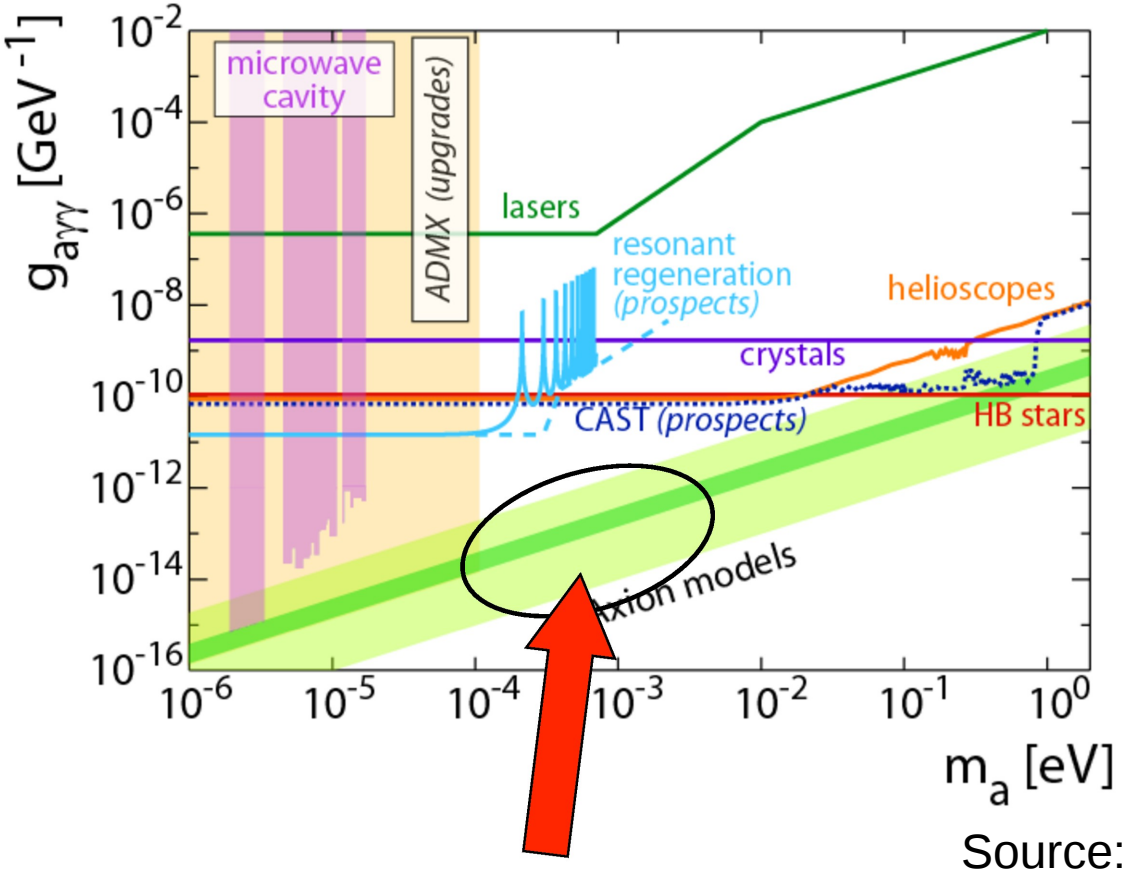
Open Cavity Resonators
The Orpheus Experiment

Gray Rybka, University of Washington

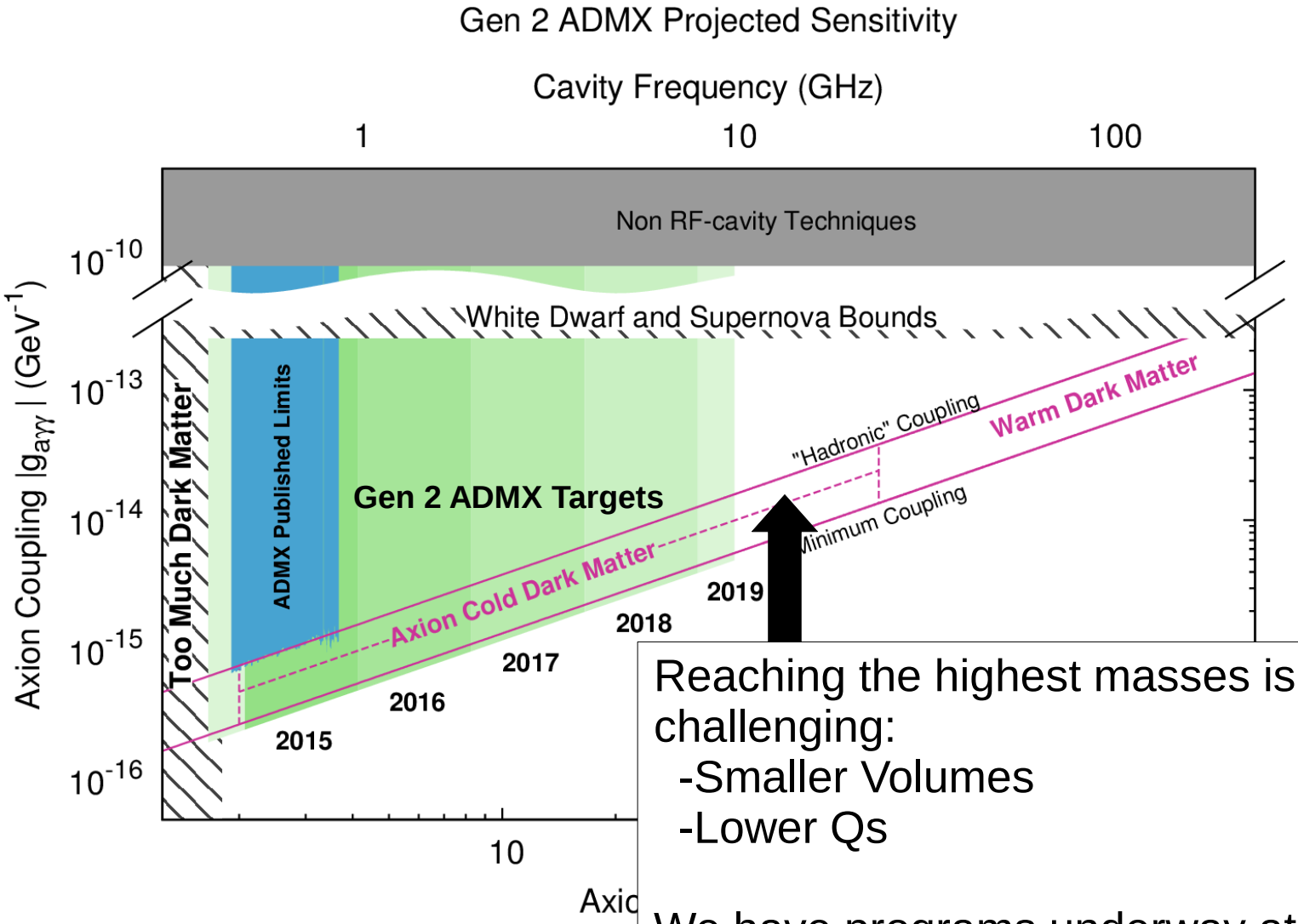
Workshop on Microwave Cavity Design for Axion Detection – LLNL - 2015



