Investigation on PN Formation at GDI Engines at High Loads

Denis Notheis (M.Sc.), Dr.–Ing Markus Bertsch, Dr.–Ing Amin Velji, Prof. Dr. sc. techn. Thomas Koch

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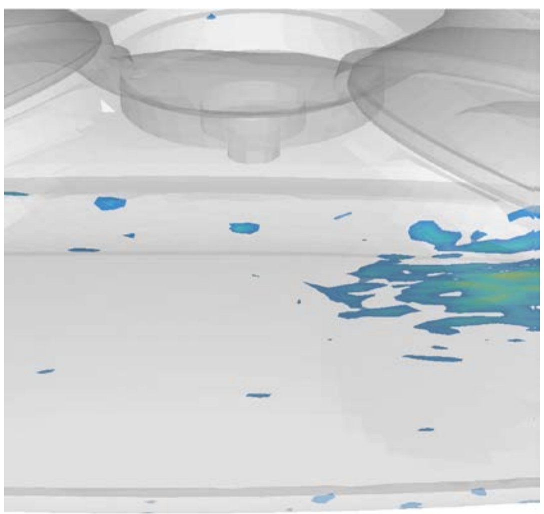
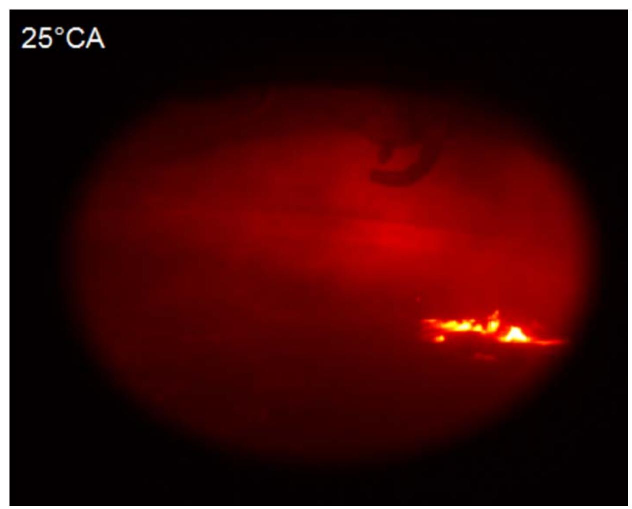
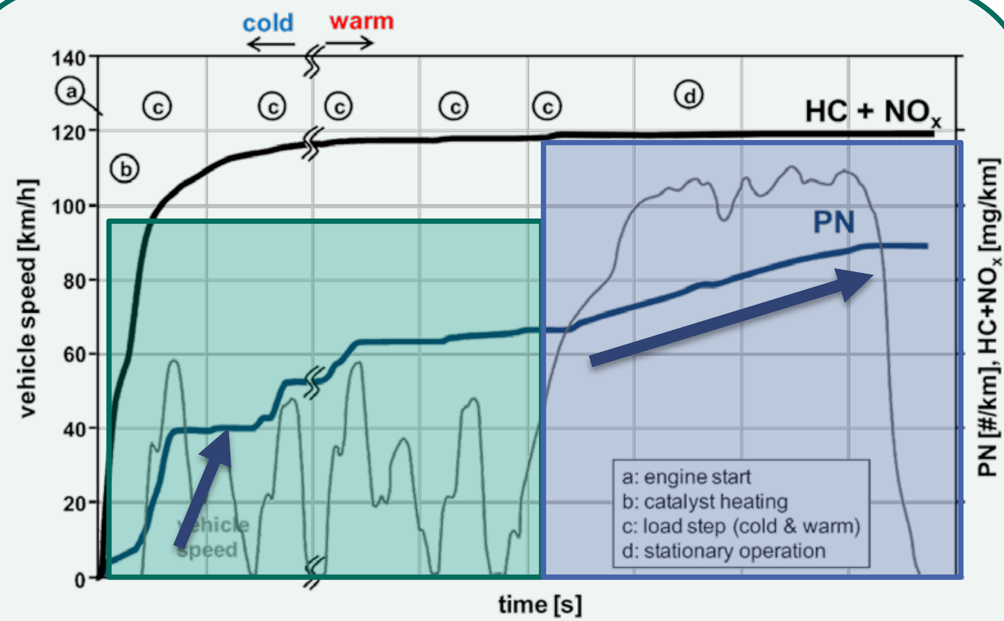




Introduction

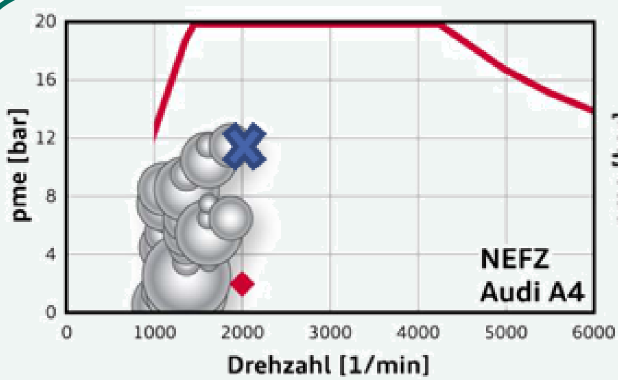


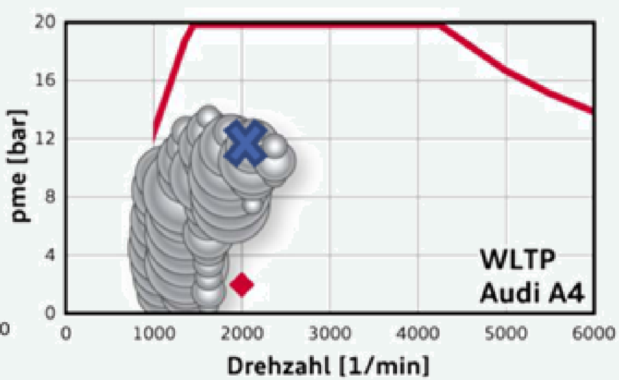
Source: Wiese et al.; Anforderungen an den Mehrlochinjektor zur Erfüllung zukünftiger Emissionsgrenzwerte beim direkteinspritzenden Ottomotor ; Int. Motorenkongress 2015

Previous research: focus of catalysator heating und moderate engine torque

At High loads the particle emissions are rising continuously!
→ This research project

High loads became more important with new test cycles



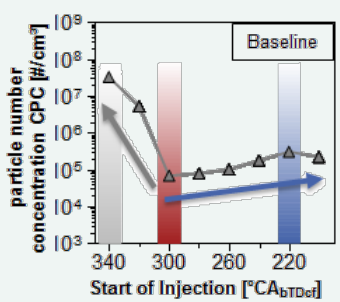


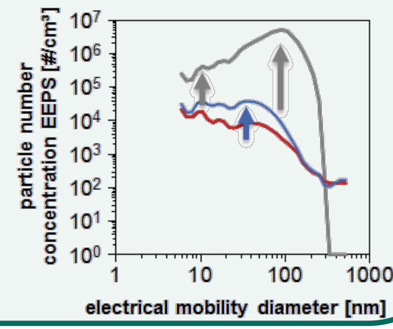
Source: Wurms et al.; Der neue Audi 2.0l Motor mit innovativem Rightsizing – ein weiterer Meilenstein der TFSI Technologie; Wiener Motorensymposium 2015

Now with Euro 6d-Temp
→ 6 $*10^{11}$ [#/km] in the WLTP and RDE
→ Small Particle size challenge of GPF!

