Mass Correlation of Engine Emissions with Spectral Instruments (2)

David KITTELSON (University of Minnesota),
Tim HANDS, Chris NICOKLAUS, (Cambustion),
Nick COLLINGS (U. Cambridge/Cambustion),
Ville NIEMELÄ (Dekati),
Martyn TWIGG (Johnson-Matthey)

nc@eng.cam.ac.uk

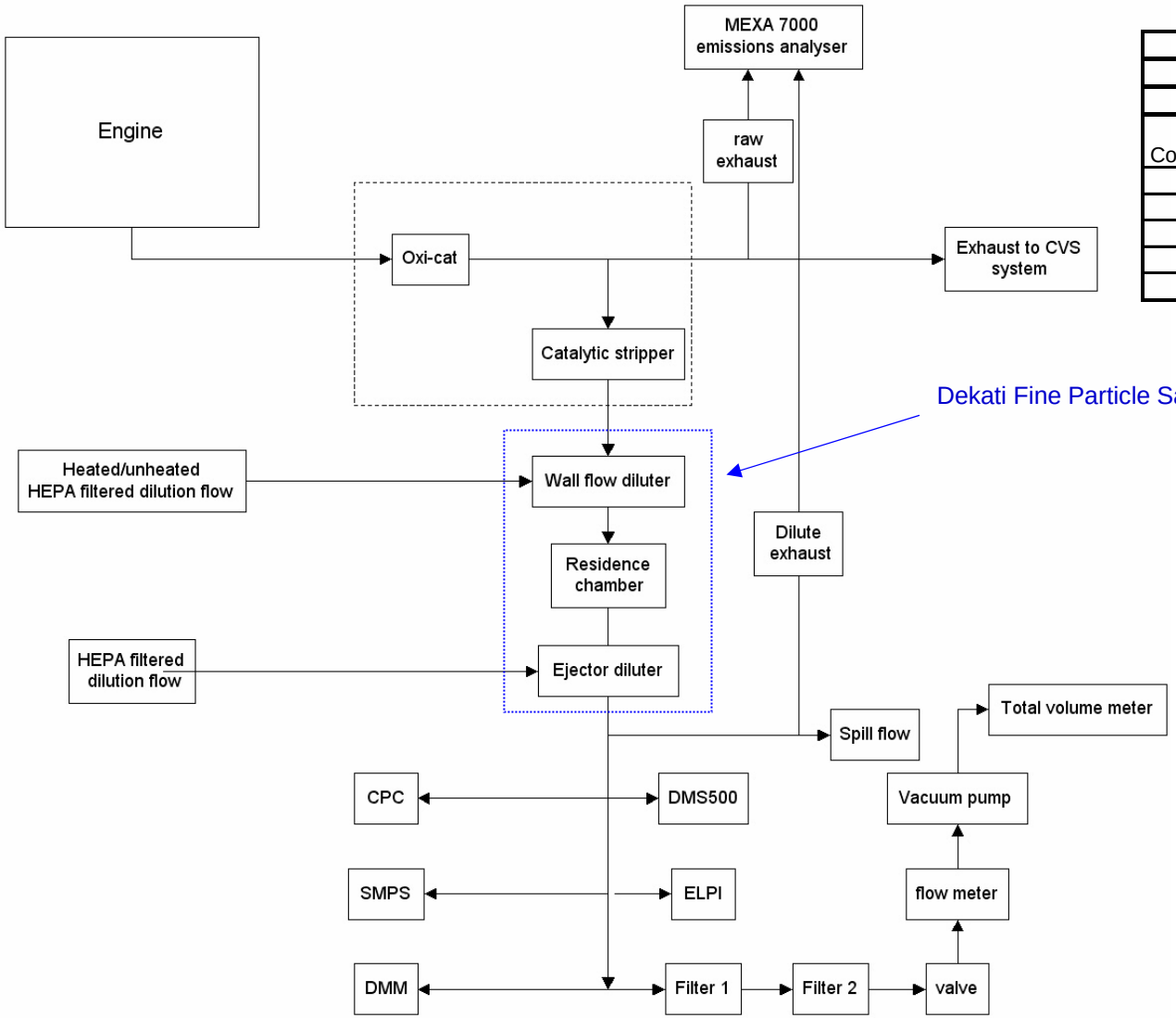
Outline

- Background
- Apparatus
- Results
  - NEDC measurements
  - Size distributions
  - Mass and number correlations
- Conclusions

Background

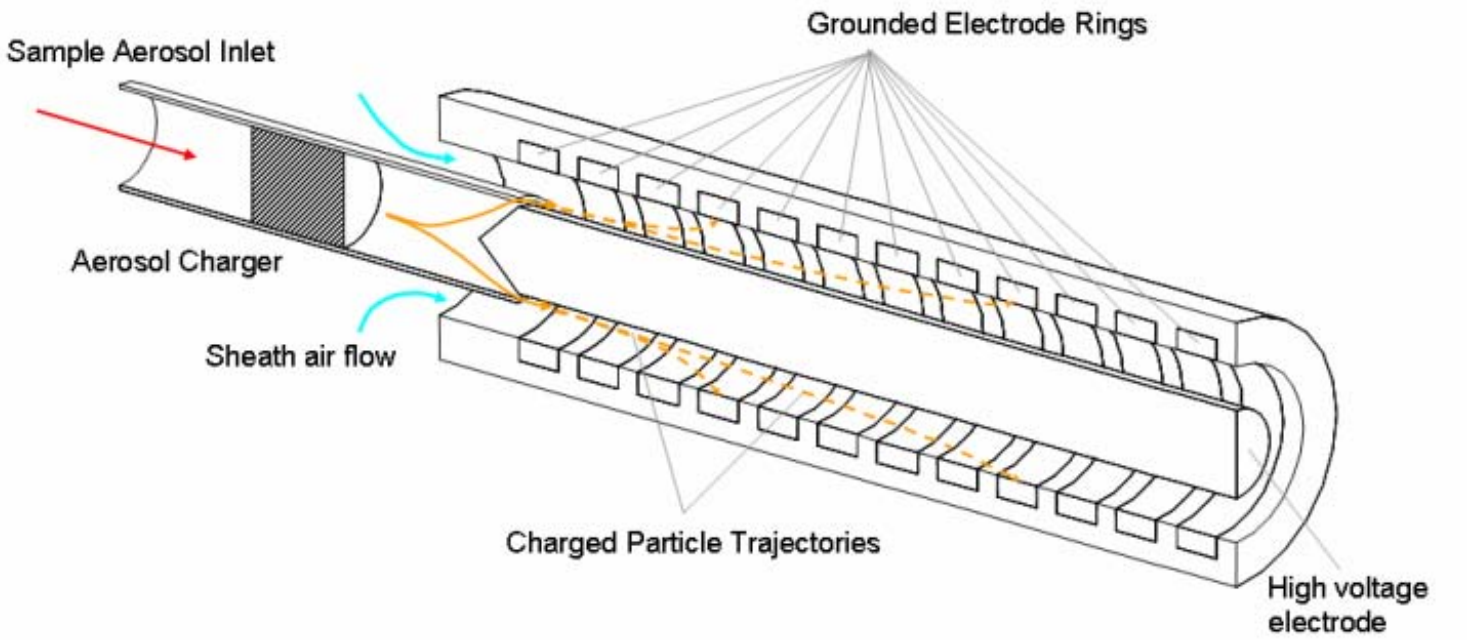
- There is a need for real time monitoring of particle emissions from engines to help identify critical conditions leading to particle formation, but….
  - Modern engines emit much less PM making traditional smoke meters unusable
  - Additional information about PM emissions like size and number may be required
- With very clean engines filter measurements are becoming unreliable.
  - We currently don’t know how make accurate measurements of PM mass emissions from post 2007 engines using filters.
  - Very large filter artifacts due to volatile material
- Unlike filters, instruments that measure suspended particles measure what we breathe

Apparatus, test conditions



Engine - Light-duty, DI, common rail, without DPF				
Fuel - Standard pump fuel, ~50 ppm S				
Test Conditions				
Condition	Speed (rpm)	Torque (Nm)	Power (kW)	
1	Idle			
2	1500	40	6.3	~70kph cruise
3	1500	225	35.3	peak torque
4	3500	140	51.3	~70% peak torque
5	NEDC			cold start

