Title Field monitoring of diesel particulate emissions

Heinz Burtscher, M. Fierz, A. Keller, and Marcel Rüegg
University of Applied Sciences, Aargau, Klosterzelgstrasse, CH 5210 Windisch, Switzerland

In the framework of the PMP program and in many other activities new metrics and measurement methods for the type approval test of modern low emission diesel engines, eventually equipped with aftertreatment devices, have been investigated.
In addition to the type approval test field monitoring in also required but so far much less activity is observed in this area. The detection limit of opacimetry and measurement of the smoke number, which are used until now, is insufficient for modern engines. Alternatives therefore are required.
Field monitoring requires portable, robust and easy to use and low cost equipment. Long installation time or warm up phases have to be avoided. In particular, it would be desirable to be able to measure in the undiluted raw exhaust to avoid conditioning of the exhaust, which always causes considerable effort. On the other hand, the requirements concerning precision are less stringent than for type approval. Major problems that have to be solved when measuring in the undiluted gas are high temperature, contamination and high concentrations. Some systems which may be suitable for this purpose will be discussed. These are

a) a light scattering measurement directly at the end of the tailpipe, which requires a measurement exposed to ambient light
b) a diffusion charging sensor, designed such that it can sample directly the hot exhaust gas
c) a simple photoacoustic sensor operating with an open windowless cell and a resonance tracker to avoid contamination problems ant to compensate for temperature changes.

Possible configurations, design considerations, and detection limits will be discussed, some preliminary results will be presented.

Institut für Sensoren und Signale

Fachhochschule Aargau
Nordwestschweiz

Field Monitoring of Diesel Particulate Emissions

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University of Applied Sciences, Aargau

Requirements

- Easily portable and easy to handle
- Operation in undiluted raw exhaust
- Allow battery operation
- Detection limit low enough for modern low emissions engines
- Requirements concerning accuracy less stringent than for type approval
- Fast enough for measurement of free acceleration

Measuring undiluted raw exhaust means that the system has to be able to handle:

- high concentrations
- high temperatures
- contamination (reasonable time between cleaning, easy to clean)

Techniques considered

- Optical methods

  allow a contactless measurement
  light extinction: problem with sensitivity
  light scattering: allows high sensitivity

- Electrical methods

  diffusion charging
  photoelectric charging
  both require sampling
  both sufficient detection limit
  for PE more problems due to temperature and contamination expected

- Photoacoustic sensor

  selectively sensitive to soot
  sufficient detection limit should be possible
  configuration avoiding contact between exhaust and optical elements should be possible

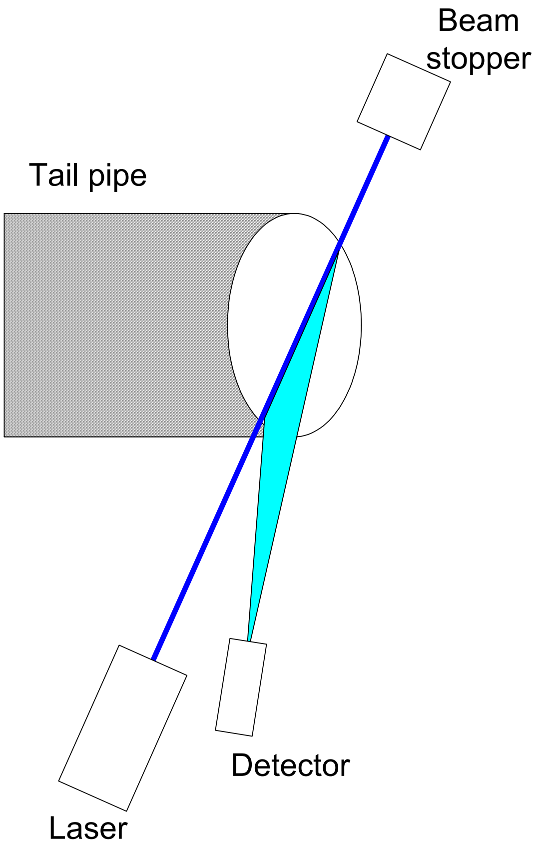
Light scattering

- Can be made very sensitive
- Very strong influence of particle size

  Raleigh: $I \propto d^6$
  - Size distribution is relatively constant
  - Droplet formation has to be prevented
  - Single events like reeintrained particle ev. have to be excluded by intelligent signal processing
- Absorbing gases as NO_x have much less influence than when measuring opacity

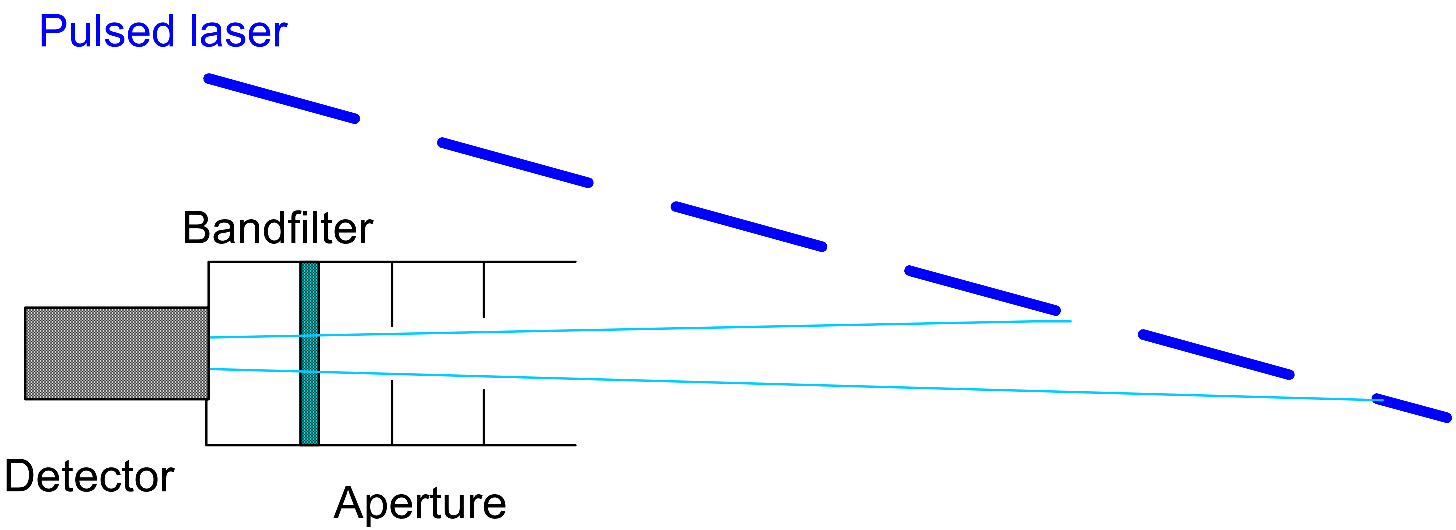
Light scattering

- Idea: as simple as possible
- No sampling, measurement directly at tail pipe
  ⇒ open system, has to work in the presence of daylight



