Brake wear particle measurement setup for quantitative emission analysis

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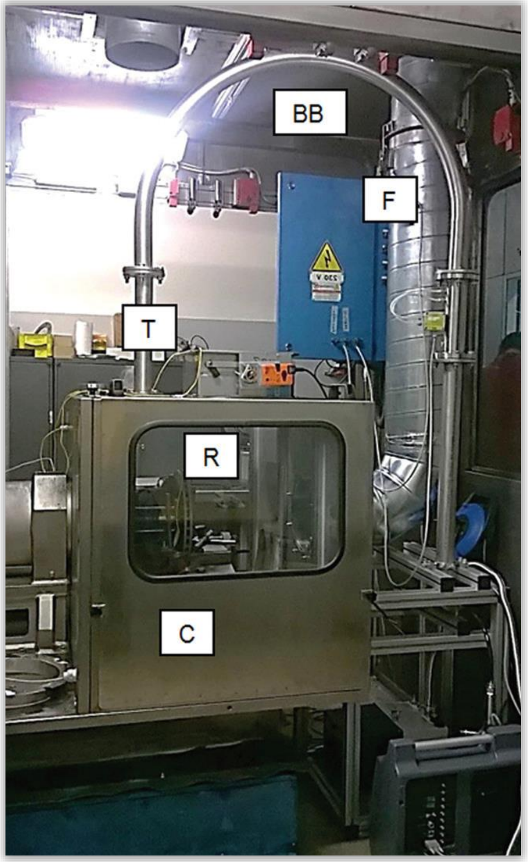
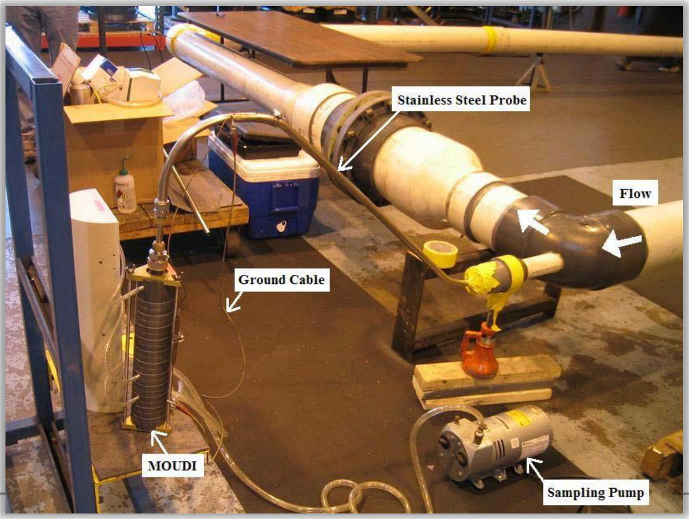
LITERATURE REVIEW

- P.G. Sanders et al. 2002

- A. Hagino et al., 2015



- G. Perricone et al., 2015



- A. Haselden et al., 2005

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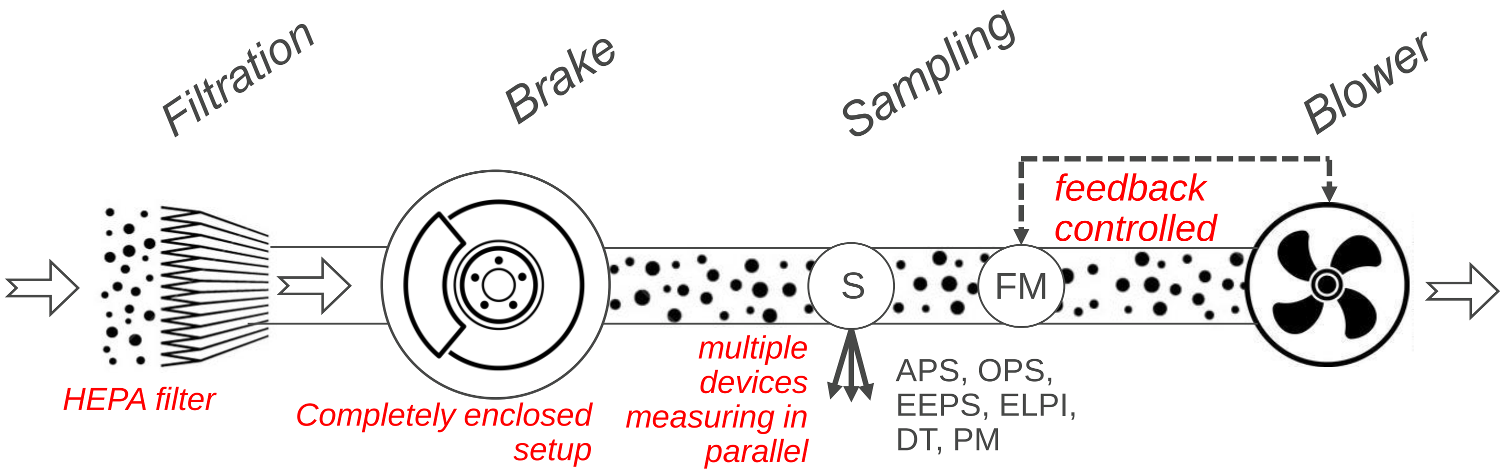
BRAKE WEAR MEASUREMENT SETUP

Requirements → **Technical needs**

- Reproducible results……………… → completely enclosed & sealed chamber
- Quantitative analysis…………….. → controlled airflow at sampling point
- Maximal aerosol yield
  - Low particle loss……………. → no aerosol bypass & low dilution
  - High sensitivity……………….. → sampling in full aerosol stream
- Measure brake aerosol only
  - low background contribution.. → filtered air
- Representative & unbiased setup. → isokinetic sampling



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SETUP - SPECS

- Circular chamber design
  - Chamber volume: ~0.2 m^3
  - Volume exchange time at 250 m^3/h: 3 s ($v_{air,tube}$ = 4 m/s)
  - Avoiding dead air spaces
- Completely sealed chamber
- Fully conductive chamber surface connected to ground potential
  - No electrostatic particle losses
- Vertical sampling with isokinetic inlets

