Combustion Development Methodologies and Challenges for Smaller Boosted Engines

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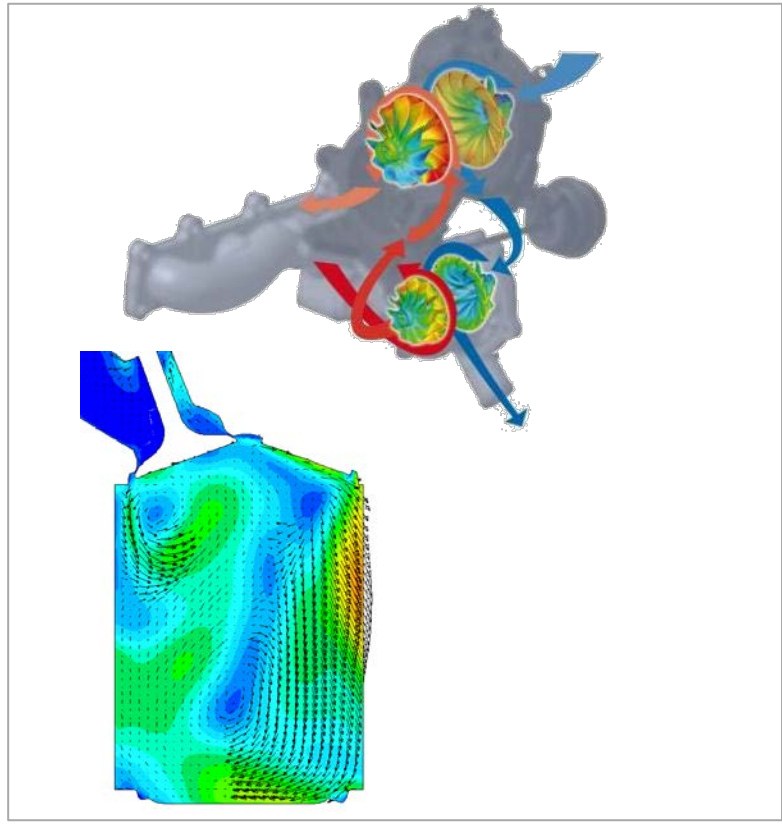

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- **Introduction**
- **Downsizing Challenges**
  - Boosting
  - Oil Dilution
  - EGR
- **Summary**

Coping with CO_2 targets: Load point shift by Downsizing

Ways of Downsizing: Smaller Displacement by

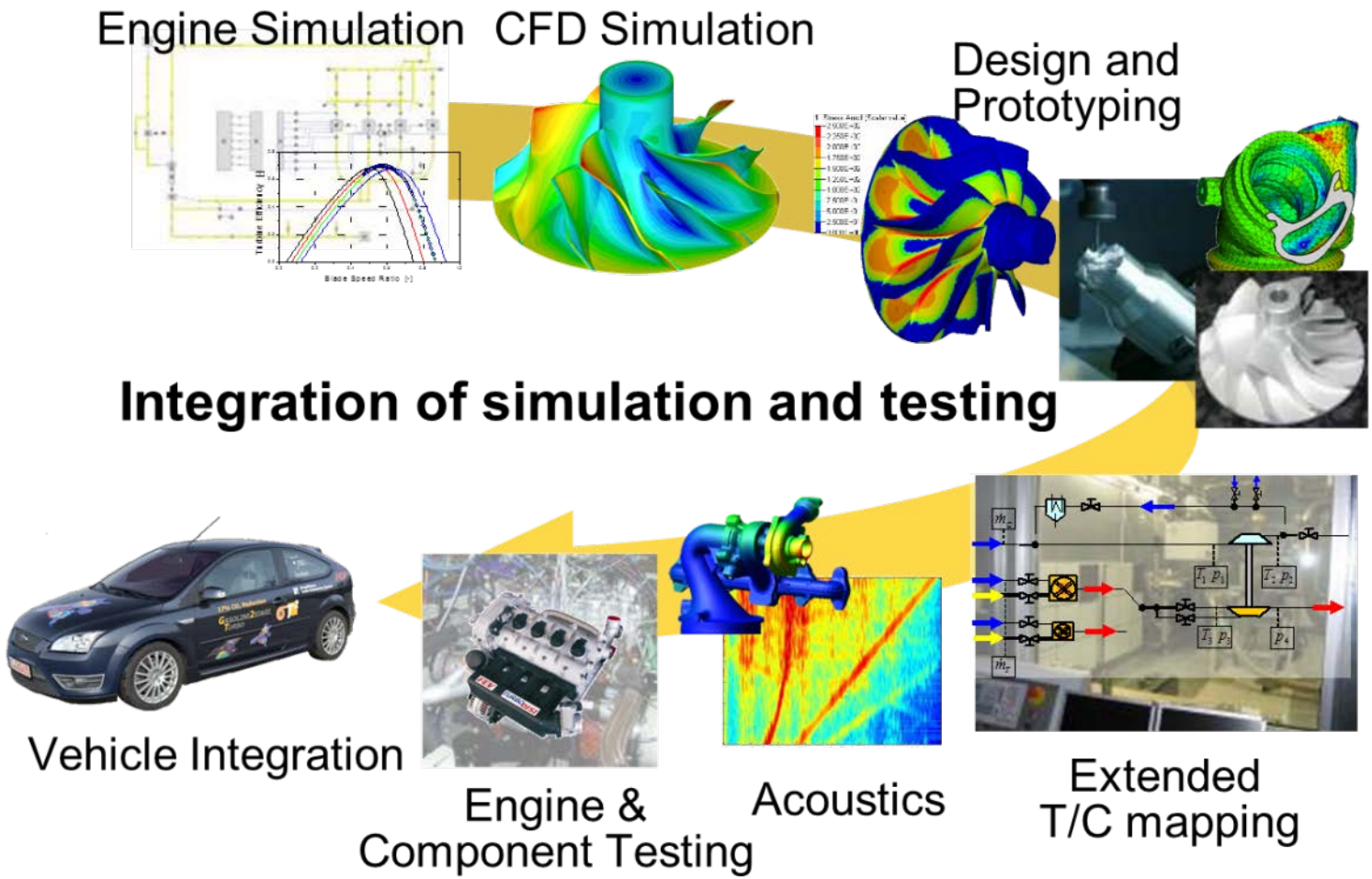
- Smaller cylinders
- Less cylinders
  - 6 → 4
  - 4 → 3
  - 3 → 2 or 4 → 2 (e.g. Fiat Cinquecento)