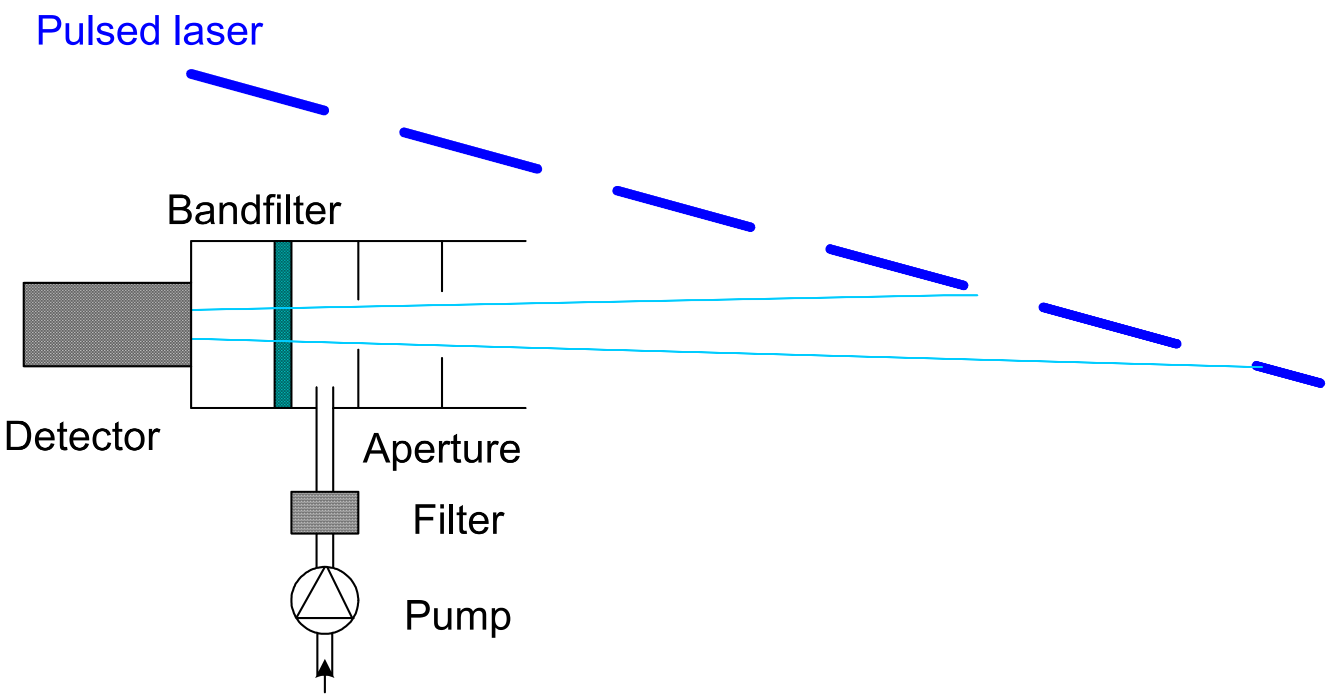
Daylight elimination

- System of apertures, followed by small bandwidth filter keeps most daylight from detector
- Pulsed laser + lock in

