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# A comparison of fuel/air mixing behavior between PLIF experiments (SNL) and simulation (CSI)

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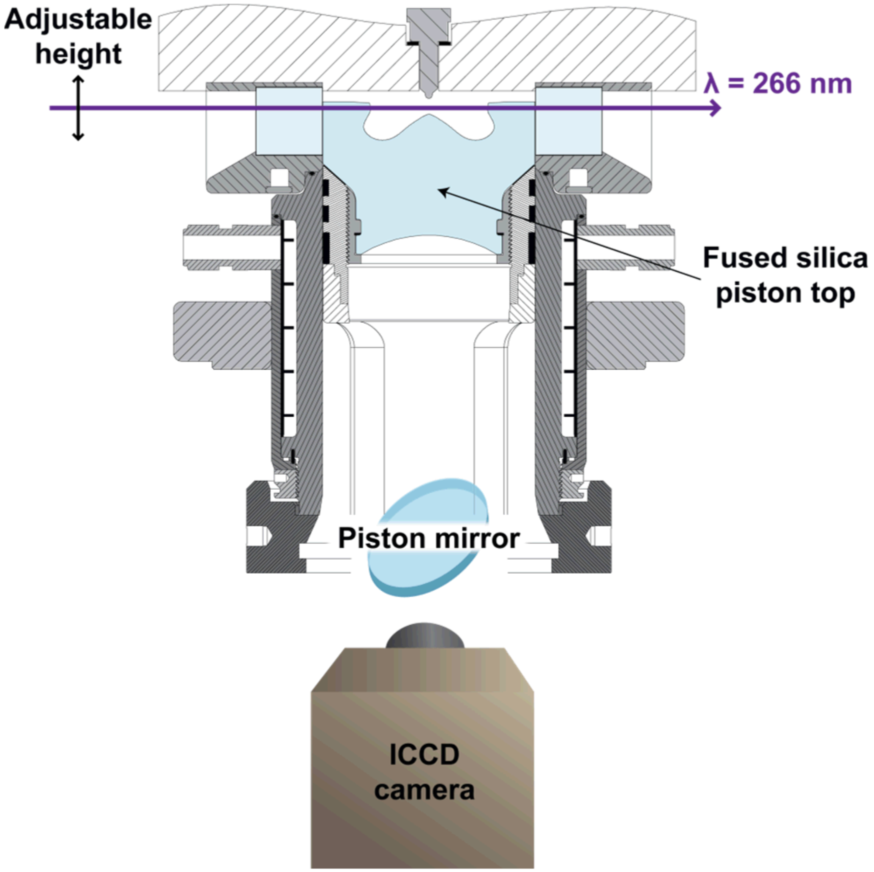
# Processing PLIF and CFD data to make comparisons of the mixture formation process

- Setup
  - Engine operation
  - Experimental uncertainties
  - CFD models used
- Metrics for comparison
  - Spreading angle and penetration length quantification
  - Spray structure: deflection of spray by swirl
  - Fuel concentration gradients
- Comparisons
- Summary

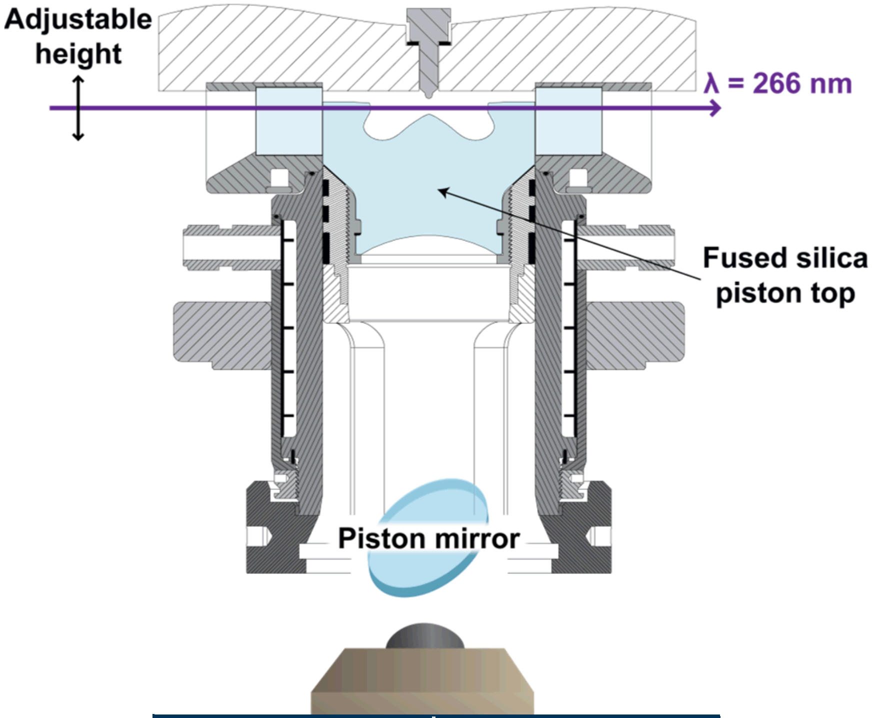
# Setup PLIF Experiments in the SNL light-duty single-cylinder optical engine

