Influence of Injection Pressures up to 300 bar on Particle Emissions in a GDI-Engine

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The upcoming Euro 6 legislation will for the first time include a limitation of the particle number emission for vehicles with gasoline engines. Following the recommendations of the Particle Measurement Program the UN/ECE will limit the particle number emission to 6.0×10^{11} #/km [2]. This will issue a challenge for gasoline engines with direct fuel injection (GDI), which tend to generate noteworthy amounts of particle emissions [3]. This problem exists because of a shorter time for homogenization and a higher tendency of wall and piston wetting compared to engines with port fuel injection (PFI) [4]. Still GDI engines have important advantages over PFI engines. Through their cooling effect inside the combustion chamber it is possible to increase the compression ratio without increasing the tendency to knock. The higher compression ratio raises the engines efficiency and makes GDI engines an essential technology to fulfill future CO_2 emission limits [1].

To evaluate countermeasures against the particle emissions of GDI engines, several techniques were investigated. In this study the focus is set on the evaluation of injection pressures of up to 300 bar on particle emissions. To investigate the effect a 1-cylinder GDI engine with a central injector position and a medium displacement was instituted. Since most of today’s series gasoline fuel pumps are not capable of providing pressures above 200 bar, a new high pressure pump was used; it was developed at the Institut für Kolbenmaschinen of the Karlsruhe Institute of Technology and is capable of providing fuel pressures of up to 800 bar (Figure 1)

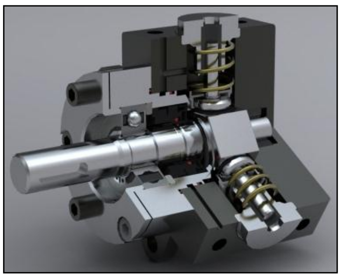

Figure 1–Prototype of the high pressure fuel pump

The high pressure injection system was applied to the engine in combination with a special 300 bar fuel injector and several particle measurement devices. With this setup several operating points from high to low loads and engine speeds were investigated. The resulting particle concentrations and particle masses were measured using the Pegasor PPS-M. A TSI Engine Exhaust Particle Sizer 3090 (EEPS) and an AVL Particle Counter (APC) simultaneously. The PPS-M is built to measure particle mass and number concentration with dynamic response over a large measurement range [5]. The EEPS also delivered information on mass and number concentration and additionally the size distribution. The APC was used to verify the measured particle number concentrations of the other sensors.

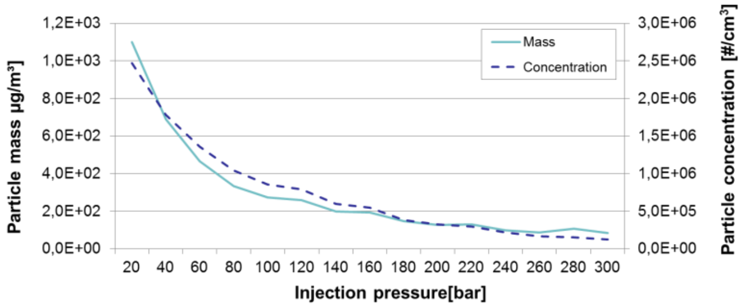

Figure 2 - Particle concentration and mass vs. injection pressure

For this research measurements were performed for a large amount of operating points from low to high loads and slow to high engine speeds. Applying higher injection pressures both the particle concentration and the particle mass were reduced. Averaged over all operating points the concentration was decreased by 70 % raising the injection pressure from 100 bar to 200 bar. By increasing the pressure up to 300 bar it was possible to reduce the concentration by another 50 % on average. The increase of the injection pressure also reduced the mean particle size (Figure 3), which in combination with the lowered concentration decreased the particle mass (Figure 2).

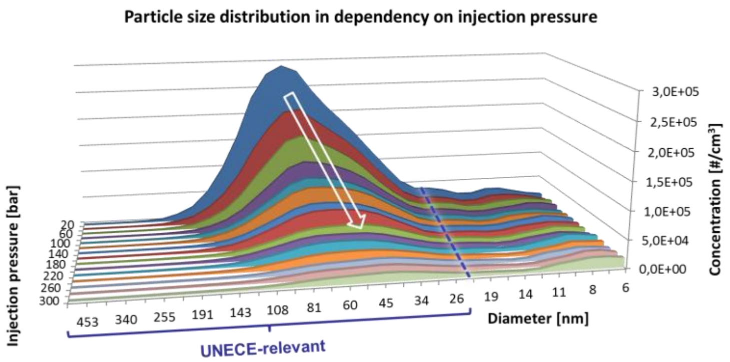

Figure 3 - Influence of injection pressure on particle size distribution

On the basis of those measurements a comparison of the different particle sensors was made to calculate correlation factors for them. This was accomplished by comparing the measurements of the number concentration that were simultaneously generated by each sensor (Figure 4). In the area of relevant particle concentrations the measurements of the PPS-M matched those of the other sensors which proved that the Pegasor PPS-M is a reliable particle sensor.

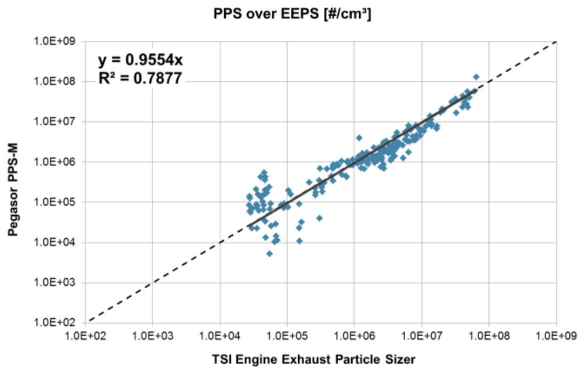

Figure 4 - Comparison PPS-M – EEPS

In conclusion, the use of higher injection pressures in GDI engines shows possibilities to reduce particle emissions considering concentration and mass. This was investigated by using multiple particle sensors which all showed the same tendencies. The tendencies are all in one line and allow for the presumption that there is still potential in increasing the injection pressure even further for operating points with high load and speed in order to reduce particle emissions even more.

References:

[1] Buri, S. (2011). *Untersuchungen des Potenzials von Einspritzdrücken bis 1000 bar in einem Ottomotor mir Direkteinspritzung und strahlgeführtem Brennverfahren.* Karlsruhe: Institut für Kolbenmaschinen.

[2] Europäische Komission. (2012). *Verordnung (EU) Nr. 459/2012 der Komission.* Europäischen Union.

[3] Kapus, P. et al. (2010). *Reduzierung der Partikelanzahl durch applikative Massnahmen.* MTZ.

