Effects of Jet-Bowl and Jet-Jet Interactions on Late-Injection Low-Temperature Heavy-Duty Diesel Combustion

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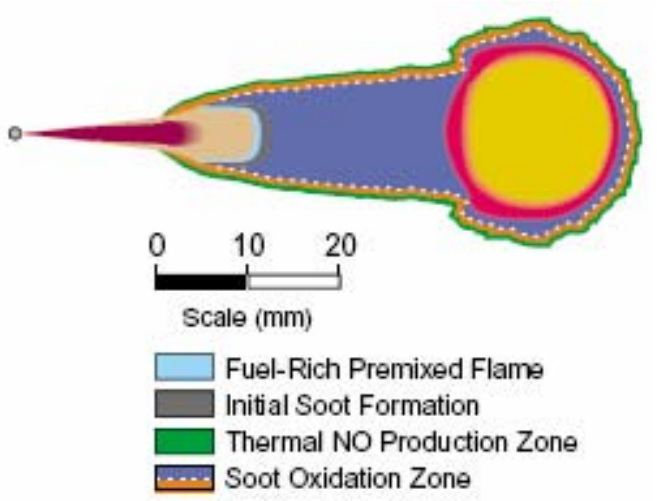
Mixing and combustion occur differently in LTC and conventional diesel regimes.

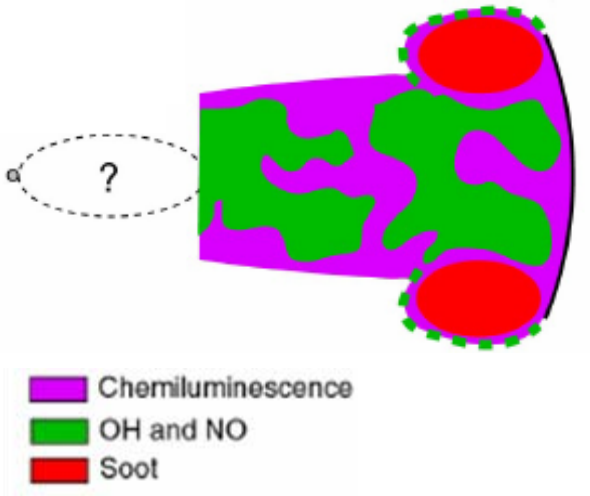
Conventional Diesel Combustion

Dec SAE970873:



Low-Temperature Combustion (LTC)

Musculus SAE2006-01-0079:



Conventional Diesel Jets:	LTC Jets:
Negative ignition dwell	Positive ignition dwell
Diffusion flame	Volumetric ignition
Fuel-rich soot-producing core	Soot formation at head of jet

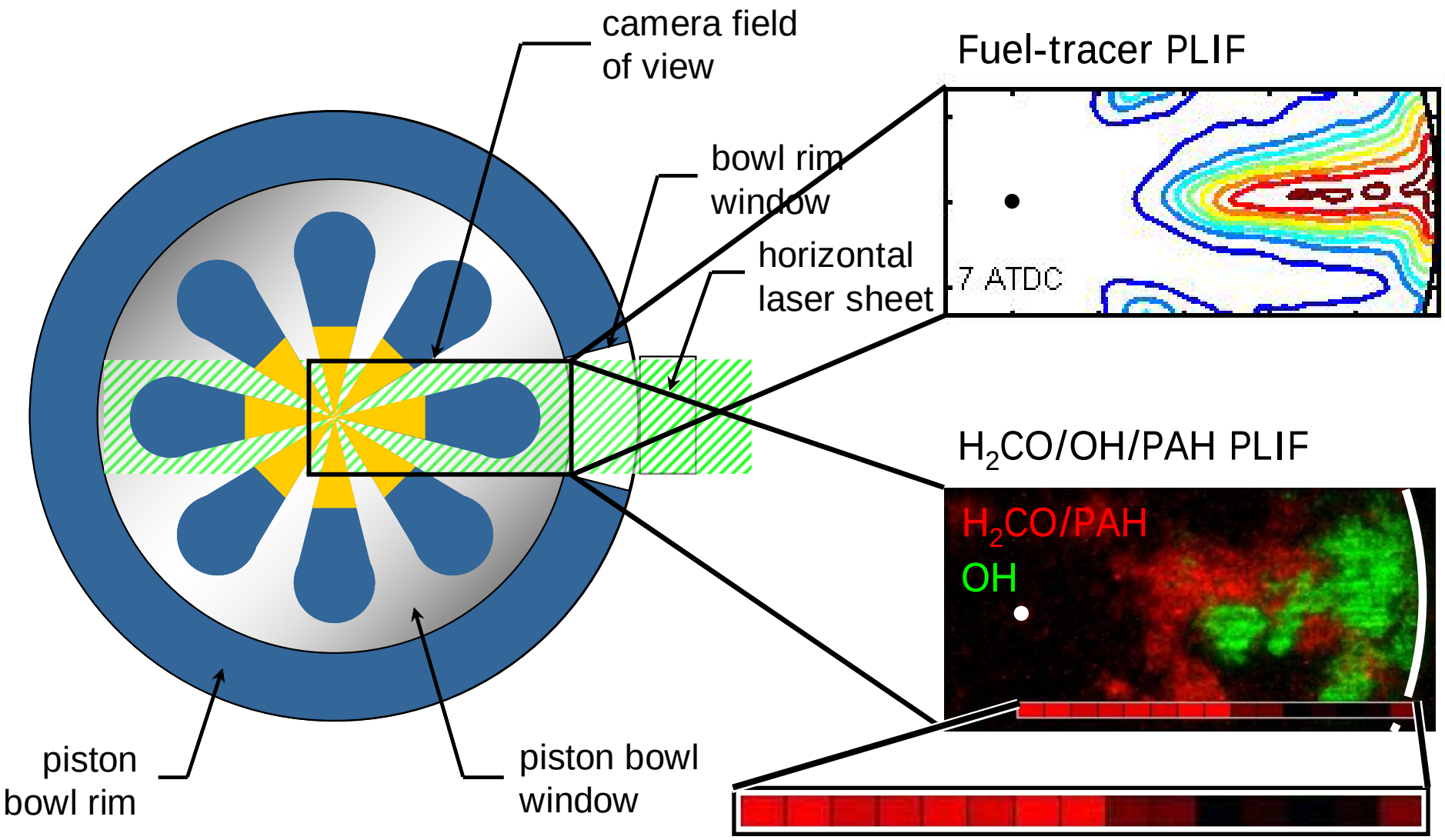
Optical engine experiments were performed at the Sandia National Labs heavy-duty engine facility.

