Advanced Resonators for Axion Searches

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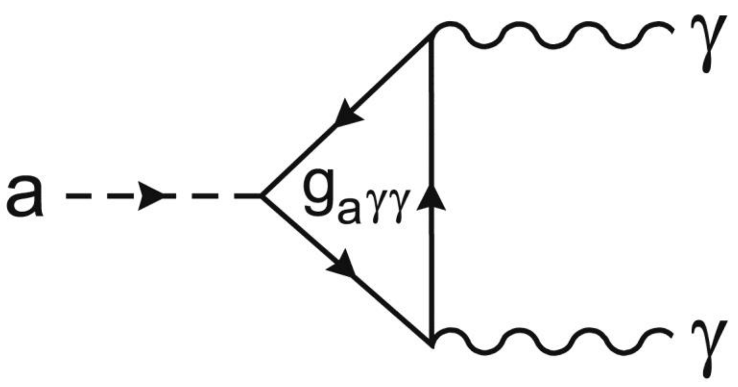
Overview

- What is dark matter?
  - The axion
- Resonators as low mass axion haloscopes
- “Pizza Cavity” resonator prototypes
  - Model 1
  - Model 2
- Future work/Conclusions

The Axion

- Well-motivated cold dark matter candidate
  - Theorized to solve strong CP problem, characteristics match that of CDM candidates



Dark Matter and Background Light - J.M. Overduin & P.S. Wesson

[1]

A bit of cosmology

CDM (cold dark matter) is slow compared to the speed of light

MANY

Axions were created abundantly during Big Bang

Low mass axions prevented other decay modes, so the universe would be filled with cold Bose–Einstein condensate of primordial axions. Hence, axions explain the dark matter problem

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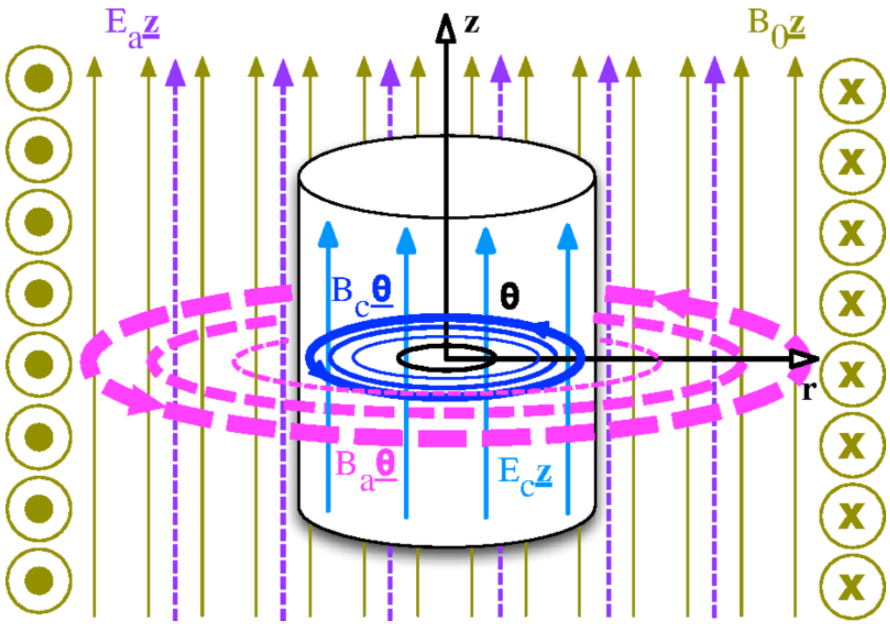
Axion Haloscopes and Resonators

Axions will convert to photons in a strong inhomogeneous magnetic field B(x)

Axion Haloscopes are typically closed microwave resonators



Axions moving through magnetic field will convert when EM resonance in cavity is tuned to frequency of the photons produced. Axions detected as excess power at this frequency