Engines with less cylinders expected in many places

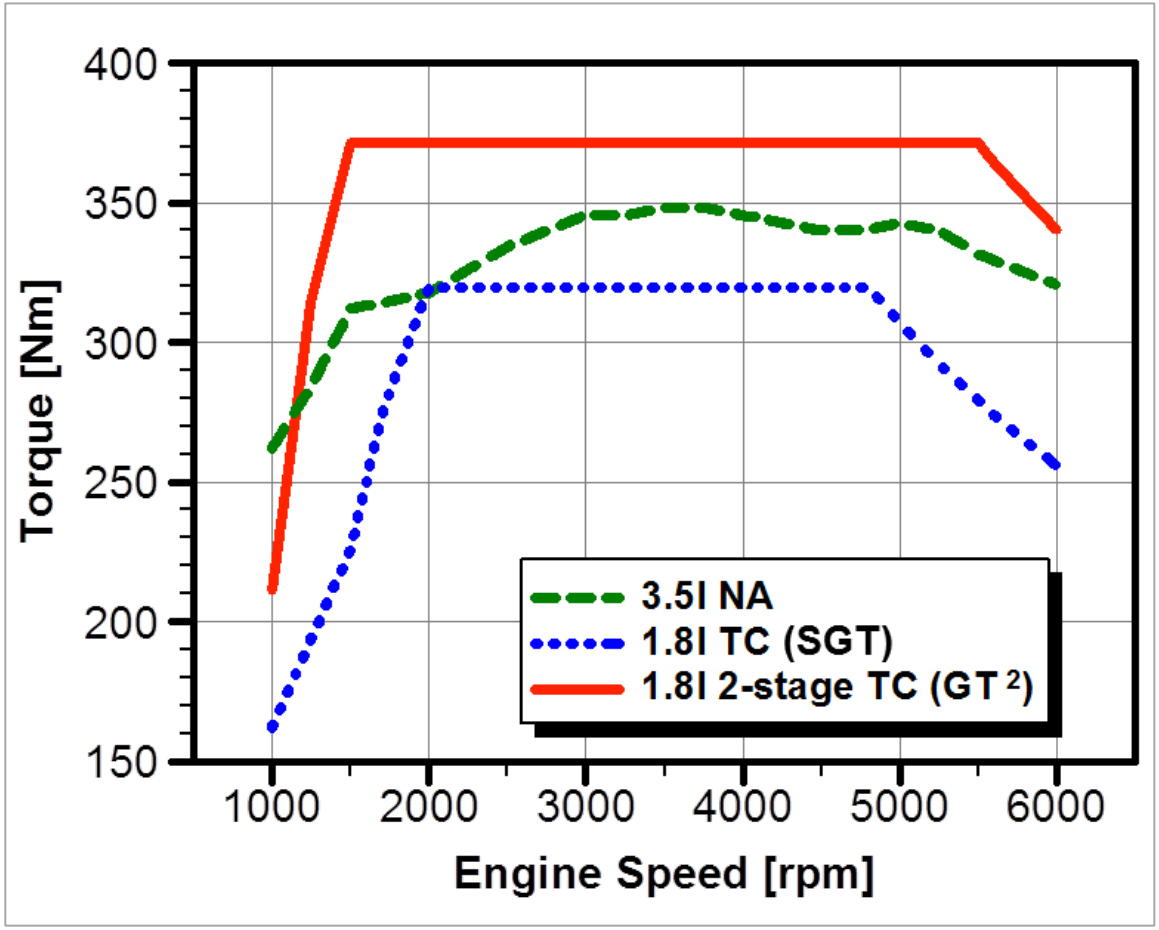
- City cars
- Compact cars
- …
- Full size + luxury vehicles: e.g. some V8 → T/C 6-cyl.

→ Cutting cylinders will be applied more frequently

Downsized Engine Boosting Tool Chain



Boosting



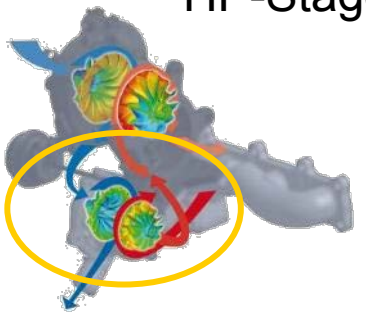
Same torque & power, smaller displacement

- Similar amount of air per cycle ⇒ air density ↑
- Single stage turbo with limited full load speed range
- 2-stage turbo or super-turbo enables larger spread from low-end to rated speed

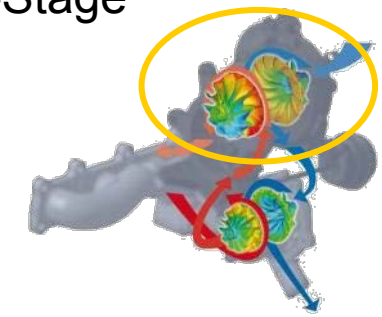
Ref.: Schernus, Wedowski, Sauerstein et al., “Vehicle Demonstrator w/ 2-stage turbo SI engine”, GT-SUITE Conf. 2009

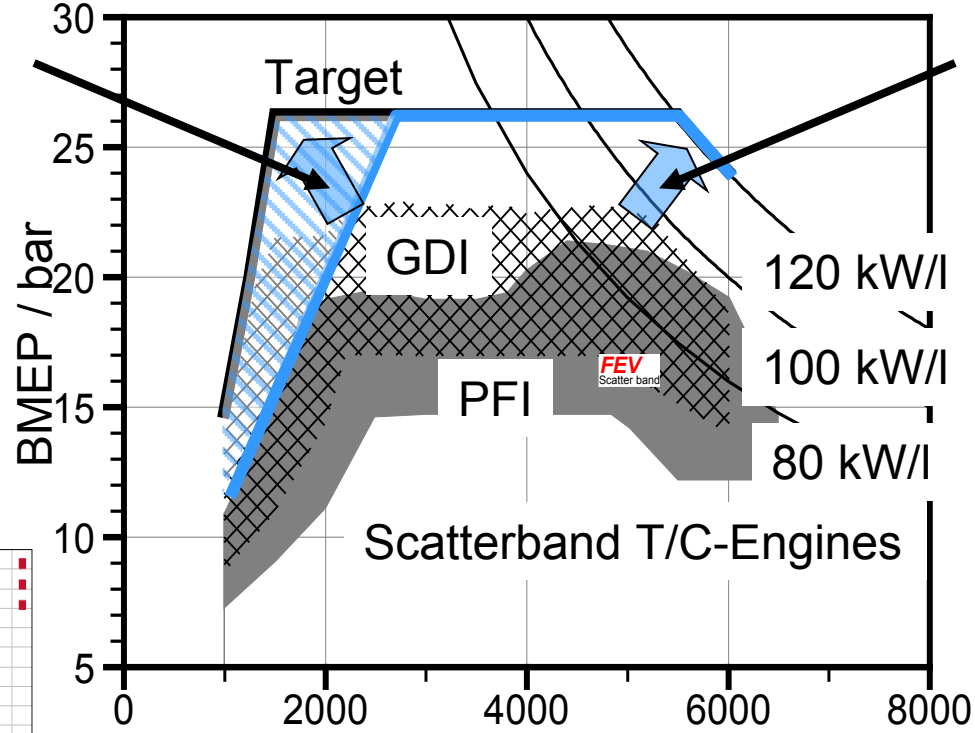
2-stage boosting ⇒ same wide-range torque and power from even smaller displacements

