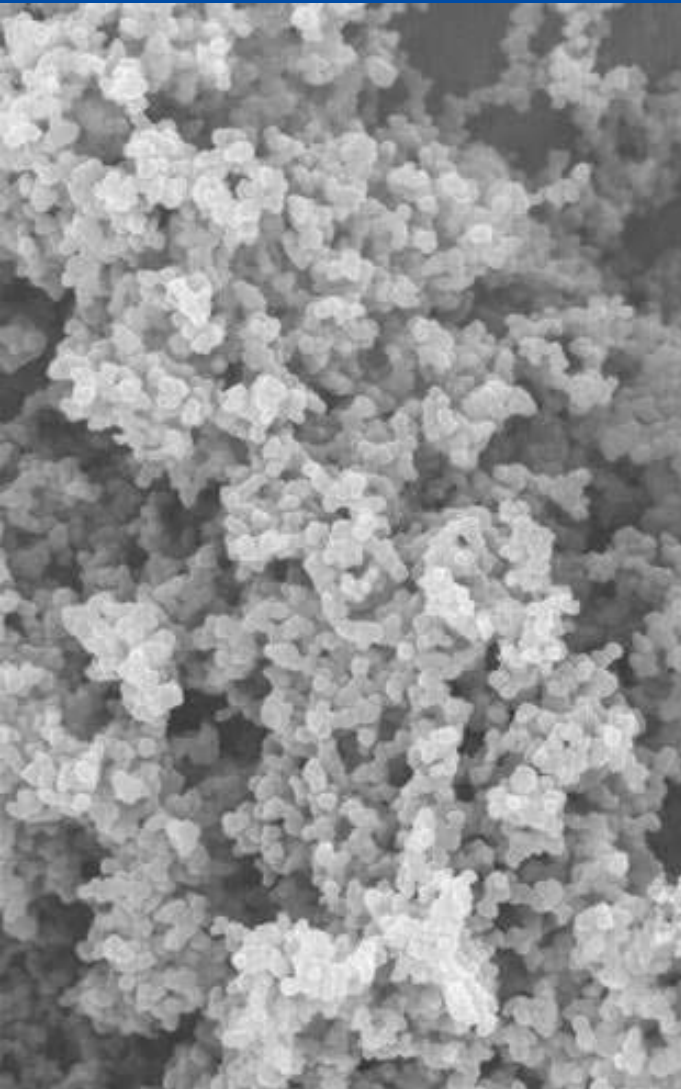


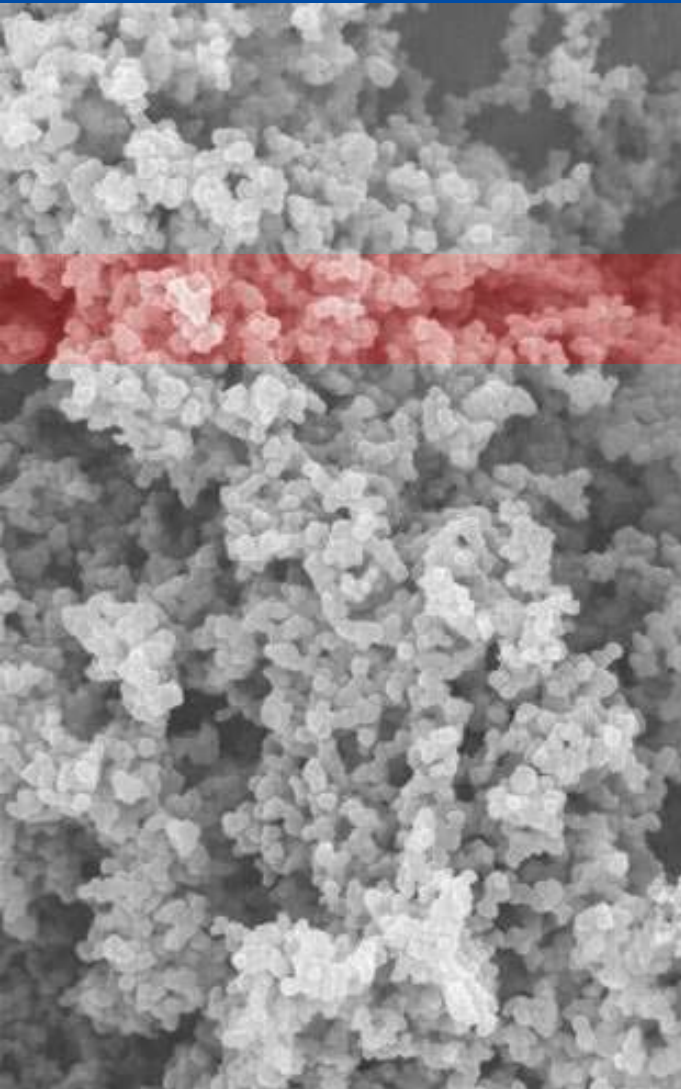


Reducing the particulate emission numbers in DI Gasoline Engines

Kody Klindt, IAV Automotive Engineering Inc.



- 1. Motivation**
- 2. Particle Formation and Measurement**
- 3. Process Description**
- 4. Applying Calibration Measures to a GDI Concept**
- 5. Summary**



