Development of Miniature Sizers for Ultrafine Particle Measurements

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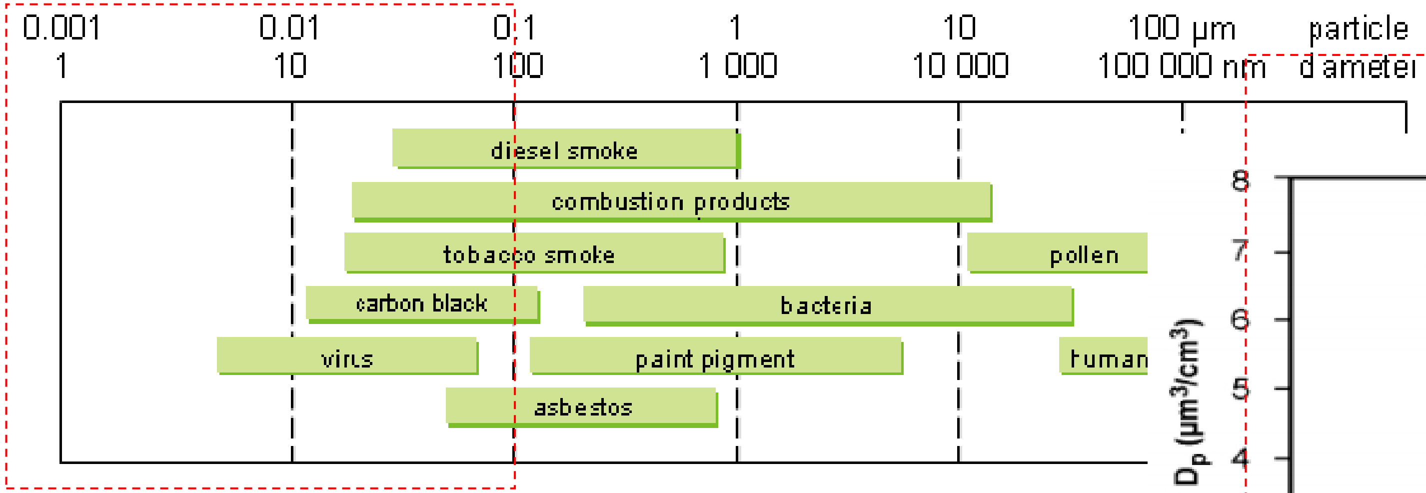
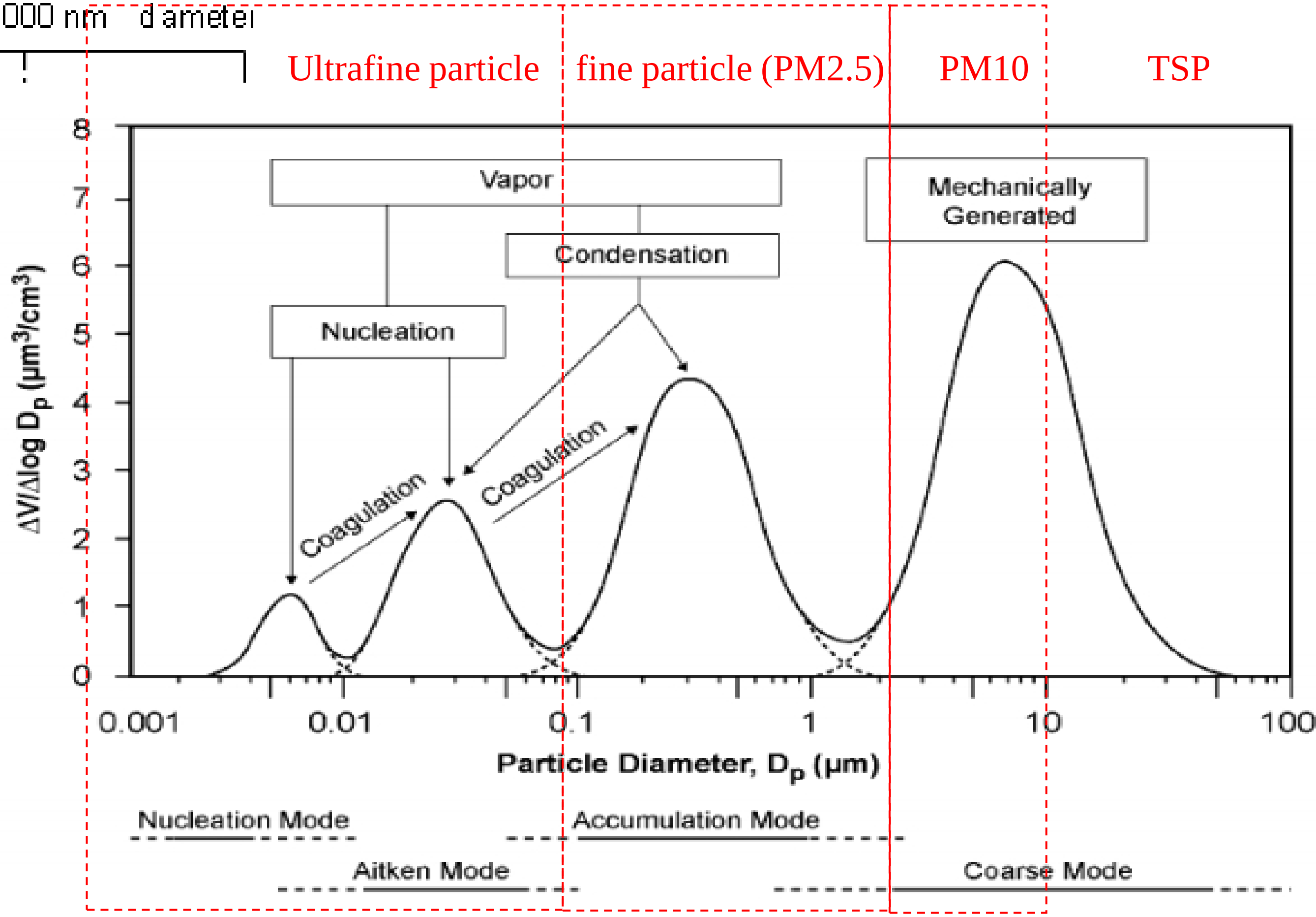
Outline

- Introduction and Overview
- Development of key components for UFP sizers
- Integration of miniature electrical particle sizers
- Conclusion

Introduction – UFP in Ambient Air



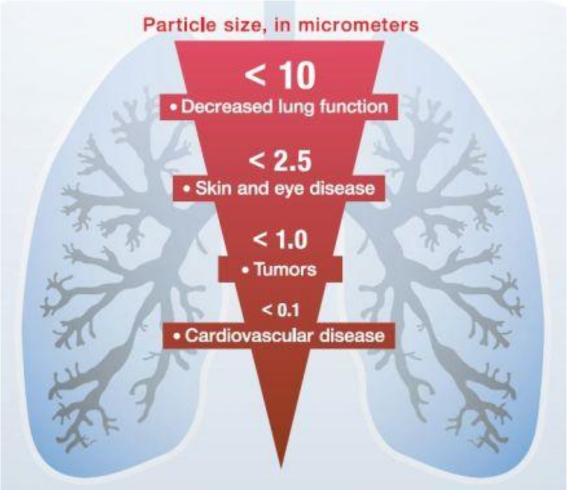
http://www.aerasense.com/index.php?pageID=6



USEPA: Air quality criteria for particulate matter (Final Report, Oct 2004). U.S. Environmental Protection Agency, Washington, DC, EPA 600/P-99/002aF-bF; 2004.

- **Ultrafine Particles (UFPs), Dp < 100 nm**
- **Source:** natural sources (e.g. gas-to-particle conversion, forest fires, viruses, etc.) combustion engine, metal fumes (e.g. smelting, welding), vehicle exhaust, nanoparticle industry, etc.

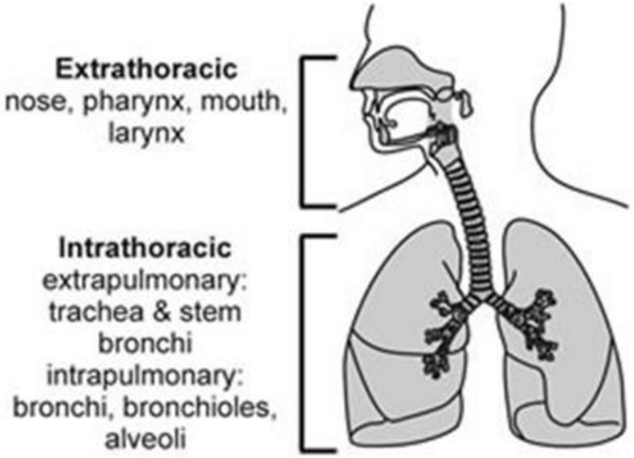
Introduction – UFP Health Effect

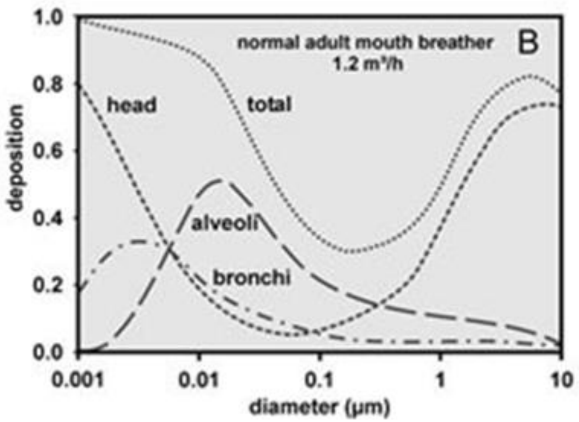


http://www.tesa-clean-air.com/eng/fine_dust_particles

- Nanomaterial (10 to 50 nm) could easily enter the human body and deposit in the **alveolar region** of a human lung, even entering in the blood stream and being transported to vital organs (Kreyling et al., 2002; Takenaka et al., 2001; Oberdörster et al., 2004; Paur et al., 2011).

- UFPs are particularly relevant to pulmonary diseases, cancer and mortality because of **their higher diffusion coefficient and greater accumulation ability** (Hoek et al, 2002; Oberdörster et al, 2005; Bräuner et al, 2007; Stewart et al, 2010).





From Geiser and Kreyling, Particle Fibre Toxicol, 2010, 7:2

- The increased asthma prevalence has been found to often occur in the area with **high UFP levels in ambient air** or **high motor vehicle traffic density** and residence community in close proximity to **freeways** (Samet et al, 2000; Holguin, 2008; Salam et al, 2008; Patel and Miller, 2009).

