Bestimmung der Konzentration und Größe von Aerosolpartikeln über mehrere Größenordnungen

Anforderungen an die elektrische Messtechnik und Kalibrierverfahren

Dr. Gerhard Steiner

senior scientist

GRIMM Aerosol Technik GmbH & Co. KG Ainring
Dorfstraße 9, 83404 Ainring, Germany

gerhard.steiner@grimm.durag.com

Grimm Aerosol Technik

- founded 1981 as “Grimm Labortechnik GmbH & Co. KG”
- since 1999: Grimm Aerosol Technik Ainring GmbH & Co. KG
- network of 60 dealers
- with more than 6.000 sold instruments
- to 16.000 customers worldwide
- in 2015 take-over by DURAG group (Hamburg)

Pouch
- Produktion
- R&D
- Service
- Administration

Ainring
- Management
- Administration
- Sales
- Order Processing

fields of research

ENVIRO

environmental monitoring


EDM 180


EDM 164


EDM 365


11-E

UFP and WRAS instruments


EDM 465 UFP


EDM 665 WRAS

IAQ (Indoor Air Quality)


11-B (Bio)


11-R (Research)


11-C


11-S (Sky)


MiniWRAS

NANO


CPC 4


sky-CPC


SMPS + C


S, M, L - DMA


FCE

SMPS + E

What are aerosols ?

a stable suspension of solid particles and/or liquid droplets in a carrier gas

2- component system: **particle + carrier gas**

particle: solid / liquid
gas: air (or any other gas)

highly dynamic, reactive and complicated systems

→ need simplifications and statistical methods for description

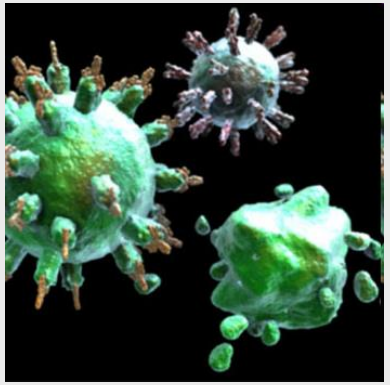
Why care about aerosols?

air pollution

http://www.tropical-rainforest-animals.com

http://pixdaus.com/pics/1205600171th4UdUS.jpg

biotechnology



http://medical-animation-studio.com

health effects

http://www.vetsonline.com

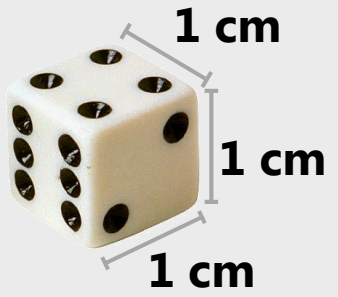
nanotechnology

http://www.tennesseemetallizing.com/flamespray.html

climate change patterns

http://global-warm-ing.co.cc/

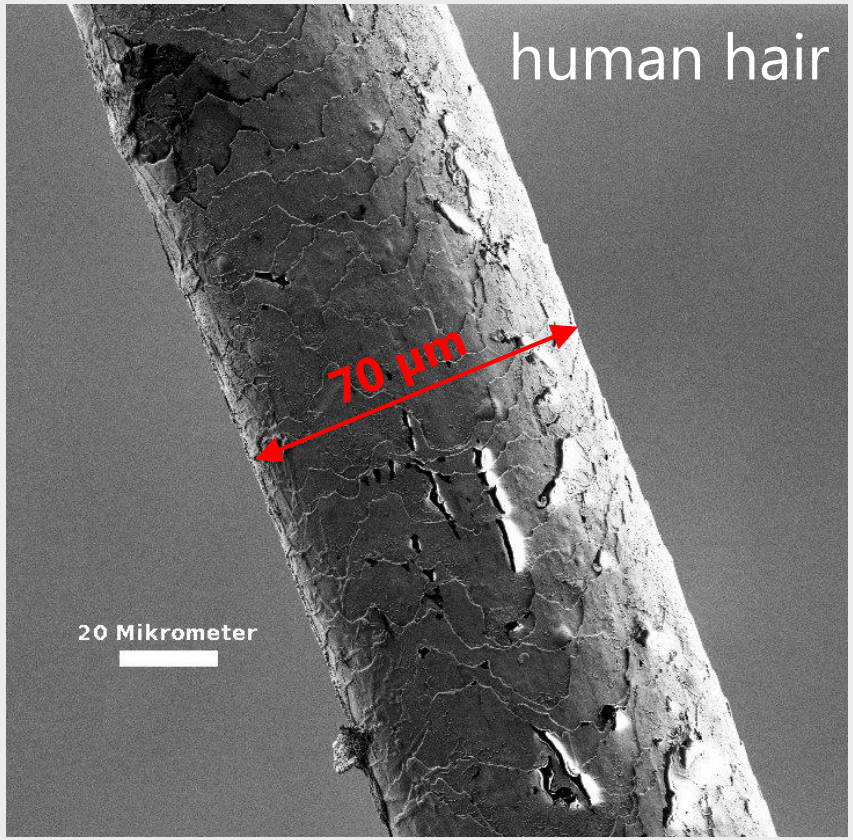
typical aerosol number concentrations



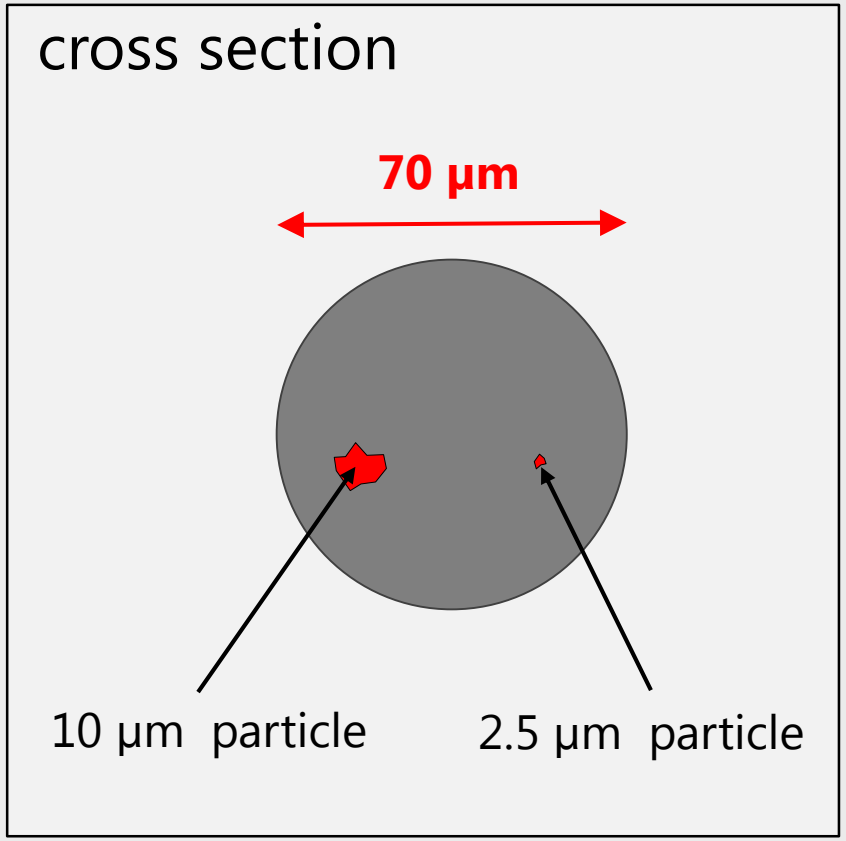
	number conc. ($1/cm^3$)	
stratosphere	0.1	10^{-1}
Antarctic	1.0	
sea surface (background)	400	
continental background	2,000	
mean city	140,000	
city highway	2,000,000	
reactor / generator aerosol	100,000,000,000	10^{11}

12 orders of magnitude !

