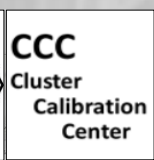
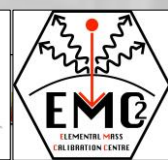
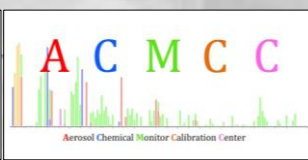


Mobility Particle Size Spectrometer - ITINERIS Training IV

Alfred Wiedensohler
Director ACTRIS CAIS-ECAC



Types of Mobility Particle Size Spectrometers

Mobility Particle Size Spectrometer (MPSS)

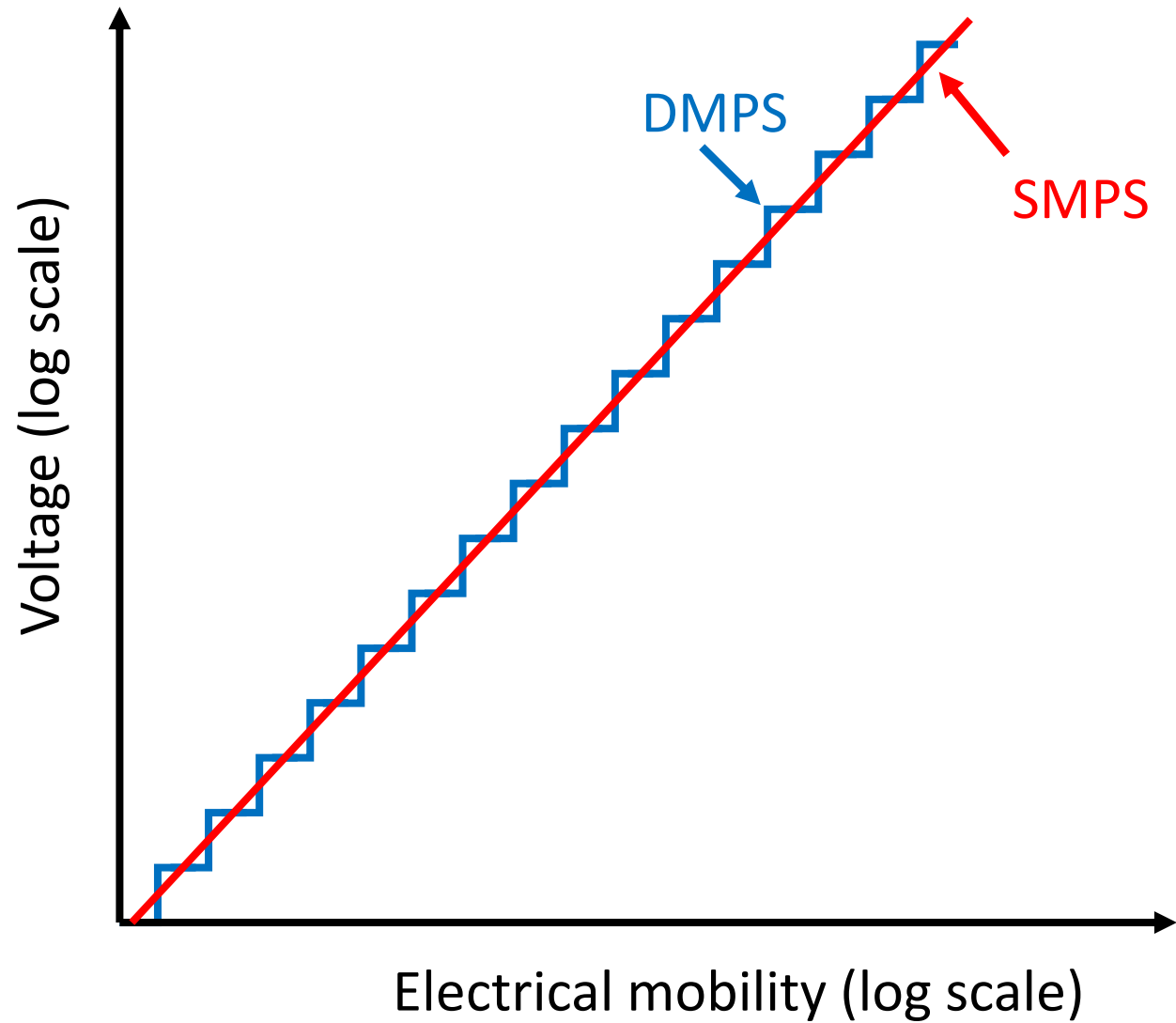
Main components:

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

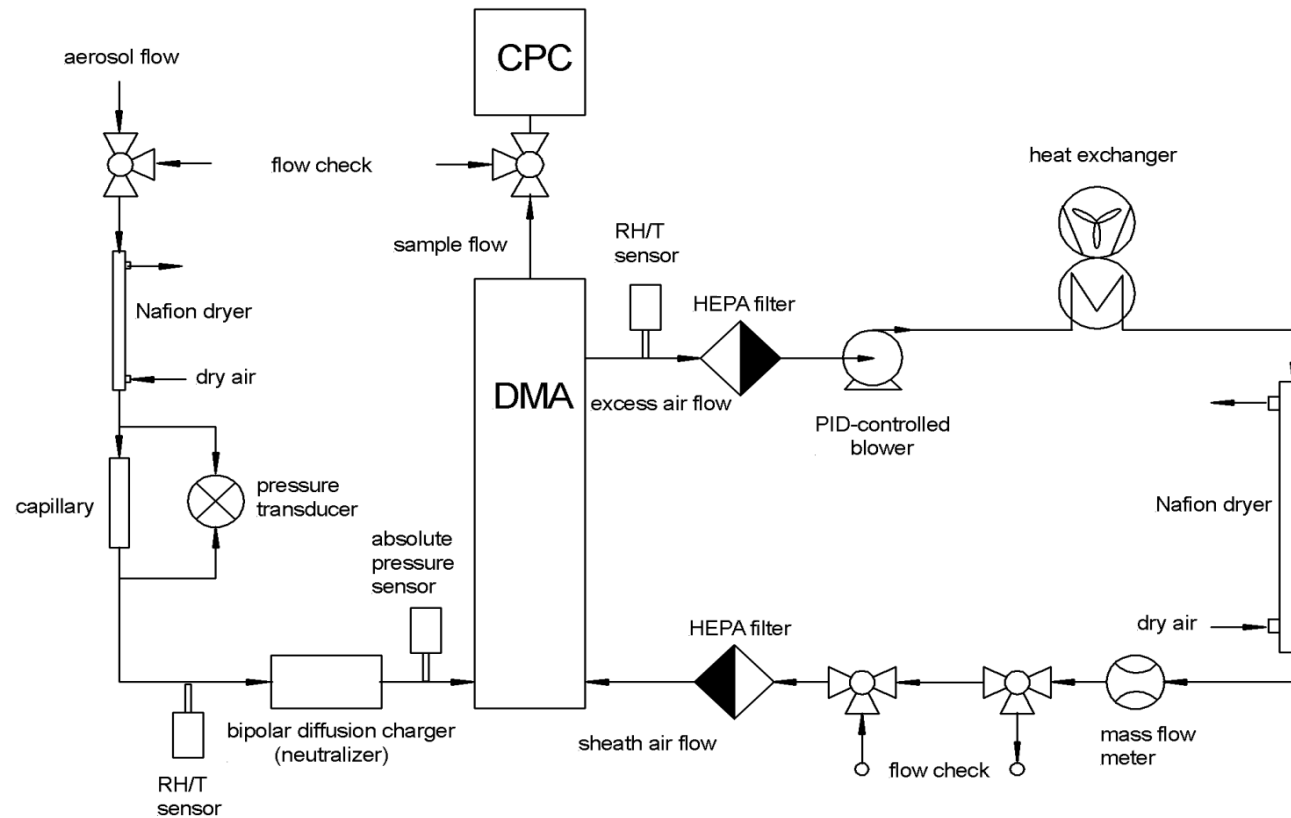
Different principles:

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

Voltage Ramp



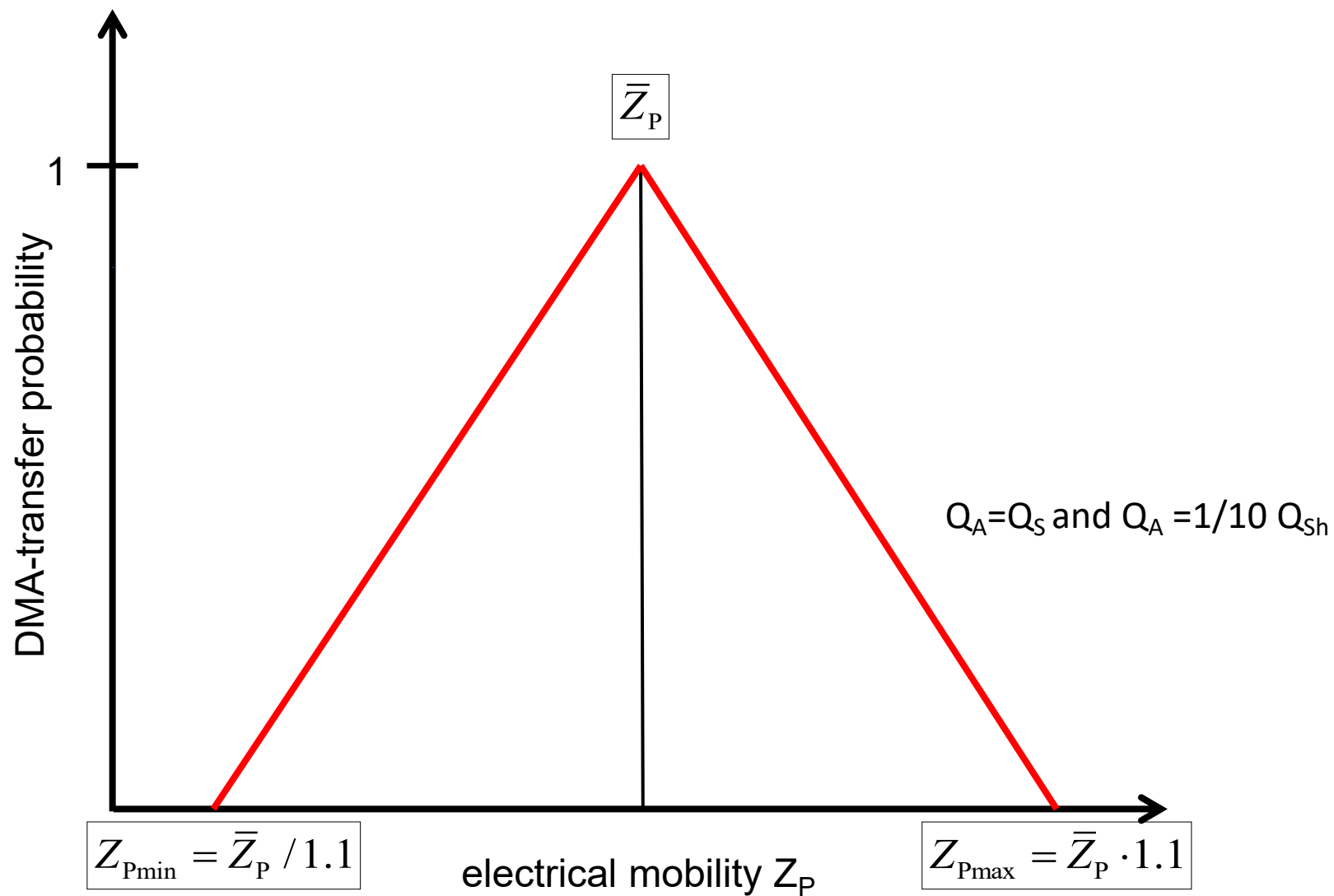
MPSS – Recommended Setup in GAW and ACTRIS



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

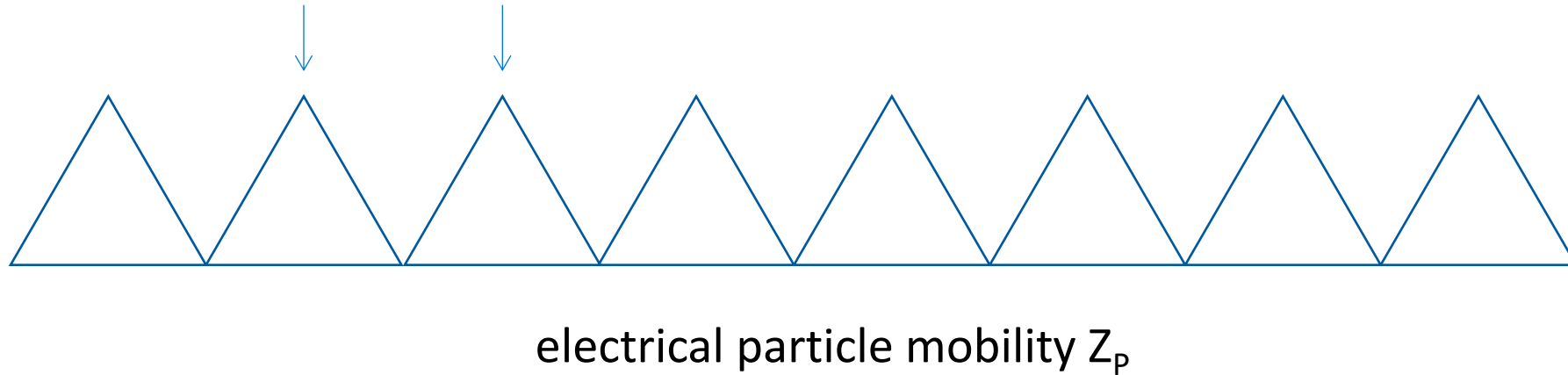
Principle of the Inversion Routine

Transfer Function



Stepping mode (DMPS)

Factor 1.21 (1.1×1.1)
between $Z_{p\text{peaks}}$

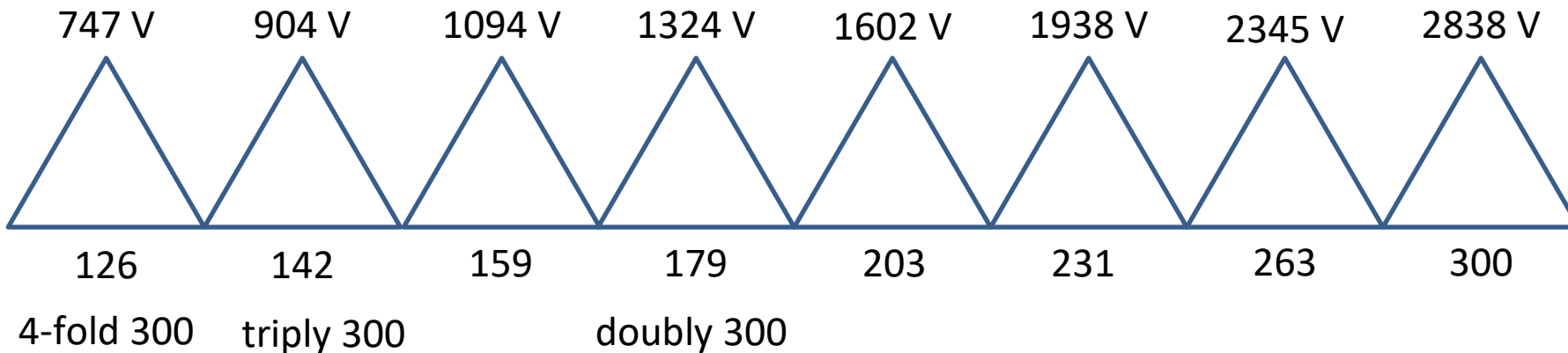


Example: Vienna-type DMA

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

Factor 1.21
between $Z_{p,peaks}$ or voltage

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



particle diameter D_p (nm) →

← electrical particle mobility Z_p

Voltage U (V) →

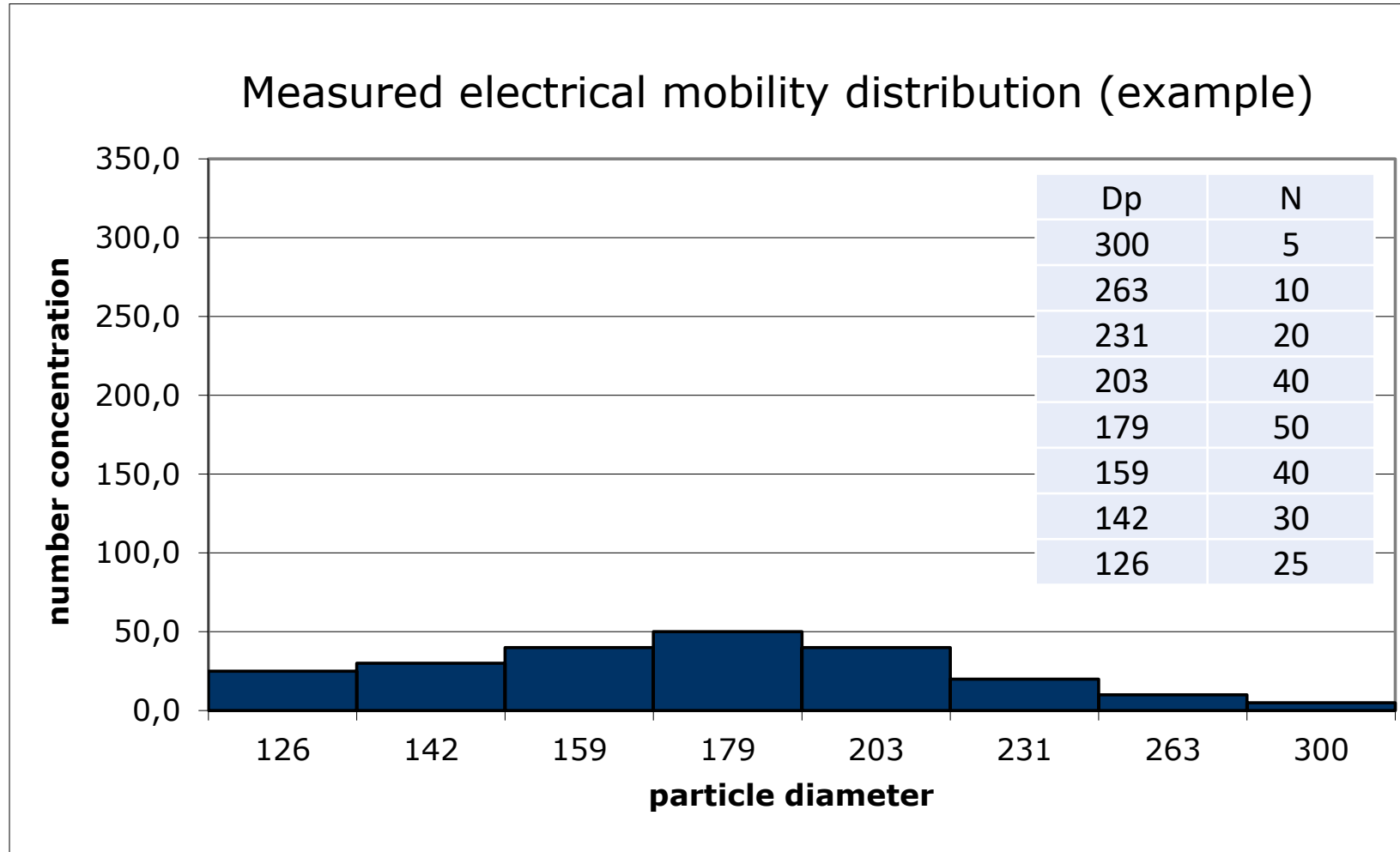
Bipolar Charge Distribution (for this example)