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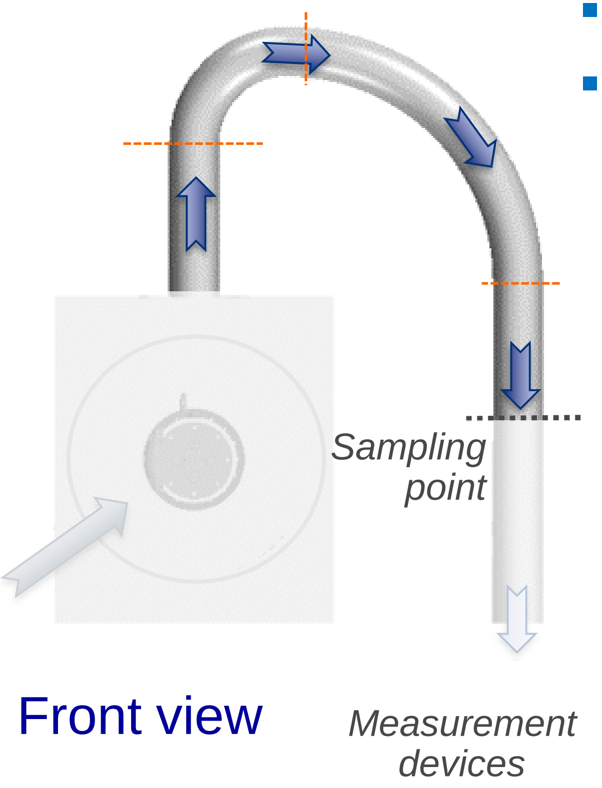
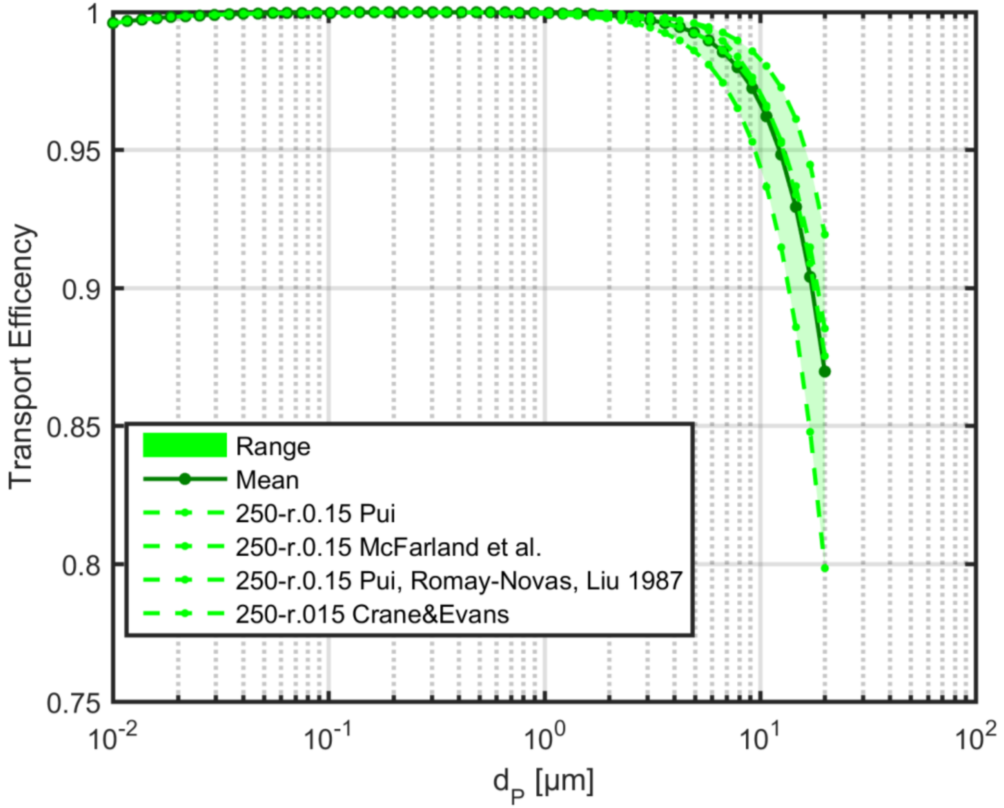
BRAKE WEAR MEASUREMENT SETUP

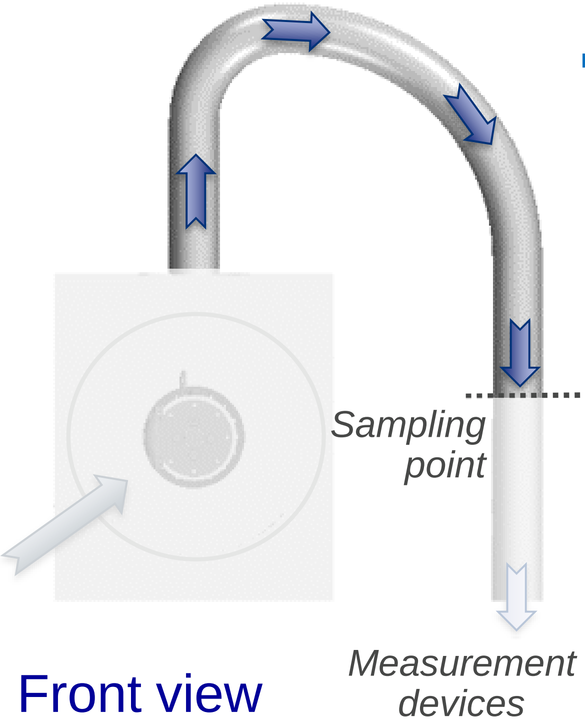


- Aerosol pathway is designed for small particle losses
- Transport efficiency is used to evaluate aerosol pathway:

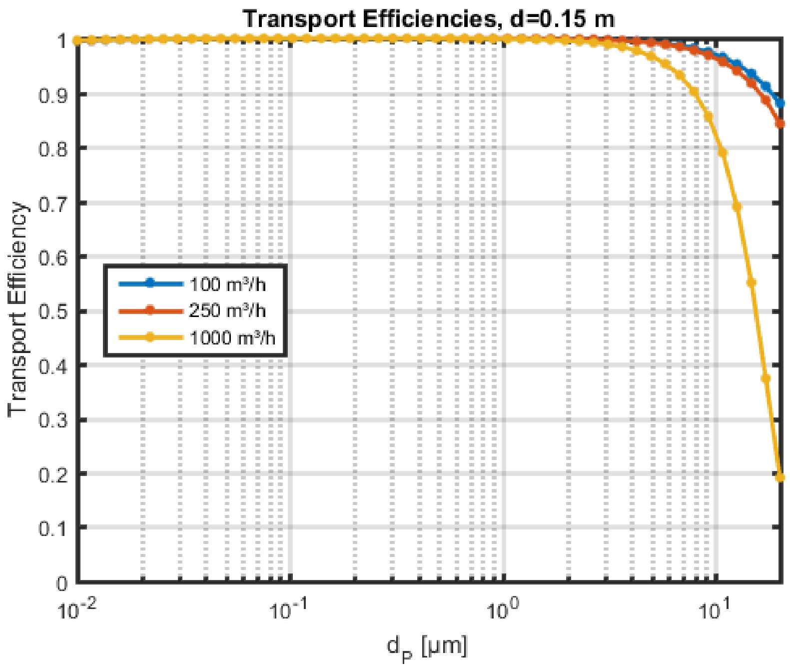
$$\eta_{\text{trans-port}} = \prod_{\text{flow elements}} \eta_{\text{tube, turb. inert.}} \cdot \eta_{\text{bend, inert.}} \cdot \eta_{\text{tube, diff.}} \cdot \eta_{\text{tube,grav.}}$$

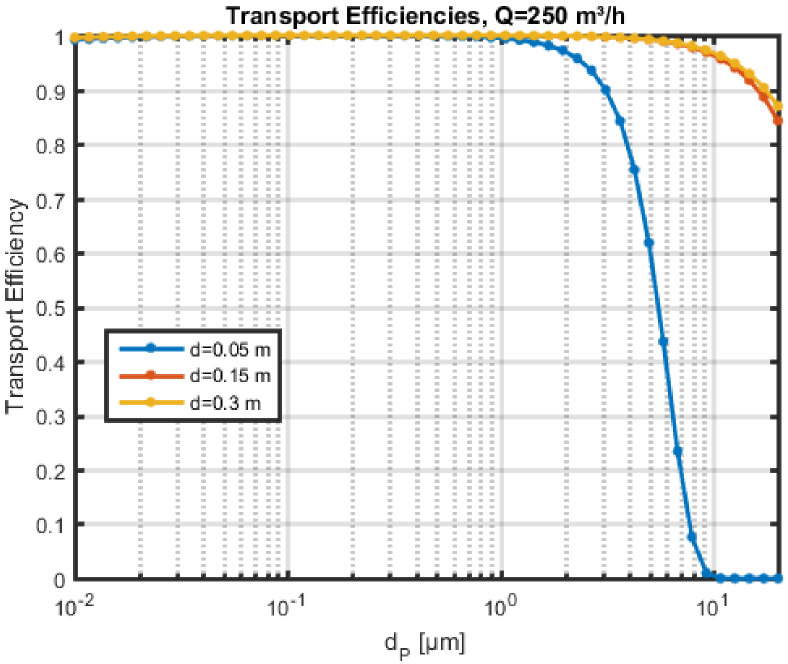


BRAKE WEAR MEASUREMENT SETUP



- Why 250 m³/h ?
- Why tube diameter of d=0.15 m ?





- 250 m³/h with d=0.15 m appears to be “sweet spot” for our setup with regards to sampling losses, signal strength, isokinetic sampling correction.

