First Results from Yale 34GHz Cavity Experiment

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For

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Outline

- Motivation
- Experimental setup
  - Cavities
  - Receiver
  - Sensitivity
- New data
- Summary

Why look at 0.1 meV

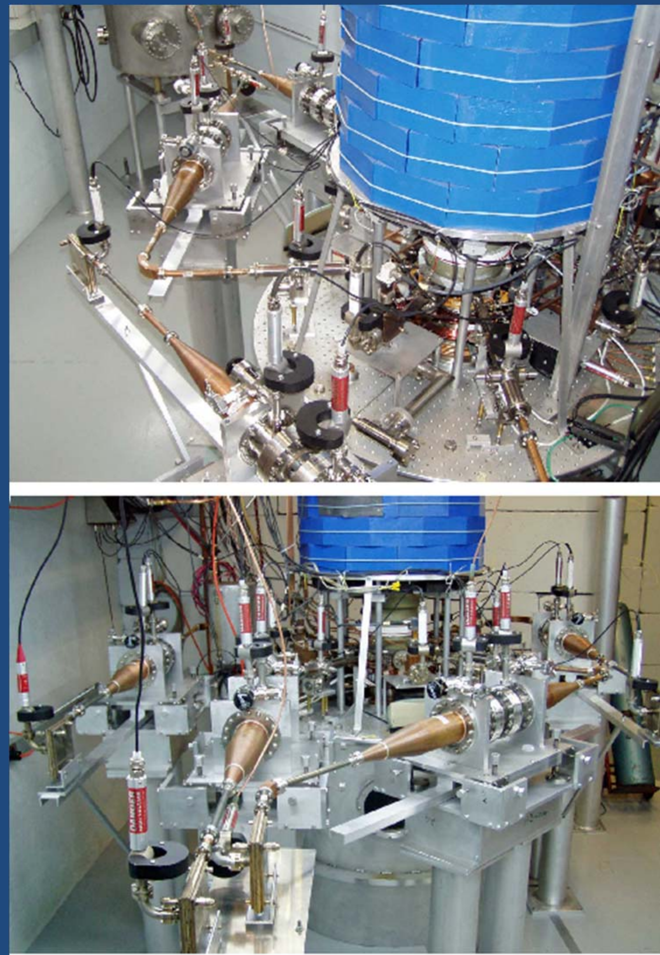
- Several models beyond the Standard Model allow light particles
  - Pecci-Quinn axion (pseudoscalar)
  - Pseudoscalar and scalar fields from string theory
  - Hidden Sector Photons (HSP) from string theory
- Cannot be explored with particles at most accelerators. Thus provides a good complement to the LHC and Tevatron.

Experimental Setup

- Magnicon ~34.29 GHz pulsed power source
- Drive cavity is thermally tuned with H_2O
- Cold (~4 K) tunable frequency signal cavity
- HEMT (~6 K)
- Room temperature triple heterodyne receiver
- Infinium scope
- Laptop to collect data

