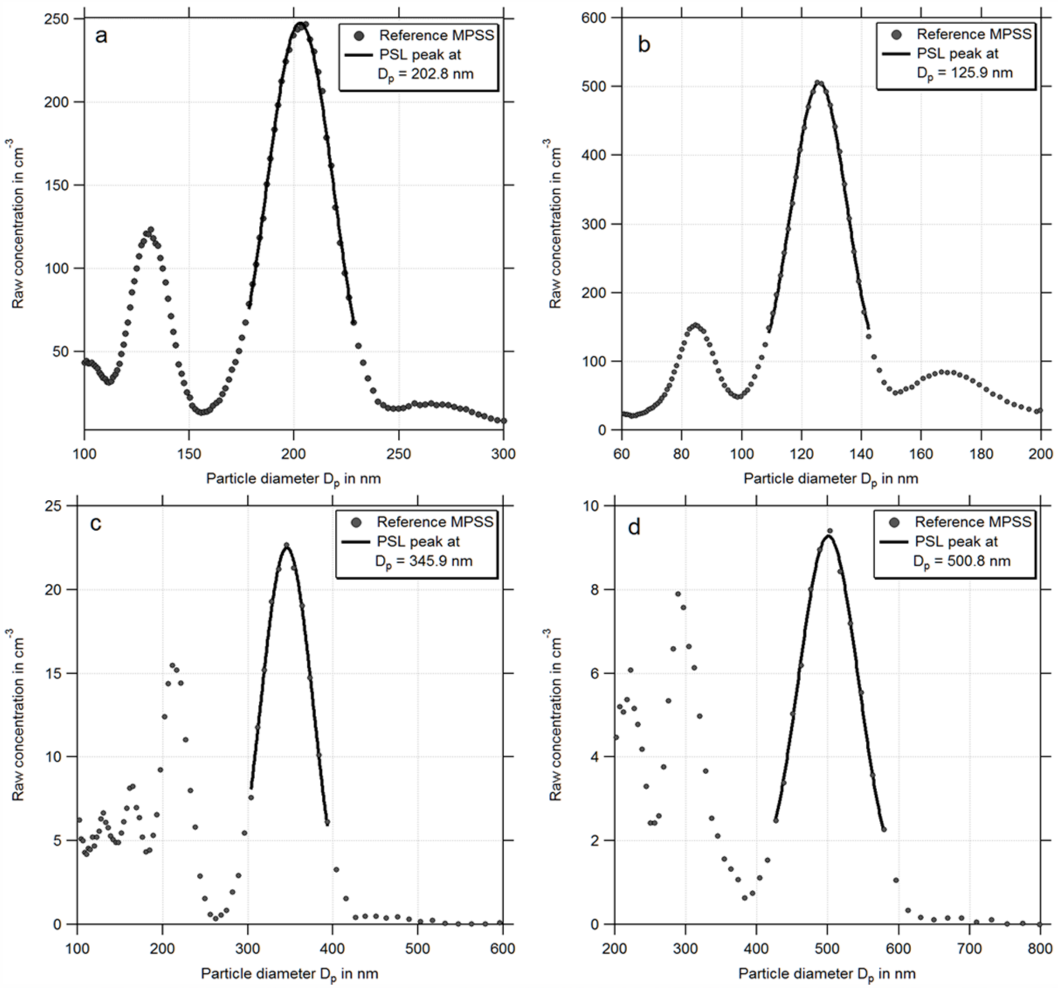
Wiedensohler et al. (2012). Mobility Particle Size Spectrometers: Harmonization of Technical Standards and Data Structure to Facilitate High Quality Long-term Observations of Atmospheric Particle Number Size Distributions. AMT 5, 657–685.