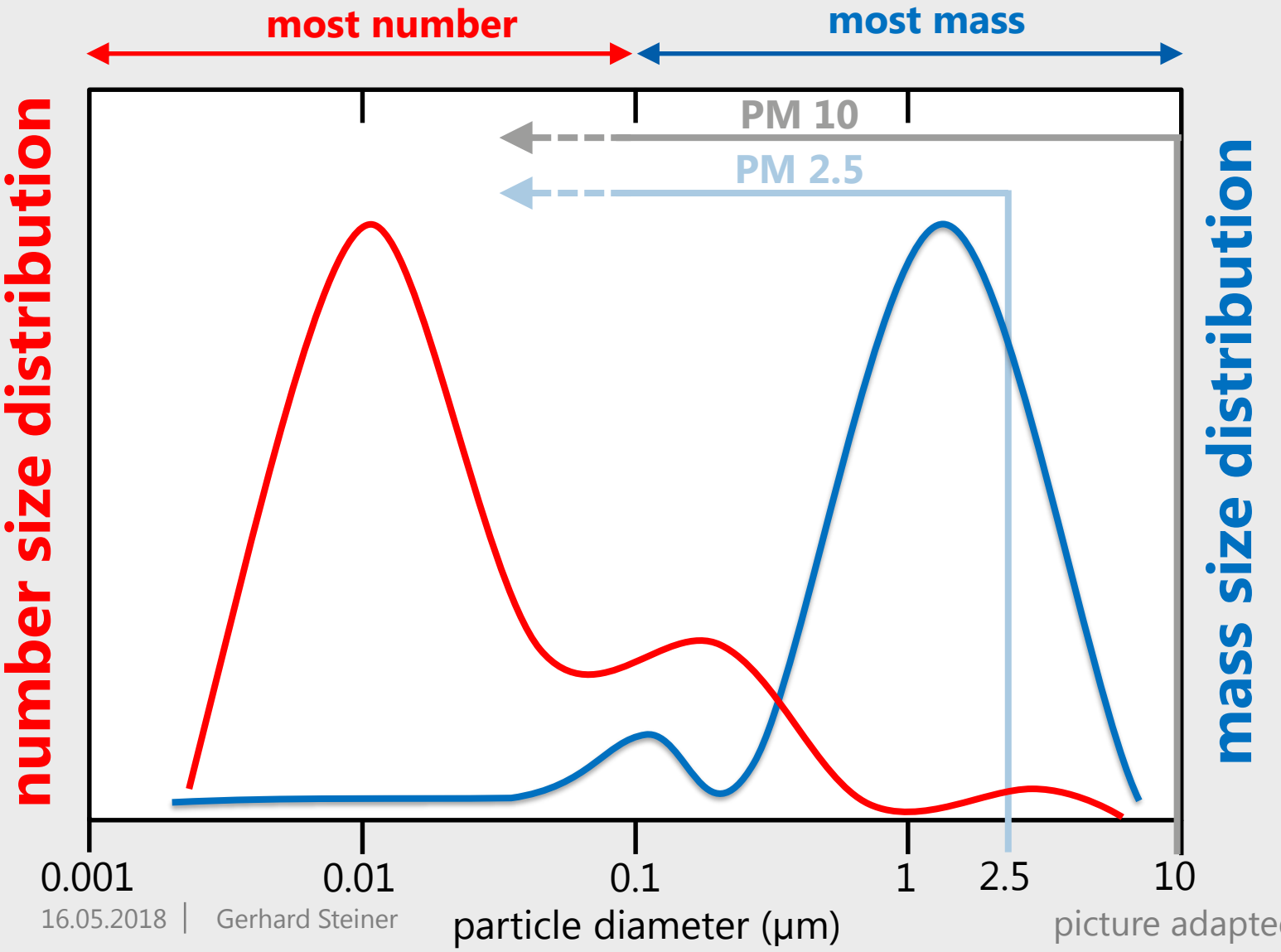
size relations ....



https://www.spektrum-neo.de/nanologo/



Atmospheric Aerosol



PM10 regulations imply:
one 10 µm-particle poses same health hazard as 8 million 50 nm-Particles.

measure for ultrafine particles (<100nm) is **number concentration**

picture adapted from Anna Wonaschütz (UniVie)

size relations ....

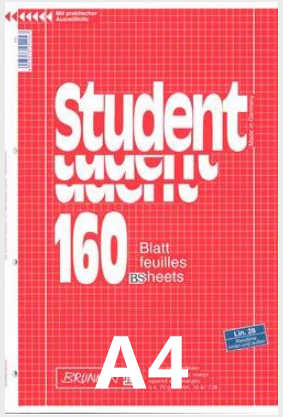
5 orders of magnitude !

0.001 µm	**0.01 µm**	**0.1 µm**	**1 µm**	**10 µm**
1 nm	10 nm	100 nm	1000 nm	10000 nm

