The Impact of Flow and Turbulence on Spray G Direct Injection

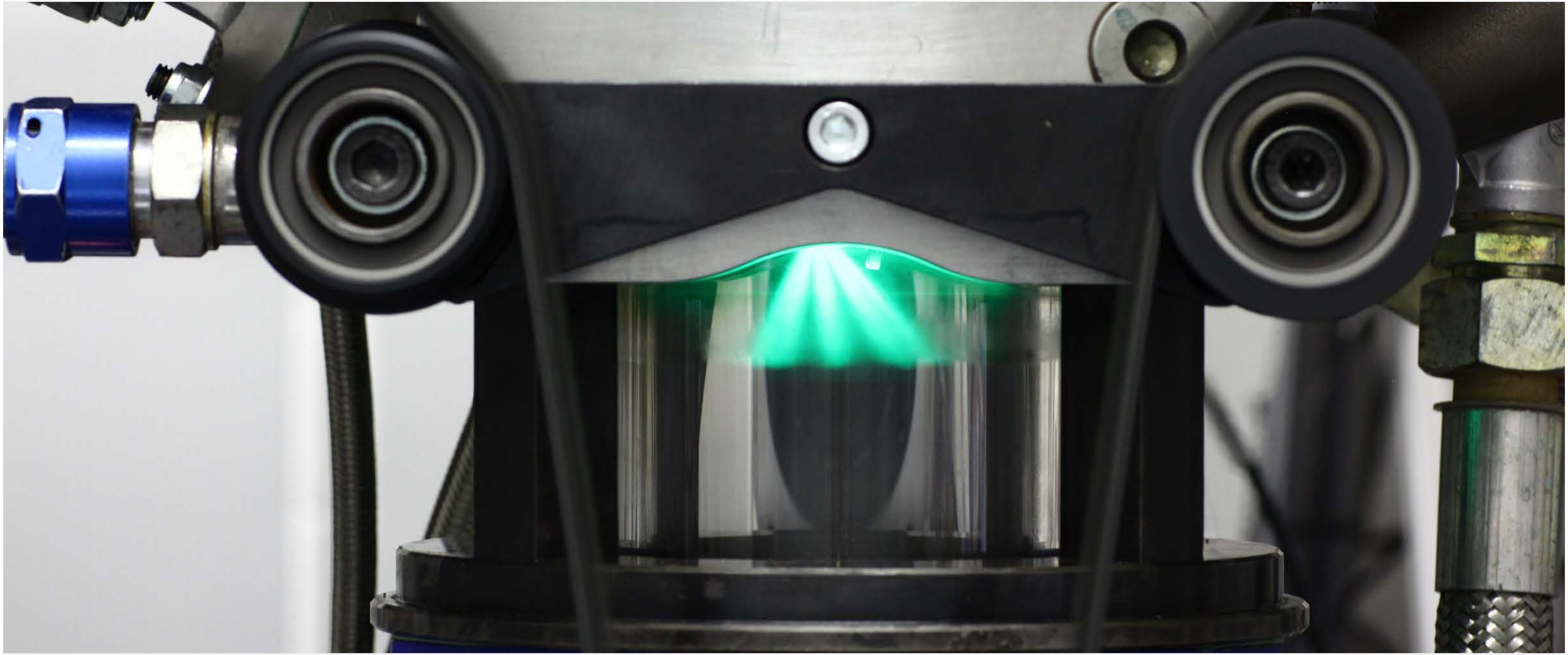
LES4ECE 2021 · Injectors and Sprays

C. Welch · L. Illmann · M. Schmidt · B. Böhm

Technical University of Darmstadt, Department of Mechanical Engineering, Reactive Flows and Diagnostics

TECHNISCHE UNIVERSITÄT DARMSTADT

RSM

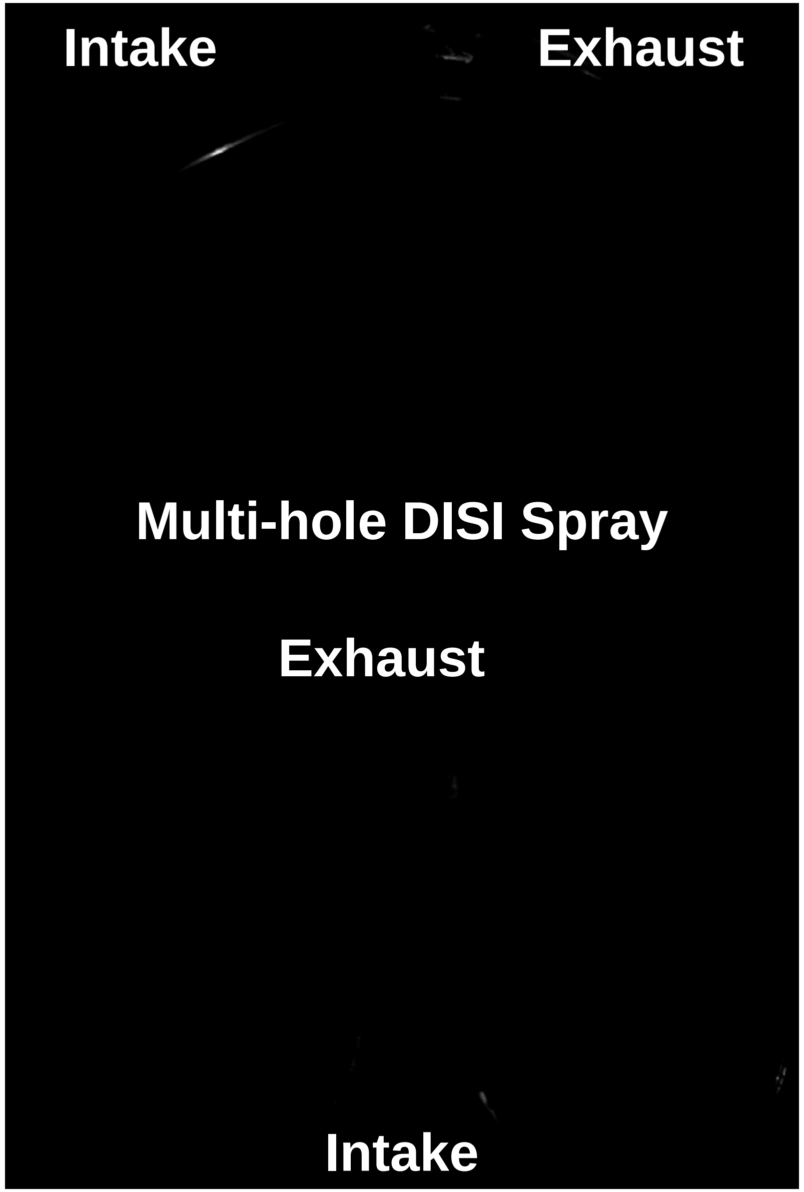


How can we continue to reduce emissions?

Homogeneous direct injection spark-ignition (DISI) allows us to

- ► control amount of fuel
- ► control injection timing
- ► control location of injection
- ► use in full load and speed range
- ► charge cooling from evaporation
- ► couple with 3-way catalysts

