

Physical Modelling of Combustion Engine Processes and Gas Exchange for Real-Time Applications

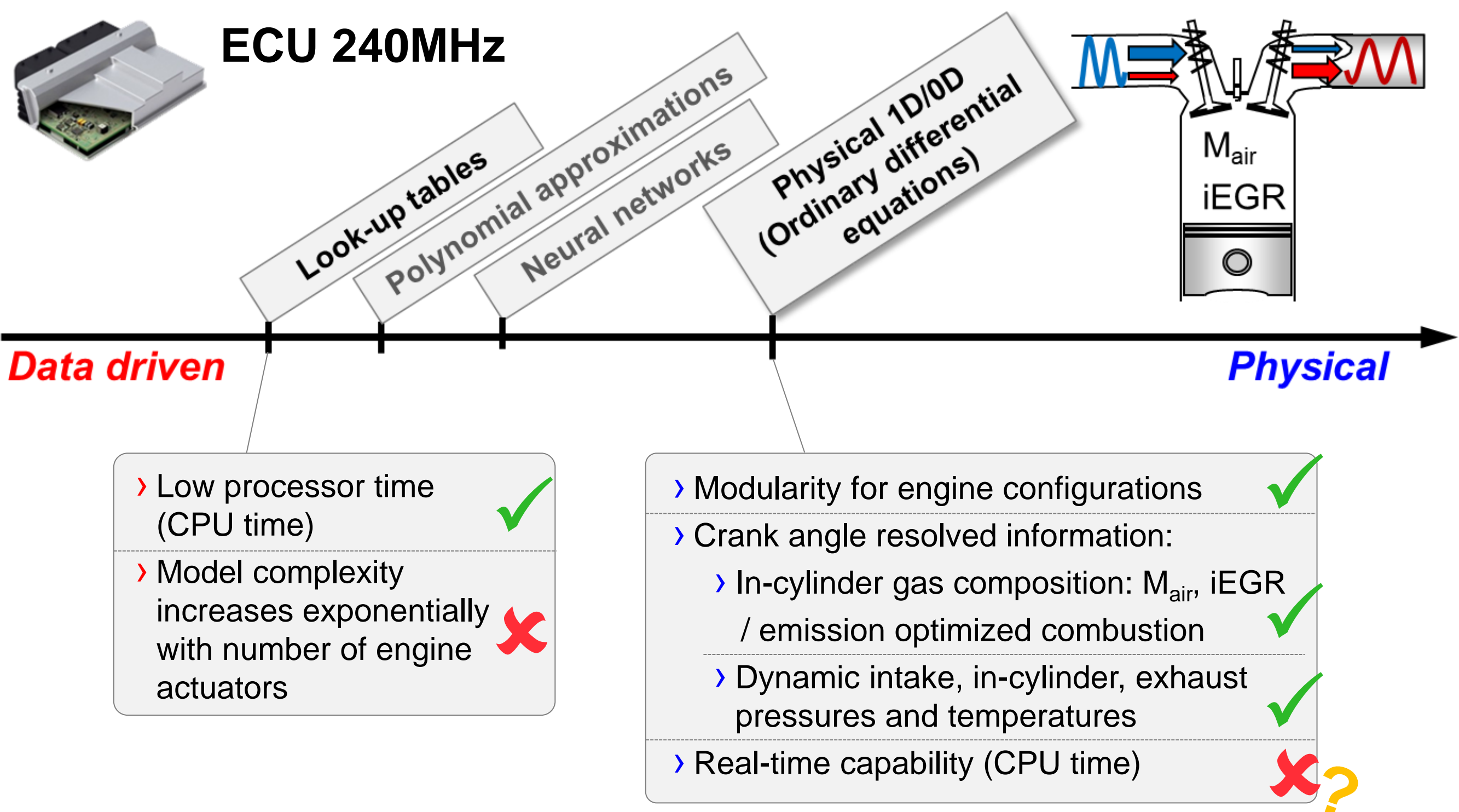
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Why Physical Modelling Instead of Data Driven Models?

For spark ignited engines, torque control is realized in the Engine Control Unit (ECU) by managing the cylinder charge exchange, while keeping the air-fuel ratio stoichiometric in order to minimize exhaust emissions. For this purpose, the ECU needs a real-time capable model, giving an accurate prediction based on the current sensor information.



