

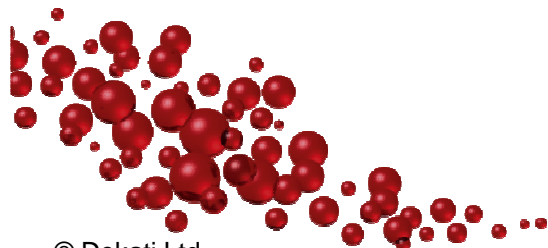
# Combustion particle research

Measurement setups and application data  
for automotive and combustion sources



# Dekati Solutions

- Sample conditioning devices
  - Fine Particle Sampler FPS-4000
  - DEED, Dekati® Engine Exhaust Diluter
  - Dekati® Diluter (DI-1000)
  - Dekati® Cyclone
  - Dekati® Thermodenuder

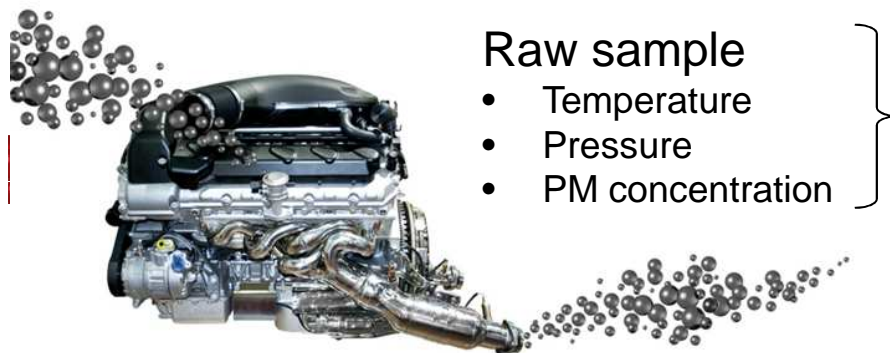
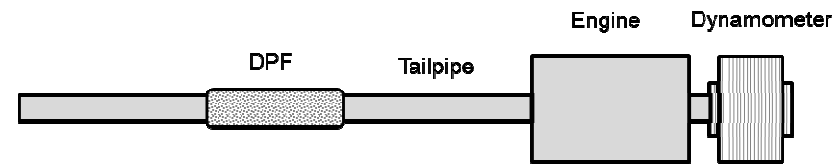


# Engine Emissions

Engine emissions measurements present a wide range of challenges for a sample conditioning system

Depending on:

- sampling location
- type of engine
- Fuel and lubricant oil
- installed after-treatment devices
- Driving parameter
- Etc...



Raw sample

- Temperature
- Pressure
- PM concentration

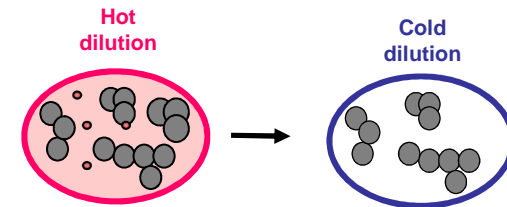
Can vary  
High to Low



# Diesel Engine

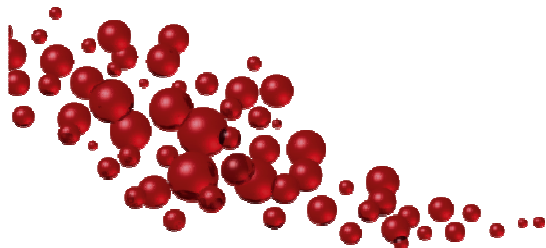
## Tailpipe or CVS measurements high concentration

- typically sample is first diluted in a heated diluter and then in a cooled diluter to eliminate condensation and nucleation effects.



If measurements are carried out with Dekati® ELPI+™ or DMM

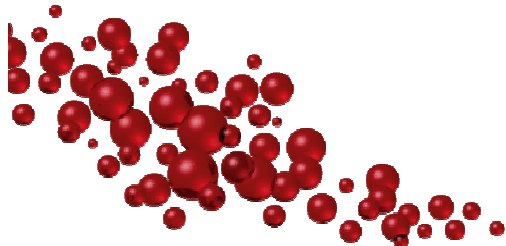
- Dilution factor (DF) 50 – 100
- Dilution temperature for the first stage dilution is 200 – 300 °C
- Cooled dilution also possible
- Dekati Double Diluter, DEED-100 or FPS-4000 for dilution



# Low concentration measurements

## Efficient after treatment or gasoline engines

- Very low particle concentration
- Usually DF 1 – 20
- Setup options
  - Nucleation of vapors with cooled dilution
  - Removal of vapors
  - Removal of vapors with low dilution
  - EURO5b / EURO6 compliant sample conditioning (high DF!)
  - Direct measurement with HT-ELPI+

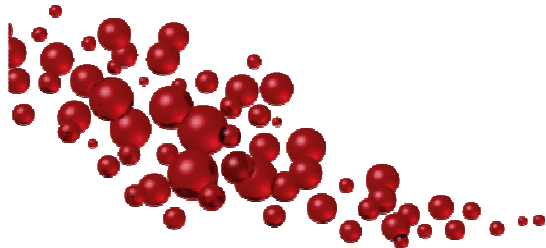


# Pre-DPF measurements



# Exhaust pre-DPF measurements

- Measurements from “raw combustion gas”
- High concentration of PM
  - Dilution factor from 100 to 10000
- Moderate to high pressure level
  - Can be stable, slowly changing or with high variation
  - DEED-300 guarantees a stable dilution factor in all high pressure conditions
- The recommended setup for sample conditioning
  - DEED-300 with DEED-100
  - DEED-300 with Dekati double diluter or Dekati diluter
  - FPS-4000





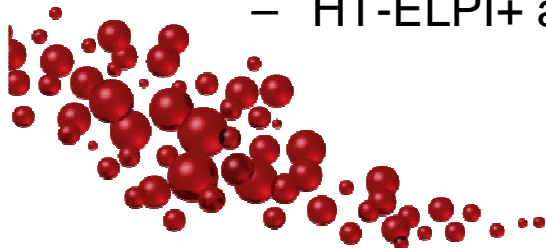
## On-board measurements





# On-Board measurements

- Major interest from automotive companies due to
  - Upcoming legislation
  - Cost savings
  - Information on real-world emissions and vehicle performance
- The most critical parameters are the consumption of dilution air, consumption of electricity, weight and space
- Some type of sample conditioning or sample transfer is always needed
  - Low dilution factor preferable with some removal of condensible vapors
    - Thermodenuder or catalytic stripper
  - HT-ELPI+ allows direct measurement



