

Long-term validation of propylene glycol CPCs for urban ultrafine-particle monitoring

Lessons from the Net4Cities network



EUROPEAN STANDARD

EN 16976

NORME EUROPÉENNE

EUROPÄISCHE NORM

June 2024

ICS 13.040.20

Supersedes CEN/TS 16976:2016

English Version

Ambient air - Determination of the particle number concentration of atmospheric aerosol

Air ambiant - Détermination de la concentration en nombre de particules de l'aérosol atmosphérique

Außenluft - Bestimmung der Partikelanzahlkonzentration des atmosphärischen Aerosols

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Agenda



Goal: Turning 24/7 urban counts into validated UFP data

- Propylene glycol - equivalence shown, and the road to ACTRIS approval
- A lean, CEN-compliant measurement system built for 25 sites
- Field lessons
 - Hotspots, extreme concentrations
 - Smart diagnostics, better data validation
 - PN uncertainty budget



<https://www.net4cities.eu/>

11

Partner cities
in 10 countries

17

Partners
in the consortium

54

**New ultrafine particle
instruments**
to be installed to expand
AQ monitoring capacity

30

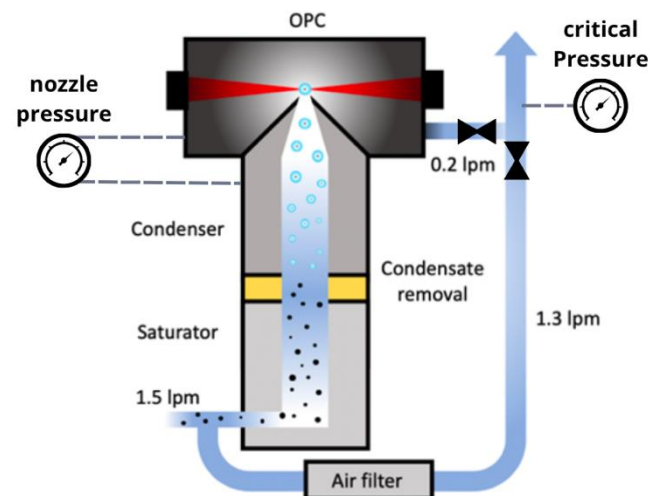
**Noise and traffic
stations**
to be established

The Net4Cities UFP network at a glance

25 counters, first installations in January 2025 – end of 2027

21x A30 (propylene glycol), 4x A20 (butanol)

1Hz data, 24/7 total particle number concentration $\sim 10 \text{ nm} - 2.5 \mu\text{m}$ particles/cm³



Propylene glycol: equivalence shown, approval in progress

Building the long-term evidence base

Butanol vs. PG equivalence & composition-insensitivity already demonstrated (Wlasits et al., 2024)

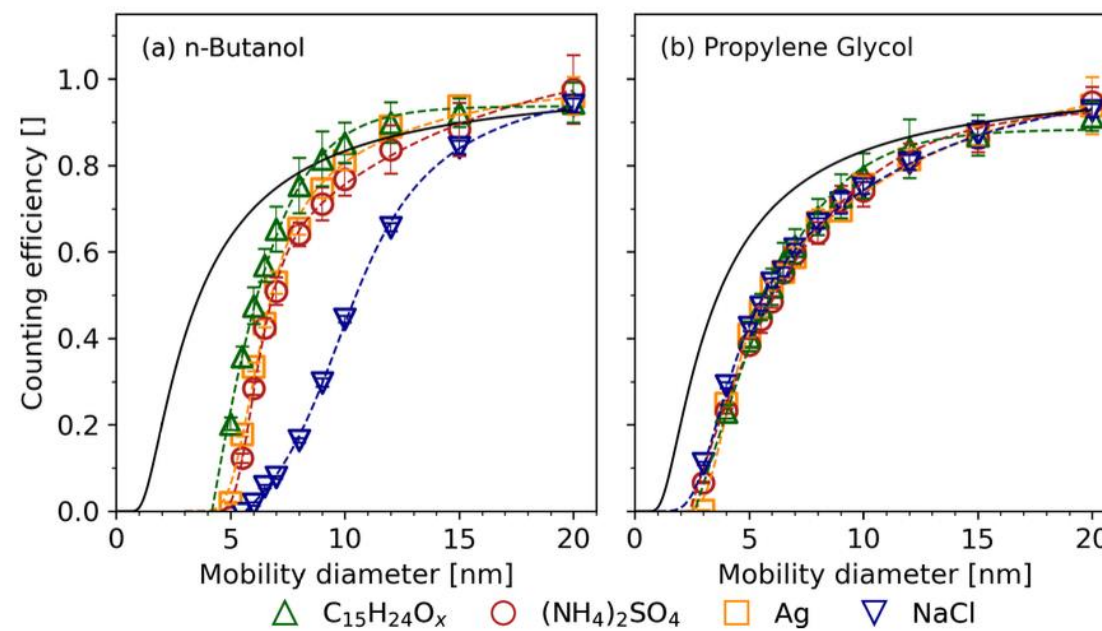
PG ACTRIS approval - pending; this network is part of the field evidence and important user experience project.

