Electrical particle number measurement for automotive applications

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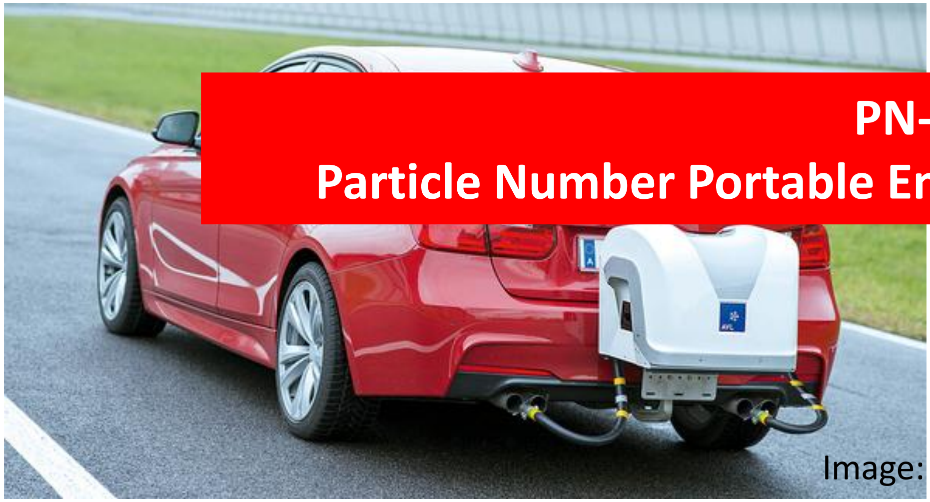
Motivation

- Particle number limit value for vehicles in EU
- Complex lab setup necessary (PMP)
- Particle detector: automotive CPC
- Legislation is moving towards real driving emissions (RDE) – think of Volkswagen scandal



PN-PEMS
Particle Number Portable Emissions Measurement System

Image: https://www.avl.com/real-driving-emissions-rde-

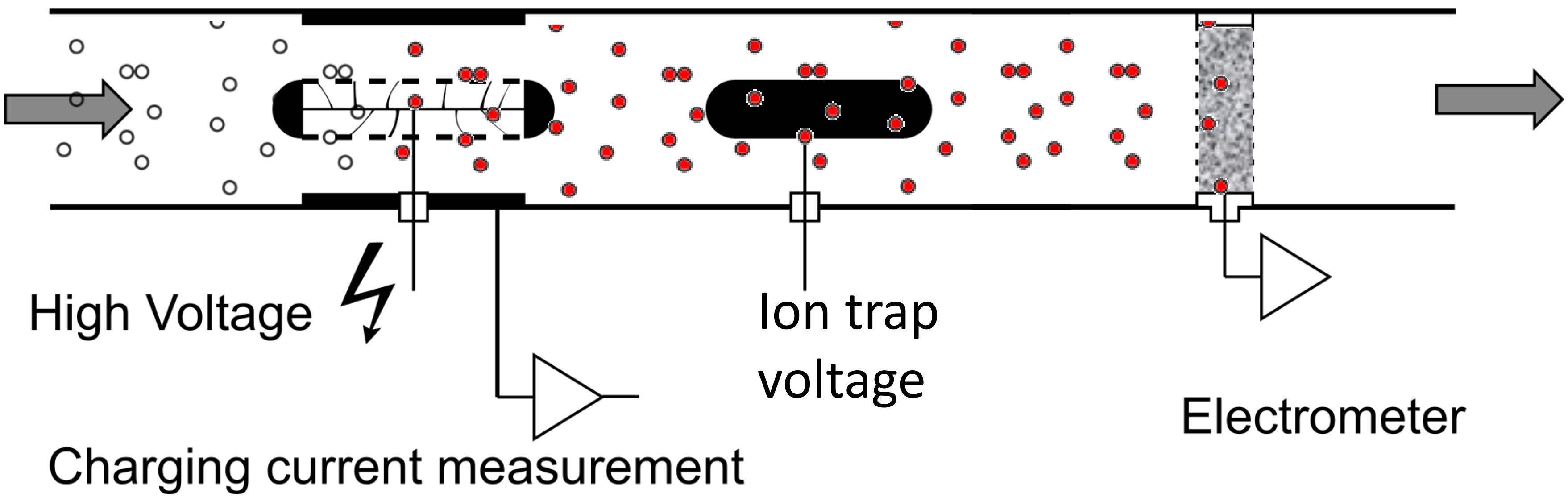
Motivation

- What options are there to replace the automotive CPC with a simpler, more robust device based on electrical charging?
- How well can such a replacement device work?

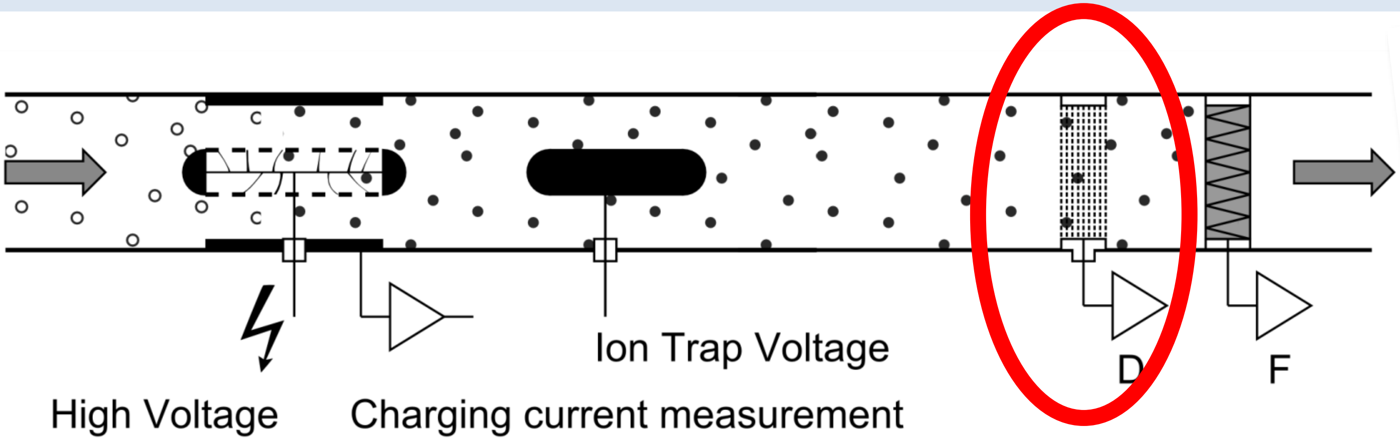
The problem with charging

- Standard setup for charging (very simple):