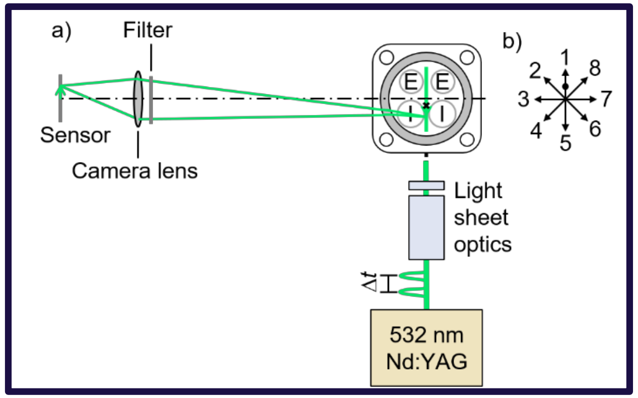
Side-view



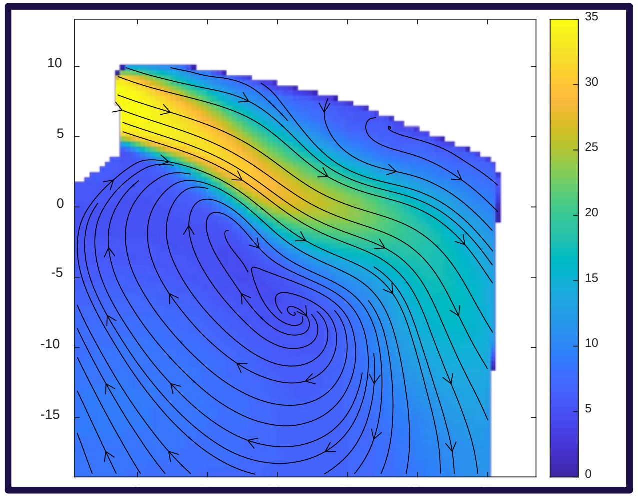
Bottom-view

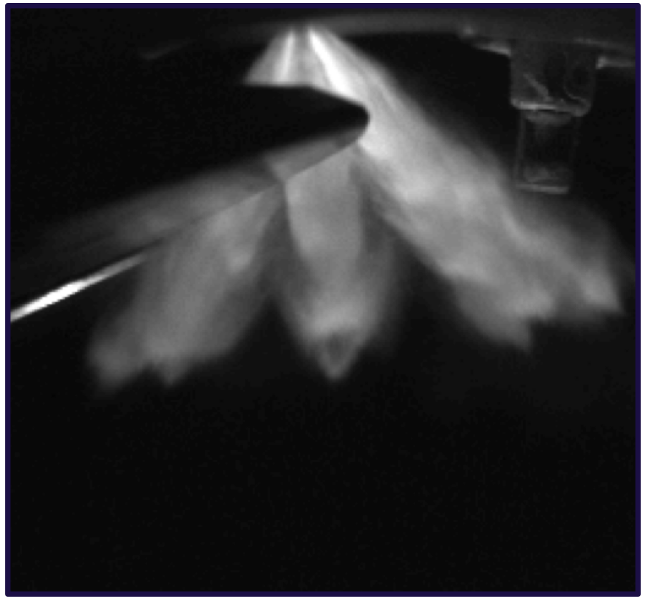
Better understand the effects of gas velocity on early injection

- Motivation
- Methodology
- Results
  - Engine Flow Bench
  - Spray G
- Conclusions/Outlook



Geschwindner et al., *Int. J. Eng. Res.*, 2020

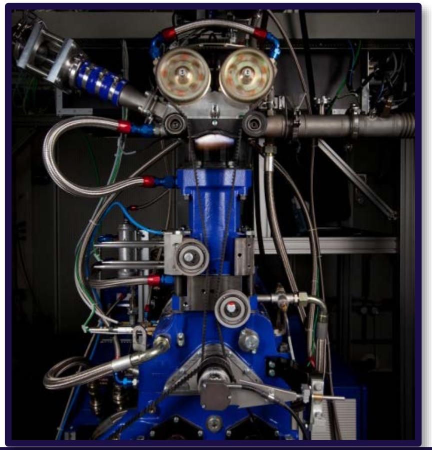


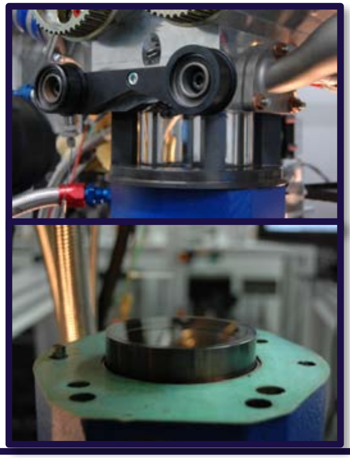


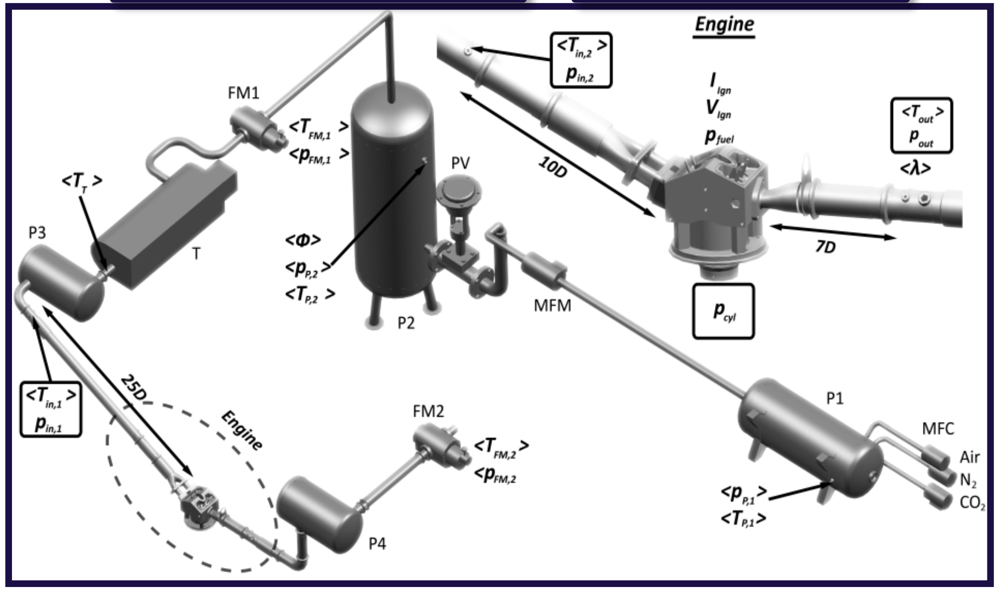
Methodology – Engine Test Bench

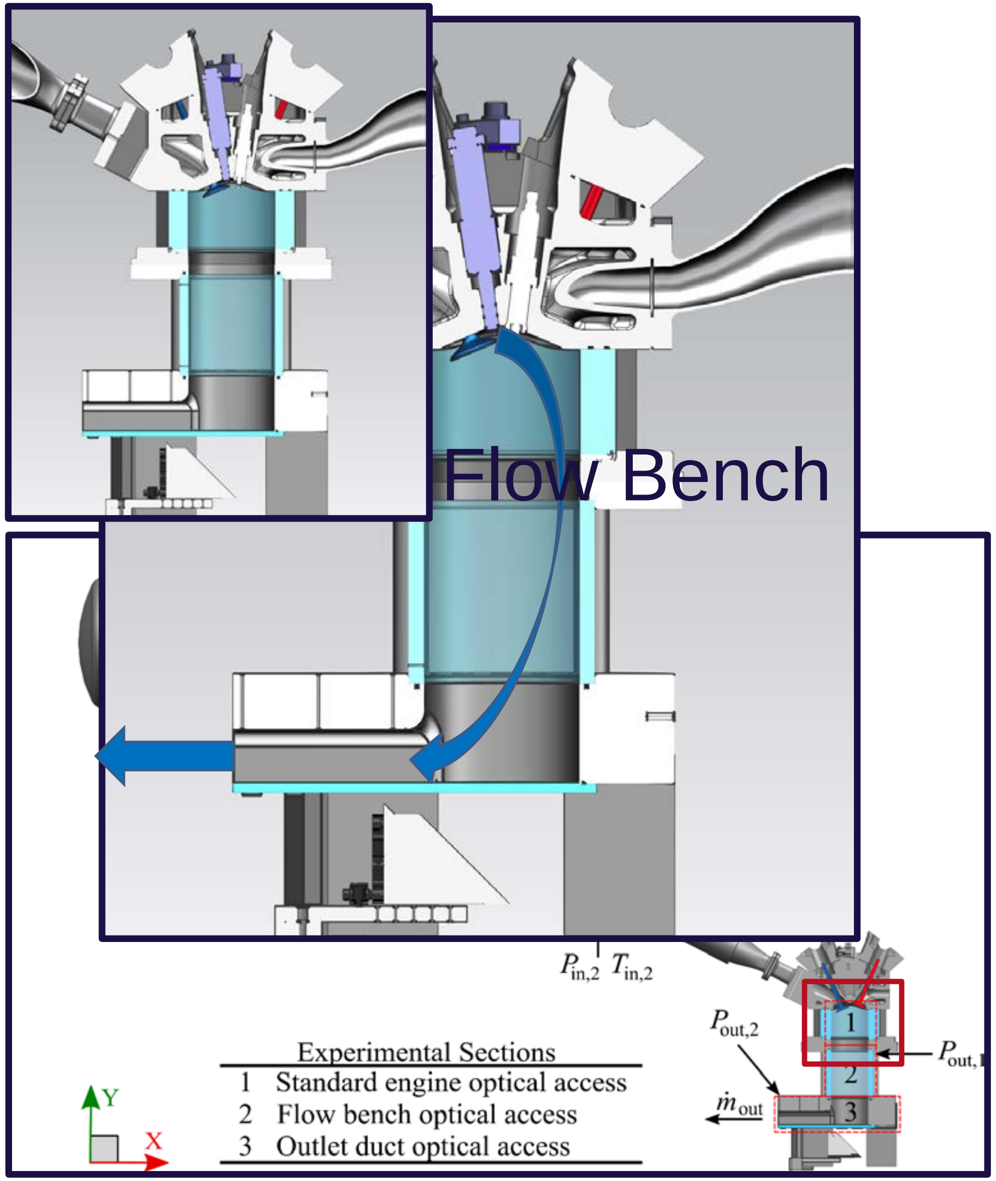
- Single-cylinder IC engine
  - 4-valve, pent-roof head
  - Bore, Stroke: 86 mm
- Designed to investigate phenomena and for model validation

