Upgrading Axion Dark Matter Detectors

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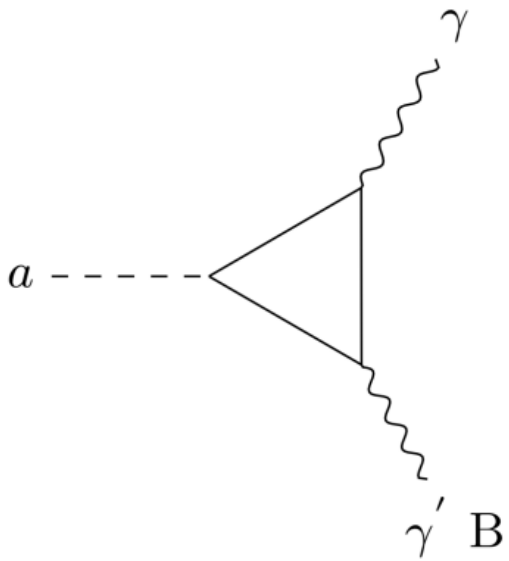
SULI Fall 2022 Presentations

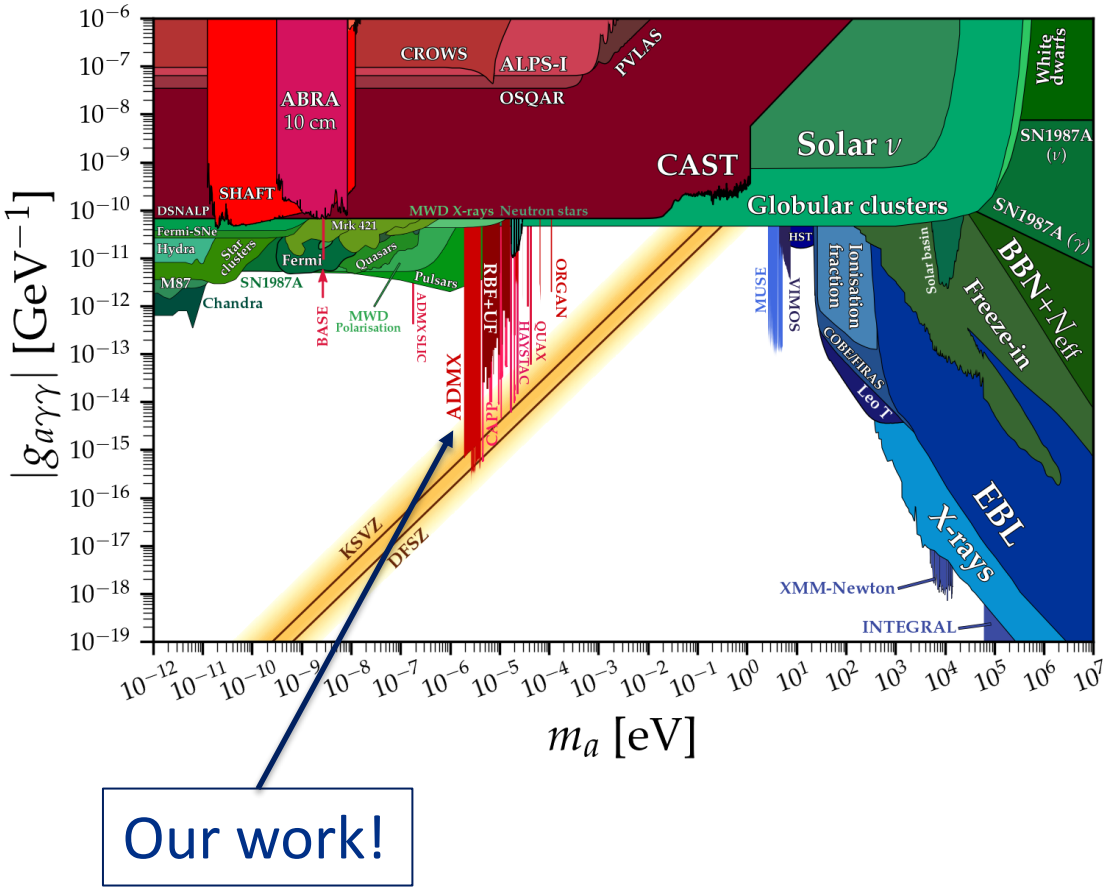
07 December 2022

What is an axion?

- Solution to the strong CP problem [Peccei, Quinn, 1977]
- Dark Matter candidate
- Axion-Photon coupling



[adapted from cajohare.github.io/axionlimits]



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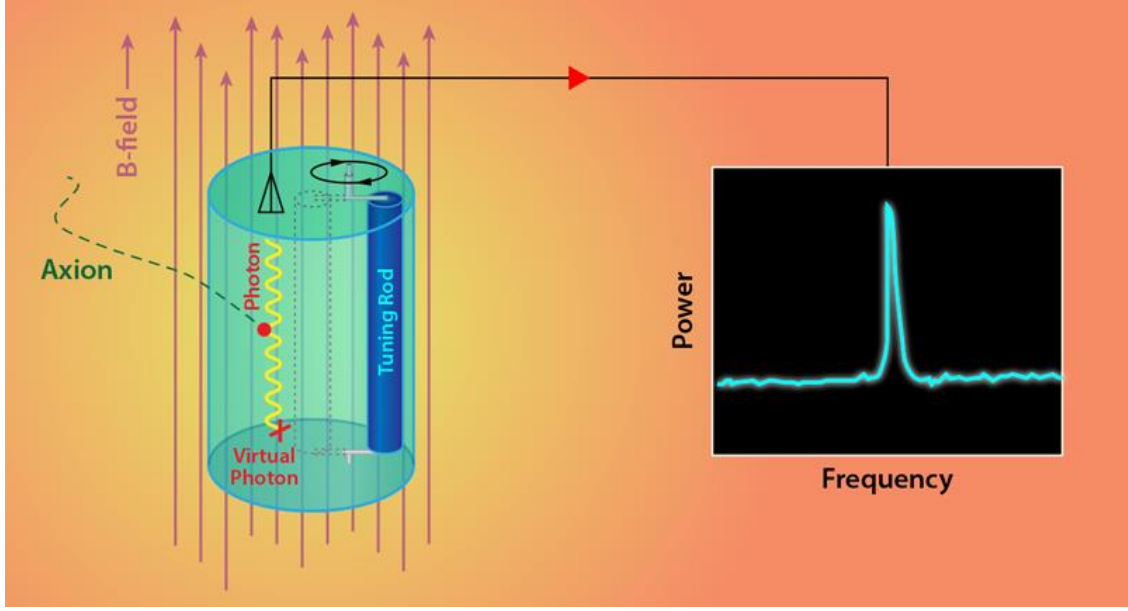
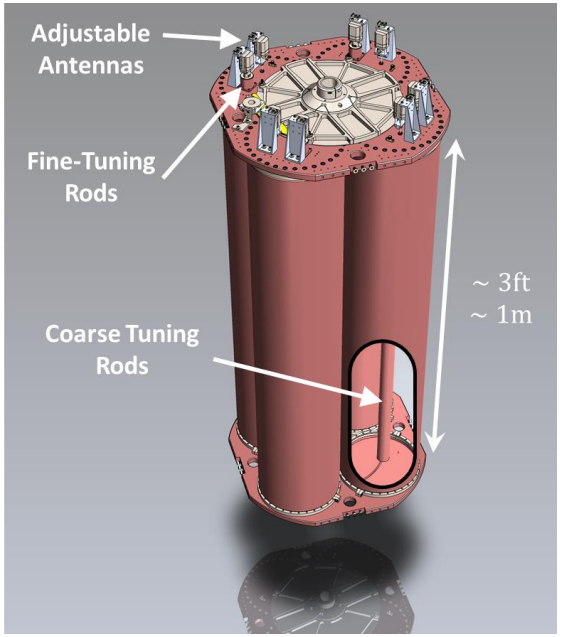
ADMX

- Axion Dark Matter eXperiment
  - Proposed by Pierre Sikivie in 1983
- Searches for resonant frequencies of photons (coupled to axions) in 4 cylindrical cavities
- Moving tuning rod changes the resonant frequency in the cavities
  - Scans for different axion masses





$$P_{\text{sig}} = 2 \cdot 10^{-23}\,\text{W} \cdot \left(\frac{B}{7.6\,\text{T}}\right)^2 \left(\frac{V}{136\,\ell}\right) \left(\frac{C}{0.4}\right) \left(\frac{Q}{30{,}000}\right) \left(\frac{g_\gamma}{0.36}\right)^2 \left(\frac{m_a}{3\,\mu\text{eV}}\right) \left(\frac{\rho_{\text{DM}}}{0.45\,\text{GeV cm}^{-3}}\right)$$

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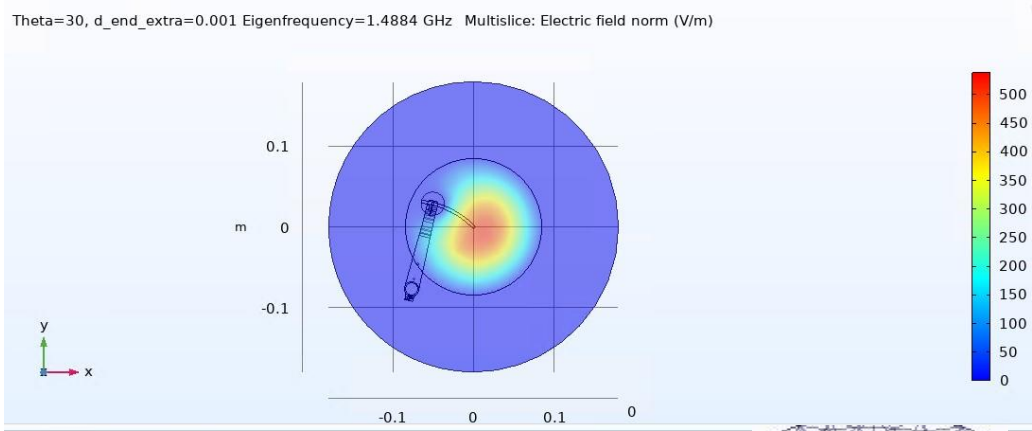
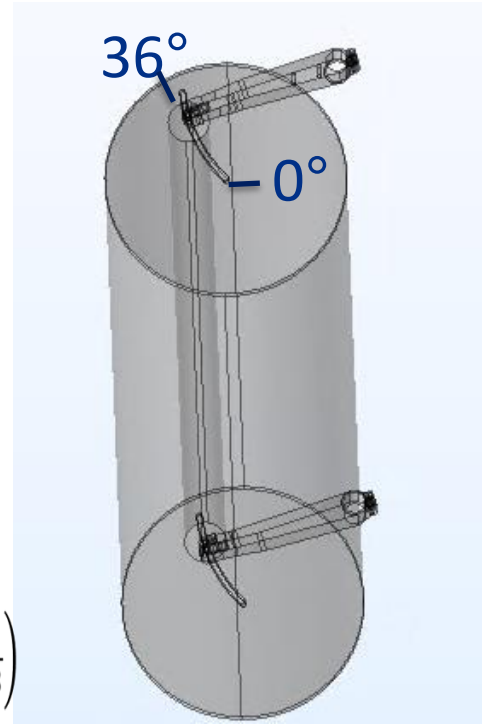
COMSOL Simulations