Ben T. McAllister et al., Phys. Rev. Lett. 116, 161804

ADMX

Field Cancellation Coil

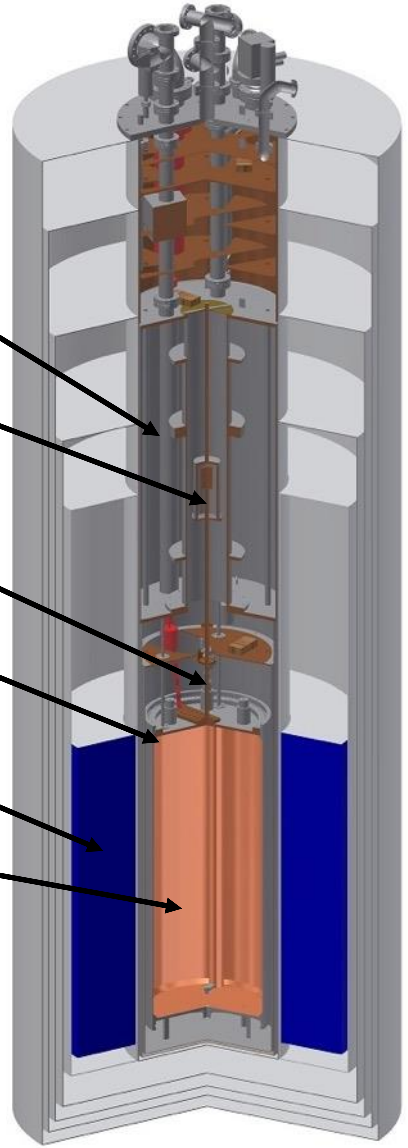
SQUID Amplifier Package

Dilution Refrigerator

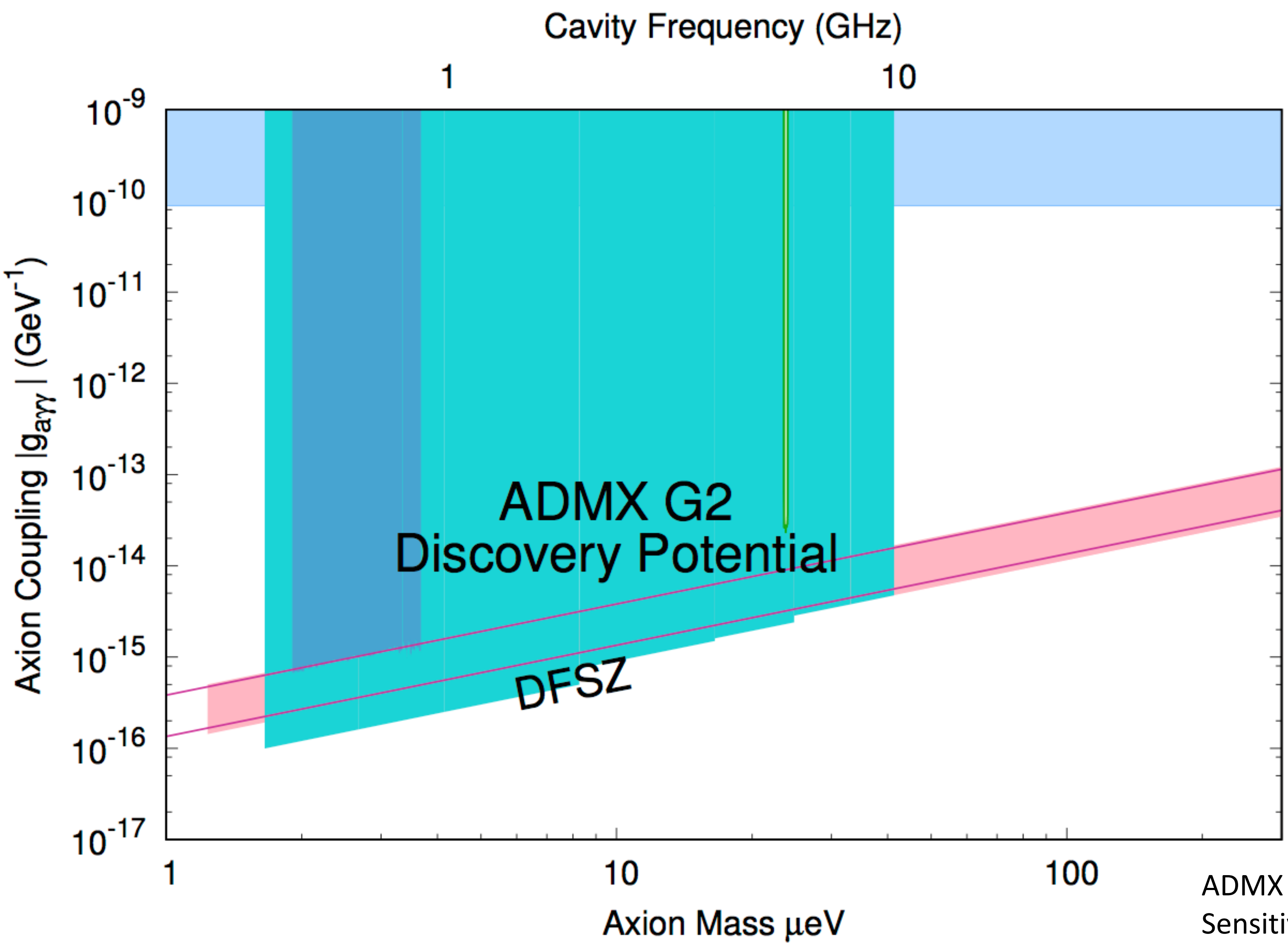
Antennas

8 Tesla Solenoid Magnet

Microwave Cavity



Motivation



ADMX Projected Sensitivity up to date Jan 12 2017 source: Gray Rybka

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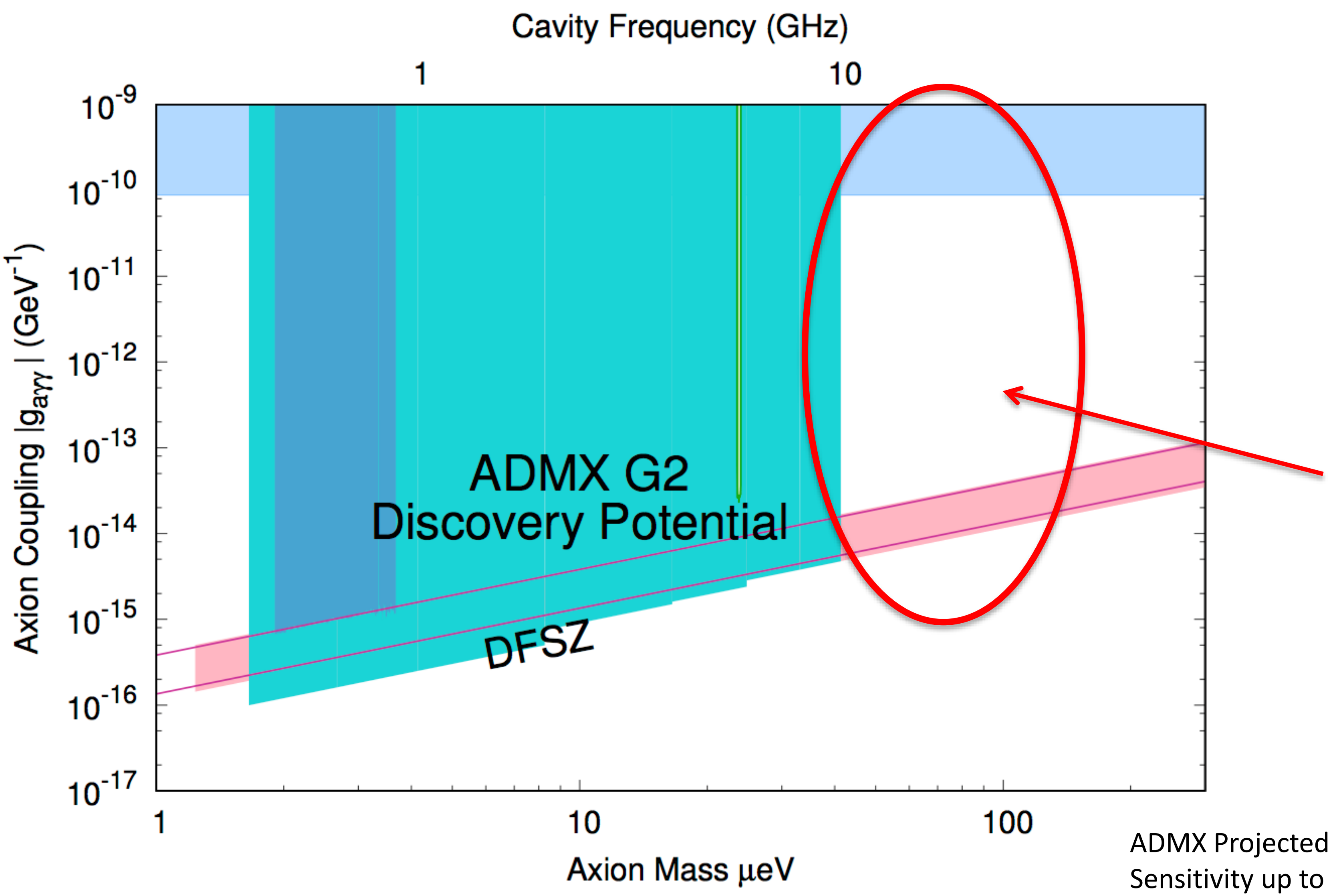


ADMX Projected Sensitivity up to date Jan 12 2017 source: Gray Rybka

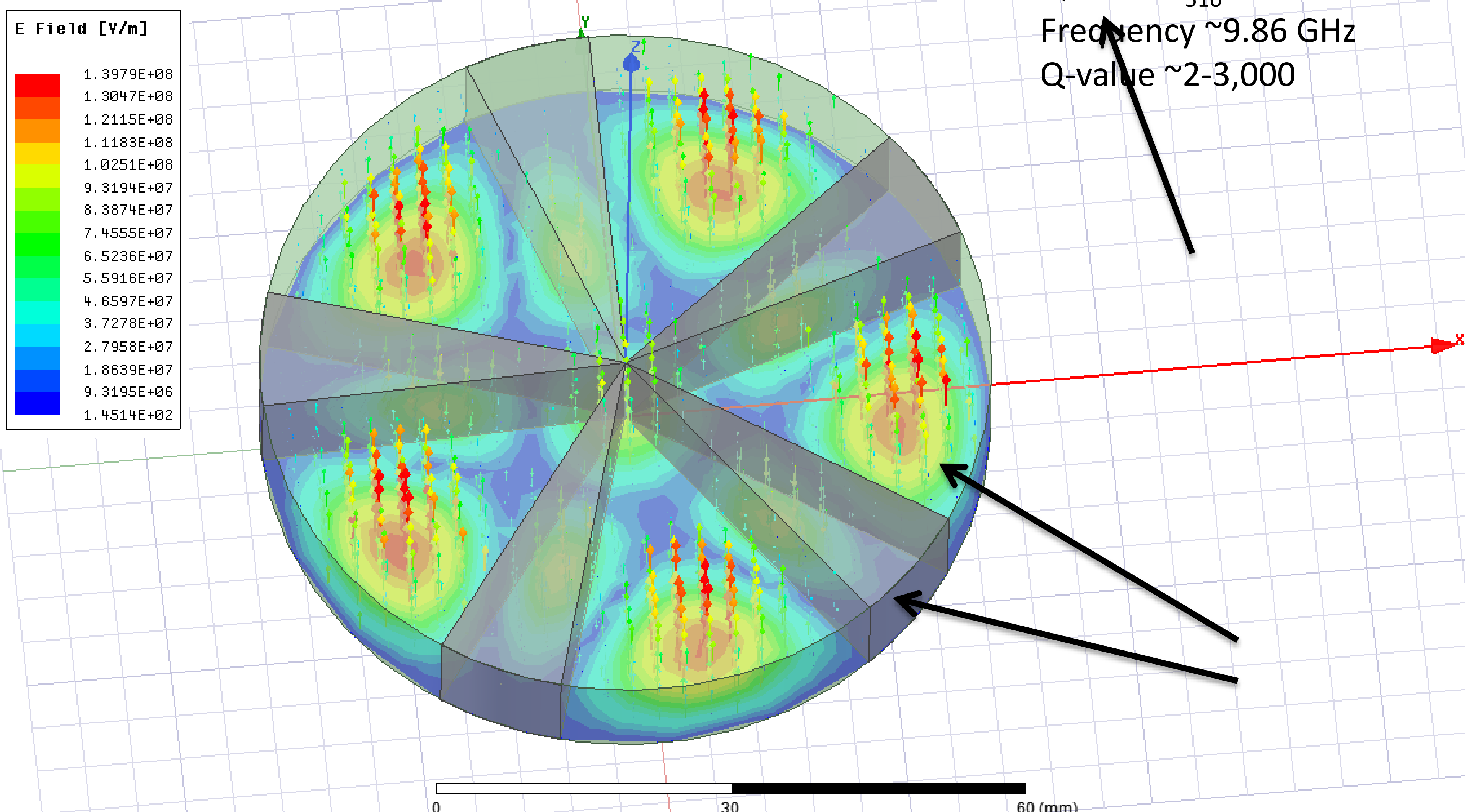
The use of dielectrics

- Allow for higher frequency searches
- Can use one tunable cavity instead of multiple smaller cavities
- Manipulate waveforms so we can look at other TM modes

