SUREAL-23

UNDERSTANDING, MEASURING AND REGULATING SUB-23 NM PARTICLE EMISSIONS FROM DIRECT INJECTION ENGINES INCLUDING REAL DRIVING CONDITIONS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 724136

Overview

- Main achievements
- Novel instrumentation
- Particle sampling and conditioning system
- Measurements
- What' next

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Main Achievements

- **Innovative instrumentation:**
  - Advanced HM-DMA
    - Exceptional resolution and fast response.
    - Capable of measuring hot aerosol sample (minimal sampling/conditioning requirements).
  - Automotive ICAD
    - Light, compact and with low power requirements.
    - Capable of measuring hot aerosol sample.
  - Sizing-CPC
    - Novel instrument, combining particle size with particle number concentration measurements.
  - Particle composition instruments
    - Particle charging using photoelectric principal shows potential to identify PAH content.
    - Photoacoustic based instrument aims at identifying different particle components (e.g. metals).

- **Advanced Sampling System:**
  - Design based on a porous-tube and ejector diluter, including a Catalytic Stripper (CS), with minimal particle losses and excellent volatile and sulphur removal efficiency.

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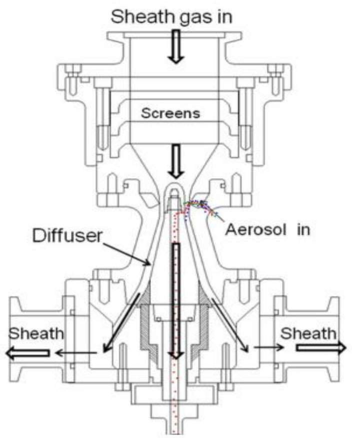
The Advanced Half-Mini DMA

- **Half-Mini DMA** is a commercially available instrument that offers:
  - High-resolution size classification in the range 1-15 nm
  - Compactness

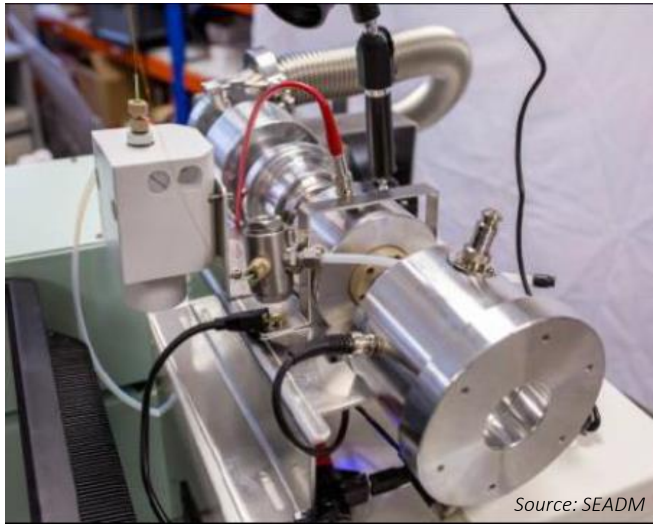
- Advancement during the project:
  - High resolution in extended size range (5–30 nm).
  - Accurate hot operation up to 200 °C.
  - Fast response time (down to 1 s).

The design



Fernández de la Mora J., Kozlowski J., *J. of Aerosol Science 57 (2013) 45–53*

The prototype



Source: SEADM

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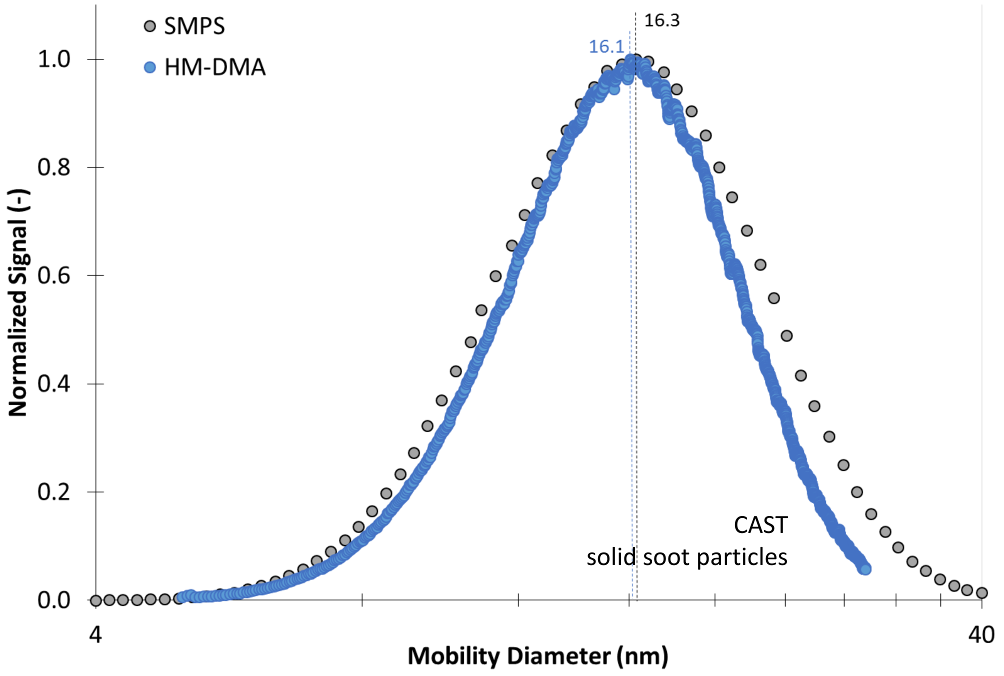
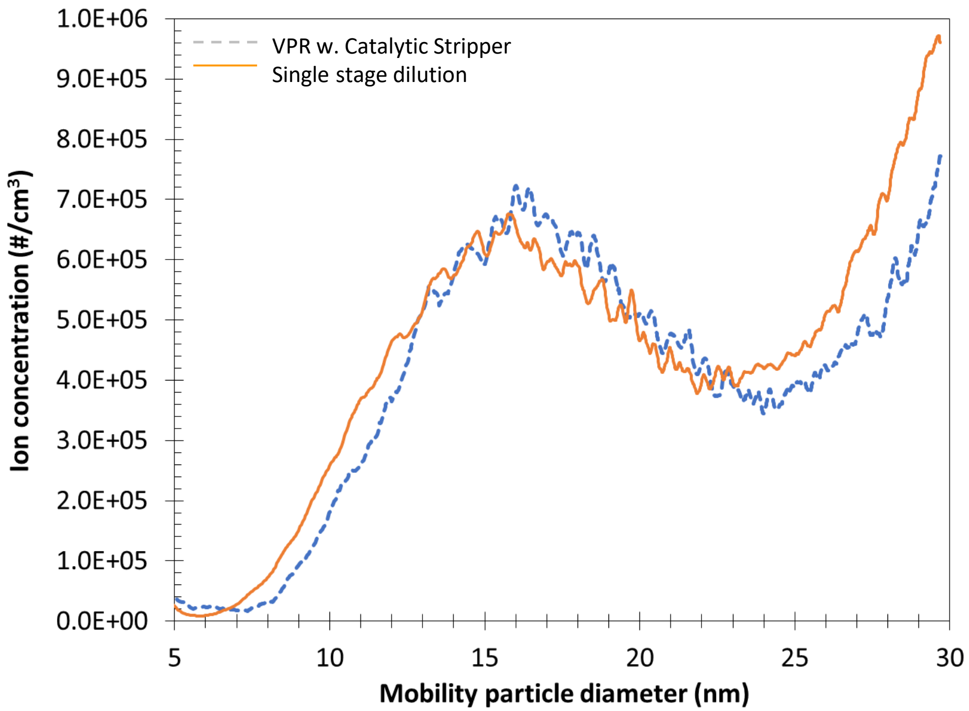
The Advanced Half-Mini DMA





- Solid soot particle size distributions measured by SMPS and Advanced HM-DMA (hot operation) are in excellent agreement.
- The excellent agreement between the two measurements indicates that a single hot dilution stage can be used alternatively to the PMP-compliant VPR.