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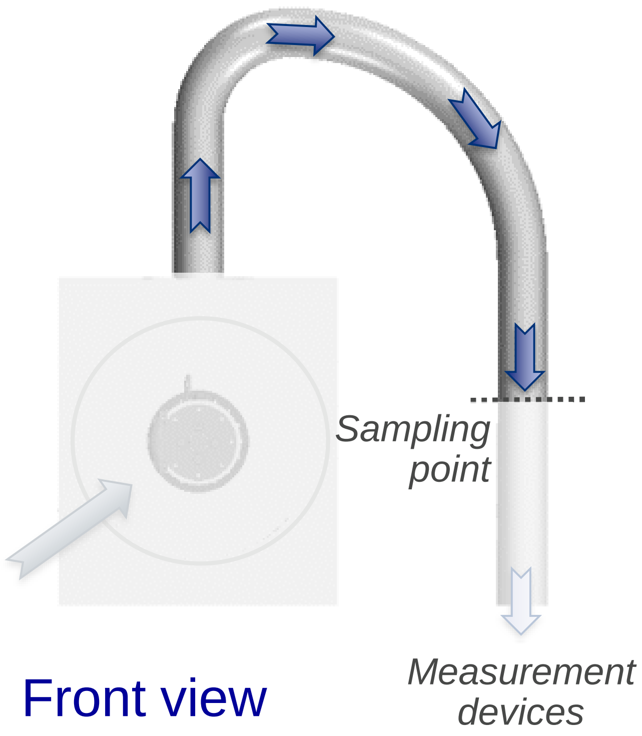
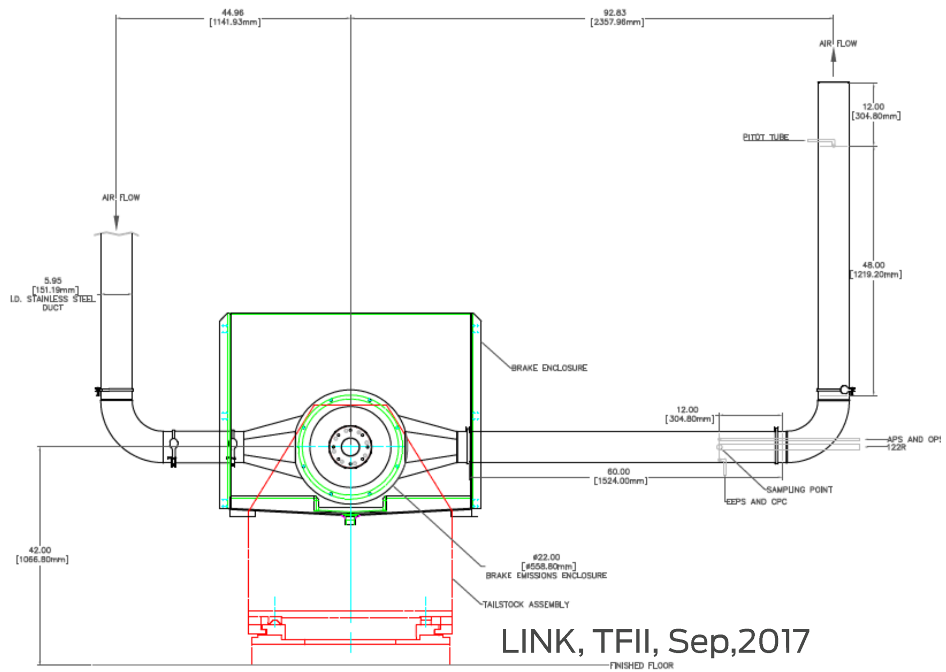
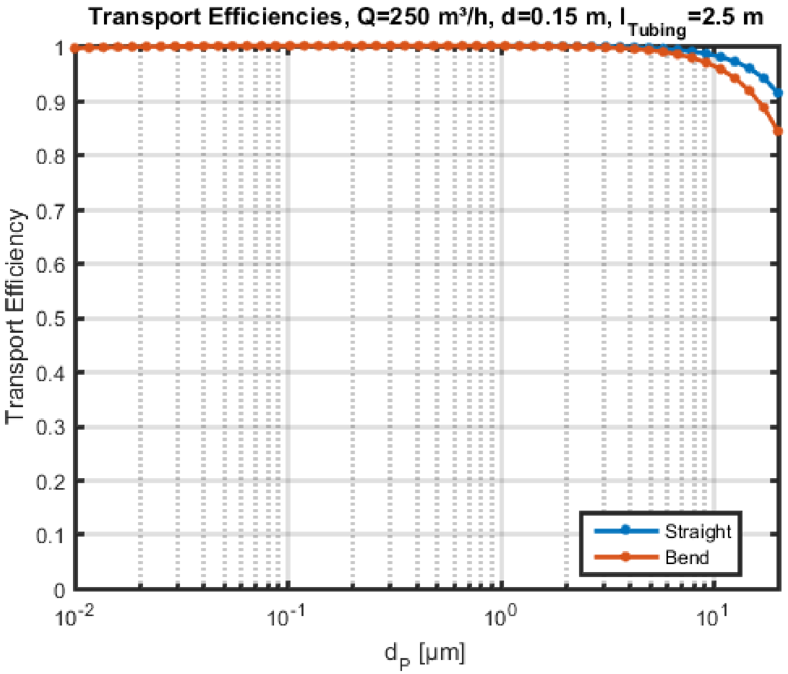
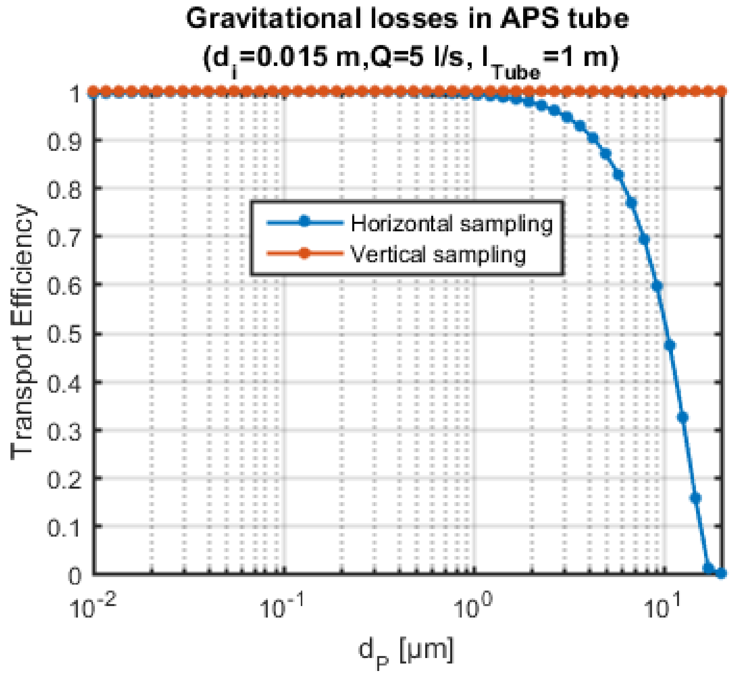
BRAKE WEAR MEASUREMENT SETUP