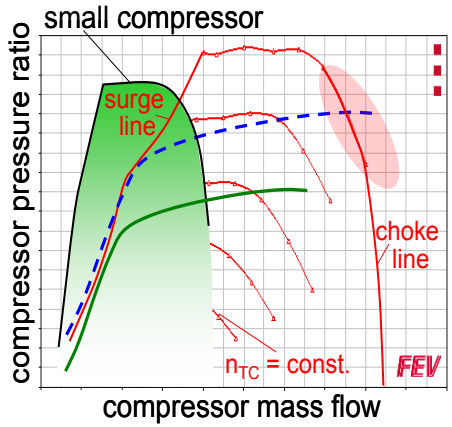
Small Turbocharger
=
HP-Stage

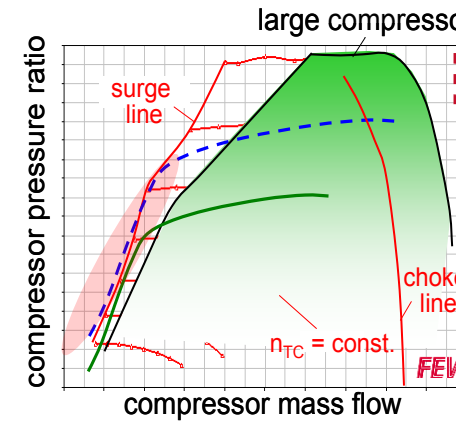


Large Turbocharger
=
LP-Stage

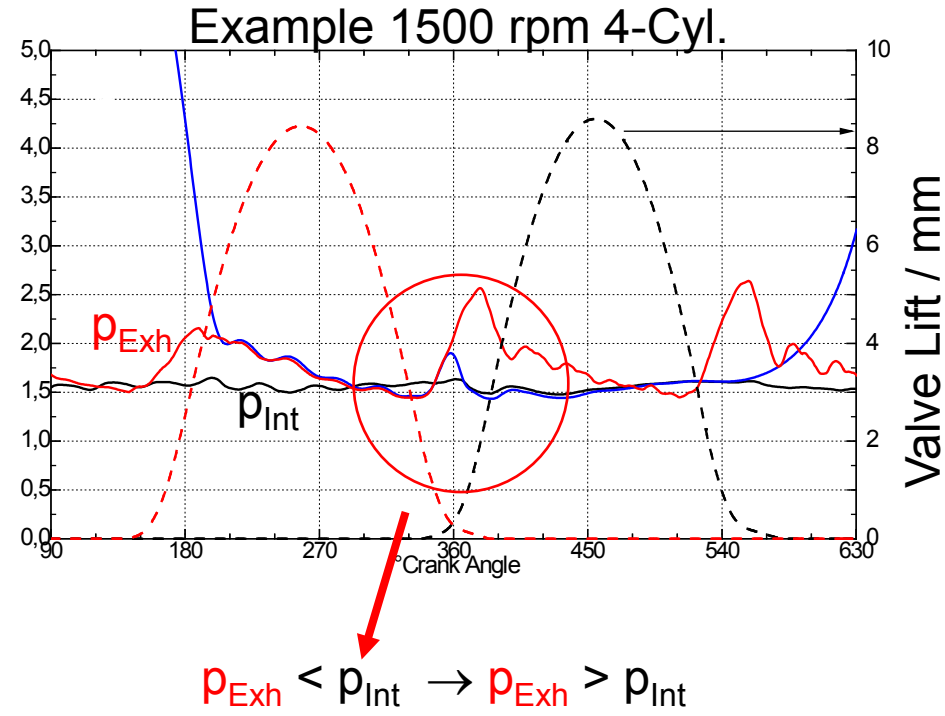








Boosting: Influence of cylinder number



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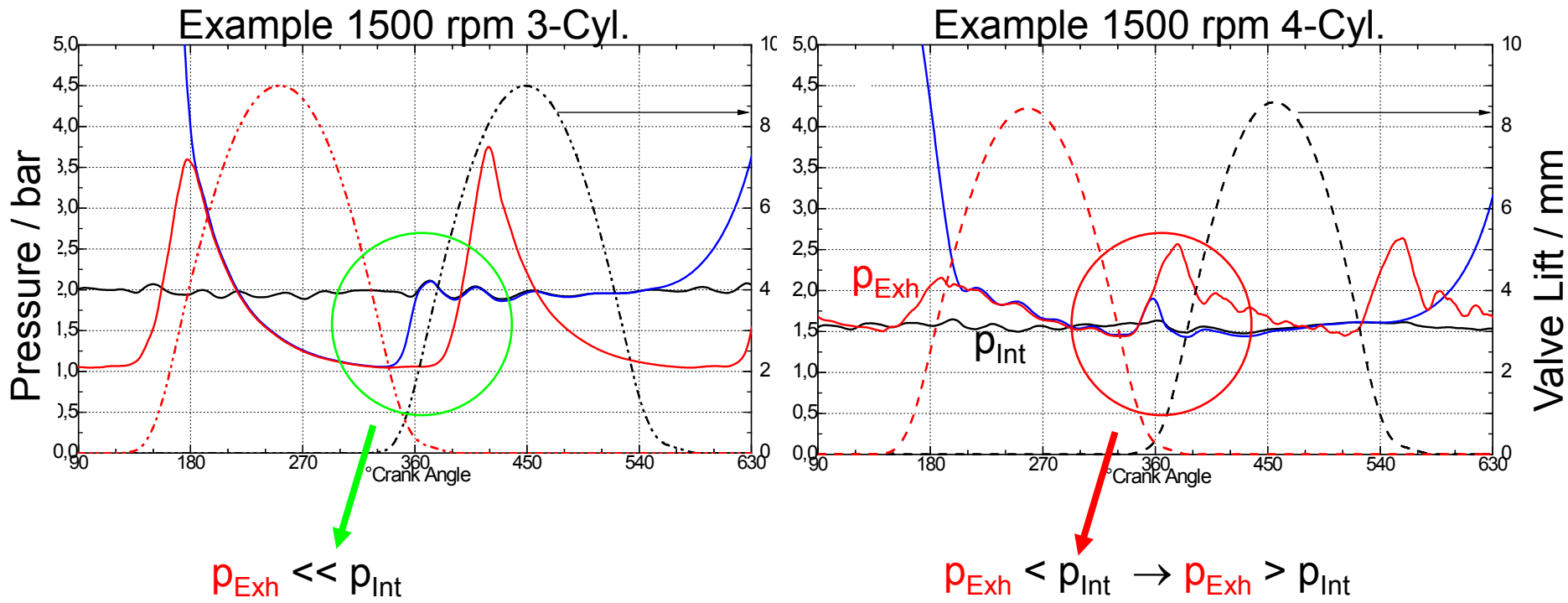
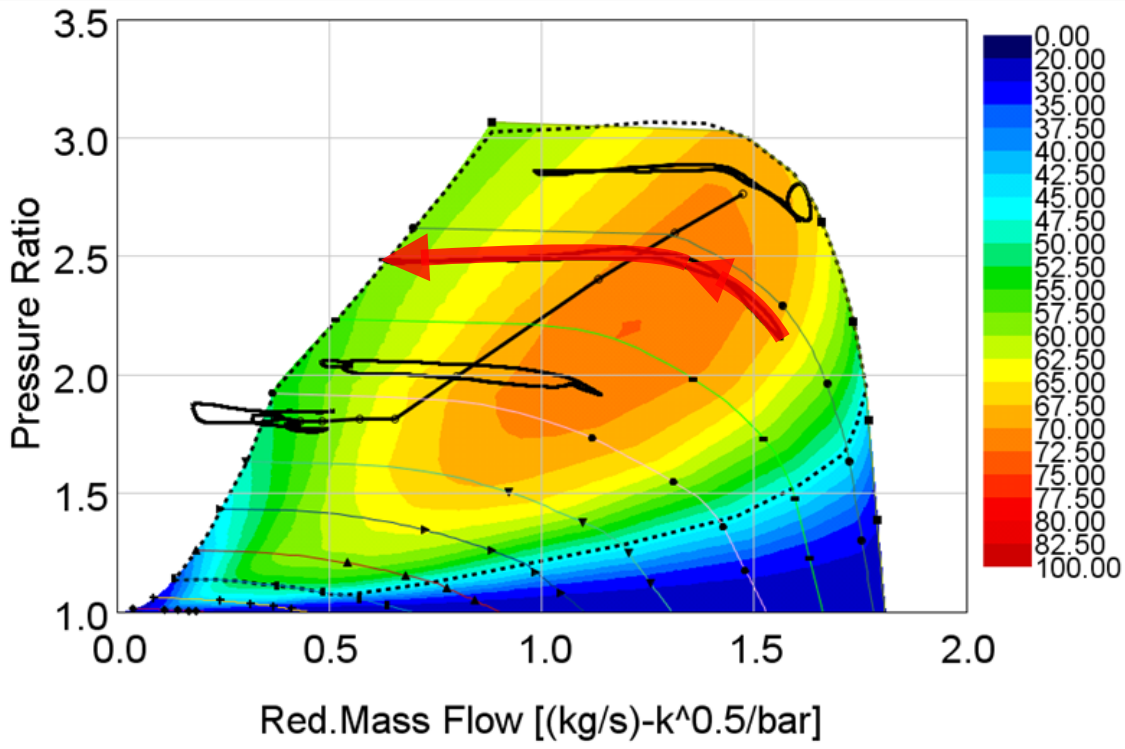


3-Cylinder engine ideal for turbocharging

- ⇒ high scavenging potential
- ⇒ very low residual gas fraction
- ⇒ good for knock mitigation

