Model Based Development and Calibration

Guillaume Broustail & Srinivasan Ananthan – **AVL UK Expo 2015**

Challenges in the Powertrain Development and AVLs Solutions

AVL

CO_2 / Fuel Consumption

Real Driving Emissions

Broad Vehicle Portfolio

Increased system complexity (EAS, OBD, Hybridization)

€ Reduction of development costs

Reduction of development time

Keep quality standards

AVL Solutions

Clustering of hardware and engineering activities

Reduced test facilities/variant through front-loading

Independence of environmental testing from seasonal conditions and vehicles availability

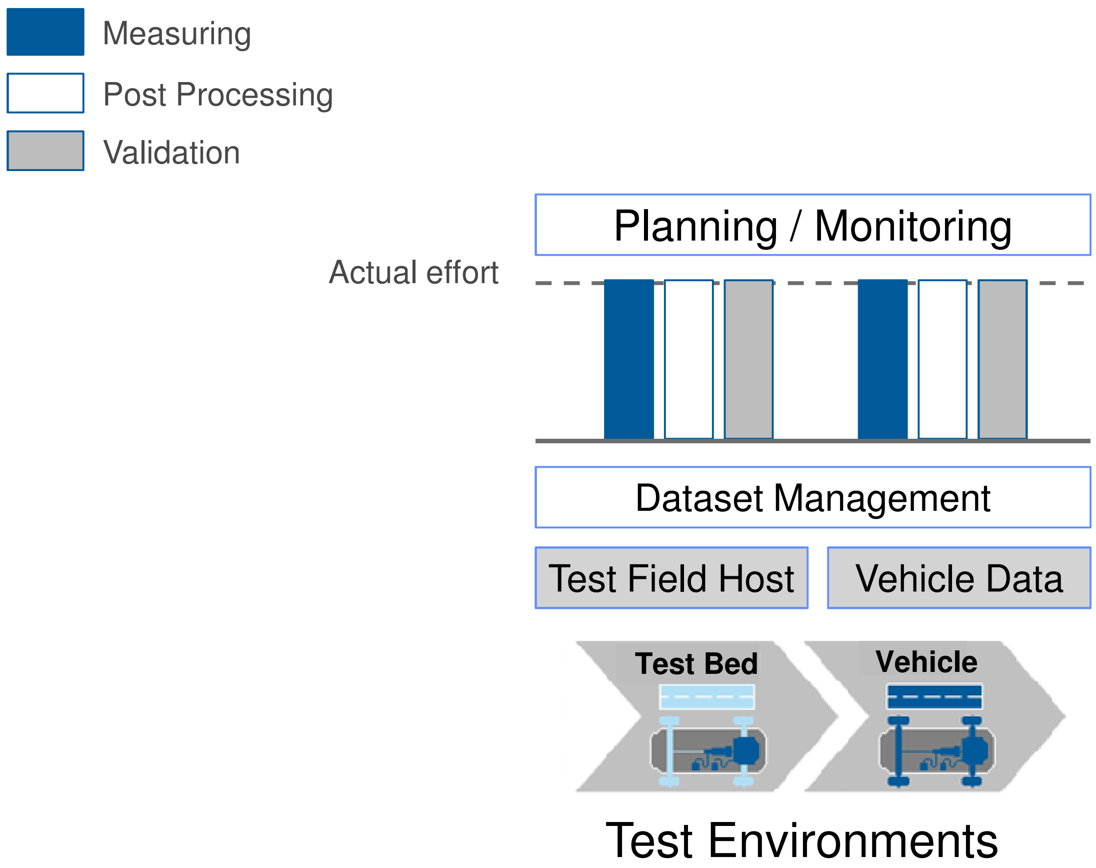
Multi-variant simulation with the same engine family (RDE, OBD, EAS)

Improved quality and robustness through additional virtual validation

Model-Based Development

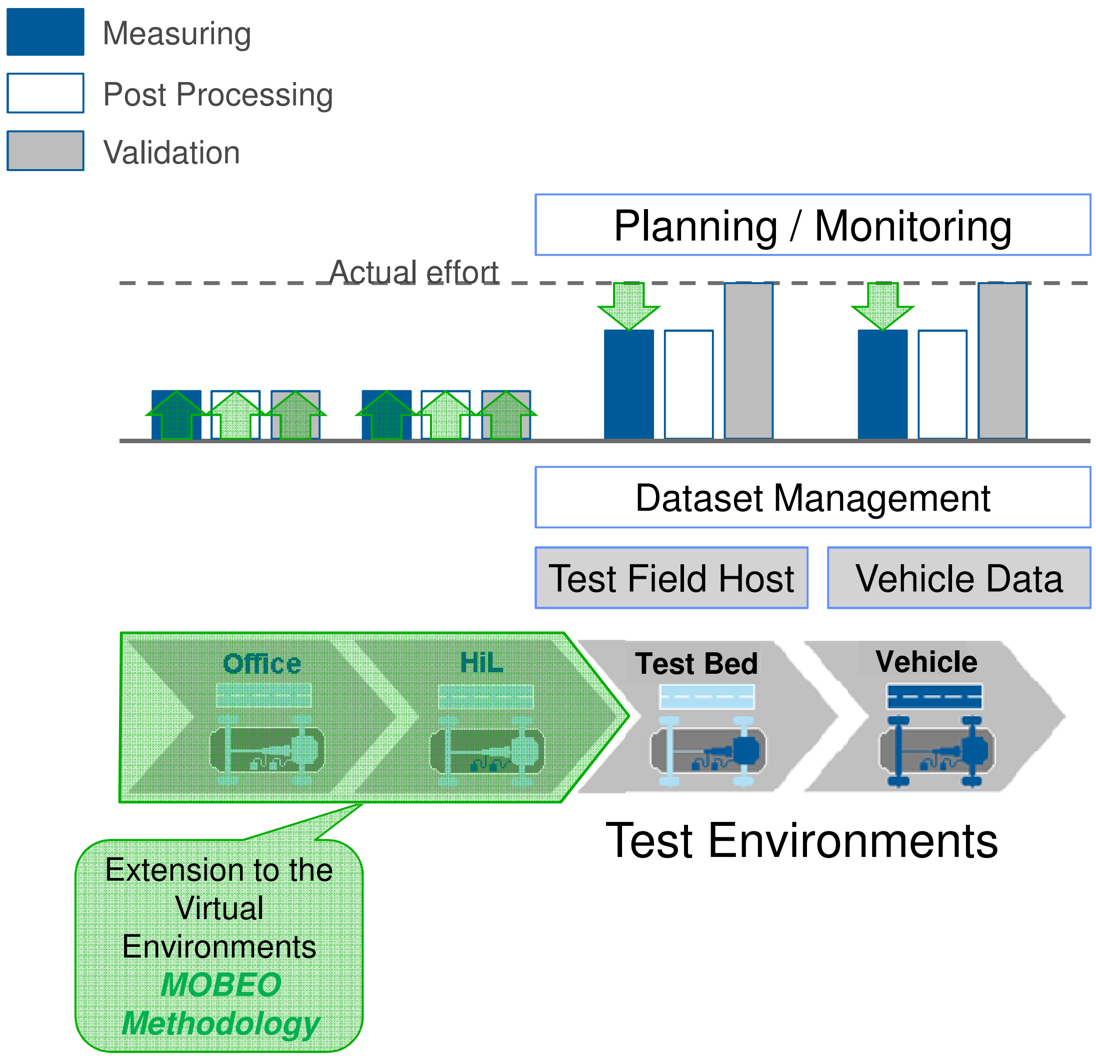
Need for Model Based Development

Front Loading: from Road to Office



Need for Model Based Development

Front Loading: from Road to Office



Need for Model Based Development

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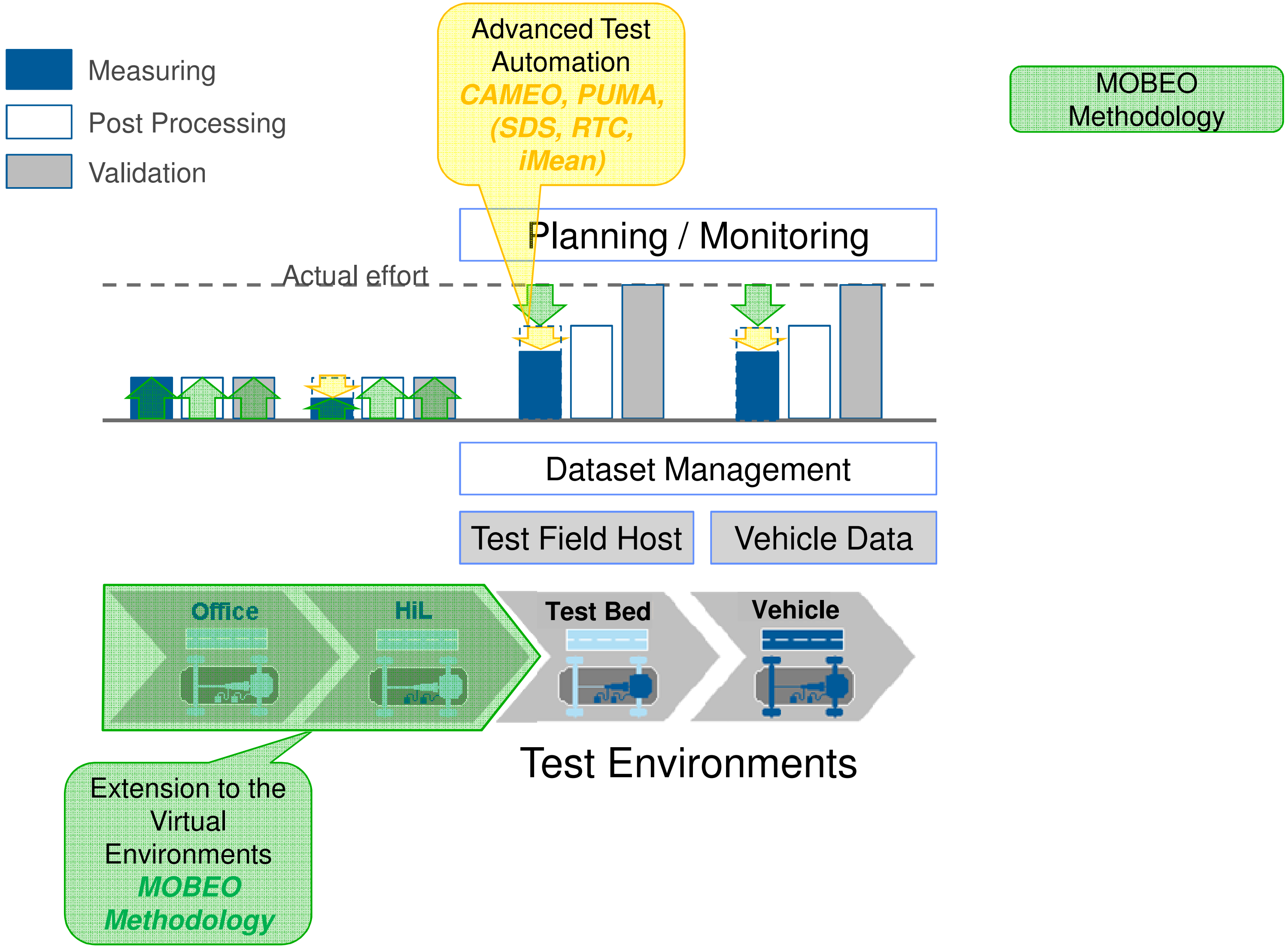