The main obstacle for using physical models for direct engine control is the low CPU performance of state-of-art production ECU's. The level of physical description for the particular application is in conflict with the runtime performance.

Current State-of-the-Art

The large majority of physical based real-time engine applications is used to calibrate data-oriented control models (look-up tables, neuronal networks etc.) used then for the purpose of the engine control during operation. With some exceptions like Ricardo Wave software, which is a commercial black-box model, there are no available codes with a potential to be real-time capable on an engine production ECU that has usually a restricted processor performance due to manufacturing costs. Most real-time applications using thermodynamic engine models require specialized HiL hardware like dSpace with high processor performance (e.g., CPU > 1GHz). There is also no available work that would transparently show the structure of computational effort (e.g., CPU load) of individual model components or modules

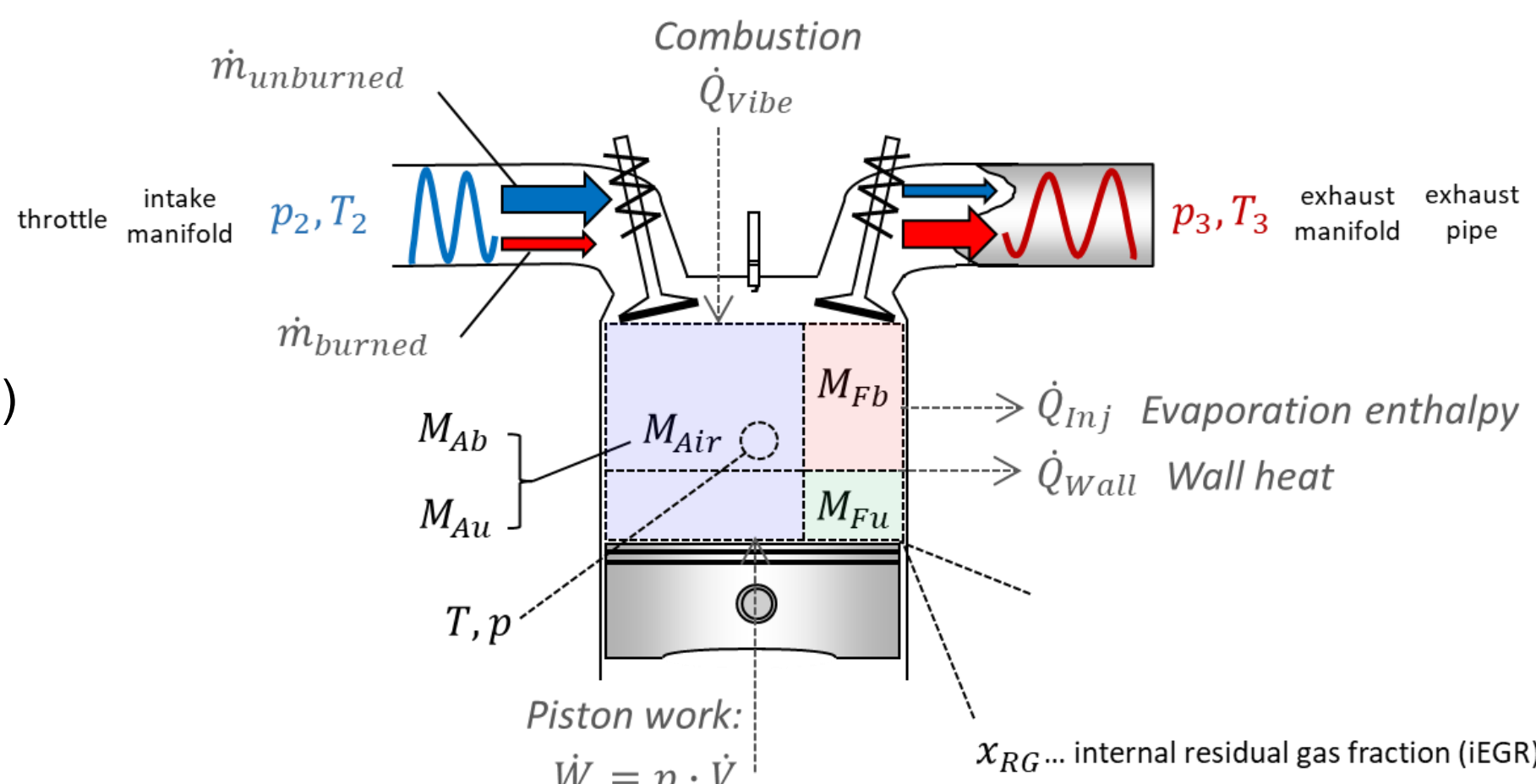
Objectives

- create a physical model, based on differential equations
- crank angle resolved information on engine in-cylinder gas mixture and charge exchange
- suitable for predictive model-based control of a turbocharged ICE
- real-time capable on a state-of-the-art production ECU
- required model calibration data should be less demanding than standard data-based models

Engine Process and Gas Exchange Model

Transport conservation laws

- **Mass** conservation:
 $M_{air}, M_{burned}, M_{unburned}$
- **Momentum** conservation in intake and exhaust runners (1D)
- **Energy** conservation (e.g. cylinder):
 - 2-zone model (0D)
 - Gas properties (polynomial approximation)

