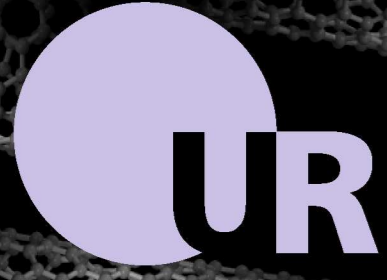


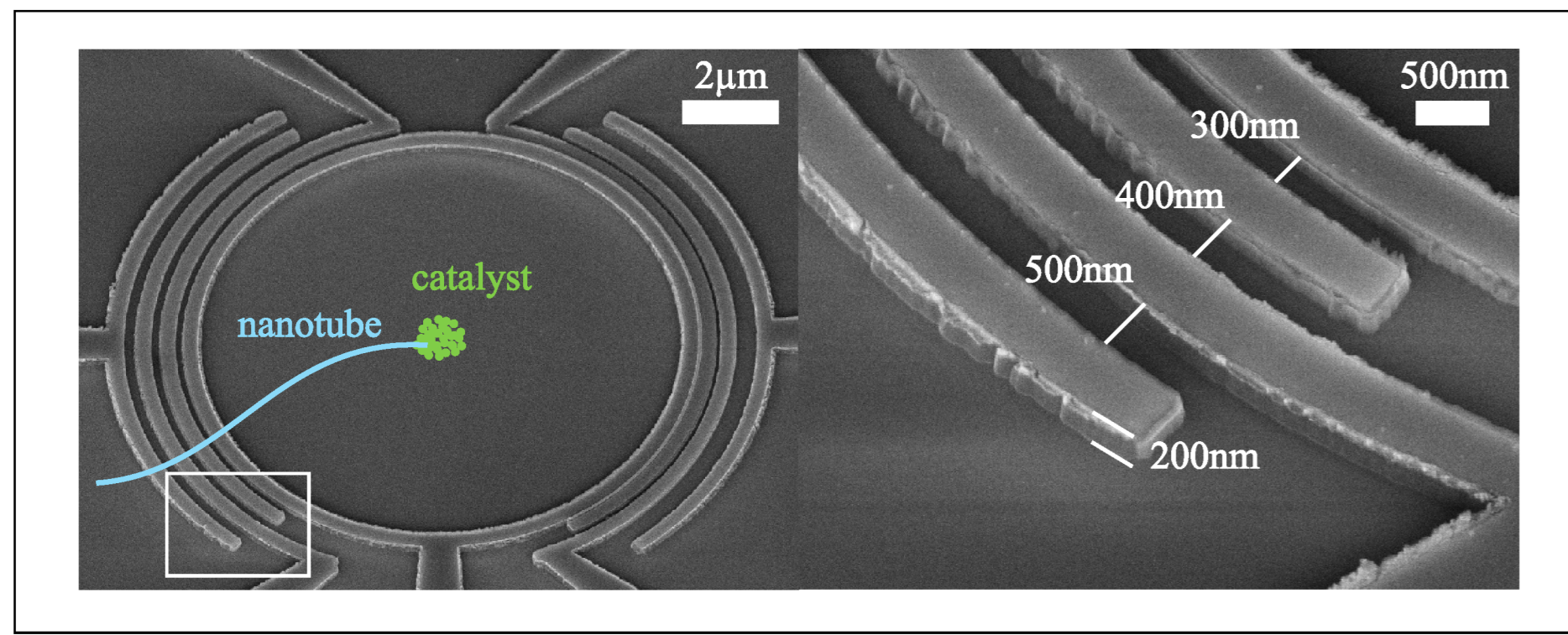
Magnetic damping of a CNT resonator

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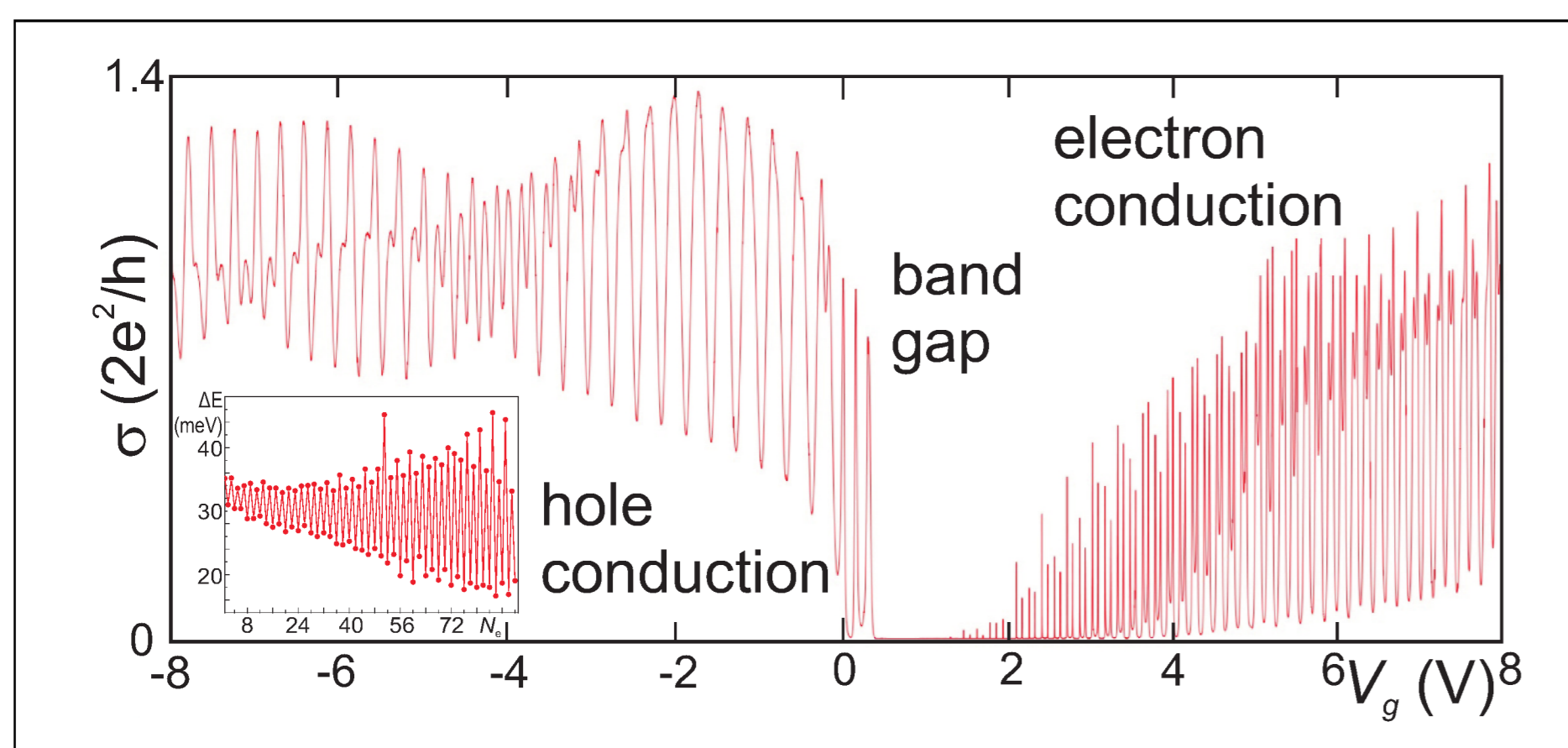
Ultraclean carbon nanotubes



- first preparation of contacts, trenches, catalyst ...
- then grow nanotubes across contacts
- no lithography or wet chemistry afterwards!
 - no chemical or mechanical damage
 - no resist residues, no e-beam irradiation
 - chip structures must survive the chemical vapor deposition (CVD) nanotube growth

