Axion Dark Matter Experiments

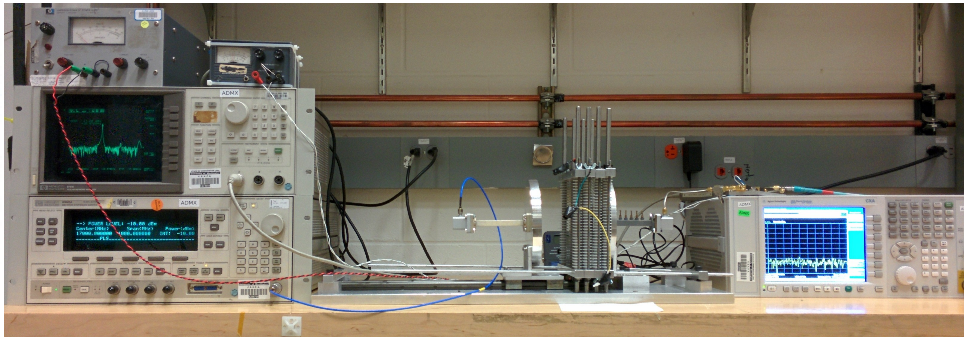
Science, Nov. 2013, 552 - 555

Gray Rybka
University of Washington

June 26, 2014

Frontiers of New Physics:
Colliders and Beyond

ICTP Trieste



Gray Rybka – Feb. 2013

My Favorite

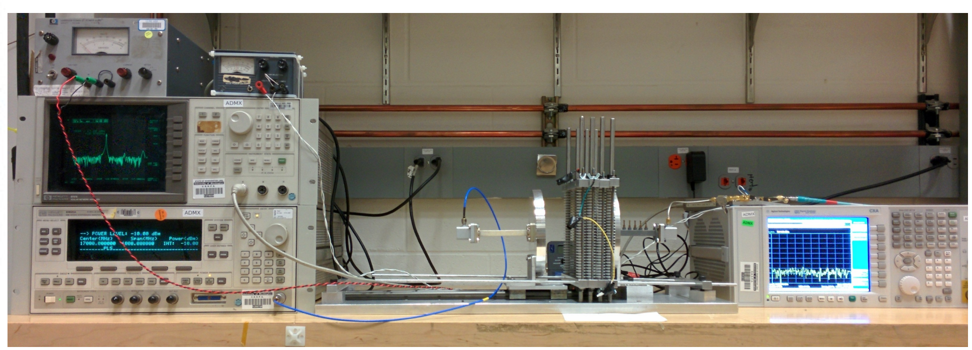
Axion Dark Matter Experiments

Science, Nov. 2013, 552 - 555

Contents

60% ADMX

40% Speculative R&D



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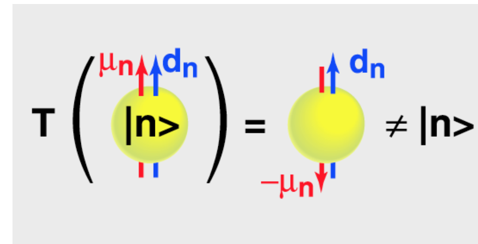
Reminder: QCD Axions

The Strong CP Problem

Lack of neutron electron dipole moment indicates strong force is CP invariant



edm<3·10-26 e-cm
Baker et al.
PRL 97 2006

How can the weak force be CP violating but the strong force remains CP invariant? $O(10^{-10})$ cancellation required

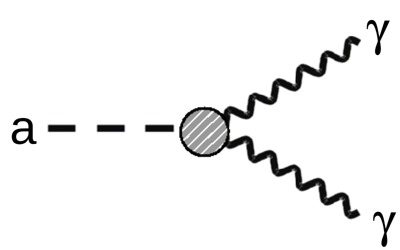
The Peccei-Quinn Solution

Add a dynamic field, spontaneously broken, which cancels any strong CP violation

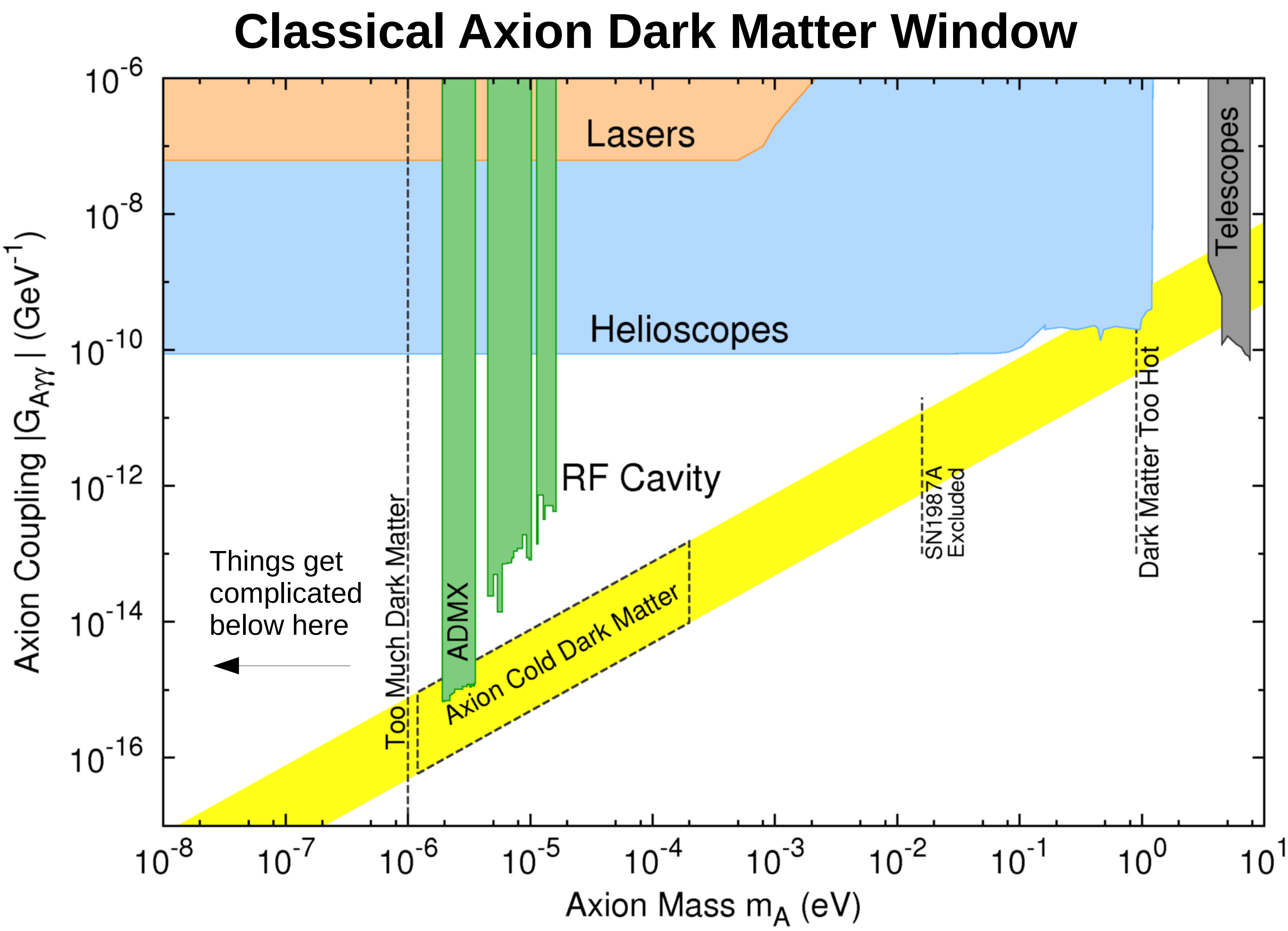
This results in a new pseudoscalar particle, the Axion

-Weinberg, Wilczek

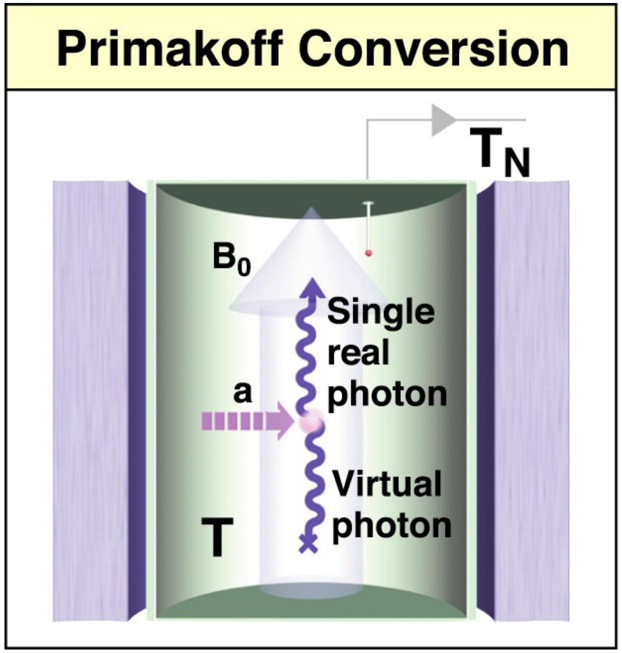
Couples to two photons



Axion Dark Matter Parameters



Axion Haloscope



Dark Matter Axions will convert to photons in a magnetic field.

The measurement is enhanced if the photon's frequency corresponds to the cavity's resonant frequency.

