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Bipolar Neutralization using Radioactive, X-ray, and AC Corona Methods

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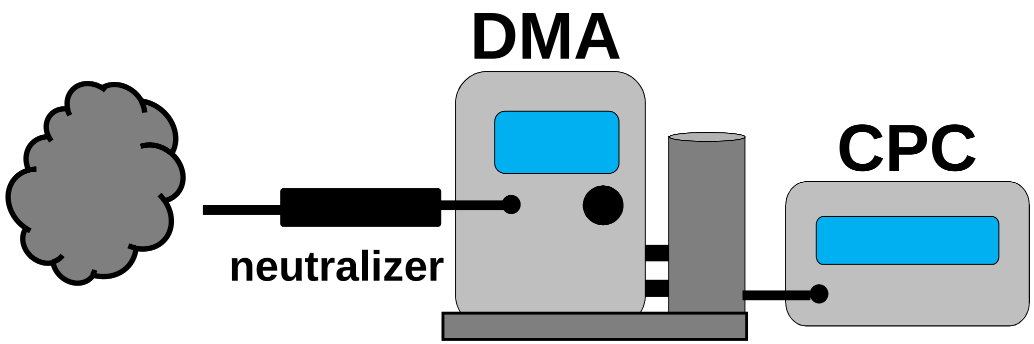
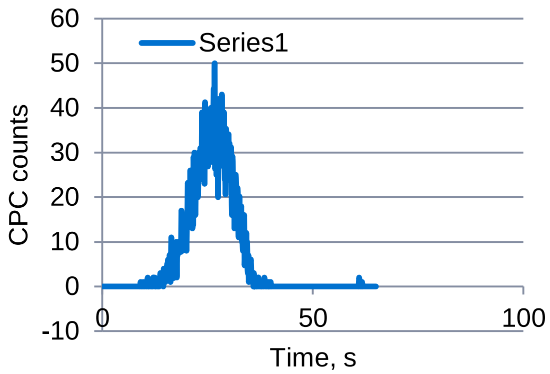
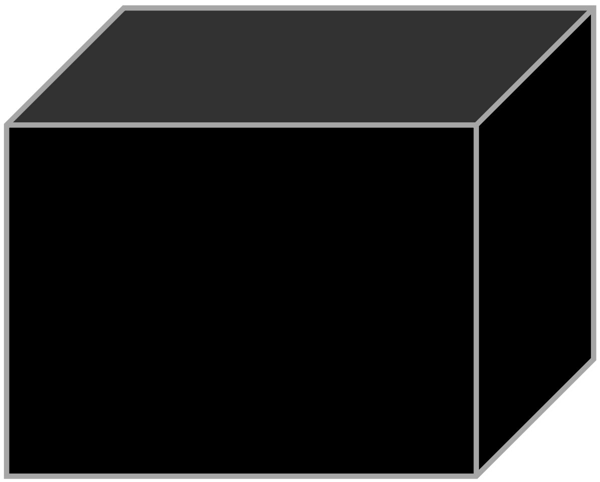
Outline

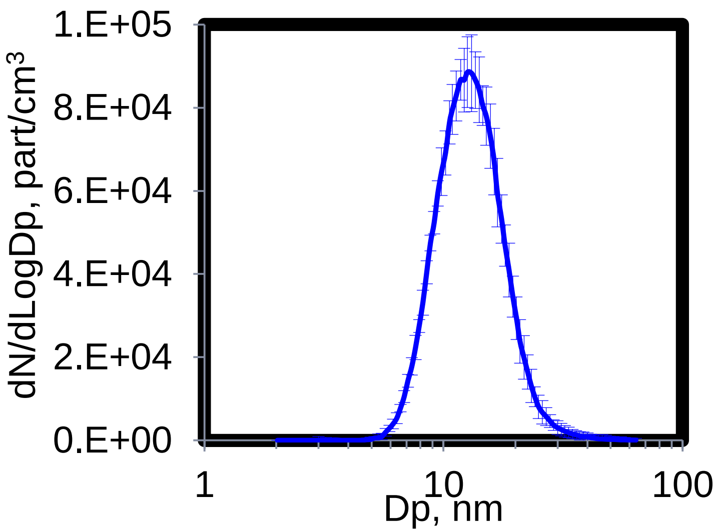
- **Motivation**
- **Background – charge fraction**
- **Experimental charging conditions**
  - Neutralizers
  - Carrier gas
- **Results**
  - Size distributions
  - Ion mobility
  - Charged fraction
- **Summary and conclusions**

Motivation – particle size distribution measurements









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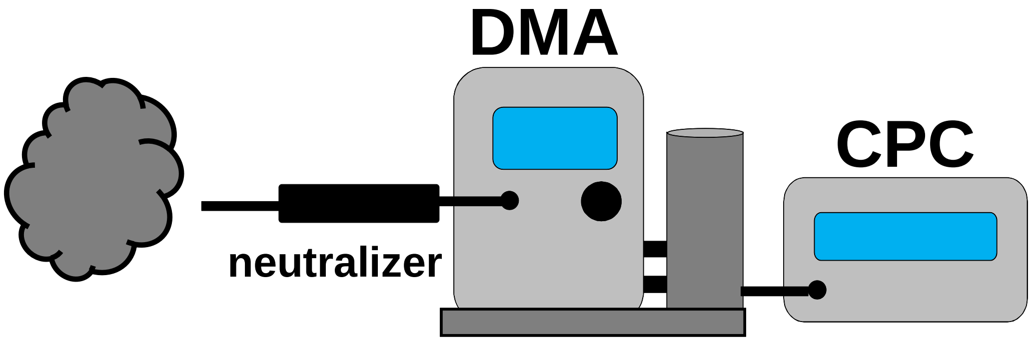
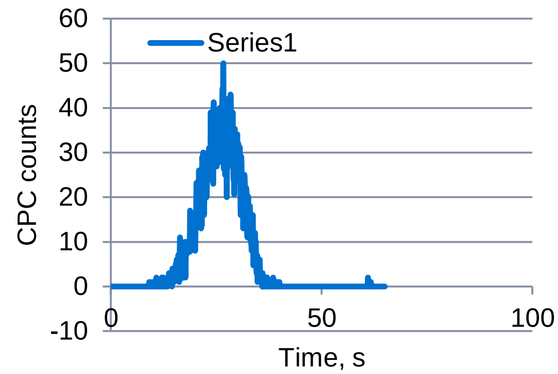
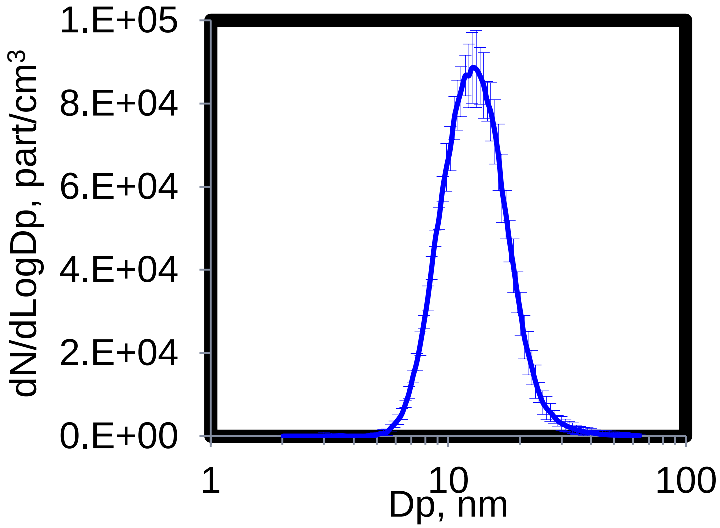




- Prevailing conditions
- Delay time
- Residence time
- Transfer function (Ω)
- Transport losses
- CPC counting efficiency
- Fraction of particles with +1 charge



Objectives and methodology

- Objective: determine sources of uncertainty in the charge-to-concentration inversion required for size distribution measurement
- **Measure charging characteristics in diverse systems using different neutralization techniques**
  - Particle charging (+1 fraction) depends on ion mobility and mass
  - Ion mobility and mass depends on carrier gas properties
    - Quantify experimentally
      - Particle size distributions
      - Ion distributions
      - Particle charge
    - Calculate sensitivity (Fuchs' theory)

