Numerical Assessment of an Innovative Piston Bowl in a Light-duty Diesel Engine

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Agenda

- Introduction
- Baseline engine model and validation
- Innovative piston bowl
  - Optimization of injector protrusion
  - Optimization of numbers of holes and EGR rate
- Conclusions

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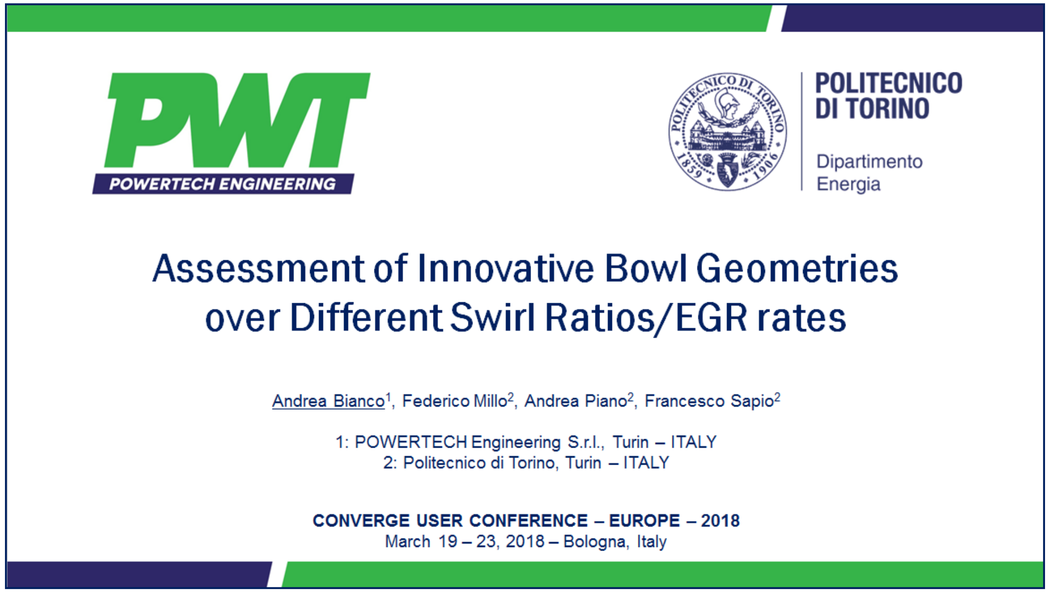
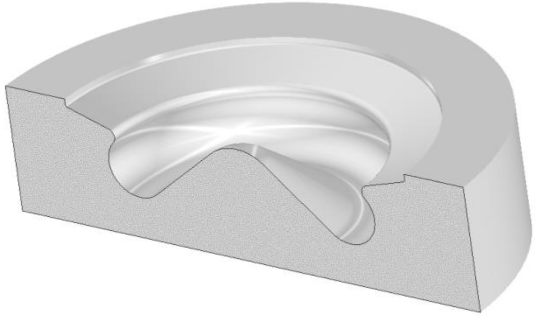
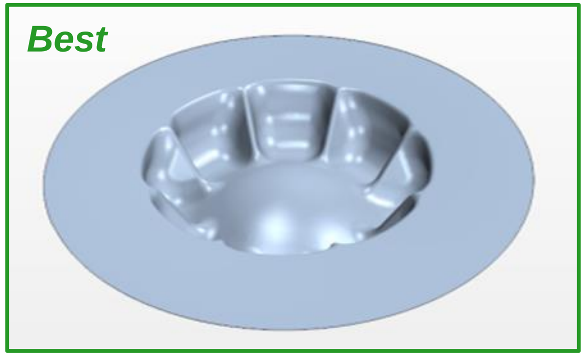
Introduction

Where we were…2018:

Is it possible to reduce in-cylinder Diesel emissions? **YES!**







	TV bowl	RB bowl
SOOT	-25%	-30%
BSFC	~0%	-4%

This is a good start, but…can we go further?

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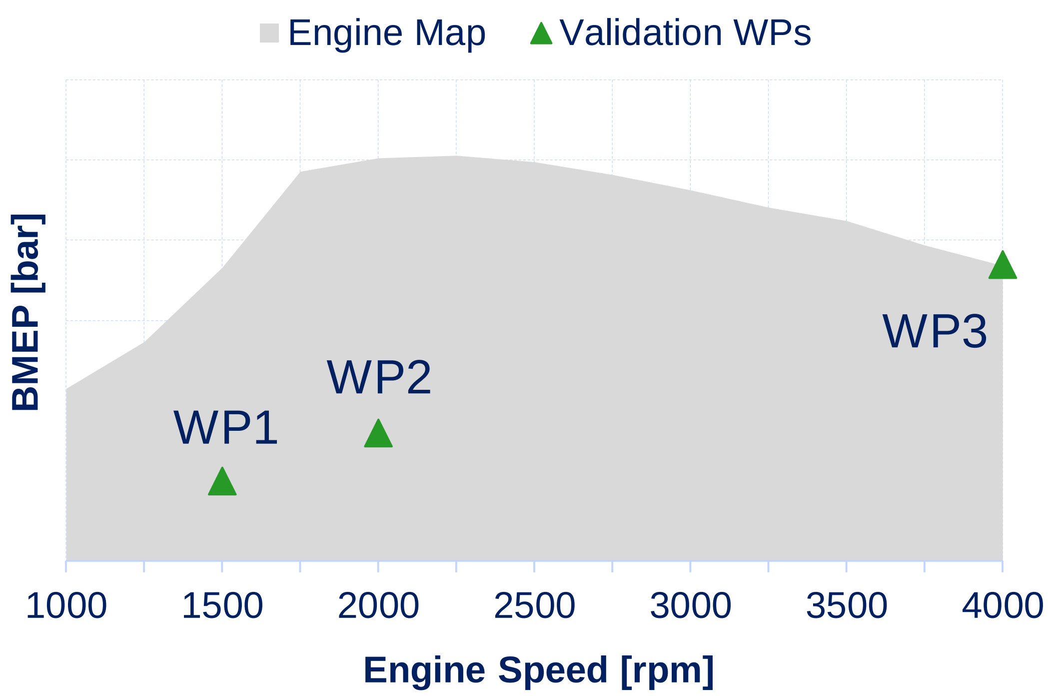
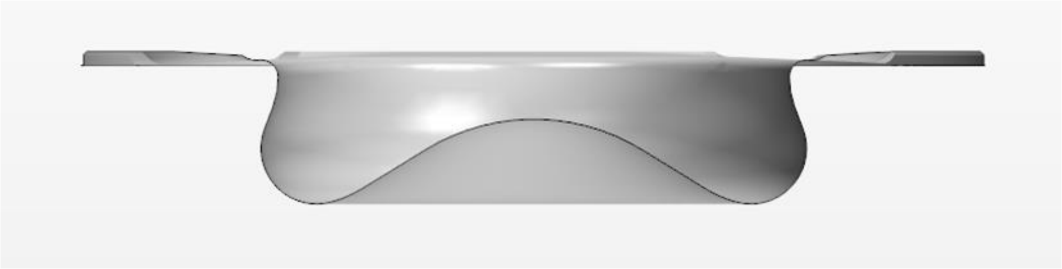
Baseline engine model and validation

CI engine appl.	LD vehicle
Cylinders #	4
Displacement	1.6L
Compression ratio	16:1
Turbocharger	Single-stage with VGT
Fuel injection system	Common Rail
Maximum power and torque	100 kW @ 4000rpm 320 Nm @ 2000rpm





Baseline: re-entrant bowl design

Two CI engine modelling pillars:

- Accurate spray modeling → Spray calibration
- Accurate combustion modeling:
  - SAGE w/ detailed chemistry scheme

Baseline engine model and validation

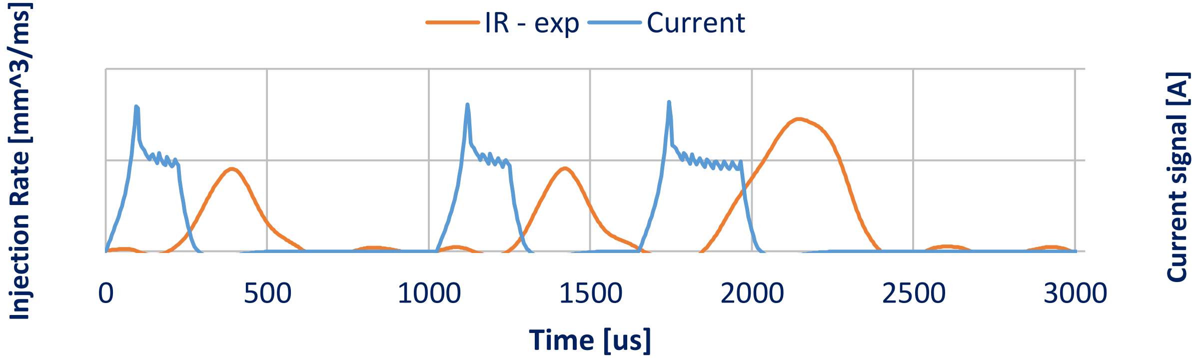
Simulation setup (Converge 2.3.17)

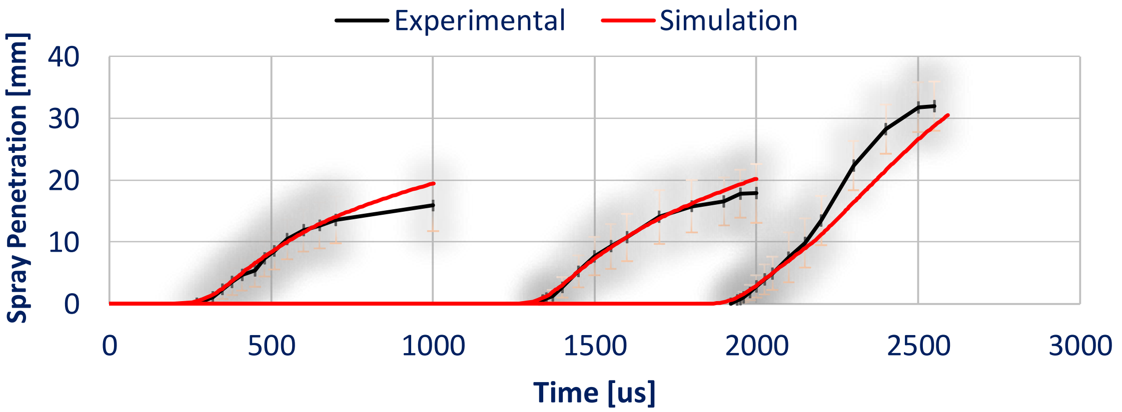
- AMR (v,T), Δx_{min} = 0.25 mm (~1e-11 kg/parcel/nozzle)
- Diesel2 liquid fuel
- O'Rourke turbulent dispersion, RANS k-eps RNG
- Frossling evaporation model
- NTC collision model w/ collision mesh (0.06 mm)
- Dynamic drop drag (default coeff.)
- KH+RT breakup model (cal. time and size const.)
- Discharge coefficient model (w/ Cv correlation)
- Calibrated spray angle