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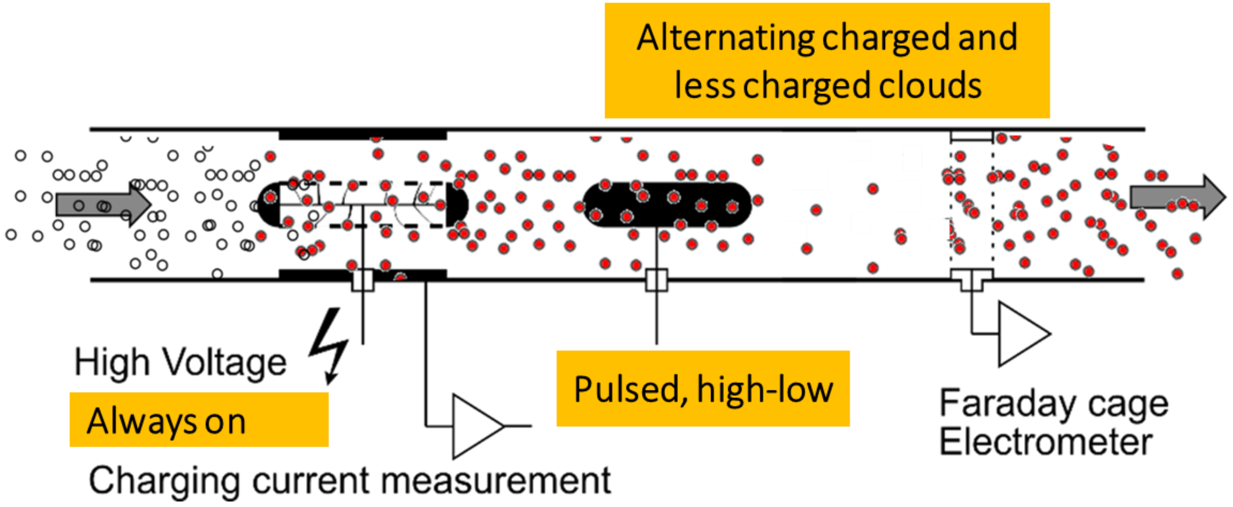
Automotive ICAD



ICAD: Induced Charge Aerosol Detector

Objectives

- Optimize settings to achieve d_{50} =10 nm.
- High temperature operation at 180 °C.
- Increase robustness and reliability for PEMS applications.

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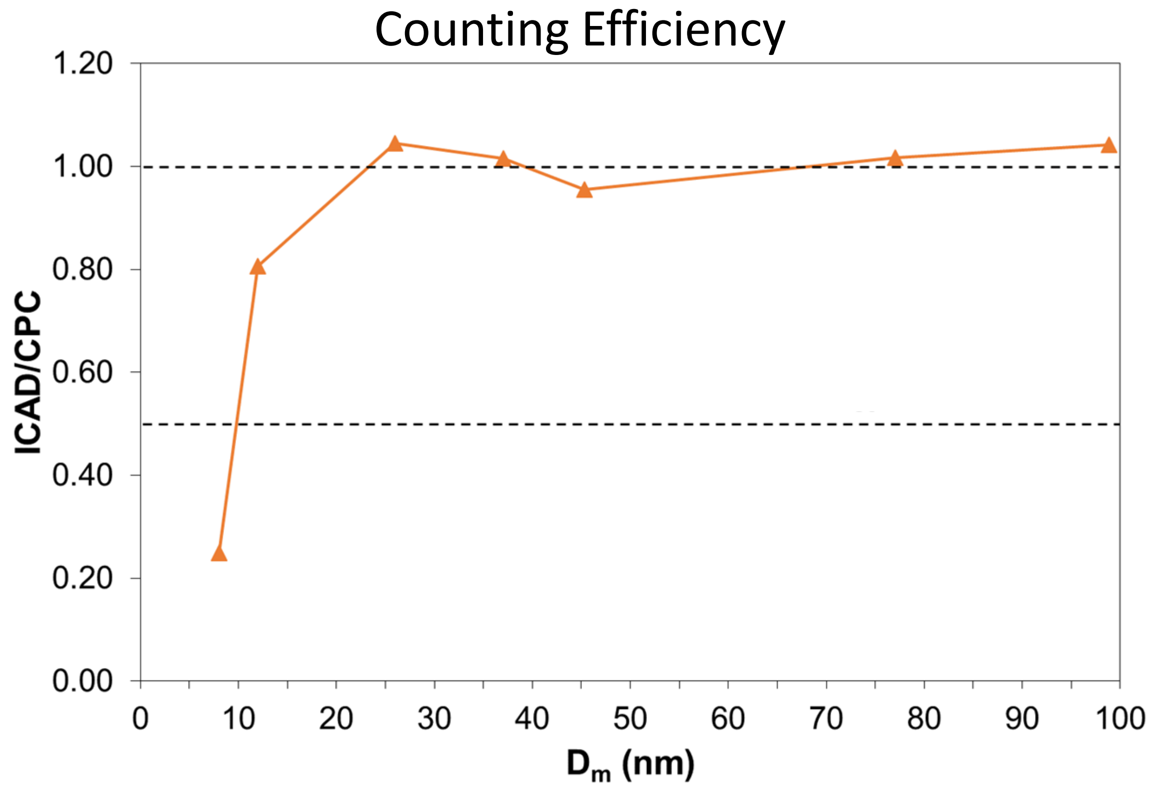
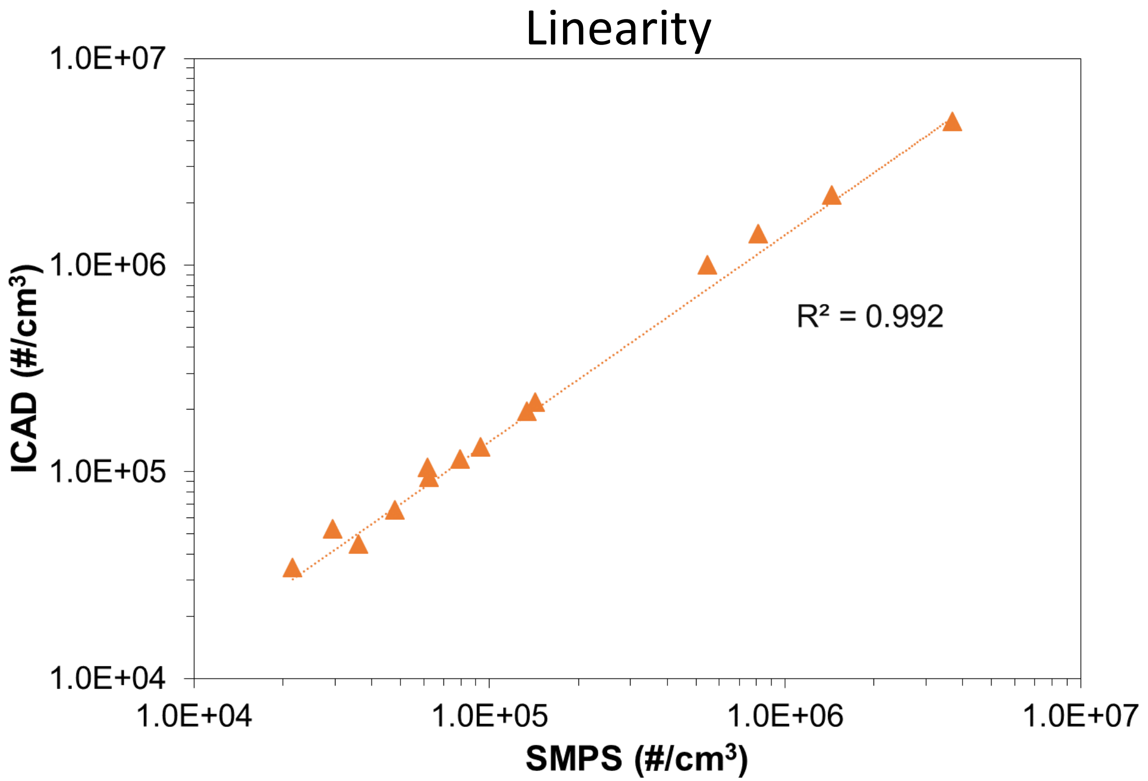
Automotive ICAD evaluation





- Counting efficiency is similar to a CPC and d_{50}=10 nm.
- ICAD counting efficiency & linearity evaluation was performed with mono- and poly-disperse CAST-generated particles.

