Sandia H_2ICE Combustion Research

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Combustion Research Facility
Sandia National Laboratories

Sponsor: DOE Office of Vehicles Technologies
Program Manager: Gurpreet Singh

IEA Task Leaders Meeting
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Goals, Targets and Objectives

Goal: Develop the science base needed by engine companies to optimize the design of advanced hydrogen engines.

"*H_2ICE is an enabling technology for building a hydrogen economy*"

Supports DOE targets:

- Peak brake thermal efficiency (BTE) ≥ 45%
- Tier2/bin5 emissions or better (NO_x ≤ 0.07g/mile)
- Power densities greater than present-day gasoline engines

Objectives:

- Focus on the direct-injection (DI) hydrogen engine (most promising)
- Investigate optimal in-cylinder hydrogen-air mixing
  - experiments and modeling to assess local mixing
    - > *develop next-generation engine design tools*

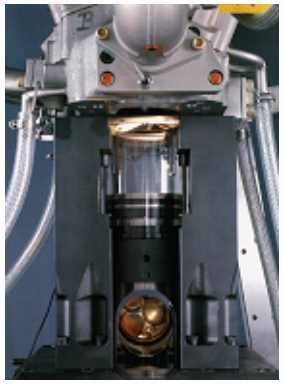
Sandia H_2ICE Program

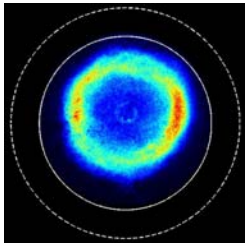
Experimental Program
PI: Sebastian Kaiser

- Single-cylinder optical test engine
- Apply advanced laser-based optical diagnostics

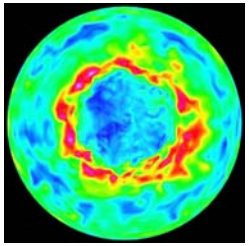
Numerical Program
PI: Joseph Oefelein

- High-fidelity simulations using the Large Eddy Simulation (LES) technique.
- Massively parallel computation facilities





One-To-One Correspondence Between Simulations and Engine Experiments



Technical Approach and Challenges

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

Benefits:

- power density improvement (no displacement of air by H_2)
- mitigate preignition and eliminate backflash
- unthrottled operation over wide range
- decreased heat losses $\rightarrow$ higher efficiency

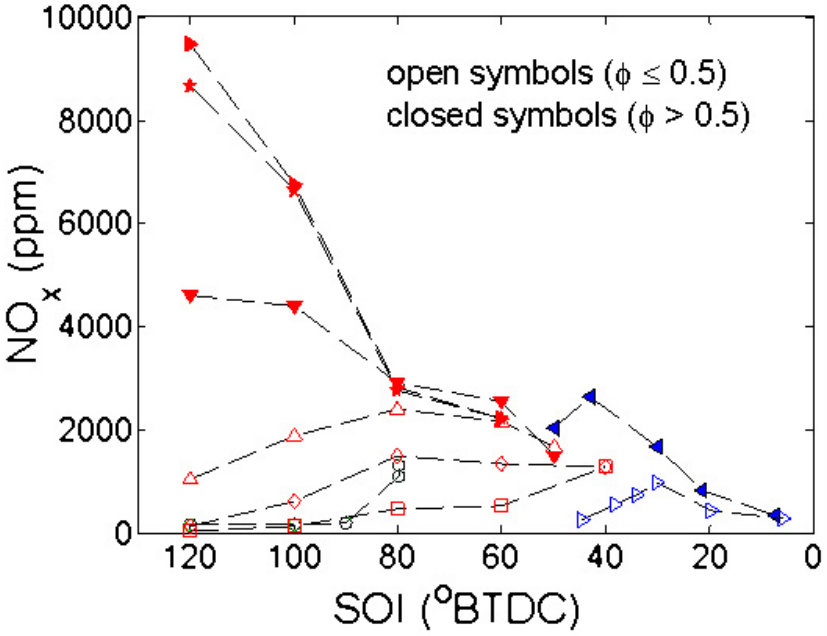
Allows attributes of HCCI but with a conventional combustion strategy

Technical challenges:

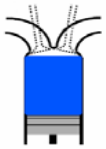
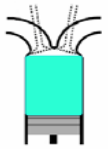
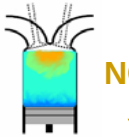
- high-pressure, high-flow H_2 injector (durability issues)
- large volume of fuel to inject
- short available mixing times (approx. 1-20 ms)
- if mixture preparation poor:
  - reduced efficiency
  - increased NO_x emissions

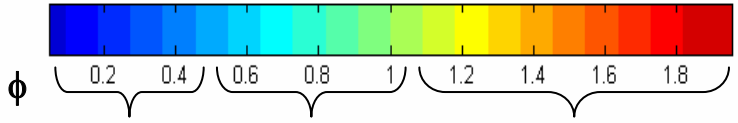
A focus on H_2-air mixing

Effect of start-of-injection on NO_x emissions



Conjecture:
Mixture inhomogeneities

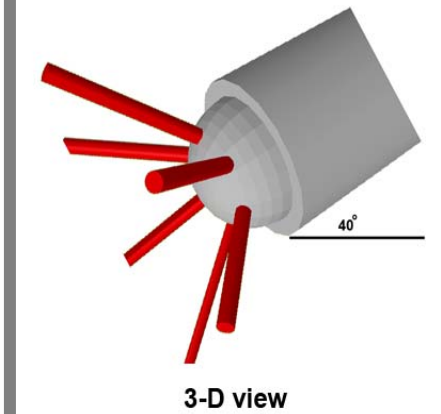
Mixture formation	ϕ = 0.3	ϕ = 0.8
well-mixed		
stratified	 NO_x ↑	 NO_x ↓



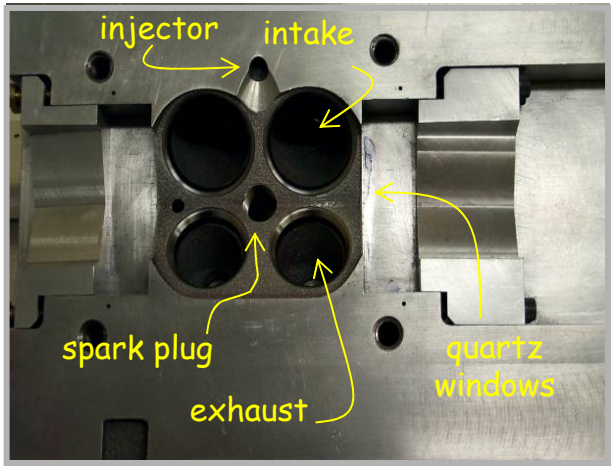
low NO_x high NO_x low NO_x

Similar effects of SOI on BTE. It is therefore critical to develop a knowledge base of in-cylinder transport processes in a DI H_2ICE

