Superconducting Quantum Magnetomechanics

MIP Seminar

Innsbruck, 27.11.2019

Christian Schneider

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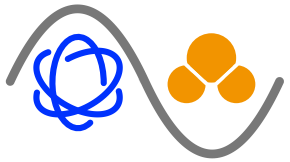
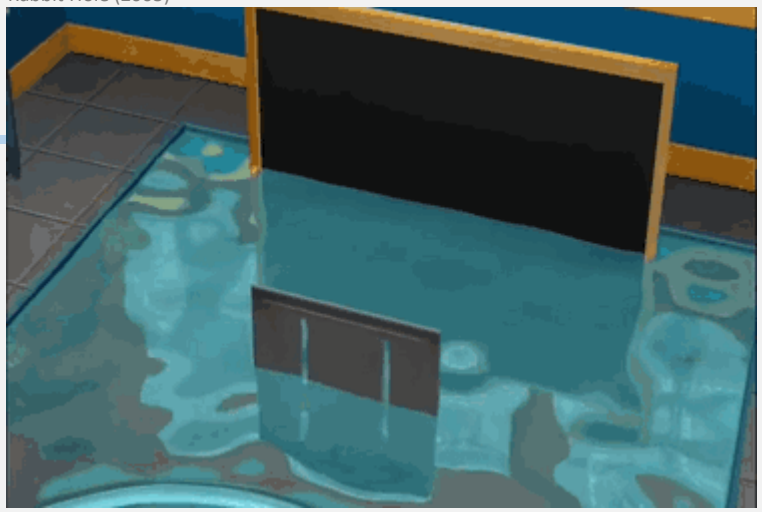


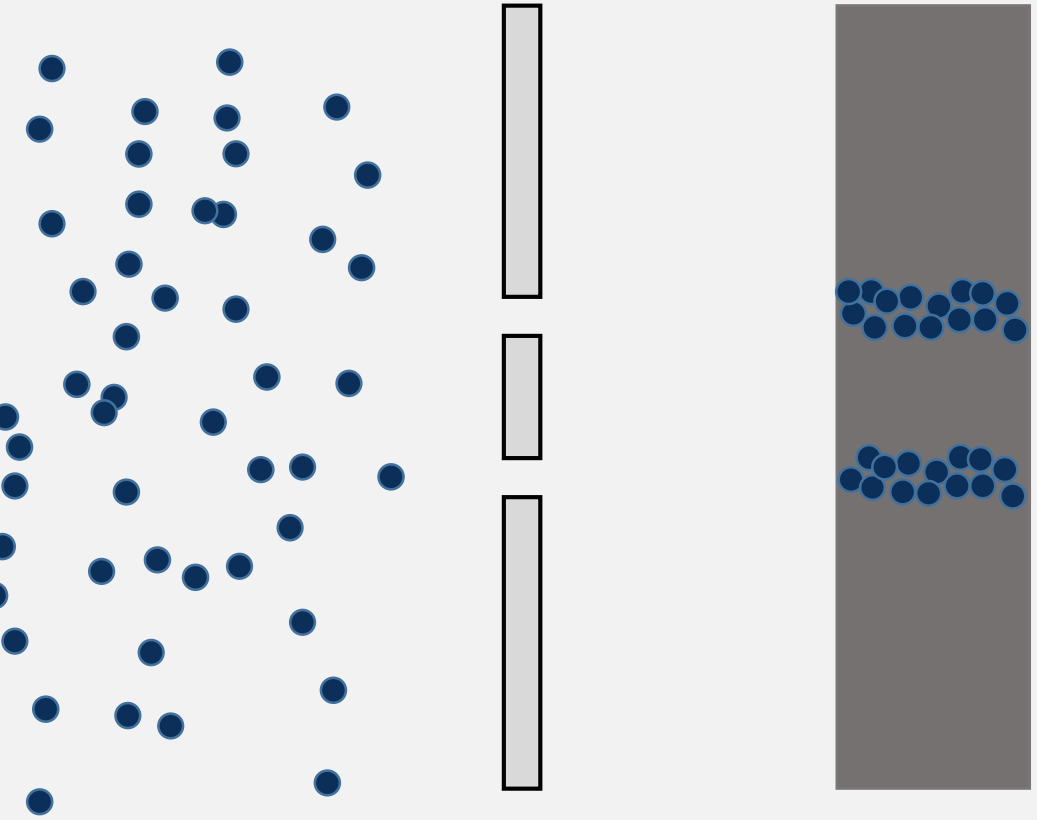
Picture by D. Jordan and M. Juan

The double slit experiment

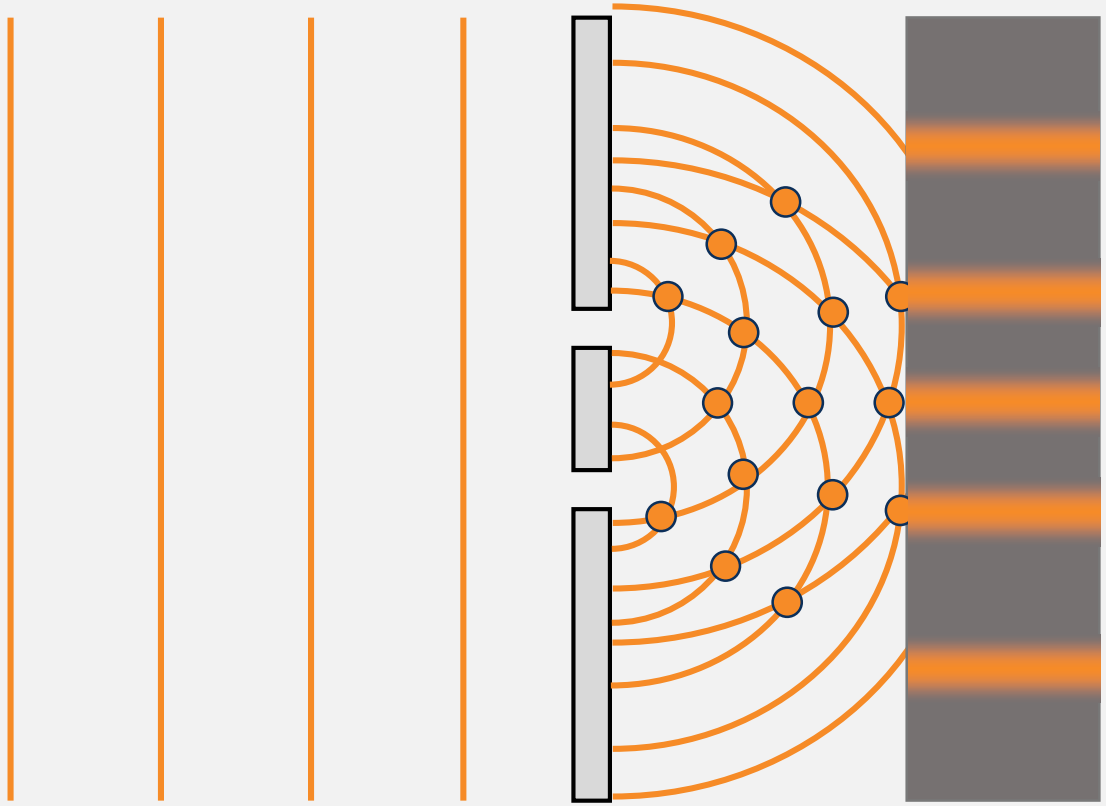
Dr Quantum – Double Slit Experiment | What The Bleep Do We know!?: Down the Rabbit Hole (2005)



