Tunable Q-Factor RF Cavity

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ABSTRACT

Intense neutrino beam is a unique probe for researching beyond the standard model. Fermilab is the main institution to produce the most powerful and wide-spectrum neutrino beam. From that respective, a radiation robust beam diagnostic system is a critical element in order to maintain the quality of the neutrino beam. Within this context, a novel radiation-resistive beam profile monitor based on a gas-filled RF cavity is proposed. The goal of this measurement is to study a tunable Q-factor RF cavity to determine the accuracy of the RF signal as a function of the quality factor. Specifically, measurement error of the Q-factor in the RF calibration is investigated. Then, the RF system will be improved to minimize signal error.

RF HADRON MONITOR

A novel gas-filled RF cavity is proposed as hadron beam profile monitor for future intense neutrino beam applications. In this concept gas in the cavity serves as an ionization media by interacting with incident charged particles. The amount of beam-induced plasma is then proportional to the number of incident particles. The plasma consumes the RF power, so called plasma loading. It is interpreted as a plasma resistance which induces the RF power dissipation in plasma. The beam profile is reconstructed by observing the amount of plasma loading from an individual cell in a multi-RF cavity which forms a hodoscope structure. Simulation study of the hadron monitor design for the LBNF application shows that the achievable position resolution of the beam centroid at the monitor is within 1 mm when a 12 x 12 pixel multi-RF cavity (the pixel size is 30 x 30 mm^2) is used.