Boosting: Influence of cylinder number

Compressor loop of a 2-cylinder engine

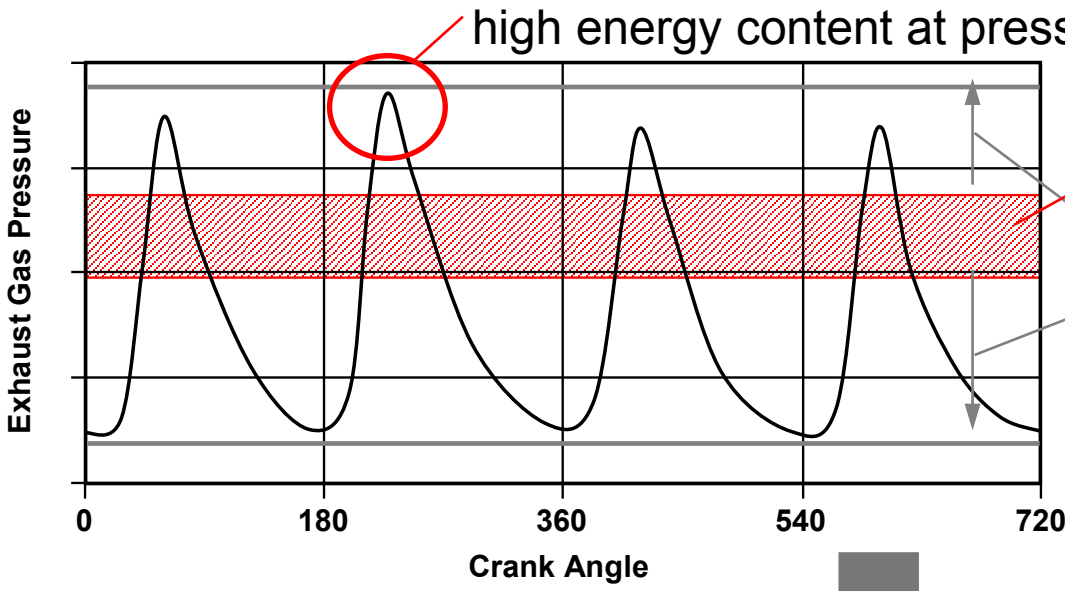


Less than 3 cylinders:

- Discontinuous sequence of intake strokes
- Turbo compressor operating point shifts toward surge in breathing pauses
- Counteraction increasing intake volume delays response
- Supercharger alternative solution for PR ≤ 2.5

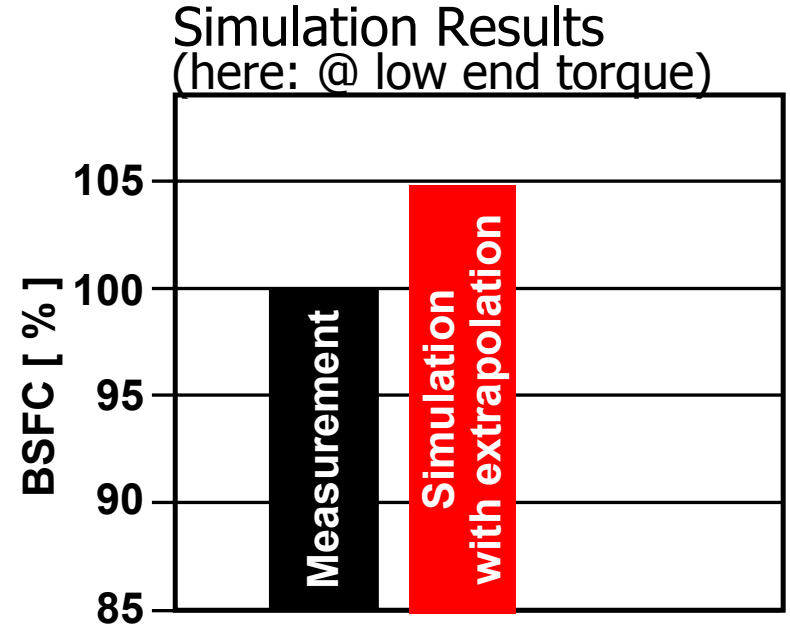
Boosting small cylinder numbers requires special attention

Boosting: Turbo Maps
Pressure pulsation of a 4 cylinder engine



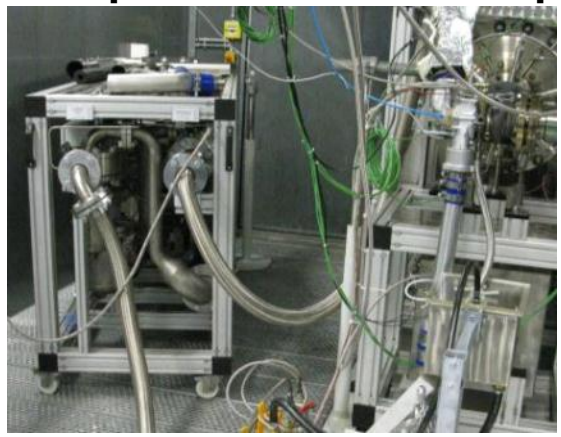
- Simulations play an important role in TC engine development
- Proper input data required

Extrapolation ⇒ simulation errors

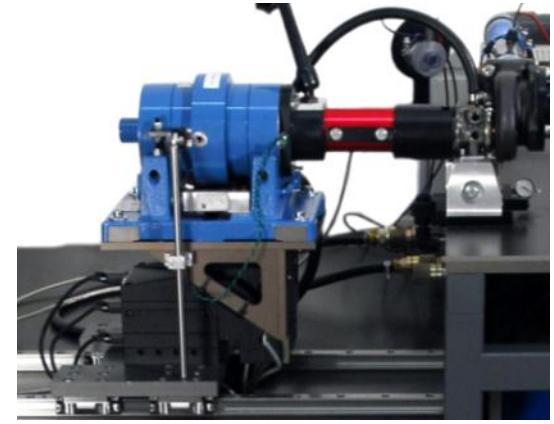


Extended Turbine Mapping Toolkit

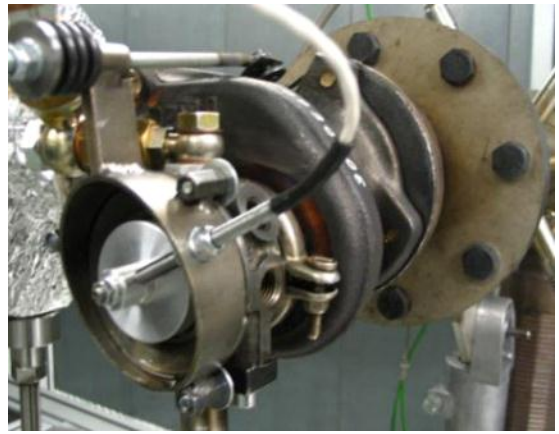
Compressor Closed Loop



Turbine Dynamometer



Run Away Measurement

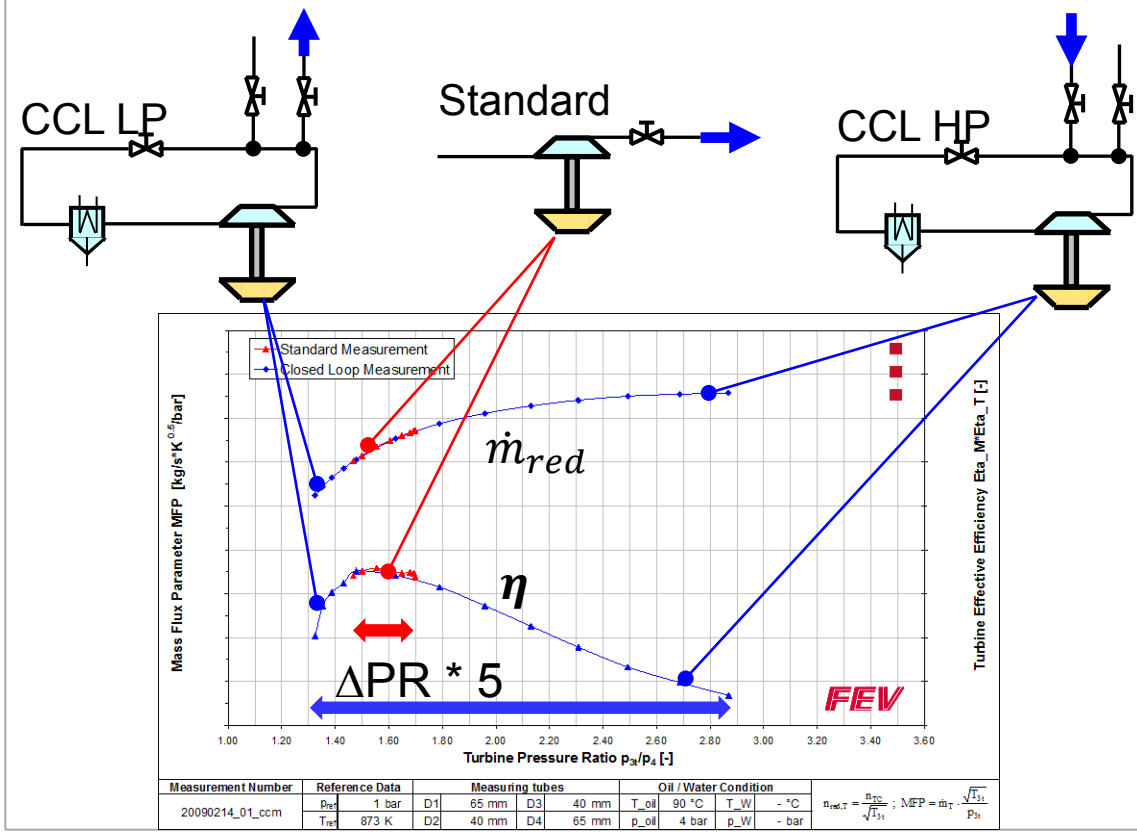


TC Friction Testing

Boosting: Obtaining the right maps for simulation

Special Turbocharger Measurement Techniques Example

Hot Gas Test Bench w/ Compressor Closed Loop (CCL)



