XXIV. Erfahrungsaustausch
Oberflächentechnologie mit Plasma- und Ionenstrahlprozessen
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Mikropartikel in einer optischen Pinzette: Messungen mit und ohne Plasma

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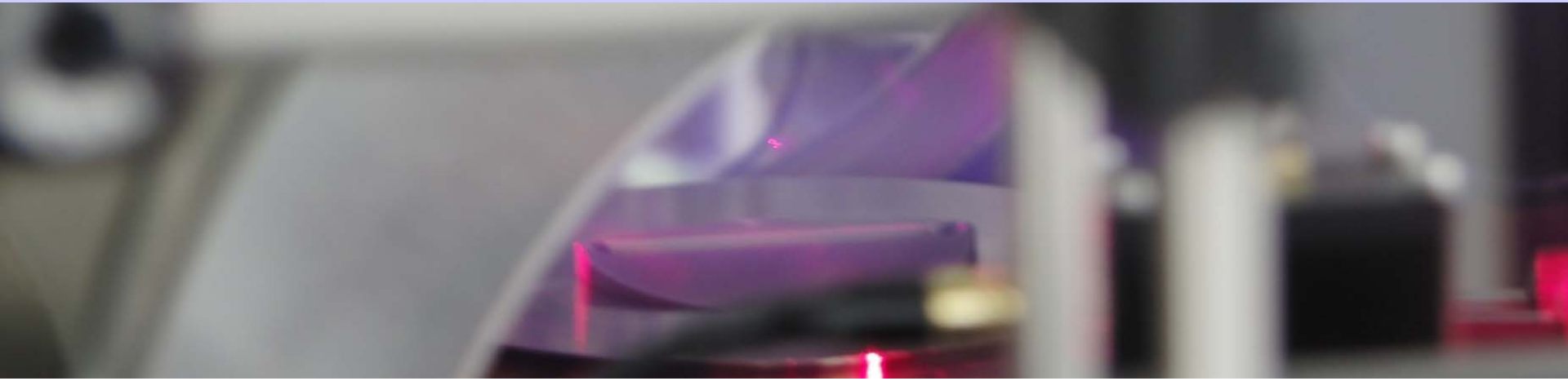
TR 24 complex plasmas