See: Sikivie, Phys. Rev. Lett. 1983

You Want:
-Large Cavity Volume
-High Magnetic Field
-High Cavity Q

You Don't Want:
-High Thermal Noise
-High Amplifier Noise

ADMX: Axion Dark Matter eXperiment

University of Washington

LLNL

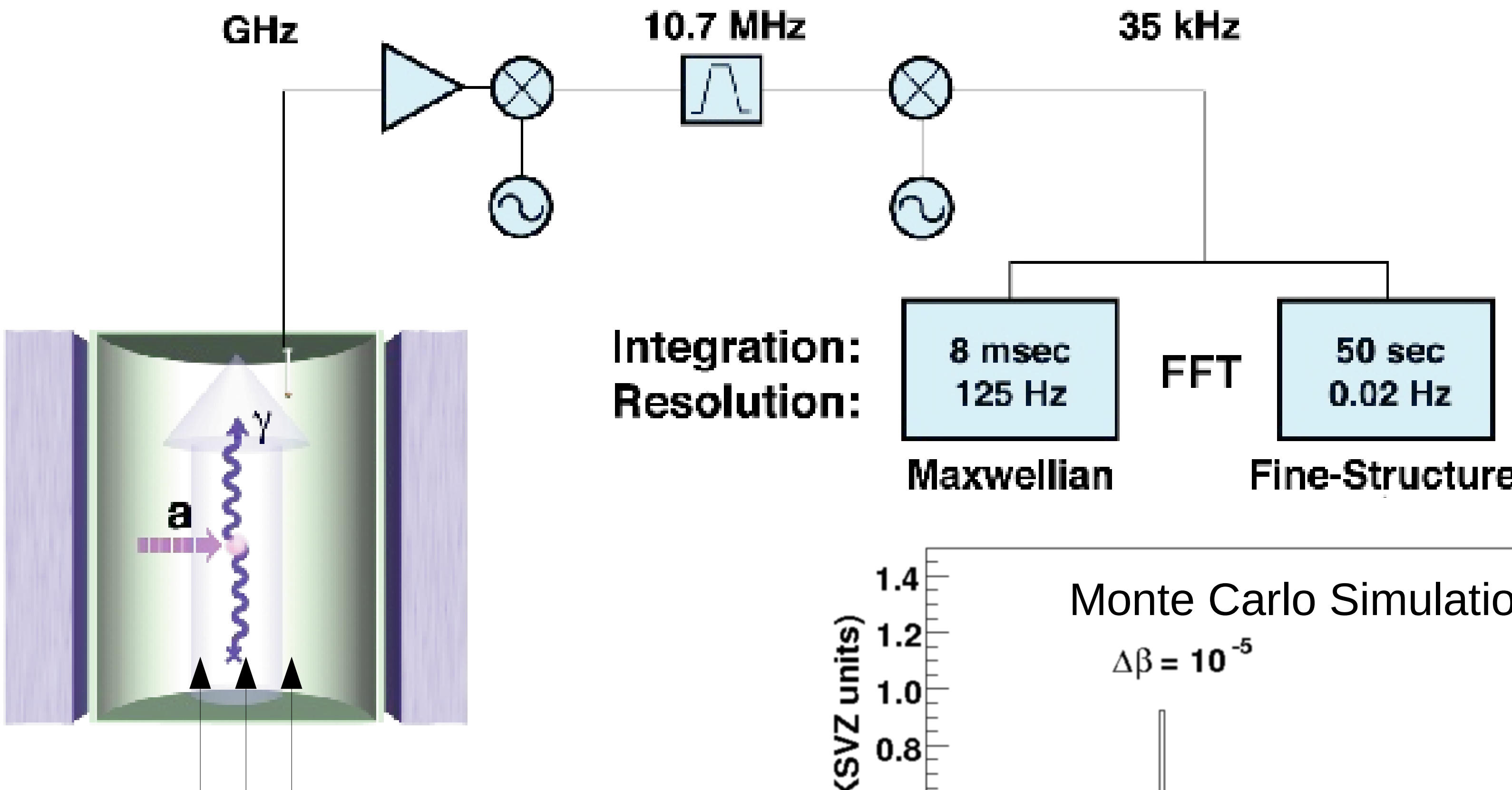
University of Florida

Yale

UC Berkeley

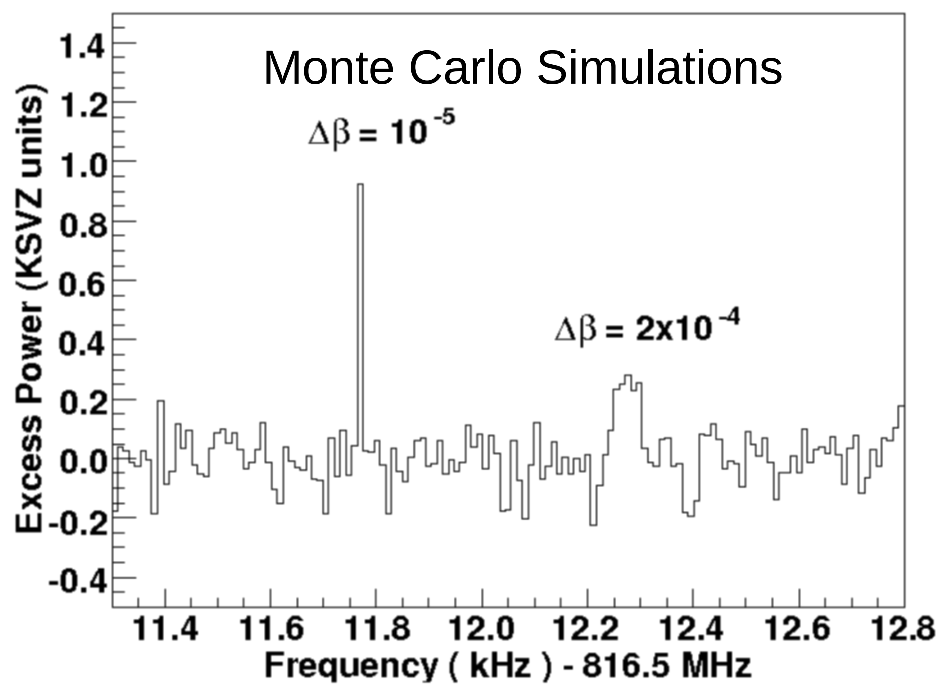
NRAO

How ADMX Works

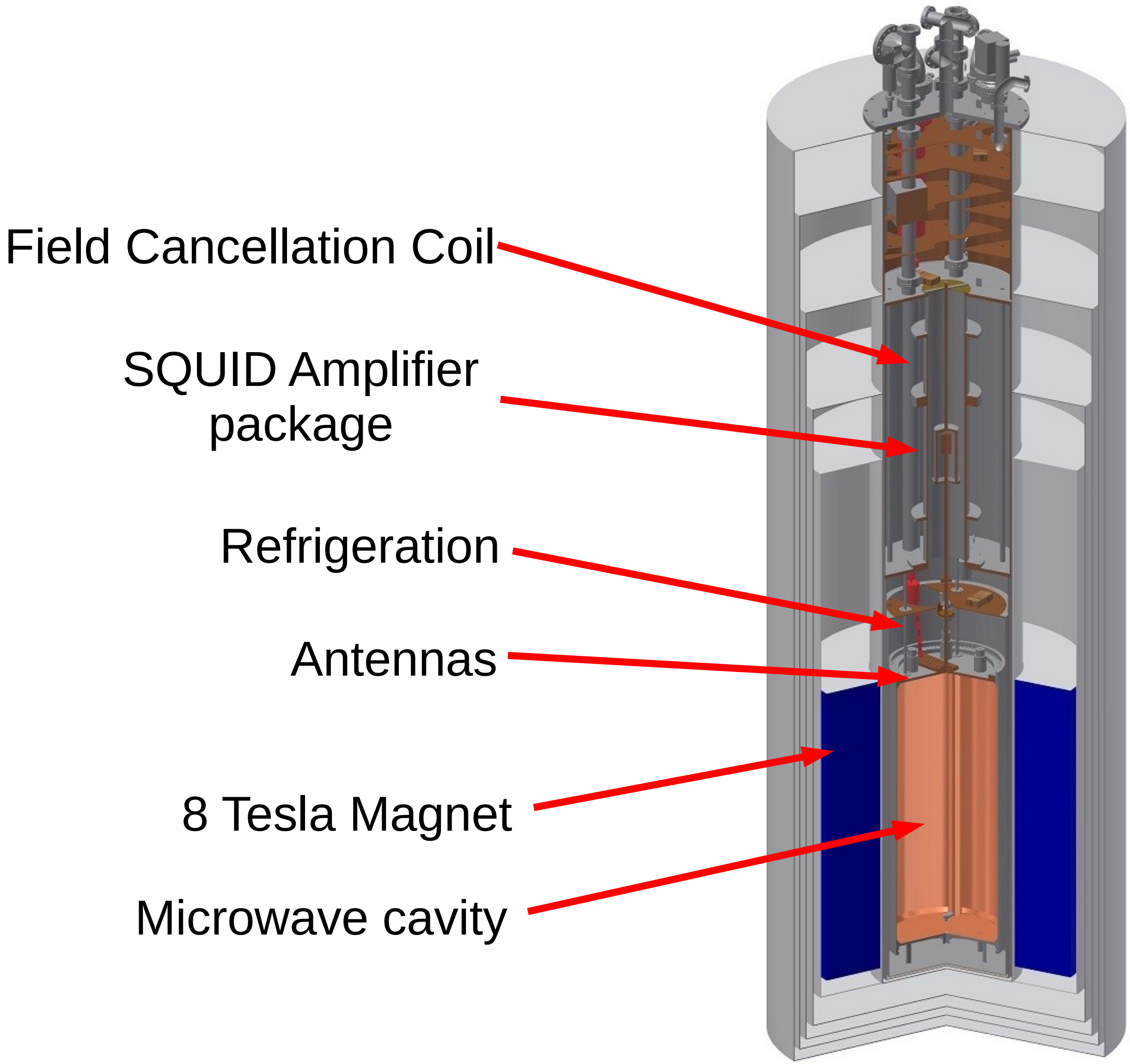


B=8 Tesla

Axions, stimulated by a magnetic field, decay into microwave photons which resonate in the cooled cavity and are amplified and read out