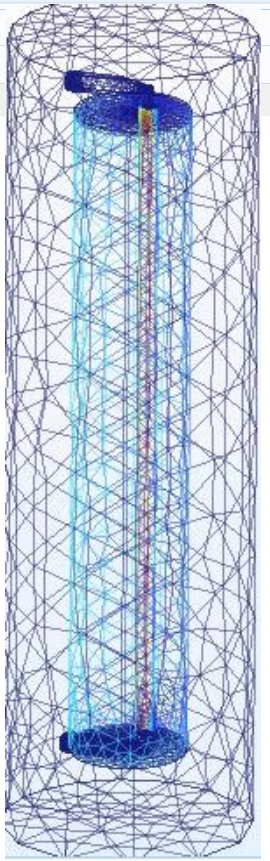
- Value of the form factor (C) requires simulation
  - Geometry Dependent
- Test designs to improve the quality factor (Q)
  - Ratio of E-fields into/out of the cavity



Messages | Progress | Log | Table 47

Theta	d_end_extra	Eigenfrequency (GHz)	Frequency (GHz)	Quality factor (1)	C (1)
30.000	0.0010000	1.4884	1.4884	2.7922E5	0.63652





$$P_{sig} = 2 \cdot 10^{-23}\,\mathrm{W} \cdot \left(\frac{B}{7.6\,\mathrm{T}}\right)^2 \left(\frac{V}{136\,\ell}\right) \left(\frac{C}{0.4}\right) \left(\frac{Q}{30{,}000}\right) \left(\frac{g_\gamma}{0.36}\right)^2 \left(\frac{m_a}{3\,\mu\mathrm{eV}}\right) \left(\frac{\rho_{\mathrm{DM}}}{0.45\,\mathrm{GeV\,cm^{-3}}}\right)$$

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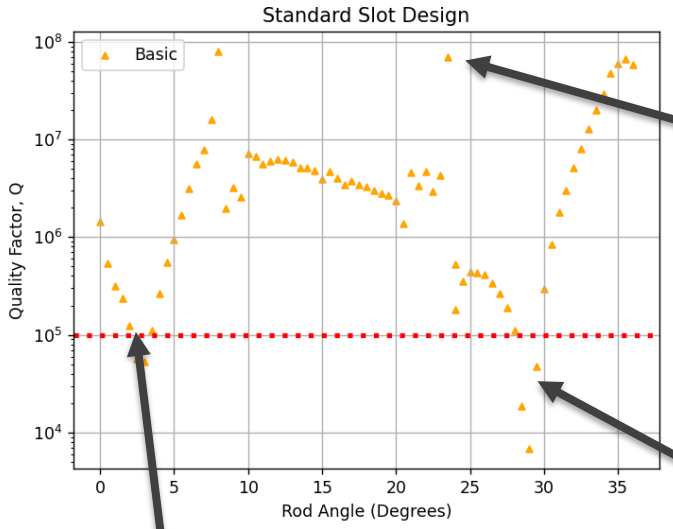
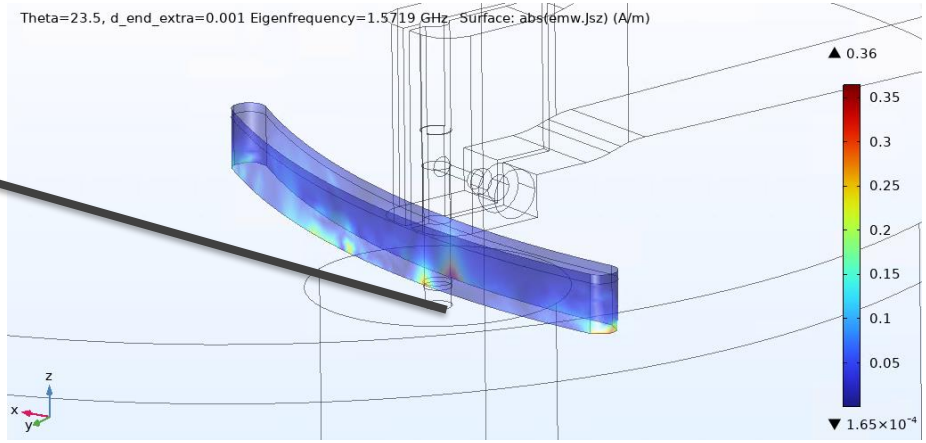
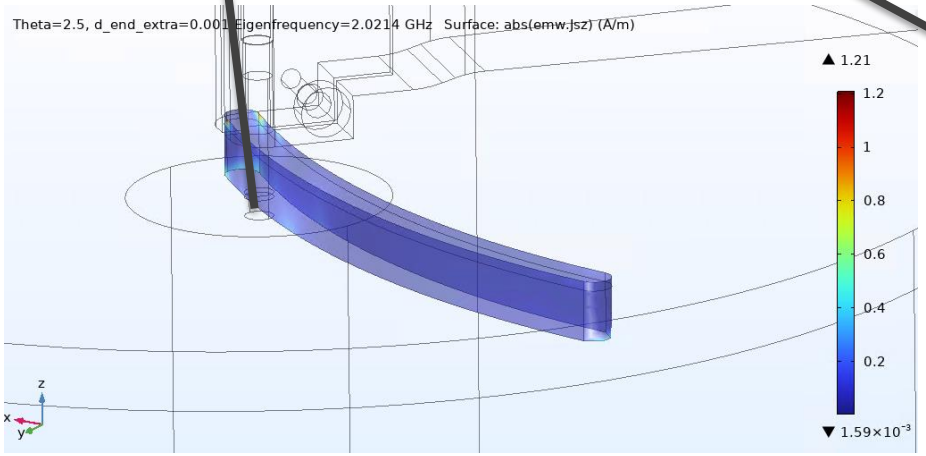
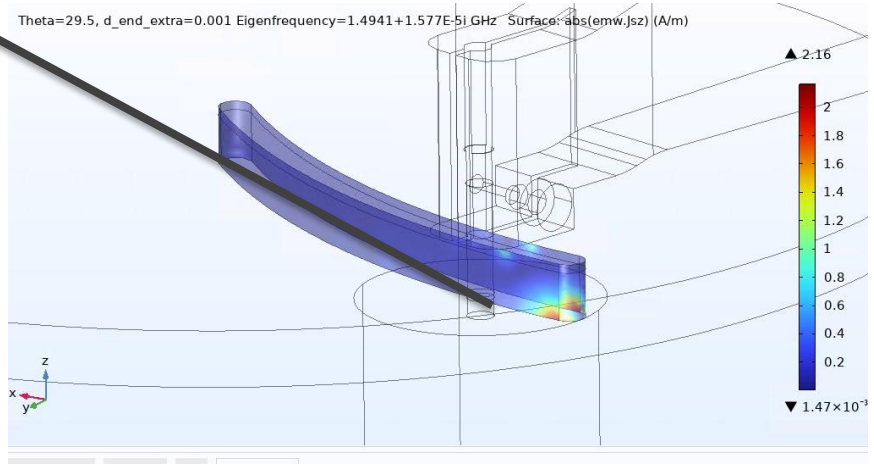
Surface Current & Q