Sandia optical H_2 engine facility



3-D view



Optical test engine

GM single-cylinder head

- 4 valves, central spark plug
- 560 cm^3 displacement
- 92 mm x 85 mm bore x stroke
- CR: 9.1-10.3 (flat piston)

Optical access

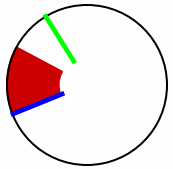
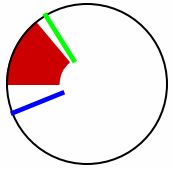
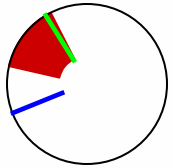
- interchangeable quartz liner
- interchangeable quartz piston

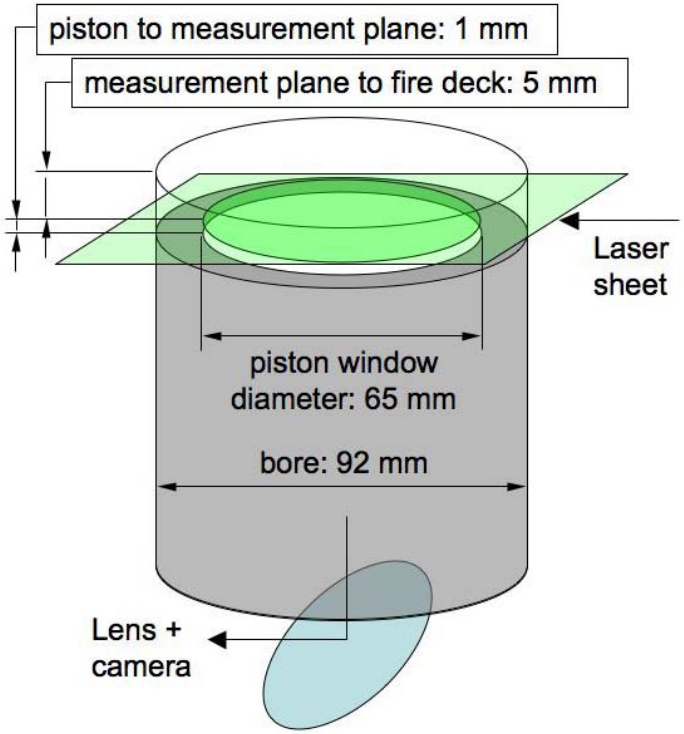
Hydrogen fueling

- side direct injection
- six-hole, 90° cone angle (Westport Innov.)

Operating point, timing, geometry

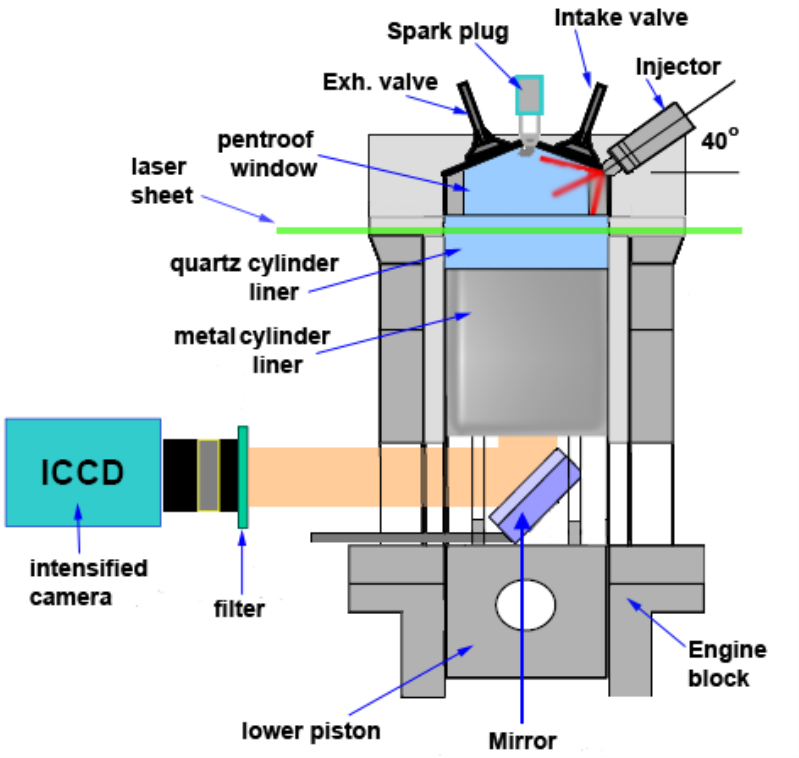
- 1200 rpm, MAP = 0.5 bar, ϕ = 0.6, p_{inj} = 25 bar
- IVC = -112° CA
- ΔCA_{inj} = 50° (7 ms)
- images at -32° CA
- three different injection timings investigated

Timing	SOI [° CA]	EOI [° CA]	
early	-112	-62	
intermediate	-90	-50	
late	-77.5	-27.5	

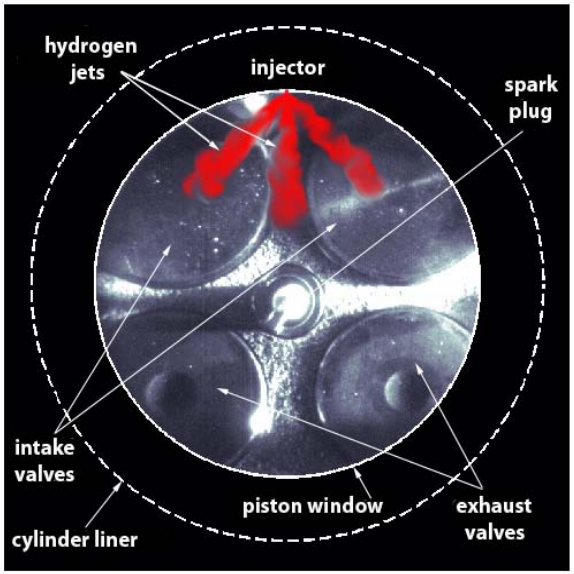


Acetone PLIF measurements

- Inject a mixture of 99.5% H_2 and 0.5% acetone (seed) by volume into N_2.
- Excitation: laser sheet at 266 nm from Nd:YAG
- Detection: broadband visible with intensified CCD
- Acetone has well-known photophysics → calibrate, quantify