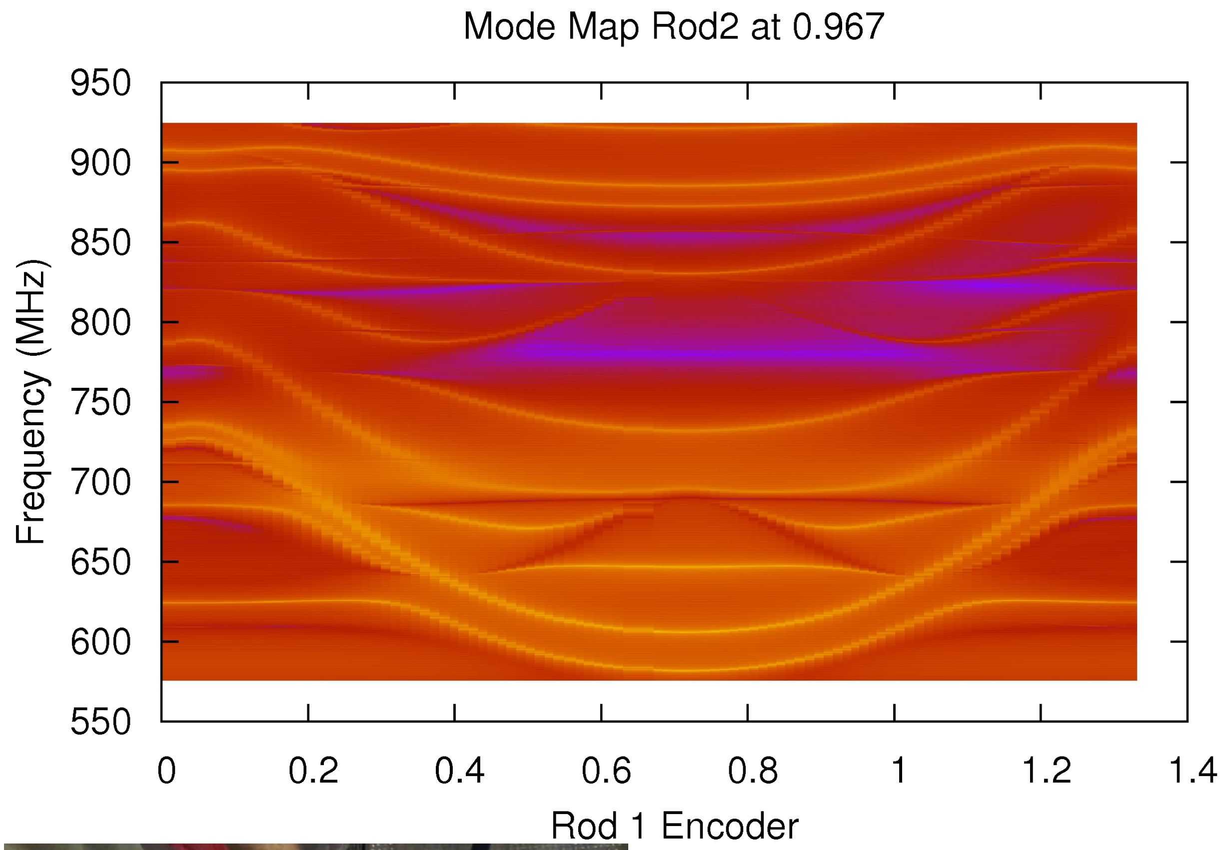
ADMX Design

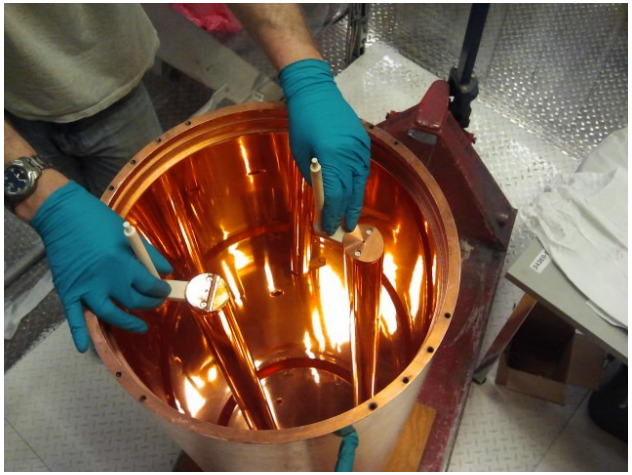


Insert + Magnet Schematic

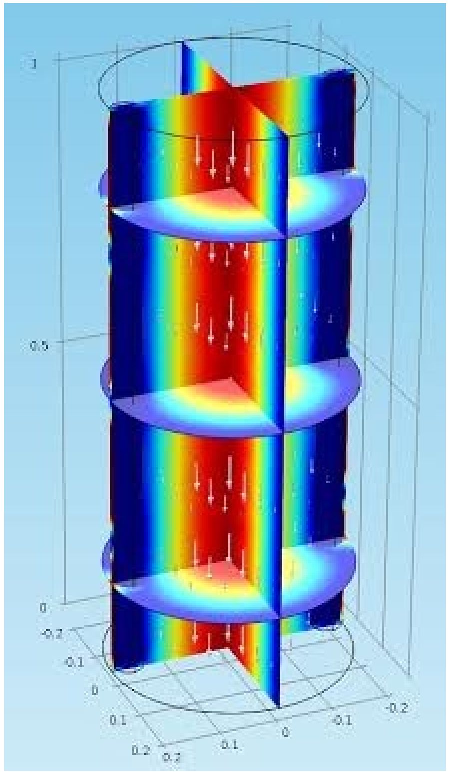
Insert extraction from magnet

Tuning



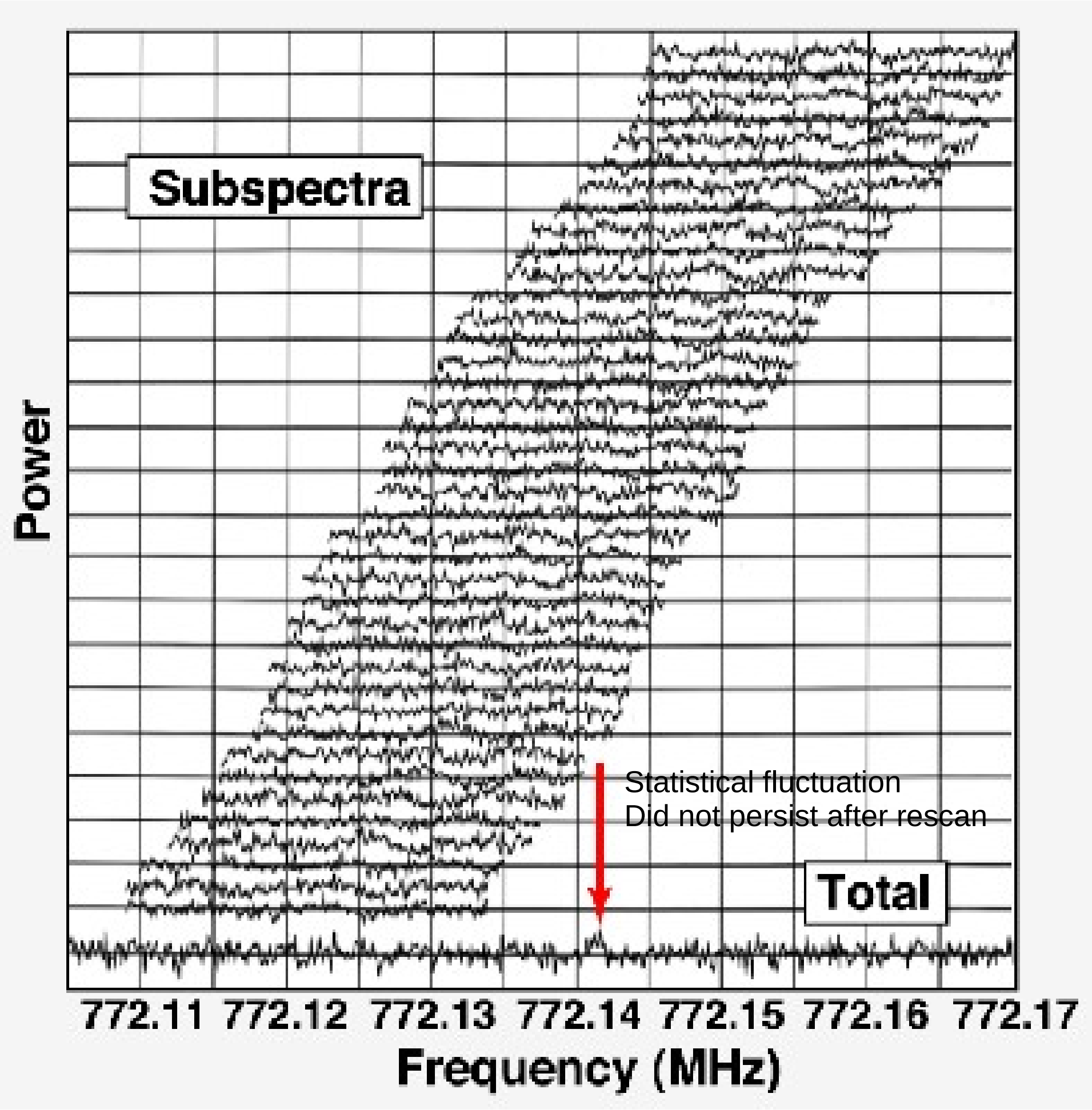


Cavity with lid off, showing tuning rods



Field simulation of TM010 mode, no rods

Axion Search Technique



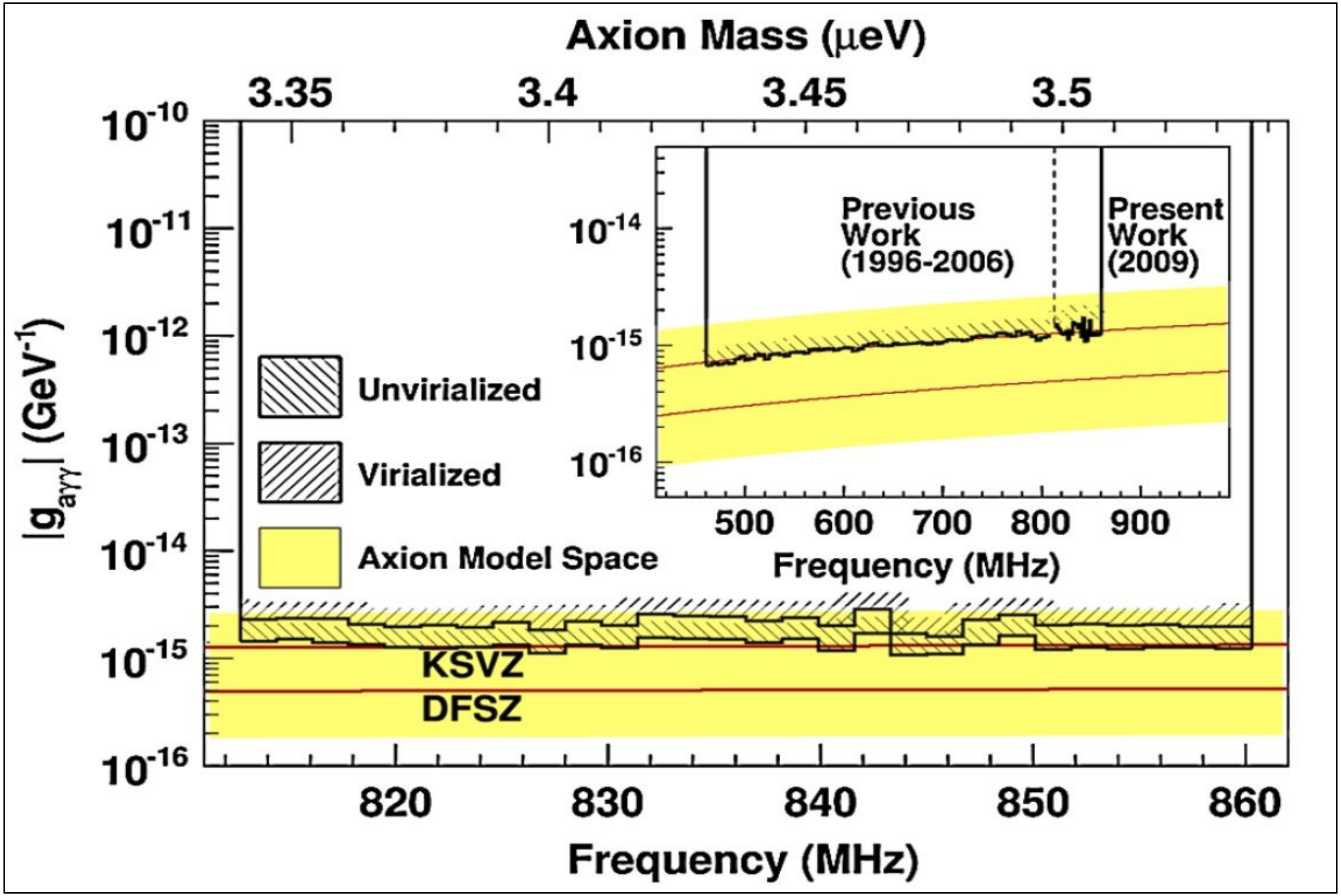
Cavity resonant frequency is tuned by two movable rods

Power spectra are measured at each rod position

Axion signal would appear as a constant power excess

Most backgrounds do not persist

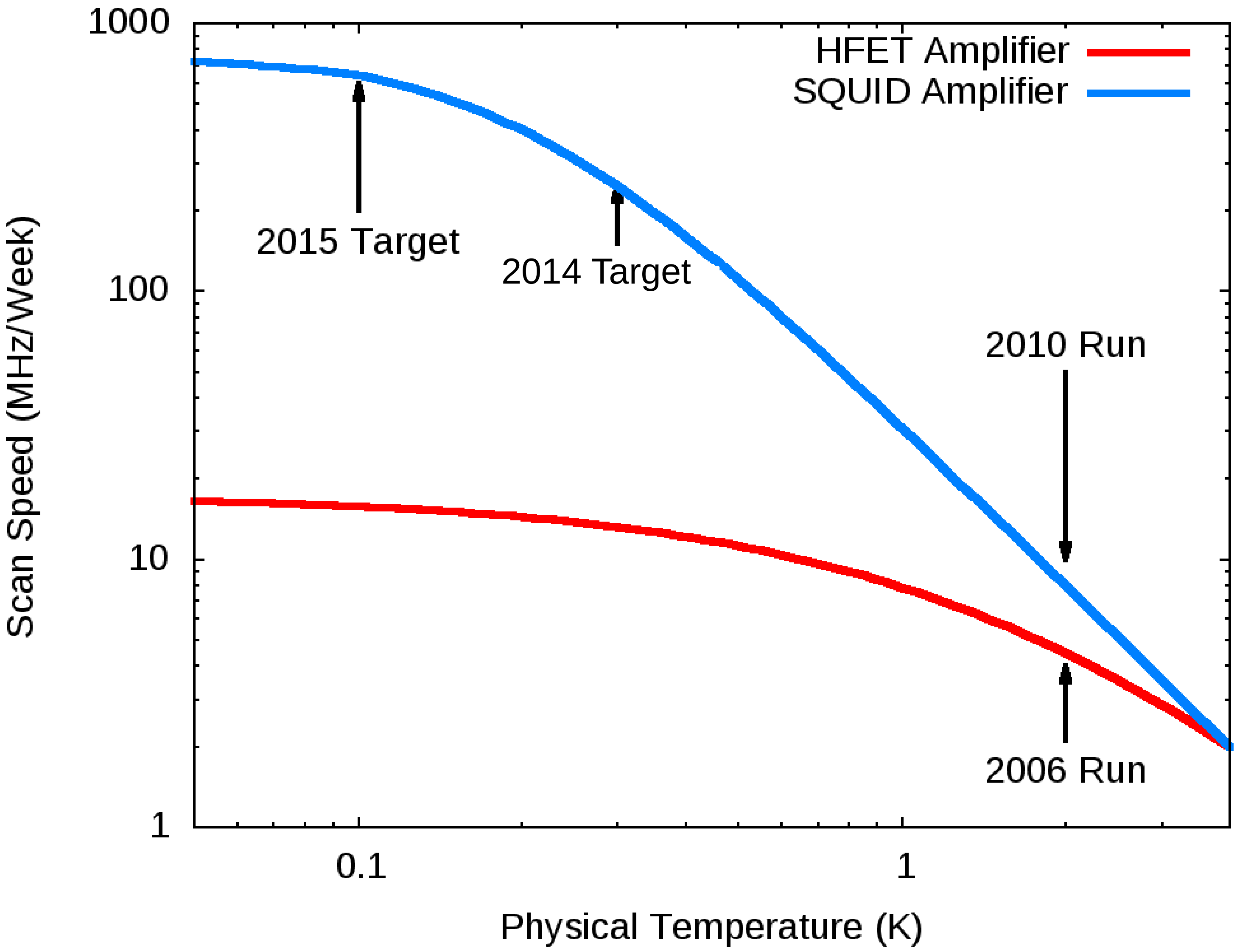
Limits from ADMX 2010 run



Asztalos et al, PRL 104, 041301 (2010)

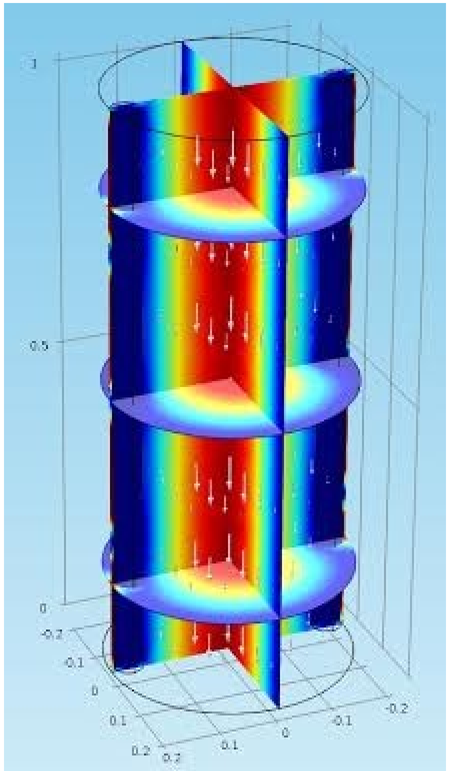
Cooling

Dilution refrigerator will allow us to reach much colder temperatures, increasing scan speed tremendously