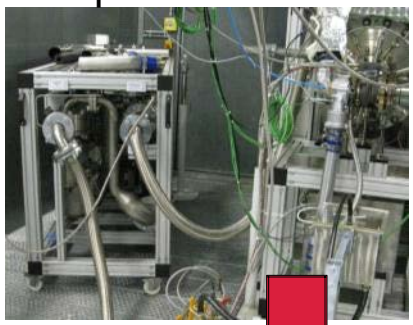
Benefits from CCL

CCL enables higher/lower inlet pressure

- CCL LP (low pressure):
  - compressor inlet density ↓
  - Less turbine power, p5/p6 ↓
- CCL HP (high pressure):
  - compressor inlet density ↑
  - More turbine power, p5/p6 ↑
- Significant increase of p5/p6 range
- Reliable data for predicting turbine power in pressure peaks (pulse turbocharging)

Extended Turbine Models for Reliable Performance Prediction in any Operation

Compressor Closed Loop



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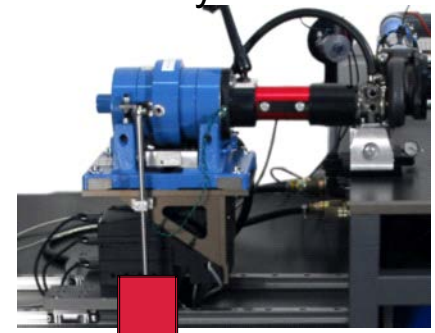
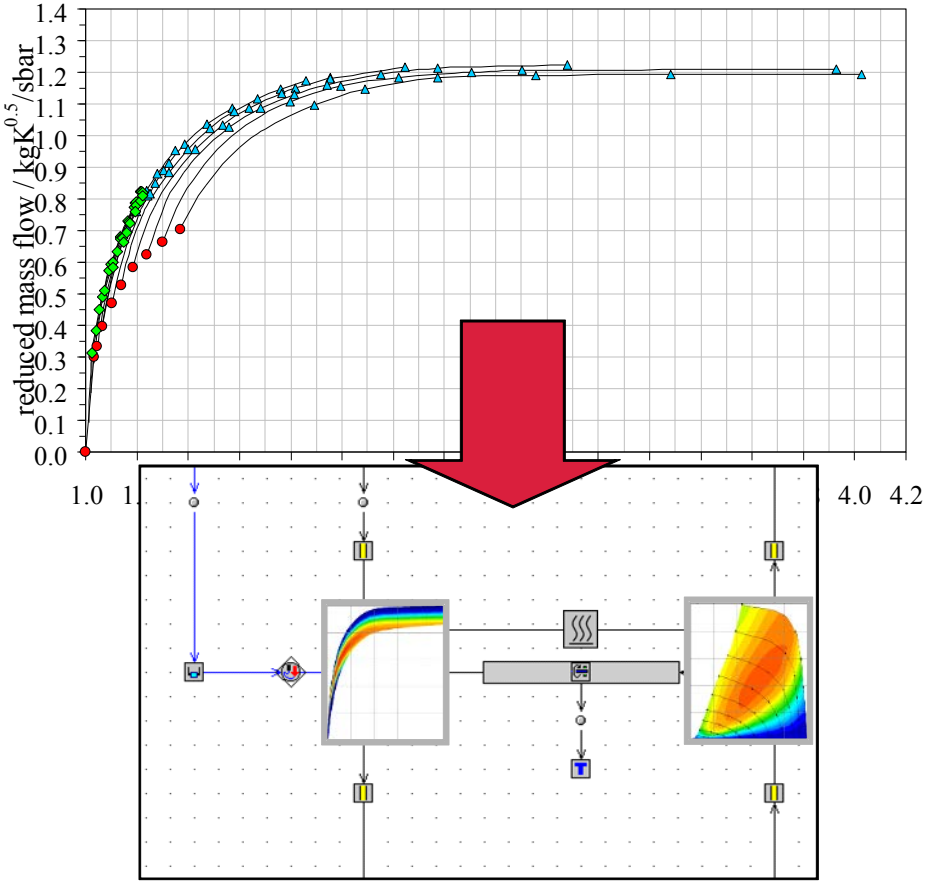
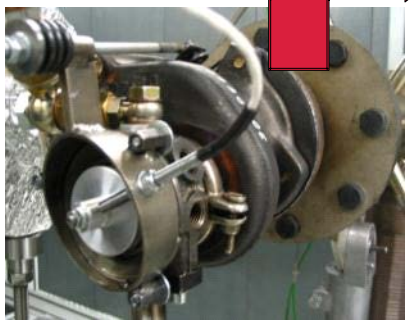






Run Away Measurement

TC Friction Testing

Fuel Injection

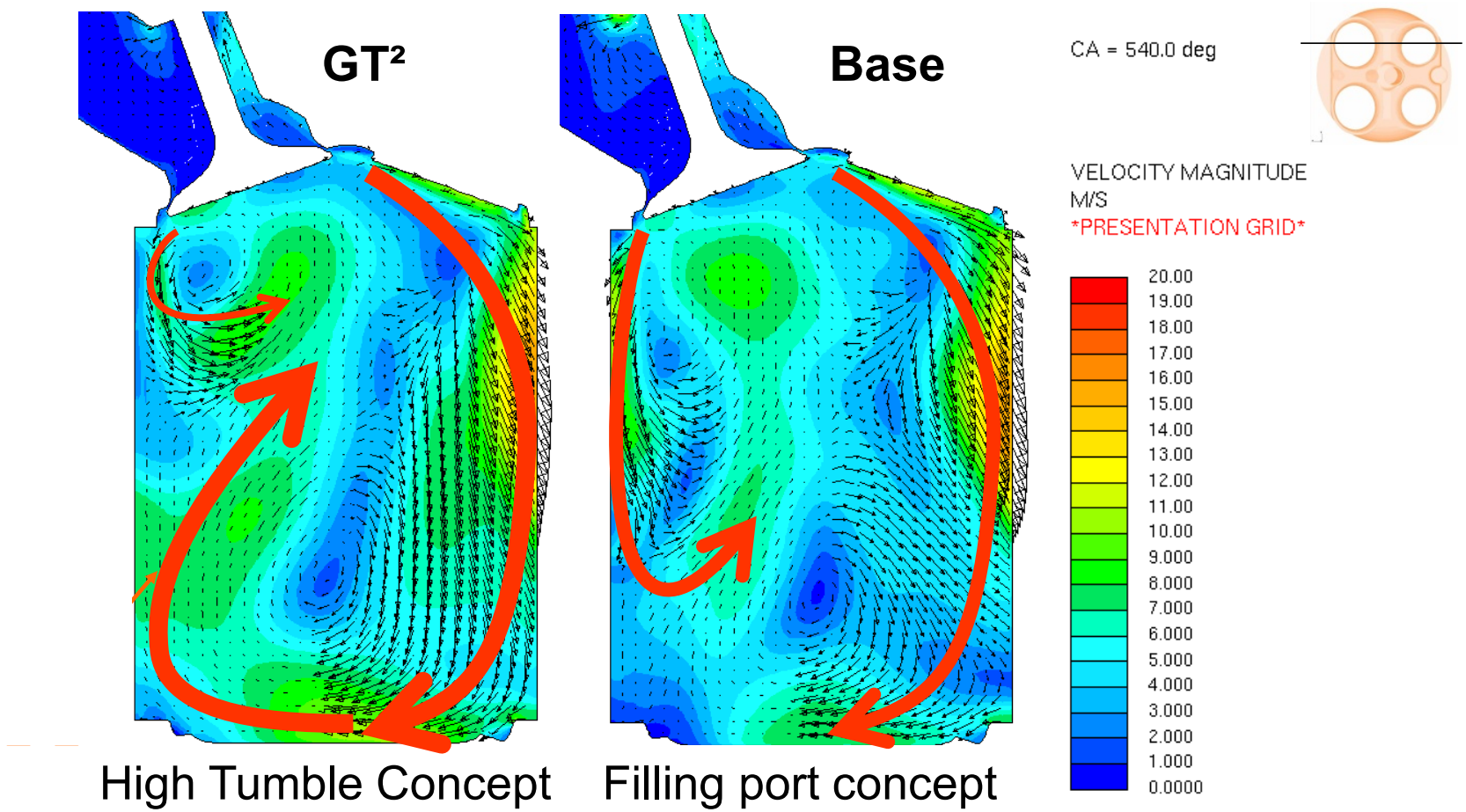
Same torque & power, smaller displacement