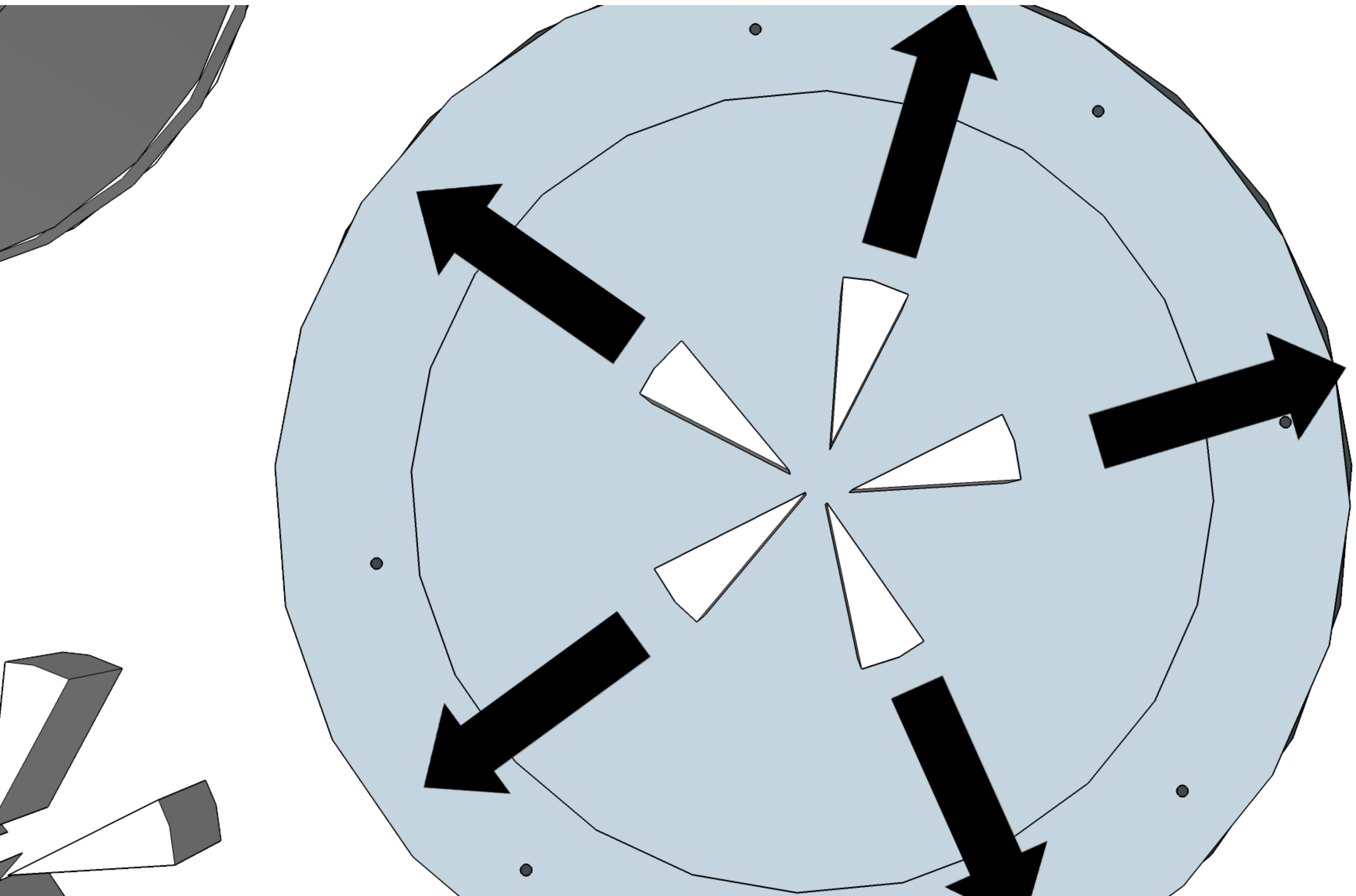
“Pizza Cavity” Simulation

R. Cervantes, cavity simulations, University of Washington (2017)

Quasi-TM_{510} mode
Frequency ~9.86 GHz
Q-value ~2-3,000



Potential Tuning Mechanisms



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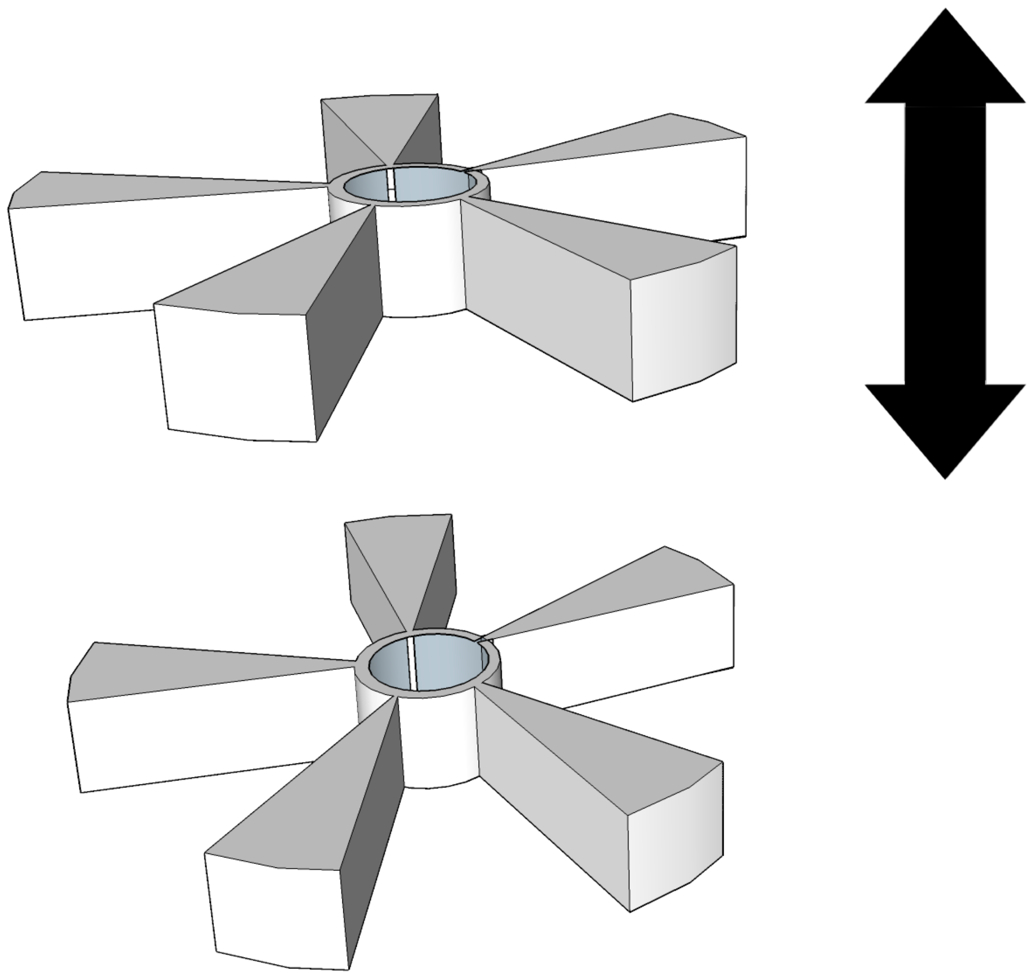
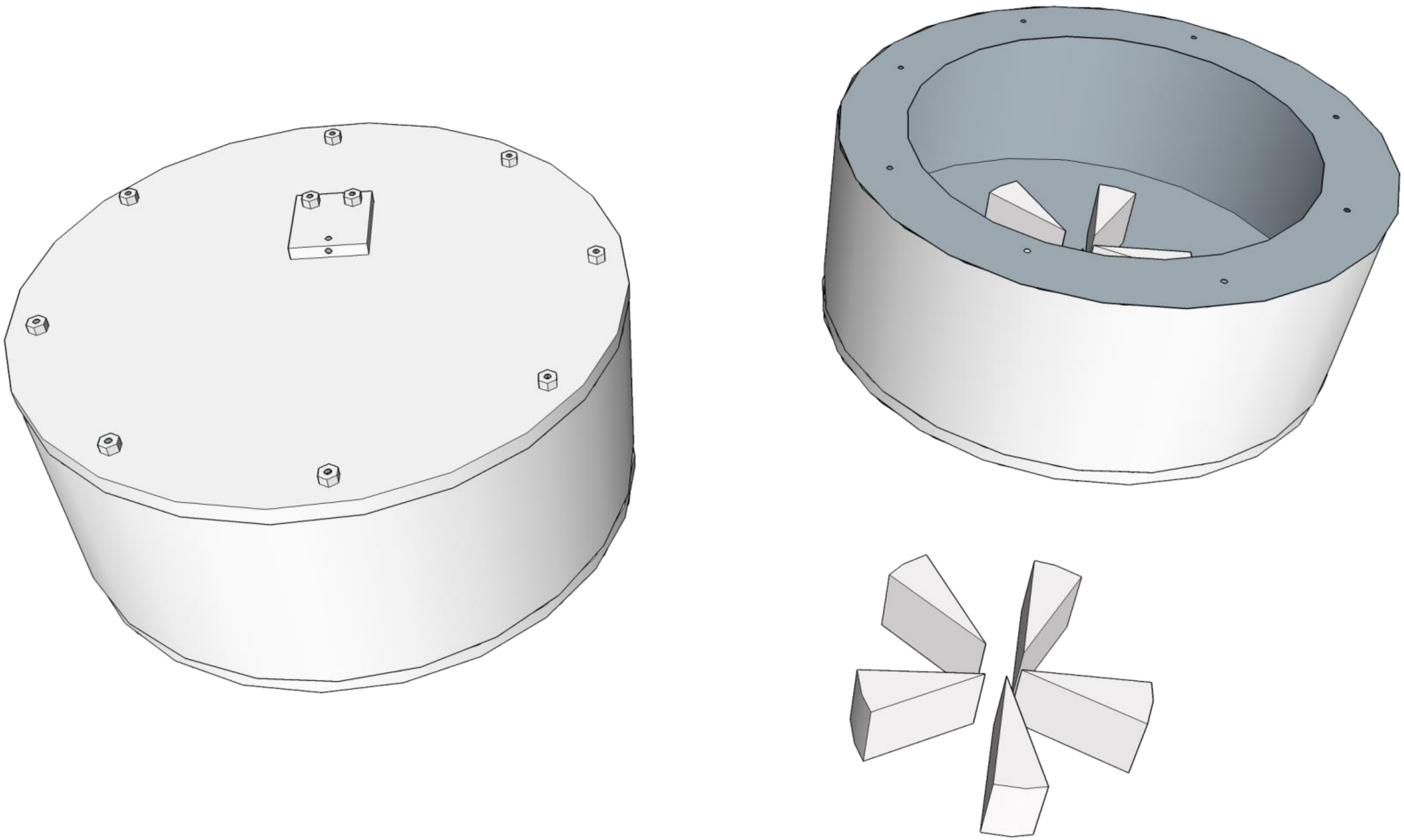


