ARGONNE NATIONAL LABORATORY
TRANSPORTATION
TECHNOLOGY R&D CENTER

X-Ray Characterization of Diesel Sprays and the Effects of Nozzle Geometry

Christopher F. Powell, Ph.D.

Argonne National Laboratory

Seong-Kyun Cheong, Stephen A. Ciatti, Jinyuan Liu, Jin Wang

Center for Transportation Research

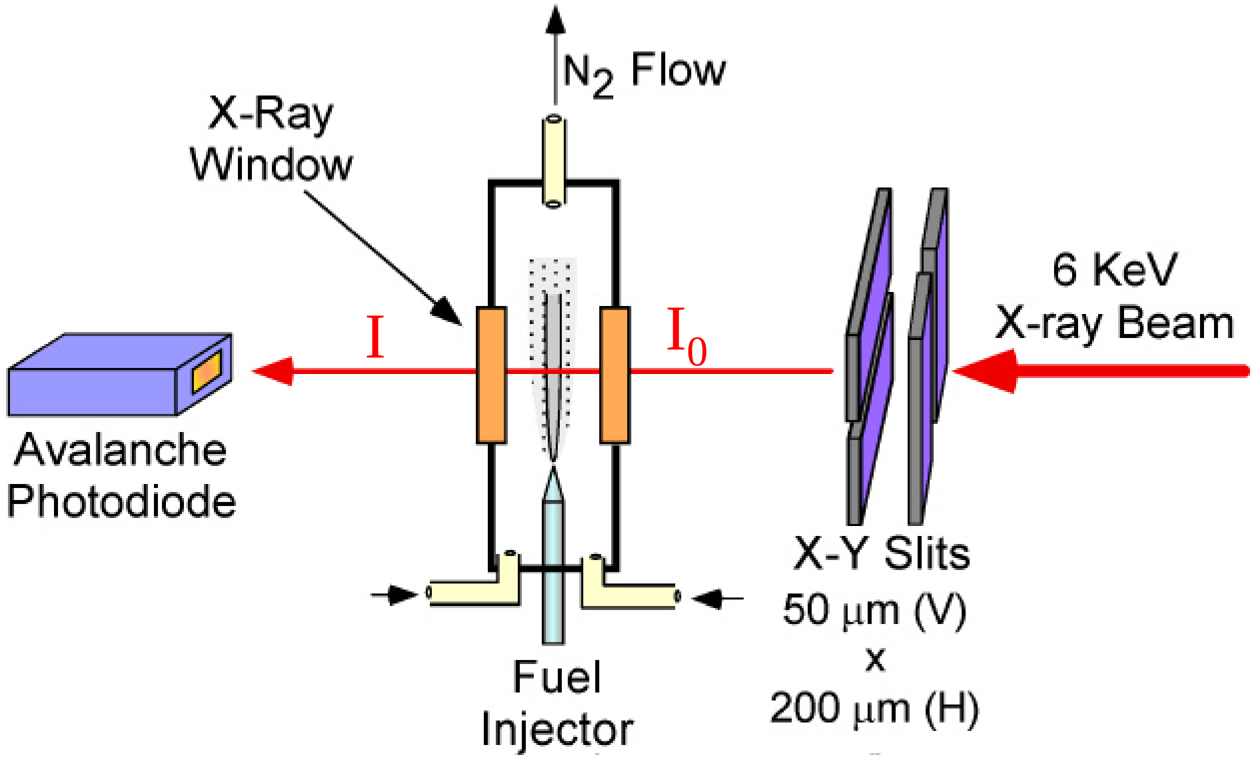
Advanced Photon Source

DEER, San Diego, CA 30 August, 2004

Project Motivation

- **Goal: Understand the mechanisms of spray atomization**
  - In-Nozzle effects - nozzle structure, cavitation
  - Aerodynamic effects - air entrainment, stripping, collisions
  - Relative magnitudes unknown
- **Near-nozzle spray studies**
  - This region determines downstream behavior
  - Aerodynamic effects have little impact
  - Lack of existing data, lack of reliable models
- **X-Ray technique**
  - Quantitative measurement of fuel, even near the nozzle
  - Provide data necessary for accurate models

