“Analysis of influence parameters during sampling of brake dust particle with a constant volume sampling system”

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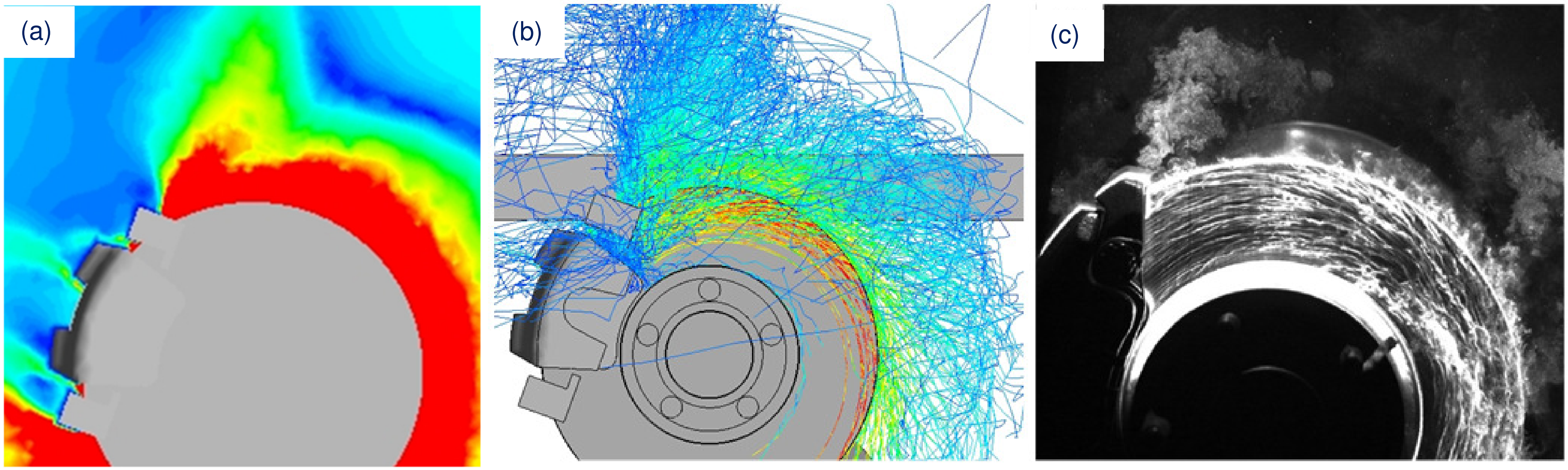
Analysis of Influence Parameters for CVS Measurement
1. Introduction: CFD Modelling



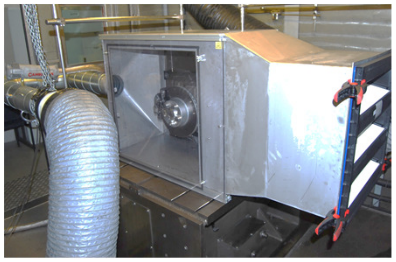
→ **flow set up validated by PIV (Particle Image Velocimetry)**

→ **visualization of brake dust particle behavior depending of pariticle properties (i.e. aerodynamic diameter)**

→ **analysis of influence parameters for sampling of brake dust particle with a constant volume sampling system (CVS).**

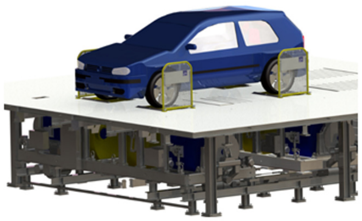
Analysis of Influence Parameters for CVS Measurement
1. Introduction: Measurement Strategy

Inertia Brake Dyno



- *reproducible load parameters and environmental conditions*
- *stationary emission measuring systems*

Chassis Dynamometer



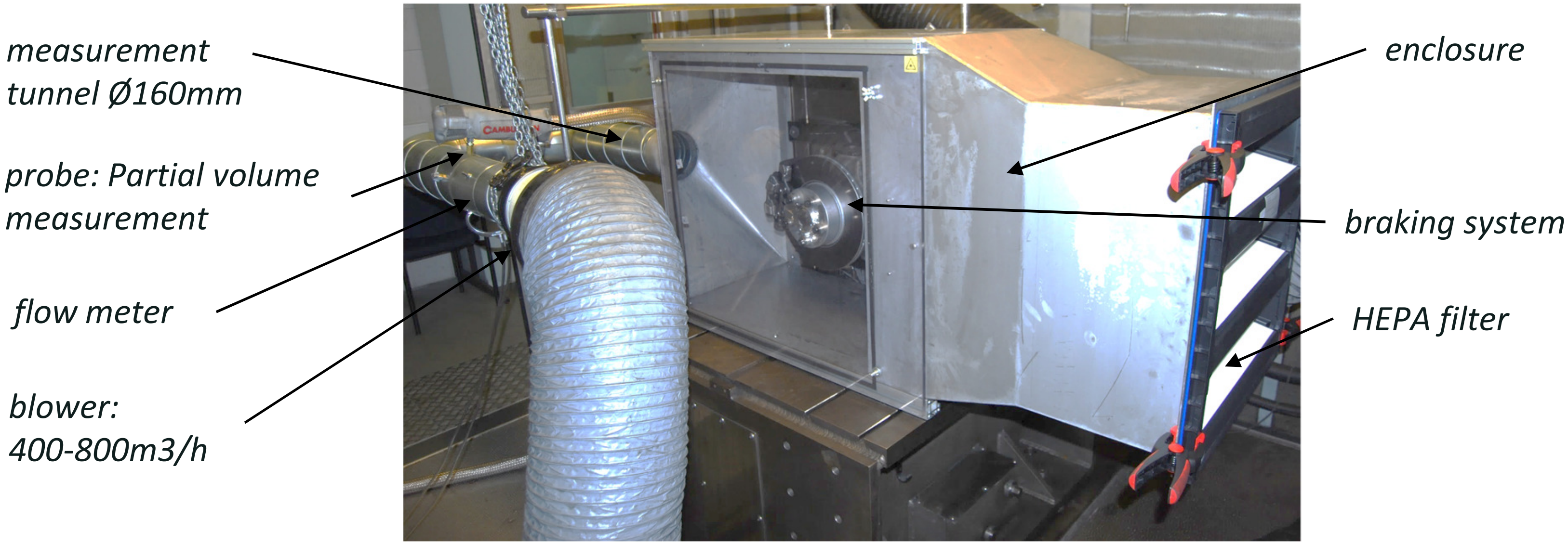
- *reproducible load parameters and environmental conditions*
- *maneuver based RDE-testing*
- *portable (PEMS) and stationary emission measuring systems*