- Sandia/Cummins heavy-duty optical diesel engine
- Engine Geometry:
  - 2.34 L displacement
  - 140 mm bore x 152 mm stroke
- Common-rail fuel injector:
  - 8-hole nozzle, 196 μm
  - 1600 bar
- Skip-fired operation: 1/10

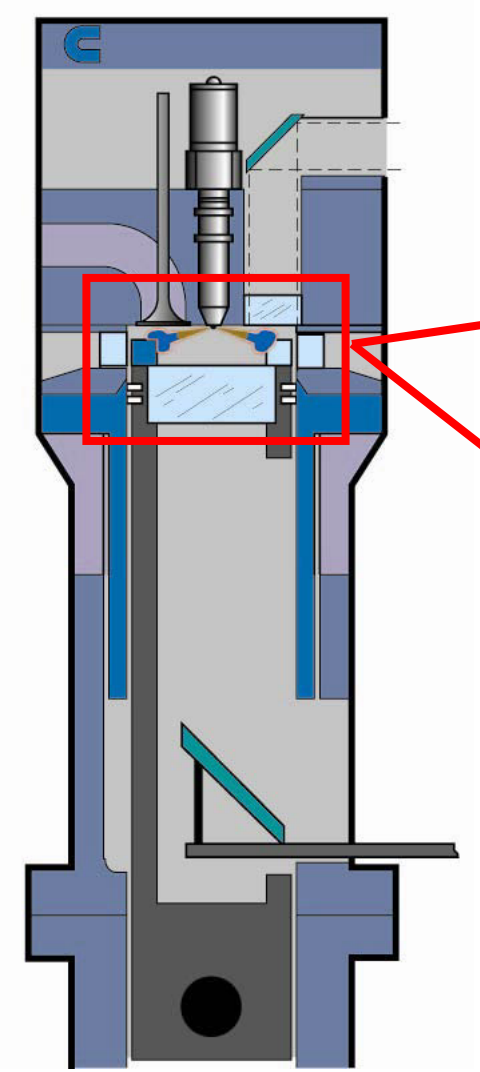
Typical LTC operating condition with late injection timing

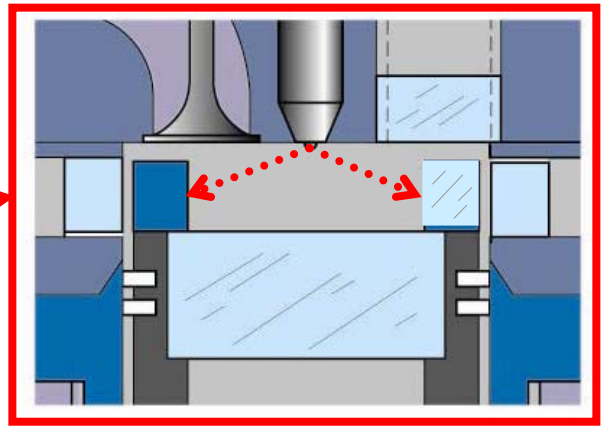
Speed	1200 rpm
Nominal IMEP	4 bar
Estimated TDC Temp.	838 K
Estimated TDC Density	22.2 kg/m^3
O2 Concentration	12.7 %
SOI	0 ATDC
Nominal Ignition Dwell	+1-2 CAD
Fuel	71% n-heptane/ 29% iso-octane

One of eight diesel jets is imaged within the camera field-of-view.



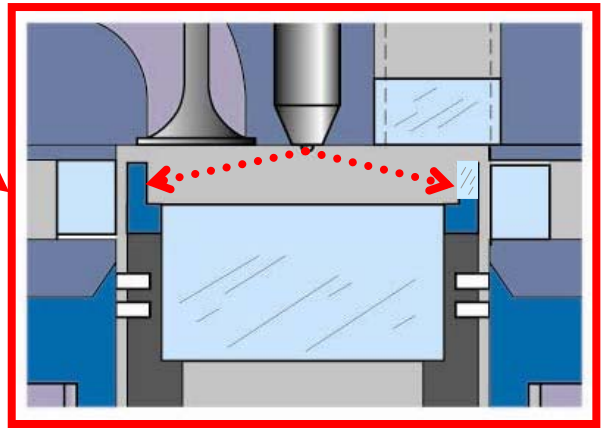
Two piston-bowl sizes alter the timing of jet-bowl interactions.