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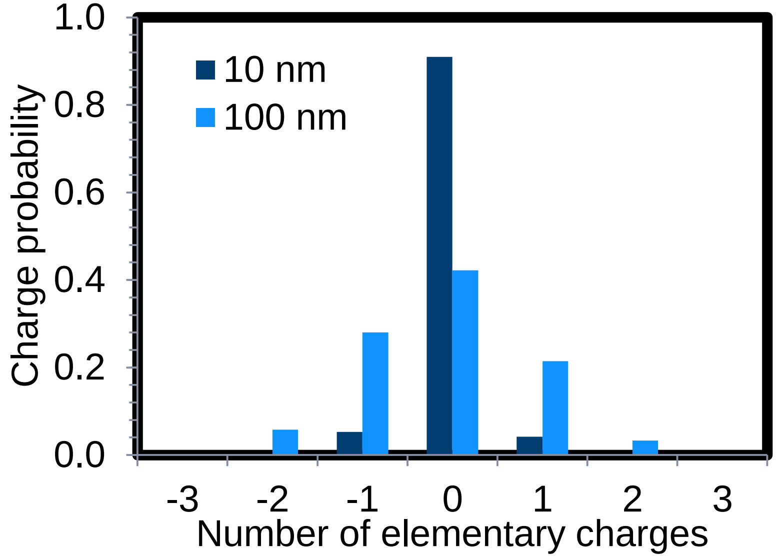
+1 fraction – stationary charge distribution

Fuchs' limited sphere model to calculate charge distribution

- Temperature
- Ion mobility
- Ion mass



Wiedensohler approximation of Fuchs' (Implemented in SMPS™ software)

- Ion mobility – measured (radioactive source)
- Ion mass – fitted result (Hussin et al. 1983)

Our calculations

- Ion mobility – measured
- Ion mass – calculated from Kilpatrick (1972) relationship

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Hussin, A., Scheibel, H. G., Becker, K. H. and Porstendorfer (1983) J. Aerosol Sci. 14, 671.
Kilpatrick, W. D. (1971) Proc. Annual Conf on Mass Spectroscopy 19th., 320-325.
Wiedensohler, A. (1988) Journal of Aerosol Science 19(3), 387-9.
Fuchs, N. A. (1963) Geofis. pura appl. 56, 185.

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Experimental apparatus

- **Aerosol neutralizers**
  - TSI 3077 (2 mCi ^{85}Kr with est. current activity = 0.84 mCi)
  - TSI 3077A (10 mCi ^{85}Kr with est. current activity = 8.3 mCi)
  - MSP M1090 Electrical Ionizer (AC corona discharge)
  - TSI 3087 Advanced Aerosol Neutralizer (soft X-ray)
- **Neutralizing conditions**
  - Dry nitrogen (N_2)
  - Humidified air (various H_2O)
  - Humidified air with 20 ppb sulfur dioxide (SO_2)

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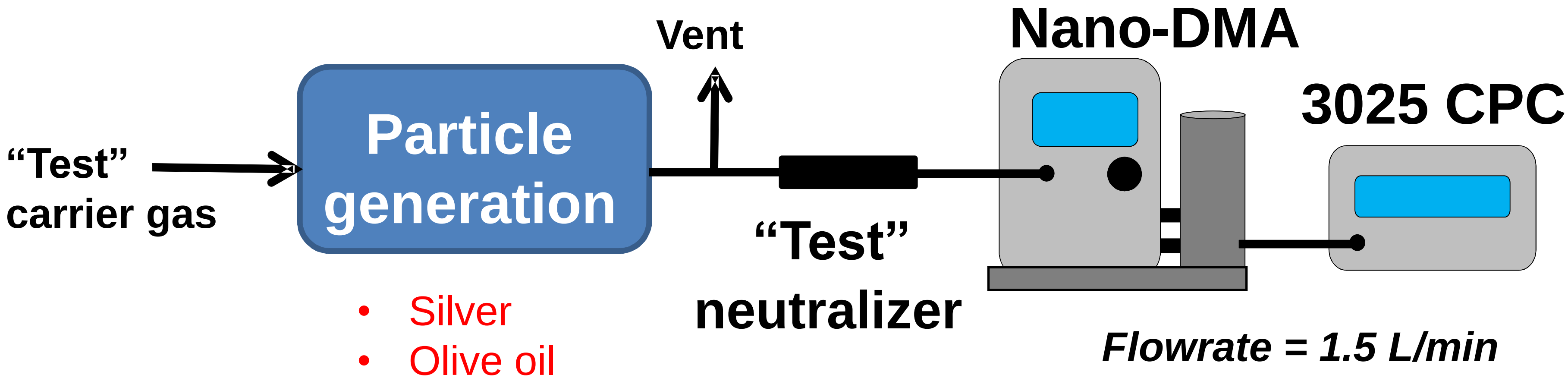
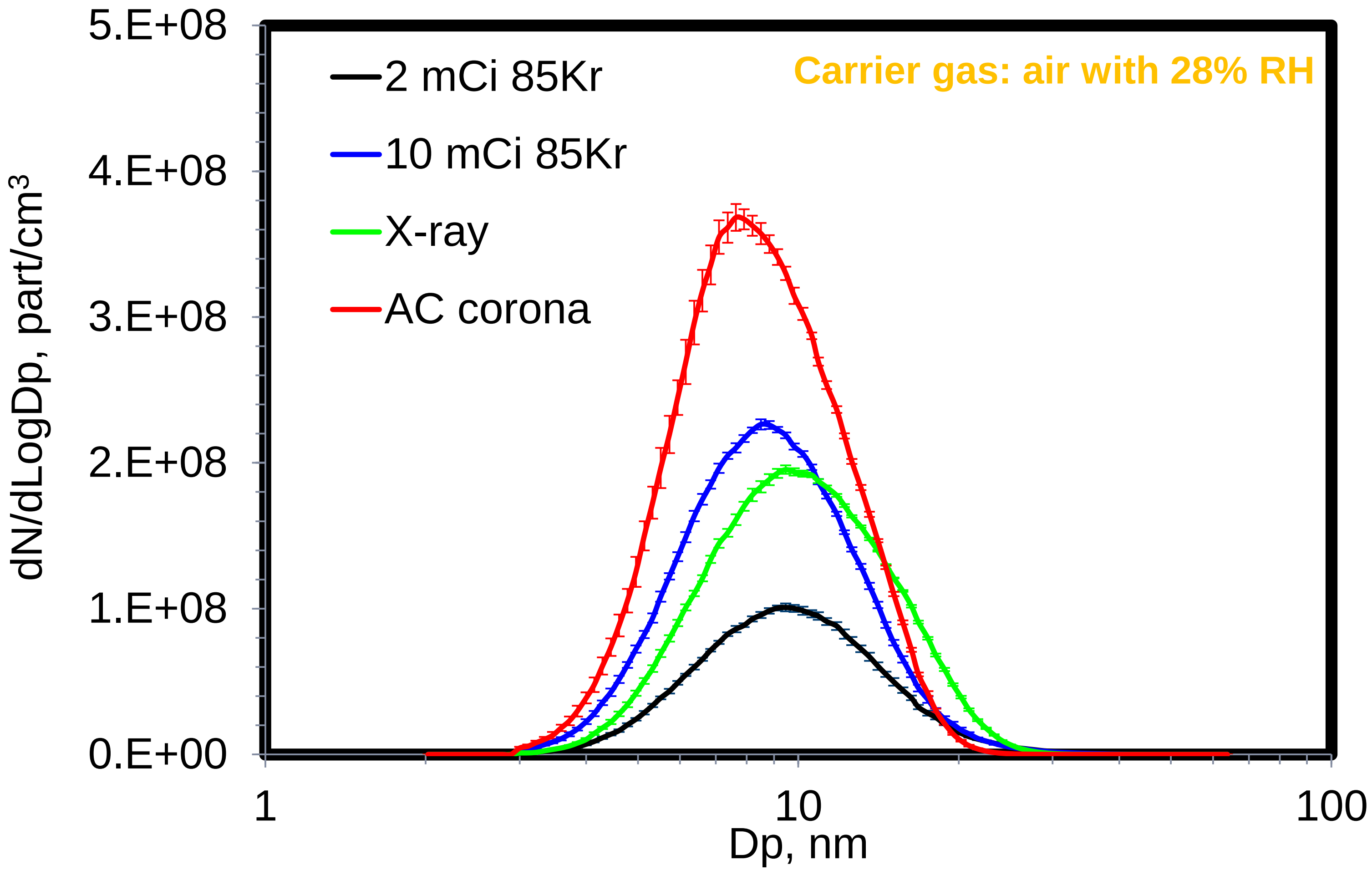
Apparatus – particle size distributions