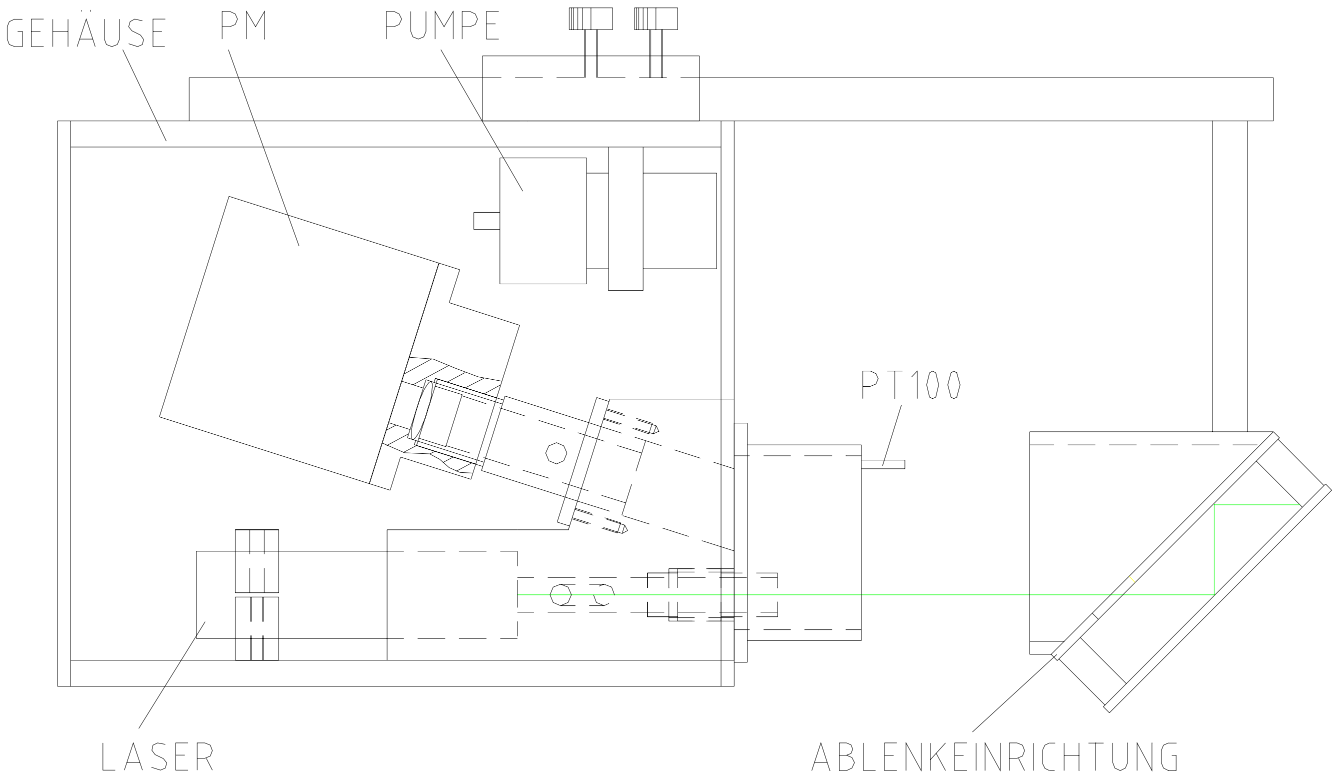


Contamination

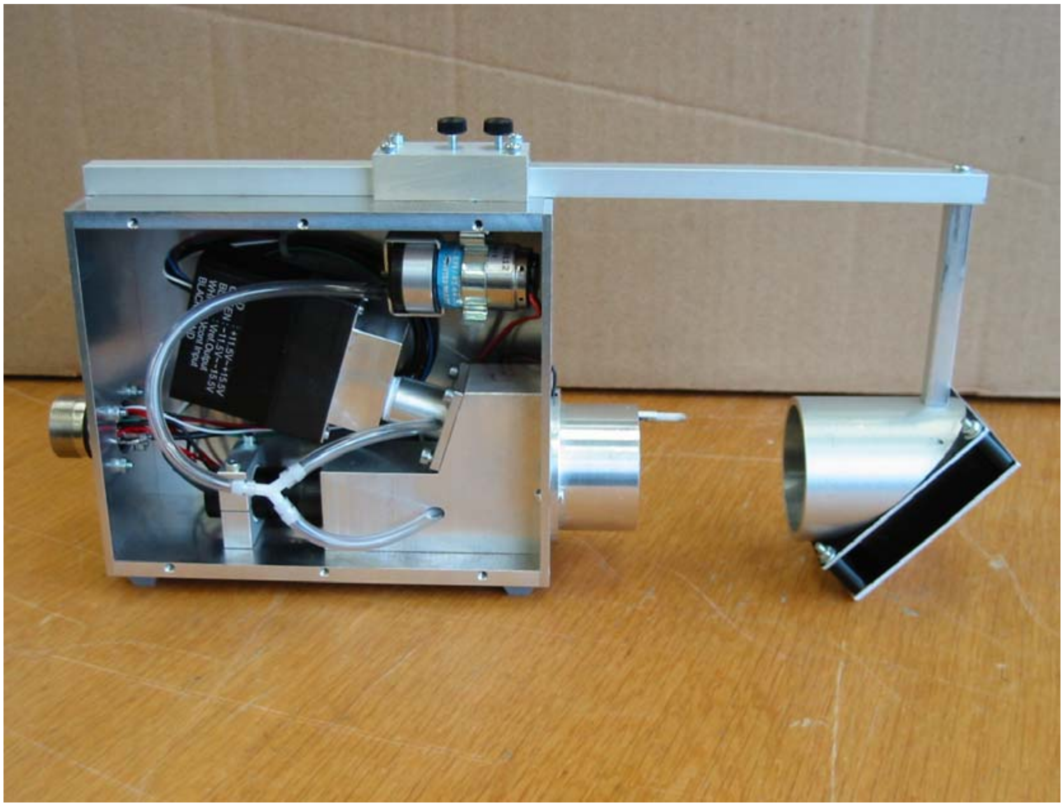
Apertures and counterflow protect optical filter and laser diode