Schematic of X-Ray Setup

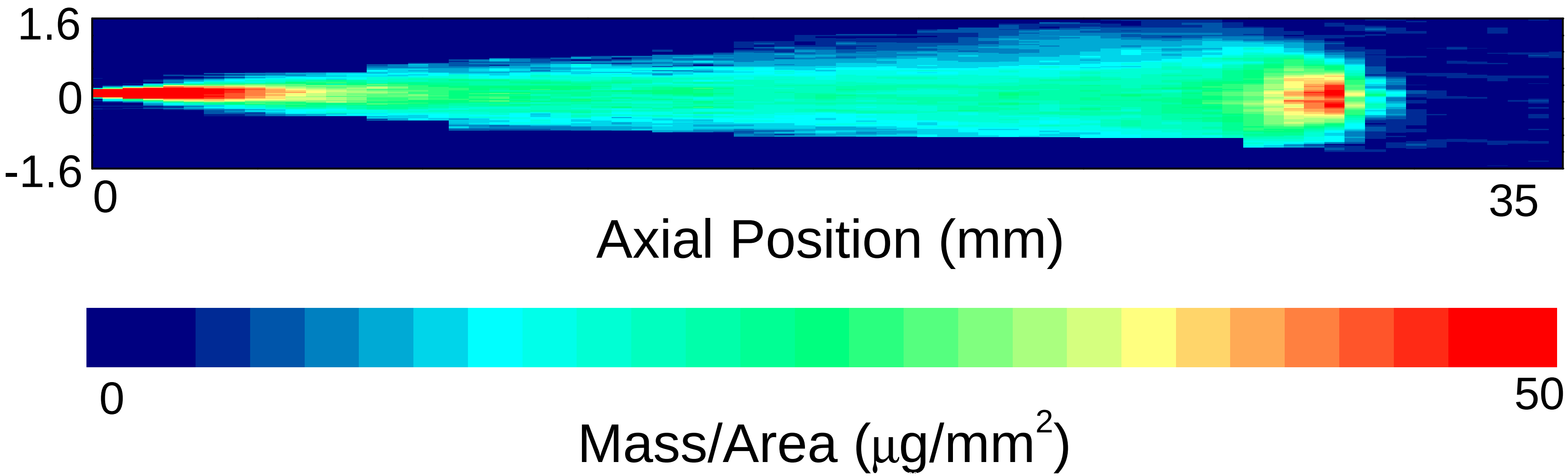


Direct relation between x-ray intensity and fuel mass

$$I/I_0 = \exp\left(-m_M M\right)$$

I_0	Incident x-ray intensity
I	Measured x-ray intensity
μ_M	Fuel absorption constant
M	Mass of fuel in x-ray beam

X-Ray Image Reconstruction

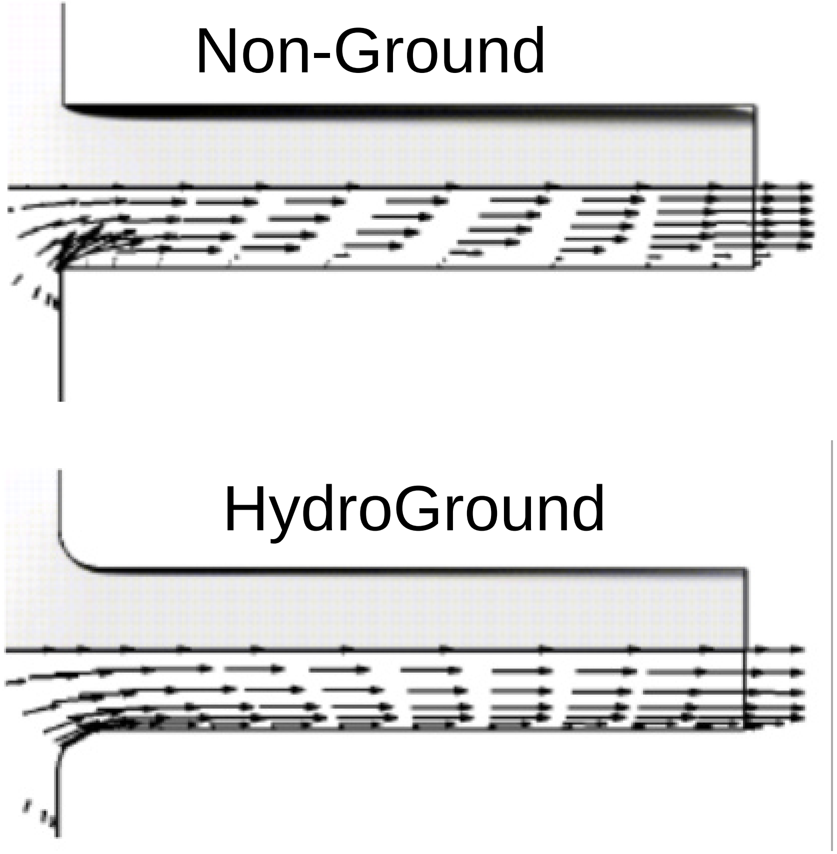


- Image represents line-of-sight mass distribution
- Image is single snapshot in time, we measured more than 250 snapshots throughout spray lifetime

Injection Pressure = 500 bar
Ambient Pressure = 1 bar N_2
200 μs after SOI

Effects of Nozzle Geometry

- Different geometries predicted to produce different mass distributions.
- Models most easily validated near nozzle exit, other influences minimized
- Quantitative data not available



Schmidt et al., SAE 971597

Measurement Conditions

Common rail, single hole, mini-sac nozzles

➢Fuel pressure	500,1000 bar
➢Pulse duration	400 μs
➢Spray chamber gas	N_2 @ 1 bar, 25 °C
➢Fuel	Calibration fluid
➢Fuel Additive	Ce compound, 10%
➢Data Averaging	50 sprays