1. Motivation

2. Particle Formation and Measurement

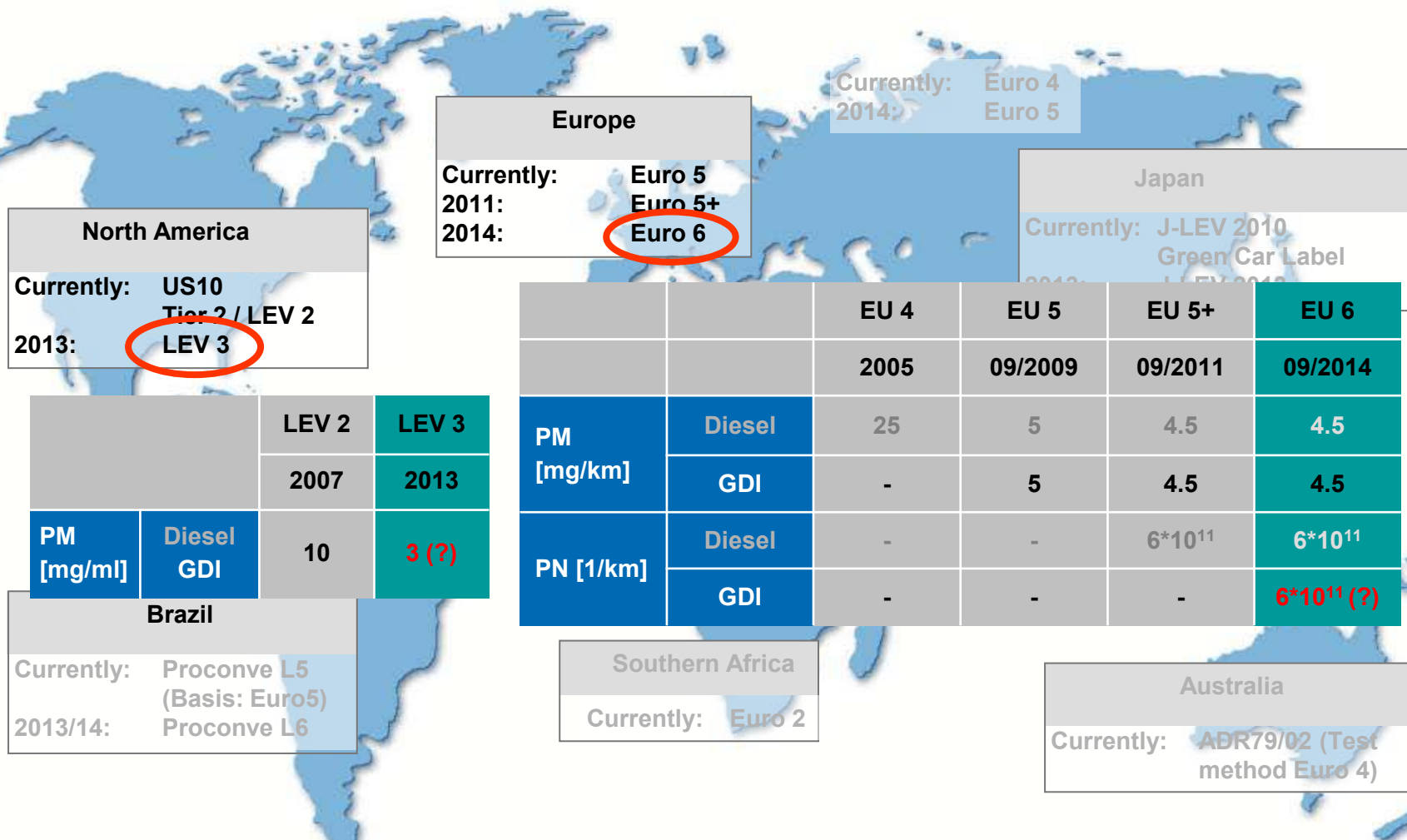
3. Process Description

4. Applying Calibration Measures to a GDI Concept

5. Summary

Motivation

Limit Values for Particulate Emissions



North America
 Currently: US10
 Tier 2 / LEV 2
 2013: **LEV 3**

Europe
 Currently: Euro 5
 2011: Euro 5+
 2014: **Euro 6**

Currently: Euro 4
 2014: Euro 5

Japan
 Currently: J-LEV 2010
 Green Car Label
 LEV 2010

		EU 4	EU 5	EU 5+	EU 6
		2005	09/2009	09/2011	09/2014
PM [mg/km]	Diesel	25	5	4.5	4.5
	GDI	-	5	4.5	4.5
PN [1/km]	Diesel	-	-	6*10 ¹¹	6*10 ¹¹
	GDI	-	-	-	6*10 ¹¹ (?)

		LEV 2	LEV 3
		2007	2013
PM [mg/ml]	Diesel GDI	10	3 (?)

Brazil
 Currently: Proconve L5 (Basis: Euro5)
 2013/14: Proconve L6

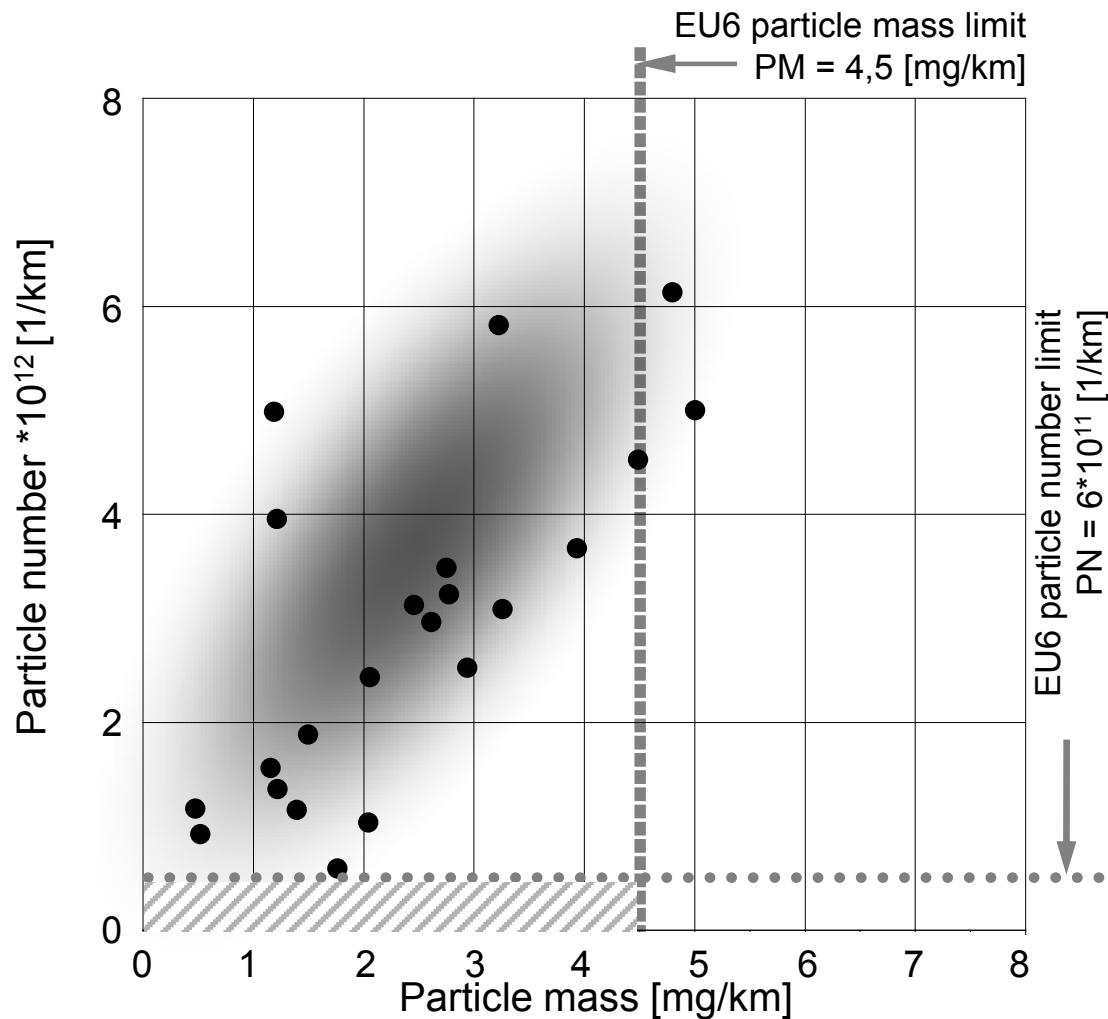
Southern Africa
 Currently: Euro 2

Australia
 Currently: ADR79/02 (Test method Euro 4)

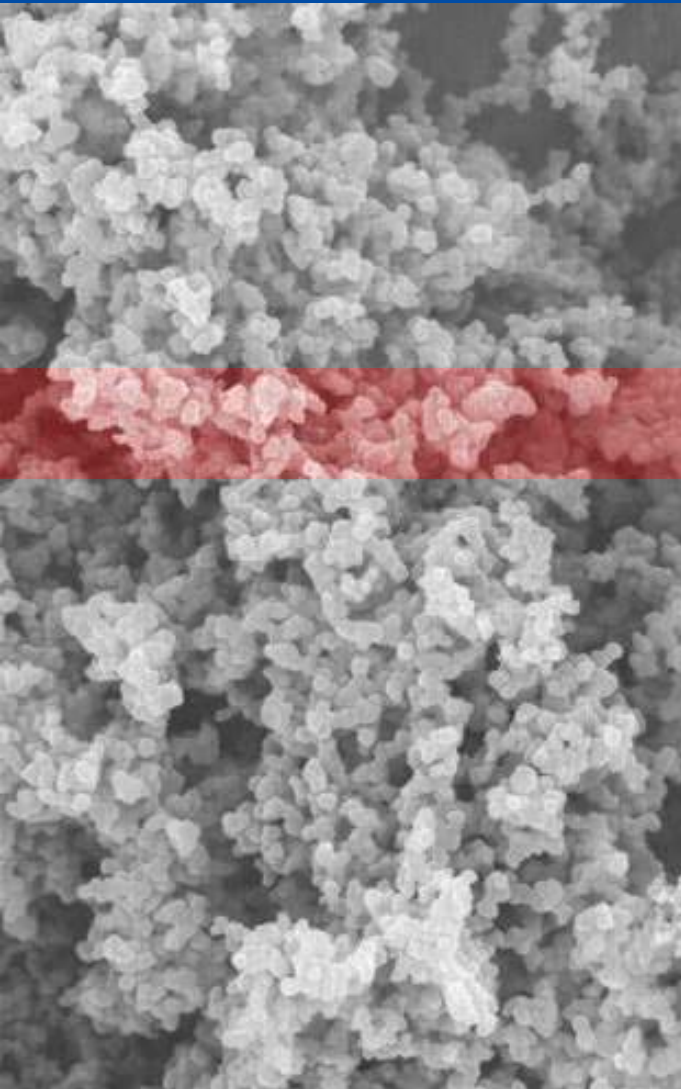
EU6 and LEV3 limit values for particulate emissions under discussion