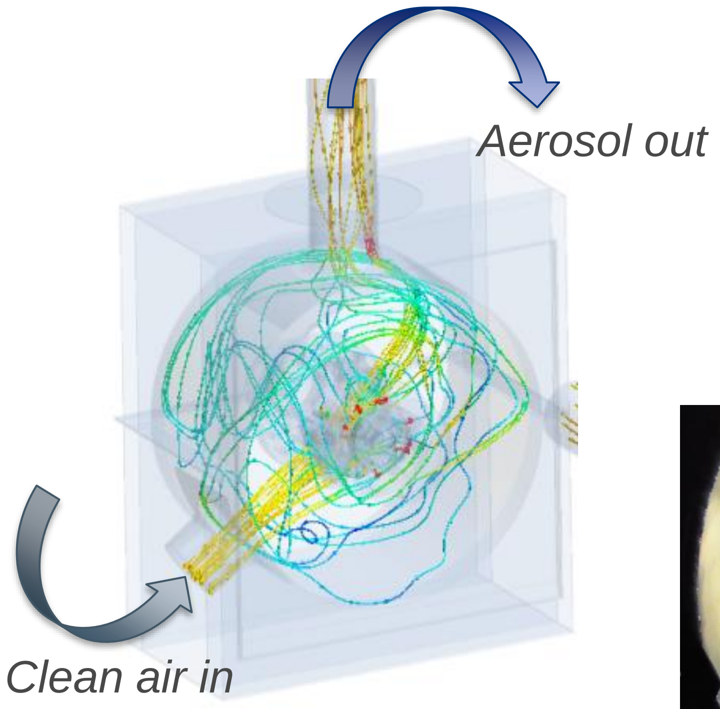




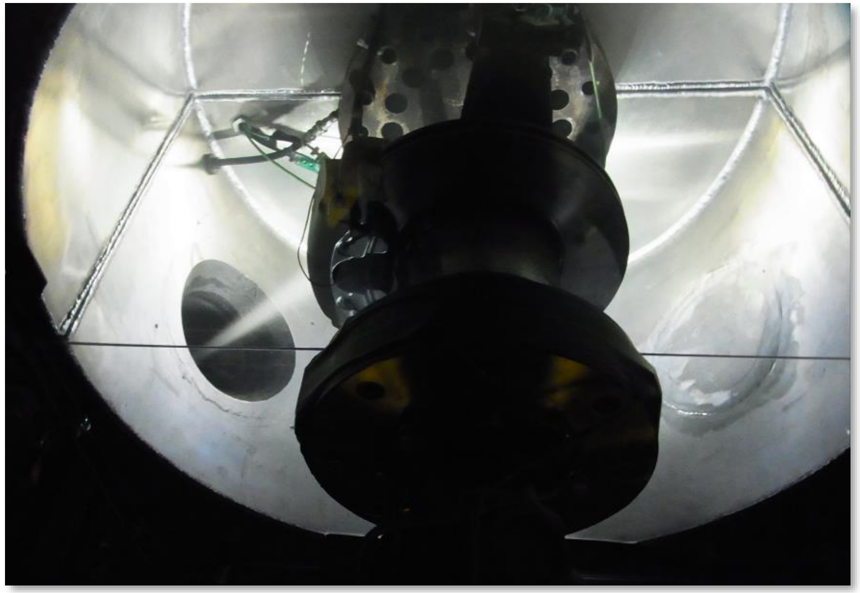


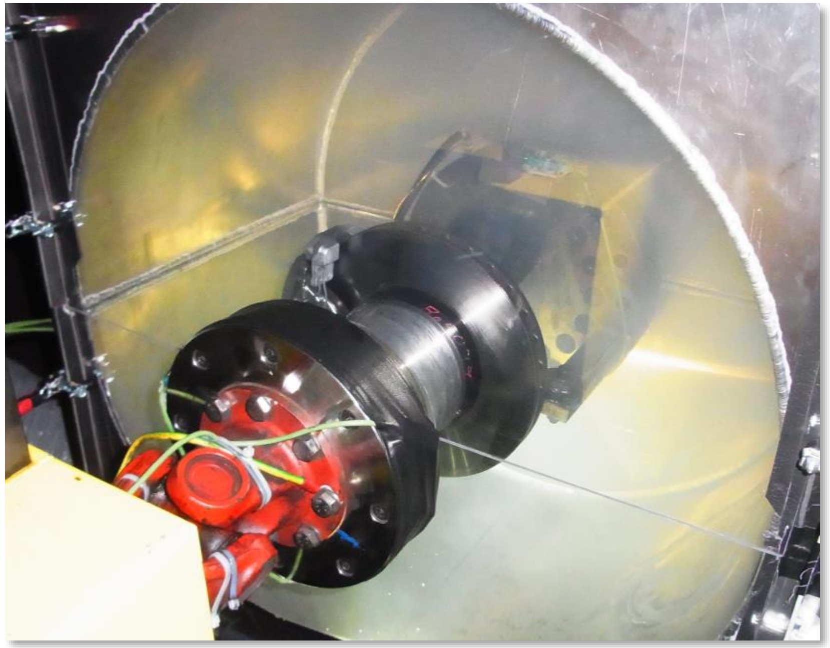
- Transport lines vs. sampling lines.
  High losses for large particles may occur
  - if sampling is performed non-vertical
  - if long (bended) sampling lines are used