Need for Model Based Development

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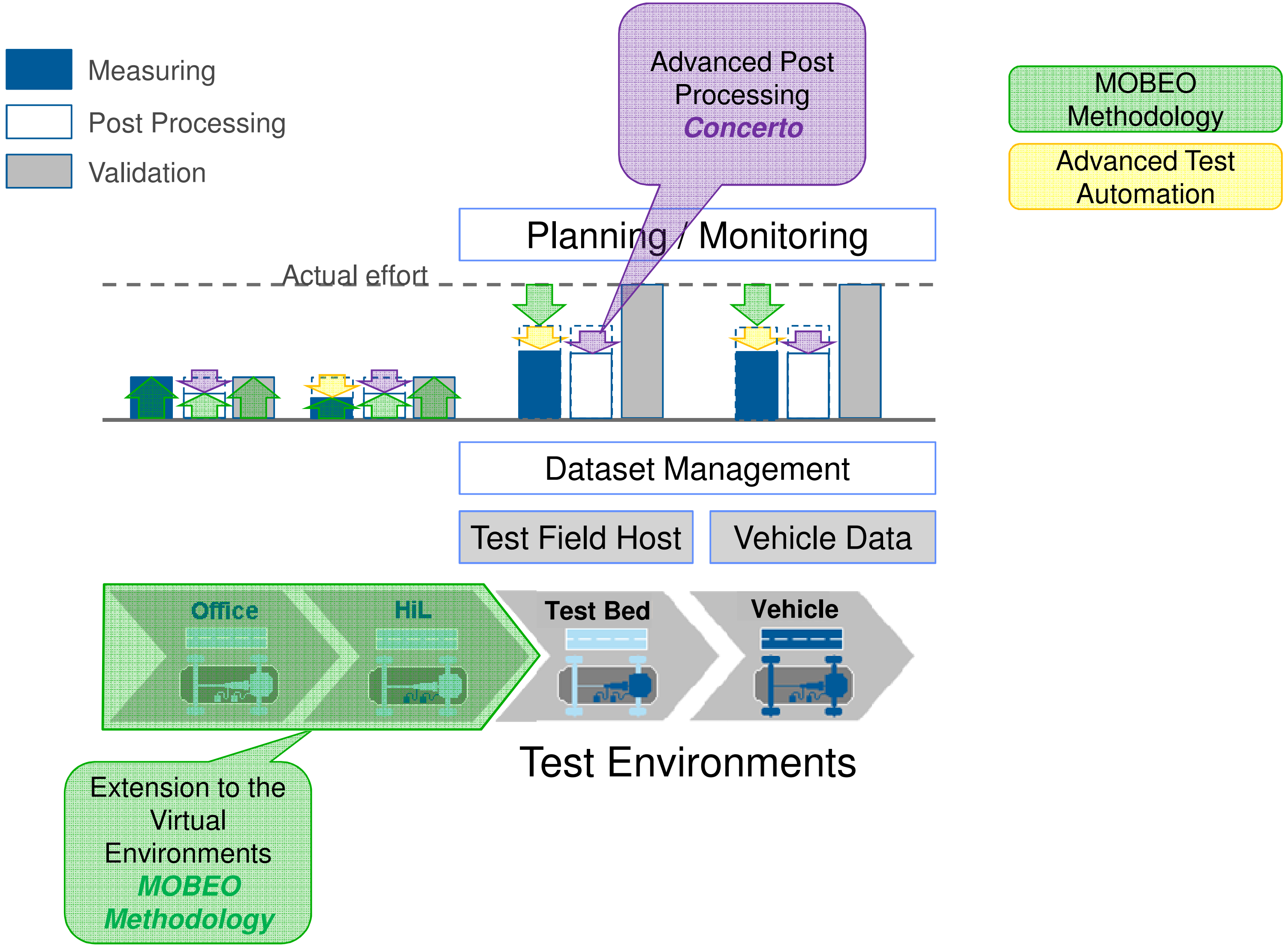
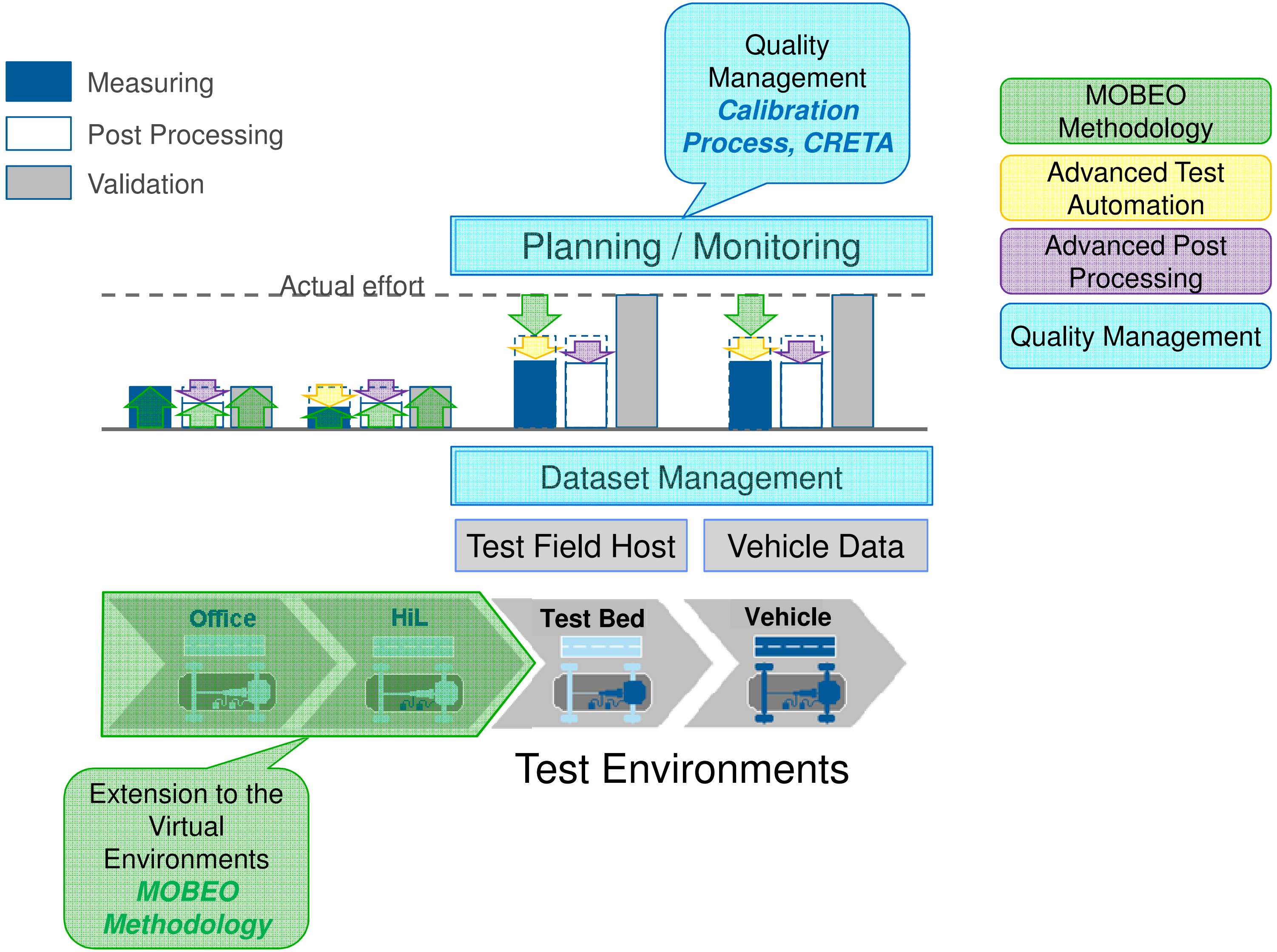
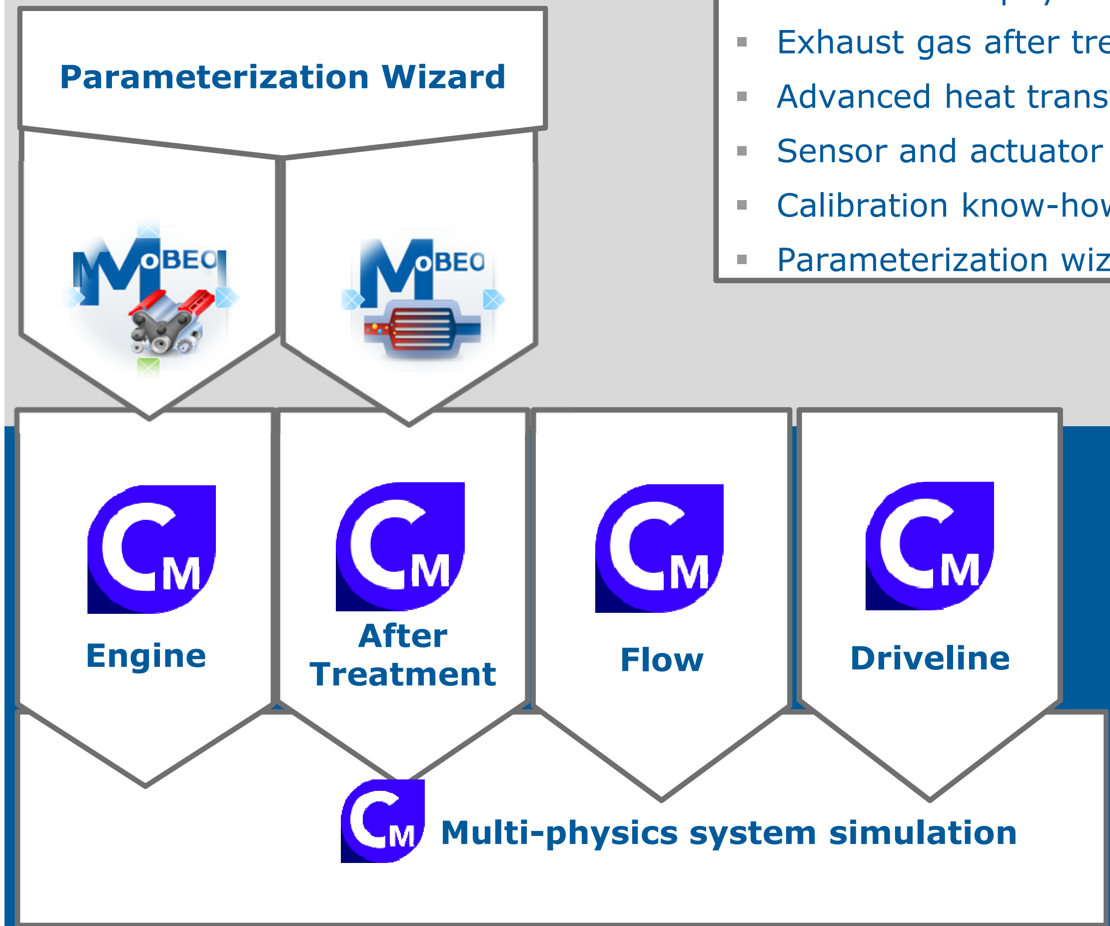