- Combustion chamber
  - Bowl volume: 0.028 L
  - Squish height: 1.35 mm
  - Geometric compre… atio: 15.8
  - Flat-top piston: … ve … uts
- Engine operati…
  - 150… IMEPg, P… 2
  - …tion, SSE 27… D …
  - …on-combusting: …
  - Fuel: 42 v… ecane + … %
    h… ne
  - … weight% 1…
    …ethylnaphtha…



# Setup PLIF Experiments in the SNL light-duty single-cylinder optical engine

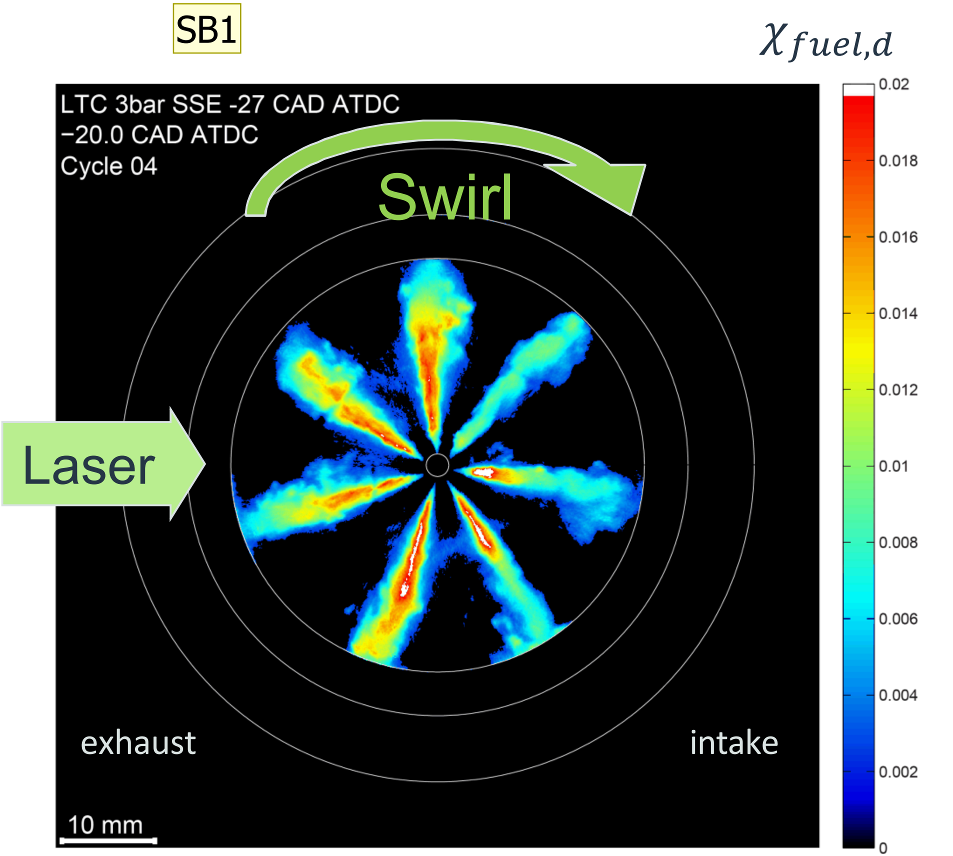
- Illumination source
  - Nd:YAG, $4^{th}$ harmonic (266 nm)
  - ~ 30 mJ/pulse (relative intensity measured for each
  - Laser sheet thickn
- Imaging
  - PI-MA era (ga 15)
  - lens (f/16
  - 295 long pass fi




| | |
|---|---|
| Bore x stroke | 82 mm x 90.4 mm |
| Compression ratio | 15.8:1 |
| Valves | 4 |
| Injector type | Solenoid |
| Holes | 7 x 139 µm |
| ks | 1.5/86 |
| Included Angle | 149° |

