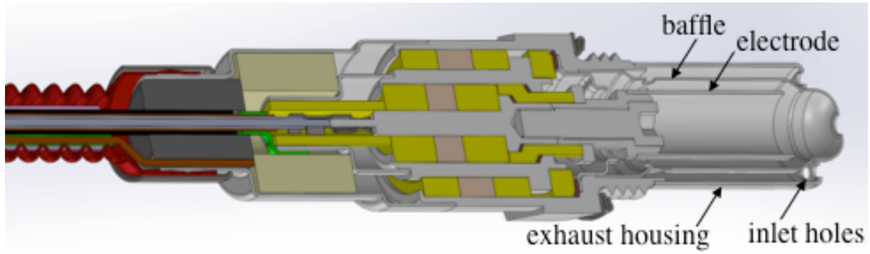
Application of PMTrac® Sensors for Low-cost PM Threshold Testing

UC Riverside PEMS 2018 International Conference & Workshop
March 22, 2018

J. Fitzpatrick, B. Henderson, and L. Woo

Investigate using low-cost electrostatic PMTrac® sensor in threshold applications

- Previously developed PMTrac® sensor for in-situ monitoring of soot and diesel particulate filter (DPF) failure detection



  - Naturally charged soot; bipolar with ~30% positive and ~30% negative
  - Novel measurement with signal amplification, real-time output, simple physical design, and tolerant of contaminants
  - Apply 1 kV (~800 kV/m field) to concentric electrostatic trap; measured current proportional to PM mass concentration (mg m^{-3})

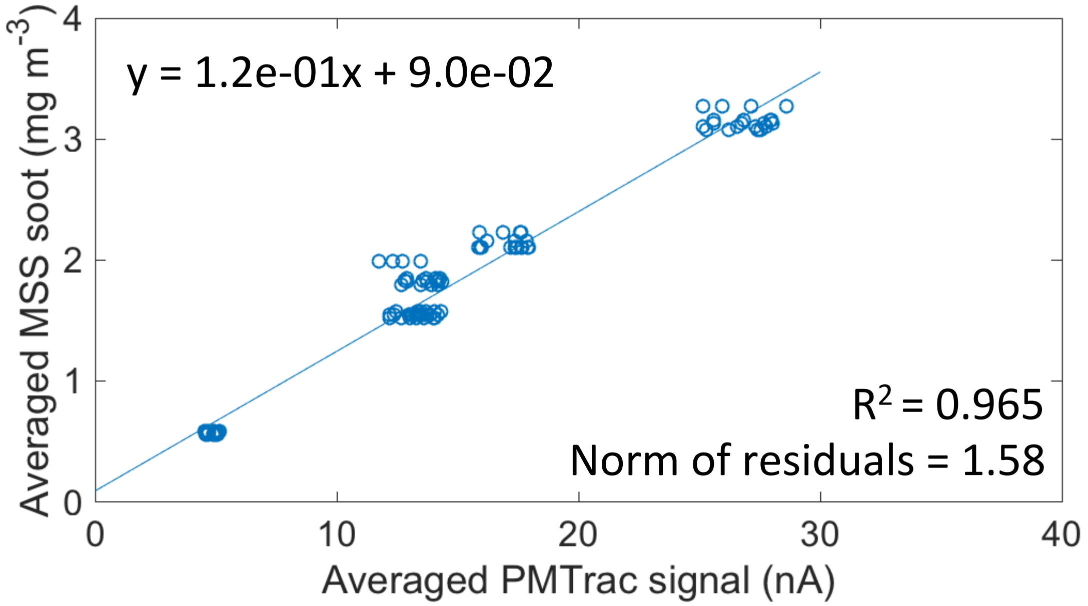
- Investigate potential for using PMTrac® in other applications that normally require much more expensive instrumentation

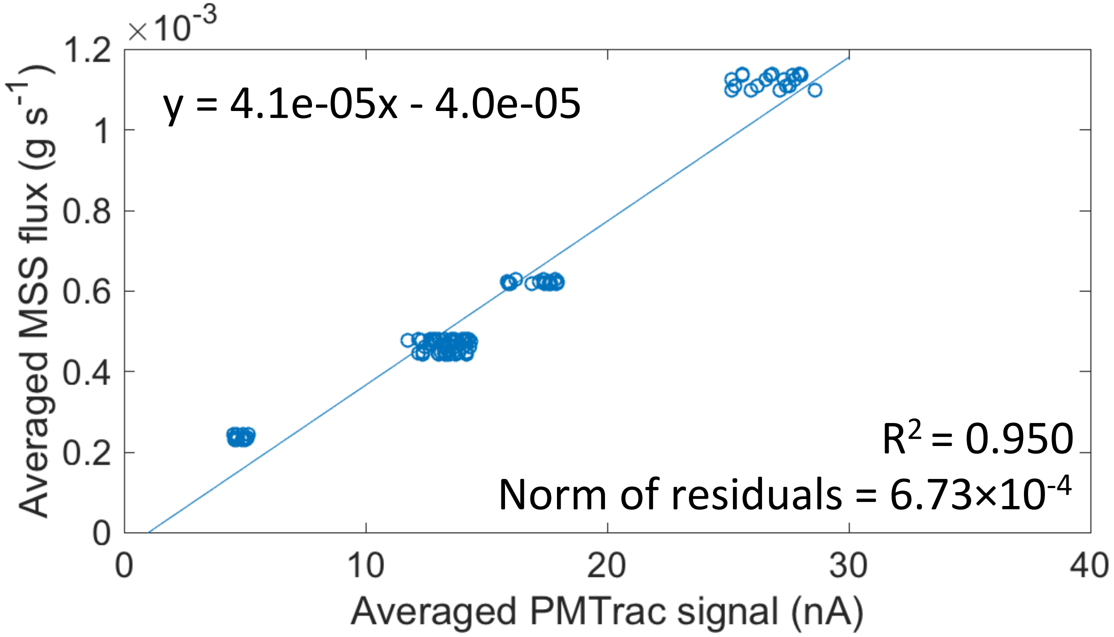
Various types of testing demonstrate the potential of PMTrac® sensors for threshold applications