0.03 m

https://www.sn.at/

0.3 m



https://www.duo-shop.de/

3 m

https://www.intersport.at

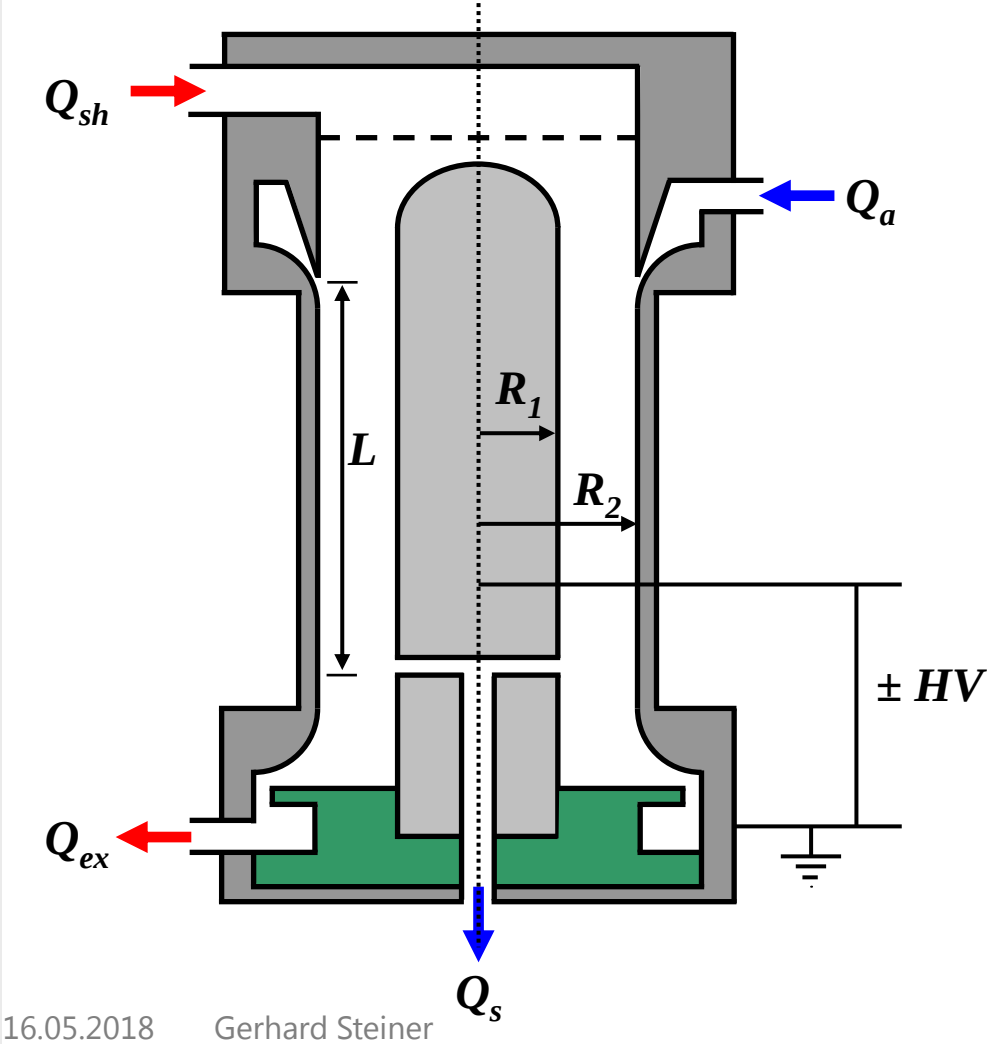
32 m

http://atelier-symbiota.de

324 m

https://img.posterlounge.de

Differential Mobility Analyzer (DMA)



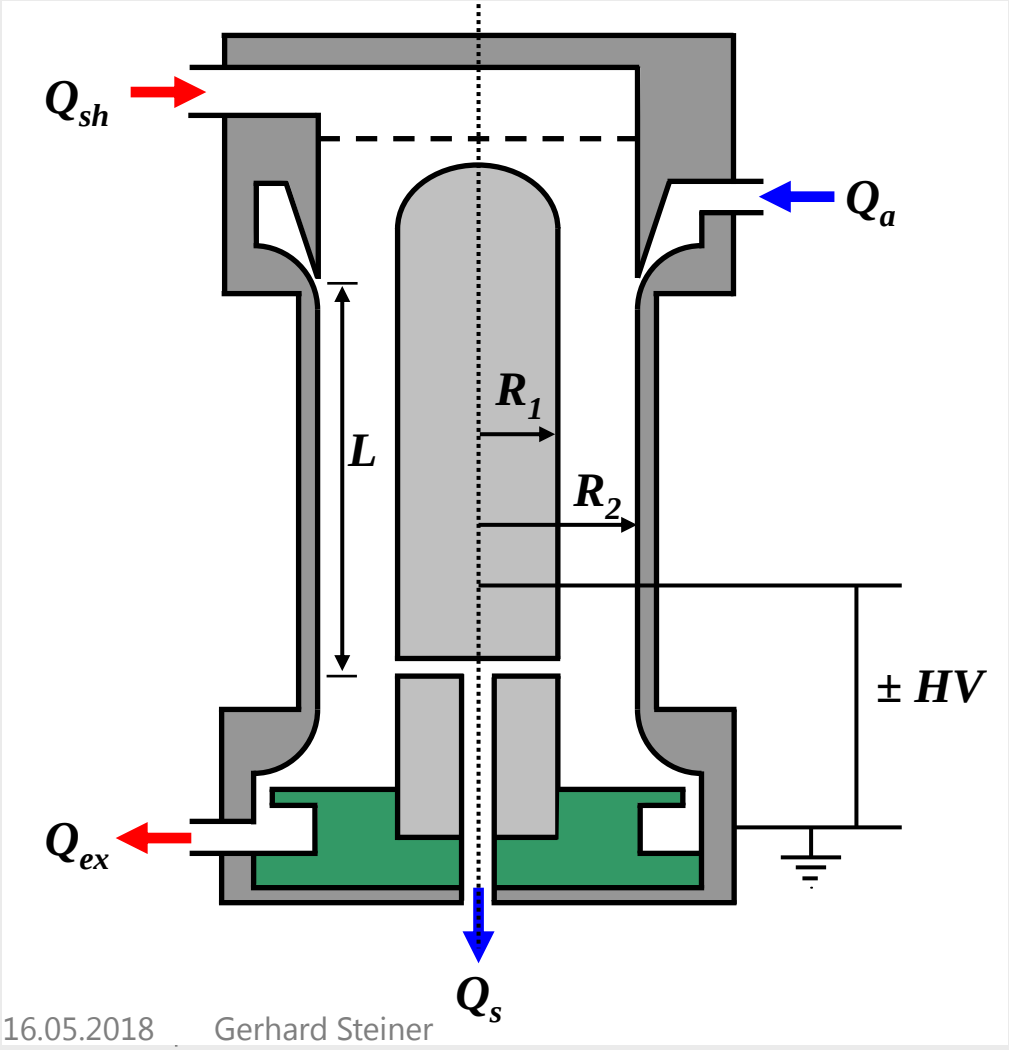
geometric parameters
R_1 … outer radius of center electrode
R_2 … inner radius of outer electrode
L … distance aerosol inlet-outlet (classification length)

operational parameters:
Q_{sh} … clean sheath-air
Q_{ex} … excess-air
Q_a … aerosol inlet-air
Q_s … aerosol sample-air)

HV … (high) voltage on center electrode

$$Z = \frac{1}{V}\frac{\ln(R_2/R_1)}{2\pi \cdot L}\frac{(Q_{sh} + Q_{ex})}{2}$$

Differential Mobility Analyzer (DMA)



Stokes' force: $\vec{F} = \frac{3\pi \cdot \eta \cdot D_p \cdot \vec{v}}{C(D_p)}$

mobility: $B = \frac{\vec{v}}{\vec{F}}$ $B = \frac{\vec{v}}{i \cdot e_0 \cdot \vec{E}}$

electrical mobility: $Z = i \cdot e_0 \cdot B$

$$Z = \frac{i \cdot e_0}{3\pi \cdot \eta} \cdot \frac{C(D_p)}{D_p}$$

electrical mobility equivalent diameter

diameter of a spherical particle having the same electrical mobility as a particle of unknown shape.

Differential Mobility Analyzer (DMA)