# Uncertainties of PLIF measurements

- Dewarping-induced error in radial locations: measurements near chamber center (R<~7mm) are less reliable.
- Beam steering effects … to show up in squish region when … n is …hin ±15 CAD around TDC…
- Injector sl… …ed by t… …ser pla…
- …plane fluoresc… …gnal from …quid brought … …tterin… plume… …ning las… …ou… …measurem…




| | CAD ATDC | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | -26 | -25 | -24 | -23 | -22 | -21 | -20 | -19 | -18 | -17 | -16 | -15 | -14 | -13 | -12 | -11 | -10 | -9 | -8 | -7 | -6 | -5 | … | 27 |
| Images | | | | | | | | | | | | | | | | | | | | | | | | |
| Injection | | SOI | | | | | | EOI | | | | | | | | | | | | | | | | |
| Combustion | | | | | | | | | | | | | | | | | | | | | SOC | | | MBF90 |

## Slide 5

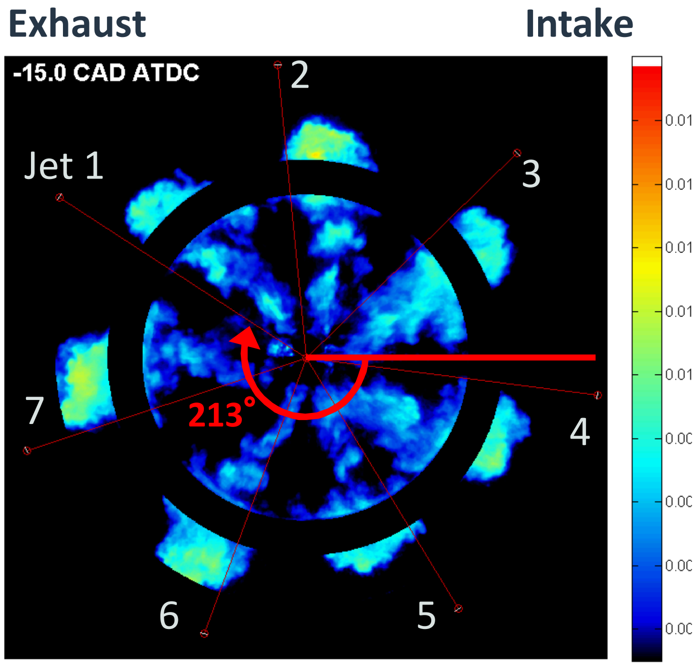
**SB1** There are many other sources of uncertainty, such as signal trapping, background reflections of fluorescence, fluorescence from laser light reflected off of chamber surfaces, camera nonlinearity at high intensities, etc.
Busch, Stephen, 8/11/2016

# Setup: CFD spray models

- Blob injection model
  - Initial drop sizes equal to effective nozzle diameter
- Rebound model
  - No wall film formation
- O'Rourke Turbulent dispersion model
- Dynamic drop drag model
- KH-RT modified breakup model
- NTC collision model
- Post model for collision outcomes
- Frossling correlation to model spray evaporation