- ICAD shows an excellent linearity against SMPS for a wide range of particle number concentrations.

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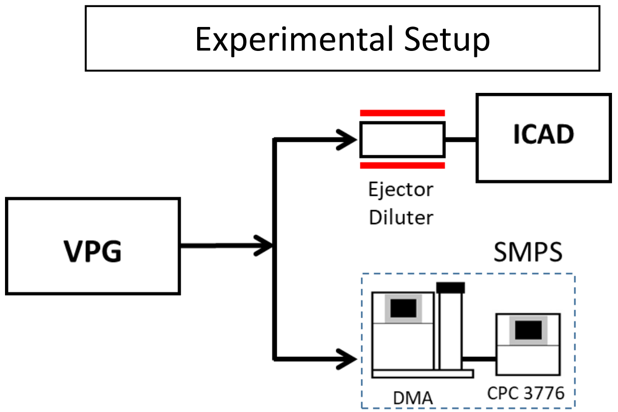
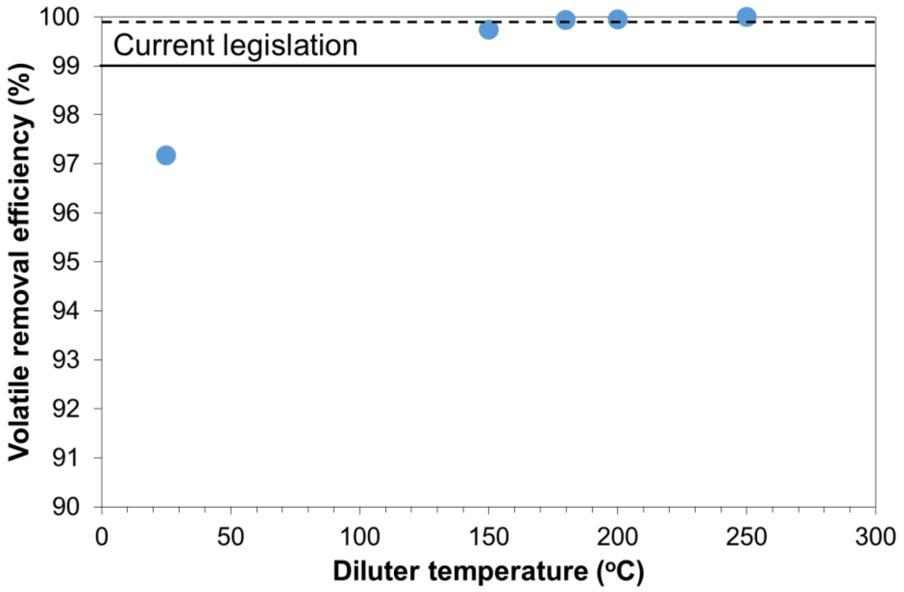
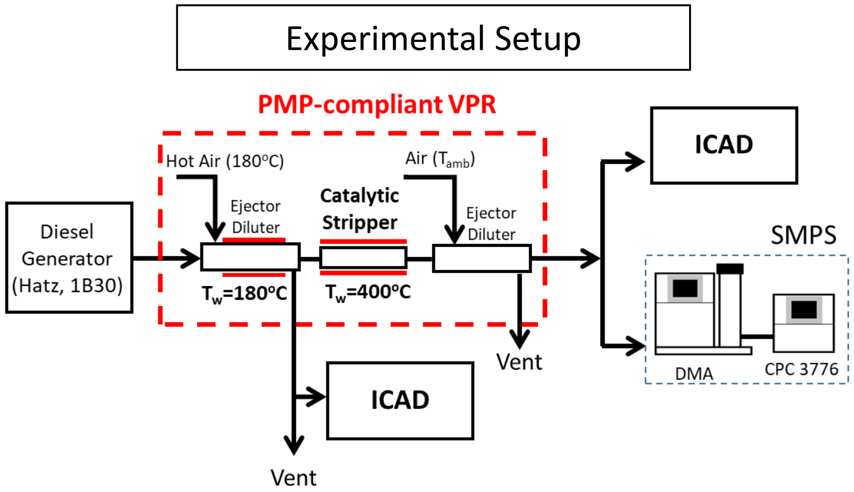
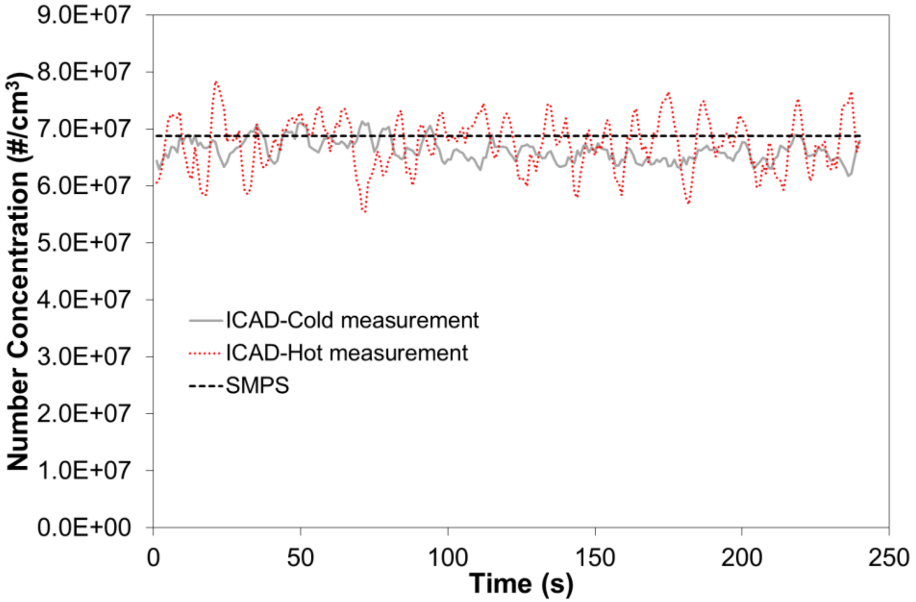
Automotive ICAD hot operation





- The proposed single hot dilution setup is tested with tetracontane particles with $D_m \geq 30$ nm and shows removal efficiency >99% for T≥150°C.





- Hot and cold ICAD measurements are in excellent agreement with SMPS, 1.9% and 3.7% respectively.