Methodology

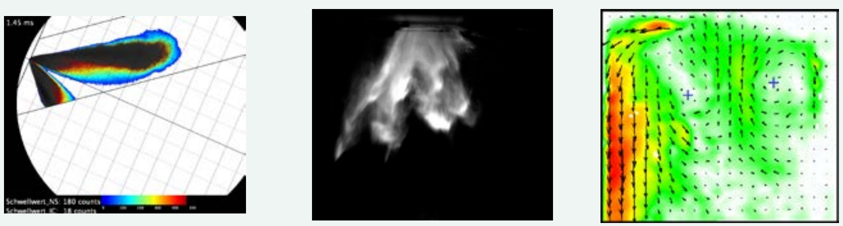
Exhaust gas primary particle number measurement



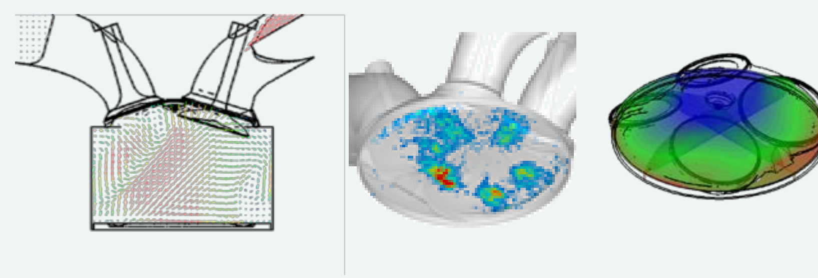


in cylinder optical investigation

Preinvestigations regarding spray and charge motion



CFD simulation of the mixture preparation



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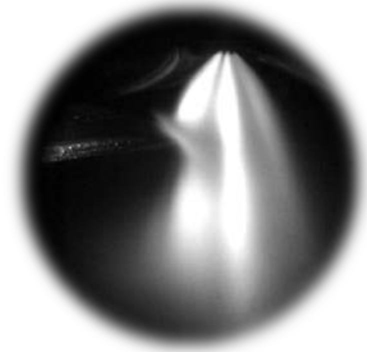
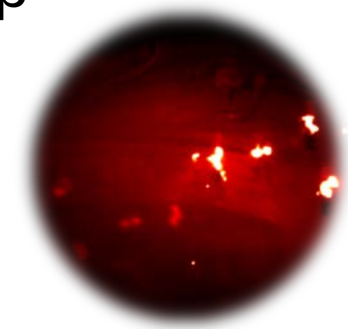
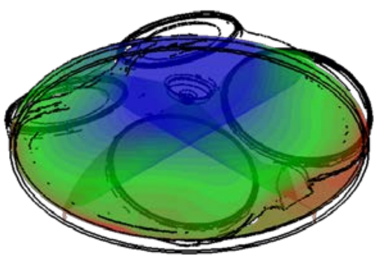
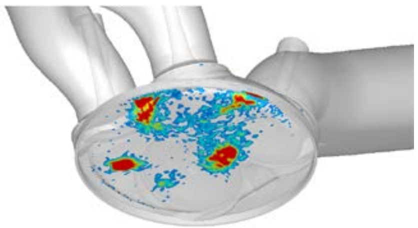
- Experimental and numerical set-up
- Results
- Conclusion



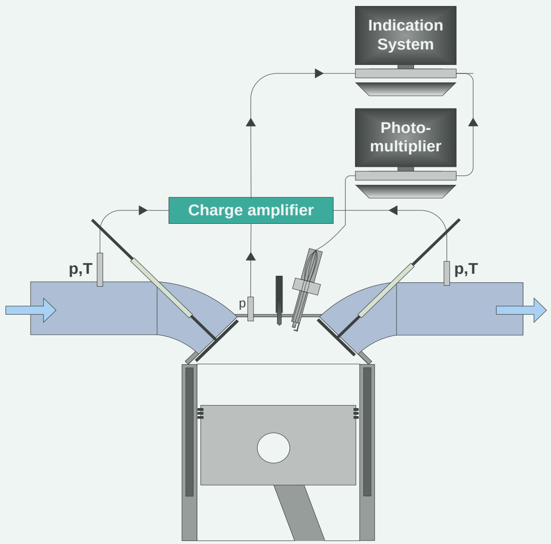


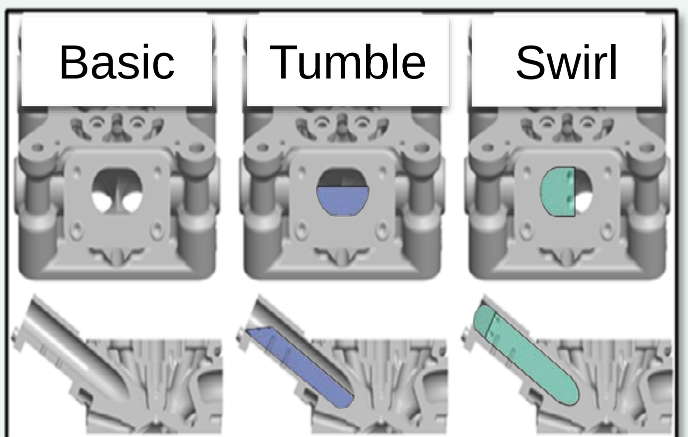




Measurement Setup

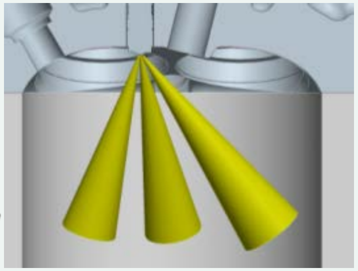
Engine conditions and technical data

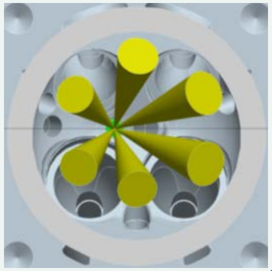




engine speed	[rpm]	2000
IMEP	[MPa]	1.4
Temperature oil, water	[°C]	90
Temperature charge	[°C]	30
relative air-fuel ratio	[-]	1