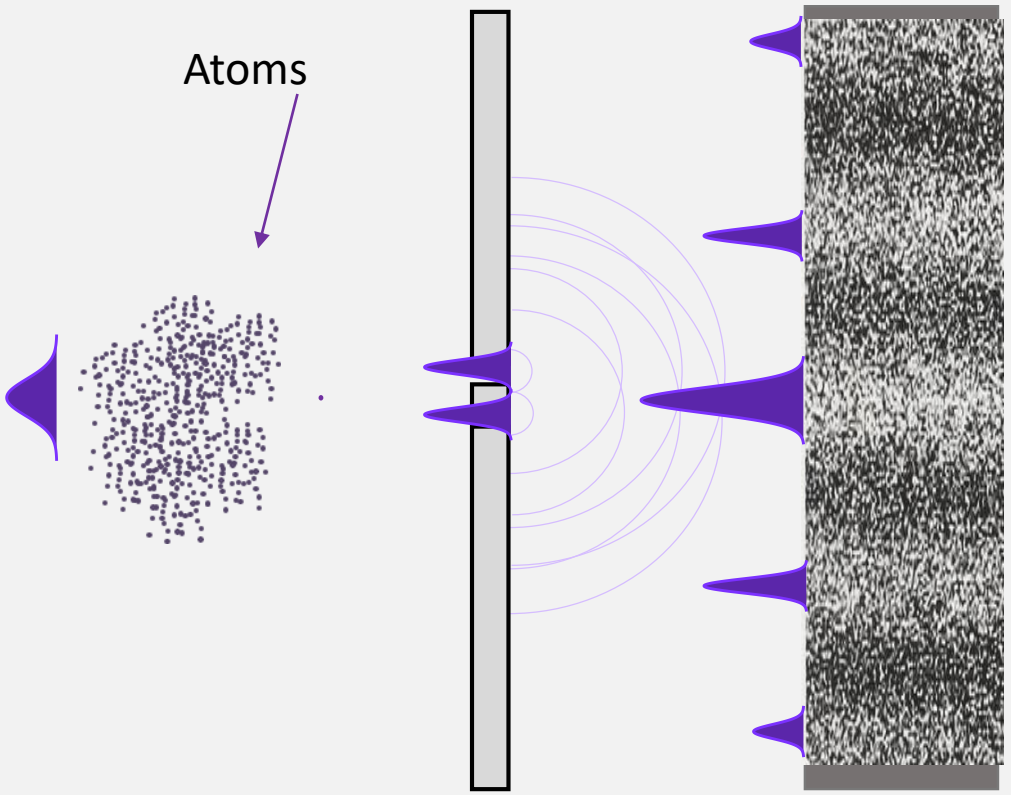
Particles



Waves



Quantum mechanics



Double-Slit-Experiment with single Electrons | Dr. Tonomura | Belsazar | CC-BY-SA-3.0

Location of a particle

Classical physics

Probability distribution

Quantum physics

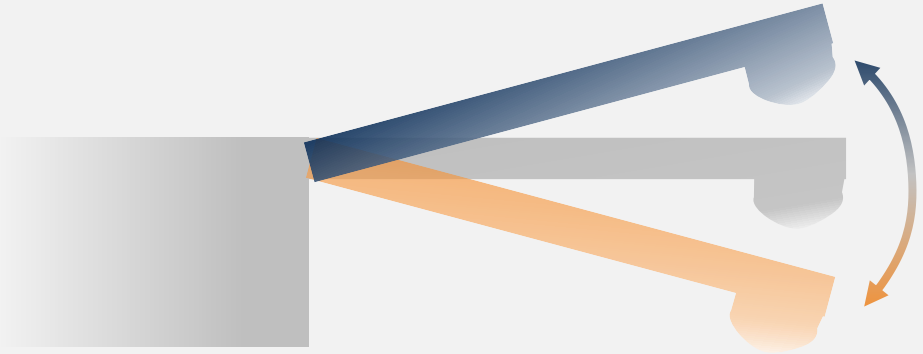
Superposition state

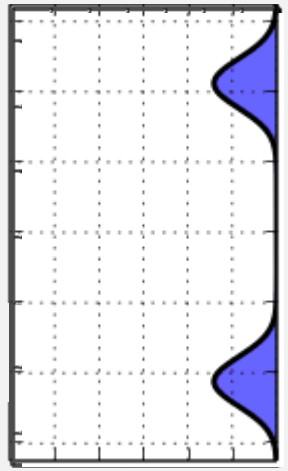
1 Electron (1930) → Carbon**60** (1999) → Biomolecules (**2000 atoms**, 2019) → ???

How big can a quantum system be?

Mechanical systems in the quantum regime

Our system: cantilever





- Is it possible to excite it in a quantum state?
- Classical to quantum transition
- Applications in sensors and transducers

But how to get it to a quantum state?

PRL 114, 143602 (2015) PHYSICAL REVIEW LETTERS week ending 10 APRIL 2015

Strong Single-Photon Coupling in Superconducting Quantum Magnetomechanics

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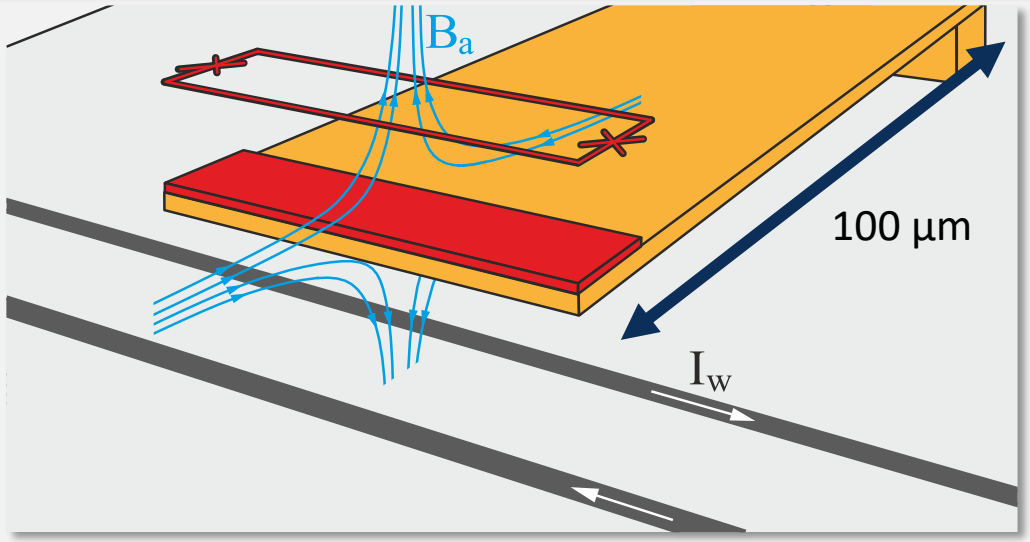


Idea: Couple strongly a **well controlled superconducting circuit** to a mechanical system with **strong magnetic coupling**

My PhD: From paper to lab

Parameter Study

- Literature research or experience about **realizable parameters**
- **Analytical calculations** and **optimization**

Simulations

- **Finite element simulations** of actual setup or simplified setup

Design

- Finalizing design and make it **compatible with fabrication process**

Sample Fabrication

- **Fabricate sample** yourself
- Or **coordinate with collaborators**

Experimental Setup

- **Design** sample holder/boxes/shields
- **Coordinate** with mechanical workshop
- **Do it yourself** (lathe, mill, drill, etc.)
- **Wire bonding, cryostat maintenance** …

Measurements

- Buy and learn how to use **state of the art measurement devices**
- **Program drivers, control Systems**, ….
- **Debugging**