Need for Model Based Development
Front Loading: from Road to Office



Model Based Development
CRUISE M and MoBEO

MoBEO Modules



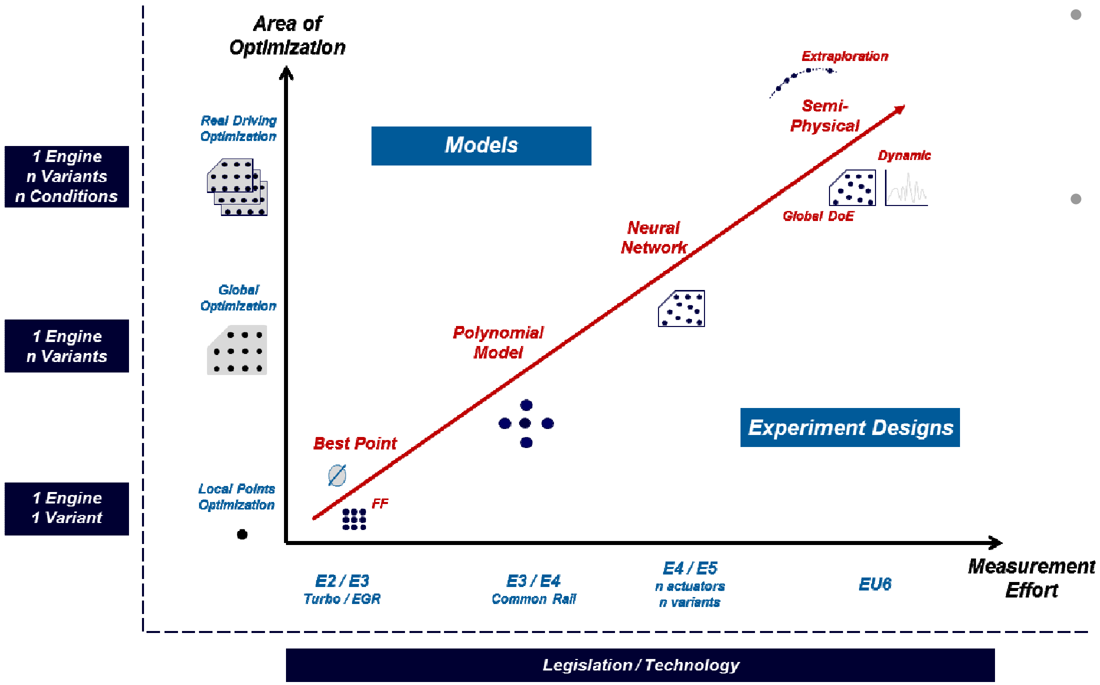
- Generic semi-physical combustion model
- Exhaust gas after treatment
- Advanced heat transfer models in the gas path
- Sensor and actuator models
- Calibration know-how included
- Parameterization wizards for cylinder and SCR

- Scalable physical modeling depth for concept, calibration and test
- Single platform for all AVL powertrain real-time models
- Open interfaces to 3rd party tools supporting standards (FMI)

MOBEO

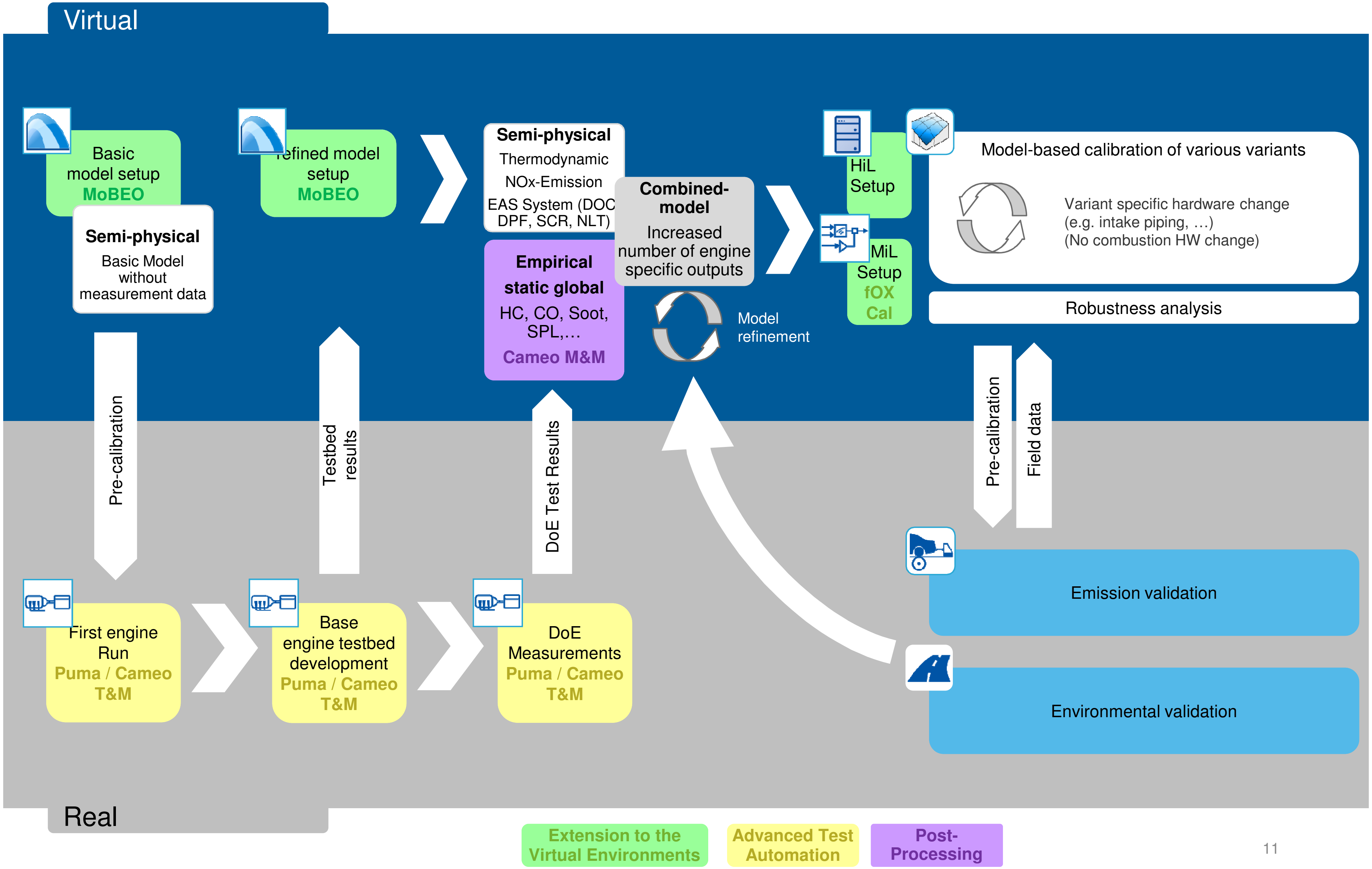
Model overview

Model Based Engine Optimization
What is it?



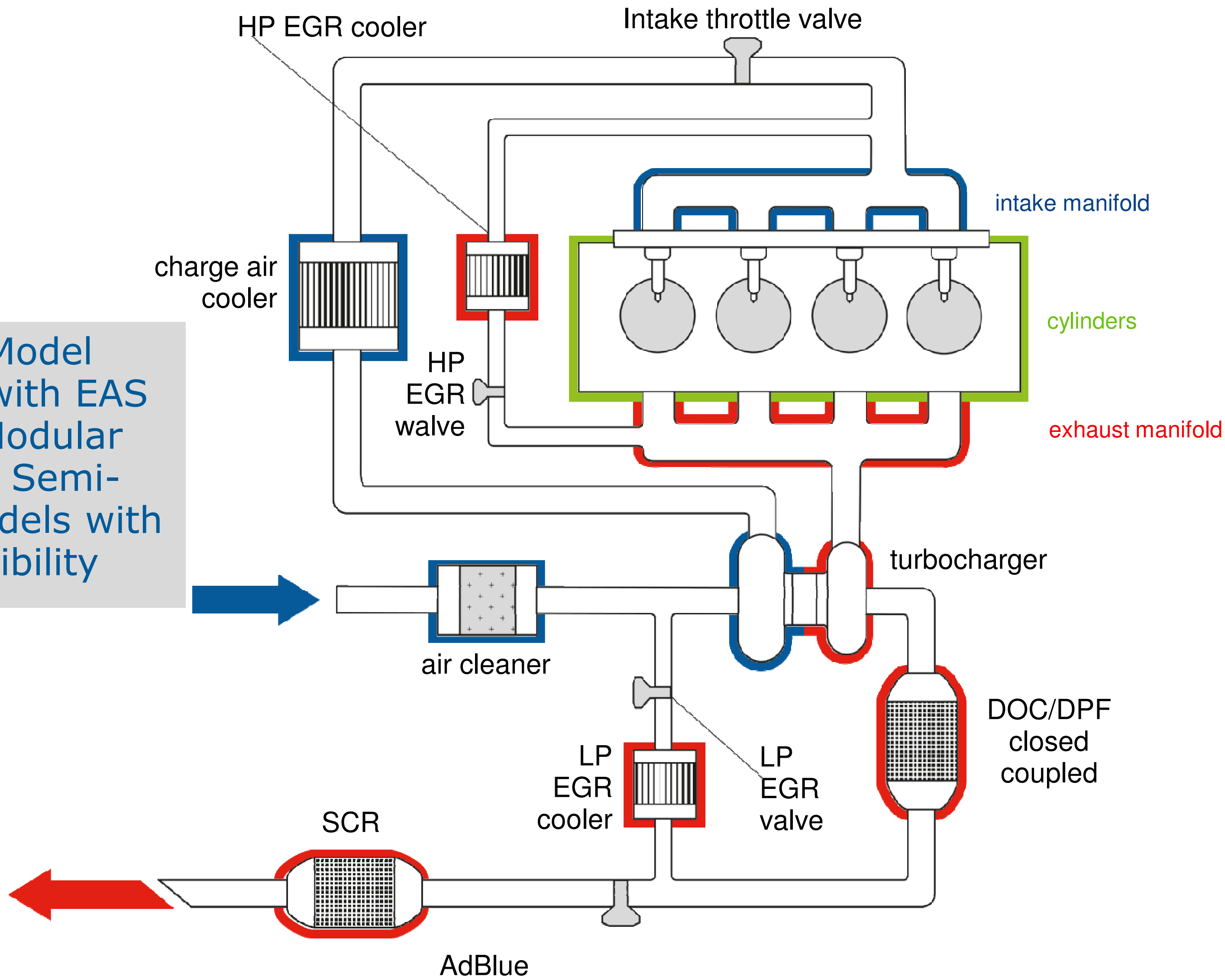
- Model based development using a **real time capable engine model**
- Starting from **concept** phase until **SOP** calibration
- Engine model based on semi-physical modeling approach
  - **→ empirical model components derived from AVL experience and test bed data**
  - **→ physical components increase the range of application due to better extrapolation**
- **Easy usability** due to the use of suitable simulation environments