Model 1



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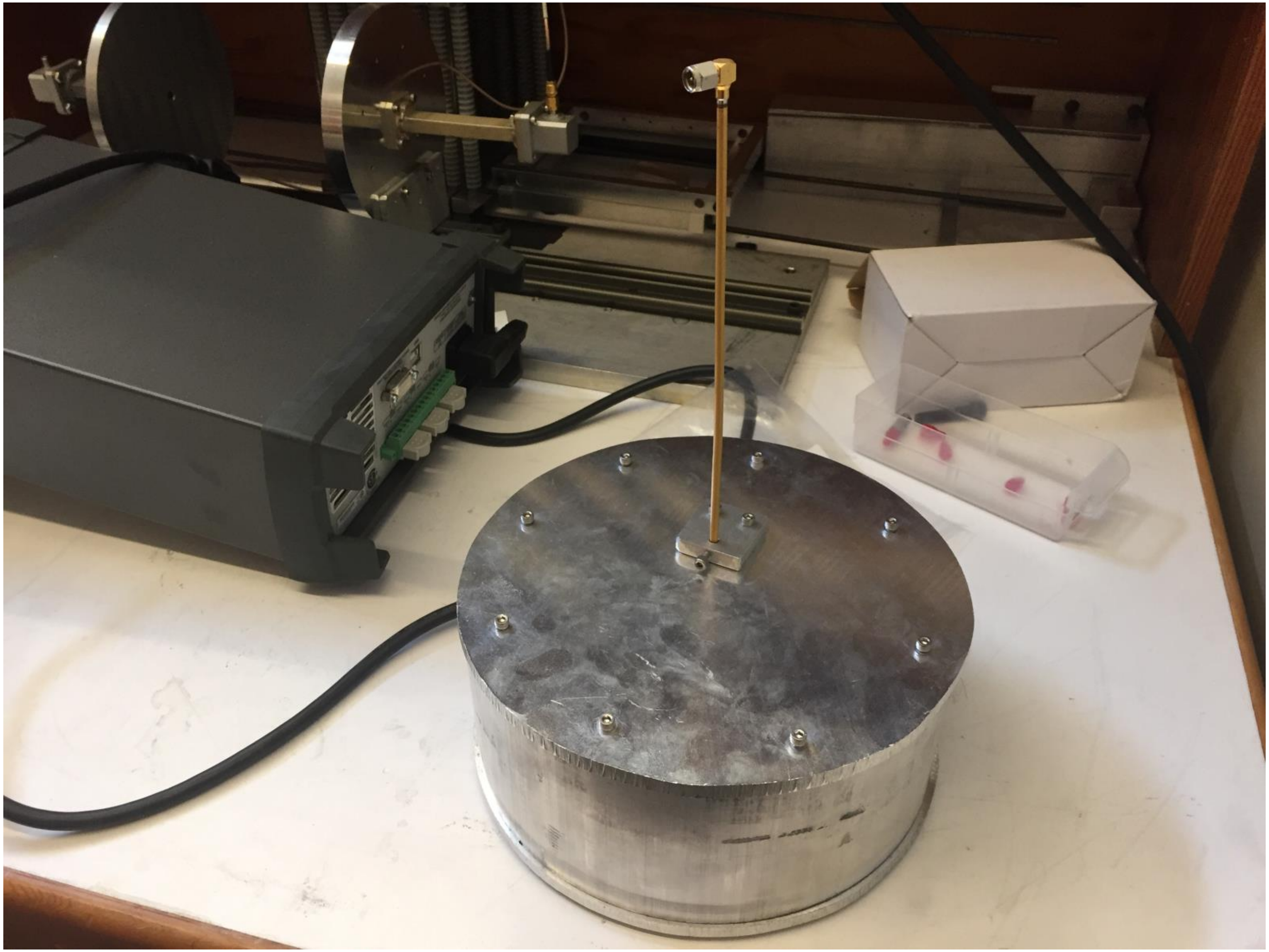
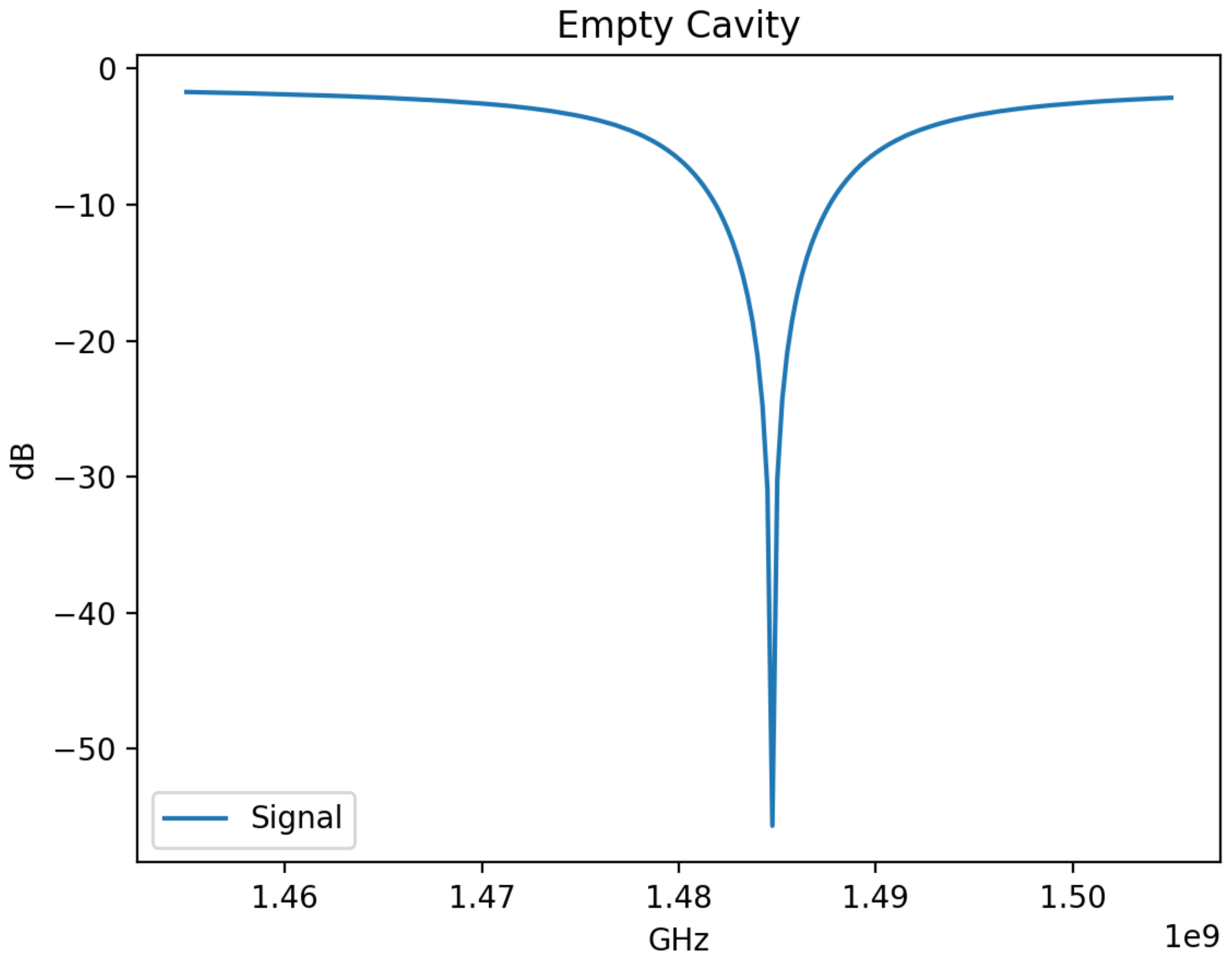
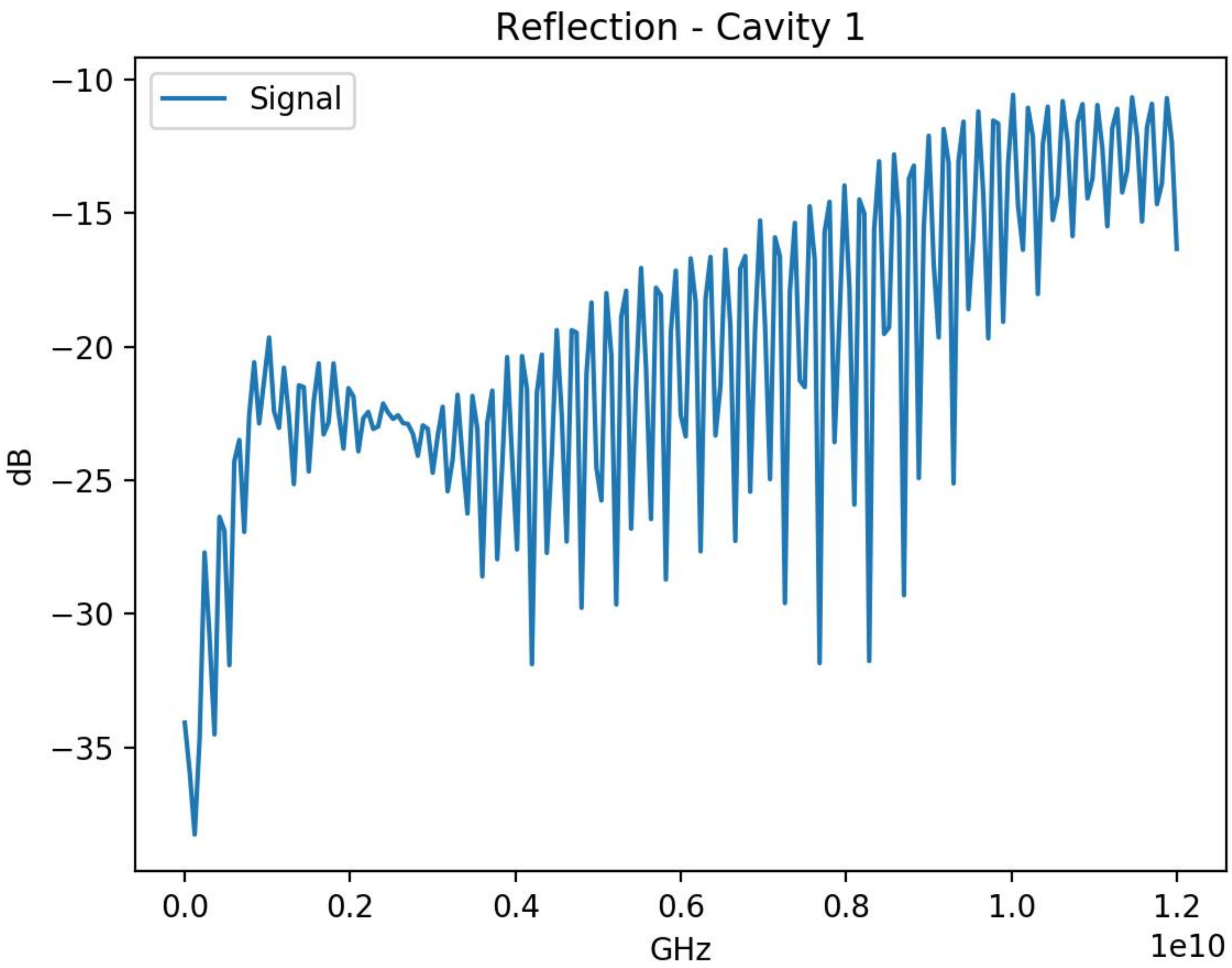


