Project SUREAL-23: Understanding, Measuring and Regulating Sub-23 nm Particle Emissions from Direct Injection Engines Including Real Driving Conditions

H2020 Research Policy
TOPIC: GV-02-2016 - Technologies for low emission light duty powertrains

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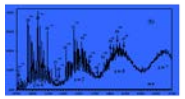
Aerosol and Particle Technology Laboratory (APTL)

22nd ETH Conf. on Combustion Generated Nanoparticles, Zurich, June 20, 2018



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Co-financed by the European Union
Connecting Europe Facility

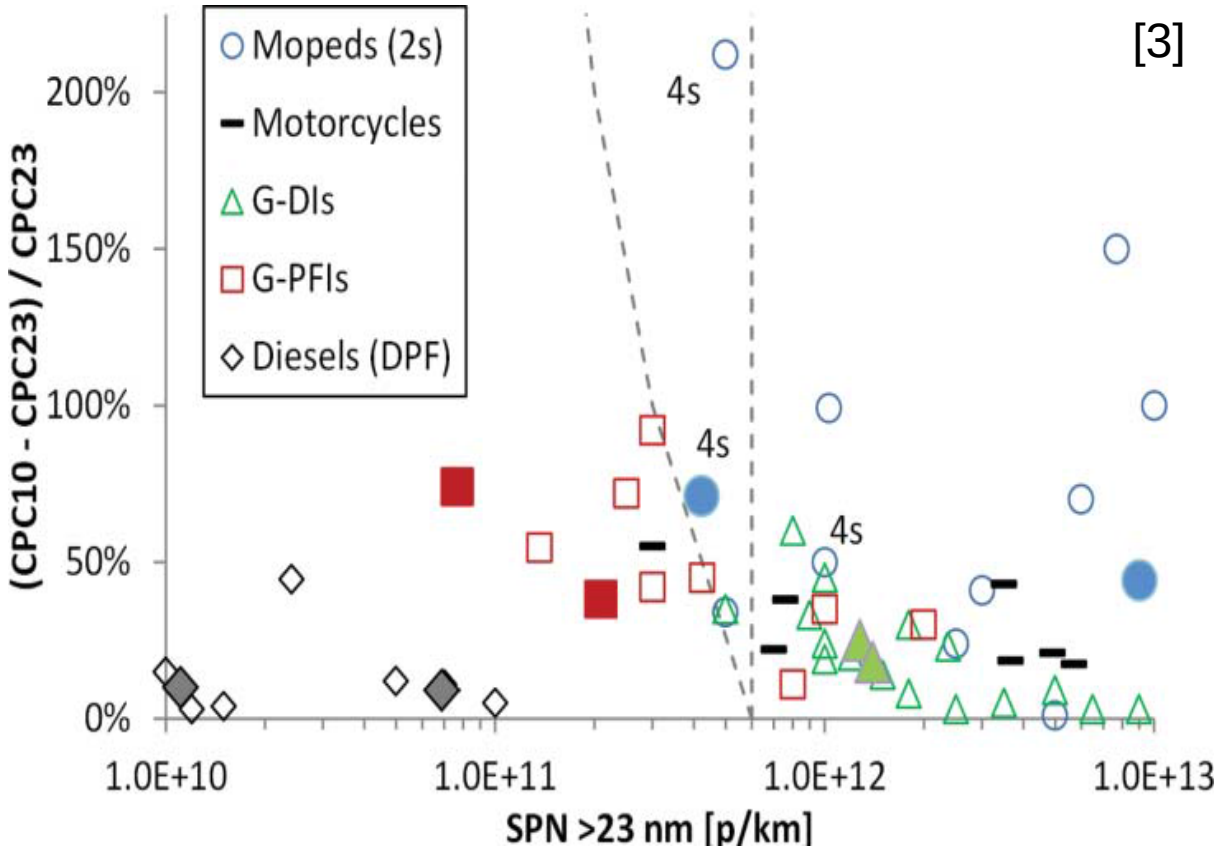
Outline

- The problem
- SUREAL-23 approach
- Project’s methodology
- Advanced particle sampling/treatment
- Advanced instrumentation
- Indicative applications
- Conclusions

The Problem

- Vehicles are subject to regulation of **solid-only particle** number (PN) since Euro 5/6 homologation for light duty, Euro 6 for heavy duty.[1]
- Protocol developed by the PMP[2]: hot dilution and an Evaporator Tube and particle counting with **50% cut-off at 23 nm** to avoid re-nucleation artifacts.
- Initial PN regulation **aimed at Diesel**, extended to Gasoline. GDI engines have greatly increased in number.
- Evidence of significant solid PN emissions **missed** due to the 23 nm cut-off.[3]
- **Health effect significance**: enhanced deposition in the respiratory track and potential translocation.[3,4]
- **How to measure below 23 nm?**

[3]



[1] *Science of the Total Environment 408:5106–5116 (2010).*
[2] *Aerosol Sci. Technol., 42:528–43 (2008).*
[3] *Aerosol Sci. Technol., 51:5, pp. 626-641 (2017).*
[4] *Inhal Toxicol., 16(6–7):437–45 (2004).*

SUREAL-23 Approach

Focus

Exhaust particles, **smaller than regulation cut-off of 23 nm**, Light Duty engines (**Diesel and gasoline**).

Objectives

- **Complement and extend** existing instrumentation for particles below 23 nm.
- Further **understand** the nature of the particulate emissions below 23 nm.
- **Support future emissions** compliance testing through technical developments in RDE.

Innovations

- **Size and composition** analysis methods applicable to transient engine emissions.
- **Novel instrumentation** for particles below 23 nm compatible with established technology for PN.
- Instrument enhancements to allow operation with **reduced sample conditioning**.
- Integration of the most suitable components of the extended sub-23 nm measurement toolset into **PEMS** and verification in real driving conditions.
- New optical instruments to **probe composition** in transient exhaust conditions.

SUREAL-23 Partnership

TECHNOLOGY DEVELOPERS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RERUM CAUSAM COGNOSCERE - 1940 -
ISTITUTO MOTORI
Consiglio Nazionale delle Ricerche

apt LABORATORY AEROSOL & PARTICLE TECHNOLOGY

NKT Photonics
the power of light

TECHNOLOGY EVALUATORS

ifp Energies nouvelles

CRF

RERUM CAUSAM COGNOSCERE - 1940 -
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ASSOCIATED / ADVISORY PARTNERS

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TSI

COORDINATION:

apt LABORATORY AEROSOL & PARTICLE TECHNOLOGY

Technology Development and Testing

Sampling/ Conditioning

- Standard PMP (with Evap.Tube)
- Advanced catalytic stripper (CS)
- Flexible sampling System