- Engine Test Bench
  - Well-characterized BCs: Flow, T, P, rel. humidity, EGR, fuel (DI, PFI), λ, spark (V,I)
- Repeatable, reliable operation and BCs









- **<u>Simplified</u>** engine test bench
- Piston is removed
- Outlet flow duct with optical access
- Emulate intake flow without moving parts

Measurement Parameters

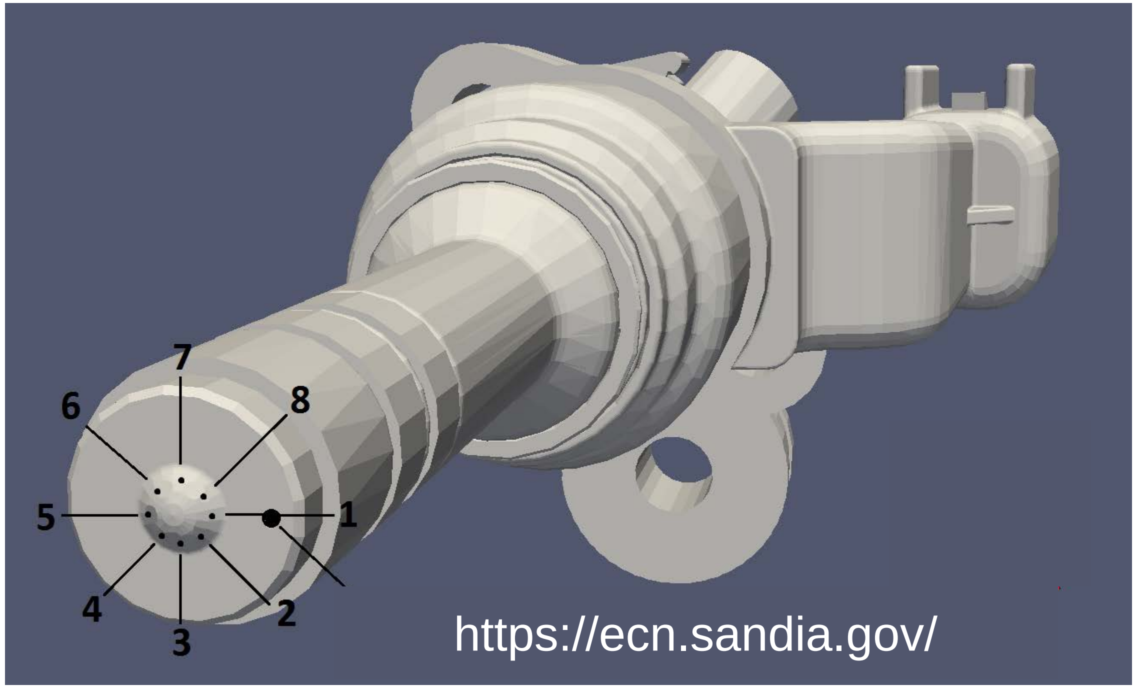
- Model intake flow of engine at:
  - 0.95 bar and 800 rpm
  - -270°CA: 9.21 mm stationary valve lift
- Introduce spray at varying mass flow rates (MFRs)

Operating Conditions of Test Stand

Condition	$\dot{m}$ [kg/h]	T_{in} [°C]	Re
NF	0.517	21.9	178
20% MFR	18.8	22.0	6,490
50% MFR	47.1	22.9	16,200
75% MFR	70.6	23.1	24,300
100% MFR	94.1	23.1	32,400

Methodology – Spray G Injector

- Initiative by Engine Combustion Network (ECN)
- Well-characterized injector boundary conditions
- Published experimental engine data is limited:
  - Gutierrez et al., SAE Paper: 2018-01-0305
  - Geschwindner et al., *Int. J. Eng. Res.*, 2020



Standard Spray G Conditions for Chamber (ECN*) and Engine (TUDa)

Name		p_{amb} [bar]	T_{amb} [K]	ρ_{amb} [kg/m³]
Spray G	ECN	6	573	3.5
	TUDa	6	525	3.98
G2	ECN	0.5	333	0.5
	TUDa	0.4	310	0.45
G3	ECN	1	333	1.12
	TUDa	0.95	310	1.07

*https://ecn.sandia.gov/

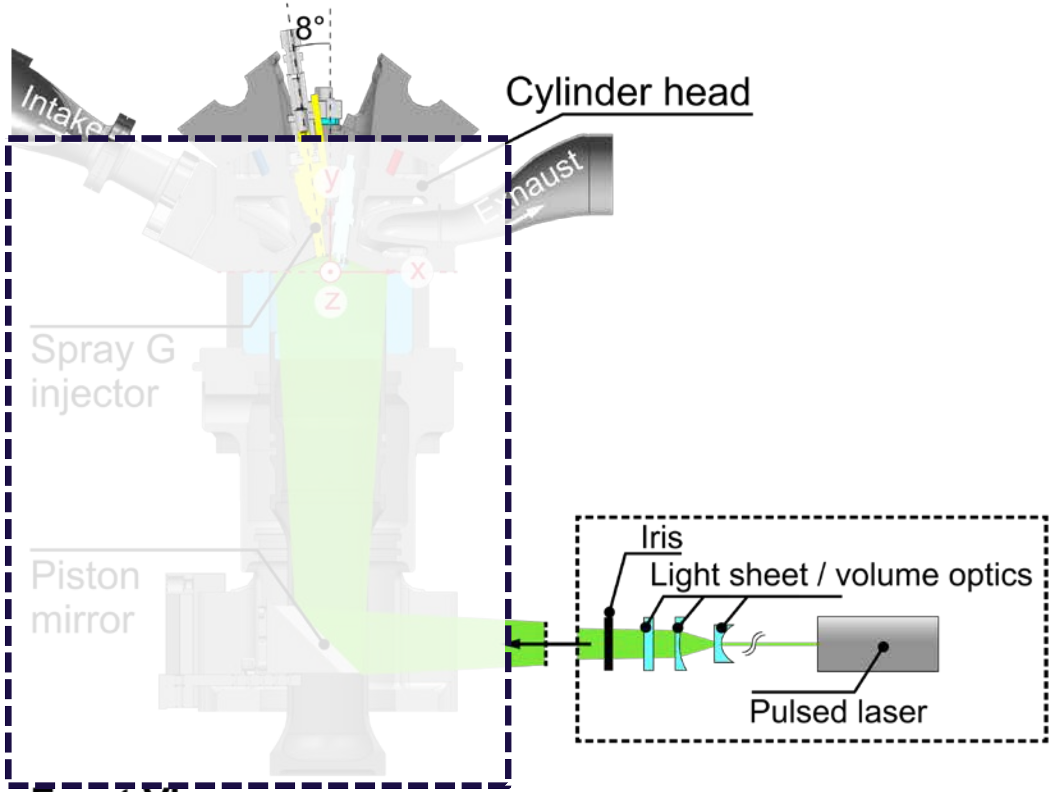
Comparable with flow bench injection
Early Injection with 680 µs duration

High-speed Particle Image Velocimetry (PIV)

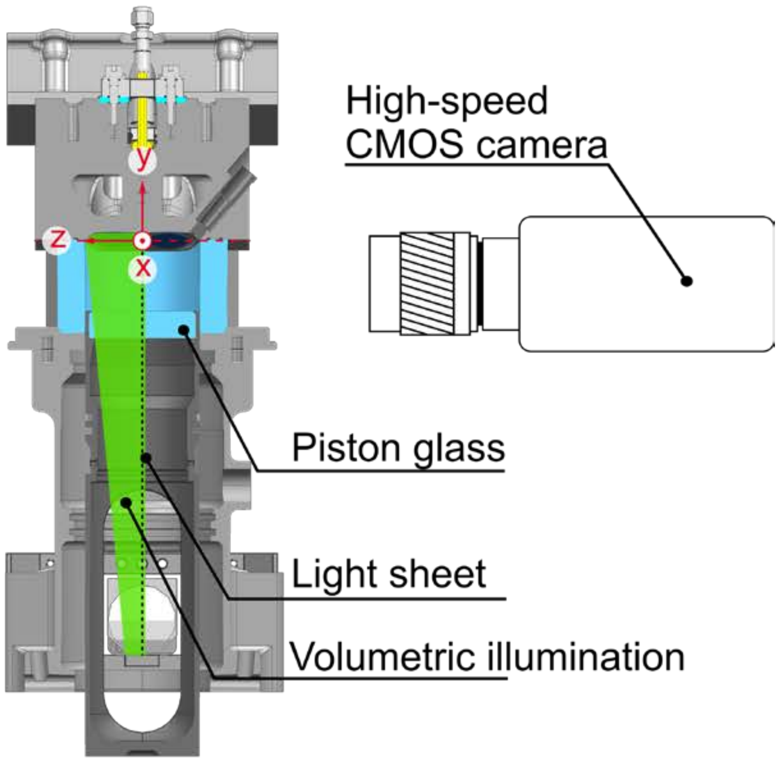
- Motored engine: 5°CA res. (960 Hz) for 222 cycles
- Flow Bench:12.5 kHz for 25000 consecutive vector fields