Model Based Development -MoBEO
Modelling Approach

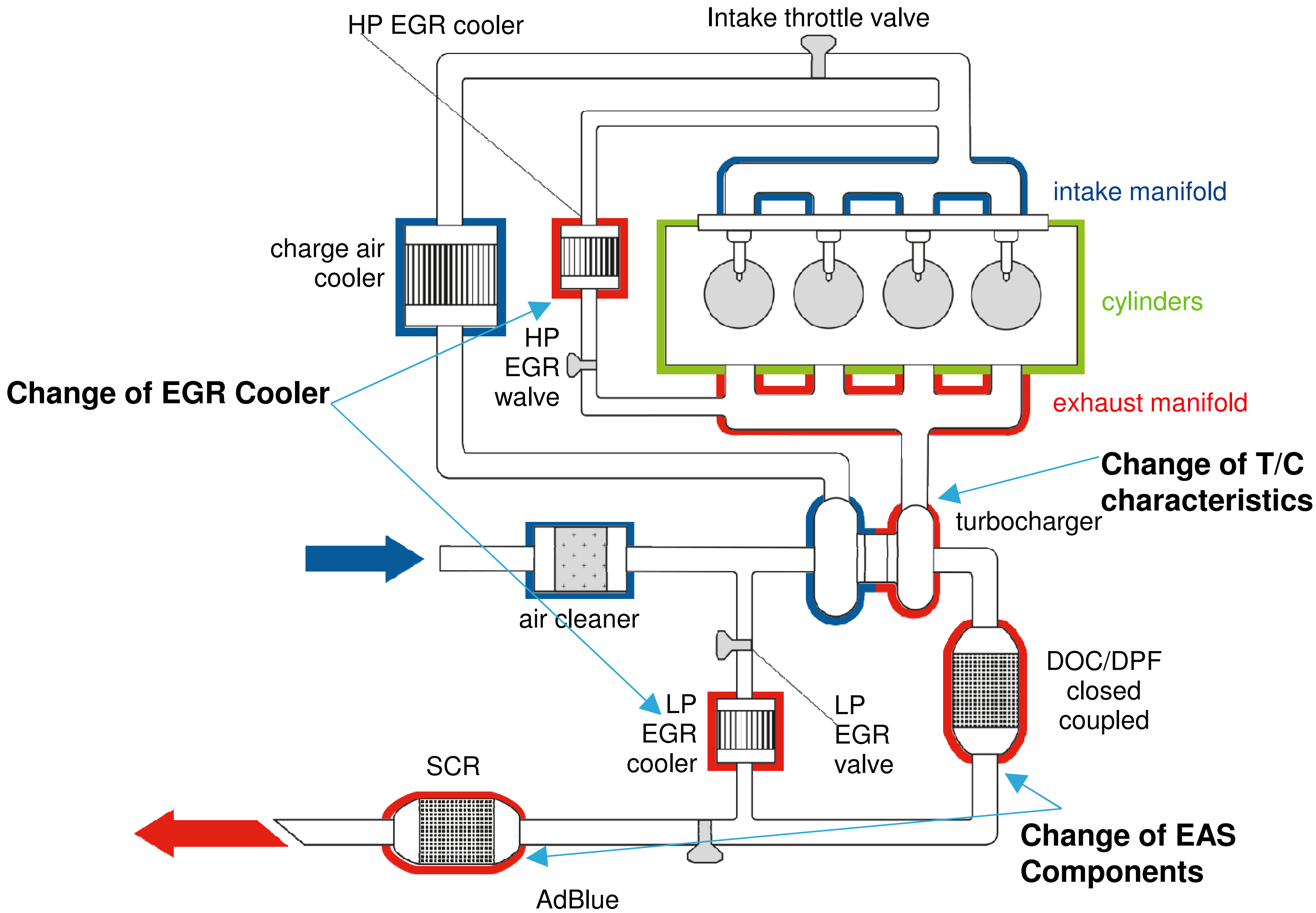


Model Based Development -MoBEO
Step 1 – Modeling EU6 Base Engine

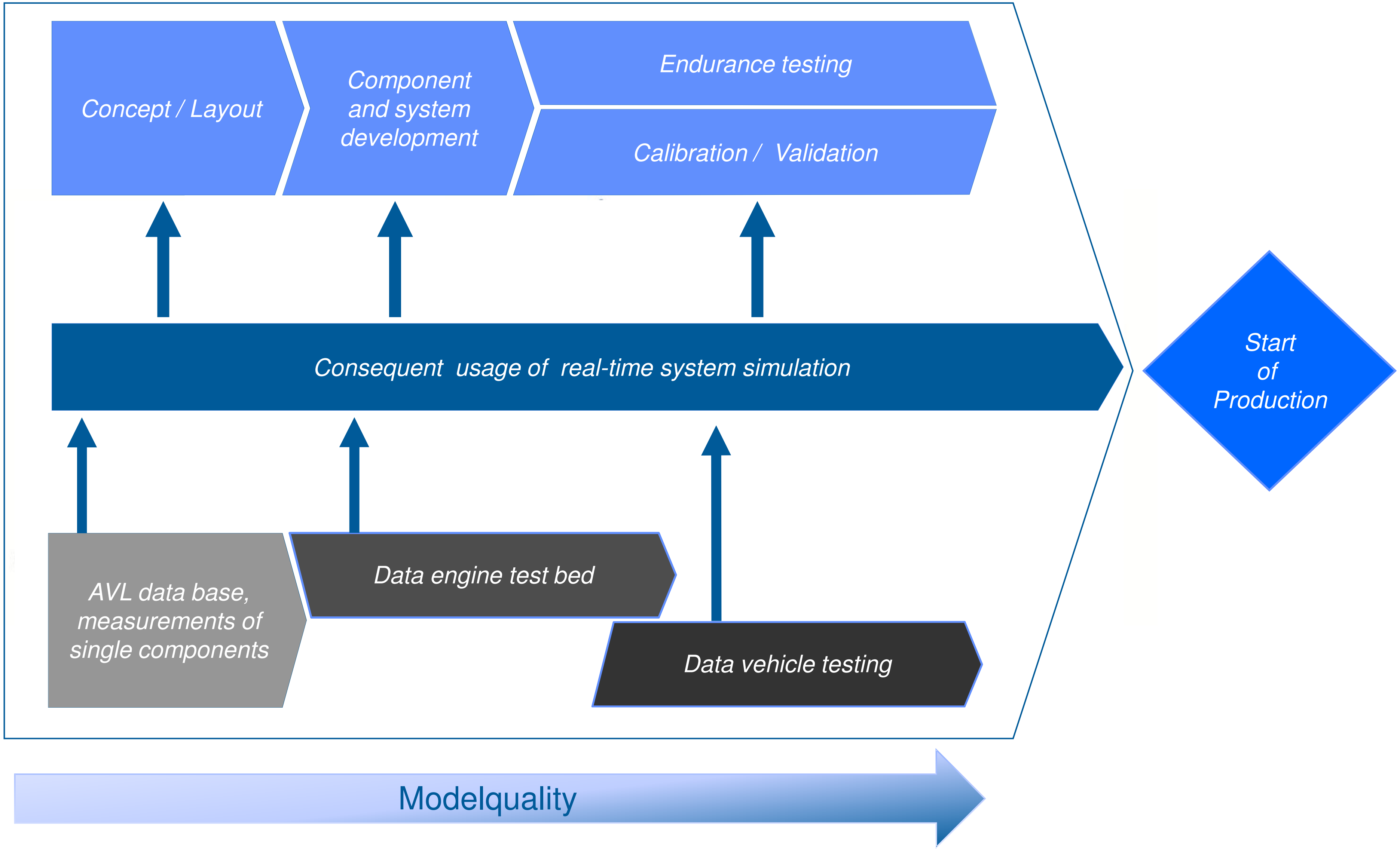
Engine Model combined with EAS Model – Modular combined Semi-physical models with high flexibility



Model Based Development -MoBEO
Step 2 – Modelling of Different Elements



Development Process
Consequent usage of real-time system simulation



MOBEO

Application environment

Changing Calibration Paradigm
The right application environment at the right time

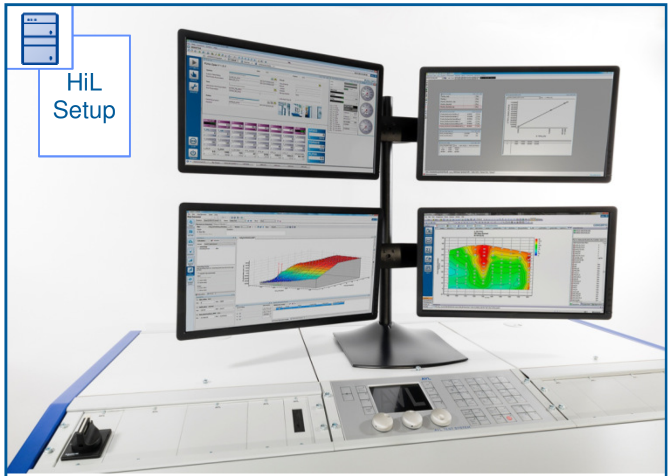
Model in the Loop (MiL)

Advantages

- \+ Simulation faster than real time (app. 5 to 10 times faster)
- \+ No hardware parts needed
- \+ Simulation on normal PC possible

Disadvantages

- \- Availability of software ECU
- \- Often not all ECU functionalities available



Hardware in the Loop (HiL)

Advantages

- \+ All ECU functions available
- \+ Pre-Calibration of all ECU functions possible
- \+ Possibility of ECU software and dataset validation

Disadvantages

- \- Only real time simulation possible
- \- Need of hardware in the loop test bed

→ Both environments can be used for pre-calibration of specific tasks

WORK ENVIRONMENTS - XIL-STATION

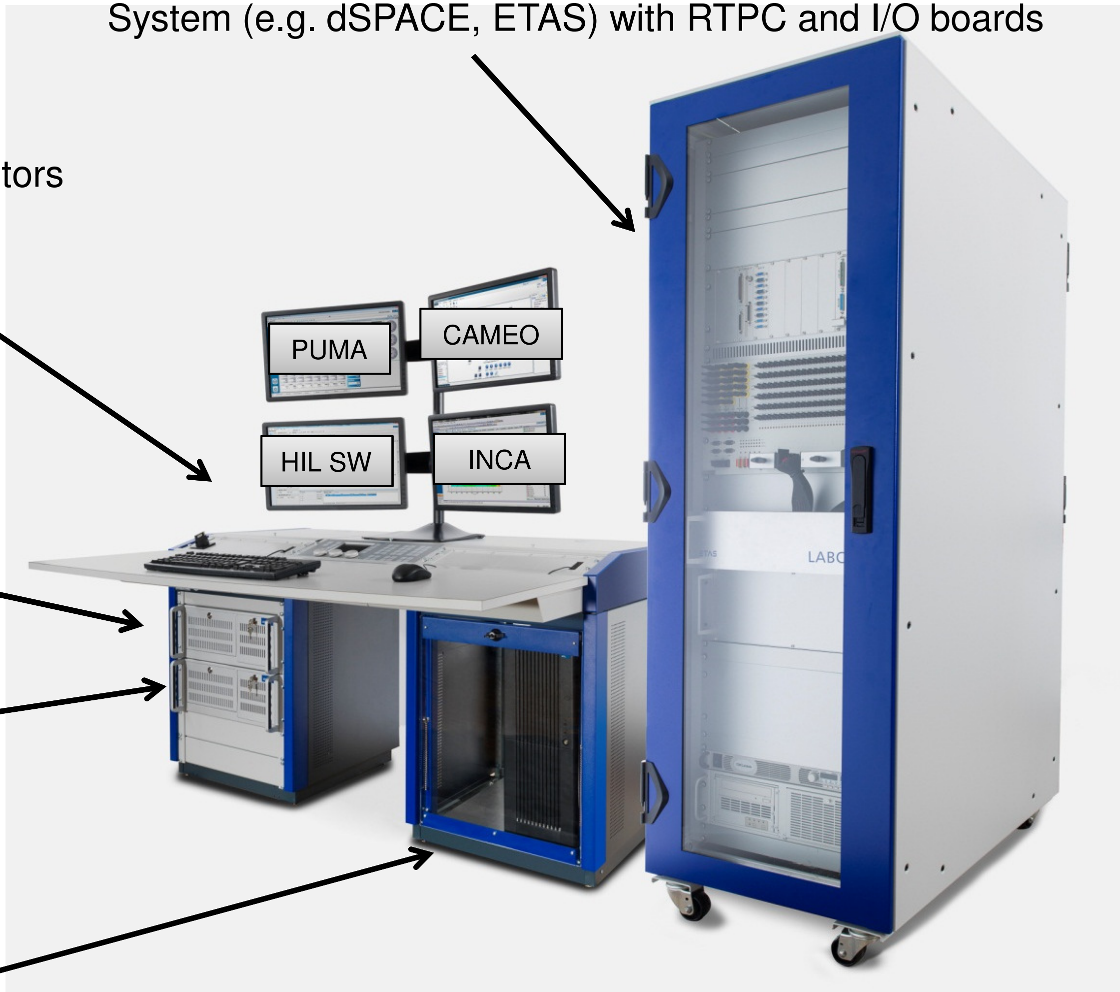
HiL Cabinet, including AVL Load-Drawer + HIL Base System (e.g. dSPACE, ETAS) with RTPC and I/O boards

