Measurement of sub-23 nm exhaust emission particles

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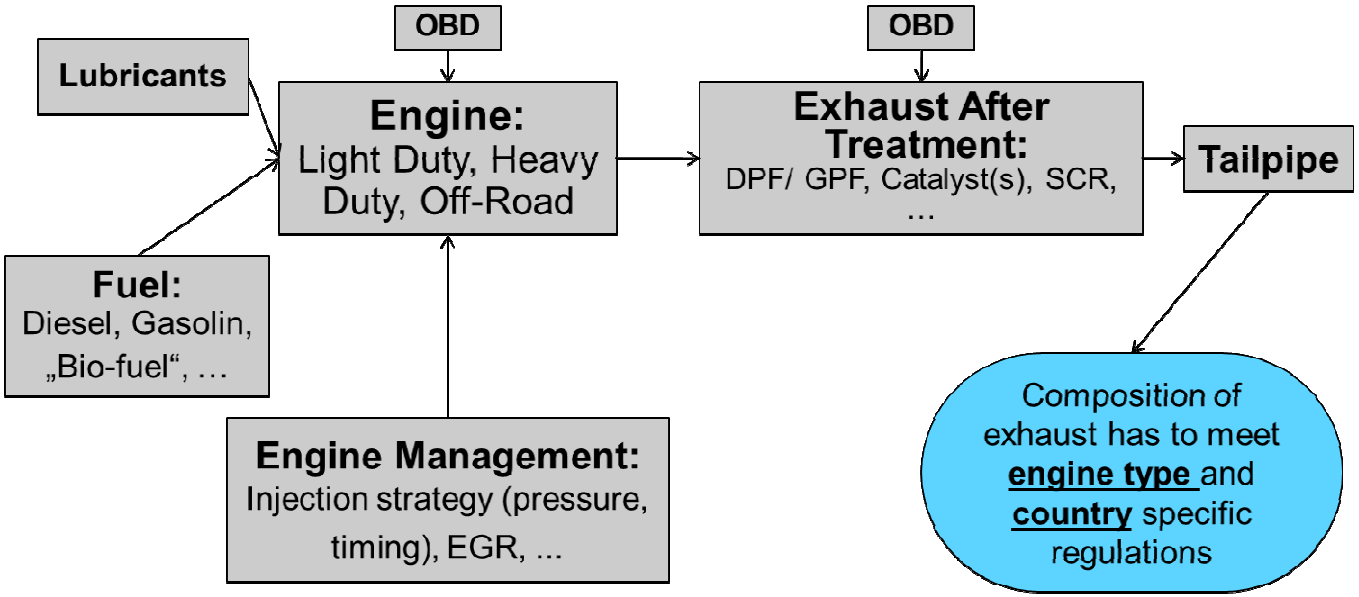
UNDERSTANDING, ACCELERATED

Background

+ Specific engine technologies such as PFI & CNG can emit significant fractions of sub-23 nm particles
+ Intention of European Commission to lower the present cut-off size of 23 nm in post EURO 6/VI regulation
+ Horizon 2020 projects PEMs4Nano, DownToTen, and Sureal23
+ Focus on accurately measuring sub-23 nm particles