Motivation

Present range of DI gasoline engine



**Broad distribution
of particle mass
and
particle number
with different
production
concepts**



1. Motivation

2. Particle Formation and Measurement

3. Process Description

4. Applying Calibration Measures to a GDI Concept

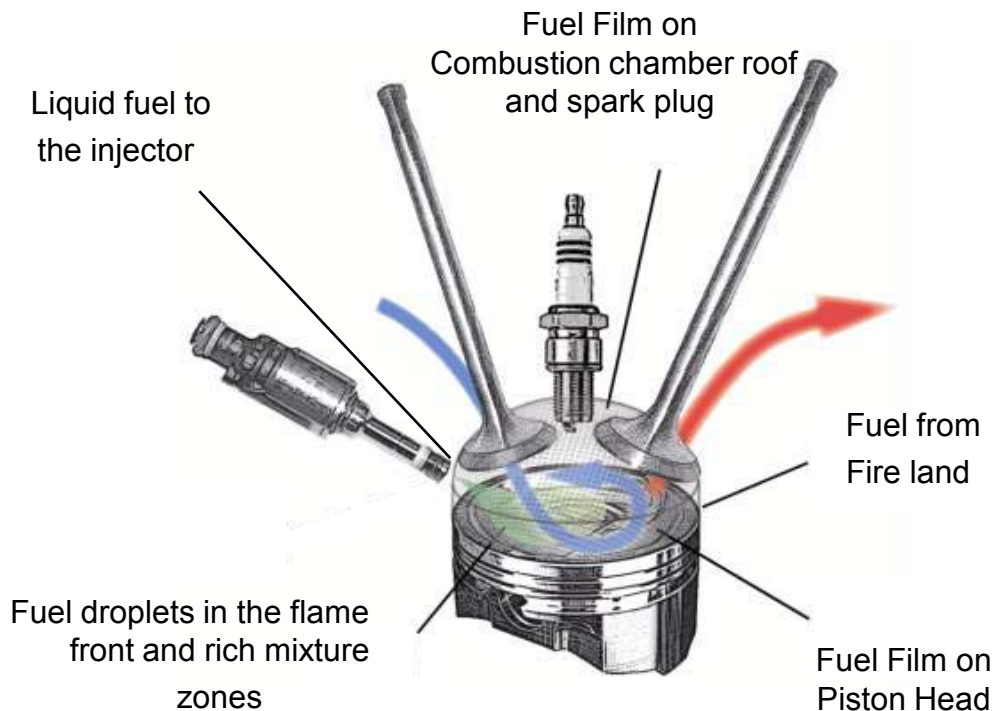
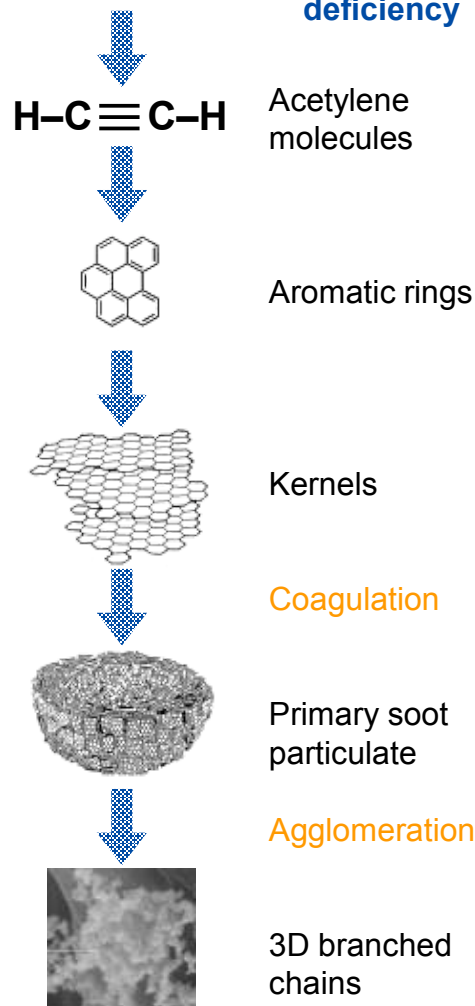
5. Summary

Particle Formation and Measurement

Soot formation mechanisms



HC in hot atmosphere with O₂ deficiency



Global rich mixture: Catalyst heating, Acceleration enrichment, Rich region in engine map

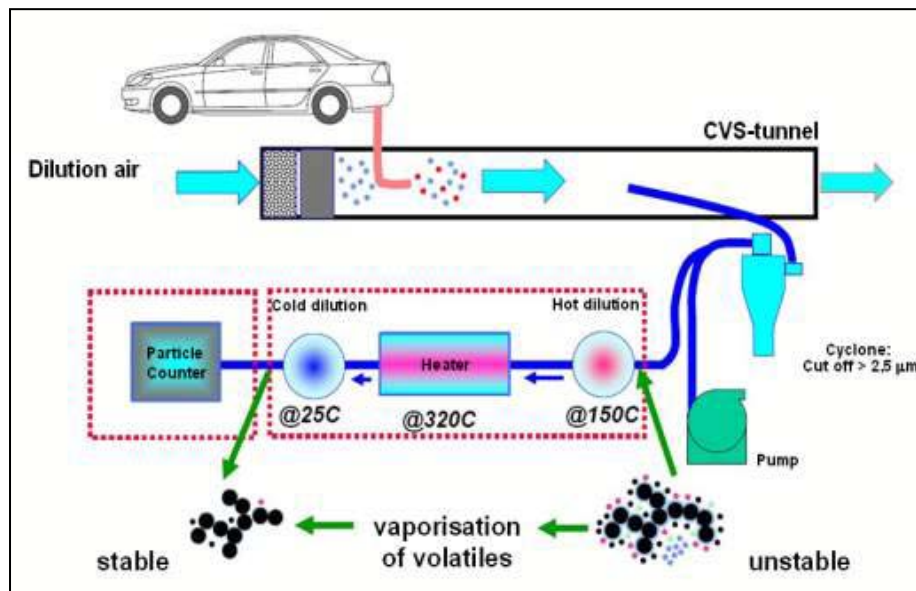
Particle Formation and Measurement

Particle number measuring systems



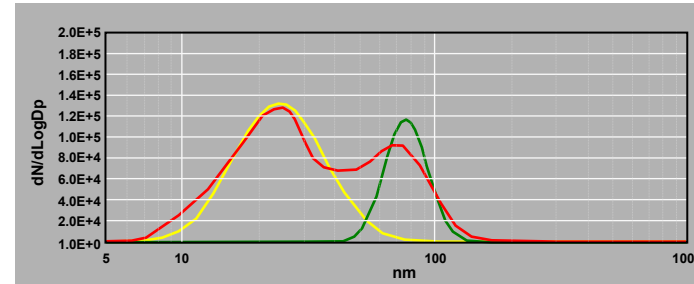
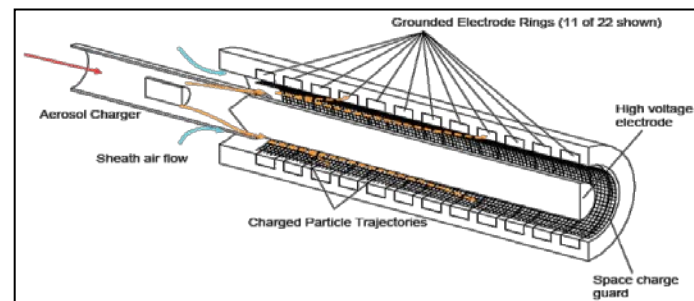
	Particle size min - max	Effective range	Size group	Sampling rate	PMP conformity
HORIBA MEXA 1000 SPCS	23 nm - 2500 nm	0 – 3x10 ⁸ #/cm ³	-	1 Hz	yes
CAMBUSTION DMS 500	5 nm - 1000 nm	2.4x10 ³ – 10 ¹² dN/dlogDp/cm ³	38	10 Hz	no