Operator Station, including 4 x 24inch Monitors

PUMA Testbed Workstation

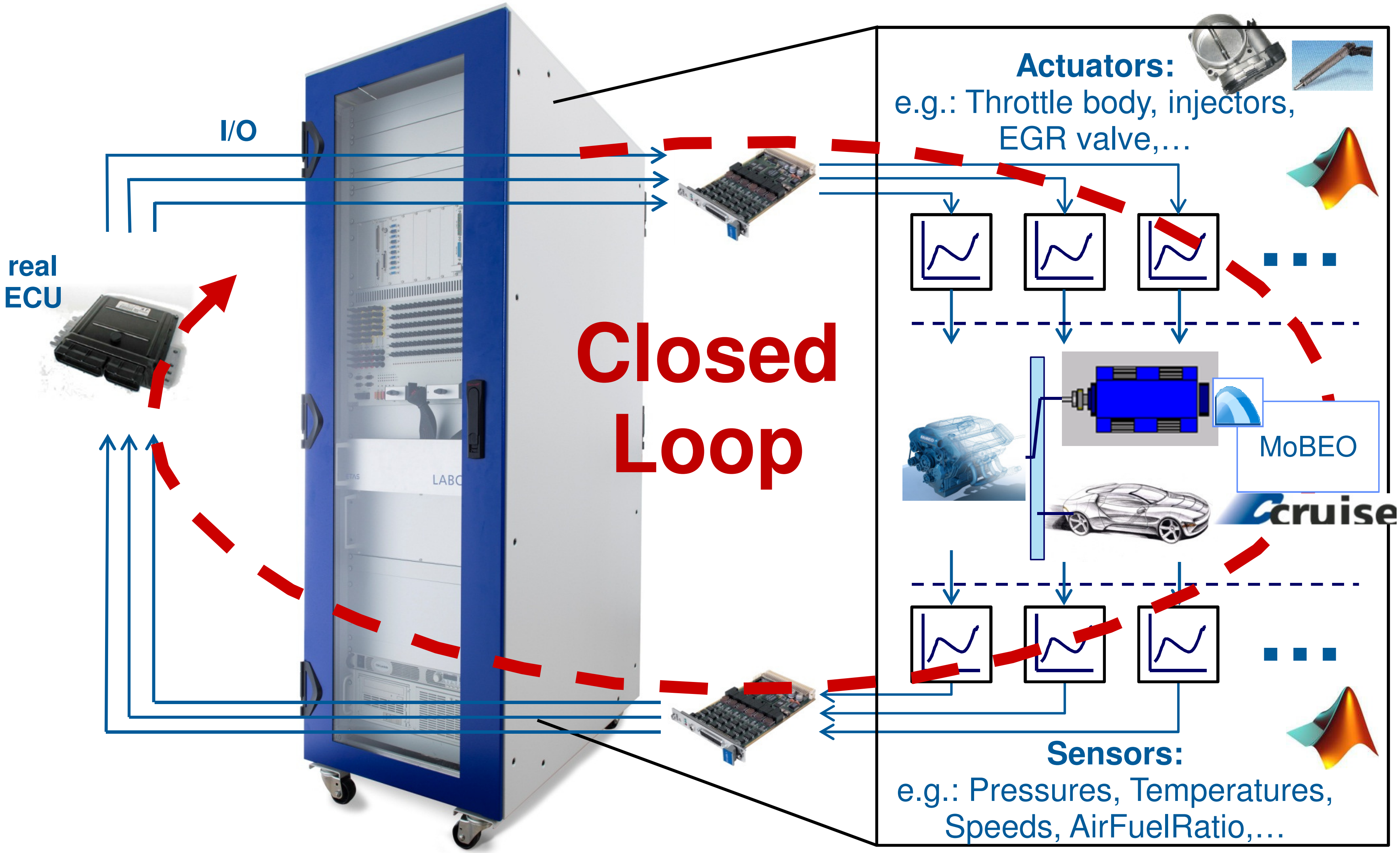
CAMEO Workstation

HiL Host PC including, HiL Operator Software and ECU Application Software



AVL Standardized HiL Simulator Concept

Real ECU & MoBEO Models in an Closed Loop



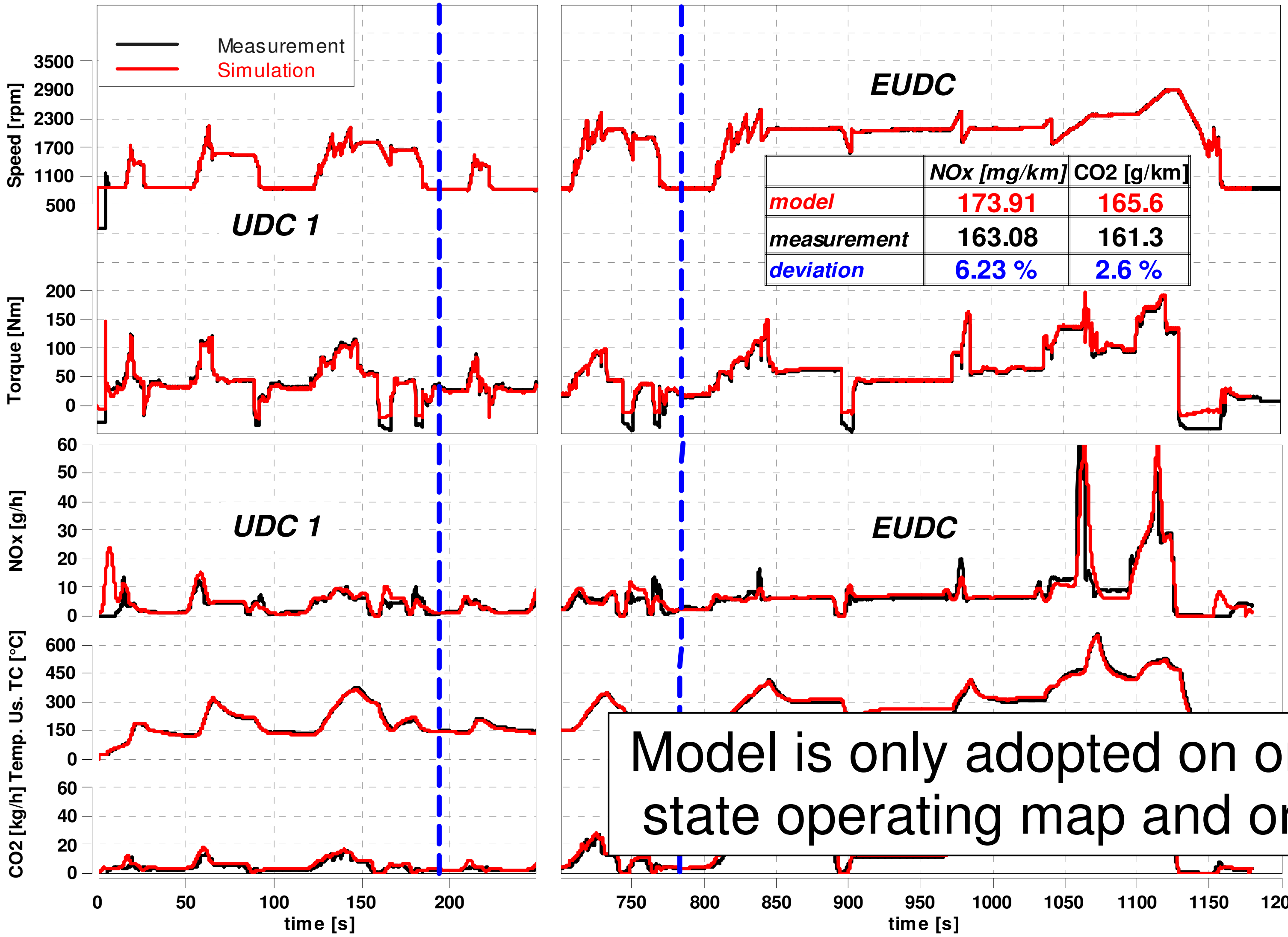
Full Size HiL System

MOBEO

Model accuracy

Model Accuracy in NEDC – Passenger Car

High model accuracy as base for model based calibration

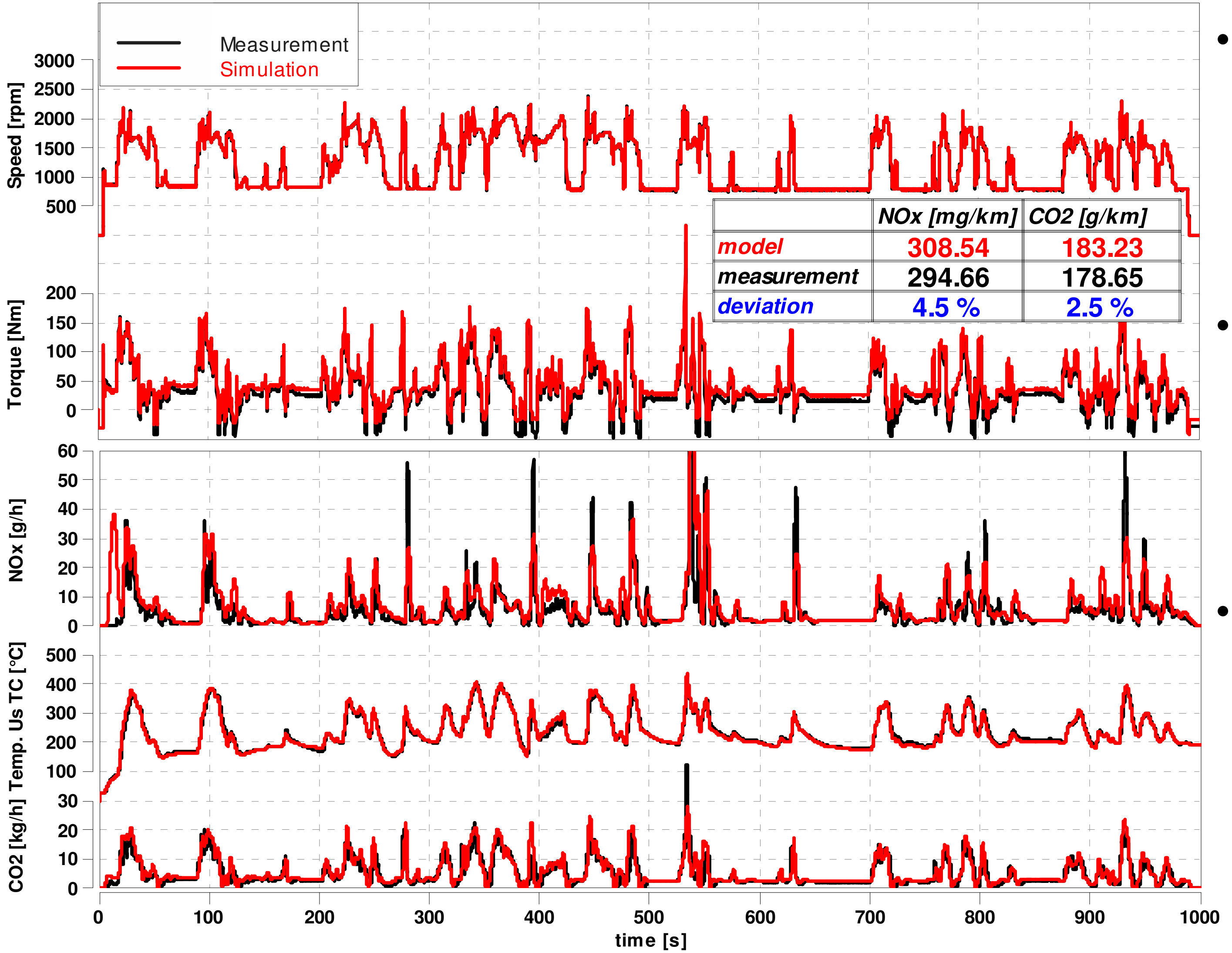


	NOx [mg/km]	CO2 [g/km]
model	173.91	165.6
measurement	163.08	161.3
deviation	6.23 %	2.6 %

