



# Measurement of diesel engine emitted nanoparticles

Zhongqing Zheng, Kent C. Johnson, Zhihua Liu, Thomas D. Durbin, and Heejung Jung  
College of Engineering, Center for Environmental Research and Technology  
(CE-CERT) University of California, Riverside

Shaohua Hu and Tao Huai  
California Air Resources Board (CARB)

David B. Kittelson  
Department of Mechanical Engineering University of Minnesota



# Measuring diesel particle emissions



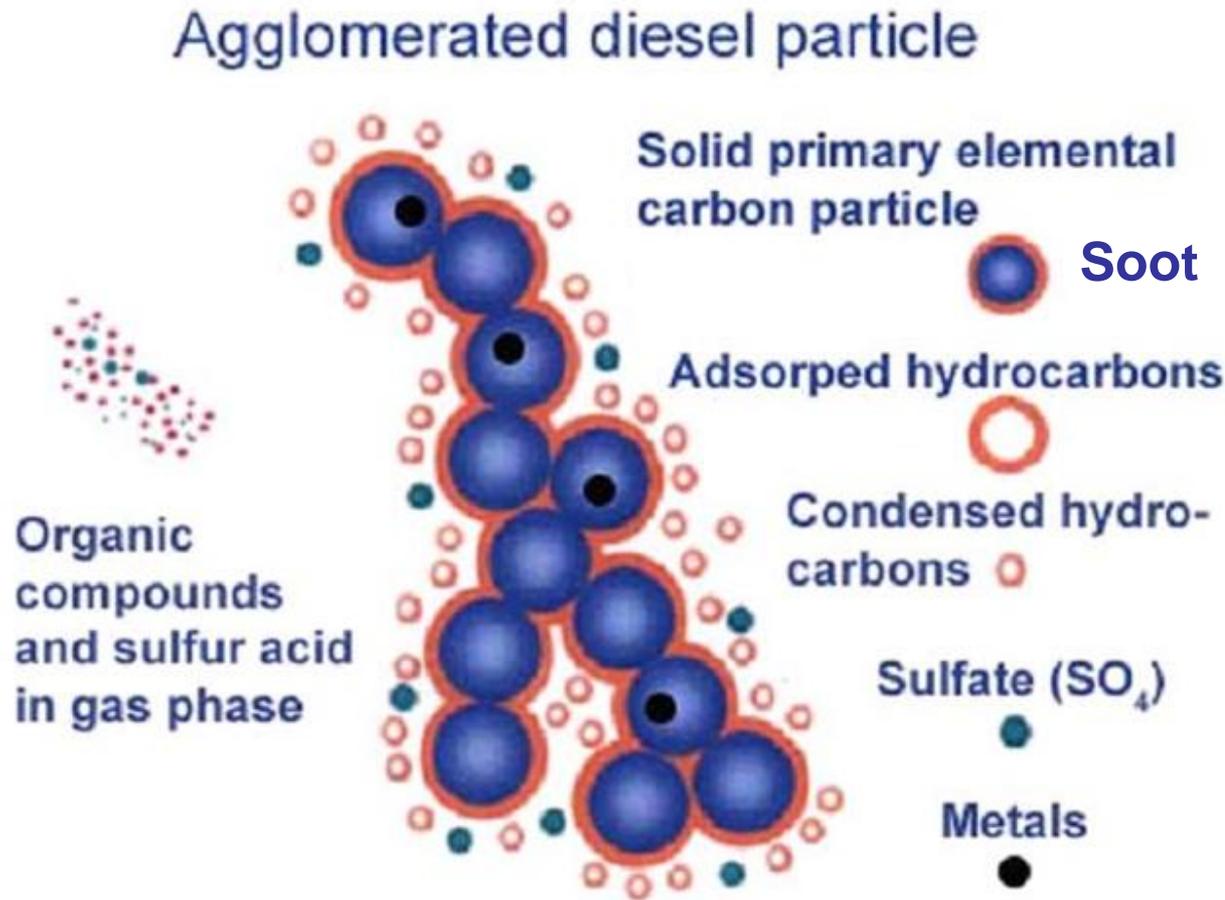