- Similar amount of fuel per cycle
  - Similar injection amount with same cylinder number
  - Larger injection amount with less cylinders
- Fuel spray length / bore ↑ ⇒ risk of wall wetting
  - Oil dilution
  - HC and soot
  - Higher risk of pre-ignition from stripped fuel-oil droplets
- Injection technology needs adaptation
  - Injection pressure
  - Multiple injections

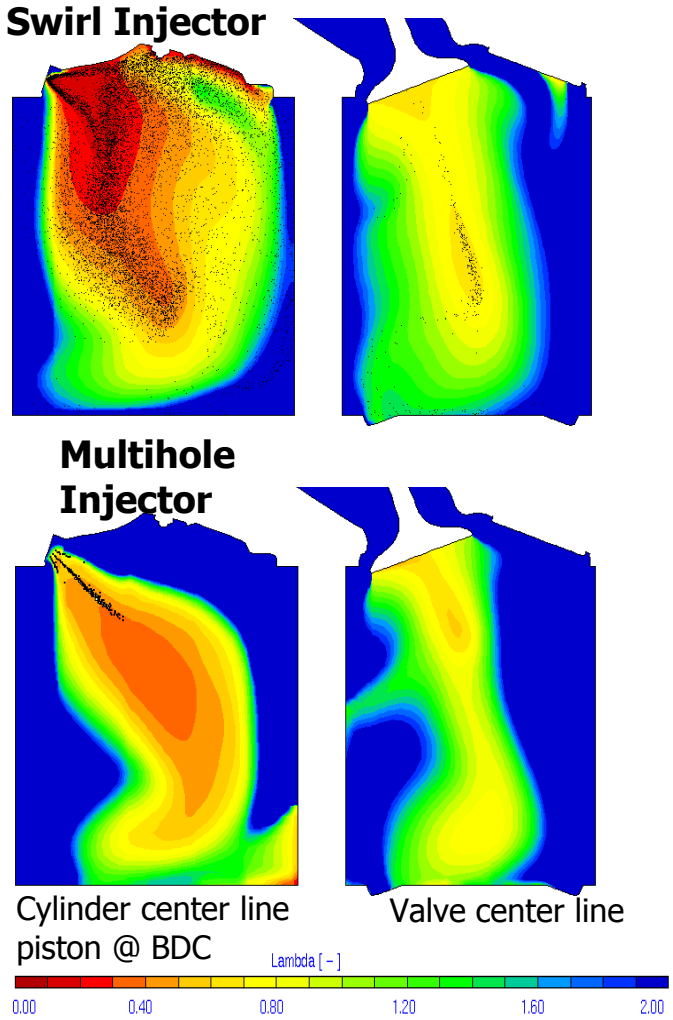
Approach: Experimental and Computational Analysis and Experimental Validation

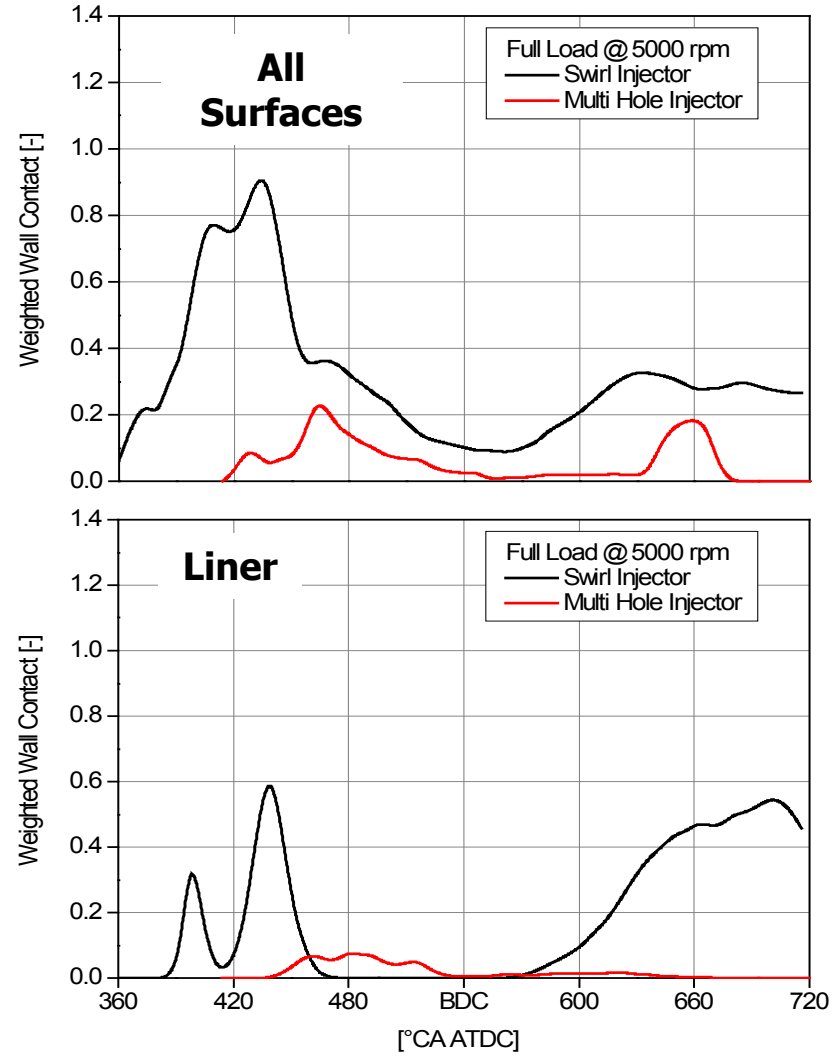
Charge Motion Design for heavily downsized gasoline engines