Baseline bowl

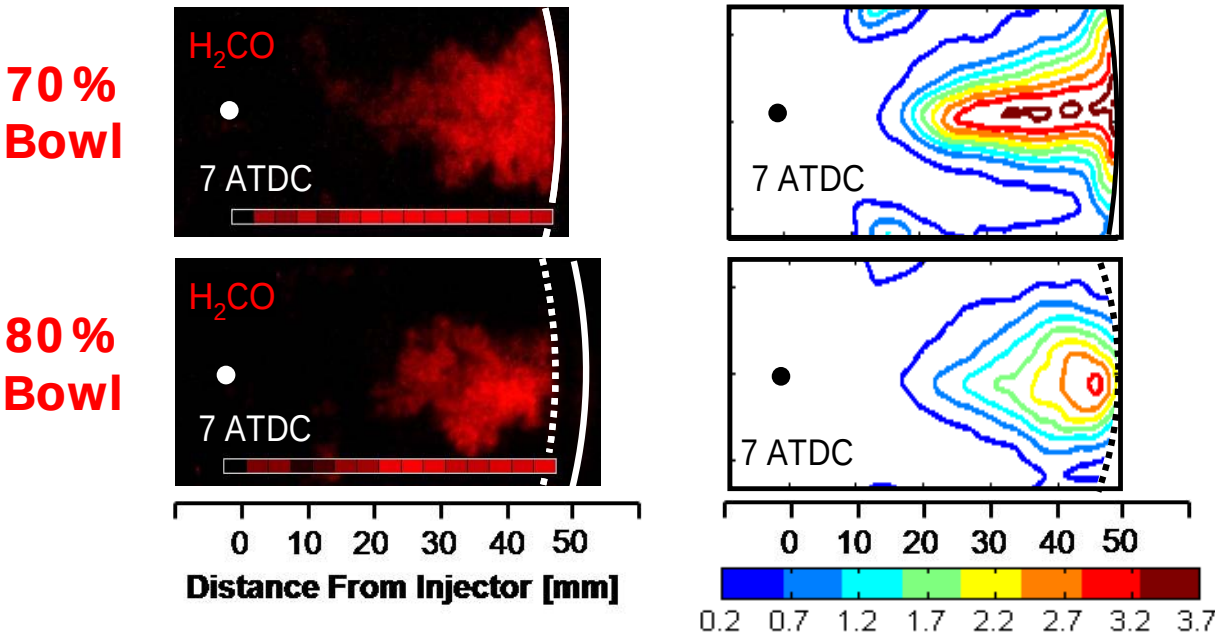
70 % BOWL

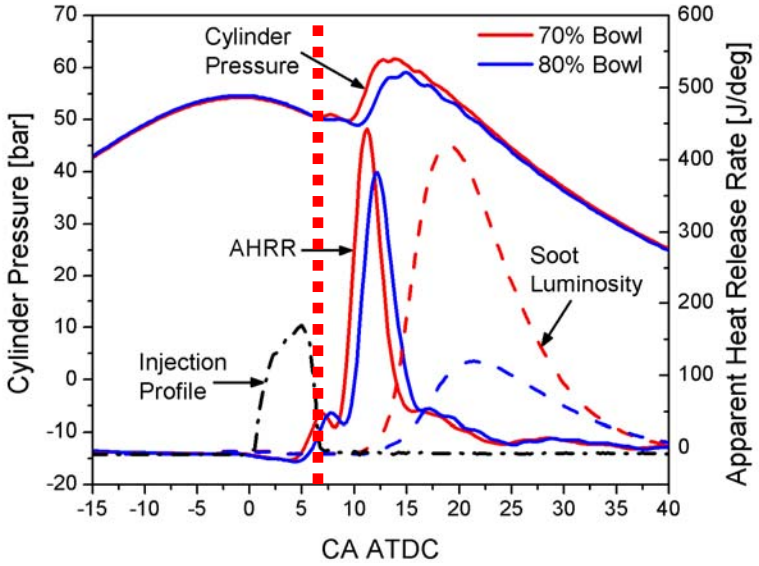


Wide diameter/ shallow bowl

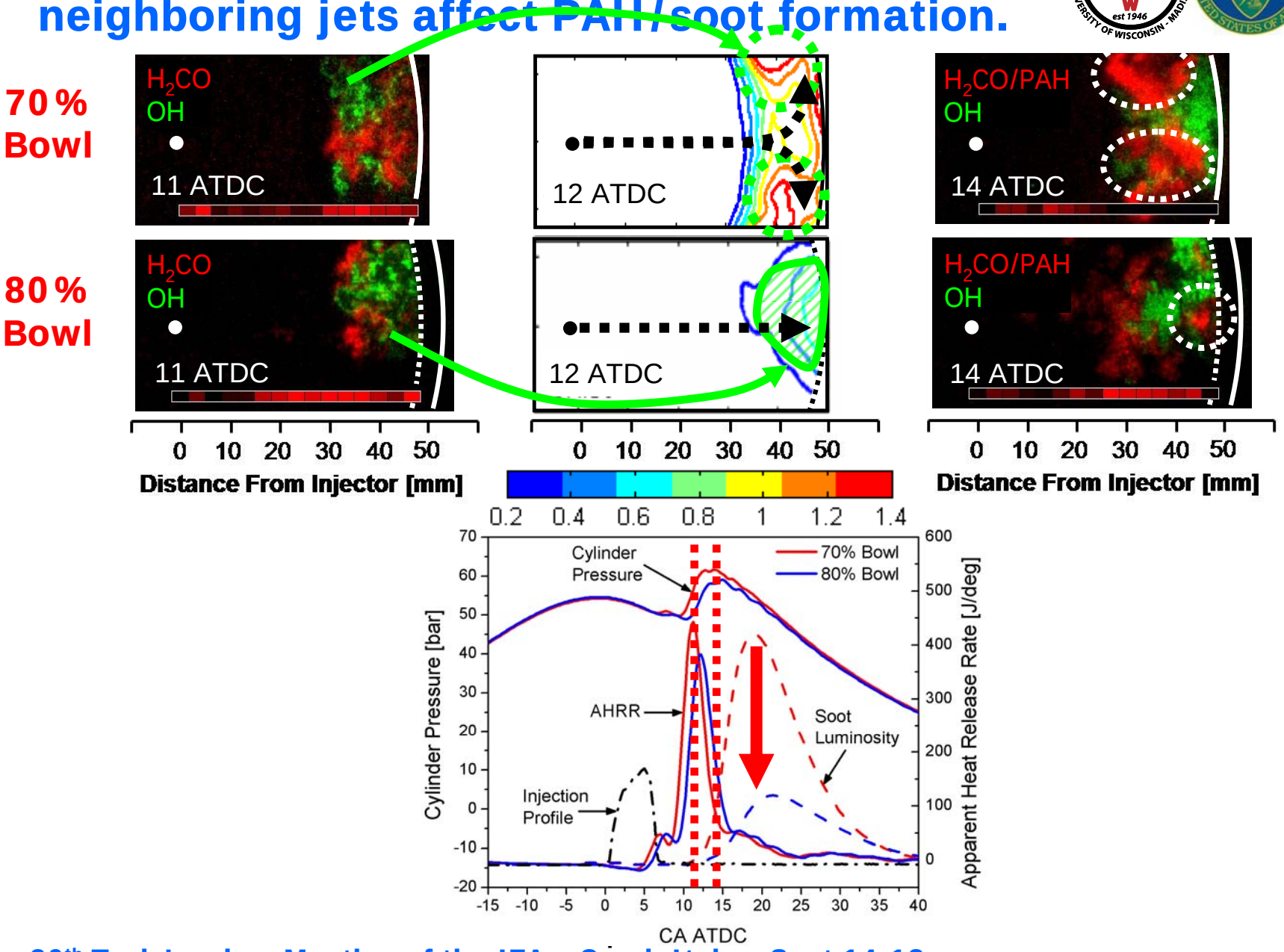
80 % BOWL

Fuel-jet interaction with bowl wall is delayed in wide-diameter piston bowl.

