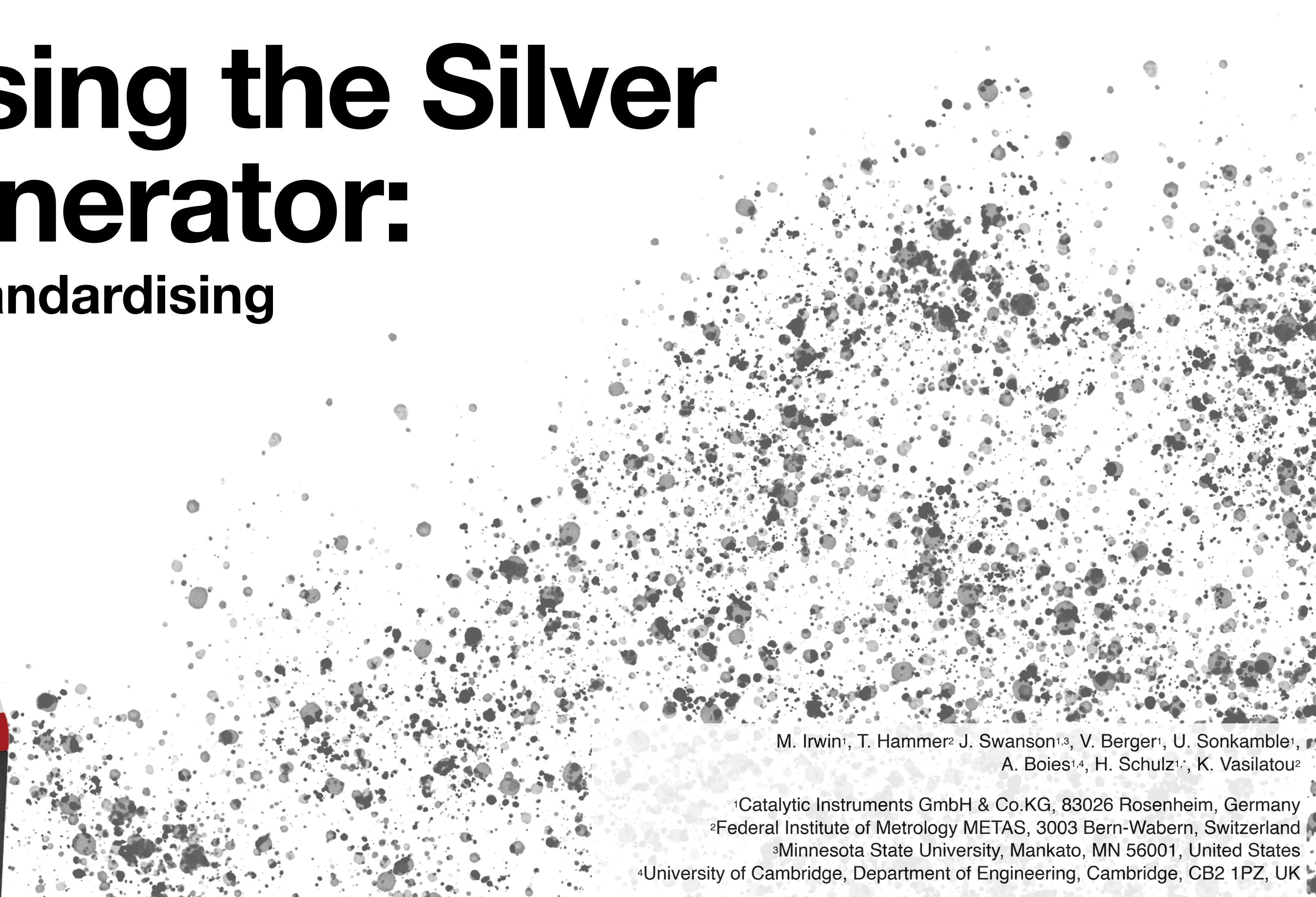
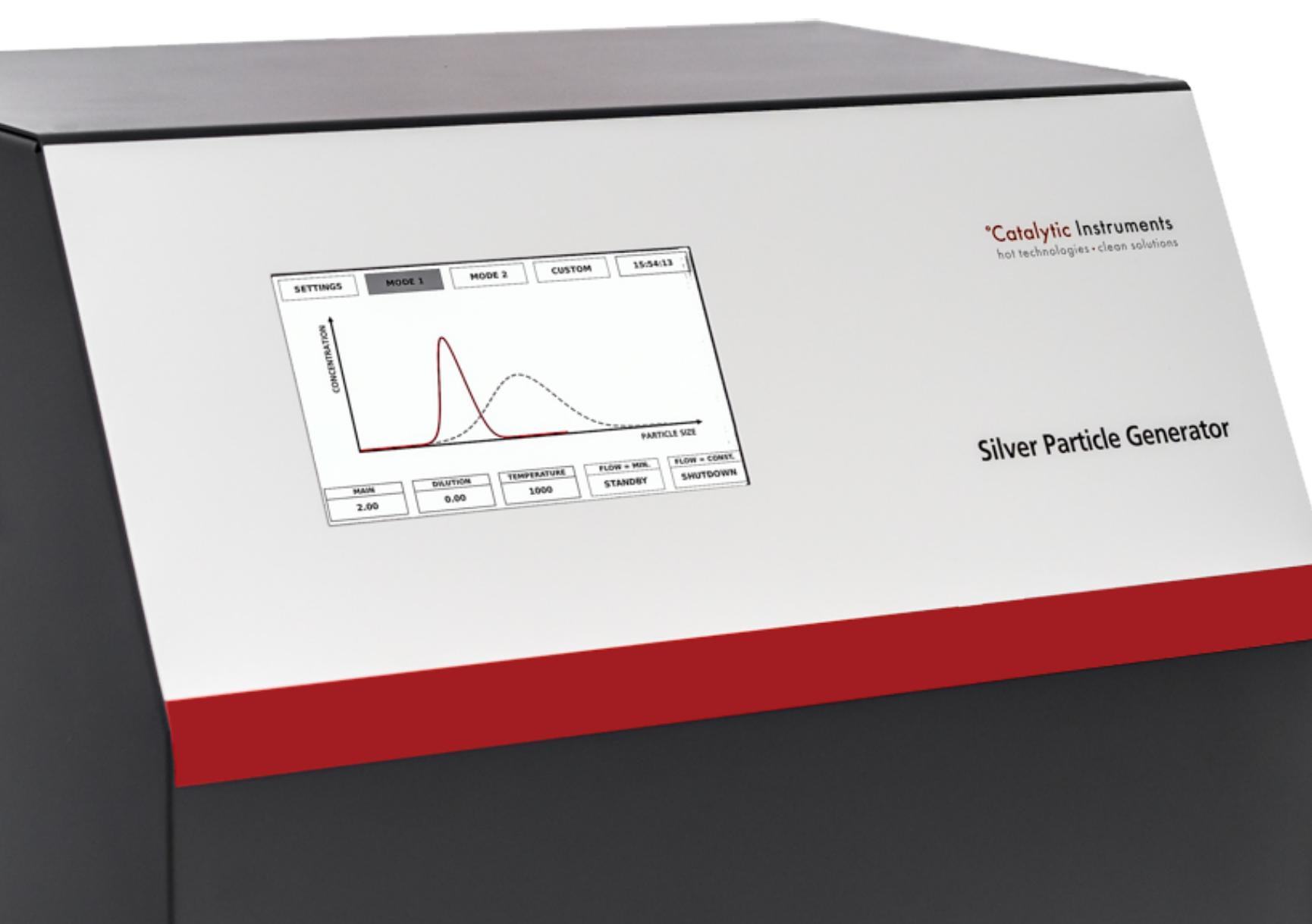


# Characterising the Silver Particle Generator:

## A pathway towards standardising aerosol generation



M. Irwin<sup>1</sup>, T. Hammer<sup>2</sup>, J. Swanson<sup>1,3</sup>, V. Berger<sup>1</sup>, U. Sonkamble<sup>1</sup>, A. Boies<sup>1,4</sup>, H. Schulz<sup>1\*</sup>, K. Vasilatou<sup>2</sup>

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<sup>2</sup>Federal Institute of Metrology METAS, 3003 Bern-Wabern, Switzerland

<sup>3</sup>Minnesota State University, Mankato, MN 56001, United States

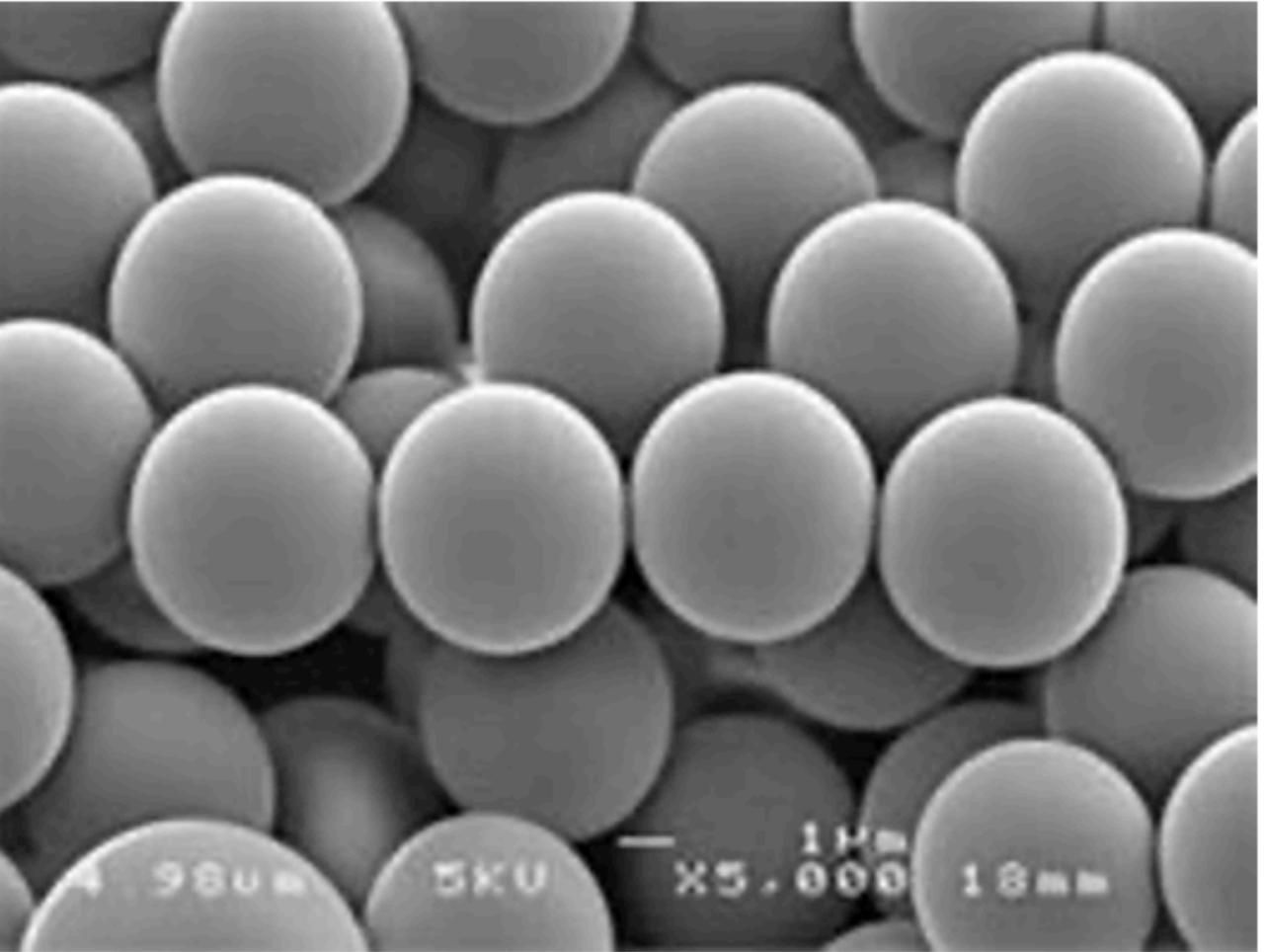
<sup>4</sup>University of Cambridge, Department of Engineering, Cambridge, CB2 1PZ, UK

# Why do we need aerosol generators?

Can't we just buy a bottle of particles?

- Aerosols vary in:
  - Number
  - Size
  - Composition & phase
- Solid aerosol are a preferred calibration source

COMPOUND	Salt	Soot	PSL
Cost	Low	High	Medium
Hygroscopic	Yes	No	Kind of
Spherical	No	No	Close
Usability	Simple	Medium	Medium



# Current generators

- Variable performance
- Fiddly to use
- Low reproducibility
- Radioactive requirements
- Dirty
- Complex
- Inorganic compounds
- Surfactants
- Short operating times



# CPC calibrations

## Why Silver?

- Well-characterised metal
- Solid at room & elevated temperature
- Low hygroscopicity
- Unreactive
- Pure compound
- Clean
- No surfactant/solution
- Traceable
- Historical link to tube furnaces

COMPOUND	Salt	Soot	PSL	Silver
Cost	Low	High	Medium	Medium
Hygroscopic	Yes	No	Kind of	No
Spherical	No	No	Close	Yes
Usability	Simple	Medium	Medium	Medium