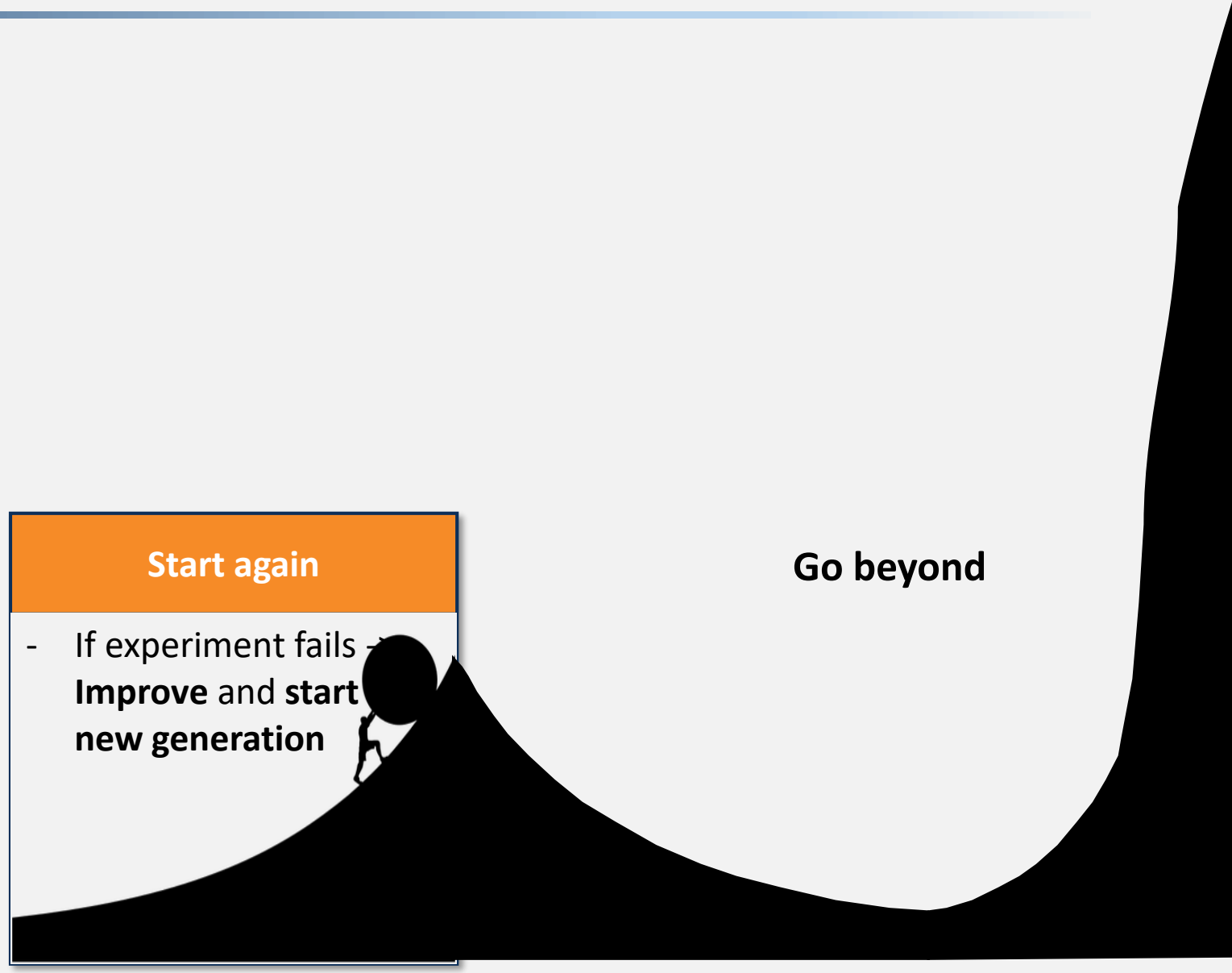
Data Analysis

- **Understand** what's going on
- **Fit data to models** and **verify results**

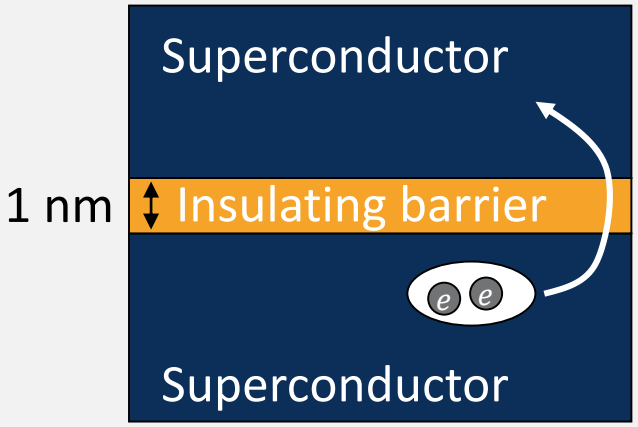
Start again

- If experiment fails -> **Improve** and **start a new generation**

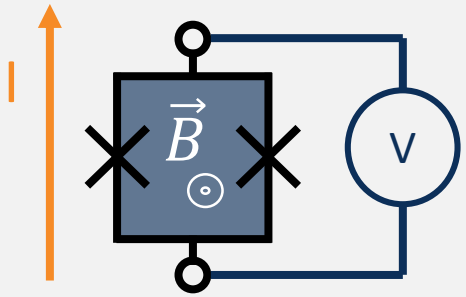
My PhD: From paper to lab



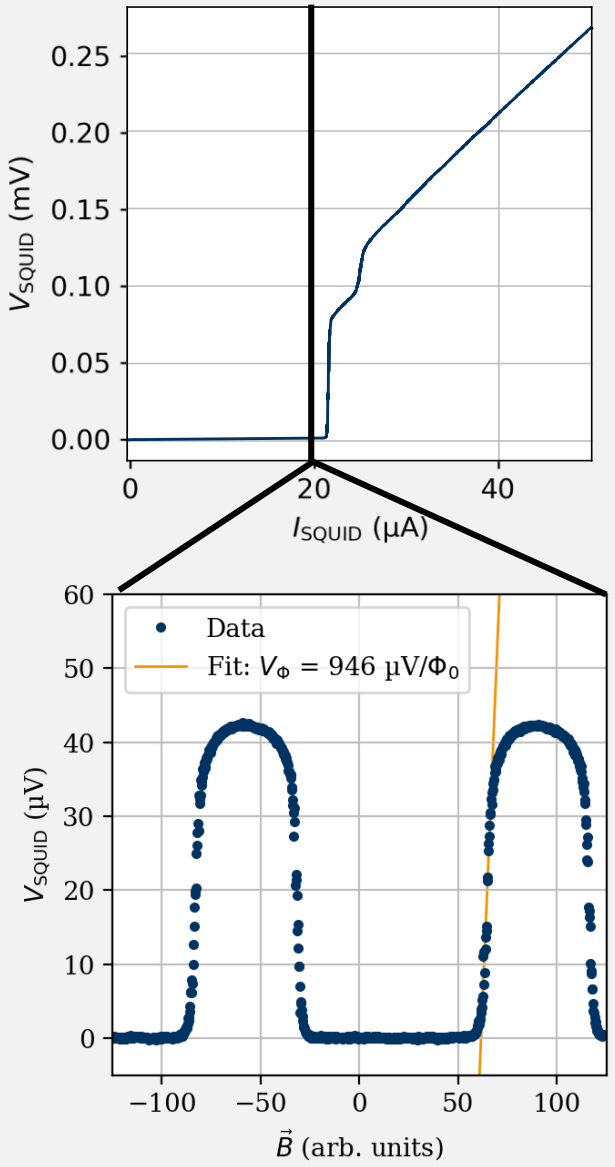
Superconducting circuits



Josephson Junction



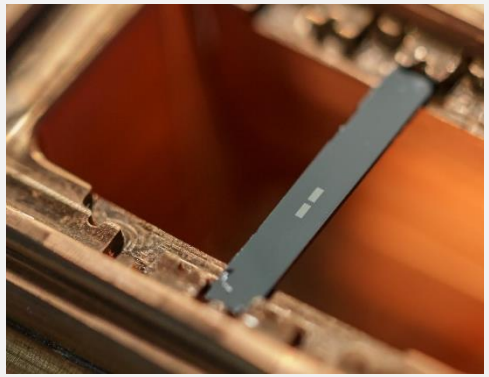
Superconducting Quantum Interference Device (SQUID)