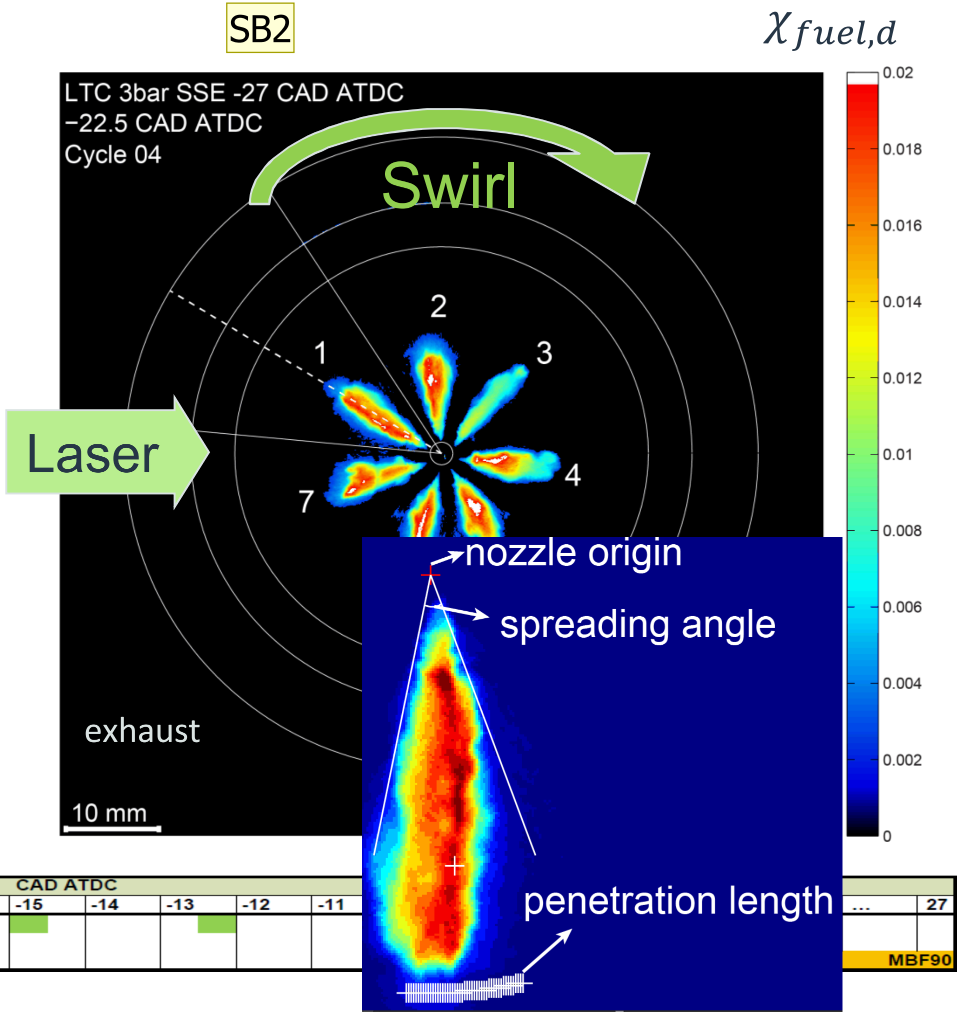
# Injector clocking

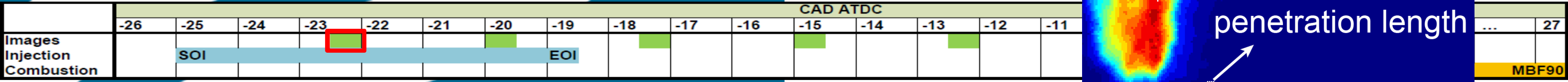
- 7 holes with equal azimuthal distribution
- Jet 1: axis oriented 21[illegible]° from horizontal axes
    - Angle estimated [illegible] initial [illegible] jet penetration[illegible]



# Spreading angle and penetration length quantification

- Background subtraction:
  - For -22.5 and -20°aTDC, $\chi_{fuel,d}$<0.0025 was removed
  - For CAD>=-17.5°aTDC, $\chi_{fuel,d}$<0.0010 was removed
- Spreading angle and p... ation length calculation using ECN ... bers, SAE Paper 960034).
  - Since me... e not t... pe... jet axis, ca... gle" is the proj... n o... ld-
- ...lculations we... ed for... plume f... dual fra...



**Slide 8**

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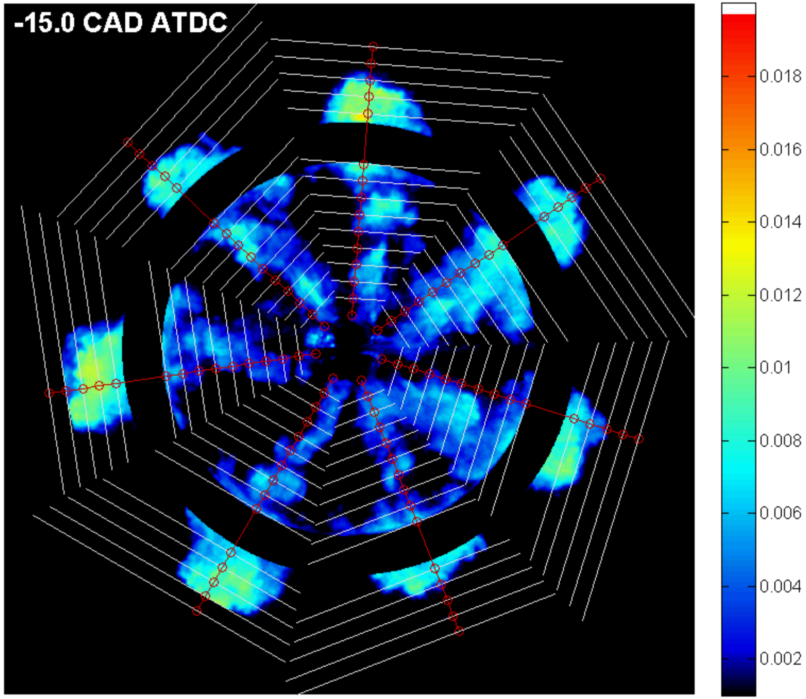
**SB2** When publishing this work, it will be important to cite work that demonstrates how fluorescence-based and schlieren measurements compare, as Siebers developed his methodology for schlieren images.