In Net4Cities project:

Calibration before / during / after -> quantify long-term drift

Helsinki ACTRIS station: parallel butanol vs PG, >6 months, with SMPS to test the size-distribution effect on Ntot

All cut-off and linearity calibrations during the project compared and analyzed (>50 calibrations done already)



Wlasits et al.; Aerosol Res., 2, 199–206, 2024

A lean, CEN-compliant measurement system

Full-flow CPC to EN 16976 - smallest reliable footprint

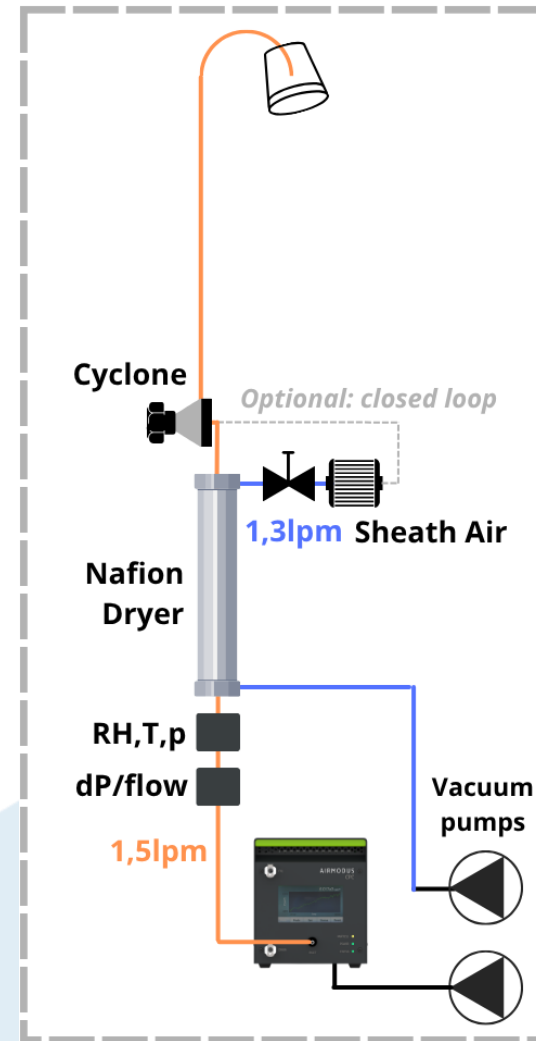
EN 16976 full-flow CPC · D50 = 10 nm · RH < 40%

Mini cyclone - removes coarse particles, protects the CPC for contamination

12" Nafion dryer + RH/T/p monitor (drying has been reliable network-wide)

Small dedicated pumps, no large bypass pump -> lower cost & power

Logger, cloud connection, automatic data pipeline to NILU data hub.