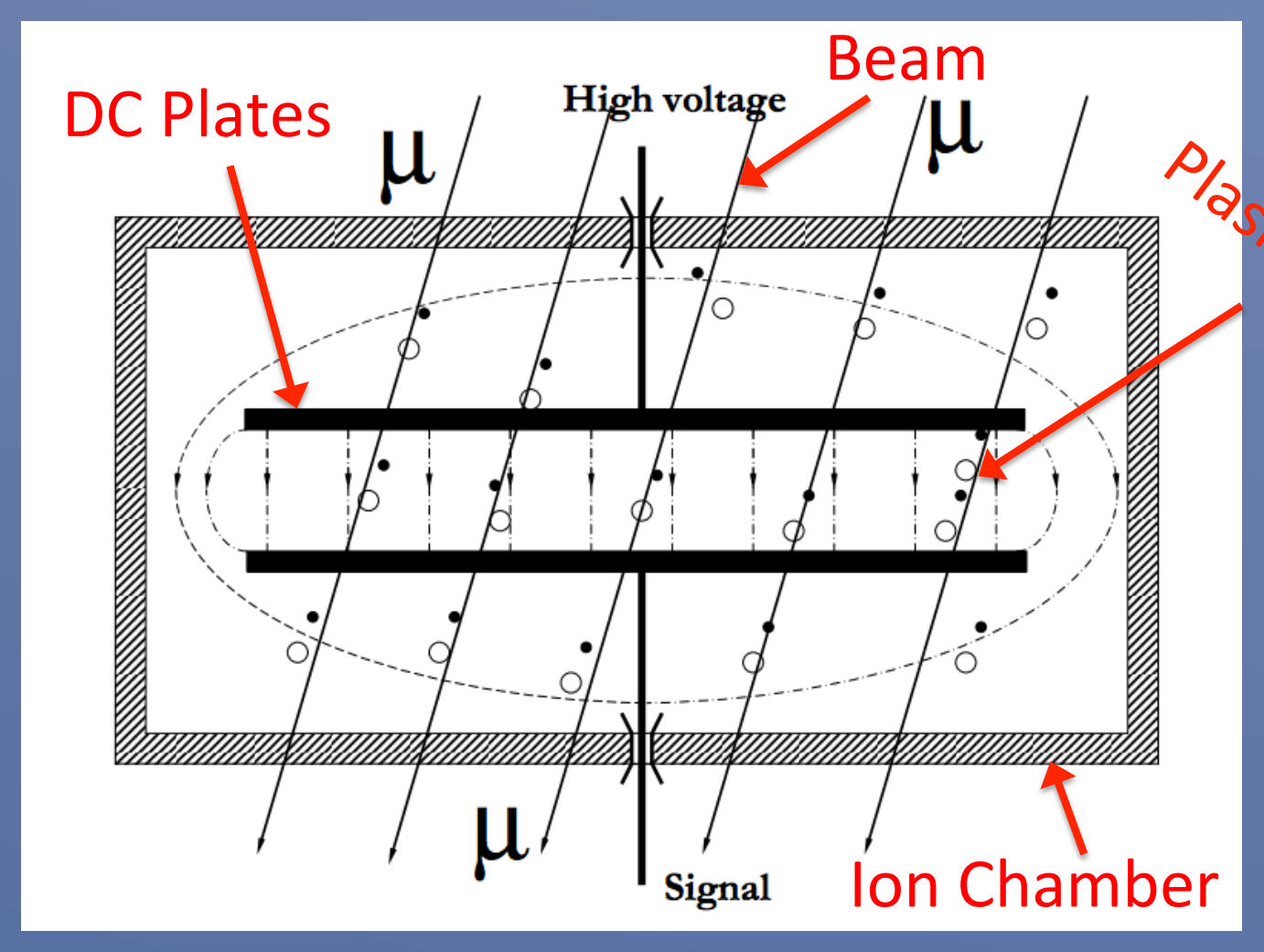


Fig. [1]: NuMI ionizing chamber hadron monitor

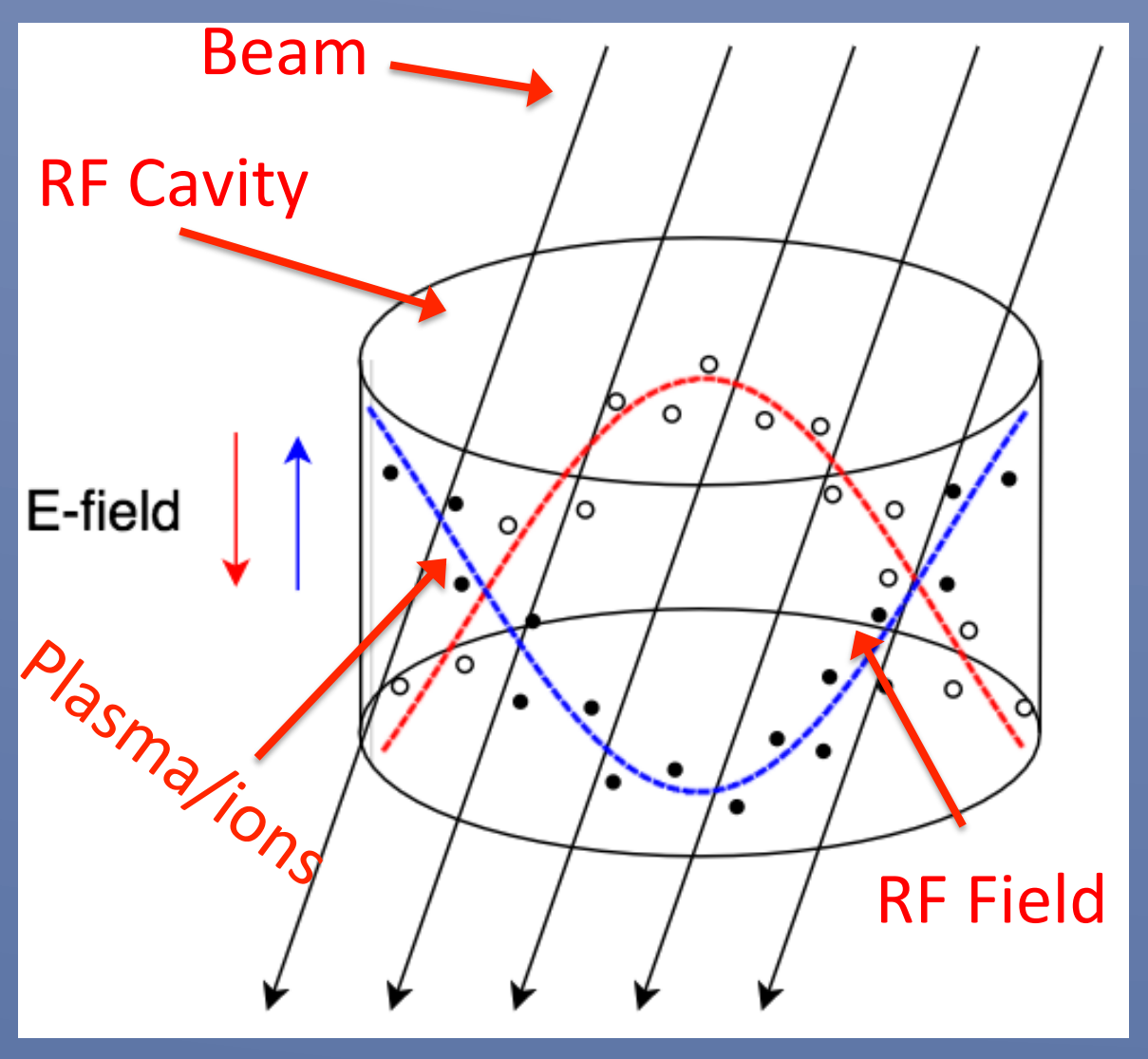


Fig. [2]: LBNF RF cavity hadron monitor.

TUNABLE Q-FACTOR RF CAVITY

During the simulations analysis it was observed that by increasing the area of the coupling loops, more power is dissipated inside the cavity and the RF power is reduced. The critical