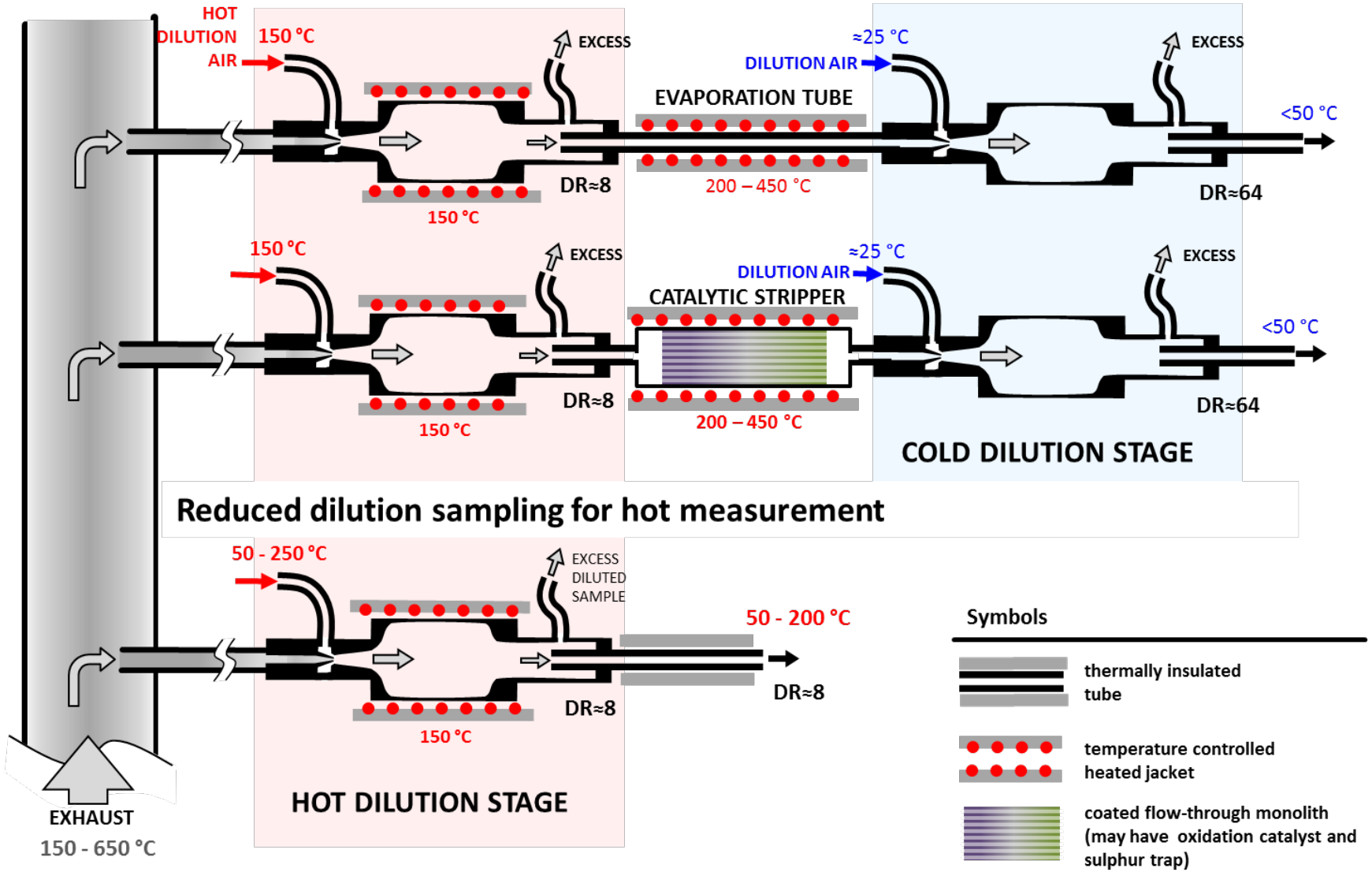
New Instrumentation

- Half Mini DMA
- Induced Current Aerosol Detector (ICAD)
- SL Multi-wavelength Photoacoustic Spectrometer (SL-MPAS)
- SL UV Photoelectric Ionisation (SL-UPVE)
- Sizing CPC

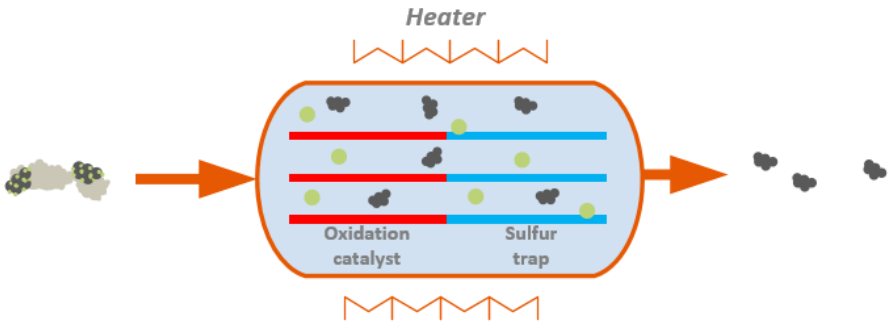
Testing Platforms

- Standard particle generators (CAST, EAG)
- Flex-fuel Engines
- Engine and Vehicle dynos (Diesel and GDI)
- Real Driving (PEMS)

