Potentials for Efficiency Improvement of Gas Engines

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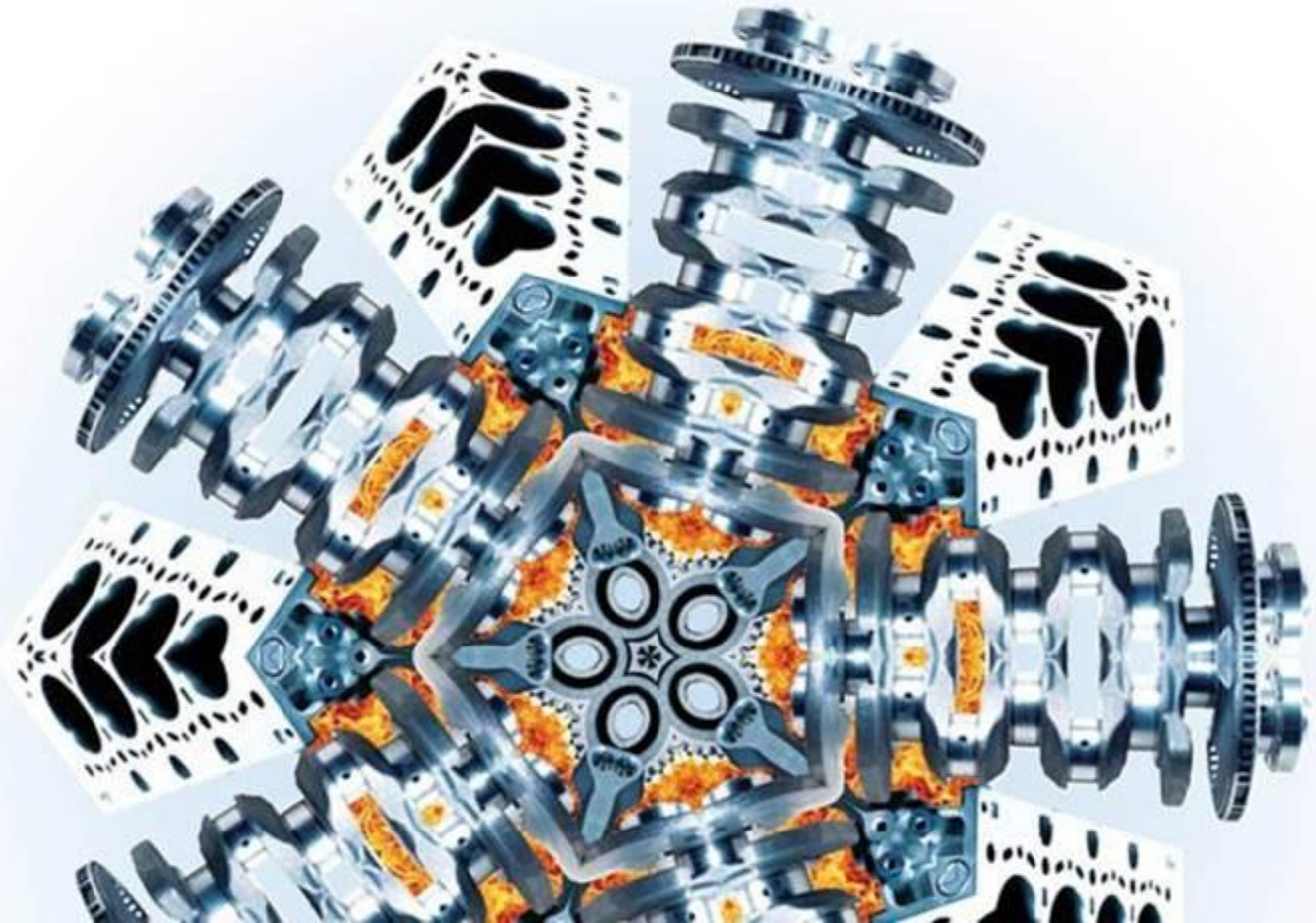


Content

“Fuel Efficiency – Are Improvements Possible?”

- Examples of AVL Gas Engine Projects for Efficiency Improvement
- Potentials for Further Efficiency Improvement
- Summary and Conclusion

Examples of AVL Gas Engine Projects

Example 1

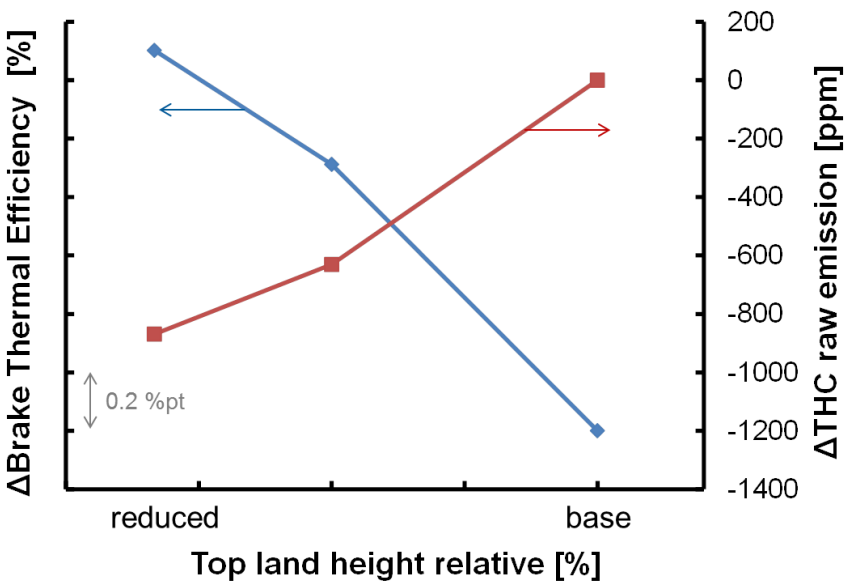
- High speed gas engine 1500 rpm
- Open chamber combustion concept with pre-chamber spark plug
- Targets
  - Efficiency increase by 2.7 % points
  - BMEP increase by 3.4 bar
  - THC 1200 mg/Nm^3 at 3 % O_2
  - NOx TA-Luft
- Tasks
  - SCE testing (set-up and commissioning + 5.5 months testing)
  - CFD simulations for optimization of charge motion and piston bowl geometry
- Results
  - All targets achieved
  - Efficiency increased by 2.8 % points

AVL Gas Engine Project - Example 1

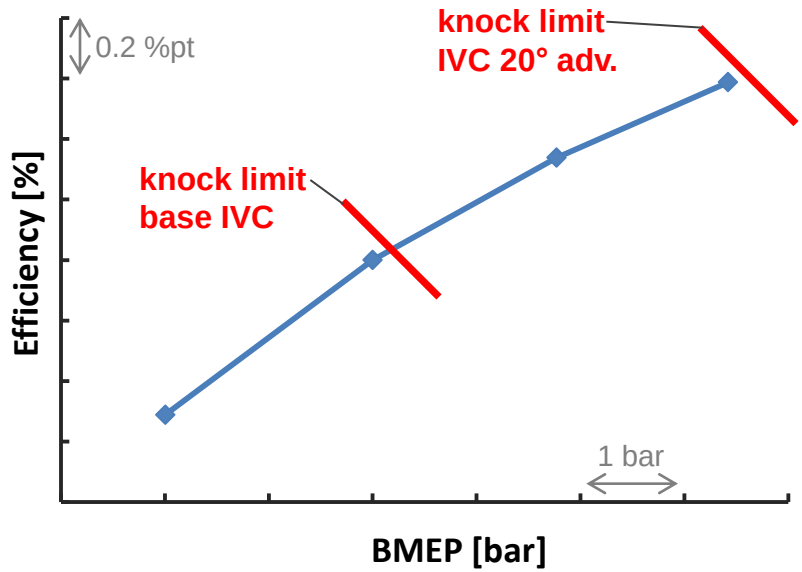
Summary of development steps

- Reduction of dead volume
- Optimization of Miller timing and BMEP increase
- Swirl optimization
- Optimization of combustion chamber geometry and compression ratio
- Optimization of pre-chamber spark plug geometry