Outline



I. Laser Trapping Principle

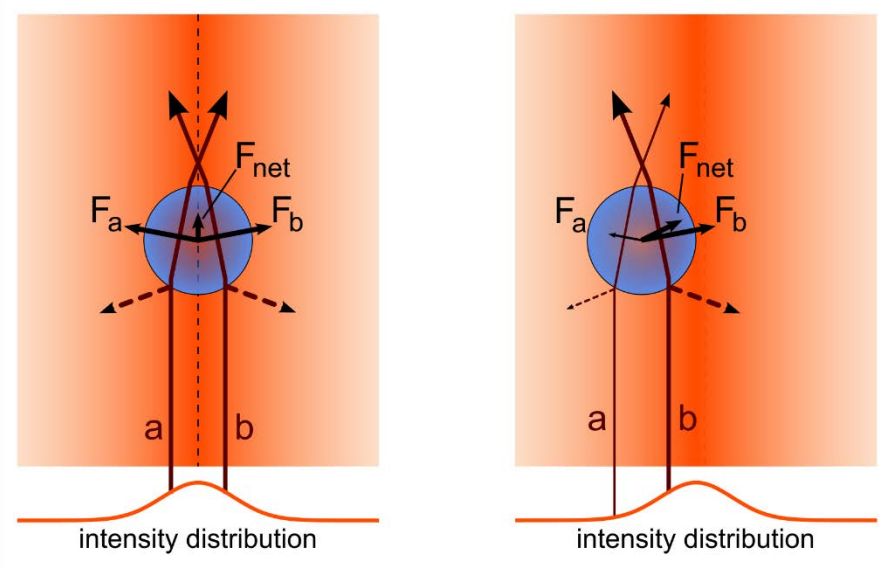
II. Experimental Setup

III. Position and Force Measurement

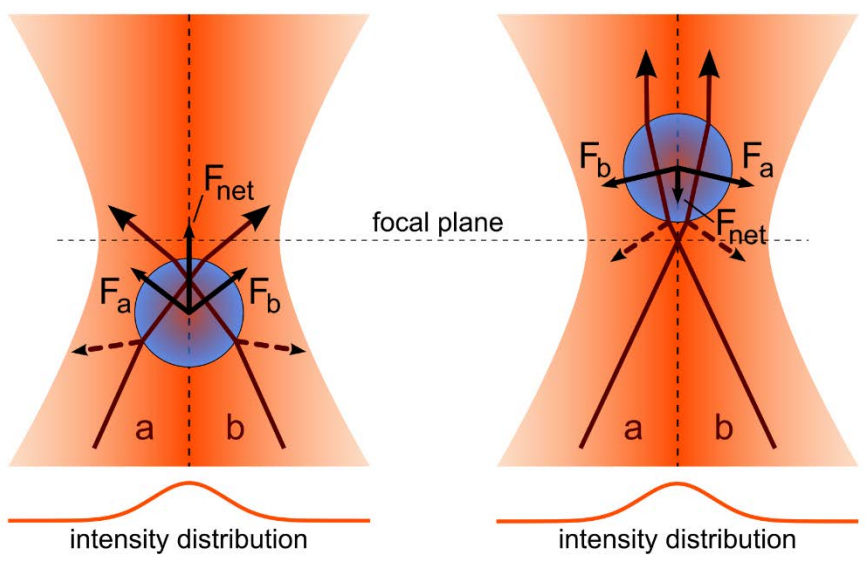
IV. Measurements

Principle of Optical Tweezers

unfocused laser beam



focused laser beam

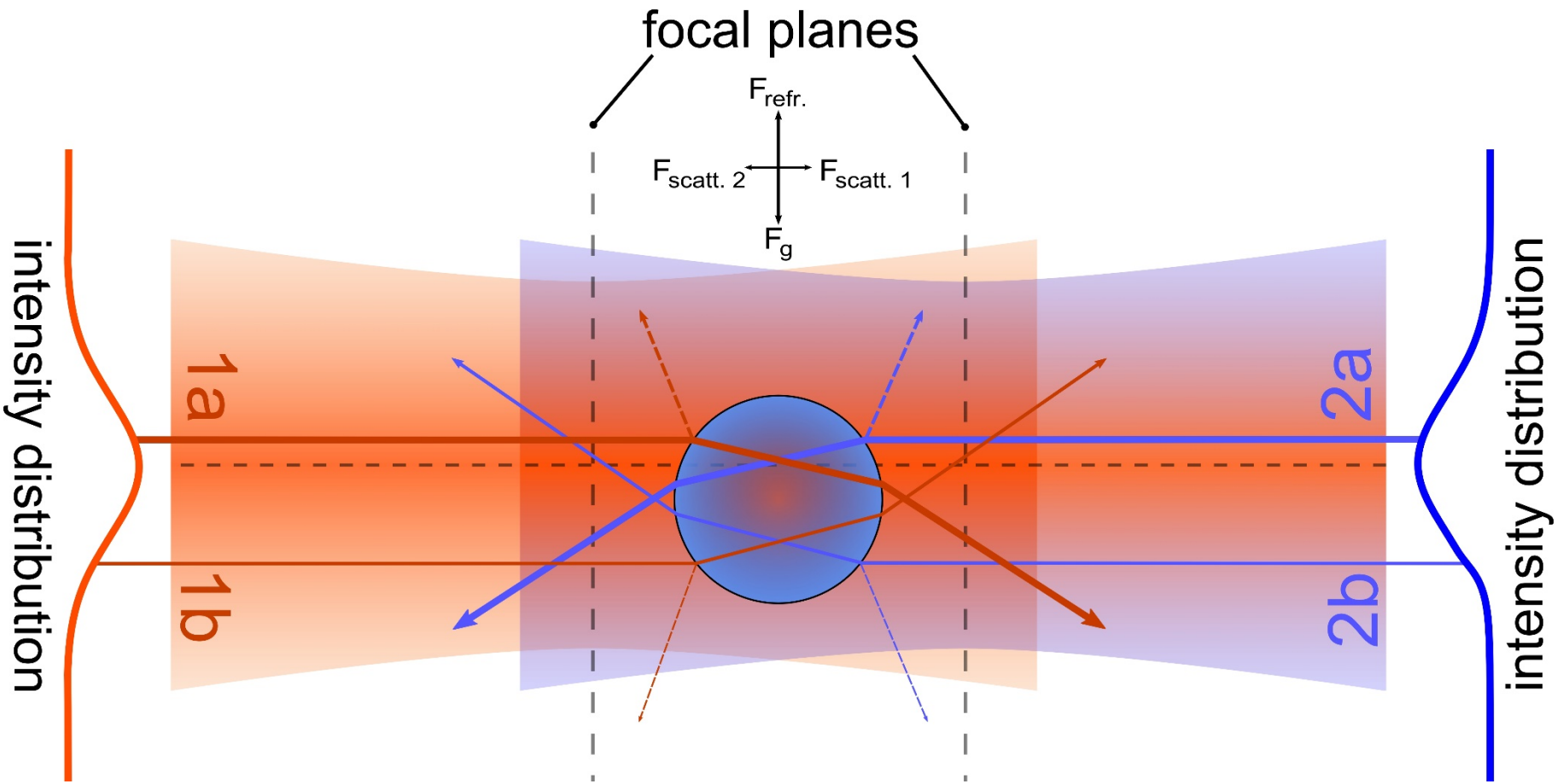


- gradient force: lateral component of F_{net}
- scattering force / radiation pressure: component along beam axis
- focused beam causes a force towards the focal point
- “single beam trap” (high NA necessary)

Review Article:
A. Ashkin, “History of Optical Trapping and Manipulation of Small-Neutral Particle, Atoms, and Molecules”, IEEE J. Sel. Top. Quant., **6**(2000)