Background
Particle Size of PN Emissions

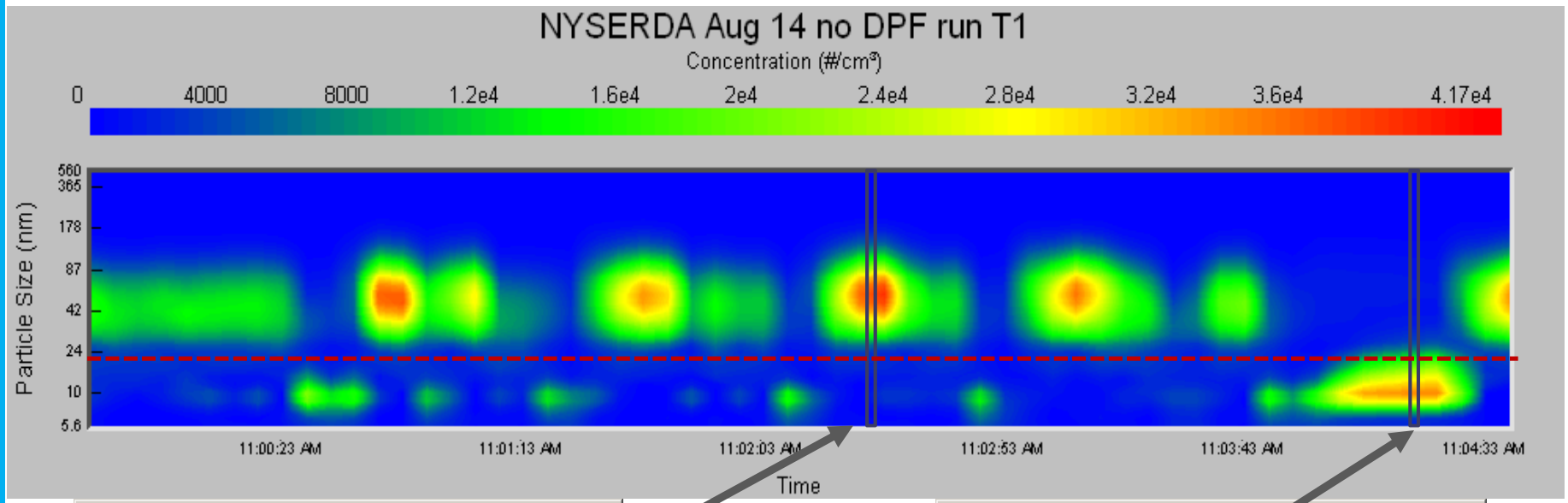
+ Particle size provides information to better understand the emission – also sub-23 nm

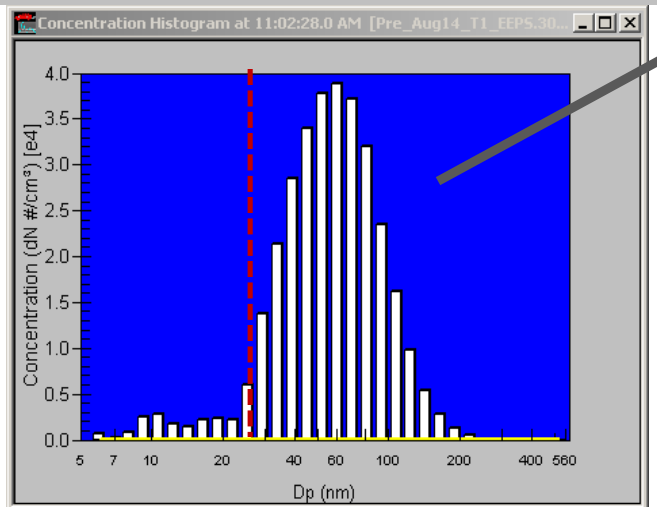


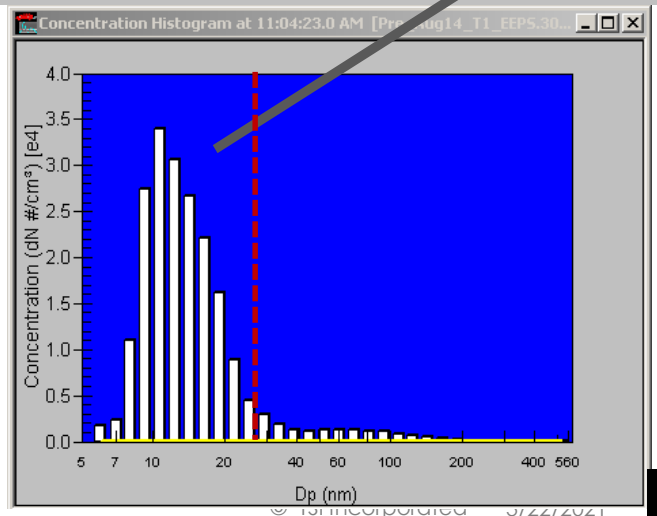
Engine Exhaust Particle Sizer (TSI 3090)

Measures ten particle size distributions from 5.6 to 560 nm in 32 size channels per second (=10 Hz sampling rate)