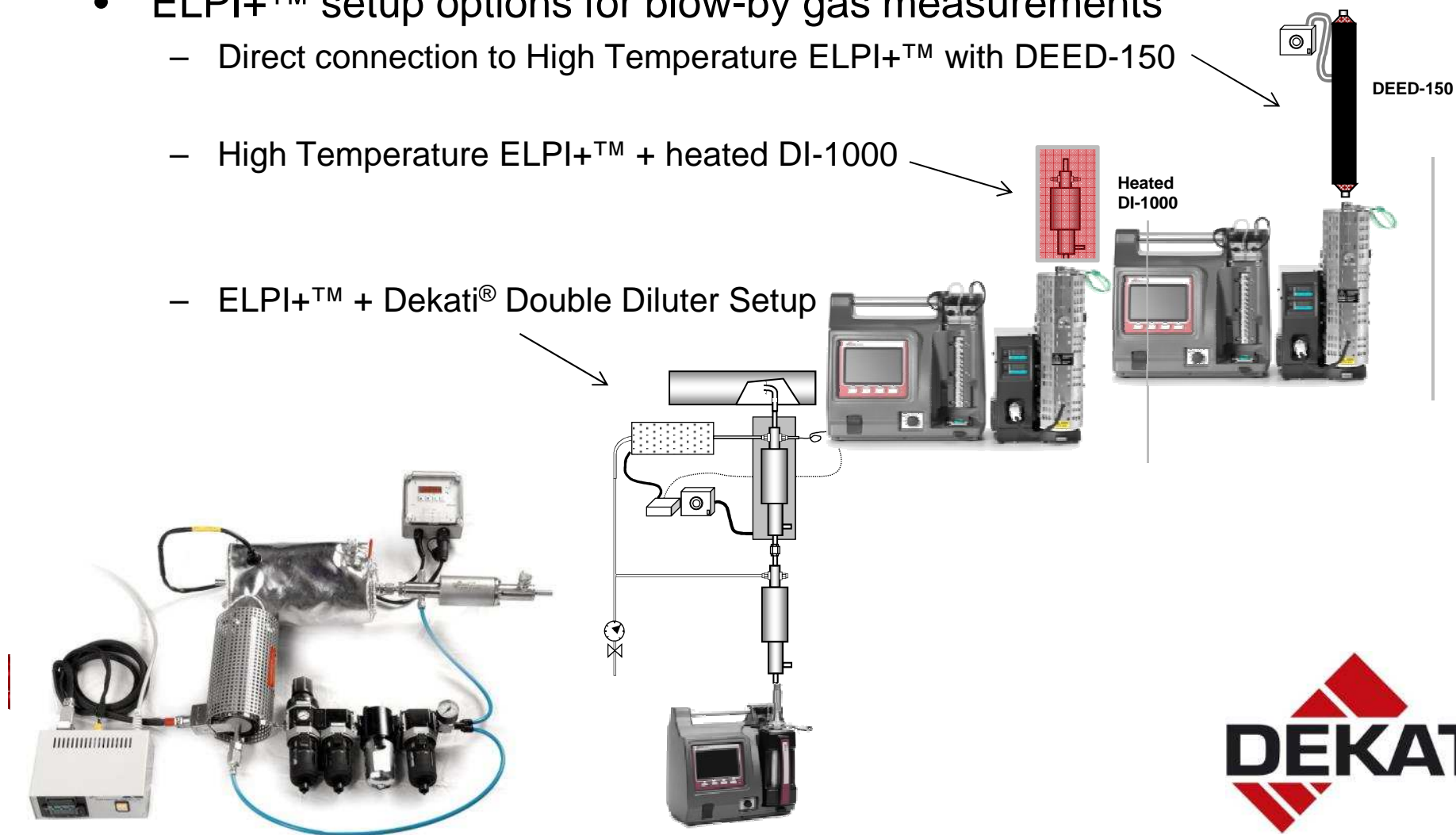
# Blow-by

Measurement of crankcase oil droplets



# Automotive: Blow-by

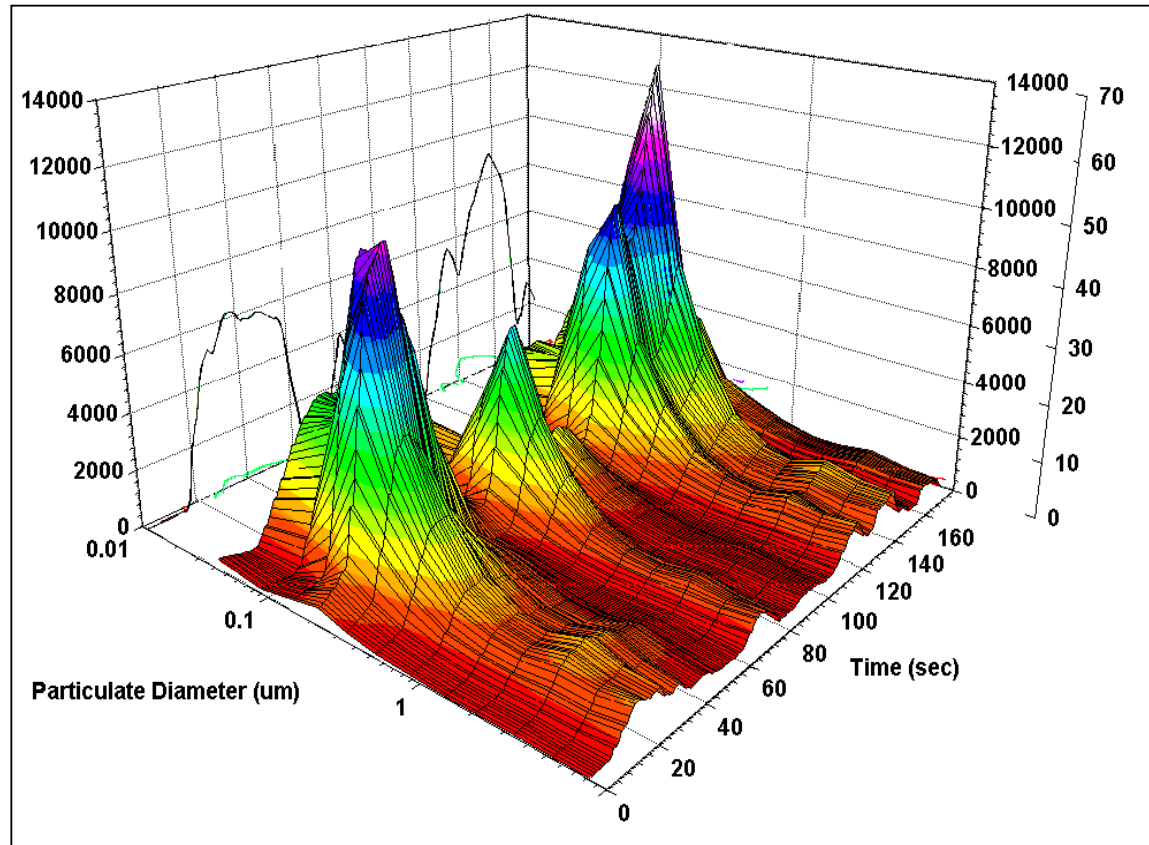
- ELPI+™ setup options for blow-by gas measurements
  - Direct connection to High Temperature ELPI+™ with DEED-150
  - High Temperature ELPI+™ + heated DI-1000
  - ELPI+™ + Dekati® Double Diluter Setup



# Application data



# Example data: Real-time particle size distribution, number and mass concentration measurement

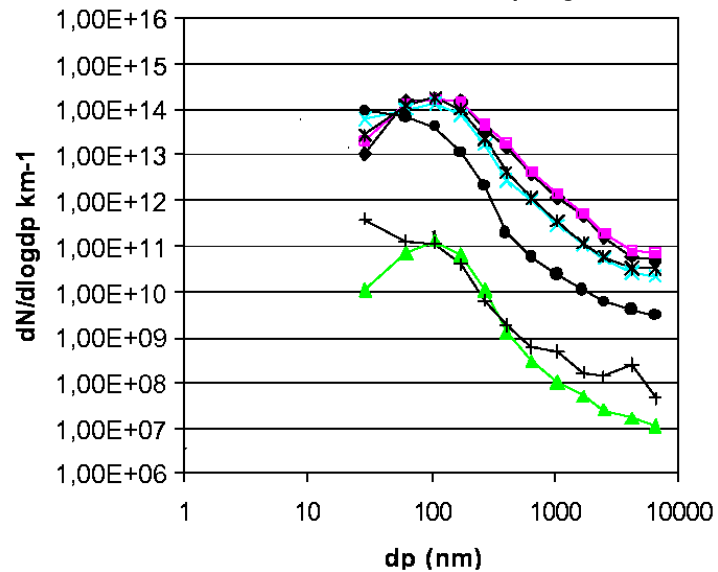


(data courtesy of Millbrook Testing Ground)



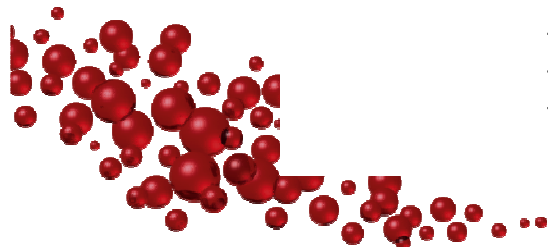
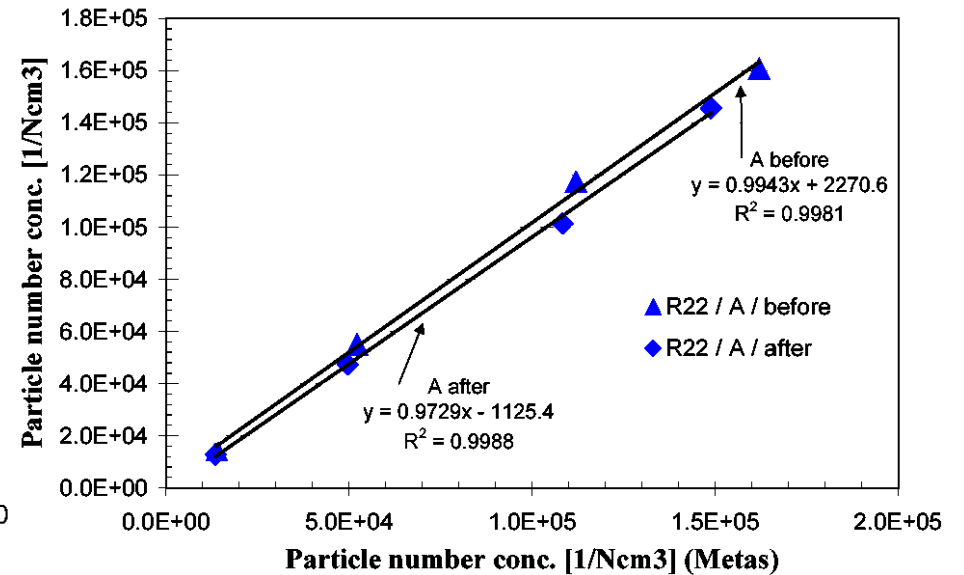
# Example data from ELPI

