Status of the New Quadrupole Resonator for SRF R&D.

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Introduction

Recent investigations of superconducting radio frequency (SRF) cavities have shown that materials such as Nb_3Sn, multilayer structures (SIS), and treatments like N-doping, N-infusion and mid-T bake of bulk Nb cavities increase the quality factors and maximum fields they can support. However, further research is required before a cavity made from these materials can go into operation. To carry out those studies, an improved version of a device called Quadrupole Resonator (QPR), originally developed and operated at CERN and HZB, has been further developed and built in a cooperation between Hamburg Universität and DESY. It will allow for systematic characterization studies of small superconducting samples over a broad parameter space defined by the resonance frequency, cryostat temperature and applied magnetic field.

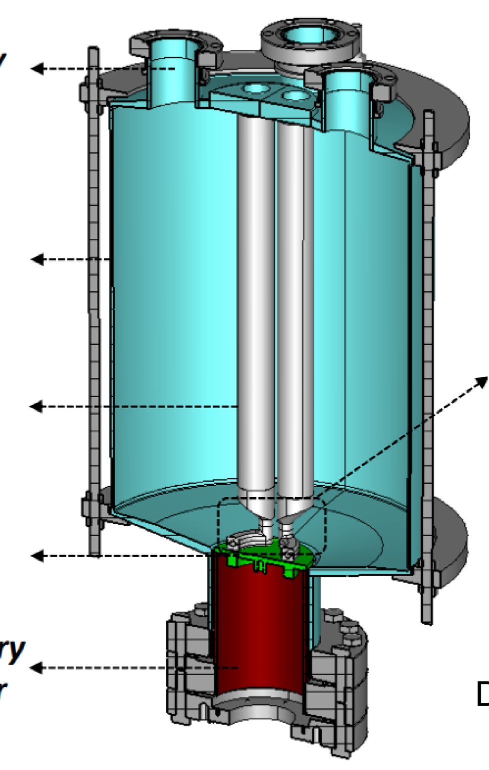
Quadrupole Resonator

Our QPR design allows for systematic investigation of **sample properties**, such as:

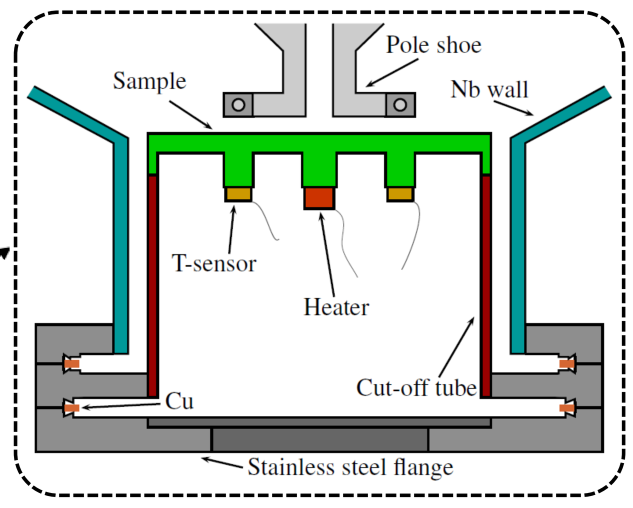
- Surface resistance $R_s(T,B,f)$
- Critical magnetic field $H_c(T)$
- Superheating magnetic field H_{SH}
- Penetration depth λ
- Mean free path ℓ
- Critical temperature T_c

QPR specifications:

- T~1.5-8 K
- f~426/860/1301 MHz
- $H_{sample,max}$~120mT
- Sample size of 7.5 cm



Schematic illustration of the QPR [1].