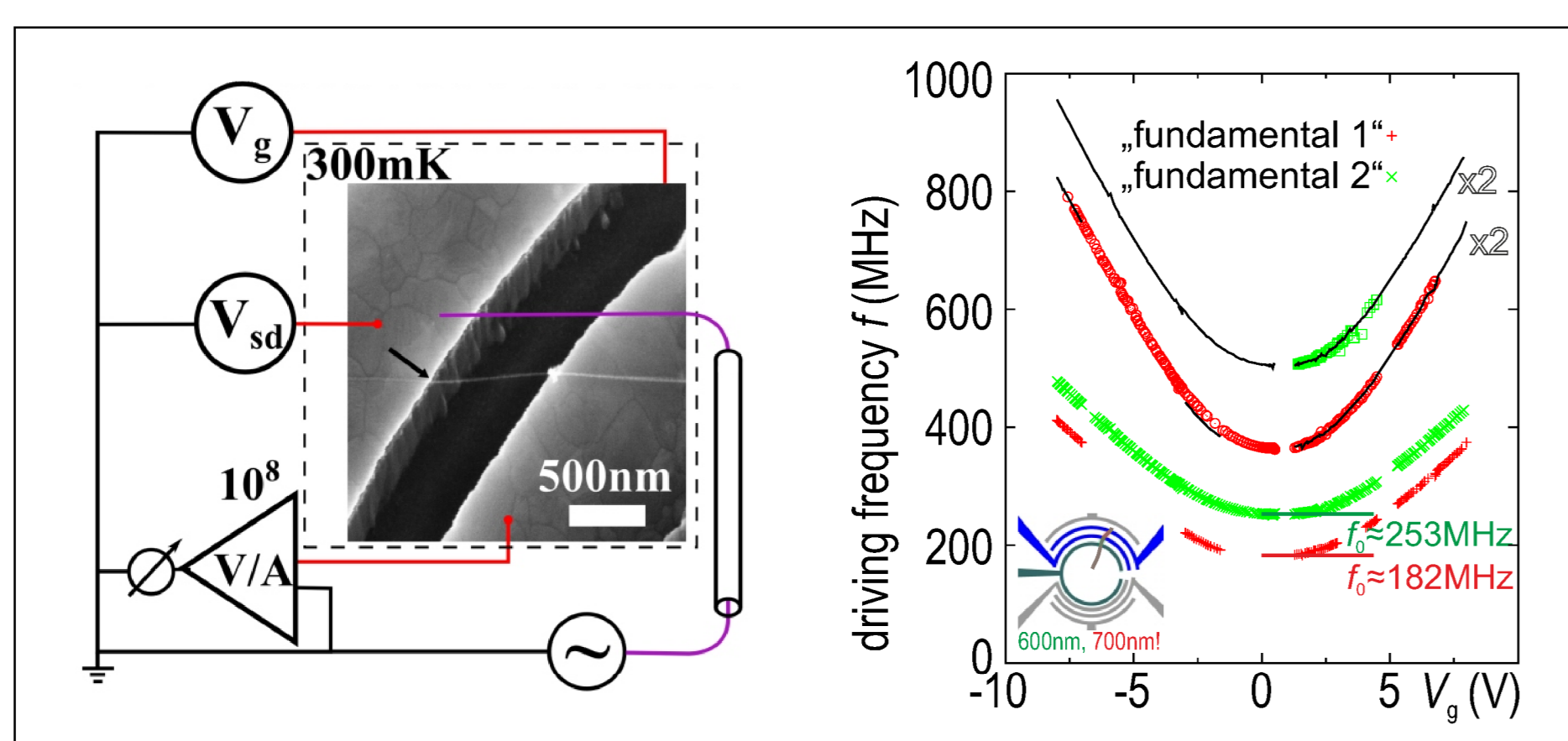
Electronic characterization

- $T \leq 300$ mK \Rightarrow highly transparent contacts
- Fabry-Perot regime for hole conduction
- Coulomb blockade (CB) with Kondo features for electron conduction
- clean few-electron system [1, 2, 3]



Nanotube NEMS resonators

- drive the carbon nanotube as resonator contact-free with RF signal from nearby antenna
- high- Q resonator at low T possible [6, 7, 8]



