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Fuel Spray Diagnostics Using X-Ray Radiography

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Advanced Photon Source

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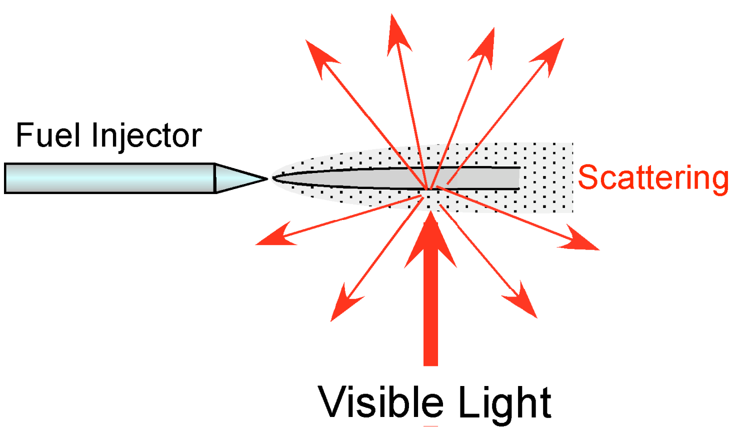
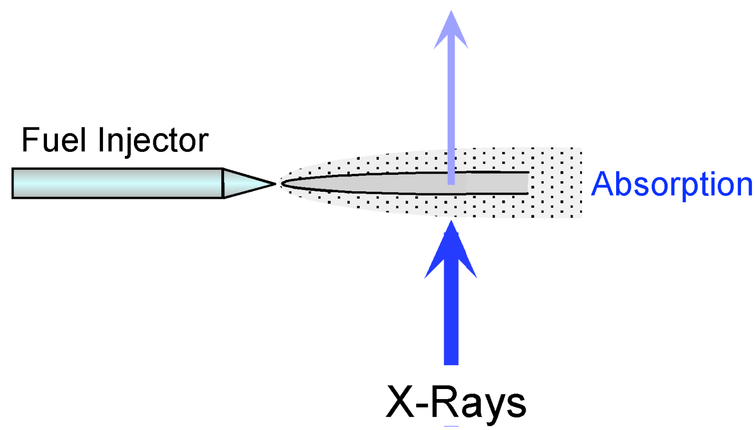
Purpose of Work

- **Sprays Have Significant Impact on Efficiency and Emissions**
  - ⇨Spray studies assist engine design
  - ⇨Provide data for spray and engine computational models
  - ⇨Critical for the development of new combustion strategies
- **Why Use X-Rays to Study Sprays?**
  - ⇨Lack of scattering provides unique information and insight