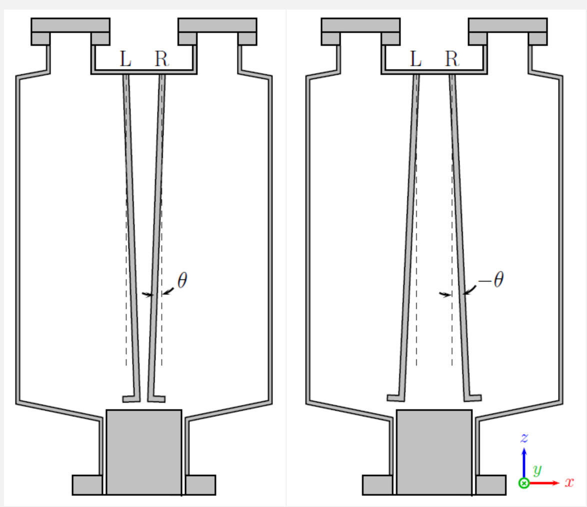


Detailed view of the calorimetry chamber.

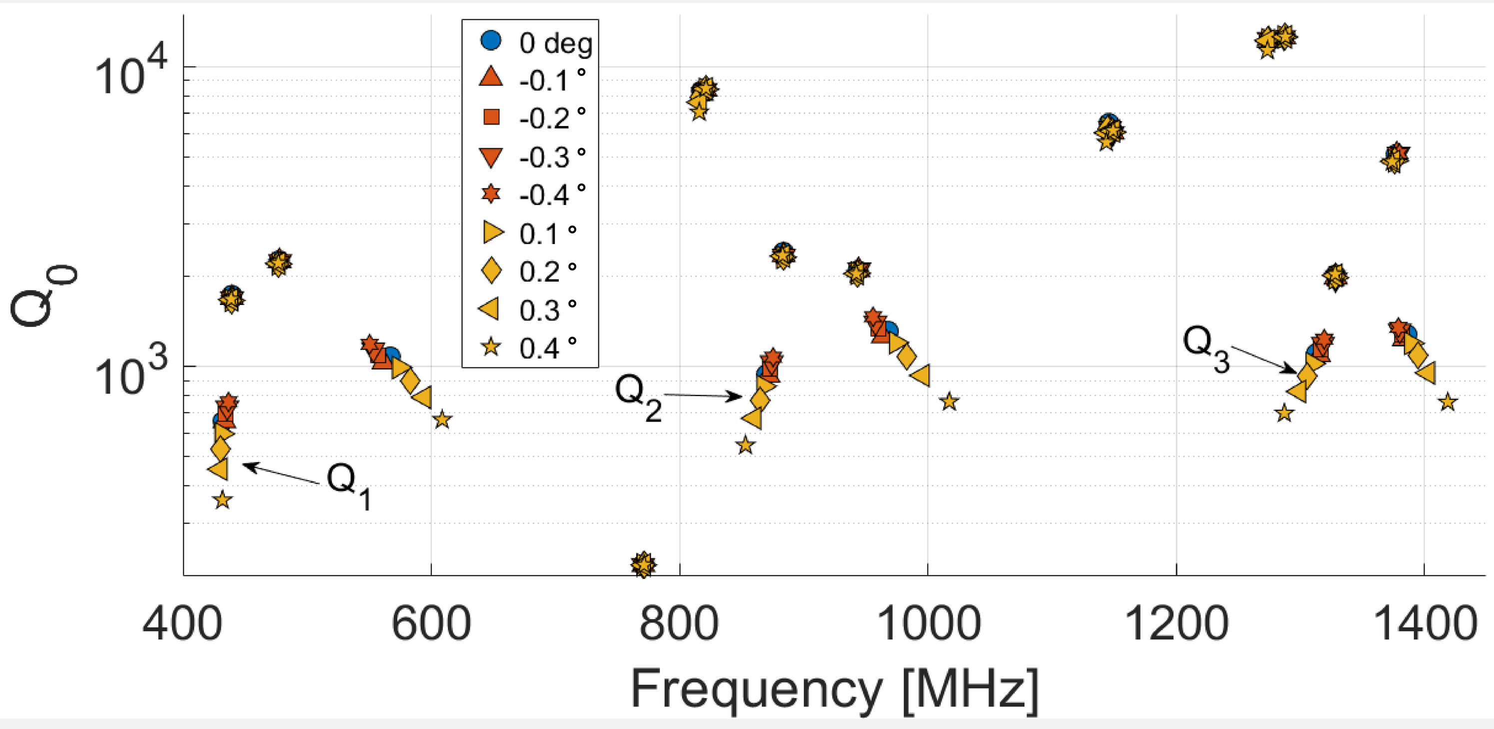
[1] R. Kleindienst, Ph.D. thesis, Universität Siegen, Germany (2017)