Sampling / Conditioning



Advanced Catalytic Stripper

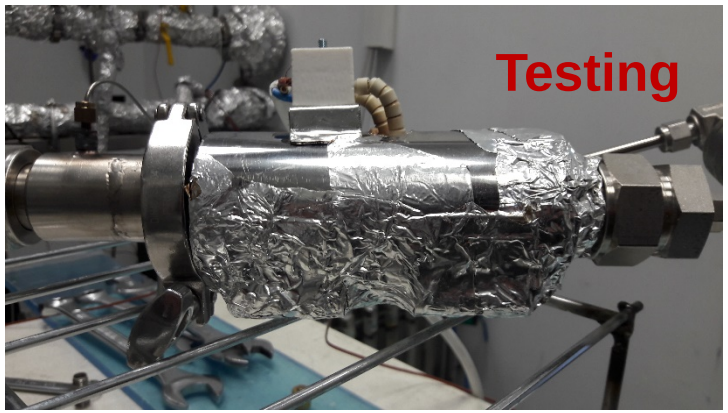


Solid particles with condensed volatile fraction

Solid particles

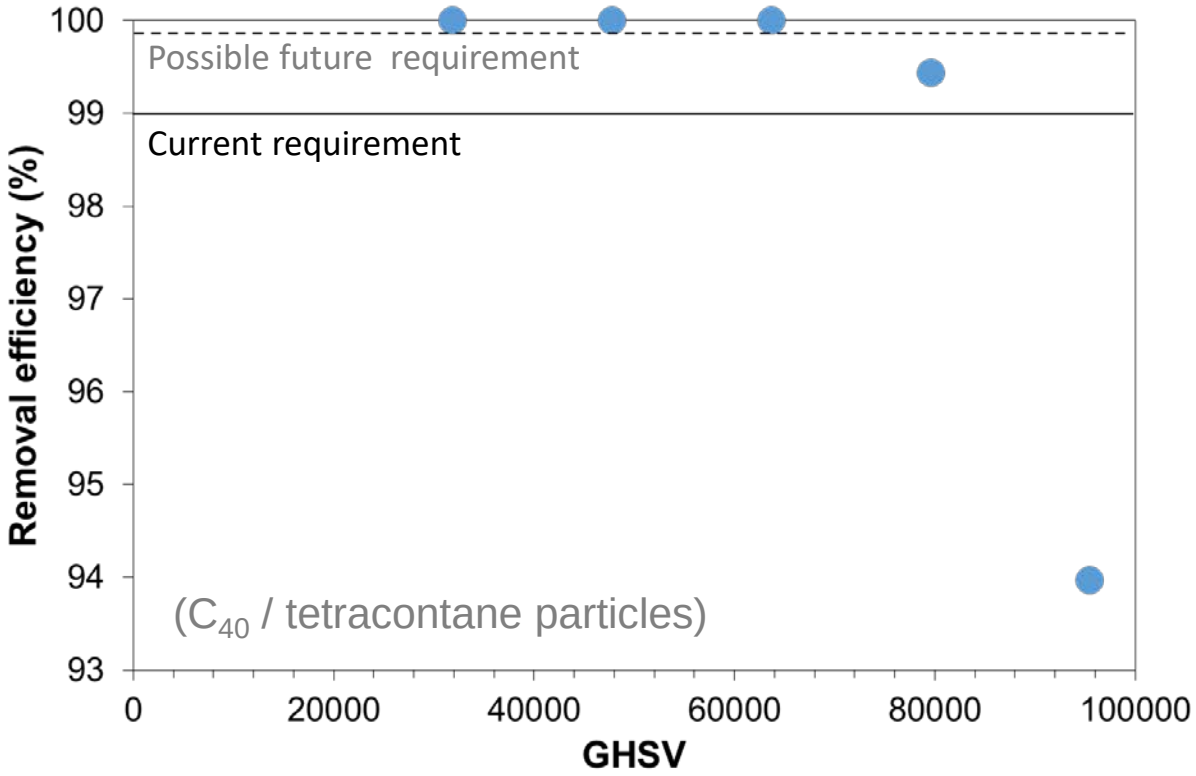
Volatile particles

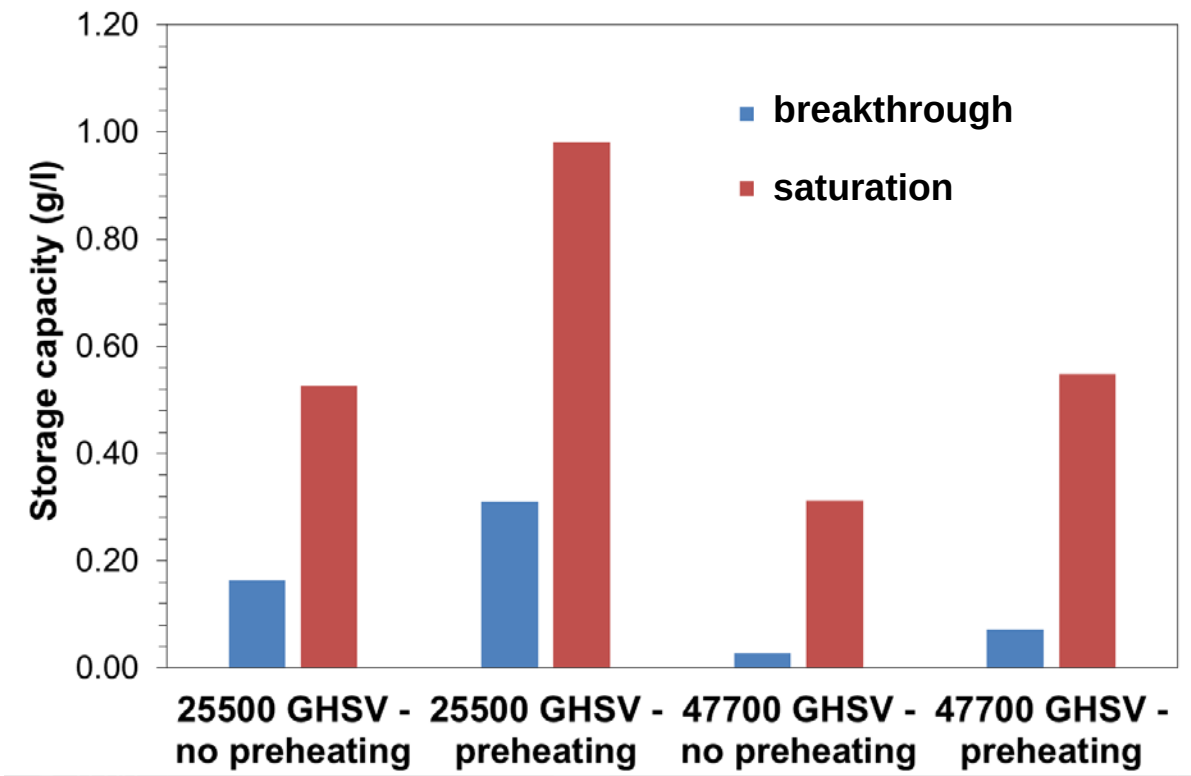
- Many mixed oxides were synthesized and tested for their SO_2 adsorption capacity.
- A dual-function monolith was coated with the most efficient powders in combination with oxidation catalyst.



- C_{40} removal efficiency
- SO_2 adsorption
- Solid particle penetration

Catalytic Stripper Evaluation



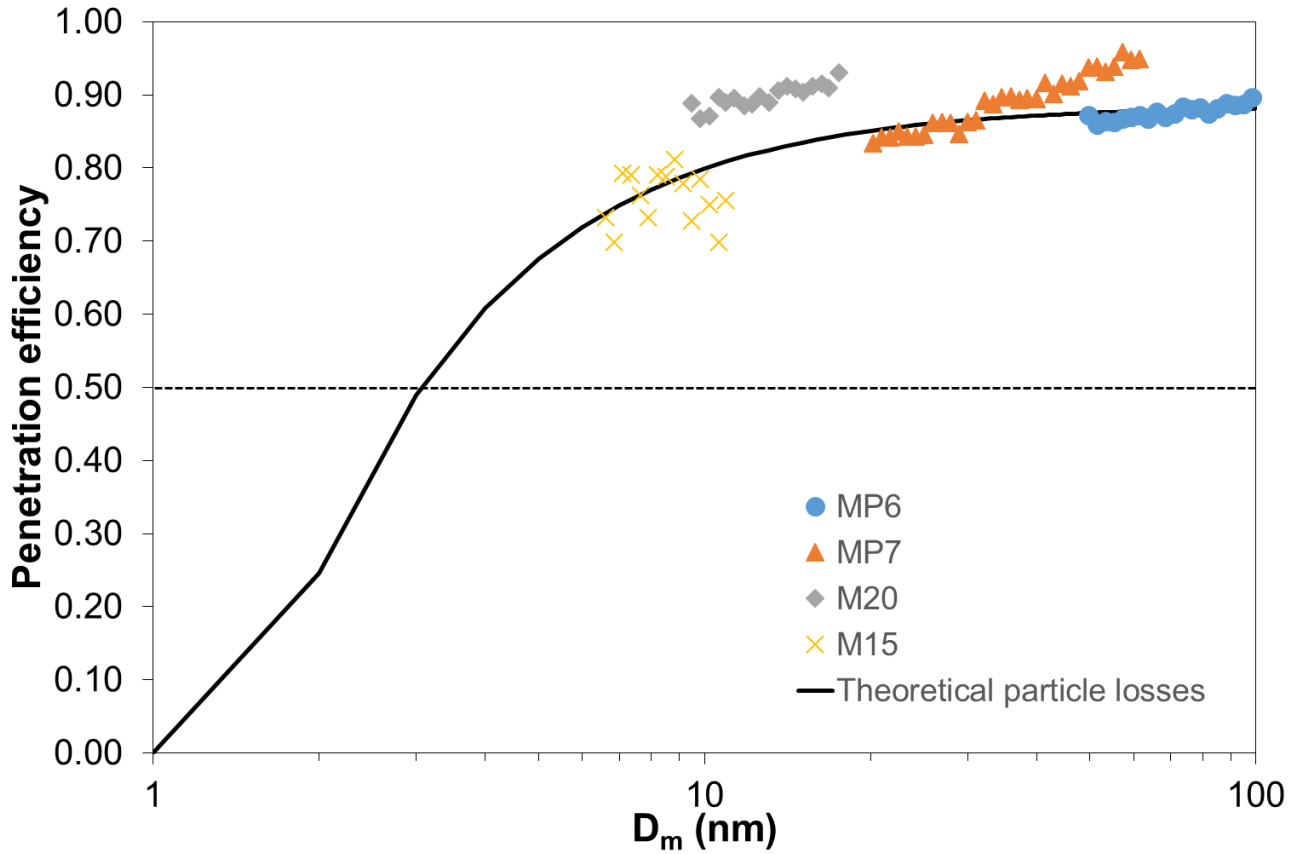


The catalytic stripper meets the current but also possible future PMP demands with **>99.9% oxidation efficiency** up to flow of 20 LPM for concentrations >10^6particles/cm^3.