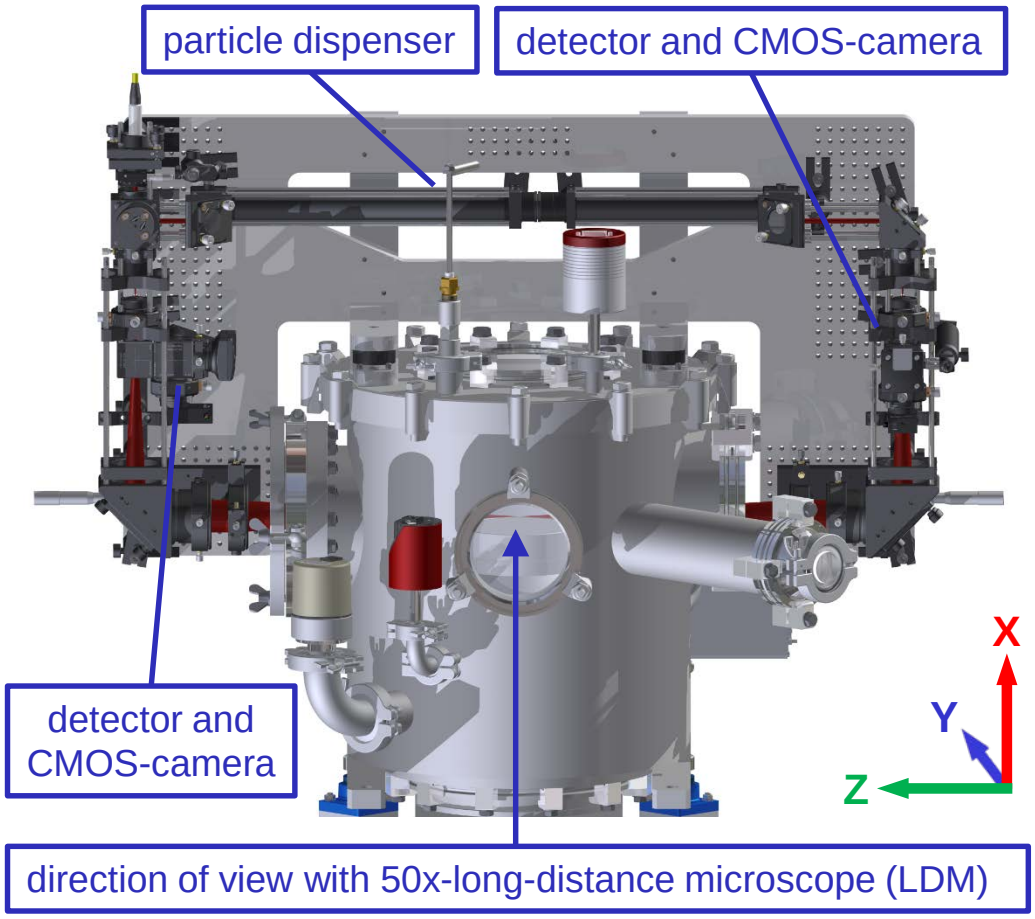
Principle of Optical Tweezers

dual counterpropagating beam trap

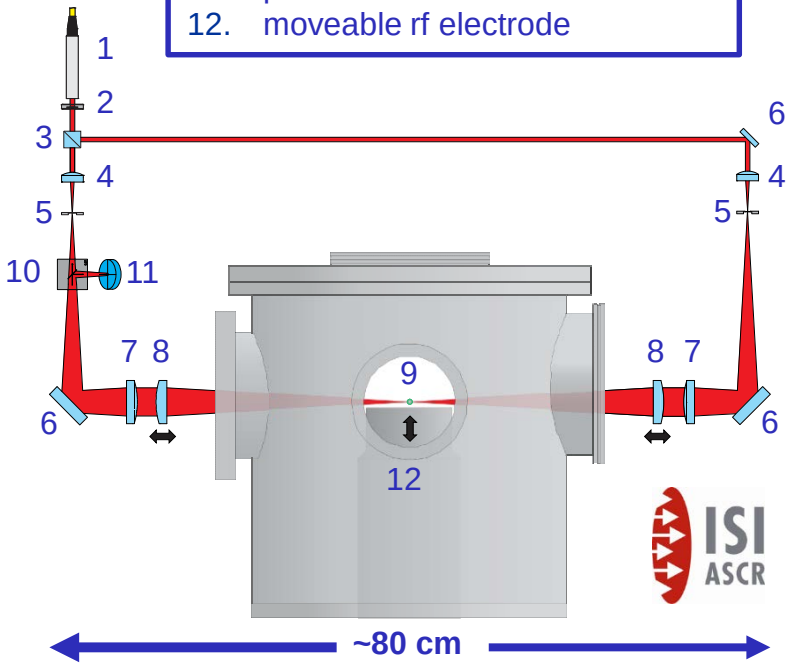


µPLASMA - microParticles in a Discharge with Laser Assisted Manipulation

- microparticle is optically trapped
- by moving the electrode up or down, the particle is moving relatively to the plasma



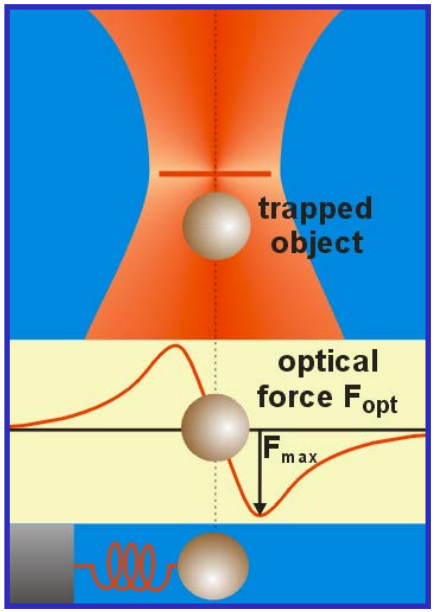
1. IR laser (λ=1070 nm)
2. $\lambda/2$ - plate
3. polarizing beamsplitter
4. beam expander
5. 10 µm pinhole
6. mirror
7. collimator
8. focusing lens (f = 30 cm)
9. beam focus, particle
10. pellicle beamsplitter
11. position detector
12. moveable rf electrode