# Overview

- Background
- Experimental setup
- Results
- Conclusion



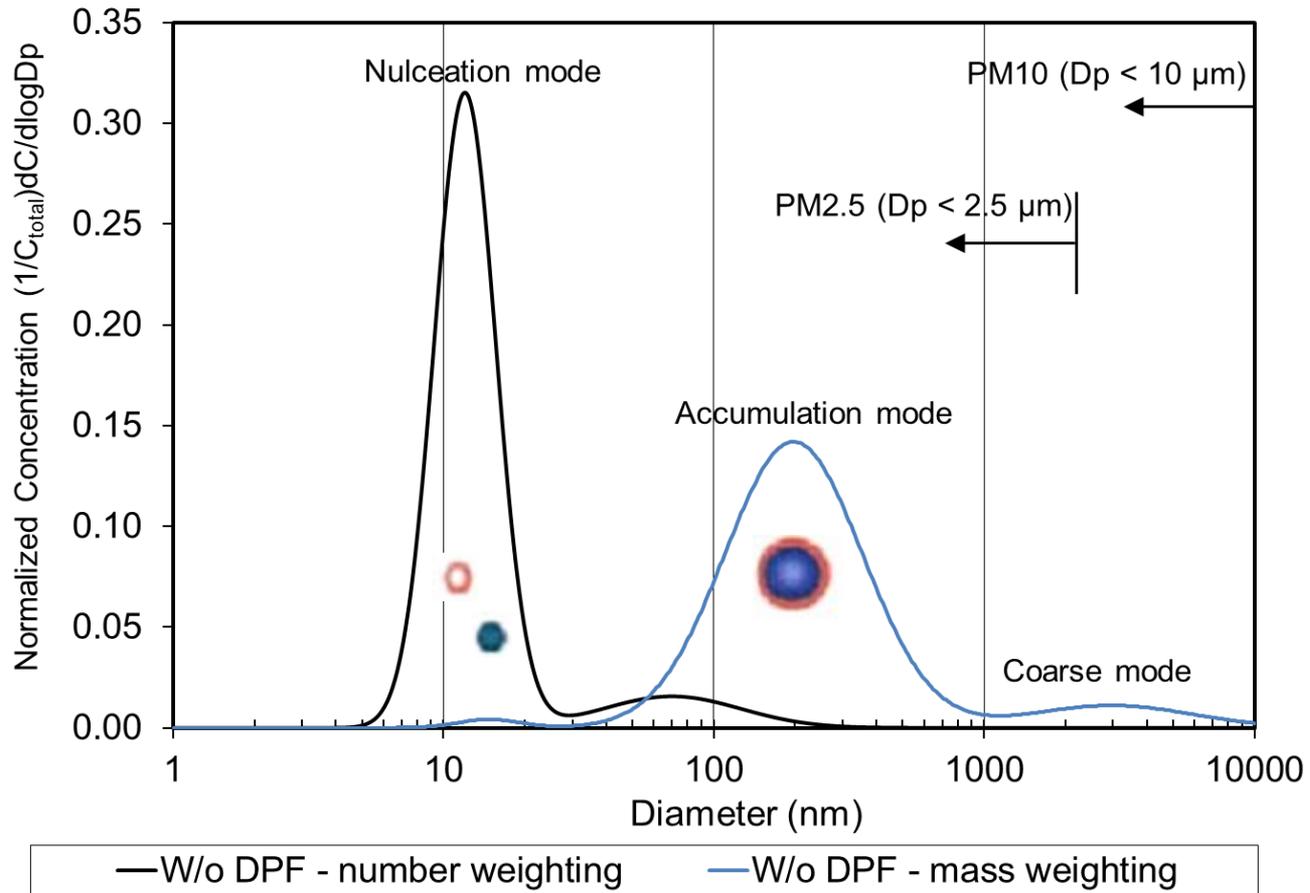
# Typical diesel particle composition





# Typical diesel particle size distribution

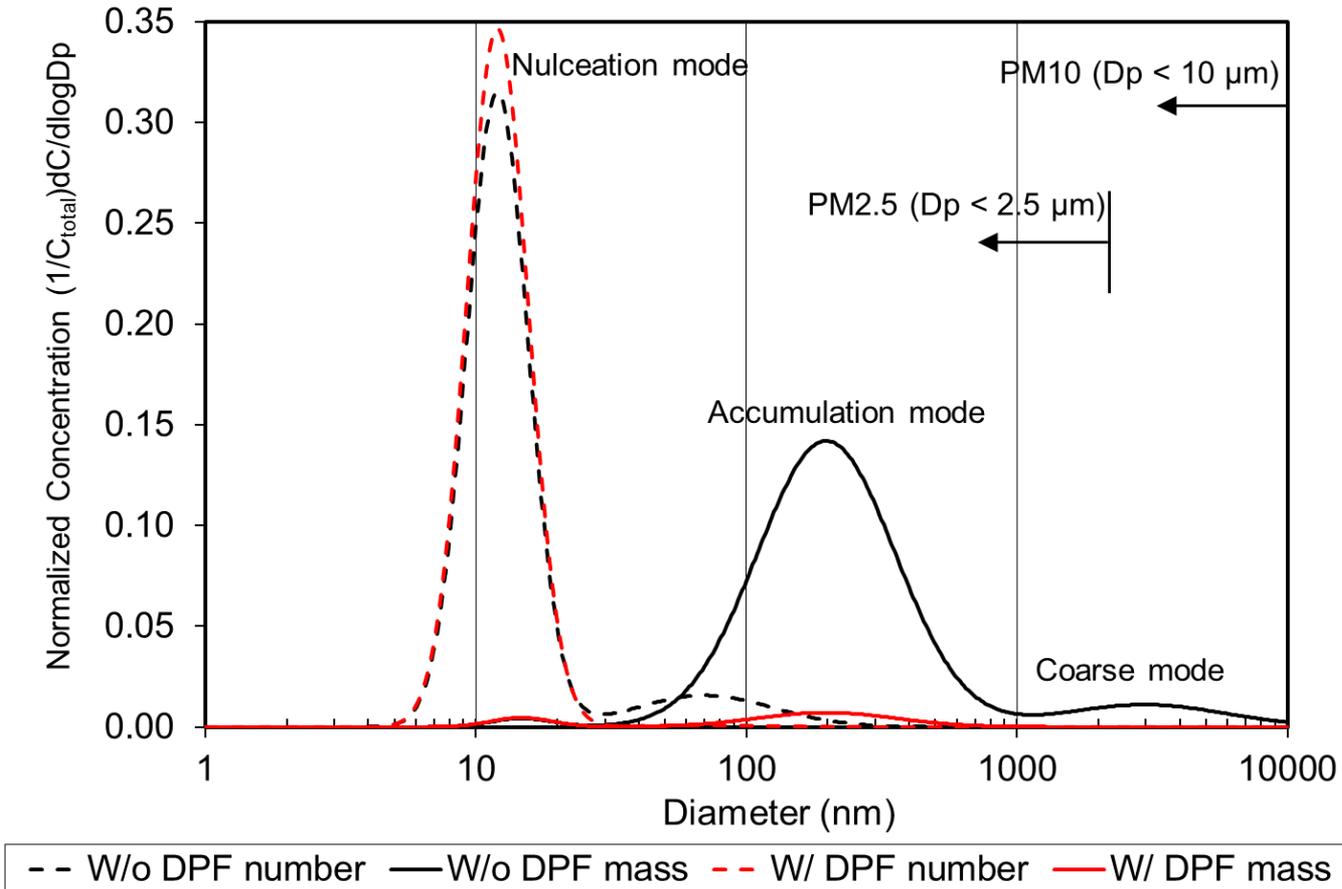
Currently, diesel PM is regulated on a mass basis





# Diesel particle size distribution

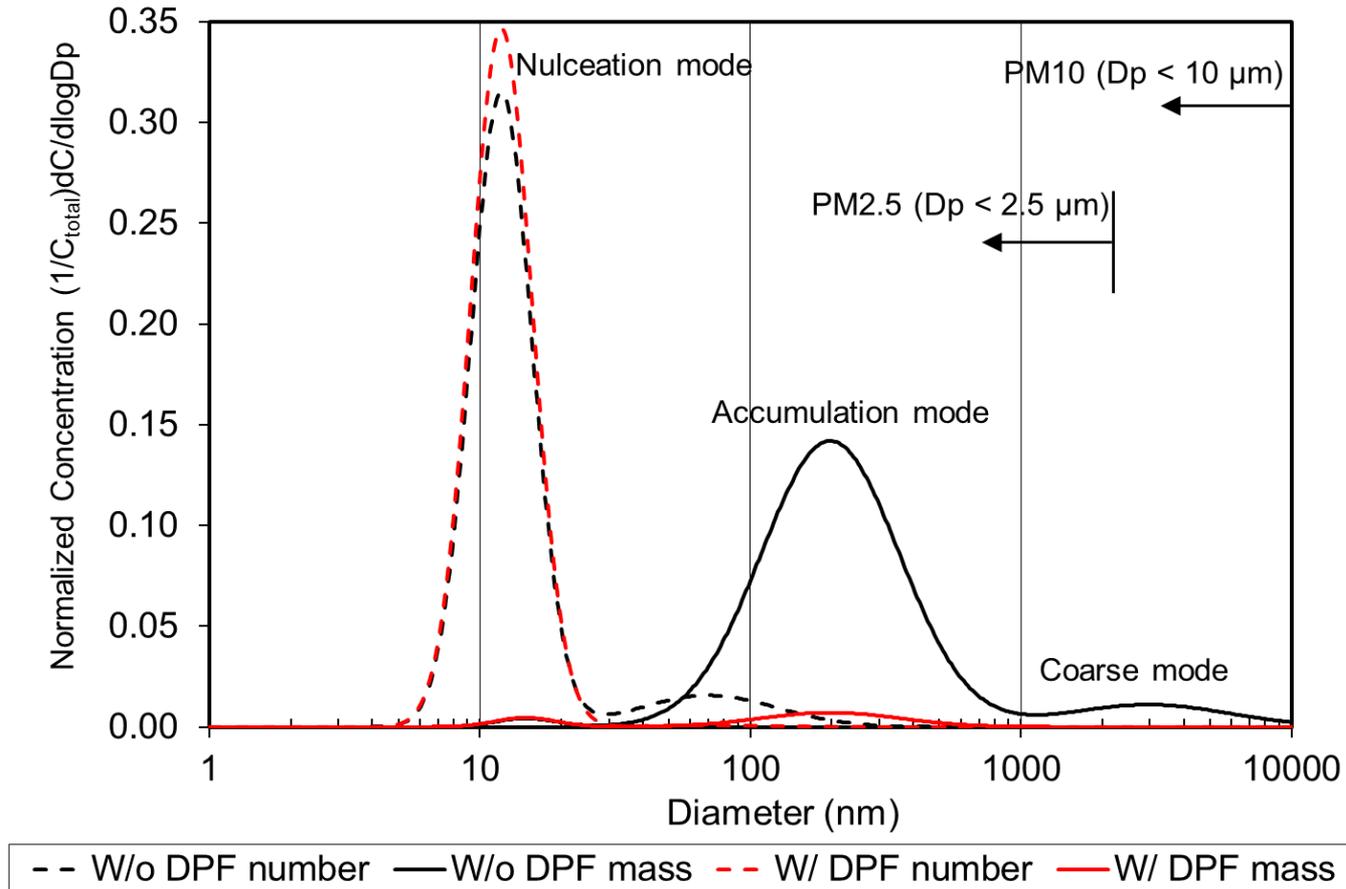
To meet regulation limit, a diesel particulate filter (DPF) is essential.