I believe Ethan's paper shows a comparison of these things.

Busch, Stephen, 8/11/2016

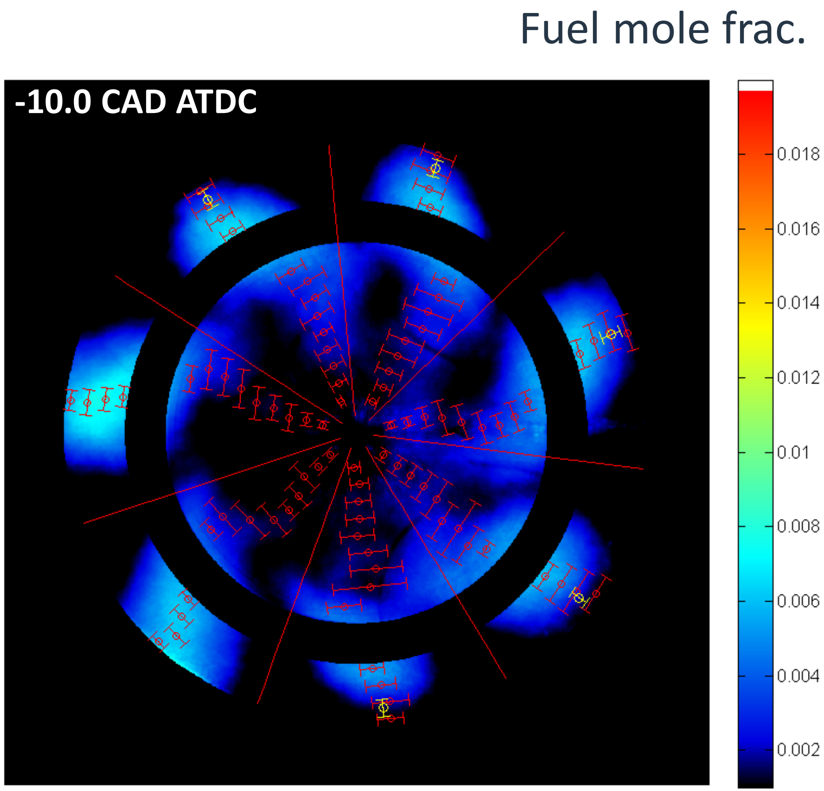
# Spray structure characterization

- Fuel concentration-weighted centroid evaluated along multiple profiles (shown as white lines) across each jet
- Ensemble average pro simplified representation of je ctu insight into how jets ar ed by sw
- The proc d to ex enta da ta