Reduction of Dead Volume



Miller Timing and BMEP



AVL Gas Engine Project - Example 1

Swirl Optimization

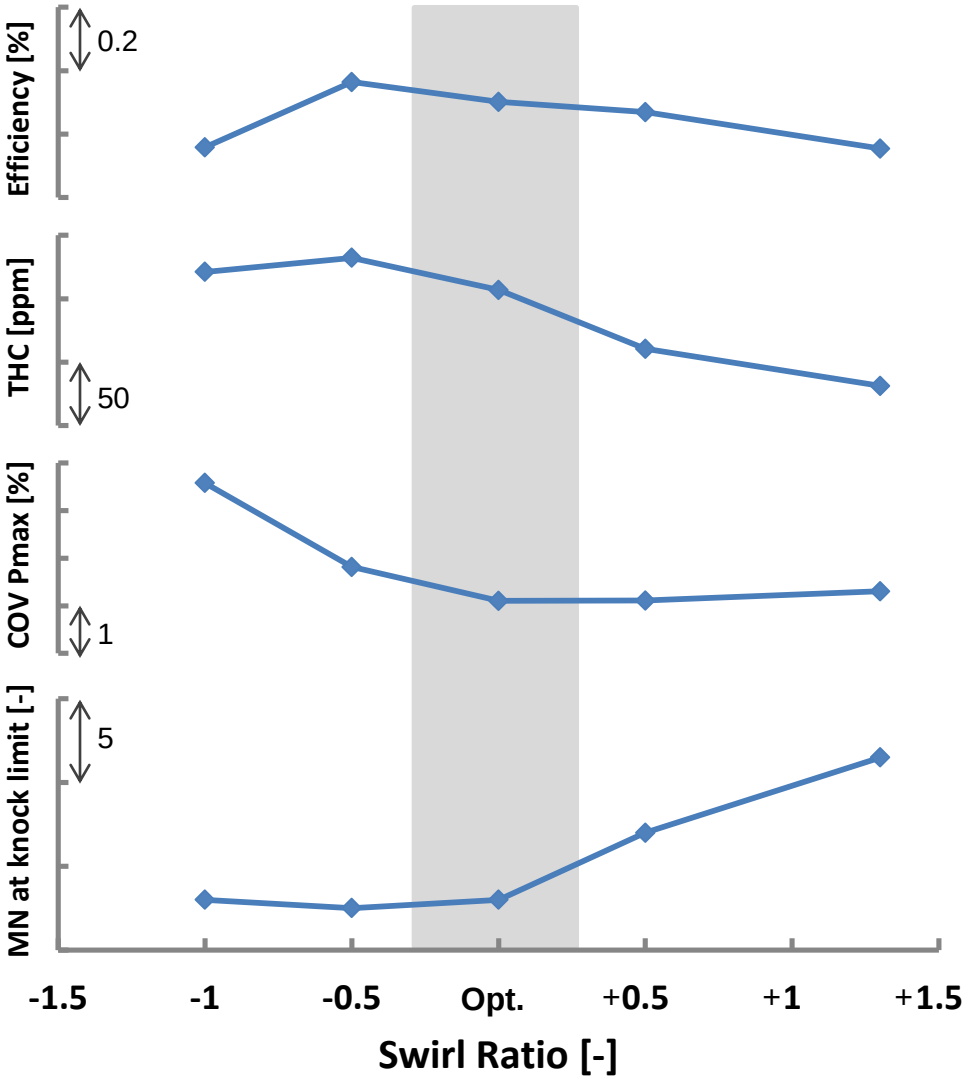
- SCE Test
- 5 different swirl ratio tested
- constant BMEP / 1500 rpm
- constant MFB50% location
- constant NOx at TA-Luft

Conclusions

→ Too high swirl ratio deteriorates knock margin significantly

→ Too low swirl ratio deteriorates THC emission and COV

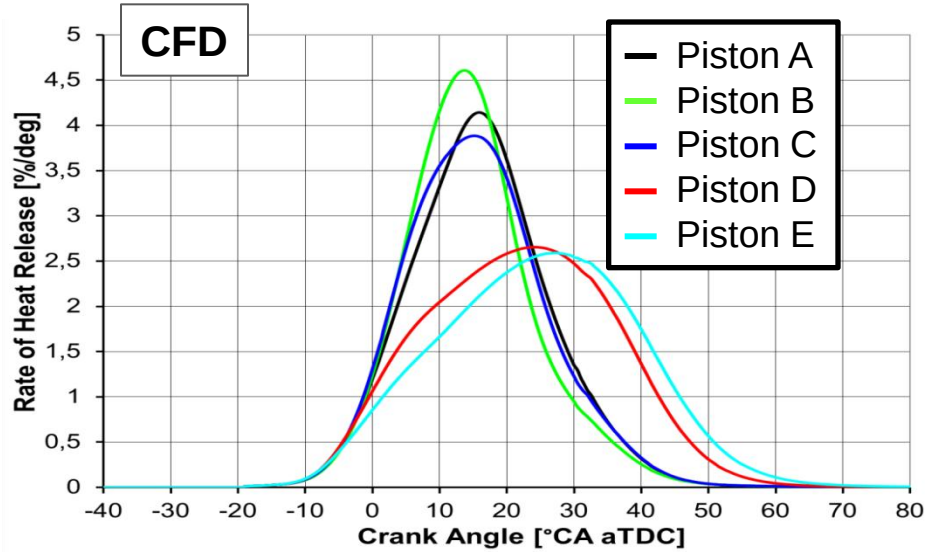
→ Swirl ratio optimized



AVL Gas Engine Project - Example 1

<u>Optimization of Piston Bowl Geometry</u>

- Pre-optimization by CFD
- SCE Test
- 4 bowl shapes tested
- 4 compression ratios tested
- constant BMEP / 1500 rpm
- constant NOx at TA-Luft

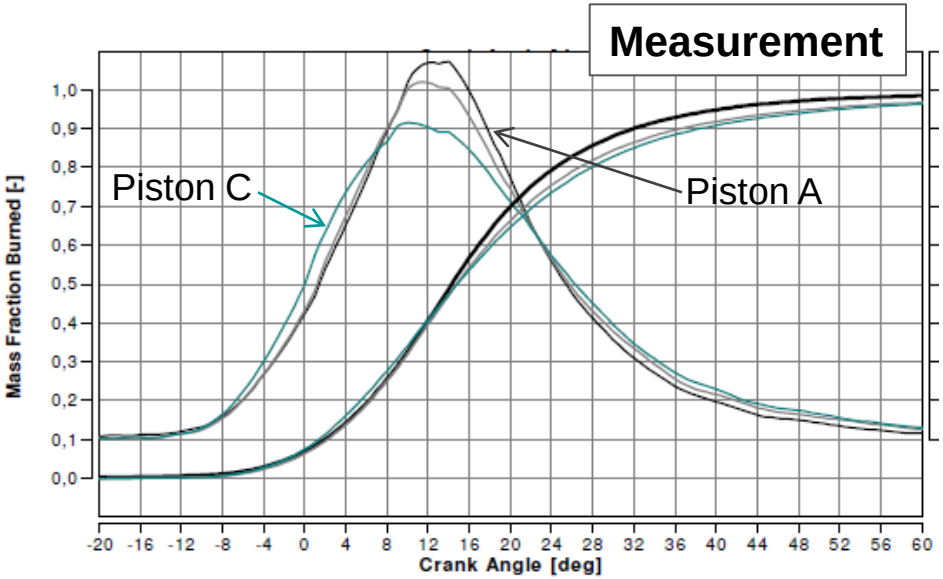


<u>Conclusions</u>

→ Piston contour to be matched with the half-spherical flame propagation

→ Minimize piston to head clearance to enhance squish flow effect

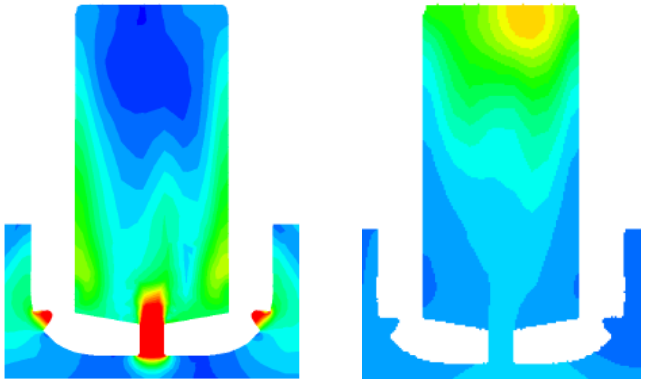
→ Piston bowl design and compression ratio optimized