CFD- TURBULENT MIXING

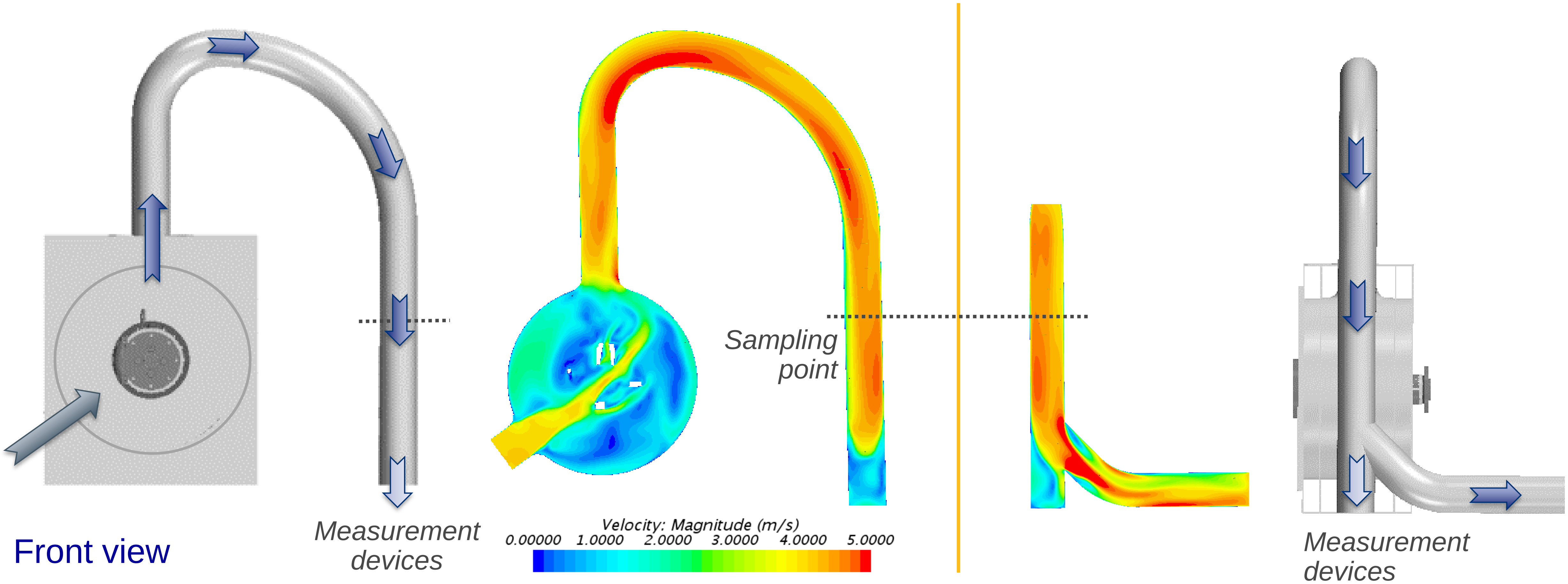


- Inlet and outlet positions are optimized to achieve turbulent mixing
- CFD confirms desired turbulent chamber flow

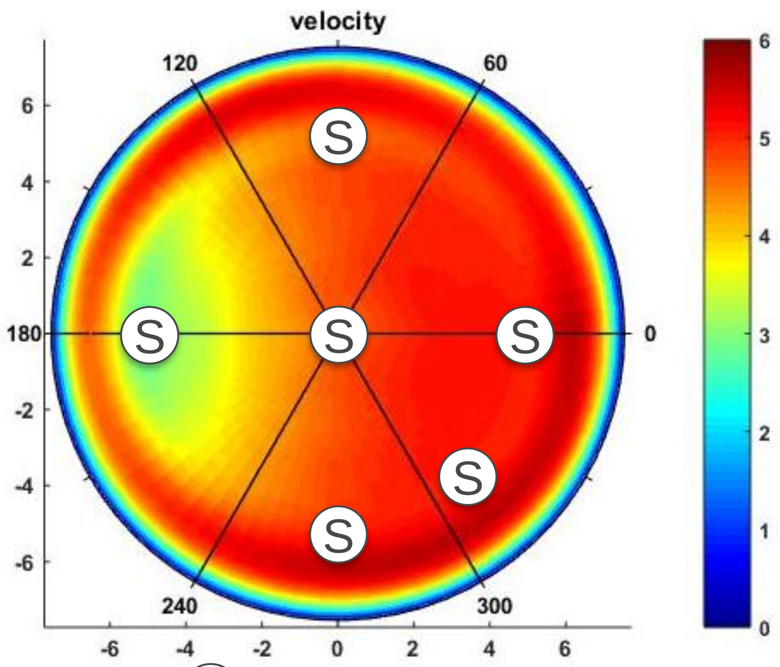




CFD – FLOW FIELD

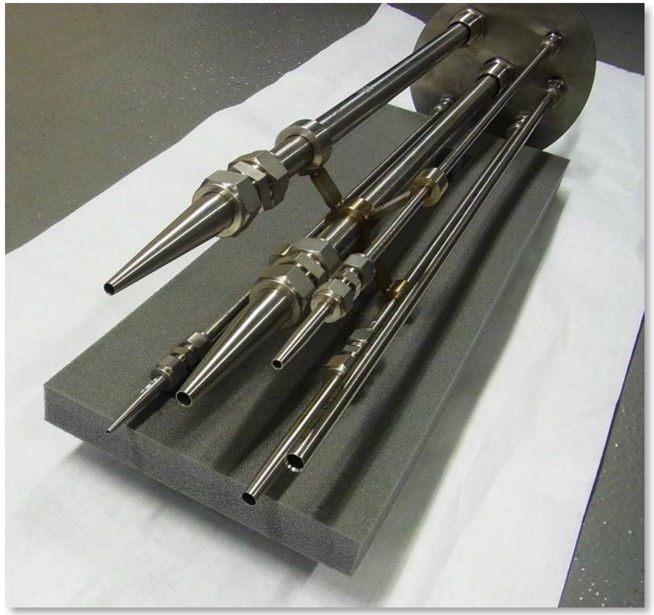


FLOW FIELD MEASUREMENTS I



S *Sampling points*

- Air velocity profile is in good agreement with CFD simulations



- Probe customized according to air velocity profile → isokinetic sampling
- Is the aerosol intermixing sufficient?
- Are there different concentrations due to different sampling points within the tube?

