„Investigation of a Piezoelectric Plasma Generator as a Charging Source for Aerosols"

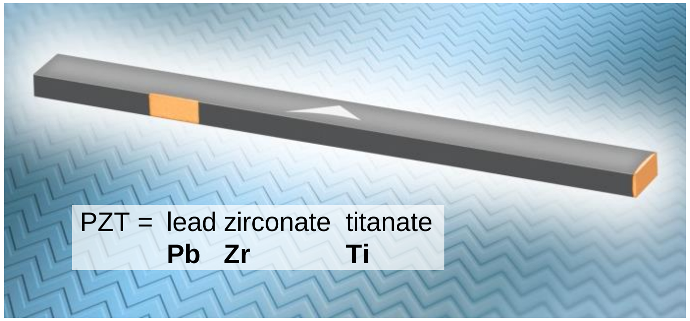
Mario Schriefl[1], Alexander Bergmann[1], Alexander Melischnig[2], Markus Puff[2]

[1] Institute of Electronic Sensor Systems, Graz University of Technology

[2] **EPCOS OHG**, A TDK Group Company

The CeraPlas™

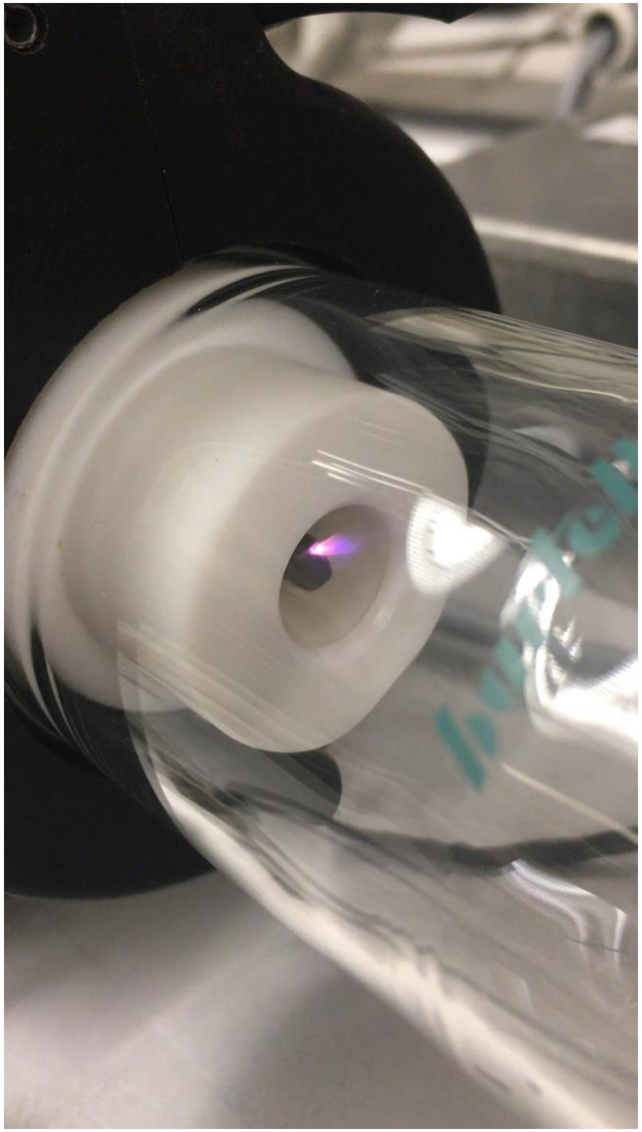
- TDK developed low-cost piezoelectric cold plasma generator "CeraPlas"
- Properties of the CeraPlas
  - cold plasma generation with ion densities up to 2E13 ions/m³ for each polarity
  - no special plasma generating electrode required
  - no high-voltage plugs or cables needed
  - low plasma temperature (< 50 °C)
  - dimensions [mm]: 45 x 4 x 2.8 or 70 x 6 x 2.8
- Applications
  - surface activation
  - ozone generation
  - sterilization of medical equipment
  - wound disinfection



Low input voltage (12V)

High output voltage (10 – 15 kV)

The CeraPlas™



Can the CeraPlas™ act as ion source for bipolar aerosol charging?

