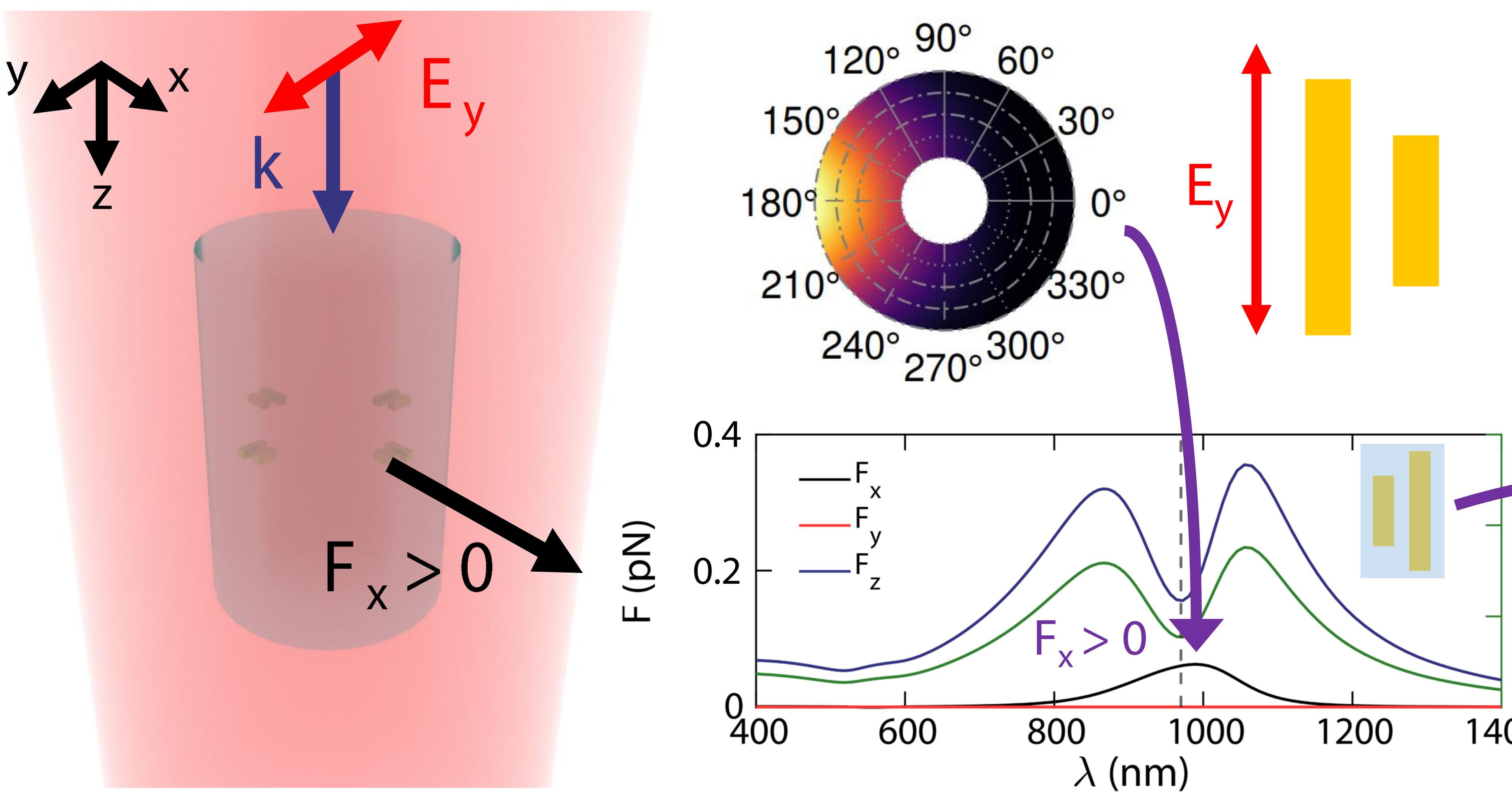
Innovative approaches to 3D motion control in plasmonic nanomotors with optical pulling forces

