Application of the LI²SA-Soot-Sensor for the characterisation of modern low emission engines

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Due to tightened exhaust legislation the automobile industry has developed new modern low emission engines and exhaust aftertreatment systems like oxidation catalysts and particulate traps, to lower on the one hand the gaseous components and on the other hand particles, mainly soot because of its insanitary properties. Hence, there is a necessity for an appropriate measurement technique for the specific characterisation of elemental carbon (EC) without interference with other exhaust components to ensure sufficient sensitivity and accuracy even under very low pollutant concentrations. Desired information in this context is the soot mass concentration, the primary particle size or the particle number density, respectively. A measurement technique which fulfils all these requirements is Laser Induced Incandescence (LII).

The basic principle of this technique is to heat soot particles within the probe volume by means of a highly energetic laser pulse up to their vaporization temperature and to subsequently detect the enhanced thermal radiation. The involved mechanisms are absorption of the laser energy, change of internal energy and different heat loss mechanism like vaporization, heat conduction to the surrounding gas and in particular thermal radiation which is in fact the measurement signal. The associated power balance and its numerical solution which yields the temporal signal course is shown in slide 3 and 4.
The signal maximum provides soot mass concentration and the signal decay yields specific surface area or equally primary particle size. To get the absolute concentration, a calibration at a carbonaeous aerosol generator in comparison with coulometric measurements is required in advance. As it is shown in slide 7 there is an excellent linear correlation between the LII signal and coulometry which verifies the EC specificity. To achieve the primary particle size, it is important to measure the ambient exhaust temperature as some tens of nanoseconds after the laser pulse the heat conduction is the dominant head loss mechanism and therefore the temperature gradient between the particles and the surrounding gas is an important feature for modelling.

To come to practise ESYTEC has developed an appropriate apparatus (LI²SA) which consists of an excitation source (Nd:YAG Laser), detector head different optional adapter rings (slide 6) and an online data evaluation device.
The LI²SA-system gives the possibility of online and in situ determination with high temporal resolution up to 20 Hz allowing investigations of highly dynamic and transient behaviour.
Main benefits of this system are, besides its high sensitivity which is currently lower than 5µg/m³ (slide 8), the flexible applicability to raw exhaust gas flow without any dilution, conditioning and sampling as well as to CVS- and partial flow systems. So it is implementable for ultra low emission engines within all relevant cycles on chassis

dynamometers and motor test benches. Other features are the good liability against electromagnetic radiation and mechanical shocks and the independence to measurement conditions like temperature and dilution ratio.
To eliminate the influence of other exhaust components on the measurement signal the impact of different fuel sulfur concentrations (slide 9) on the one hand and of varying urea metering after an SCR catalyst on the other hand was tested. It was shown, that there was no influence nor on primary particle size and on elemental carbon concentration either.
In slide 11 and 12 measurements within an ESC have been carried out before a SCR catalyst and after it. This example shows the applicability of the LI²SA-Soot Sensor to profile properties of the catalyst due to it is the high dynamic range and temporal resolution.

By combination with elastic light scattering also additional measurement of the aggregate size will be possible in the future. Further improvements of the sensitivity will also allow the measurement after particulate trap applications as well as the appliance for immission practice.

www.esytec.de/english/lisa-eng.html

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- Principle
- Sensor Concept
- Applications
- Summary and Outlook

Motivation

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Tightened exhaust legislation

Development of modern low emission engines and exhaust after treatment systems

Necessity for an appropriate measurement technique for the specific characterisation of elemental carbon (EC) (mass concentration, particle size, particle number density) without interference with other exhaust components

Laser Induced Incandescence (LII)