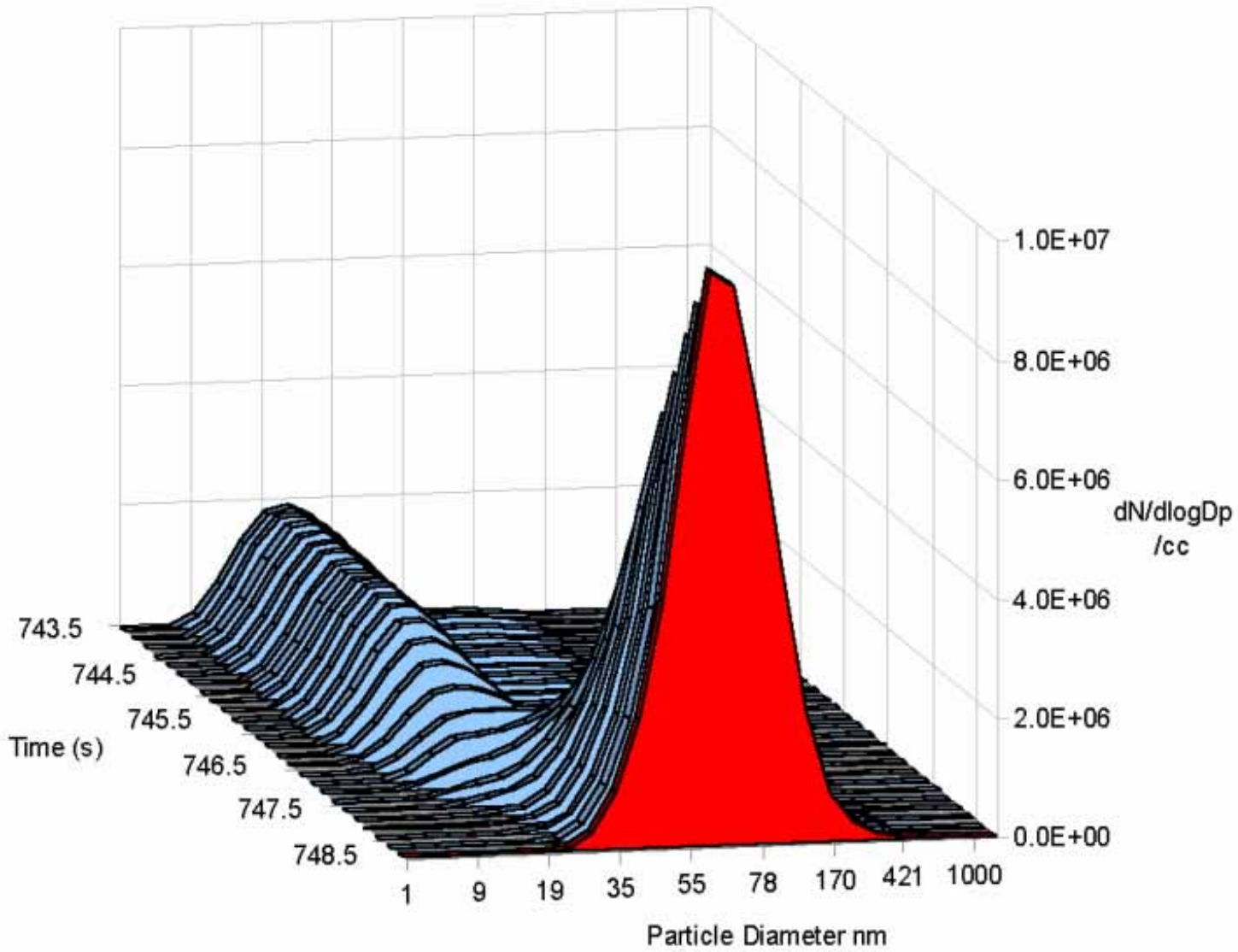
DMS500 Differential Mobility Spectrometer – a new fast response electrical mobility sizing instrument



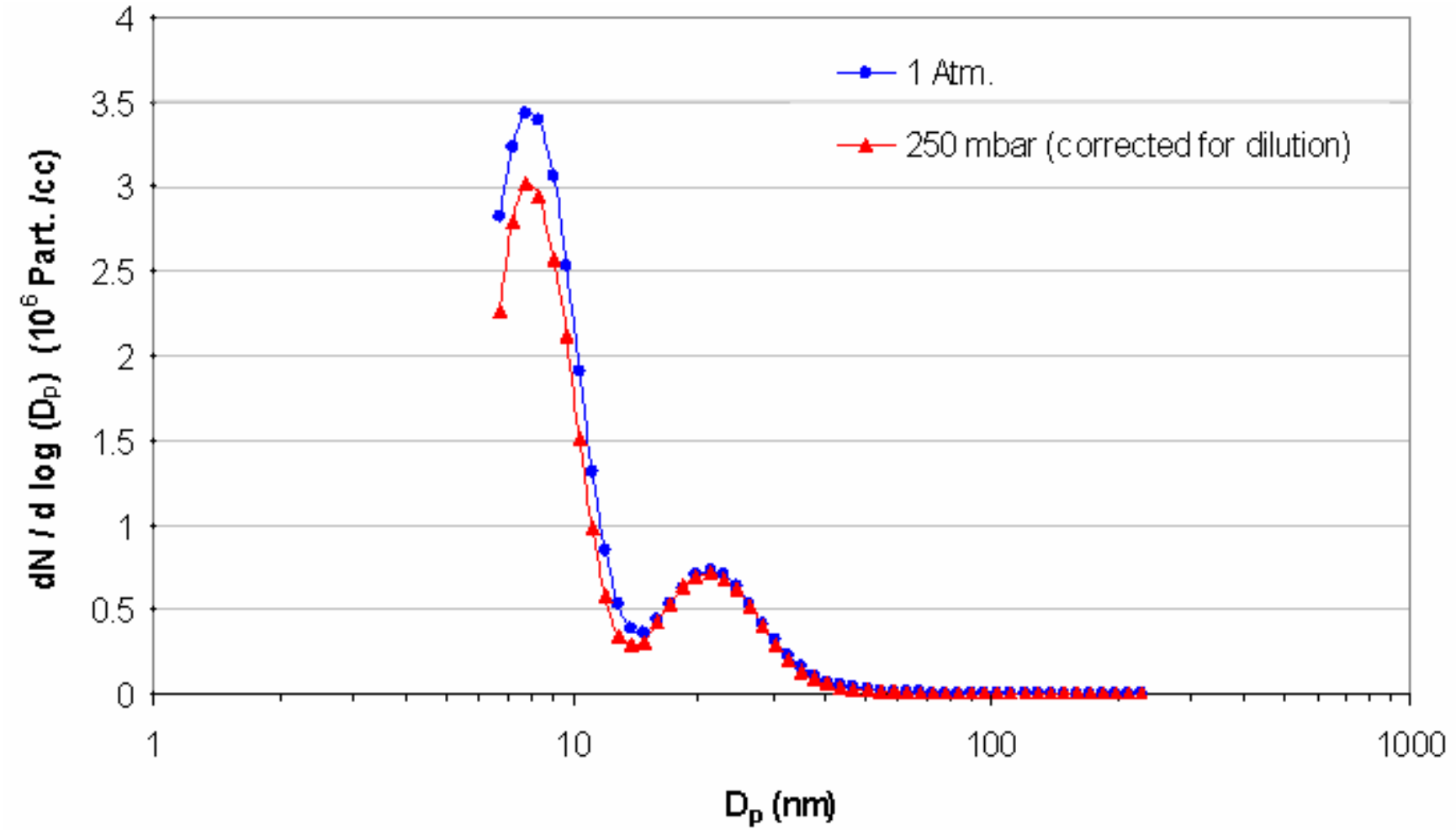
- Similar to DMA, but:
  - Aerosol inlet inside sheath flow
  - Single Monodisperse exit replaced by multiple collection electrodes.
  - Direct electrometer connection instead of aerosol particle counter.
  - Near real time size and concentration in 5 to 1000 nm range

Reavell, K., T. Hands, and N. Collings, 2002. “A Fast Response Particulate Spectrometer for Combustion Aerosols,” SAE paper 2002-01-2714

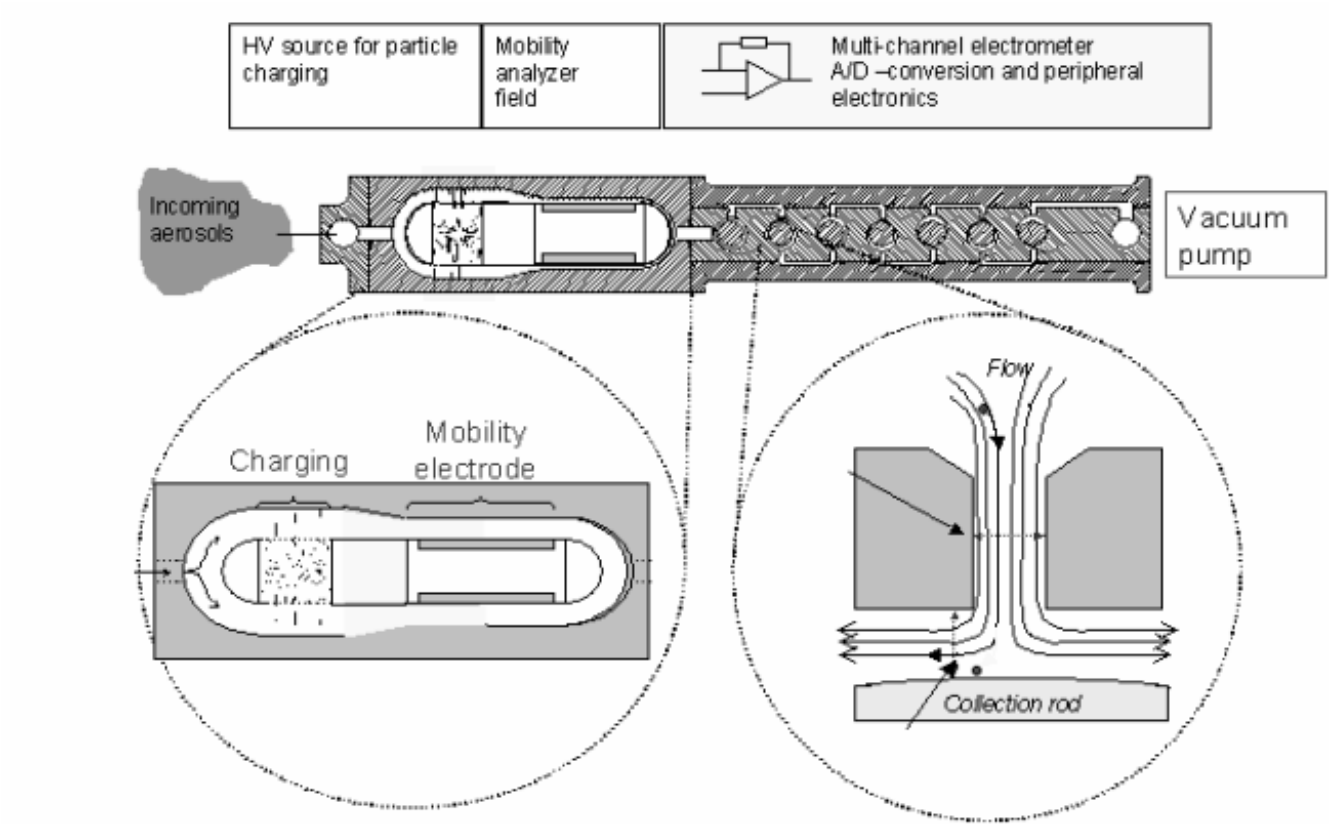
Typical DMS data during a transient cycle showing Nucleation Mode followed by an Accumulation Mode