Multiple Channel Improvements

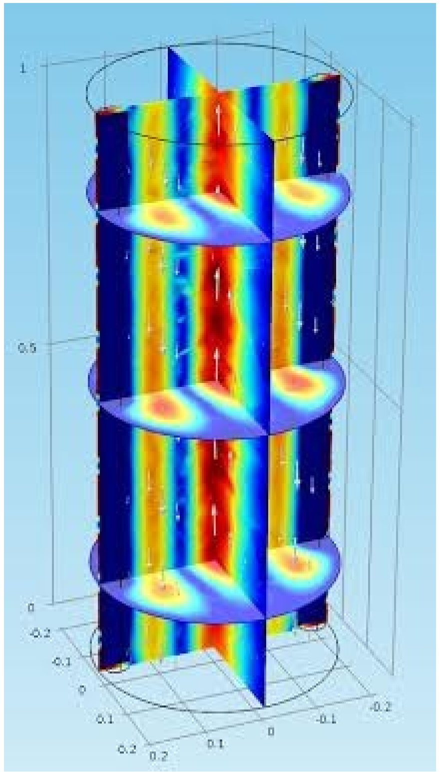
$$Sensitivity \propto E_z \cdot B_z$$



TM_{010}

Tuning Range 400-900 MHz

Relative Power 1.0



TM_{020}

Tuning Range 920-2,100 MHz

Relative Power 0.41

Current Status and Schedule

After 3 years of rebuilding the experiment,

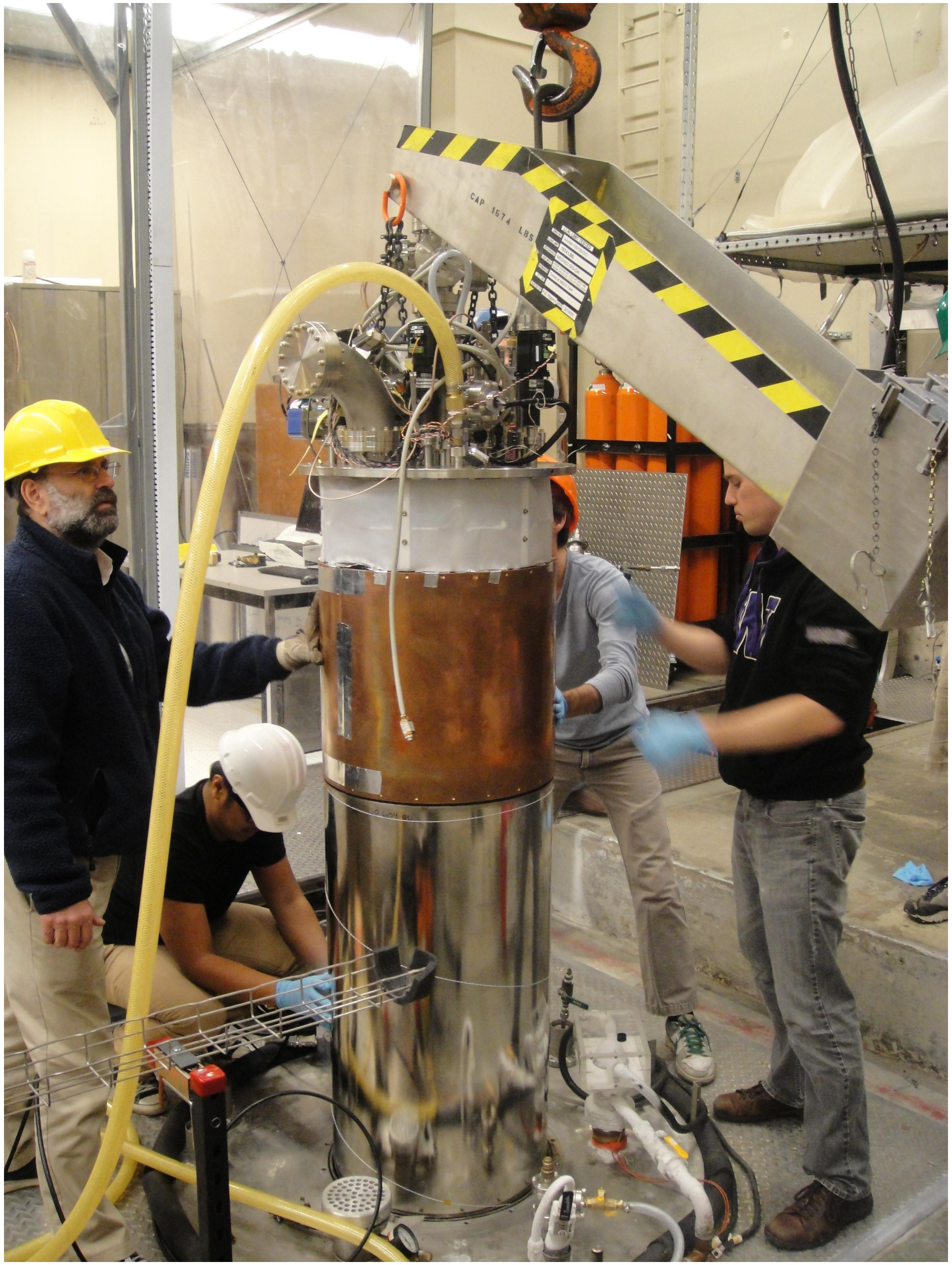
ADMX is now taking data!

Current operations are at 1.5 K

Helium 3 refrigeration stages are set to be delivered end of summer

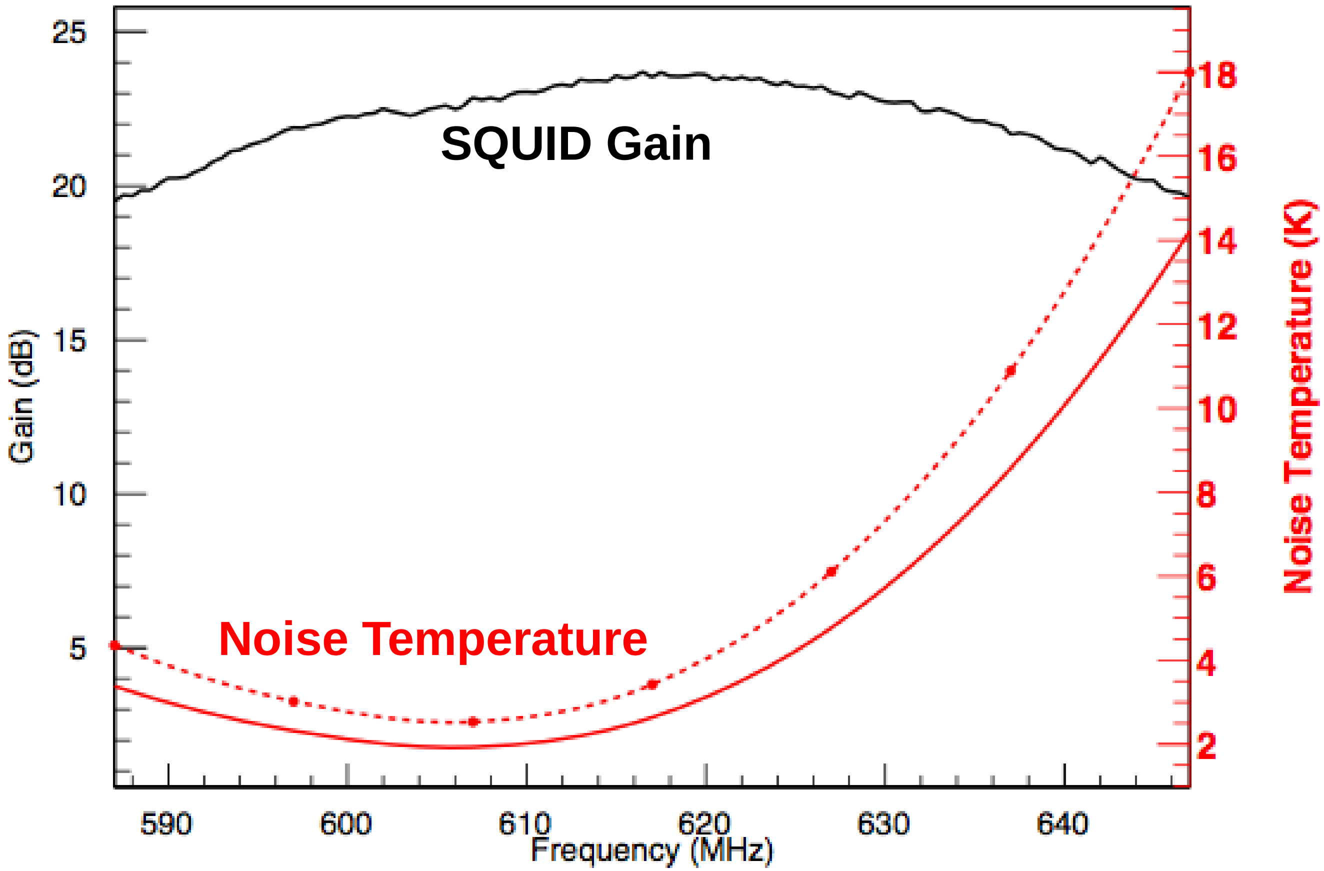
Then definitive search will begin

ADMX Cold Commissioning



In-Situ SQUID Calibration

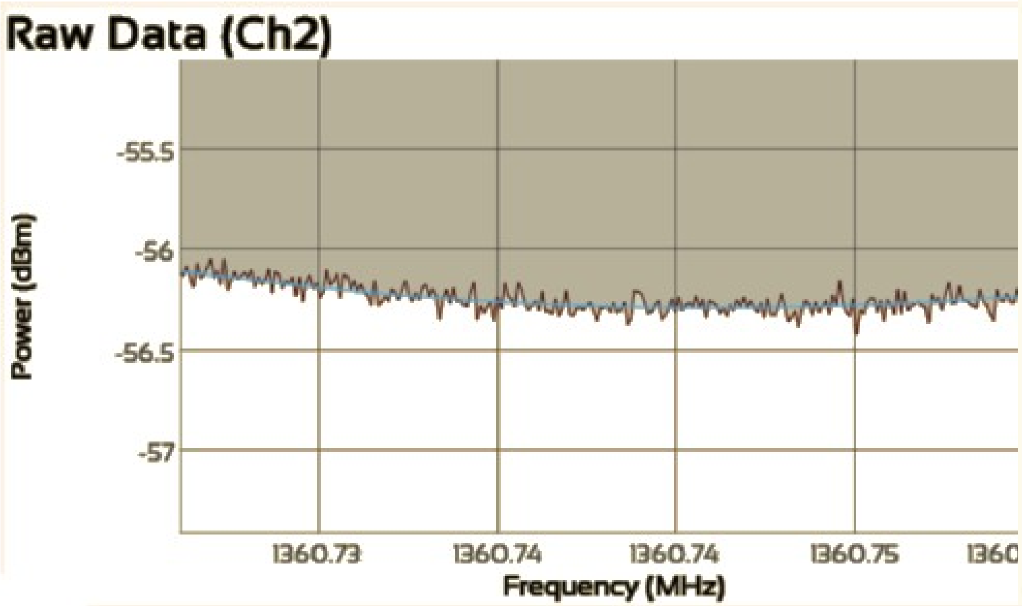
First Test of In-Situe SQUID Calibration (Not at Optimal Temperature)



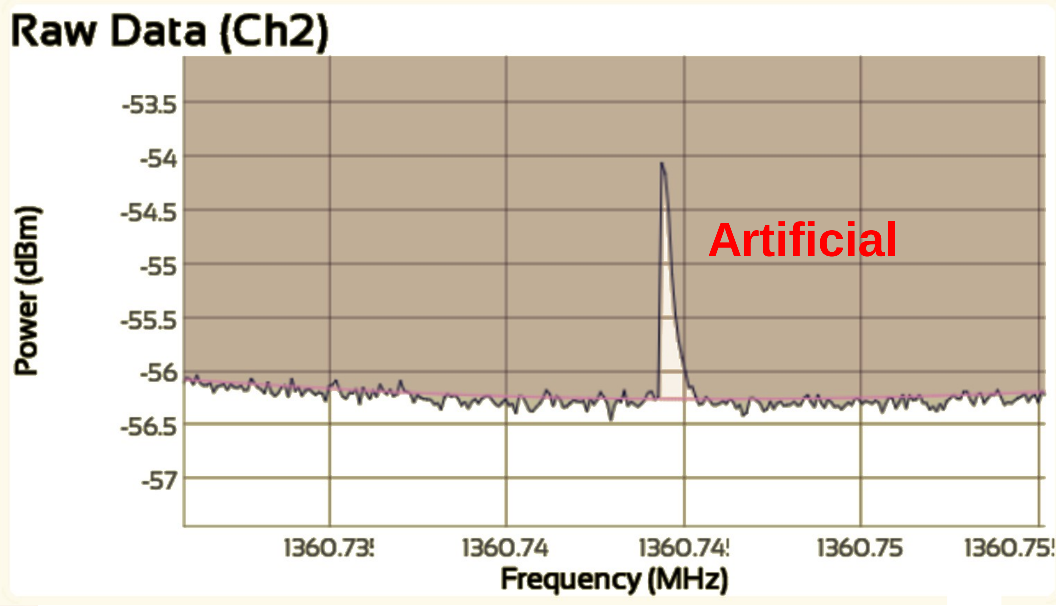
We can measure our amplifier noise temperature during data taking

Axion-Like Signal Calibration

Single Raw Power Spectrum (100 second integration)



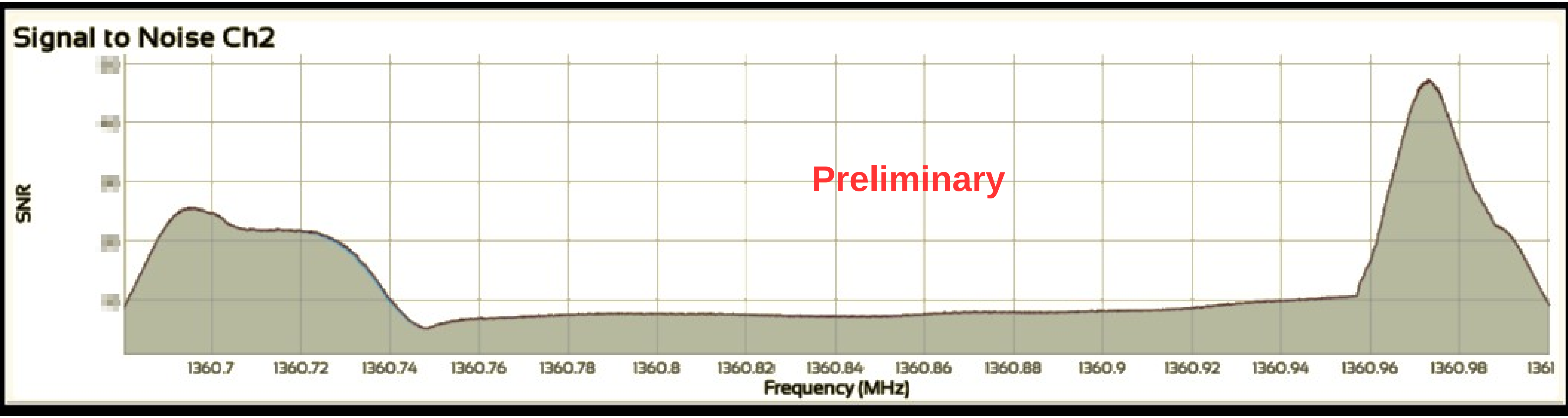
Raw Spectrum with Artificially Generated Axion-Like Signal



