

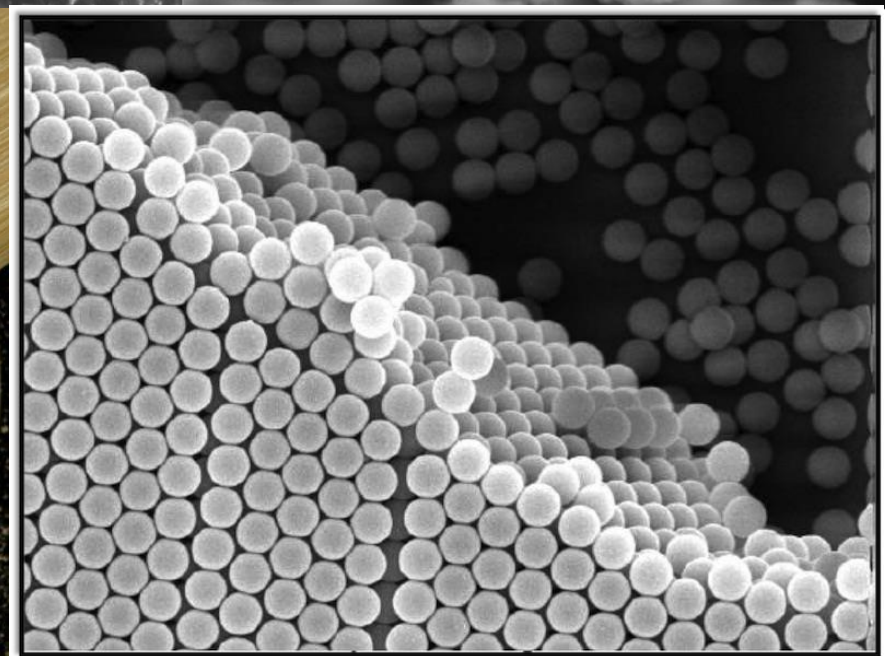
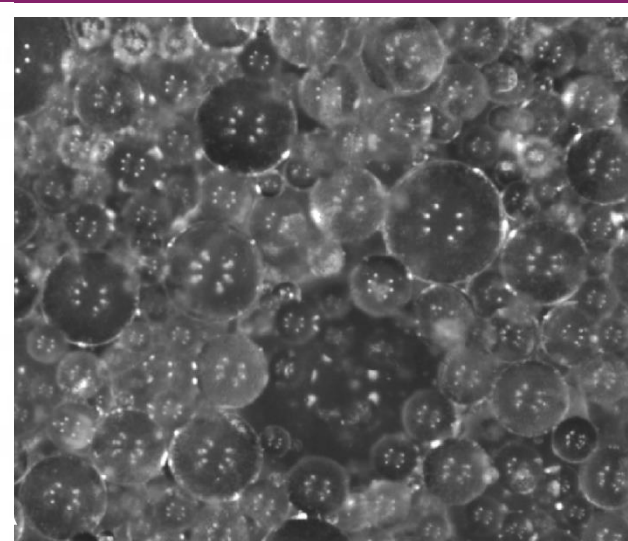
# Photon Density Wave Spectroscopy

Potsdam, 15.11.2021

Dr. Marvin Münzberg

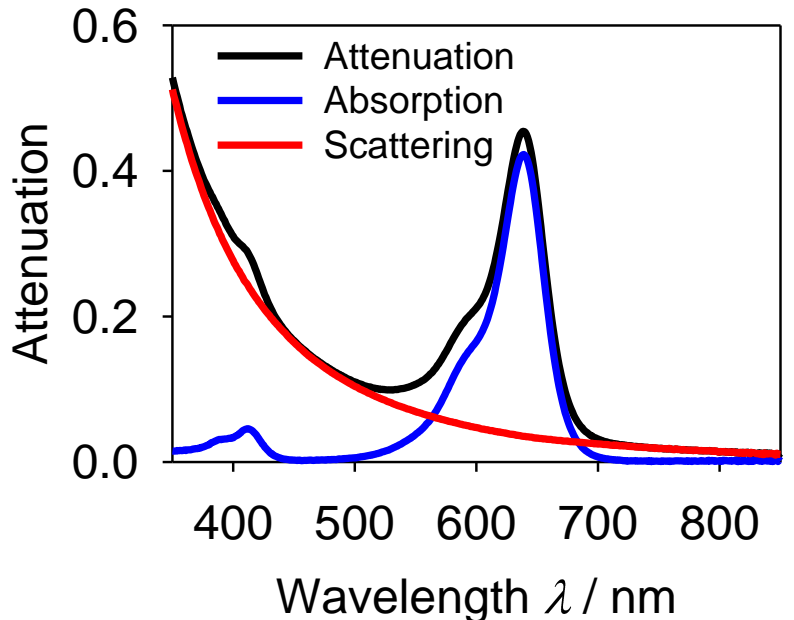
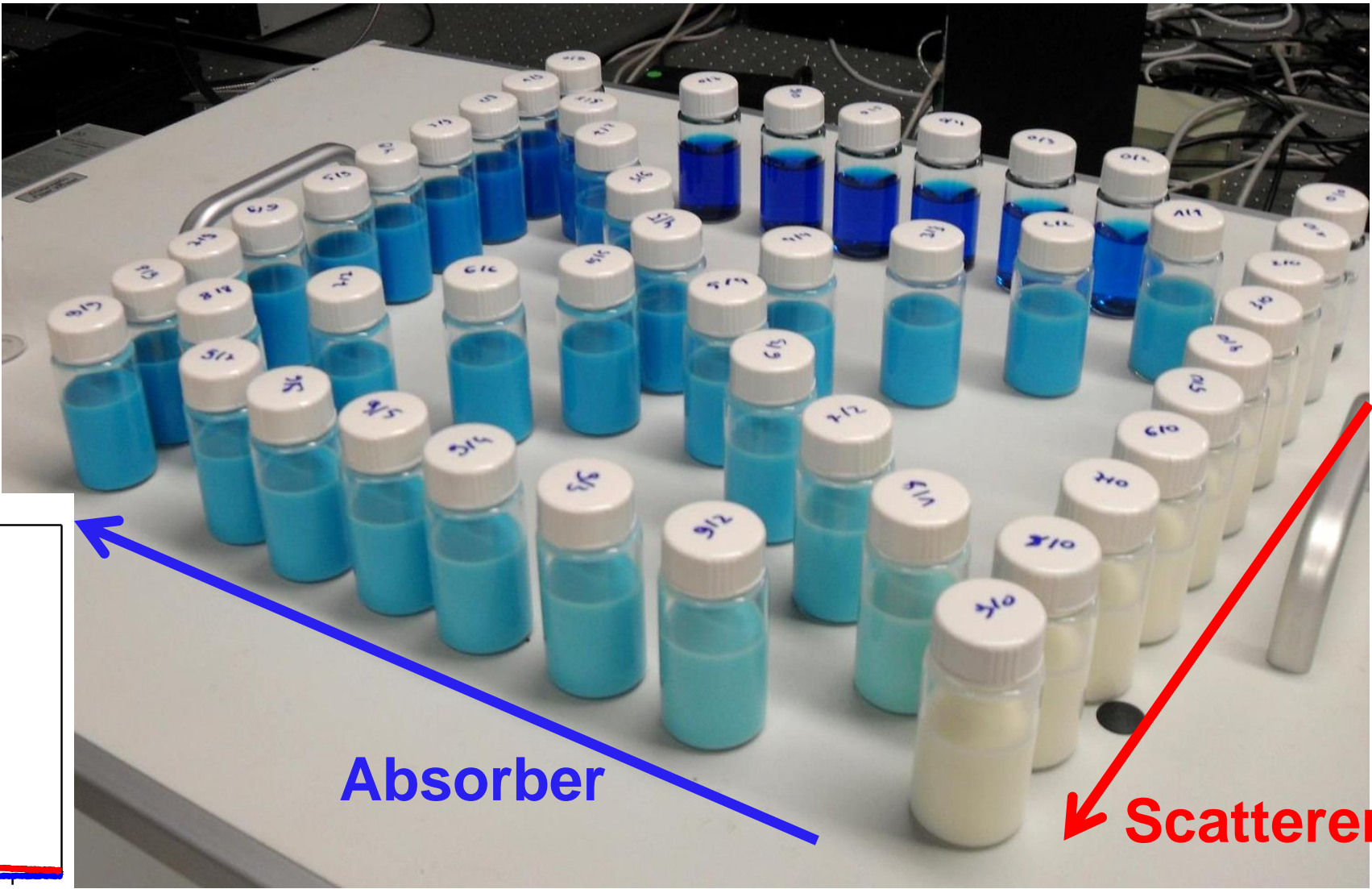
University of Potsdam, Physical Chemistry – innoFSPEC Potsdam, Applied  
Analytical Photonics

