Measurement of Particle Geometric Surface Area Using a Modified Weighted Sum Method with a Time Resolution of 1S

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Presented at 53rd CFR Review Meeting, Prior Lake, MN

April 25th, 2018

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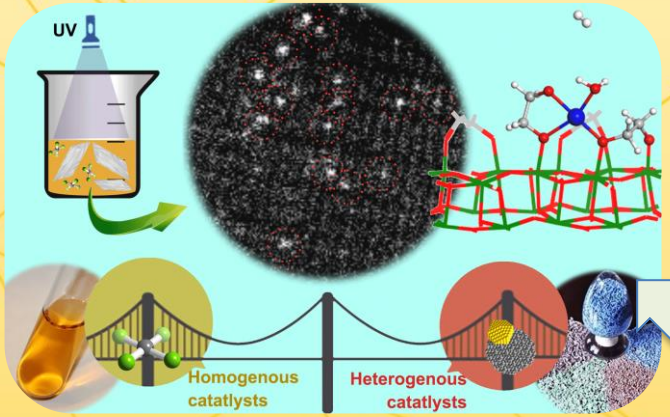
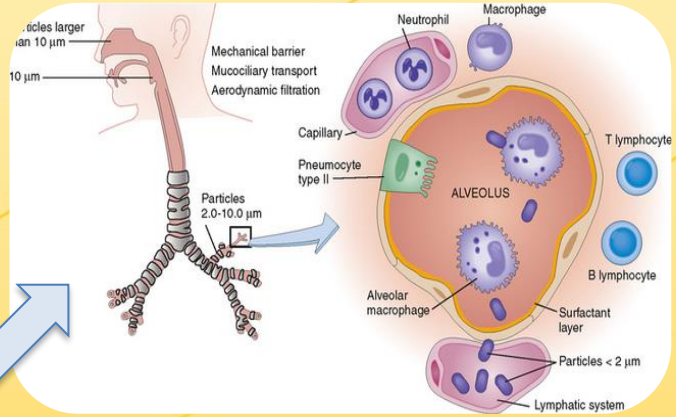
Outline

- Background and objective
- Methodology
- Experiments
- Summary

Significance of surface area

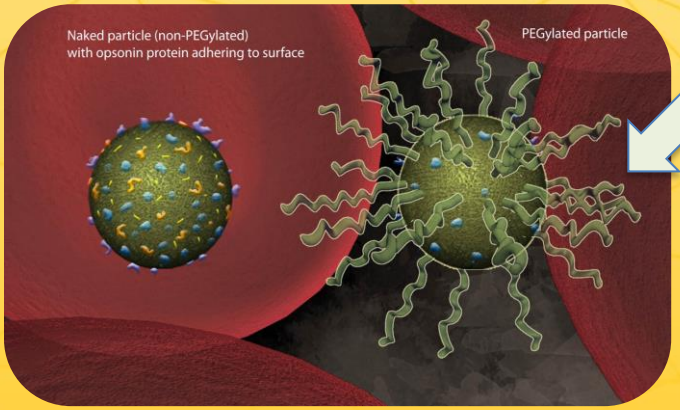


Catalytic activity

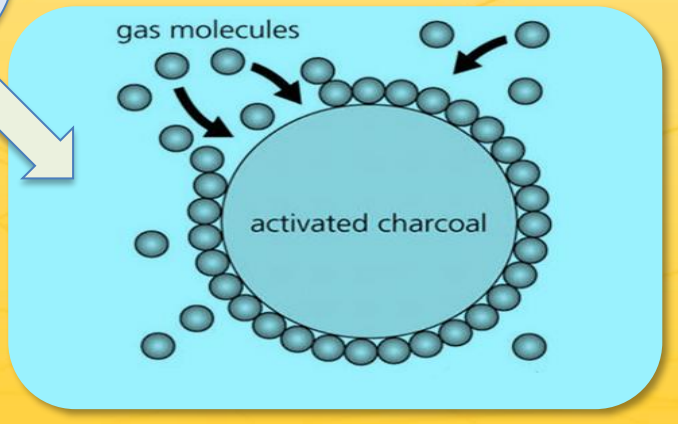


Health effect

Surface area



Drug action



Gas absorption

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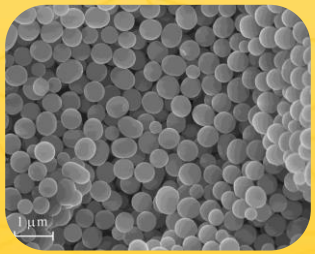
Main methods for surface area: offline

Brunauer–Emmett–Teller (BET)

Character:

- Surface area including pores
- Gas adsorption, direct
- High detection limit
- Ex-situ
- Time consuming, bulky & costly

Electron microscopy (TEM and SEM)

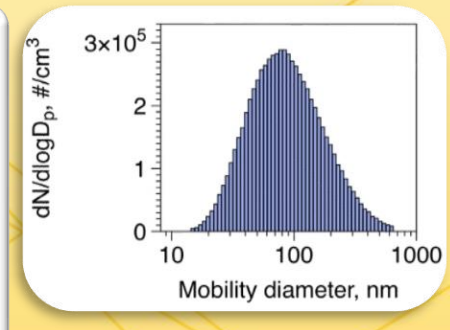


Character:

- 2D projected area-morphological information
- Low accuracy
- Ex-situ
- Time consuming, bulky & costly

Main Methods for surface area: online

Scanning Mobility Particle Sizer

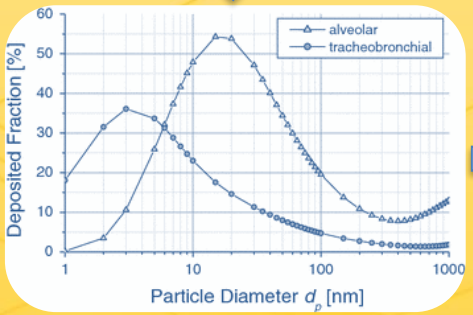


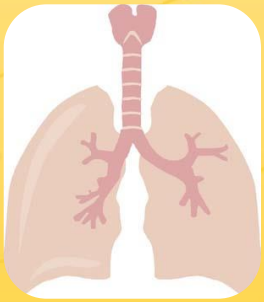
- In minutes
- Working fluid
- Bulky & costly

Electrical Low Pressure Impactor (+)

- Inertia separation
- Wide size stage
- Low accuracy
- costly

Nanoparticle Surface Area Monitor





- Only lung-deposited surface area
- Reasonable size and cost
- 1s resolution

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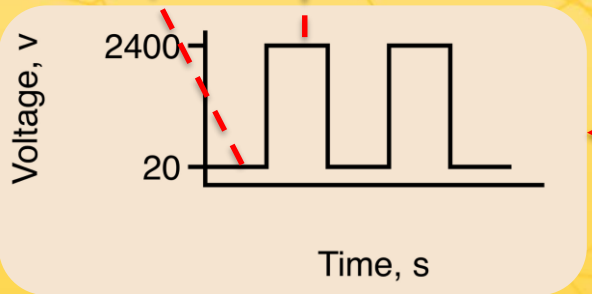
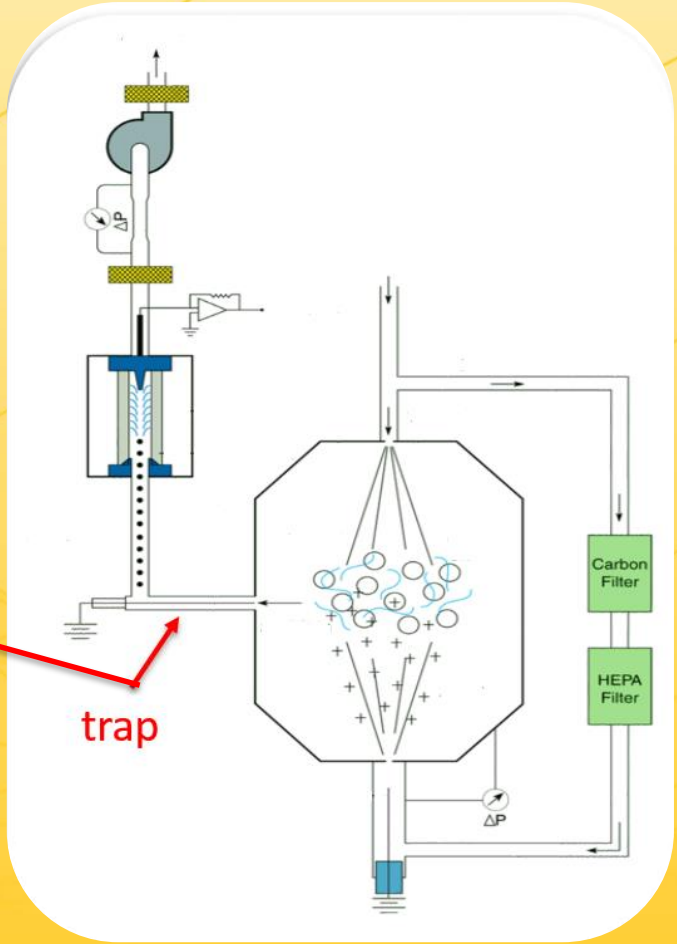
Main Method for surface area: online 2