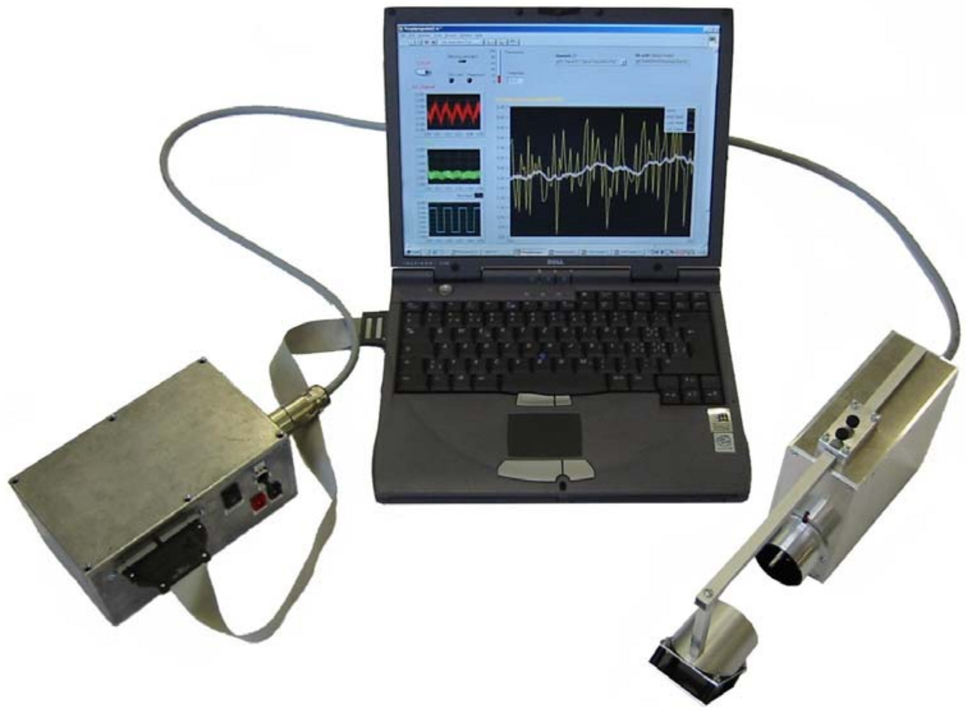
Schematic of first prototype



Picture of first prototype



Measuring system

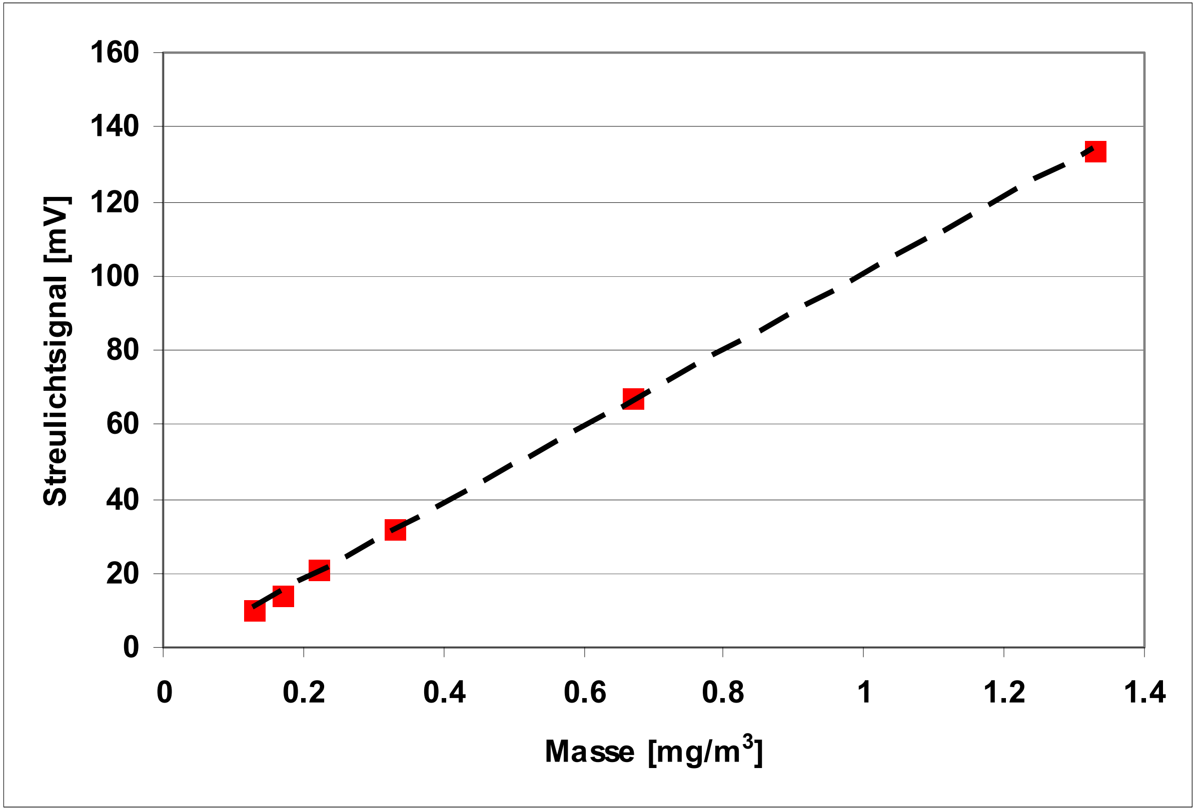


Main characteristics

Wavelength: 532 nm
Laser power:3 mW
Repetition rate: 1 kHz, 50% duty cycle
Backscattering, 20º
Exhaust gas temperature measured by PT100
Ca. 3 h battery operation

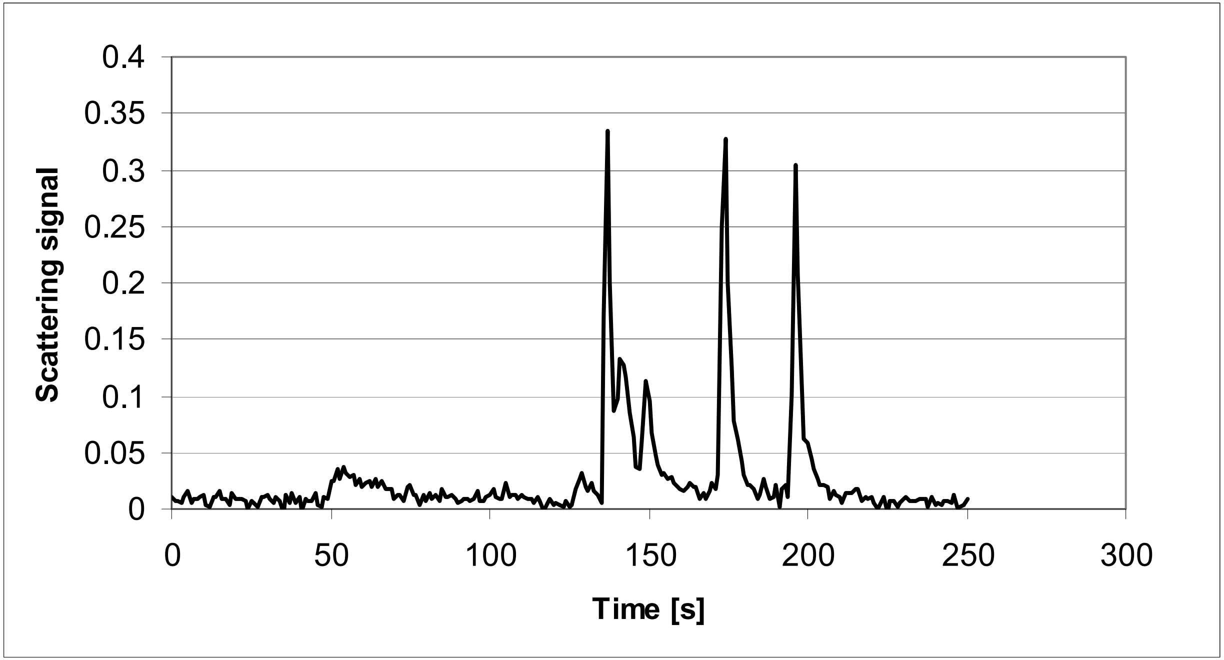
Mass versus scattering Intensity

(carbon particles produced by Palas spark generator)



First tests with car exhaust:

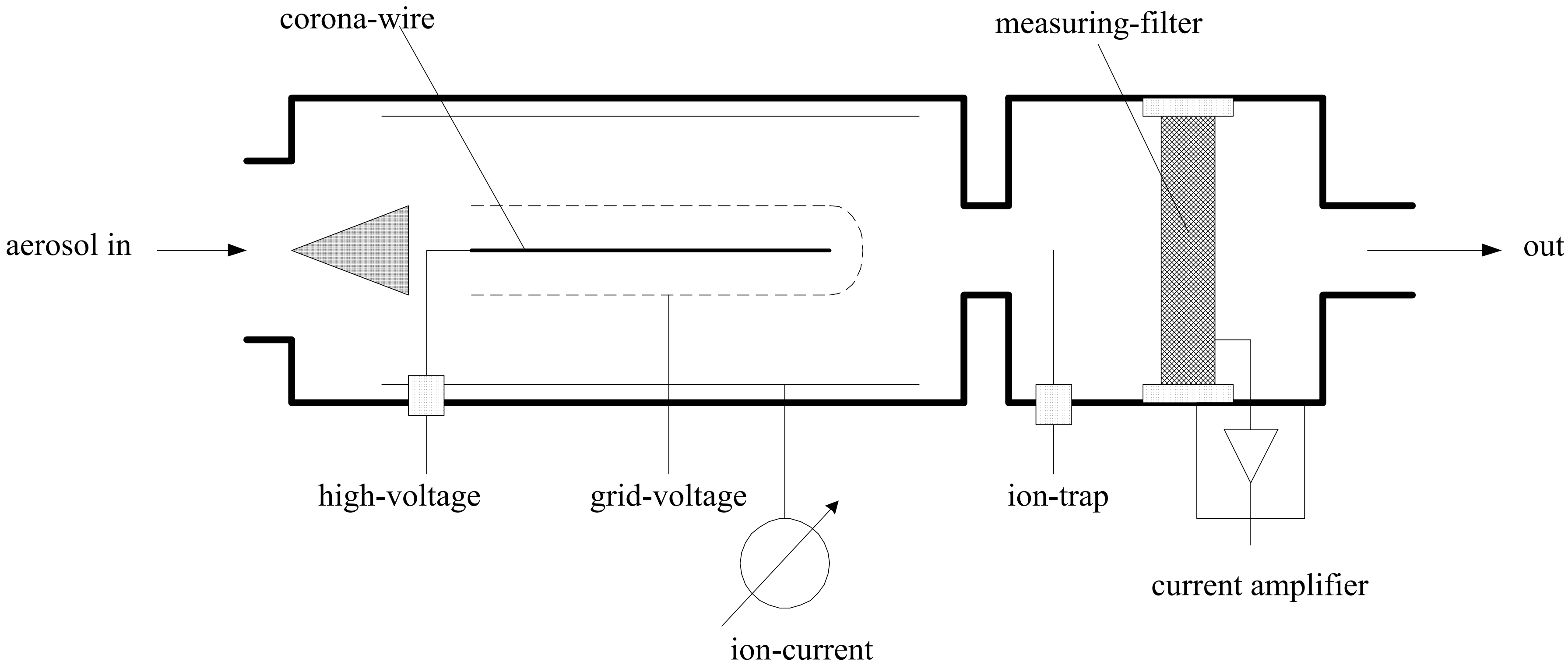
- Diesel well measurable
- Signal also during acceleration of SI engine



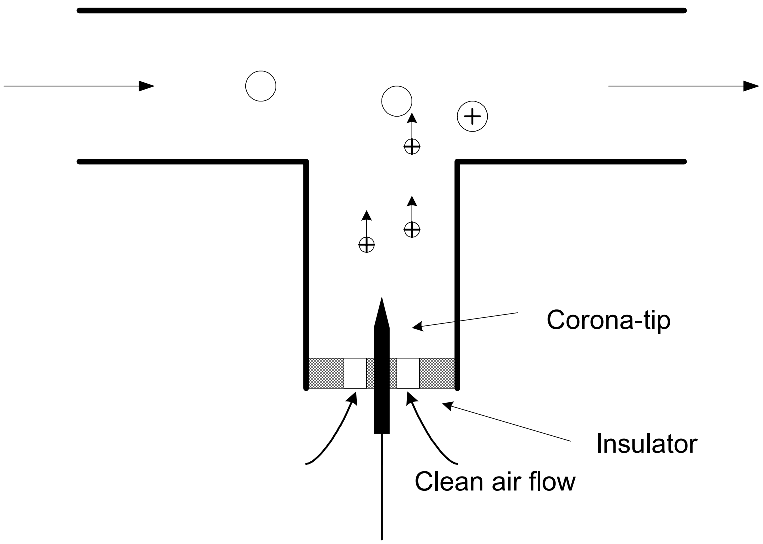
Diffusion charging (hot-DC)

- Much experience from former measurements (part of NanoMet), but always with diluted exhaust
- Conditions, for raw exhaust application:
  - Linear response up to ca. 10^7 cm^{-3}
  - All parts in contact with exhaust heatable to temperature, where nucleation/condensation is avoided; requires separation of filter and Electrometer
  - All critical parts (mainly insulators) have to be protected from contamination

Setup of a DC-sensor (as in NanoMet)