AVL Gas Engine Project - Example 1

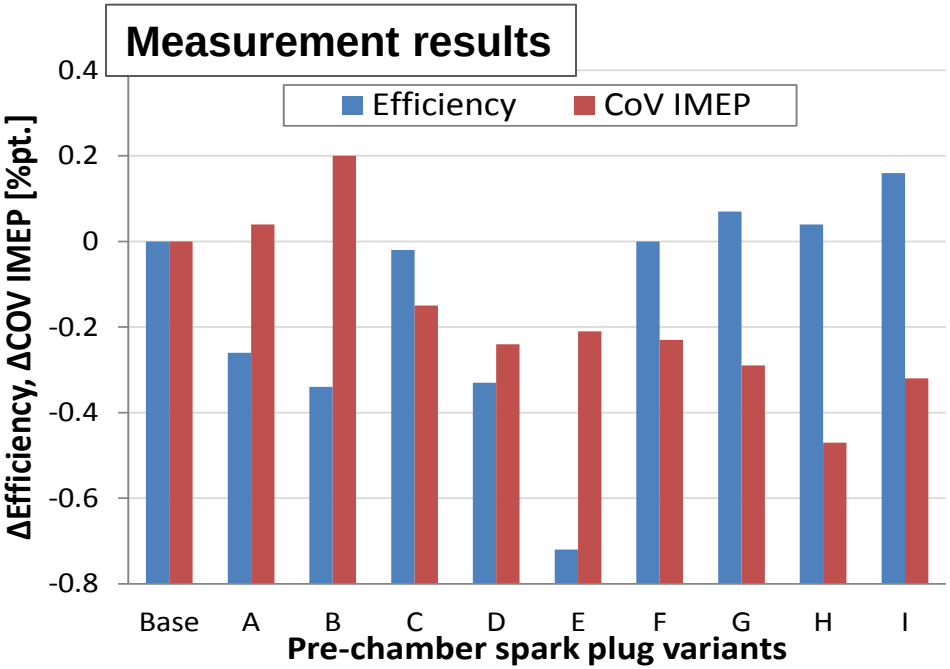
Optimization of Pre-chamber Spark Plug

- SCE Test accompanied by CFD to understand the phenomena
- 10 variants tested
  - Volume
  - number of holes, diameter
  - hole direction
- constant BMEP / 1500 rpm
- constant NOx at TA-Luft



Velocity distribution (AVL CFD resutls)

Residual gas distribution (AVL CFD results)



Conclusions

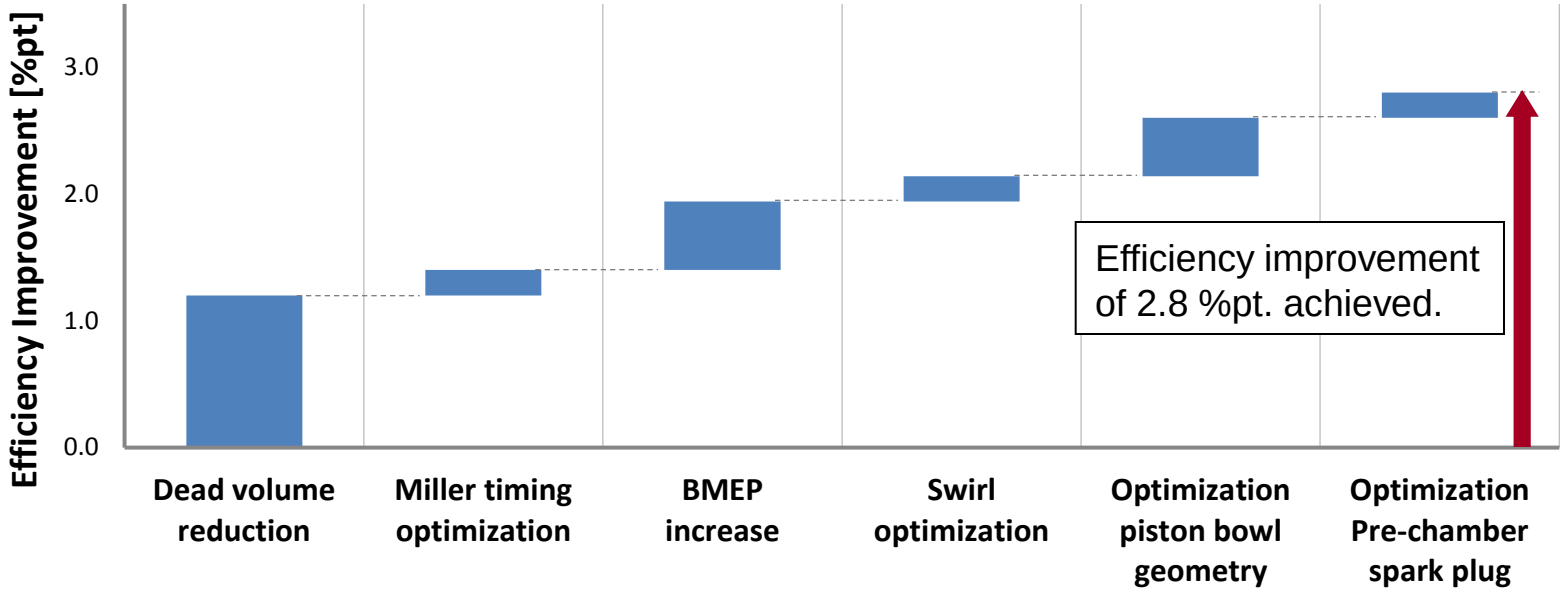
→ Pre-chamber optimized for both efficiency and COV_IMEP

AVL Gas Engine Project - Example 1

Summary of development steps

- Reduction of dead volume
- Optimization of Miller timing and BMEP increase
- Swirl optimization
- Optimization of combustion chamber geometry and compression ratio
- Optimization of pre-chamber spark plug geometry

Summary of development results



Examples of AVL Gas Engine Projects

Example 2

- Medium Speed Gas Engine 750 rpm
- Fuel-fed pre-chamber with spark ignition
- Targets
  - Efficiency increase by 2 % points
  - COV_Pmax reduction from 5~6 % to 3 %
  - NOx TA-Luft
- Tasks
  - SCE and MCE testing support
  - CFD simulations for optimization of piston bowl and pre-chamber geometries
- Results
  - COV_Pmax significantly reduced
  - Efficiency increase by 2.1 % points