Spray calibration

- Experimental data (constant volume vessel test) available for a reference injection pattern only (Perugia University)

Ref. Case – 8 hole, solenoid CR injector	
Bomb P [bar]	11.28
Bomb T [°C]	20
P Rail [bar]	400



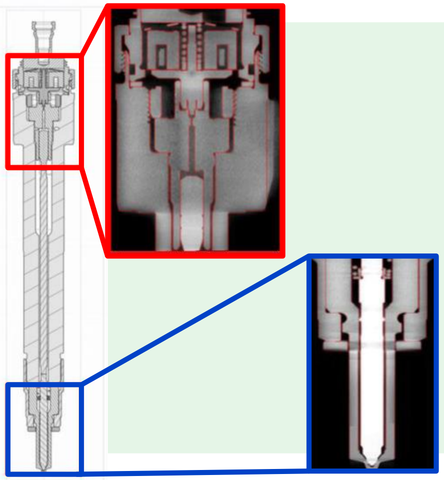


Baseline engine model and validation

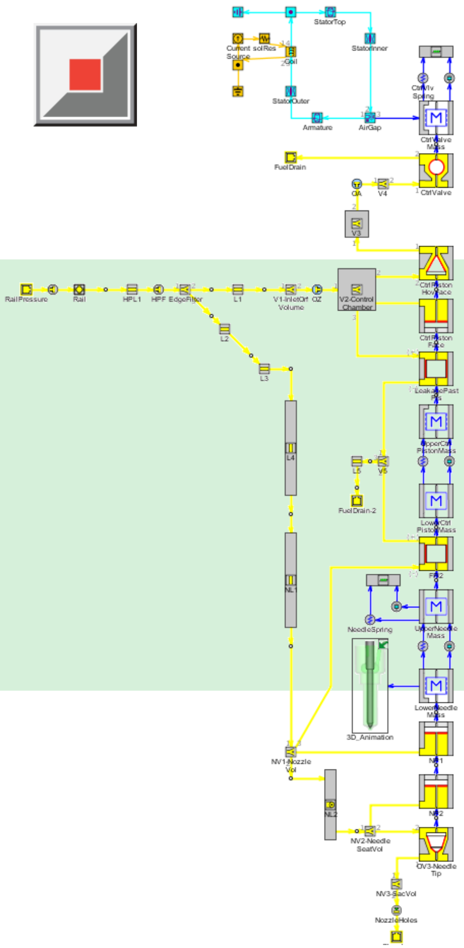
GT-SUITE Injector model

Source:
www.boschautoparts.com

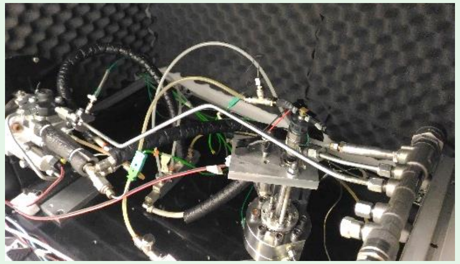
Internal geometry detection



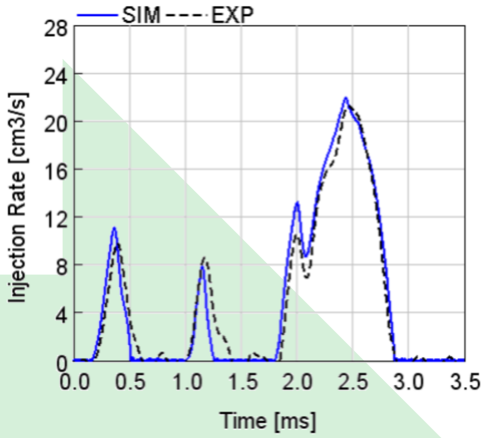
3D Computed Tomography

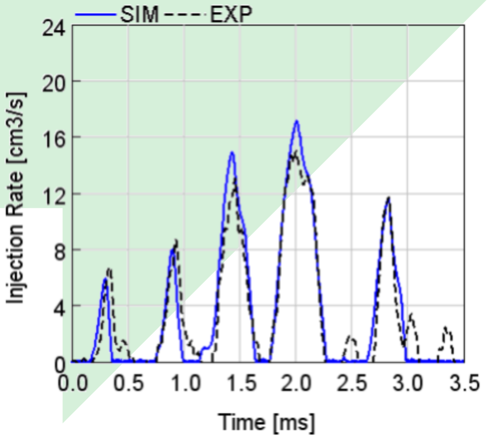


Experimental IR dataset



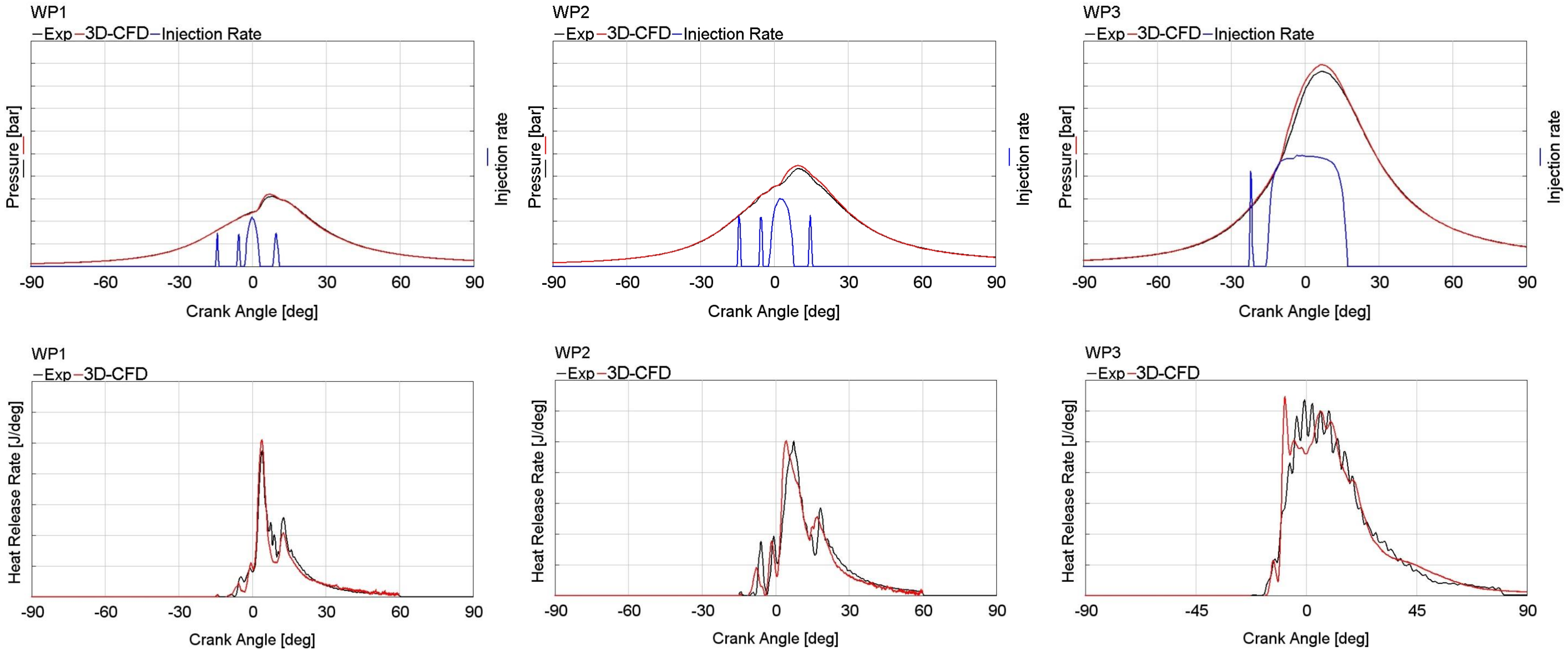
STS Injection Analyzer





Baseline engine model and validation

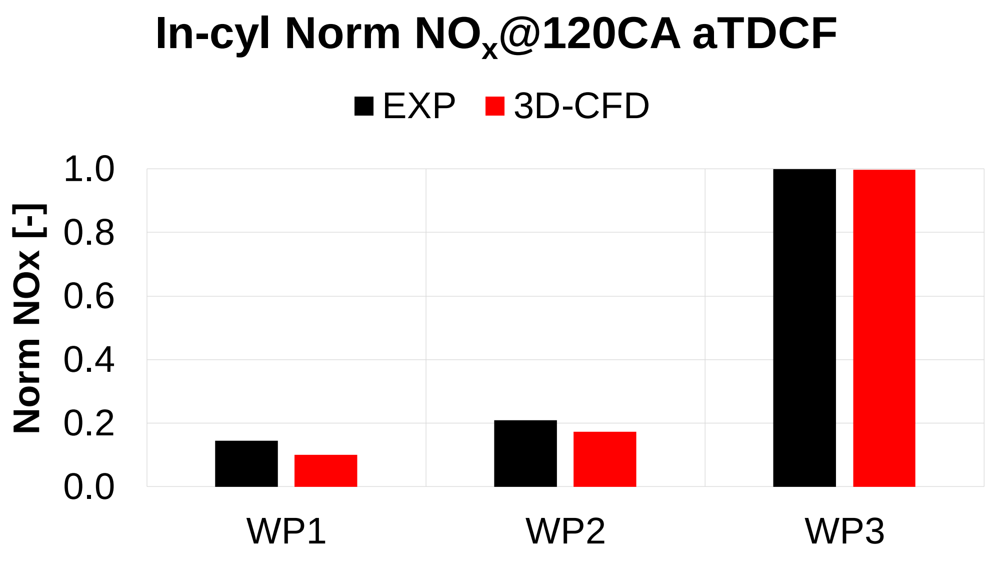
Validation results



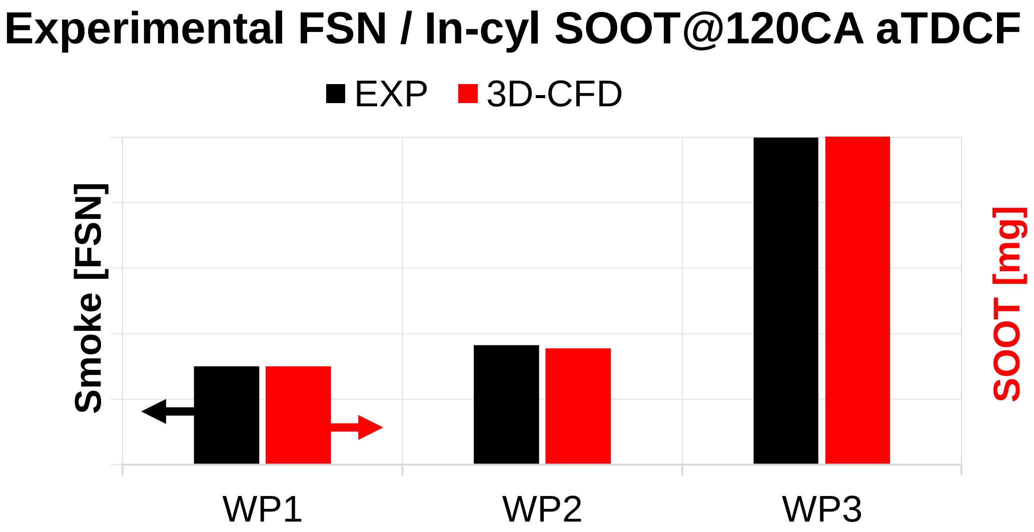
Baseline engine model and validation

Validation results

- **Very good agreement** for **NOx** emissions (embedded in mech.dat)



- **Qualitative agreement** between experimental Filter Smoke Number (**FSN**) and 3D-CFD in-cylinder **SOOT** mass (particulate mimic soot model)



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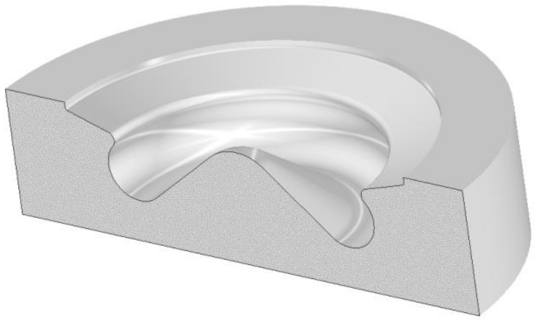