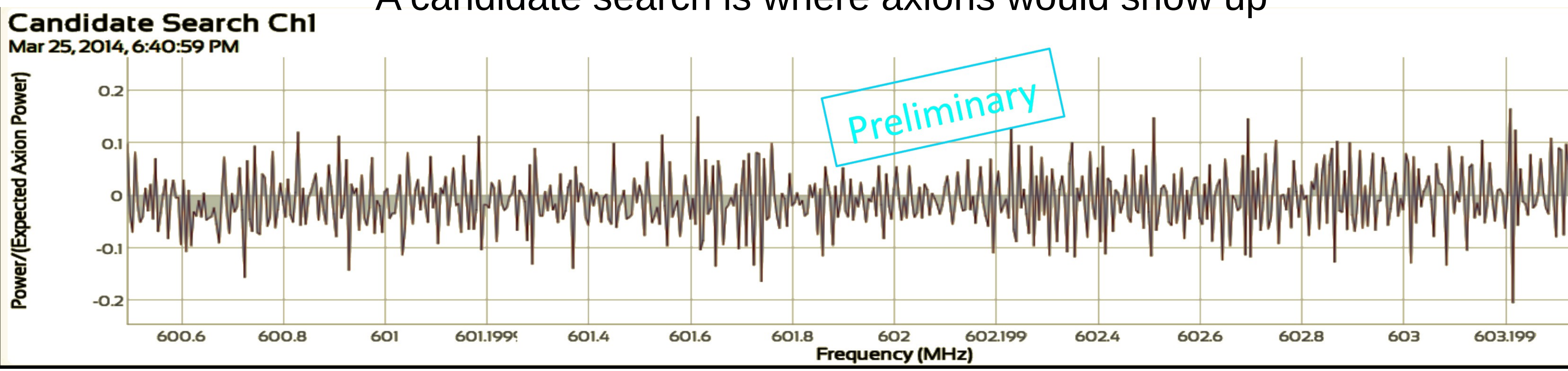
Injection of Axion-Like signals into cavity allow us to calibrate our analysis

Recent Data

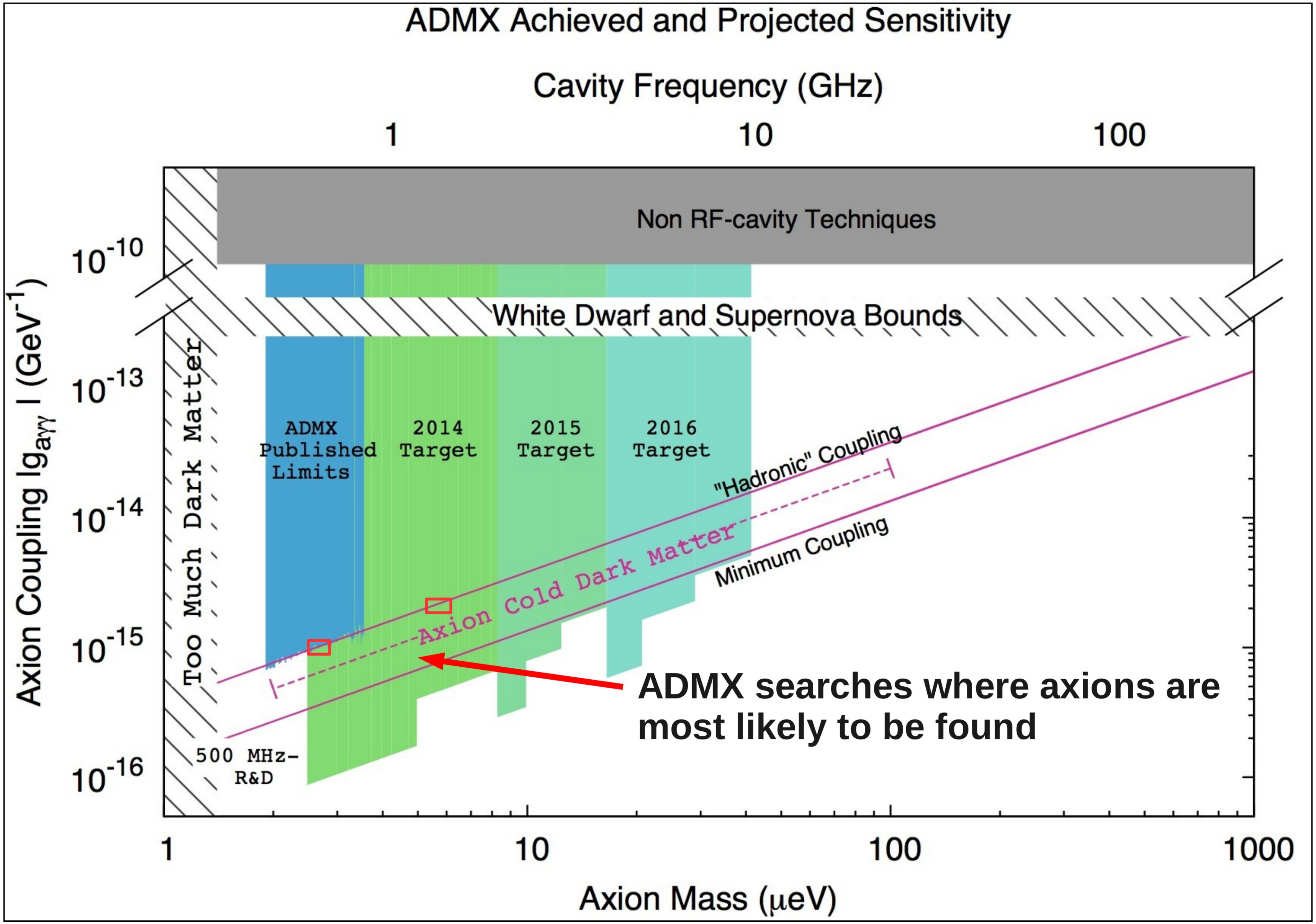
SNR determines our sensitivity



A candidate search is where axions would show up



Looking forward



Expanding Experiment Mass Range

Higher axion masses:

Cavity volume shrinks

Q's get lower

Amplifier Noise Increases

Lower Axion Masses:

Characteristic cavity radius exceeds reasonable magnet bore

Coupling decreases

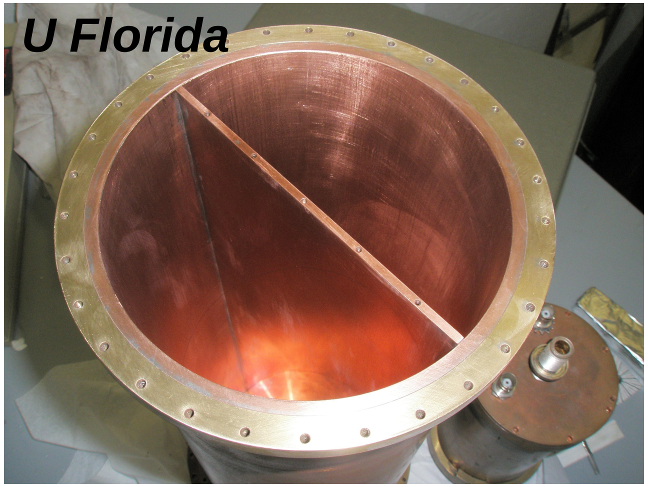
Begin Speculation

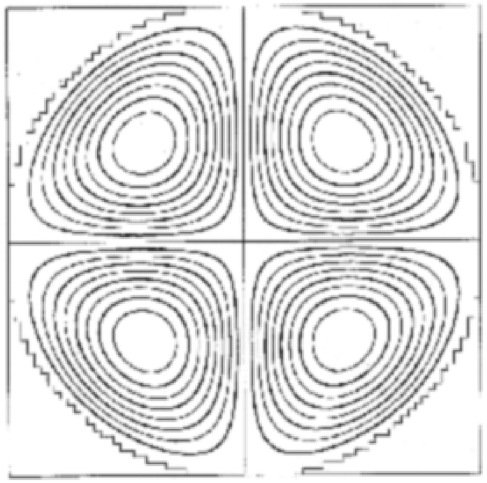
The following are some ideas to reach lower and higher axion masses

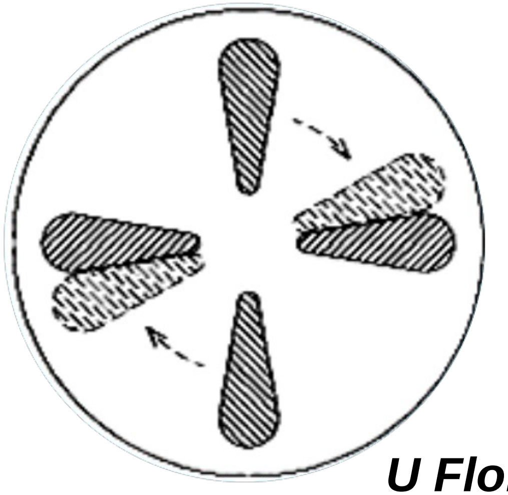
(Recall DM axion coupling to resonator goes as $\int \vec{E}\cdot\vec{B}$)

Higher Frequency Cavities

ADMX is developing higher frequency cavity structures







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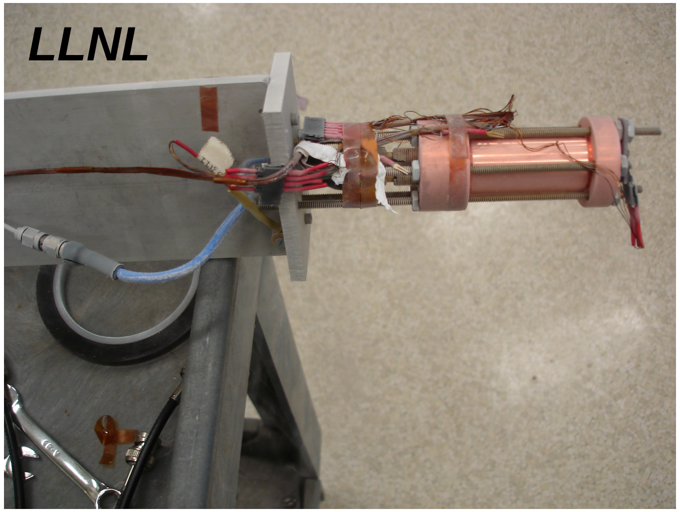
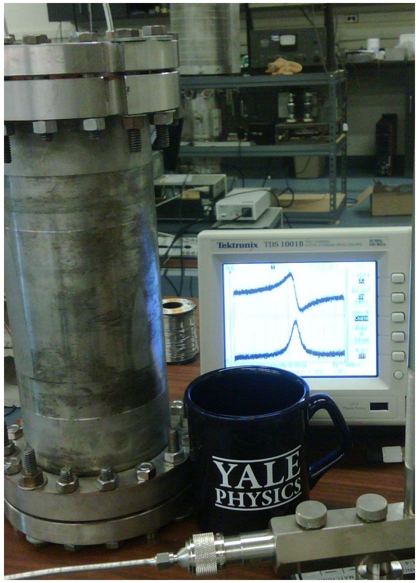
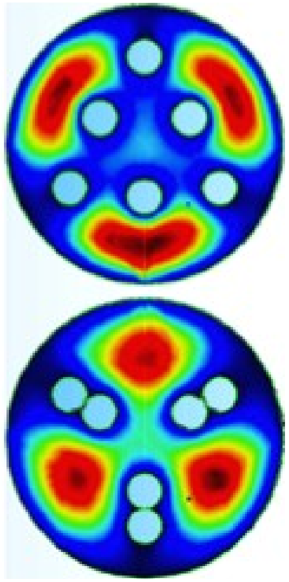
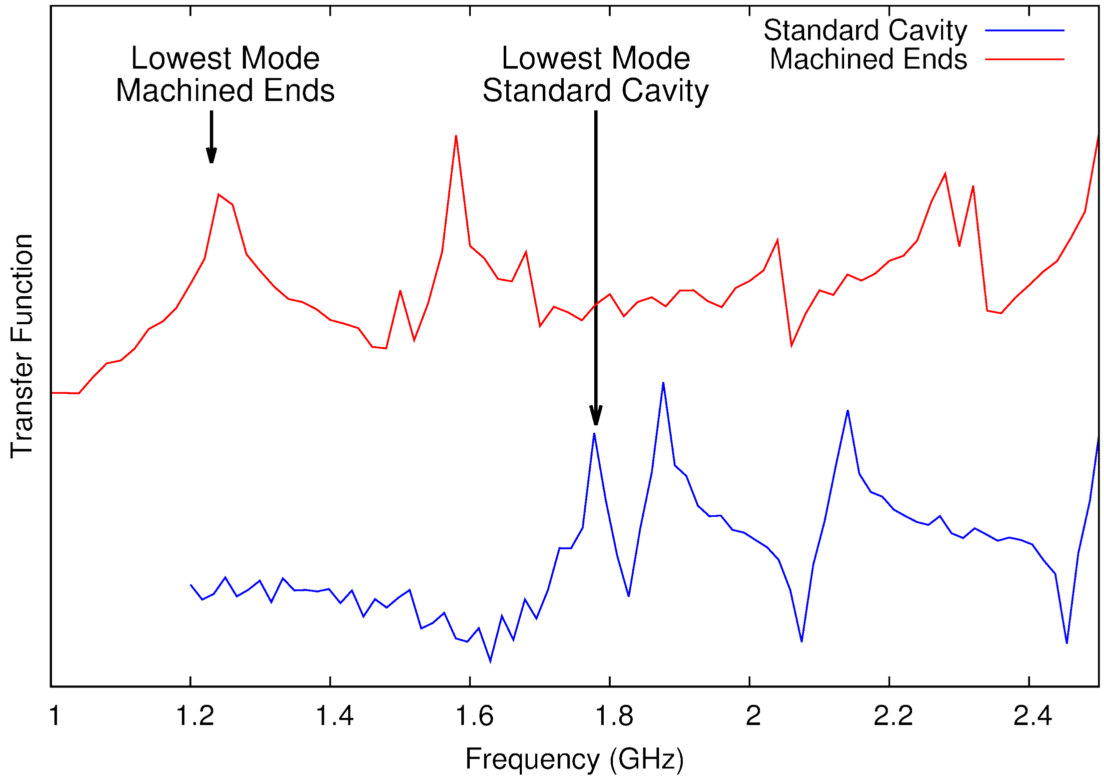
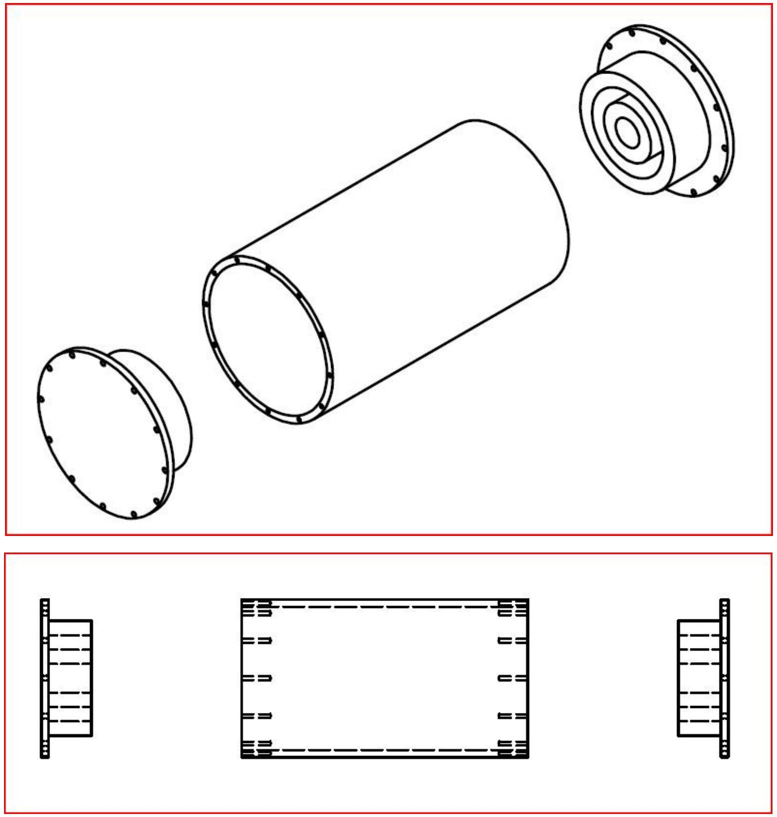