Road Tests / RDE

- *dynamic driving conditions*
- *investigation the influence of the driver*
- *PEMS measuring systems*
- *investigation the influence of different road conditions*

- realistic emissions behaviour
- complexity / poor reproducibility
- investigation costs

Analysis of Influence Parameters for CVS Measurement
1. Introduction: Measurement Strategy



Process-Related Parameters (CVS)

1. *enclosure (chamber) placed around the brake system*
2. *evacuation of the particle-volume by a constant and controlled air flow*
3. *sampling (partial volume) in the transport line*

Analysis of Influence Parameters for CVS Measurement
1. Introduction: Measurement Requirements

Aim: Dyno-Measurement of PN and PM

Requirements	Physical Processes
• high inlet efficiency	• high Transport efficiency: Low particle deposition on CVS-chamber walls • high sampling efficiency: Isokinetic sampling
• *high reproducibility*	• well premixed aerosol • constant aerosol flow
• *minimized aerosol modification (agglomeration)*	• *reduced particle-particle interaction (particle residence time)*
• multi-device-measurement	• flow splitter • multiple probes
• minimized background concentration	• filtered inlet air • fully sealed chamber

Analysis of Influence Parameters for CVS Measurement
1. Introduction: Measurement Requirements

Aim: Dyno-Measurement of PN and PM

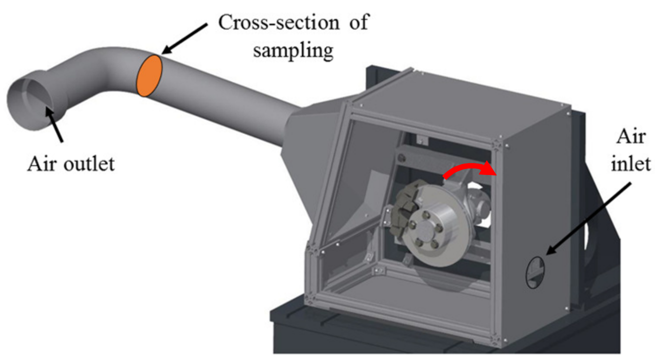
Approach

- analysis of particle behaviour within an existing CVS for brake dust emissions
- insight on how influence factors effect the measurement result

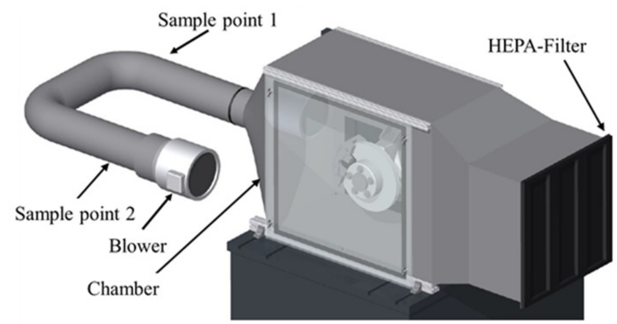
Solution

- development of a newly designed CVS based on **CFD-Simulation** results
- additional: Fully sealed chamber design / HEPA-filtered inlet air