Background
Particle Size of PN Emissions



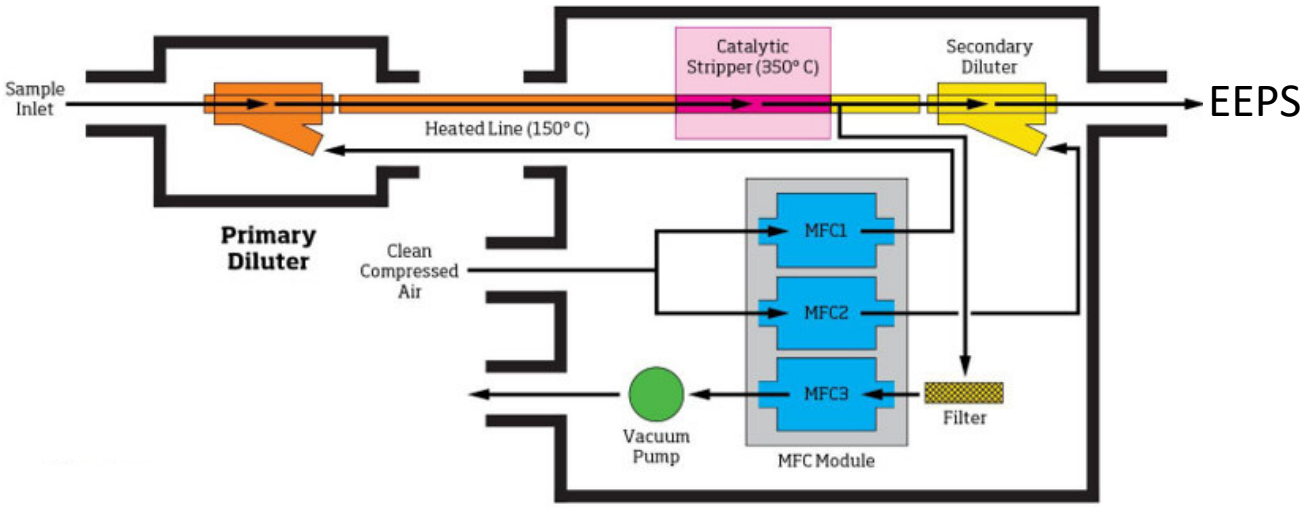




Dedicated and optimized conditioning system for the EEPS

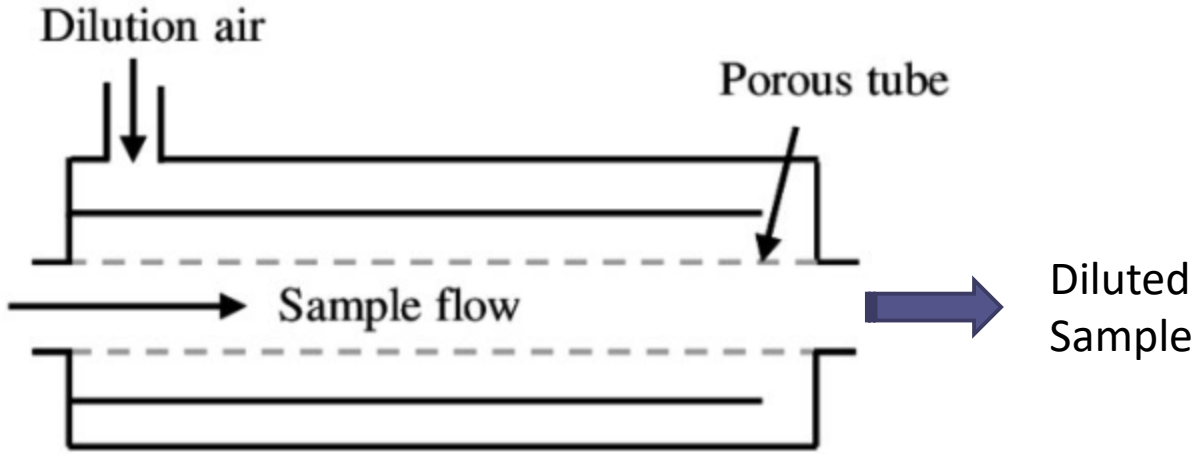
+ Aim:
  - Minimize and fully characterize size dependent particle losses

+ Porous Tube Thermodiluter, model 3098
  - Primary & secondary dilution - MFC controlled (real time)
  - Catalytic Stripper - removal of volatiles
  - AK compatibility
  - One software for both EEPS & diluter