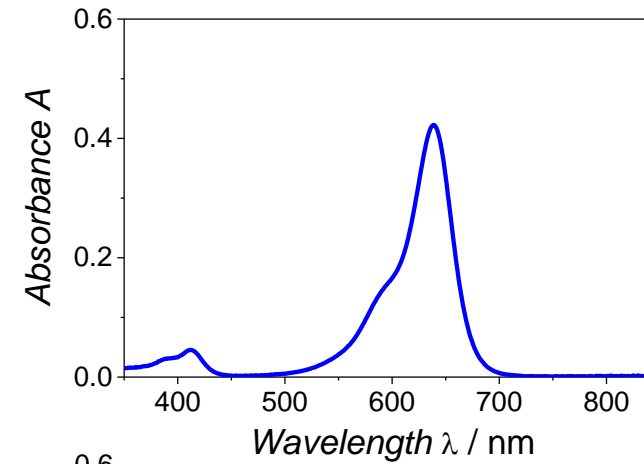
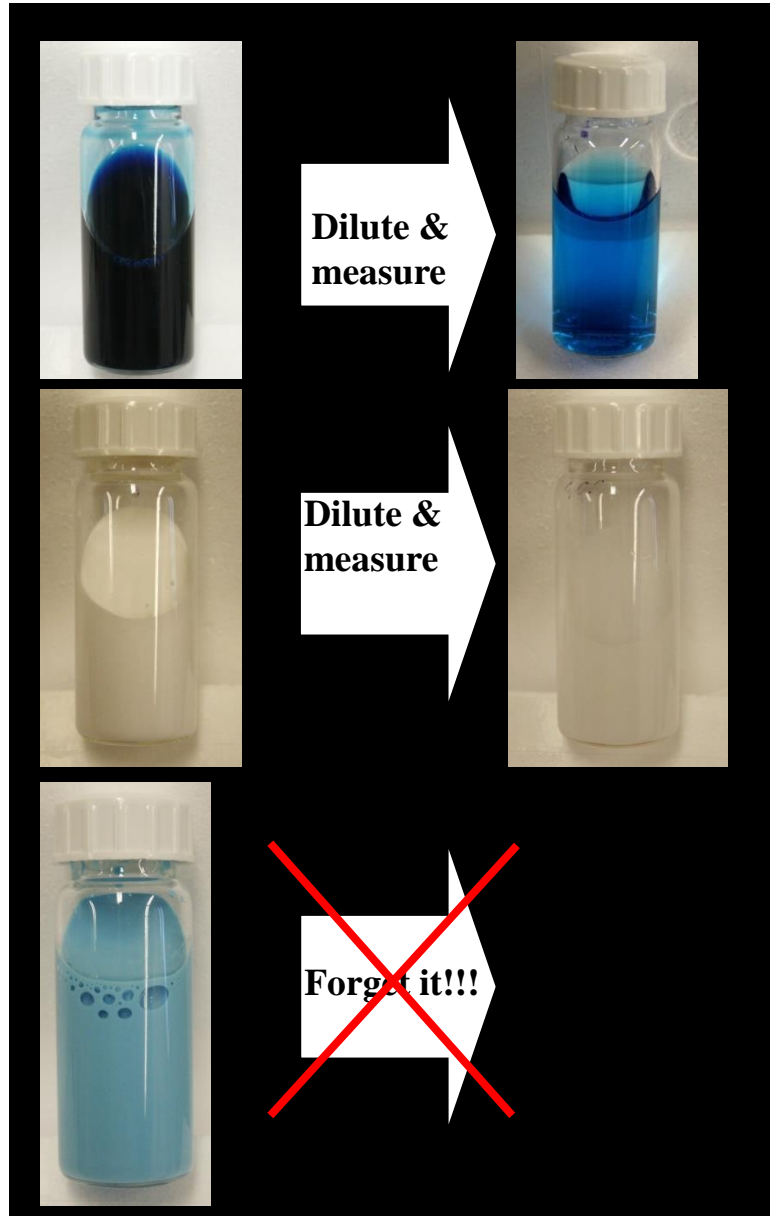
E-mail: [mmuenzbe@uni-potsdam.de](mailto:mmuenzbe@uni-potsdam.de)



Bildquellen: guardianlv.com, alleideen.com, desy.de

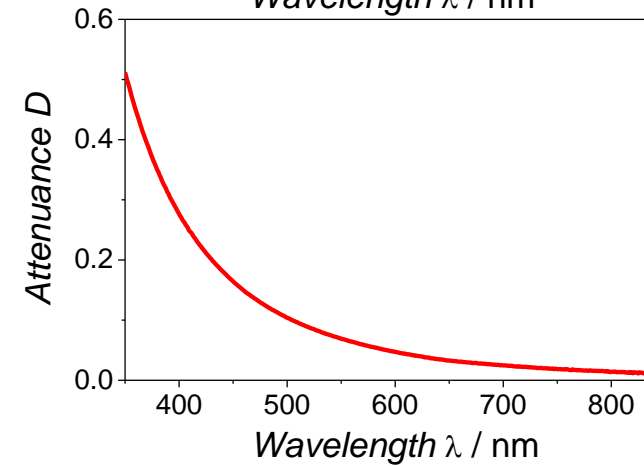
P. Werner, **M. Münzberg**, R. Hass, O. Reich, Analytical and Bioanalytical Chemistry, 09, S. 807-19, 2017





$$A = \mu_a l$$

$$= \epsilon_a c l$$

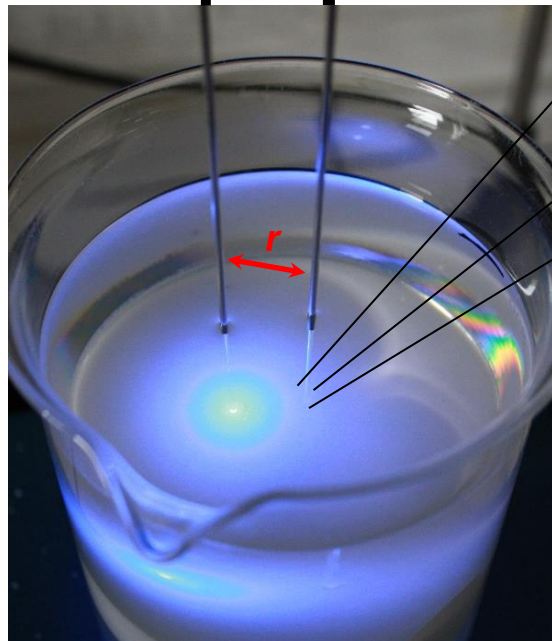
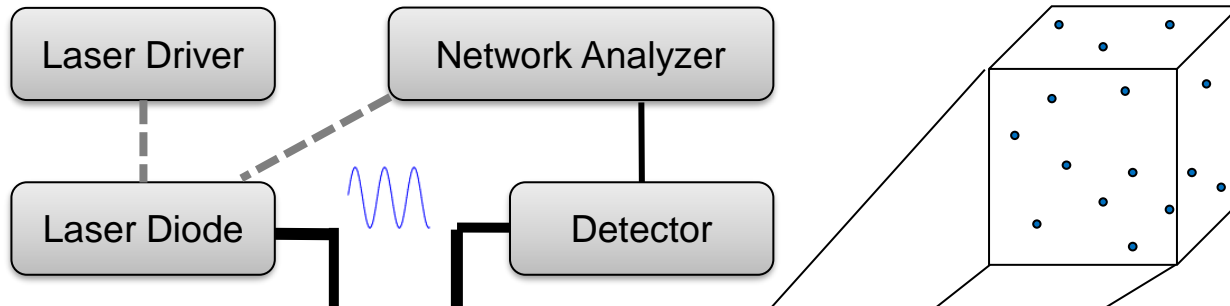