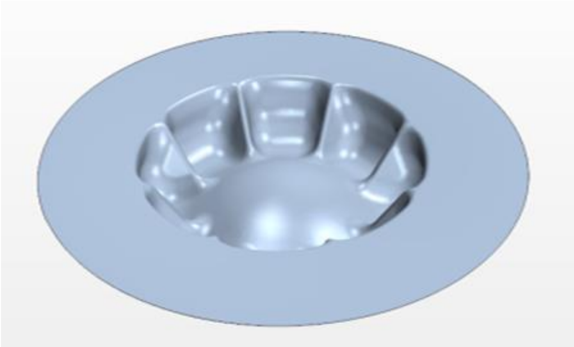
Innovative piston bowl

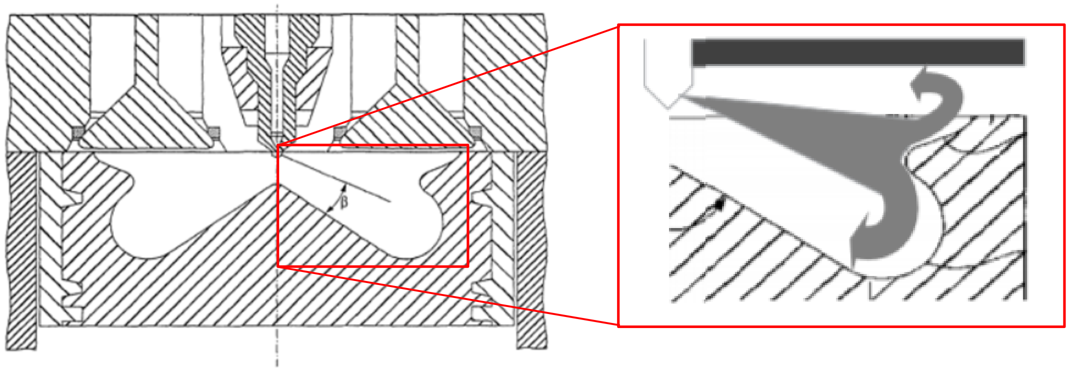


Are there synergies?

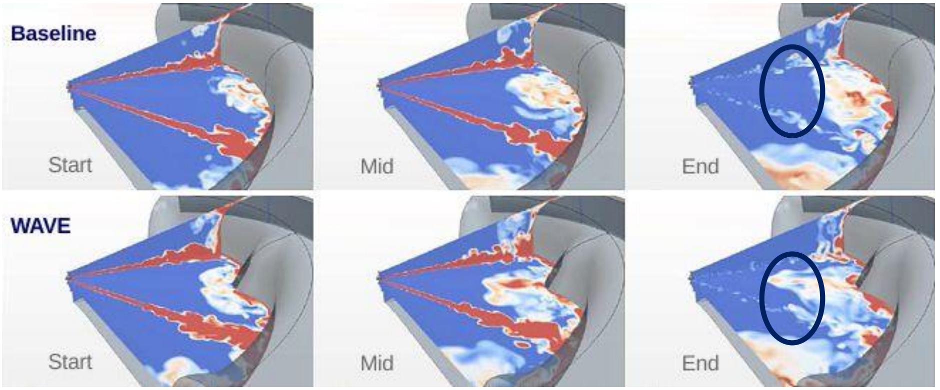


TV bowl

RB bowl



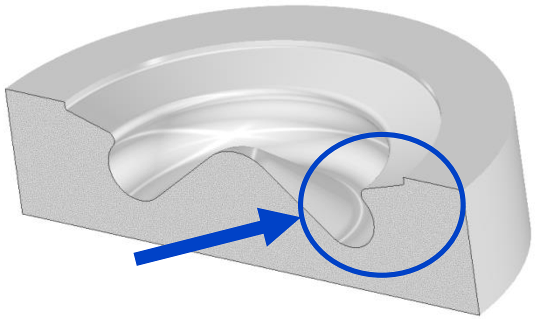
[1-2]



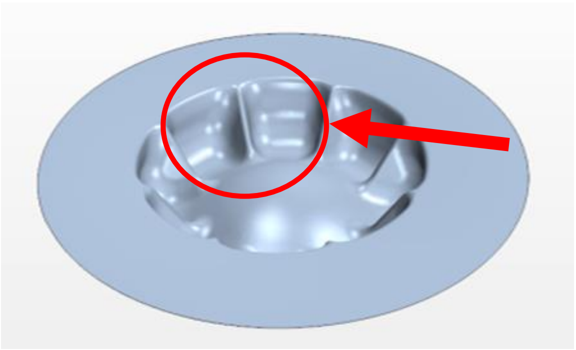
[3]

[1] https://www.dieselnet.com/tech/engine_combustion.php (28/09/2017)
[2] http://www.sae-na.it/images/download/ws2016/09%20-%20Andrea%20Trevisan%20_%20SAE-NA%20%20Aftertreatment%20system%20for%20Diesel%20Engines%2027_28%20June%2716.pdf (28/09/2017)
[3] https://www.dieselnet.com/tech/engine_combustion.php (01/10/2017)

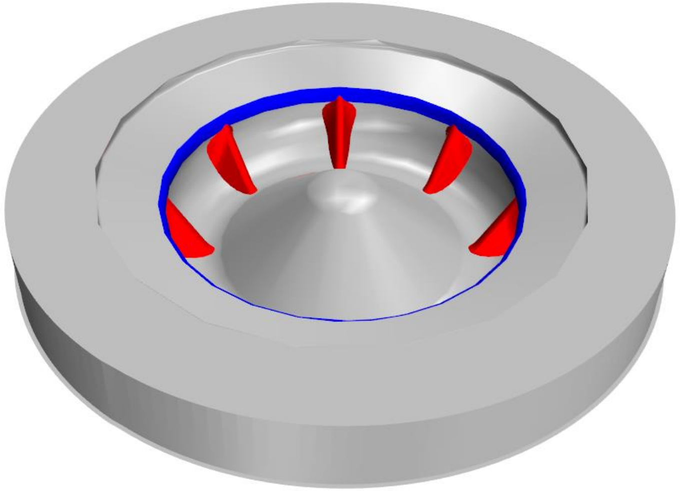
Innovative piston bowl



TV bowl



RB bowl



Hybrid Bowl proposal (bore, squish height = baseline)

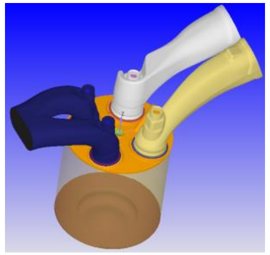
Investigate performance sensitivity to engine parameters

Innovative piston bowl

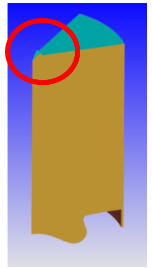
Engine parameters variation

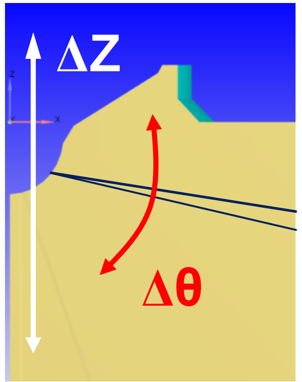
- Hardware parameters:
  - Swirl ratio
  - Compression ratio (piston shape – constant squish height)
  - Spray targeting (**<u>injector protrusion ΔZ</u>**, injector axis angle Δθ)
  - **<u>Number of injector holes</u>**