Low pressure treatment of sulphuric acid/water 2 s at low p with no significant change in size



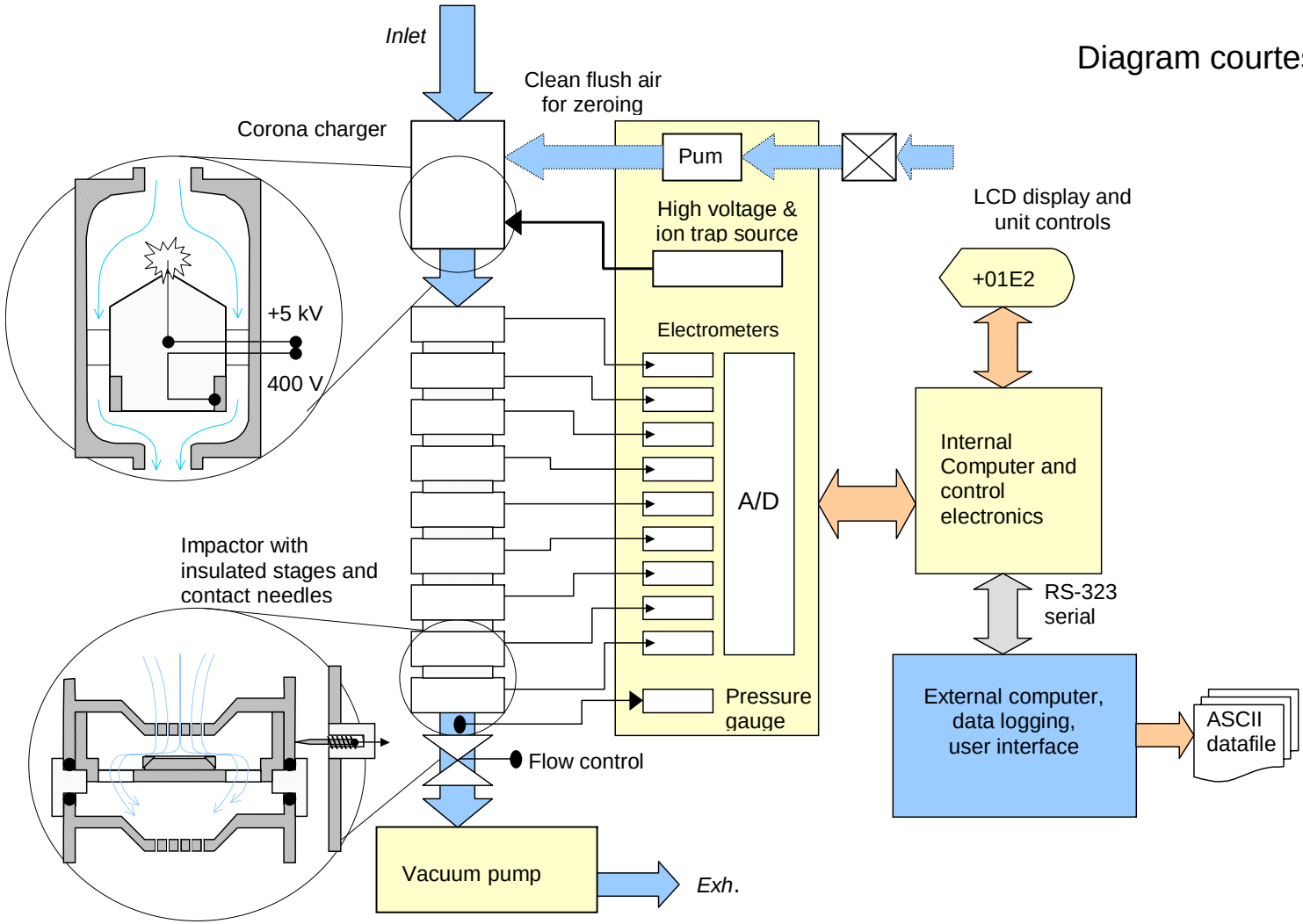
DMM230 Dekati Mass Monitor impactor and charger – real time mass measurements



- Combined mobility and impaction measurement from ~5 nm to 1.2 μm
- Simultaneous determination of density, mean diameter, and mass concentration assuming unimodal log normal distribution

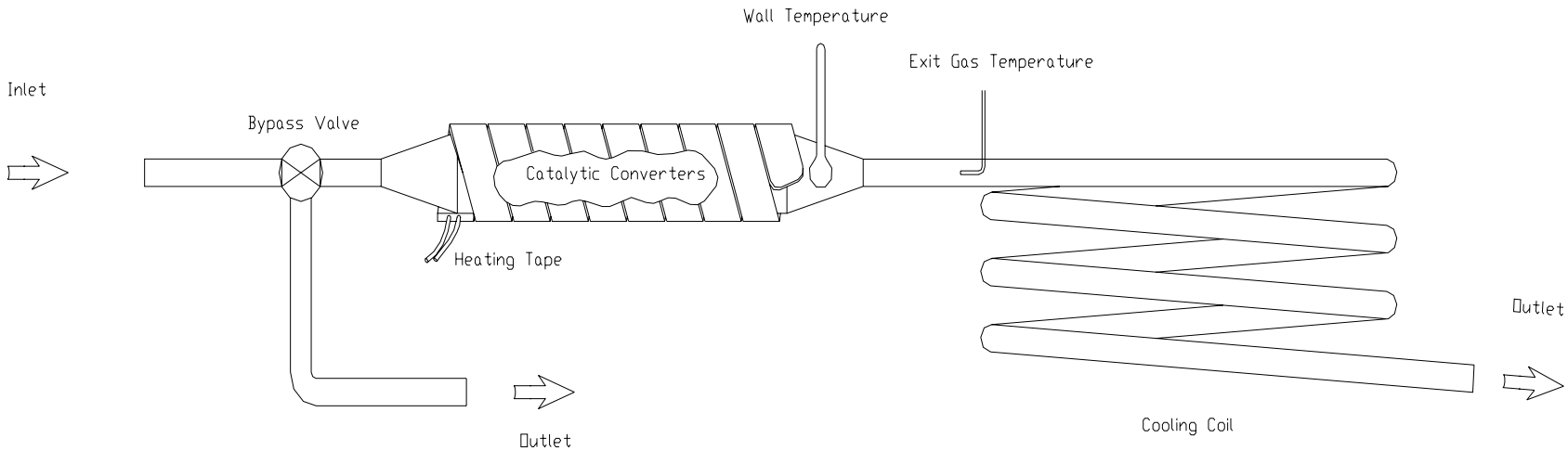
Dekati DMM 230 -- Moisio, M. Niemelä, V. Device for Continuous Measurement of Density and Mass Concentration of Vehicle Exhaust Aerosol. IAC 2002.

Electrical Low Pressure Impactor (EPLI)[1] – combines electrical charging with aerodynamic size classification



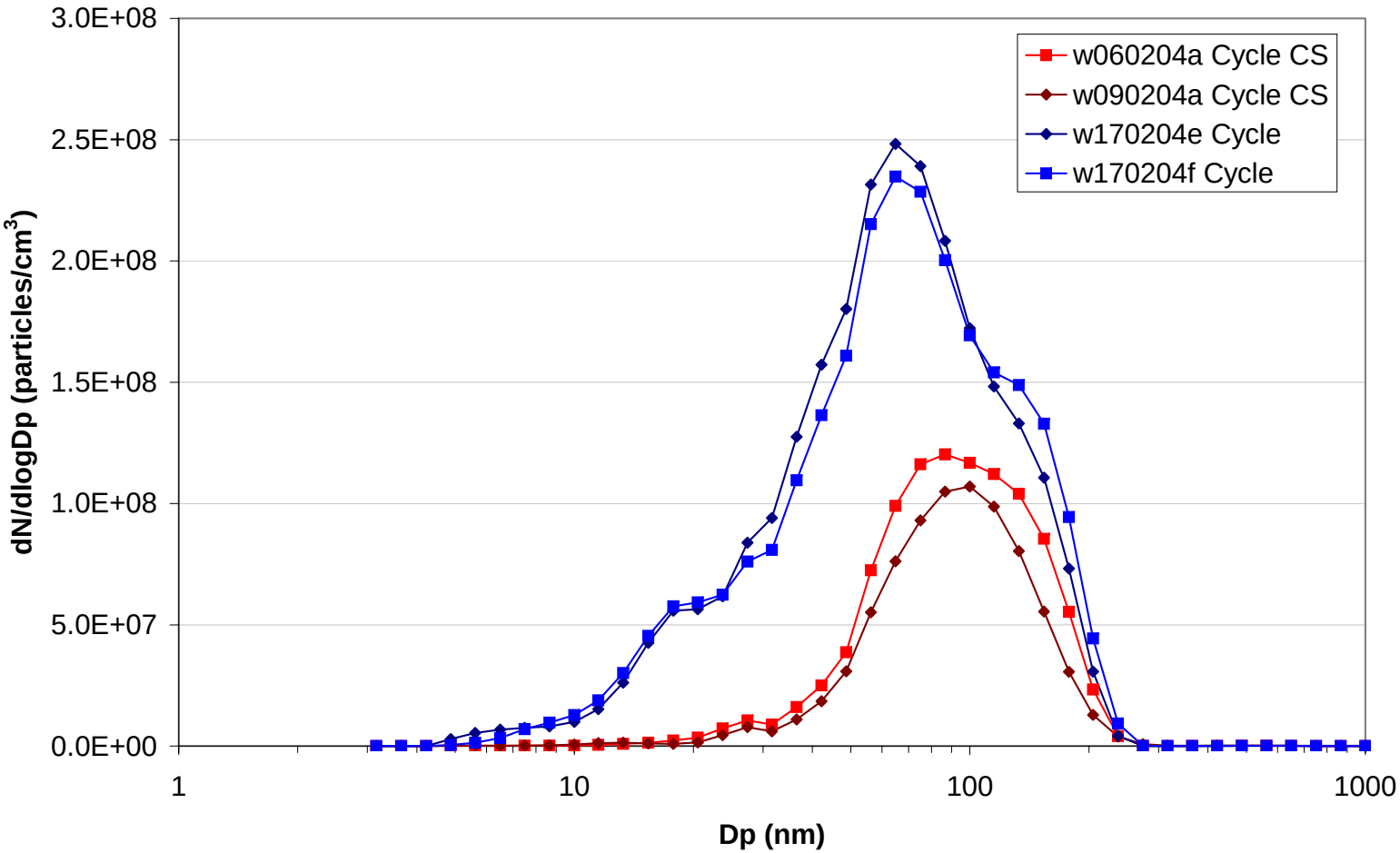
1 - Keskinen, J., Pietarinen, K. and Lehtimäki, M. (1992) Electrical Low Pressure Impactor, J. Aerosol Sci. 23, 353-360.