The axion from hell

Source: K. Van Bibber,
Vistas in Axion Physics 2012

Beyond Current Axion Experiments

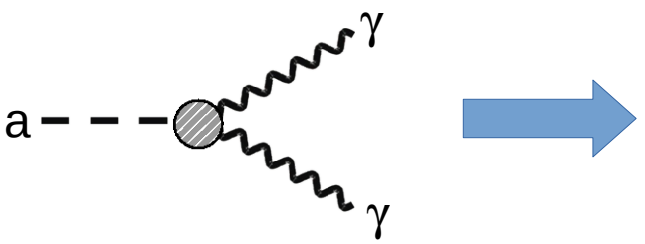


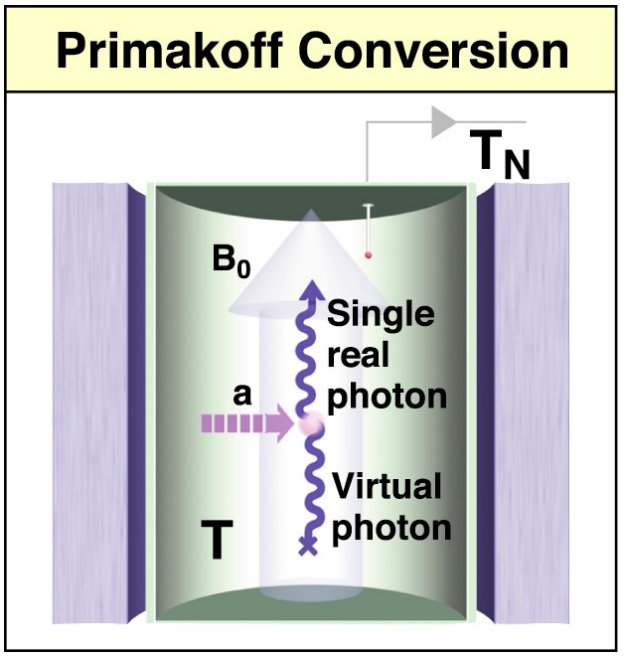
Reaching the highest masses is challenging:

- -Smaller Volumes
- -Lower Qs

We have programs underway at UW (and elsewhere) to mitigate these challenges

Axion Haloscope





Dark matter axions will convert to photons in a magnetic field. A high-Q cavity can enhance the conversion rate.

See: Sikivie, Phys. Rev. Lett. 1983

To make an axion haloscope as sensitive as possible -

You Want:

-Large Cavity Volume
-High Magnetic Field
-High Cavity Q

You Don't Want:

-High Thermal Noise
-High Amplifier Noise

Power From Axion Conversion

Axion-Photon Coupling

Axion Frequency

Resonator Quality

$$P = 1.5\times10^{-21}\, W \left(\frac{B}{7.6\,T}\right)^2 \frac{g_\gamma}{0.97} \frac{\rho_a}{0.45\,GeV/cc} \frac{f_a}{750\,MHz} \frac{Q}{70{,}000} \frac{Vf}{220\,l}$$

Magnetic Field

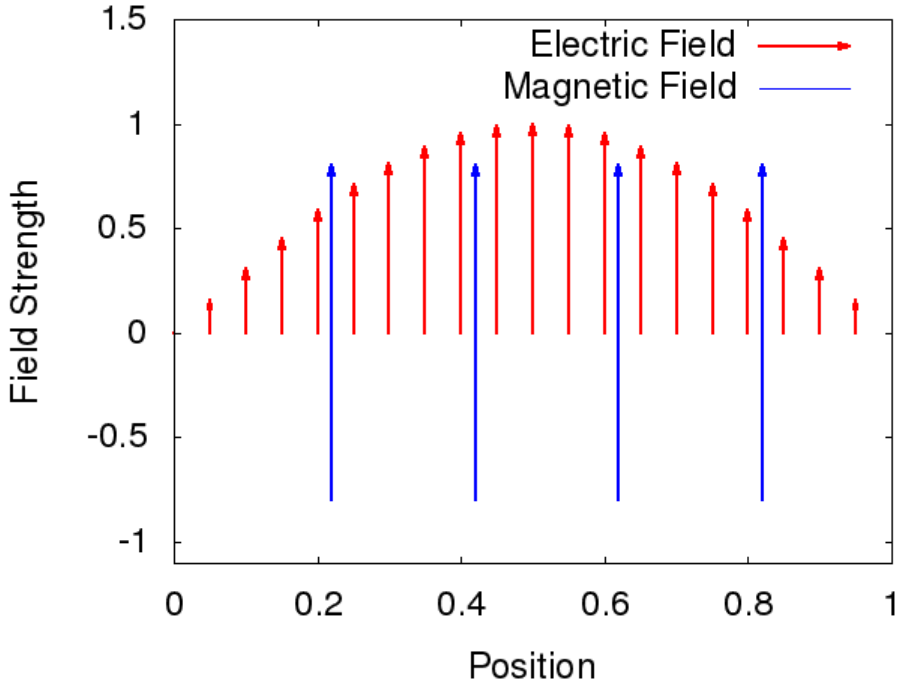
Dark Matter Density

Overlap of integral of electric field of resonance and magnetic fields

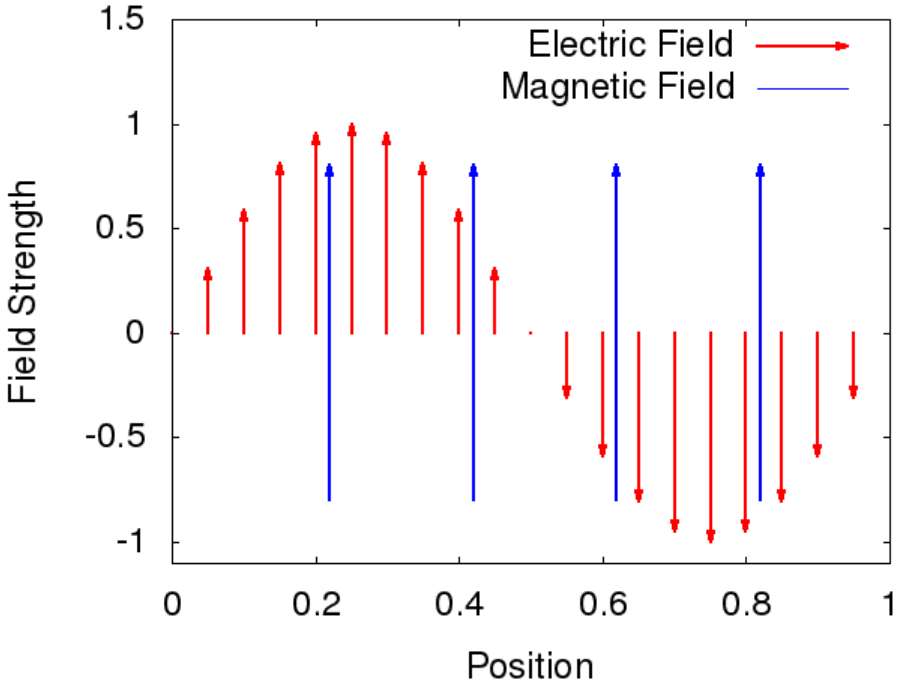
$$\frac{\left(\int \vec{E}\cdot\vec{B}\,dV\right)^2}{B^2 \int \vec{E}\cdot\vec{E}\,dV}$$

Maximizing Power at High Frequencies

Q decreases with increasing frequency, and volume decreases with wavelength in a constant magnetic field