$$Z = \frac{1}{V}\frac{\ln(R_2/R_1)}{2\pi \cdot L}\frac{(Q_{sh} + Q_{ex})}{2}$$

$$Z = \frac{i \cdot e_0}{3\pi \cdot \eta} \cdot \frac{C(D_p)}{D_p}$$

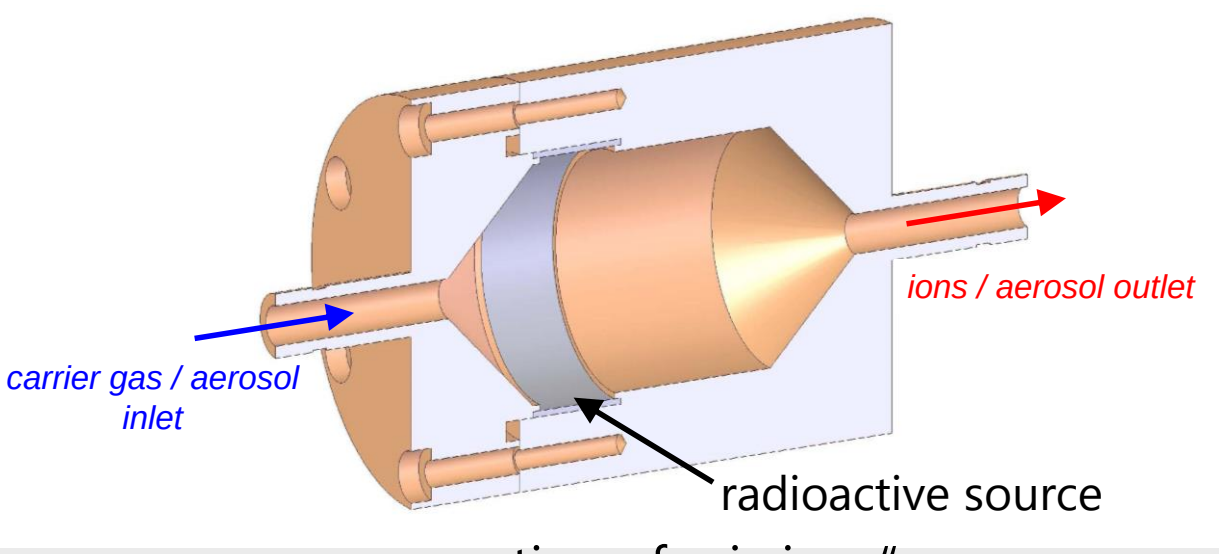
data inversion necessary!

neutralizer / charger

radioactive source

- ^{210}Po (α)
- ^{241}Am (α)
- ^{85}Kr (β)
- ^{63}Ni (β)

=> bipolar



generation of „air-ions“

^{241}Am

^{63}Ni

alternatives

- corona / dielectric barrier discharge
- soft x-ray

aDBD

charging probability

Fuchs / Boltzmann stationary state charging probability (Fuchs, 1964)

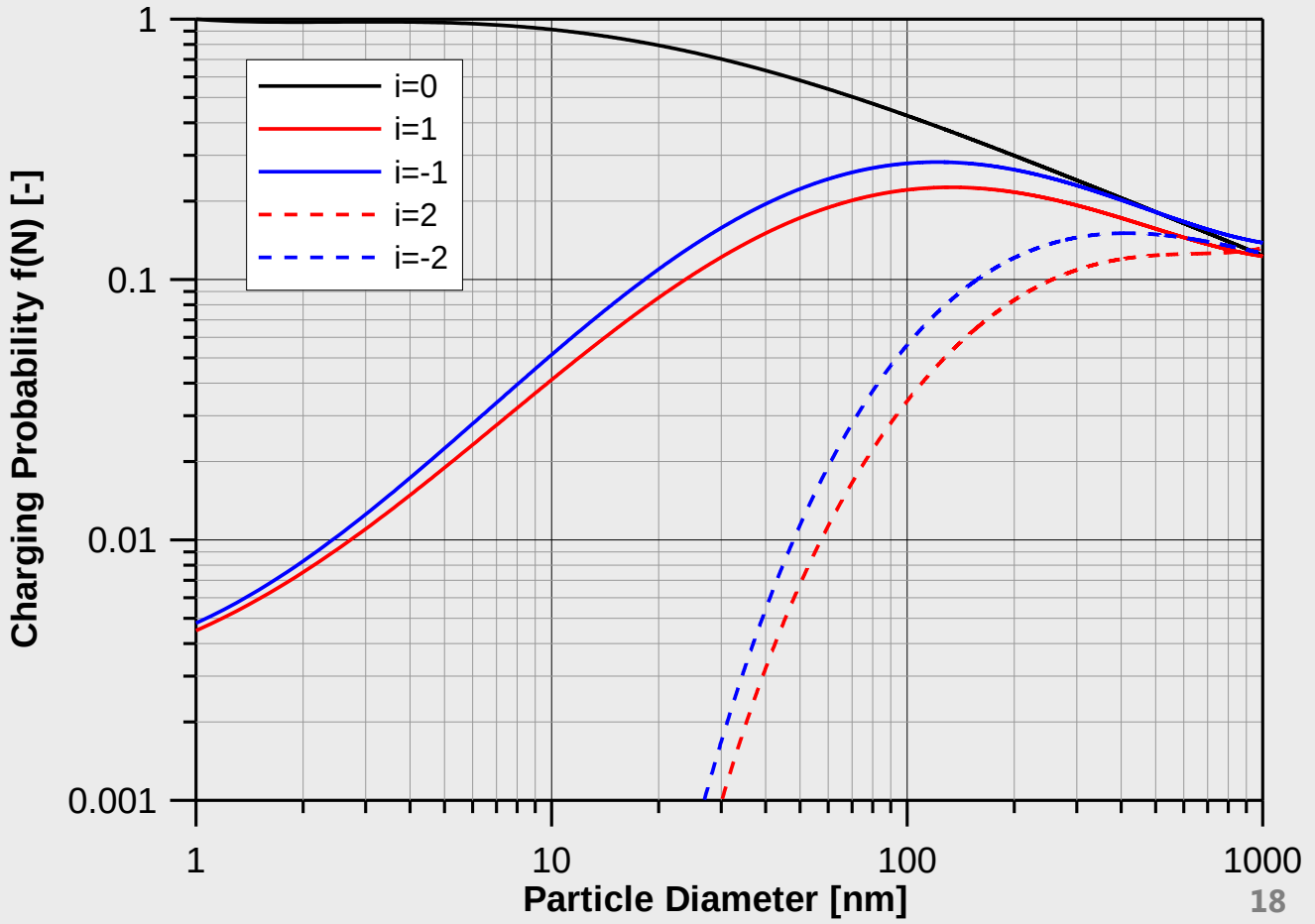
Wiedensohler parametrisation: (Wiedensohler, 1988)

$$f(N) = 10^{\left[\sum_{j=0}^{5} a_j(i)\cdot(\log D_p)^j\right]}$$

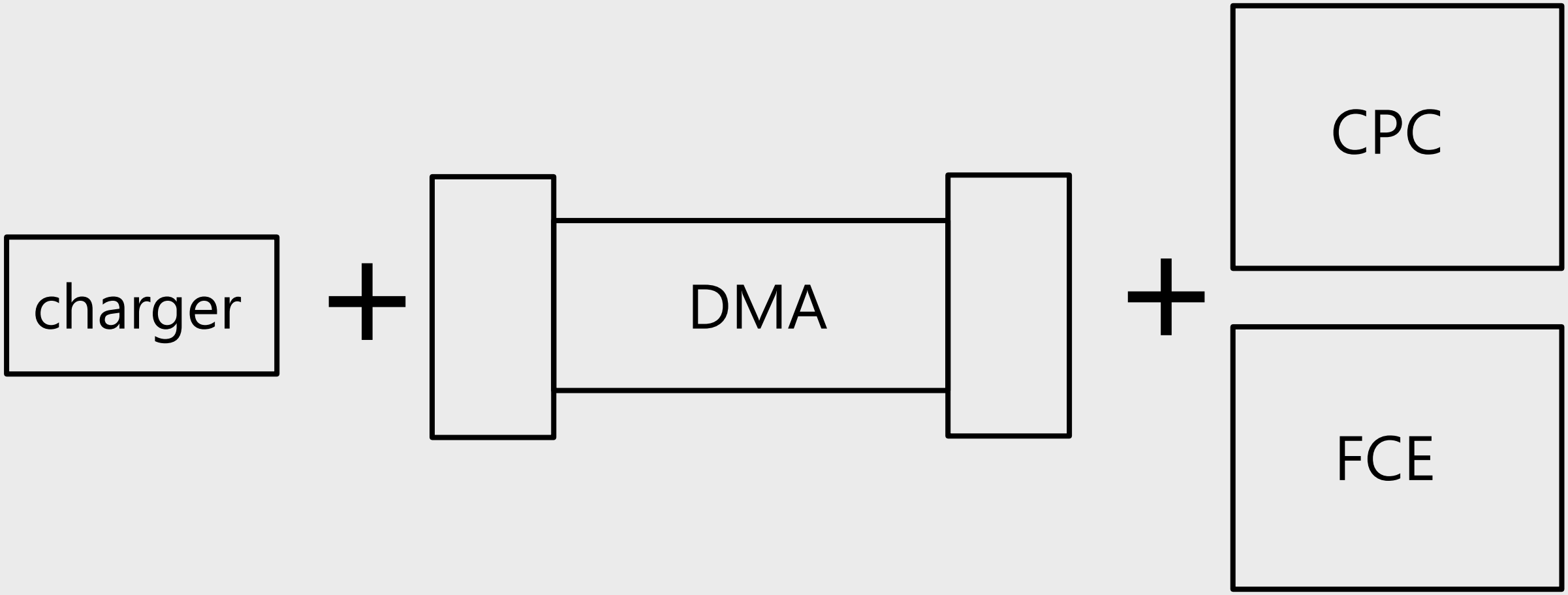
D_p in (nm)