- Various types of testing include:
  - Drive cycle data from Southwest Research Institute (SwRI)
  - On-road vehicle testing from Continental
  - Drive cycle and other testing from Ford Motor Company
  - Our own testing using modified diesel generator
- Possible threshold applications include augmenting opacity measurements used to detect compromised DPFs in "Smog Shops" or other continuous monitoring devices

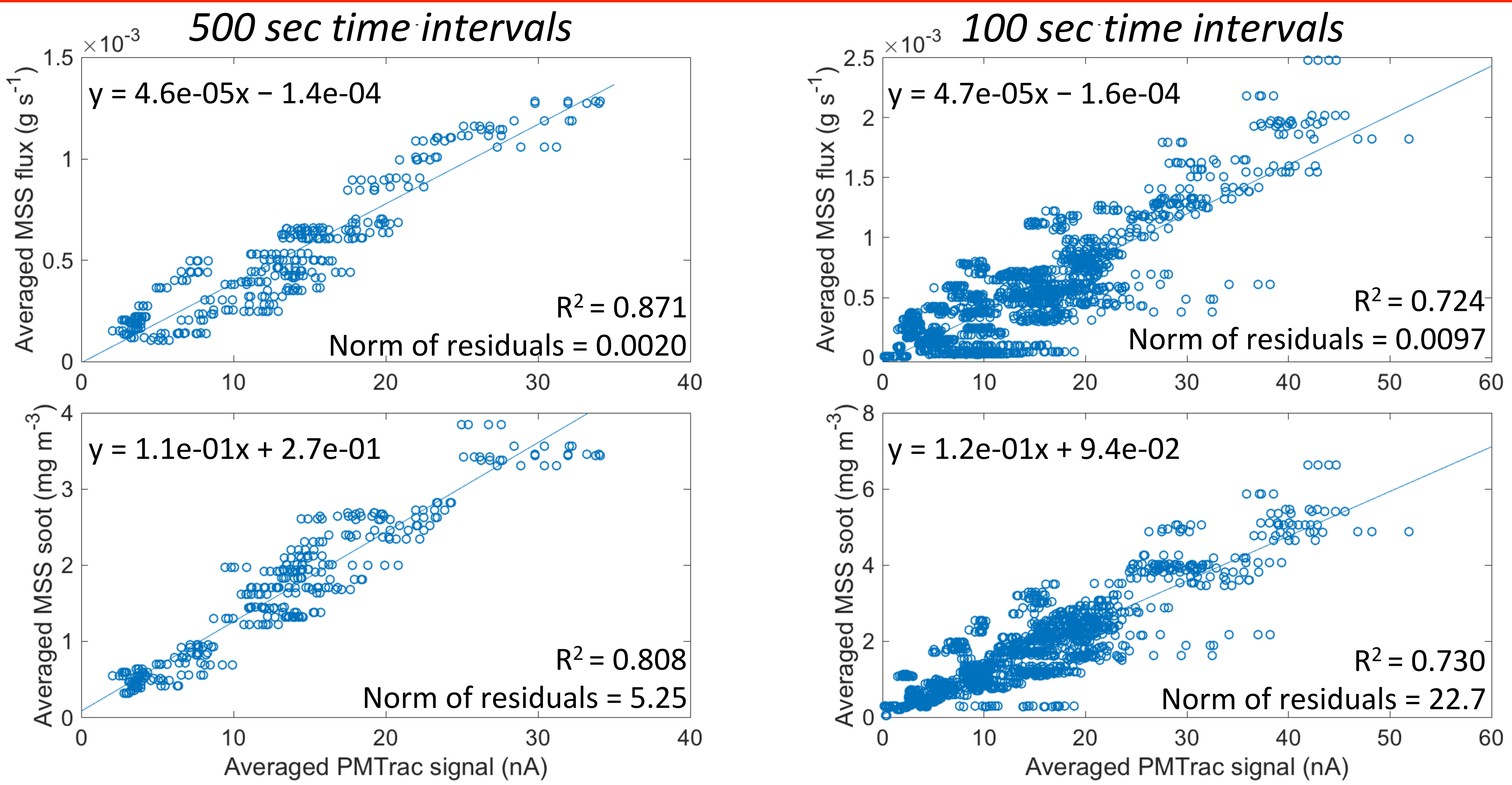
Southwest Research Institute (SwRI) – PMTrac® sensors on 2010 heavy-duty diesel engine platform

- 5 times each, FTP, NRTC, WHTC, and RMC drive cycles for 4 sensors
- Additional 5 times FTP drive cycle for 7 sensors
- Good agreement with MSS when averaging raw current signal (no calibration or correction) over full drive cycles



