Direct Detection Searches for Axion Dark Matter

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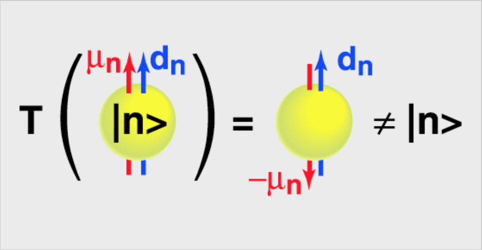
TAUP 2013, Asilomar, CA

Axions: Motivation

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

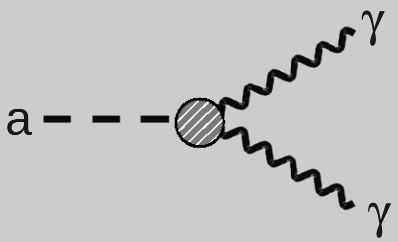
The Peccei-Quinn Solution

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

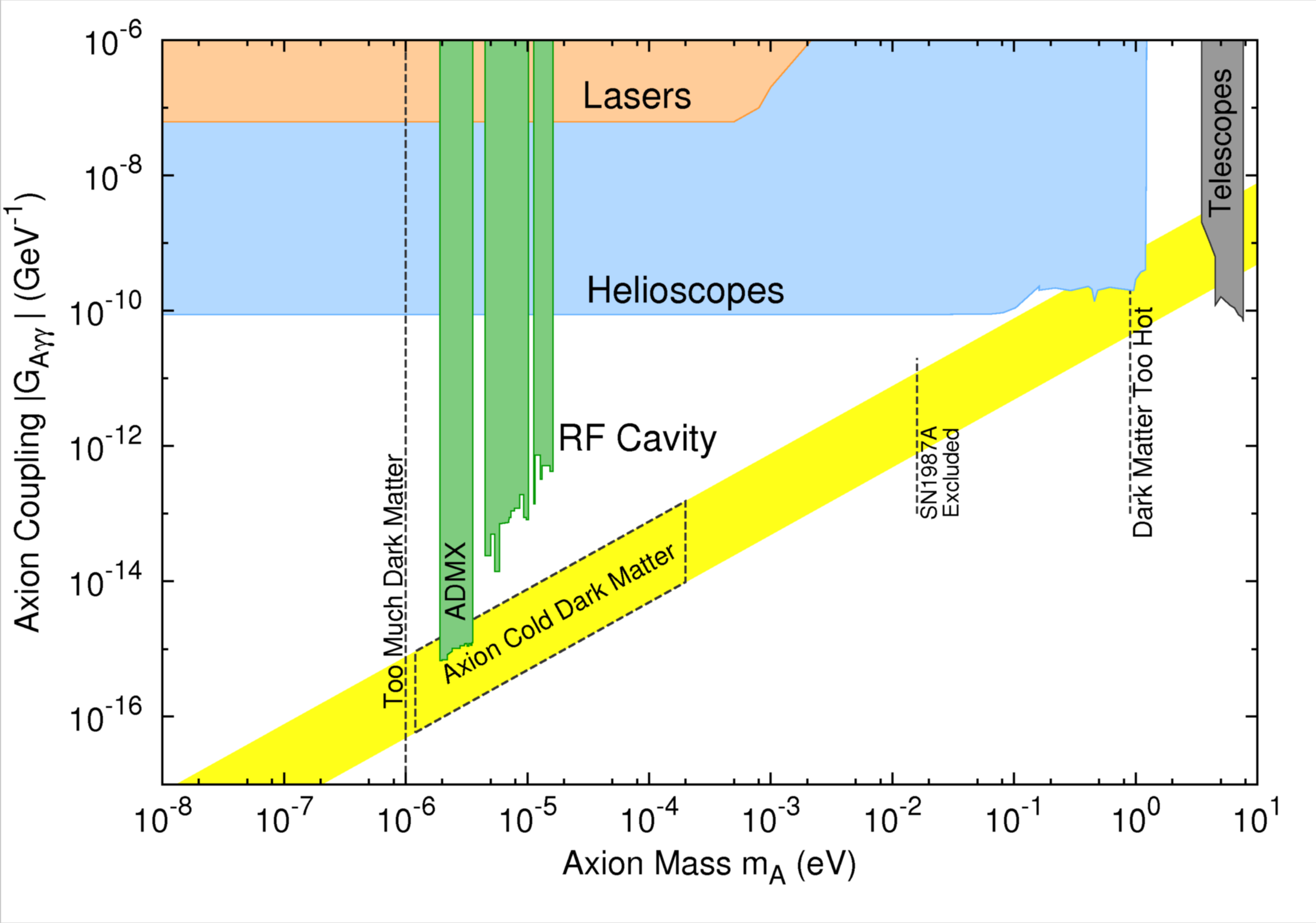
This results in a new pseudoscalar particle, the Axion

-Weinberg, Wilczek

Couples to two photons

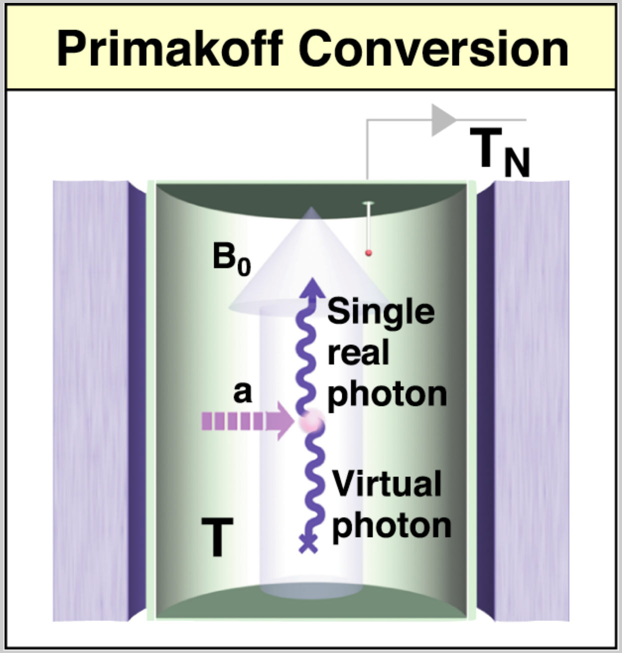


Axion Dark Matter Parameters



(Exact mass range debatable, depends on pre-/post- inflation production)