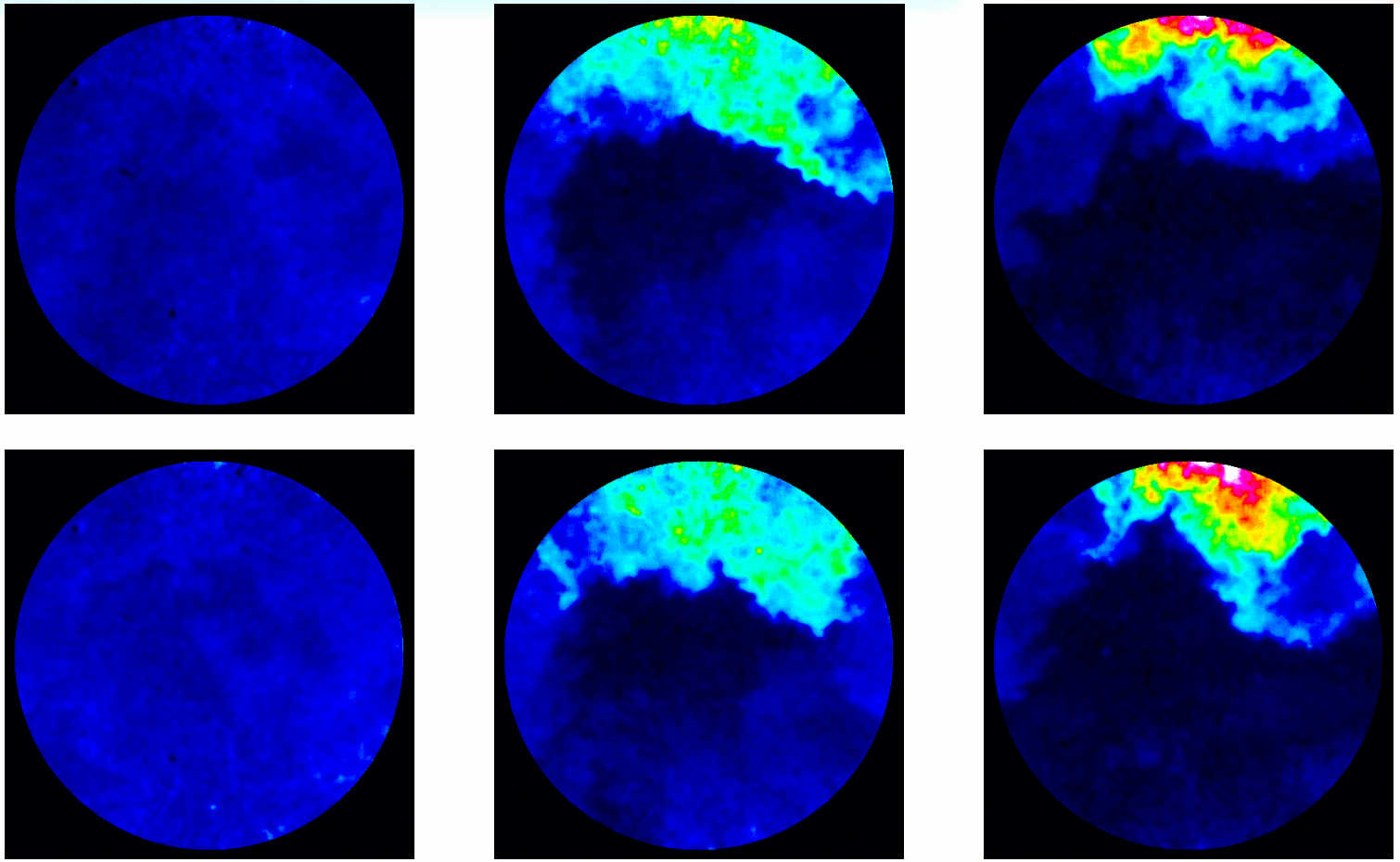


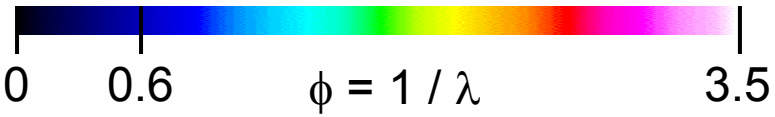
imaged field-of-view



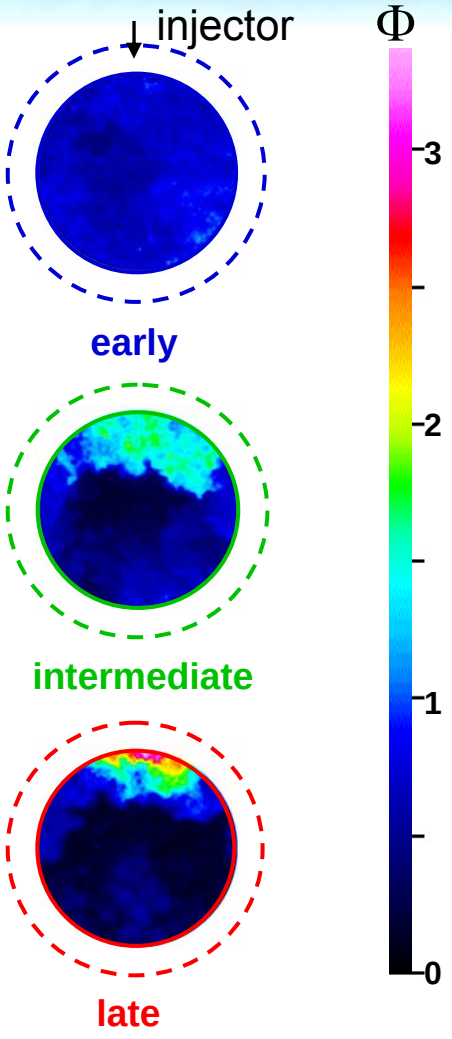
Spatial fuel distribution: sample shots

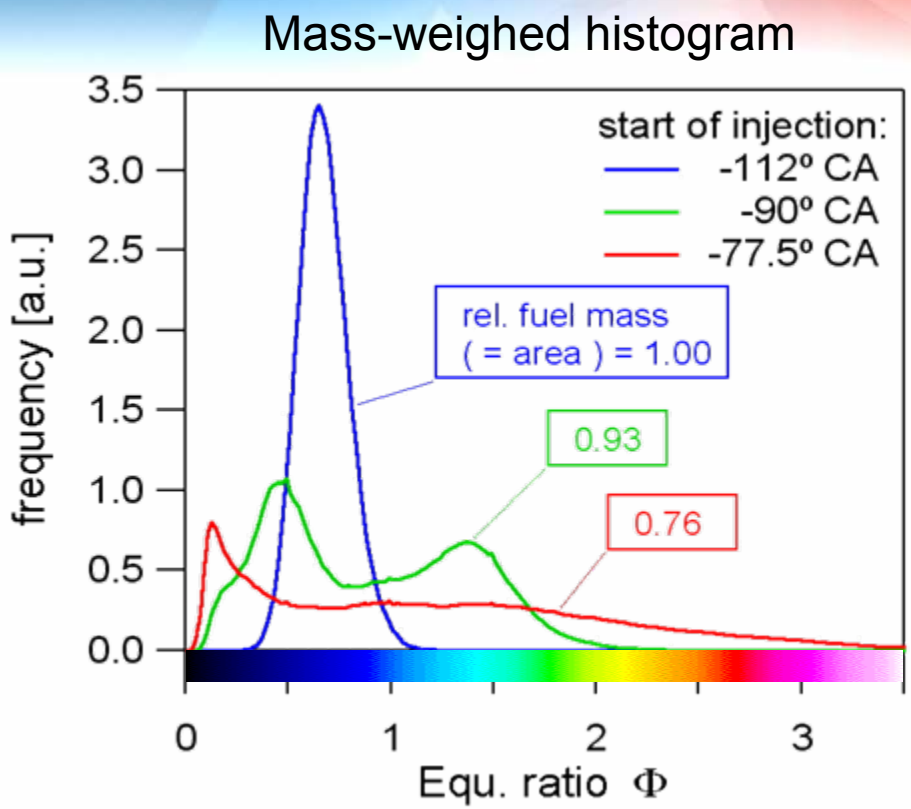
Early injection | Intermediate injection | Late injection





Fuel occurrence histogram

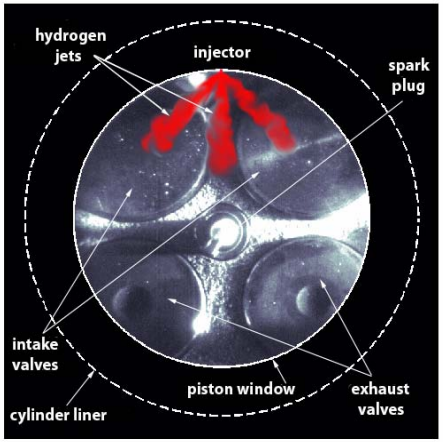


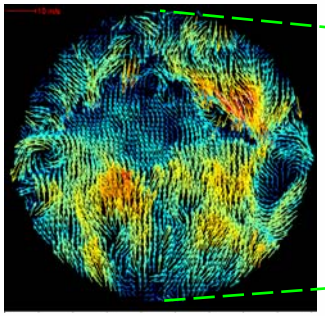


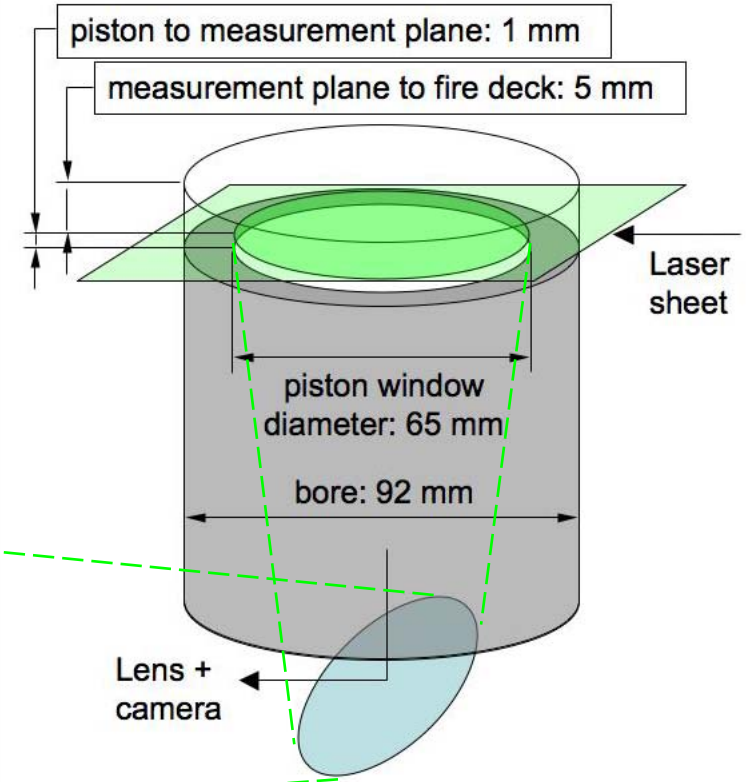
- Later injection yields broader, bimodal histograms
- More fuel outside of images area
- Note: IMEP for *fired* case roughly constant

PIV measurements

- Measure the two in-plane velocity components in r - θ plane
- Seed particles: 2 μm SiO_2 into N_2 in intake plenum
- Excitation: double-pulse Nd:YAG at 532 nm
- Detection: dual frame CCD
- Evaluation with DaVis©
- 32 x 32 pixels (2 x 2 mm^2) interrogation areas
- Interframe time 12.5 - 45 μs