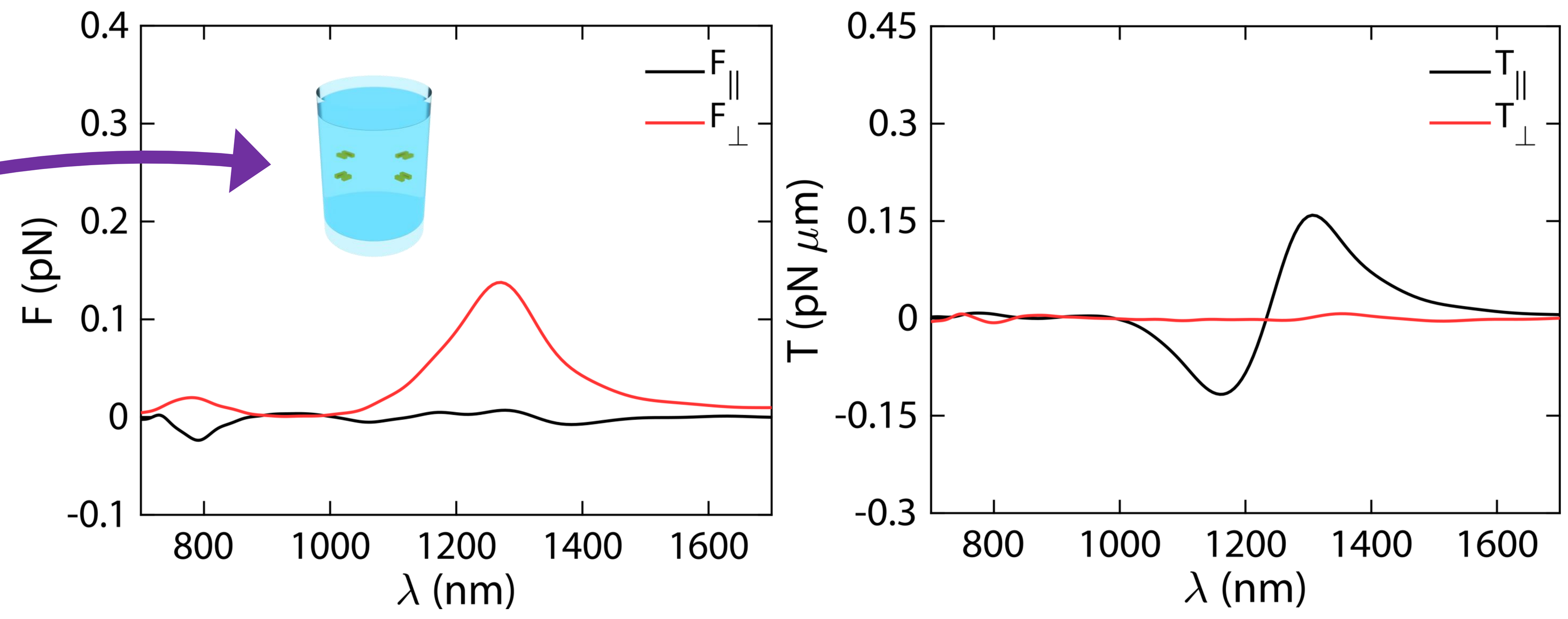
G. Serrera[1,*], Y. Y. Tanaka[2] & P. Albella[1]
[1] Group of Optics, Department of Applied Physics, University of Cantabria.
[2] Research Institute for Electronic Science, Hokkaido University.
Email: * guillermo.serrera@unican.es

Abstract: Recent advancements in nanophotonics have led to the use of scattering forces from plasmonic nanoantennas or dielectric metasurfaces to enable transverse two-dimensional motion [1-3]. However, achieving control over longitudinal motion remains a significant challenge. Here, we introduce a novel nanomotor design that facilitates both transversal and longitudinal motion control. Our system relies on optical pulling forces by an azimuthally polarized Bessel beam [4] on a glass cylinder, while asymmetric plasmonic dimers drive lateral motion under plane wave illumination.