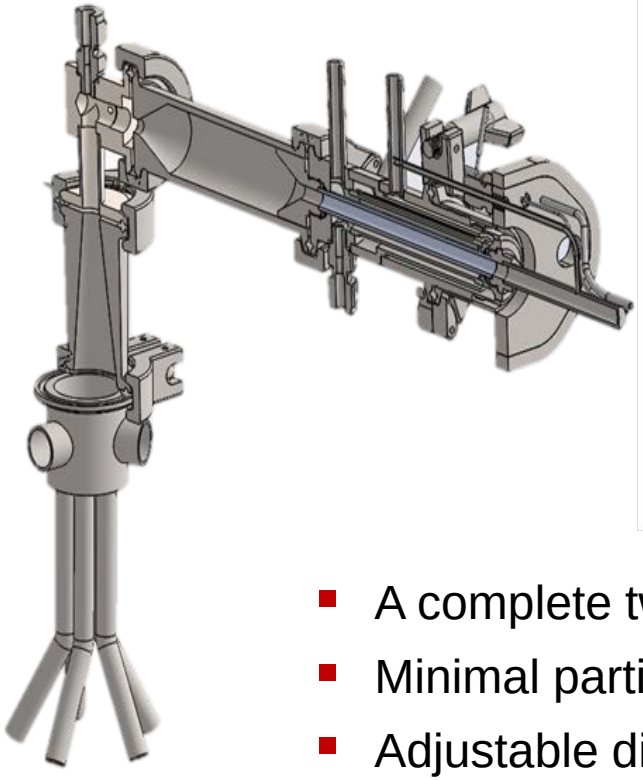
The **sulphur adsorption** capacity at the onset of breakthrough is **7.3mg** or **0.31g/L** while the total (saturated) capacity is 23.1mg or 0.98g/L.

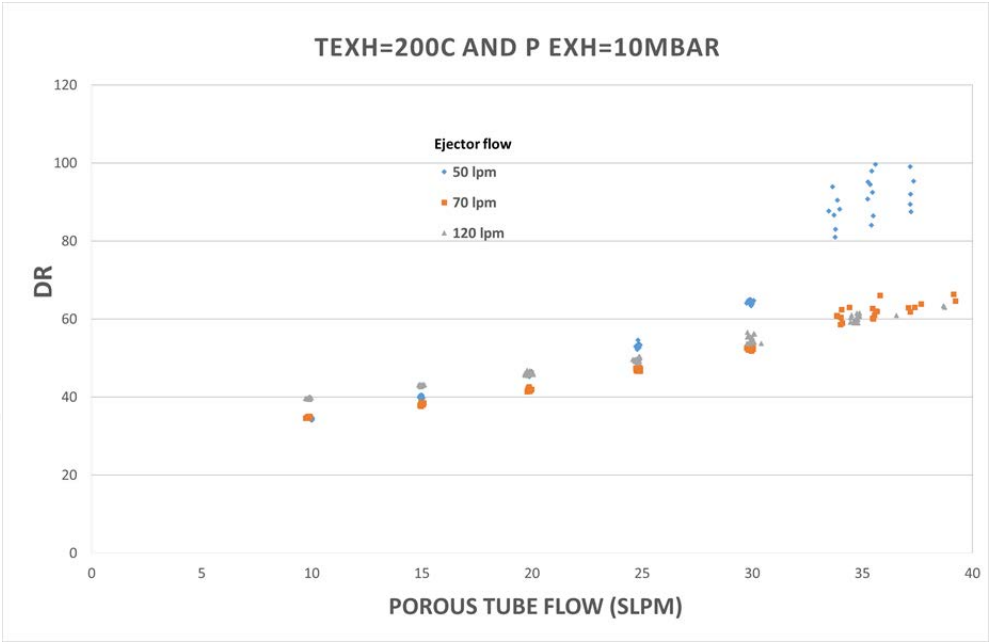
Catalytic Stripper Evaluation (2)

- Solid particle penetration was tested with catalytically pre-treated CAST generated particles
- 75% penetration down to 10 nm



Flexible/variable sampling and dilution system

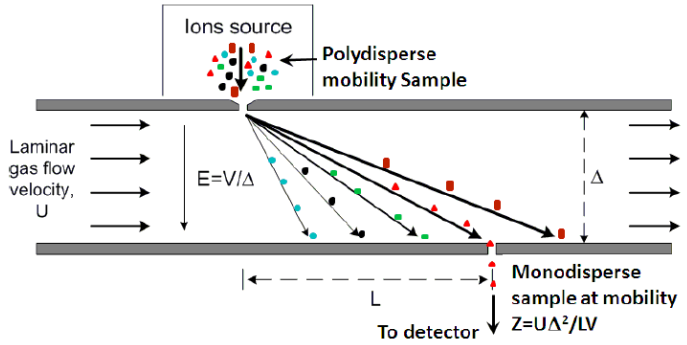


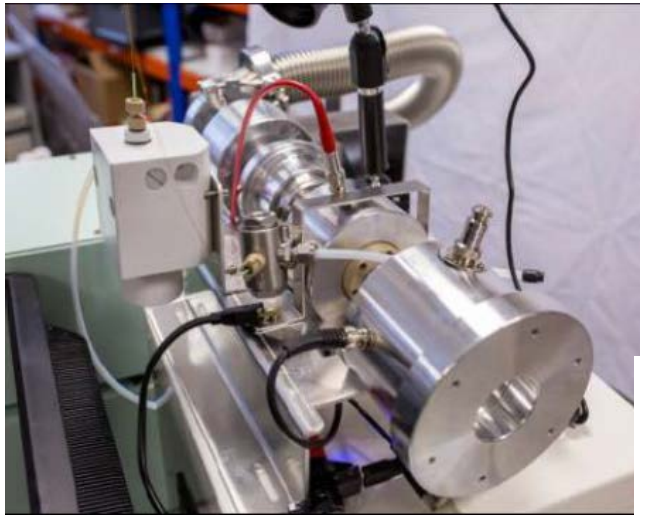


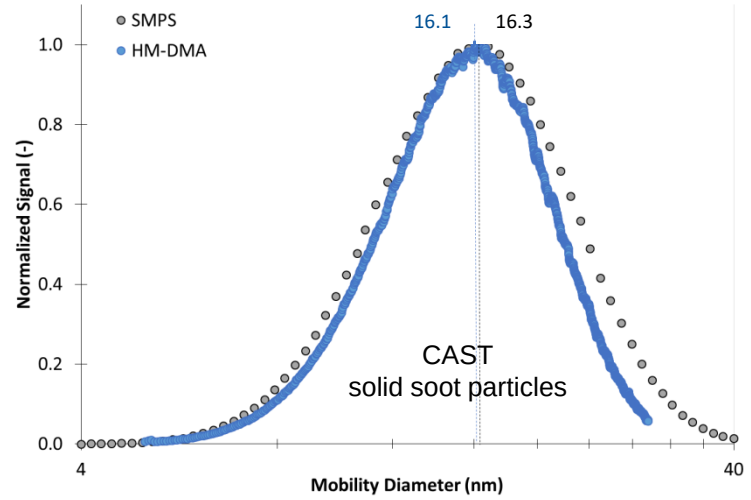
- A complete two-stage dilution system, including a CS.
- Minimal particle losses in the sub-23 region.
- Adjustable dilution ratio (DR).
- Stable DR under transient engine operation.