[4] Kufferath, A. et al. (2012). The EU6 Challenge at GDI – Assessment of Feasible System Solutions. *33. Internationales Wiener Motorensymposium*, (S. 248-270). Wien.

[5] Ntziachristos, L. et al. (2013). Application of the Pegasor Particle Sensor for the Measurement of Mass and Particle Number Emissions. *SAE Paper*, 2013-01-1561.

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Agenda

MOT GmbH
Motorentechnik - Optik - Thermodynamik
Prof. Dr.-Ing. U. Spicher

Motivation

Why?

Health risk

- **Respirable (< PM_{10})**
- **Carcinogenicity, mortality rate**

Legislation

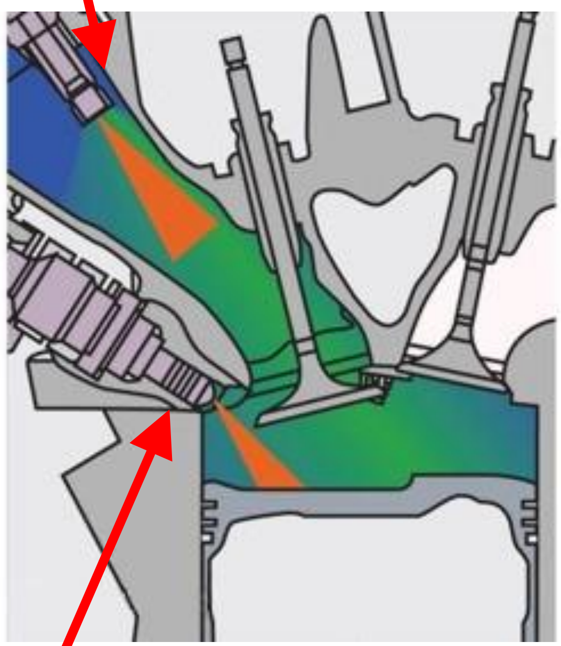
- **Low-Emission zones (LEZ)**
- **Euro 6 - GDI particle limit**

Reduction of particle emissions

- **Particle filters**
- **Application & design**

Motivation - GDI vs. PFI

Port fuel injection - PFI



Source: Motornature - Lexus

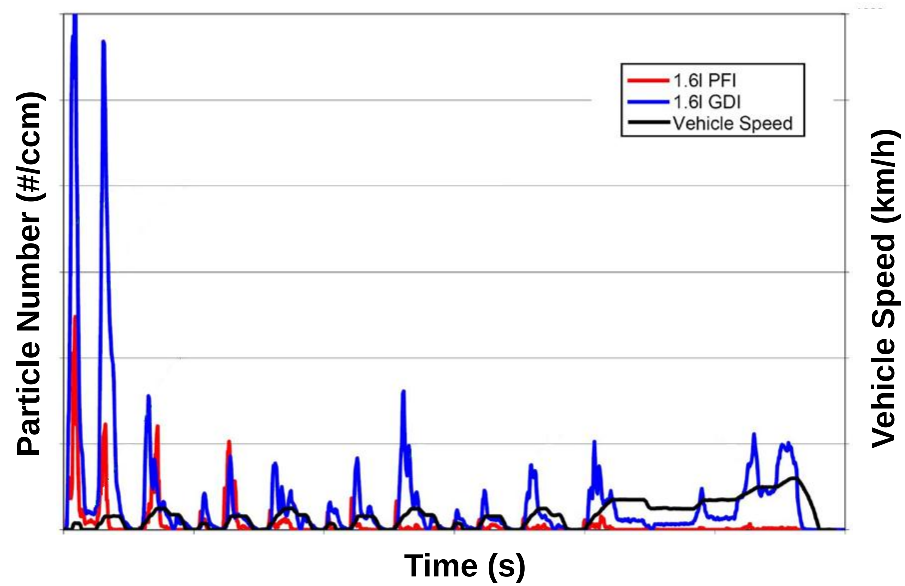
Gasoline direct injection - GDI

- **Mixture formation**
- **Homogenization**

} **GDI WORSE** ⬇

- **Fuel efficiency**
- **Engine performance**

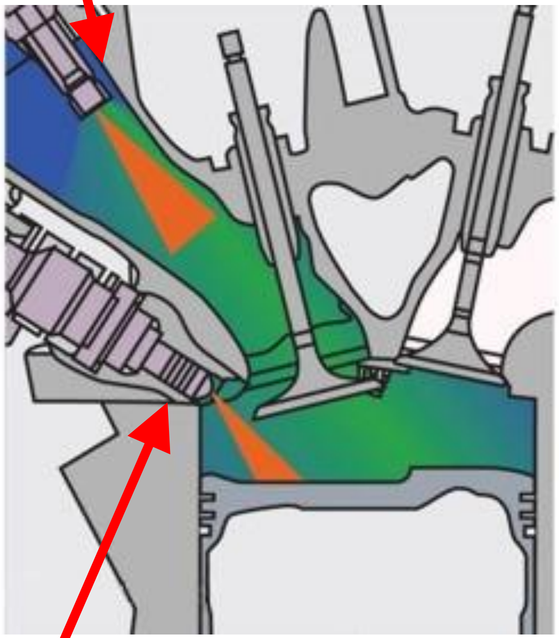
} **GDI BETTER** ⬆



Source: SAE Technical Paper 2011-01-1219

Motivation - GDI vs. PFI

Port fuel injection - PFI



Source: Motornature - Lexus

Gasoline direct injection - GDI

- Mixture formation
- Homogenization
} **GDI WORSE** ⬇

- Fuel efficiency
- Engine performance
} **GDI BETTER** ⬆

Higher injection pressure:

- Higher spray velocity
- Shorter injection time
- Smaller droplets

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Test setup

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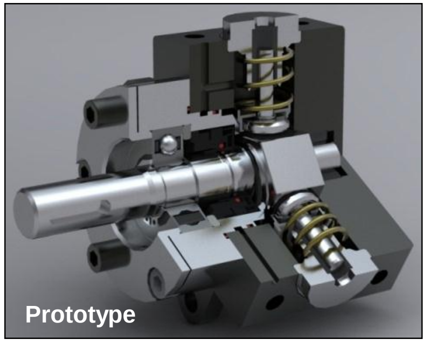
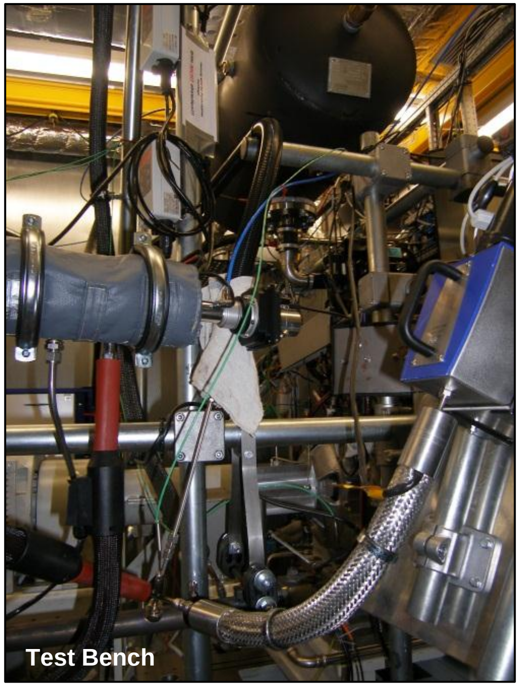
High-pressure pump:

- Developed at the IFKM
- Max. delivery pressure: 800 bar
- Ceramic parts in tribologic pairings



Fuel injector:

- Magnet injector with 8 holes
- p_{max} = 300 bar
- Optimized spray pattern



Engine:

- Single-cylinder, central injector
- Gasoline direct injection, homogenous
- Compression ratio ≈ 10:1
- Displacement ≈ 500 cm^3

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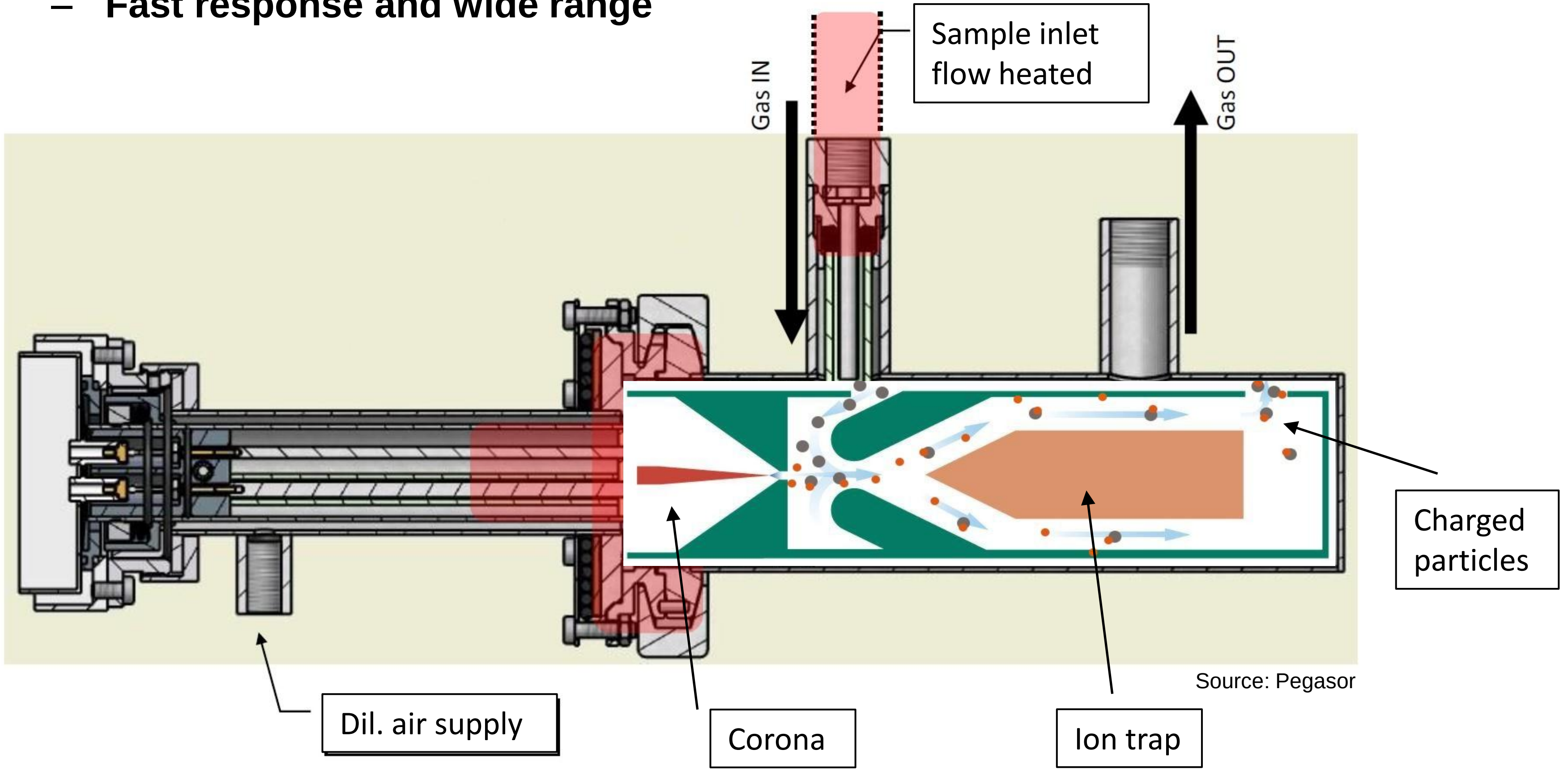
Particle sensors

- **Pegasor PPS-M**
  - **Electrical charging and detection of airborne PM**
  - **Measurement of mass and number concentration**
  - **Fast response and wide range**



Source: Pegasor

Particle sensors

- **TSI - Engine Exhaust Particle Sizer (EEPS)**
  - **Electrical mobility of charged particles depending on size**
  - **Concentration and size distribution (6 nm - 523 nm)**

Source: TSI

- **AVL Particle Counter 489 (APC)**
  - **Concentration is measured by light scattering**