Charging is linear in particle diameter d, Q~N·<d>
⇒ Unless d is known, N cannot be measured



Options: Dual-stage detection



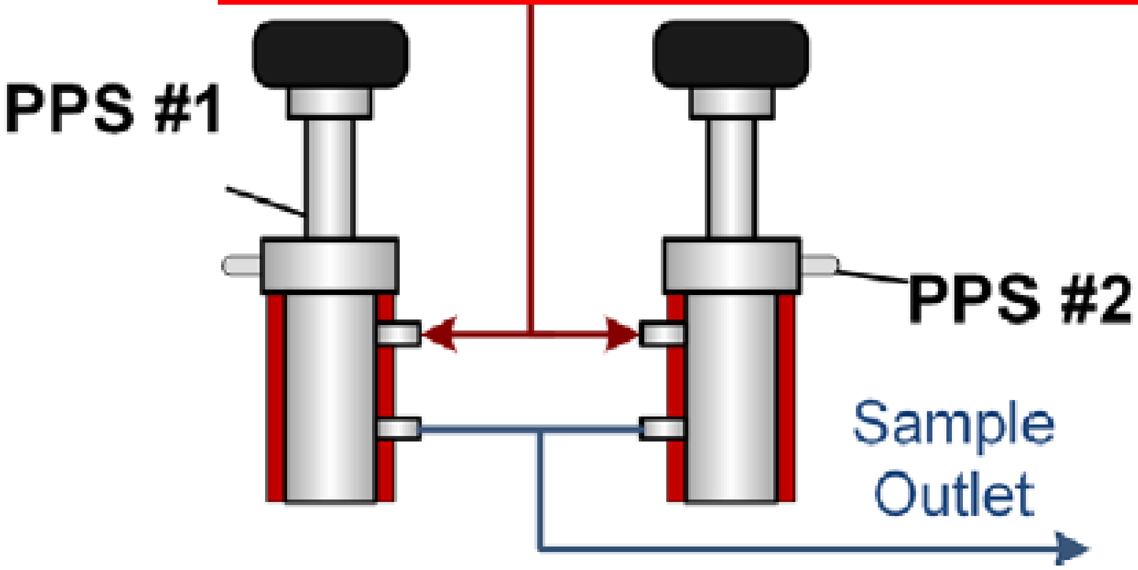
Size-selective detection in two stages ⇒ diameter ⇒ number

M. Fierz et al. Design, Calibration and Field Performance of a Miniature Diffusion Size Classifier, Aerosol Science and Technology 45 (1), 1-10, 2011

More options: two devices

- 2 Pegasor devices operating at different ion trap voltages

Parallel detection with two devices ⇒ diameter ⇒ number

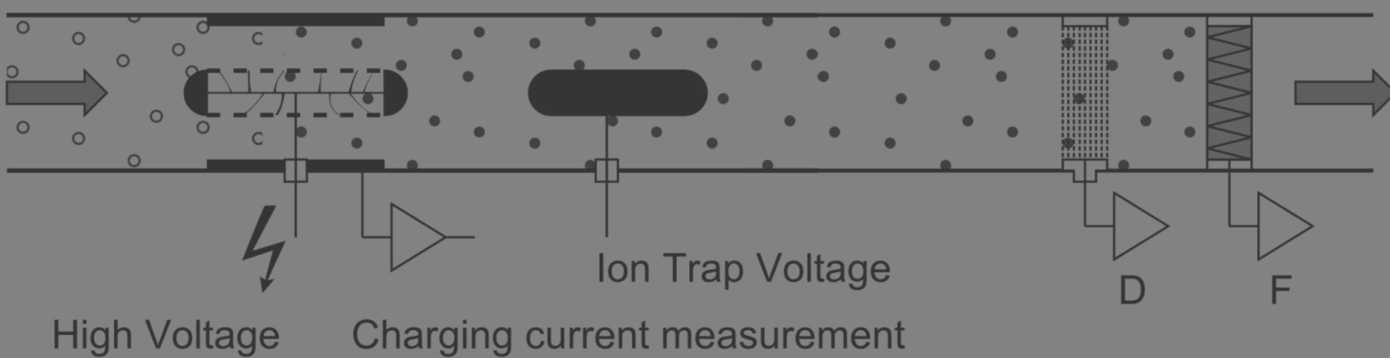


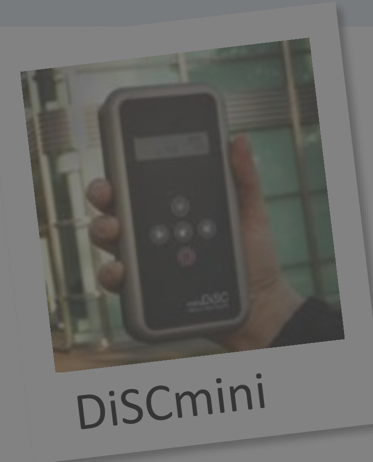
S. Amanatidis et al: Measuring number, mass, and size of exhaust particles with diffusion chargers: The dual Pegasor Particle Sensor, Journal of Aerosol Science 92 (2016) 1-15

Challenges

- These (and similar) schemes use sensible assumptions to determine average particle diameter, and with that also particle number (so they offer more information than a CPC)
- But they have drawbacks too...