Injector		**Lowflow**	**Highflow**
Type		Solenoid actuated	
$\dot{Q}_{stat}$	[g/min]	**620**	**820**
Max. pressure	[MPa]	50	35





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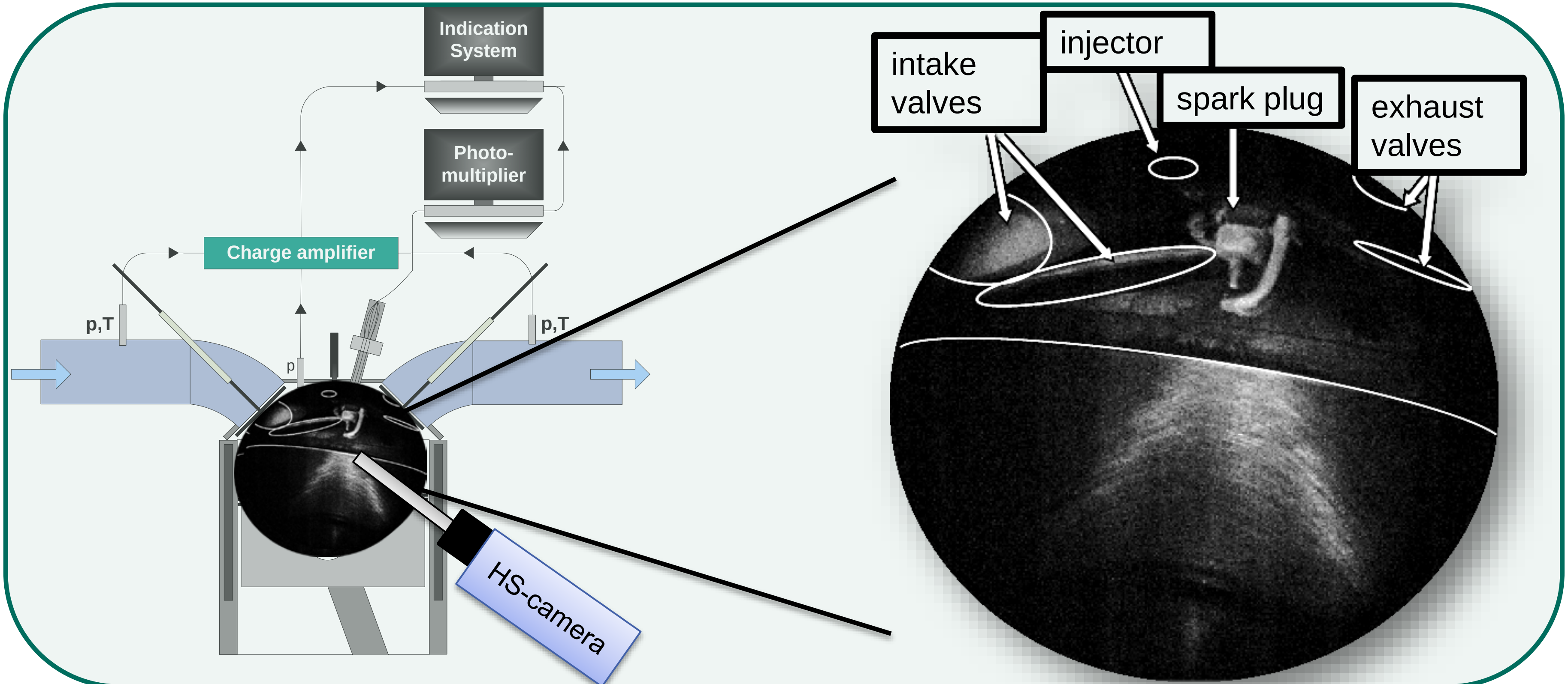
Measurement Setup

Optical investigations in the engine

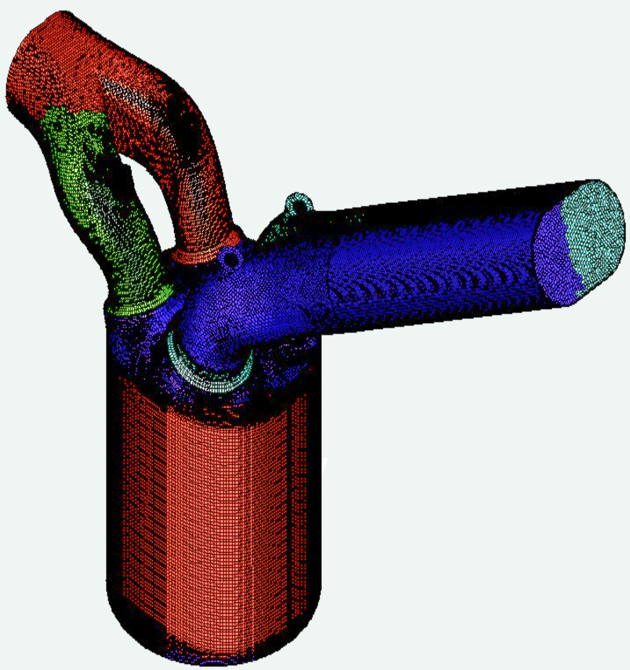


displacement	[cm³]	498 cm³
stroke	[mm]	90 mm
bore	[mm]	84 mm
compression ratio	[-]	10.5:1
setting range cam phasor	[°CA]	80
max. valve lift I/E	[mm]	0.5-9.7 / 9.7

camera		La Vision HSS 6
recording rate	[kHz]	13.5
image chip	[Pixel]	512 x 512
recording window	[°CA aTDCf]	-310 bis 90
Light source		Storz Technolight 270