# Issues of current mass based method

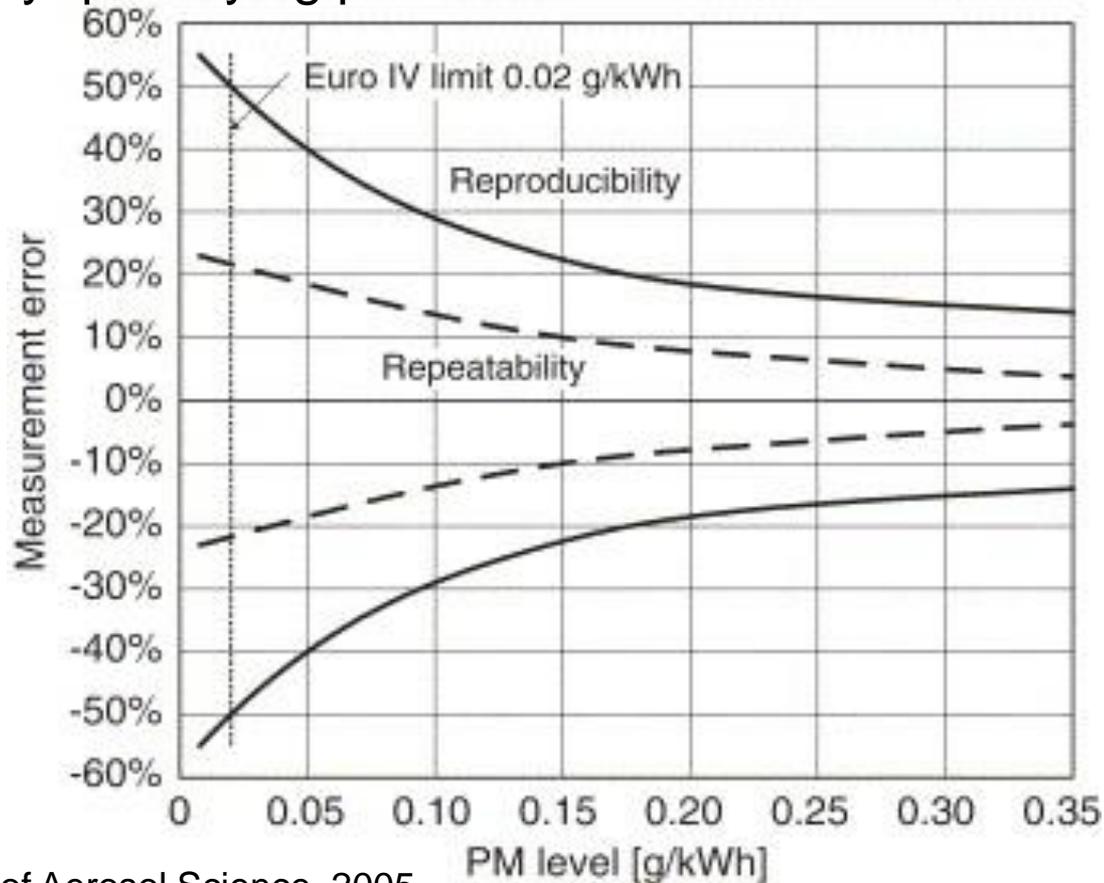
- Not regulating nanoparticles – which might be more toxic





# Issues of current mass based method

- Not regulating nanoparticles – which might be more toxic
- Difficulty quantifying particle mass emissions accurately





# So, What should we do?

- Particle number vs Particle mass
- The European Particle measurement programme (PMP)
  - The PMP measures number of solid particles bigger than 23 nm.



# So, What should we do?

- However, Particle number is trickier than mass
- Particle mass is conserved
- Particle number is **NOT** conserved
  - Diesel particle number is dominated by nucleation mode
  - Nucleation mode particles are formed by nucleation and condensation from volatiles
  - Nucleation and condensation are nonlinear functions of exhaust temperature, dilution ratio, DPF fill state, etc..
- **PMP only measures solid particles**