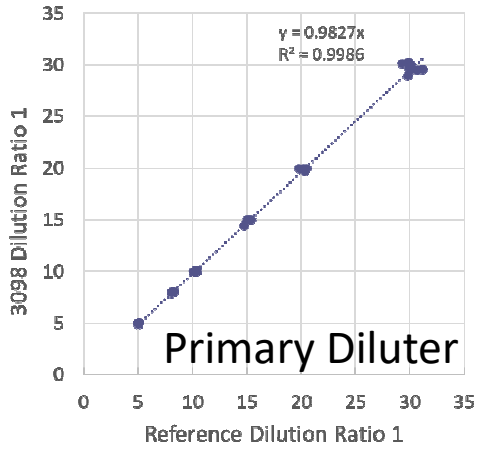
Porous Tube Diluter

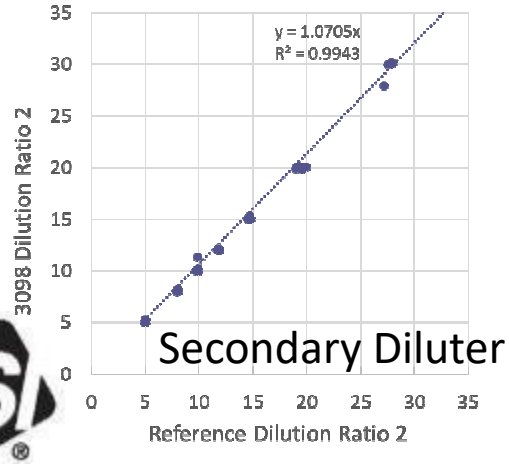
- Mounted right after exhaust probe
- Minimize diffusion losses for particles ≤ 23 nm, e.g. research for post-EURO 6/VI
  - low residence time due to high flow rate
  - dilution flow introduced through porous wall along tube
- No moving parts and stays clean (low maintenance)