Magnicon

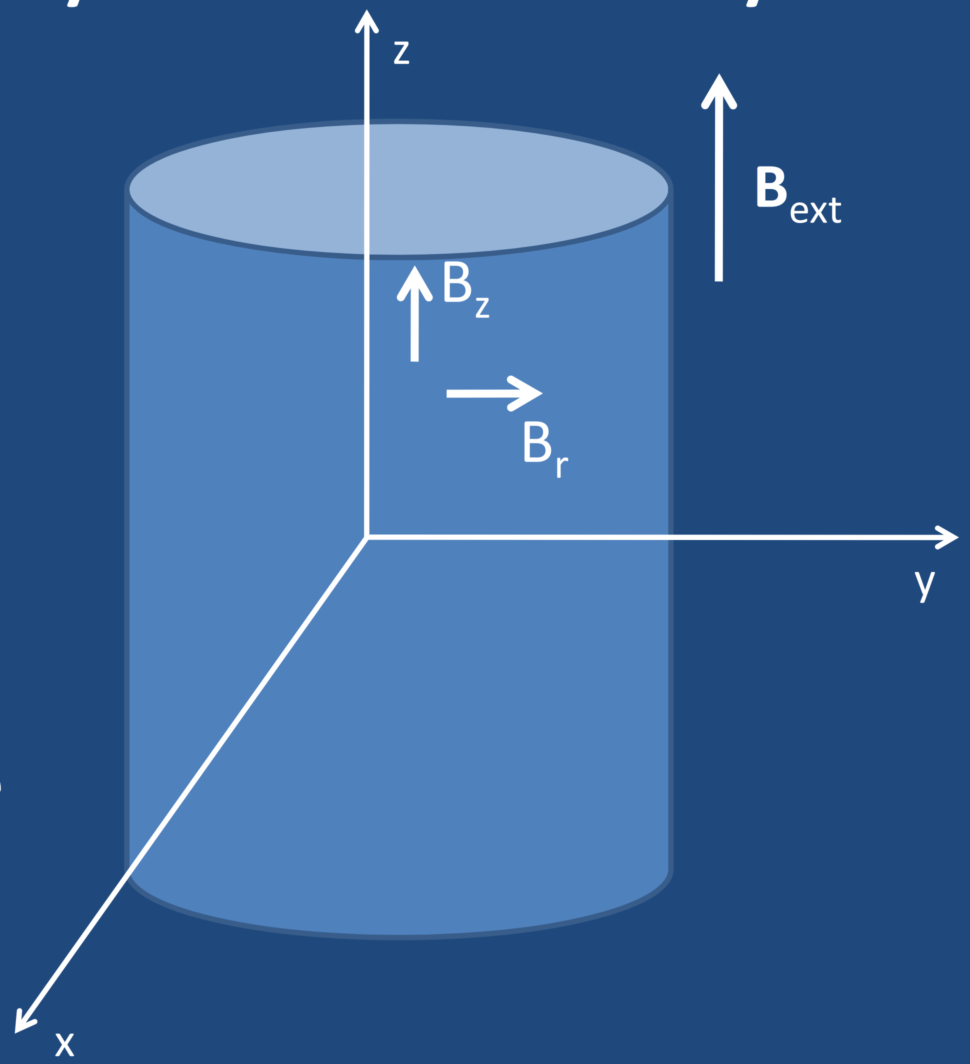
- Output: 1 MW, 1μs pulses at 10 Hz. Bandwidth=1 MHz.
- 500 kV, 215 A e- beam transverse deflection system:
  - Drive cavity (11.4 GHz), 3 gain cavities, and two final cavities.
  - Transverse beam momentum is transferred to RF fields at high efficiency.



O. A. Nezhevenko et al., IEEE Transactions on Plasma Science, 0093-3813/04, 2004.

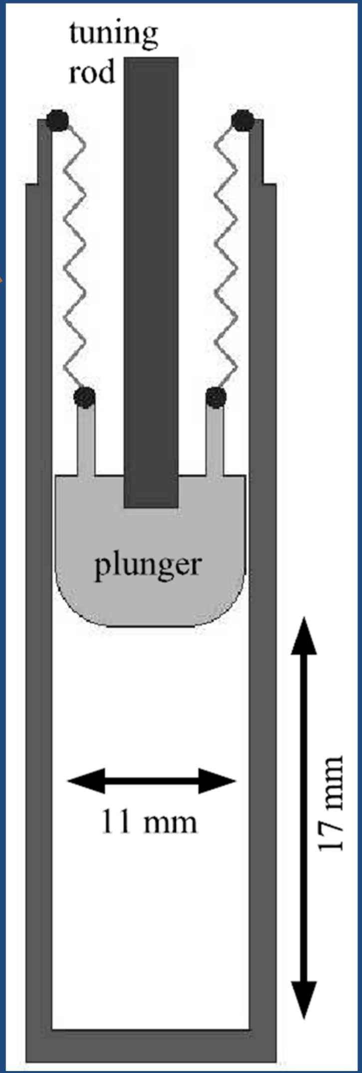
TE_{011} mode for cylindrical cavity

- In μ-wave regime, LSW with resonant cavities becomes 3-D.
- For example, scalar coupling $\mathbf{B}_{ext} \cdot \mathbf{B}_{cav}$ does not include entire $\mathbf{B}_{cav}$ in any TE mode.
- But, pseudoscalar coupling $\mathbf{E}_{cav} \cdot \mathbf{B}_{ext}$ can use entire $\mathbf{E}_{cav}$ in TM_{010} mode.