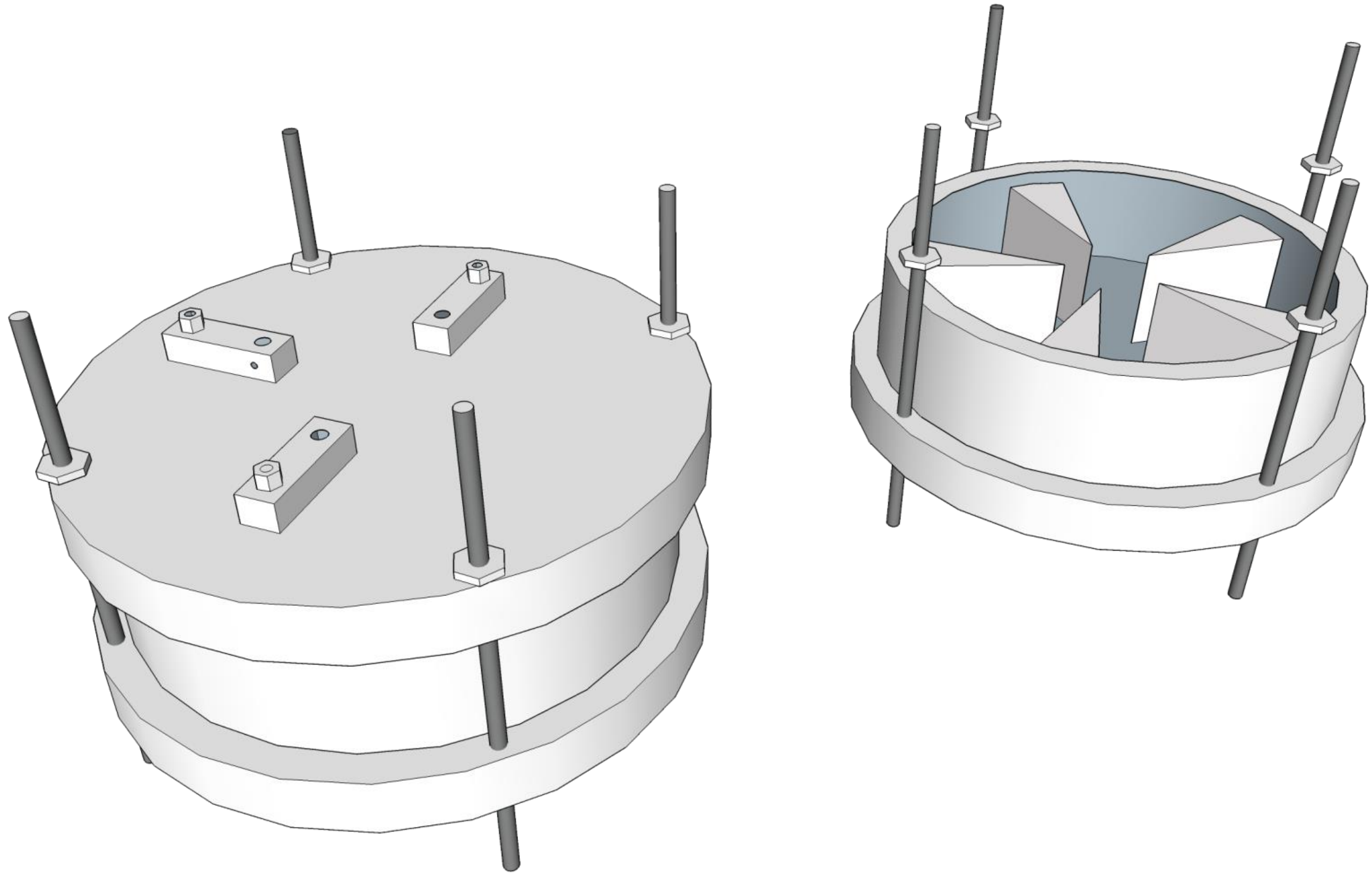
Empty Model 1 cavity reflection result



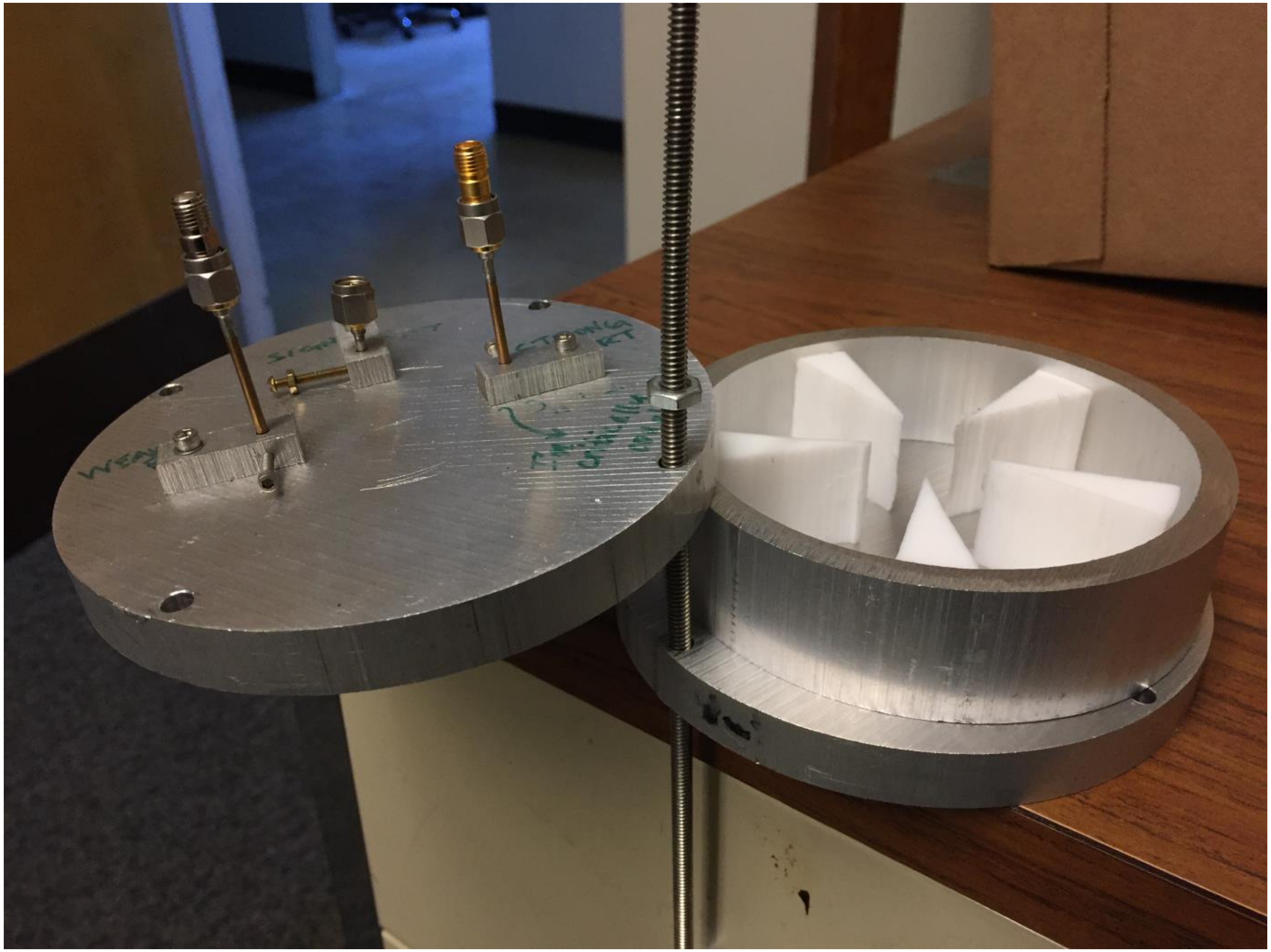
A mess


Reflection - Cavity 1
Signal
dB
−10
−15
−20
−25
−30
−35
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1e10
GHz

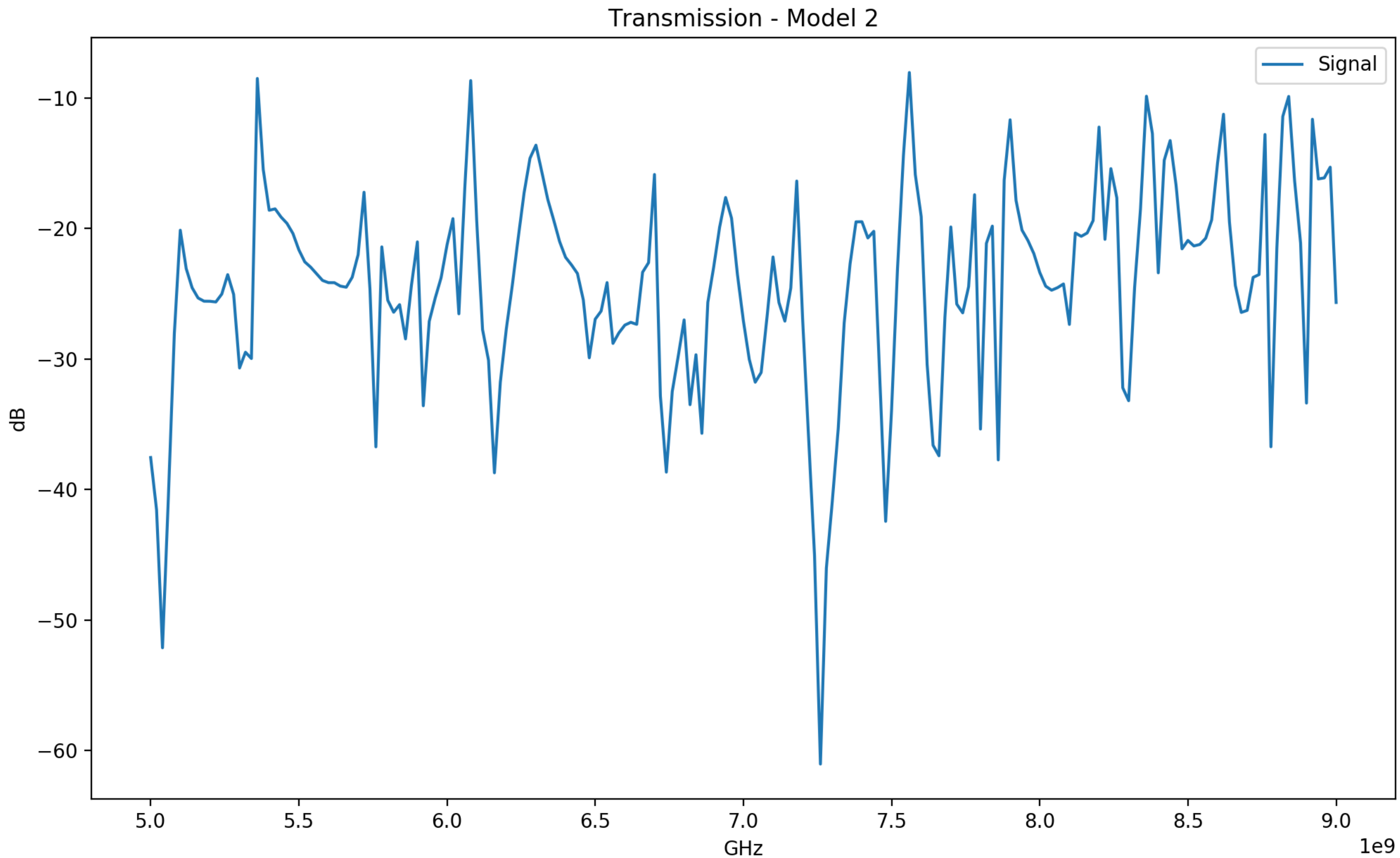