$$D = \mu_s l$$

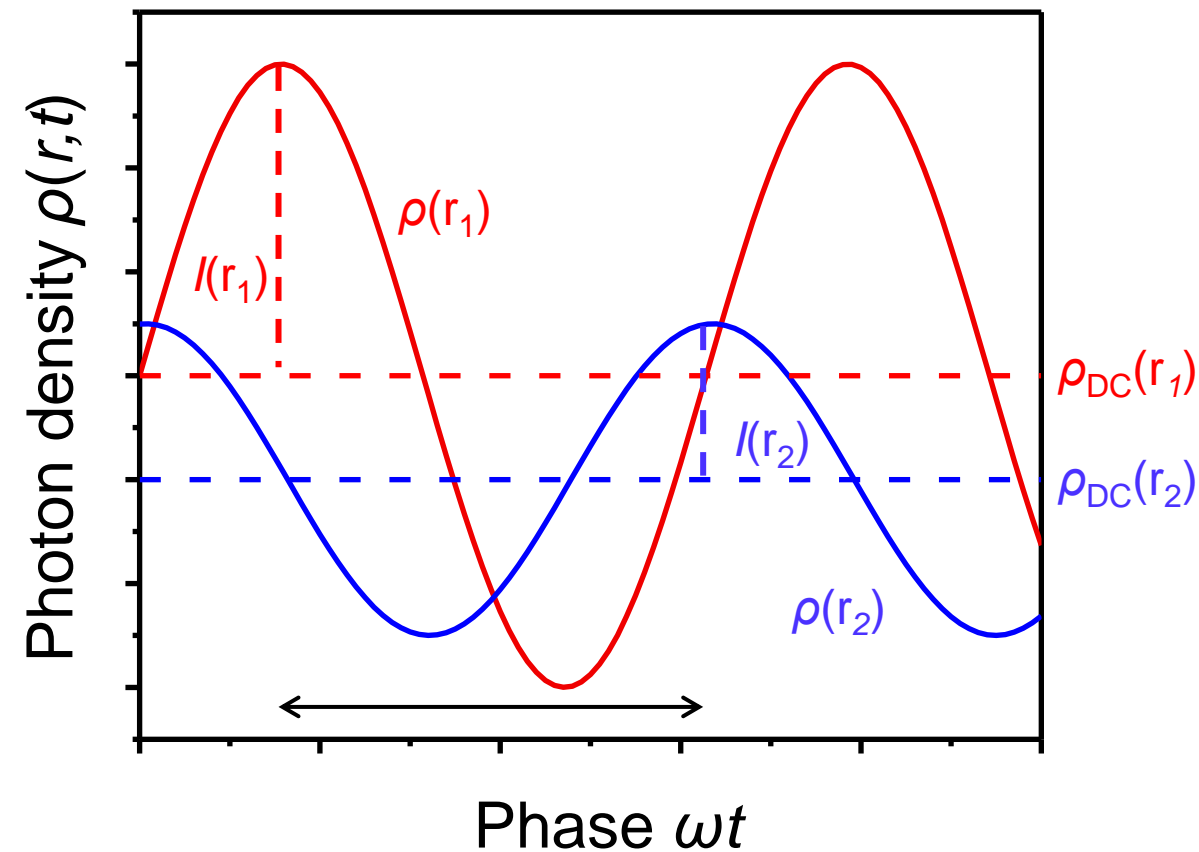
$$= \epsilon_s c l$$

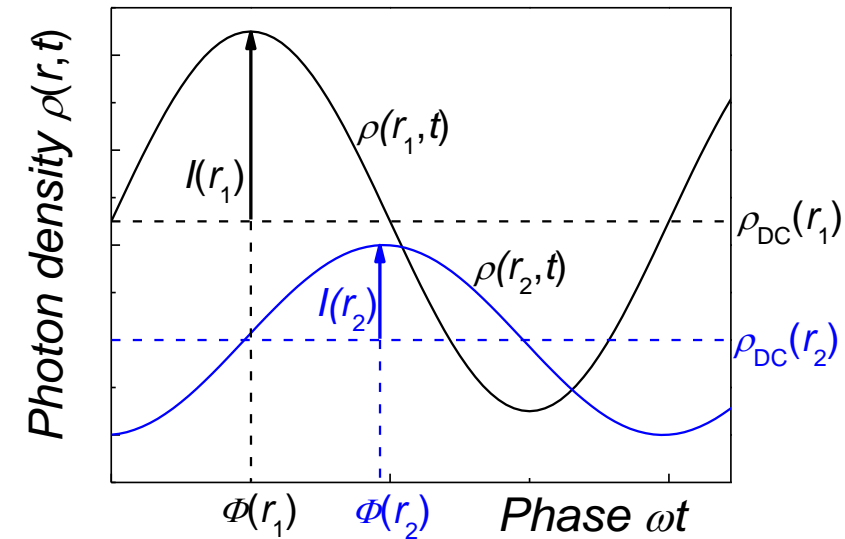
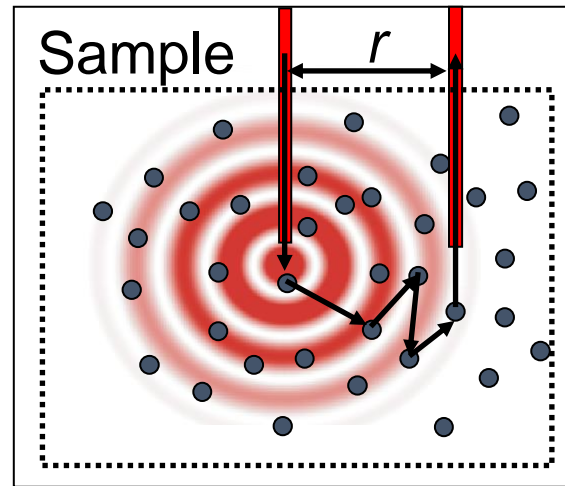
~~$$D = \ln \frac{I_0}{I} = [\mu_a + \mu_s] z$$~~

No linear correlation



**Photon Density** =  
number of photons  
per volume





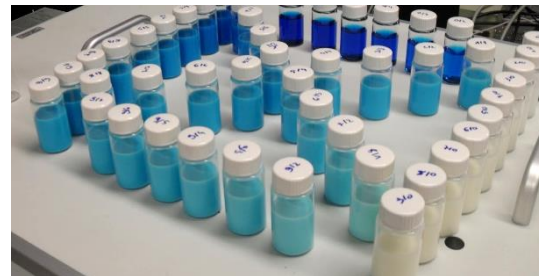
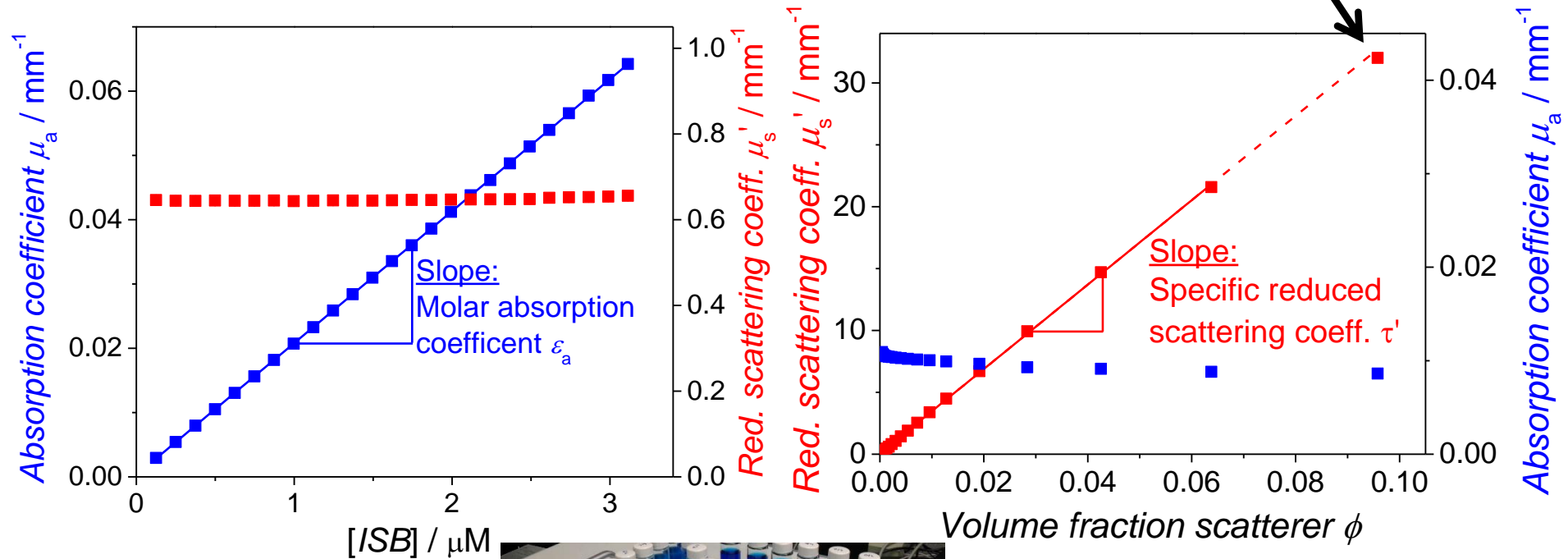
Photon density: 
$$\rho(r,t) = \underbrace{\frac{\rho_{DC}^0}{r} \exp[-k_{DC}r]}_{\text{const. in time}} + \underbrace{\frac{\rho_{AC}^0}{r} \exp[-k_1 r]}_{\text{Intensity } I(r,\omega)} \cos[\omega t - \underbrace{k_\phi r}_{\text{Phase } \Phi(r,\omega)}]$$

$$\text{Int.-/Phase coeff.: } k_{1/\phi} = \sqrt{\frac{3}{2} \left\{ \sqrt{\left[ \left[ \frac{\mu_a}{3} + \mu_s' \right]^2 + \frac{\omega^2}{c^2}} \right] \left[ \mu_a^2 + \frac{\omega^2}{c^2} \right] \pm \mu_a \left[ \frac{\mu_a}{3} + \mu_s' \right] \mp \frac{\omega^2}{c^2} \right\}}$$