PG vs butanol



PROPYLENE GLYCOL

- + No butanol-removal system needed
- + Refill every 4-6 months
- + Odorless, user-friendly fluid
- + Very low consumption - liquid level a non-issue

BUTANOL

- Butanol-removal system required
- Refill / site visit ~every 23 days
- Odorous; harder for host sites
- Frequent visits - tough for remote stations
- Some gas monitors (and users ;)) sensitive to butanol vapor

Save EUR 5,000-10,000 / system upfront + up to EUR 1,200 / year / system

Field reality: hotspots break the assumptions



Urban peaks far exceed the calibration range

Peaks of **300,000-500,000** #/cc near traffic & local sources

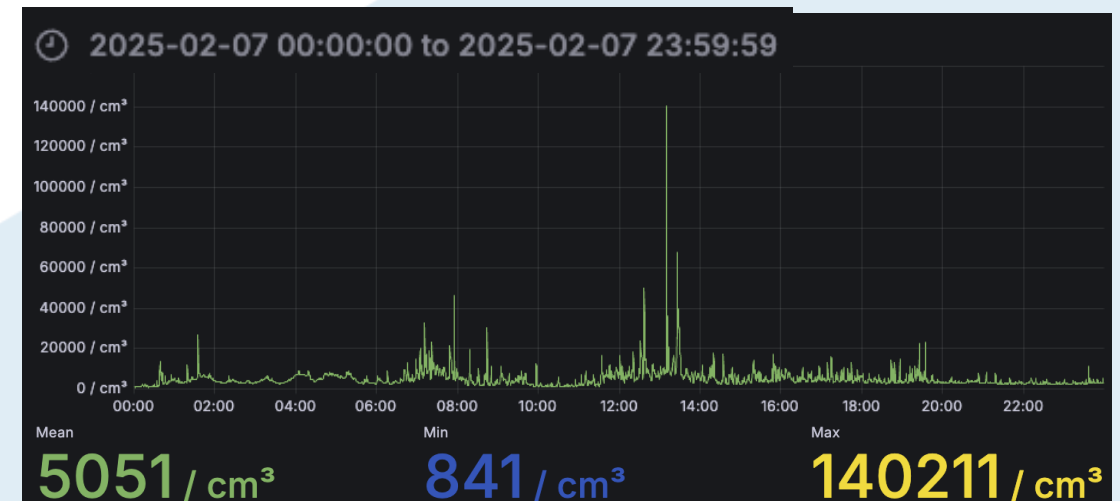
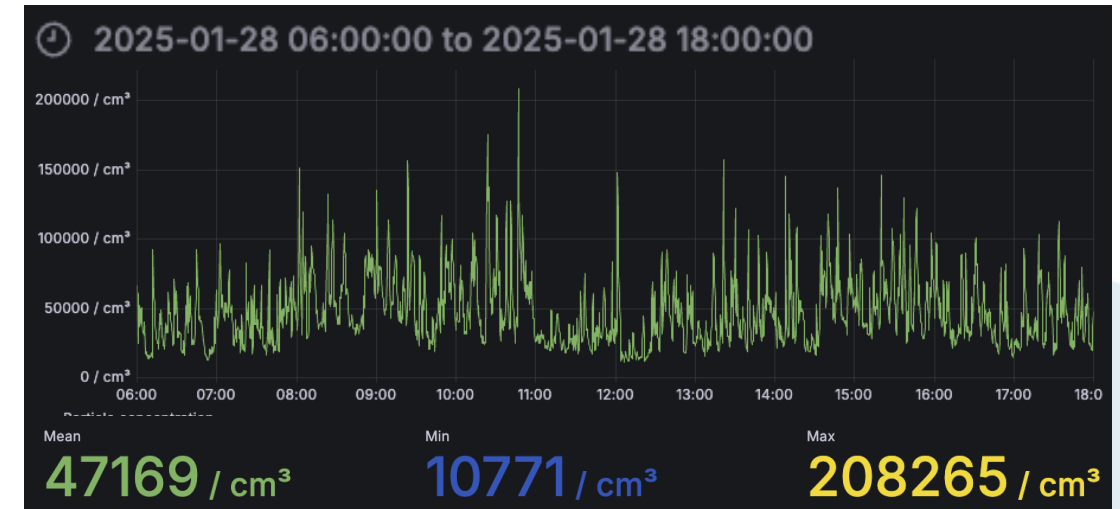
ACTRIS calibration only to 50,000 #/cc -> these sites would need a dilutor

Main issues: nozzle contamination (tiny optics aperture) & critical-orifice contamination - both cleanable

Cyclone cut-off ran high -> bypass flow added to survive extreme loads

1 day examples – HIGH and LOW – (1 minute avg data)

- Note: the min/max values are 1minute min/max, not 1Hz
- High peaks in CPC data are not outliers or noise, they are real data!



