Department of Engineering Science

Solid Particle Measurements with a DMS500

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Motivation

1. **DMS500 useful development tool for engine test cells and vehicle test cells without a dilution tunnel (fast time response, particle size, discrimination of nucleation and accumulation modes).**

2. **but can the DMS500 provide a solid Particle Number (PN) count comparable to a regulation compliant counter?**

3. **…i.e. can the DMS500 mode-fitting software accurately distinguish between solid and volatile particles? What are the limitations?**

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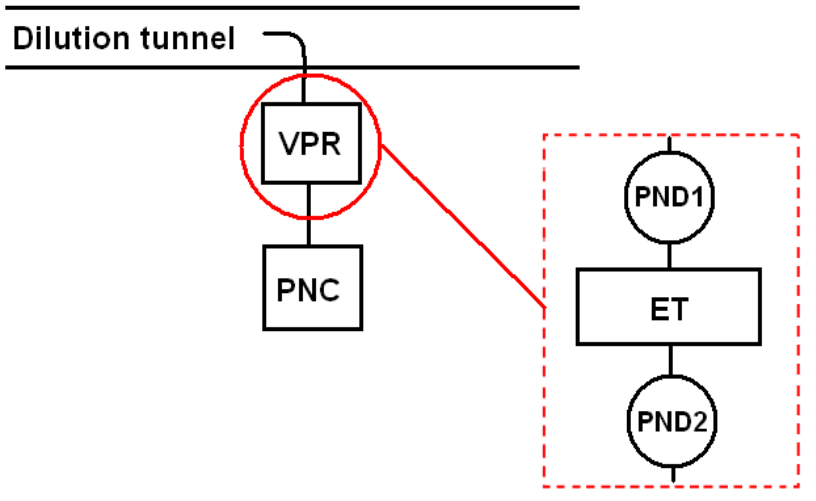
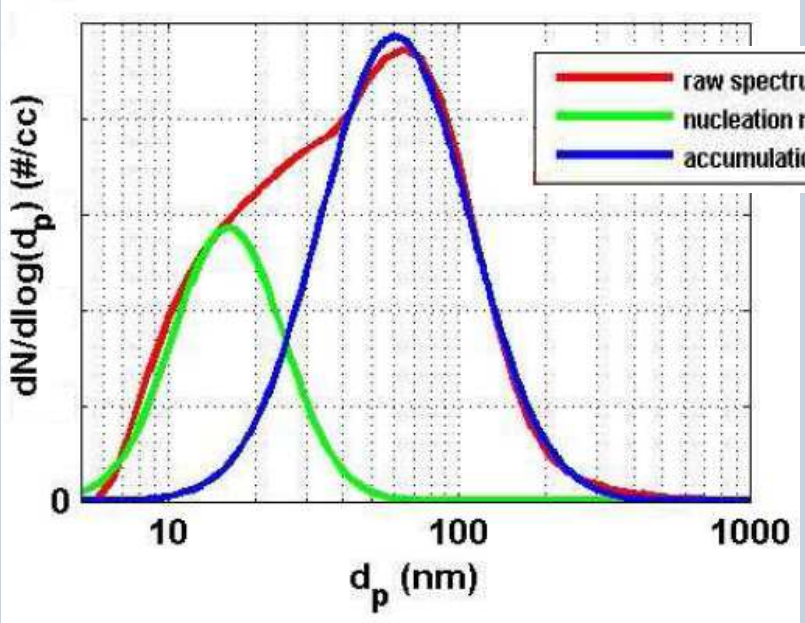
Solid and volatile particle discrimination

Regulation compliant counter



R-83 (2009), "Uniform provisions concerning the approval of vehicles with regard to the emission of pollutants according to the engine fuel requirements"

DMS500



Symonds *et al.* (2007), "Diesel soot mass calculation in real-time with a differential mobility spectrometer", *Journal of Aerosol Science* **38**(1), 52-68.

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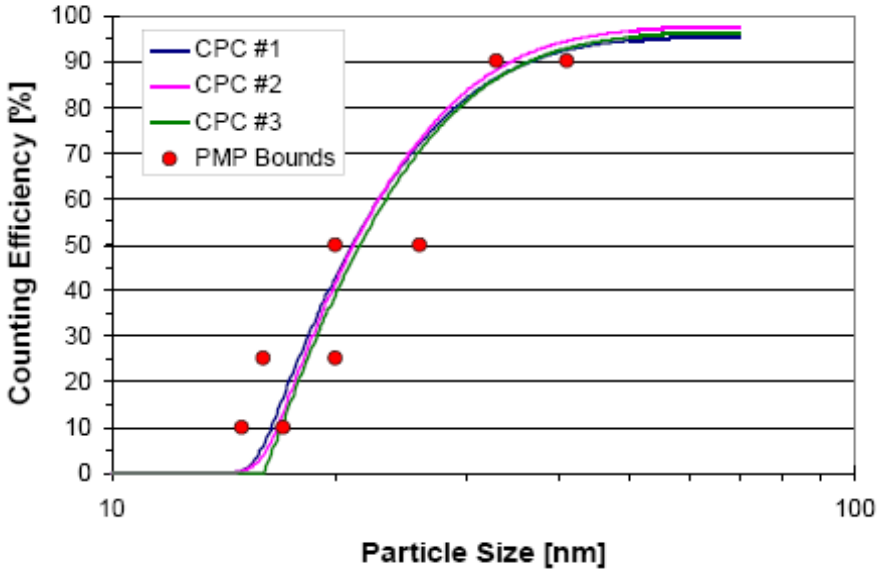
Hypothesis: *Accumulation mode will correlate well with solid PN measurements taken from a regulation-compliant counter*