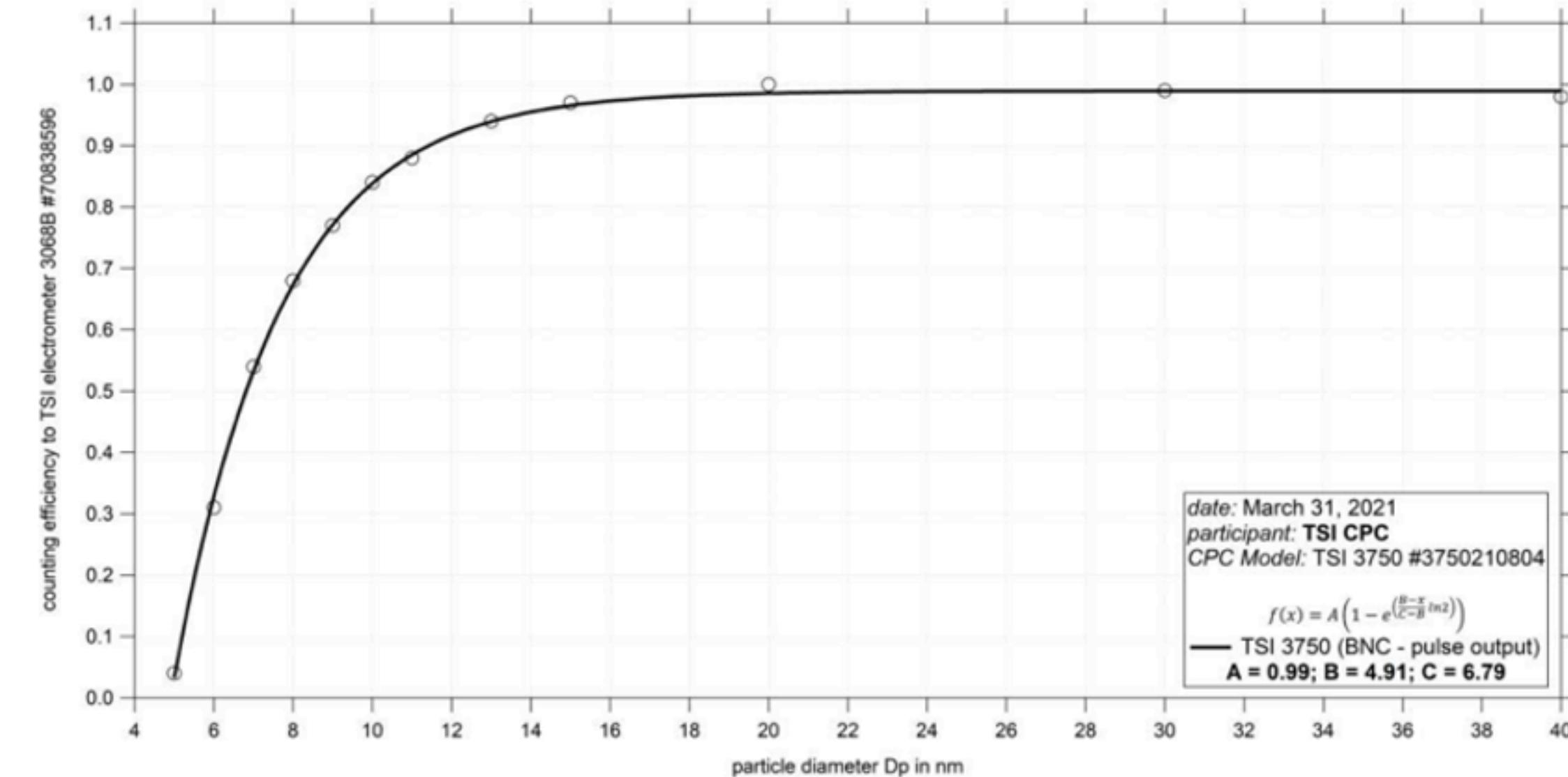
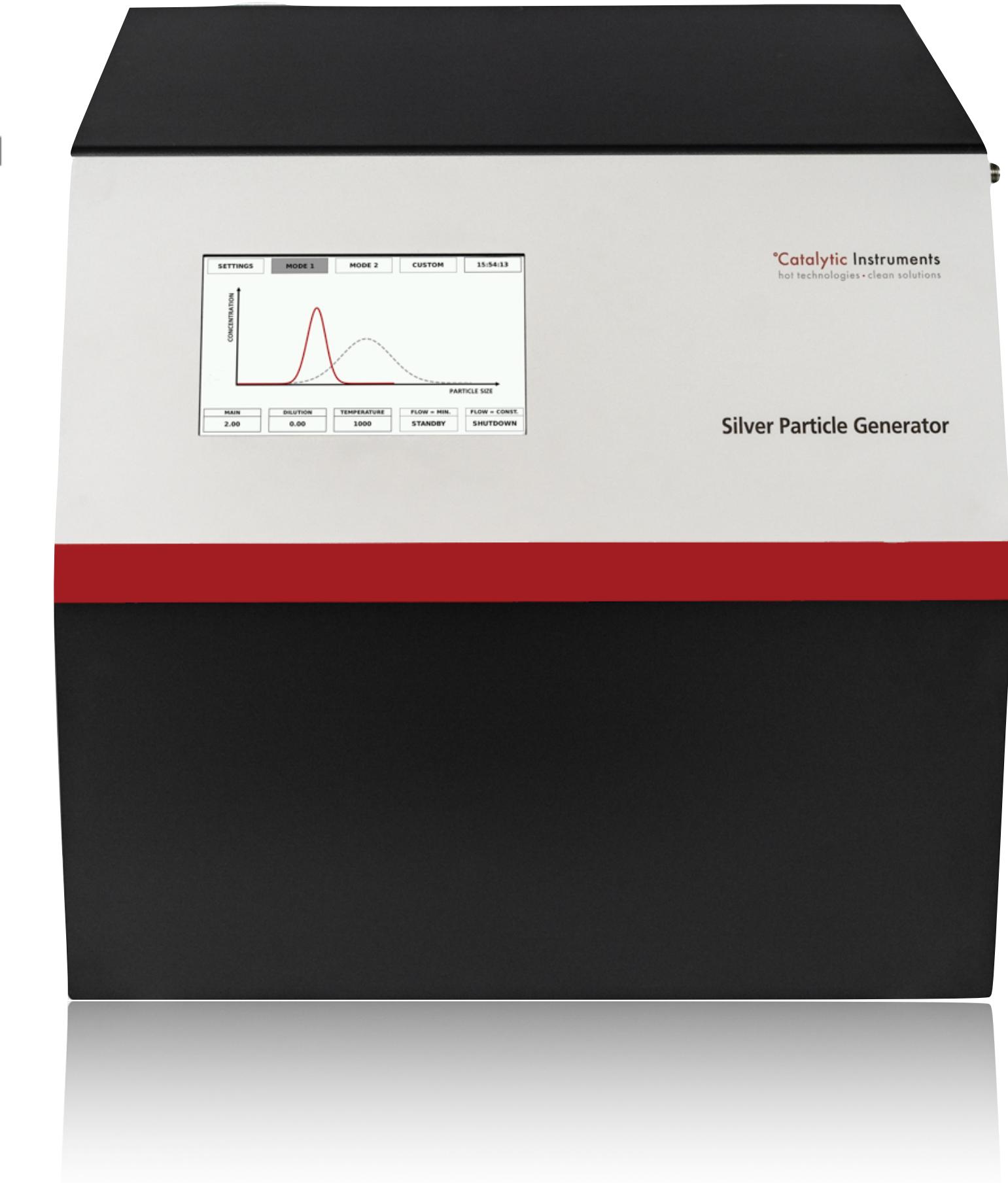
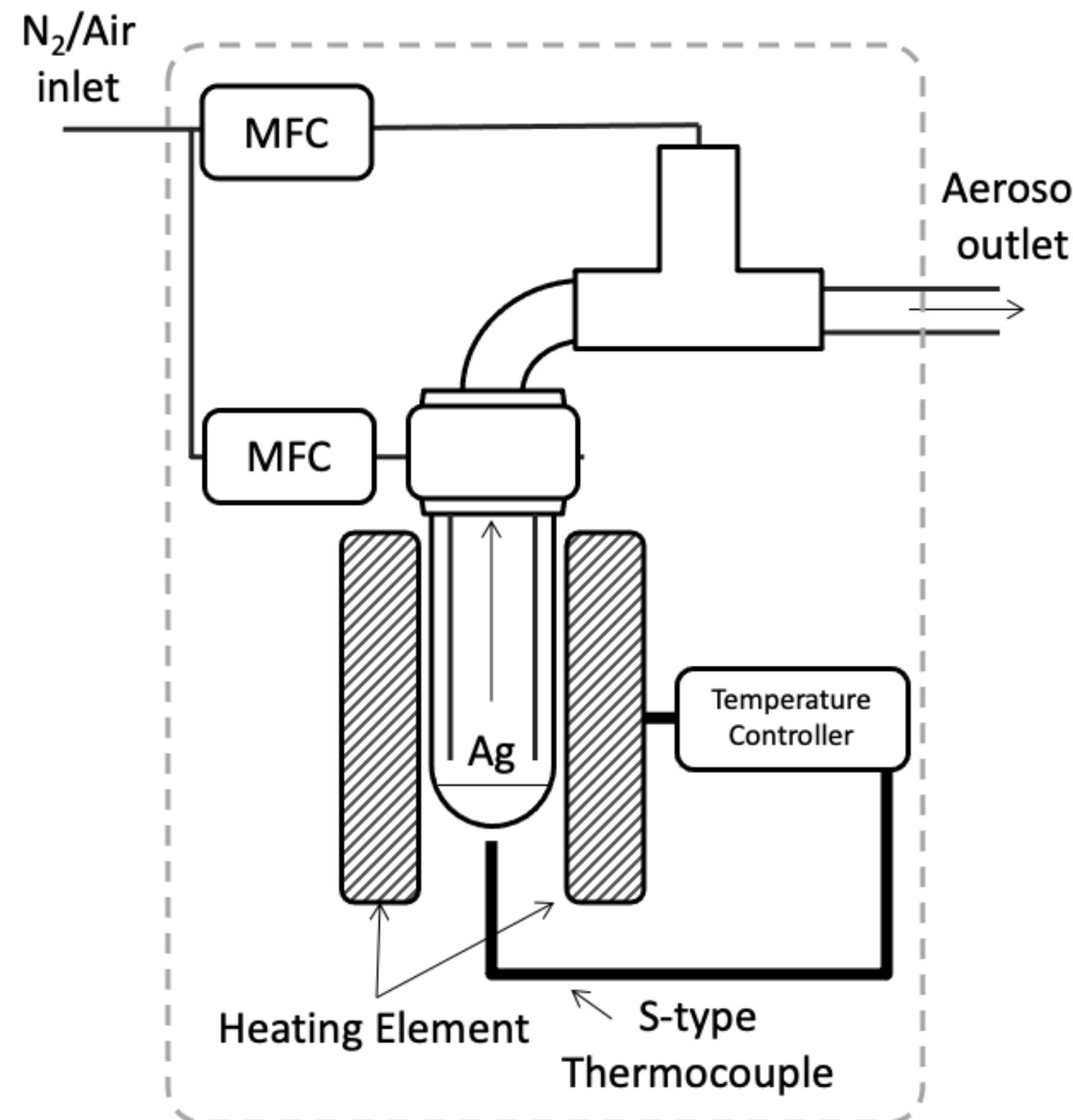


Fig. 1: Counting efficiency for TSI-CPC 3750 SN 3750210804 against aerosol electrometer 3068 SN 70838596; silver particles between 5 nm and 40 nm were used for calibration; the calculated  $D_{p50}$  from the BNC (pulse output) is 6.79 nm.

# Silver Particle Generator (SPG)

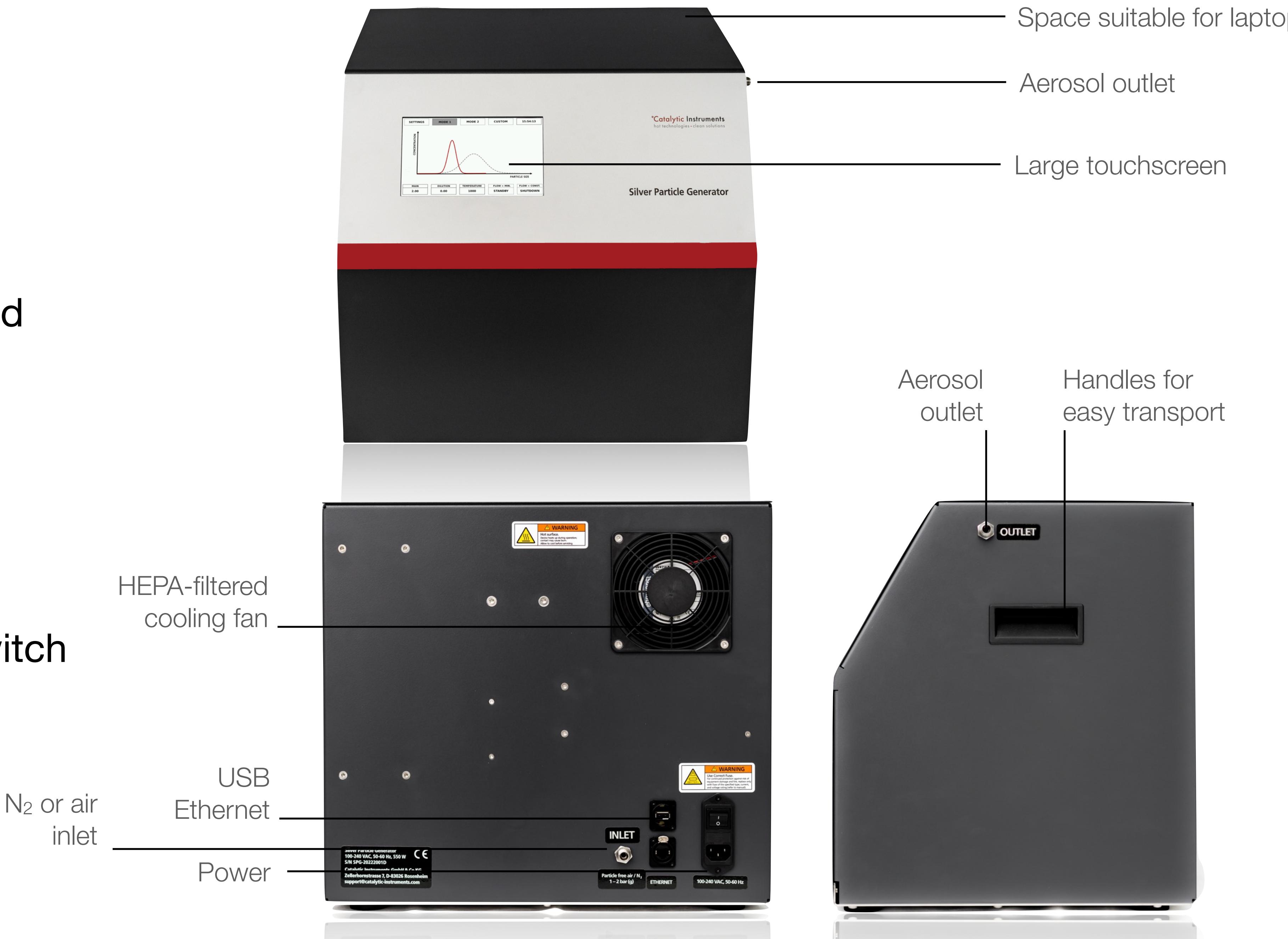
## A pathway towards standardising aerosol generation

- Evaporation & condensation method
- Finely regulated flow control
- Ceramic heater
- Extremely stable particle generation
- 1-touch operation
- User set points



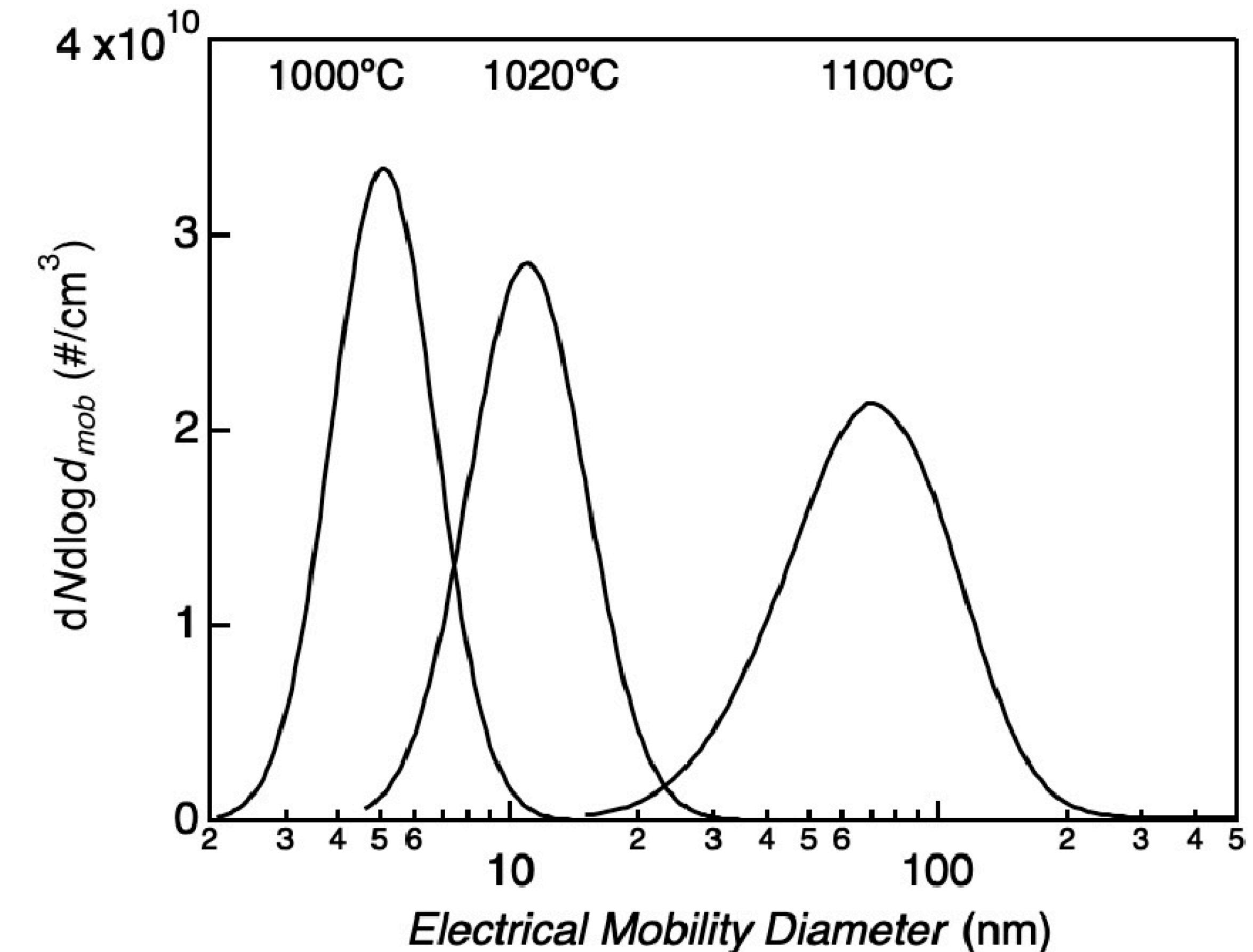
# Design

- Simple
- Thermally insulated
- No vibrations
- Quiet cooling fan
- USB & Ethernet
- Remote control
- N<sub>2</sub> or air
- Thermal safety switch