Size distributions from different vehicles, Particulates project

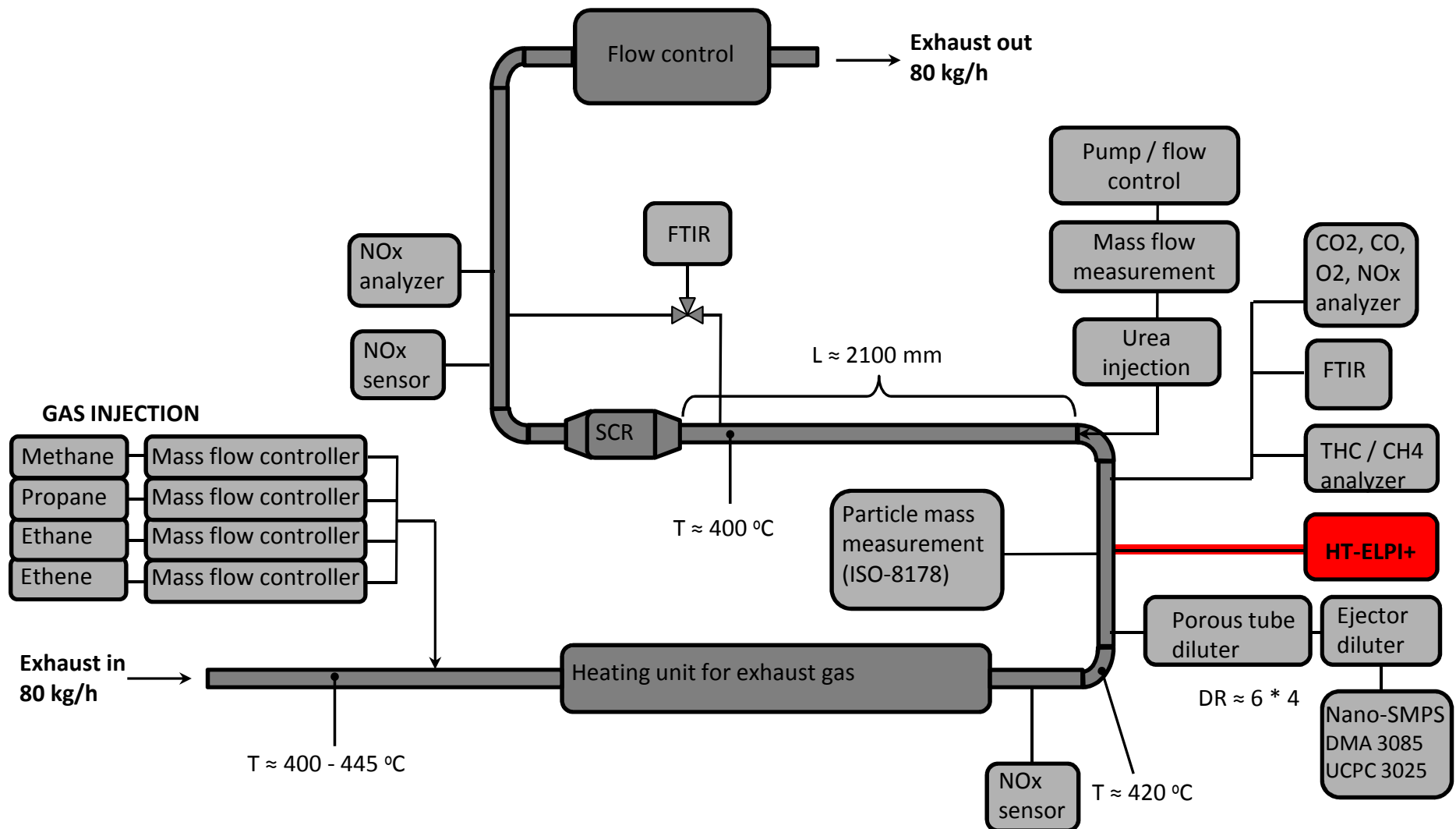


- ◆ Renault Laguna
- VW Golf DI
- ▲ Peugeot 607 (DPF)
- ✕ Peugeot 406
- \* VW Golf TDI
- VW Golf 1.9 TDI
- + Peugeot 607 2.2. DPF

ELPI vs. CPC, PMP project

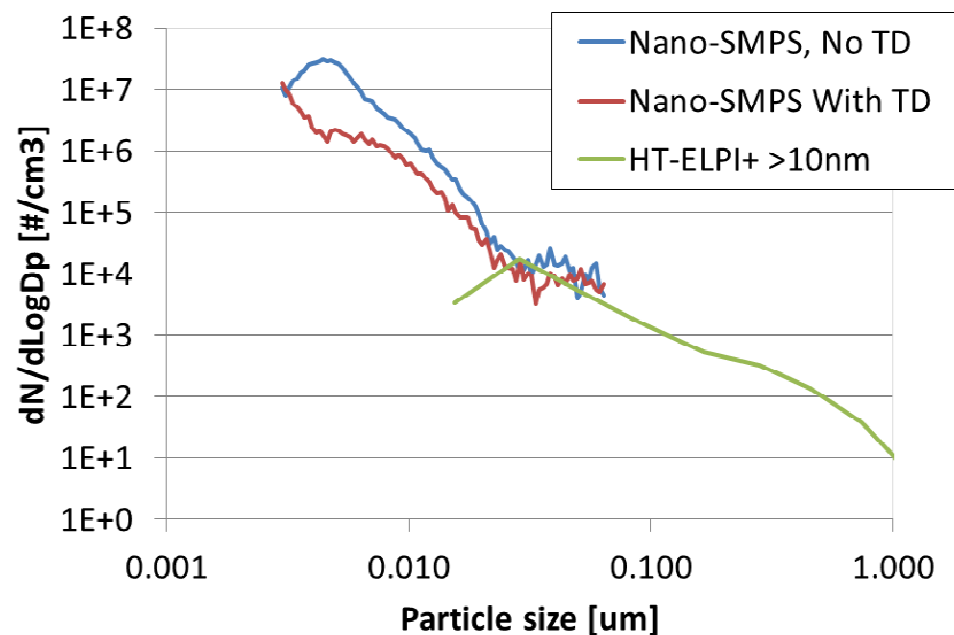


# NG Engine test bench

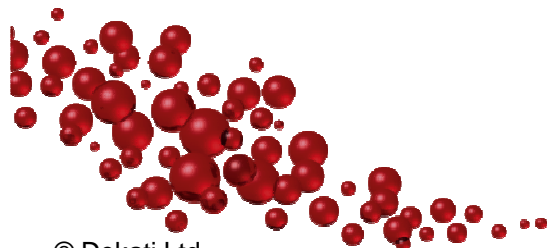


# Comparison to diluted measurements

Particle size distributions



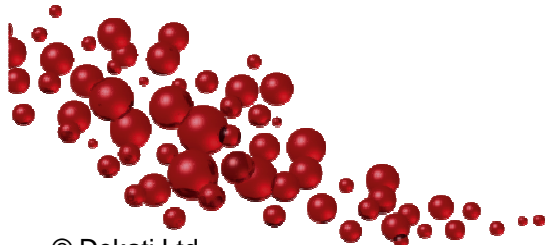
Number [#/cm3]	
HT-ELPI+	3.0e+4
HT-ELPI+ >10 nm	7.0e+3
SMPS Without TD	3.5e7
SMPS With TD	2.7e6
Mass [mg/m3]	
HT-ELPI+ (dens=1)	0.0078
ISO 8178 (AVL SS)	7000





# Conclusions

- High Temperature ELPI+ measures exhaust particles in tailpipe conditions:
  - High Temperature measurement, up to 180C
  - No dilution required
    - No uncertainties or particle transformations caused by dilution
    - Low concentration measurements
- Provides information for
  - Tailpipe particle characterization
  - OBD sensor studies at OBD conditions
  - Tailpipe particle charging studies
  - Particle formation studies
  - PEMS
- Diluted measurements may provide different results