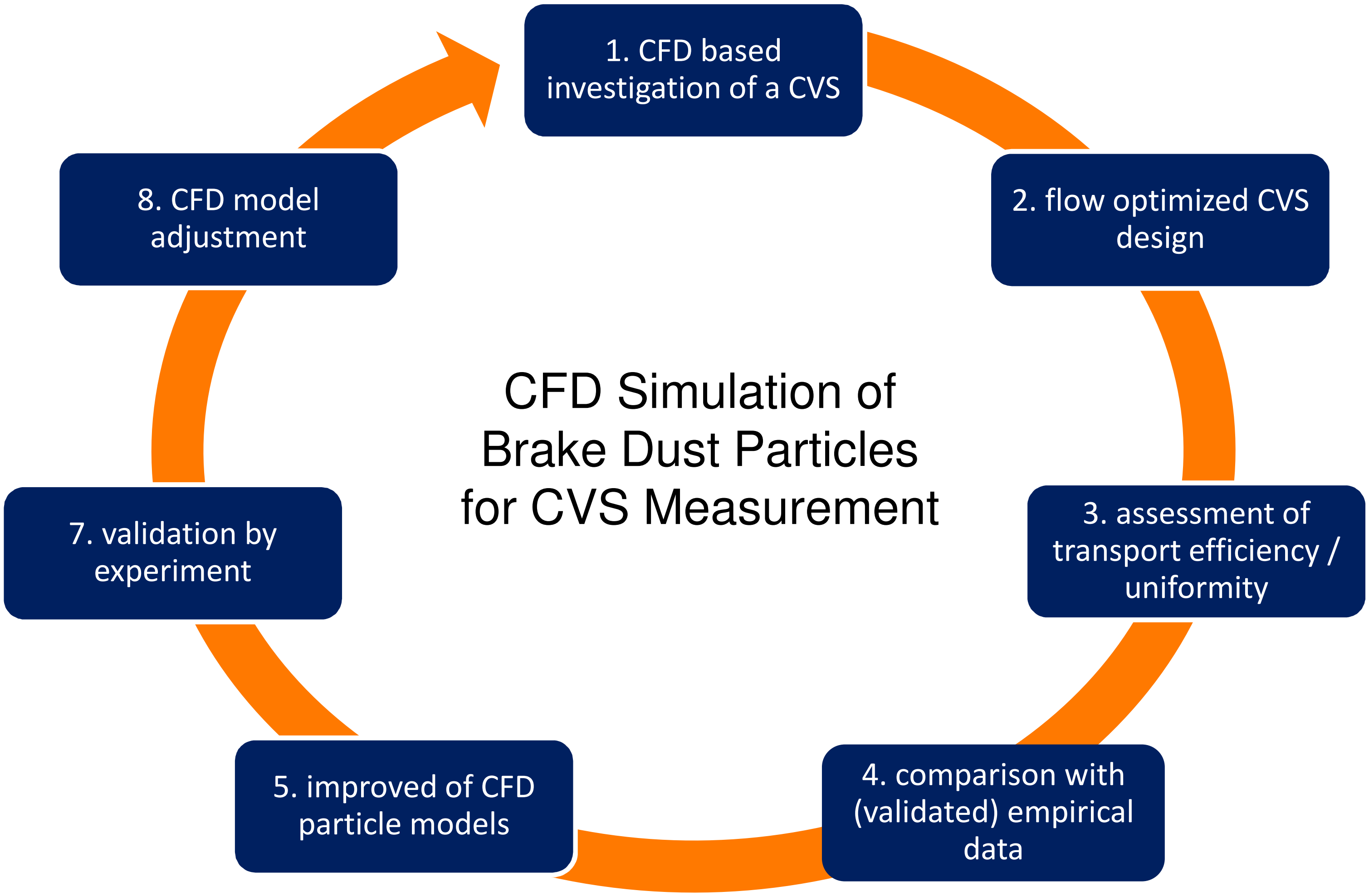
CVS - 1st Generation



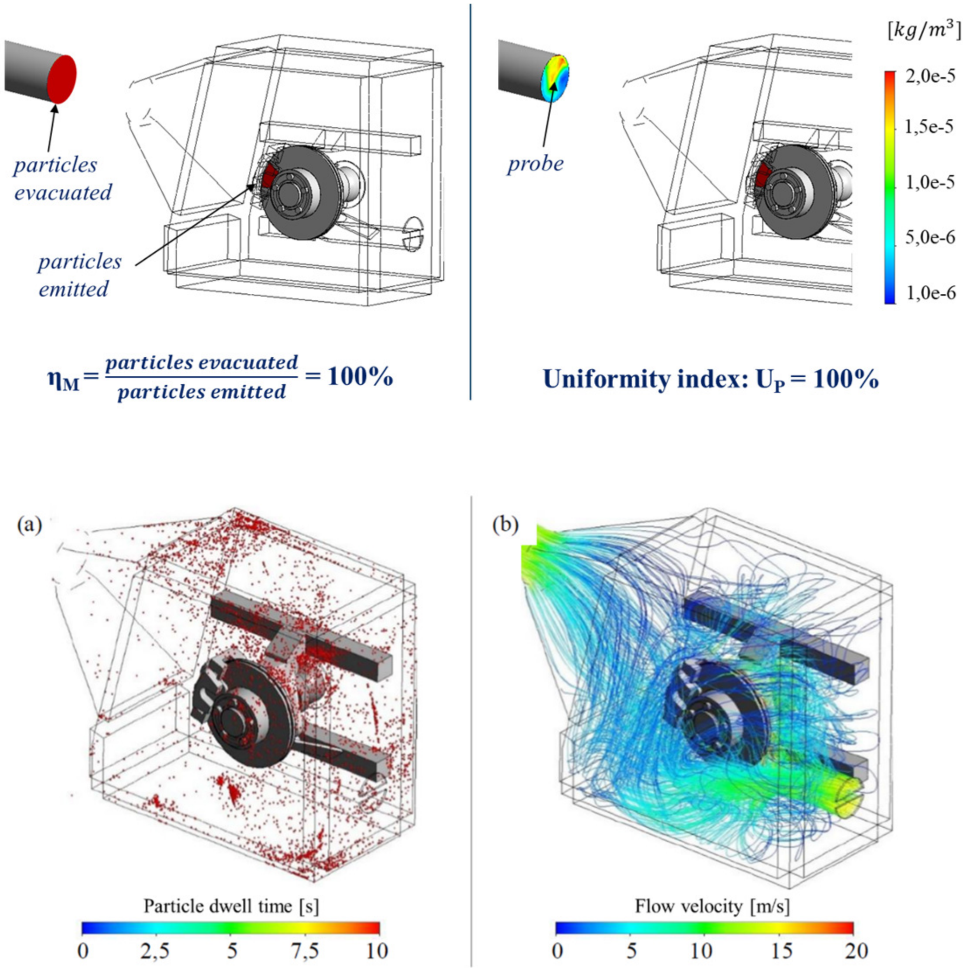
CVS - 2nd Generation



Analysis of Influence Parameters for CVS Measurement
2. Analysis: Roadmap – Improved CVS / CFD Model



Analysis of Influence Parameters for CVS Measurement
2. Analysis: CVS 1st Generation



*Investigation of particle **transport efficiency*** η_m *and **particle uniformity*** U_p *across the measurement tunnel diameter, where the particles sample is abstracted by the probe. (particle size range 0,1-4µm)*

Results:

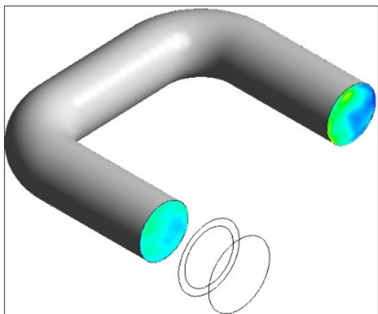
- *Highly turbulent flow inside the enclosure leads to inconsistent particle-air mixing as well as inconsistent particle deposition, which results in a nosy measurement signal (observed during measurement).*
- *High particle residence time inside the chamber up to 8s (diffusion losses / agglomeration).*

