FERMILAB-POSTER-24-0194-STUDENT

Axion Dark Matter EXperiment 2A Cavity Characterization

Diego Maglione[1 2], Stefan Knirck [2] - [1]Stanford University, [2]Fermi National Accelerator Laboratory

Introduction

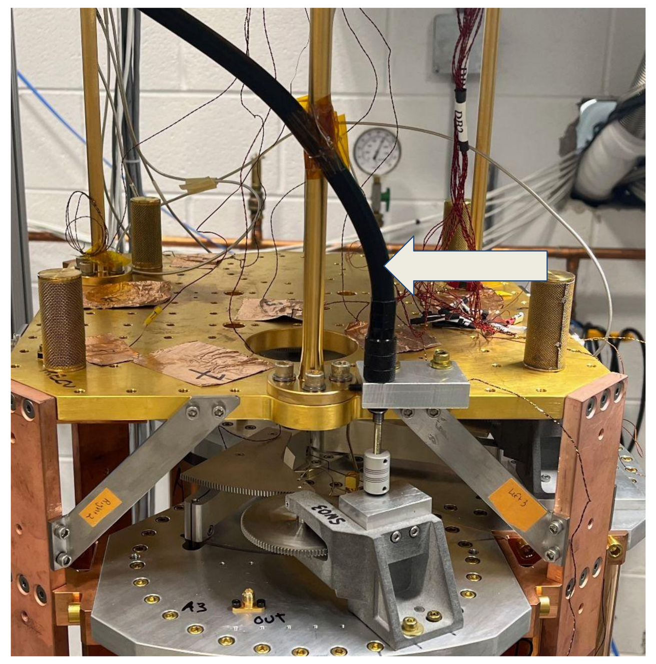
The axion is a highly motivated dark matter candidate for its capacity to solve the strong CP problem in quantum chromodynamics. To detect the axion, the 2A phase of the Axion Dark Matter EXperiment (ADMX) utilizes four identical cylindrical resonant cavities that can detect the photons converted from axions in a strong magnetic field. The axion-photon conversion predominantly excites the TM010 mode of each cavity, which we can tune from 1.4 - 2.1 Ghz. To achieve sufficient sensitivity, we need a high quality factor only achievable at temperatures around 4K, which can cause unpredictable deformations in the cavity.

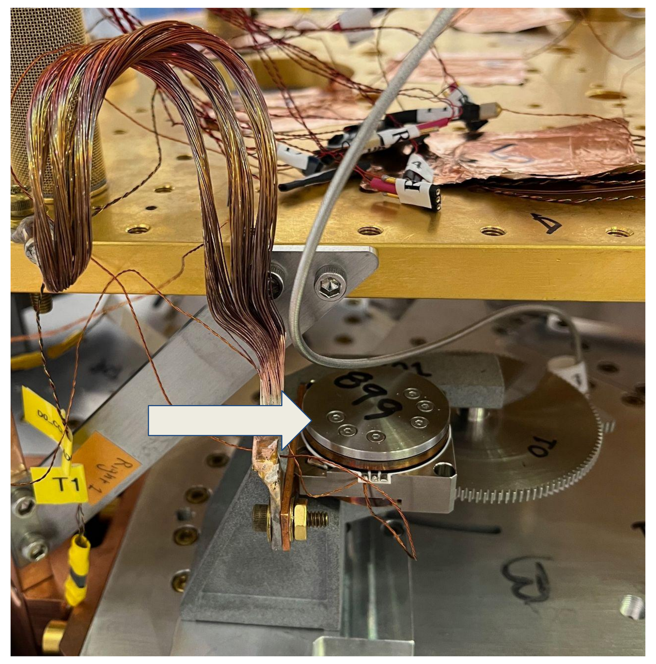
Goals

- Determine how the quality factors and mode frequencies change with temperature.
- Determine how the quality factor is affected by tuning.
- Test the function of the tuning piezo motors during cooldown and warm up.

Methods

Three cavities–A, B, and D–were connected to a vector network analyzer to track EM wave transmission. The cavities were placed in vacuum and cooled to about 5K. We tracked the TM010 and TM011 modes of Cavities A and B and tested the piezo motor tuning over the range 1.610-1.692 Ghz. Cavity D was connected to a flexible shaft that allowed manual tuning over the entire tuning range. The absolute transmission of each mode was fitted to a Lorentzian to minimize vibration effects when measuring quality factors.

