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 the 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 the systematic study 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 **SRF sample properties**, such as:

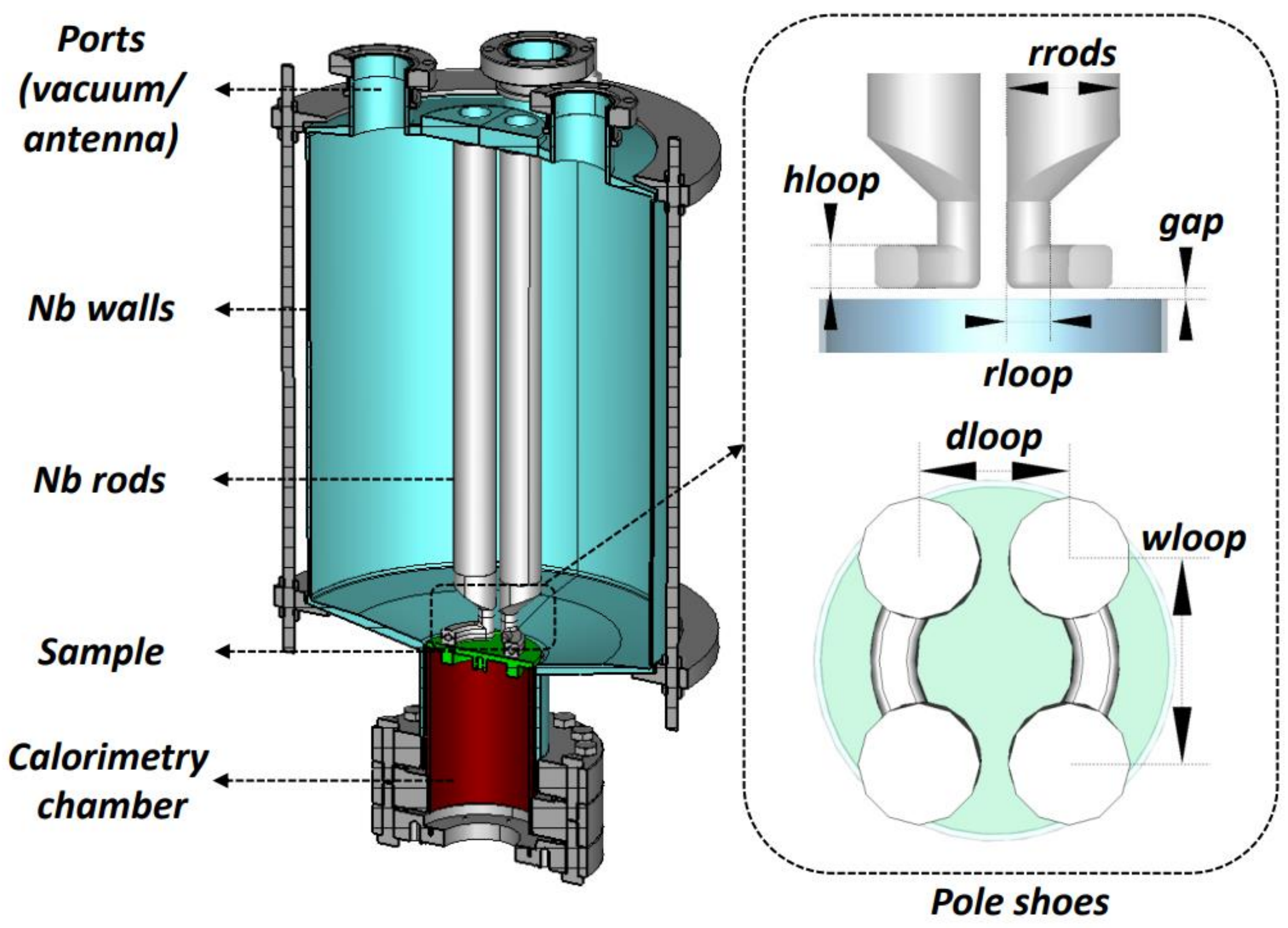
- Surface resistance $R_s(T, B, f)$
- Critical magnetic field $H_c(T)$
- Superheating magnetic field H_{SH}

and enables determining the following **material properties**:

- Penetration depth λ
- Mean free path ℓ
- Critical temperature T_c

QPR specifications:

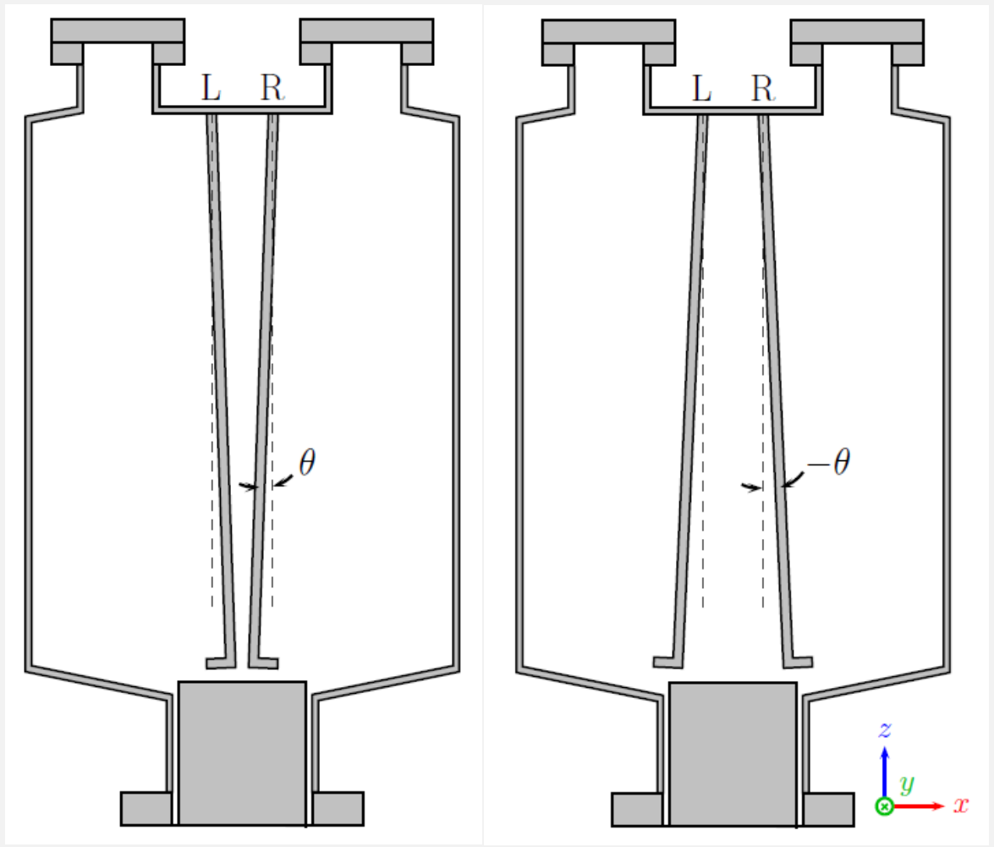
T~1.5-4 K, $H_{sample,max}$~120mT and f~433, 870, 1310 MHz