Source: AVL

Agenda

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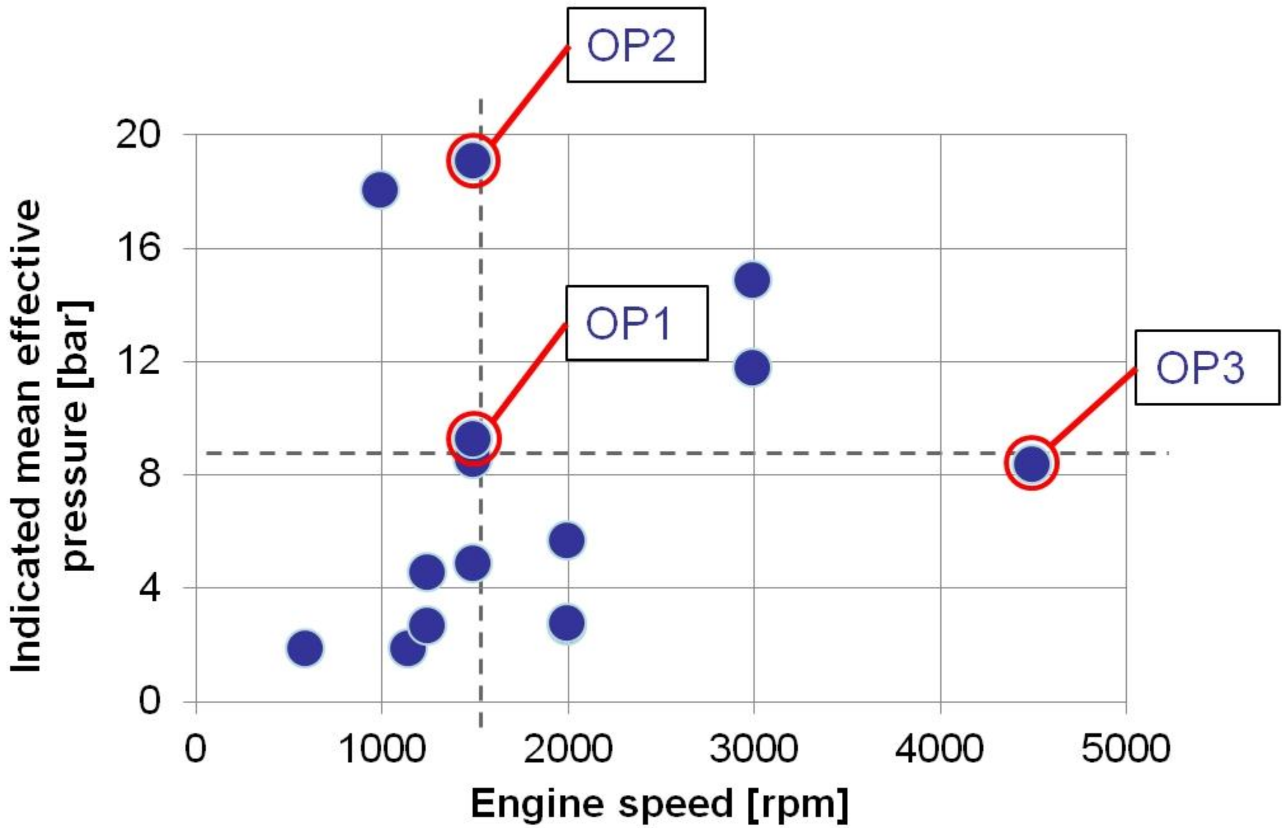
1	Motivation
2	Test setup
3	Particle sensors
4	**Influence of injection pressure**
5	Comparison of sensors
6	Conclusion

Influence of injection pressure

Operating Points

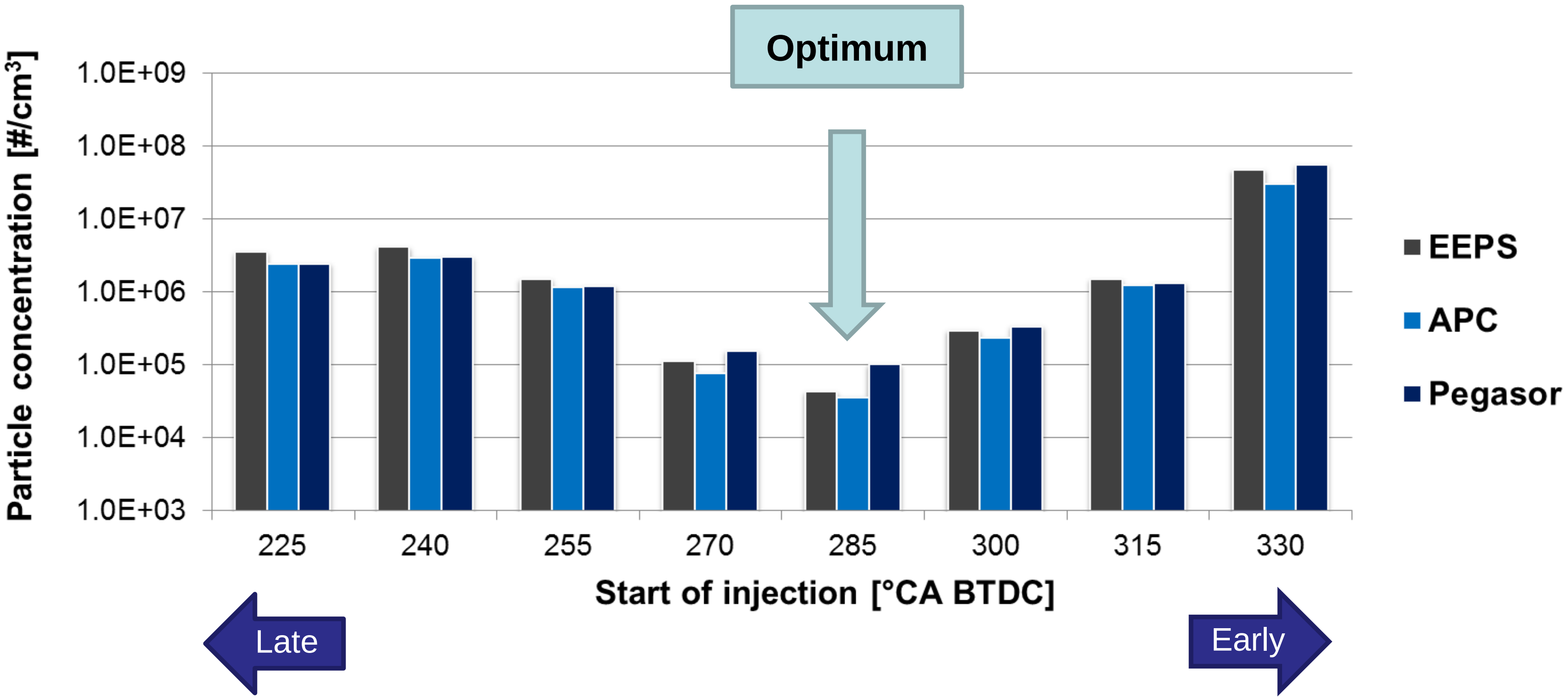


Operating points:

1) 1500 rpm @ 9.2 bar IMEP
2) 1500 rpm @ 19.0 bar IMEP
3) 4500 rpm @ 8.3 bar IMEP

