

## Ambient UFP Measurements

*– Options & Limitations of current measurement techniques –*



Frederik Weis

# Palas serves aerosoltechnology since 1983...

based in Karlsruhe, Germany  
R&D and Manufacturing 100% inhouse

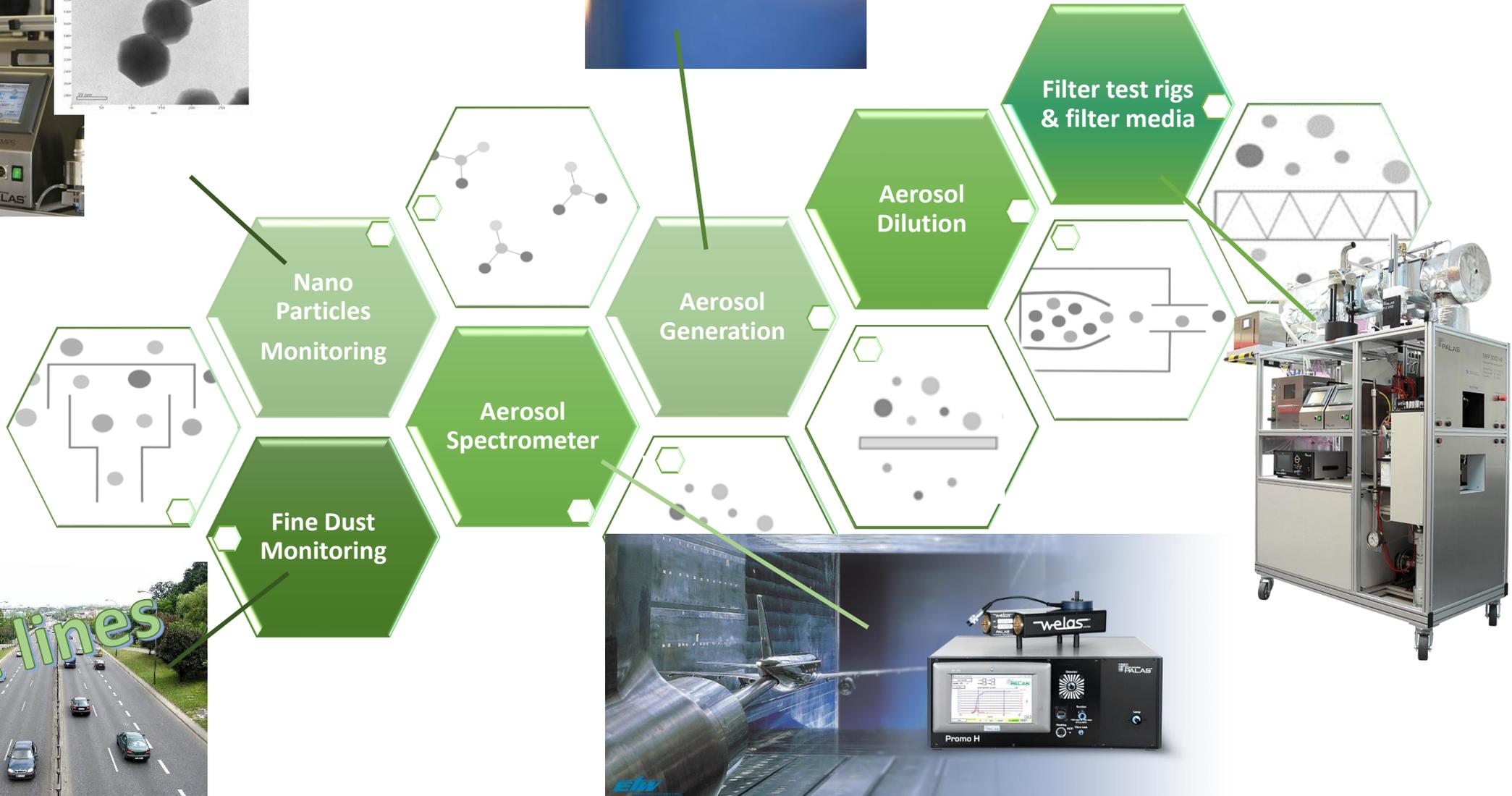
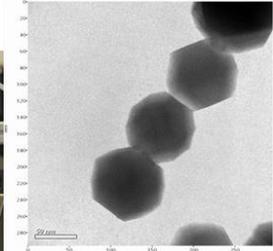
certified according to DIN EN ISO 9001:2015

Core competencies:

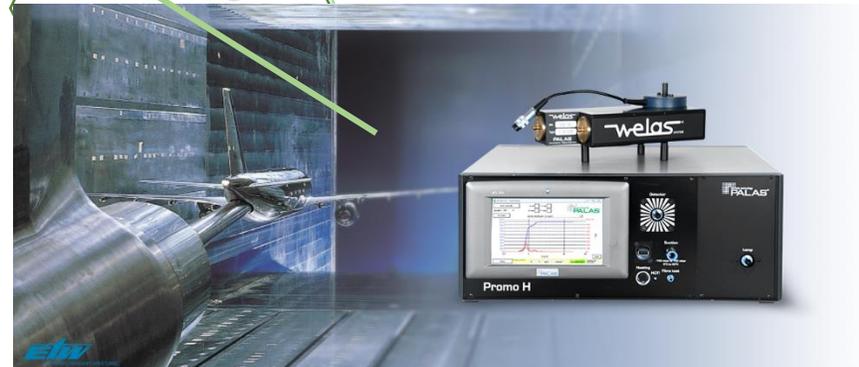
- Filter test systems
- Aerosol spectrometer systems
- Fine dust monitoring systems
- Nanoparticle measurement technology
- Particle generation systems
- Dilution systems
- Clean room particle technology
- Special developments
- Calibration systems
- Services
- Training courses and seminars



# Product lines



Product lines



# Overview of Nanoparticle Measurement Systems



NANOPARTIKELMESSGERÄTE

Nanoparticle Measuring Devices

Universal-SMPS



Classifier

CPCs

**ENVI-CPC system**

Condensation Particle Counter for environmental monitoring integrated pump & interface for additional Nafion® aerosol dryer large external butanol reservoir size range: 7 nm – 10 µm

**UF-CPC system**

Universal Fluid Condensation Particle Counter 3 models optimised for different concentrations limit single count mode: 10,000 particles/cm<sup>3</sup> (UF-CPC 50), 70,000 particles/cm<sup>3</sup> (UF-CPC 100), 2,000,000 particles/cm<sup>3</sup> (UF-CPC 200) limit photometric mode: up to 10<sup>7</sup> particles/cm<sup>3</sup> working fluid: butanol (or others for research applications) size range: 4.5 nm – 10 µm (PMP-CPC with  $d_{50} = 23$  nm and  $d_{90} = 41$  nm)

**U-SMPS system**

Universal Scanning Mobility Particle Sizer size range: 2 – 1,200 nm\* highest flexibility<sup>1</sup> in choice of counter (UF-CPC/Charme) & classifier (DEMC 1000/DEMC 2000) optional: integrated soft X-ray neutralizer (DEMC X) and/or bipolar high voltage module (DEMC XB, DEMC B) simultaneous recording of two counters & built-in counter comparisons integrated U-RANGE option: combination of Fidas®/Promo® & U-SMPS for large size range from 8 nm – 40 µm with high resolution!

**DEMC system**

Differential Electrical Mobility Classifier with short/long column GUI with integrated data logger user adjustable scan time, scan mode (UP/DOWN) & size range compatible to counters and columns of other manufacturers: 4 – 600 nm (DEMC 1000), 8 – 1,200 nm (DEMC 2000) size channels: up to 64/decade

**Charme**

Reference Aerosol Electrometer range: ± 1 – 24,000 FA, 2 nm – 100 µm user-exchangeable 50 mm filter

Neutralizer  
Soft X-ray and Kr85

Aerosol FCE

size range: 1,2 nm to 1400 nm



**XRC**

Soft X-ray charge neutralizer defined aerosol charge distribution as alternative to radioactive neutralizers ionisation energy < 5 keV

**Kr-85 system**

Radioactive aerosol charge neutralizer with Krypton-85 for U-SMPS activity: 57 or 370 MBq

<sup>1</sup>counters and columns of other manufacturers can be integrated

\* depending on counter and column

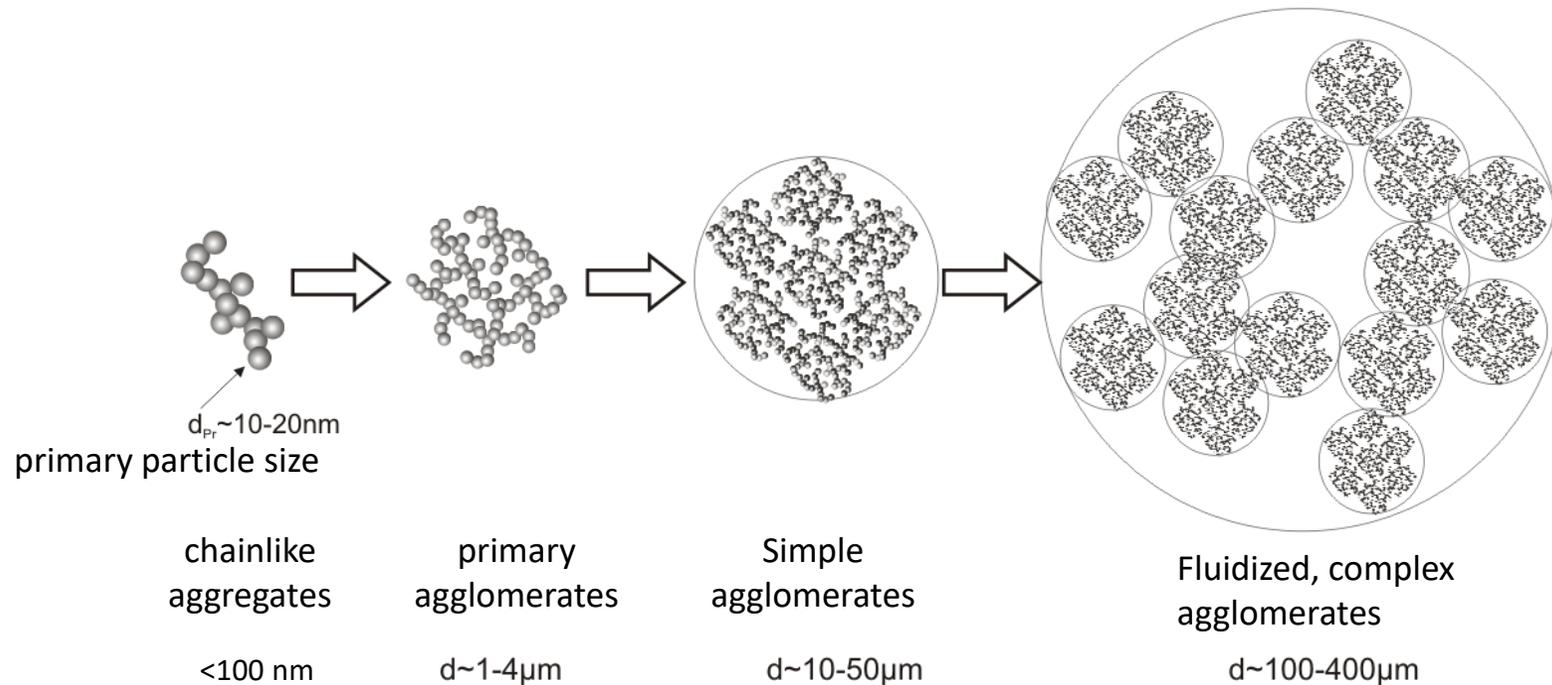
# „Nano“ is trendy in everyday life....and marketing



# Talking about the correct dimension

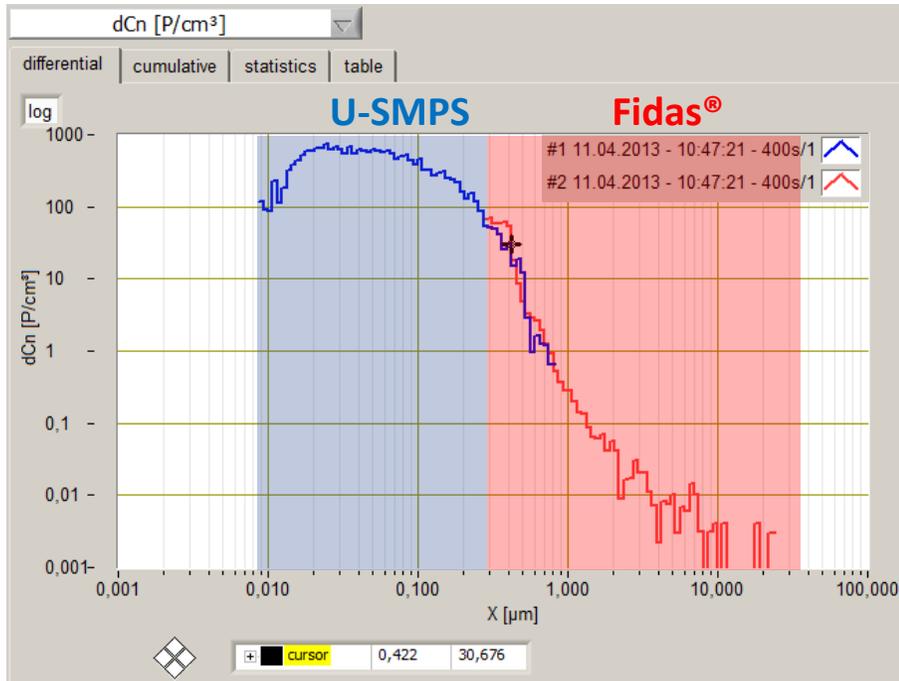
It's not only marketing....also in real world, dimensions can be mixed.

Example: Fluidization of nanoparticles and nanopowders like Aerosil® in a fluidized bed reactor.



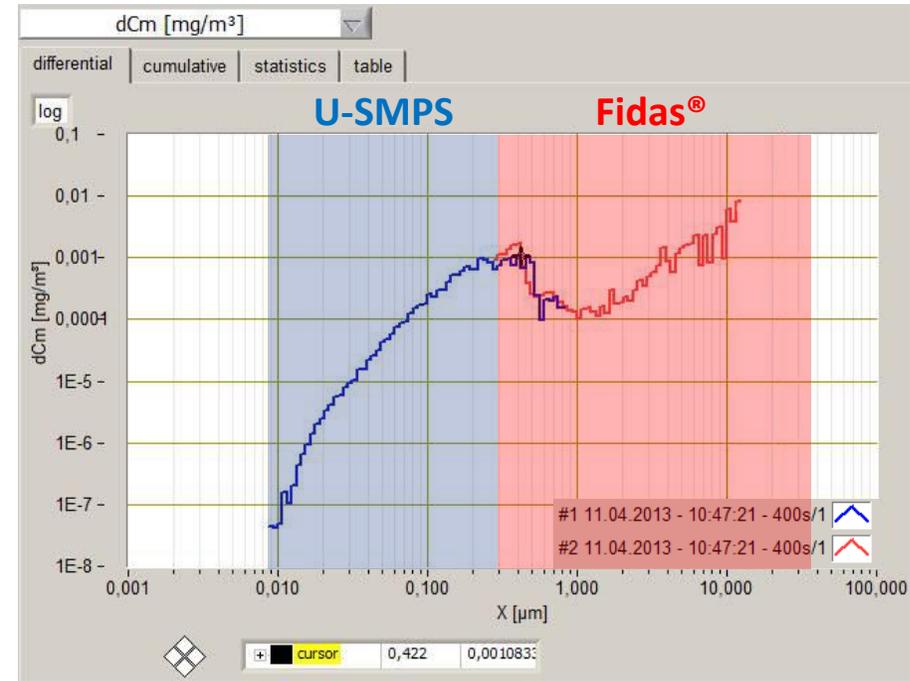
# U-RANGE measurement for ambient air

Number concentration



**416 particles/cm<sup>3</sup>**  
**19767 particles/cm<sup>3</sup>**

Mass concentration



**67.9 µg/m<sup>3</sup>**  
**6.1 µg/m<sup>3</sup>**

Down to...

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***“There’s Plenty of Room at the Bottom”***  
**(Richard Feynman, 1959)**

# Application examples and related questions

## Ambient Air monitoring for UFP



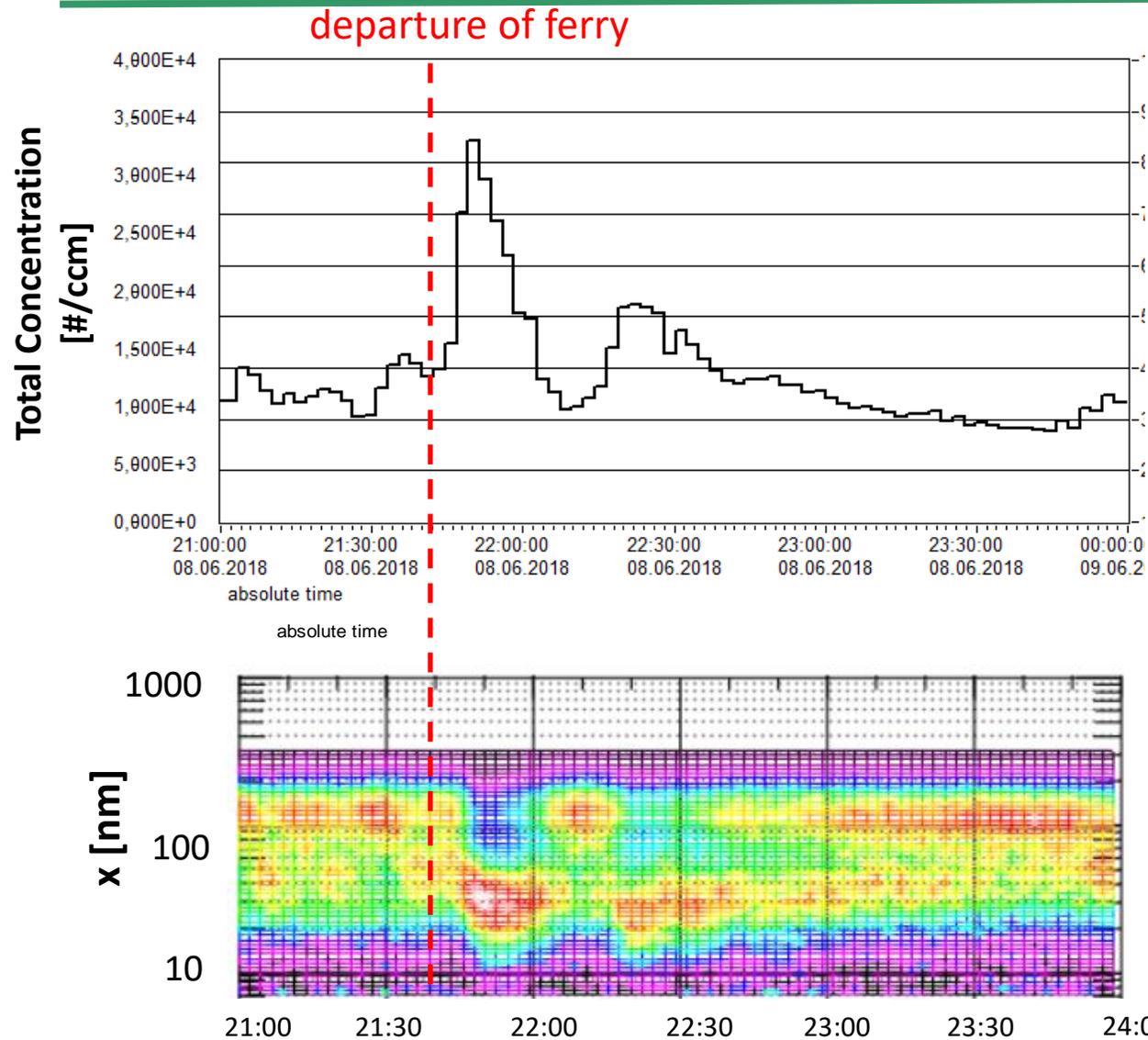


## UFP monitoring at harbours



**Scope: identify ship emissions**

# UFP monitoring at harbour

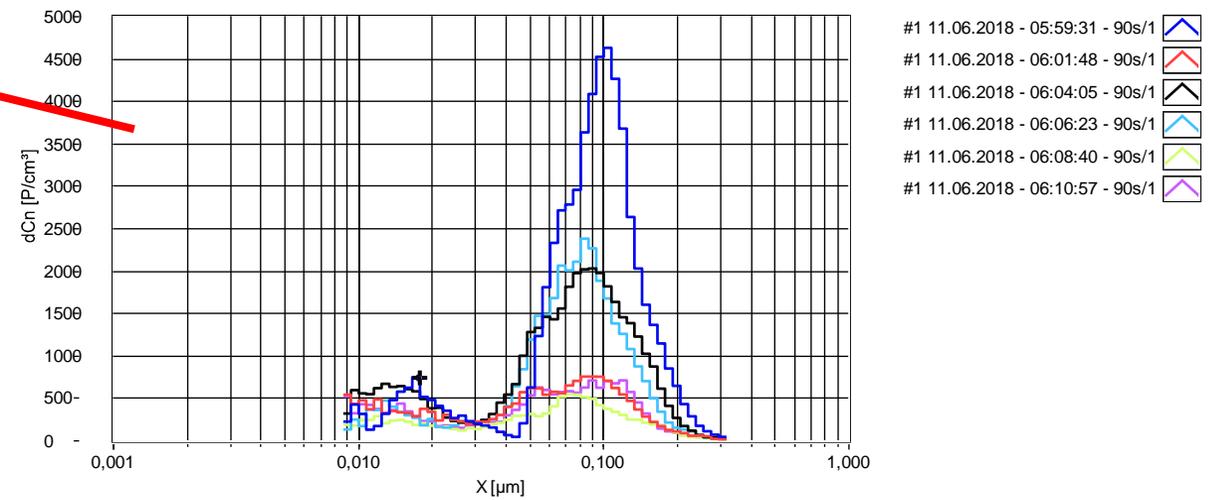
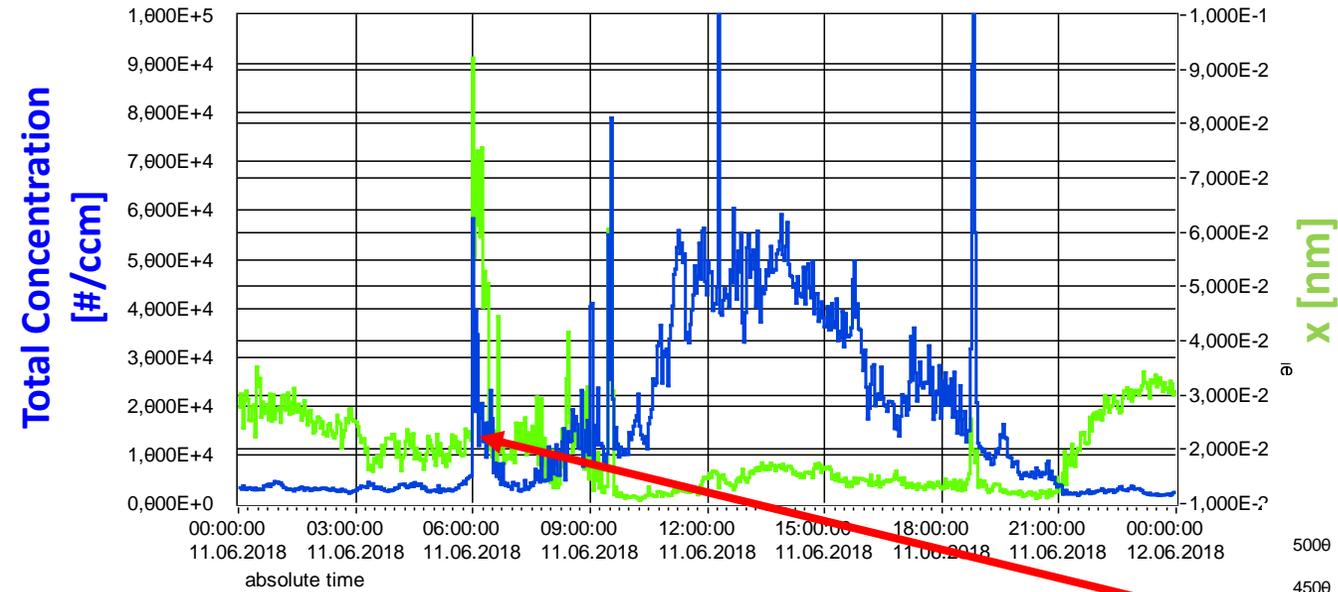


data: measured by Palas® U-SMPS 2100 X  
graphs by Palas® PDAnalyze

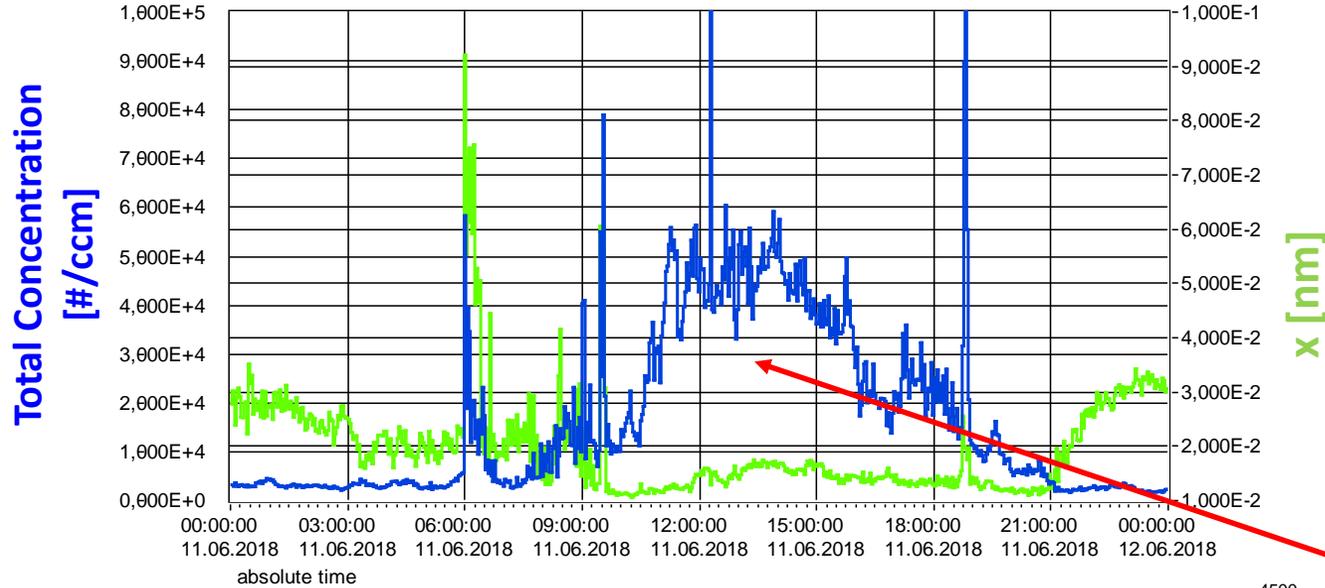
# UFP monitoring at harbour



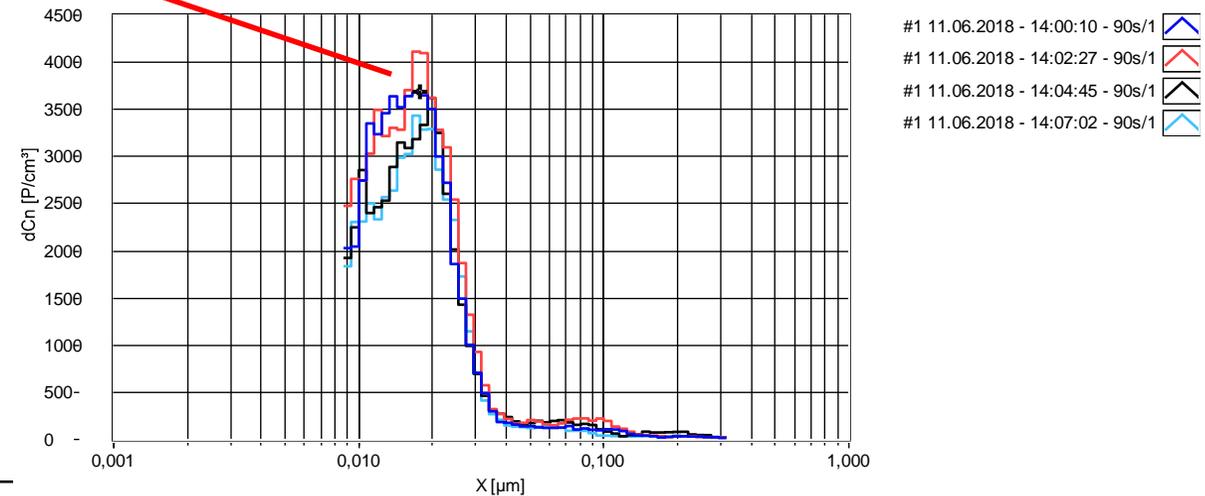
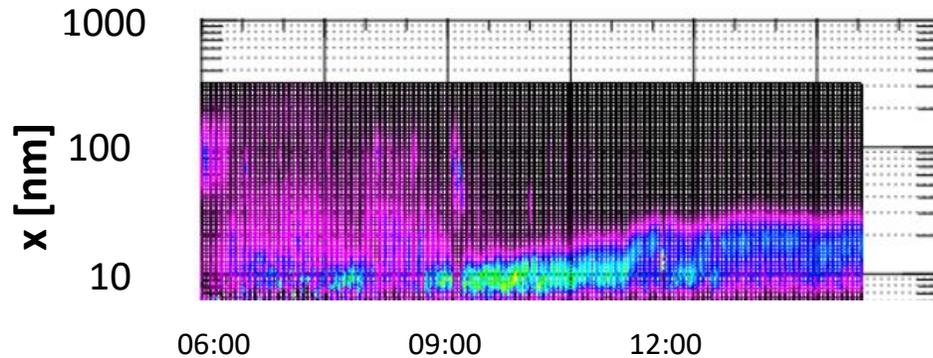
Arrival of ferry scheduled at 6:00 Uhr