→ Development of improved CVS 2nd generation with streamline flow design

Analysis of Influence Parameters for CVS Measurement
2. Analysis: Development CVS 2nd Generation

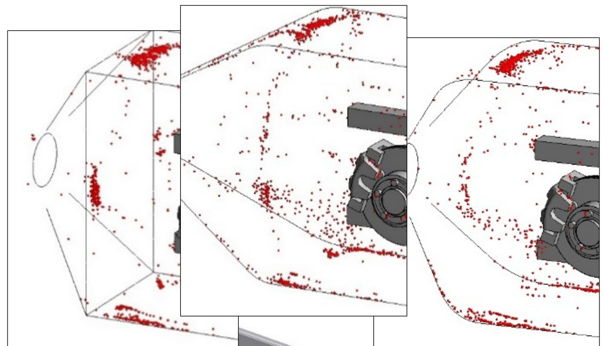
Measurement Tunnel:

- *well premixed particle flow: Strongly improved uniformity*



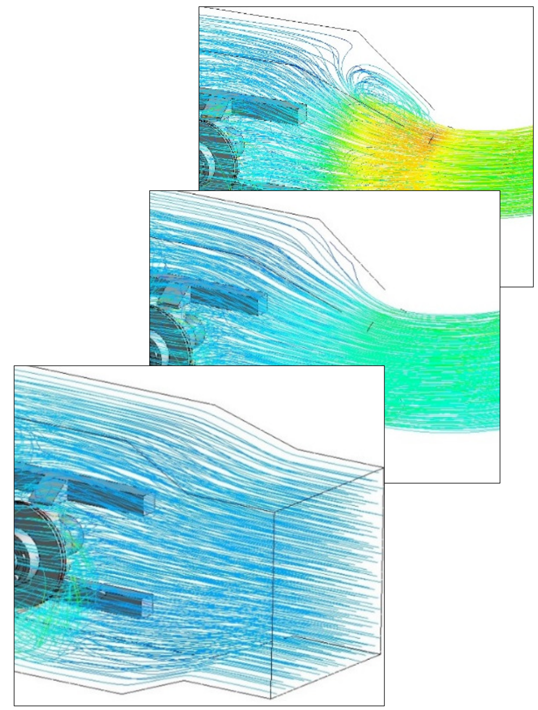
Chamber Outlet:

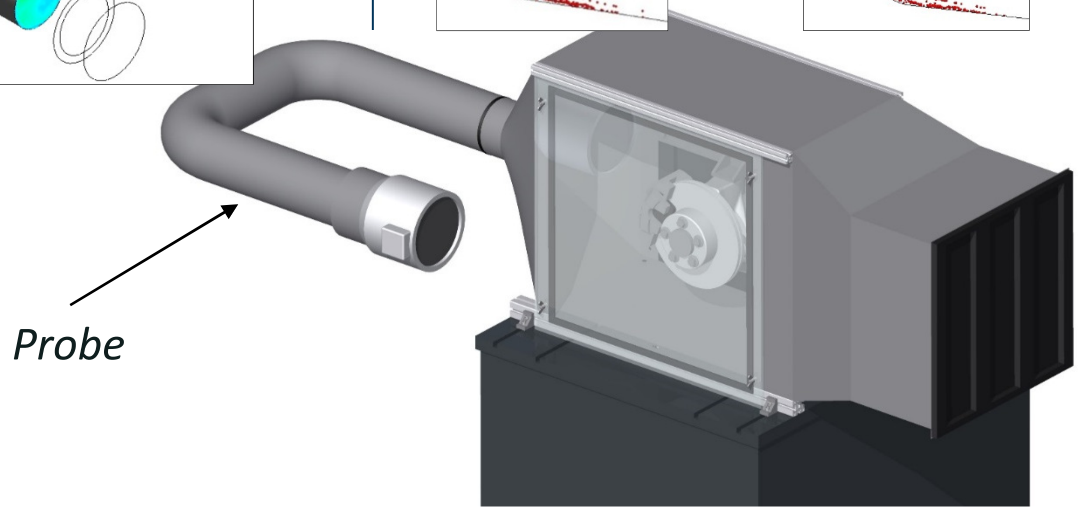
- *improvement of transport efficiency*



Chamber Inlet:

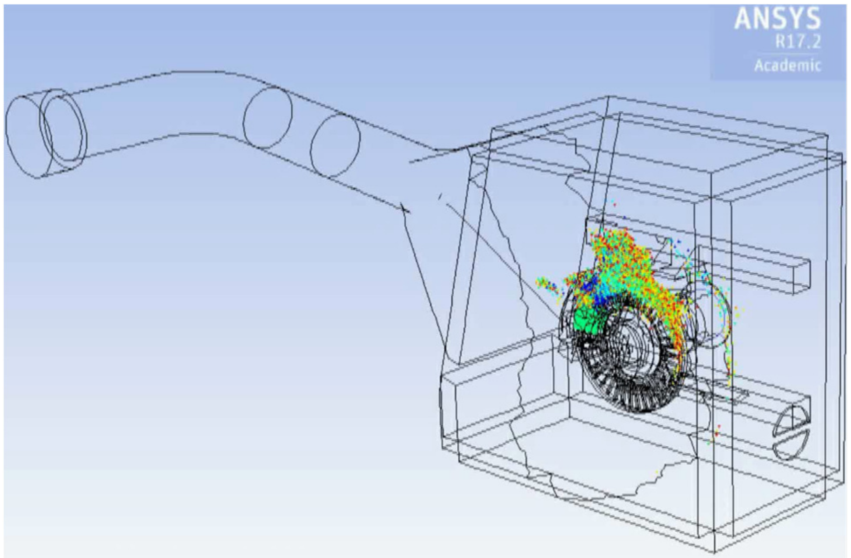
- *linearized air flow*
- *Integration of a particle filter (H13)*