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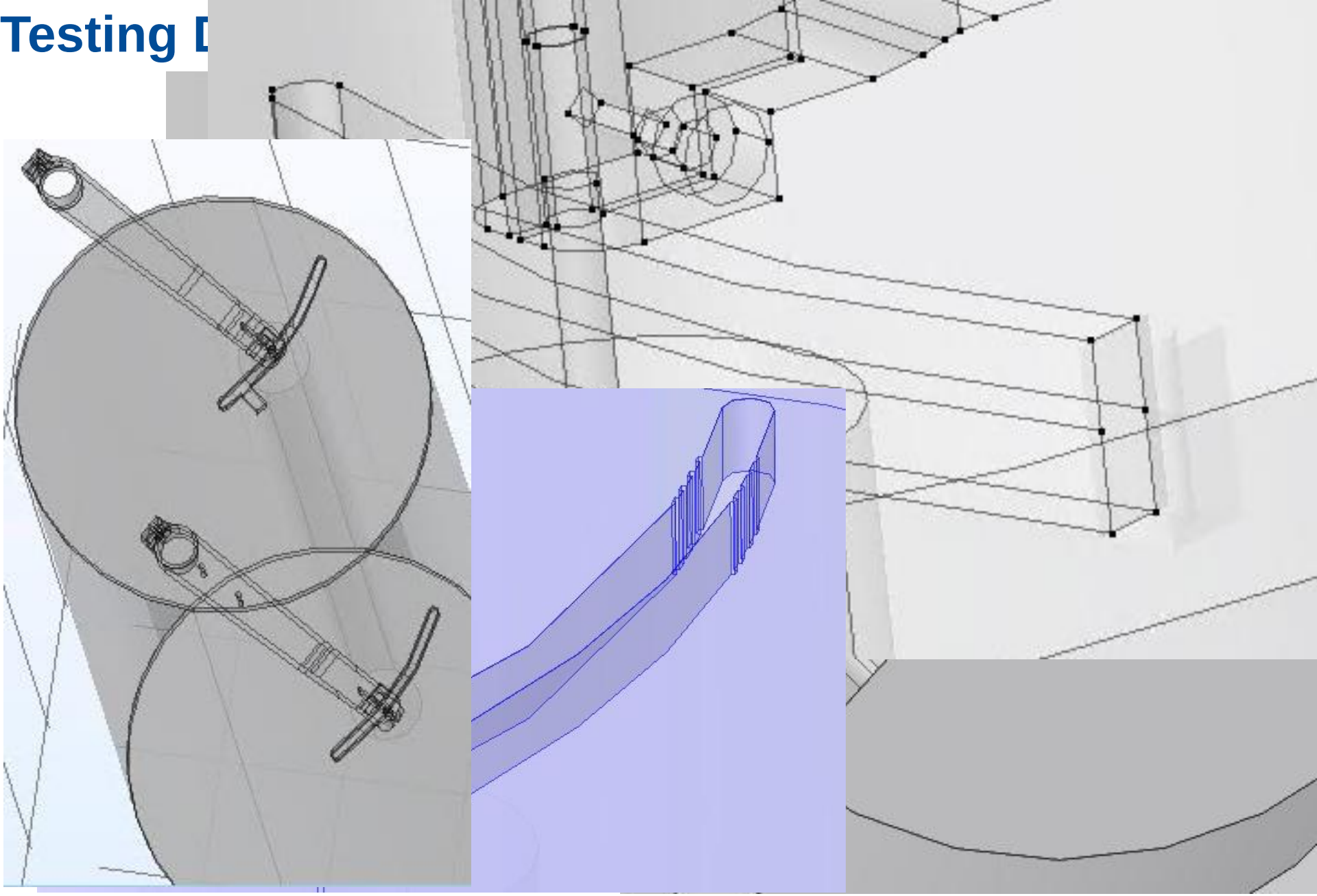
Testing D



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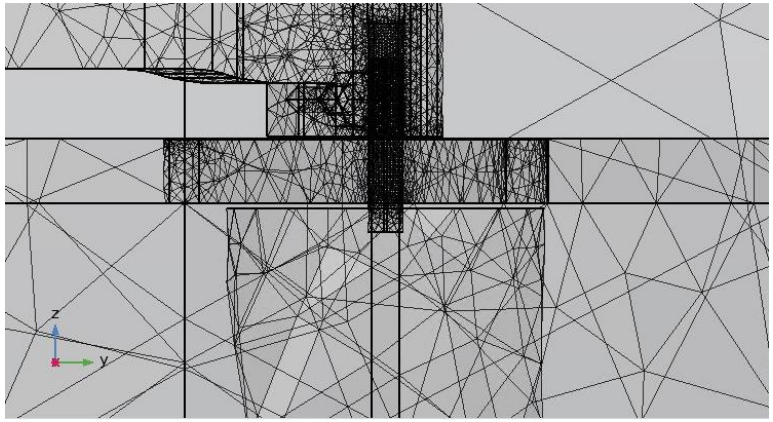
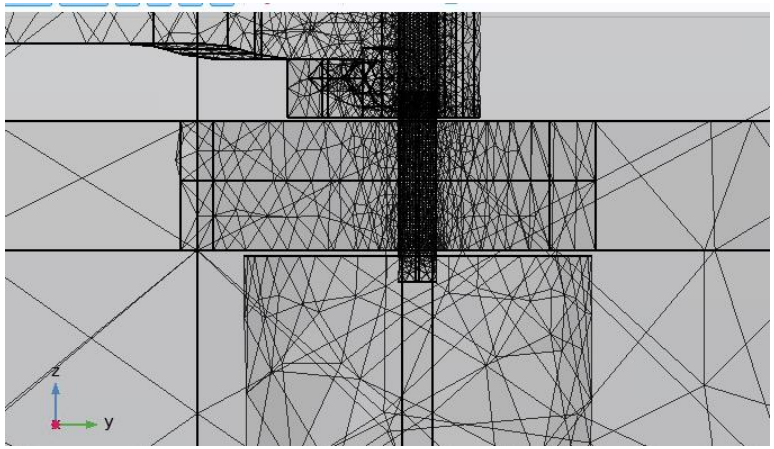
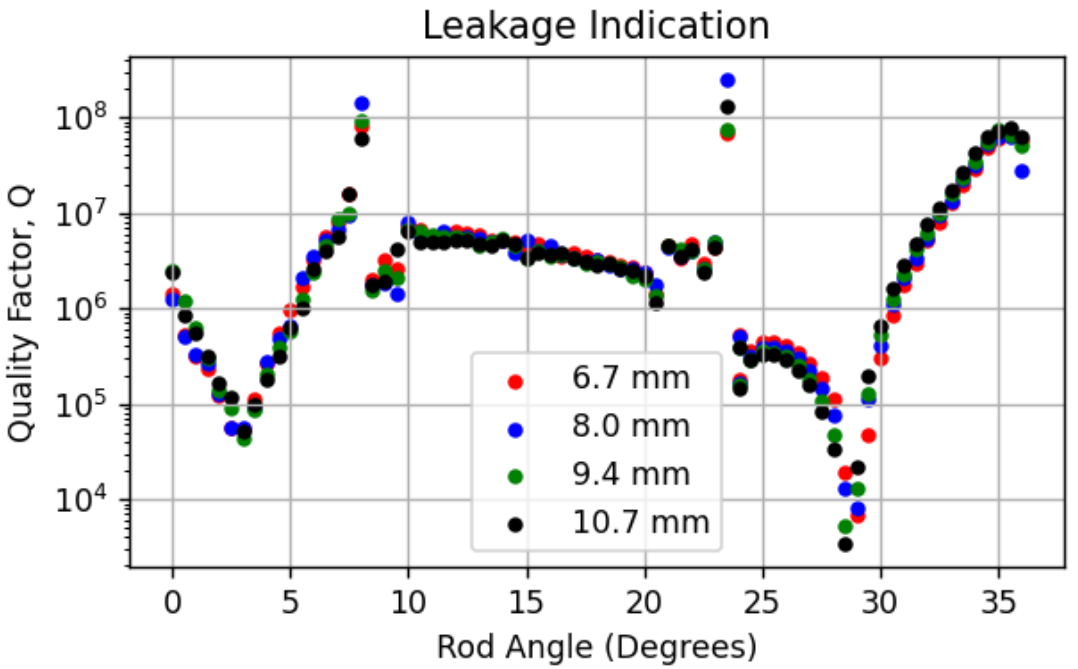
Q for Different Endplate Thickness







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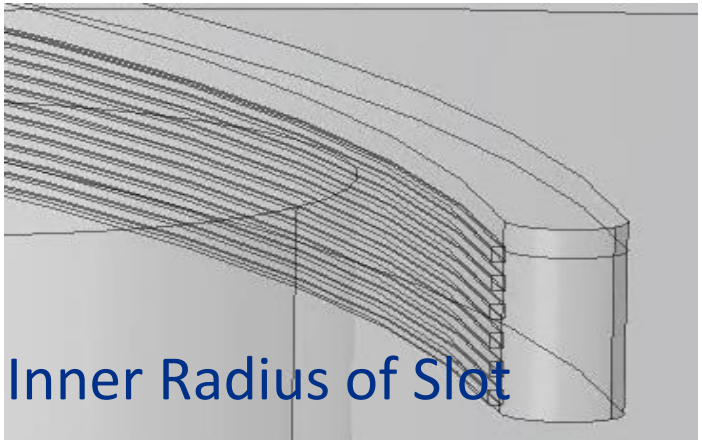
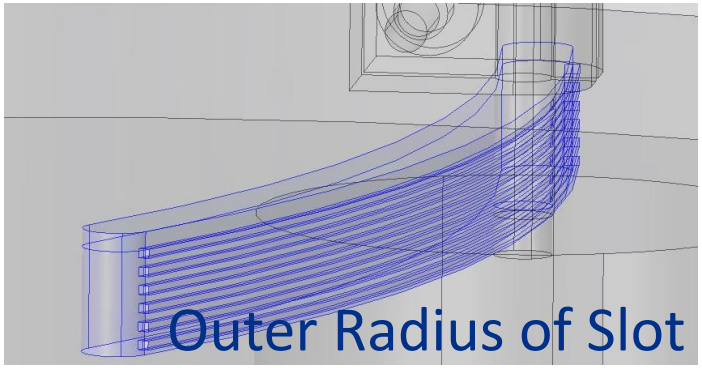
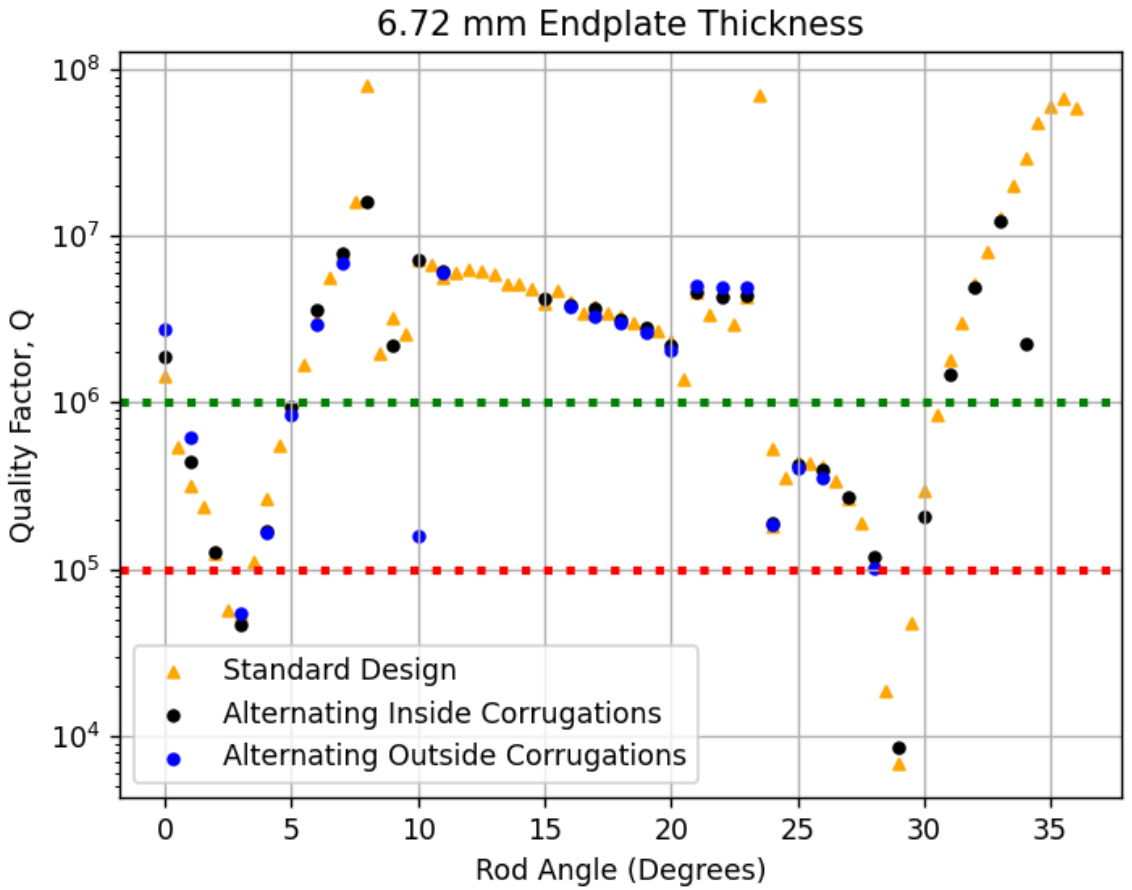
Horizontal Corrugations

