Laser-based imaging at Sandia to understand the in-cylinder processes in a DI-H_2ICE

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Sponsor:

DoE / OVT

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There is a lack of fundamental knowledge about in-cylinder processes in hydrogen DI engines.

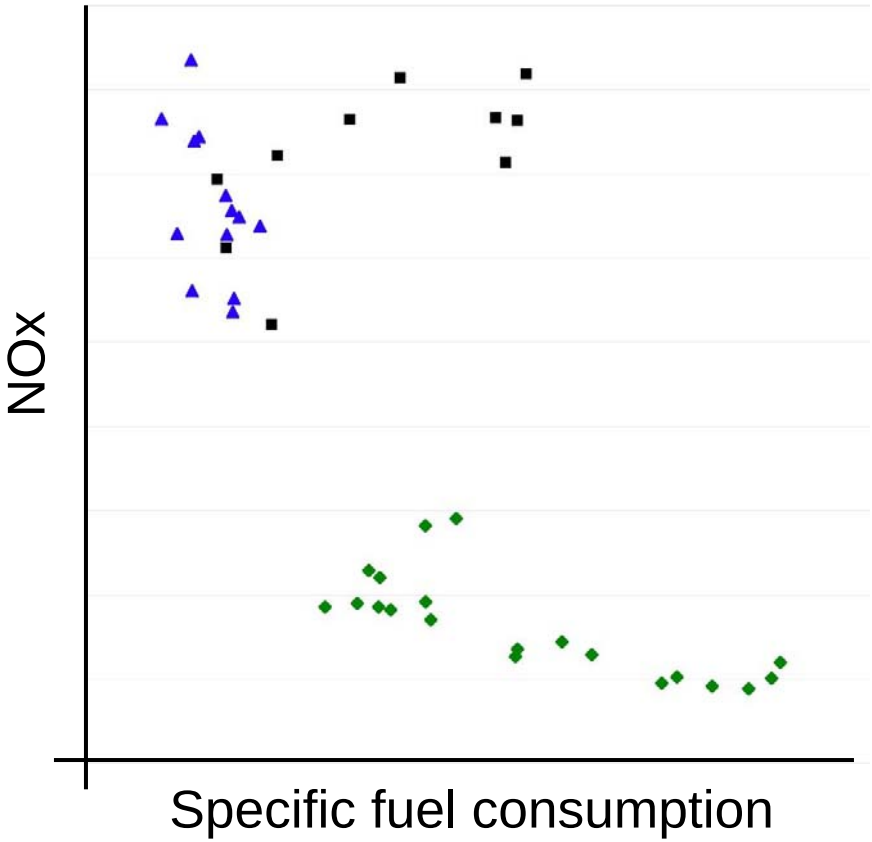
Direct injection: In-cylinder injection after intake valve closure (DI H_2ICE)

Benefits:

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

Technical challenges:

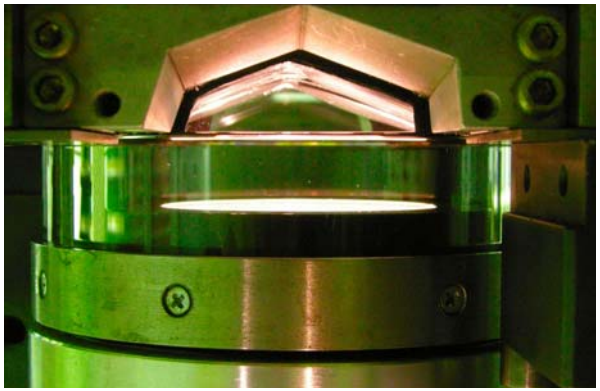
- DI operation relies on control of fuel-air mixing and combustion regimes.
- short available mixing times (1-20 ms)
- Complex flow and fuel distribution dynamics

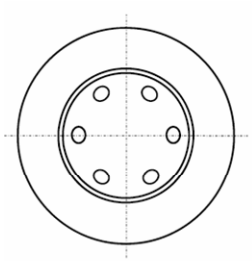


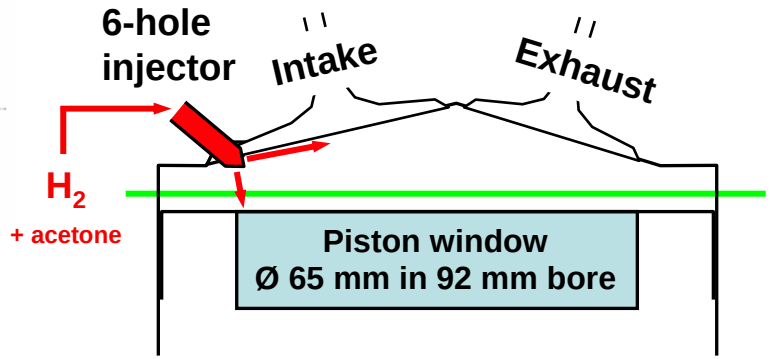
Data: Ford R&D

→ **Optical engine and Large Eddy Simulation**

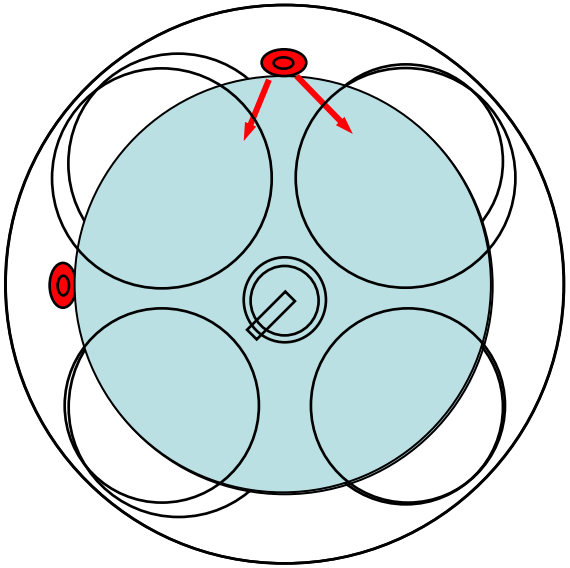
Sandia's optical H_2ICE is based on a GM head similar to the Ford / ANL geometry .