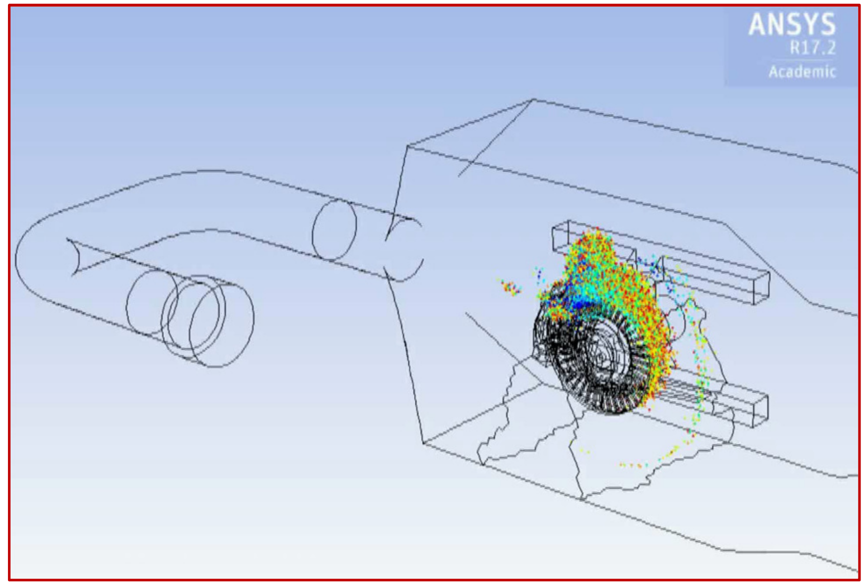
Analysis of Influence Parameters for CVS Measurement
2. Analysis: Development CVS 2nd Generation

CVS - 1st Generation



- *complex assessment of particle behaviour*
- *slow evacuation / high particle residence times*

CVS - 2nd Generation

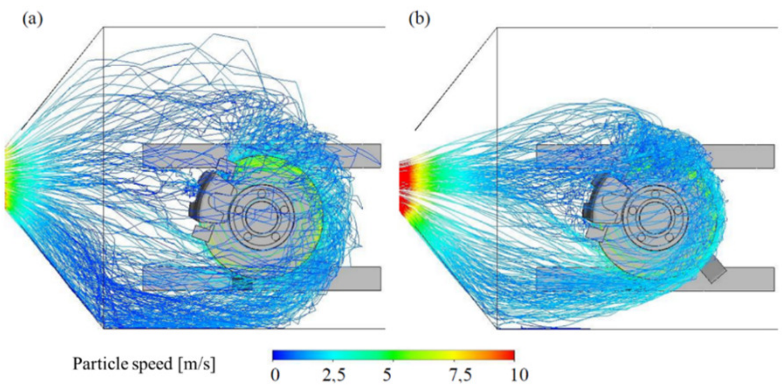


- *Foreseeable particle trajectories*
- *fast and direct evacuation*

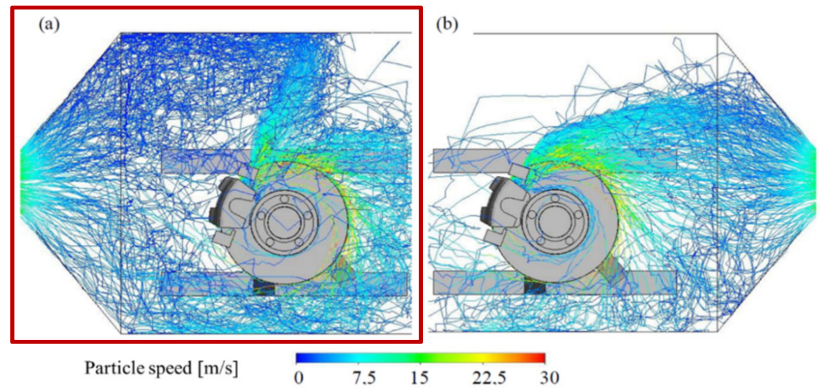
→ ***TU Ilmenau focus***

Analysis of Influence Parameters for CVS Measurement
2. Analysis: Volume Flow and Suction Direction

Volume Flow:



Suction Direction:



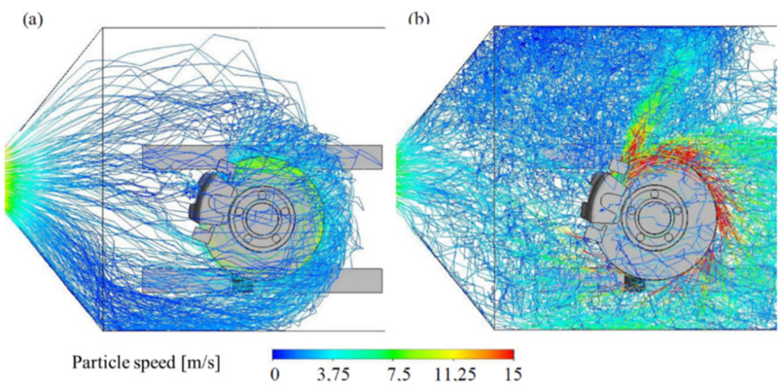
CFD based results indicate a significant dependence of transport losses and particle uniformity form:

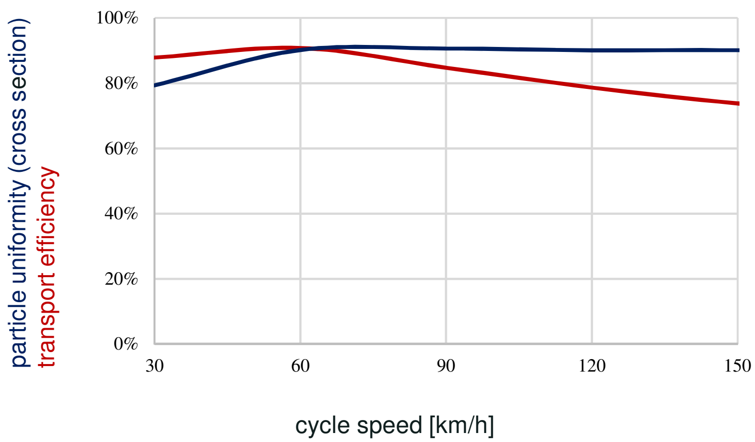
- *volume flow*
- *suction direction*
- *disc rotation speed*