Count efficiency correction

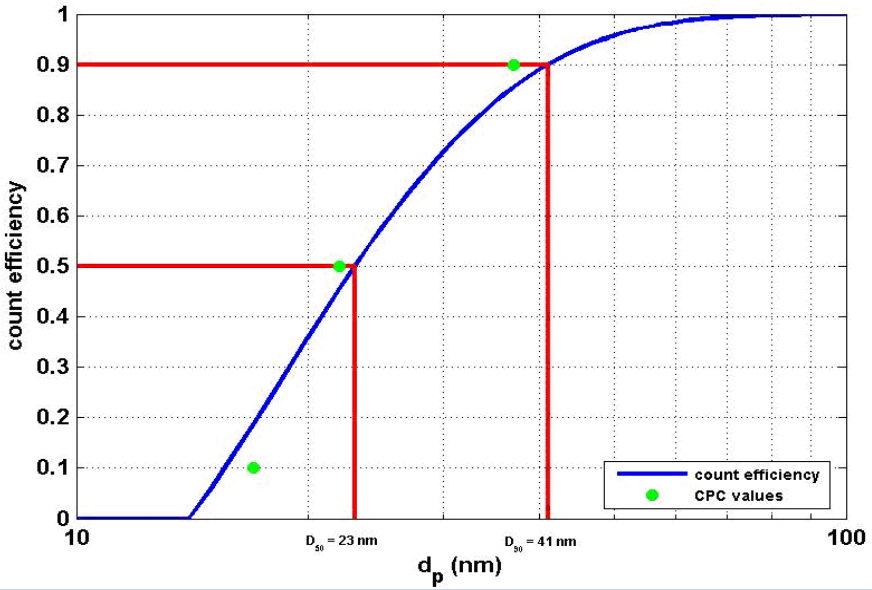
50% count efficiency: D50 = 23 nm
>90% count efficiency: D90 = 41 nm

Regulation compliant counter



TSI (2007), "Model CPC-100 Condensation Particle Counter Operation and Service Manual", *P/N* 1980553, Revision C. TSI Inc.

DMS500



$$f = 1 - \exp\left[-3.54\left(\frac{d_p - 14}{40}\right)^{1.09}\right]$$

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Vehicles on test

Vehicle Description	Fuel Injection Equipment	Induction Strategy	Exhaust After-treatment
Gasoline PFI	Multi-point, Port Fuel Injection	Naturally aspirated	3-way catalyst
Gasoline DISI	Spray-Guided Direct Injection	Naturally aspirated	3-way catalyst
	Wall-Guided Direct Injection	Naturally aspirated	3-way catalyst, lean NOx trap
Diesel DPF	High pressure common rail	Turbocharged	Diesel oxidation catalyst, wall-flow Diesel Particulate Filter
Diesel Non-DPF	High pressure common rail	Turbocharged	Diesel oxidation catalyst

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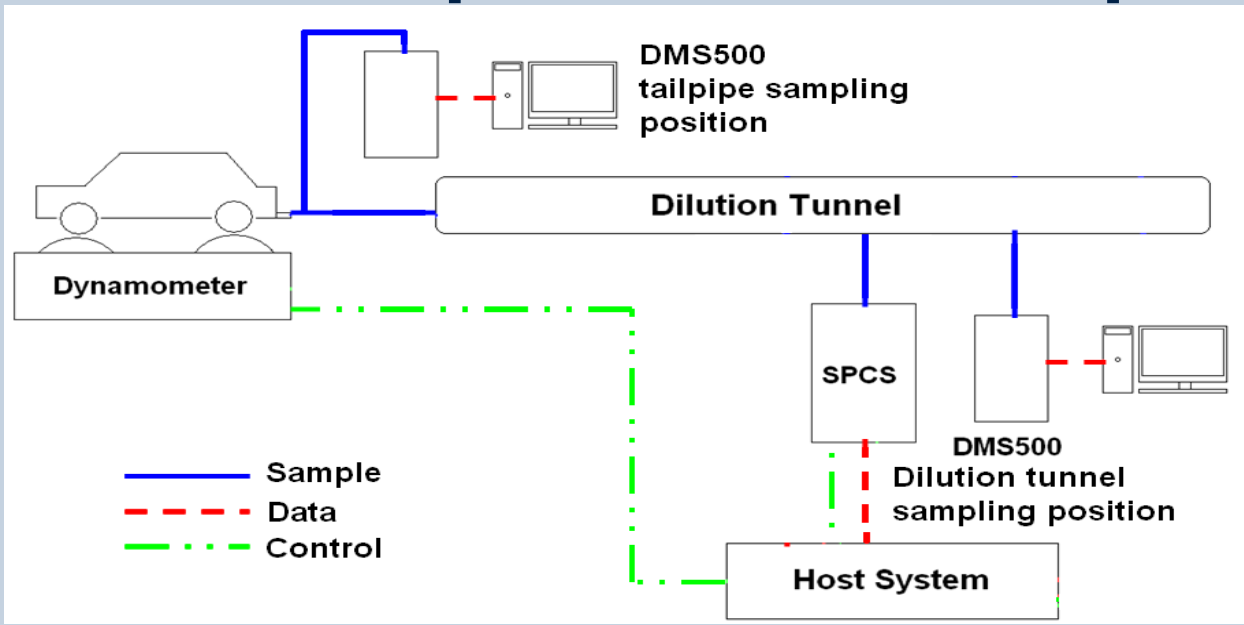
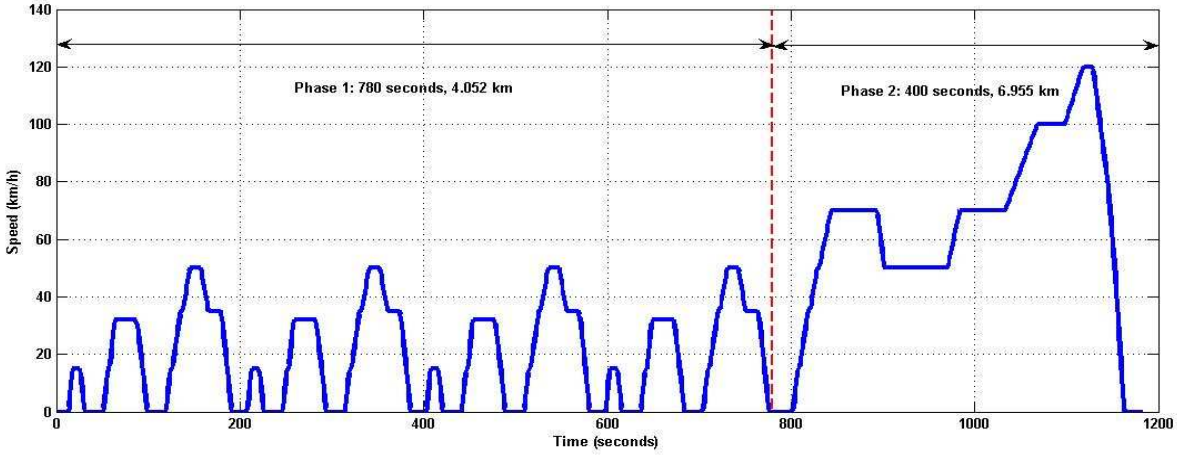
Production and prototype vehicles of different emissions levels.