X-Ray Diagnostics Reveal the True Structure of Sprays

Visible Light Image

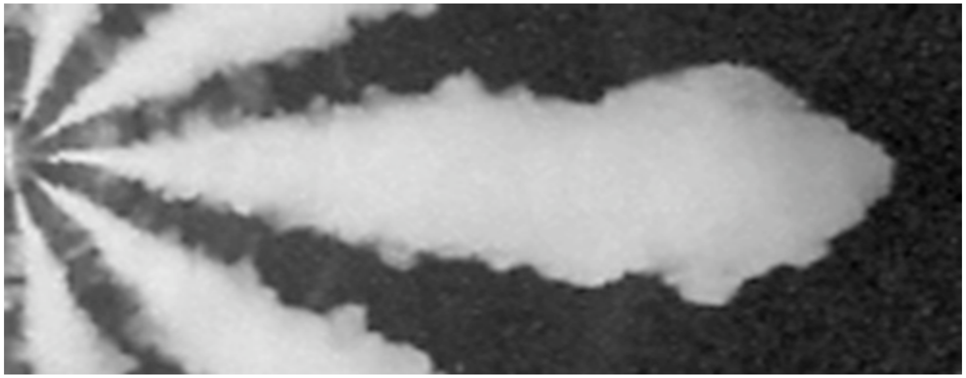
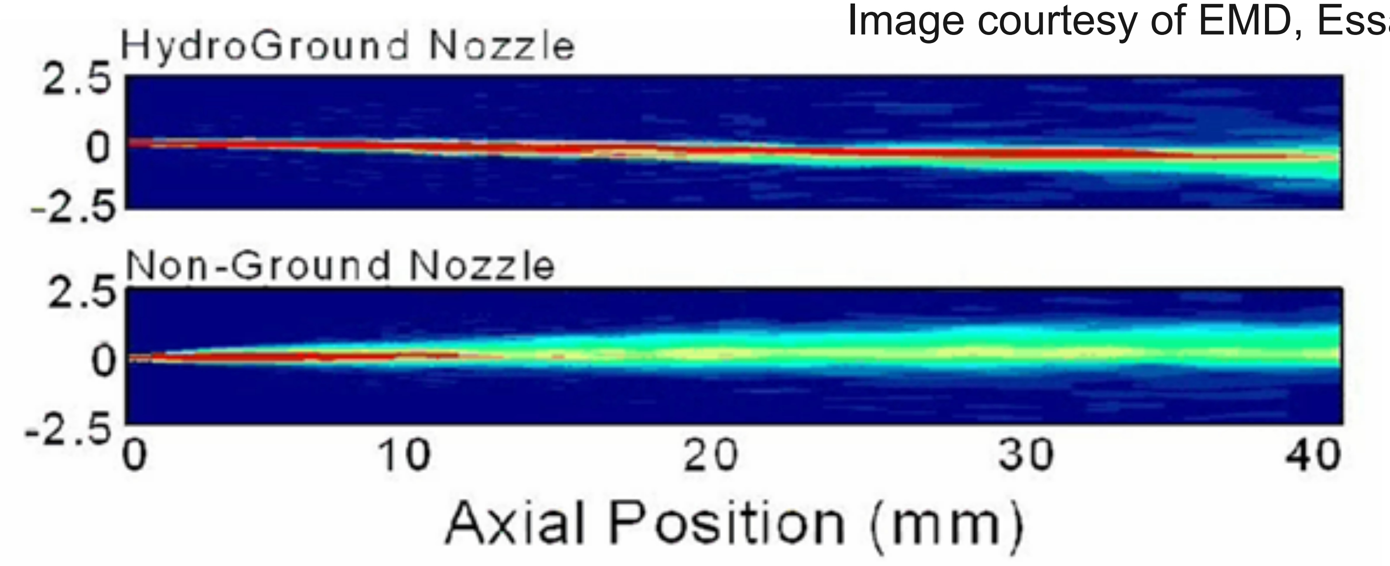


Image courtesy of EMD, Essam El-Hannouny



Radiography "Image"

- Quantitative measurement of the fuel distribution
- Stringent test for spray models

Experiment Conditions Simulate an Operating Engine

- Recent Measurements performed at ambient pressure of 30 bar
- Gas density inside the spray chamber exceeds that of a light-duty diesel at TDC
- Long-term tests of x-ray pressure windows shows they are capable of further pressure increase

X-Ray Experiments

Ambient Pressure (bar)	Ambient Density (kg/m^3) (300K)
20	23
25	29
30	35
35	41
40	46

	Light-Duty	Heavy-Duty
Crank Angle Degrees	Ambient Density (kg/m^3) (Mercedes 1.7L, 9 psi boost)	Ambient Density (kg/m^3) (CAT 3406E, 23 psi boost)
-20	17	30
-15	19	35
-10	21	41
-5	23	46
0	24	47

