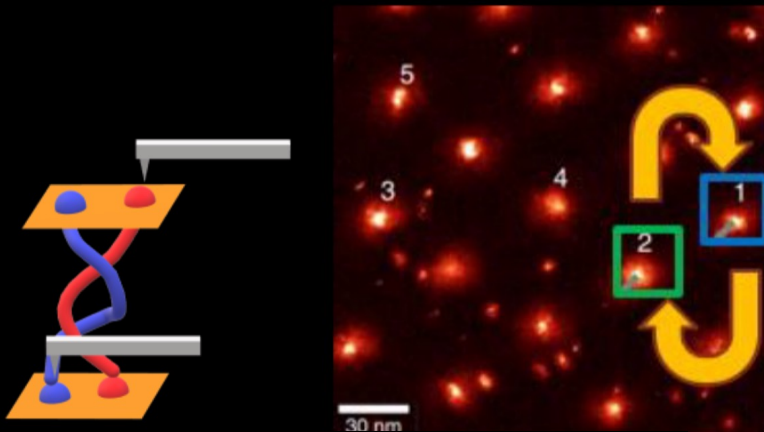
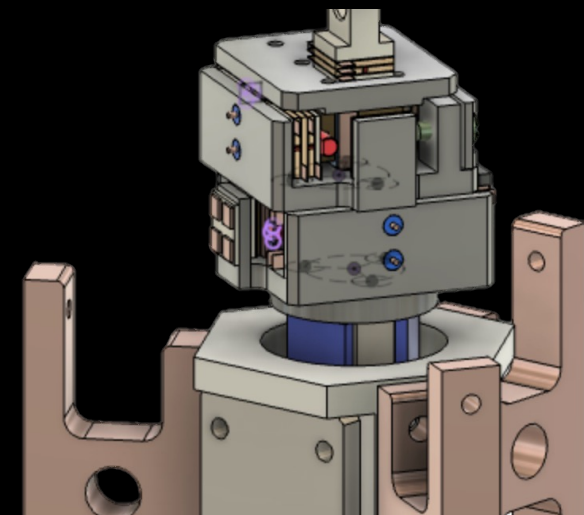
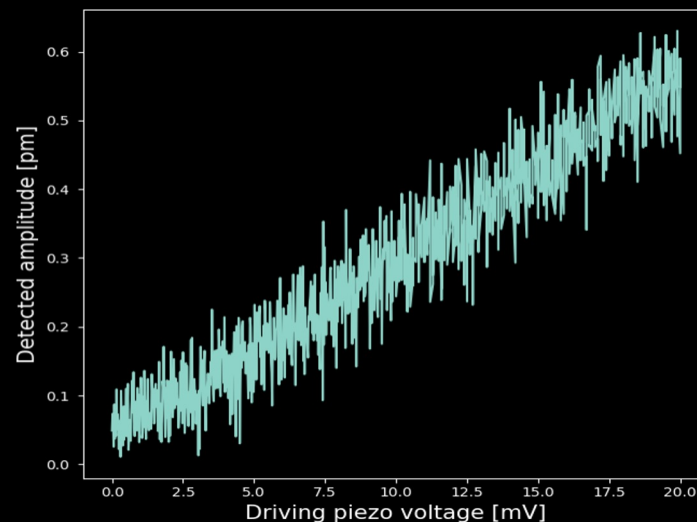


Fabry Perot fiber interferometer for millikelvin pendulum atomic force microscope cantilever detection

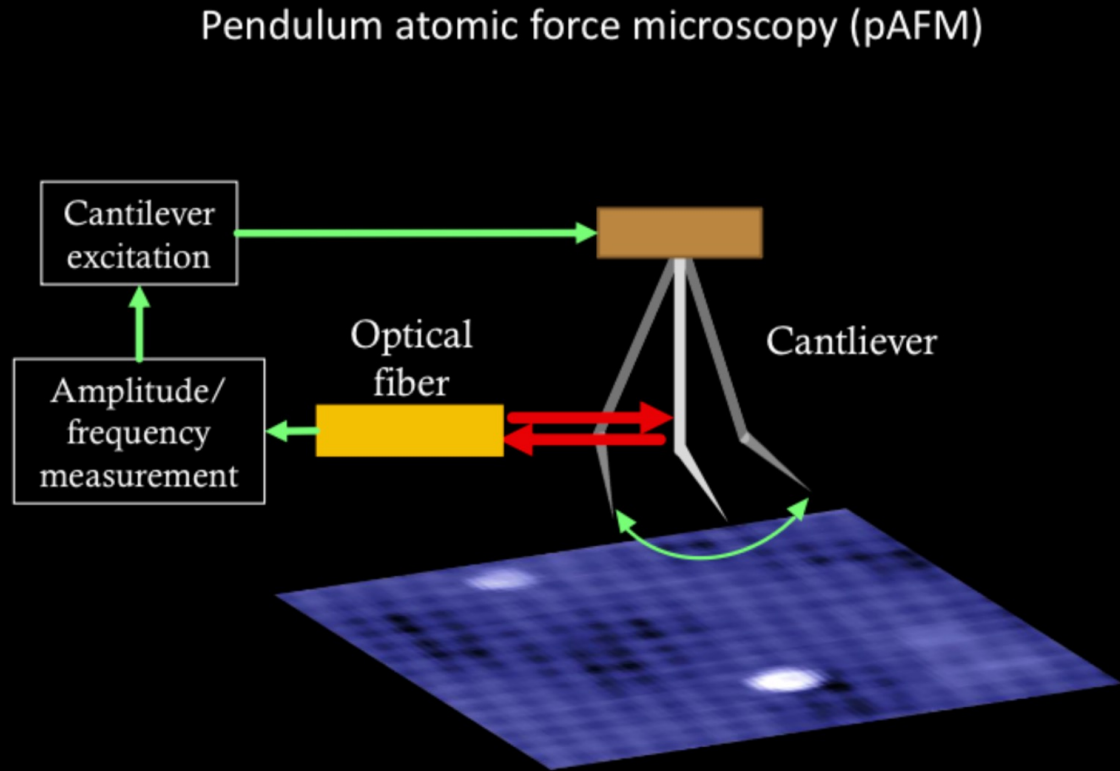
Federico Maccagno, Aaron Coe, Ben November, Stefan Ulrich, Jennifer Hoffman



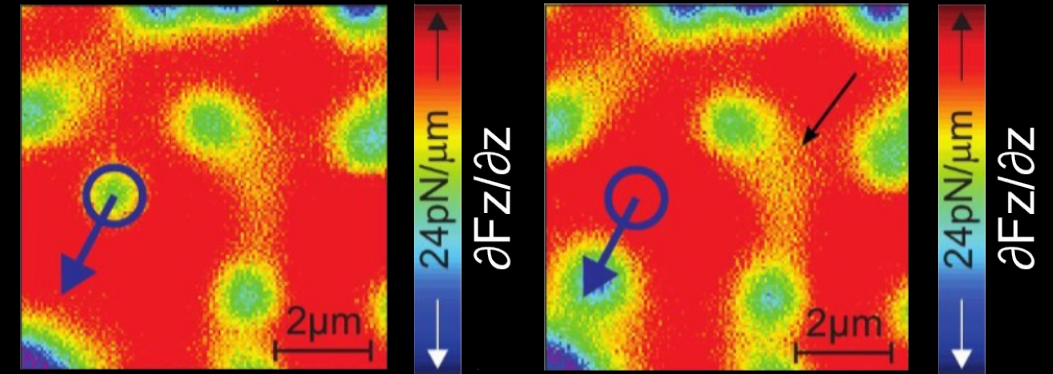
Machida, T., Sun, Y., Pyon, S. *et al. Nat. Mater.* **18**, 811–815 (2019).



pAFM & MFM enable cutting edge experiments:

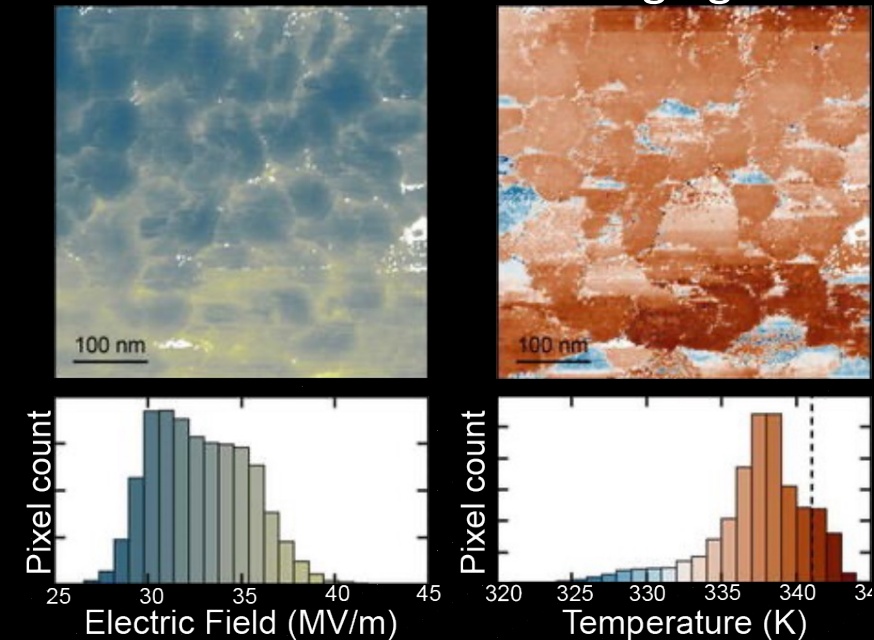


MFM manipulation of superconductive vortices



J.Zhang, *et al.* Phys. Rev. B **92**, 134509 (2015)