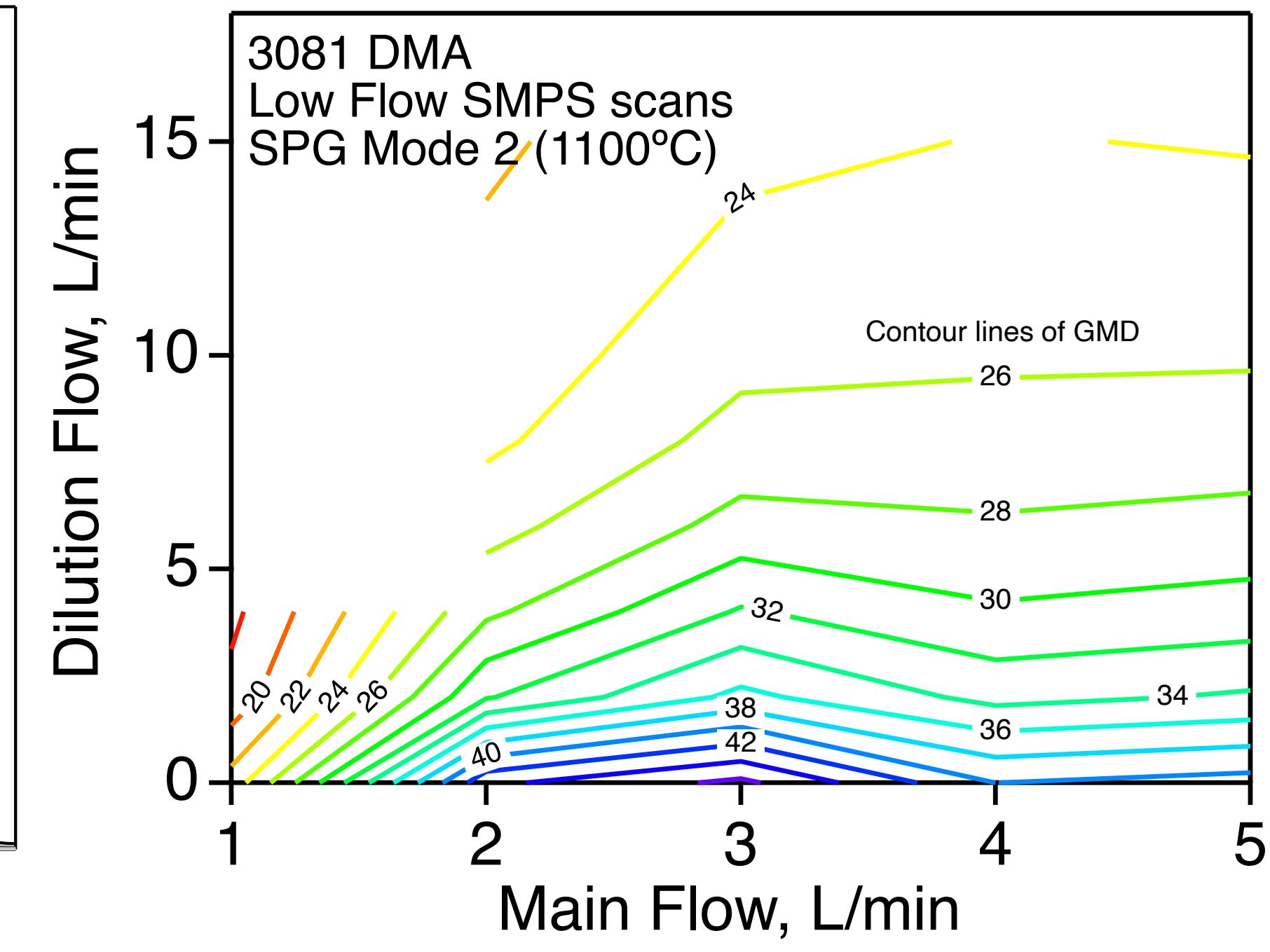
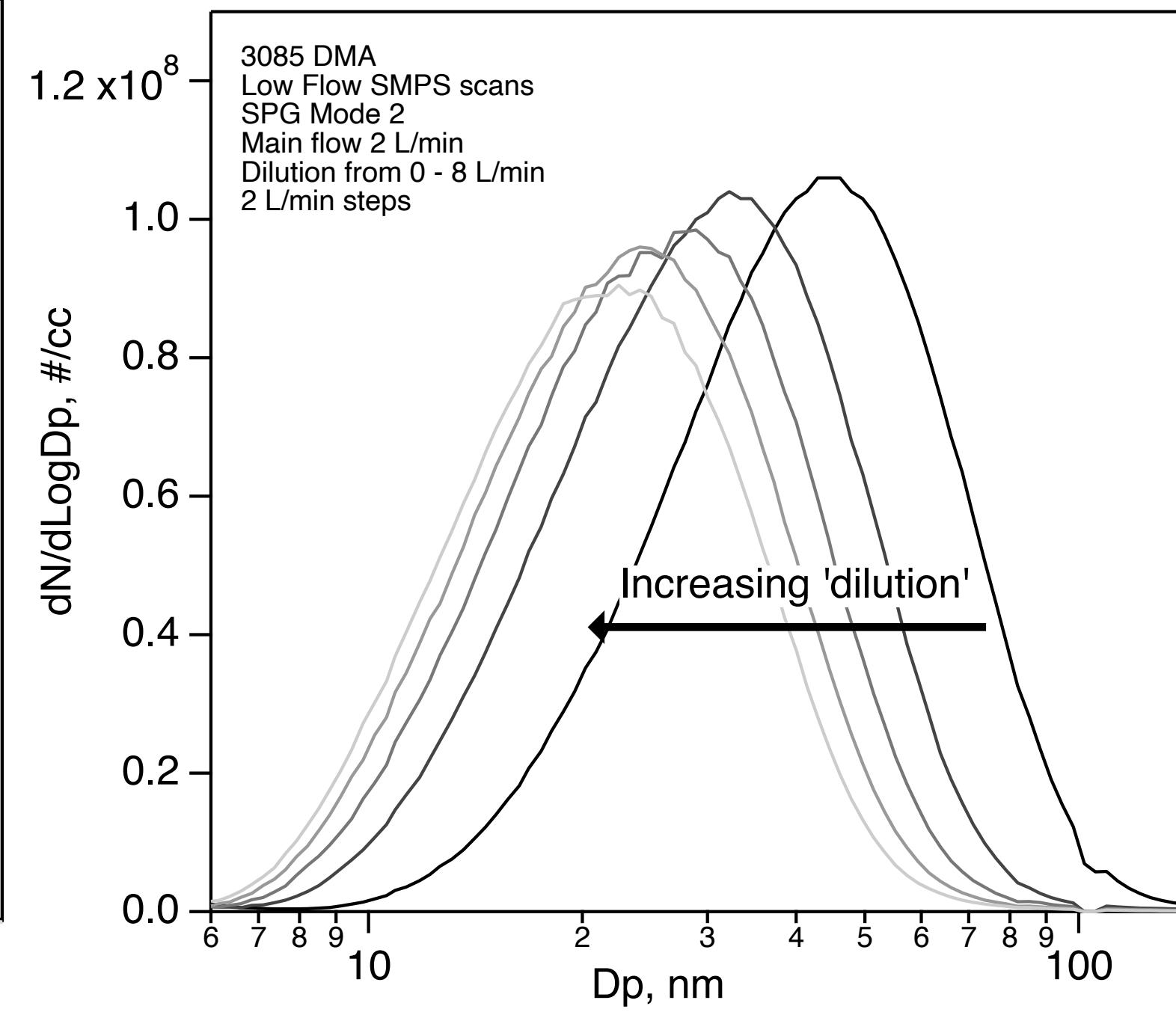
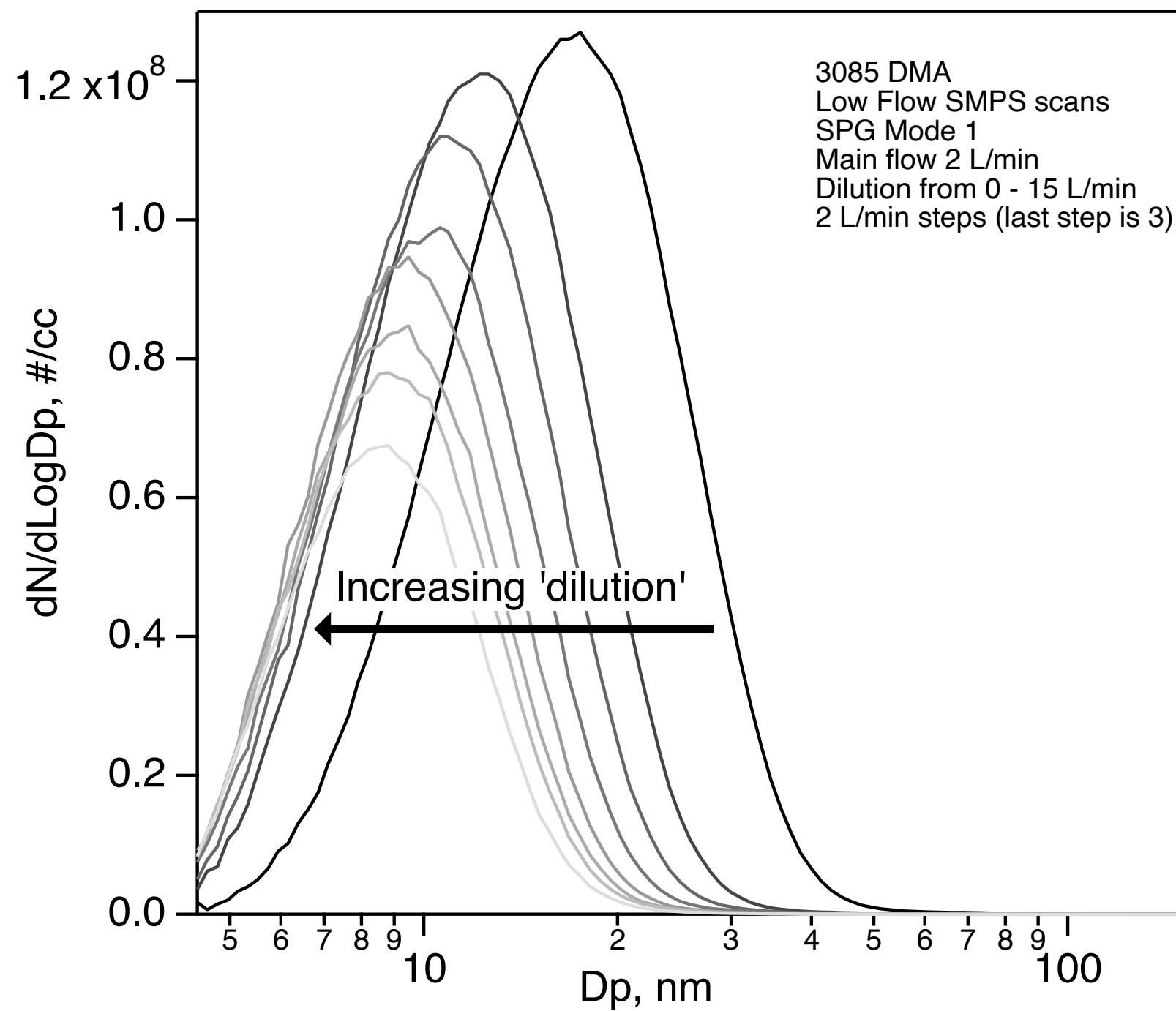
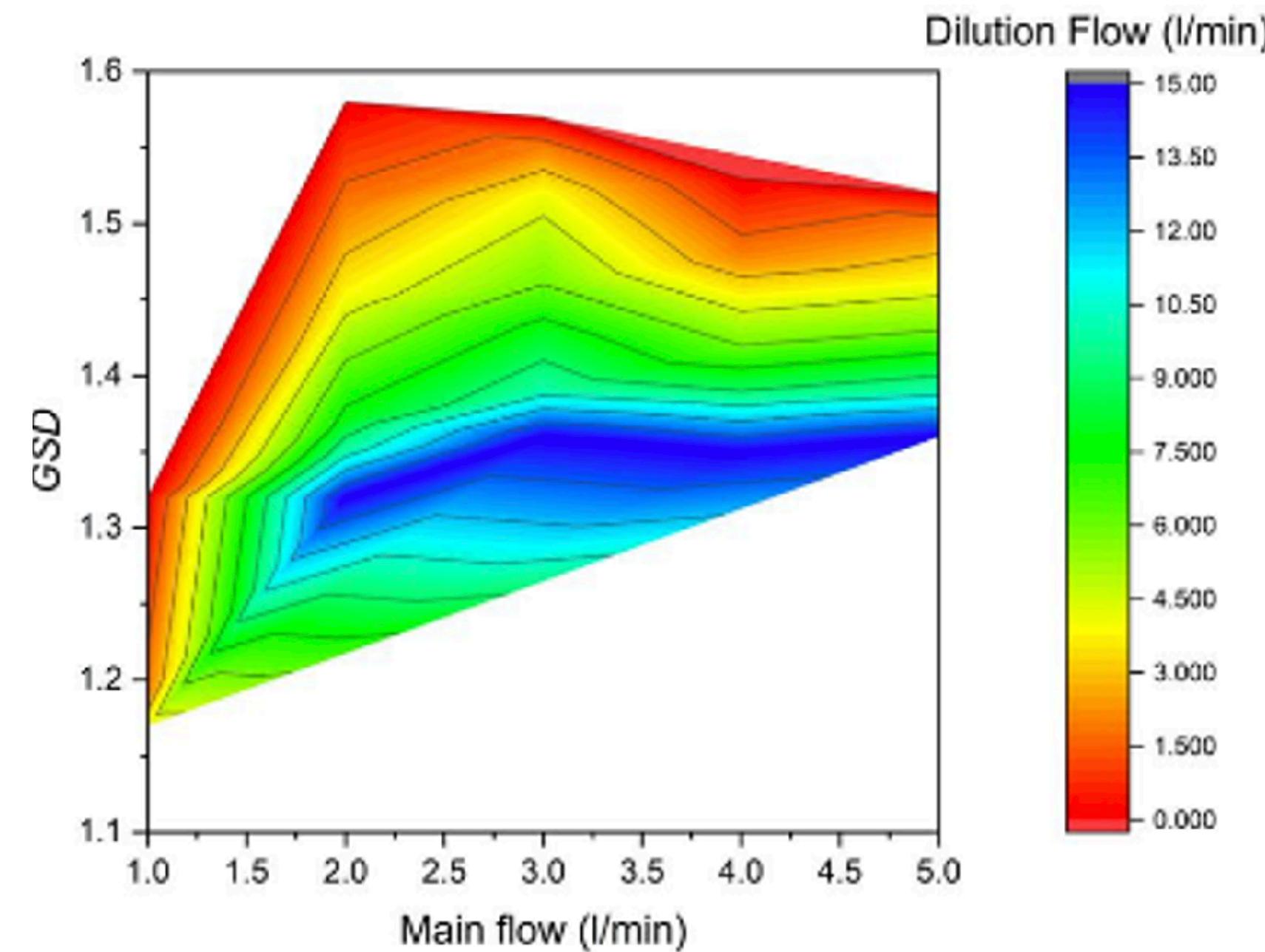
# Size range