Based on NSAM, *Cao and Pui et al., (2017a, 2017b) developed a Geometric Surface Area Monitor (GSAM) and an weighted-sum method.

- However, GSAM Needs additional impactor even to spherical particle;
- Weighted-sum method Needs ten or more seconds of response time

$$I_{c_1} + aI_{c_2} \propto d_{p_1}^2 + d_{p_2}^2 + \ldots\ldots d_{p_n}^2$$





So far, NO instrument measures the particle geometric surface area (GSA) with a time-resolution of 1s

Objective

A simple method measuring geometric surface area (GSA) concentration of aerosol nanoparticles in real time with 1s resolution.

Features:

- GSA, 1s response time
- Cost effective and Transportation friendly
- no working fluid, no radiation source, high accuracy, and large range.

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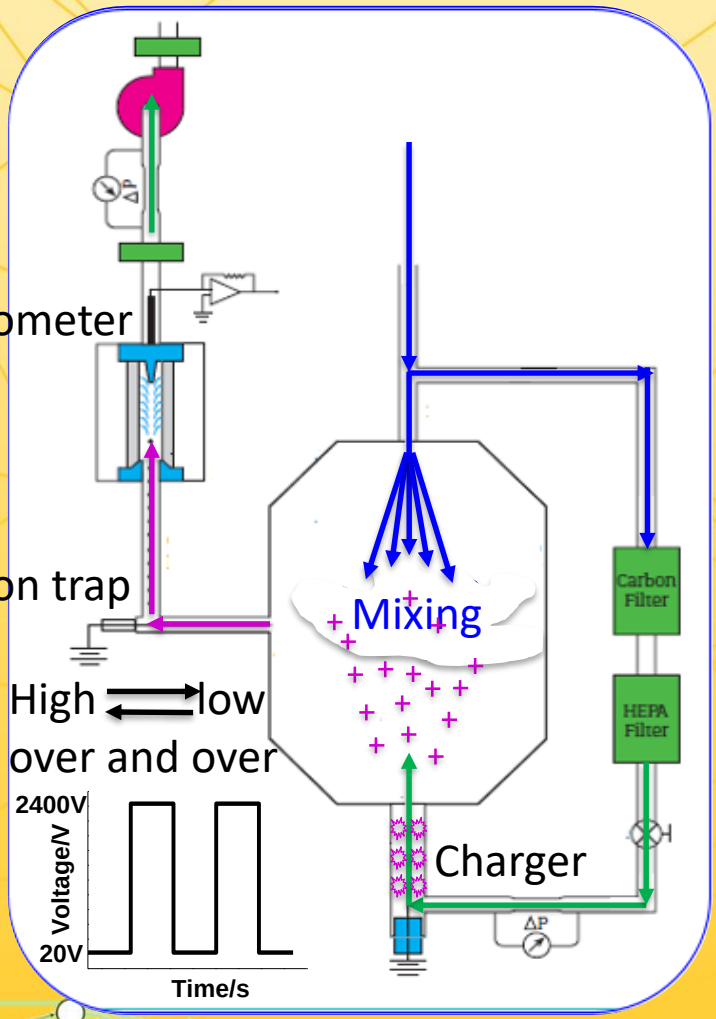
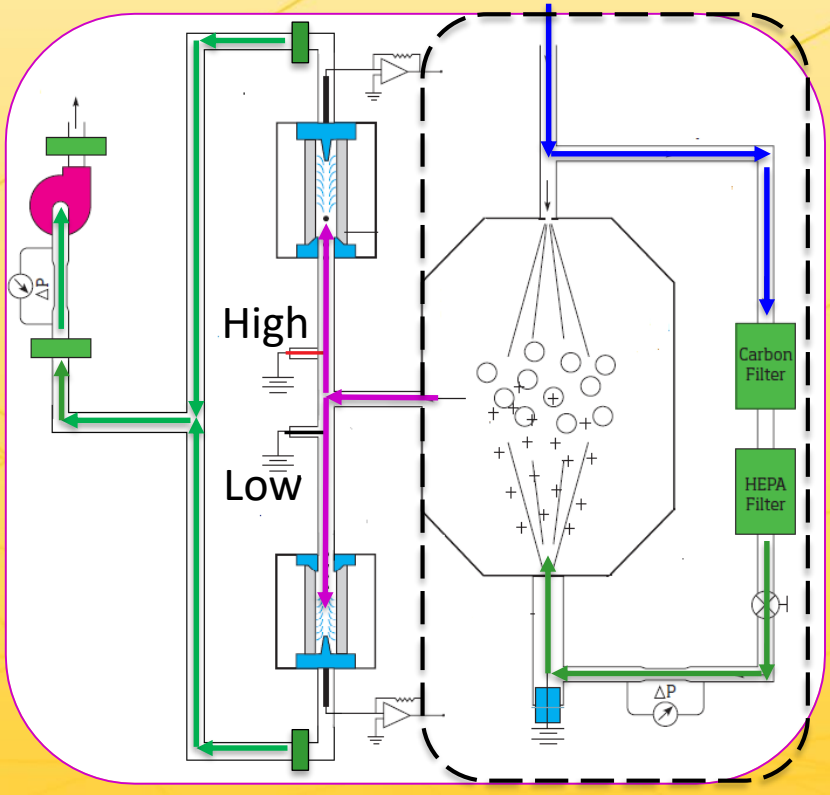
Methodology

Single Channel **(Cao and Pui)**



Two Parallel Channels (This Work)