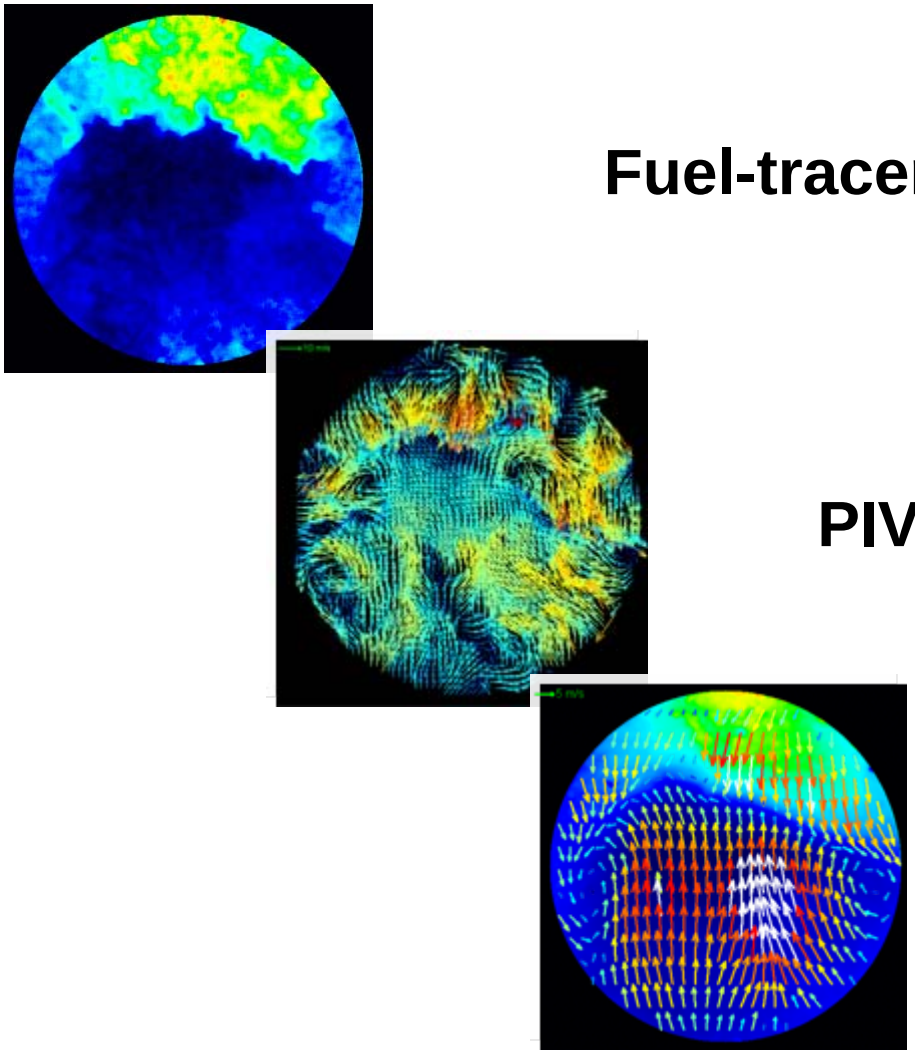




Bore	92 mm
Stroke	85 mm
Displacement	560 cm^3
CR	9.1 - 11



First, we focused on the influence of injection-induced flow on the fuel distribution.