Model 2



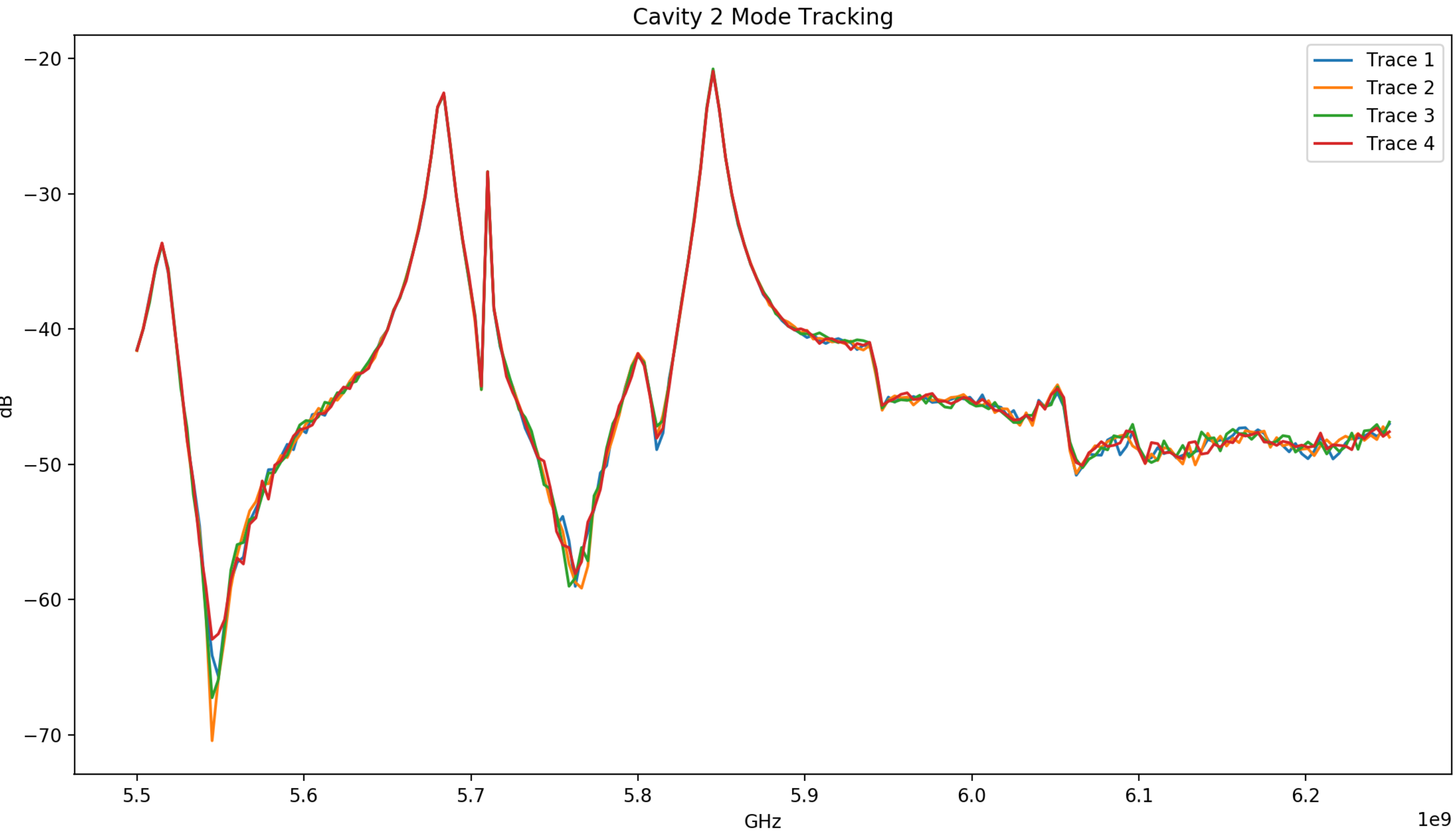
Model 2



Model 2 Transmission Data



Model 2 – Tracking Modes



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Future work:

Confirm tuning methods are workable

Focus on cavity optimization, Q value, etc.

