

High-Energy, Pulsed-Laser Diagnostics for Real-Time Measurements of Reciprocating Engine PM Emissions

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Outline

- Motivation
- Overview of High-Energy Laser Diagnostic (HELD) techniques
- HELD specifics and example applications
- Technology transfer (national lab to customer)
- Commercialization (industry to customer)
- Summary of HELD status

Motivation for HELD R&D

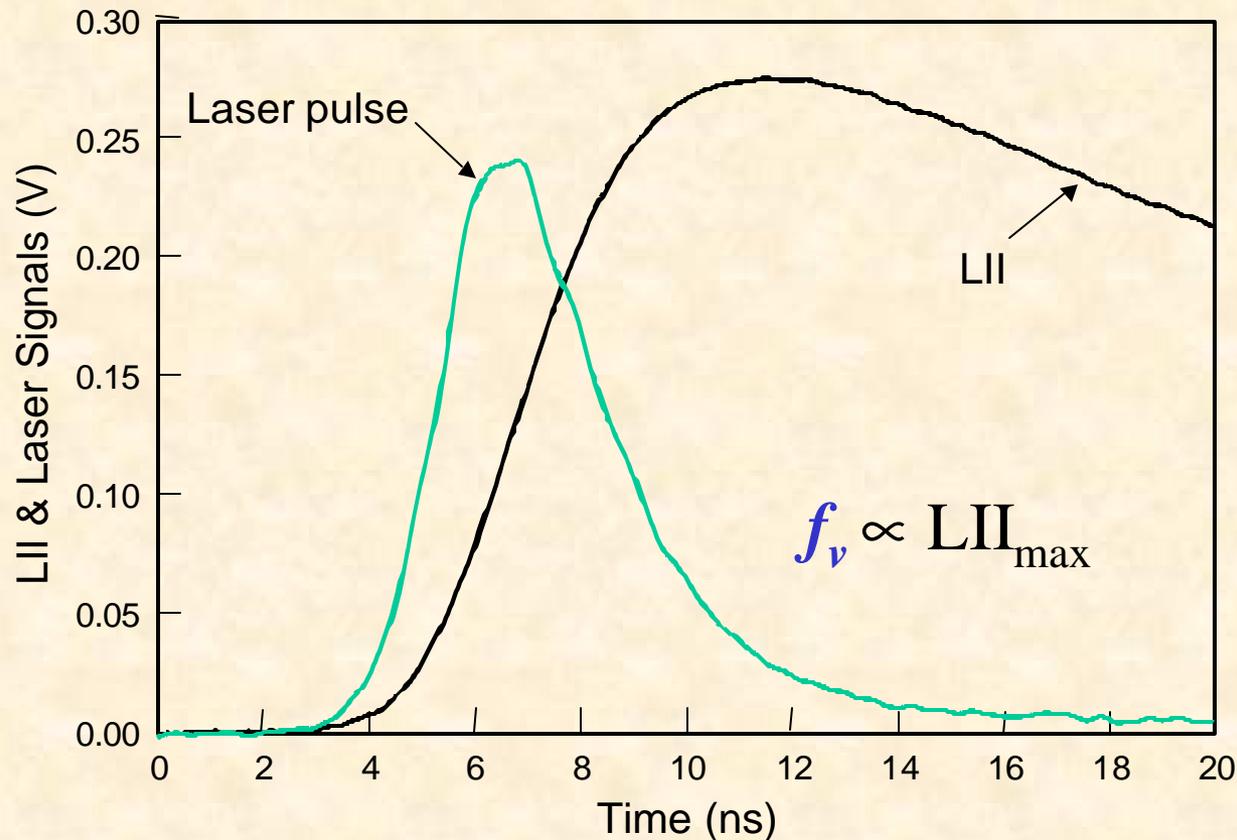
- Sensitive PM measurement techniques are needed to study cleaner vehicles
- Real-time PM measurement techniques are needed to investigate transients
- ★ *In situ* PM measurement techniques are needed to characterize engine-out/aftertreatment-in conditions for design optimization and life-cycle simulations

HELD techniques for PM measurements

- Laser-induced incandescence (LII) for inorganic carbon (soot) volume fraction and primary particle size
- Elastic light scattering (ELS) for total volume fraction
- LII + ELS for aggregate size, number, and structure
- Laser-induced desorption (LID) + ELS (LIDELS) for volatile volume fraction
- Laser-induced breakdown spectroscopy (LIBS) for metallic ash (species and concentration)
- Laser-induced fluorescence (LIF) for composition

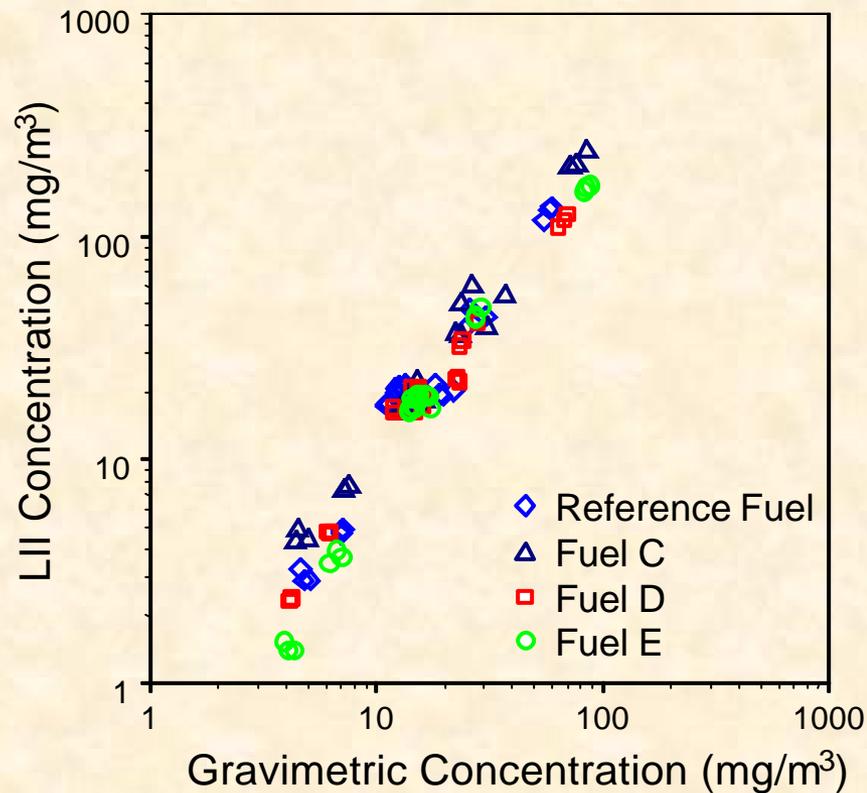
LII for volume fraction f_v

- High-energy laser pulse heats PM to sublimation temperature of carbon
- Black-body radiation is proportional to soot volume fraction