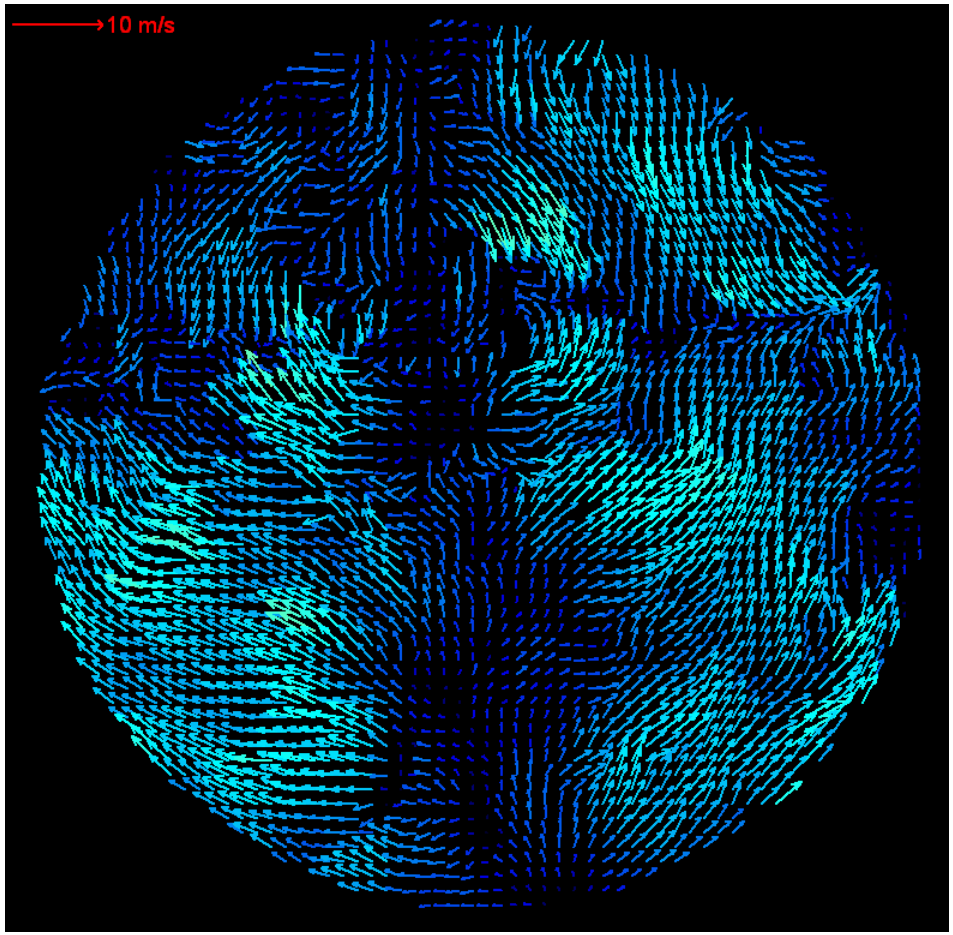




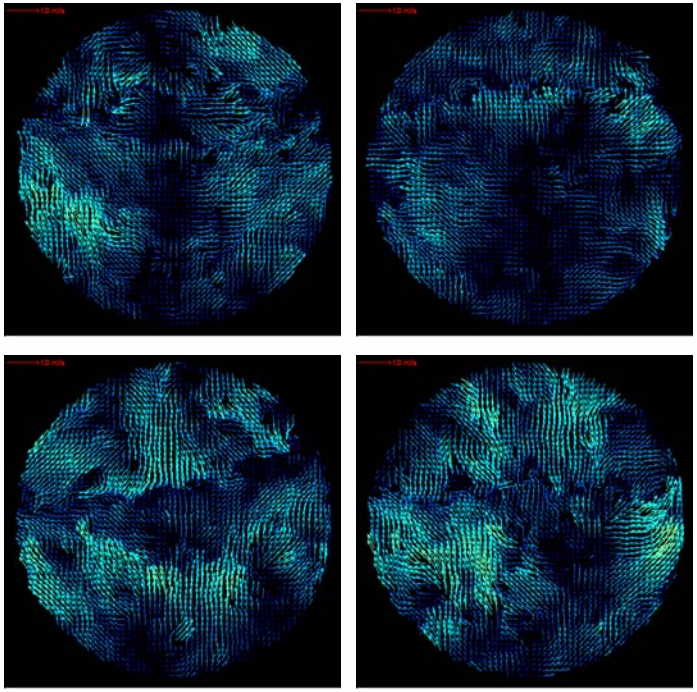


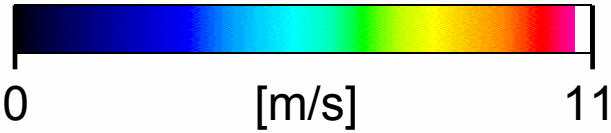
Sample velocity fields - no injection

No injection



- Smooth velocity field
- No strong mean flow
- Random turbulent fluctuations, as expected