Look into other more complex modes: whispering galleries with more exotic materials

We still don’t have a catchy name..

PRNCESS - **P**izza **R**eso**N**ant **C**avity **E**xperiment using **S**apphire**S**

POP TART - **P**eri**O**dically-**P**laced **T**eflon **A**xion/**A**luminum **R**esona**T**or

DARTH VADER - **D**ark matter **A**xion **R**esonating **T**ube **H**aloscope with **V**acuum **A**nd **D**i**E**lectric **R**?

DARK - **D**ark matter **A**xion **R**esonating **K**avity??

GRAY (Rybka) - **G**Hz **R**ange **A**xion cavit**Y**

PENTAGRAM – **P**eriodic r**E**so**N**a**T**or for **A**cquiring **G**Hz-**R**ange **A**xionic **M**atter

ALAKAZAM - **AL**uminum **A**xion **C**avity, **AZ**imuthally **A** **M**ess

PANDeMiC - **P**izza **A**xio**N** **D**ark **M**atter dete**C**tor

PARADOX - **P**izz**A** **R**esonator c**A**vity **D**etect**O**r **X**periment

PROTOCOl - **P**izza **R**es**O**na**TO**r **C**avity detect**O**r

DANC Experiment - **D**ielectric **A**xio**N** **C**avity **Experiment**

TBD…

Conclusions

Dielectrics are beneficial in achieving high-frequencies

Similar R&D projects proven necessary to scan larger areas for axion

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NSF

HEISING-SIMONS FOUNDATION

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All of ADMX, for providing me an incredibly warm and welcoming environment to be a part of,

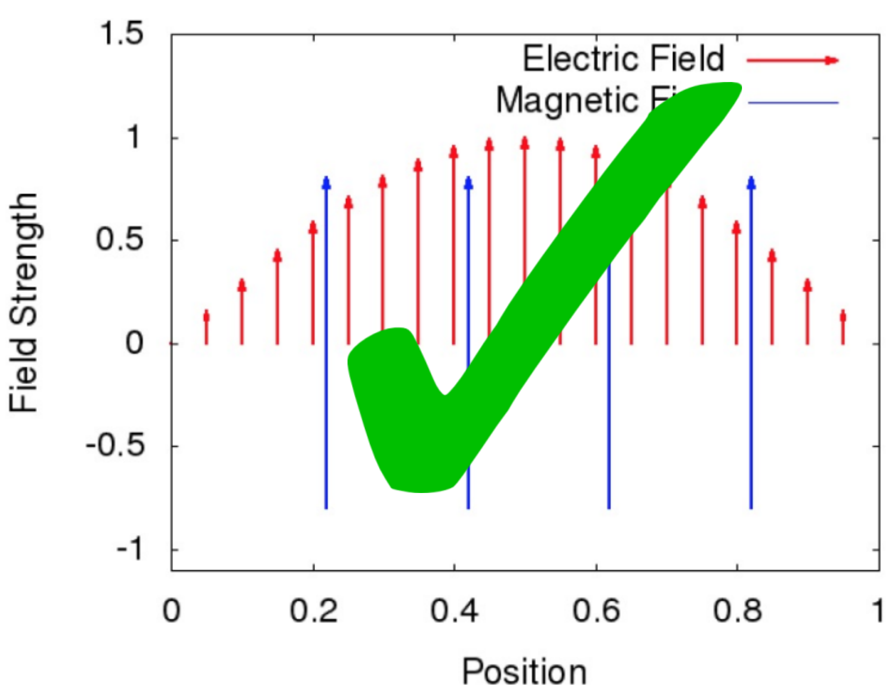
Jenny Smith, for being an amazing friend, and

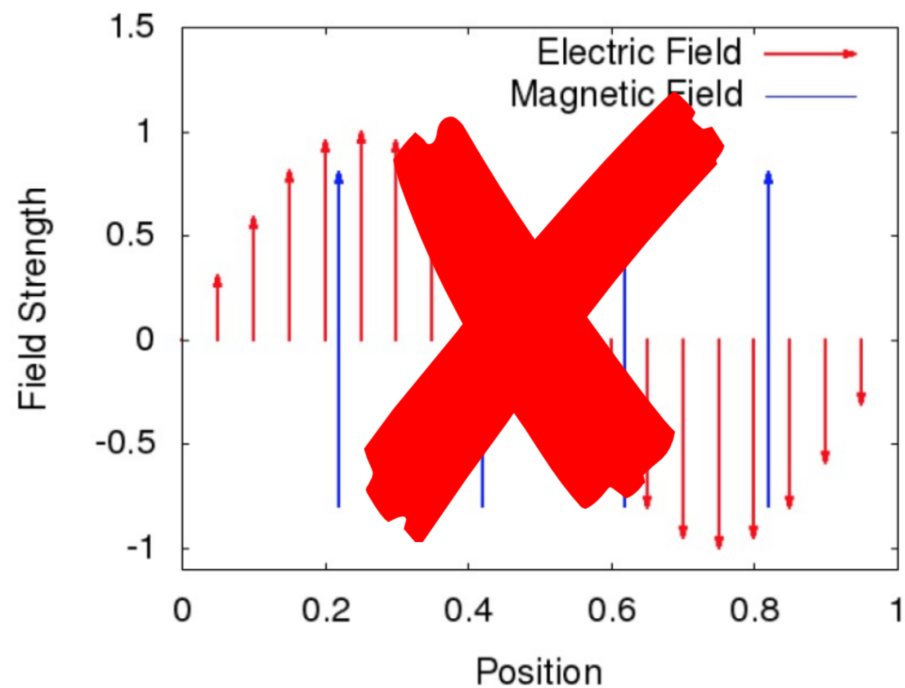
Nick Du, because he asked to be in my acknowledgements.

(Who even let the REU students into this photo?)

Backup Slides

Form Factor (E • B)