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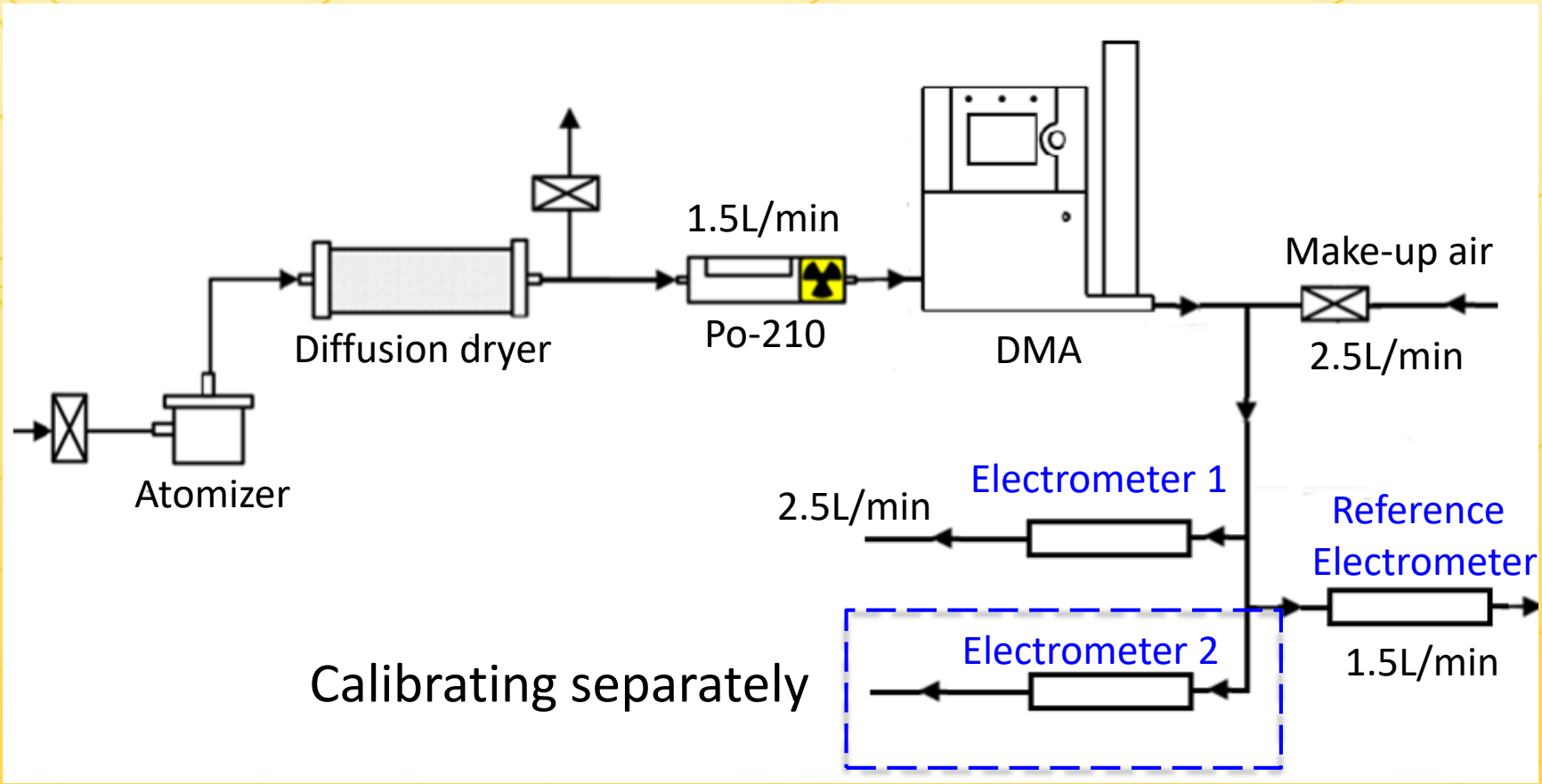
1. Calibration (electrometer)

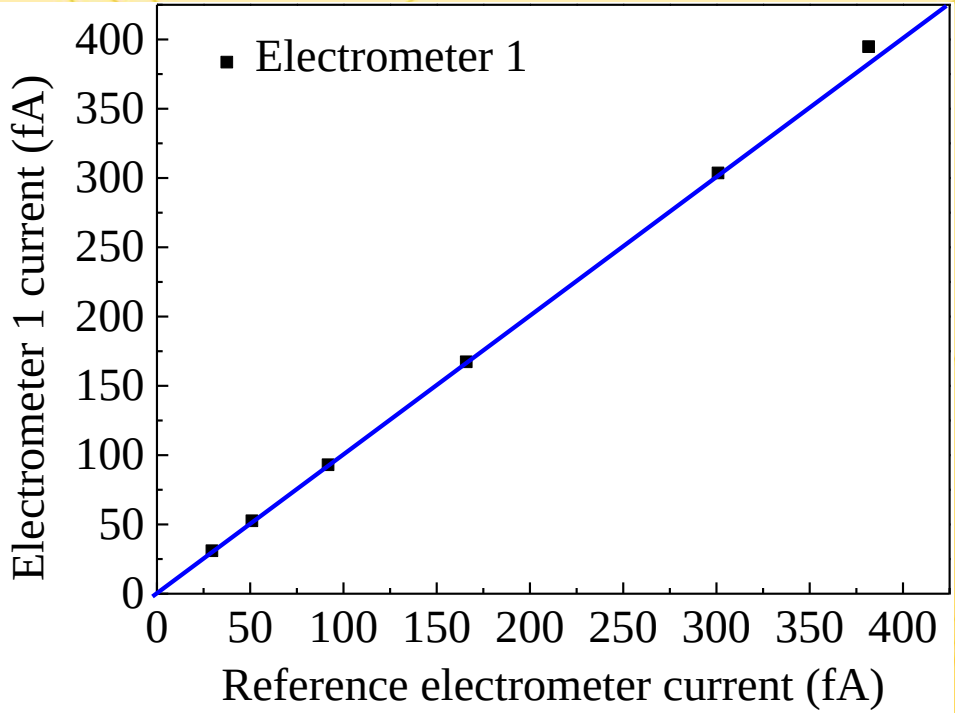
setup

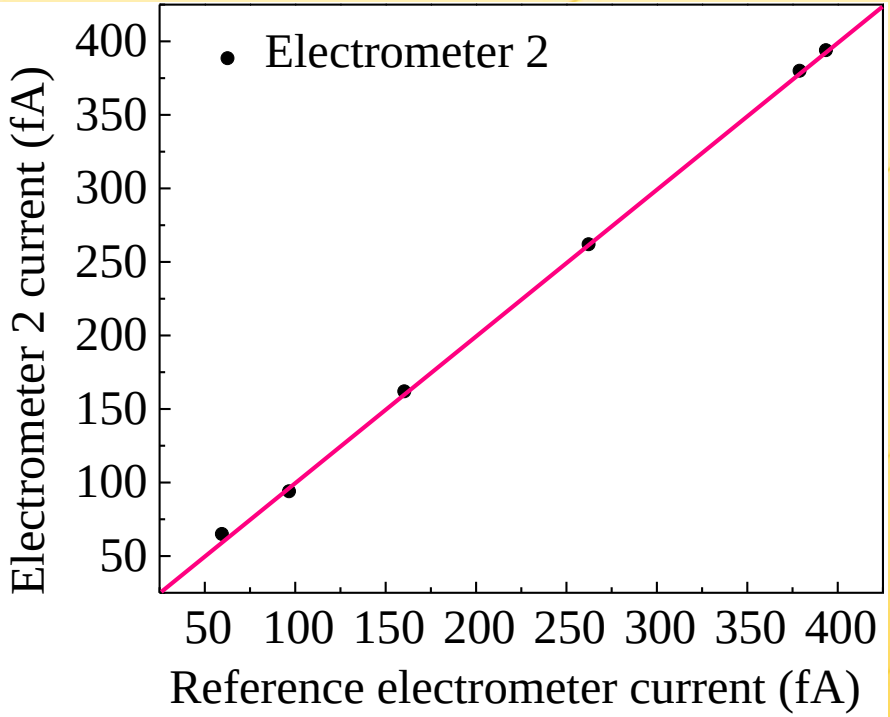


- **Monodisperse Singly charged particle**
- **Reference electrometer** : Using electrometer TSI 3068B

1. Calibration (electrometers)

results





- **Testing particle size： 40nm, 100nm, 150nm, 200nm, 250nm, 300nm**
- **Good accuracy could be found in both electrometers**
- **Reference electrometer** : Using electrometer TSI 3068B