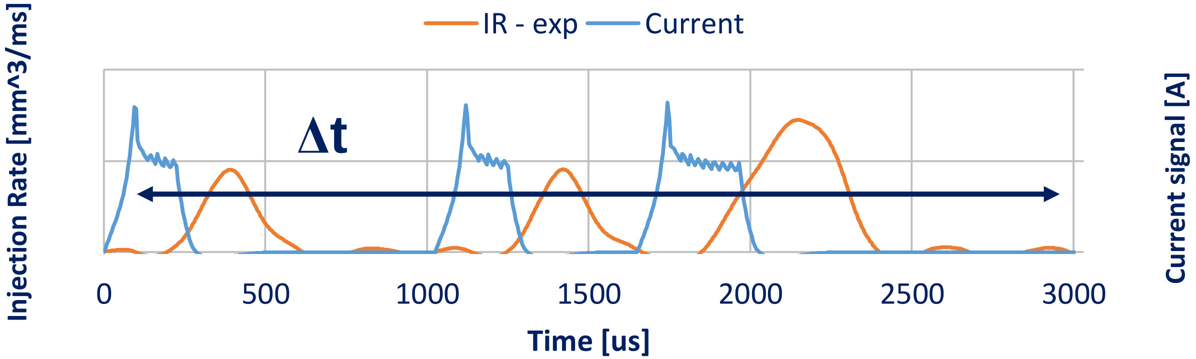
- Calibration parameters:
  - Spray targeting (SOI timing Δt)
  - Injection pressure
  - **<u>EGR rate</u>**



Mapping @IVC







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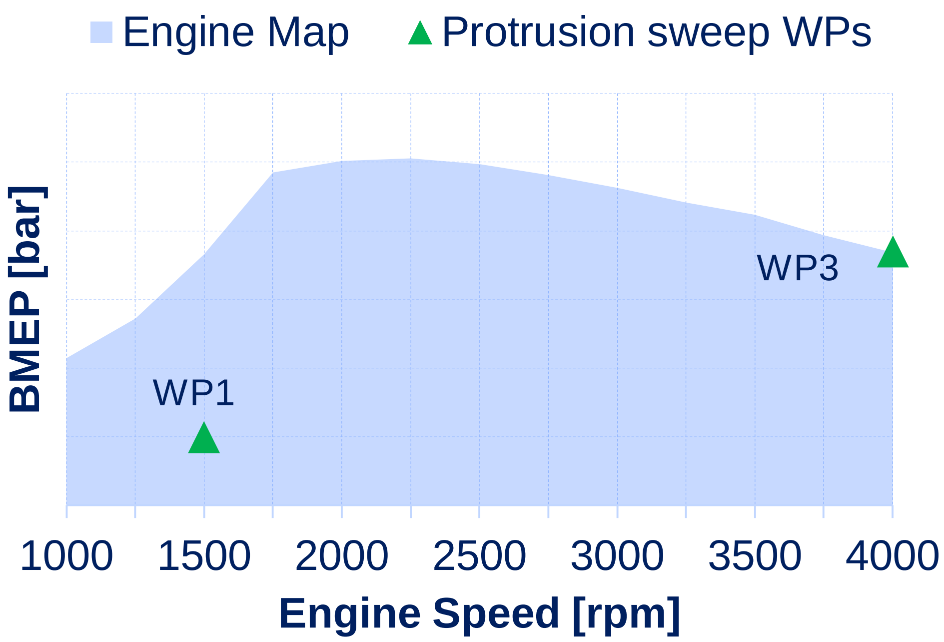
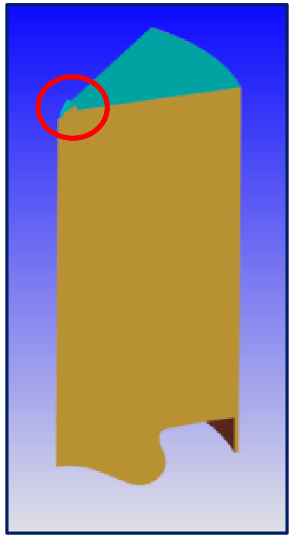
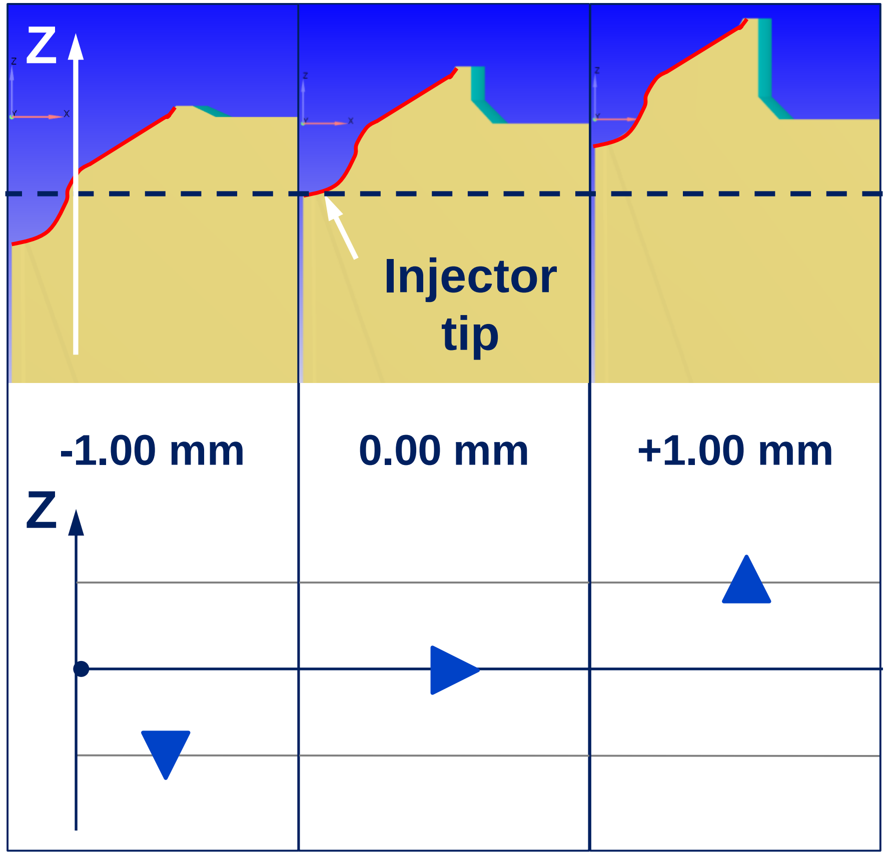
Innovative piston bowl: Optimization of spray targeting

Optimization of injector protrusion (ΔZ)





Injector tip protrusion test matrix

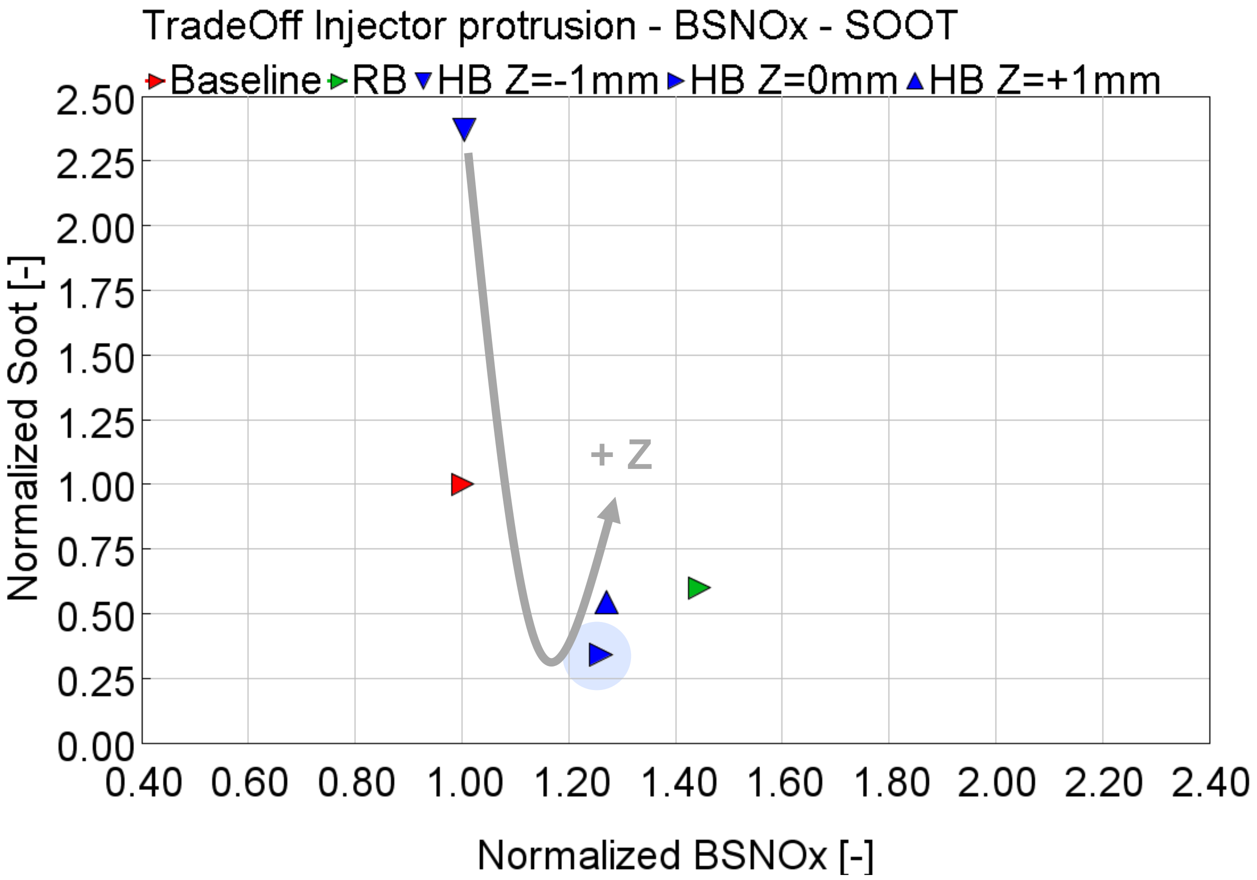


Assumptions:

- Negligible differences in in-cylinder flowfield @IVC
- Baseline EGR%
- Constant injected fuel mass (same inj. rate, SOI, etc.) and number of injector holes

