Sandia Hydrogen Combustion Research

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Sponsor:
DoE / OVT

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This presentation does not contain any proprietary or confidential information.

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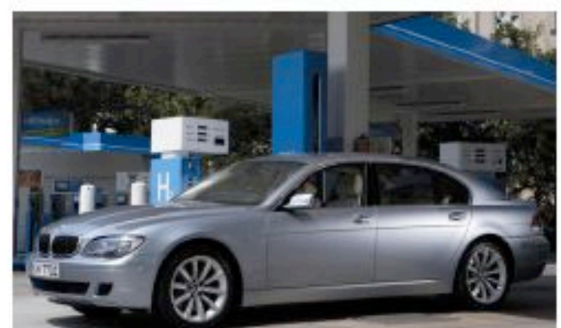
The purpose of this work is to understand hydrogen engine combustion.

- Hydrogen energy chain includes production, transportation, storage, conversion.
- For transportation use, hydrogen engines are an option building on existing, mass-produced, cost-effective technology.
- This program aims to develop the science base needed by engine companies to optimize the design of advanced hydrogen engines.
- All existing vehicles have port injection, but advanced hydrogen engine concepts are based on direct injection.

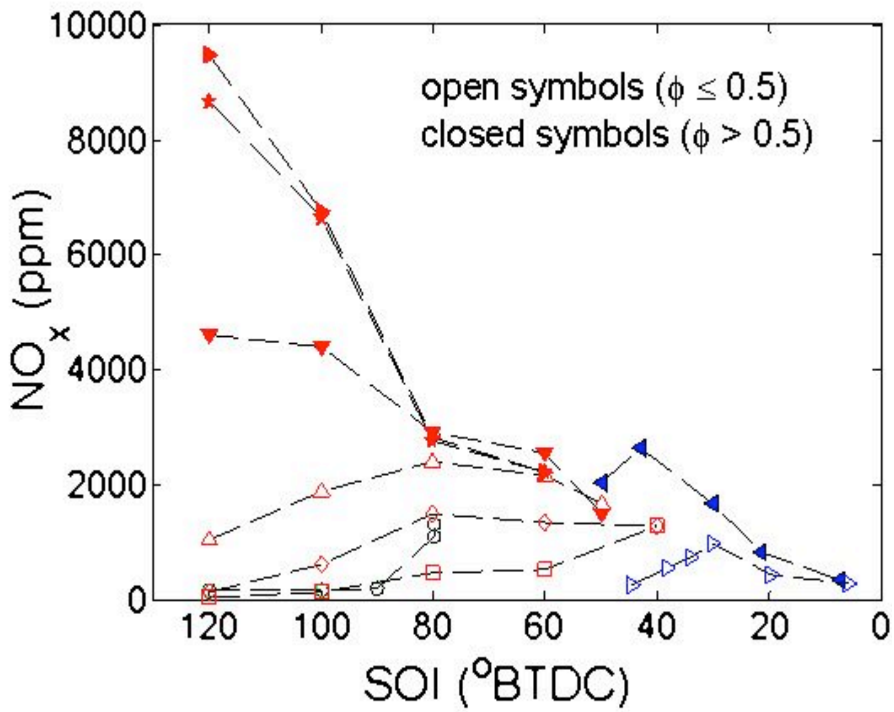


Barrier: Lack of fundamental knowledge about in-cylinder processes in hydrogen DI engines.

Strategy: In-cylinder injection after intake valve closure (DI H_2ICE)

Benefits:

- Higher power density
- Less preignition, no backflash
- Partial recovery of tank energy
- With optimal mixture preparation:
  - increased efficiency (> diesel)
  - reduced NOx



Technical challenges:

- DI operation relies on control of fuel-air mixing and combustion regimes.
- short available mixing times (1-20 ms)
- Complex flow and fuel distribution dynamics
- H_2 injector (durability issues)