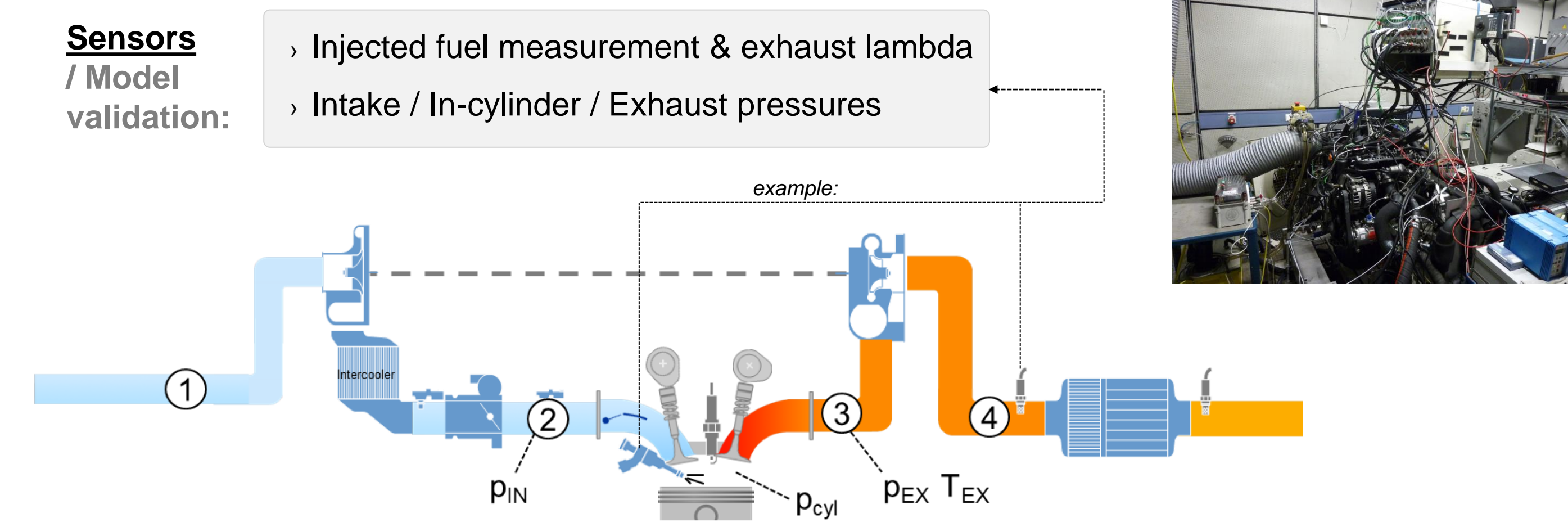


The Engine Development Platform - Experiment

Commercial 4 Cylinder, 1.8 Liter Turbocharged SI-Engine

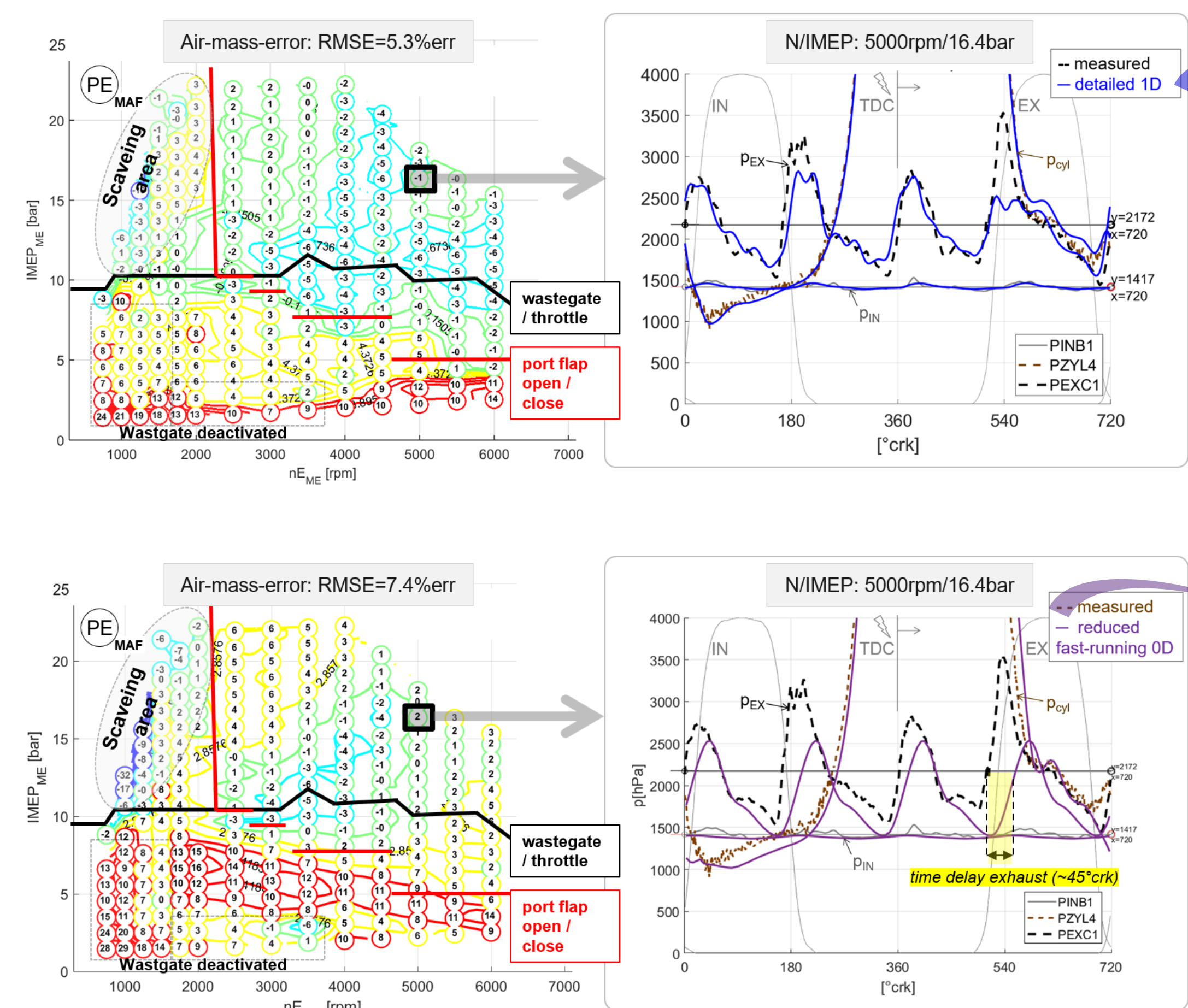
Firing order	1-3-4-2
Displacement	1.8 cm³
Compression ratio	9.5
Rated power	125 kW at 5000 rpm
Injection	Both DI and MPI
Valve train	DOHC, double H-VCT, two-stage VVL
Charging system	Single stage turbocharger with mono scroll turbine
Emission class	EU 6

The experimental engine was installed on a test bench with an asynchronous machine was tested under steady-state as well as transient conditions.