Innovative piston bowl: Optimization of spray targeting

Simulation results – WP1 – combustion



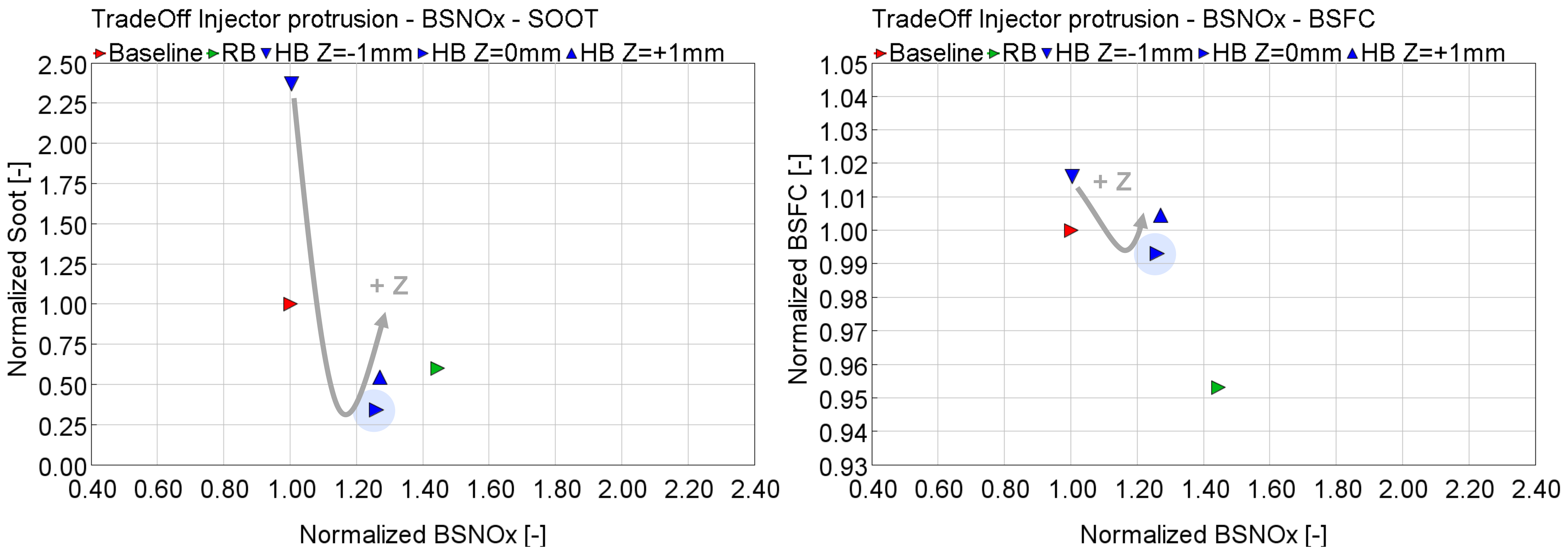
- HB bowl:

- Results show high sensitivity of SOOT to injector protrusion

- Baseline injector protrusion shows the best results:
  - the lowest SOOT emissions among the different designs (-70% vs baseline)
  - BSNOx between baseline bowl and RB bowl

Innovative piston bowl: Optimization of spray targeting

Simulation results – WP1 – combustion



- HB bowl w/ protrusion Z = 0 mm shows BSFC aligned with baseline

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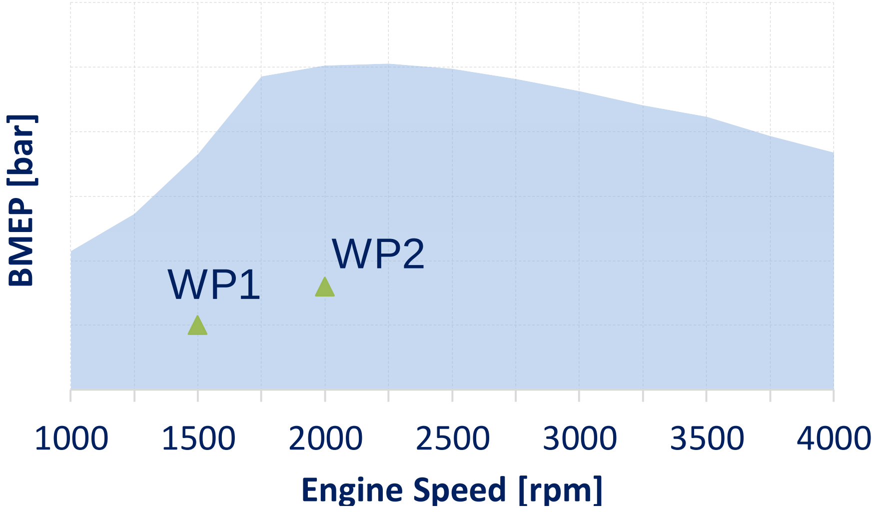
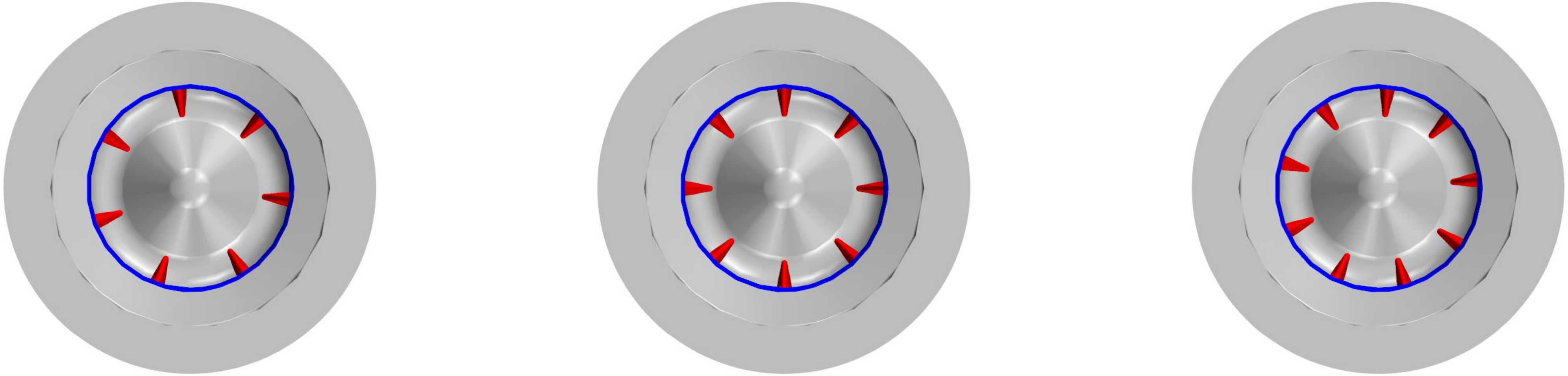
Innovative piston bowl: Optimization of numbers of holes and EGR rate

Simulation procedure

- **3 injector configuration** evaluated:
- **7 holes (7H)**
- **8 holes (8H) (= baseline bowl)**
- **9 holes (9H)**



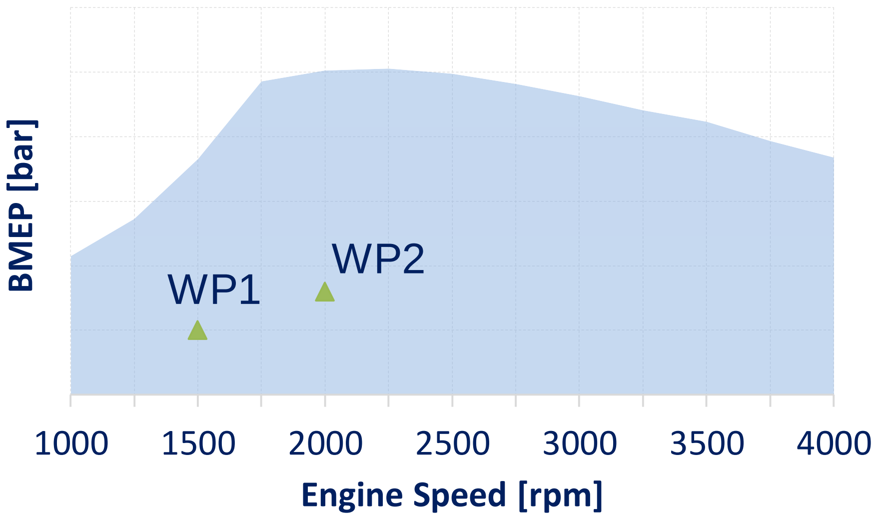


7 holes 8 holes 9 holes

Innovative piston bowl: Optimization of numbers of holes and EGR rate

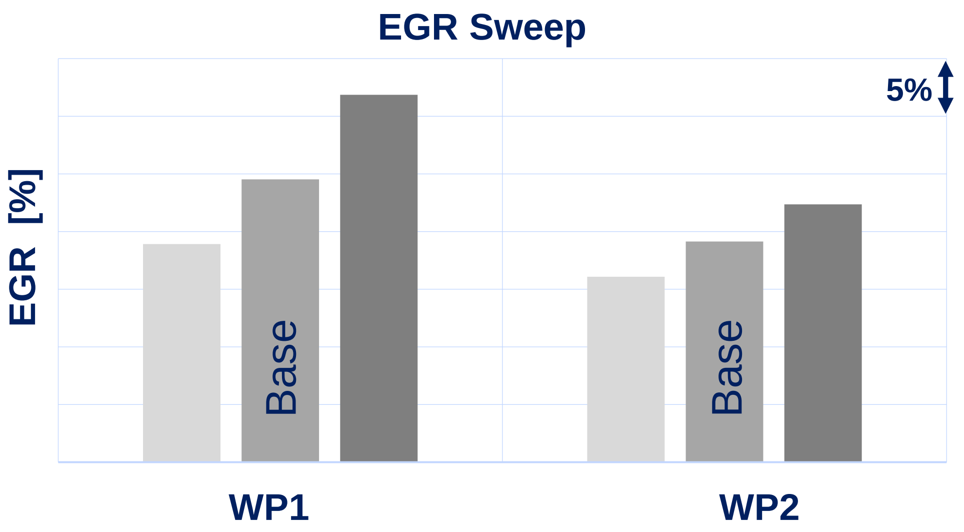
Simulation procedure

- **3 injector configuration** evaluated:
  - **7 holes (7H)**
  - **8 holes (8H) (= baseline bowl)**
  - **9 holes (9H)**
- **EGR Sweep** (3 levels) carried out on **WP1** and **WP2** for each injector configuration