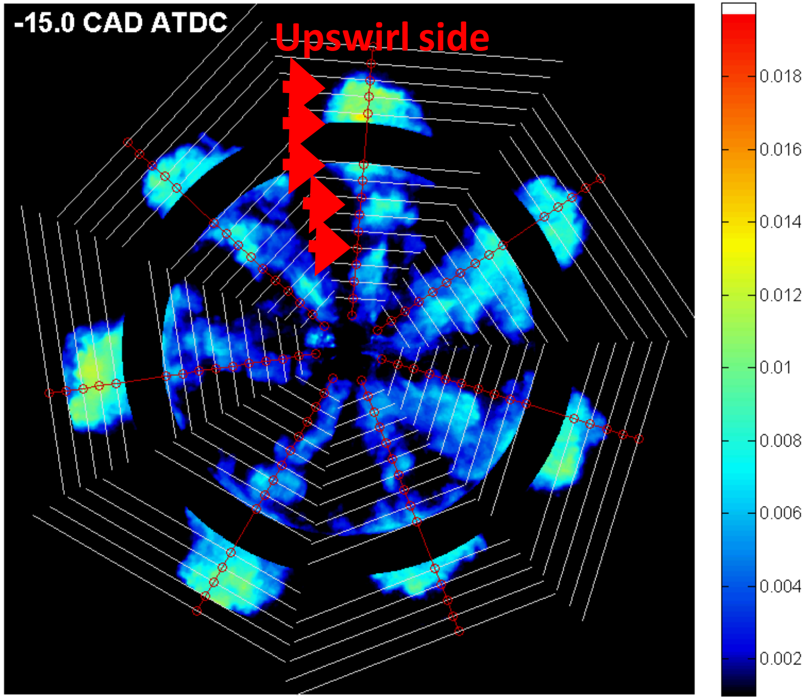
# Characterization of jet deflection

- Ensemble averaged image shown with red lines indicating jet axes
- Red bars show ensemble averaged fuel concentration-weighted ce... oids for each jet
- Jet deflection increases w... angle; detection capability (... arly in ... l) diminishes
- Swirl inte... ore inte... he bo... tha... region
- ...ize each jet by i... ar deviation ... m the jet axis a... of radi... each imaged cr...



# Characterizing fuel concentration gradients

- Fuel concentration data have been collected along the white profiles shown on the right
- For each cycle, jet, anc ... l position, the gradient on the ... in ... of the jet is estimated
  - see ri ... efinitio ... nswi
- ... ncentration ... nts are a ... omputed bas ... ocatio ... the jet hea

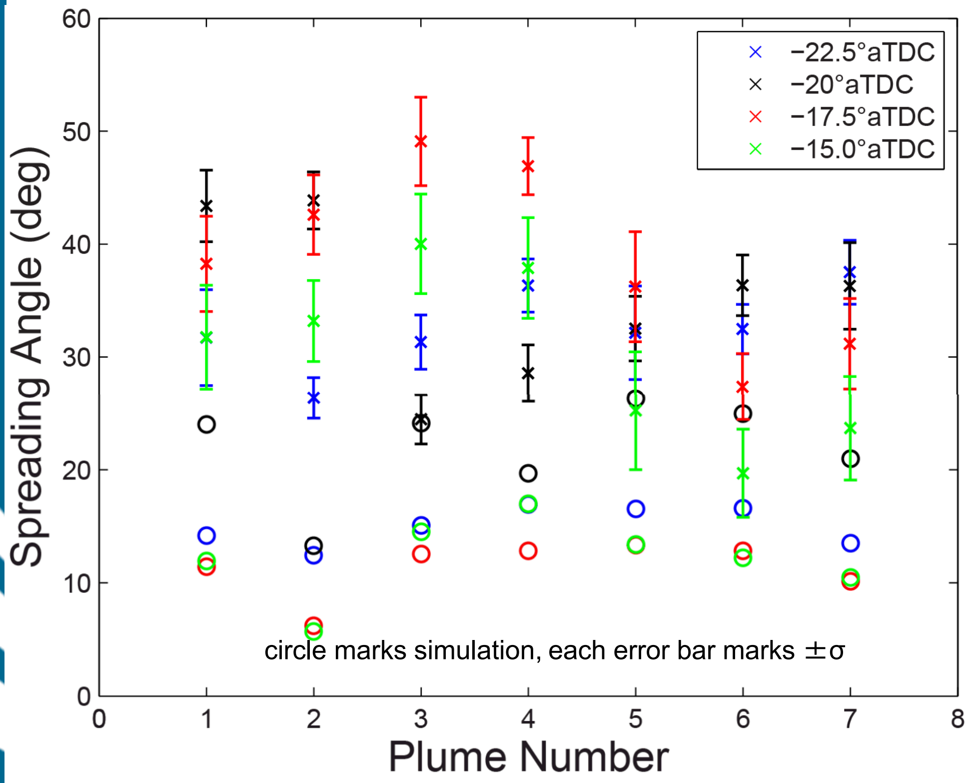


# Results

# Spreading angle comparison

- Simulated spreading angles are typically smaller than experimentally determined angles
- The experimentally de…rmined spreading angle chang… …matically with crank angle
  - Can this be i… …ed in the simul…
- Po… …vements
  - …d interrogation … …depth (she… thickness) f… … outpu… und… …ty to fini…

