The Flex-Gen project

FPLG >50% efficiency with HCCI combustion and alternative fuels

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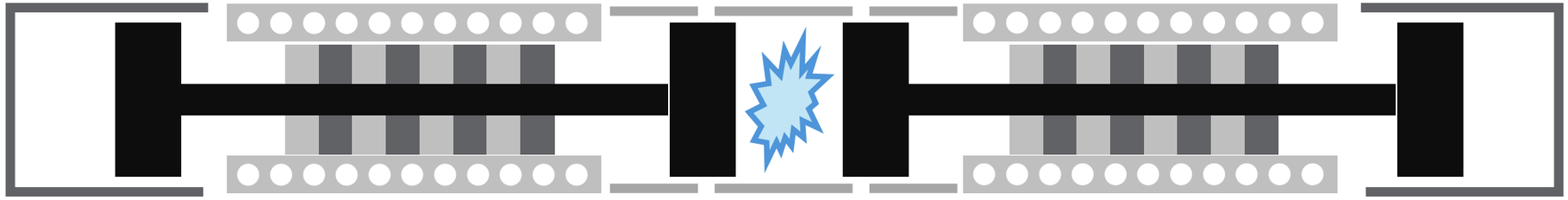


Acknowledgments

- Giovanni Gaetano Gianetti
- Nicola Morandi
- Matteo Ferrarini

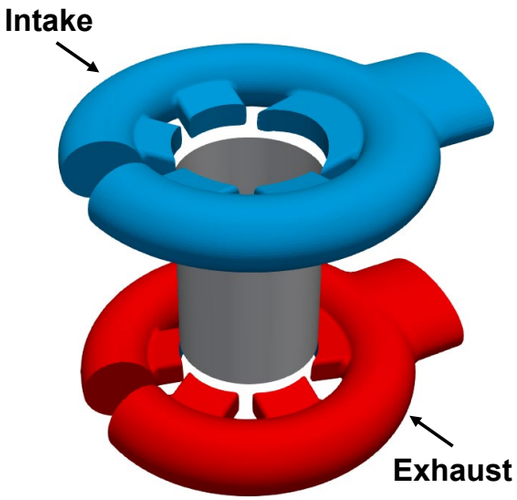
Topics

- Assessment of a multi-fuel, high-efficiency FPLG for power generation
- Opposed piston configuration
- Fuels: (bio)methane and H_2
- Low temperature combustion (HCCI)

Polimi Flex-Gen activities

CFD study of gas exchange and combustion in FPLG geometries

SI-FPLG: mobility



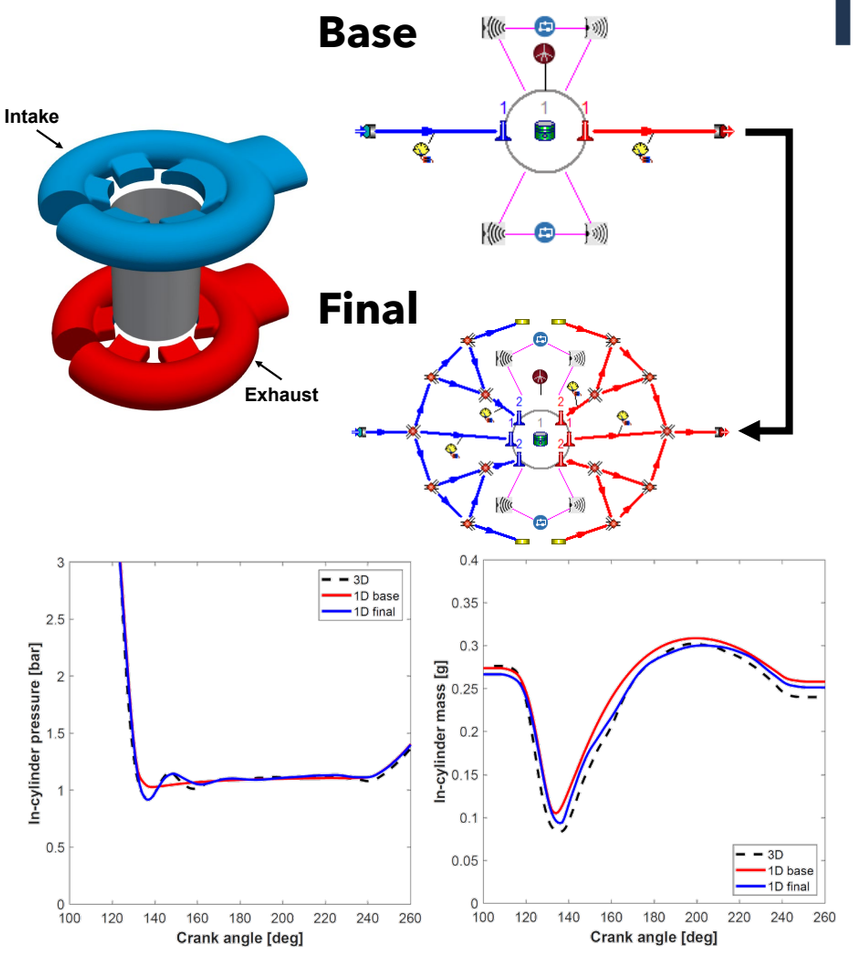
Target: 10-20 kW
SI stoichiometric combustion with tumble flow
Low-Pressure direct-injection
Bore: 56.5 mm
Stroke: 49 mm
Compression ratio: 12

HCCI-FPLG: power generation

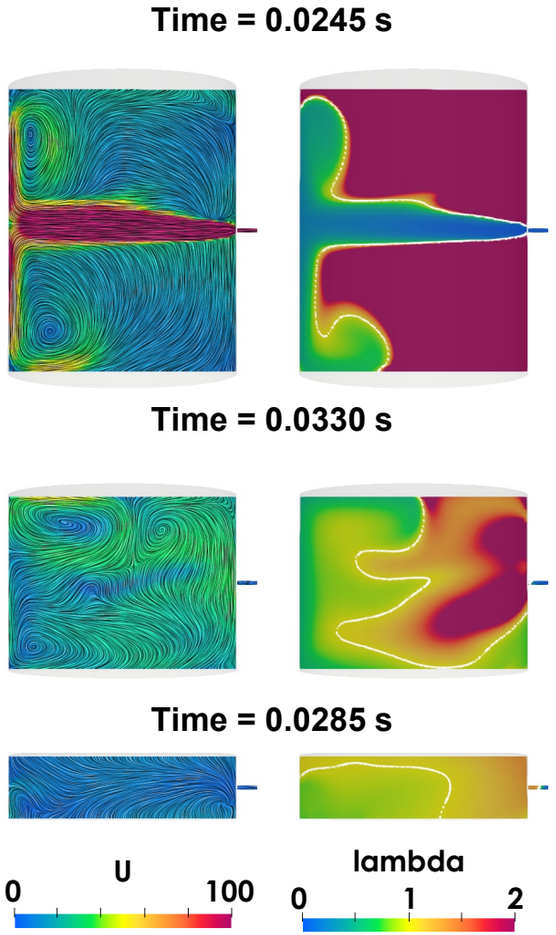
Target: 40-60 kW
HCCI ultra-lean combustion
Port-fuel injection (gas from the grid)
Bore: 80 mm
Stroke: 450 mm
Extreme compression ratio

SI-FPLG

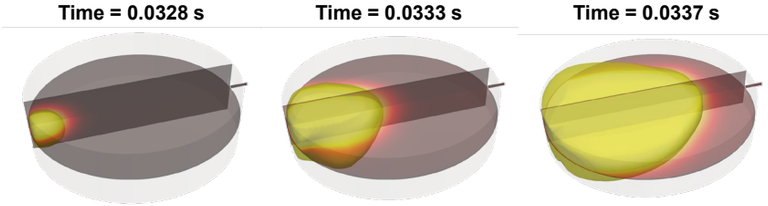
1D realistic schematic definition with CFD simulation results