Review of UFP Measurement (1)

UFP Measurement

Number concentration

- Condensation Particle Counter (CPC)

Surface area

- Nanoparticle Surface Area Monitor (NSAM)

Composition

- Aerosol Mass Spectrometer (AMS)

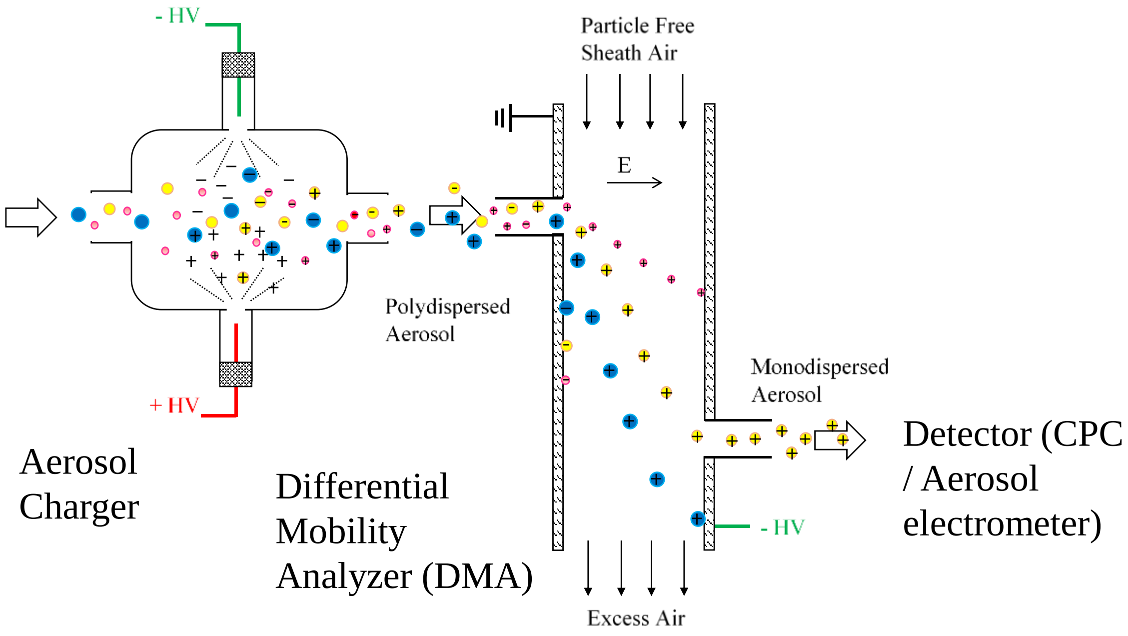
Size distributed number concentration

- ELPI, **SMPS**, FMPS, EEPS, DMS

Size distributed mass concentration

- Nano-MOUDI

- The technique based on **particle electric mobility** has been applied in aerosol community to characterize size distribution of ultrafine particles



Review of UFP Measurement (2)

- Existed instruments to characterize UFPs are mainly designed for scientific studies in the laboratories and are often **expensive in price, bulky in package and heavy in weight.**

SMPS

FMPS

DMS

Review of UFP Measurement (3)

- **Portable Aerosol Sizers developed based on particle electric mobility**

Instrument	Dimensions / Weight	Price
TSI Nanoscan 3910	45 cm x 23 cm x 39 cm < 8kg without batteries; < 9kg with 2 batteries	*$~30K*
Kanomax portable aerosol mobility spectrometer (PAMS)	23 cm x 23 cm x 15 cm 4.5 kg	
Naneum Nano-ID PMC500	30 cm x 33 cm x 26 cm 6.25 kg	
Grimm Mini wide range aerosol spectrometer (WARS)	34 cm x 31 cm x 12 cm 7.6 kg	*$30-40K*

- Large in size, heavy and high cost
- Single-alone operation
- Not easy to be networked (a much desired feature for modern UFP monitoring.)

A **more compact and cost-effective** UPF sizers and wireless mesh network using eUFP sizers as the nodes are needed in the modern UFP monitoring (i.e., spatio-temporal monitoring).

Potential Applications for Miniature Ultrafine/Fine Particle Sizers

- Air pollution and quality study
- Vertical profiling of ultrafine particles
- Indoor air quality monitor
- Early fire detection (office and hospital buildings)
- Industrial hygiene and worker protection
- Epidemiology study
- Identification of particulate emission sources
- Nano-manufacture process control (nanopowders, pharmaceutical products..)
- Pharmaceutical R&D
- and more…..

Motivation of Our Development of mini- Sizers

- **To enable the spatio-temporal distribution measurement and personal exposure monitoring**

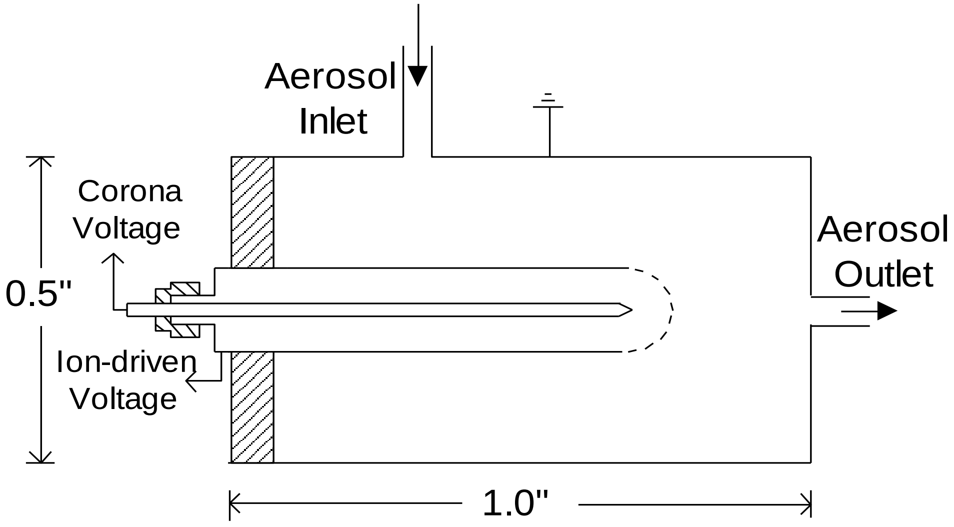
  → miniature aerosol sensor/sizer:

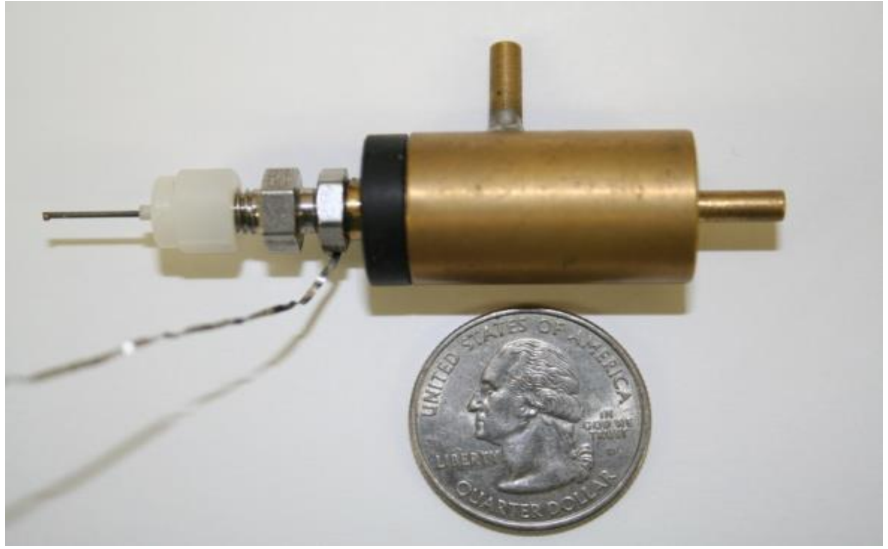
  (1) cost-effective;
  (2) light in weight;
  (3) small in package;
  (4) easy in use;
  (5) having the feature of networking

A miniature electrical ultrafine particle sizer

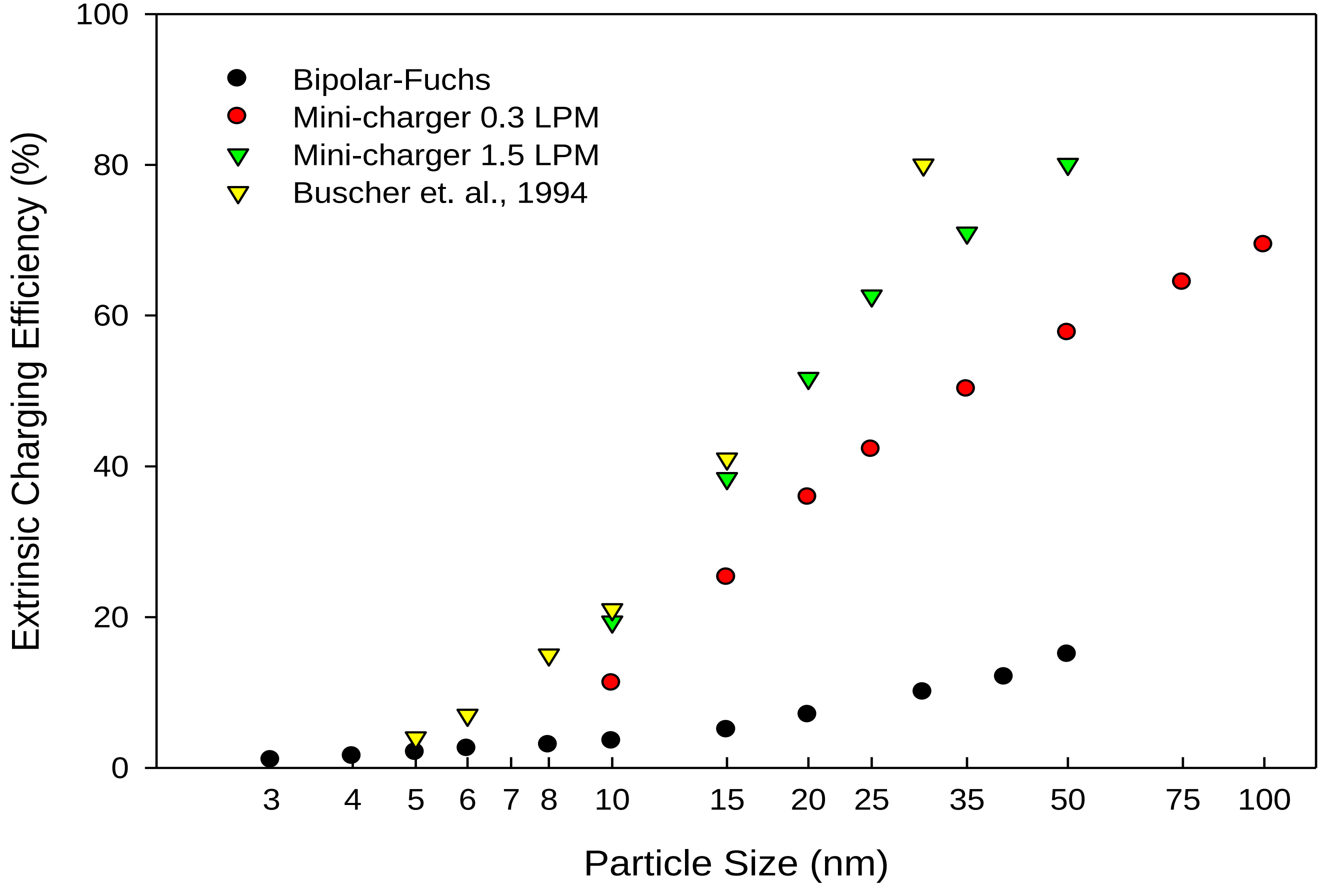
- Aerosol charger
  - Unipolar/bipolar particle chargers
- Electrical mobility classifier
  - Precipitator/EAA/DMA
- Particle concentration detector
  - Faraday cage with pre-amp or CPC
- Data inversion scheme