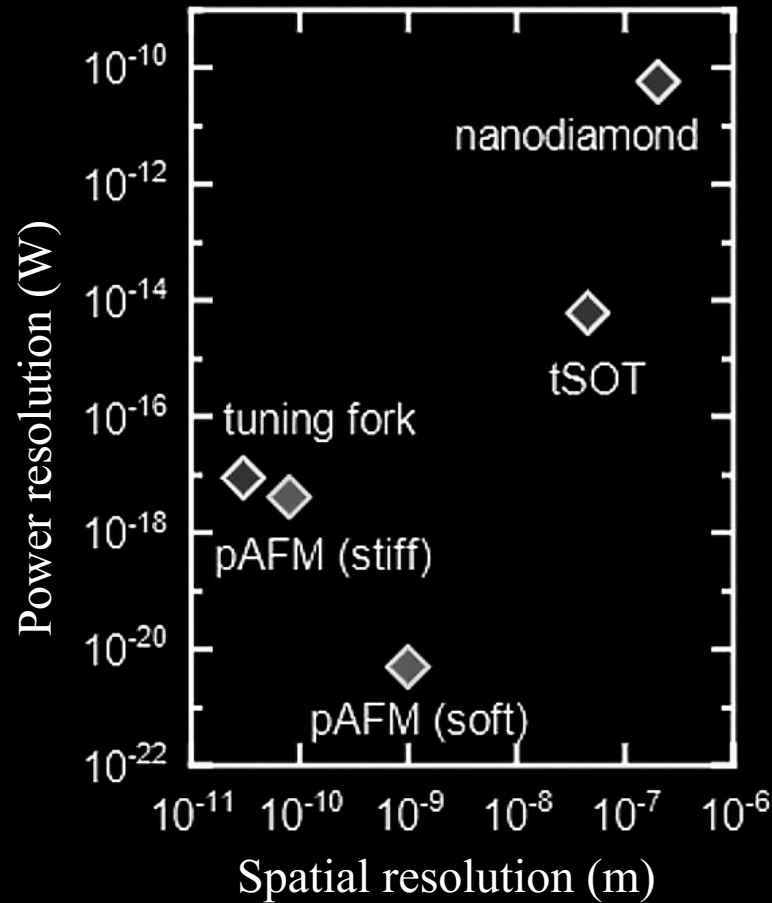
Nanoscale thermal imaging



Spitzig, A., *et al.* Appl. Phys. Lett. **120**, 151602 (2022)

Experiments that are enabled by mK pAFM

Use pAFM to achieve ultra high force sensitivity

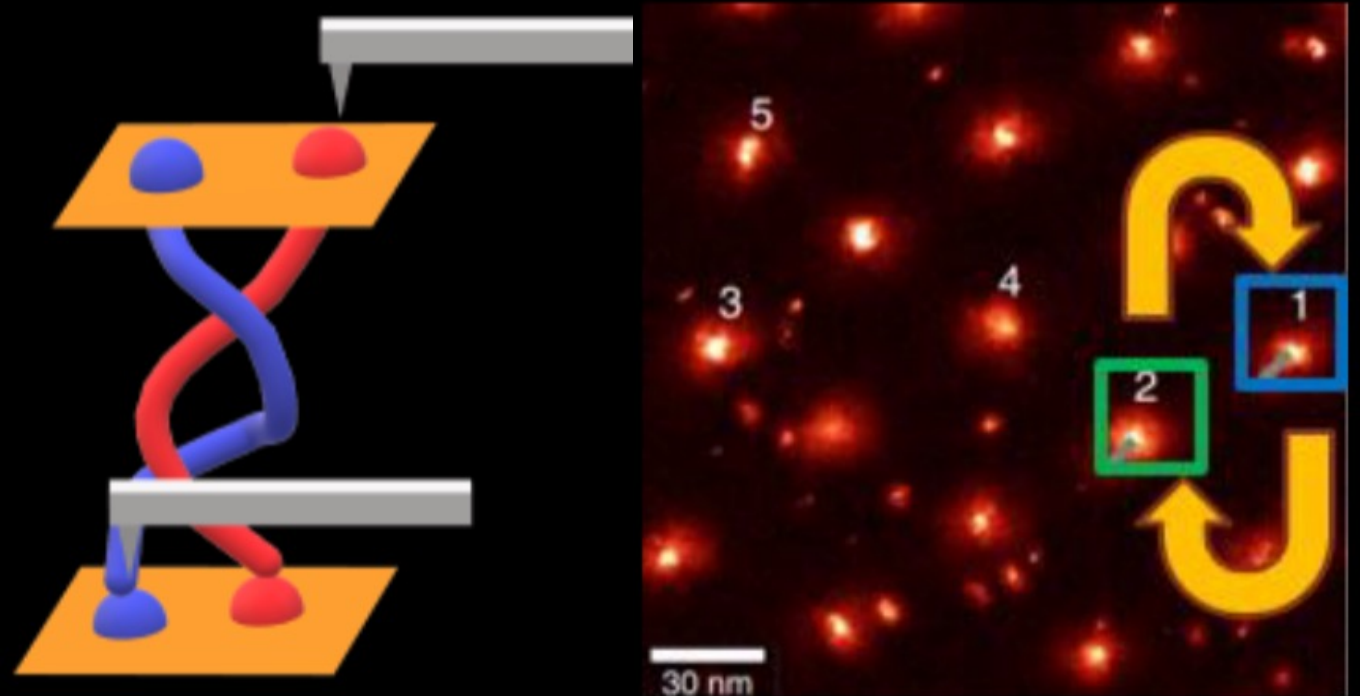


Halbental, D., M. *et al.* *Nature* **539**, 407-410 (2016).

Kisiel, M., *et al.* *Nat Commun.* **9**, 2946 (2018).

Figure by Jason Hoffman

Manipulation of Majorana bound states in superconductive vortices



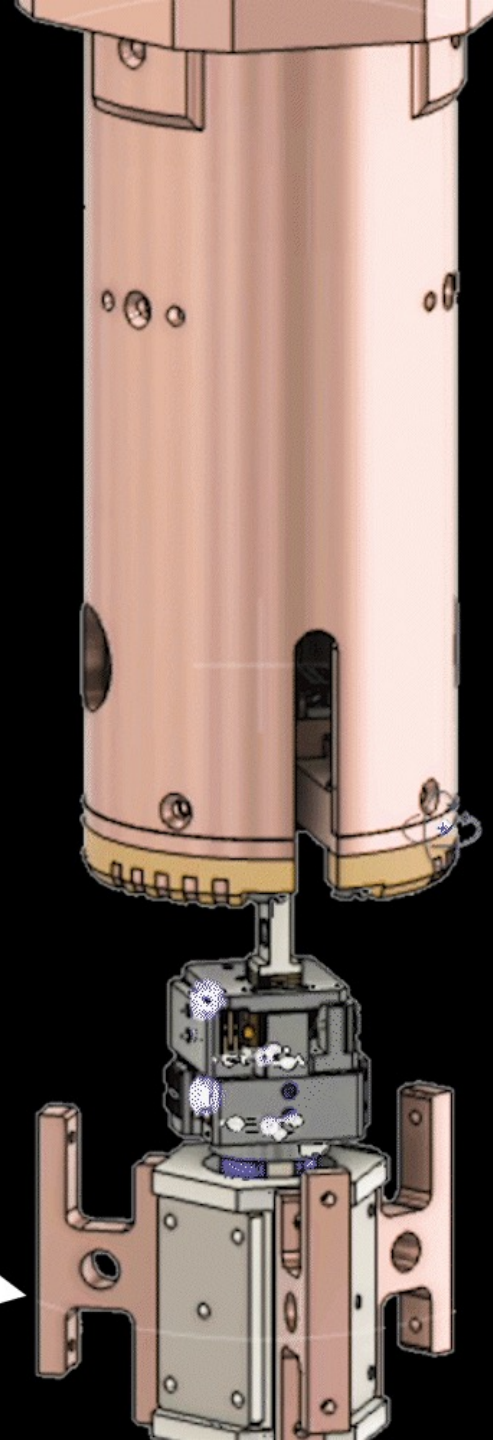
Machida, T., Sun, Y., Pyon, S. *et al.* *Nat. Mater.* **18**, 811-815 (2019)