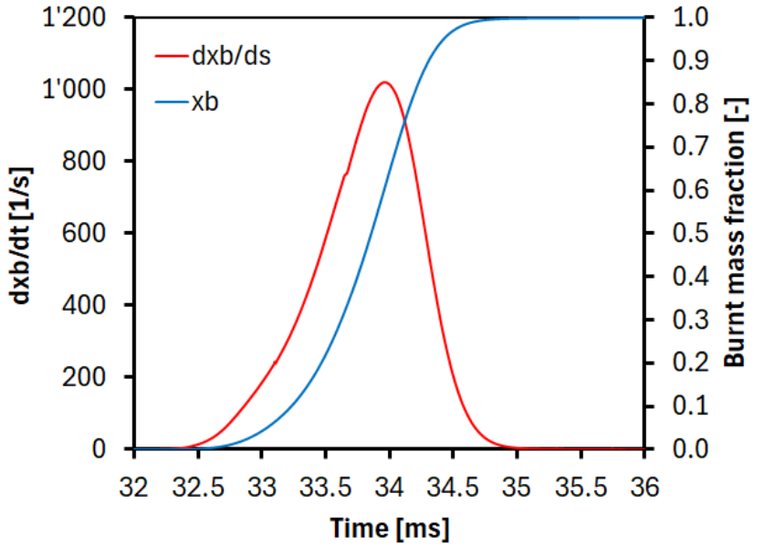
Understanding charge motions and fuel-air mixing



Combustion simulations



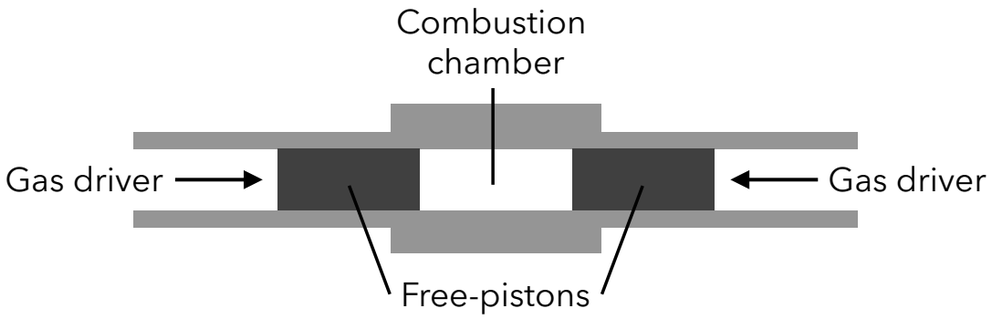
CFD computed burned mass fraction unconventional profile used in 1D simulations



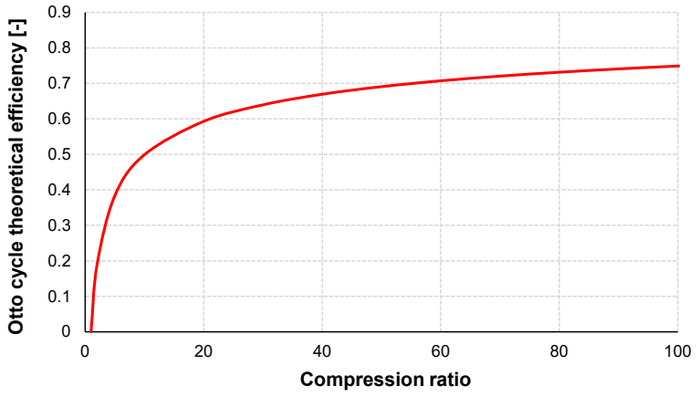
How to maximize the efficiency of an IC engine?

Svreck (2011) *Exploration of Combustion Strategies for High-Efficiency, Extreme Compression Engines*

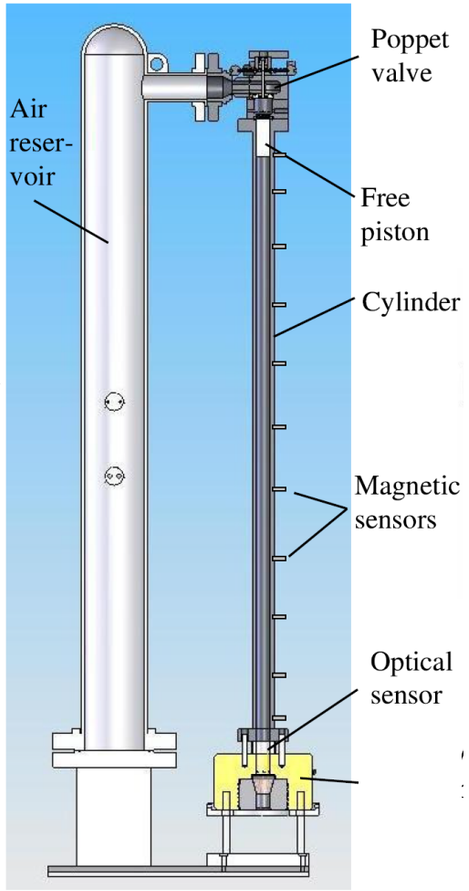
Opposed free-piston configuration



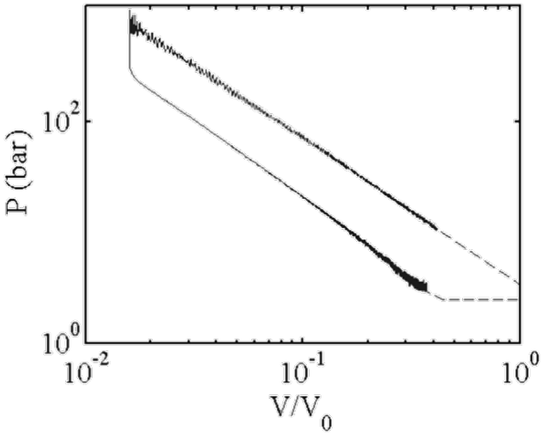
HCCI combustion with extreme compression ratio (>50)



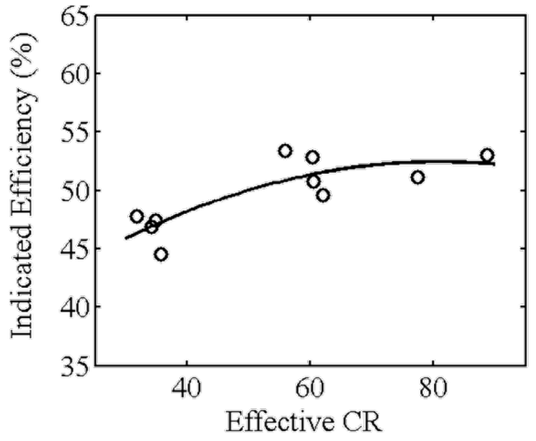
Rapid compression machine (RCM)



Extrapolated cycle from experiment

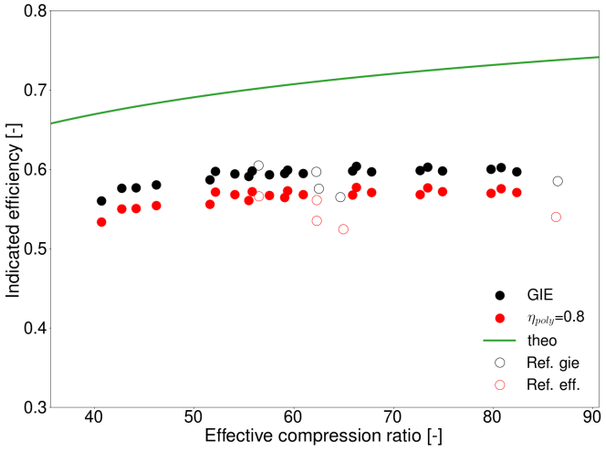


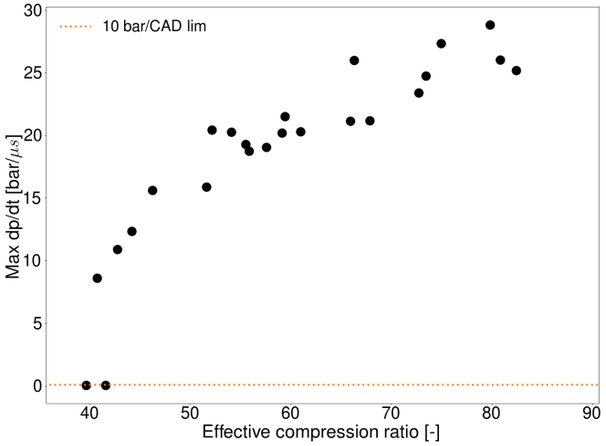
Measured indicated efficiency (CH_4, $\phi = 1$)