- Most sensitive magnetic field sensor we have
- Wide range of applications

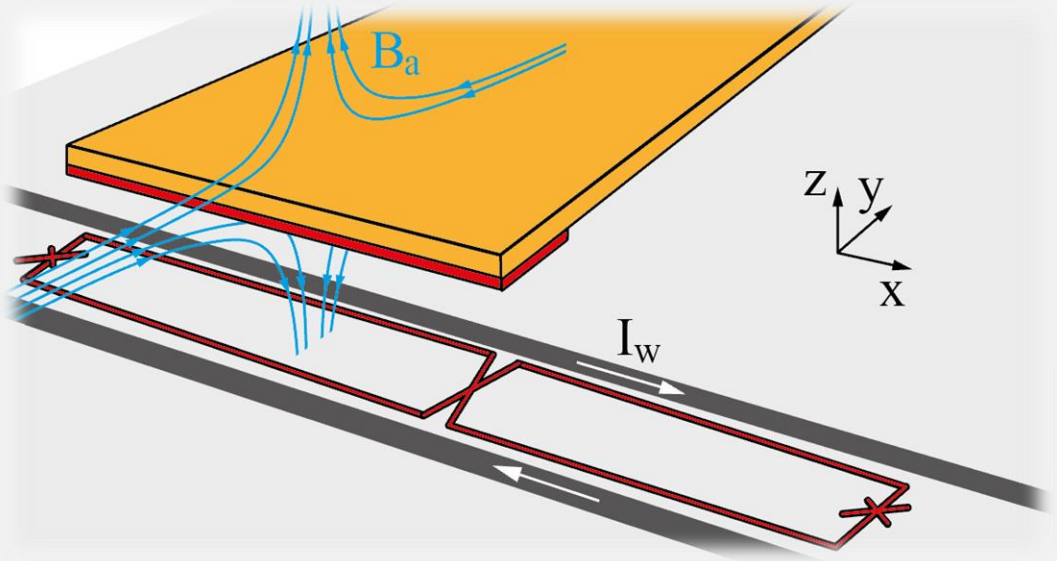
Wikipedia/ NIMH / Public Domain

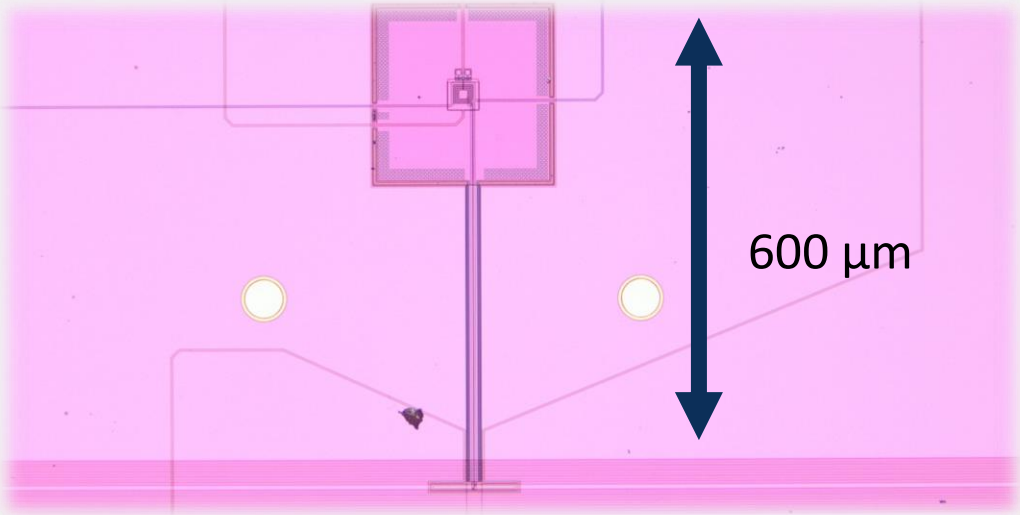
Picture of an MFI System / T-kruemmel / CC-BY-SA-3.0