Designing for hotspots: three ways to protect the CPC

1

Dilute with dry air

70% dry air / 30% sample -
> also removes the need for
a Nafion dryer – **WINWIN**

- MFC and dried compressed
air needed

2

Pre-cut at 1-2 μm

PN above 1 μm is negligible -
> near-zero effect on total
PN



3

Use a full SMPS instead of a CPC

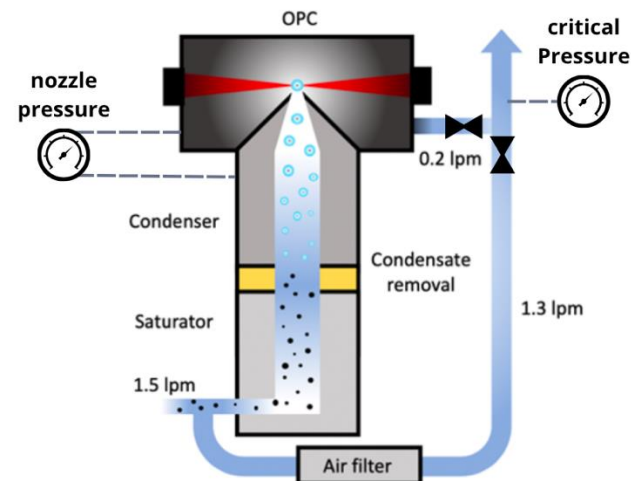
DMA sheath dilutes sample
>1:5; N_{tot} from the scan ->
no separate dilutor needed



Smart diagnostics: catch faults early

TOP4 problems, quick fixes and how shall the future be:

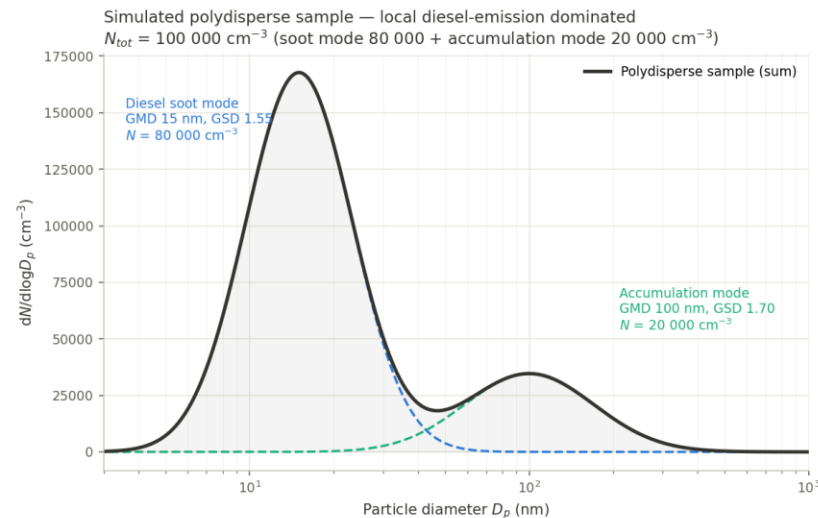
Problem	Today	Future (24/7)
Critical orifice contamination	Monthly inlet-flow check	dP-based inlet-flow monitoring
Nozzle contamination	dP over nozzle	dP over nozzle + dP at CPC inlet
Optics (mirrors/lenses/windows)	Pulse-shape & pulse-ratio	Continuous pulse-health -> DE 24/7
Liquid level	Manual check	PG low consumption -> non-issue