Influence of injection pressure

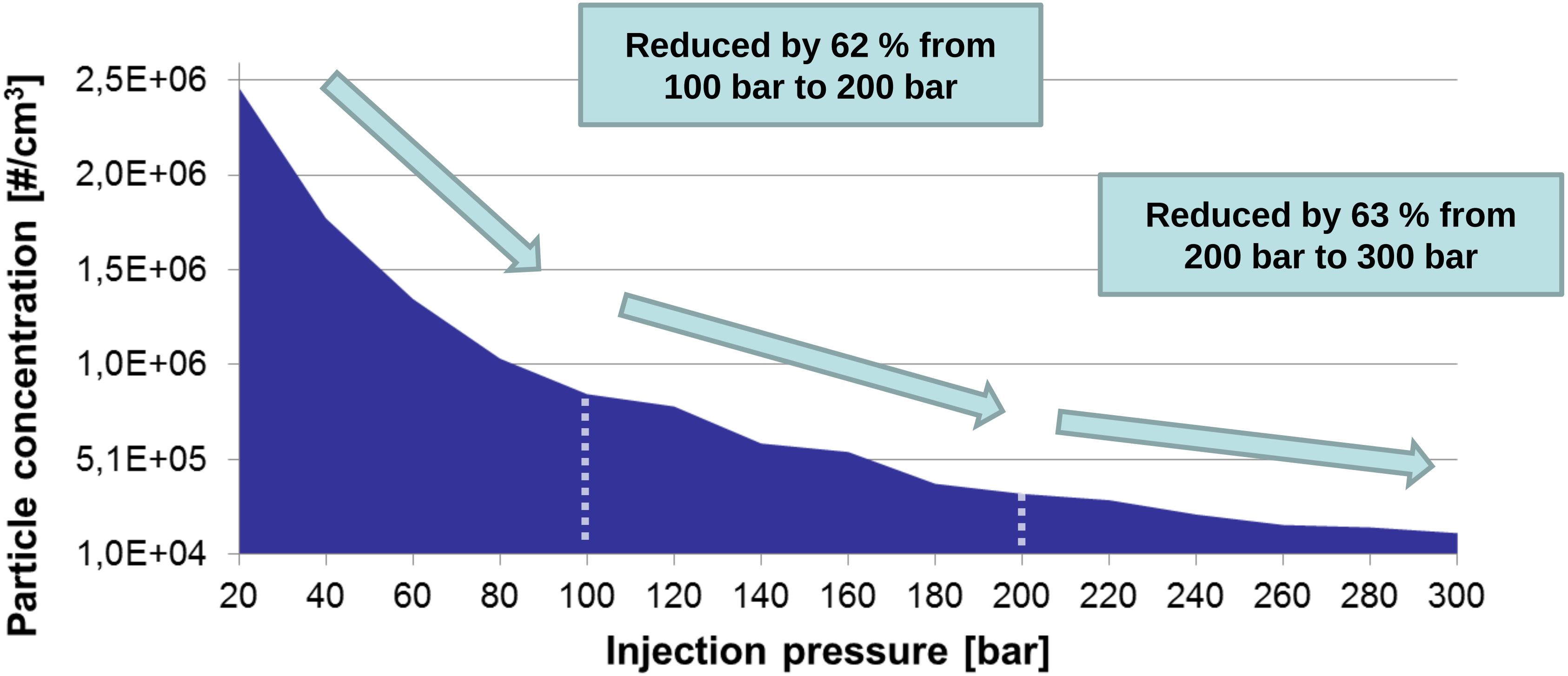
Start of injection



Operating Point 1 - 1500 rpm @ 9.2 bar IMEP

Influence of injection pressure

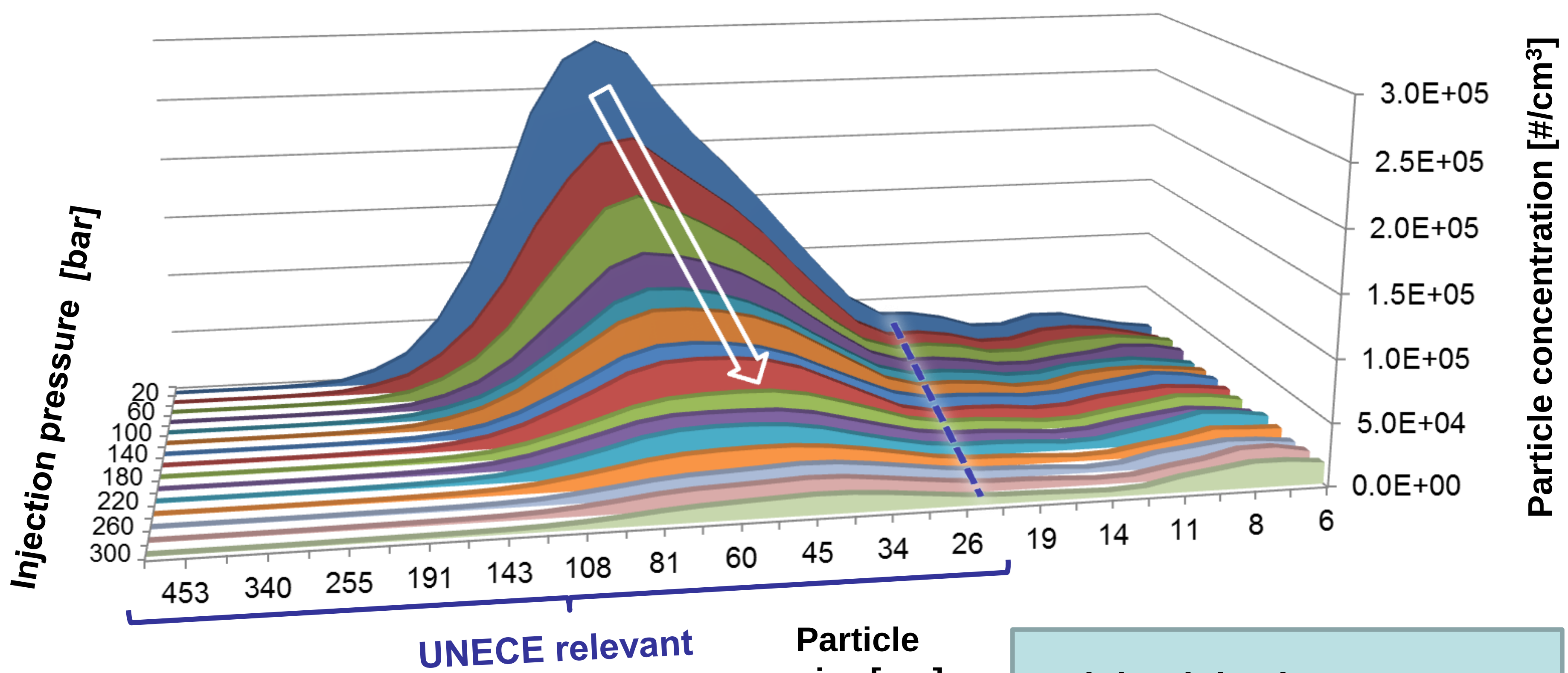
Particle concentration



Operating Point 1 - 1500rpm @ 9.2 bar IMEP

Influence of injection pressure

Particle size distribution