coupling and decoupling of the the loading loops then shows the possibility of increasing and decreasing the excitation of the TM010 resonant mode of the cavity. This degree of freedom in turns results in the ability to tune the quality factor of the RF Cavity.

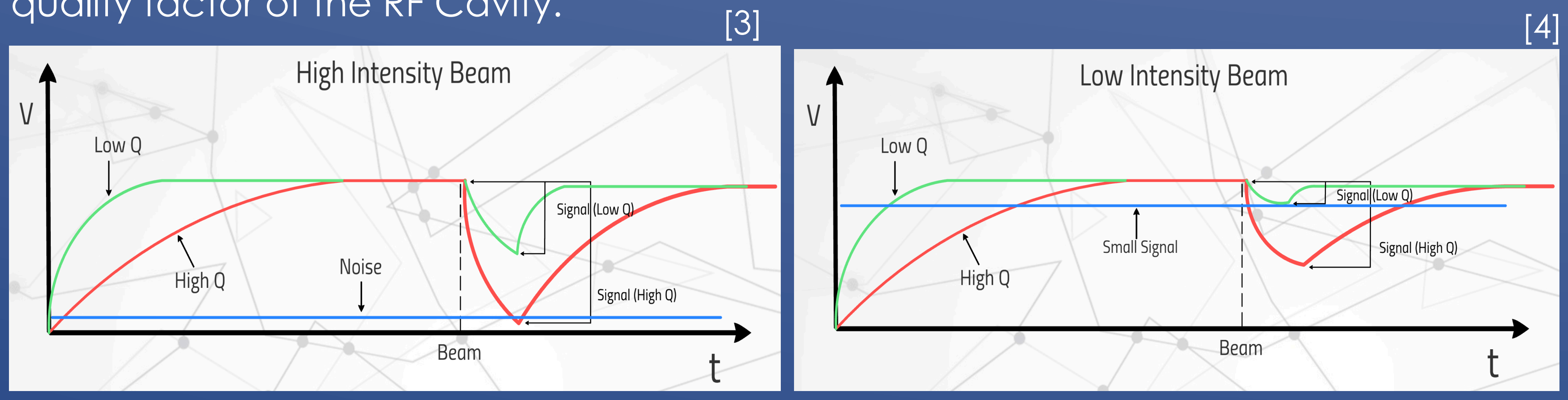


Fig. [3], [4]: Energy loss inside the cavity is proportional to the beam intensity.