CFD simulations: from RCM to CH_4-FPLG

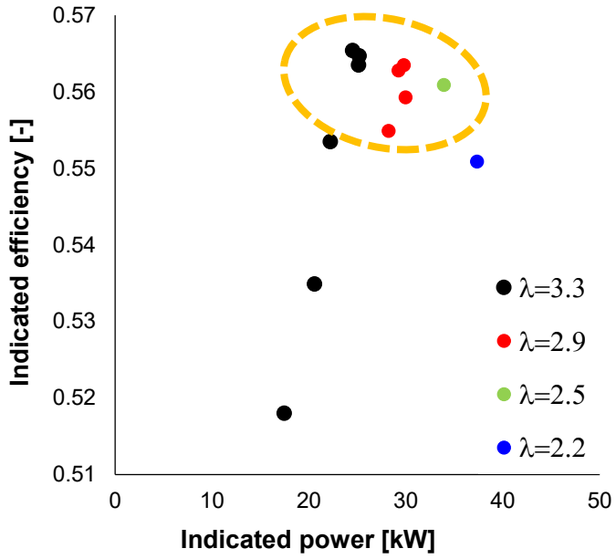
RCM Experiment CFD validation (CH_4, $\lambda = 1$)





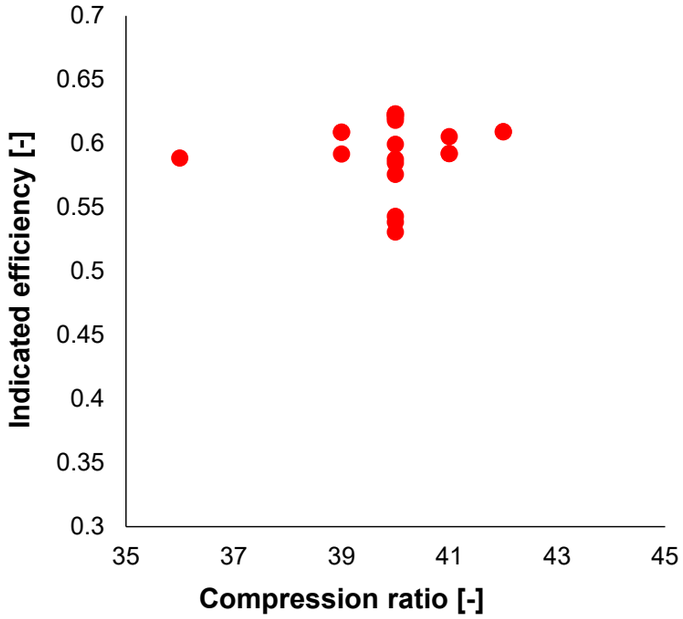
RCM Simulations (CH_4,lean)

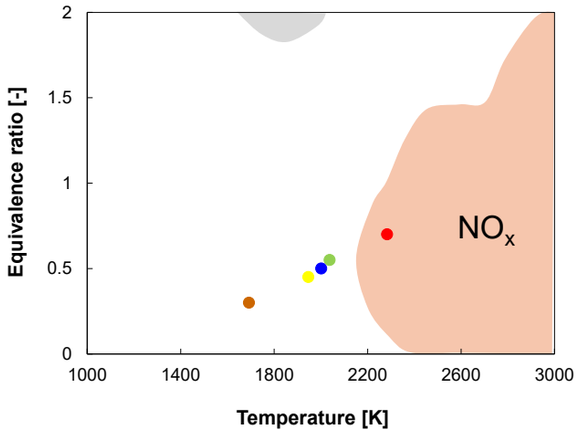
- Original RCM geometry
- Max dp/dt limited to ~10 MPa/ms to avoid knock
- Bore = 50 mm
- Stroke = 1700 mm

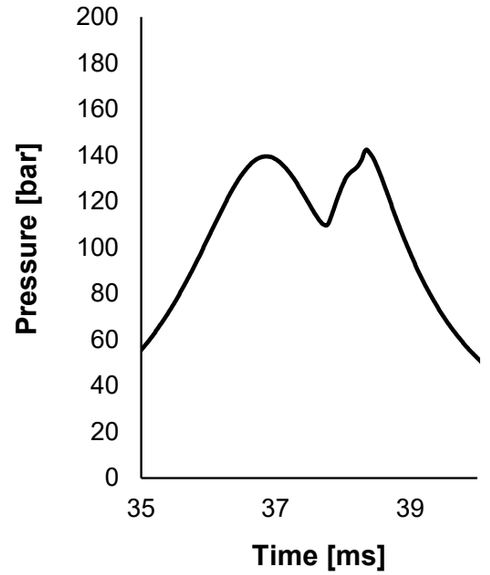


RCM *engine-like* geometry (CH_4,lean)

- Bore = 80 mm
- Stroke = 400-600 mm
- Variable pressure in the gas spring
- Piston mass: 10 kg
- $\lambda = 1.5 - 3.3$



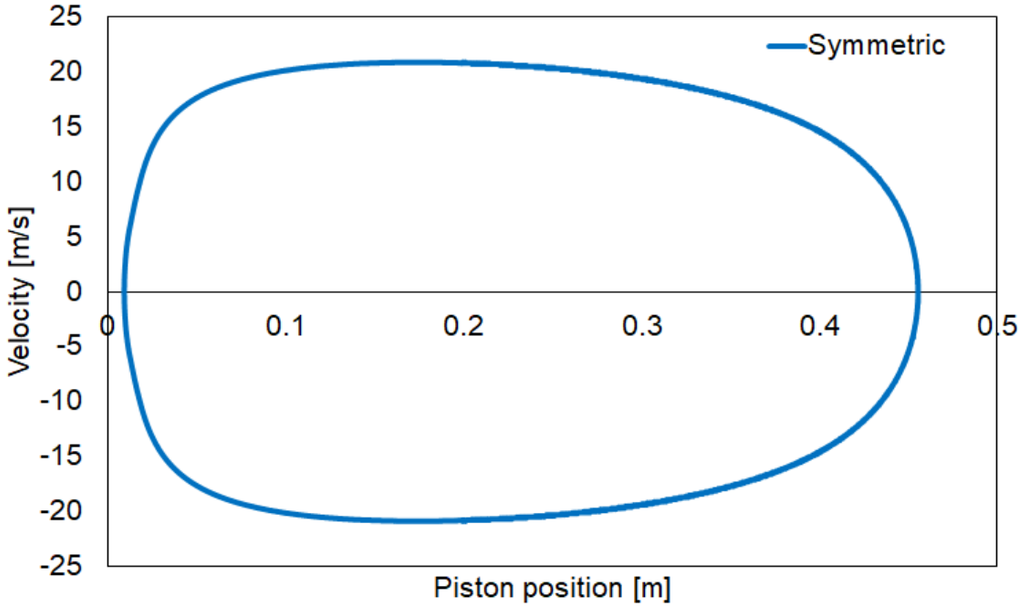


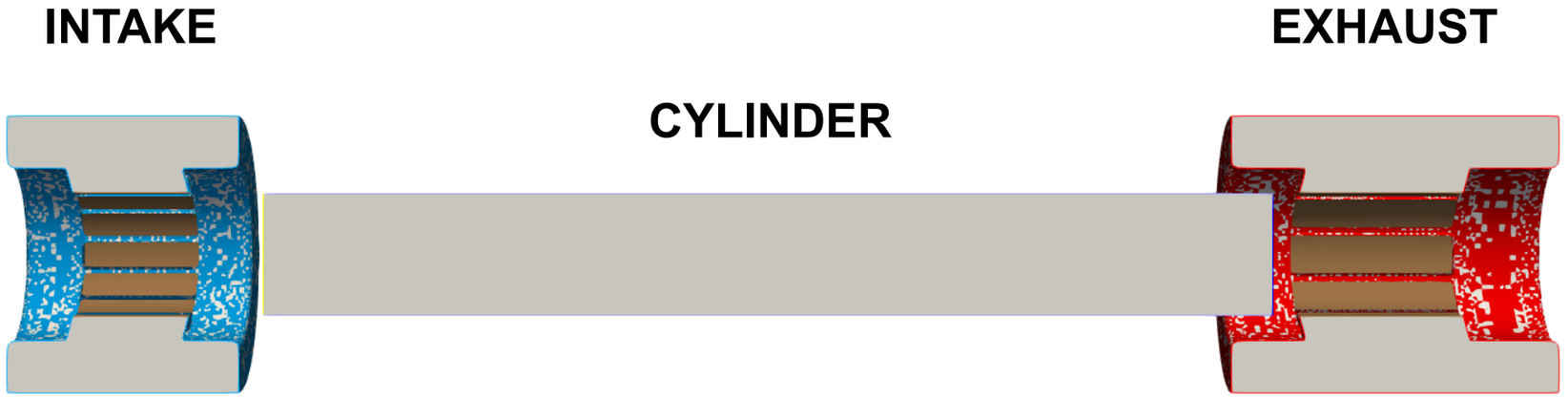


CH_4-FPLG CFD simulations: first geometry

First assessment of the FPLG:

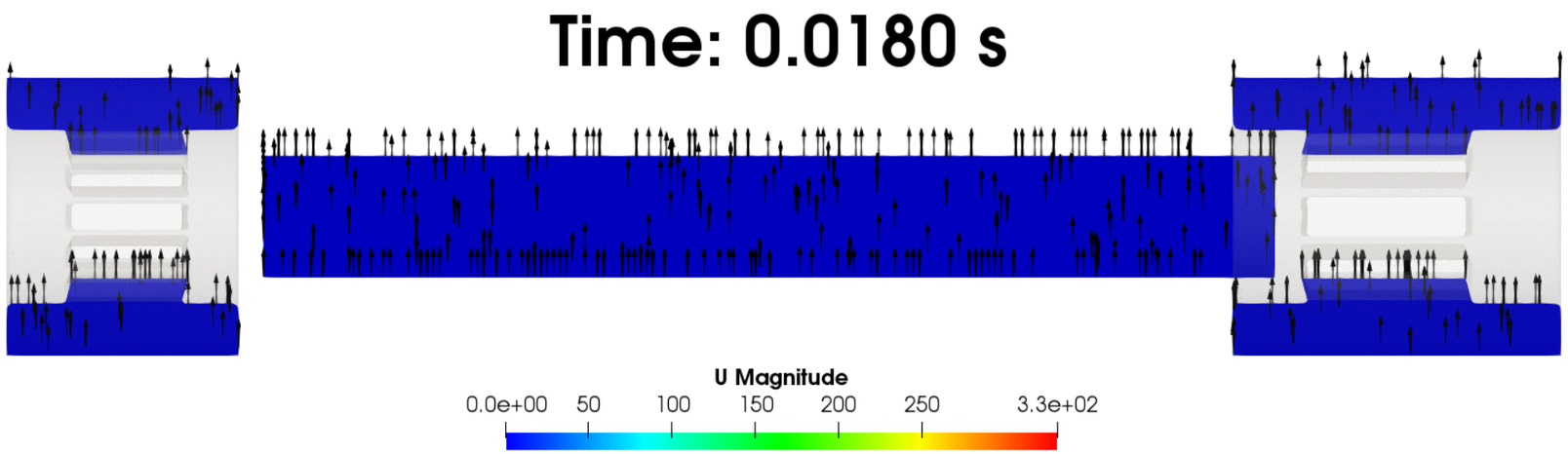
- Uniflow configuration
- 8 ports exhaust
- 12 ports intake
- Symmetric piston motion law profile obtained from RCM *engine-like* experiment



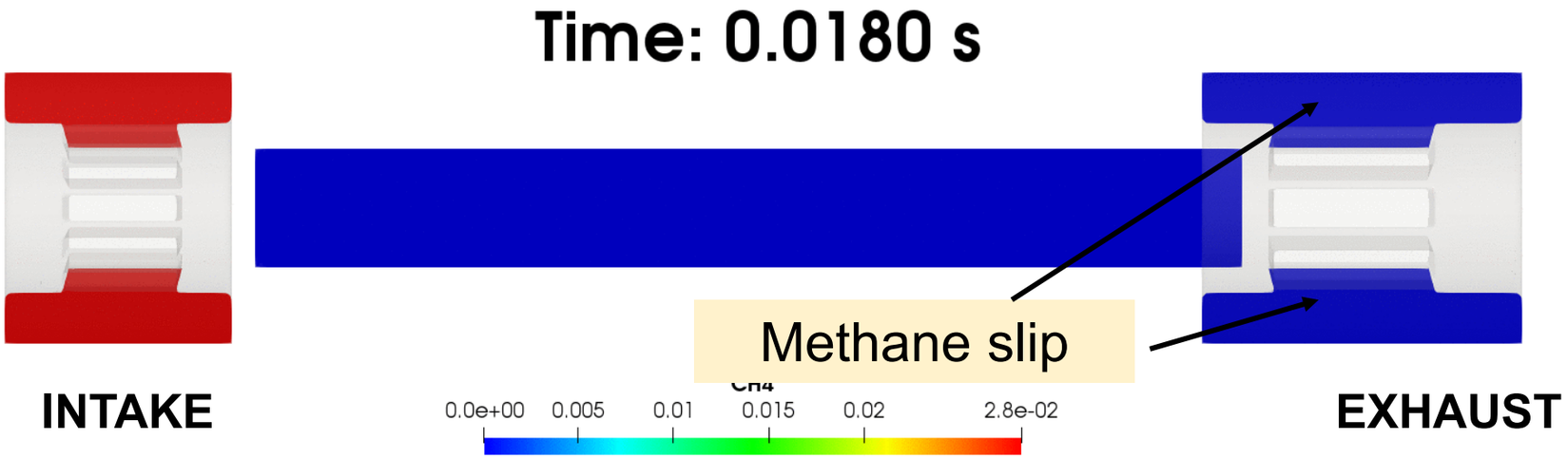


Engine data	
Bore	80 mm
Stroke	446 mm
Compression ratio	50

CH_4-FPLG CFD simulation results : gas exchange



Operating condition	
Frequency	16.5 Hz
Intake pressure	1.05 bar
Injection	Port fuel
Lambda	≈ 2



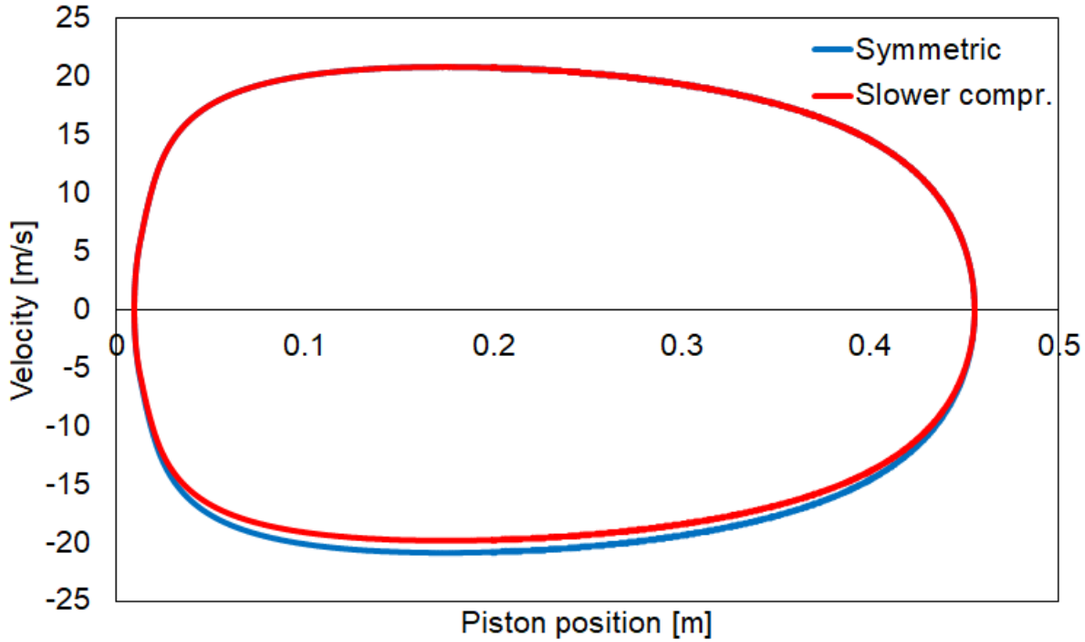
Methane slip:
>5000 ppm

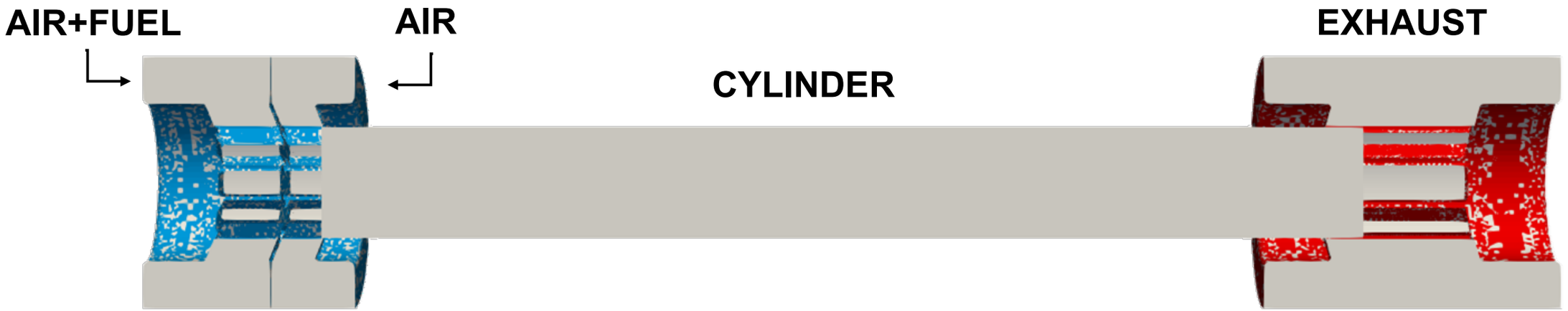
CH_4-FPLG CFD simulations: final geometry