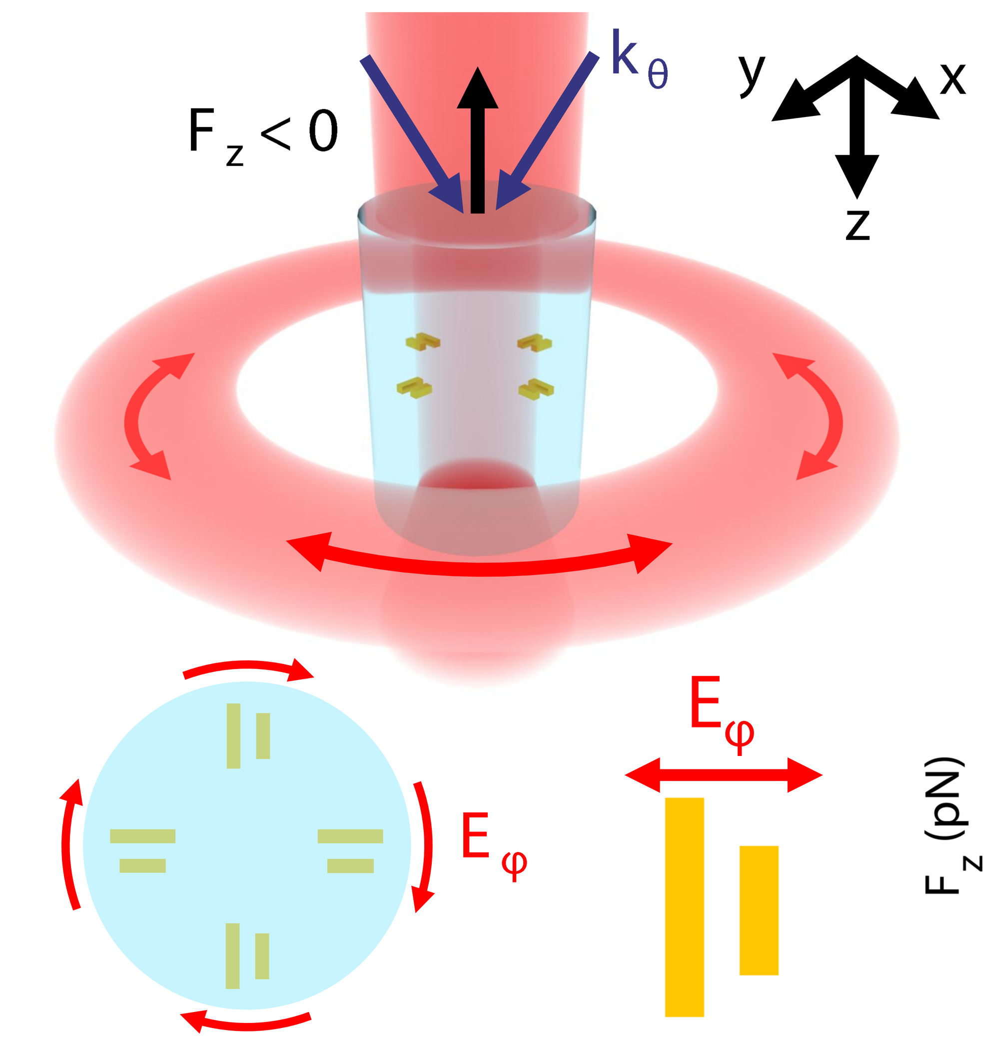
Lateral movement powered by asymmetric scattering



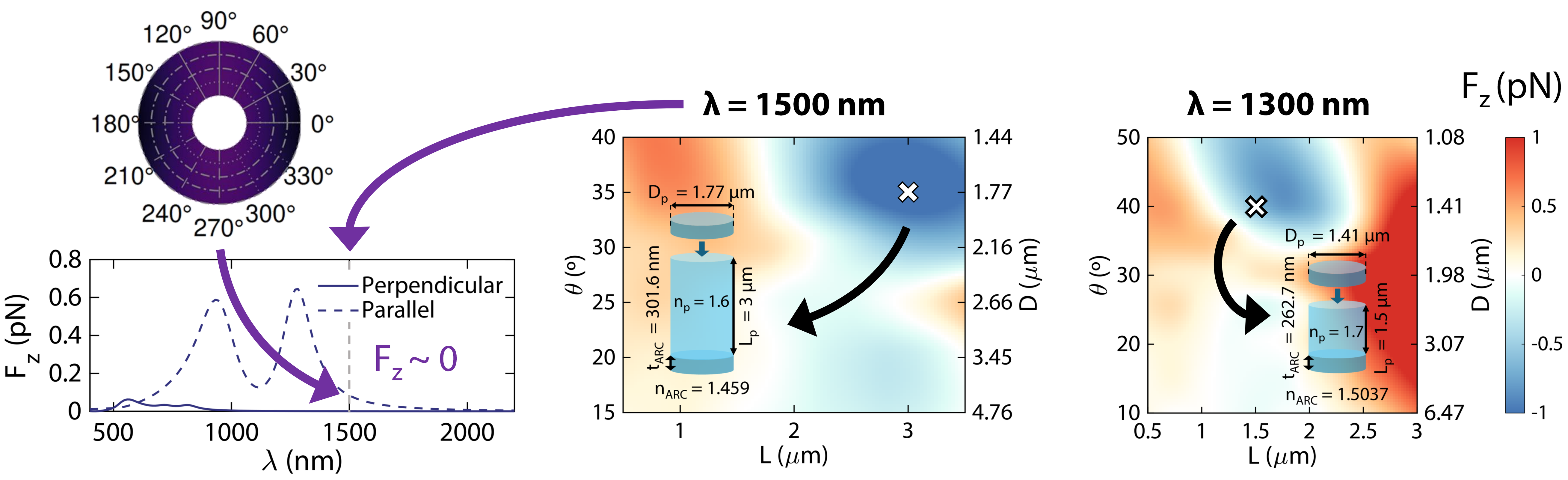
- Linearly polarization (along rod direction).
- Asymmetric scattering drives lateral force.
- Lateral forces up to 0.15 pN (0.4 mW/µm² illumination).
- Torques can be compensated using other wavelengths.