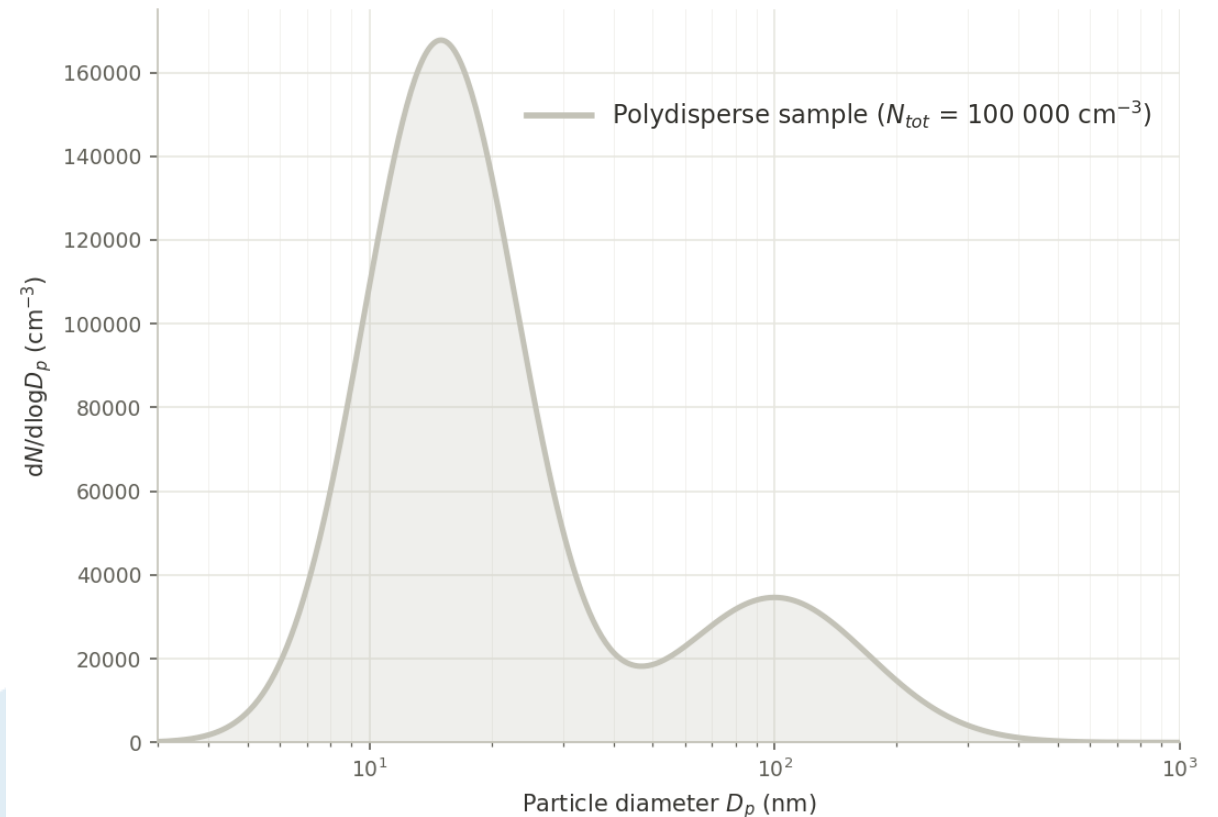
What actually limits PN accuracy: the uncertainty budget

Extreme Example:

- Urban traffic station, next to street
- Diesel car driving by - emission peak
- Accumulation mode - urban background



Simulated polydisperse sample — local diesel-emission dominated ($N_{tot} = 100\,000\text{ cm}^{-3}$)



