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Mass Concentration of Nonvolatile Nanoparticle Emissions: Comparison of Autocompensating Laser-Induced Incandescence (AC-LII) to Other Techniques

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25-29 July 2010 Nara, Japan

National Research Council Canada | Conseil national de recherches Canada

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Outline

- Background
- Calibration for Autocompensating Laser-Induced Incandescence (AC-LII)
- Comparisons
  - Mini-CAST Soot Generator (LII 200)
  - Turbulent Gas Flare (LII 200)
  - Atmospheric Black Carbon (High Sensitivity LII)
  - Diesel Exhaust (LII 300)
  - Gas Turbine Engine (LII 300)
- Issues with Gravimetric Filter Sampling
- Summary

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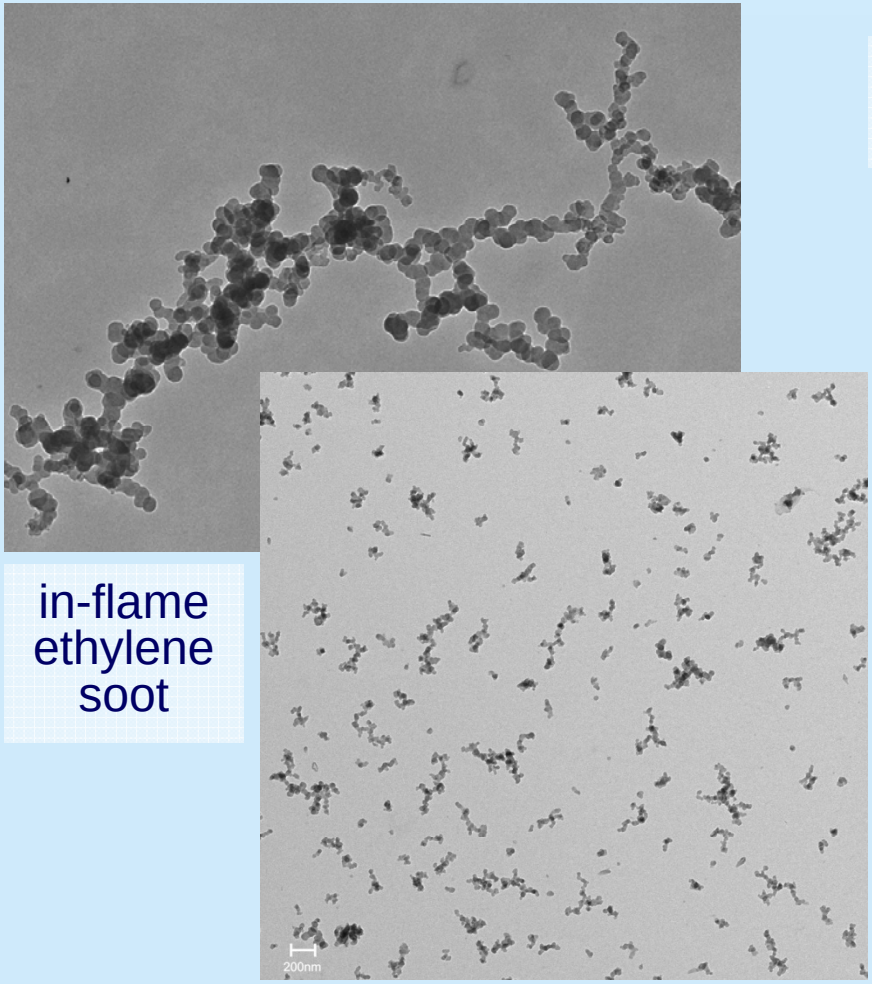
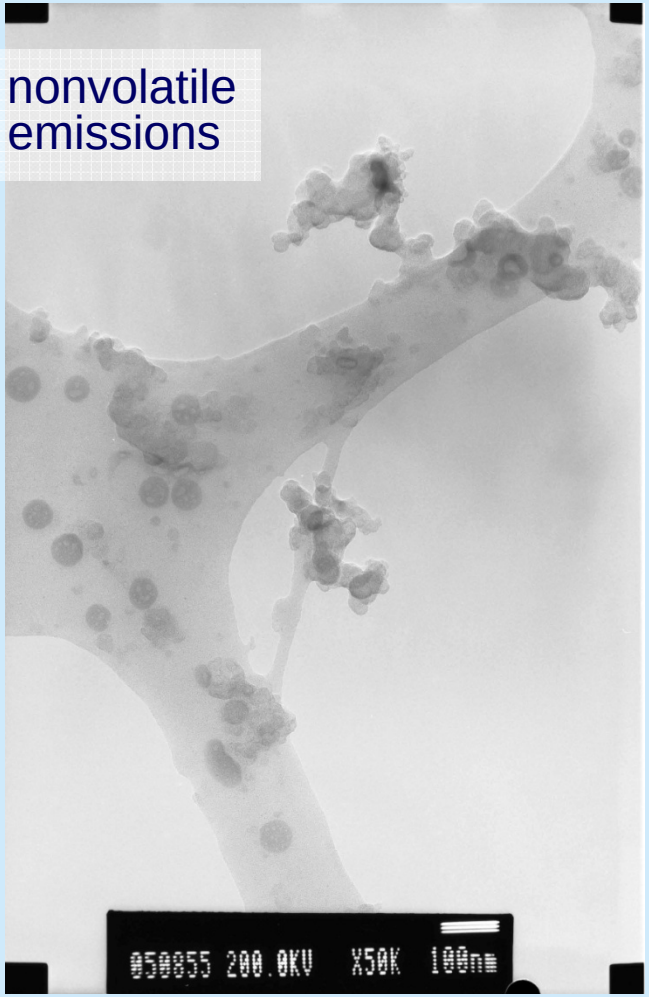
TEM Images of Nanoparticles



in-flame ethylene soot

[Schulz *et al.*, Applied Physics B **83**, 2006]

gas turbine nonvolatile particulate emissions



[Delhaye *et al.*, SAE E-31 Meeting, 2009]

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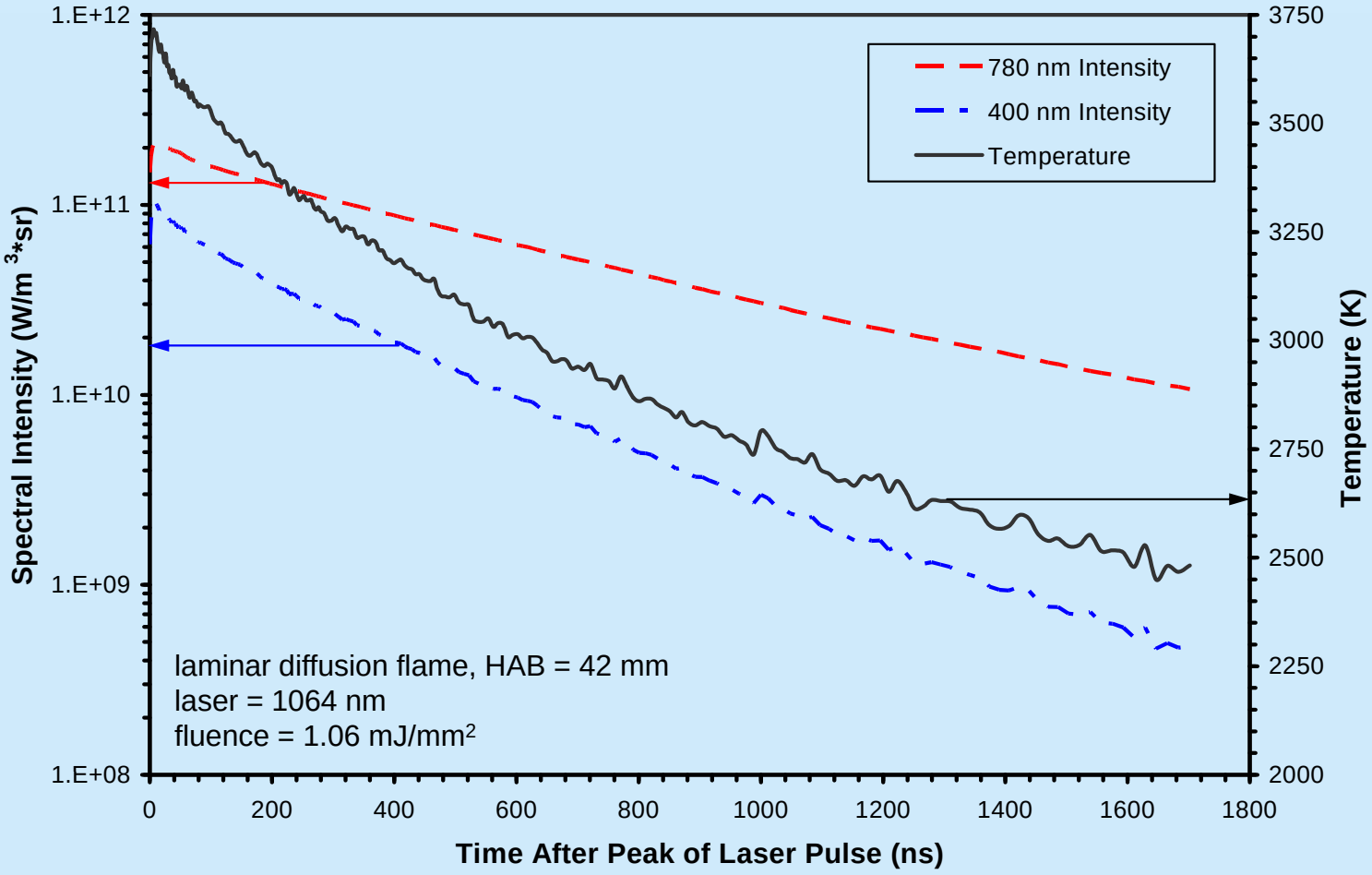
Auto-Compensating LII (AC-LII) Absolute Signals



[Smallwood, Ph. D. Thesis, Cranfield University, 2009]

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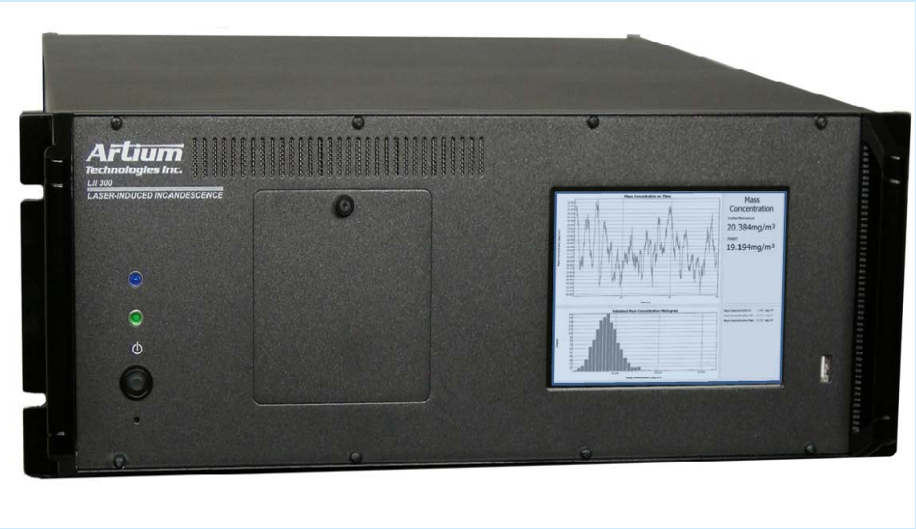
Artium Technologies LII 300 Instrument



- Artium Technologies LII 300 instrument
  - Easy to use
  - Low maintenance system
  - Low operating costs
  - Very high sensitivity
  - No warm-up time required
  - Compact rugged and portable instrument
  - Built-in computer and display, touchscreen control
  - Built-in pneumatics controller and sampling system
  - Completely enclosed laser, optics, and sampling cell
  - Increased automation features including autosensitivity control
  - Fail safe valve prevents sample from entering cell if purge air or power are off
  - Includes real-time pressure and temperature measurements to reduce data to STP

[Artium LII 300 improvements over LII 200 in teal]

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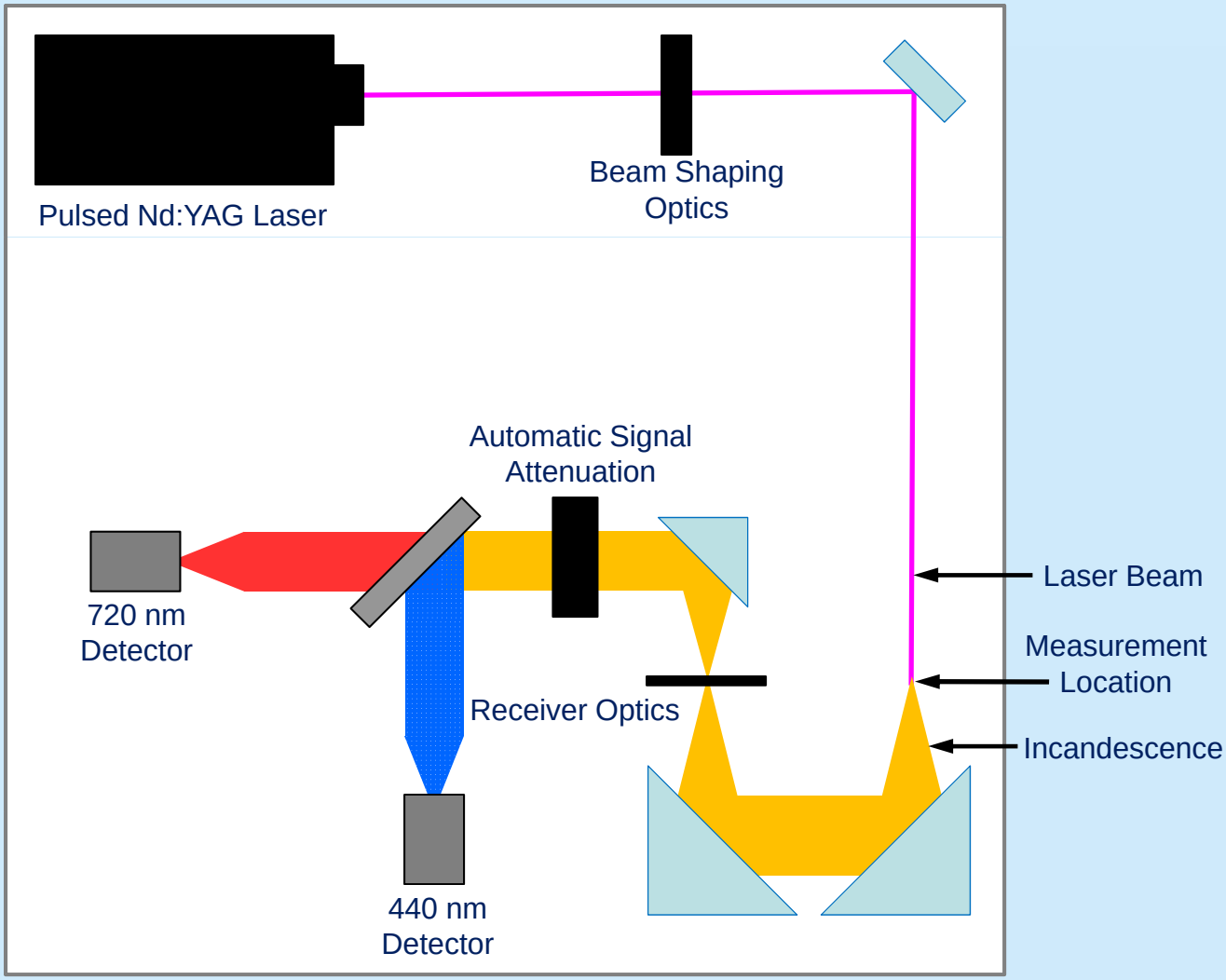
Schematic of LII 300 Instrument



