Homogeneous Charge Compression Ignition (HCCI) R&D

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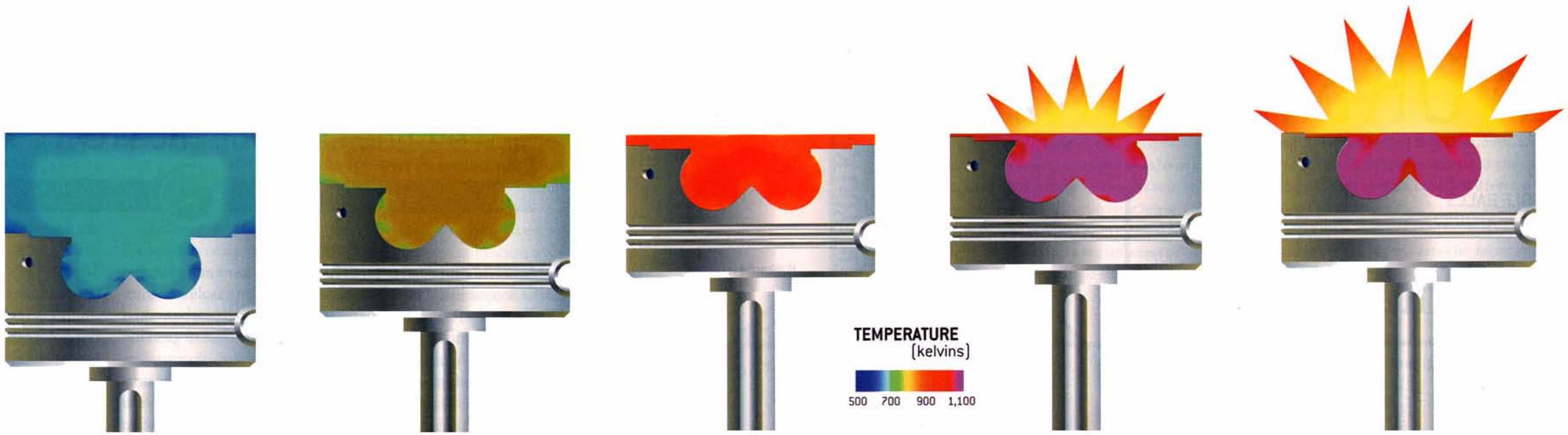


LLNL HCCI combustion simulation results for thermal autoignition of the fuel during compression.

Scientific American, June 2001

Objectives:

Develop a new combustion system that can provide the high efficiency and durability of diesel engines with very low NOx and particulate matter emissions.

Plans:

Find inexpensive, practical solutions for the problems of HCCI engines:

- control
- multi-cylinder balancing
- high HC and CO emissions
- low power output
- startability

We are addressing the problems of HCCI combustion through a combination of analysis and experiments

Control:

- Detailed analysis of possible control strategies
- Experimental testing
- Additives

Multi-cylinder balancing:

- Achieved balanced combustion in VW TDI engine

High HC and CO emissions:

- Detailed analysis for optimized engine geometry

Low power output:

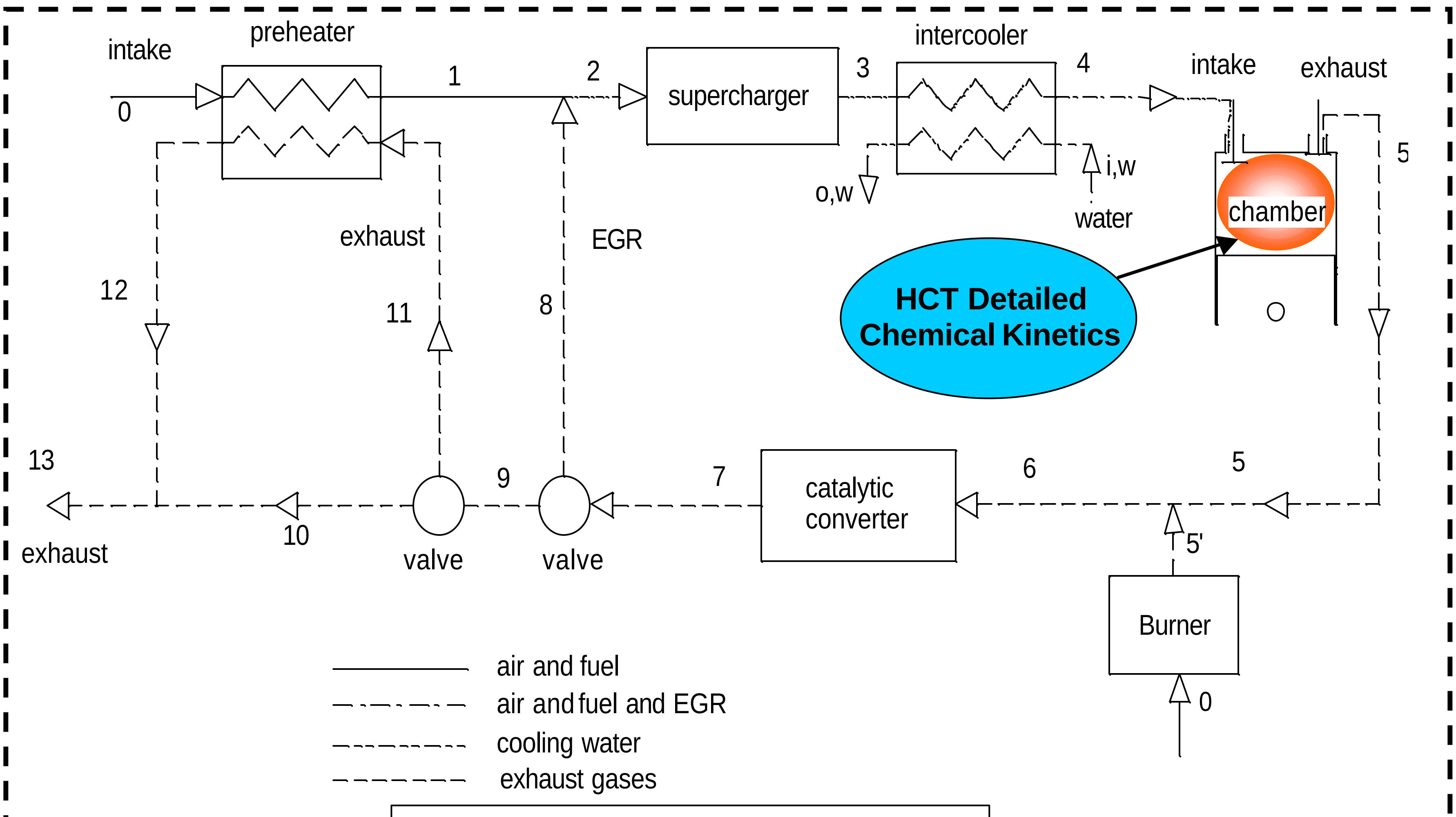
- Optimization of engine performance map
- Transition to SI/CI combustion

Startability:

- Analysis of transition between SI/CI and HCCI combustion

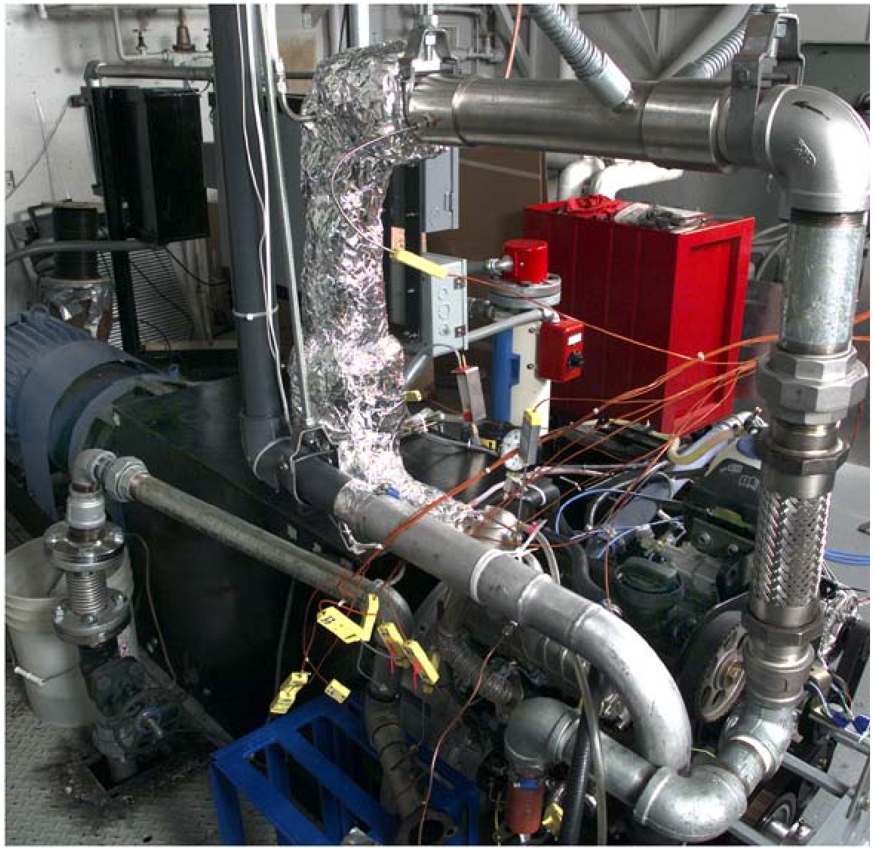
We have analyzed potential methodologies for control of HCCI combustion (SAE 2000-01-2869)

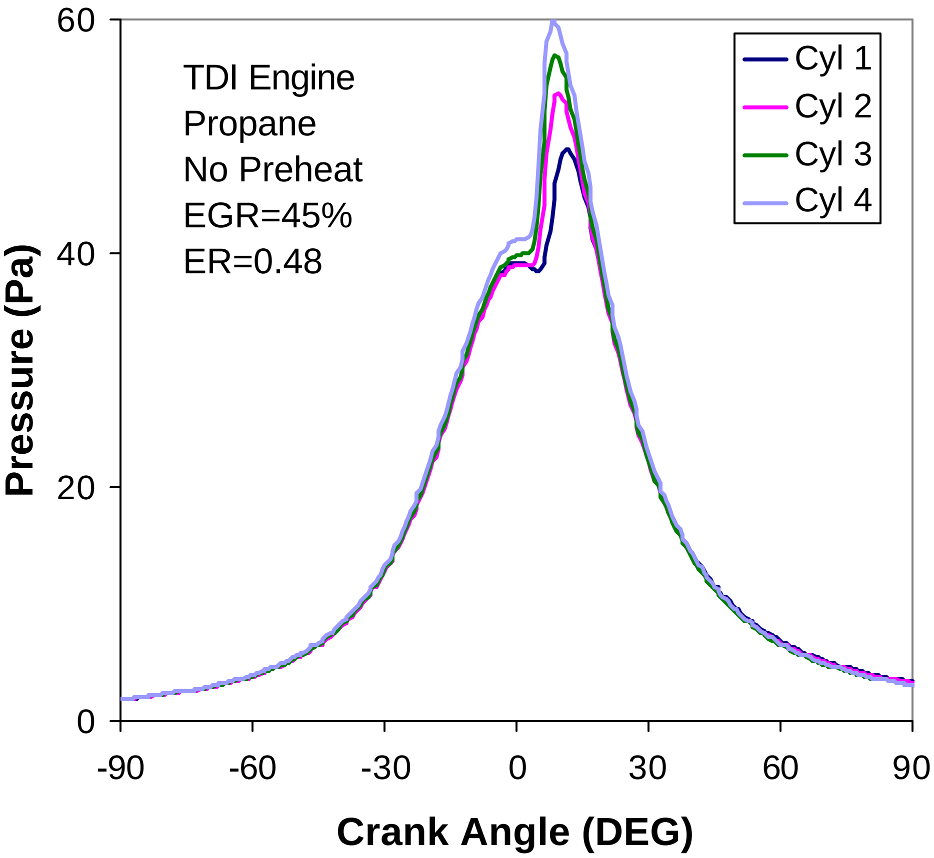
Example of thermal control system



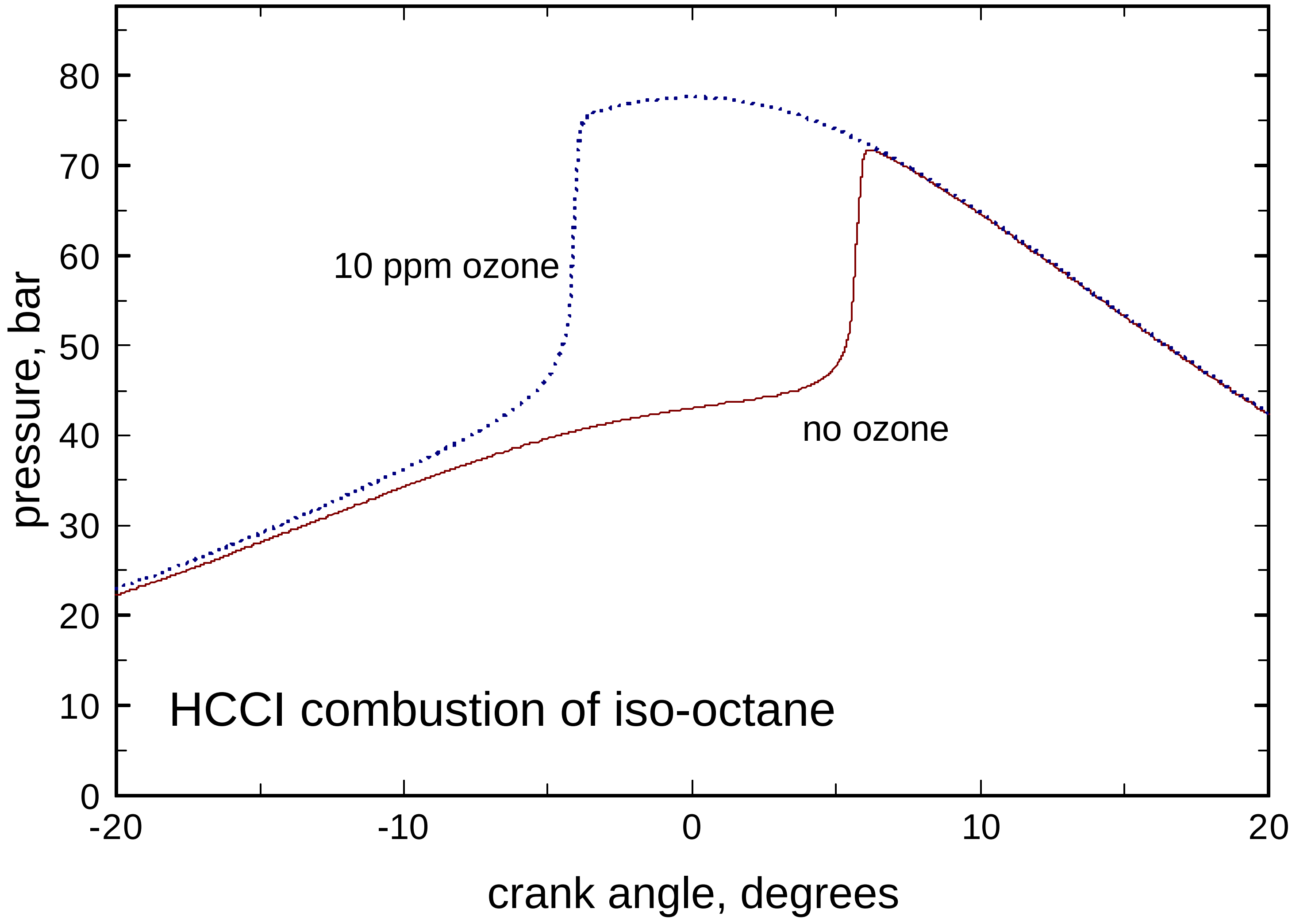
SuperCode Optimization

We have successfully operated the TDI engine with an EGR-equivalence ratio control with no intake heating