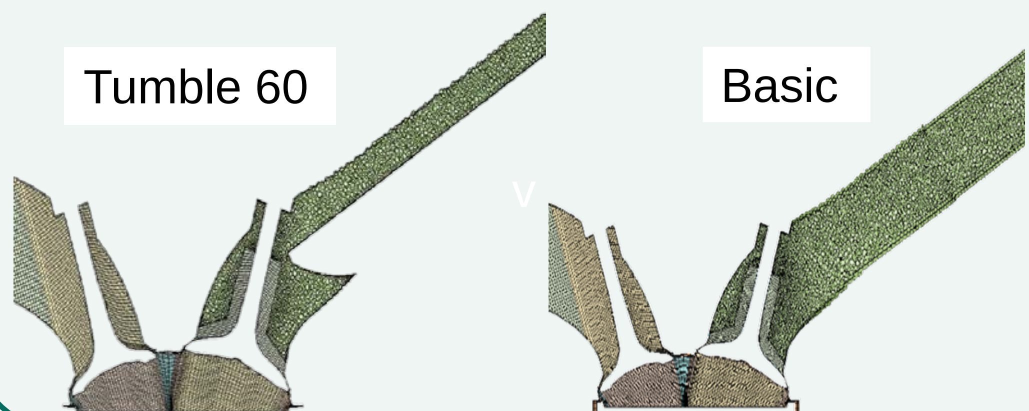
Simulation Setup

Mesh and Models



Calculation with StarCD© and es-ice© ~ 2 mio. cells

Flow field	Air composition	N_2 ,O_2 ,CO_2 , H_2O
	Turbulence	RANS k-ε /RNG Model
Spray	Multicomponent fuel	n-hexane (34 - % m) iso-octane (45 - % m) n-decane (21 - % m)
	Primary breakup	Distribution function
	Secondary breakup	Reitz and Diwakar
	Wall - Impingement	Bai – Gosman
	Liquid Film boiling	Rosenow



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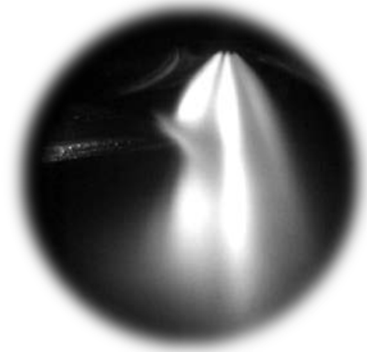
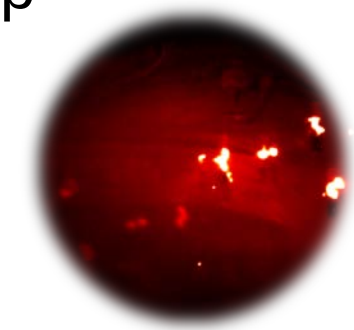
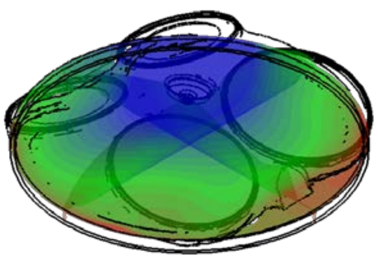
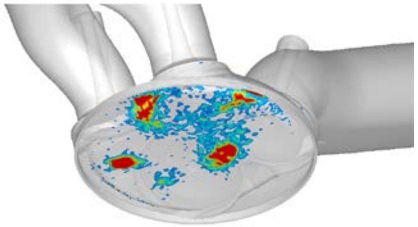
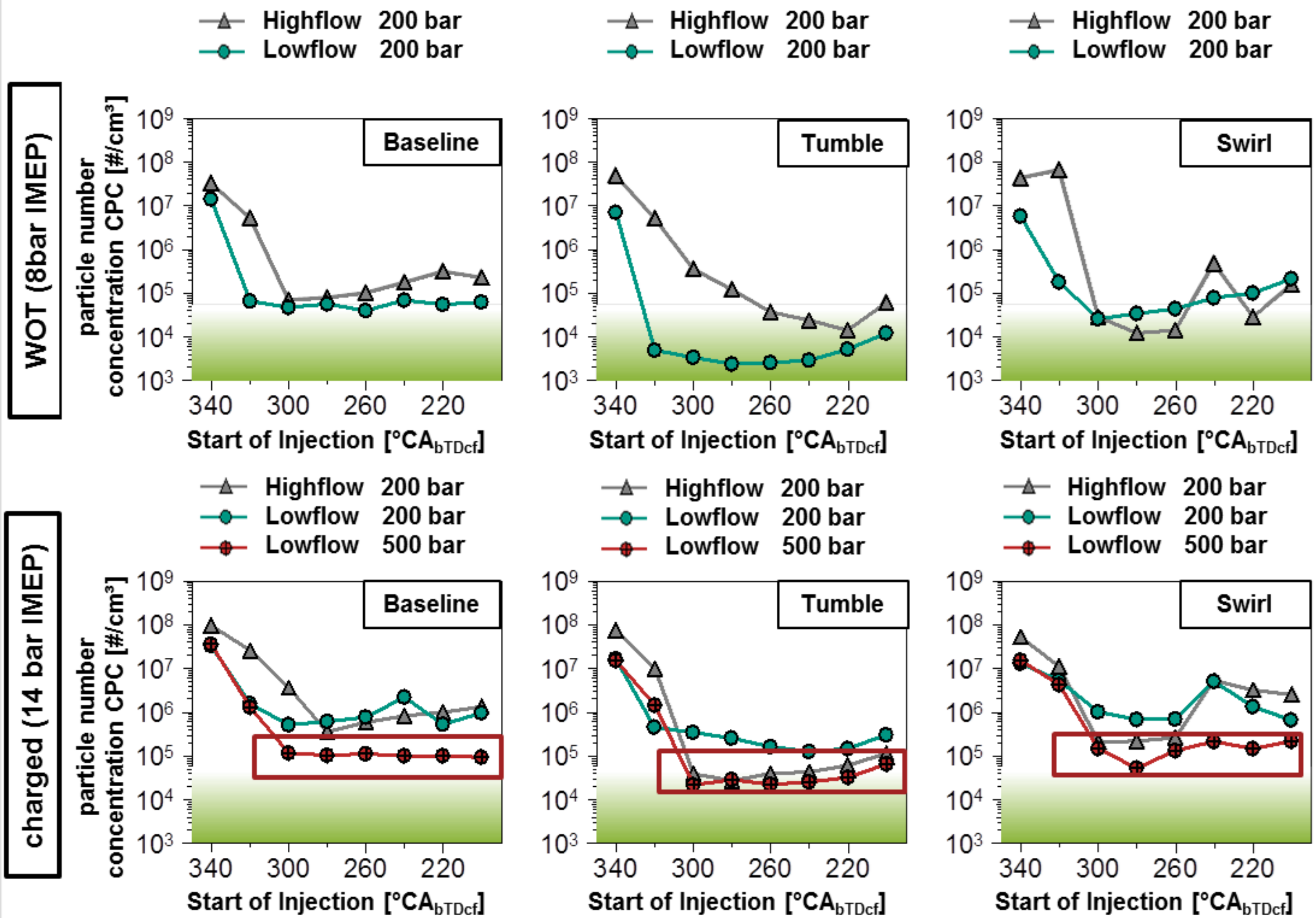