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%

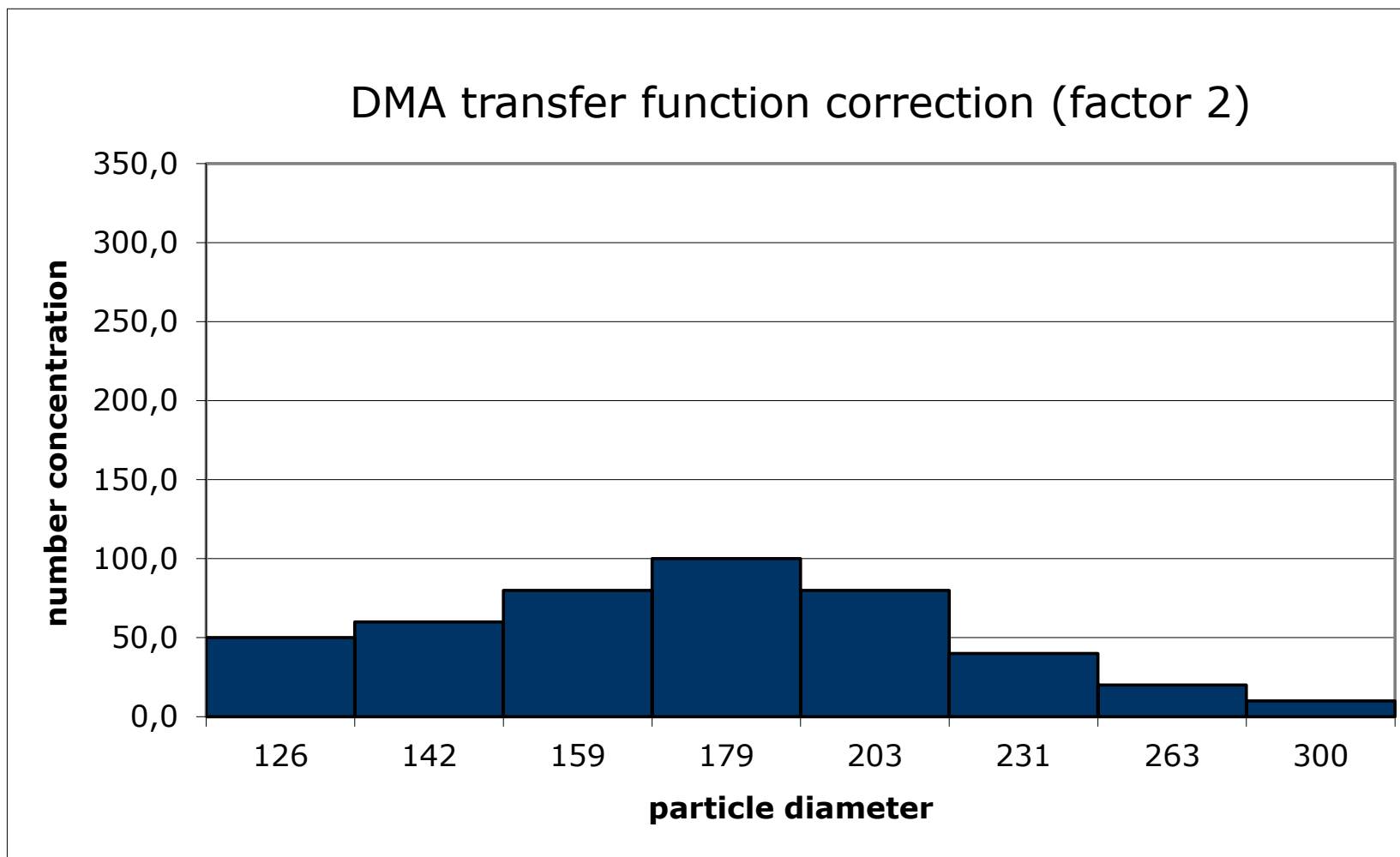
Main components

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

Electrical Mobility Distribution



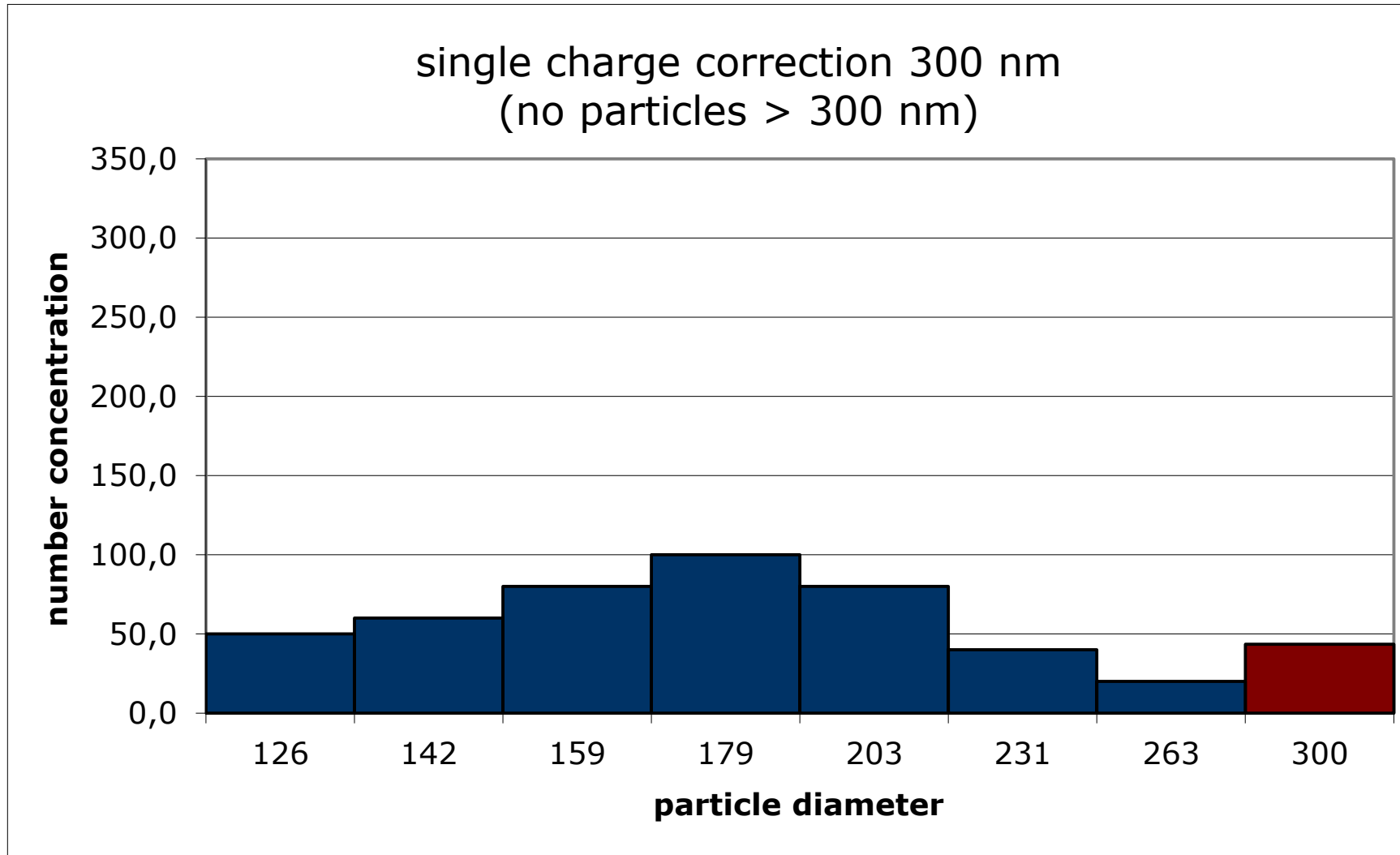
Correction Transfer Function (ideal triangle)



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%
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%