Method of the Equivalent Length

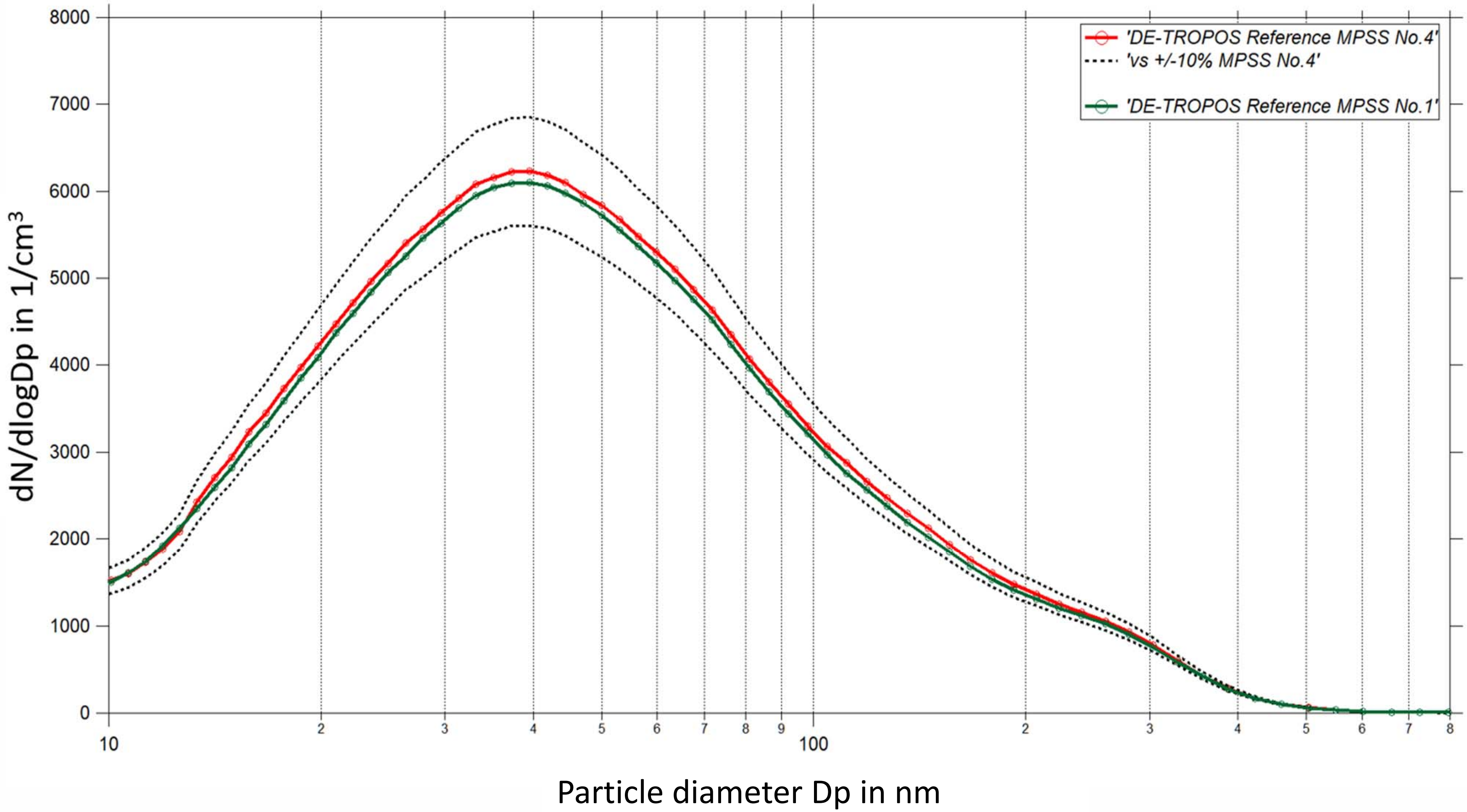
Instruments or parts	Equivalent length	
Hauke-type medium-DMA (28 cm effective length)	4.6m	Karlsson and Martinsson (2003)
Hauke-type short-DMA (11 cm effective length)	4.6m	TROPOS internal calibration
TSI long-DMA (444mm effective length)	7.1m	Karlsson and Martinsson(2003)
TSI nano-DMA (49.9mm effective length)	3.64m	Jiang et al. (2011)
Permapure Nafion dryer SS2400	2.5m	Dick et al. (1995)
Permapure Nafion dryer SS1200	1.25m	Dick et al. (1995)
Diffusion dryer (e.g. TOPAS)	5m	estimated from Tuch et al. (2009)
90 bend (less than 5 cm radius)	0.15m	estimated from Wang et al. (2002)
Bipolar diffusion charger (TROPOS custom-made)	1m	Covert et al. (1997)