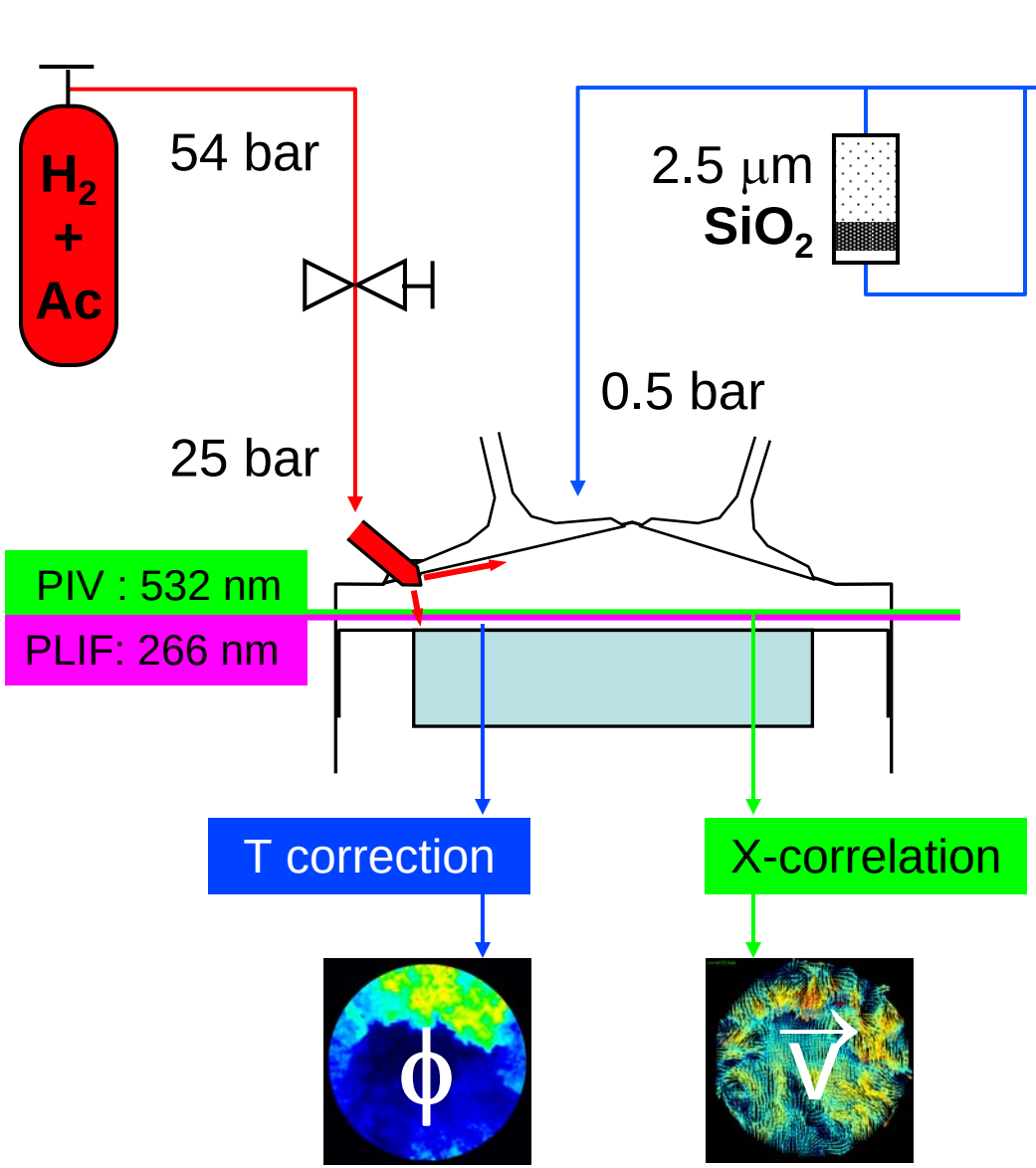
Fuel-tracer PLIF → Equivalence ratio

Separate measurements

PIV → Velocity

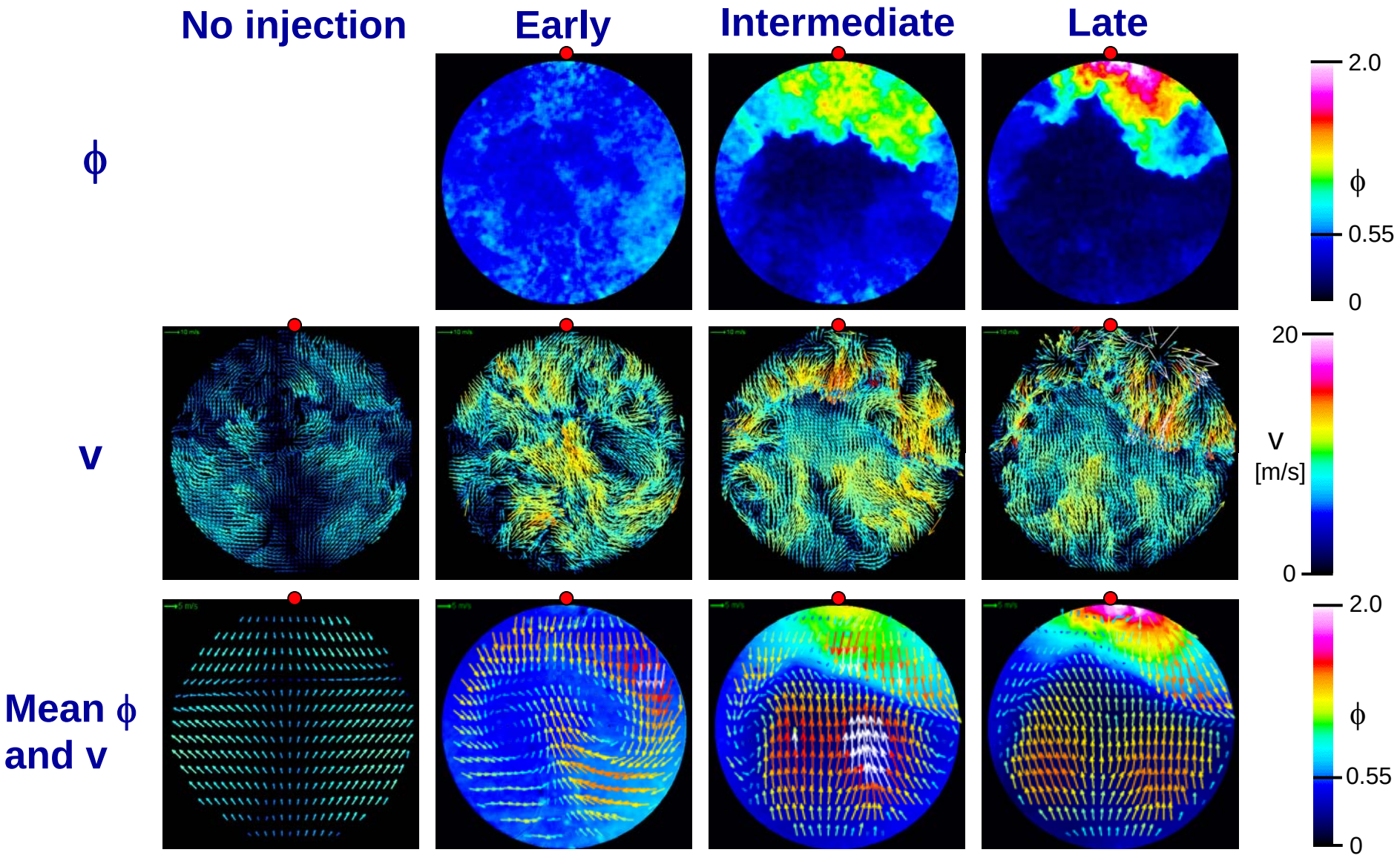
Injection-induced flow

For PIV, the bulk gas is seeded with SiO_2 particles; For PLIF, acetone is added as a tracer to H_2.

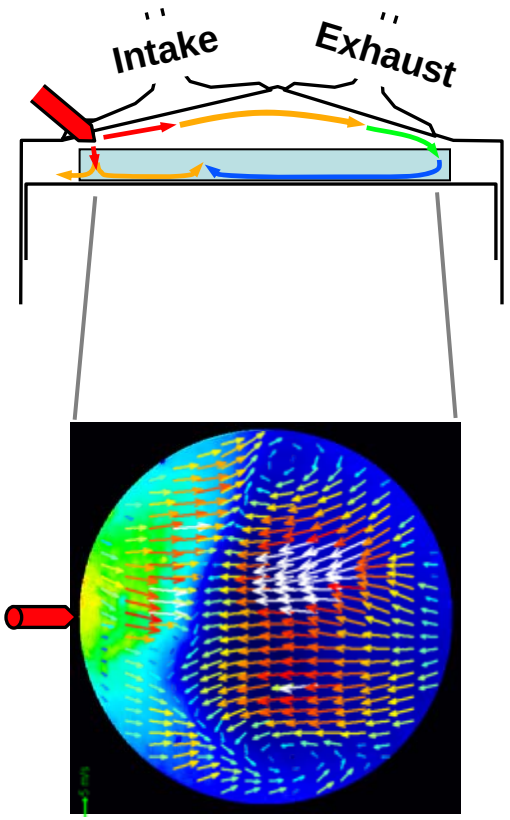


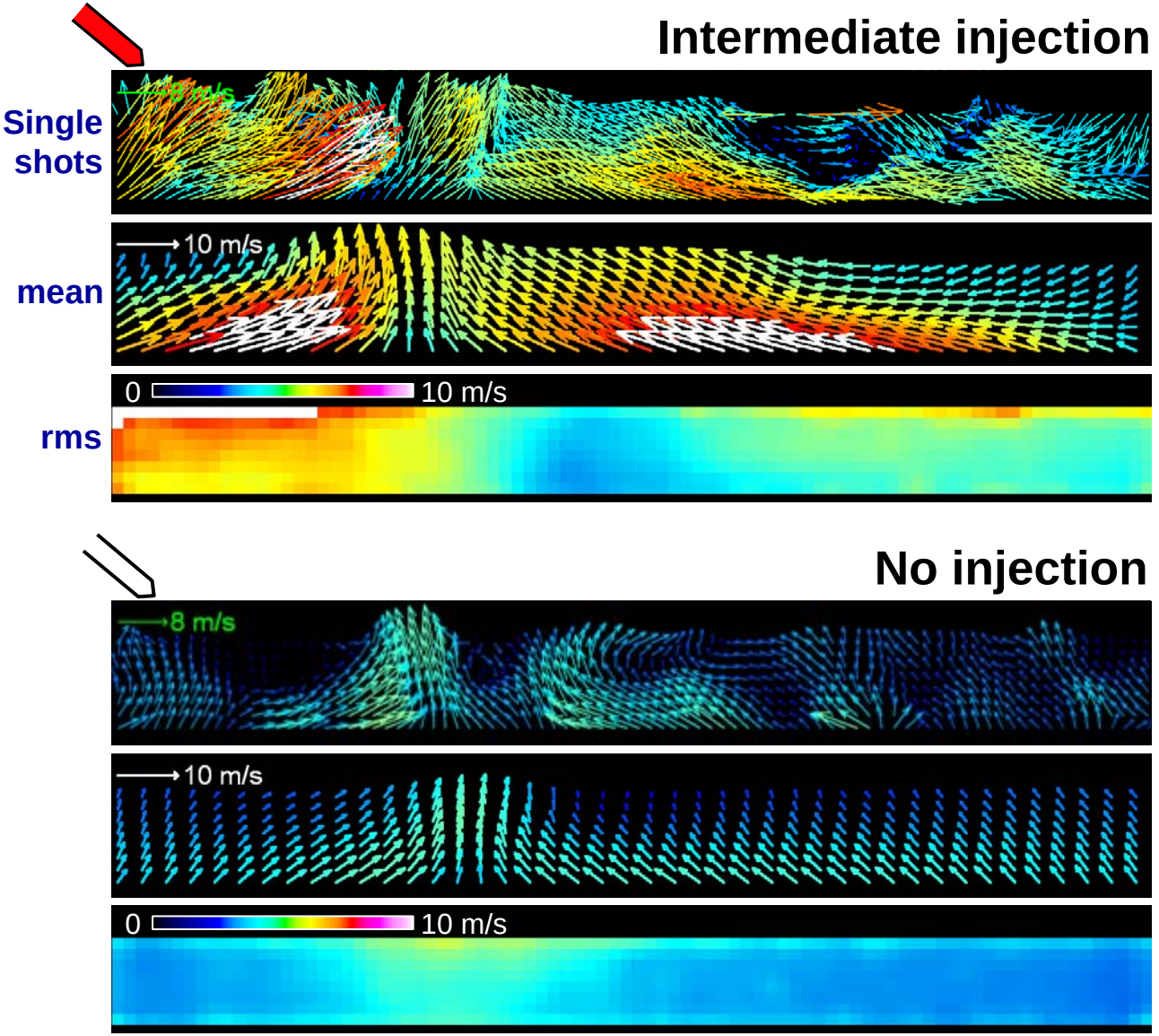
ϕ	**0.55**
$p_{injection}$	**25 bar**
Injection duration	**50 °CA**
Speed	**1200 rpm**
p_{intake}	**0.5 bar**
Imaging at	**-32 °CA**
***Early* injection**	**-112 / -62 °CA**
Intermediate	**-90 / -40 °CA**
Late	**-77 / -27 °CA**

Retarded injection results in a surprising amount of charge stratification.



A counter-flow situation is created by jet redirection at the walls and piston top.





The injection induces strong flow, which then determines where the fuel is near TDC.

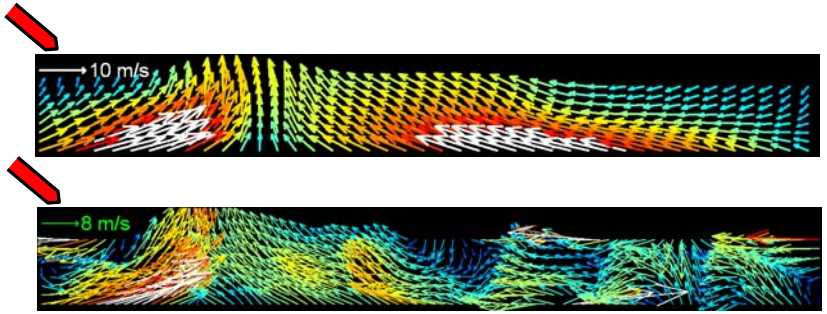
Squish and tumble also contribute to mixing-inhibiting flow pattern.