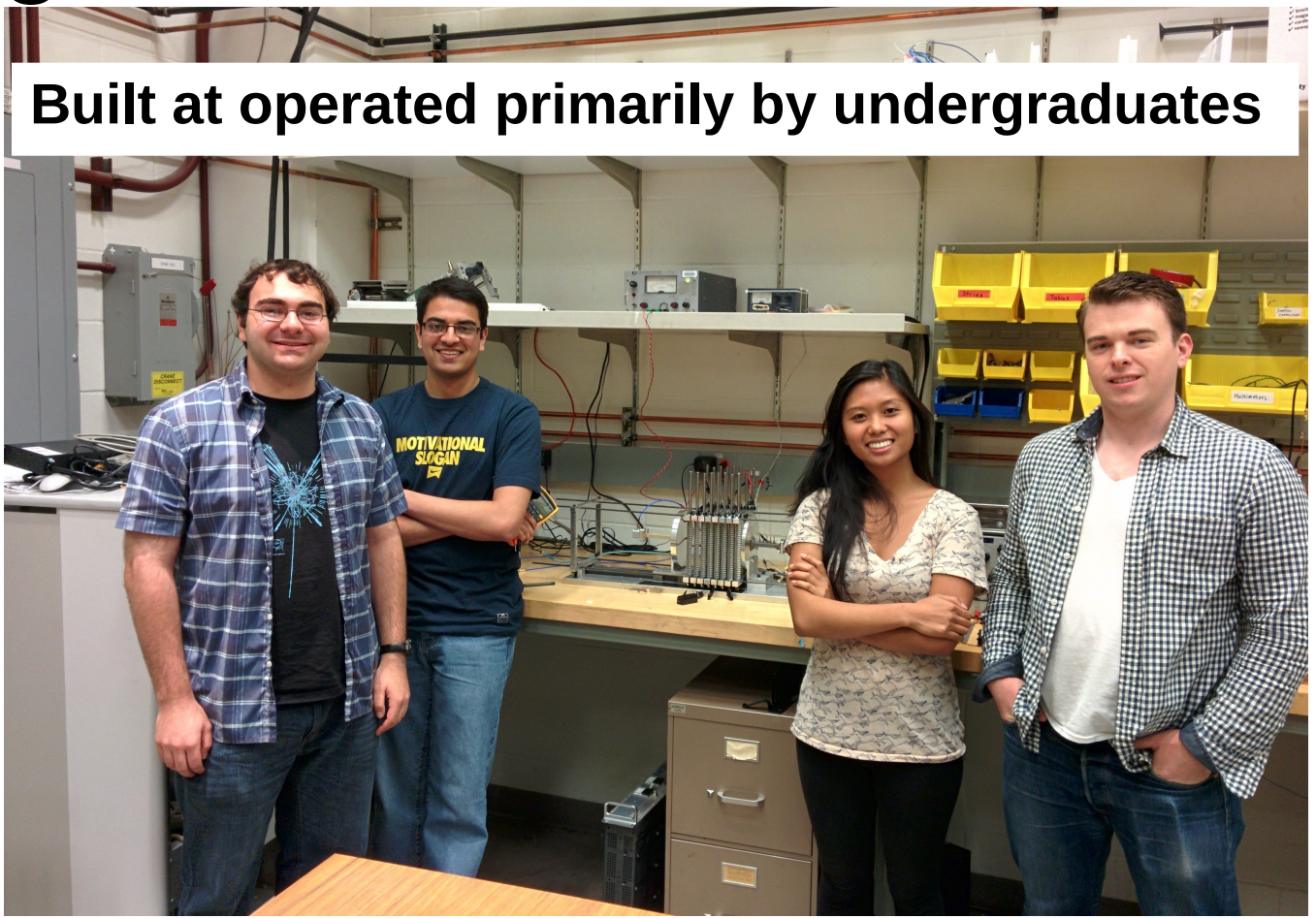


This mode couples to axions.
(Form Factor 0.8)



This mode does not.
(Form Factor 0)

“Orpheus” An experiment to look for higher-mass dark matter axions



Ari Brill
(Yale REU Student)