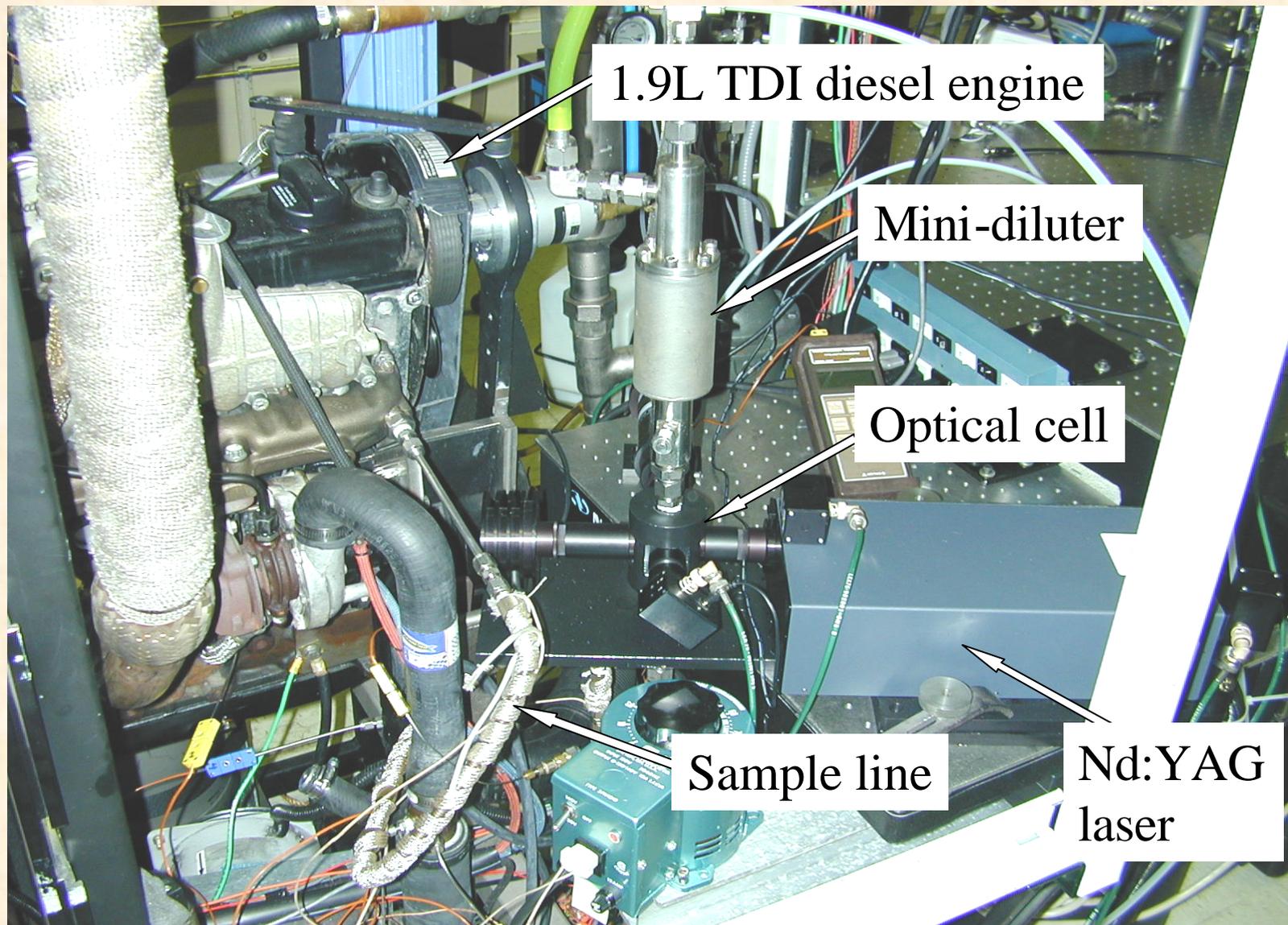


Correlation of LII and gravimetric methods

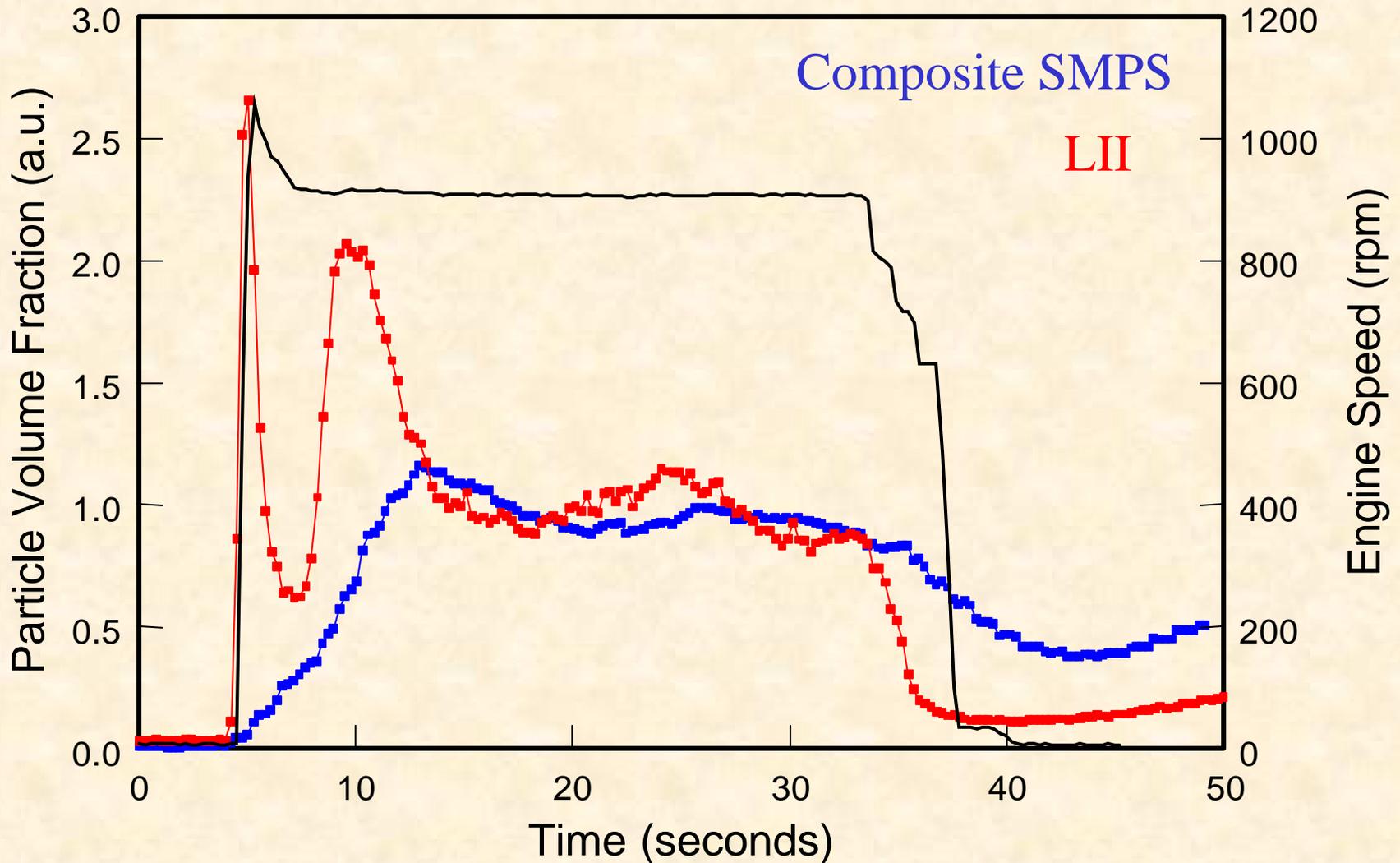
Measurements for the AVL 8-mode steady-state simulation of
US EPA heavy-duty transient test procedure