HydroGround Nozzle

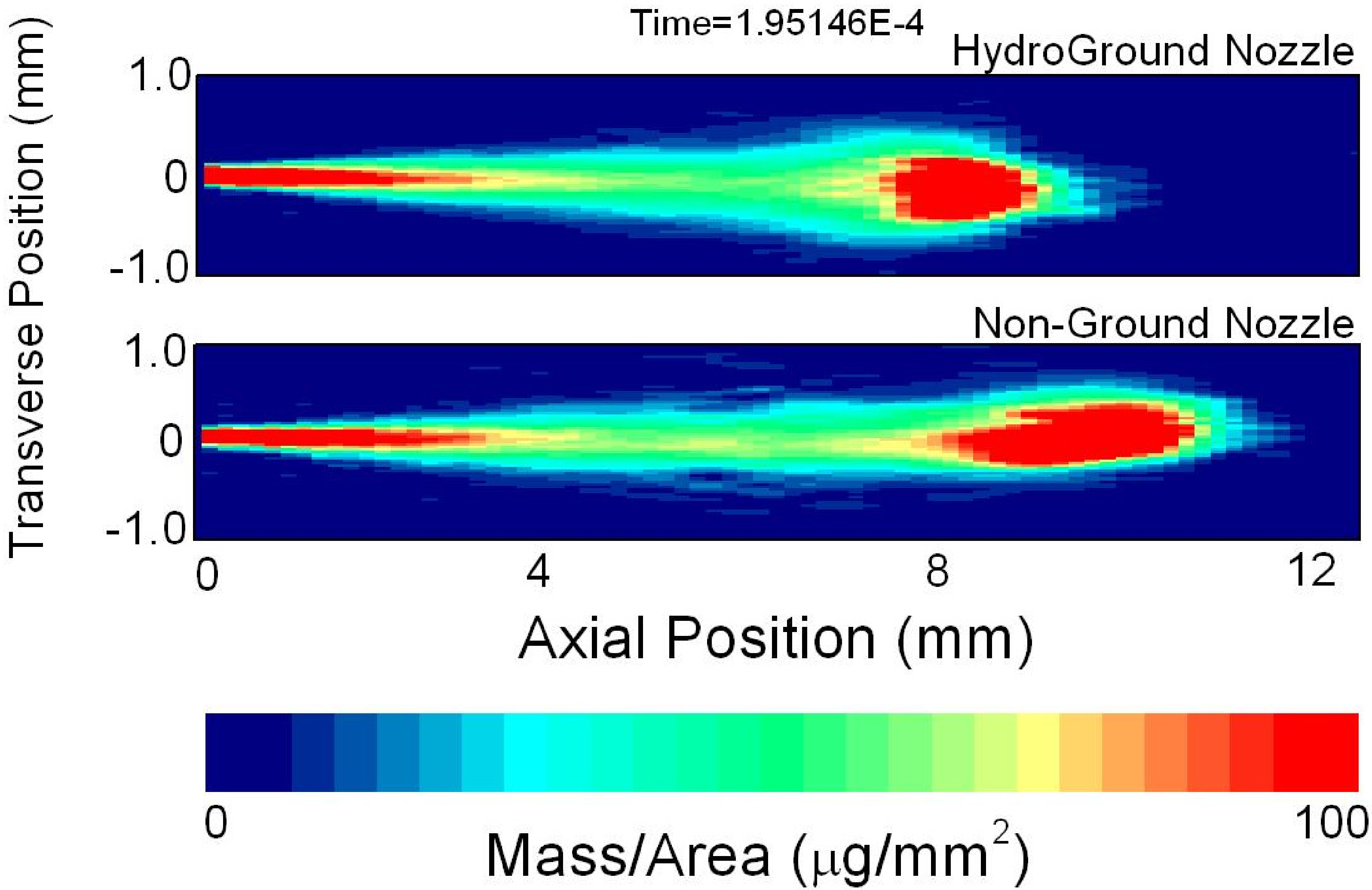
- 183 mm Orifice
- 24% Hydrogrinding
- 109 cm^3/30s @ 100bar