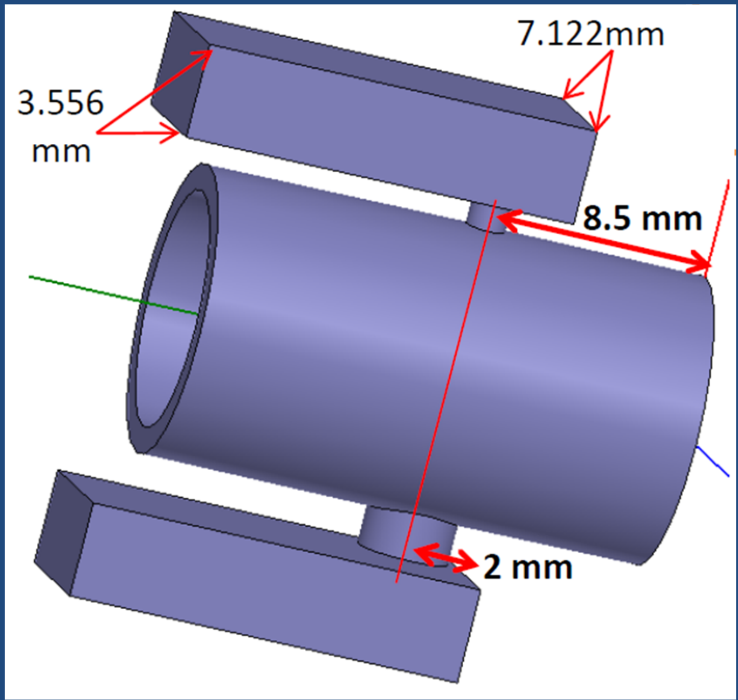


Signal Cavity

- Cu signal cavity resonant at 34 GHz, cooled to T=4 K, tunable, TE011 mode.
- Experiment can be a 2-cavity LSW experiment or a 1-cavity galactic halo ALP measurement.