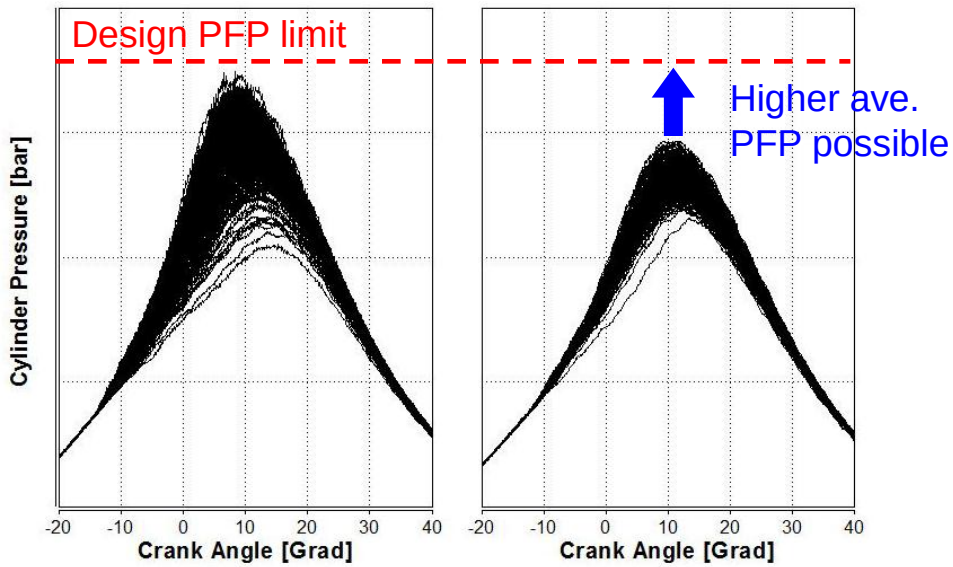
AVL Gas Engine Project - Example 2

Summary of development steps

- Reduction of dead volume
- Optimization of combustion stability
- Optimization of Miller timing and compression ratio
- Optimization of piston bowl geometry
- Optimization of pre-chamber geometry

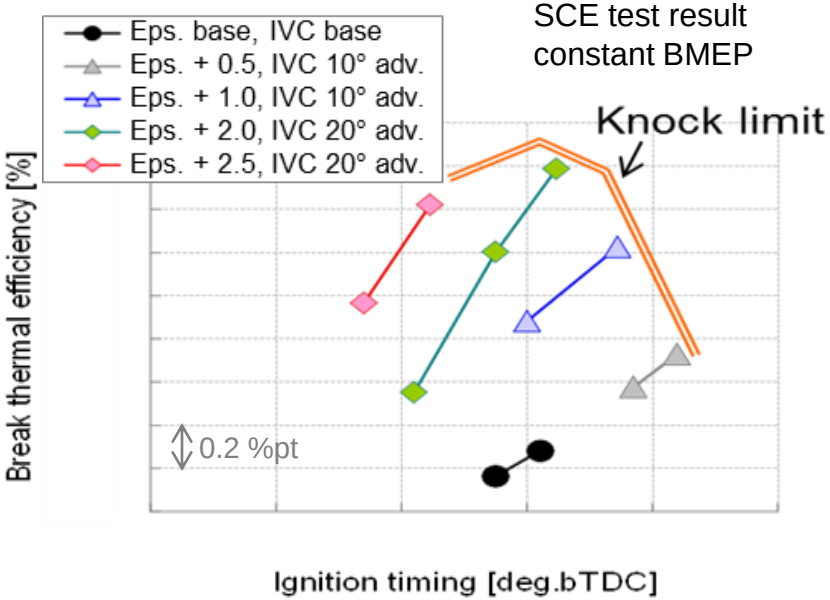
Optimization of combustion stability

SCE test result | constant BMEP | same ave. PFP



Miller Timing and Compression Ratio

SCE test result
constant BMEP



AVL Gas Engine Project - Example 2

<u>Optimization of Combustion Stability</u>

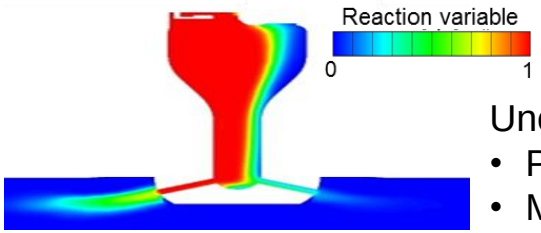
- Pre-optimization by CFD
- SCE Test
- MCE Test for confirmation
- Gas supply to pre-chamber
- Pre-chamber geometry
- constant BMEP / 750 rpm
- constant NOx at TA-Luft

<u>Conclusions</u>

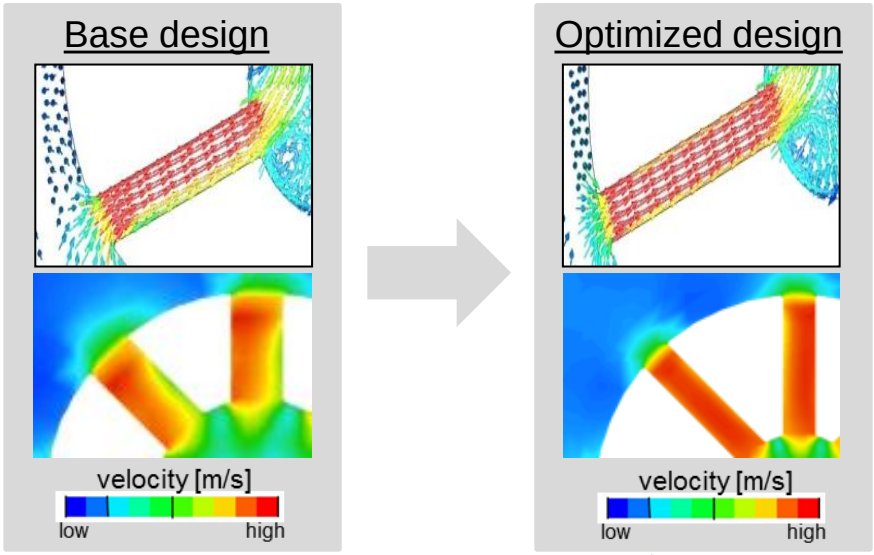
→ Even combustion in the pre-chamber to be targeted

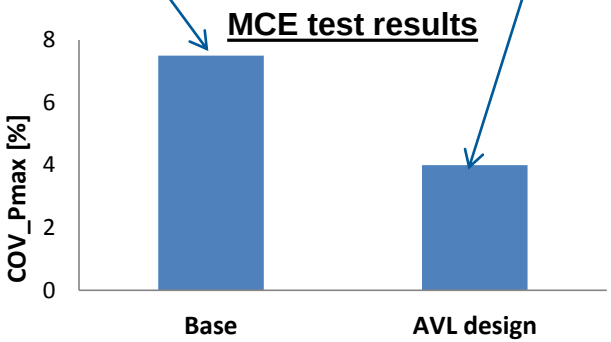
→ Flow separation at holes to be avoided