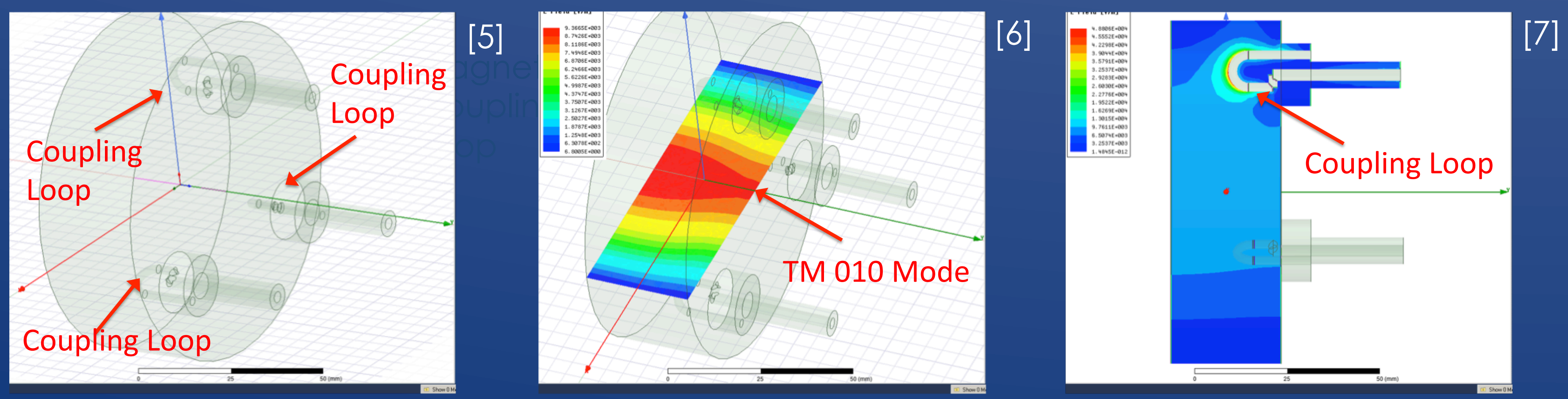


Fig. [5], [6], [7]: Simulations of the TM010 mode inside the RF cavity performed in HFSS.

CAVITY CALIBRATION TEST

The test bench utilizes a network analyzer in order to study the variation of the bandwidth around the resonant frequency of the RF cavity . The loading loops inside the cavity are rotated in order to apply more coupling strength and tune the quality factor. The measurement is performed systematically in 10 degrees rotation increments while recording the matching impedances, loaded Q-factor, and computing the resultant resonant Q-factor. Currently, multiple different coupling loops have been studied which excite the TM 010 resonant mode in a greater or lesser way.