Options: Dual-stage detection





For rapidly changing aerosols:

- **Induced currents on diffusion stage**
- **Different response time of the two stages**

M. Fierz et al. Design, Calibration and Field Performance of a Miniature Diffusion Size Classifier, Aerosol Science and Technology 45 (1), 1-10, 2011

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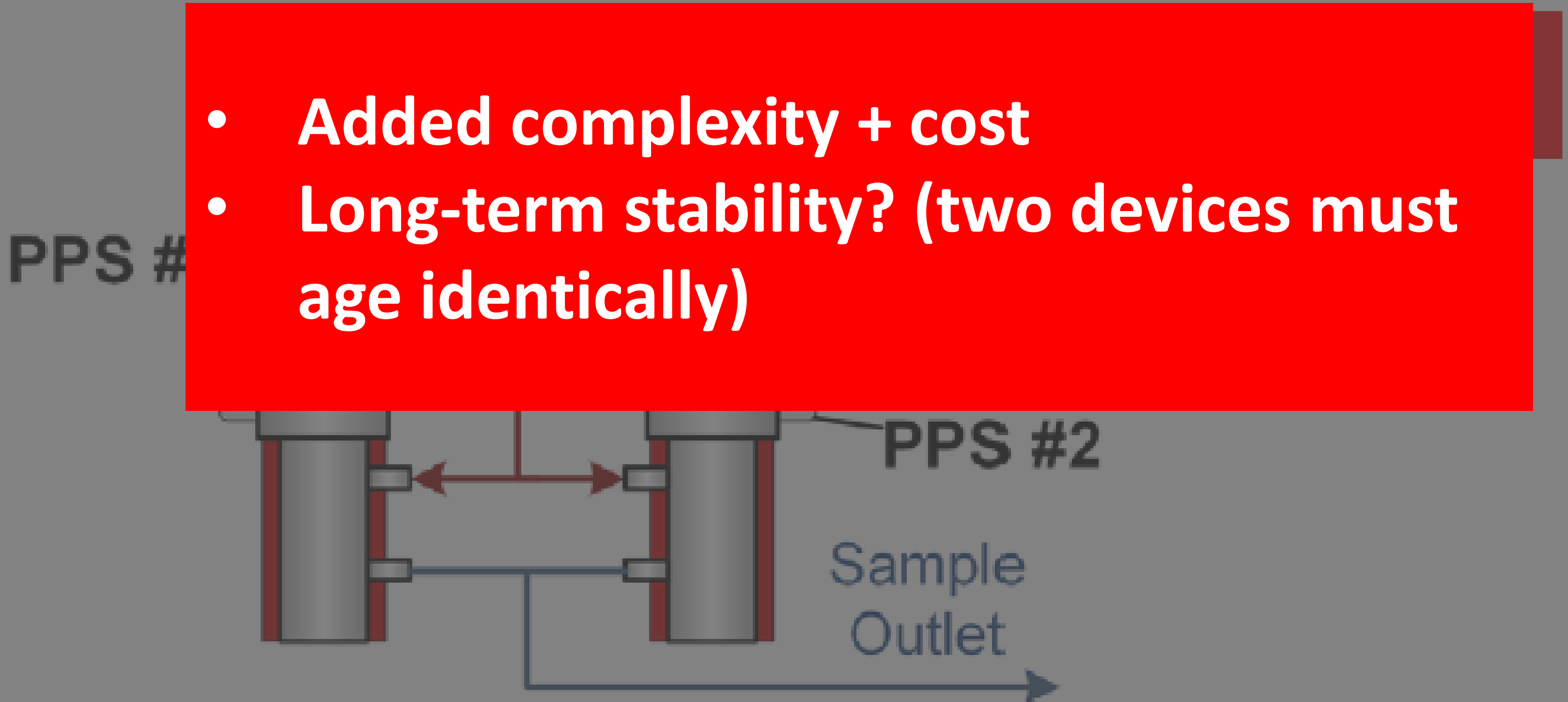
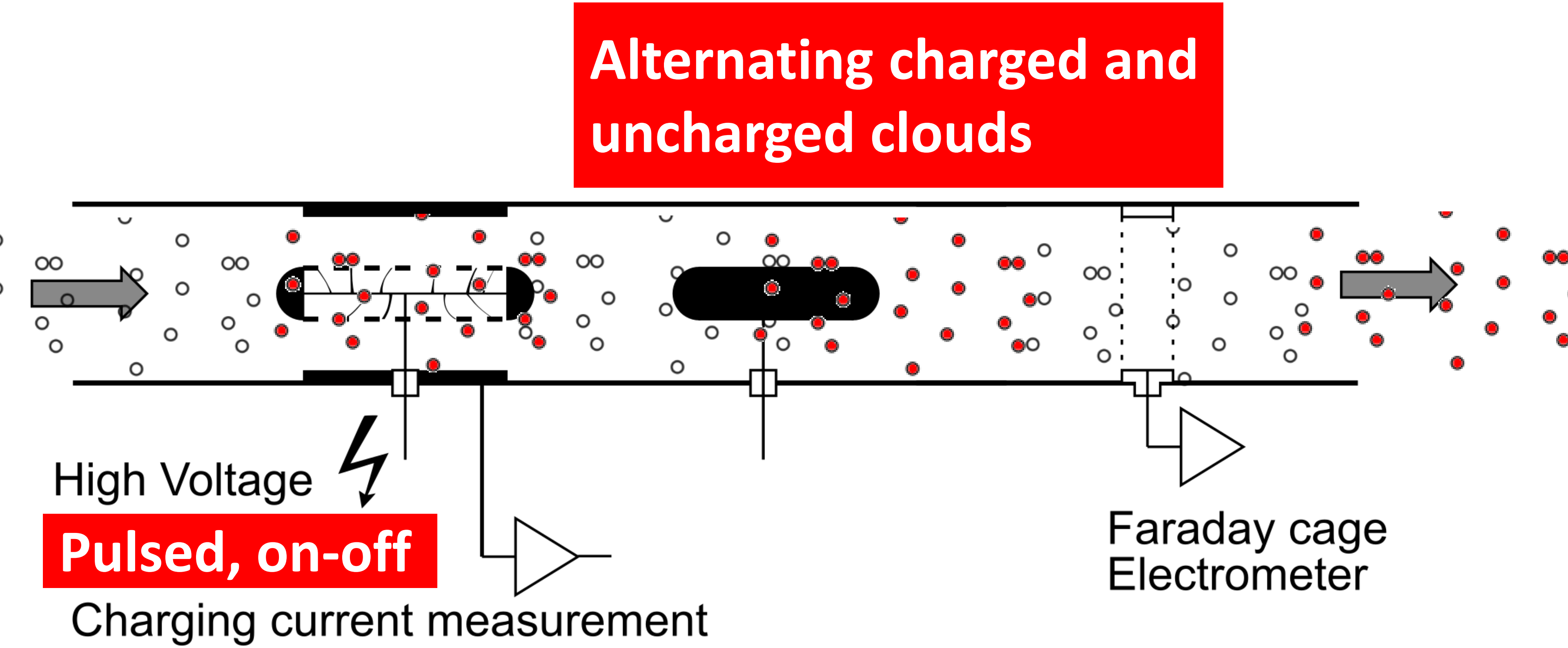