Why is this a relevant question?

- Established neutralizers for aerosol size distribution measurements (radioactive, x-ray, Corona) suffer from some drawbacks
  - ineffective for highly charged or small particles and high particle concentrations
  - permission needed for laboratory usage → expensive
  - high voltage generation (Corona)
- CeraPlas benefits
  - high ion concentrations at low power
  - safe operation
  - low-cost
  - small form factor (comparable to lambda sensor)

Can the CeraPlas™ act as ion source for aerosol charging?

How can this question be answered?

- determination of charging parameters based on ion density measurements
- measurement of charge distributions
- tuning of charge distributions to be comparable to reference (Wiedensohler approximation[1])
- Scanning Mobility Particle Sizer (SMPS) spectra: DBD-charger vs. ^{85}Kr charger

Ozone-free post-DBD aerosol bipolar diffusion charger: Evaluation as neutralizer for SMPS size distribution measurements

Rémi Mathon, Nicolas Jidenko, and Jean-Pascal Borra

Laboratoire de Physique des Gaz et des Plasmas, CNRS, Univ Paris Sud, CentraleSupelec, Université Paris-Saclay, Gif-sur-Yvette, France

Our strategy

- Quick-and-dirty SMPS measurements
  - replace neutralizer by CeraPlas
  - can aerosol particles principally be charged by the CeraPlas?
- Charge distribution measurements
  - charge distribution comparison to reference (^{85}Kr, Wiedensohler)?
- Determination of charging parameters
  - measurement of ion densities
  - $N_i t$ product → estimation of steady-state charge distribution
- Tuning of charge distribution
  - tuning of operating parameters to become comparable to reference

[1] Wiedensohler A., “An approximation of the bipolar charge distribution for particles in the submicron size range,” J. *Aerosol Sci.*, vol. 19, no. 3, pp. 387–389, 1988