Experimental set-up





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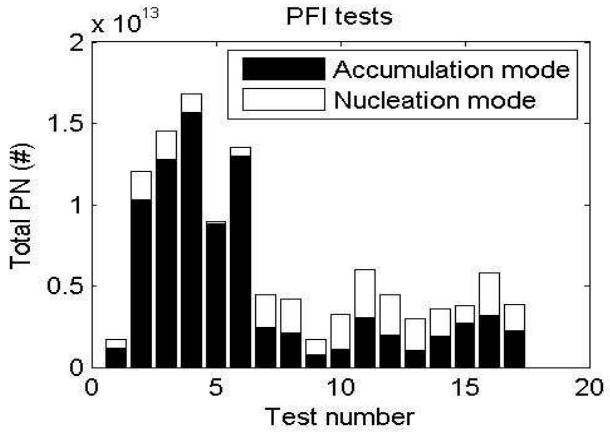
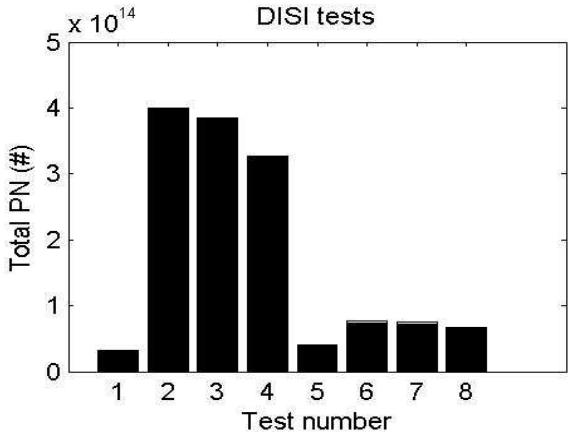
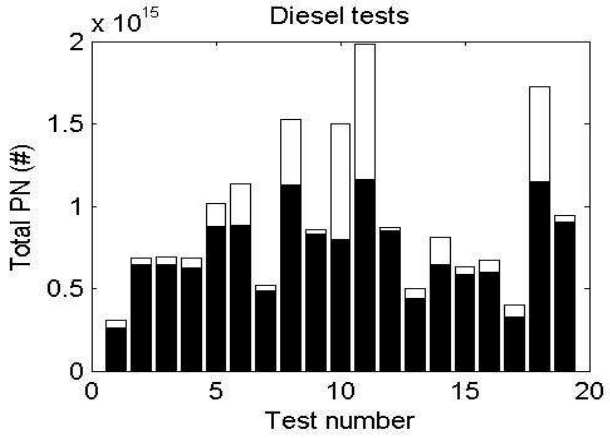
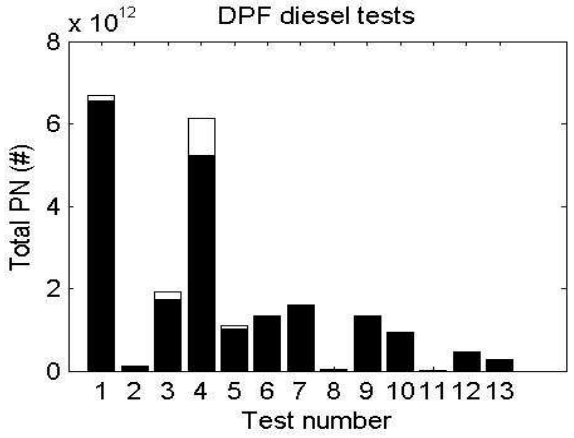
DMS500 as a development tool: Accumulation and nucleation mode data









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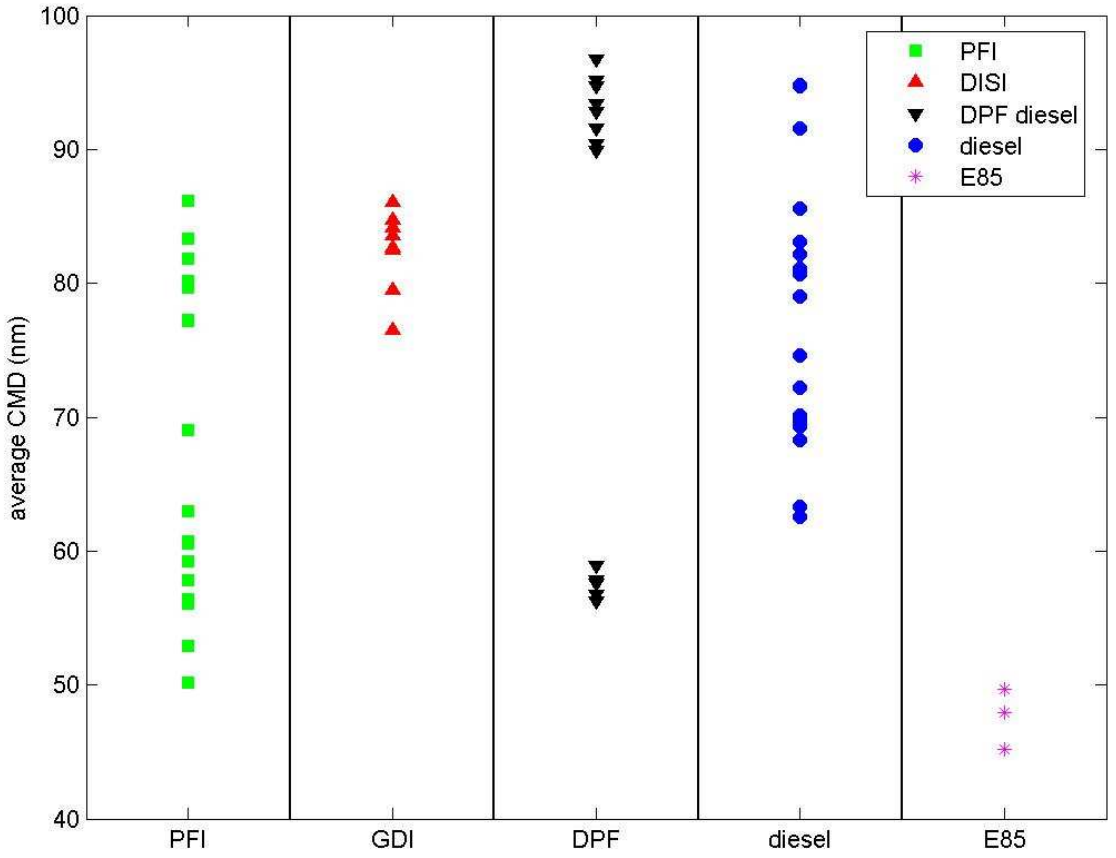
DMS500 as a development tool: accumulation mode particle size