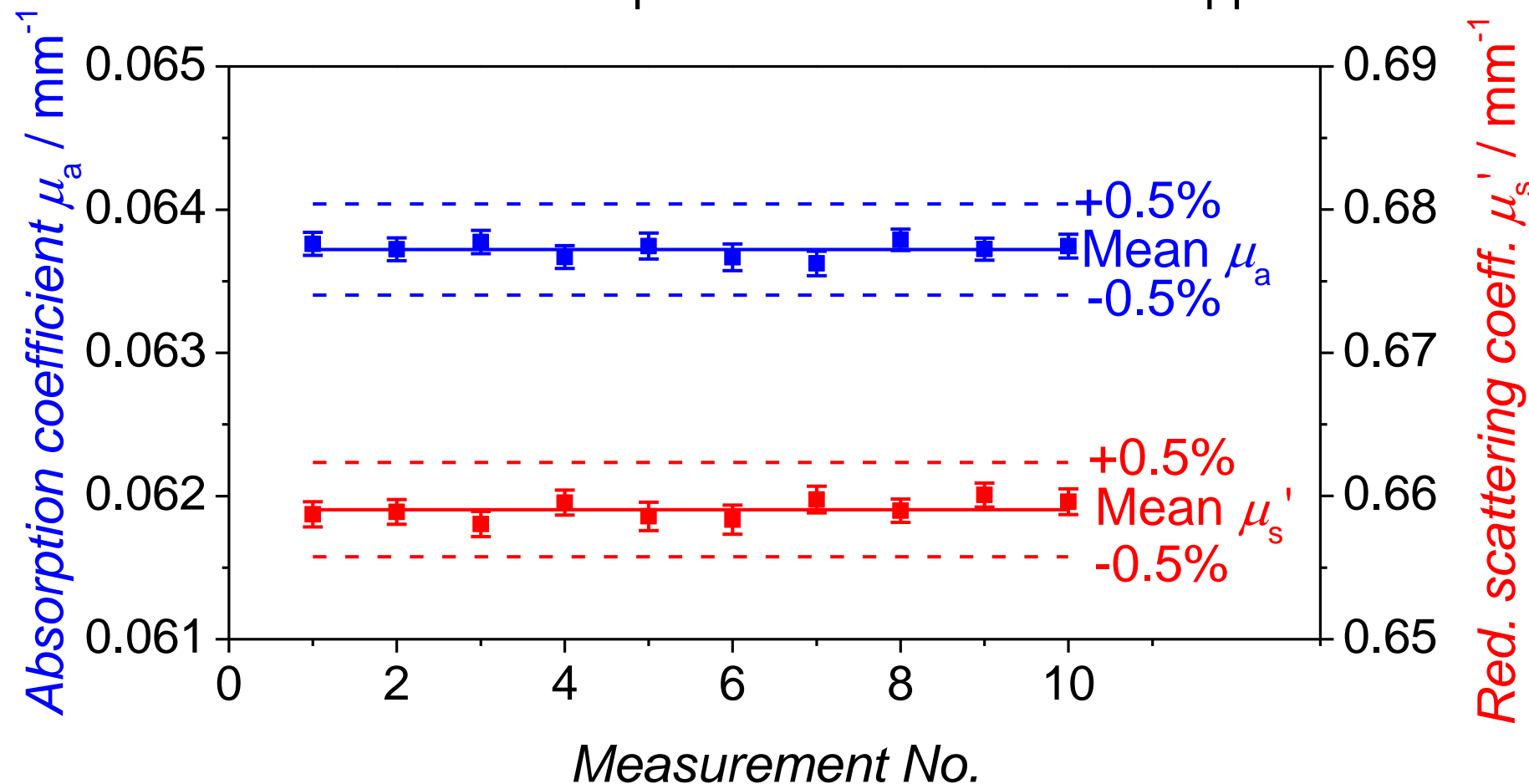
Absorption & scattering properties independently accessible!

- Determination of concentration (via absorption)
- Determination of particle size (via scattering)

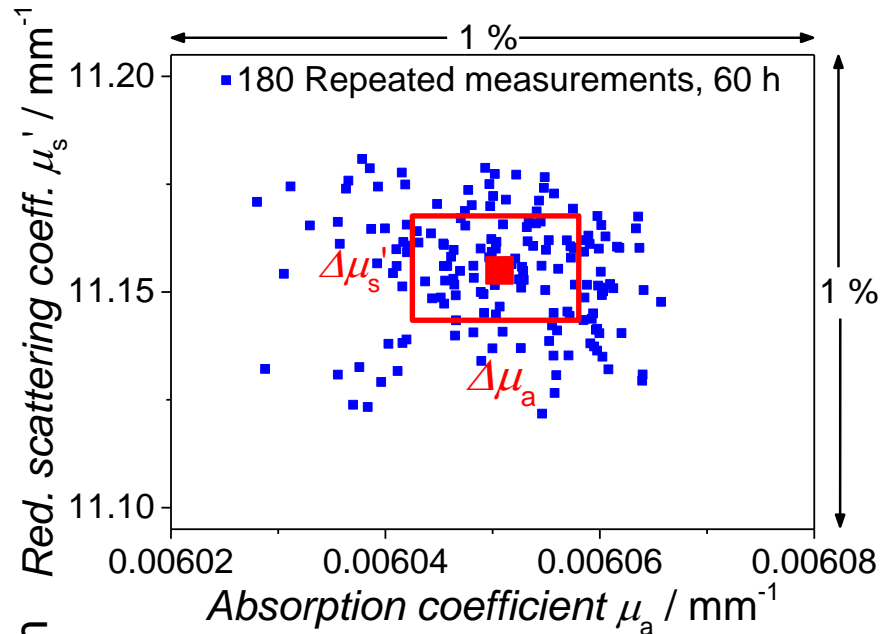
1 cm-cuvette:  
 $D = 3000!!!$   
 $D_{\max}(\text{Turbidim.}) = 3$



- „Precision“ often far better than 1 %, good error estimates
- Translates to precision of: particle size = sub nm  
abs. concentration = sub nM  
particle vol. fraction = sub ppm





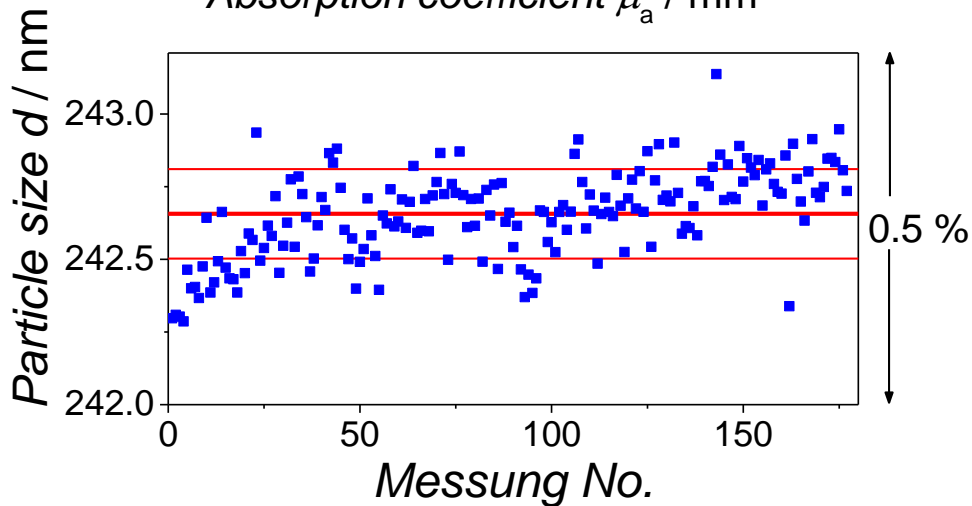


## Precision of optical coefficients:

$$\Delta\mu_s' : 1.4 \times 10^{-2} \text{ mm}^{-1} \text{ (0.12\%)}$$

$$\Delta\mu_a : 8.4 \times 10^{-6} \text{ mm}^{-1} \text{ (0.14\%)}$$

equals [Abs] of 400 pM or  
equals absorption length of 120 m!



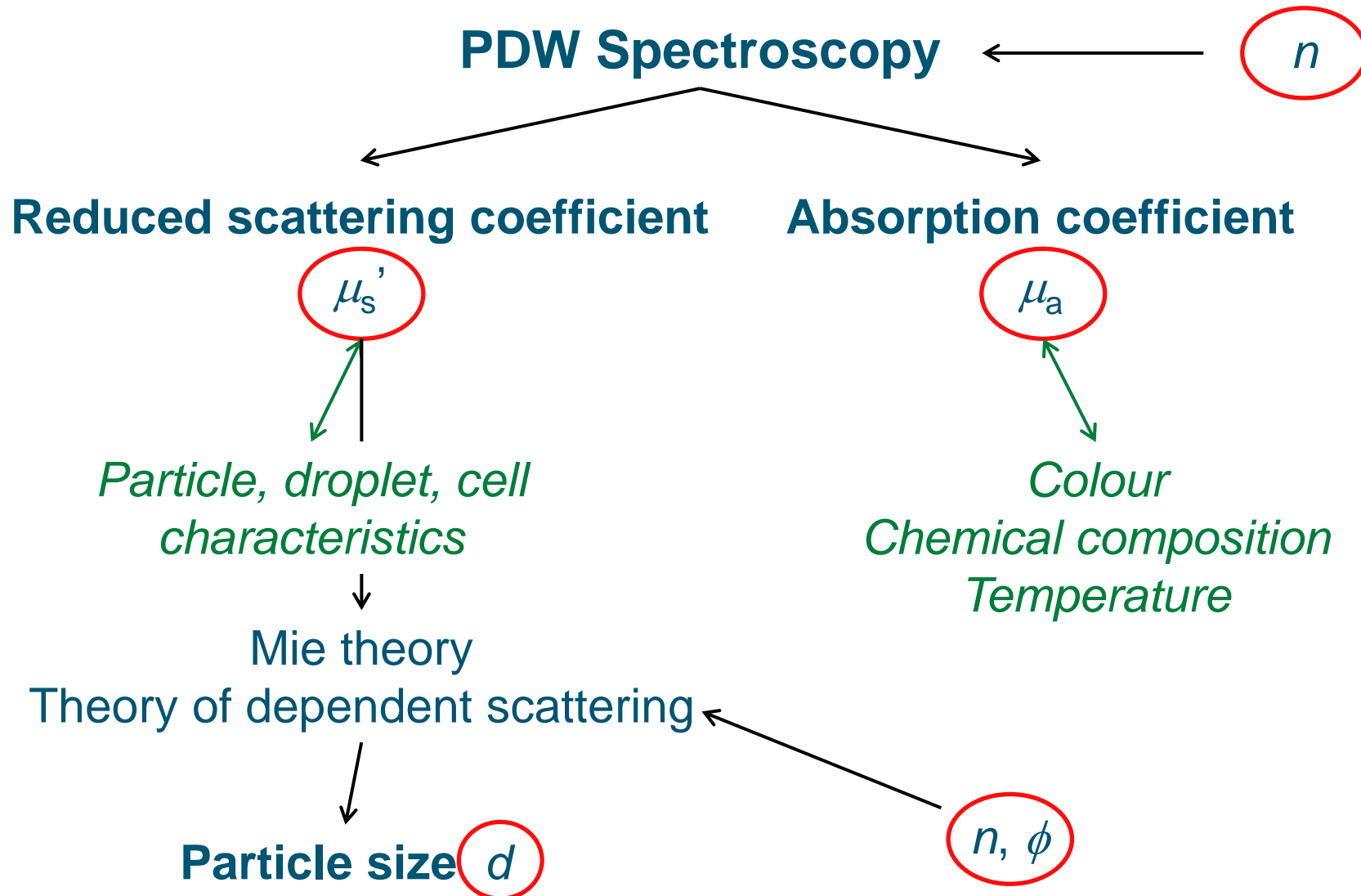
## Precision particle size:

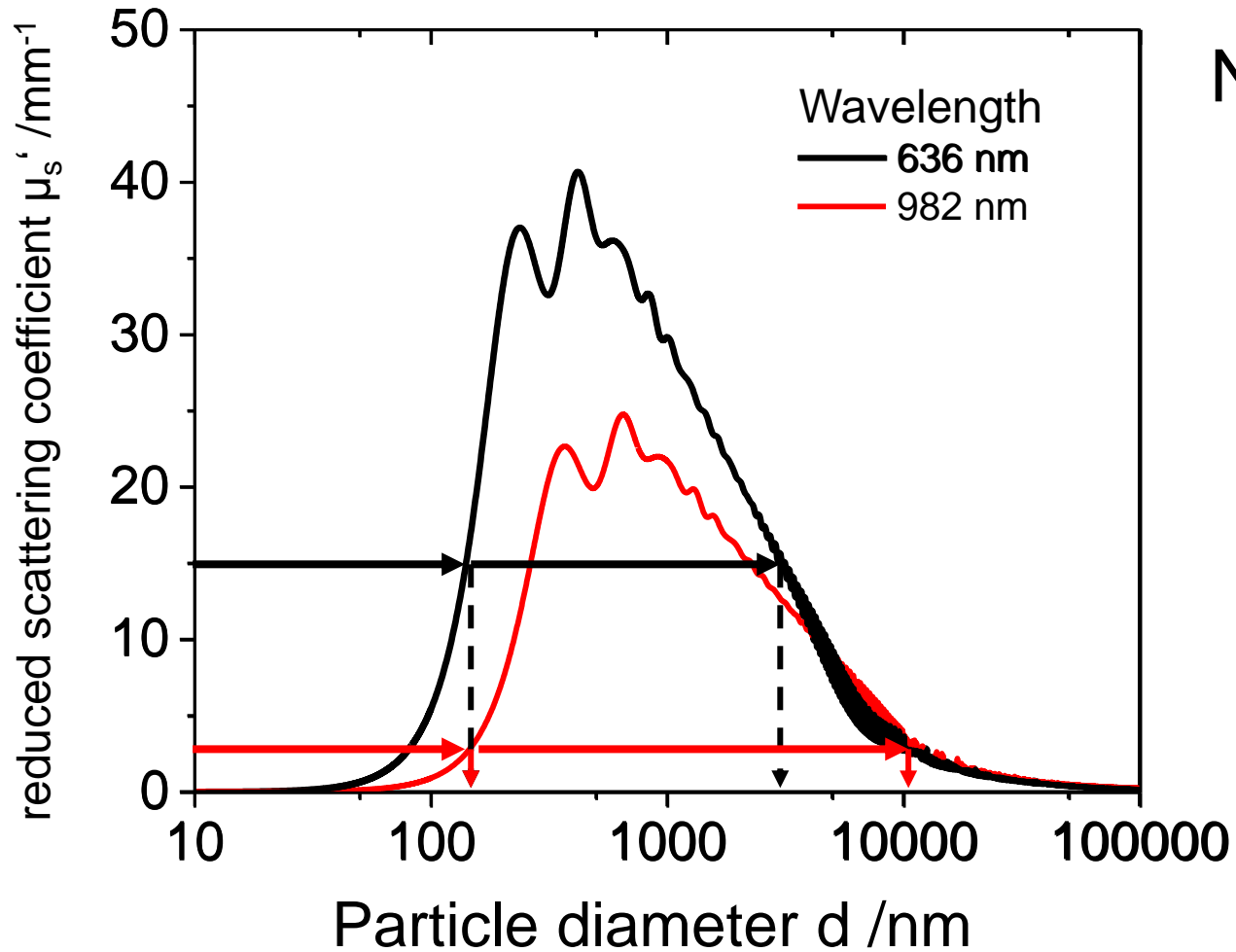
$$\Delta d : 0.15 \text{ nm (0.06 \%)}$$

equals a single C-C-bond length!

Important:

Absorption and reduced scattering coefficients not correlated!