$a_j(i)$	$i = -2$	$i = -1$	$i = 0$	$i = 1$	$i = 2$
a_0	-26.3328	-2.3197	-0.0003	-2.3484	-44.4756
a_1	35.9044	0.6175	-0.1014	0.6044	79.3772
a_2	-21.4608	0.6201	-0.3073	0.4800	-62.8900
a_3	7.0867	-0.1105	-0.3372	0.0013	26.4492
a_4	-1.3088	-0.1260	0.1023	-0.1544	-5.7480
a_5	0.1051	0.0297	-0.0105	0.0320	0.5059

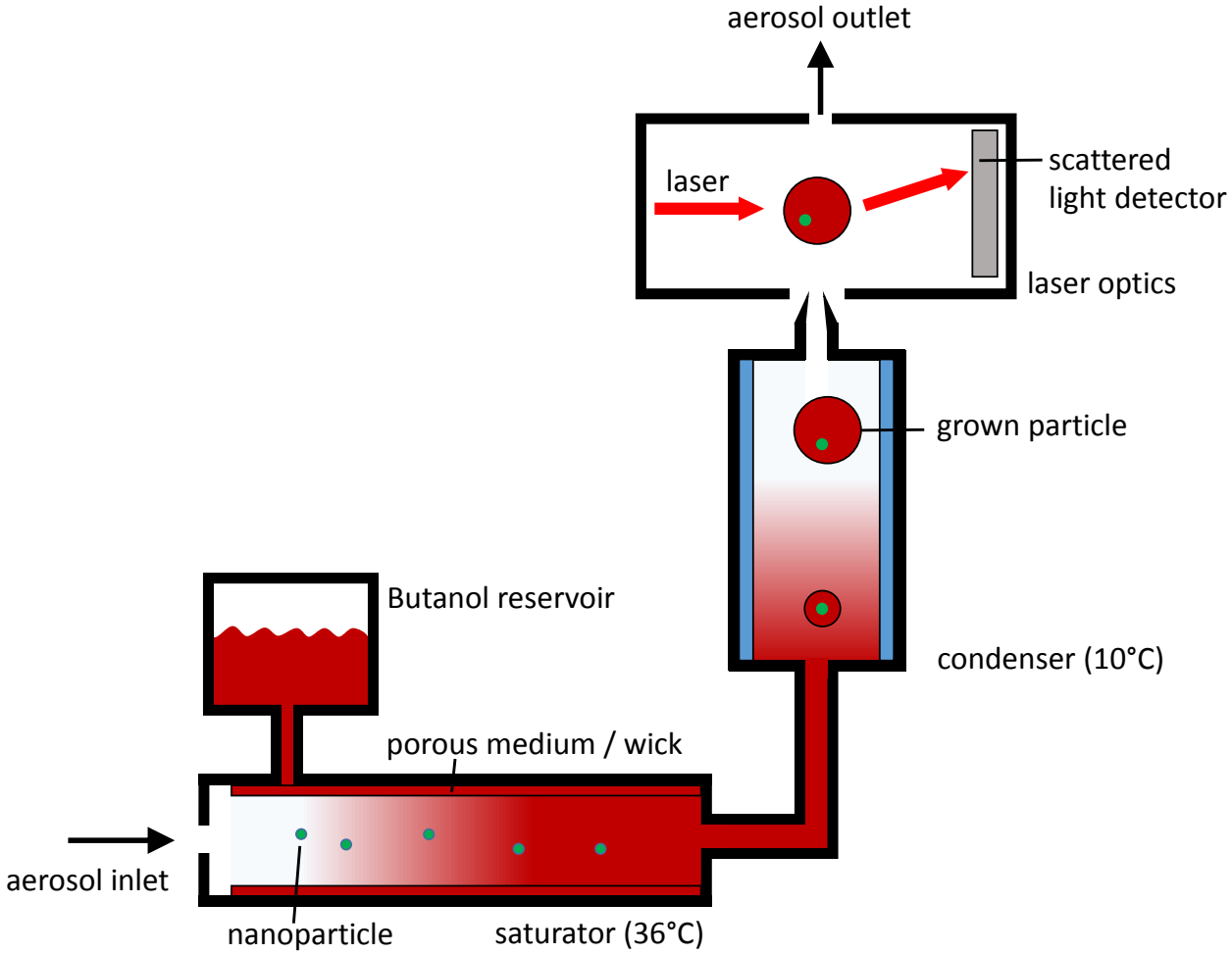
Tab. 2.1 Approximation coefficients $a_j(i)$ of Wiedensohler's formula



SMPS
Scanning Mobility Particle Spectrometer



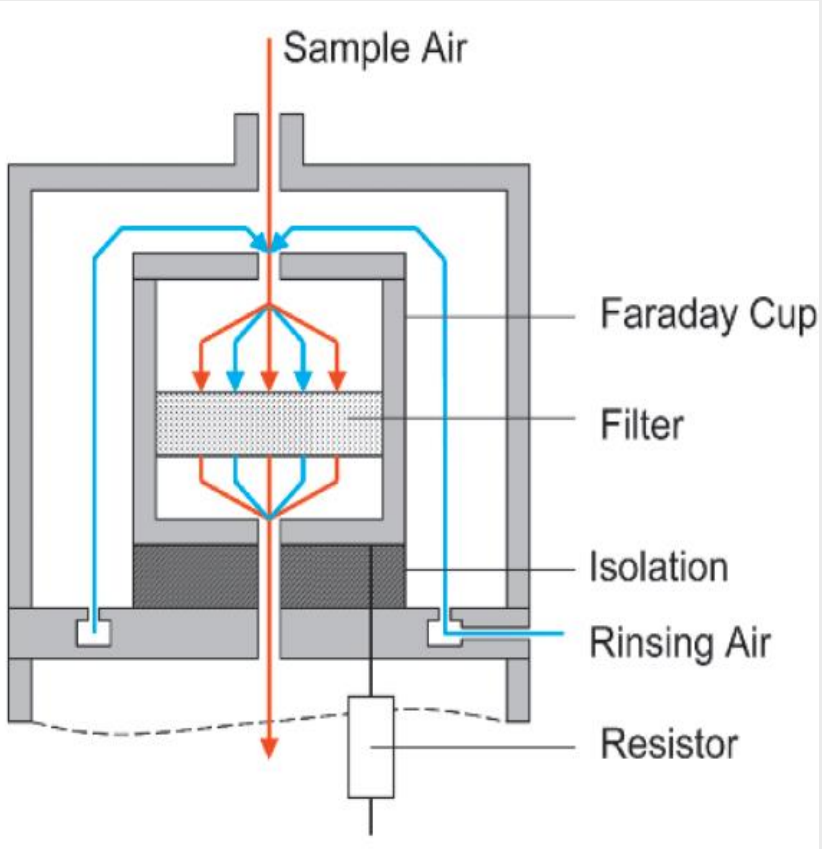
Condensation Particle Counter (CPC)