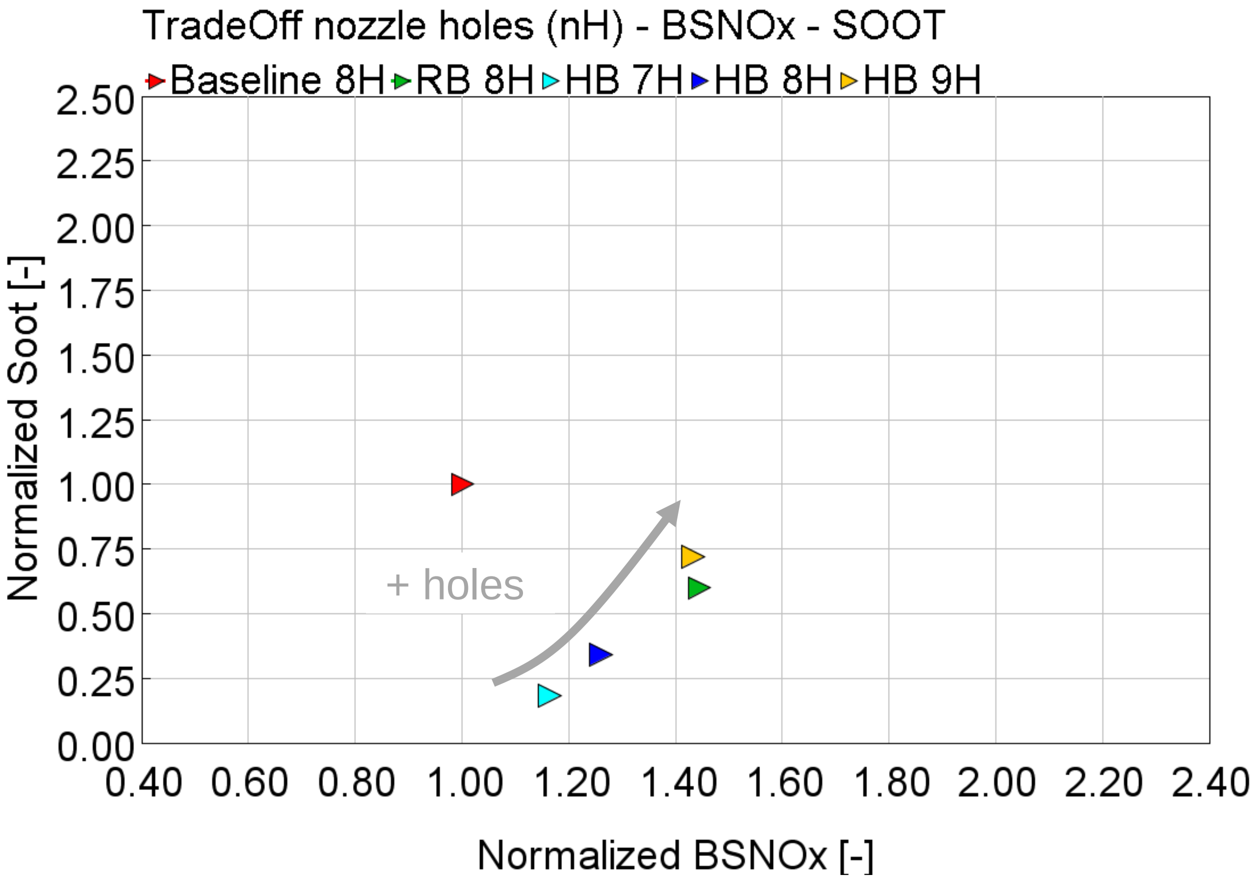
Assumptions:

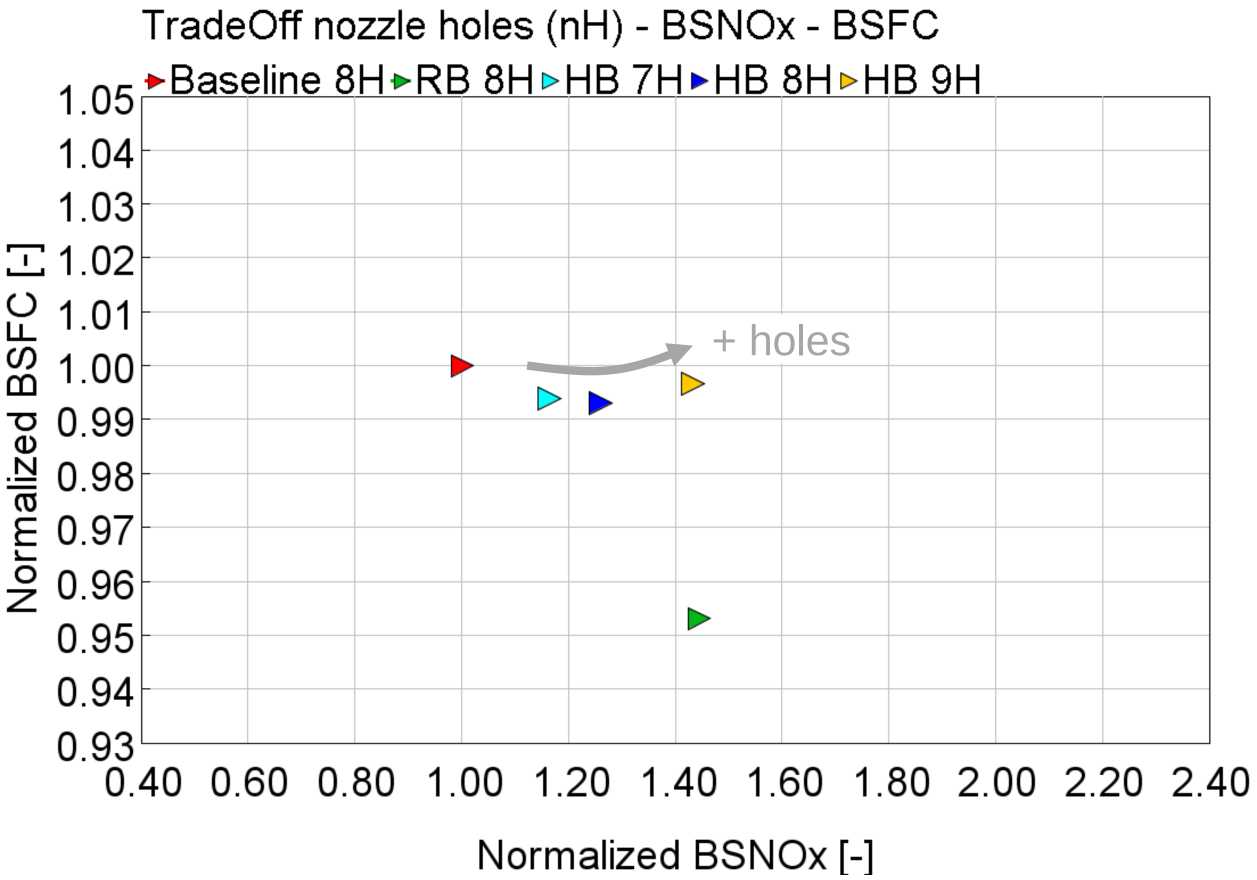
- Constant volumetric efficiency, **EGR varied through mapping**
- **Constant injected fuel mass** (same inj. rate, SOI, etc.)
- **FMEP** evaluated by means of **calibrated 1D model** to account for the maximum pressure differences



Innovative piston bowl: Optimization of numbers of holes and EGR rate

Simulation results – WP1 – combustion – investigation on number of injector holes