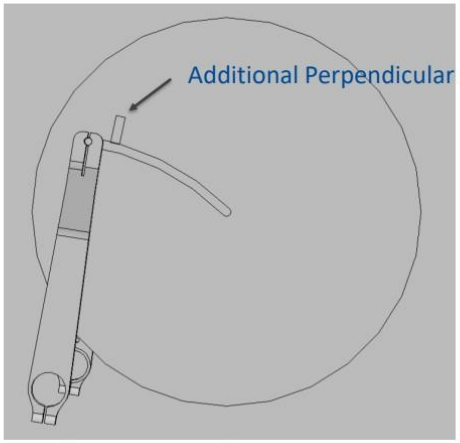






Adding a Slot Extrude

Additional Slot?



- Can we use an additional small slot at the angles of increased leakage to change the current distribution and potentially minimize leakage?

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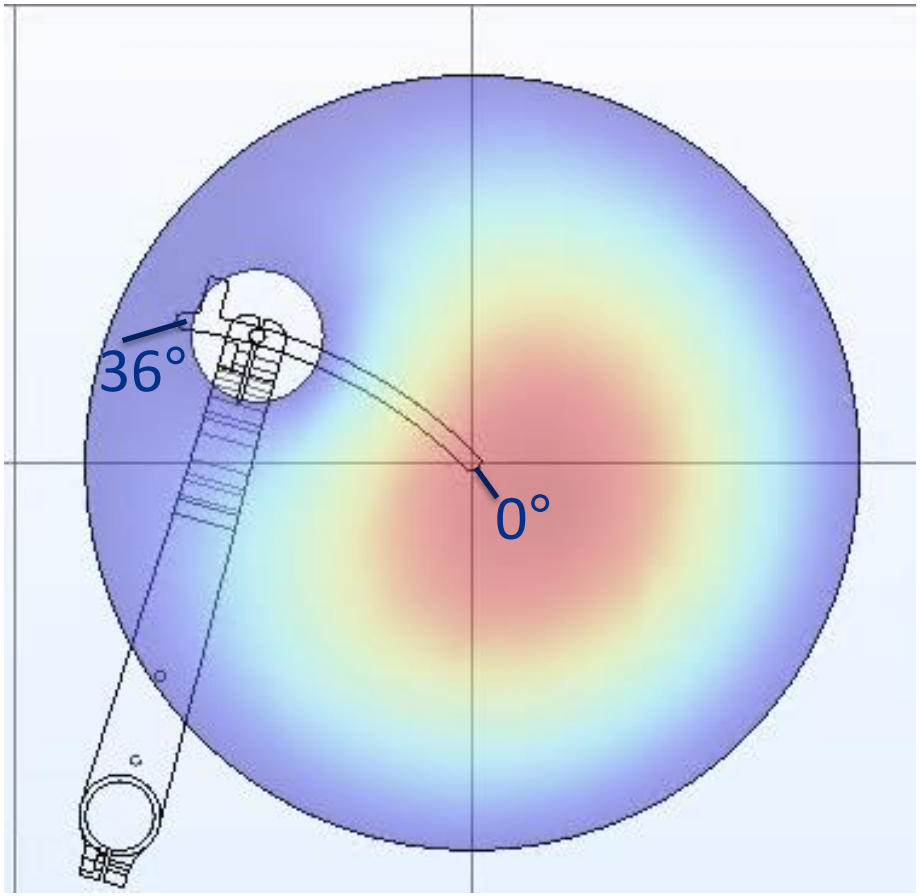
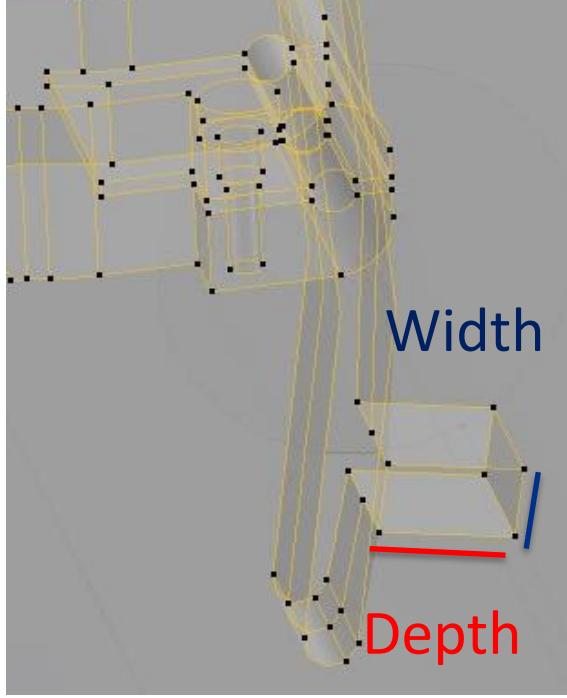
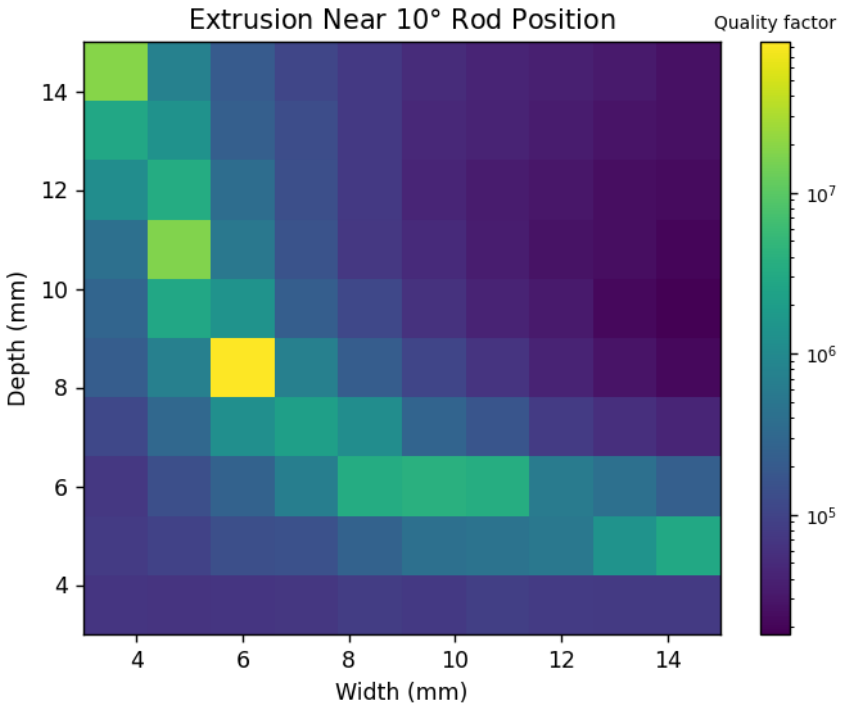


Optimizing Extrude Dimensions

- Fix rod position at region of low Q (3, 10, 28)
- Sweep over extrusion parameters (width, depth)
- Choose combination giving highest Q