- particle growth by heterogeneous nucleation
- requires working fluid (butanol, water, DEG,….)
- charged & neutral particles
- single particle counting for low number concentrations
- photometric mode for high number concentrations

- **requires calibration!**

Faraday Cup Elecotrometer (FCE)

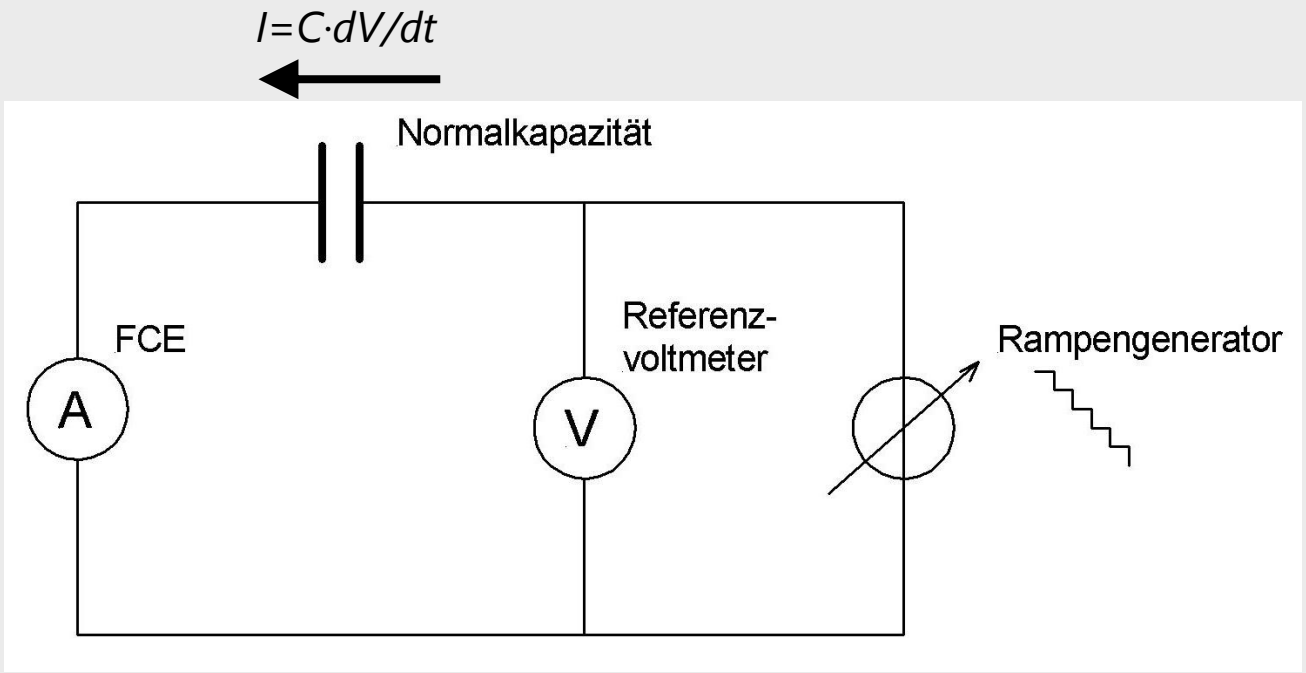


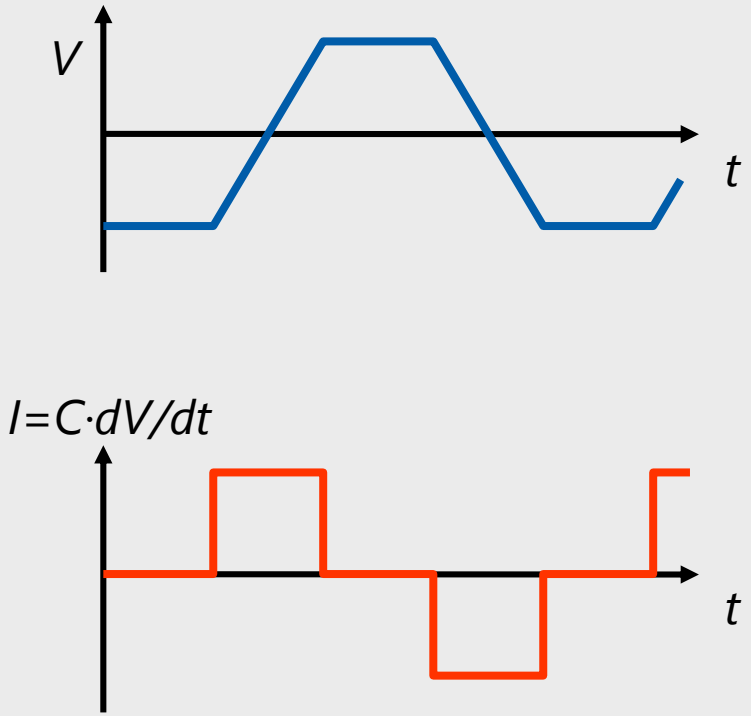
- charged particles collected on filter inside a Faraday-Cup
- change potential of Cup
- rinsing air keeps Cup free of contaminants
- inflow or outflow of e^- balance potential of Cup
- potential difference at high resistance proportional to current of charged particles
- measure for particle number concentration

$$N = \frac{I}{i \cdot e \cdot Q}$$

- only charged particles – very low currents (fA)
- relatively low limit of detetction (0.1 fA $\triangleq 37.5/\mathrm{cm}^3$ @ $1\mathrm{L/min}$)
- in principle no calibration needed, but deduction to standard desireable