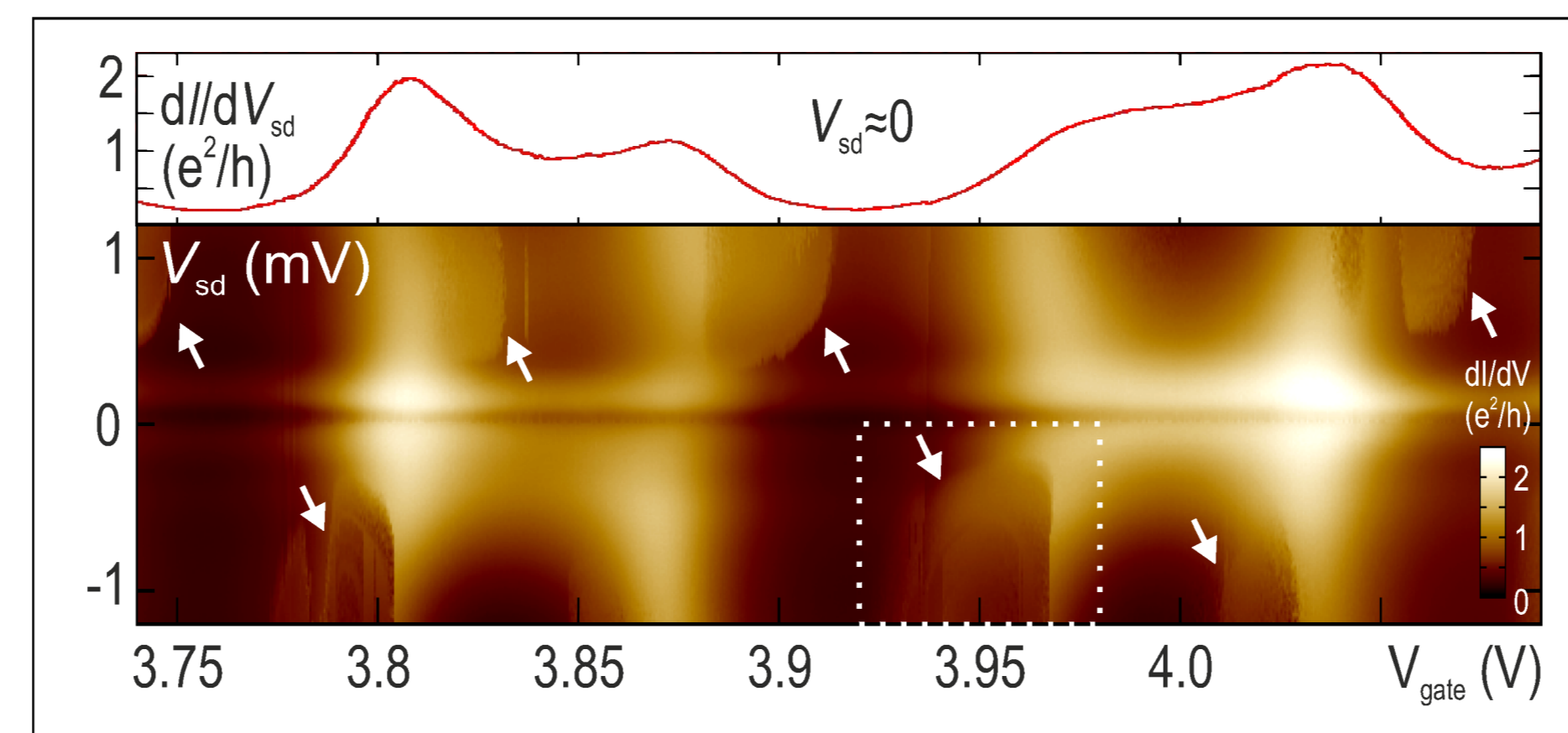
- clear mechanical resonance features
- visible down to band gap $N_{el} = N_h = 0$
- backgate voltage builds up mechanical tension
- two "fundamental frequencies" \leftrightarrow neighboring nanotube segments 600nm, 700nm
- approximation: tension $\mathcal{T} = 0 \rightarrow f_0 \propto L^{-2}$

$$\frac{253 \text{ MHz}}{182 \text{ MHz}} = \left(\frac{594 \text{ nm}}{700 \text{ nm}} \right)^{-2}$$

- detection mechanism of second segment?
- $2f$ features: parametric resonance [9]?