Model is only adopted on one steady state operating map and one NEDC

Model Accuracy in Artemis – Passenger Car

High model accuracy as base for model based calibration

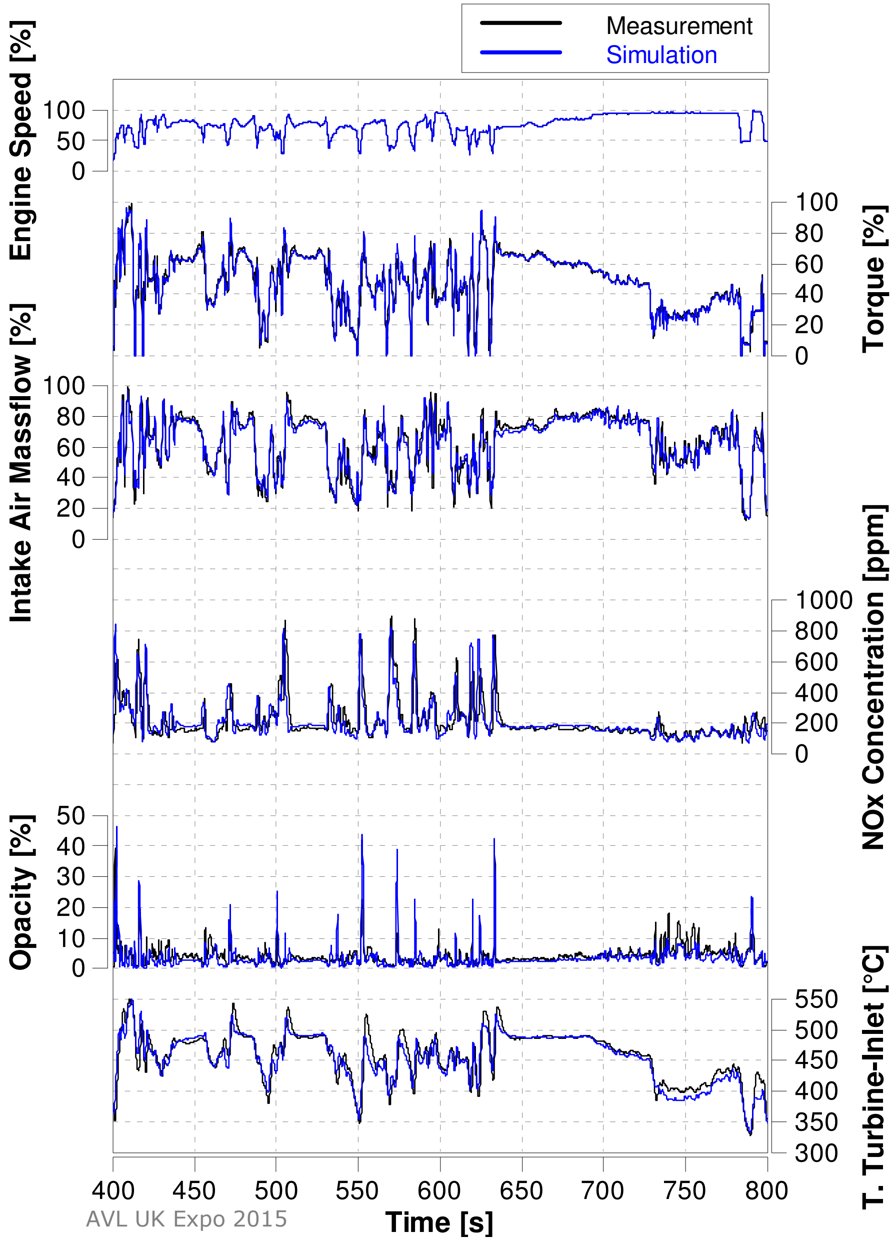


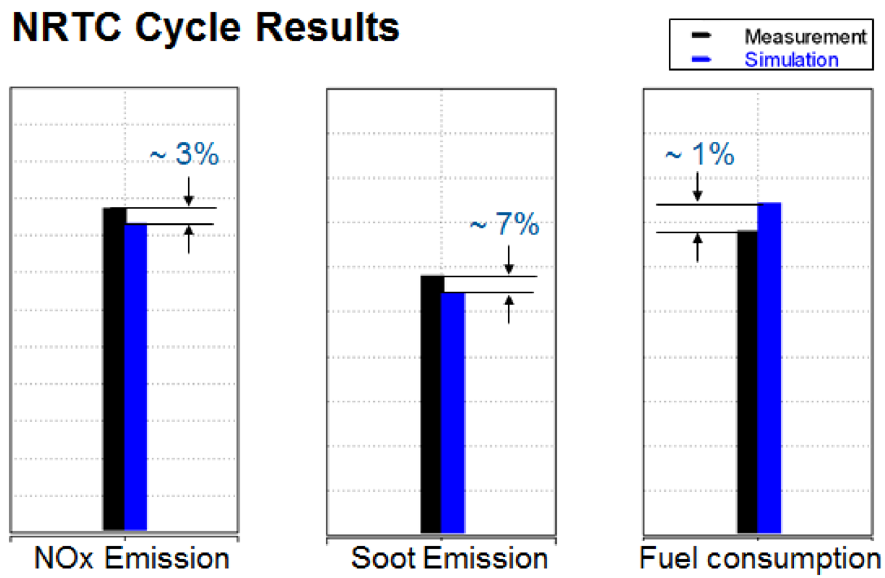
	NOx [mg/km]	CO2 [g/km]
model	308.54	183.23
measurement	294.66	178.65
deviation	4.5 %	2.5 %

- Minimal parameterization effort due to semi-physical modeling approach
- Simulation of different driving profiles without model refinement possible
- High model quality independent from calibration and operating conditions

Model Accuracy – Commercial Vehicle

High model accuracy as base for model based calibration





Typical deviations of the cycle emissions and fuel consumption as well as achievable temperature accuracy:

- Fuel Consumption < 3%
- NOx Emission < 10%
- Insoluble Particulate Emission < 15%
- Temperature Intake Side < 10°C
- Temperature Exhaust Side < 20°C

MODEL BASED DEVELOPMENT

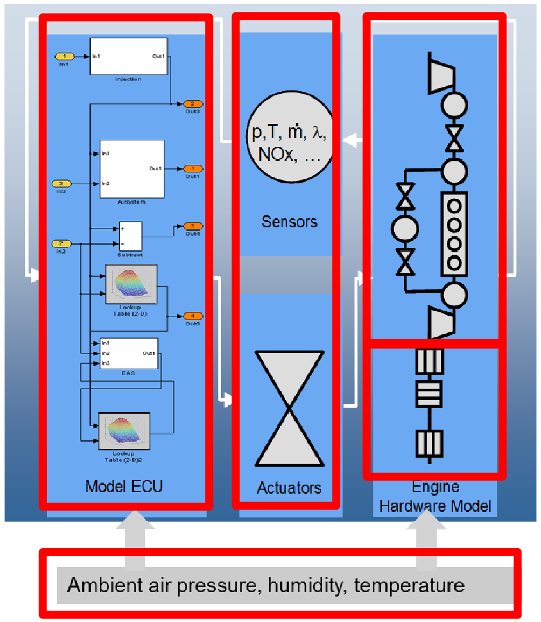
Use - Cases

Model Based Development
Concept Investigations

Model based concept investigations

- Assessment of technology route
- Simulation of transient behaviour of engine in early concept phase on MiL environment
- Definition of possible concepts considering the interaction between
  - engine
  - exhaust aftertreatment system
  - software and calibration
  - Sensors and actuators
  - environmental conditions

Vehicle & drivetrain simulation



Model Based Development
Powertrain Use cases

HW Testing & Calibration

engine & EATS modeling

Virtual Testing & Calibration

Powertrain Calibration tasks for MiL/HiL:

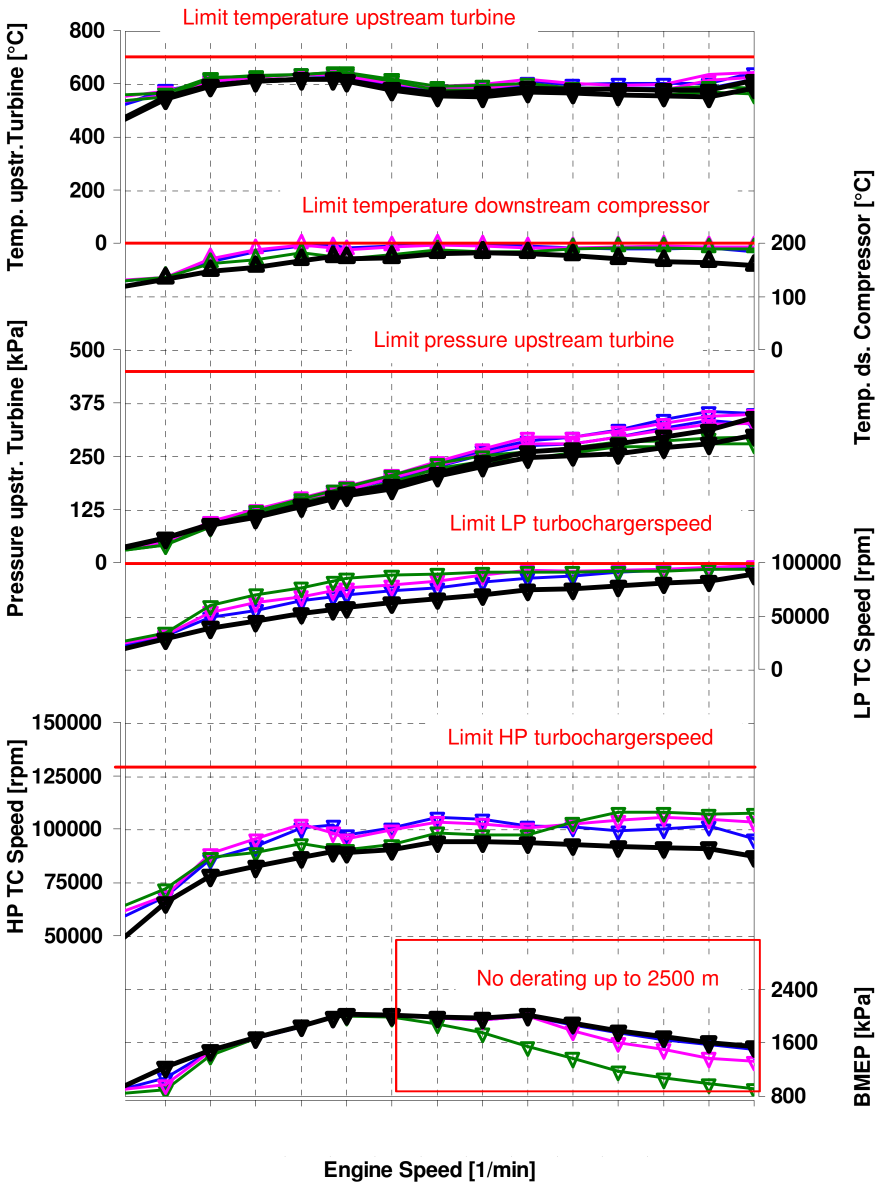
- RDE – Real Driving Emission evaluation
- EAS Simulation
- Calibration for non-standard ambient conditions
- Calibration of component protection
- In-Use Compliance - PEMS
- Sensitivity studies taking into account system interactions
- OBD – Diagnoses, IUPR
- Software and dataset validation