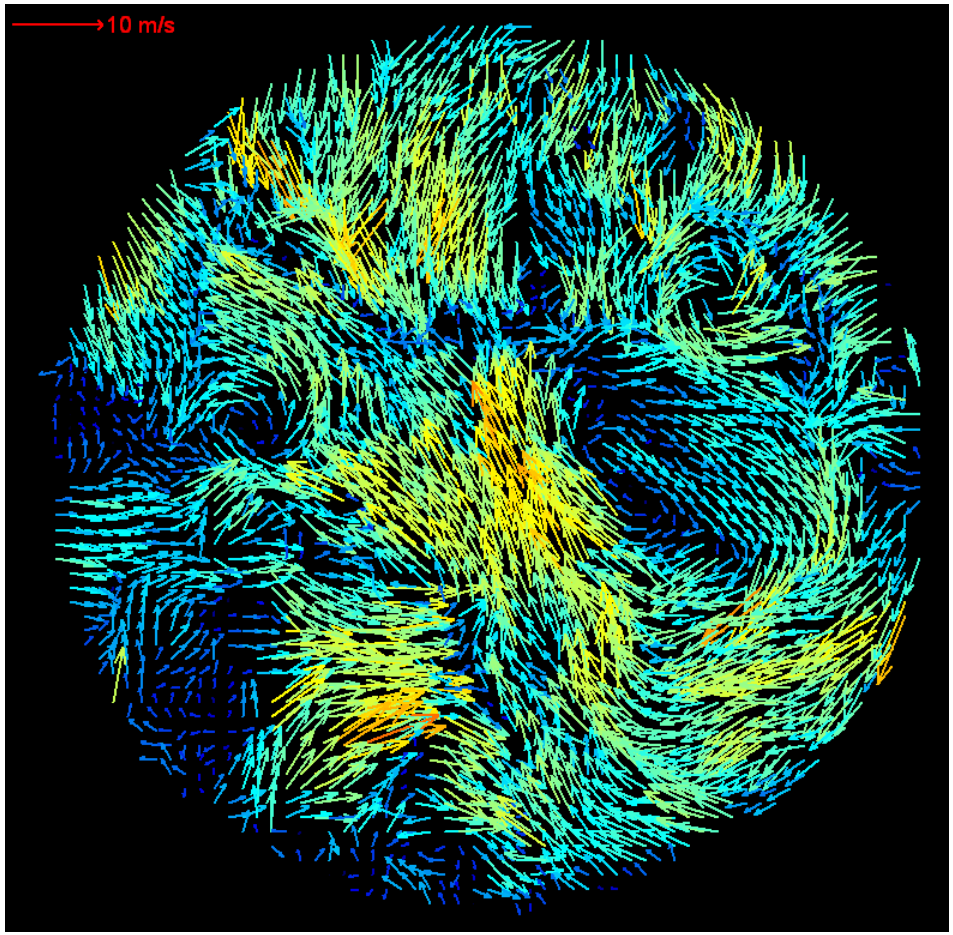




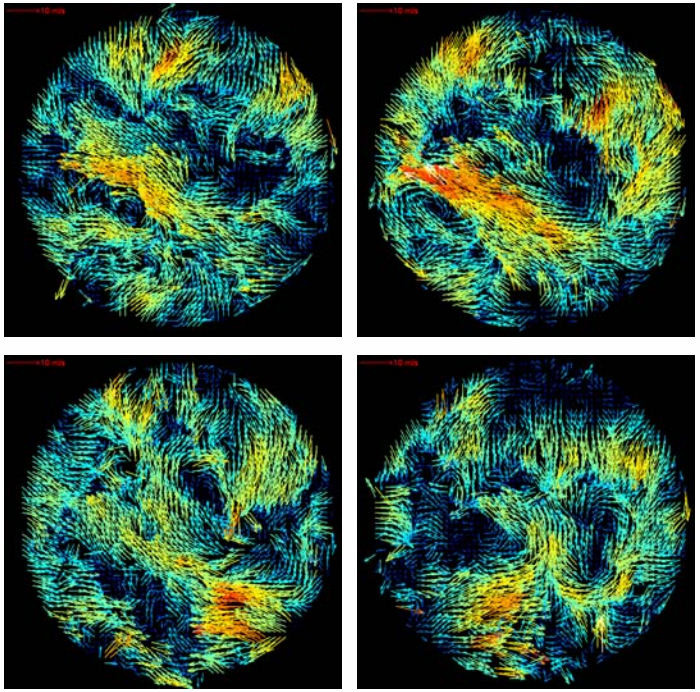
$\Delta t = 45\ \mu s$

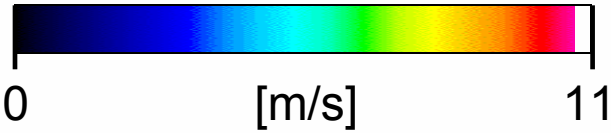
Early injection

SOI: -112° / EOI: -62 °



- Distinct large-scale structures
- Some mean flow
- Velocities greatly increased