Optical pulling by an azimuthally polarized Bessel beam

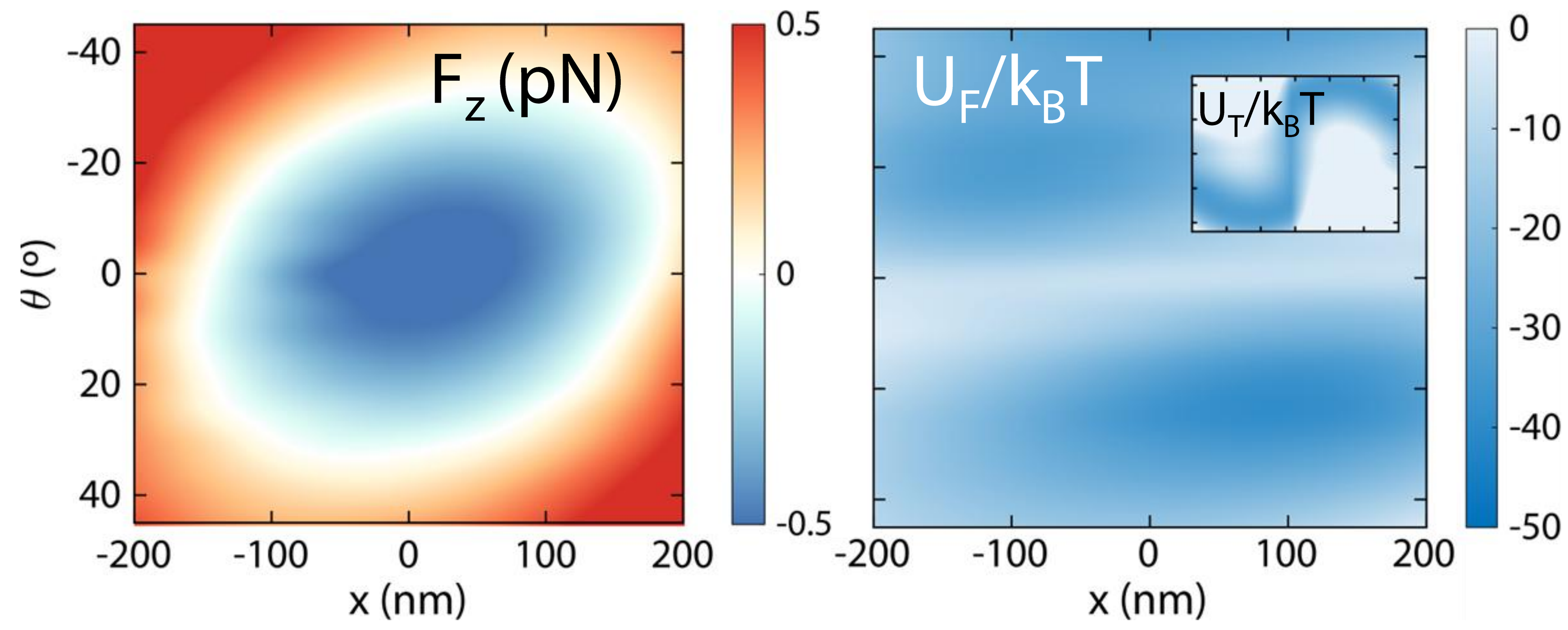


- Cylinder dimensions given by refractive index combination and incident wavelength.
- Different aspect ratios can be achieved.
- Dimers arranged perpendicular to polarization to prevent pushing forces.