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

University of Washington

LLNL

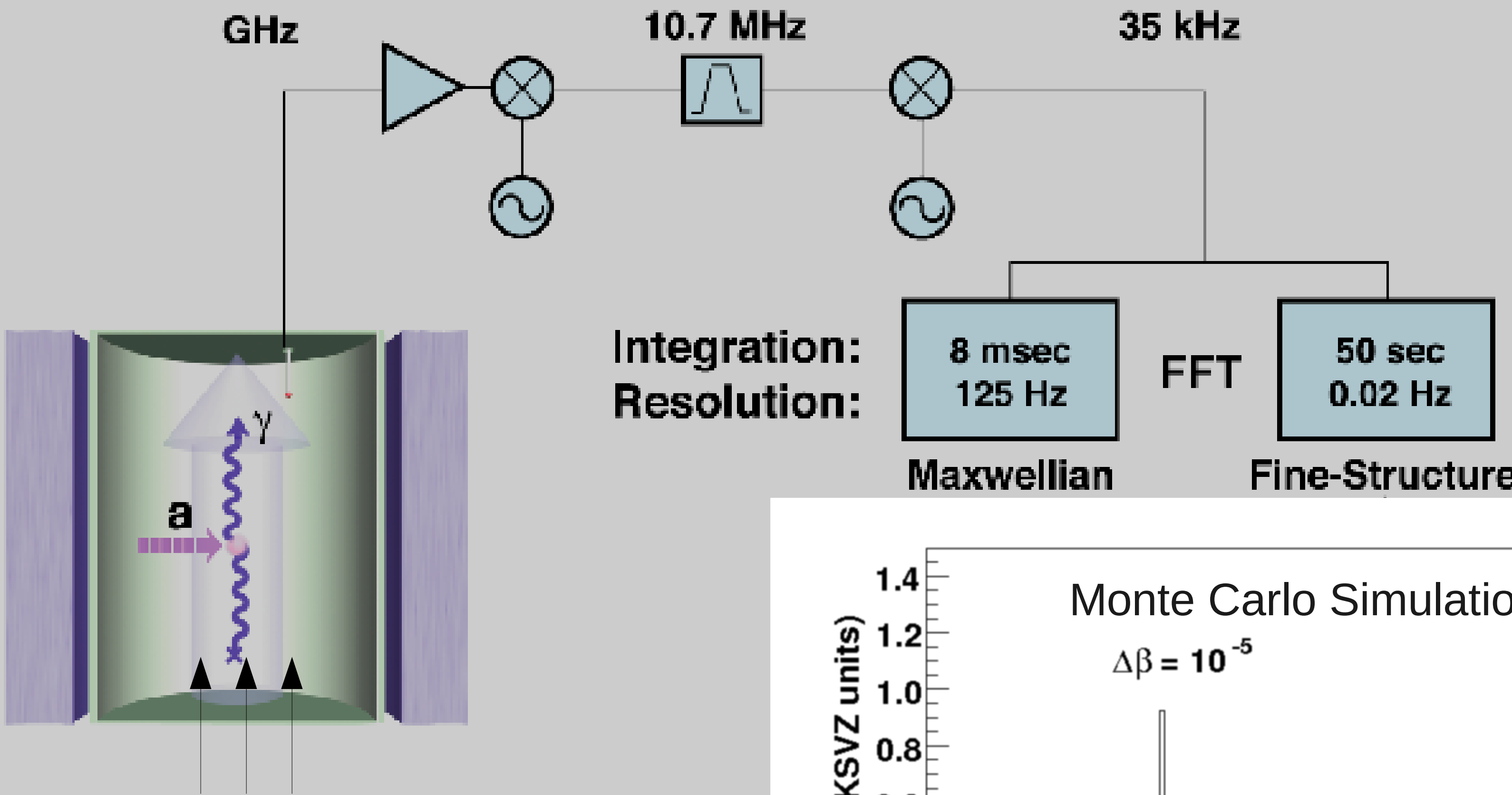
University of Florida

Yale

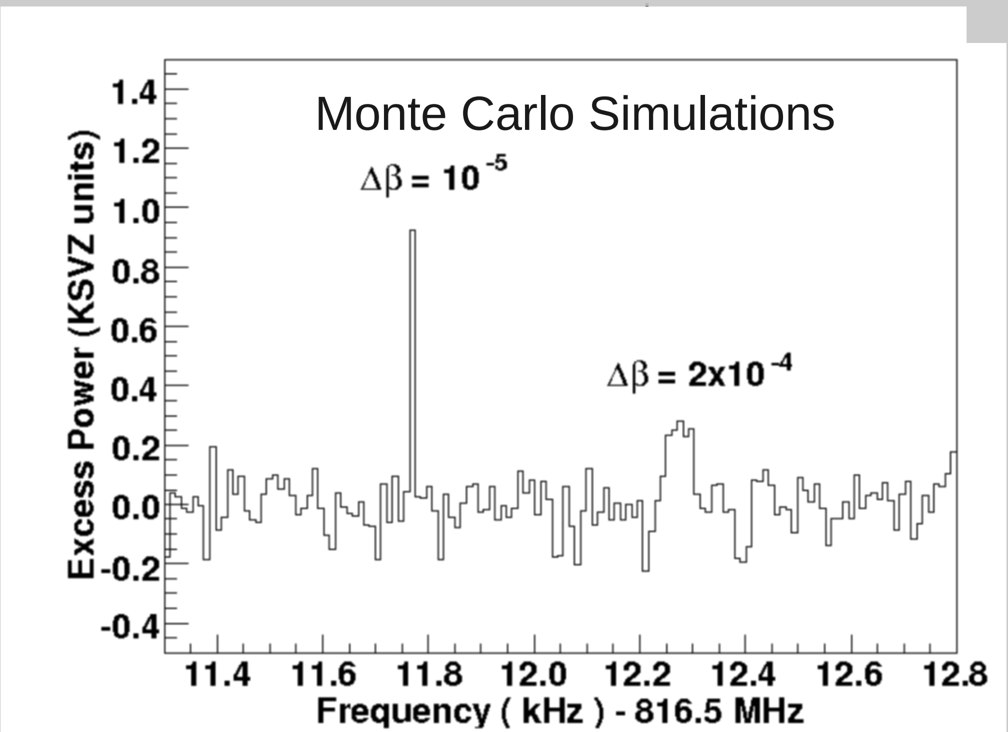
UC Berkeley

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

Dump liquid helium in here

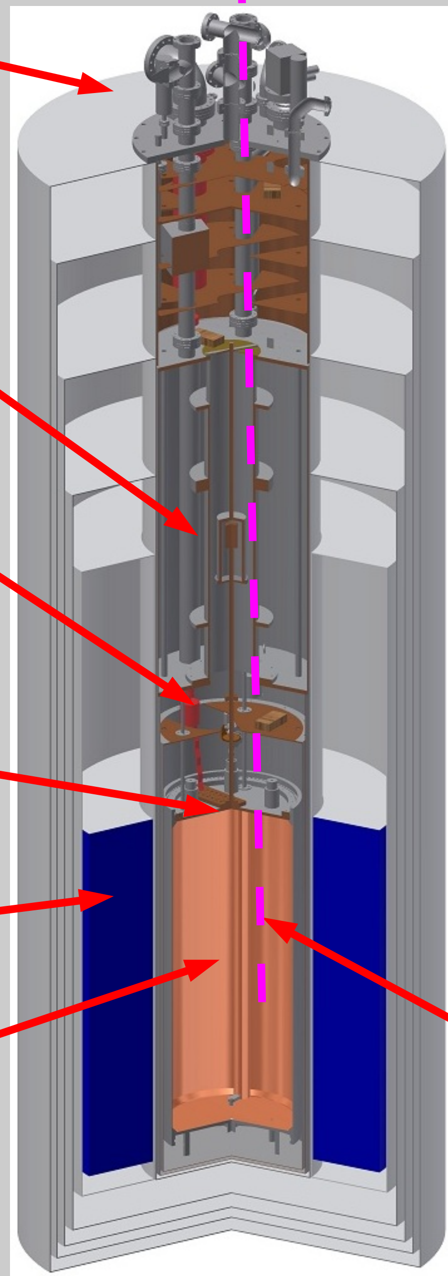
SQUID Amplifier package

Refrigeration

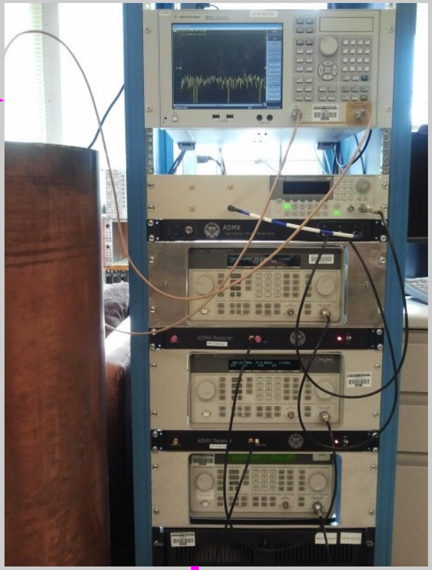
Antennas

8 Telsa Magnet

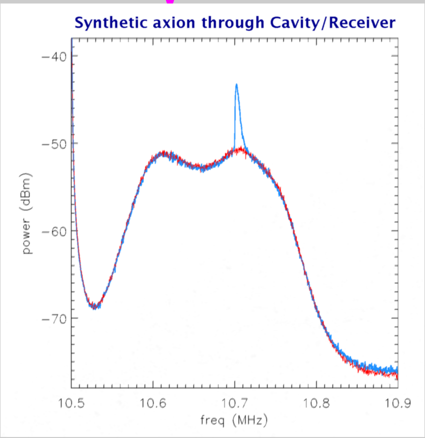
Microwave cavity (axions go in here)



Change frequency/ mass sensitivity with tuning rods



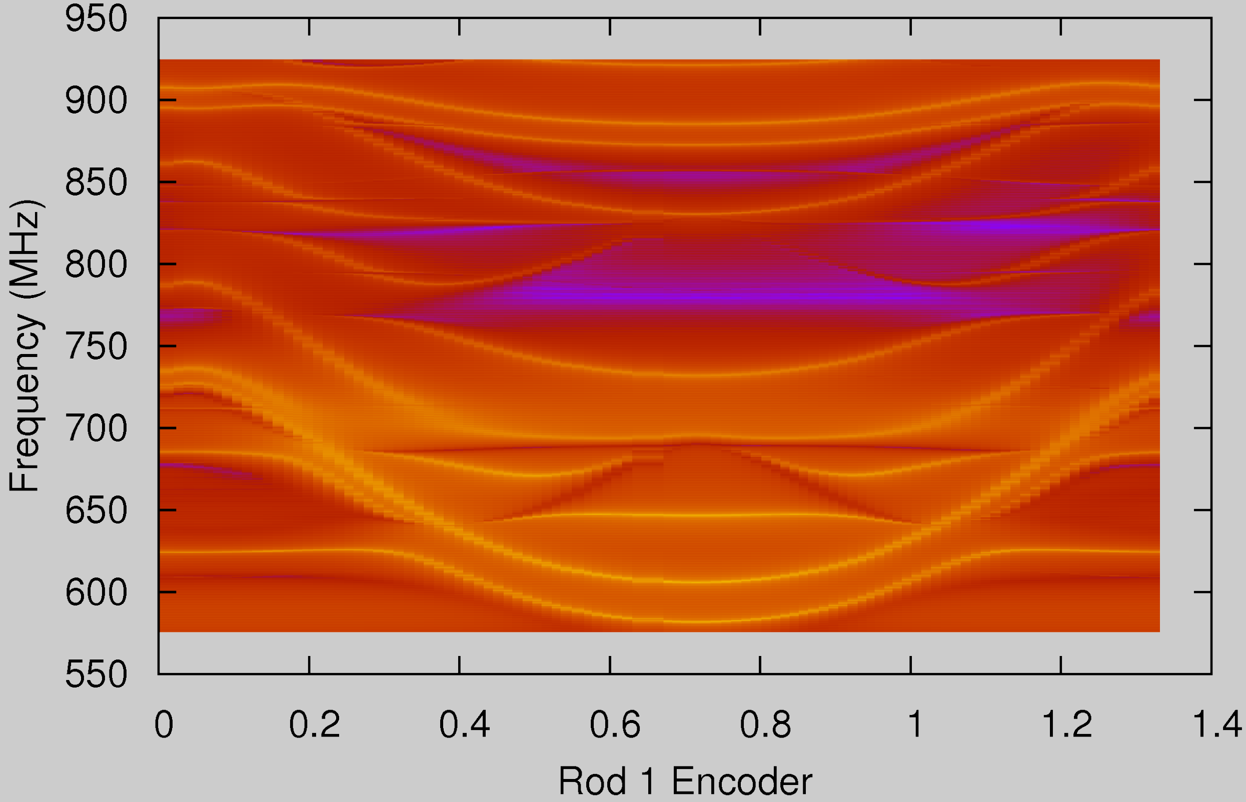
Amplify, mix signal from ~1 GHz to ~10.7 MHz, then digitize



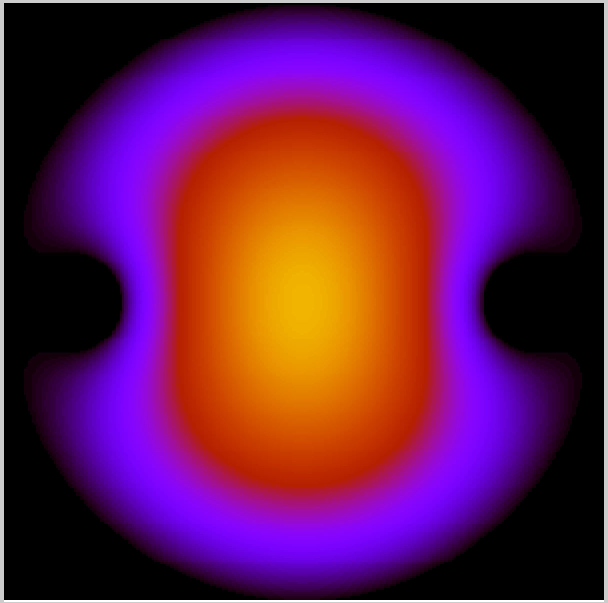
Look for excess power in power spectrum

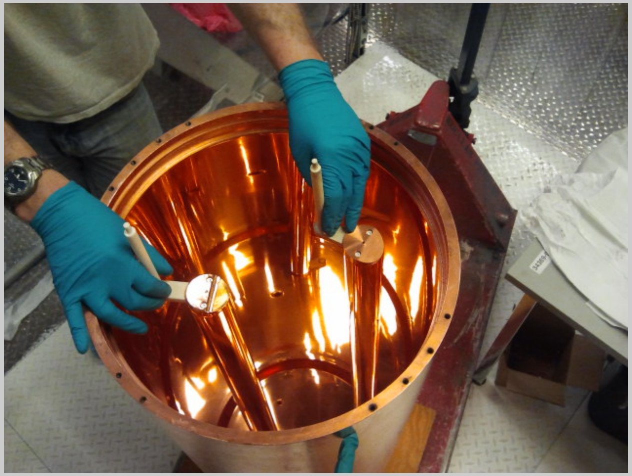
Tuning

Mode Map Rod2 at 0.967

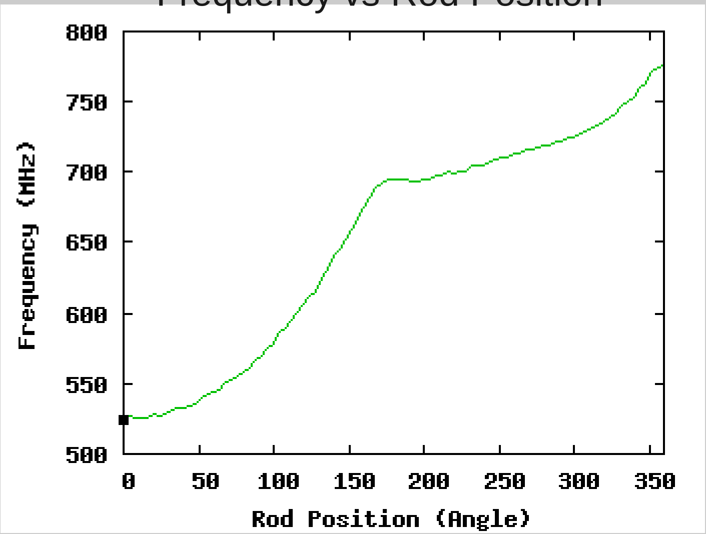


Electric Field as Rods Move (simulation)