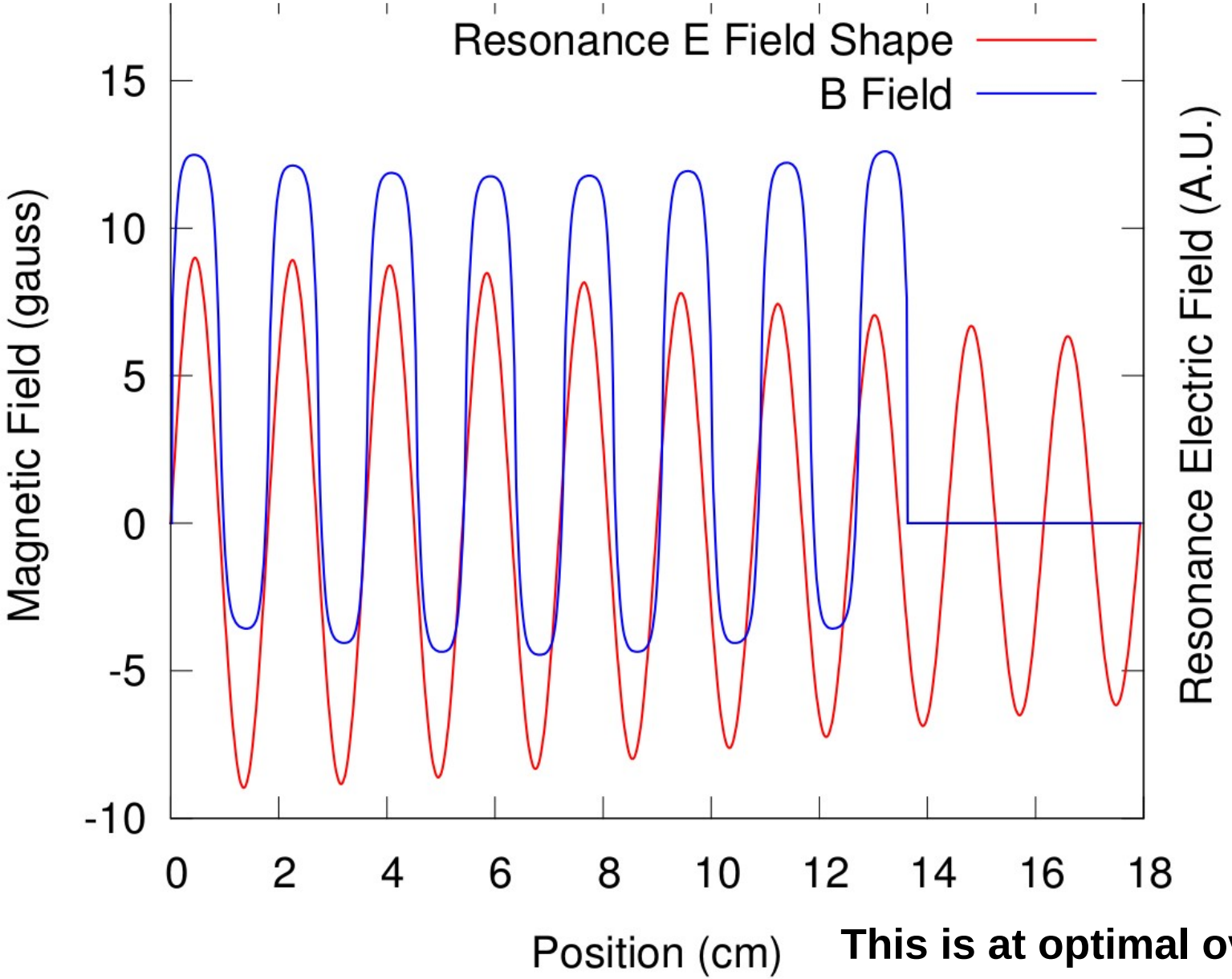
Kunal Patel
UW

Katleiah Ramos
UW

Robert Percival
UW

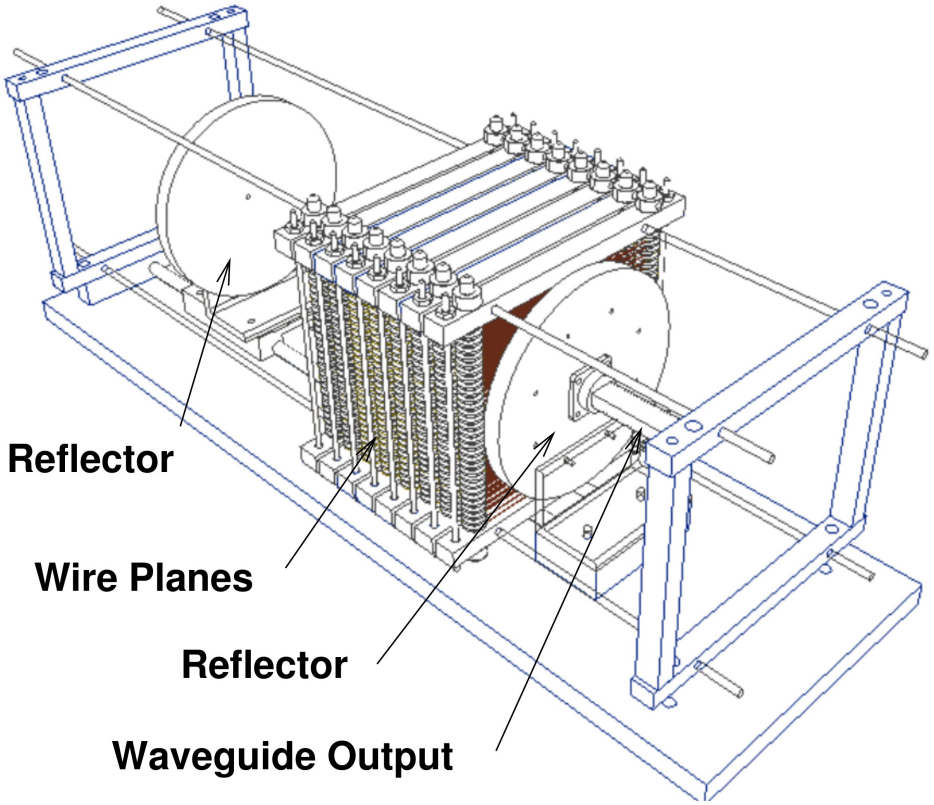
Not Pictured: Gray Rybka, Andrew Wagner (postdoc)

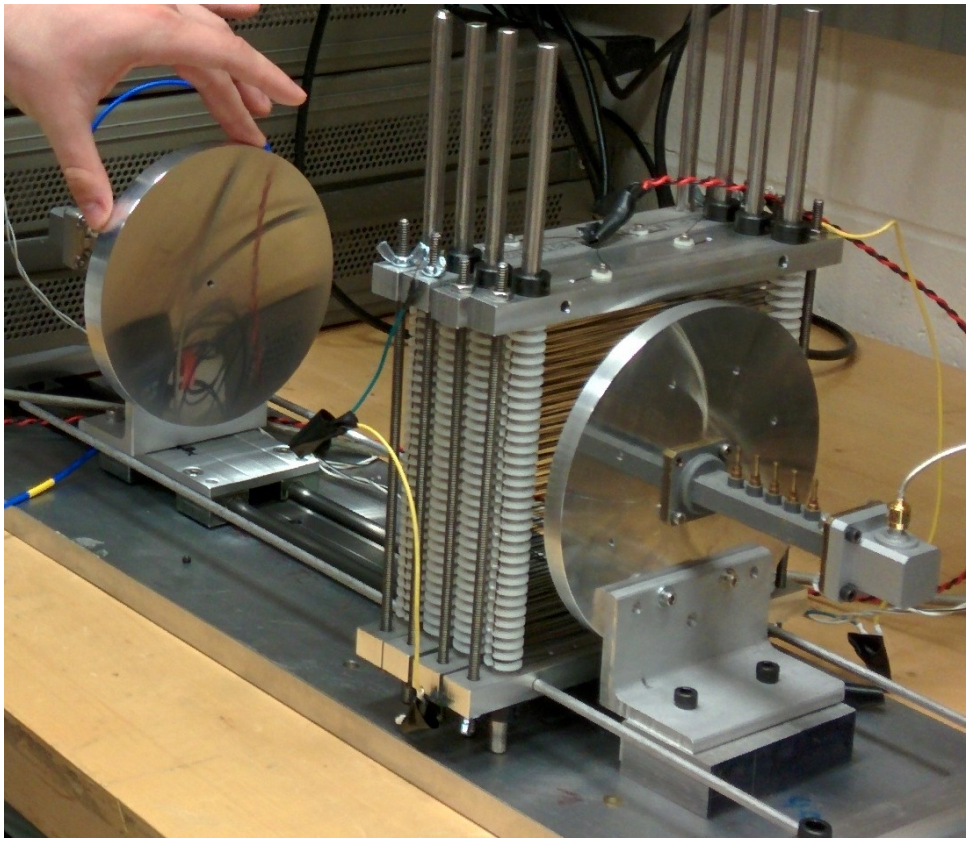
Key Concept: Spatially varying magnetic field matches E&M mode structure