→ ***Challenge:*** *Indirect proportional correlation between particle mixing and transport efficiency.*

→ ***Compromise needed****: Evacuation in* ***reverse particle stream initial direction*** *(depending on disk rotation and caliper layout) with* ***maximum air flow****, to ensure maximum particle mixture and transport efficiency at the same time.*

Analysis of Influence Parameters for CVS Measurement
2. Analysis: Disc Rotation Speed



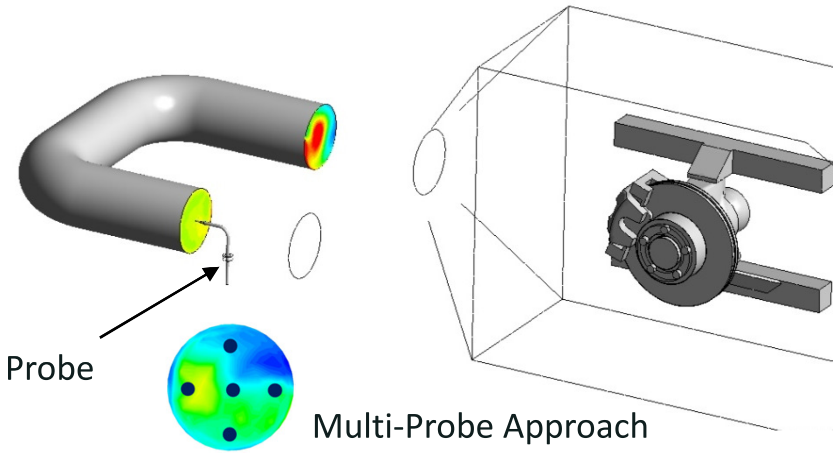


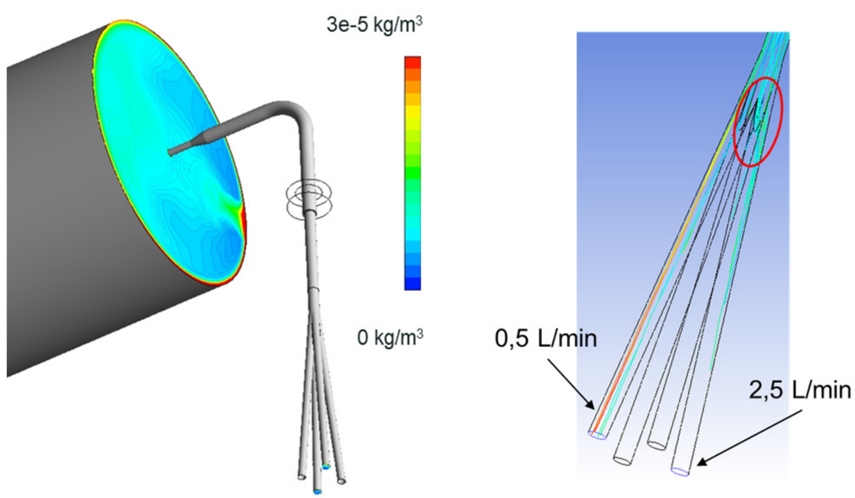
Disc Rotation Speed:

- *Disc rotation velocity is the only influence factor that varies during measurement.*
- *Centrifugal forces affect the initial particle velocity, which leads to additional particle mixing but also has a negative effect on particle deposition as particles are forced against the chamber walls.*
- *The CFD models shows a optimal particle uniformity across the measurement tunnel diameter for 60-150km/h while transport efficiency decreases linearly with increasing rotational speed.*

→ CFD Simulation offers the possibility to assess the amount of particles lost inside the CVS depending on the test cycle.

Analysis of Influence Parameters for CVS Measurement
2. Analysis: Probe and Flow Splitter



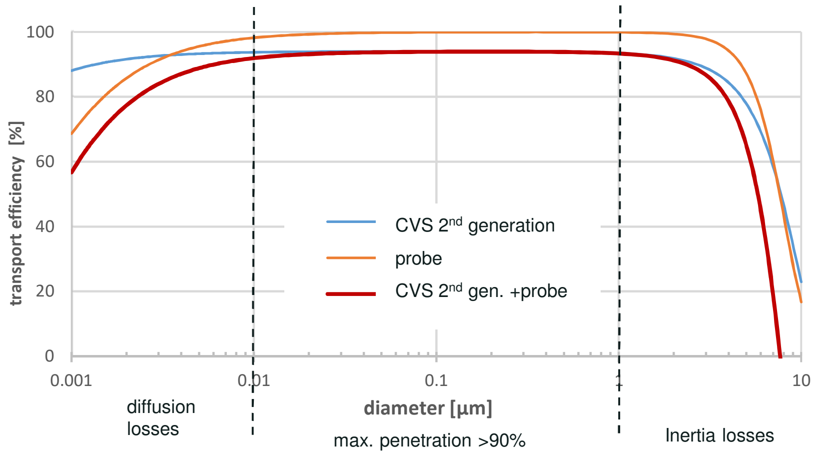


- *Isokinetic sampling: Probe inlet diameter has to be adjusted with regard to the measurement device sample flow.*
- *For $PM_{2,5}$ no considerable measurement deviation (<5%) due to partial volume sampling was found (validated by experiment). For bigger particle sizes deviation increases significantly due to inertia (CFD).*
- *For coarse particles (>2,5µm) parallel measurement by means of a flow splitter should be avoid, as coarse particles tend to keep their initial path, which leads to over / under representation.*