Volumetric Mie Scattering

- Flow Bench: 25 kHz for 100 consecutive sprays



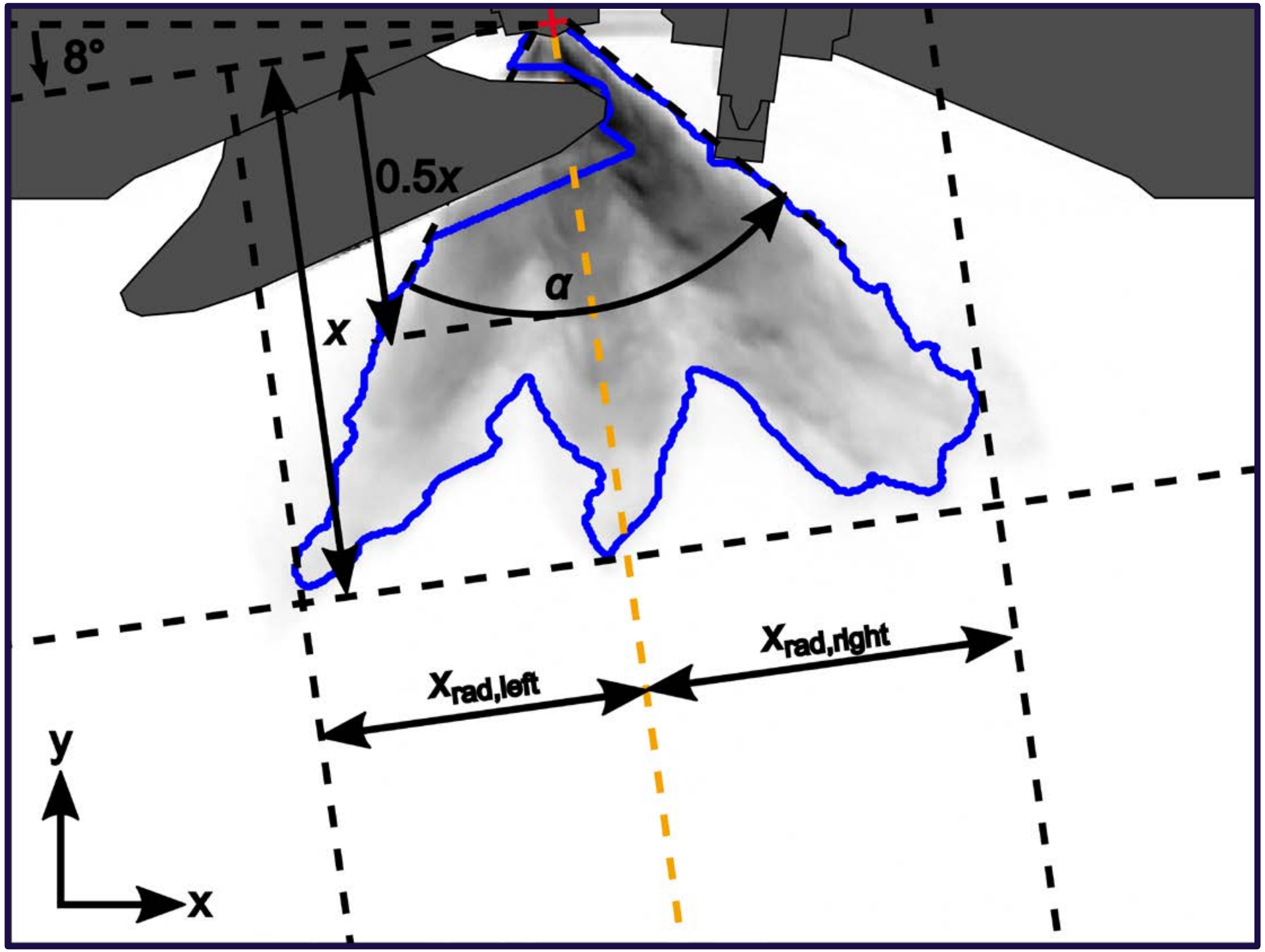
Front View



Side View

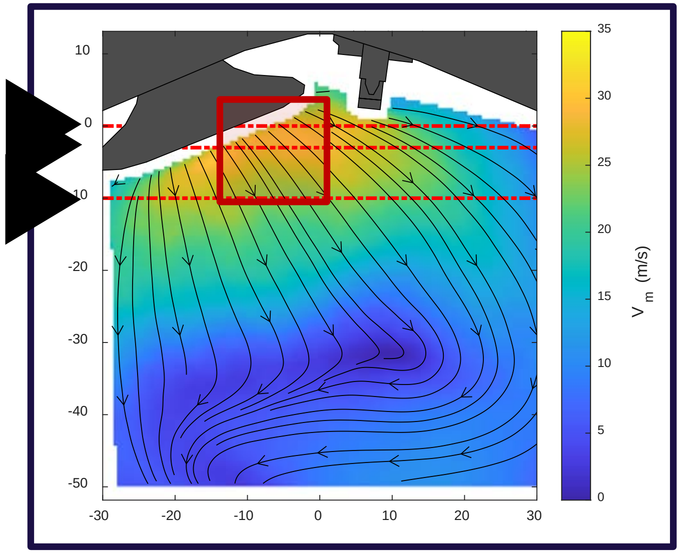
Each spray event

- Normalize by max. intensity
- Binarize with threshold ~ 11% max. intensity
- Calculate parameters
  - x Axial penetration
  - α Spray angle
  - x_{rad} Radial penetration