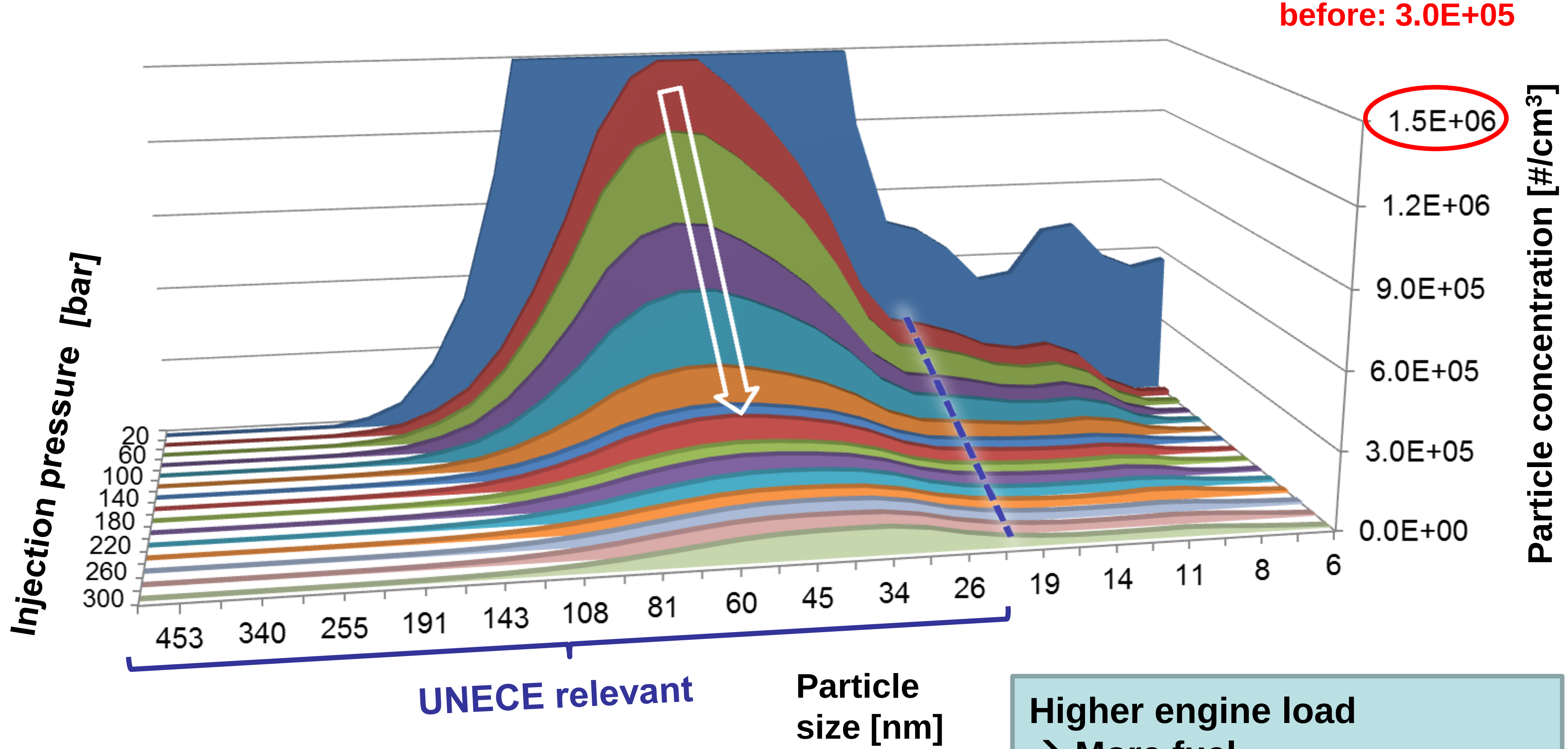


Higher injection pressures effectively reduce particles in accumulation mode

Operating Point 1 - 1500 rpm @ 9.2 bar IMEP

Influence of injection pressure

Particle size distribution

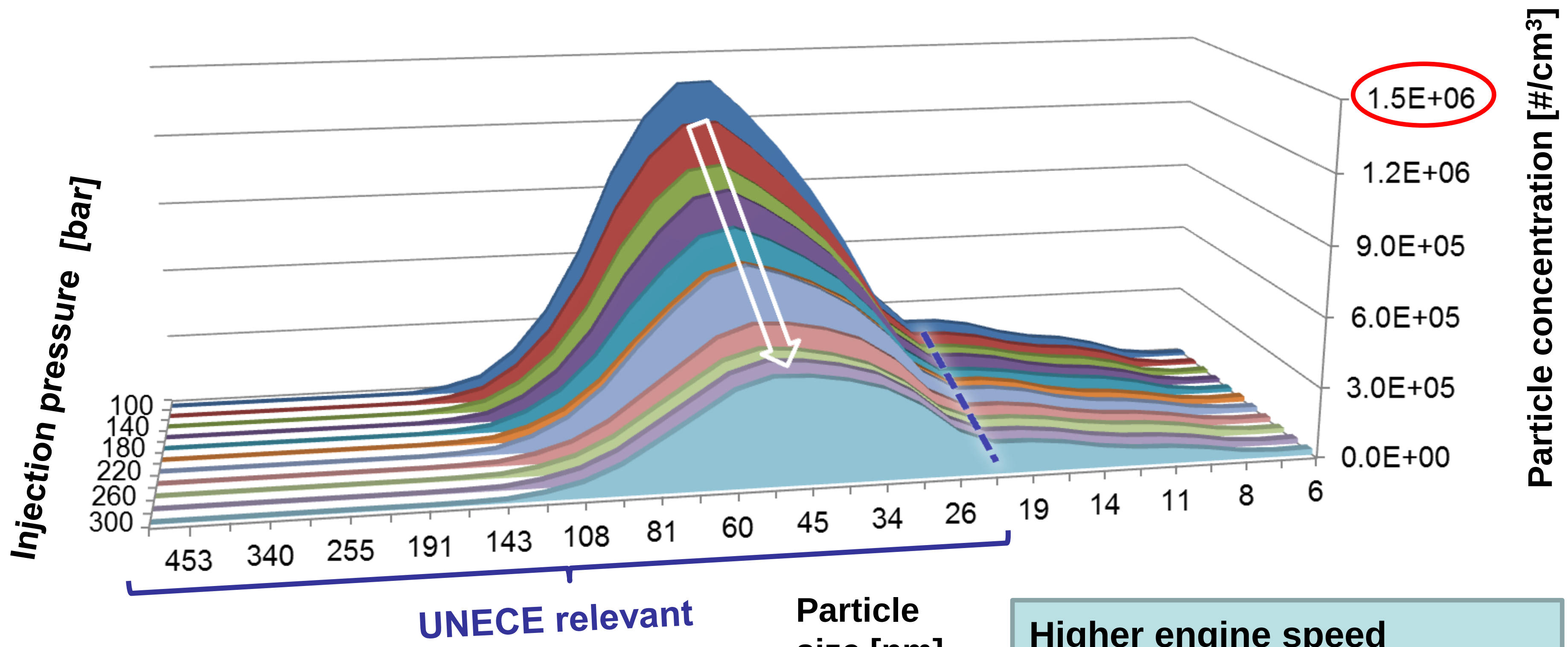


Higher engine load
→ More fuel
→ Less time for evaporation
→ Worse mixture formation