Influencing factors on particle emissions timing, charge motion and injection rate



charge motion: reduction PN

Red. hydr. flow: Reduction of PN in higher a higher variation of SOI

higher load: increase PN

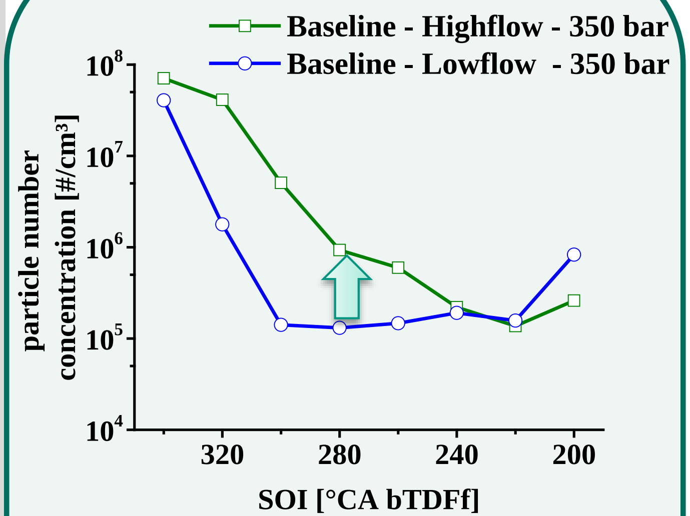
charge motion: significant reduction PN

Red. hydr. flow: Increase PN

higher injection pressure: Reduction PN

Results

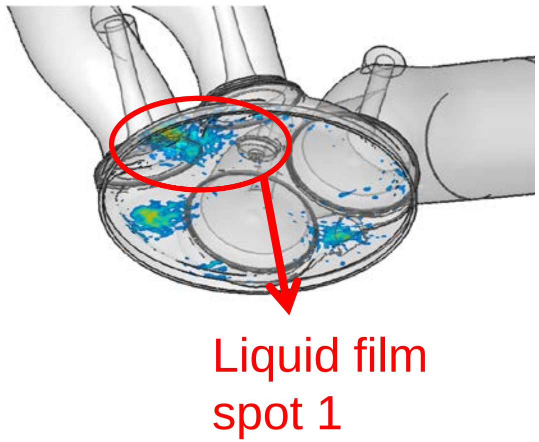
Influence of injection rate on poolfire



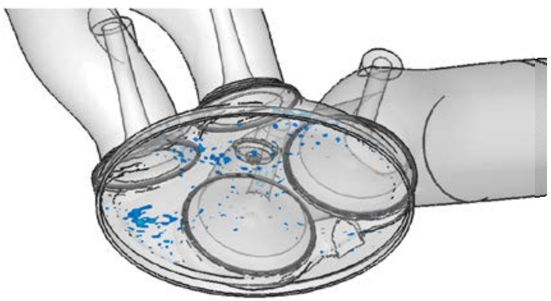
High increase of particle number emission at early injection timings with the highflow injector

More liquid film spots in the simulation of the highflow injector

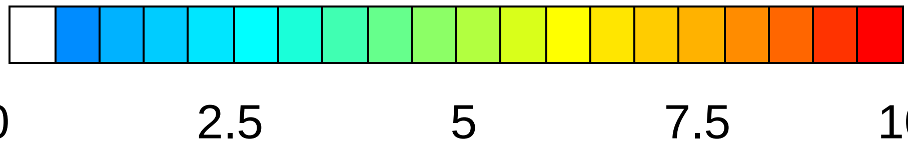
Highflow 350 bar



Lowflow 350 bar

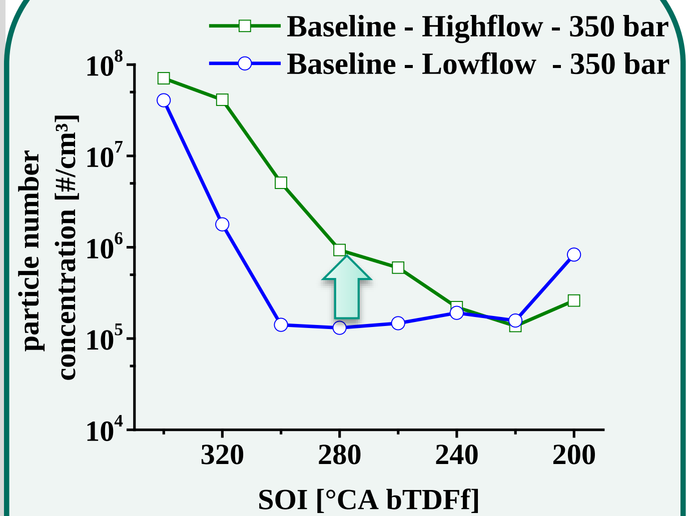


Liquid film Thickness [µm]



Results

Influence of injection rate on poolfire



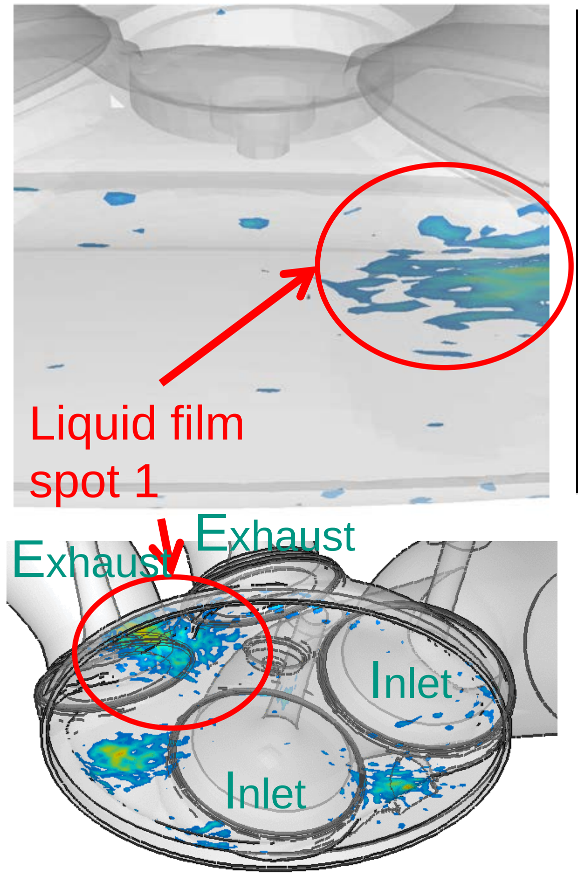
High increase of particle number emission at early injection timings with the highflow injector