Charge motion must involve all of the charge to provide a homogenous mixture



CFD Evaluation of Wall Wetting





Injection and Oil Dilution

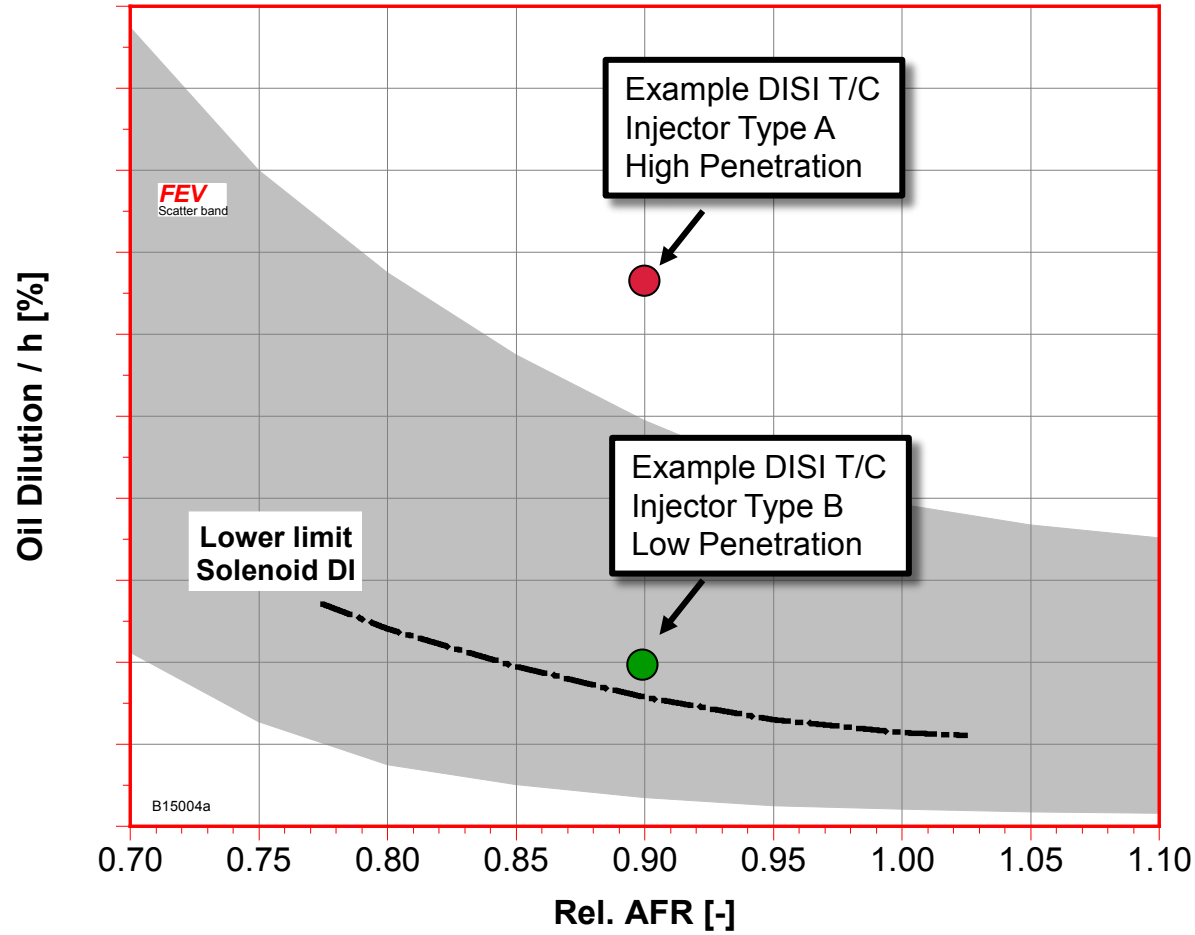
Standardized Test Procedure

Oil Dilution

2500 rpm / BMEP = 10 bar

- Dilution analysis method: Gravimetry for Gasoline Fuels

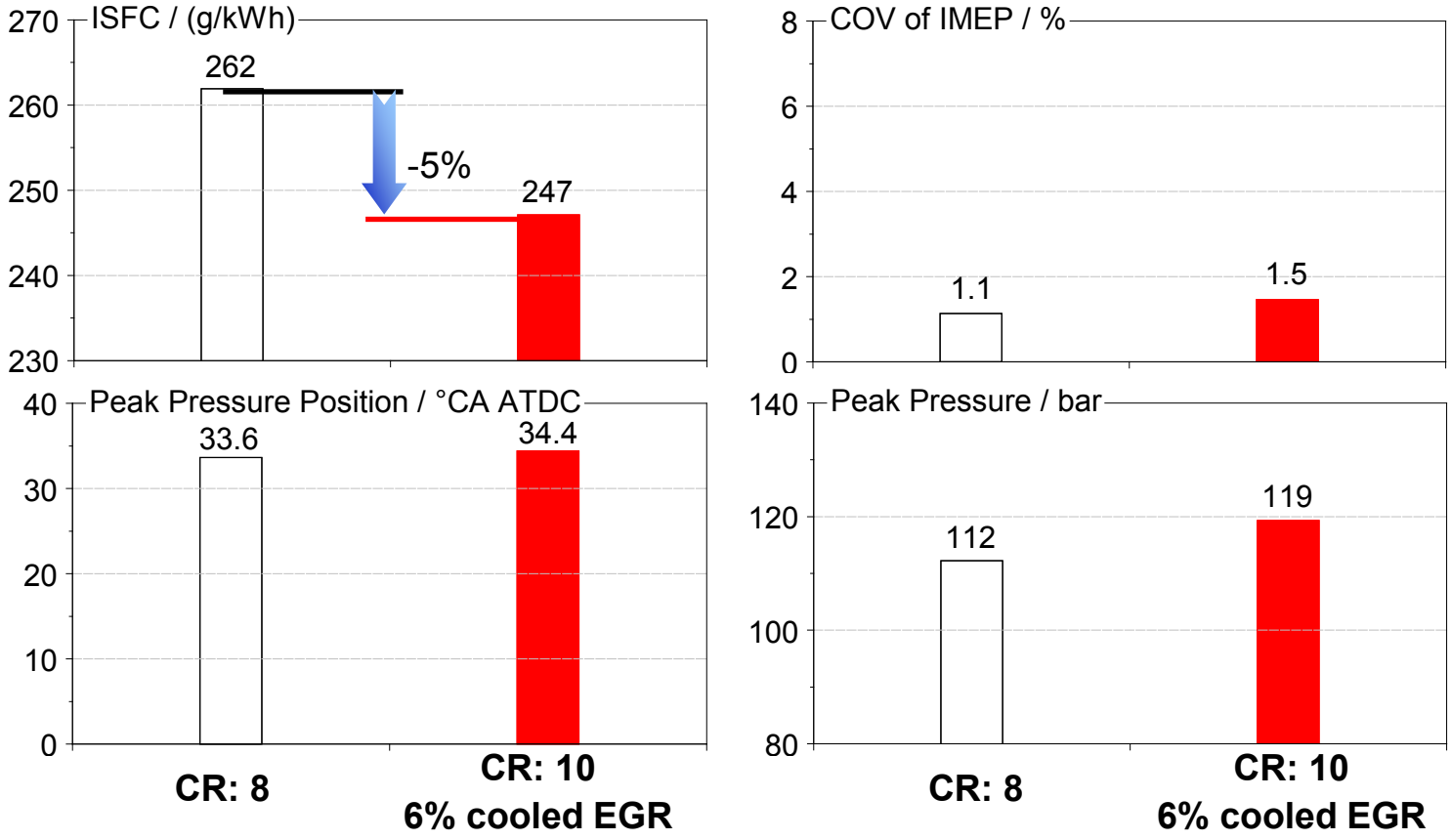
- Operating duration: 1 h
- Coolant temperature: 50 °C
- Oil temperature: uncontrolled
- Production PCV system
- Oil/Fuel acc. to OEM specs