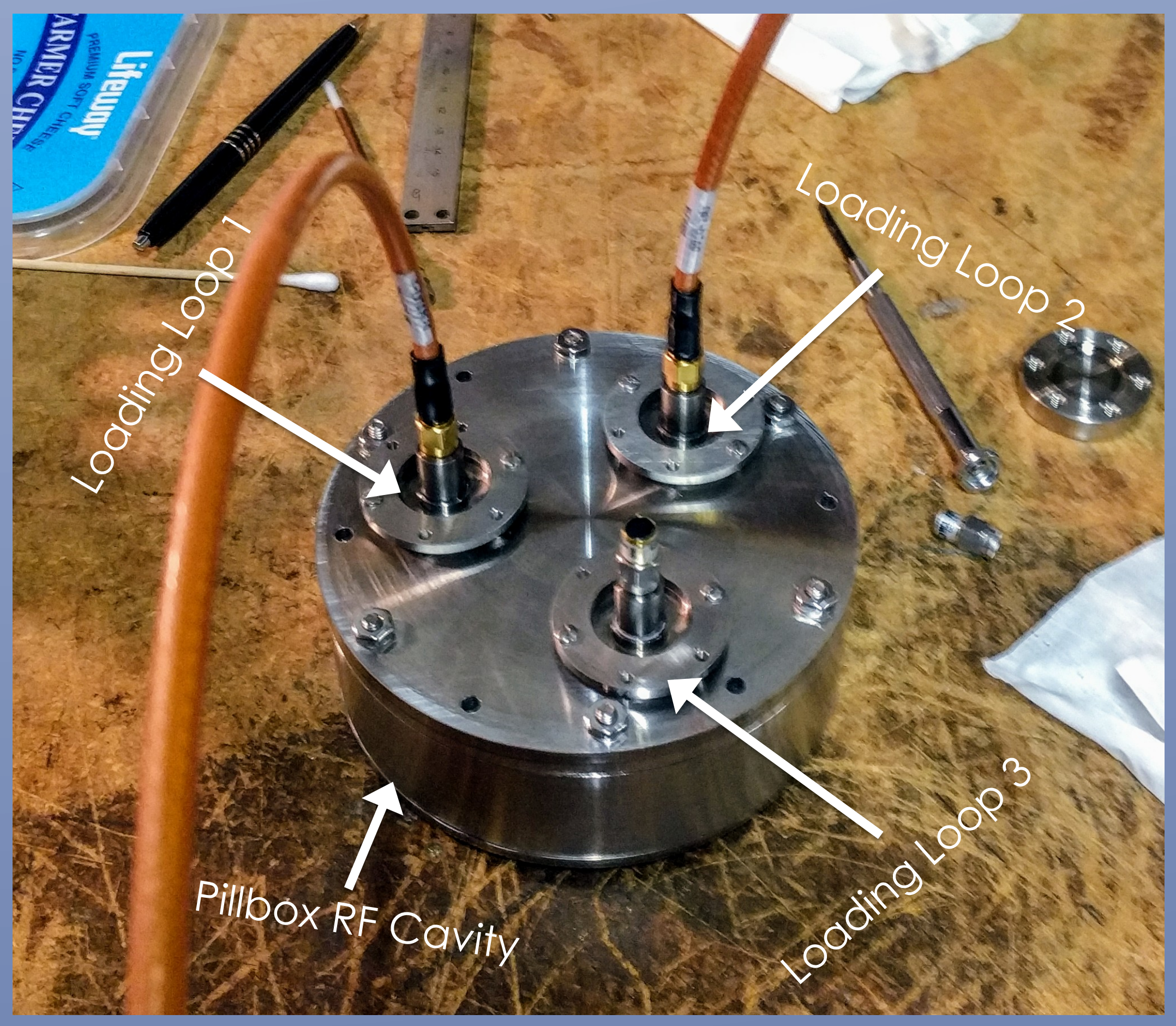


Fig. [8]: Tunable quality factor RF cavity.