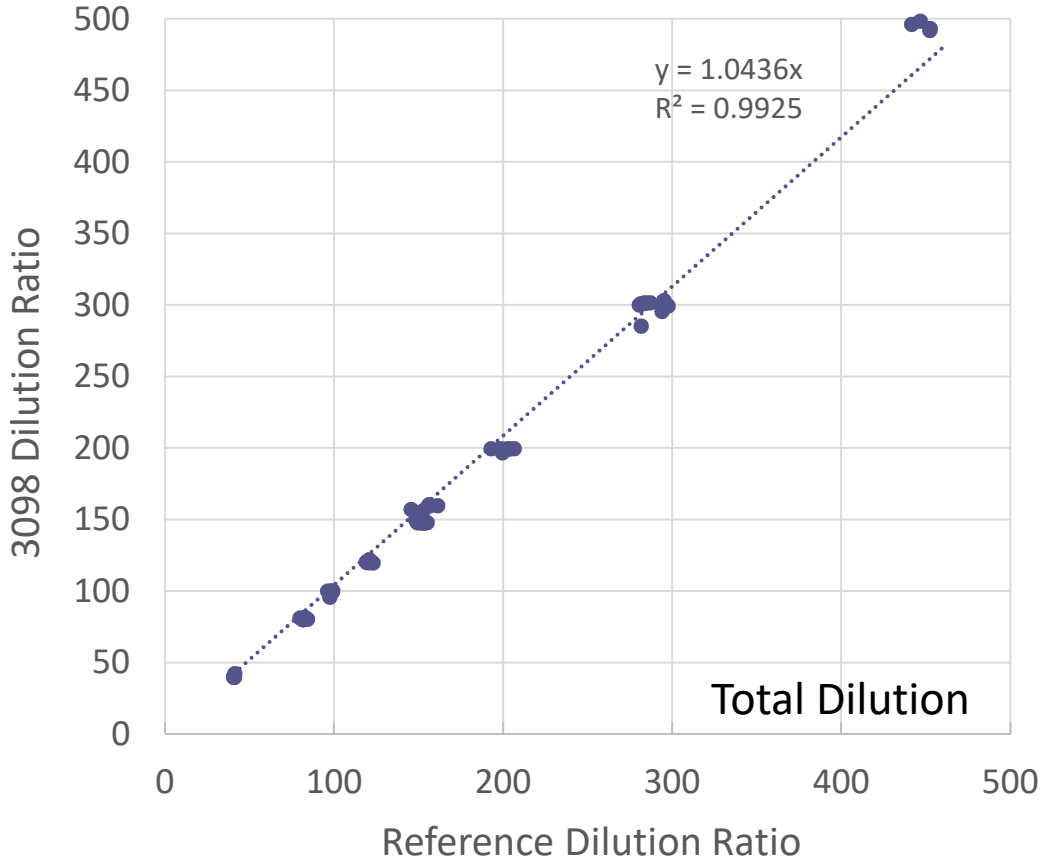


Total Dilution Control Performance (1 min averages)

- Higher accuracy and better dilution ratio control at low dilution ratios
- This is what is needed to characterize low emission engines!

