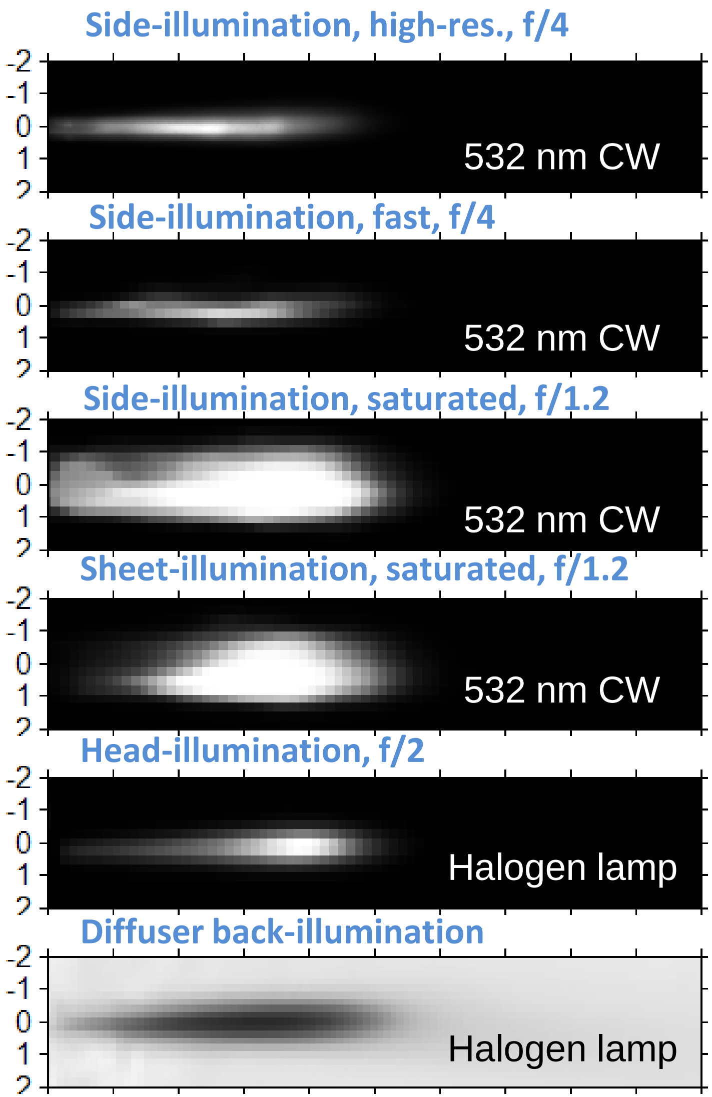
Topic 3 – Vaporizing Diesel Spray

Spray A and Spray B

Presenter: Caroline Genzale, Georgia Tech

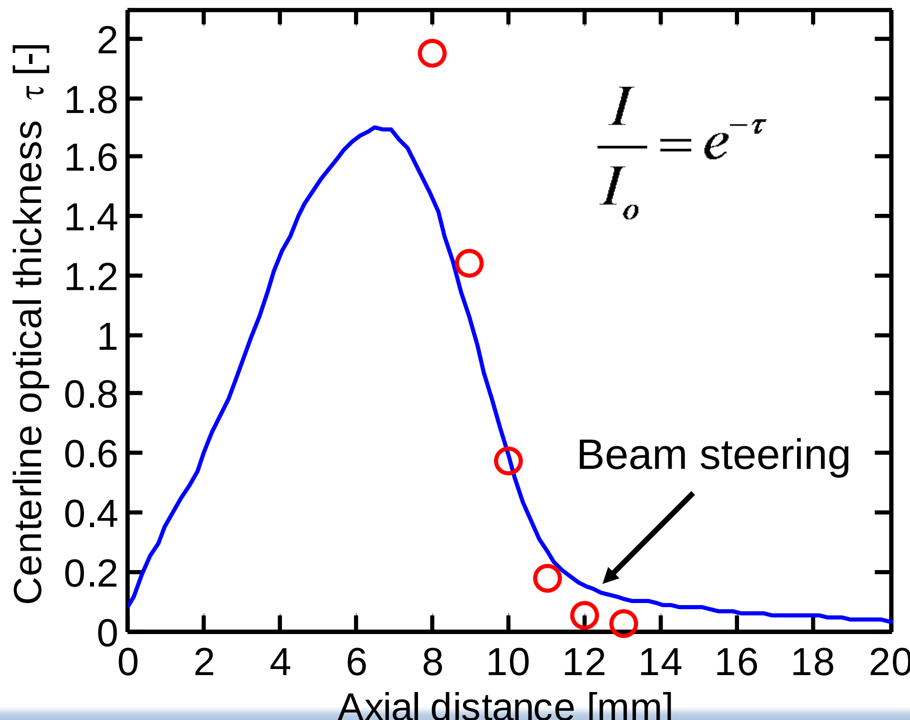
September 5th, 2015

Some history: We've made several attempts to standardize liquid length measurements within the ECN.



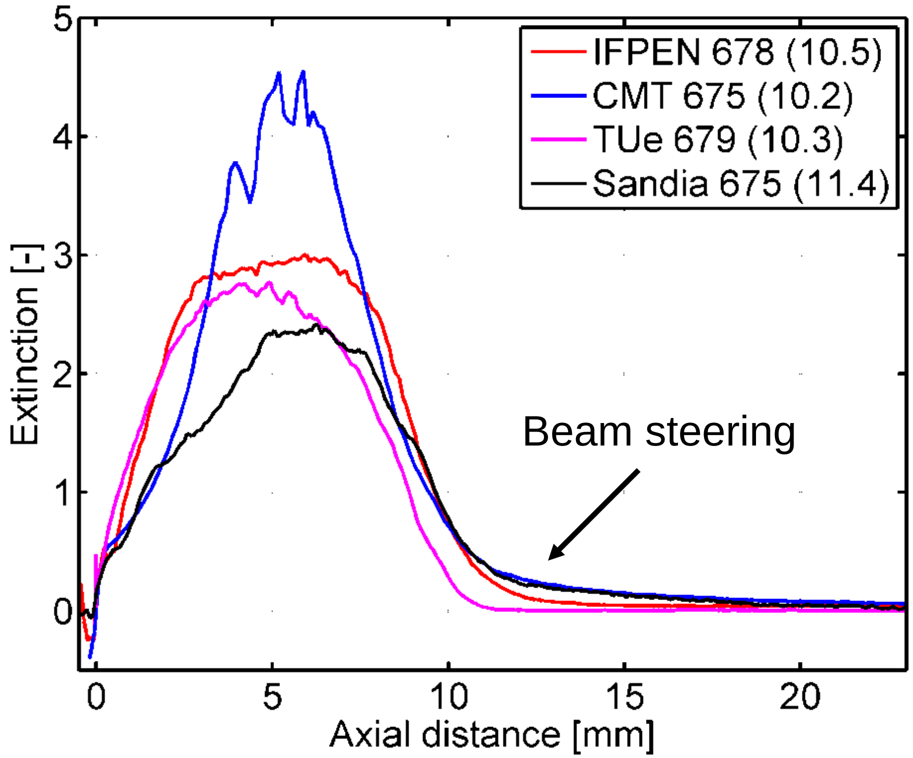
ECN1: **Detection of liquid boundary near the LL is sensitive to optical method and setup**

Extinction offers referenced intensity measurement.



Some history: We've made several attempts to standardize liquid length measurements within the ECN.

ECN2: Adoption of DBI imaging to measure I/Io

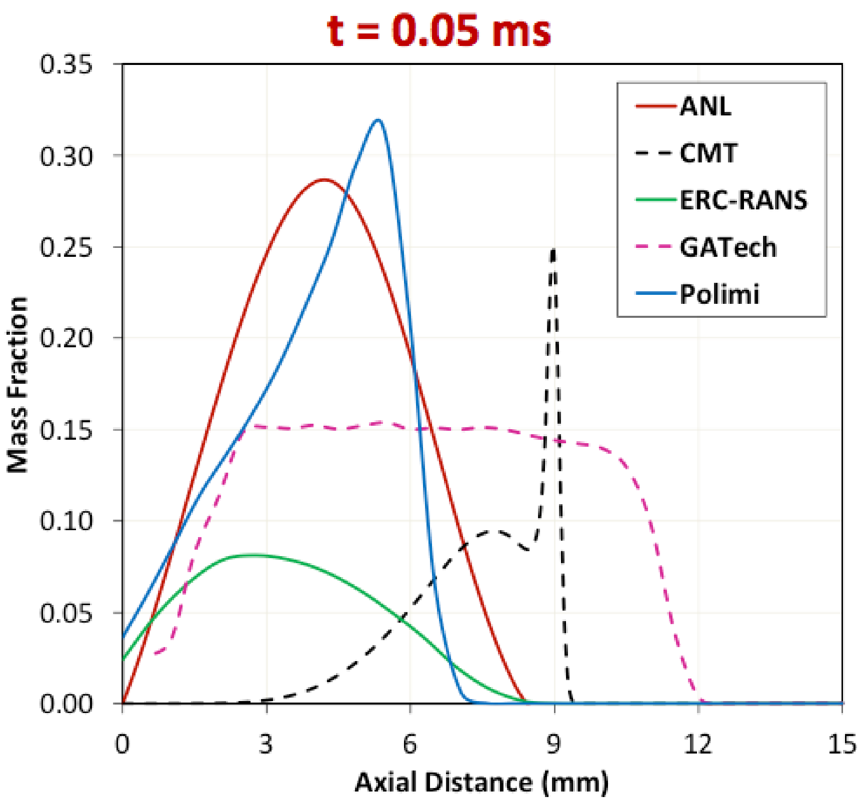


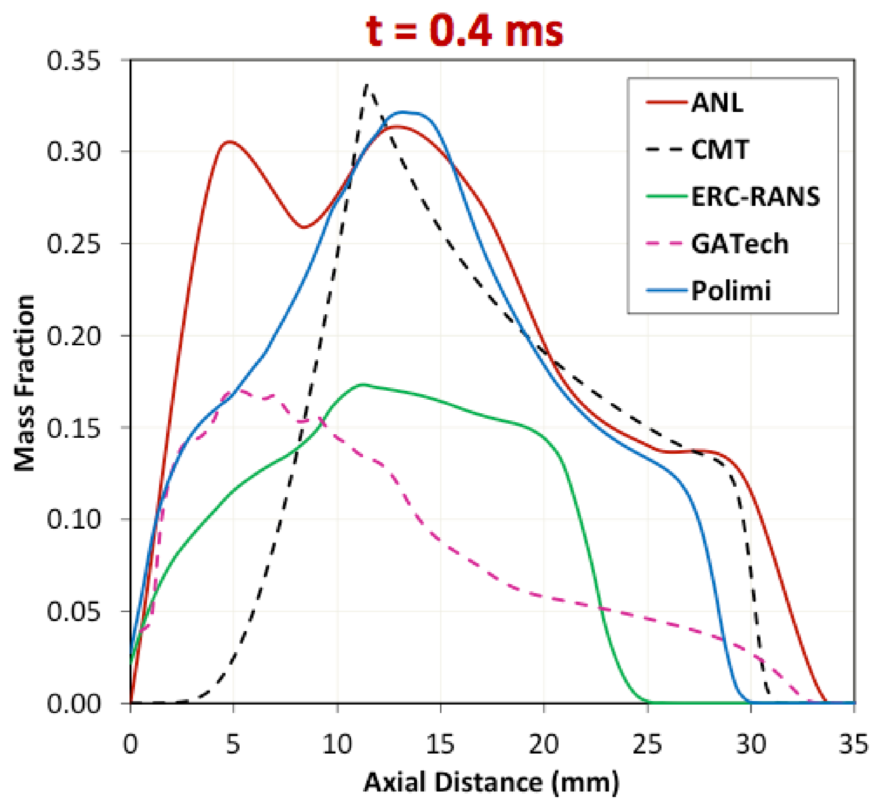
- "Extinction profiles measured on the centerline are somewhat different between institutions."
- "The variations observed are believed to come from differences in optical arrangement (mainly illumination and collection angles)."
- "A methodology must be setup to consistently measure liquid length from extinction without the influence of beam steering."

ECN4: Fredrick Westlye will provide us an update on this topic next!

More history: We've seen consistent predictions of liquid/vapor penetration between CFD codes, but not in the details of the spray.