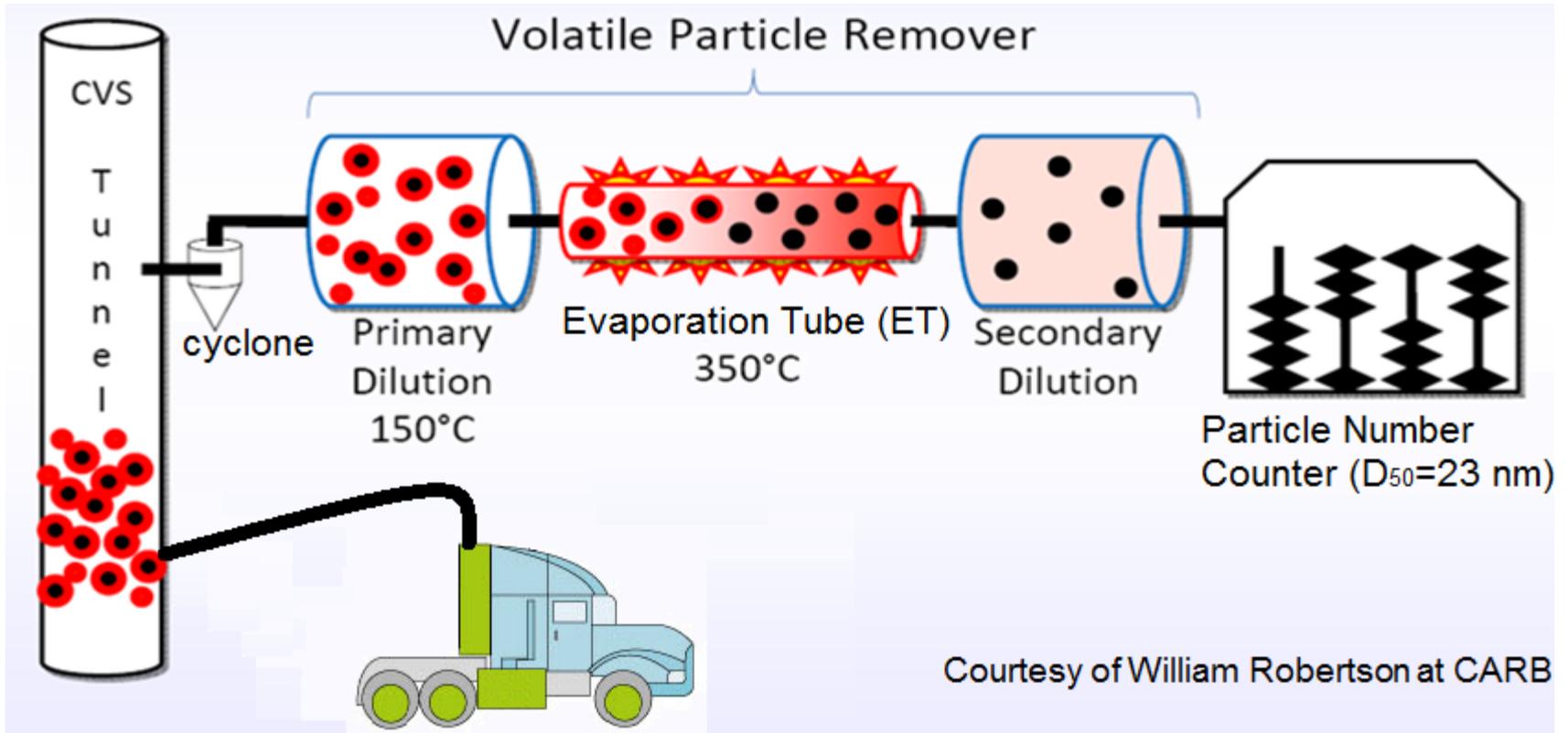
# How to measure only solid particles

Remove volatiles before measuring:

- PMP method
- Catalytic stripper



# PMP method

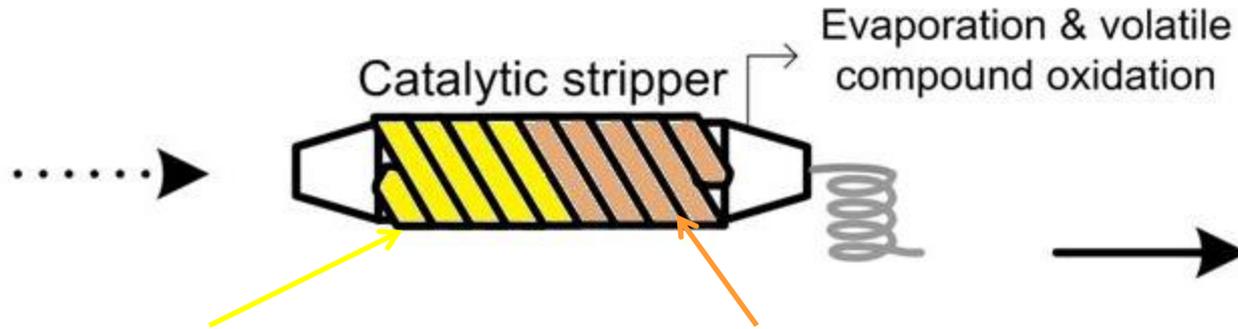


Courtesy of William Robertson at CARB

PMP uses post-dilution thermo-conditioning to remove volatile species



# Catalytic stripper (CS)



## Sulfur-trap (S-Trap):

- Wall temperature: 300°C
- $\text{BaO} + \text{SO}_3 \rightarrow \text{BaSO}_4$

## Oxidation catalyst:

- Wall temperature: 300°C
- 75 g/ft<sup>3</sup> of Pt

CS uses catalyst to remove volatile species

Swanson, J. and Kittelson, D.B.. Fundamental evaluation of methods for “solid” particle measurements. 28<sup>th</sup> AAAR Conference , Minneapolis, Minnesota, October 26 – 30, 2009.



# Objective

- Evaluation and comparison of the PMP and CS



# Experimental setup

UCR CE-CERT Mobile Emission Laboratory (MEL)





# Experimental setup

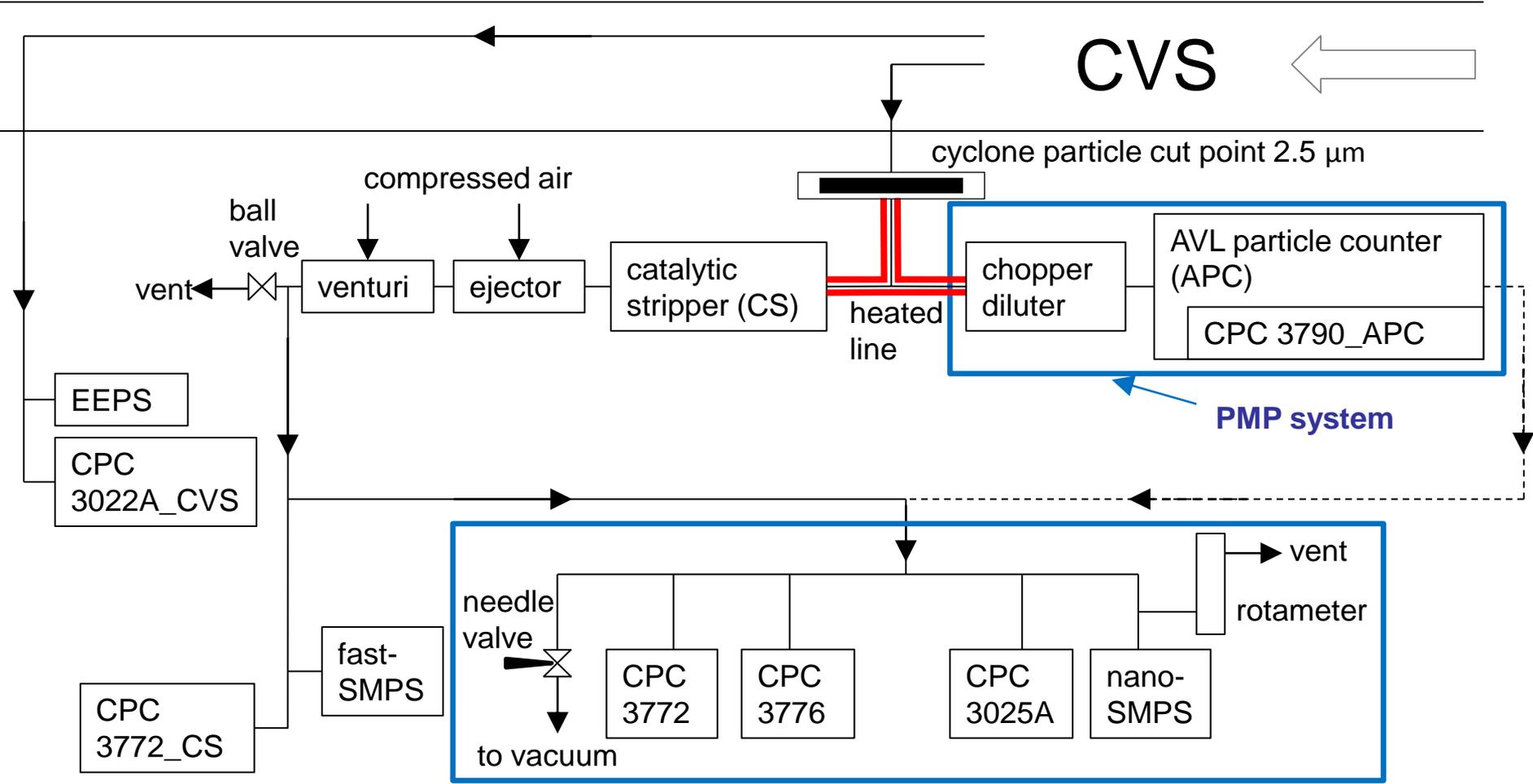


To dilution tunnel (CVS)