Principle of the LII technique

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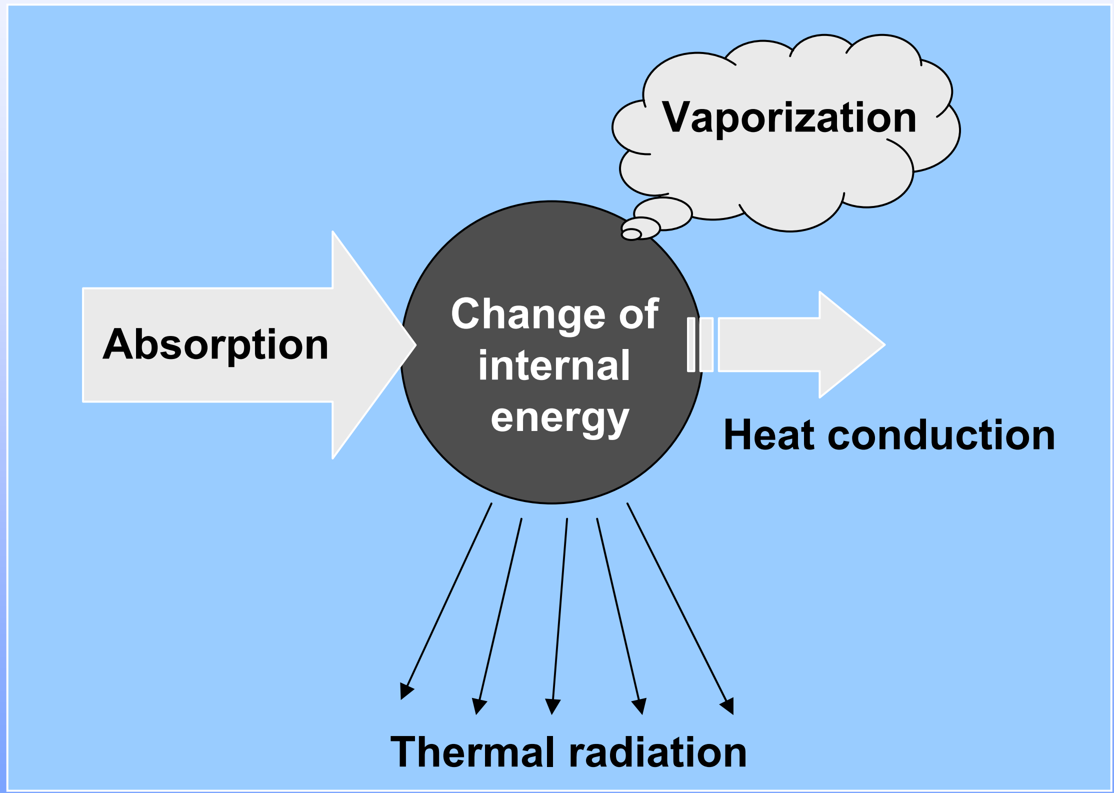
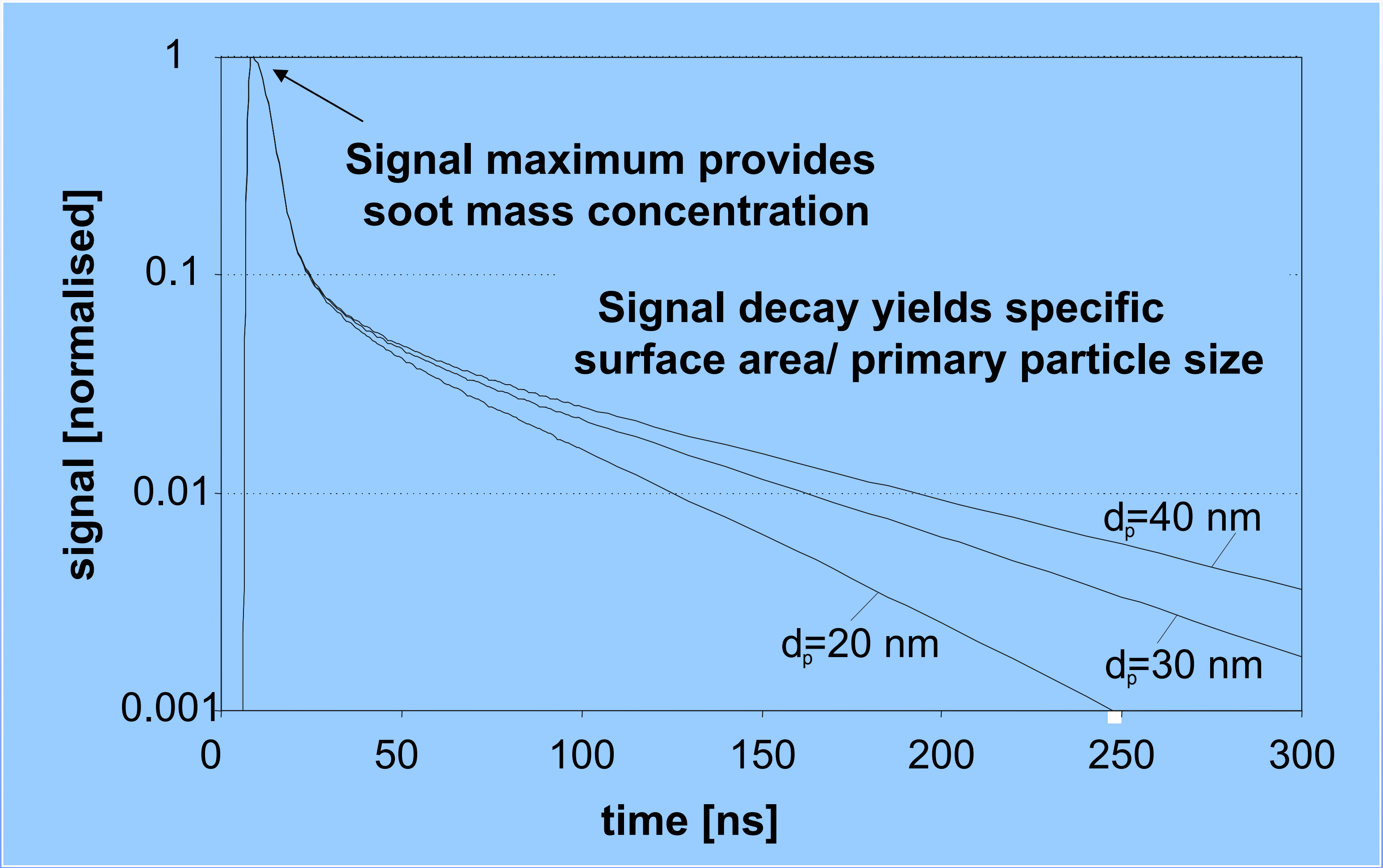
Particle heating by means of a highly energetic laser pulse → **Detection of the enhanced thermal radiation**



$$\underbrace{Q_{abs}\cdot\frac{\pi d_p^2}{4}\cdot E_i}_{Absorption}-\underbrace{\Lambda\cdot(T-T_0)\cdot\pi d_p^2}_{Heat\ conduction}+\underbrace{\frac{\Delta H_v}{M}\cdot\frac{dm}{dt}}_{Vaporization}-\underbrace{\pi d_p^2\int\varepsilon(d_p,\lambda)M_\lambda^b(T,\lambda)\cdot d\lambda}_{Thermal\ radiation}-\underbrace{\frac{\pi d_p^3}{6}\rho_S\cdot C_S\cdot\frac{dT}{dt}}_{Change\ of\ internal\ energy}=0$$