Condensation particle counter

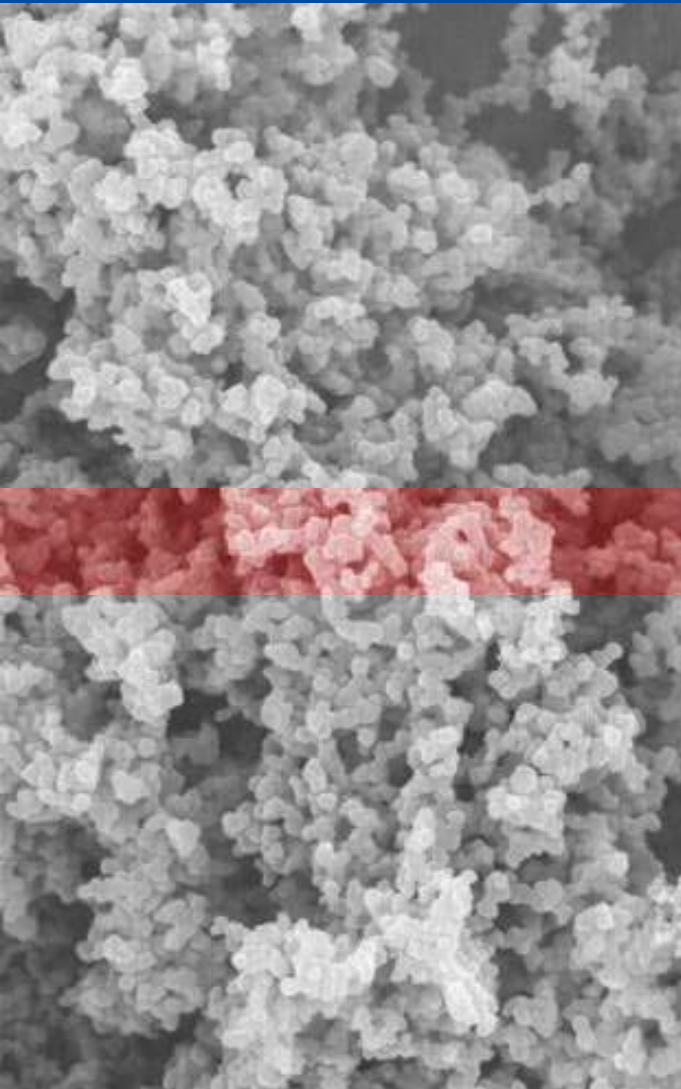


Quelle: Horiba Ltd.

Electric mobility classification



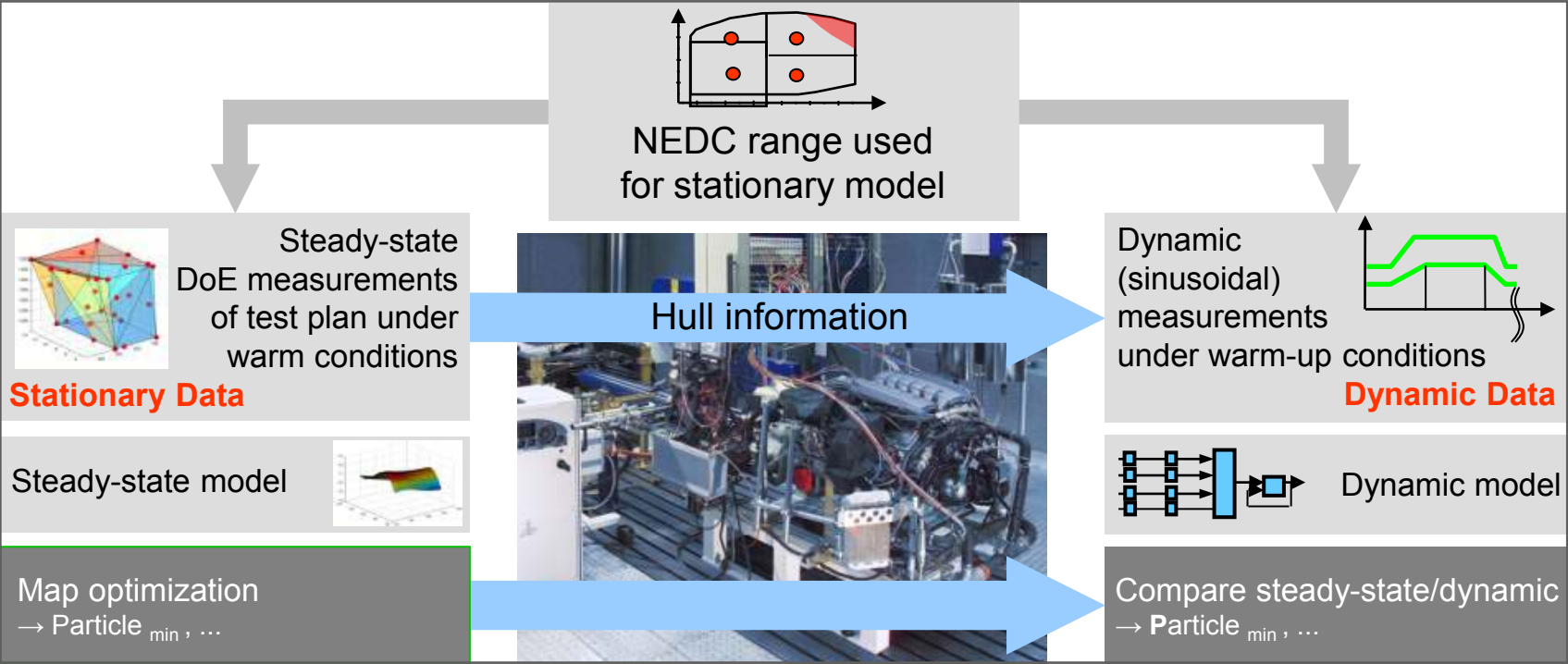
Quelle: Cambustion Ltd.