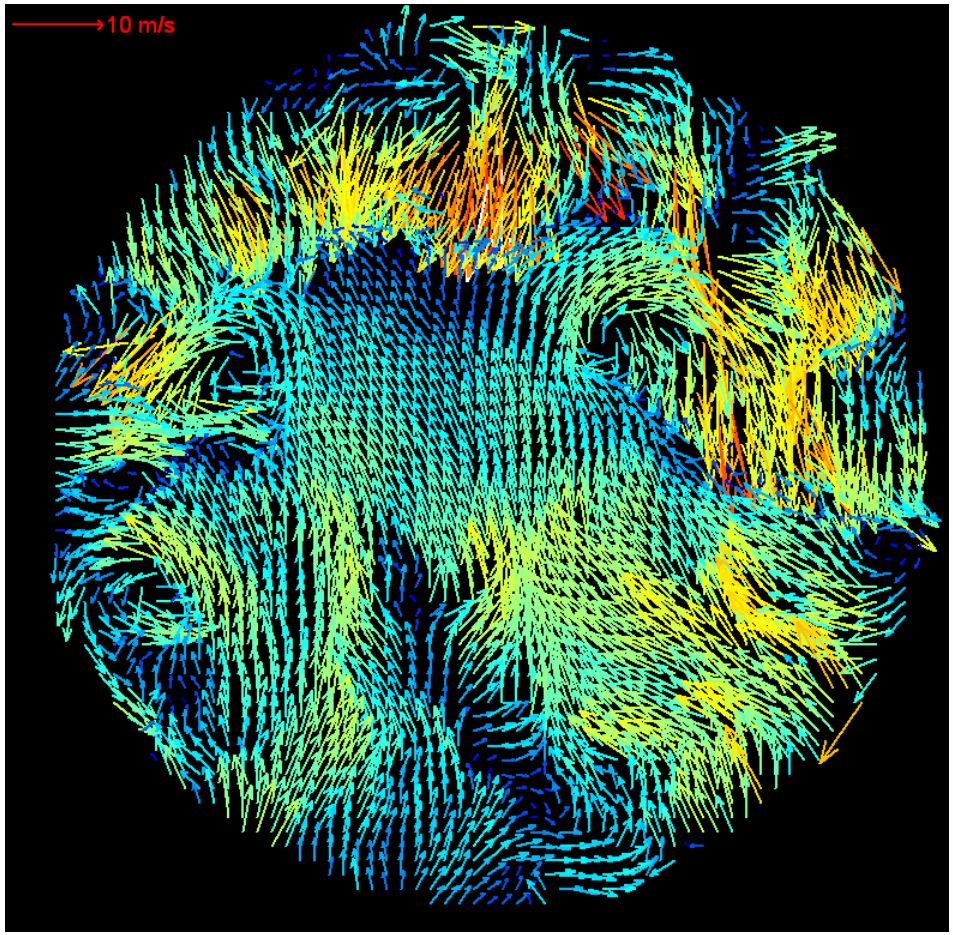


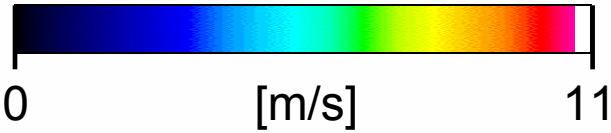


$\Delta t = 25\ \mu s$

Intermediate injection

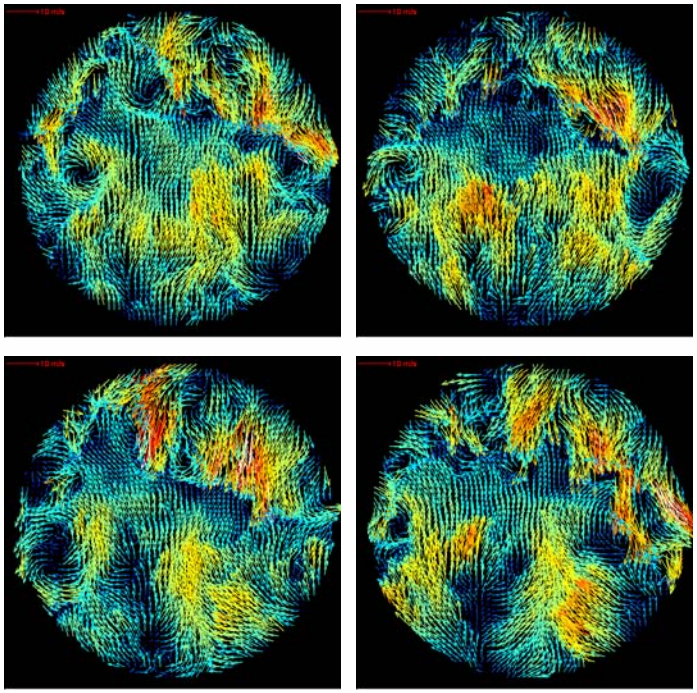
SOI: -90° / EOI: -40 °





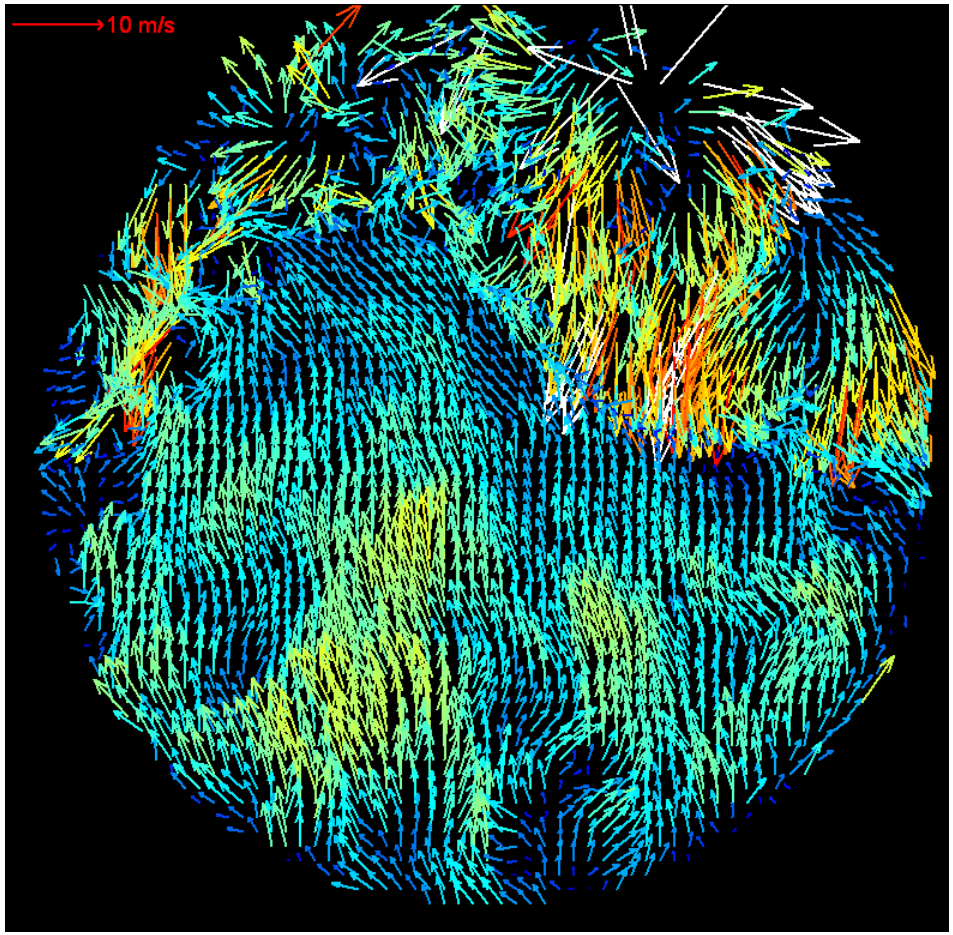
$\Delta t = 20\ \mu s$

- Higher velocities and turbulence near injector
- Mean flow has changed direction towards injector (“up”)
- Vortices ~5-10 mm diameter

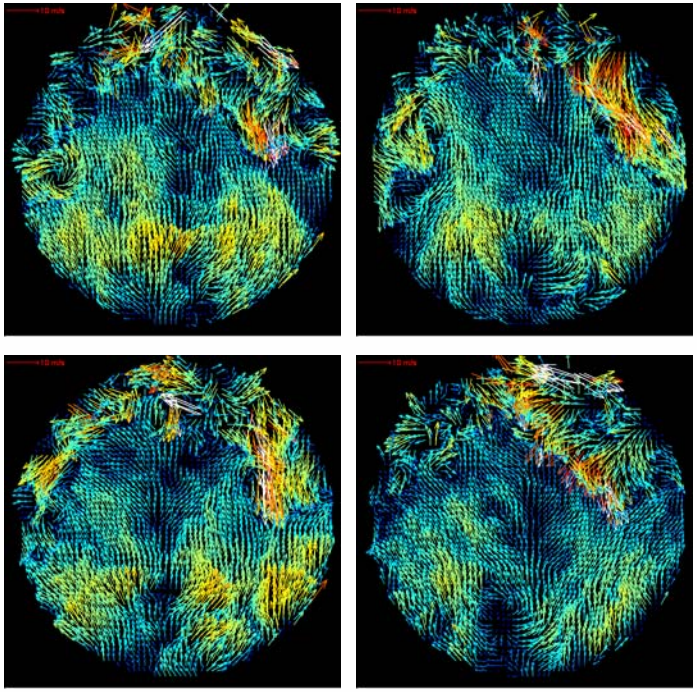


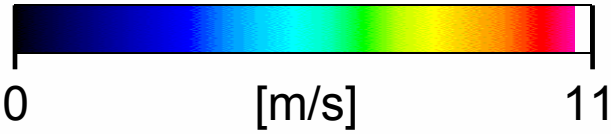
Late injection

SOI: -77.5° / EOI: -27.5 °



- High velocities and turbulence near injector, small scales
- Turbulent “front”
- Lost vectors: high out-of-plane velocity