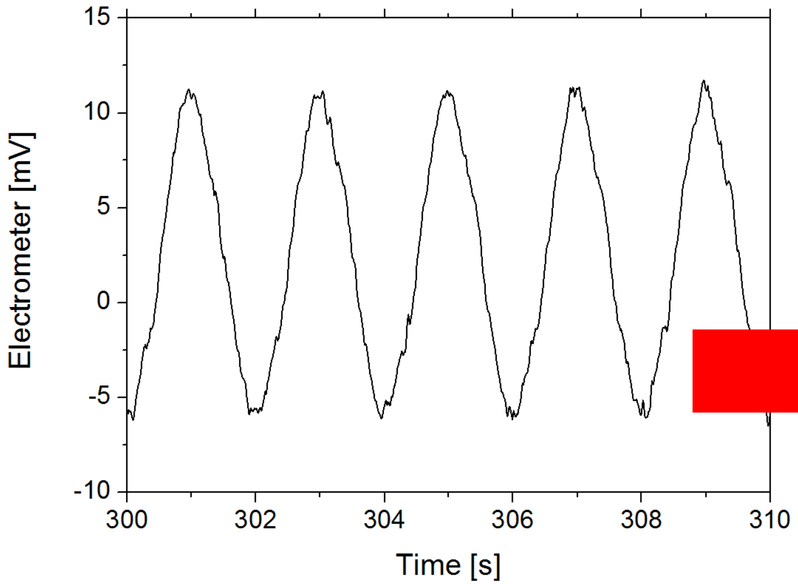
- **Added complexity + cost**
- **Long-term stability? (two devices must age identically)**

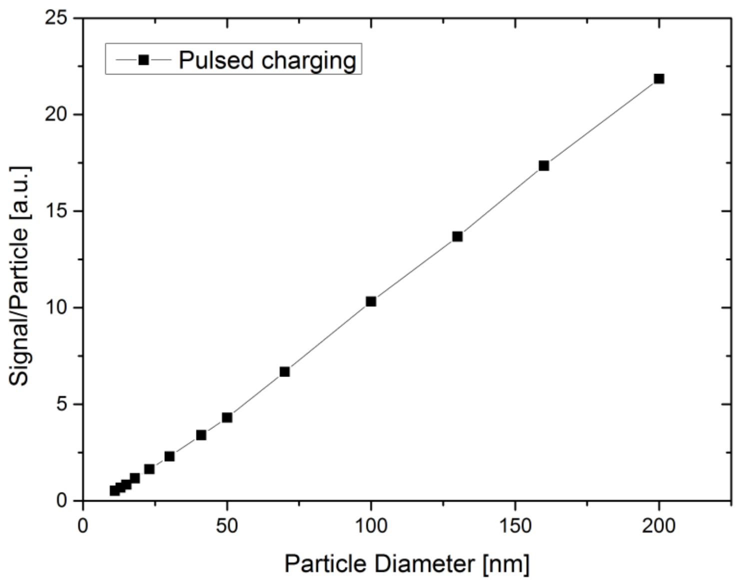
Use induced currents (pulsed charging)



M. Fierz et al. Aerosol detection by induced currents, Aerosol Science and Technology 48 (4), 350-357, 2014

Instrument response





Electrometer zero offset (and its drift!) is irrelevant

☺

But it's not a particle number counter

☹

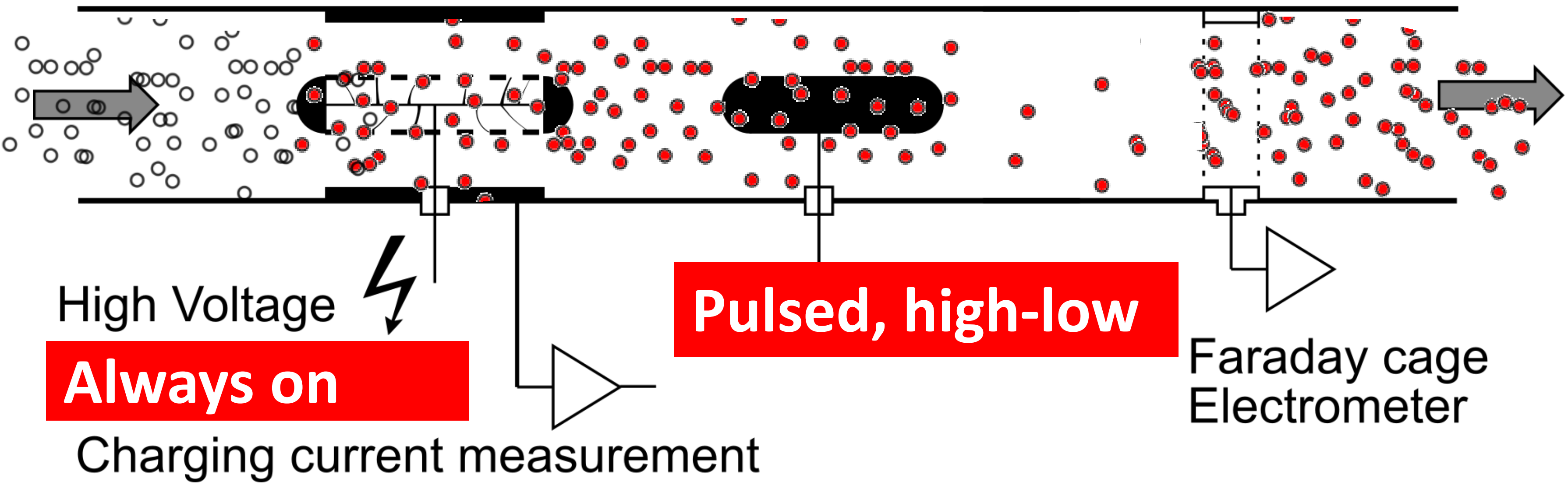
The inventors

- Heinz Burtscher Andreas Schmidt Ott

After unipolar diffusion charging, the conductivity of an aerosol is proportional to the particle number concentration