Model Based Development
Calibration of Ambient Corrections

Simulation of full load altitude operation for validation of ambient correction and engine protection functions

970mbar = 350m (Graz)
750mbar = 2500m
660mbar = 3500m
540mbar = 5000m

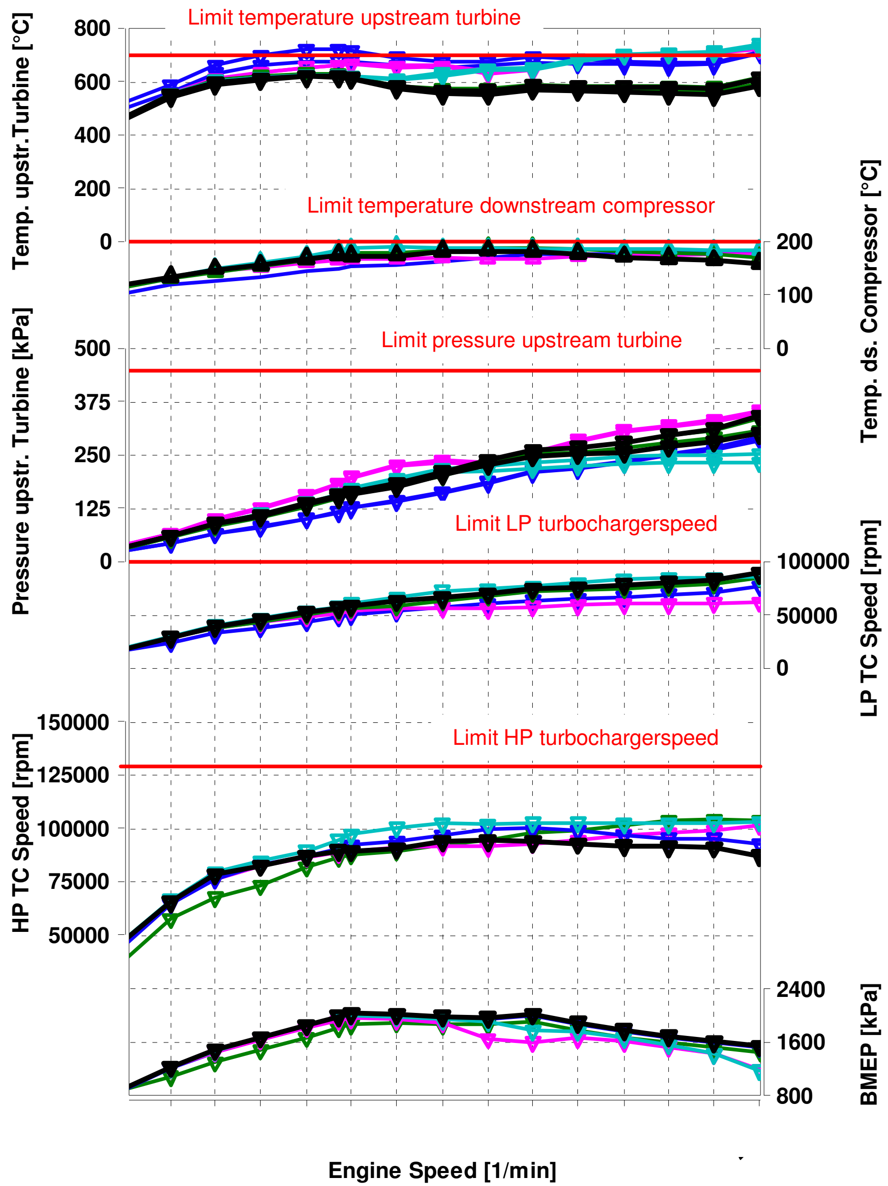
Limits for component protection



Model Based Development

Calibration of Component Protection Functions

Simulation of engine failure at full load for validation of engine protection functions



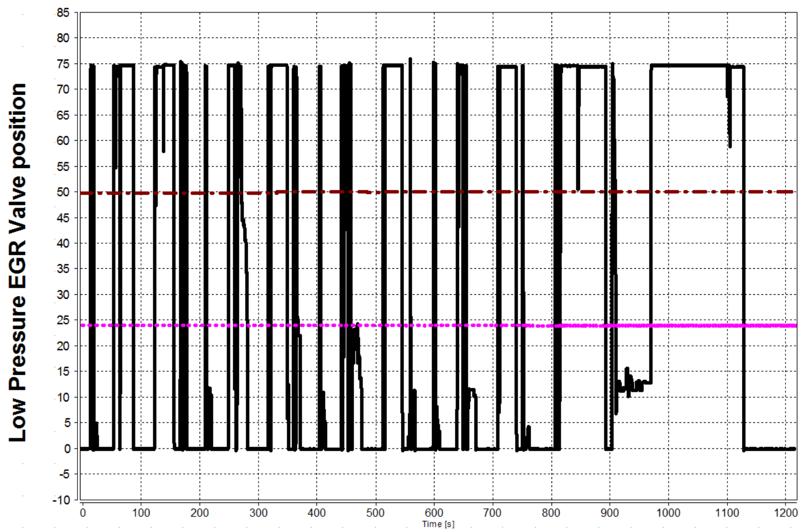
—	5% leakage downstream turbocharger
—	25% leakage downstream turbocharger
—	50% exhaust restriction
—	50% intake restriction
—	Baseline

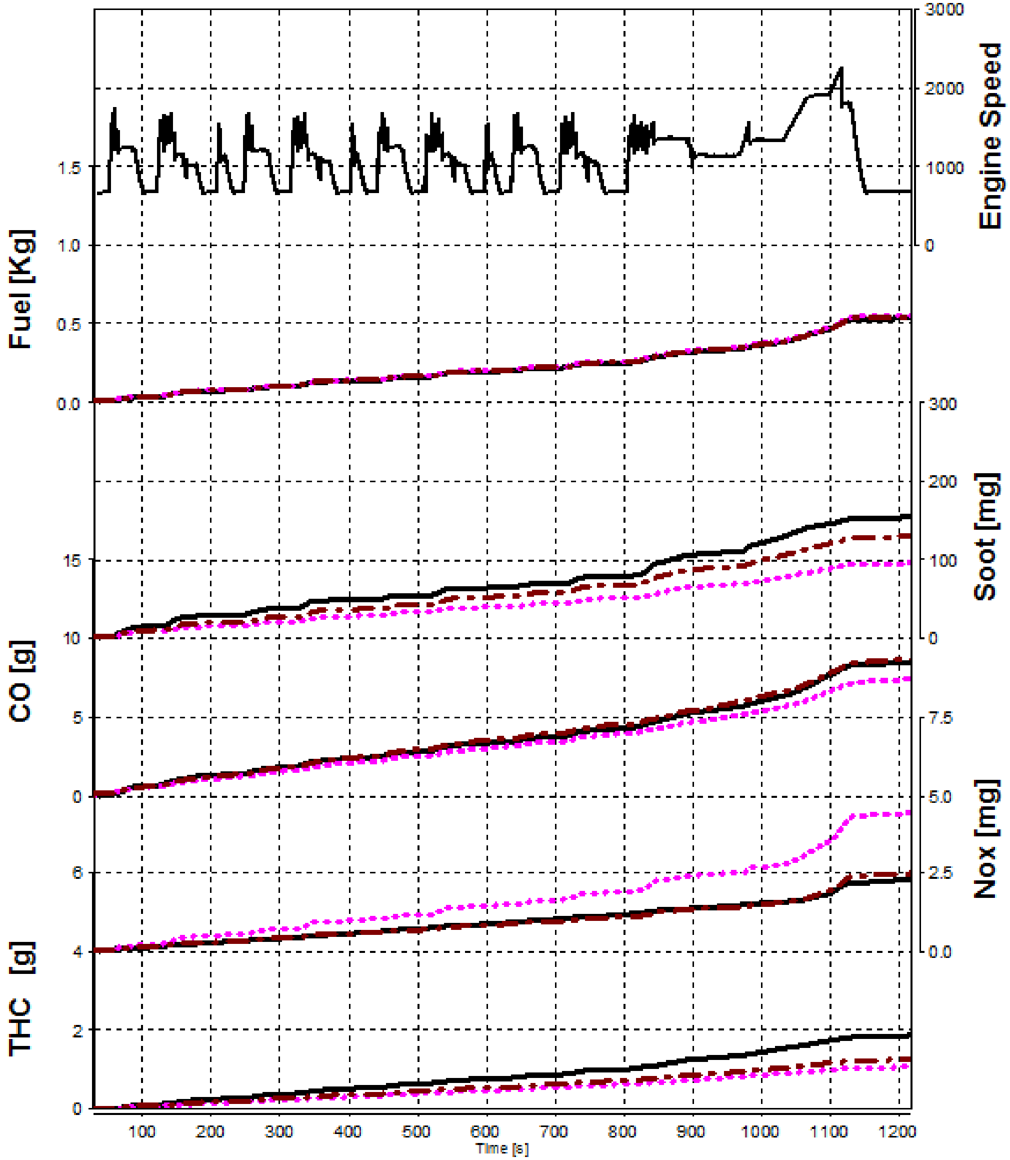
Limits for component protection

Model Based Development
OBD validation

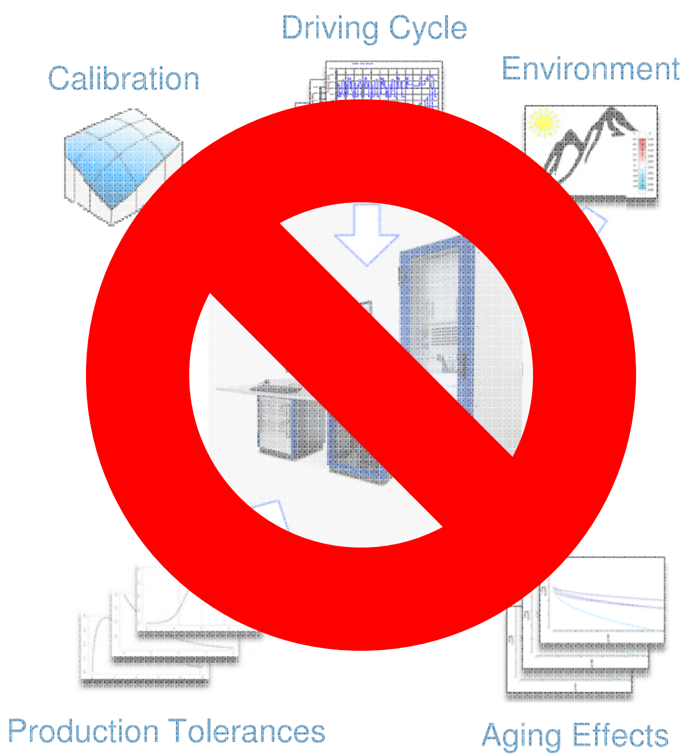
Simulation of Low Pressure EGR valve struck