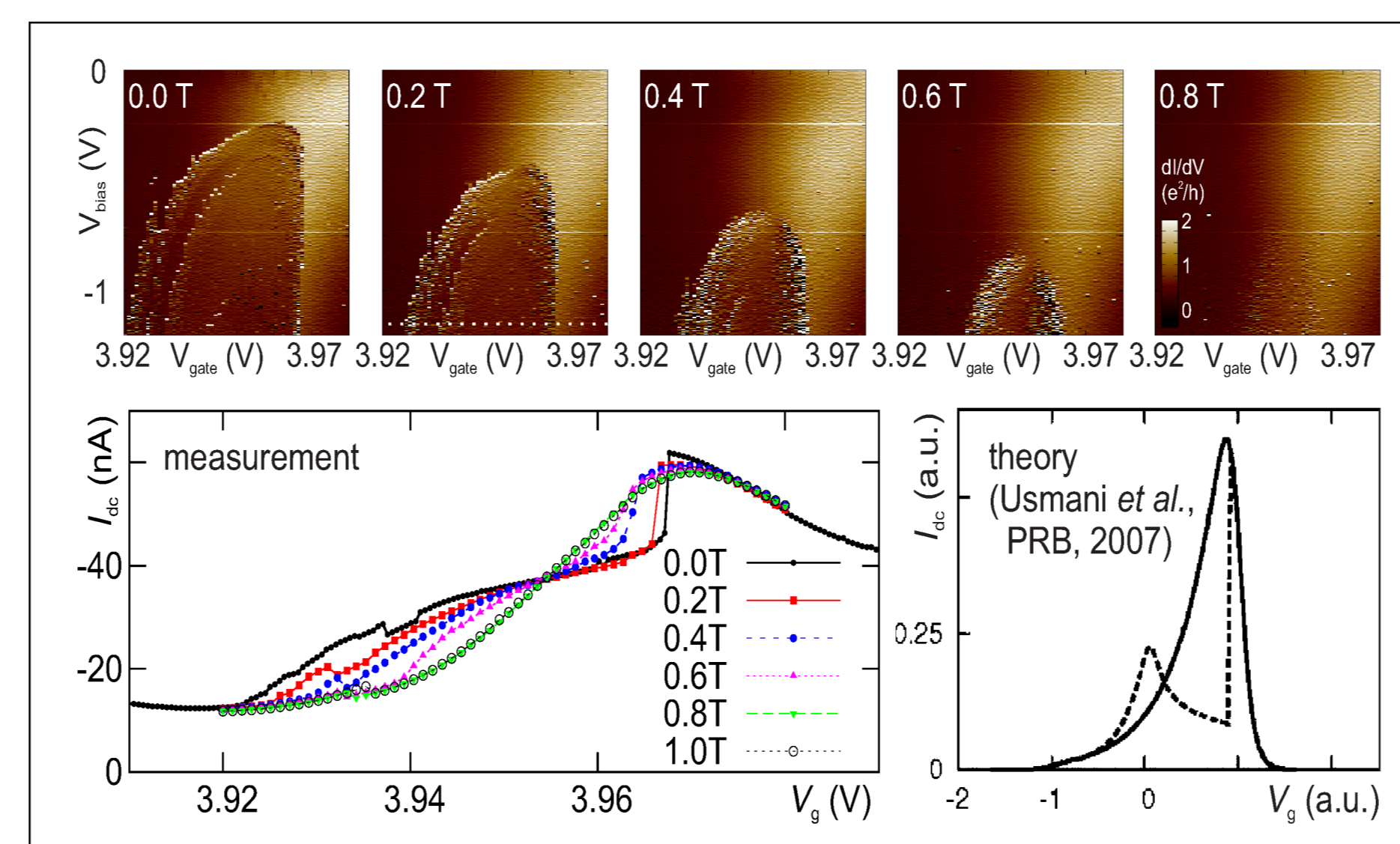
Transport spectrum at $N_{el} \approx 40$

- $T = 25$ mK \Rightarrow four-fold shell filling, Kondo effect
- superconductivity in the leads: energy gap
- mechanical self-driving of the CNT resonator without external RF signal [4, 5], see arrows