Miniature Unipolar Aerosol Charger



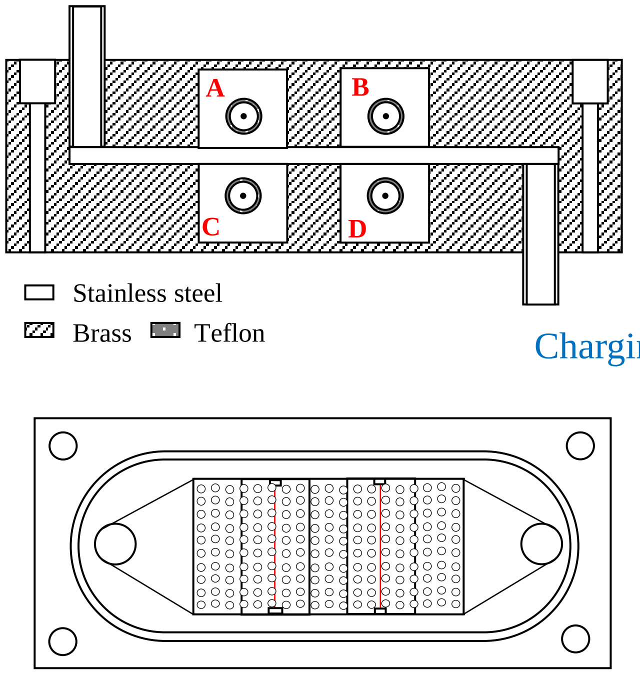


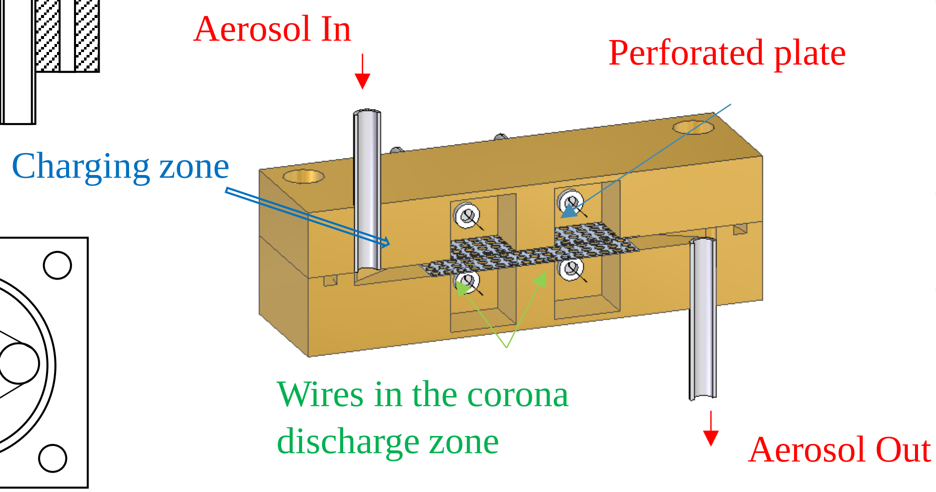
Extrinsic Charging Efficiency of mini- Charger



- Mini-charger, with a simple and very compact design, is capable of providing much better charging efficiency than bipolar charging
- In 1.5 lpm flowrate, its charging efficiency can even be compared with Buscher's charger with a much more complicated design

Mini-plate Particle Charger: Design





- Overall size: 2.2" (5.59 cm) × 1.25" (3.18 cm) × 0.69" (1.75 cm) (L × W × H)
- Charging zone spacing: 0.125" (0.32 cm)
- Tungsten wires of 50 μm in diameter

Schematic diagram of prototype DC-corona-based mini-plate charger

Mini-plate Particle Charger: Experimental Evaluation

Test Aerosol: NaCl, 10 – 200 nm

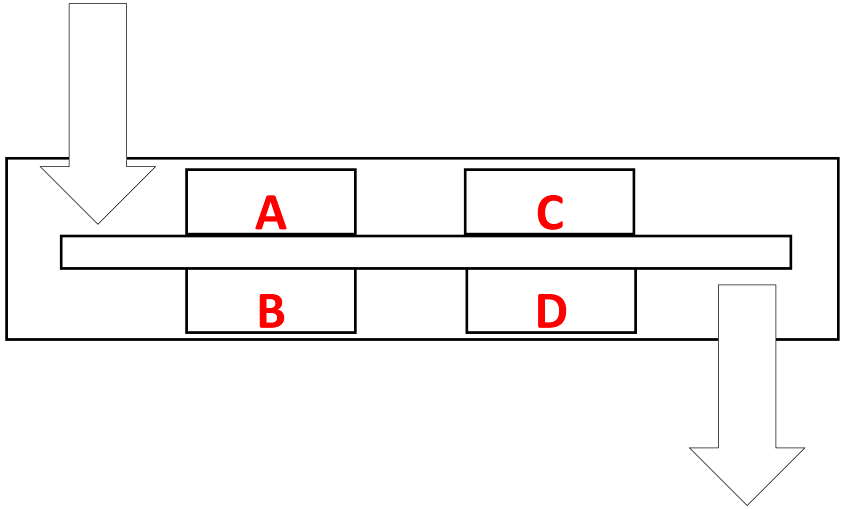
Key aspects of charger performance:

(1) intrinsic/extrinsic charging efficiency;

(2) charge distribution on aerosol

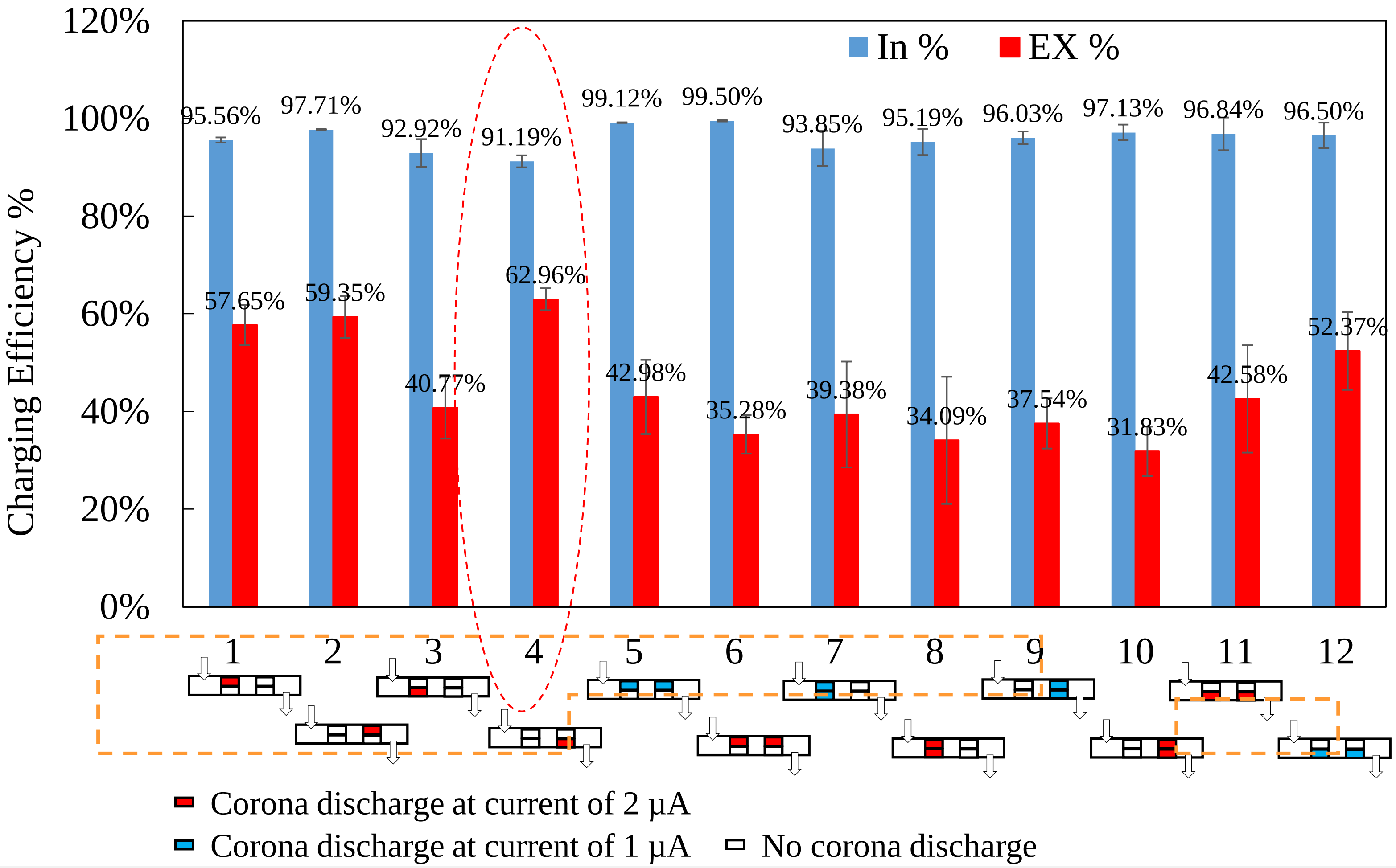
Charger performance depends on:

- ✓ Charger configuration
- ✓ Aerosol flowrate
- ✓ Corona current
- ✓ Particle size



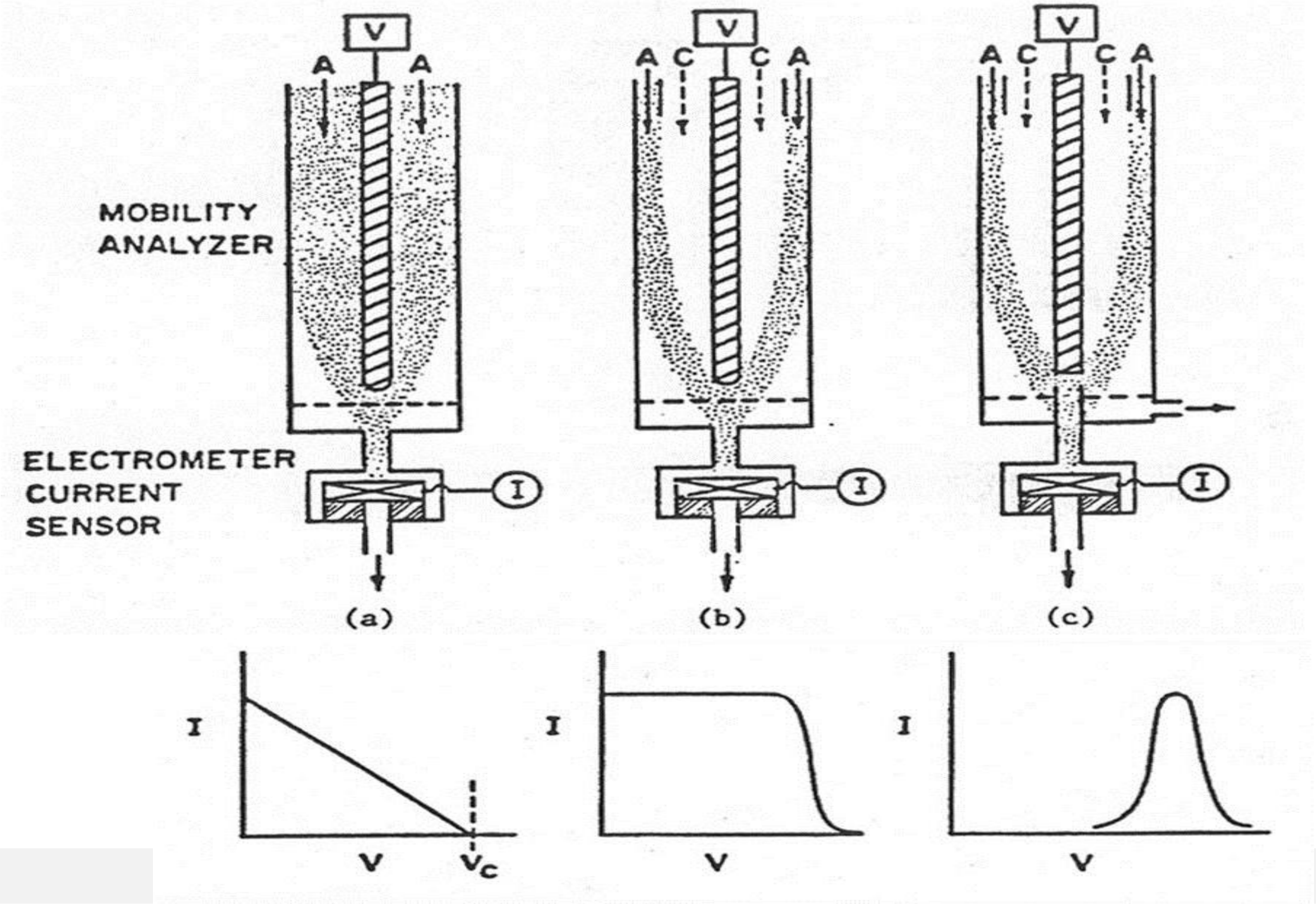
Mini-plate Particle Charger: Optimization of charger configuration

- 40 nm NaCl nanoparticle
- 0.3 lpm aerosol flowrate

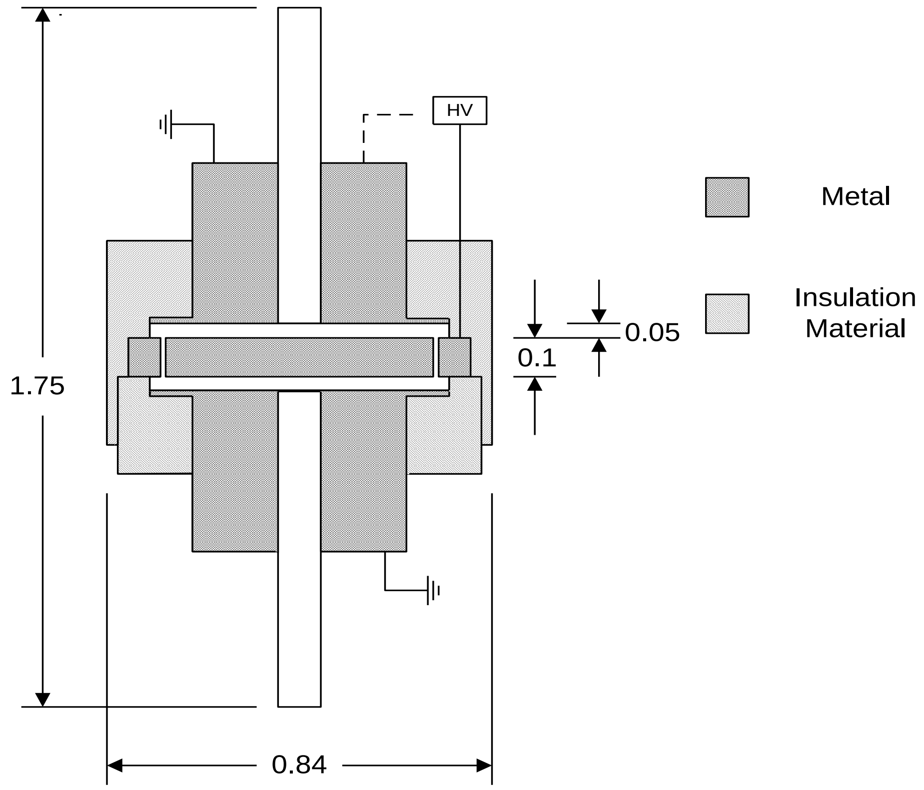


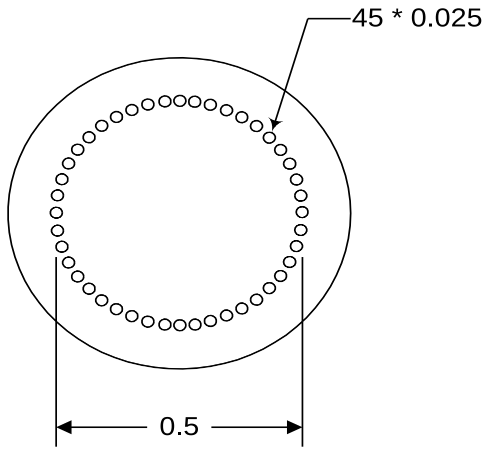
Evolution of Mobility Classifier Development

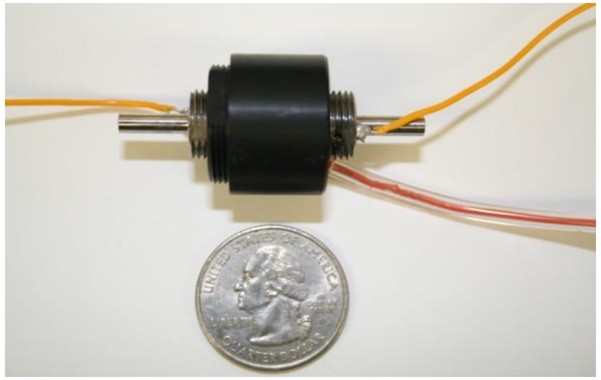
(a) Zeroth order
(b) 1^{st} order
(c) 2^{nd} order



Miniature Disk-type Electrostatic Precipitator
(Aerosol Classifier in the zeroth order)