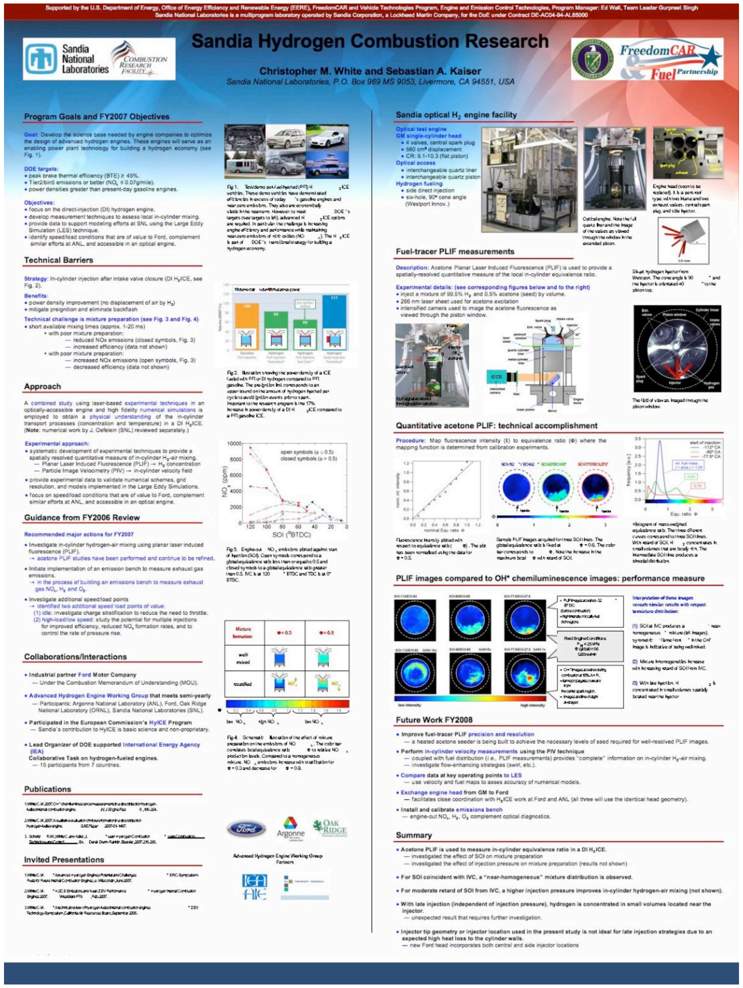
Approach: Data from optical engine provides physical understanding and simulation validation.

Numerical Simulation	Optical Measurements	Metal Engine
Sandia	Sandia	Argonne Ford (non-DoE)

- Spatially resolved measurements of in-cylinder processes
  - Fuel distribution } Mixture formation
  - Flow field } Mixture formation
  - Combustion
- Provide data for validation of high-fidelity calculations (and learn from those)
- Investigate operating strategies of interest to Ford and Argonne
- Experimental facility similar to those of other SNL presenters

There were no specific reviewer comments last year.

Sandia's experimental H_2ICE work was presented at the poster session.



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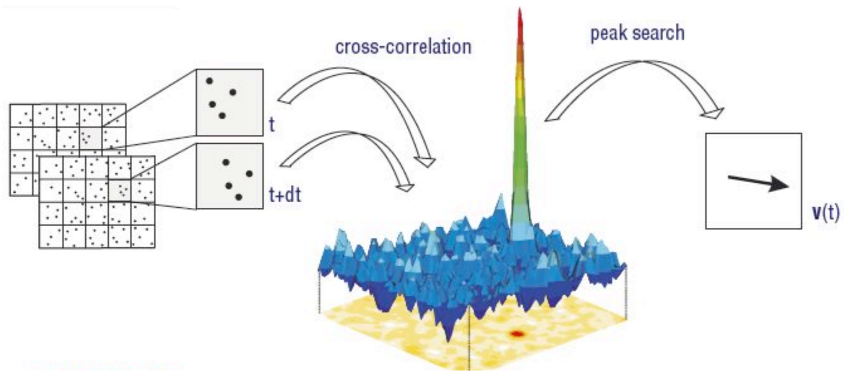
This year's major accomplishment was the investigation of in-cylinder flow.

- Quantitative imaging of fuel distribution for representative post-IVC injection timings (March 2007).
- Established high-quality 2D velocity measurements by PIV (July 2007).



- Extensively mapped flow field throughout intake and compression stroke, with and without injection (August 2007 - current).
- Comparison to Large Eddy Simulation is in progress.
- New engine head (Ford) is at Sandia. Install when current measurement series is complete.