Static detuning simulation study

Fabrication errors can induce angle deviations of the Nb rods, which could result in a **place swap between two neighboring modes**. This will cause a systematic overestimation of the surface resistance of the sample. To study such a phenomenon, simulations were carried out using CST MICROWAVE STUDIO® varying the angle of both rods symmetrically. A **spread of the quadrupole modes** on the *f*-axis was observed, and an exchange of the **third quadrupole mode with the previous dipole mode** happened for a **0.4 °** tilting of both rods.

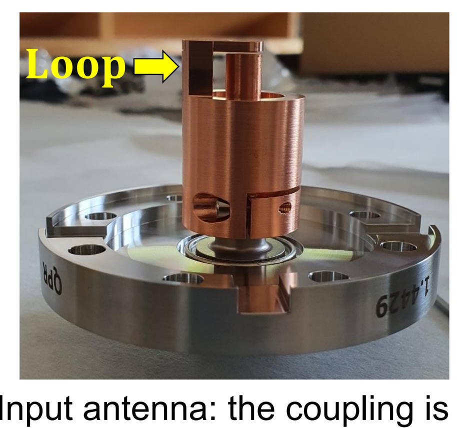


Schematic illustration of the angle variation of the rods. The Nb rods are rotated around the y-axis

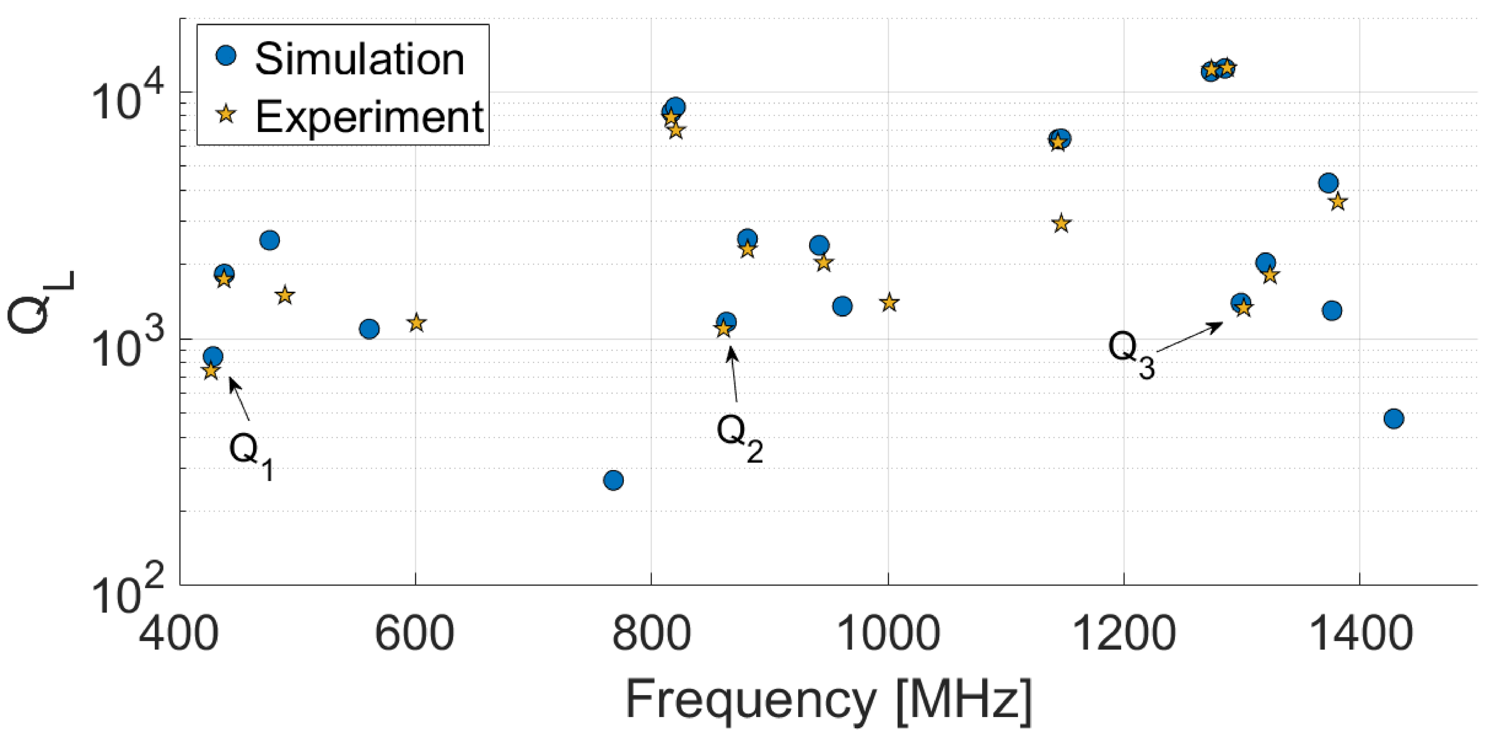


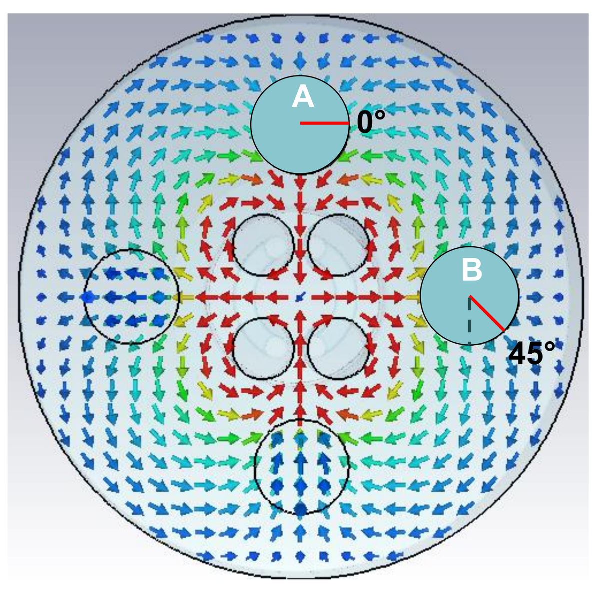
RF spectrum measurements at room temperature

The RF spectrum was also measured and the results were compared to simulated values. For the measurements, the input antenna loop area was oriented perpendicular to the magnetic field, while the pick-up antenna was oriented at 45°. For the simulations, a model with 10^6 hexahedrons was employed considering the geometrical information of the QPR after fabrication, *i.e.*, a test at Zanon R. I. showed both rods bending at an angle of **-0.05 °** around the *y*-axis. The **simulated frequency values** were found to be within a **4% deviation with respect to the real measurements** and no dynamic mode order swapping was observed.



Input antenna: the coupling is controlled via the angle between the loop area and the field orientation.





Input antena fixed in port position A and the probe in position B.