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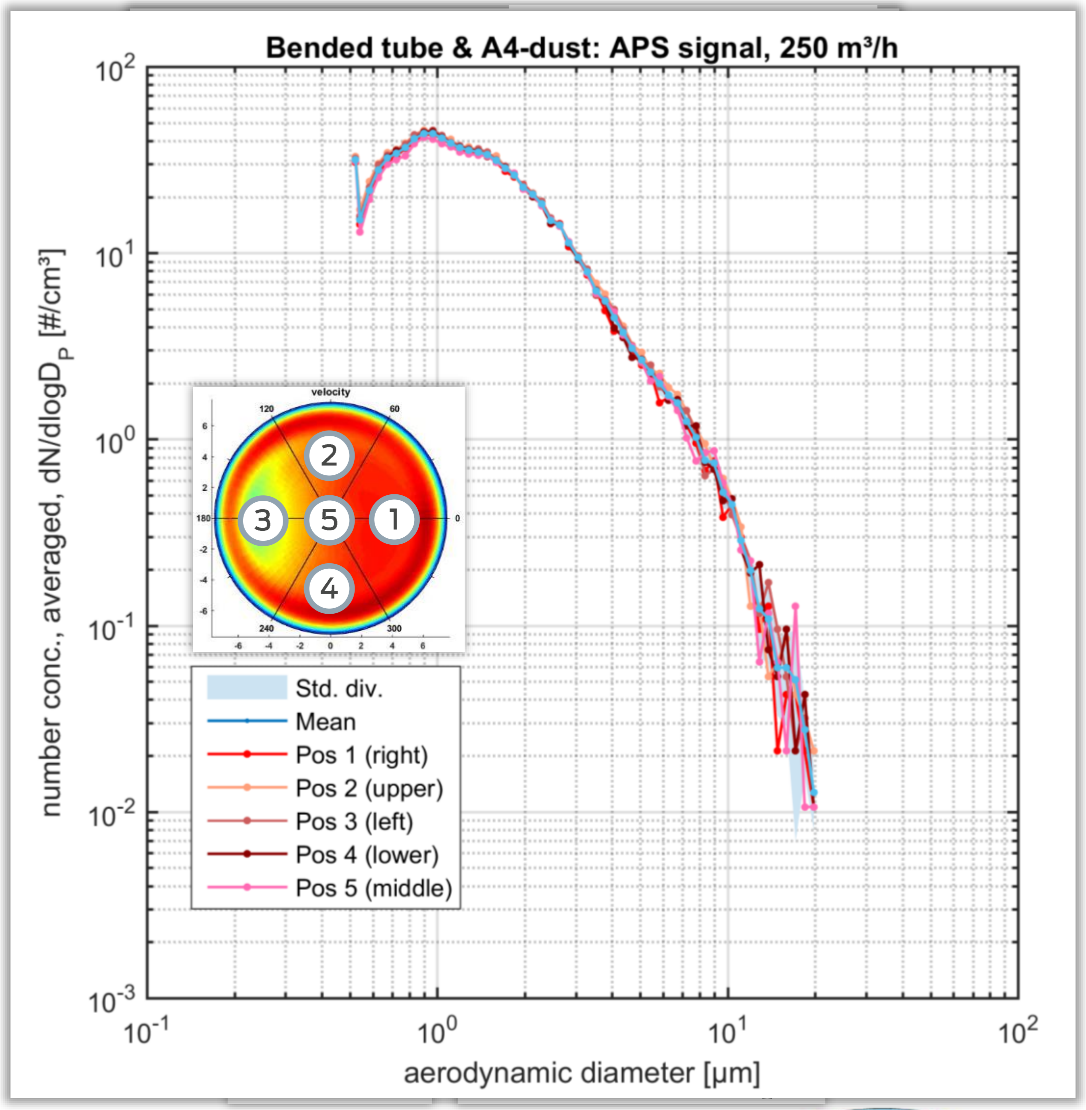
FLOW FIELD MEASUREMENTS II

Potential pitfalls:

- Is the aerosol intermixing sufficient?
- Are there different concentrations due to different sampling points within the tube?

- Pre-tests series starting with straight tube only. Afterwards repetition with “bend-setup” using A1 & A4 test dust.
- Finally, testing with measurement chamber and “bend-setup”.
- Conclusions:
  - No influence of inhomogeneous flow field on particle concentration found. Aerosol is well-mixed, i.e. no measurable differences in particle concentrations found.



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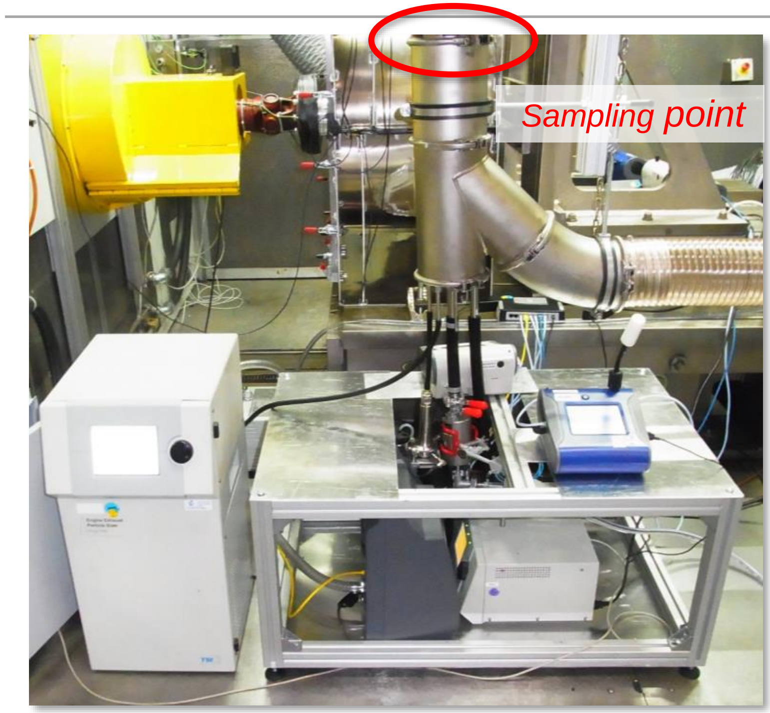
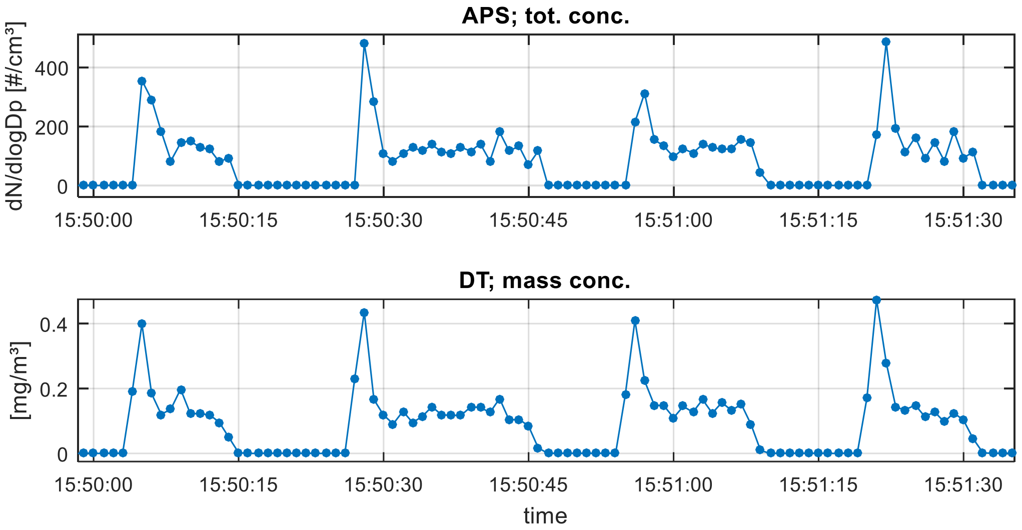
CHAMBER EXCHANGE RATE