Operating Point 2 - 1500 rpm @ 19.0 bar IMEP

Influence of injection pressure

Particle size distribution



Higher engine speed
→ Shorter combustion
→ Less time for evaporation
→ Worse mixture formation

Operating Point 3 - 4500 rpm @ 8.3 bar IMEP

Influence of injection pressure

Particle mass concentration

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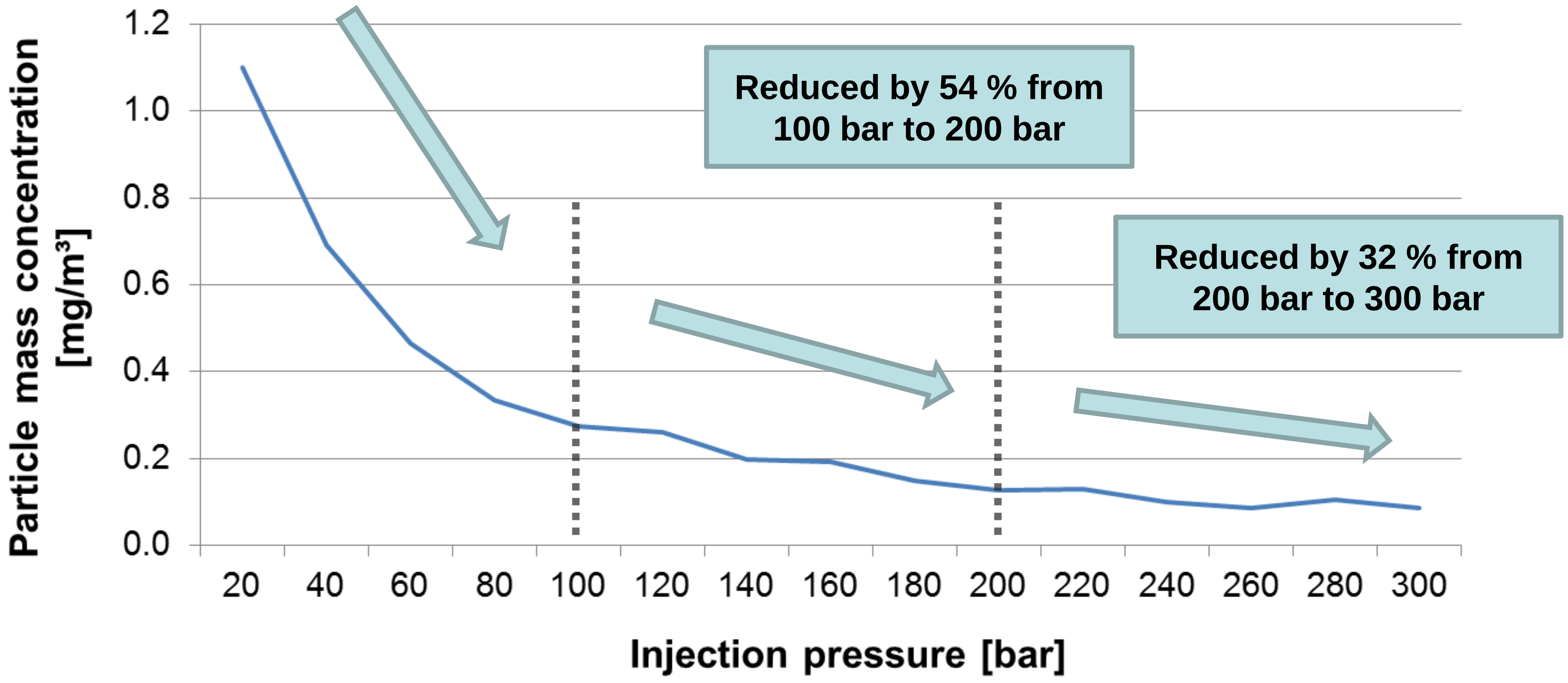
$$\bar{m} = \sum_i N_i \cdot \rho_i \cdot {}^1/_6 \cdot \pi \cdot {d_i}^3$$



Operating Point 1 - 1500 rpm @ 9.2 bar IMEP

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Prof. Dr. sc. techn. Thomas Koch