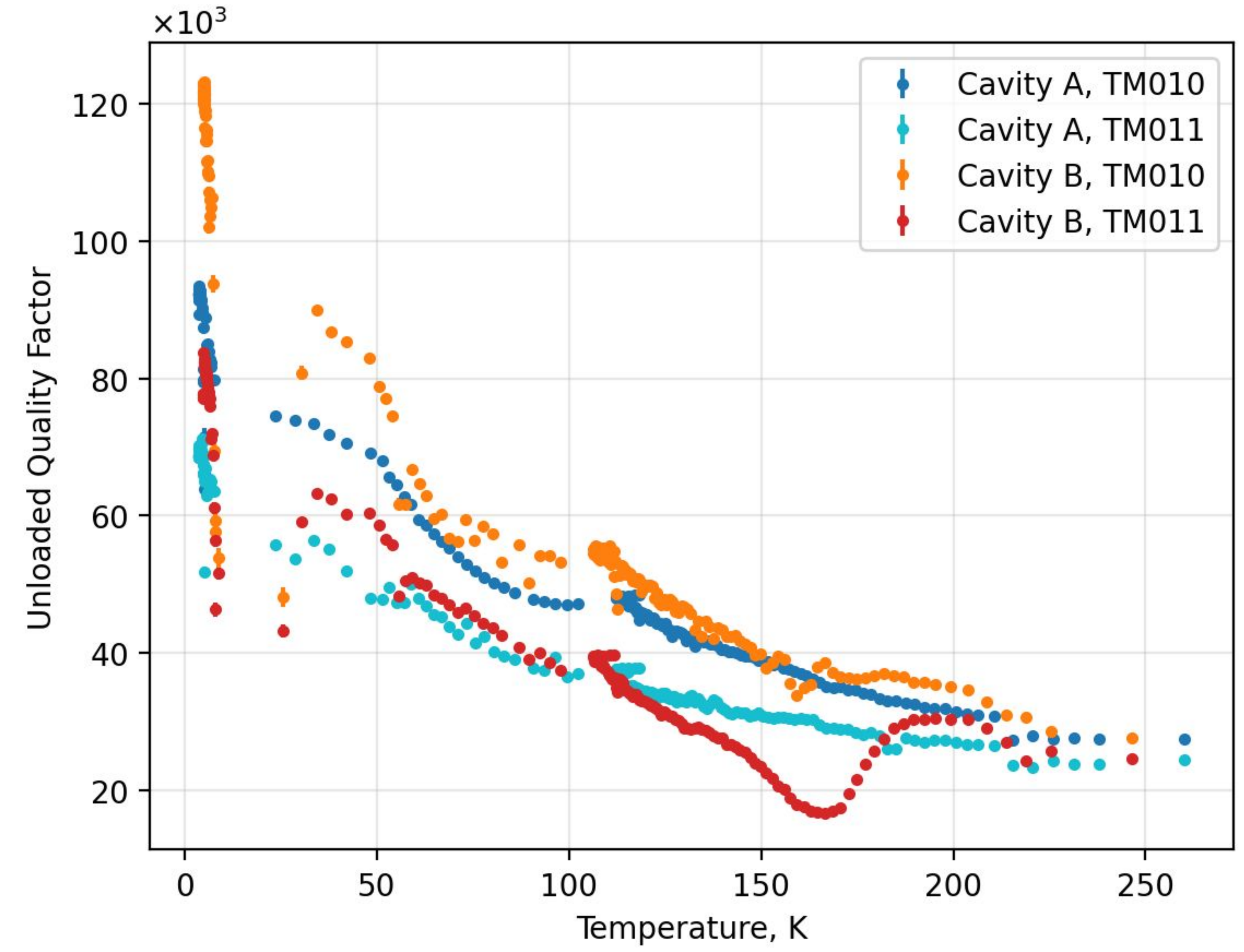




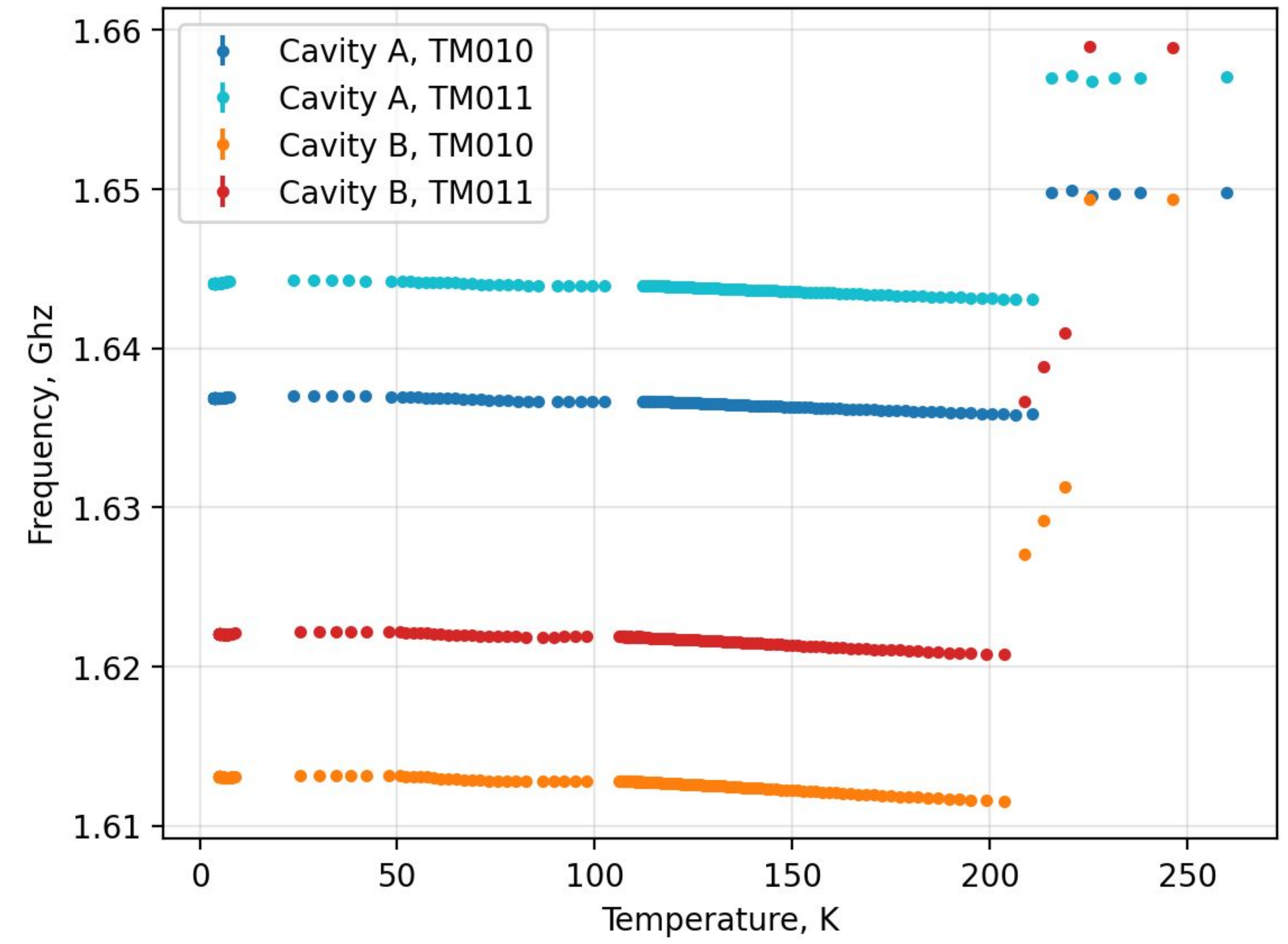
Flexible Shaft and Manual Tuning on Cavity D (left).

Piezo Motor and Gearbox on Cavity B (right).