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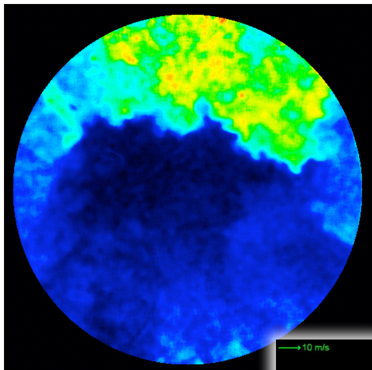
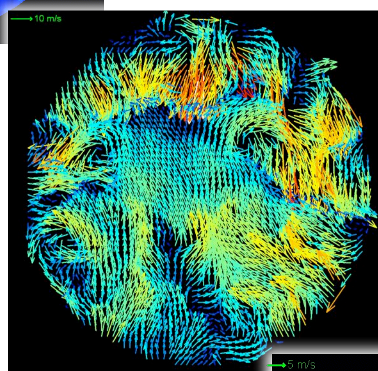
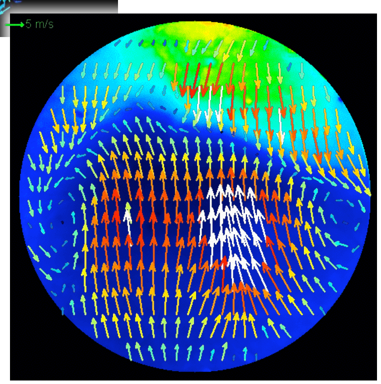
Here, we focus on the influence of injection-induced flow on the fuel distribution.







Fuel-tracer PLIF → Equivalence ratio

Separate measurements

PIV → Velocity

Injection-induced flow

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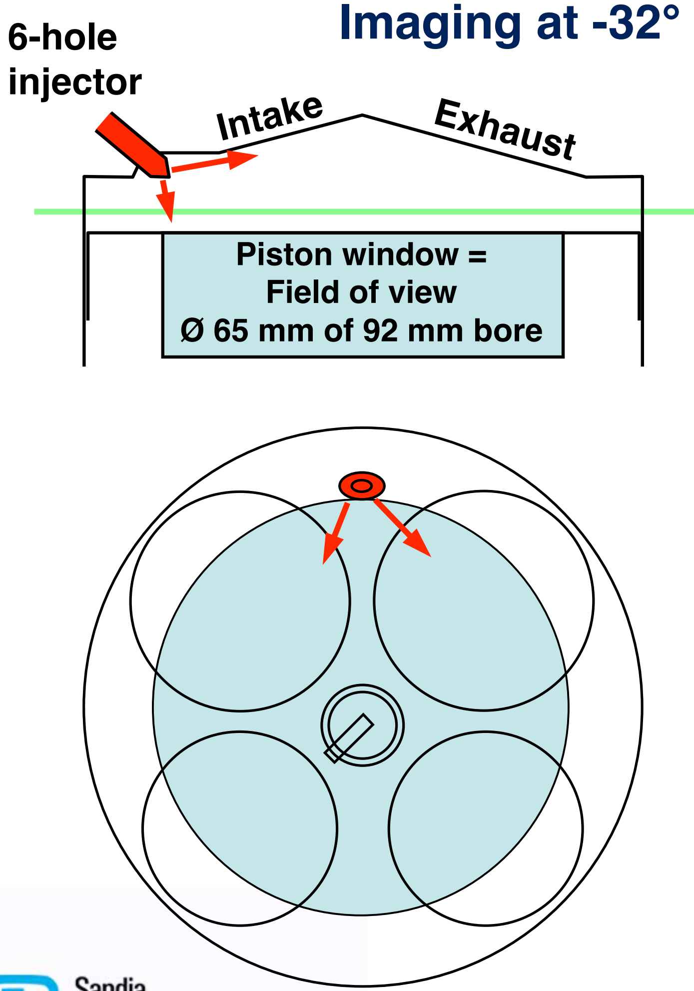
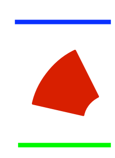
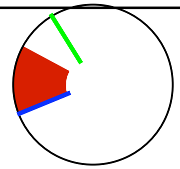
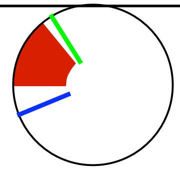
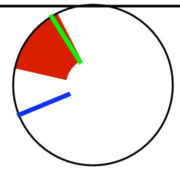
Three different post-IVC injection timings were used: Early, intermediate, late.