Signal course

⇒ Numerical Solution of the power balance yields temporal signal course



→ online and in situ determination possible (non-invasive)

→ high temporal resolution (investigation of highly transient behaviour up to 20 Hz)

LI²SA: Laser Induced Incandescence Soot Analyser

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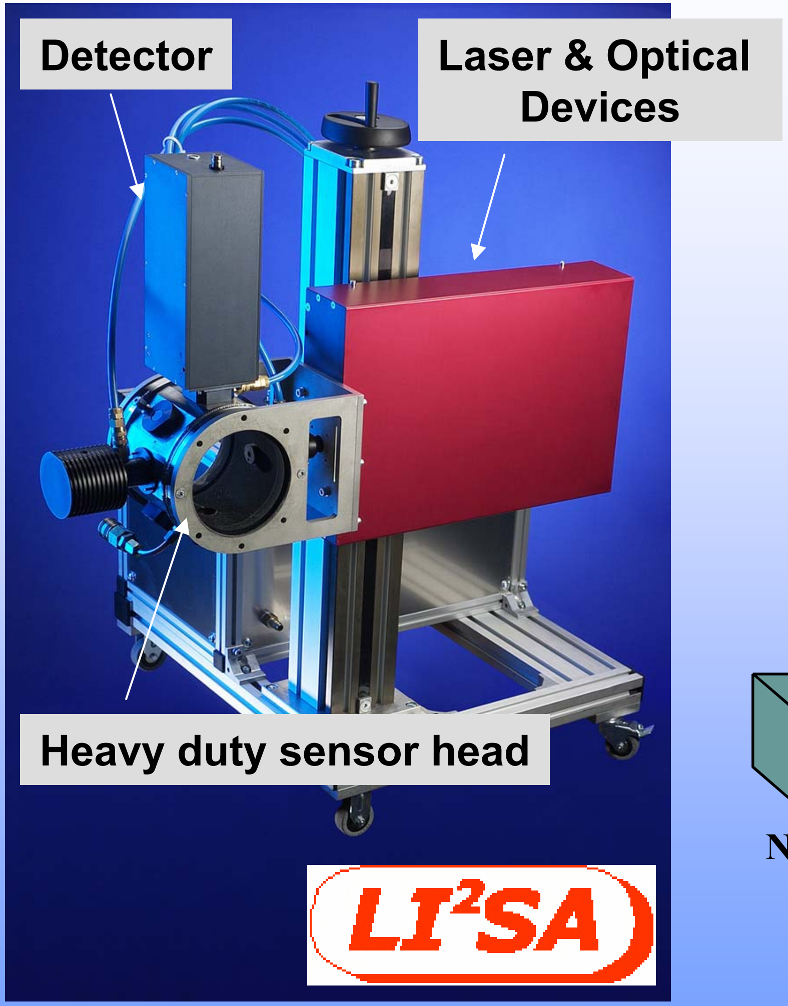
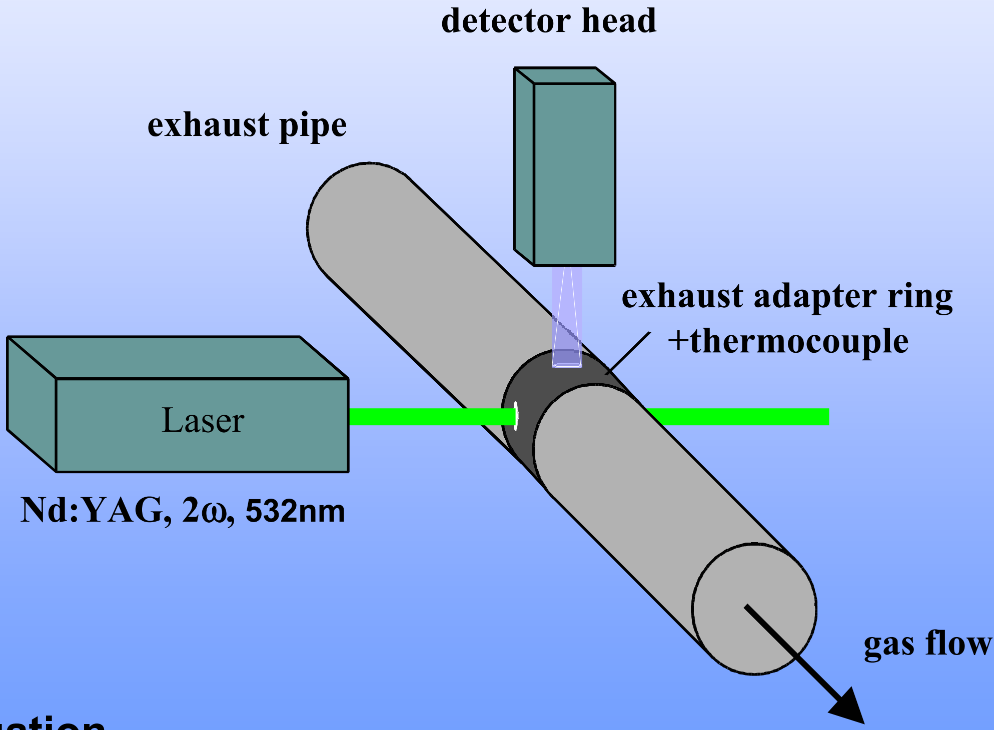


Direct integration of an adapter ring into the raw exhaust pipe on chassis dynamometers and motor test benches possible (full flow sensor head)