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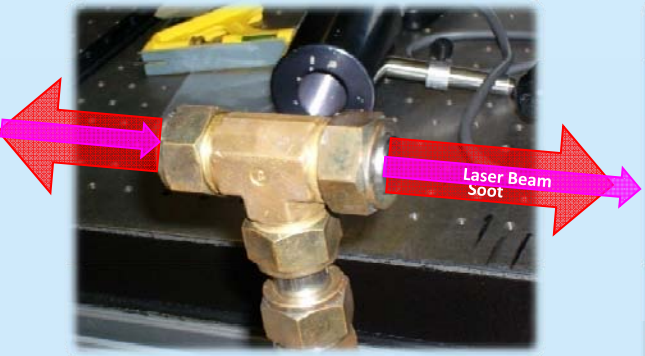
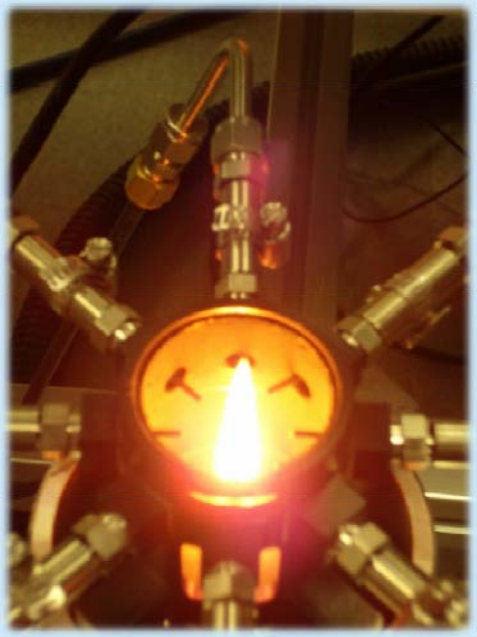
Incandescence Signal in LII





0.50 mJ/mm^2 Peak Fluence

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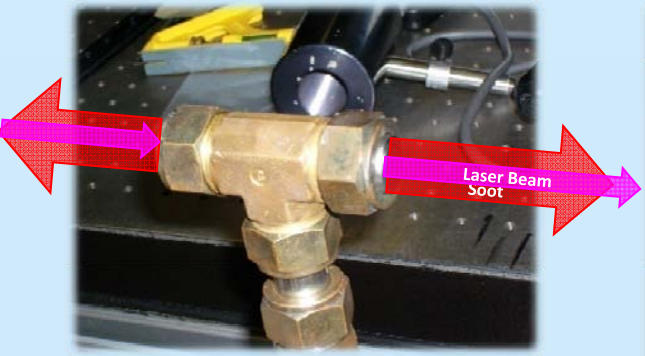
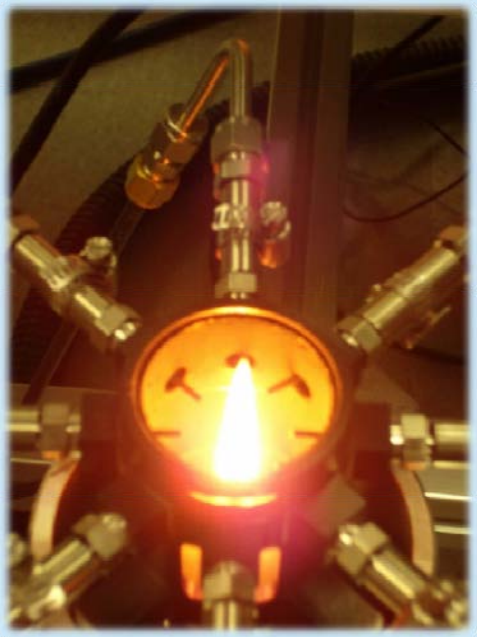
Incandescence Signal in LII: Fluence Effects





0.50 mJ/mm^2
Peak Fluence

0.67 mJ/mm^2

0.83 mJ/mm^2

1.25 mJ/mm^2

2.50 mJ/mm^2

3.75 mJ/mm^2

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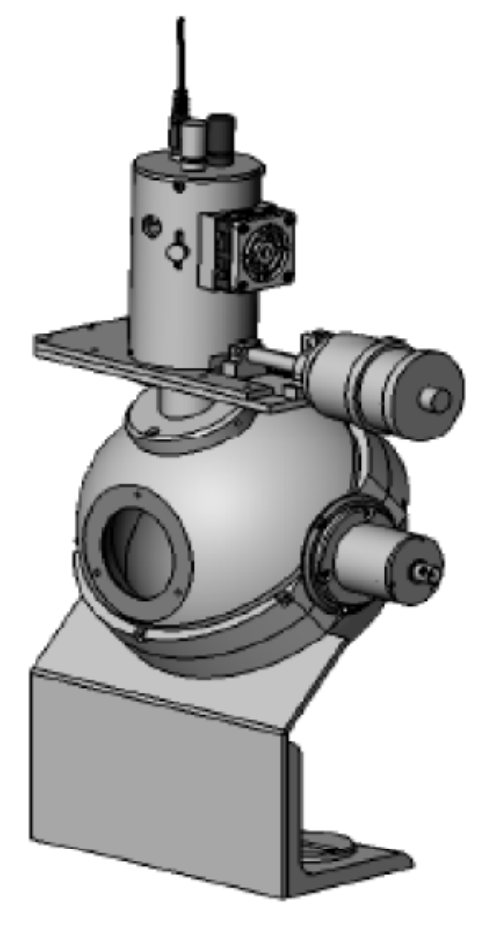
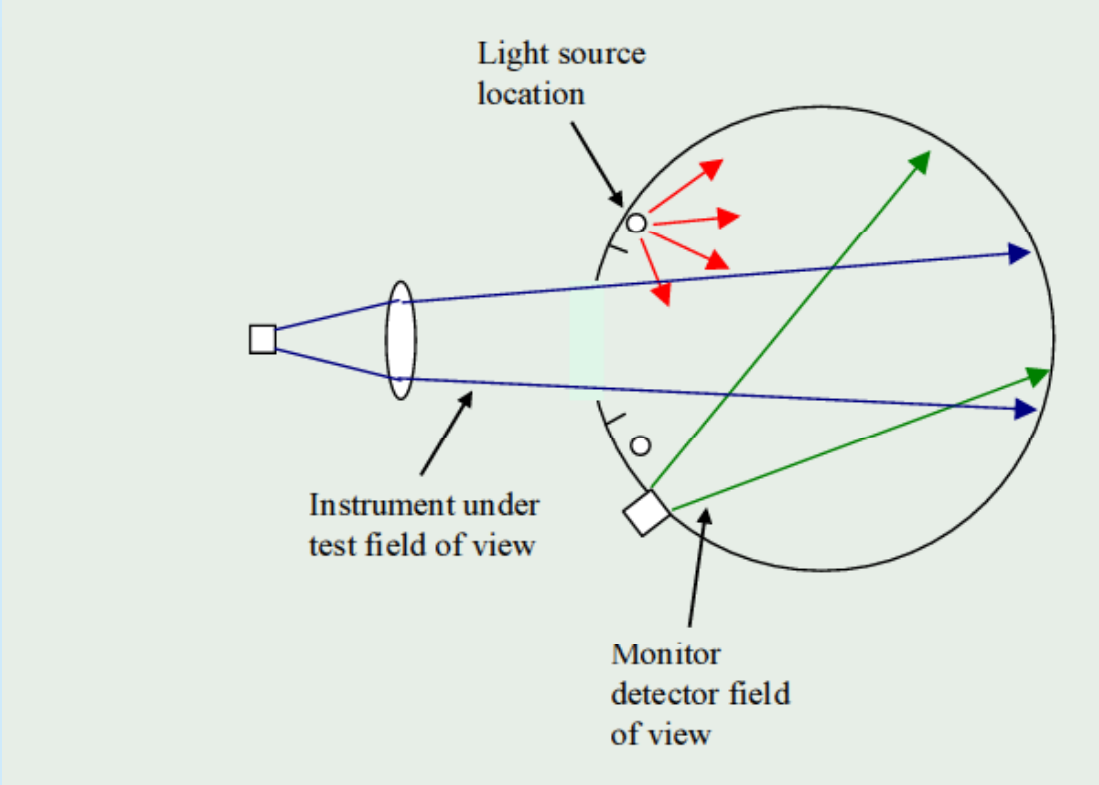
Integrating Sphere Calibration Source





- Spectral radiance is NIST-traceable
- Lamp is monitored by built-in spectrometer

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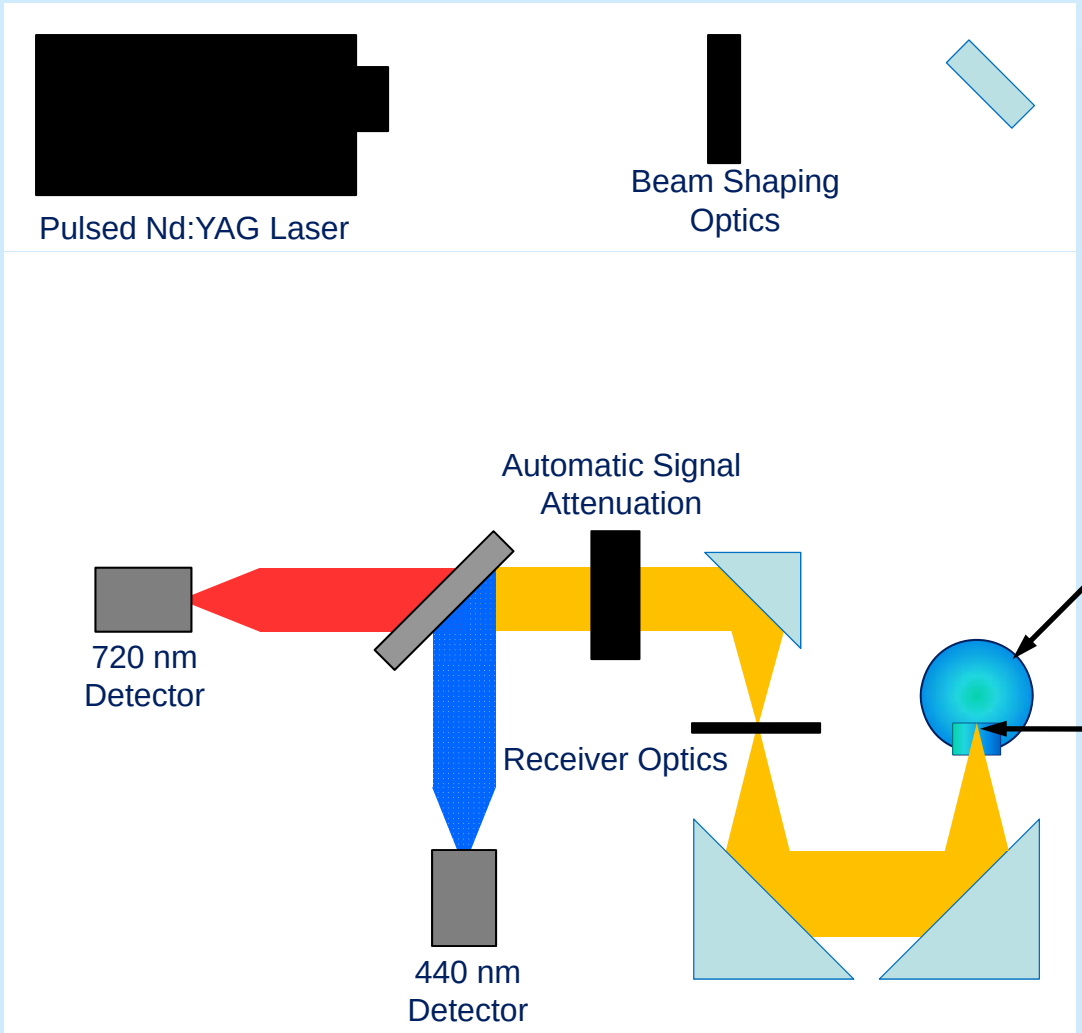
Primary Calibration of LII 300 Instrument