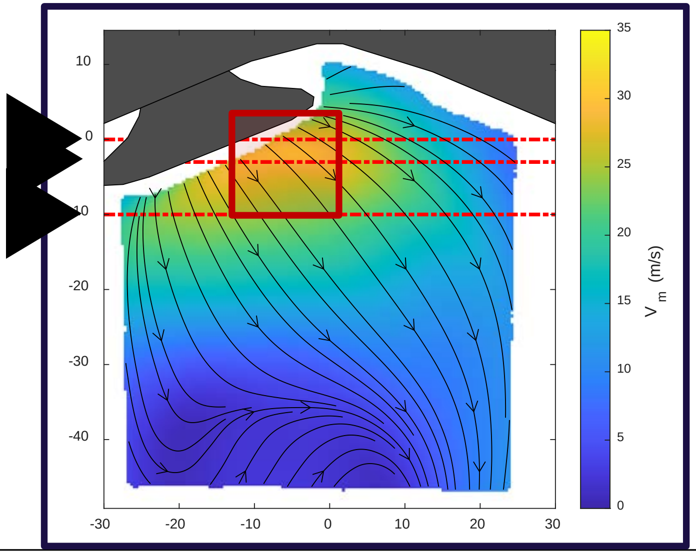


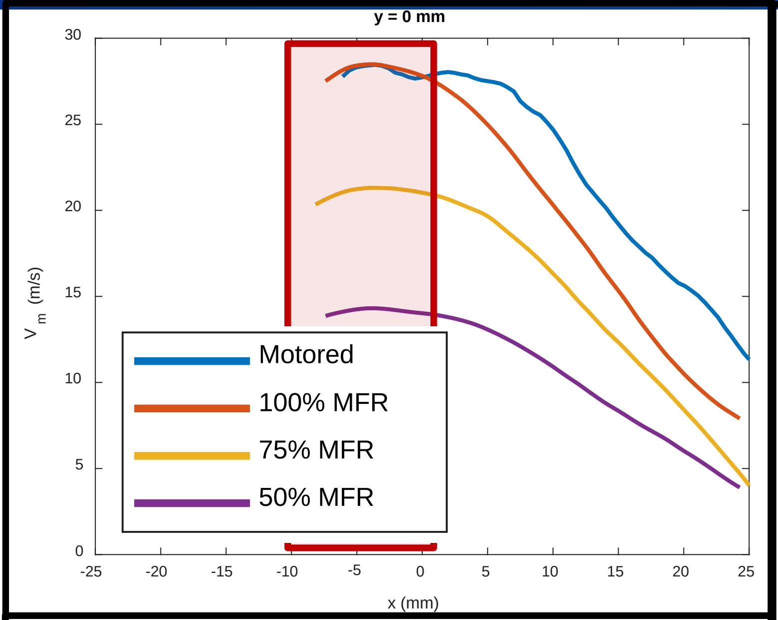
Results – Flow Comparison

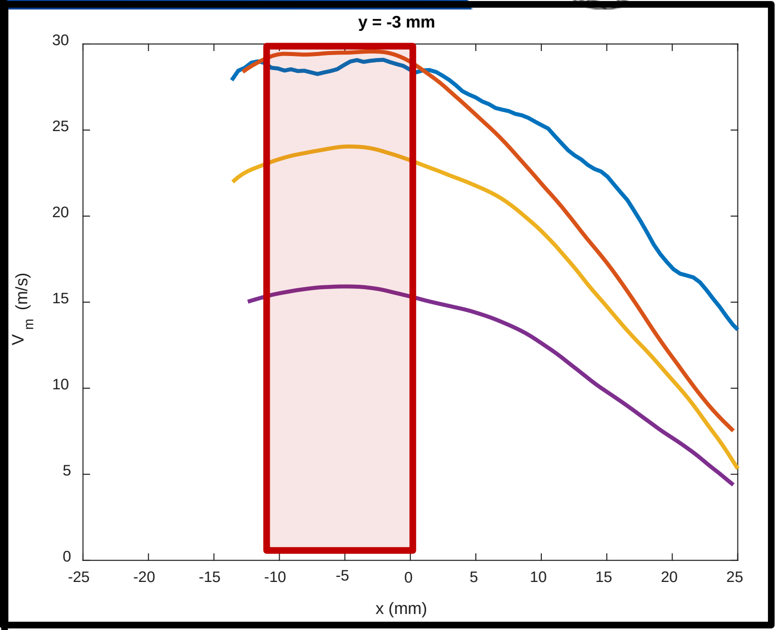
Motored: -270°CA

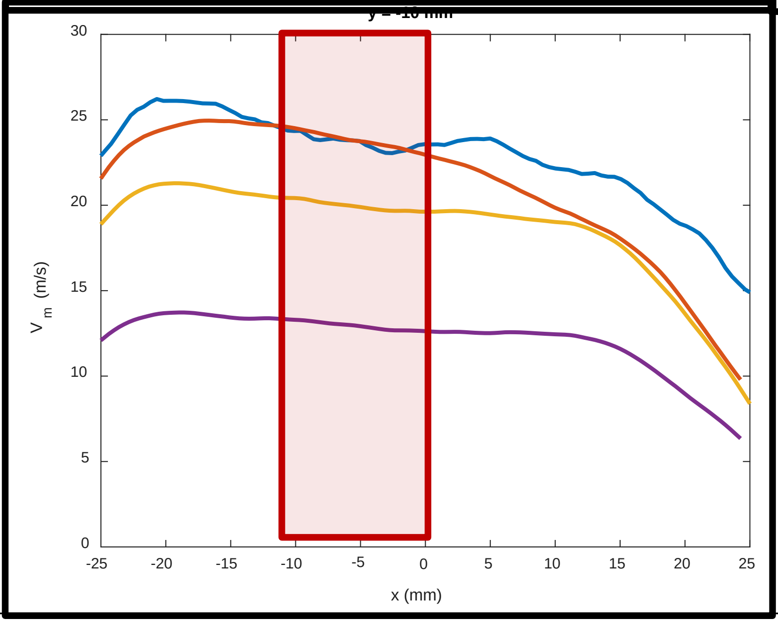


Flow Bench: 100% MFR









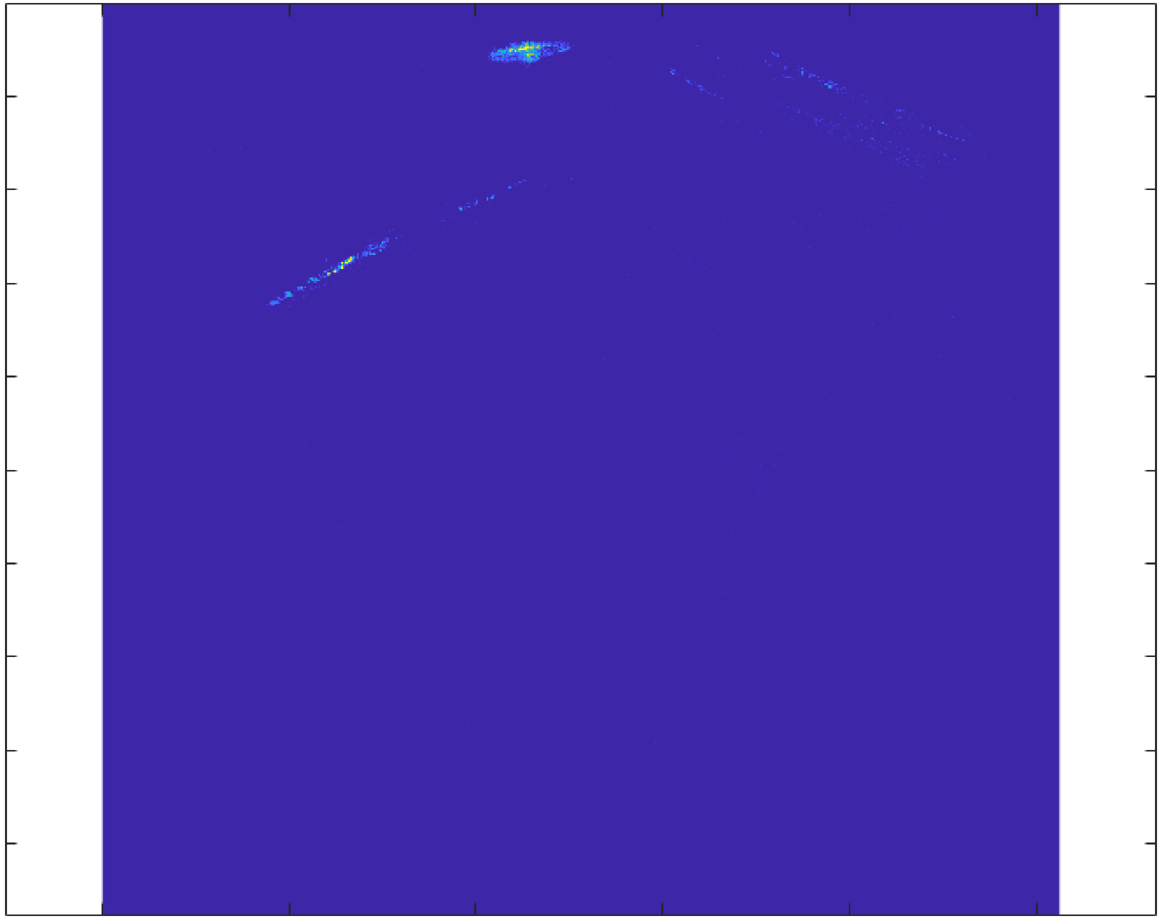
Recall

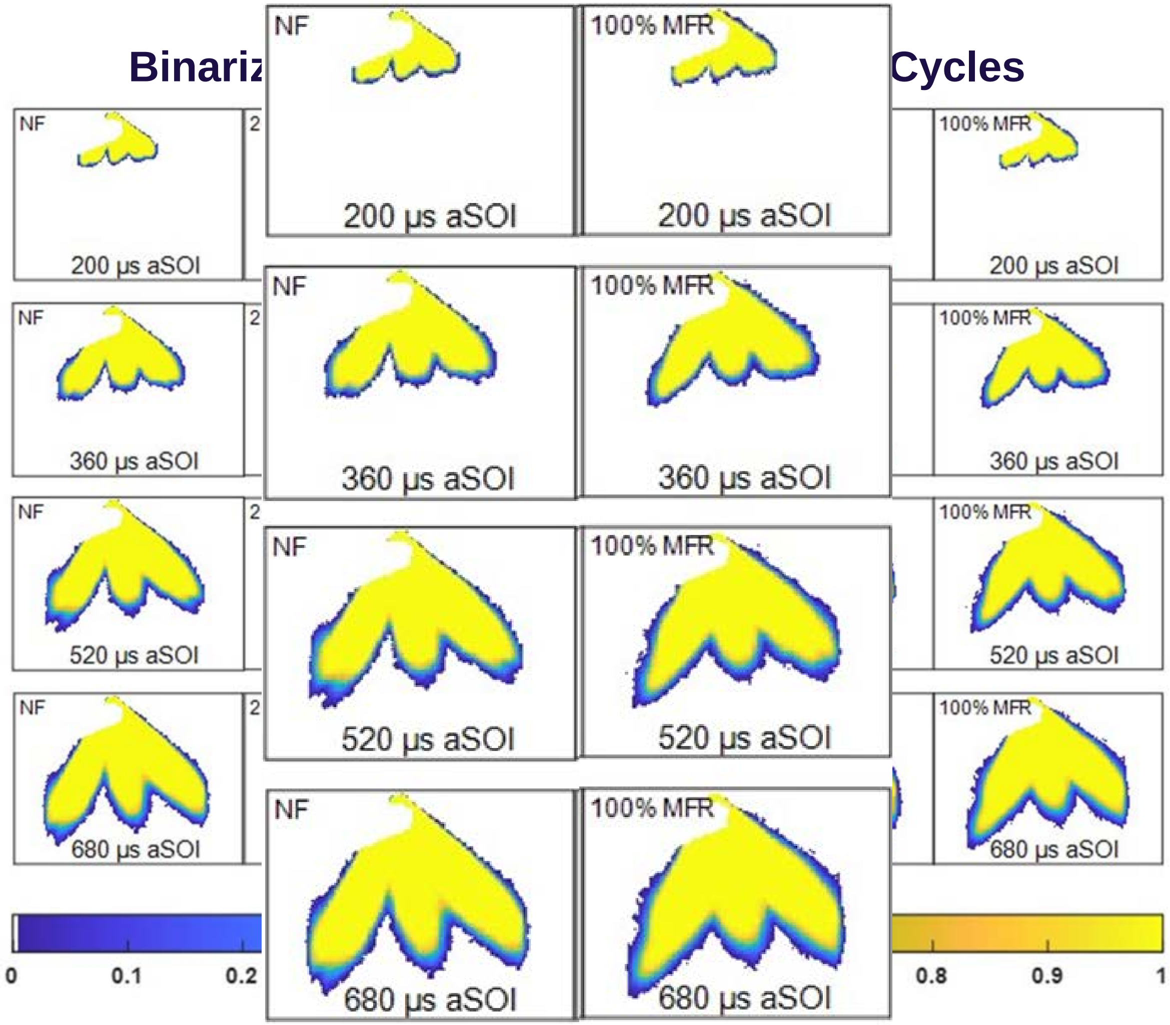
- Flow bench 100% MFR designed to match motored engine at 0.95 bar/800 rpm
- Optimized near the valve
- Streamlines differ at y=-30mm due to piston-induced tumble