Suppression of self-driving

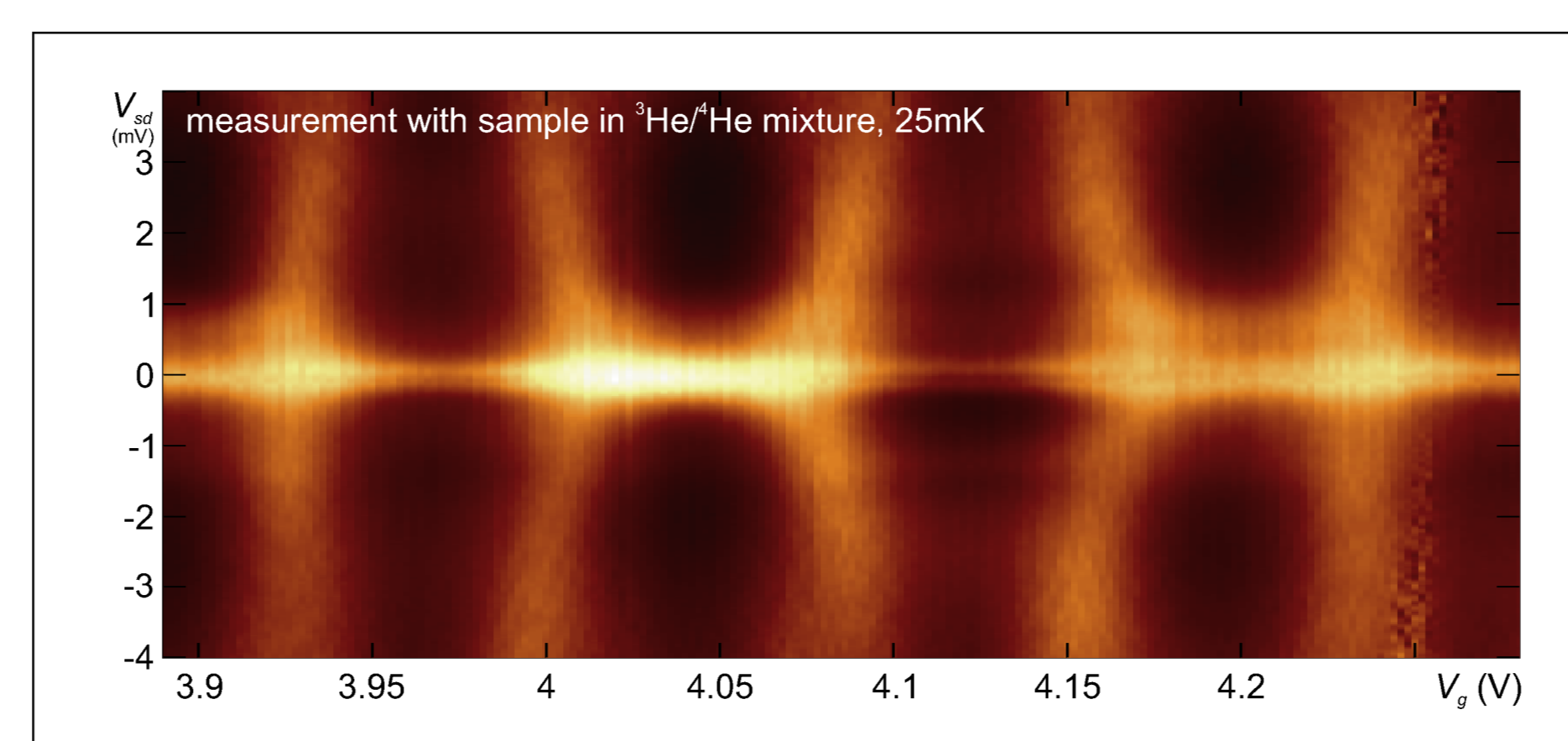
- feedback effects suppressed by magnetic field