Imaging at -32° CA

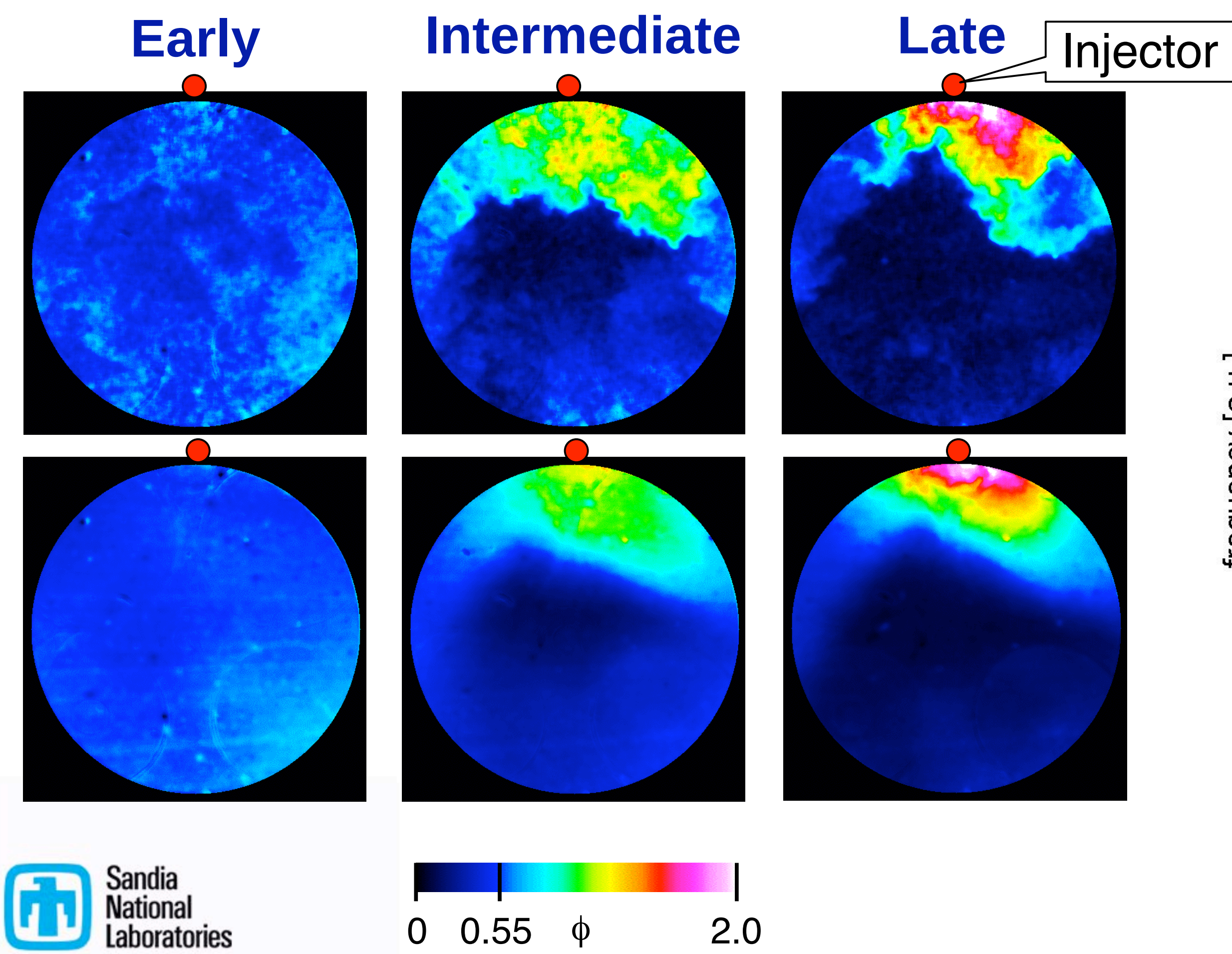


Timing	SOI [CAD]	EOI [CAD]	
early	-112	-62	
inter-mediate	-90	-40	
late	-77.5	-27.5	