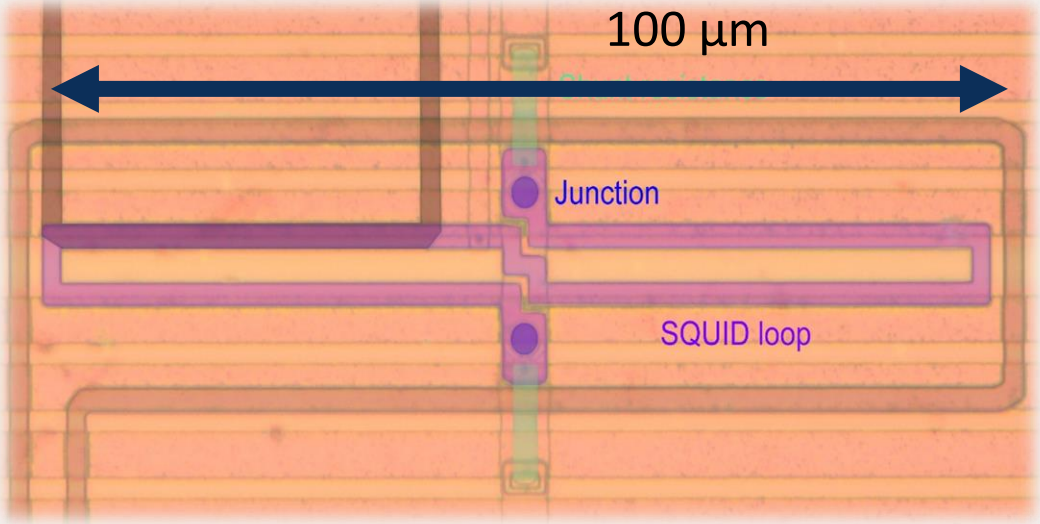


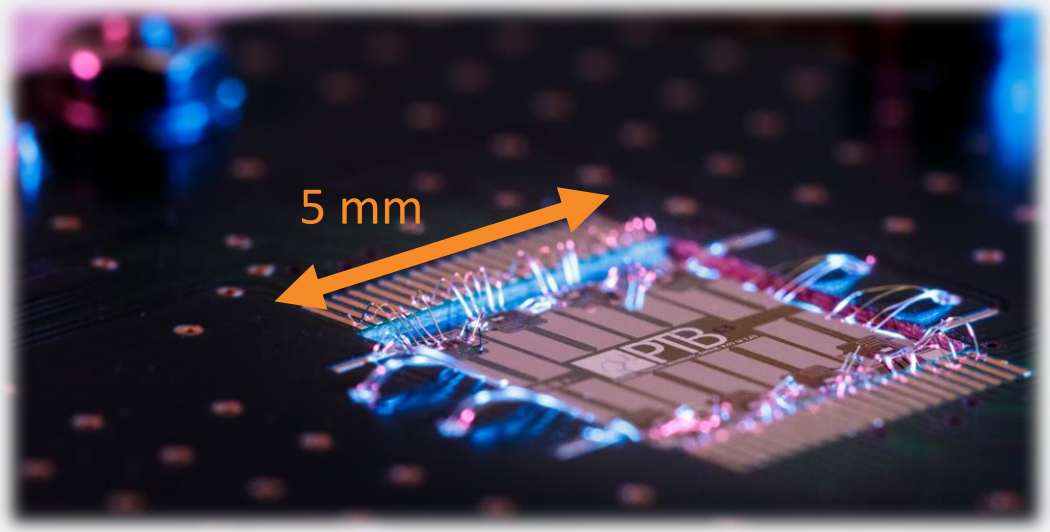
Superconducting qubits

DC Setup

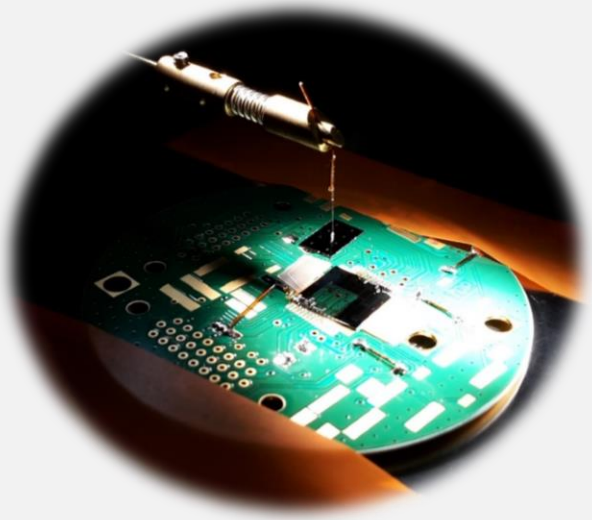


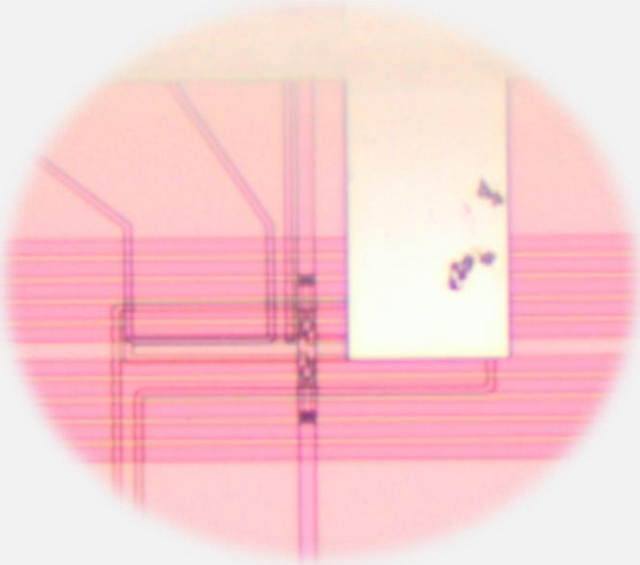


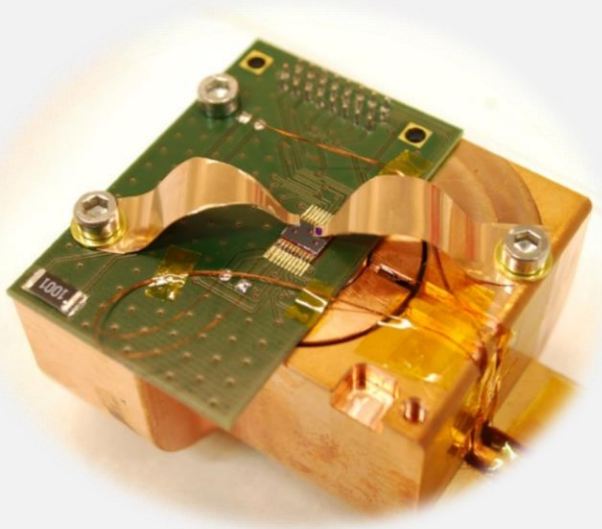


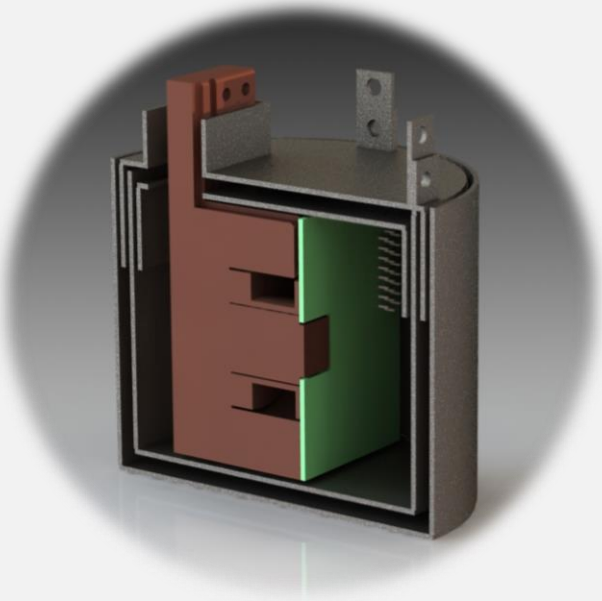


DC Setup + Cantilever

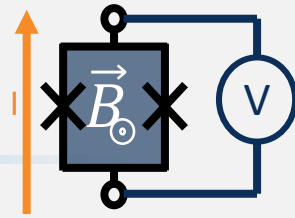




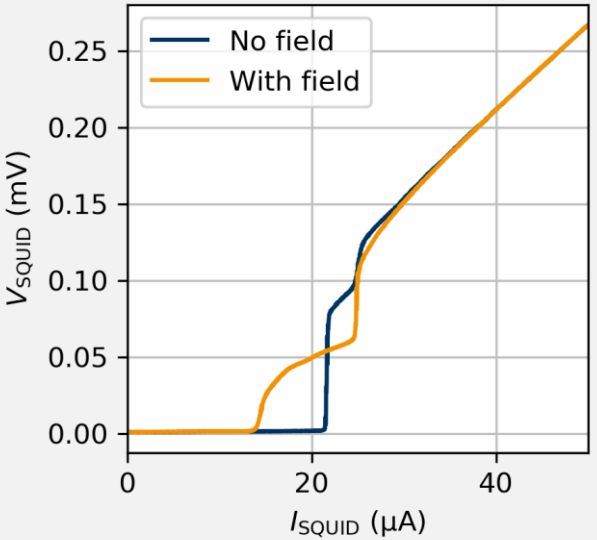


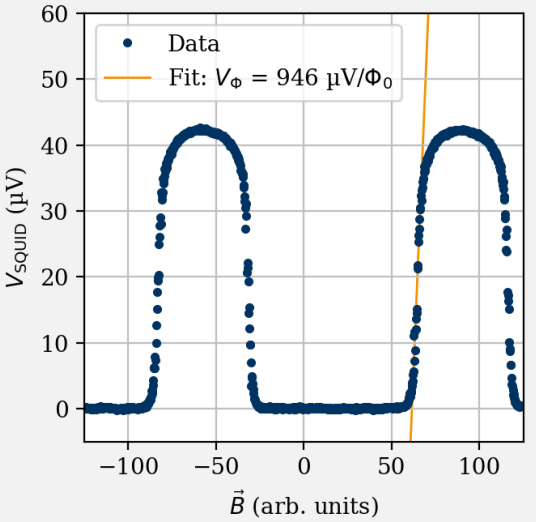


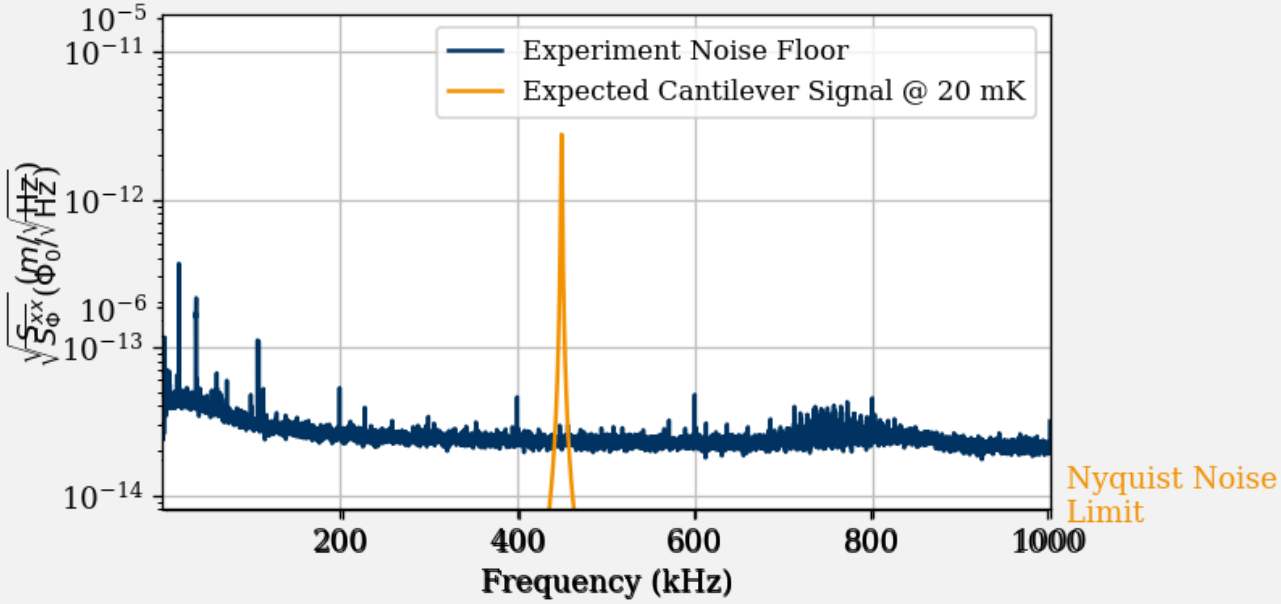
Results



- SQUIDs working
- Excellent noise performance
- Until now, no verified cantilever detection