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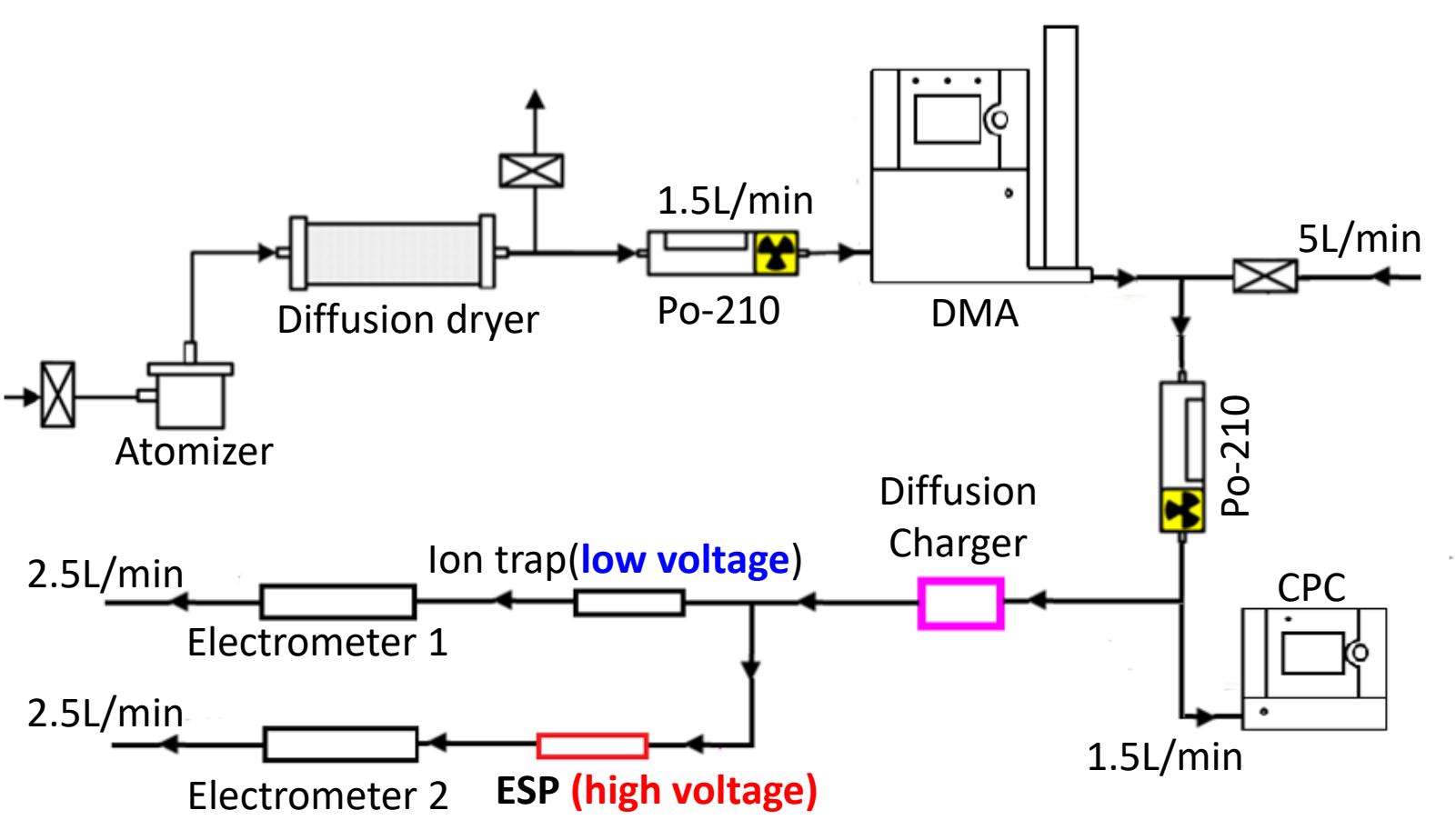
2. Calibration (Sensitivity)

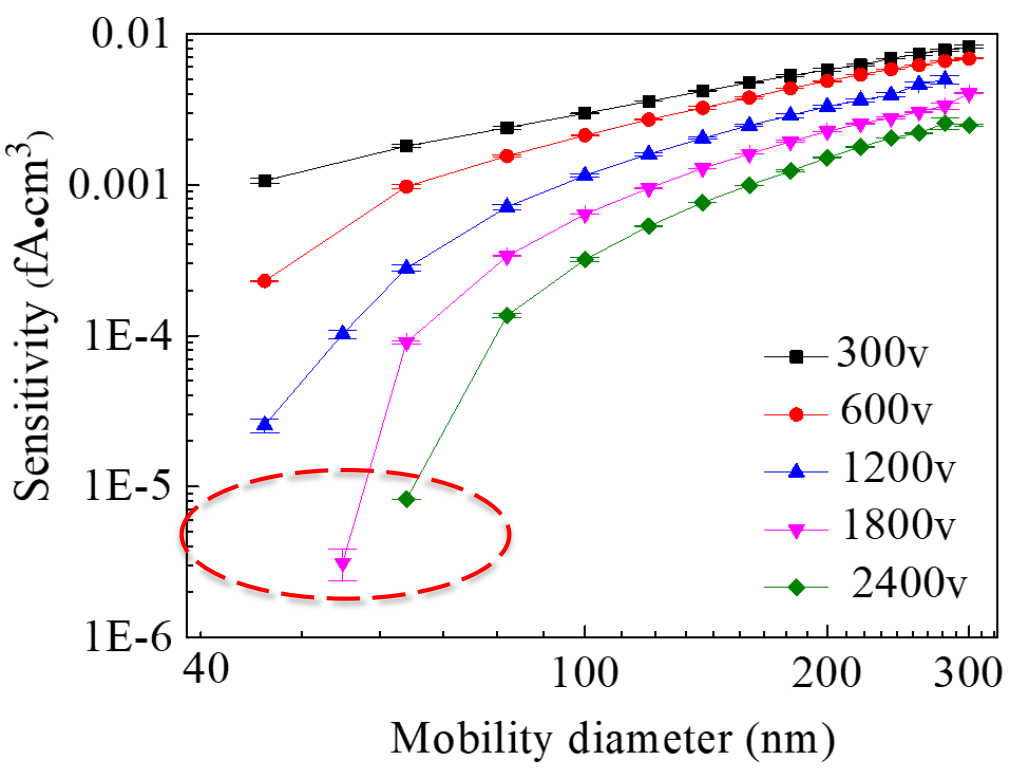
setup



- **Ion trap**: low voltage
- **High voltage**: from 300V to 2400V

2. Selection of appropriate voltage (spheres)

- **Low voltage: 20V (default voltage):** only removing excess ions; covering the whole size range
- **High voltage: Which voltage should we choose?**



S=I/C

S: Sensitivity

I: Electric current from electrometer 2 (corresponds to high voltage)