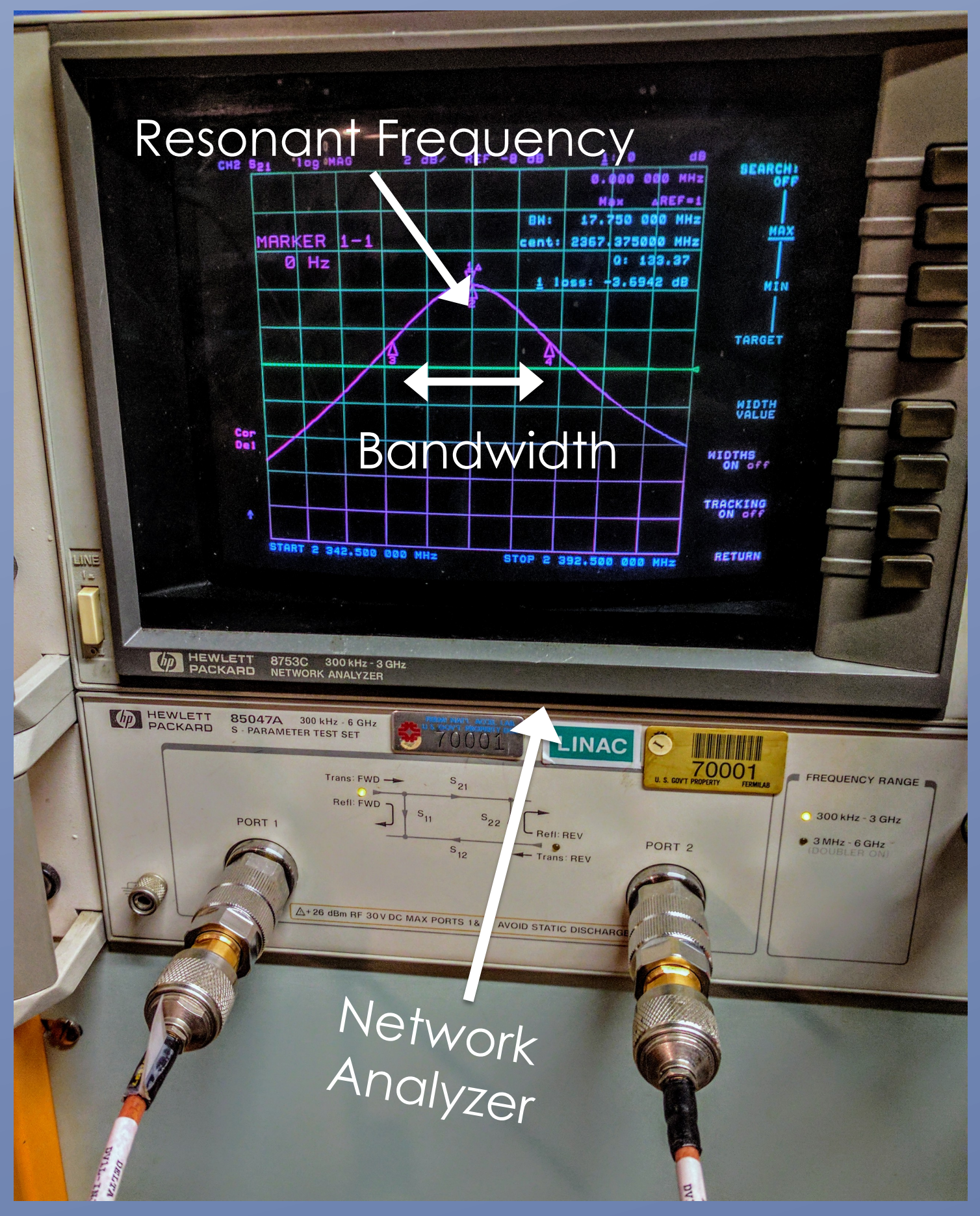
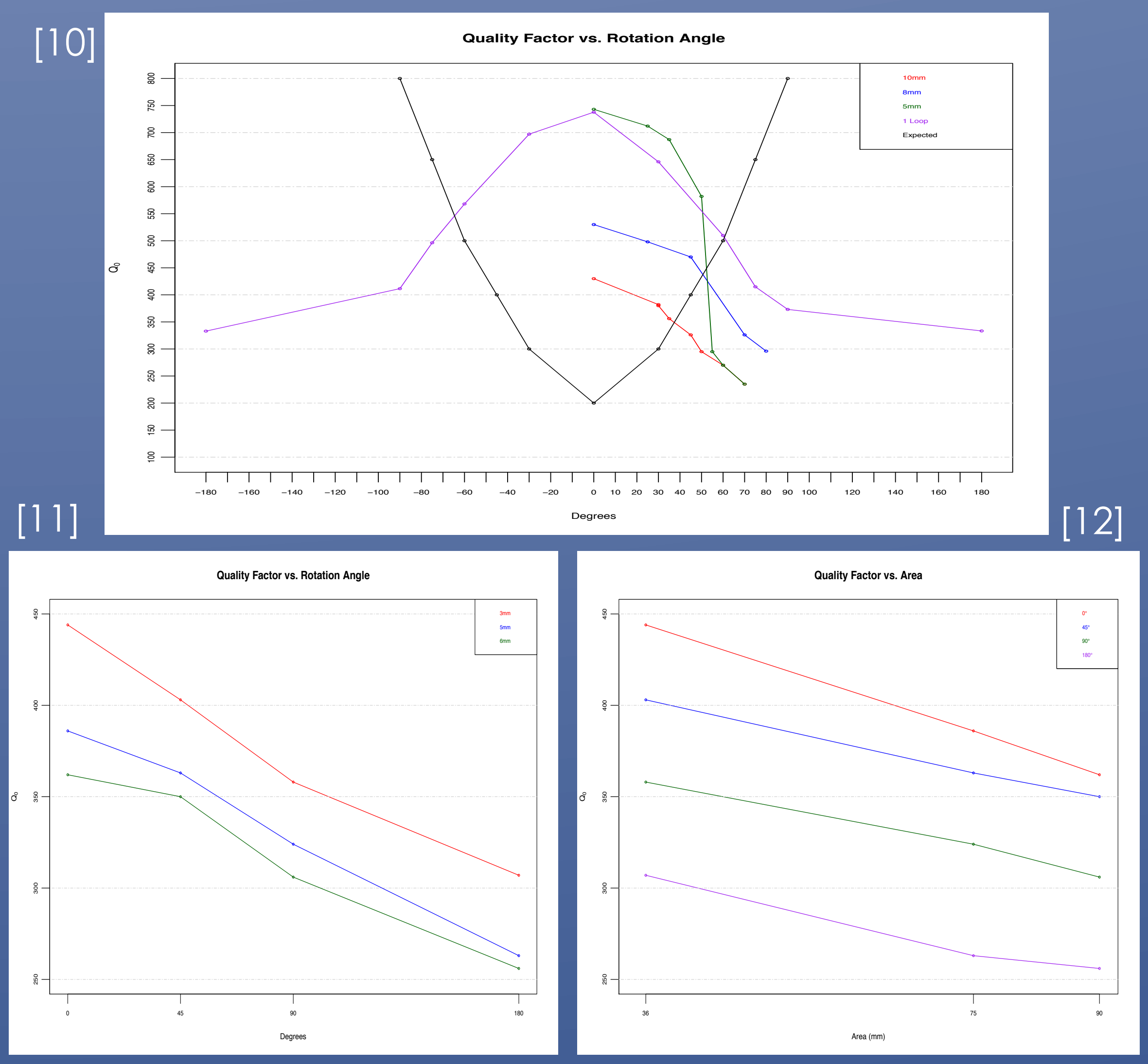