MPSS - Reference Instrument & Calibration

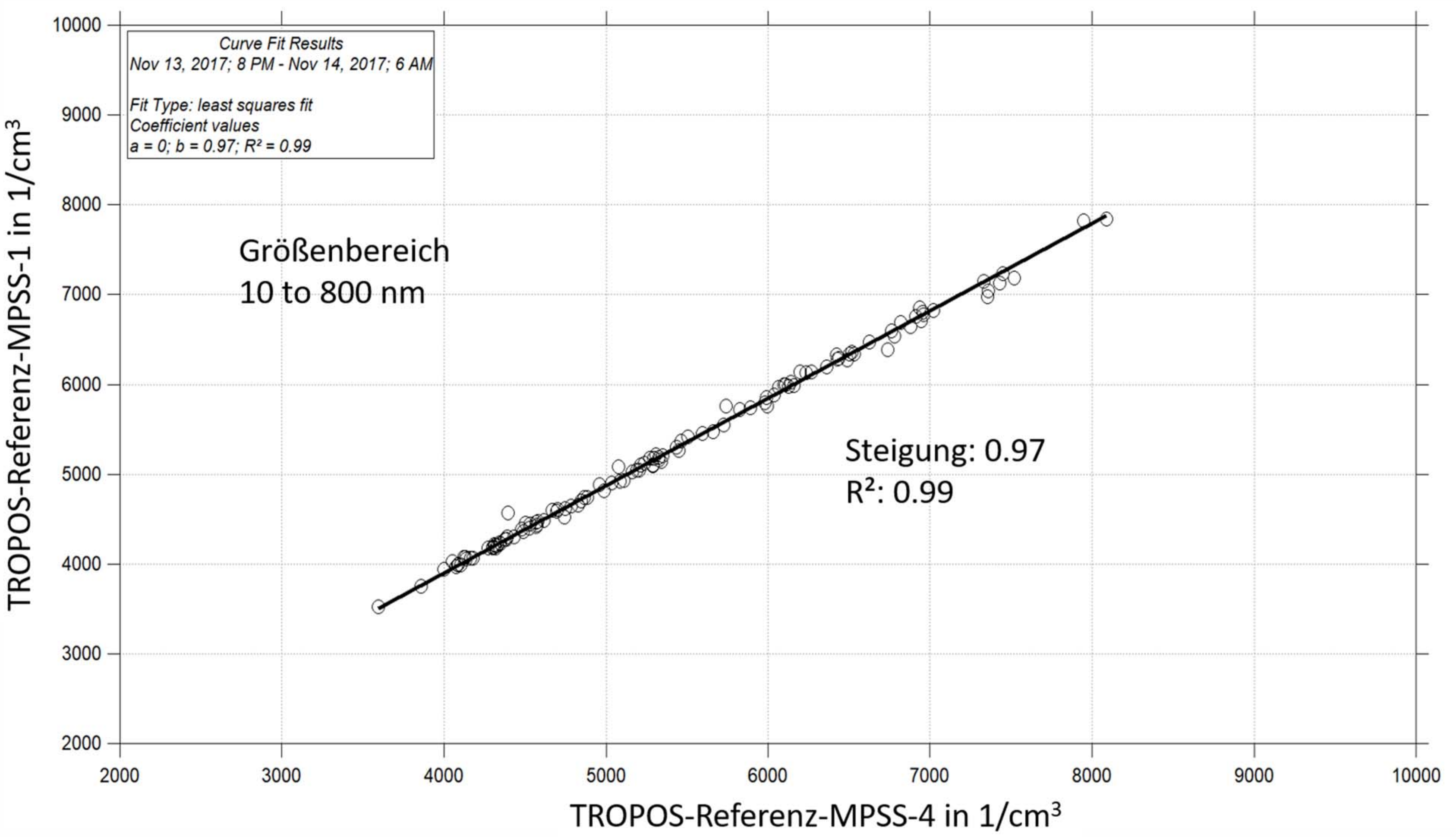
MPSS – Size Calibration Using PSL-Spheres