→ Significant improvement of combustion stability confirmed by MCE testing



Uneven combustion in PC
- Plug location
- Mixture distribution





AVL Gas Engine Project - Example 2

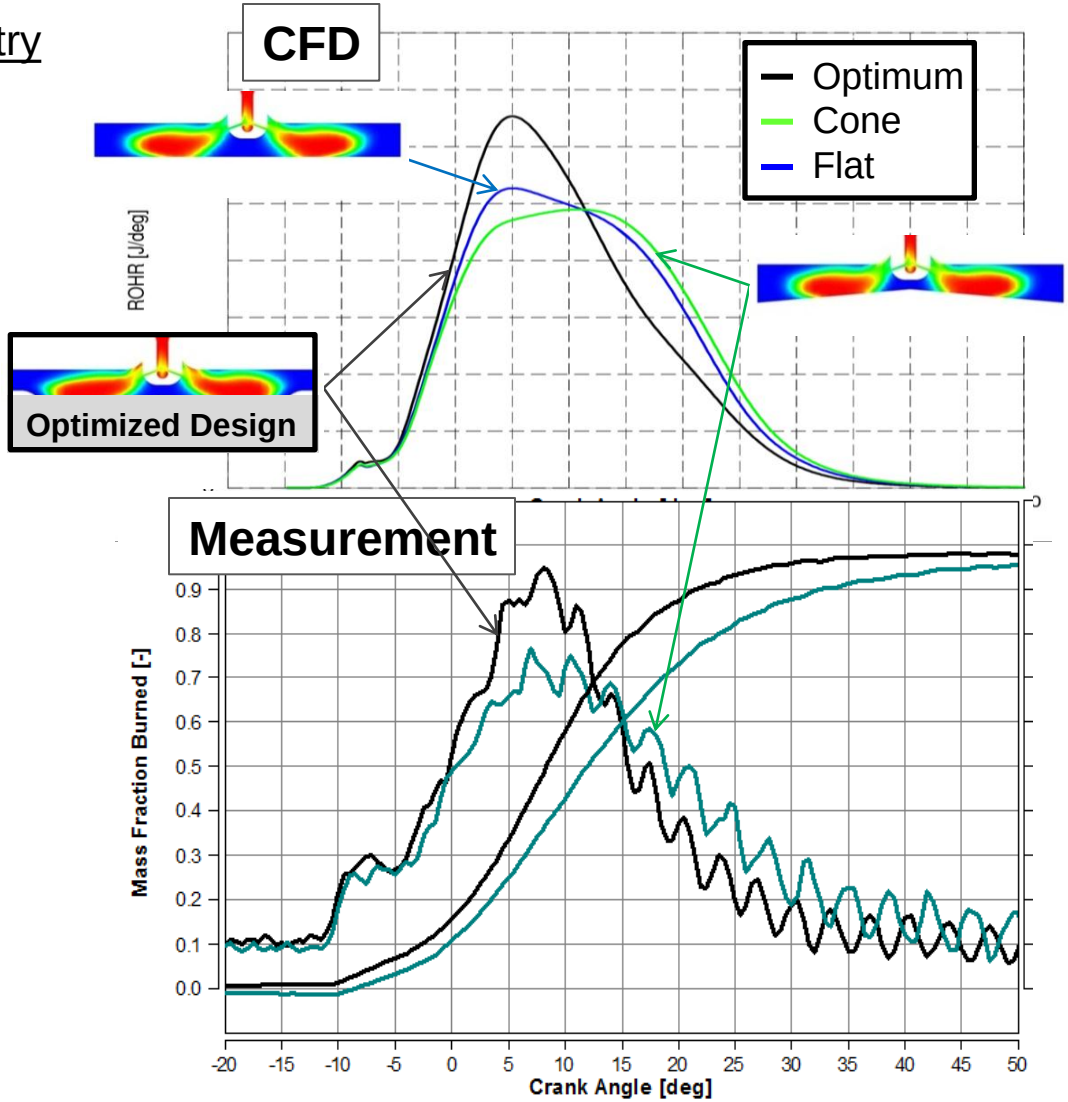
<u>Optimization of Piston Bowl Geometry</u>

- Pre-optimization by CFD
- SCE Test
- MCE Test for confirmation
- 3 bowl shapes tested
- 5 compression ratios tested
- constant BMEP / 750 rpm
- constant NOx at TA-Luft

<u>Conclusions</u>

→ Piston bowl contour to be matched with the flame propagation from the flame jet out of pre-chamber

→ Piston bowl to be optimized together with pre-chamber nozzle configuration

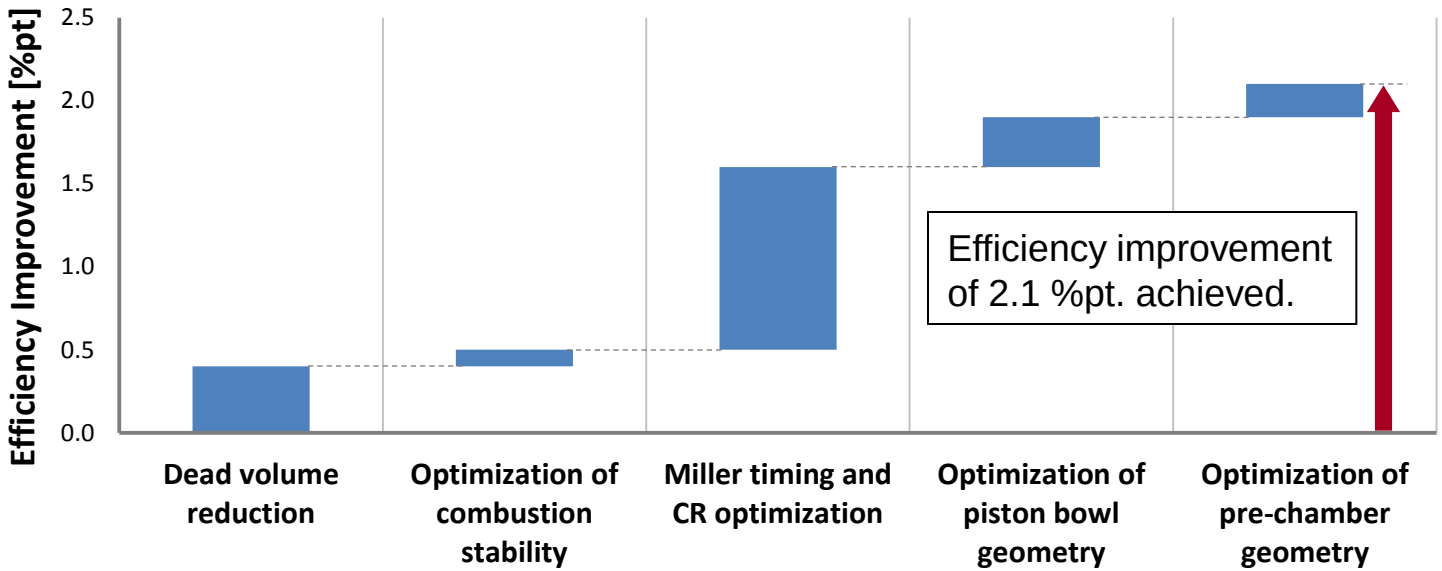


AVL Gas Engine Project - Example 2

Summary of development steps

- Reduction of dead volume
- Optimization of combustion stability
- Optimization of Miller timing and compression ratio
- Optimization of piston bowl geometry
- Optimization of pre-chamber geometry