This is at optimal overlap

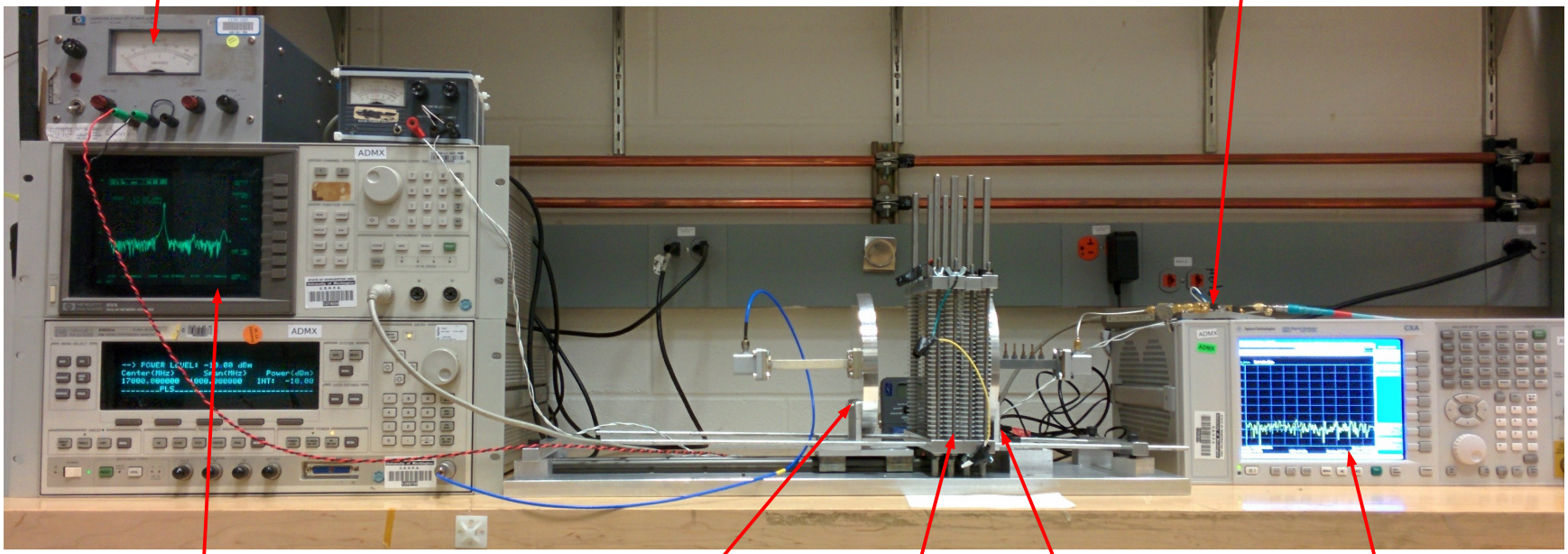
Orpheus Design



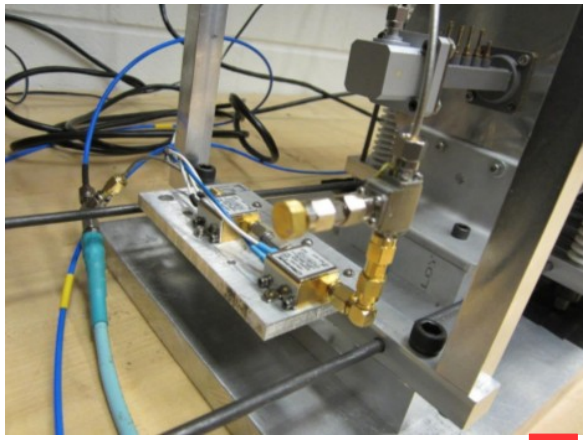


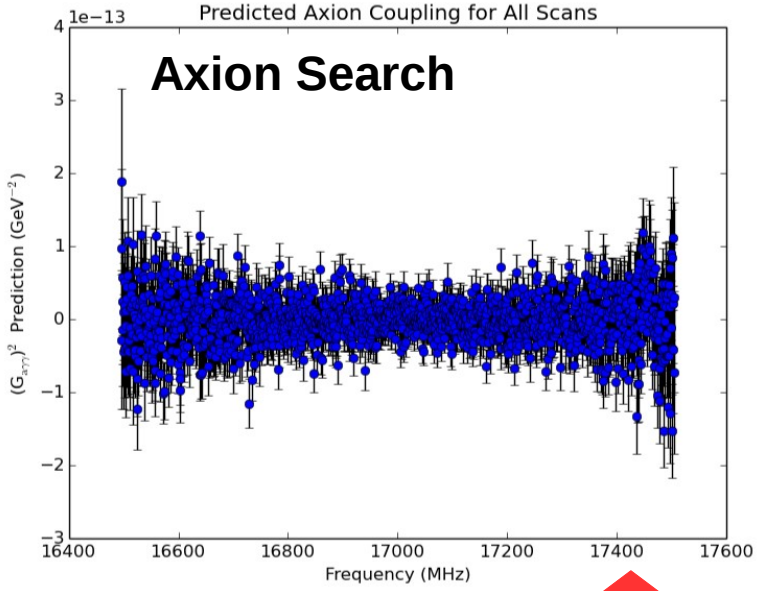
Open Resonator Prototype

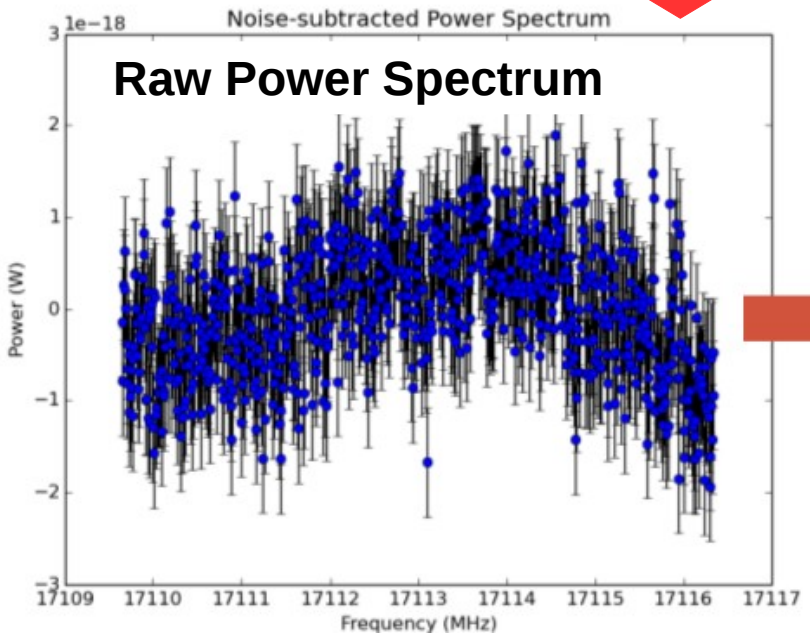
ADMX R&D: Orpheus

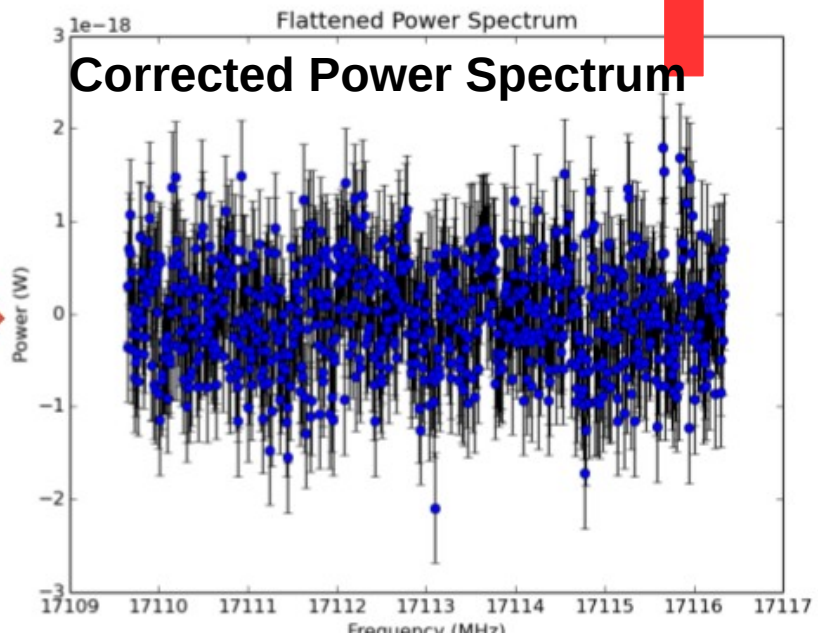


Orpheus Data Analysis



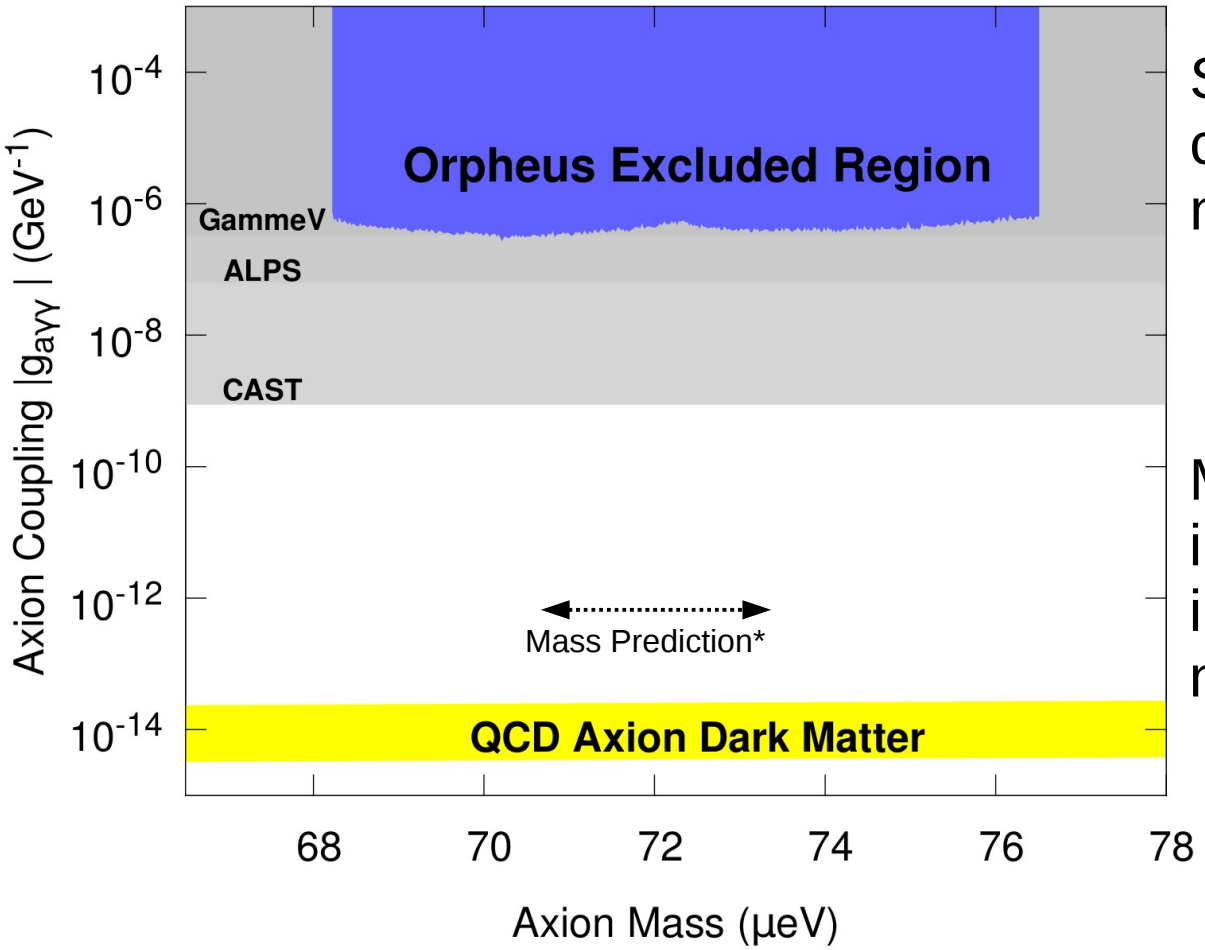






Orpheus Results

Orpheus was operated for two weeks. Results published in Rybka et al. Phys. Rev. D 91, 011701(R) (2015)