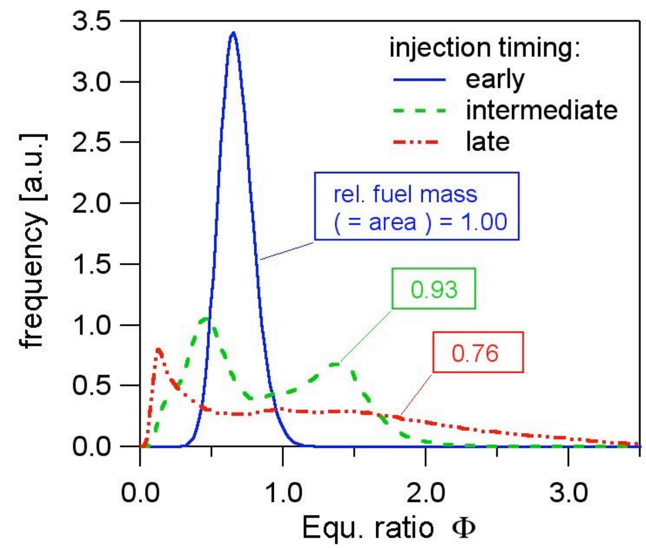
1200 rpm, $\phi = 0.55$
p_{in} = 0.5 bar, p_{H2} = 25 bar.

Early injection leads to near-homogenous mixture, intermediate and late timing to stratification.

Equivalence ratio fields for different injection timings



Mass-weighed histogram



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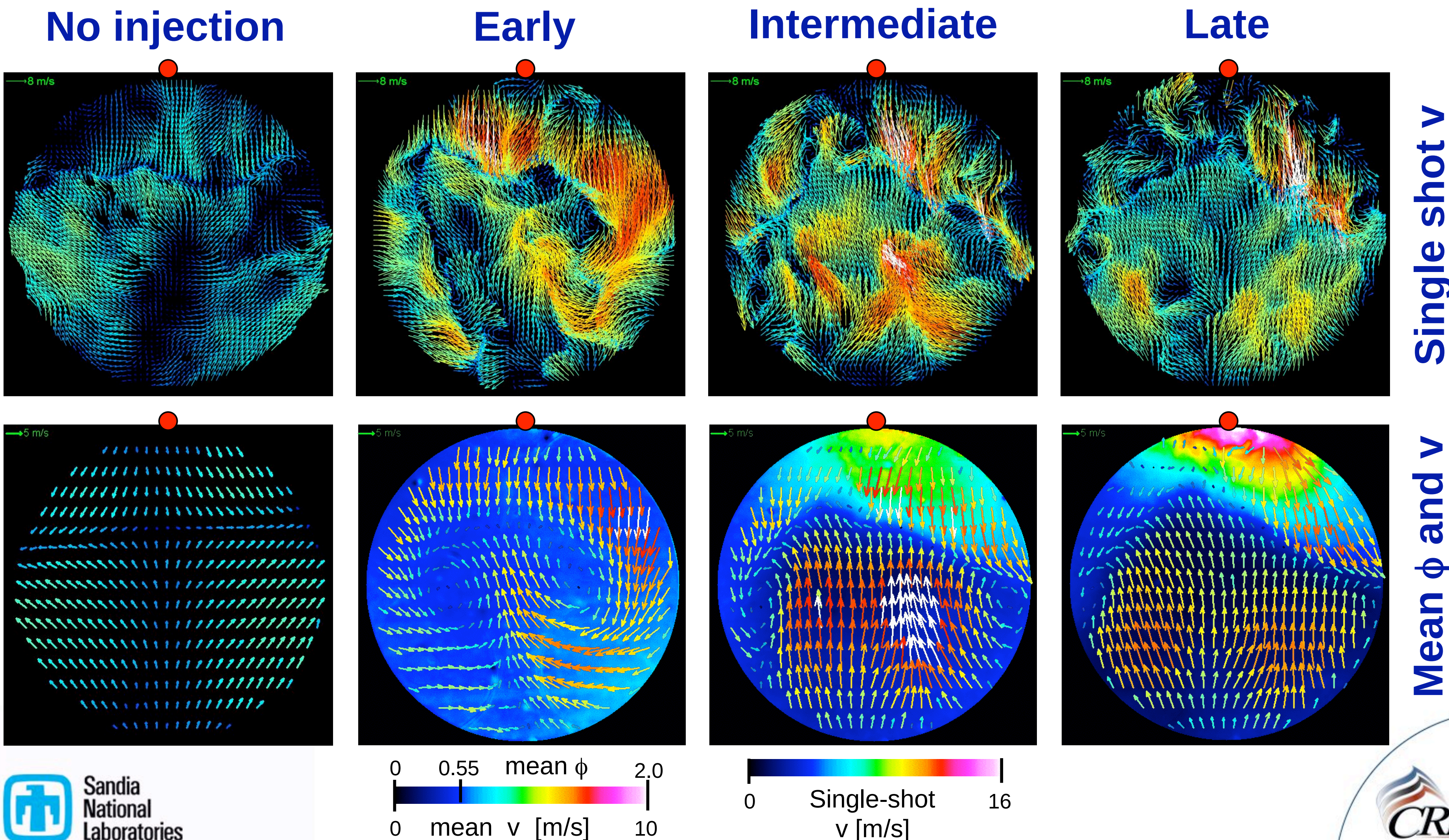
In the multi-cycle mean, fuel distribution and velocity correlate very well.