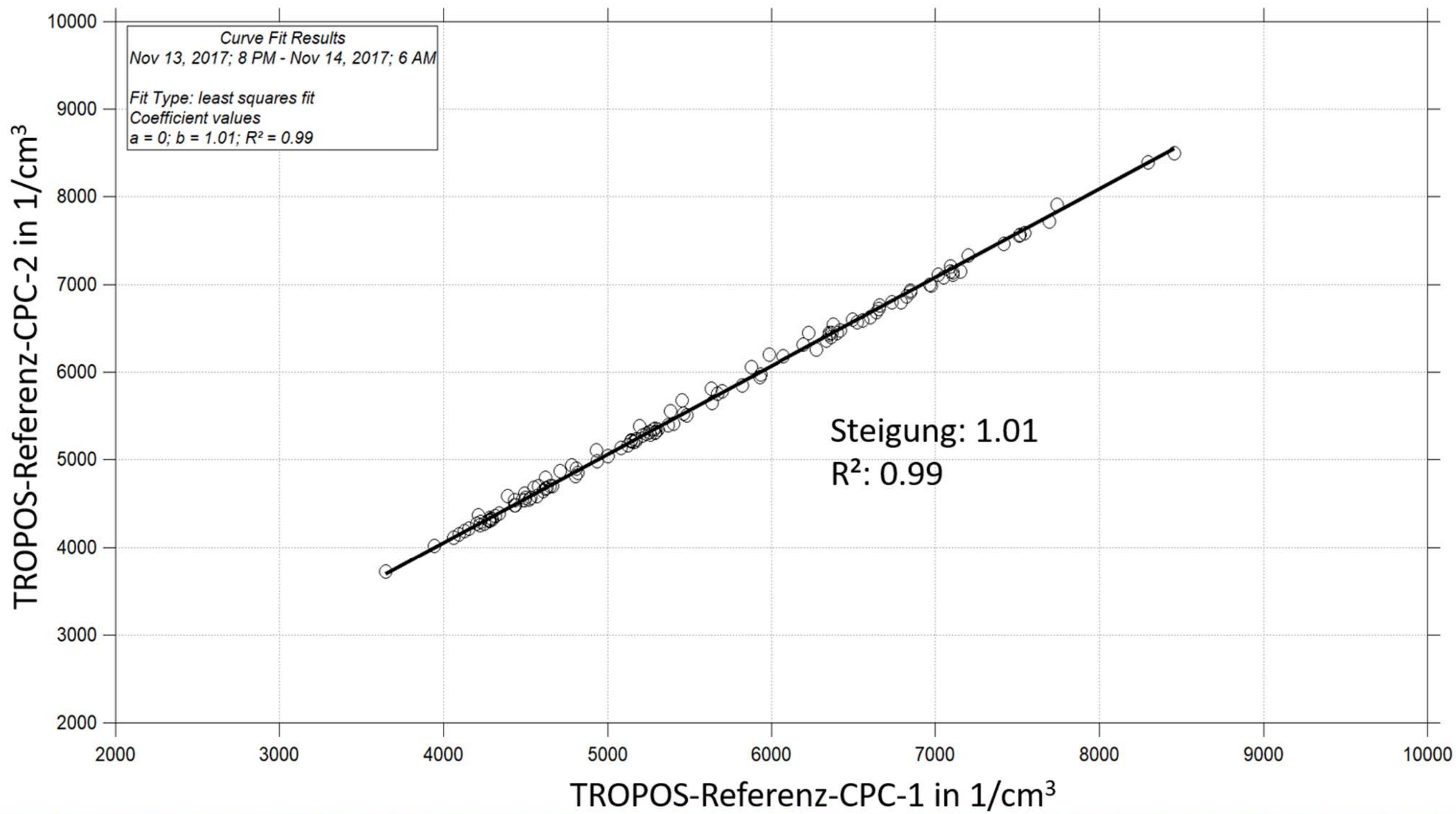
Reference MPSS: Comparability



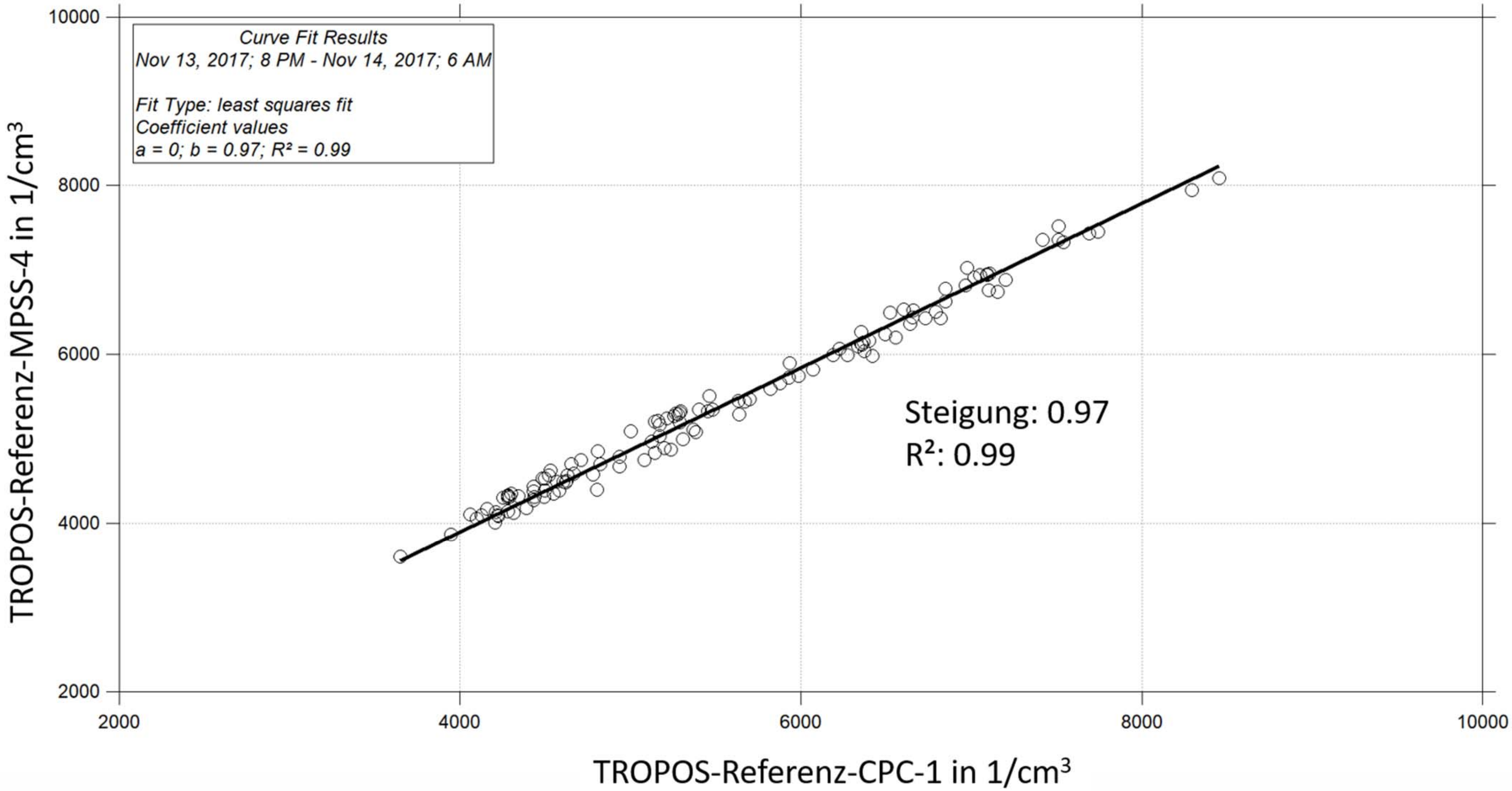
Reference MPSS: Comparability



Reference CPCs: Comparability



Reference CPC vs MPSS



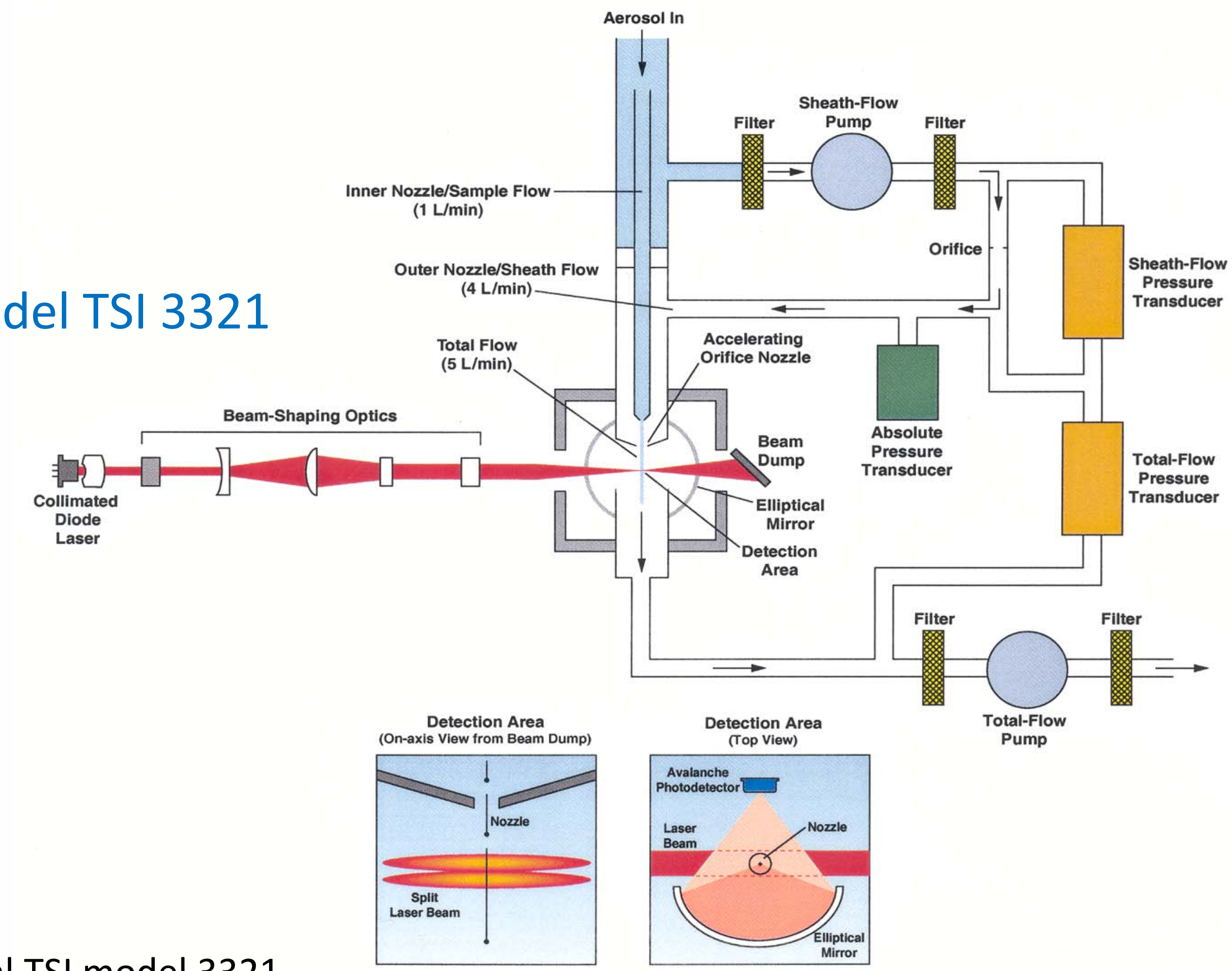
Aerodynamic Particle Size Spectrometer

Aerodynamic Particle Number Size Distribution

- The aerodynamic particle diameter is defined as the „diameter of a spherical particle with the density of One with the same sedimentation velocity of the measured particle“.
- Aerodynamic Particle Size Spectrometer can measure the aerodynamic particle diameter.
- Aerodynamic Particle Size Spectrometer determines the aerodynamic particle number size distribution.