The system is custom built

Microscope
assembly
shuttle



Fiber walker
assembly

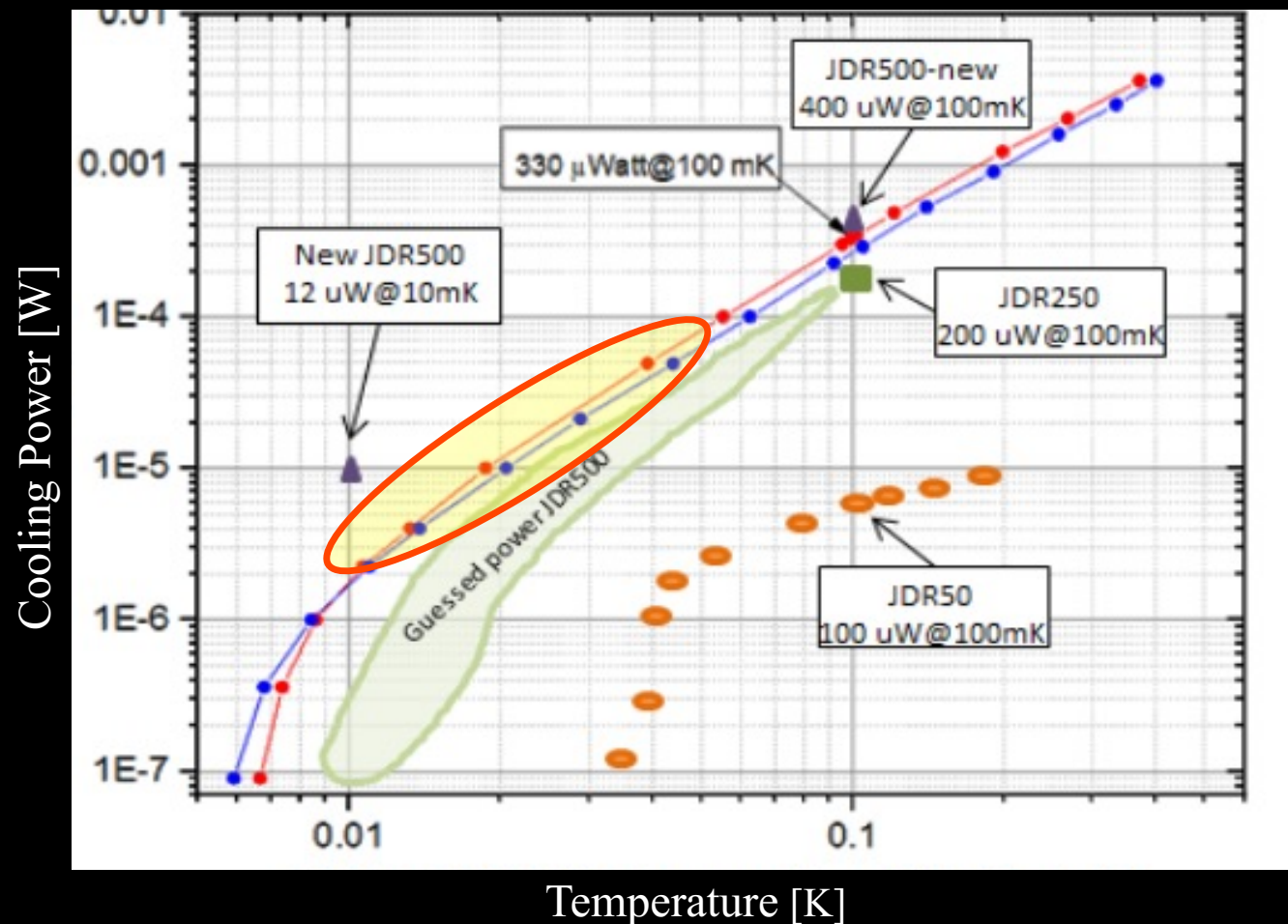


<50 mK dilution fridge

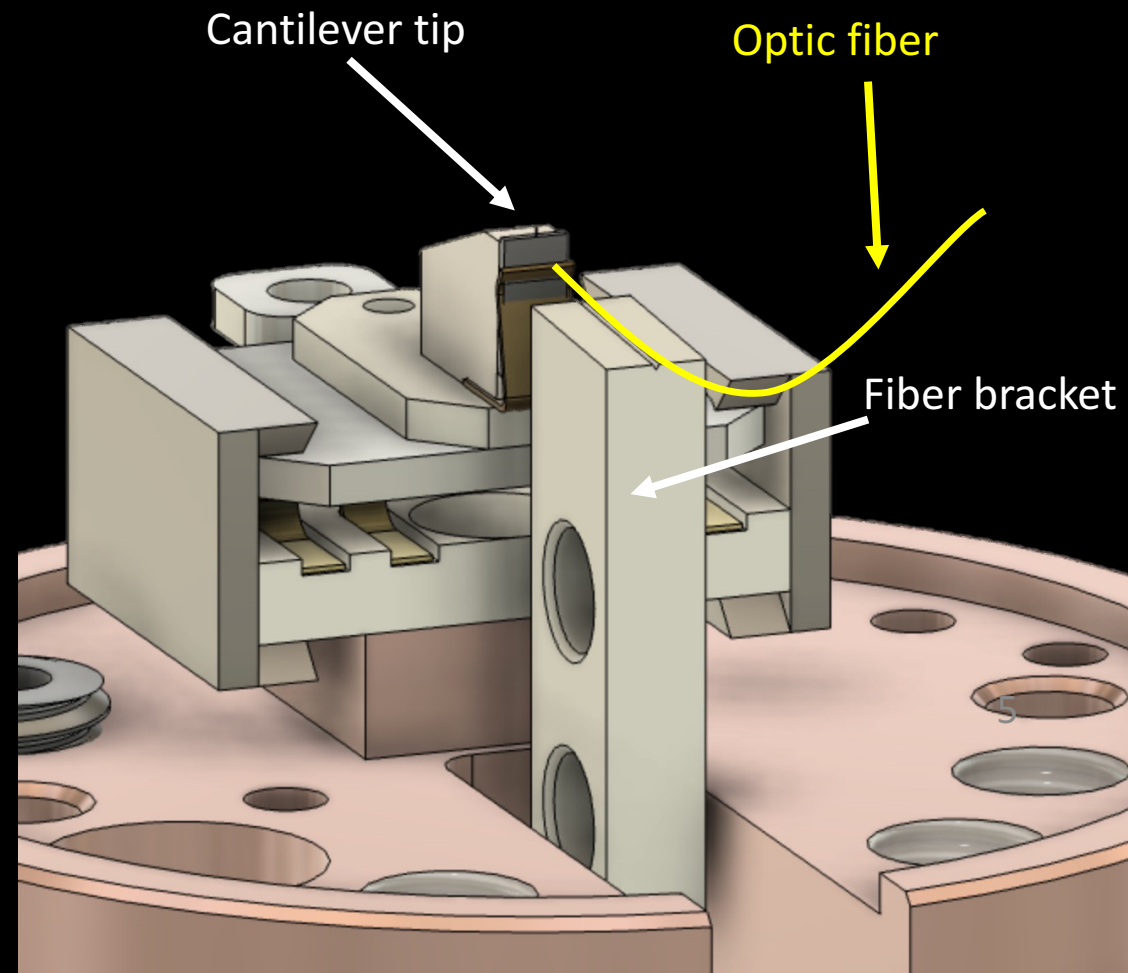
Fiber interferometer compatible with < 50mK

Dilution refrigerator:

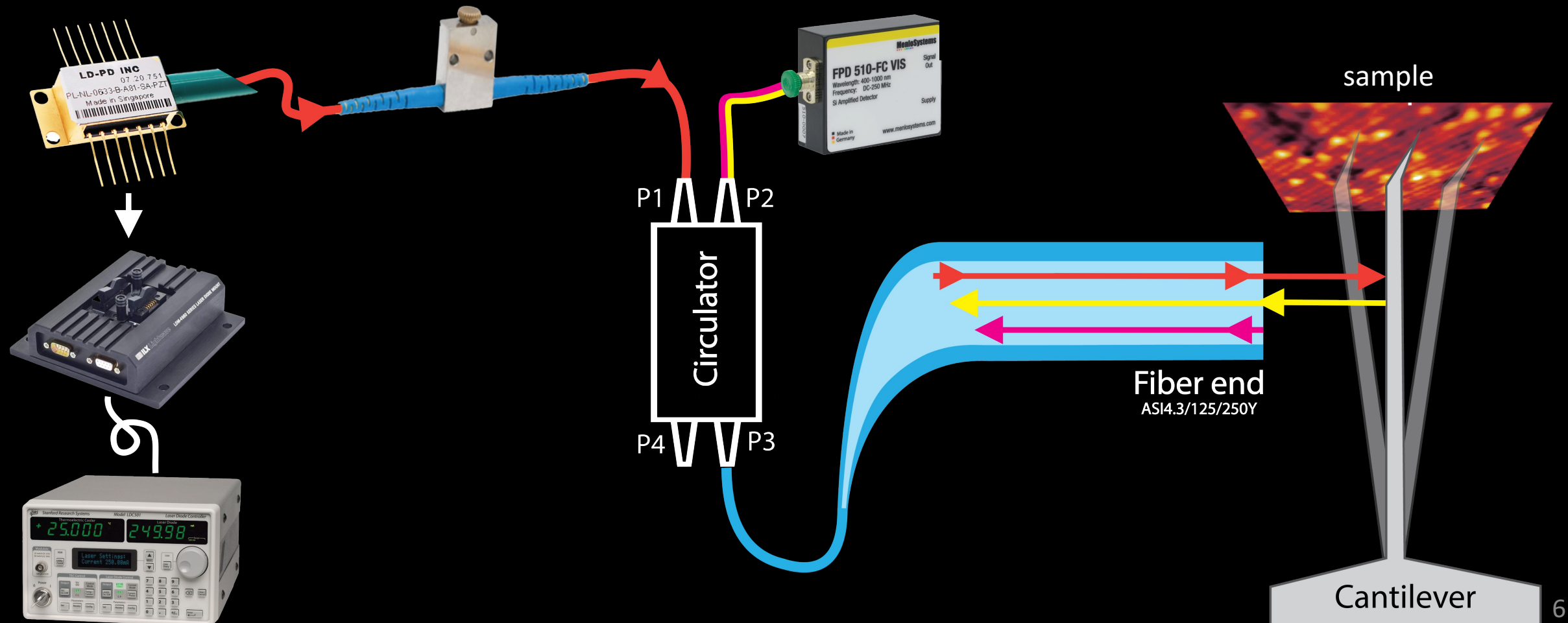
Cooling power (JDR500)



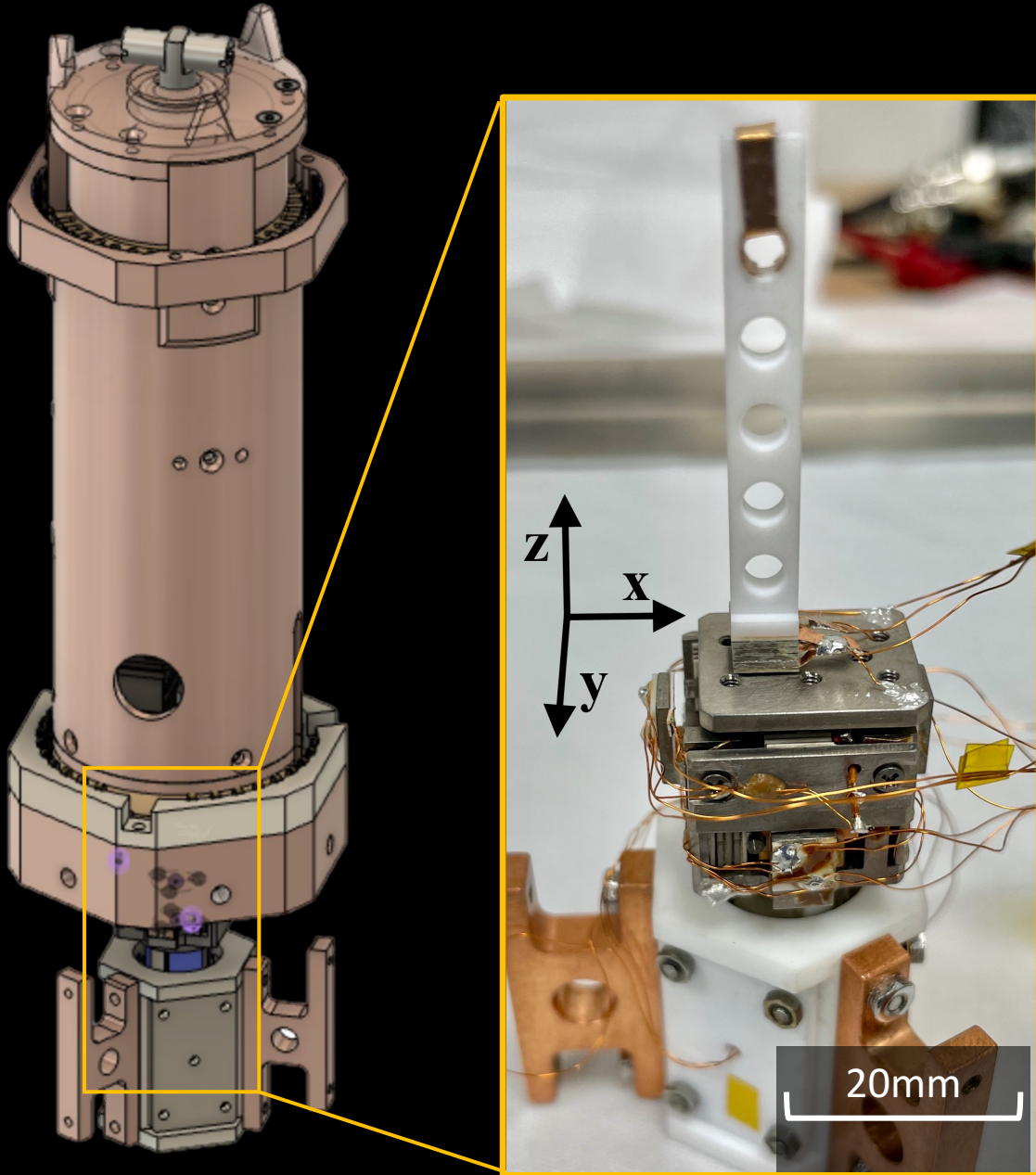
Fiber interferometer occupies a minimal in situ space near tip-sample junction.