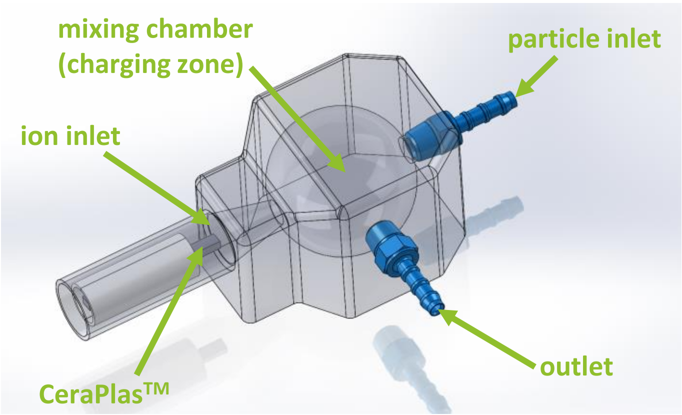
Strategy

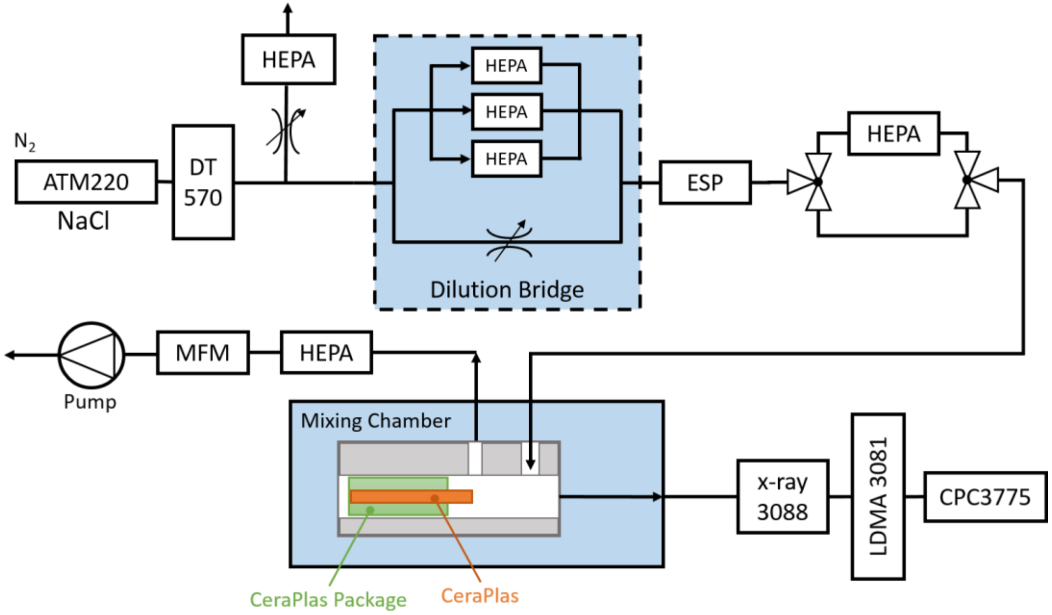
- **Quick-and-dirty SMPS measurements**
- Charge distribution measurements
- Determination of charging parameters
- Tuning of charge distribution

Quick-and-dirty SMPS Measurements

- CeraPlas was mounted inside a pipe
- A charging chamber was designed for mixing of ions and particles to avoid particle contamination of the device
- With an electrostatic precipitator the charging effect of the CeraPlas was compared to a TSI 3088 x-ray source