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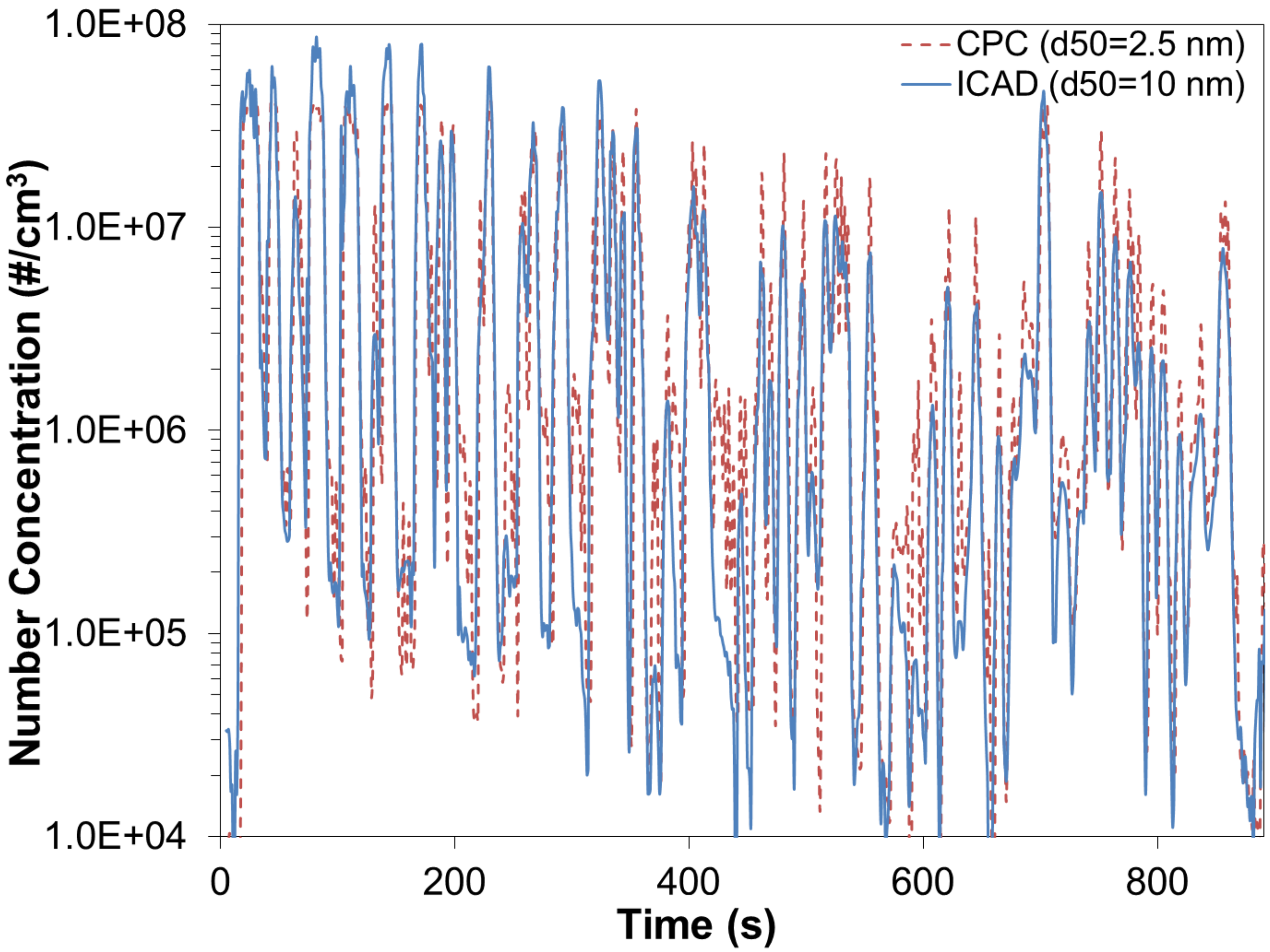
Automotive ICAD hot operation & response time



- Automotive ICAD and a CPC (d_{50}=2.5 nm) were employed for particle number measurements emitted by a G-DI engine during RTS95 cycle.
- Automotive ICAD measurements are in very good agreement with CPC under transient conditions (~12% difference).

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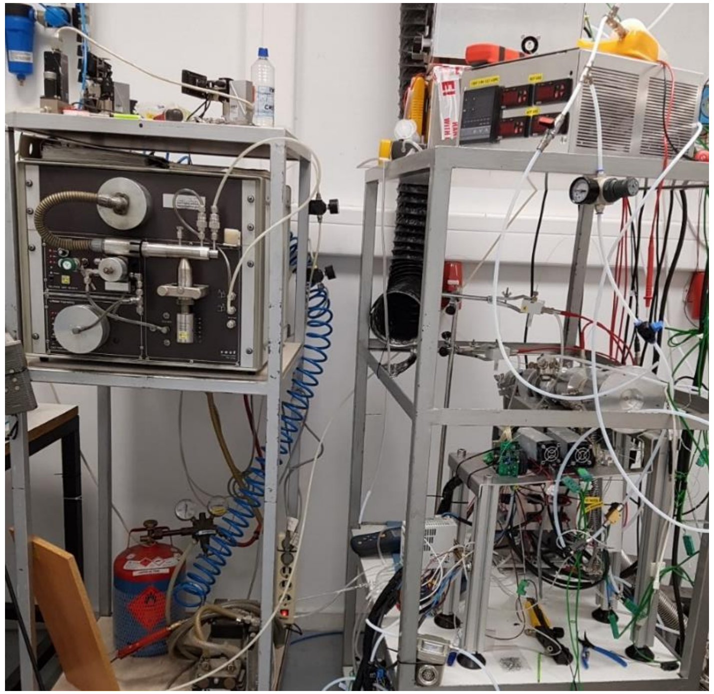
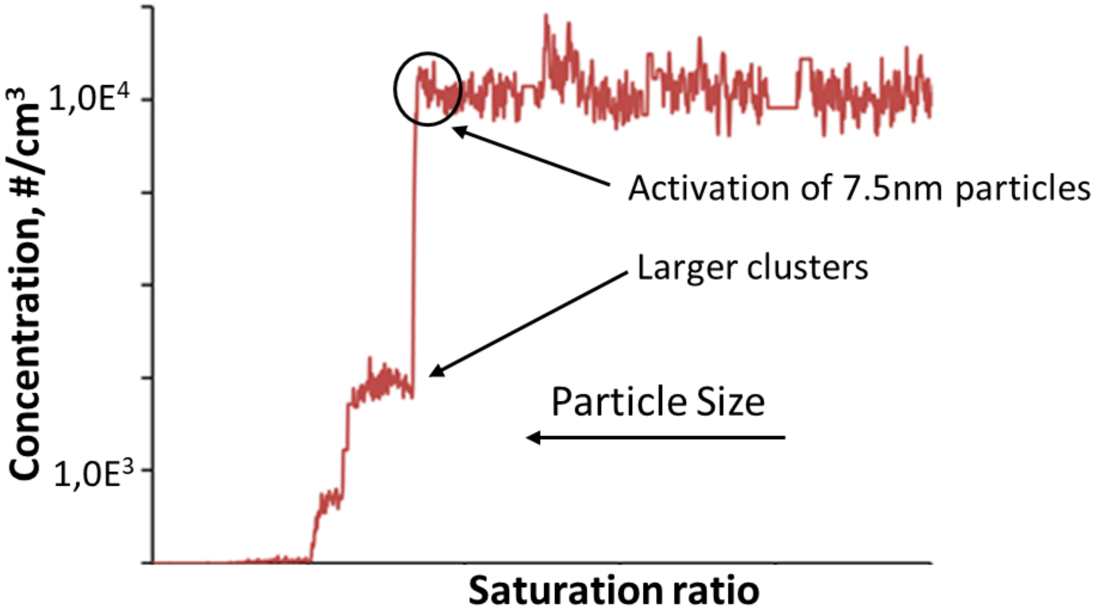
Sizing CPC

- **Objectives**
  - Develop a standalone CPC with particle sizing capabilities without the need of a mediating DMA.
  - Optimized function for sub-23nm particles.
  - Robust and compact instrument for PEMS implementation.