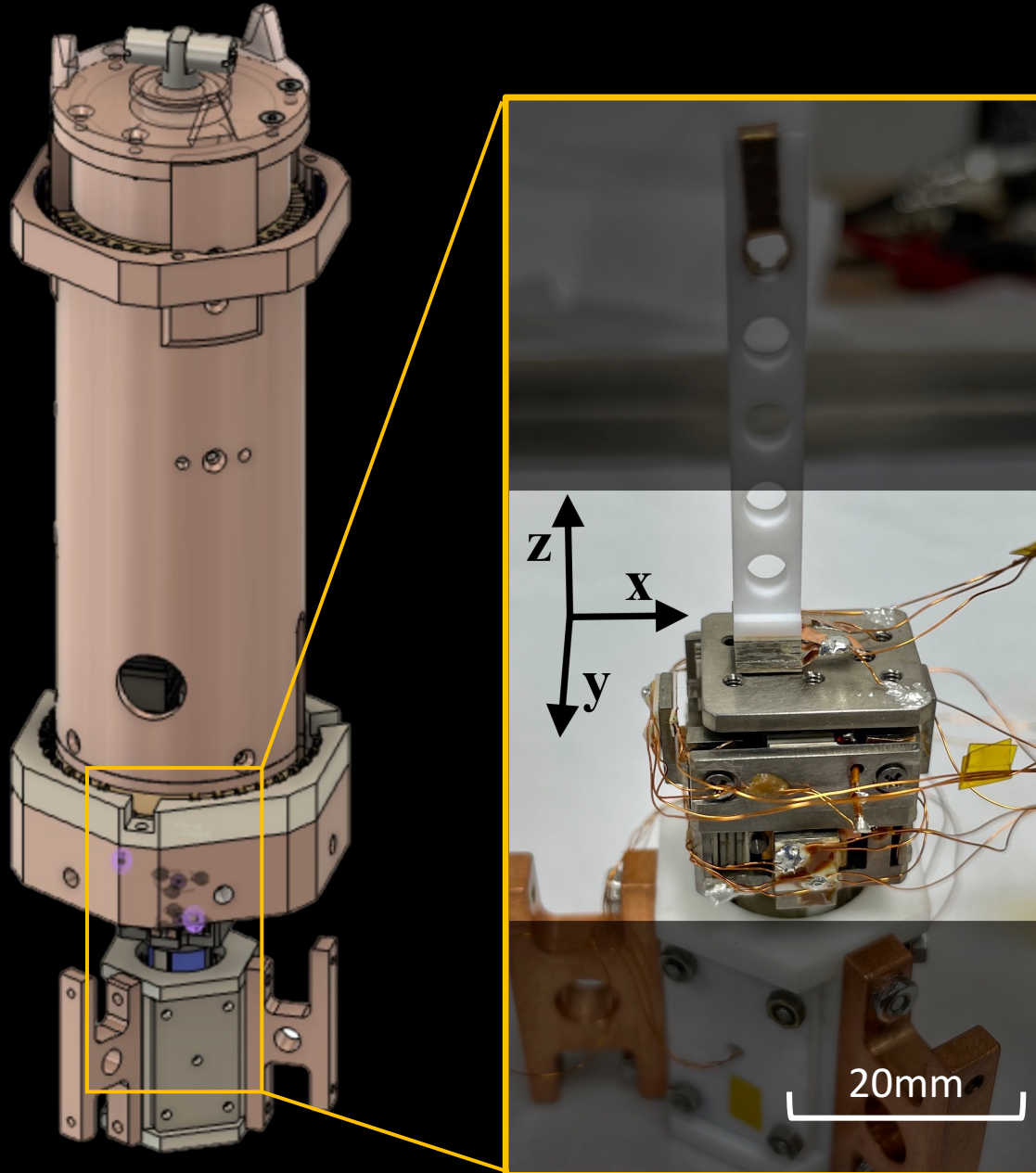
Fiber interferometer setup:



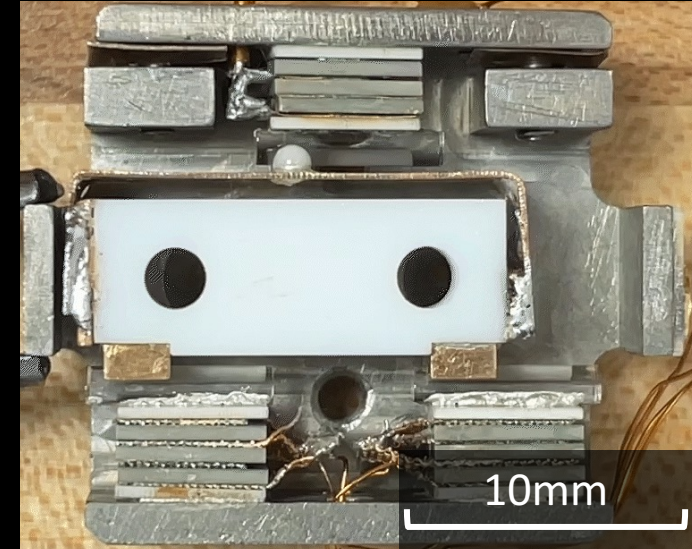
Use XYZ walkers to coarsely align fiber to cantilever



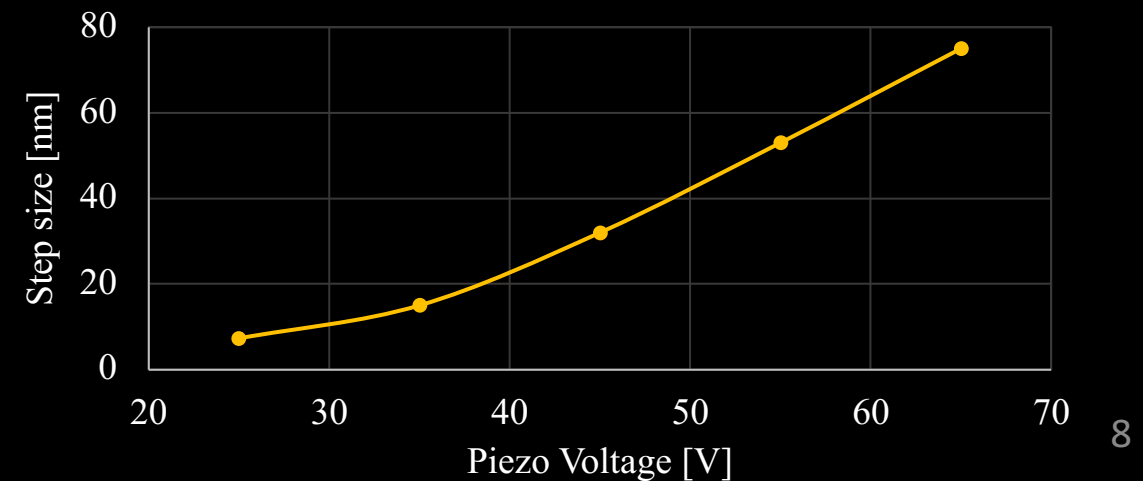
Use XYZ walkers to coarsely align fiber to cantilever