# UFP monitoring at harbour – identifying the sources



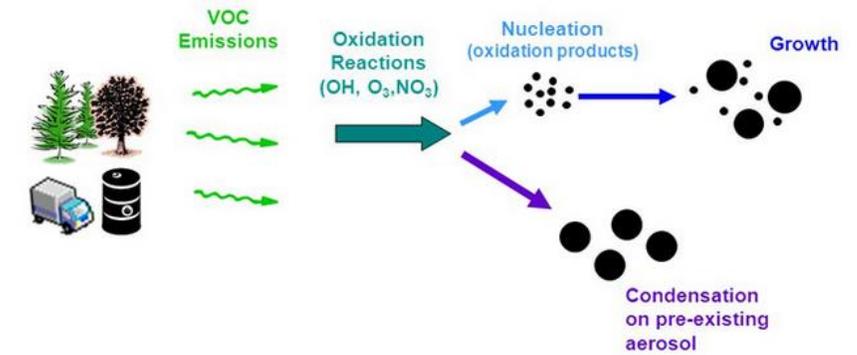
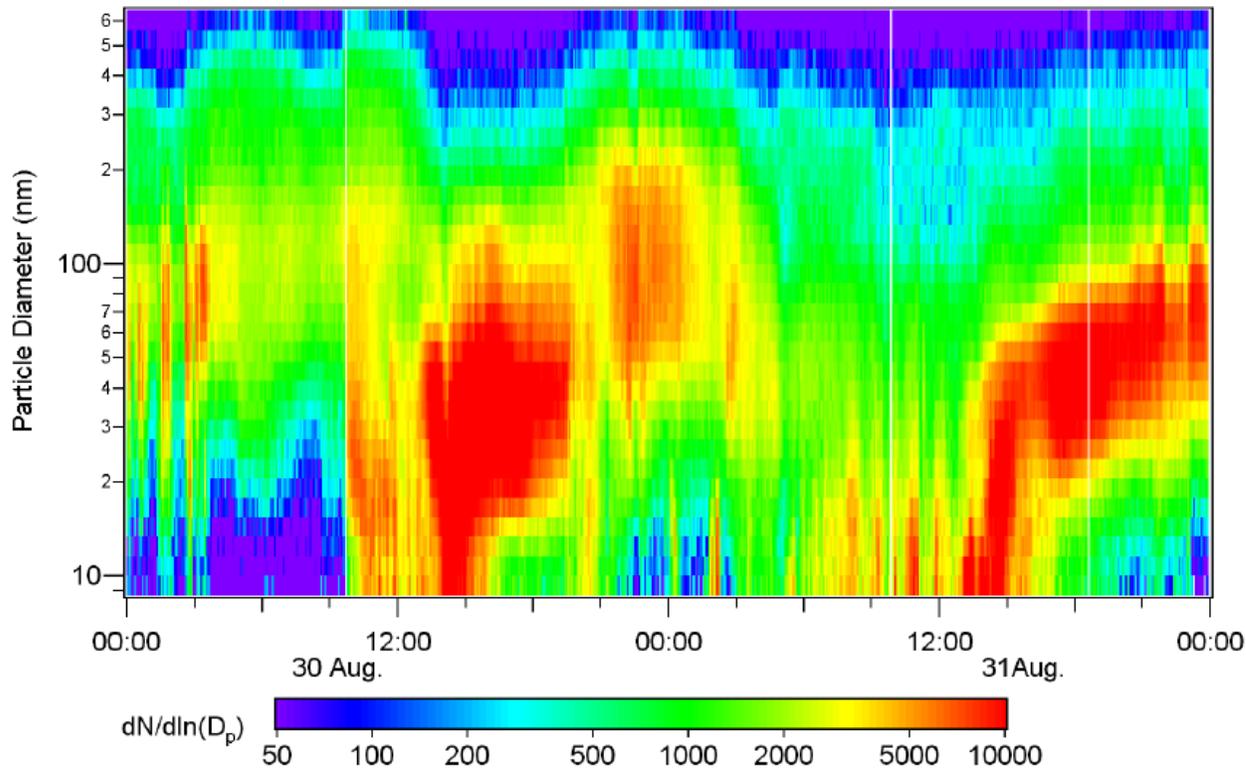
**Ultra fine particle formation event**



- #1 11.06.2018 - 14:00:10 - 90s/1 
- #1 11.06.2018 - 14:02:27 - 90s/1 
- #1 11.06.2018 - 14:04:45 - 90s/1 
- #1 11.06.2018 - 14:07:02 - 90s/1 

SECONDARY ORGANIC AEROSOL PRODUCTION

M. Mozurkewich et al.: Particle nucleation and growth i

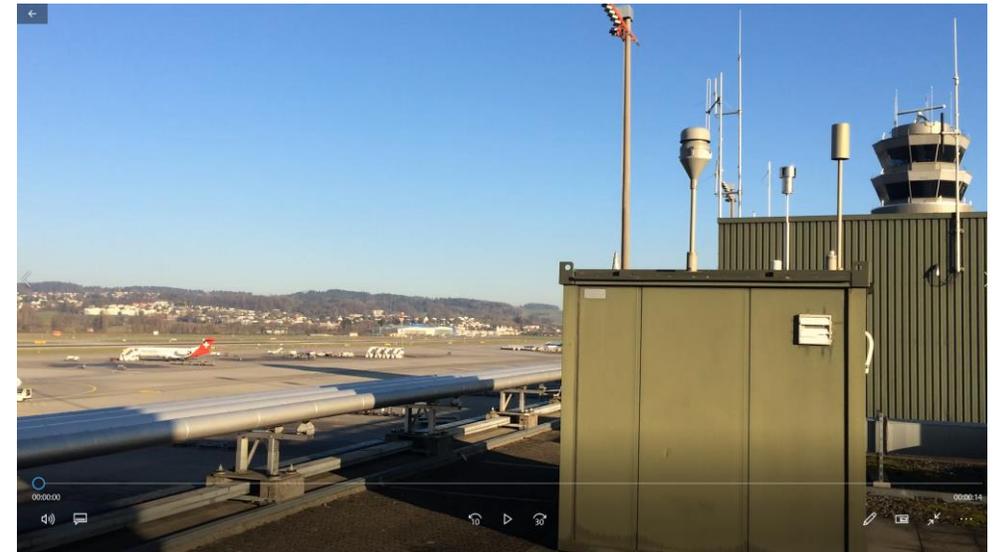


Over 500 reactions to describe the formation of SOA precursors, ozone, and other photochemical pollutants [Griffin et al., 2002; Griffin et al., 2005; Chen and Griffin, 2005]

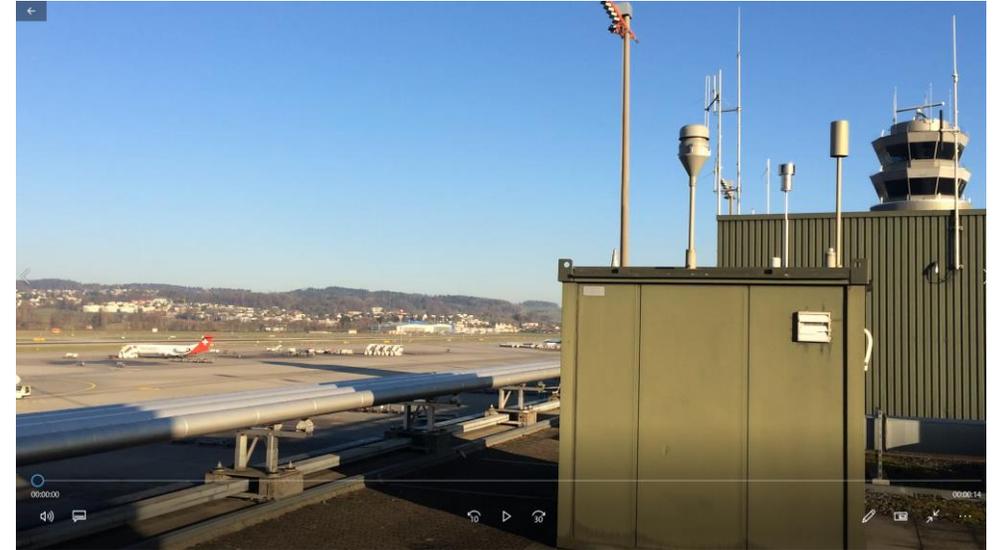
growth rates were approximately 5 to 10 nm hr<sup>-1</sup>. The nucleation events seem to have been triggered when the UV flux reached about 25 W m<sup>-2</sup>. We can not identify the nucleating species, but the growth appears to have been driven by the photochemical oxidation of biogenic organic compounds.

**Fig. 10.** DMA number size distributions for 30 and 31 August 2001 at Eagle Ridge showing the particle growth event on the 30th and the nucleation event on the 31st.

## UFP monitoring at airports



## Example A

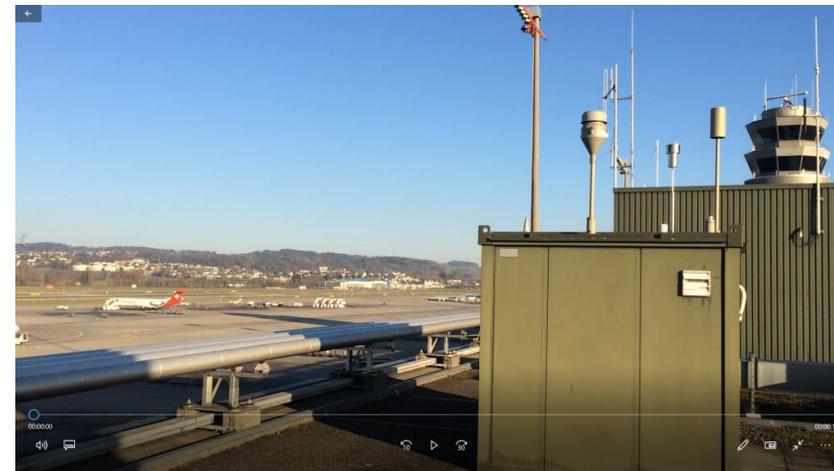
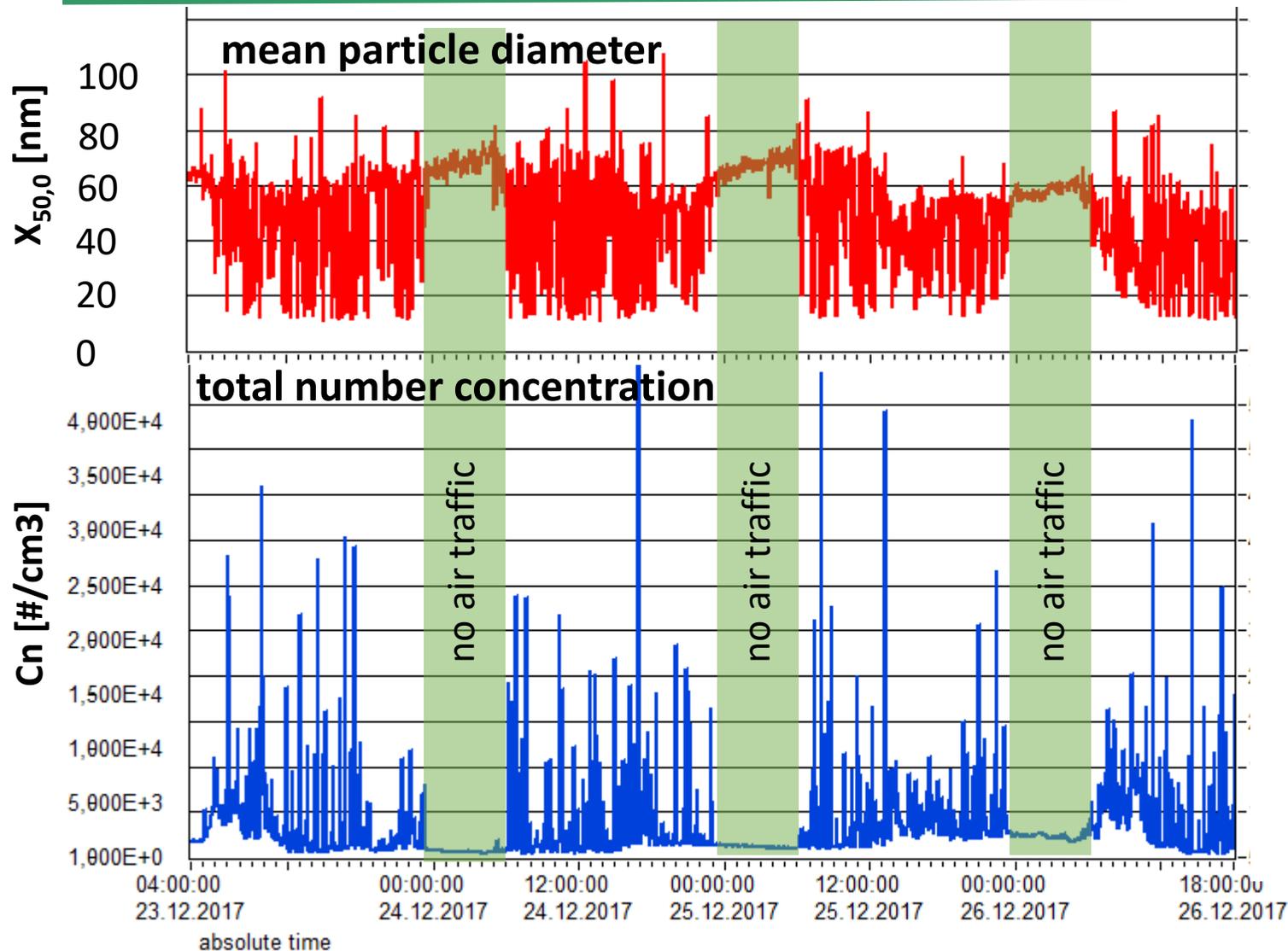


Station at terminal (400 m to runway for landings / departure)

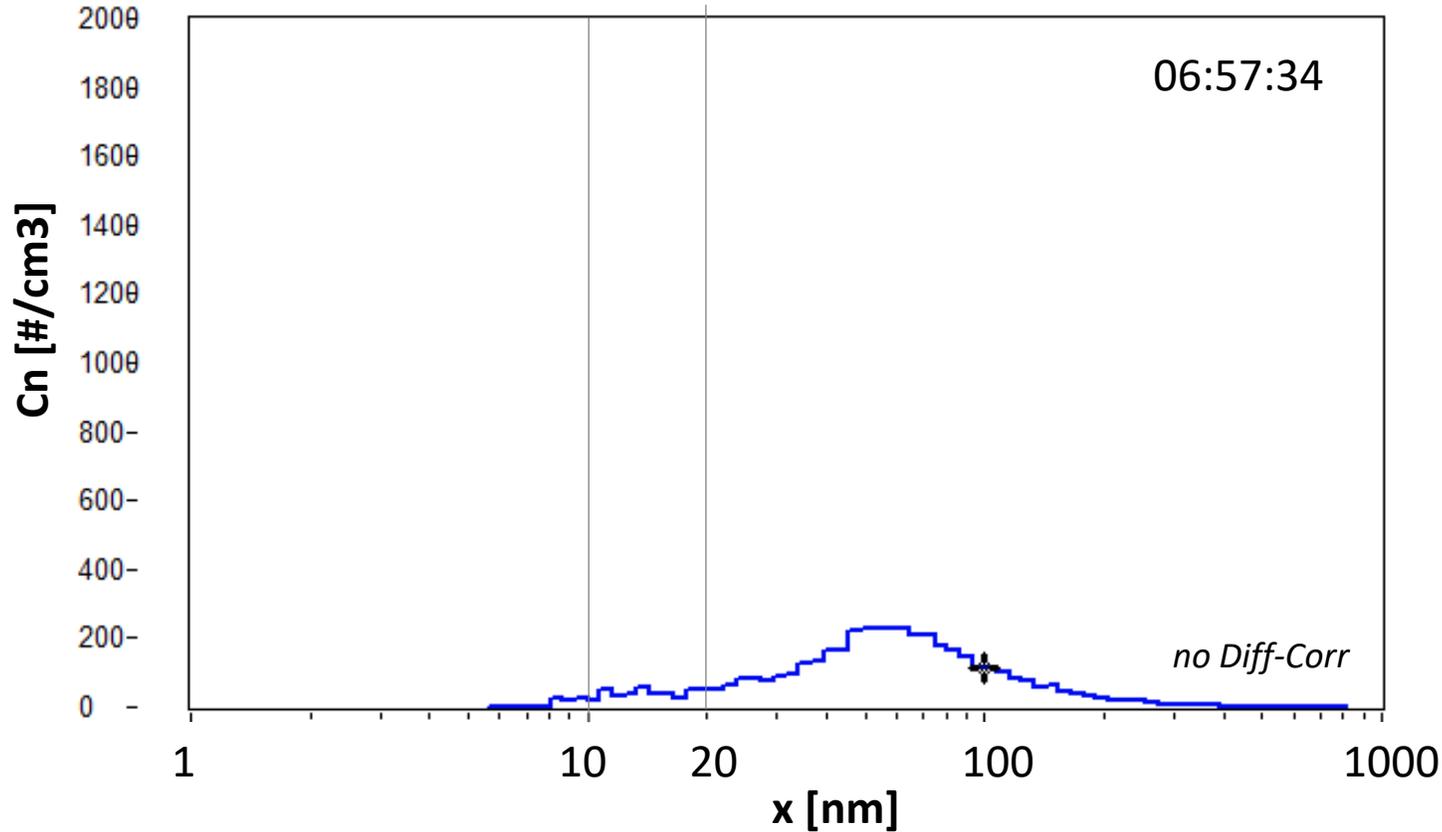
**scope: general monitoring, air traffic visible ?**

data: measured by Palas® U-SMPS 2100 X  
graphs by Palas® PDAnalyze

# UFP monitoring at airport



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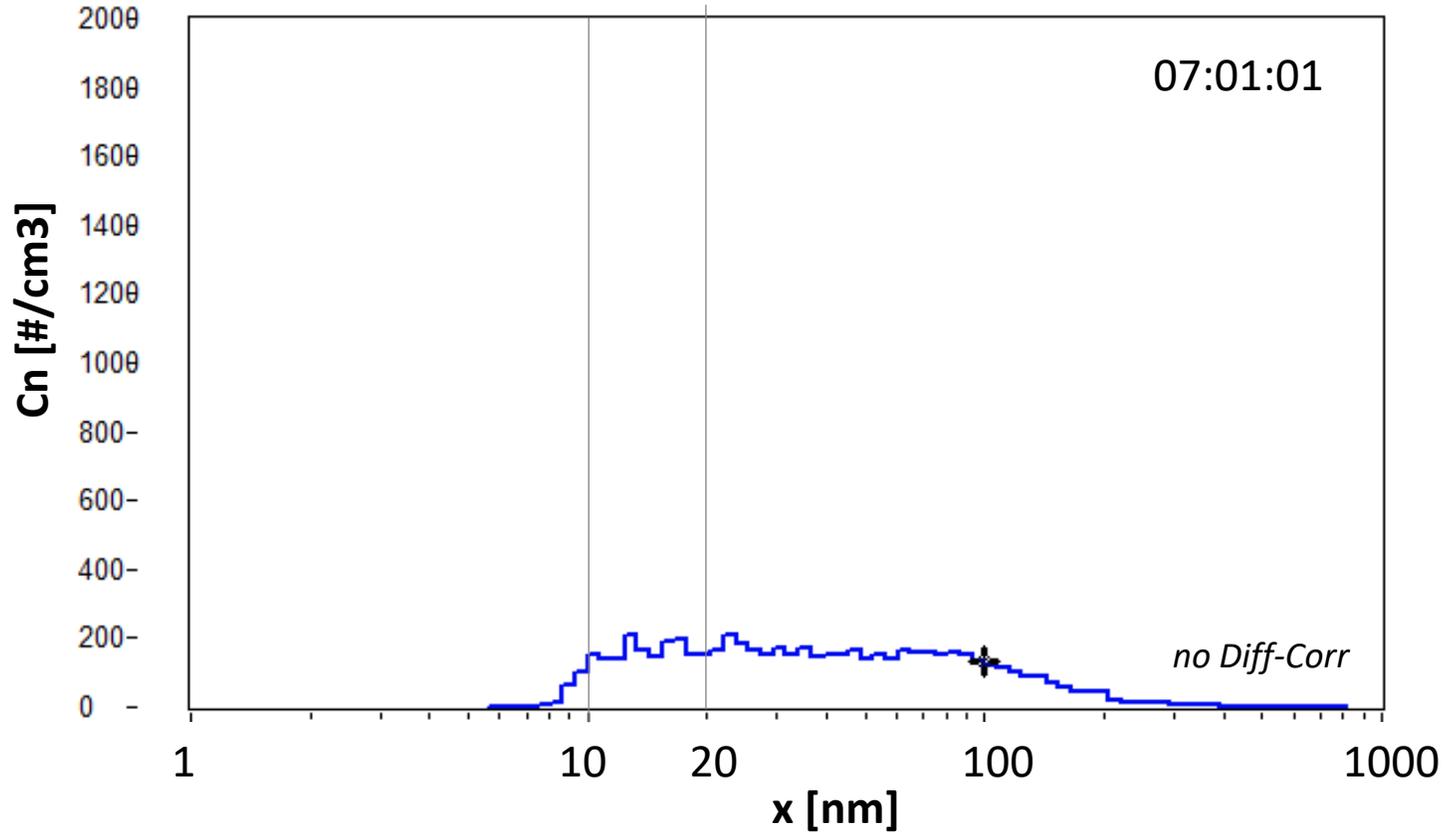
Example 1