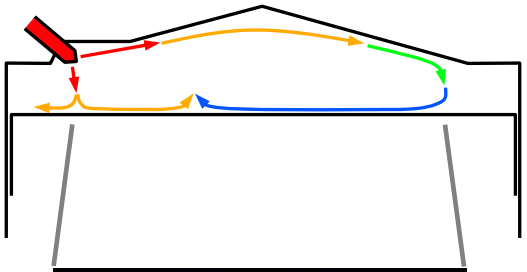
This configuration is not suitable for late injection.

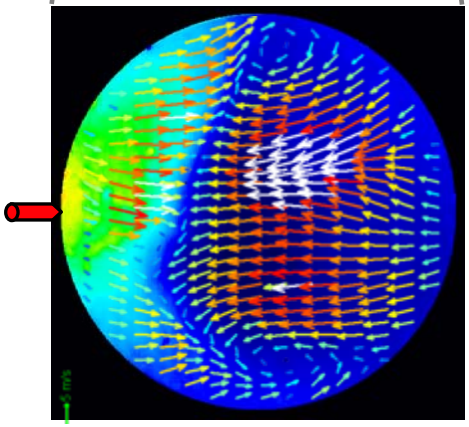
Result confirmed by drop-off in efficiency measured at ANL for SOI later than -100 CAD

Together, PIV and PLIF are powerful tools to understand mixture formation.

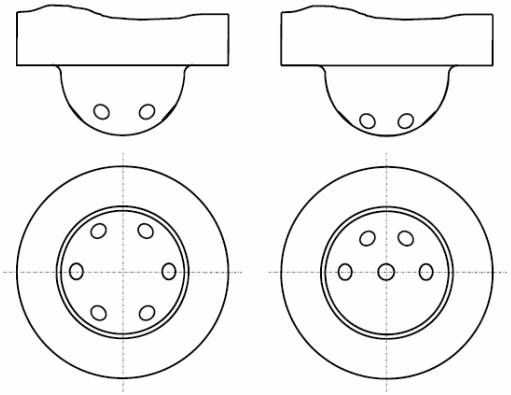
Next: different injector geometries & locations in coordination with ANL

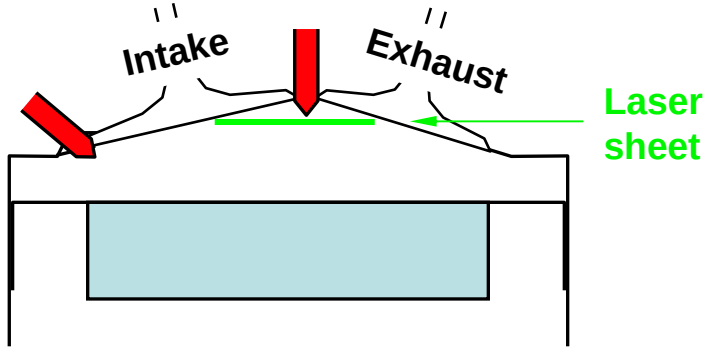






The current study on the injection configuration is closely coordinated with ANL.





Ford - ANL

GM - Sandia

Initially, a low-load point was investigated.

		ANL	SNL
IMEP	bar	2	-
ϕ		0.25 - 0.35	0.29
speed	min^{-1}	2000	1200
p_{intake}	bar	1.0	1.0
p_{inj}	bar	100	65, 80
Δt_{inj}	°CA	20.2 - 23.6	21.5

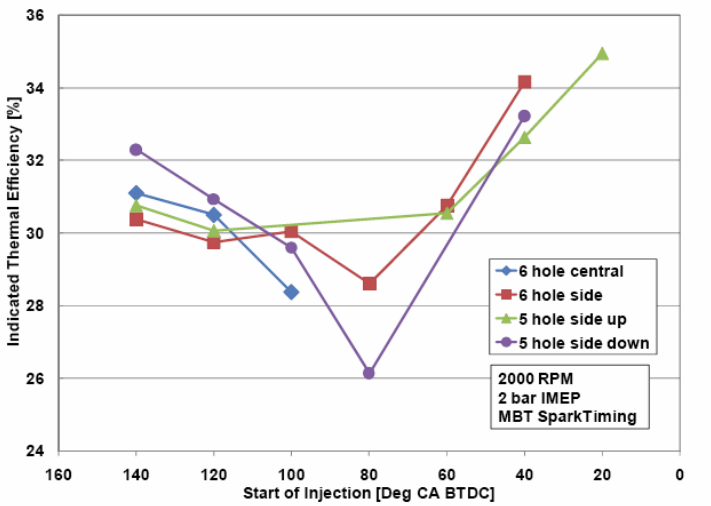


Figure 4: Indicated thermal efficiency as a function of start of injection at low engine load (2 bar IMEP)

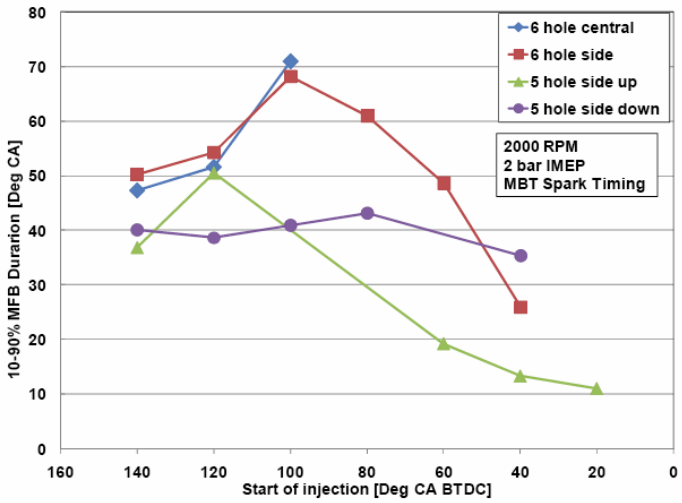


Figure 7: Influence of start of injection on combustion duration at low engine load (2 bar IMEP)

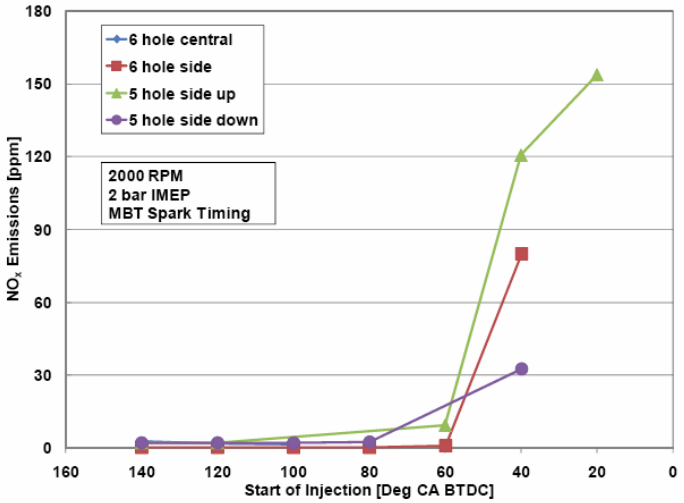


Figure 8: Influence of start of injection on NO_x emissions at low engine load (2 bar IMEP)

The measurement precision is greatly improved.