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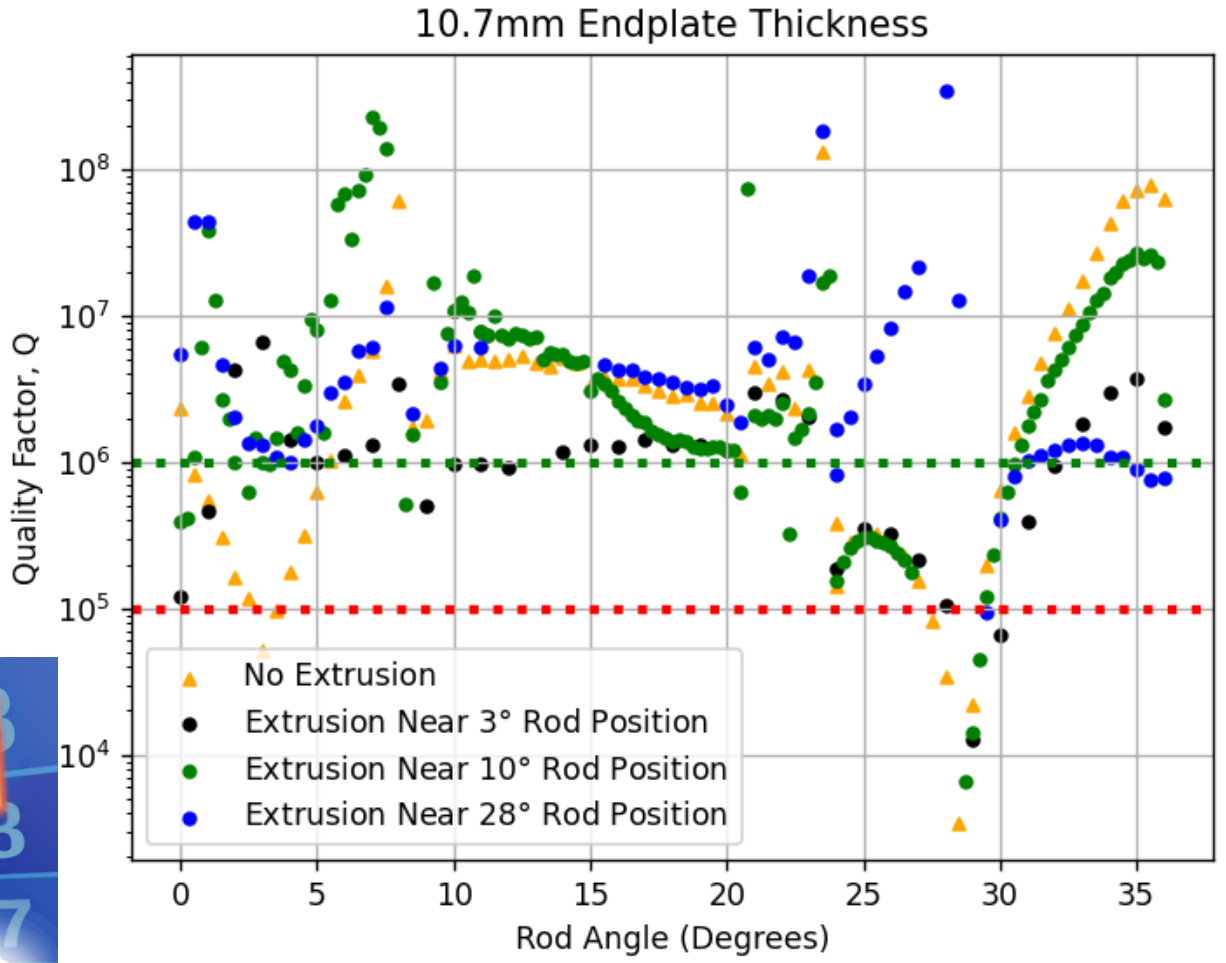
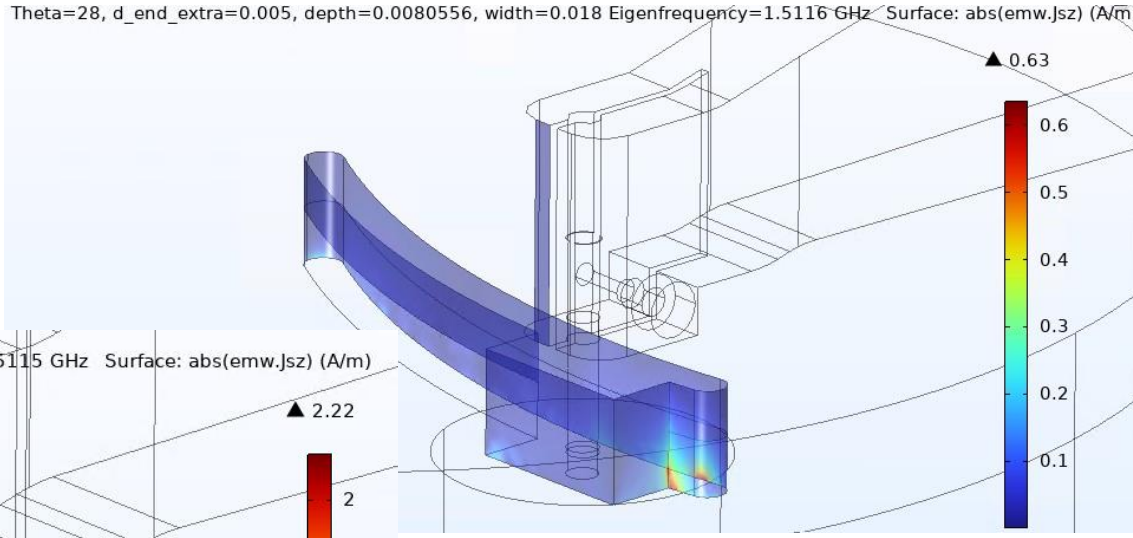
Q for Different Extrusions

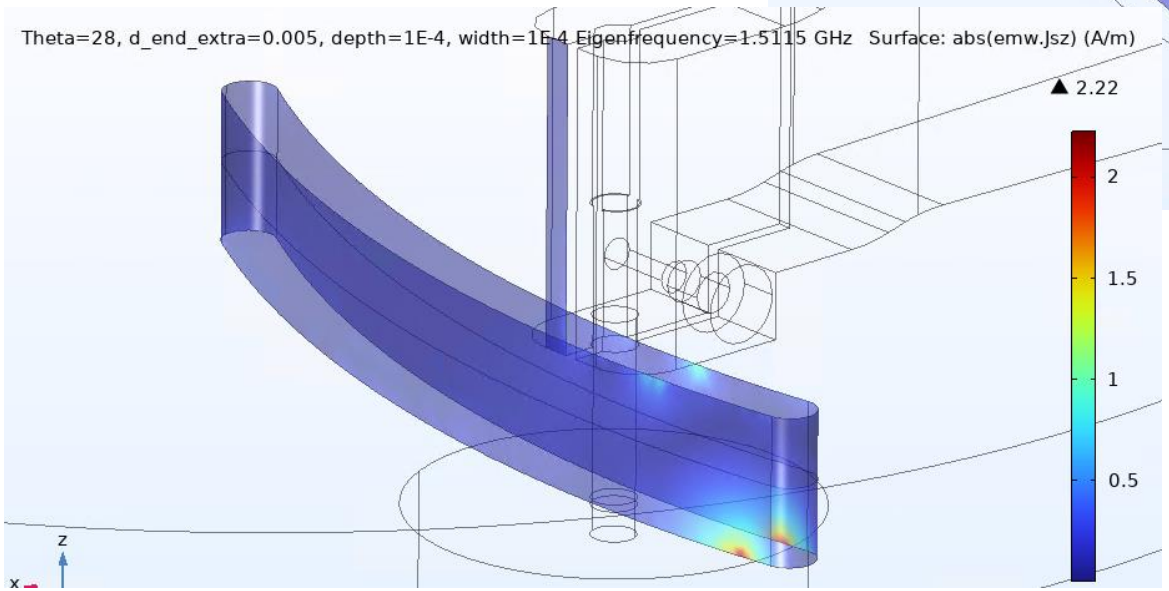
- The areas of low Q are increased near an added extrusion, but Q decreases in other regions
- Why does this extrusion work?



How Extrusions Improve Q

The extrusion (bottom right) changes the current distribution and decreases overall flow out of the slot





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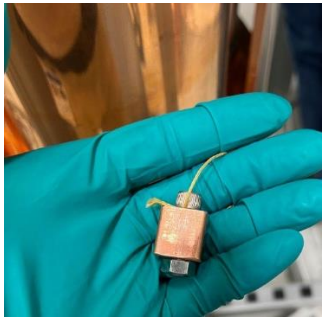
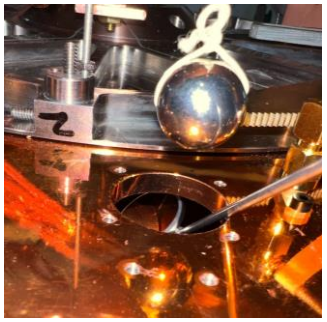
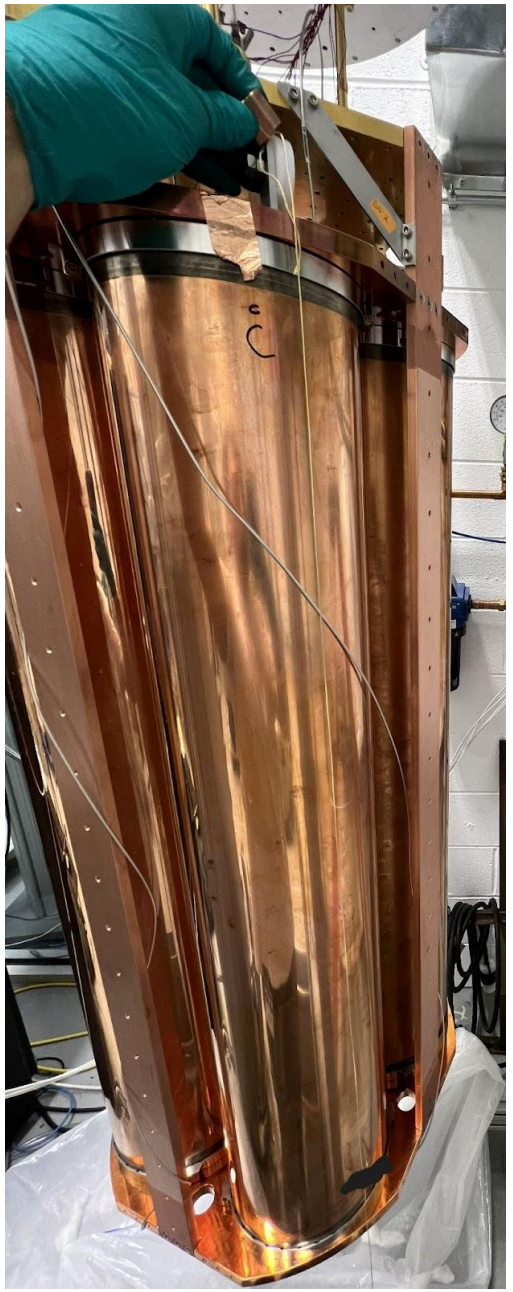
Bead Pull: Simulation vs. Reality