time-resolved particle size distributions

- Scans from 7 – 800 nm every 150 seconds

data: measured by U-SMPS 2100 X  
graphs by PDAnalyze

# UFP monitoring at airport



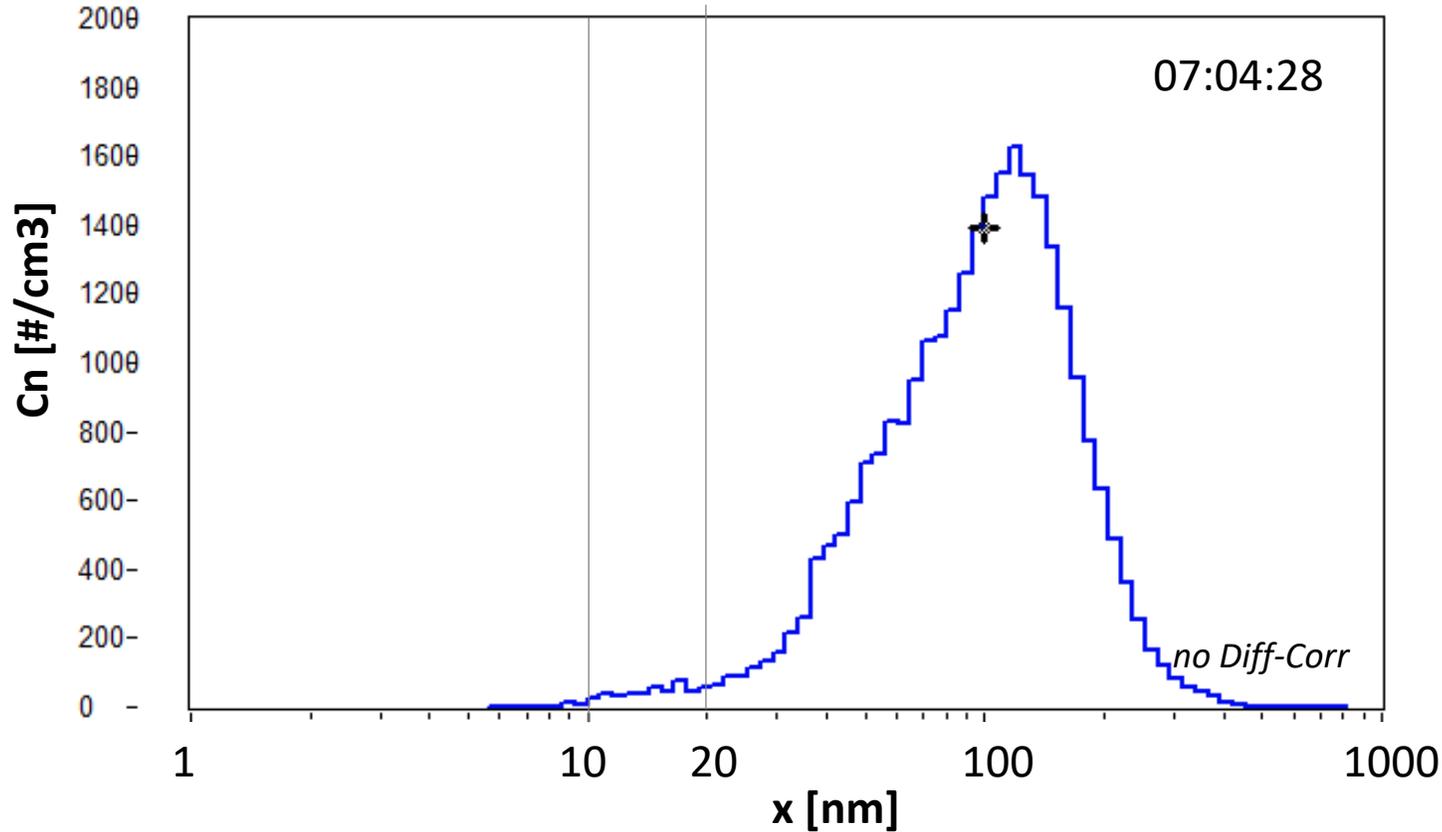
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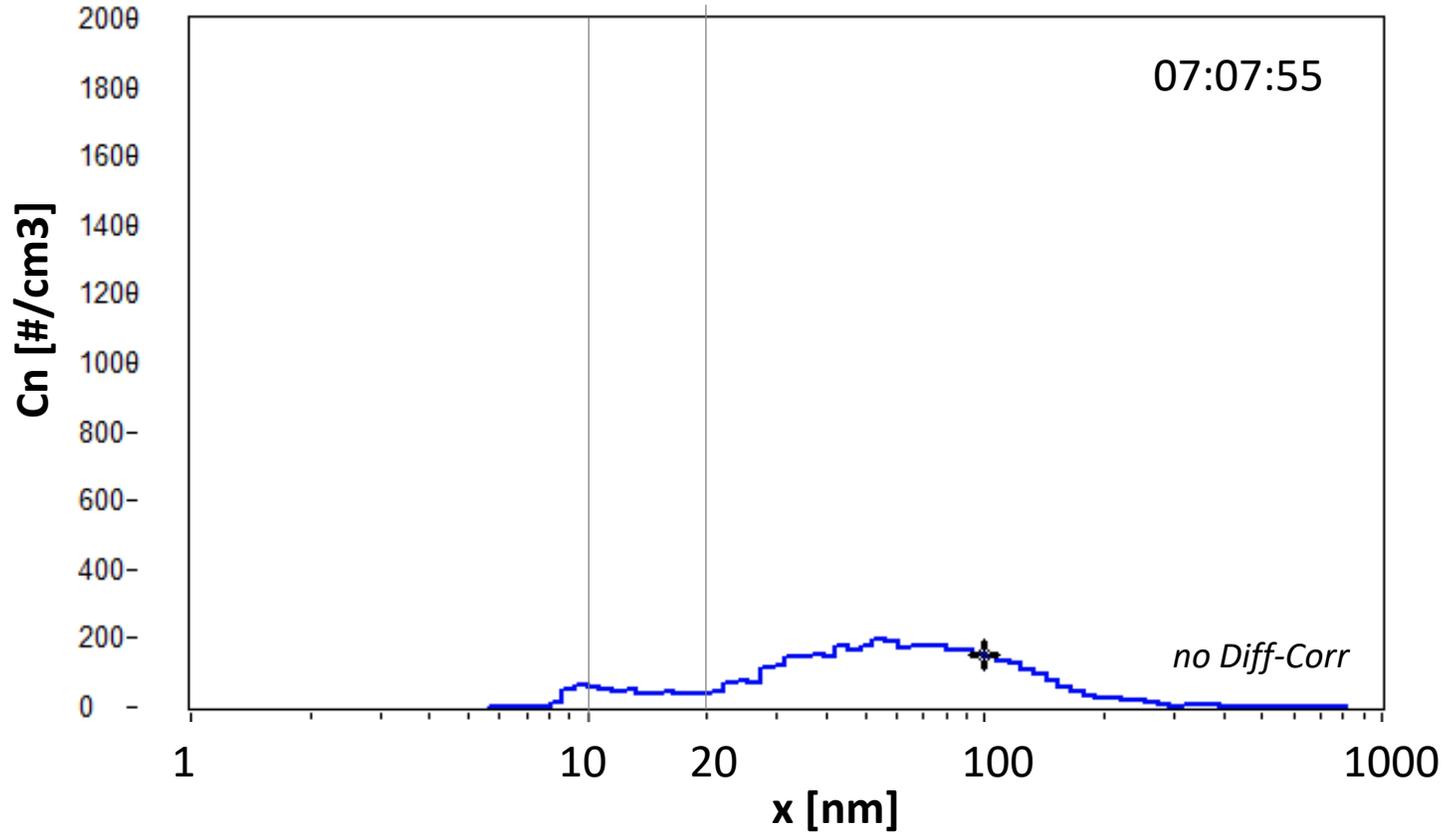
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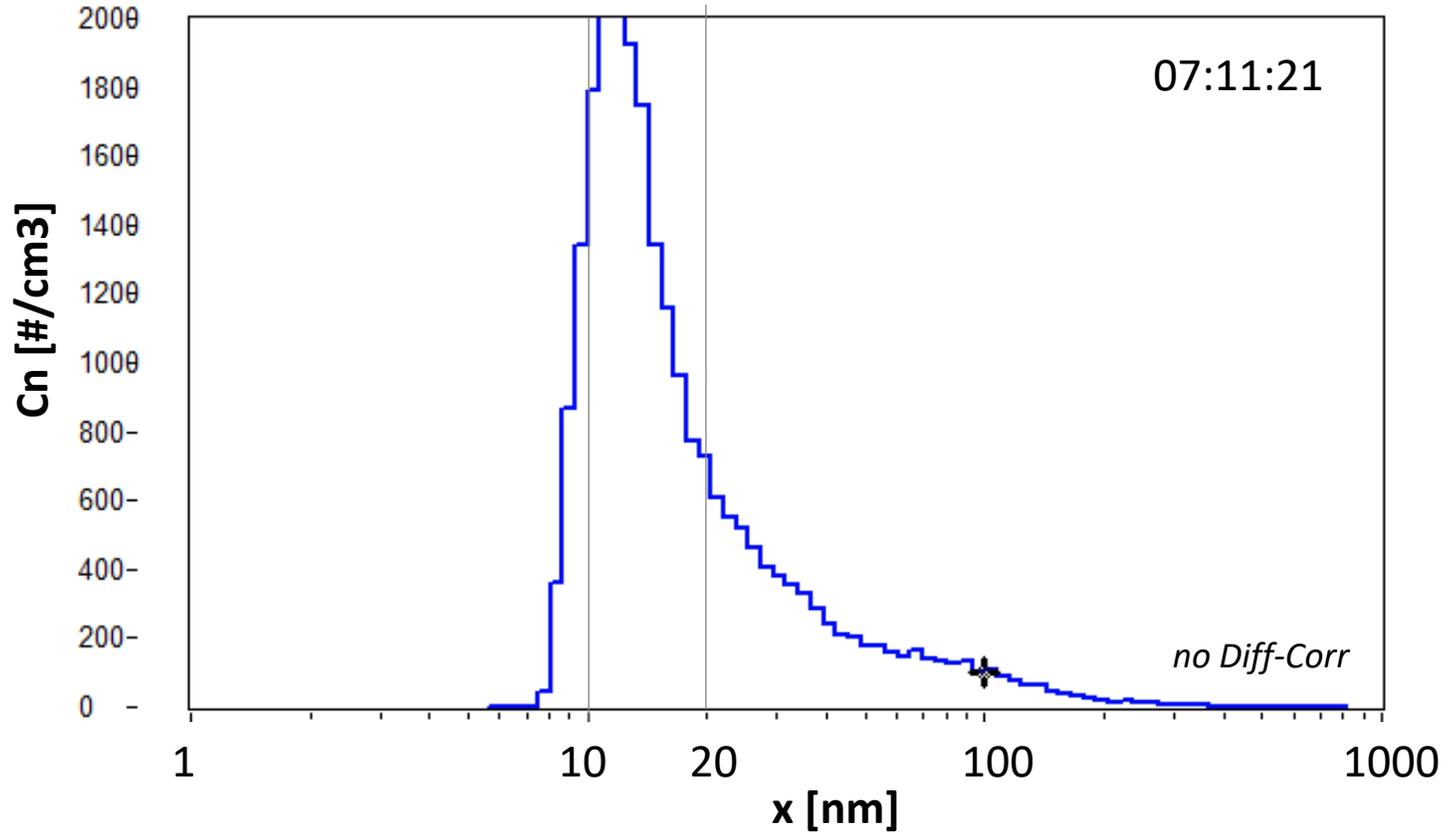
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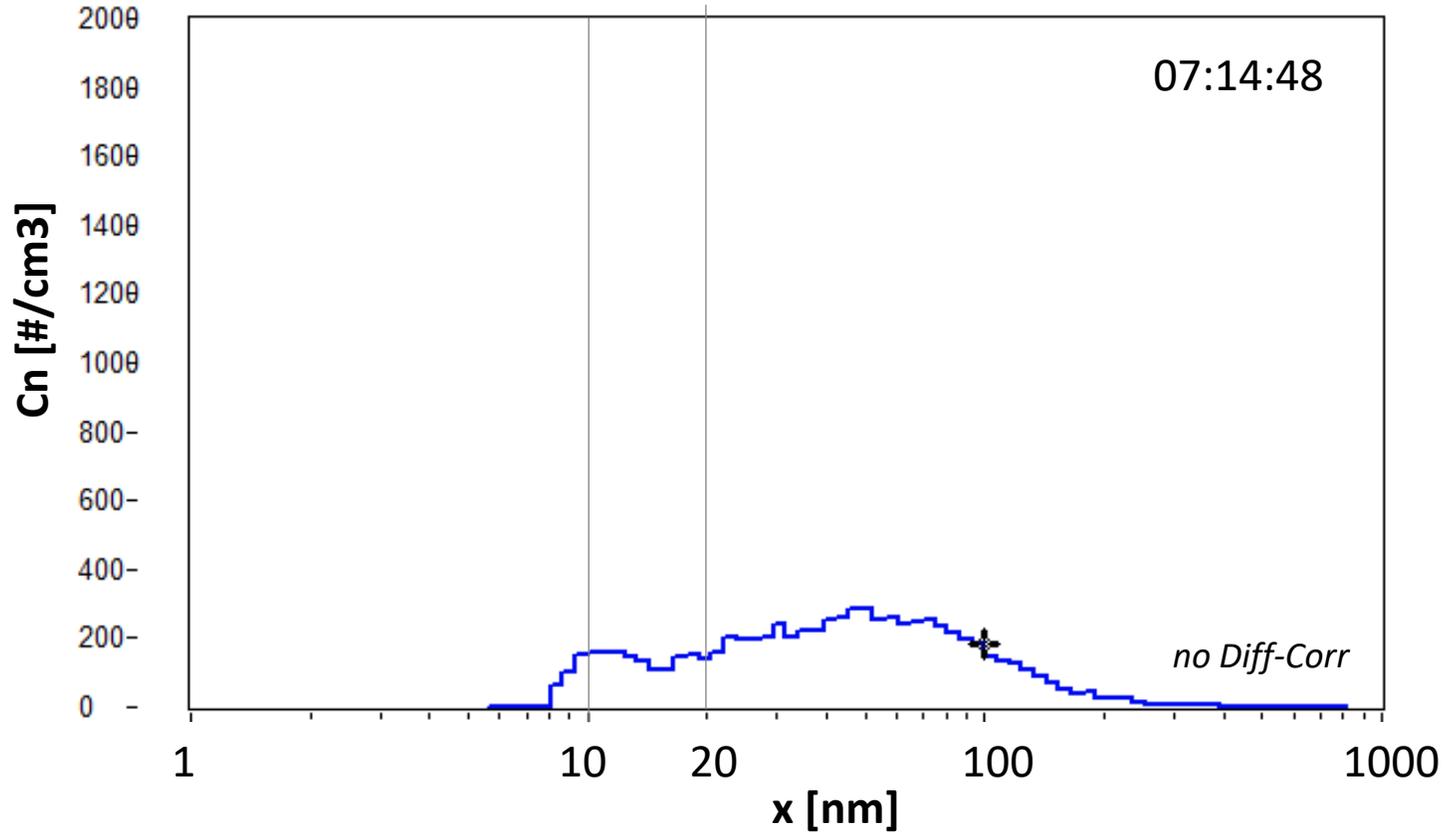
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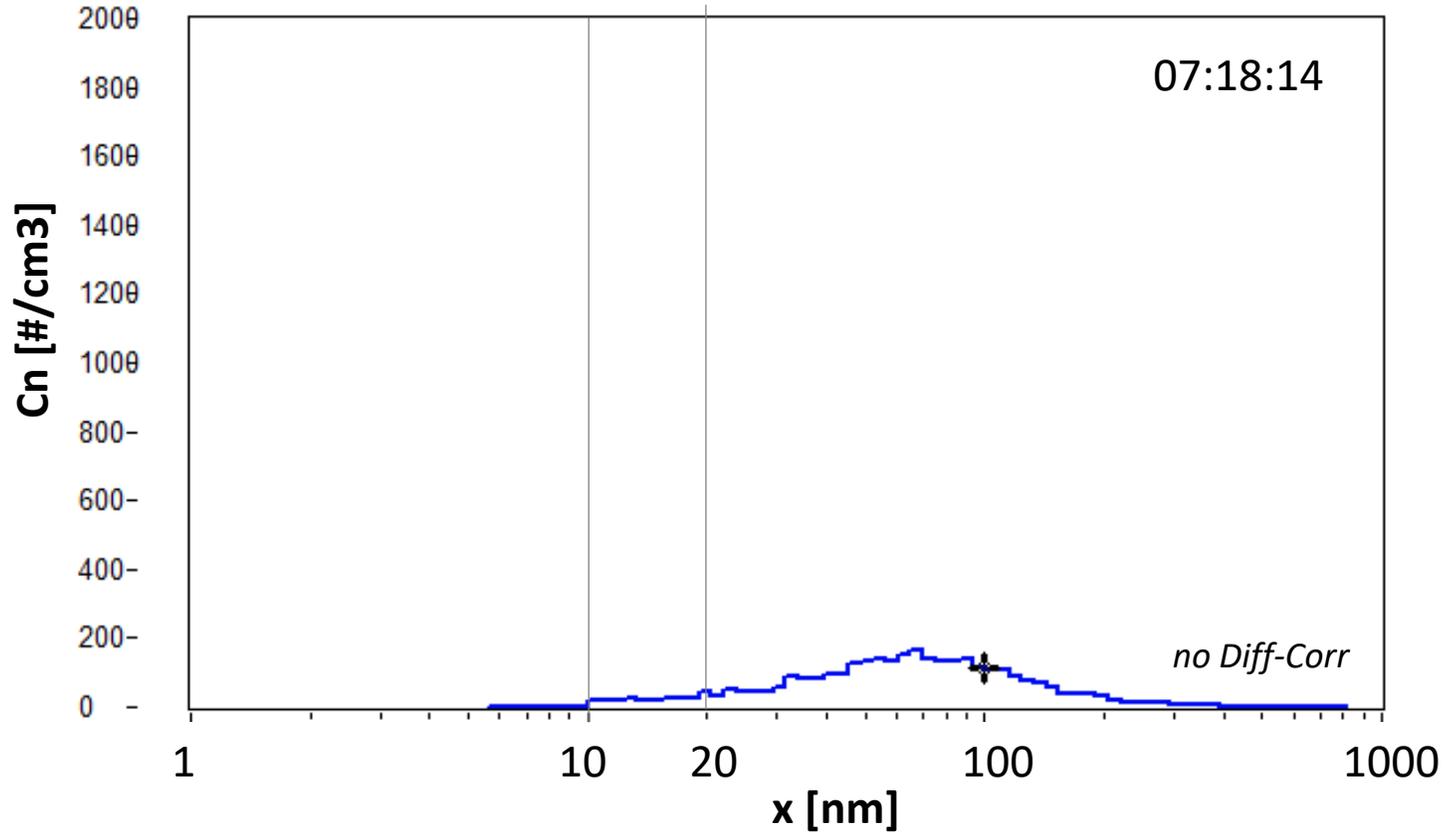
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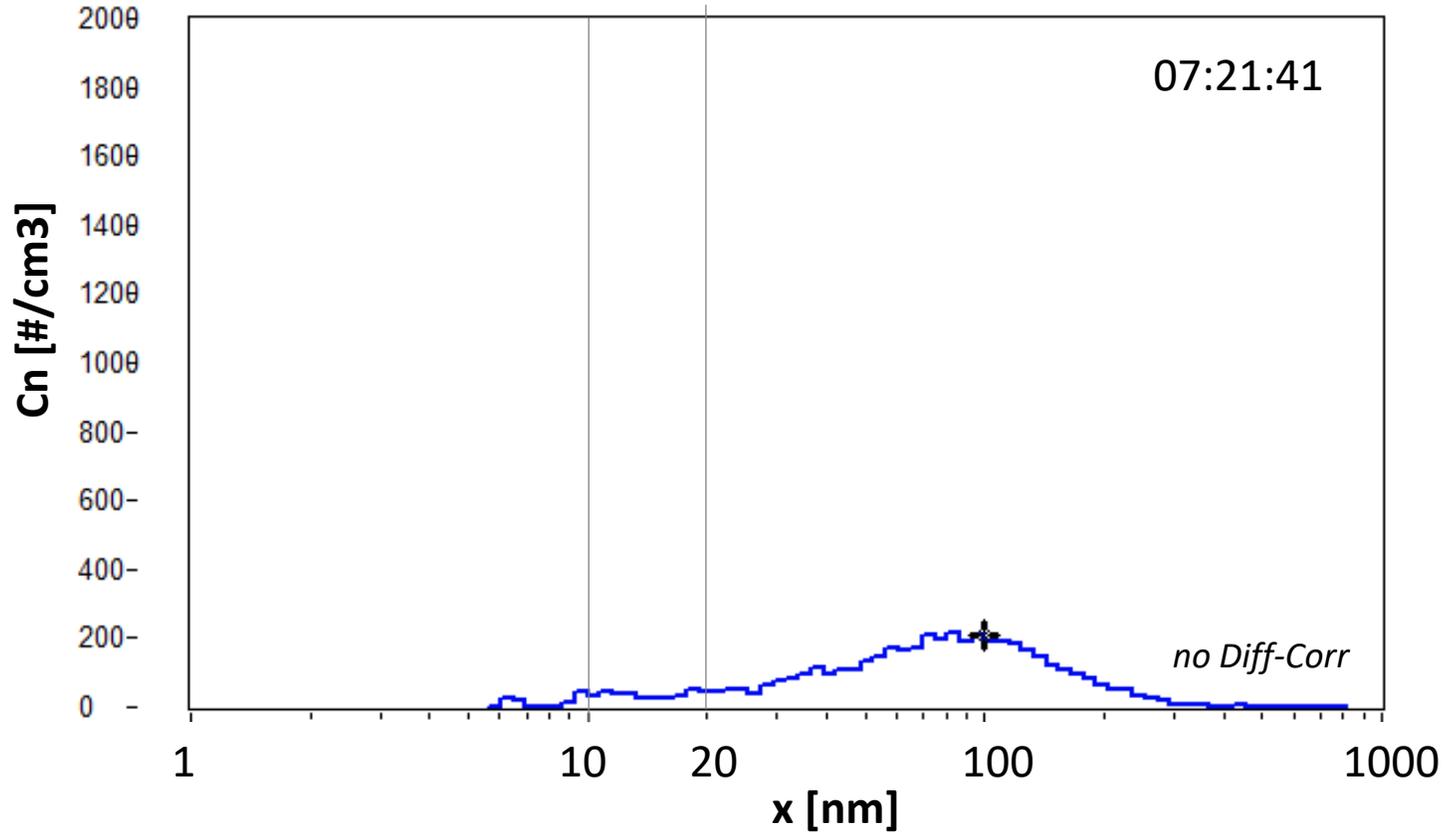
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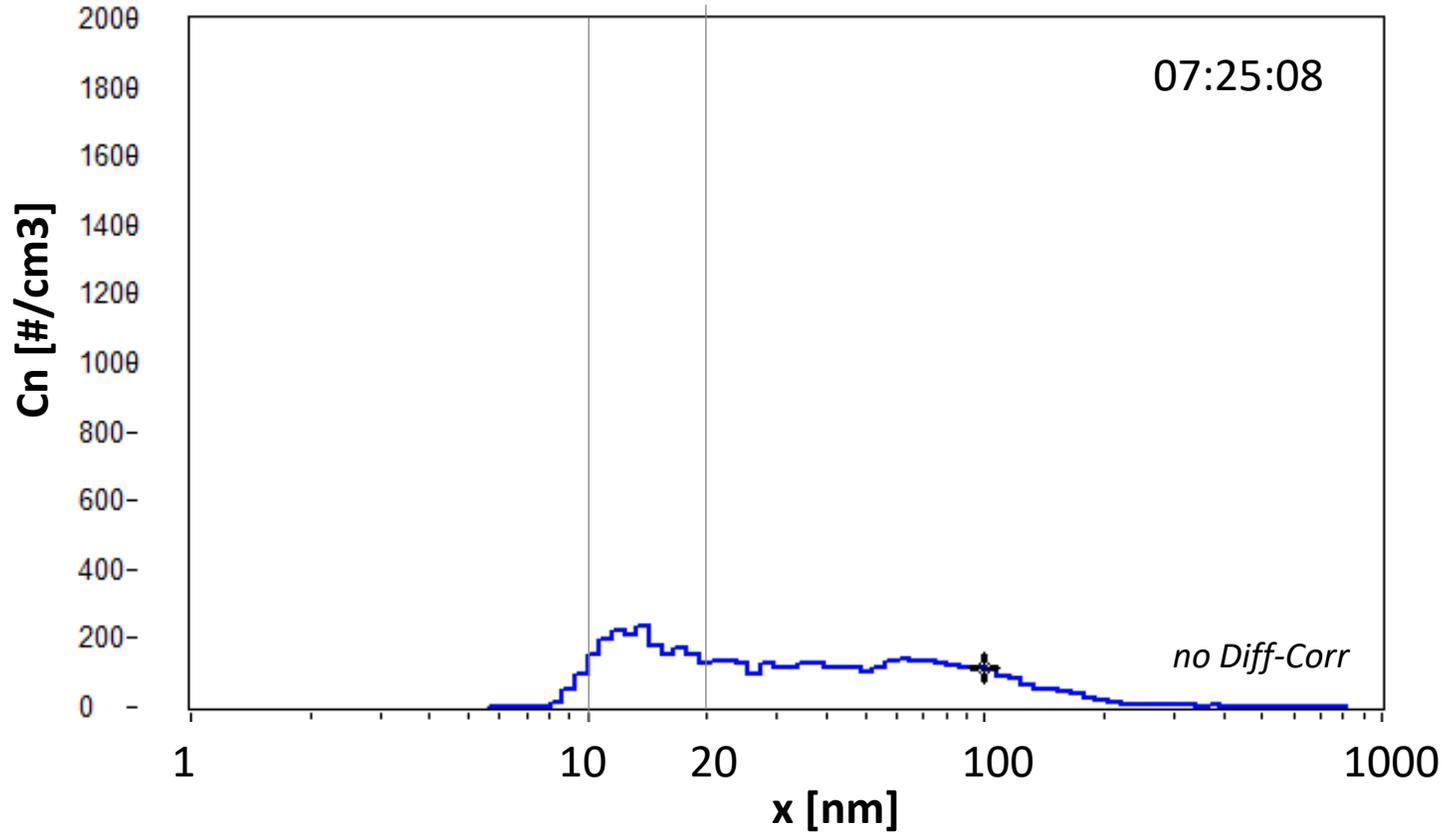
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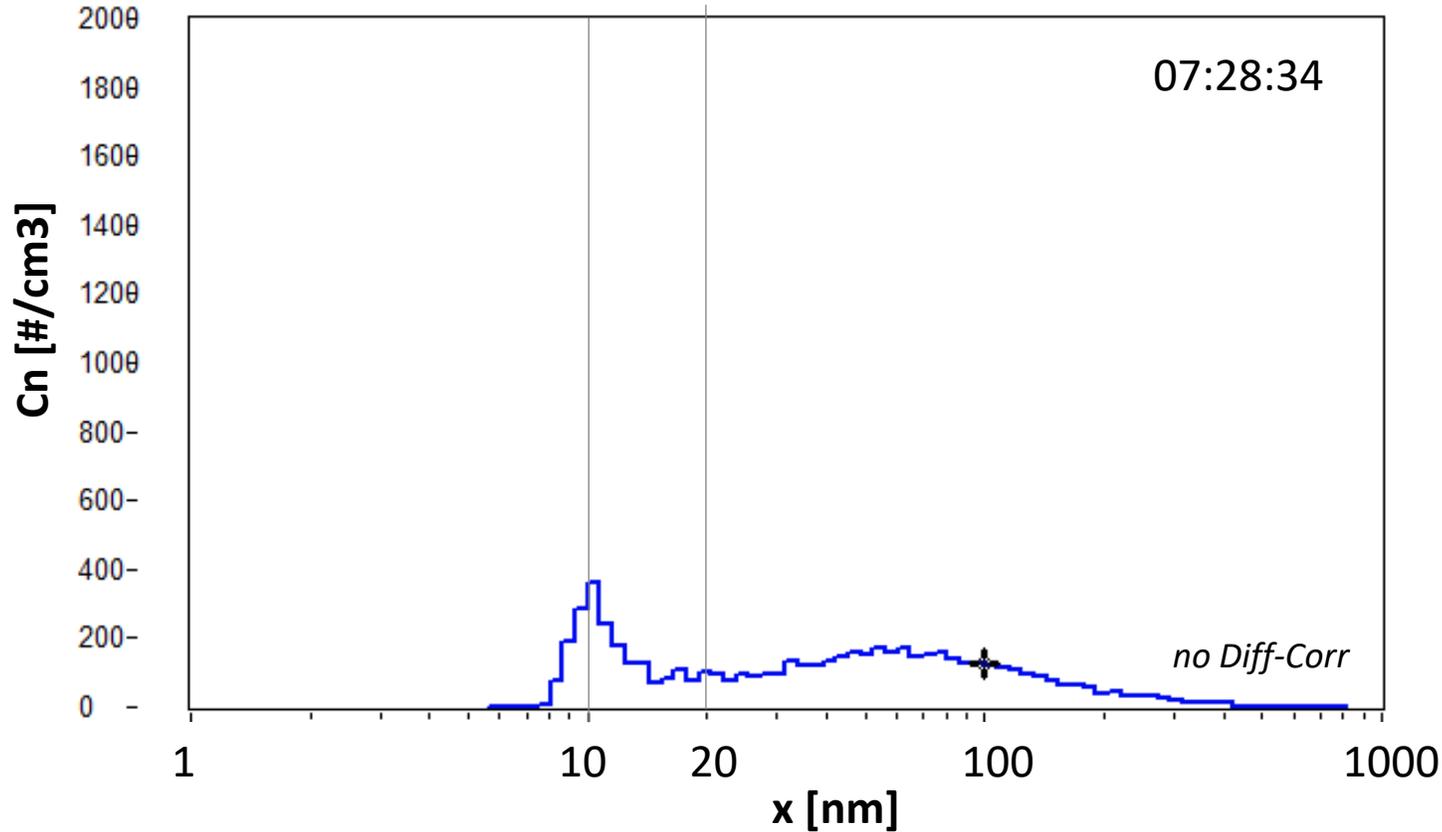
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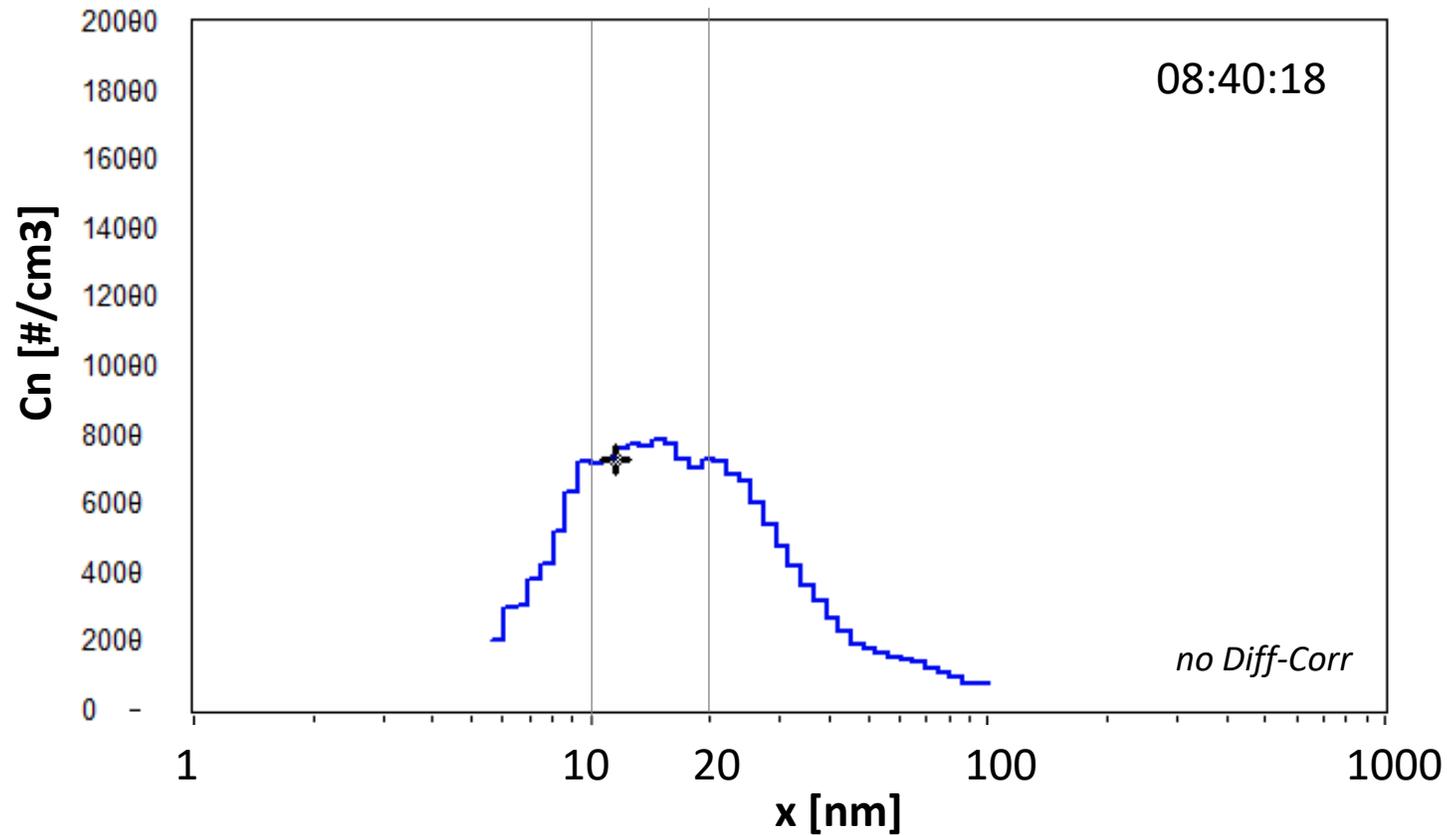
## Example B



very close to runway for landings / departure (~50m)