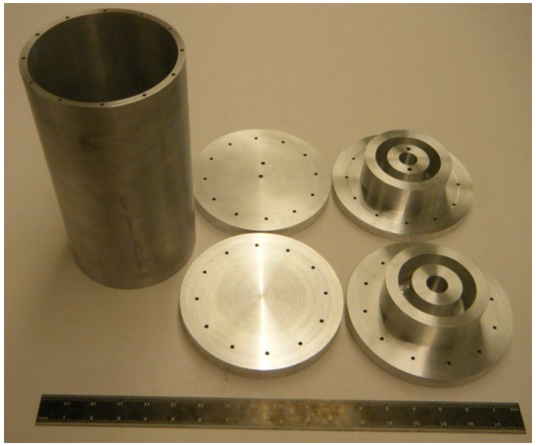




Lower Frequency Cavities



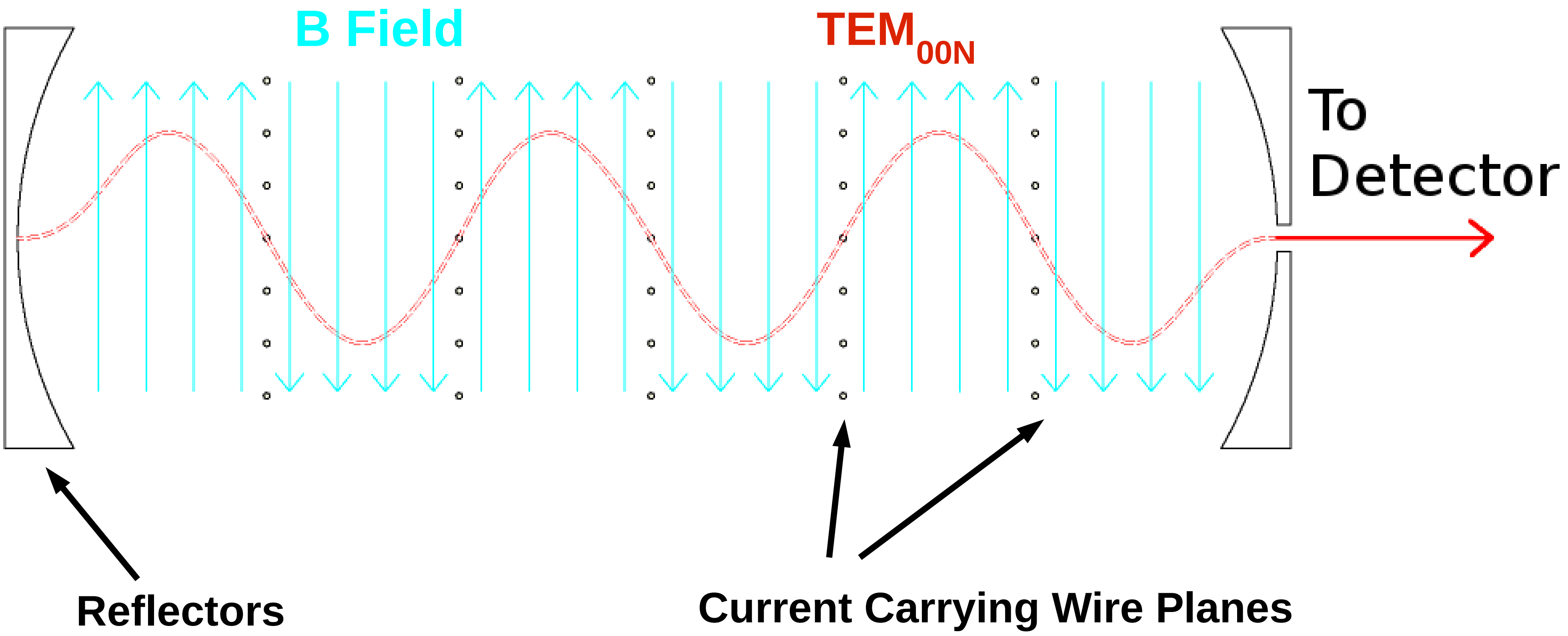




R&D is underway to access frequencies below those of previous cavities

Current work promises factor of two or more frequency reach increase

Open Resonator Concept

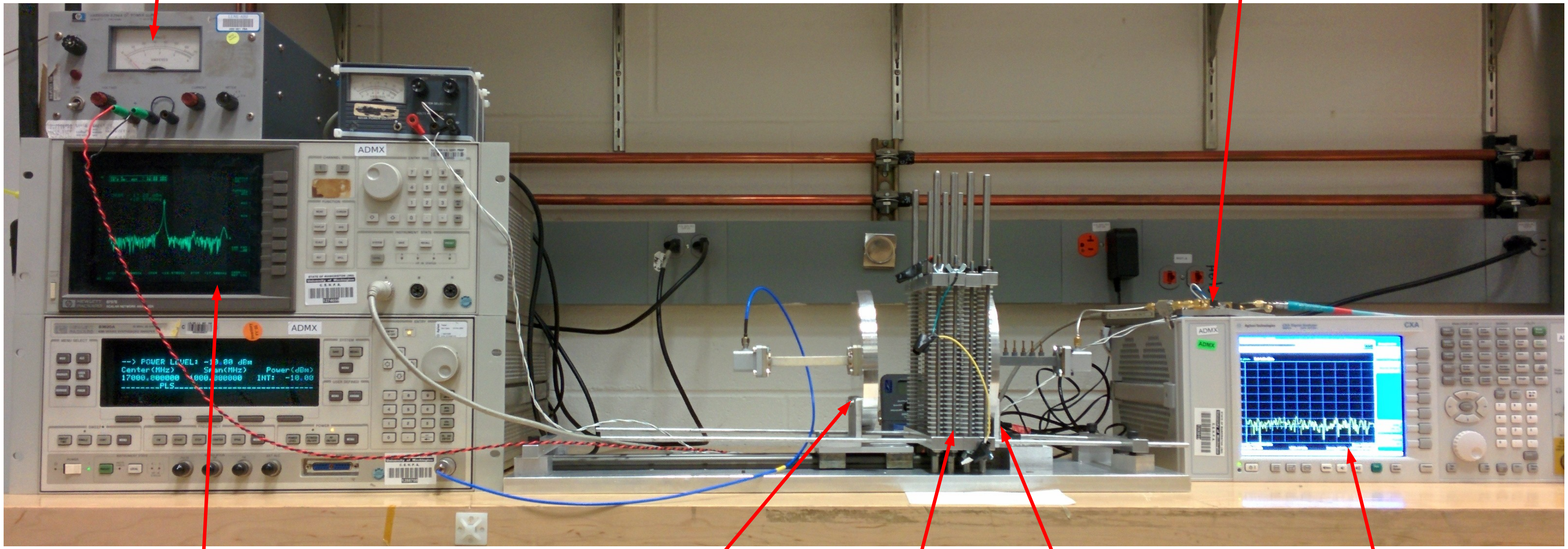


Open Resonator Prototype

ADMX R&D: Orpheus

Wire Plane Power Supply

Amplification



Reflector

Reflector

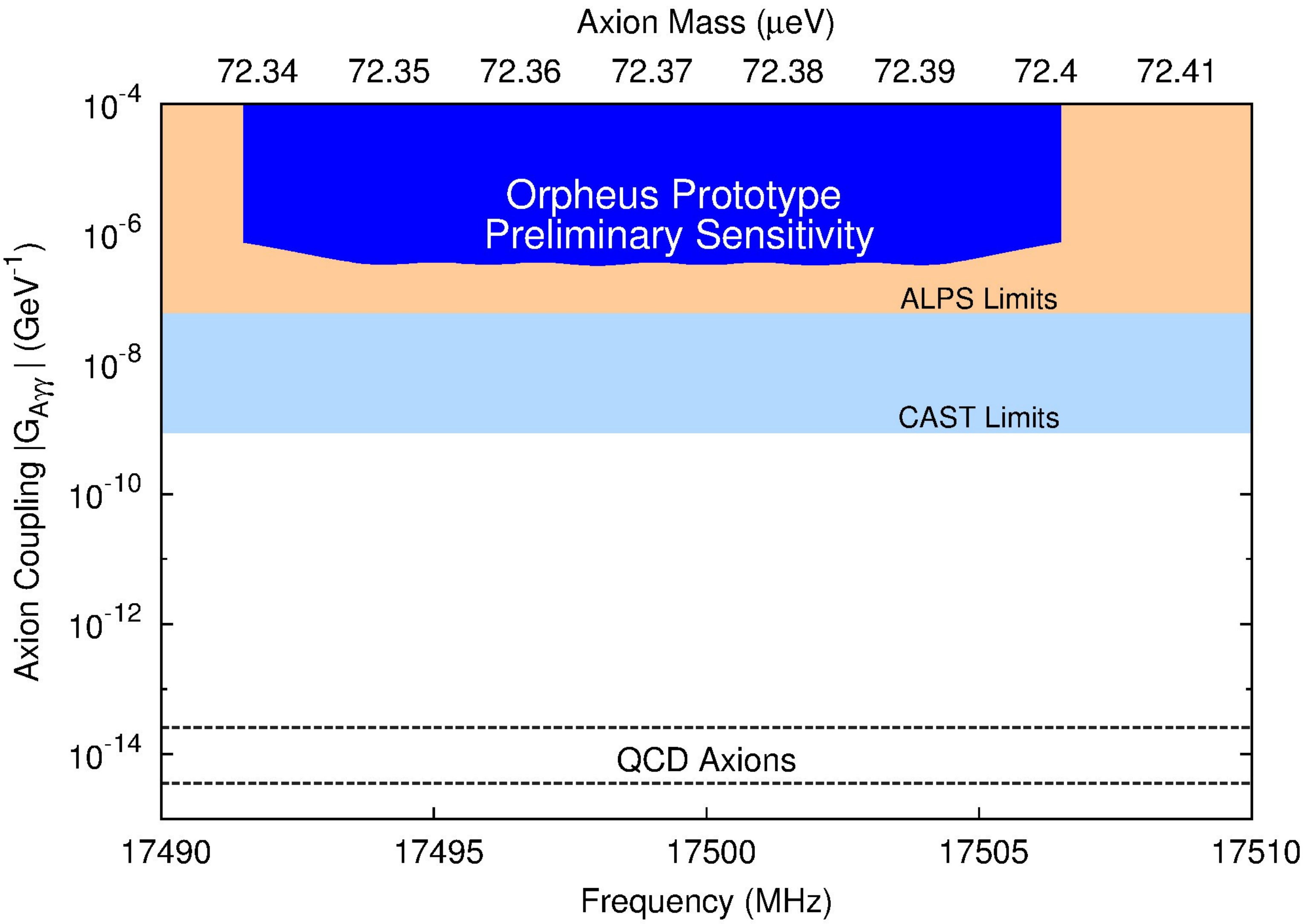
Network Analyzer
(Measures Q)