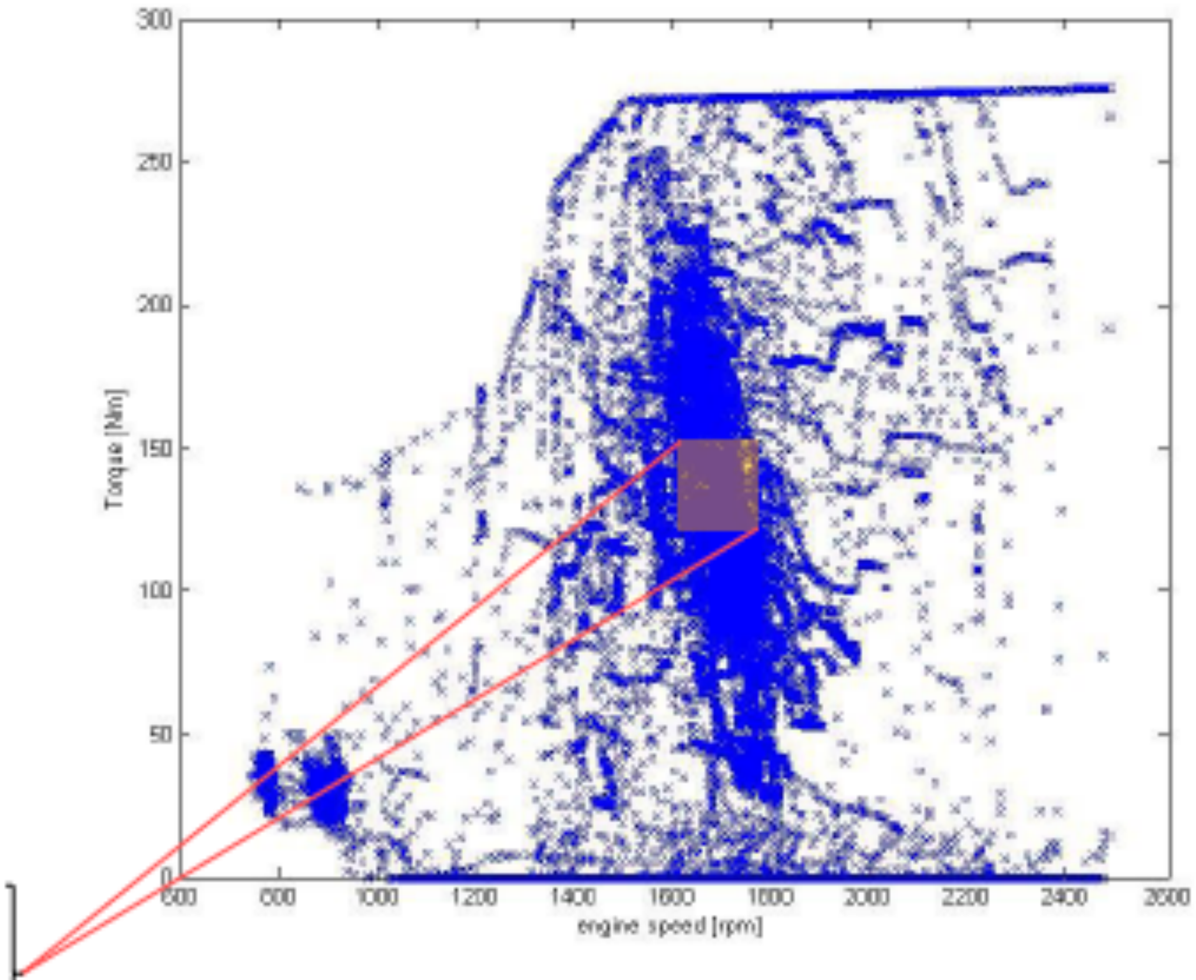


Reduced correlation with MSS for shorter time intervals of 500 and 100 sec – still meaningful signal



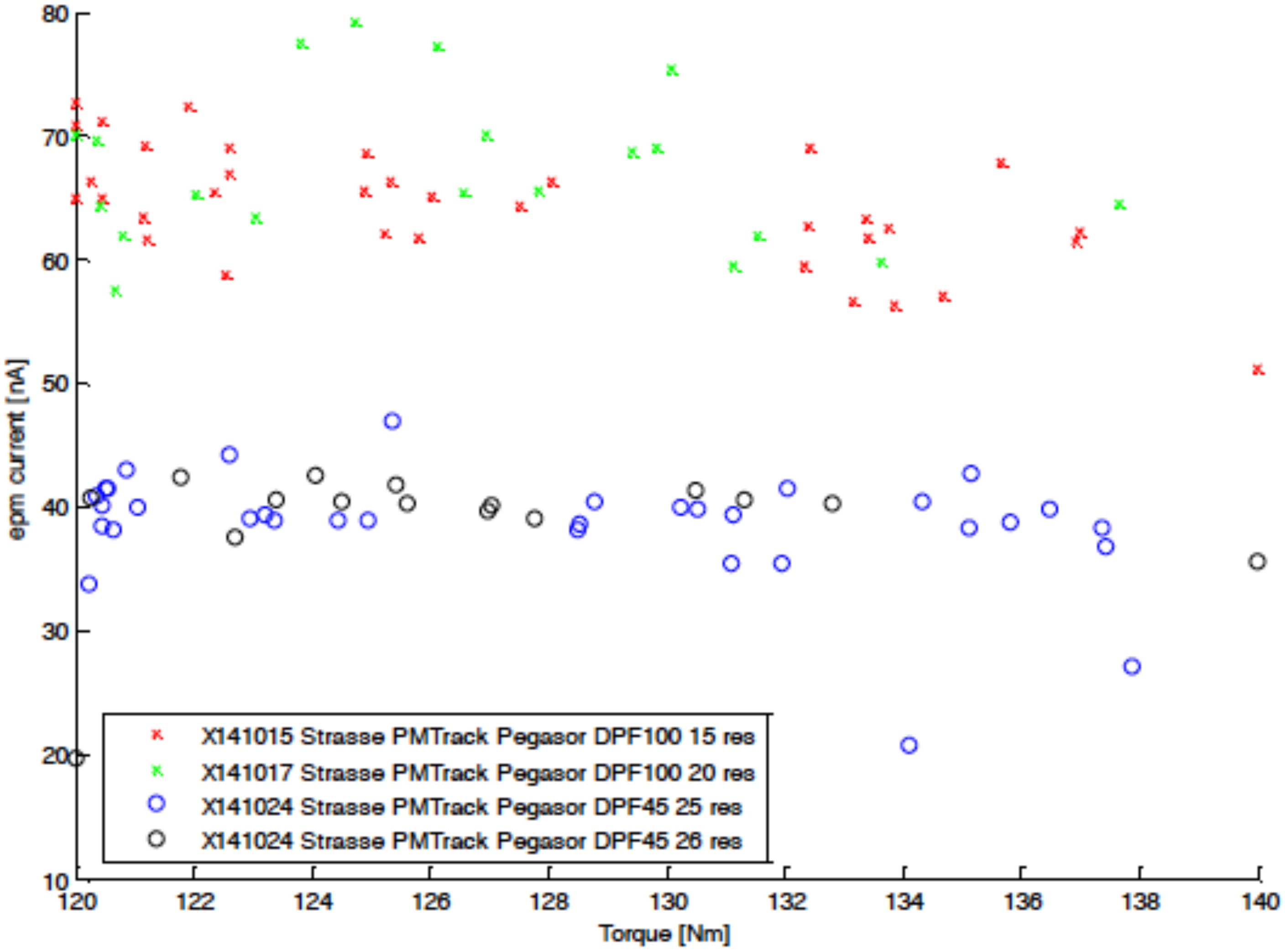
Continental – diagnostic capability of their electrostatic ‘epm’ sensor during real driving on public road