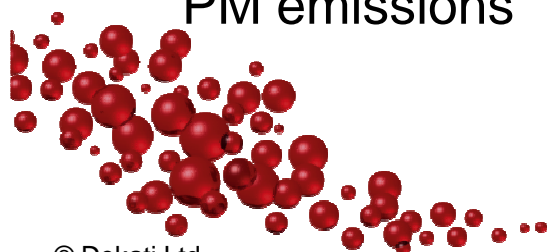
# Combustion plant

Measurements from stationary combustion units

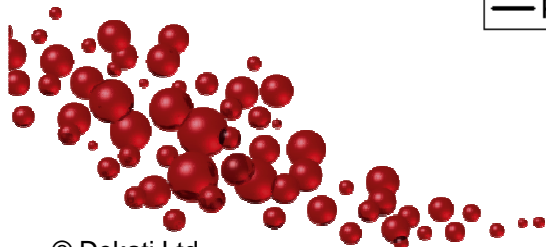
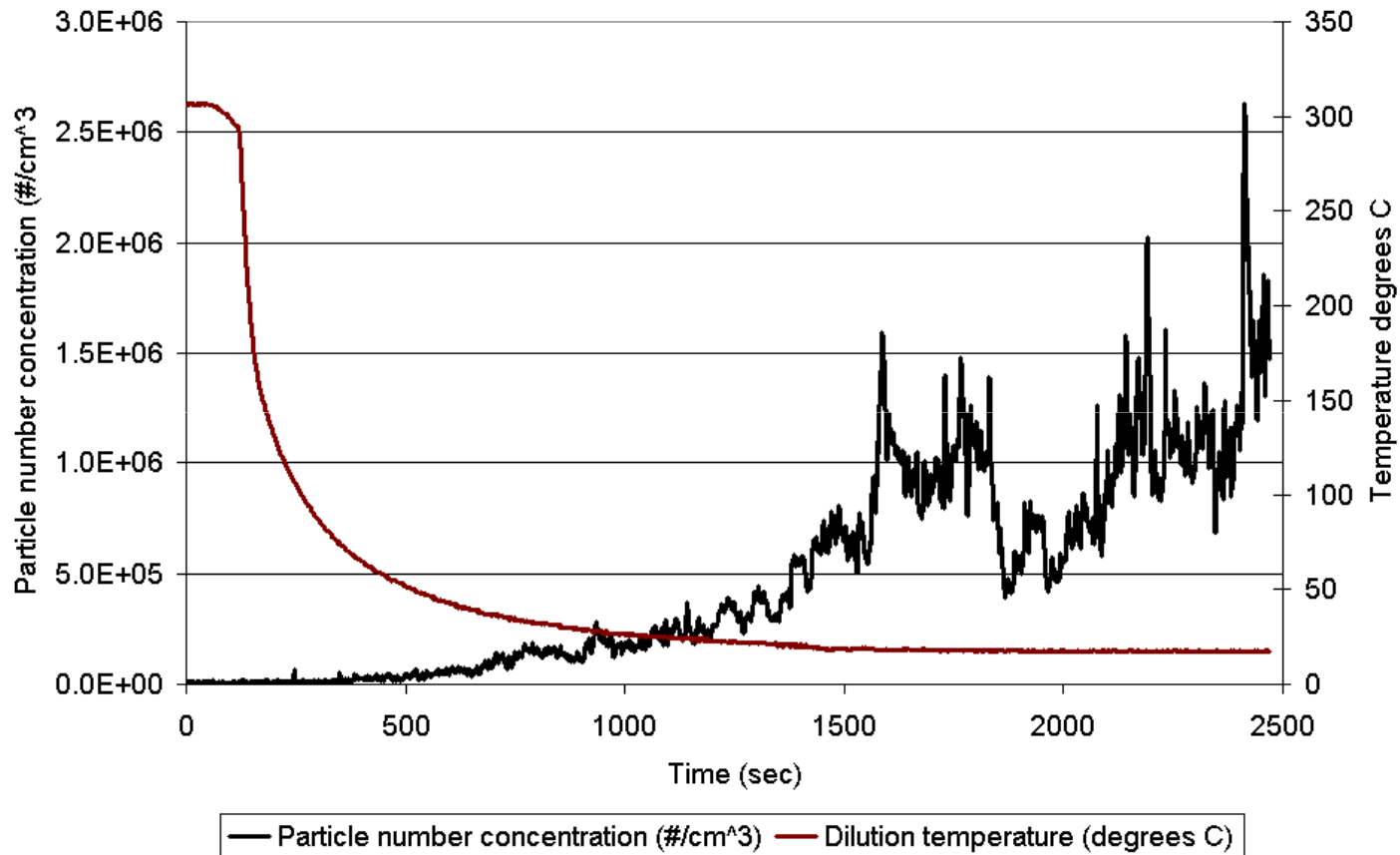


# Sample conditioning

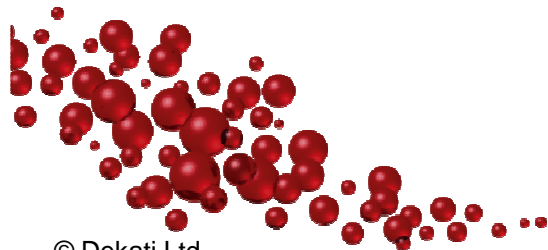
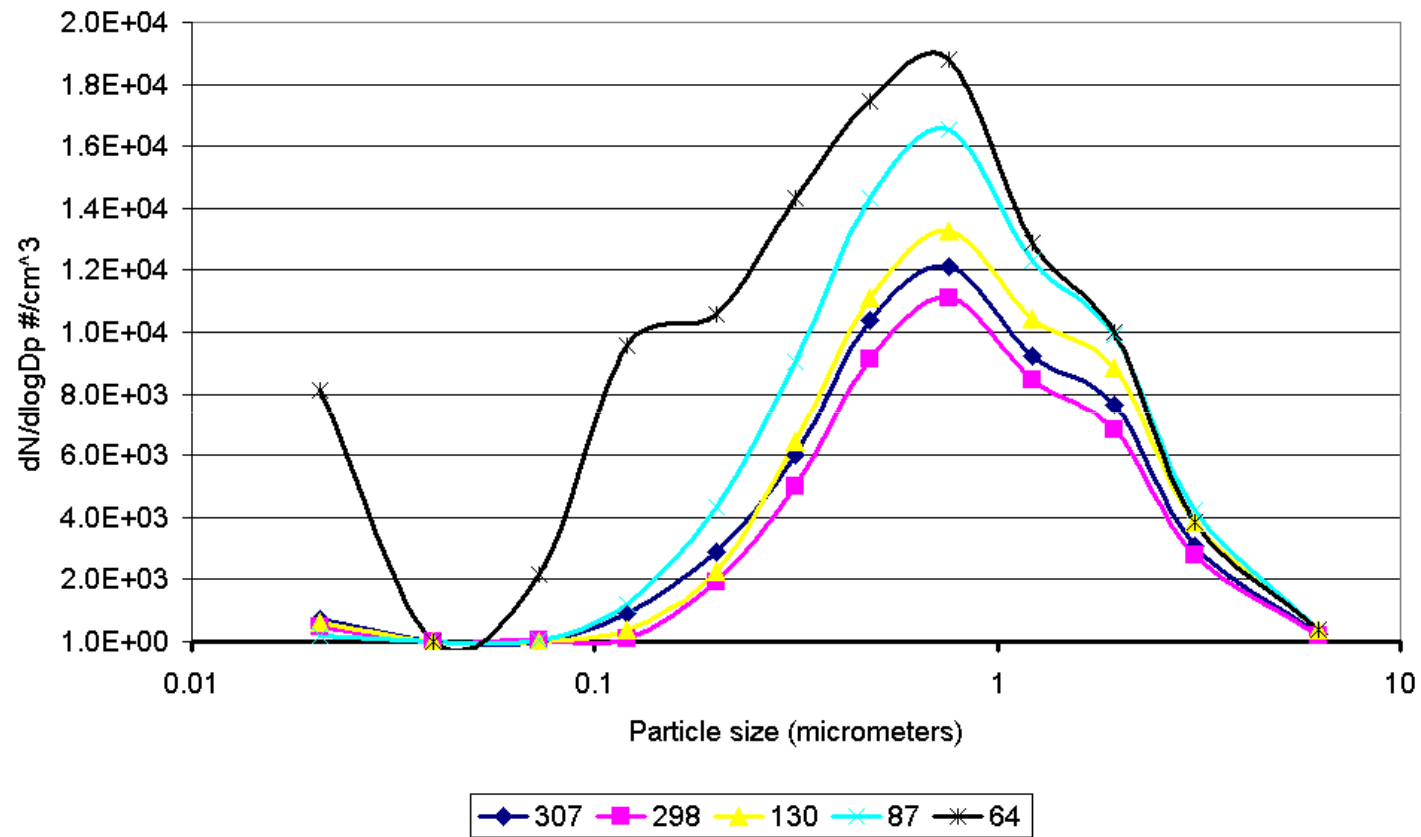
- Critically important in PM measurements and especially in real-time size resolved measurements
  - Use conductive lines
  - Aim is to transfer the sample with minimal losses - no need for rinsing
  - Typical setup two stage dilution with heated first stage
- Sample conditioning can also be used to estimate secondary PM emissions



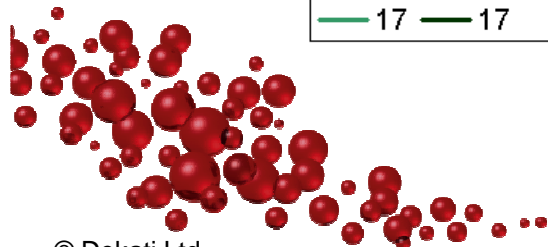
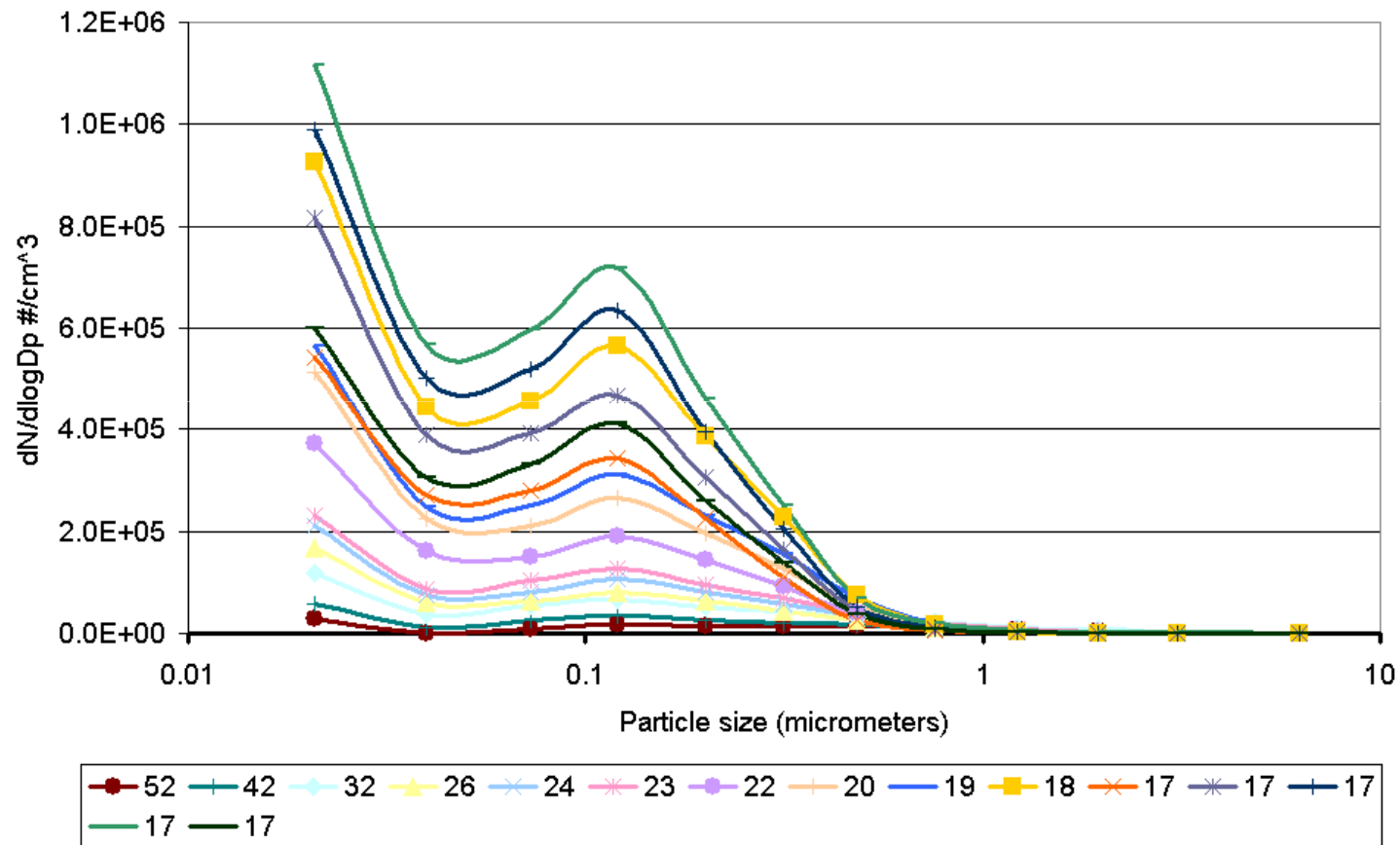
# Effect of Dilution Temperature on Particle Number Concentration