More liquid film spots in the simulation of the highflow injector

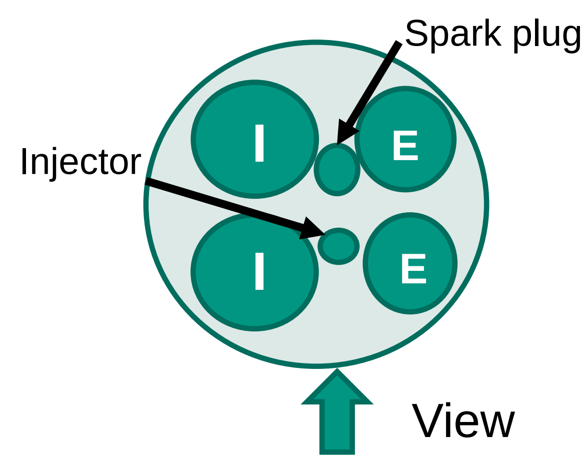
Optical investigation shows pool fire on the same spot as predicted by CFD simulation

Highflow 350 bar

simulation at TDC

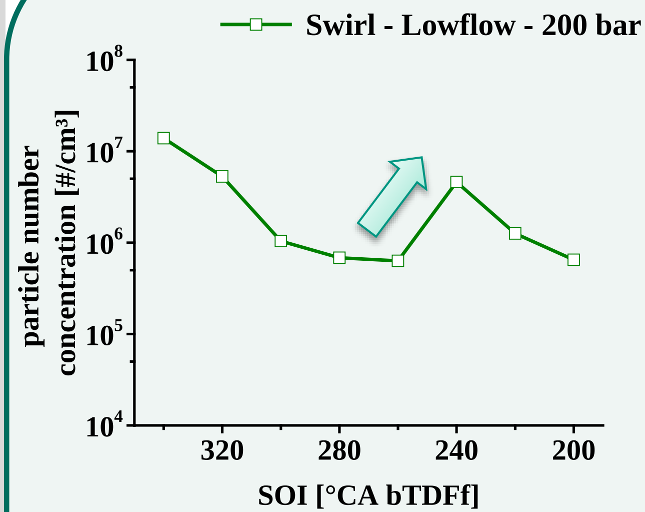


optical investigation



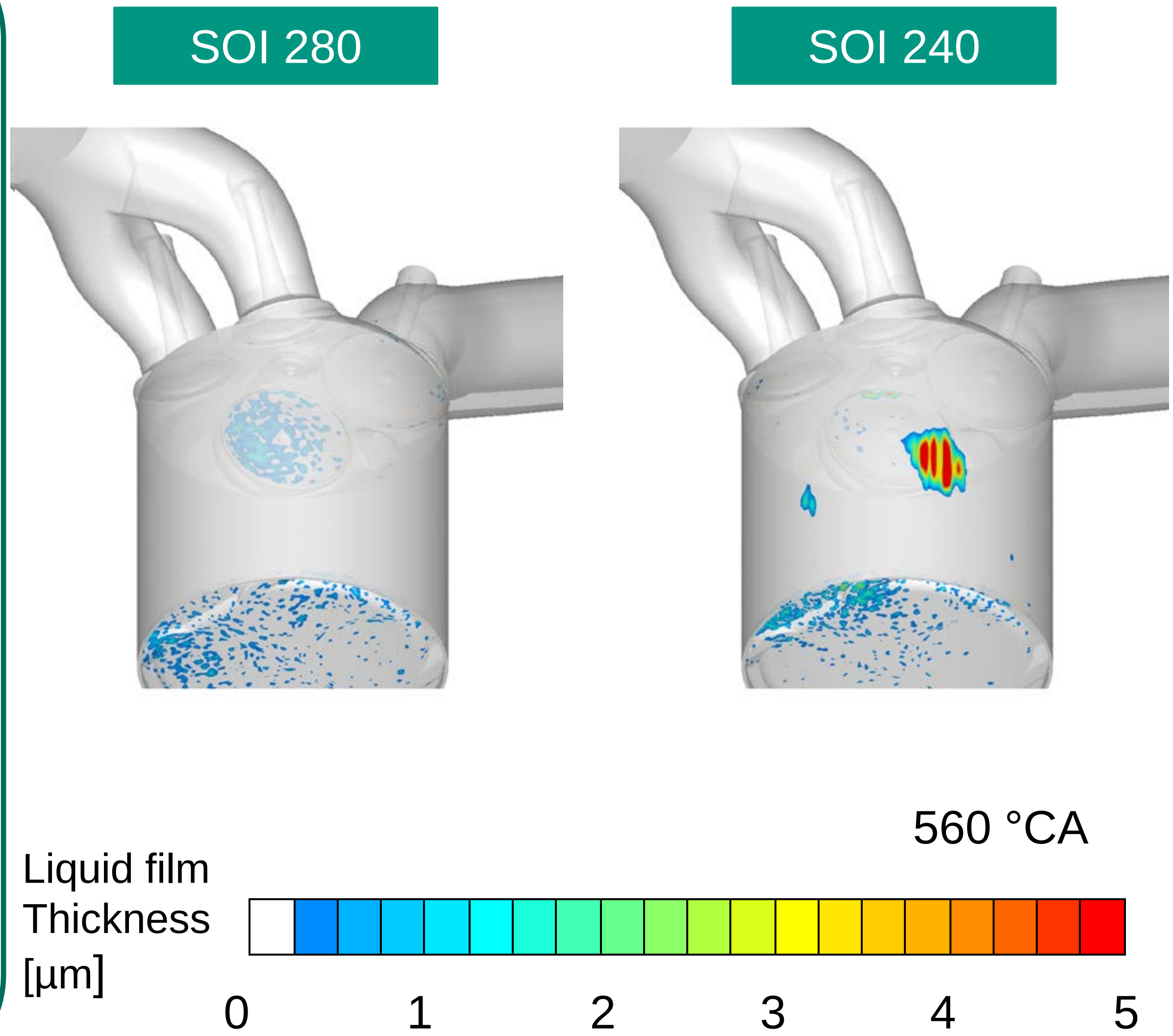
Results

Influence of large scale motion



high decrease of particle number emission from SOI of 280 to 240 °CA bTDCf

High impingement on one spot on the wall caused by the influence of swirl on spray targeting at late injection timings