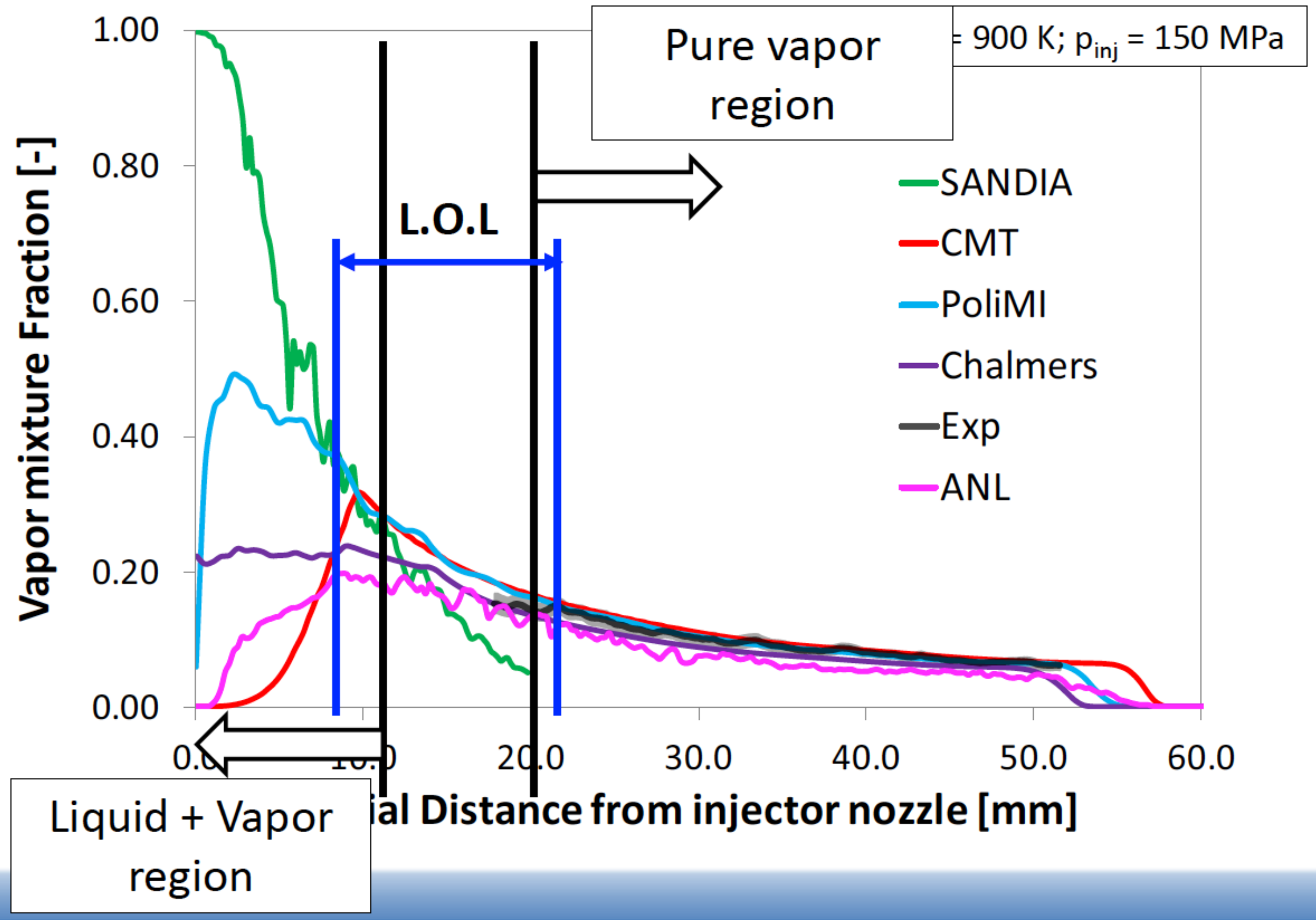
ECN2: Significant differences between CFD codes in the predicted spray structure.





More history: We've seen consistent predictions of liquid/vapor penetration between CFD codes, but not in the details of the spray.

ECN3: Even when downstream profiles are consistent, upstream spray structure can vary greatly. These regions can be coincident with LOL region.



Experimental Objectives for Vaporizing Diesel Sprays

Following up on prior themes:

•Further assess institutional variations in DBI measurements and develop a standardized (and consistent) measurement approach for liquid penetration.

•Pursue further insight into phase transition behavior at Spray A conditions.

Vaporization data at new target conditions:

•Spray A multiple injection conditions

•Spray B

•Spray C and D injectors

Modeling Objectives for Vaporizing Diesel Sprays

Following up on prior themes:

- Deep dive into near-nozzle spray structure variations between codes and sensitivities to ambient conditions.
- Understand impact of these differences on combustion predictions.

Simulations at new target conditions:

- Spray A multiple injection conditions.

Engine Combustion Network

Spray A Parametric Modeling Study

CMT

Adrian Blanco, Raul Payri

PoliMi

Tommaso Lucchini, Gianluca D’Errico

GA Tech

Gina Magnotti, Caroline Genzale

Bosch

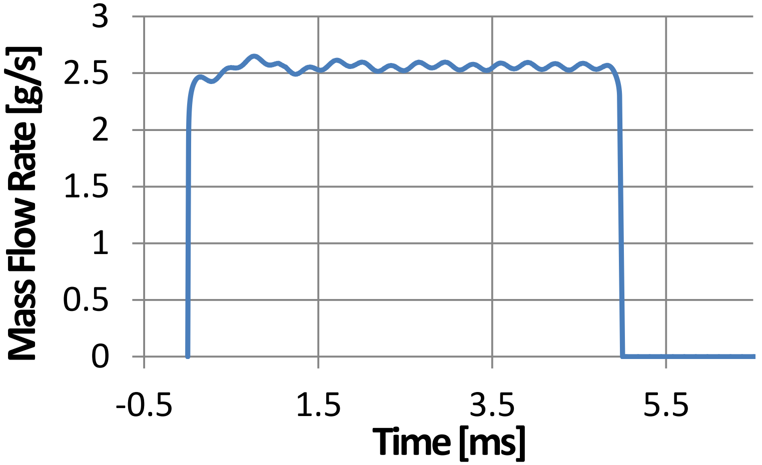
Edward Knudsen

Sandia

Guilhem Lacaze, Joe Oefelein

Target conditions for Spray A parametric modeling study

- Injector 675
- 89.4 µm, $C_a = 0.98$, $A_{eff} = 6.15\text{x}10^{-9}\ m^2$, $\rho_{liq} = 713\ kg/m^3$
- Standard injection rate profile provided to all institutions



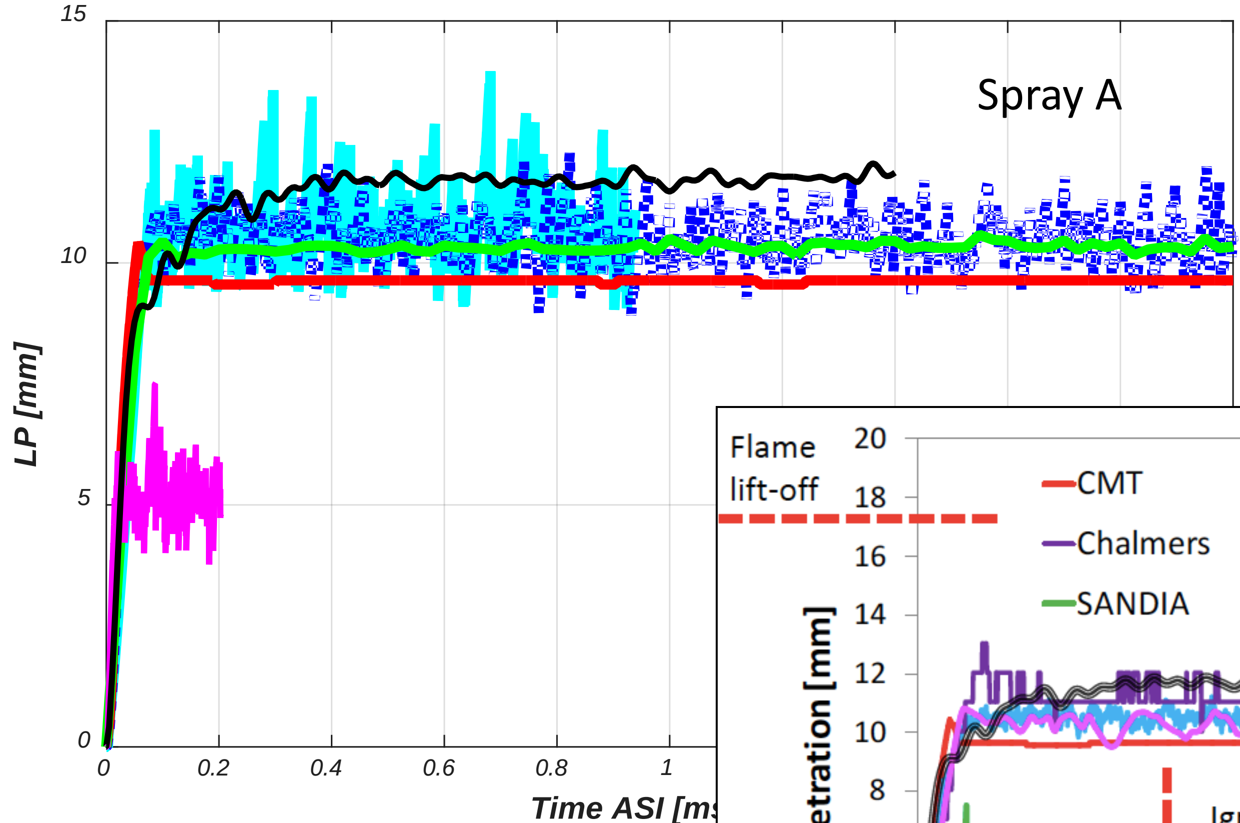
Parametric Variable	O_2 [%]	T_{amb} [K]	ρ_{amb} [kg/m^3]	P_{inj} [bar]
Standard Spray A	0	900	22.8	1500
Temperature	0	700	22.8	1500
	0	1200	22.8	1500
Density	0	900	7.6	1500
	0	900	15.2	1500
Injection Pressure	0	900	22.8	500
	0	900	22.8	1000

Comparison of spray and CFD models

	PoliMi	GA-Tech	CMT	Bosch	Sandia
Code	OpenFOAM	CONVERGE	OpenFOAM	Cascade Technologies	Raptor
Spray model	Blob, KH-RT	Blob, KH-RT	Eulerian Σ-Y model	Eulerian dense fluid	Eulerian dense fluid
Evaporation model	Frossling drop evaporation	Frossling drop evaporation	State relationships from locally homogeneous flow assumption	Peng-Robinson EOS	Real fluid model
Turbulence model	RANS, k-ε	RANS, k-ε	RANS, k-ε	LES	LES Dynamic Model
Mesh Dimensionality Grid size	2D 0.5 mm	3D 0.0625 – 2 mm	2D 0.009 mm – 0.7 mm	3D w/ internal nozzle 3.2M cells	3D 0.002 mm – 0.1 mm

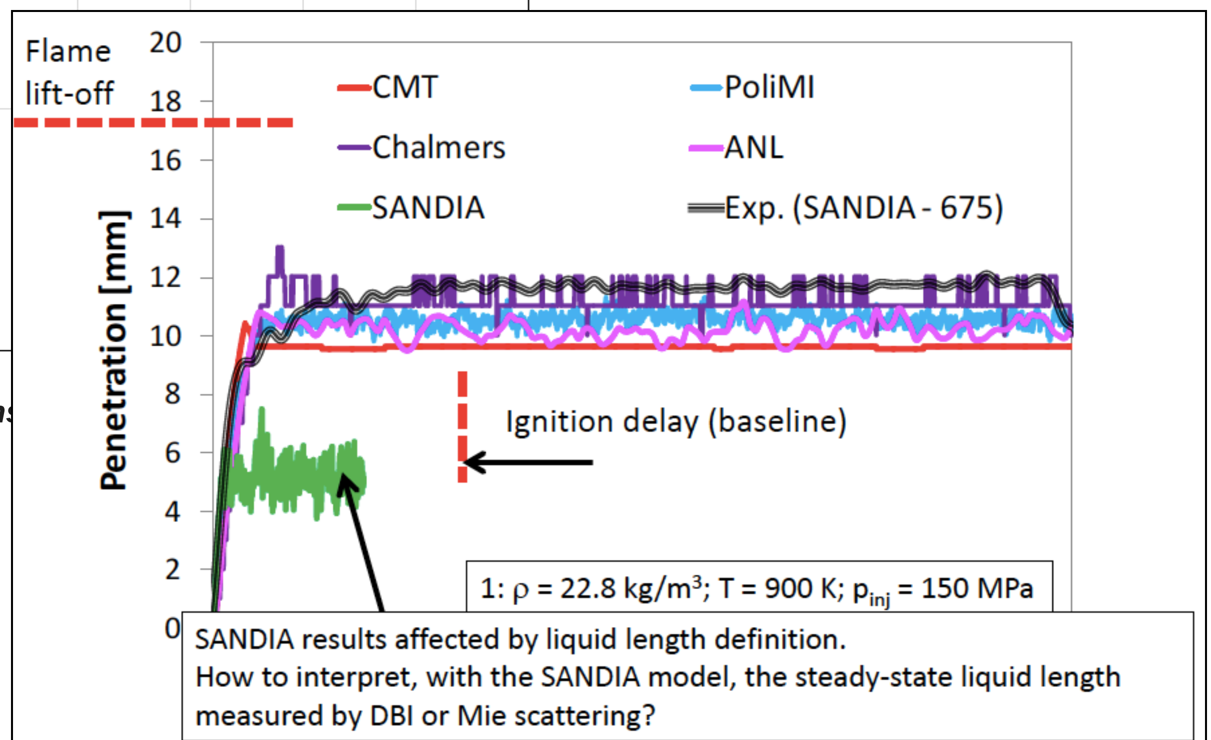
Standard Spray A Condition

Simulations of quasi-steady liquid penetration cluster around the experimental data, similar to previous workshops.