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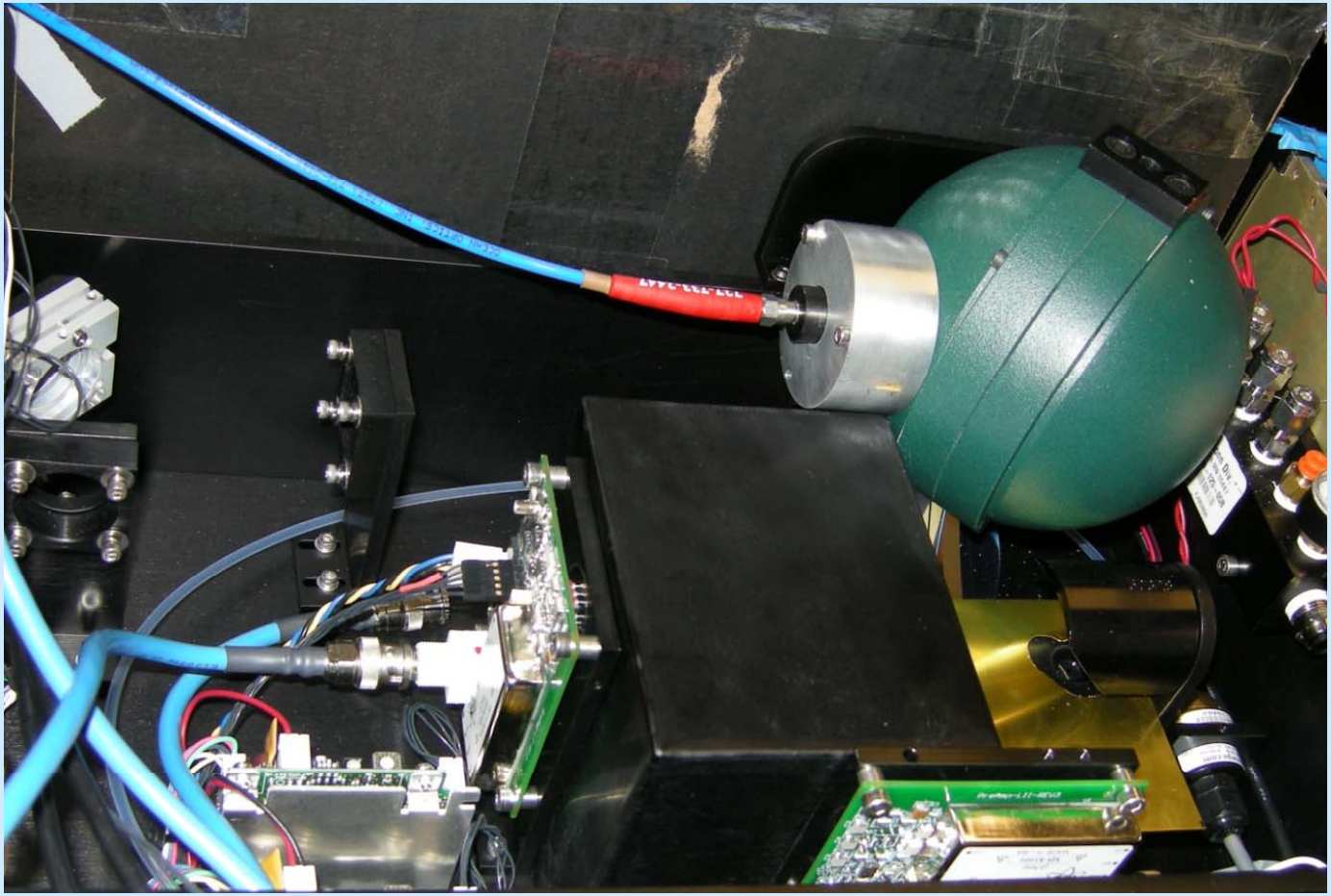
Integrating Sphere Calibration Source



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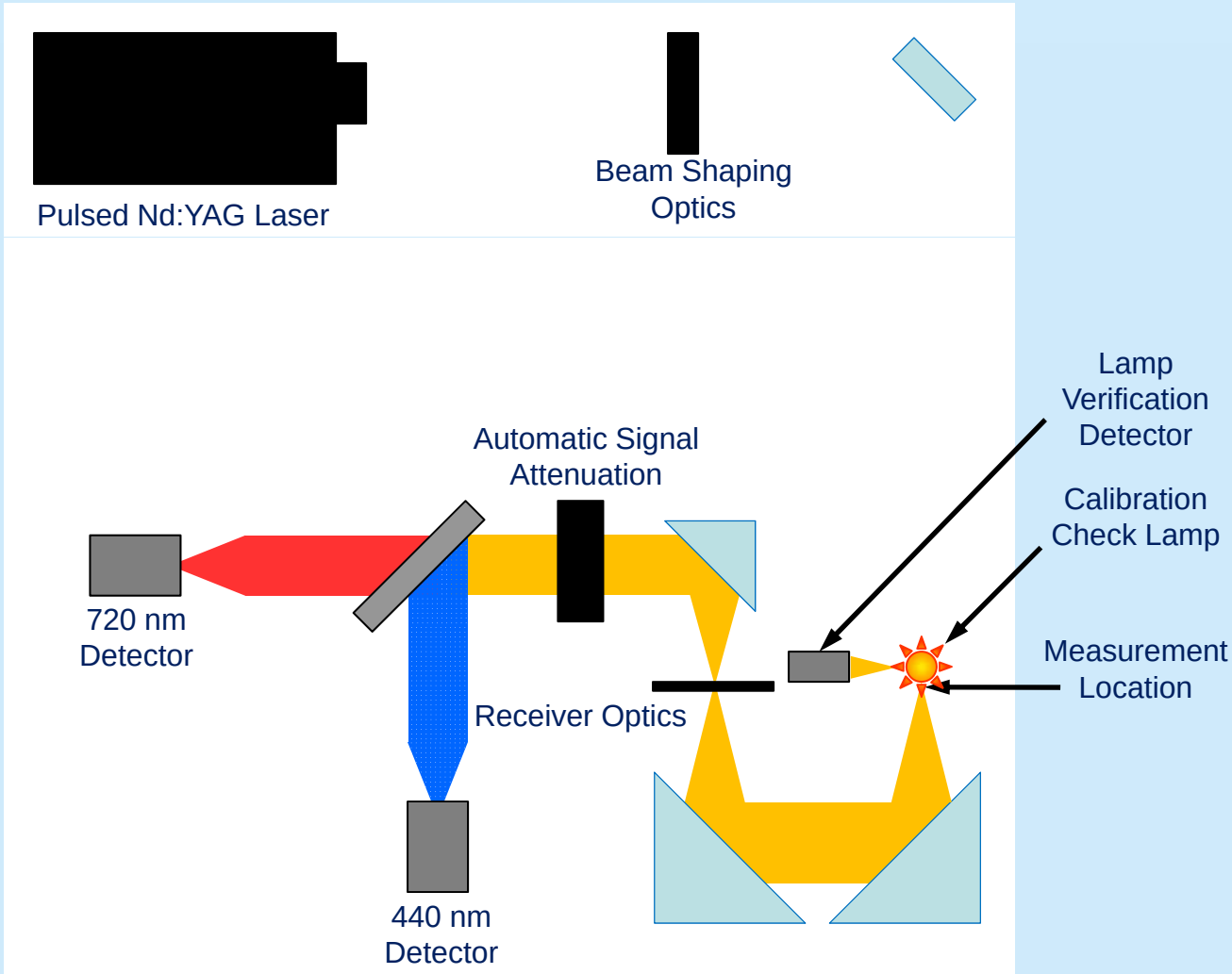
Development of Calibration Check



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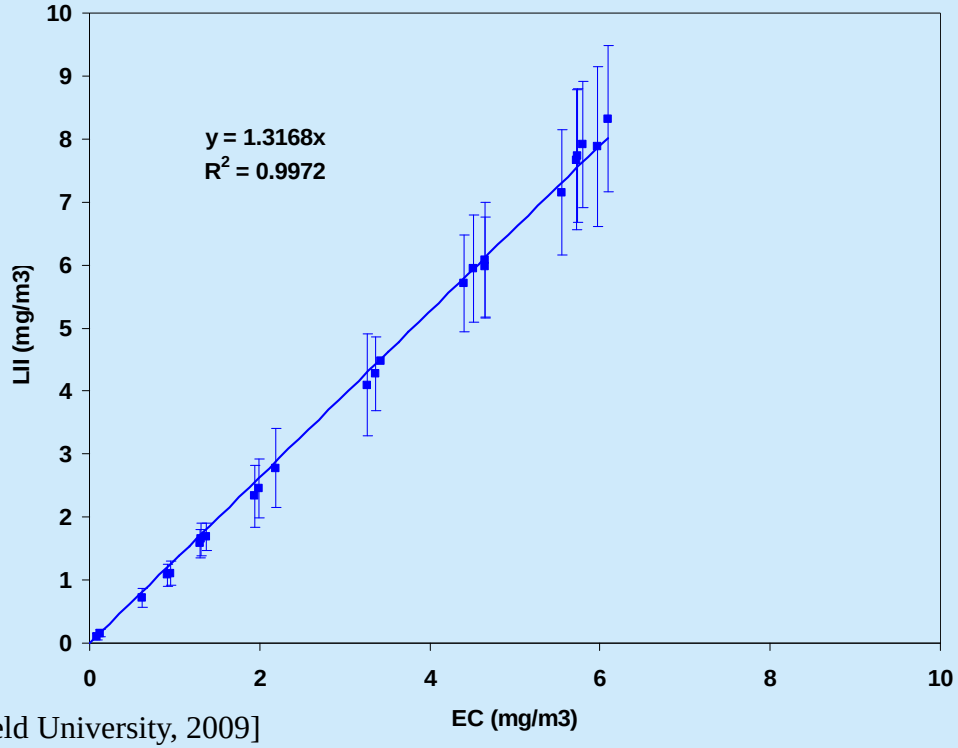
Mini-CAST Soot Generator: LII 200 vs. EC/OC

- LII 200 measurements of soot concentration from miniCAST soot generator compared to elemental carbon concentration determined by the NIOSH 5040 method
  - error bars represent single shot precision



[Smallwood, Ph. D. Thesis, Cranfield University, 2009]

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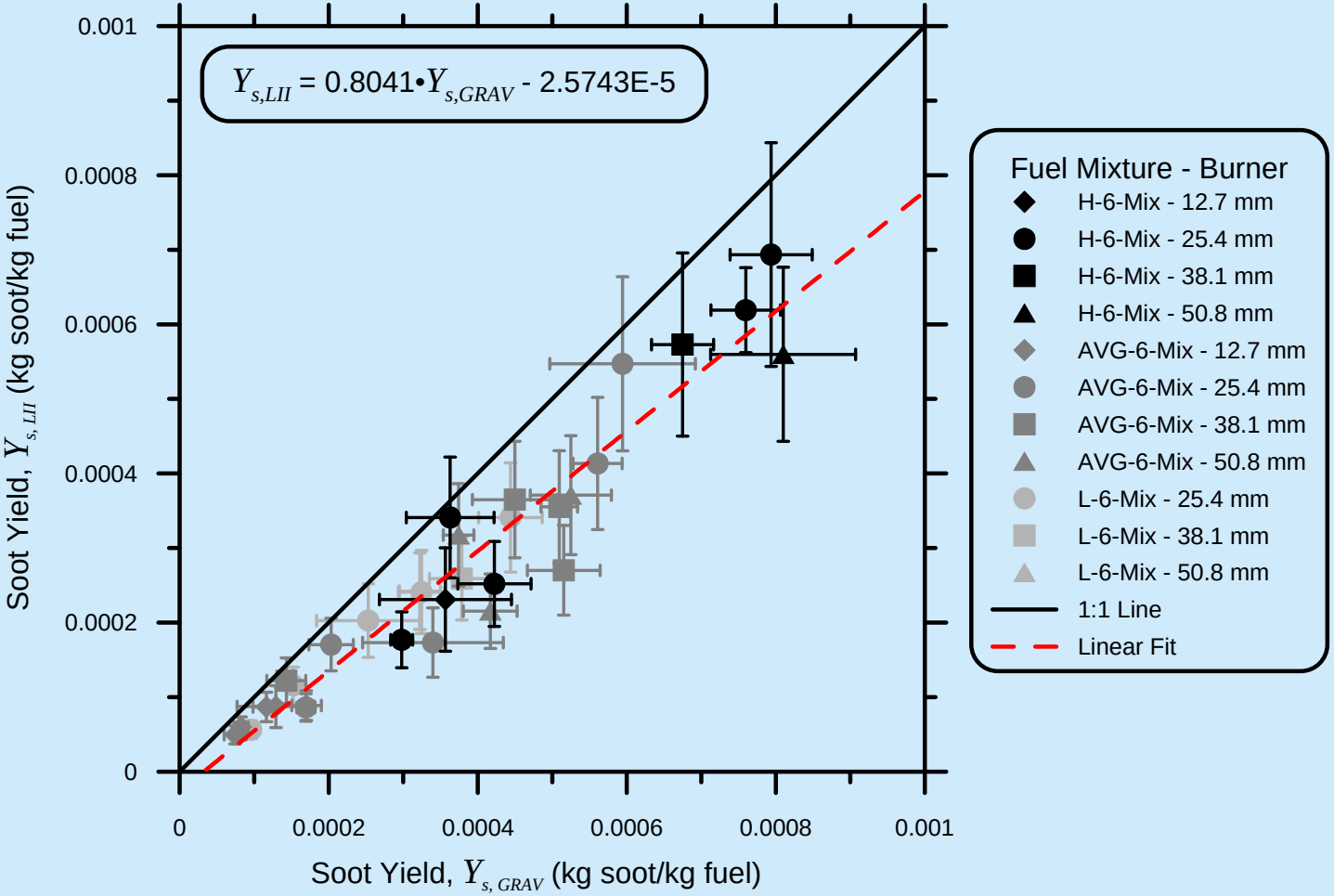
Turbulent Gas Flare: LII 200 vs. Gravimetric



[McEwen, M.Sc. Thesis, Carleton University, 2010]

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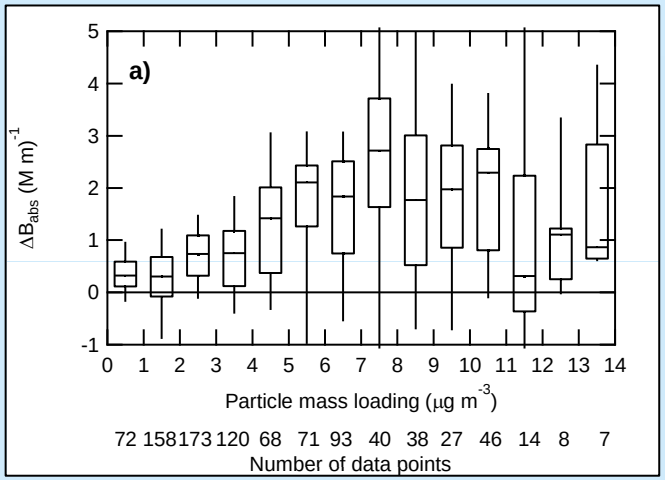
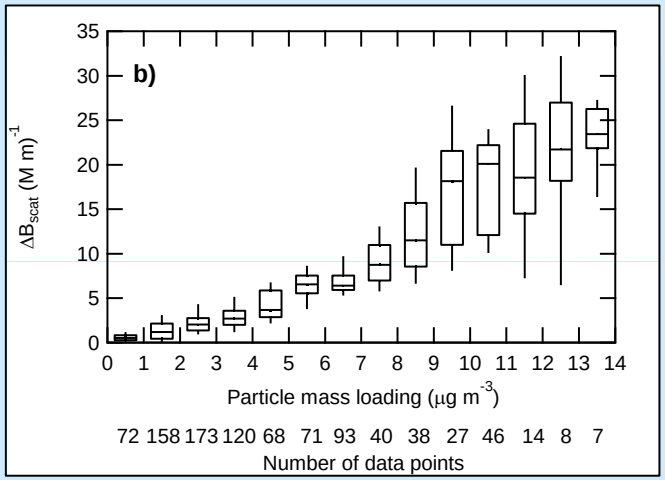
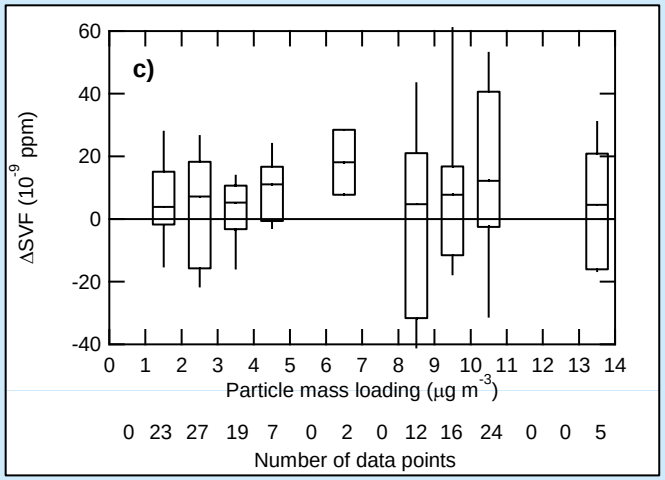
Atmospheric Black Carbon: HS-LII vs. Photoacoustic