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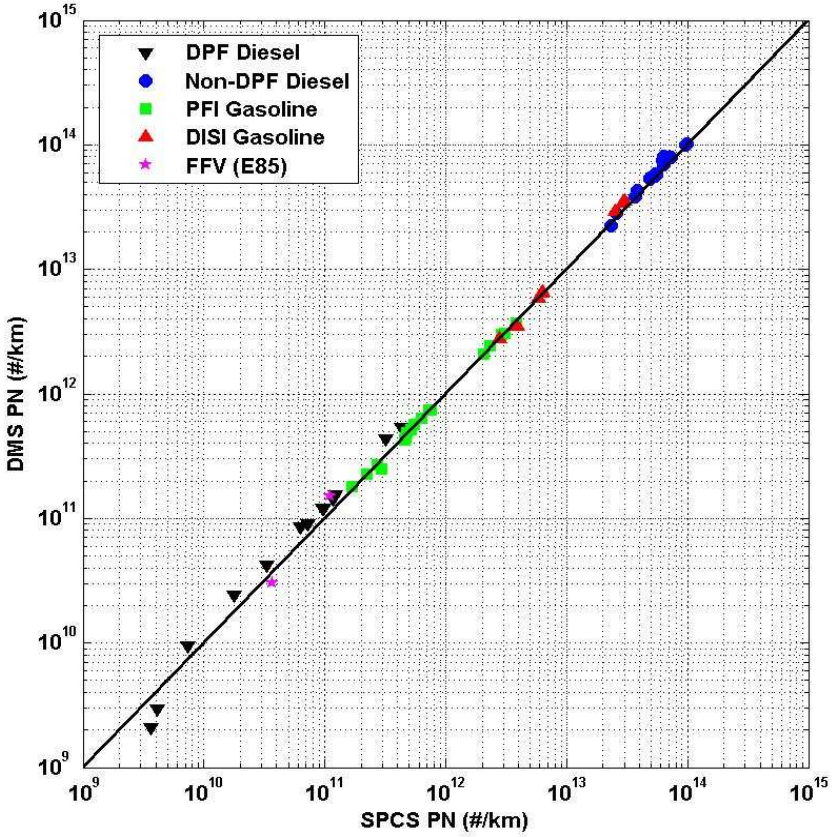
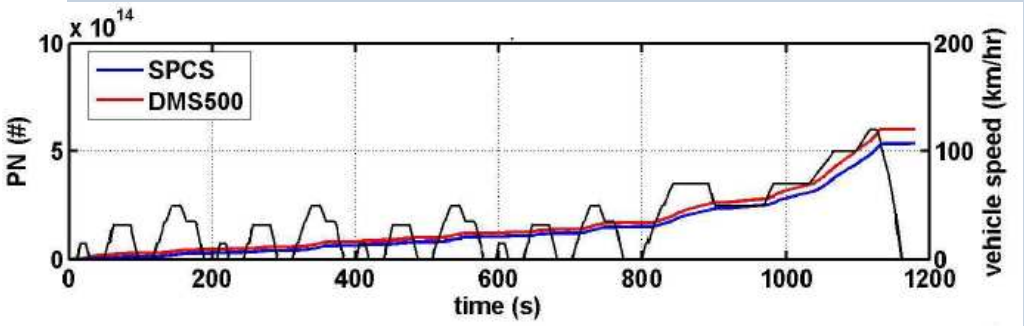
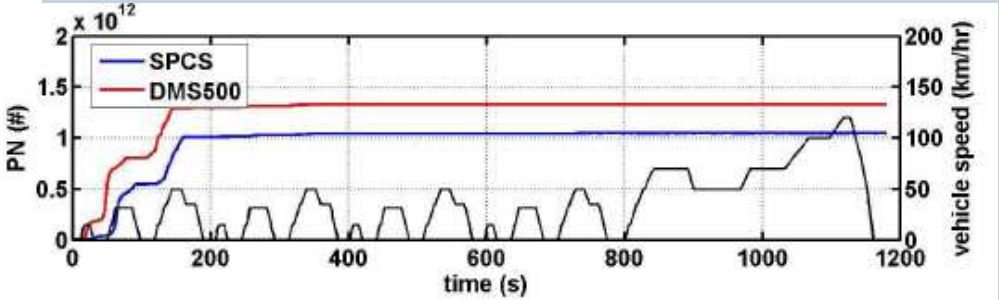
Dilution tunnel solid PN measurement results: DMS500 accumulation mode versus SPCS



Diesel test



DPF diesel test



PFI PN data taken over Part 1 of the NEDC only.