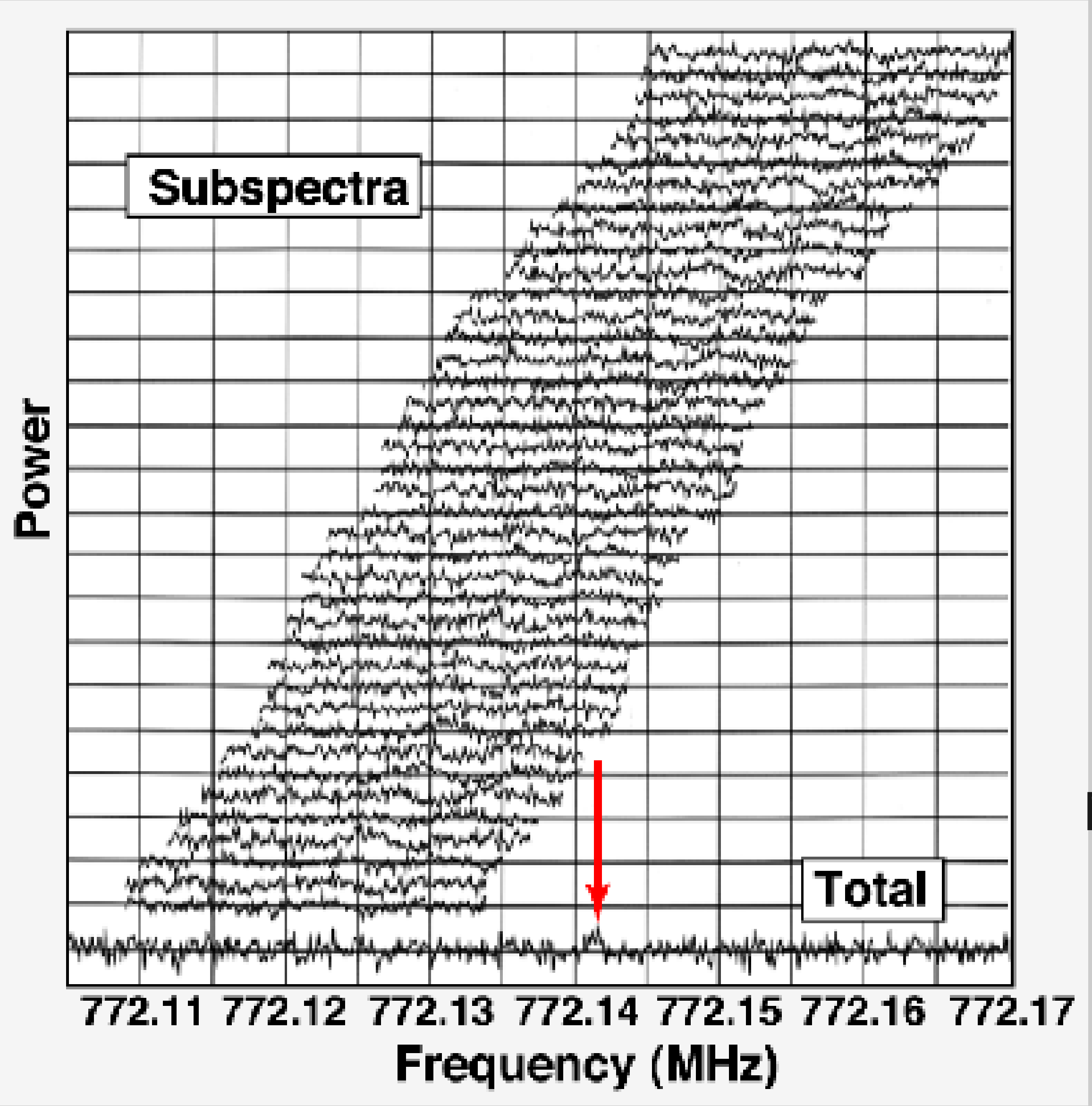




Frequency vs Rod Position



Axion Search Technique



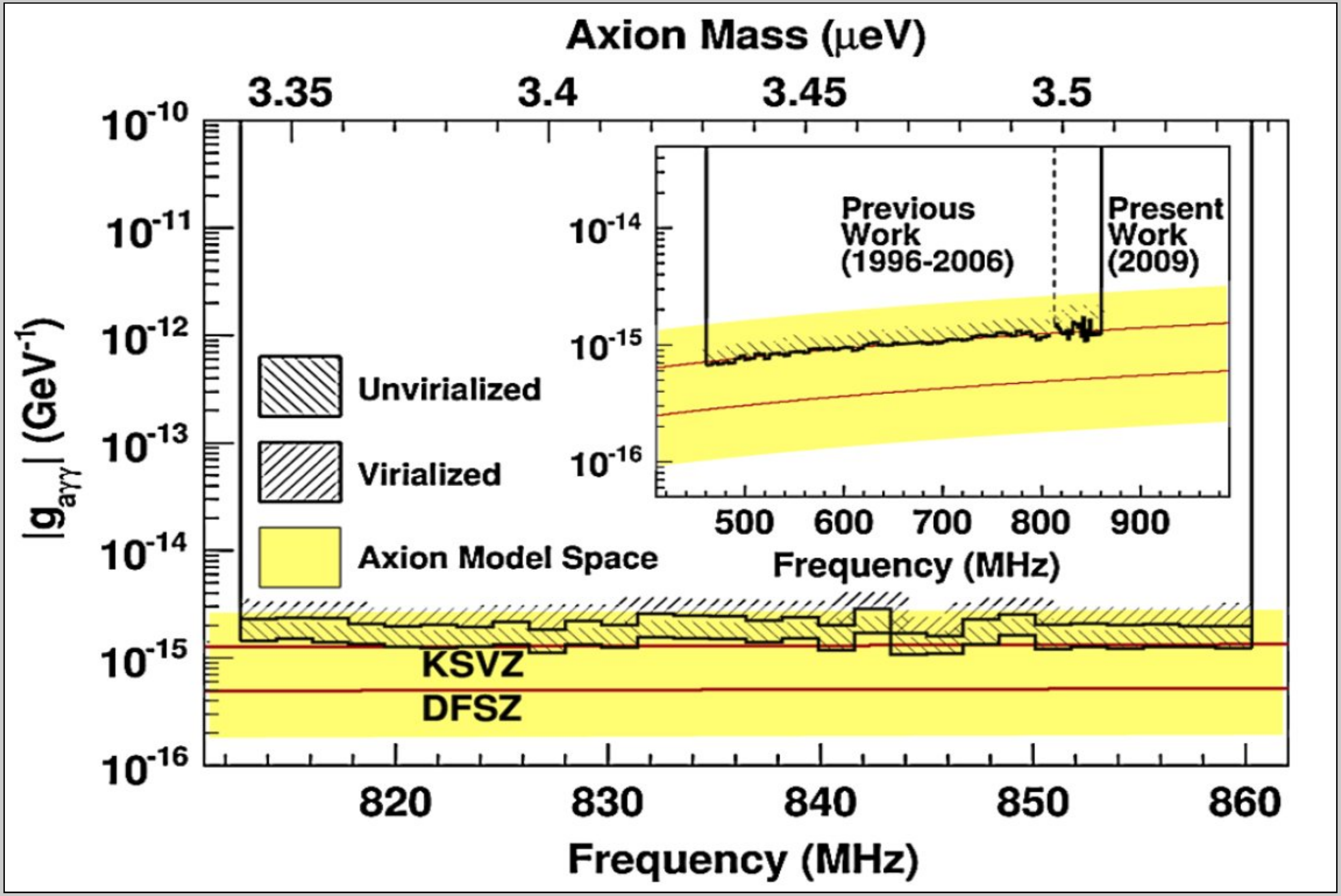
Cavity resonant frequency is tuned by two movable rods

Power spectra are measured at each rod position

Axion signal would appear as a constant power excess

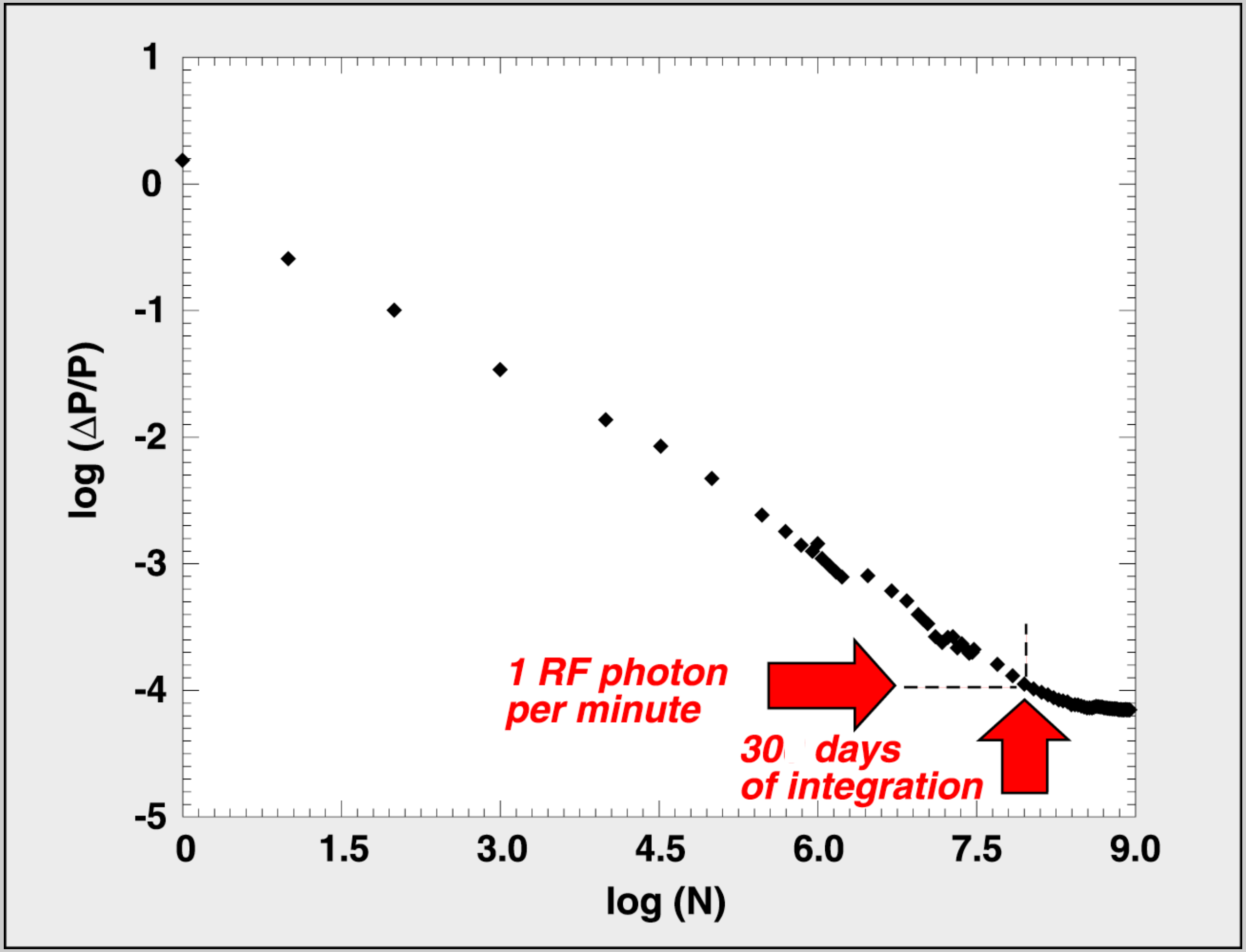
Most backgrounds do not persist

Current Limits



Asztalos et al, PRL 104, 041301 (2010)