Summary of development results



Content

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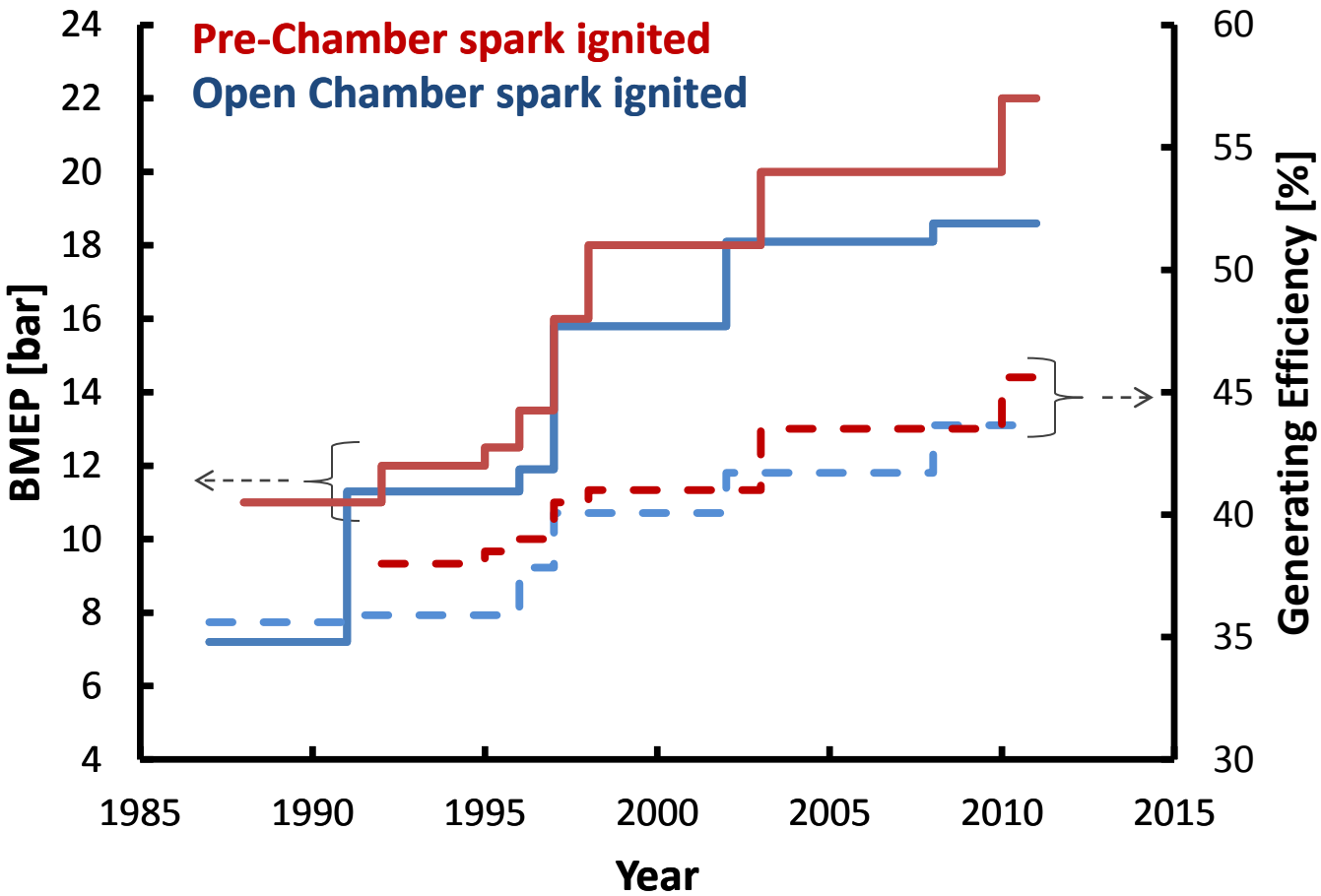
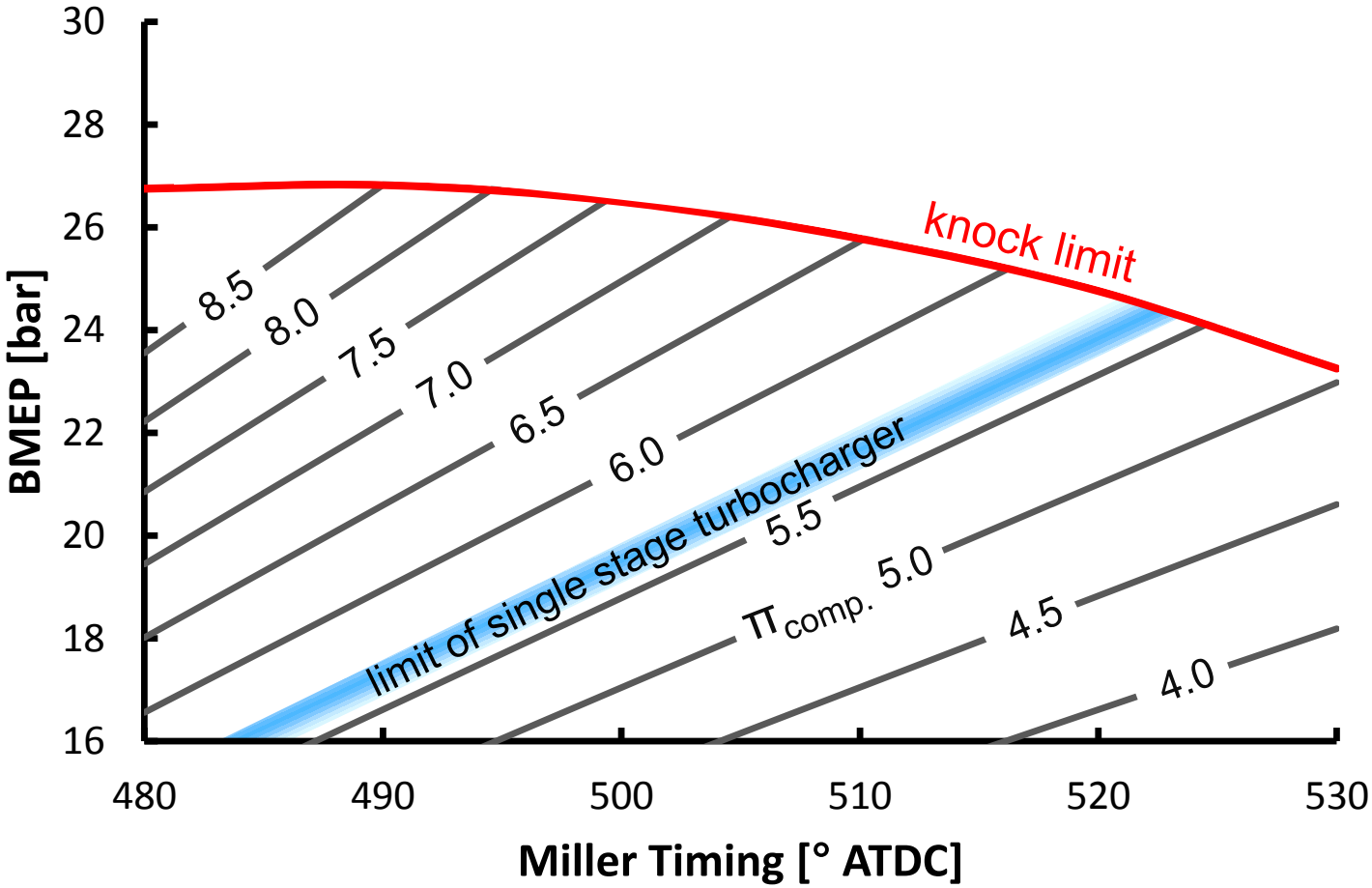
Looking Back



- **Efficiency improvement coupled with BMEP increase.**
- **Higher BMEP for higher efficiency?**