Intake manifold divided into two regions to limit methane slip:

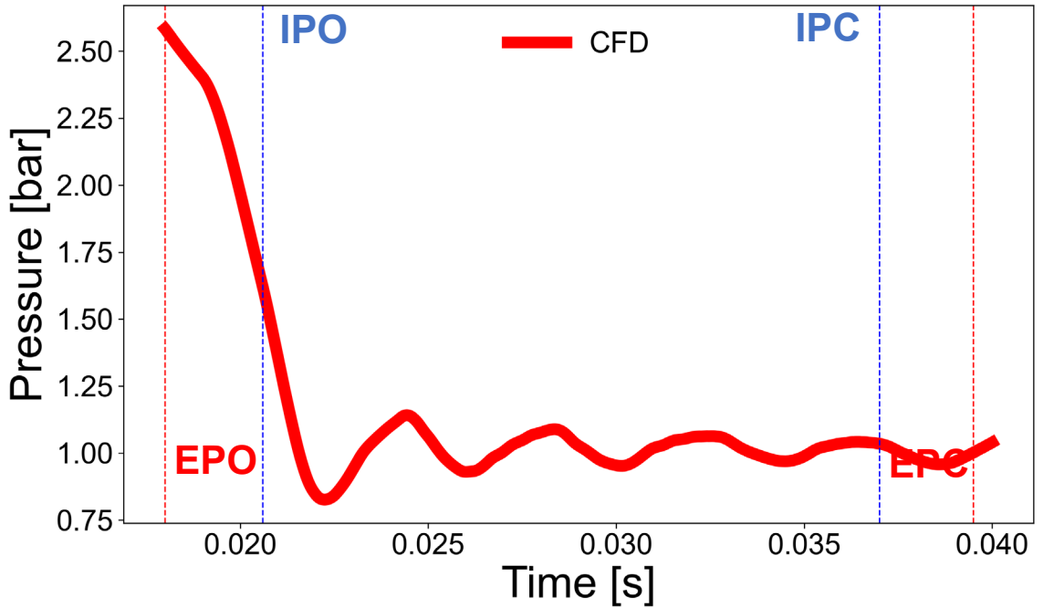
- First one that is open filled with air only
- Second one with air and fuel

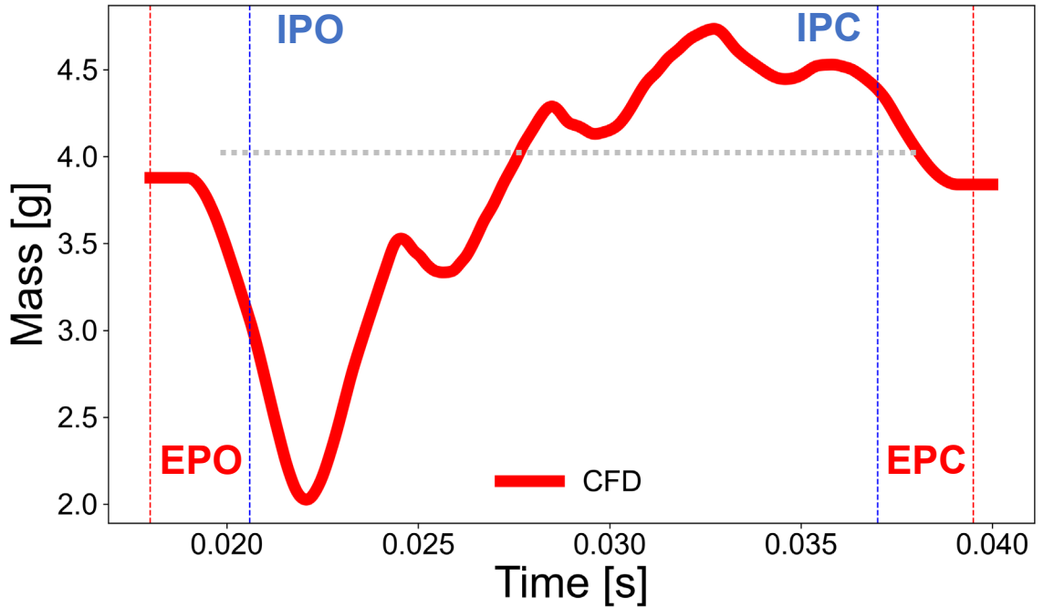
Compression stroke was slowed down by a 5% compared to expansion