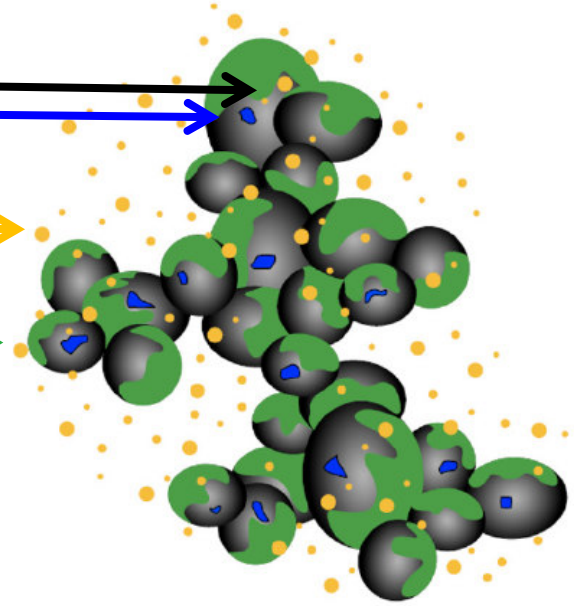




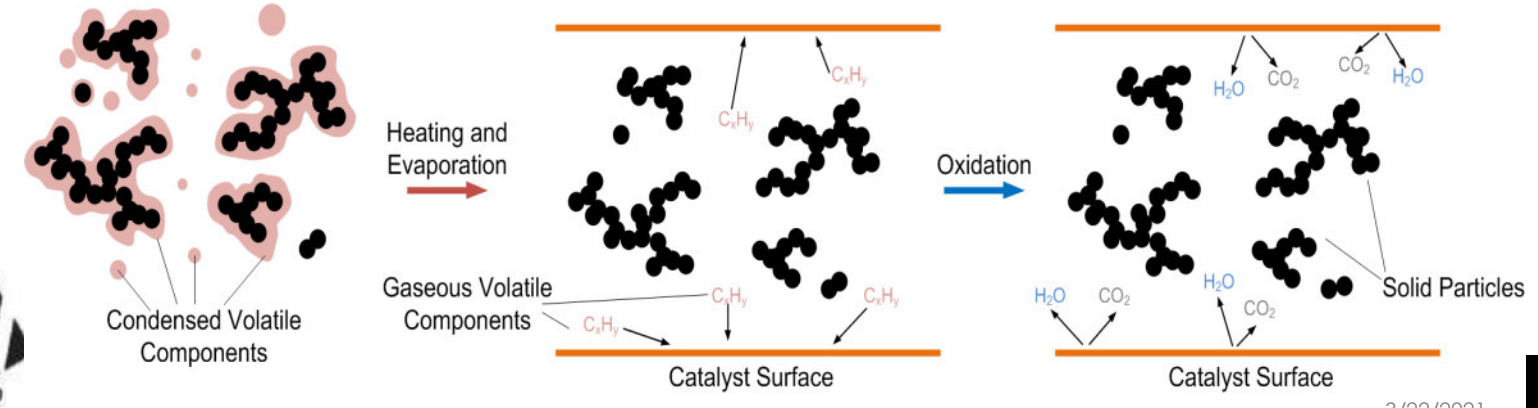


Catalytic Stripper for the removal of volatile material

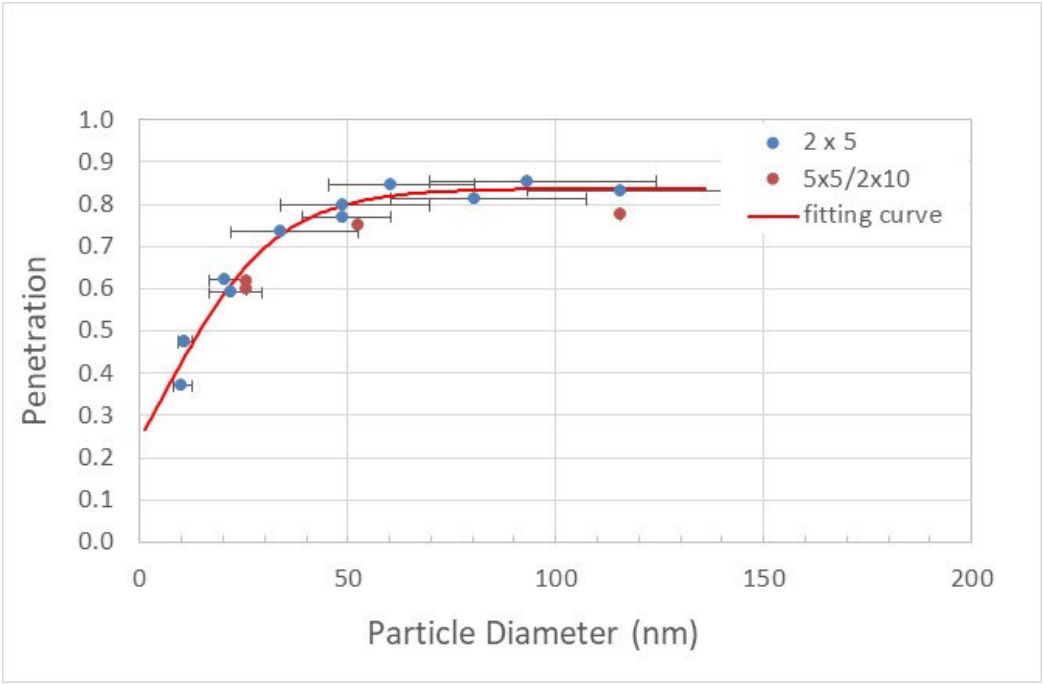
- Solid carbonaceous agglomerates
- Solid ash particles
- Semi-volatile sulfuric acid + hydrocarbon particles
- Adsorbed and condensed sulfuric acid and hydrocarbon vapors



Volatiles are oxidized using a catalyst:



Characterization of size dependent penetration through the system



Particle Diameter (nm)	Penetration
5.6	0.35
10	0.43
15	0.51
23	0.62
41	0.77
55	0.81
100	0.84