- Sampling geometry according to $v_{air,tube}$ → isokinetic sampling
- Simultaneous measurement with multiple devices is possible
- Almost all devices are placed directly underneath sampling point
  → Gravitational losses and particle deposition in bend are avoided

Initial experiments:

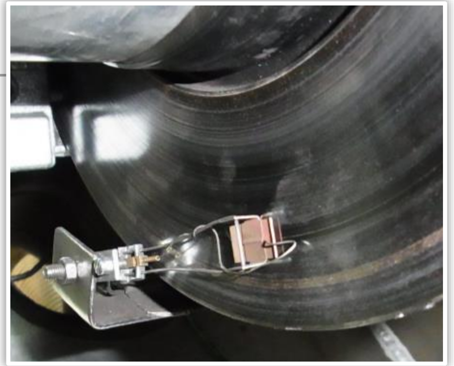
- A1 dust released in chamber
- On/off signals



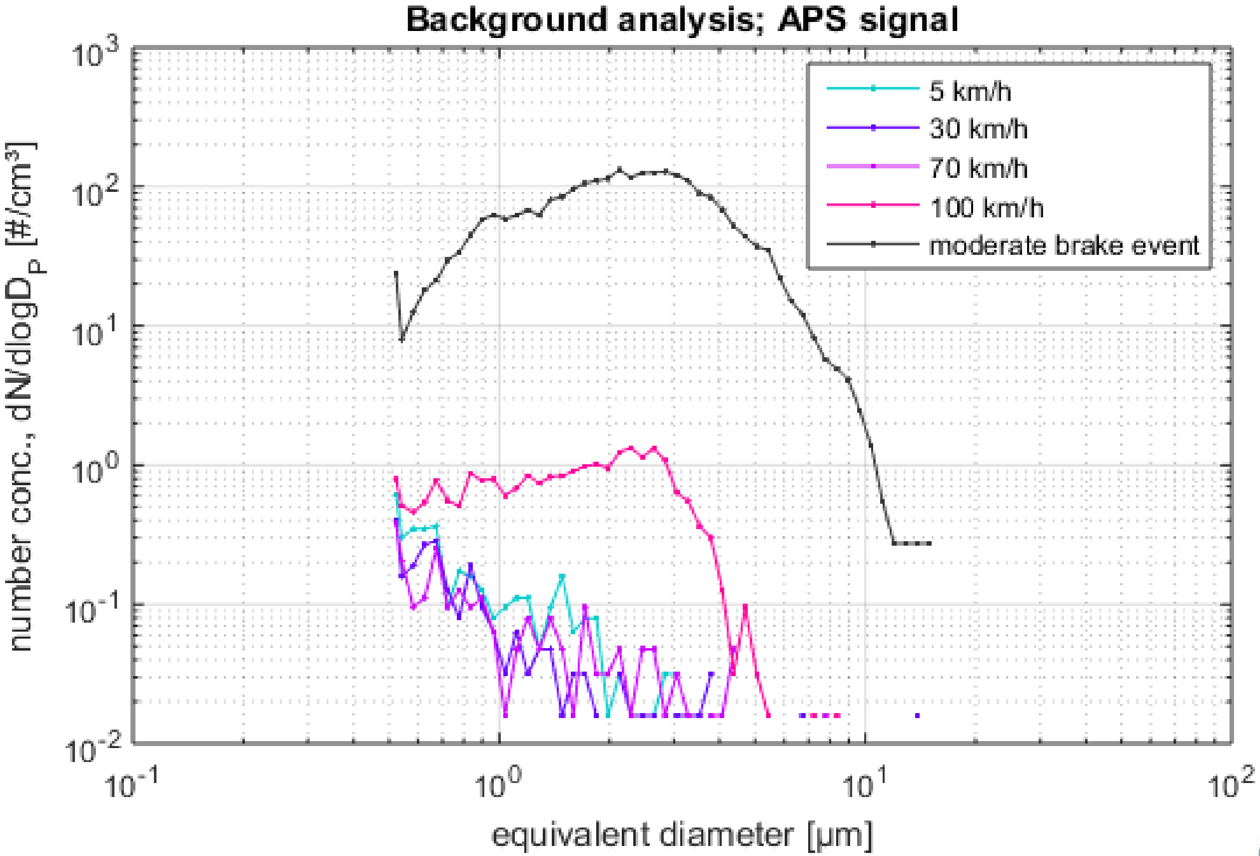
Signal decay time ~ 2 s

→ Agreement with exchange time of chamber volume (3 s)

BRAKE WEAR MEASUREMENT SETUP



- Are there particle contributions from the **drive shaft sealing/sliding thermocouple**?
  - Enclosed chamber, almost zero background contribution
  - Disc rotation stepwise from 0 to 100 km/h (brake caliper dismounted)



- ➢ A small increase above background concentration levels appears at 100 km/h with sliding thermocouple installed
- ➢ Setup is capable of detecting even very subtle increases in concentration levels

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SUMMARY

- Systematic development and characterization of a measurement system for brake wear particle emissions
- Key advantages of setup design:
  - High transport efficiencies over large particle size range
  - Controlled dust dilution → quantitative measurements
  - Parallel sampling → multiple analysis is possible
- Initial results:
  - Very low background signal due to HEPA filtered air
  - High signal to noise ratio → high sensitivity
  - Fast response time → precise signal mapping