Low Pressure EGR Valve - Normal
Low Pressure EGR Valve - struck @ 25%
Low Pressure EGR Valve – struck @ 50%





Model Based Calibration on XiL - test beds
Virtual Test Beds as Extension of Real Test Facilities



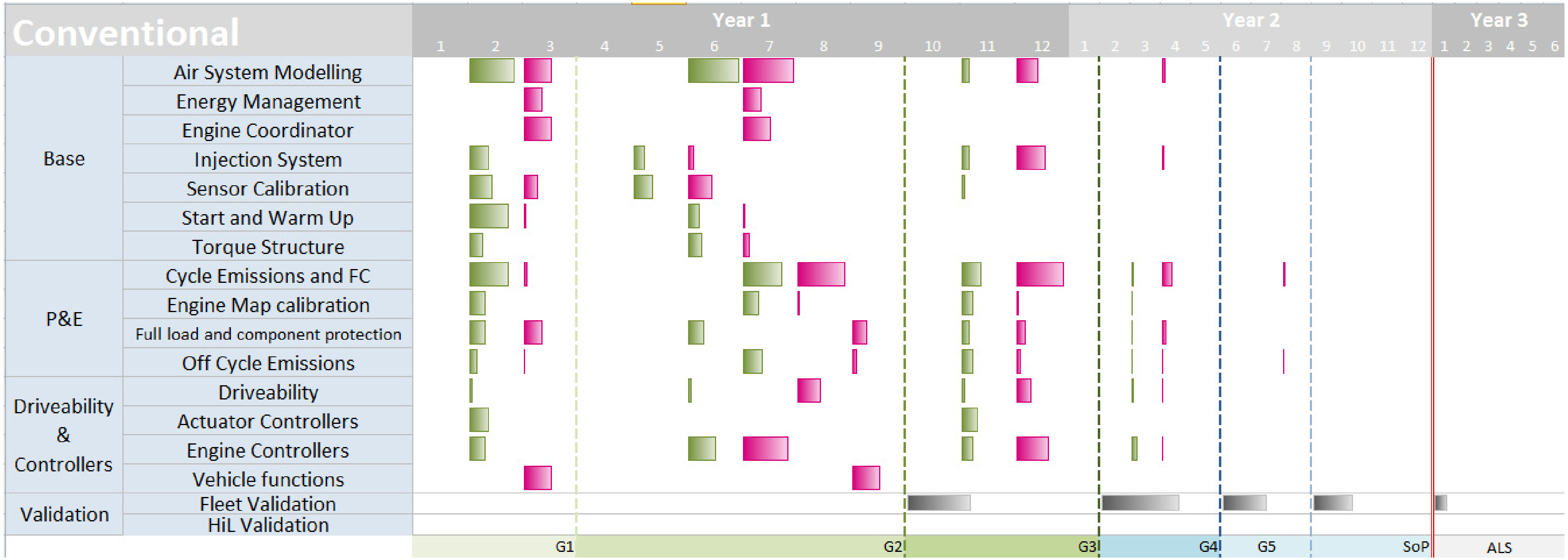
Boarders of applicability for HiL test bed

- Final Calibration Validation
- Certification
- Durability testing
- Pre-calibration of Start and Cold Start
- Idle stability
- Missfire

Model Based Calibration on XiL - test beds
Front Loading

Ideal Lead Variant Calibration Project (i.e. no relevant H/W changes)

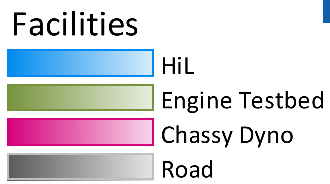
Facilities
- HiL
- Engine Testbed
- Chassy Dyno
- Road

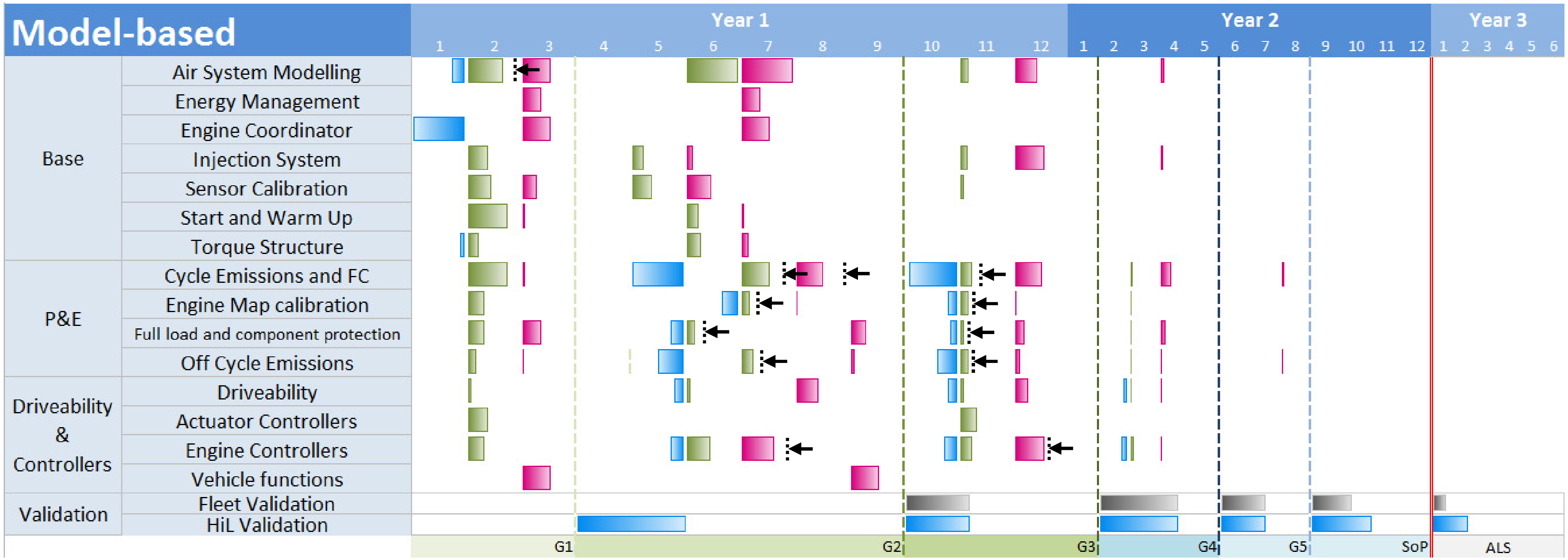


Model Based Calibration on XiL - test beds

Front Loading

Ideal Lead Variant Calibration Project (i.e. no relevant H/W changes)





Multi-variant projects can be addressed by: an extension of the test environment through HiL (MiL/SiL) Testing

- Keep calibration quality through additional HiL testing, though high number of variants
- Multi-variant simulation (calibration clustering, RDE, EAS, OBD)
- Keep test facilities usage by a feasible level
- Make environmental testing more flexible and efficient

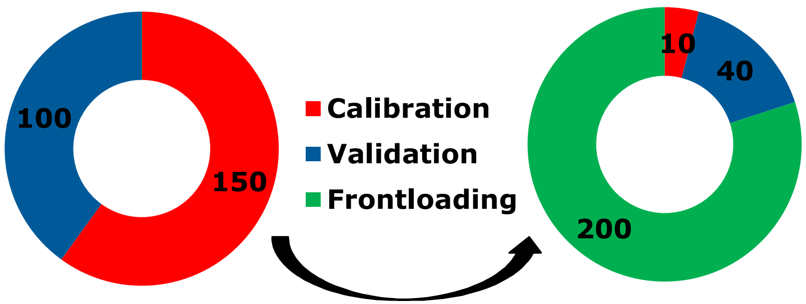
Model based calibration approach

Example based on customer feedback:

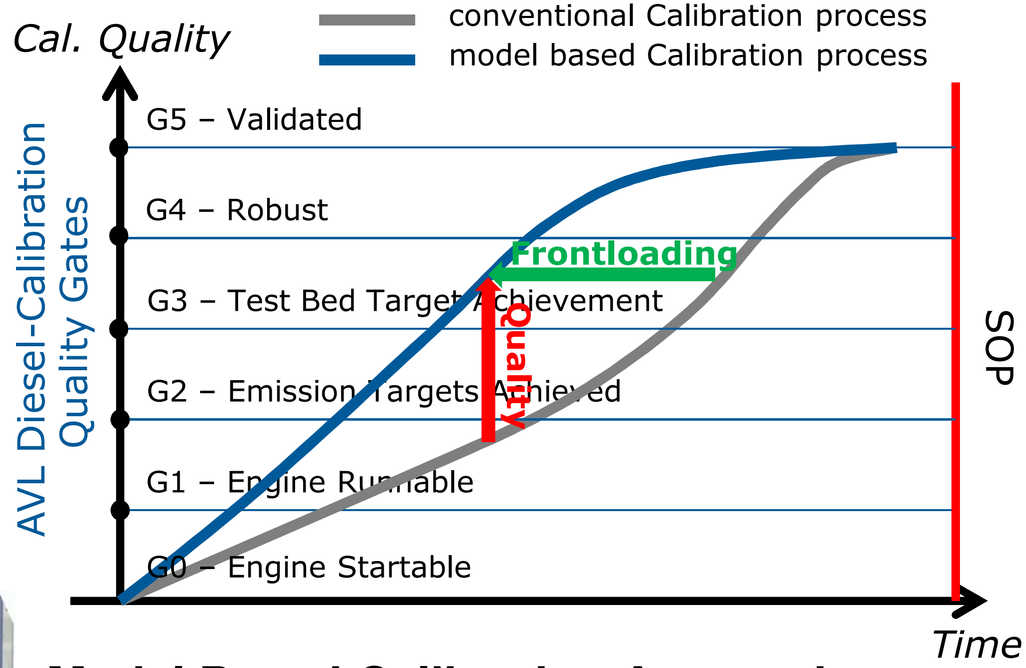
NTE, Engine Protection and Ambient Corrections (1 Mode)

Test Bed Time in Hours

Conventional Approach | **Model Based Approach**



80% Test Bed Time saved!



Model Based Calibration Approach:

- ✓ Calibration on XiL instead of Test Bed
- ✓ 80% Test Bed Time Saved per Engine Mode
- ✓ Test Bed available for Frontloading Tasks
- ✓ Dataset Quality & Maturity increased in earlier phase of Development

Changing Calibration Paradigm:
Innovative ways to increase xCU calibration quality

AVL model based development methodology is the consequent usage of real-time system simulation from concept to SOP on suitable development environments with smart calibration tools