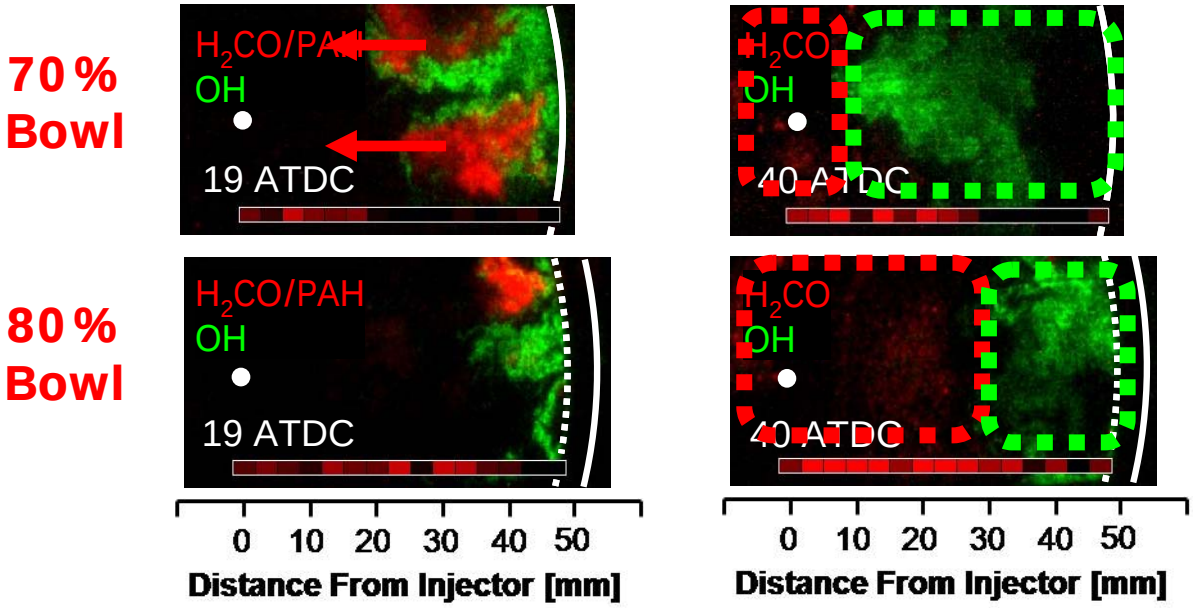


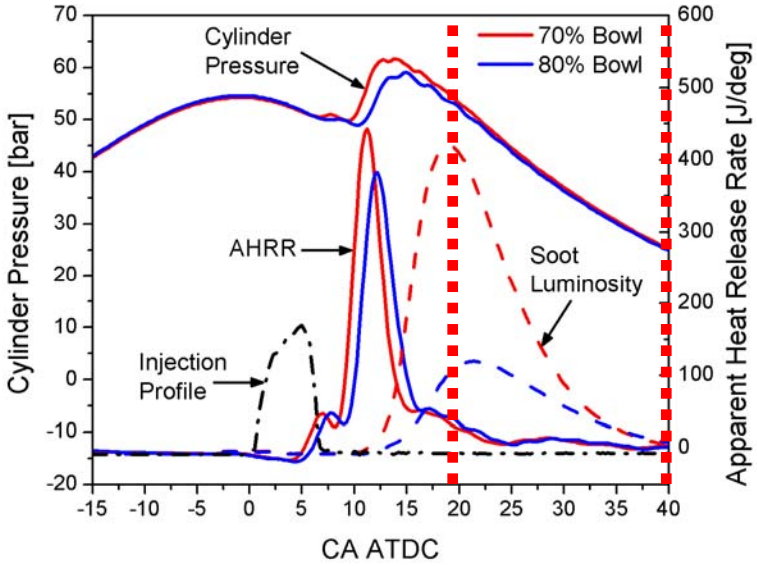


Fuel-jet interactions with bowl and with neighboring jets affect PAH/soot formation.



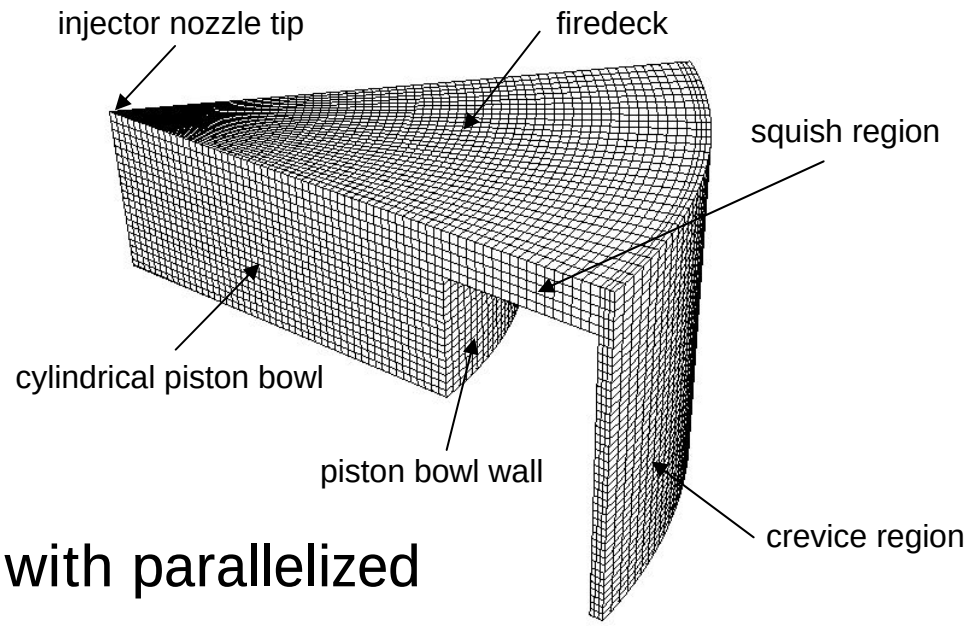
Jet-bowl and jet-jet interactions also influence late-cycle flows.