- **Principle of operation**
  - A N_2 flow (saturated with a low diffusive vapor) is mixed with the aerosol sample flow.
  - Fine control of N_2 flow determines the critical value of the vapor saturation ratio (S) that dictates the smallest particle size that can be detected after growth.
  - Sweeping through a range of S values a size distribution can be obtained.



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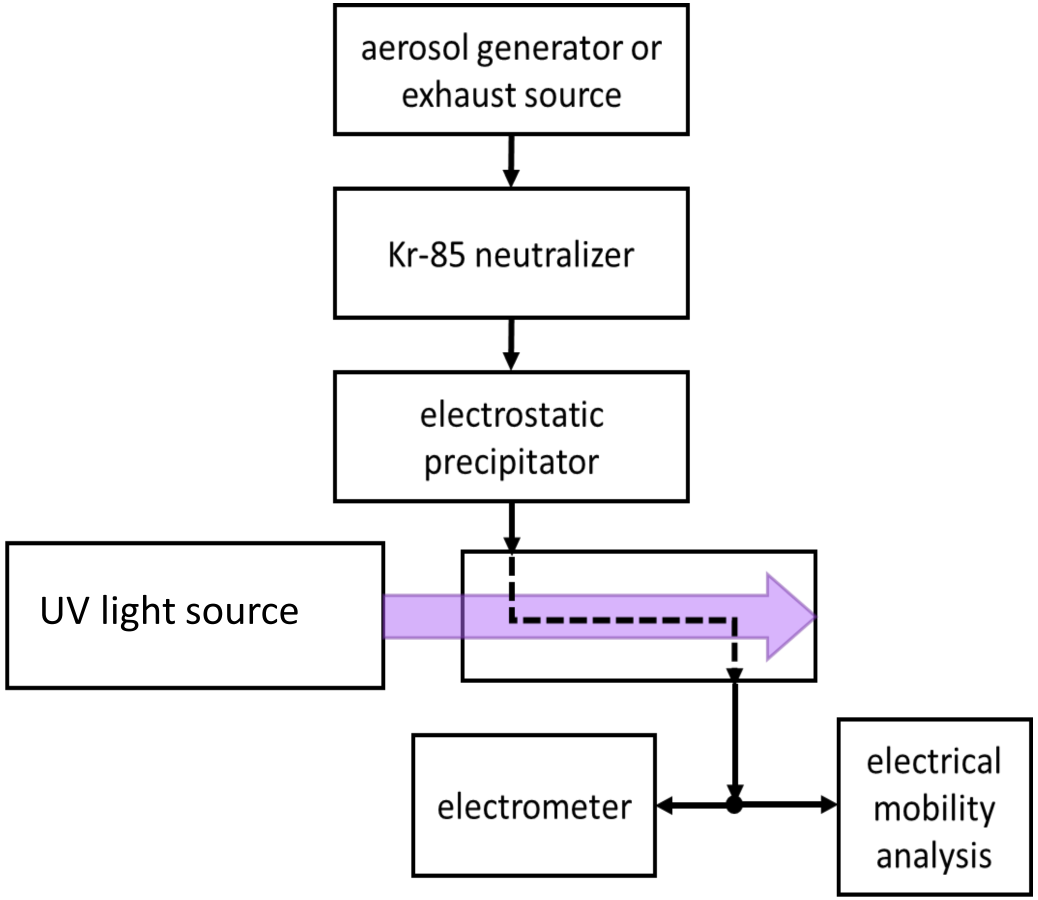
UV Photoelectric Charger (UV-PEC): Principle of operation

- When an aerosol is irradiated with ultraviolet (UV) light of energy above the photoelectric threshold of surface material, electrons may be emitted / particles acquire a positive charge.
- The photoionization threshold is strongly **material dependent**. This can be used to distinguish the chemical fingerprint of condensed matter on the exhaust particles.



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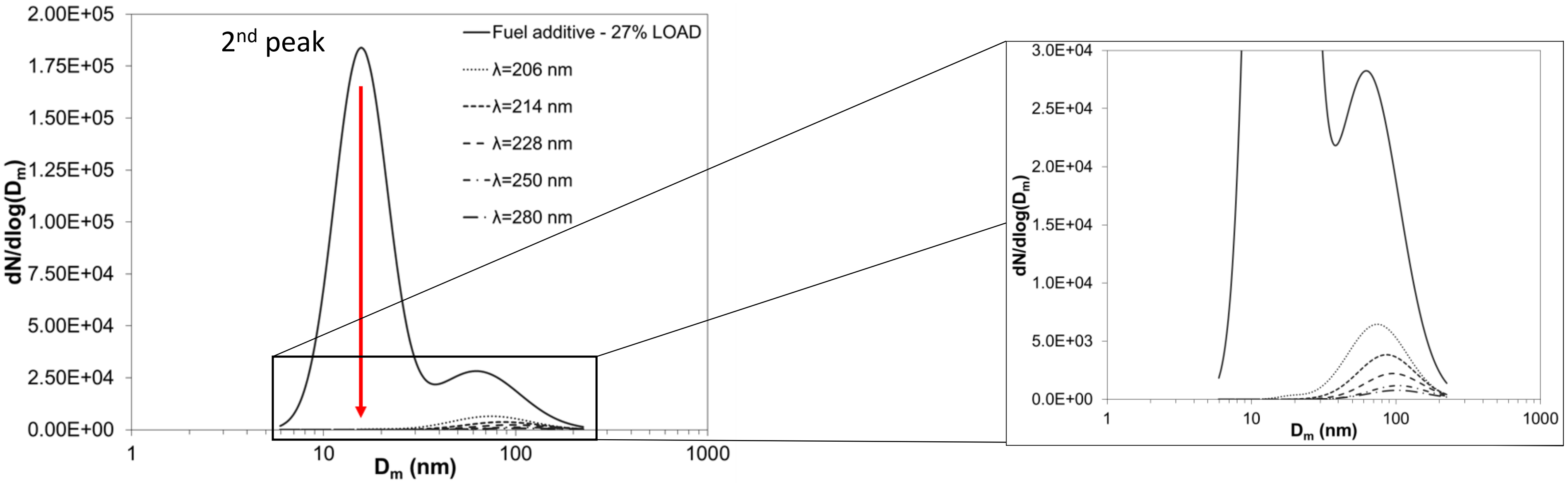
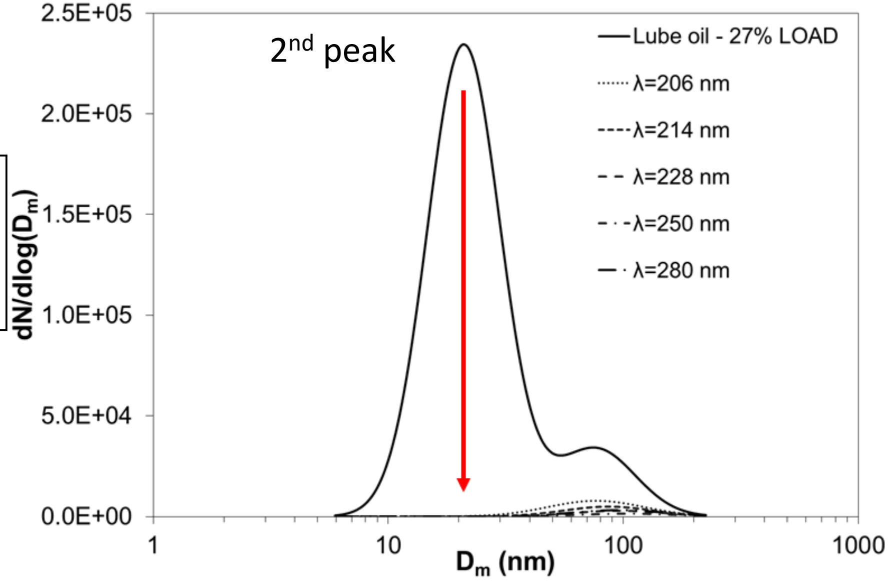
UV-PEC: Fuel effect

Ce-based
fuel additive
29.5 ml/l of fuel
(low Sulphur diesel)



Lubrication oil
60 ml/l of fuel
(low Sulphur diesel)



- By adding a fuel additive or a lubrication oil, a second peak appears at sub-23 nm particles.
- UV-PEC does not charge these sub-23 nm particles showing that no PAH exists on their surface.