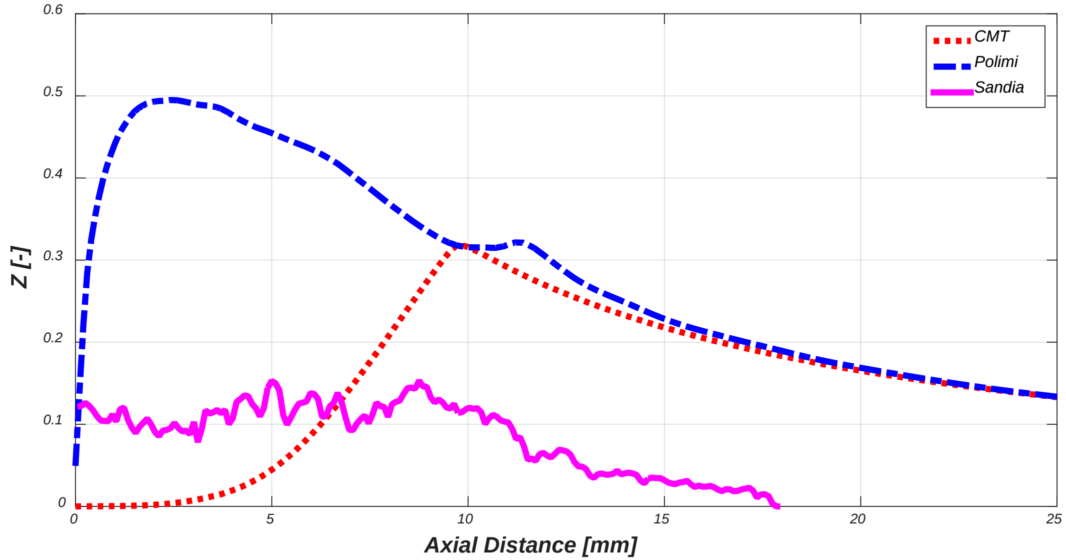


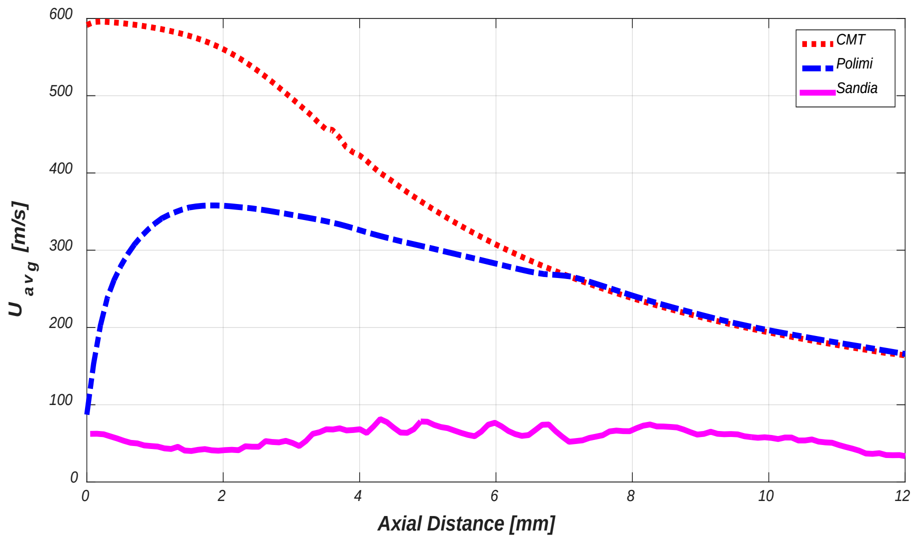
Liquid boundary definition:

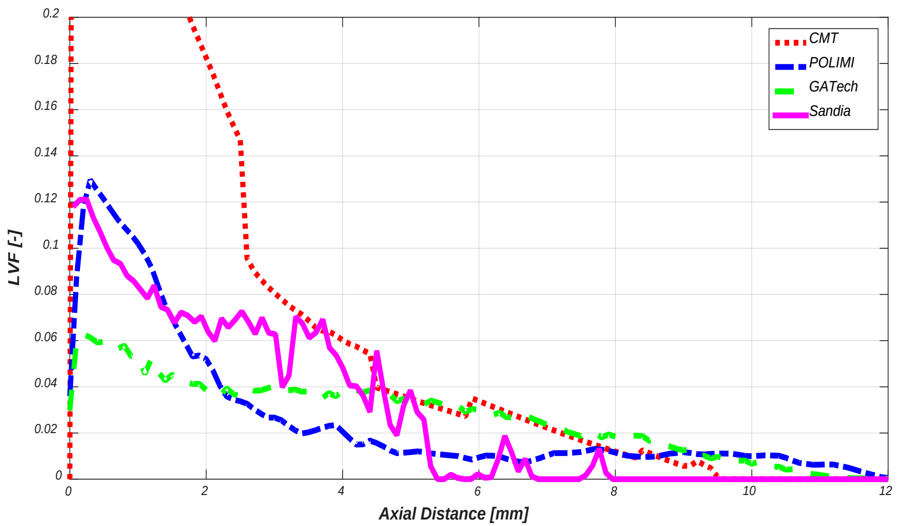
Axial position where path-averaged liquid volume fraction is 0.15%



Differences in fuel vapor fraction upstream arise from combined effects of spray model and momentum coupling.



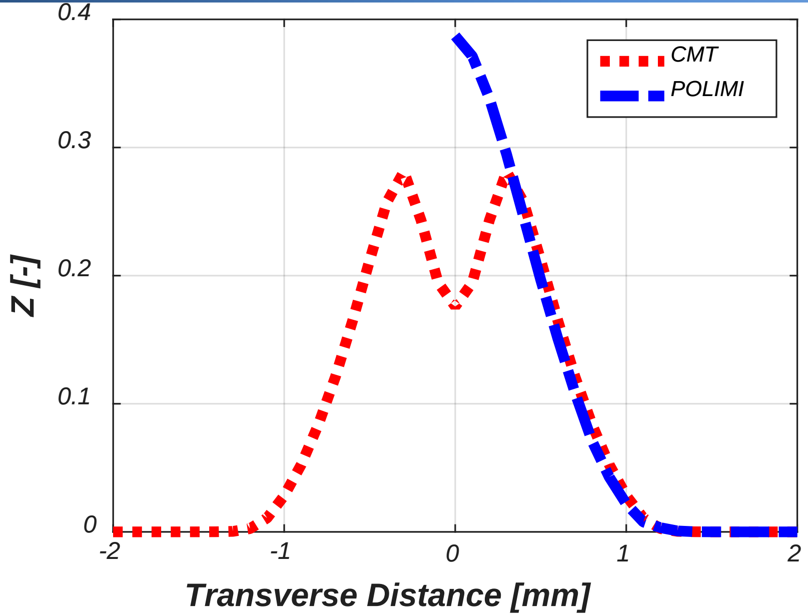


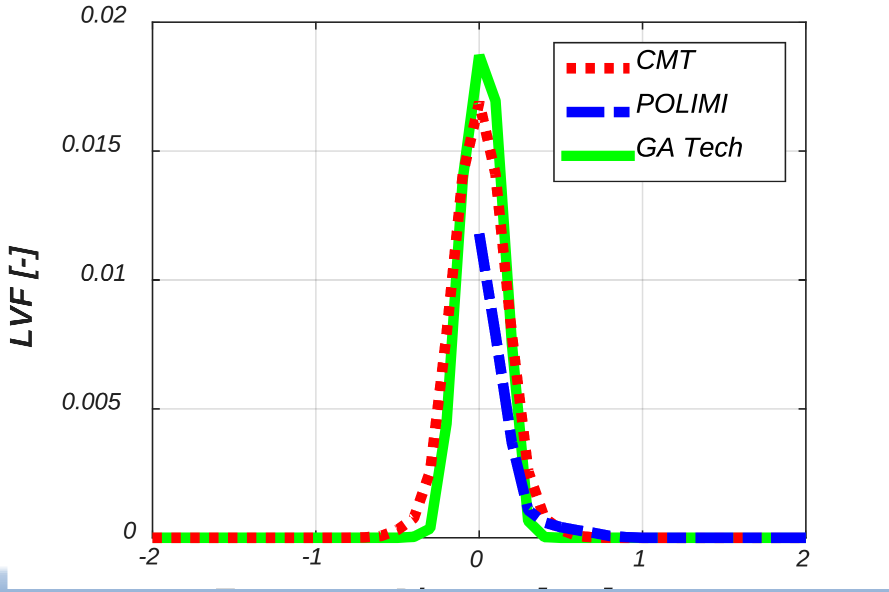


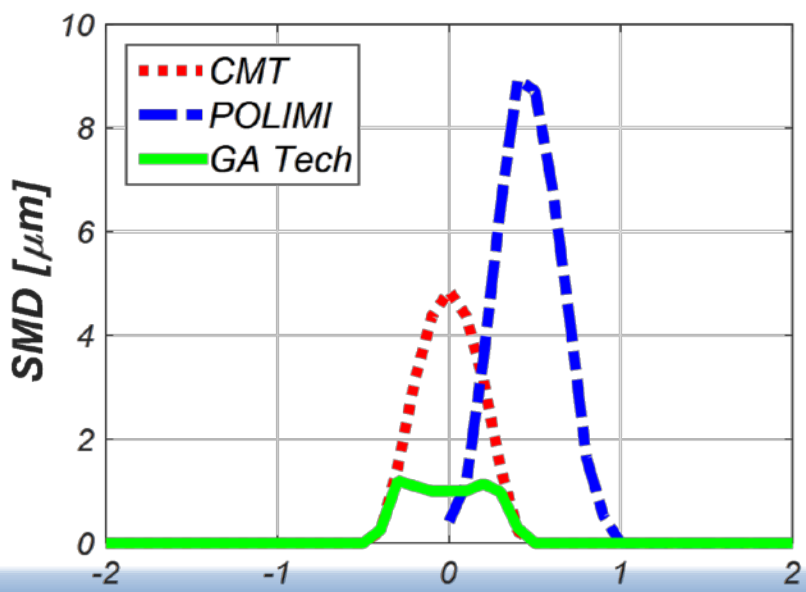
Jet dispersion well matched, but predicted spray structures vary significantly between institutions as we approach the LL.

Spray A
time averaged
spray structure
1 - 3 ms

7.5 mm



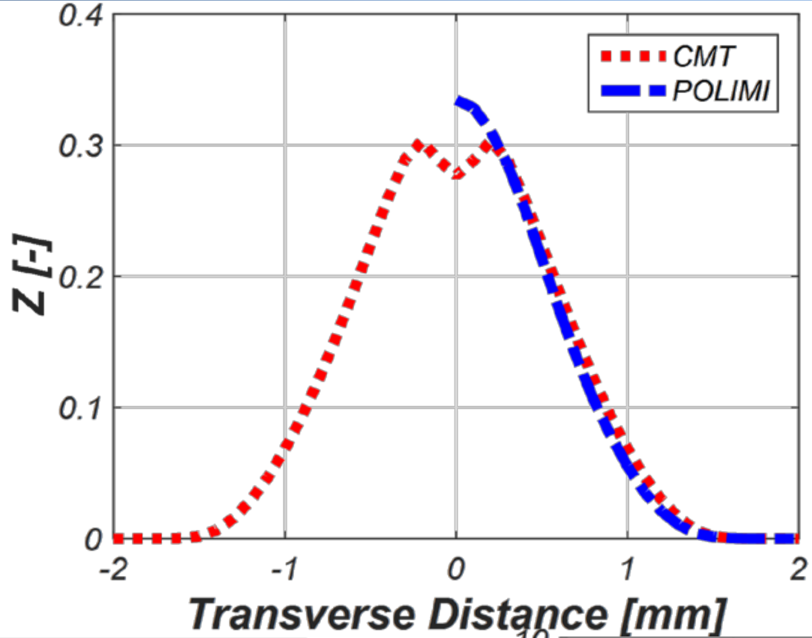


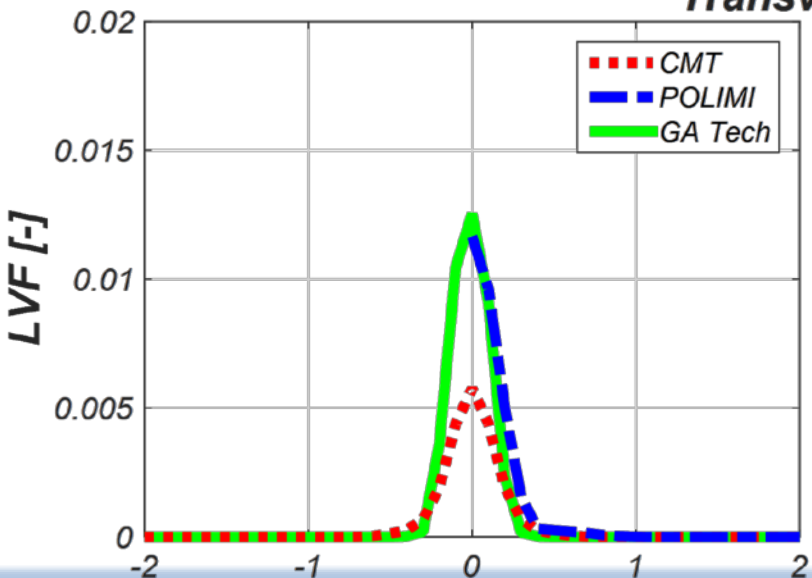


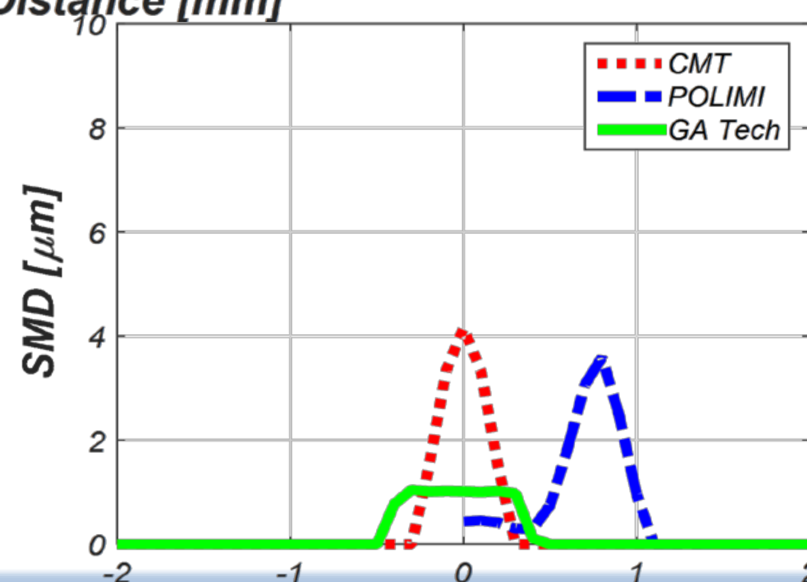
Predicted spray structures vary significantly between institutions as we approach the LL.