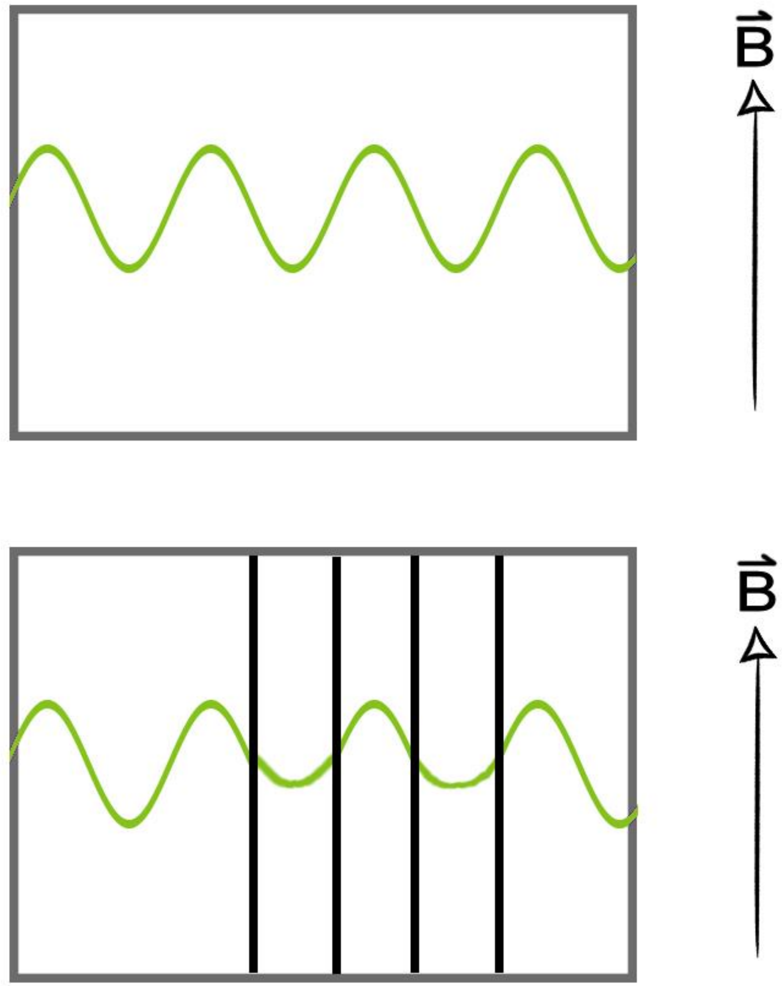


Will couple to the axion, form factor (E • B) is positive

Will NOT couple to the axion, form factor is 0 due to cancellations

G. Carosi – ADMX, UCLA Dark Matter Symposium (2016)

Dielectrics and form factor

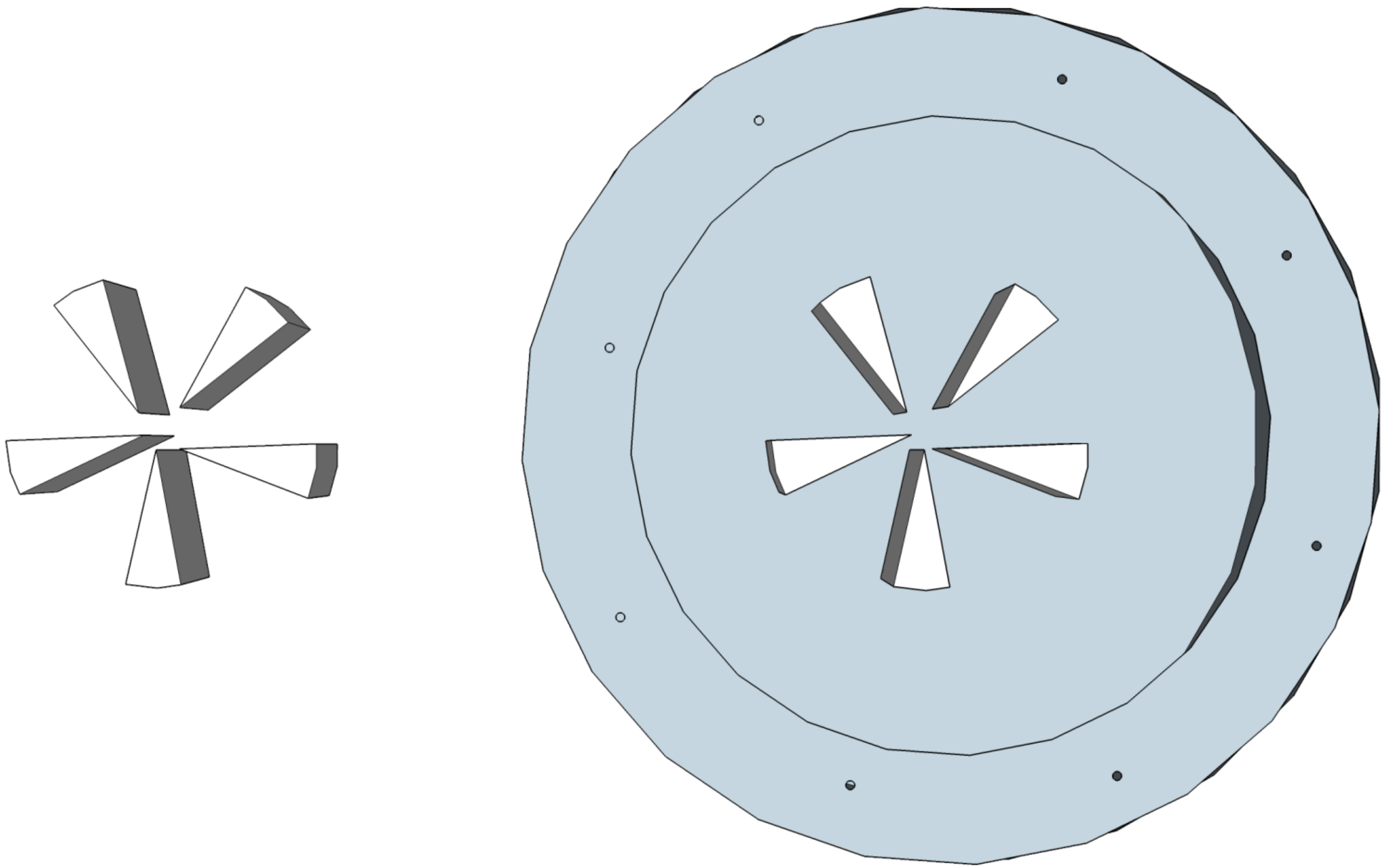


Q Factor of Resonators

- The Q factor (quality factor) of a resonator is a measure of the strength of the damping of its oscillations, or for the relative linewidth.

$$Q = 2\pi \frac{\text{energy stored in cavity}}{\text{energy lost per cycle to walls}}.$$

Model 1 (top)



Basic geometric solution for slice size

$$5\theta_D + 5\theta_V = 2\pi$$

$$\frac{\theta_D}{\theta_V} = \frac{\epsilon_V}{\epsilon_D} = \frac{1}{2.1}$$

$$2.1\theta_D = \theta_V$$

$$5\theta_D + 5(2.1\theta_D) = 2\pi$$

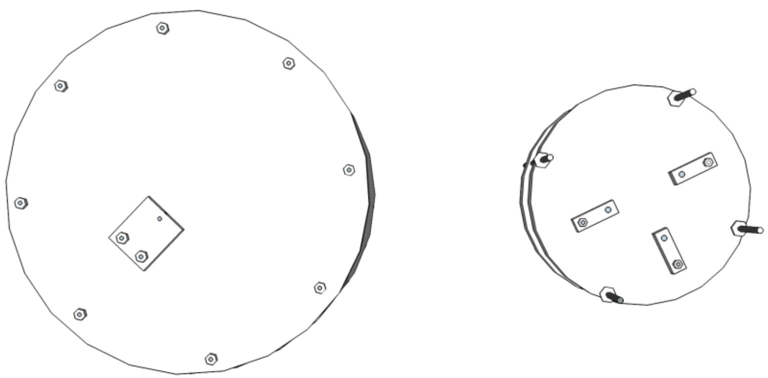
$$\theta_D = 0.40536 rads = 23.225^\circ$$

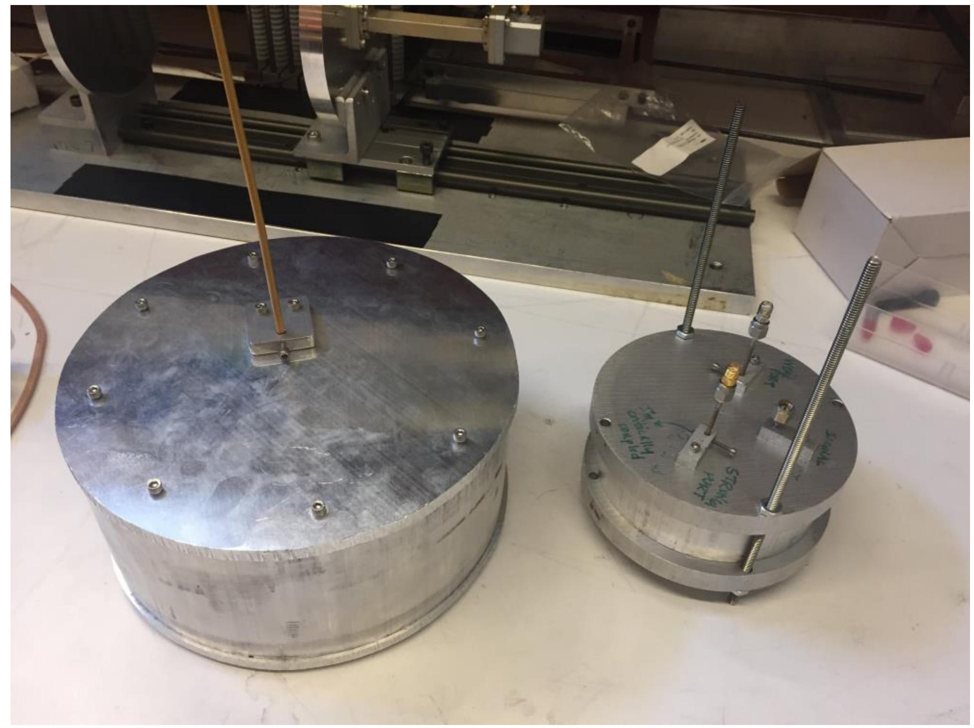
$$\theta_V = 0.85127 rads = 48.774^\circ$$

Method for solving for resonant frequencies

$$\omega_{mnp} = \frac{1}{\sqrt{\mu\epsilon}}\sqrt{\frac{x_{mn}^2}{R^2} + \frac{p^2\pi^2}{d^2}}$$

Size comparison





Axion Haloscopes (cont'd)

$$\sigma = \frac{1}{16\pi^2|\vec{\beta}_a|}\left(\frac{e^2 N}{3\pi^2 v}\right)^2 \sum_{\lambda} \int d^3k_\gamma \delta(E_\gamma - E_a) \left| \int_V d^3x\, e^{i\vec{q}\cdot\vec{x}} \vec{B}_0(\vec{x}) \cdot \vec{\epsilon}(\vec{k}_\gamma, \lambda) \right|^2$$

P. Sikivie, Phys. Rev. Lett. 51, 1415 – Published 17 October 1983

Multiplying the cross section by the axion flux of the Milky Way dark matter halo, one obtains rate of detection

$$\frac{\text{No. of photons}}{\text{time}}$$