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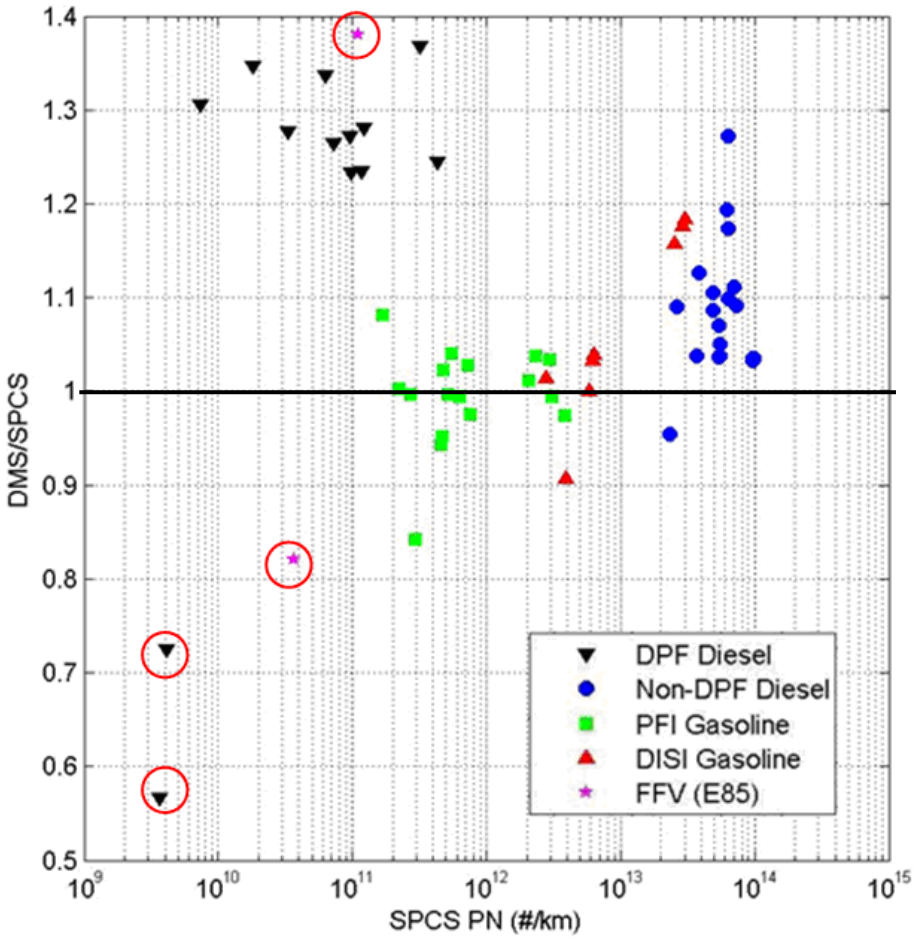
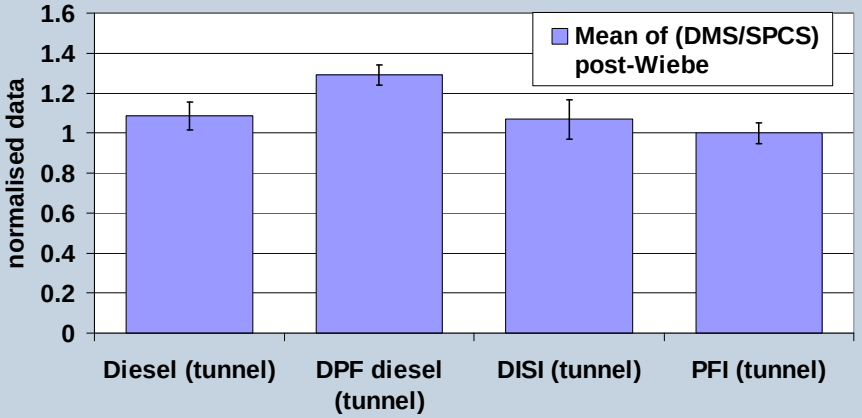
Dilution tunnel DMS500:SPCS solid PN comparison





Vehicle type	Mean	Standard deviation
Diesel (tunnel)	1.086	0.071
DPF diesel (tunnel)*	1.29	0.05
DISI (tunnel)	1.07	0.099
PFI (tunnel)	1.00	0.052

*Excluding two outliers

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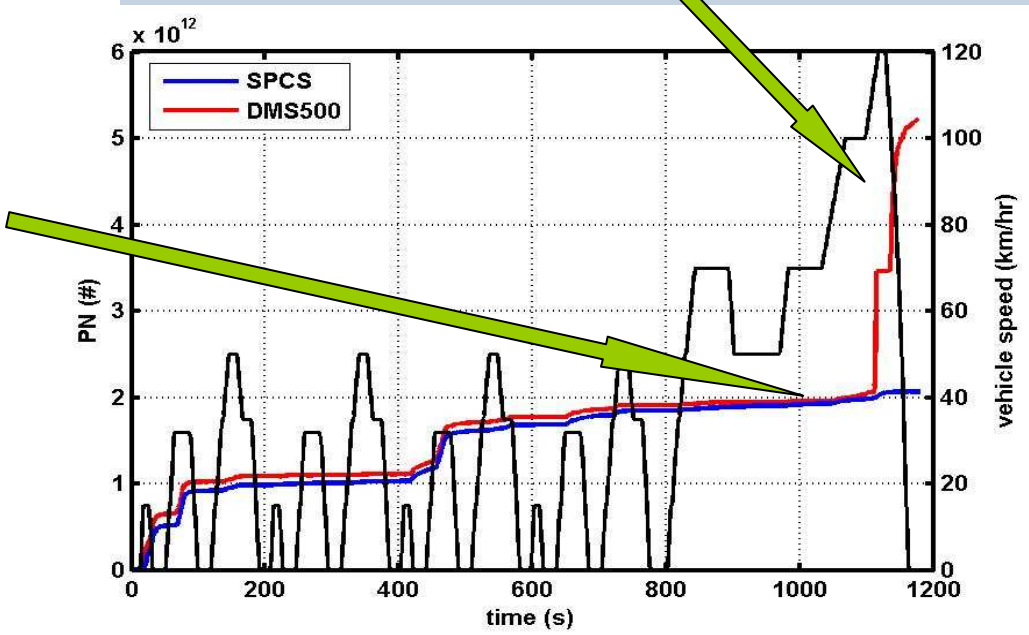
Limitation 1: Silicone transfer hose

Emitted only during part 2 of the NEDC and only found to be of significance for PFI (gasoline + E85) vehicles.