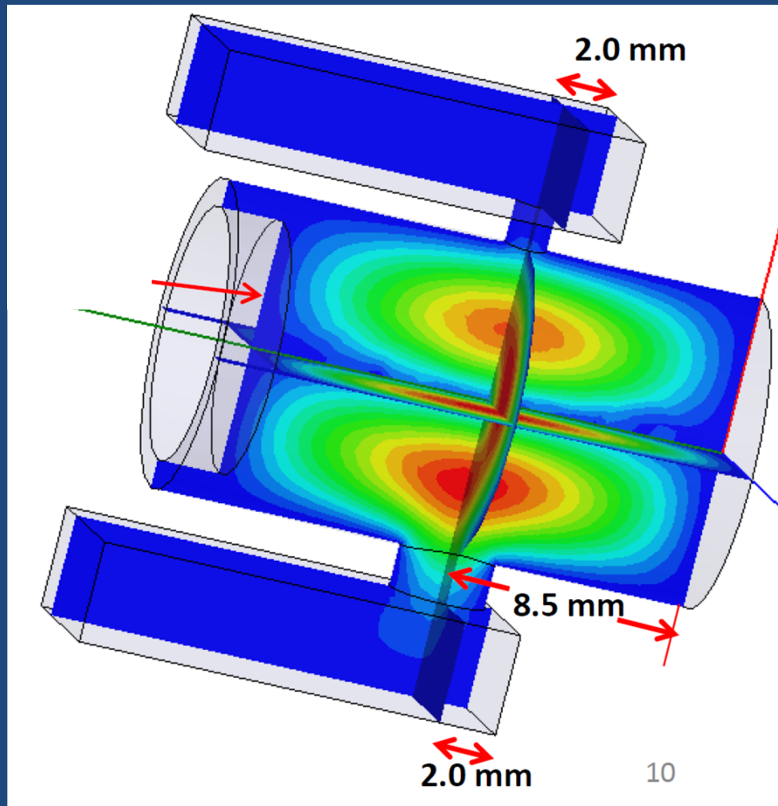


Signal Cavity Field Simulation



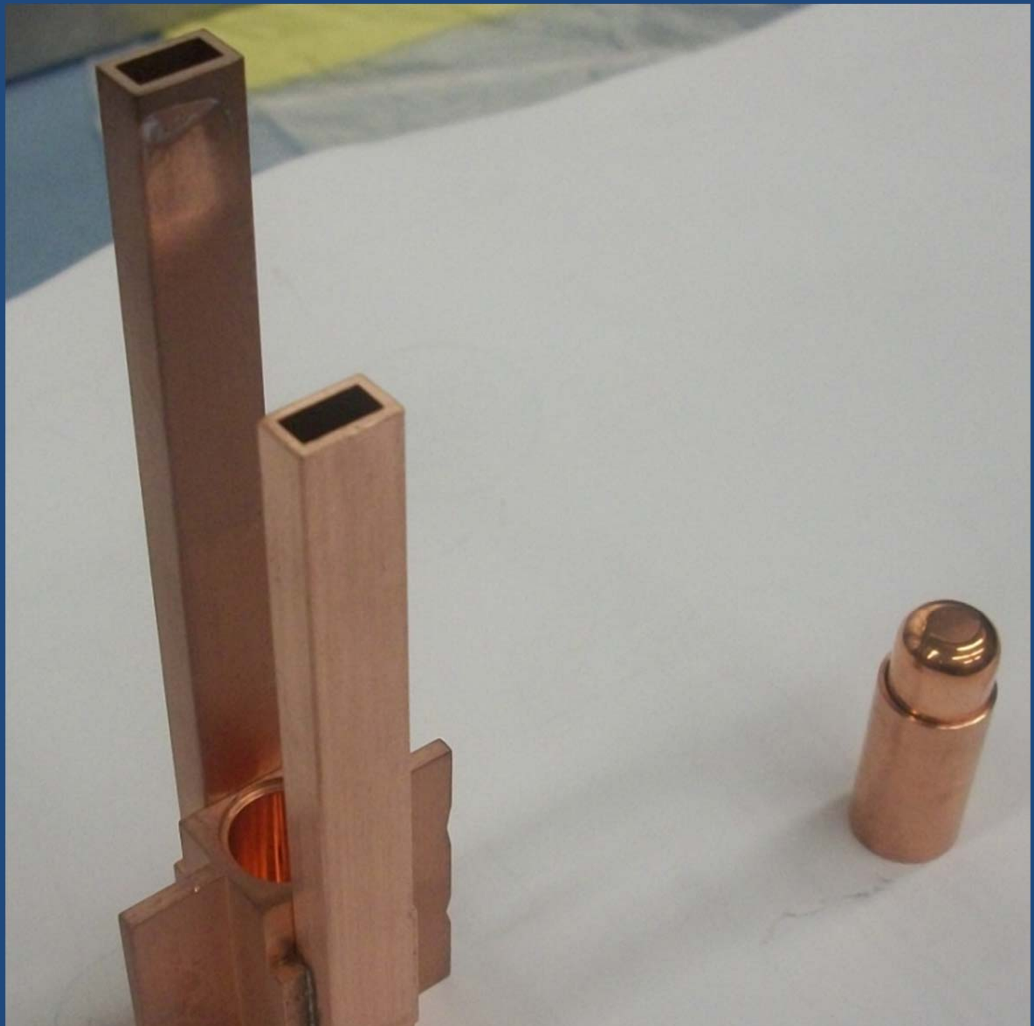
TE_{011} mode:

$E_\Theta = J'_0(kr)\sin(\pi z/L)$

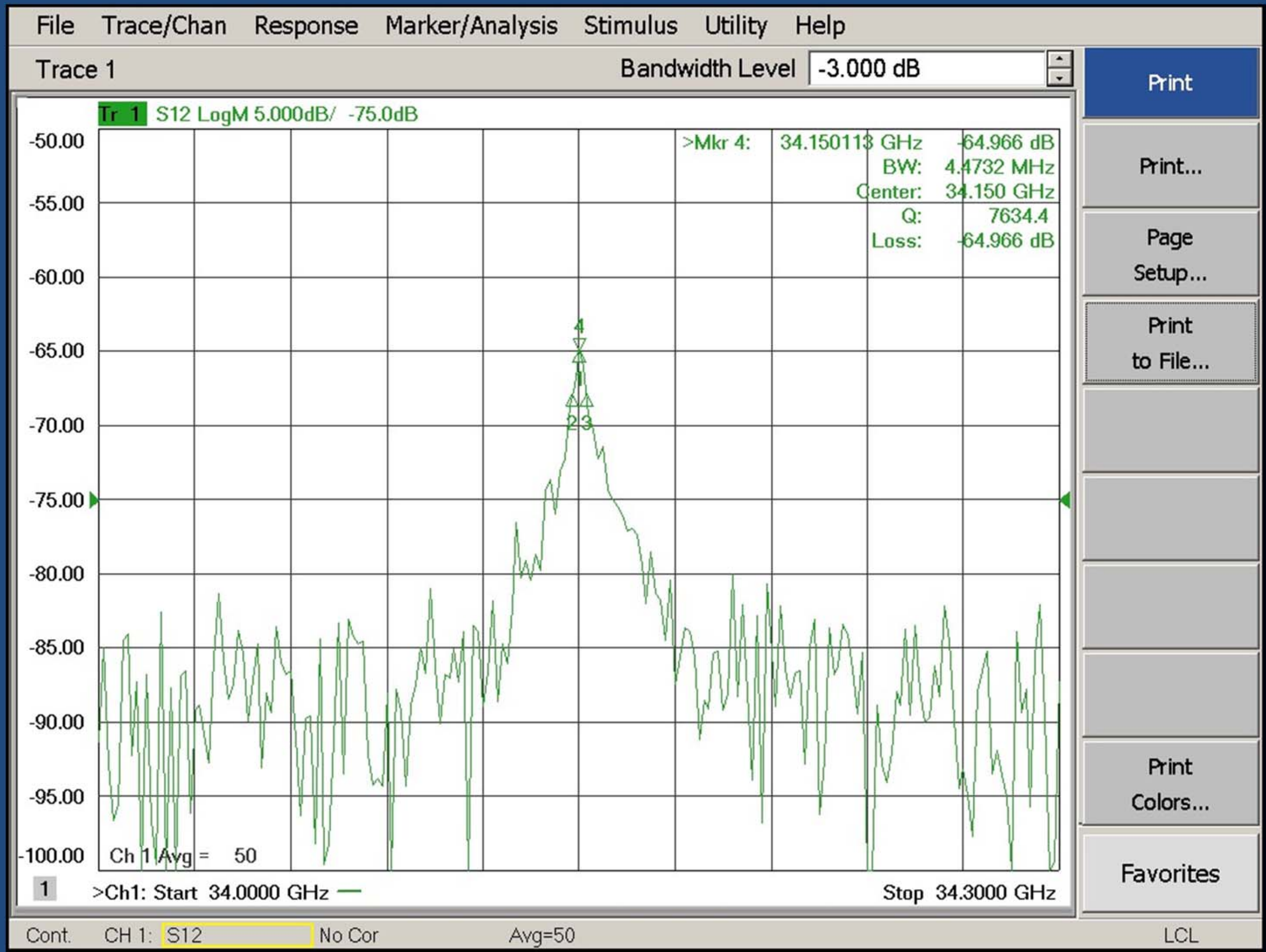


$Q = Q(\lambda/\delta)$, $\delta = (2\rho/\omega\mu)^{1/2}$,

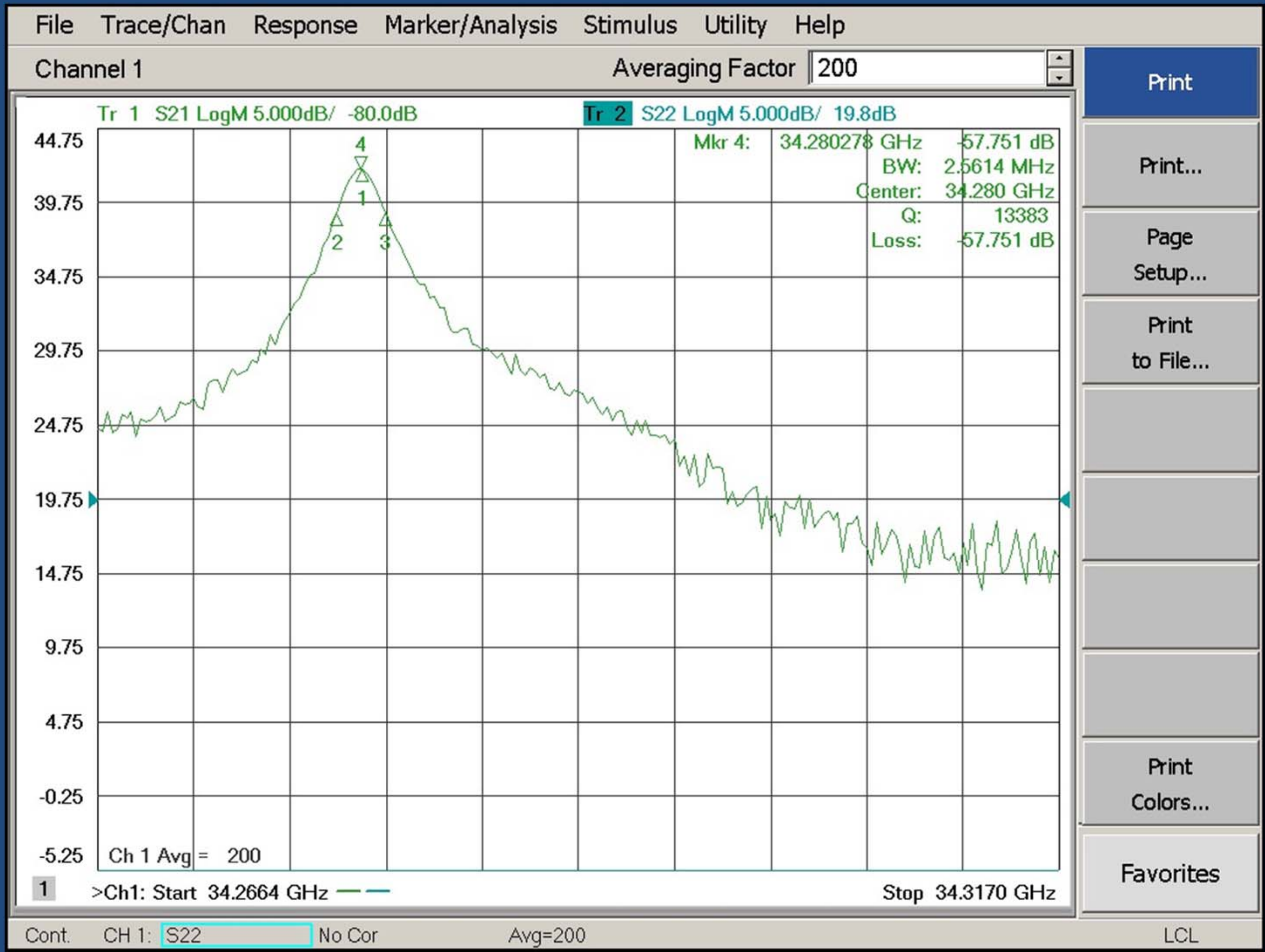
→ Q increases with cooling.