- Output size determined by two variables:
  - Temperature
  - Flow (main flow, and dilution flow)
- Different sampling methods may observe different sized particles
  - e.g. short DMA and high flow vs long DMA and low flow
- Max temperature set point 1100°C
- GMD range 2 - 70 nm
- GSD range 1.15 - 1.8



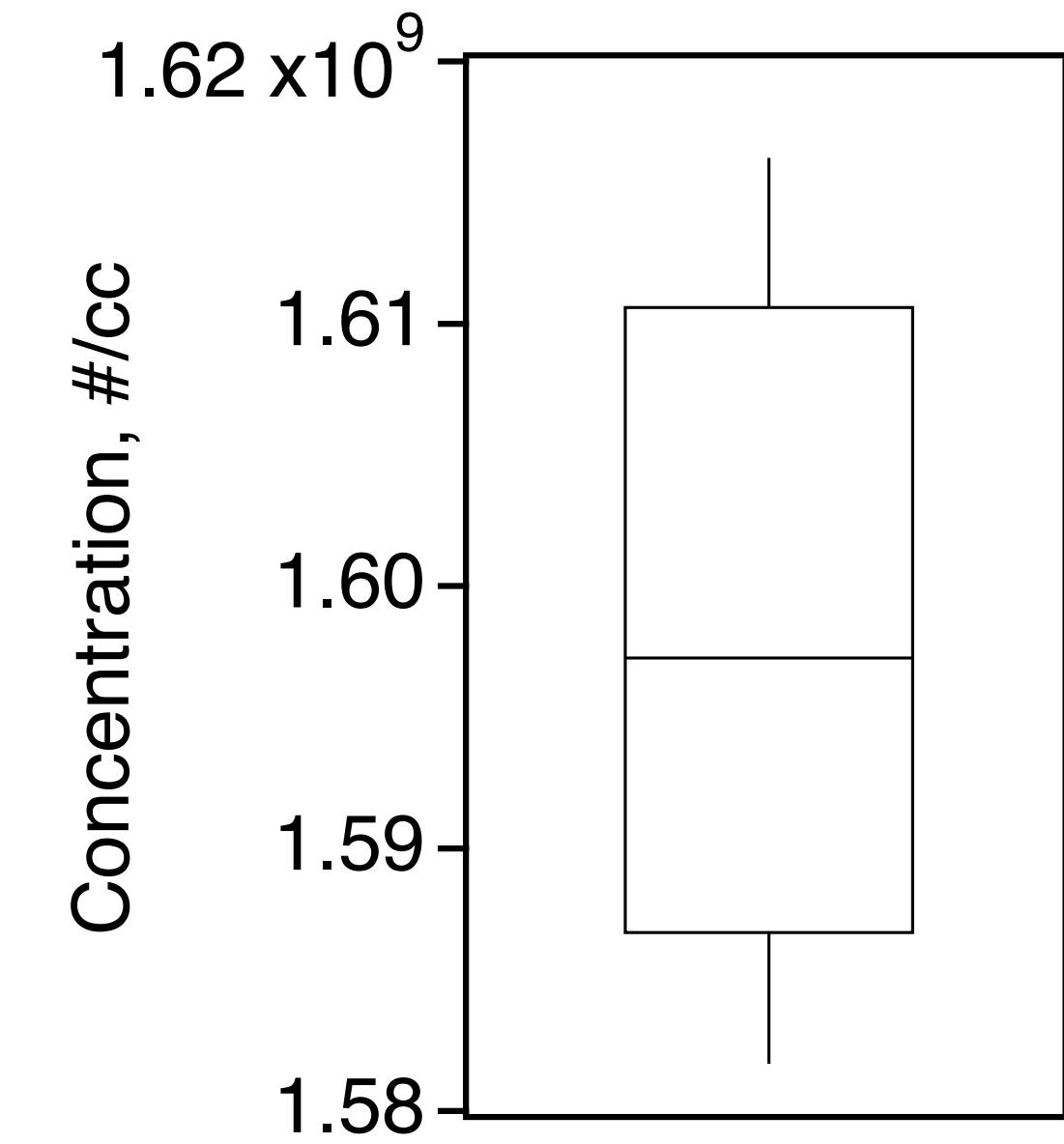
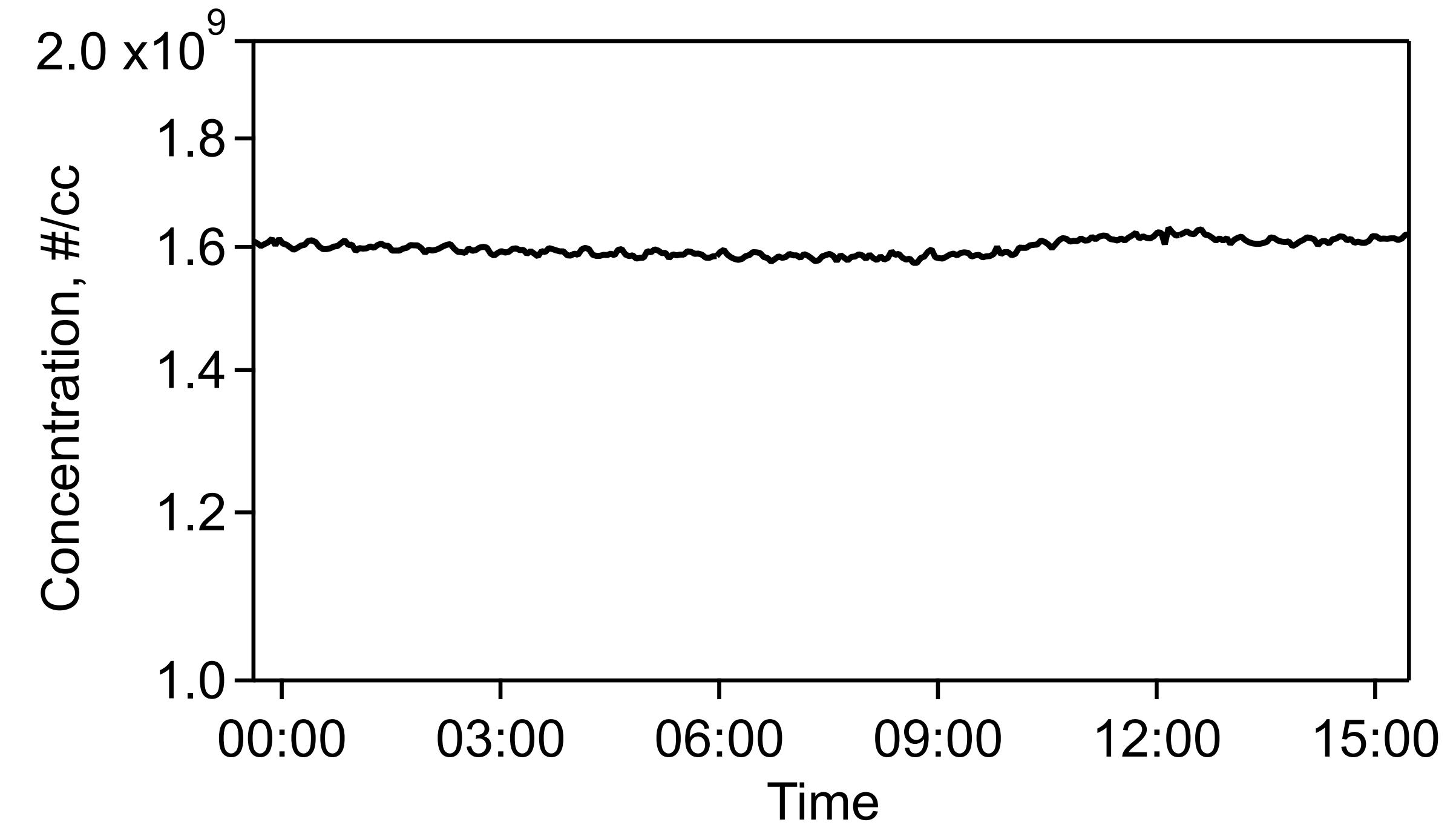
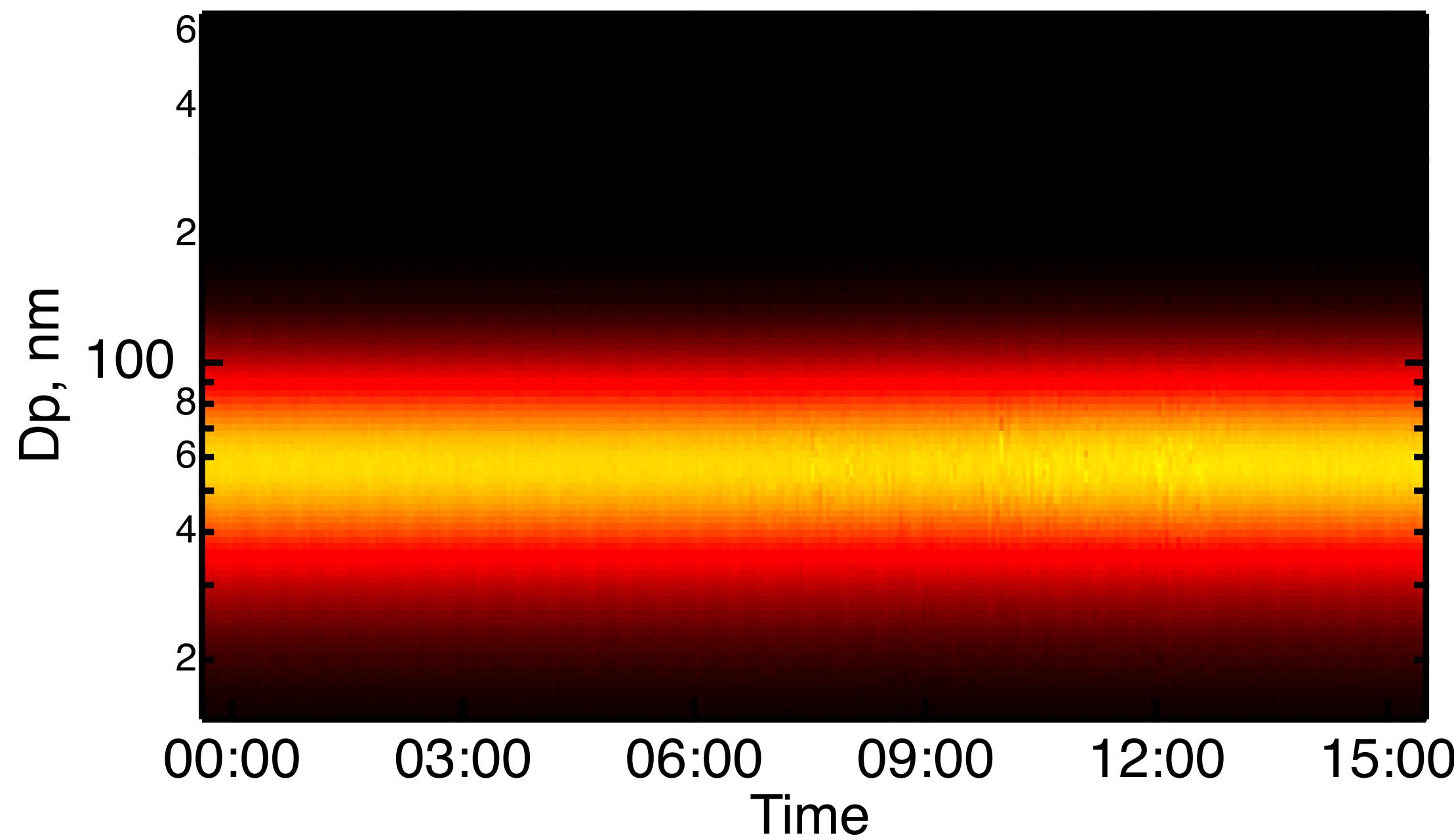
# Size range

- Changing flow parameters allows even finer control over the GMD & GSD
- Shift the mode around in *nm* steps
- All settings saveable as a start condition, or a separate custom mode