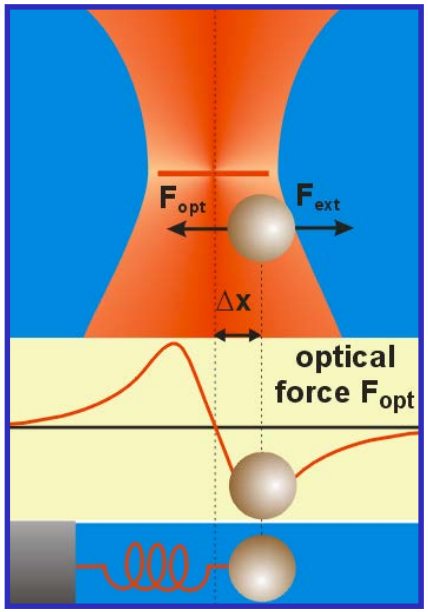


V. Schneider and H. Kersten, "On the use of optically trapped dust particles as micro-probes in process plasmas", Prob. At. Sci. Technol., **1**(2013), 164

Position and Force Measurement

Force Measurement





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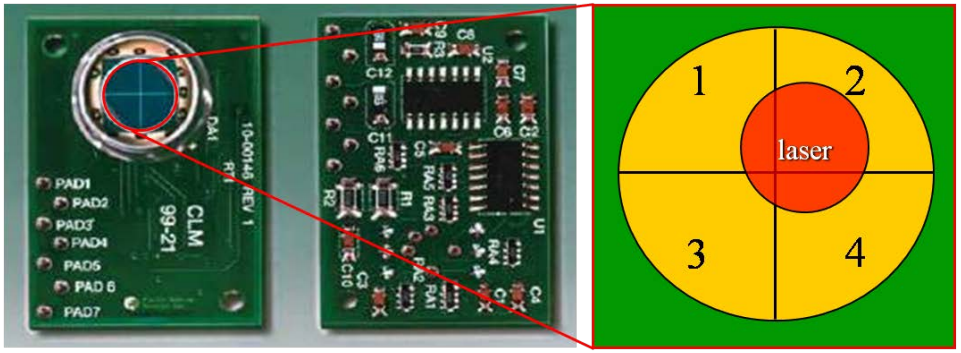
- for small deviations Δx the force can be assumed as