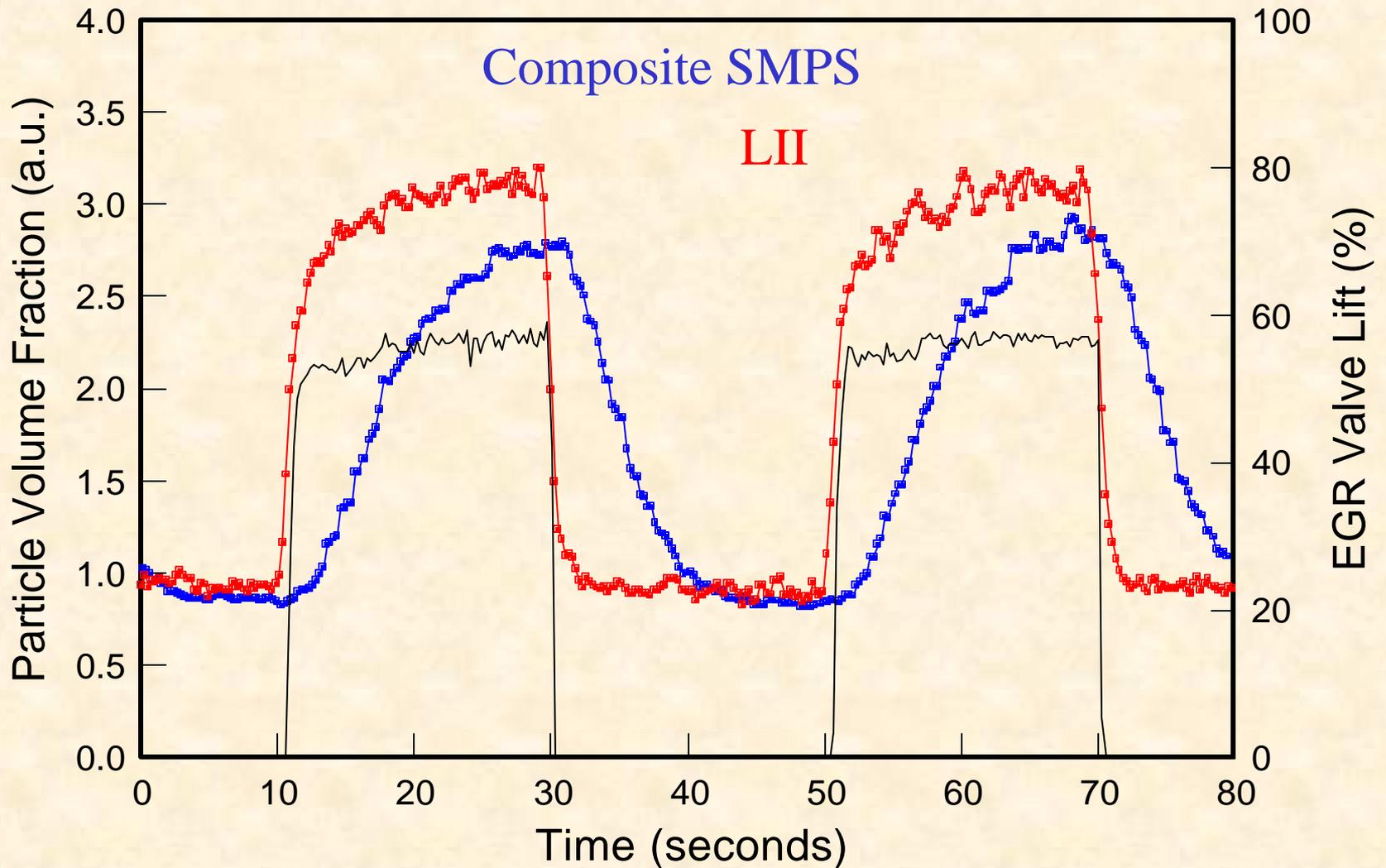
Continuous exhaust sampling



Speed-transient measurements of f_v

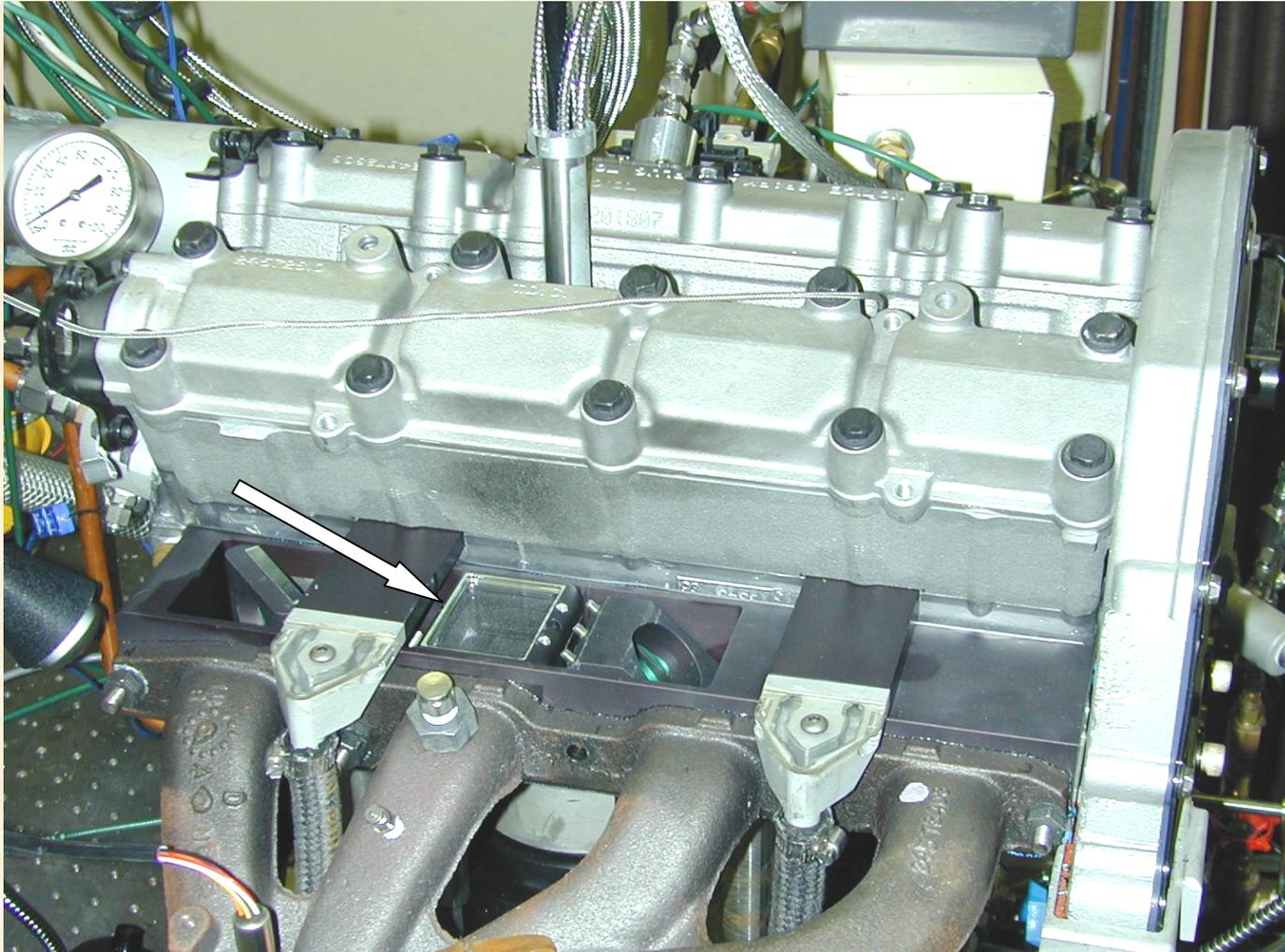


EGR-transient measurements of f_v

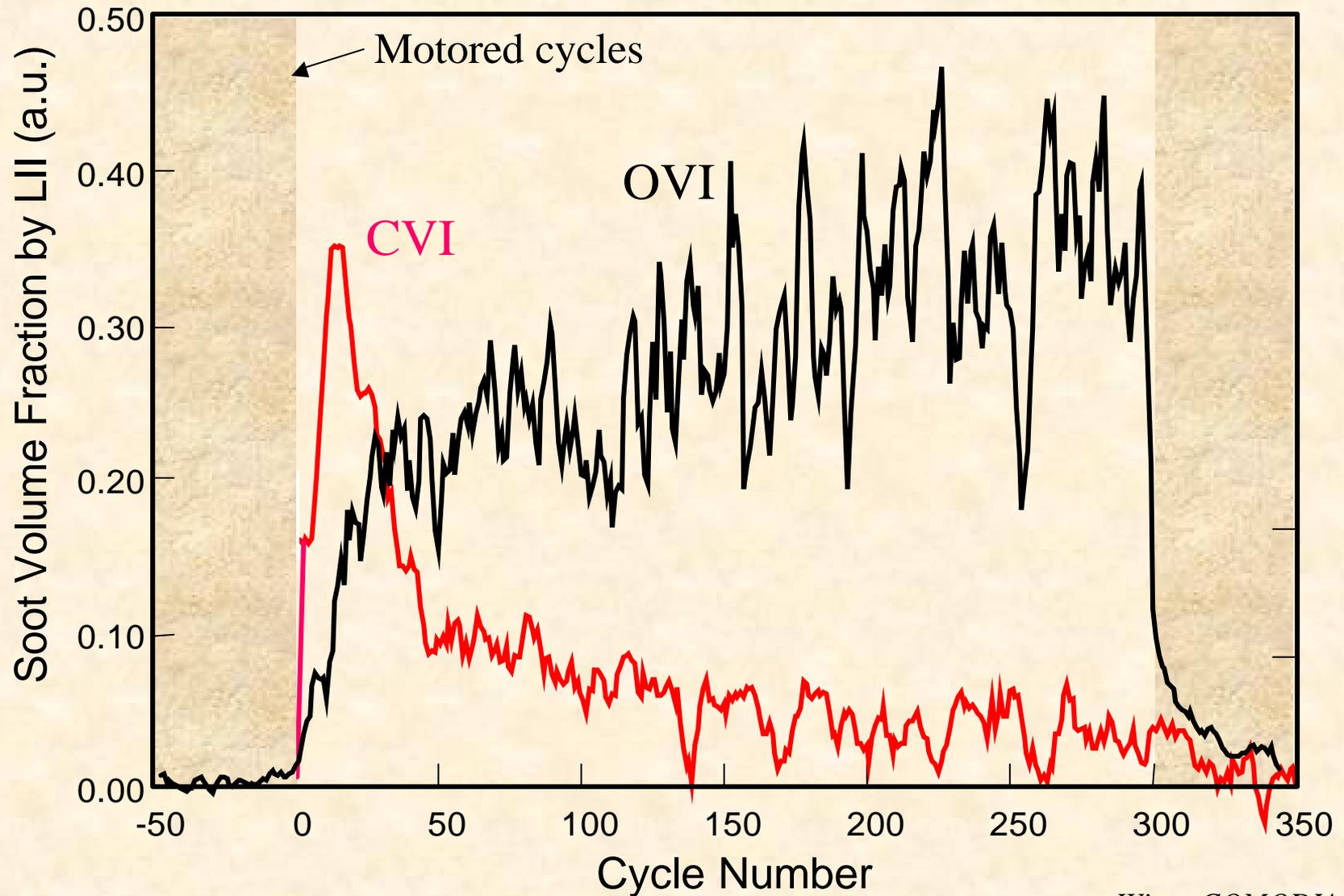


Exhaust-port optical cell for *in situ* measurements

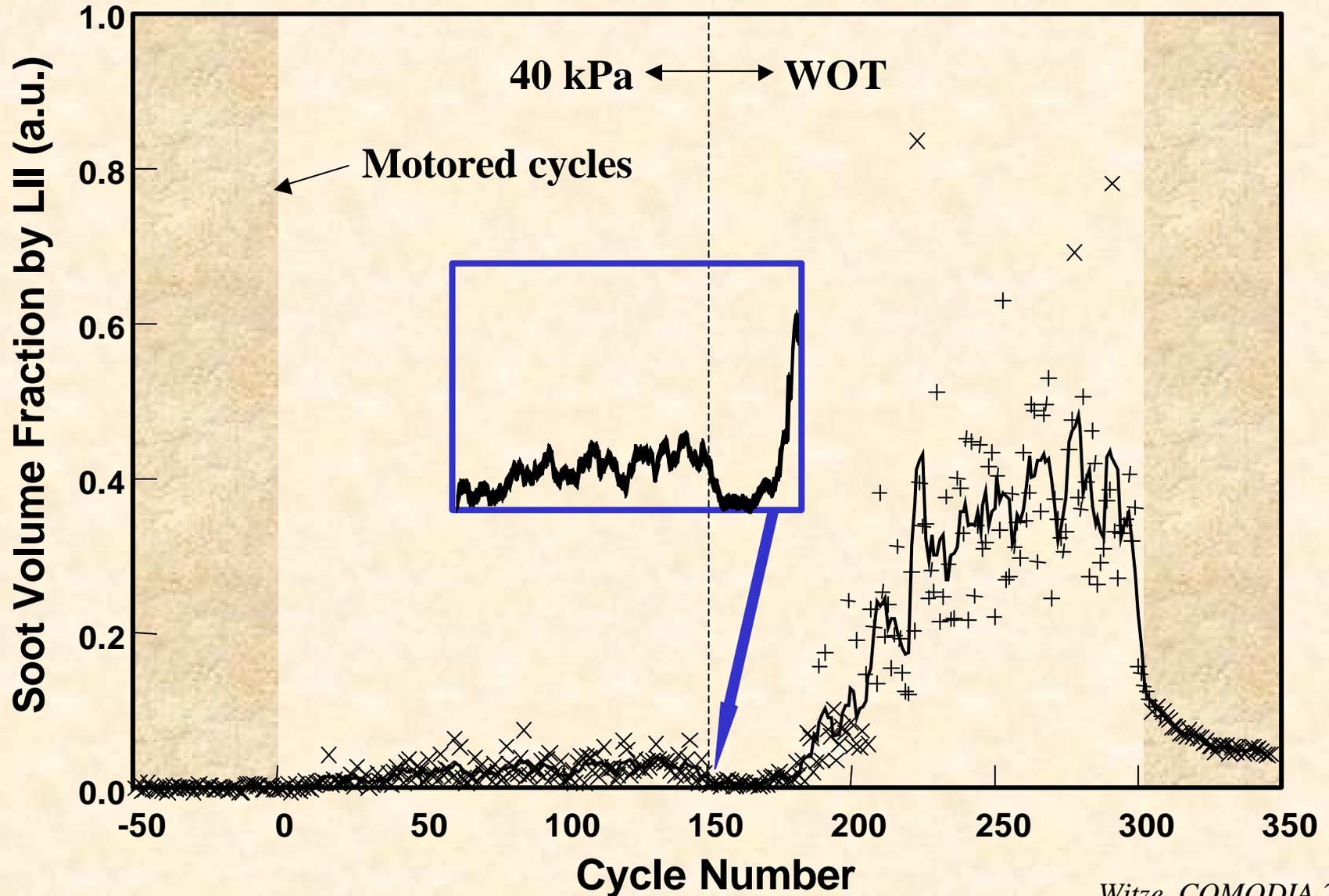
1994 GM Quad-4 PFI engine



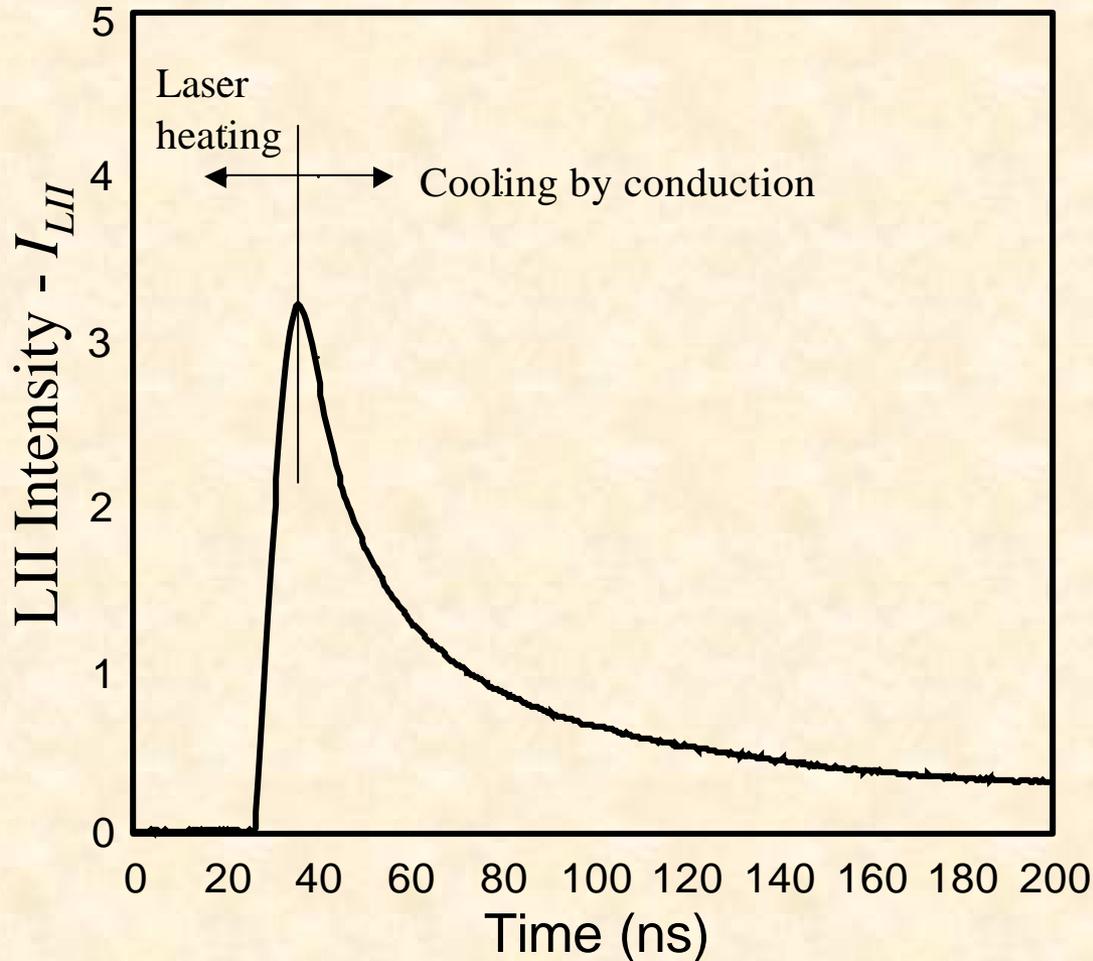
Simulated cold-start transient, $\phi=1.24$