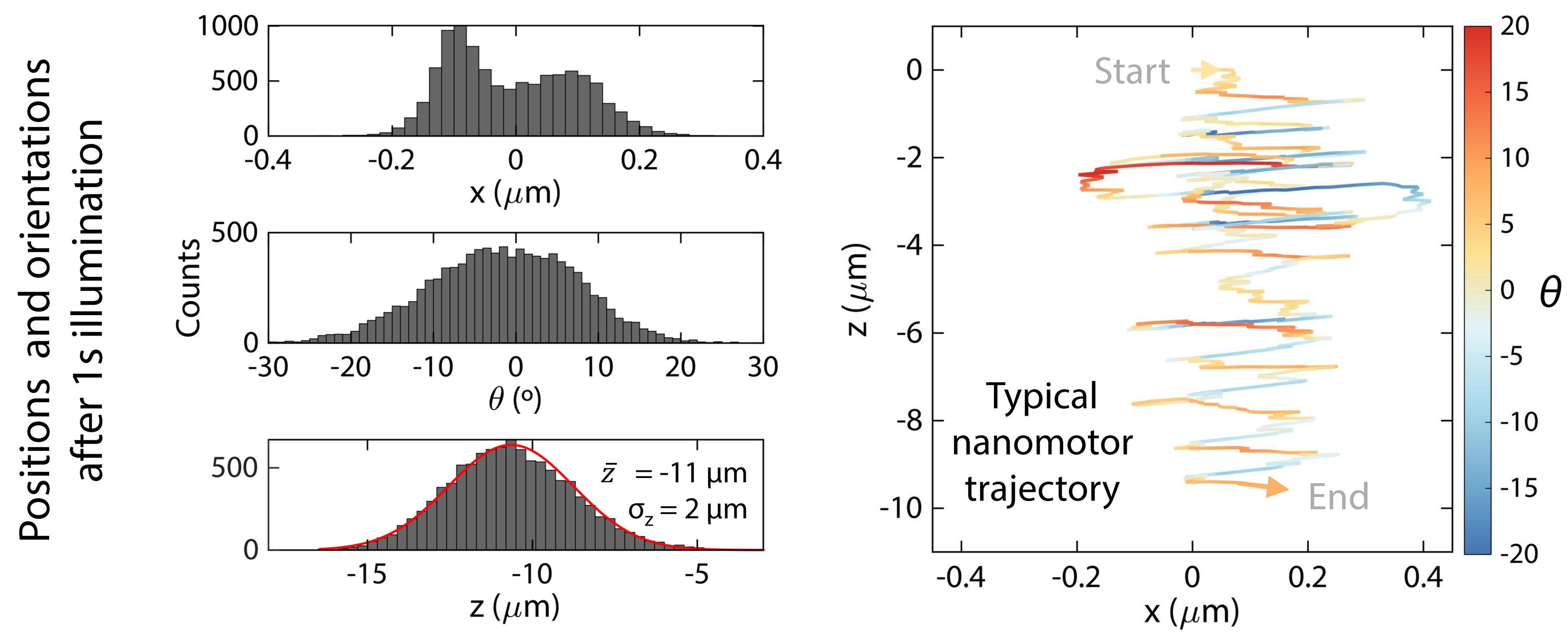


Optical pulling stability and diffusion simulations

- Optical pulling is stable to displacements and rotations.
- Non-trivial dynamics: mismatch between force and torque potential wells → Need for diffusion simulations.



- Cross-talk between torques and transverse forces make the nanomotor travel mainly through the optical pulling region → Stable pulling for long times.



References

[1] Y. Y. Tanaka et al., *Sci. Adv.*, **6**, 45 (2020).
[2] X. Wu et al., *Nat. Nanotech.* **17,** 5 (2022).
[3] D. Ardrén et al., *Nat. Nanotech.* **16,** 9 (2021).
[4] X. Li et al., *Sci. Adv.*, **5**, 3 (2019).

Conclusions

- Our design allows for independent control of transversal and longitudinal motion.
- Despite the non-trivial lateral forces and torques, optical pulling is stable for long illumination times.
- This design can be further optimized or extended with other structures/materials.

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