⇒ online data acquisition and evaluation

⇒ good liability against electromagnetic radiation and mechanical shocks

Laser Induced Incandescence Sensor Head

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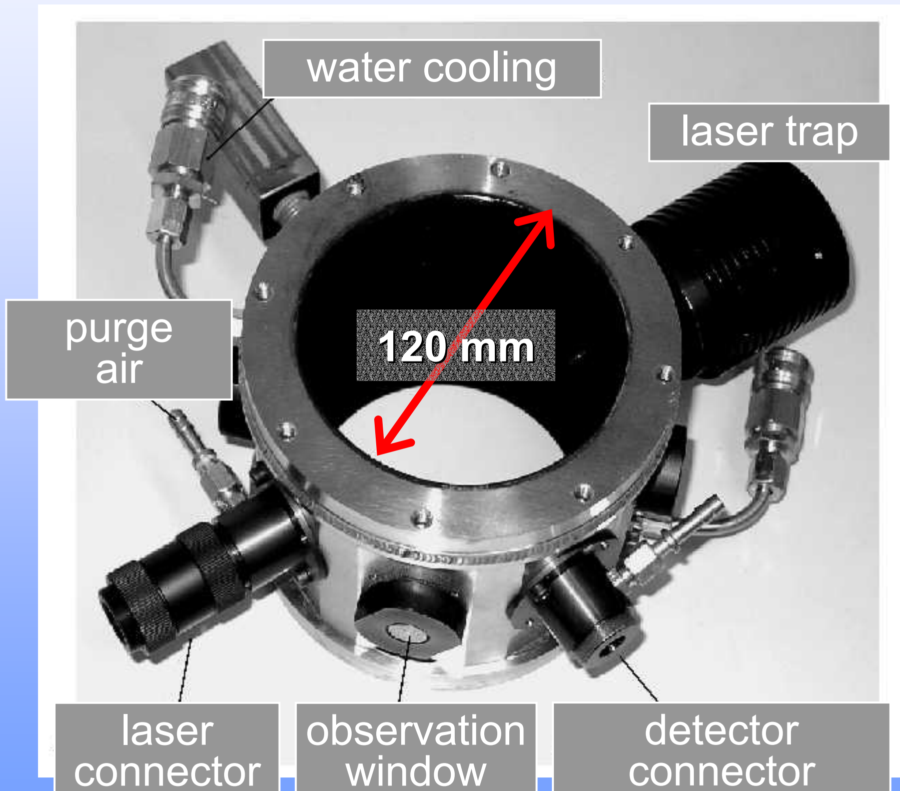
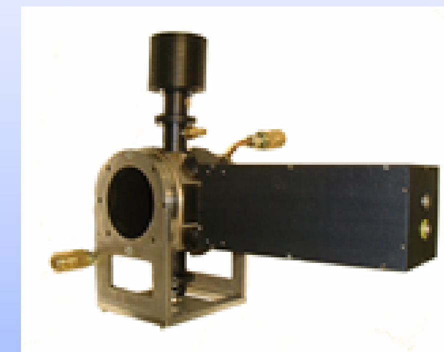
Individual choice of the appropriate adapter ring

Heavy duty sensor head



CVS sensor head

Light duty head



⇒ **no influence of measurement conditions (temperature, dilution ratio)**

⇒ **no conditioning, sampling procedure and dilution necessary**

⇒ **no further adjustment**

⇒ **blinding free optical access**

⇒ **cooling allows application up to 600 °C**

Measurement example : CAST test aerosol generator

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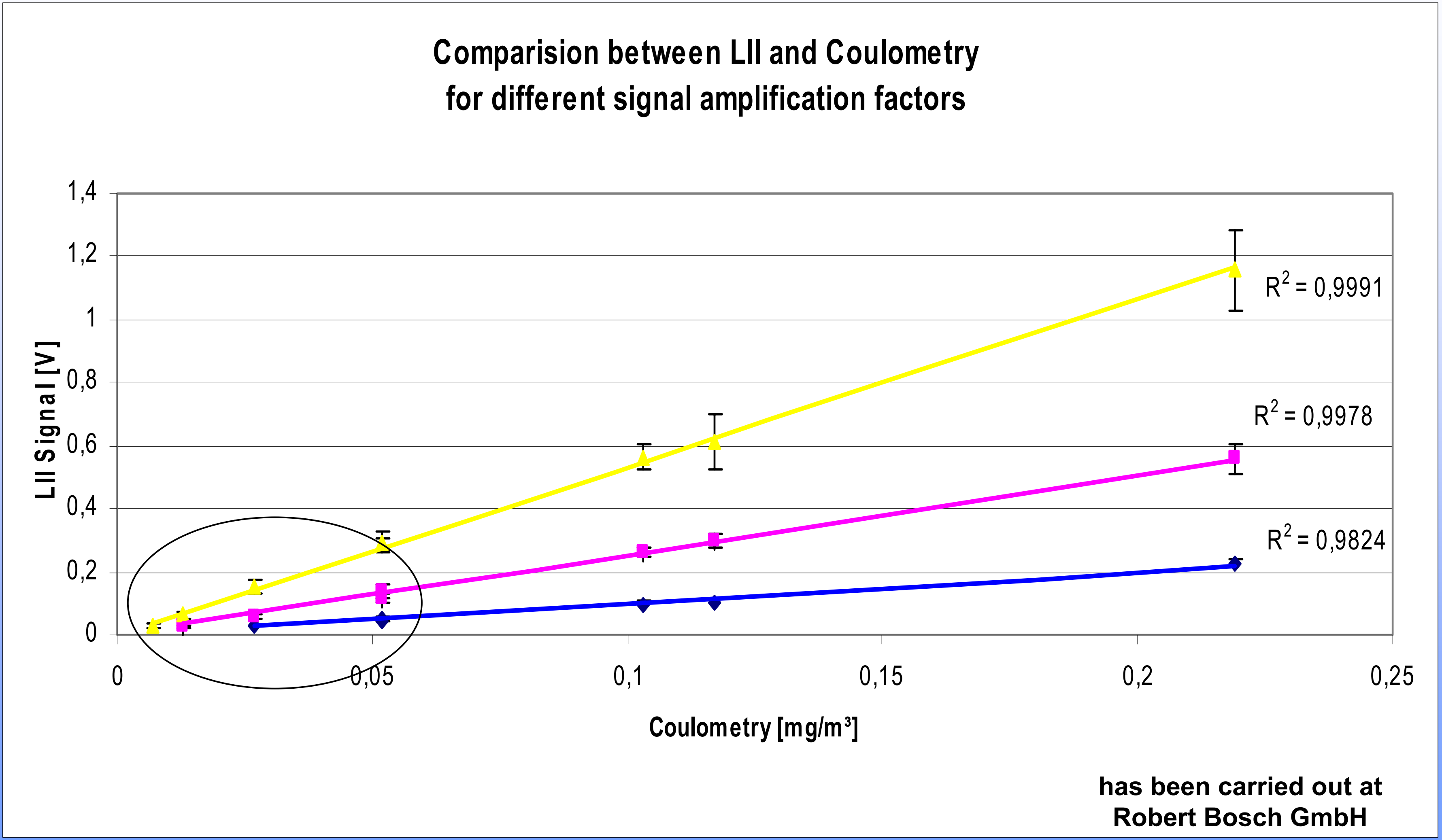