Snap-throttle transient, $\phi=1.0$, OVI



LII for primary particle diameter d and number n



$$I_{LII} \propto T^5$$

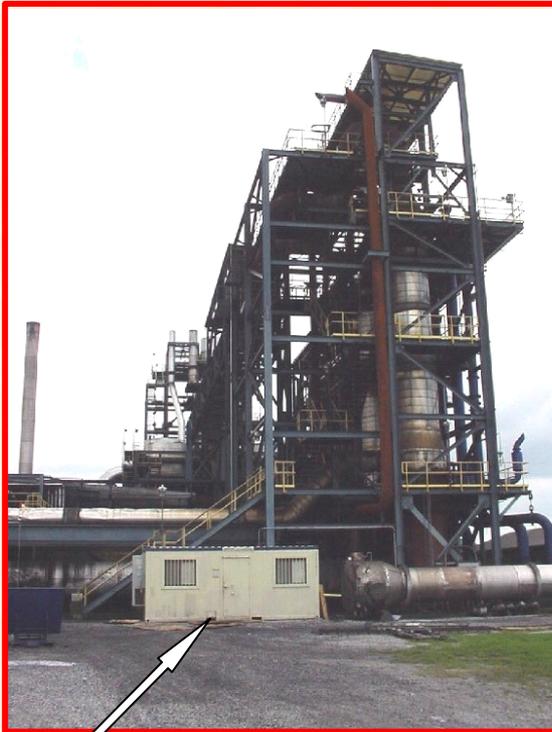
$$T(t) \propto e^{-k/d t}$$



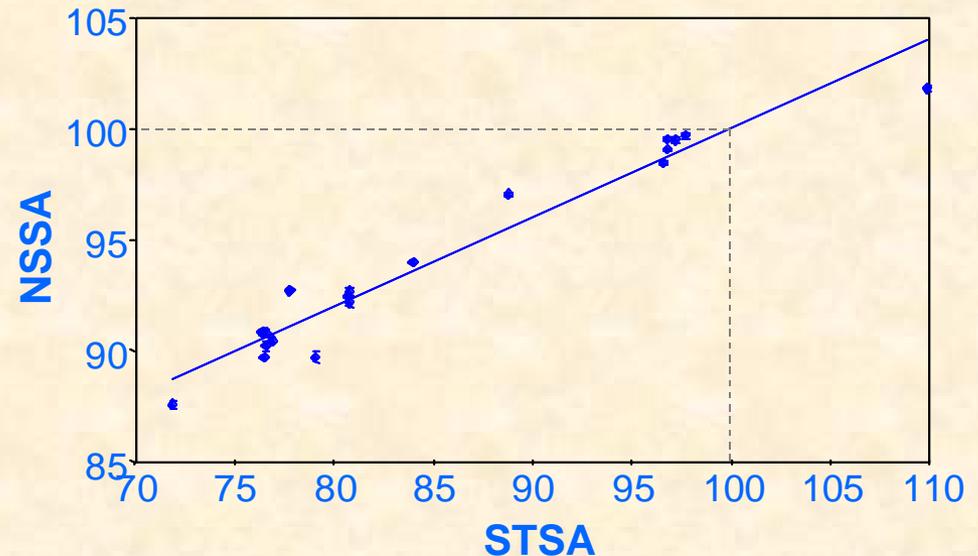
d

$$n = f_v / d^3$$

LII measurements of d and n for carbon black



LII test site at carbon black plant



Normalized specific surface area (NSSA) determined by LII is closely correlated with conventional statistical thickness surface area (STSA).