**scope: identify individual airplanes, high-time resolution**

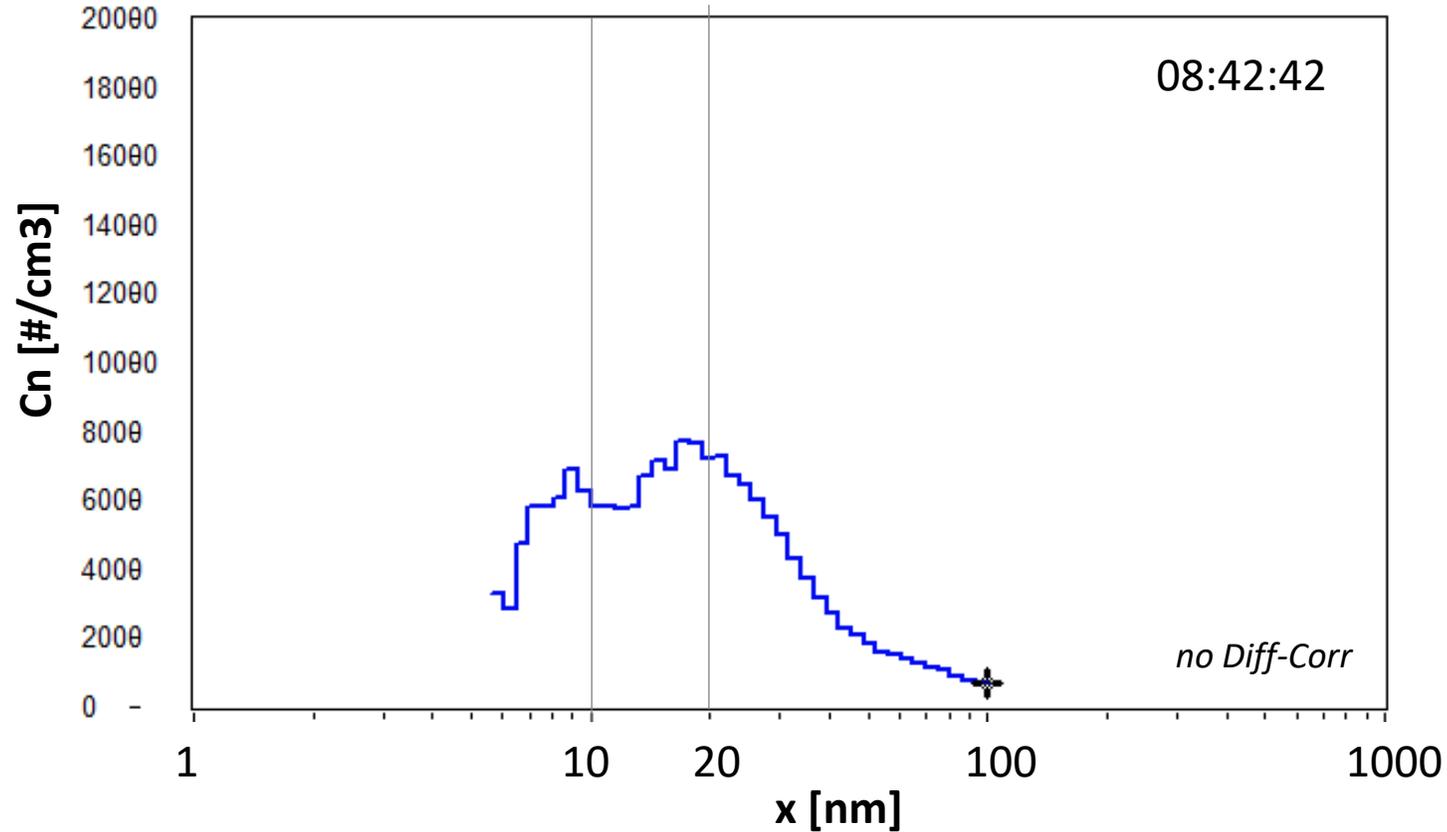
## UFP monitoring at airport



### Scenario B

- Close to departure/arrival runway
- Fast scans 7 – 100 nm in 40 seconds

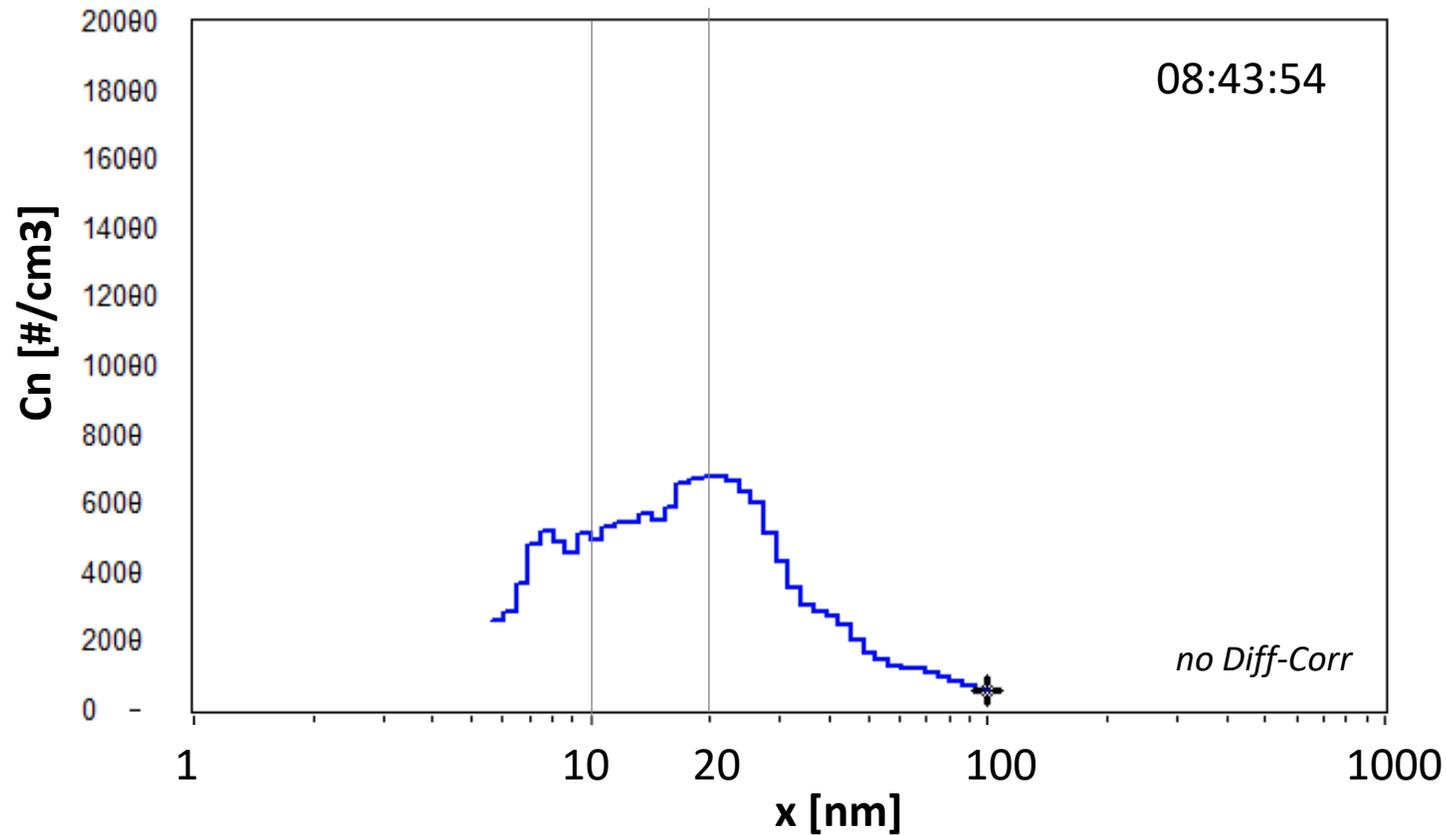
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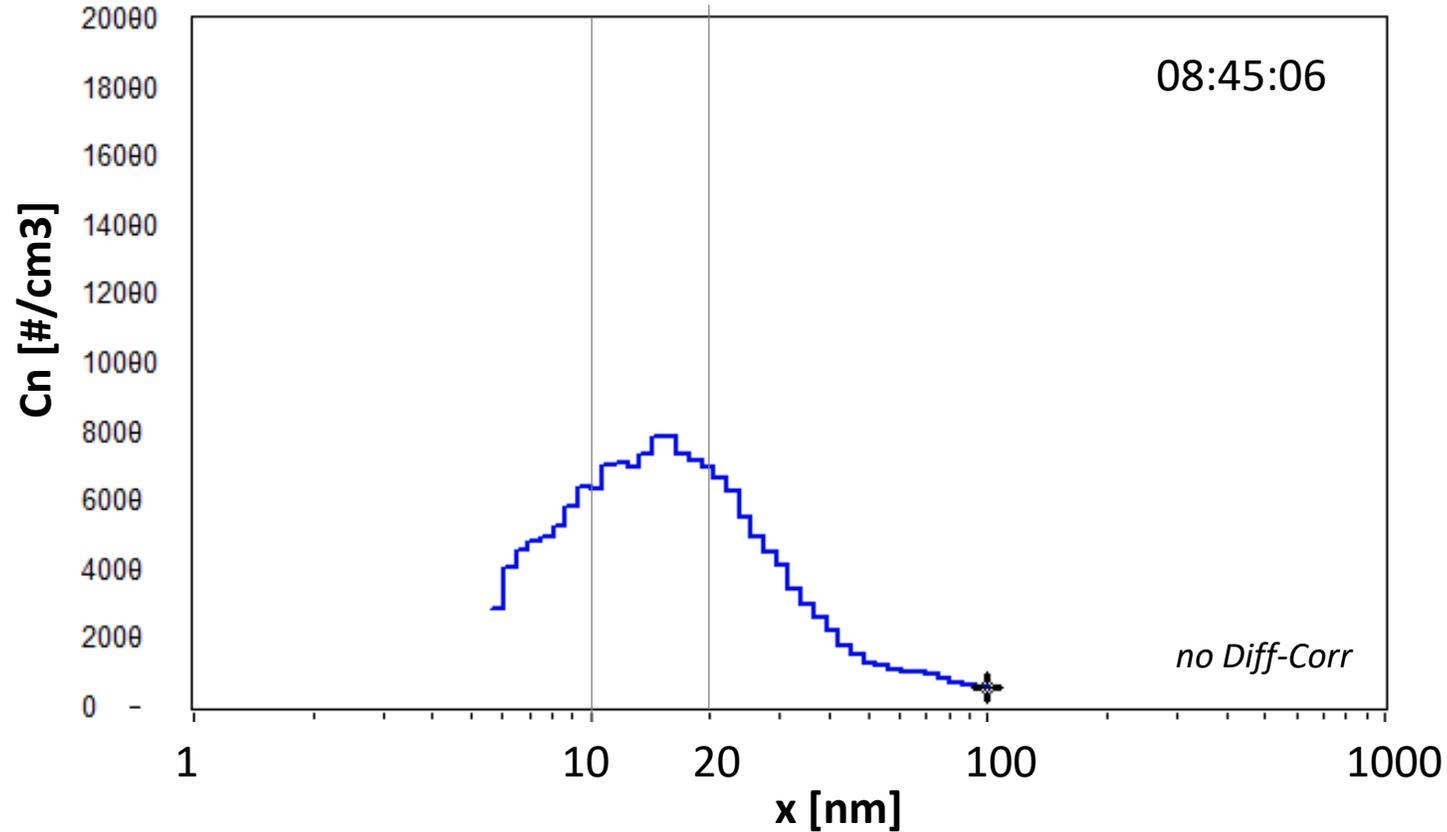
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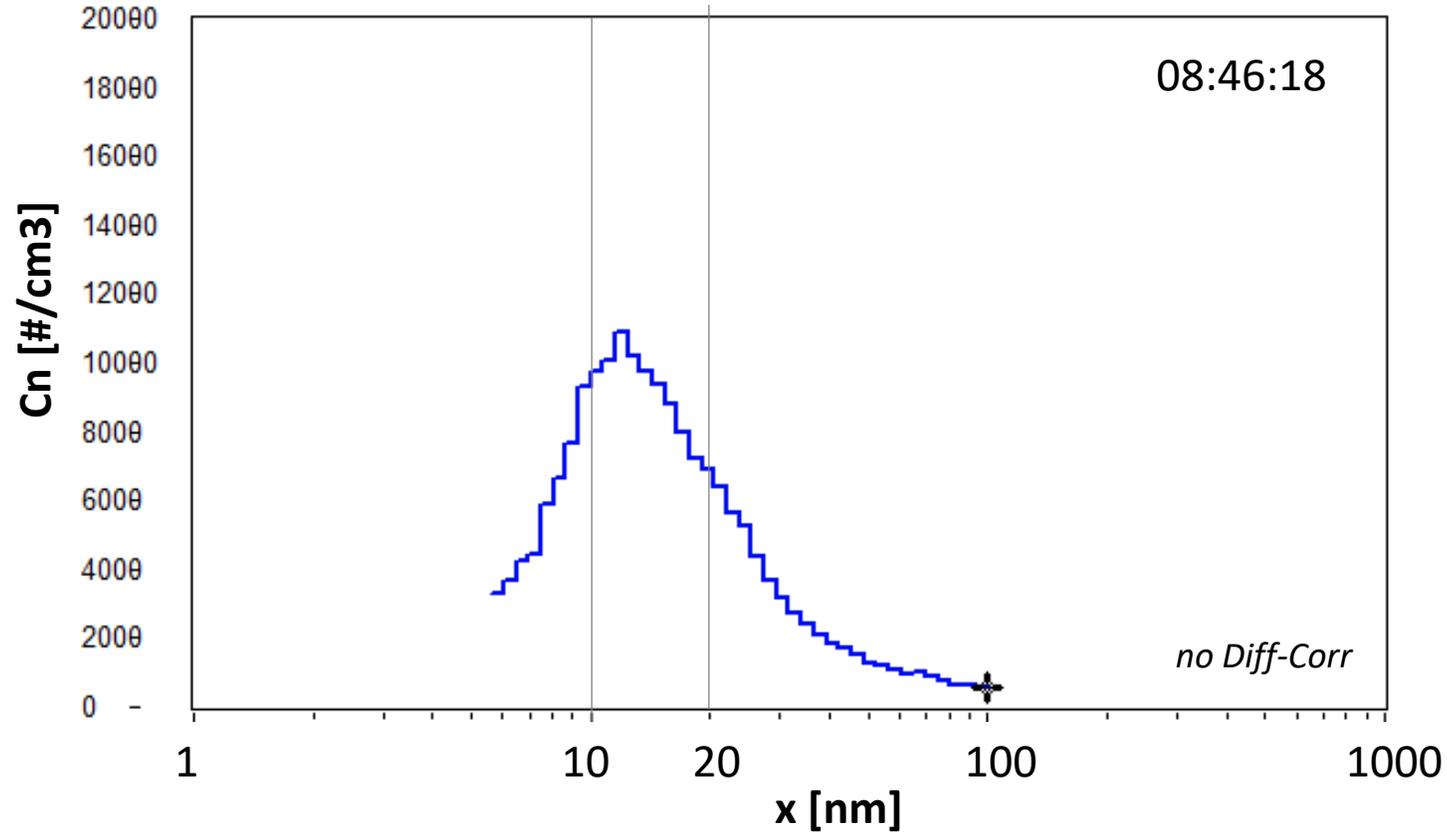
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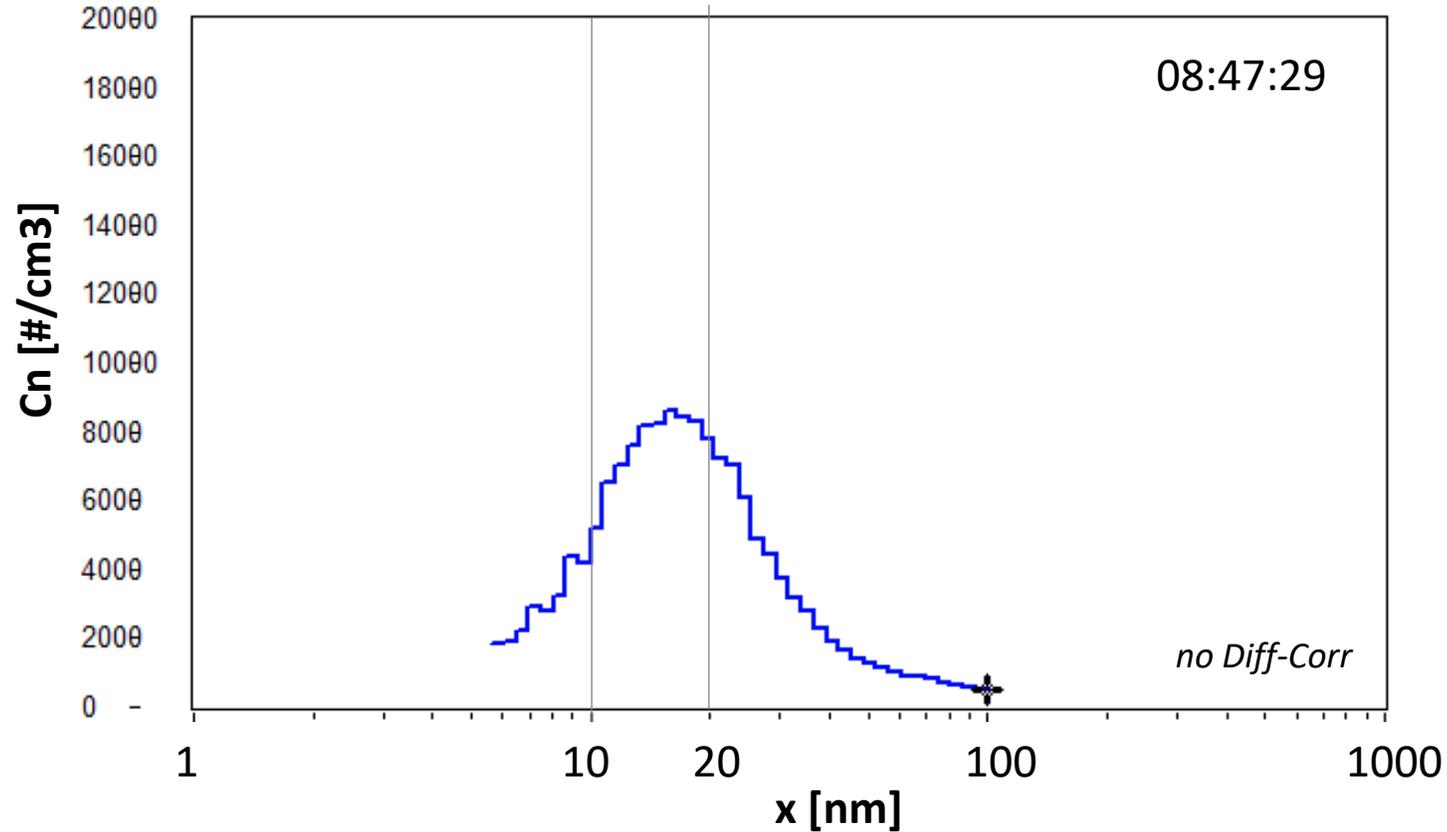
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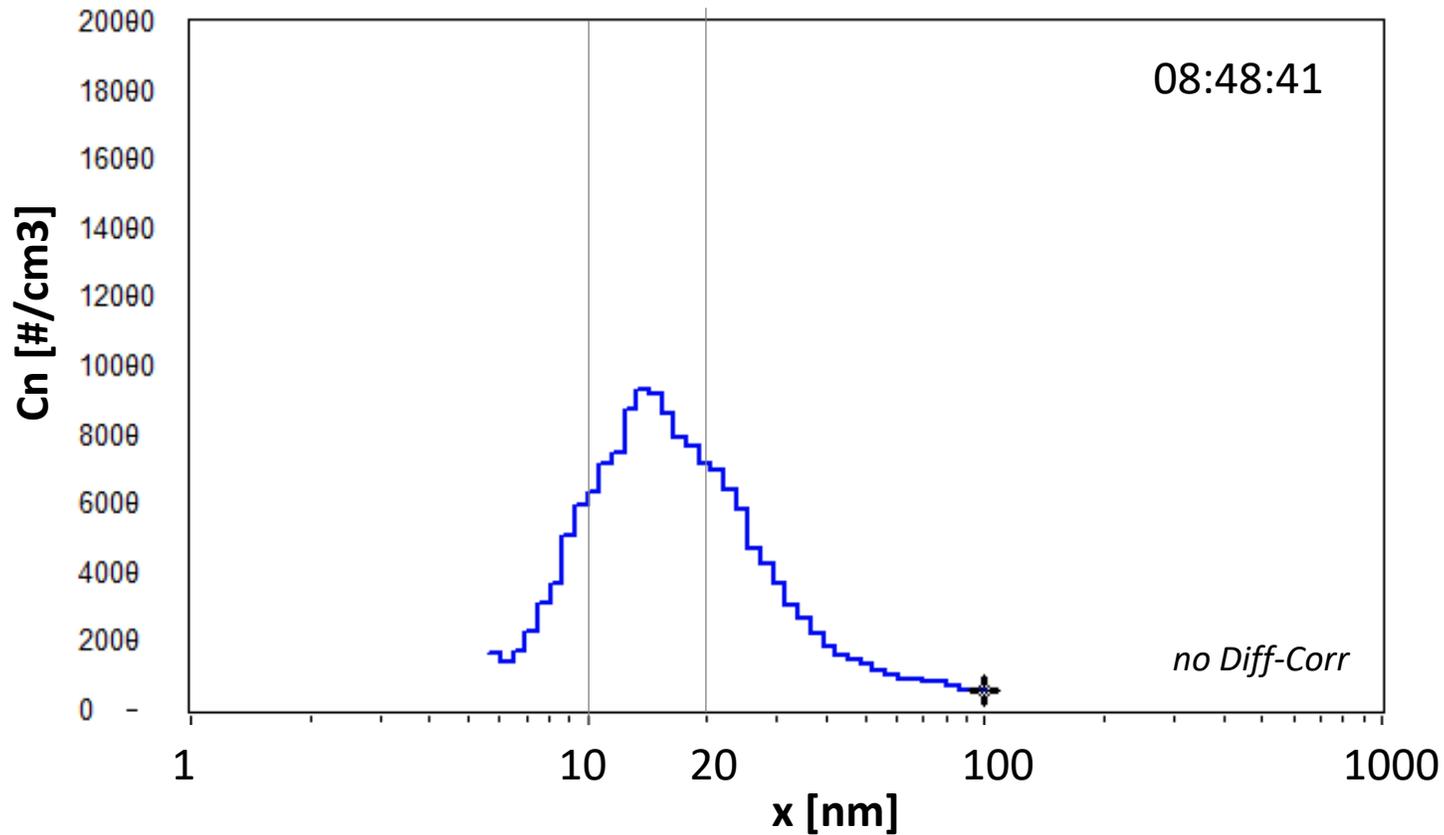
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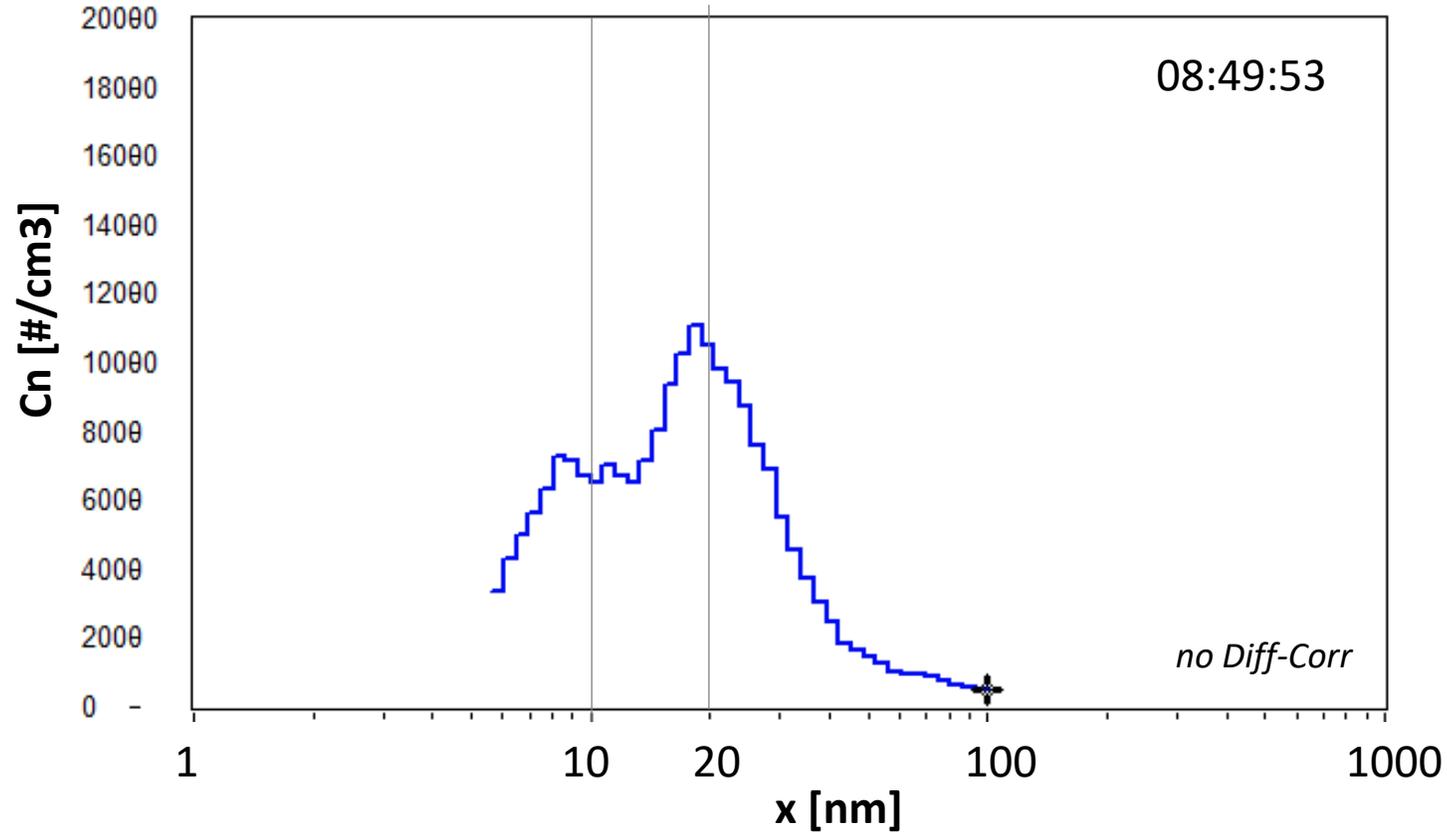
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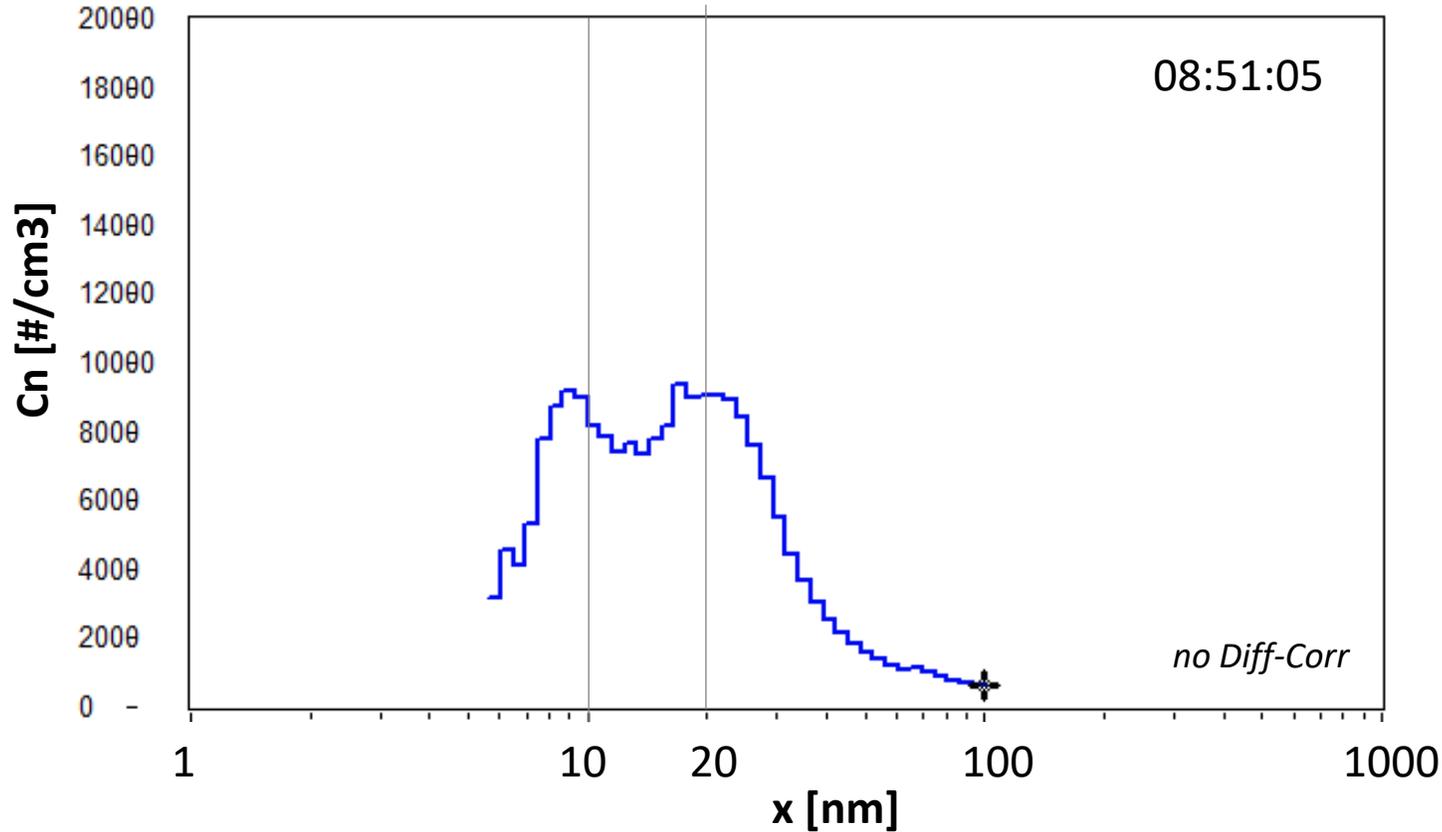
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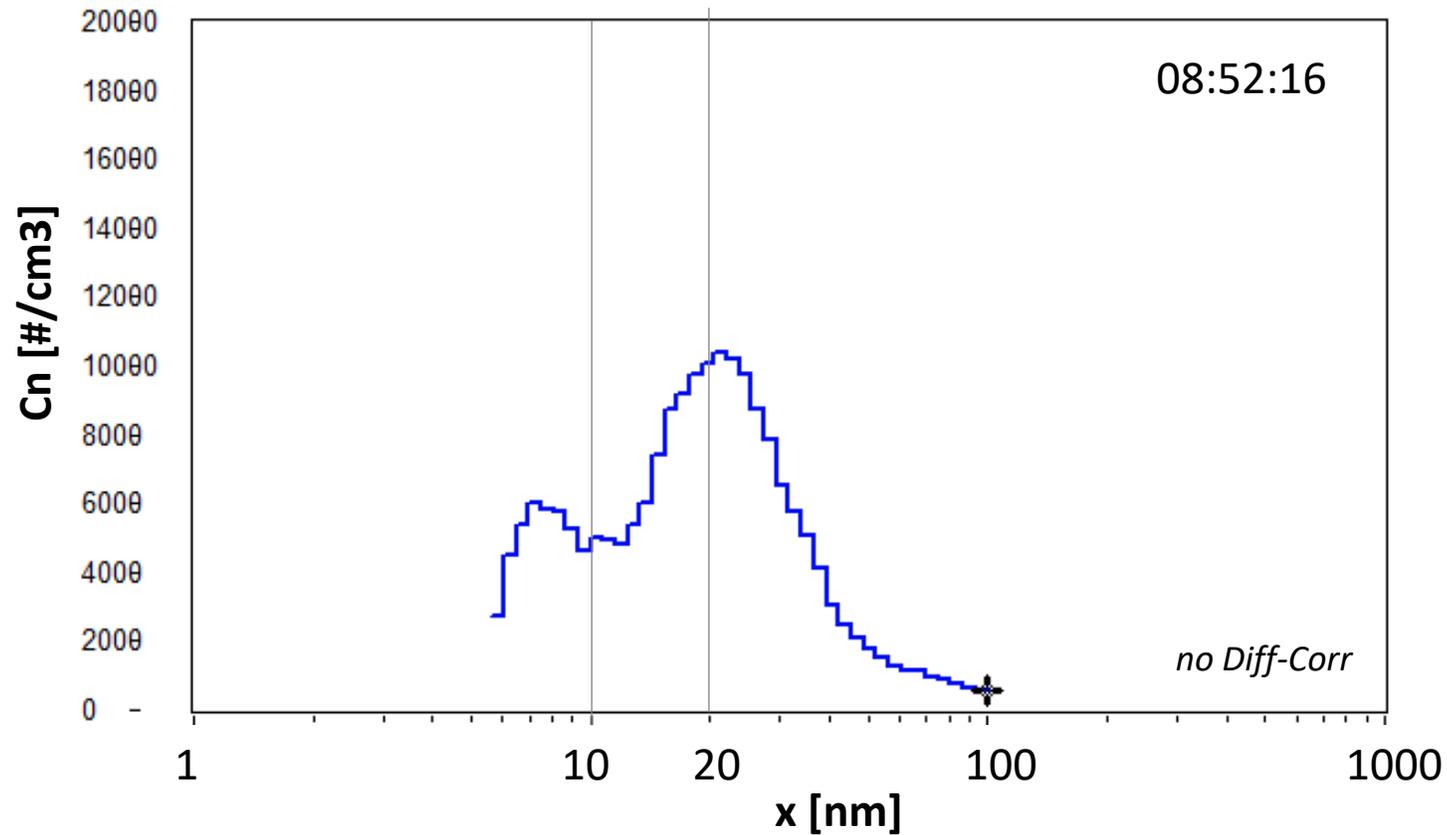
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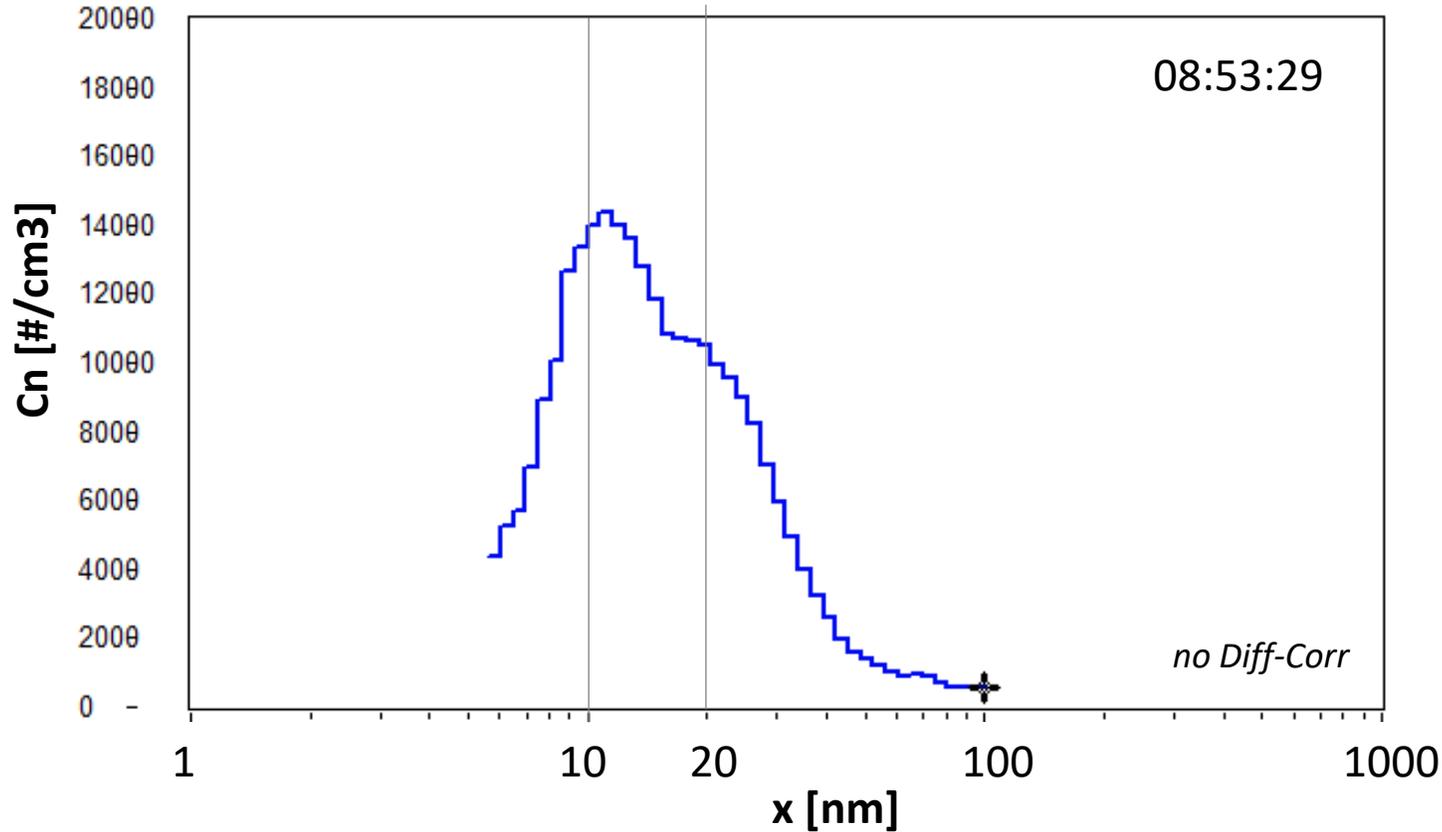