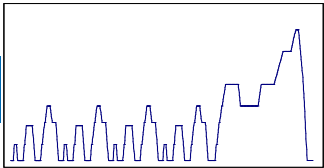
1. Motivation
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Process Description

IAV's approach to gasoline engines

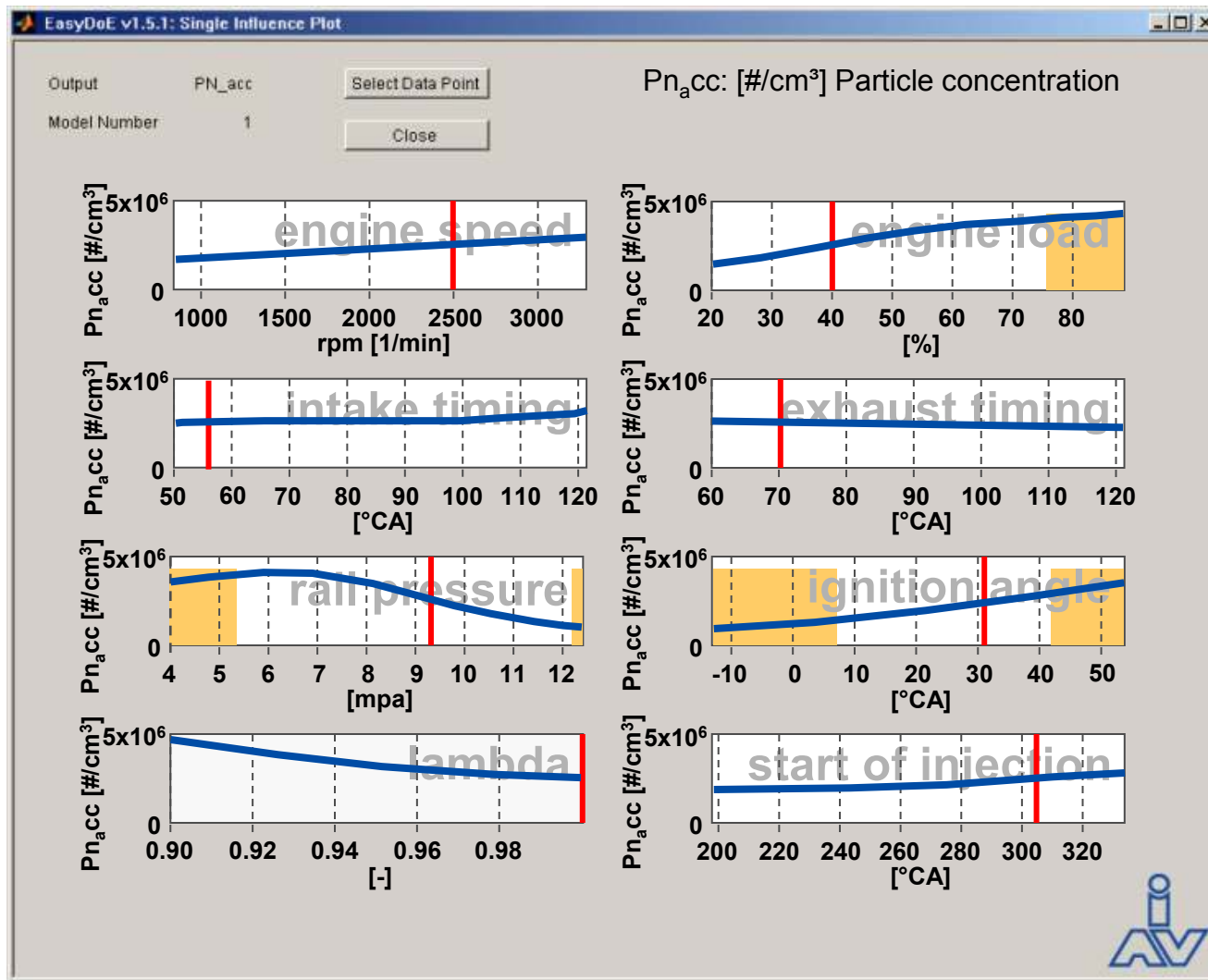


Vehicle emission calibration



Process Description

Steady-state model



Output:

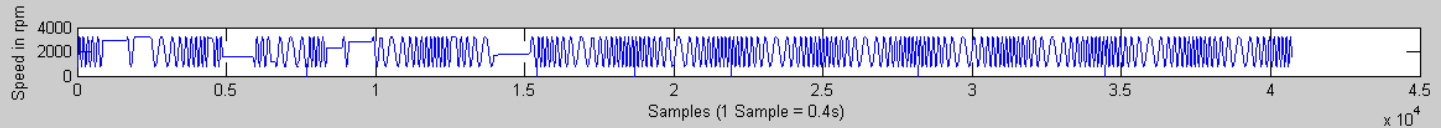
- Torque
- Fuel consumption
- AL50
- COV
- Exhaust temperature
- NOx, HC, CO
- Particle concentration

Process Description

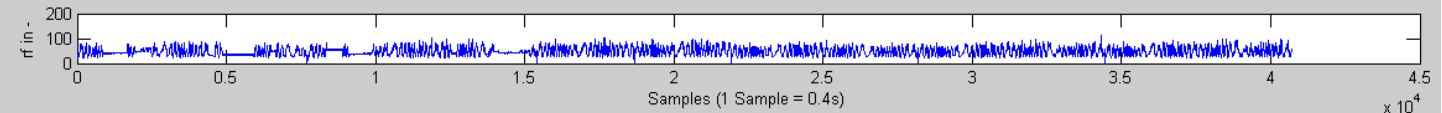
Dynamic (sinusoidal) measurements under warm-up conditions