Spray A
time averaged
spray structure
1 - 3 ms

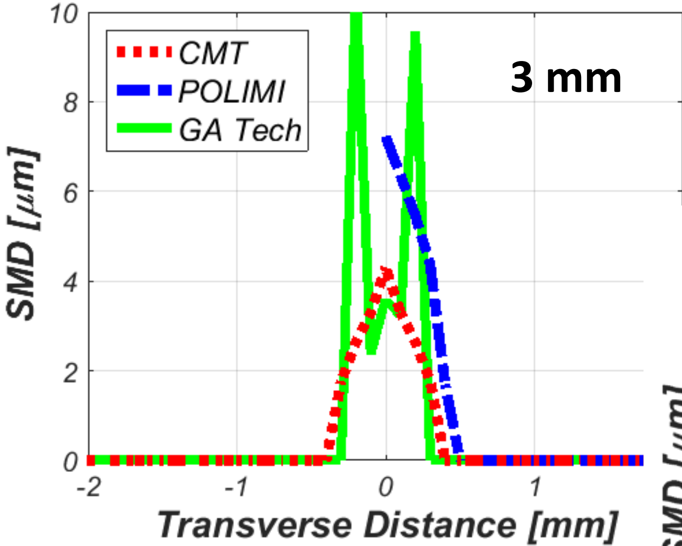
9.0 mm

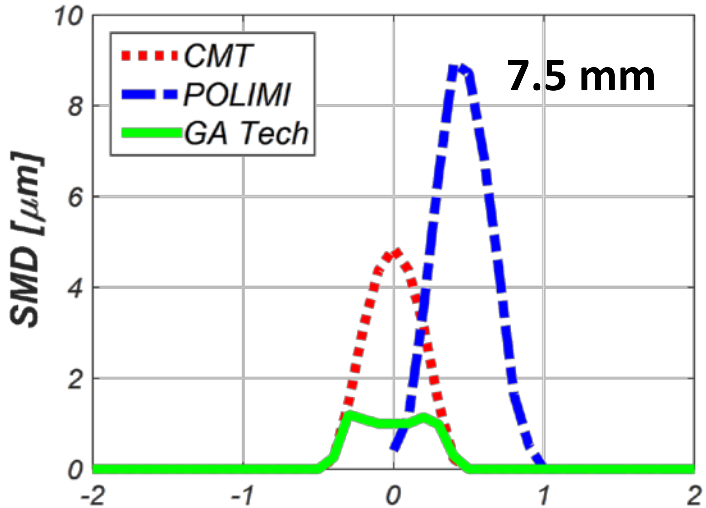


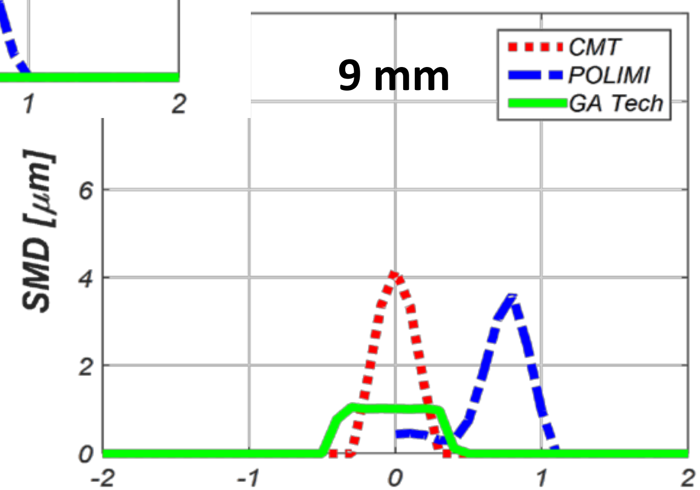




SMD profiles can take on different distribution behaviors as breakup and evaporation proceed.







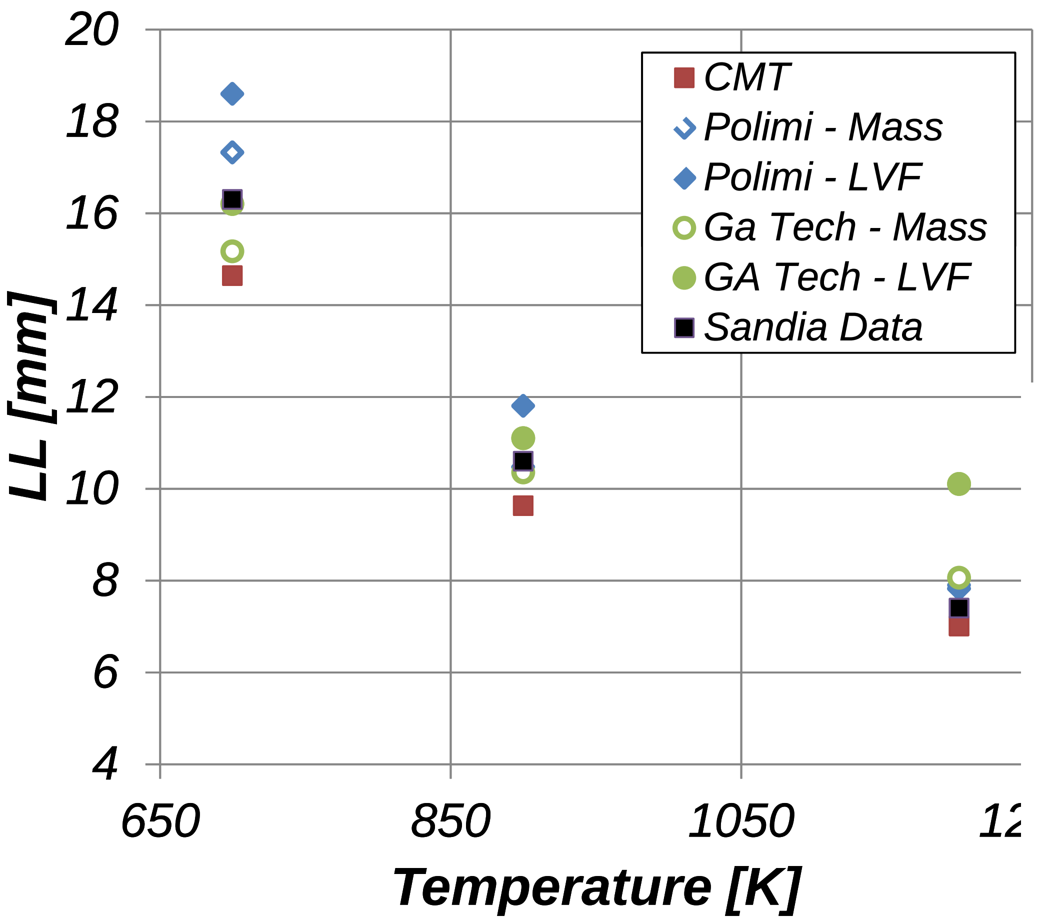
Spray A
time averaged
spray structure
1 - 3 ms

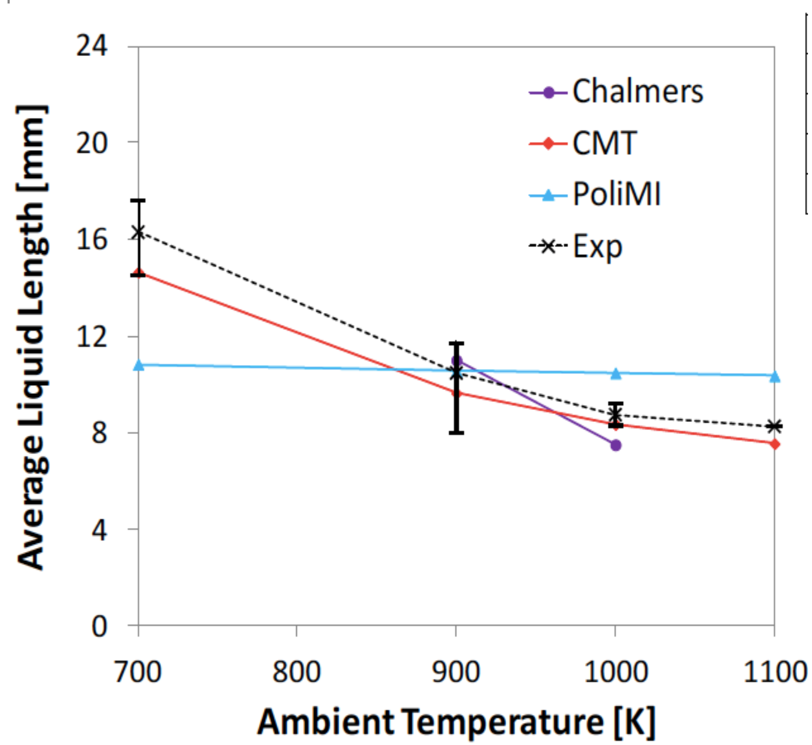
Which solution is the “accurate” one?

Spray A Parametric Study:

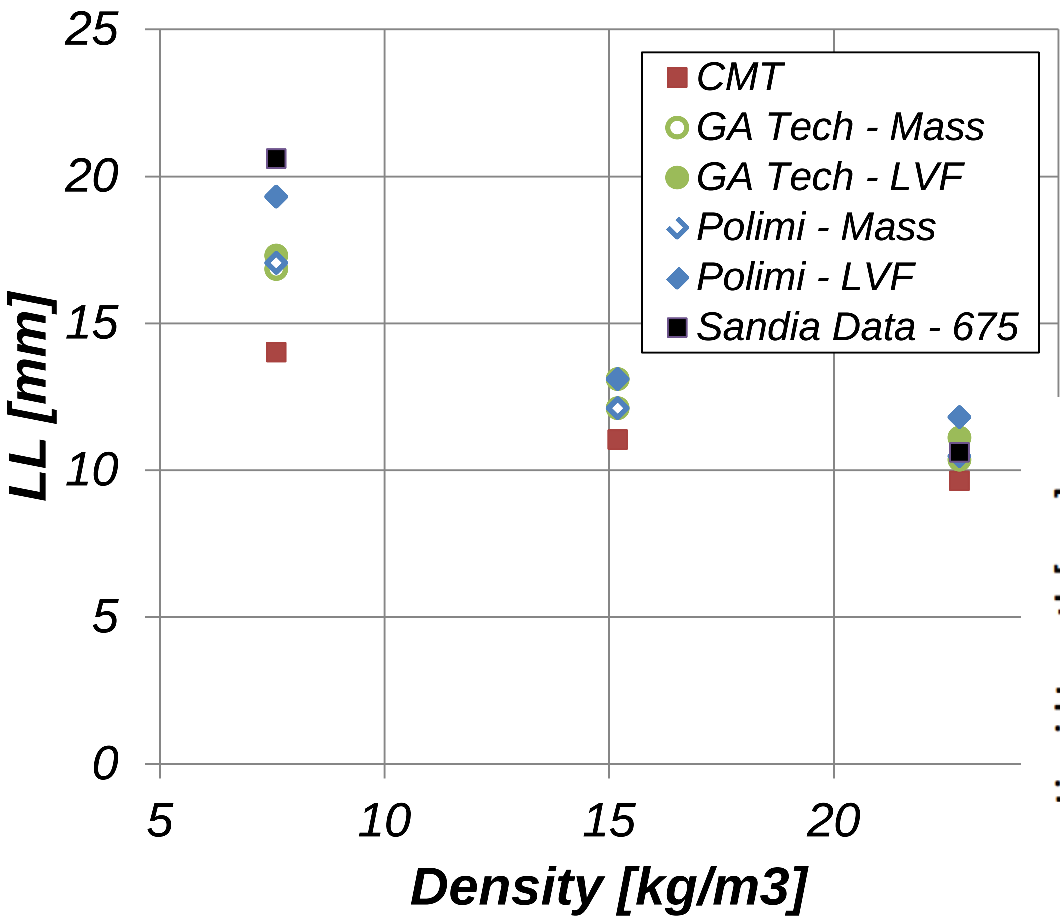
Exploration on what information we'd really like to have to validate evaporating sprays