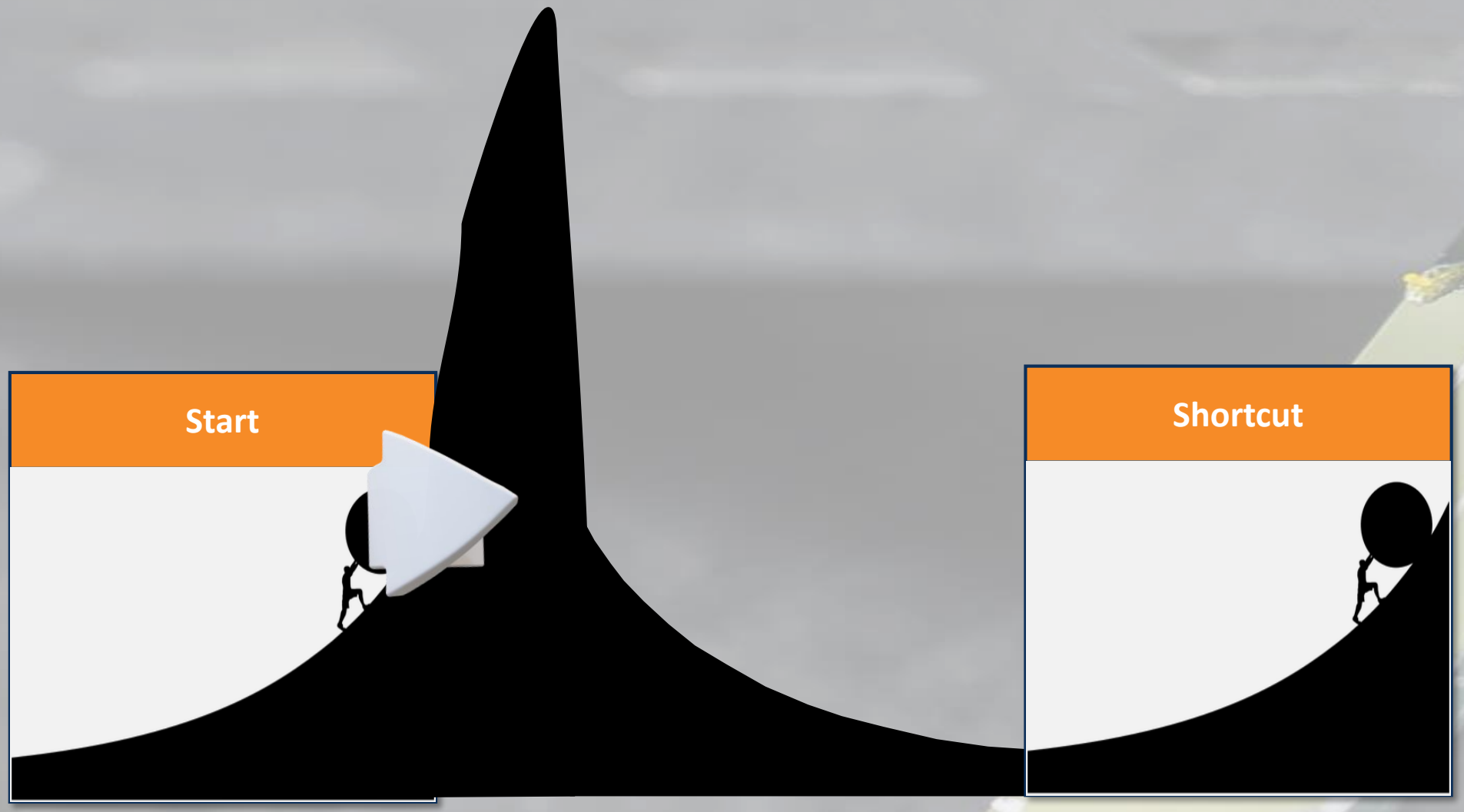




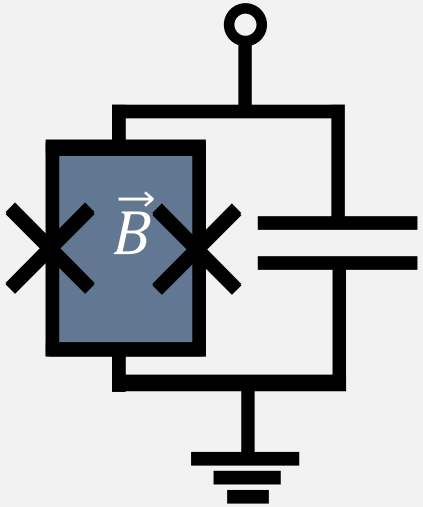
Nyquist Noise Limit

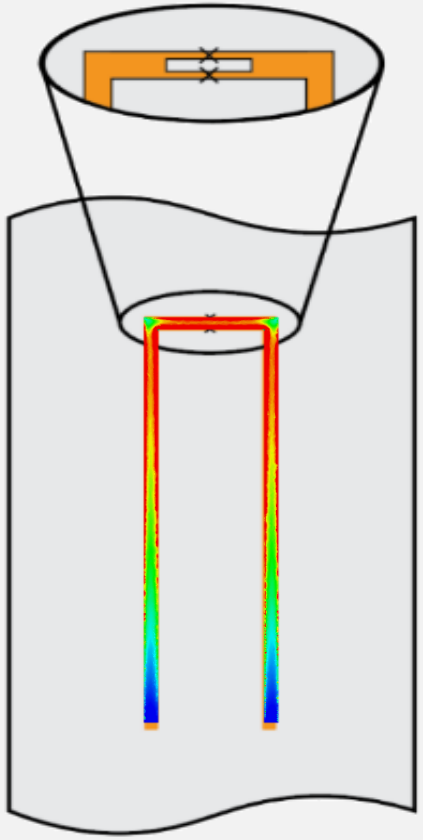
Microwave setup

Sometimes you have to walk around

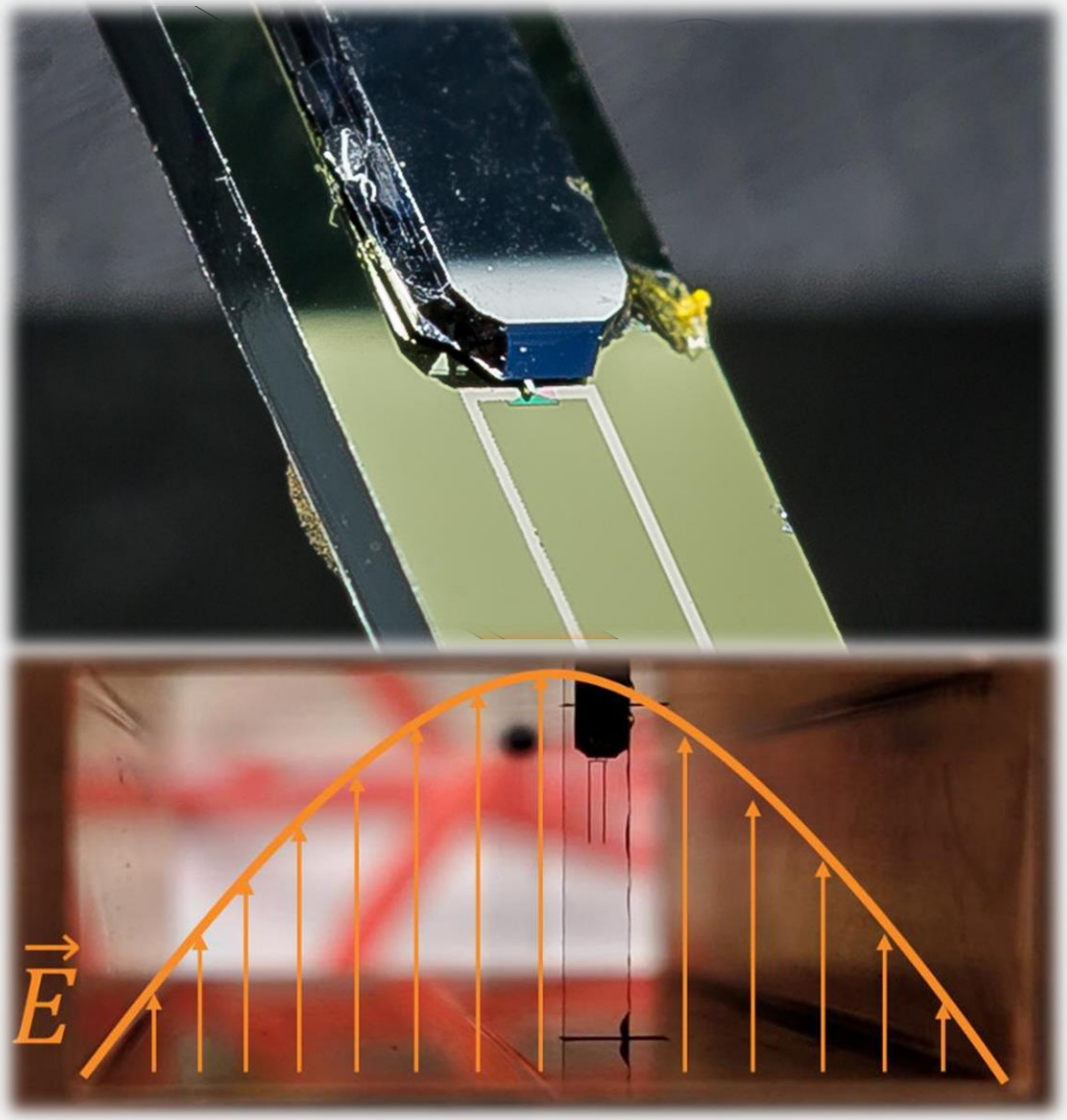


Microwave setup



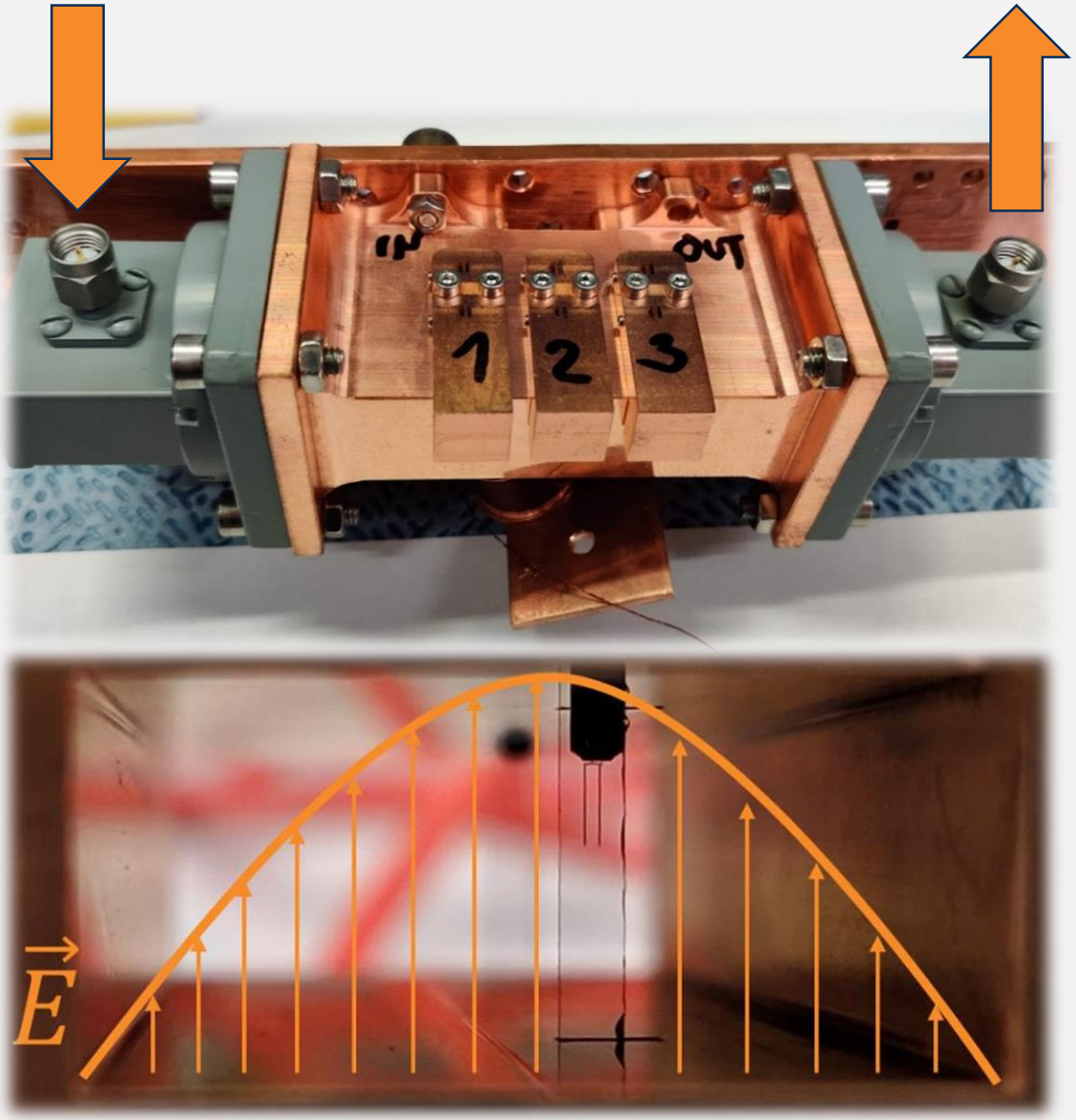


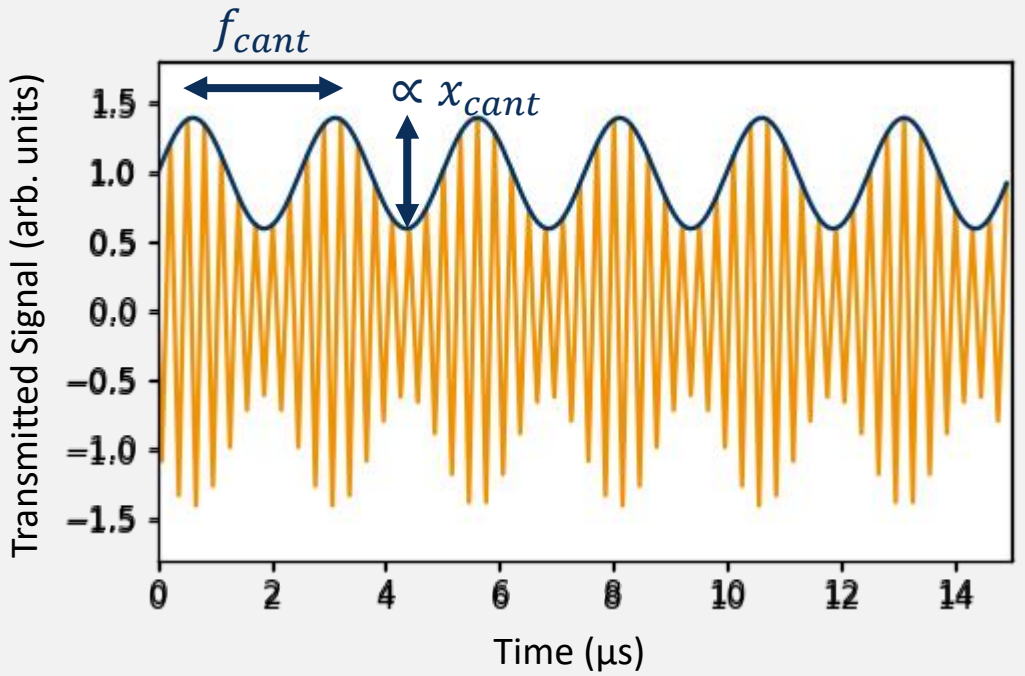
Current distribution



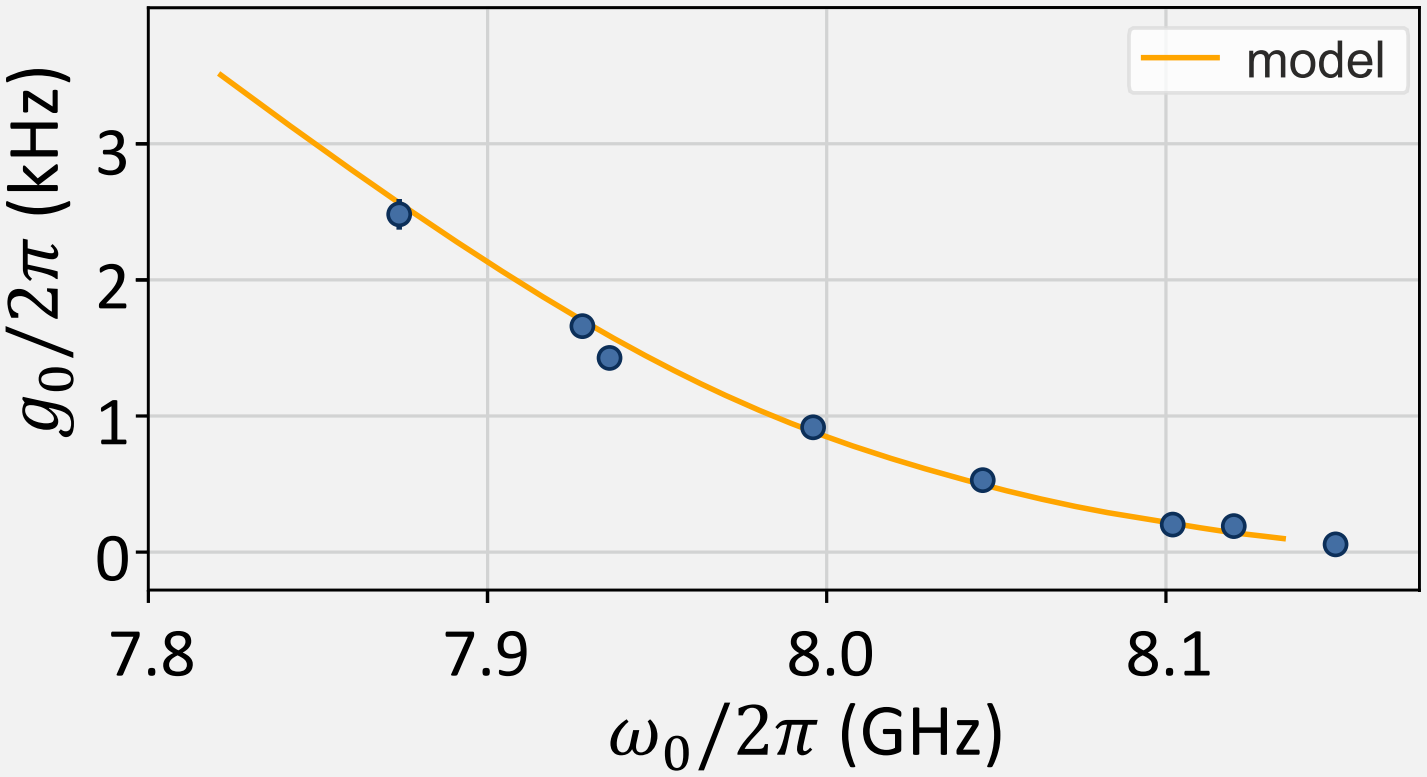
D. Zoepfl, P.R. Muppalla, CMF. Schneider, S. Kasemann, S. Partel, G. Kirchmair, AIP Adv. **7**, 085118 (2017)