- The variations of (a) the particle light absorption (PA), (b) particle light scattering (PA), and (c) the soot volume fraction (LII), as a function of particle volatile coating mass
- The photoacoustic results are significantly affected by the presence of a volatile coating
- LII shows no significant effect

[Chan *et al.*, Atmospheric Chemistry and Physics (submitted), 2010]

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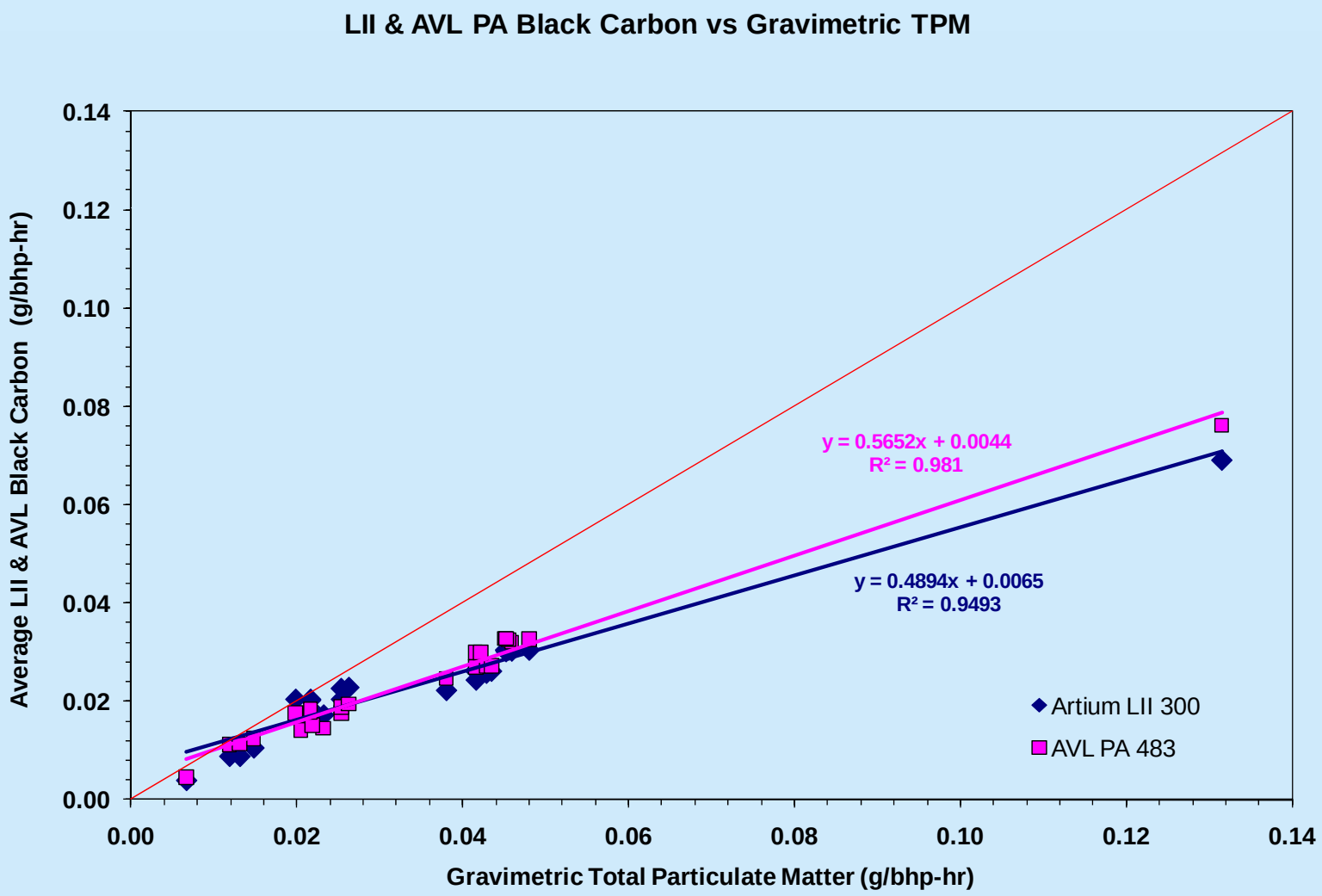
HD Diesel: LII 300 and Photoacoustic vs. TPM



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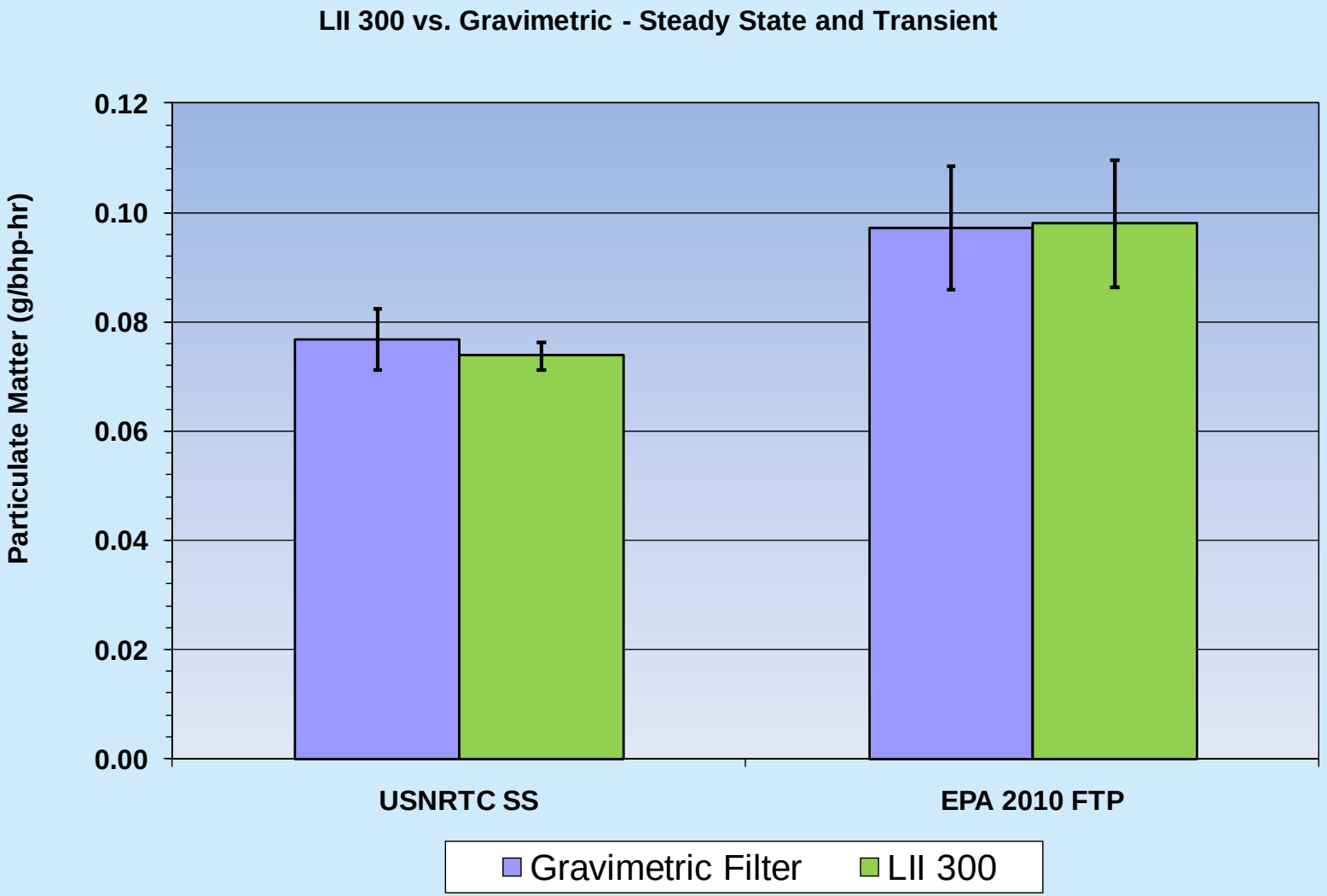
HD Diesel: LII 300 vs. Gravimetric TPM



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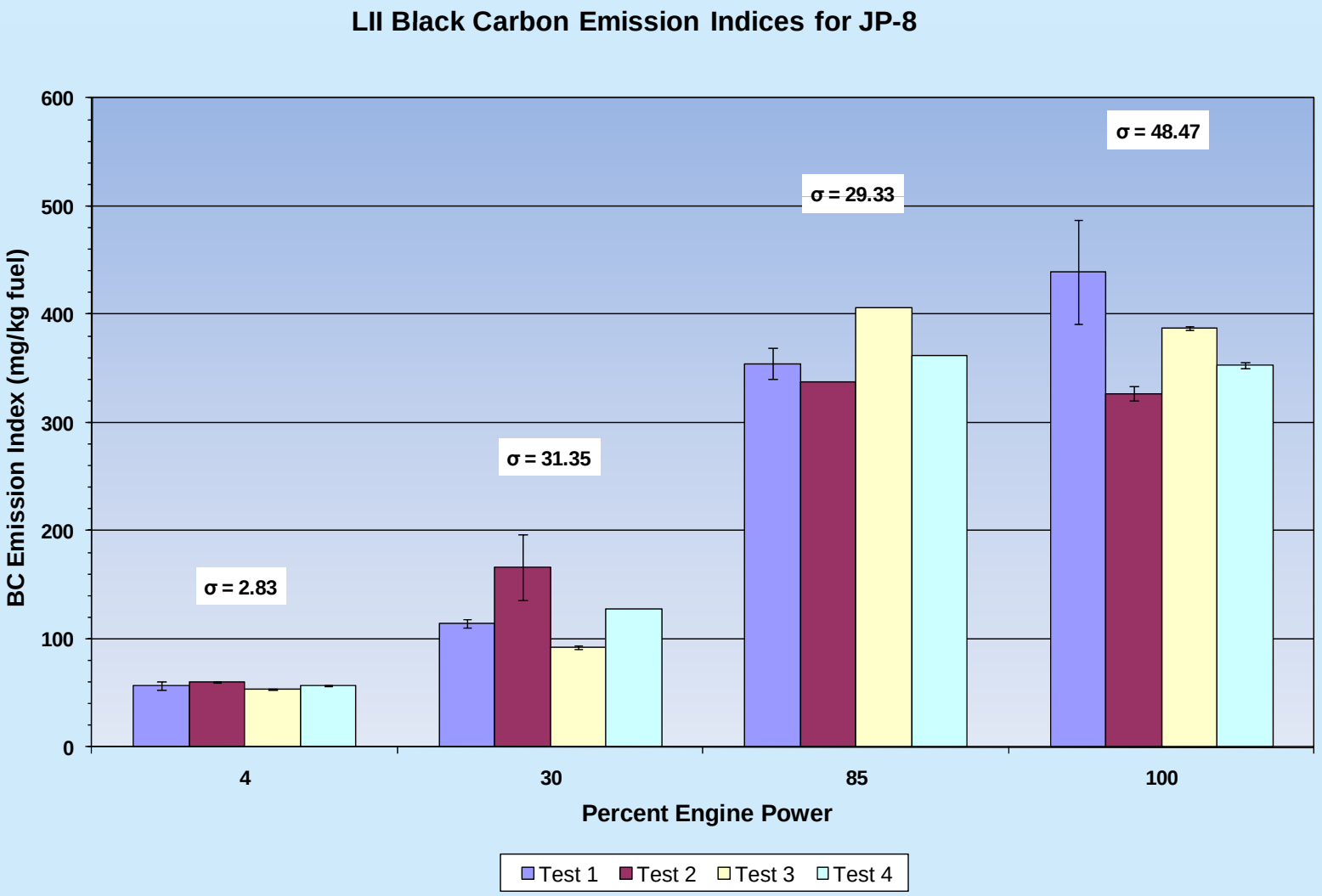
Gas Turbine Engine: LII 300 Repeatability