- In comparison, a cascade impactor measures the aerodynamic particle mass size distribution with a limited size resolution.

Principle Aerodynamic Particle Size Spectrometer

Model TSI 3321

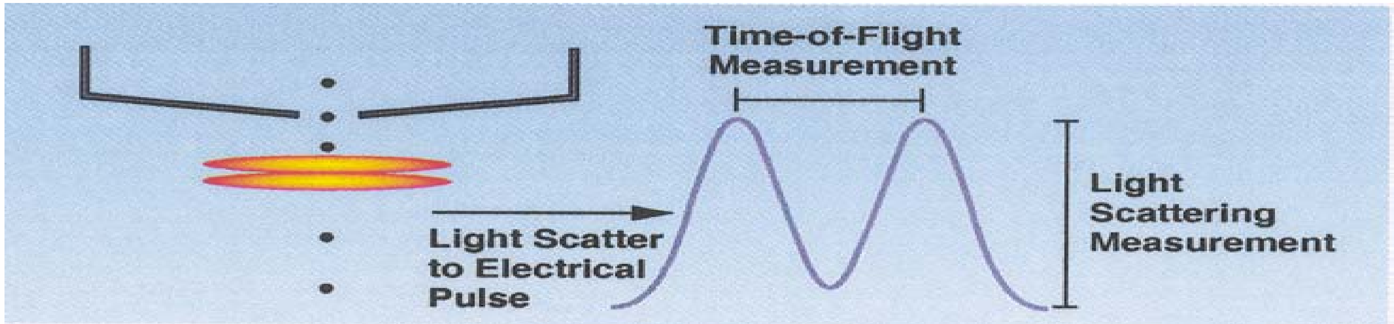


All figures: APS manual TSI model 3321

Acceleration Nozzle

- The acceleration nozzle consists of an inner and outer nozzle.
- The inner nozzle focuses the aerosol flow. The aerosol flow is then surrounded by the sheath air flow.
- The entire flow is then accelerated through the outer nozzle.
- The total flow rate of 5 l/min consists of 1 l/min aerosol flow and 4 l/min particle-free sheath air.
- The velocity of the aerosol flow in the center is assumed to be constant.