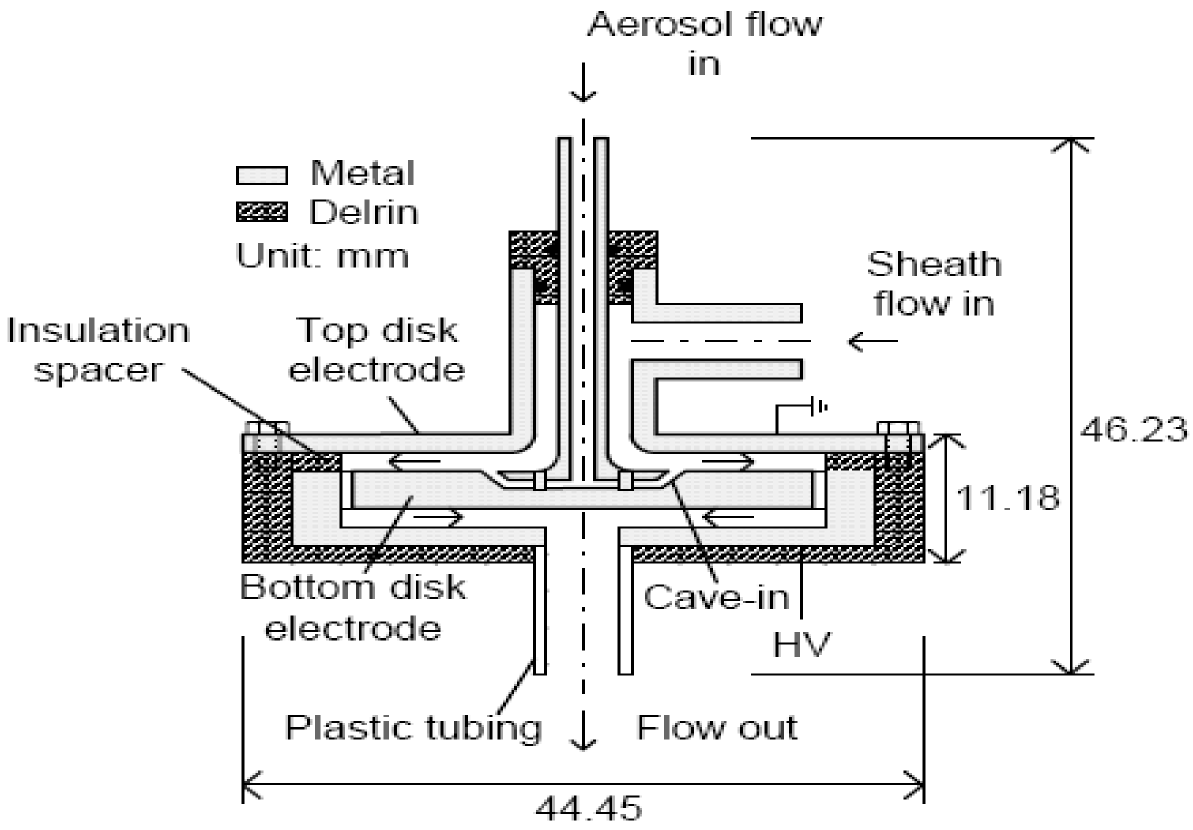


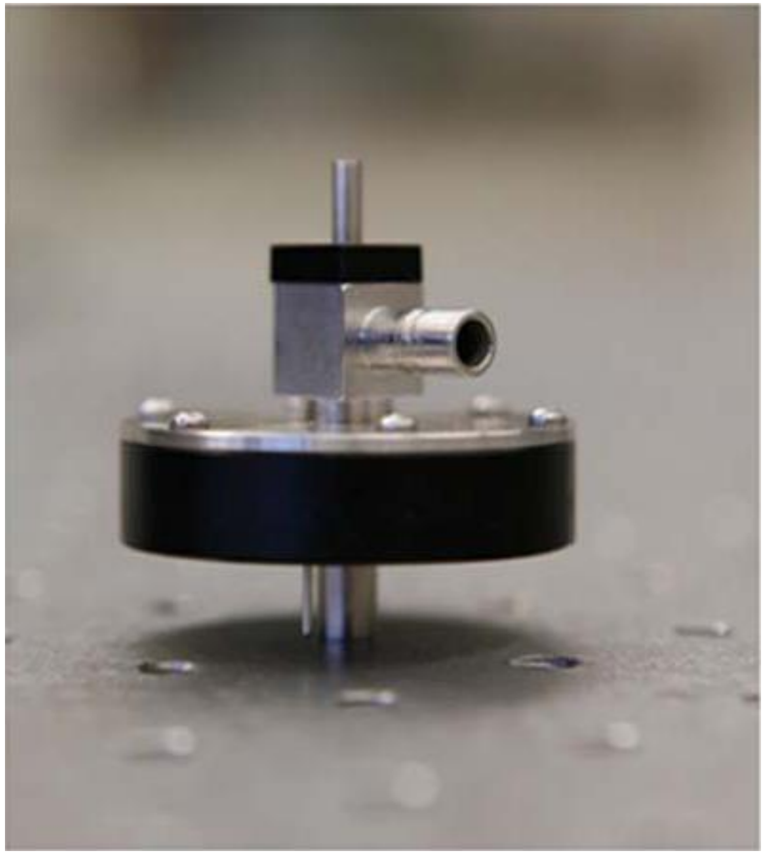




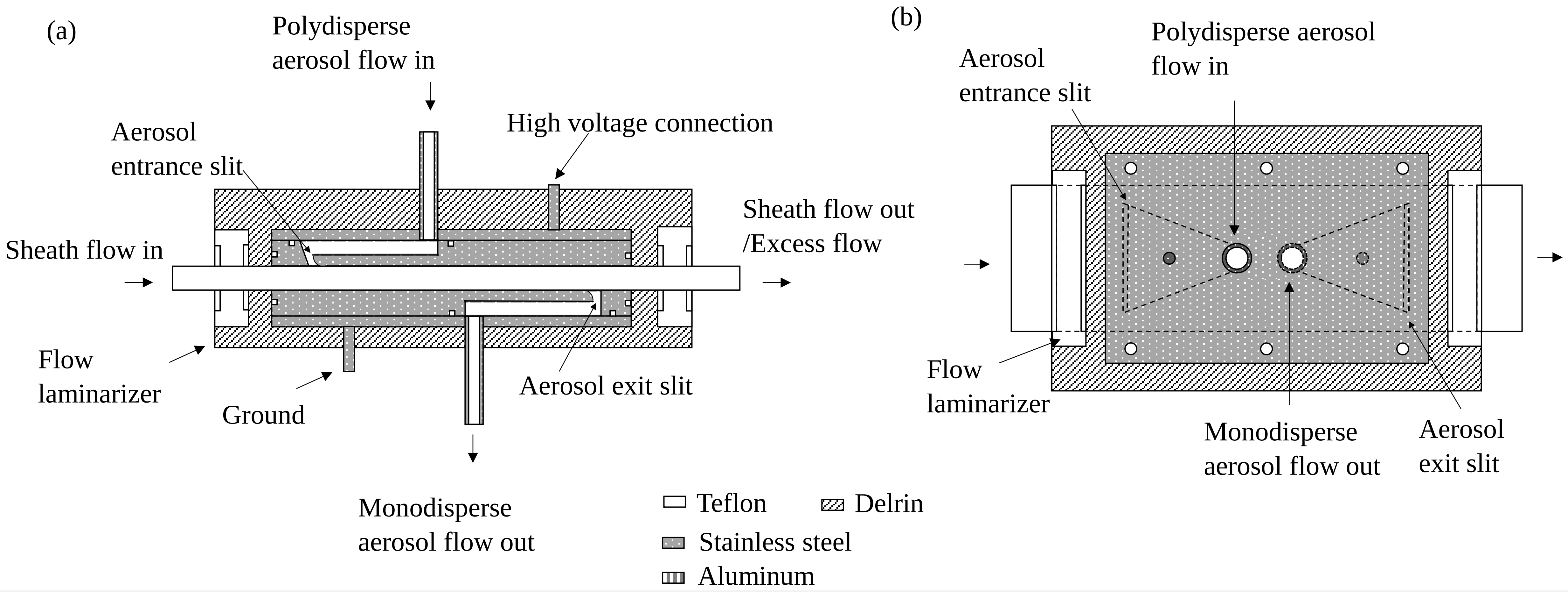
Mini-disk Electrical Aerosol Classifier (mini-disk EAC)

(Aerosol Classifier in the 1st order)



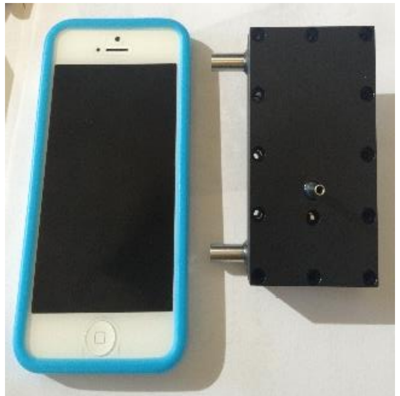


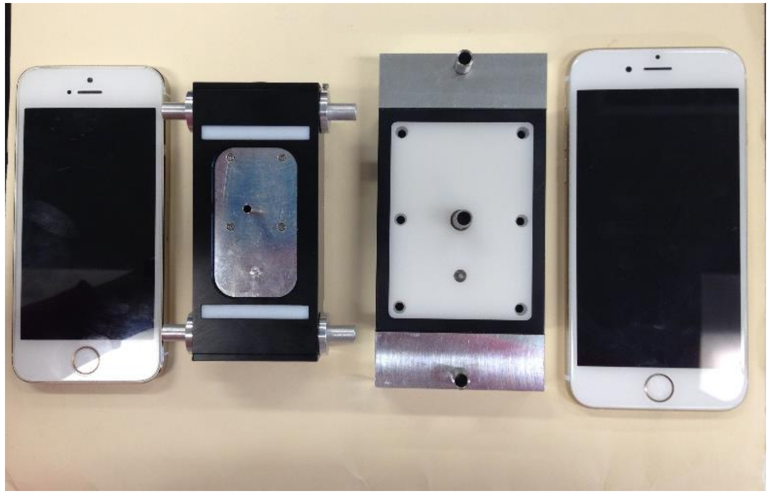
Mini-plate Differential Mobility Analyzer (mini-plate DMA)
(Aerosol Classifier in the 2nd Order)