# Effect of Dilution Temperature on Particle Size

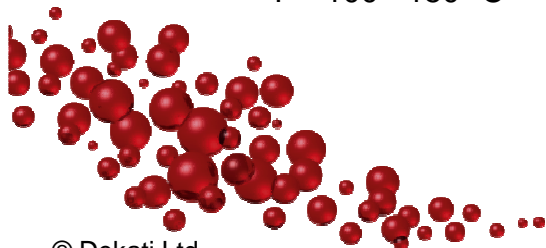


# Effect of Dilution Temperature on Particle Size



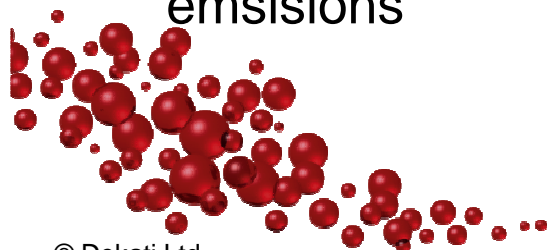
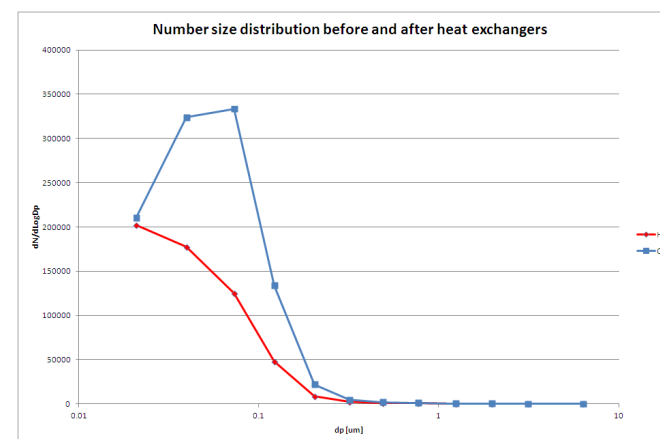
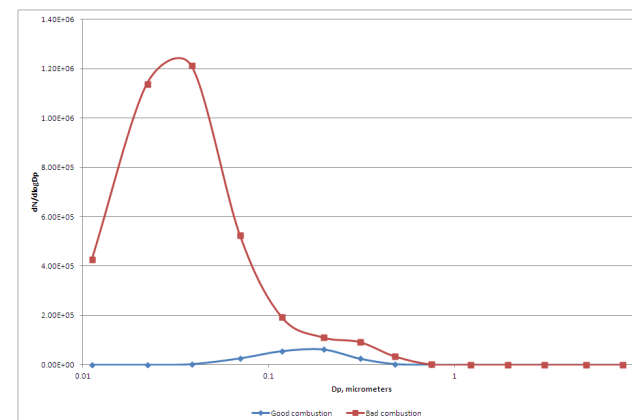
# Stationary combustion – Measurement locations

- Before flue gas treatment devices
  - Conc. up to grams/m<sup>3</sup>
  - DR ~ 500 – 10000
  - T ~ 200 – 1200 °C
- After flue gas treatment devices
  - Conc. up to 50-100 mg/m<sup>3</sup>
  - DR ~ 20 - 100
  - T ~ 80 - 150 °C
- After flue gas treatment devices / Natural gas
  - Conc. down to few µg/m<sup>3</sup>
  - DR ~ 1-20
  - T ~ 100 - 150 °C



# Combustion

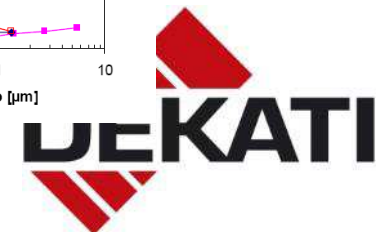
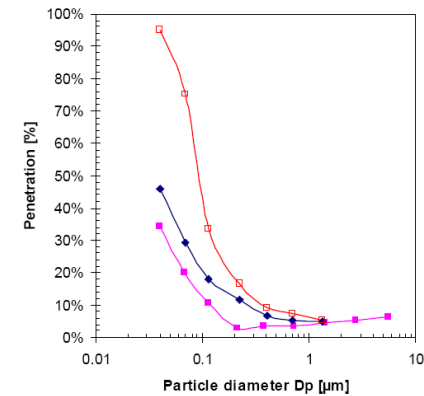
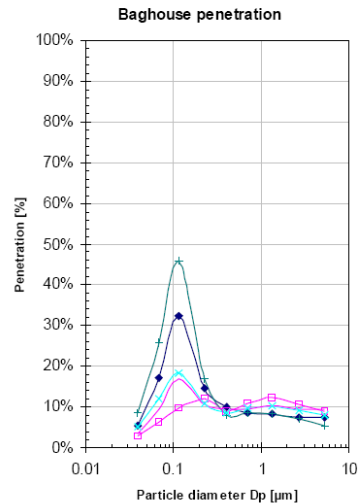
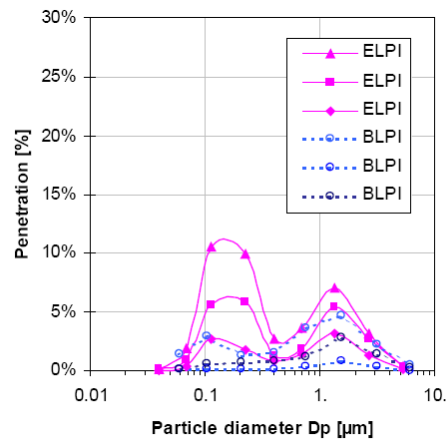
- PM size distribution and concentration is the most sensitive marker for combustion process
  - Fuel quality
  - Air/Fuel ratio
  - Incomplete combustion
- Real-time measurement of PM allows fast detection of changes and quick optimization cycles
- Effect of heat exchangers on emissions





# Flue gas cleaning systems

- Representative measurements have to be carried out right before and after flue gas cleaning equipment
  - Preferably simultaneously to achieve real-time size resolved penetration efficiency data
- Particles below 10  $\mu\text{m}$  of main interest
  - High collection efficiency for large particles, settling after emission
  - Particles above 10  $\mu\text{m}$  can be analysed from impactor pre-cut and/or from cyclone
- Optimization of
  - ESPs
  - Baghouse filters
  - Scrubbers