Catalytic stripper layout

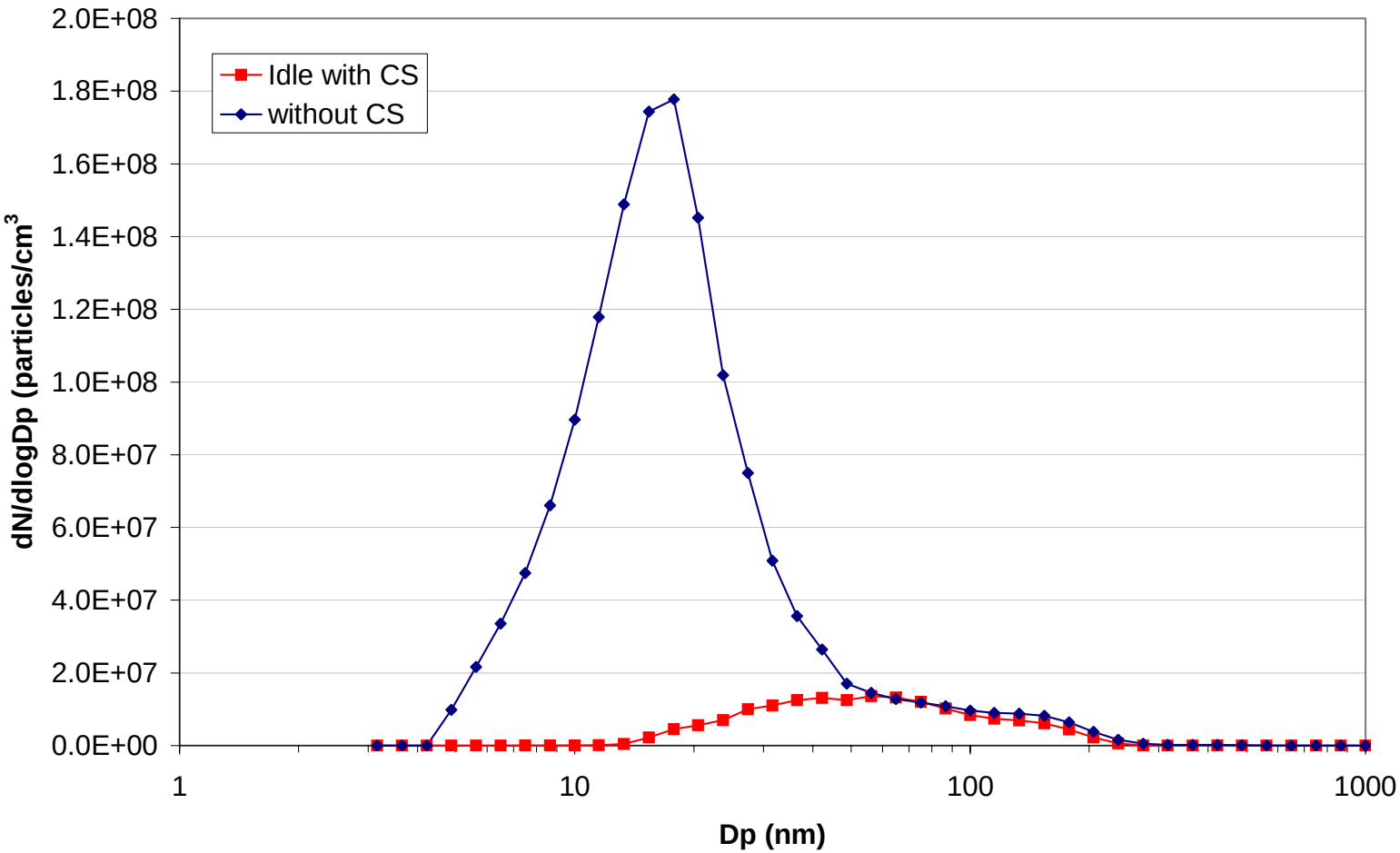


- The stripper consists of a 2 substrate catalyst followed by a cooling cool
  - *For these tests the cooling coil was not used*
  - *The stripper outlet stream passed directly in the first stage of dilution*
- The first substrate removes sulfur compounds
- The second substrate is an oxidizing catalyst
- The catalysts were provided by Johnson-Matthey

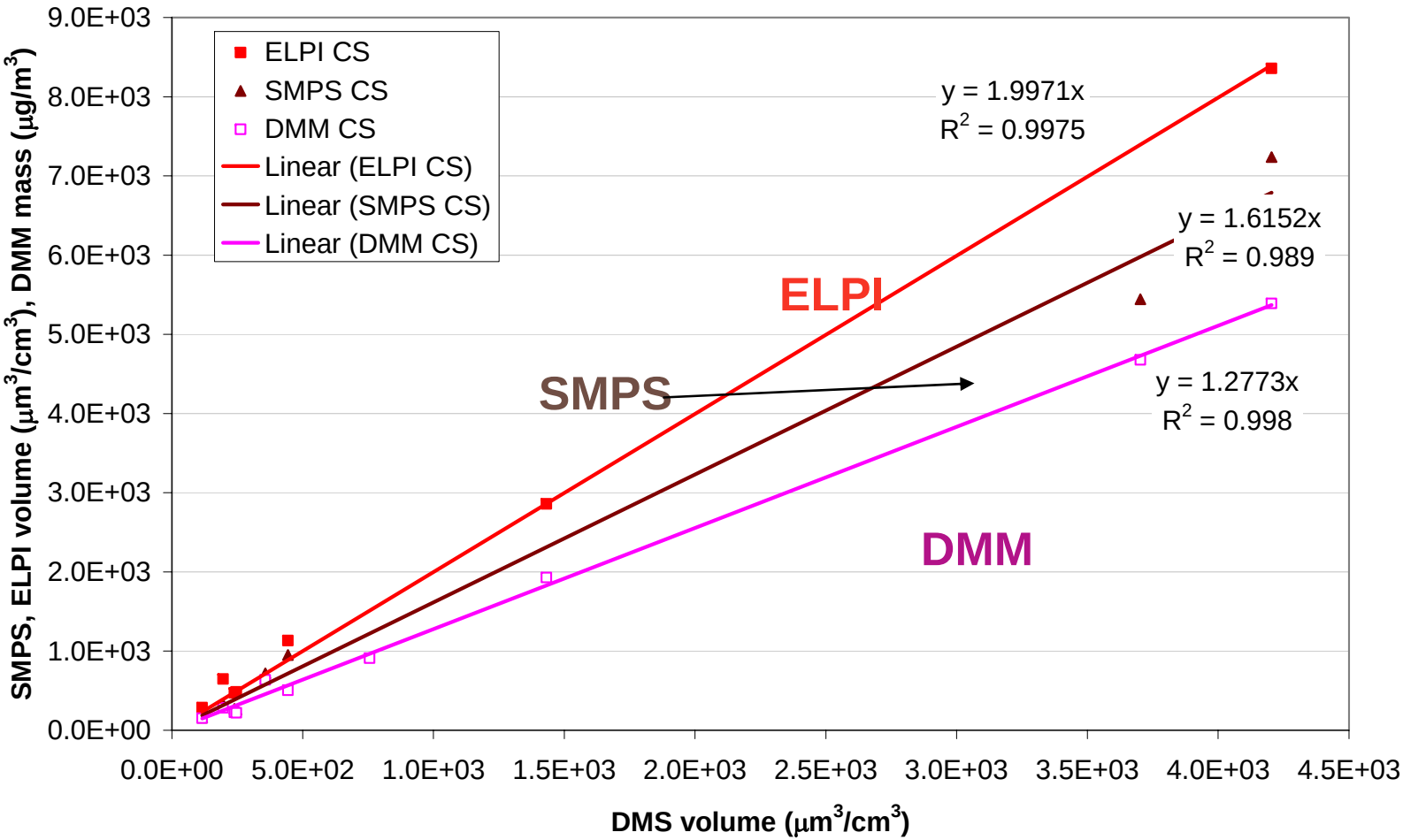
Cycle average size distributions measured with DMS for NEDC with and without CS