$$\frac{\Delta\omega}{\omega_0} \approx \frac{\varepsilon - 1}{\varepsilon + 2} \frac{V_{\text{bead}}}{V_{\text{cav}}} \frac{|\mathbf{E}(\mathbf{r}_{\text{bead}})|^2}{\langle |\mathbf{E}|^2 \rangle_{\text{cav}}}$$

https://www.bnl.gov/isd/documents/78761.pdf







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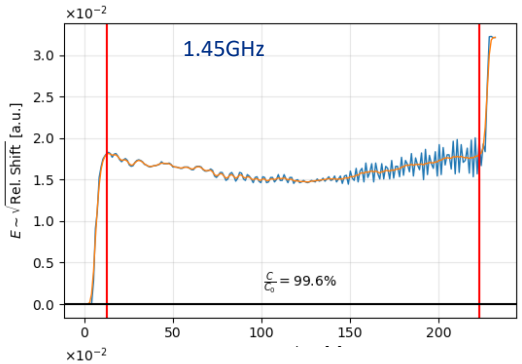
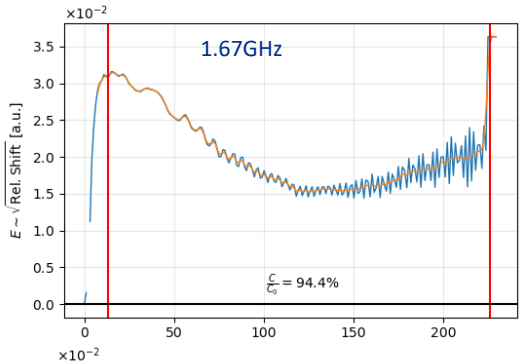
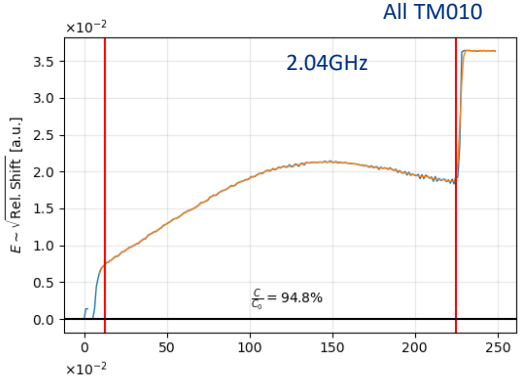
Bead Pull to Adjust Rod Position

All TM010

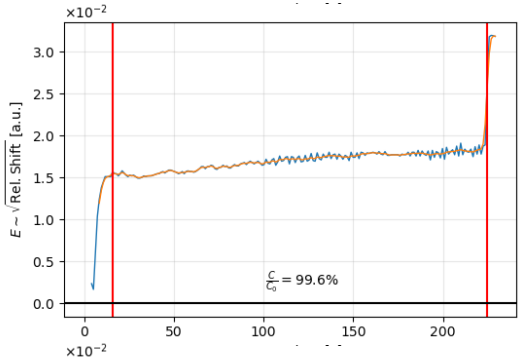
Cav. A

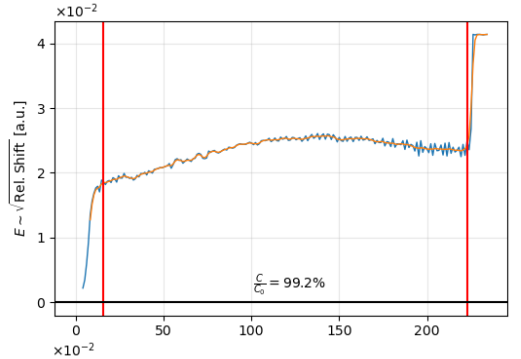


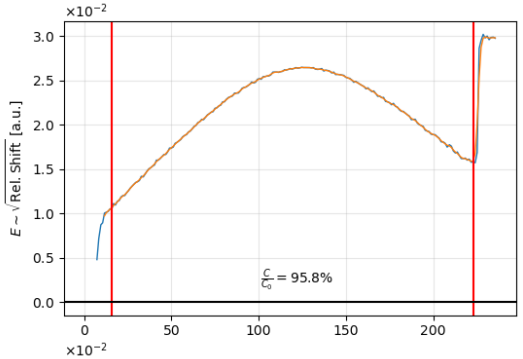




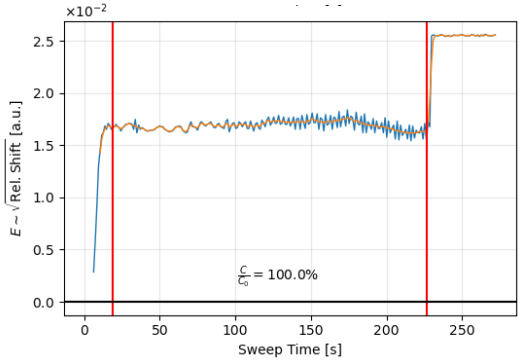
Cav. C

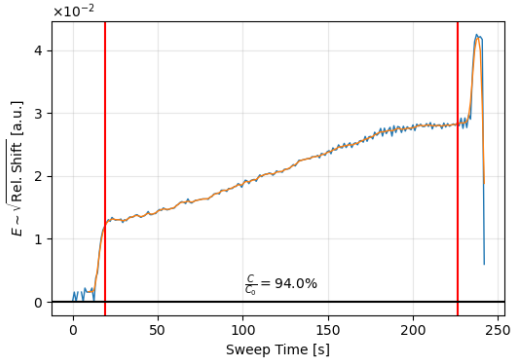


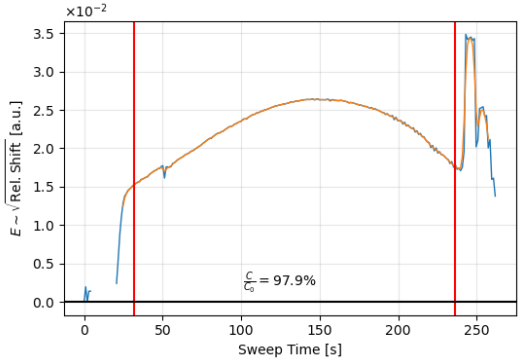




Cav. D







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Collaborations / Acknowledgements

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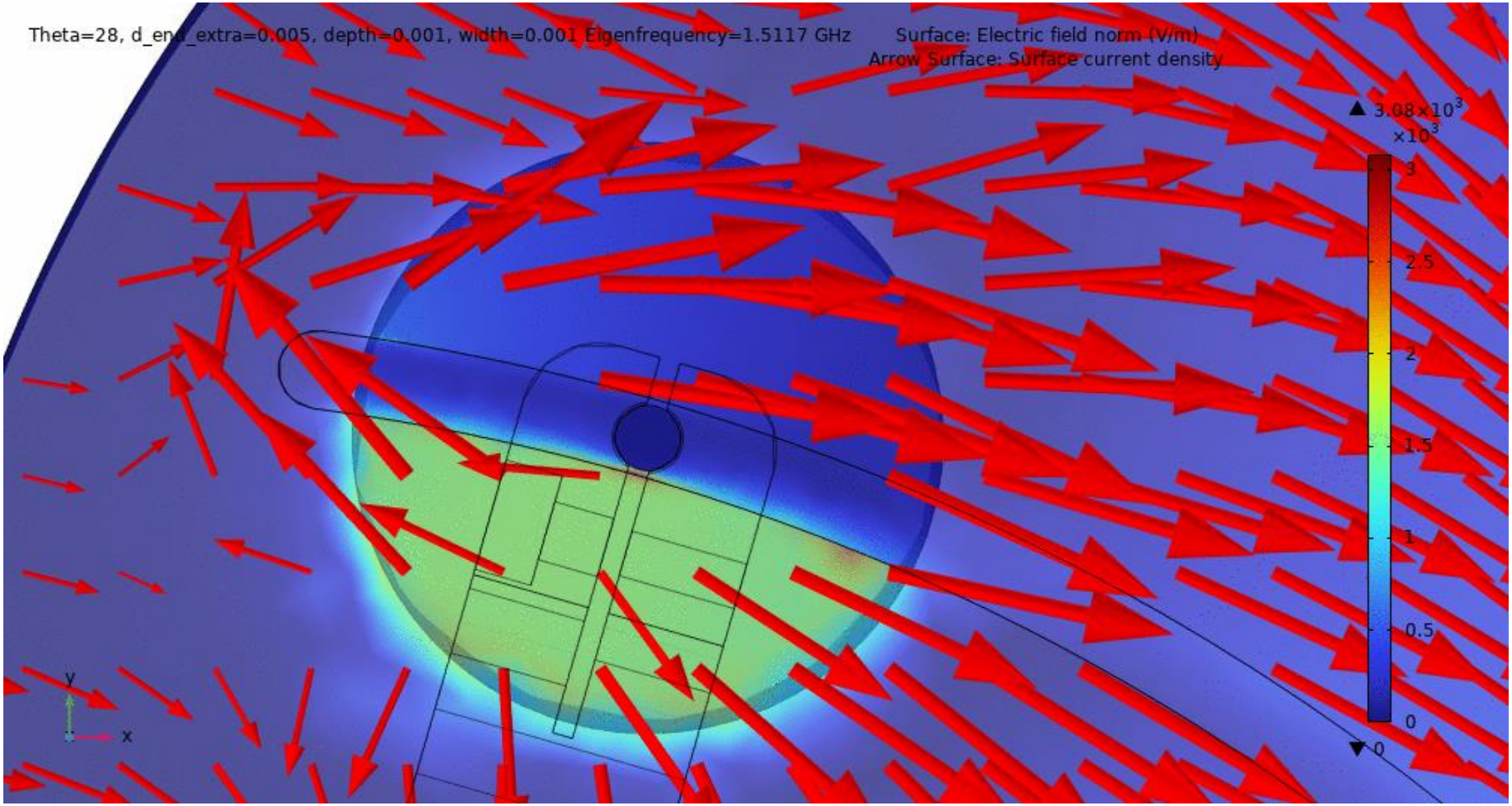
Presentation Abstract

My research project is in collaboration with the Axion Dark Matter eXperiment (ADMX). ADMX uses a detector to search for a dark matter candidate (axion) via its interaction with light (photons). I discuss the various detector designs I simulated, attempting to reduce the signal leakage out of the system. I describe an upgrade to be implemented for the next cavity, which adds an extrusion to a region of the slot which was known to work poorly. Another way I helped enhance the detector involved performing a bead test, where I moved a metallic bead through the vertical (z) axis of a single cavity. The bead produces measurable perturbations of the electric fields as it moves from the top to the bottom of the cavity. Taking measurements, I discuss how the data helps us fix the physical system.