Wire Planes

Spectrum Analyzer
(Measures Power Out)

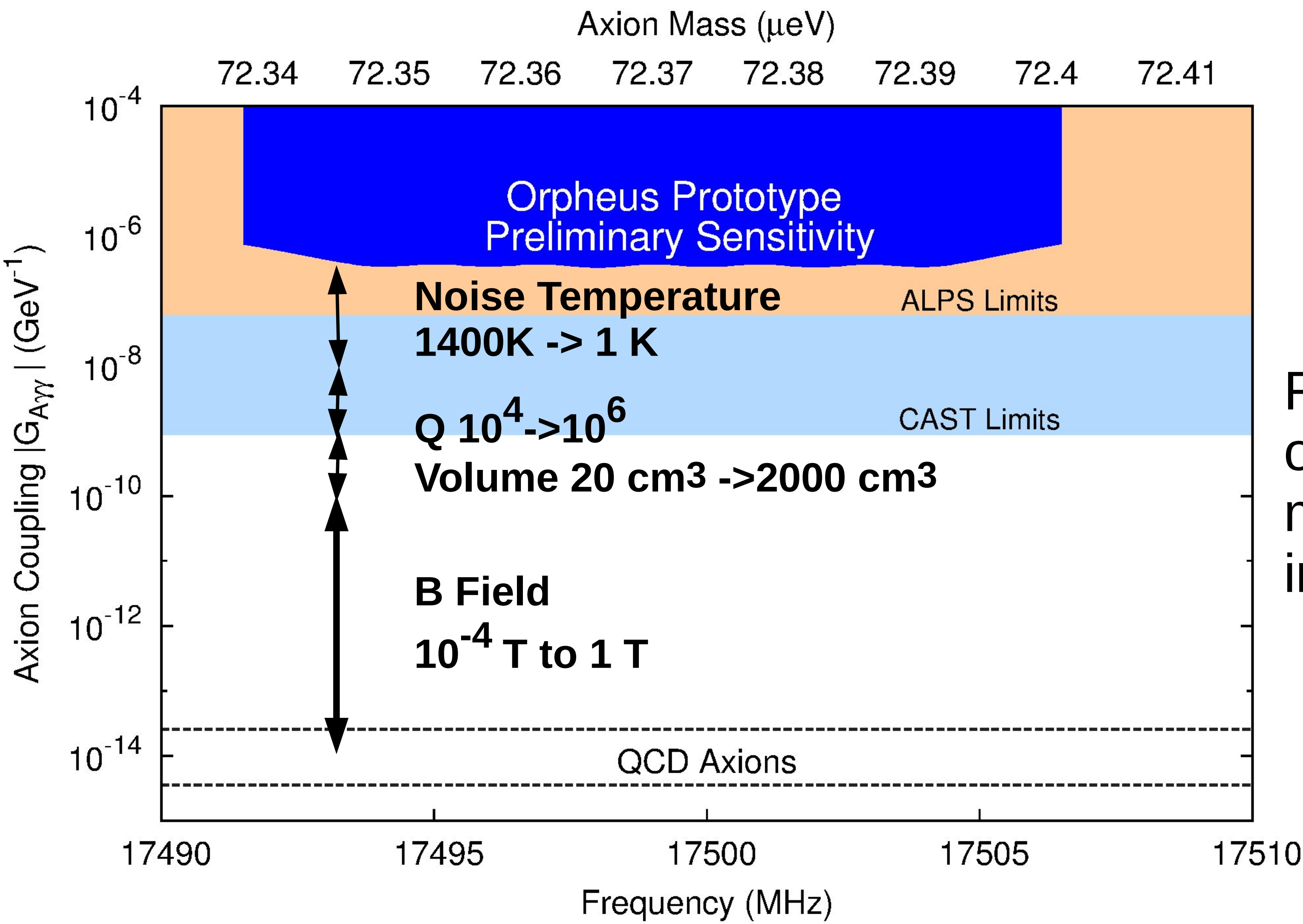
Open Resonator Preliminary Sensitivity

From a few hours of test data



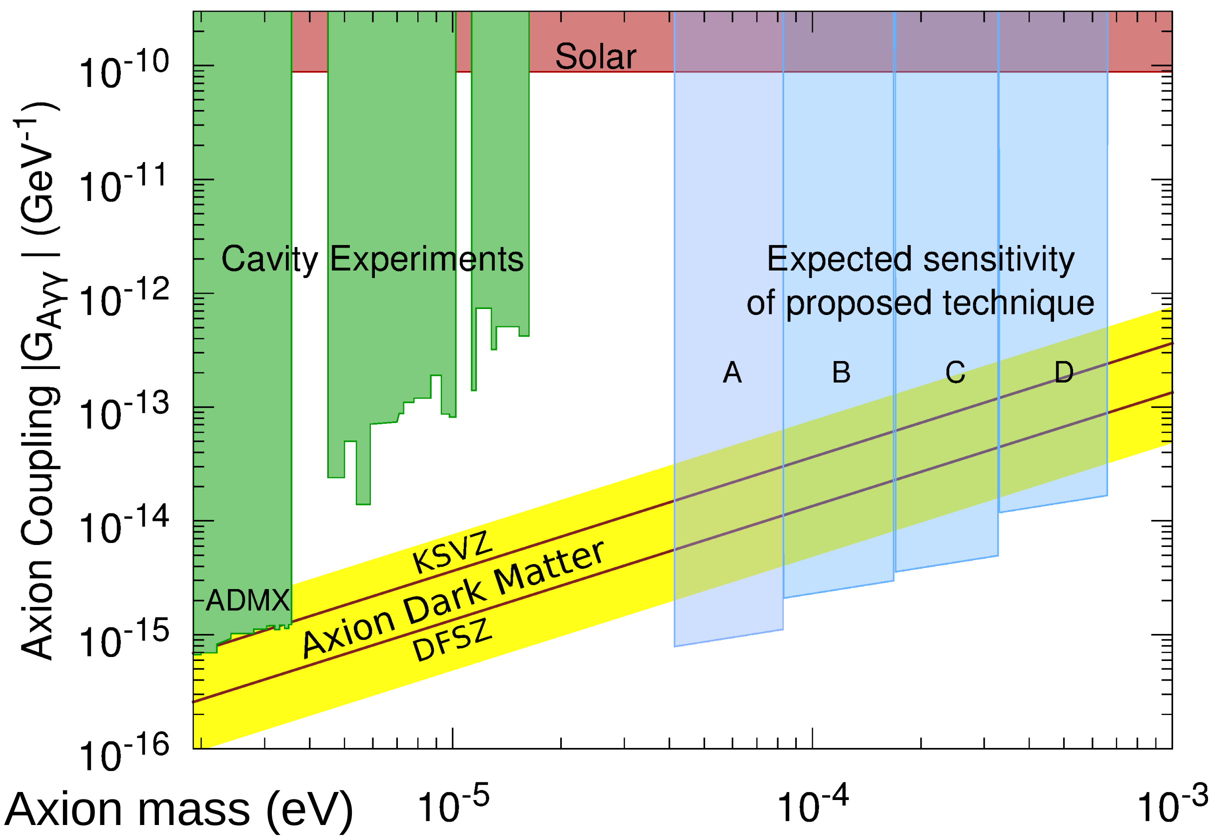
Open Resonator Preliminary Sensitivity

From a few hours of test data



Room for 8 orders of magnitude of improvement

Open Resonators Potential Reach



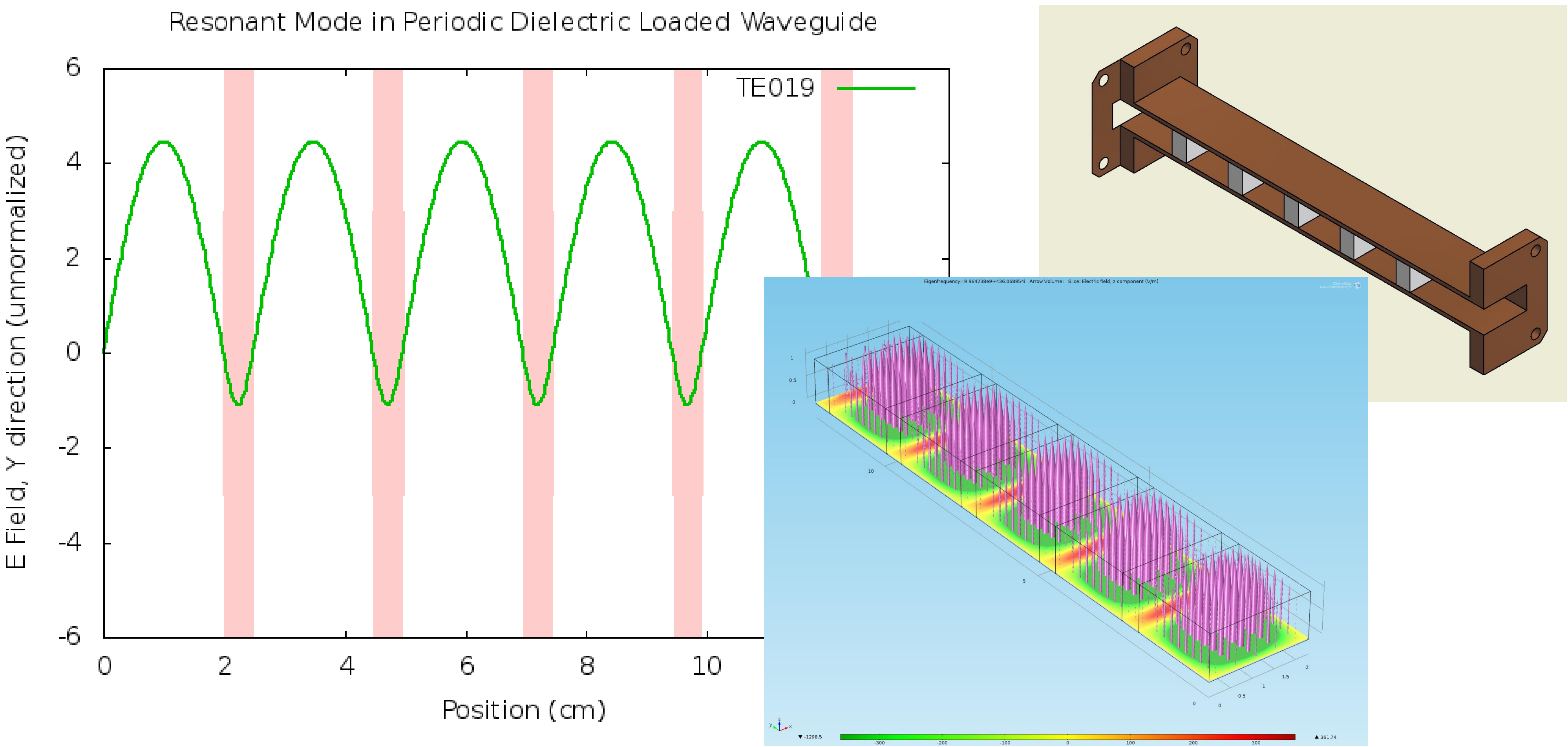
May be able to extend ADMX reach to meV masses
See: arxiv:1403.3121

Experiment	Mass Target	Frequency	B Field	Q	Volume	Noise Temperature	Run Time
A	52 μeV	15 GHz	3 T	10^6	1×10^6 cm^3	750 mK	1 Year
B	103 μeV	30 GHz	3 T	10^6	8×10^5 cm^3	1.5 K	1 Year
C	207 μeV	60 GHz	6 T	10^6	4×10^5 cm^3	3 K	1 Year
D	414 μeV	120 GHz	6 T	10^6	2×10^5 cm^3	6 K	1 Year