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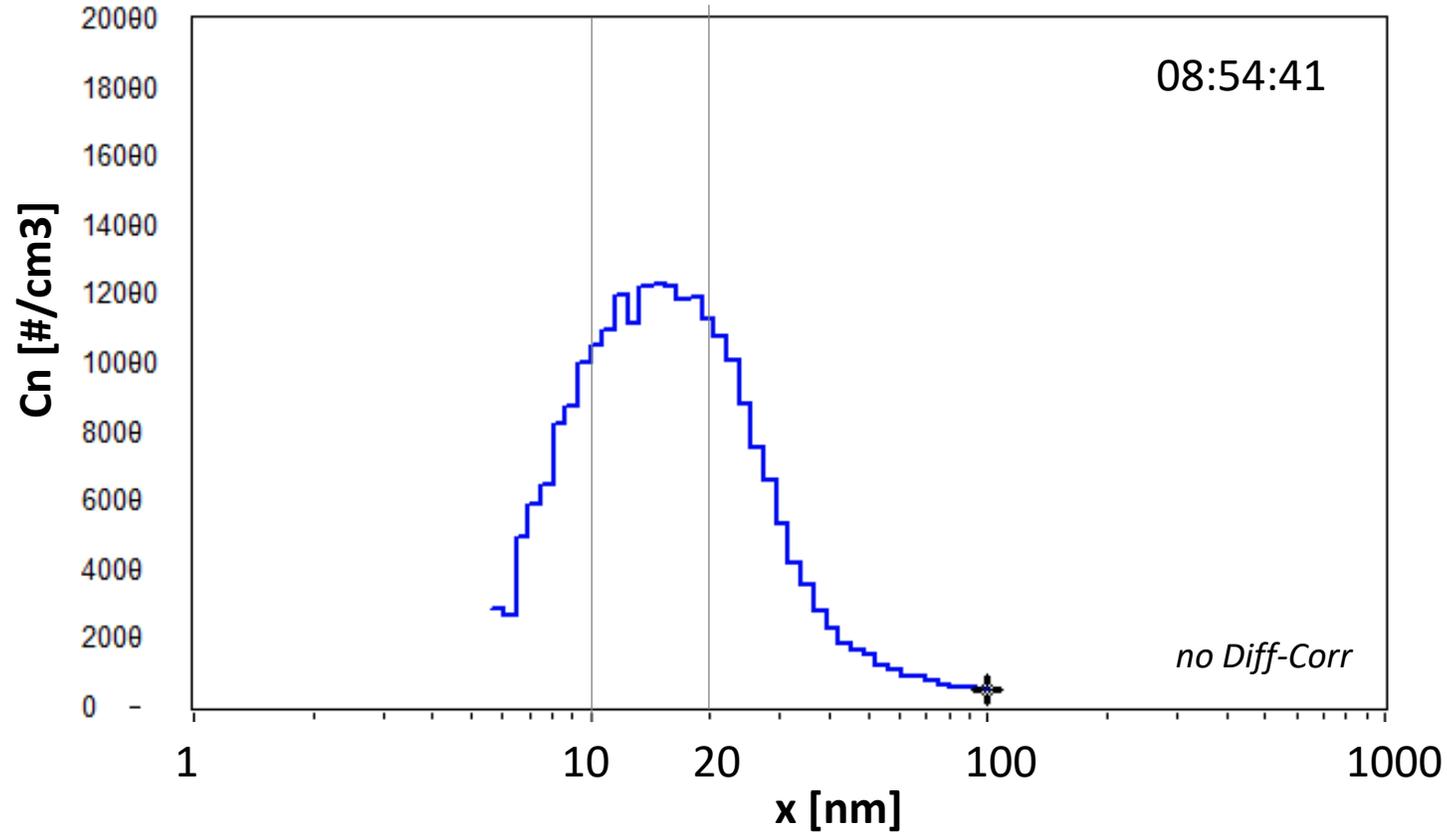
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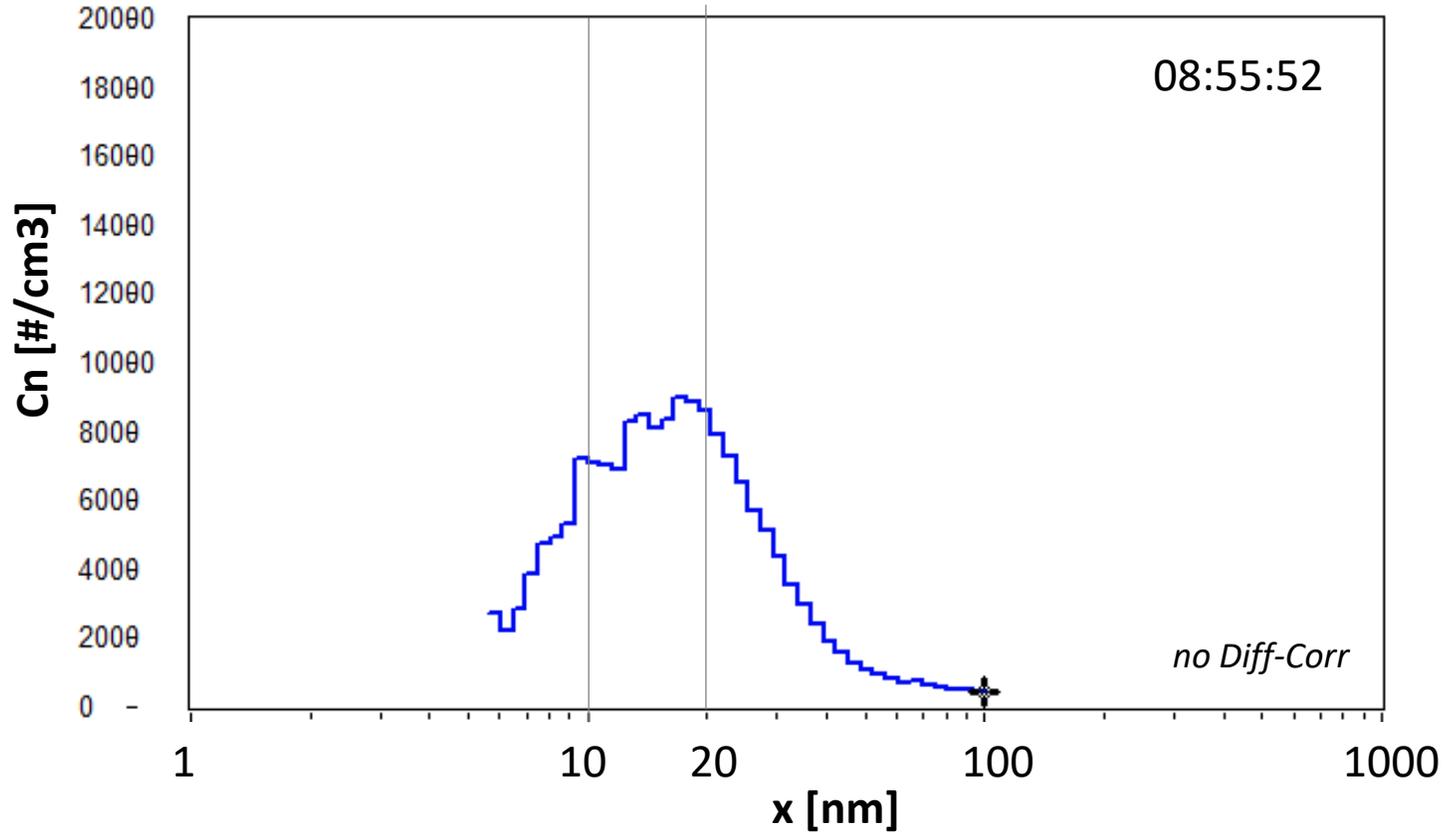
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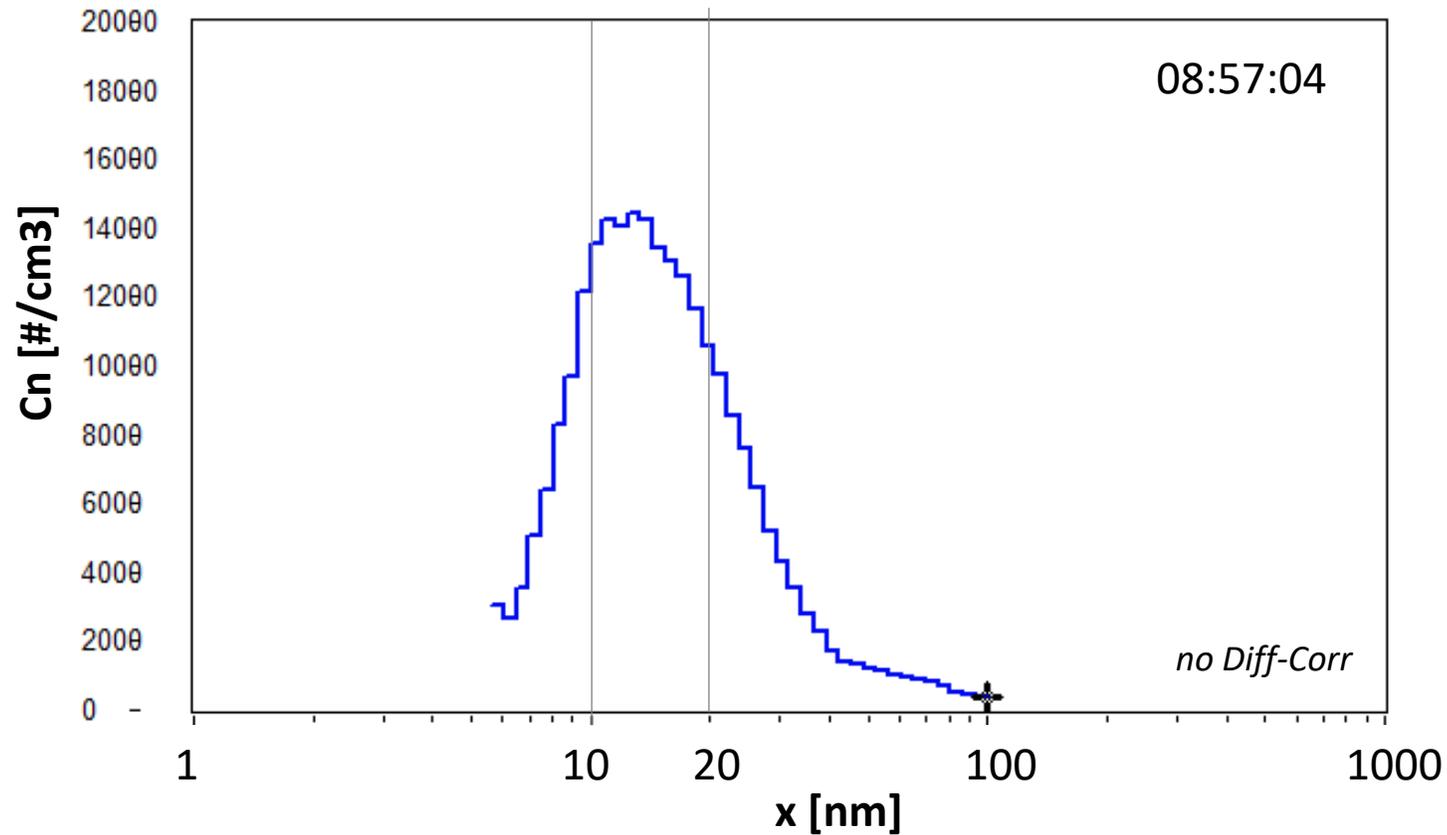
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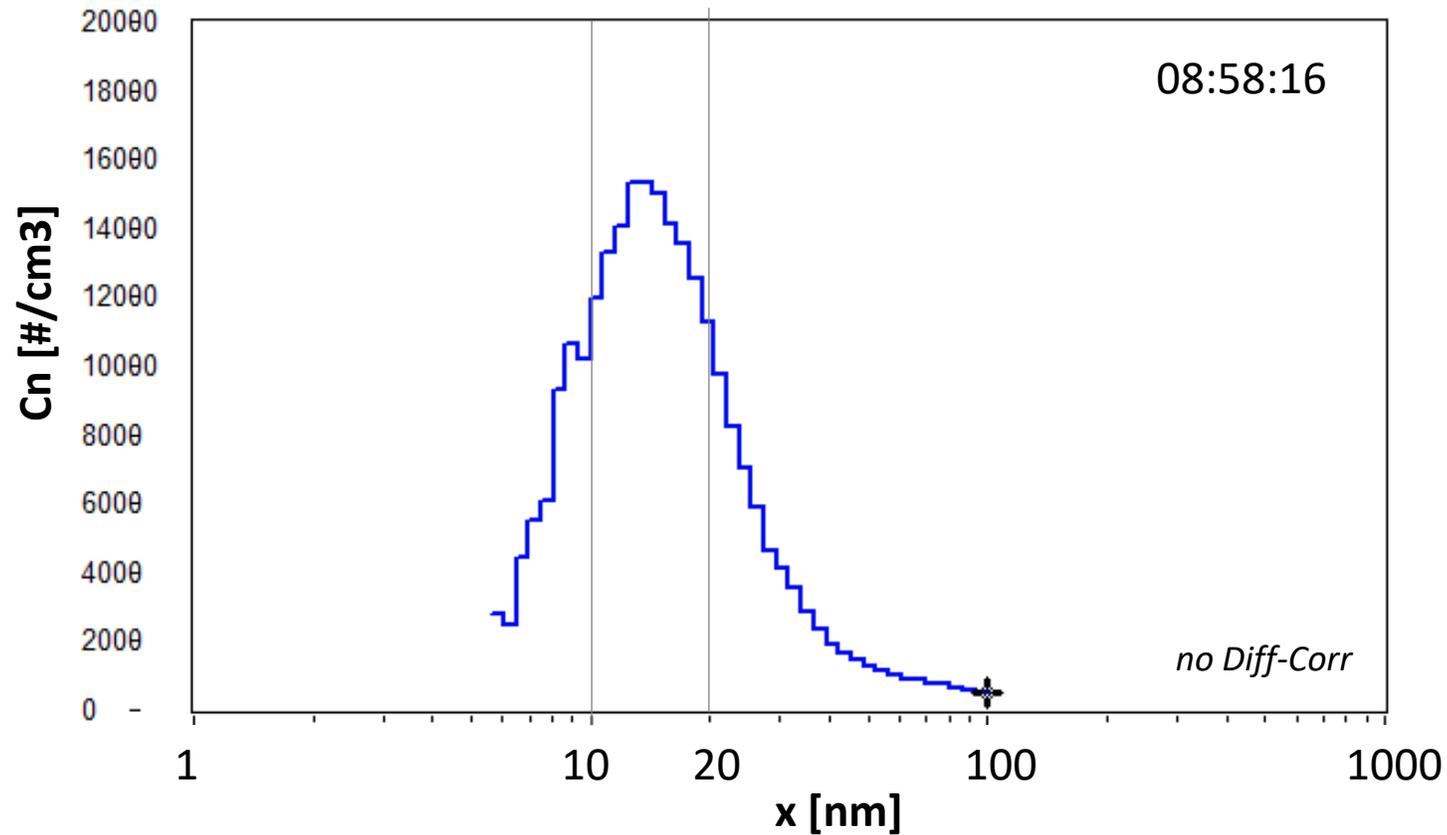
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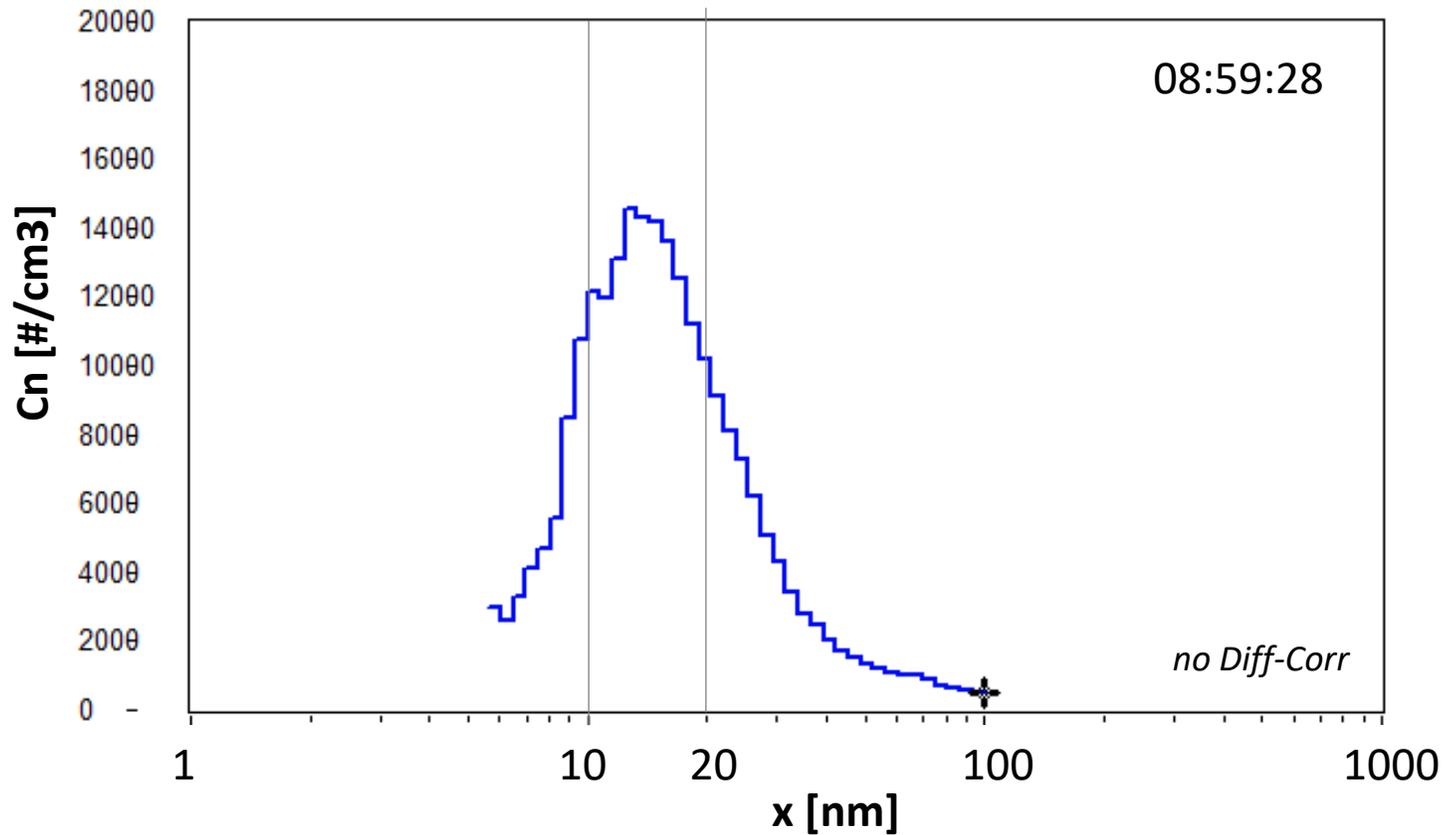
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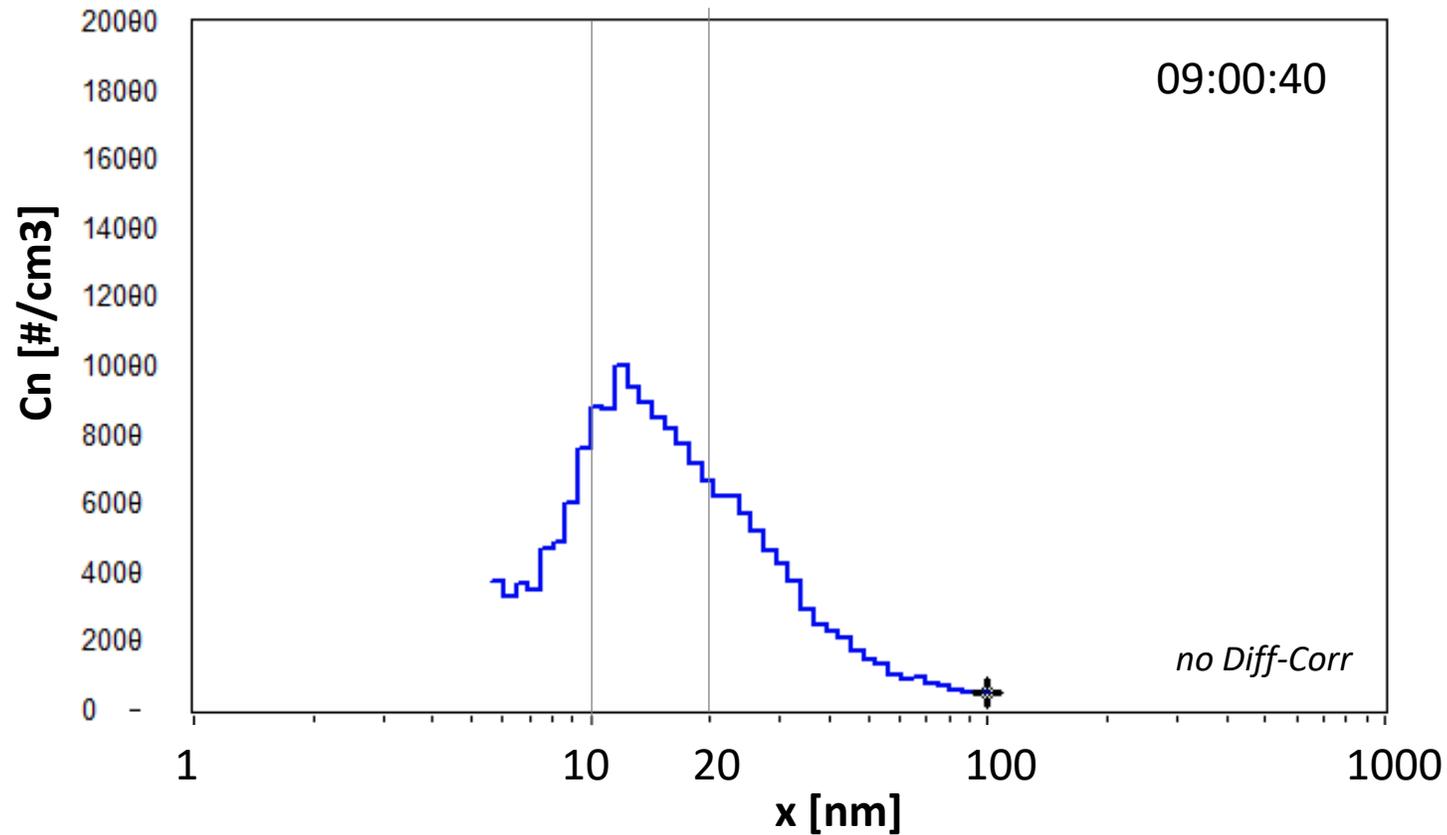
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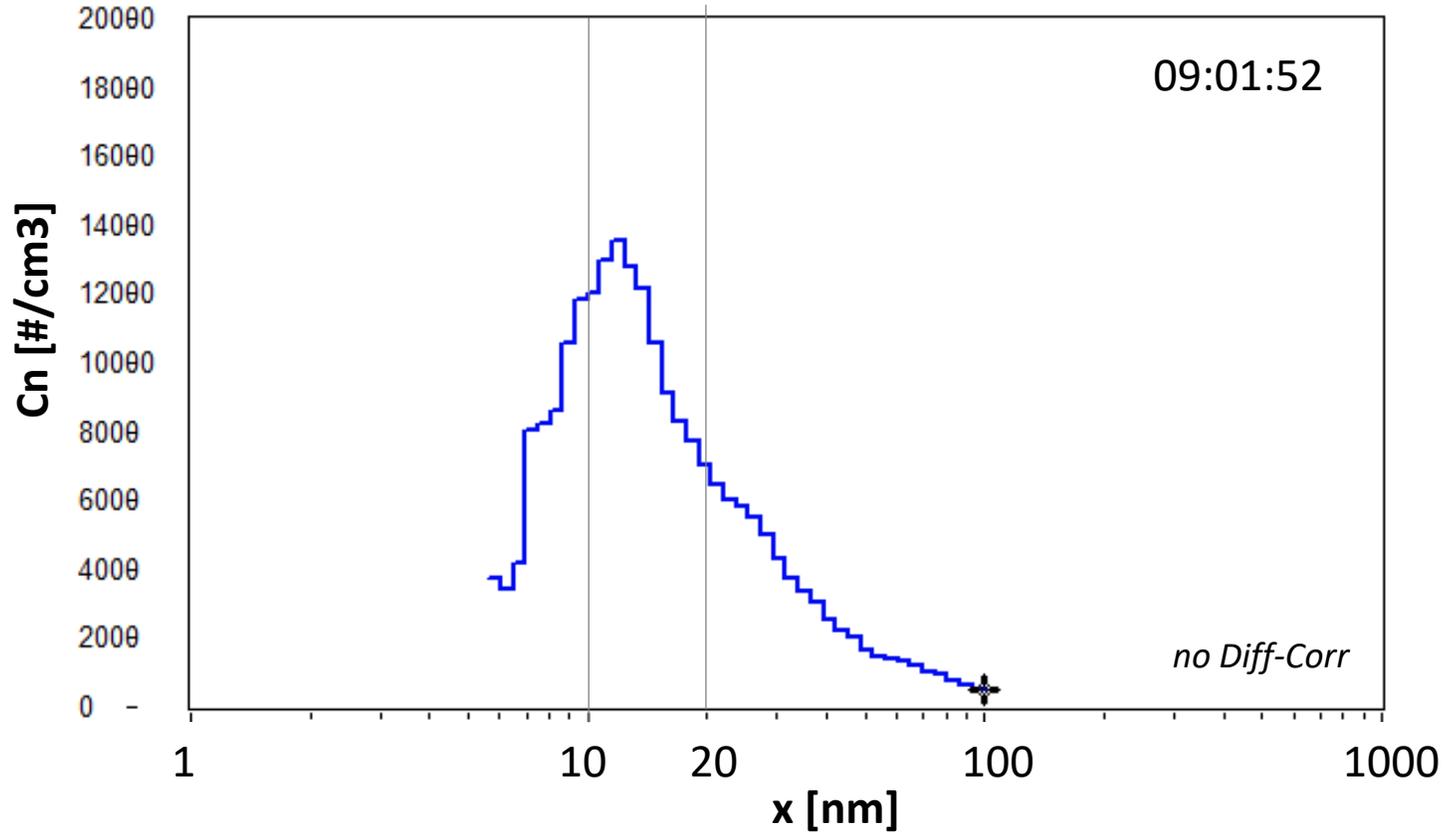
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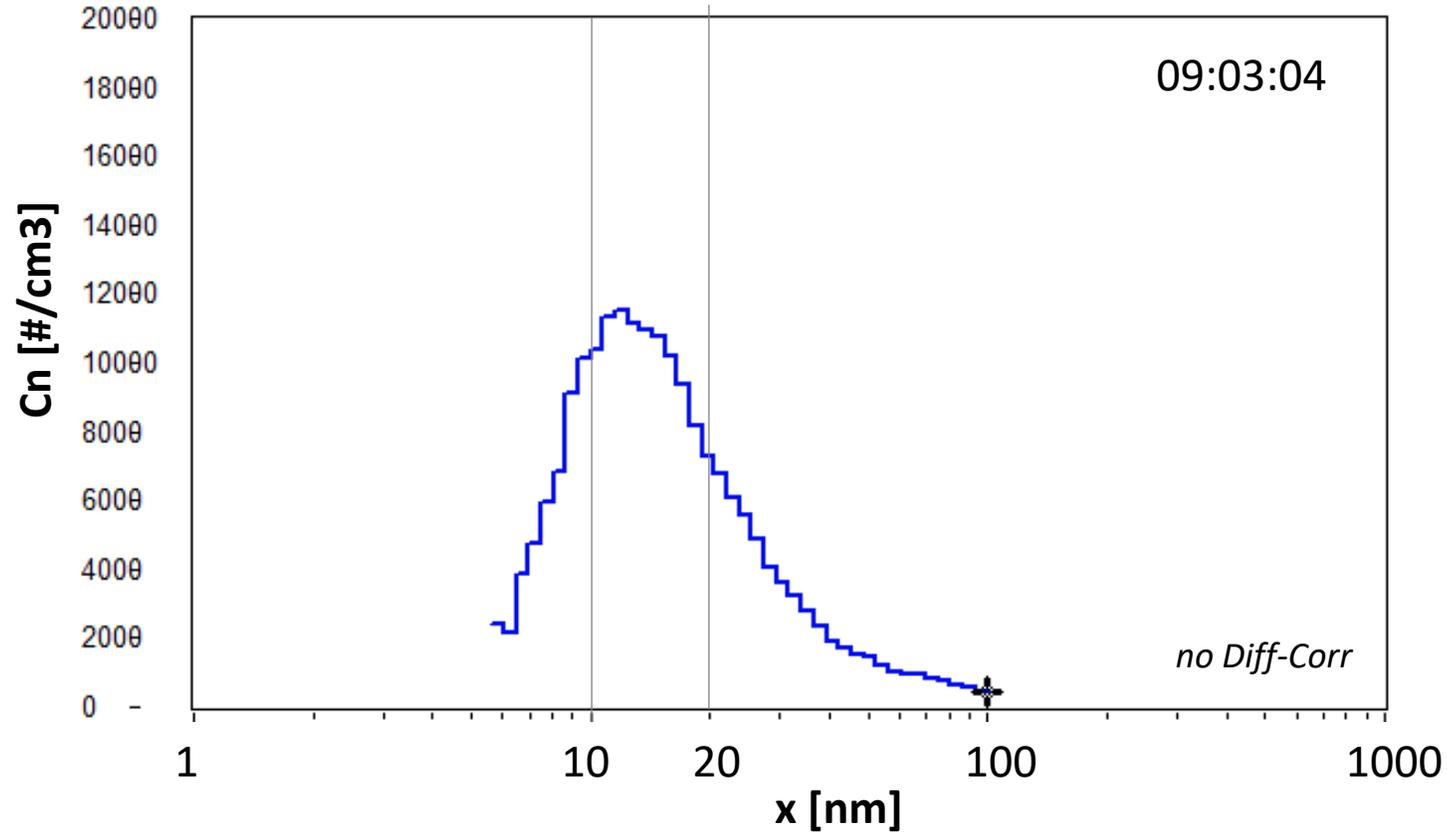
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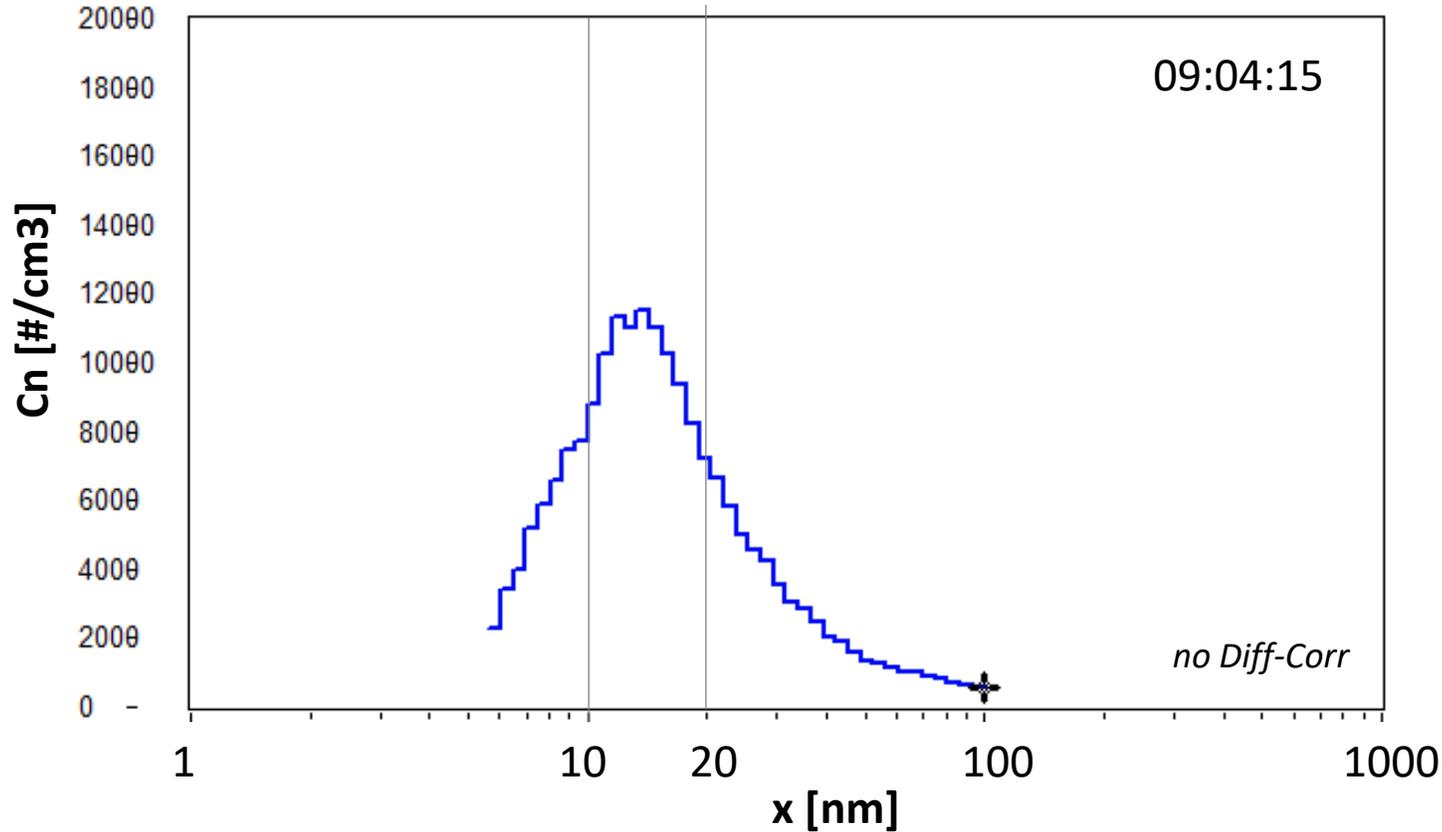
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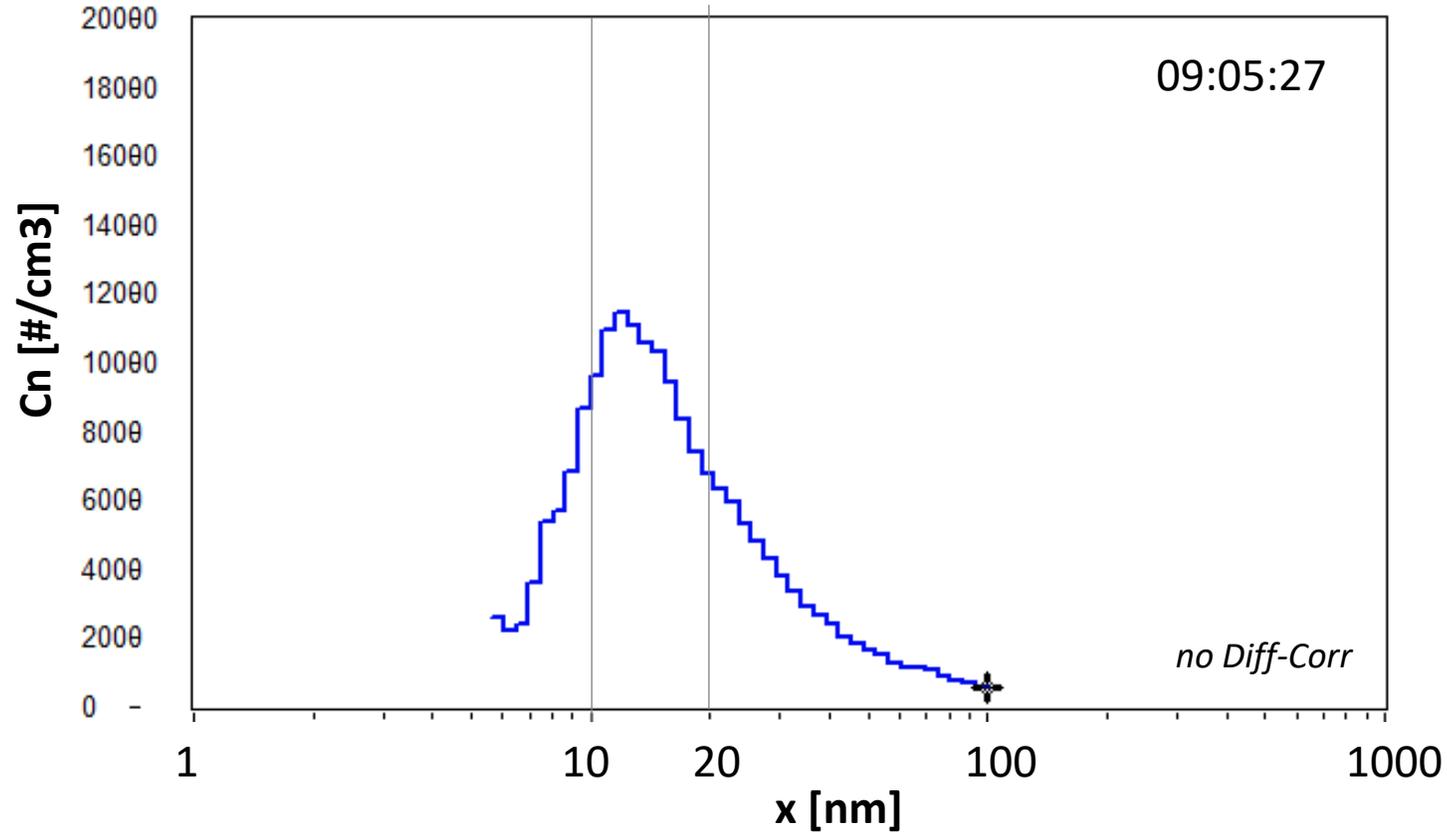
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## UFP monitoring at airport