- Diesel engine (1.6L, Euro 5) with downstream Pegasor sensor
  - 2 drives with DPF of PM=28 mg/km in NEDC (DPF 100)
  - 2 drives with DPF of PM=16 mg/km in NEDC (DPF 45)
- Raw sensor signal (no calibration or correction) averaged over 5 seconds compared to expected threshold value in selected window



Window selected for
these speed/torque values

Raw sensor signals measured in selected window of speed/torque values

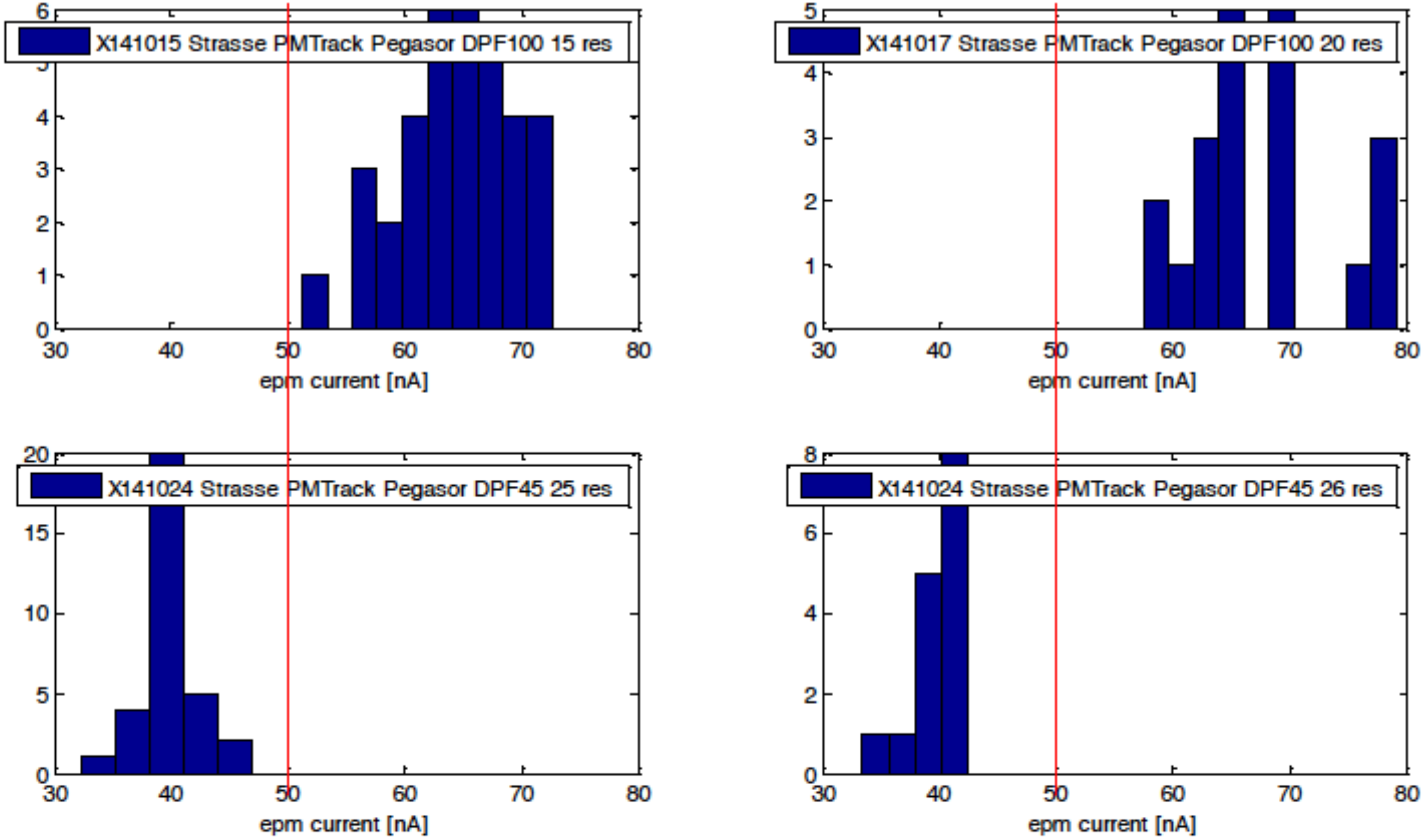


	Driving duration	Diag events
DPF 100 (15)	65 min	35
DPF 100 (20)	70 min	20
DPF 45 (25)	68 min	35
DPF 45 (26)	66 min	16