- Due to inertia, particles with a large aerodynamic diameter cannot follow the acceleration. (different relaxation times)
- This means that particle with different aerodynamic diameters have different velocities directly behind the nozzle.

Laser Anemometer



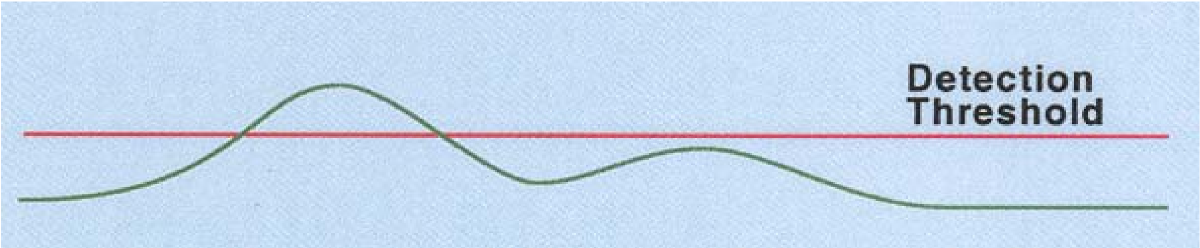
- The laser anemometer measures the time-of-flight between two laser beams.
- The laser beams are positioned directly behind the outer nozzle.
- Particles passing the laser beams emit two light pulses.
- The time difference between the two pulse maxima is the time-of-flight.
- The time-of-flight is a measure for the aerodynamic particle diameter.
- The relation between time-of-flight and aerodynamic particle size must be calibrated for each device.