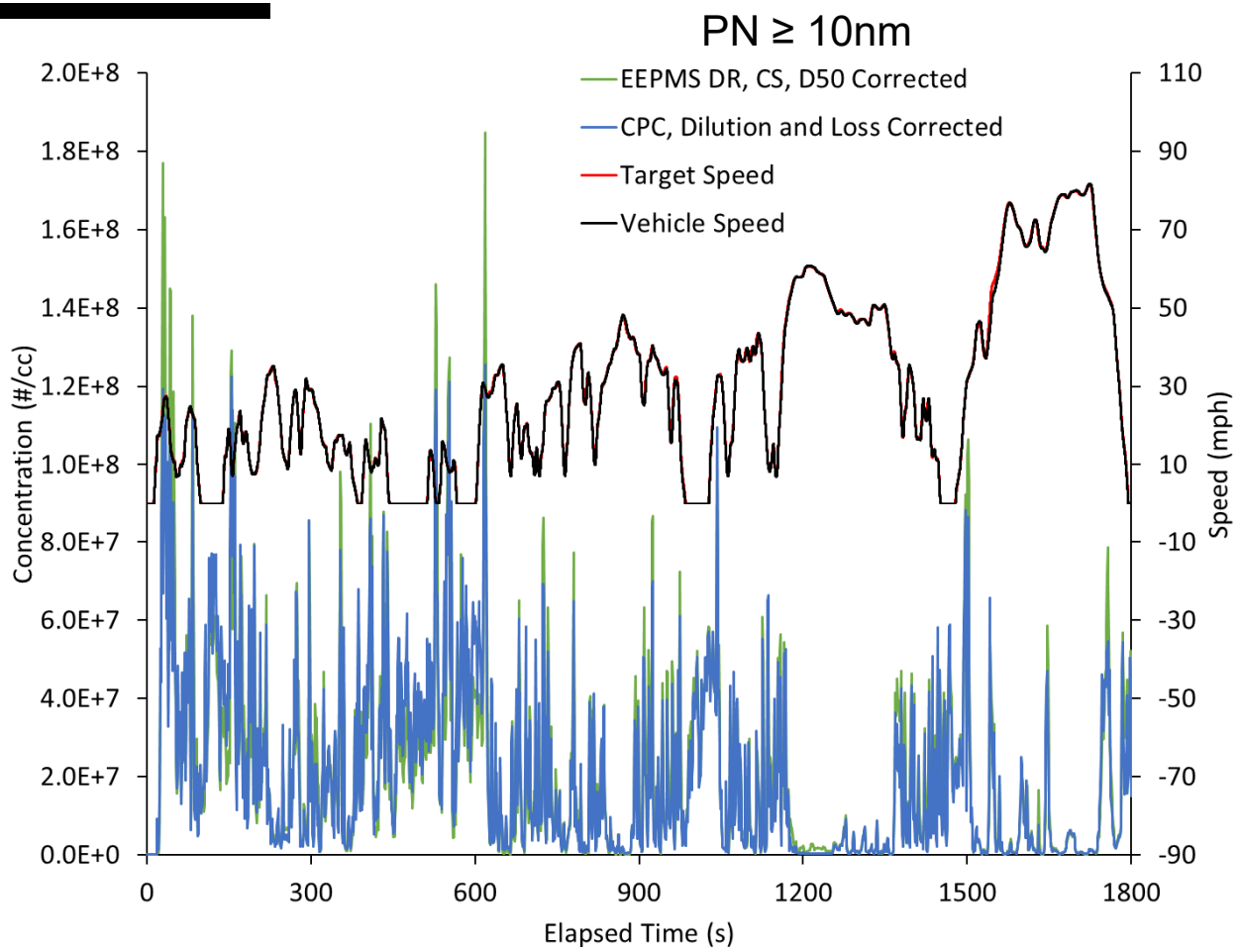
+ Measured at d1=2, d2=5, d1=2, d2=10, and d1=5, d2=5 dilution ratios
+ Thermophoretic losses are about 20%
+ Diffusion losses increase as particle size goes down
+ At 10 nm total penetration is about 40-50%

Particle Penetration Comparison for comparable complete systems

Dp (nm)	3098 PTT (typical)	DownToTen[1] (HPD,CS,PT) (avg values)	JRC[2]system (RDD/ET/mixing diluter)	Horiba[3] SPCS (WRCD/ET/sec diluter)	AVL[4] APC (RDD,ET,PT) (avg values)
10	**0.43**	~ 0.40	<0.40 (est)		
30	0.70	~ 0.70	0.49	0.71	0.63
50	0.80	~ 0.80	0.60	0.83	0.73
80	0.83		0.78	0.82	
100	0.84	0.80 to 0.90	0.83	0.86	0.78

1. Sub-23nm particle measurement methodology, Down-To-Ten project, April 2019
2. PMP light-duty inter-laboratory exercise: comparison of different particle number measurement systems, Giechaskiel et al., Meas. Sci. Technol., 2008
3. Calibration and validation of various commercial PN measurement systems, Giechaskiel et al. SAE International, 2009
4. Calibration and accuracy of a PN measurement system, Giechaskiel et al., Meas. Sci. Technol., 2010

WLTP results
EEPMS vs. CPC concentration



- EEPMS corrected for dilution, system losses, and CPC counting efficiency
- CPC corrected for dilution and system losses

Thank you for your attention! Questions?

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- Dedicated porous tube diluter system for EEPS
  - Fully characterized losses down to 5/10 nm
  - Optimized conditioning of sub-23 nm particles
  - Accurate & fast measurement of particle size distributions
- Applications
  - R&D:
    - Understand contributions from lubricants and fuel types
    - Optimize engine management
    - Analyze exhaust aftertreatment strategies
  - Brake wear particles studies