$$F_{opt} = -\kappa \Delta x \ ,$$

with the optical trap stiffness κ

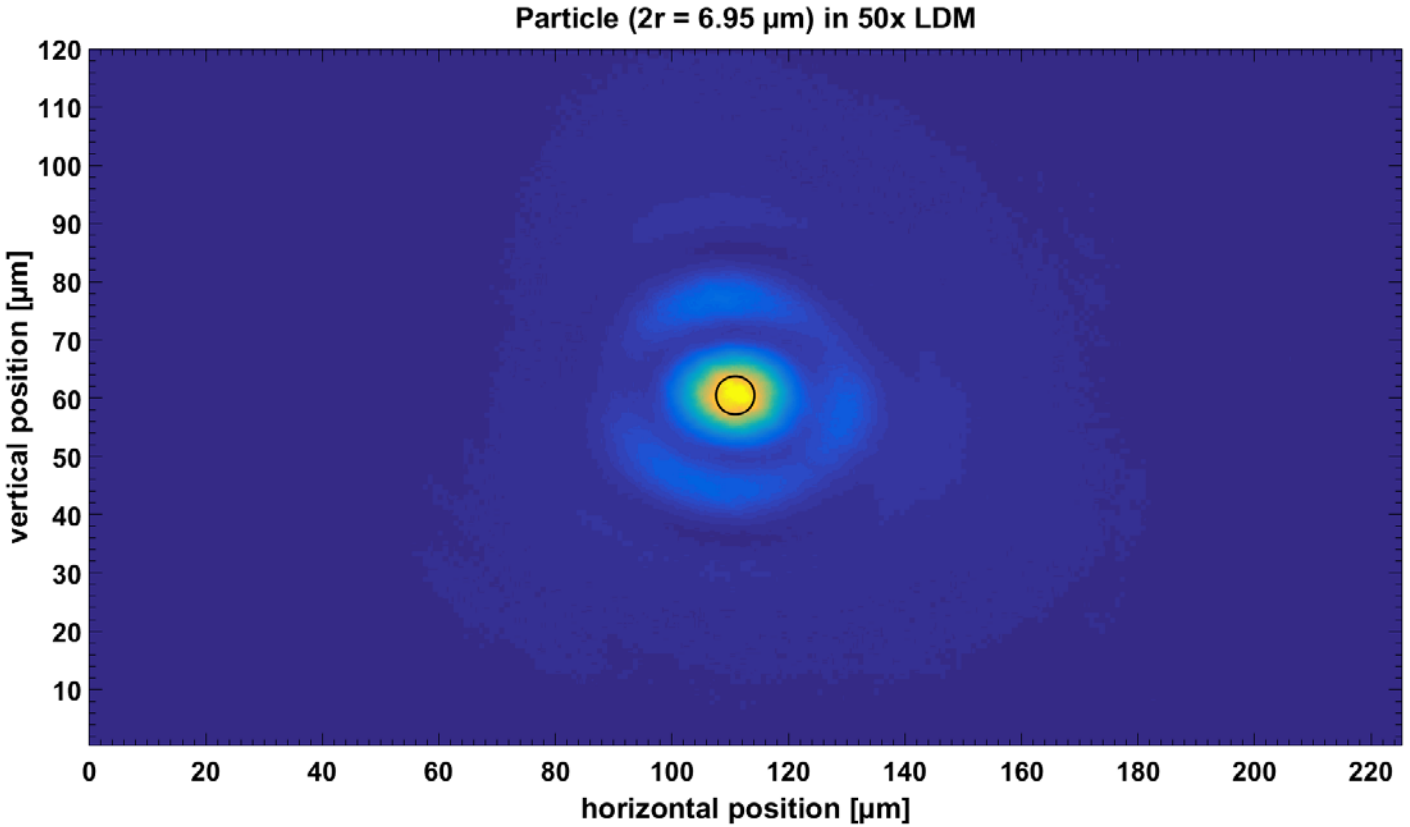


- in a ray-optic approximation, the microparticle acts as a simple lens producing an intensity pattern, which depends on the object position
- a quadrant photodiode (QPD) is positioned in the optical axis

K. Visscher and S.M. Block, "Versatile optical traps with feedback control", Meth. in Enzym. **298**(1998), 460

Position Measurement

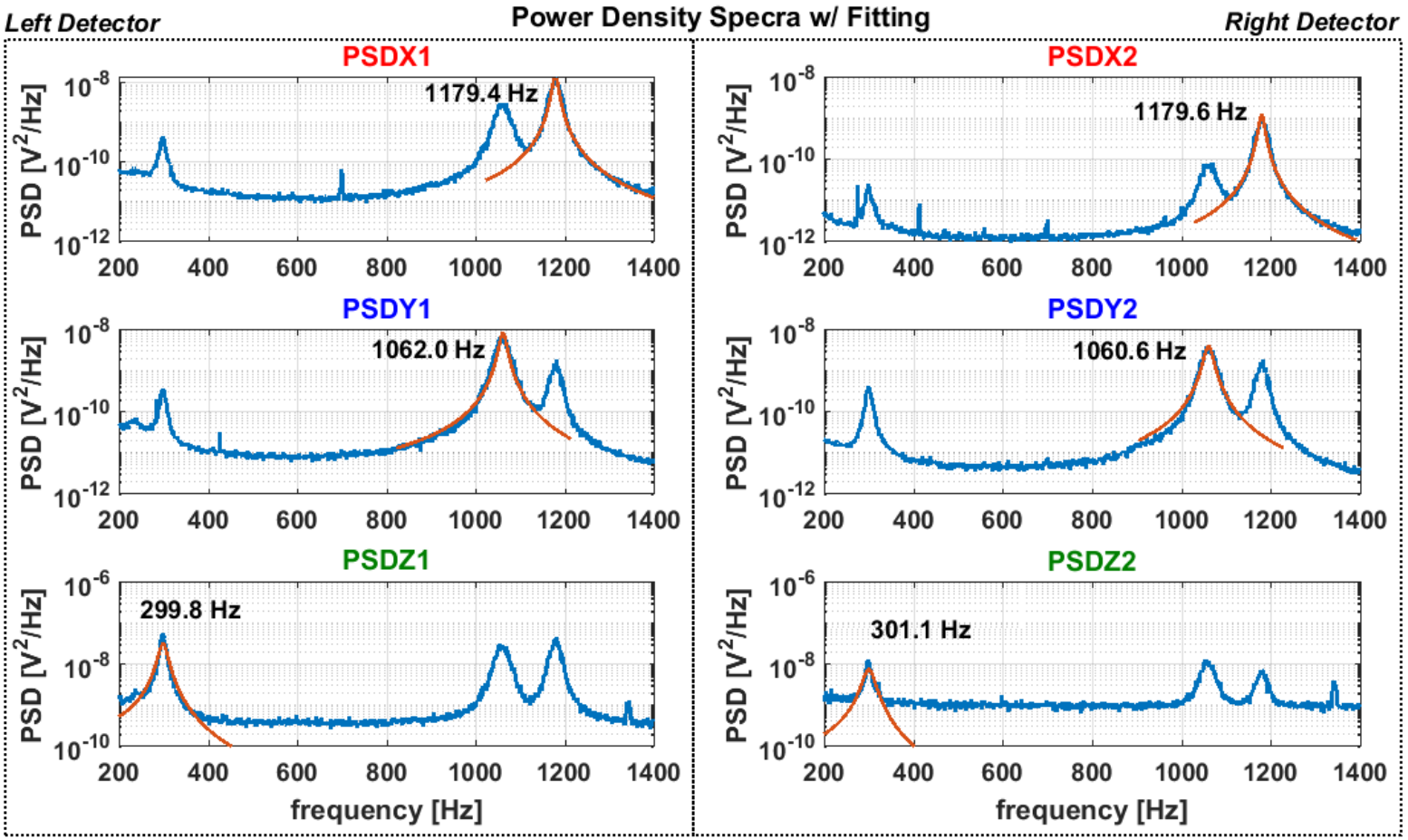
- particle observation with the 50x-Long-Distance-Microscope
- particle position with sub-pixel resolution is determined by intensity weighted centroid method (1px ≙ 0.11µm)