Coincidence

- Particle coincidence occurs when two or more particles are in the measuring volume at the same time.
- The leads to an incorrect classification of the particles.
- The higher the particle number concentration, the higher is the risk of coincidence.
- In the APS 3331, coincidence cases are excluded from the size distribution measurement (Event 3).

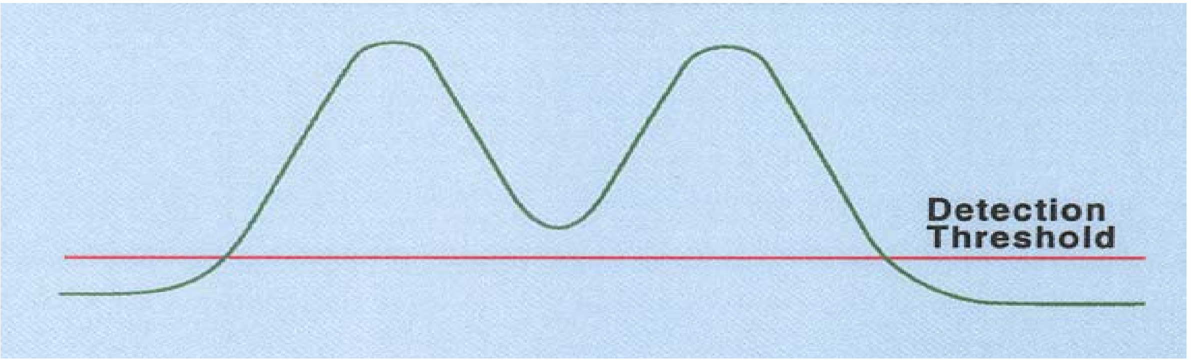
Particle Classification and Error Correction

Event 1:



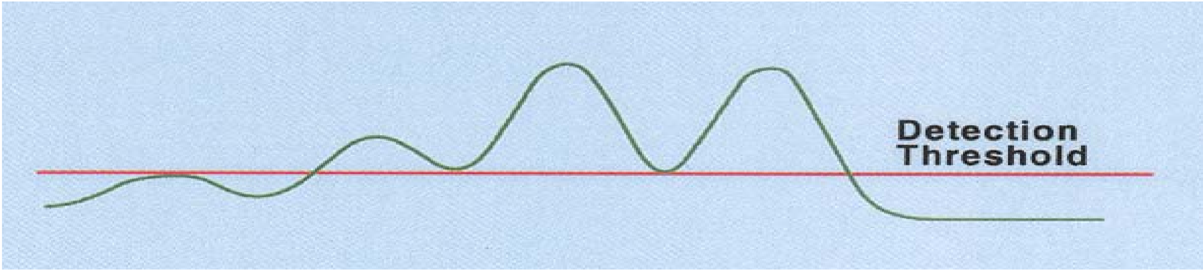
Event 1 occurs when the signal of a small particle is below a certain threshold. The particle is put into the lowest size class < 0,523 µm.

Event 2:



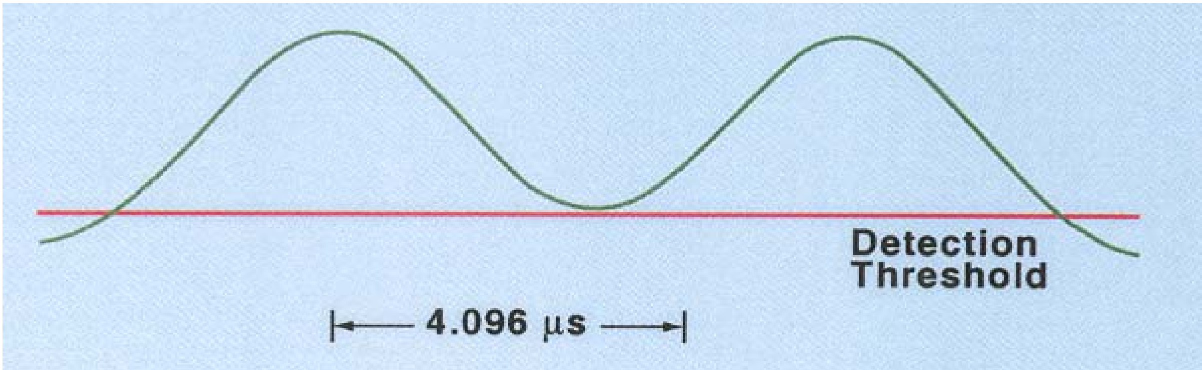
Event 2 is a valid measurement. The particle is classified.