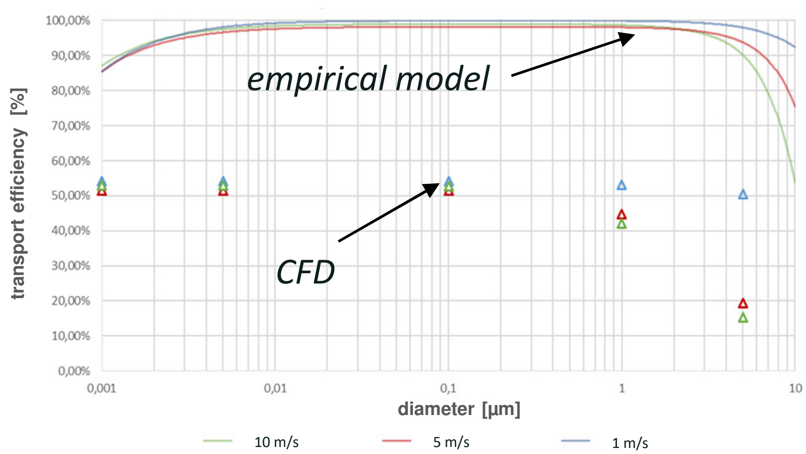
→ ***CVS 2nd Generation is $PM_{2,5}$ ready***

→ ***Better solution for PM_{10}: Multi-Probe?***

Analysis of Influence Parameters for CVS Measurement
2. Analysis: Comparison CFD / Empirical Model



Simple Bend Tube



- *Empirical model (validated by experiment) shows transport efficiency optimum between 0,01-1µm for CVS.*
- *Below 0,01µm diffusion losses and above 1µm inertia losses are observed. Due to inertia, sufficient measurement of particles >5µm is not possible.*
- *Currently there is no CFD particle deposition model available to match the empirical results.*

→ ***CVS 2nd generation is PM2,5 ready / New Approach for PM_{10} needed***

→ ***Advantage CFD: Contemplation of brake system specific effects / assessment of PN and PM measurement***

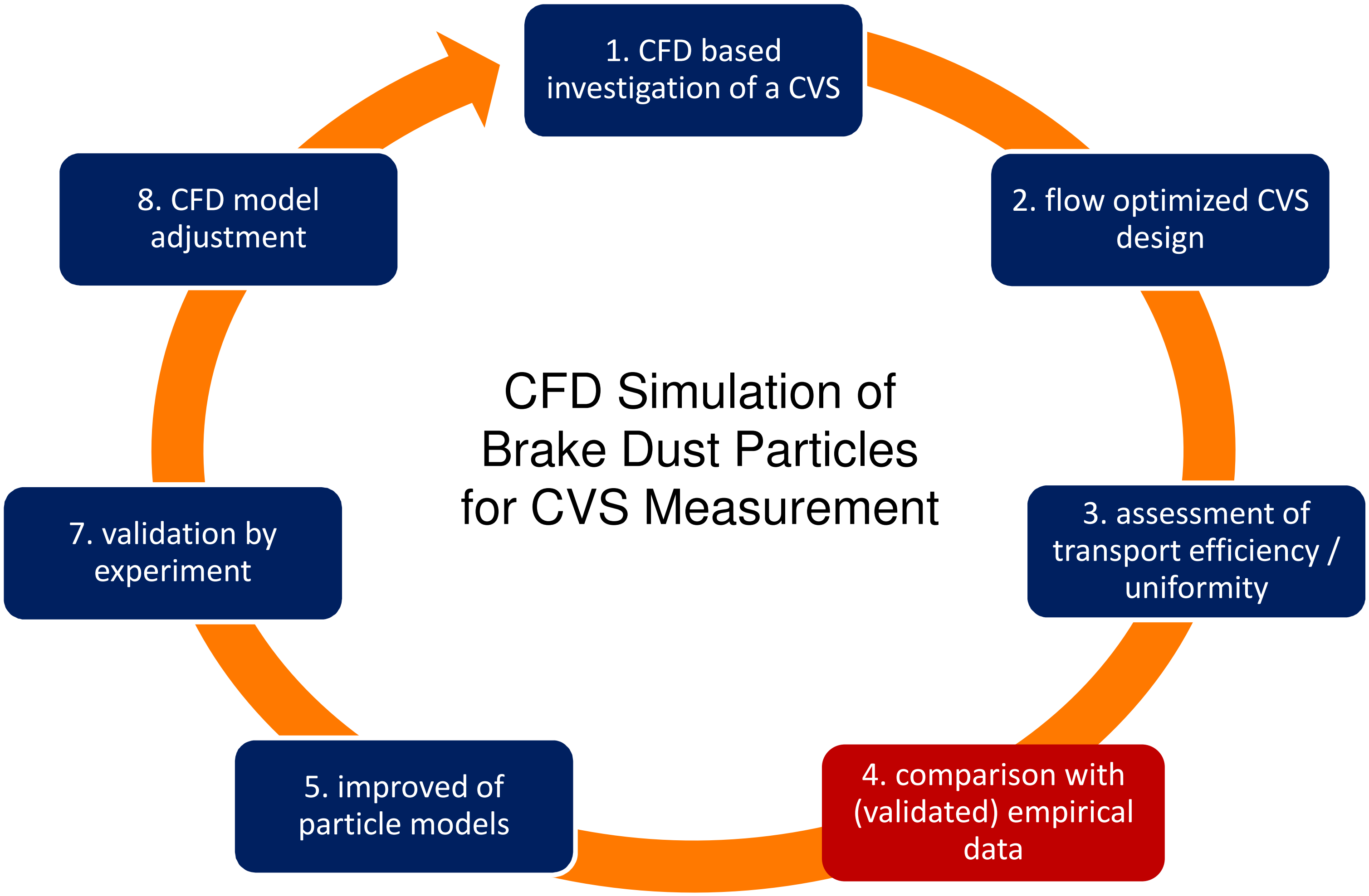
→ ***Current work: Development of an CFD-deposition model for brake dust emissions***