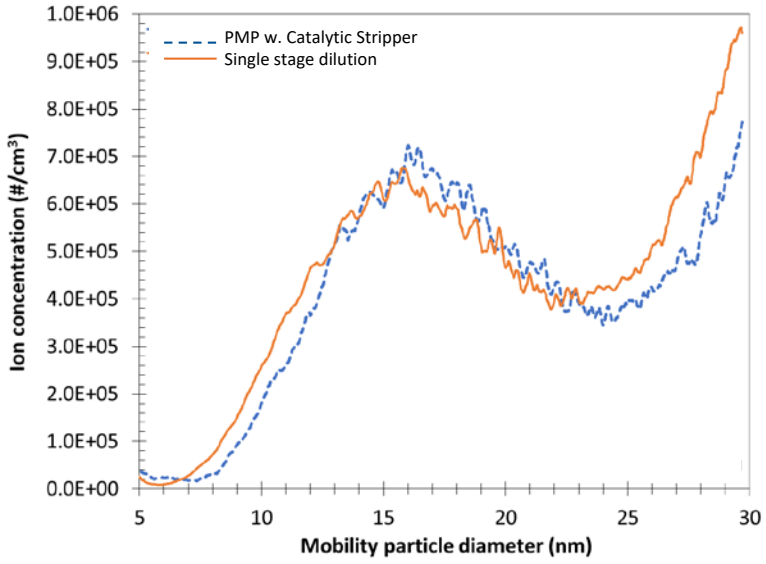
The advanced half-mini DMA

The concept of HM-DMA







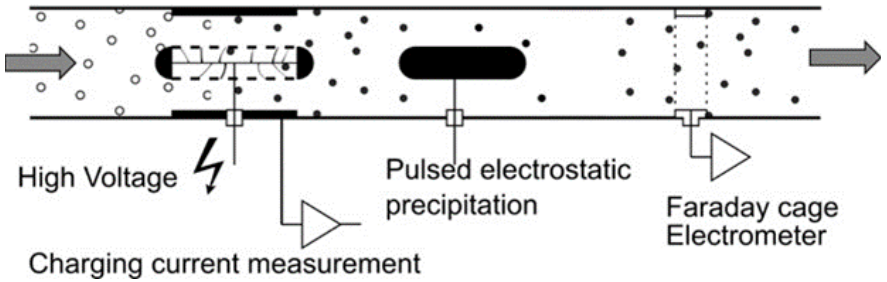


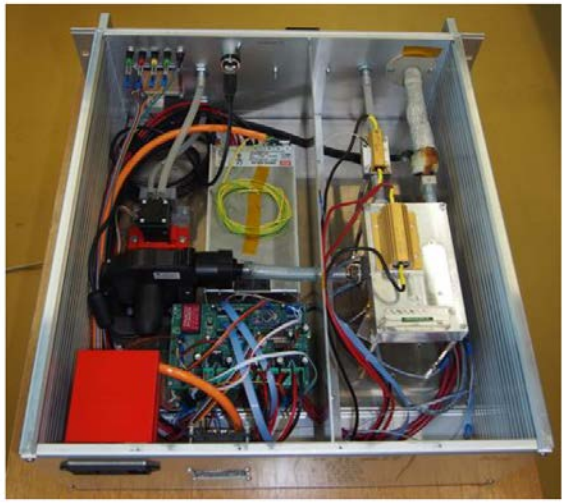
Achieved:

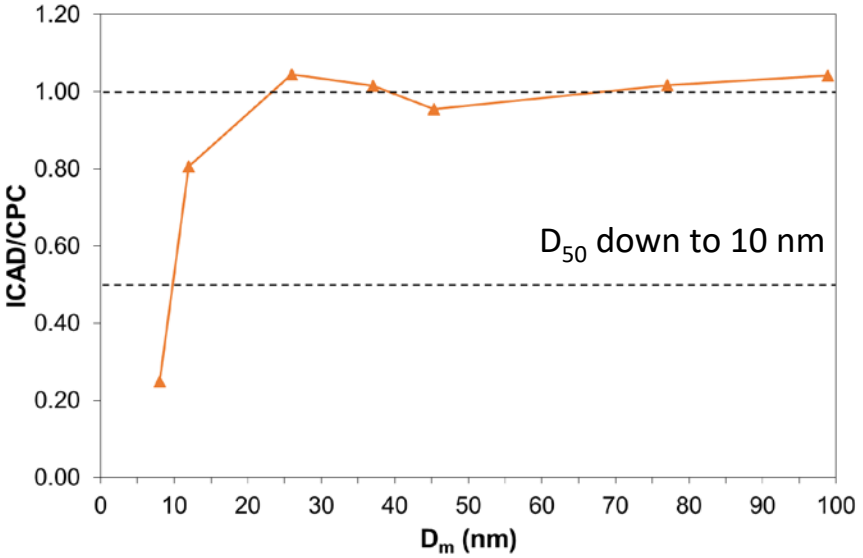
- **High resolution** in the sub-23nm particle size range (4 – 30 nm)
- **Accurate hot operation** up to 200ºC (Reduced exhaust aerosol conditioning, Measurements with a single hot dilution stage)
- **Fast response time** (100 ms; 10 times higher response capability than traditional electrometers)
- **Compactness** (2 cm working section)

Automotive induced charge aerosol detector

Diffusion charging

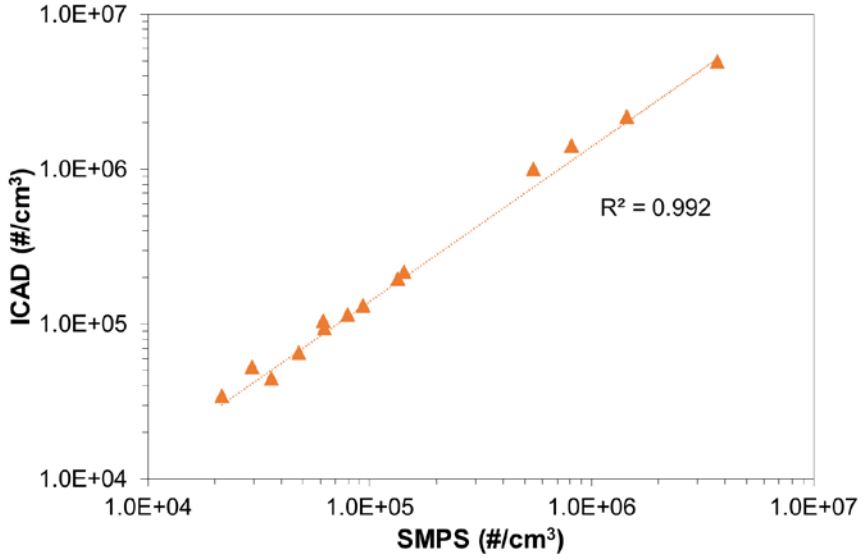






The goals achieved

- Operate at high temperature (150^{0}C) to allow minimum dilution
- 50% counting efficiency at 11.5nm
- Absolute sensitivity increased



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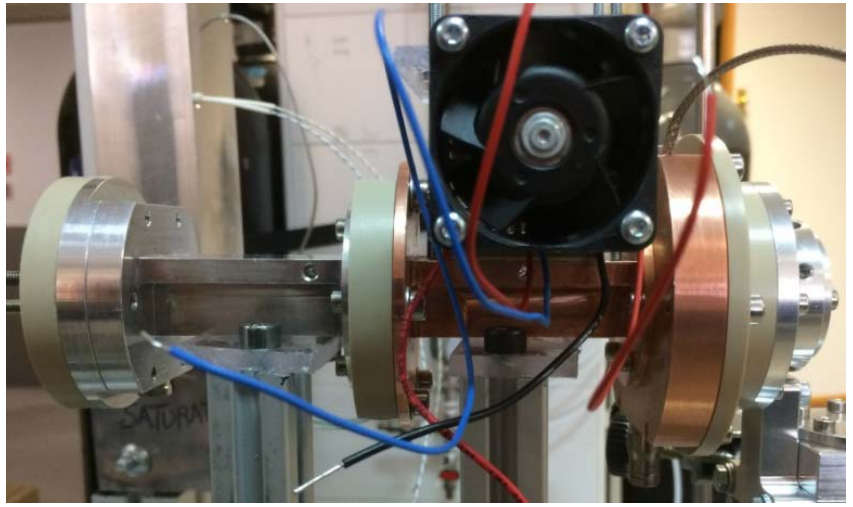
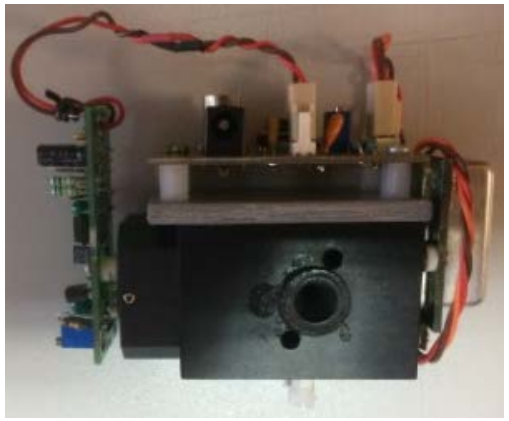
Sizing CPC development

Saturator 1 (low mass diffusivity)