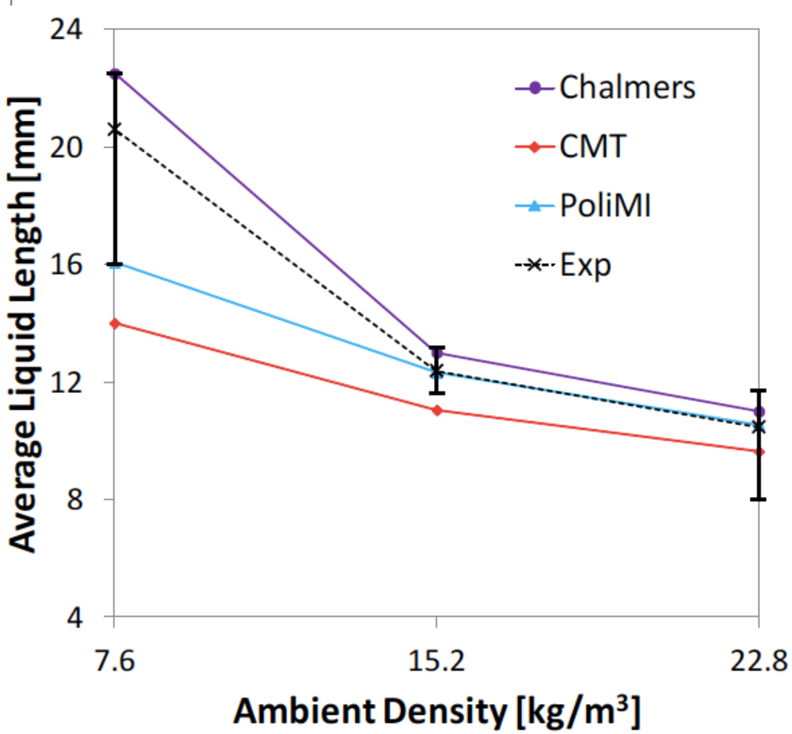
Revisit of global model response to parametric variations in ambient and operating conditions.





Revisit of global model response to parametric variations in ambient and operating conditions.





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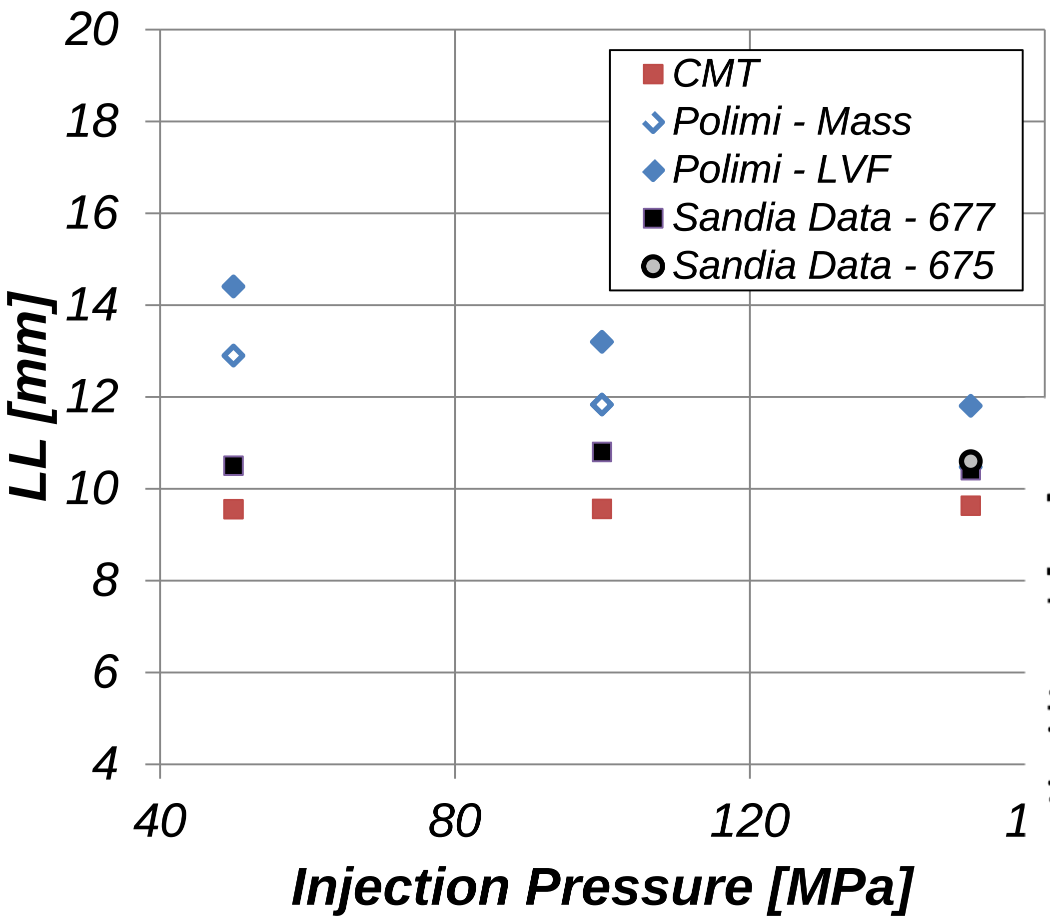
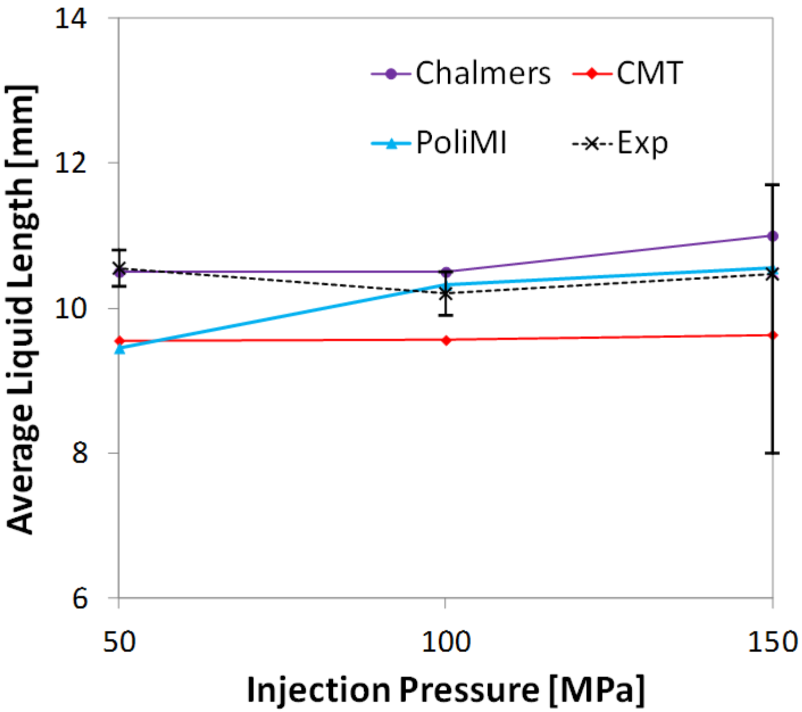
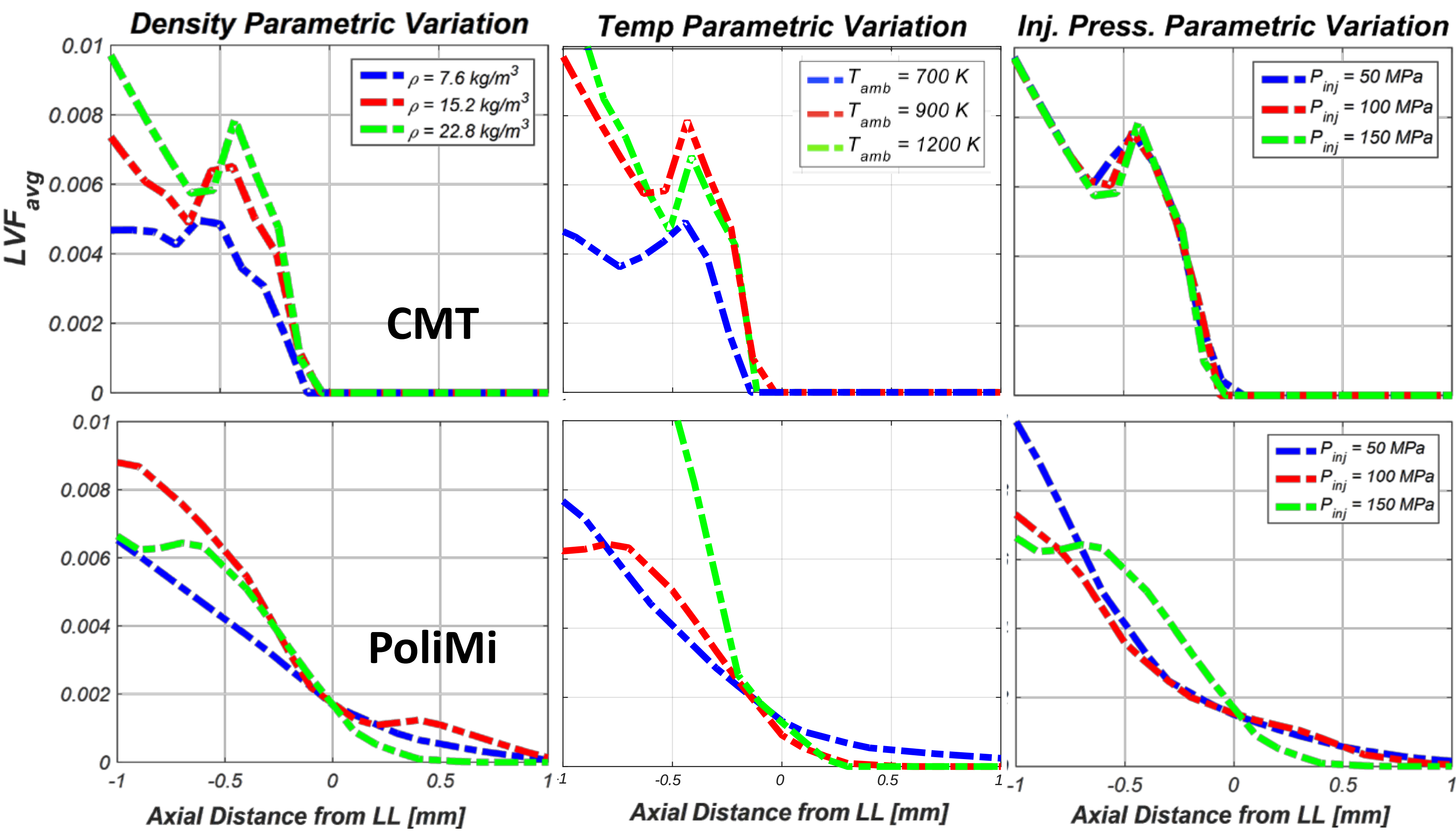
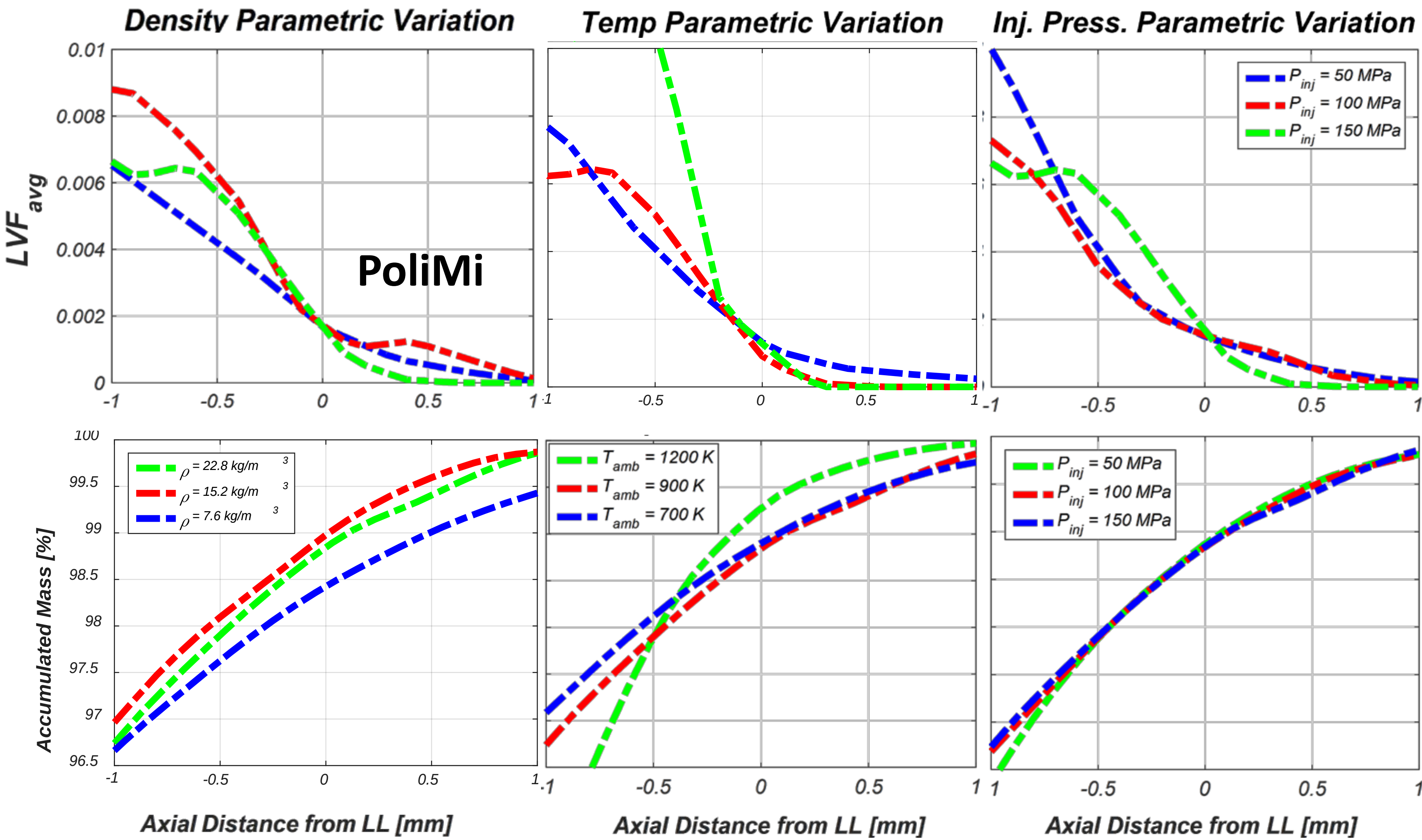