Analysis of Influence Parameters for CVS Measurement
3. Summary and Conclusions

Aim: Dyno-Measurement of PN and PM

Summary	Conclusions / Limitations
• investigation of CVS 1st generation regarding particle-air interaction	• highly turbulent flow: Inconsistent uniformity and transport losses, high particle residence time
• development of an advanced CVS 2nd generation	• linearized particle behaviour, enhanced uniformity and transport efficiency
• investigation of Influence factors	• *CVS 2nd Generation is $PM_{2,5}$ ready* • indirect proportional correlation of uniformity and transport efficiency • CFD provides possibility to assess particle losses depending on the test cycle
• comparisons with empirical models	• development of an CFD-particle deposition model fitted for brake dust emissions • further validation necessary

Analysis of Influence Parameters for CVS Measurement
3. Summary and Conclusions



Analysis of Influence Parameters for CVS Measurement
4. Outlook: Open Questions

Aim: Dyno-Measurement of PN and PM

Outlook	Open Questions
• Influences of particle deposition	• material properties: particle chemical composition (Hamakar-constant, density etc.)? material and surface condition of the CVS? • particle shapes: depending on particle size? • electrostatic effects? • thermophoresis: heated particles / cold chamber walls?
• PM_{10}-Measurment	• transport efficiency: Sufficient measurement possible? (inertia) • Uniformity: Multi-Probe?
• *further influences*	• *background concentration: cleaning of chamber walls?*

Analysis of Influence Parameters for CVS Measurement
4. Outlook: RDE Testing

Aim: Real Drive Emission Measurement of PN and PM

Outlook

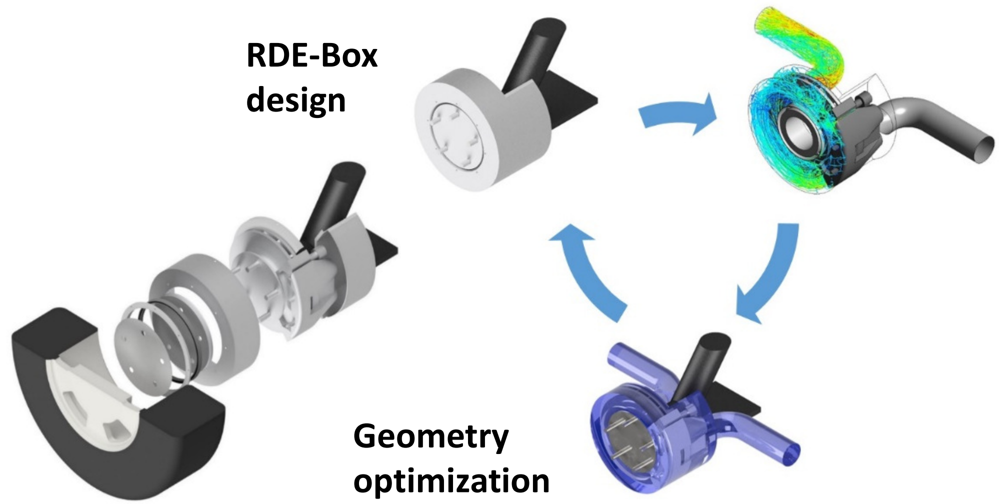
RDE Testing

- *Use lessons learned under reproducible conditions at the brake inertia dynamometer to develop a RDE system.*

→ ***Challenge: Fully enclosed system in proximity to rotating components (brake disk / rim), exposed to heated brake disk as well as environmental influences (moisture).***

CFD:

- Max. transport efficiency
- Max. uniformity
- Min. pressure difference



Analysis of Influence Parameters for CVS Measurement
4. Outlook: RDE Testing

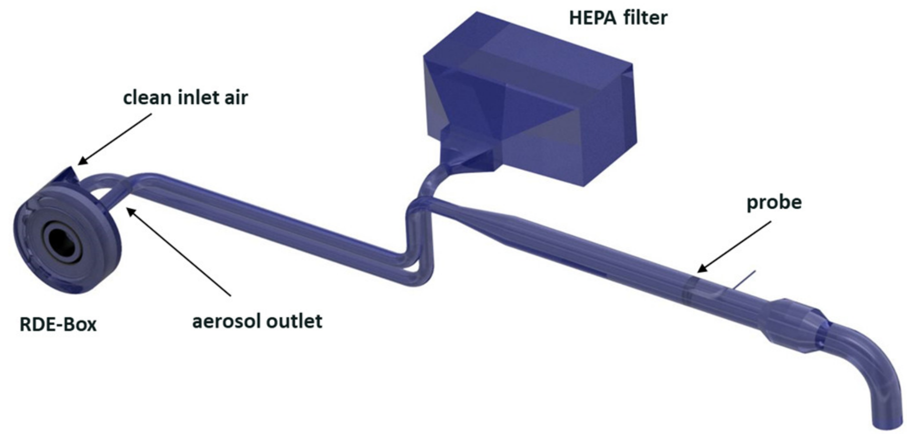
Aim: Real Drive Emission Measurement of PN and PM

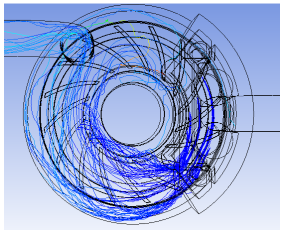
Outlook → **RDE Testing**

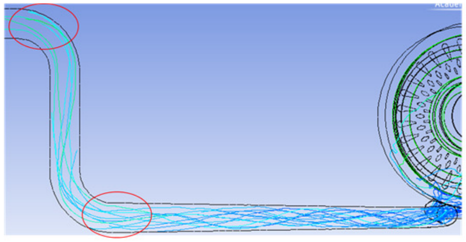
Measurement set up

- *Fully enclosed brake system: Complete collection of brake dust / exclusion of environmental influences.*
- *A H13 filter is used to eliminate external influences / battery powered blower is supplying volume flow.*
- *Particle loaded air is passed into the measurement tunnel / probe.*

→ Current work: Further CFD investigation for improved transport efficiency







Thank You for Your Attention!