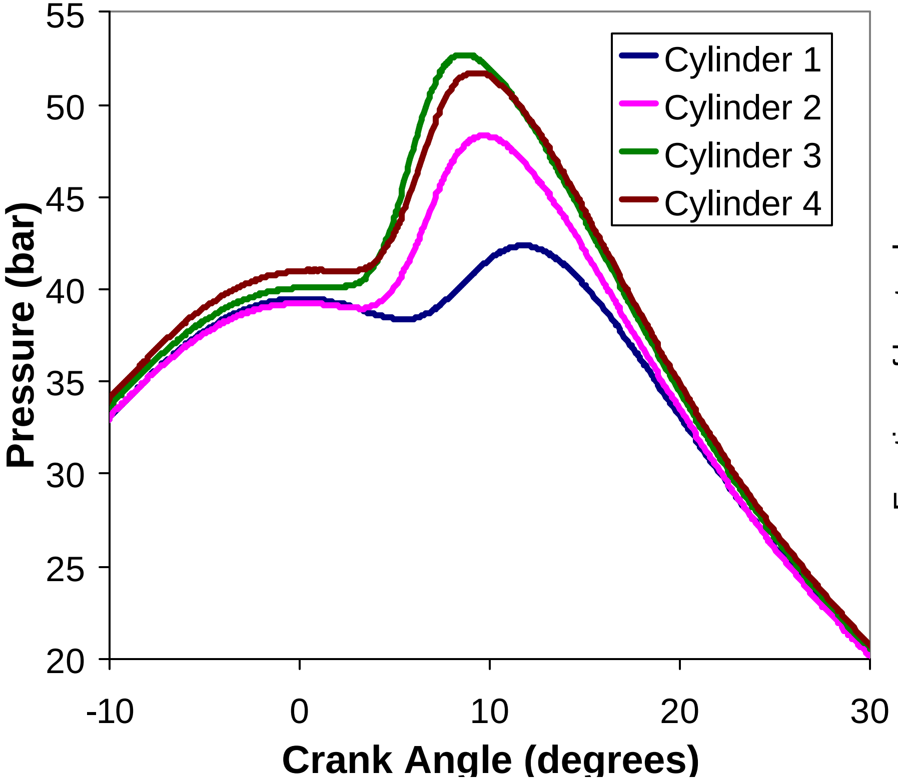


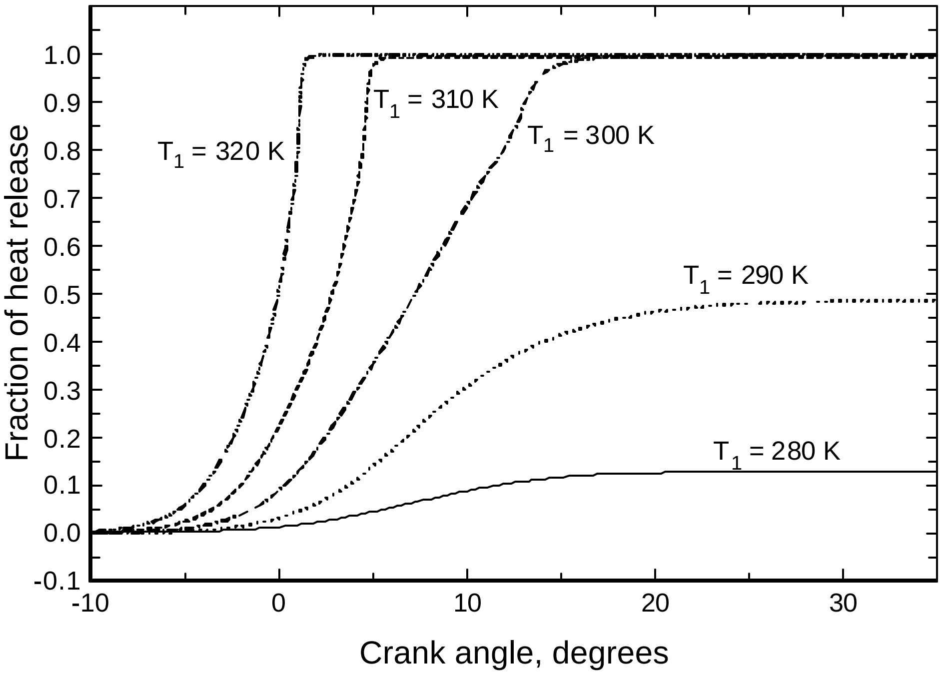


We are looking at the use of additives for control of HCCI engines



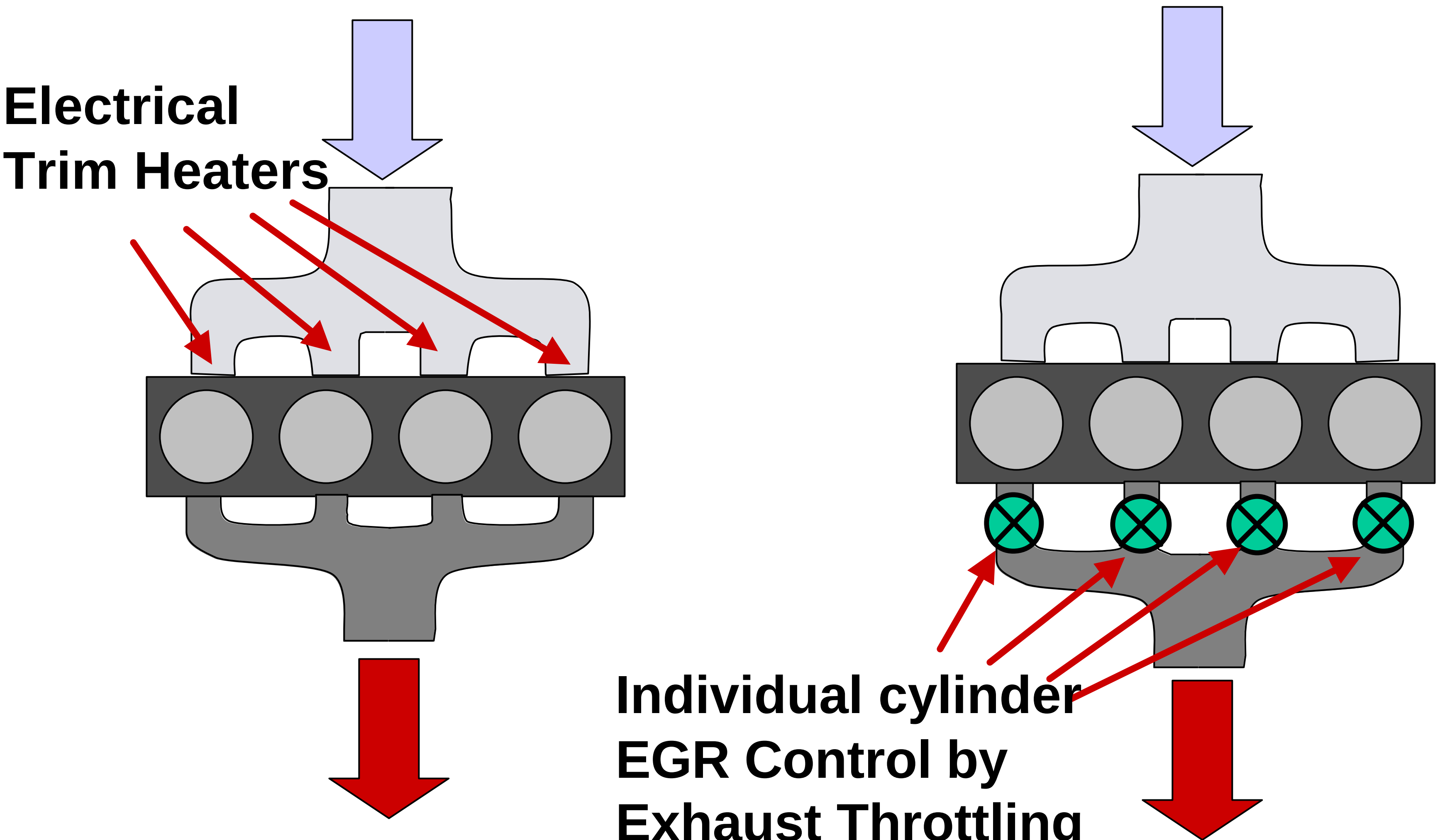
Control of multi-cylinder HCCI engines is a challenge