Detection


IN
OUT
1
2
3
$\vec{E}$


f_{cant}
$\propto x_{cant}$
Transmitted Signal (arb. units)
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
0
2
4
6
8
10
12
14
Time (μs)

Results



Cantilever

$\omega_{\mathrm{mech}}/2\pi$	300 kHz
$\Gamma_{\mathrm{mech}}/2\pi$	0.15 Hz
τ_{mech}	1 s

Microwave resonator

$\omega_{\mathrm{res}}/2\pi$	7-9 GHz
$\kappa_{\mathrm{res}}/2\pi$	2 MHz
$\tau_{\mathrm{microwave}}$	80 ns ☹

Interaction

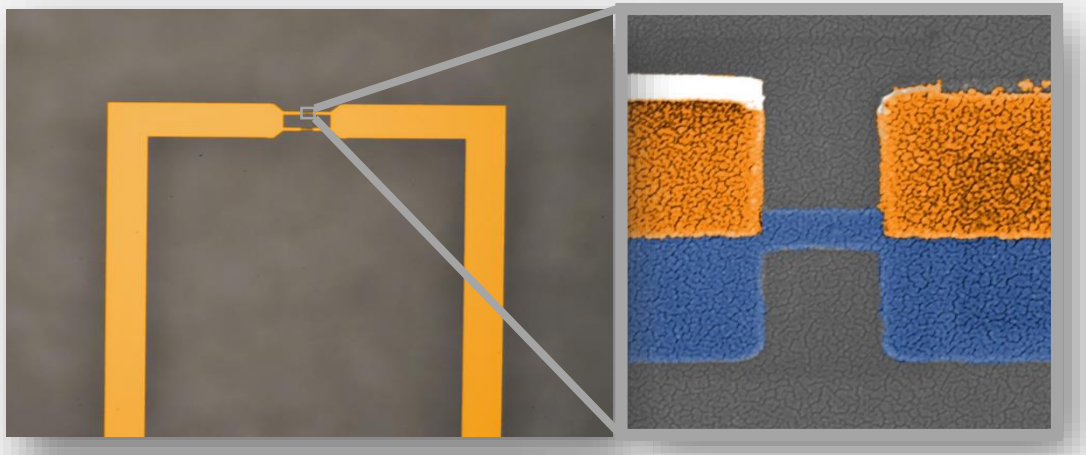
$g_0/2\pi$	2.4 kHz ☺☺