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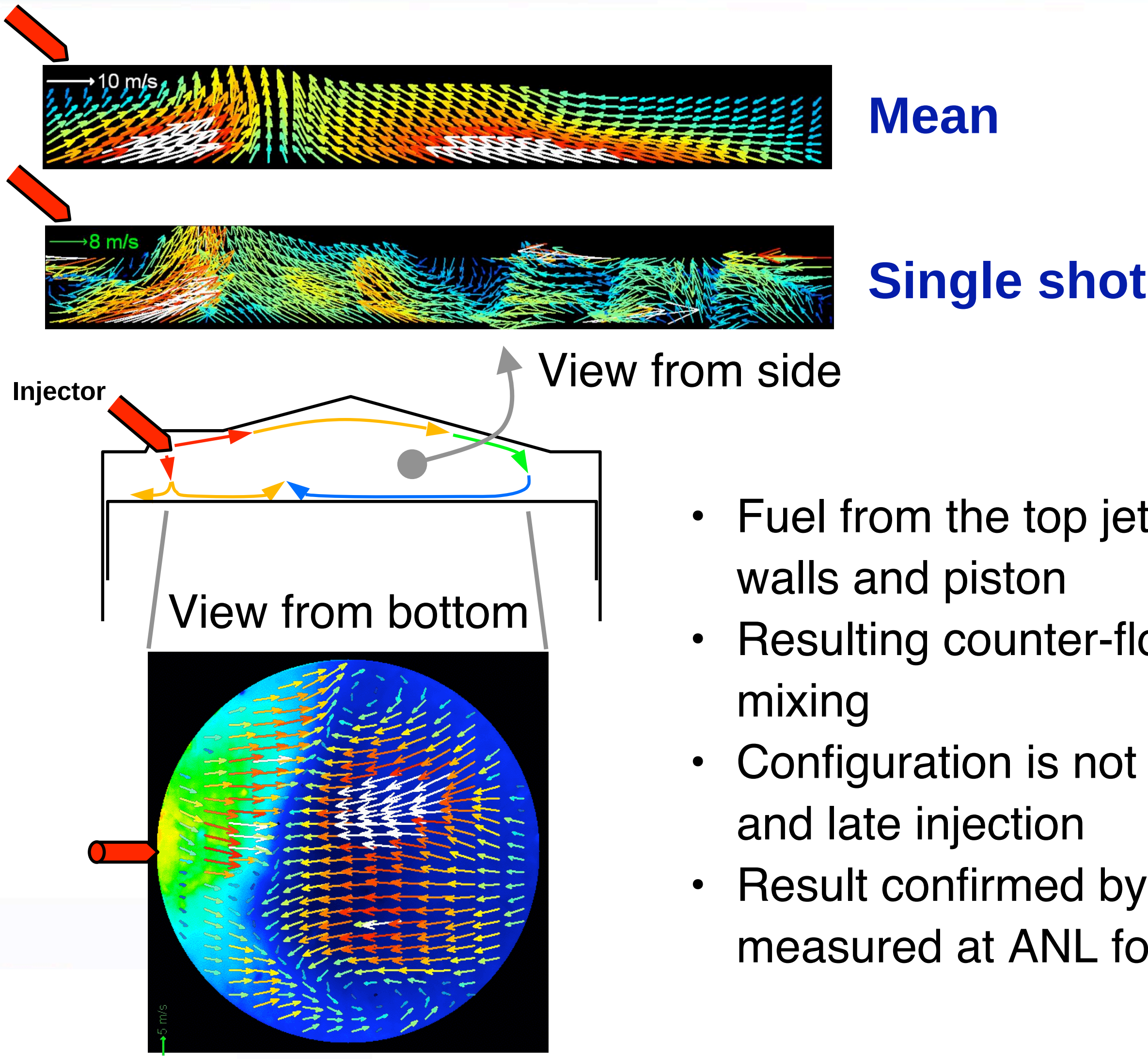
For intermediate and late timing, injection-induced flow prevents effective mixing.