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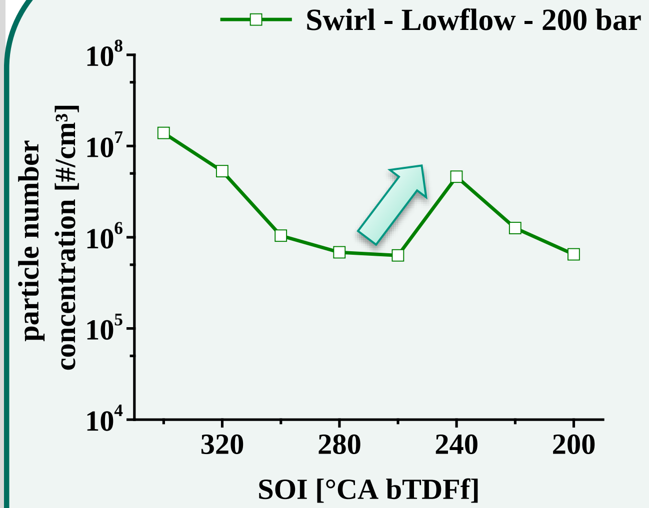
Results

Influence of large scale motion

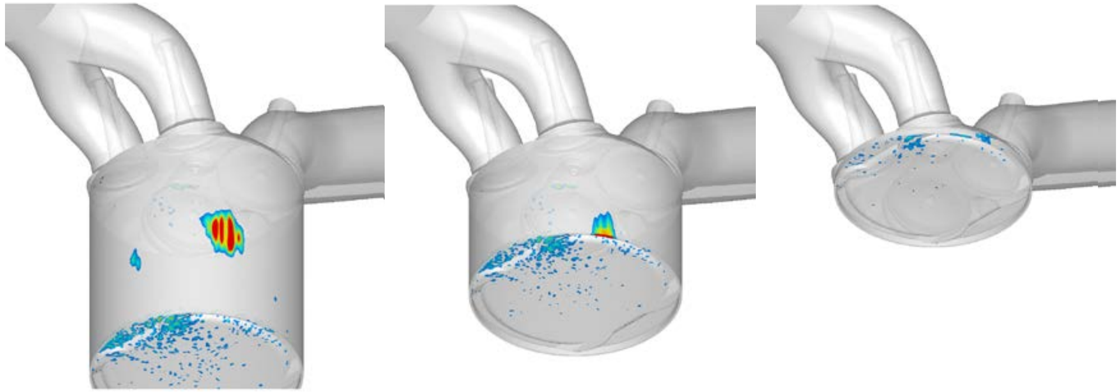


high decrease of particle number emission from SOI of 260 to 240 °CA bTDCf

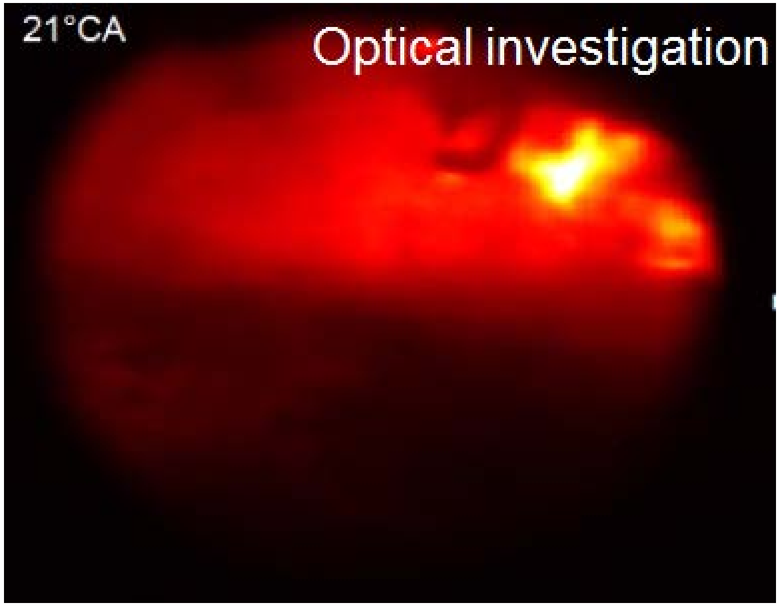
High impingement on one spot on the wall caused by the influence of swirl on spray targeting at late injection timings

Optical investigation shows soot luminescence outwards from top land on the same spot as predicted by the CFD

SOI 240



560 °CA 640 °CA 720 °CA



Results -

Summary of highest influence factors

++ = strong influence
+ = influence
0 = no significant influence

Parameter		TKE Ign.		TKE Inj.		Mixing grade		Liquid droplet mass at TDC		Liquid Film mass Piston		Liquid Film mass Wall		Liquid Film mass Valves		PN	
Valve overlap/ valve timing		+	\	+	\	+	/	+	\	0		0		+	\	+	/
Large scale charge motion	Tumble	++	/	++	/	++	/	+	V	++	\	+	/	++	/	++	V
Large scale charge motion	Swirl	++	/	++	/	++	/	+	\	++	\	++	/	0		++	\
Valve lift		++	/	+	\	++	/	0		+	\	+	/	++	/	+	/
Temperature cooling		0		0		0		++	\	++	\	++	\	0		++	\
Rail pressure		0		+	/	++	/	++	\	+	/	+	\	+	\	++	\
nozzle diameter		0		+	/	+	\	+	\	++	/	+	\	0		++	\
Injection timing		0		++	\	+	V	+	/	++	\	++	/	++	Λ	++	V

/ = increase \ = fall V = minimum exist Λ = maximum exist

by increasing the parameter

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Results -

Summary of highest influence factors

Karlsruher Institut für Technologie

Large scale motion strongly affected the spray targeting.

With a Tumble Inlay the best mixture preparation was possible.

If the valve is been impinged the mixture preparation is influenced negatively.

High injection pressure influenced the evaporation rate of the spray and improve the mixture preparation if not influenced by the valves.

Colder wall temperature affect only the liquid mass.

With early injection timings piston impingement is increased otherwise with late injection timings mainly the liner is impinged.