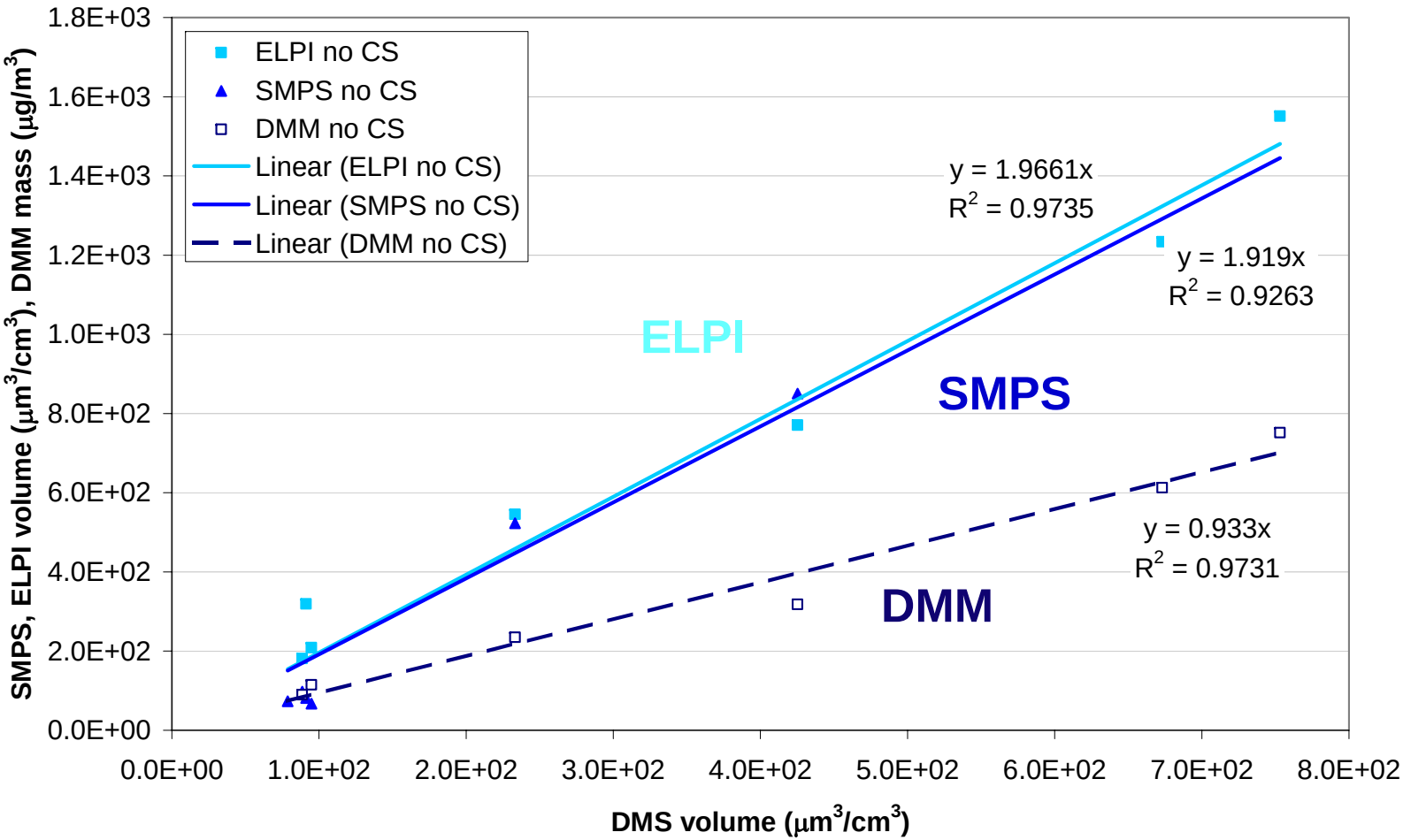
Steady stage idle DMS size distributions with and without CS, volatile nuclei mode present without CS



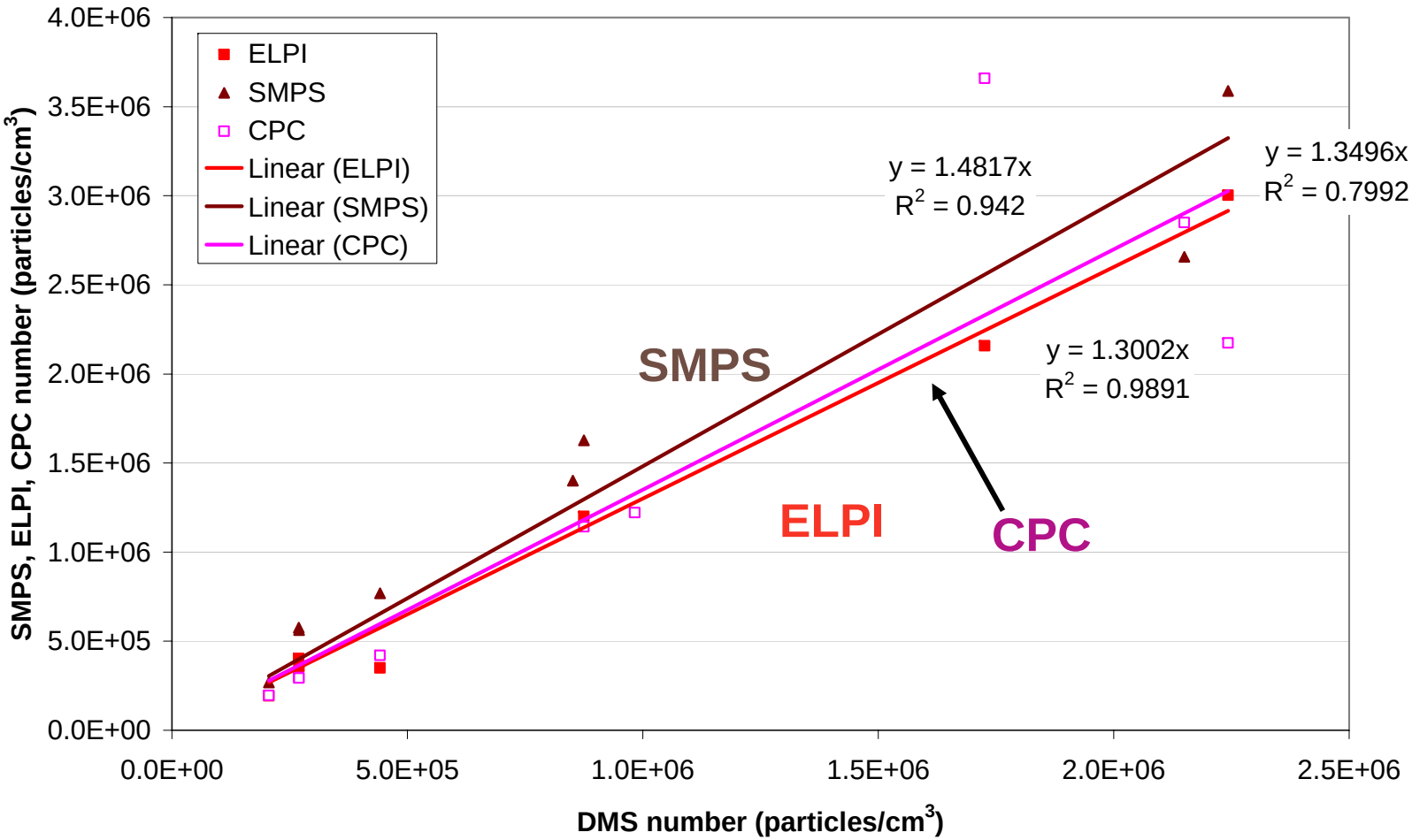
Indications of Volume – with Catalytic Stripper – steady state and transient data



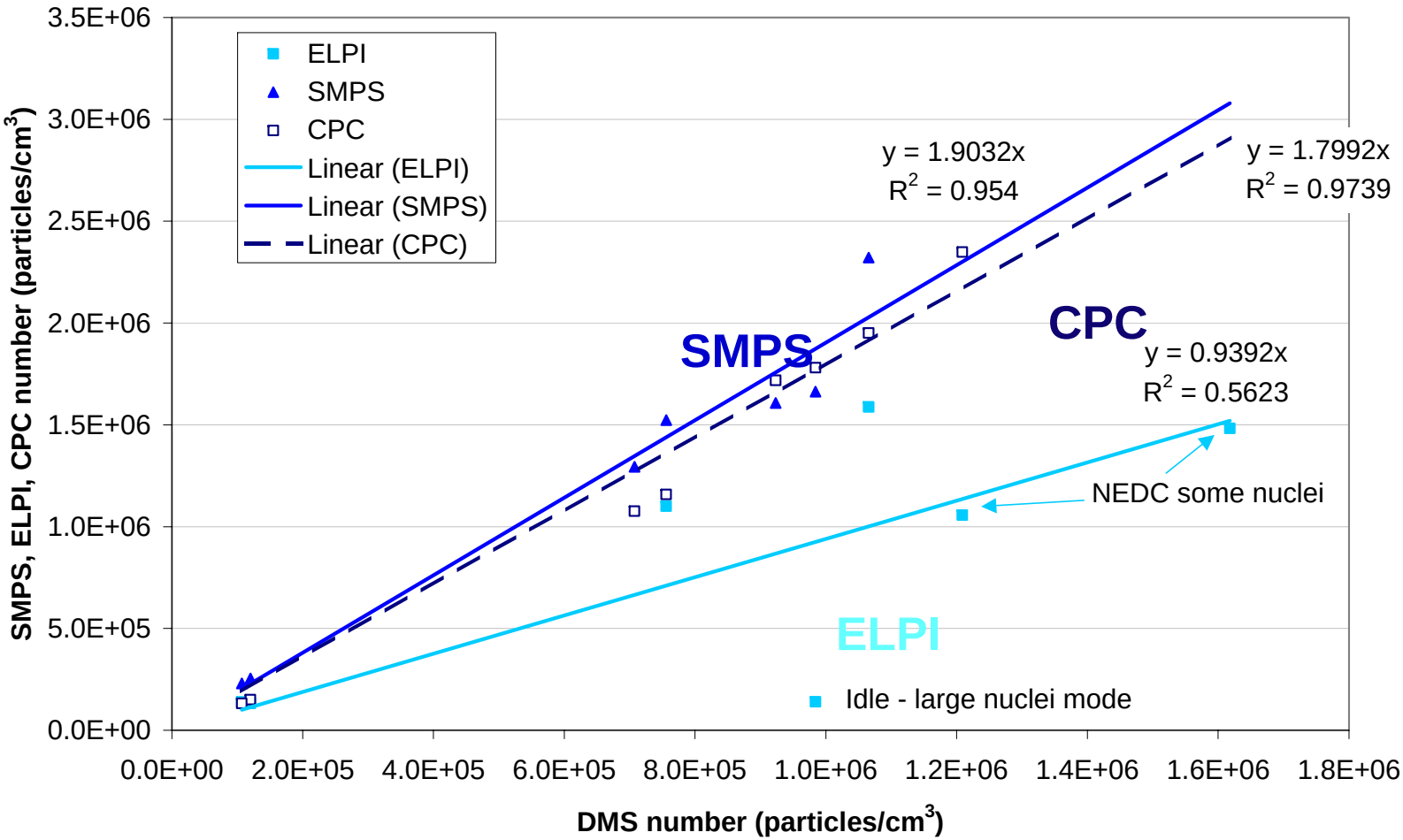
Indications of Volume – without Catalytic Stripper