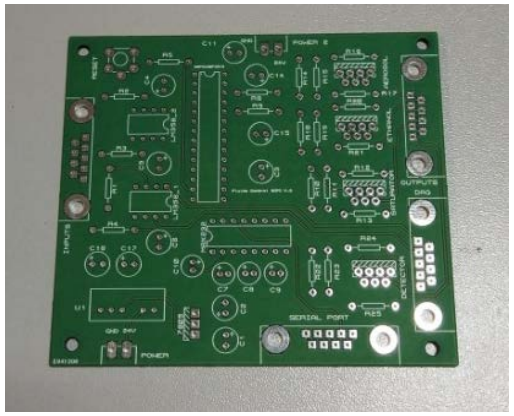
Saturator 2 (ethanol)



Main CPC body



Optical head



Flow control PCB

Co-financed by the European Union
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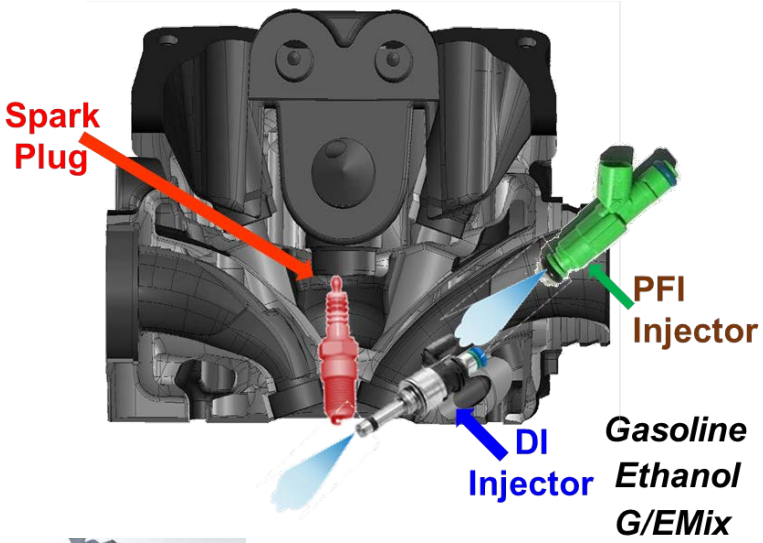
Testing Platforms (APTL, IM, IFPEN, CRF)

- **Vehicle Testing on chassis dyno and road**
  - Euro 6 Diesel DI
  - Euro 6 Gasoline DI
  - Euro 6 Gasoline DI/PFI

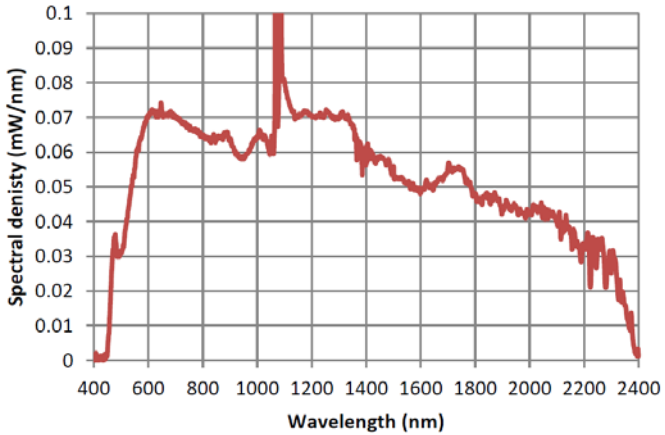


- **Portable emissions measurement system (PEMS) instrumentation**

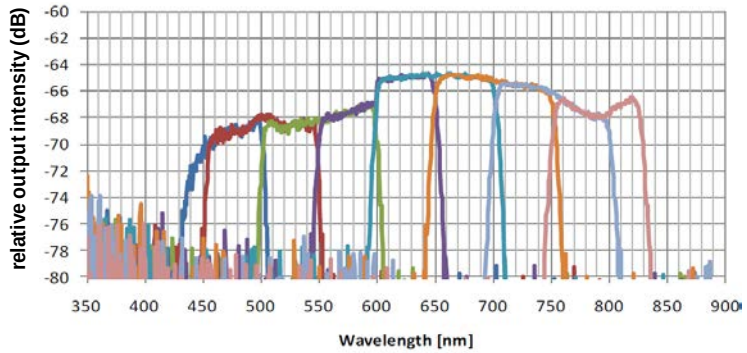
Optical instruments for probing sub-23nm exhaust aerosol composition

- Photoacoustic particle spectrometer
- Variable wavelength UV photoionization charger

SuperK COMPACT® typical output spectrum.

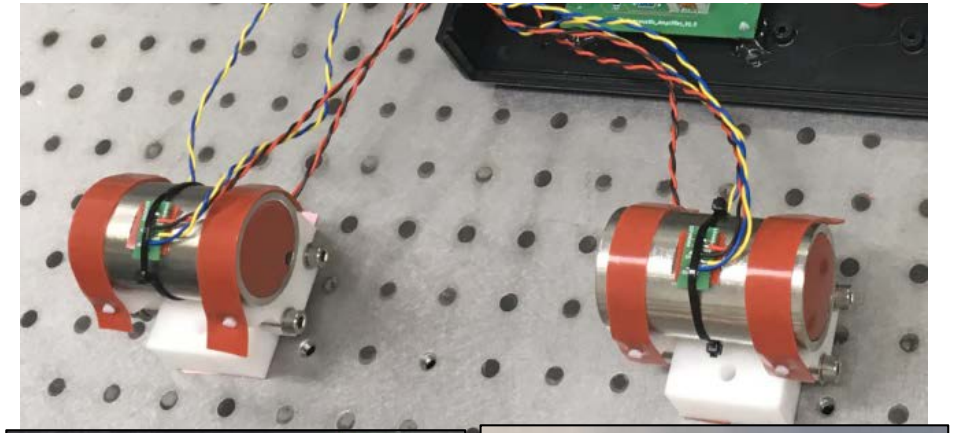


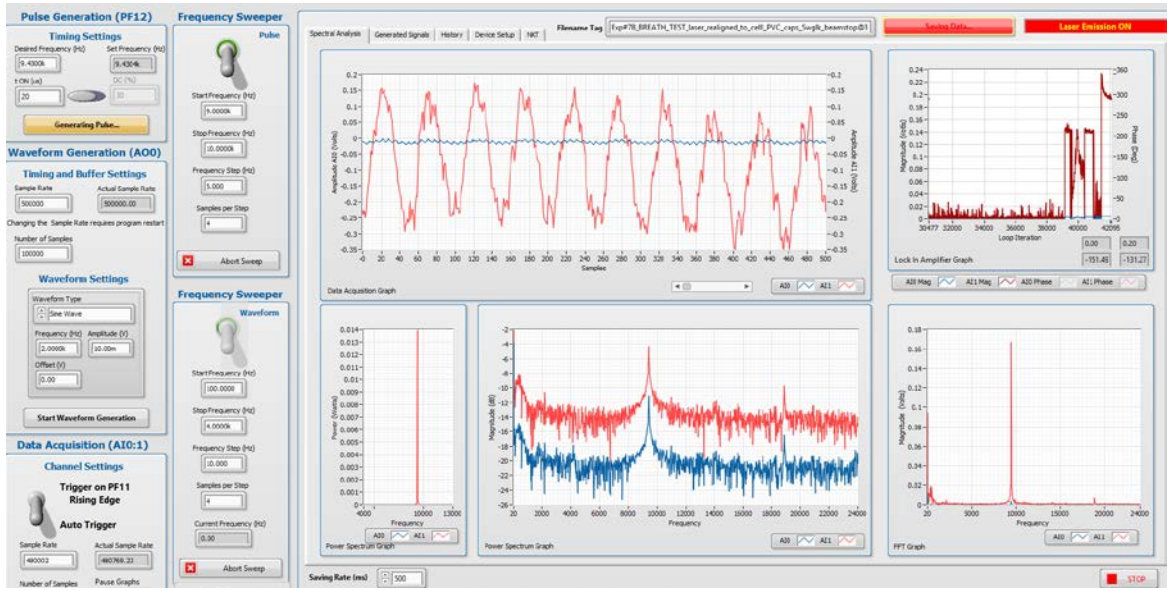
Examples of *SuperK VARIA*® output spectra.