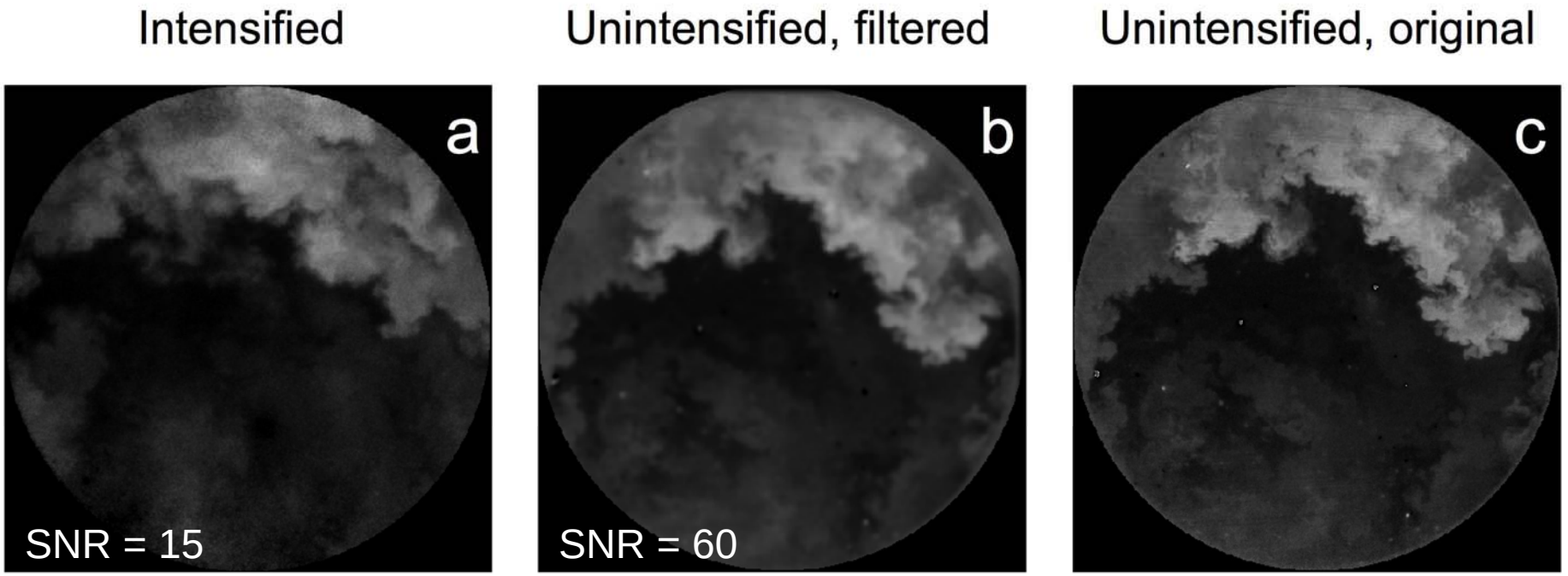
Compared to earlier measurements at 25 bar:

- Lower acetone concentration: 0.25% at 100 bar vs. 0.50% at 50 bar (bottle pressure)
- Lower equivalence ratio: 0.25-0.35 vs. 0.55

→ *4 times less signal if nothing is done.*

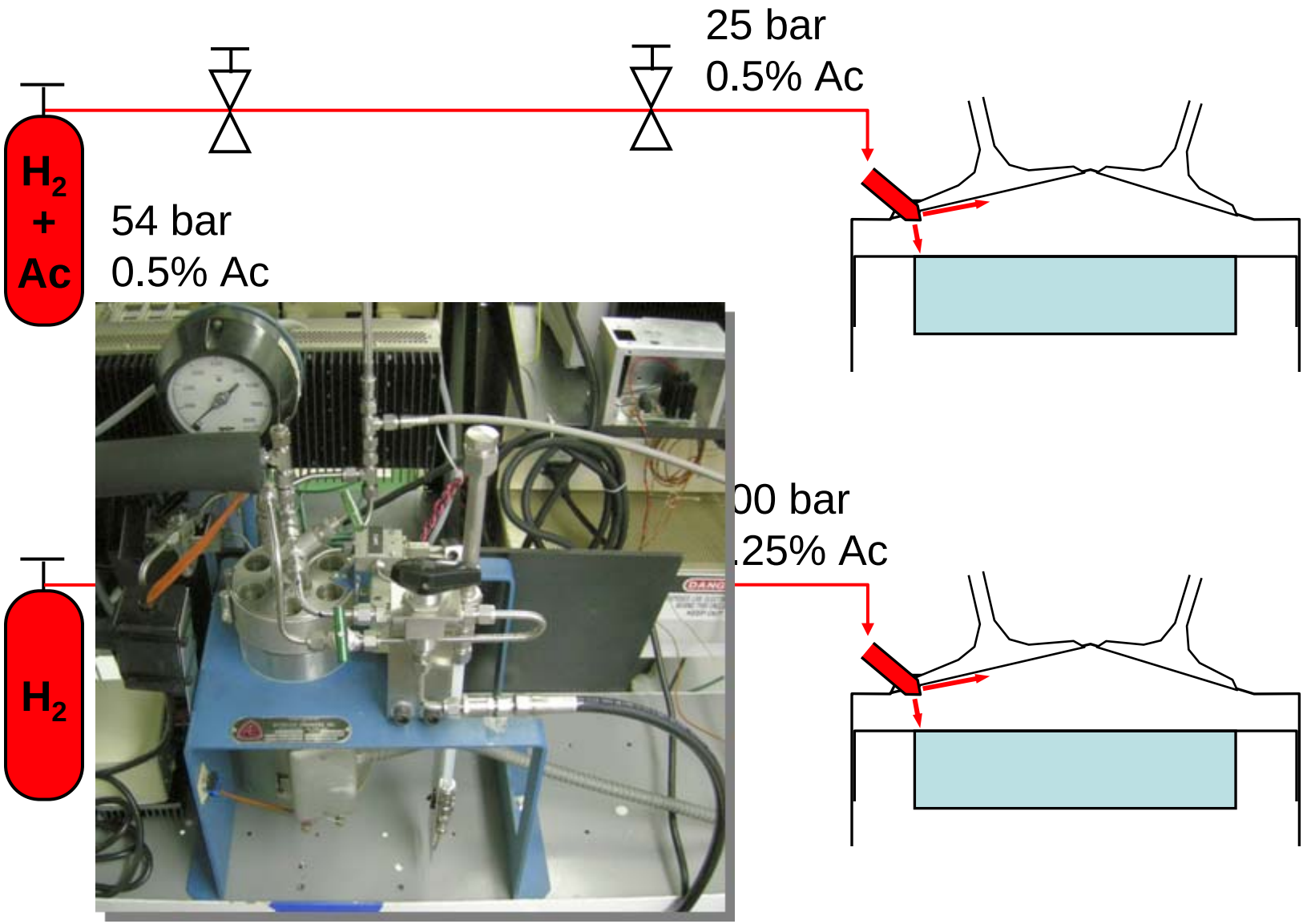
Optical improvements:

- Unintensified camera: QE ~ 60% at 450 nm vs. ~ 15% for S-20 phosphor
- Unintensified camera: higher resolution can be traded for more measurement precision
- Optimized lens system
- Passive-cavity beam stretcher: 2x more laser input power possible