⇨ **excellent correlation between LII signal and coulometry**

Measurement example : CAST Test aerosol generator

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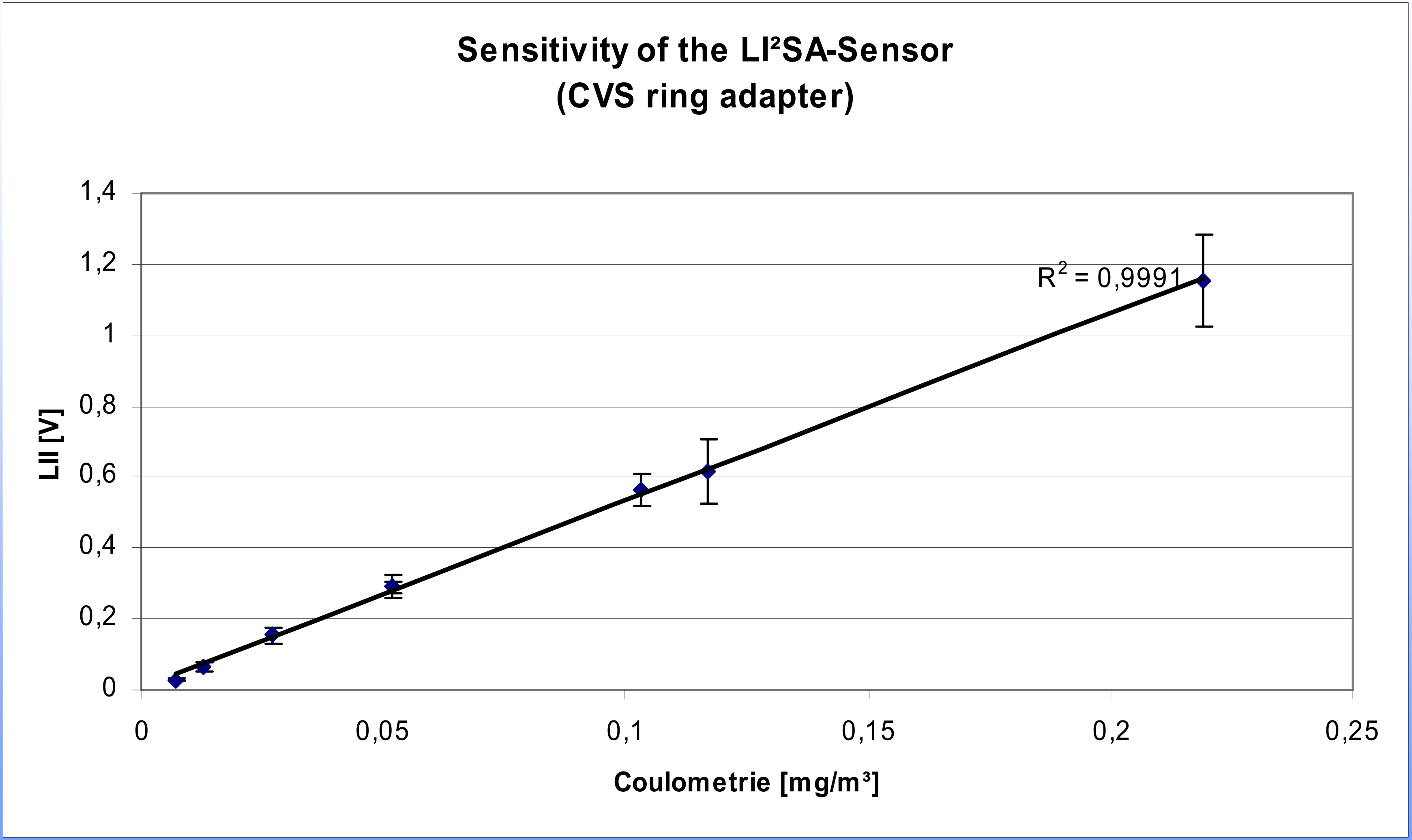
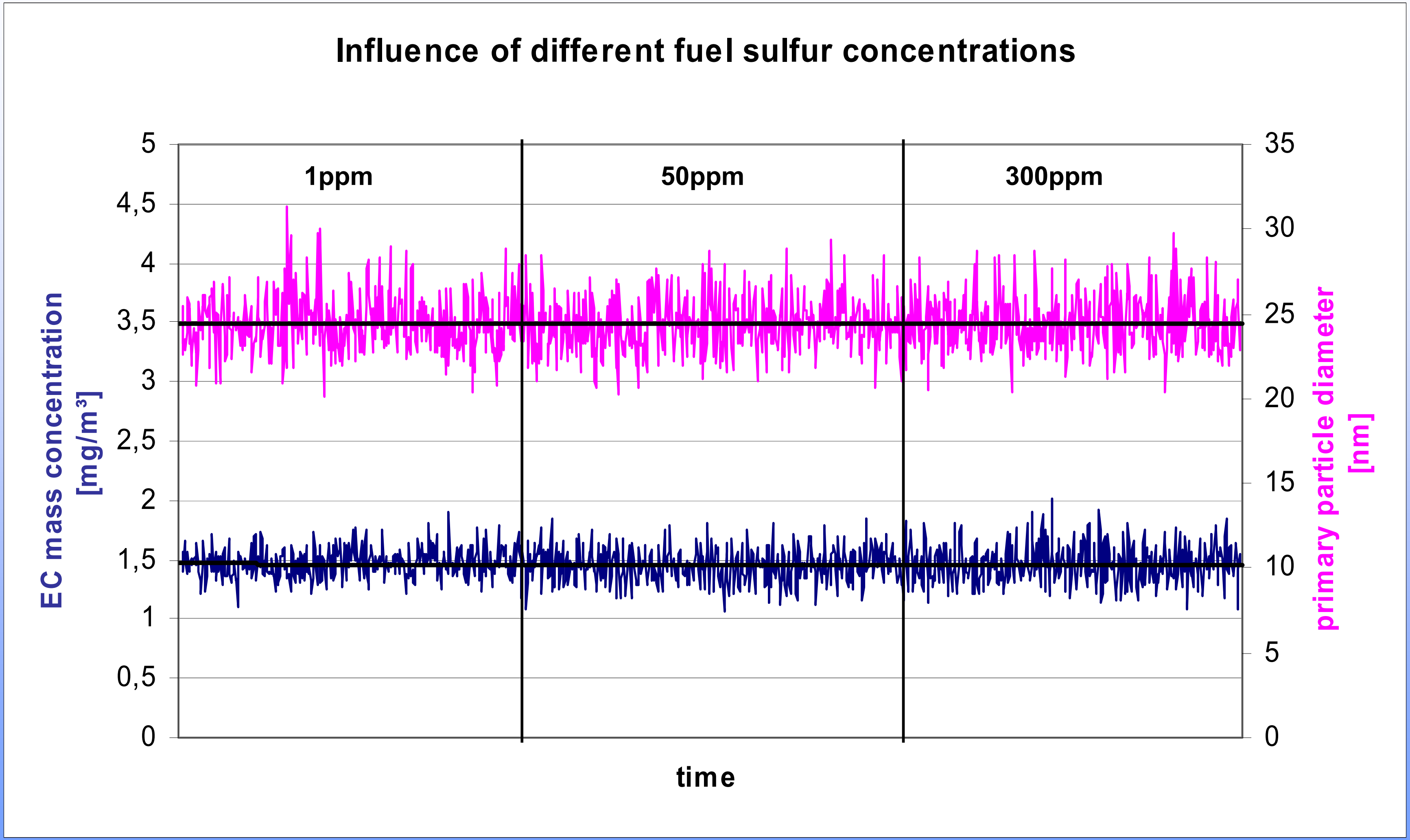