Power Sensitivity



Systematics limited after 1 month integration

Sensitivity 0.01 Yoctowatt. Characteristic Axion Power: 100 Yoctowatts

Speed is the key issue

The Need for Speed

Time to scan axion mass range a 2010 speed: ~100 years

Scan Speed $$\frac{df}{dt} \propto \frac{1}{T^2_{noise}}$$

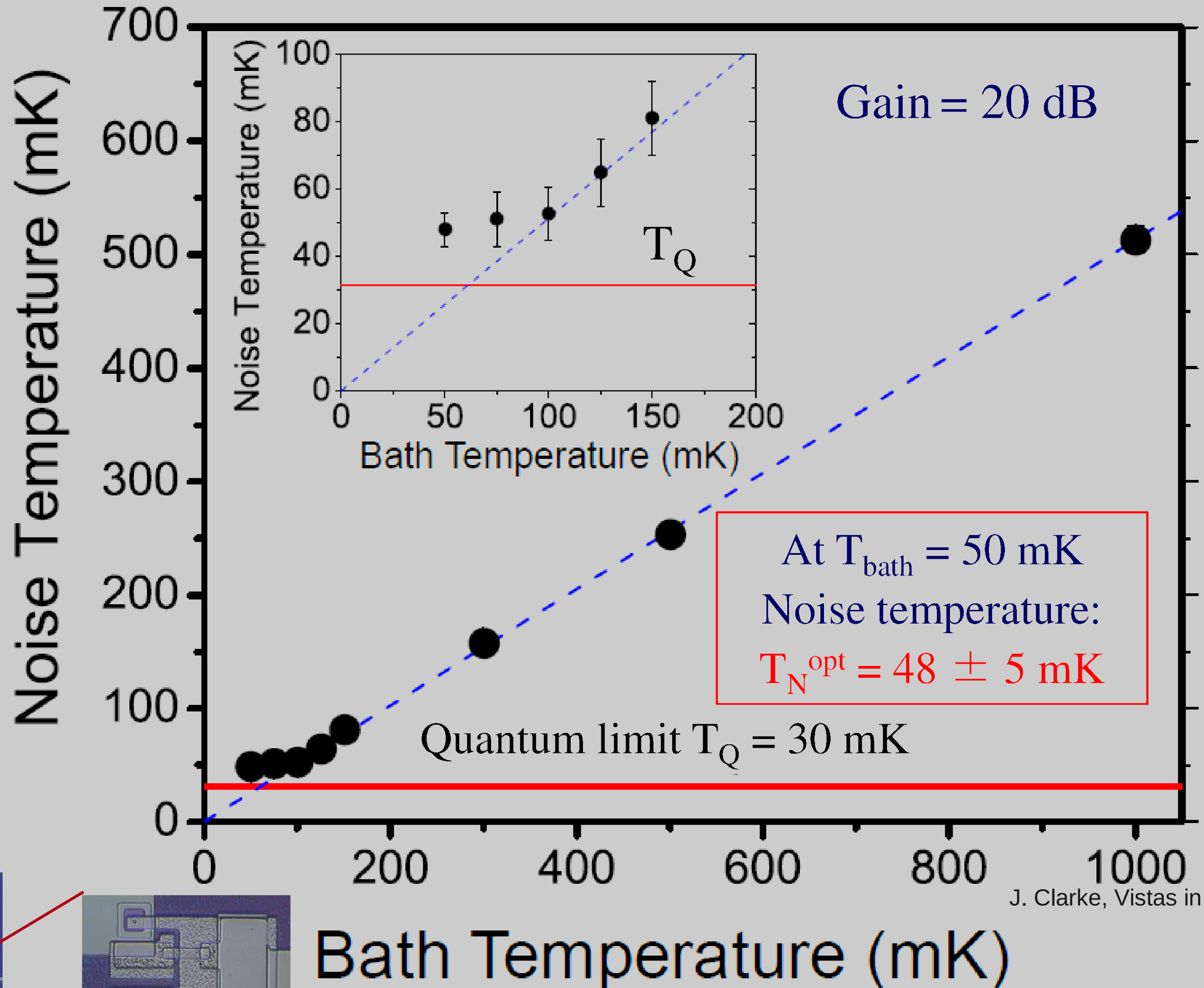
Want to run faster?

Run colder!

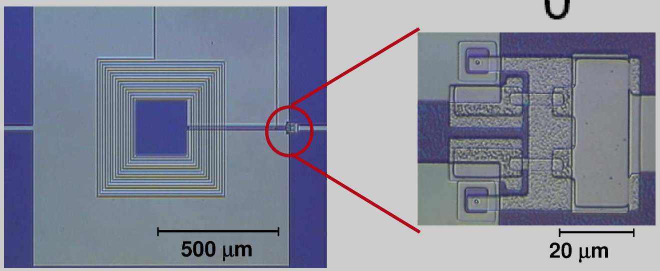
Noise comes from amplifiers and physical temperature