# ESP rapping – different operation

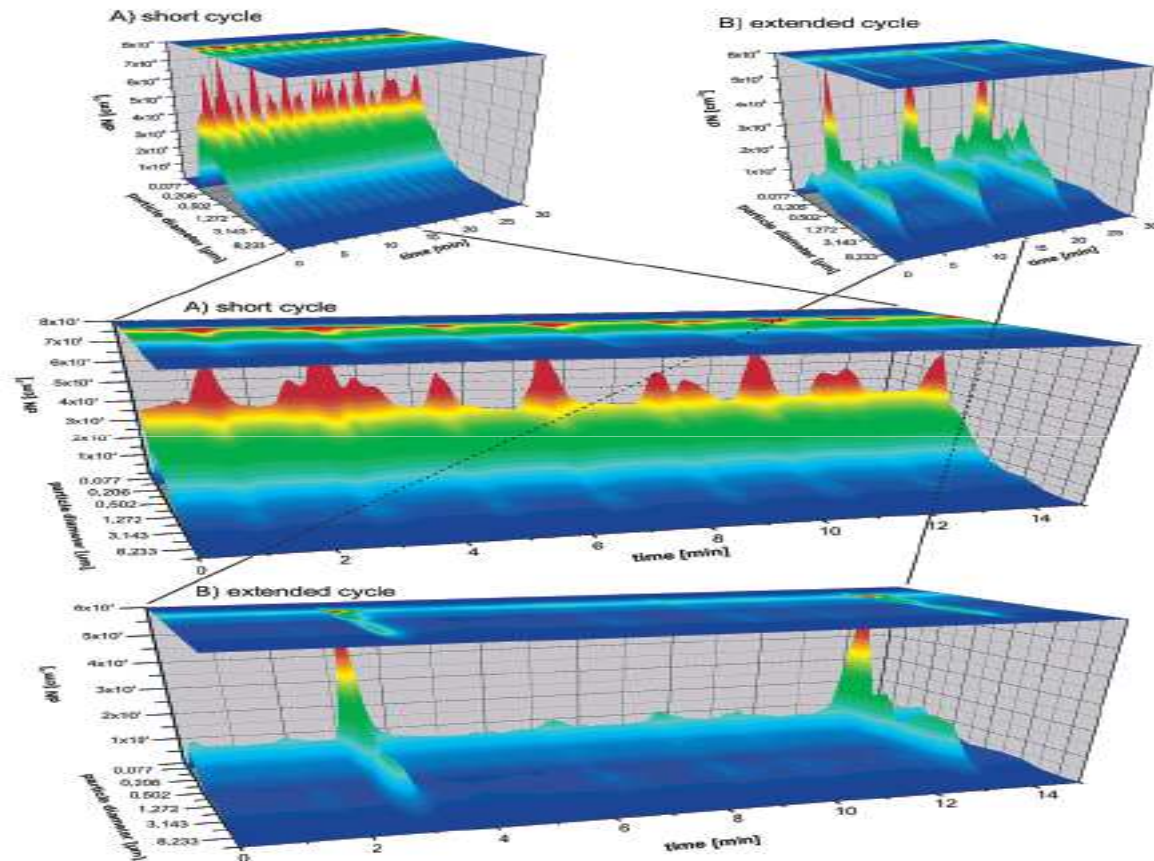
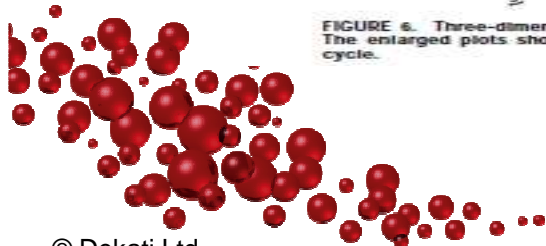
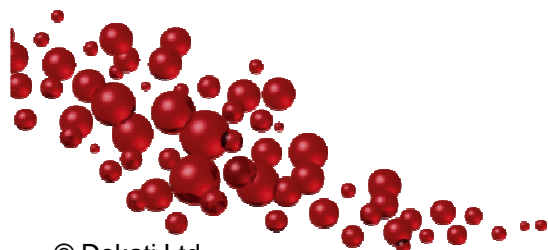
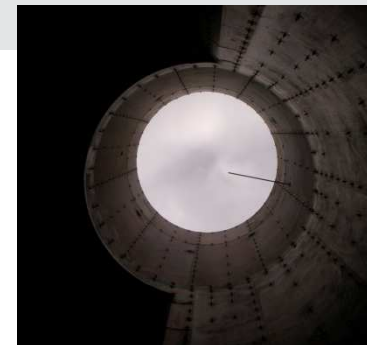


FIGURE 6. Three-dimensional plots of the particle size distribution time course downstream from the ESP measured with the ELPI. The enlarged plots showing 15 min measurements show clearly the elevated level of fine and ultrafine particles during the short cycle.



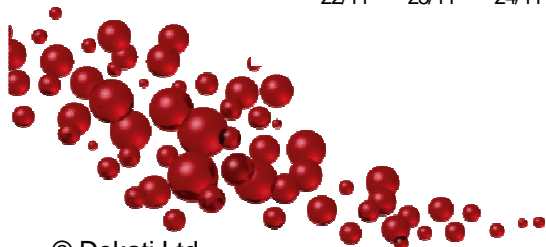
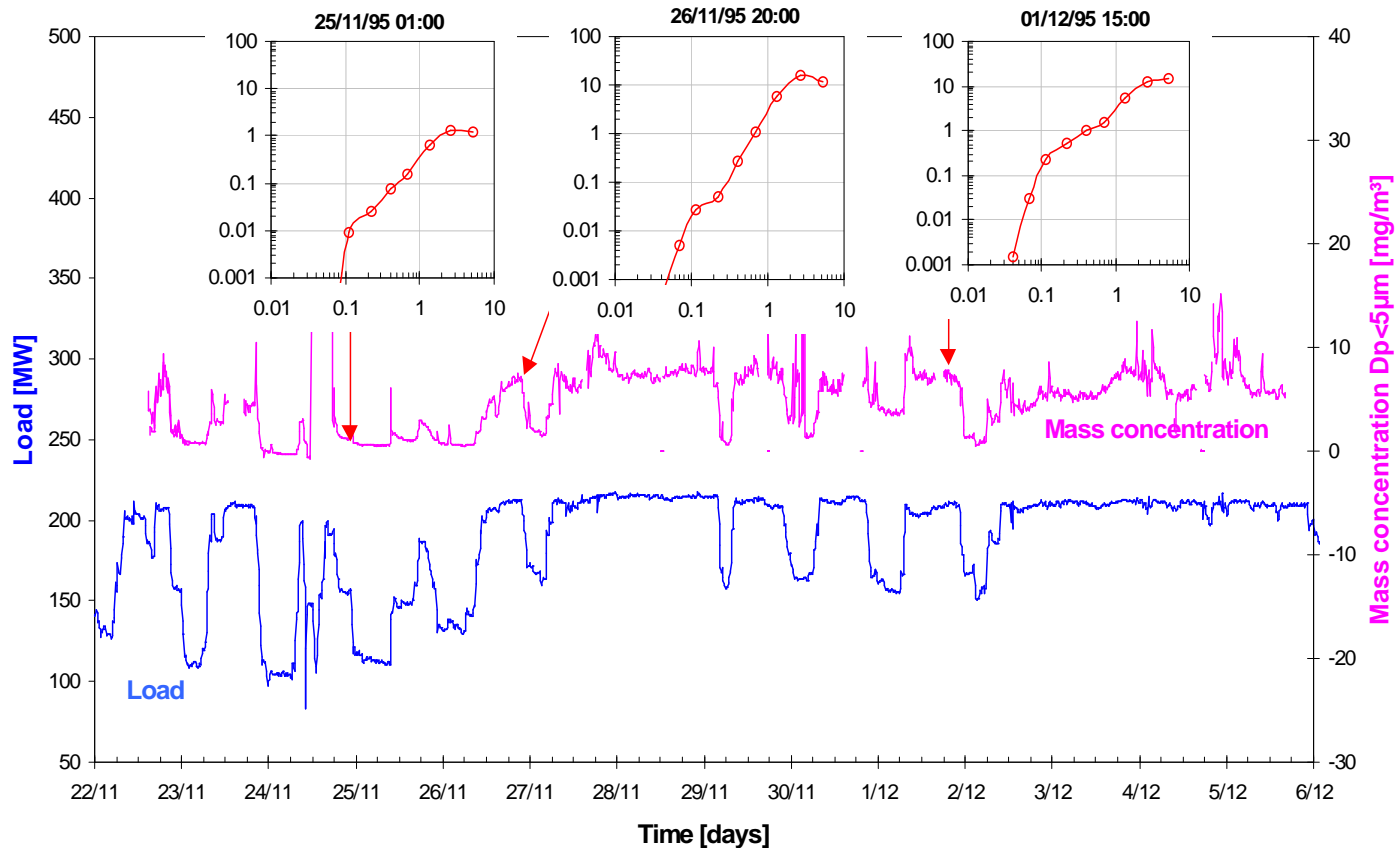
# Stack measurements

- Emission measurements
  - Simultaneous measurement of PM fractions from PM10 to PM0.006 in 14 size classes
  - Real-time data to show emissions at any specific time
- CEM operation checks
- Source apportionment
  - Fingerprinting stack emissions through size resolved chemical analysis
  - Ambient measurements using the same instrument