⇨ **sensitivity lower than 5 µg/m³ at the moment**

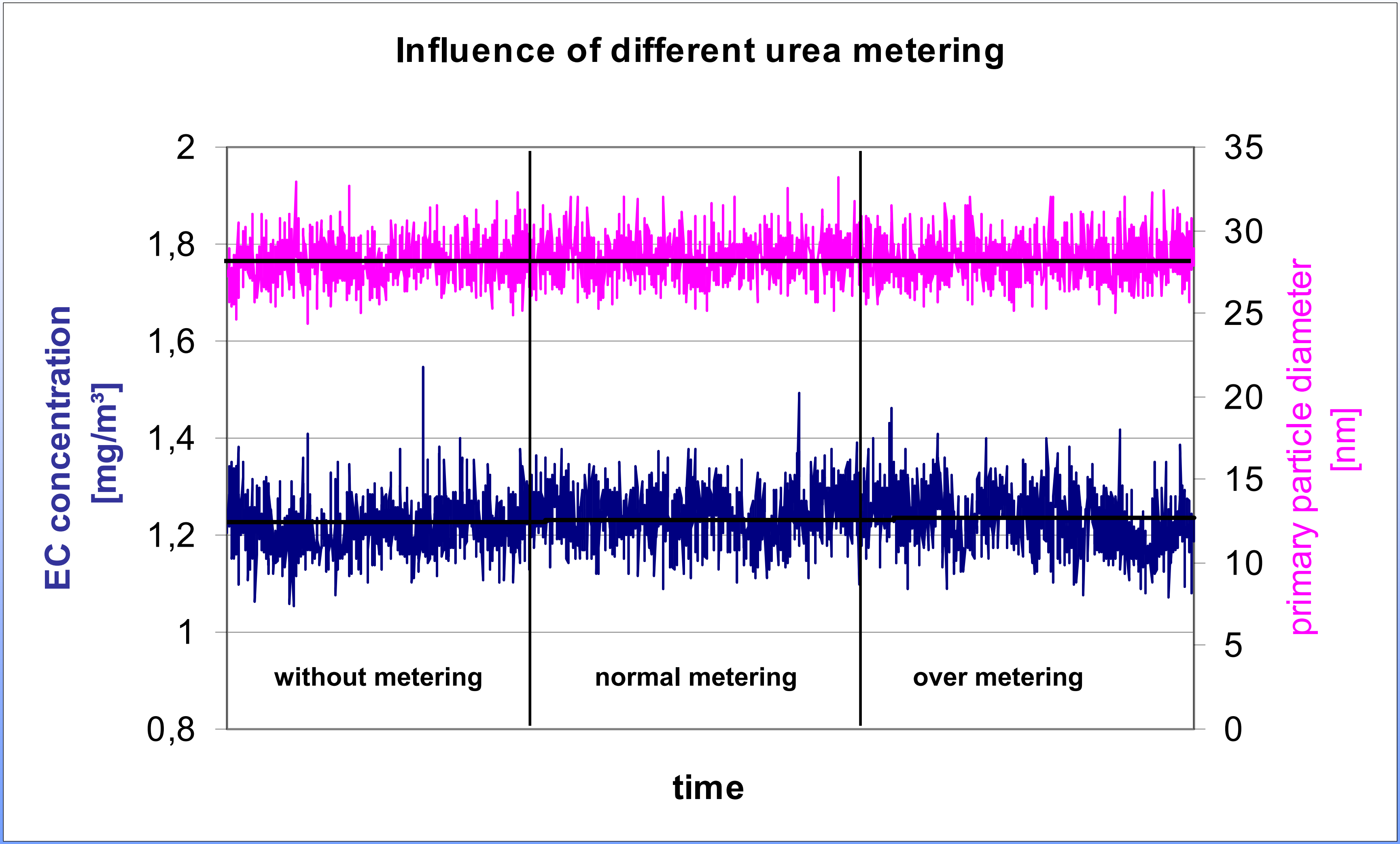
applicable for ultra low emission engines within all relevant cycles