$$T_{noise} = T_{amplifier} + T_{physical}$$

SQUID Advantage

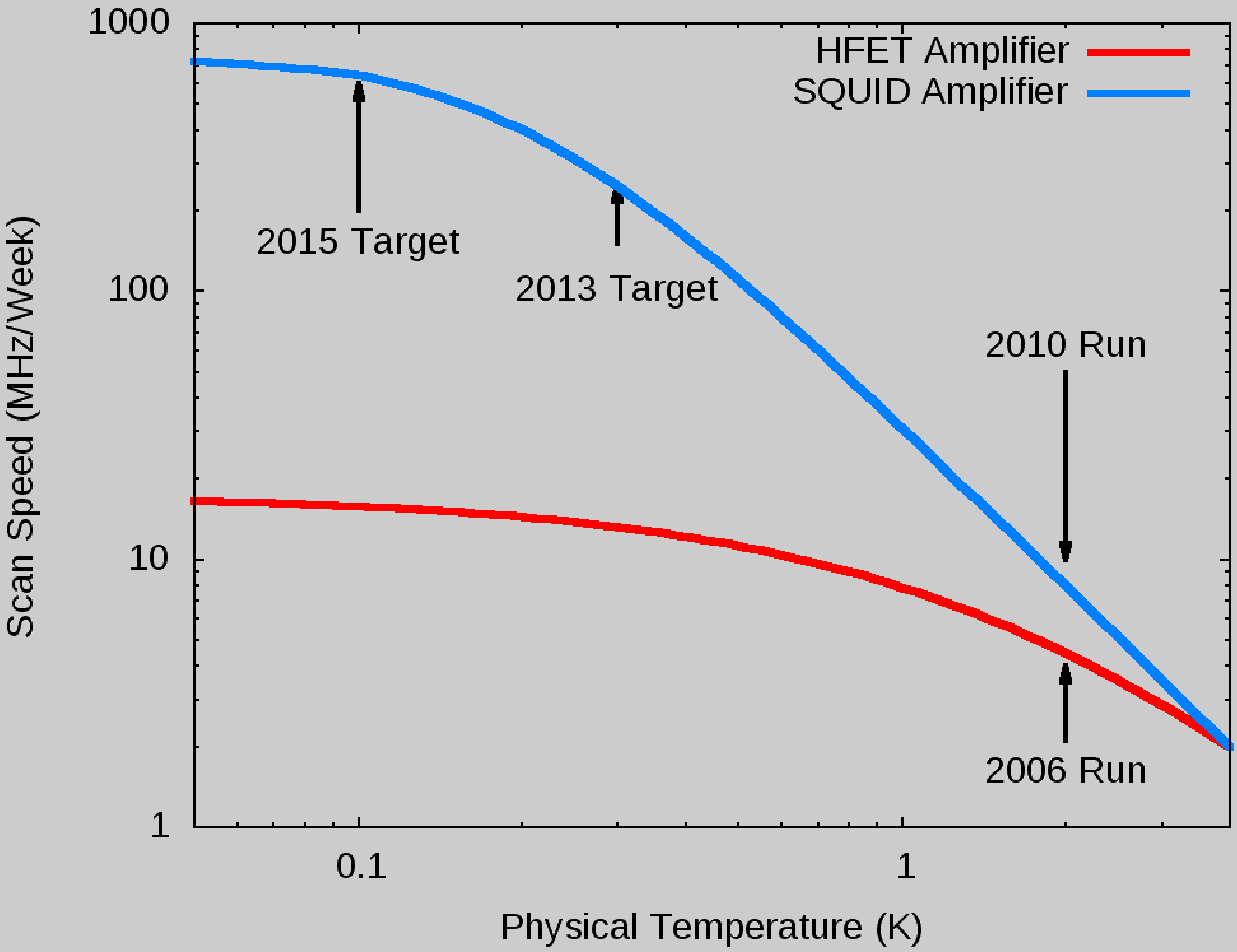


J. Clarke, Vistas in Axion Physics, 2012



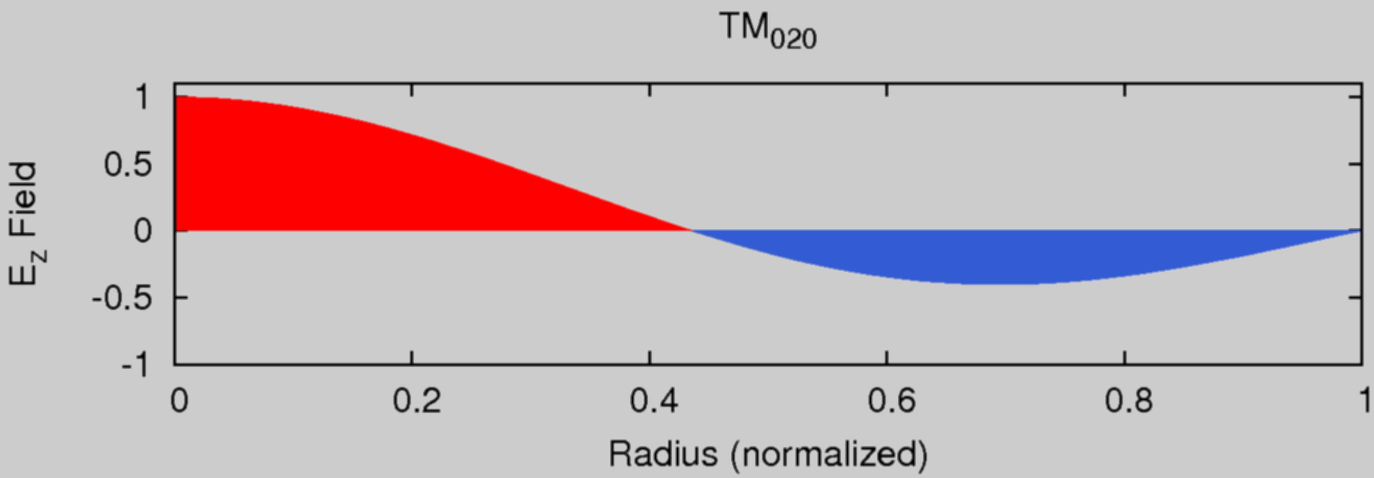
Cooling

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



Multiple Channel Improvements

$$Sensitivity \propto E_z \cdot B_z$$

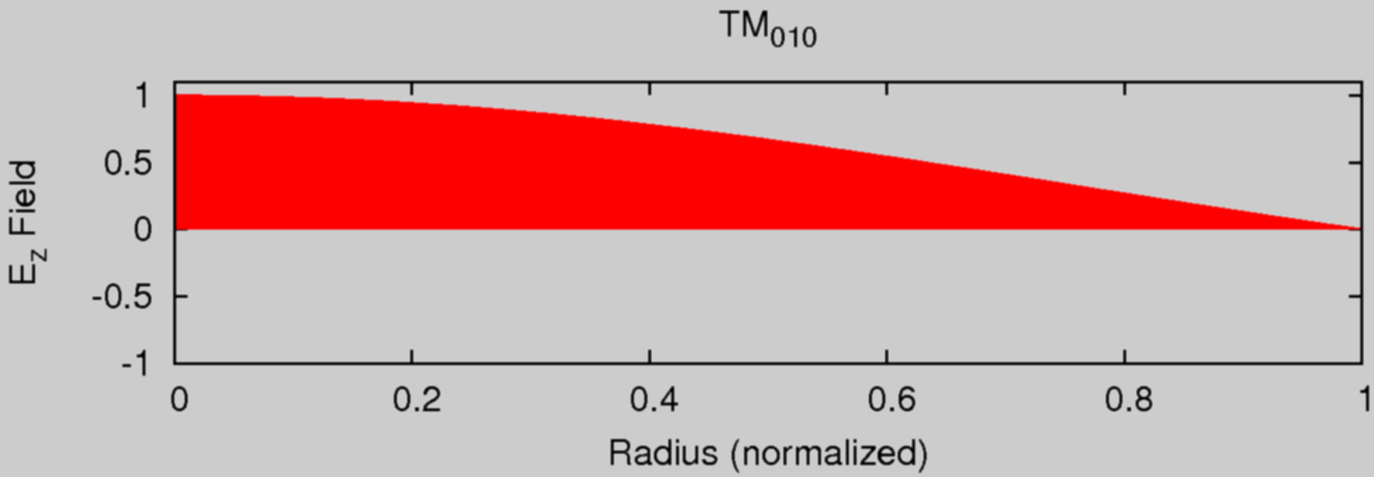


TM_{020}

Relative Frequency
2.3

Tuning Range
920-2,100 MHz

Relative Power
0.41



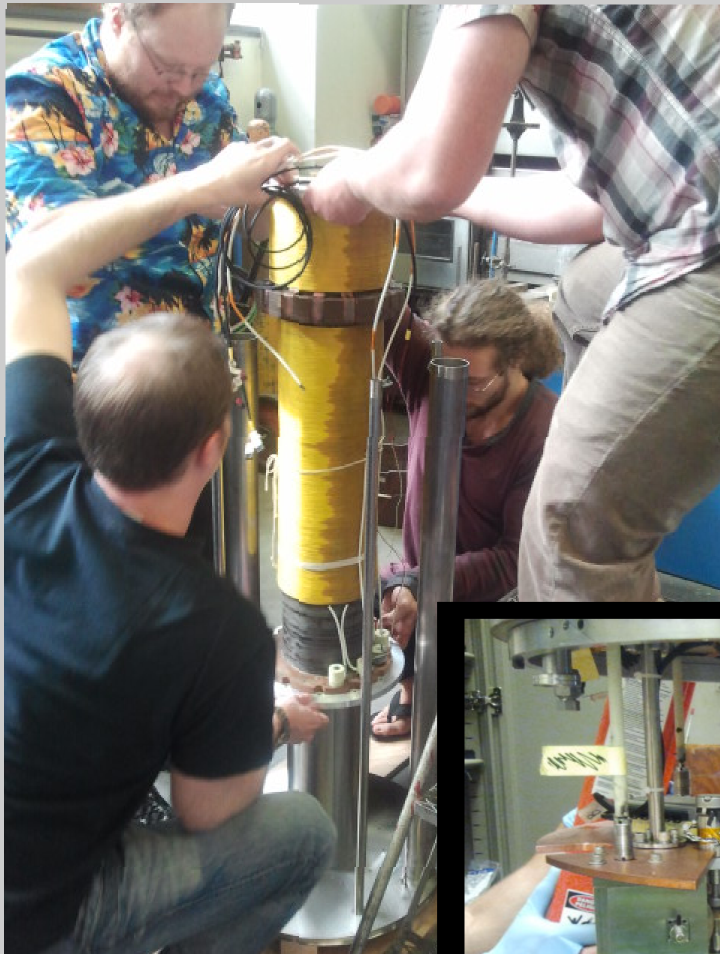
TM_{010}

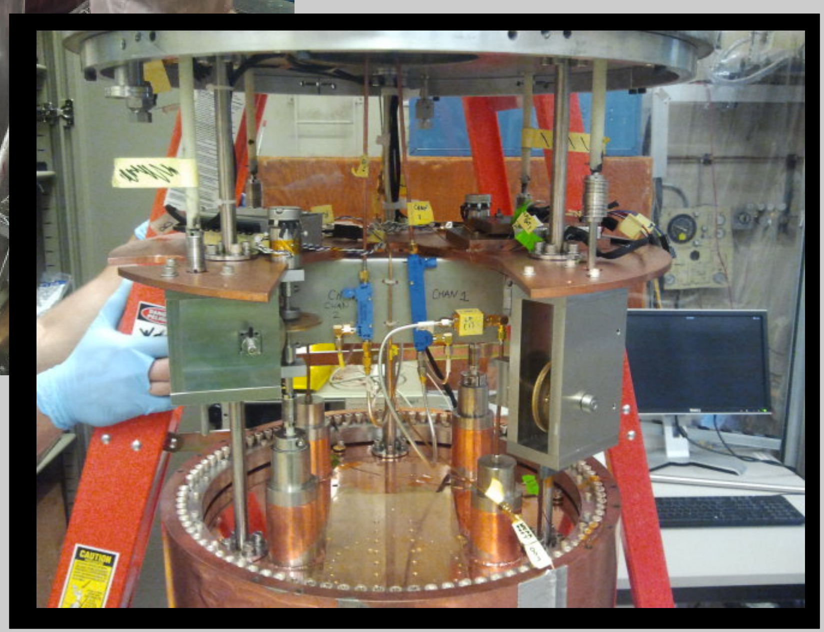
Relative Frequency
1.0

Tuning Range
400-900 MHz

Relative Power