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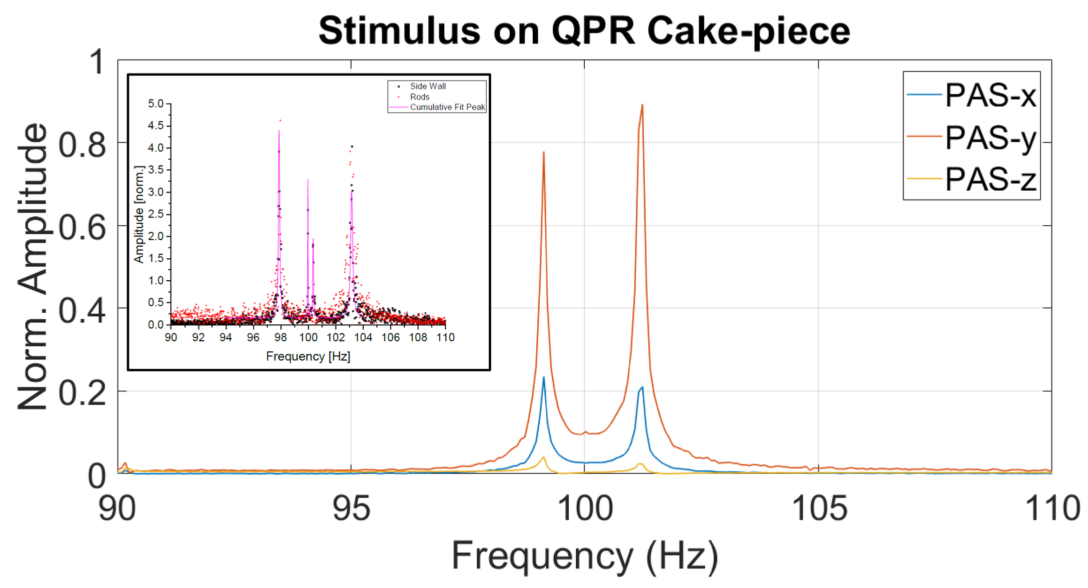
Mechanical resonances

Microphonics can trigger a dynamic detuning of the QPR. At HZB [2], a 100 Hz modulation on top of the driving RF signal was observed. Since **the mechanical eigenmode of the Nb rods also lies at 100 Hz**, they were excited, causing a build up of the detuning until the measurement system lost the resonance. To mitigate this problem in our QPR, a redesign of the inside of the Nb rods was done to improve their **stiffness**.

Four piezoelectric accelerometers on the QPR's surface measured vibrations in the x, y, and z axes.

To identify the mechanical spectrum in our resonator, several piezoelectric accelerometer sensors (PAS) were mounted and stimuli were produced on it. As was expected from its design, when hitting the resonator on the top part (called "cake-piece") **the mode at 100 Hz is not present**.



Normalized fast Fourier transform vs. Frequency. The smaller plot shows the mechanical modes of HZB's QPR [1].

[2] S. Keckert, Ph.D. thesis, Universität Siegen, Germany (2019)

Next step: surface treatment

After the commissioning phase, the **QPR will undergo a standard chemical treatment typical for Nb SRF cavities**. This treatment will be done at Zanon Research & Innovation SRL and consists of the following steps:

- Coarse BCP (>150 µm)
- 800 °C/3 h
- Fine BCP (20-40 µm)
- 120 °C/48 h

Subsequently, the resonator is going to be **tested at cold temperatures** throughout the operation phase.

Summary

A test cavity called Quadrupole Resonator, further developed and built in a collaboration between Hamburg Universität and DESY, will allow for systematic studies of superconducting samples in the *f*, *T*, and *B* space.

The QPR was expertly manufactured at Zanon R. I. and successfully commissioned at DESY, where its mechanical and RF spectra were identified. As was expected from its design, no mechanical mode at 100 Hz is detected, and the RF modes are within a 4% deviation with respect to the simulated values.

The QPR surface is going to be chemically treated like a Nb SRF cavity, and the tests at cold temperatures will be performed afterwards during the operation phase.

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