The idea

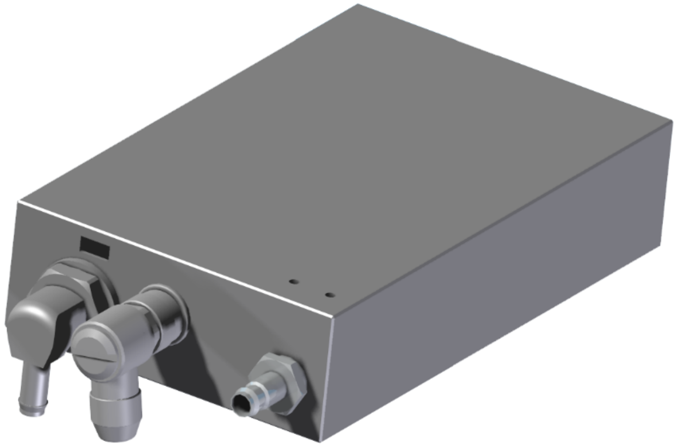
Alternating charged and less charged clouds



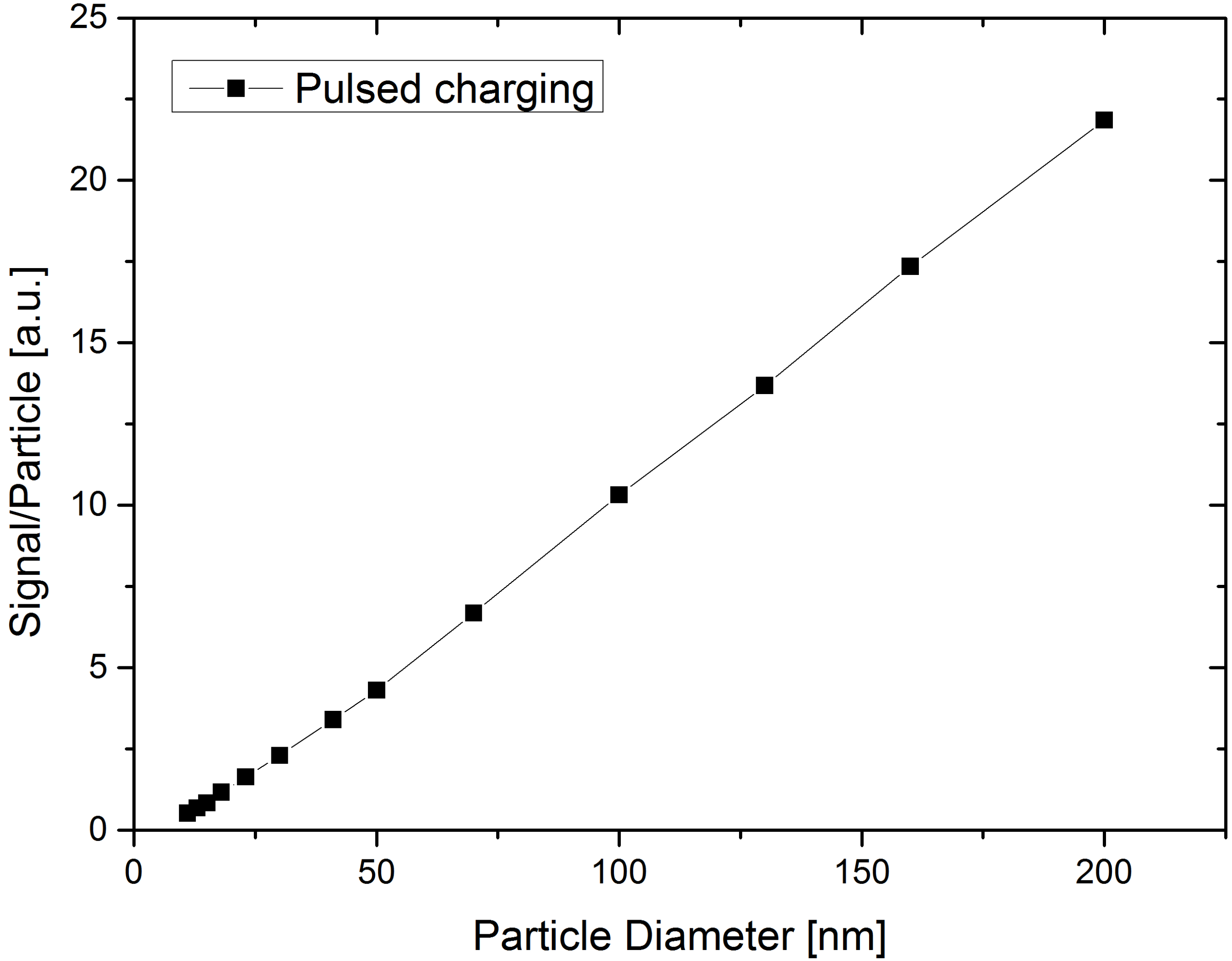
Single detection stage! All issues of other schemes solved!