X walker moving at 40V, 2kHz voltage, room temperature

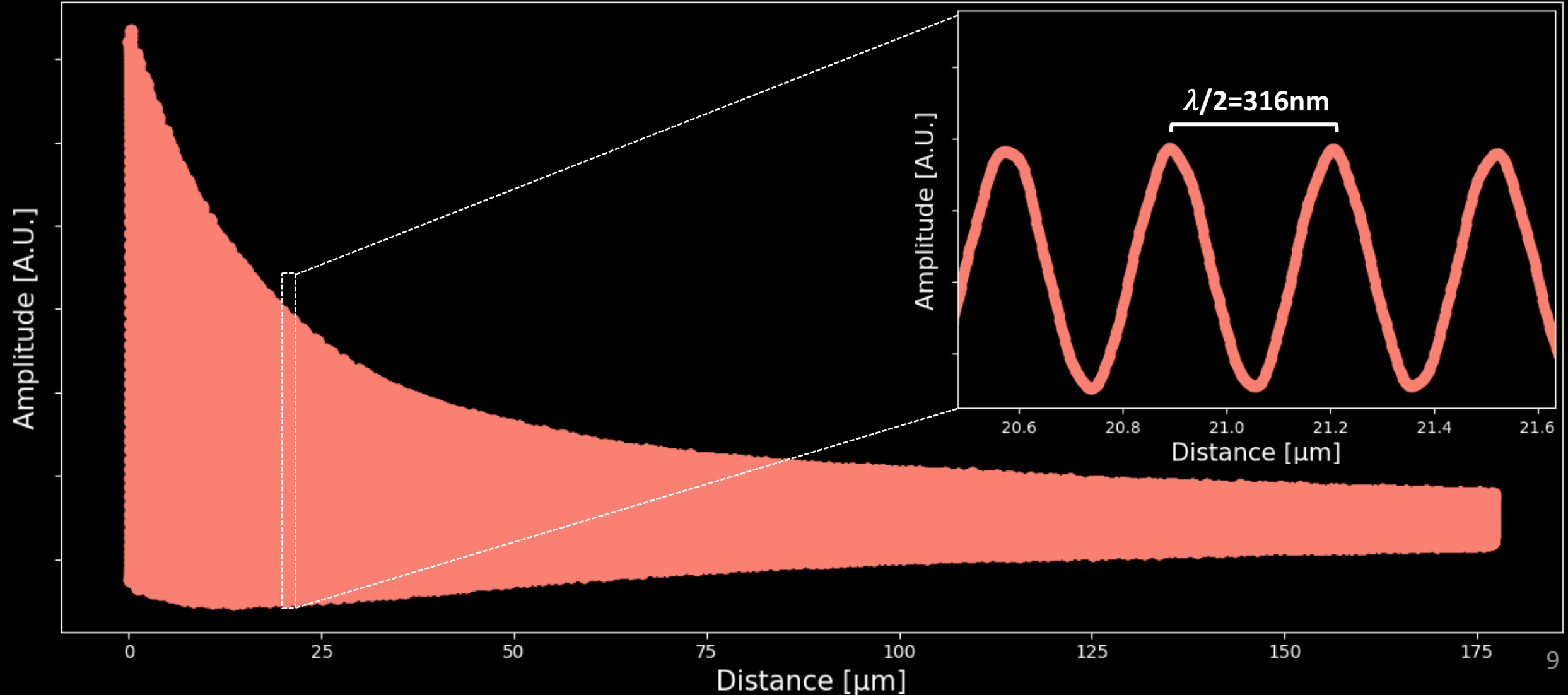


Piezo walker average step size vs piezo ramp voltage

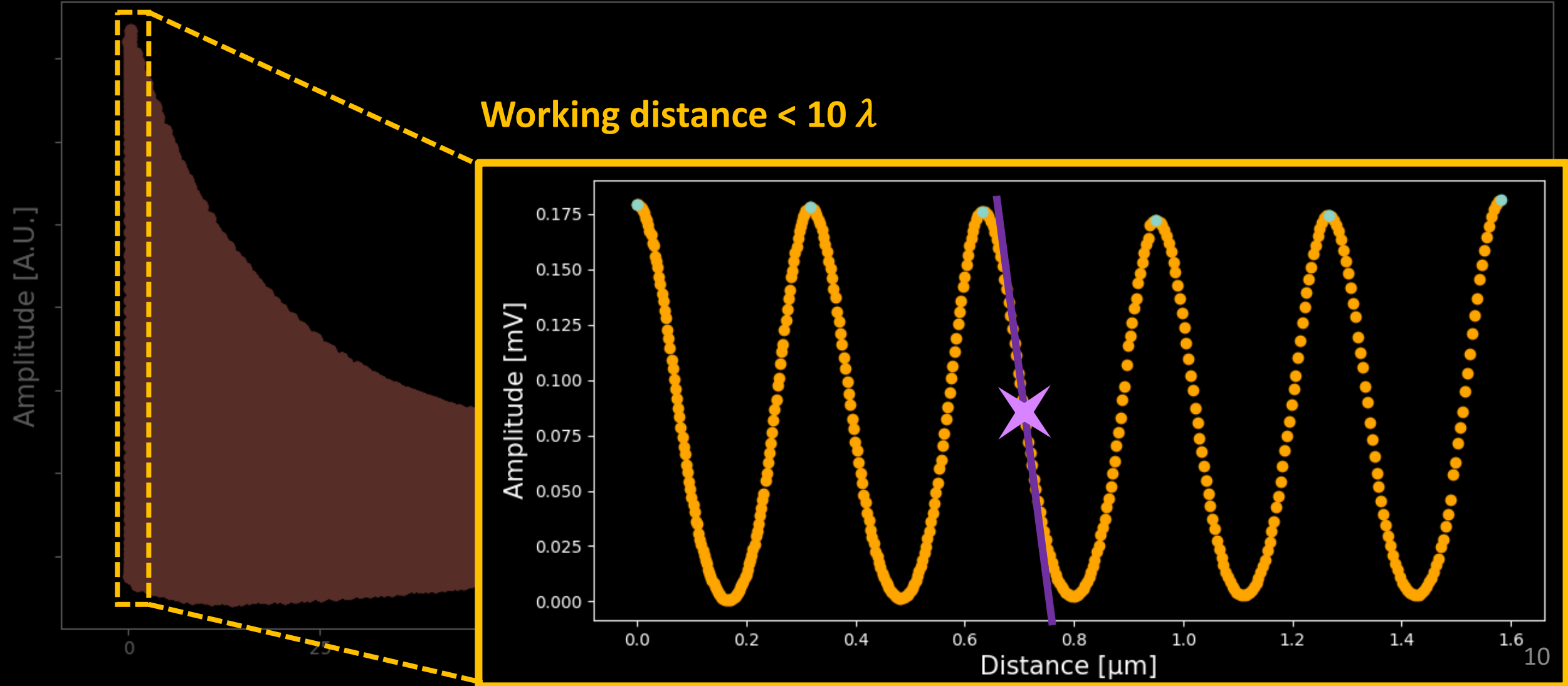


Signal response vs coarse distance adjustment

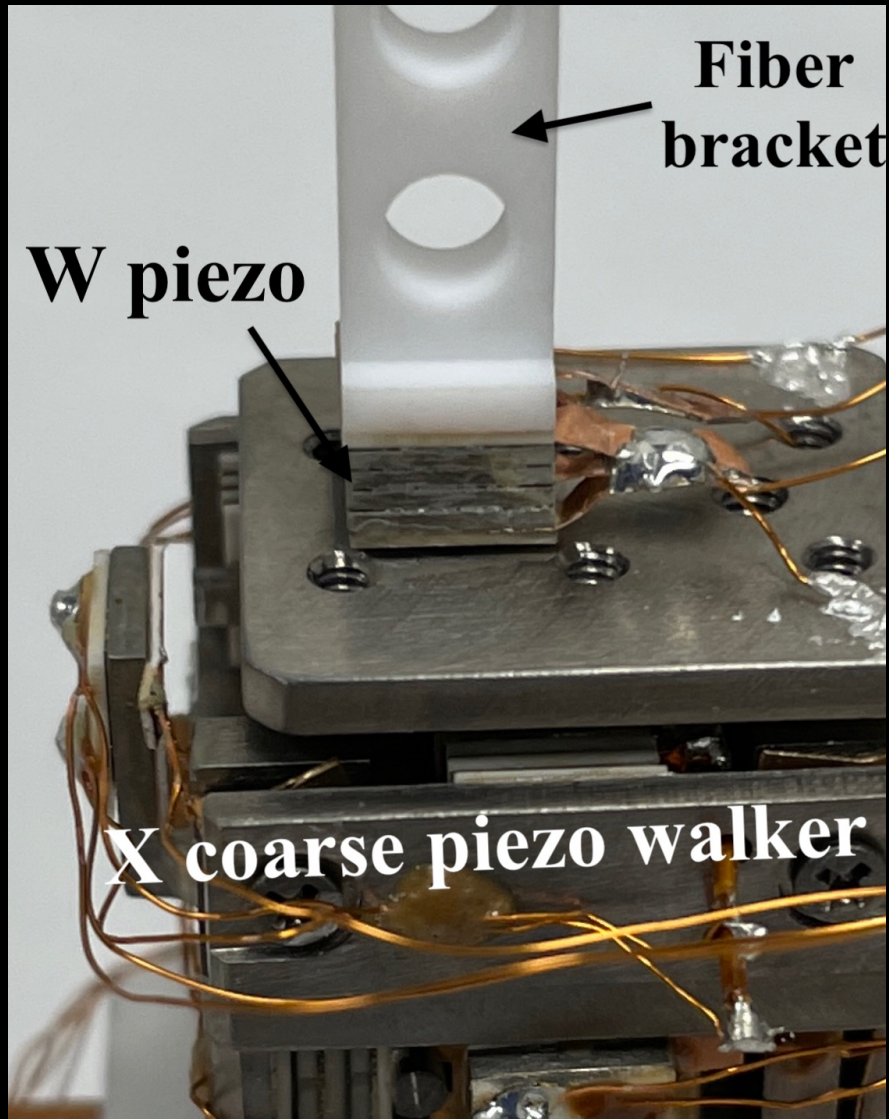
Plot of the signal amplitude as the fiber-cantilever distance is varied using the coarse X positioning system:



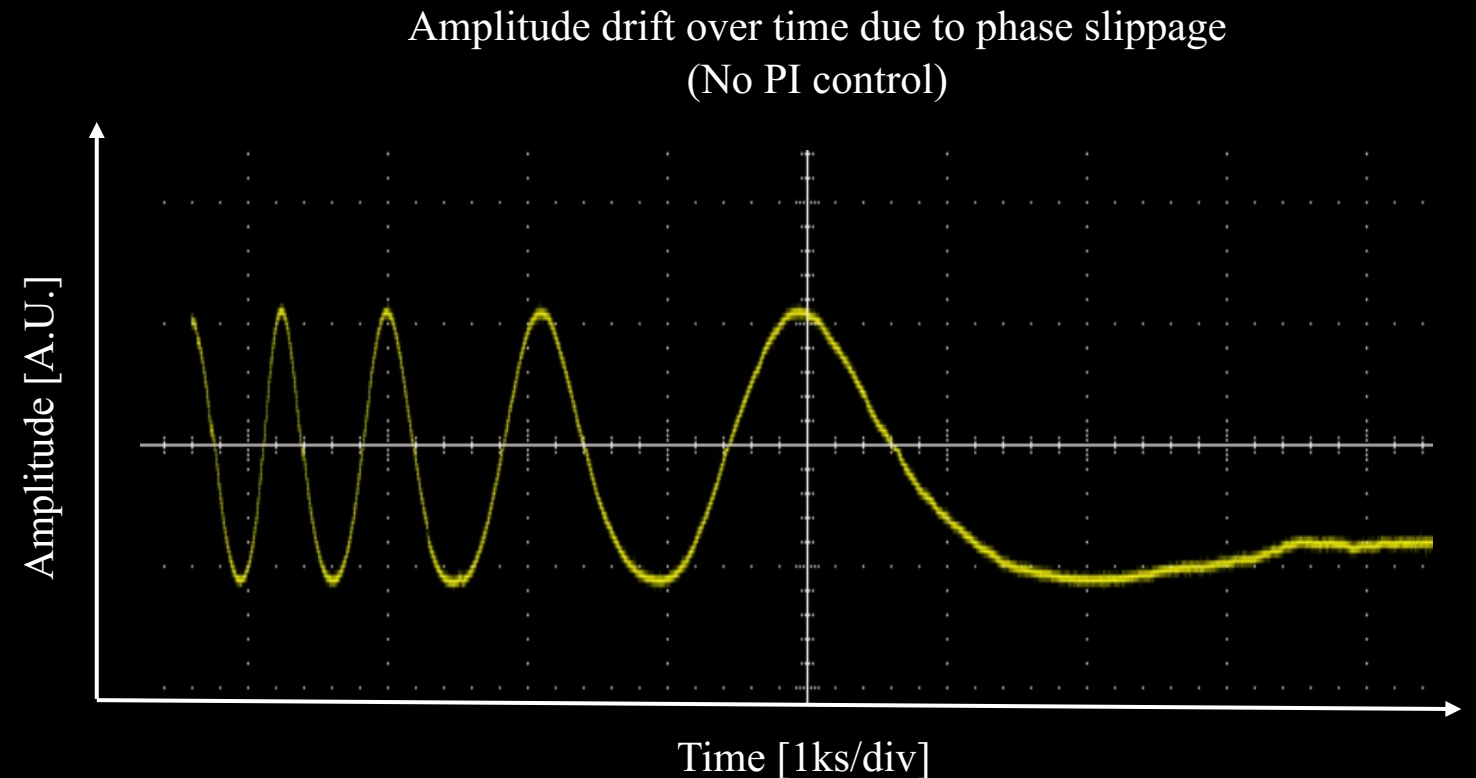
Best sensitivity is achieved at the **maximum slope**



Maintain the optimal position using W piezo

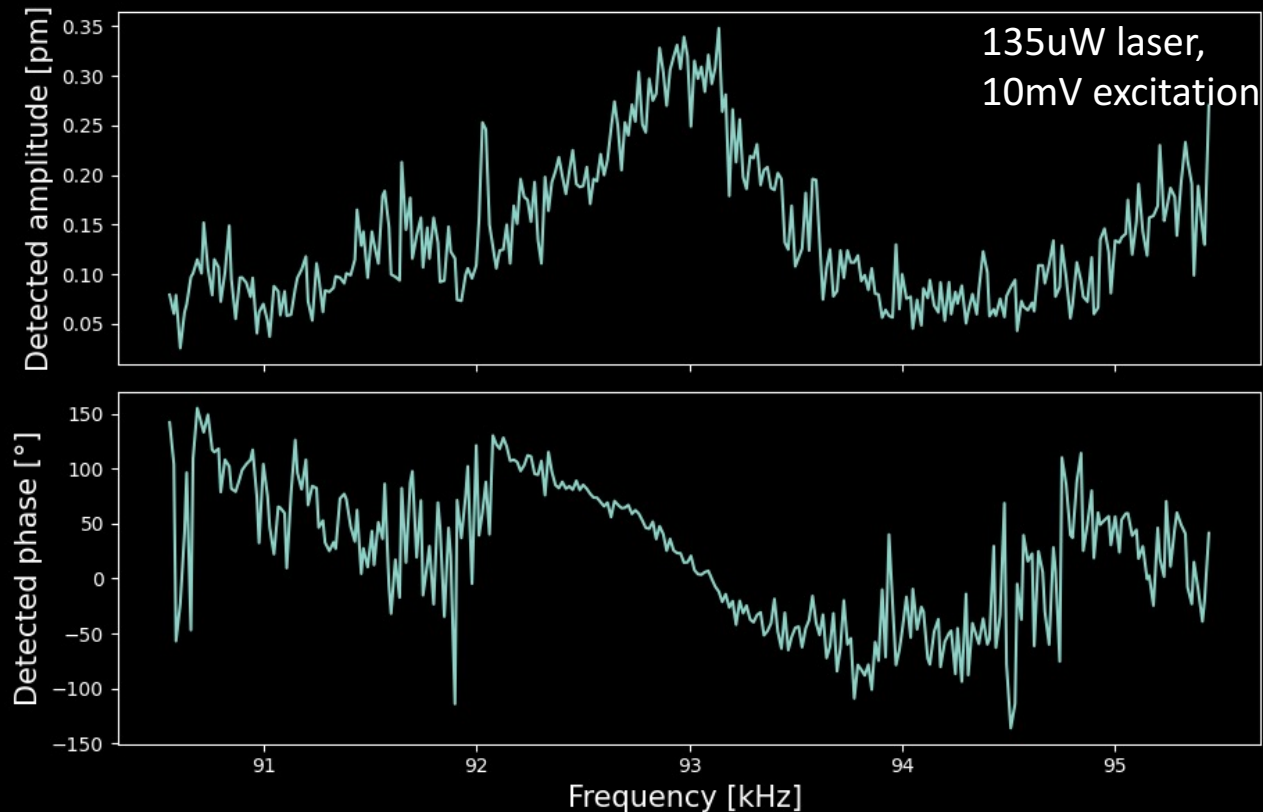


Also compensates signal drifts due phase slippage.

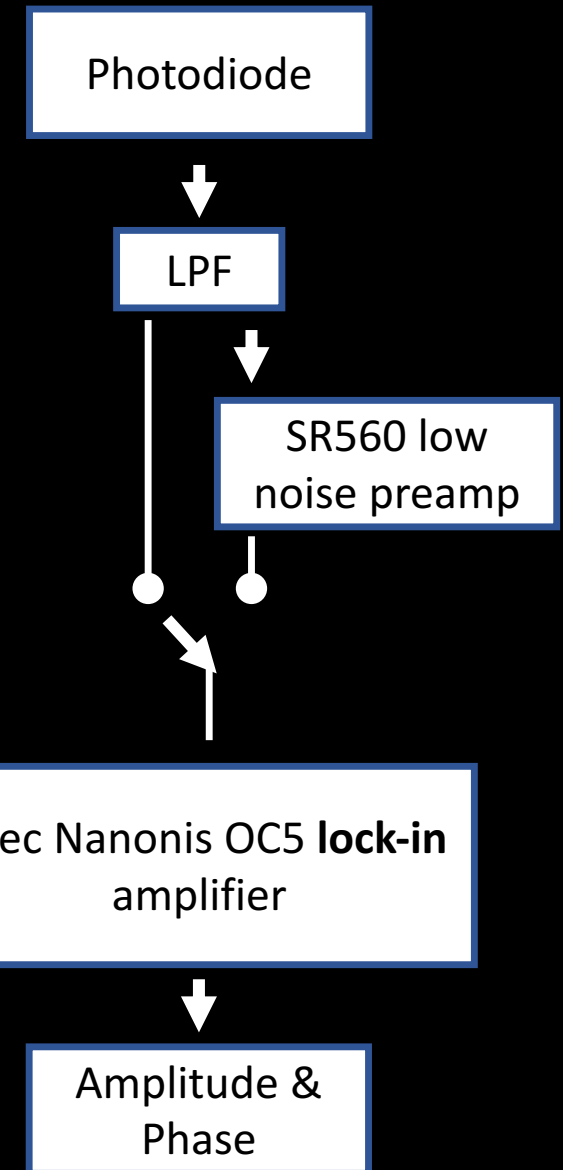


The interferometer resolution is measured experimentally for different laser power

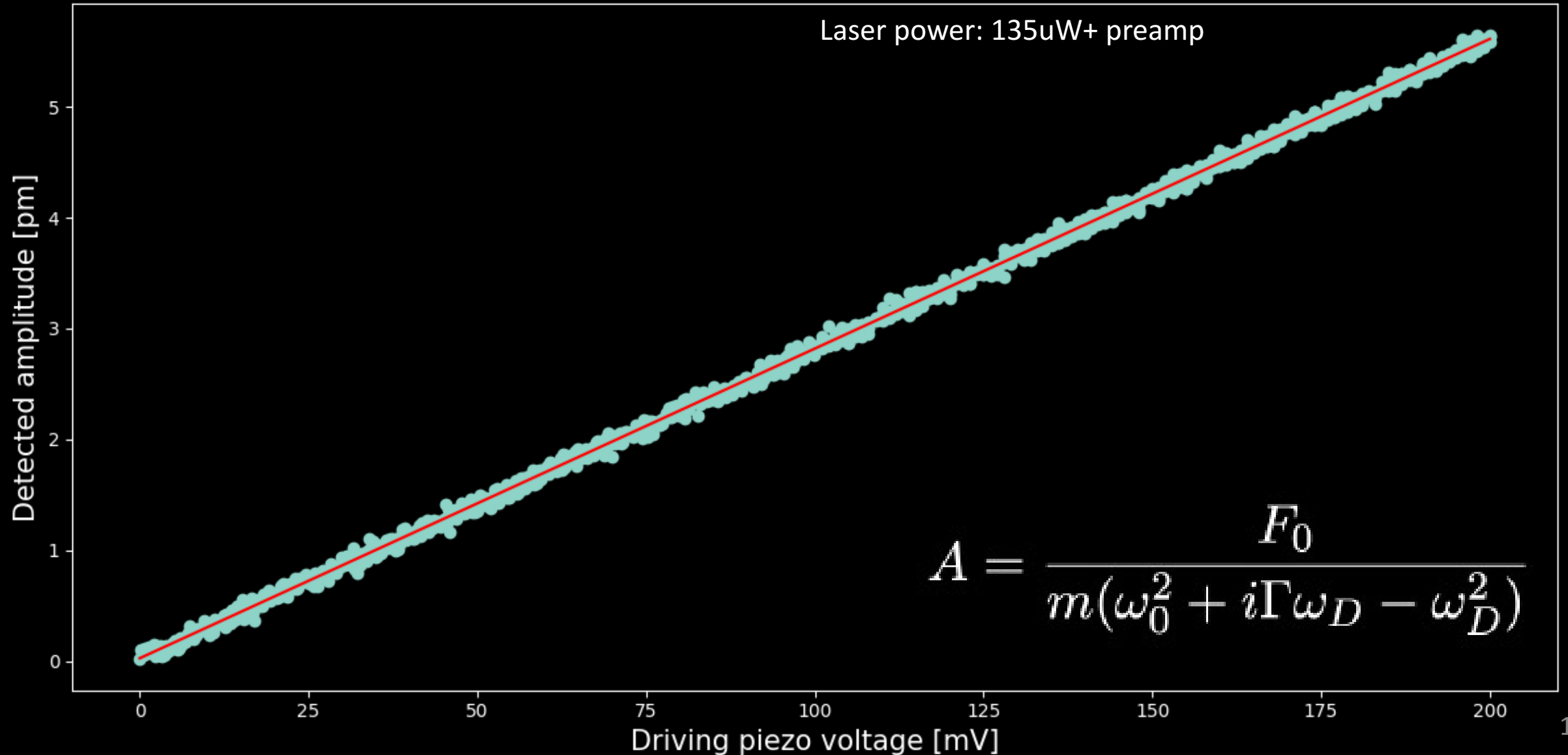
1. We measure the laser power and calibration factors.
2. We excite the cantilever via a shaking piezo.
3. We measure amplitude and phase of oscillation with lock-in loop.