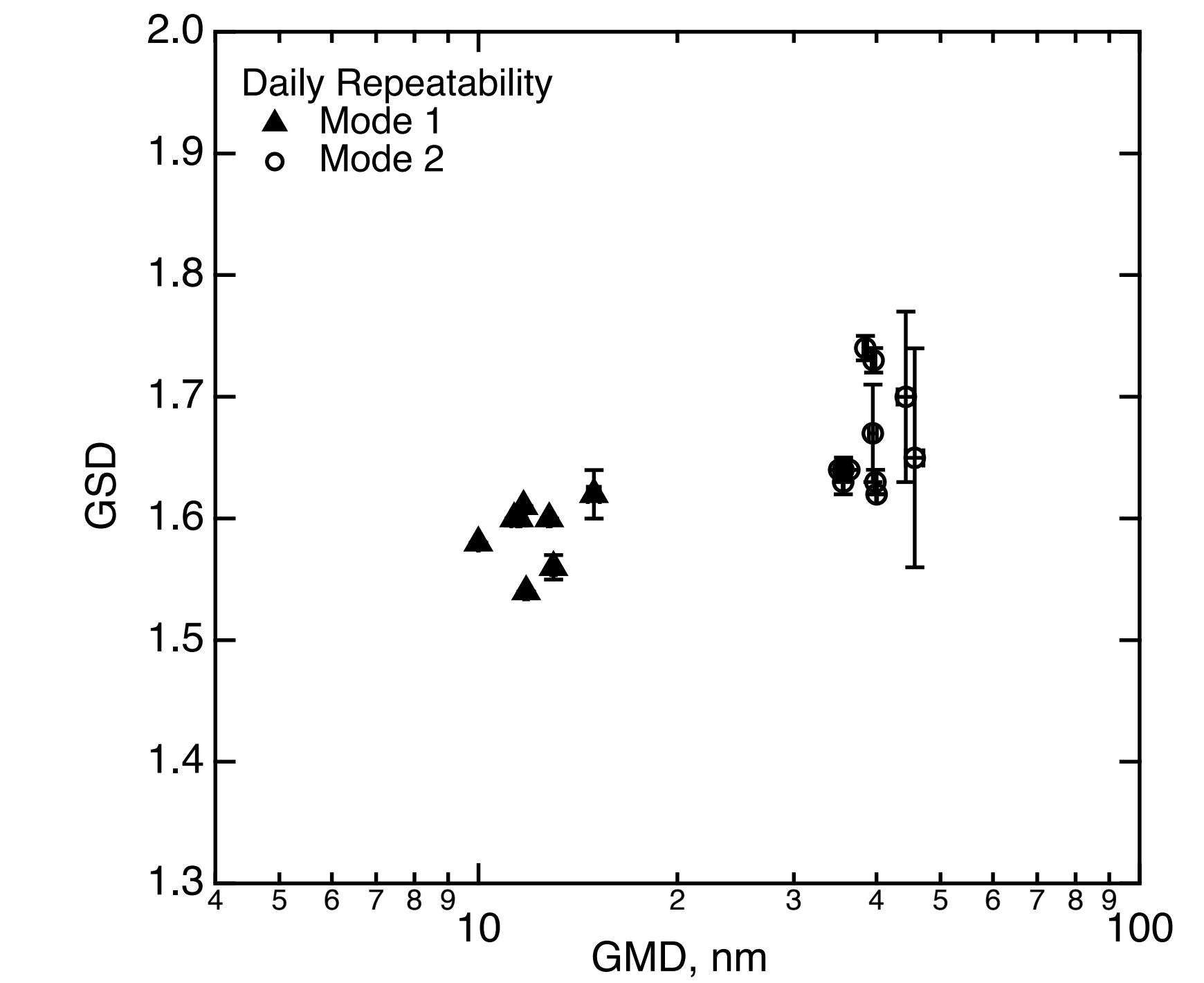
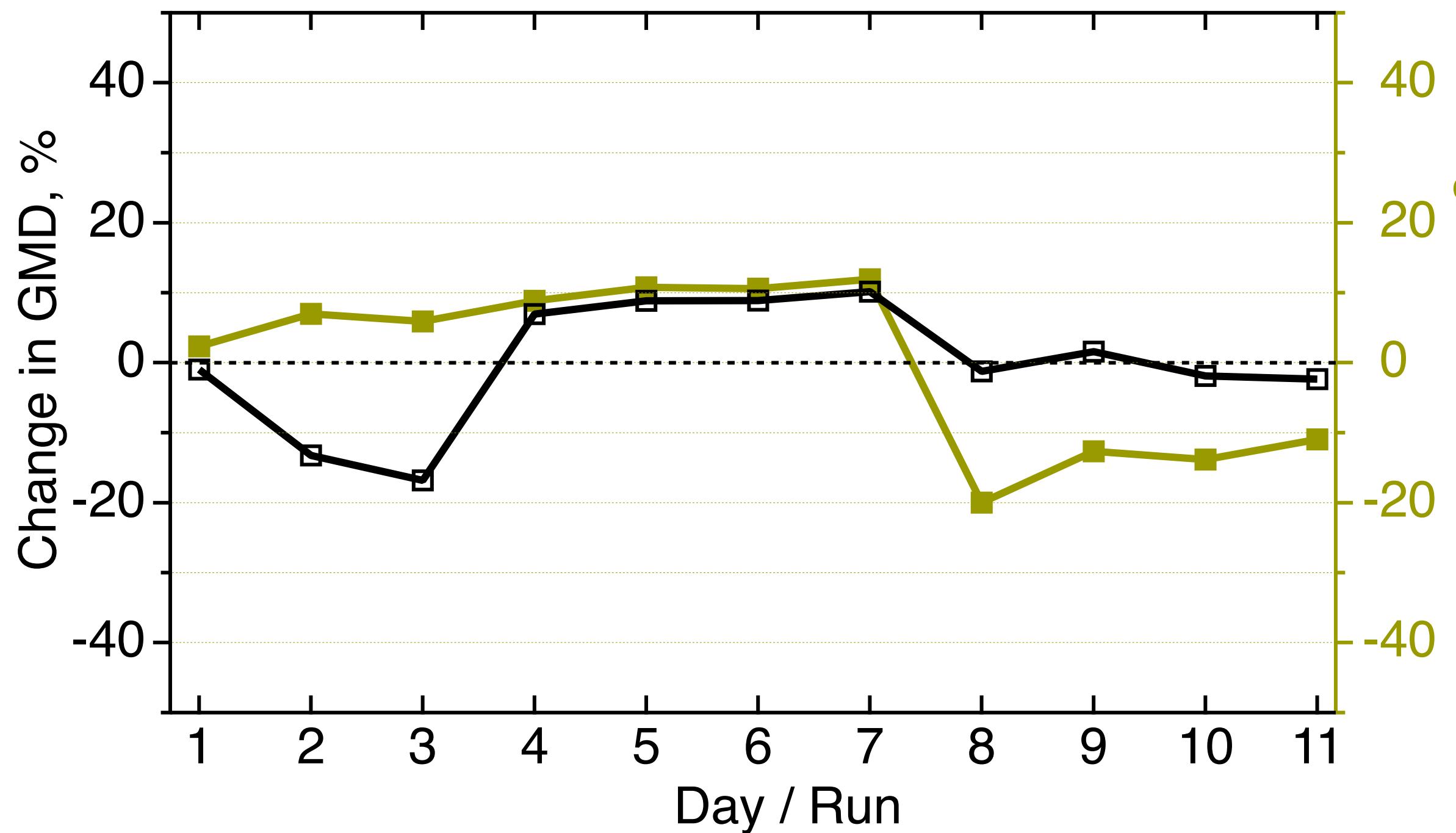
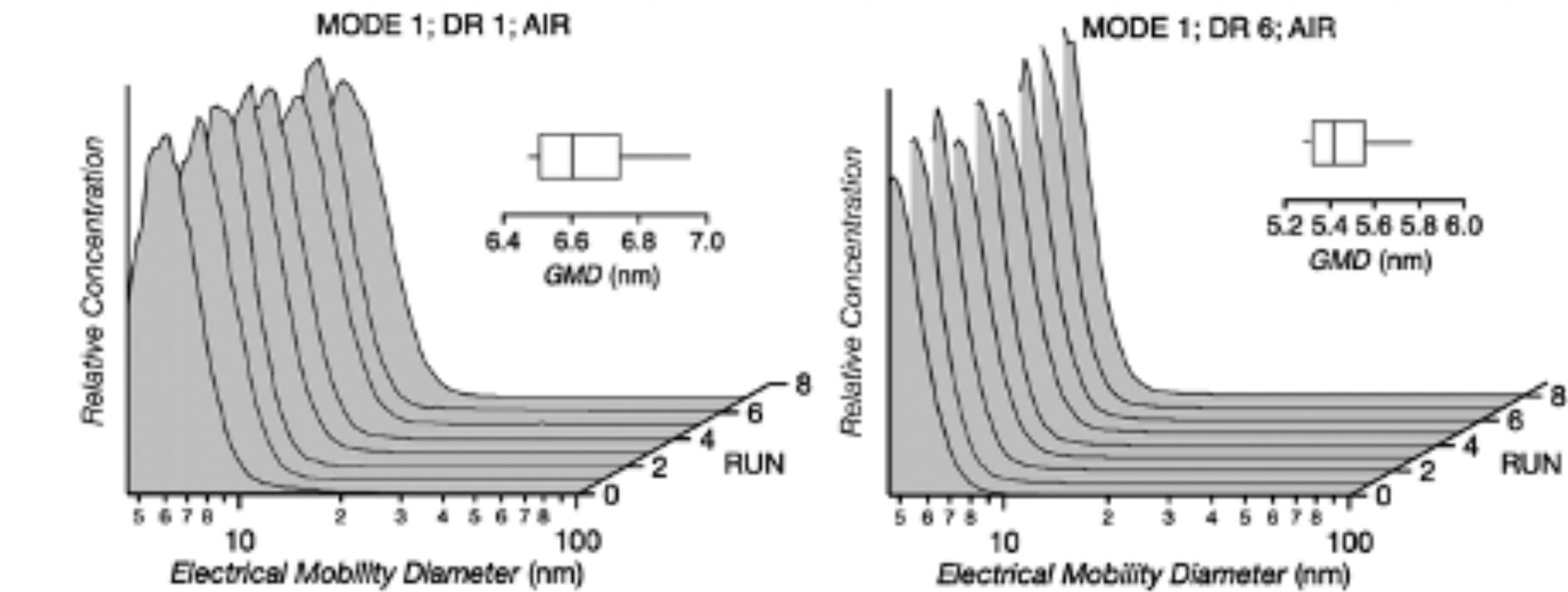
# Concentration stability

- Example 15-hour operation
- Extremely high concentrations achievable
  - $\sigma_{\text{concentration}} = 1.25\%$
  - $\sigma_{\text{GMD}} \leq 1\%$
- Constant aerosol supply
- Max output flow 20 L/min



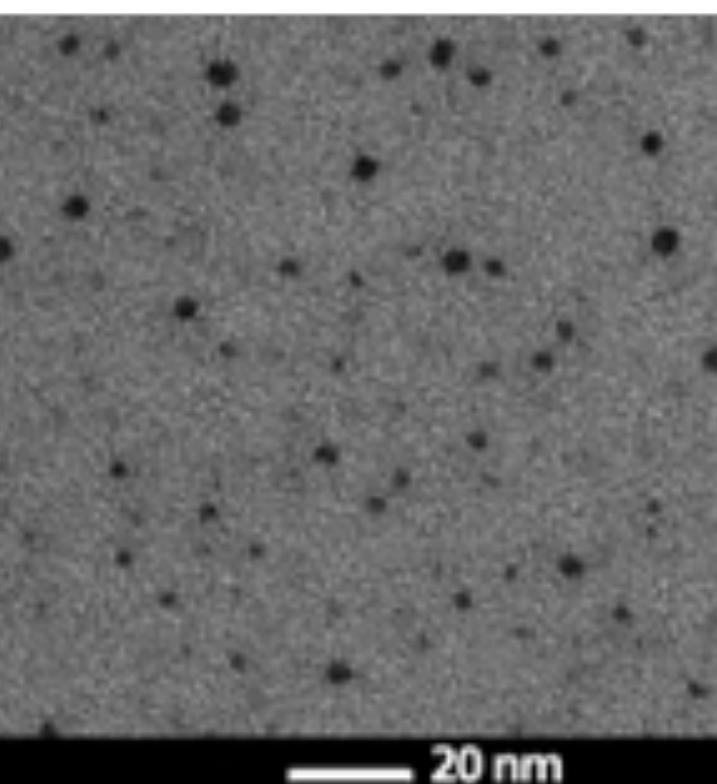
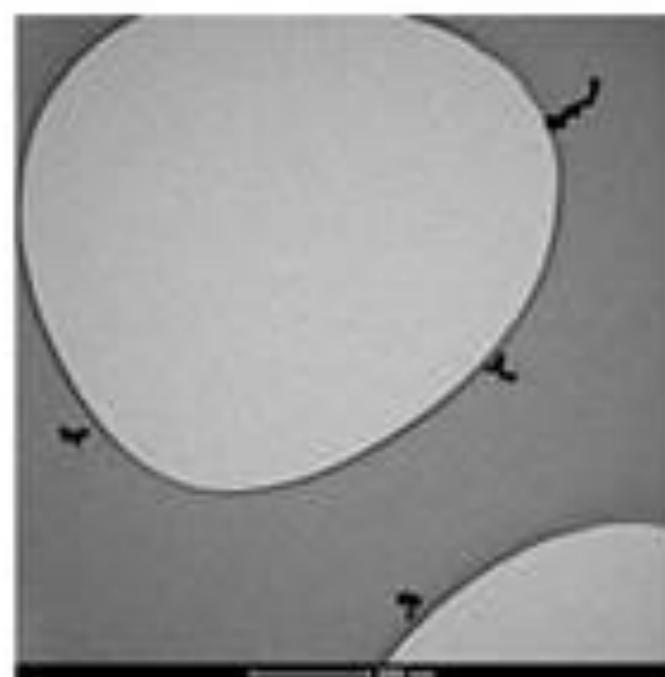
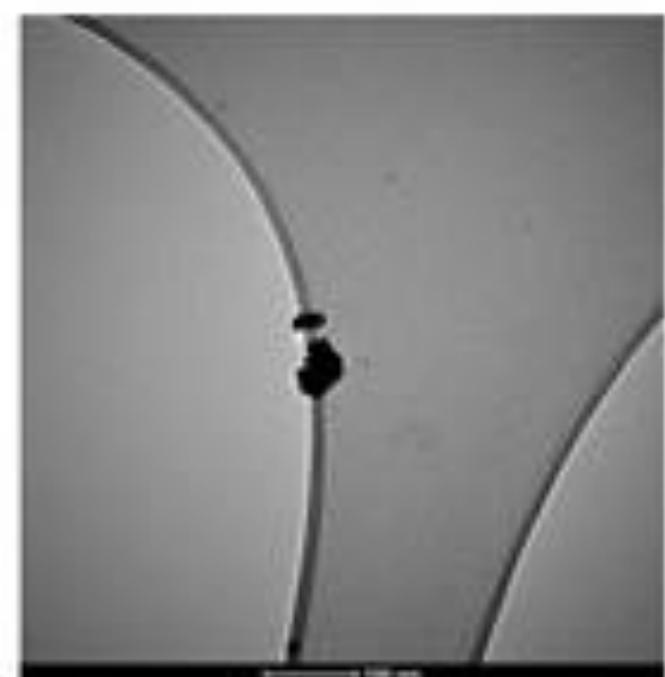
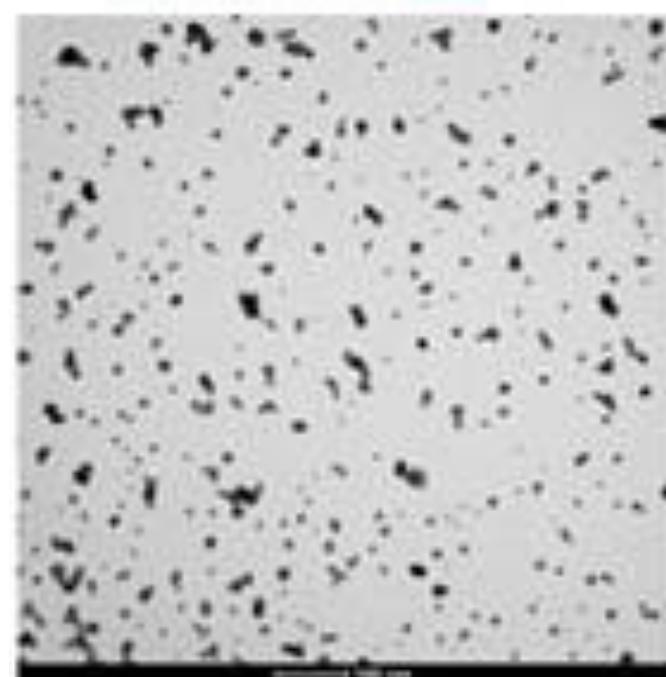
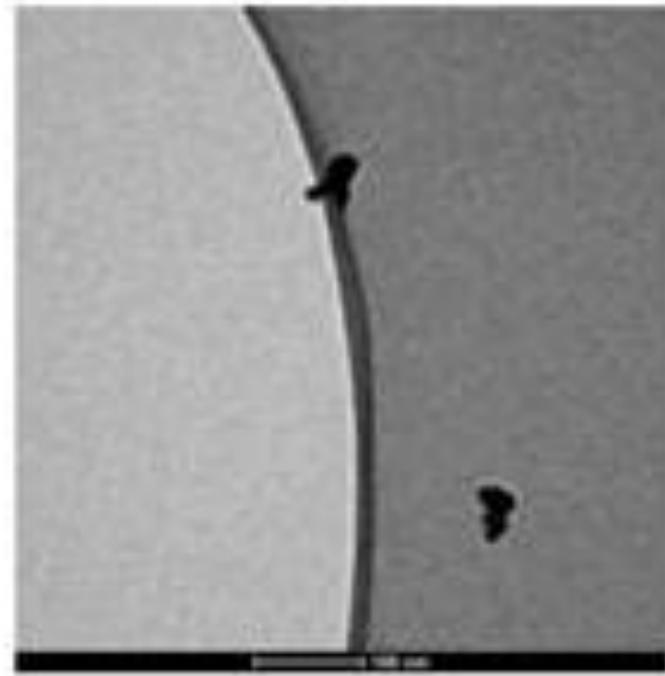
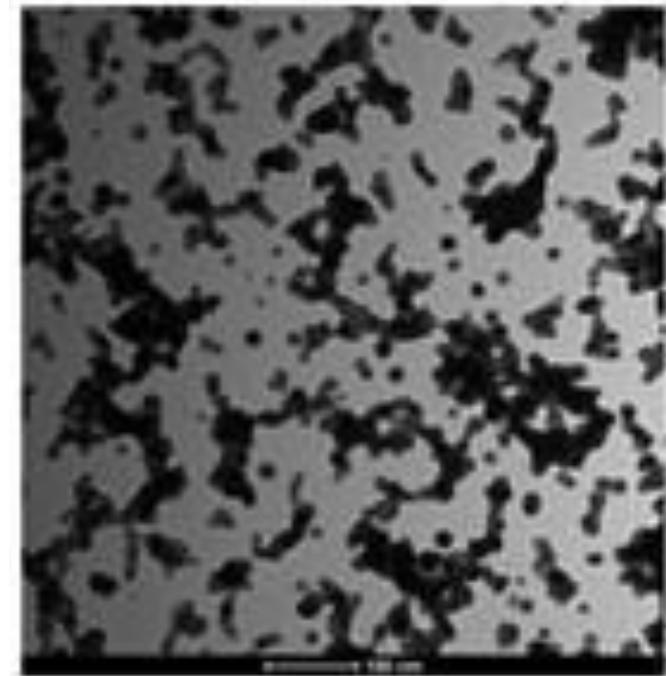
# Concentration stability