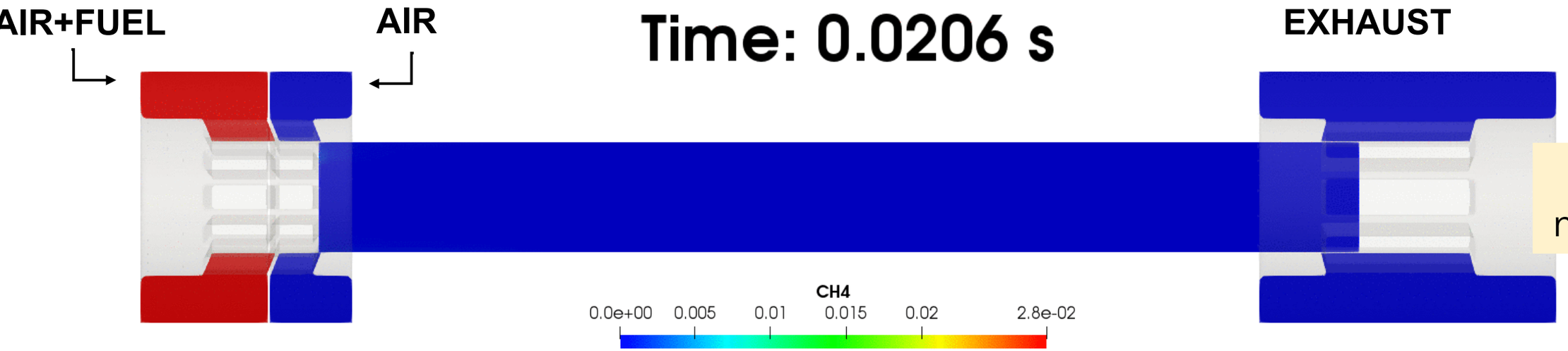




CH_4-FPLG CFD simulations: gas exchange

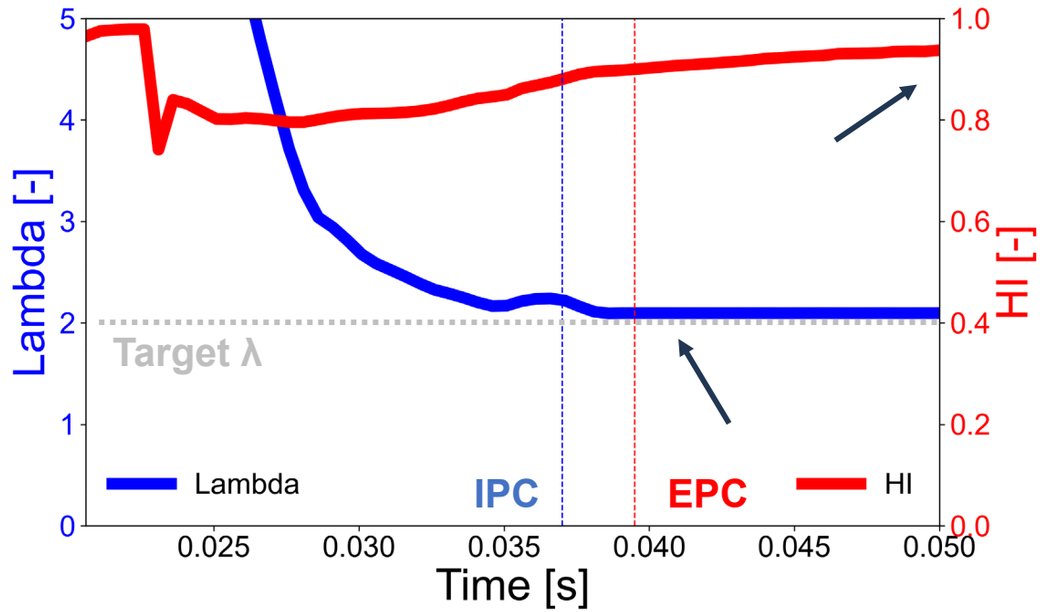






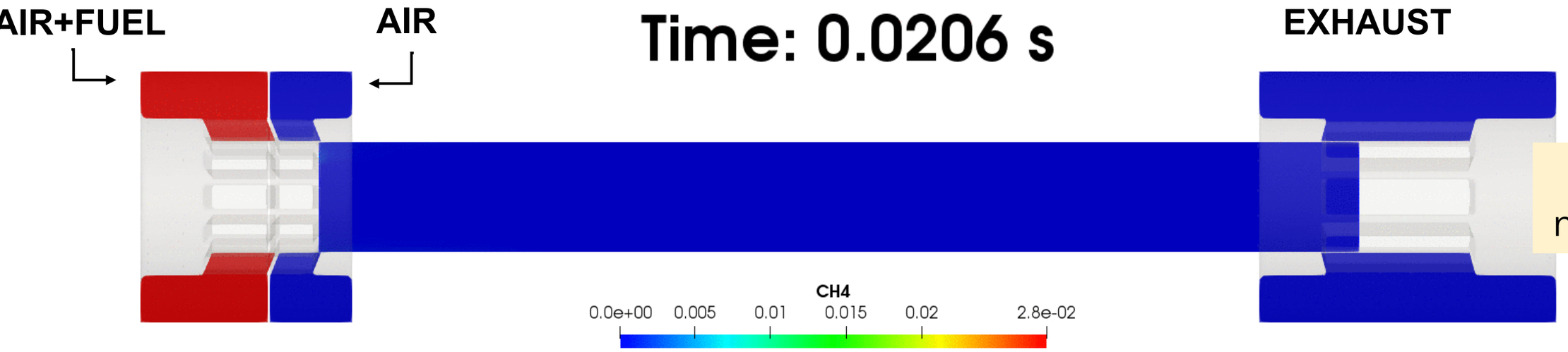
Reduced methane slip

CH_4-FPLG CFD simulations: gas exchange



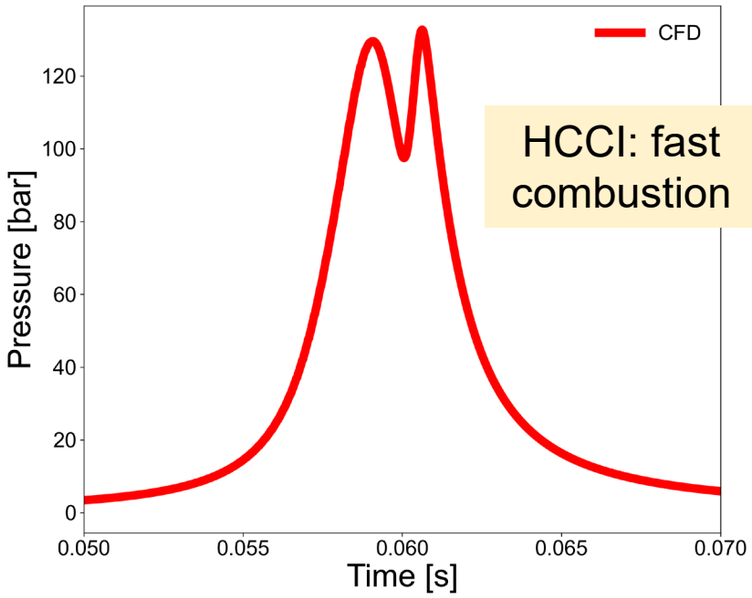
Main outputs after gas exchange:

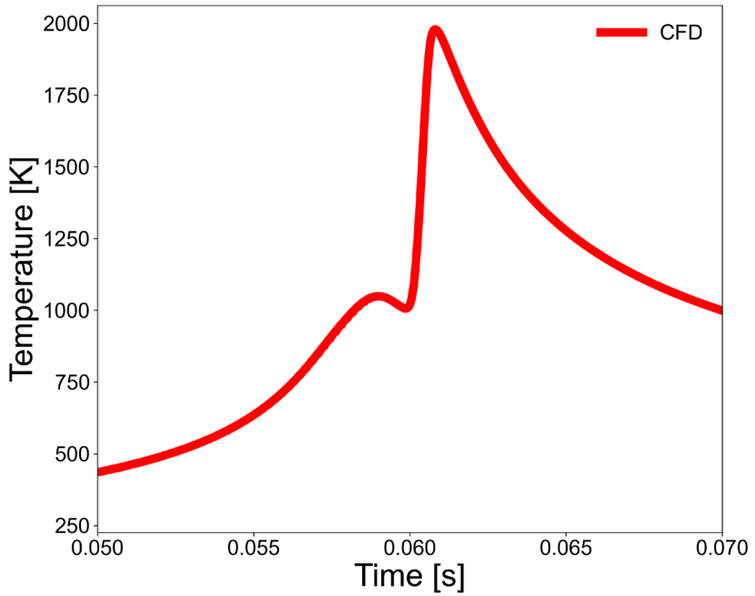
- Target $\lambda = 2$ reached
- Good homogeneity index before TDC
- Methane slip reduced (-70%) but some improvements are required