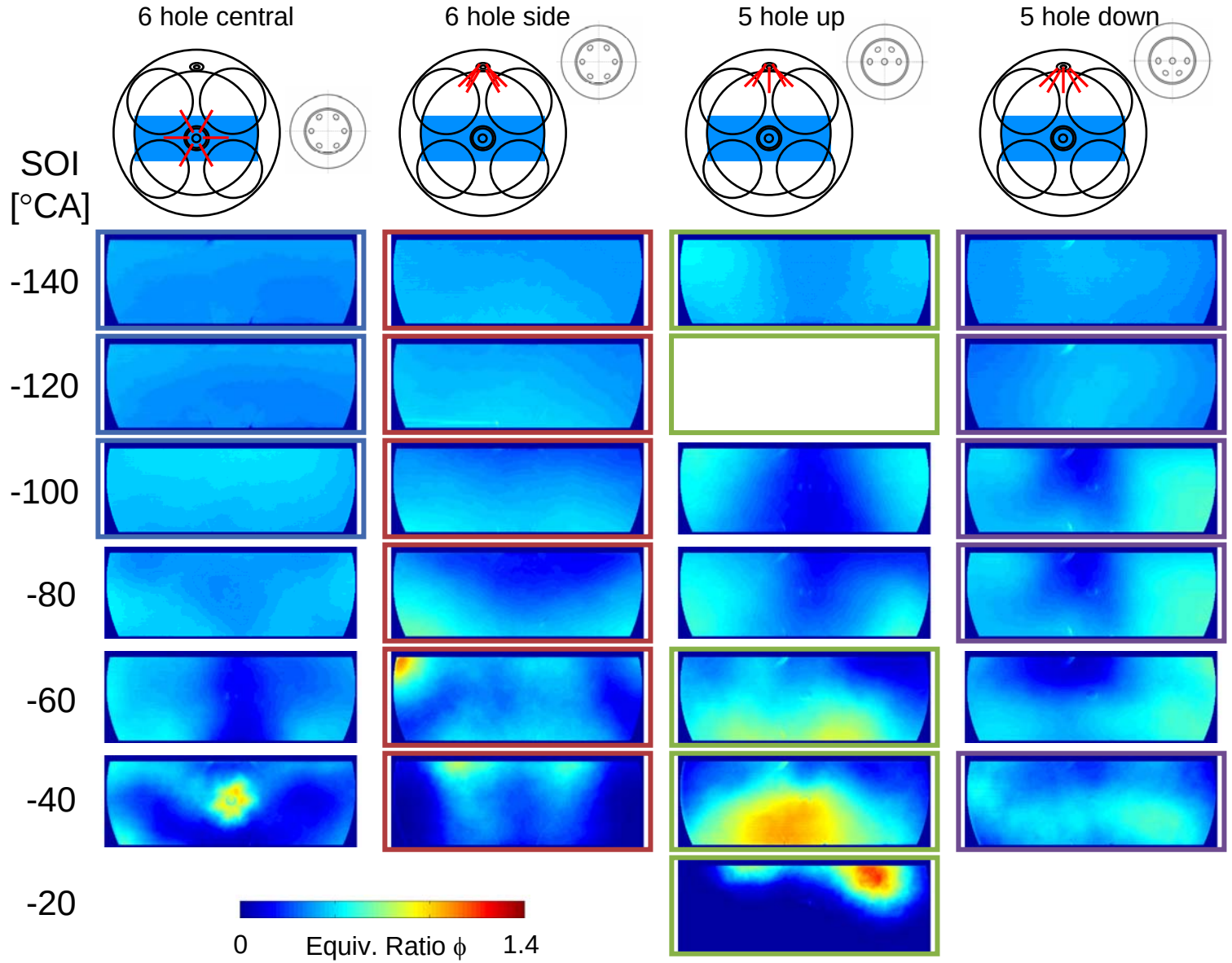


The PLIF acetone seeding system is improved.

$p_{acetone} / p_{total} = x_{acetone} / x_{total}$



Mixture ignitability is reflected reasonably well in optically measured fuel distribution.



- Frames denote stable fired operation at ANL
- Imaging at MBT spark timing from metal engine
- ϕ is approximate (no T correction)

Sandia will continue to target fundamental issues of H_2ICE combustion in collaborative work.

Compile reference data set on fuel-air mixing

- PIV and fuel-PLIF in motored operation
- Injector geometry and location, inj. pressure, engine speed and load

Mount and validate new engine head

- Ford head is at Sandia but needs modifications
- Validate against Ford and ANL

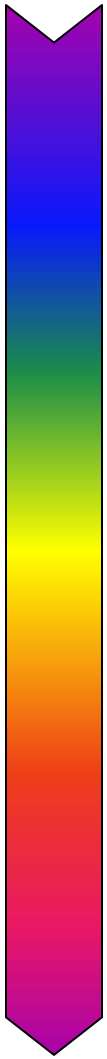
Investigate multi-injection strategies

- Combustion modes and efficiency vs. NOx trade-off
- OH-PLIF, PIV, and fuel-PLIF in fired operation

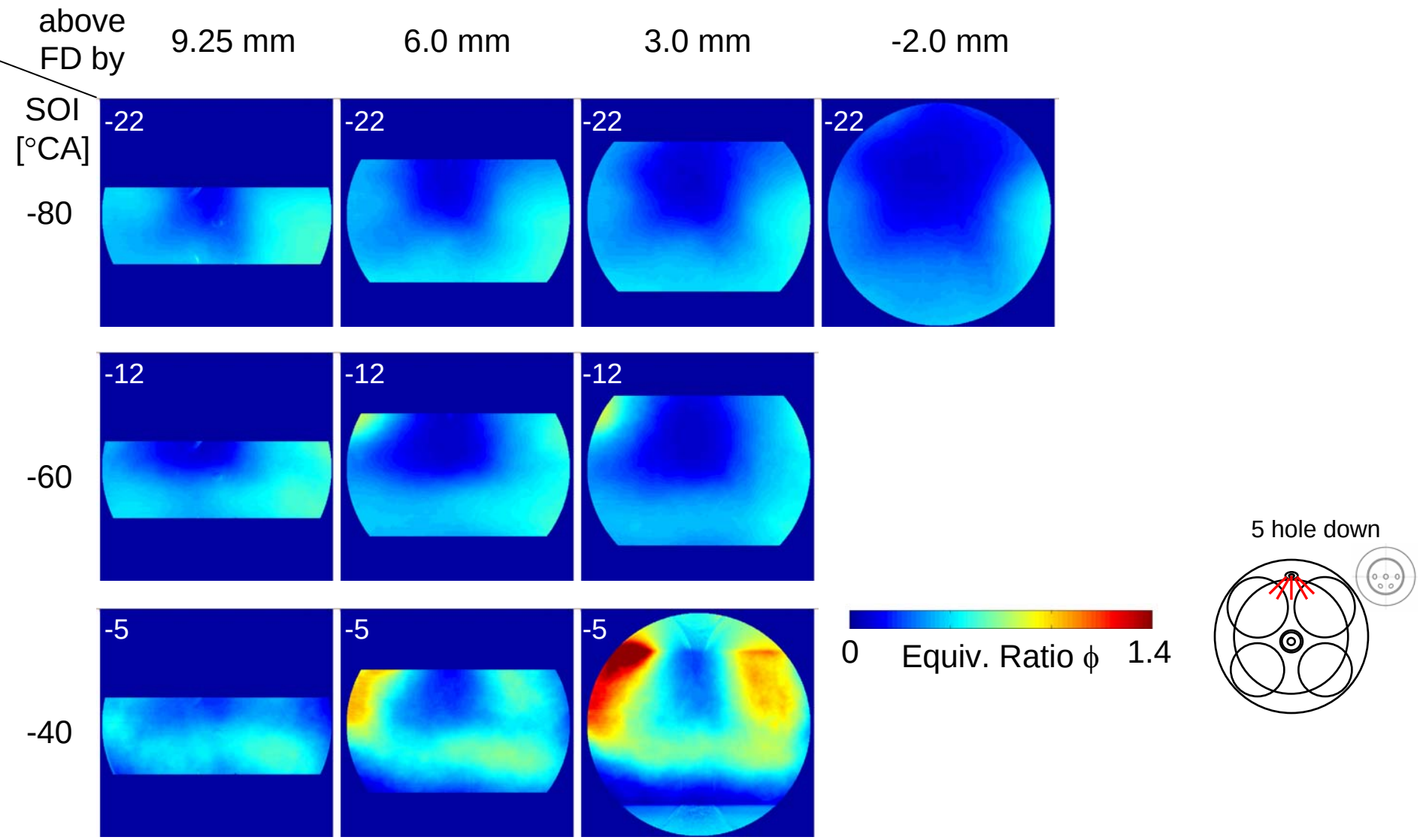
Advanced DI-H_2ICE operation

- EGR, turbocharging
- ? ? ?