Non-Ground Nozzle

- 207 mm Orifice
- No Hydrogrinding
- 115 cm^3/30s @ 100bar

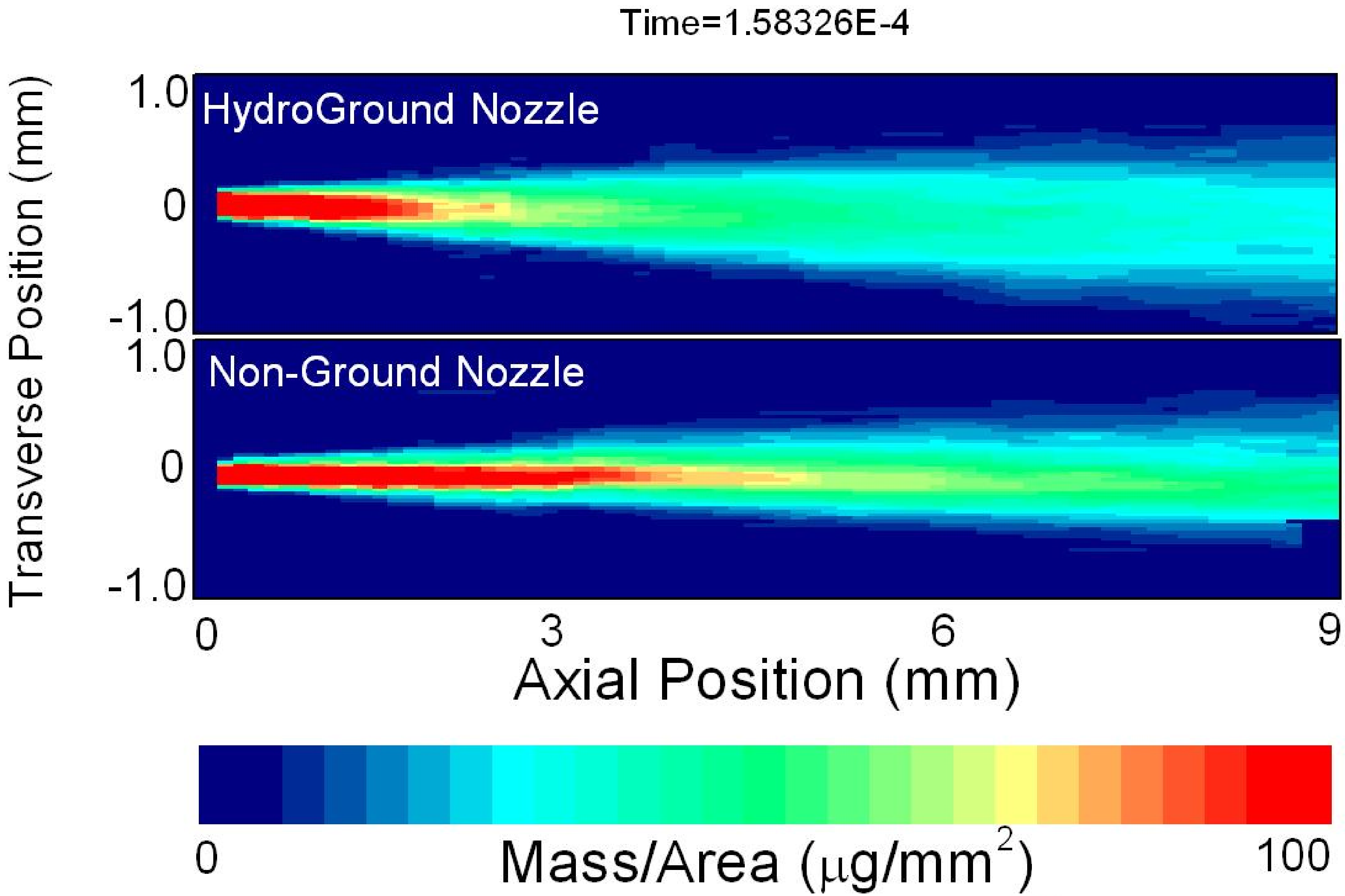
X-Ray Images of Sprays

500 bar
100 µs after SOI



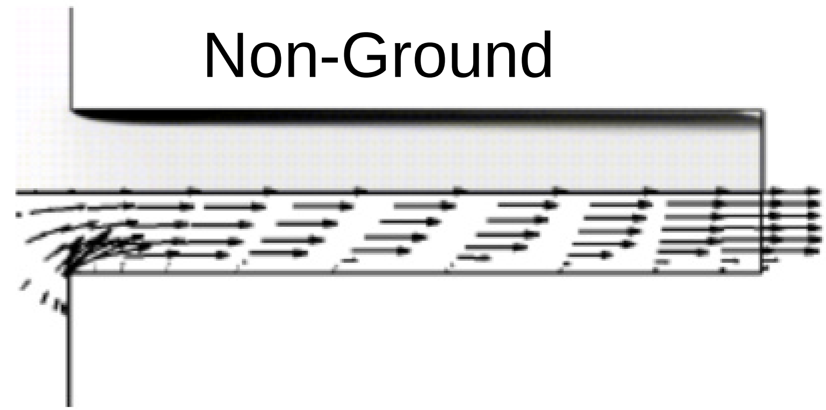
X-Ray Images of Sprays

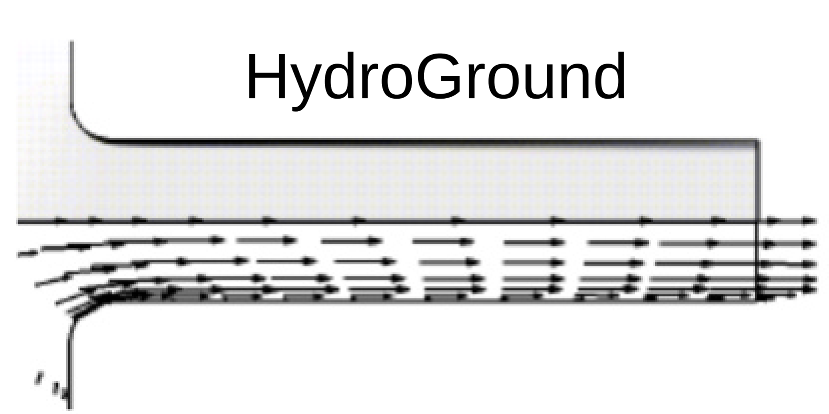
1000 bar
100 µs after SOI



Effects of Nozzle Geometry

- Different geometries predicted to produce different mass distributions.
- Models most easily validated near nozzle exit, other influences minimized
- Quantitative data not available