Dielectric Loaded Resonators

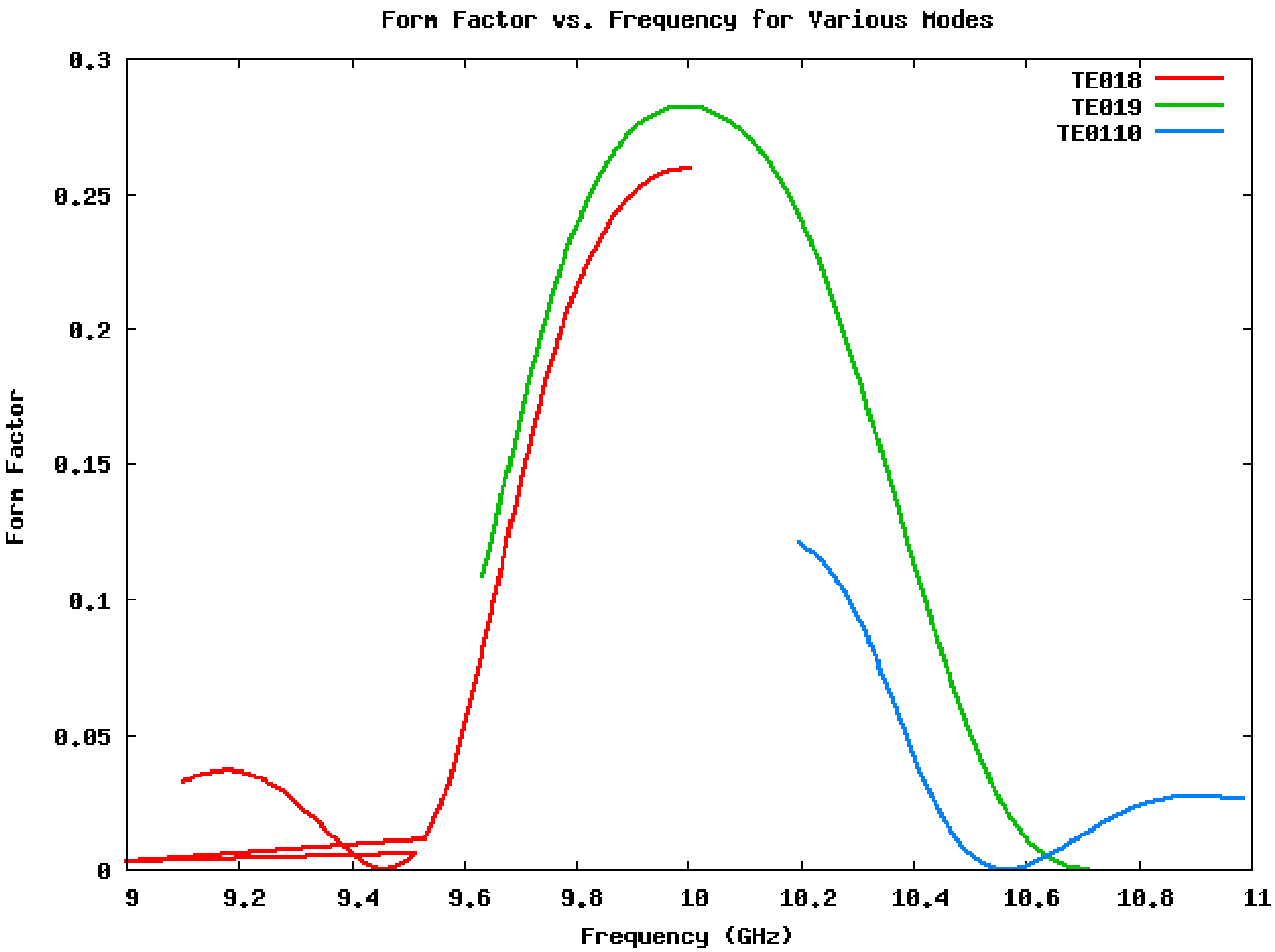
Strategically placed dielectric in resonators can enhance coupling

Example: Dielectric blocks spaced by half wavelength in a waveguide



Dielectric Loaded Resonators

Initial calculations show promising form factors



Right circular cylinder form factor: 0.6

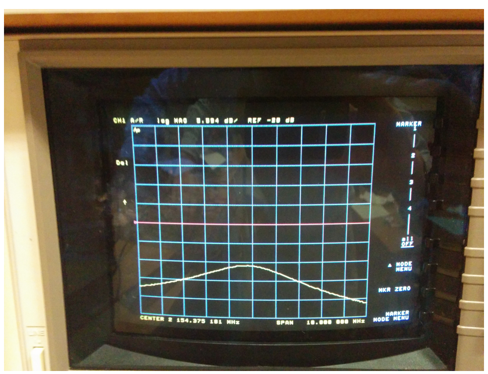
However, this structure can be made arbitrary long with the same form factor

Prototype planned for this summer

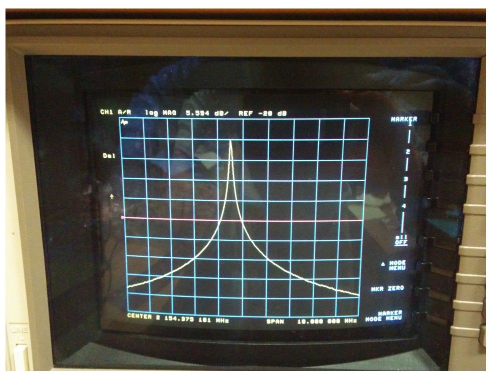
Active Resonators

Active feedback resonators can increase the Q of a resonant system by factors in excess of 1000

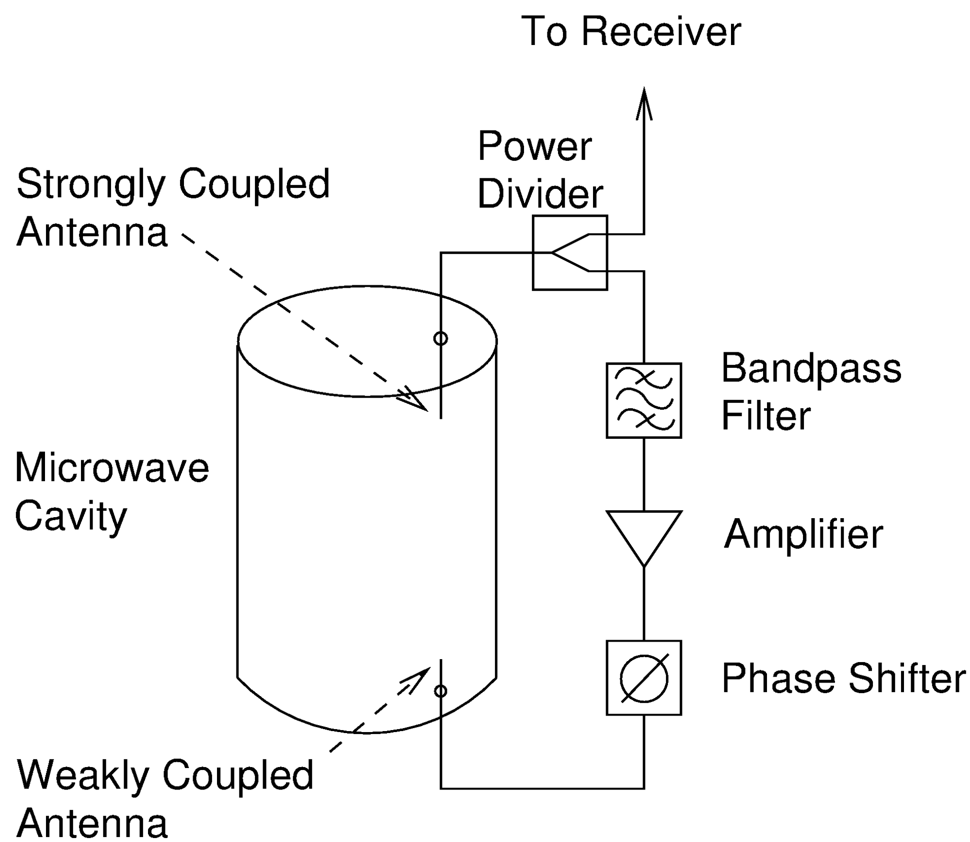
This could increase axion conversion signal, but noise increases as well



Passive



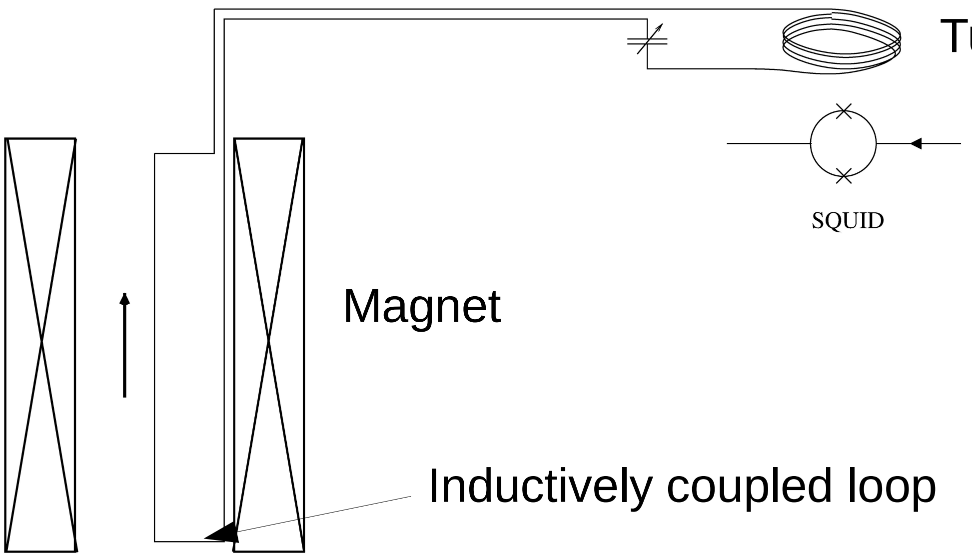
Active



The use of active resonators to enhance sensitivity in ADMX is currently under study: arxiv:1403.6720

Dark Matter Axion Circuits

Resonant circuits can take the place of cavities

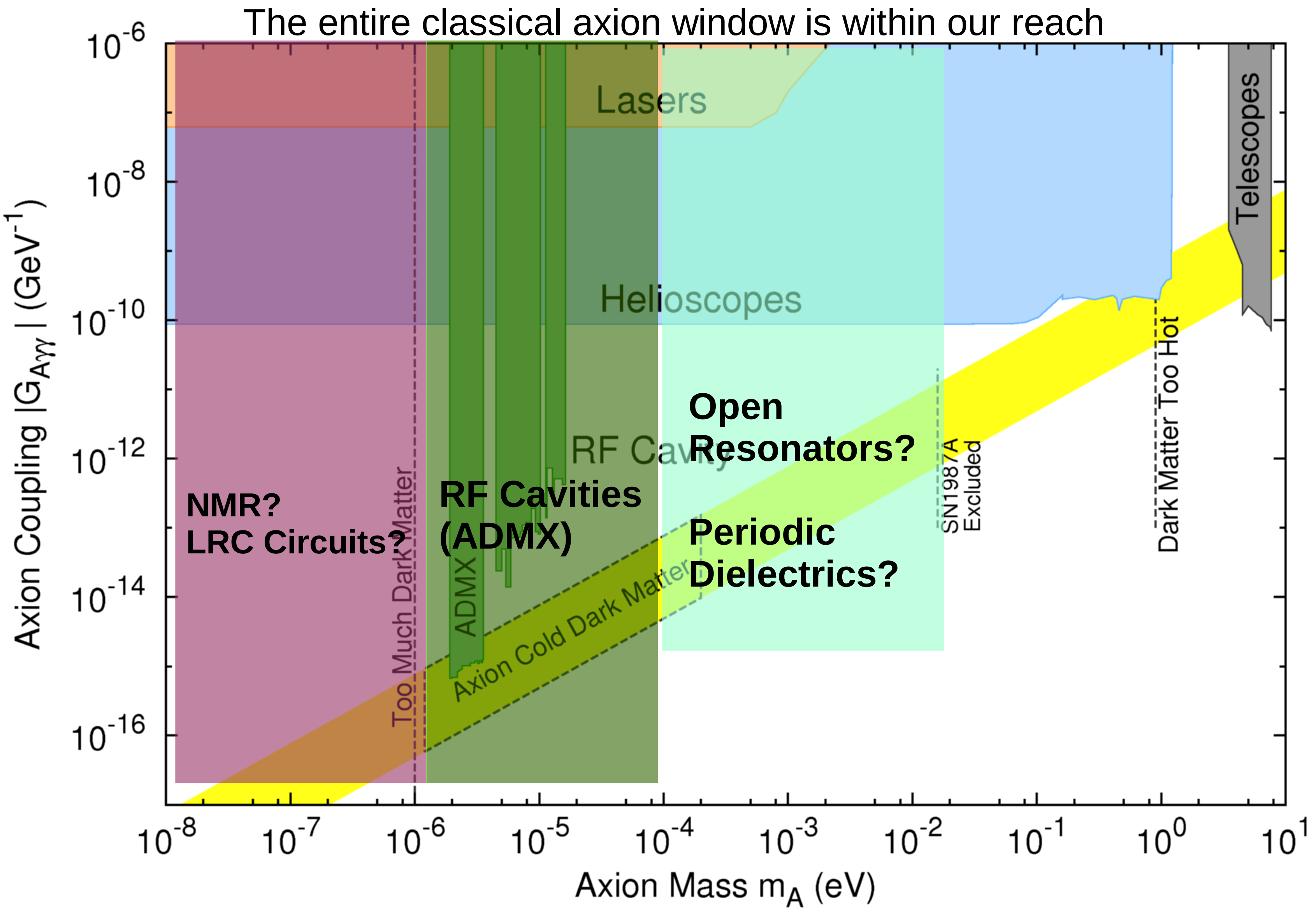


See:
Sikivie, Sullivan, Tanner
arXiv: 1310.8545

This allows access to much lower frequencies

Perhaps axion powered circuits are the future?

Conclusions



Complete Exploration of Viable QCD Axion Dark Matter Masses may be Possible!