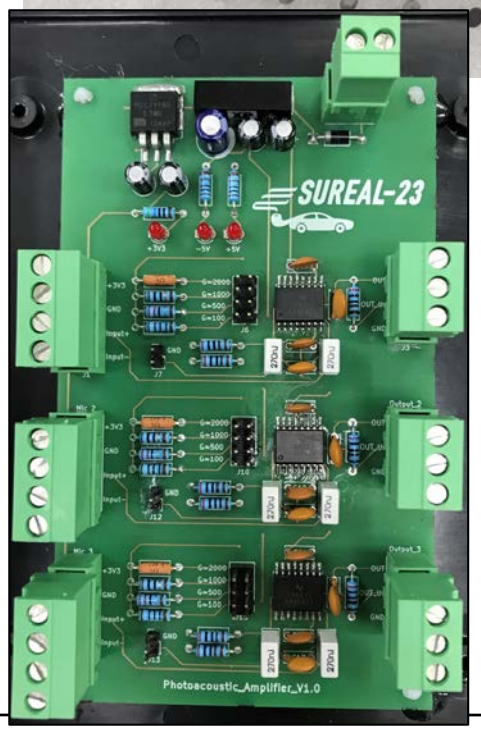


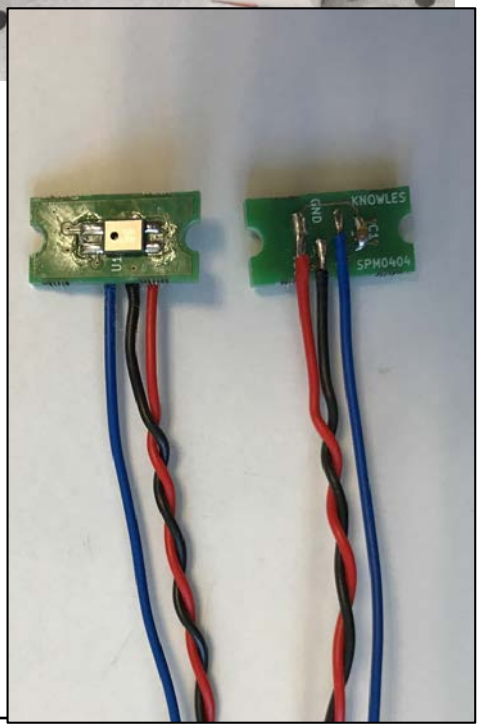
Photoacoustic exhaust particle spectrometer

- Based on resonant photoacoustic cell (cylinder in azimuthal mode, f ≈ 6 – 10 kHz)
- Lock-in amplifier implemented as virtual instrument
- 2-cells: particle measurement cell and filtered sample reference