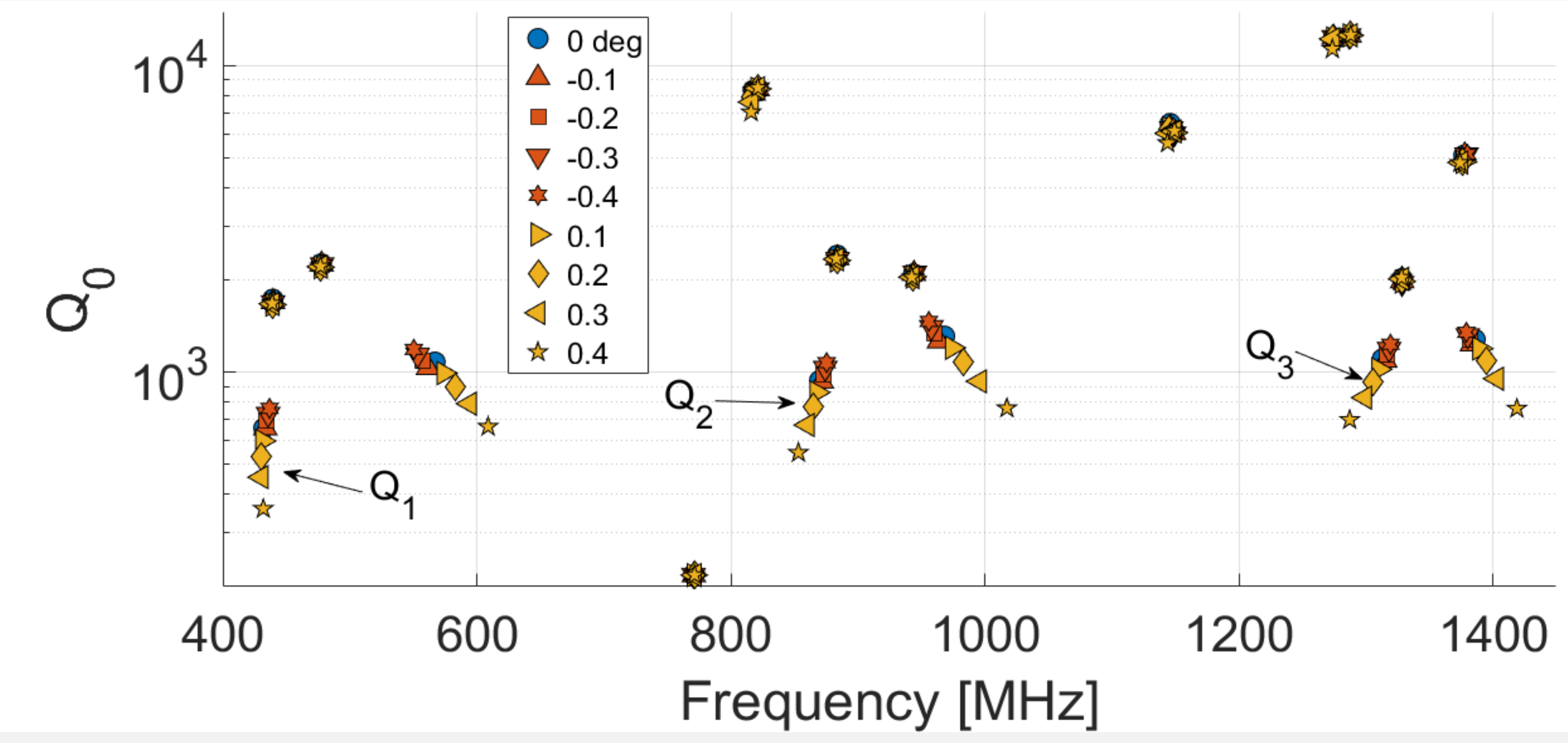
Schematic illustration of the QPR [R. Kleindienst, Ph.D. thesis, Universität Siegen, Siegen, Germany (2017)].

Static detuning study

Fabrication errors induce angle deviations of the Nb rods, which could result in a simultaneous excitation of more than one mode. Such an additional undetected mode will contribute to the losses measured, and subsequently cause a systematic overestimation of the surface resistance of the sample. To study such a phenomenon in our device, simulations of the static detuning were carried out using CST MICROWAVE STUDIO® varying the angle of the right rod, both rods and both pole shoes. In the case of the bending of both rods, a spread of the quadrupole modes on the *f*-axis was observed, and an **exchange** of the third quadrupole mode with the previous dipole happened for 0.4°.