Size distribution inversion from Wiedensohler, 1988 (standard method)

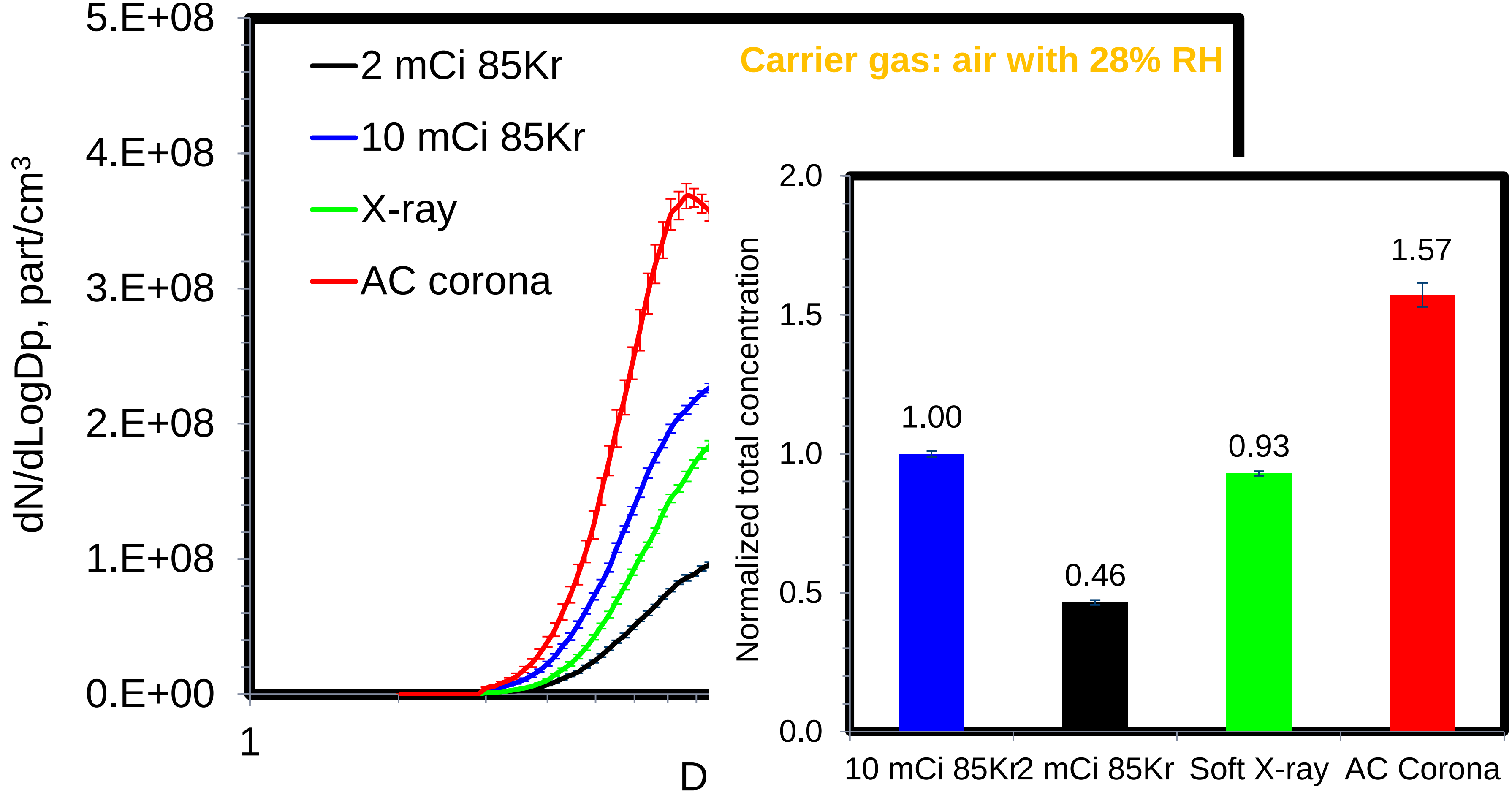


- Silver
- Olive oil
- Soot

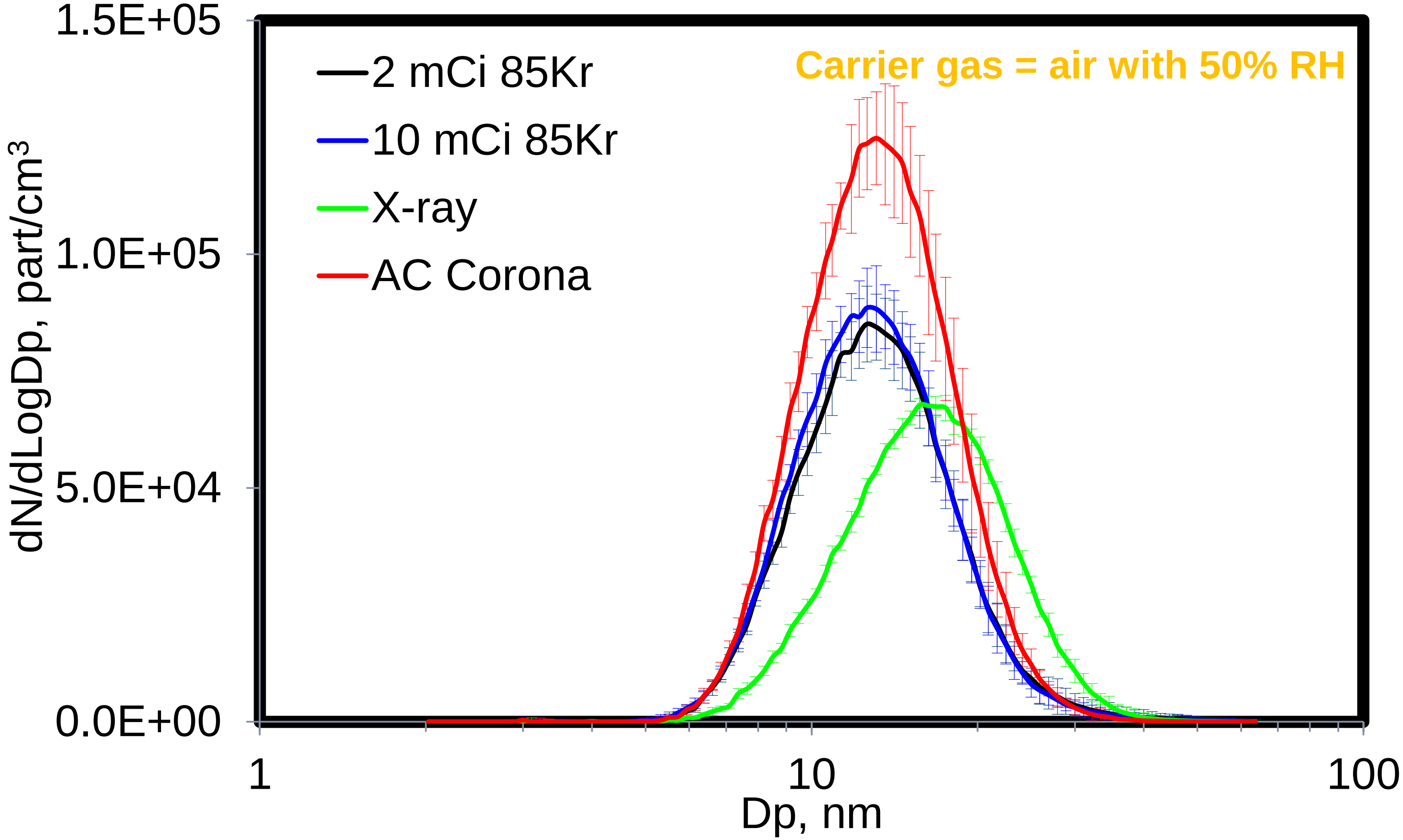
Silver size distributions (high concentration)