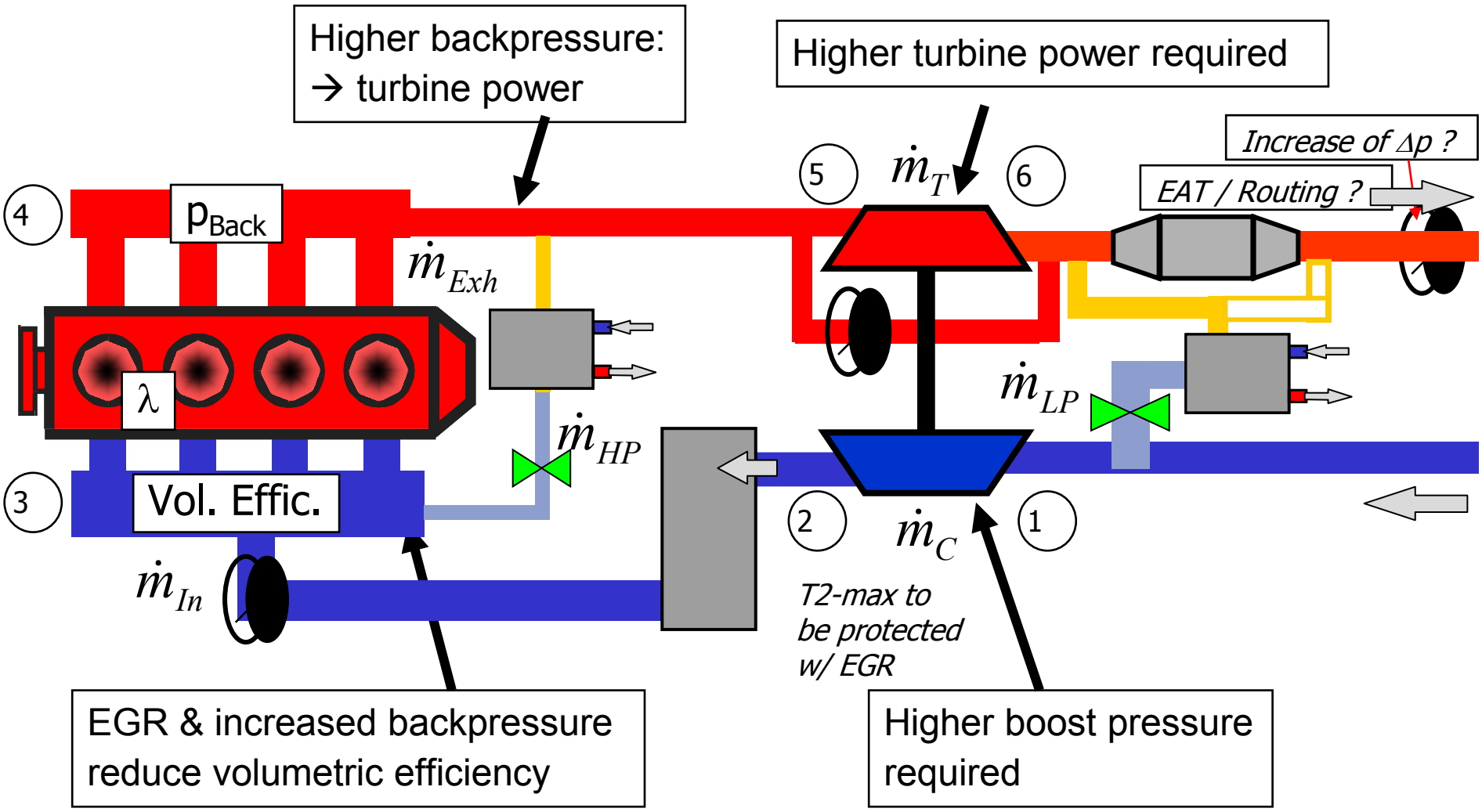
Cooled EGR benefit

CR increase by 2 units and fuel consumption benefit of 5% possible

- n = 1500 1/min, IMEP = 35 bar, rel. AFR= 1.0, with scavenging, RON 95

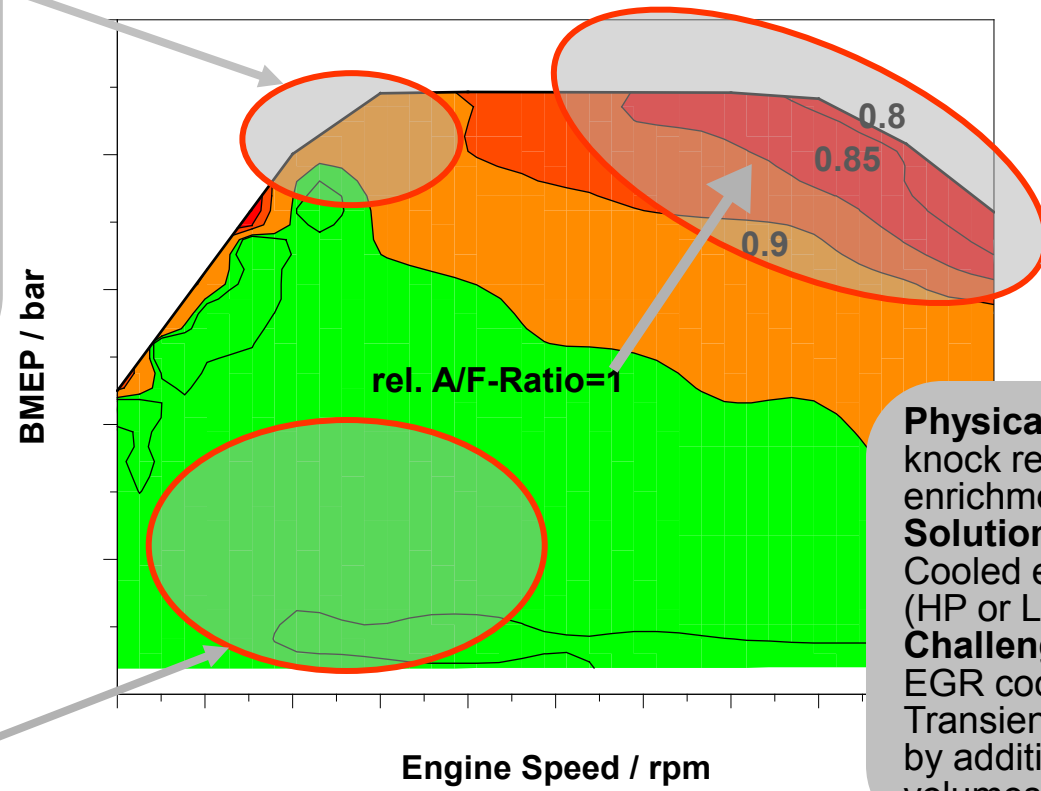


Cooled HP/LP EGR



EGR = F.E. benefit for T/C GDI
Map = example for turbocharged gasoline engine 2.0l class

Target:
knock reduction
→ FC benefit
Solution:
Cooled external EGR
Challenges:
Interaction with scavenging (HP – EGR)
Transient boosting affected by additional HP EGR volumes
→ only LP solution if best low end torque demanded



Physical effect:
Dethrottle engine
Solution:
Internal or external (uncooled) EGR
Challenges:
none (state of the art)

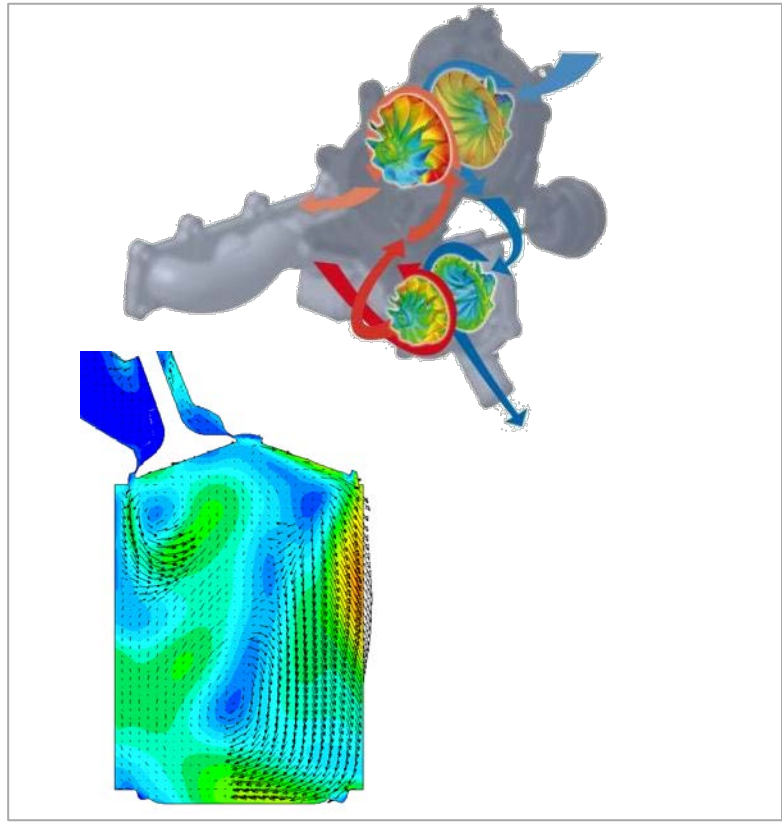
Physical effect:
knock reduction + reduced enrichment
Solution:
Cooled external EGR (HP or LP)
Challenges:
EGR cooling capacity
Transient boosting affected by additional HP EGR volumes

Conclusion

Future improvement of Downsizing engines

- Further reduction in size
  - Advanced boosting systems
  - Appropriate cylinder dimensions
  - Matched injection technology
- Proper control of auto-ignition (pre-ignition, knock, HCCI/RCCI)
  - Cooled LP+HP EGR
  - Thermodynamic cycle
- Thermal management
- Friction

Combustion Development Methodologies and Challenges for Smaller Boosted Engines



Thank you for your attention!

Questions?

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