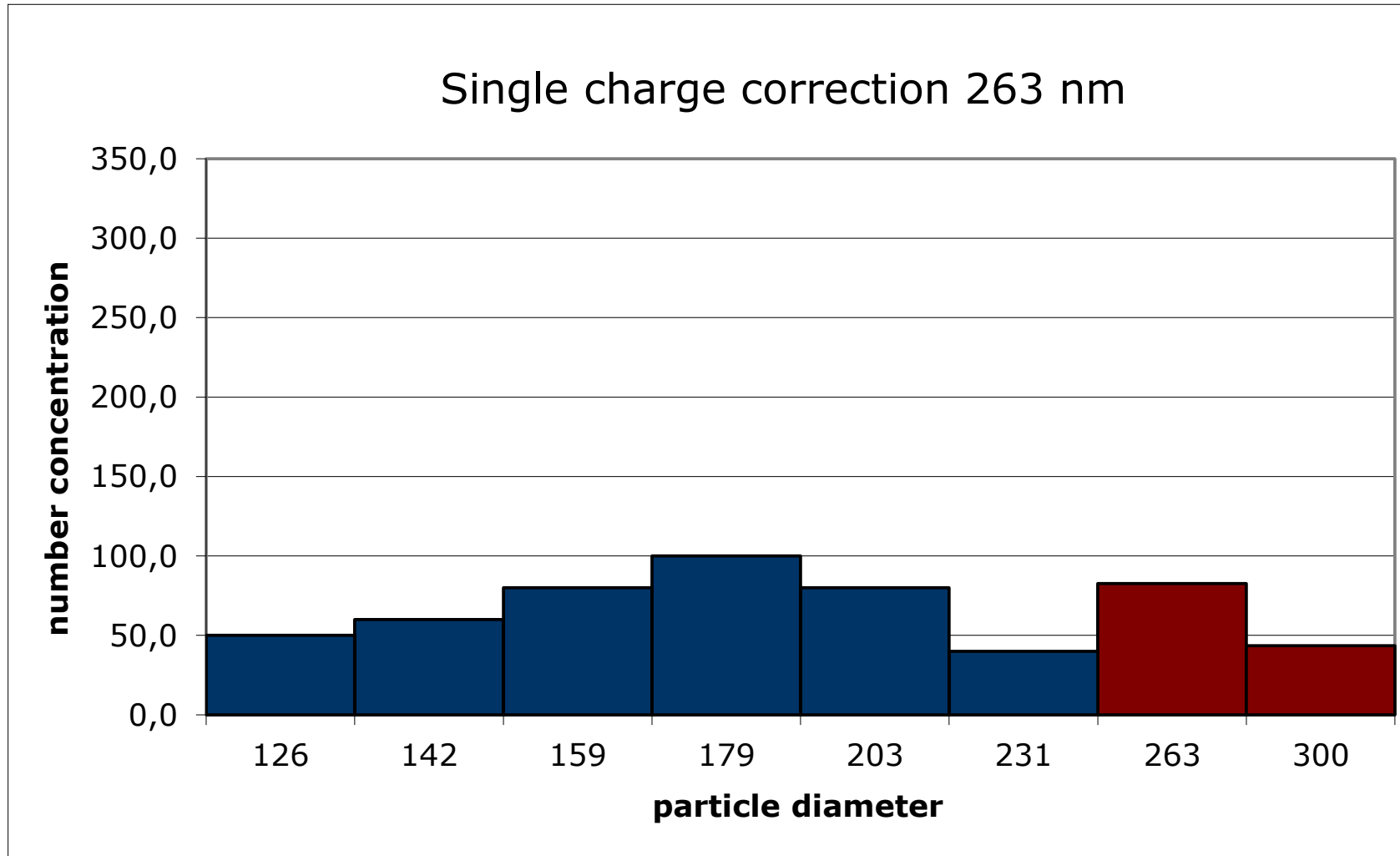
Multiple Charge Correction: Step 1



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%
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%

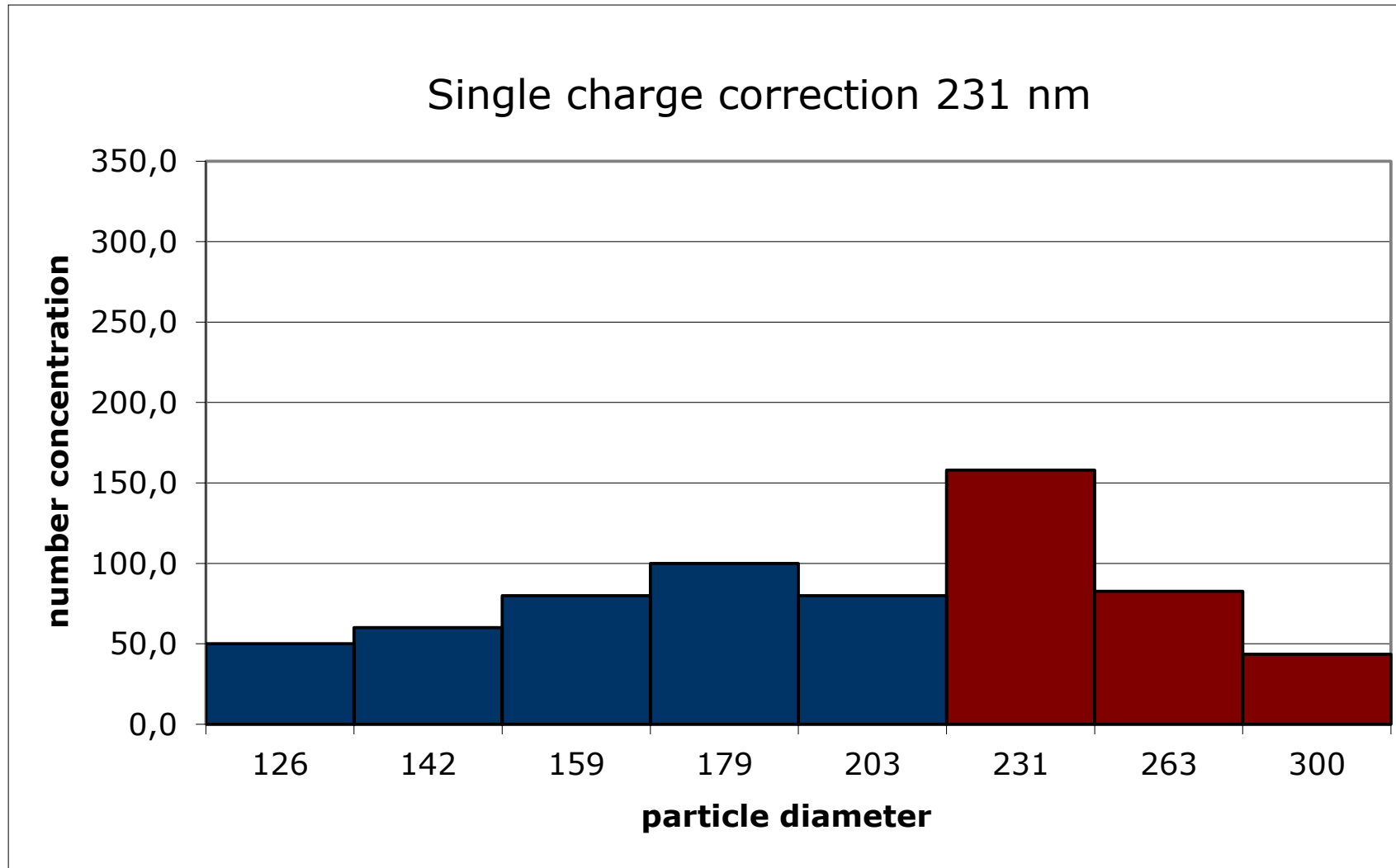
Multiple Charge Correction: Step 2



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%
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%

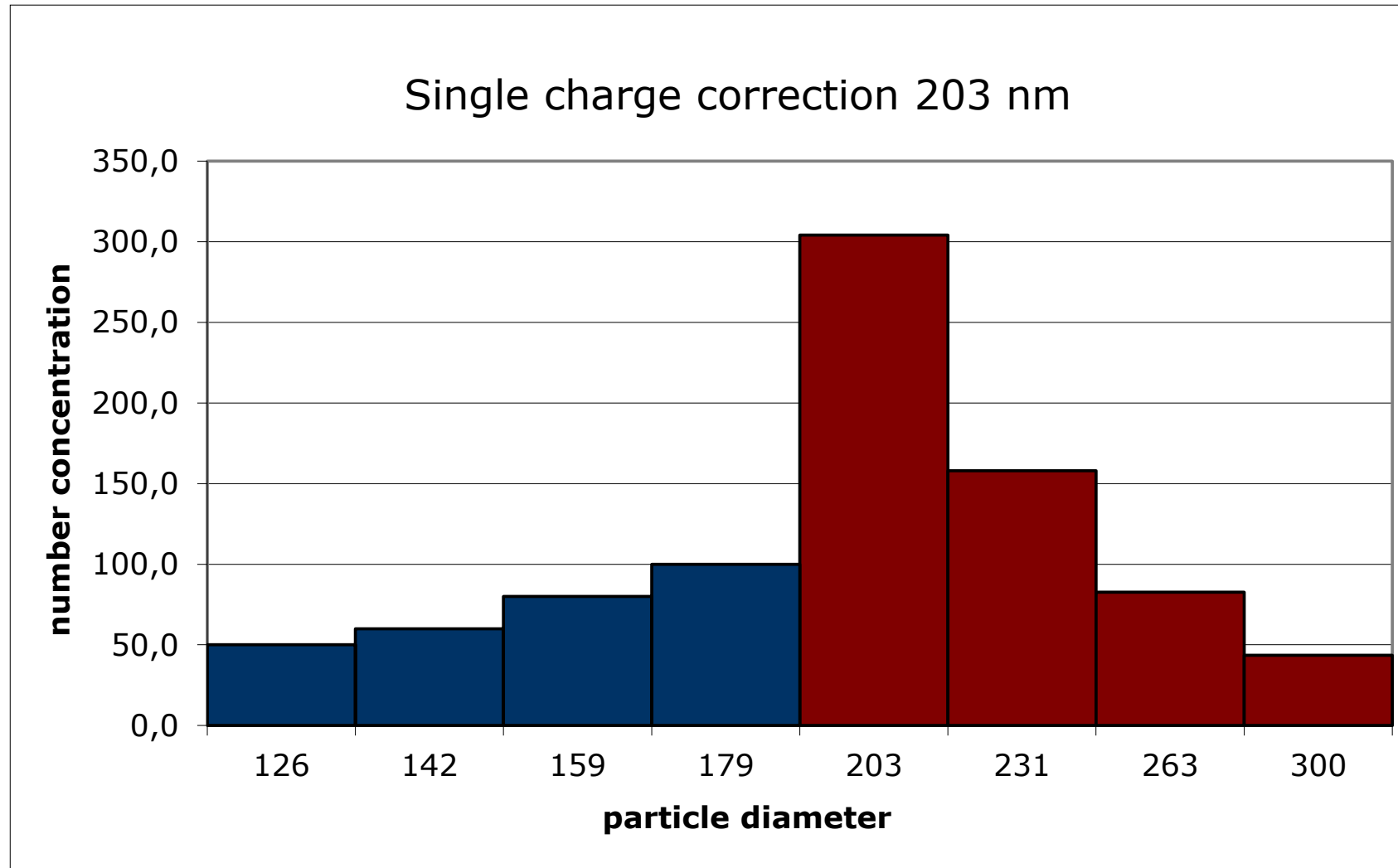
Multiple Charge Correction: Step 3



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%
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%