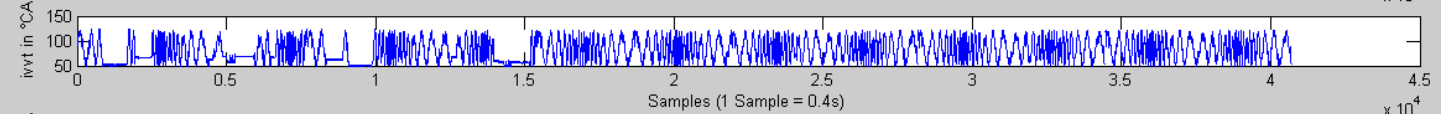
Engine speed



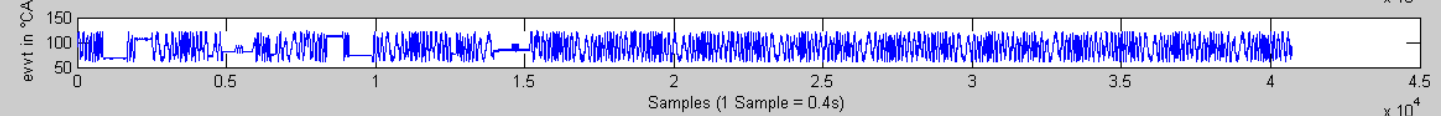
Engine load



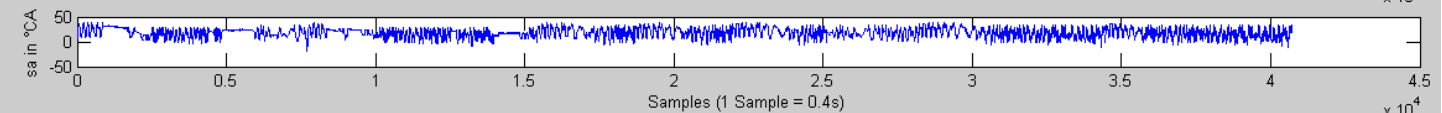
Intake timing



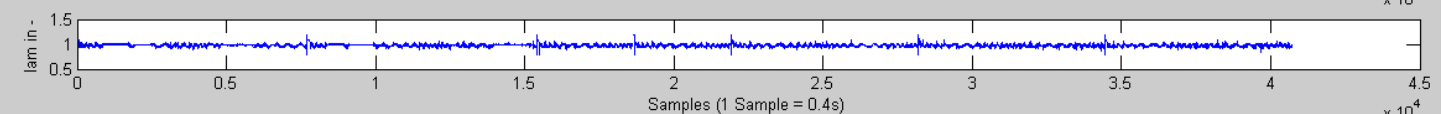
Exhaust timing



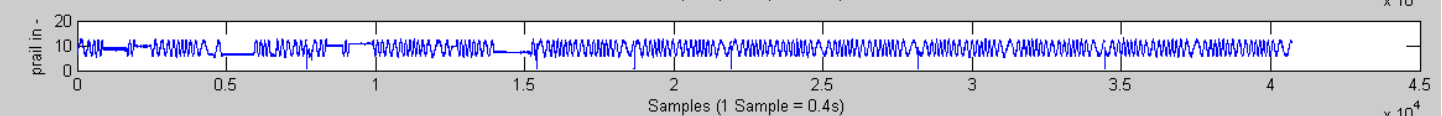
Ignition angle



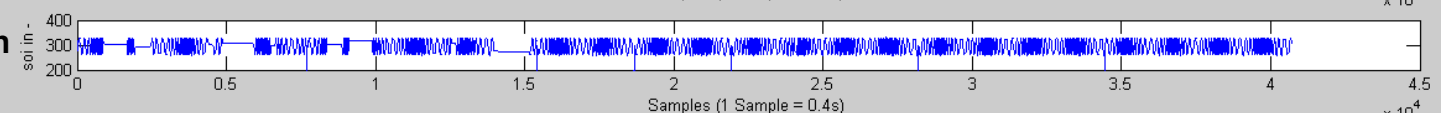
Lambda



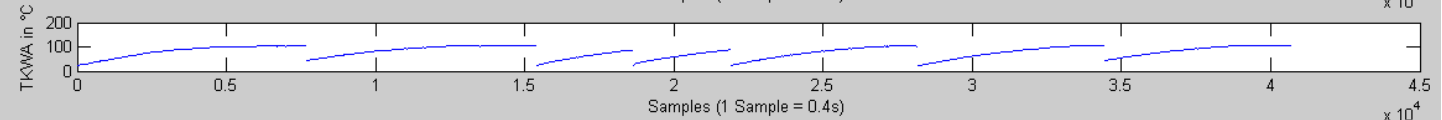
Rail pressure



Start of injection

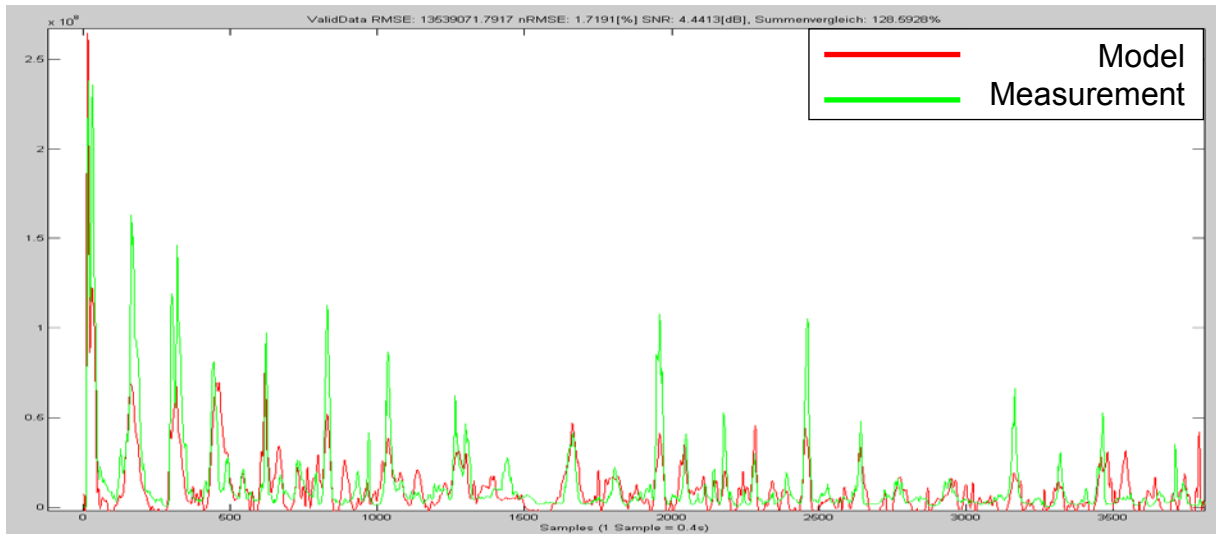
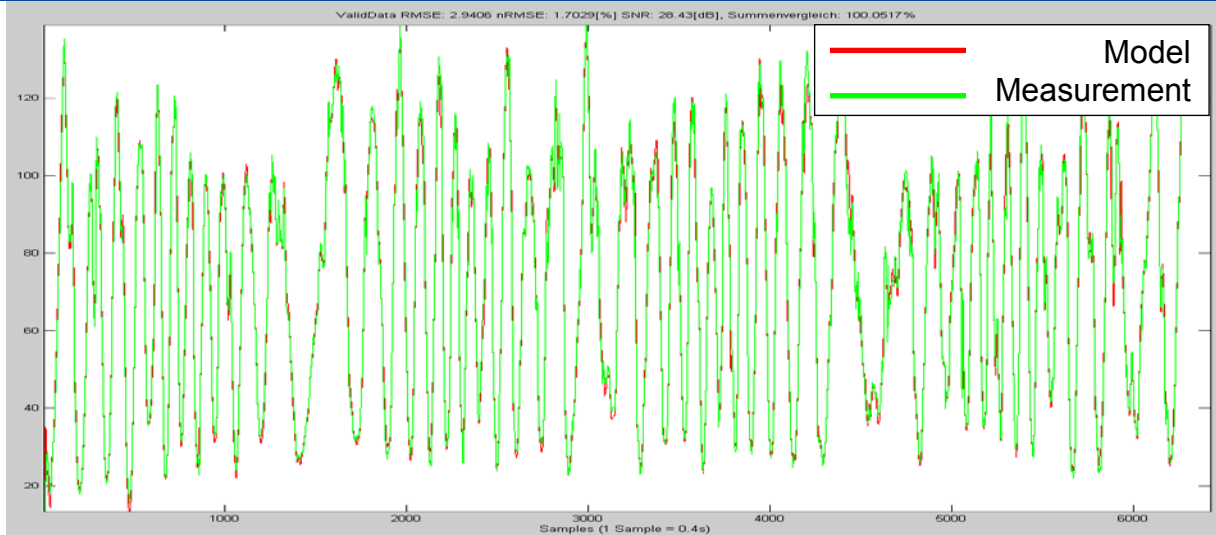


Water temperature



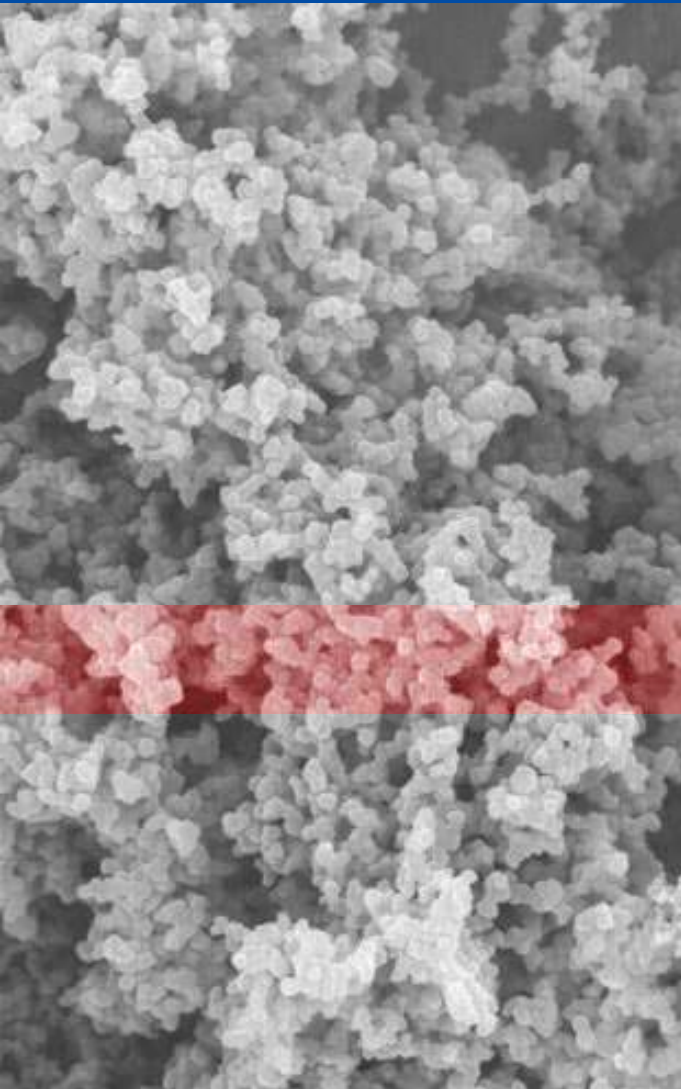
Process Description

Dynamic model - validation



Output:

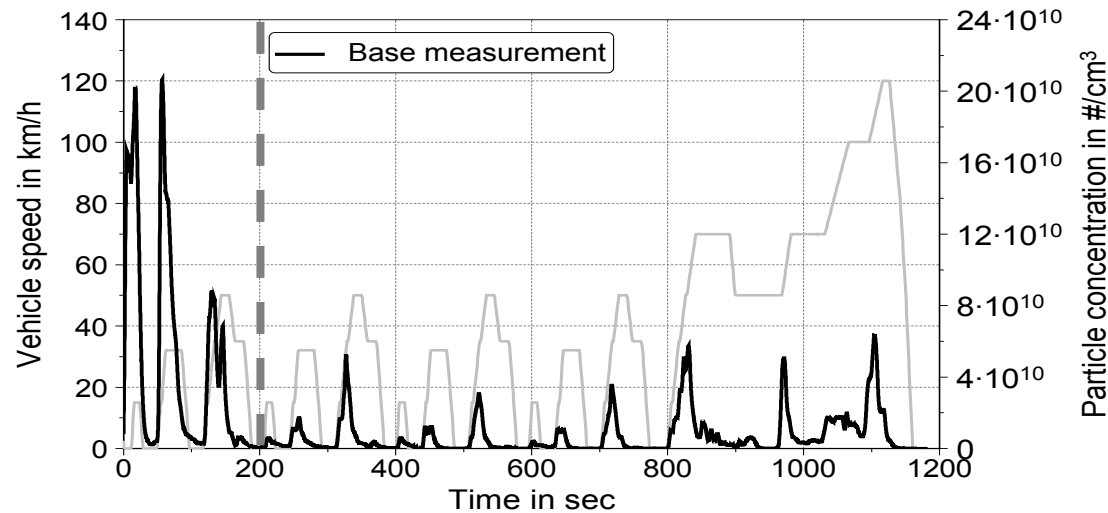
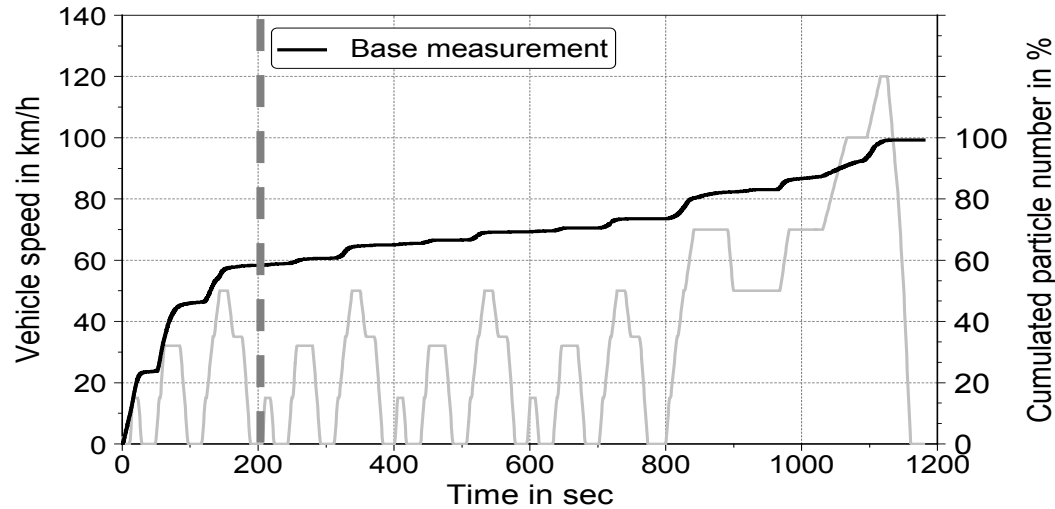
- Torque
- Fuel consumption
- AL50
- COV
- Exhaust temperature
- NO_x, HC, CO
- Particle concentration



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Applying Calibration Measures to a GDI Concept

Basis of investigations



GDI Concept

4-cylinder homogeneous
Turbocharged engine with

- Solenoid injector
- Sideways position
- Max. double injection

Boundary conditions

No influence on

- Exhaust emissions
- Drivability
- Consumption

Applying Calibration Measures to a GDI Concept

Calibration in “cold range”



- + **Start of injection** Start of 1st injection was adjusted ($\sim 35^\circ$ CA later)
- + **Injection split** Was matched with regard to particle number and rough running
- + **End of injection** The end of 2nd injection was adjusted to the split
- + **Fuel pressure** Was set near the maximum fuel pressure after engine start and to maximum at the start of 2nd hill
- + **Air fuel ratio** Better air/fuel ratio pilot control up to start of engine, reaching ideal Lambda as fast as possible
- + **Ignition angle** Subsequent adjustment at 7° CA on 1st hill and at 12° CA on 2nd hill

- **Valve timing** Changed valve timing results in efficiency reduction and increased fuel consumption



Applying Calibration Measures to a GDI Concept



Calibration in “warm range”

- + **Fuel pressure** Was set to maximum fuel pressure in complete range except idle and at low loads (near to minimum injection quantities)
- + **Start of injection** Start of 1st injection was adjusted ($\sim 20^\circ\text{CA}$ later)
- + **Injection split** Was matched with regard to particle number



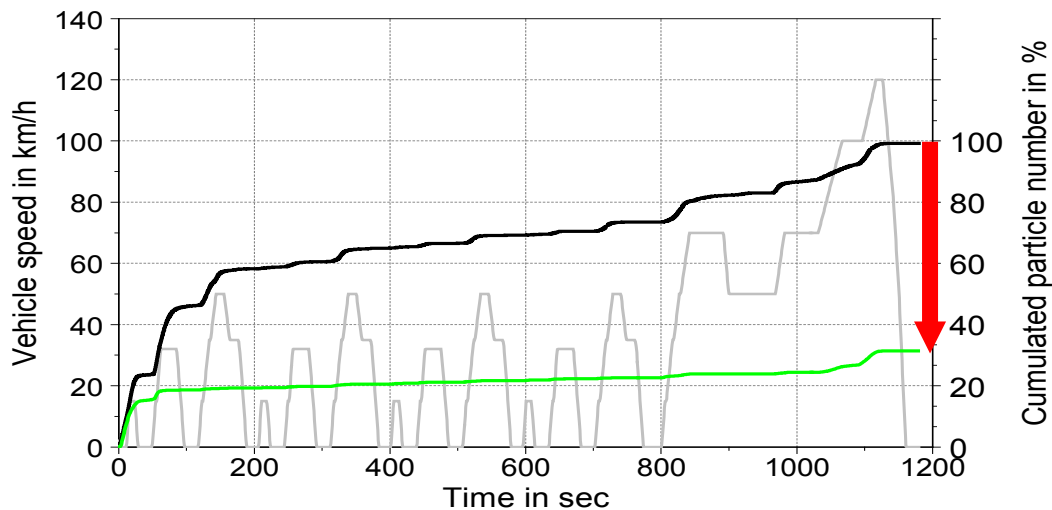
- **Ignition angle** Later ignition angle results in particle reduction - but comes with rising fuel consumption
- **Valve timing** Changed valve timing results in efficiency reduction and increased fuel consumption
- **Air/fuel ratio** Operating at $\lambda = 1$ ensures particle optimum regarding the other emission components