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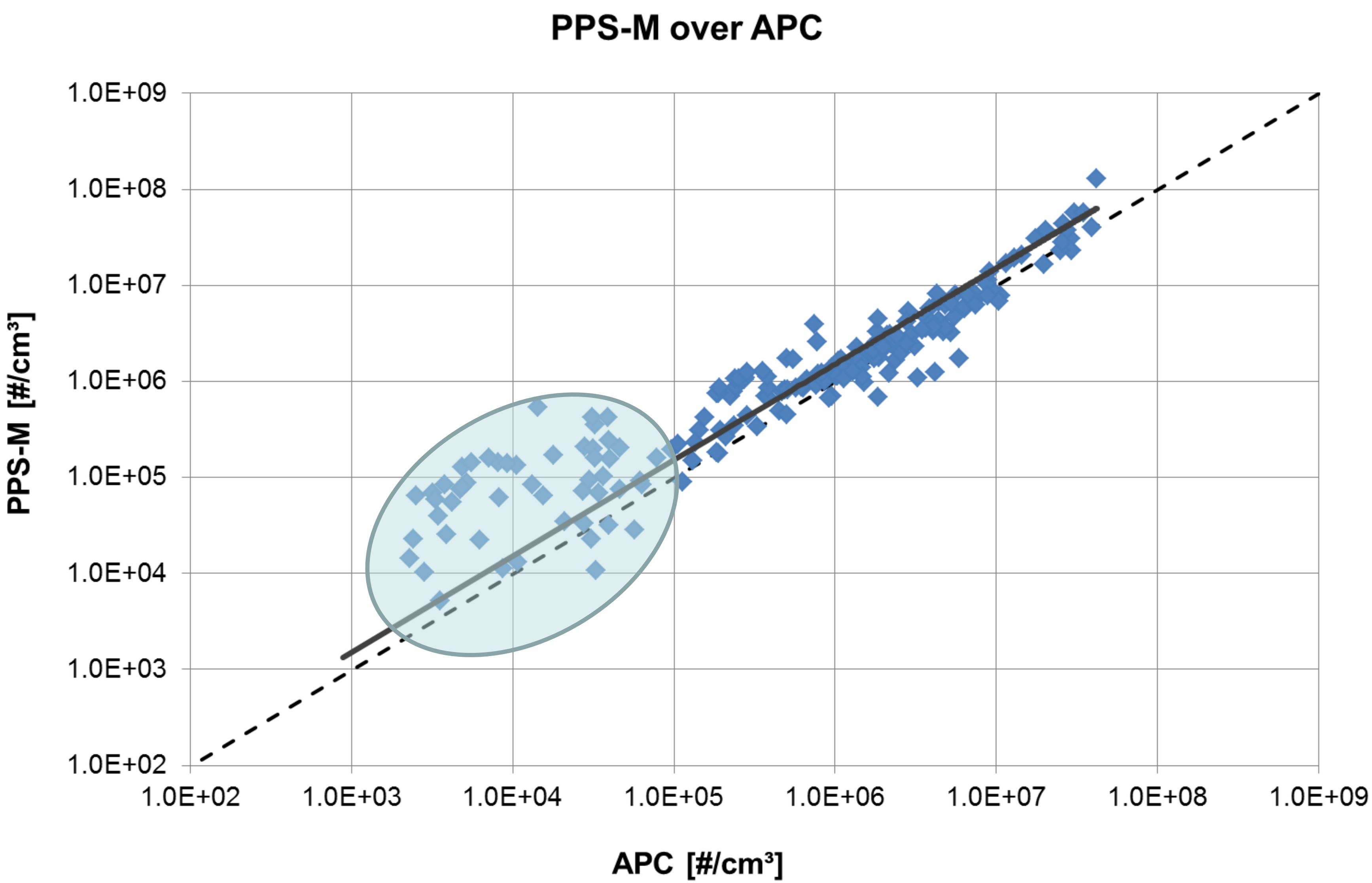
Comparison of sensors



Comparison of sensors

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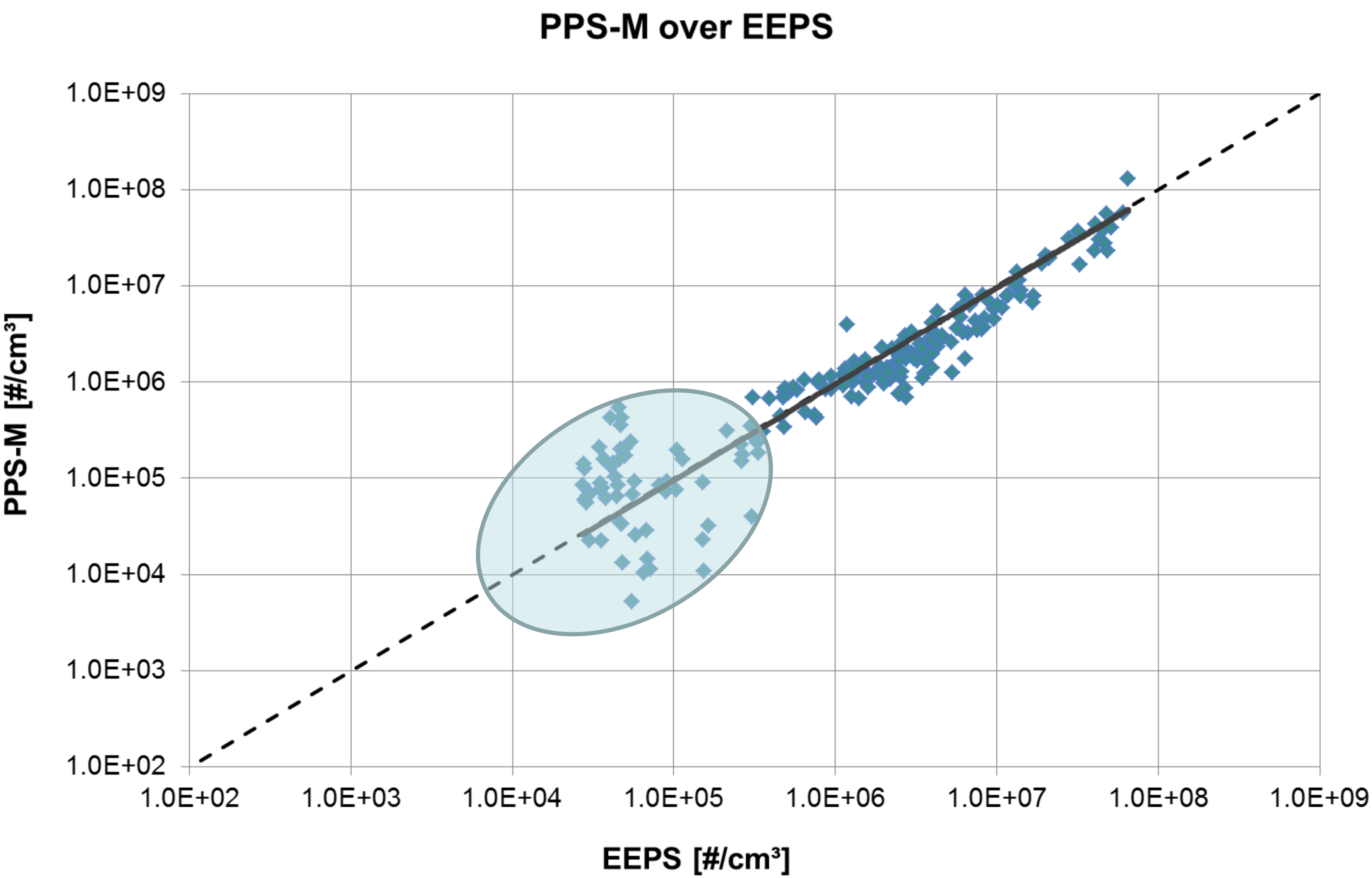

Agenda

Conclusion

- Influence of injection pressures up to 300 bar:
  - Particle number reduced by 70 % using 200 bar instead of 100 bar and by another 50 % by using 300 bar injection pressure
  - Particle mass and mean size were also reduced

- Comparison of the particle sensors:
  - PPS-M showed good results in correlation to EEPS and APC
  - Knowledge of mean particle size is relevant

- Outlook:
  - Multiple injections, highly heated fuel
  - Measurement under transient conditions

Any questions?

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