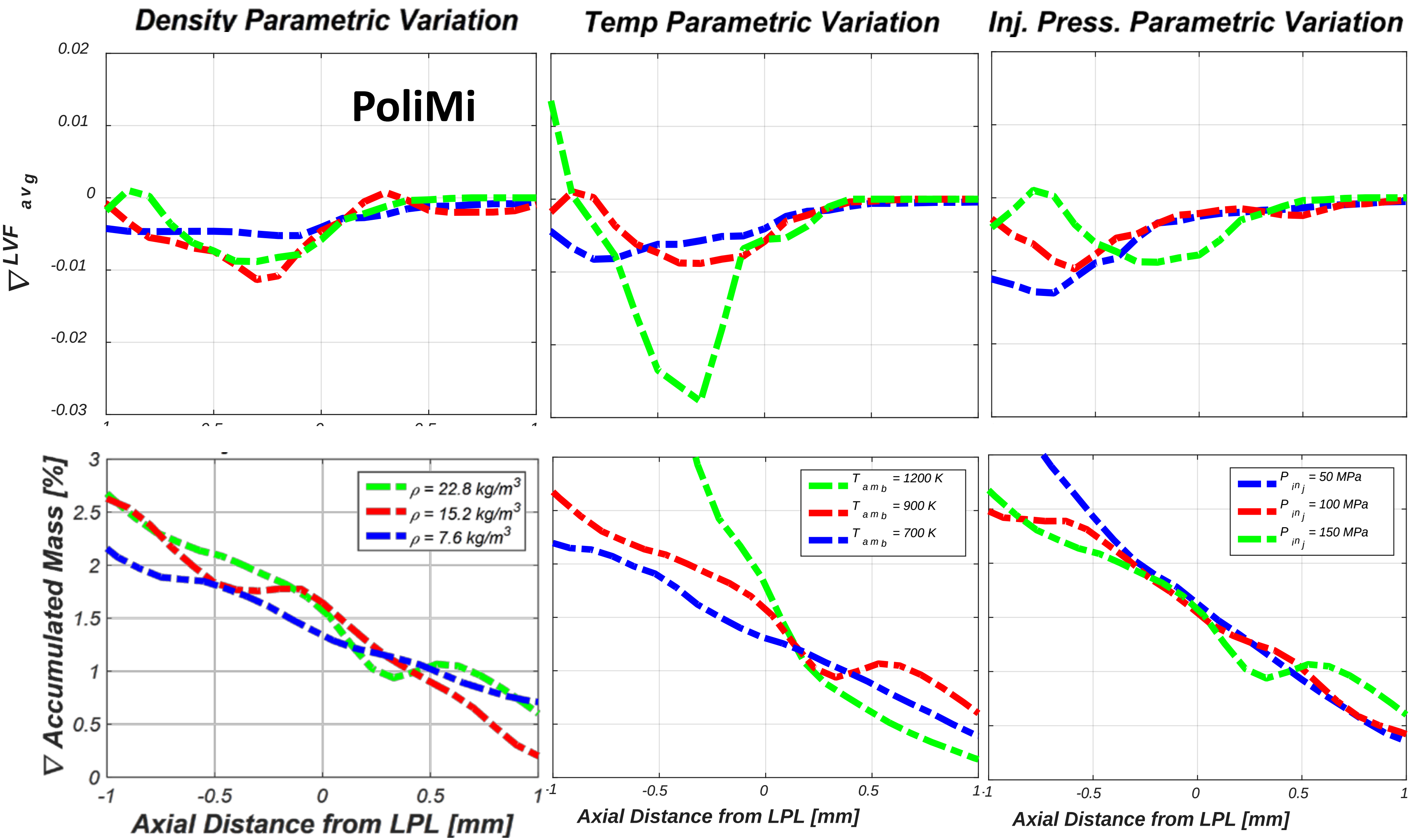
How do the spray and evaporation models respond to changes in ambient and operating conditions?



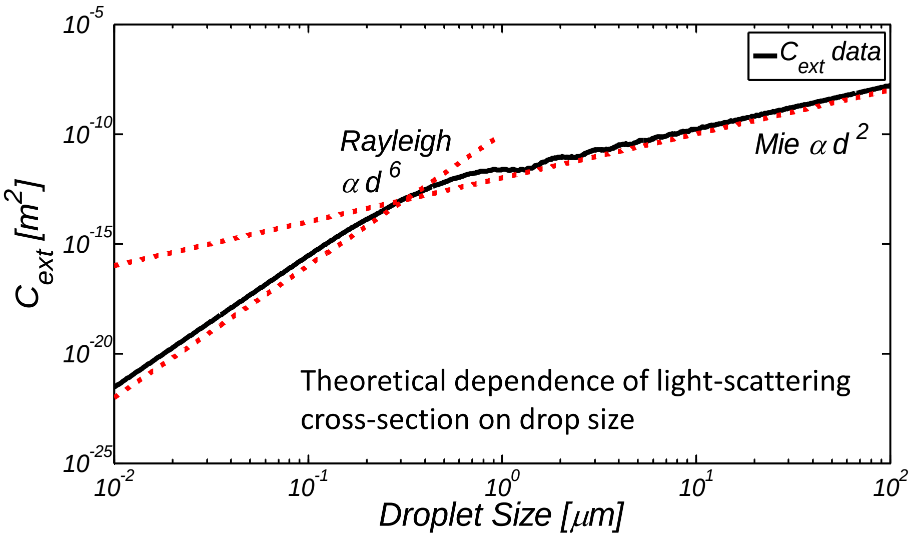
Comparison of LVF behavior and accumulated mass… they both show *some* sensitivity to ambient conditions.



Gradients near LL show that LVF shows more sensitivity to correctly capture the liquid boundary



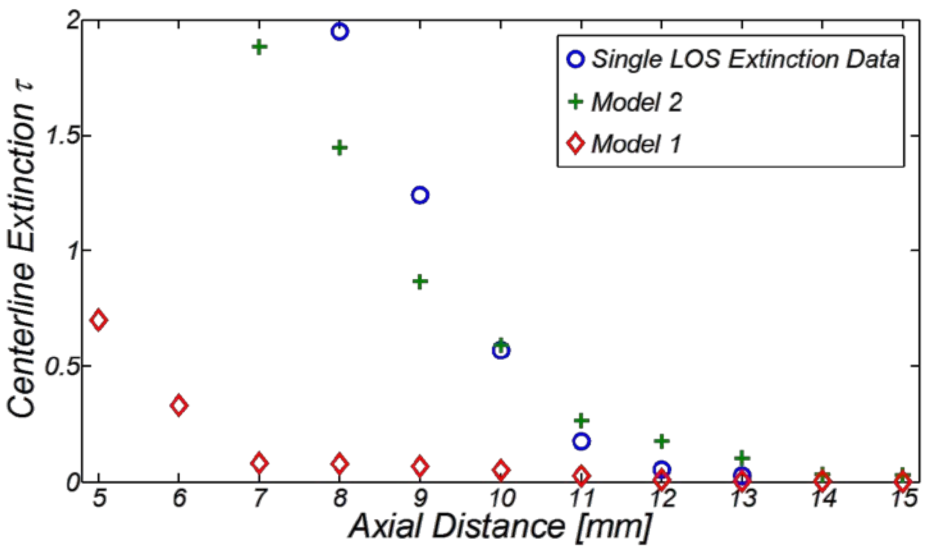
Is there a potential pathway forward to validated modeling of the local liquid structure and evaporation process?

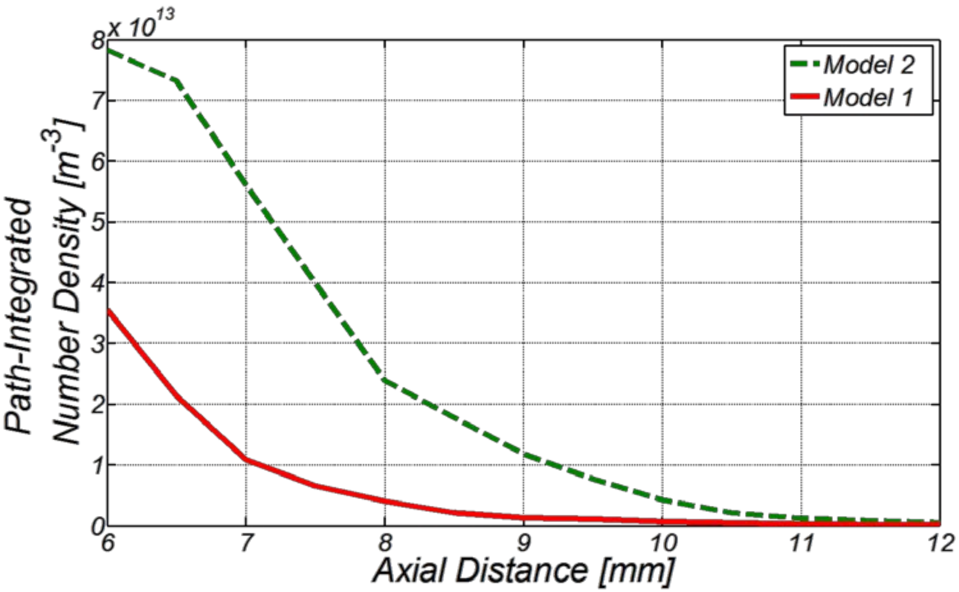


Modeling of light extinction measurements could provide some validation at vaporizing conditions.

Quality extinction measurements needed (next talk).

Validation of near-spherical droplets in these regions (previous talk).





Conclusions from Spray A parametric modeling study:

- Old news revisited: Validation of evaporating sprays solely against liquid and vapor penetration measurements does not adequately validate the evaporation process.
- Somewhat old news revisited: It is difficult to isolate effects of spray model choices on near-nozzle mixture discrepancies.
  - Lagrangian models lead to errors in gas momentum exchange
    - Error cascades to affect breakup and vaporization models
  - Eulerian models don't necessarily predict evaporation well either
- To accurately validate evaporating sprays, we need a validation methodology that responds to changes in the mixing and evaporation rate appropriately.
- Liquid volume fraction is physically consistent with extinction and scattering measurements AND drops rapidly near the liquid length.
- High quality extinction measurements may help.