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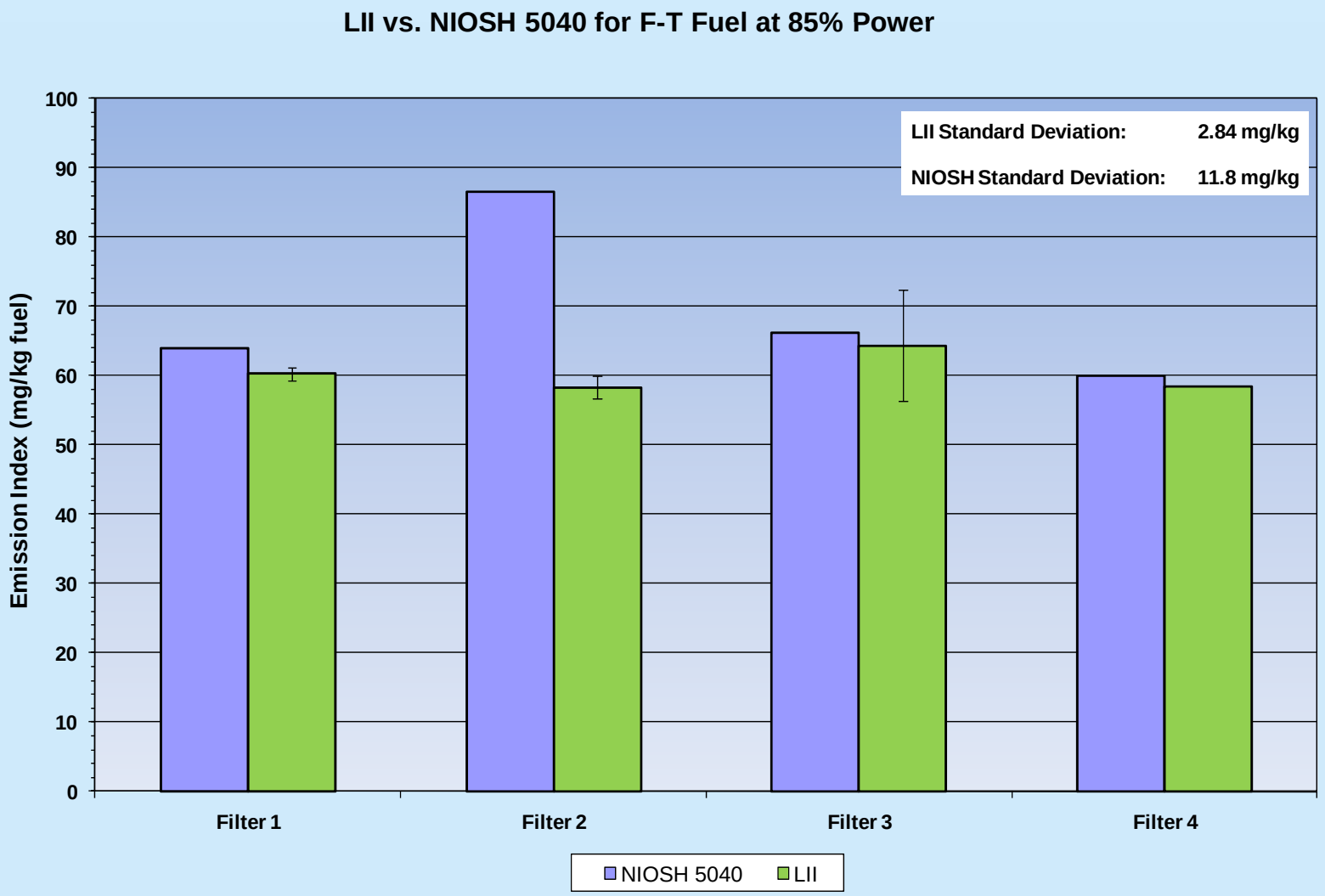
Gas Turbine Engine: LII 300 vs. EC/OC



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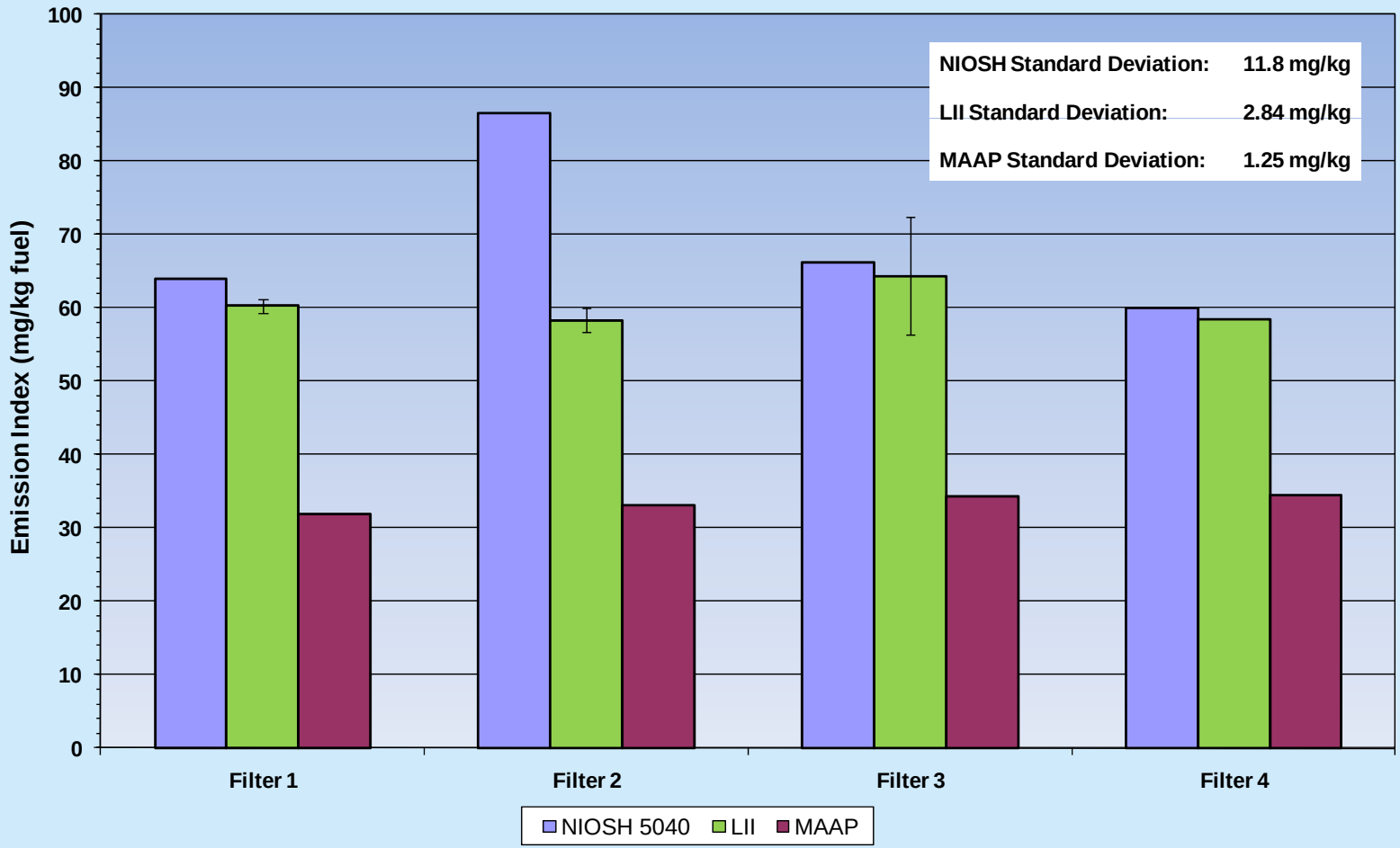
Gas Turbine Engine: LII 300 vs. EC/OC & MAAP



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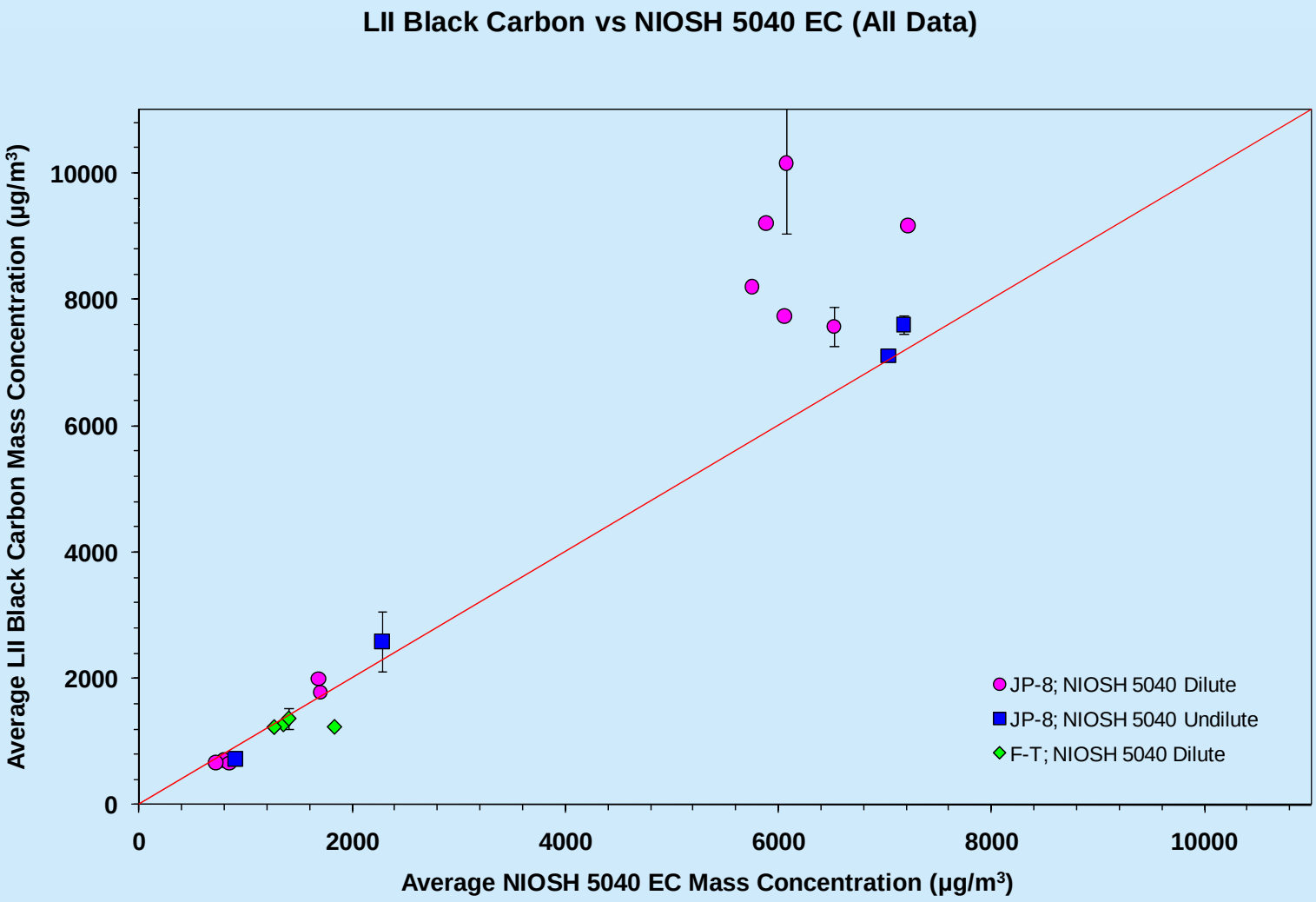
Gas Turbine Engine: LII 300 vs. EC/OC



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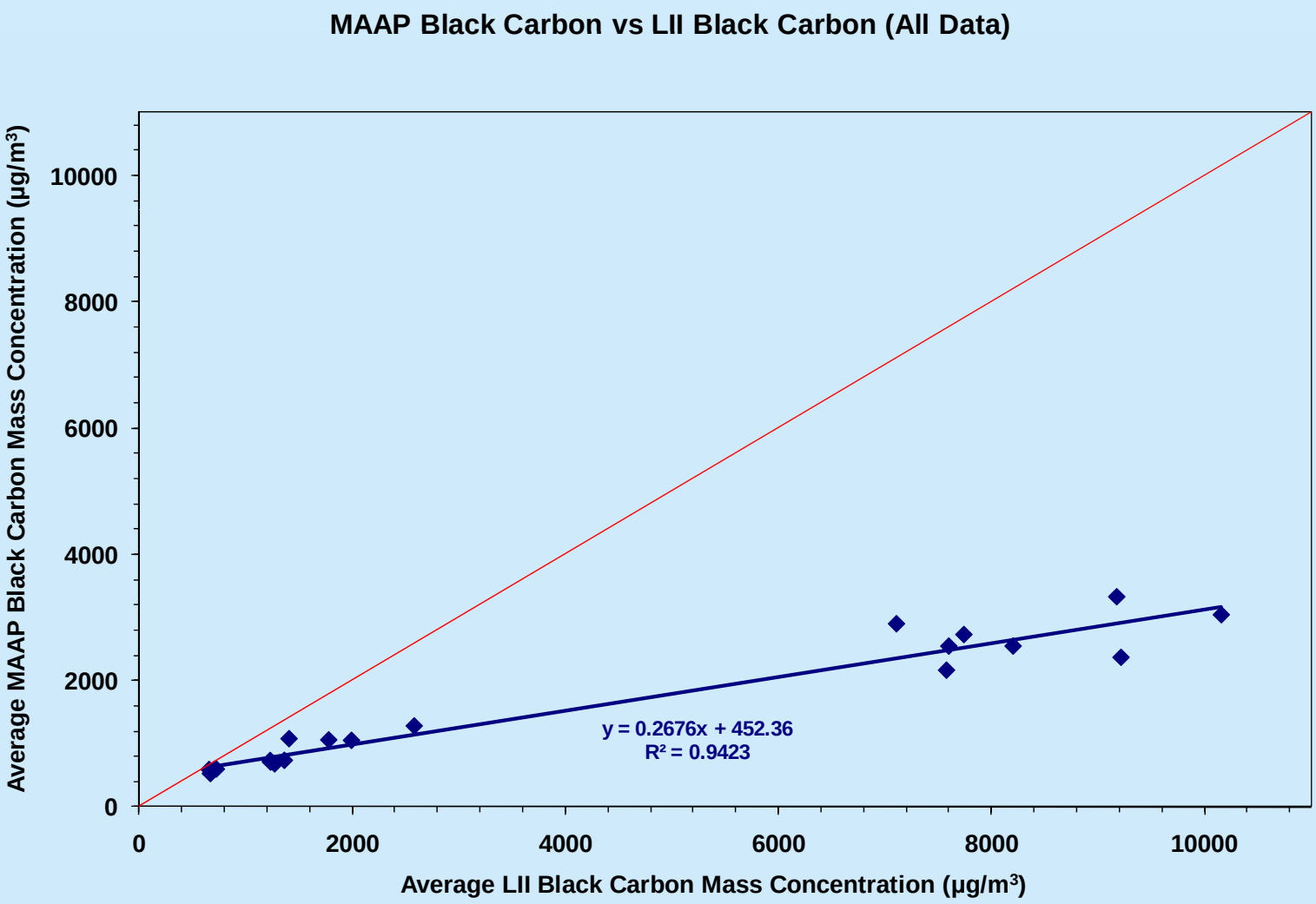
Gas Turbine Engine: MAAP vs. LII 300