Required Compressor Pressure Ratio

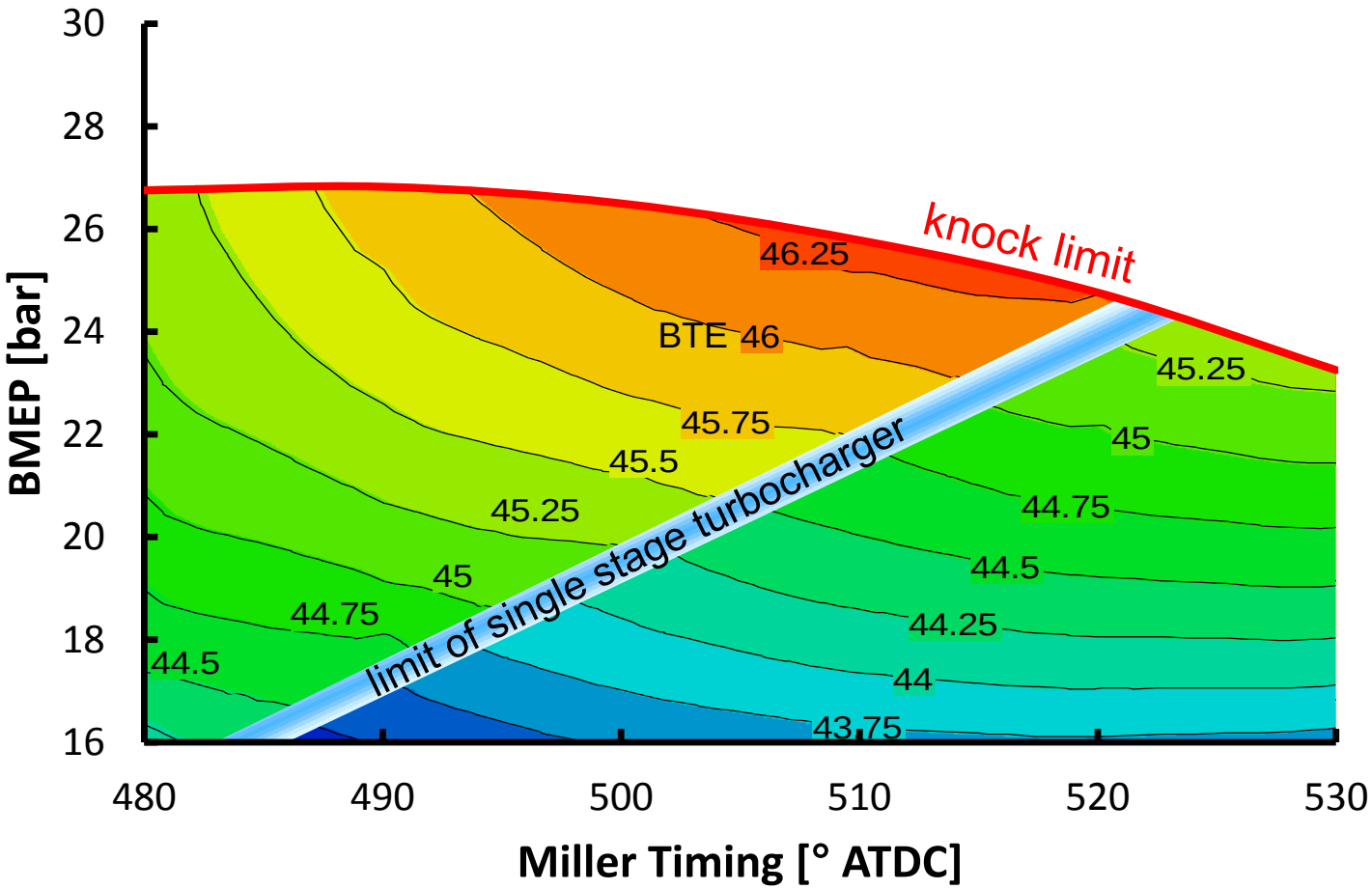


- Model-Based Analysis
- 1500 min^{-1}
- Pre-chamber
- Spark ignition
- NOx TA-Luft
- MN 80
- const. ε of 12

➢ **Key Technologies to achieve higher BMEP**

→ Aggressive Miller timing and Two-Stage Turbocharging

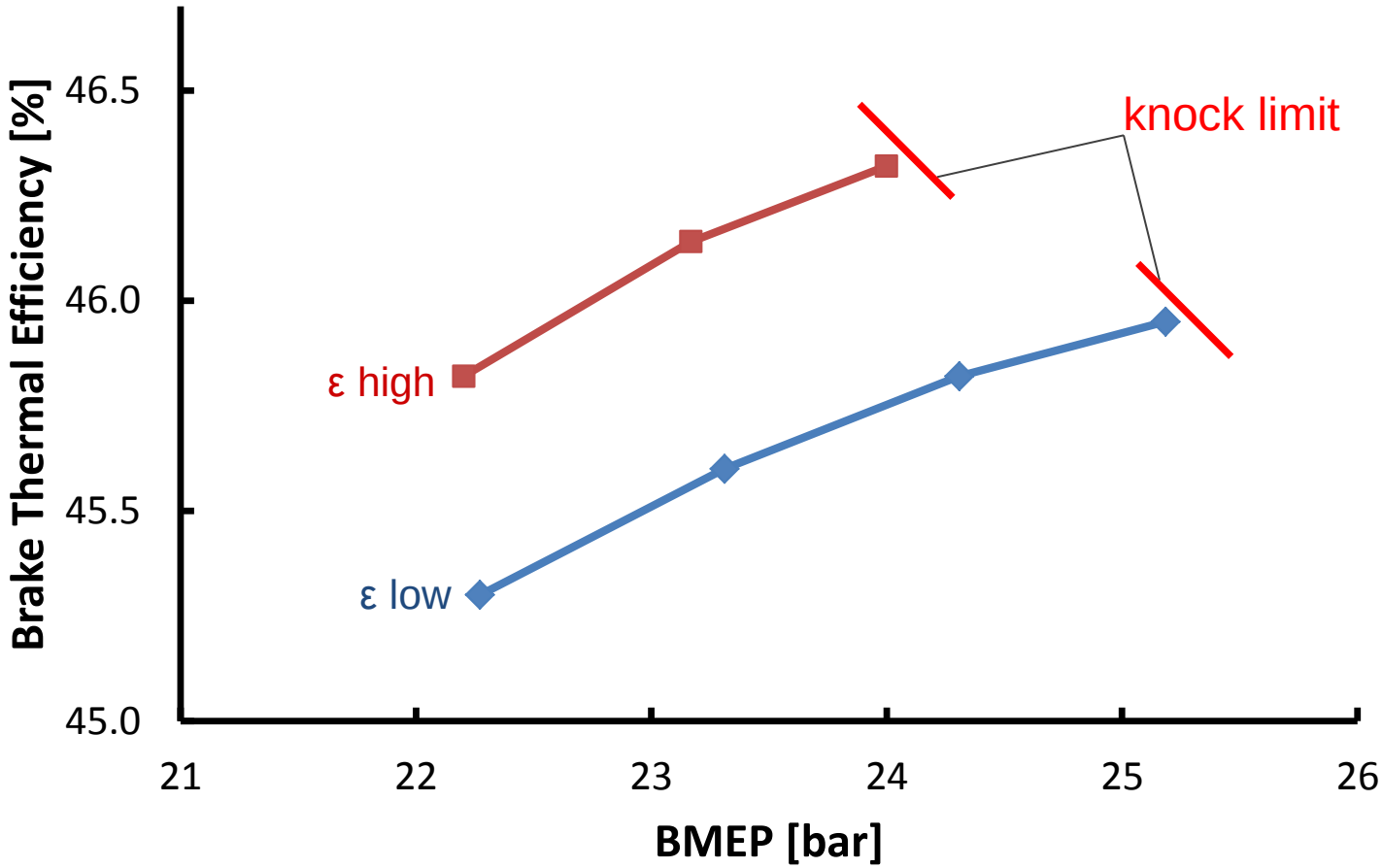
BMEP – Miller – BTE Matrix at const. ε



- Model-Based Analysis
- 1500 min^{-1}
- Pre-chamber
- Spark ignition
- NOx TA-Luft
- MN 80
- const. ε of 12