Results – Turbulent Kinetic Energy *k*

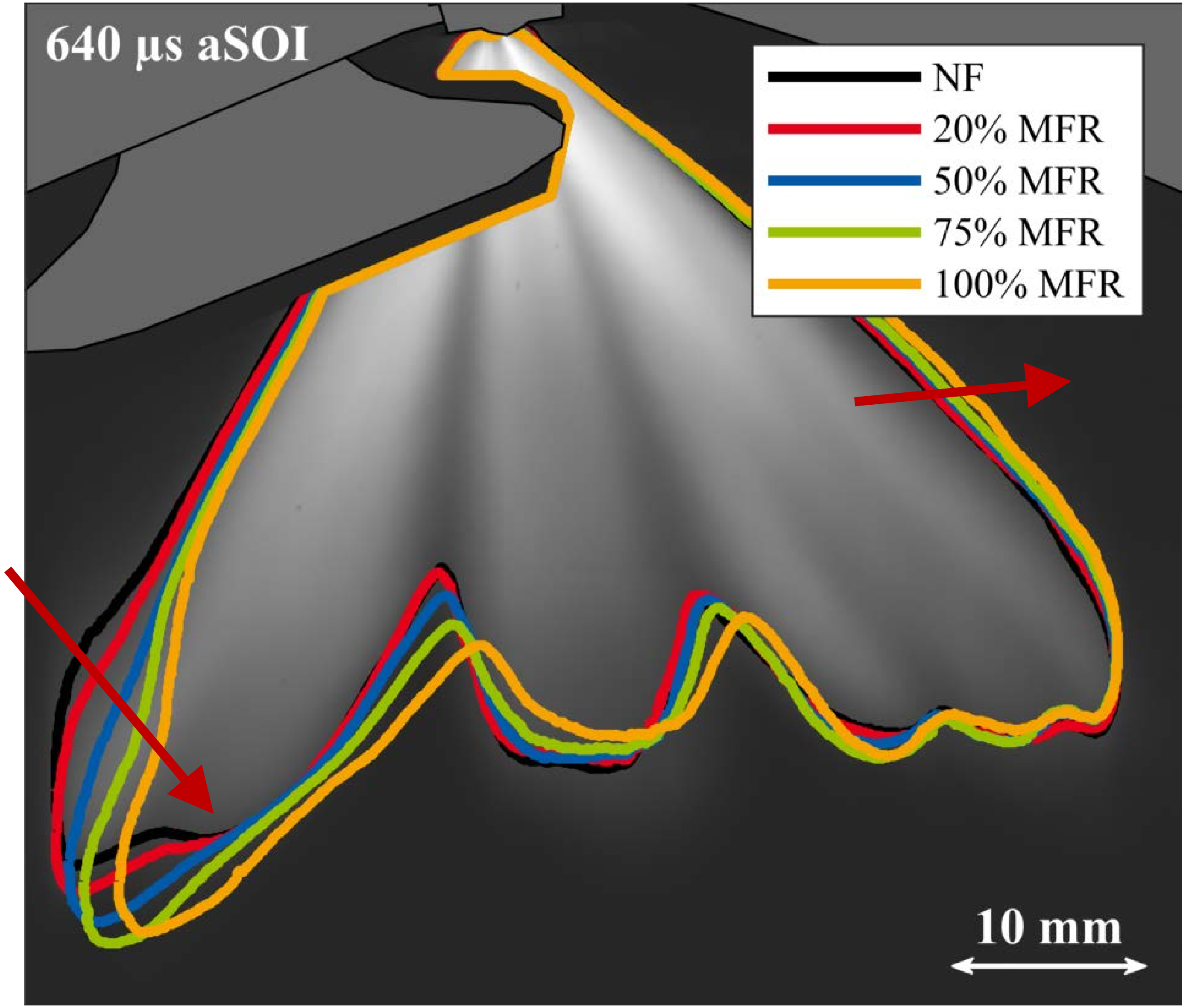
Spray develops in entire field of view

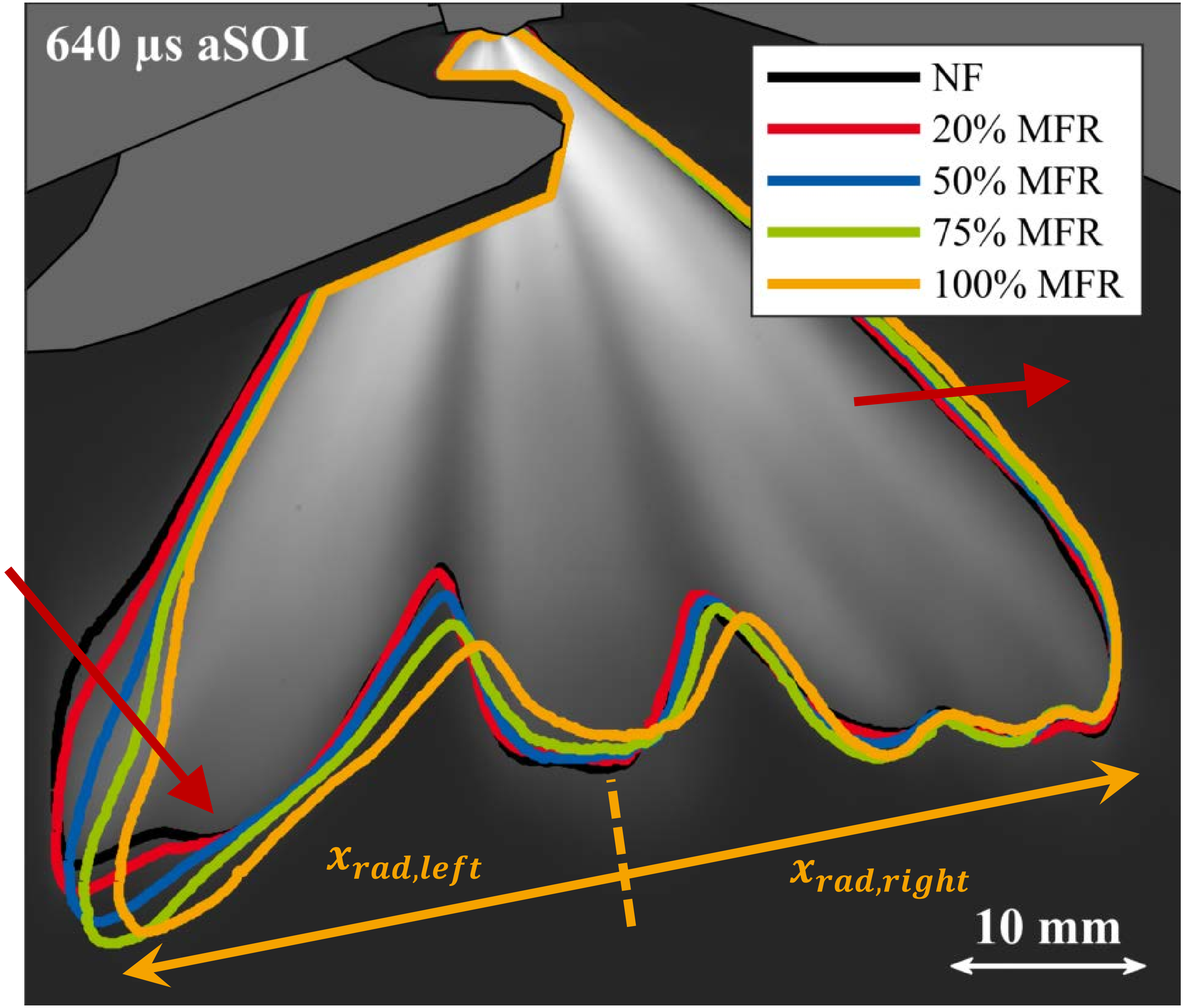
Volumetric Mie Scattering with No-flow (NF)