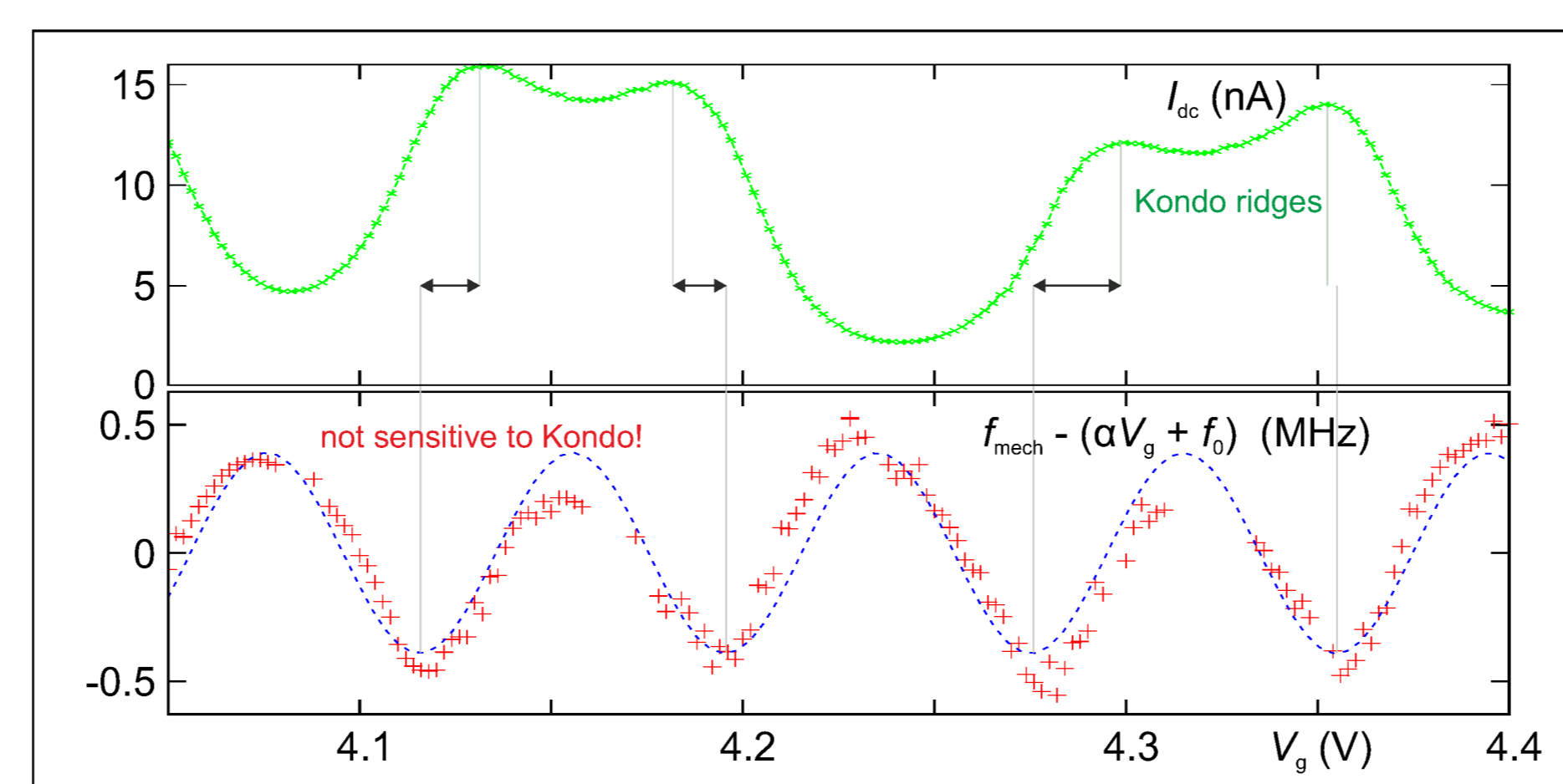
- line plot, comparison with theory [5]: magnetic field \rightarrow "as if there were no feedback"
- requirements for self-driving, neg. damping:
 - large electronic tunnel rate $\Gamma \gg 2\pi f$
 - high Q factor
- tunnel rates do not change in this field range
- magnetically induced damping?

Consistency: All damped in LHe

- in $^3\text{He}/^4\text{He}$ mixture instead of vacuum: no mechanical instability even at much higher bias