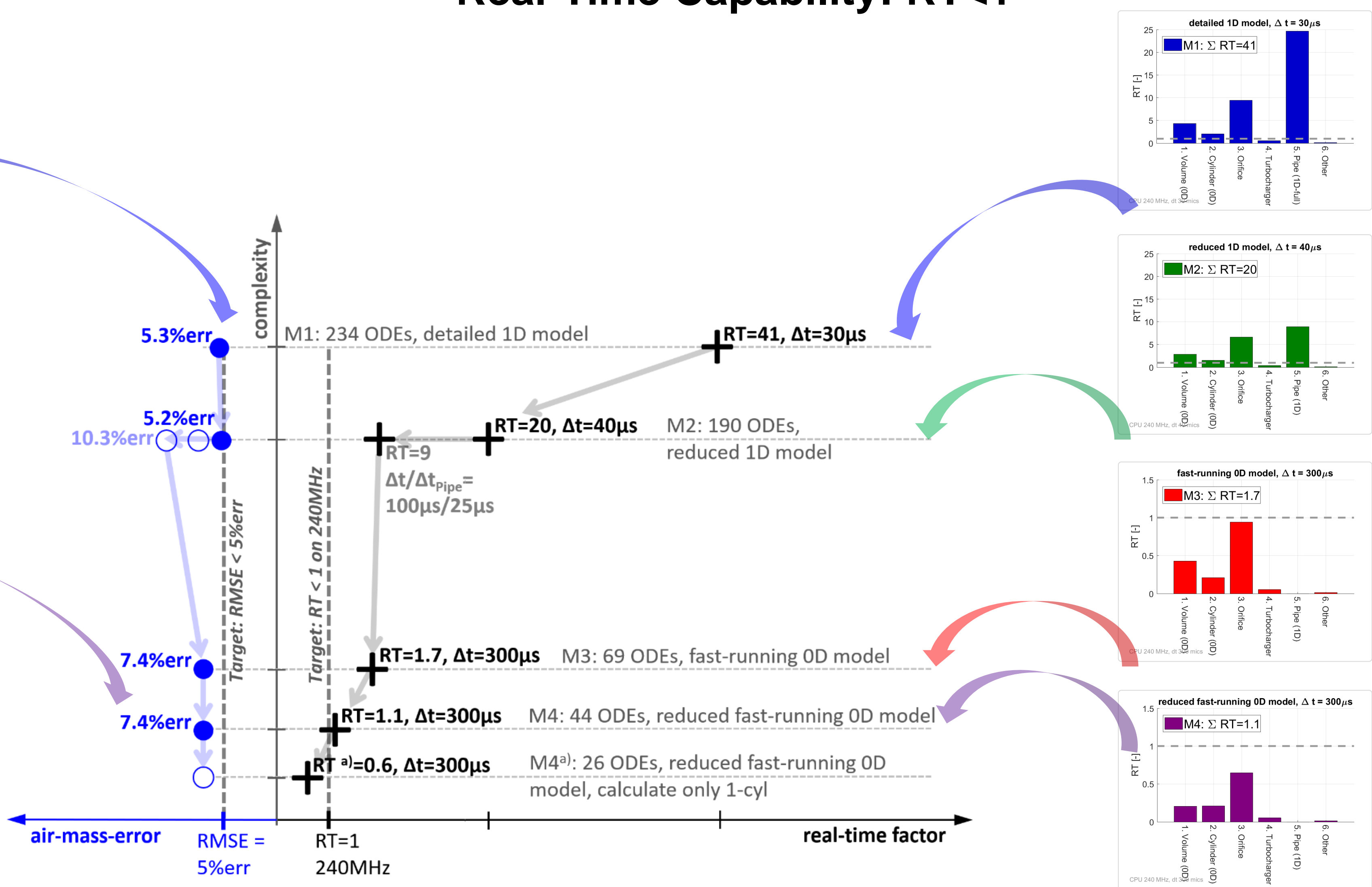


Recorded actuator positions define the later model inputs. The model validation is based on the measured in-cylinder air mass as well as pressures and temperatures in specified engine operating conditions.

Accuracy Objective: RMSE<5%



Real-Time Capability: RT<1



Numerical Solver

Explicit system of ODE's

$$\dot{q} = f_{ODE}(t, q), \quad q = (q_1, q_2, \dots, q_n)$$

is solved by 2nd order Runge-Kutta integration method

Conclusions

Modular, physical-based model and simulation environment was implemented based on the principles of causal modelling approach. The model provides crank angle resolved information on engine in-cylinder gas mixture and charge exchange including performance of a turbocharger.

Models with different level of complexity from 1D to strongly reduced 0D models were validated with measurements. The results show potential of physical based modelling to extend and/or replace data driven models in future ECUs.