B.C. Carter et. al., “Tracking single particles: a user-friendly quantitative evaluation”, Phys. Biol. **2**(2005), 60

Stiffness-Calibration Method

$$\ddot{x} + \gamma_0 \dot{x} + {\omega_0}^2 x = \frac{F_{therm}(t)}{m}\xi(t) \quad \Rightarrow \quad S(\omega) = \frac{2k_B T}{m}\frac{\gamma_0}{({\omega_0}^2 - \omega^2)^2 + \omega^2 {\gamma_0}^2}, \qquad \omega_0 = \sqrt{\kappa/m}$$

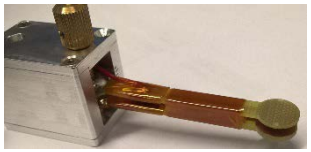


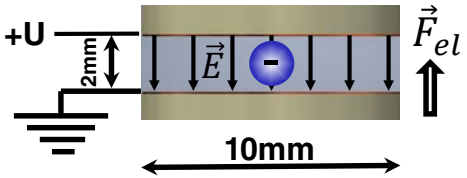
T. Li and M. G. Raizen, "Brownian motion at short time scales", Ann. Phys. (Berlin) **525**(2013), 281–295

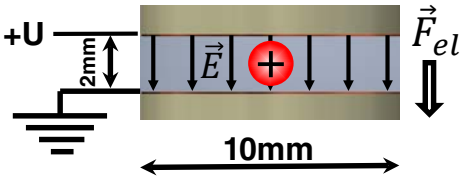
J. Gieseler et al., "Subkelvin Parametric Feedback Cooling of a Laser-Trapped Nanoparticle", Phys. Rev. Lett. **109**(2012), 103603

Measurements

UV Light Charging / Decharging





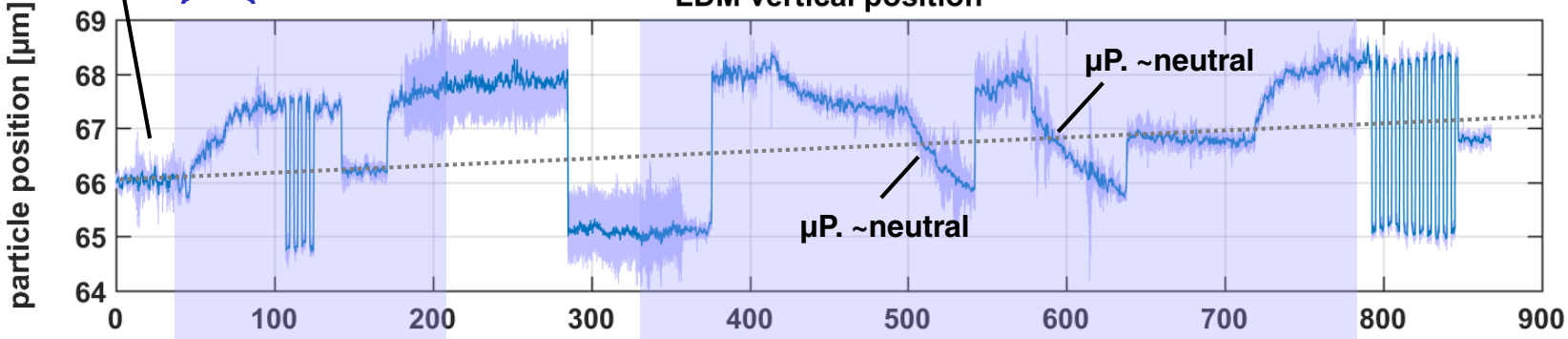


µParticle negative µParticle positive µParticle negative

µP. ~neutral

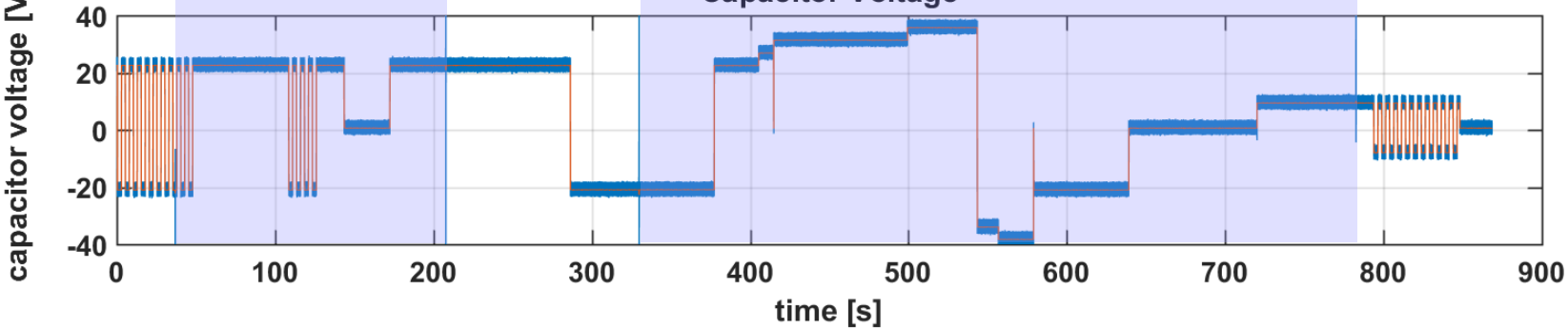
negative charging positive charging negative charging