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Sampling and Conditioning System (SCS)

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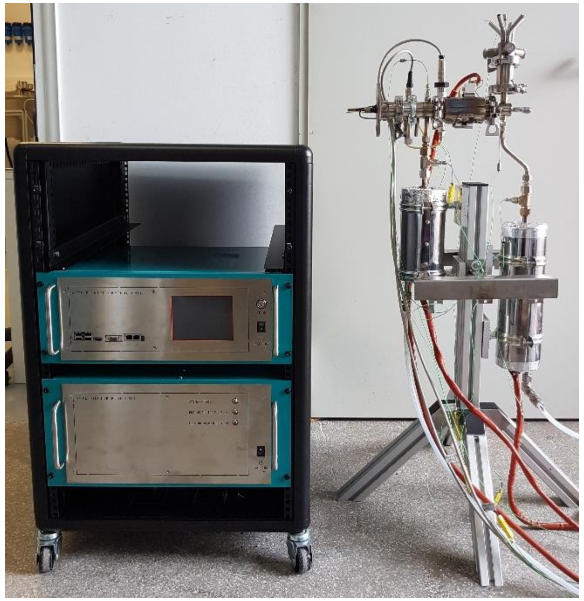
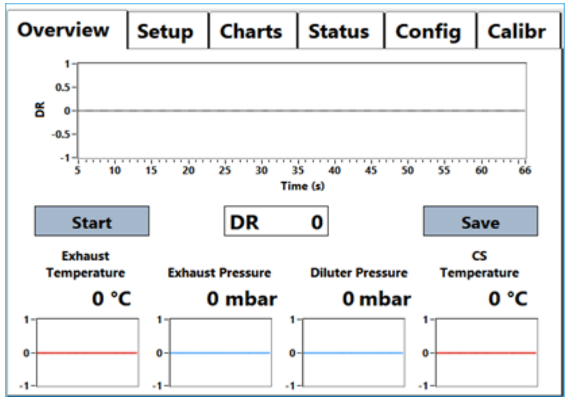
Design parameters

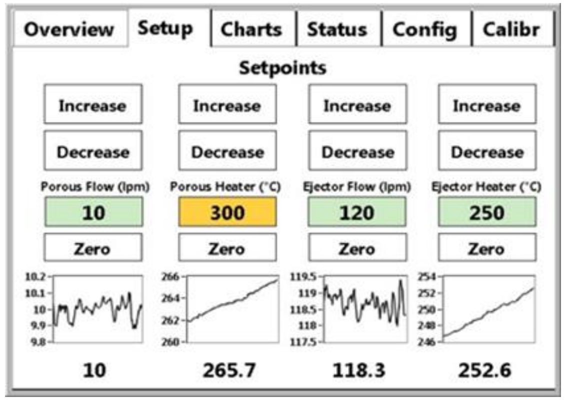
- Two-stage dilution, with adjustable dilution ratio (DR=30-120).
- Porous tube diluter as first stage to minimize sub-23 nm particle losses.
- Ejector diluter as a second stage to maintain stable DR under transient engine operation.
- Option for catalytic stripper/evaporation tube installation between the two dilution stages.



Objectives

- Minimum particle losses
- Artefacts elimination (with CS)
- Dilution ratio stability and flexibility





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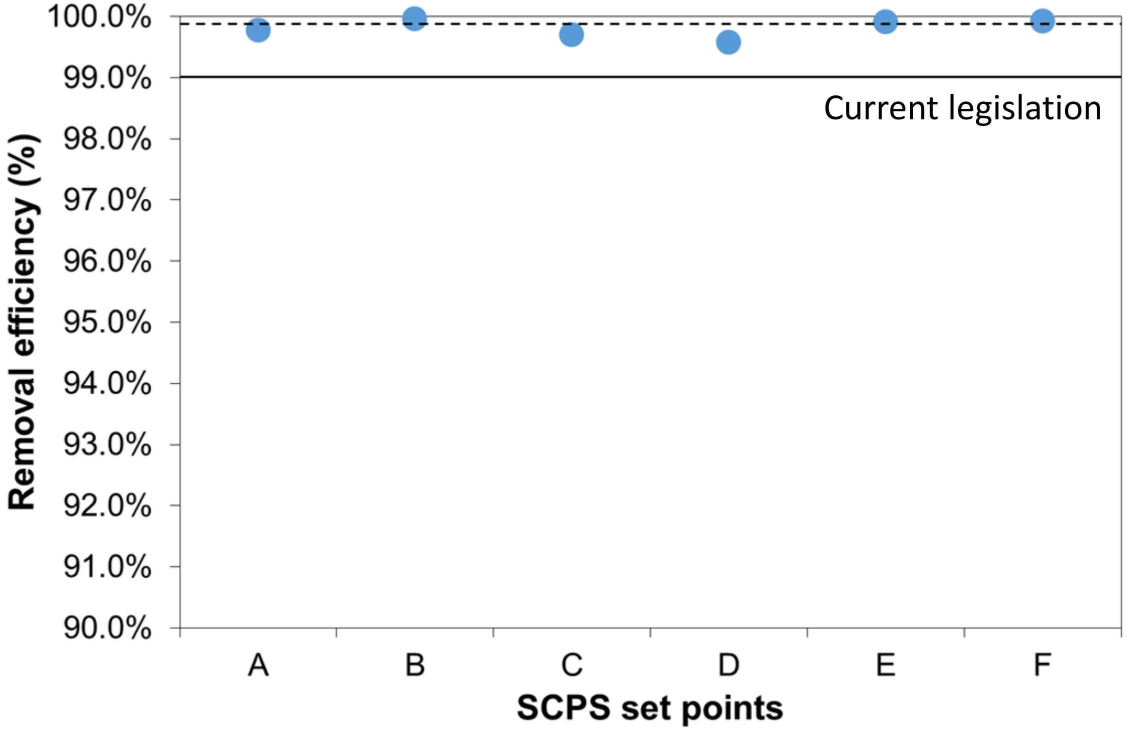
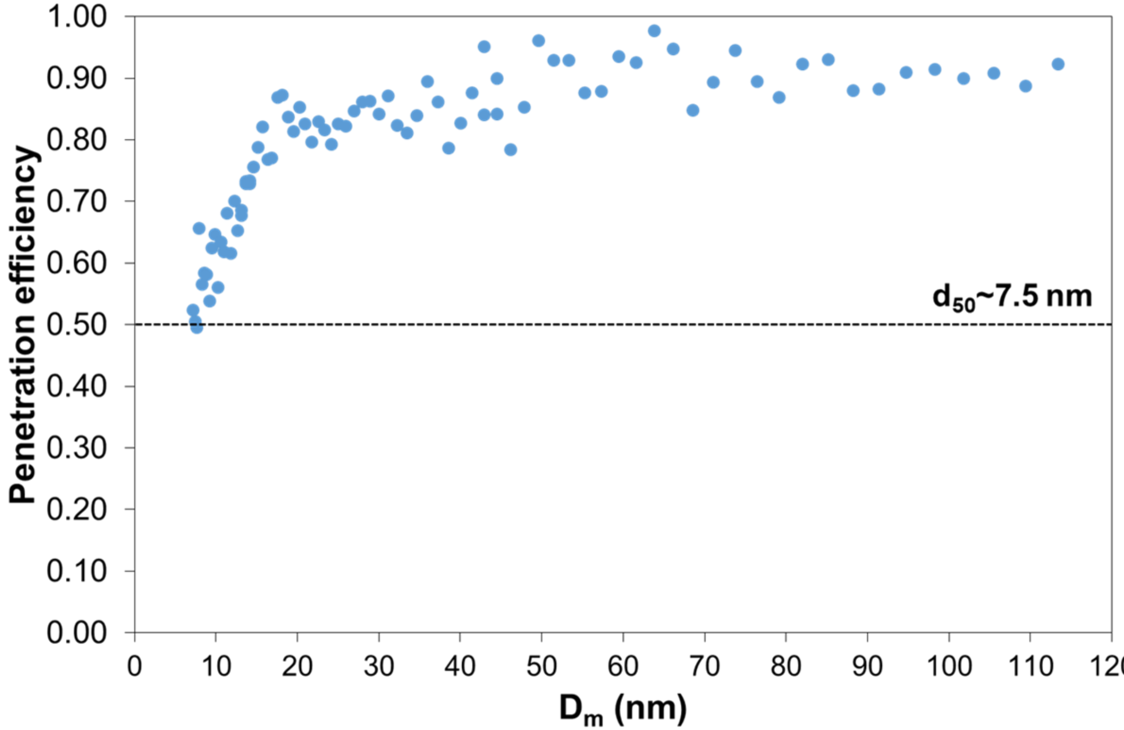
SCS evaluation