C: Particle concentration from CPC

2. Selection of appropriate voltage (spheres)

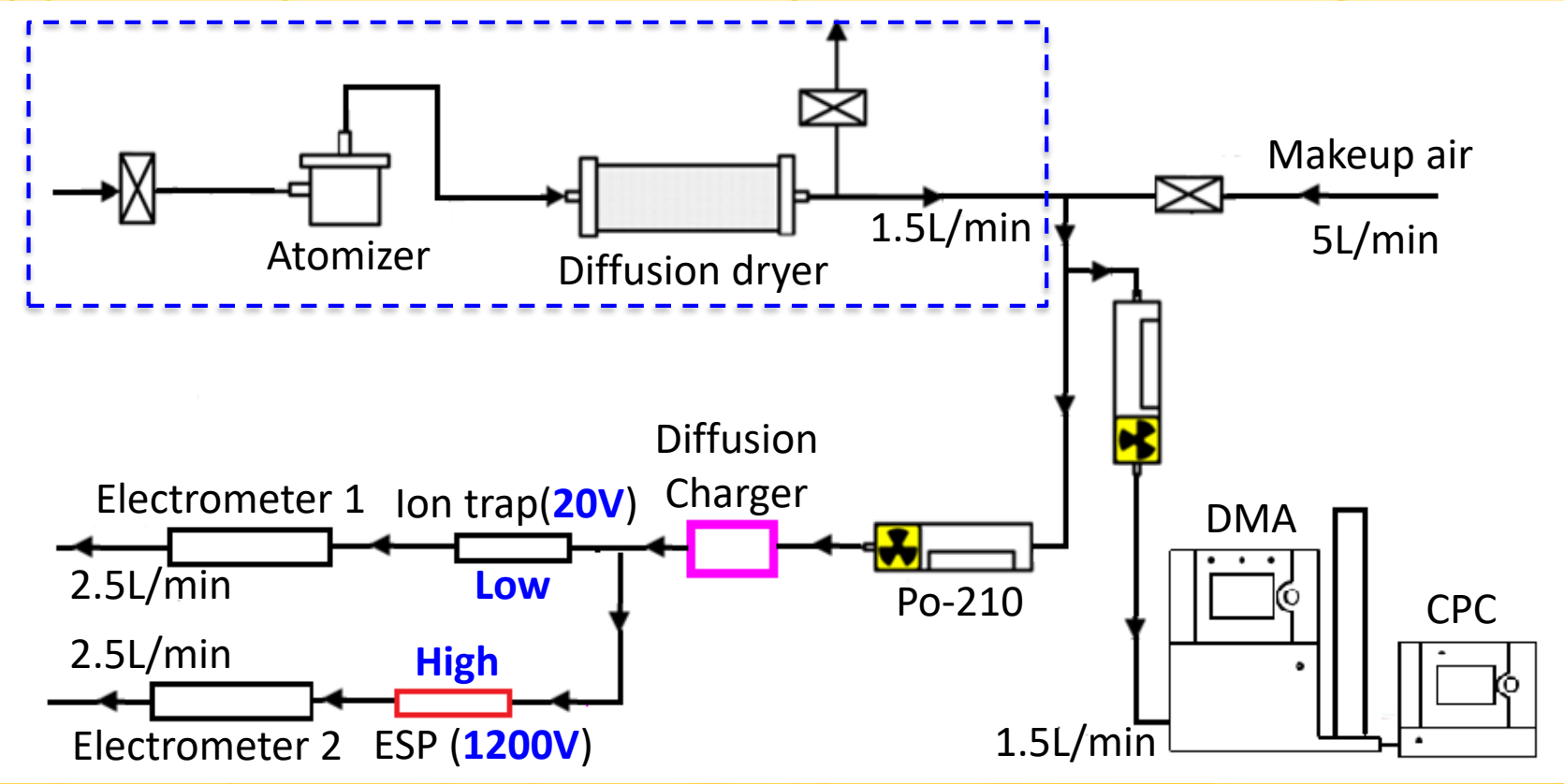
- **Low voltage: 20V (default voltage):** only removing excess ions; covering the whole size range
- **High voltage: Which voltage should we choose?**

I1	I2	Fitting equation	R^2
20V	2400	$S = 3.23 \times 10^7 I_2 - 5.4 \times 10^5 I_1$	0.9868
20V	1800	$S = 2.45 \times 10^7 I_2 - 1.49 \times 10^6 I_1$	0.9903
20V	1200	$S = 1.84 \times 10^7 I_2 - 2.5 \times 10^6 I_1$	0.9901
20V	600	$S = 1.89 \times 10^7 I_2 - 7.04 \times 10^6 I_1$	0.9661
20V	300	$S = 2.53 \times 10^7 I_2 - 1.55 \times 10^7 I_1$	0.9642

1200V is selected, which is a tradeoff between:

- ❑ **minimal sensitivity limit (enough signal-to-noise ratio)**
- ❑ **Goodness of fitting (under different high voltages)**

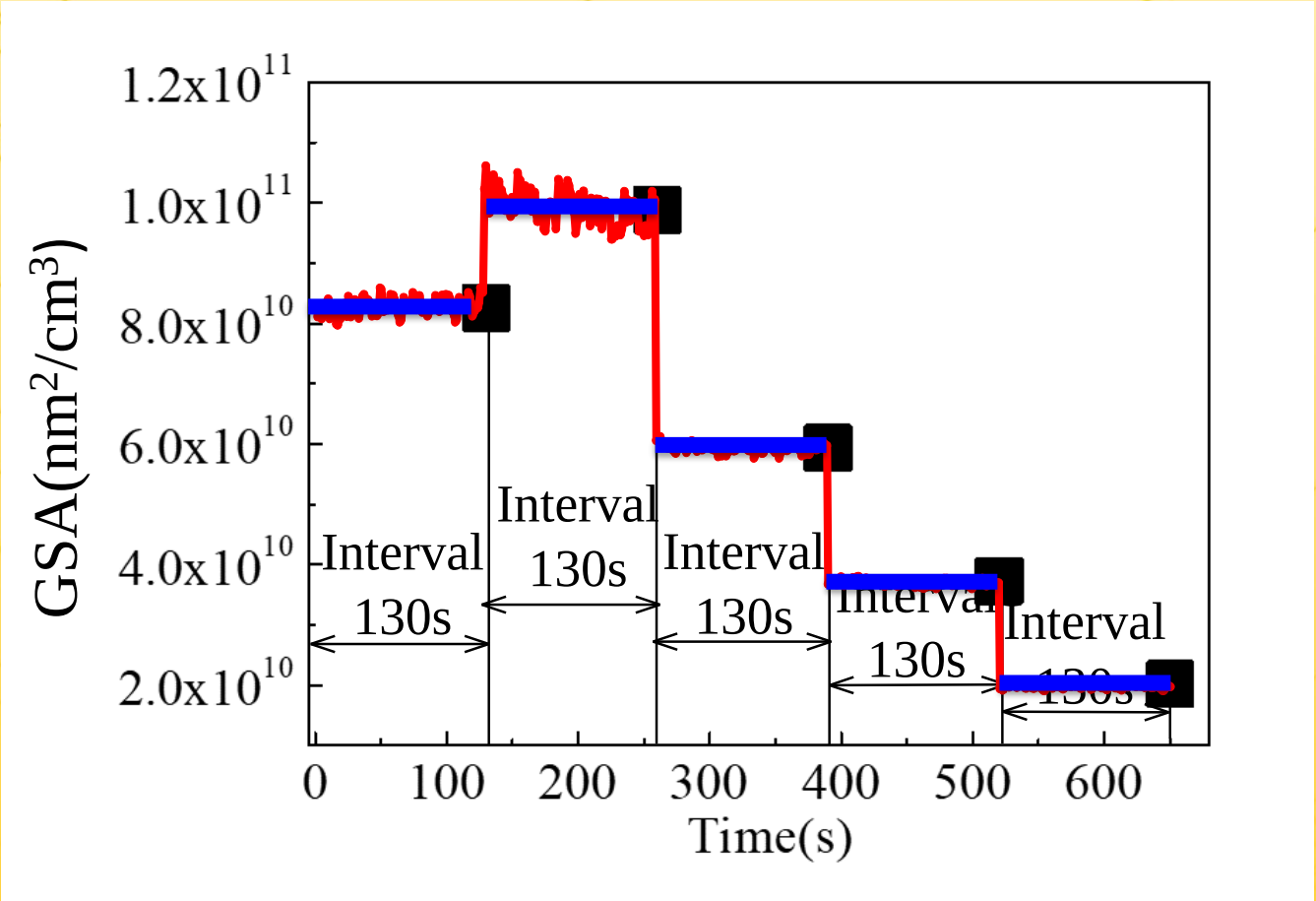
3. Validation (New method vs. SMPS) setup



- **High voltage:1200V, Ion trap: 20V**
- **Compared to SMPS (Polydisperse particles)**