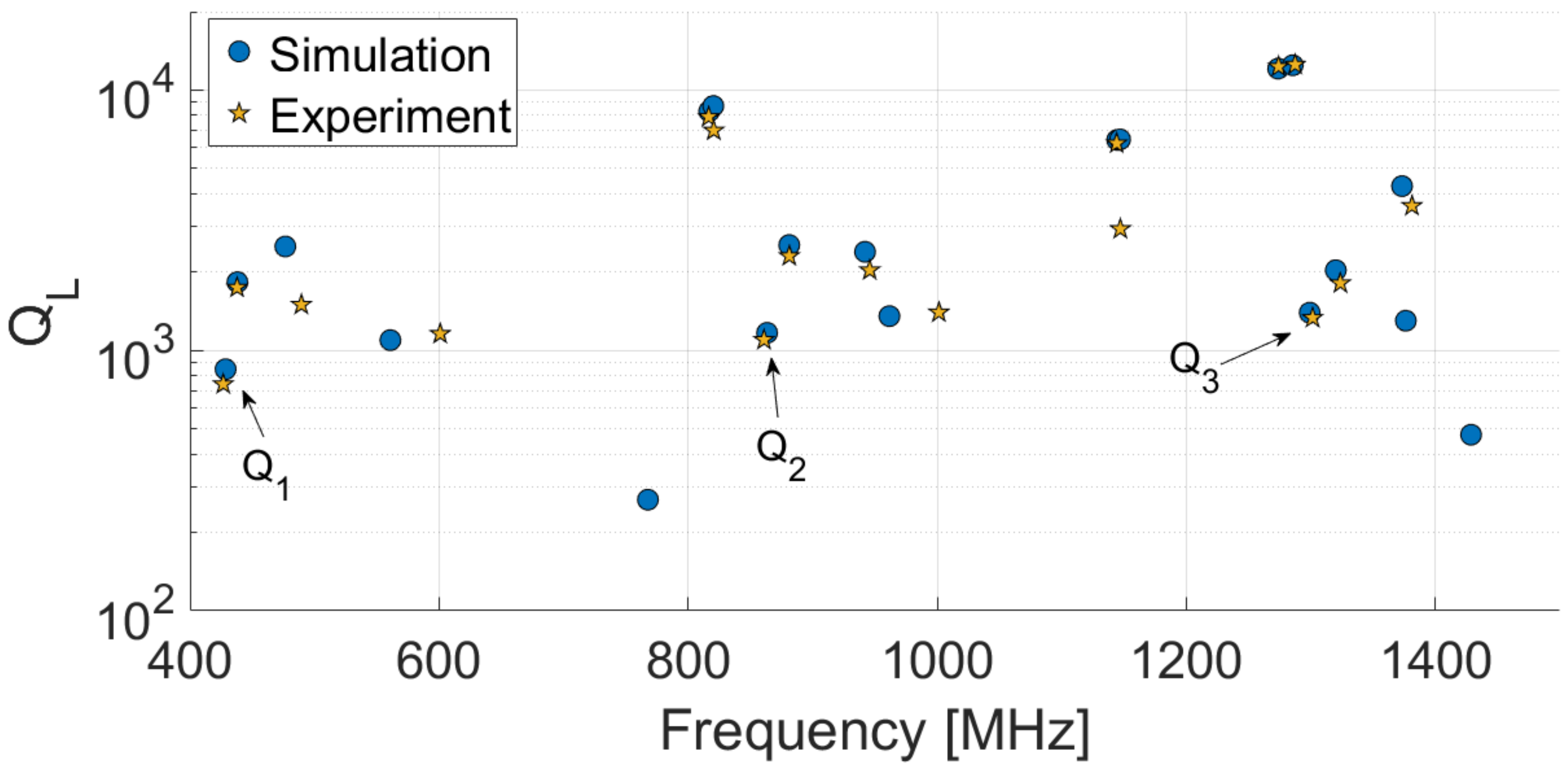
Schematic diagram of the angle variation of the rods.