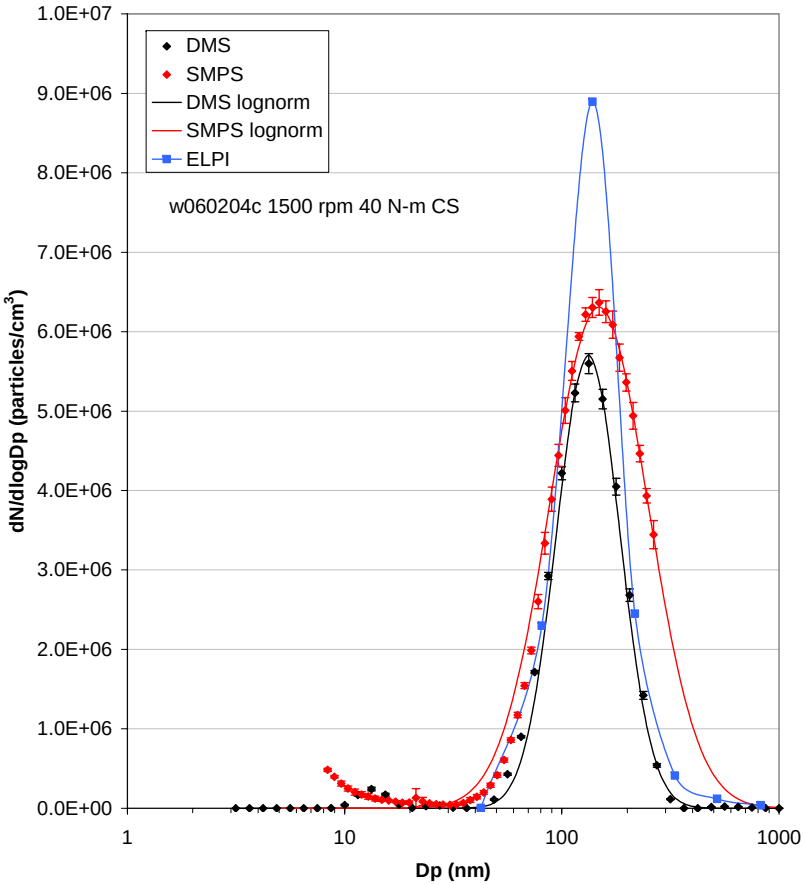
Indications of Number

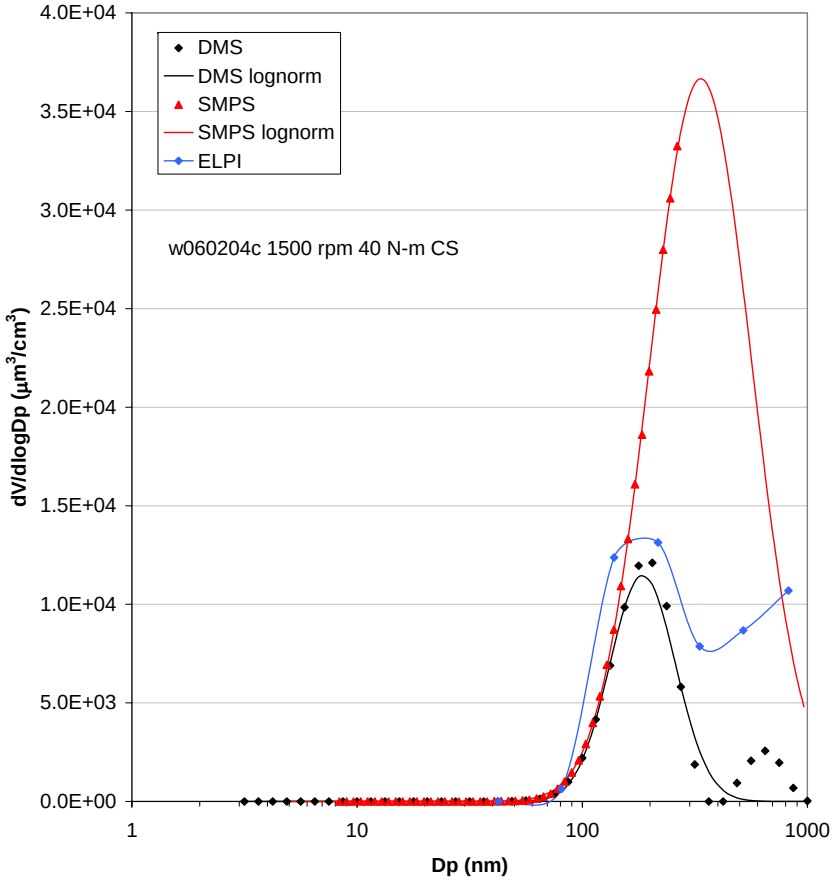


Indications of Number

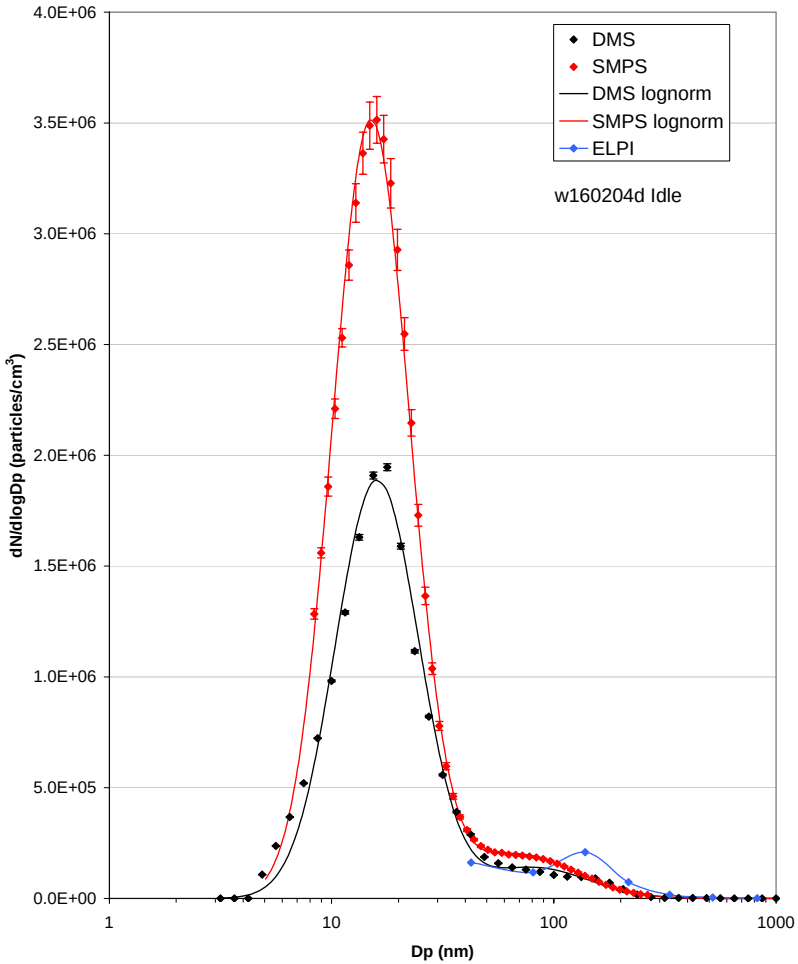


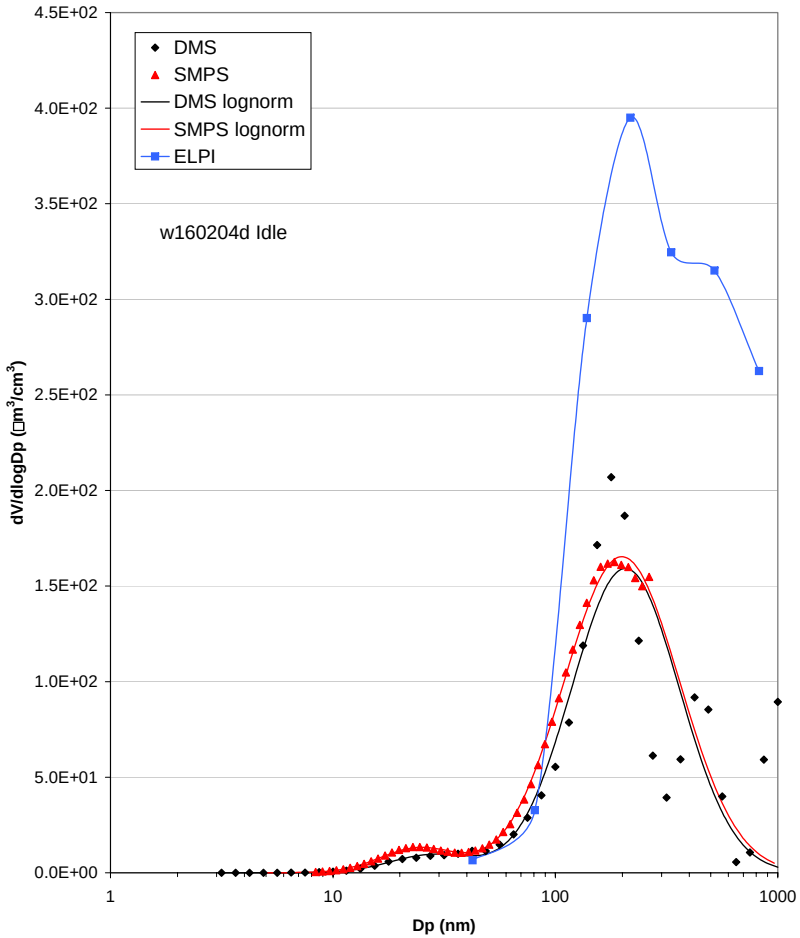
Comparison of DMS, SMPS, and ELPI size distributions – light load cruise with catalytic stripper, no nuclei mode



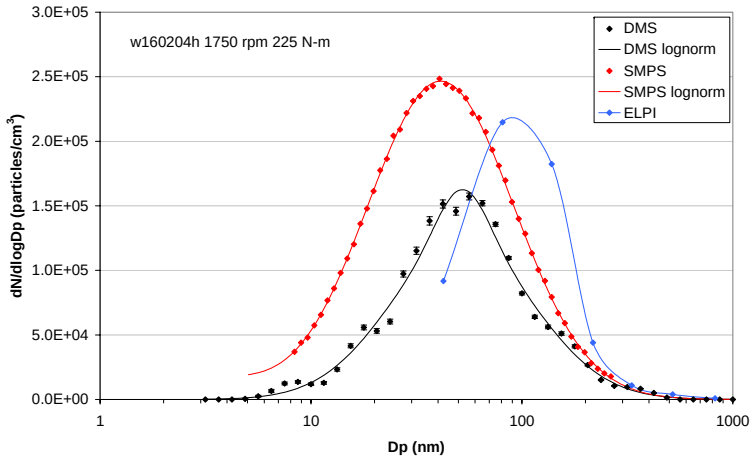


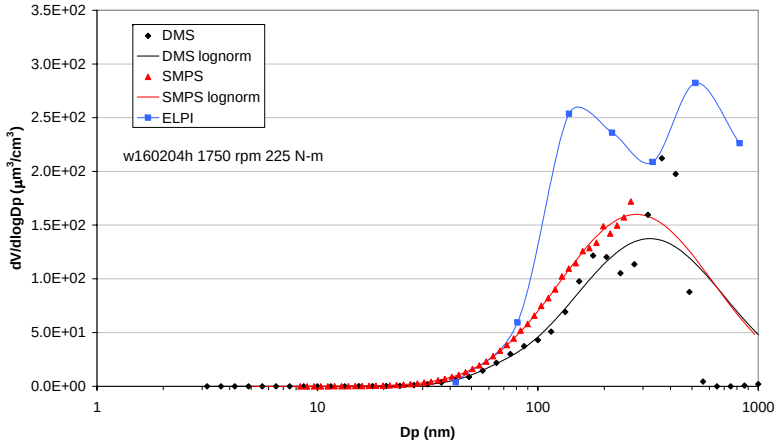