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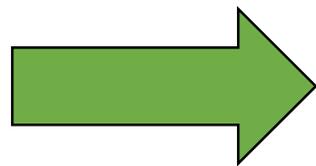
Example data interpretation for one data set:

- Air traffic is clearly visible
- high UFP-fraction < 20 nm → very small particles directly from jet combustion

**but**

**daily average**

	Cn_total [#/ccm] > 7 nm	Cn_total [#/ccm] > 23 nm	
no Diff-Correction	281 000	63 000	4,5x higher
with Diff-Correction	811 000	81 000	10x higher

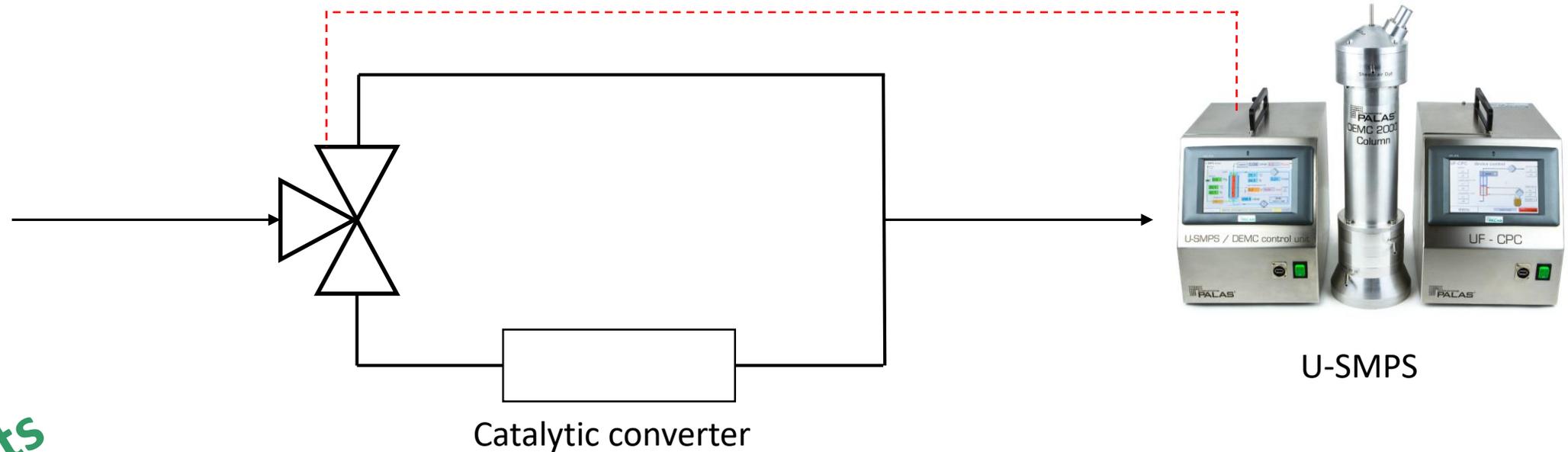


**Quantitative conclusions and comparisons among different sites are critical!**  
**(especially for different measurement systems and different Cutoffs)**

**Going one step further...**

## Going one step further

+ use of built-in AUX port for valve switching

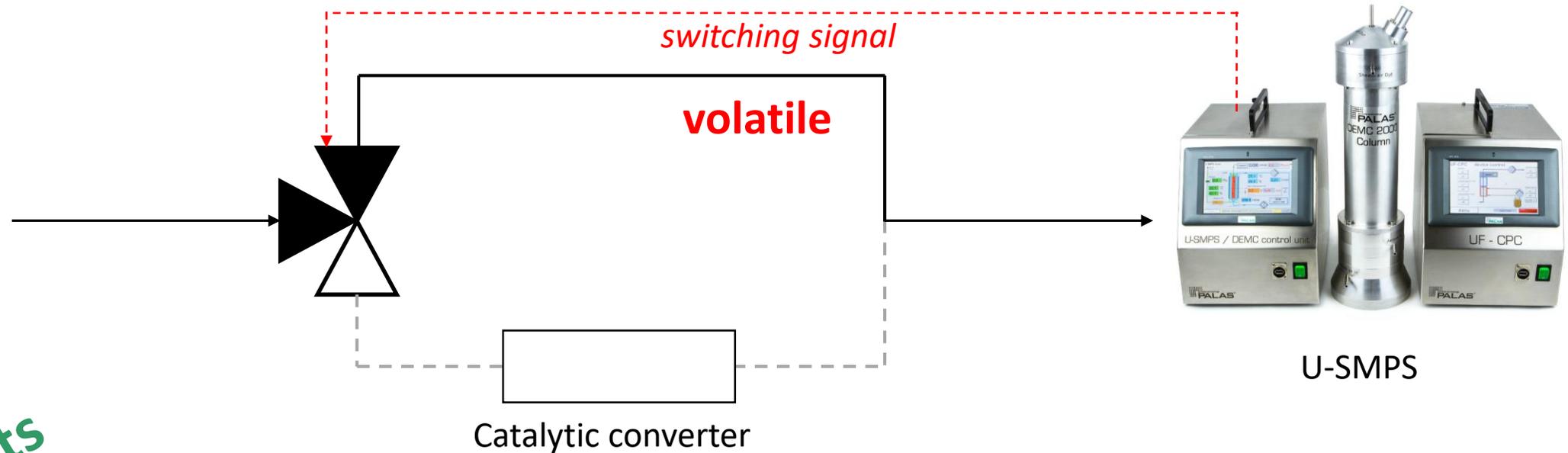


**Benefits**

- differentiate between volatile and semi-volatile compounds

# Unique features of Palas® U-SMPS

+ built-in AUX port for valve switching (digital or analog)

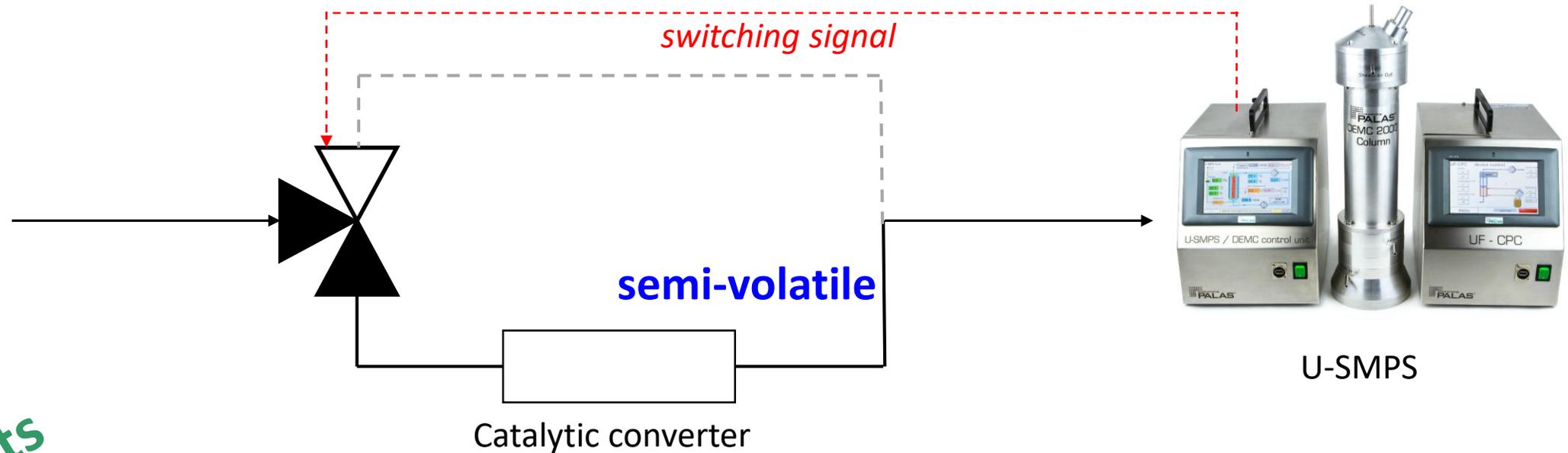


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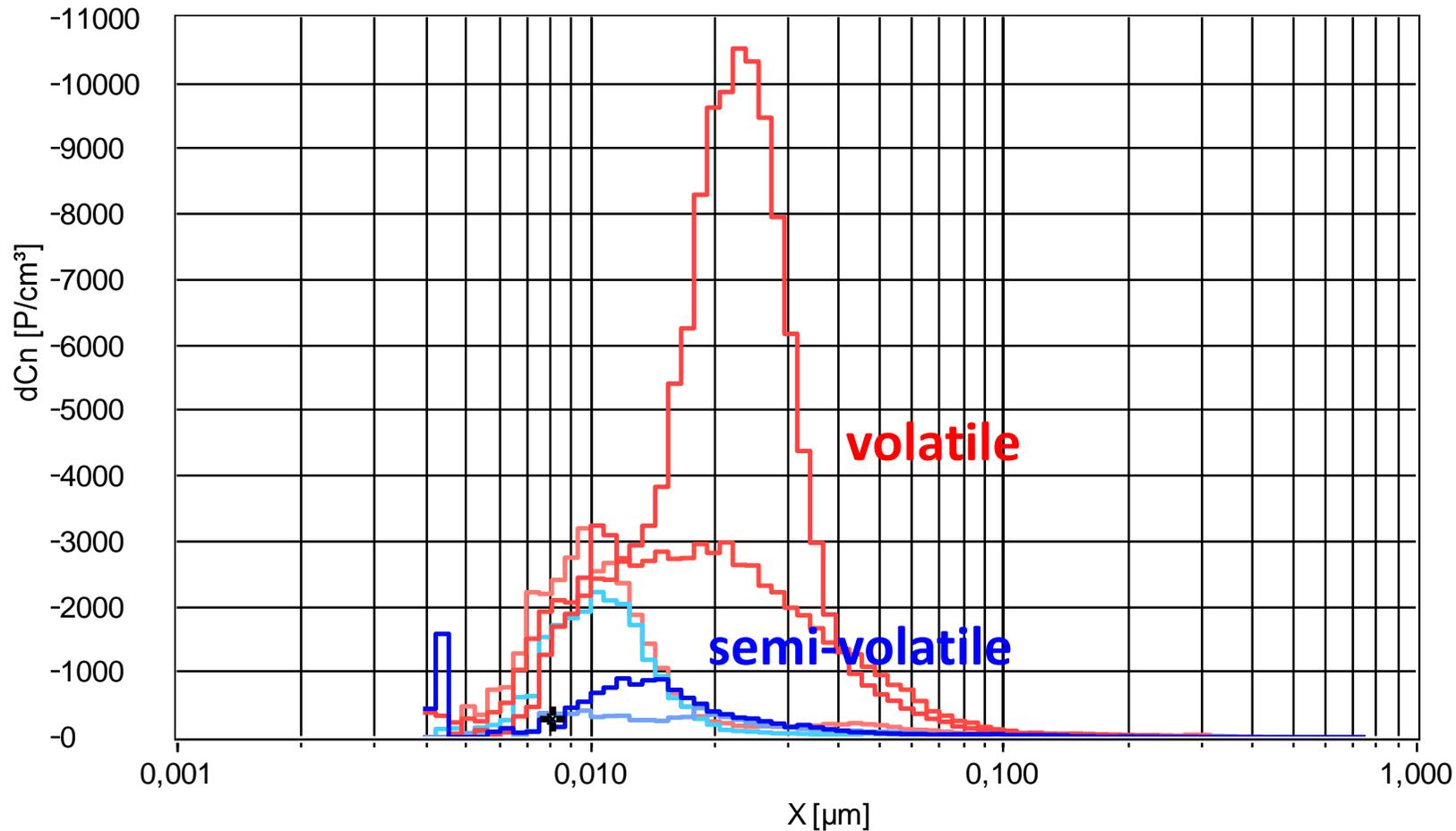
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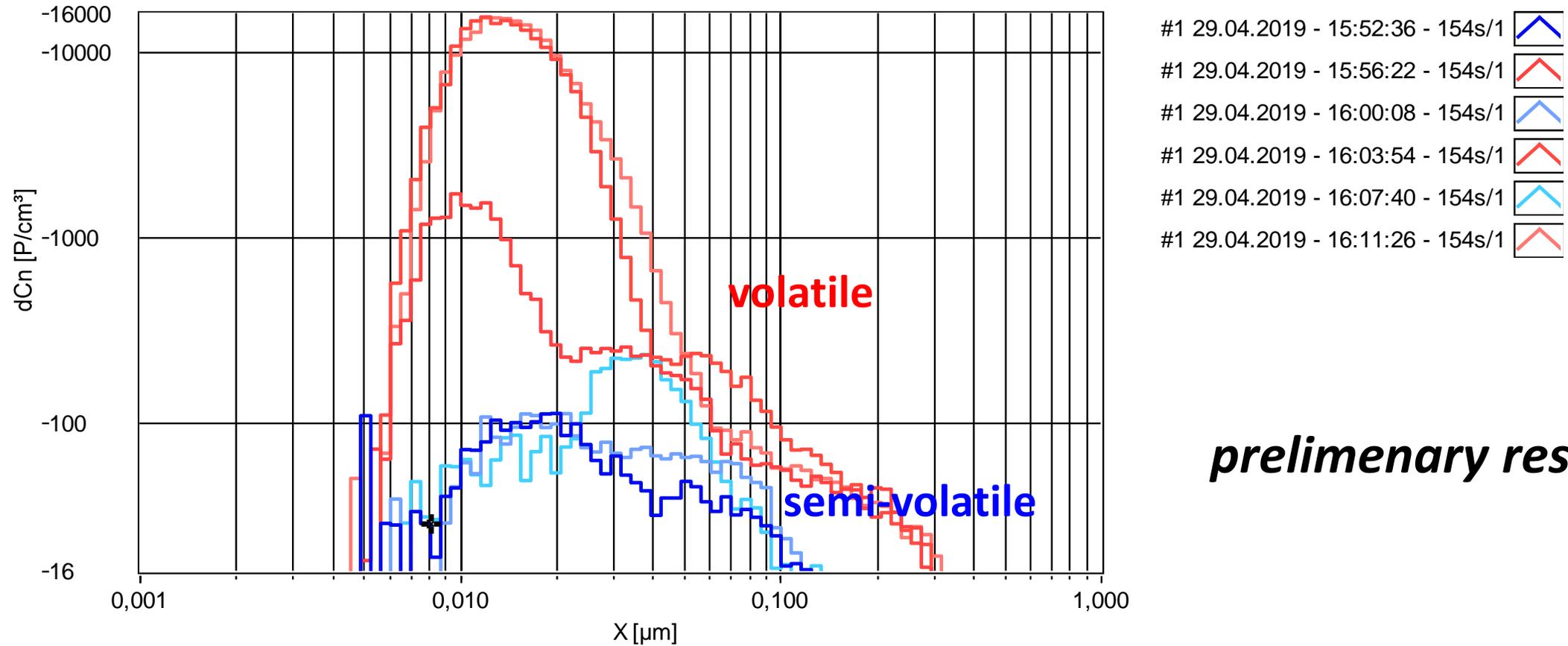


- #1 29.04.2019 - 09:06:10 - 154s/1 
- #1 29.04.2019 - 09:09:56 - 154s/1 
- #1 29.04.2019 - 09:13:42 - 154s/1 
- #1 29.04.2019 - 09:17:27 - 154s/1 
- #1 29.04.2019 - 09:21:13 - 154s/1 
- #1 29.04.2019 - 09:24:59 - 154s/1 

*preliminary results*



size range <30nm is dominated by volatile particles



*preliminary results*

 size range <30nm is dominated by volatile particles

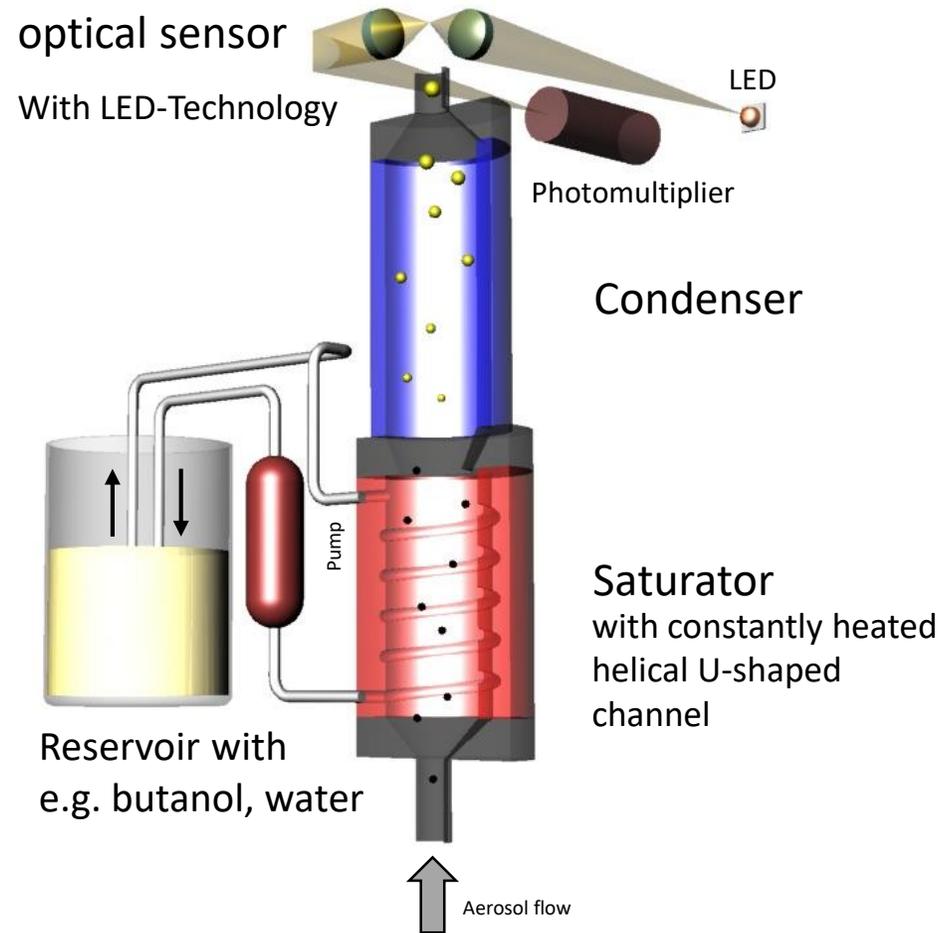
Down to... pushing the limits

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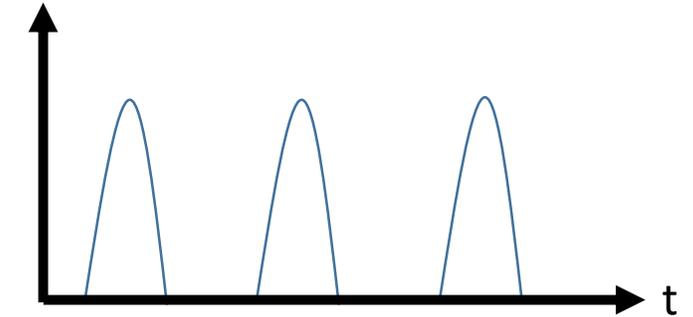