- Daily repeatability also high
  - ~ 15% in concentration
  - ~ 10% in GMD

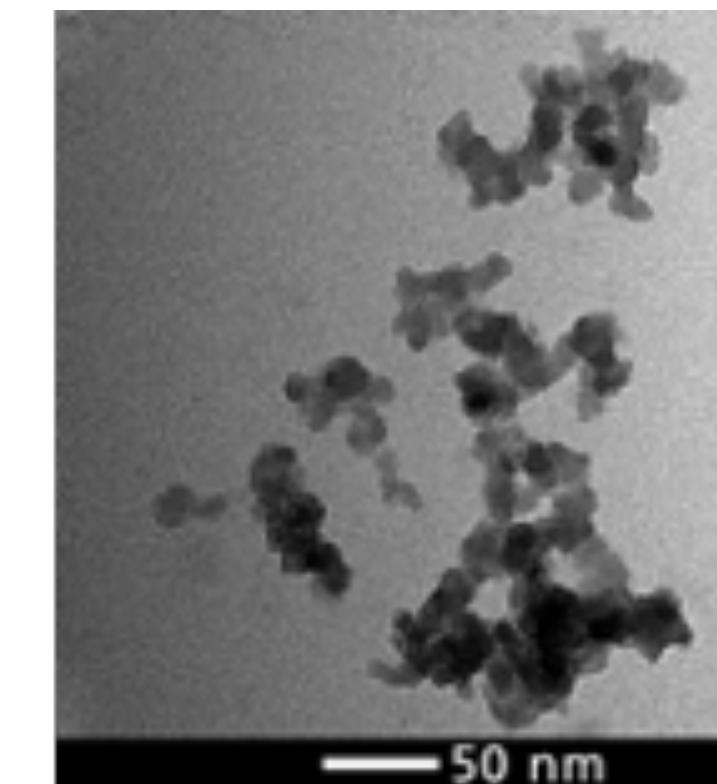


# TEM

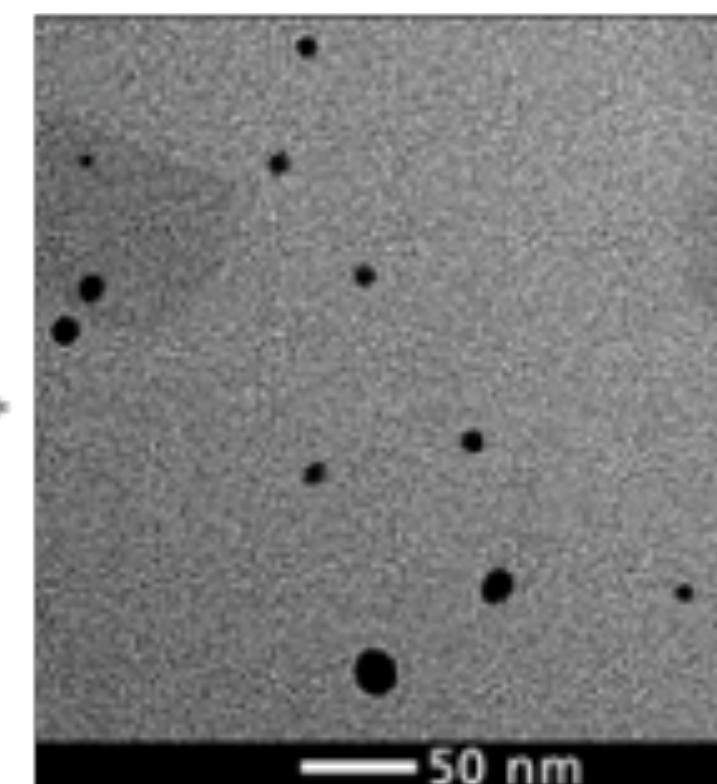
- Mode 1 aerosol spherical
- Mode 2 aerosol contains some fraction of agglomerates
  - Estimated fraction c.a. 5%
- Sintering stage in development, to allow for completely spherical aerosol generation



Example TEM image



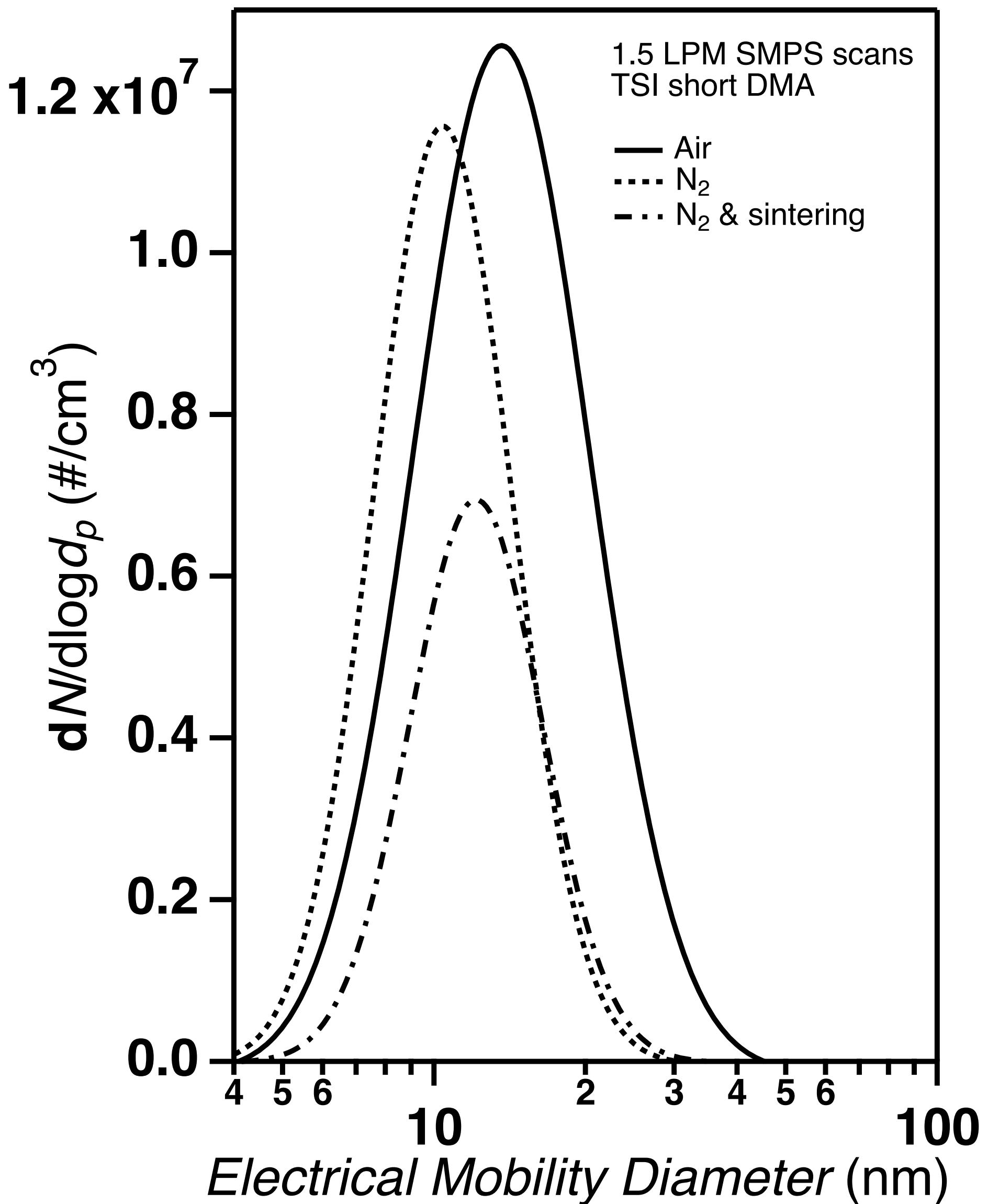
Example TEM image



Example TEM image of *sintered* silver

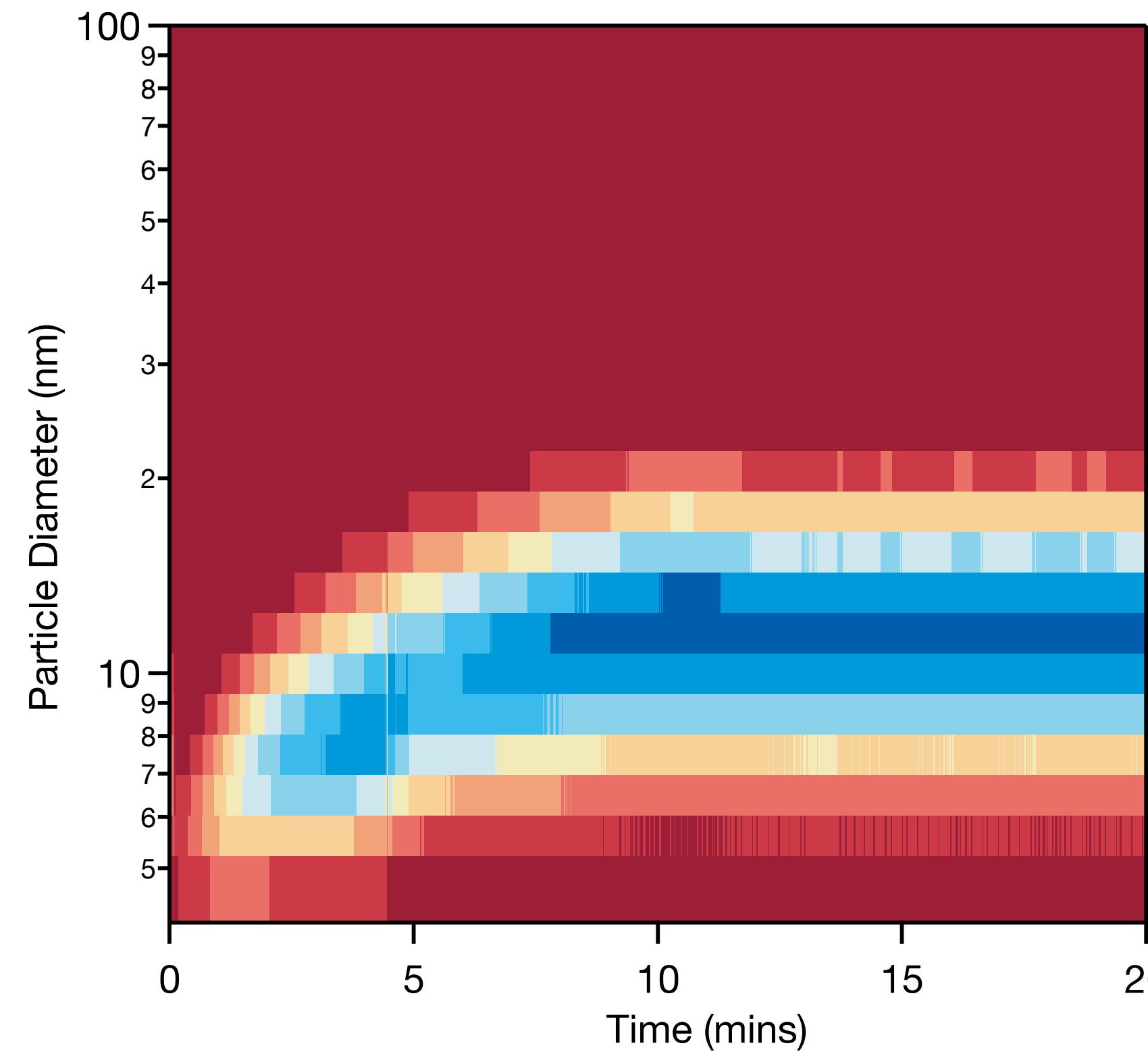
# Nitrogen vs Compressed Air

- N<sub>2</sub> avoids silver oxide generation
- Compressed air is somewhat simpler to use/readily available
- Nitrogen generates a smaller GMD and slightly narrower GSD
- Sintering to spherical further reduces concentration