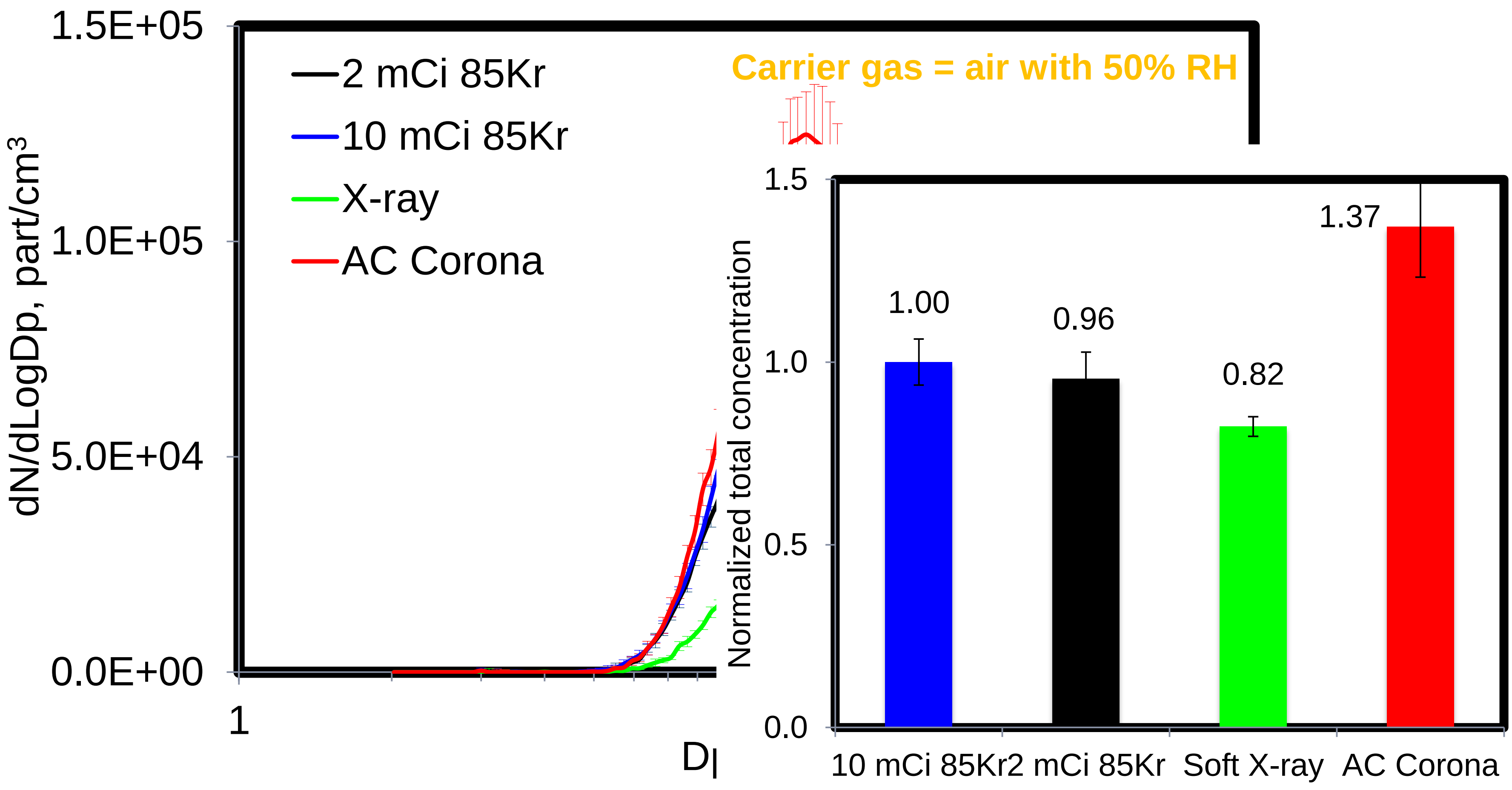
Silver size distributions (high concentration)



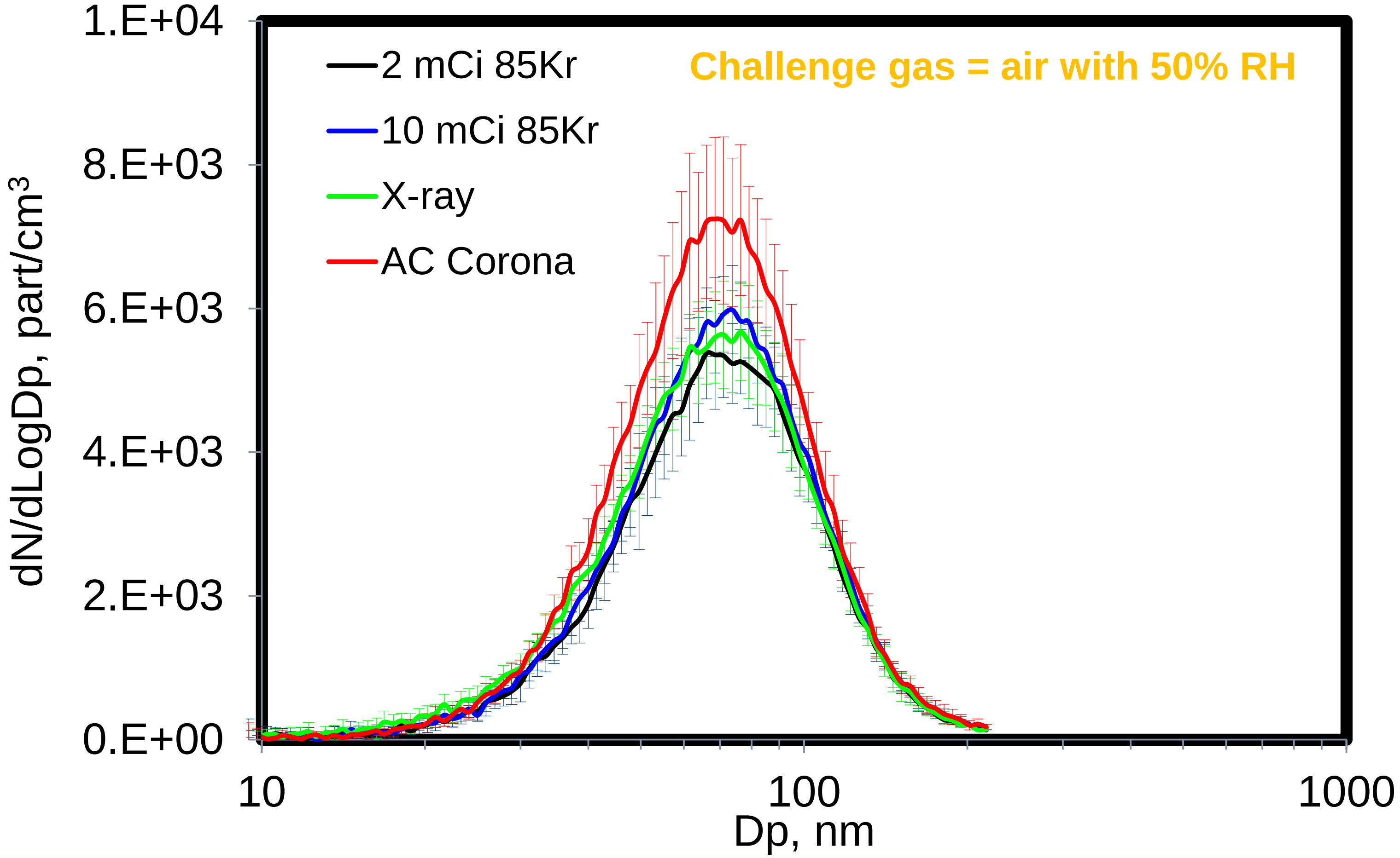
Silver size distributions (low concentration)