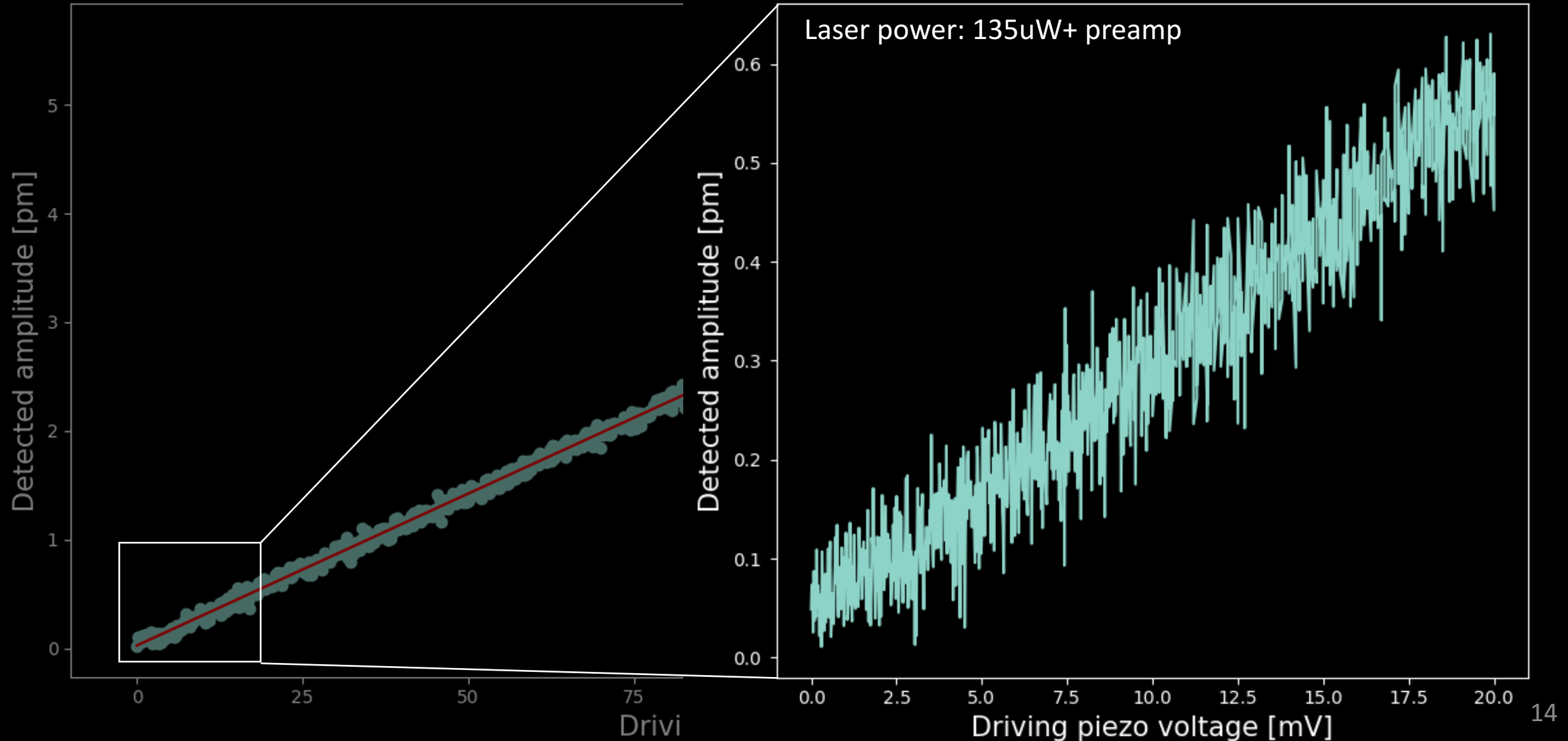
$\omega_{\text{excitation}}$
LOCK-IN REF



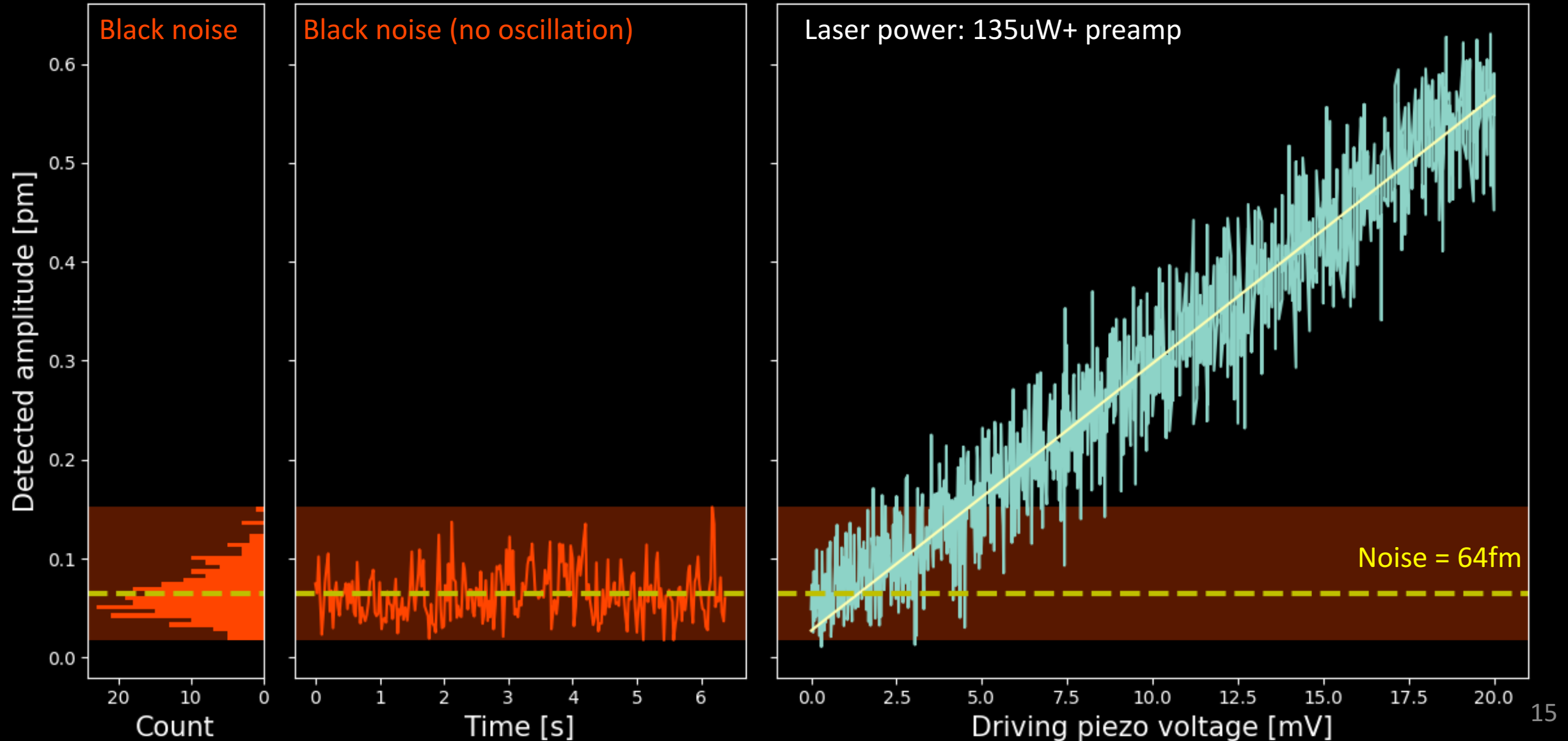
Ultimate amplitude resolution found by varying excitation voltage.