- The tetracontane particle removal is tested in a wide DR range (30-60).
- SCPS removes >10^6 (#/cm^3) tetracontane particles with >99% efficiency in all tested set points.
- d_{50}=7.5 nm.
- Particle number concentration reduction factor (PCRF) including $PCRF_{15}$ is 1.15±9%.

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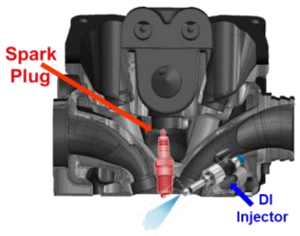
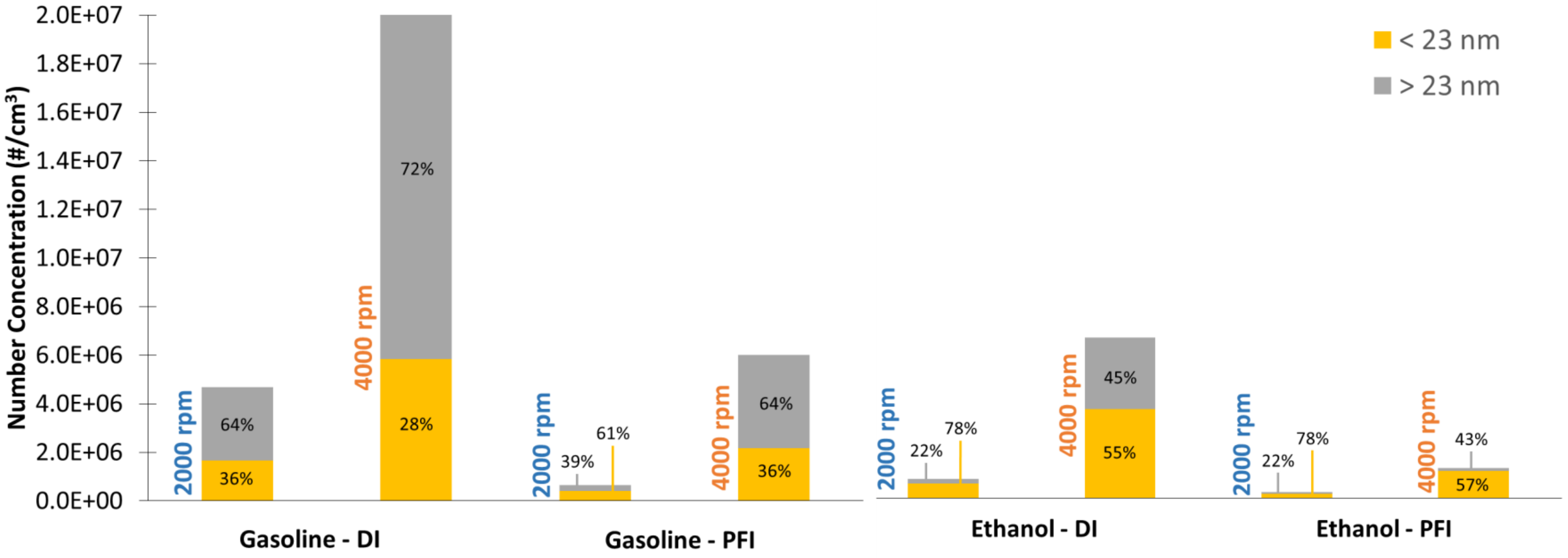
Effect of fuel injection strategy, engine speed & ethanol

Prototype **gasoline** engine:
250cc, 1cylinder, PFI/GDI, 4v, 24PS





- Port Fuel Injection (PFI) emits far less sub-23 nm particles comparing to Direct Injection (DI).
- For both fuels (gasoline, ethanol) and both injection strategies (DI, PFI) increased engine speed leads to increased emission of sub-23 nm particles.
- Ethanol causes an decrease in sub-23 nm particle number concentration, however an increase in the sub-23nm fraction, in both DI and PFI configurations.

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Engine bench tests - Experimental setup

- **Engine:**
  - Gasoline Direct Injection Engine w/Turbocharger
  - Volume displacement 1.3 L
  - Engine Power = 120 kW
- **Tests matrix:**
  - Tailpipe PN measurement w/ and w/o GPF
  - 3 driving cycles : WLTC, RTS95 and RTS95
    - ✓ Cold and hot start