LDM vertical position

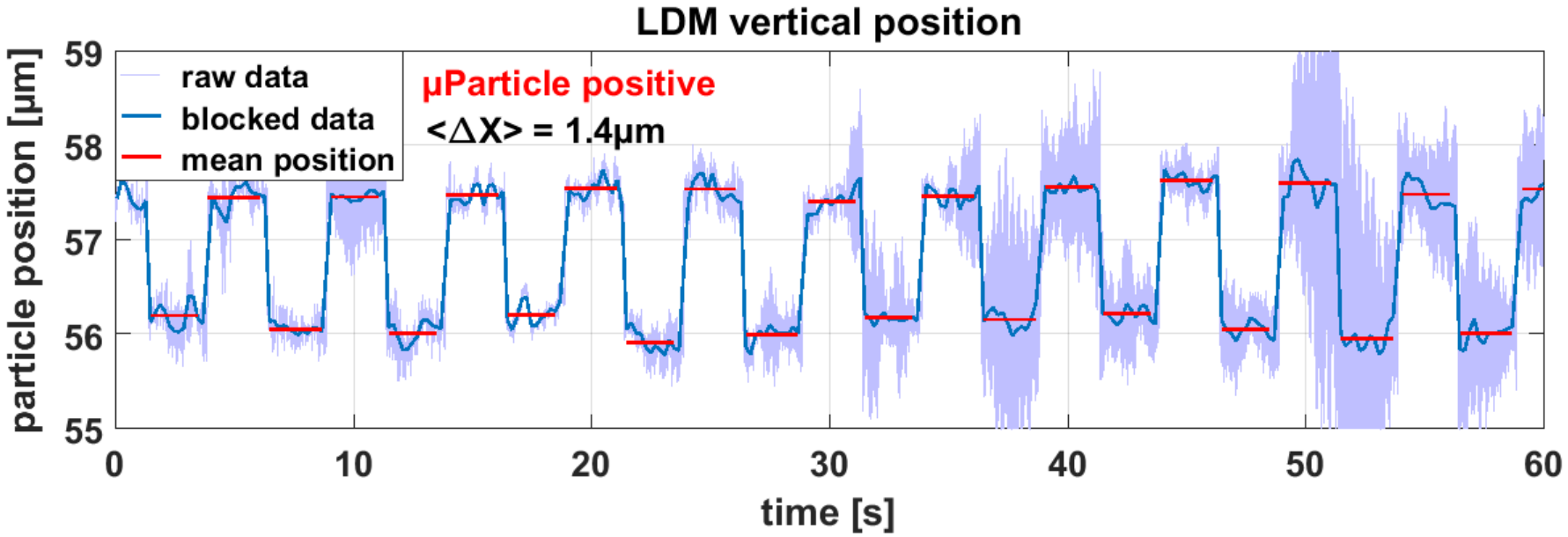


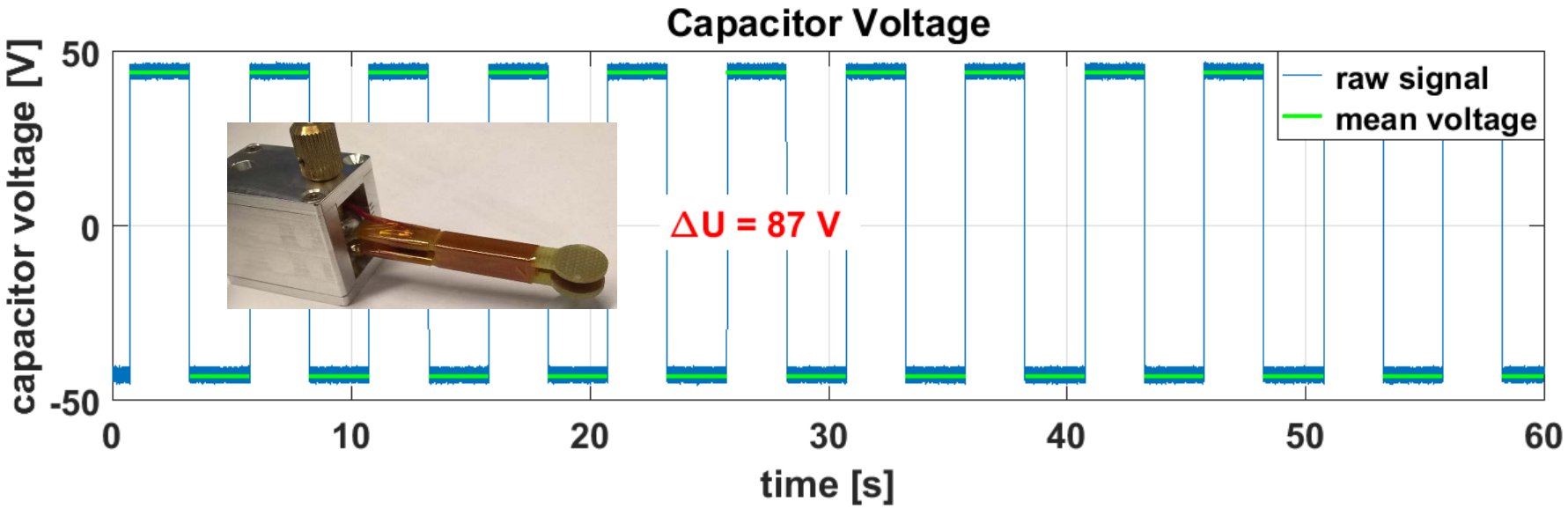
UV Light on UV Light on

Capacitor Voltage



UV Light Charge Estimation





UV Light Charge Estimation

with $\omega_0 = 2\pi \cdot 1179\ \mathrm{Hz}$ and $\kappa = \omega_0^2 \cdot m = 17.8\ \mathrm{pN/\mu m}$