Mini-plate DMAs

V1 V2 V3

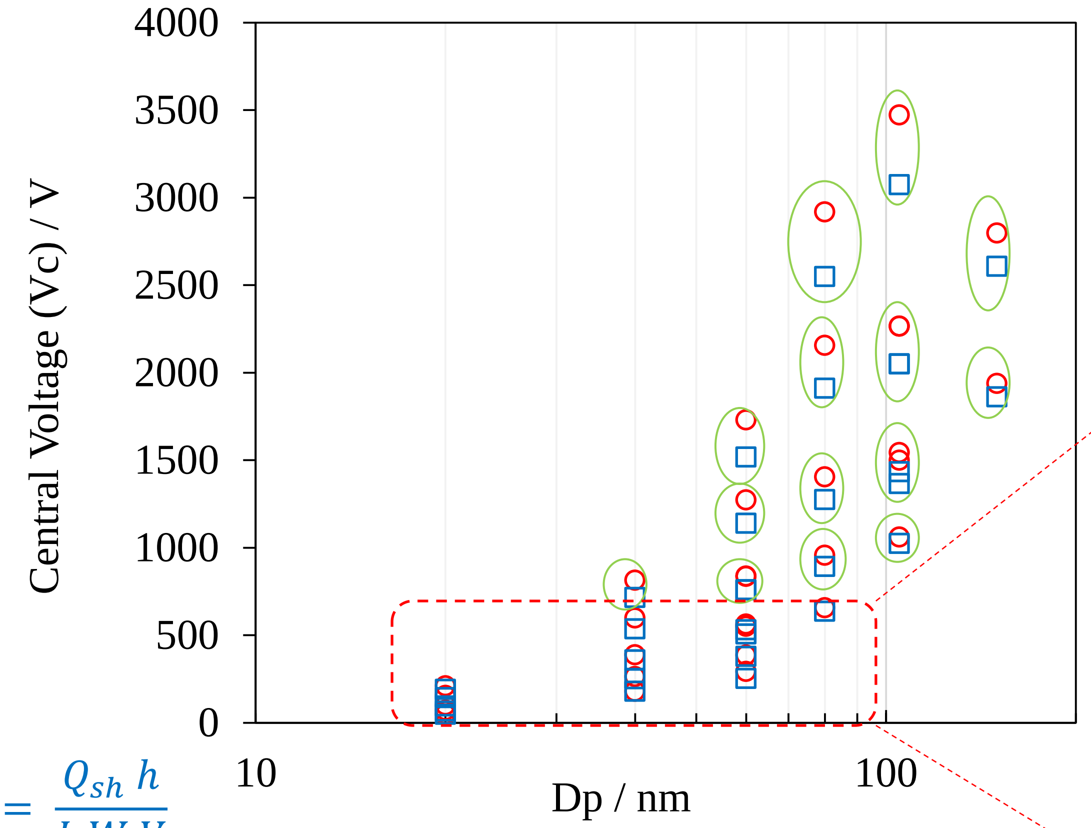




	Classification Zone			Aerosol slit opening	Overall Size		
	Length	Width	Height		Length	Width	Height
V1	1 39/64" (40.88)	1" (25.4)	(2.06)	1/2" × 1/32" (12.7 × 0.79)	3 7/32" (81.76)	1 3/4" (44.45)	13/16" (20.64)
V2	1 13/32" (35.72)	1" (25.4)	1/8" (3.18)	1/2" × 3/32" (12.7 × 2.38)	3 7/8" (98.43)	1 3/4" (44.45)	7/8" (22.23)
V3	2 1/16" (52.39)	1 1/2 " (3.81)	(2.11)	1 1/8" × 1/32" (28.58 × 0.79)	4 7/8" (123.83)	2 7/16" (61.91)	21/32" (16.67)

Key dimensions in mini-plate EAA/DMAs, units: in (mm)

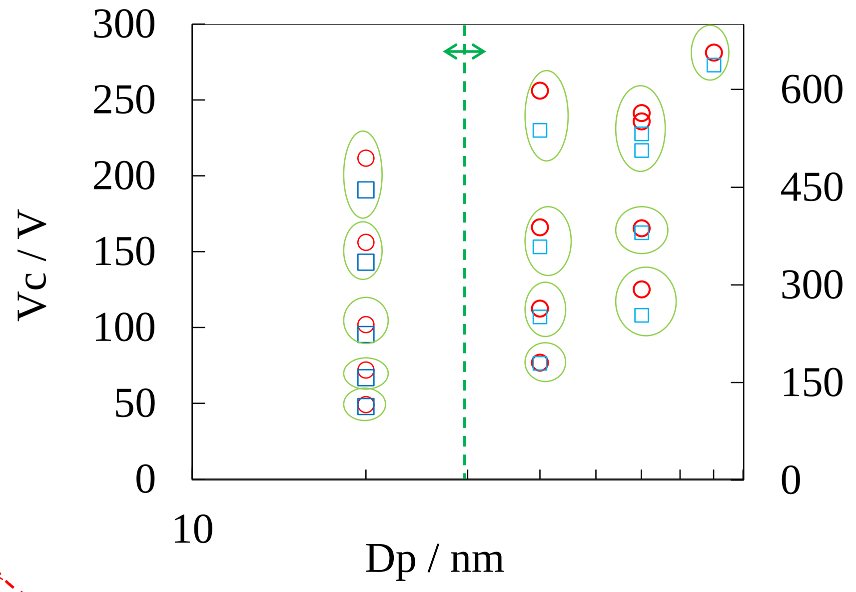
Mini-plate DMA: Sizing accuracy (1)



$$Z_{p,c} = \frac{Q_{sh}\, h}{L\, W\, V}$$

○ Experimental Vc ☐ Calculated Vc without correction

The deviation between the experimental and calculated voltages at the given particle sizes is **not negligible**.

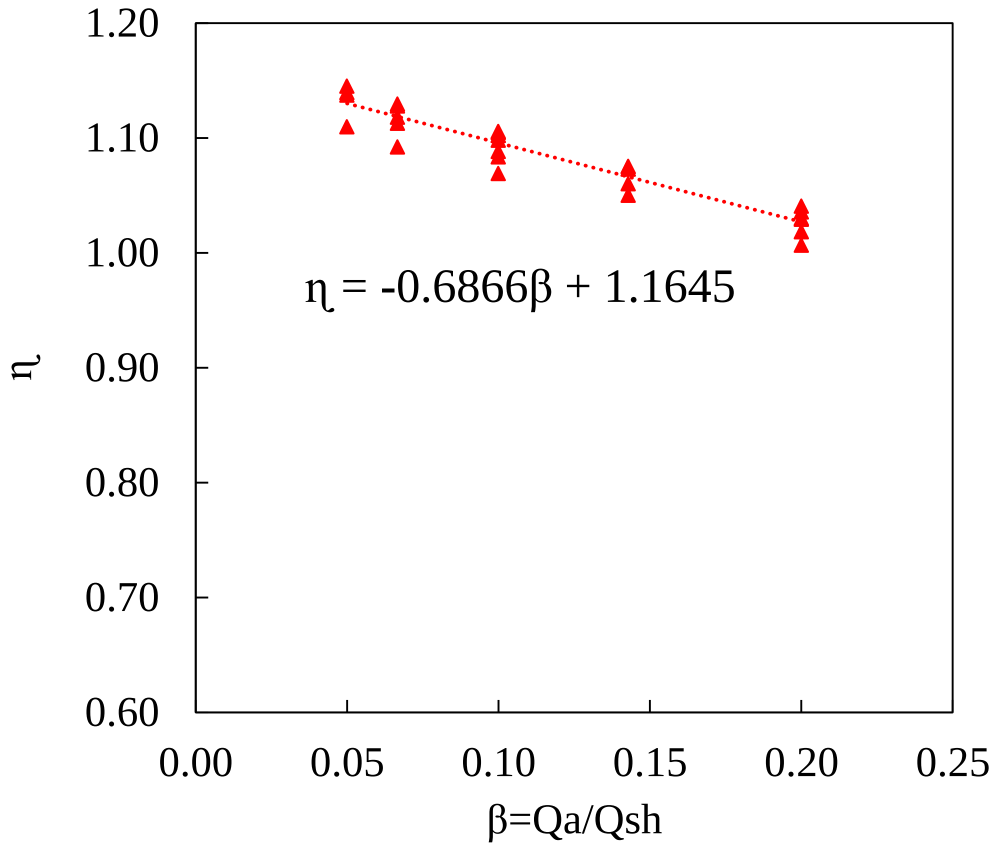


Mini-plate DMA: Sizing accuracy (2)

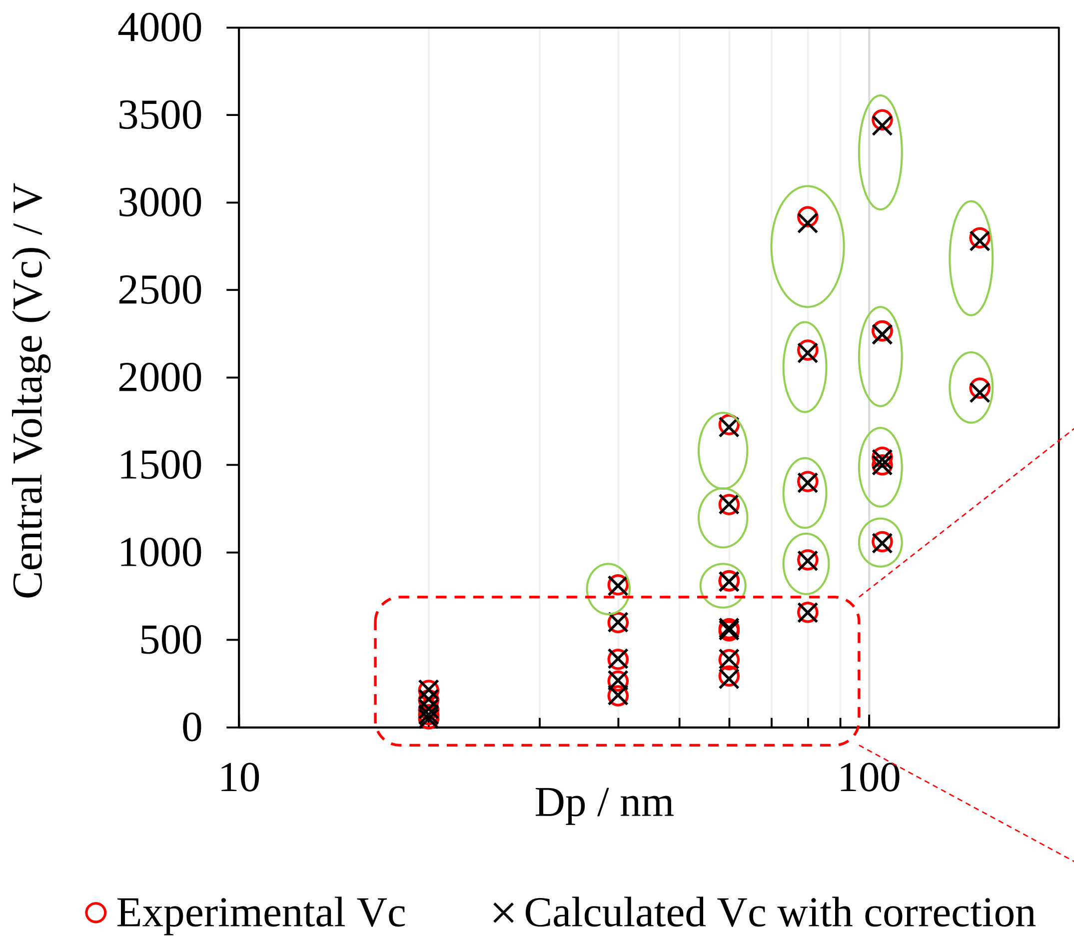
- It is further found that the voltage needed for classifying particles with a given electrical mobility varied when varying the aerosol and sheath flowrates.