LII + ELS for aggregate size D and number N

if

$$I_{\text{ELS}} \propto V^2 = ND^6$$
$$I_{\text{LII}} \propto V = nd^3 = ND^3$$

where

n = # primary particles
 d = primary particle diameter
 N = # aggregates
 D = equivalent-sphere aggregate diameter

then

$$\frac{I_{\text{ELS}}}{I_{\text{LII}}} \propto \frac{ND^6}{ND^3} = D^3$$

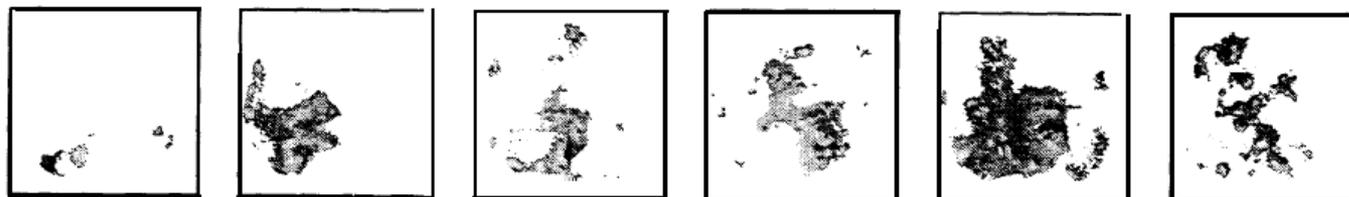
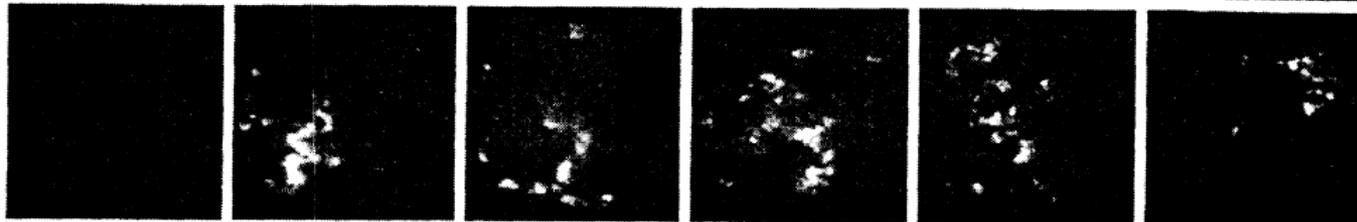
$$f_v/D^3 = N$$

LII + ELS images of D and N for diesel combustion

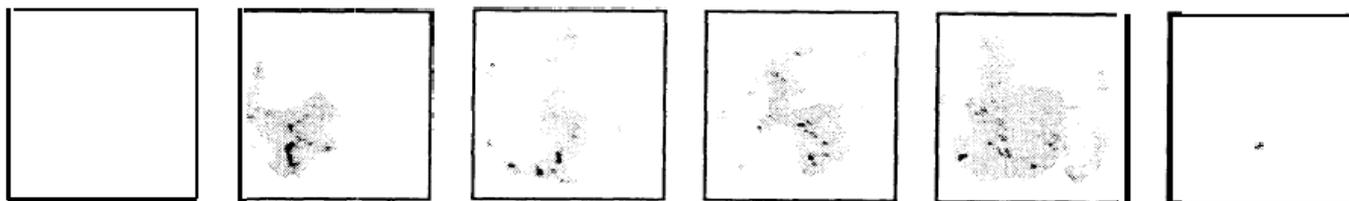
ELS



LII



Relative soot diameter



Relative soot number density

-4

-2

T.D.C.

5

10

15

RDG/PFA for aggregate structure

Rayleigh-Debye-Gans polydisperse fractal aggregate theory
(ELS with 3-angle detection)

$\overline{N}_{p/a}$ geometric mean of number of primary particles per aggregate (assumed log-normal distribution)

$S_{p/a}$ geometric standard deviation of number of primary particles per aggregate

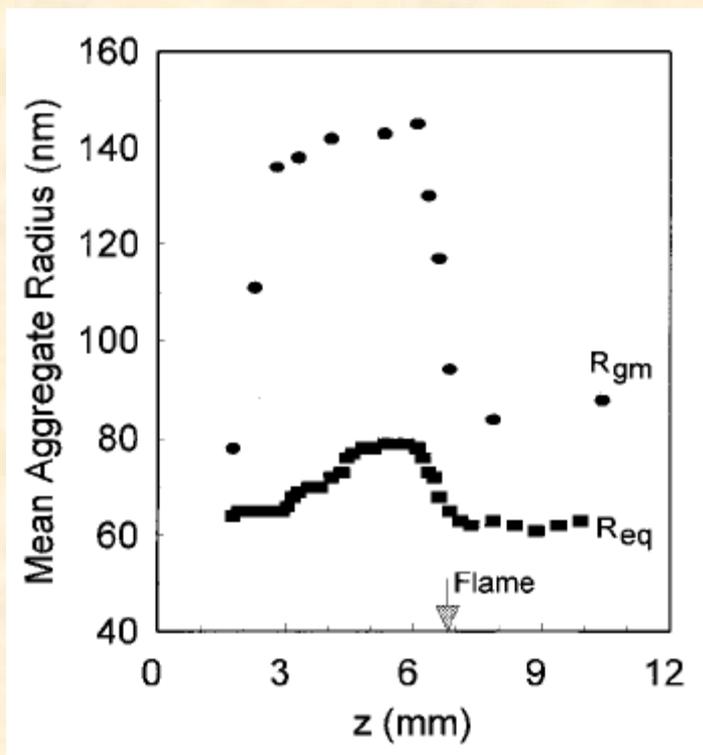
D_f fractal dimension (irregularity of shape)