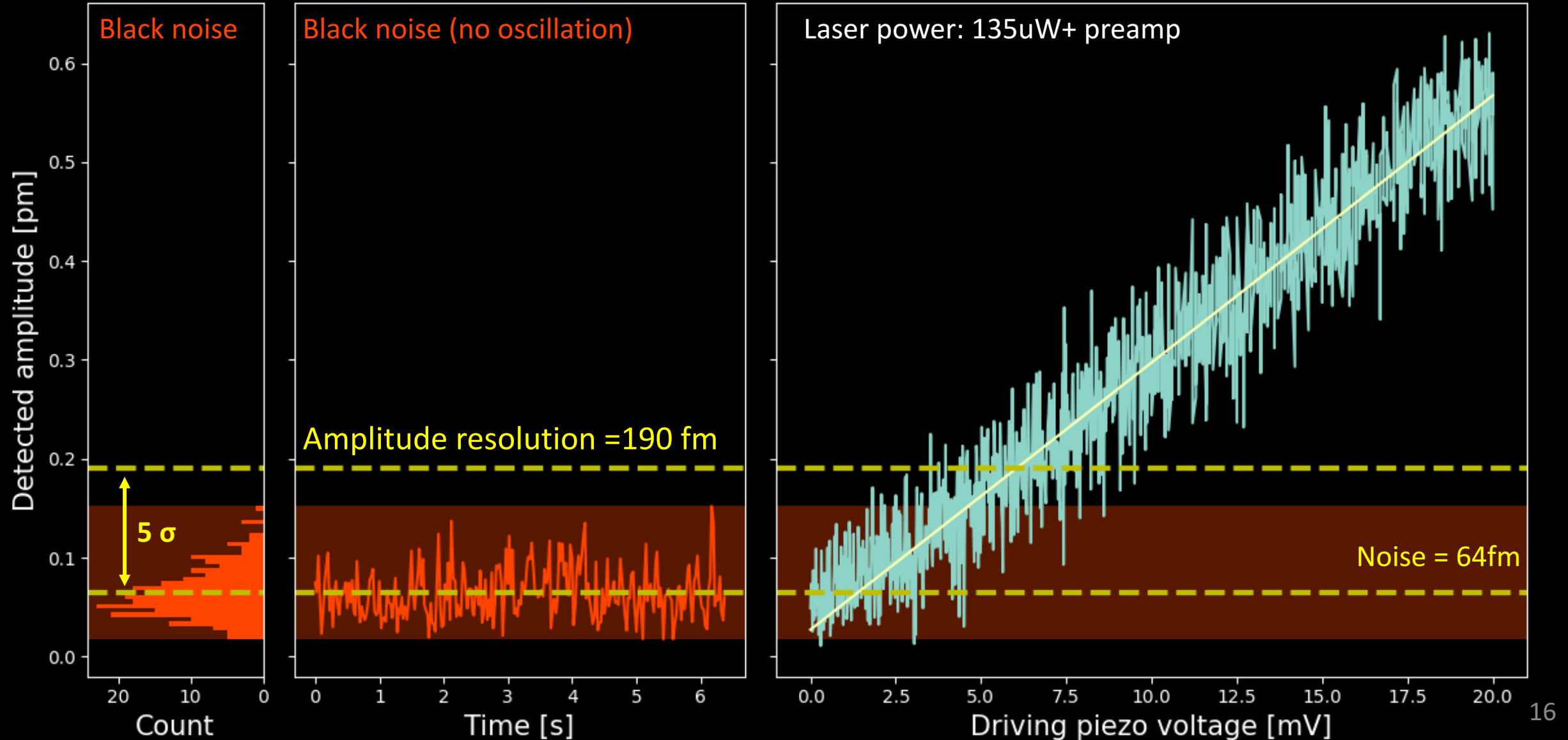
Ultimate amplitude resolution found by varying excitation voltage.



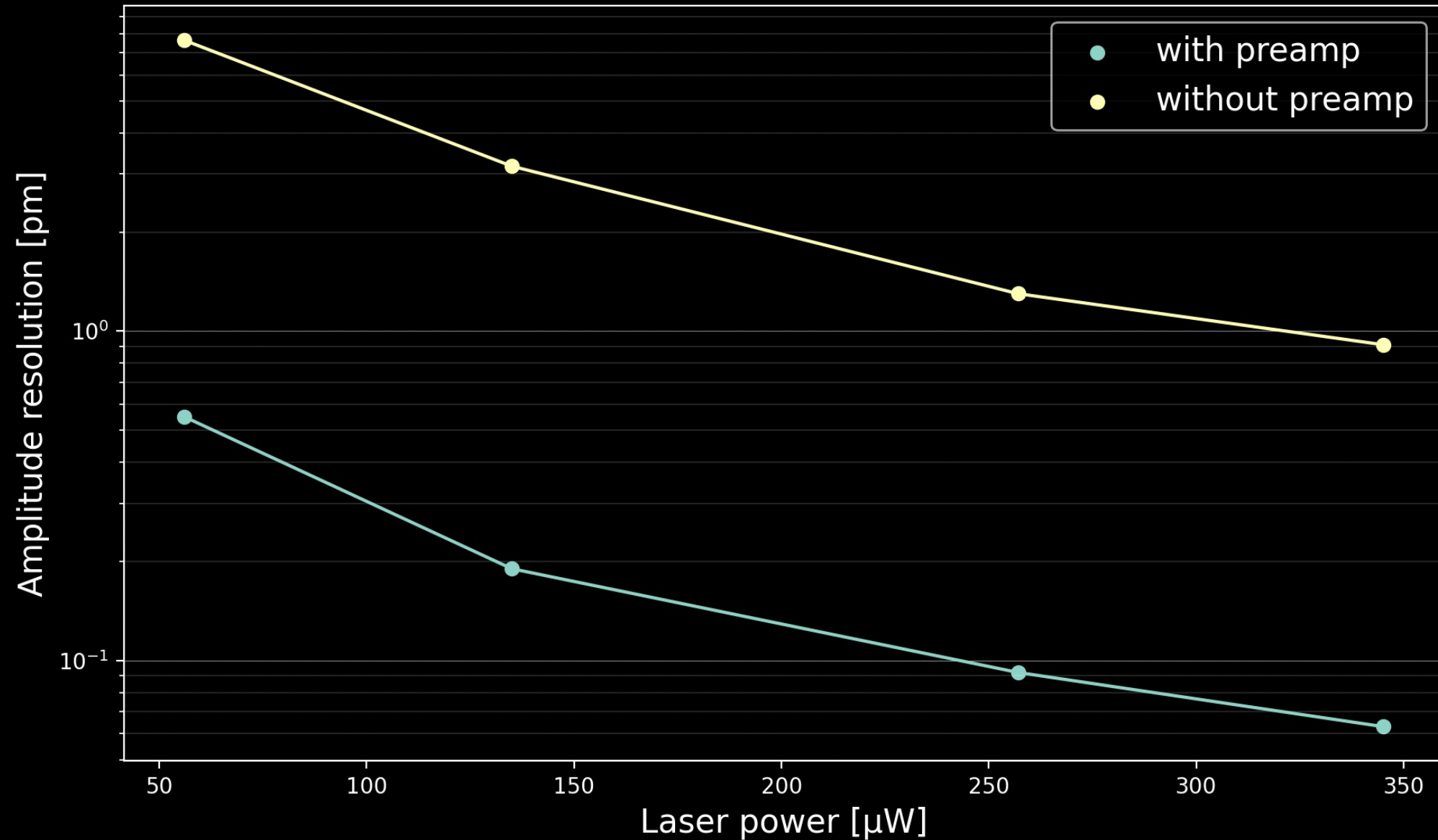
Ultimate amplitude resolution = 5σ away from noise



Ultimate amplitude resolution = 5σ away from noise

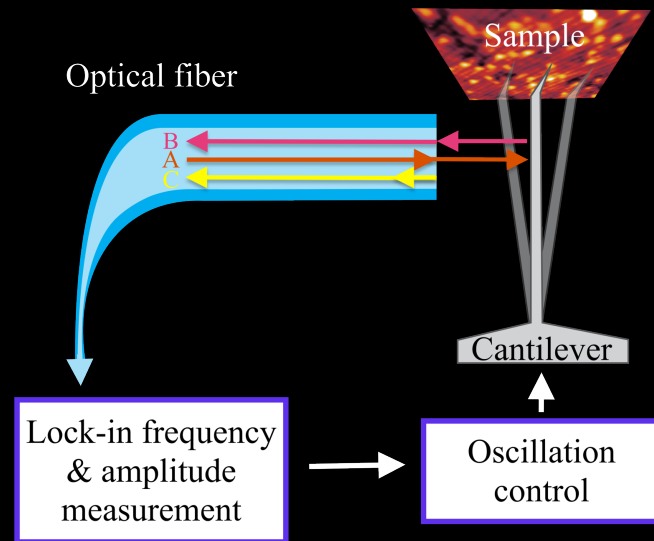


Amplitude detection resolution vs laser power

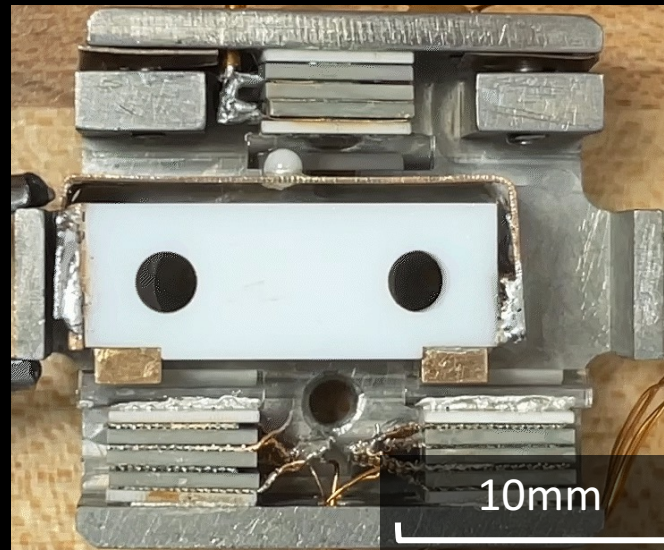


Summary:

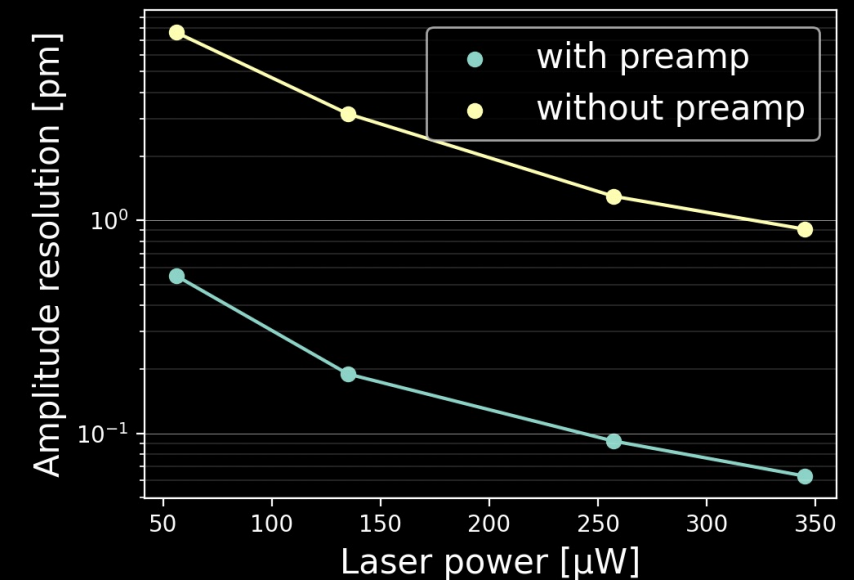
- Use Fabry Perot fiber interferometer for cantilever detection in DR environment



- Use custom XYZ fiber alignment



- Use preamplifier together with lock in amplifier to achieve sub-picometer resolution



Thank you!