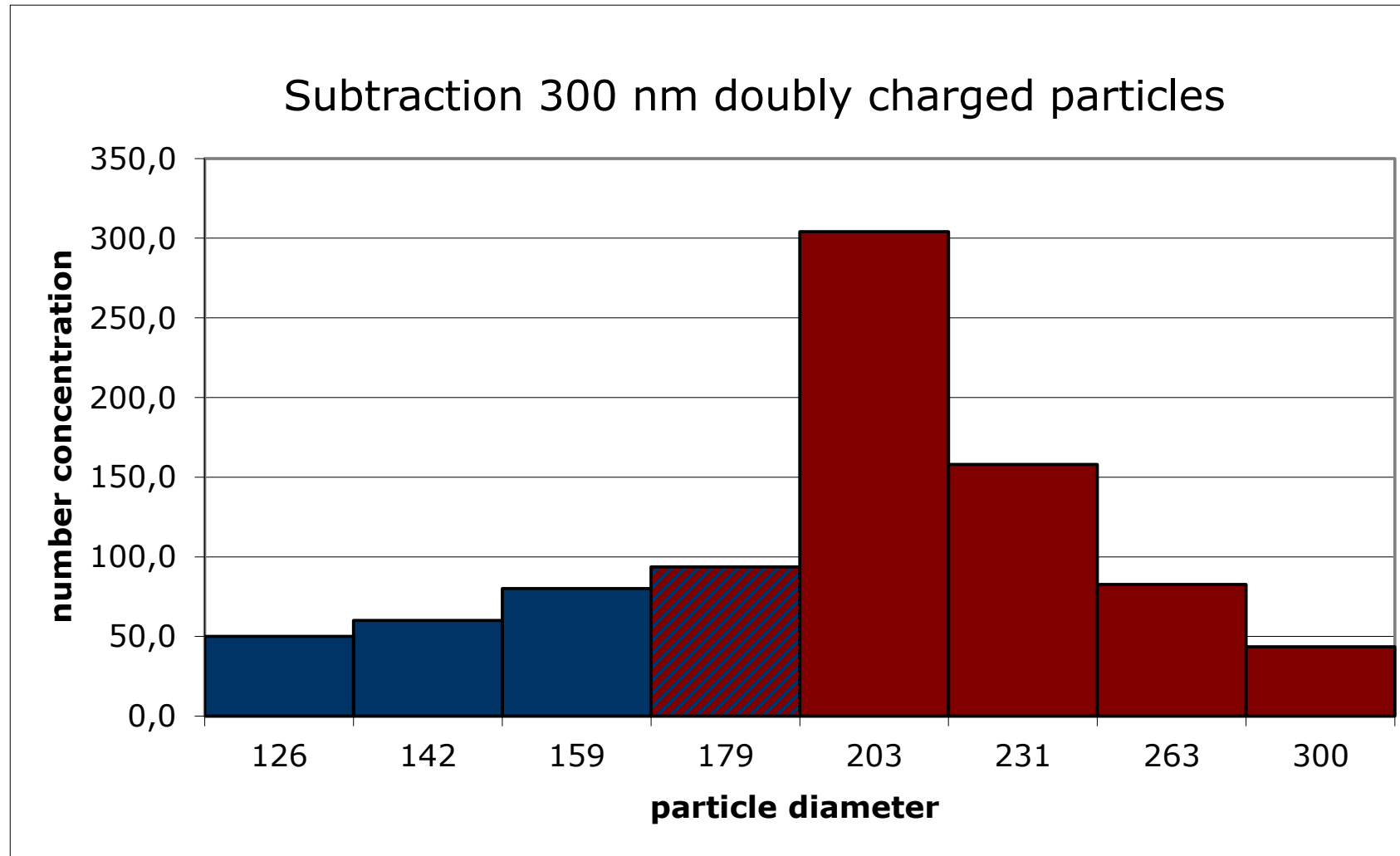
Multiple Charge Correction: Step 4



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%
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%

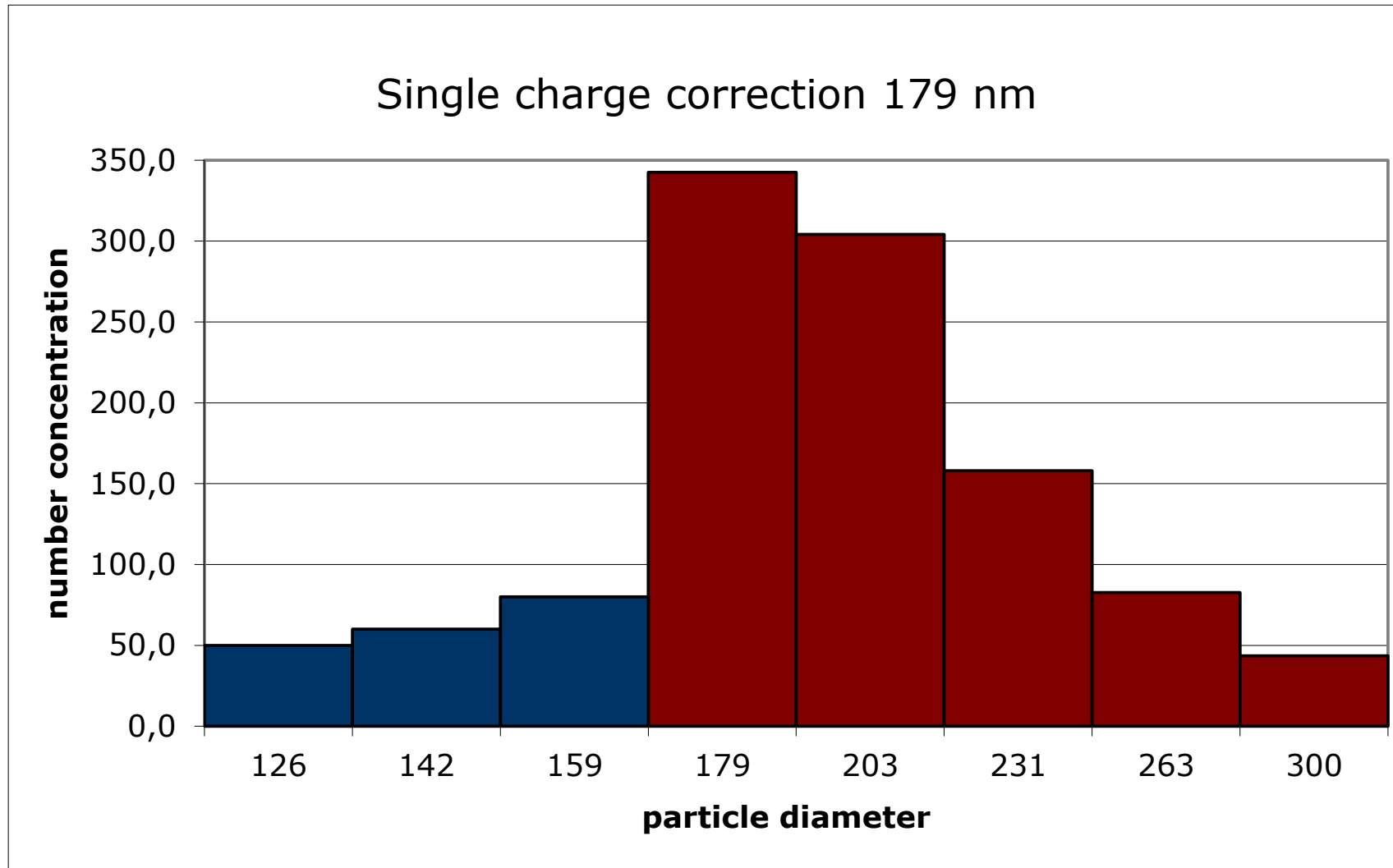
Multiple Charge Correction: Step 5



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%
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%