$$Z_{p,c} = \frac{\eta \, Q_{sh} \, h}{L \, W \, V}$$

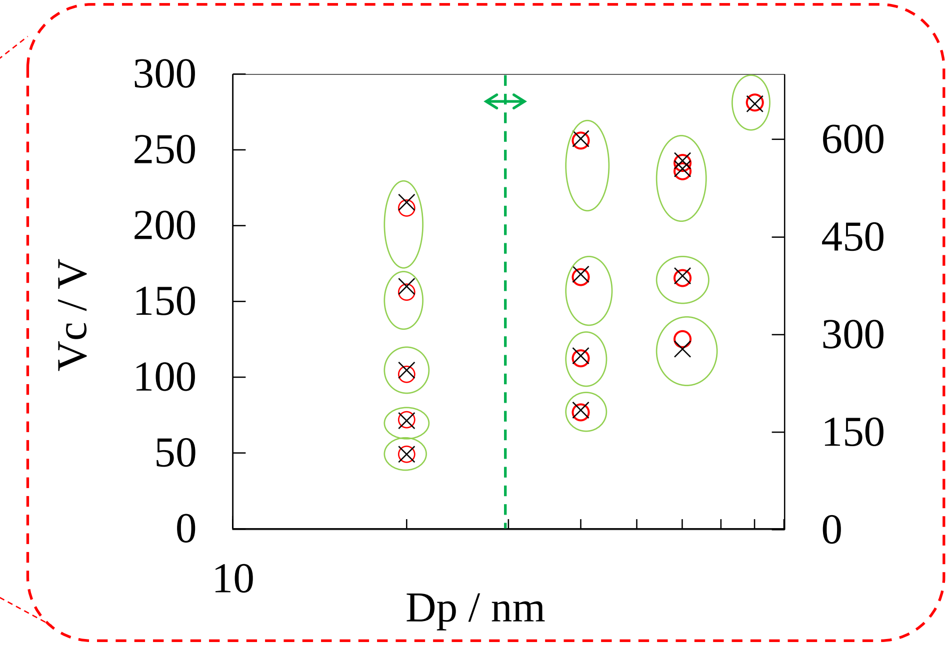
- The relationship between η and β is **linear.**



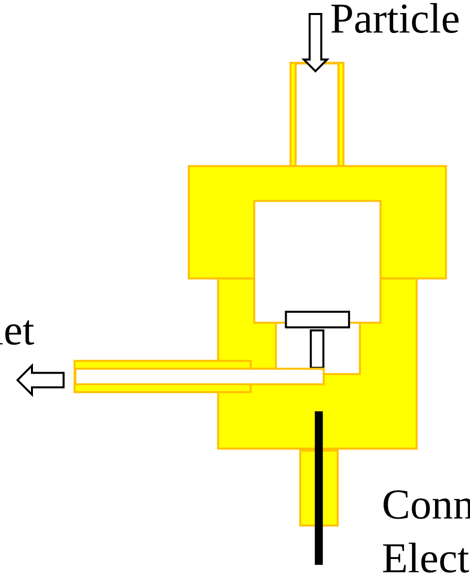
Mini-plate DMA: Sizing accuracy (3)

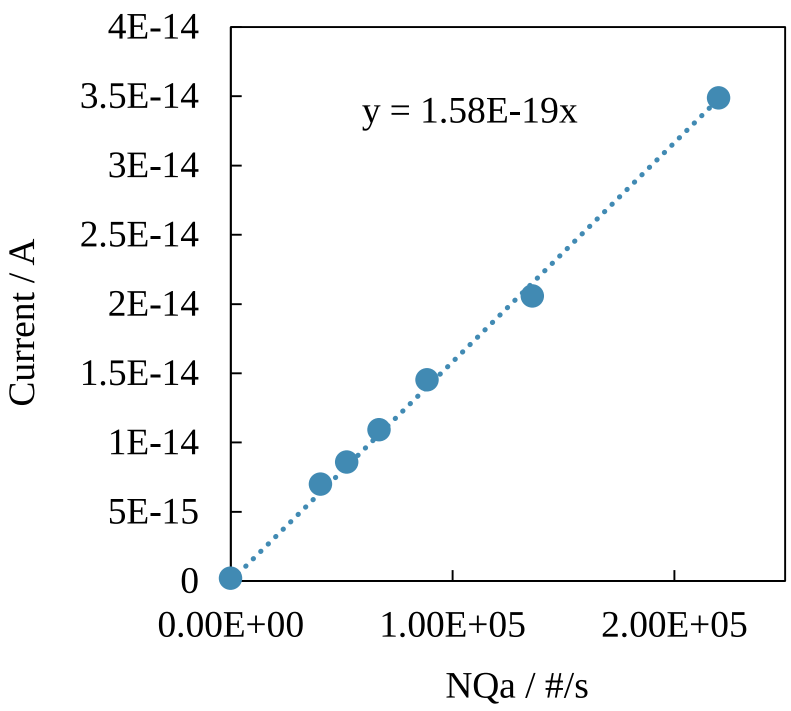


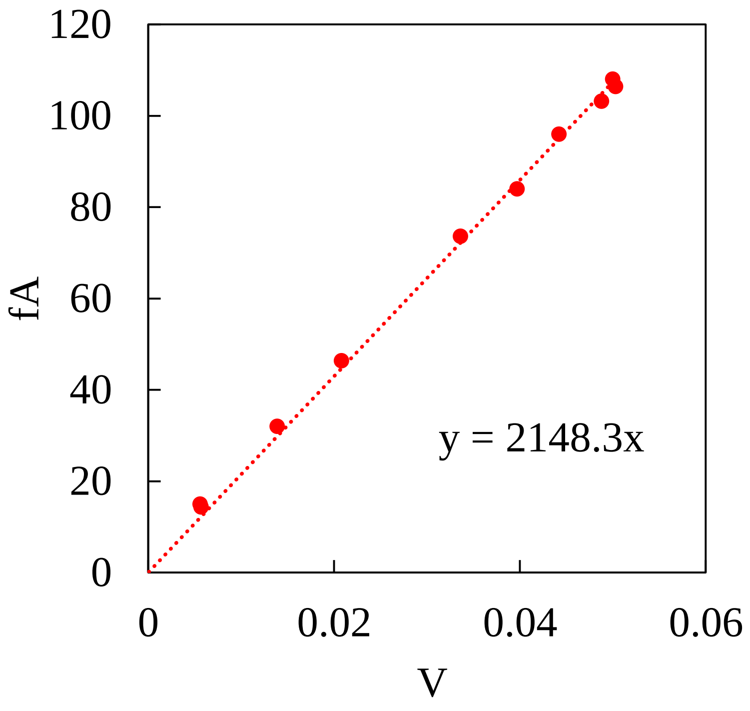
- The **±2.5%** for the voltage deviation might be attributed to the accuracy in the flowrate control and measurement as well as the possible 3D flow effect



Mini- Faraday Cage with pre-amp





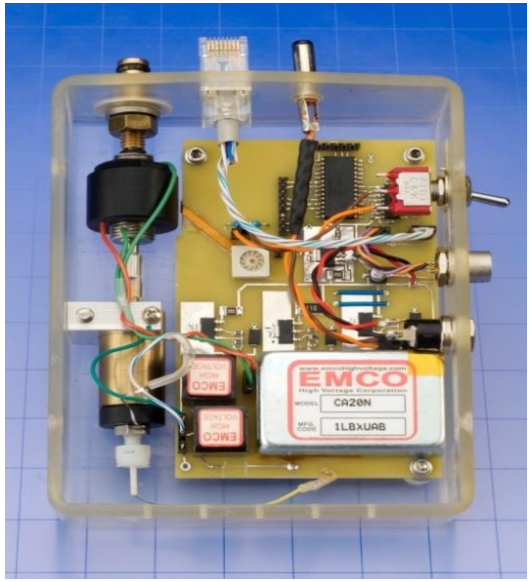


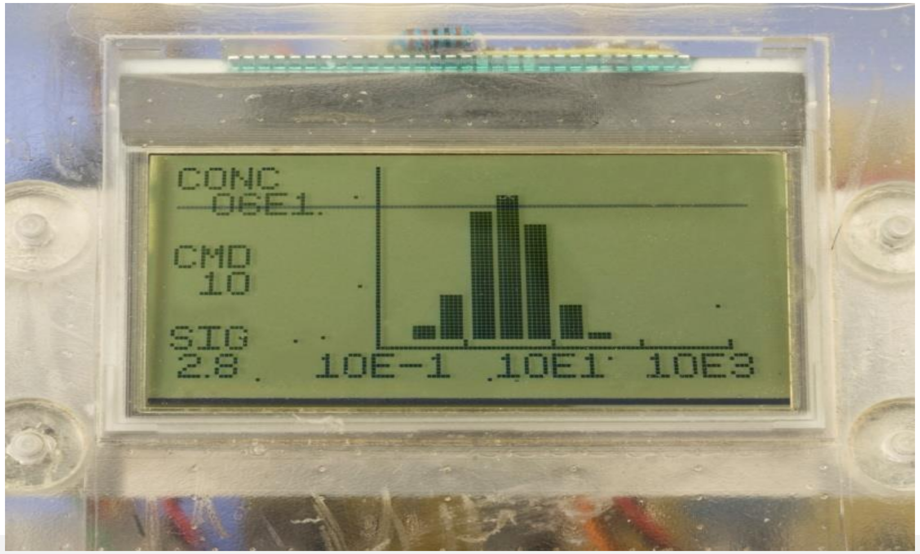
$$\boldsymbol{I} = n\ e\ (\boldsymbol{N} Q_a)$$

where, I is the current measured by electrometer; ne is the charge carried by particles; Q_a is aerosol flow rate and N is the particle number concentrations.