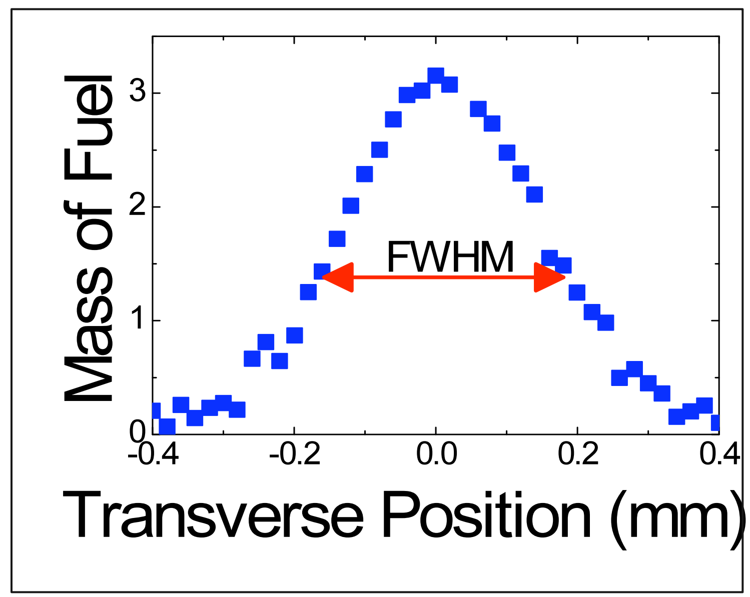
The Influence of Ambient Density on Diesel Spray Structure

- Effect of ambient pressure is important for spray models, has been studied by several groups:

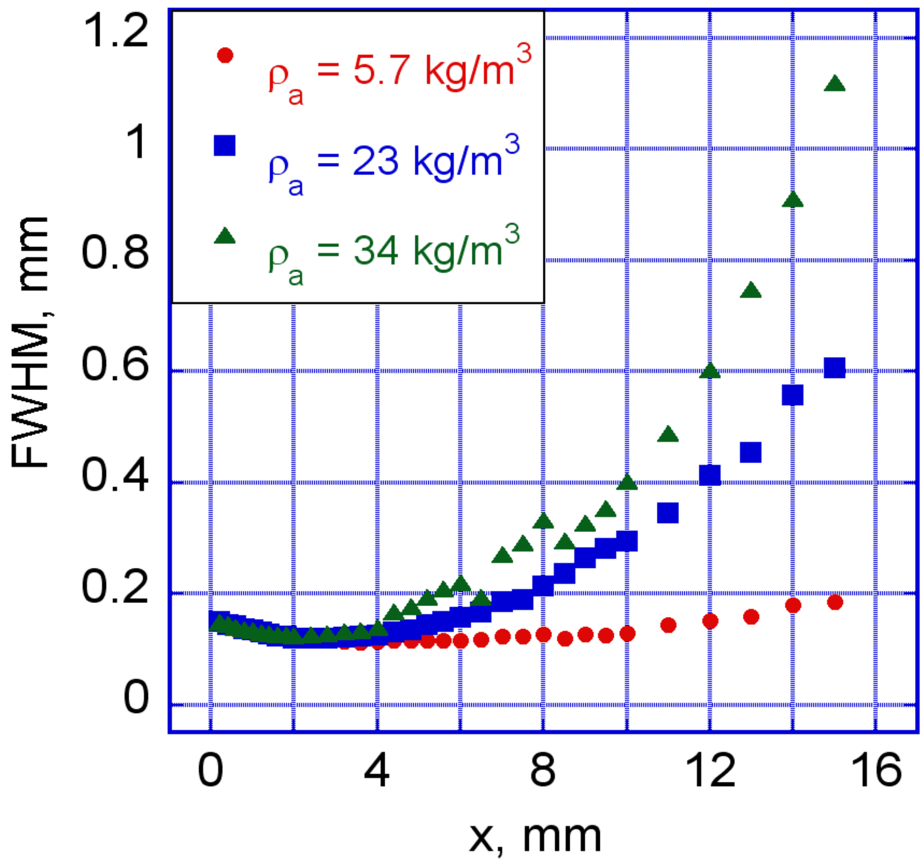
Cone Angle Dependence on Density

Hiroyasu & Arai SAE 900475:	$\tan \theta$ Q $\rho^{0.26}$
Naber & Siebers SAE 960034:	$\tan \theta$ Q $\rho^{0.19}$
Araneo *et al.* SAE 1999-01-0525:	$\tan \theta$ Q $\rho^{0.5}$