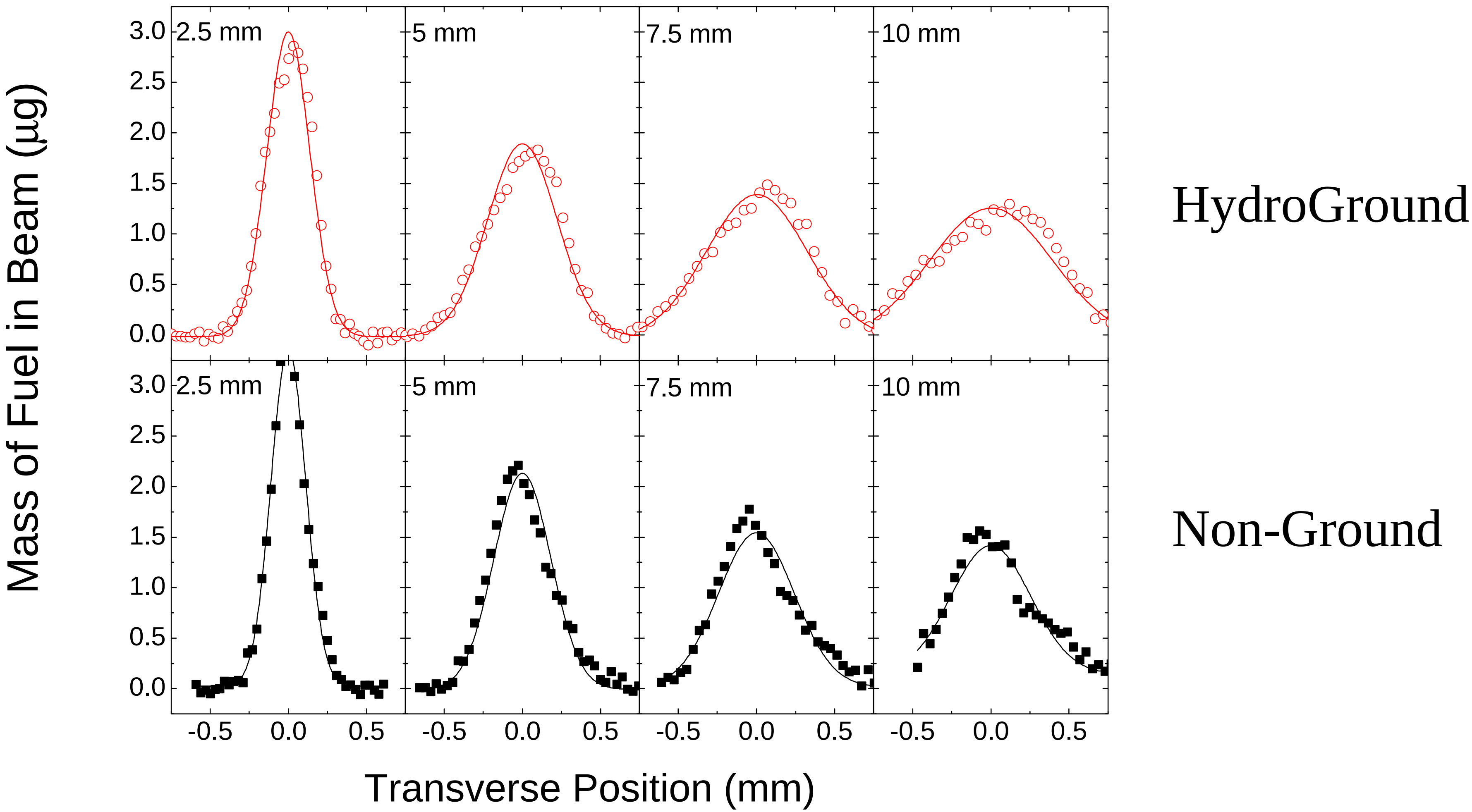




Schmidt et al., SAE 971597

Transverse Mass Distributions

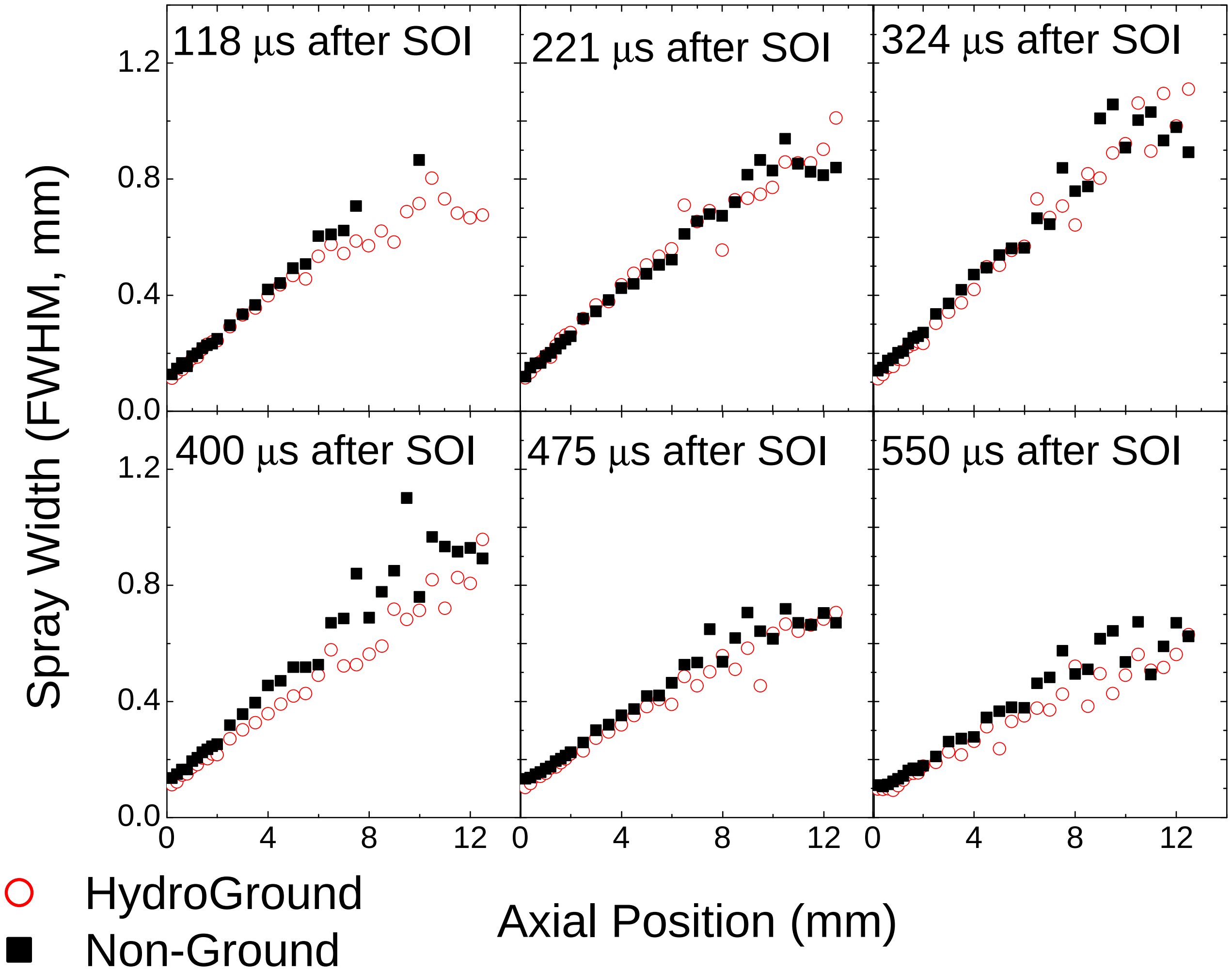
1000 bar
221 μs after SOI



ARGONNE NATIONAL LABORATORY
TRANSPORTATION
TECHNOLOGY R&D CENTER

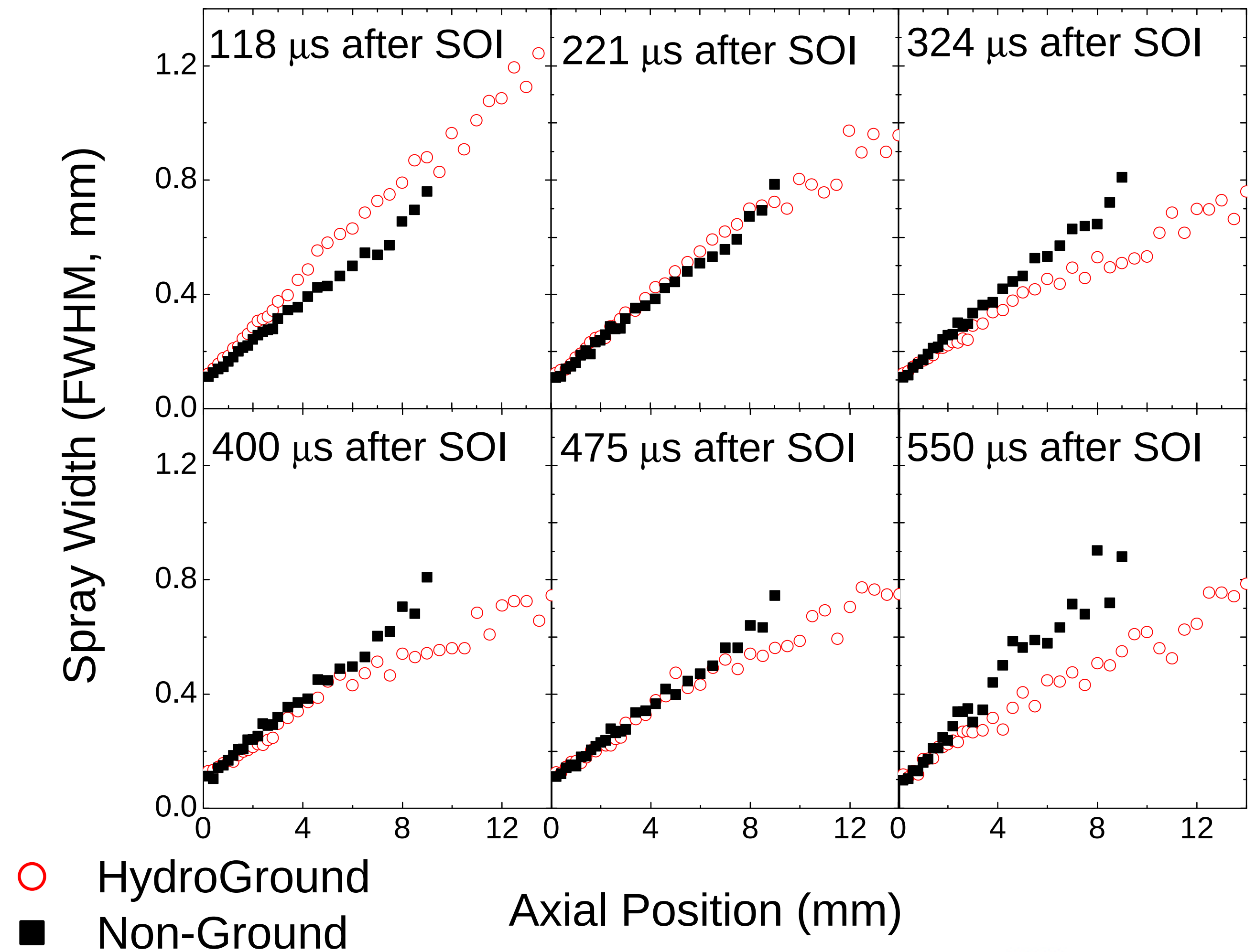