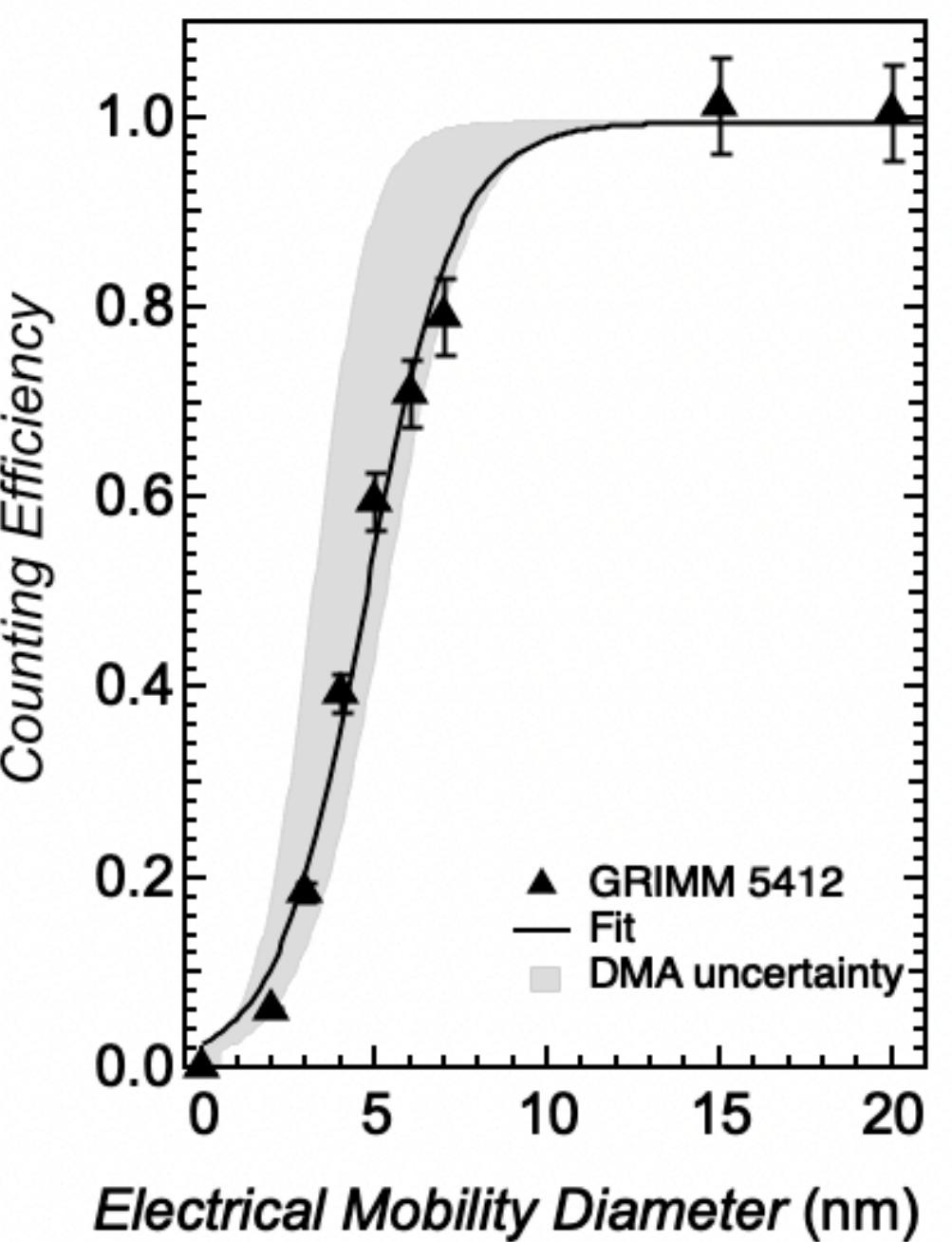
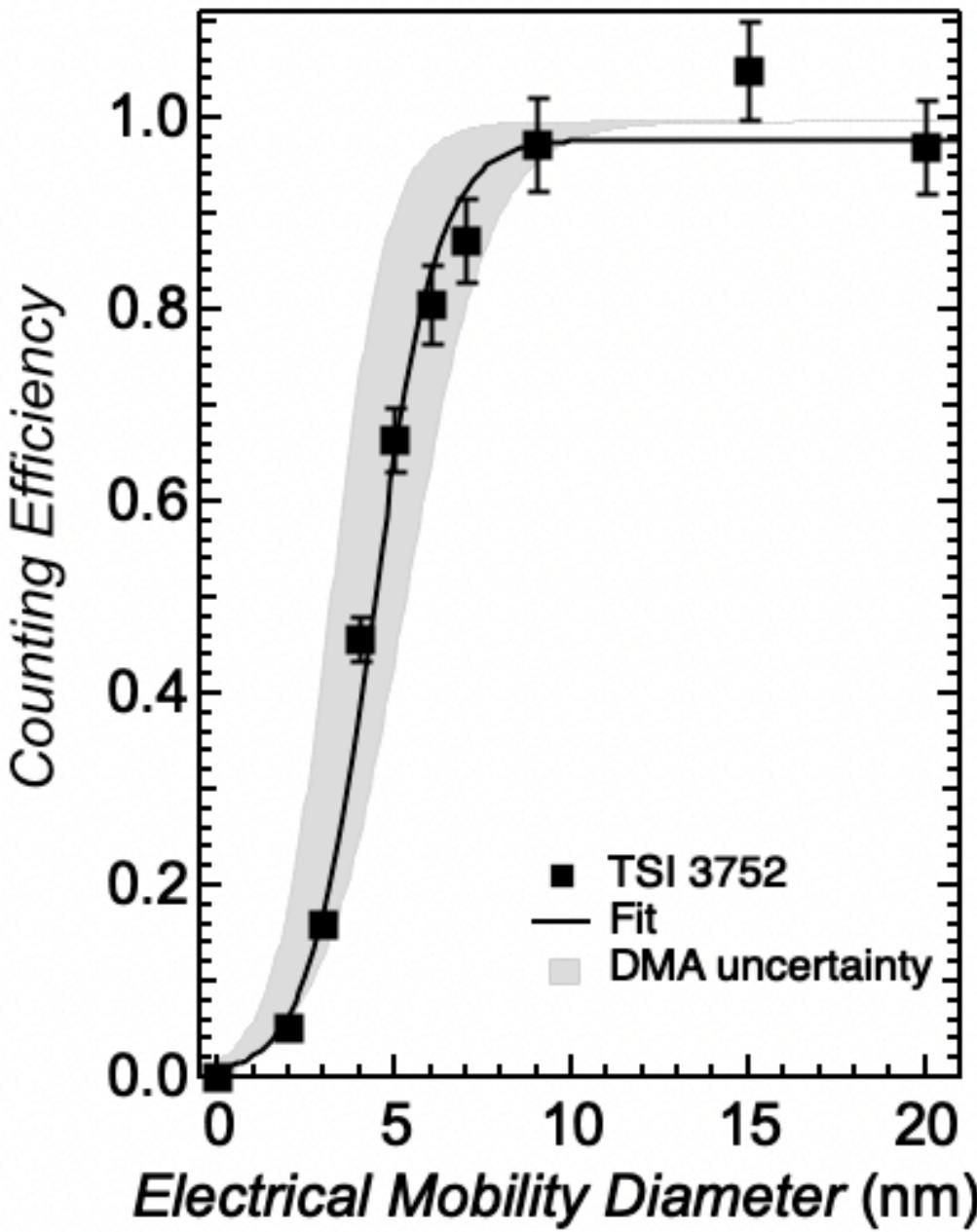
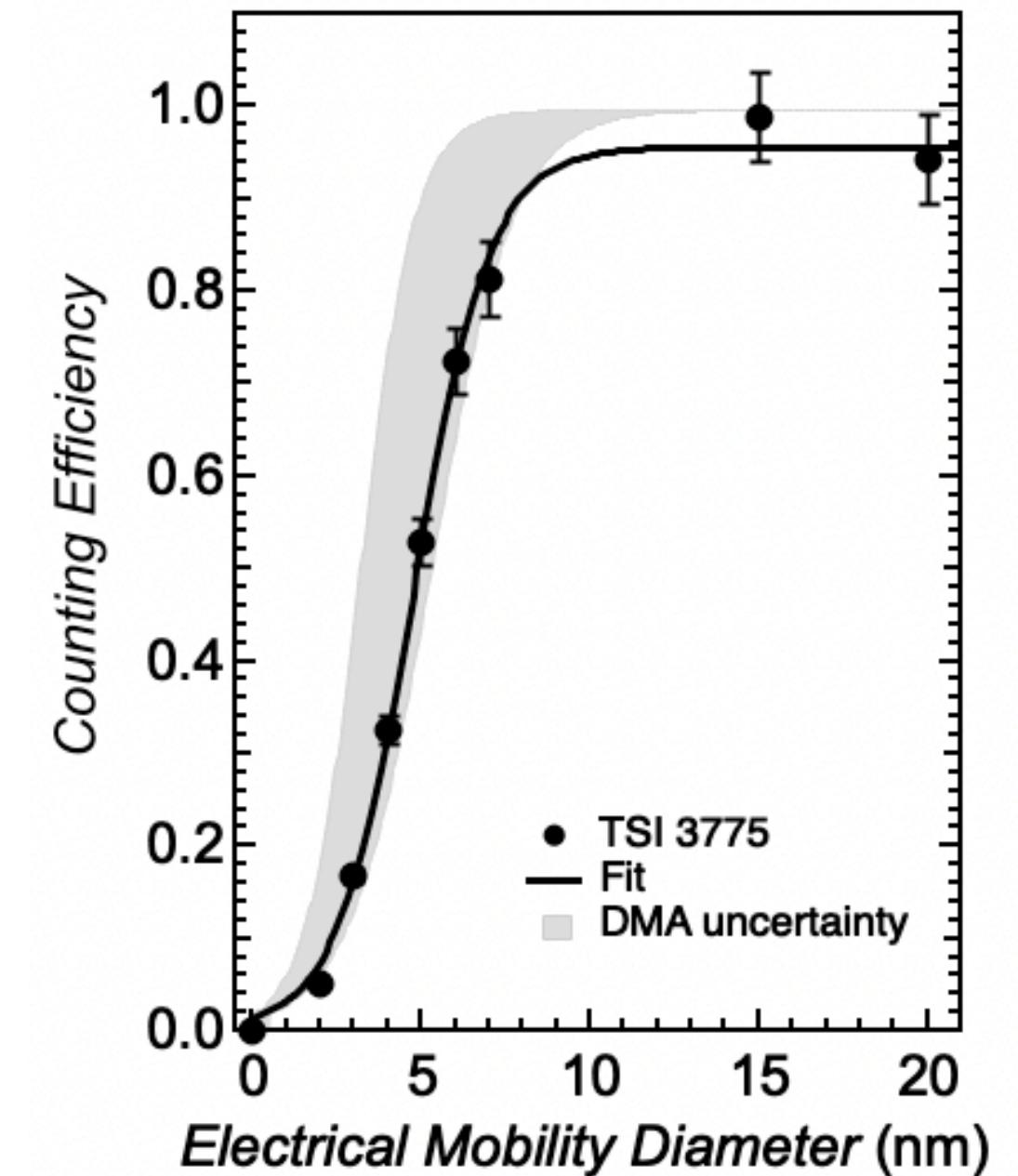
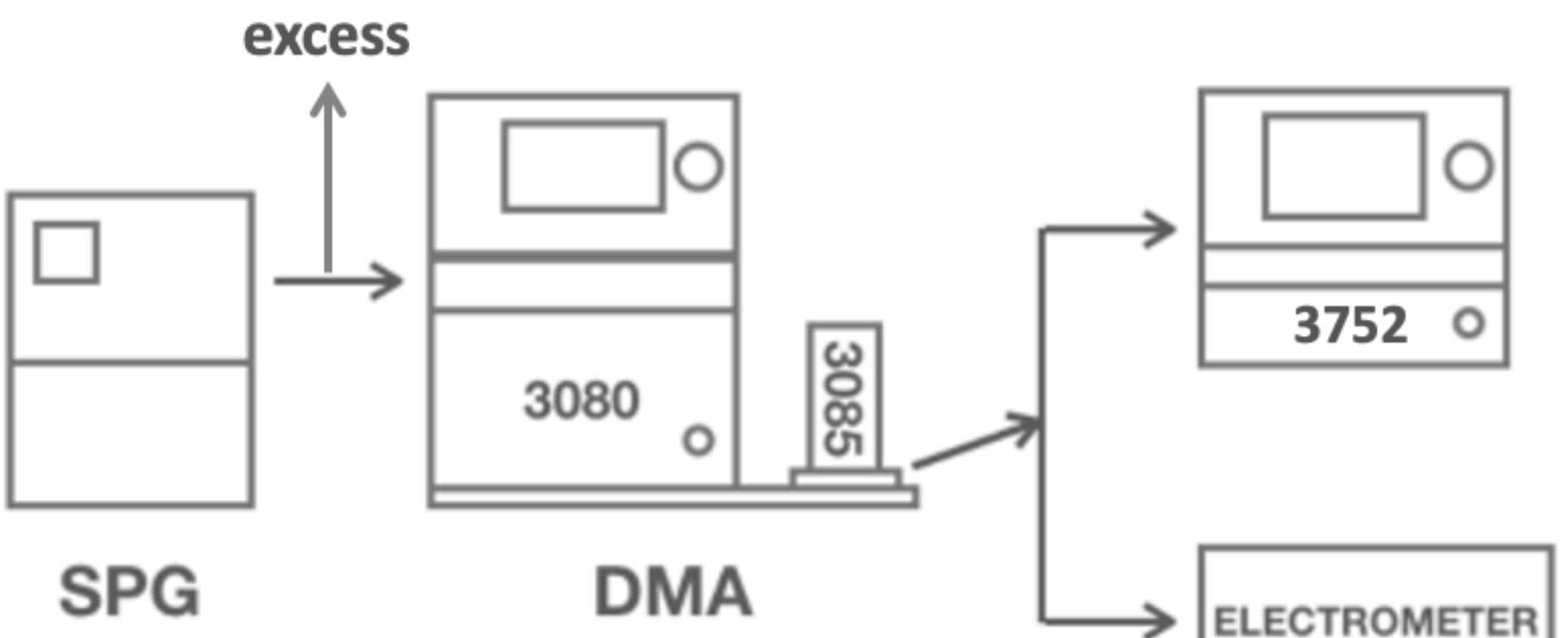
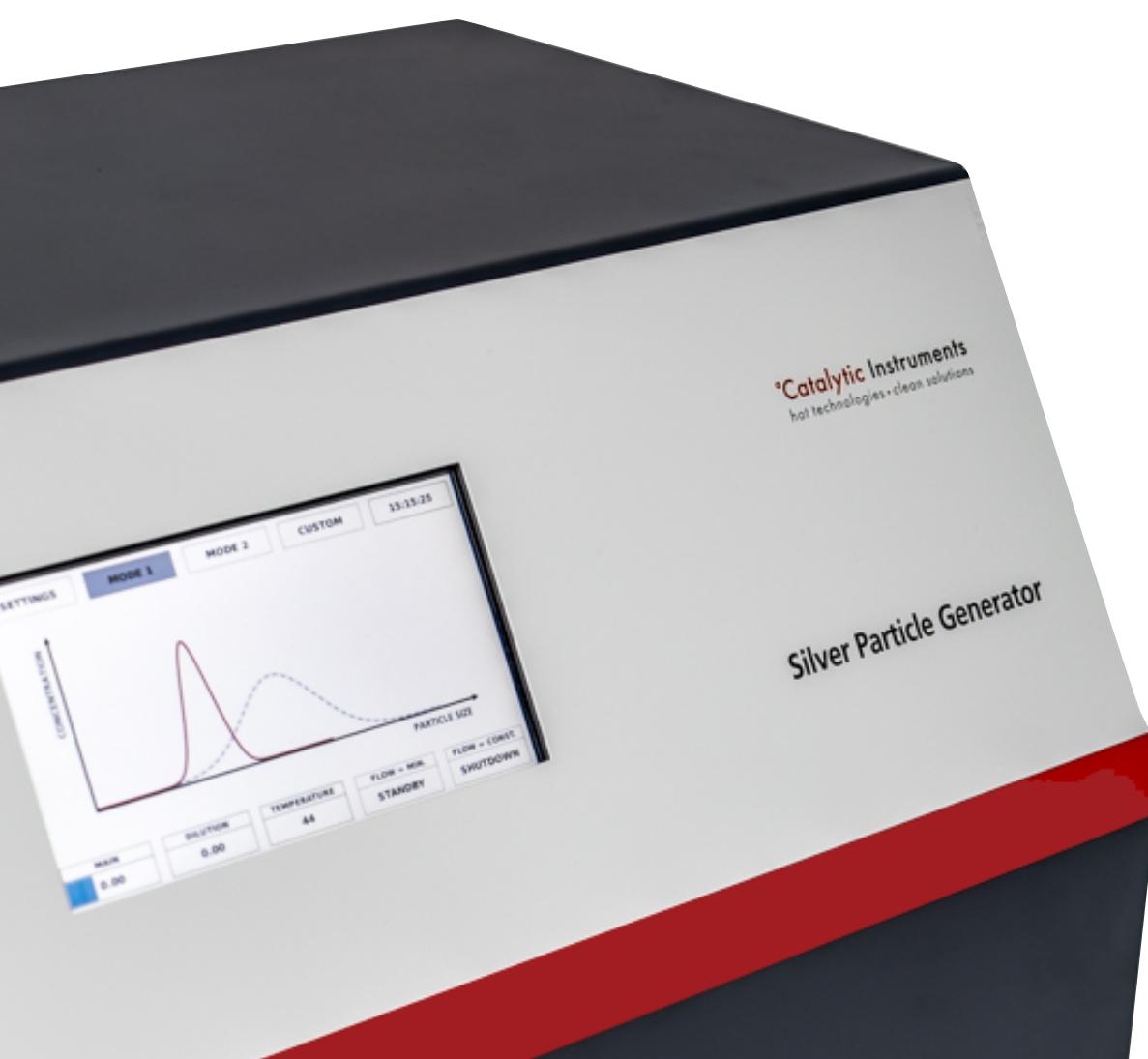
# Operating the SPG

- Touch screen interface
- Stable within ~ 10 minutes
- Temperature changes in ~ 5 mins
- Flow changes in a few seconds



# Example use CPC calibration

- SPG set to Mode 1
- Primary dilution 5 LPM
- All CPCs nominal 4 nm D<sub>50</sub>
- Shaded grey area shows DMA uncertainty