Simple benchtop sensitivity competitive with large-scale national lab laser experiments

Many orders of magnitude improvement possible with improved B-Field, volume, Q, noise temperature

*prediction from Visinelli et al. PRL 11, 011802 (2014)

The Next Open Resonator Experiment

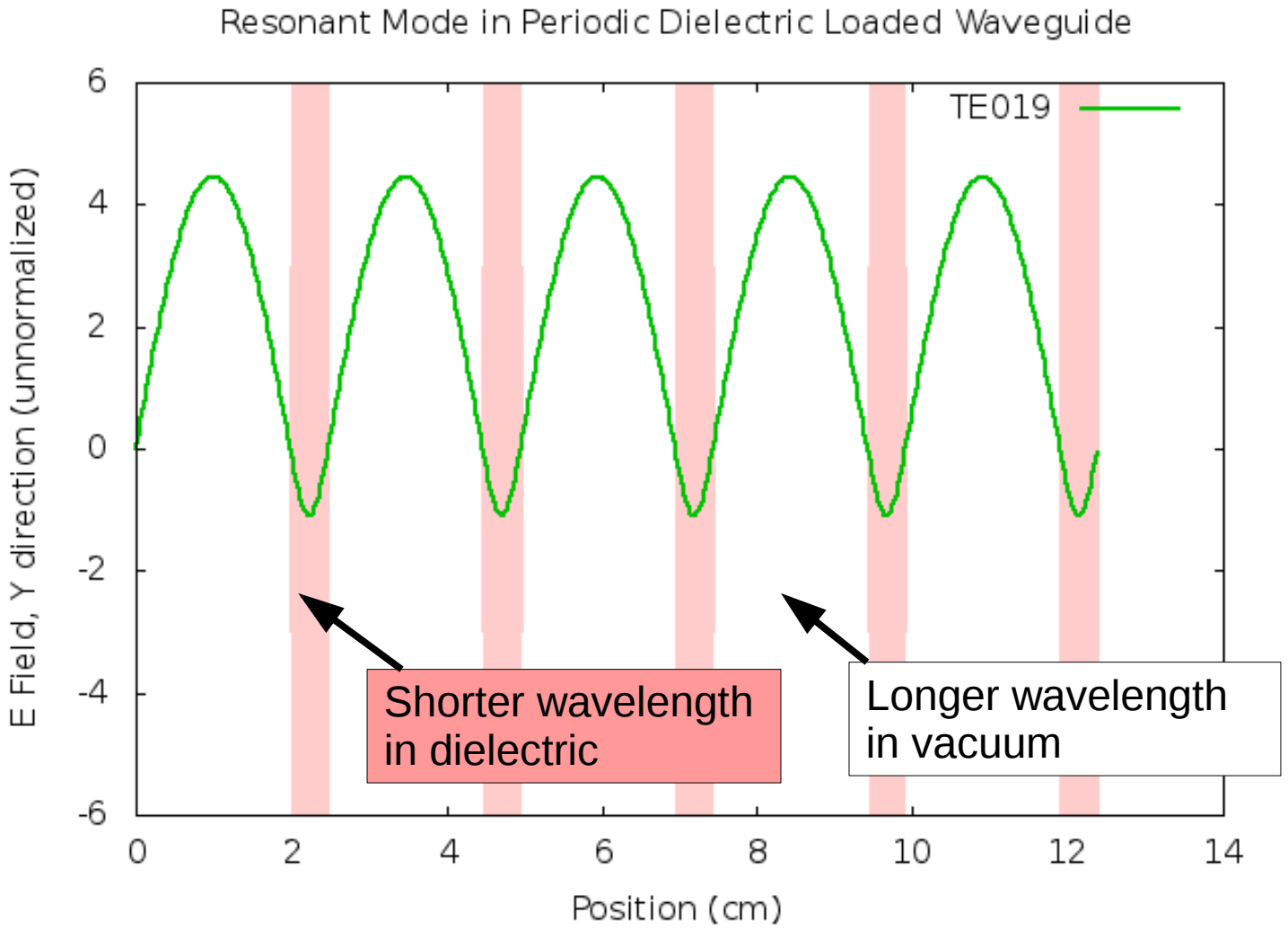
- Operate at liquid helium temperatures
- Operate at tesla scale fields
- Explore new axion-like particle couplings