500 bar

Spray Widths



1000 bar

Spray Widths

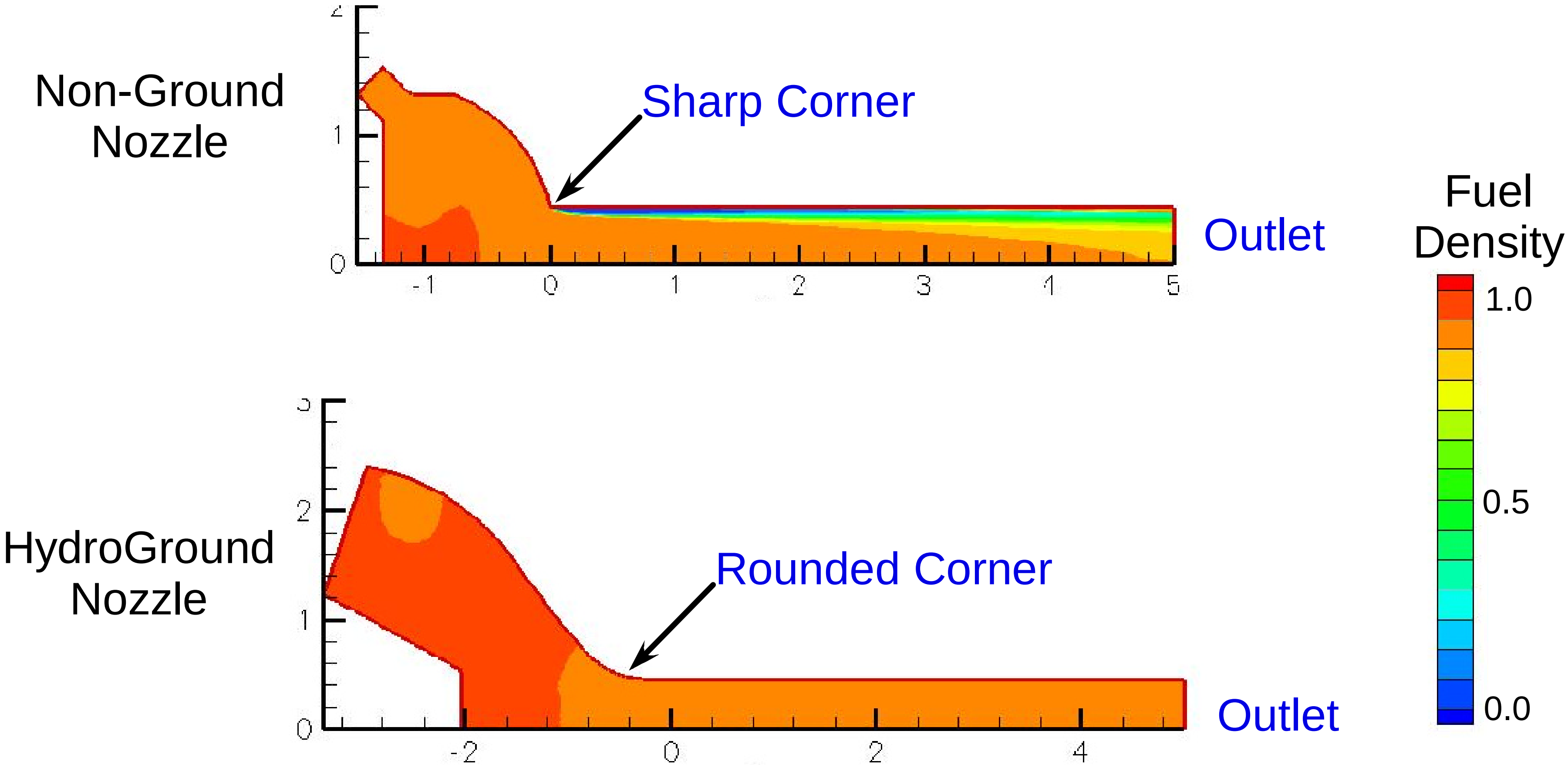


ARGONNE NATIONAL LABORATORY
TRANSPORTATION
TECHNOLOGY R&D CENTER

Conclusions

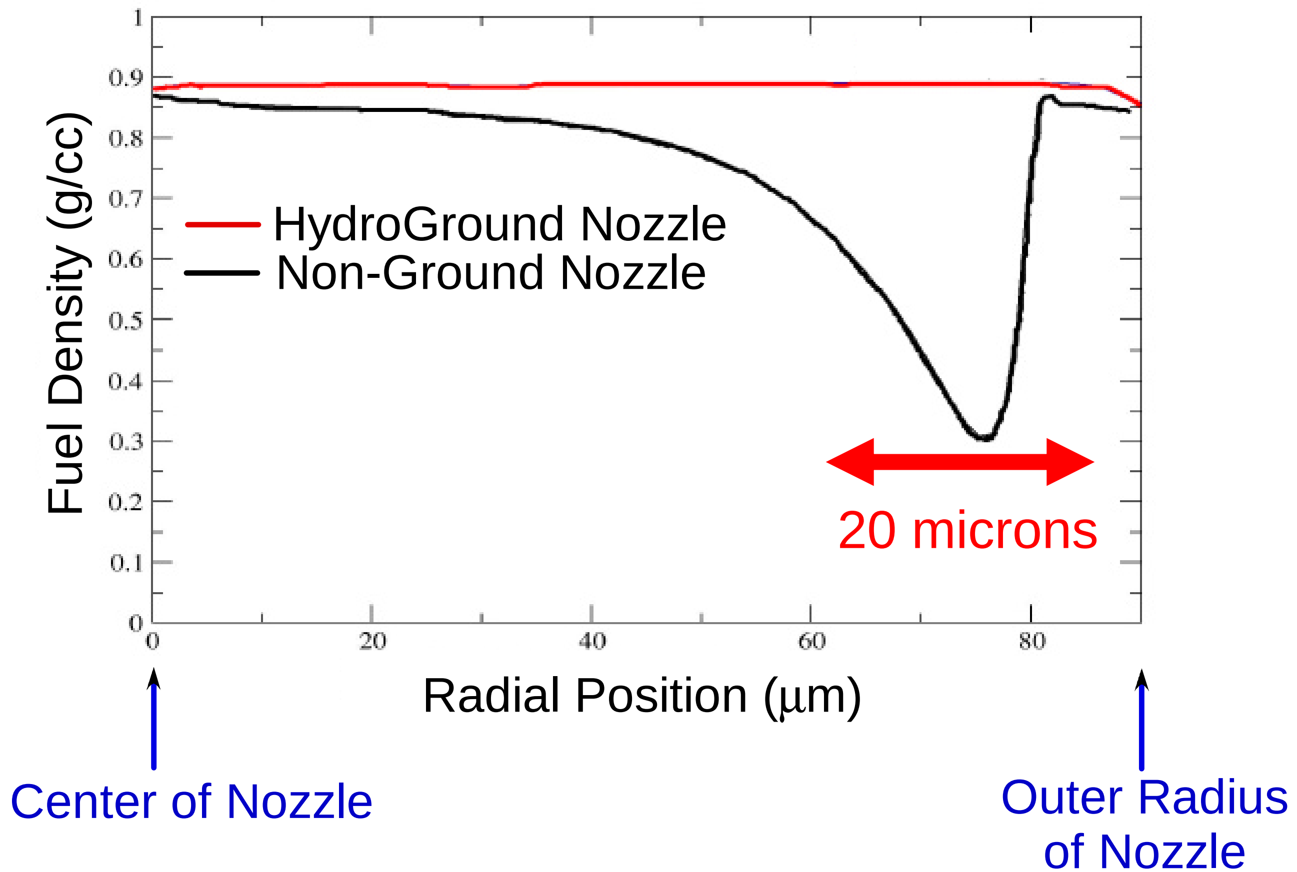
- **We observe differences in sprays between nozzles**
  - Differences are small, fluctuate over lifetime of spray
  - Difficult to measure, model

Modeling Fuel Density in the Nozzle



D. P. Schmidt and S. Gopalakrishnan, 17th Annual Conference on Liquid Atomization and Spray Systems, Arlington, VA, May 2004