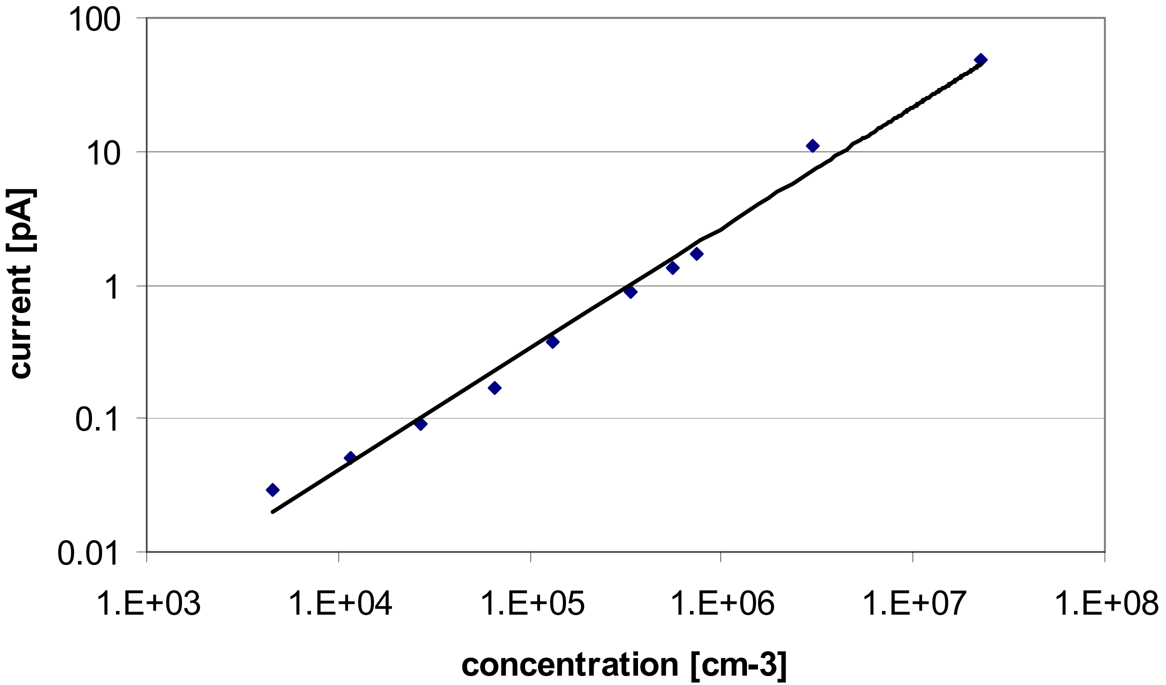
Corona charger



- Ions reach gas flow by space charge pressure
- Corona and insulator protected by small clean air flow
- Easily heatable