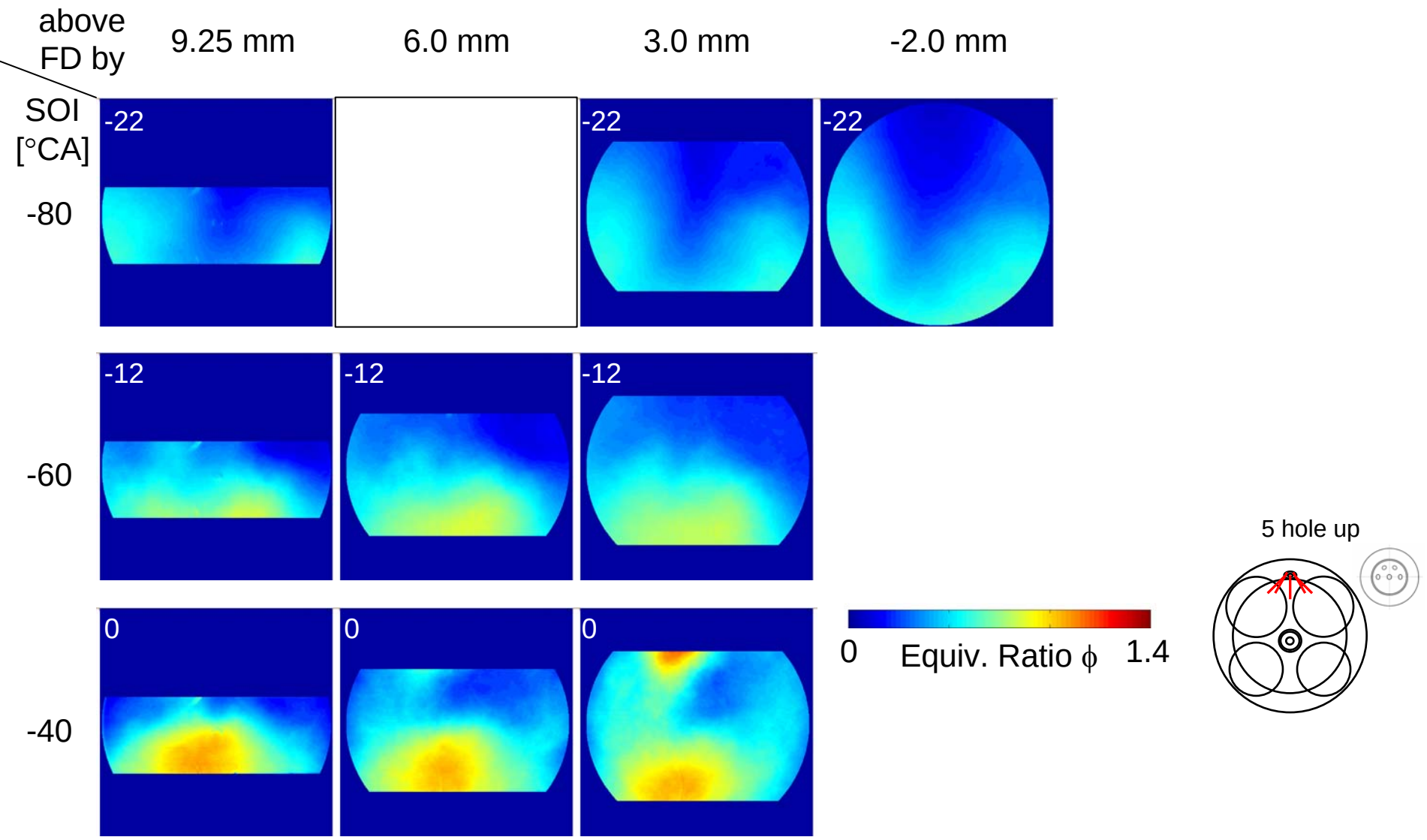
Validate, learn from, and advance LES



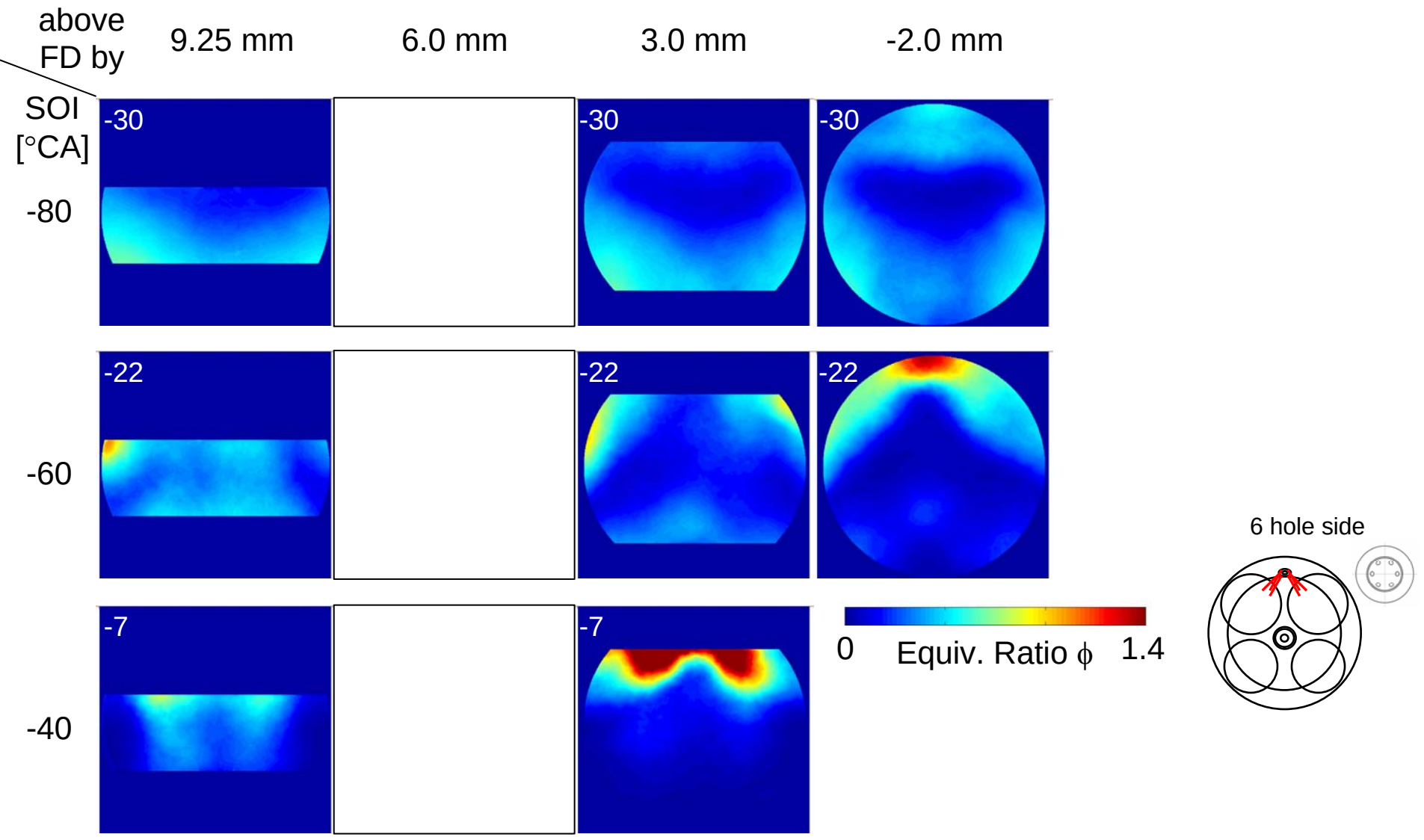
5 hole down multi-plane at MBT spark



5 hole up multi-plane at MBT spark

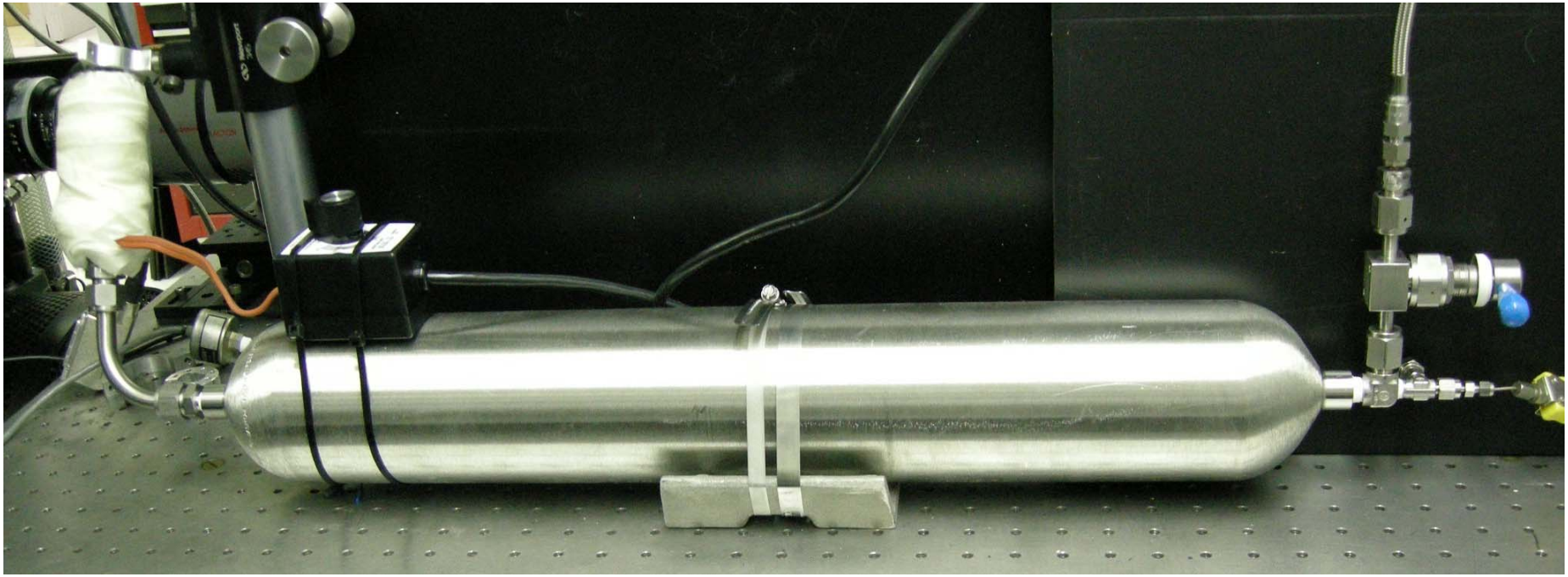


6 hole side multi-plane at MBT spark



The injector can be mounted centrally instead of the spark plug.

The injector is calibrated off-line.



Ford and GM head are close but not the same. Ports in GM head are much more limiting.

Bore	**89 mm**