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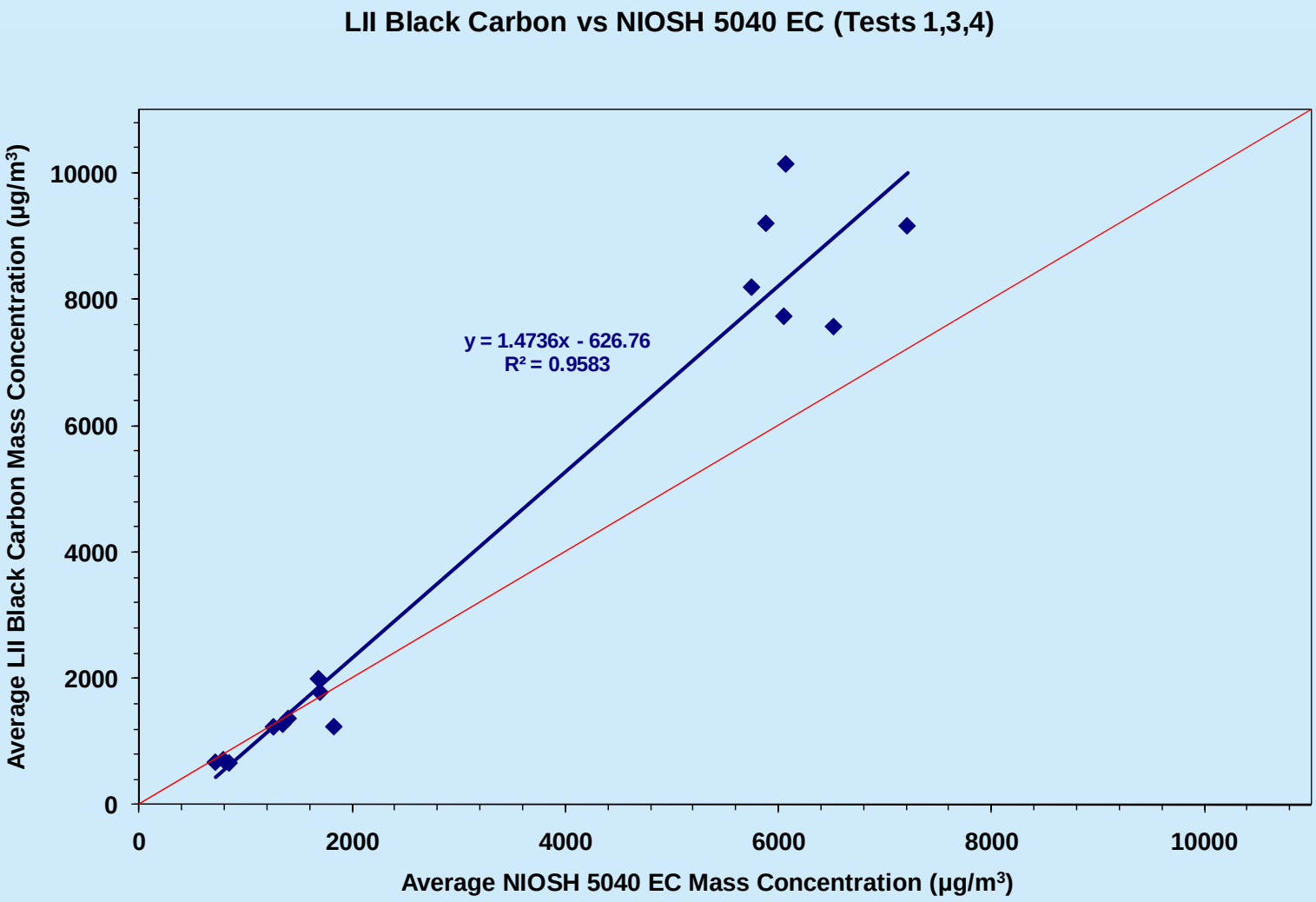
Gas Turbine Engine: LII 300 vs. EC/OC - Dilute



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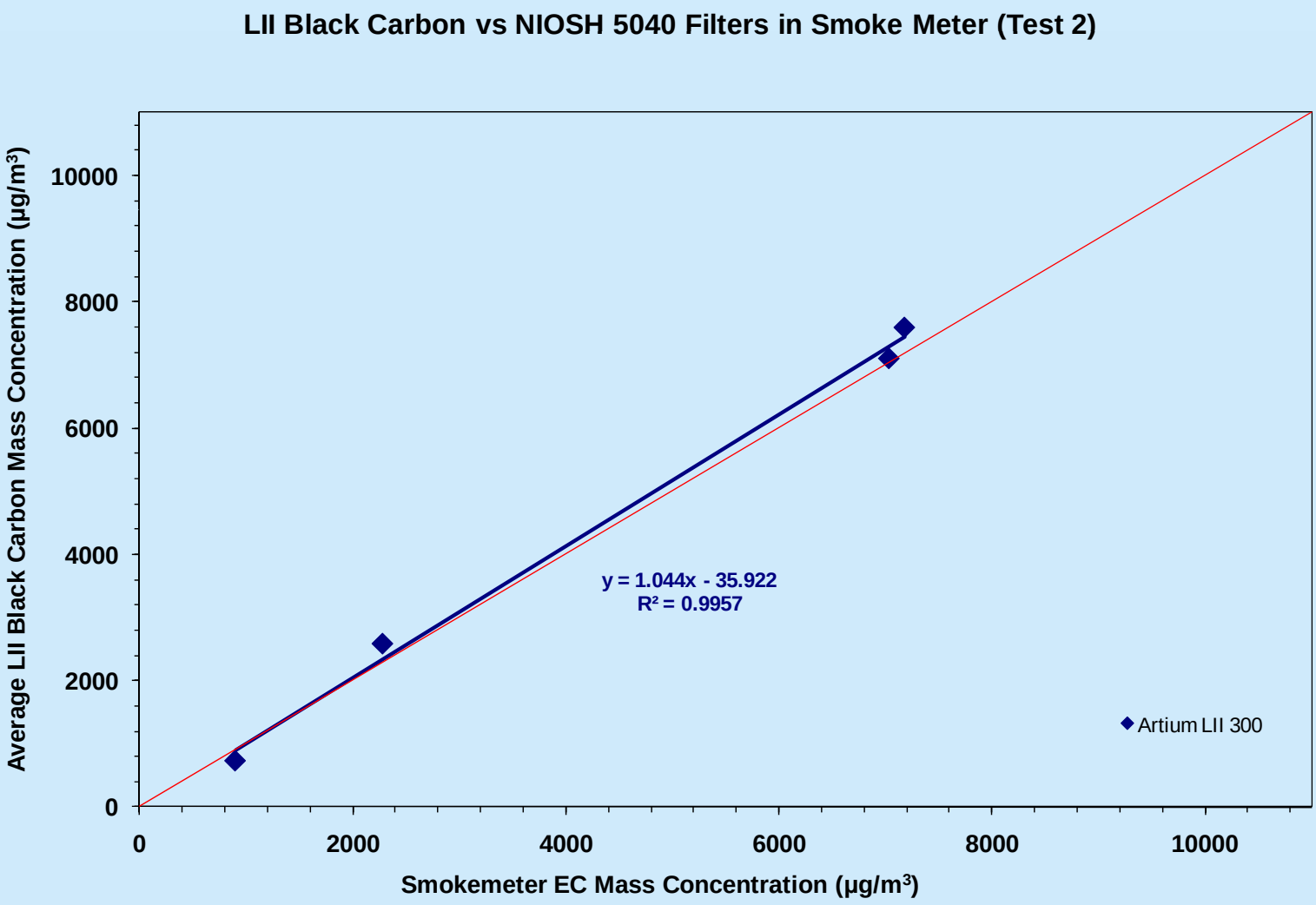
Gas Turbine Engine: LII 300 vs. Undilute EC/OC Sample Only



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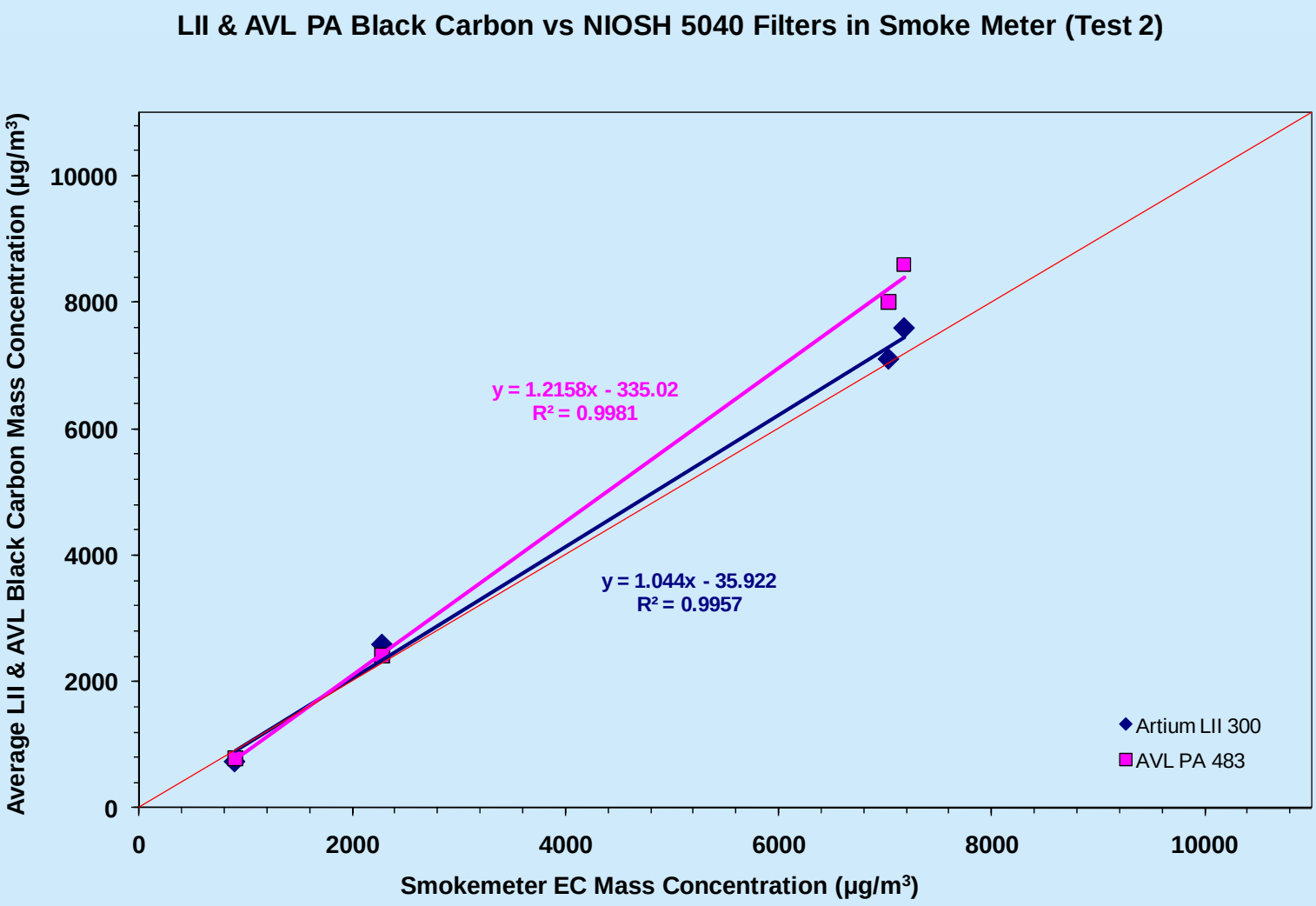
Gas Turbine Engine: LII 300 & PA vs. Undilute EC/OC Sample



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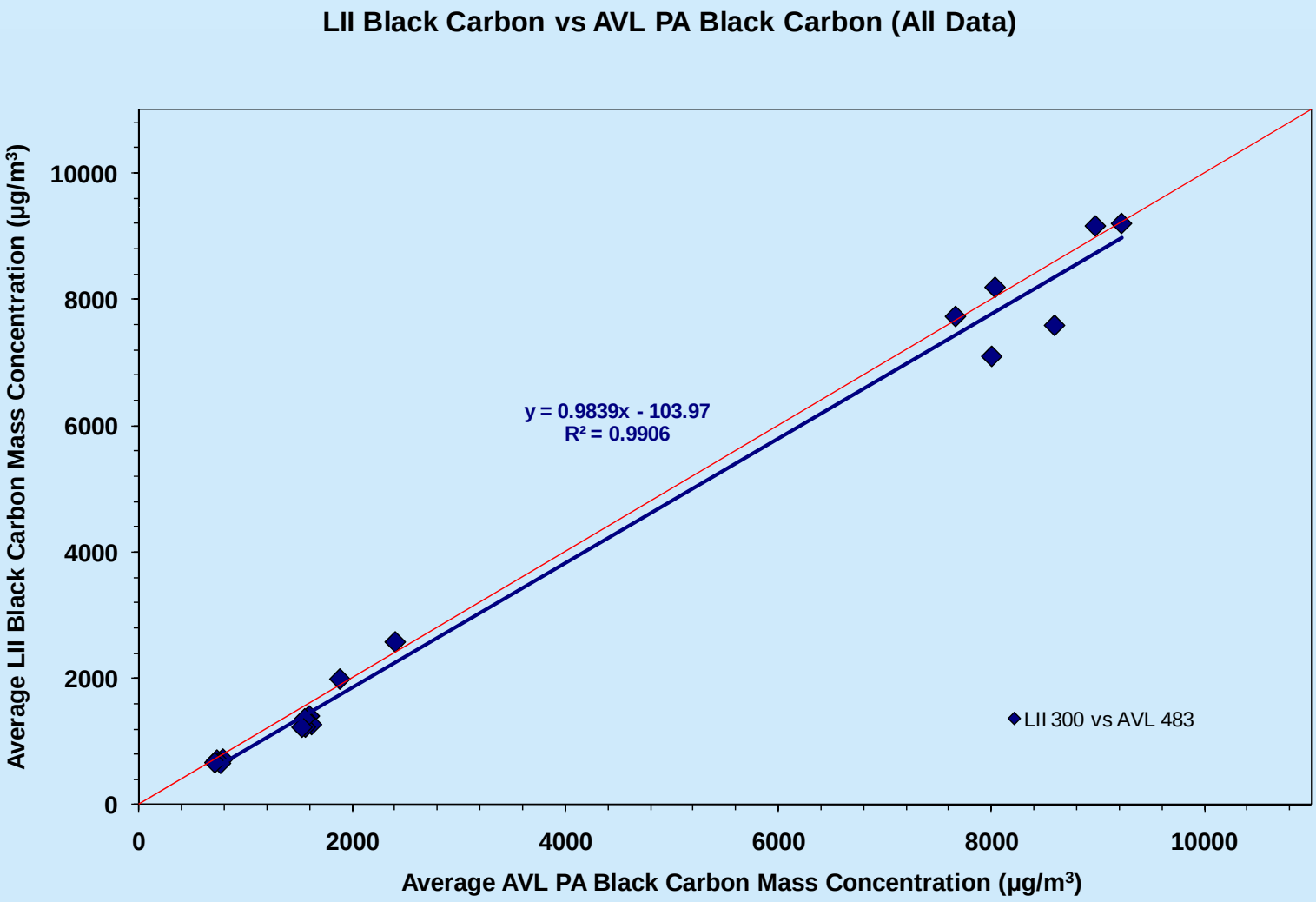
Gas Turbine Engine: LII 300 vs. Photoacoustic