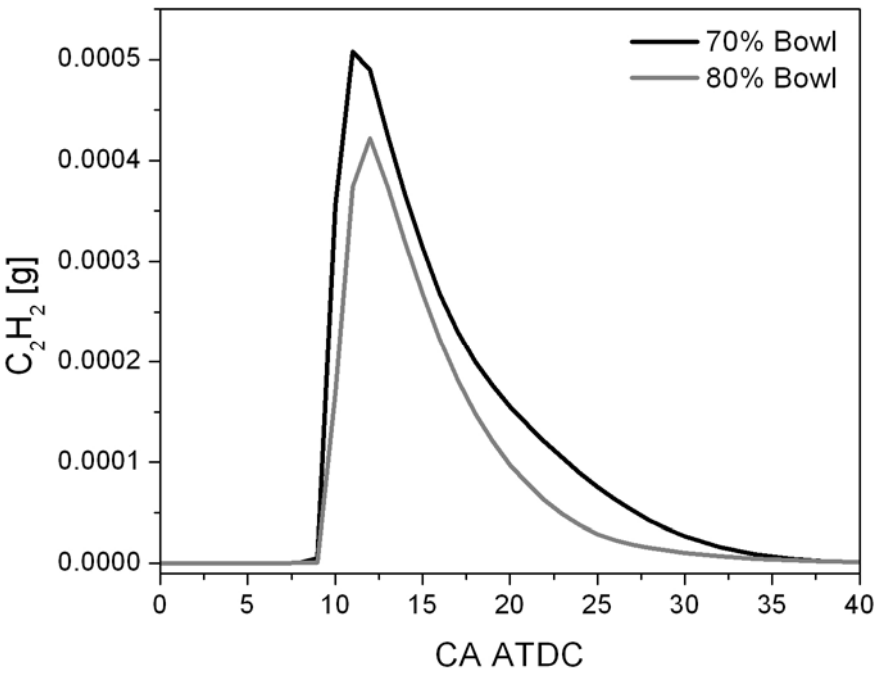
The Sandia/Cummins optical engine was modeled to further explore these experimental results.

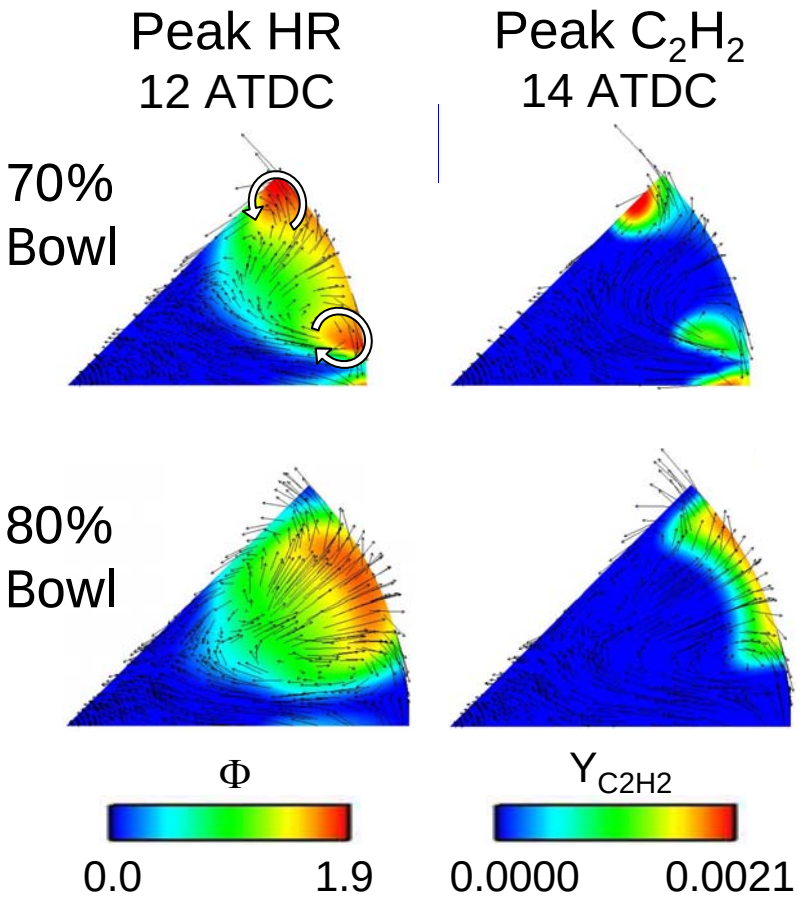
- KIVA-3V – Release 2
- 45^{o} sector mesh (8-hole injector nozzle)
- ~110,000 cells
- Simulation of closed valve portion of cycle



- Reduced chemical kinetics with parallelized CHEMKIN solver:
  - Diesel surrogate (n-heptane based): 30 species, 56 rxns
- Soot emissions:
  - C_2H_2 used as a representative precursor species