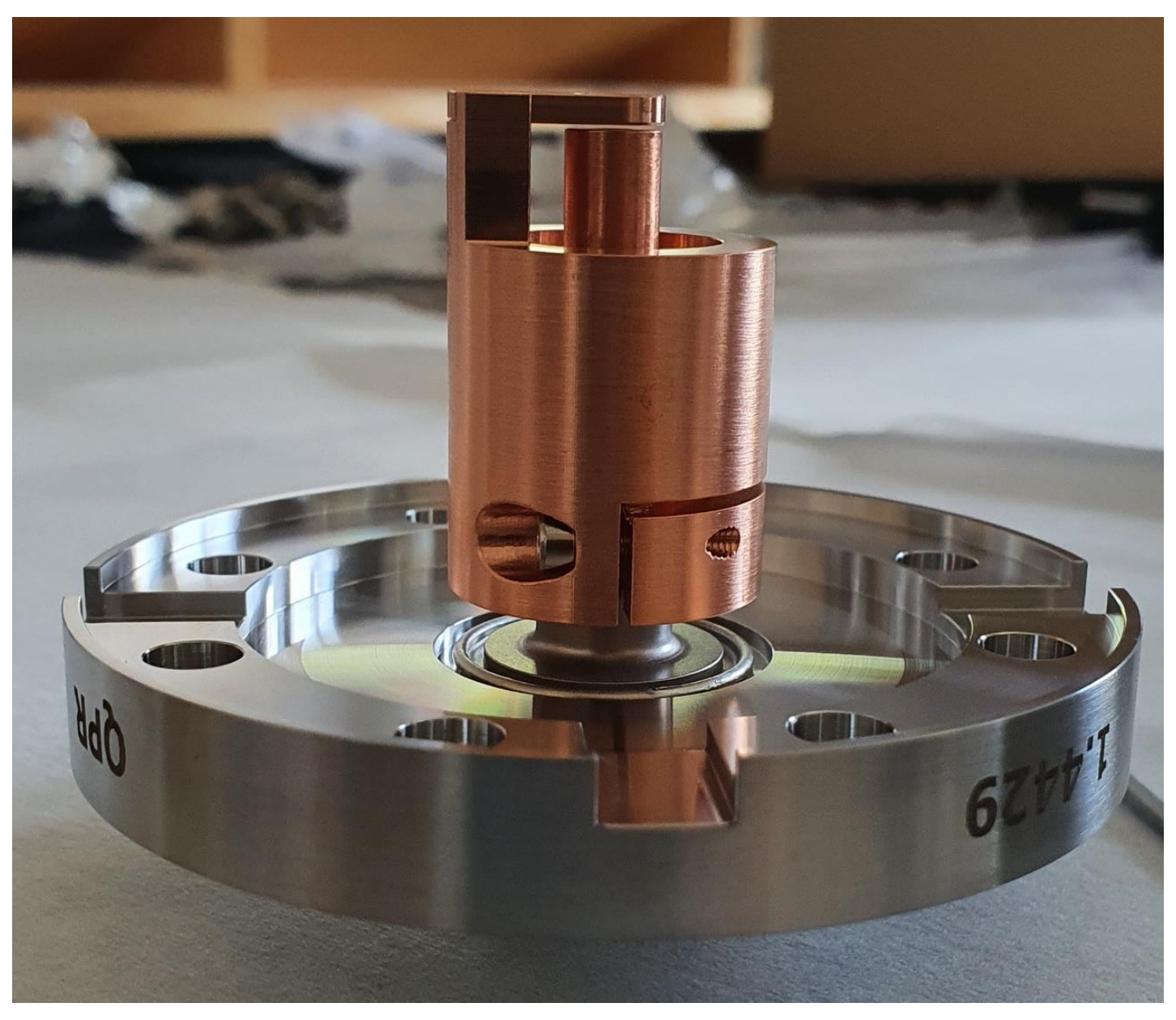
Quality factor vs. Frequency at room temperature with a rotation of the rods around the y-axis.