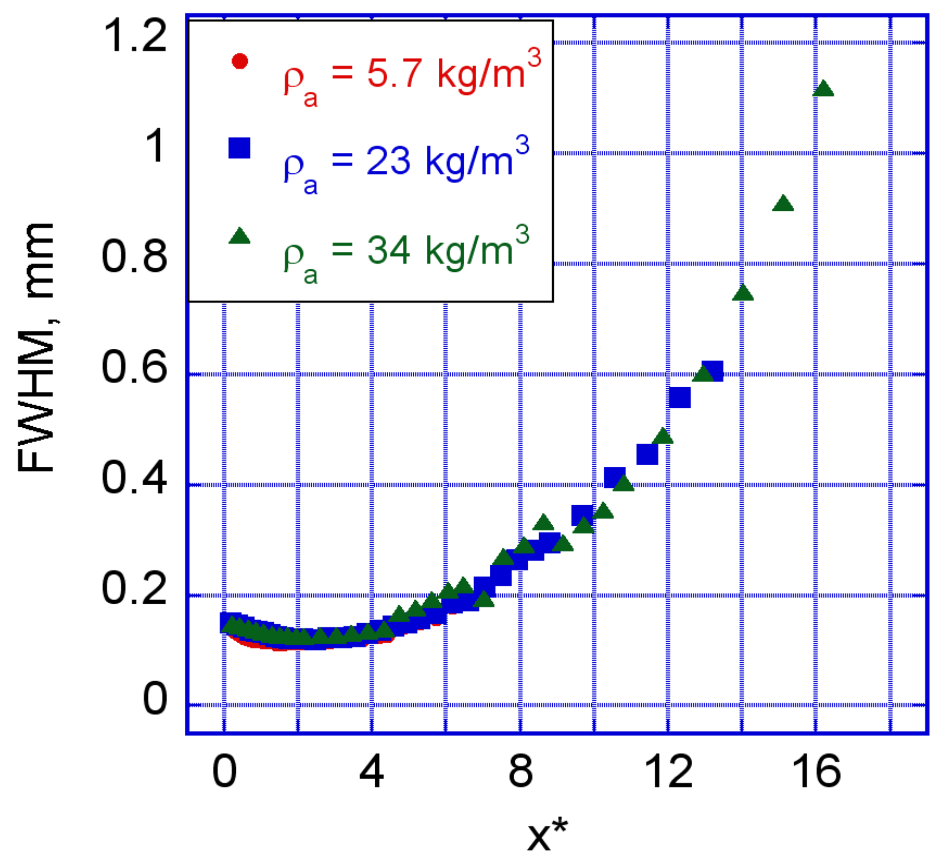
- These correlations are only applicable far from nozzle, and have only been validated using light imaging
- X-ray radiography measures the fuel distribution, spray width can be determined quantitatively