Fig. [9]: Network analyzer.

Q-FACTOR VS. COUPLING

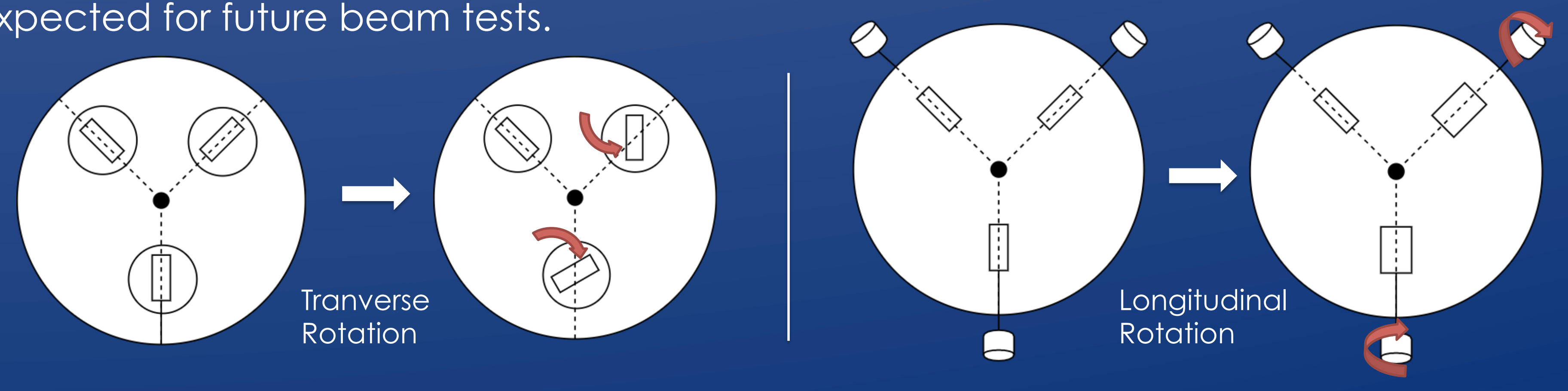


The critical coupling of the loops span a quality factor range from ≈ 150 – ≈ 800. The network analyzer is capable of performing a loaded quality factor calculation that in turn allows to estimate the quality factor of the cavity. Challenges found with the coupling loops include: the symmetry of the loops, the size of the loops exciting undesired modes, and little control for arbitrarily tuning the Q-factor by rotation of a single loading loop.

Fig. [10], [11], [12]: Plots of Q-factor of the cavity as a function of rotation angle and coupling area.

IMPROVED DESIGN

We are developing different coupling loops which function with the tunable Q-factor cavity. In the future system, accurate tuning of quality factor can be performed. The RF cavity also allows in addition to quality factor tuning, high-radiation beam profile monitoring for such as those generated by the LBNF experiment at Fermilab. Initial table-top tests are being performed now on the RF cavity, and an improved design is expected for future beam tests.



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