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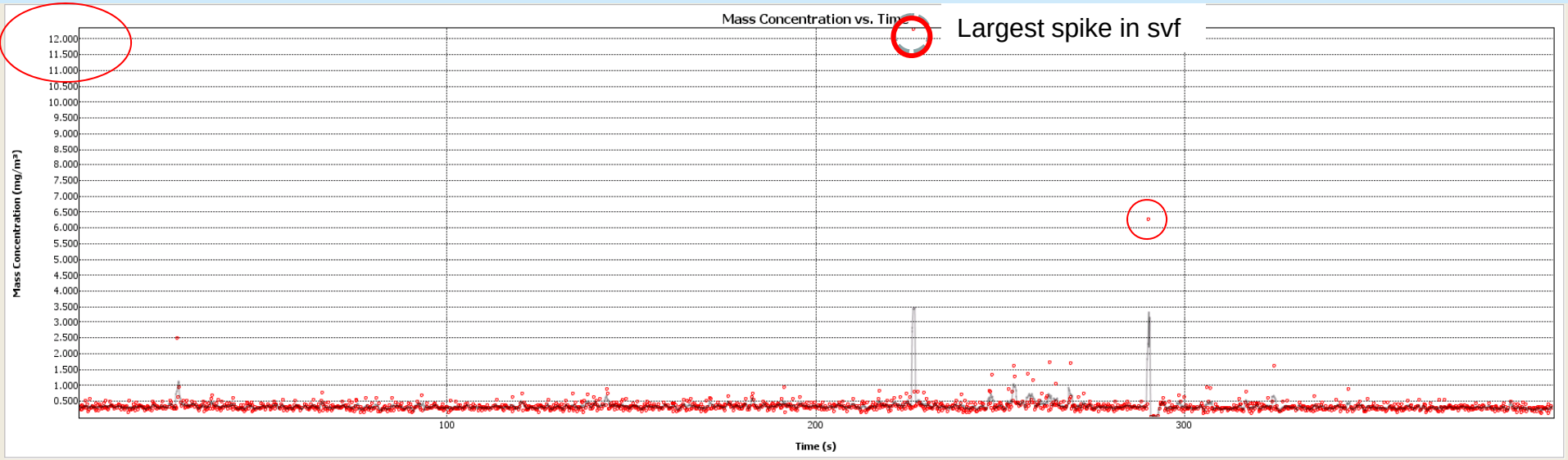
LII 200 Data from SAMPLE I (gas turbine)

- Concentration versus time plots show isolated spikes in the concentration values which cannot be accounted for as large numbers of soot aggregates passing the sample volume
- In the turbulent flow, such high concentration gradients do not exist for long
  - Each red dot represents an LII soot measurement



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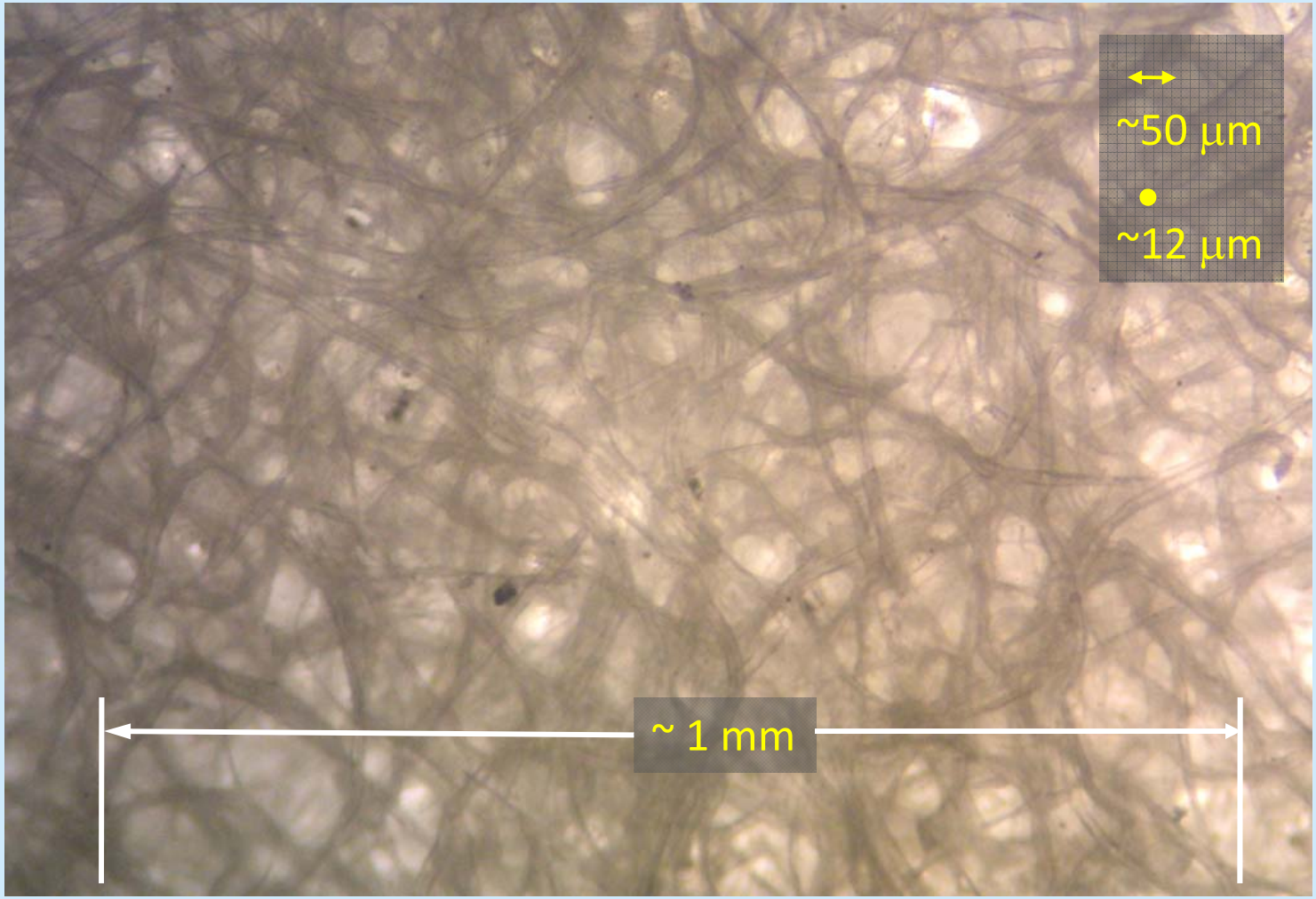
SAMPLE I Filter under an Optical Microscope



[SAMPLE I - Cardiff Tests 31-3-09 to 1-4-09]

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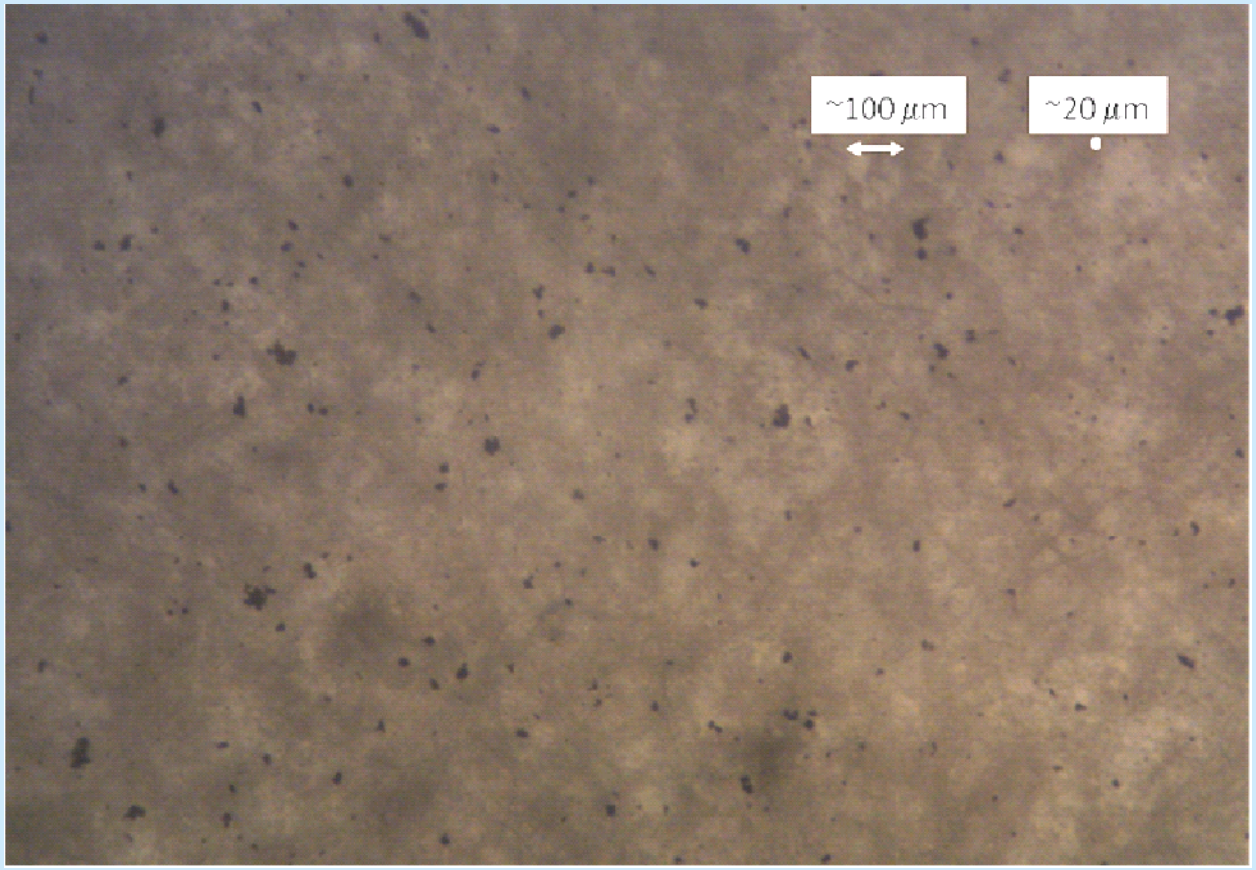
Filter contamination with large agglomerates of soot shed from sampling line surfaces



[From HD Diesel Exhaust]

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Summary

- AC-LII was demonstrated to be highly correlated, repeatable, precise, selective, and linear with respect to some other particle measurement techniques
  - real-time measurements and high sensitivity also achievable
- however, AC-LII has shown differences in the absolute concentration when compared to some other methods
  - comparisons to total particulate matter are difficult due to:
    - presence of volatiles and other non-carbon substances
    - large particles if a $PM_{1.0}$ cutoff cyclone is not used
- PM mass measurements are highly sensitive to sampling conditions, including dilution, and instrument operation
  - care must be exercised when comparing measurement techniques

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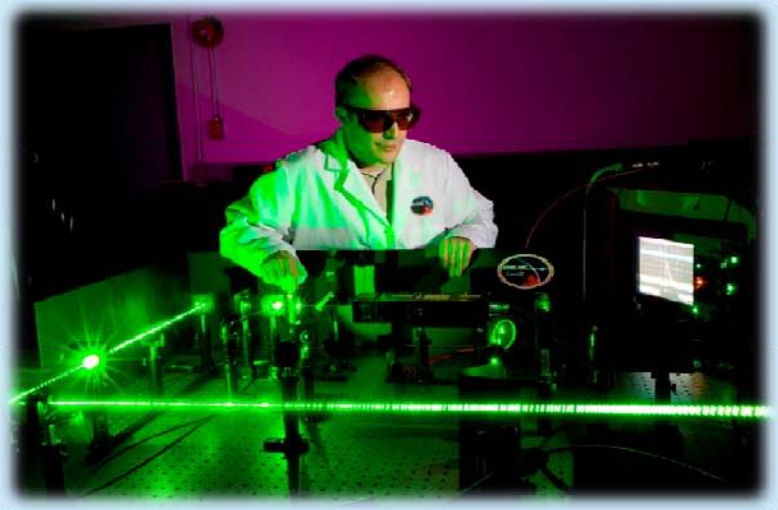
Acknowledgements

- Funding
  - PERD AFTER Project C23.006
  - PERD Particles and Related Emissions Project C11.008
  - NRC/Helmholtz Program (collaboration with DLR)
  - NRC/NSERC/BDC Nanotechnology Initiative Program (collaboration with Canadian universities and industry)



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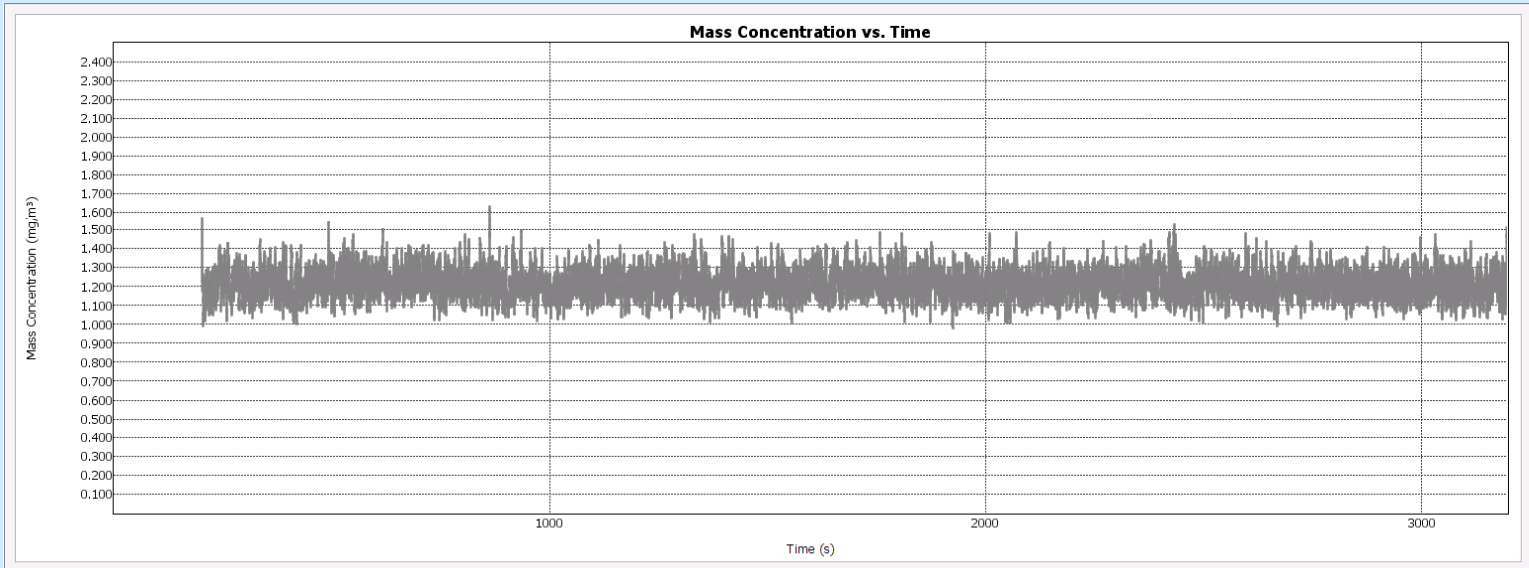
LII 300 Front Panel Display