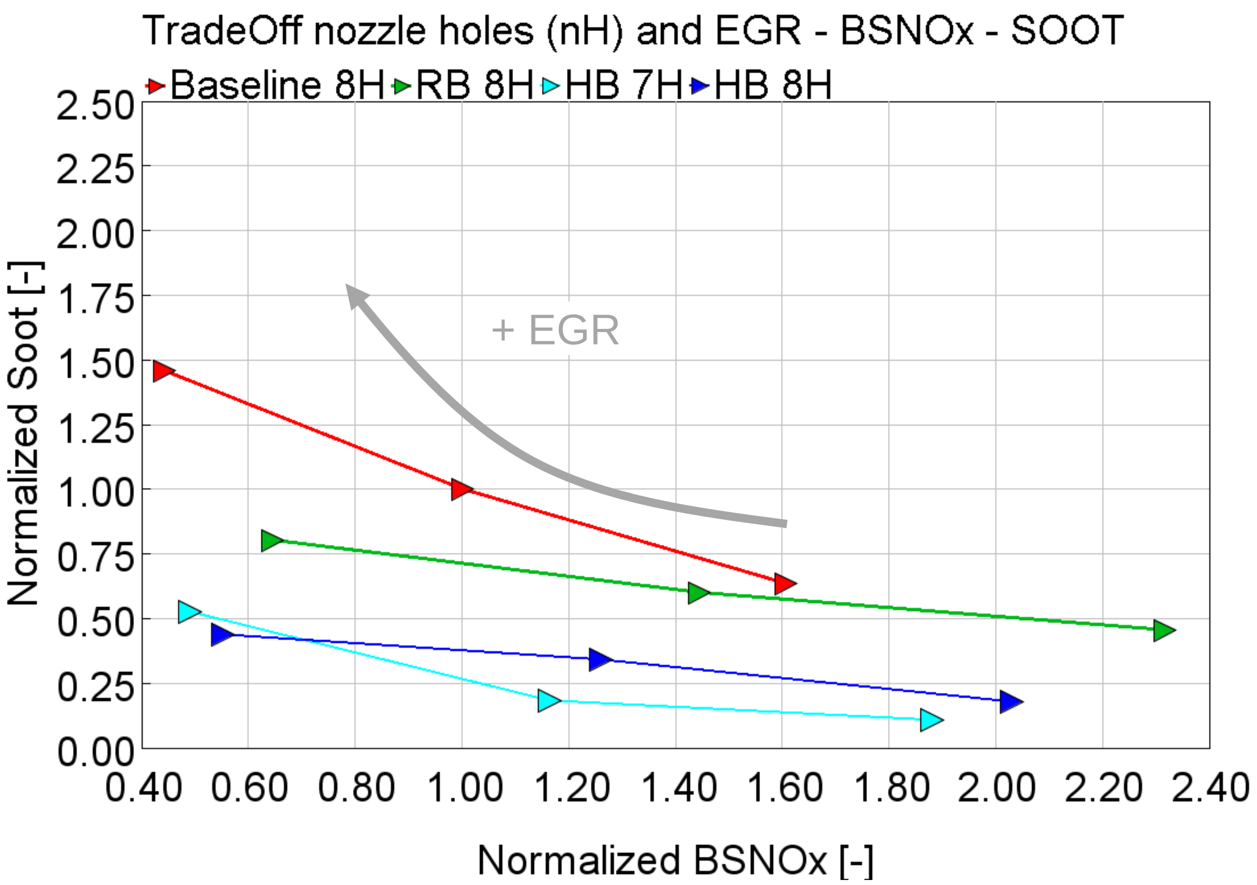


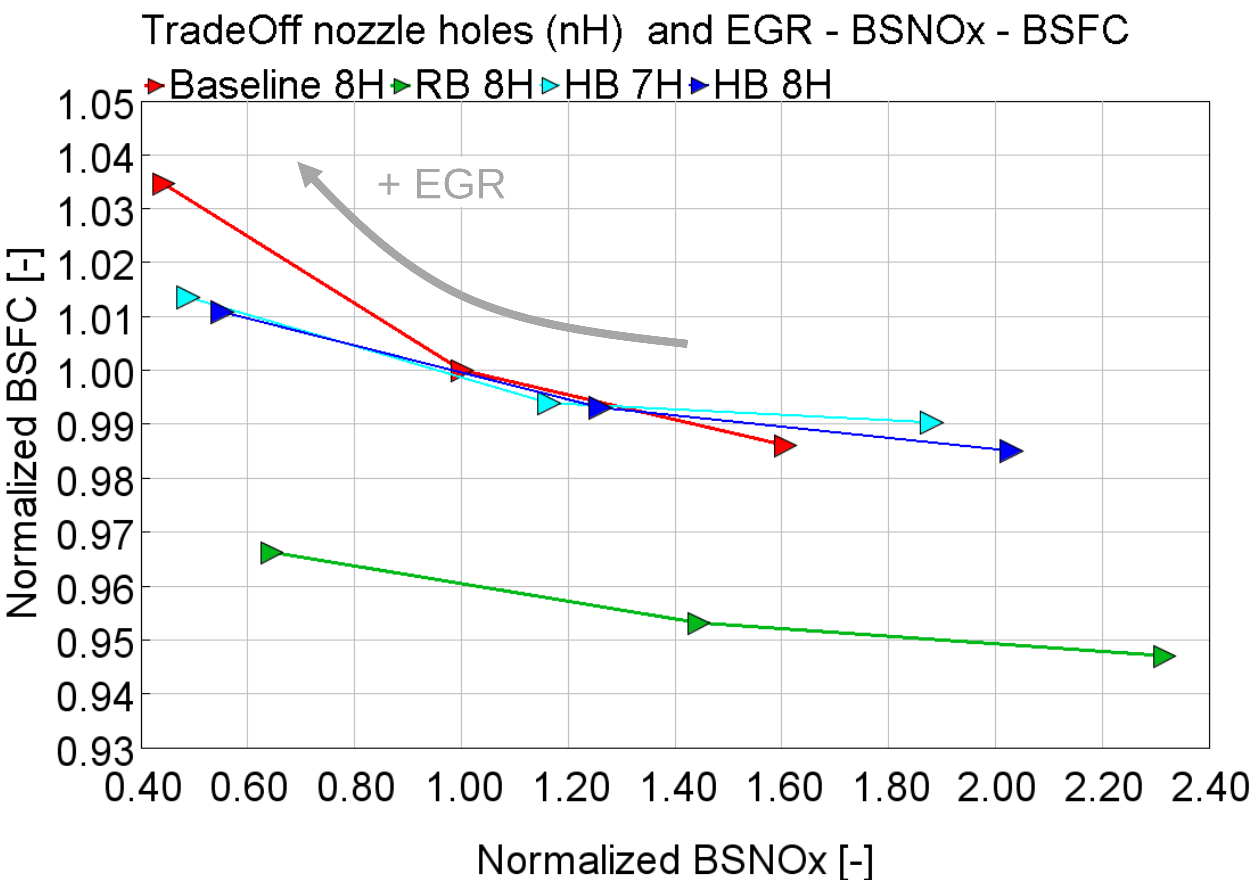


- Configuration w/ 7 and 8 holes are the most promising in terms of SOOT
- Negligible differences in BSFC

Innovative piston bowl: Optimization of numbers of holes and EGR rate

Simulation results – WP1 – combustion – investigation on number of injector holes + EGR