Support from Heising-Simons Foundation

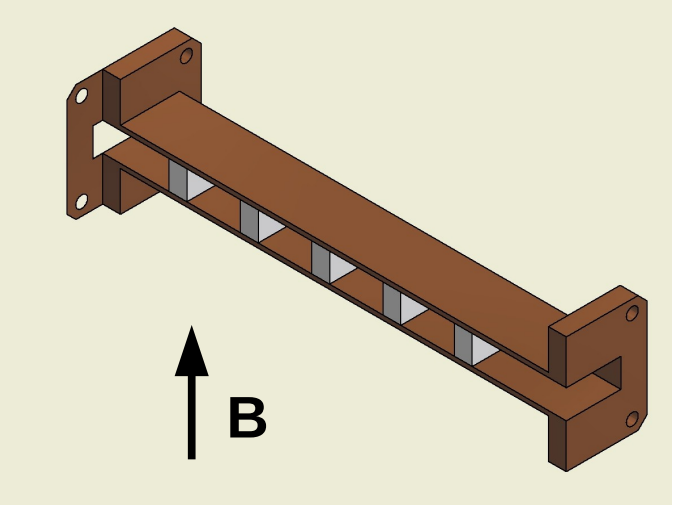
Design Change: Loaded Resonators

Strategically placed dielectrics modify resonant mode electric field instead of changing magnetic field direction

Conceptually similar to multiple wire planes, but easier to implement with high fields



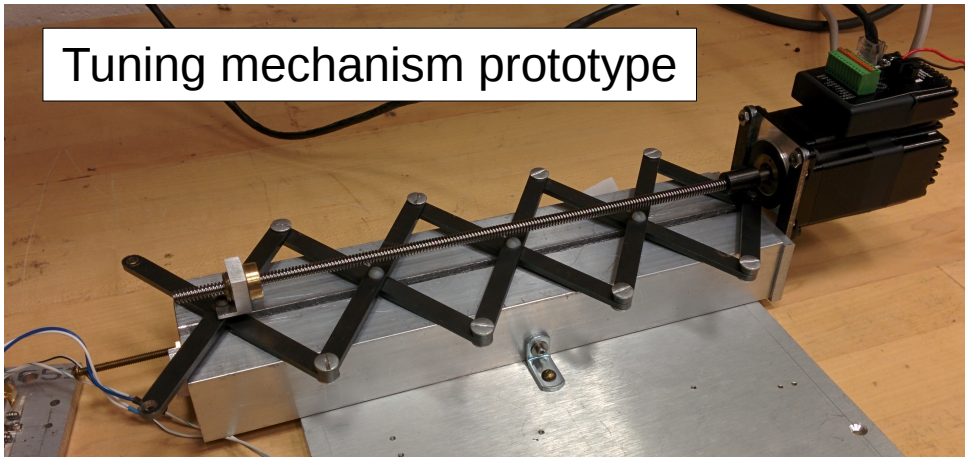
Loaded Resonators: Implementation



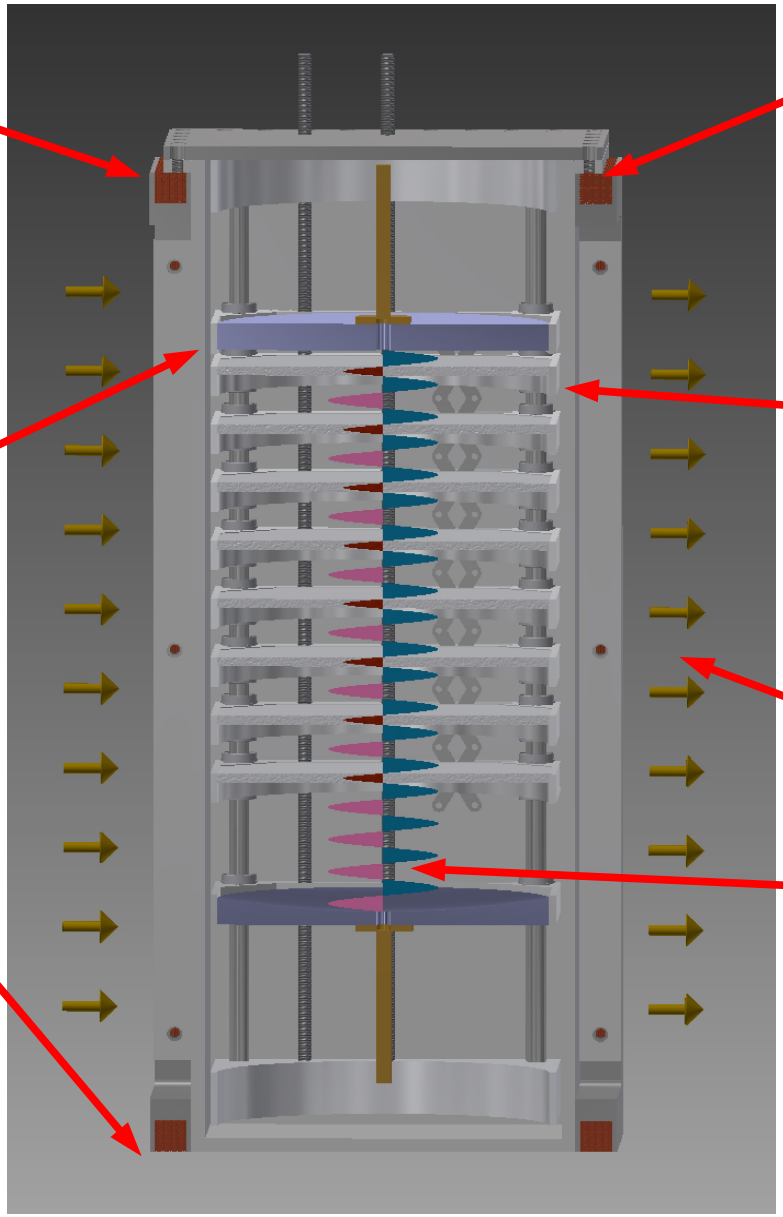
Using dielectric blocks placed periodically in a waveguide placed in a dipole field, TE Modes can couple to dark matter axions

To tune, blocks are moved inside waveguide in a “breathing” motion

Demonstrated here with waveguide, but we'll still use open resonators to reach maximum Q and volume