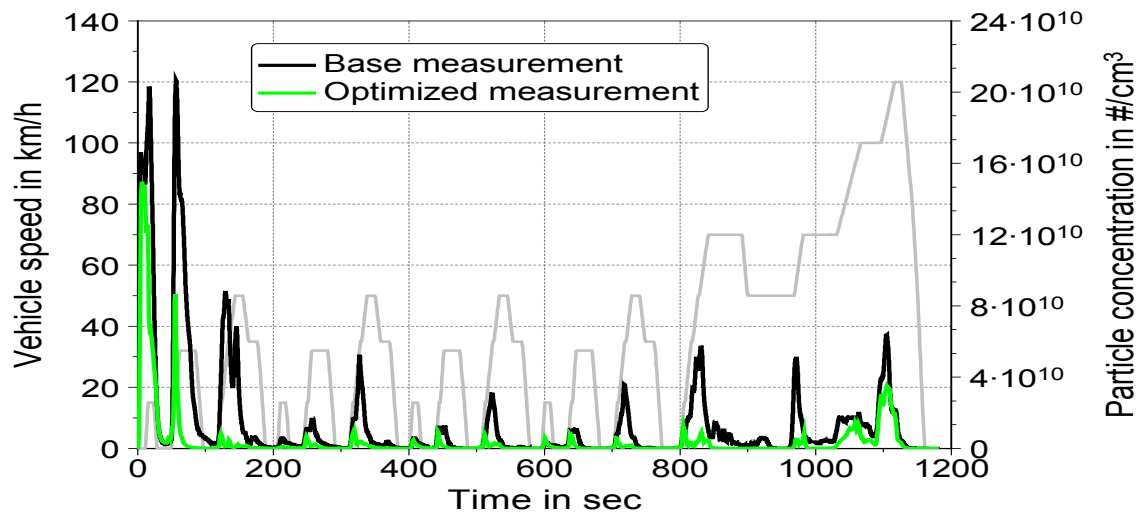
Applying Calibration Measures to a GDI Concept

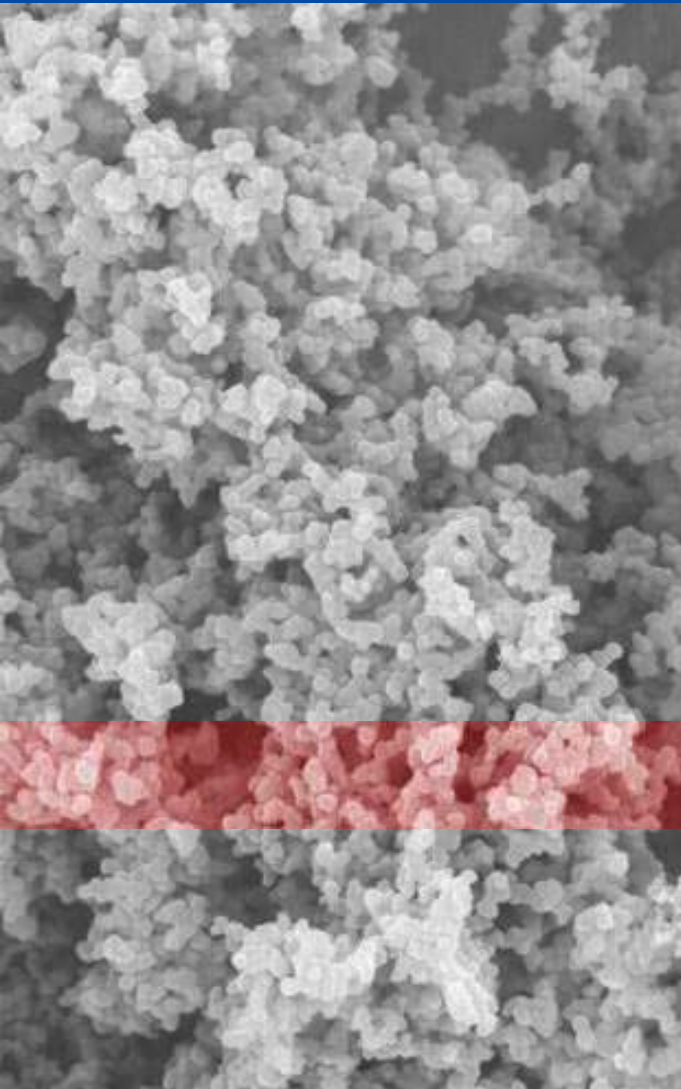


Result of particle optimization

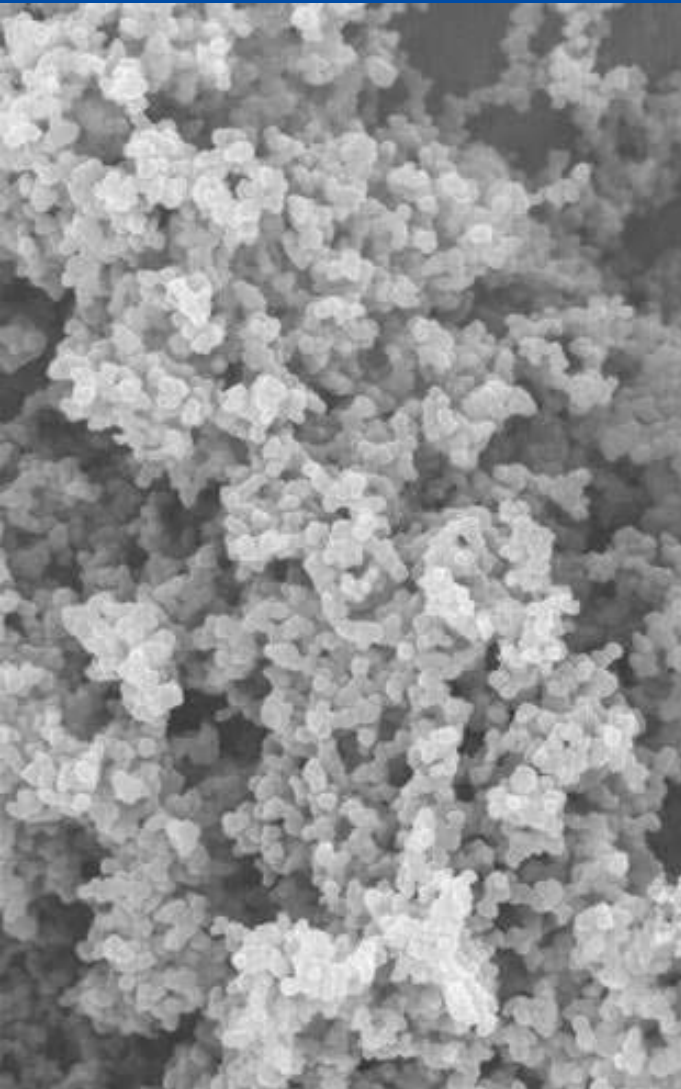


Reduction of 65 %





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5. **Summary**



- **Future particle limits require optimized calibration and optional hardware adjustment**
- **IAV has developed a steady-state and a dynamic model to optimize particulate emissions**
- **Significant decrease of particle number in a GDI concept**



IAV GmbH

- **Matthias Kratzch**
- **Olaf Kannapin**
- **Dr. Stephan Liebsch**
- **Michael Preisner**
- **Thomas Guske**