Threshold set at 50nA: for 107 incidences, all were correctly identified

DPF 100

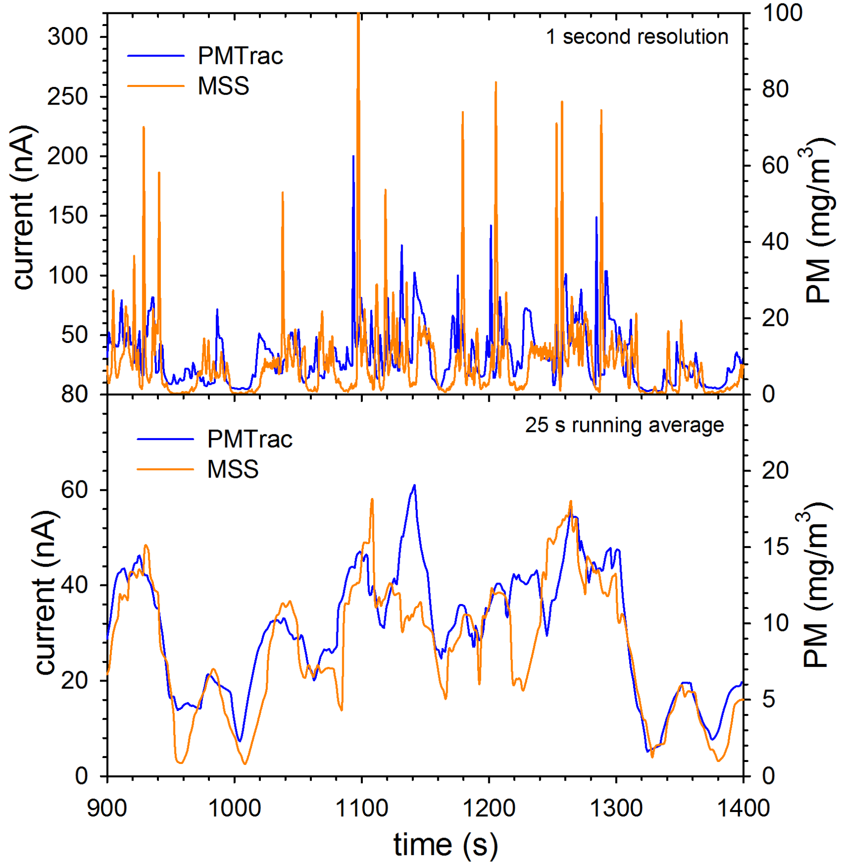
DPF 45



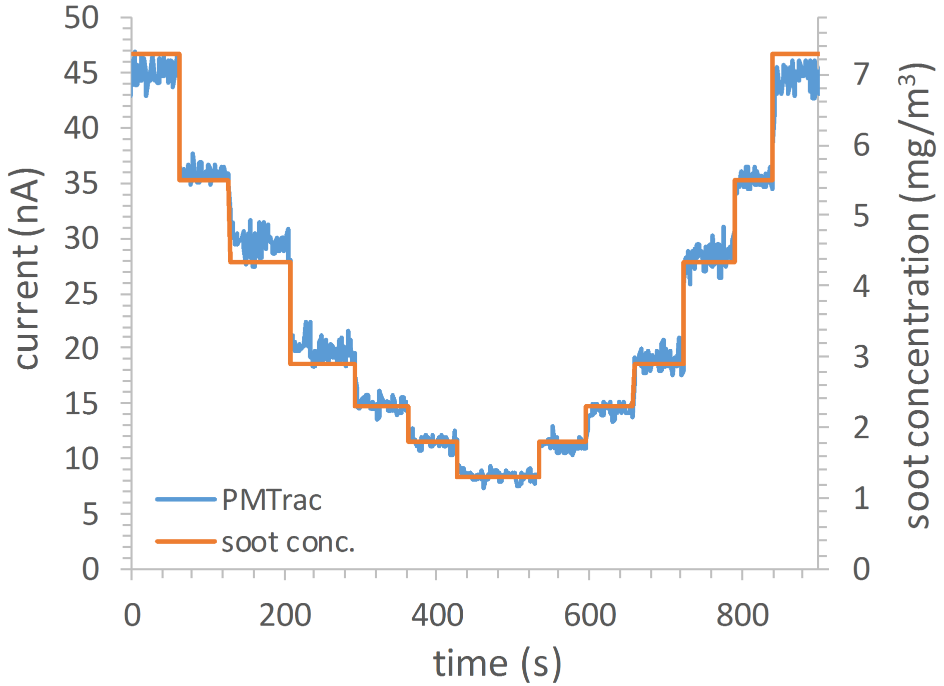
Ford – Growth/fragmentation/charge transport model for understanding PMTrac® performance

- Previous Ford work: D. Bilby et al., *J. Aerosol Sci.*, 98, 41 (2016)
  - Captured soot grows to critical height where electric field exceeds binding force
  - Fragmentation and charge transport leading to amplification effect
- Maricq and Bilby, submitted to J. Aerosol Sci. (2018) – role of changing voltage and flow transients on PMTrac® performance
  - Averaging over time intervals (similar to SwRI work)
  - Holding flow constant (which could be related to using speed/torque engine condition window in Continental work)

Maricq and Bilby, submitted to J. Aerosol Sci. (2018)

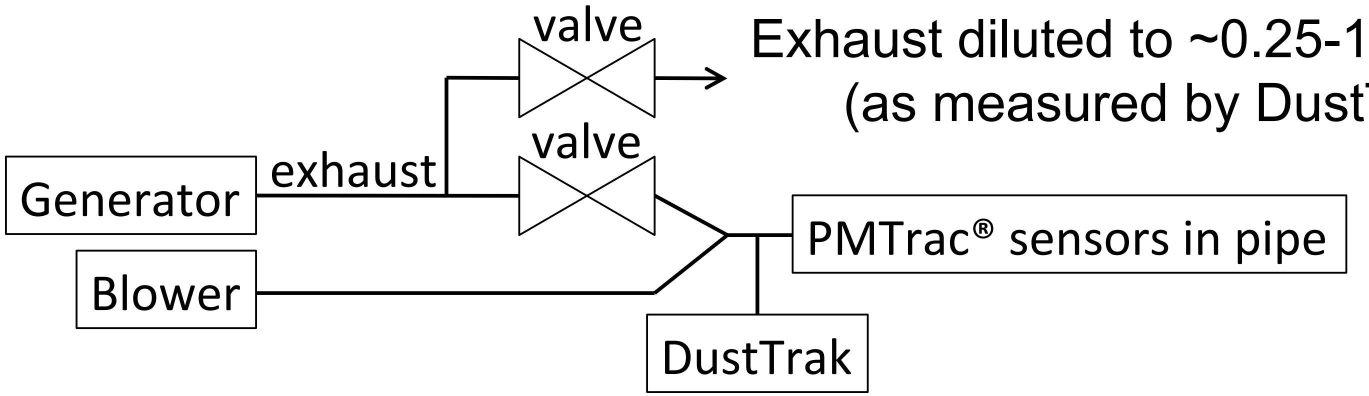


- Portion of LA92 drive cycle vehicle exhaust with leaky DPF (~65 mg/mi or ~40 mg/km)
- 25 sec running average showed better correlation than second by second