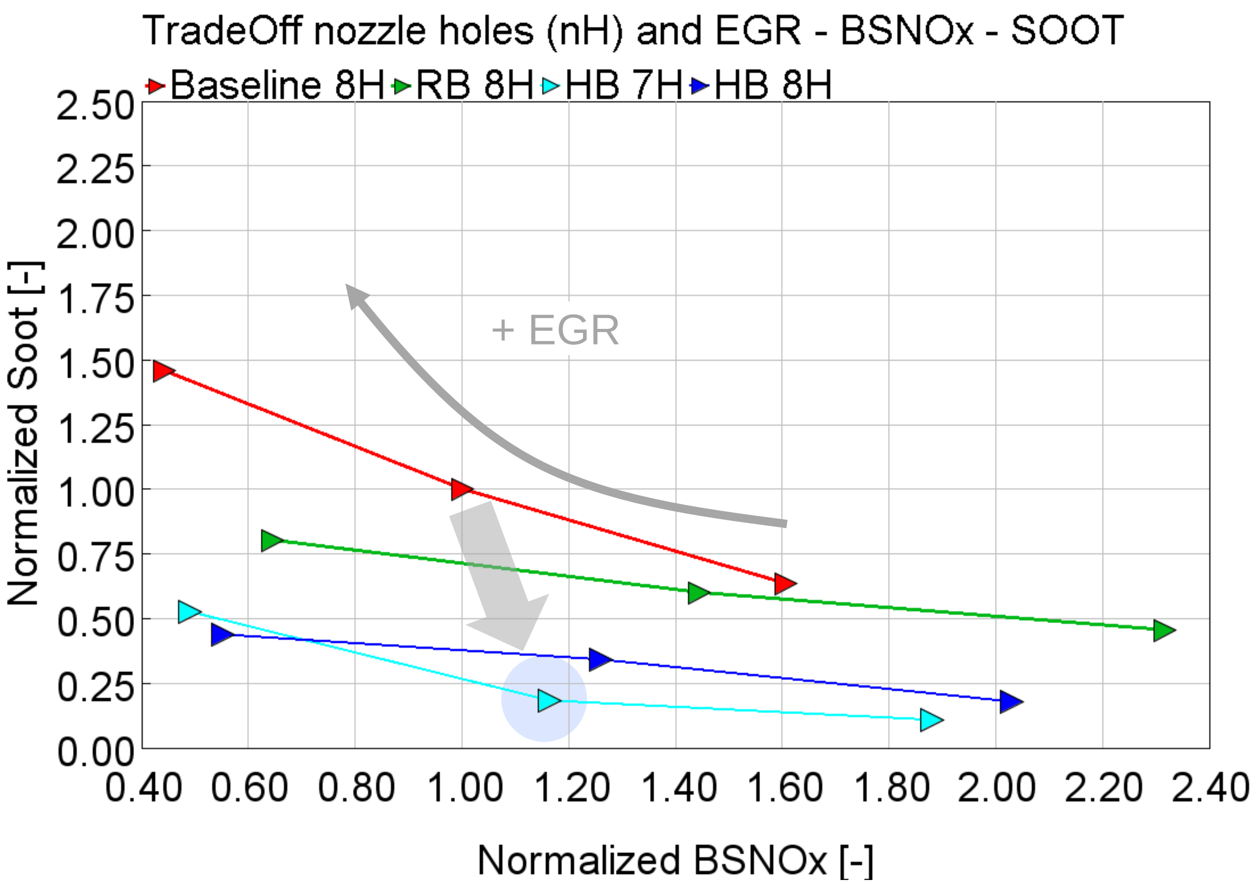


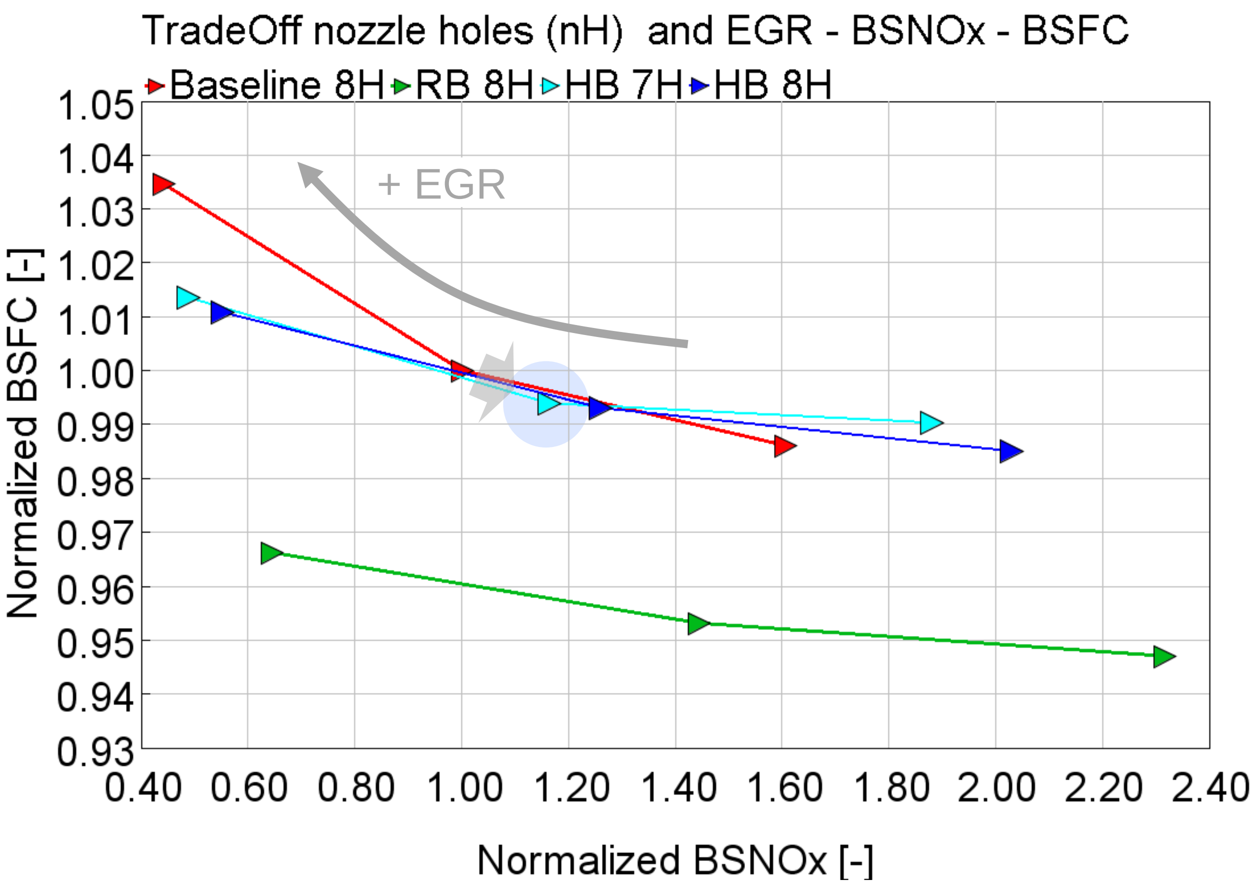


- Configuration w/ 7 holes show the lowest SOOT emission (-75% vs baseline)
- RB bowl has still the lowest BSFC (-4% vs baseline)

Innovative piston bowl: Optimization of numbers of holes and EGR rate

Simulation results – WP1 – combustion – investigation on number of injector holes + EGR





- Configuration w/ 7 holes show the lowest SOOT emission (-75% vs baseline)
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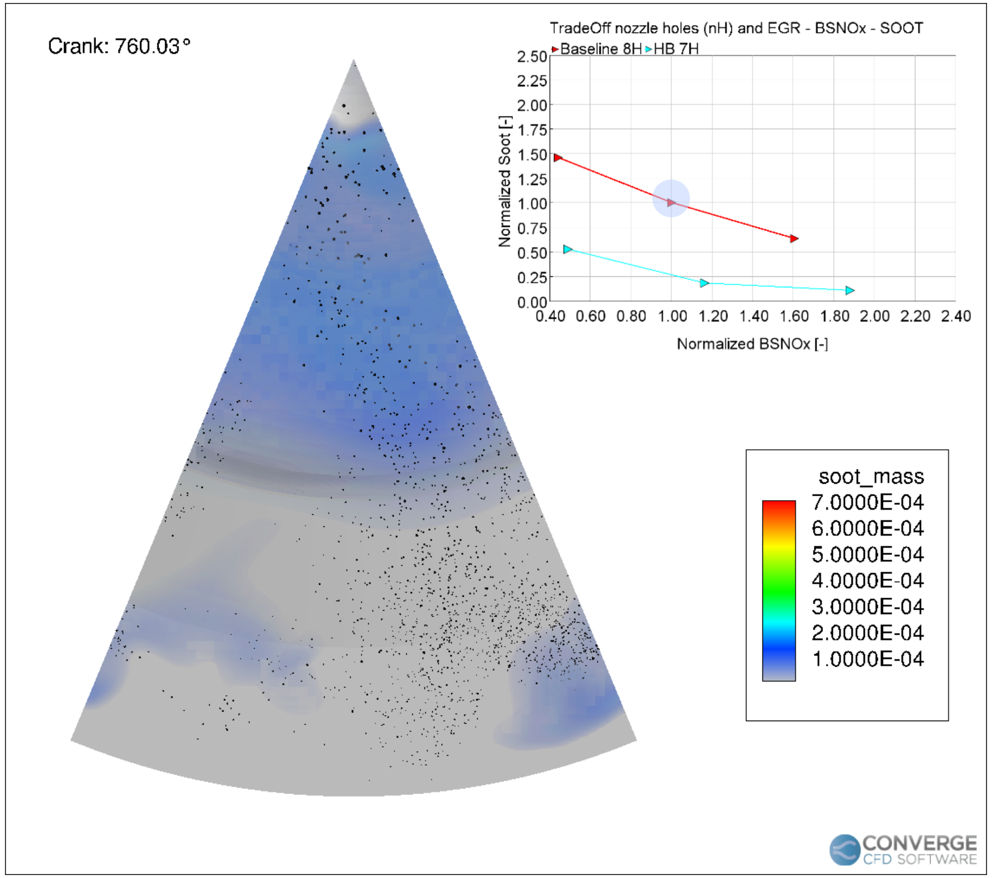
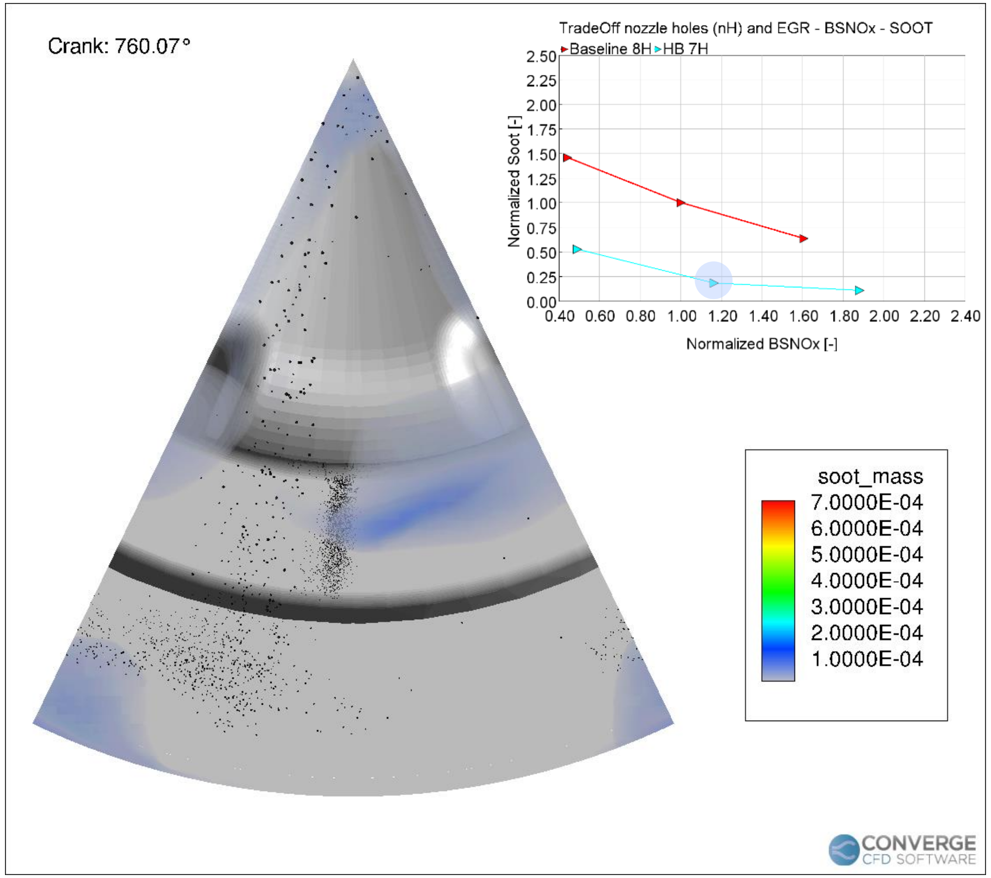
Innovative piston bowl: Optimization of numbers of holes and EGR rate

Simulation results – WP1 – combustion

Baseline – base EGR



HB – 7H – base EGR



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- An **innovative piston bowl** (hybrid bowl) **was created,** sharing design features of TV and RB bowls

- The **hybrid bowl** shows the **best trade-off for pollutant emissions** (-75% SOOT w/ baseline NO_x emission), while **fuel consumption is comparable** to the **baseline bowl**. **Trend is confirmed on other engine WPs**

- It is **possible** to **further reduce Diesel engines** in-cylinder **emissions**, and **3D-CFD predictive combustion** simulations could **help** in investigating and developing **innovative bowl designs**

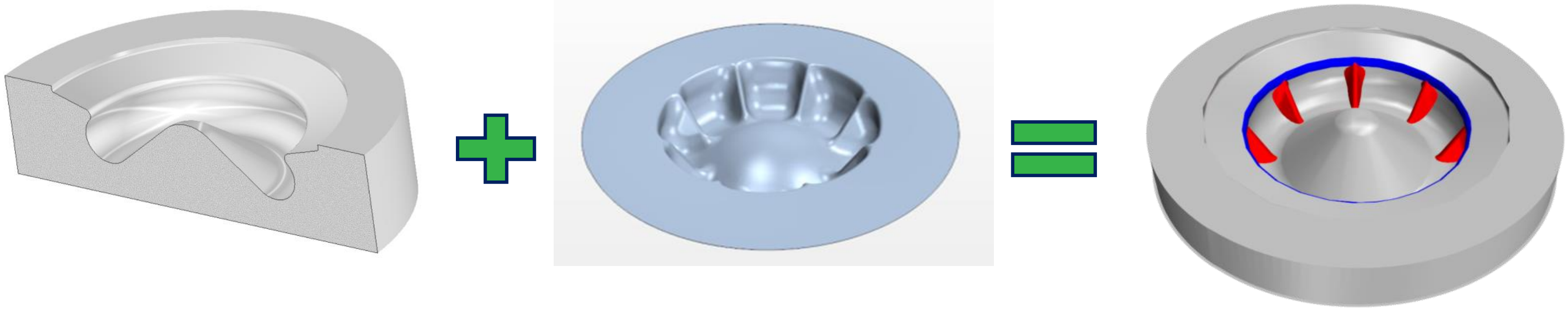
Future work

- **Further investigation and optimization** of bowl designs

- Experimental tests on selected configurations

Conclusions

Conclusions



	TV bowl	RB bowl	HB bowl
SOOT	-25%	-30%	-75%
BSFC	~0%	-4%	~0%

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Special thanks to

CONVERGENT SCIENCE

team for their support

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