Influence of different fuels



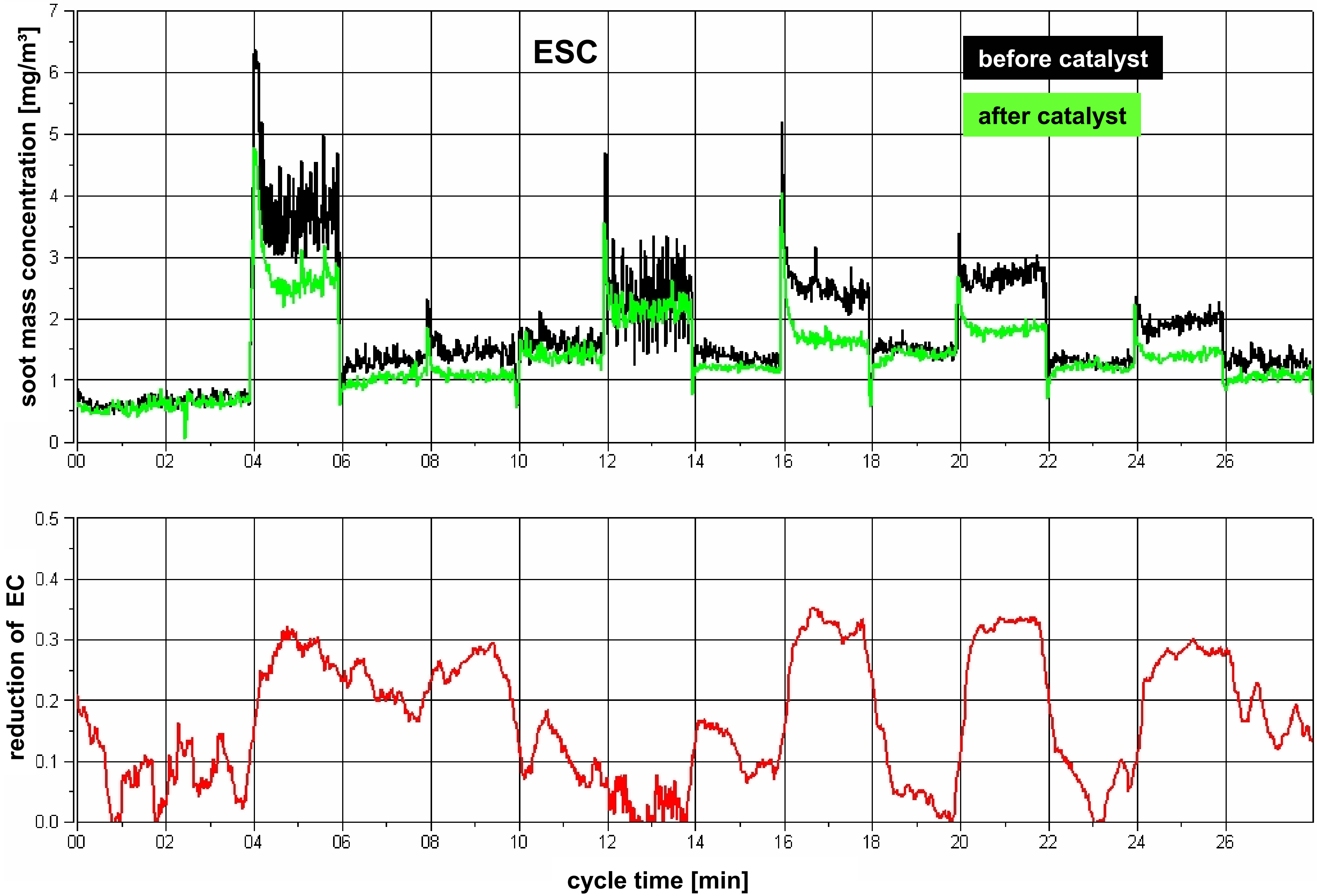
- ⇨ **no influence on primary particle**
- ⇨ **no influence on EC concentration with increasing sulfur content**