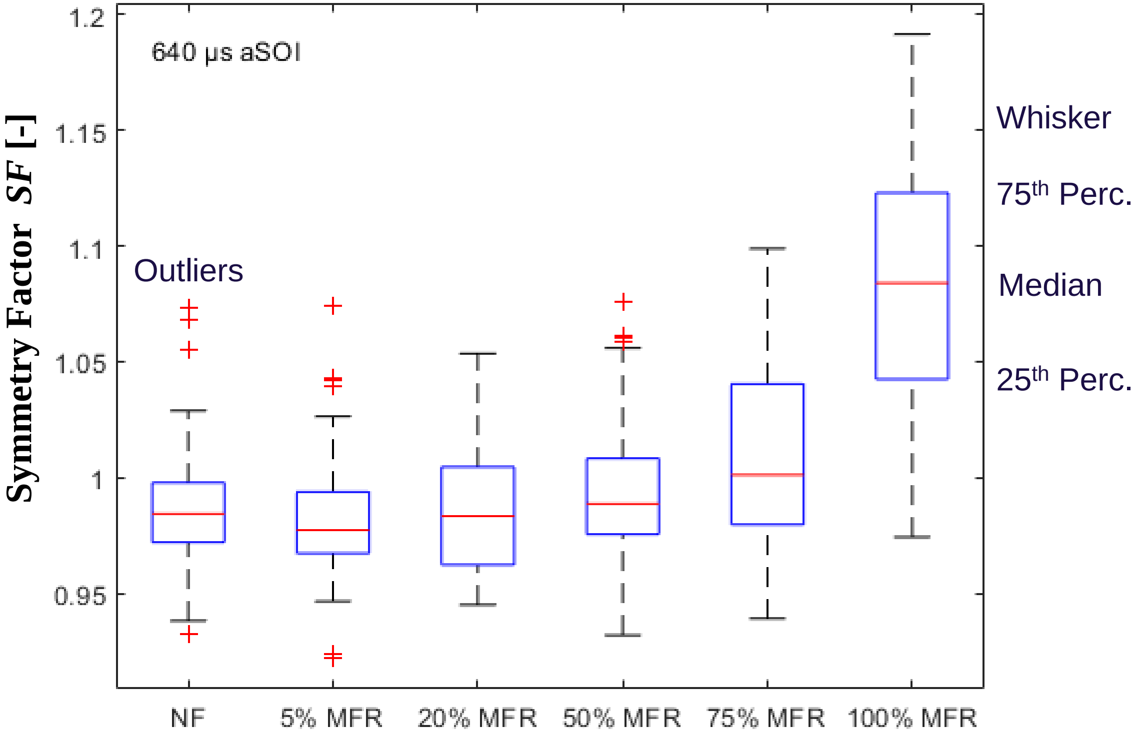
Results – Spray Morphology



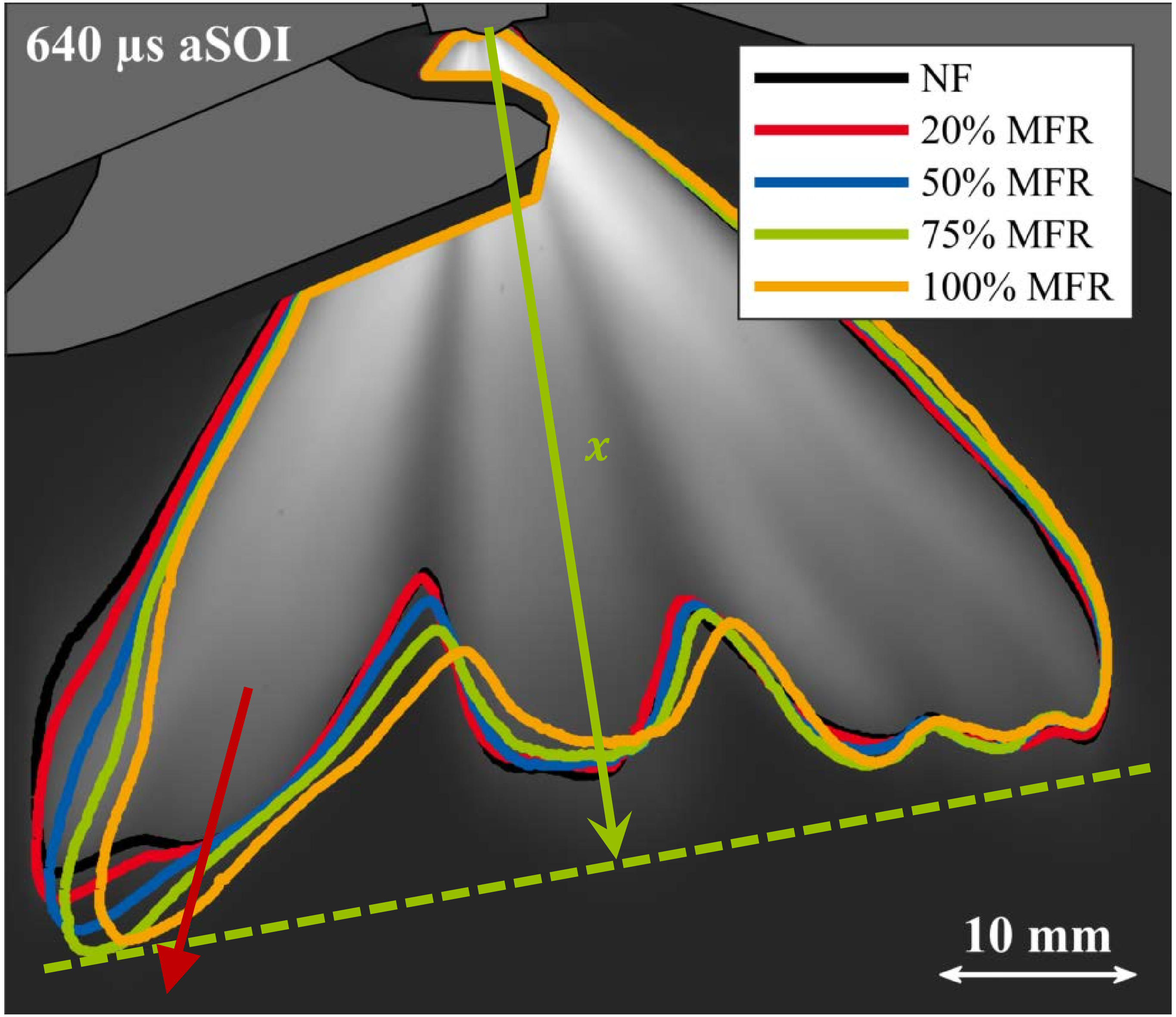


$$SF = \frac{x_{rad,right}}{x_{rad,left}}$$

- Shift to the right
- Increase in spread of symmetry
- Much greater SF for 100% MFR