Diesel particle filter (DPF)



# Experimental setup

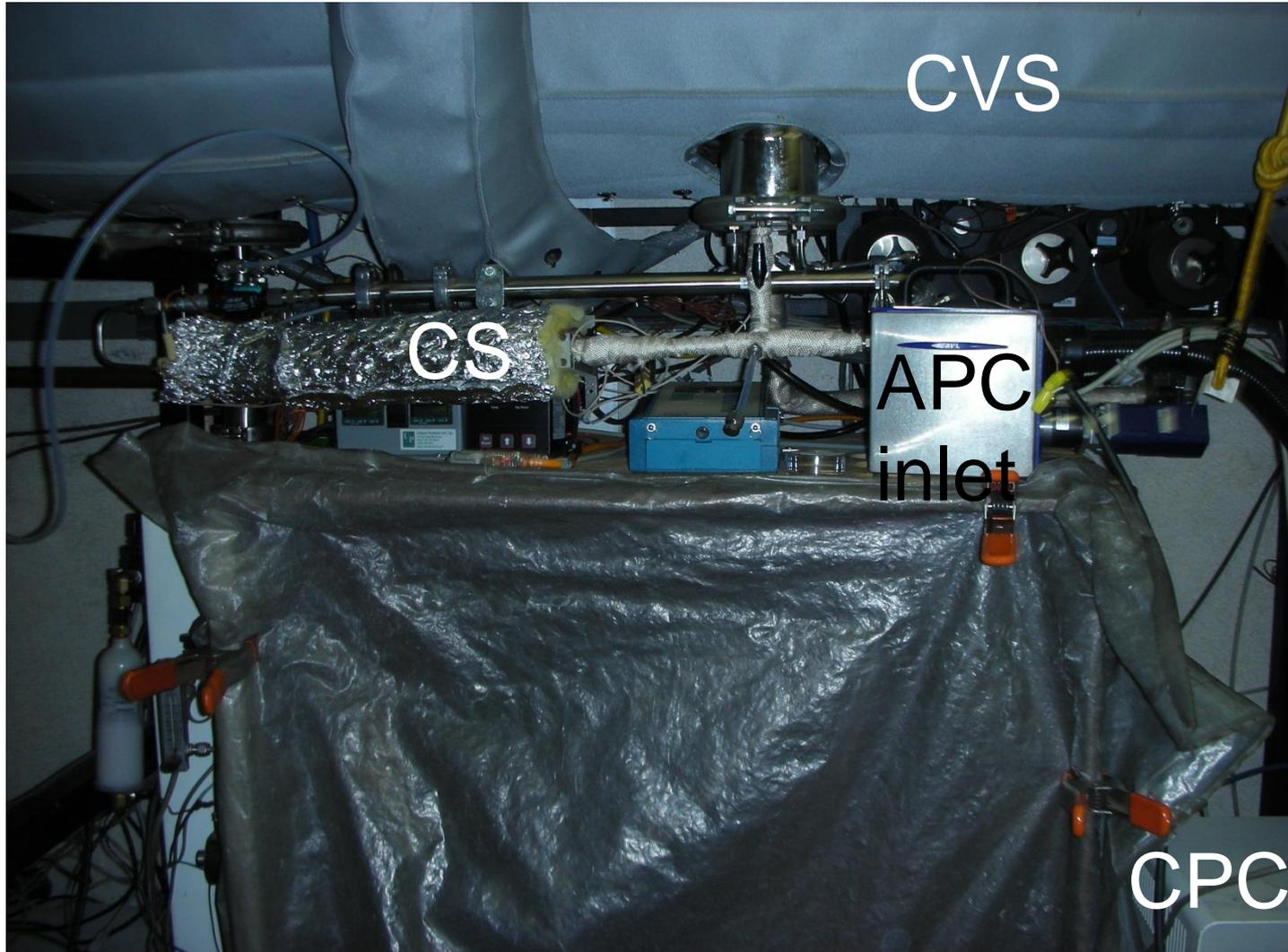


CPC measures particle number concentration

Alternate between the APC and CS

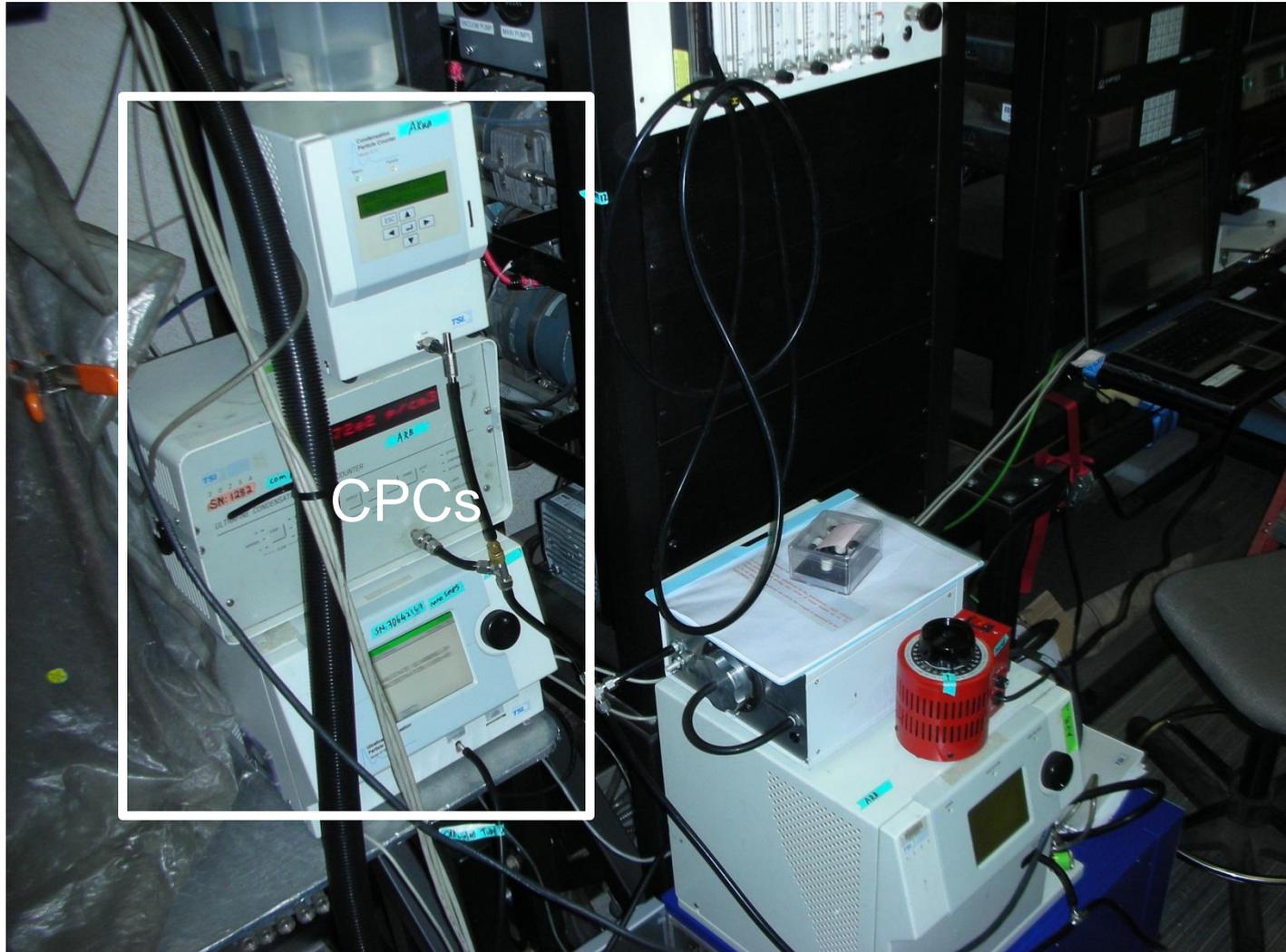


# CVS, inlets of the APC and CS





# Different CPCs





# Experimental conditions

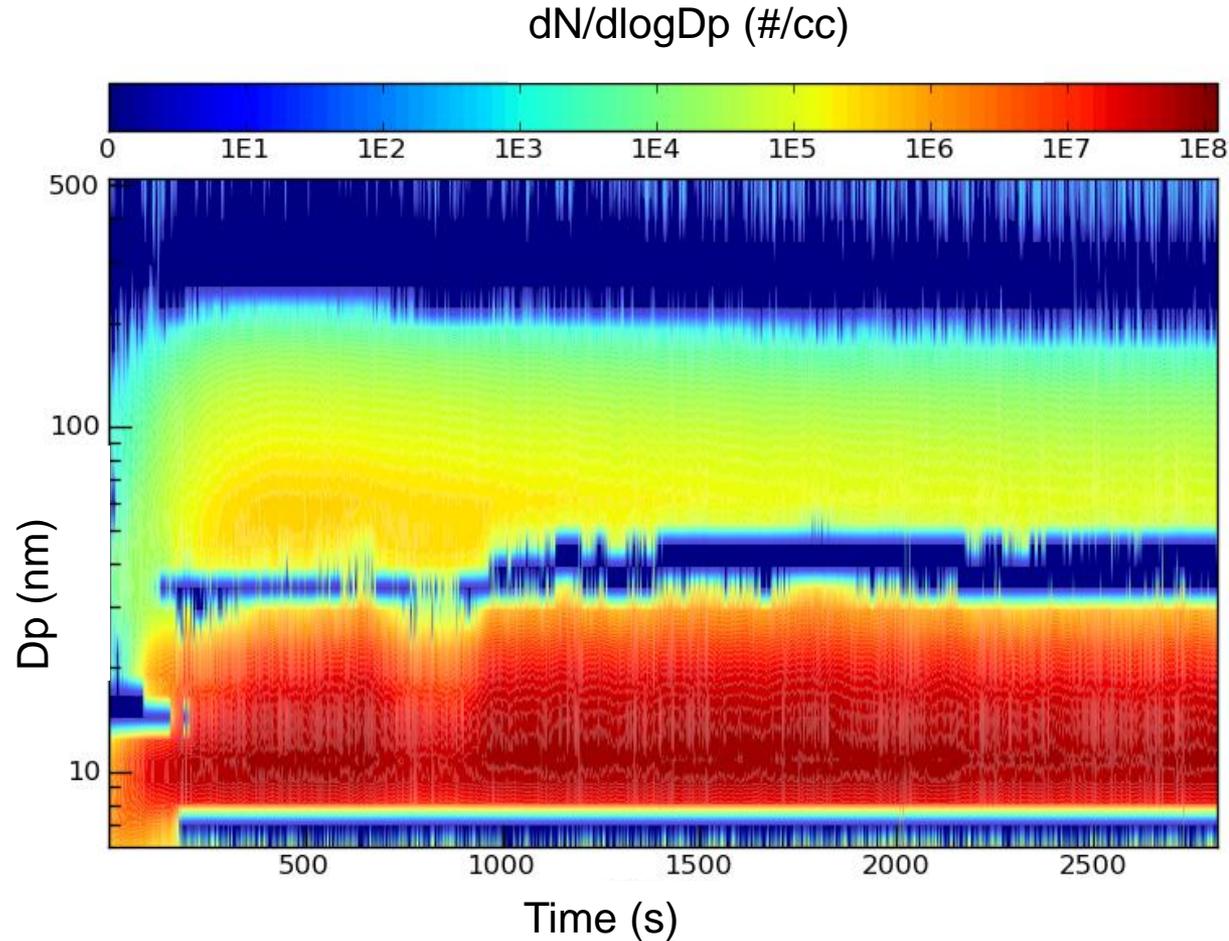
Base	CE-CERT HD Chassis dynamometer