Comparison of DMS, SMPS, and ELPI size distributions – idle without catalytic stripper, large nuclei mode

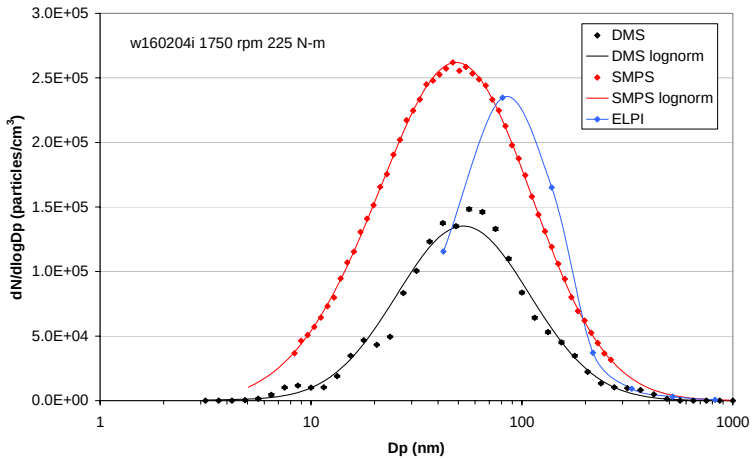


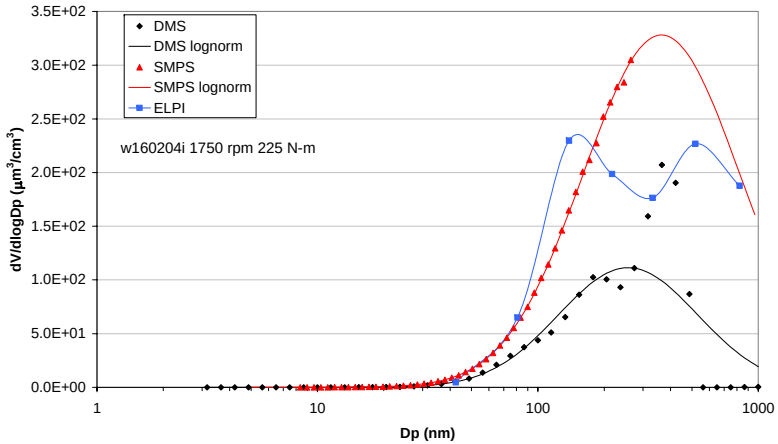


DMS, SMPS, and ELPI size distributions, high speed, high load. Subtle shifts in upper end of SD strongly influence total particle volume (mass)

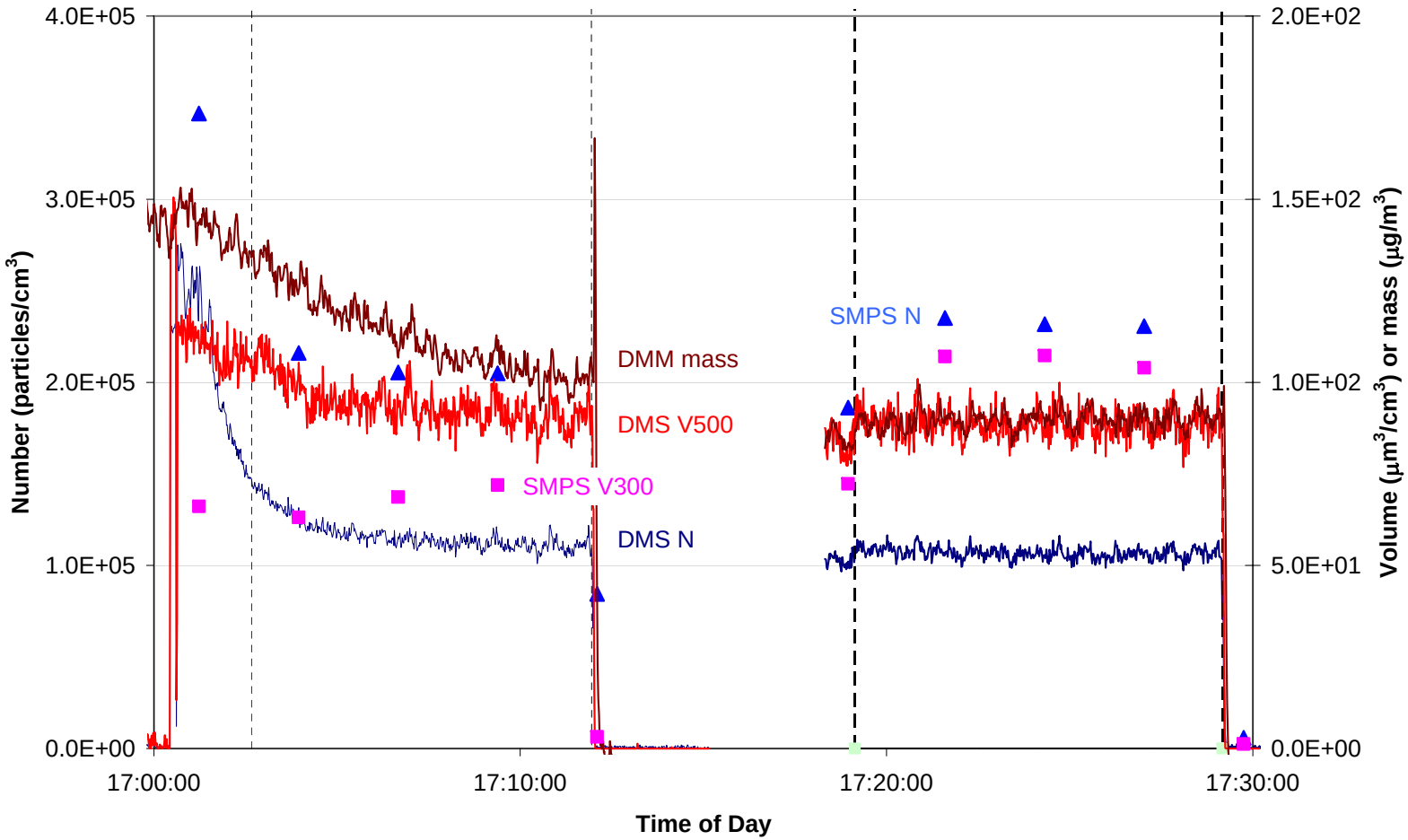








Changes in number, volume, and mass emissions under “steady state” high speed, high load conditions