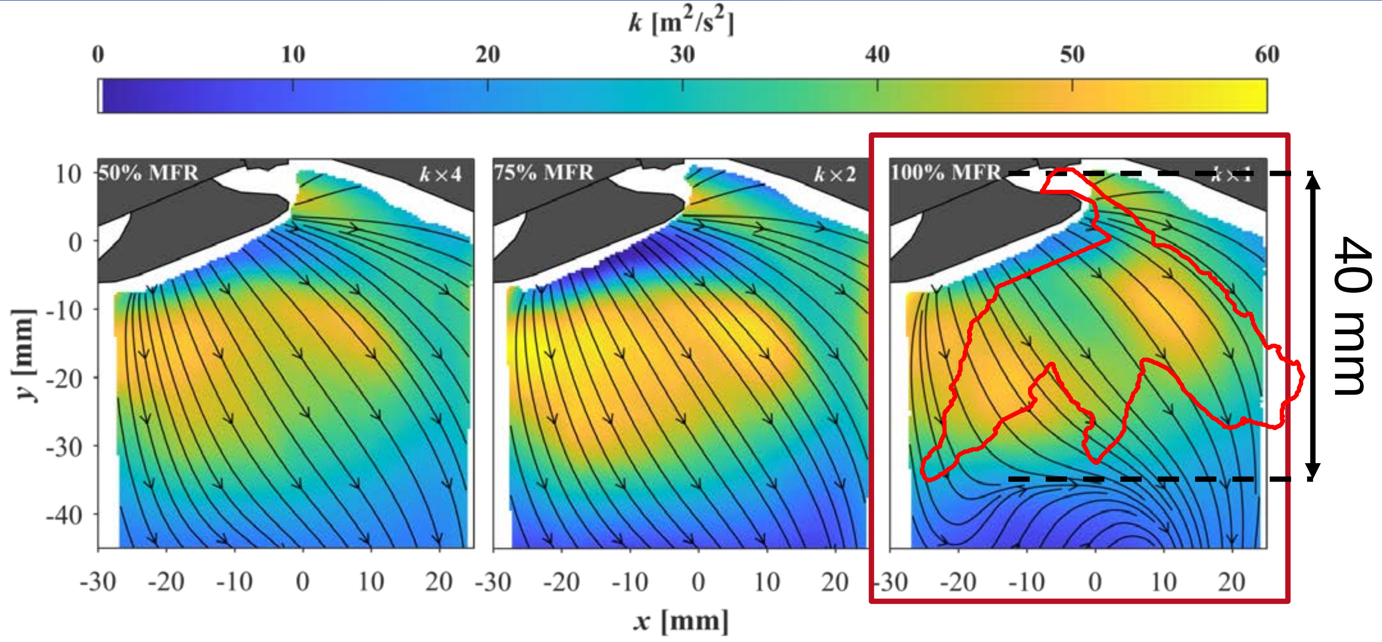


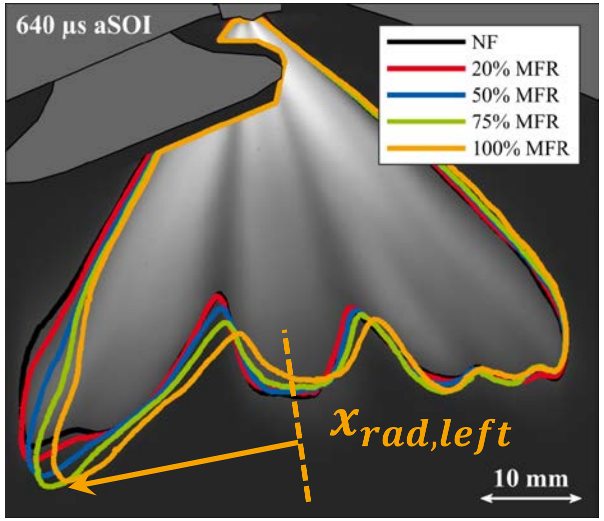
Results – Axial Penetration

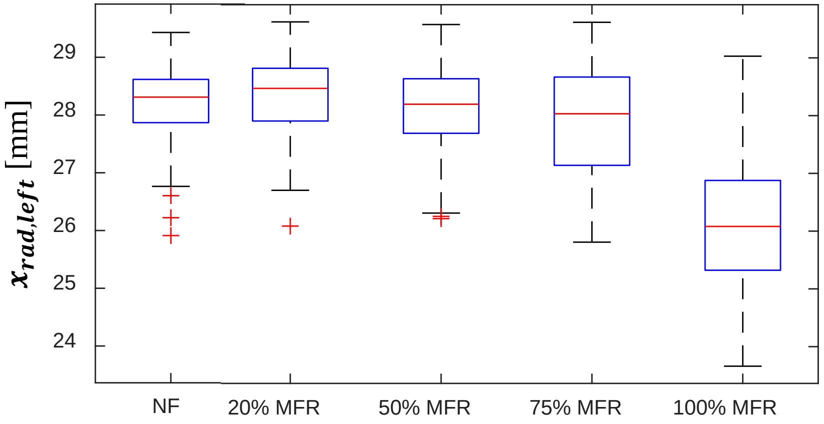


Greater intake velocity

- ► Increased axial penetration
- ► **Why not for 100% MFR?**







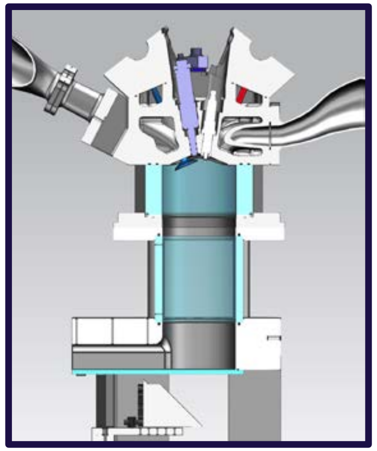
Recirculation causes

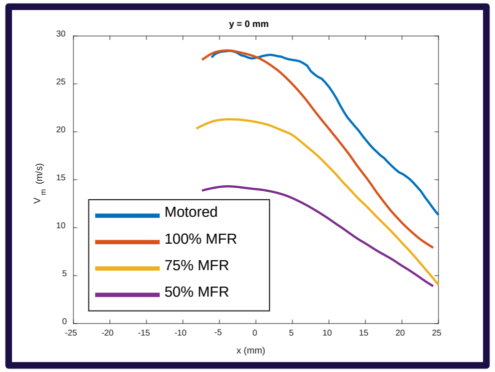
- Increased resistance to spray
- Decreased axial penetration
- Decreased left-radial penetration

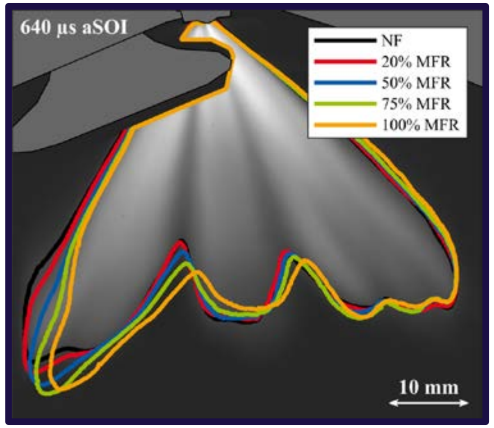
- Flow bench developed for simplified investigation of phenomena
- Flow bench designed to match motored engine at 0.95 bar/800 rpm
- Flow bench coupled with direct injection allowed quantification of effects of flow on spray development
- Increased mass flow rate causes
  - Increased asymmetry towards the exhaust side
  - Increased axial penetration
- Recirculation of 100% MFR causes
  - Decreased axial penetration
  - Decreased left-side radial penetration

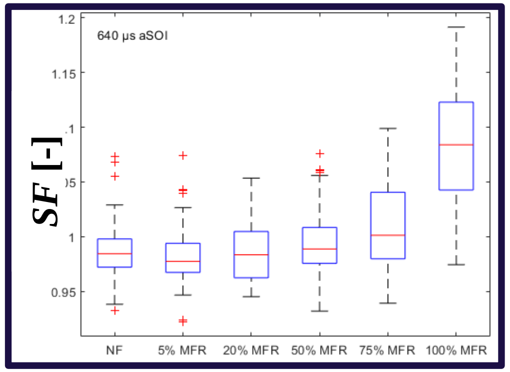
Outlook

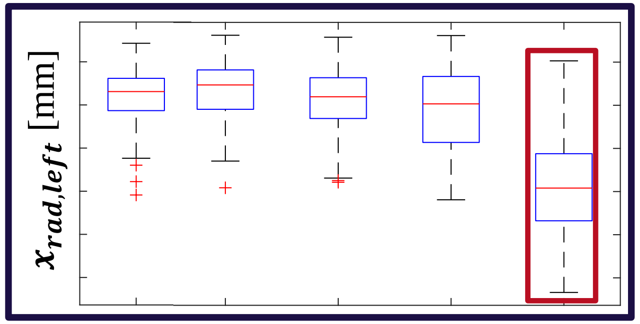
- Further analyze results of spray with the motored engine, e.g., correlation between radial penetration and tumble strength
- Examine individual plumes closer, and provide validation for LES simulations in e.g., plume angle, exit velocity, entrainment, etc.

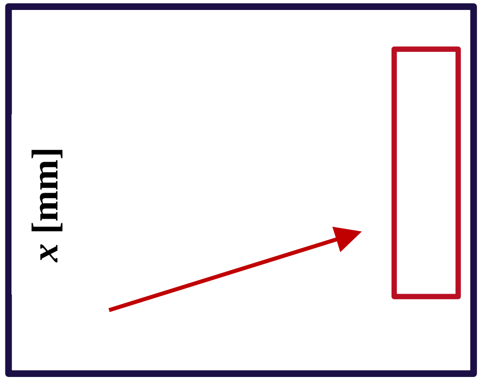












TECHNISCHE UNIVERSITÄT DARMSTADT

Funding

- We kindly acknowledge generous support by Deutsche Forschungsgemeinschaft through SFB-Transregio 150 Project Number 237267381-TRR150
- C. Welch and B. Böhm acknowledge the financial support by the Fritz un Margot Faudi-Stiftung under project number 94

SFB/Transregio 150
Turbulente, chemisch reagierende Mehrphasenströmungen in Wandnähe

FAUDI STIFTUNG

Authors

Cooper Welch

Lars Illmann

Marius Schmidt

Benjamin Böhm