Spray A Multiple Injections

Modeling

CMT: Adrian Blanco, Raul Payri

Polimi: Tommaso Lucchini, Gianluca D'Errico

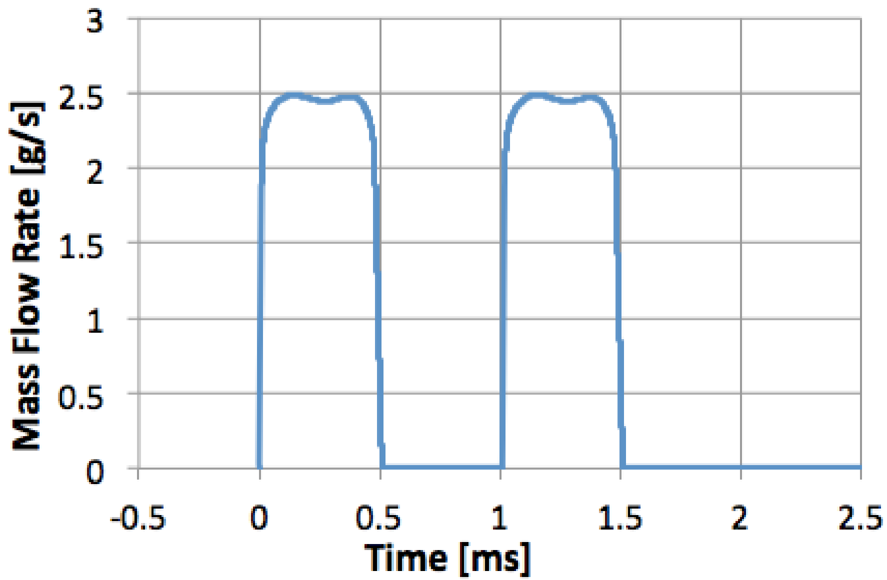
Experiments

Sandia: Julien Manin, Scott Skeen, Lyle Pickett

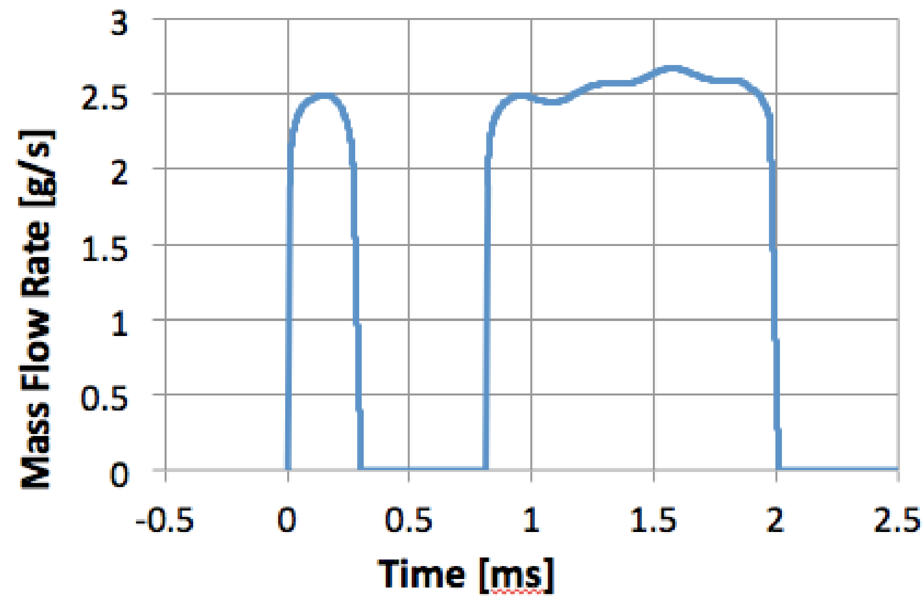
Spray A multiple injection target conditions

- Same model setup as parametric study. Nozzle 675.

Split Injection 0.5 ms – 0.5 ms dwell – 0.5 ms



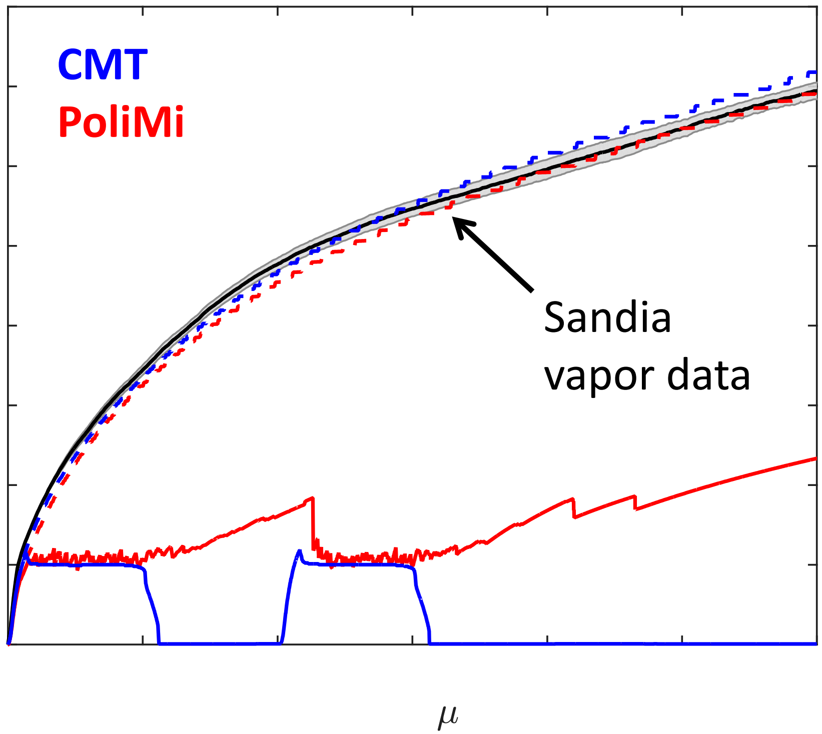
Pilot-Main 0.3 ms – 0.5 ms dwell – 1.2 ms



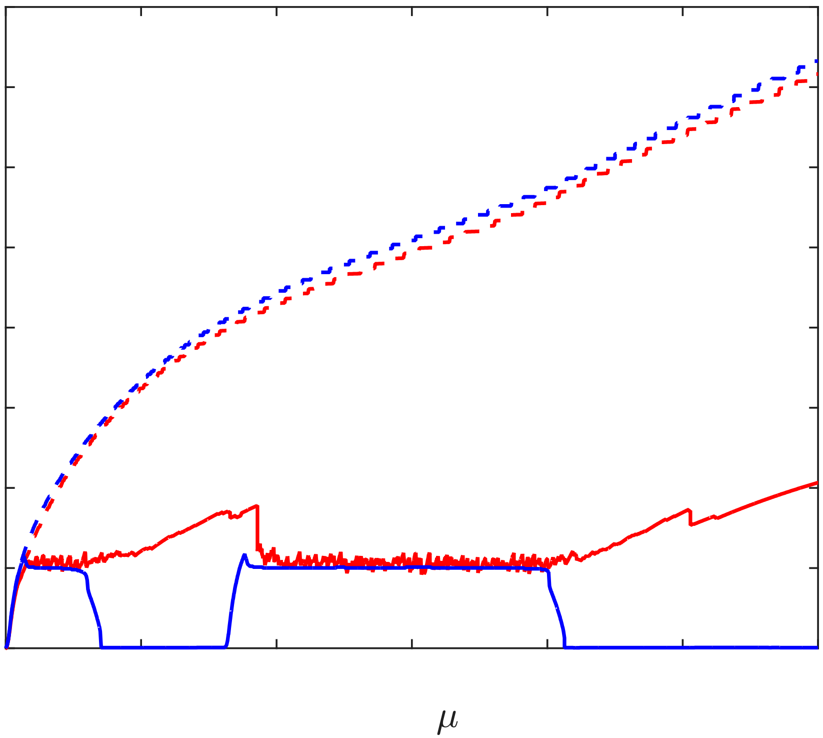
	O_2 [%]	T_{amb} [K]	ρ_{amb} [kg/m^3]	P_{inj} [bar]
Standard Spray A	0	900	22.8	1500

Multiple injection simulations compare well between institutions and with Sandia vapor penetration data.

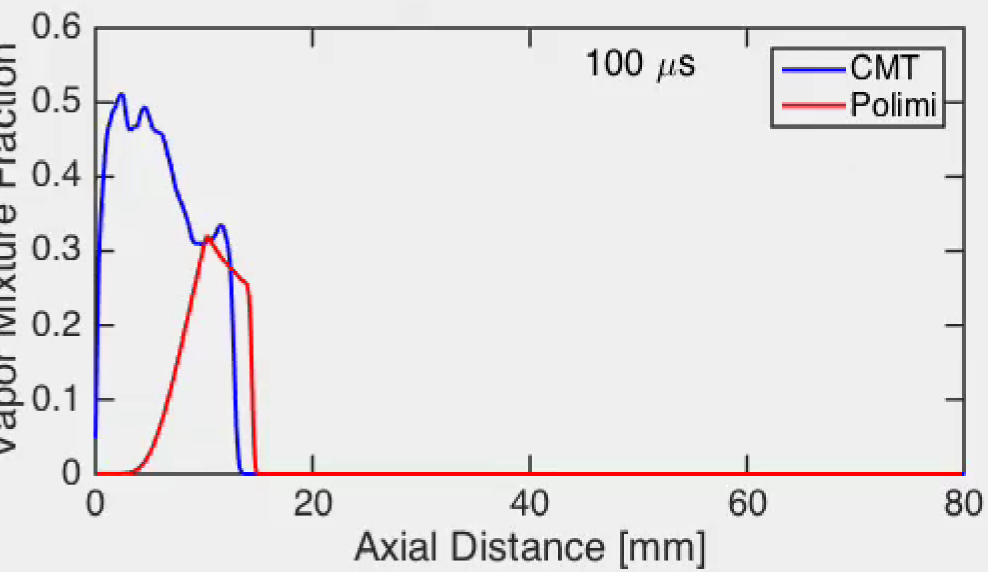
Split Injection 0.5 ms – 0.5 ms dwell – 0.5 ms

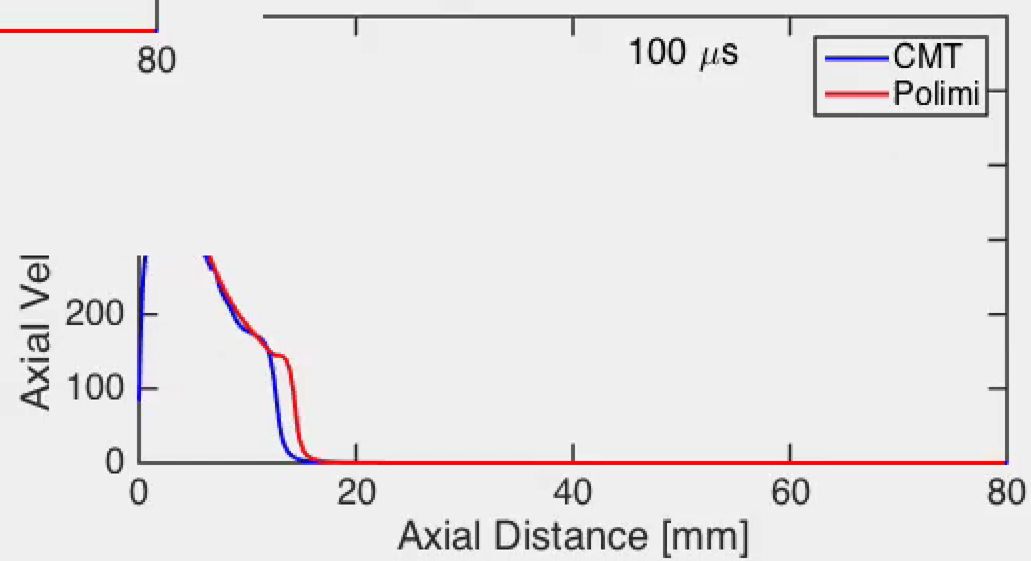


Pilot-Main 0.3 ms – 0.5 ms dwell – 1.2 ms



Transient mixing process is well matched between CMT and PoliMi downstream of liquid regions.