Prototype Portable Fine Particle Sizer (portable FPS; Funded by NASA)

2009 R&D 100 Award
(R&D magazine)





Aerosol flowrate: 0.7 lpm

Miniature Electrical Ultrafine Particle Sizer (mini- eUPS) (funded by US EPA)

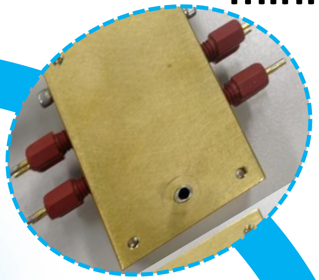
mini- eUPS

Features included

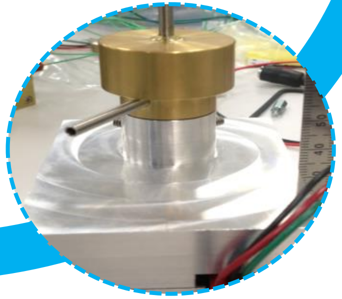
- Portable, Cost-effective, Energy efficient
- Real-time on particle size distribution, temperature, Humidity, GPS, pressure and Altitude
- Self diagnosis
- Wireless networking
- Wireless data transmission
- Data hubbing

Key components

mini-plate aerosol charger

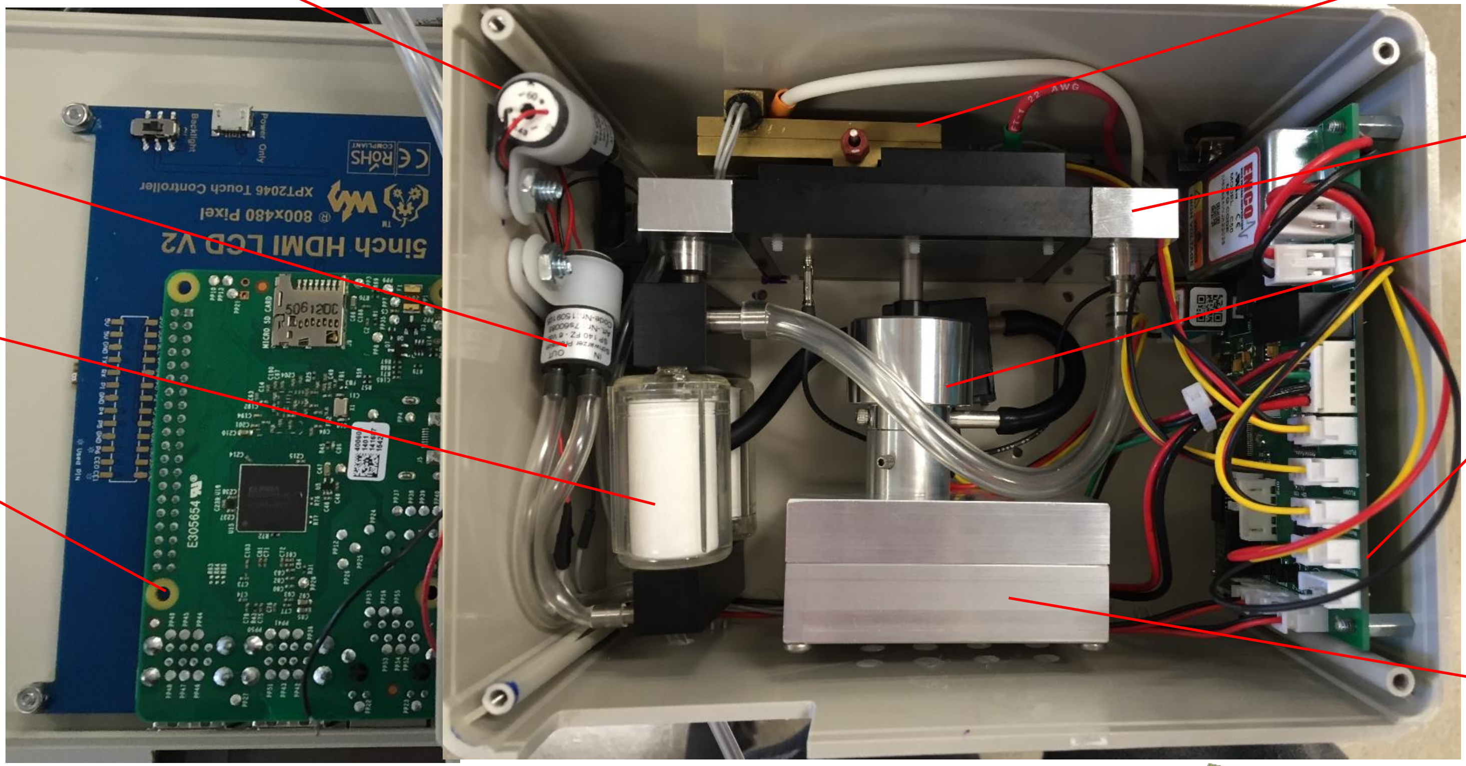


mini-plate DMA/EAA

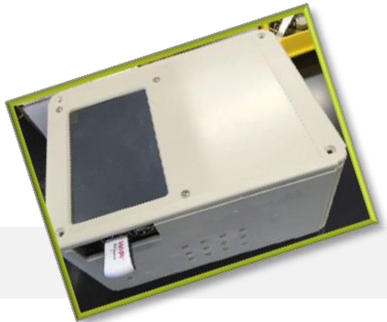


mini-Faraday cage with pre-amp

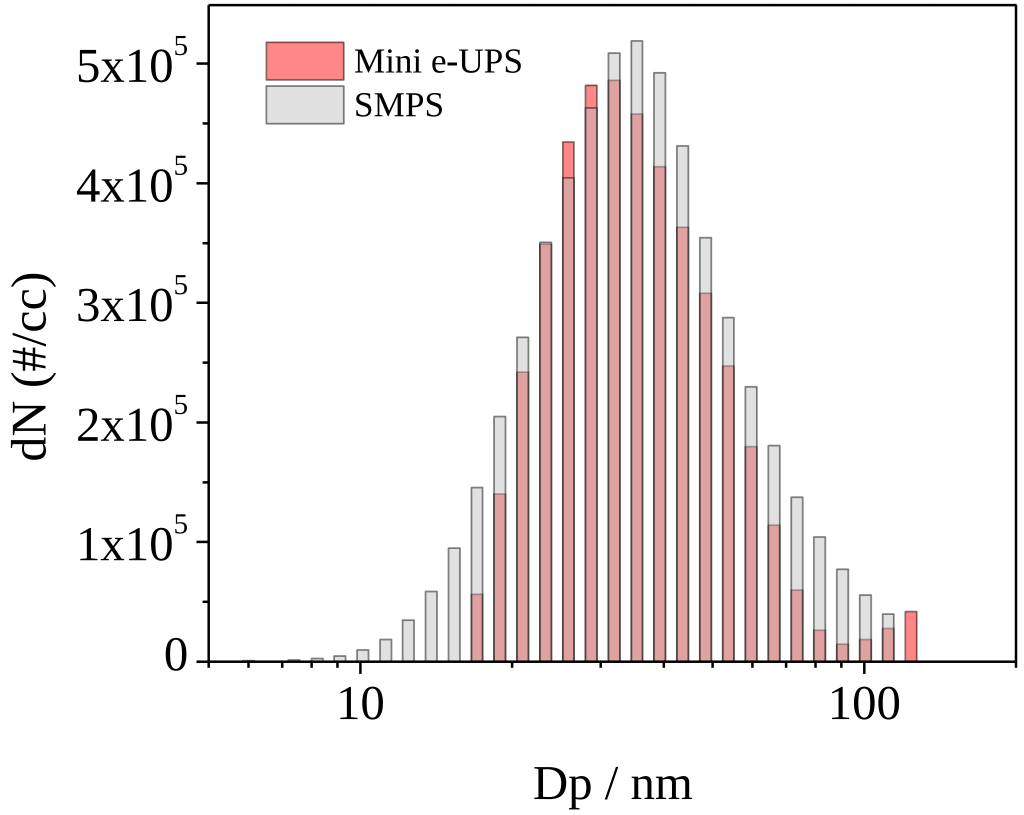
Prototype mini- eUPS

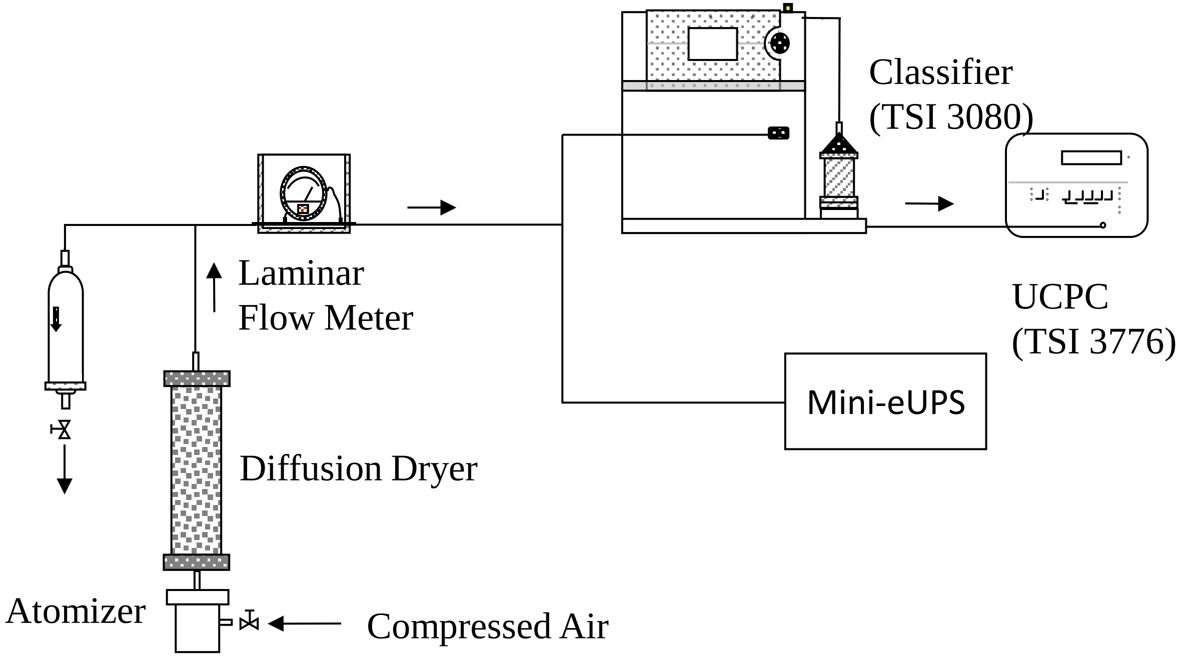


- **Final package**: 7.5" (L) × 5.5" (W) × 4.5" (H)
- **Weight:** < 3.5 lb



Performance of Prototype mini eUPS





Conclusion Remarks

- Electrical mobility based particle analyzers are powerful tools for the characterization of particles in fine and ultrafine size ranges

- Miniaturization of electrical mobility particle sizers have been realized for measuring the spatial and temporal size distribution of fine and ultrafine particles

- Portable FPS (with CPC) and mini- eUPS (with aerosol electrometer) have been assembled and evaluated using the lab-generated particles.

Thank you for your attention

Acknowledgement
The authors are grateful for the financial support provided by NASA Glen Research Center and STAR program, US EPA (Grant # 83513201).

COI statement
Chen, one of the authors, holds the licensed IP, which is similar in name, but unrelated in configuration, to this project.