3. Validation A (New Method vs. SMPS)

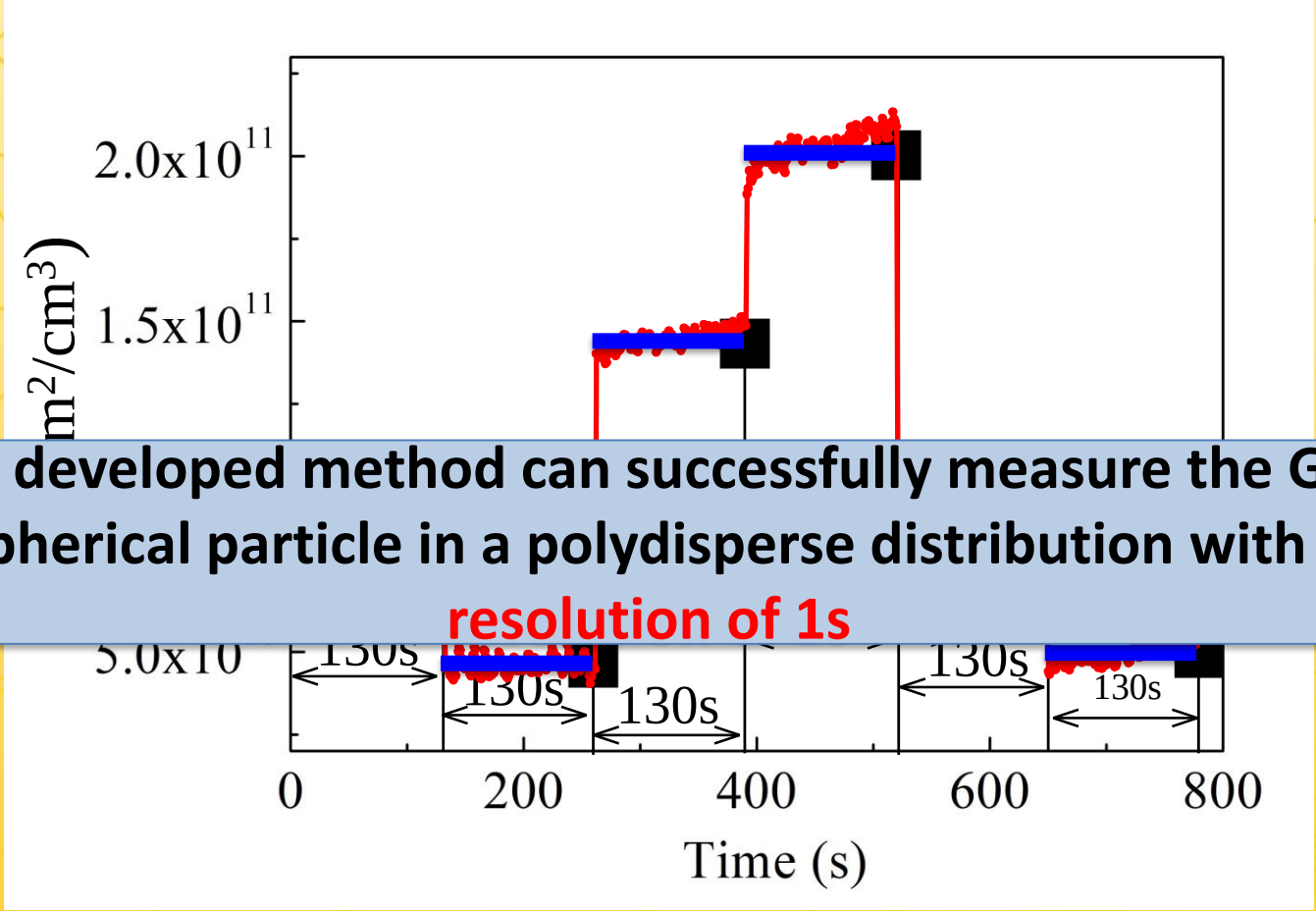
- Polydisperse KCl aerosol (salt)



Continuous Sampling

3. Validation B (New Method vs. SMPS)

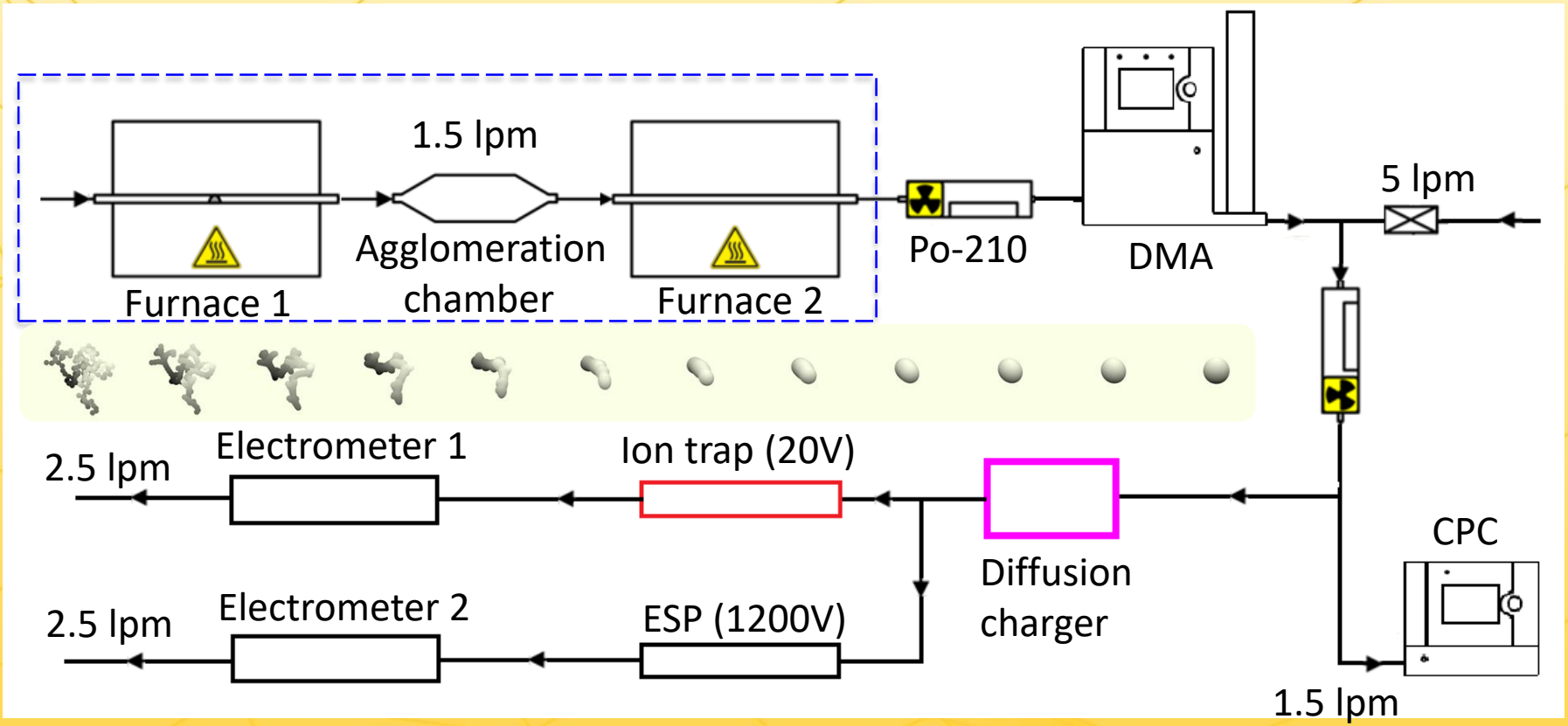
- Polydisperse **DEHS** aerosol (oil)



The developed method can successfully measure the GSA of spherical particle in a polydisperse distribution with the resolution of 1s

Continuous Sampling

4. Setup diagram- Agglomerate



- Furnace 1: **1200℃** (generating silver spheres); Furnace 2: **room temperature to 600℃** (sintering to tune aggregates structure)[a]

[a] Seong C. Kim, et al. (2009) Structural property effect of nanoparticle agglomerates on particle penetration through fibrous filter, Aerosol Science and Technology, 43:4, 344-355.