Simple Correlation Describes How the Spray Width Changes With Ambient Density

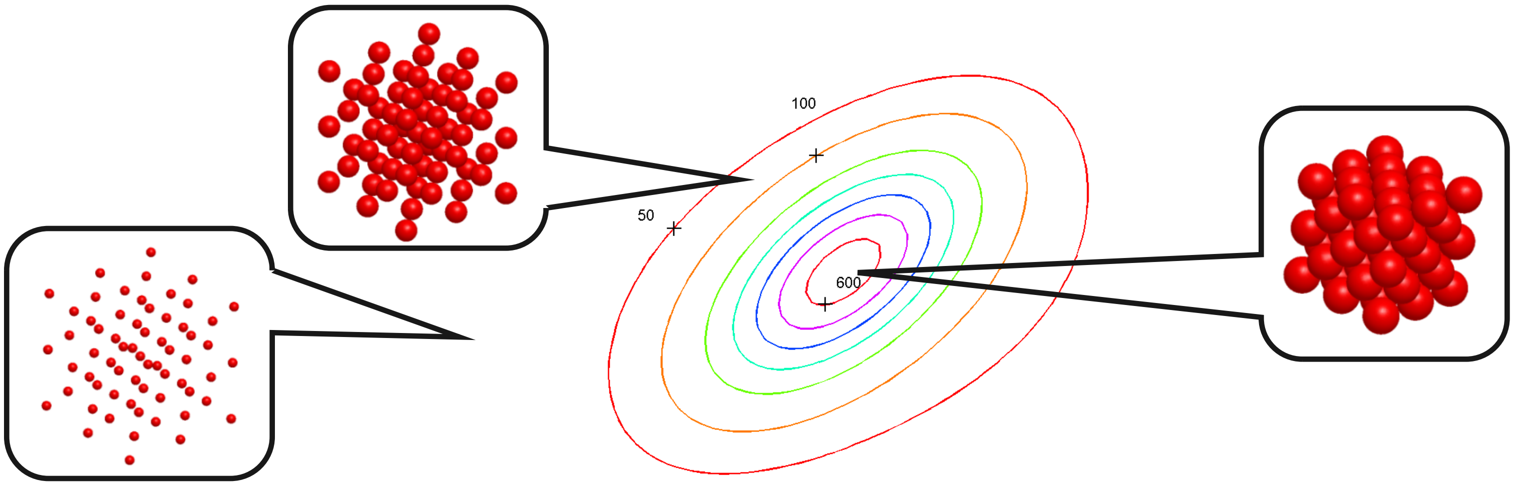


$$x^* = \frac{x}{d_{eff}} \qquad d_{eff} = d_0 \left(\frac{\rho_\ell}{\rho_a} \right)^{0.5}$$



X-Ray Measurements Highlight Flaws in Current Spray Models

- New measurements of diesel sprays under high pressure conditions show a strikingly asymmetric fuel distribution
- If one assumes that the spray is composed of fuel droplets, and the droplets are all the same size, illustrations of the droplet distribution can be generated:



Density contours of a slice through the spray 6 mm from nozzle, and droplet packing at several locations

- Current spray models assume spray is composed of discrete droplets, and that drag on one droplet is not influenced by neighboring droplets
- A new collaboration between Argonne and UW-ERC modeling group will use x-ray data to improve the existing droplet drag model and incorporate into KIVA

Technology Transfer

- **DOE AEC Working Group** – Lab, university, and industrial partners.
- **Robert Bosch GmbH** –Dr. Philippe Leick spent five weeks at Argonne in June 2008, tests of "state-of-the-art" nozzle geometry for model development. Non-proprietary
- **Caterpillar** – Heavy-duty project. Providing tech support for injection system.
- **University of Illinois at Chicago** - Heavy-duty project. Experiments, spray modeling and model development
- **Engine Research Center, UW-Madison –** Collaboration with engine modeling group, Nidheesh Bharadwaj to spend two months at Argonne in 2009
- **Wayne State University** – Experiments, modeling, joint publication in preparation.
- **Convergent Science** – commercial Engine model, using data for validation and development

Future Work

- Strengthen the link between x-ray spray studies and engine performance
  - Study hardware and conditions that match GM1.9 liter TDI
  - Engine is running at Argonne, other labs also have this engine
  - Enables direct comparison between x-ray measurements and Argonne's full suite of engine diagnostics: endoscopic imaging, emissions, performance.
  - Bosch has donated custom injectors built to our specs
- Measurements at elevated ambient temperature
  - X-ray pressure windows, co-evaporation of fuel and additive
- Collaboration with ERC modeling group
- Expand collaborations with industrial and university partners
- Lean-burn Gasoline? Fuels?