Conclusions (1)

- DMM230, SMPS, ELPI and DMS500 are reasonably well-correlated on number.
  - but in a conversion to volume (or mass) the ELPI and DMS are very sensitive to noise/error at larger particle sizes
  - This can be ameliorated to some extent by fitting log-normals
- Mass estimation from SMPS data is consistent with previous studies.
  - Effective densities of ~0.5 g/cm^3 due to decreasing density with size
  - Mass estimation from DMS500 implies somewhat different relationship between measured diameter and particle mass from SMPS

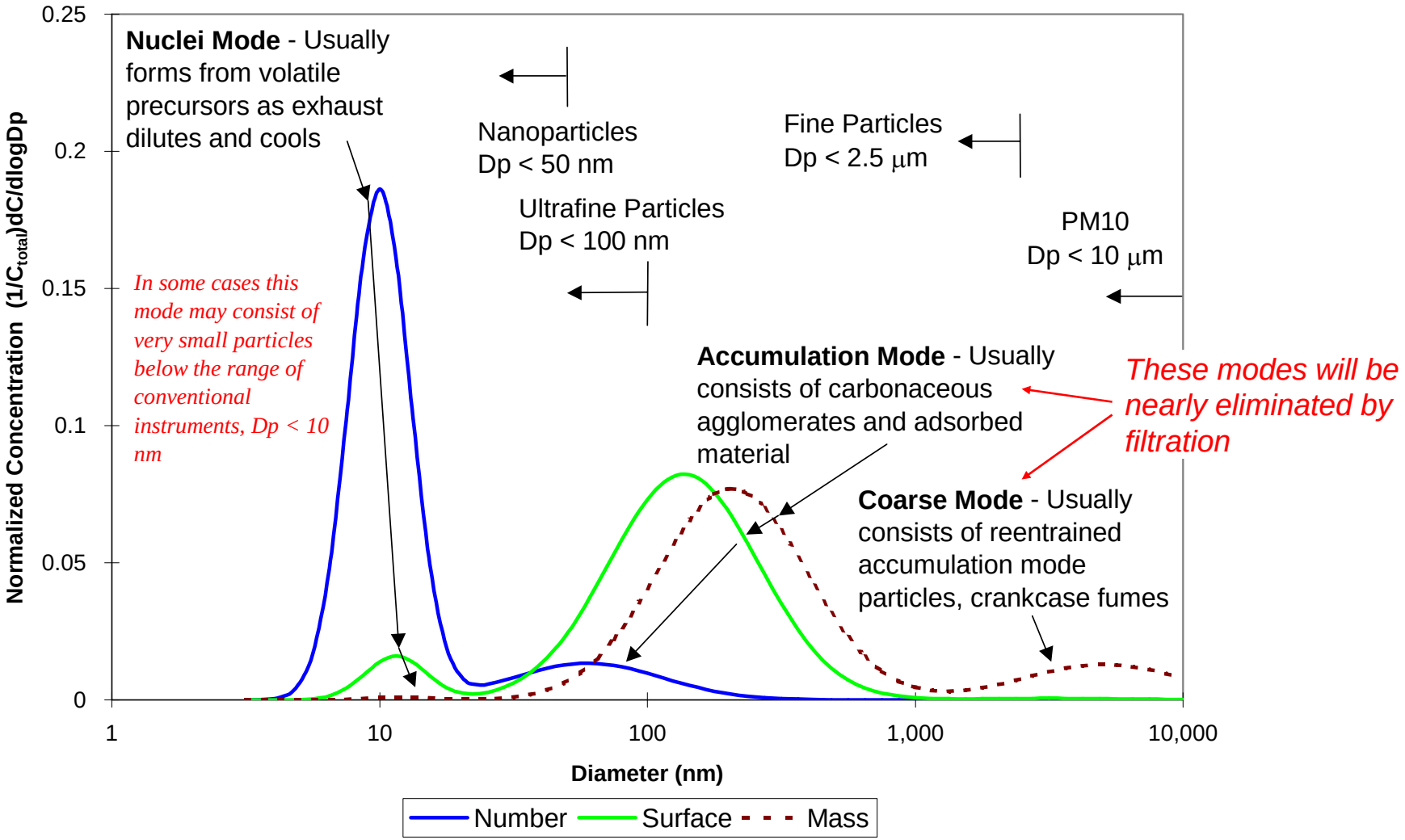
Conclusions (2)

- Good correlations also obtained when nuclei material present, but the relationship is different
  - The engine tested here had much less tendency to make a nuclei mode than modern heavy duty engines
  - The only steady state condition to show a large nuclei mode was idle
- DMM230 and DMS500 offer useful way of monitoring real time particle emissions and identifying critical episodes.

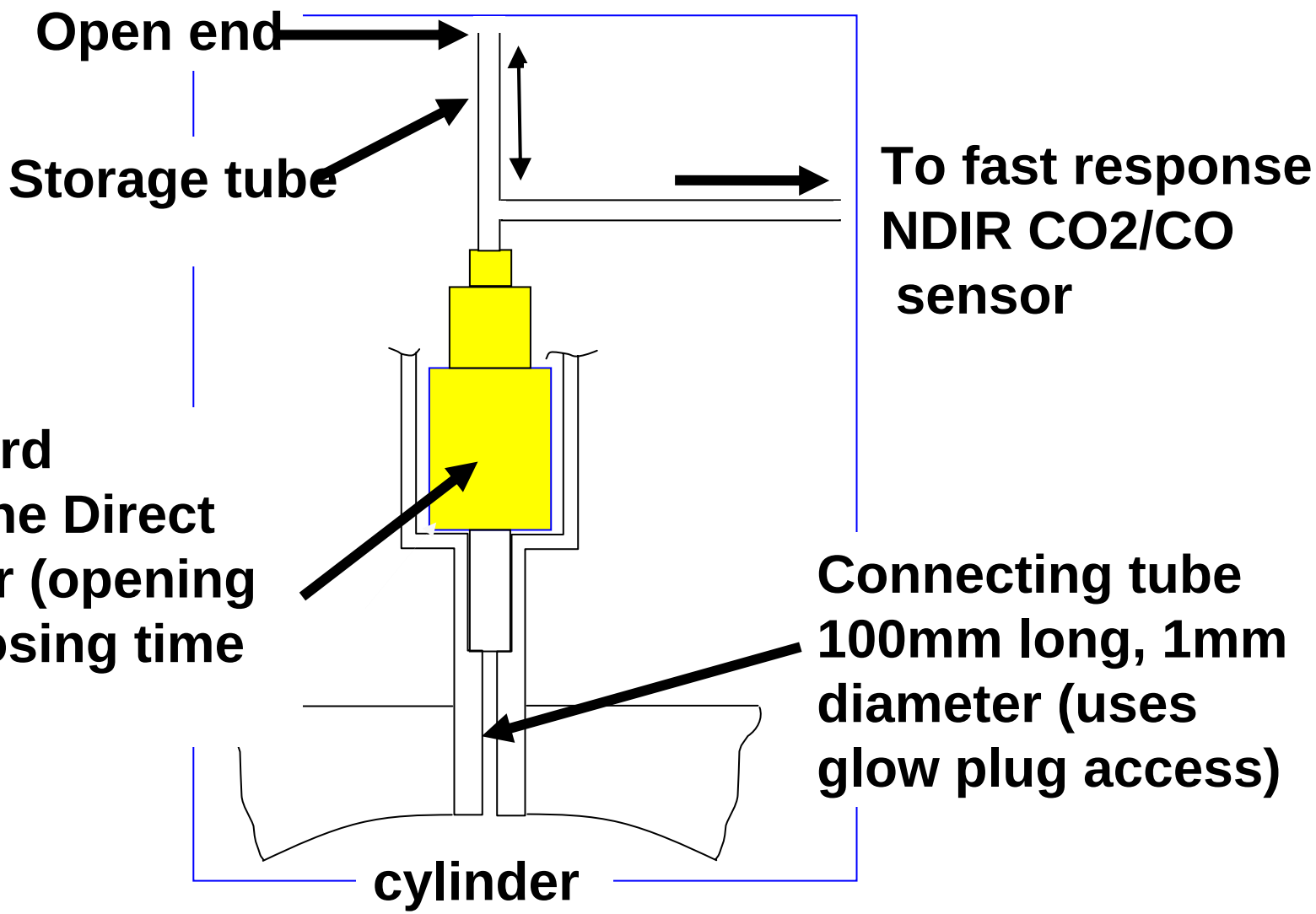
Future work

- Results presented here are an initial analysis of a larger dataset which will be further analyzed and reported elsewhere (including filter analysis). It is also hoped to perform a similar study on an engine fitted with a DPF.
- We would like to conduct similar tests in Minnesota with a post 2007 heavy-duty engine and a wider range of spectral instruments

Typical Diesel Particle Size Distributions, Number, Surface Area, and Mass Weightings Are Shown



In-cylinder sampling system with a GDI injector (Cyclic residuals measurement)



Typical results: Common rail LD Diesel, AFR switch, (1500 rpm)