Experimental Setup

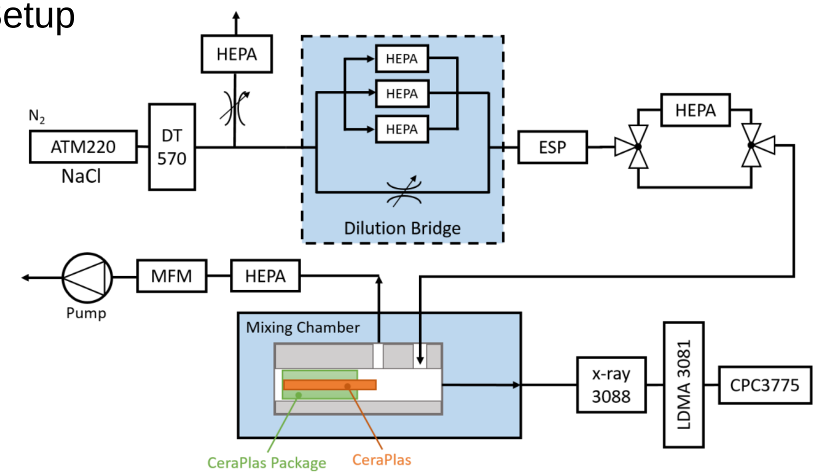


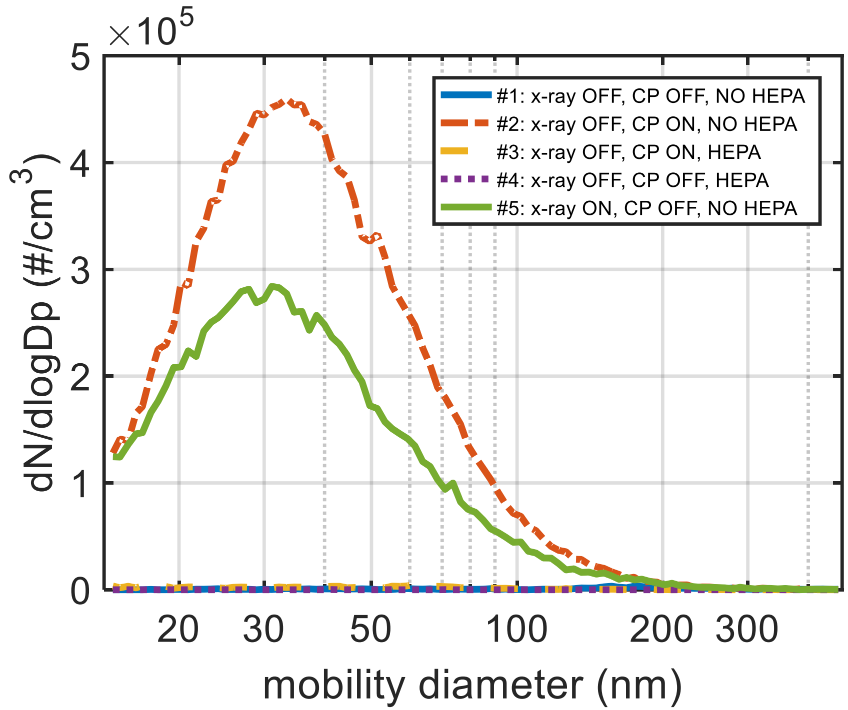


First Results

- No particles "visible" without charging source (#1, #4)
- Charging of neutral particles with CeraPlas (#2)
- Charging of neutral particles with TSI 3088 x-ray neutralizer (#5)
- Particle emissions from device (tested with HEPA filter): no particle contamination from CeraPlas (#3)

Experimental Setup



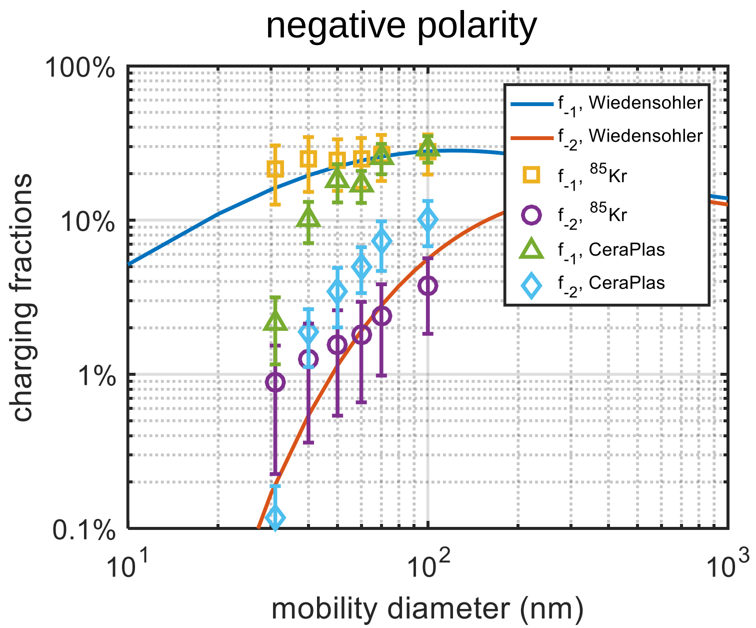


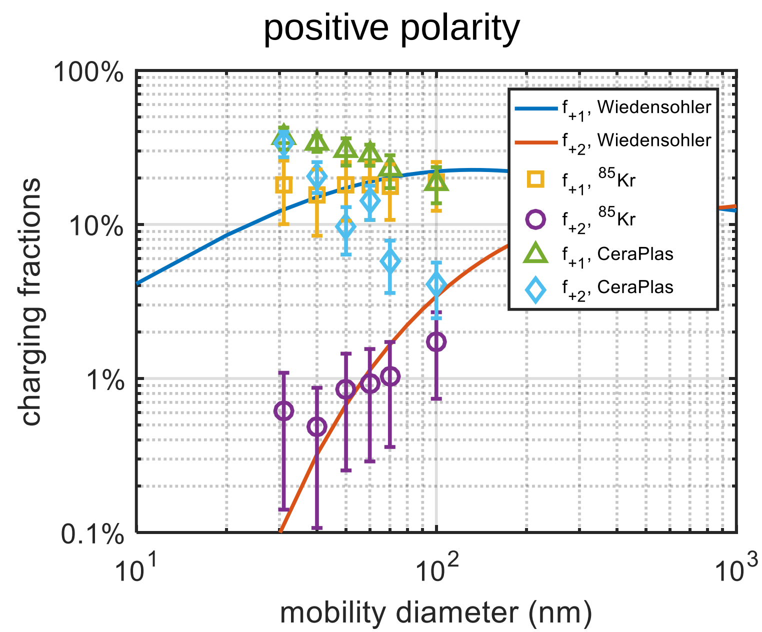
→ **Basically it is possible to charge particles using the CeraPlas**