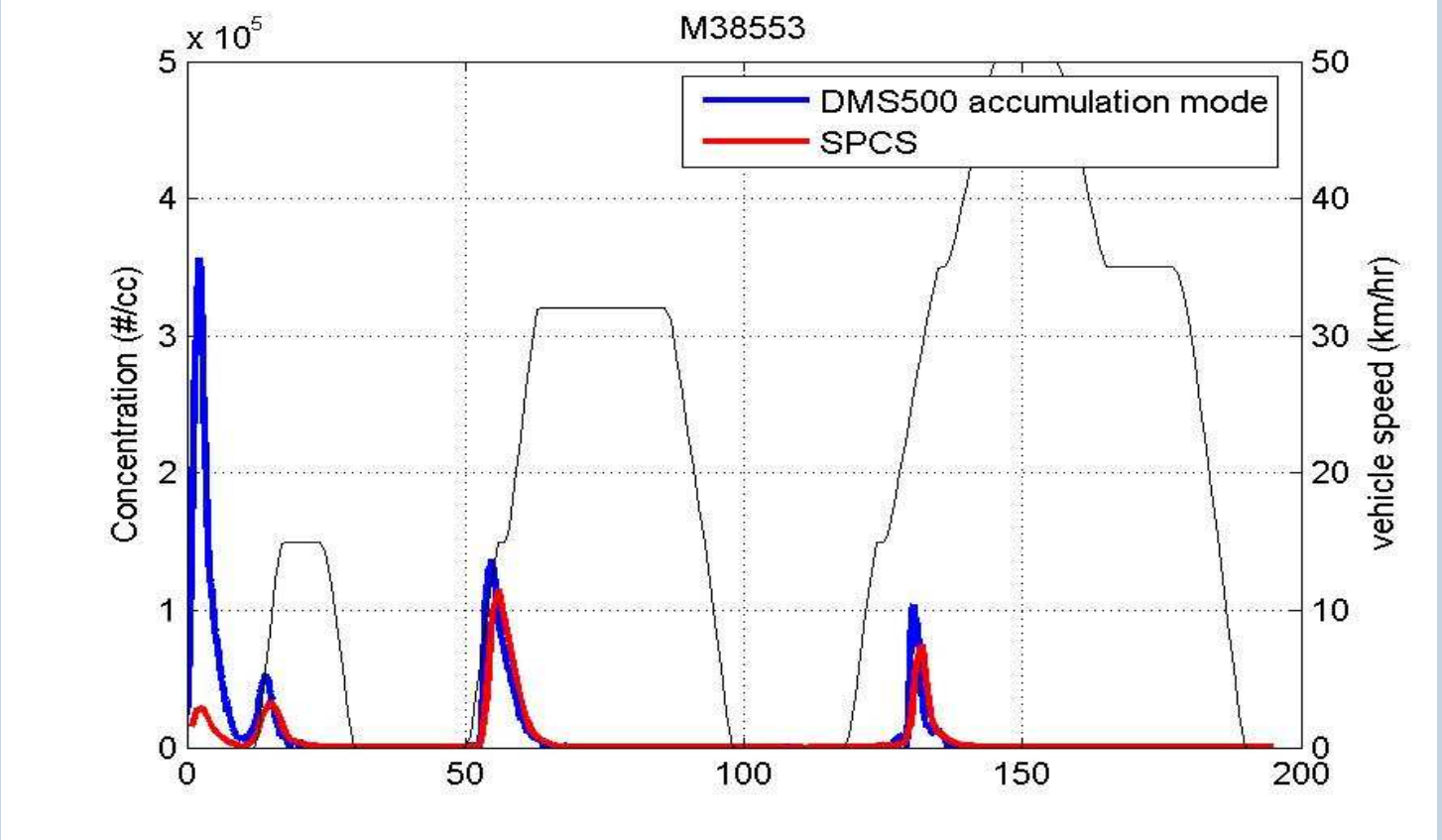
SPCS counter insensitive to these particles. DMS500 accumulation mode not.

PFI PN data therefore only represented over part 1 of the NEDC.



Can ‘produce’ up to 3×10^{11} particles per km.

Limitation 2: Cold-start E85 fuel



High accumulation mode concentration during cranking. SPCS demonstrates it is not solid particulate matter. Condensed ethanol droplets in the accumulation mode?