1.0

ADMX Recent Past

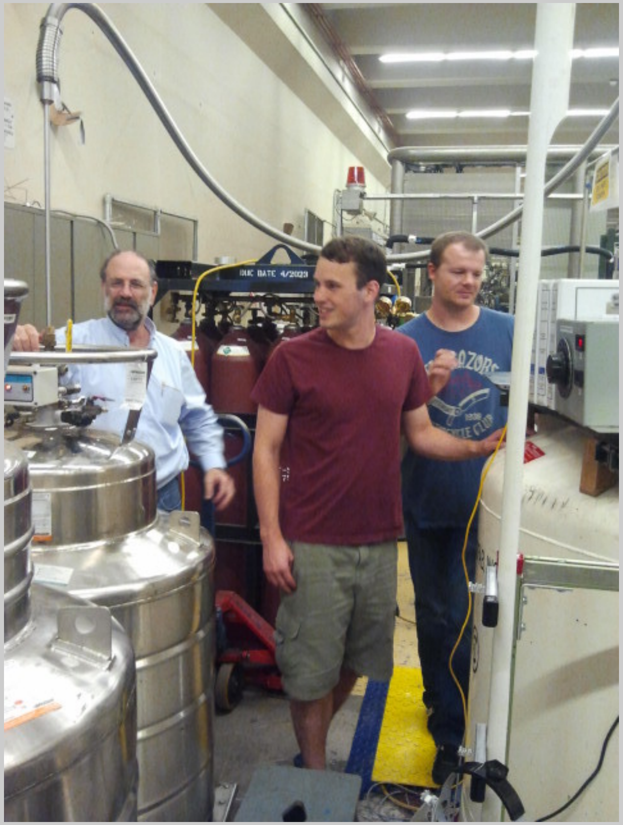


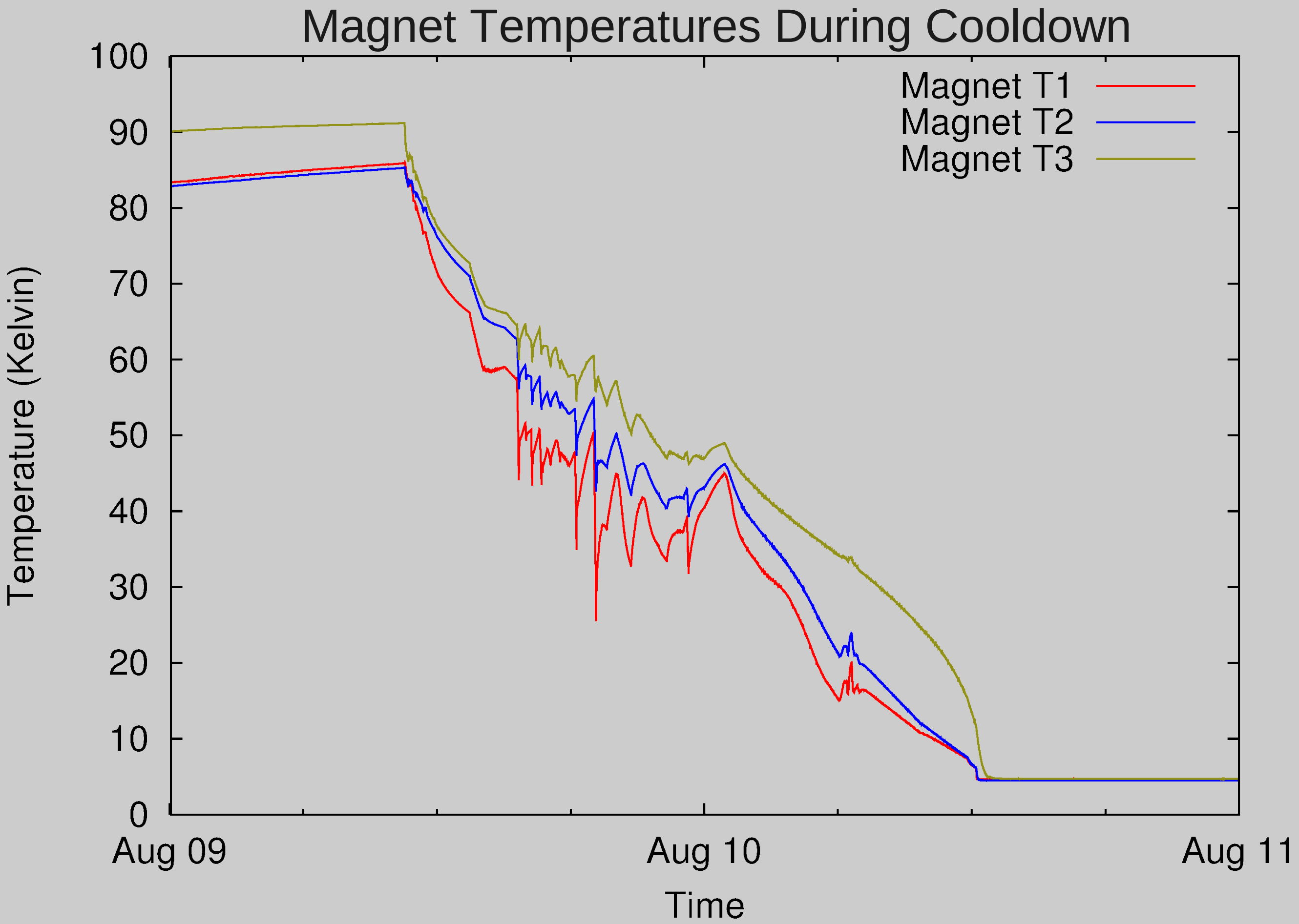


ADMX has been completely redesigned and rebuilt at UW to work at colder temperatures

ADMX Present

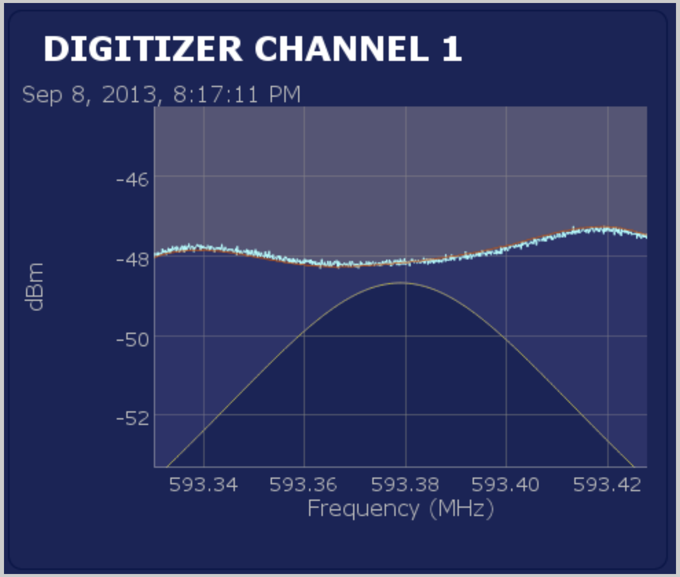
The magnet was cooled down in August and warm commissioning has finished
We anticipate cooling down the insert this week or next

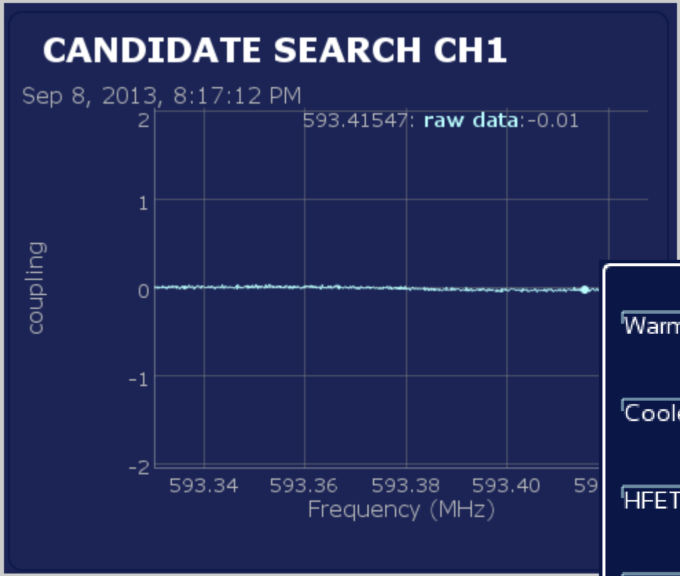


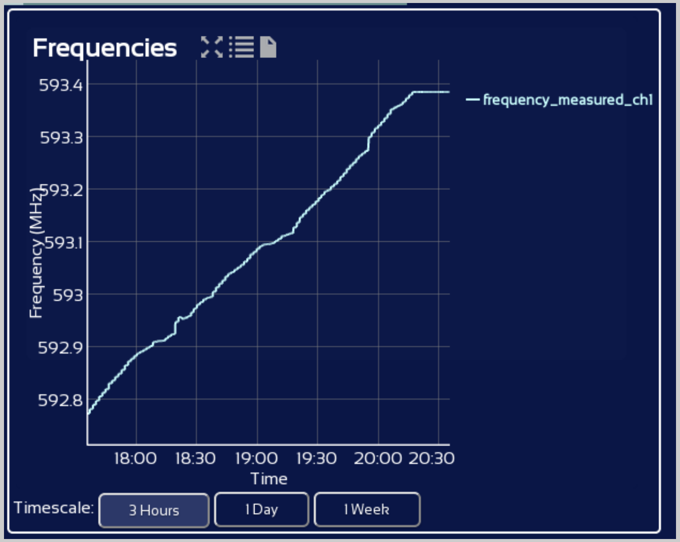


ADMX Near Future

Data taking will begin shortly after cooldown. Scan speed will increase rapidly as refrigeration stages are brought online