Strategy

- Quick-and-dirty SMPS measurements
- **Charge distribution measurements**
- Determination of charging parameters
- Tuning of charge distribution

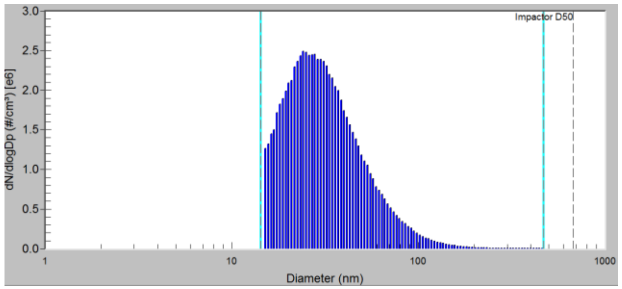
Results: Charge Distributions CeraPlas vs. Reference





- negative charging fractions show correct trend
- big deviations for positive charging fractions
- for bigger particle sizes results fits better to reference
  → steady state conditions??

Size distribution of test aerosol



→ **investigation of charging parameters!!**

Strategy

- Quick-and-dirty SMPS measurements
- Charge distribution measurements
- **Determination of charging parameters**
- Tuning of charge distribution

Determination of Charging Parameters

- Ion densities measurements
  - important to characterize CeraPlas
  - input parameter for calculation of $N_i t$ product
  - determination of N_i/N_p which should be > 10 [3]
- $N_i t$ product
  - product of ion density times the residence time of particles in that ion atmosphere
  - a value of 6E12 sm^{-3} necessary to achieve steady state charge distribution which is independent from aerosol concentration and initial charge [2]
  - high $N_i t$ product important for reliability and reproducibility of SMPS measurements
- Methods
  - measurement of **inlet ion concentrations** with Ionometer IM806V2

    $$\mathbf{N_i^+ = (3.48E6 \pm 0.05E6)\ cm^{-3}}$$

    $$\mathbf{N_i^- = (3.15E6 \pm 0.08E6)\ cm^{-3}}$$

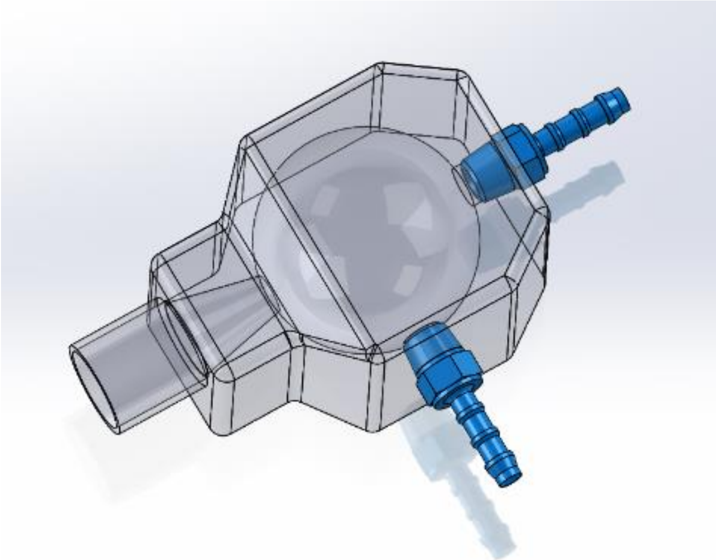
  - calculation of $N_i t$ product with multiphysical simulation