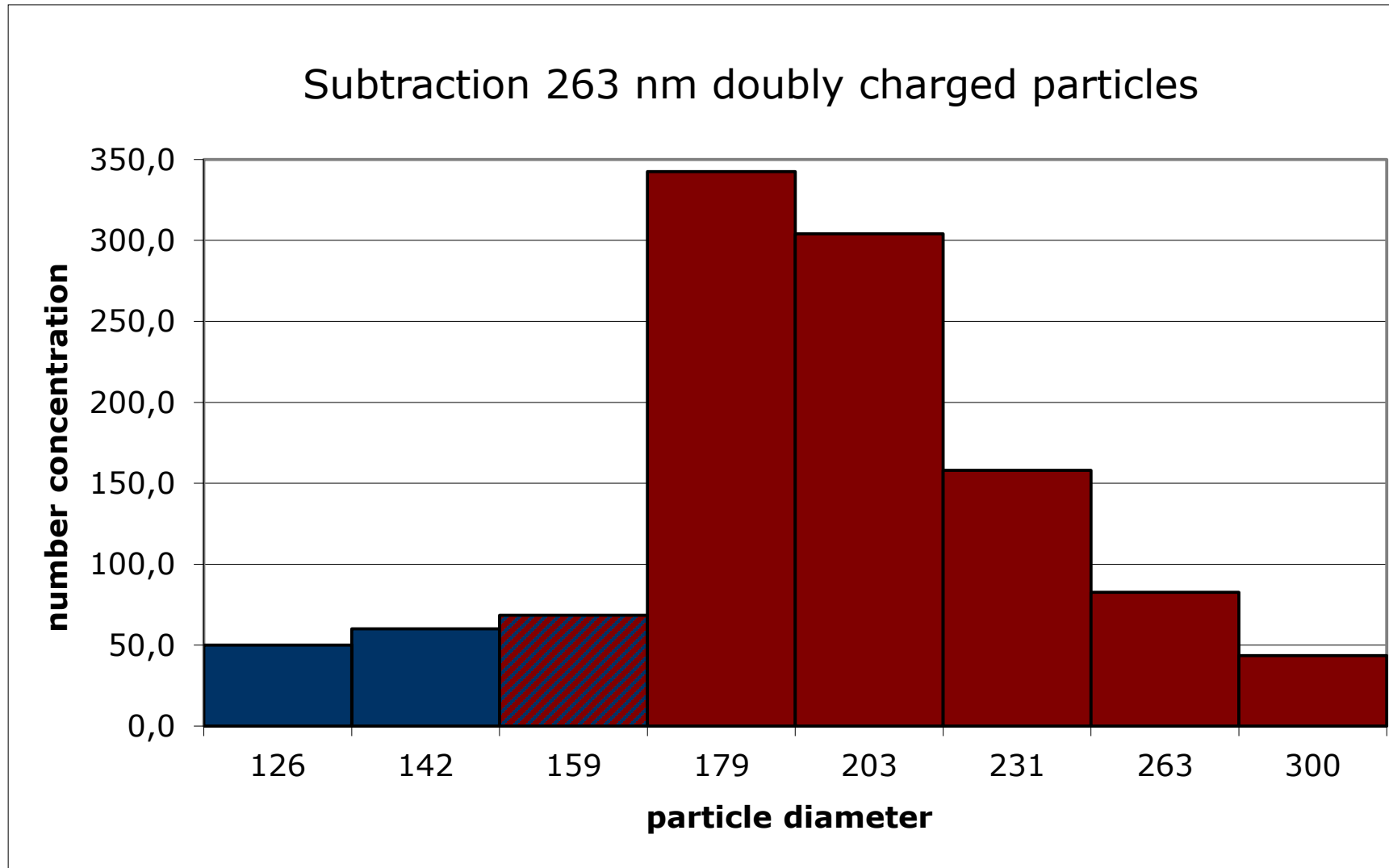
Multiple Charge Correction: Step 6



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%
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%

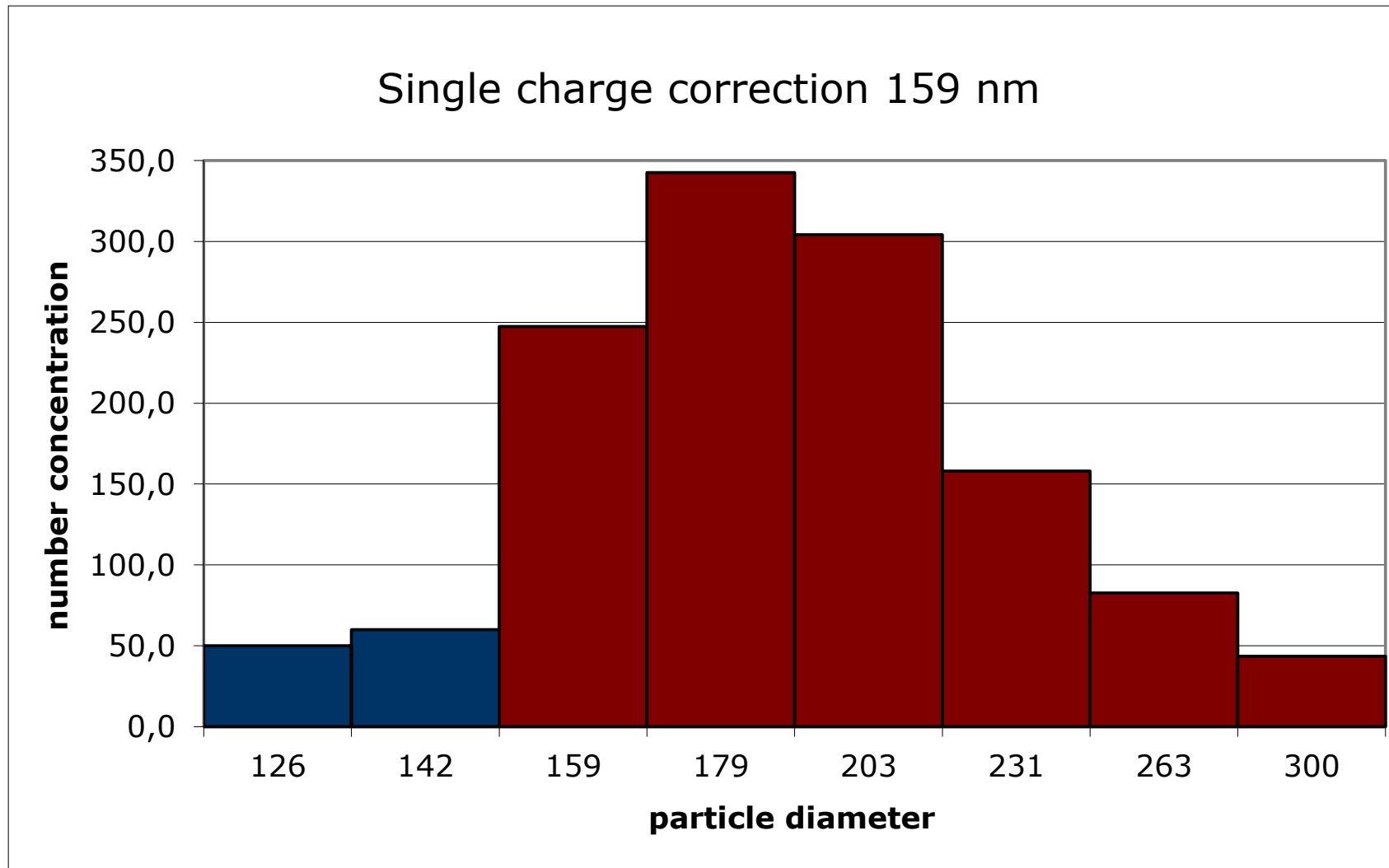
Multiple Charge Correction: Step 7



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%
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%