Vehicle	Freightliner class 8
Engine	Caterpillar C-15 (14.6L)
Fuel	ULSD
Lubricating oil	SAE 15W-40
DPF	JM CRT
Vehicle weight	65,000 lb
Truck mileage	41442 miles
<b>Cycles</b>	<b>(a) 56 mph cruise at 74% engine load; (b) 56 mph cruise at 26% engine load.</b>



# Results



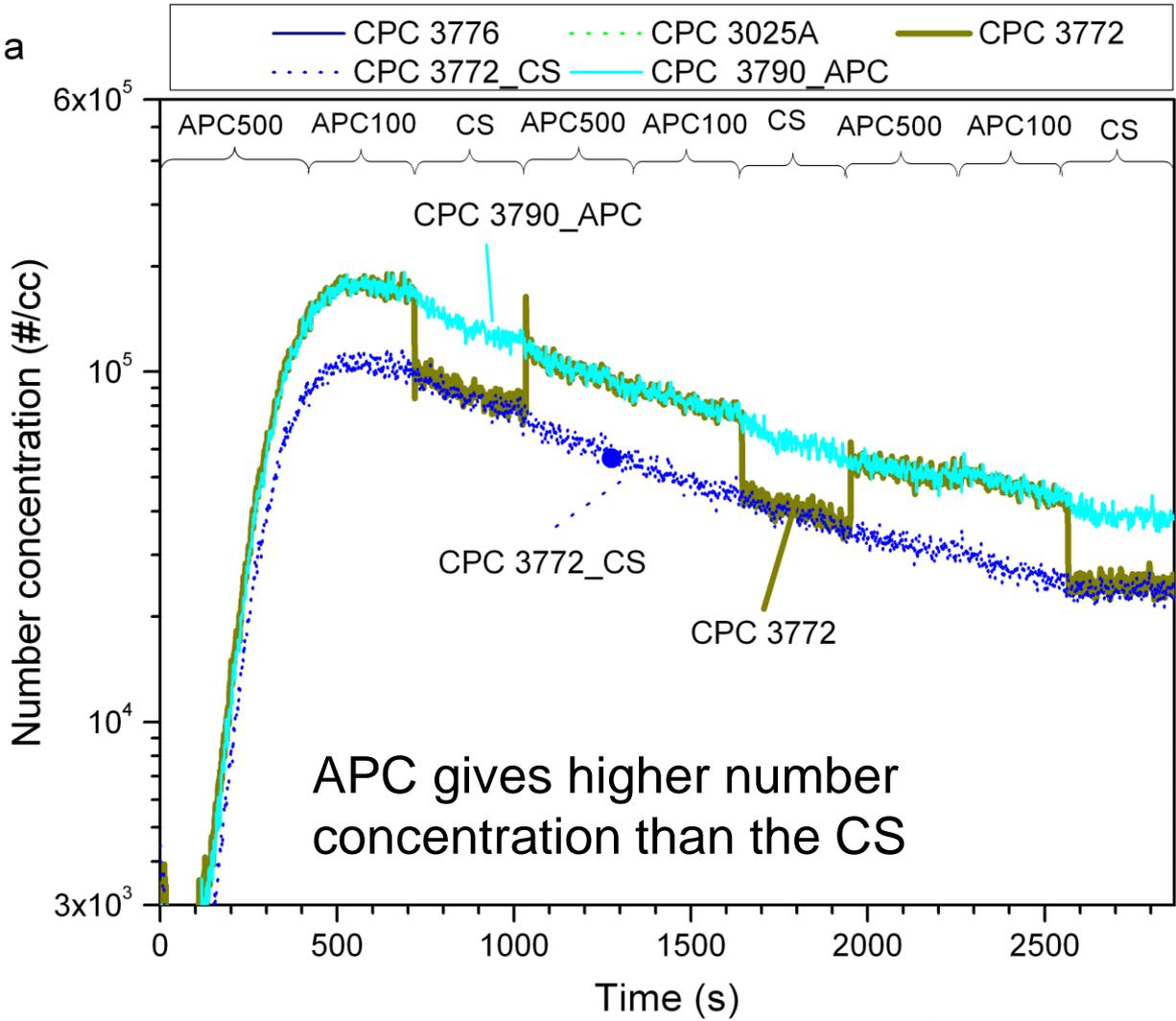
# CVS particle size distribution-by EEPS