What actually limits PN accuracy: the uncertainty budget

Four independent terms – all depend on size

1

Cut-off: ACTRIS allows D50 of 9-11 nm -> shifts total PN

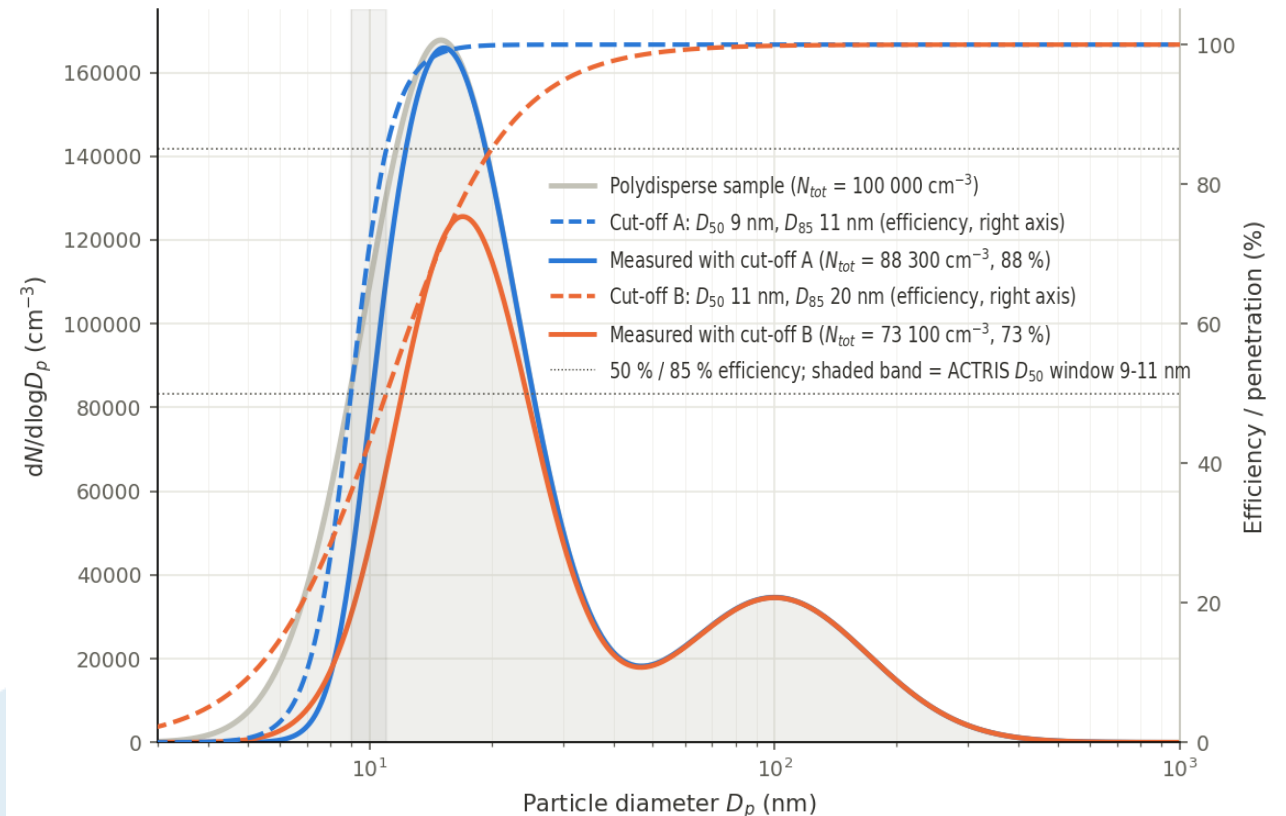
100 000 => 73 000 - 88 000 #/cm³

Sampling losses: up to 30% allowed at 10 nm (simulate 10-30%)

Detection efficiency: >90% required -> 90-100% in practice -> ~10%

Flow through optics: direct 1:1 (-5% flow = -5% PN)

Effect of CPC cut-off calibration — two extremes within ACTRIS acceptance (D50 9–11 nm, D85 ≤ 20 nm)