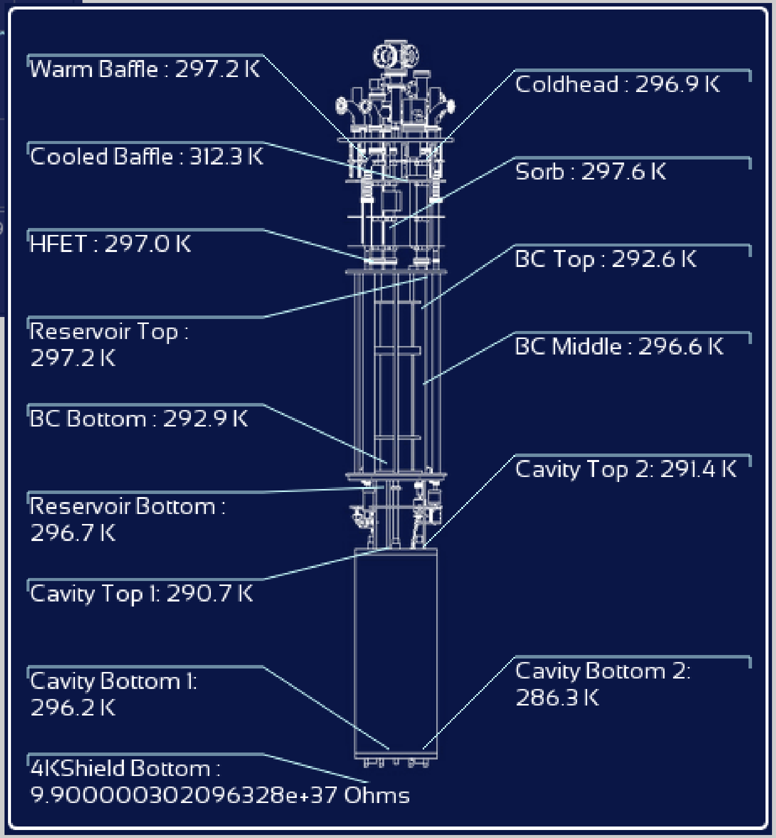




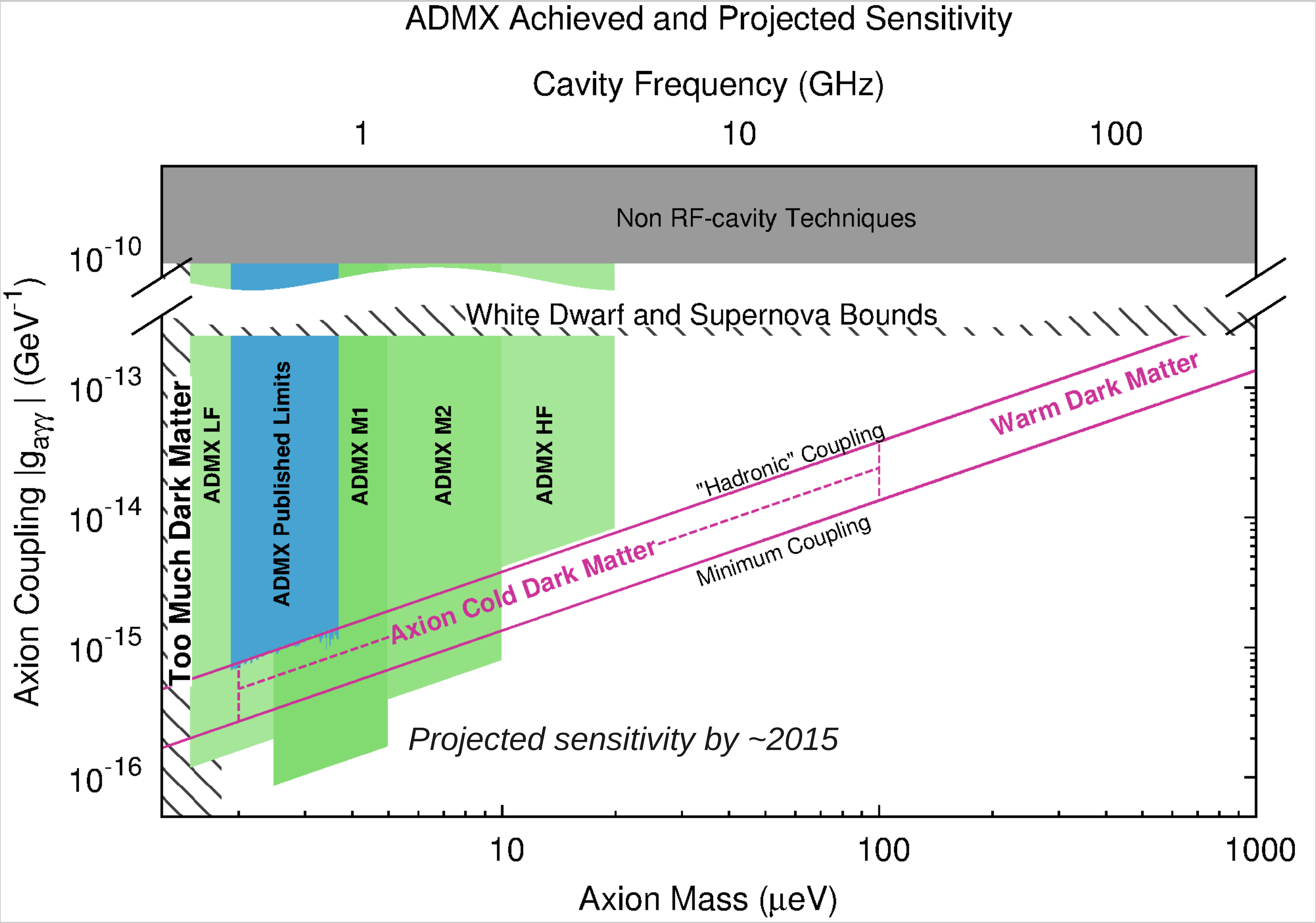


Screenshots from latest 'data challenge'.

We are ready to take science data!



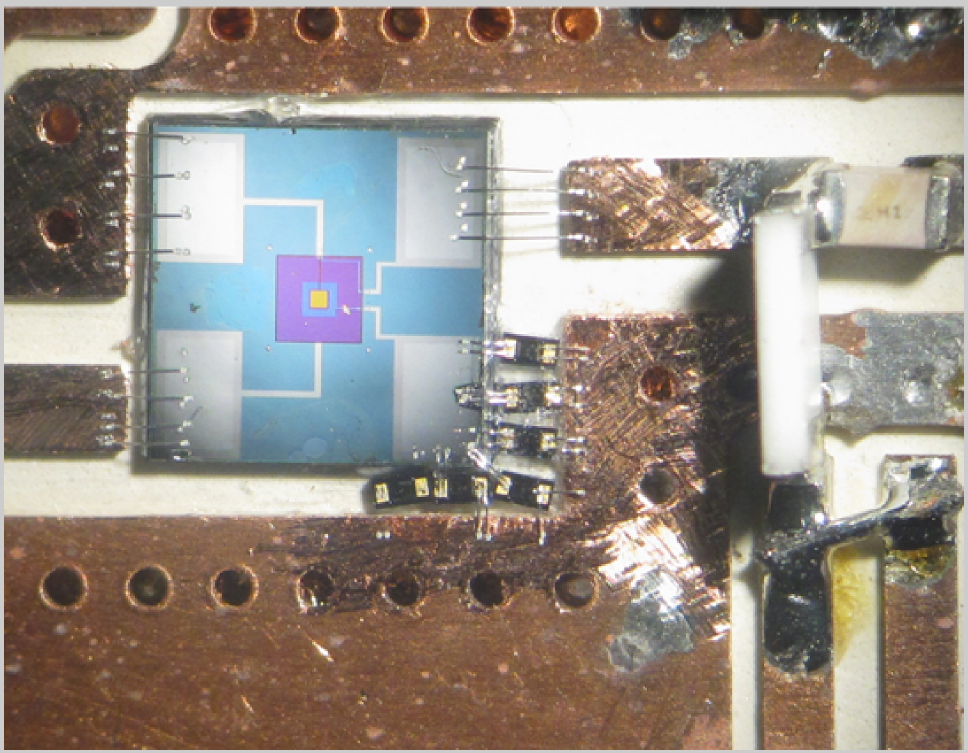
ADMX Near Term Targets

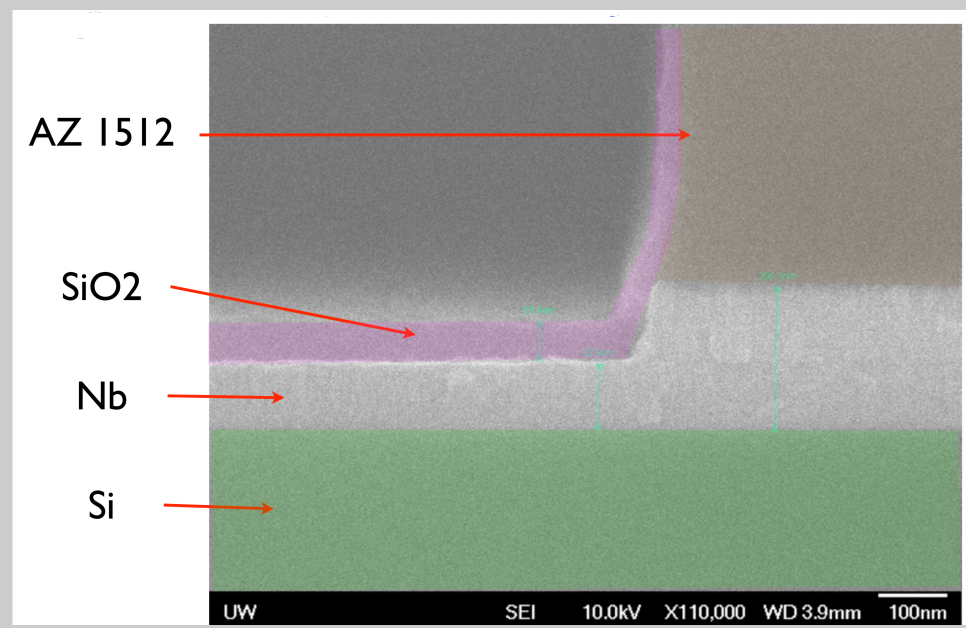


Long Term Goal:
Find or exclude axions in entire plausible mass range

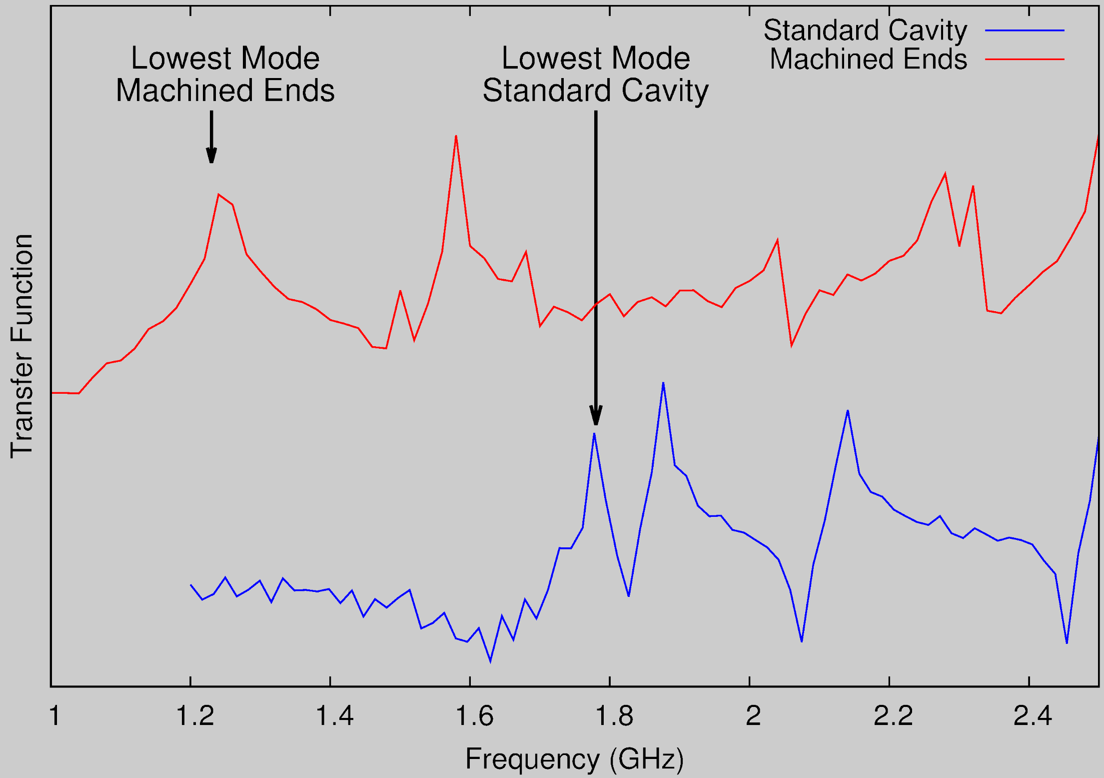
Amplifier R&D

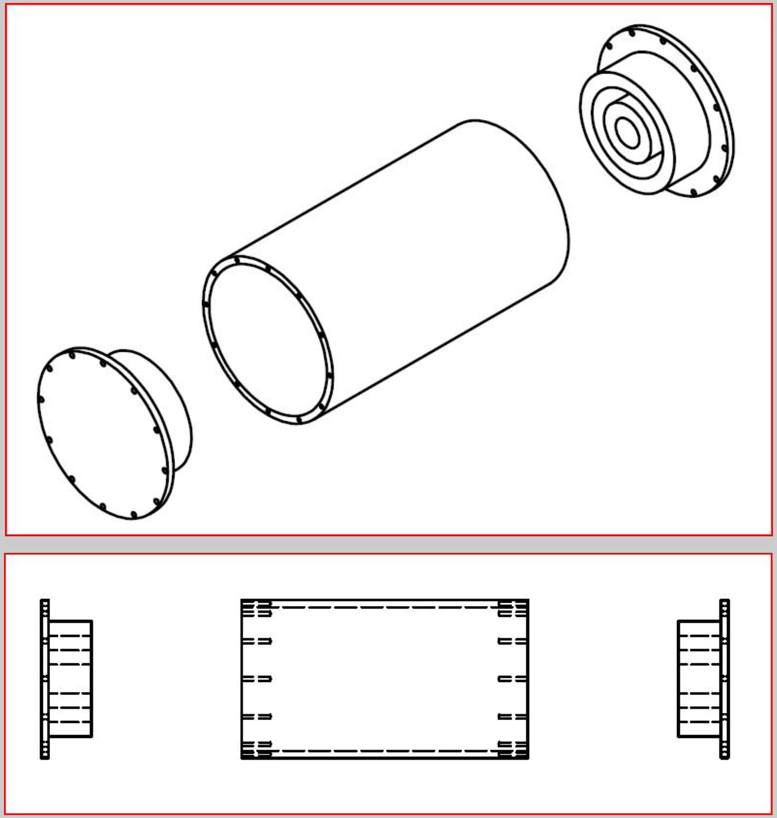
We are developing higher frequency quantum electronics (SQUIDs and JPAs) at Berkeley and UW