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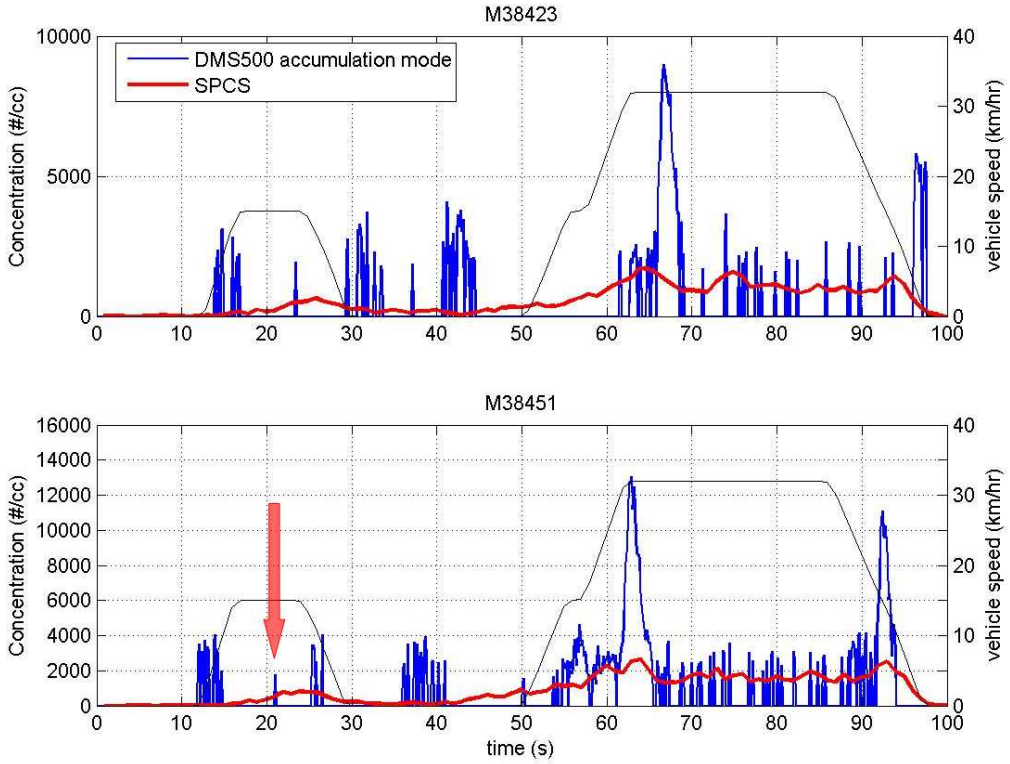
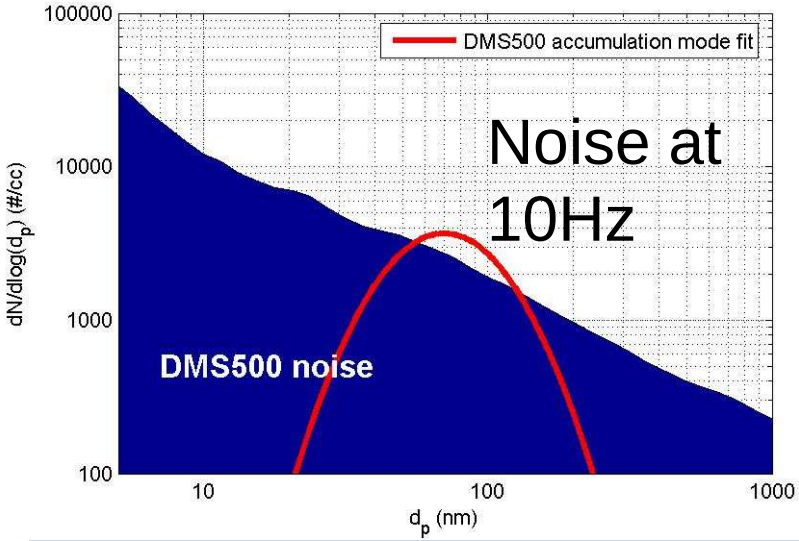
Limitation 3: Low Signal-to-Noise Ratio





PN emission rate < 4×10^9 per km.

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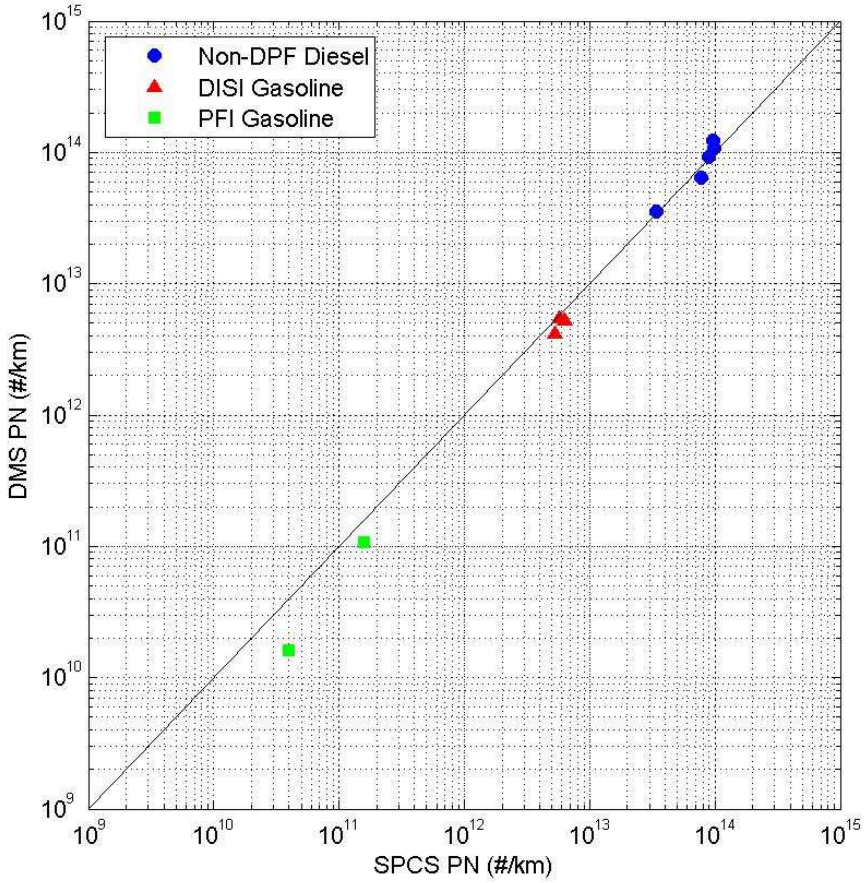
Tailpipe solid PN measurement results: DMS500 accumulation mode versus SPCS



Limited data set, but indicates good instrument-to-instrument agreement.

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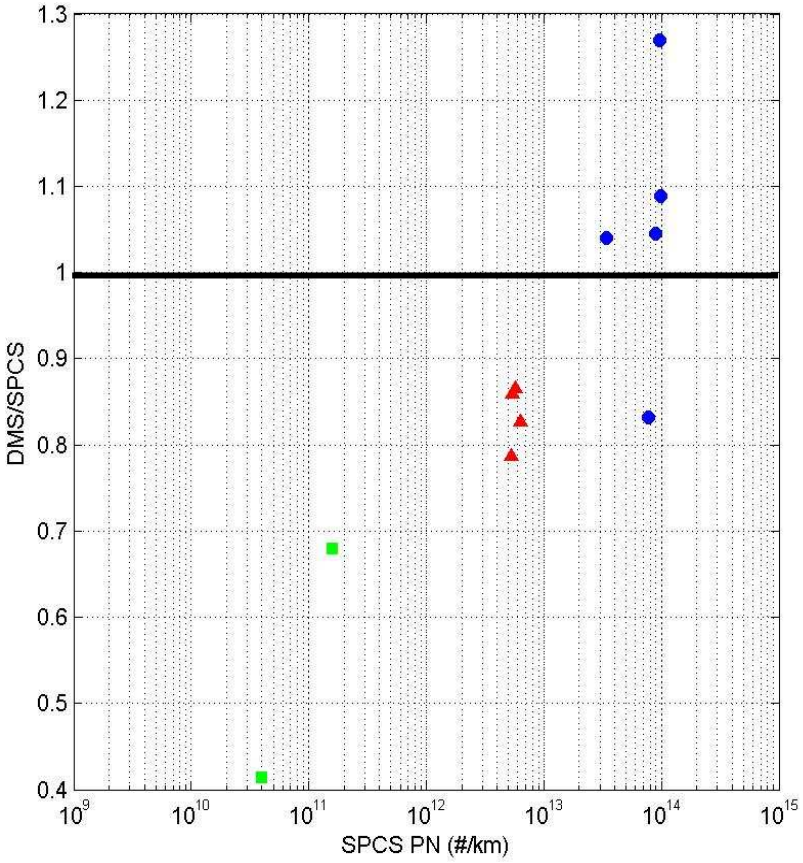
Tailpipe DMS500:SPCS solid PN comparison