Influence of different urea metering



⇨ **no influence of urea metering concentration**

Metabolic rate of the SCR catalyst (Ceramics, Redwitz)



Metabolic rate of the SCR catalyst (Ceramics, Redwitz)

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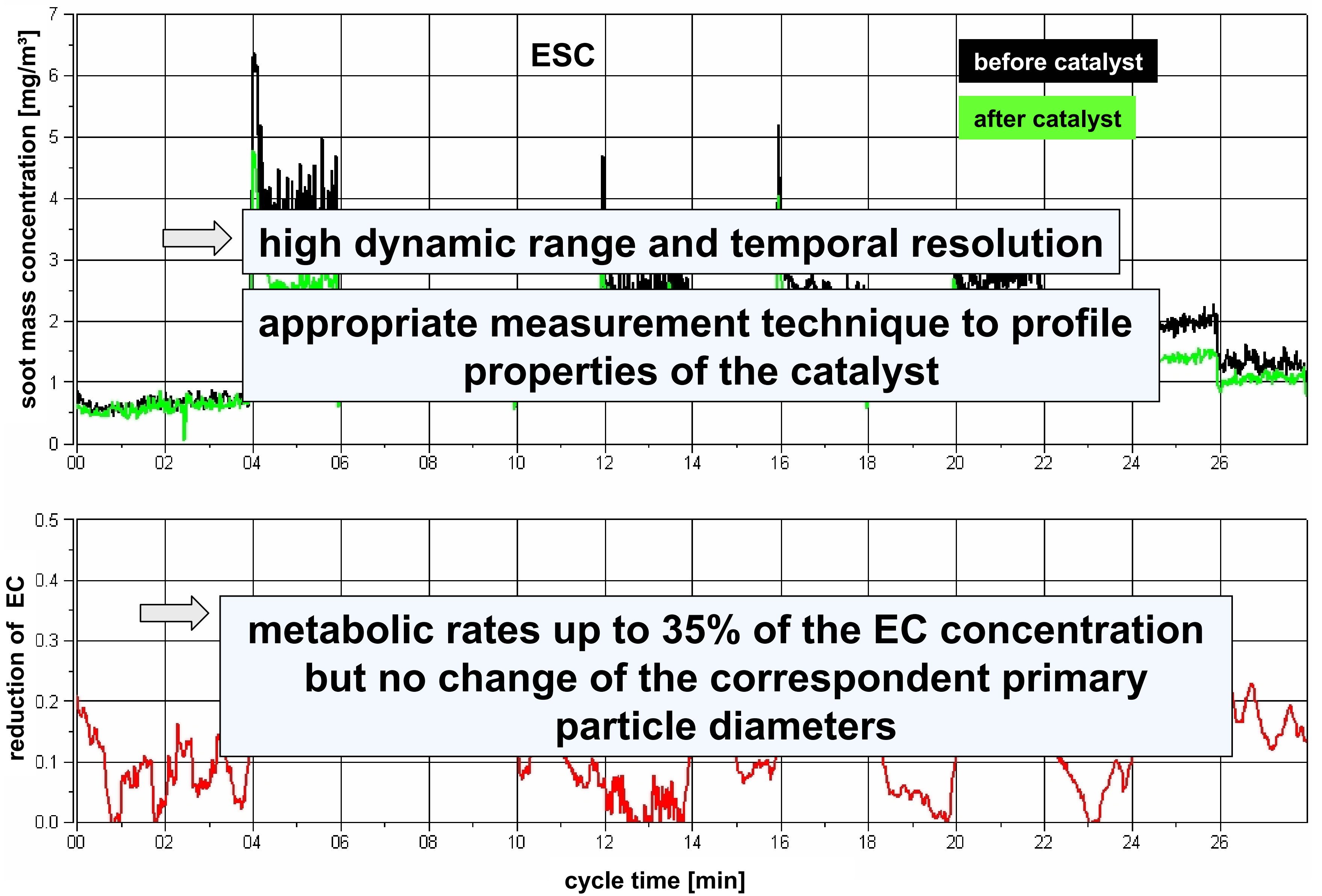

Summary and Outlook

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Summary

- Robust sensor concept for EC characterisation:
  - applicable for ultra low emissions
  - applicable for all relevant cycles and engines
- Comprehensive information
  - soot mass concentration
  - primary particle size

Outlook

- By combination with elastic light scattering additional measurement of aggregate size possible
- Further improvement of sensitivity
  - ⟹ measurement after particulate trap applications possible
  - ⟹ applicable for immission practice