$\tau_{\mathrm{interaction}}$	63 µs

D. Zoepfl, M. Juan, C. Schneider, G. Kirchmair, Publication in preparation

Current work & Outlook

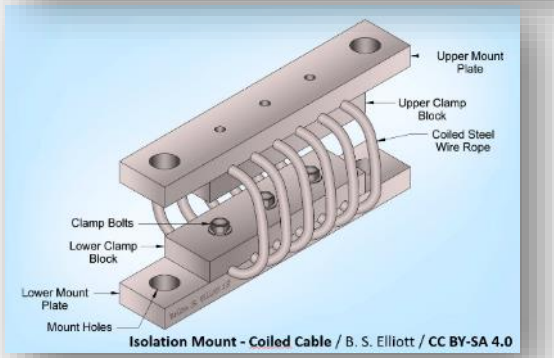
High Quality SQUID resonators

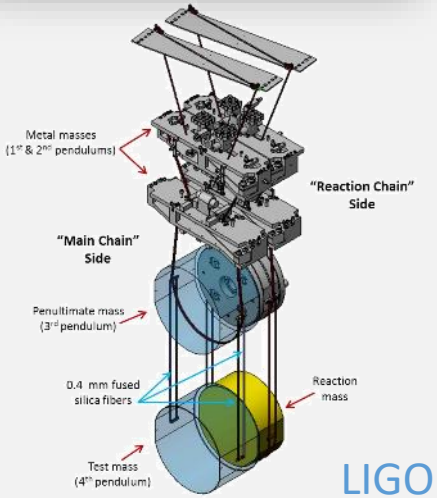
- Reduce loss
- Compatible with high magnetic fields



Vibration Isolation

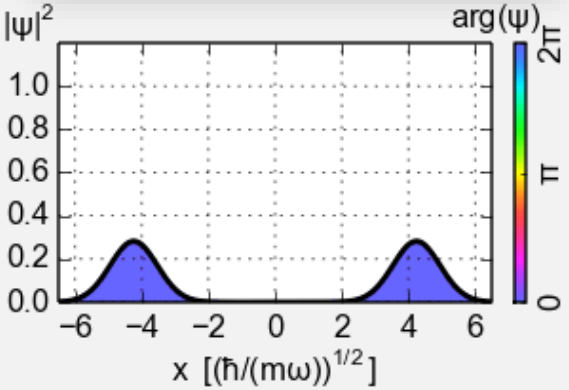
- Mechanical decoupling
- Cryogenic compatible





LIGO

Towards quantum state engineering of macroscopic objects



Thank you