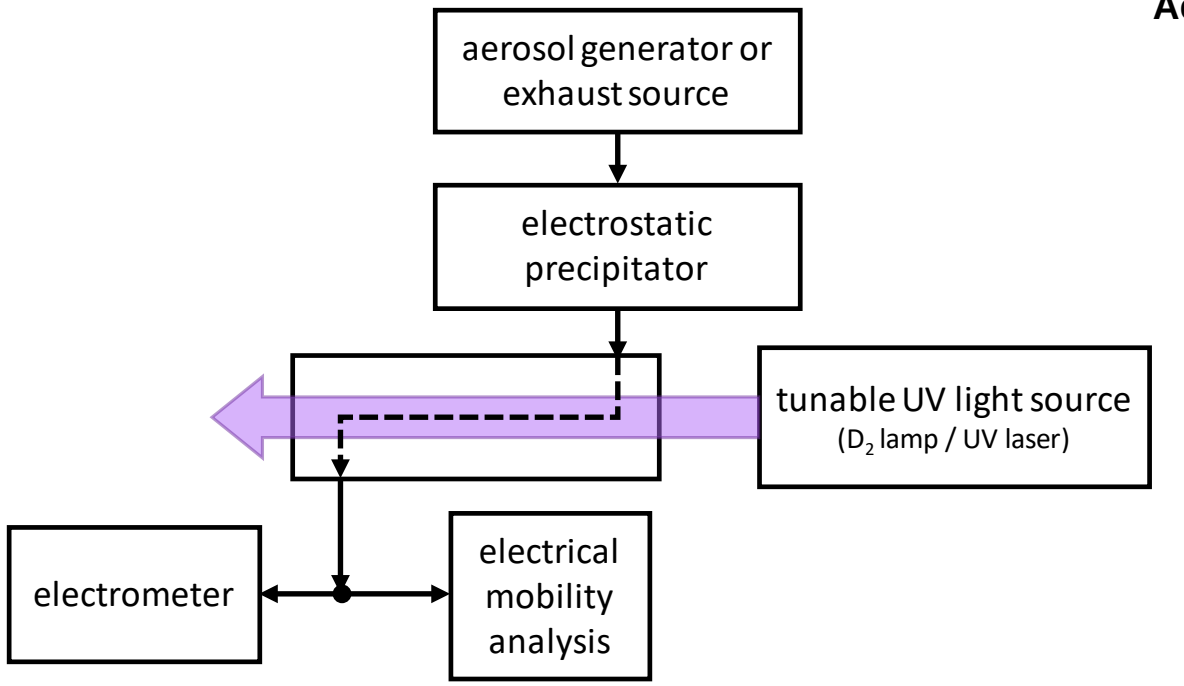


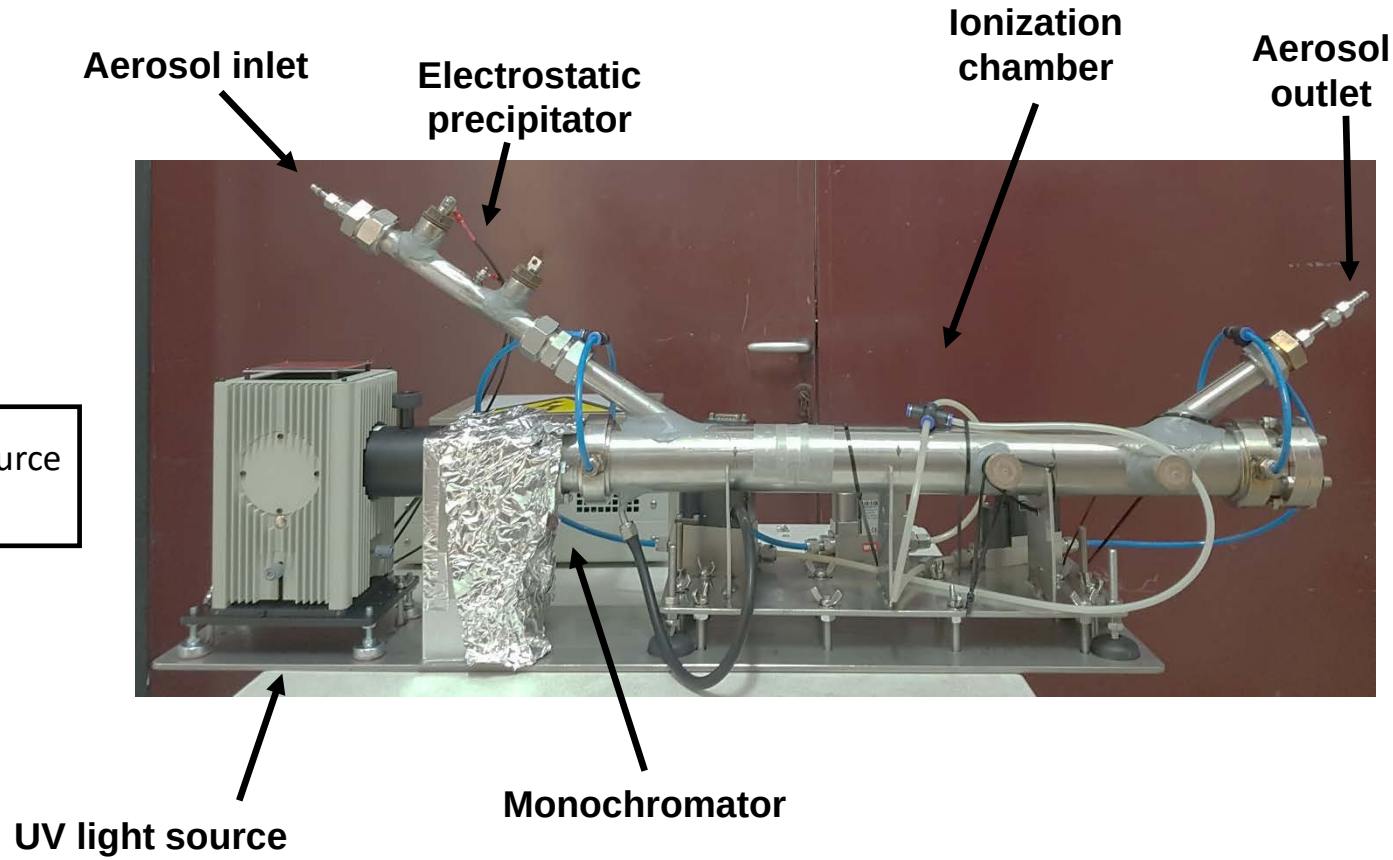




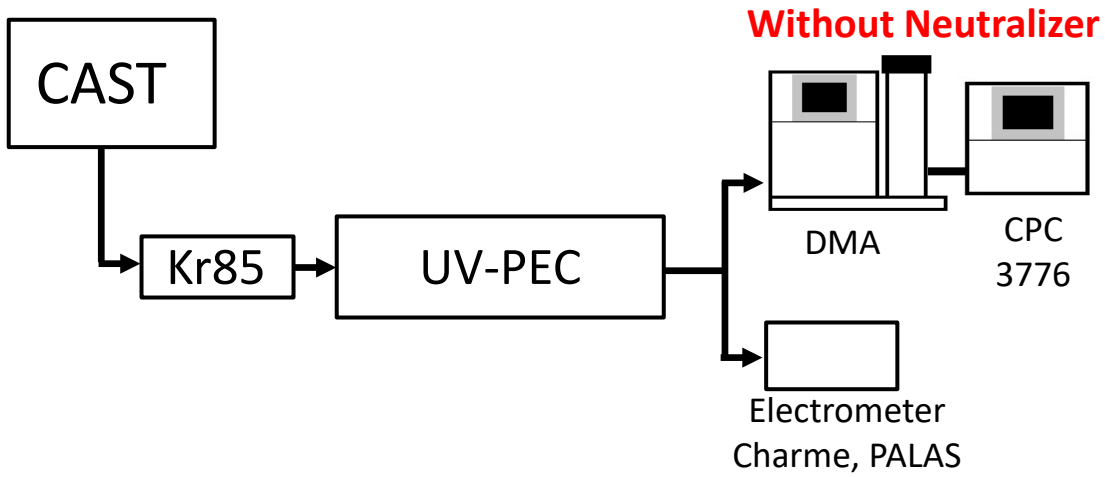


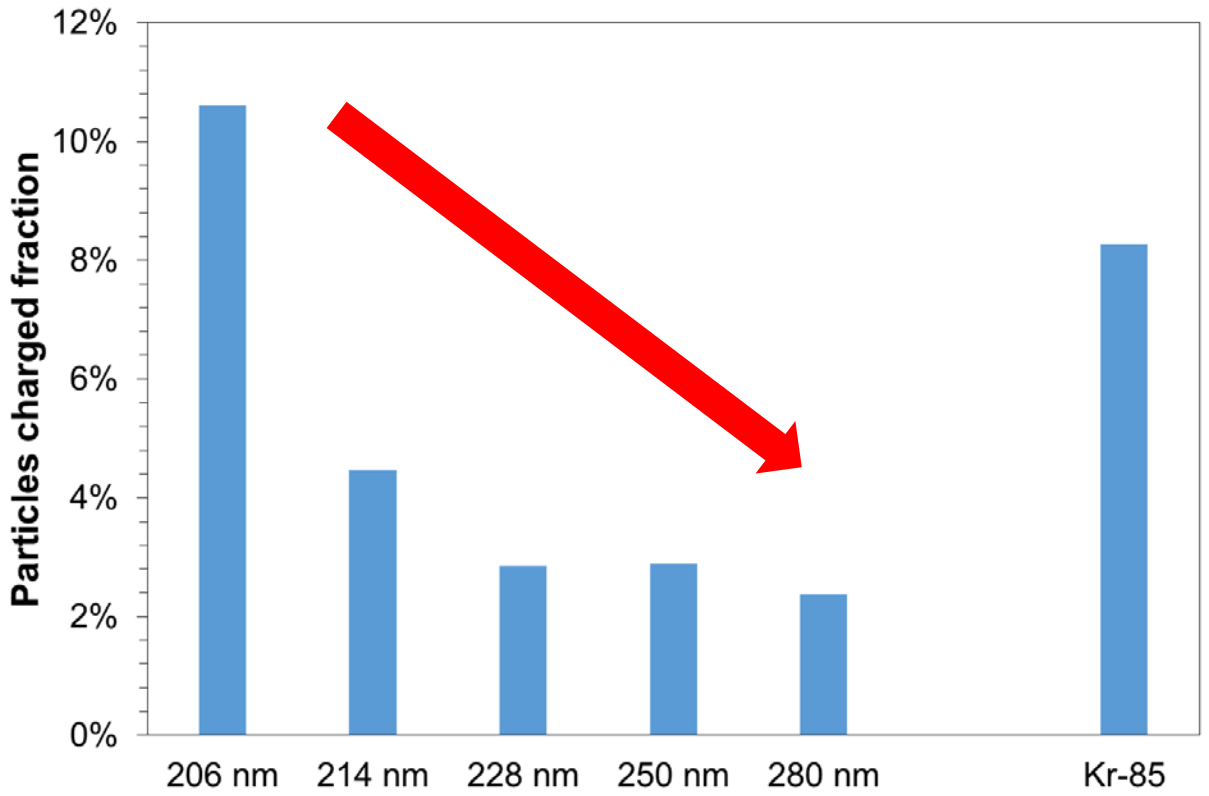
Multiwavelength UV photionization charger





Evaluation with CAST-generated particles





- UV-PEC was tested with the custom “M20” CAST set point (D_{mean}~19 nm).
- As the wavelength increases the charged fraction decreases.
- The high photoemission obtained at 206 nm shows the existence of polyaromatic hydrocarbons (PAHs) on the surface of the particles.

Conclusions – Next Steps

- Advances in particle sampling / treatment / measurement systems for sub 23nm particle emissions are necessary
- SUREAL-23 demonstrates that these are possible with:
  - Increased resolution below 23 nm
  - Advanced catalytic treatment
  - Lower sampling requirements
- Next Steps:
  - Finish developments for all proposed instruments
  - Perform measurements to a variety of testing platforms (Test Matrix)
  - Chose among best solutions for PEMS application

Workshop invitation

Save the date!

The three GV-02-2016 projects:

DownToTen

PEMs4nano

SUREAL-23

cordially invite you to the:

1st Joint Workshop on “Measurement and characterization of nanoparticle emissions from powertrains”

October 9-10, 2018, Thessaloniki, Greece

- Partners from the projects DiePEr, EAGLE, PaREGEn, THOMSON, UPGRADE and experts from research and industrial organisations in USA and Japan will present their recent findings in the area topics of the workshop .
- Contributions from representatives from the EU and EGVIA.
- The keynote speaker will be Prof. Fleming Cassee, Dutch Nat. Inst. for Public Health and the Environment (RIVM)

Acknowledgements

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Manos Daskalos
Anastasios Melas

Thank you for your attention!

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ICE 2017 Conference (Capri)

TRA 2018 Conference (Vienna)