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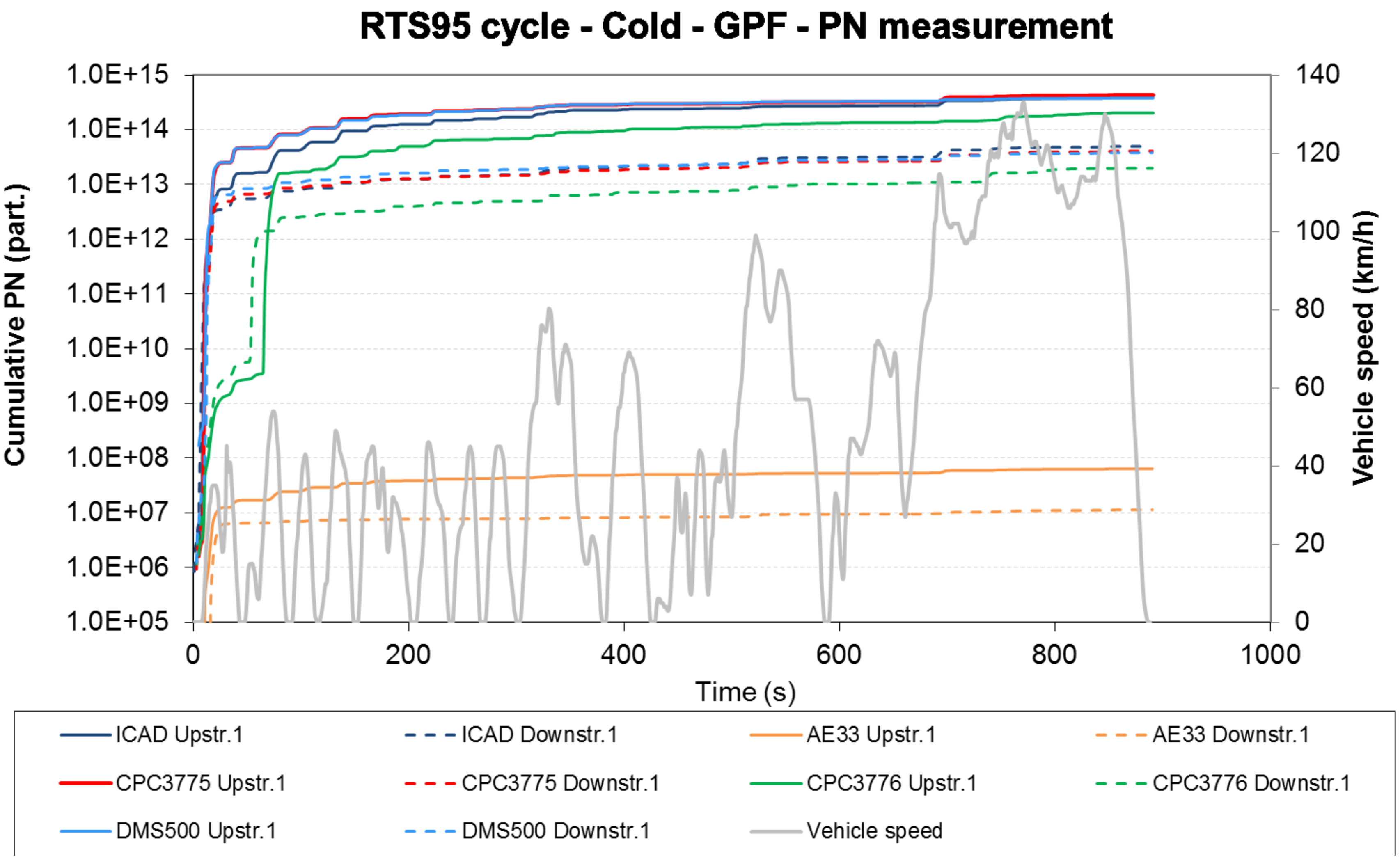
Engine test bench phase: focus on results w/ & w/o GPF

- **Example of RTS95 cycle, cold start**



Part/km	Upstr. GPF	Downstr. GPF	GPF eff.
ICAD	2.97E+13	3.82E+12	87.1%
CPC3775	3.33E+13	3.15E+12	90.6%
CPC3776	1.56E+13	1.52E+12	90.3%
DMS500	2.93E+13	2.93E+12	90.0%
AE33 (ng)	4.9	0.9	82.2%

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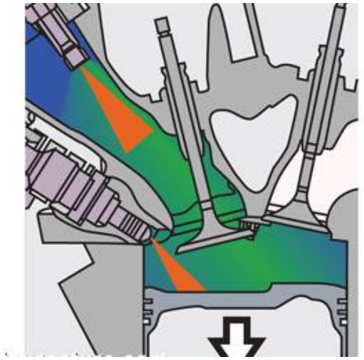
Chassis dyno tests - Experimental setup

- **Euro 6b vehicle : Audi 2.0L TFSI**
  - 4 Cylinder Gasoline with Turbocharger
  - Dual injection system: Direct + indirect
  - Standard EATS system: 3WC only



- **PN measurement devices**
  - Prototypes : SUREAL-23 diluter + ICAD + HM-DMA
  - Reference : VPR + DMS 500

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Chassis dyno tests - Tests matrix

- **Parametric variations:**
  - 4 fuels : E10 (std), high sulfur content (150 ppm S), high aromatic content (39 %), E25
  - 2 lubricants : Audi 507 (low SAPS), Total Full SAPS (1.1%)
  - 3 driving cycles : WLTC, RTS95 and RTS95
    - ✓ Cold and hot start

Fuel	Lub.	WLTC		NEDC		RTS95	
		Cold	Hot	Cold	Hot	Cold	Hot
E10	Low	✓	✓	✓	✓	✓	✓
High S	Low	✓	✓	✓	✓	✓	✓
High Aro	Low	✓	✓	✓	✓	✓	✓
E25	Low	✓	✓	✓	✓	✓	✓
E10	Full	✓	✓	✓	✓	✓	✓

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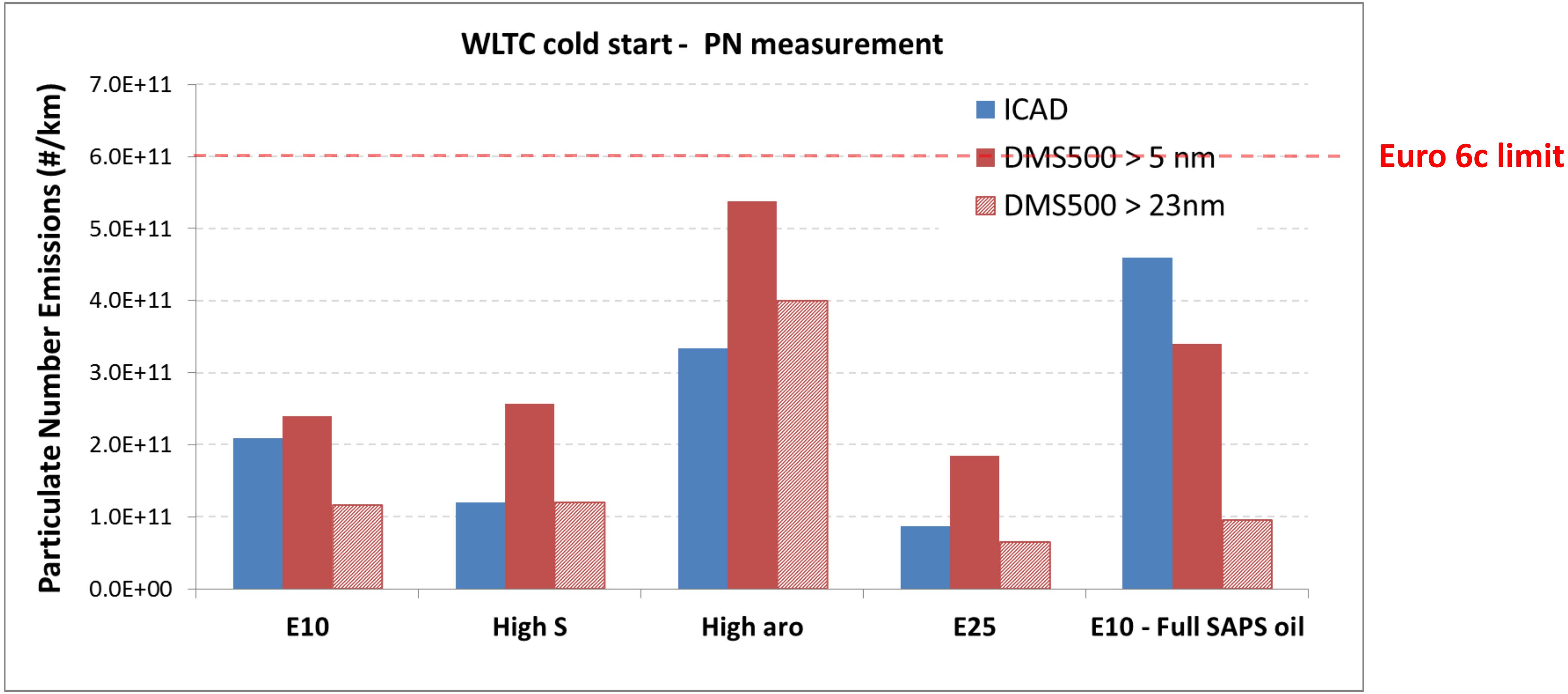
Chassis dyno tests - Results

- Fuel effect on particle emissions



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What’s next

- Continue testing with photoacoustic and photoelectric based instruments
- Continue measurement campaigns on chassis dynos
- PEMS integration
- RDE testing

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Thank you for your attention!

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