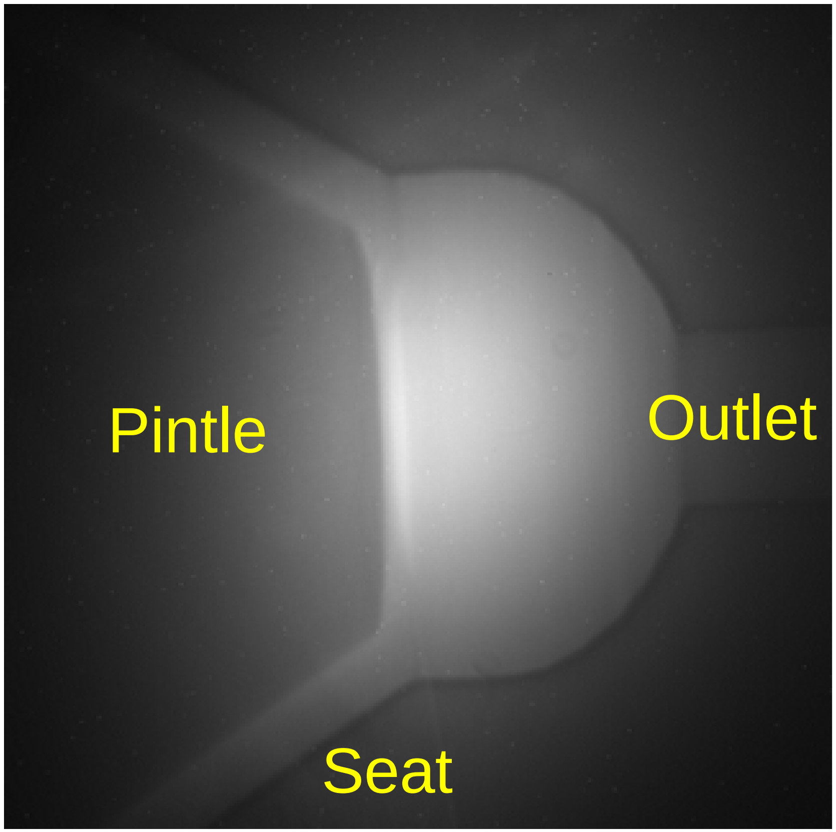
Predicted Fuel Density at Nozzle Exit



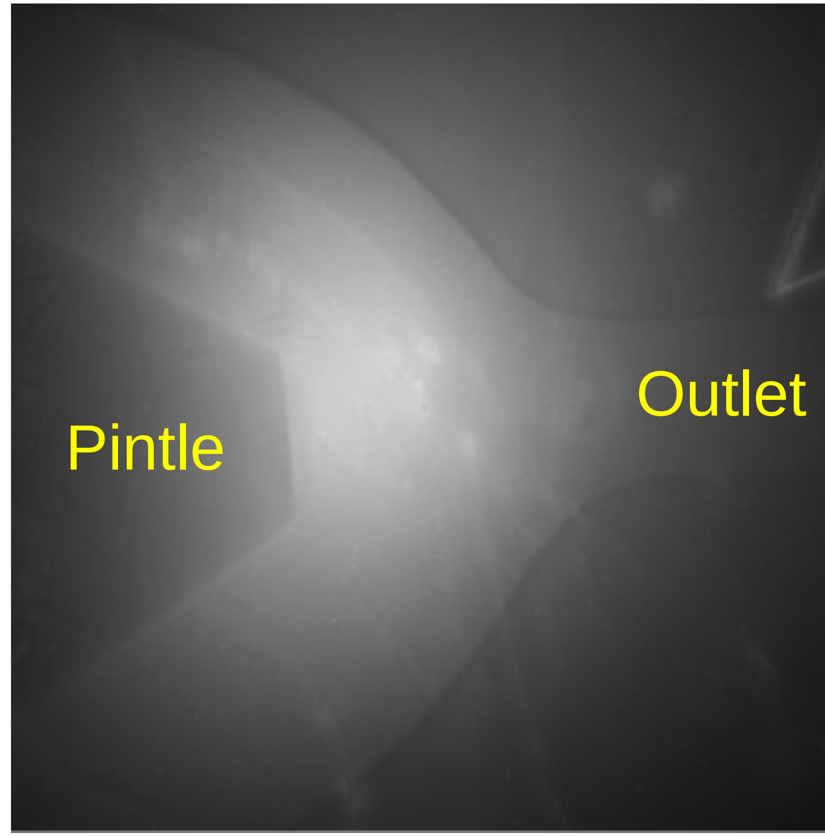
D. P. Schmidt and S. Gopalakrishnan, 17th Annual Conference on Liquid Atomization and Spray Systems, Arlington, VA, May 2004

X-Ray Imaging of Nozzle Structure

Non-Ground



HydroGround



Images Courtesy of Kamel Fezzaa and Wah-Keat Lee

Future Work

- **Studies of Nozzle Geometry**
  - Need better position resolution
  - Small-area x-ray beam to probe near-nozzle region
  - Conical nozzles, VCO nozzles
- **Measurements at Higher Ambient Pressure**
  - We recently completed measurement at 20 bar
- **Measurements at High Pressure, Temperature**
  - Rapid Compression Machine
  - “Diesel-Like” conditions
- **X-Ray Imaging of Nozzle Structure**
  - Image the pintle in motion

Acknowledgements

U.S. Dept of Energy
Gurpreet Singh

Robert Bosch GmbH
Gerd Bittlinger
Phillip Bohl
Manuel Hesser
Johannes Schaller
Jochen Walther

DaimlerChrysler
Christoph Espey
Gerhard Konig
Eberhard Wagner

Visteon Corp
David Hung
John Stefanski

General Motors
Scott Parrish

This work supported by the U.S. Department of Energy under contract W-31-109-Eng-38 and by the **Office of FreedomCar and Vehicle Technologies**. Experiments were performed at the 1-BM Beamline of the Advanced Photon Source, Argonne National Laboratory.