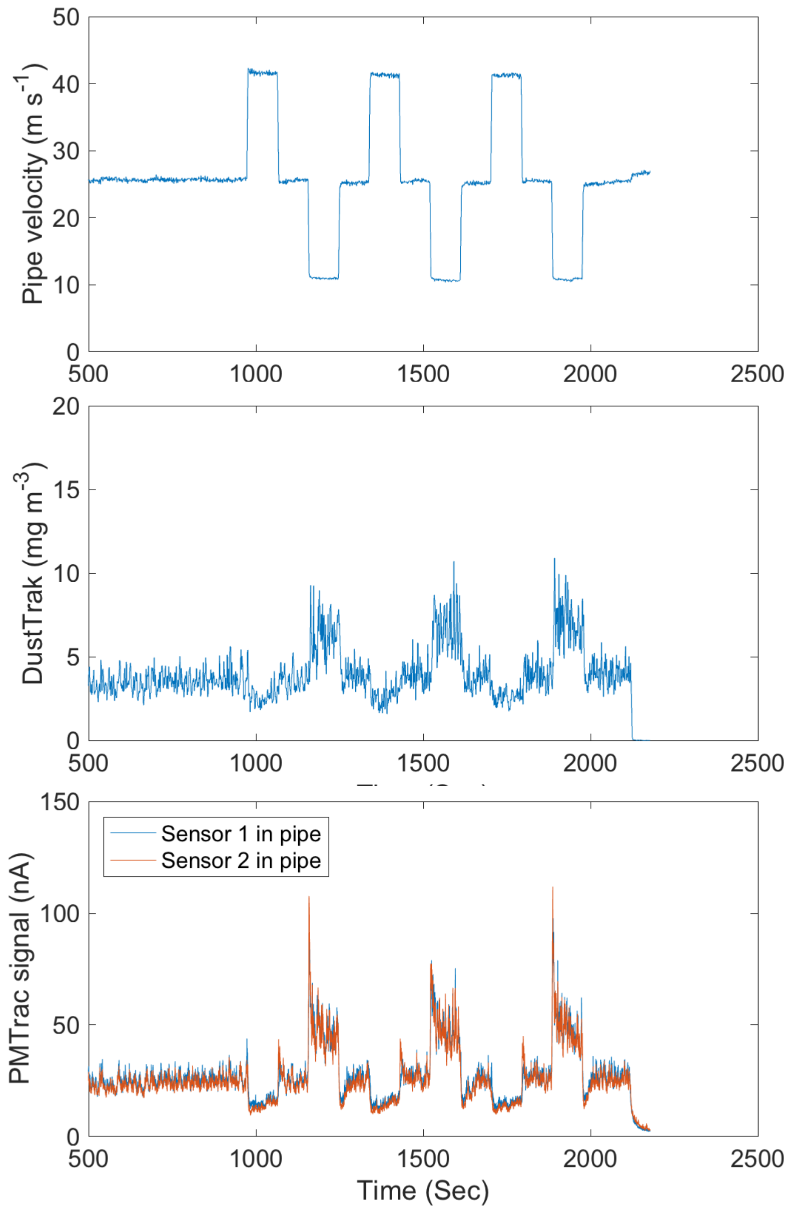


- Flow held constant at 0.9 L/min showed good correlation with soot concentration
- Using speed/torque engine condition window in Continental work could also improve correlation by reducing flow transients

Experiments to verify influence of flow transients using modified 4 kW diesel generator



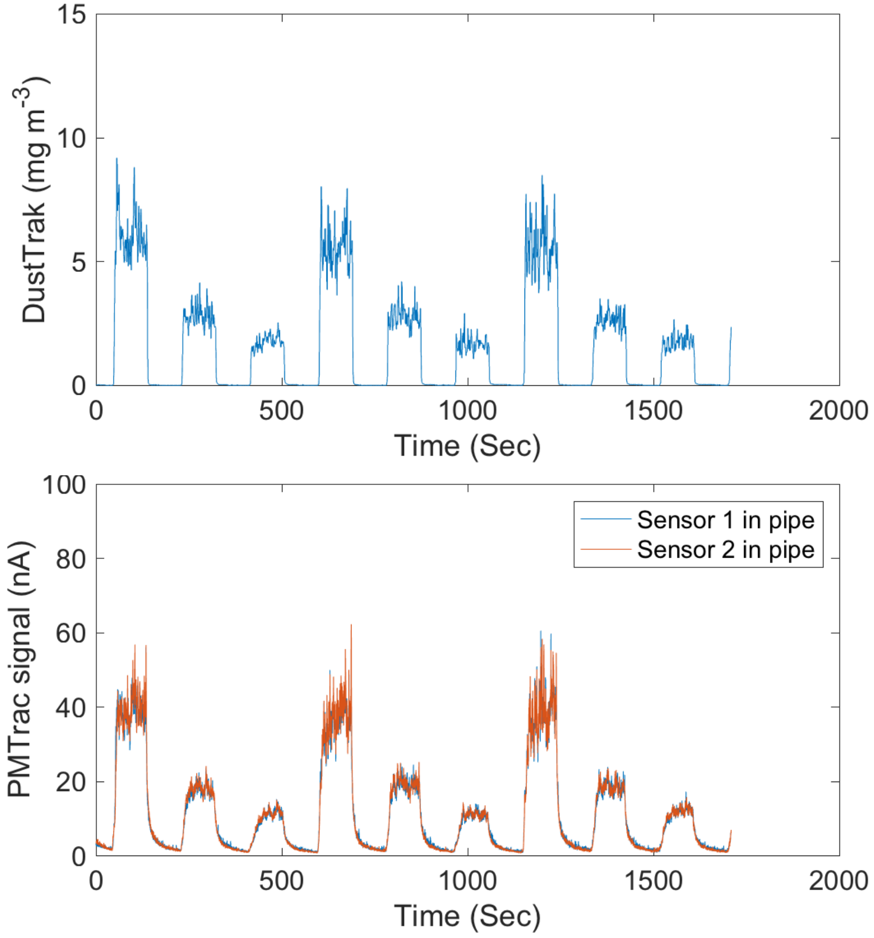
Exhaust diluted to ~0.25-18 mg m^{-3}
(as measured by DustTrak)