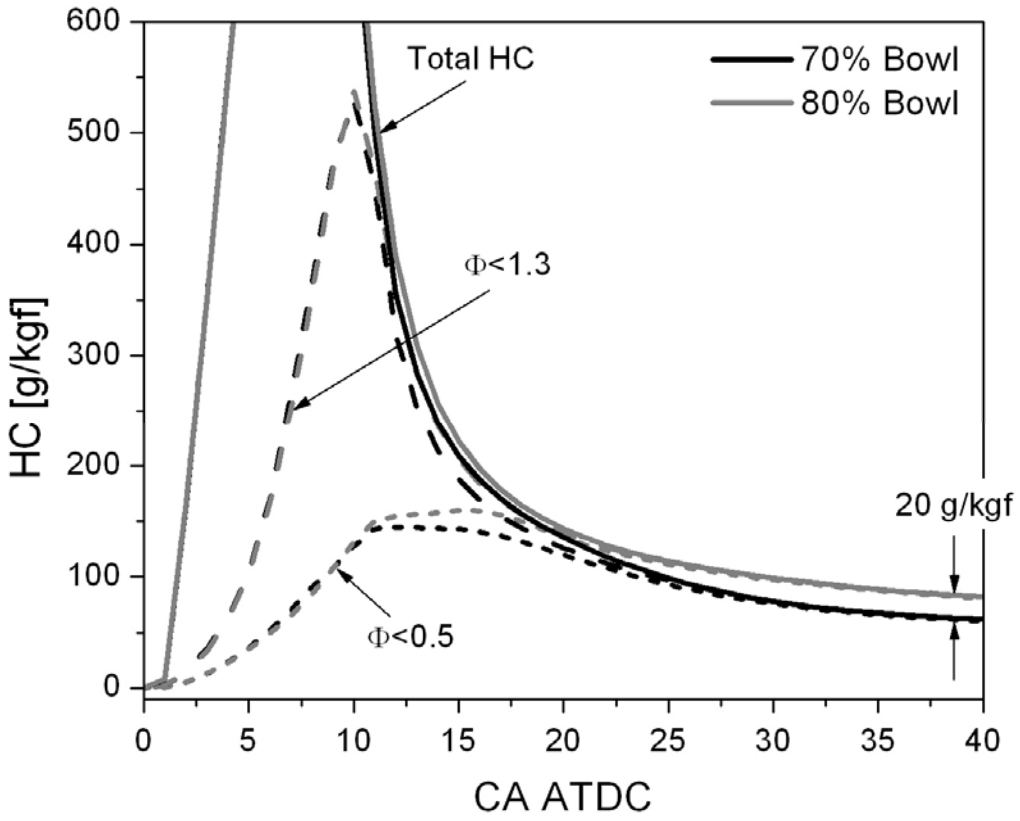
Does delay of jet-bowl and jet-jet interactions reduce soot formation in the 80% bowl?





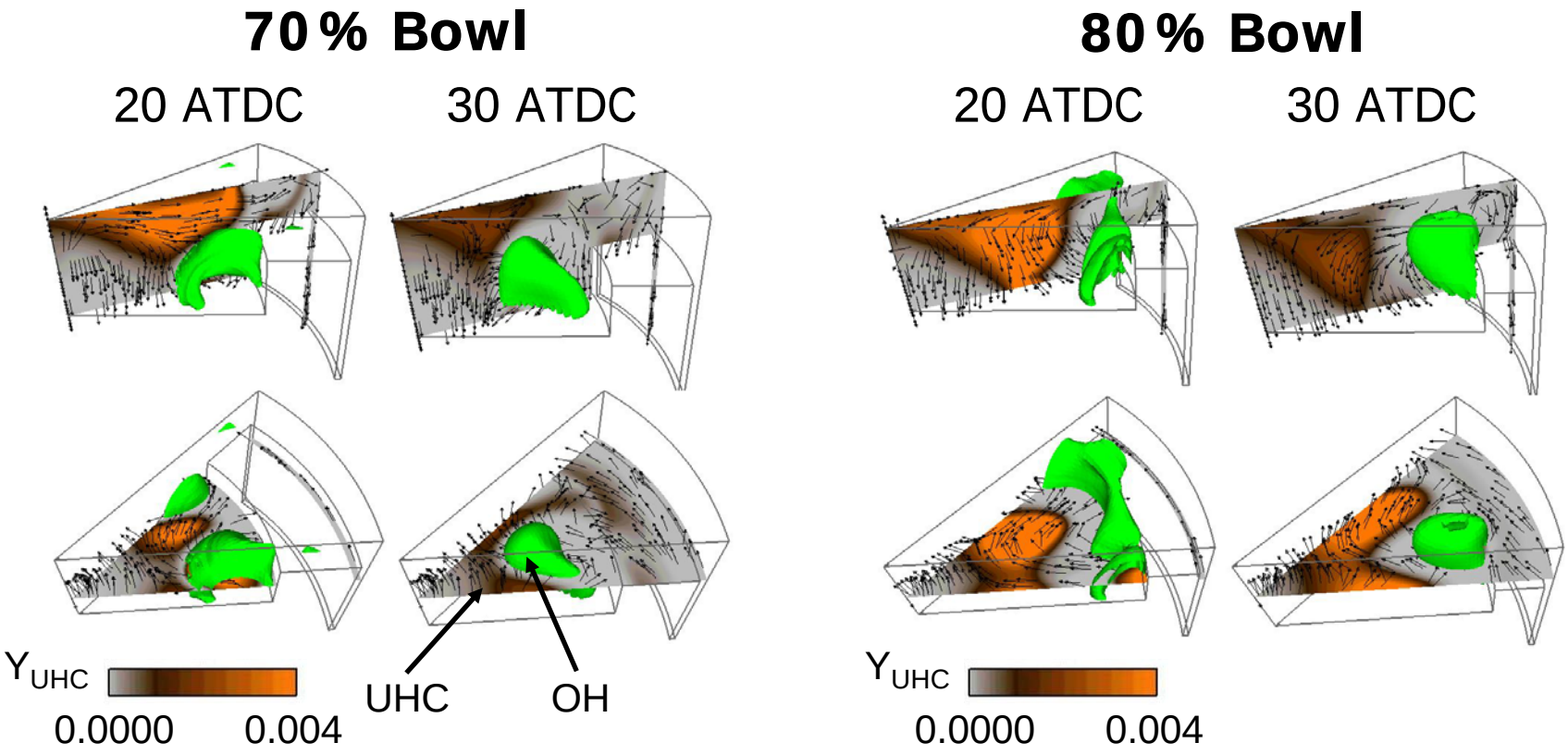
- **Jet-jet interaction vortices trap fuel-rich soot-forming mixtures and cause increased soot-precursor (and soot) formation in 70% piston bowl geometry.**

Can jet-bowl and jet-jet interaction flows contribute to reduced UHC emissions?



- **Total UHC lower in 70% bowl.**
- **Nearly all of the UHC emissions are predicted to stem from lean mixtures (Φ<0.5).**

Jet-bowl and jet-jet interaction flows enhance the oxidation of over-lean near-nozzle mixtures.