S aggregate surface area per unit volume

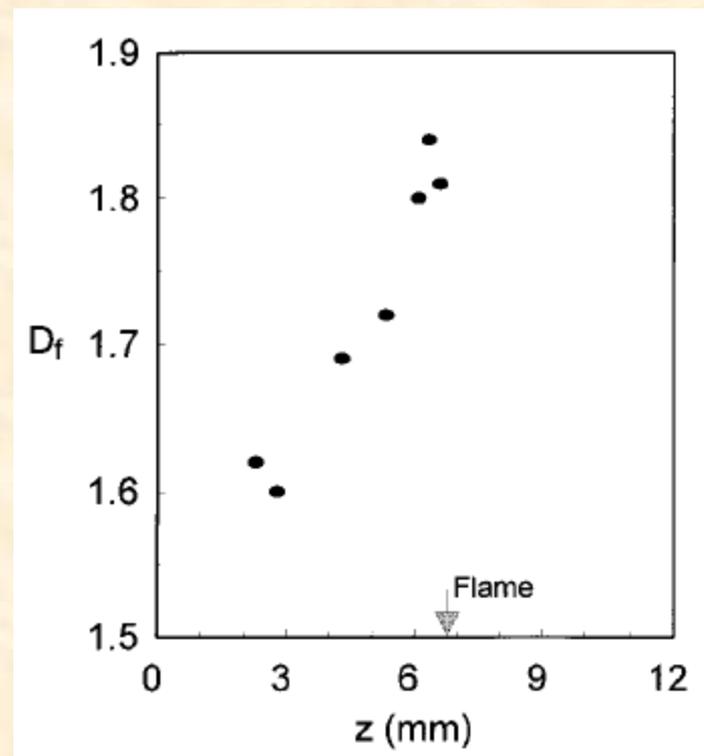
R_a radius of gyration of an aggregate

RDG/PFA for R_{gm} , R_{eq} and D_f

Al_2O_3 aggregates produced in a laminar counterflow nonpremixed methane flame



Mean aggregate radius of gyration R_{gm} and volume-equivalent radius R_{eq}

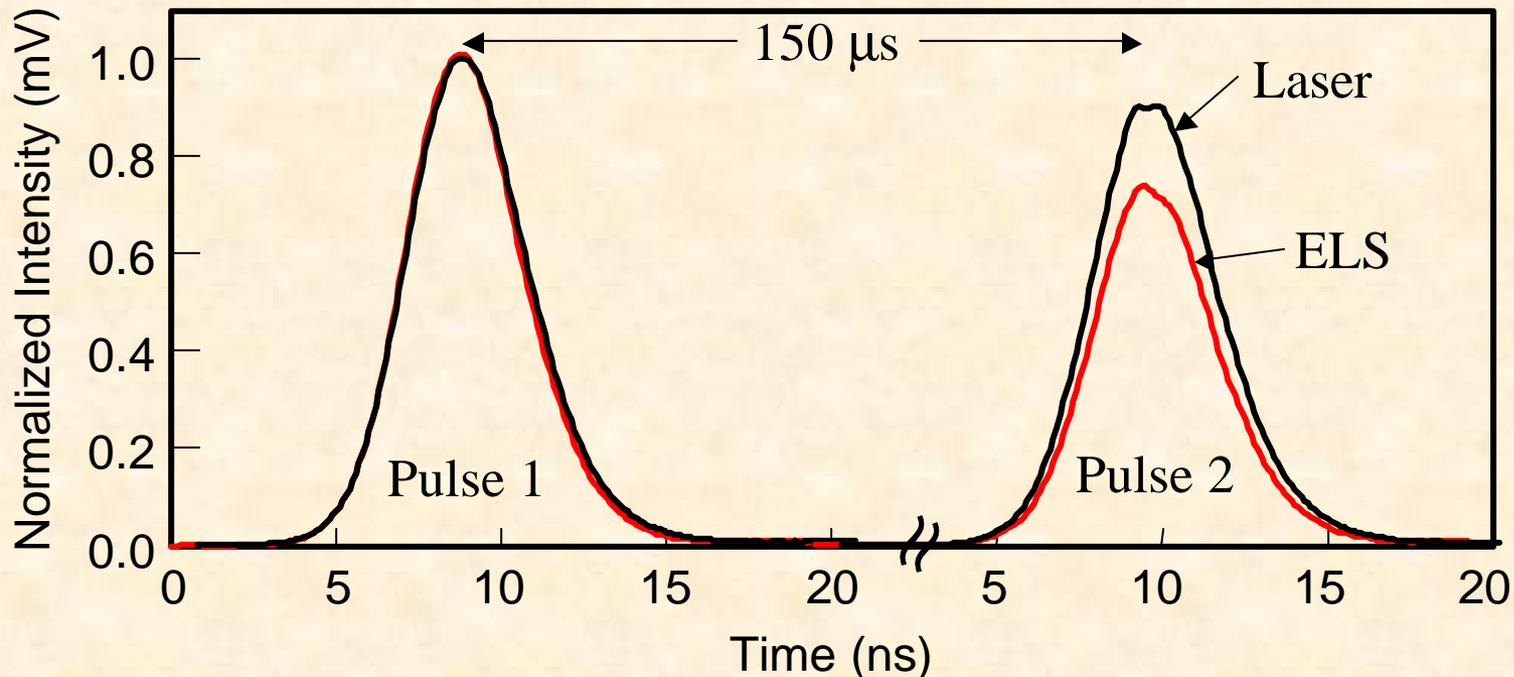


Aggregate fractal dimension

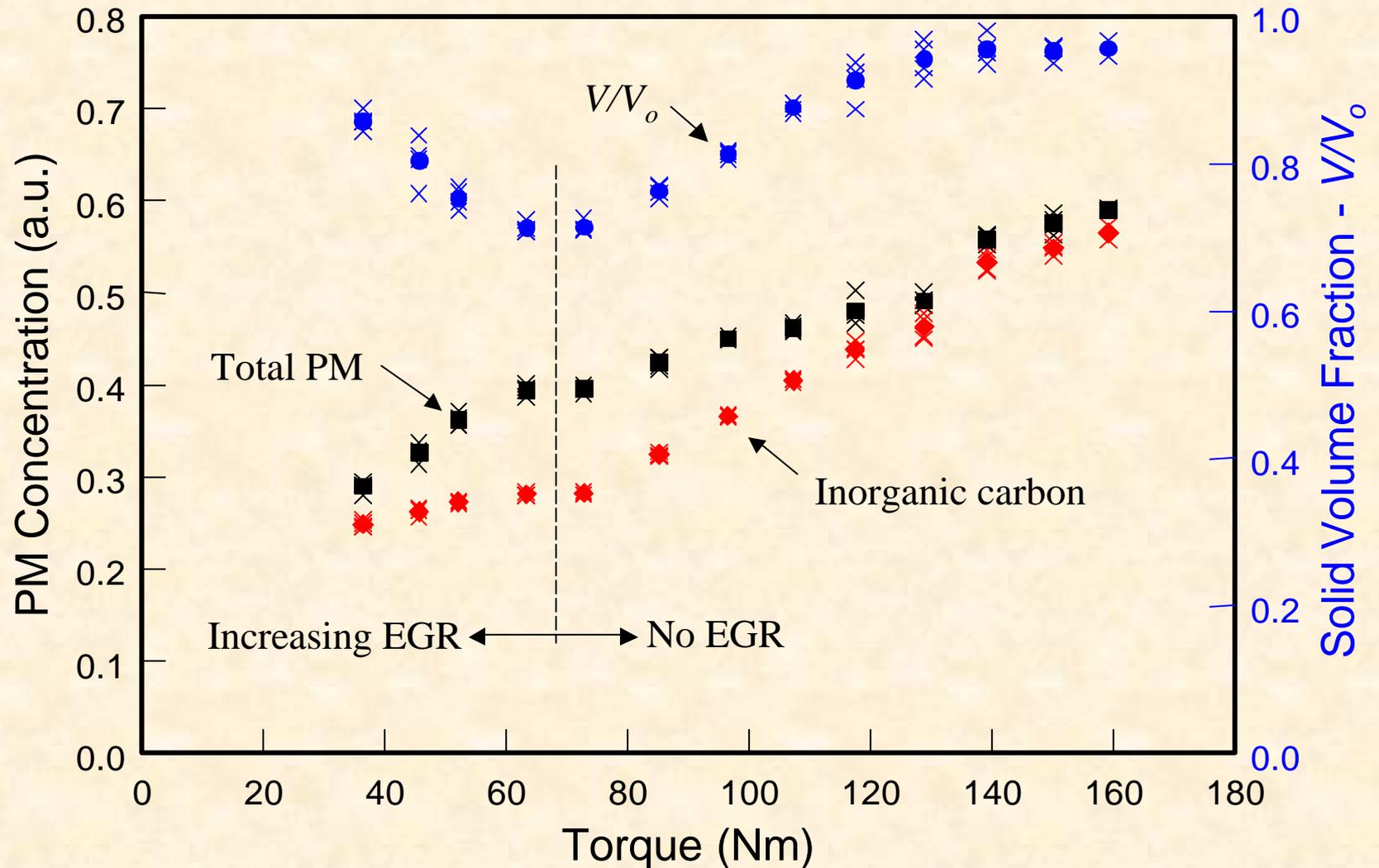
Laser-induced desorption (LID) + ELS (LIDELS)

Double-pulse laser with 150 μs interval

The ratio of ELS measurements before and after LID of volatile matter gives the solid fraction (**SOL**) in real-time

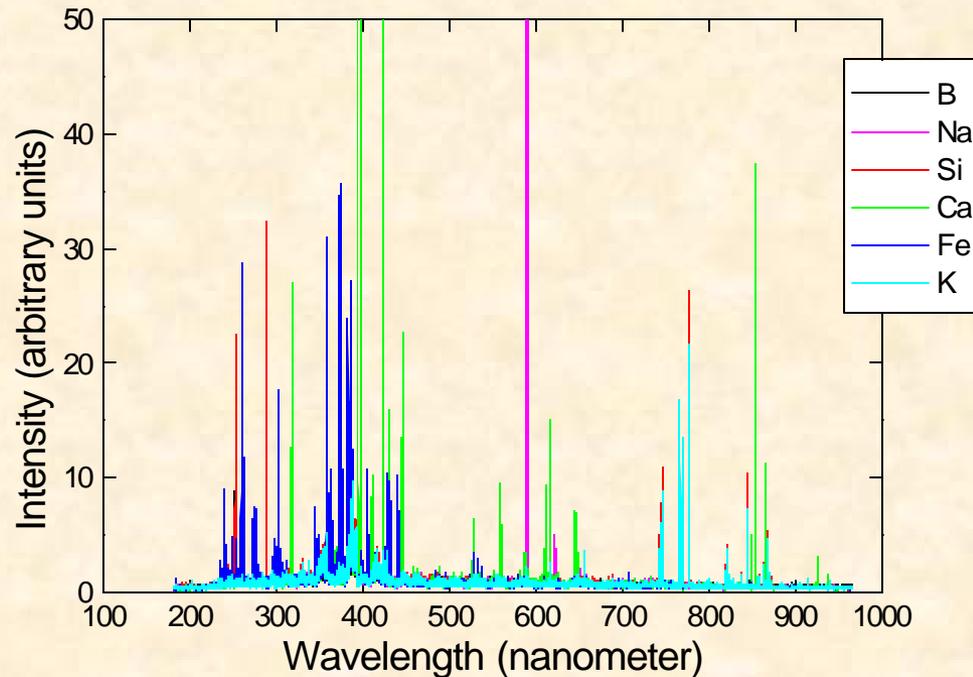


LIDELS load sweep for SOL



Laser-induced breakdown spectroscopy (LIBS)