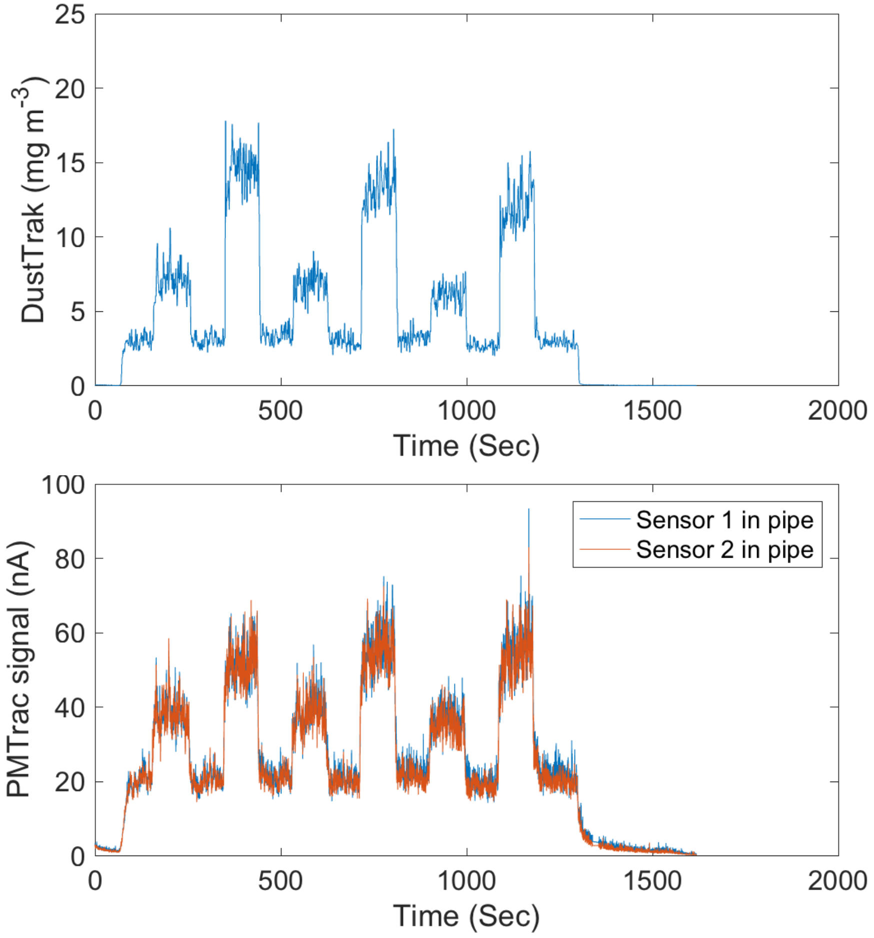
- Flow transients - alter pipe velocity by adjusting blower settings to achieve ~10-40 m s^{-1}
  - Dilution with blower alters soot concentration – higher pipe velocity yields lower soot levels
  - 90 second steps for each condition
- Evidence of PMTrac® spikes when changing pipe velocity

Pipe velocity constant at ~12 m s^{-1}; changing soot with valve or load settings – good agreement with DustTrak