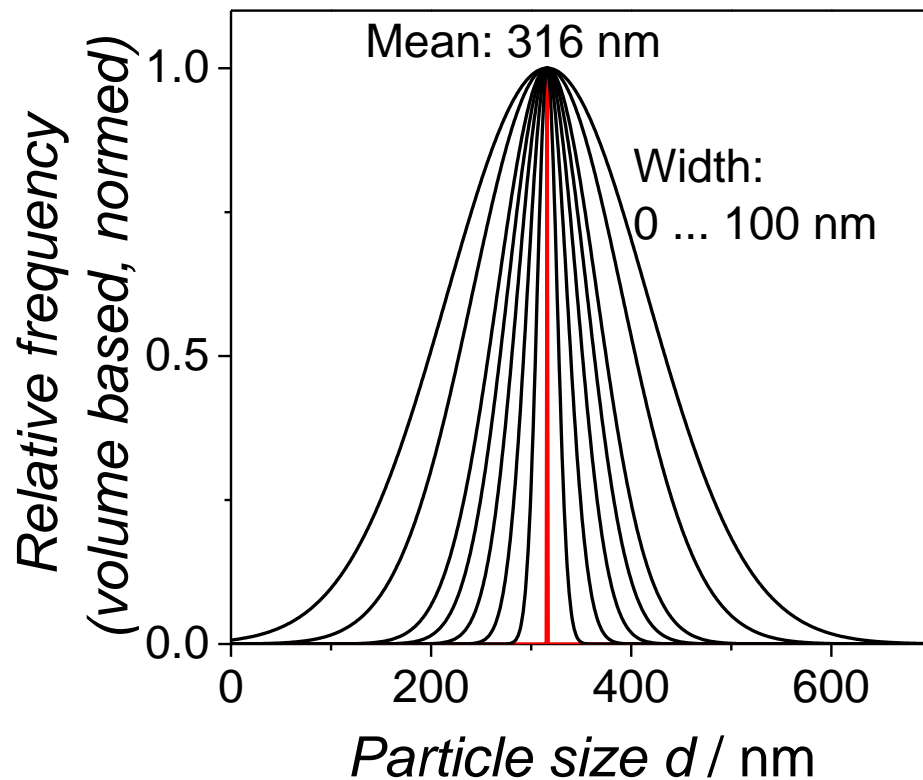




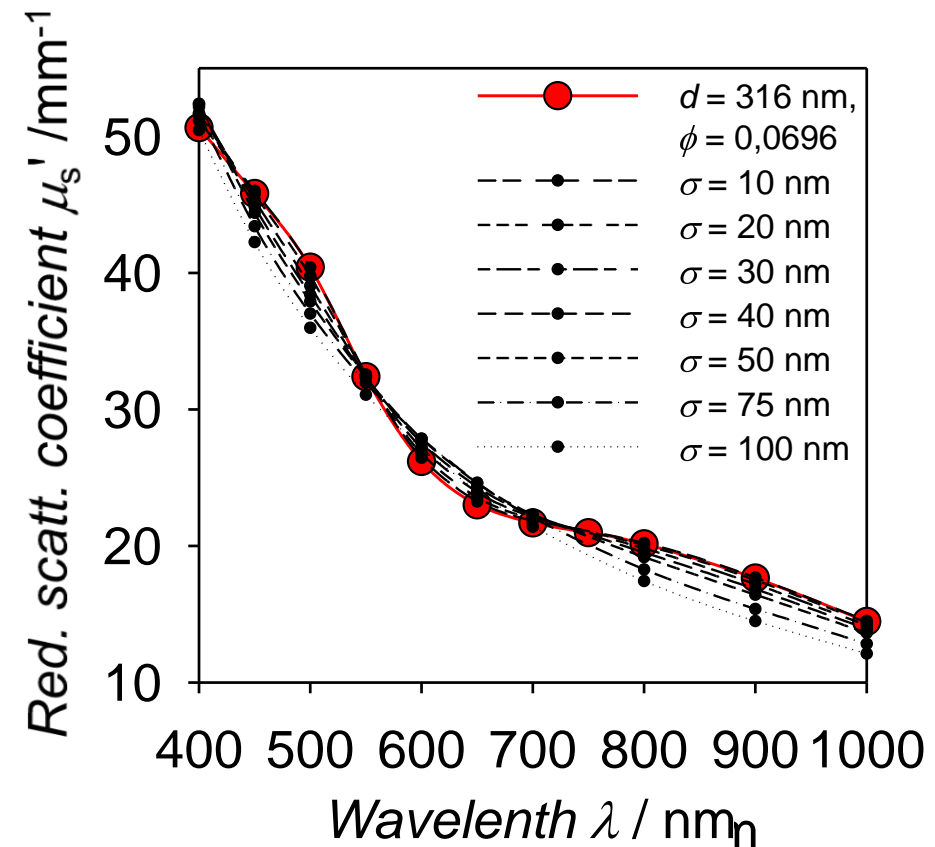
## Number of Wavelength $\lambda$

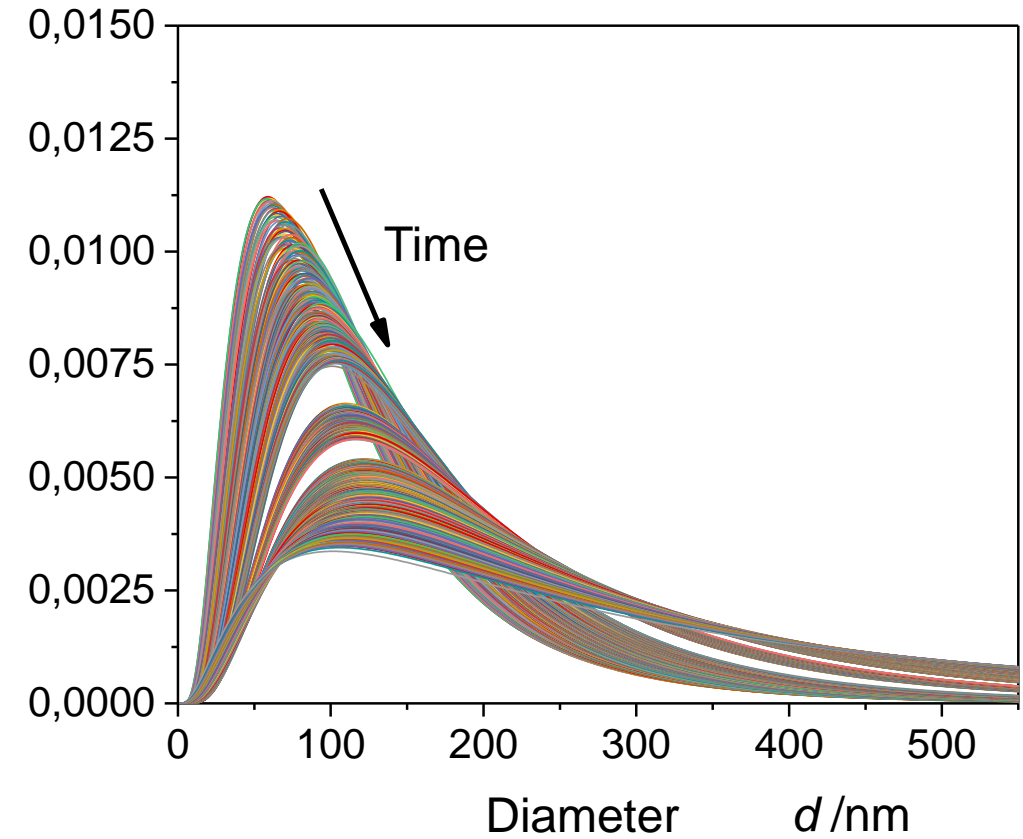
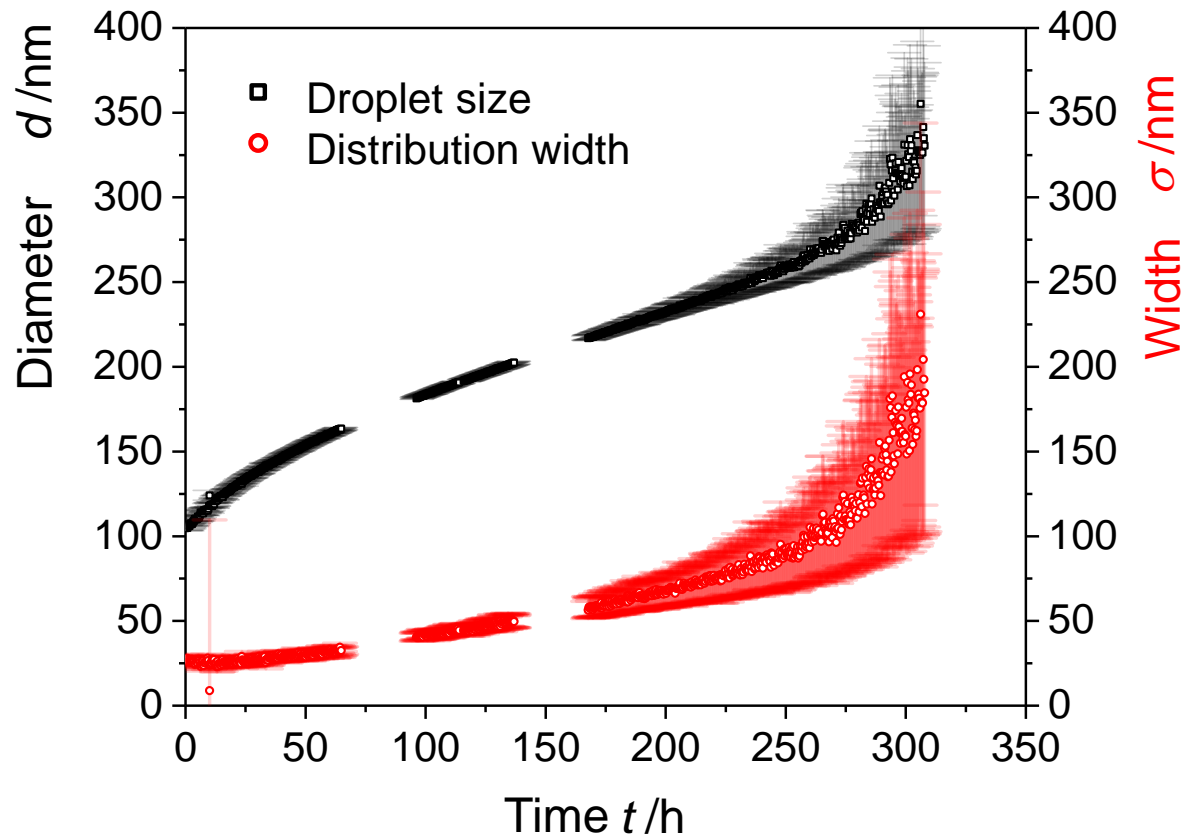
- 1 no choice
- 2 average size
- many distribution  
(500-1000 nm)

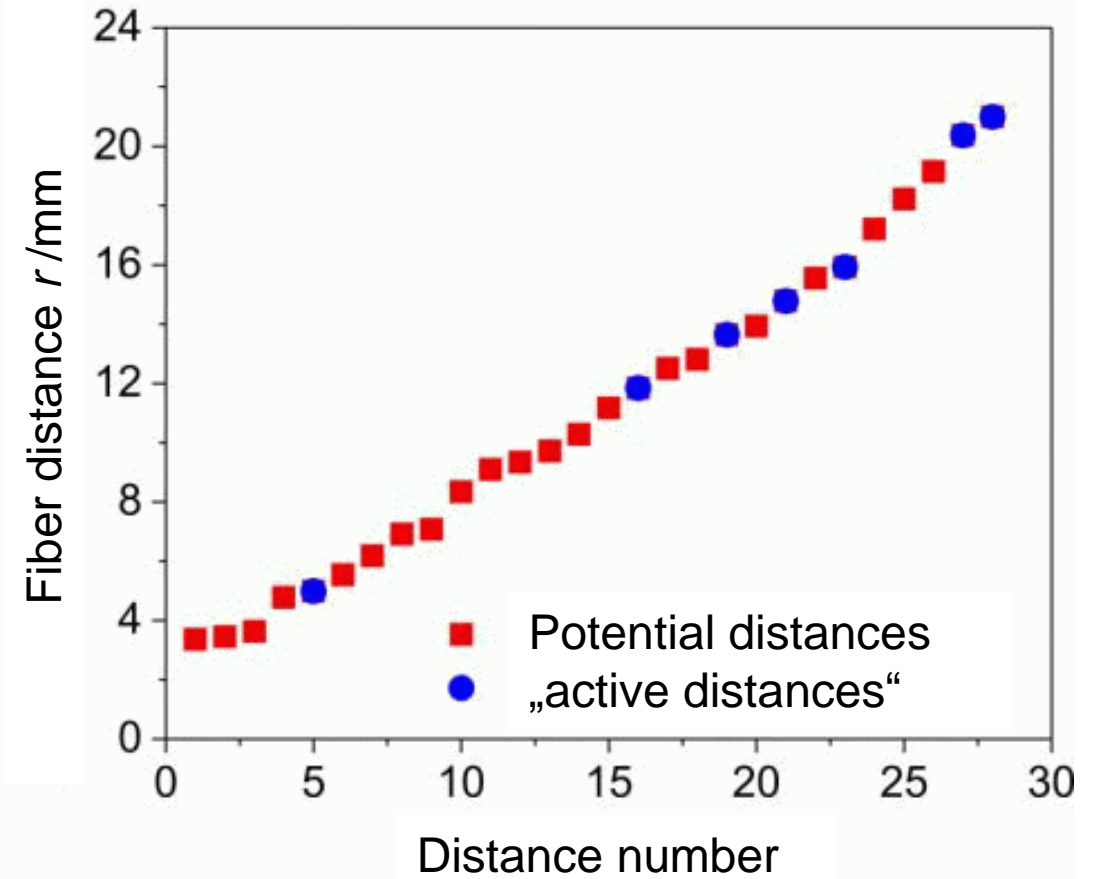
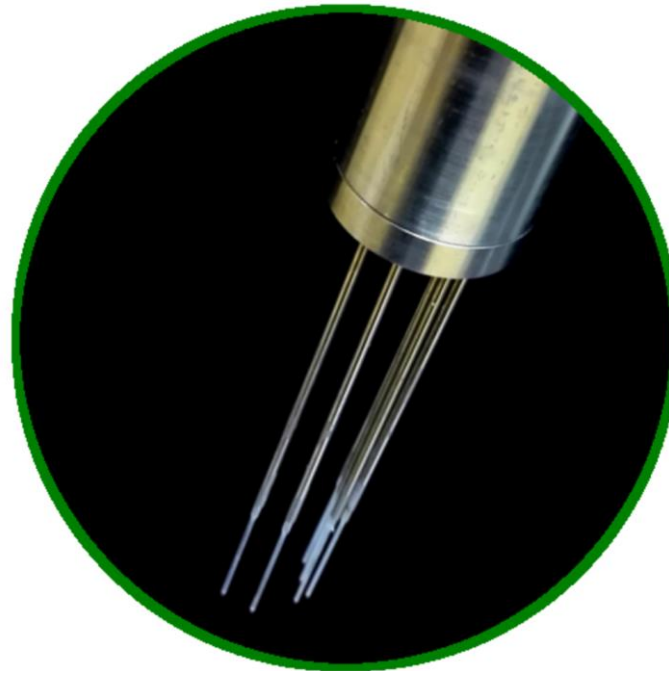
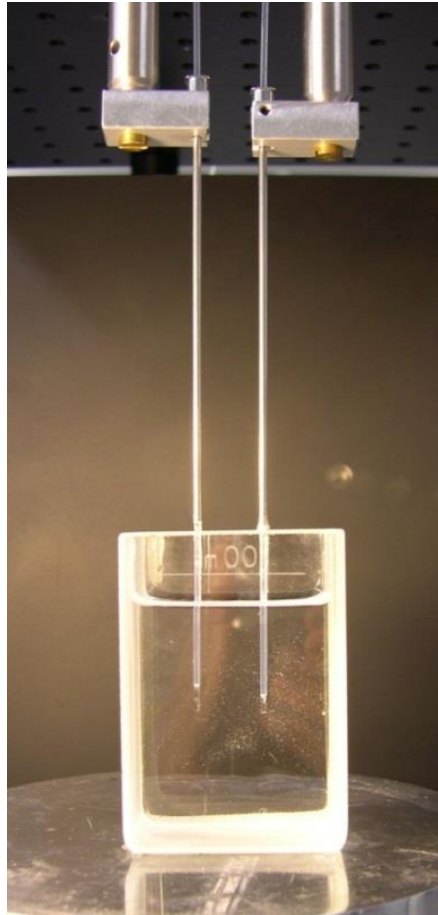
Parameterized PSDs  
(here: volume based  
Gaussian distribution)