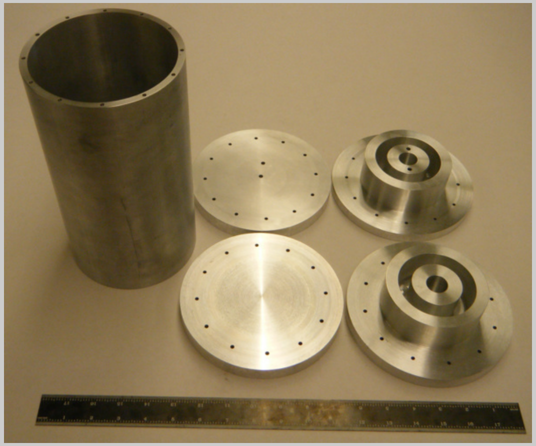




Lower Frequency Cavities





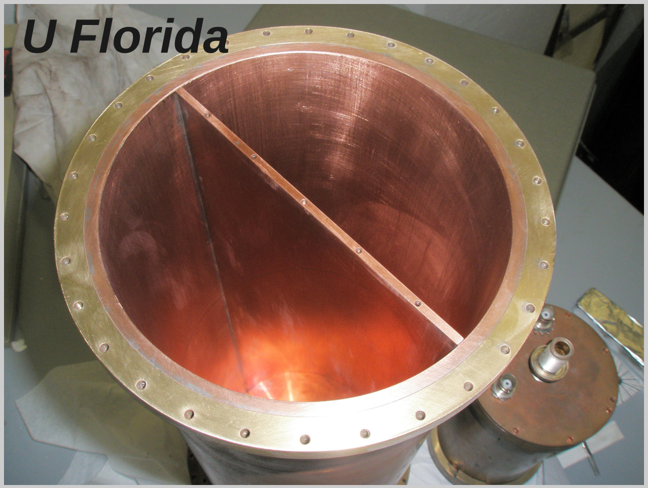


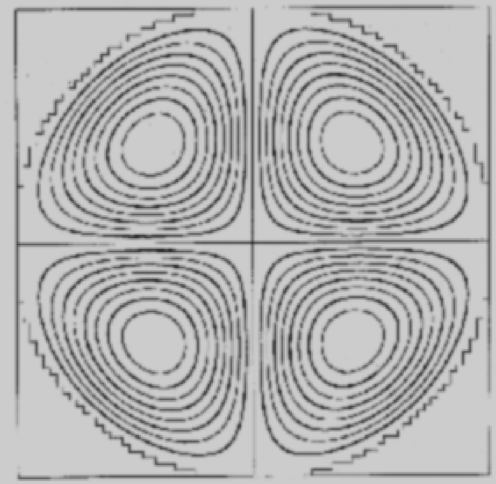
R&D is underway to access frequencies below those of previous cavities

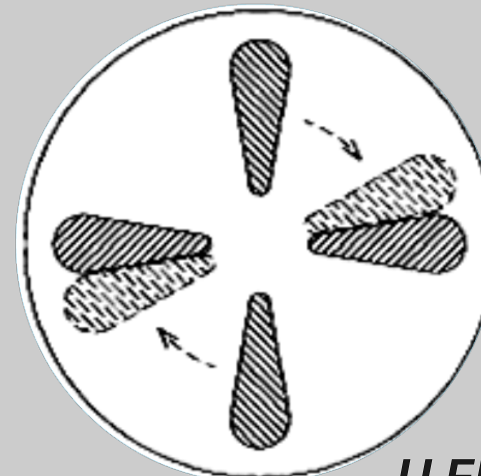
Current work promises factor of two or more frequency reach increase

Higher Frequency Cavities

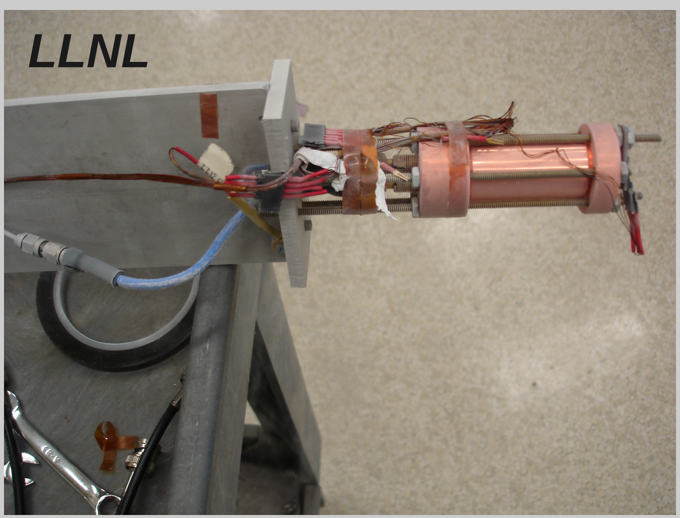
We are developing higher frequency cavity structures

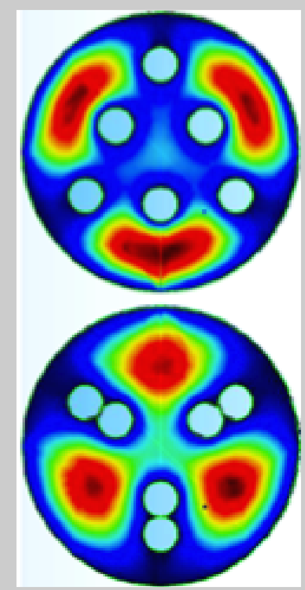






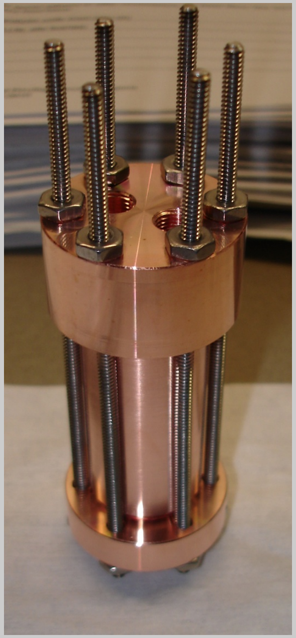
U Florida



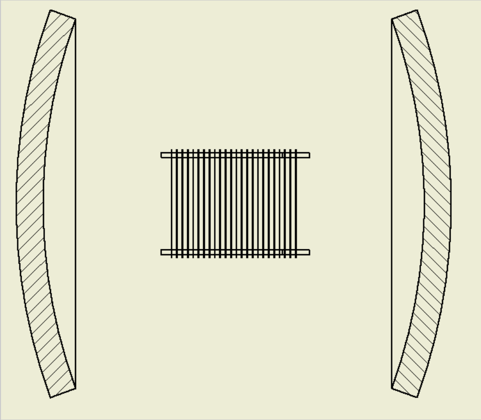


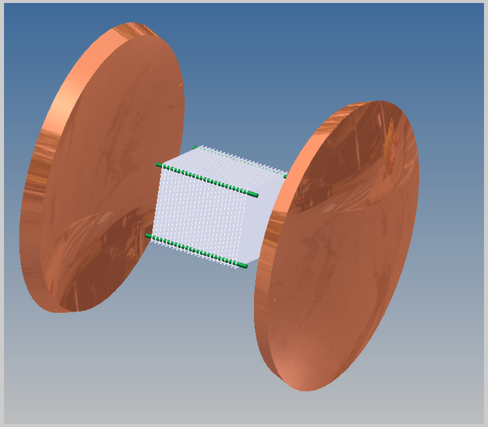
More Exotic Improvements

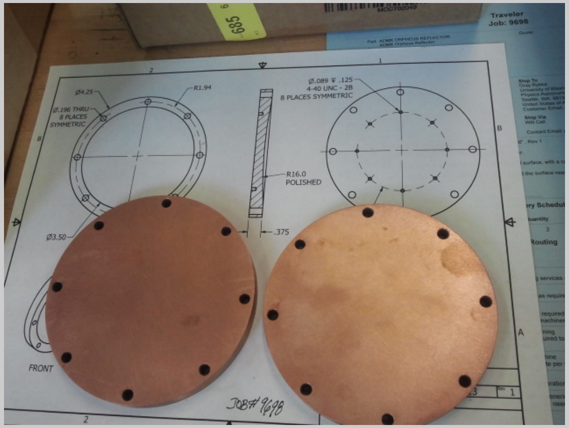
“Hybrid” superconducting cavities may increase Q, and thus increase signal power



Open resonators may be the key to explore axion masses up to meV

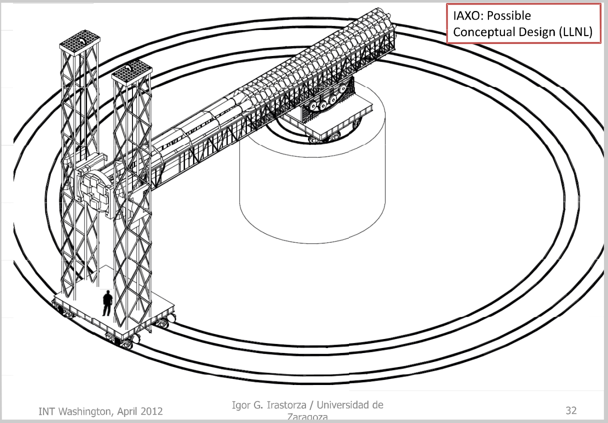






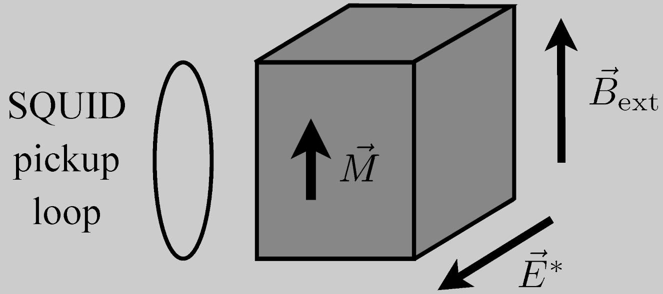
Other Ideas for Axion DM

IAXO: search for solar axions; could find high mass axion, a component of hot dark matter



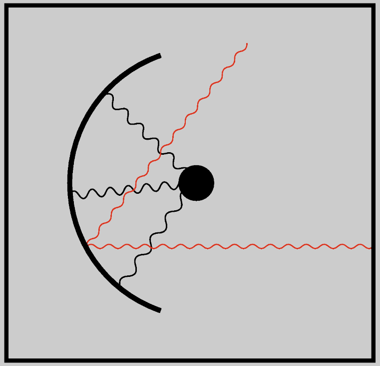
See:
J. Vogel's talk, Tomorrow

Detect CP violation from axion field oscillation to search for ultralow mass axions



See:
Budker et al. arXiv:1306.6089

Focused axion conversion on boundaries



See:
Horns et al. JCAP04 (2013) 016

Concluding Remarks

Axions are a well motivated dark matter candidate

ADMX will explore a significant fraction of likely axion dark matter masses in the near future

Work is underway to explore the entire plausible axion mass range