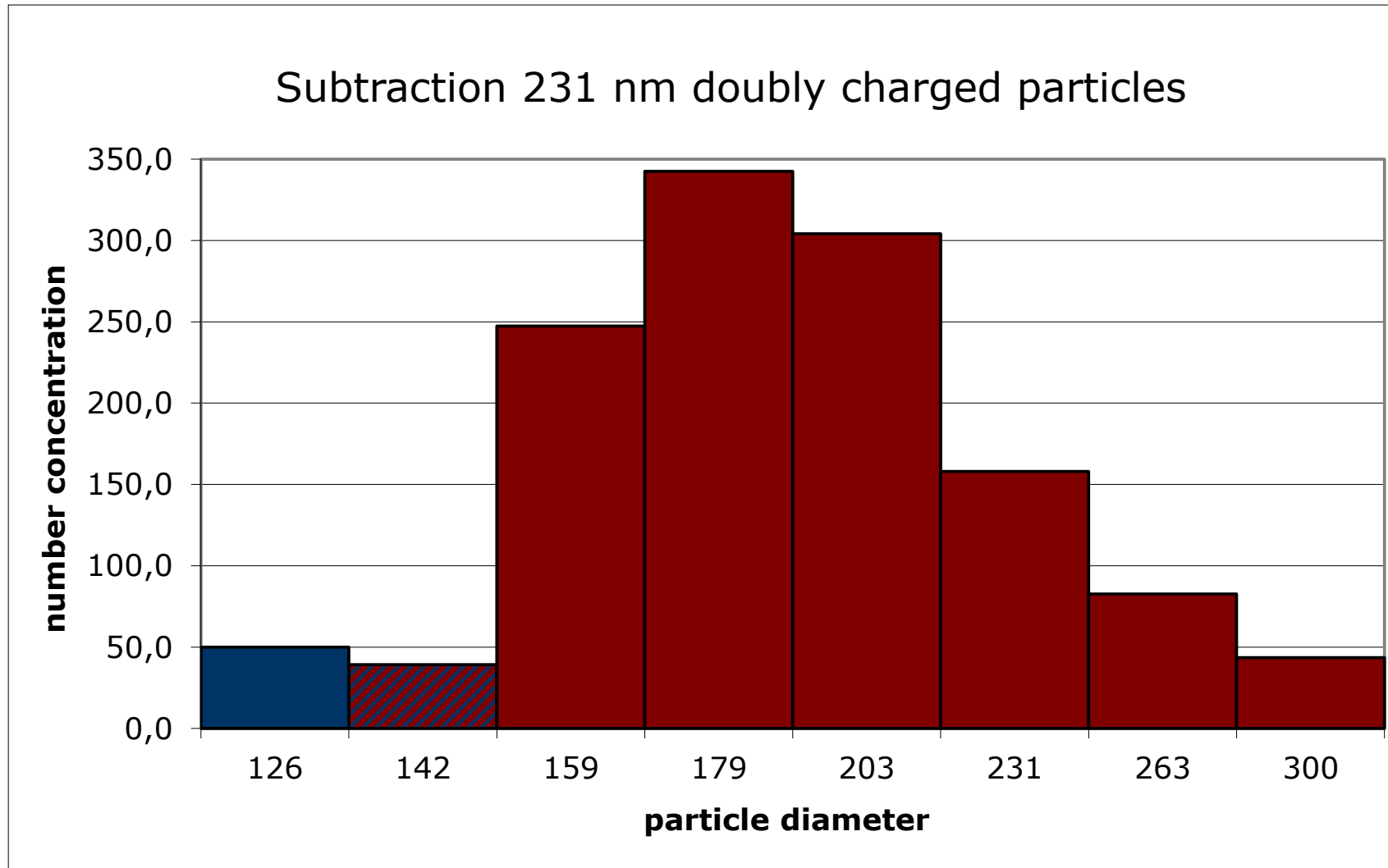
Multiple Charge Correction: Step 8



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%

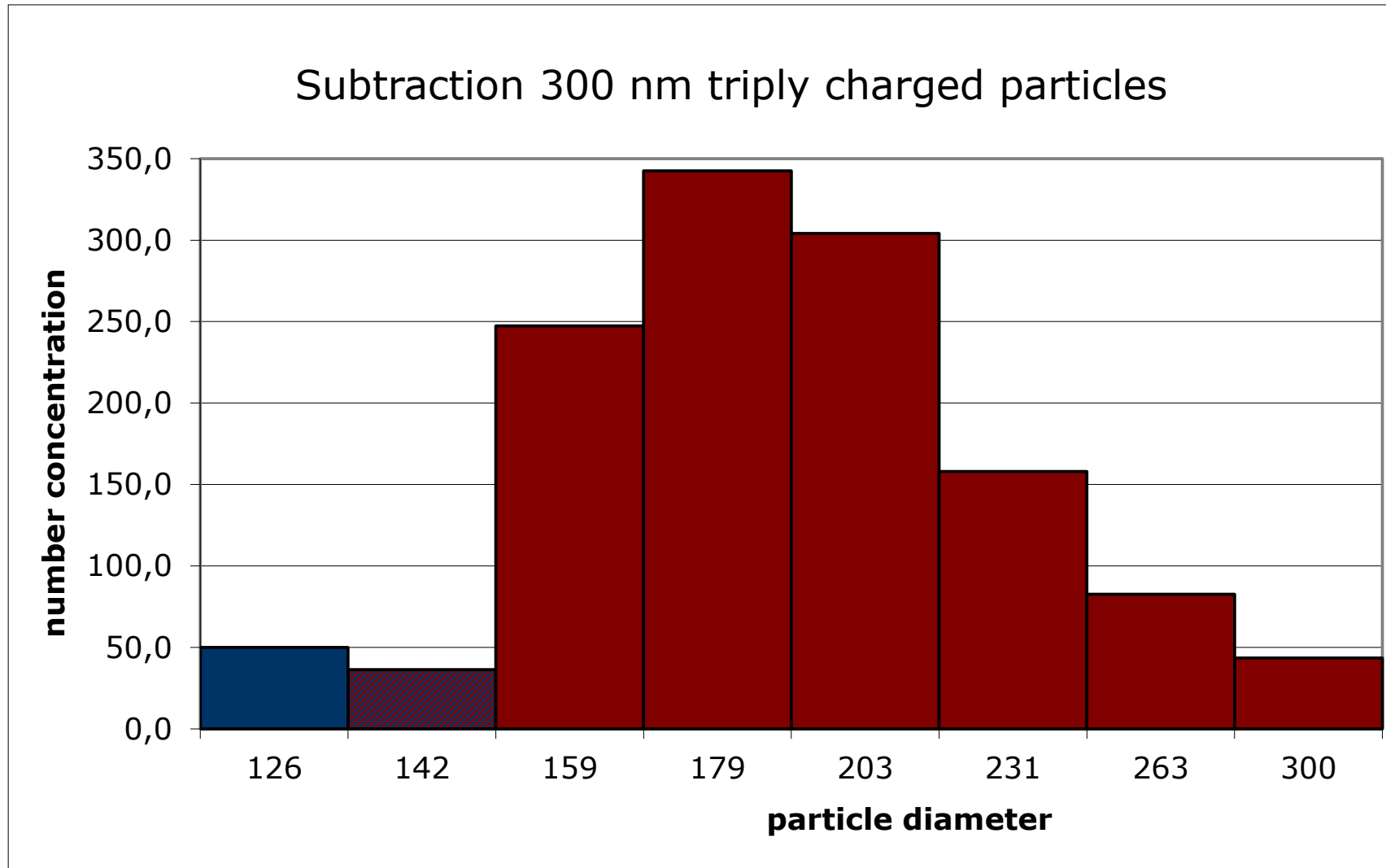
Multiple Charge Correction: Step 9



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%
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%

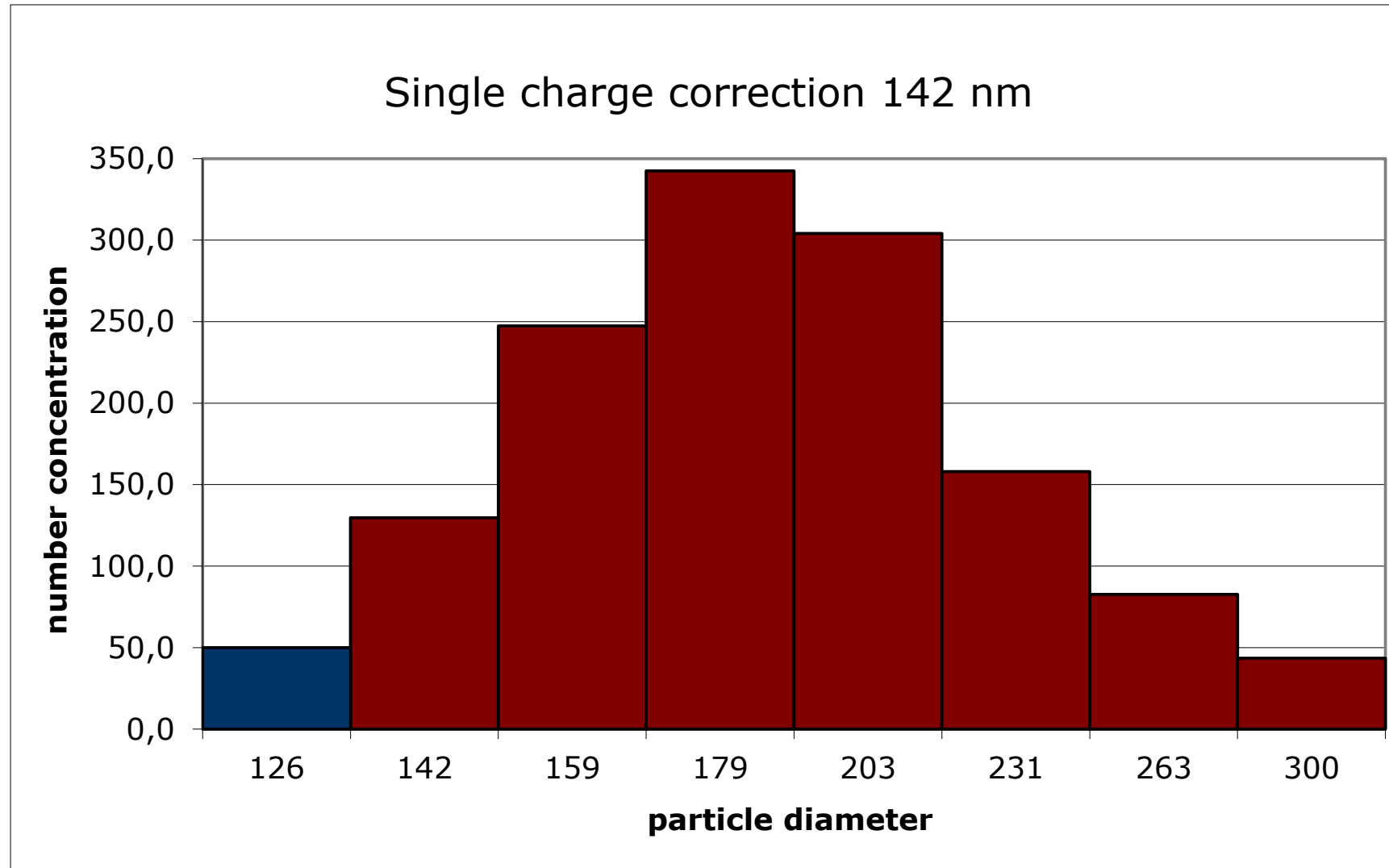
Multiple Charge Correction: Step 10



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%
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%