FCE calibration set-up @ PTB

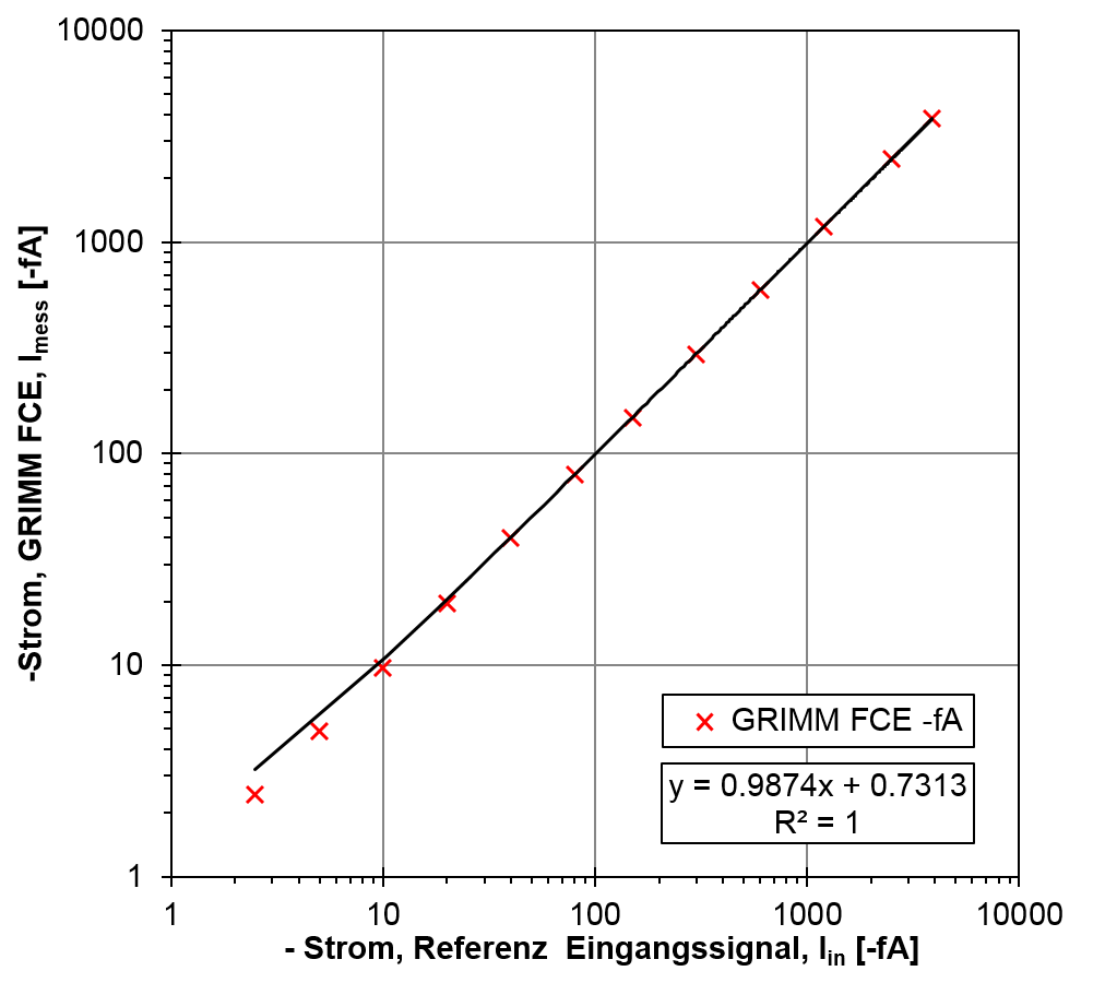


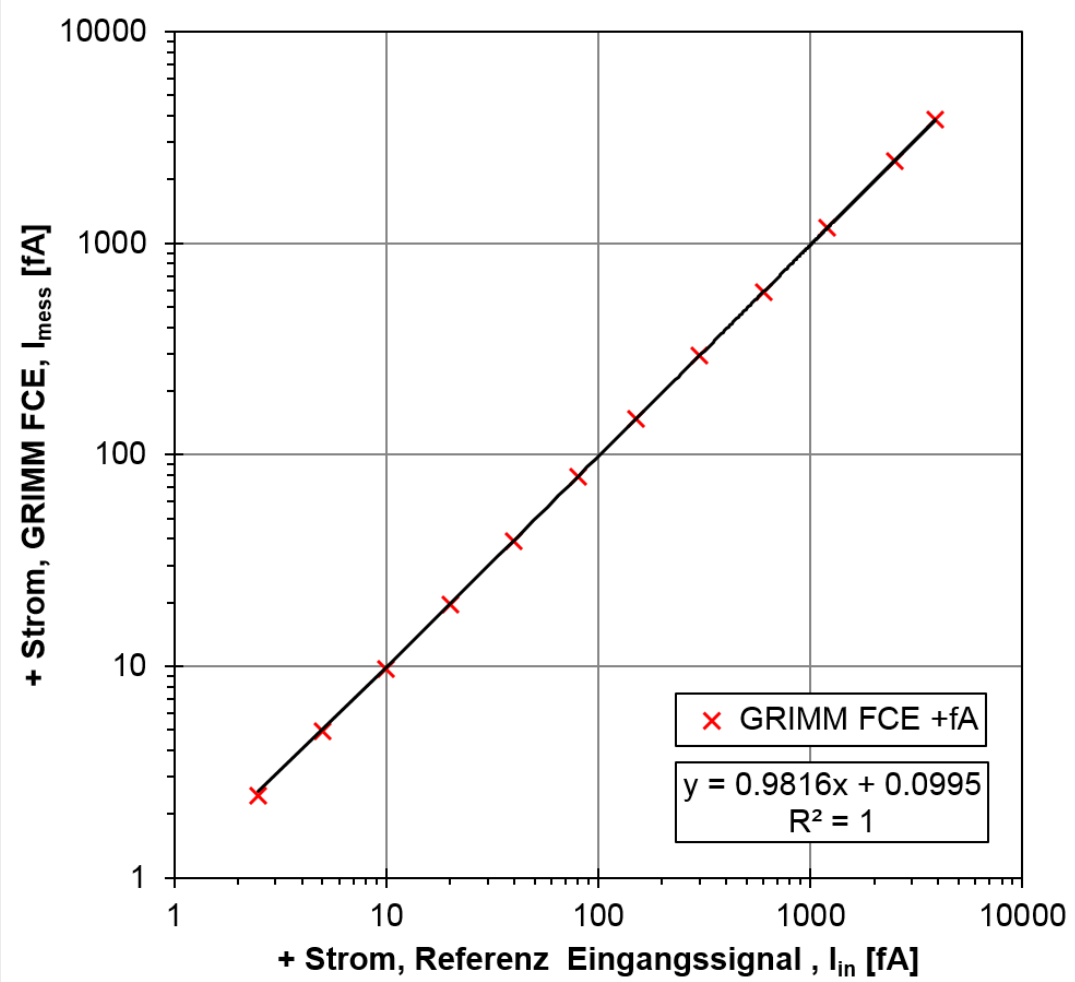


The current is traced back to **Volt**, **Second**, and **Farad**.