RF spectrum at room temperature

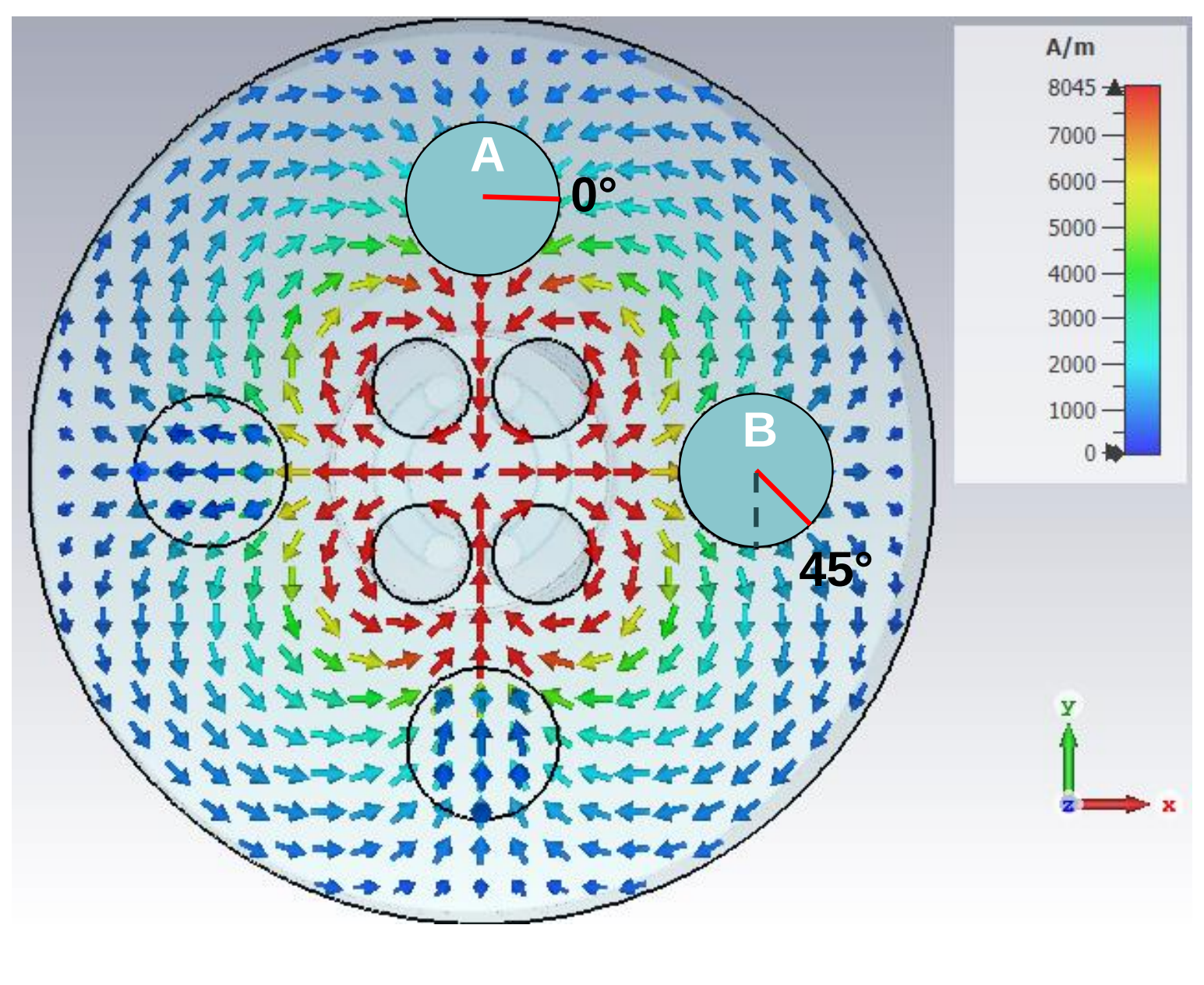
After fabrication, the commissioning of the QPR started at DESY. In addition to the mechanical spectrum, the RF spectrum was measured and the results were compared to the simulated modes. For the measurements, the input antenna was positioned in such way that its loop area was perpendicular to the magnetic field (a condition only valid for the quadrupole modes), while the pick-up antenna was oriented at 45°. For the simulations, 10^6 hexahedrons were employed in a model that included the geometrical information of the QPR after the fabrication to consider any deviations from the ideal design. The simulated frequency values were found to be within a 4% error with respect to the real ones.



Loaded Quality factor vs. Frequency. Comparison between simulations and experiment.



Input antenna: a loop antenna design was chosen. Hence, the coupling is controlled with the angle between the loop area and the field orientation.



Input antena loop area fixed perpendicular to the magnetic field in position A and the probe oriented at 45° in position B.