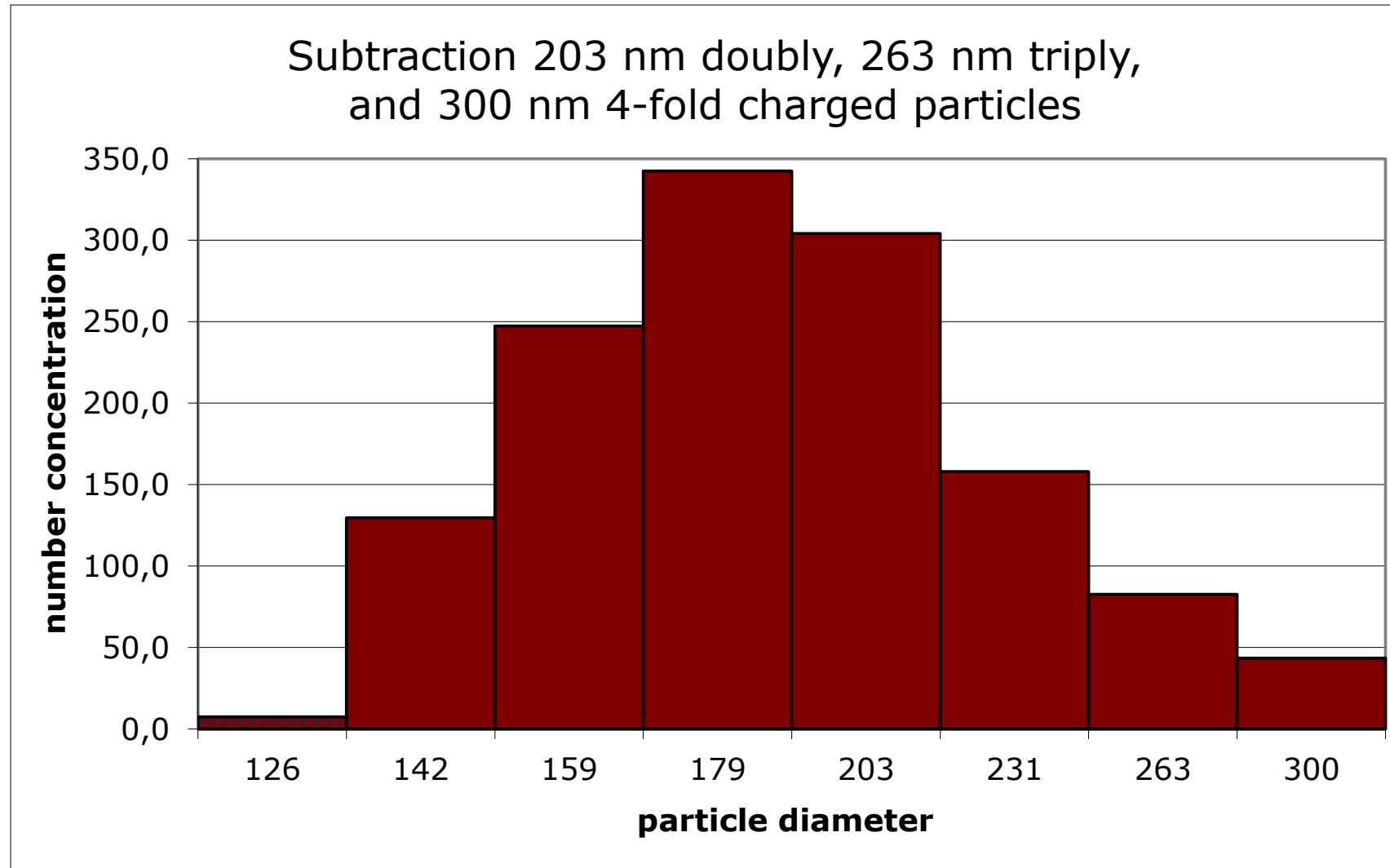
Multiple Charge Correction: Step 11



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%

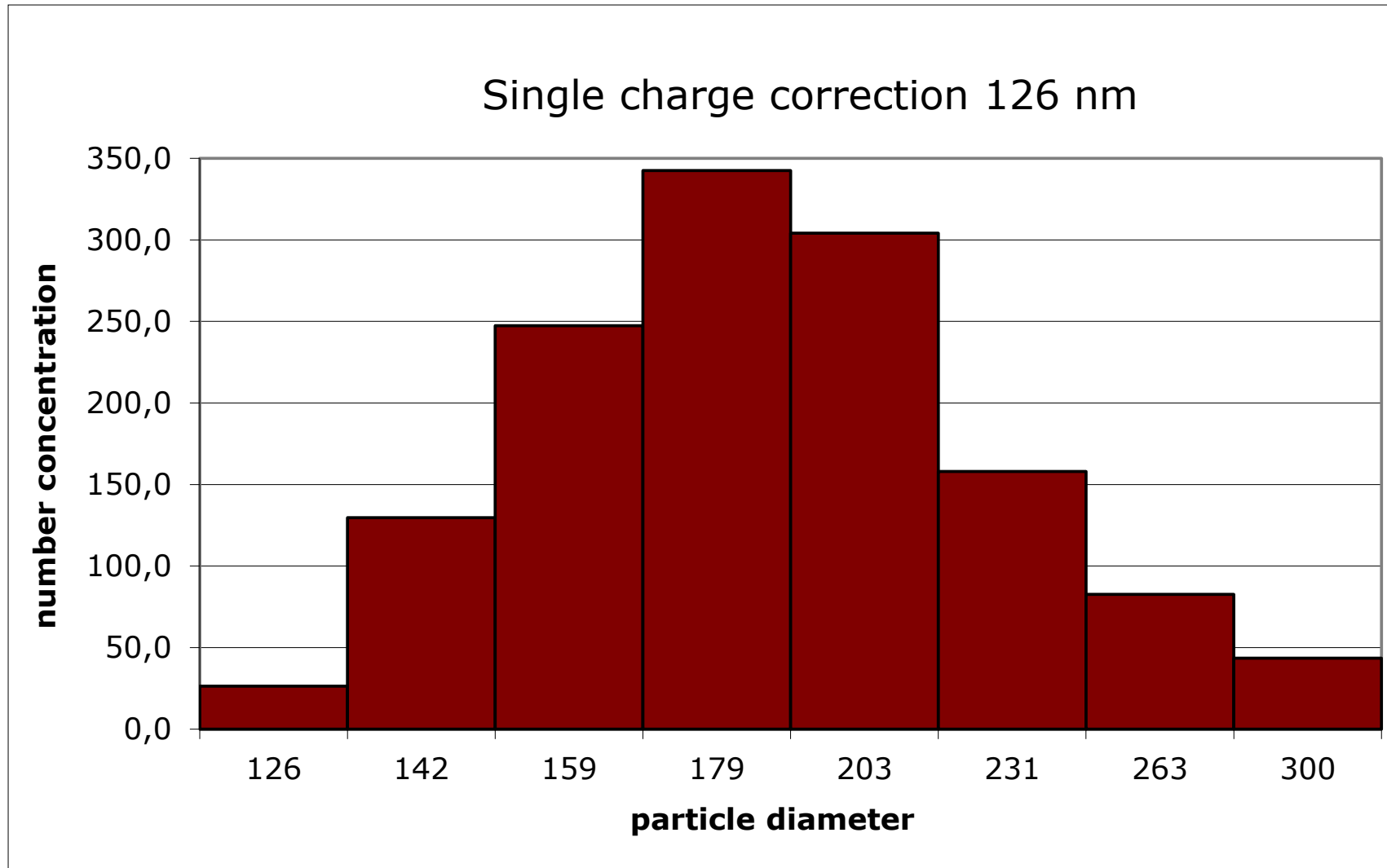
Multiple Charge Correction: Step 12



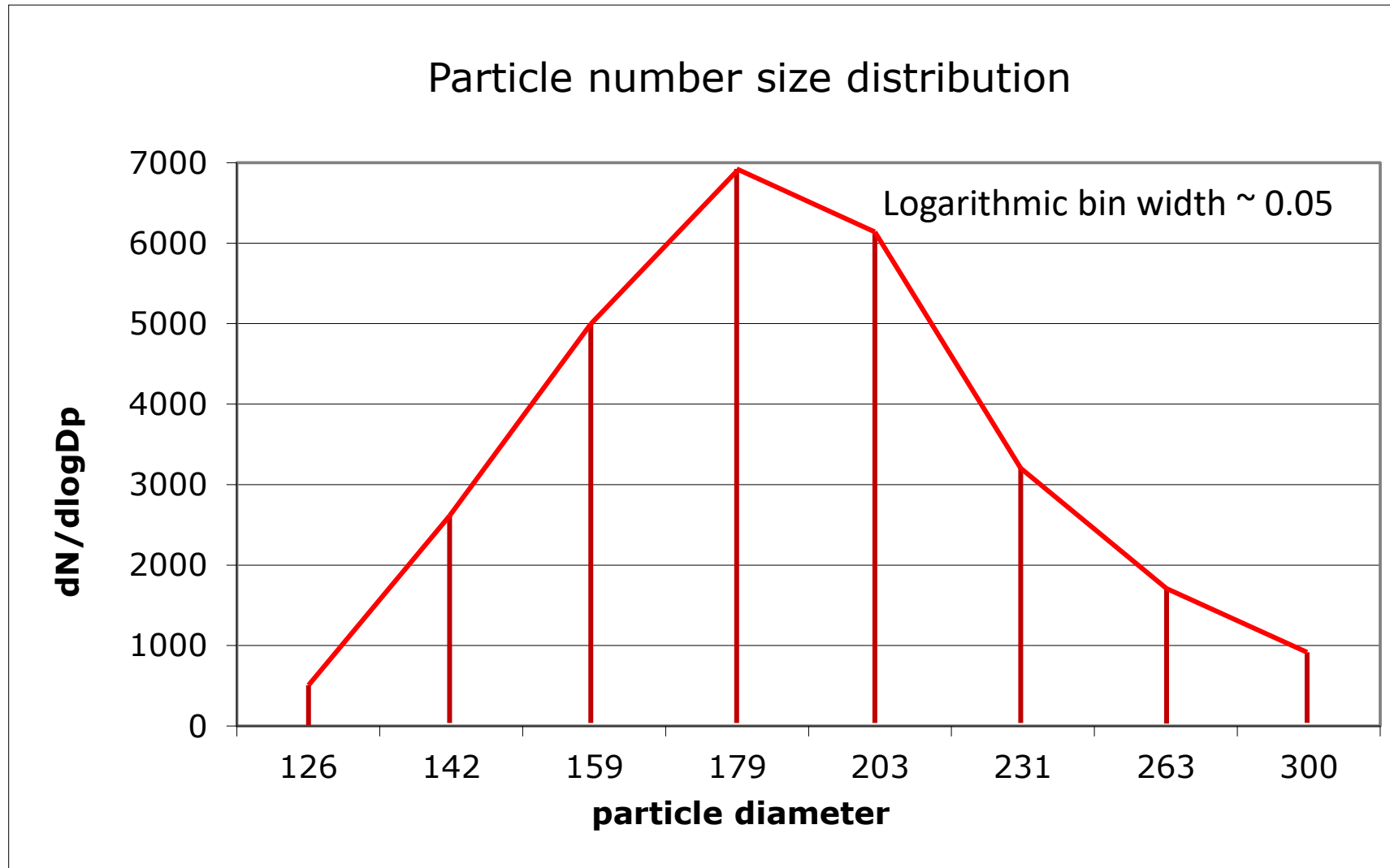
Bipolar Charge Distribution (for this example)

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



Particle Number Size Distribution – $dN/d\log D_p$



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)

Calculation of Particle Losses due to Diffusion

Losses due to Diffusion in Cylindrical Pipes

Approximation formulas are used to describe the losses due to diffusion in pipes.

Laminar flow ($Re_{\text{flow}} < 2000$):

The particle size-dependent penetration can be calculated to:

for $\mu < 0,007$

$$P = 1 - 5,5\mu^{2/3} + 3,77\mu$$

for $\mu > 0,007$

$$P = 0.819 \cdot \exp(-11.5\mu) + 0.0975 \cdot \exp(-70.1\mu) + 0.0325 \cdot \exp(-179\mu)$$

with:

$$\mu = \frac{D \cdot L_{\text{pipe}}}{Q}$$

D ... Diffusion coefficient

L_{pipe} ... length of the pipe

Q ... volume flow rate