What actually limits PN accuracy: the uncertainty budget

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2

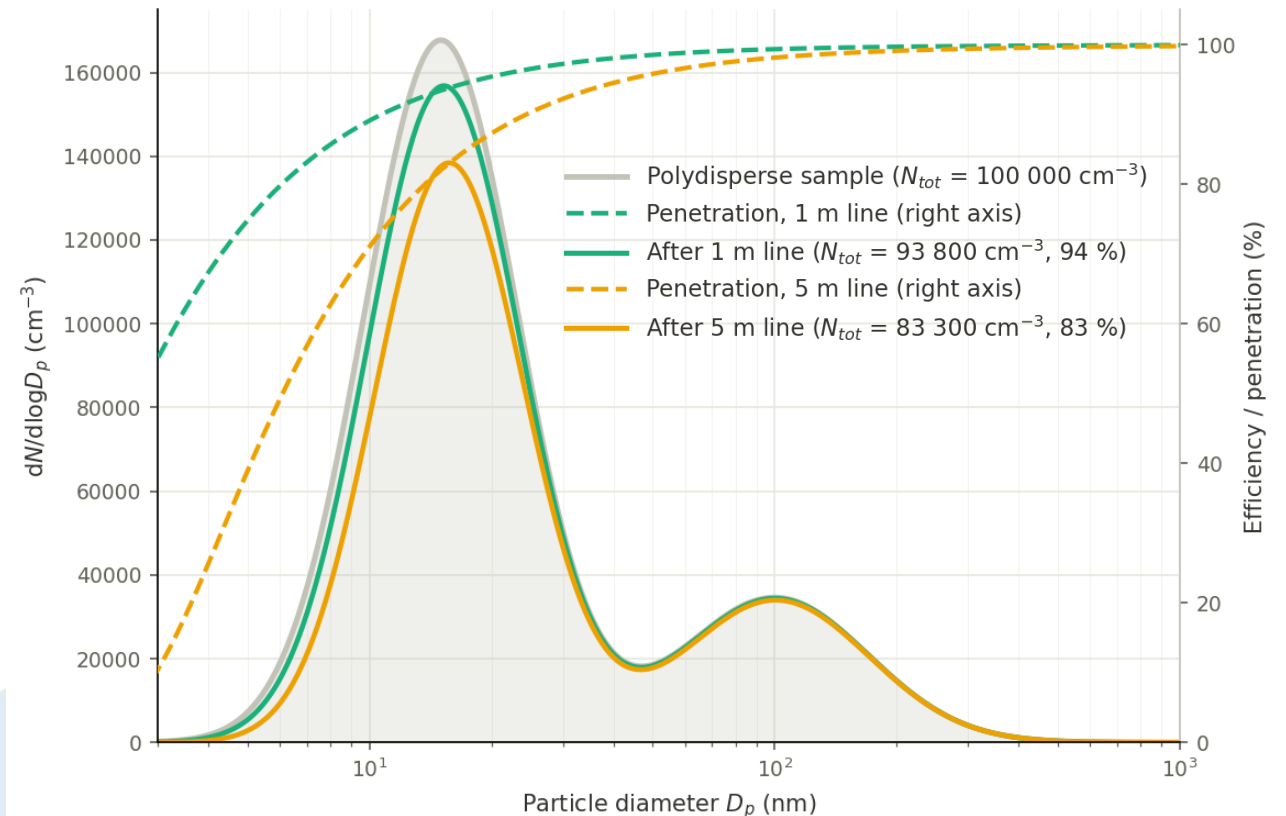
Sampling losses: up to 30% allowed at 10 nm (simulate 10-30%)

100 000 => 83 000 - 94 000 #/cm³

Detection efficiency: >90% required -> 90-100% in practice -> ~10%

Flow through optics: direct 1:1 (-5% flow = -5% PN)

Effect of sampling-line diffusion losses — 1 m vs 5 m effective length (laminar, 1.0 lpm)