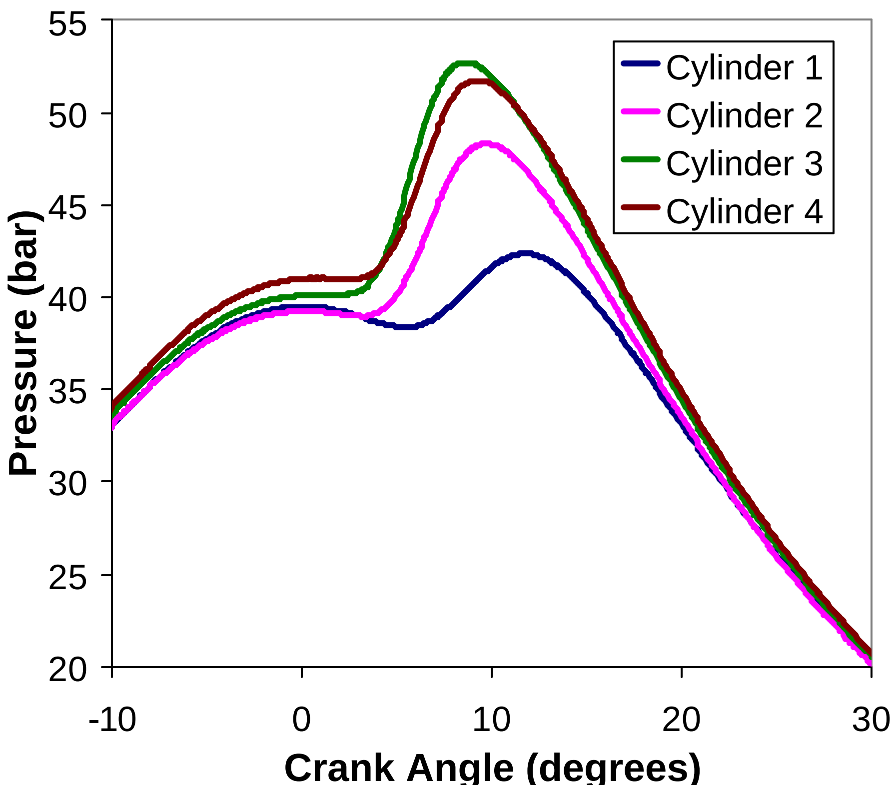
We are exploring many means of cylinder-by-cylinder timing control

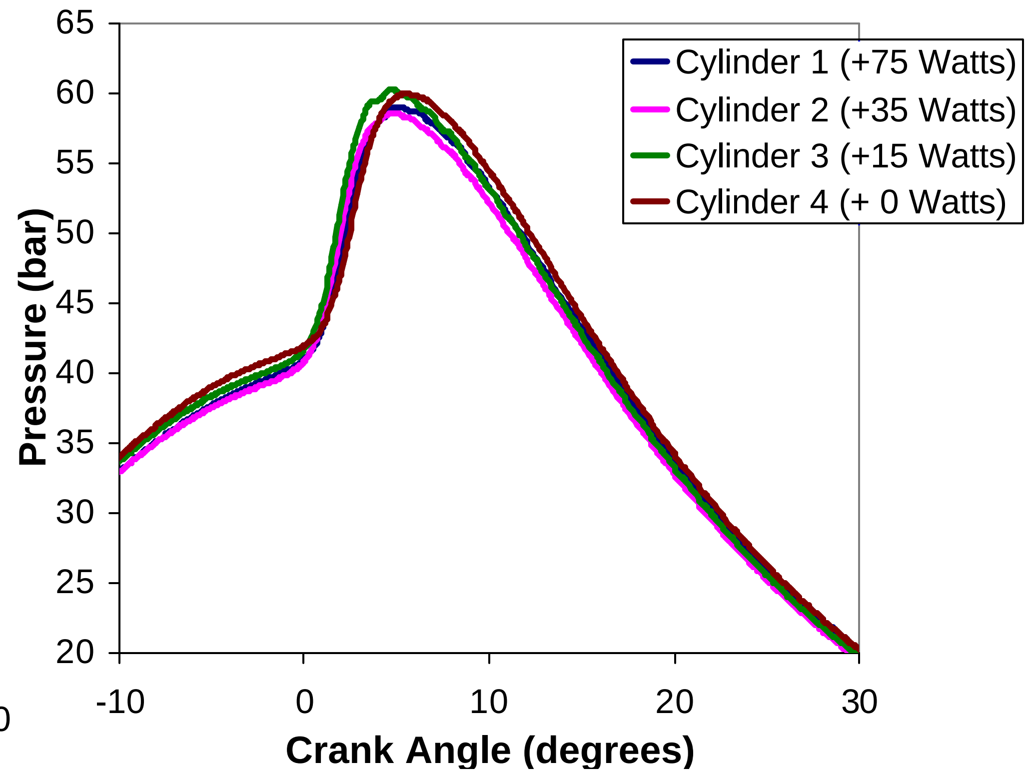
Control systems are being implemented for two generic, low cost control options:



Multi-cylinder engine operation requires balancing of combustion timing between cylinders

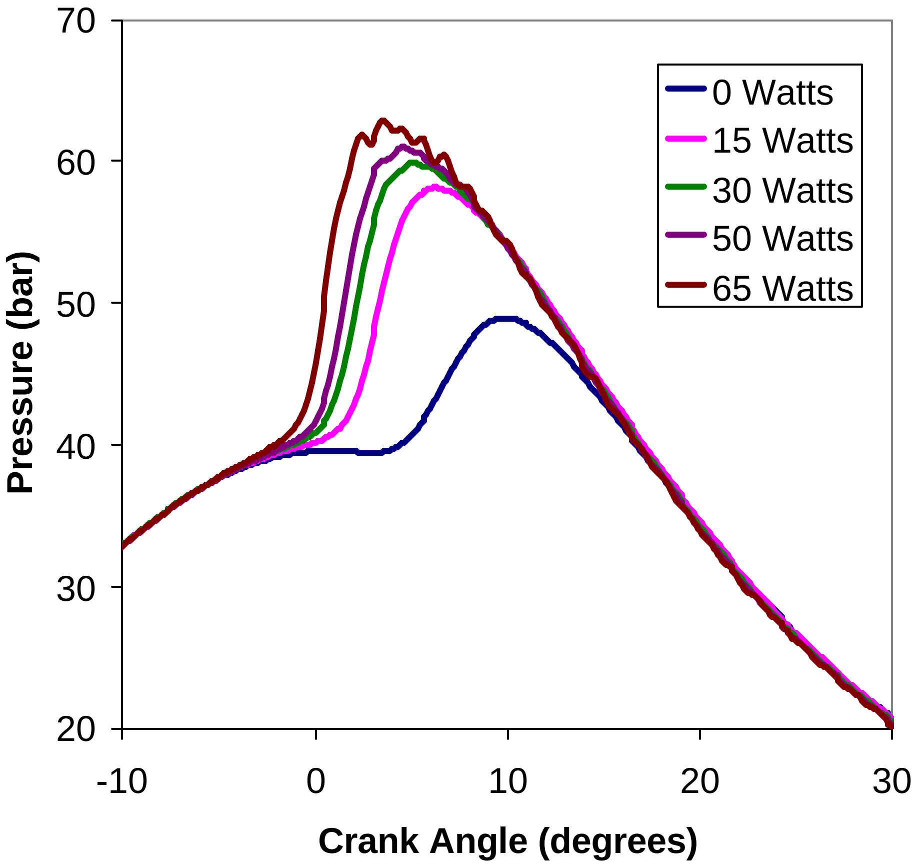
Trim heaters using less than 1% of mechanical energy output can effectively balance the cylinders in steady operation