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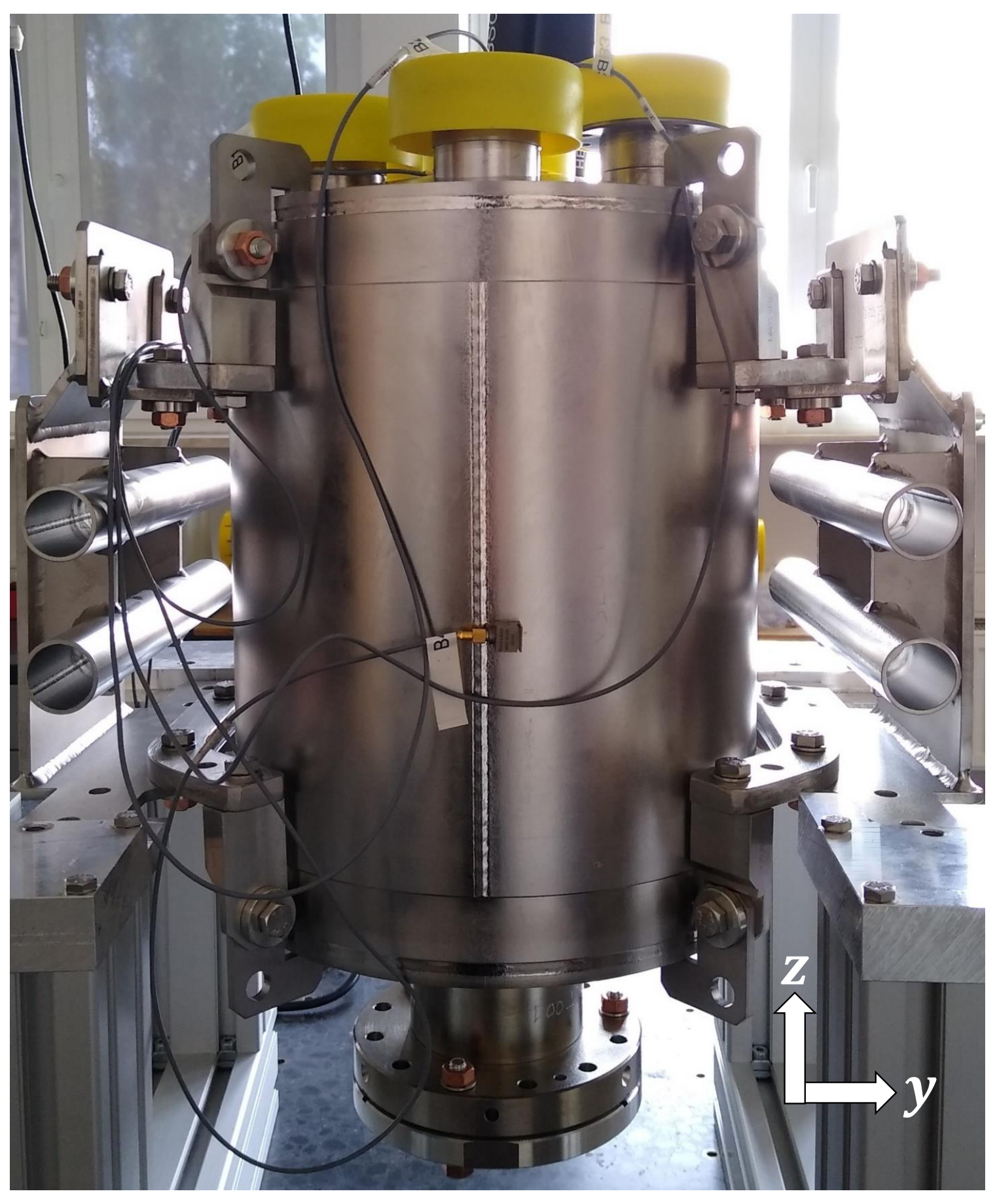
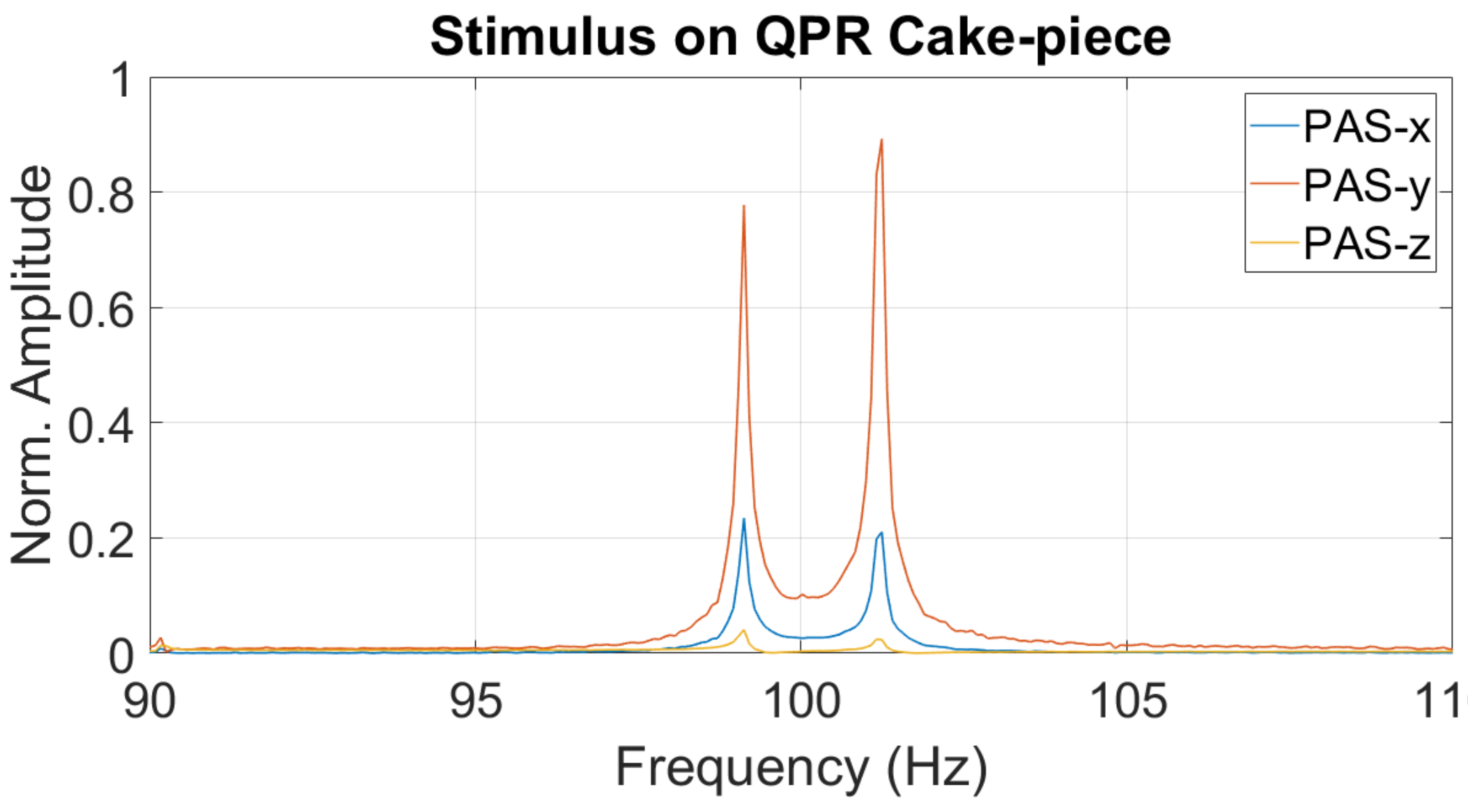
Mechanical resonances

Microphonics, introduced by vibrations of RF noise, can trigger a dynamic detuning of the QPR. The Nb rods are especially prone to mechanical oscillations. At HZB [S. Keckert, Ph.D. thesis, University Siegen, Siegen, Germany (2019)], a 100Hz modulation on top of the driving RF signal was observed. Unfortunately, the mechanical eigenmode of the oscillating rods also lies at 100 Hz, and hence, they were excited, causing a resonant build up of the detuning until the measurement system lost the resonance. To mitigate this problem, a redesign of the inside of the rods was done to improve the stiffness and shift the resonance frequency.



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. Three PAS mounted on the top part measured vibrations in the three dimensions.

Surface treatment

After the commissioning phase, the QPR will undergo a standard chemical treatment typical for Nb SRF cavities to ensure both high quality factors and high magnetic fields.

This treatment will be done at Zanon Research & Innovation SRL and consists of the following steps:

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