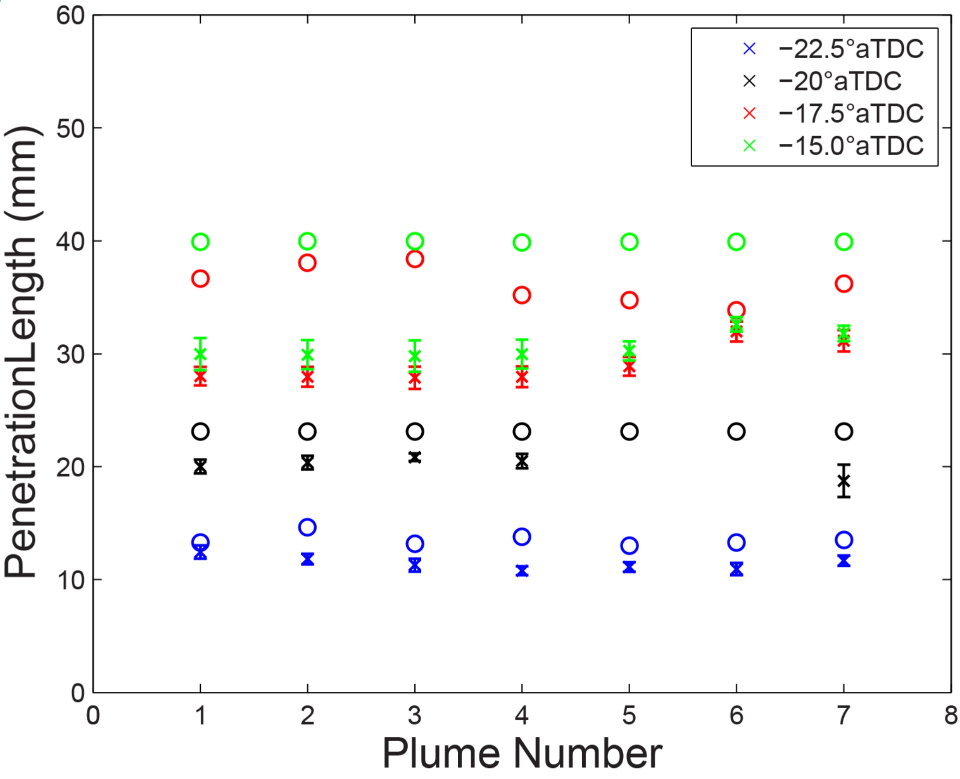
Cone angle initialized as 15deg



# Penetration length comparison

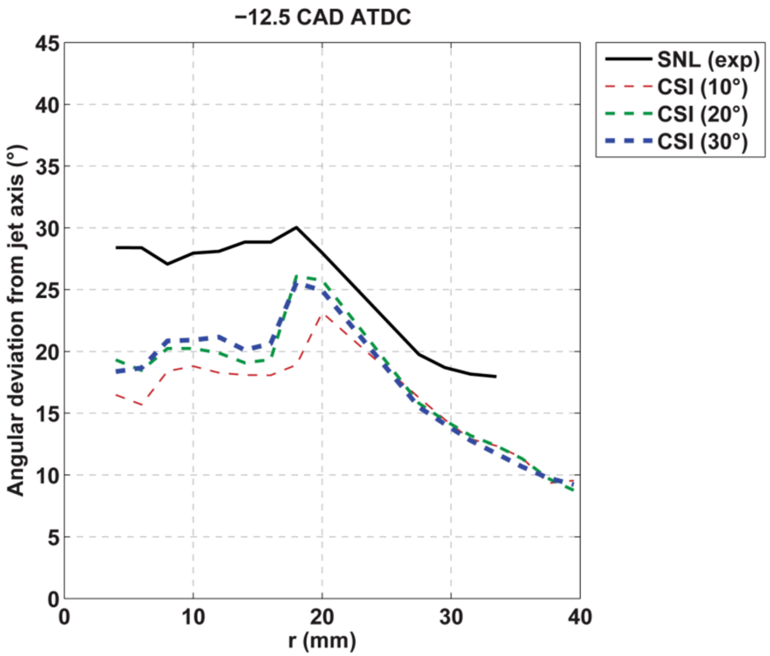
- Simulation over predicts spray penetration regardless of spray angle
  - Larger spreading angles may provide better results
- Over prediction is rela… mall early in the injection eve… 2.5 … C) but increases with … gle
  - At -1… …lated va… …reaches bo… …se …xperiments)
- …ter EOI, high… variat… observ… …periment… si…
  - …symmetric fl…
  - Hole…