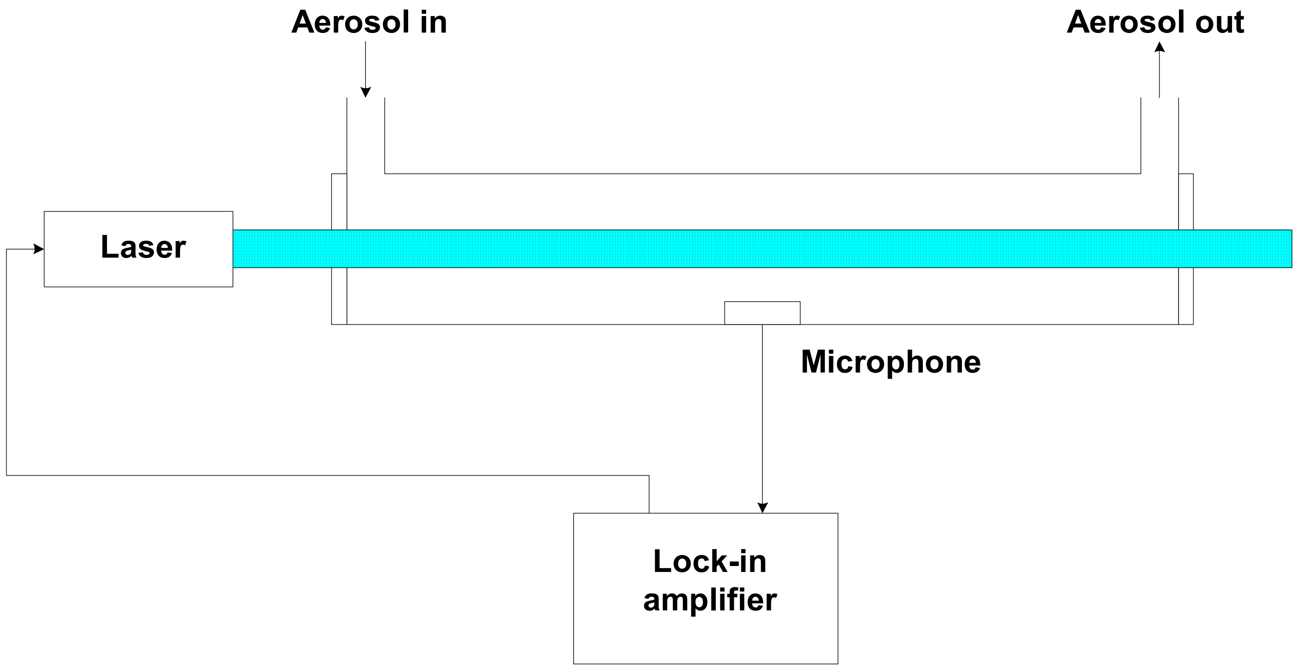
DC-signal versus concentration

Diameter: ca. 70 nm



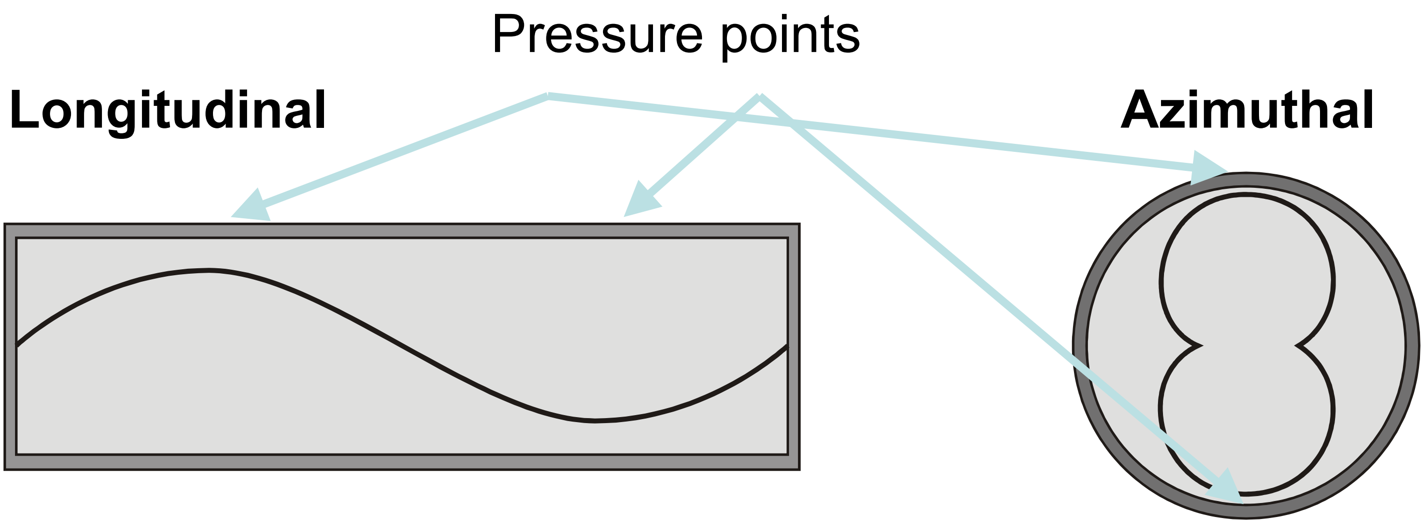
Photoacoustic sensor

Principle of operation

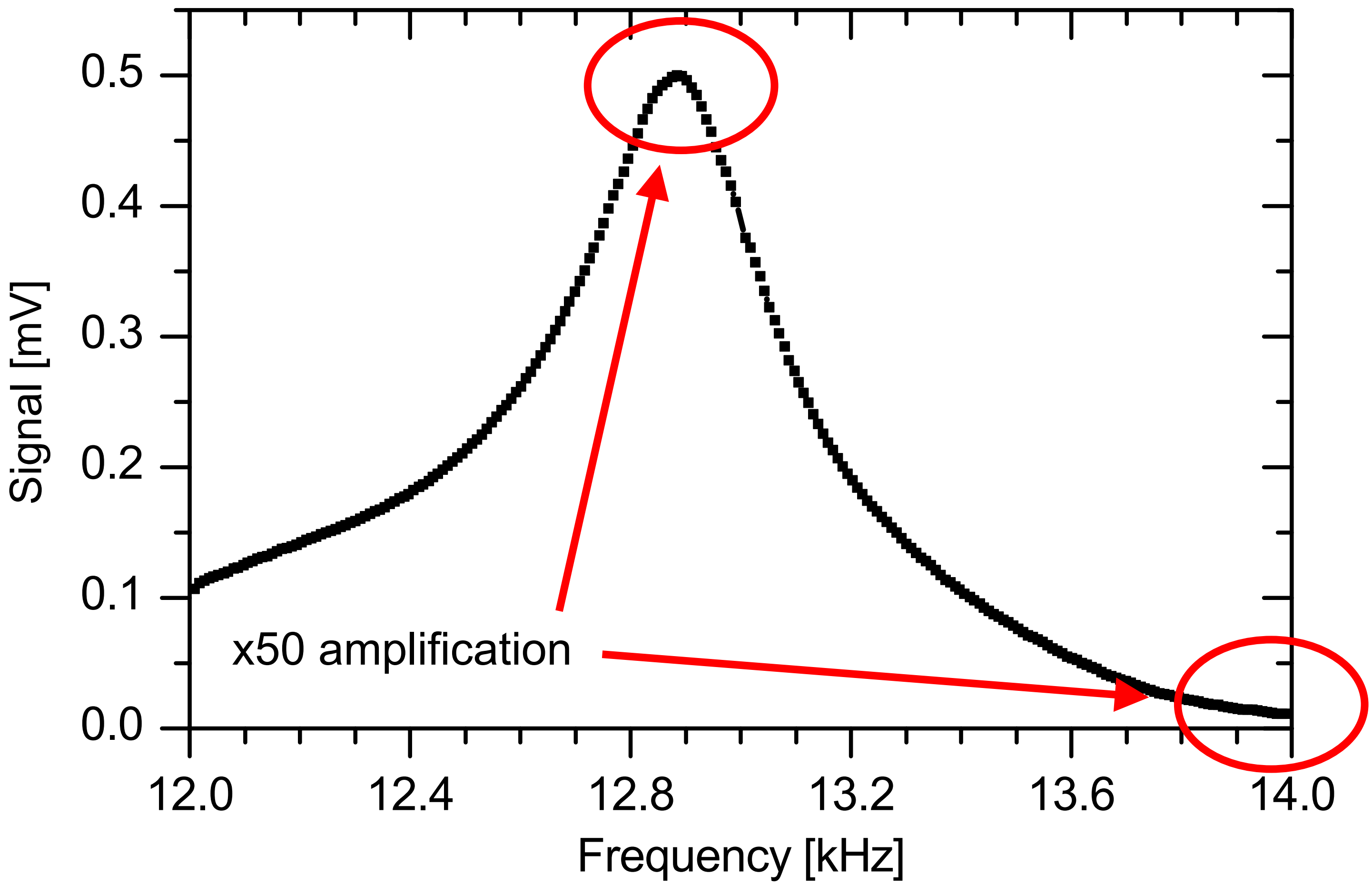


Resonant Photoacoustics

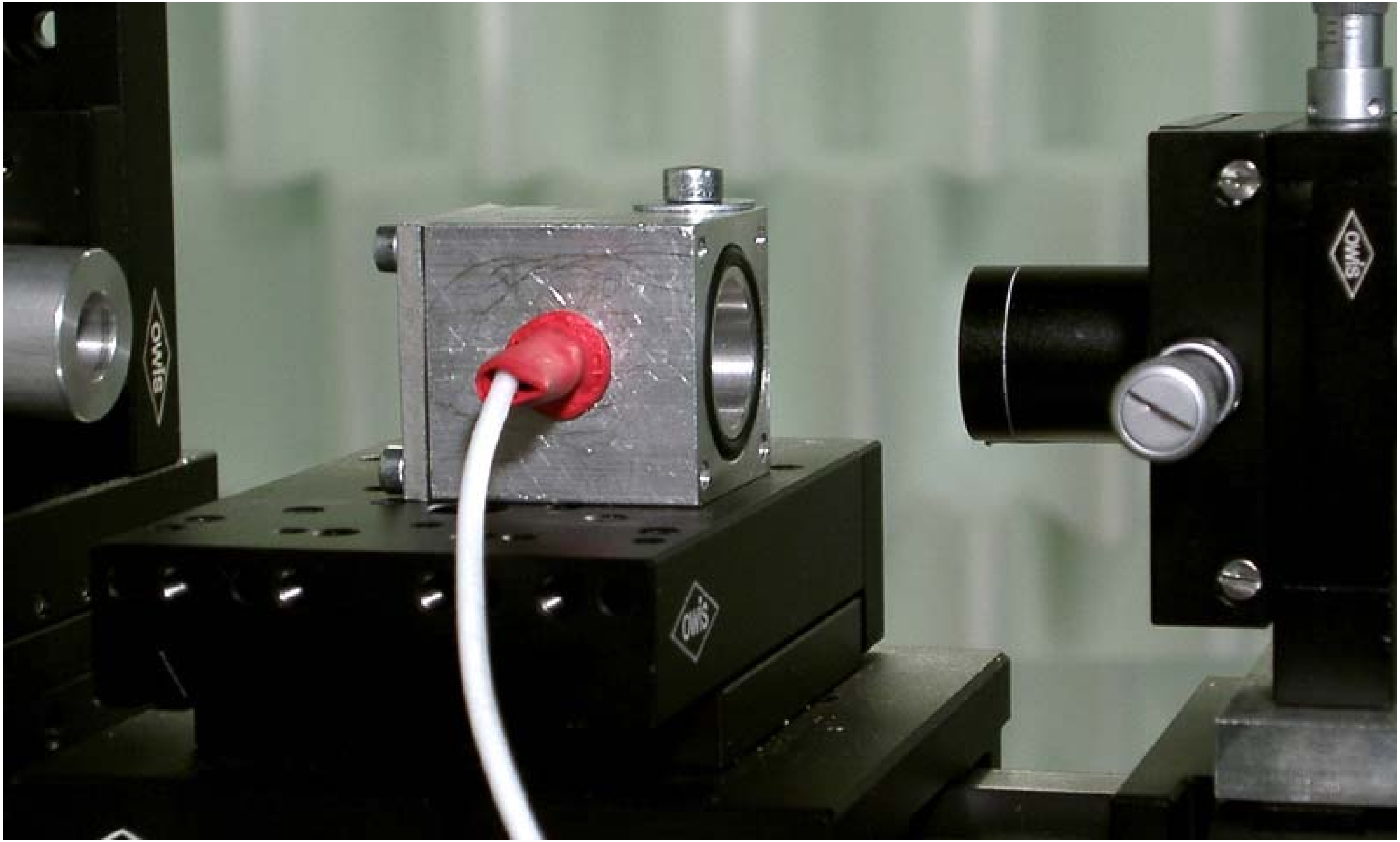
- Amplification of the signal with an acoustic resonator
- Only the correct frequency will be amplified
- We use a cylindrical geometry and the azimuthal resonances