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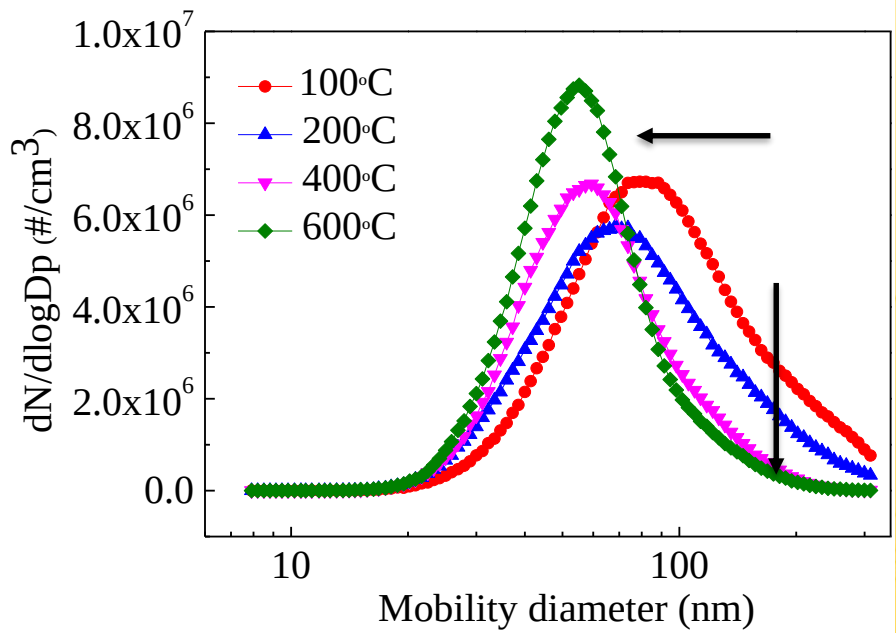
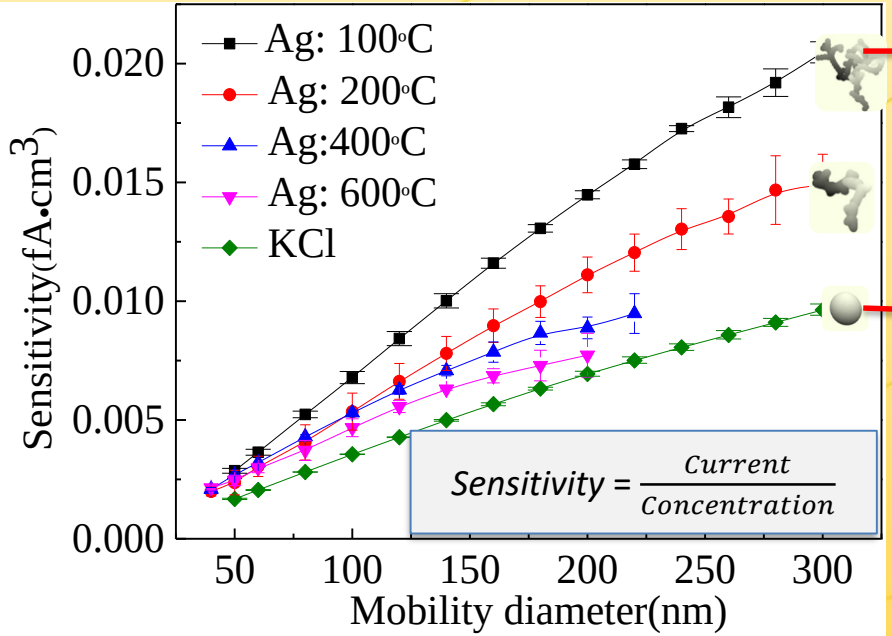
5. Results -Agglomerate

- Effect of sintering temperature (Change of particle morphology)





- Increasing temperature, particle size distribution changes.
- Increasing temperature, the sensitivity decreases significantly
- Comparing to spheres, higher sensitivities were found for aggregates

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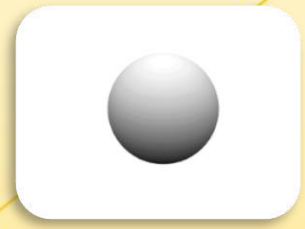


Summary

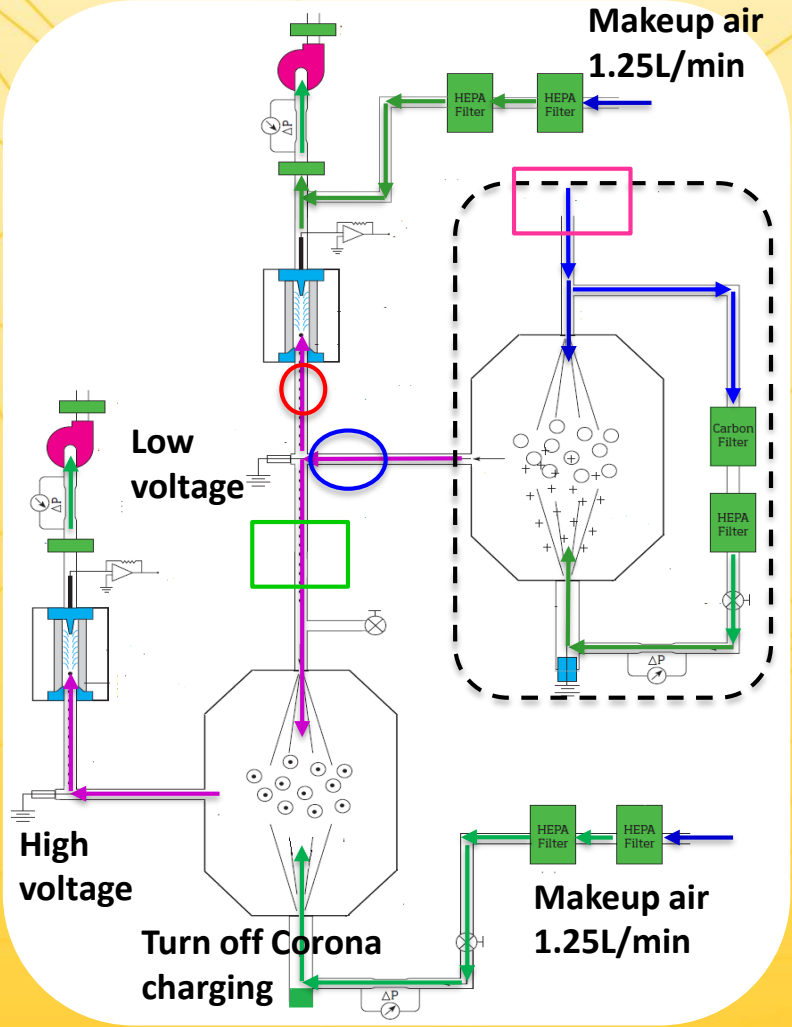
- The developed method (by combining one ion trap and one ESP) can successfully measure the Particle Geometric Surface Area of polydisperse aerosols with the following features:
  - With 1s time resolution
  - In a wide concentration range
  - Adapting to polydisperse particle distribution
  - Cost-effective
  - With simple setup

Future work

- Developing the method that can measure GSA of Agglomerate particles with 1s response time
- Adding APM (Aerosol Particle Mass Analyzer) to the set-up to offer more substantial and valuable information for agglomerates
- Investigating the effect of humidity on the GSA measurement by the developed method to apply it to different operating conditions