with $\Delta x \approx 1.4\ \mu\mathrm{m}$

$\Rightarrow F_{el} \approx 24.9\ \mathrm{pN}$

with $U = 86.98\ \mathrm{V}$ and $d = 0.002\ \mathrm{m}$

$\Rightarrow E = U/d = 43492\ \mathrm{V/m}$

$\Rightarrow Q = F_{el}/E = 5.91\ e^{-16}\ \mathrm{C} \approx +3680\ e$

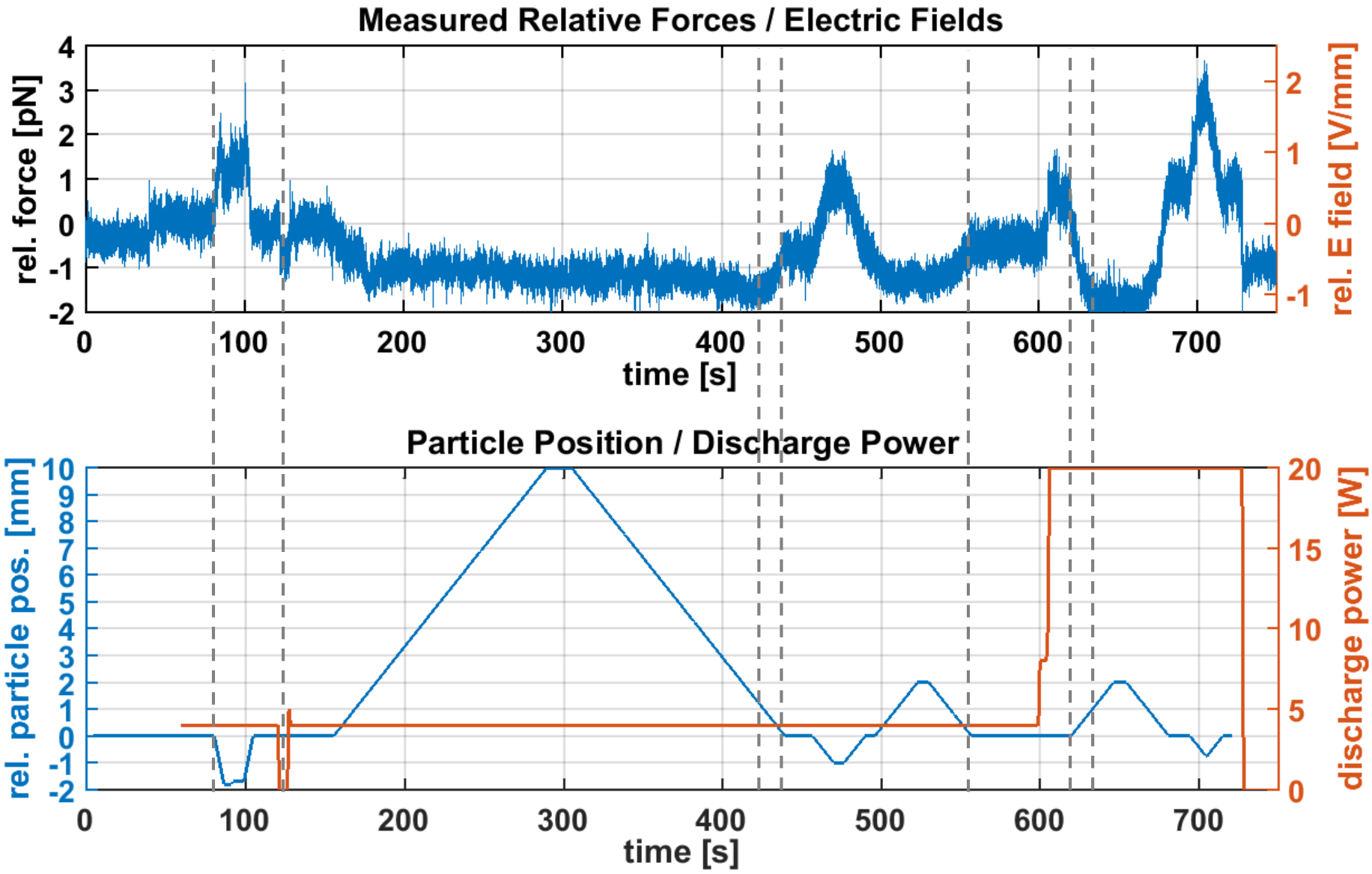
charging with a filament leads to a charge of

$Q \approx -14000\ e\ \ldots\ -18000\ e$

residual charges after the plasma are always positive

$Q_{res} \approx +500\ e\ \ldots\ +1000\ e$

Plasma Sheath



Thank you!