74% engine load



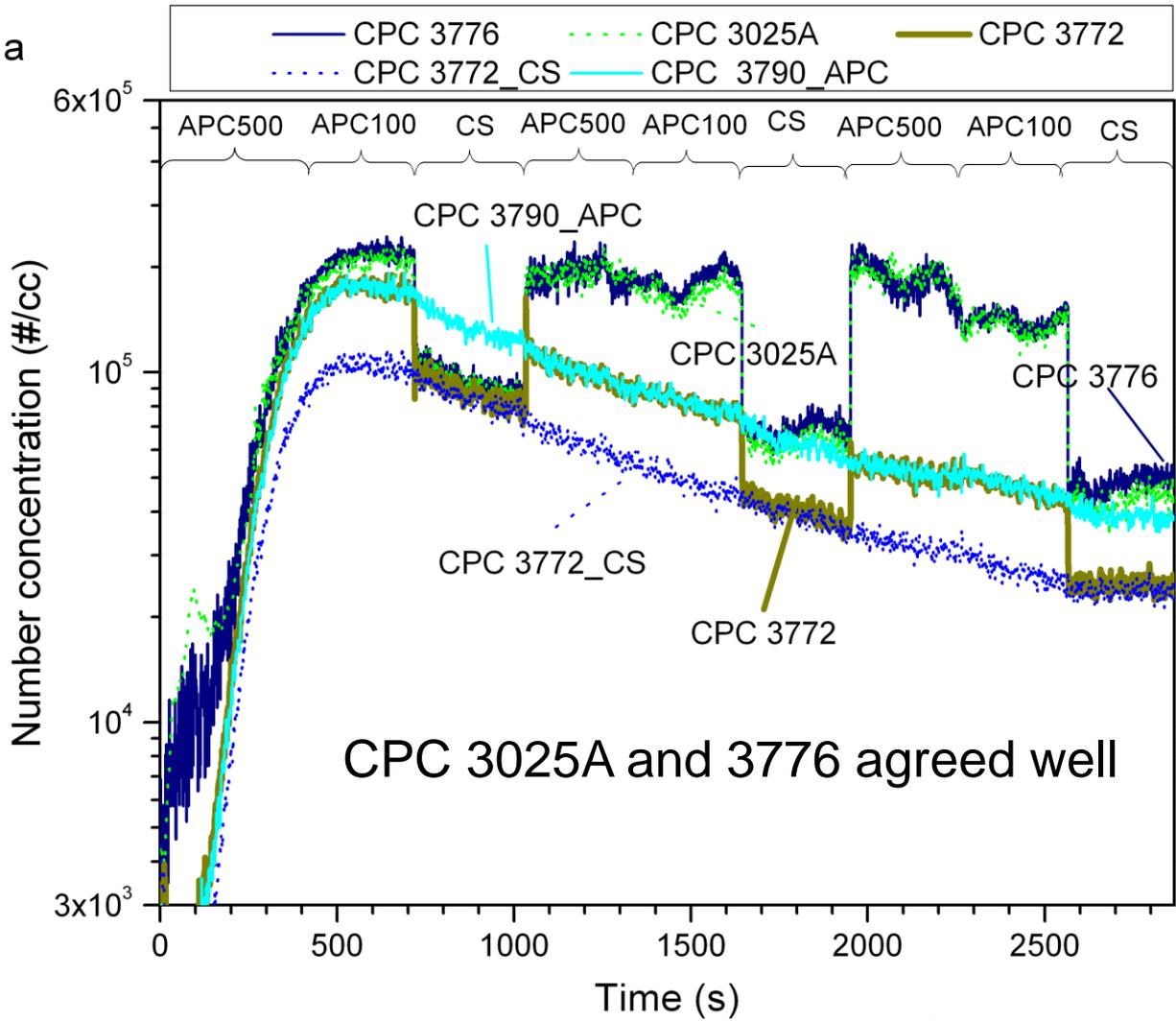
# CPC concentrations-74% load



CPC	Cut point (nm)	Sample location
3790_APC	23	Always at APC
3772_CS	10	Always at CS
3025A	3	Alternate
3772	10	Alternate
3776	3	Alternate