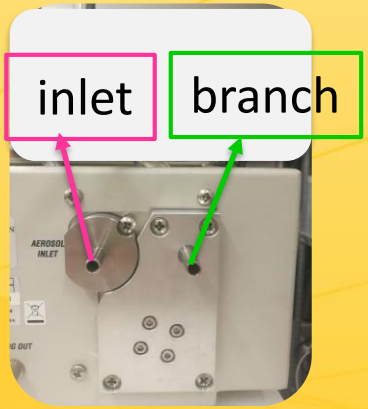
Thank you

Appendix 1-Practical model



Overall

Back side



Front side

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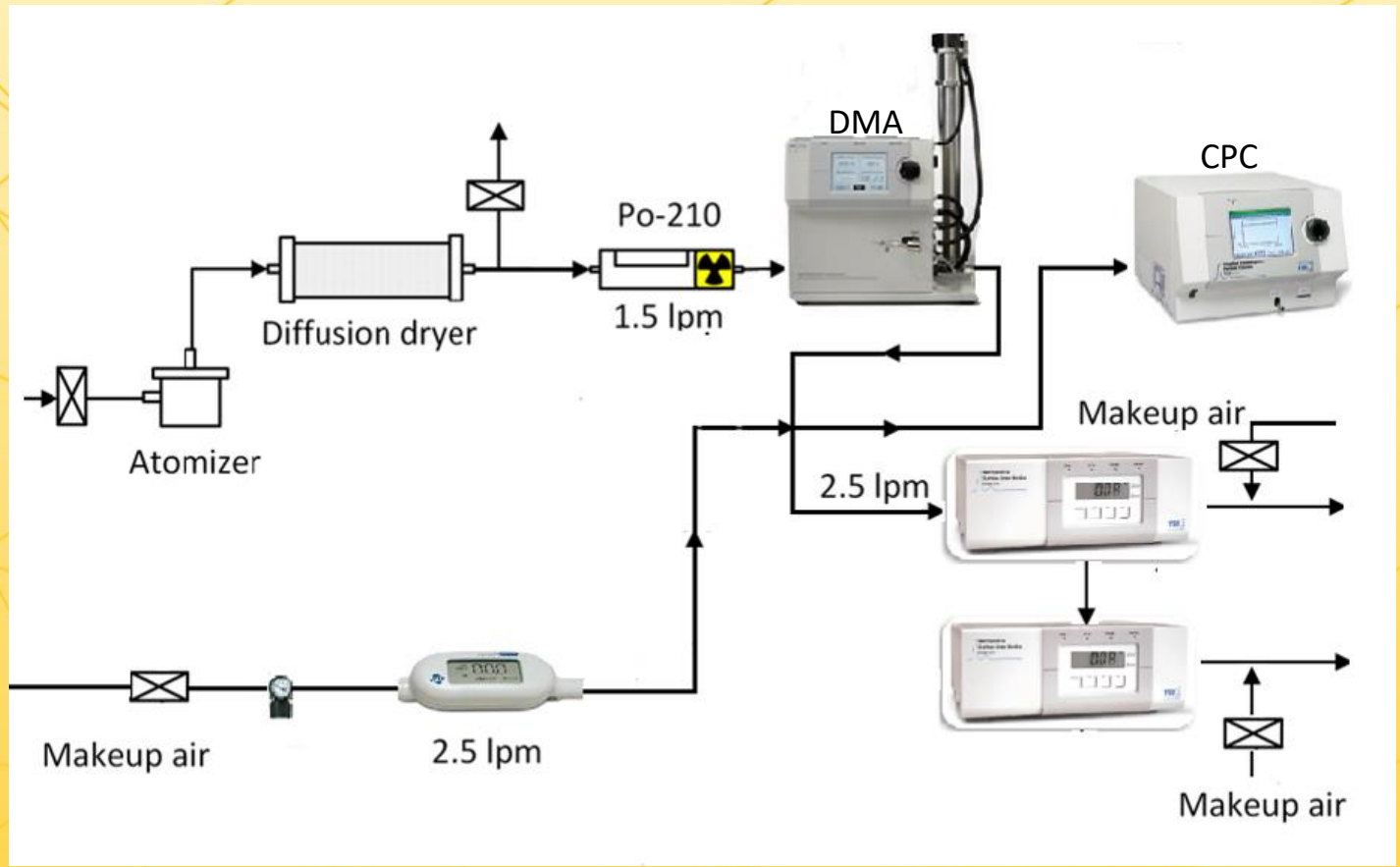
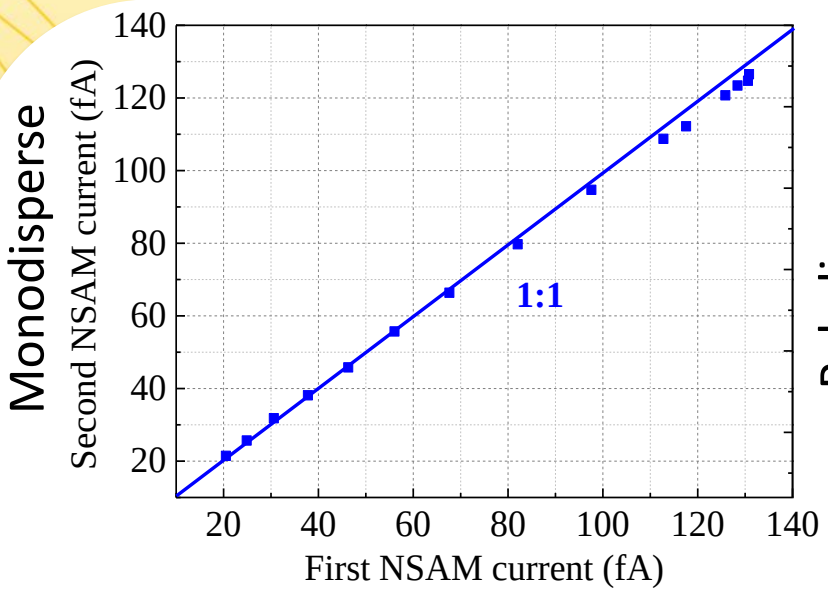
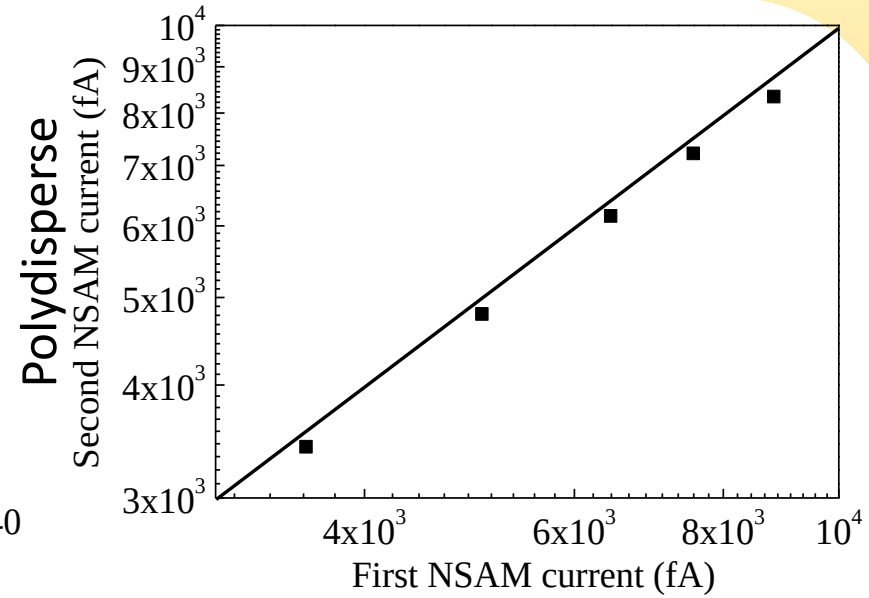
Appendix-Calibration setup



- **Monodisperse Particle loss calibration**: The first NSAM charger and ion trap **on** while the second NSAM charger and ion trap **off**. Comparing results between two NSAMs.
- **Polydisperse calibration** is similar to Monodisperse calibration

Appendix 3-Loss calibration





$$\frac{first\ current - second\ current}{first\ current} < 5\%$$

The developed method has a negligible particle loss in 40 to 300nm, confirming the feasibility of new set-up

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