Event 3:



Event 3 occurs due to coincidence. The particle is not classified, however, added to the total concentration.

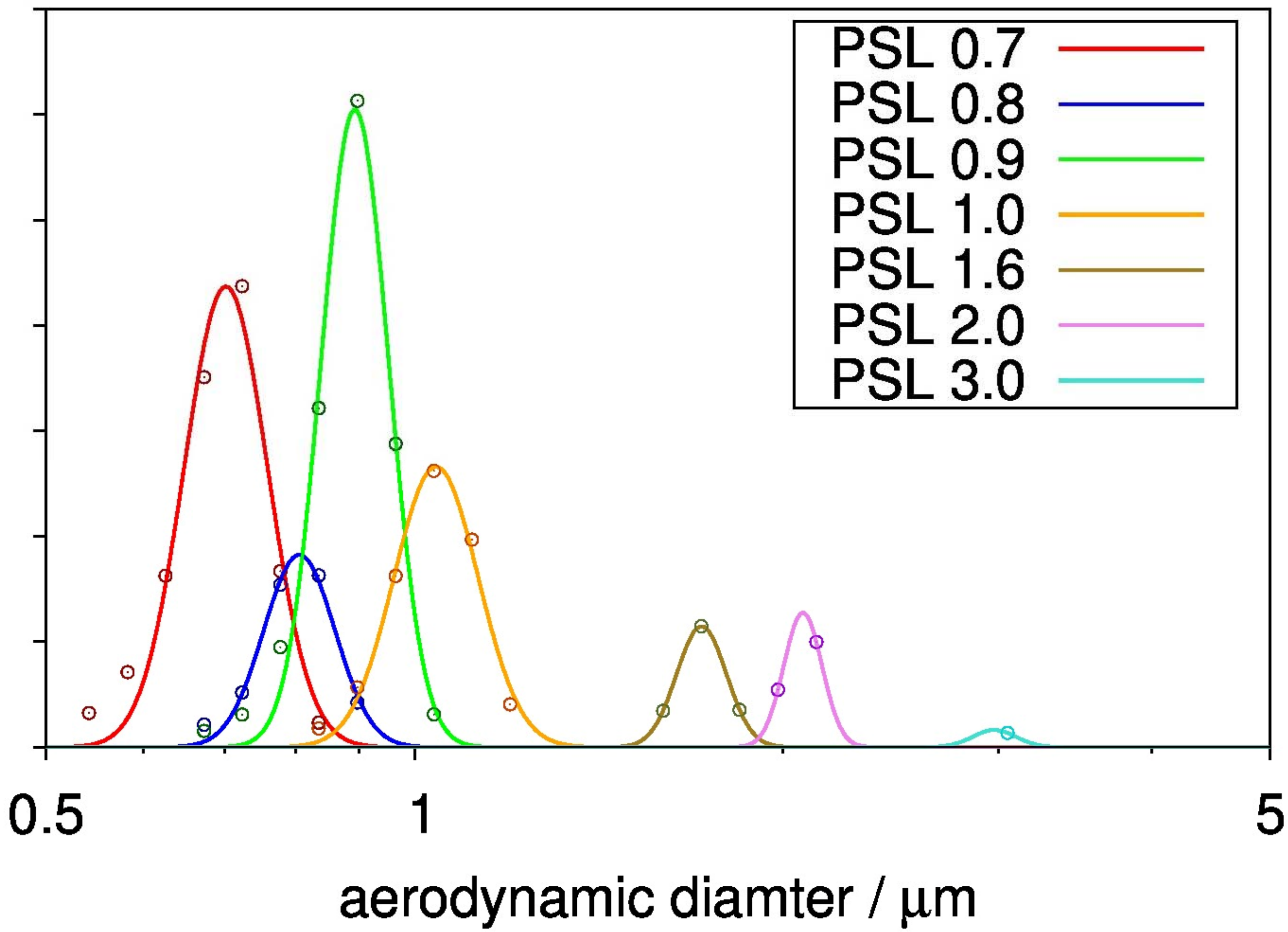
Event 4:



Event 4 occurs when the time-of-flight is longer than the maximum time. The reason therefore is usually due to a re-circulation particle. The particle is not classified, however, added to the total concentration.

APSS Calibration

Latex Calibration



Optical measurements

- Beside the determination of the aerodynamic particle size, the signal can also be taken to determine the optical diameter.
- Each particle is classified in relation to the refractive index of latex spheres.