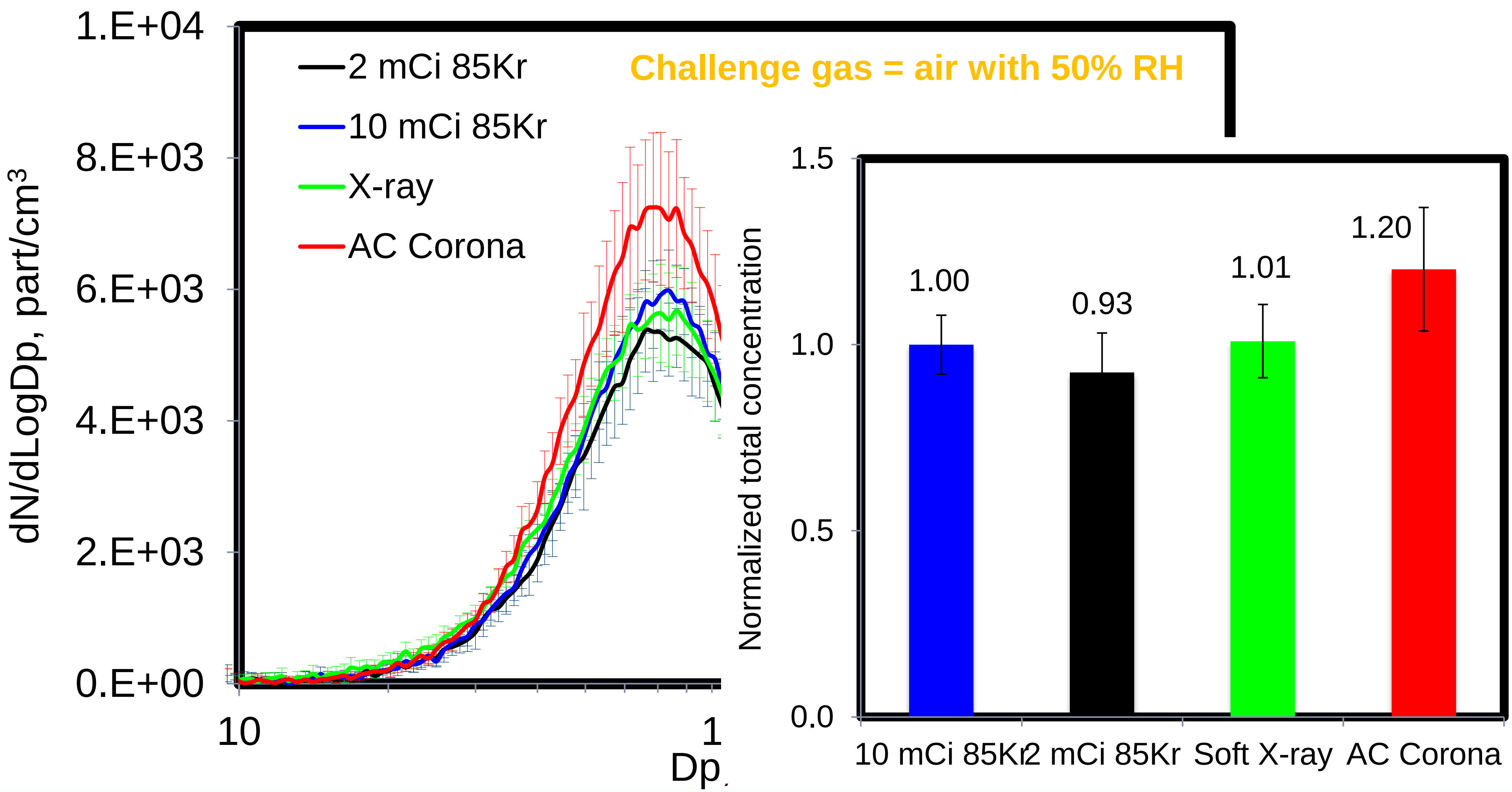
Silver size distributions (low concentration)