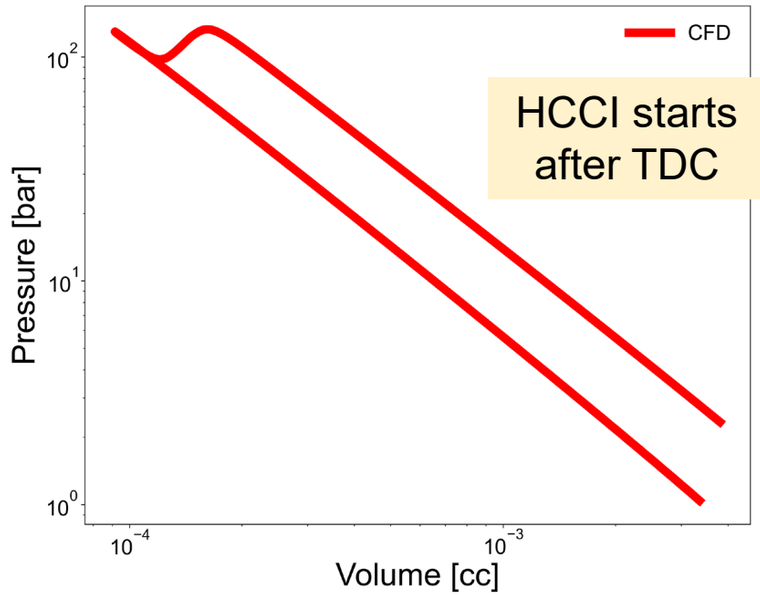


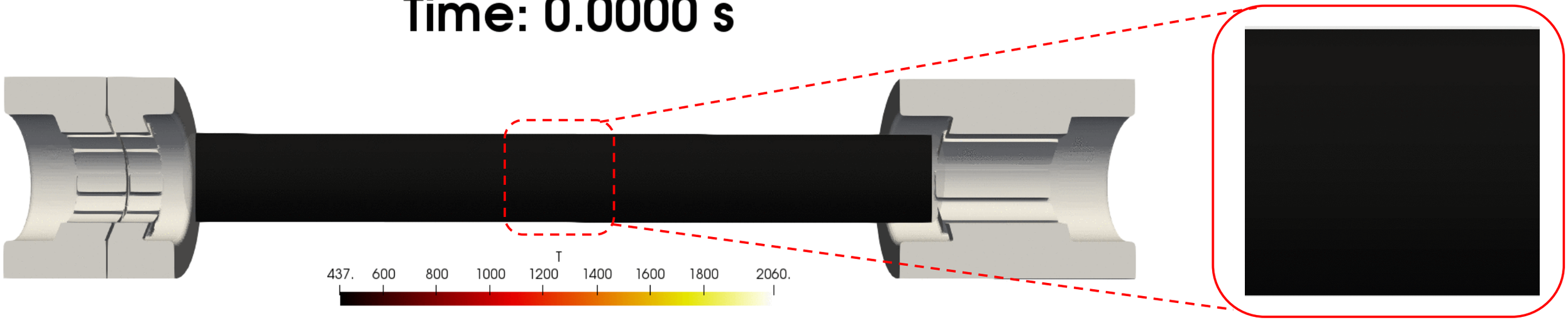
Reduced methane slip

CH_4-FPLG CFD simulations: combustion

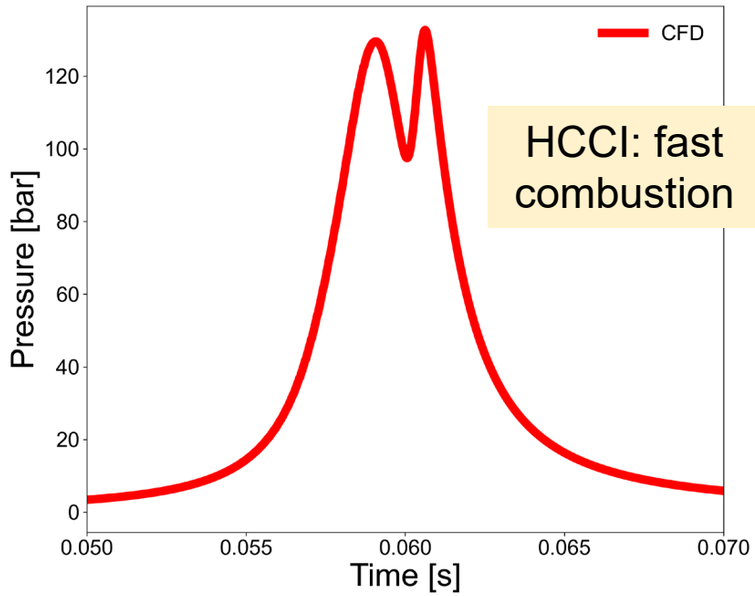




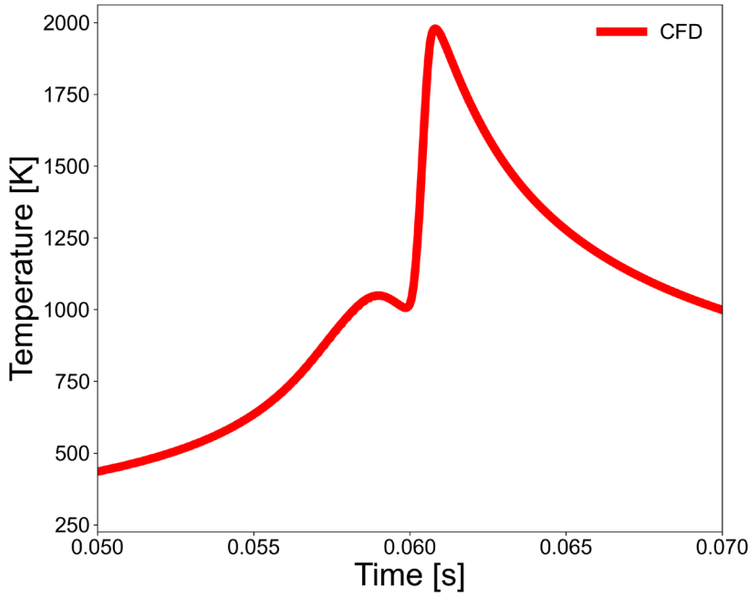




CH_4-FPLG CFD simulations: combustion



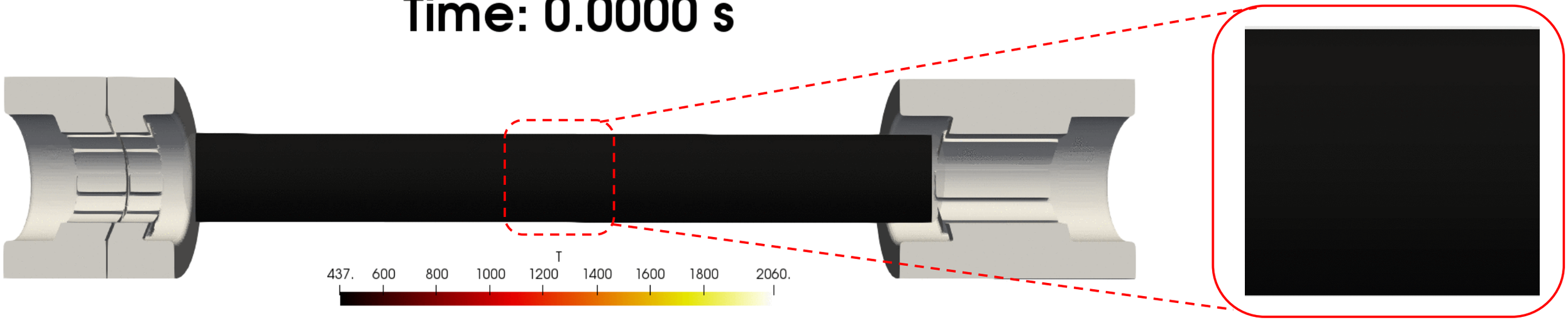
HCCI: fast combustion



CFD output	
IMEP	6.7 bar
Indicated power	49 kW
Indicated efficiency	58%

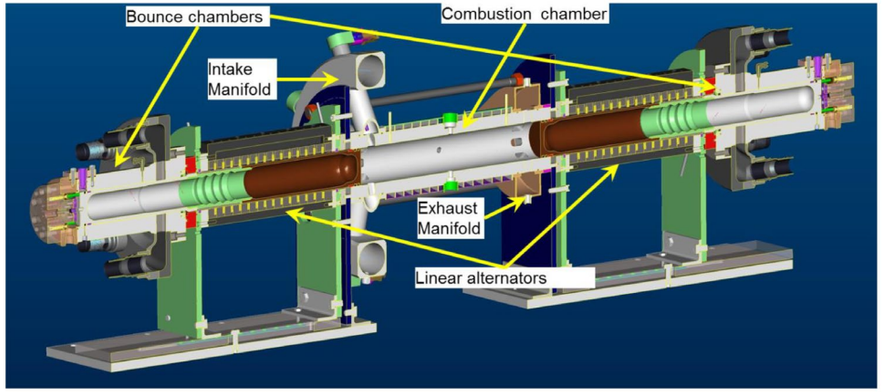
Possible issues:

- Blowby not considered
- HCCI ignition control
- After-treatment (no TWC)