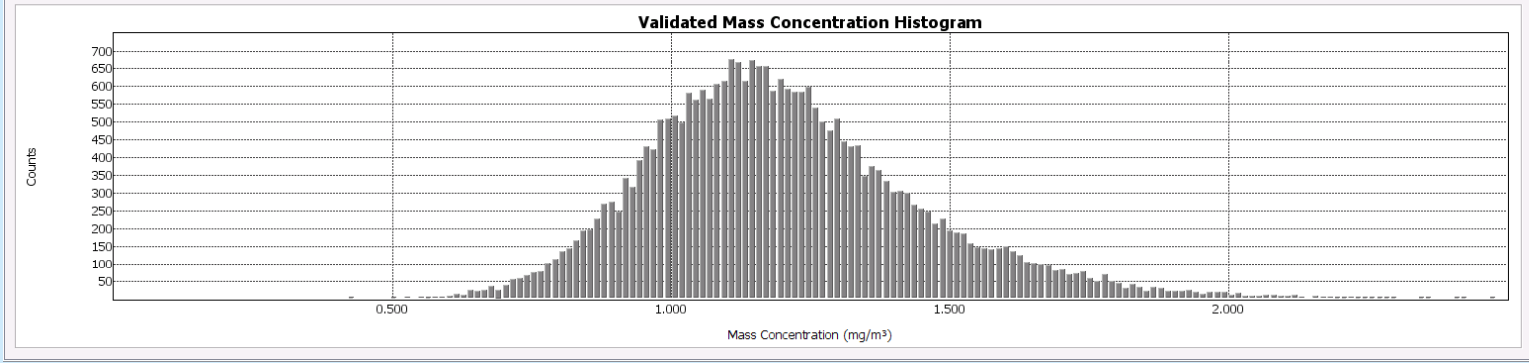
Mass Concentration

instantaneous

mg/m³

mean

1.212mg/m³



Mass Concentration σ:	0.247	mg/m³
Mass Concentration Min:	0.432	mg/m³
Mass Concentration Max:	4.047	mg/m³

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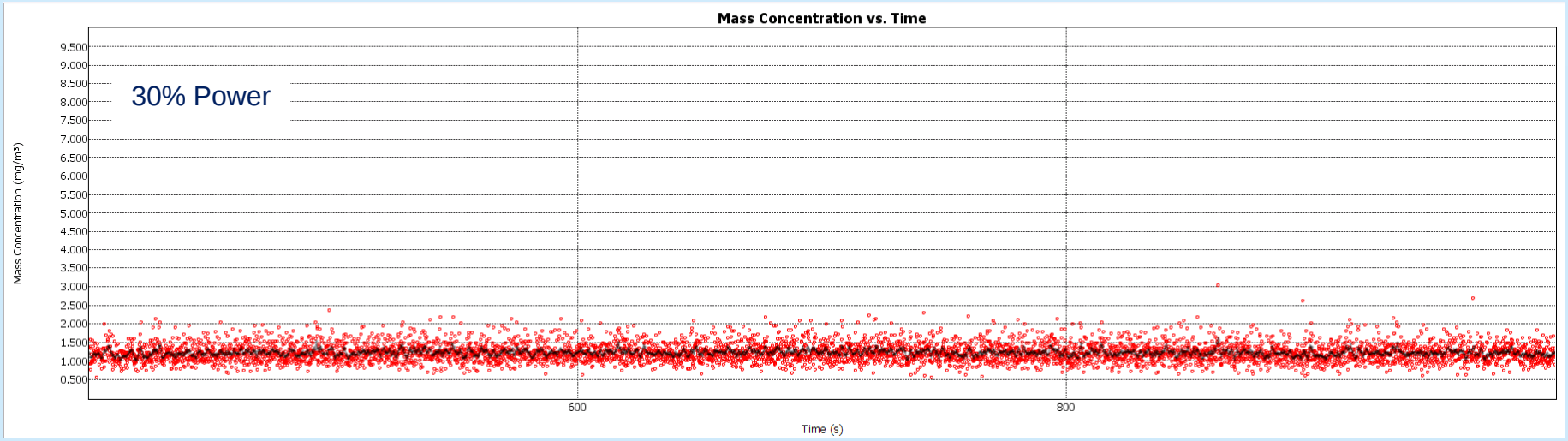
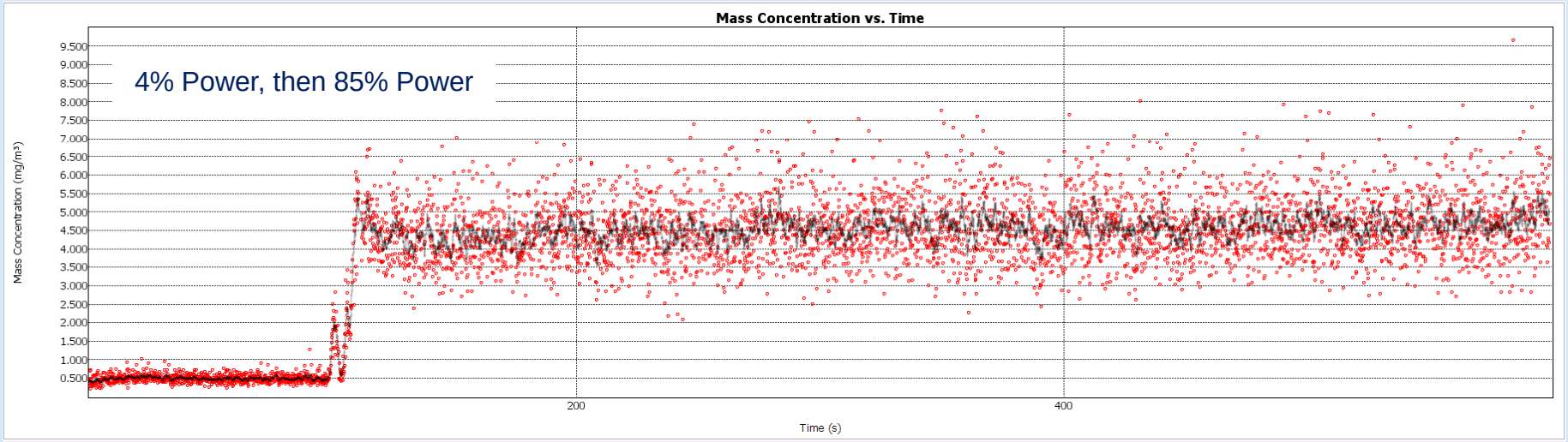
LII 300 Single-Shot Data from Gas Turbine Engine





[Red dots are single-shot data; Black line is 1 Hz running average]

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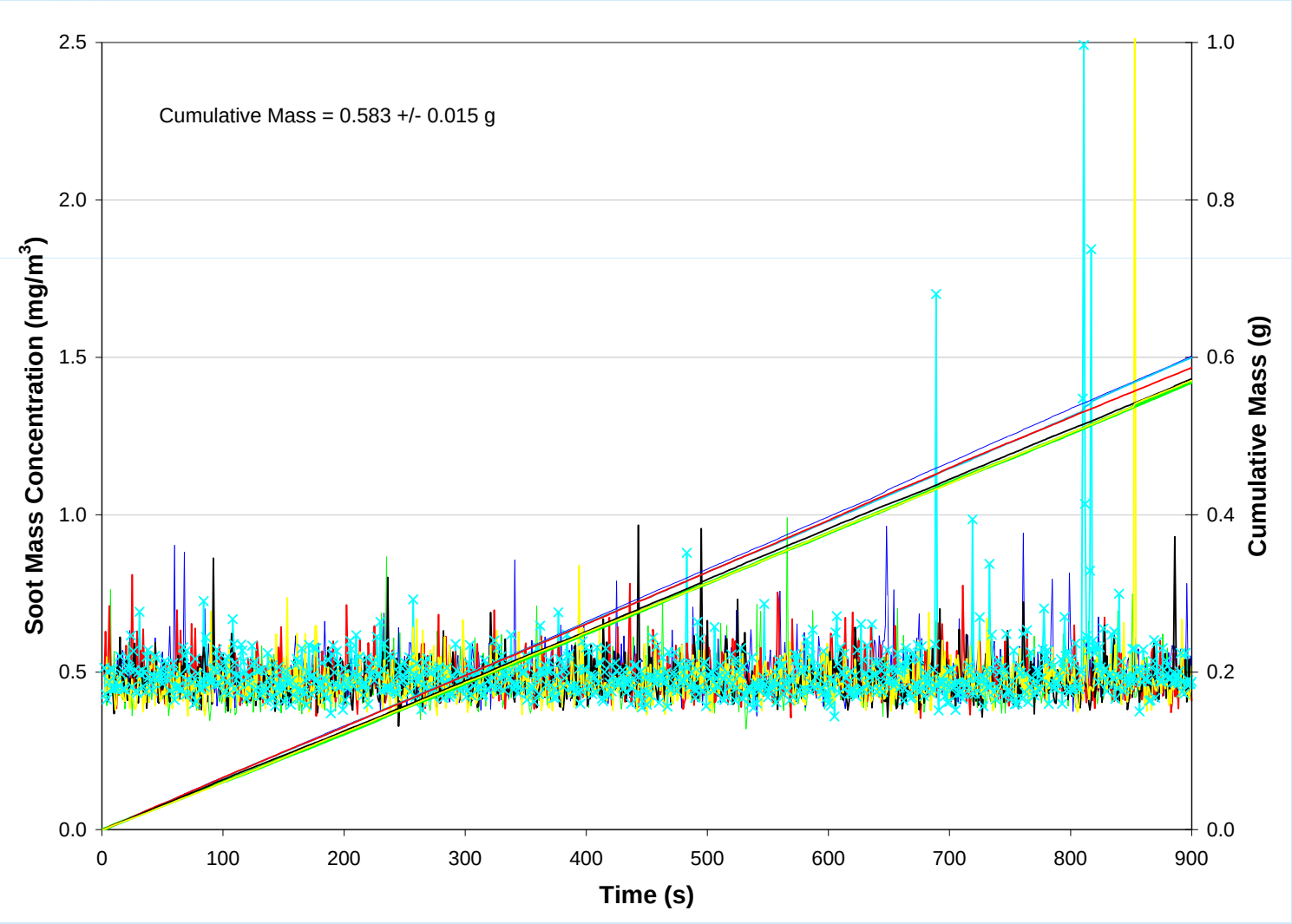
LII 200 with HD Diesel – Steady State – 6 Repeats



[Smallwood, Canadian Section of the Combustion Institute, 2008]

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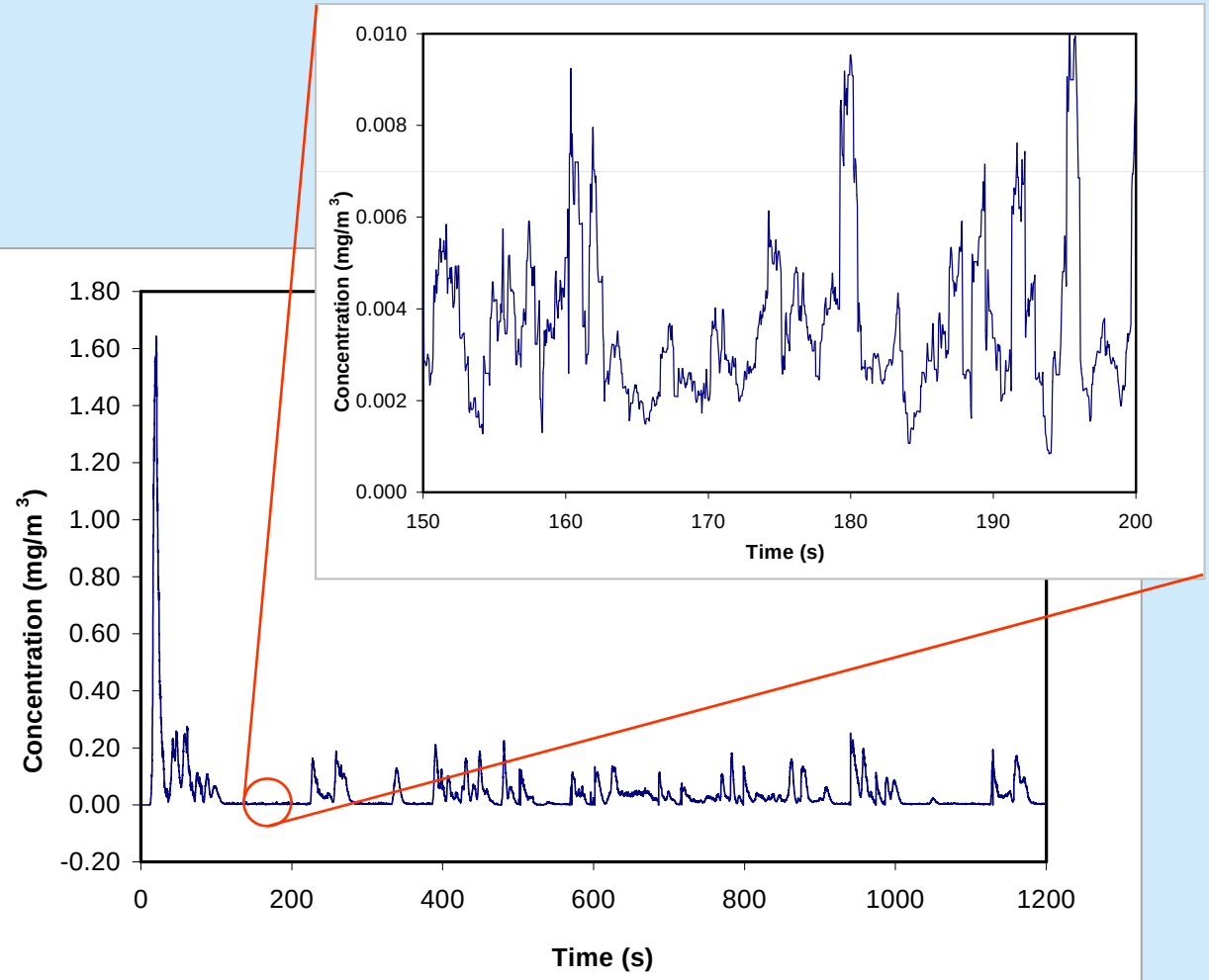
LII 200 – HD Diesel post DPF sensitivity and dynamic range



- Post DPF (diesel particulate filter) soot emissions from a 2007-compliant heavy-duty diesel engine operating on the EPA FTP cycle
- Demonstrated range, sensitivity, and time response of Artium LII 200 instrument (<2 $\mu g/m^3$ at 20 Hz)

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