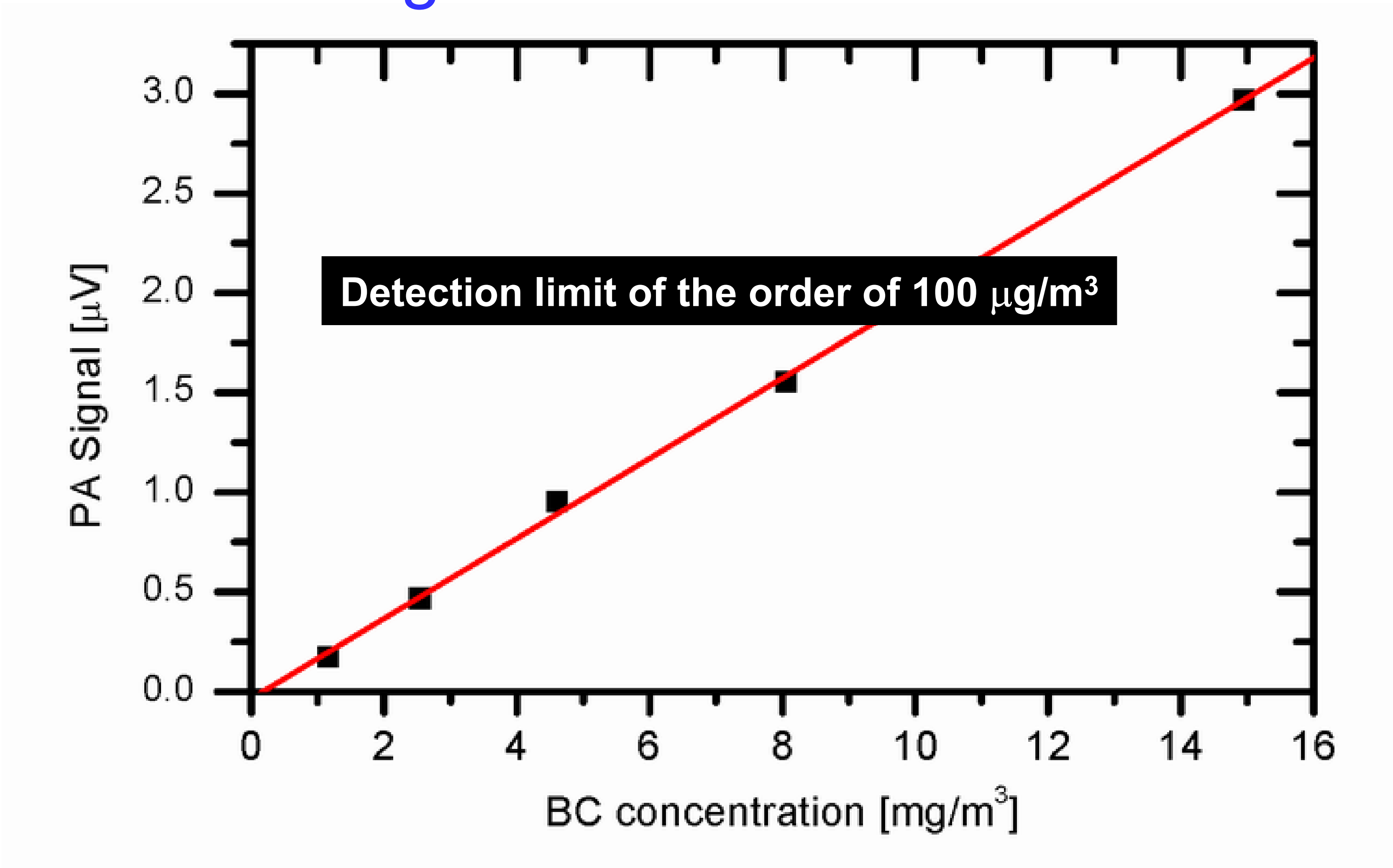
Acoustic Spectrum



Open Photoacoustic Detector



PA signal vs. BC concentration



Conclusions

- Several approaches for a field sensor have been studied
- To make the sensor as simple and portable as possible it is desirable to avoid conditioning
- Light scattering allows a contact less system, requiring no sampling at all, the strong dependence on particle size is problematic,
  possible solution: measurement at several angles allows to determine mean diameter
- A DC-sensor able to handle high concentrations has been realized, but not jet heatable
- A third promising technique is PA