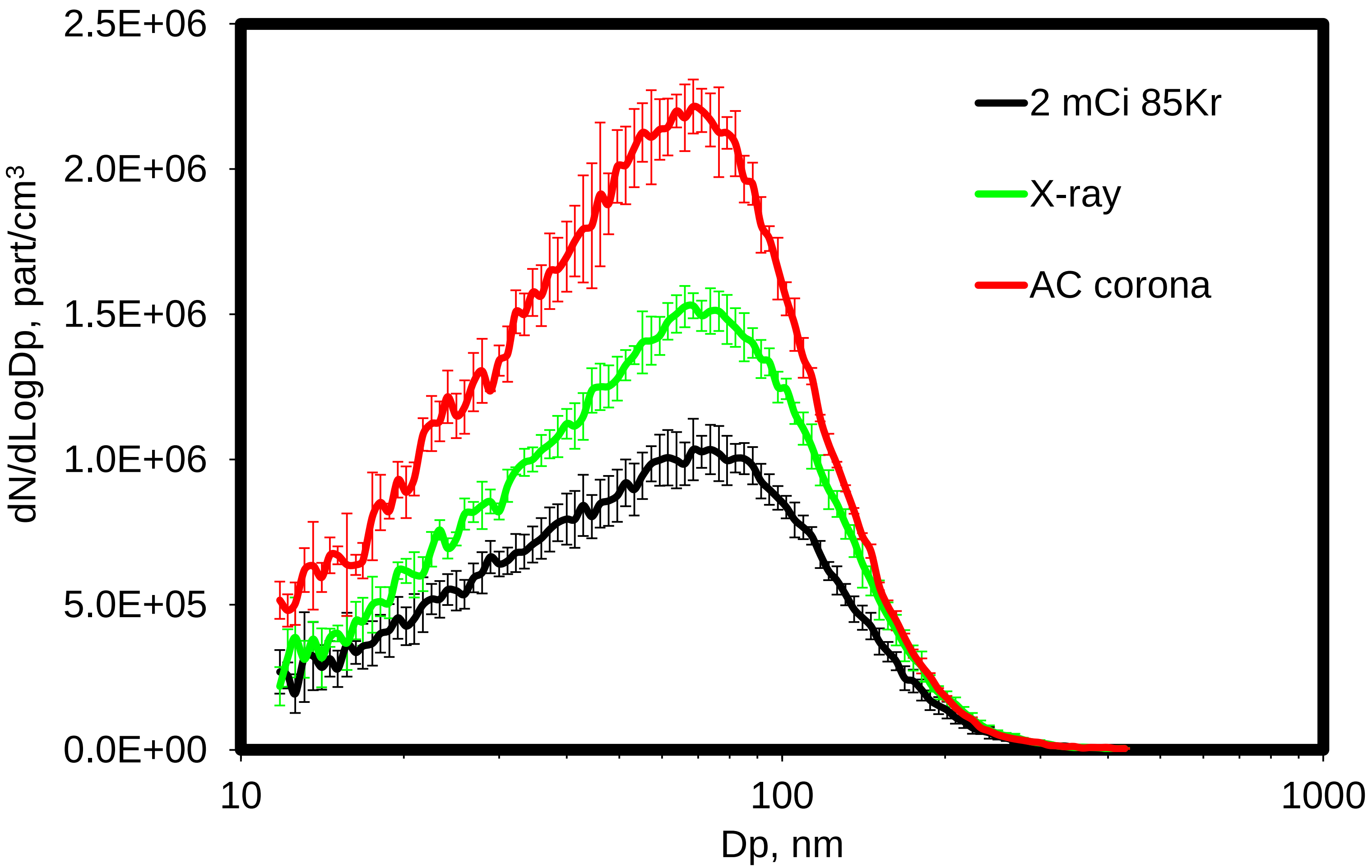
Oil droplet size distributions



Oil droplet size distributions

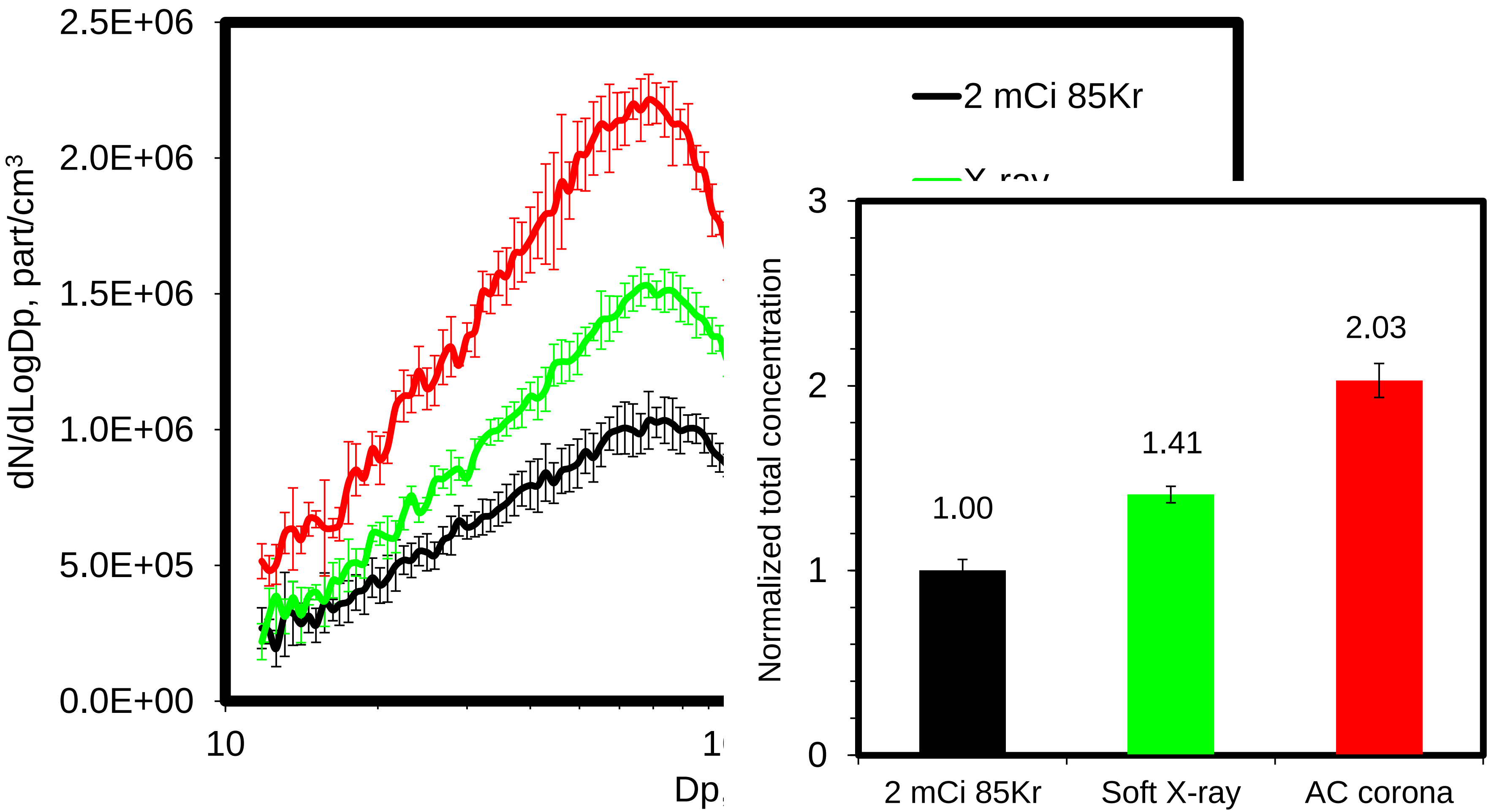


Soot size distributions

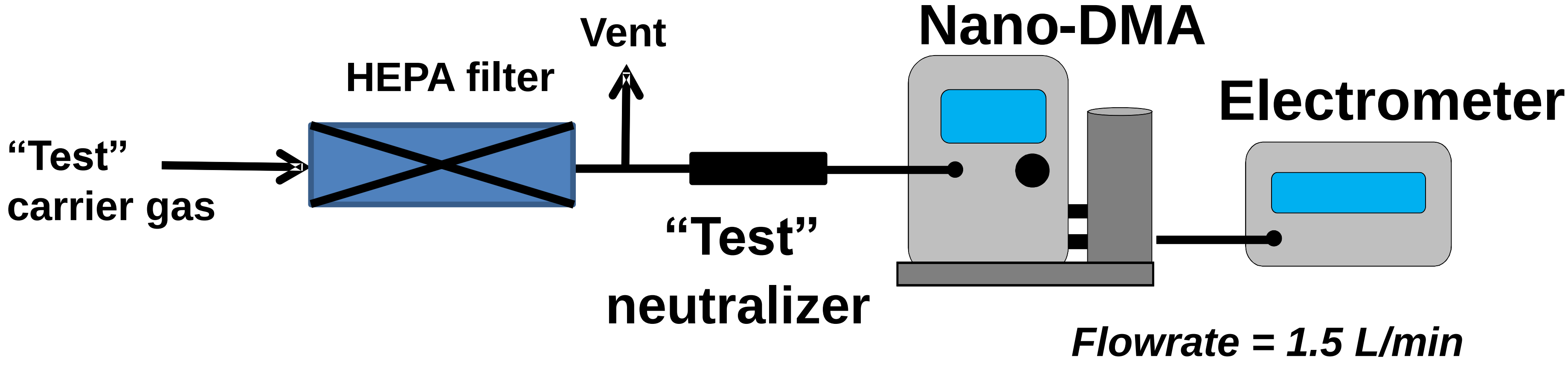


MARC STETTLER, Jacob Swanson, Adam M Boies. 2012. **Evaluation of Uncertainties in Aircraft Engine Soot Emissions Derived from Engine Smoke Number, 2012 AAAR conference**