Backup Slides



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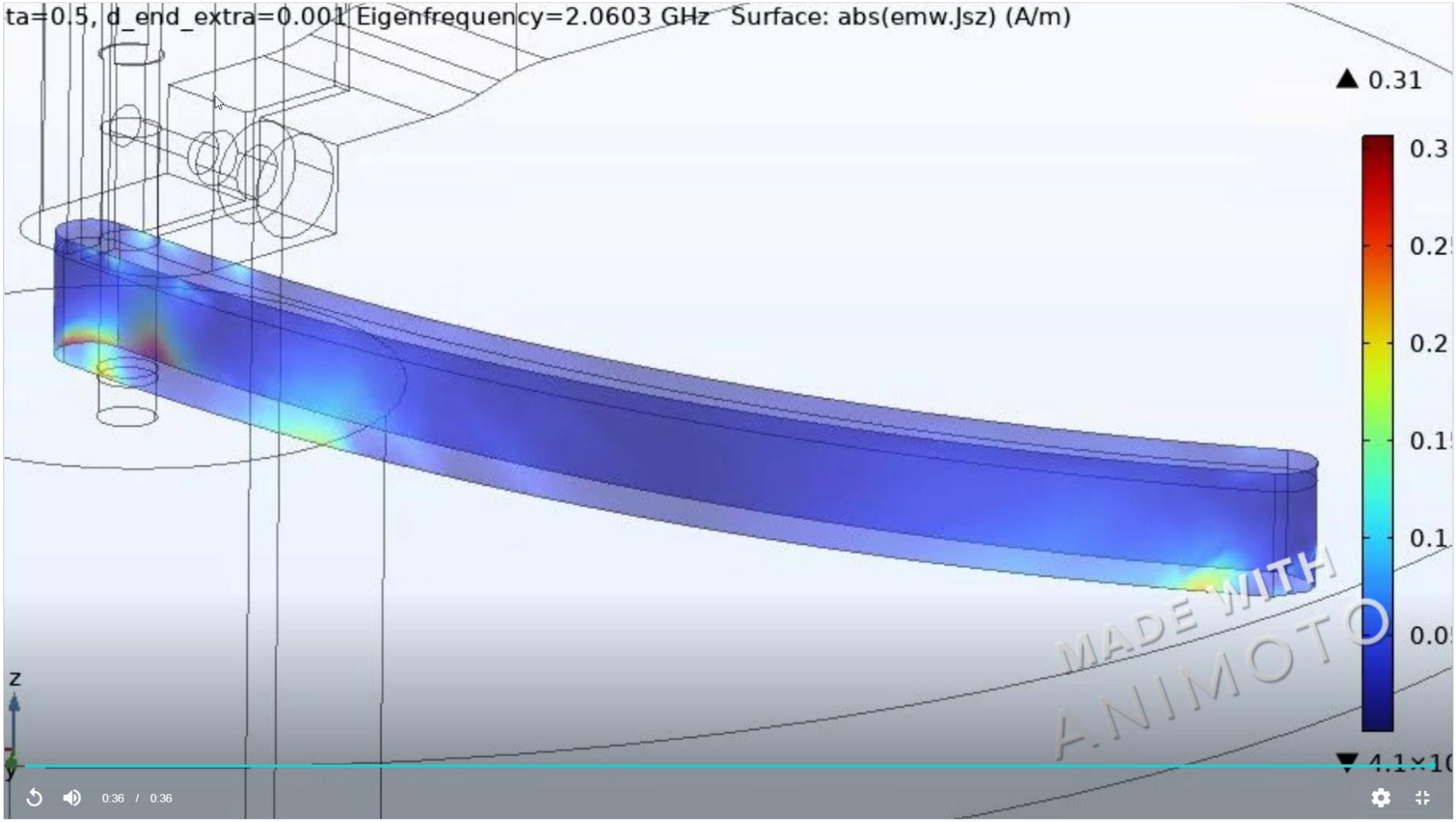
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▲ 0.31
0.3
0.2
0.2
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0.1
0.0
▼ 4.1×10
z
y
0:36 / 0:36
MADE WITH ANIMOTO

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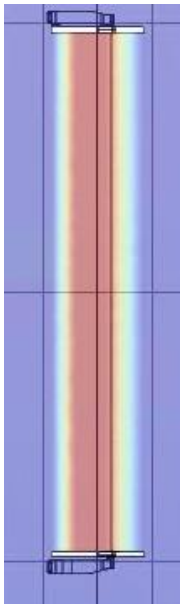
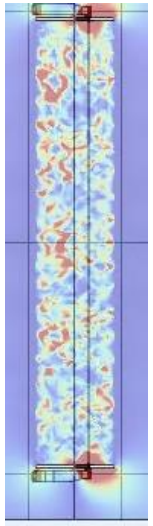
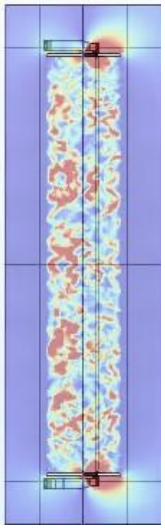
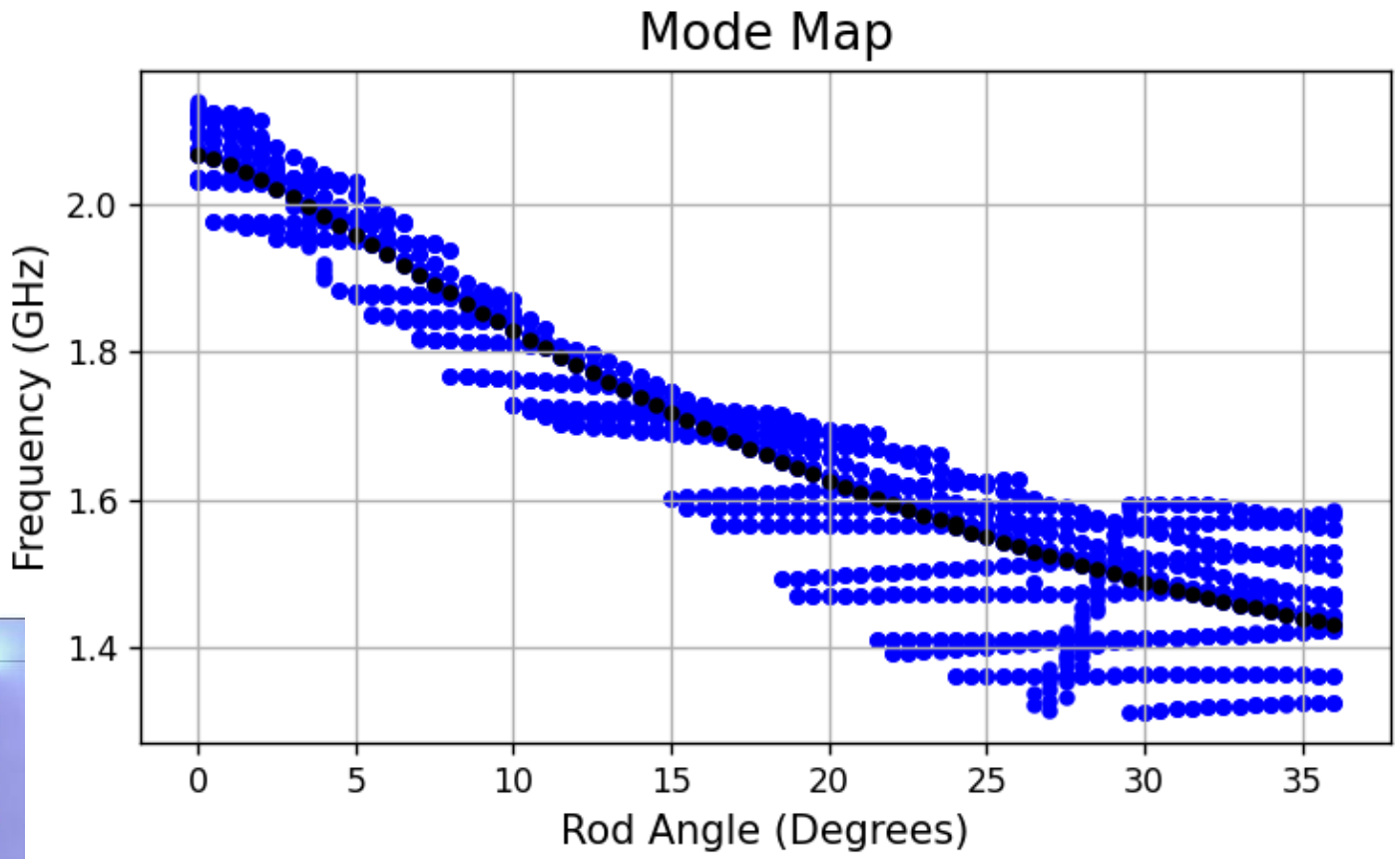
Values of Interest