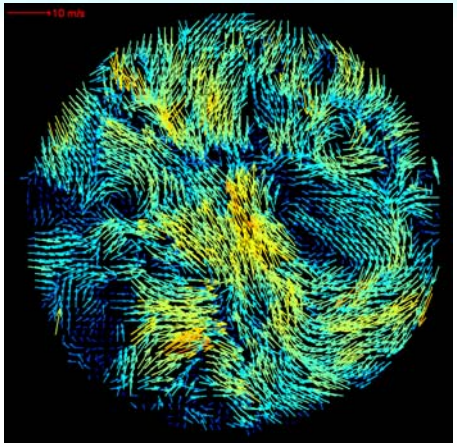
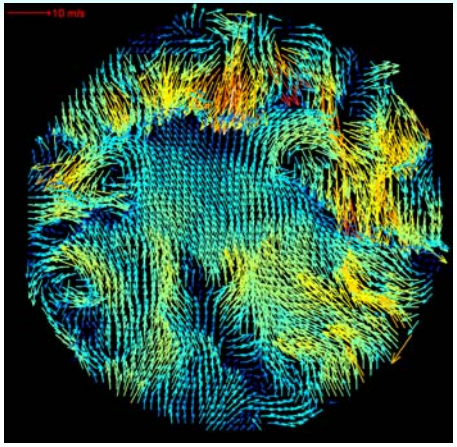
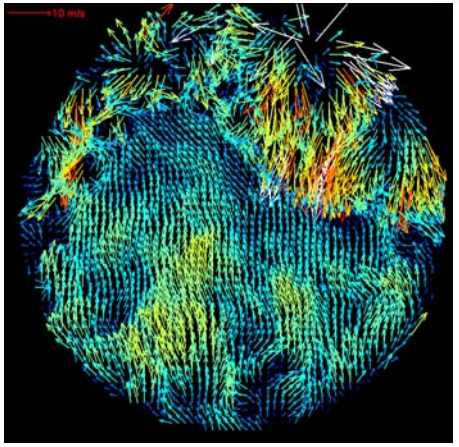
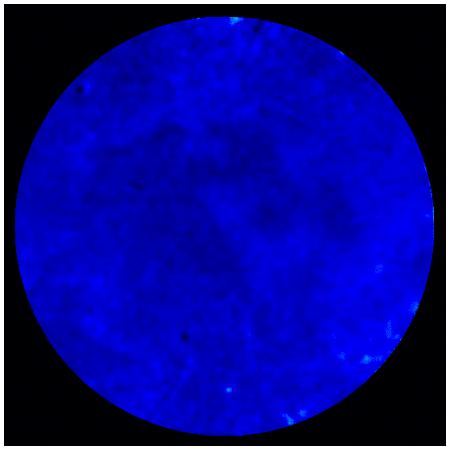
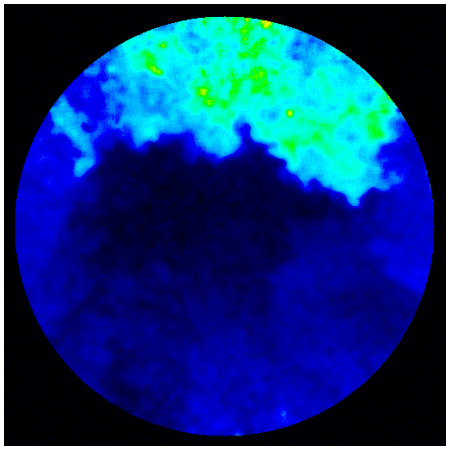
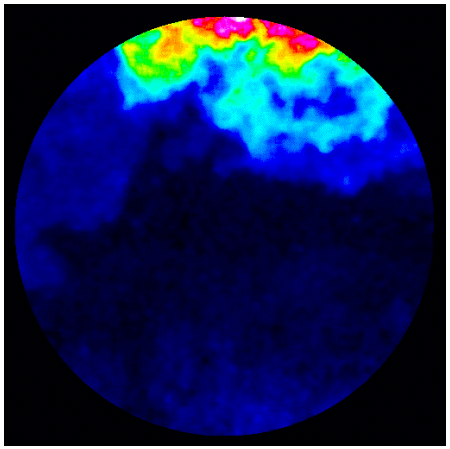




$\Delta t = 12.5\ \mu s$

Scalar and velocity fields

Early injection | Intermediate injection | Late injection

Qualitative correspondence… but would like to have *simultaneous* measurements!

Conclusions and future work

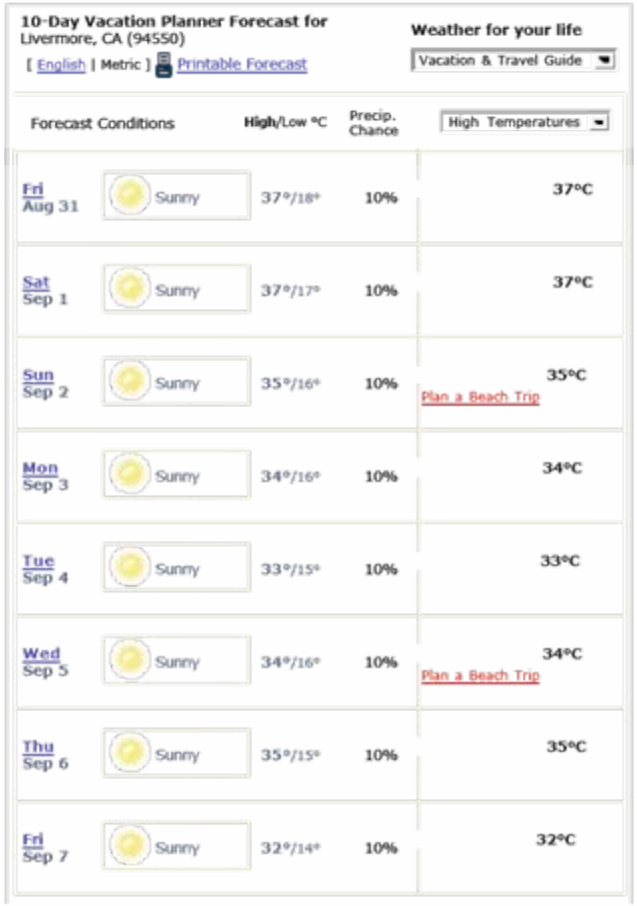
- Mixture formation in a DI-H_2ICE has been investigated using tracer-PLIF and PIV.
  - PLIF needs further improvement (low SNR, high background)
  - Simultaneous PLIF and PIV is work-in progress.
- Engine head - injector combination is not ideal. Fuel stays close to walls for late injection timings.
  - Will be switching to central injection Ford head
- Velocity field is greatly impacted by injection event.
  - Early injection $\rightarrow$ increased turbulence throughout
  - Late injection $\rightarrow$ turbulent, fuel-rich regions and “more-uniform” lean regions with sharp boundary
- LES simulations are in progress
  - Data are starting point for LES validation.
- Part of a collaboration with Ford, Argonne National Laboratory, and EU HyICE Program

Post-doc opportunity

Interested in working at Sandia as a post-doc?

- The H_2ICE and other engines labs have openings.

Contact: Dennis Siebers siebers@sandia.gov



10-Day Vacation Planner Forecast for
Livermore, CA (94550)
[English | Metric] Printable Forecast

Weather for your life
Vacation & Travel Guide

Forecast Conditions		High/Low °C	Precip. Chance	High Temperatures
Fri Aug 31	Sunny	37°/18°	10%	37°C
Sat Sep 1	Sunny	37°/17°	10%	37°C
Sun Sep 2	Sunny	35°/16°	10%	35°C Plan a Beach Trip
Mon Sep 3	Sunny	34°/16°	10%	34°C
Tue Sep 4	Sunny	33°/15°	10%	33°C
Wed Sep 5	Sunny	34°/16°	10%	34°C Plan a Beach Trip
Thu Sep 6	Sunny	35°/15°	10%	35°C
Fri Sep 7	Sunny	32°/14°	10%	32°C