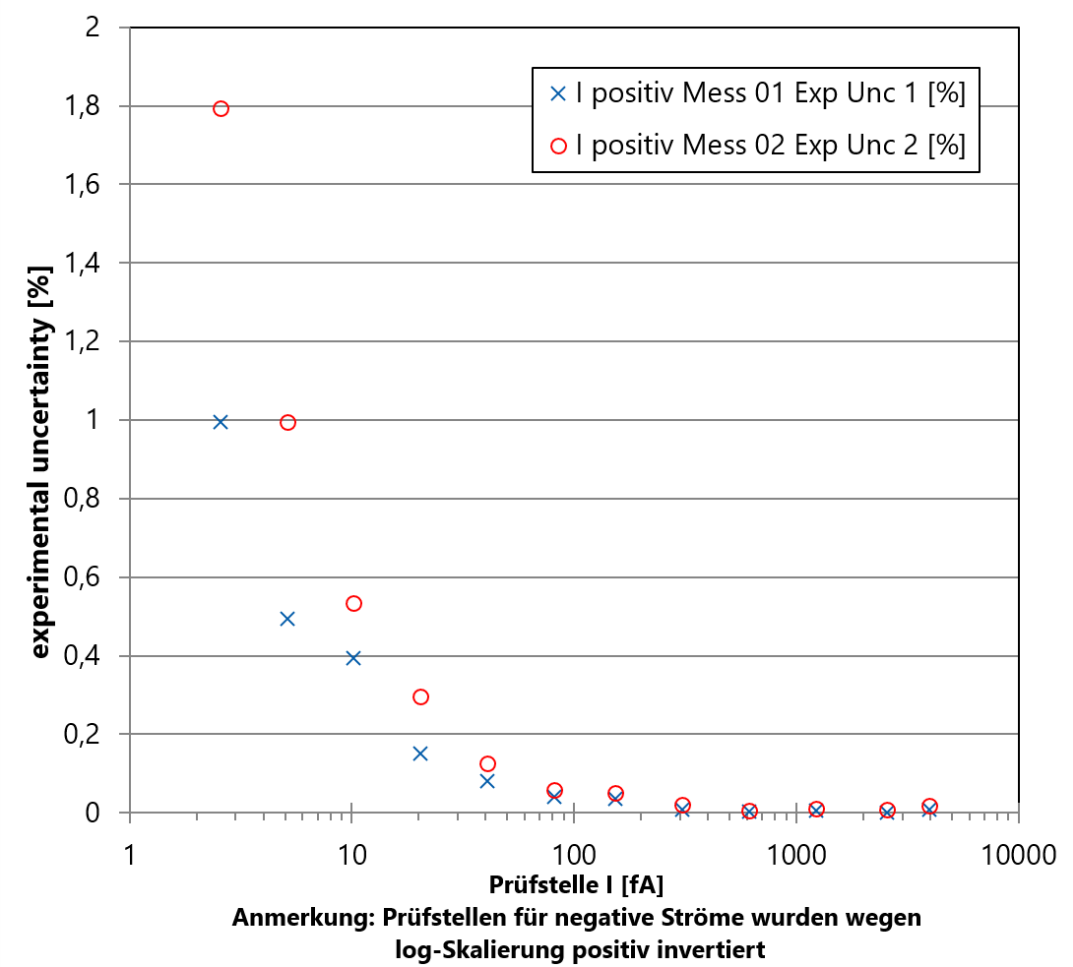
pictures : Rohrig, Willenberg, PTB

FCE calibration results @ PTB





FCE calibration results @ PTB

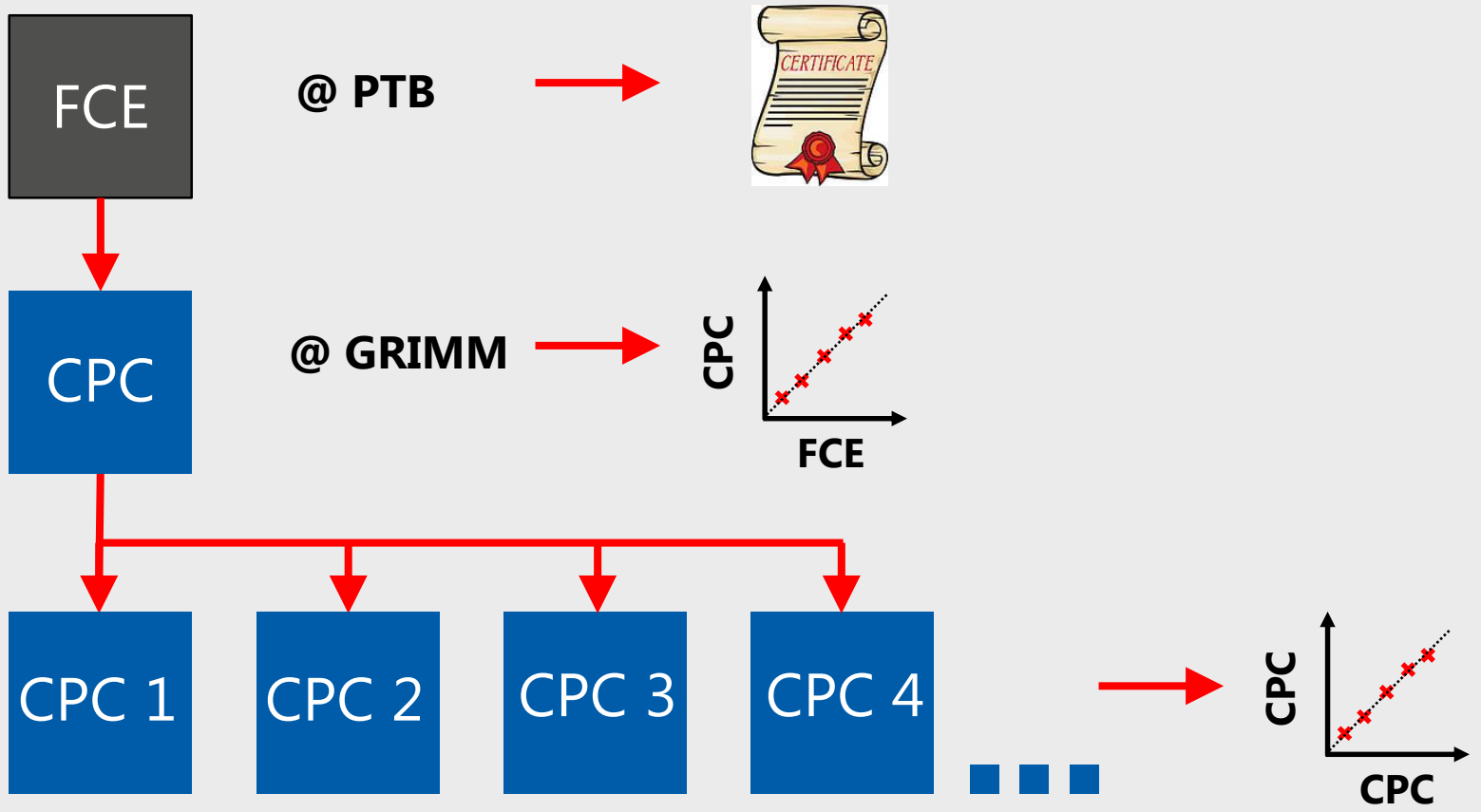


Application of calibrated FCE

1 calibration with traceable official standard

2 company internal standard

3 production units



Application of calibrated FCE & CPC

FCE as reference:

ISO 9001:2015-09 (Quality management)
ISO 27891:2015-1 (CPC calibration)

FCE or CPC as reference:

ISO 21501-1:2009-6 (Aerosolspectrometer calibration)
ISO 21501-4:2006-2 (Clean room counter calibration)
ISO 15900:2009-05 (SMPS calibration)

CPC as reference:

DIN EN ISO 10808:2011-04 (Nanoparticel inhalation)
DIN EN ISO 28439:2011-07 (Nanoparticel workplaces)
RAL-UZ 171:2013-03 (Blauer Engel Laserdrucker)
ISO IEC 28360:2016-02 (Office equipment)
ECMA-328:2017-06 (Electronic equipment)

summary

- aerosols highly complex, dynamic systems
- range of particle size and number concentration over several orders of magnitude
- measure for ultrafine particles (<100nm) is number concentration
- electrostatic techniques for size segregation
- require charging mechanisms
- electrostatic techniques for determination of number concentration
- traceable calibration of electrometer enables calibration of other instruments
- …. and makes many measurments according to ISO standards possible.

Thank your for your attention