Soot size distributions

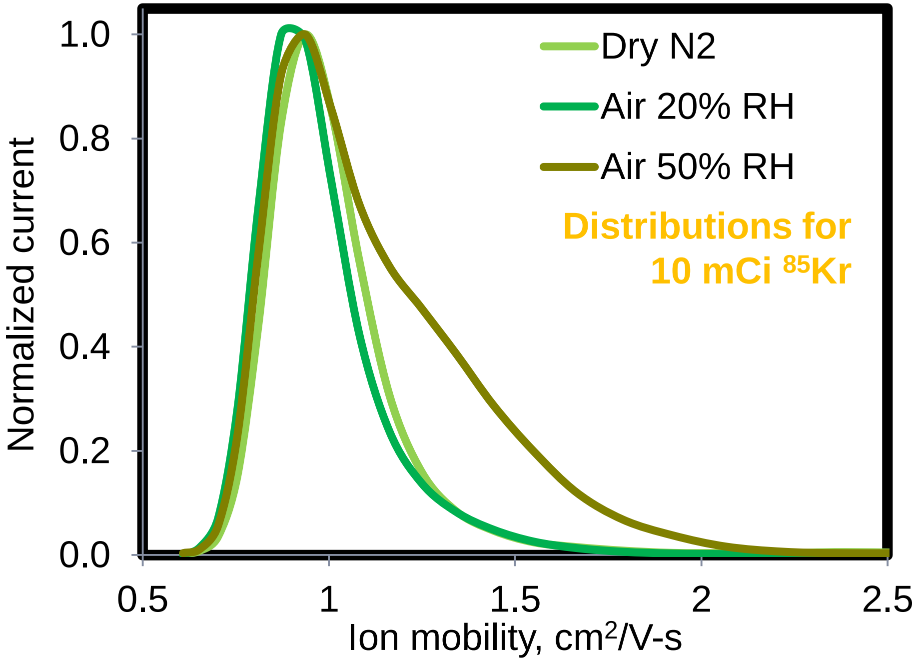


Apparatus – ion mobility distributions

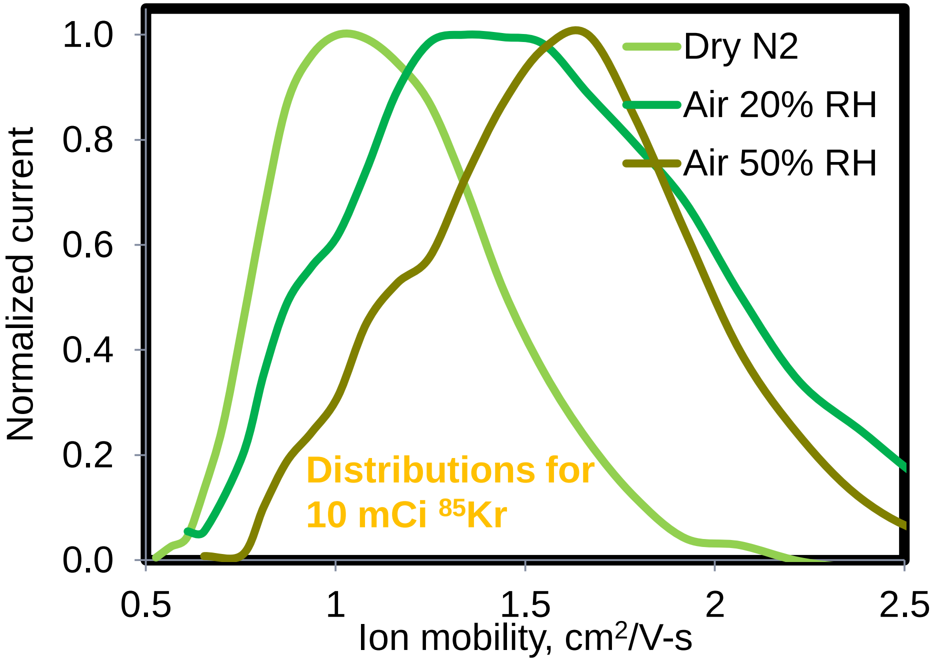


Measured mobilities from radioactive source

Positive ions



Negative ions



Ion mobility depends on carrier gas properties

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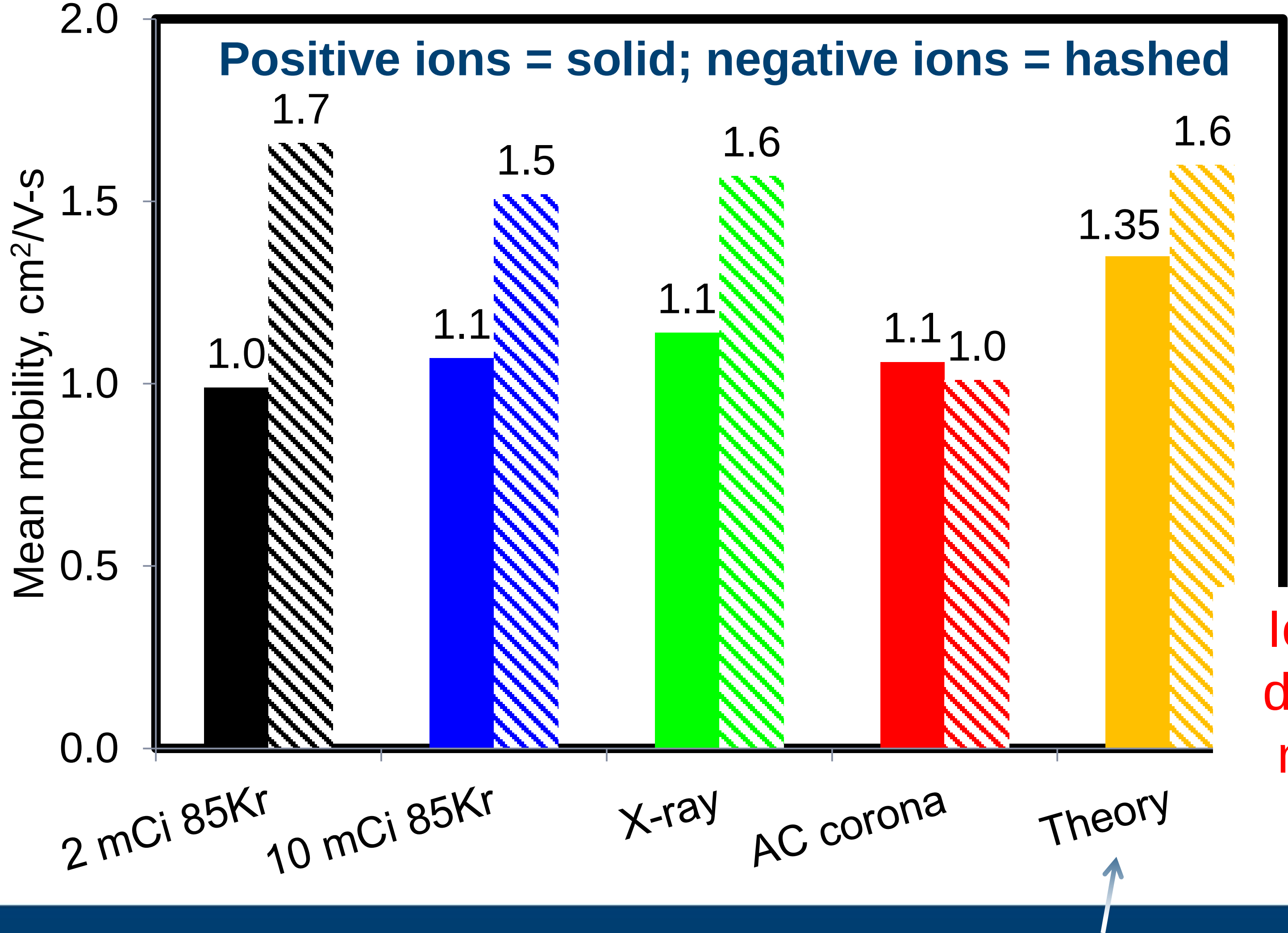
Measured ion mobilities for air, 50% RH

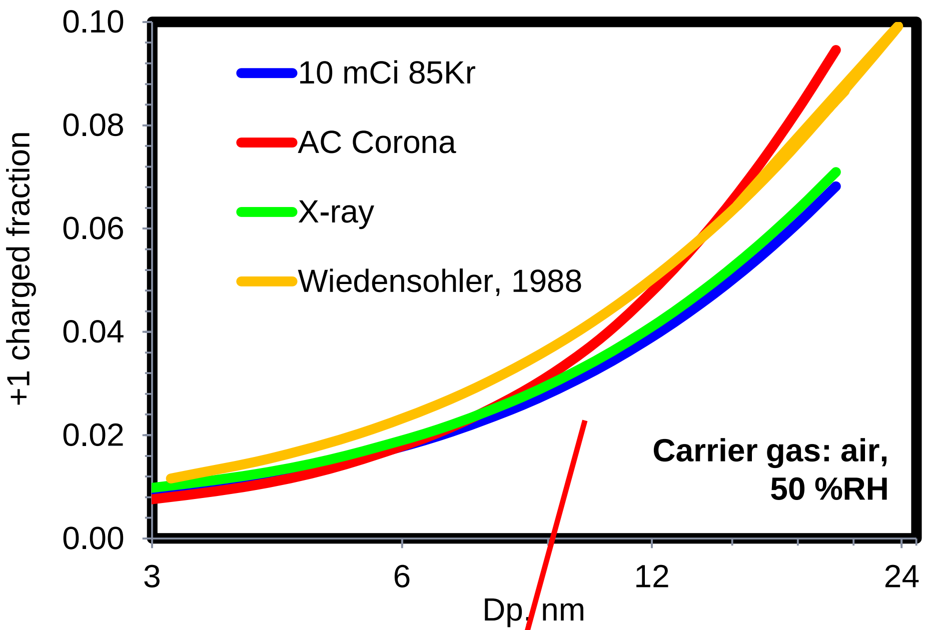


Ion mobility depends on neutralizer

Wiedensohler, A. (1988) Journal of Aerosol Science 19(3), 387-9.