Calculation of spectral  
dependency of  $\mu_s'$



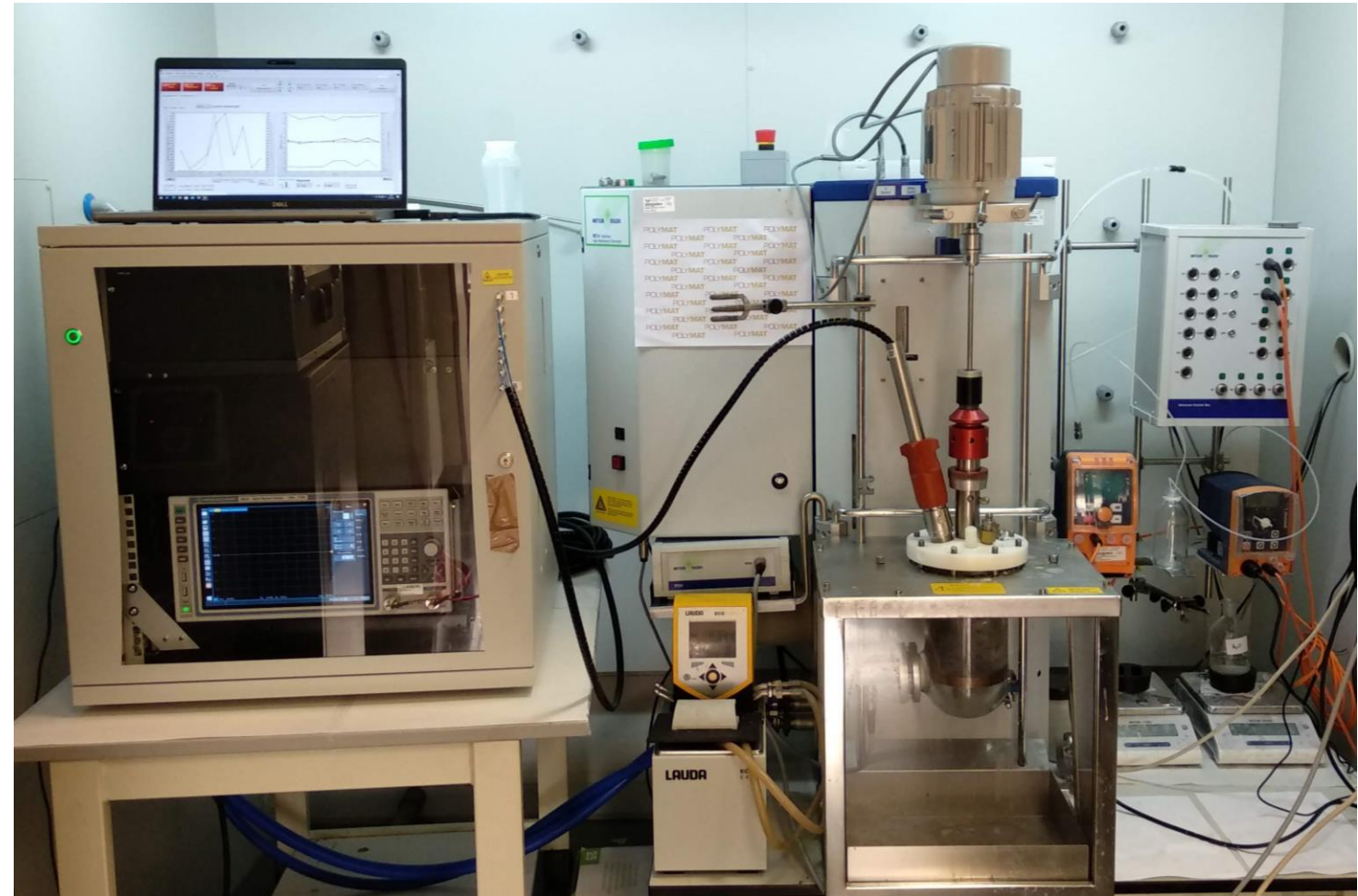




- Portable size
- High performance
- Adaptable to the process



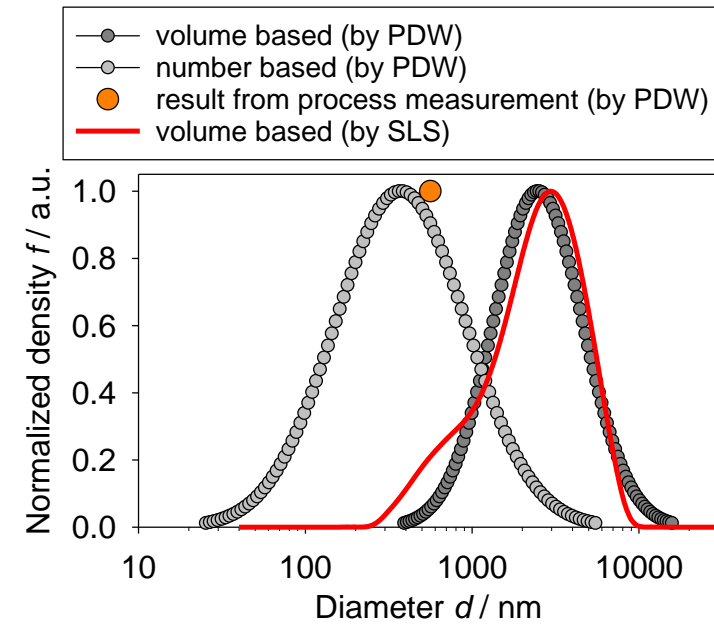
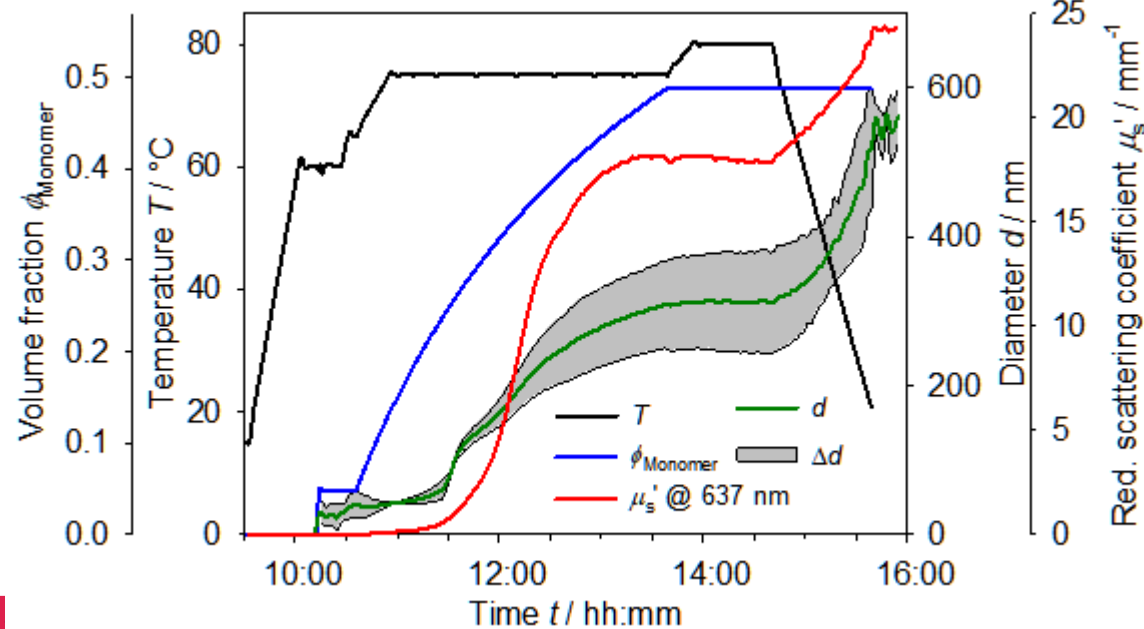
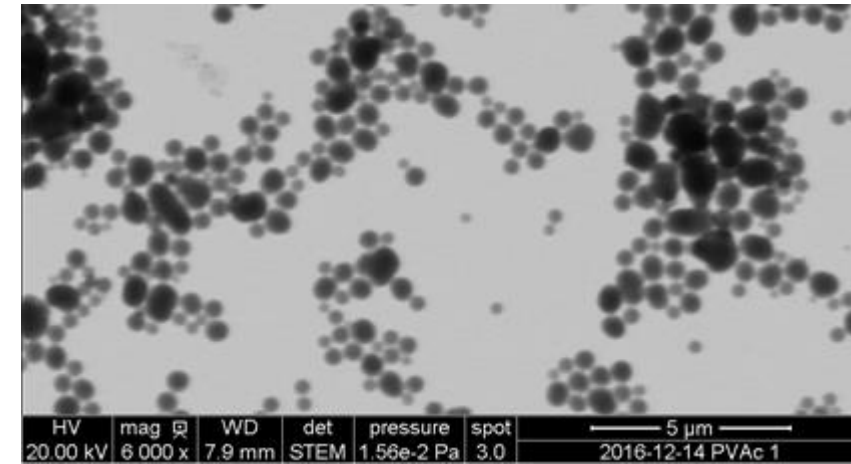
[www.pdw-analytics.de](http://www.pdw-analytics.de)  
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**POLYMAT**