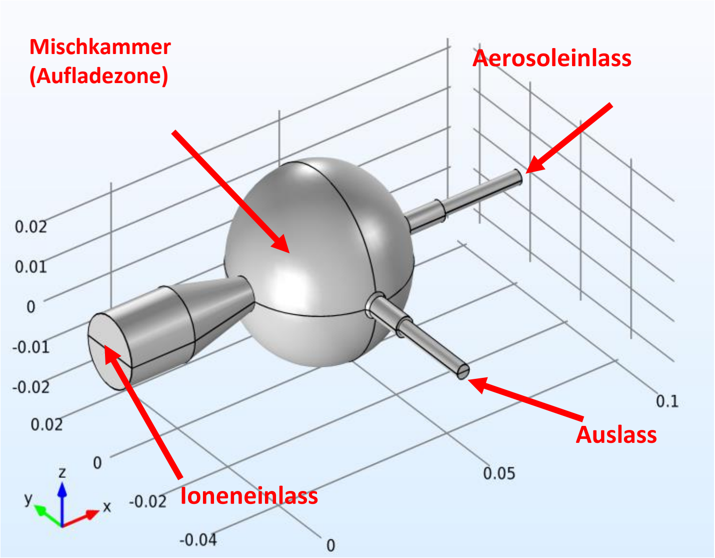
[3] M. Adachi, K. Okuyama, Y. Kousaka, H. Kozuru, and D. Y. H. Pui, “Bipolar Diffusion Charging of Aerosol Particles Under High Particle/Ion Concentration Ratios,” *Aerosol Sci. Technol.*, vol. 11, no. 2, pp. 144–156, 1989.

[2]… R. Mathon, N. Jidenko, and J.-P. Borra, “Ozone-free post-DBD aerosol bipolar diffusion charger: Evaluation as neutralizer for SMPS size distribution measurements,” *Aerosol Sci. Technol.*, vol. 6826, no. January 2017, pp. 1–10, 2016

$N_i t$ Product

- …is the product of ion density times the residence time of particles in that ion atmosphere
- …is an important charging parameter (indicator of steady state charge distribution)
- normally the $N_i t$ product is determined via
  - measurement of ion density in charging area
  - calculation of residence time from flow rate assuming plug flow
  - → not very accurate
- Idea: determination via 3D model → simulation of mixing chamber





$N_i t$ Product – Modelling of Mixing Chamber

- Determination of the $N_i t$ product
  - turbulent flow profile within mixing chamber
  - ion density profile: transport of positive/negative ion species

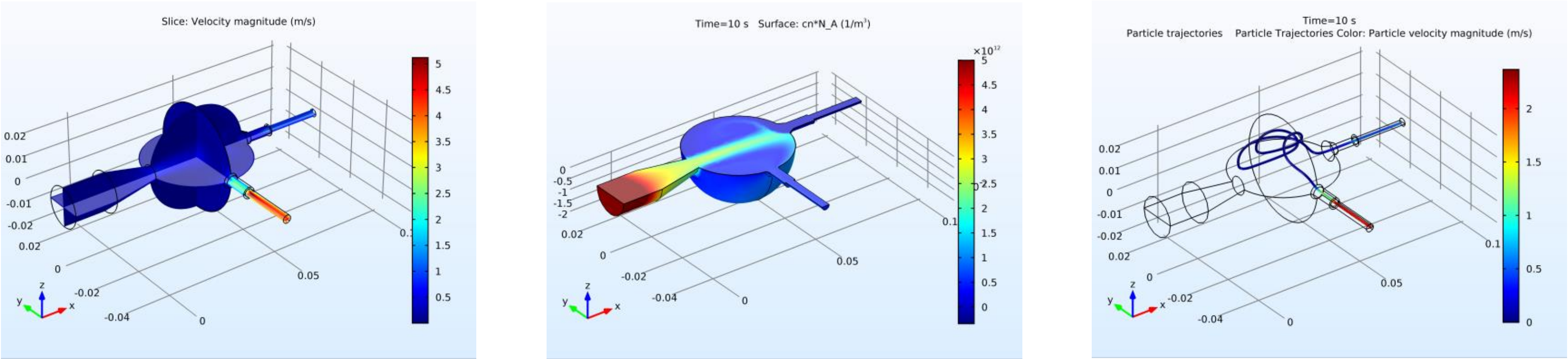
$$\frac{\partial N_i^+}{\partial t} = \nabla(-D_i^+ \nabla N_i^+) + u \cdot \nabla N_i^+ - \alpha N_i^+ N_i^-$$