Results

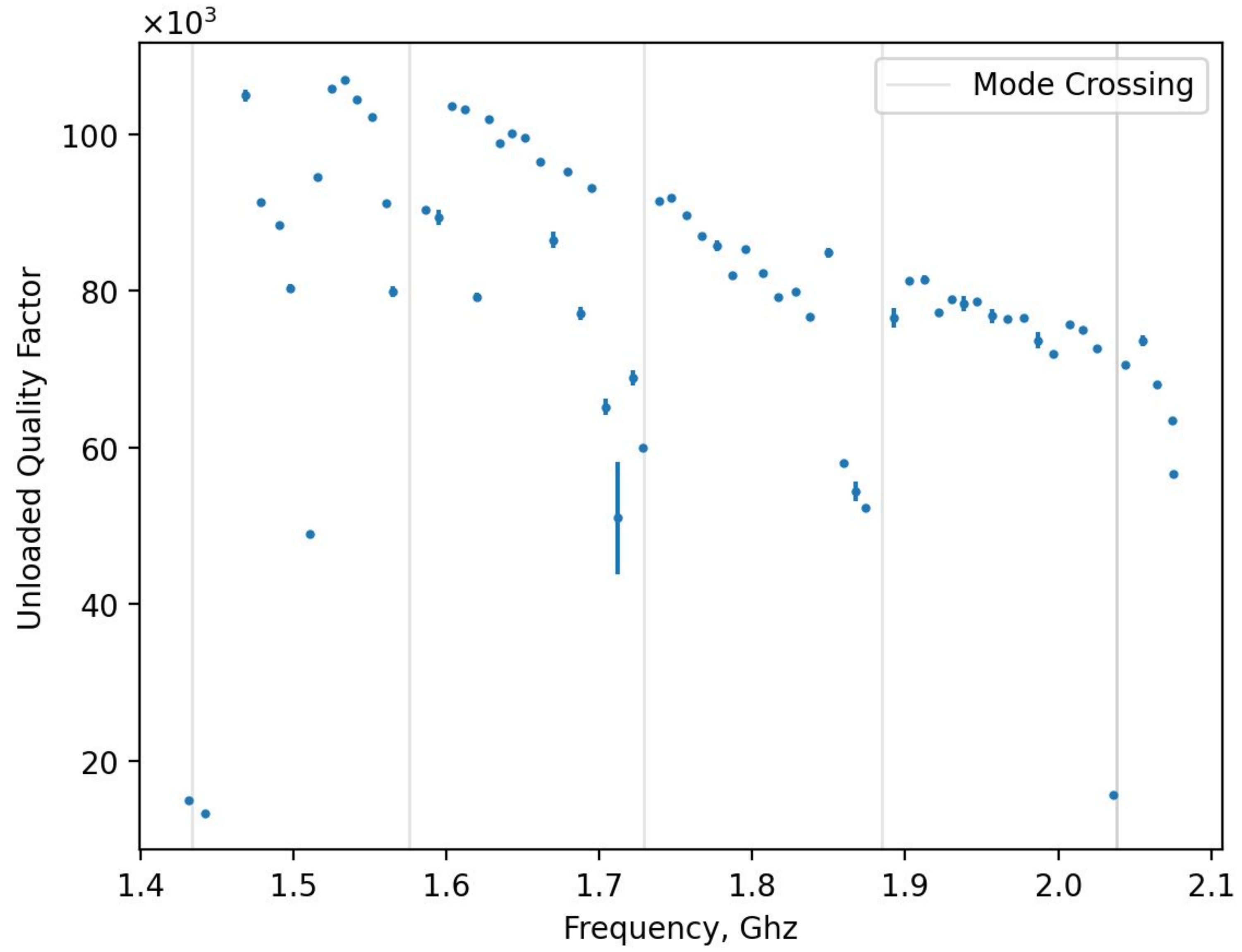


Quality factor versus temperature of cavities A and B. We see an unexpected dip in both modes around 160K for cavity B, which also demonstrates a significantly higher Q at the lowest temperatures than cavity A.



Frequency versus temperature of cavities A and B. Around 220K, the piezo motors stopped tuning and could not reset to their starting frequency of 1.65 Ghz. We see that as we cooled, there is a small increase in mode frequency.

We found higher Q (quality factors) in cavity B than A because the piezo motors froze at different frequencies. We also observe a slight increase in the mode frequency without changing the tuning. Cavity shrinkage in cold temperatures is the likely culprit.



Q vs Frequency of TM010 Modes in Cavity D at 5.1K.

We see that in general, Q increases as we tune to lower frequencies. Q decreases sharply at the TE mode crossings. There is a sharp decrease in Q near 1.5 Ghz that does not correspond to any mode crossings. This may be because of the tuning rod's proximity to the cavity wall at low frequencies.

Conclusions and Next Steps

We found the quality factors for various tunings in cavity D, and we also learned that the piezo motors are not currently equipped to handle cryogenic temperatures. These quality factors are more promising than those shown in the last 2A cooldown, which only reached up to around 20,000.

In my remaining four weeks, I will assist in conducting bead pull tests to estimate the form factor of these resonant cavities. These tests will help us correct any localized modes that are non-uniform along the cylindrical length, ensuring that the tuning rods are oriented correctly and that the data we read is accurate. I will also assist in figuring out what caused the piezo motors to fail.

Acknowledgements

I would like to thank my mentors, Stefan Knirck and Andrew Sonnenschein, for their kindness, invaluable knowledge in the field, and consistent assistance.
This manuscript has been authored by Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 with the U.S. Department of Energy, Office of Science, Office of High Energy Physics.
This work was supported in part by the U.S. Department of Energy, Office of Science, Office of Workforce Development for Teachers and Scientists (WDTS) under the Science Undergraduate Laboratory Internships Program (SULI).