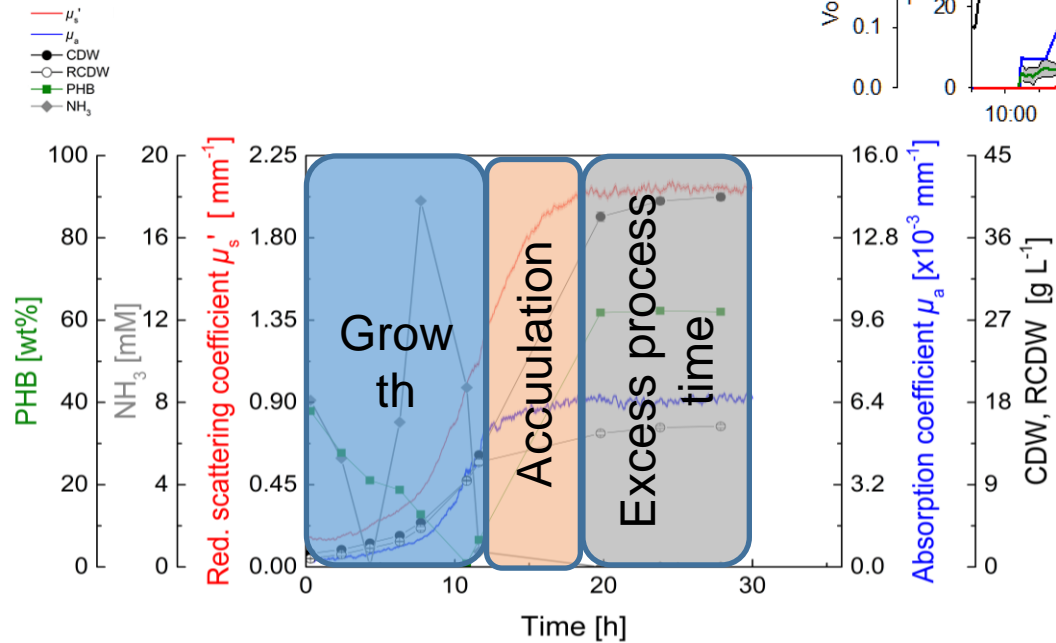
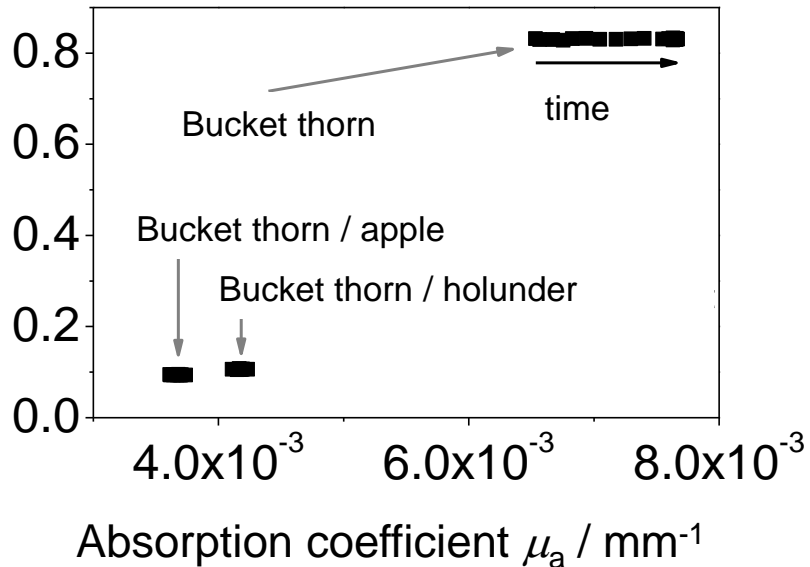
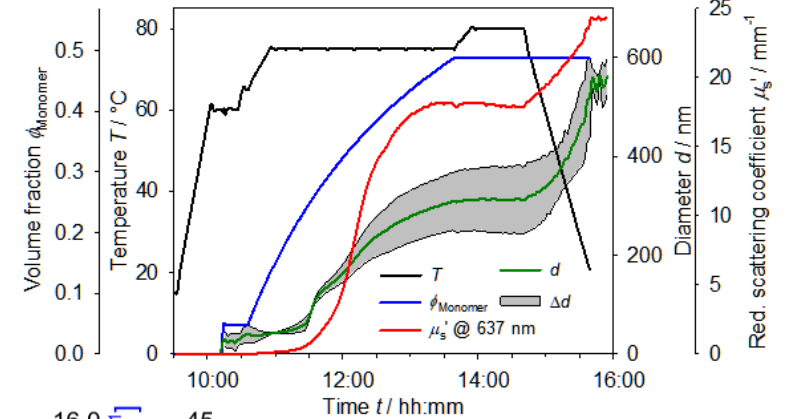
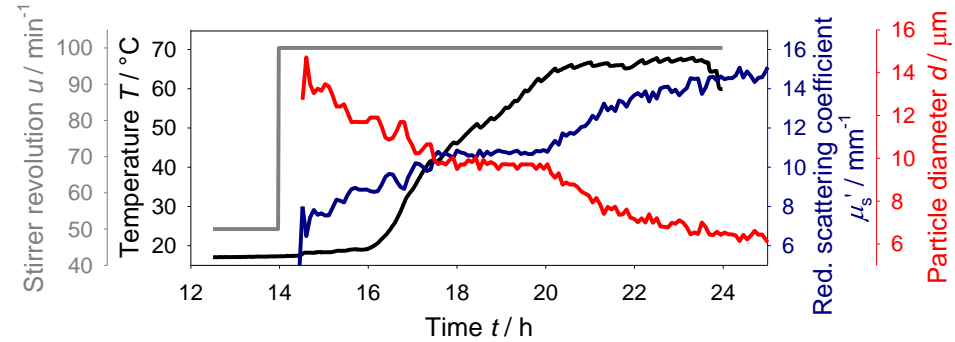
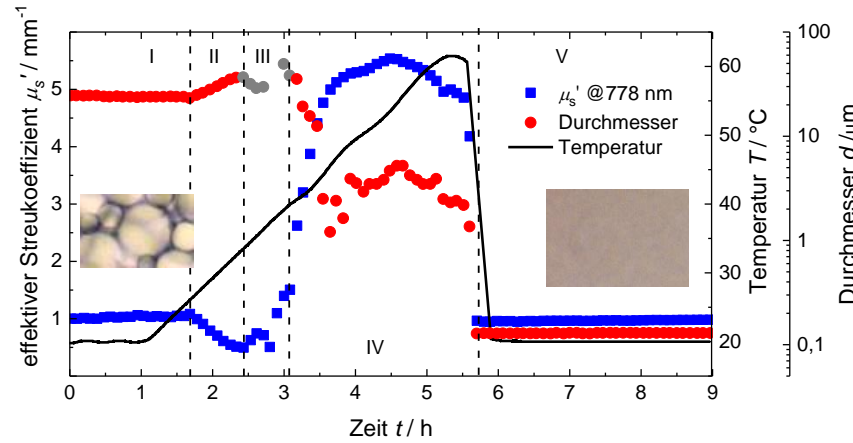


Dr. D. Zehm, Fraunhofer IAP





- Polymerization
- Emulsification
- Crystallization
- Fermentation
- Bioprocesses





GEFÖRDERT VOM



Bundesministerium  
für Bildung  
und Forschung

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AIP

Leibniz-Institut für  
Astrophysik Potsdam



# Questions?