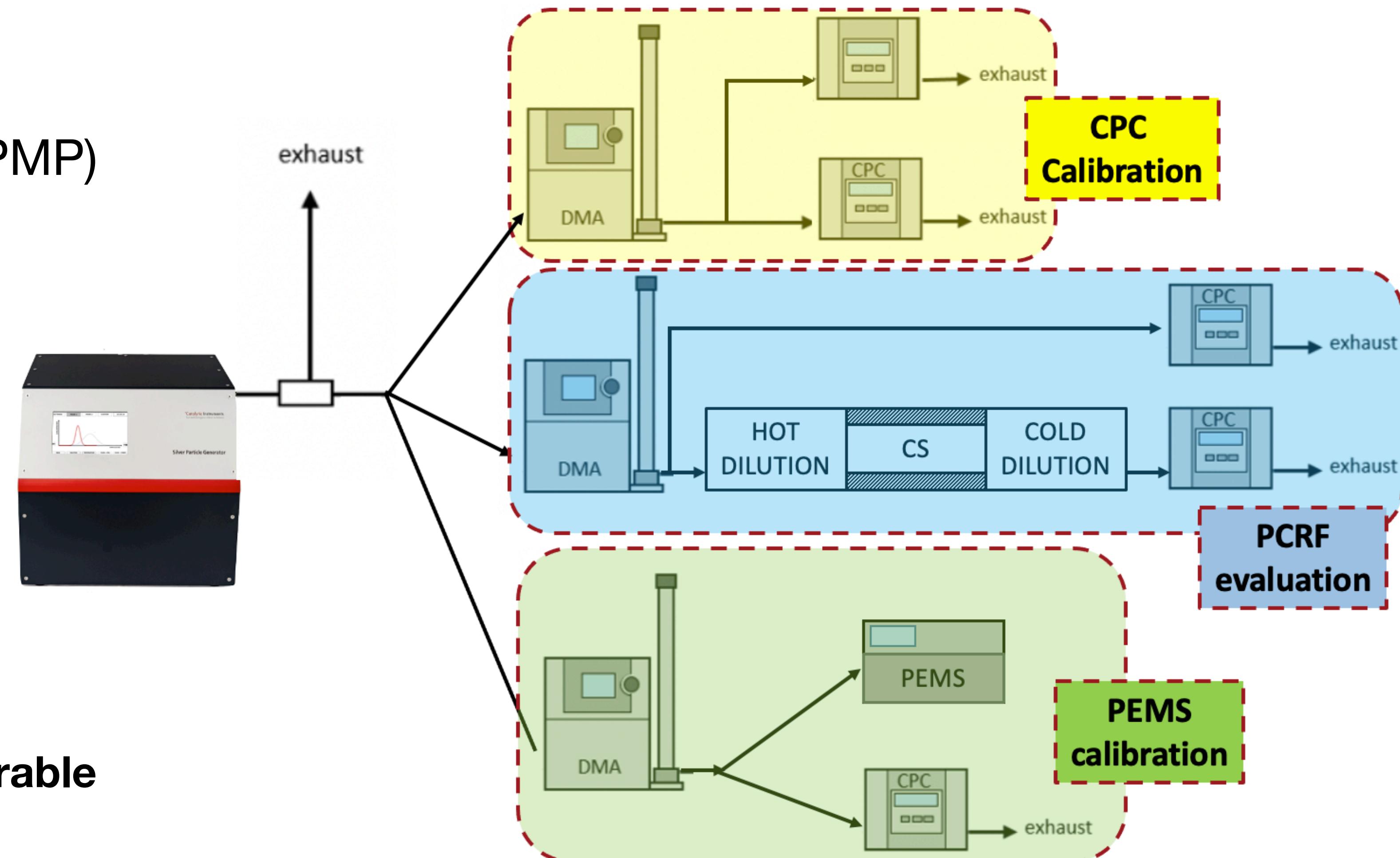


# Example use

## PEMS & PTI calibration

- Silver remains stable at 350°C (PMP)
- The SPG can be used for:
  - PMP-compliant calibration
  - PEMS
  - PTI
  - standalone CPC calibration

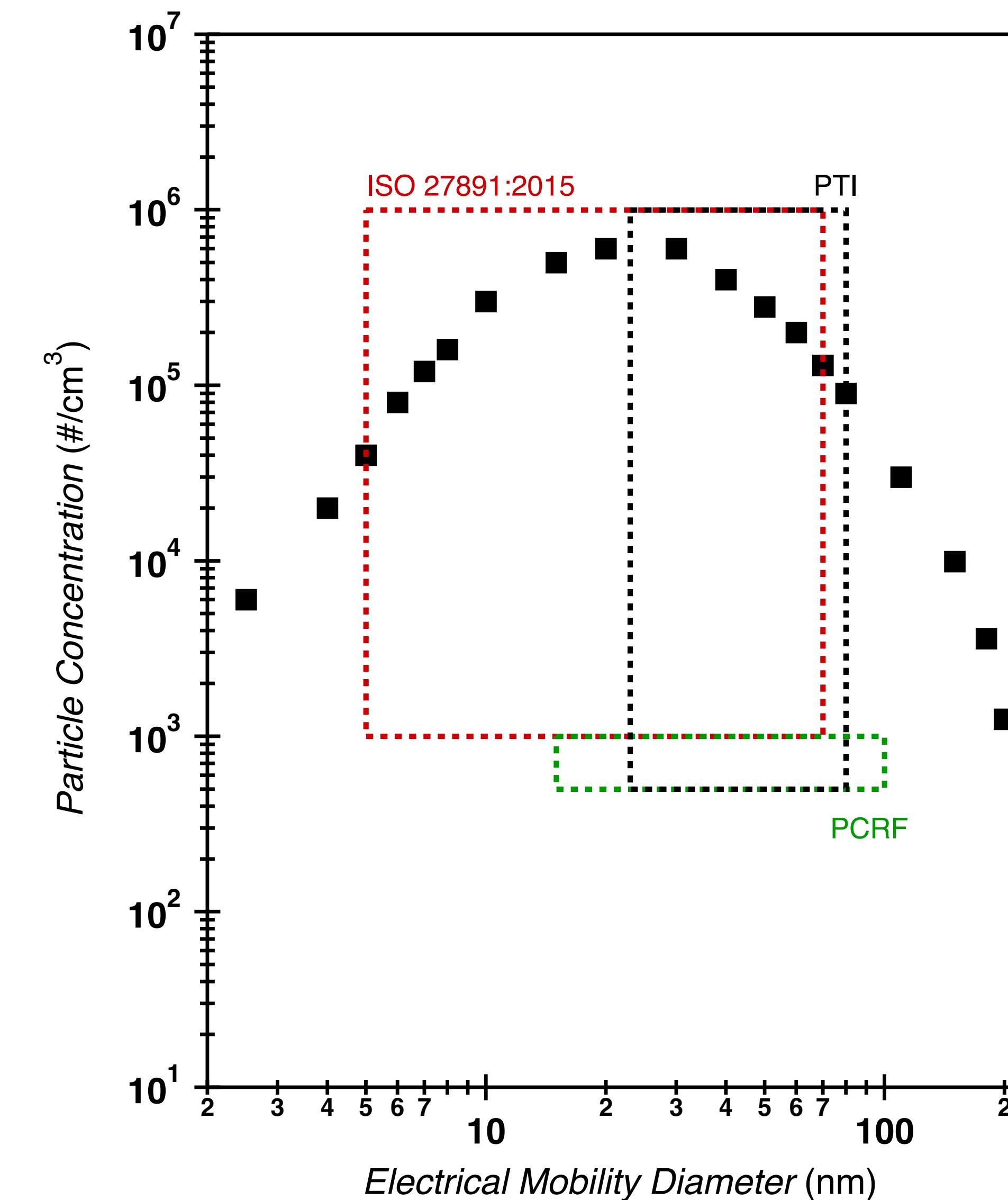
**One aerosol generator for comparable  
& traceable calibrations**



# High concentrations

Downstream of DMA...

- Wide diameter range
- DMA flows adjusted to maximise concentration (high/low mode)
- SPG output adjusted to maximise concentration at a given size (temp & flow)
- High concentrations, ideal for:
  - CPC ISO27891:2015(E)
  - PCRF compliance testing
  - PTI
  - Line loss experiments
  - and much more...!
- Simultaneous multiple-device calibrations are possible (up to 20 L/min output)



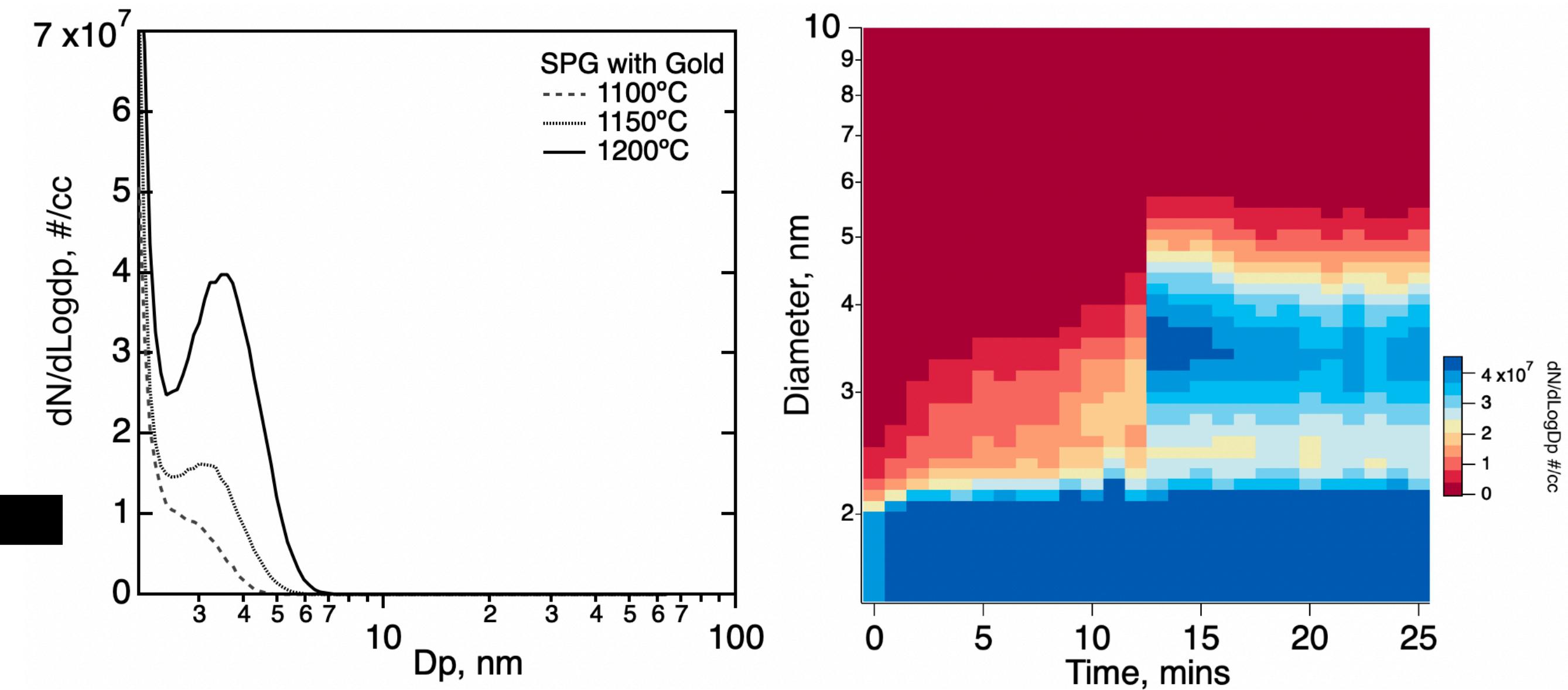
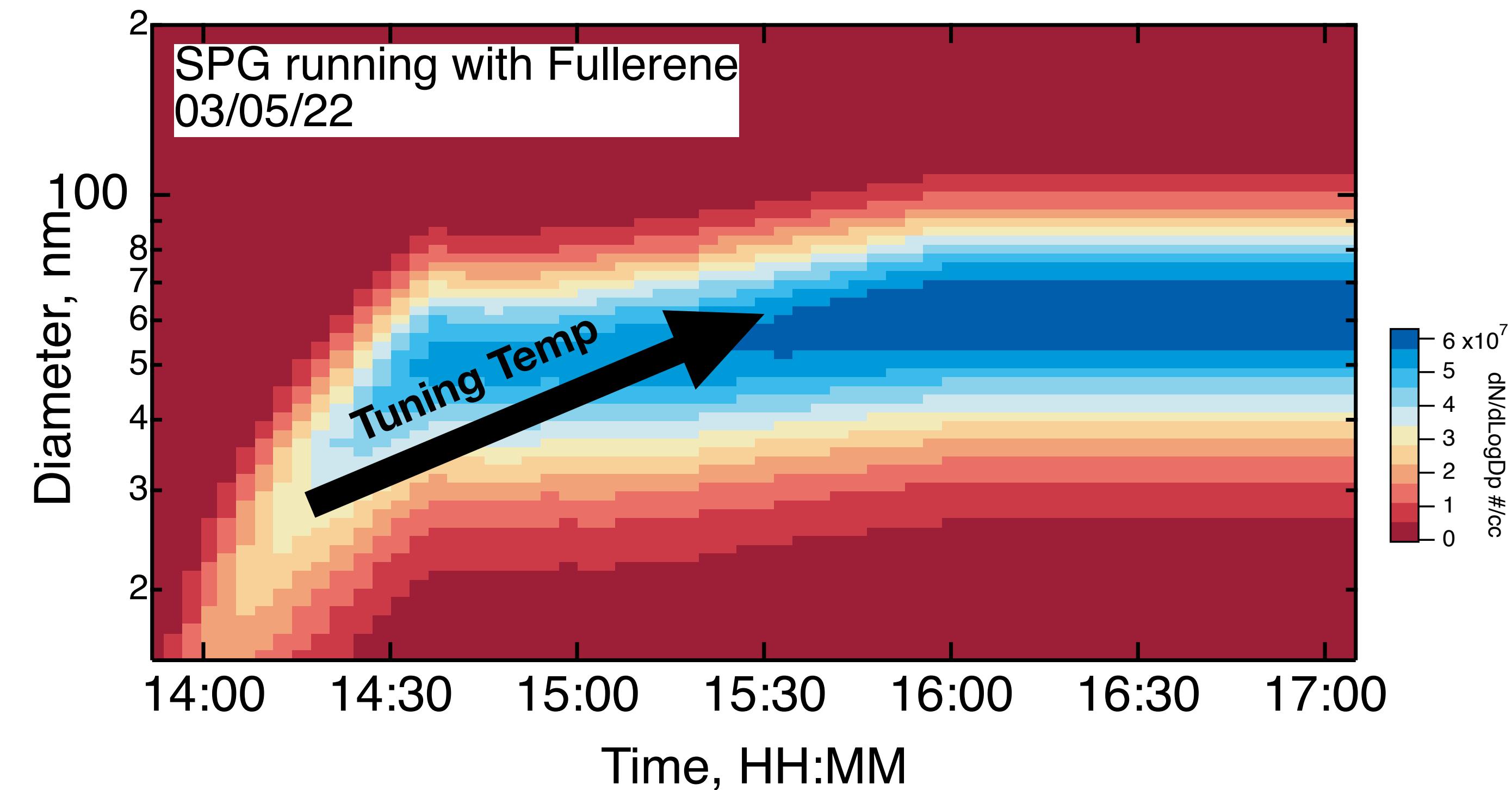
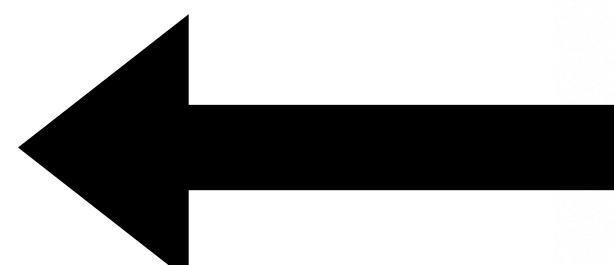
# Coming soon...

## Additional materials

- Fullerene & other soot proxies being tested
- Gold
- Salts
- ... potential for community requests

## SPG – *Solid Particle Generator*

Note: Gold data is taken with prototype device (lower performance) and large aerosol are expected with the production device



# Summary

- GMD range 1- 70 nm
- > 1000 #/cc from 2 - 200nm downstream of DMA
- GSD range 1.15 - 1.8
- High stability solid aerosol generation
- ~ 1 % in number and concentration
- User-configurable set points
- 15 min warm up
- 5 min mode change
- Flow: 2 - 20 L/min
- Power: 90–240V 50/60Hz
- Weight: 20 kg