The implementation

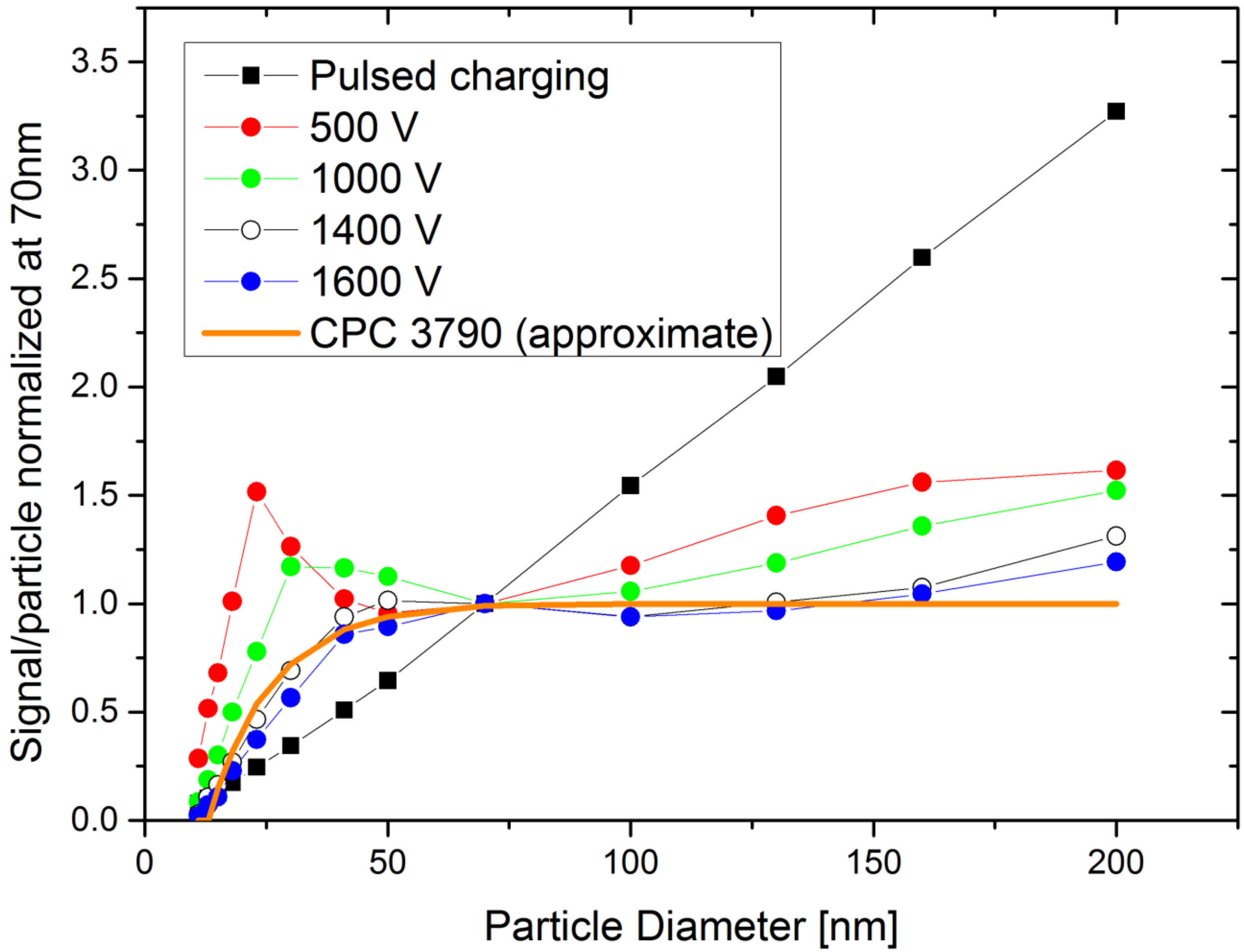
- Limits of detection: ~500 – $1.5 \cdot 10^6$ pt/cm^3
- Particle size range: 15-200 nm
- Size: 16.5 x 8.8 x 3.2 cm
- Weight: 500g
- Power: ~2W
- Response time: 1 second
- Flow rate: 2.0 lpm
- Operating temperature up to 55°C



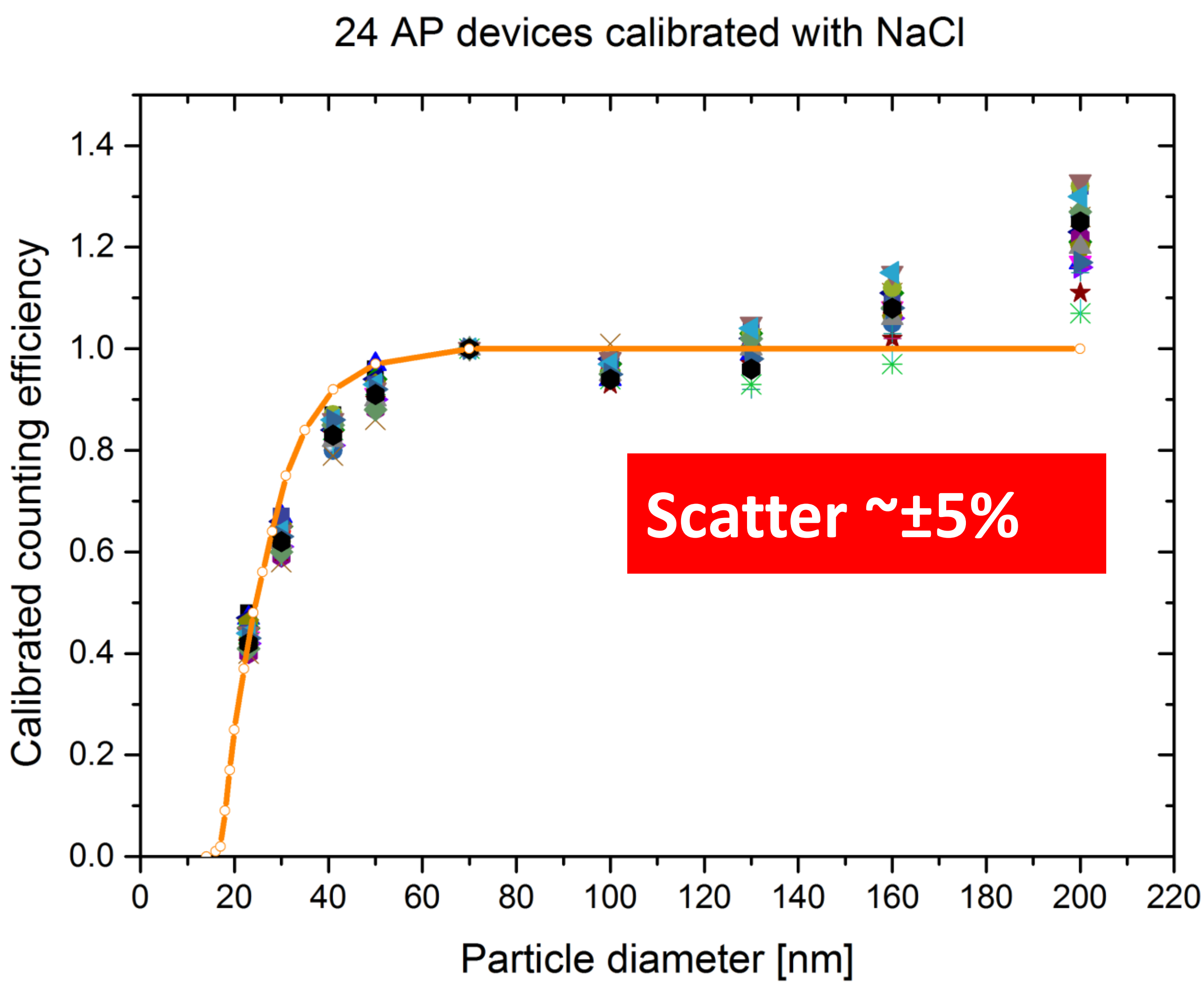
New instrument response (NaCl)