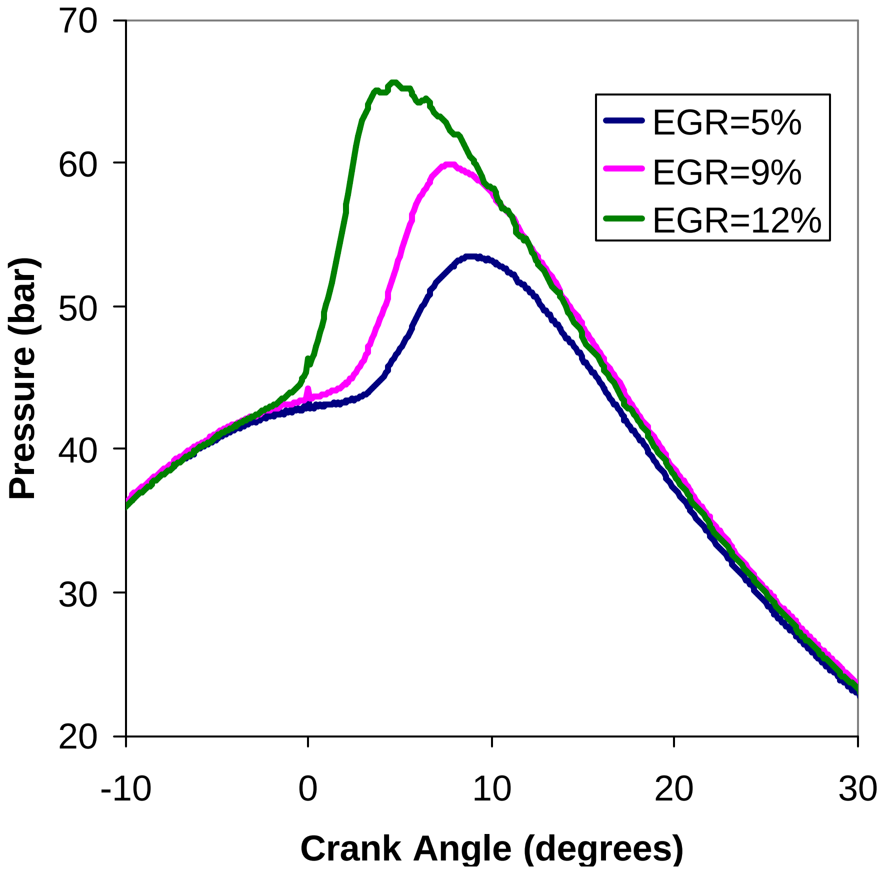


Unbalanced **Balanced**

We have successfully demonstrated two possible means of individual cylinder combustion timing control

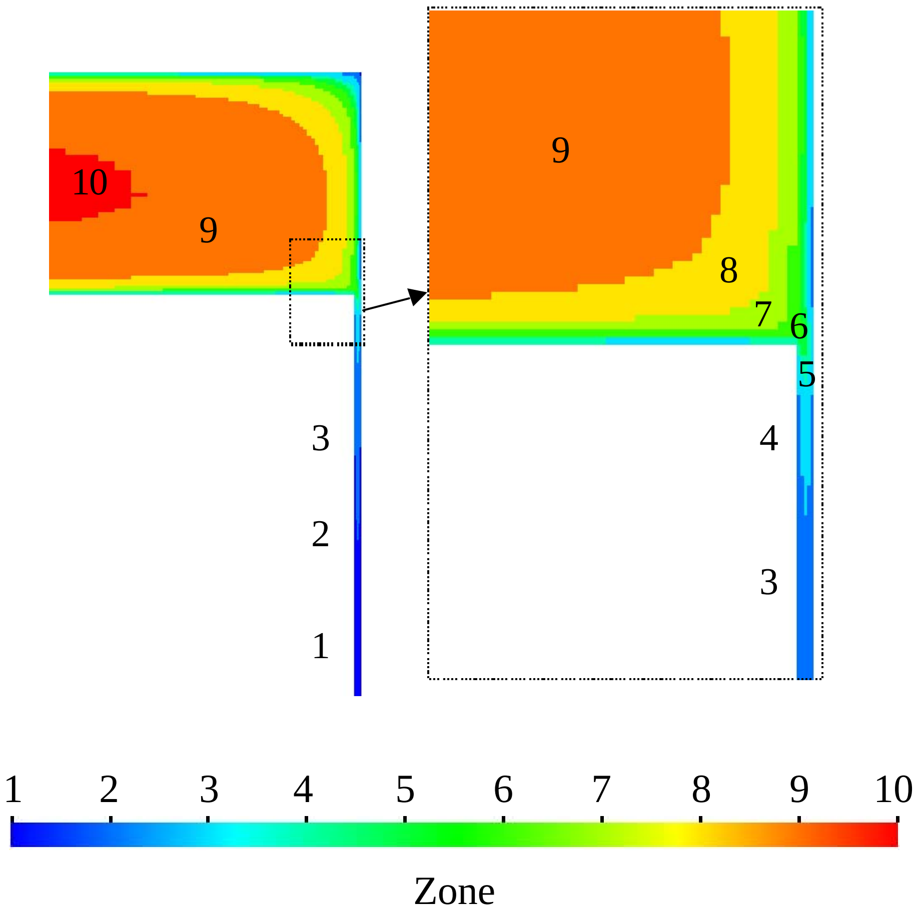


Timing Control with Trim Electrical Heater

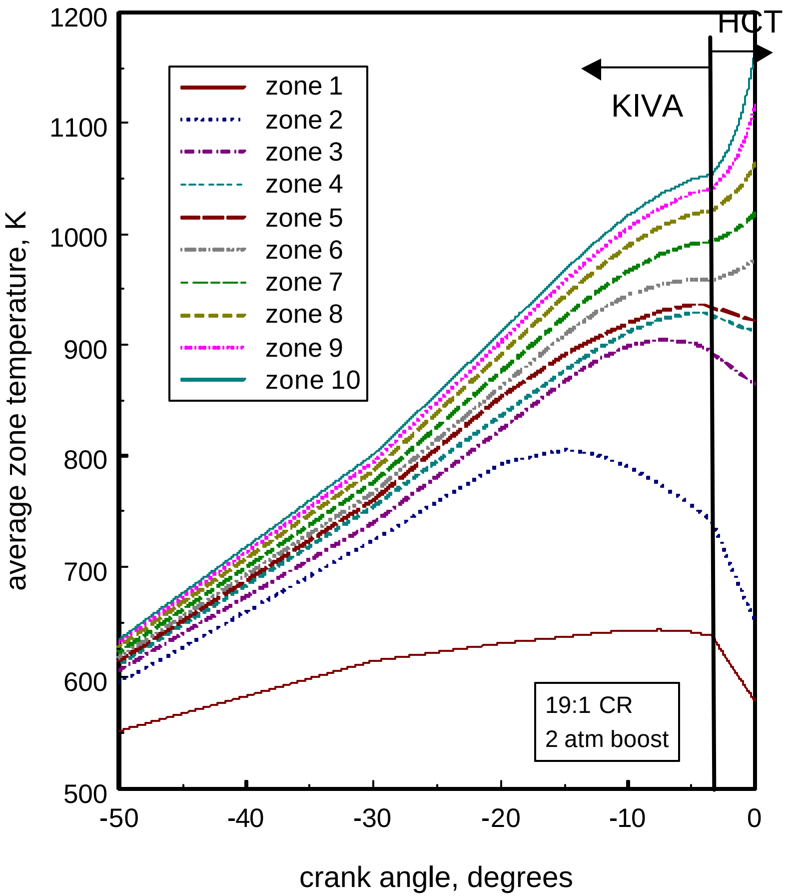


Timing Control with Exhaust Throttle EGR

Our multi-zone methodology can successfully predict geometry effects on HC and CO emissions



Location of isothermal zones in cylinder (SAE 2000-01-0327)