***“There’s Plenty of Room at the Bottom”***  
**(Richard Feynman, 1959)**

# Condensation Particle Counter



droplet detection



CPC counts single light pulses  
 $dN/dt$



**Total Number Concentration**  
 $c_N$  : Particles/cm<sup>3</sup>

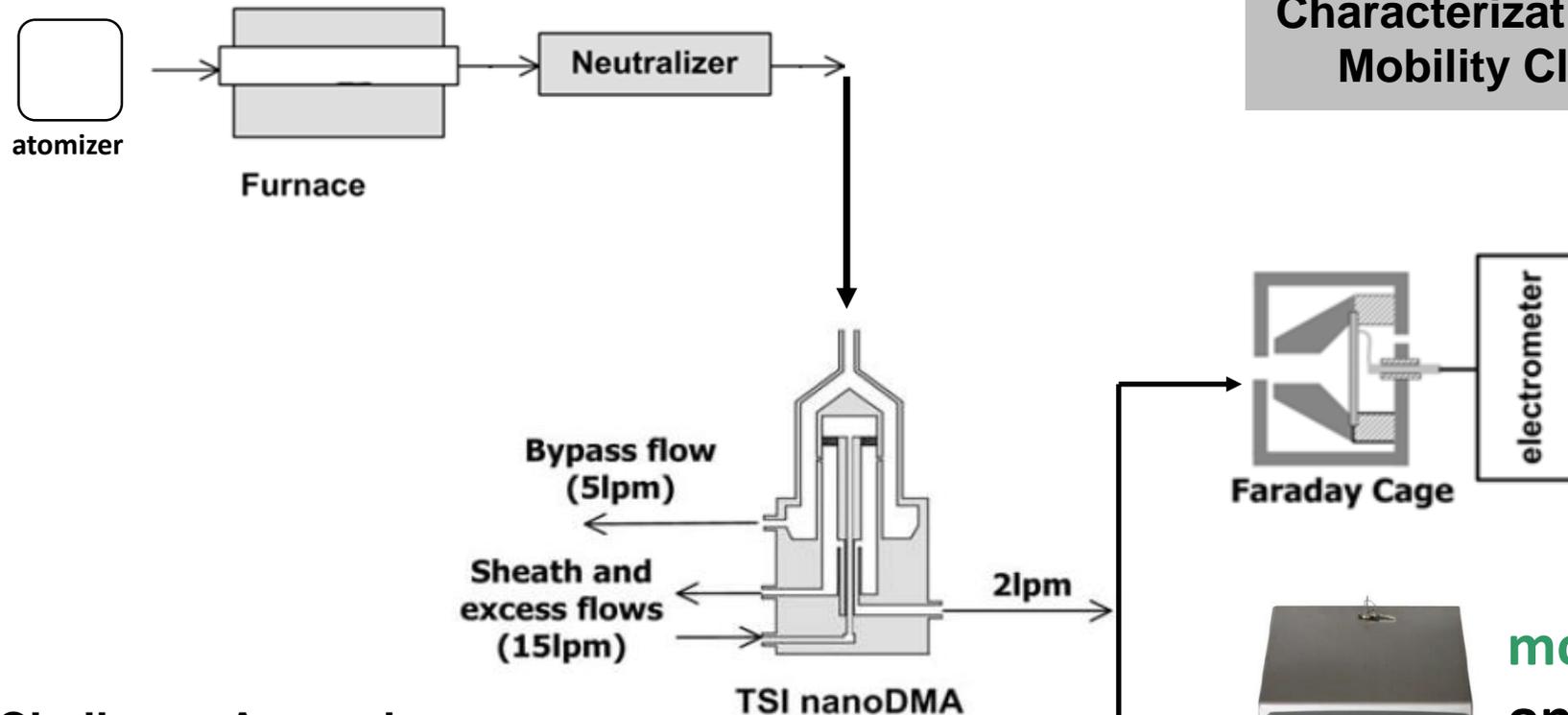
*No particle size can be obtained !*



• (nano)particle

# Down to...10nm...1nm

Slides taken from: presentation C.Kuang, AAAR conference 2016 + 2017



Characterization Schematic with Mobility Classified Aerosol

## Challenge Aerosols

- ammonium sulfate (+, -)
- neutralizer ions (+, -)

modified Palas® UF-CPC  
operated with DEG  
Di-ethylene-glycol

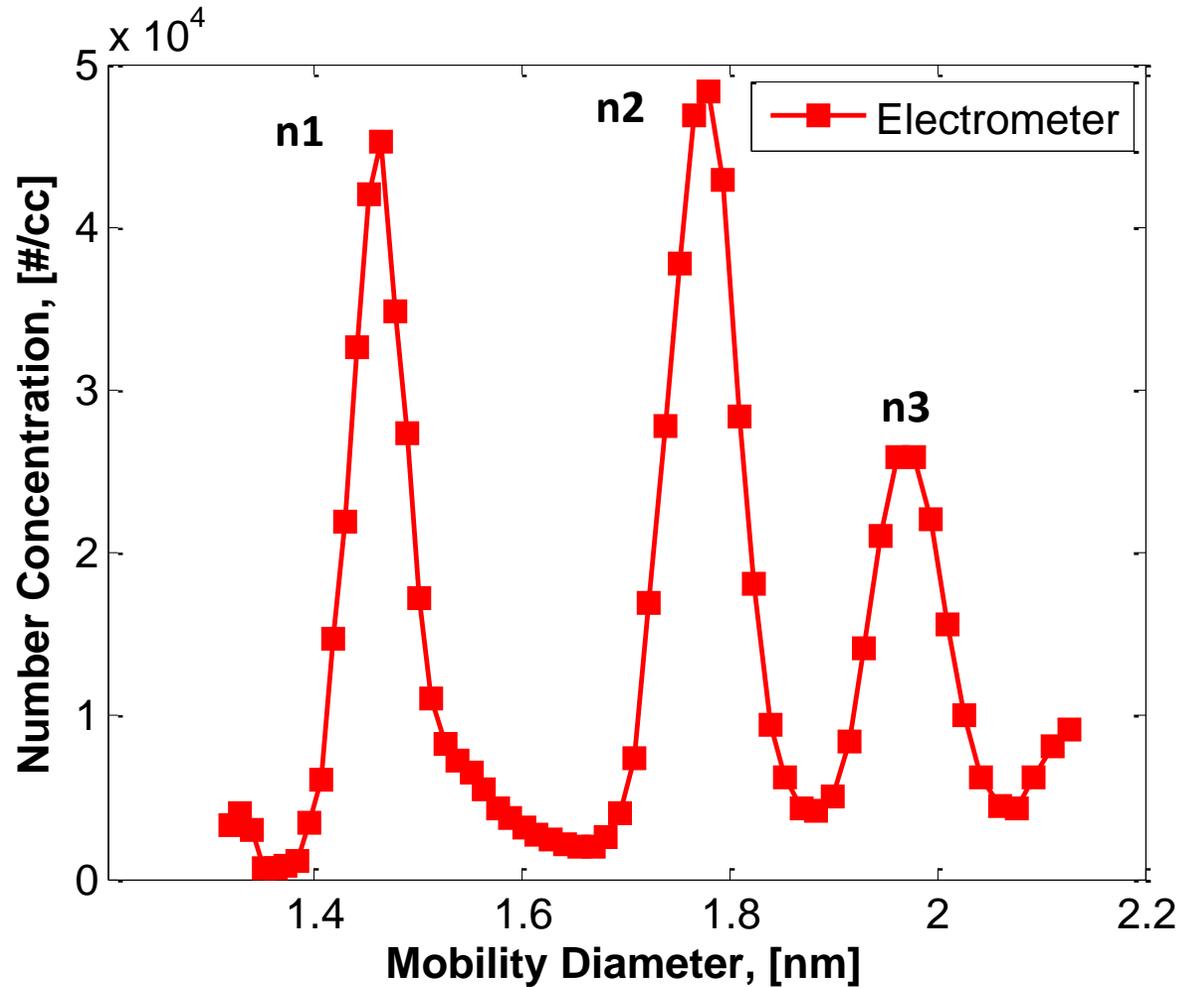
\*Adapted from Jiang, J., et al. (2011). Electrical Mobility Spectrometer Using a Diethylene Glycol Condensation Particle Counter for Measurement of Aerosol Size Distributions Down to 1 nm. *Aerosol Sci. Technol.* 45:510 - 5

# Down to...

Slides taken from: presentation C.Kuang, AAR conference 2016 + 2017

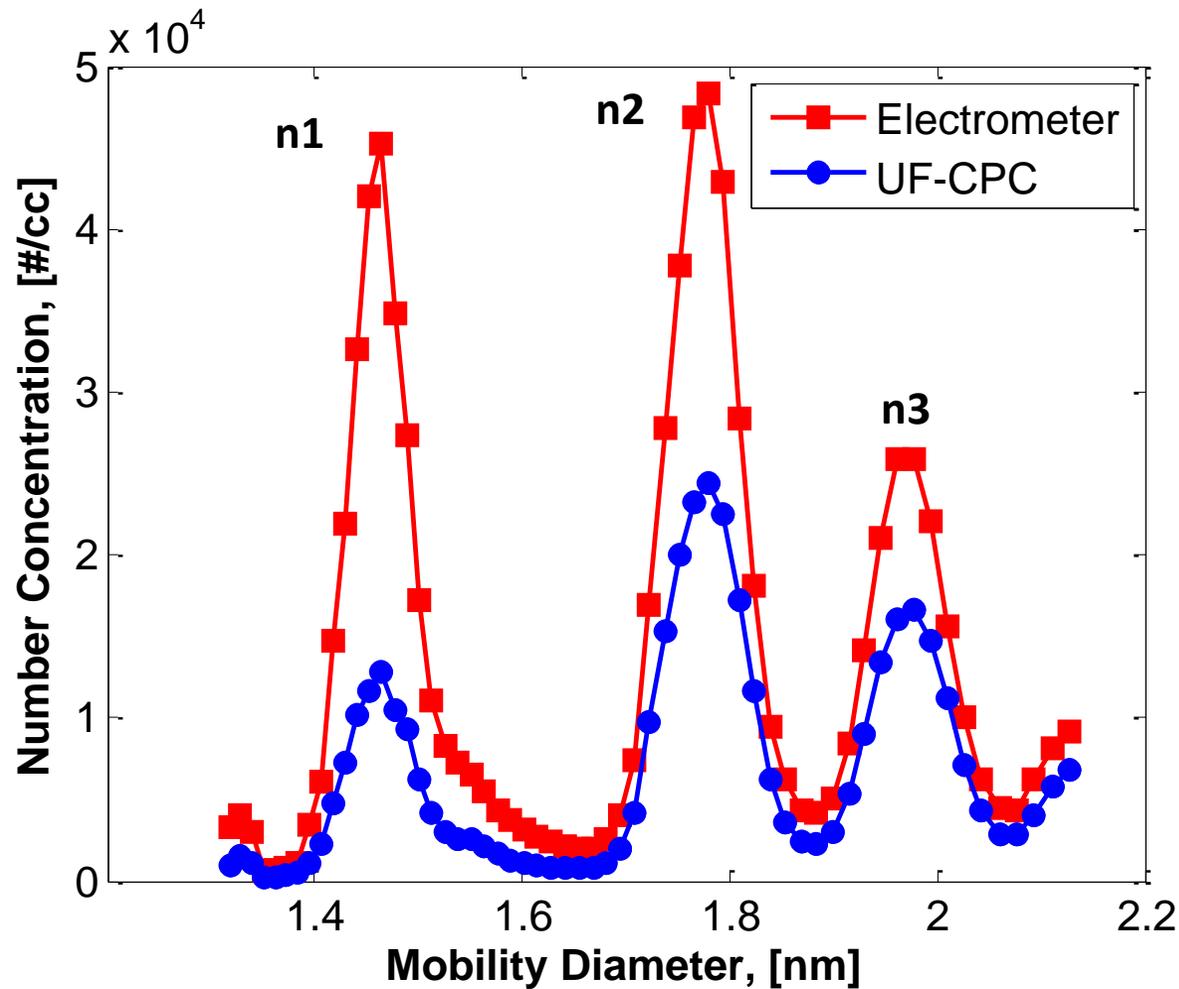
**Ion Mobility Standard:  
HRDMA Calibration**

Tetra-heptyl ammonium bromide (THAB)  
 $[\text{CH}_3(\text{CH}_2)_6]_4\text{N}(\text{Br})$



# Down to...

Slides taken from: presentation C.Kuang, AAAR conference 2016 + 2017

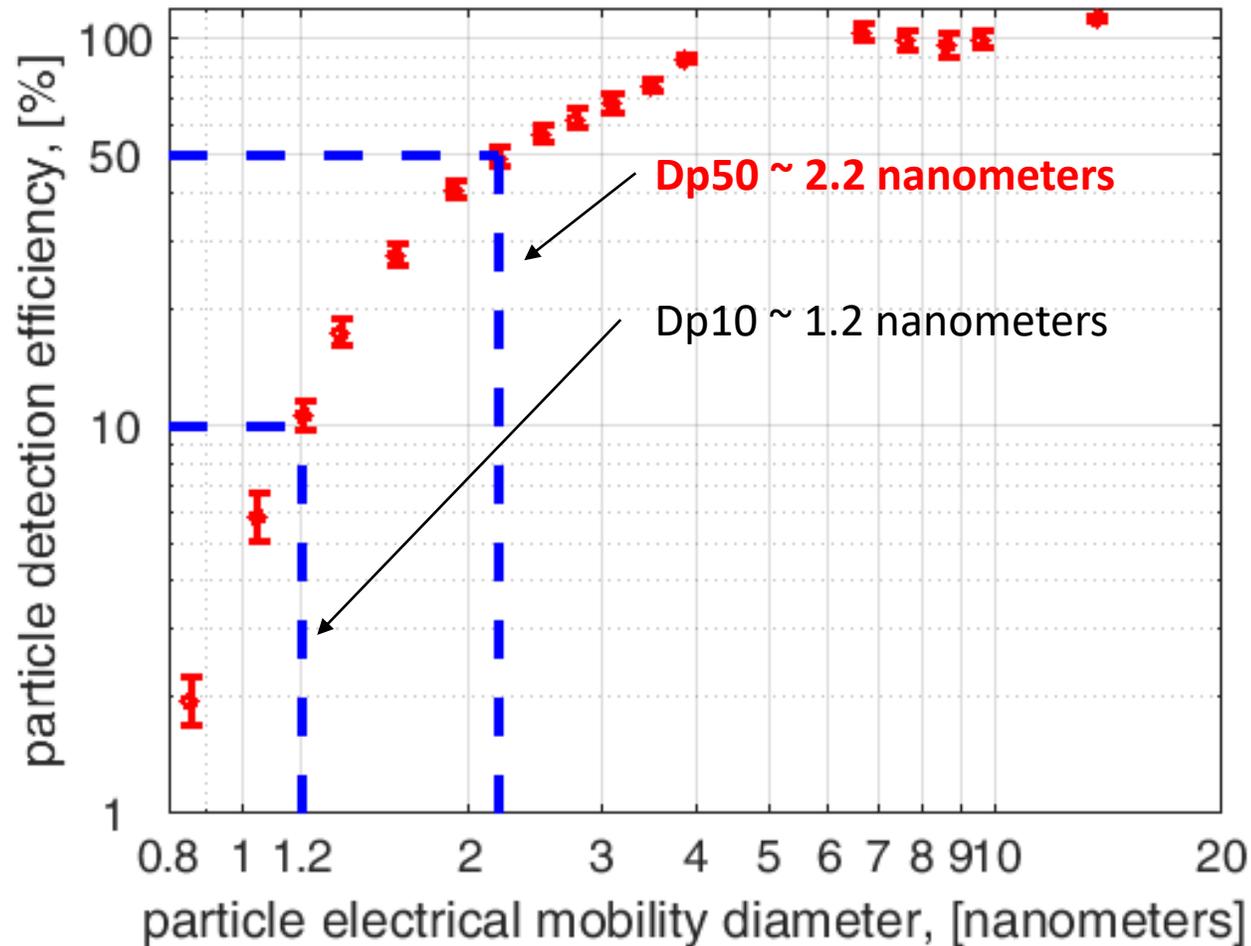


**Ion Mobility Standard:  
HRDMA Calibration**

Tetra-heptyl ammonium bromide (THAB)  
 $[\text{CH}_3(\text{CH}_2)_6]_4\text{N}(\text{Br})$

- UF-CPC operated with DEG enables for Cluster detection down to 1.47 nm

# Down to...1nm

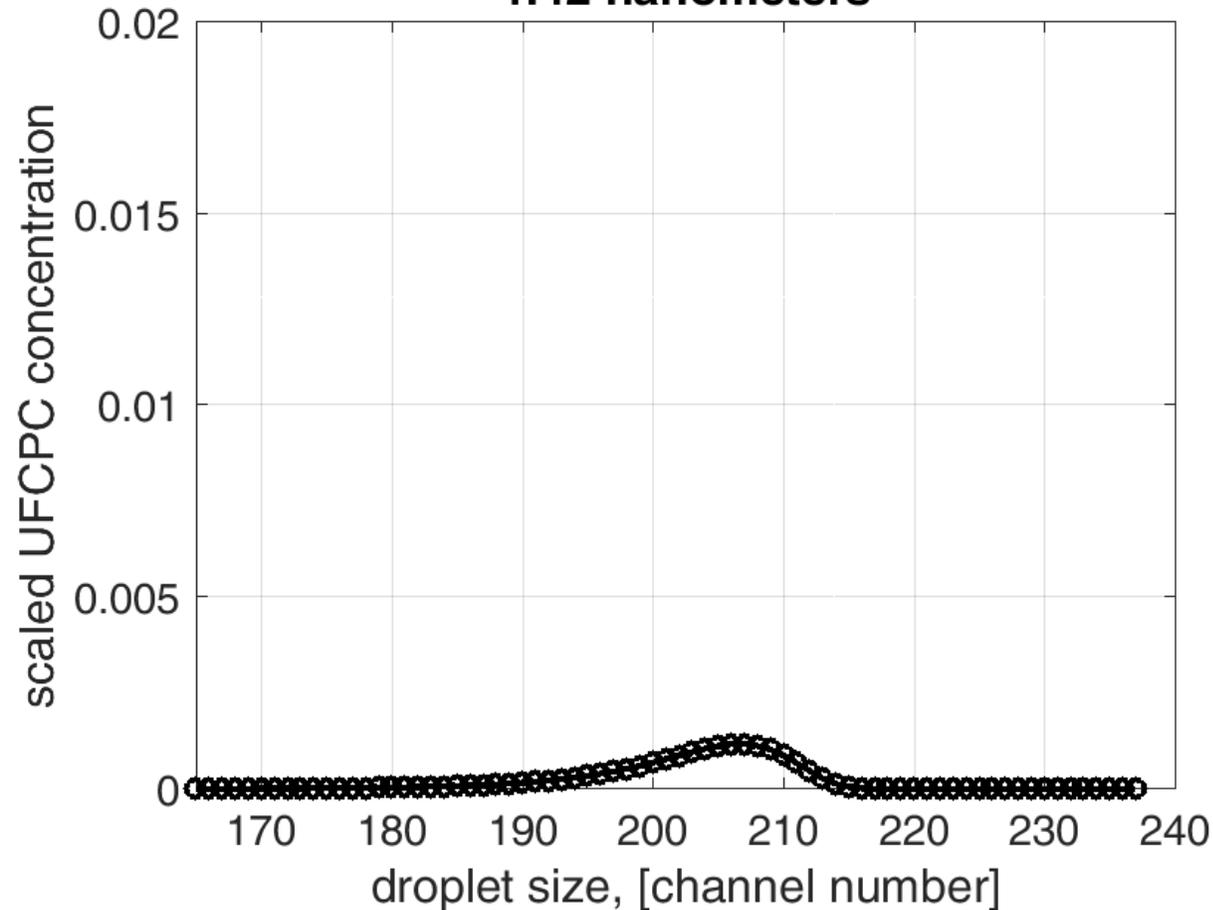


## Ammonium Sulfate Calibration: Detection Efficiency

- Negatively charged ammonium sulfate
- UF-CPC operating temperatures: **55C/10C** (saturator/condenser)
- tuned optics

# Down to...

1.42 nanometers



**Ammonium Sulfate Calibration:  
Droplet Size As a Function of Initial Size**

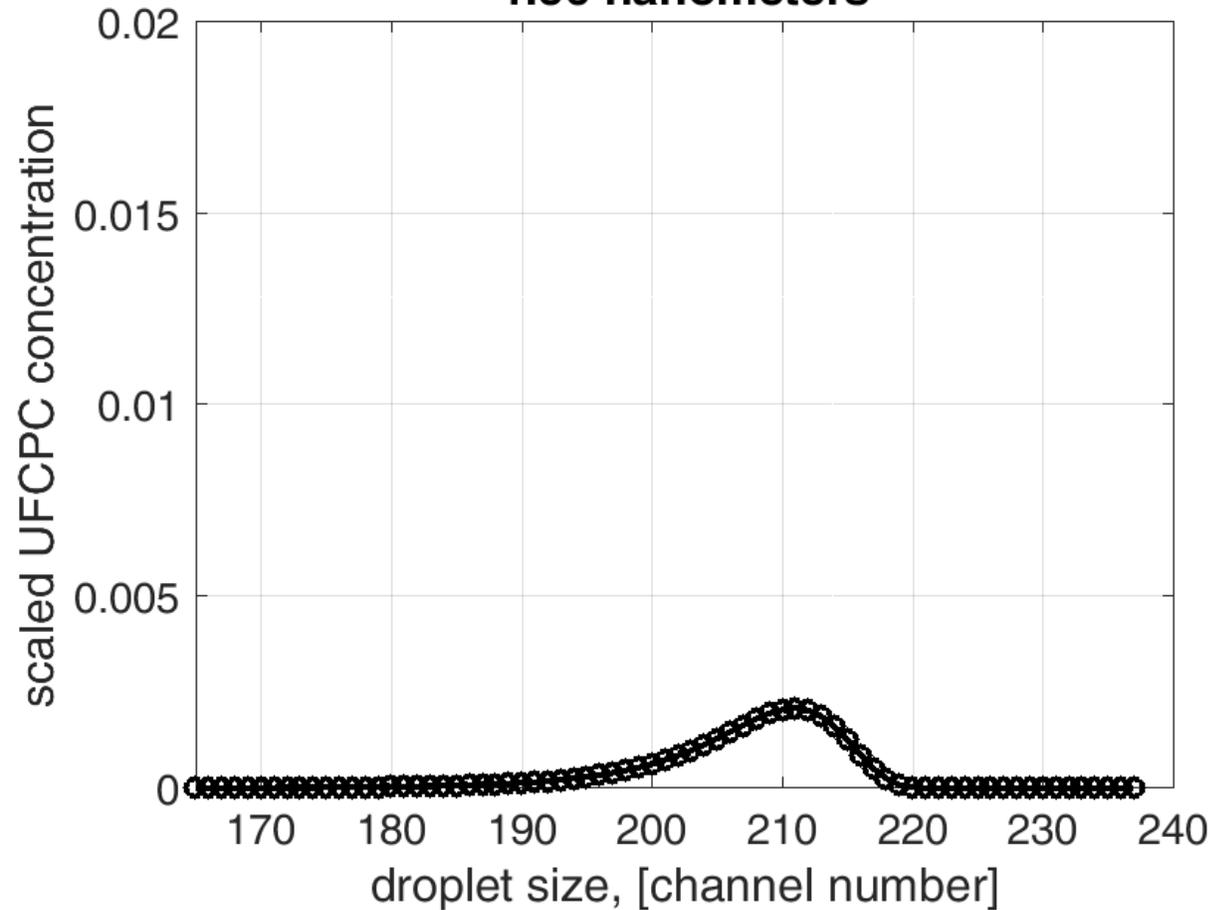
Tuned optics: setup 2

**Use of tuned photomultiplier settings  
and optic setup to detect droplet size  
distribution**

- Chongai Kuang (2018): A Diethylene Glycol Condensation Particle Counter for Rapid Sizing of sub-3 nm Atmospheric Clusters, Aerosol Science and Technology, DOI:10.1080/02786826.2018.1481279

# Down to...

1.56 nanometers



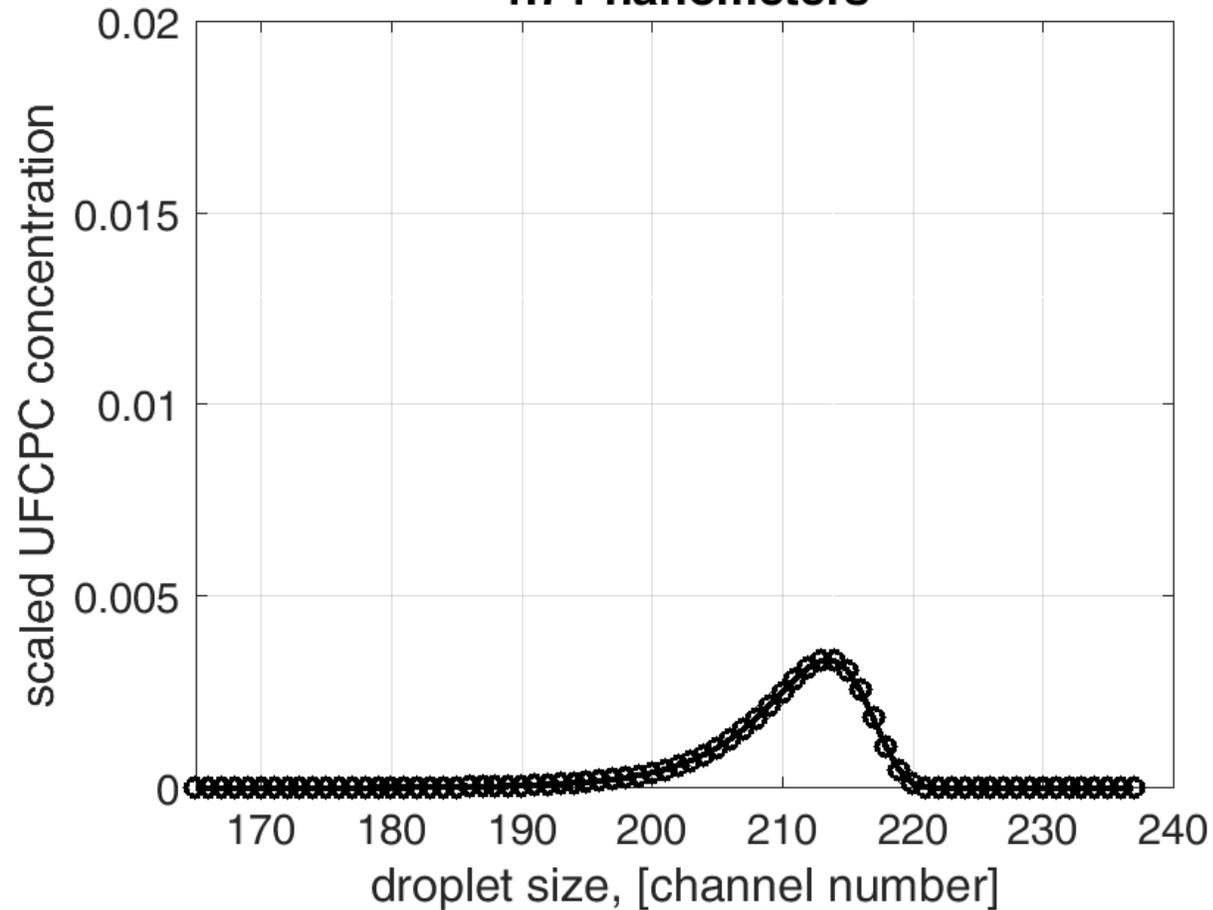
**Ammonium Sulfate Calibration:  
Droplet Size As a Function of Initial Size**

optics: setup 2

- Chongai Kuang (2018): A Diethylene Glycol Condensation Particle Counter for Rapid Sizing of sub-3 nm Atmospheric Clusters, Aerosol Science and Technology, DOI:10.1080/02786826.2018.1481279