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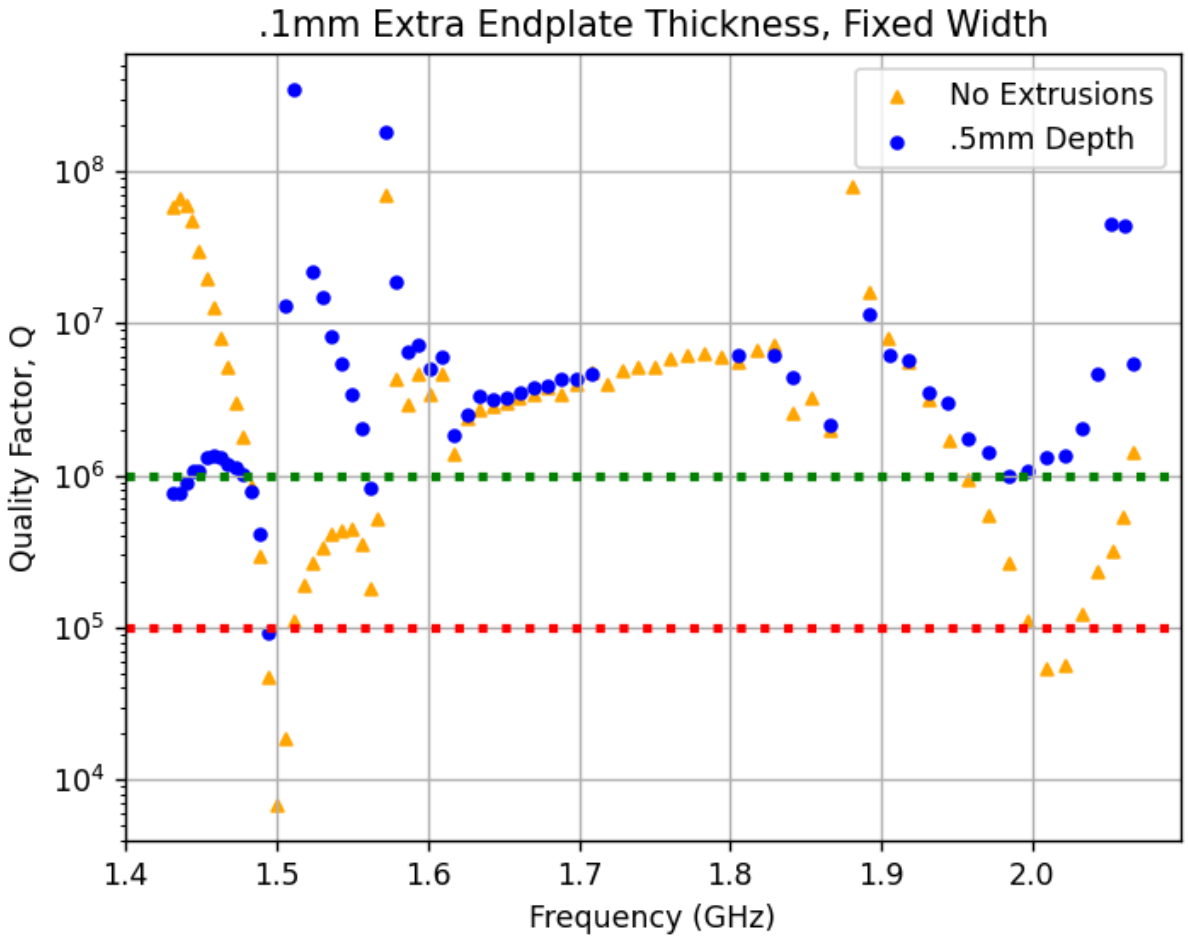
Sacrificing Regions of Low Q (Frequency Ranges)



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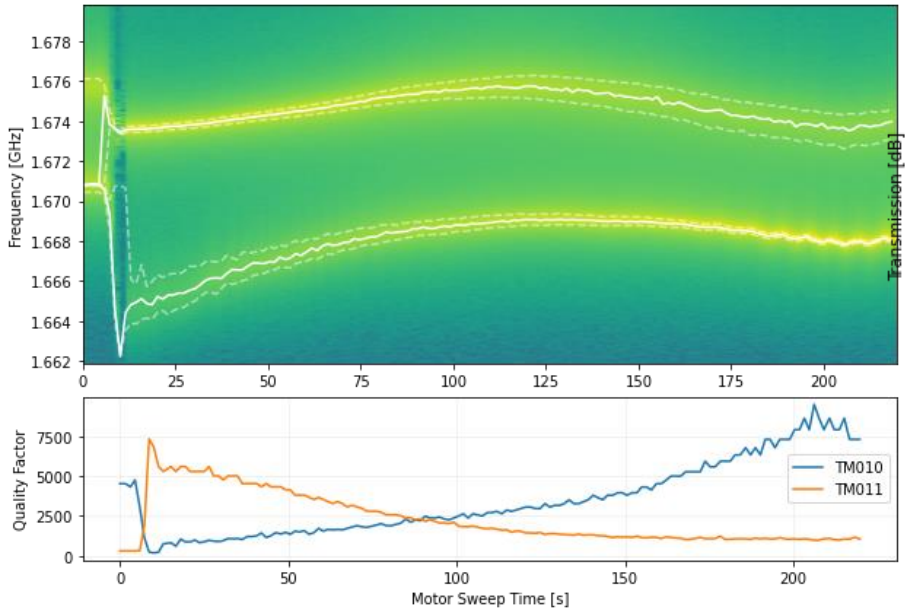
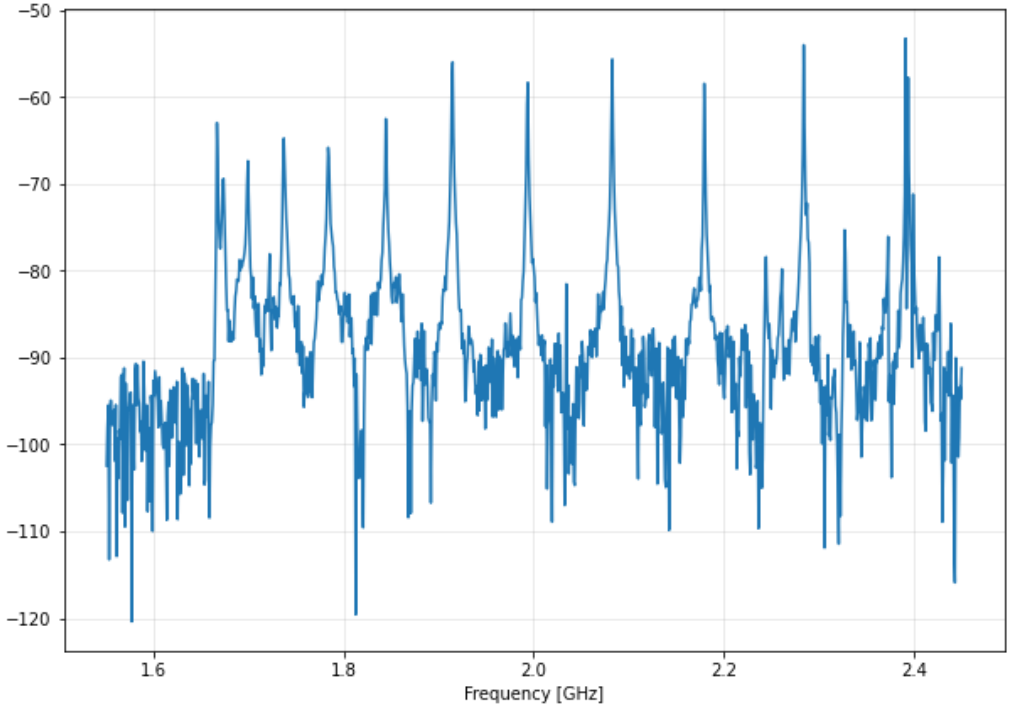
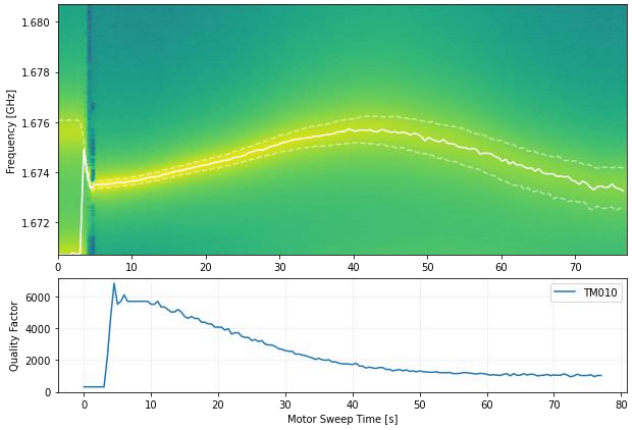
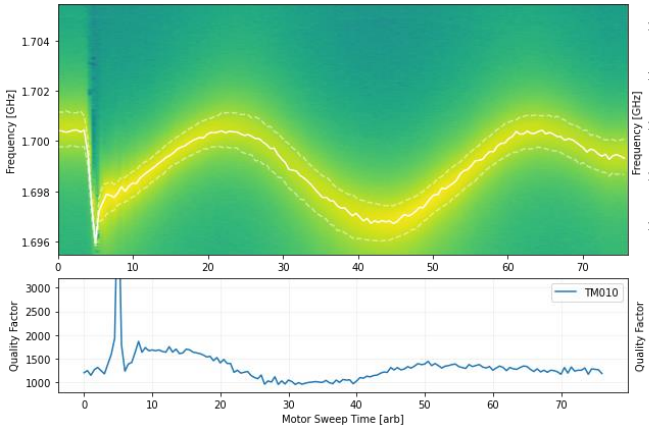
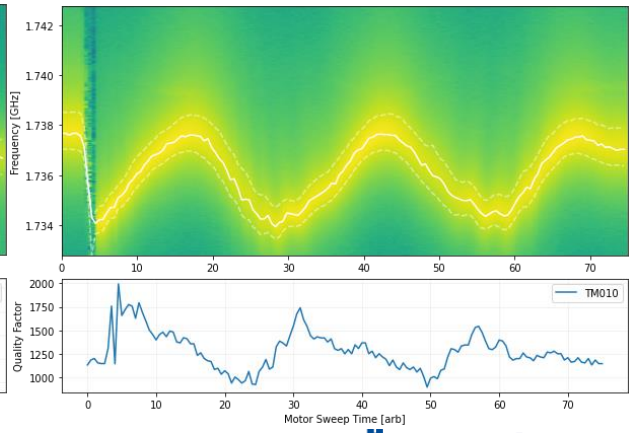
Copper Bead











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