Normalized instrument response (@ 70nm), NaCl

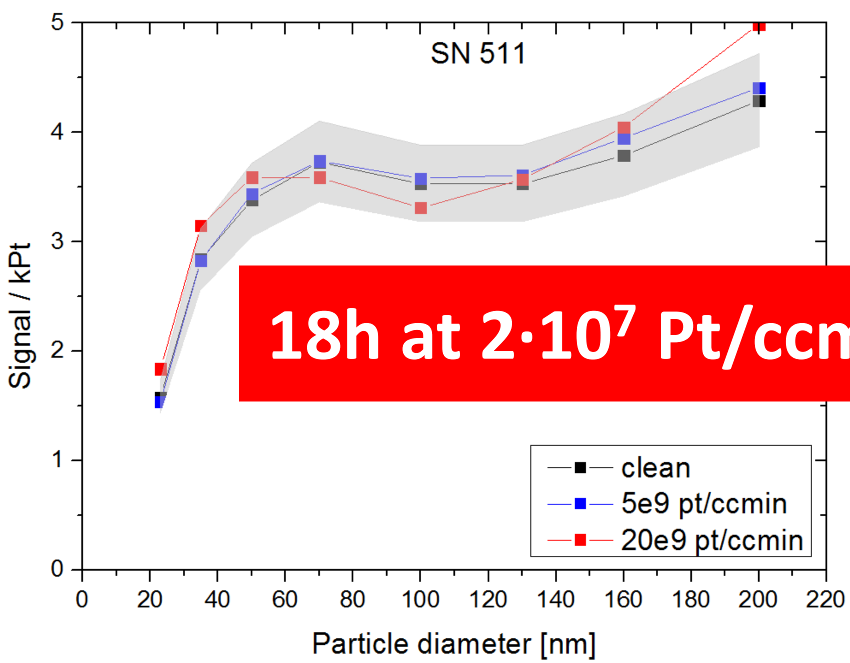


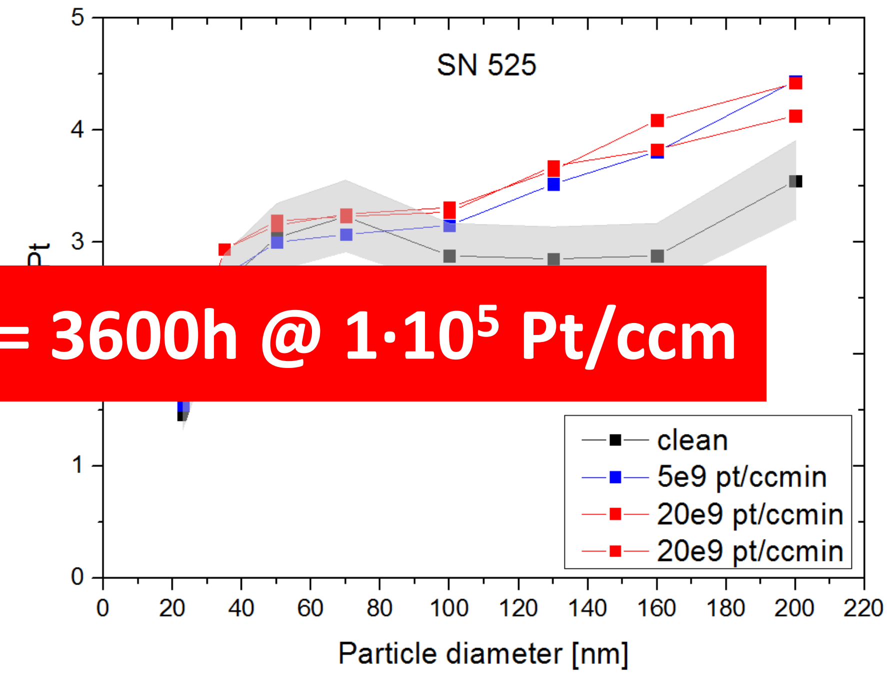
Comparability for multiple instruments (initial calibration only! NaCl)



Aging

- 2 devices were contaminated for 18 hours with undiluted CAST soot ($2 \cdot 10^7$ Pt/ccm)
- Shaded area = ± 10% deviation of initial calibration