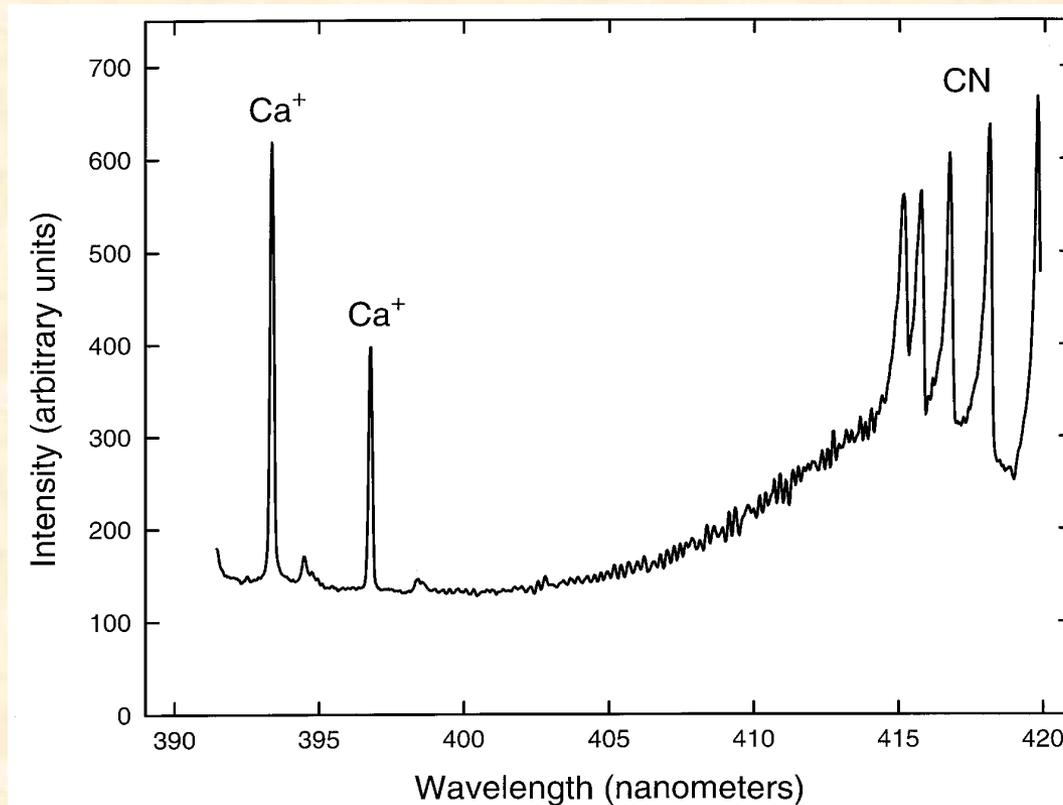
- Laser-induced spark causes atomic emissions from metallic elements
- Line position provides species identification
- Line intensity provides species concentration C



LIBS calibration spectra

LIBS measurements for C

LIBS measurements of calcium in the exhaust of a stationary, natural-gas-fueled SI engine provide a measure of oil consumption



(Walsh et al., 94th Annual Conference, Air & Waste Management Association, Orlando, FL, June 24-28, 2001, Paper No. 867)



CIDI team at GMR R&D is interested in both the LII and LIDELS techniques.

We are building a portable, stand-alone system to take to their facilities for demonstration and evaluation.

System requirements:

- Tap into exhaust line

- Tap into vent line

- 110 v power

Target date: Fall, 2002



2' x 4' cart



General Motors R&D Center CIDI Vehicle Emissions Laboratory



Particulate Matter Collaboratory web page



Sandia National Laboratories/California - Collaboratories - Particulate Matter - Netscape

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Home
Team
Laser-Induced Incandescence
Laser-Induced Vaporization with Elastic Scattering
Laser-Induced Desorption with Elastic Light Scattering
Publications

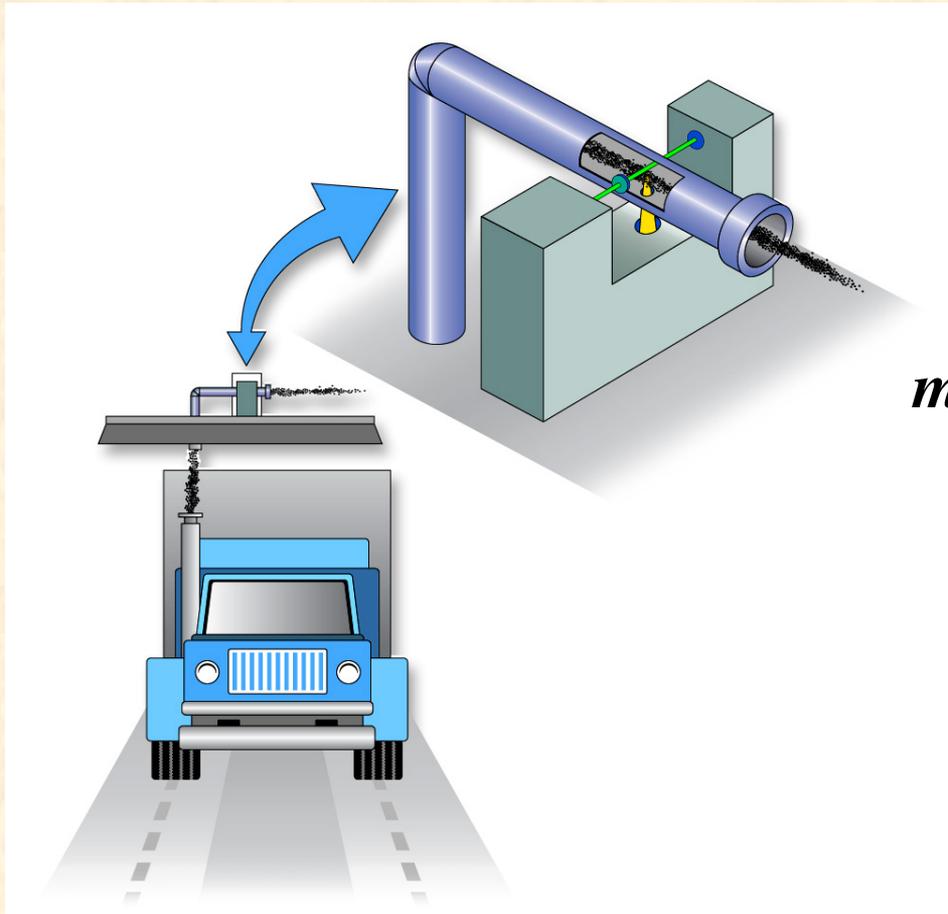
Concept

The diagram illustrates the experimental setup for Laser-Induced Incandescence (LII). A green arrow labeled "Pulsed laser beam" points from left to right. It passes through a "Filter" and a "Collection lens" which is angled upwards. The laser beam then hits a "Particulate source" at the bottom, which is emitting a plume of orange and red particles. A "Photo-detector" is positioned above the collection lens to capture the light emitted by the heated particles.

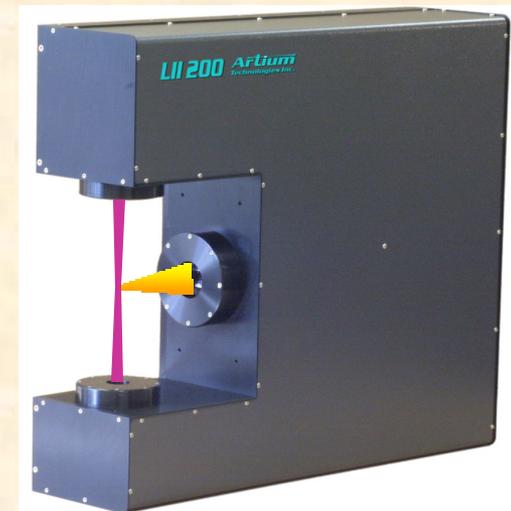
A photograph showing three researchers in a laboratory setting. They are gathered around a piece of scientific equipment, which is the LII instrument. One person is seated at a computer workstation, while two others are standing and looking at the equipment. The environment appears to be a clean, well-lit laboratory.