Cycling between three levels of valve settings

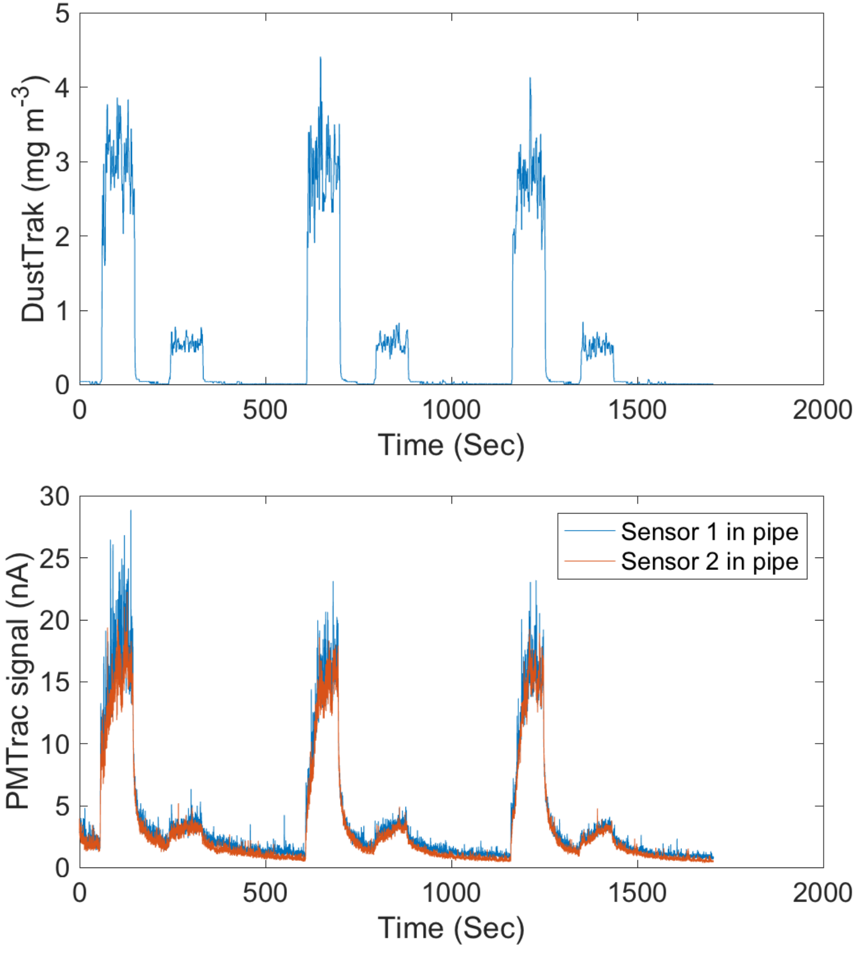


Cycling between two levels of load settings

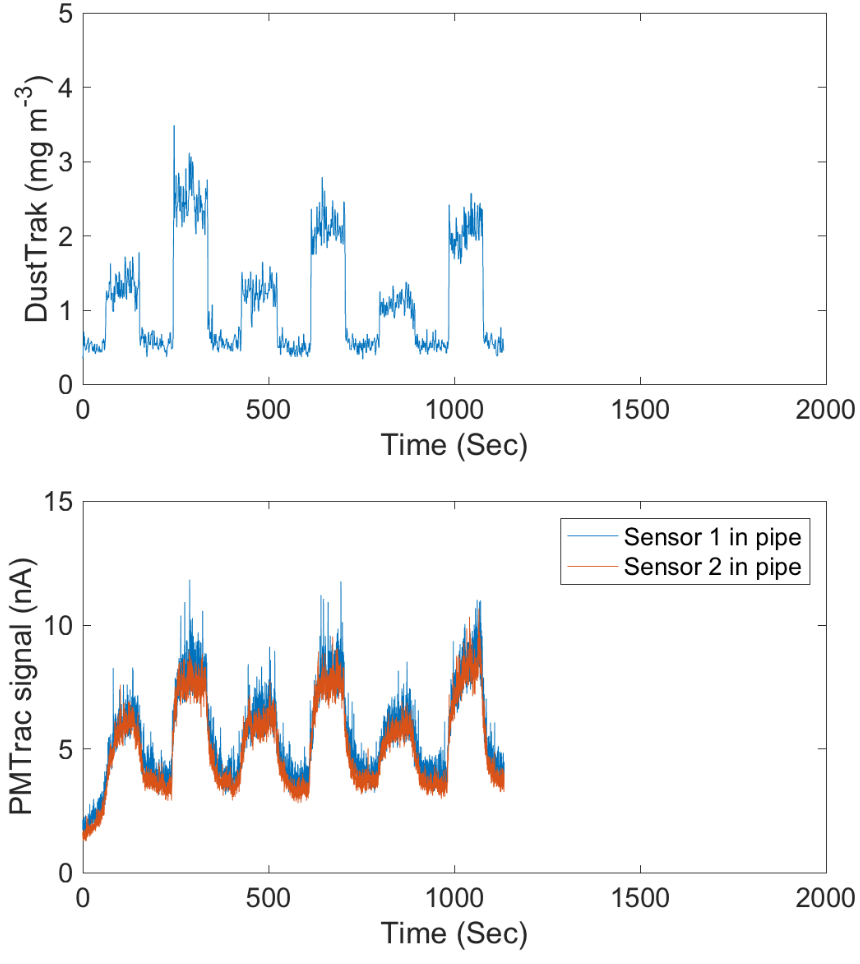


Pipe velocity constant at ~42 m s^{-1}; changing soot with valve or load settings – good agreement with DustTrak

Cycling between three levels of valve settings



Cycling between two levels of load settings



Exploring possible system architectures for rapid remote PM detection

- Preliminary work to build a system to pump exhaust through PMTrac® sensor installed into a housing
- Initial results look promising for removing effects of flow
- Ongoing work to put together proof of concept instruments that would be appropriate for smog shops
- Seeking input and collaboration from regulators and potential channel partners on configuration and requirements

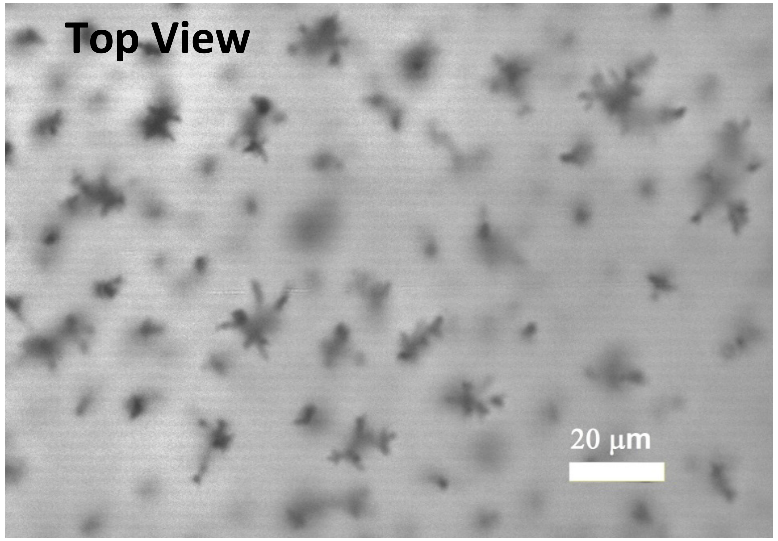
Summary and Conclusions

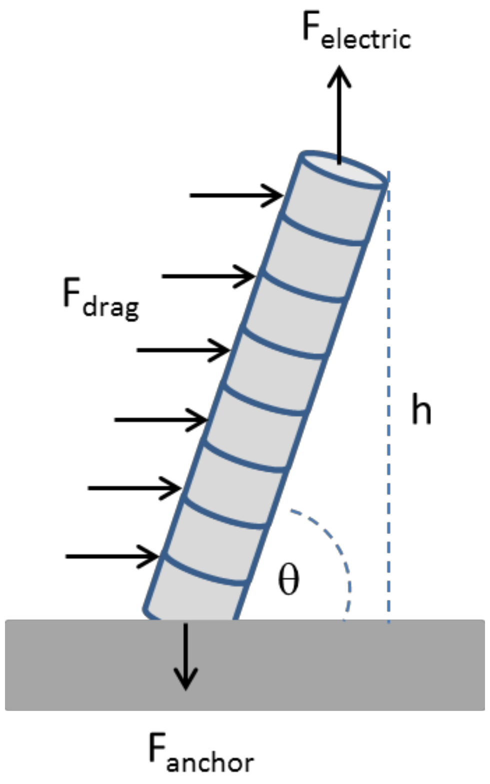
- Investigated potential for using low-cost electrostatic PMTrac® sensors in other applications that normally require much more expensive instrumentation
- Work from Ford supported findings from SwRI and Continental for better performance when averaging over time or removing influence of flow transients
- Our testing confirmed the Ford findings that the PMTrac® sensor had significantly better correlation with reference instruments when removing flow transients
- We are actively developing a low-cost sampling prototype setup that will then be further developed into prototype instruments for field testing

Questions? Thank you for you attention! lw@emisense.com

Additional slides

Measurement principle not completely understood, but seems related to soot growth to critical height





D. Bilby et al., 2016 PEMS Workshop.

- Captured soot grows filamentous dendrites with high surface charge density that collapse without electric field
- Critical height where electric field exceeds binding force – highly charged fragments deposit on opposite electrode in chain reaction
- Growth, fragmentation, and charge transport – up to three orders of magnitude increase in measured charge current amplification

D. Bilby et al., *J. Aerosol Sci.*, **98,** 41 (2016).