Cone angle initialized as 20deg



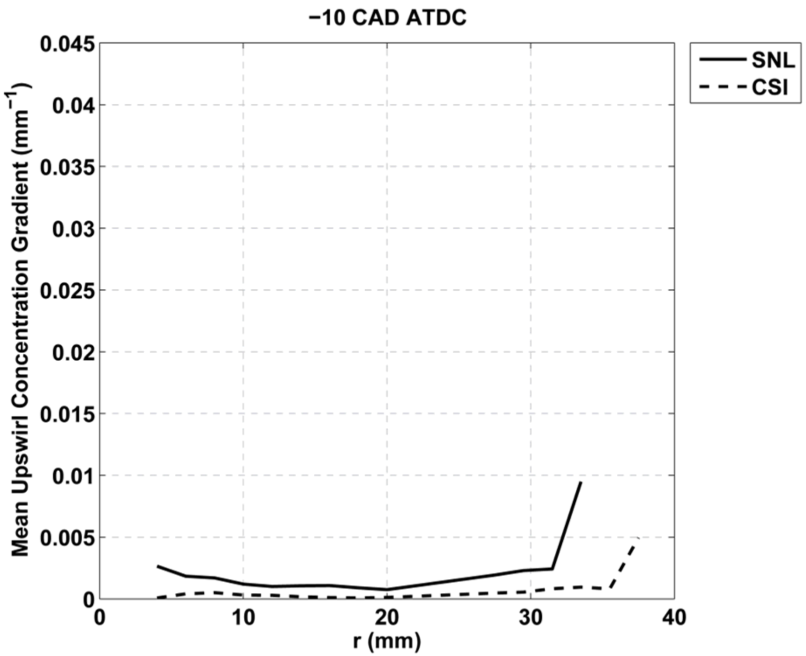
# Spray structure: jet-averaged angular deviation from jet axes

- Squish region: deviation under-predicted after 15 CAD ATDC
    - At 12.5 CAD BTDC, swirl-induced displacement of mix n the squish region is under pr
- Bowl: deviation u edicted ter 12.5 CAD AT
    - TDC, expe ta less reliable c varia increases



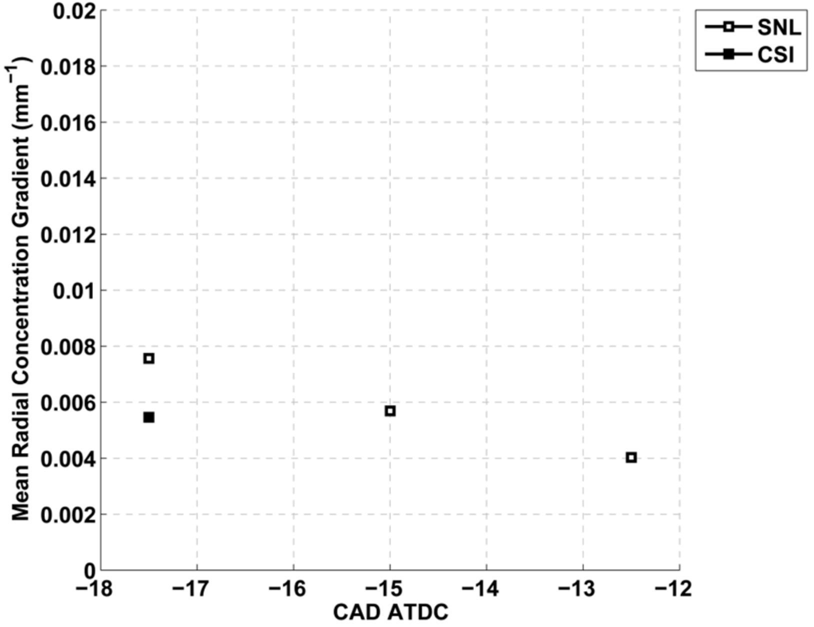
# Upswirl fuel concentration gradients

- Experimentally-derived fuel concentration gradients are likely not reliable for earlier injection timings
  - Calibration for lean ... l ratios, not liquid fuel
  - Bright backgr ... ections ... to liquid fu ... centra ... ns of ... l
- Tren ... gradients t ... ree ... 7.5 CAD BTD
  - Gradients dec ... time
  - Som ... on of gr ... ngles
    - ... bly related to ... n of fuel concentrati ... easurements



# Radial gradients in jet head

- Experimental data are available / reliable for crank angles of 17.5, 15.0, and 12.5 CAD BTDC
- Simulated jets reach th … ll by 15 CAD BTDC; radial gradien … rm … n is not available after th …
- Reasonab … nt (wit … yclica … vari … y given jet … 1 … AD



# Summary

- Simulated jet spreading angles are smaller than experimentally determined spreading angles
  - Experimentally determined spreading angles change with crank angle
- Simulated spray penetration is over predicted
  - Spray reaches the bore wall much sooner in the simulation than in the experiment (if the jets reach the wall at all in the experiment)
- Jet deflection by swirl is under predicted, especially after ~15 CAD BTDC
- Concentration gradients seem to match within reason
  - Match within range of cycle-to-cycle variability for a given jet