➢ **The higher the BMEP, the higher the efficiency at constant ε.**

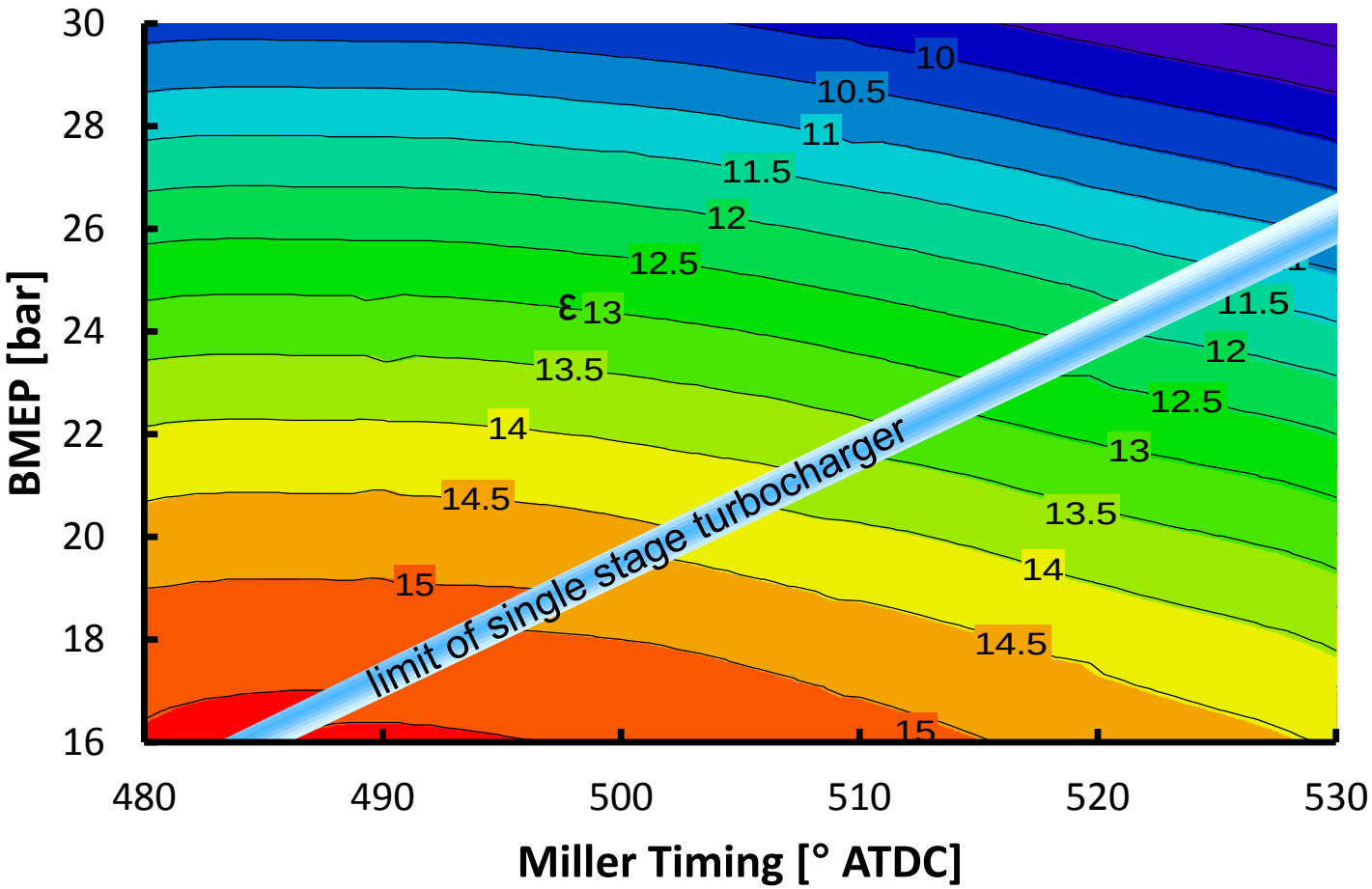
SCE Result | BMEP Variation with two different ε



- SCE Test Results
- 1500 min^{-1}
- Pre-chamber
- Spark ignition
- NOx TA-Luft
- MN80

➢ **The higher the BMEP ≠ the higher the knock limited efficiency.**

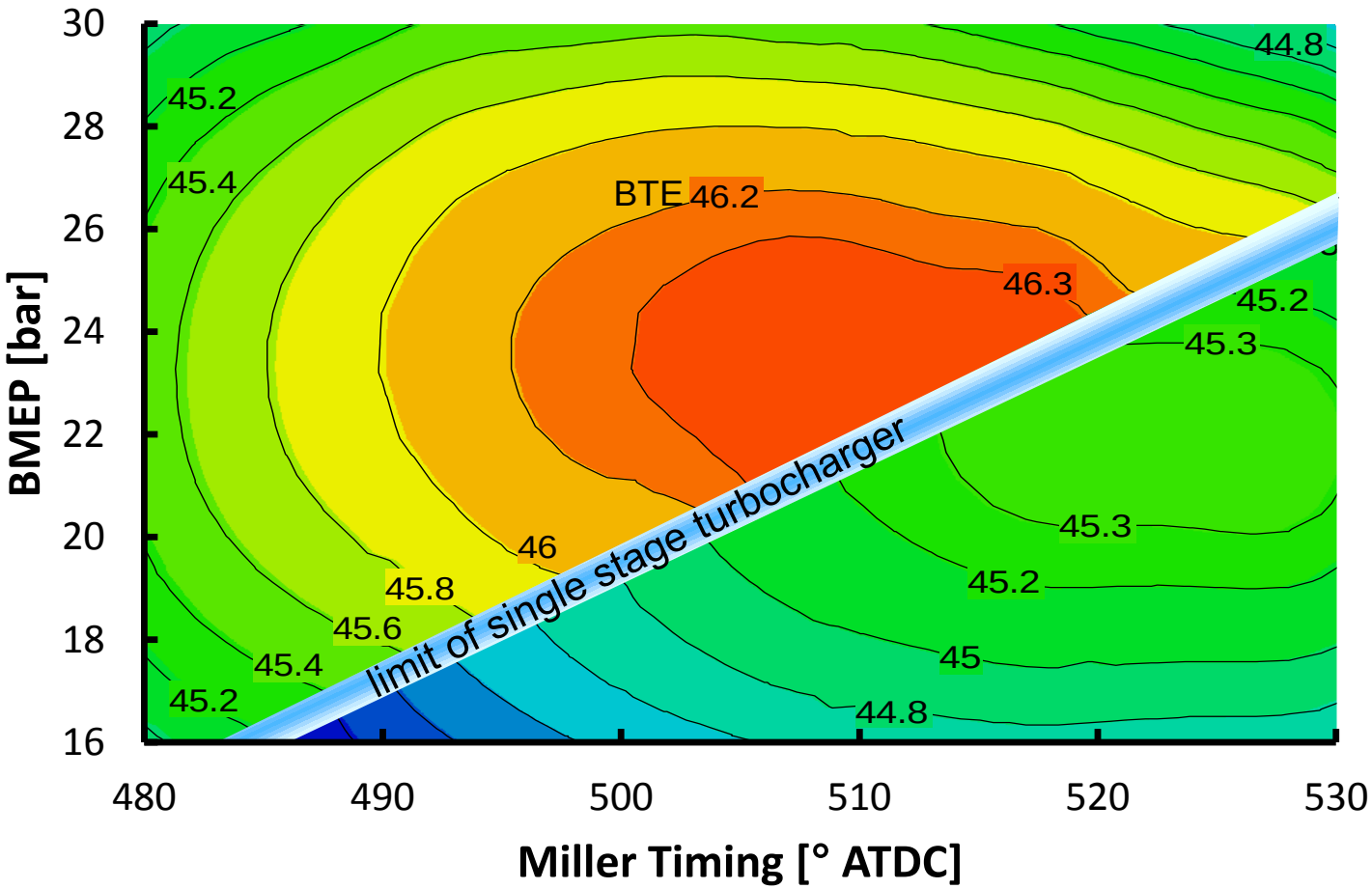
BMEP – Miller – ε Matrix at Knock Limit



- Model-Based Analysis
- 1500 min^{-1}
- Pre-chamber
- Spark ignition
- NOx TA-Luft
- MN 80
- ε at knock limit

➢ **High BMEP with low ε or high ε with low BMEP?**

BMEP – Miller – BTE Matrix at Knock Limit



- Model-Based Analysis
- 1500 min^{-1}
- Pre-chamber
- Spark ignition
- NOx TA-Luft
- MN 80
- ε at knock limit

- **Optimum BMEP Target for the highest efficiency → 24 – 26 bar**
- **Design PFP requirement of 250 bar**

Content

- Examples of AVL Gas Engine Projects for Efficiency Improvement
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Summary

- Examples of AVL Gas Engine Projects for Efficiency Improvement were reviewed.
- Incremental development will result in “Many a little makes a mickle.”
  - CFD Simulation and SCE Testing are effective for rapid development.
- Key Enablers for the further efficiency improvement are;
  - High BMEP of 24 – 26 bar
  - Aggressive Miller Timing
  - Two-stage turbocharging
  - High PFP capability

Conclusion

“Fuel Efficiency – Are Improvements Possible?”

“Where there is a will, there is a way!”

Thank you for your attention!