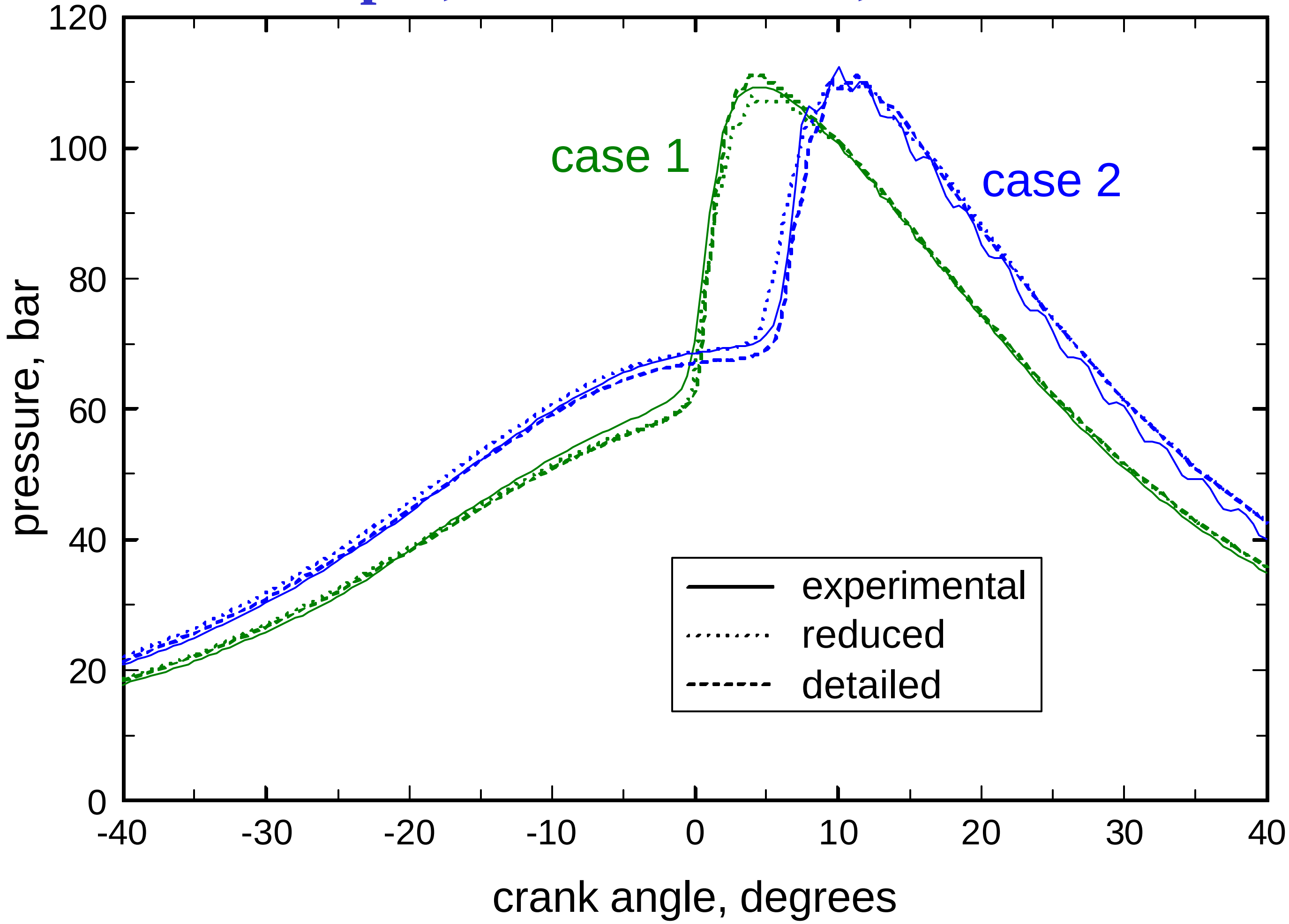
Temperature history of 10 zones during compression stroke

Our multi-zone model generates accurate predictions for HCCI combustion

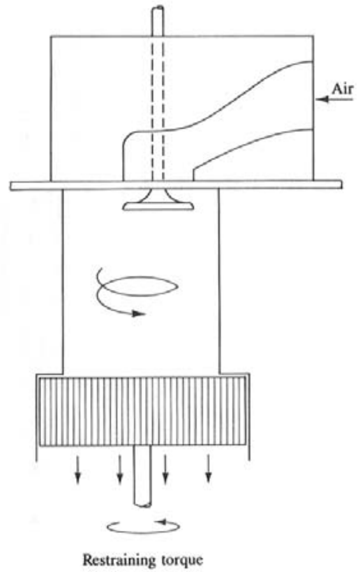
Iso-octane data from Cummins

Case 1: 1010 rpm, 2.41 bar intake, f=0.346

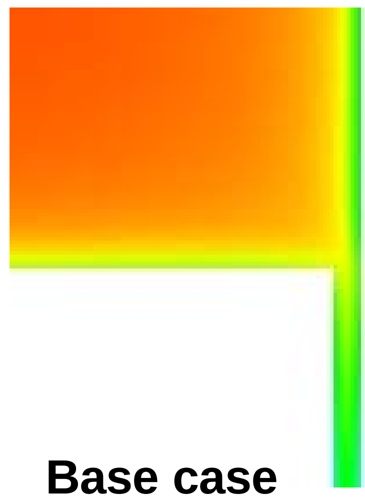
Case 2: 2007 rpm, 3.11 bar intake, f=0.348



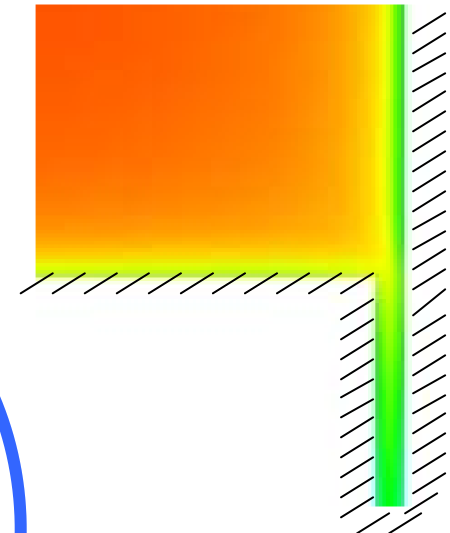
We have applied the multi-zone methodology to four engine designs to evaluate their effect on emissions



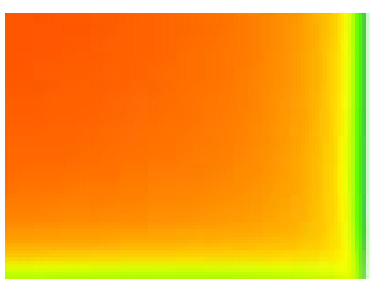
Low swirl (0.43 vs. 4.3)



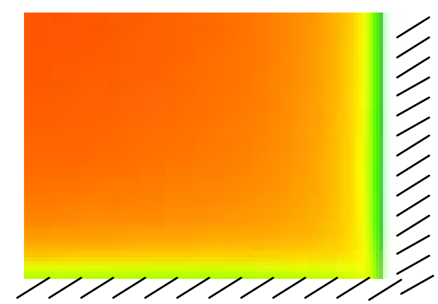
Base case



Hot wall (600K)