# Emission monitoring, 14 days

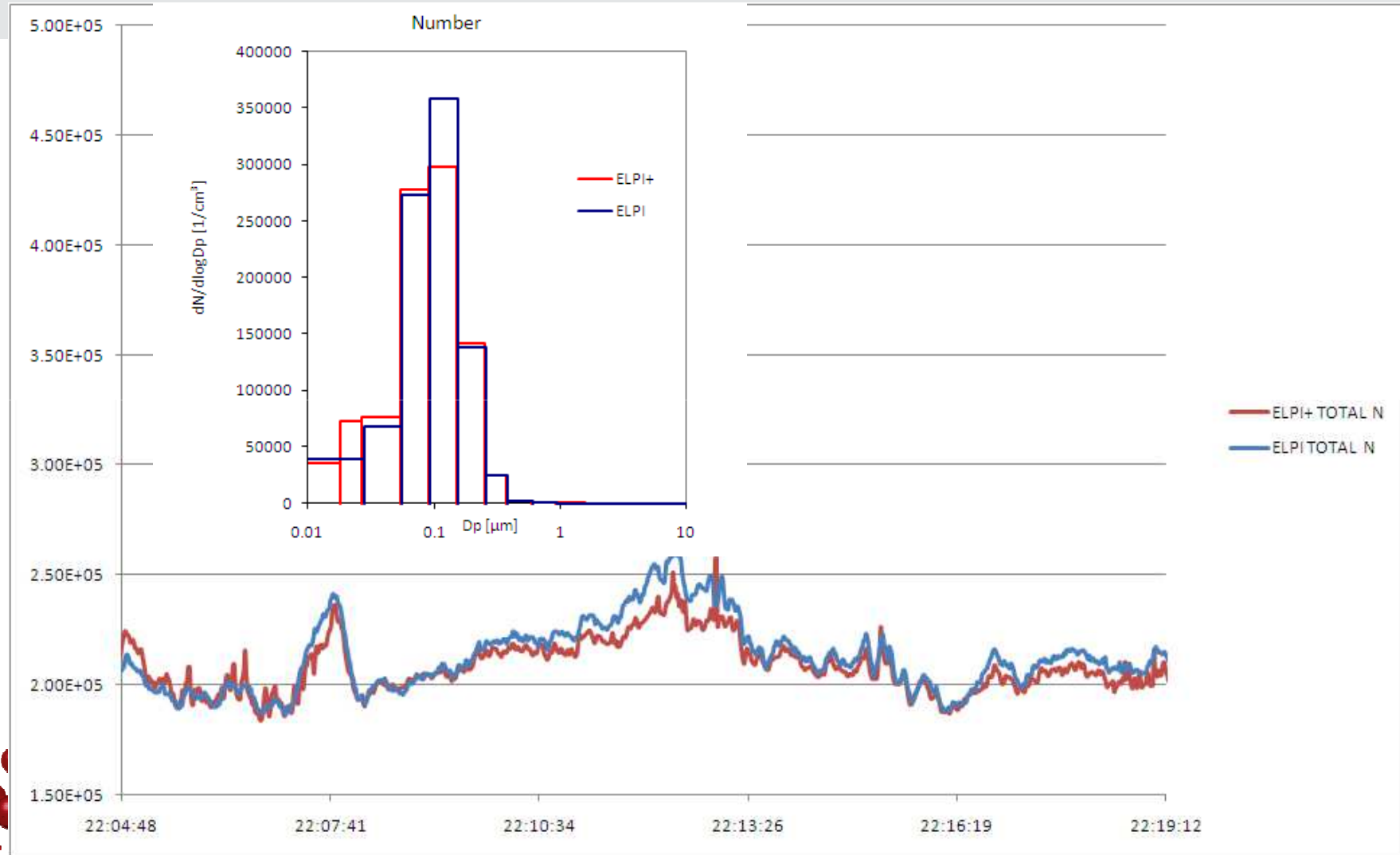
Fine particle emission changes



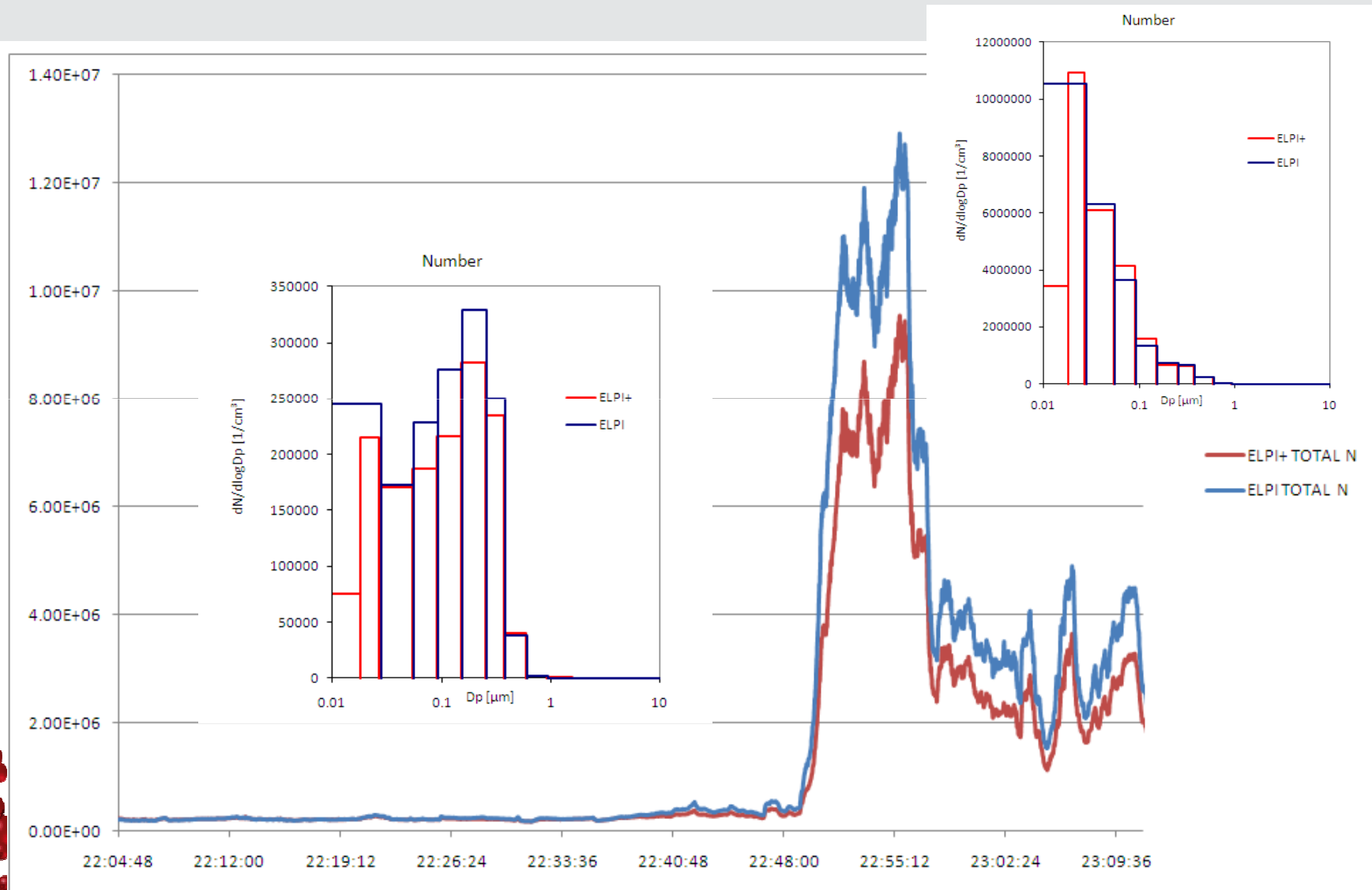
# Measurements in small scale biomass power plant



# Results 3: Flue gas channel



# Results 4: flue gas channel / low load



# Charge measurement

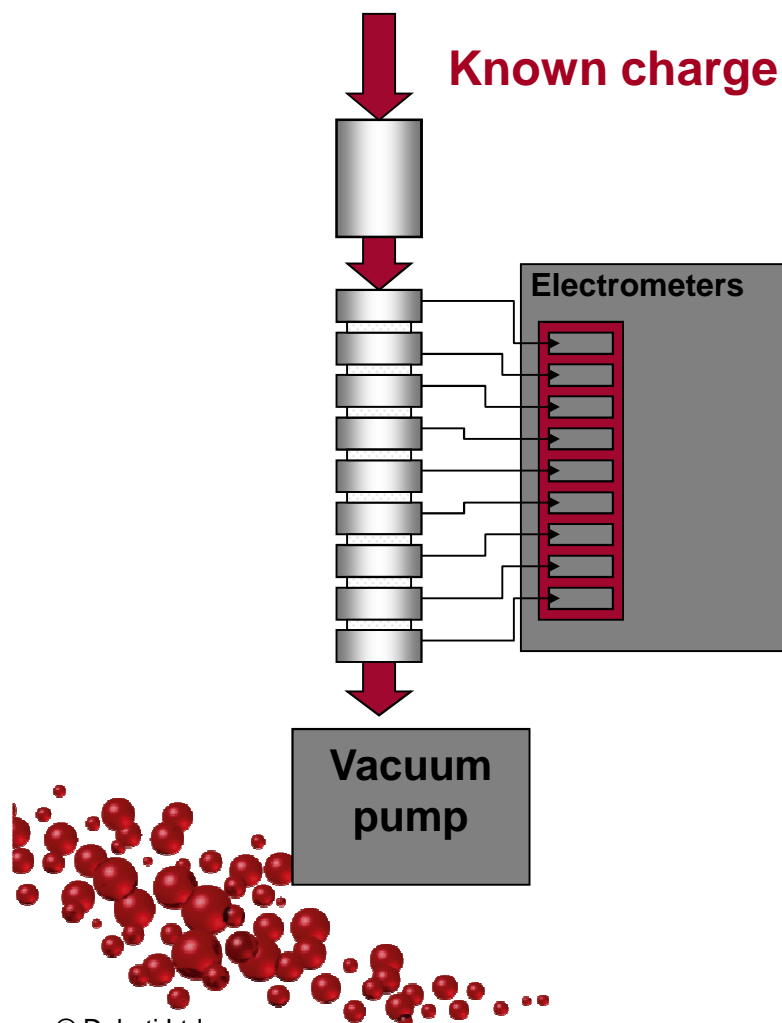
Special application for ESP and filtration studies