$$\frac{\partial N_i^-}{\partial t} = \nabla(-D_i^- \nabla N_i^-) + u \cdot \nabla N_i^- - \alpha N_i^+ N_i^-$$

$N_i^{\pm}$… pos./ neg. ion density
$D_i^{\pm}$… ion diffusion coefficient (0.357E-5 m²/s, [4])
α … ion recombination coefficient (1.6E-12 m³/s [2])

  - "typical" particle trajectory: drag force acting on aerosol particle
  - calculation of $N_i t$ product by integrating the ion density along particle trajectory

$$N_i t = \int N_i\left[\vec{q}_p(t)\right] dt$$



flow velocity profile (Q_1=0.3 lpm, Q_2=1 lpm)

ion density profile ($N_i^{\pm,\ inlet}$ = 2E13 m^{-3})

particle trajectory, released at midpoint of inlet cross section

[4]… G. Biskos, "Theoretical and experimental investigation of the differential mobility spectrometer," no. January, 2004
[2]… R. Mathon, N. Jidenko, and J.-P. Borra, "Ozone-free post-DBD aerosol bipolar diffusion charger: Evaluation as neutralizer for SMPS size distribution measurements," *Aerosol Sci. Technol.*, vol. 6826, no. January 2017, pp. 1–10, 2016

$N_i t$ Product – Results

- used parameters
  - Flow: Q_1=0.3 lpm, Q_2=1 lpm,
  - ion densities from measurement: $N_i^+ = 3.48E12\ m^{-3}$, $N_i^- = 3.15E12\ m^{-3}$,
  - particle diameter d_p = 100 nm, number of released particles N_p^{rel} = 1000
- **$N_i t$ Product:** $N_i^+ t$ = 3.95E+11 s/m³, $N_i^- t$ = 3.89E+11 s/m³ → **$N_i t$ = 4E+11 s/m³**
- Shortcomings of the model
  - diffusion coefficient of ions not known → uncertainty

    (for model hydrated proton ionic clusters with $D_i^{\pm}$ = 0.357E-5 m²/s were assumed)
  - ion recombination coefficient from literature
  - no consideration of other ion loss mechanisms (ion diffusion, space charge, etc.)
- Benefits of the model
  - flow consideration (usually plug flow is assumed)
  - ion density distribution considered
- Conclusions
  - new method of $N_i t$ product was introduced
  - $N_i t$ values of about 4E11 s/m³ is critically low
  - $N_i t$ product must be increased!!!

Strategy

- Quick-and-dirty SMPS measurements
- Charge distribution measurements
- Determination of charging parameters
- **Tuning of charge distribution → t.b.d.**

Summary and Outlook

- Bipolar aerosol particle charging is principally possible with CeraPlas
- Measured charge distributions show strong deviations from reference results
- Method for calculation of $N_i t$ product was introduced
- Charging conditions ($N_i t$ product) need to be enhanced

Next steps:

- Increase $N_i t$ product
  - increase residence time t → flow / geometry optimization
  - increase ion density N_i → power / positioning of CeraPlas
- Detailed investigation of charge distribution
  - steady-state conditions: is it possible to be comparable to reference?
  - impact of particle concentration / size

Thank you for your attention!!

Questions?????