# CPC concentrations-74% load

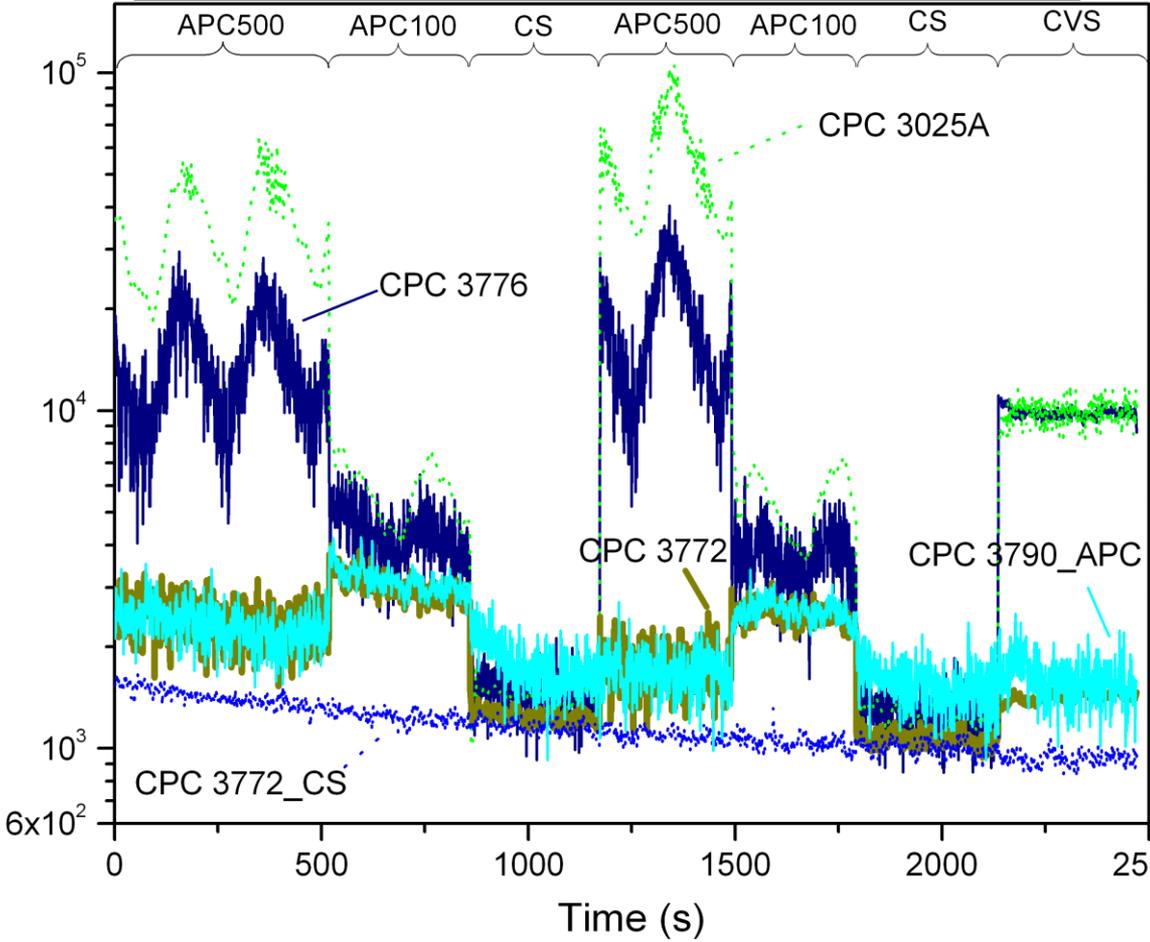


CPC	Cut point (nm)	Sample location
3790_APC	23	Always at APC
3772_CS	10	Always at CS
3025A	3	Alternate
3772	10	Alternate
3776	3	Alternate



# CPC concentrations-26% load

b

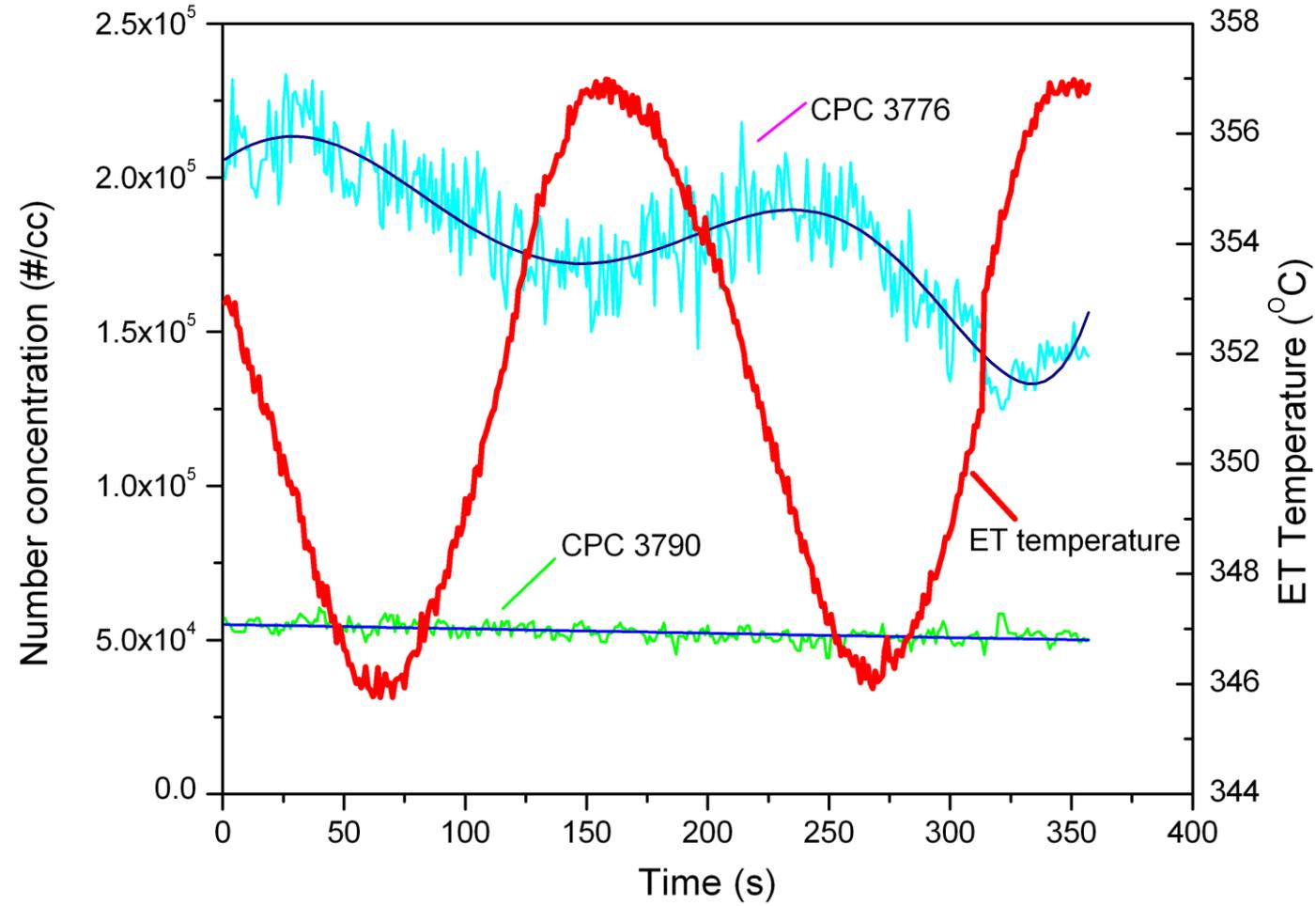


CPC	Cut point (nm)	Sample location
3790_APC	23	Always at APC
3772_CS	10	Always at CS
3025A	3	Alternate
3772	10	Alternate
3776	3	Alternate

3025A had slightly smaller cut point than 3776



# APC ET temperature oscillation





# Conclusion

- Nucleation mode particles dominated number concentrations of diesel particle emissions.
- Particle number emissions for both the PMP and CS were higher than the Euro VI HD limit at the 74% engine load and lower at the 26% engine load.
- Particle number concentrations were always higher under the PMP than under the CS.
- CPCs with cut off sizes of 3 nm measured higher concentrations than CPCs with larger cut off sizes, indicating particles below 10 nm present downstream the PMP and CS.
- Most of the sub 10 nm particles downstream the PMP were formed in the ET of the PMP, because:
  - CPC 3025A had higher concentration than CPC 3776;
  - Particle concentration of those sub 10 nm particles oscillated in relation with the oscillation of the PMP ET temperature.



# Acknowledgements

- **CARB**

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- **University of Minnesota**

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