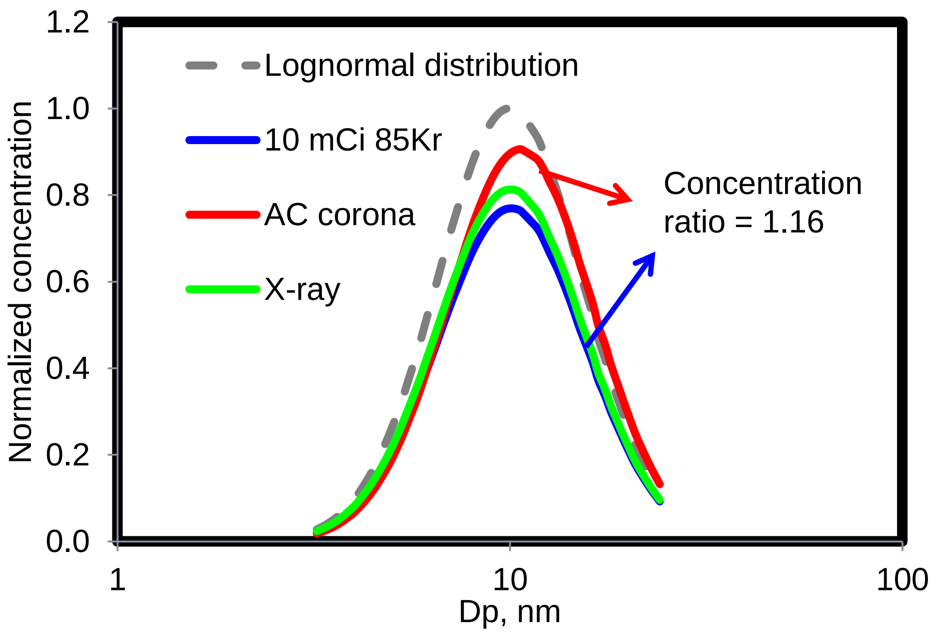
Effect of mobility on inverted size distribution

Calculated +1 charge fractions



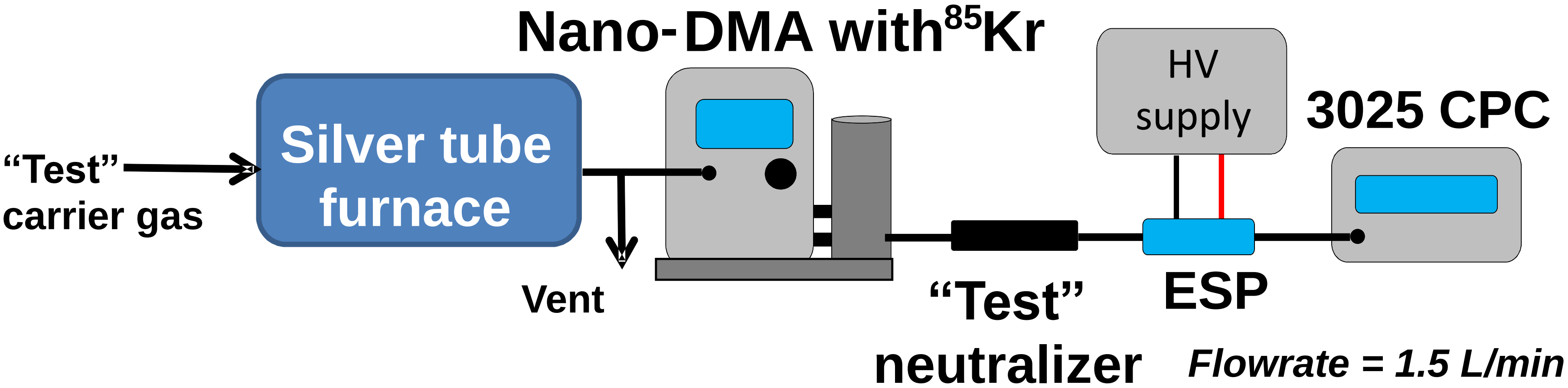
30% higher charge fraction =
30% concentration of particles

Inverted arbitrary distribution



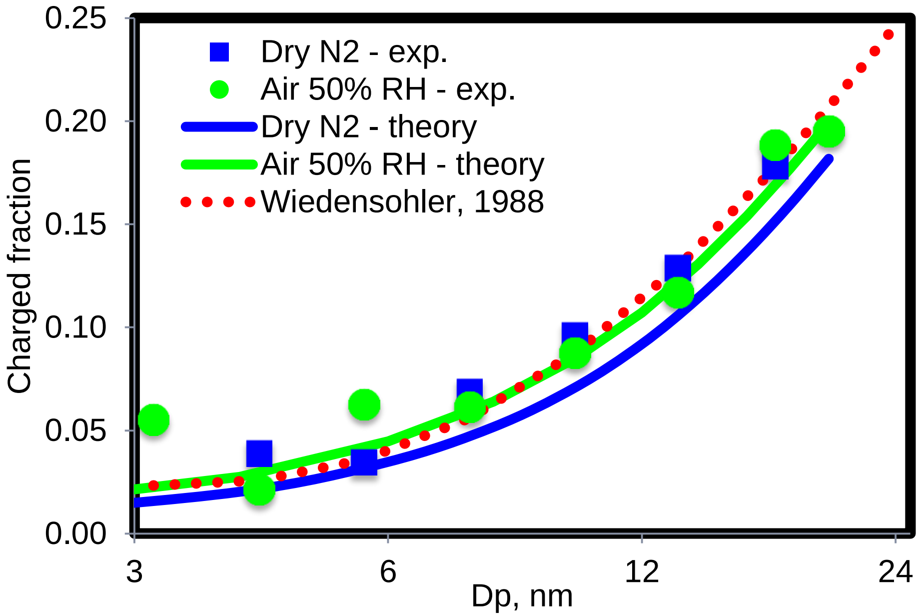
Arbitrary particles are "charged" according to the corresponding ion mobility but all distributions are inverted using the same Wiedensohler (1988) charge fraction approximation

Apparatus – particle charged fractions

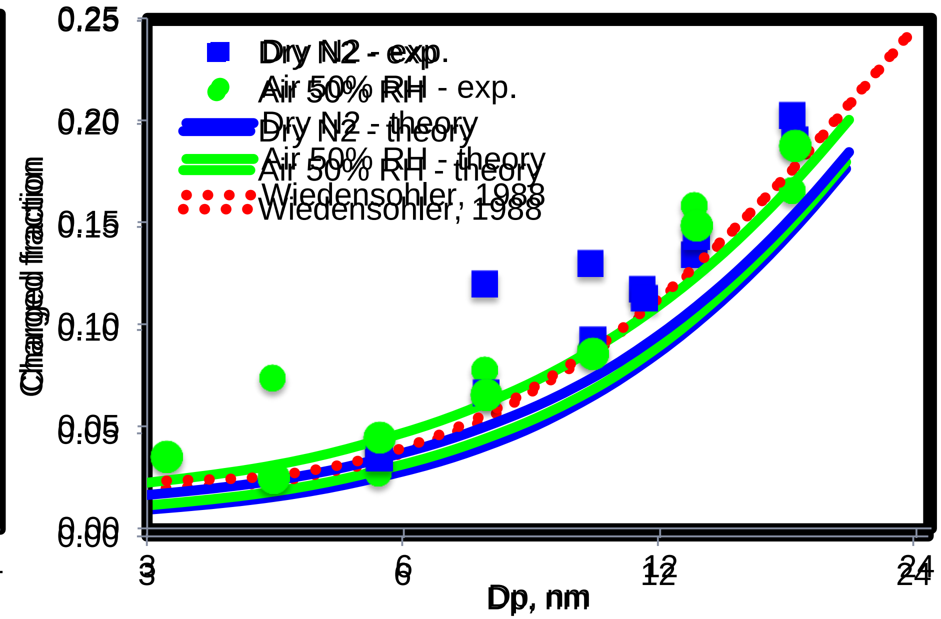


Charged fractions – theory and measurements

10 mCi ^{85}Kr



ACX-ray Corona



Measurements are compared with the Wiedensohler approximation and with calculations using Fuchs' theory (as adapted by Wiedensohler) with measured ion mobilities but calculated masses as input parameters

Summary and conclusions

- Measurements of size distributions of diverse aerosols revealed large differences, even for low particle concentrations
  - The incorrect +1 fraction is being used to invert data
- Why is this?
  - Measurements showed ion mobility (thus, charging) depends on:
    - Carrier gas composition
    - Relative humidity
    - Neutralizer type
  - These parameters are different for every measurement

Summary and conclusions cont.

- "If ultimate absolute concentration accuracy is of utmost importance to a project, it is recommended that a CPC…be used as a concentration reference in addition to a [sizing spectrometer]."[1]
  - YES!
- Hypothesis: Fuchs' theory alone not sufficient to predict differences in neutralizers, even if all else is known.

[1]TSI soft x-ray literature (2012)

Thank you for your attention

- **Acknowledgements**
  - UK EPSRC
  - MSP Corp and Copley Scientific for loan of M1090 Electrical Ionizer
  - Dr Francisco Romay and Aaron Collins (MSP Corp) for technical assistance
  - Cambustion Ltd. for loan of TSI 3077A