Spray B

Experiments

CMT: Alberto Viera, Raul Payri

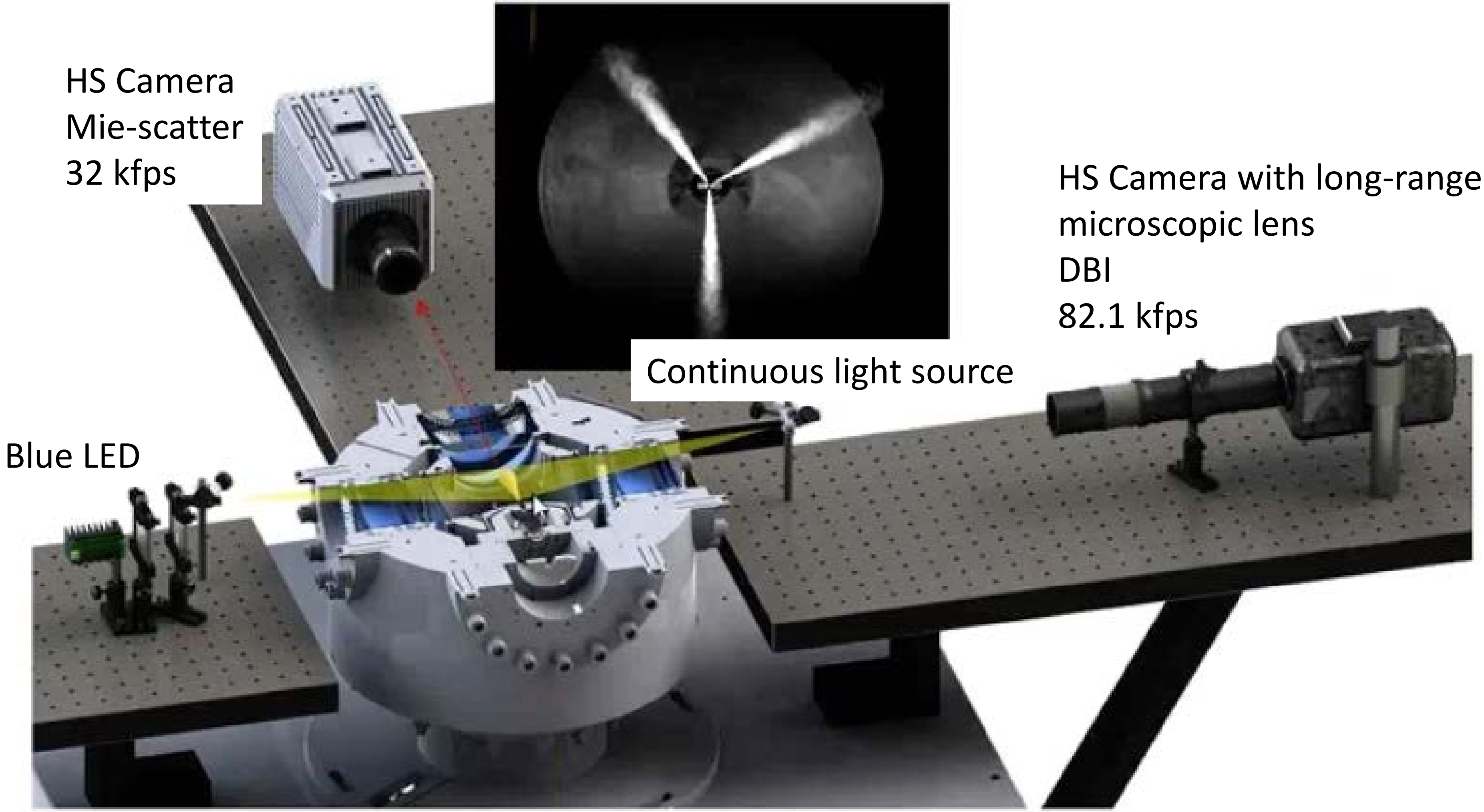
Nozzle 211200

Sandia: Julien Manin, Scott Skeen, Lyle Pickett

KAIST: Yongjin Jung

Nozzle 211201

Simultaneous Mie scatter and DBI at CMT

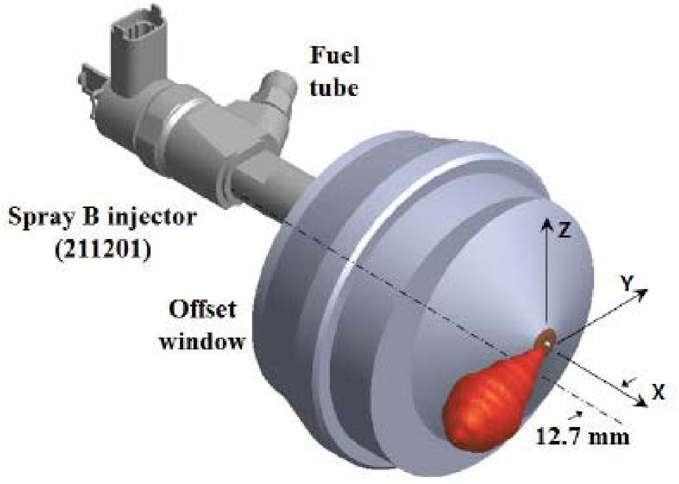


Mie scatter and DBI imaging at Sandia

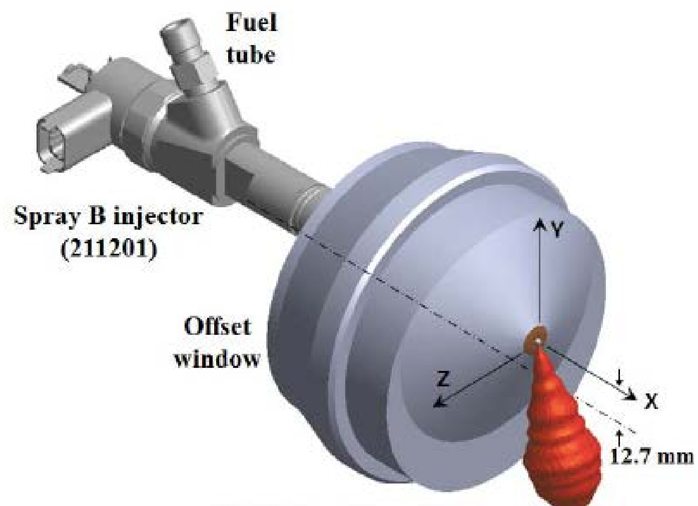
Two different liquid penetration measurement techniques and two spray orientations:

- **Horizontal Configuration**
  - Mie scattering: Phantom v710, 105 mm, f/2.8, 80 kfps

- **Vertical Configuration**
  - Diffused back illumination (DBI), Photron, 100 kfps



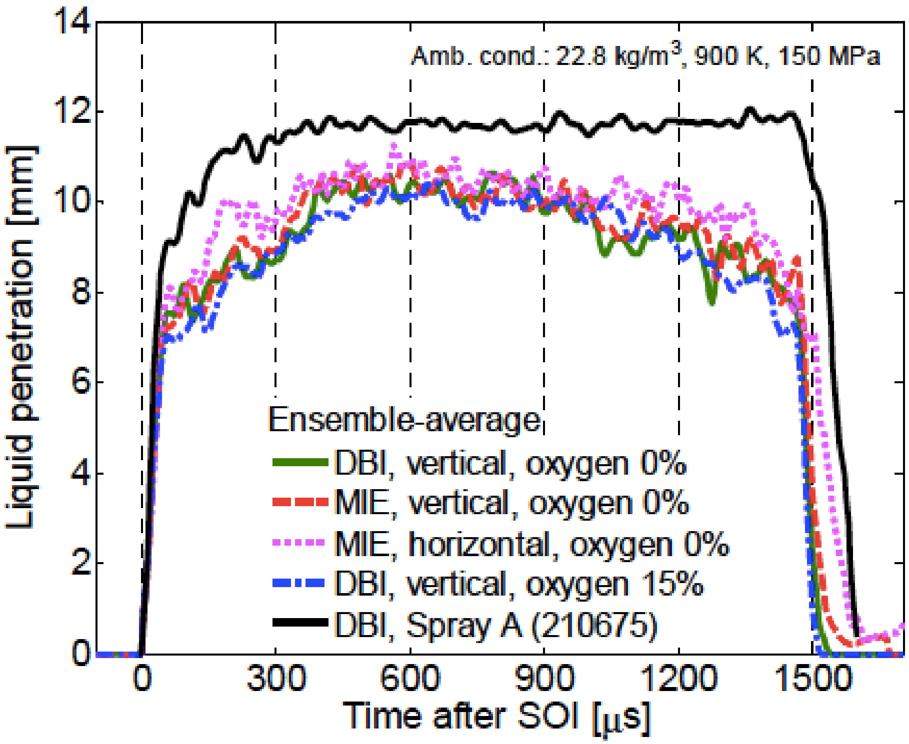
< Horizontal configuration >

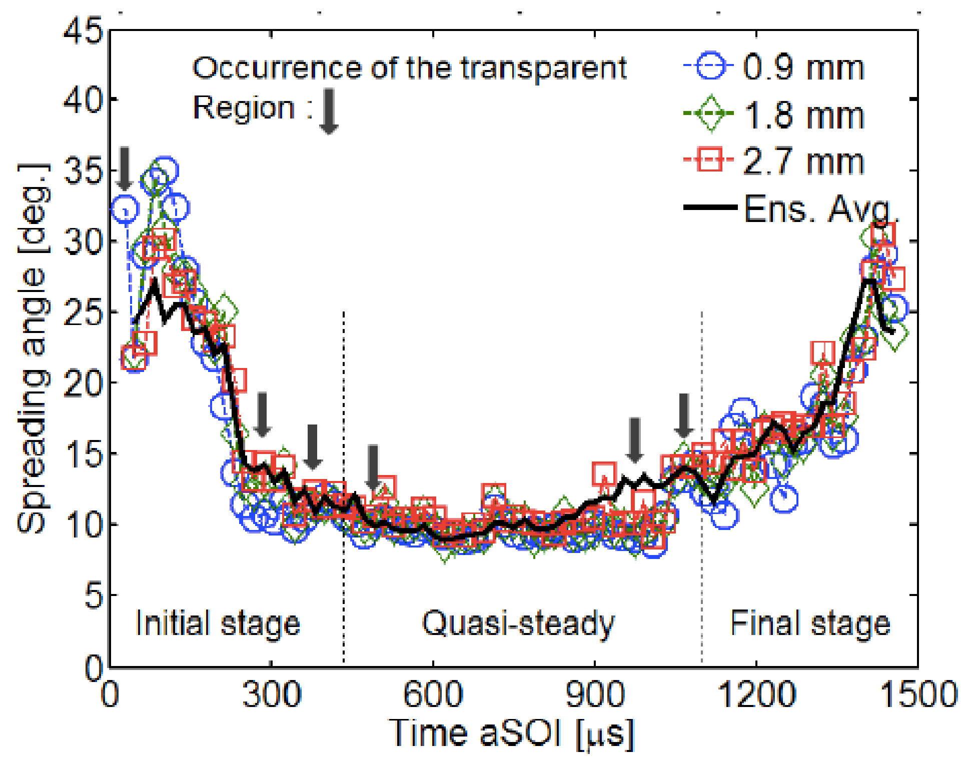


< Vertical configuration >

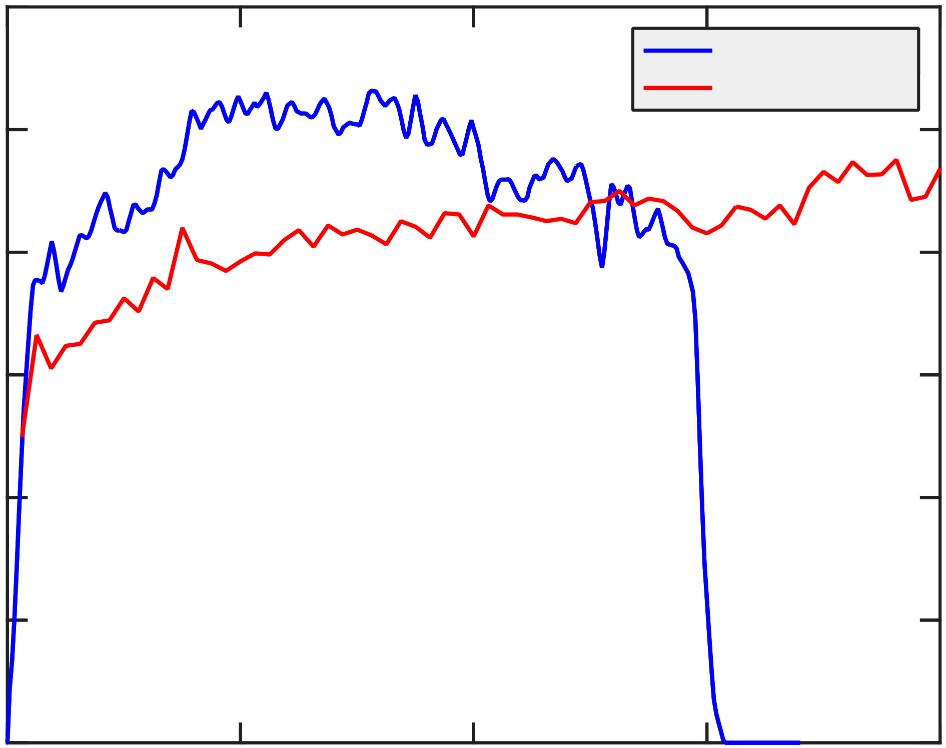
Sandia has shown that liquid penetration profile is correlated with transient spreading angle behavior.

Jung et al. SAE 2015-01-0946





CMT also measures a transient liquid penetration rate, but with a shorter penetration length.



Moving forward with Spray A multiple injections and Spray B:

- First look at modeling multiple injections: predictions of mixture profiles and transient behavior is not any worse that steady-state Spray A.
  - Near-nozzle mixture discrepancies, but these are rapidly diffused by vaporization and transient mixing process.

Spray B measurements:

- Transients in measured liquid penetration is well correlated with transient spreading angle behavior.
- Measurements at CMT display similar transient behavior, but injection conditions are different so it's hard to make further conclusions.
- Seems to be a consistent trend that CMT measures shorter LL's than Sandia.
- Modeling of the transient behavior will require more than the usual Lagrangian spray modeling approach.

Conclusions from Spray A parametric modeling study:

- Old news revisited: Validation of evaporating sprays solely against liquid and vapor penetration measurements does not adequately validate the evaporation process.
- Somewhat old news revisited: It is difficult to isolate effects of spray model choices on near-nozzle mixture discrepancies.
  - Lagrangian models lead to errors in gas momentum exchange
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- To accurately validate evaporating sprays, we need a validation methodology that responds to changes in the mixing and evaporation rate appropriately.
- Liquid volume fraction is physically consistent with extinction and scattering measurements AND drops rapidly near the liquid length.
- High quality extinction measurements may help.

EXTRA SLIDES

Some history: We've made several attempts to standardize liquid length measurements within the ECN.

ECN3: Still differences in measured LL between institutions. No significant advancement of "standardized" LL measurement method.

Spray A Measured Liquid Length			
Sandia - 675	CMT - 675	IFPen - 678	TU/e - 679
11.7	9.7	10.5	10.3

Parametric Spray A Conditions			
	Sandia - 675	CMT - 675	Δ
900 K, 7.6 kg/m^3	16.0	22.8	43%
700 K, 22.8 kg/m^3	14.5	17.6	21%

ECN4: Fredrick Westlye will provide us an update on this topic next!