Intermediate injection timing

- Fuel from the top jets is re-directed by the walls and piston
- Resulting counter-flow is stable and prevents mixing
- Configuration is not suitable for intermediate and late injection
- Result confirmed by drop-off in efficiency measured at ANL for SOI later than -100° CA

Technology transfer is an integral part of our approach.

- Industrial partner Ford Motor Company under the Combustion Memorandum of Understanding.

- Advanced Hydrogen Engine Working Group that meets semi-yearly:
  Argonne National Laboratory (ANL), Ford, Oak Ridge National Laboratory (ORNL), Sandia National Laboratories (SNL)

- Lead Organizer of International Energy Agency's Collaborative Task on Hydrogen-fueled Engines; participated in the European Commission's HyICE Program

- New collaborations with University of New Hampshire, University of Orléans

Activities for next year include measurements coordinated with Ford and ANL.

- Further optical characterization of fuel distribution and flow at key operating points as identified by Ford in metal-engine tests.

- Optical measurements with multiple injection
  - Multi-DI strategies have shown great promise at Ford.
  - Why they work? Fuel distribution? Combustion regime?
  - Imaging will provide understanding for optimization.

- New engine head from Ford is at Sandia
  Ford, ANL, and Sandia will have identical geometry (Summer 08)

- Validation of companion Large Eddy Simulation (J. Oefelein, SNL):
  Motored cycles - in progress
  Injected cycles - September 08

In summary, DI-H_2ICE development profits from measurements in the optical engine.

- H_2ICE will be a highly efficient transportation power plant in the hydrogen energy chain. Petroleum displacement is dependent on overall energy system.
- Direct injection is an enabling technology for power density and emissions.
  - Control of fuel-air mixing and combustion regimes is critical.
  - Experiments in optical engine provide physical understanding.
  - Quantitative measurements for simulation validation.
- Accomplishments:
  - Fuel distributions imaged for representative injection timings.
  - In-cylinder flow field mapped extensively.
  - High-quality velocity measurements now routine.
- Technology transfer through collaboration with Ford, ANL, other national labs, IEA.
- Next: Advanced injection strategies, homogenization of experimental platform (Ford head), simulation validation.

Publications and presentations

S.A. Kaiser, C.M. White, *PIV and PLIF to Evaluate Mixture Formation in a Direct-Injection Hydrogen-Fuelled Engine*, paper 08PFL-743, SAE World Congress, April 14-17, 2008, Detroit, MI.

C.M. White, *A Qualitative Evaluation of Mixture Formation in a Direct-Injection, Hydrogen-Fuelled Engine*, SAE Paper 2007-01-1467, 2007.

C.M. White, *OH* chemiluminescence measurements in a direct injection hydrogen-fuelled internal combustion engine*, Int. J. Engine Res. 8:185-204, 2007.

C.M. White, *Advanced Hydrogen-Fueled Engines: Potential and Challenges*, presented at the ERC Symposium on Fuels for Future Internal Combustion Engines, University of Wisconsin, Madison, WI, June 6, 2007.

S.A. Kaiser, C.M. White, *Sandia Optical H_2ICE*, presented at the Ford/National Labs H_2ICE Meeting, Combustion Research Facility at SNL, Livermore, CA, February, 2008.

S.A. Kaiser, C.M. White, J.C. Oefelein, D.L. Siebers, *Sandia Hydrogen Combustion Research: Simulation and Experiment*, presented at the International Energy Agency Task Leaders Meeting, Gembloux, Belgium, September 2007.