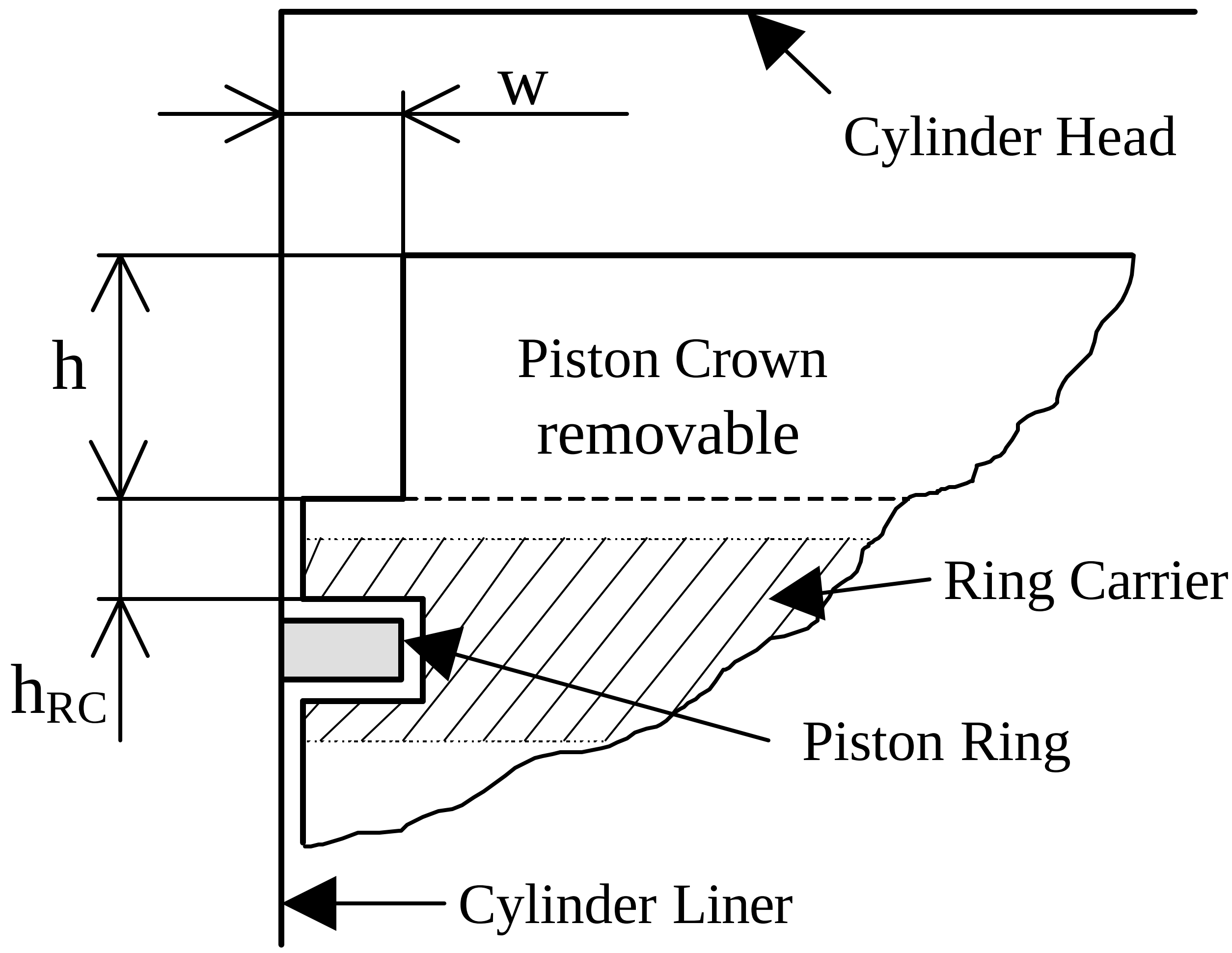


No crevice



All — Low swirl, hot wall, no crevice

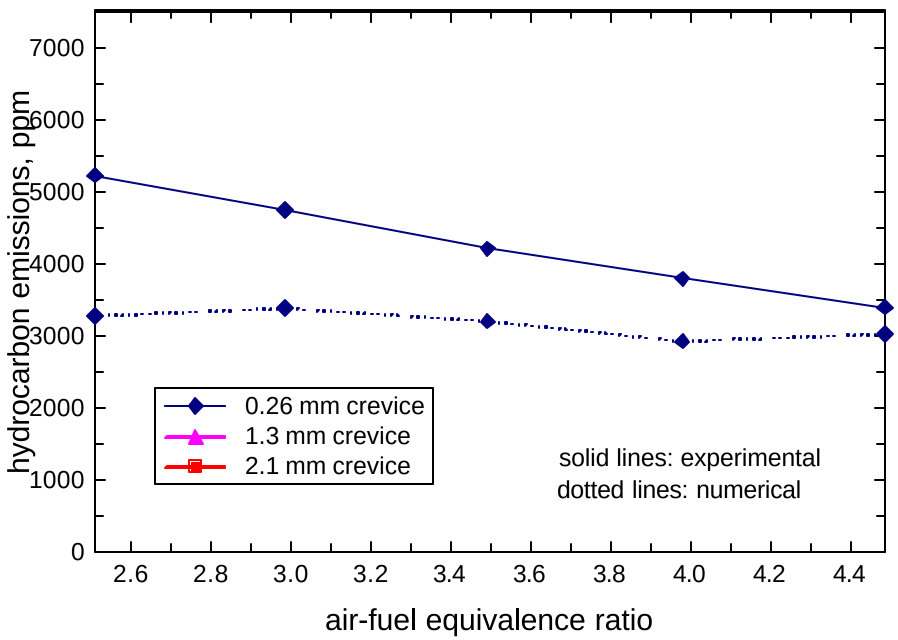
We have analyzed three engine geometries experimentally tested at the Lund University

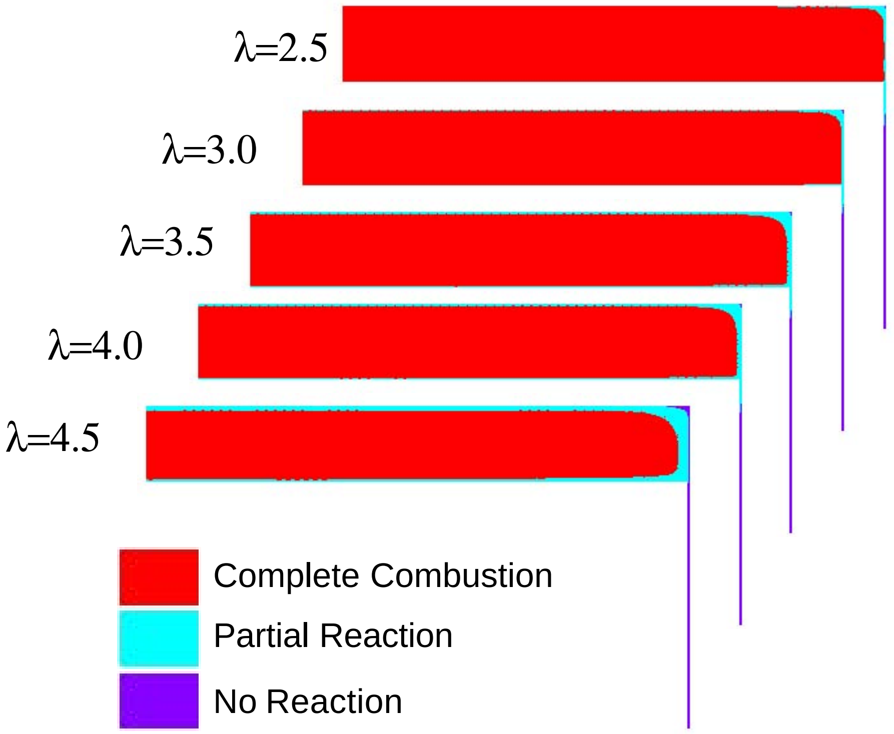


Crevice width w=0.26 mm, 1.6 mm and 2.1 mm

Constant compression ratio 17:1

Our analysis can explain the non-monotonic behavior in HC emissions as a function of equivalence ratio