Does the solid PN agreement hold when sampling directly from the tailpipe with the DMS500?



DMS500/SPCS results

Vehicle type	Mean	Standard deviation
Tunnel (Diesel)	1.086	0.071
Tunnel (DPF diesel*)	1.29	0.05
Tunnel (DISI)	1.07	0.099
Tunnel (PFI)	1.00	0.052
Tailpipe (All vehicles)	0.88	0.23

*Excluding two outliers

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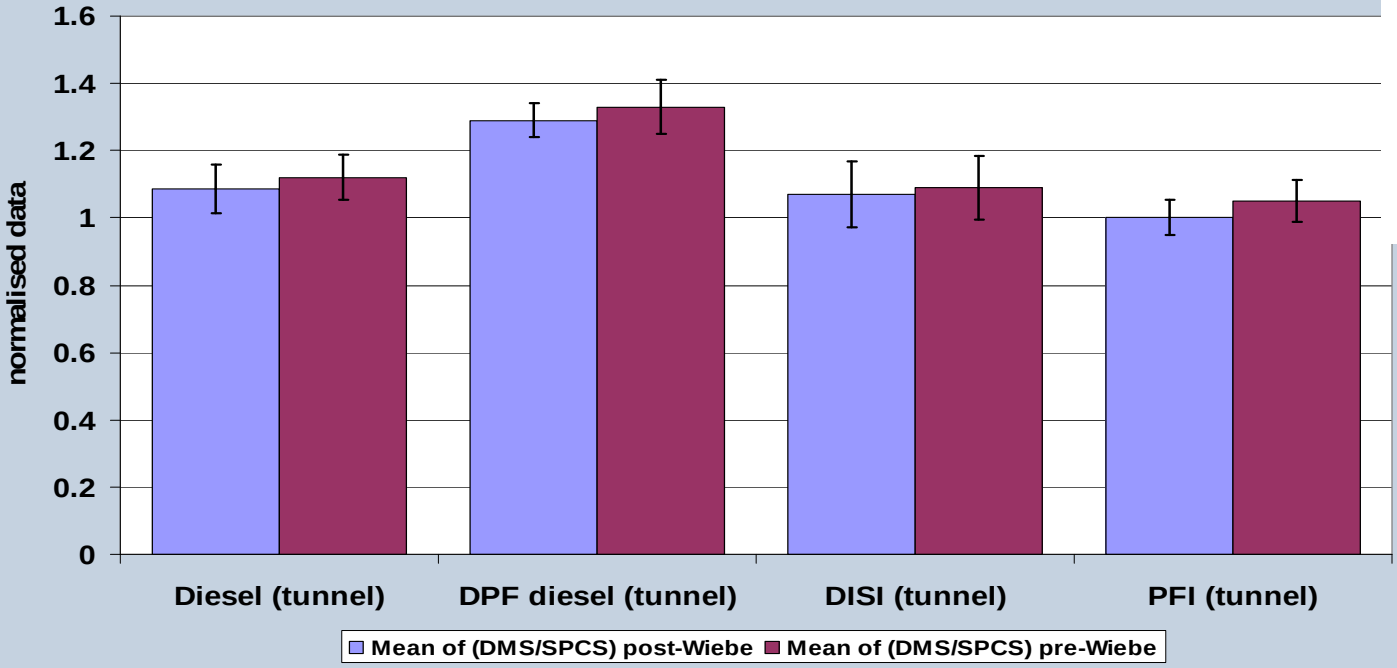
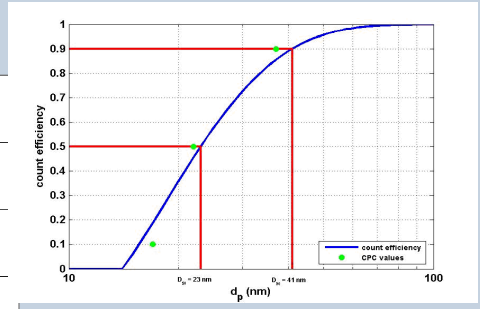
Effect of Wiebe function on DMS500 solid PN measurements

Was applying the Wiebe function to the DMS500 accumulation mode PN data necessary?





Slightly improved agreement between DMS500 solid PN and SPCS PN with Wiebe function. Extra data processing required.

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Conclusions (1/2)

- DMS500 has been demonstrated to be a useful development tool:
  - PFI and diesel vehicles most likely to provide a significant nucleation mode.
  - Differences in particle size observed for 2 different types of DPFs

- DMS500 accumulation mode demonstrated to successfully correlate with solid PN results from a regulation-compliant counter, when sampling either from the dilution tunnel or tailpipe.

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Conclusions (2/2)

- Accumulation mode, however, can be prone to non-solid particles:
  - Silicone particles
  - Ethanol droplets
- At a PN emission rate of < $4x10^9$ per km, the DMS500 appeared to be on the SNR limit (at 10Hz). However, measurements were taken with a mk1 DMS500. Latest units have 3x sensitivity. Suggested that data is logged at 1Hz for DPF-diesel tests to improve SNR.
- Wiebe function, for count efficiency correction, has been shown to slightly improve solid PN agreement, but probably does not warrant extra data processing required.

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Thank you for listening. Any Questions?

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