# Down to...

1.71 nanometers



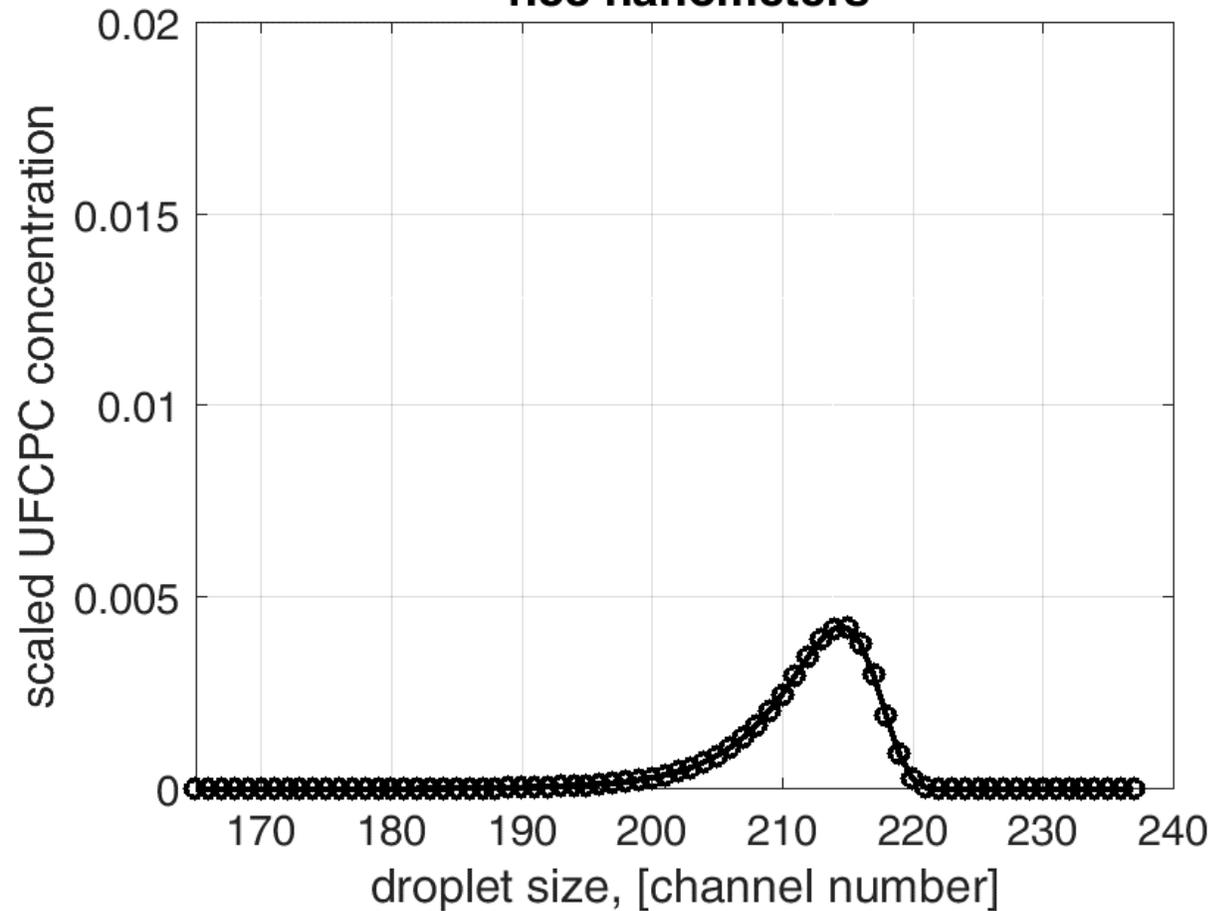
**Ammonium Sulfate Calibration:  
Droplet Size As a Function of Initial Size**

optics: setup 2

- Chongai Kuang (2018): A Diethylene Glycol Condensation Particle Counter for Rapid Sizing of sub-3 nm Atmospheric Clusters, Aerosol Science and Technology, DOI:10.1080/02786826.2018.1481279

# Down to...

1.88 nanometers



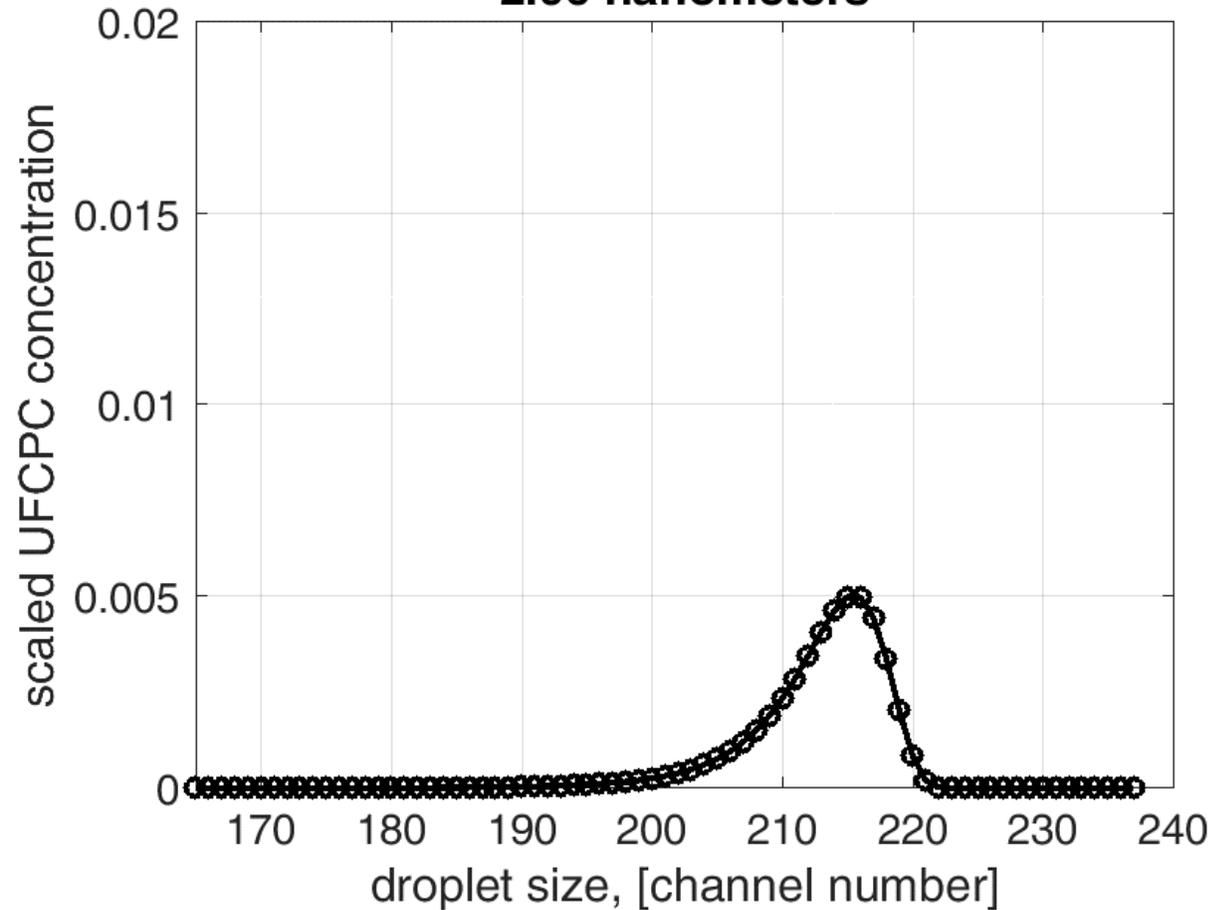
**Ammonium Sulfate Calibration:  
Droplet Size As a Function of Initial Size**

optics: setup 2

- Chongai Kuang (2018): A Diethylene Glycol Condensation Particle Counter for Rapid Sizing of sub-3 nm Atmospheric Clusters, Aerosol Science and Technology, DOI:10.1080/02786826.2018.1481279

# Down to...

2.06 nanometers



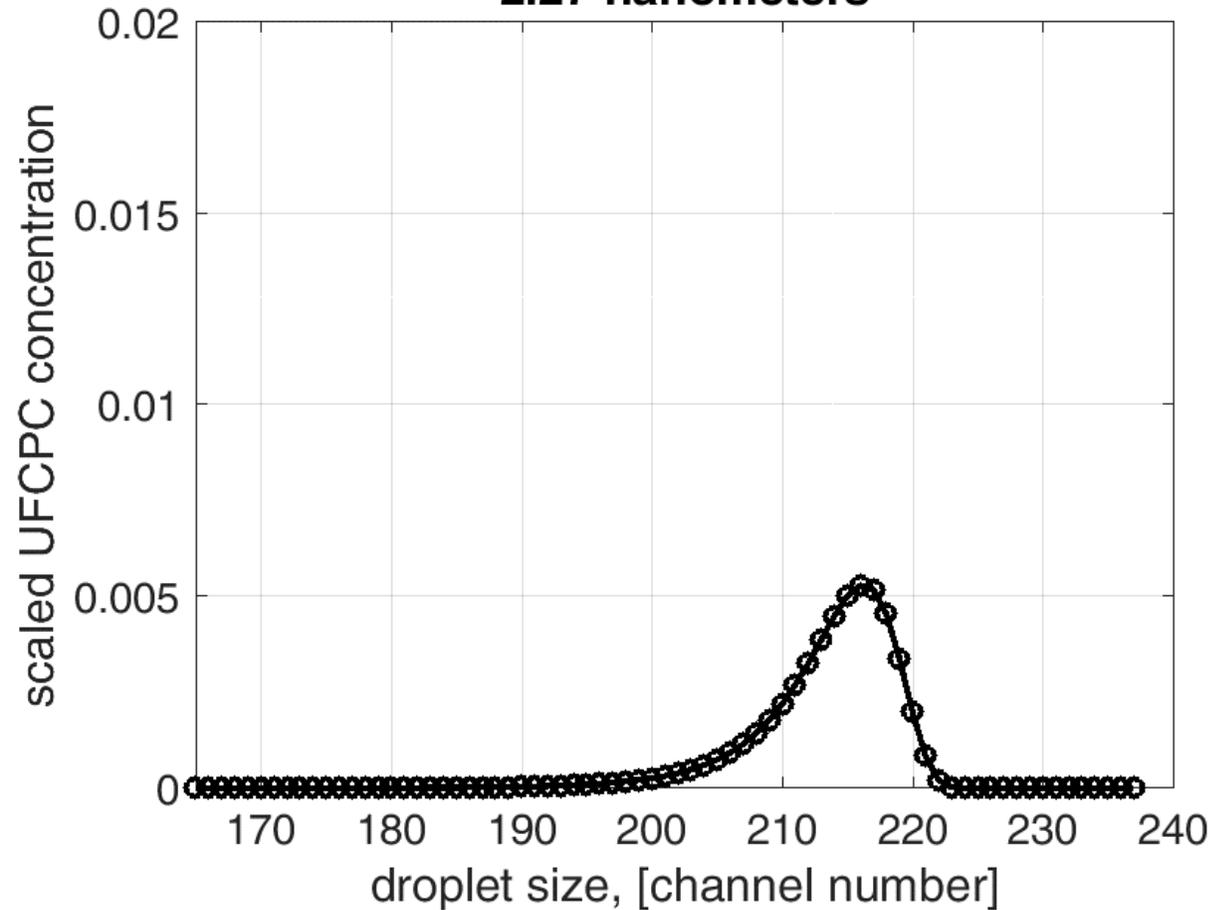
**Ammonium Sulfate Calibration:  
Droplet Size As a Function of Initial Size**

optics: setup 2

- Chongai Kuang (2018): A Diethylene Glycol Condensation Particle Counter for Rapid Sizing of sub-3 nm Atmospheric Clusters, Aerosol Science and Technology, DOI:10.1080/02786826.2018.1481279

# Down to...

**2.27 nanometers**



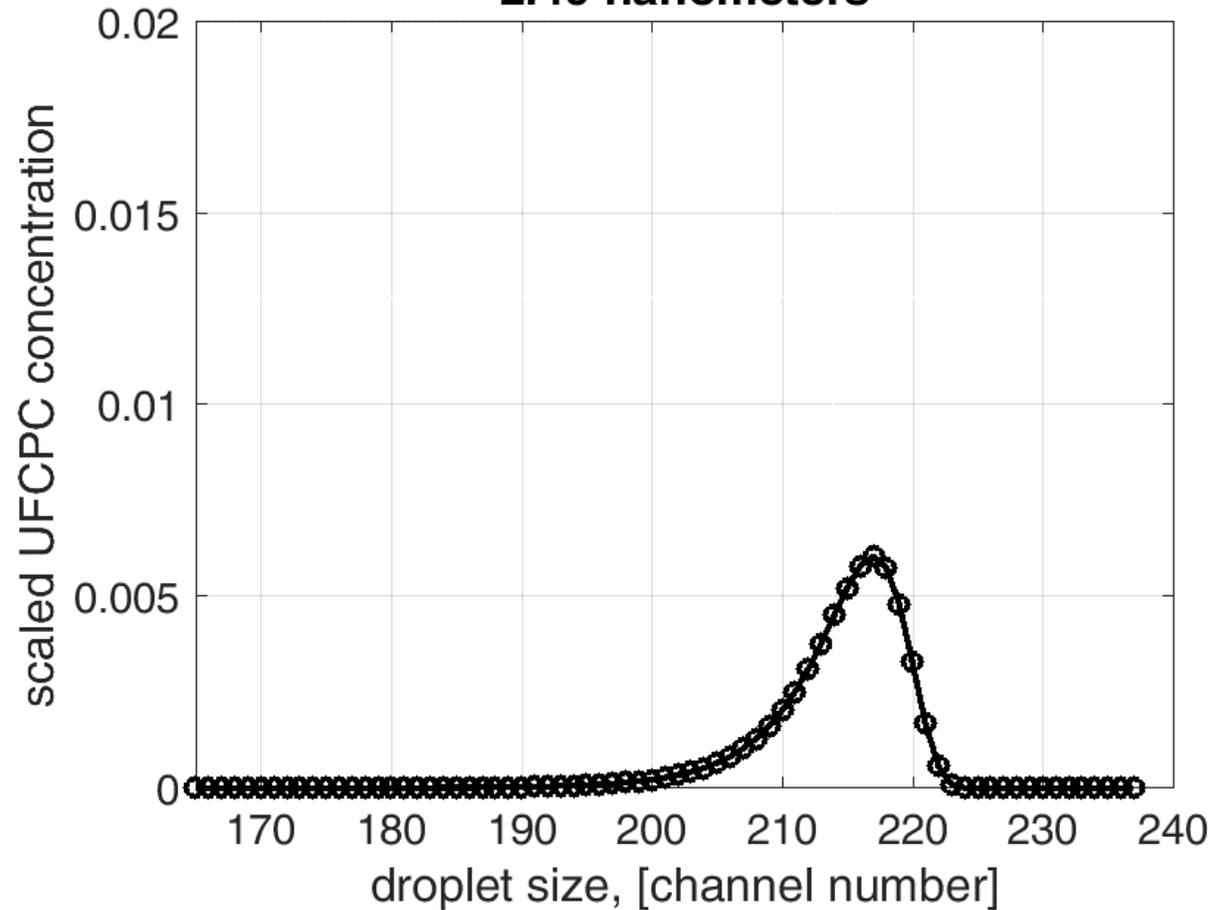
**Ammonium Sulfate Calibration:  
Droplet Size As a Function of Initial Size**

optics: setup 2

- Chongai Kuang (2018): A Diethylene Glycol Condensation Particle Counter for Rapid Sizing of sub-3 nm Atmospheric Clusters, Aerosol Science and Technology, DOI:10.1080/02786826.2018.1481279

# Down to...

2.49 nanometers



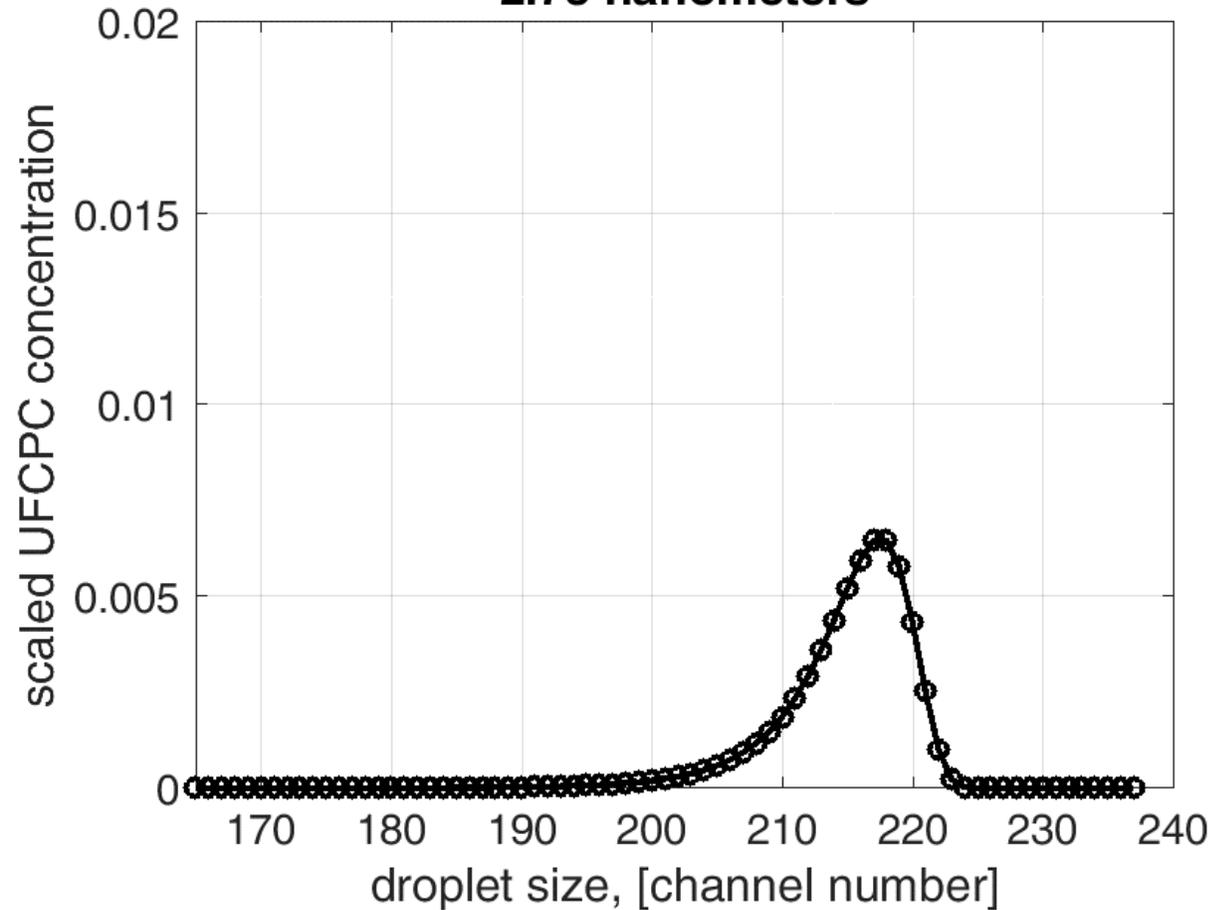
**Ammonium Sulfate Calibration:  
Droplet Size As a Function of Initial Size**

optics: setup 2

- Chongai Kuang (2018): A Diethylene Glycol Condensation Particle Counter for Rapid Sizing of sub-3 nm Atmospheric Clusters, Aerosol Science and Technology, DOI:10.1080/02786826.2018.1481279

# Down to...

2.73 nanometers

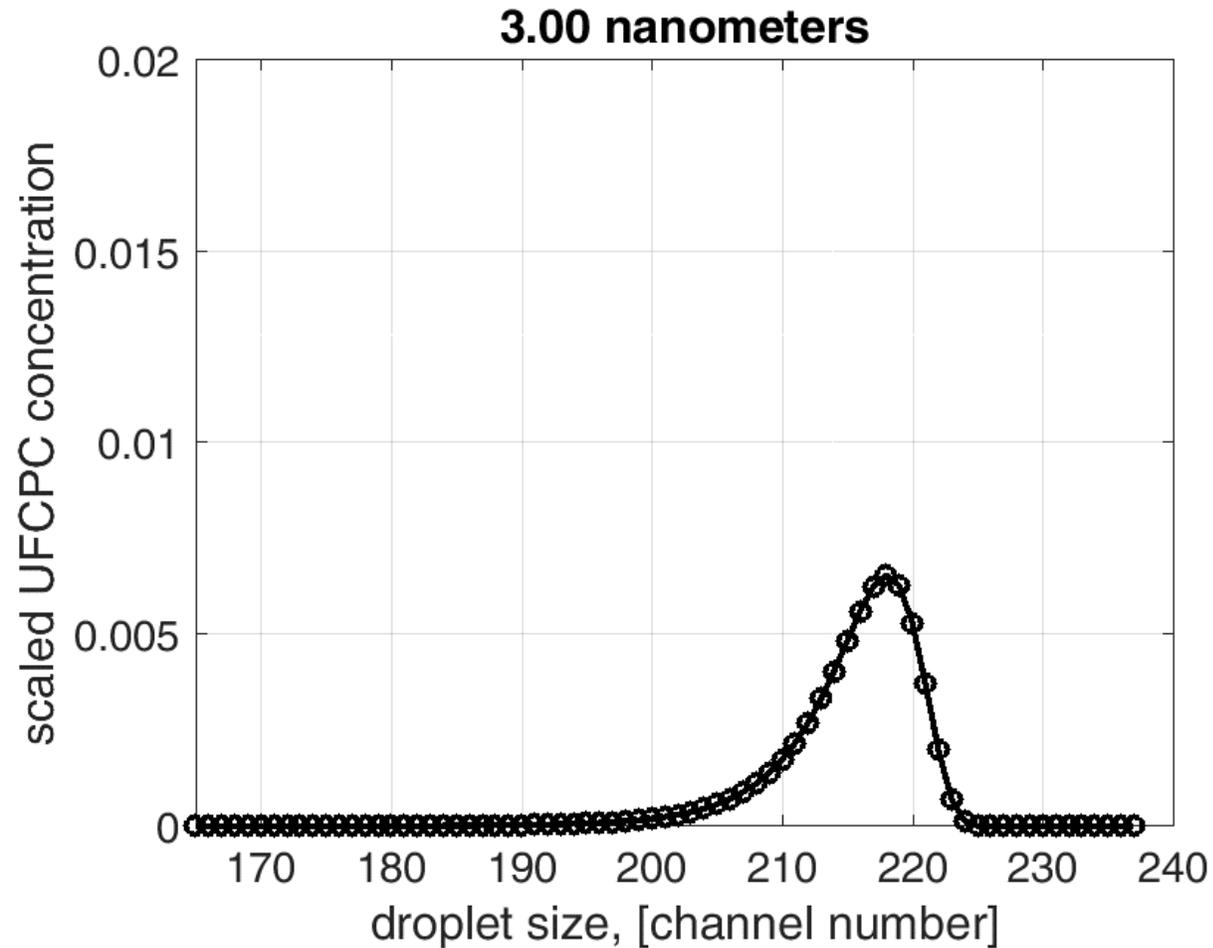


**Ammonium Sulfate Calibration:  
Droplet Size As a Function of Initial Size**

optics: setup 2

- Chongai Kuang (2018): A Diethylene Glycol Condensation Particle Counter for Rapid Sizing of sub-3 nm Atmospheric Clusters, Aerosol Science and Technology, DOI:10.1080/02786826.2018.1481279

# Down to...



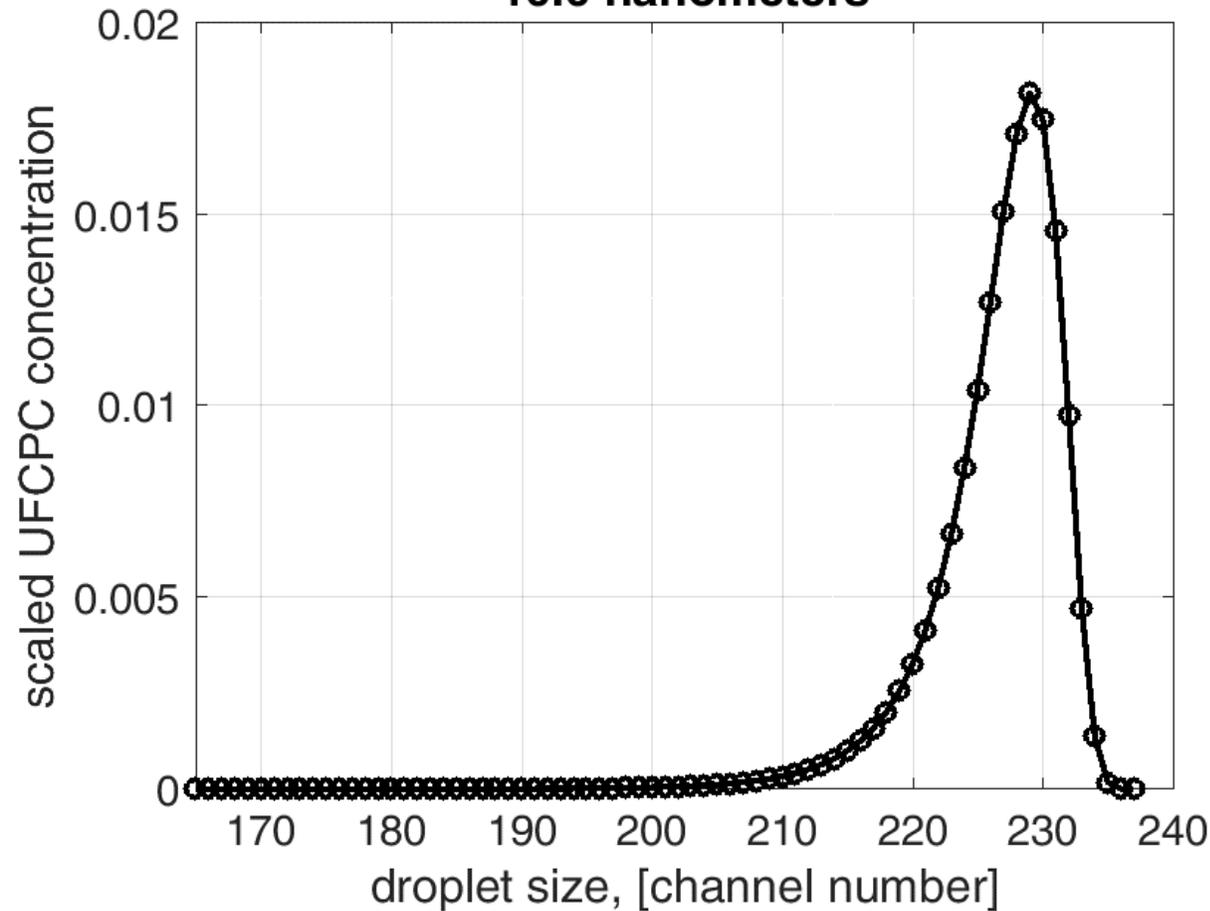
**Ammonium Sulfate Calibration:  
Droplet Size As a Function of Initial Size**

optics: setup 2

- Chongai Kuang (2018): A Diethylene Glycol Condensation Particle Counter for Rapid Sizing of sub-3 nm Atmospheric Clusters, Aerosol Science and Technology, DOI:10.1080/02786826.2018.1481279

# Down to...

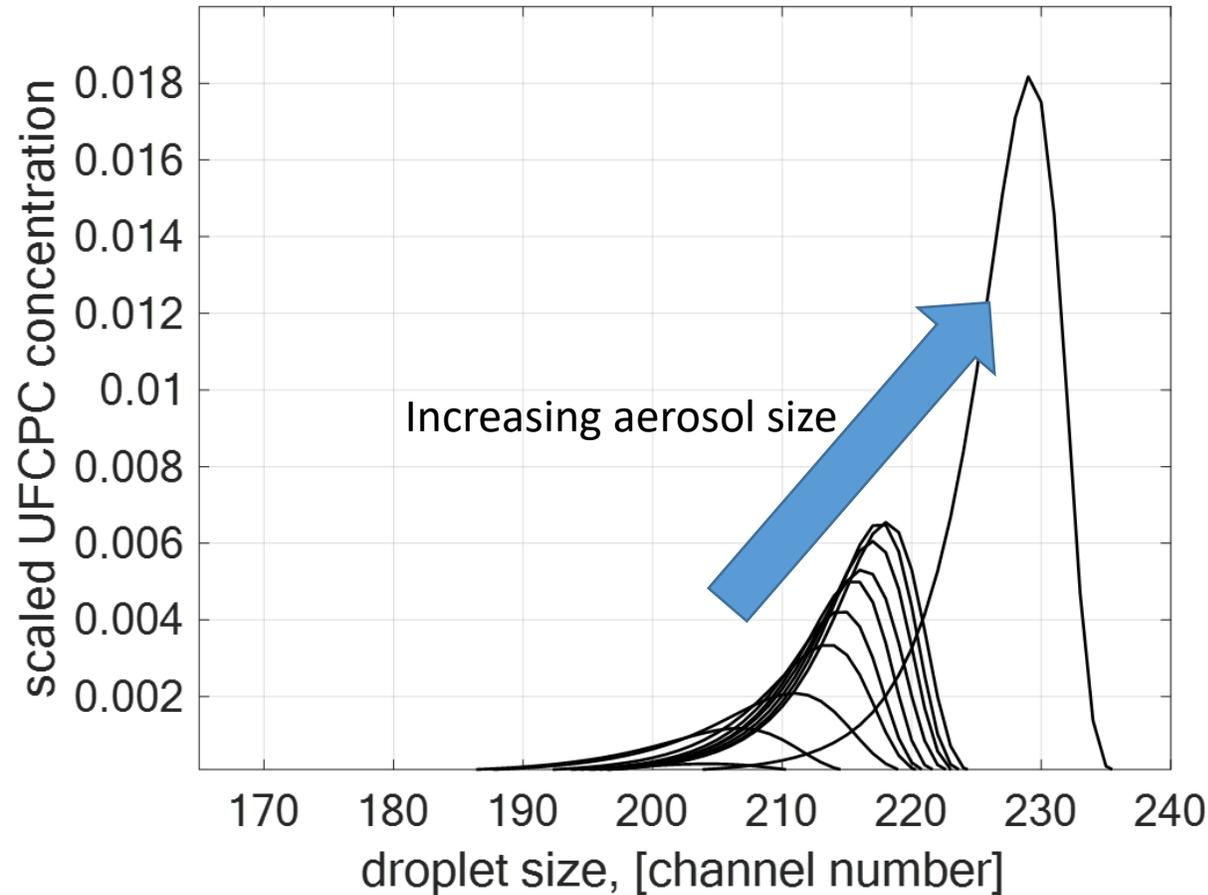
## 10.0 nanometers



**Ammonium Sulfate Calibration:  
Droplet Size As a Function of Initial Size**

- Chongai Kuang (2018): A Diethylene Glycol Condensation Particle Counter for Rapid Sizing of sub-3 nm Atmospheric Clusters, Aerosol Science and Technology, DOI:10.1080/02786826.2018.1481279

# Down to...



**Ammonium Sulfate Calibration:  
Droplet Size As a Function of Initial Size**

Outlook:

***Is detection of initial particle size  
with a single-stage CPC possible?  
based on droplet size distribution***

- Chongai Kuang (2018): A Diethylene Glycol Condensation Particle Counter for Rapid Sizing of sub-3 nm Atmospheric Clusters, Aerosol Science and Technology, DOI:10.1080/02786826.2018.1481279



*urther questions?*

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*Thank you for your attention !*