Engine with narrow crevice
0.26 mm

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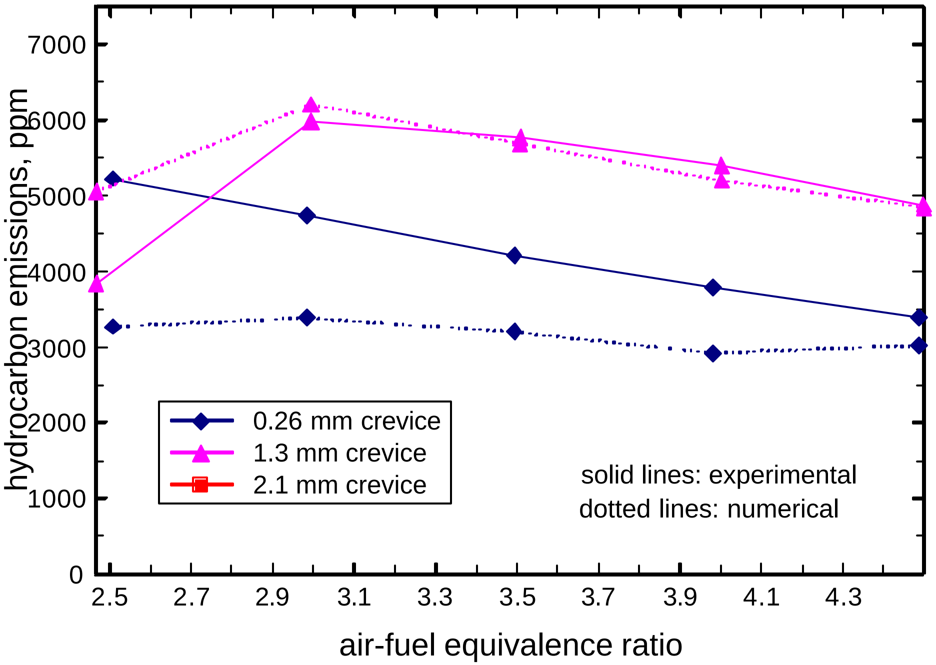
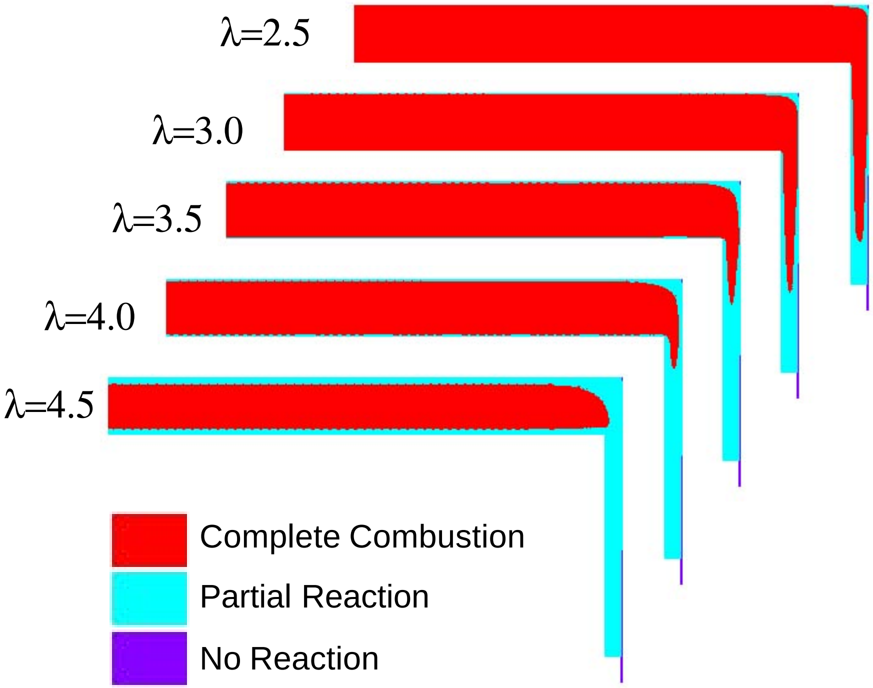
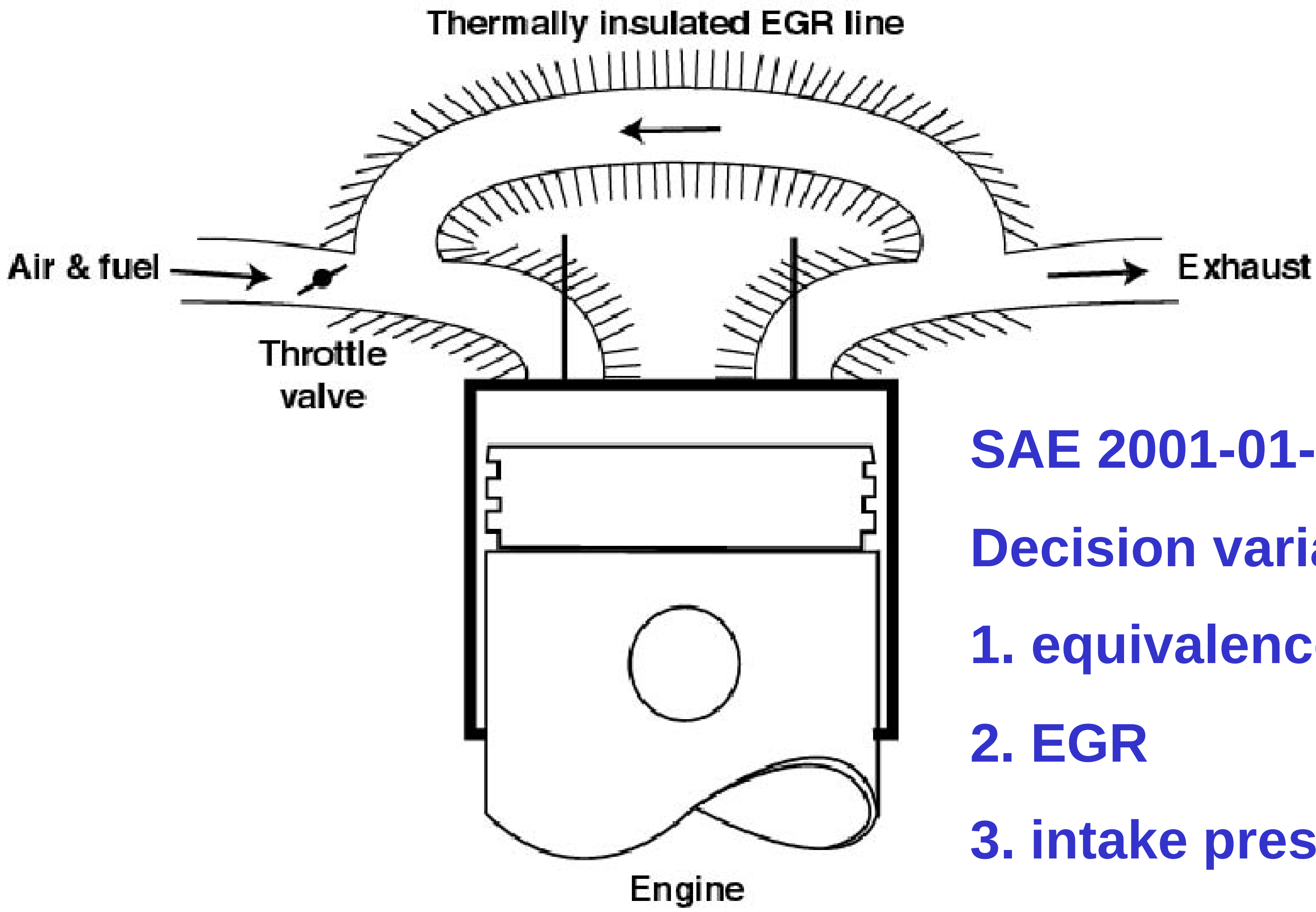




Engine with wide crevice

We have applied the system simulation and optimization tool to evaluate transition between HCCI and SI ignition



SAE 2001-01-3613

Decision variables:

1. equivalence ratio
2. EGR
3. intake pressure

We are collaborating with multiple industrial and academic partners

- **Cummins**
  - 2-year long CRADA, 2 joint papers
  - working on establishing a new CRADA
- **Caterpillar**
  - donated experimental engine 3401
- **Sandia National Laboratories**
  - detailed analysis of experimental data
- **Lund Institute of Technology**
  - 2 joint papers, collaboration on analysis
- **University of Wisconsin**
  - joint work on KIVA analysis
  - 3 joint papers
- **UC Berkeley**
  - joint experimental and numerical work, 18 joint papers
  - four graduate students obtaining degrees on HCCI

HCCI roadmap