H_2-FPLG simulations

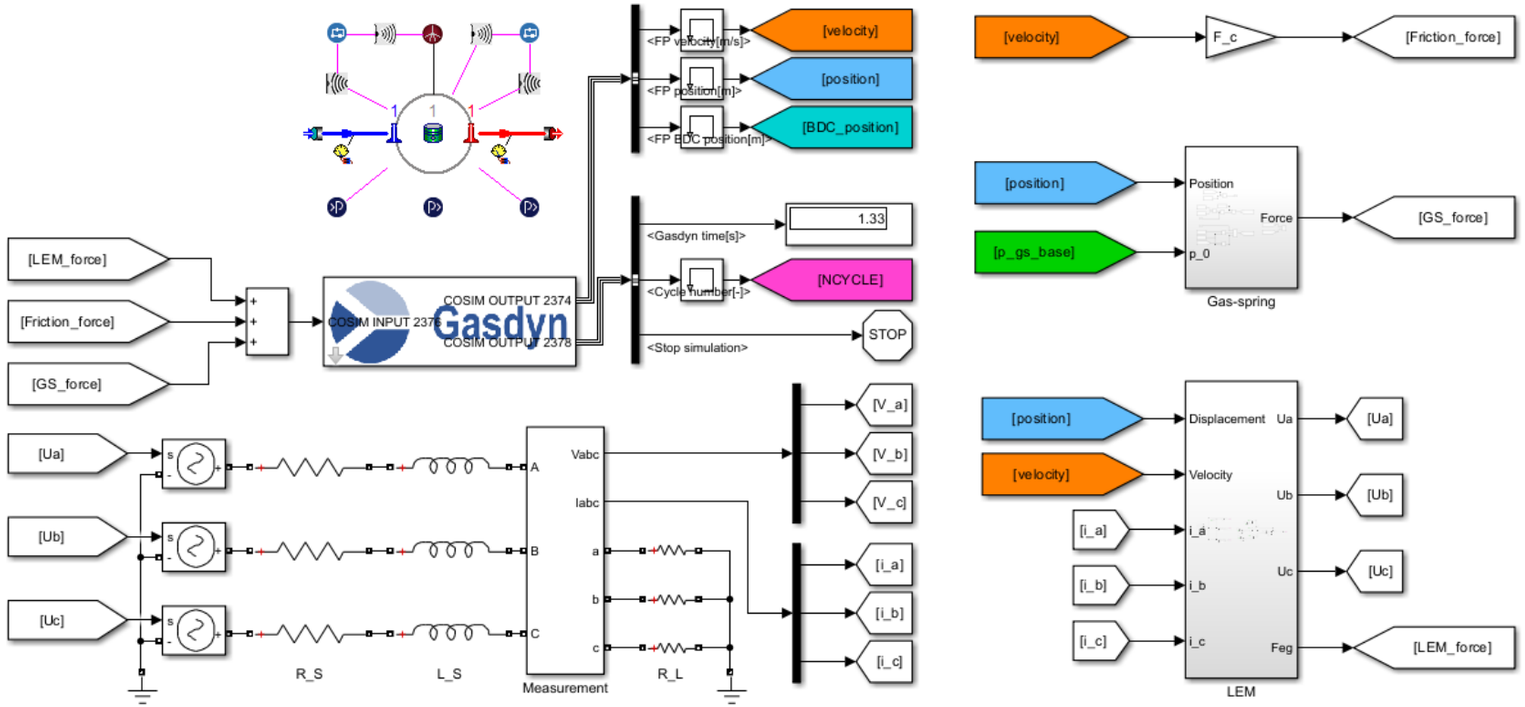
Sandia prototype (2016)



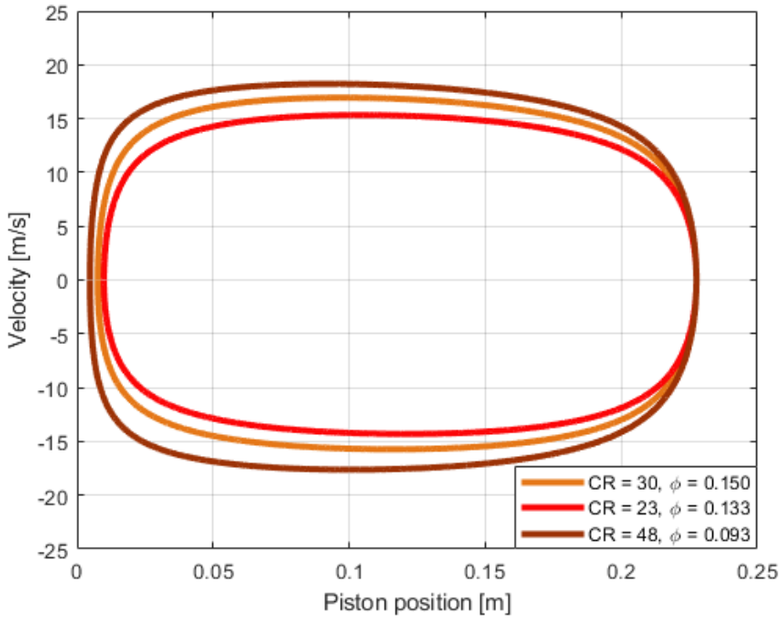
Bore	81.15 mm
Stroke	220 mm
Mover mass	4.9 kg
Compression ratio	~ 30
Frequency	~ 30 Hz
Power	~ 15 kW
Intake pressure	1.2 bar
Intake temperature	300 K
Equivalence ratio	0.15

Gasdyn+Simulink integrated model

- Gasdyn for combustion chamber and ducts
- Simulink for gas-spring and electric machine

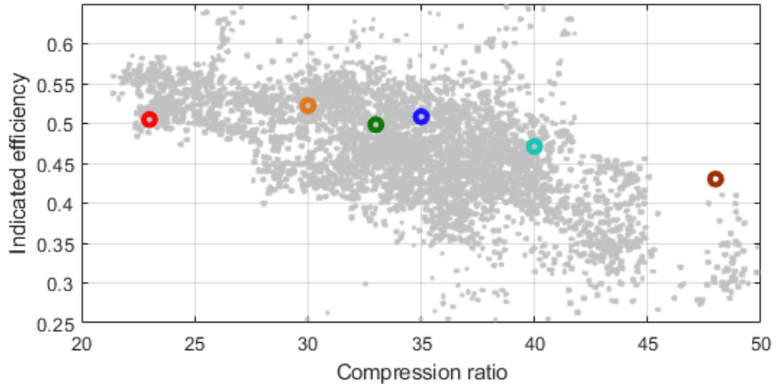


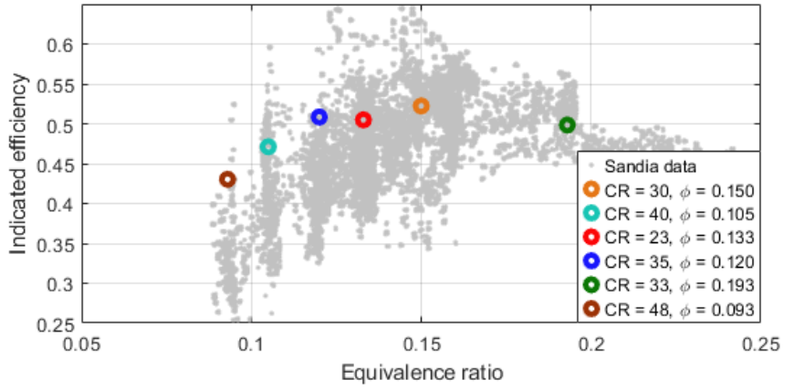
H_2-FPLG simulations

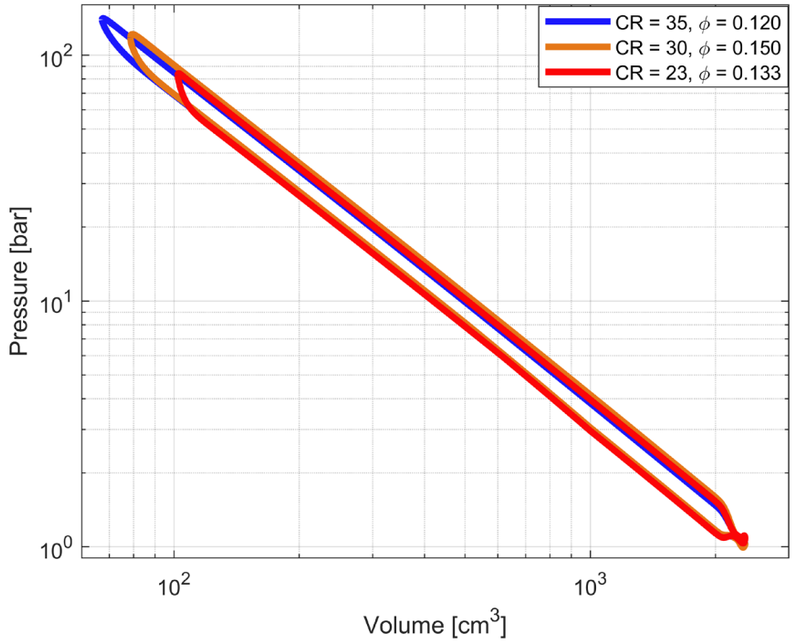


- Stroke increases with CR
- Symmetry of position-velocity diagram increasing with stroke

- Slightly lower efficiency values (H_2 ignites earlier than CH_4)
- Efficiency decrease after CR = 35







- H_2 ignites always before TDC (compression ratio limitation)
- All cases with $dp/dt < 10\ MPa/ms$

Conclusions

- 1D and CFD simulations supporting opposed-FPLG development for mobility and power generation applications;

- Definition of a SI combustion system for mobility applications

- Potential of HCCI combustion for power generation:
  - Definition of a preminiary combustion chamber configuration
  - Very lean combustion ($\lambda > 2$)
  - Indicated efficiency > 55%
  - Near-zero emissions