Experiment Design



Plate/reflector position control rods

In-house wound 1.5 T superconducting coil fits into cryostat

Alumina plates

Reflectors

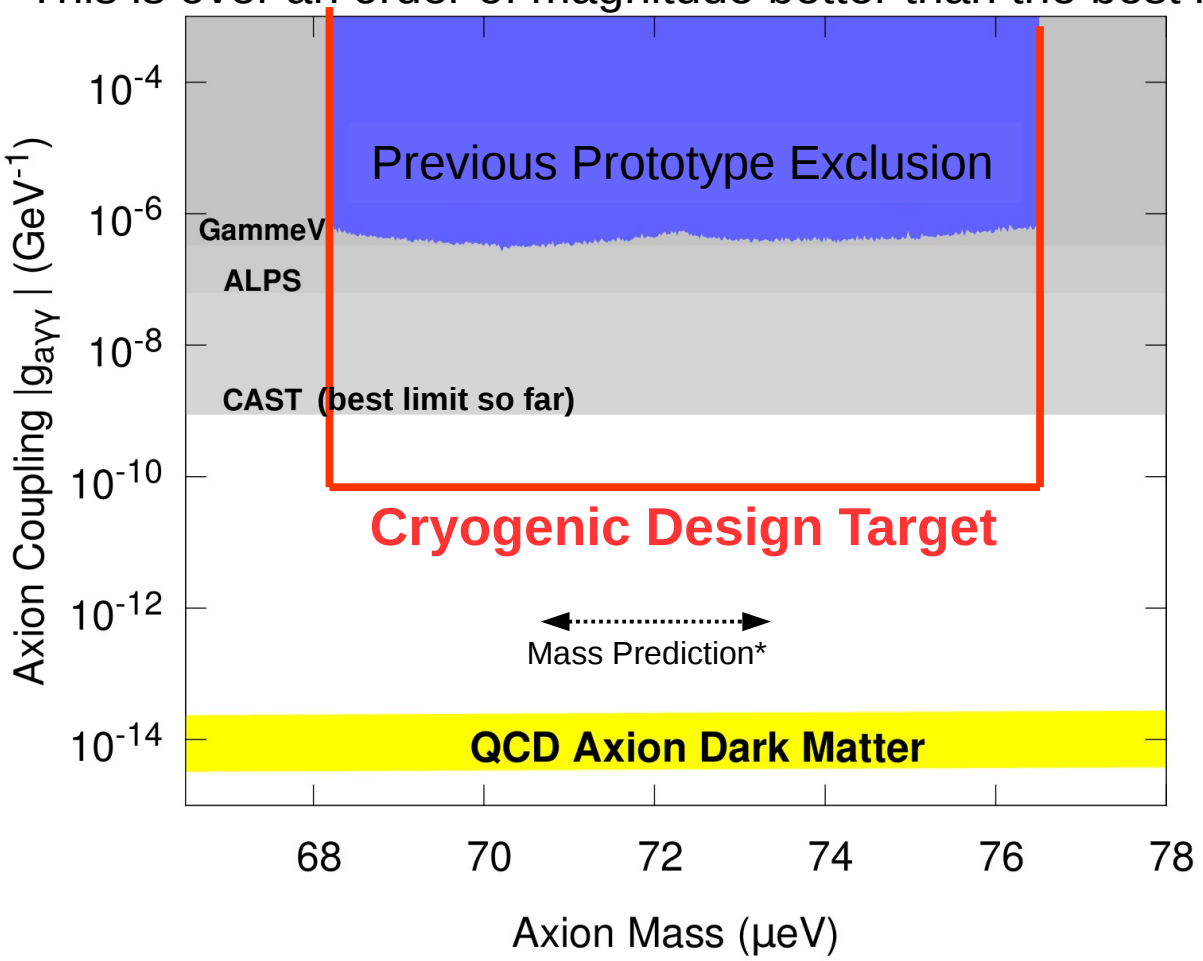
Magnetic Field Direction

Resonant mode electric field profile (estimated shape)

(This is lowered into a LHe cryostat)

Sensitivity Estimate

We anticipate sensitivity to unexplored axion-like-particle couplings in a theoretically interesting mass range. This is over an order of magnitude better than the best limits so far.



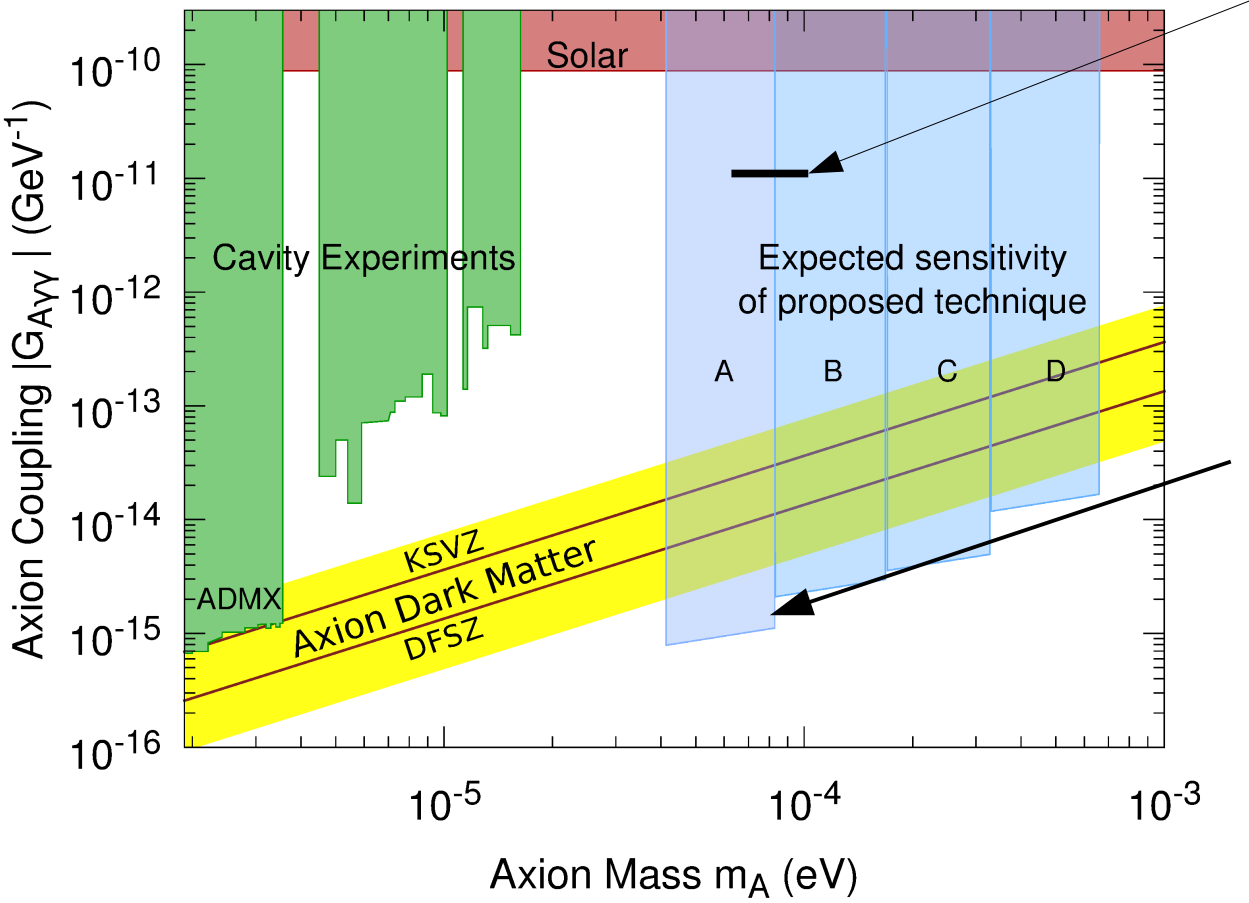
*prediction from Visinelli et al. PRL 11, 011802 (2014)

A more accurate prediction will be available once RF simulations are complete

Next Steps

- RF Simulation & Engineering to start soon
- Fabrication early next year
- Assembly, testing, data taking in 2016

Far Future



Current design target

Potential Reach With
- -mK temperatures
- -2+ T fields
- -Qs of 10^5 or more
- -Larger Volumes

Conclusions

- Benchtop open resonator prototype demonstrated technique is feasibly and powerful
- Cryogenic experiment being built to explore new ALP parameters and pave way for larger experiments
- This is a promising technique: ultimate sensitivity should be able to probe realistic axions up to 100 of μeV.