Stroke	**79.5 mm (ANL)**
Displacement	**500 cm^3**
CR	**11.5**

Bore	**92 mm**
Stroke	**85 mm**
Displacement	**560 cm^3**
CR	**9.1**

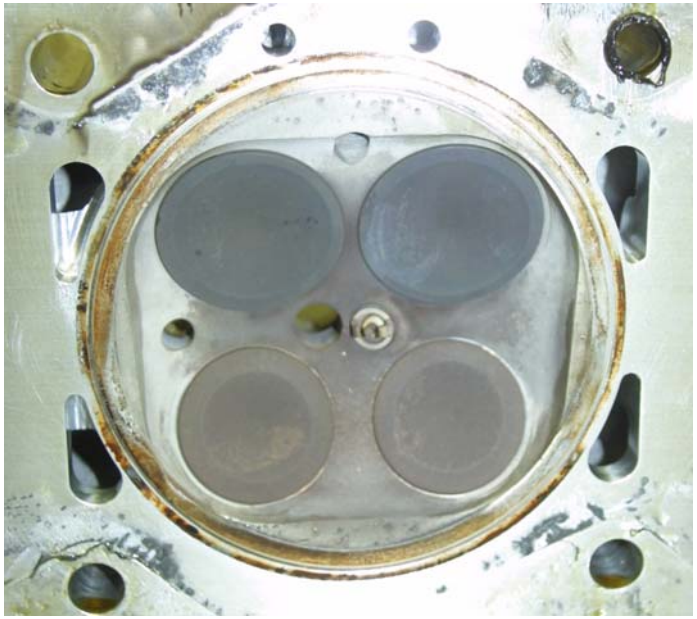
Ford - ANL

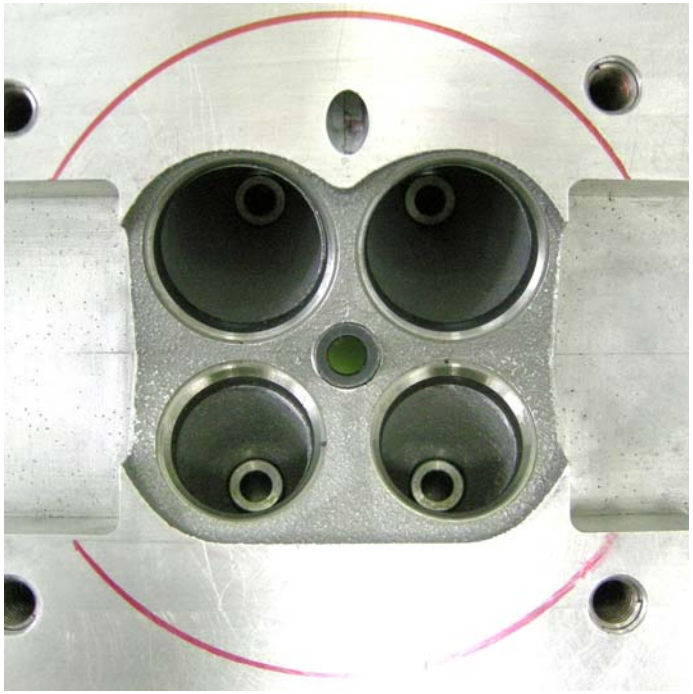
GM - Sandia

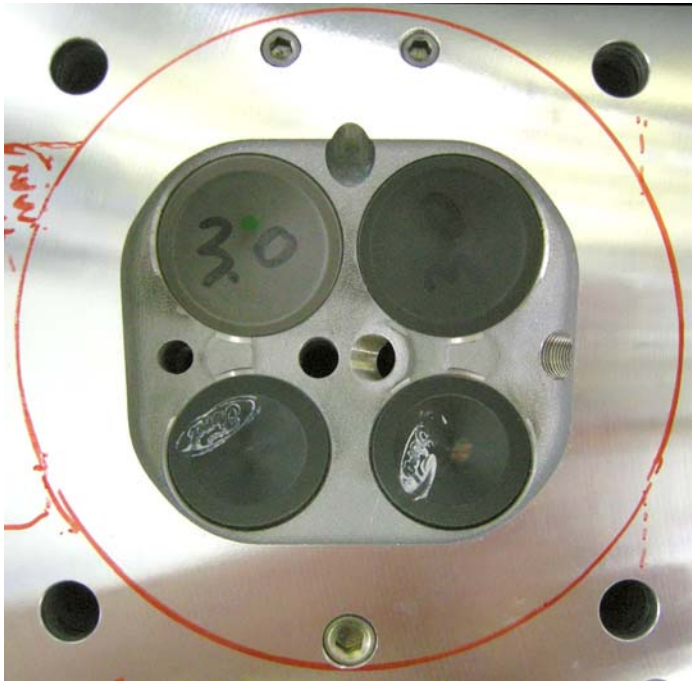
Further out…

Modifying and installing Ford head:

- Main issue is optical access to pent-roof
- Modifications at Sandia or Ford?
- Installations seems relatively easy







Piezo injectors and driver

Emissions system (NOx and O2)