In an LII experiment, a pulsed laser beam is used to rapidly heat particulates so that they radiate light as they cool. The incandescence signal is collected to determine the volume fraction of soot and the primary particle size. Laser-induced incandescence is a powerful optical diagnostic for the study of particulate matter in vehicle exhaust. It can be applied in any environment as the exhaust gas travels from the combustion chamber to the atmosphere; neither cooling nor dilution are required.

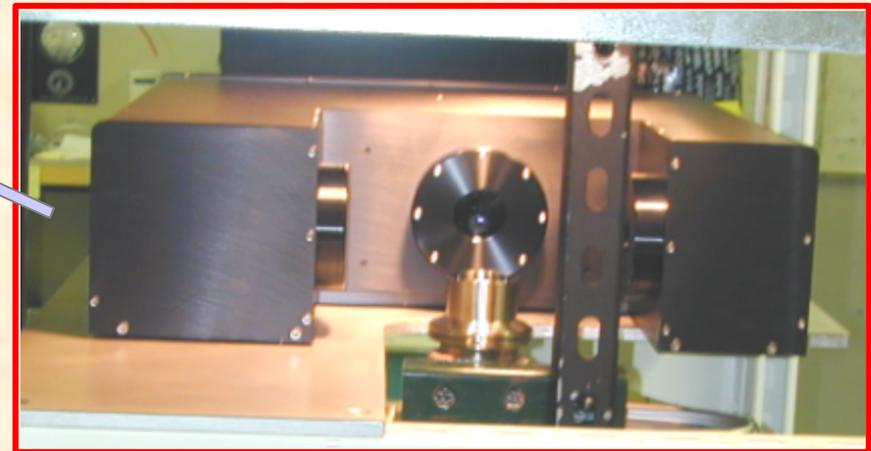
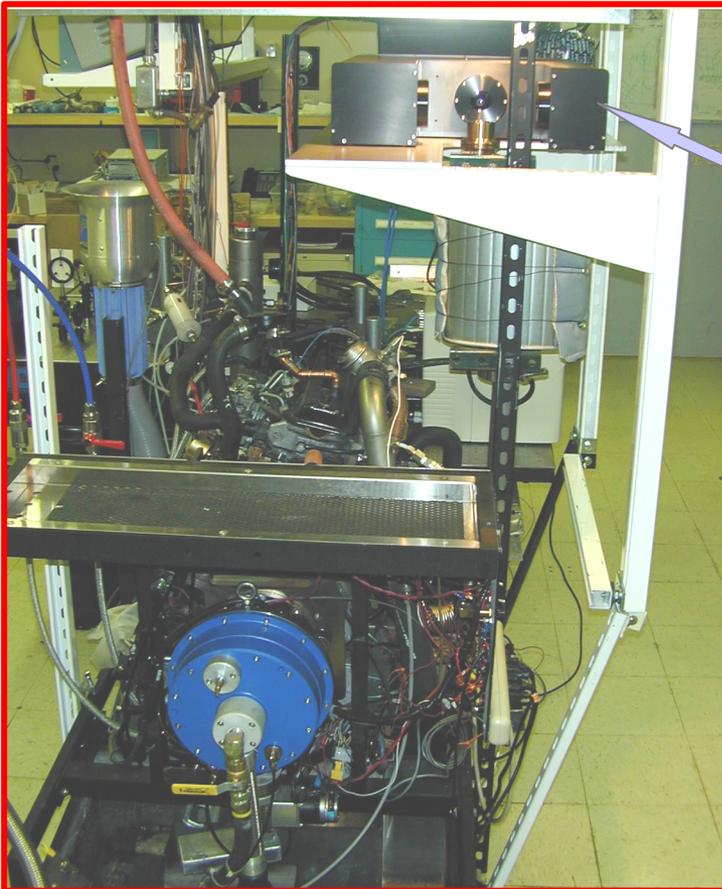
NRC's prototype LII instrument was brought to the CRF for evaluation in April, 2001. The effects of exhaust gas recirculation (EGR) on PM emissions were measured for a 1.9L turbo direct injection (TDI) diesel engine. A scanning mobility particle sizer (SMPS) was also used to obtain particle size distributions.



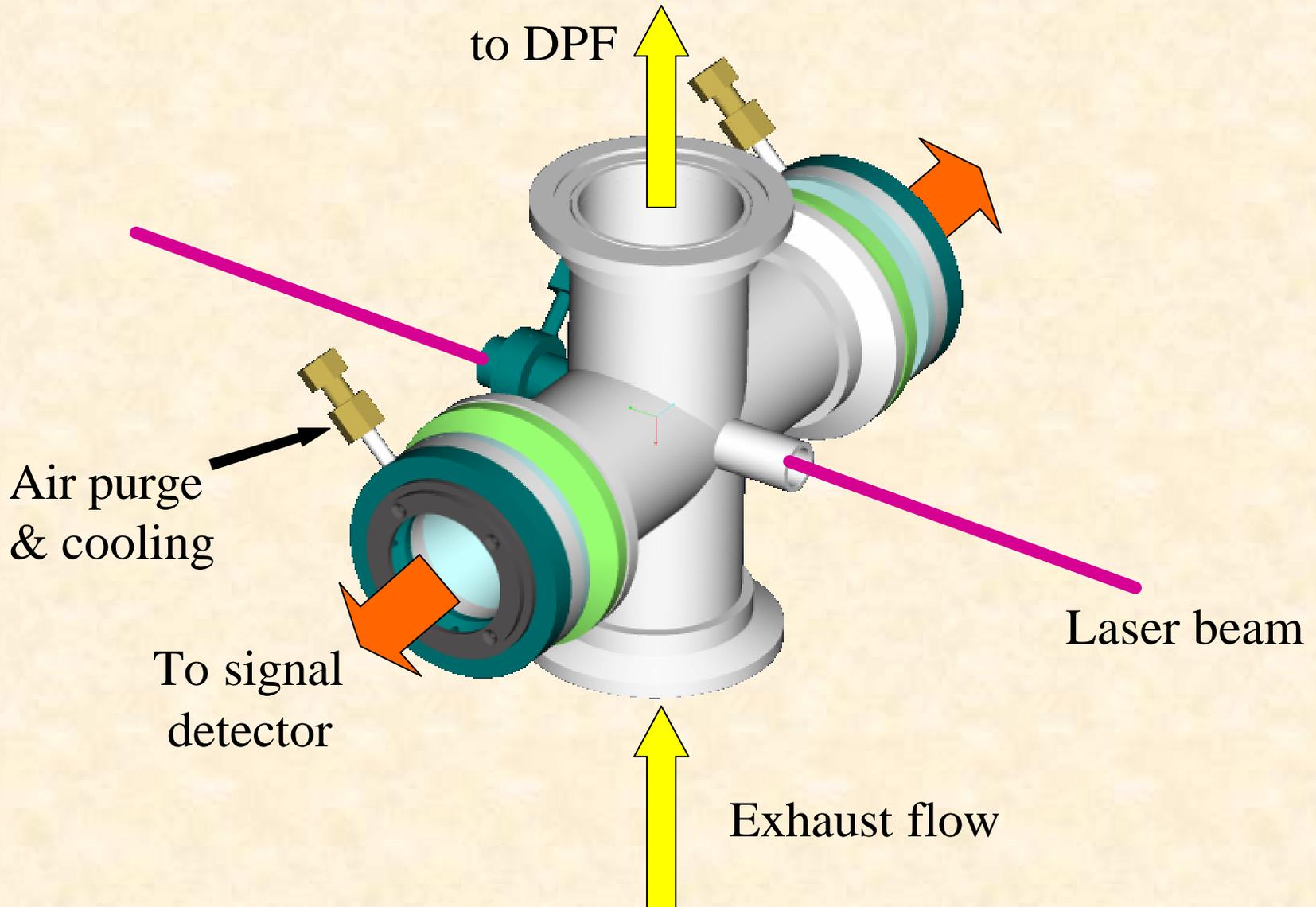
*Collaborating to
develop, evaluate,
and commercialize
LII systems for online
monitoring of exhaust PM*



The Sandia Combustion Research Facility is providing facilities and support for testing and evaluating the commercial product, in addition to advice on design and development. The engine shown is a 1996 Volkswagen 1.9L TDI diesel.



The LII instrument is located on a shelf under a ventilation hood. For the application shown, the measurements are obtained in the open exhaust after the muffler. We also have the capability to use an inline optical cell for in situ measurements, enabling us, for example, to measure soot concentrations entering and exiting a DPF (diesel particulate filter).



Summary - Status of HELD techniques

- Commercial LII instruments already exist for volume fraction and primary particle size
- LII + ELS for aggregate size and number has been demonstrated in laboratory flames and in-cylinder for diesel engines
- RDG/PFA has been demonstrated only in laboratory flames
- LIDELS has been demonstrated on diesel exhaust, but need validation of VOF measurement and calibration for TPM
- LIBS has been demonstrated for a natural-gas-fueled stationary engine