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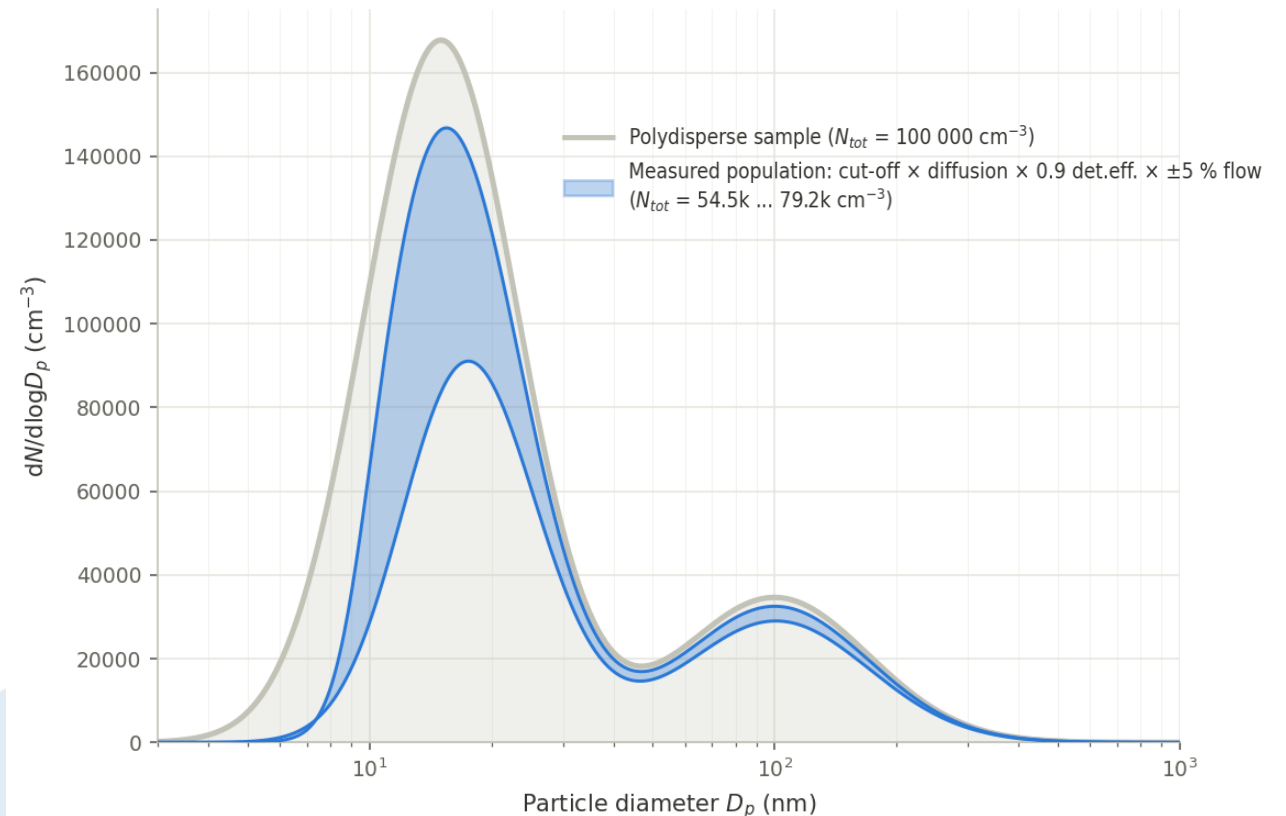
Detection efficiency: >90% required -> 90-100% in practice -> ~10%

4

Flow through optics: direct 1:1 (-5% flow = -5% PN)

100 000 => 54 500 - 79 200 #/cm³

Final measured particle population — combined effect of cut-off, diffusion losses, detection efficiency ($\times 0.9$) and flow accuracy ($\pm 5\%$)



The key insight: losses depend on particle size

So validated PN needs SMPS - or the night shift

- Cut-off, tubing, DE losses and flow variations all vary with particle size
- Ideal correction? -> continuous SMPS size distribution
- No SMPS? Use nighttime data - a stable condensation sink (accumulation mode) keeps the size distribution $\sim$ constant
 - Minimizes the size-dependent effect on N_{tot}

Six habits that keep an urban UFP network honest



1

Characterization of sampling line and meta information for data quality process.

2

Protect the counter upstream at hotspots - dilute, 1 μ m pre-cut, or SMPS

3

Monitor health signals (dP flow, dP nozzle, pulse ratio) - not just concentration

4

Design diagnostics for continuous, remote validation

5

Know your uncertainty budget - and that it is size-dependent

6

Exploit stable nighttime periods when SMPS is not available

THANK YOU



AIRMODUS



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Ref: Wlasits et al., Aerosol Research 2, 199-206, 2024 | Net4Cities · NILU Data Hub · Horizon Europe GA 101138405