Summary and Conclusions

- Pollutant emissions formation processes in LTC fuel jets may be significantly influenced by jet-bowl and jet-jet interactions.
  - Baseline piston bowl geometry (70% bowl):
    - Prior to peak heat release, fuel jet interacts with piston bowl and pushes fuel-rich mixtures out into neighboring jets (jet-jet interaction regions).
    - **Soot formation**: Jet-jet induced vortices trap rich mixtures, leading to higher PAH/soot formation.
    - **UHC:** Jet-bowl interactions transport active combustion regions into center of combustion chamber, enhancing oxidation of over-lean unburned mixtures.
  - Wide-diameter piston bowl geometry (80% bowl):
    - Interaction of fuel jet with piston bowl is delayed and jet-jet interactions are suppressed near peak heat release.
    - **Soot formation:** PAH/soot formation is shifted towards center of fuel jet where entrainment is enhanced, reducing PAH/soot formation.
    - **UHC:** Weak jet-bowl interaction reduces late-cycle bulk mixing, leaving over-lean unburned mixtures at center of chamber.

Additional Material

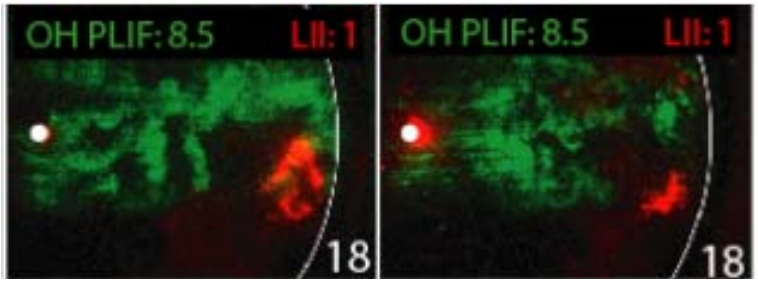
Surrogate research fuel: 71% n-heptane/ 29% iso-octane (PRF29) + 1% toluene

Motivations:

1. Identification of 1st and 2nd stage combustion regions relies on clean H_2CO and OH fluorescence signal

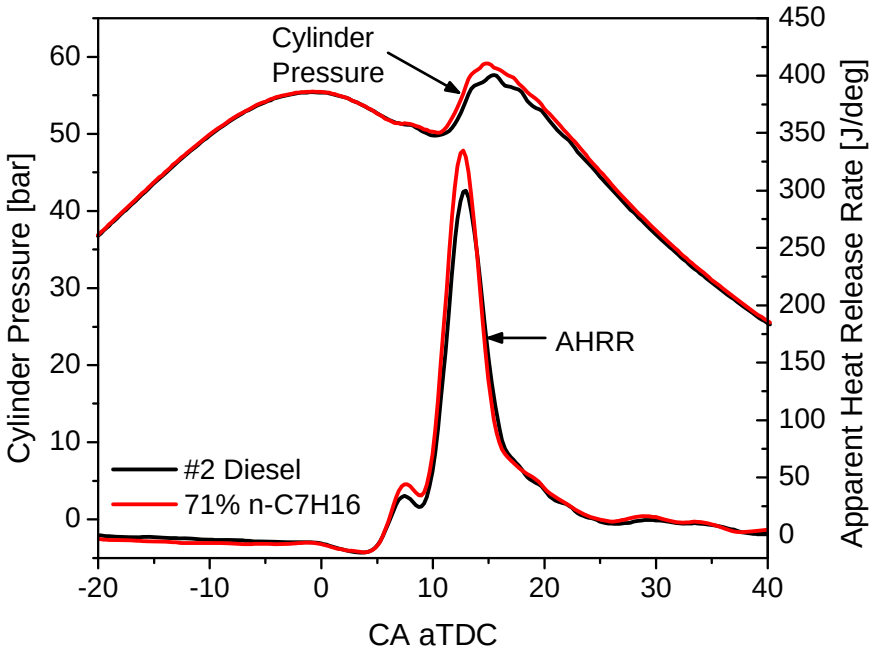
OH PLIF with D2:

OH online **OH offline**

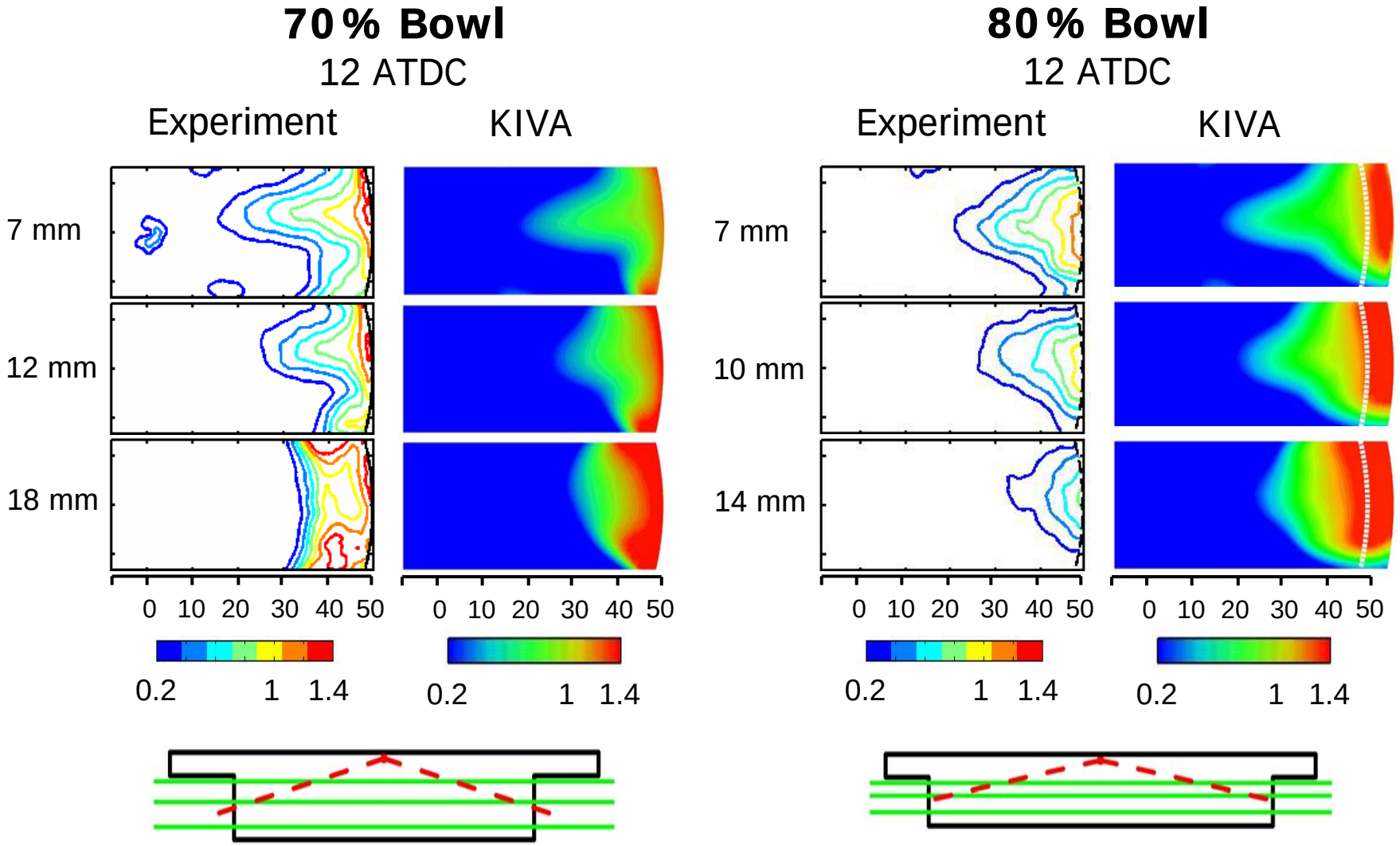


2. Fuel components are compatible with toluene fuel tracer – similar boiling points.
3. Well defined fuel properties are necessary for model development and validation.

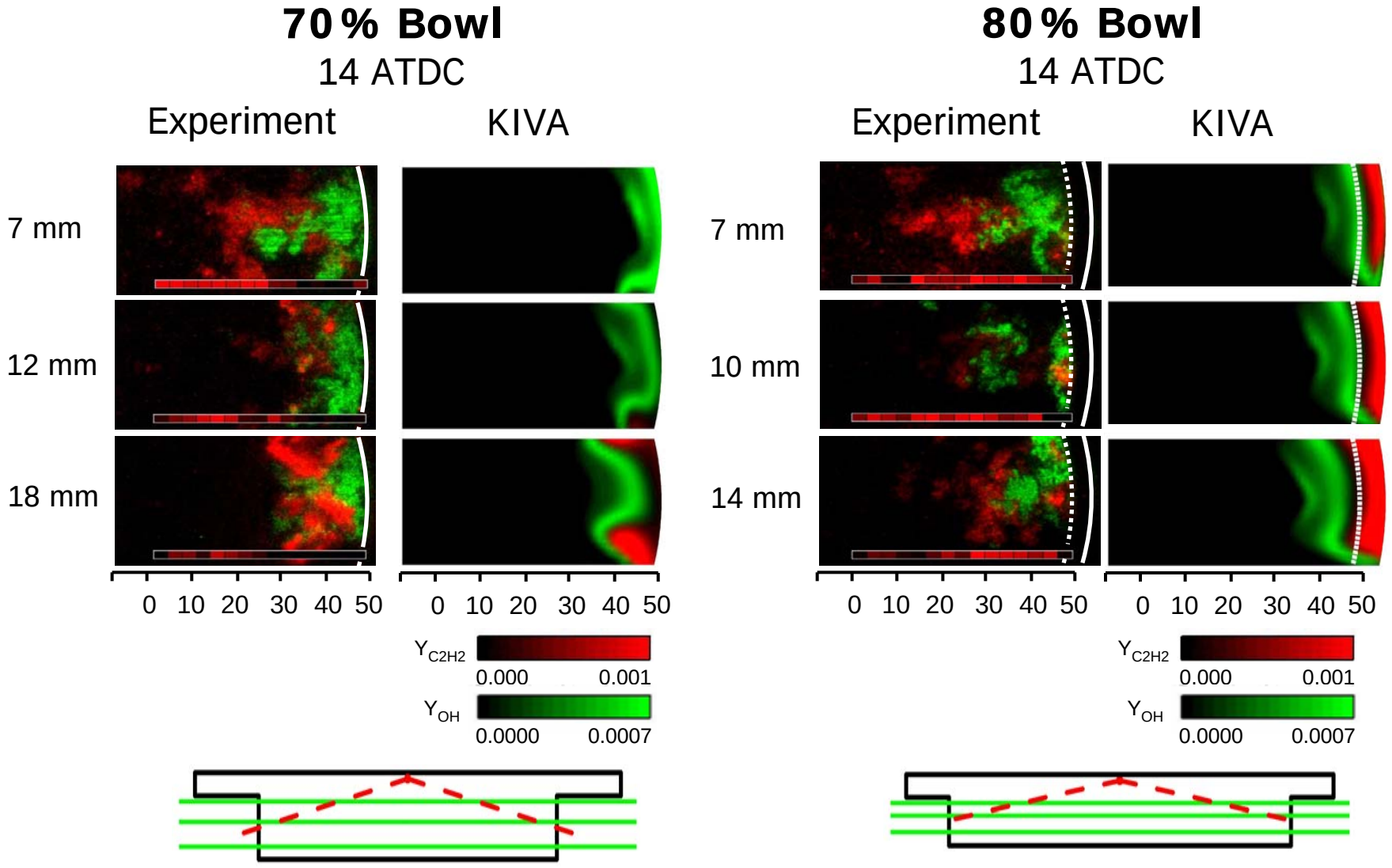
- Blend was chosen to reproduce the ignition timing of a US #2 diesel (CN 45).



The model confirms a lack of jet-jet interaction flows in the larger piston bowl.



The model also captures the effect of these of jet-jet interactions on soot formation.



Late in the cycle, the model shows that OH and formaldehyde occupy distinct regions of the cylinder.