Mechanical charge detection



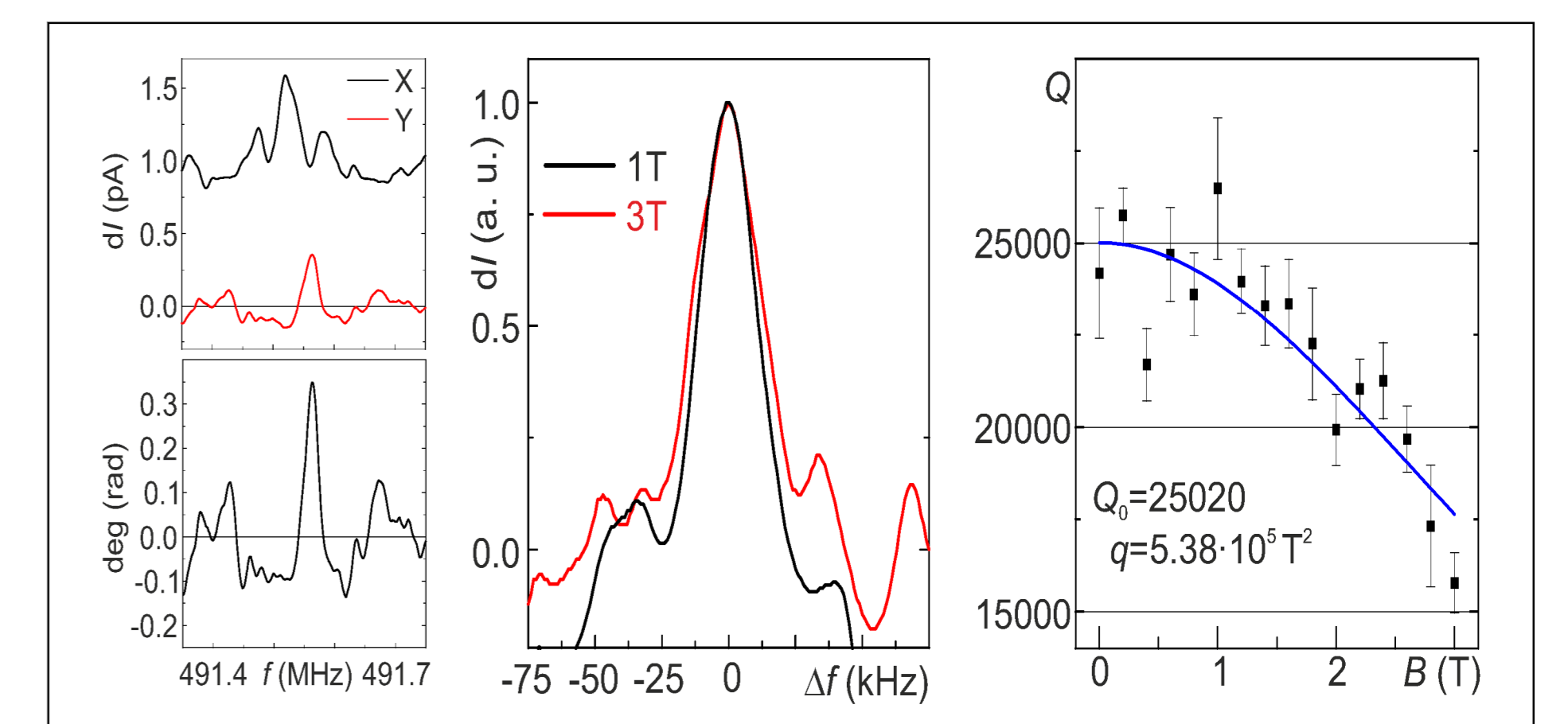
Magnetic damping [10]

- partial shortcut via parasitic capacitance (large) and resistance
- electromechanical damping: eddy current, Ohmic dissipation
- limitation of the observable Q factor as

$$Q_m(B) = \frac{q}{B^2} \quad \text{with} \quad q = 2\pi f \frac{Rm}{2\sqrt{2}L^2}$$

- quality factor Q_0 for zero external field
- resulting expected magnetic field dependence:

$$Q(B) = \frac{Q_0 Q_m(B)}{Q_0 + Q_m(B)}$$



- use double-frequency resonance and amplitude-modulated driving for better signal/noise ratio
- multi-peak signal visible
- at resonance, system response is delayed with respect to amplitude modulation
- $\Delta t \approx 0.3$ ms is consistent with mechanical energy storage, $Q \approx 10^5$
- use induced out-of-phase signal for fitting
- peak broadening in magnetic field observed, agrees very well with damping model



Postdoc position!

FAKULTÄT FÜR PHYSIK
Institute for experimental and applied physics

Postdoc position in NEMS available!

You have already been working successfully with millikelvin RF equipment in your PhD research, and have a good understanding of **low temperature physics** as well as **gigahertz technology**? Ideally, you are coming from a research group specialized in superconductor-related mesoscopic physics, quantum information, or cavity QED? You are interested in contributing to a young and dynamic team, trying to push the limits of what is doable in nano-electromechanical systems?

Then you might be just about right here. Your will conduct measurements on coupled **superconductor-carbon nanotube nano-electromechanical systems**, with a low-temperature high frequency measurement setup in a state-of-the-art dilution refrigerator. Our NEMS team consists at the moment of one PhD student and two MSc students (who you'll help supervise). We expect your work to lead to exceptional publications!

Your salary will be based on the German TV-L E13. Regensburg university has a strong focus on nanophysics, in particular on spin phenomena and carbon-based systems. The natives are friendly, and while our university buildings feature classic 1965 concrete, the medieval city of Regensburg is a jewel on its own, with a vibrant young atmosphere. Both mountains and Munich airport are not far away.

Interested? Have a look at <http://www.physik.uni-r.de/forschung/huettel/> and contact **Andreas K. Hüttel** (e-mail: andreas.huettel@physik.uni-r.de) for more information!

References

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