++ = strong influence
+ = influence
0 = no significant influence

		TKE				Mixing grade		Liquid droplet mass at TDC		Liquid Film mass						PN	
		Ign.		Inj.						Piston		Wall		Valves			
Valve overlap/ valve timing		+	\	+	\	+	/	+	\	0		0		+	\	+	/
Large scale charge motion	Tumble	++	/	++	/	++	/	+	V	++	\	+	/	++	/	++	V
	Swirl	++	/	++	/	++	/	+	\	++	\	++	/	0		++	\
Valve lift		++	/	+	\	++	/	0		+	\	+	/	++	/	+	/
Temperature cooling		0		0		0		++	\	++	\	++	\	0		++	\
Rail pressure		0		+	/	++	/	++	\	+	/	+	\	+	\	++	\
nozzle diameter		0		+	/	+	\	+	\	++	/	+	\	0		++	\
Injection timing		0		++	\	+	V	+	/	++	\	++	/	++	Λ	++	V

/ = increase \ = fall V = minimum exist Λ = maximum exist
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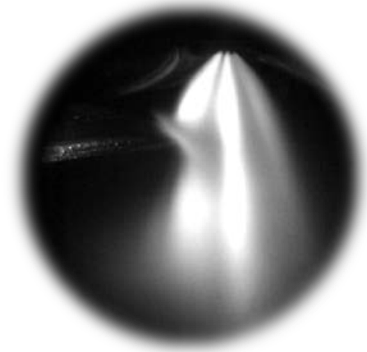

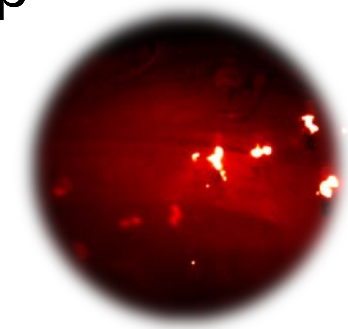

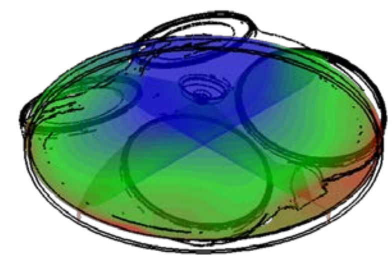

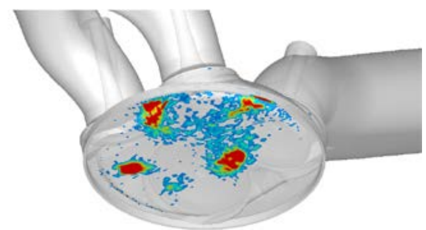

Conclusion

- The potential of the different variation parameters to reduce the particle number emission is not additive. The variation parameters (valve overlap, tumble, rail pressure, …) affect each other mutually!

- The simulation shows the trends of the mean particle measurement results, cycle-to-cycle variations could not be predicted with the used models

- CFD-simulation predicted that the highest influencing factors on particle is the remaining liquid phase in the cylinder.

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- Forschungsvereinigung Verbrennungskraftmaschinen e.V. (FVV, Frankfurt)
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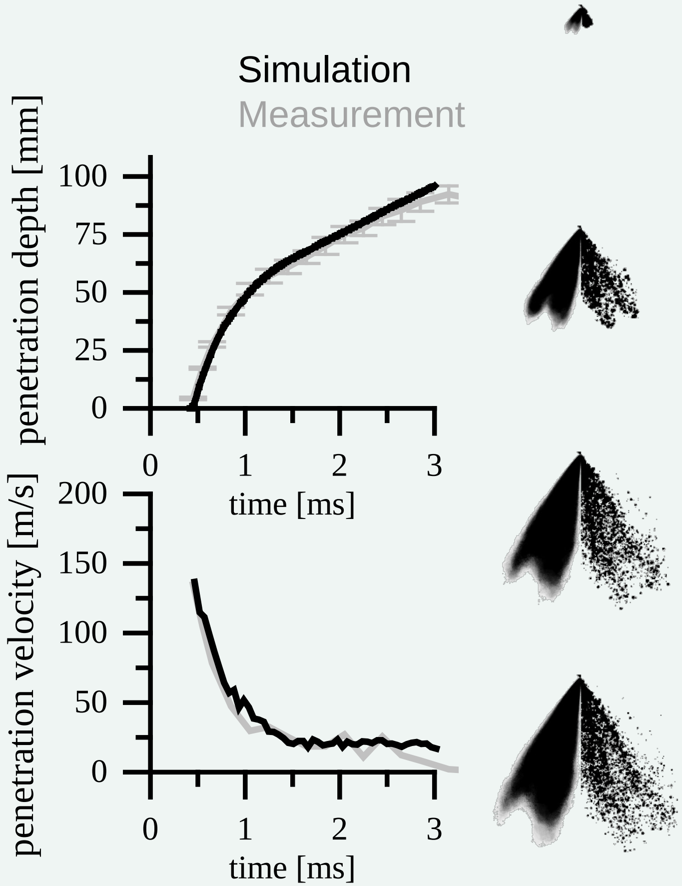
- FVV working group, especially Bosch and Delphi
- Siemens PLM ICE-Support Team, especially Dr. Oleksiy Kochevskyy

and for your kind attention

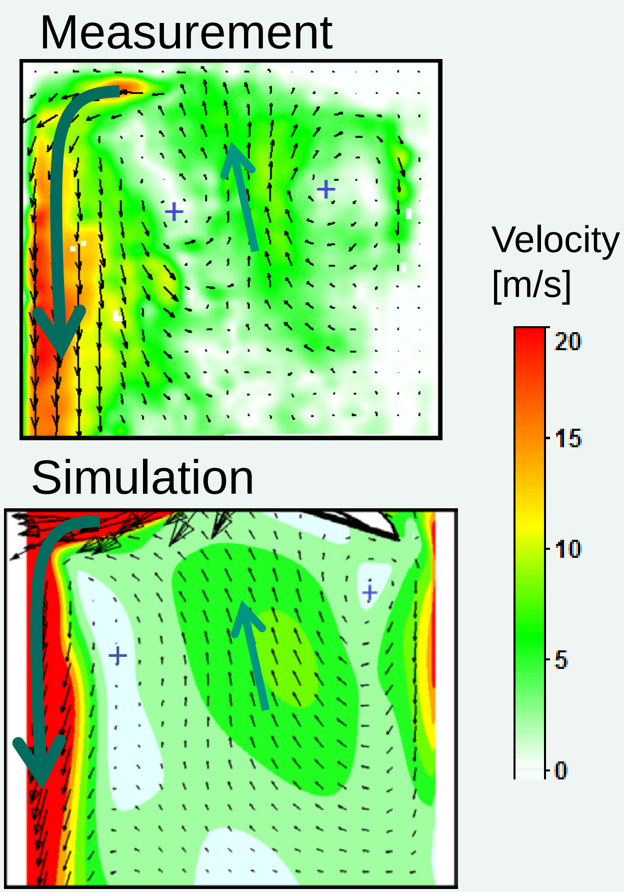
Appendix: Validation

Spray and flow validation

Spray Validation in pressure chamber



Flow Validation in flowbench



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