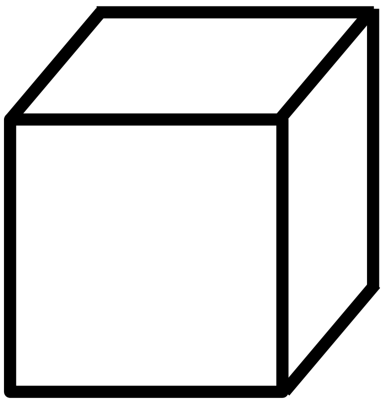


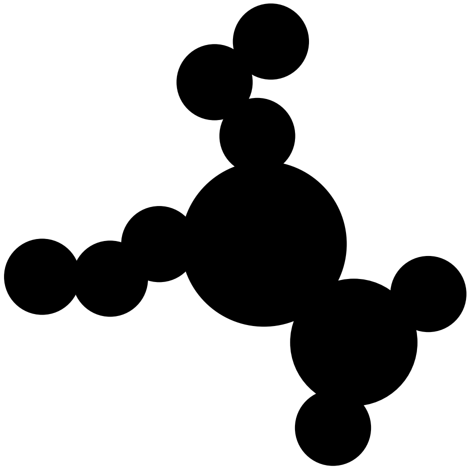


18h at $2 \cdot 10^7$ Pt/ccm = 3600h @ $1 \cdot 10^5$ Pt/ccm

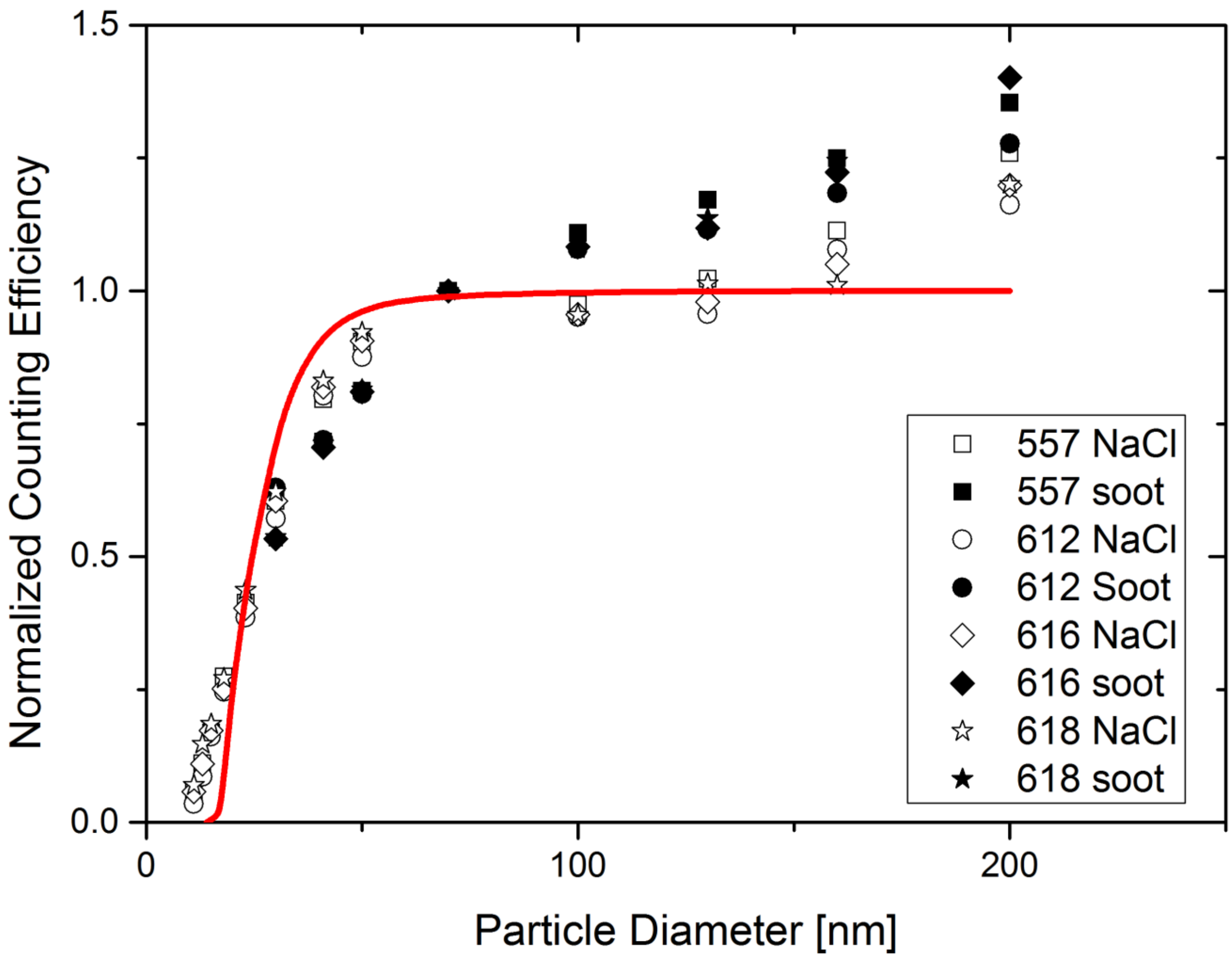
Soot

- NaCl produces cubic particles, soot consists of agglomerates – how does this affect the device?

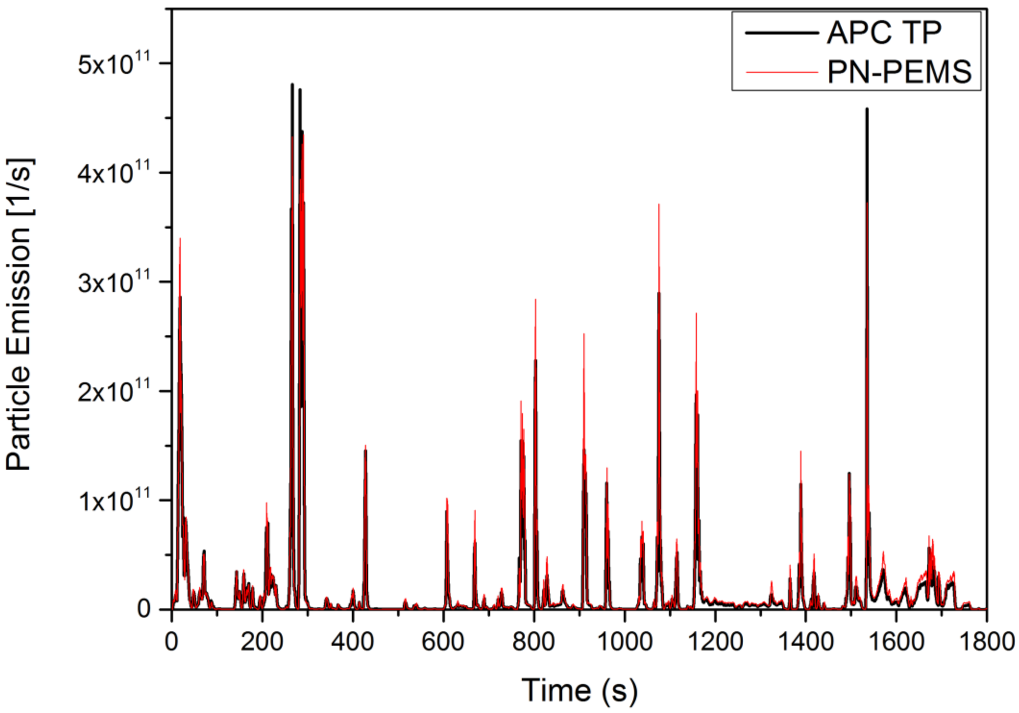




Soot: Morphology is relevant



Real world example



Cycle average:
APC Tailpipe $1.09 \cdot 10^{12}$ Pt/km
PN-PEMS Tailpipe $1.26 \cdot 10^{12}$ Pt/km (+16%)

Conclusions

- New all-electrical "particle number" counter demonstrated (in PMP sense)
- Single-stage design avoids all drawbacks of similar attempts to measure particle number (but doesn't measure diameter!)
- Fits PMP curve very nicely for NaCl particles, a bit less nicely for (CAST) soot
- Interesting technology for future applications outside of the lab environment

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