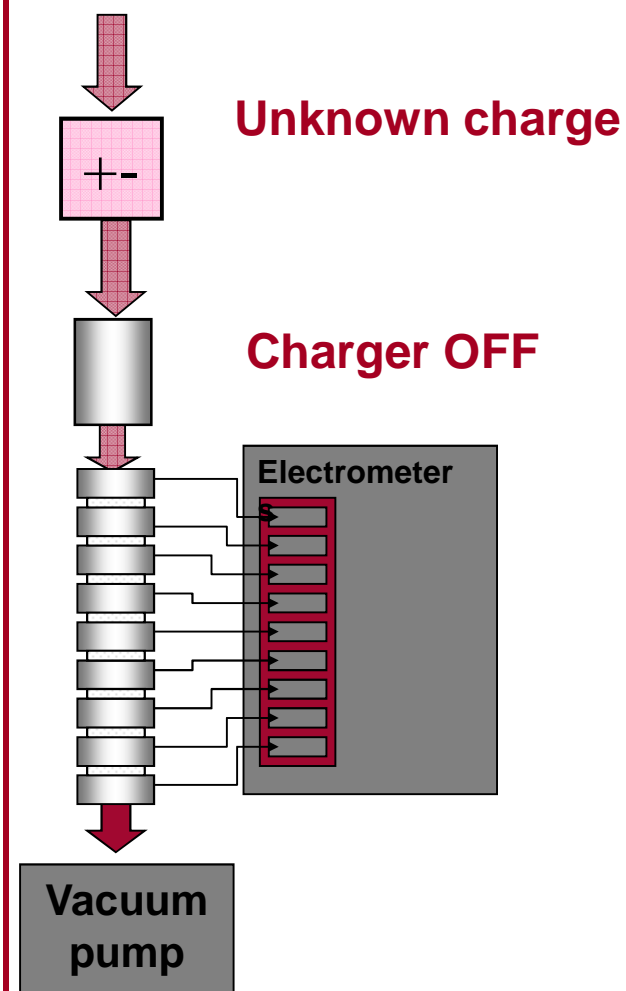


# Particle Charge measurement

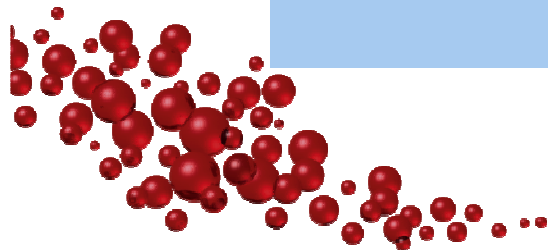
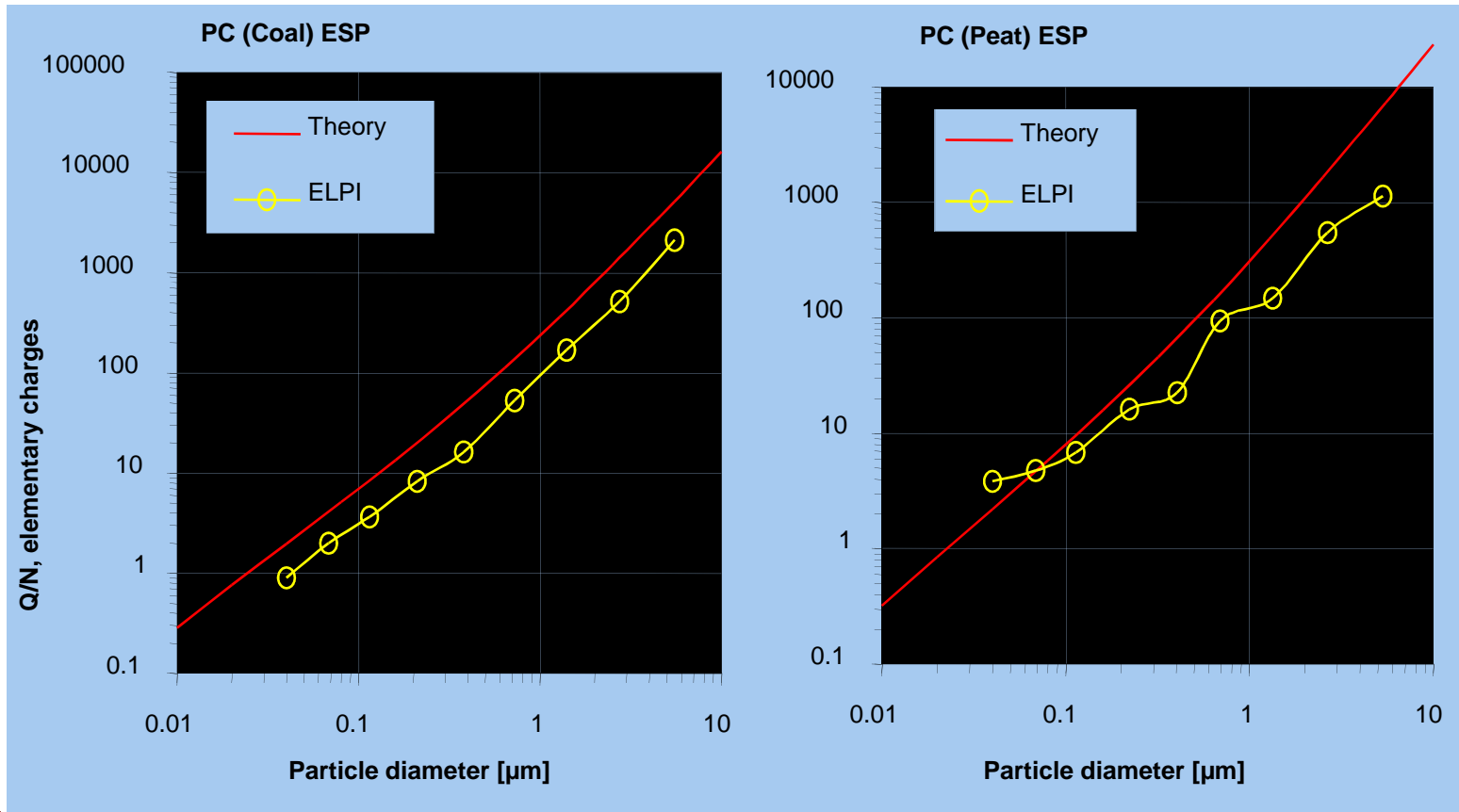
Number size distribution



Charge distribution



# ESP efficiency studies



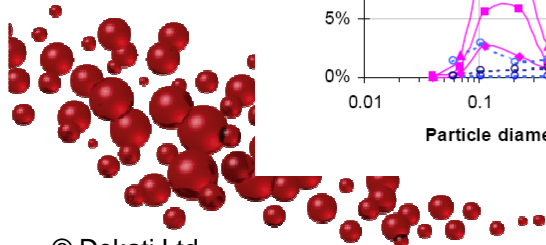
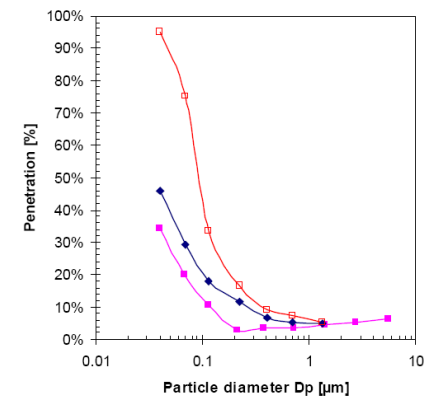
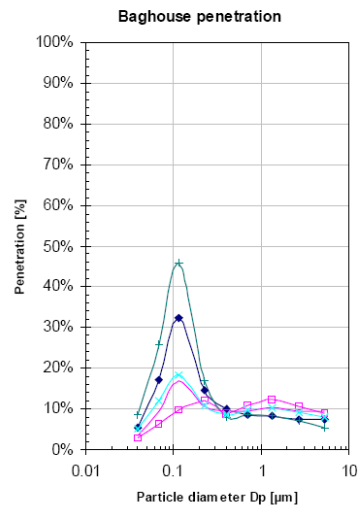
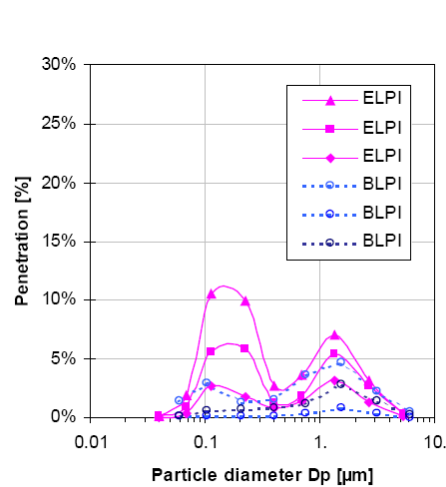
Data courtesy to TUT



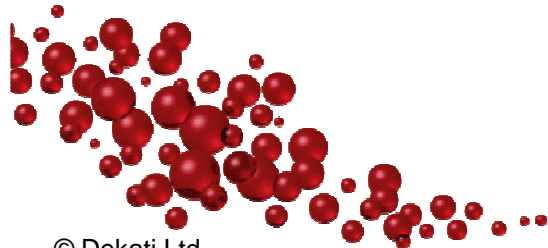
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# Filtration system and particle charge

- Testing of filtration systems is generally carried out by using generated aerosols
- Freshly generated aerosols may have significant charge levels
- Charge affects aerosol behavior and filtration efficiency



# Demo measurement – After a short break



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