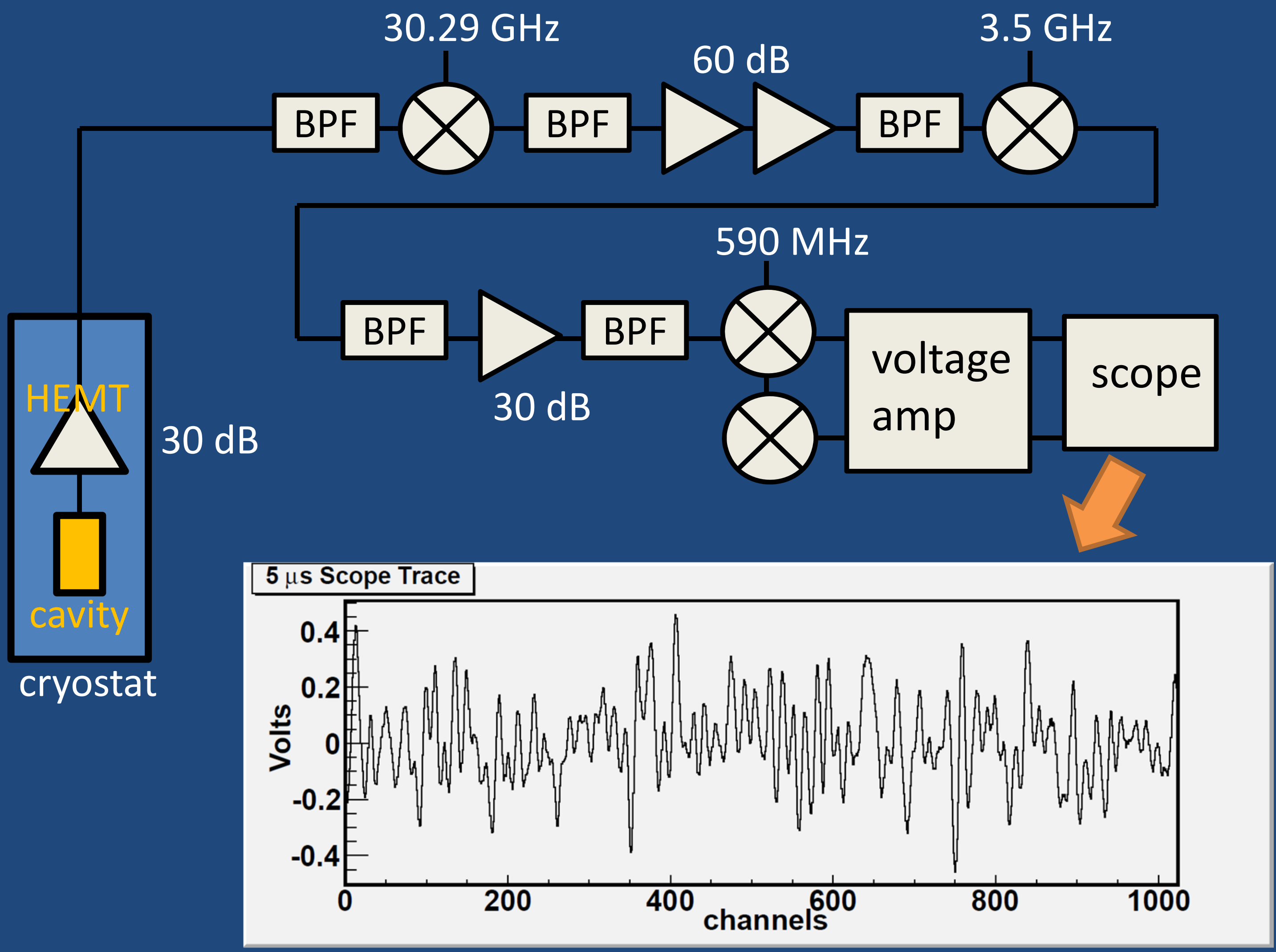
Cavity resonance at room temperature
Q=7500



Cavity resonance at T = 6 K
Q=13383

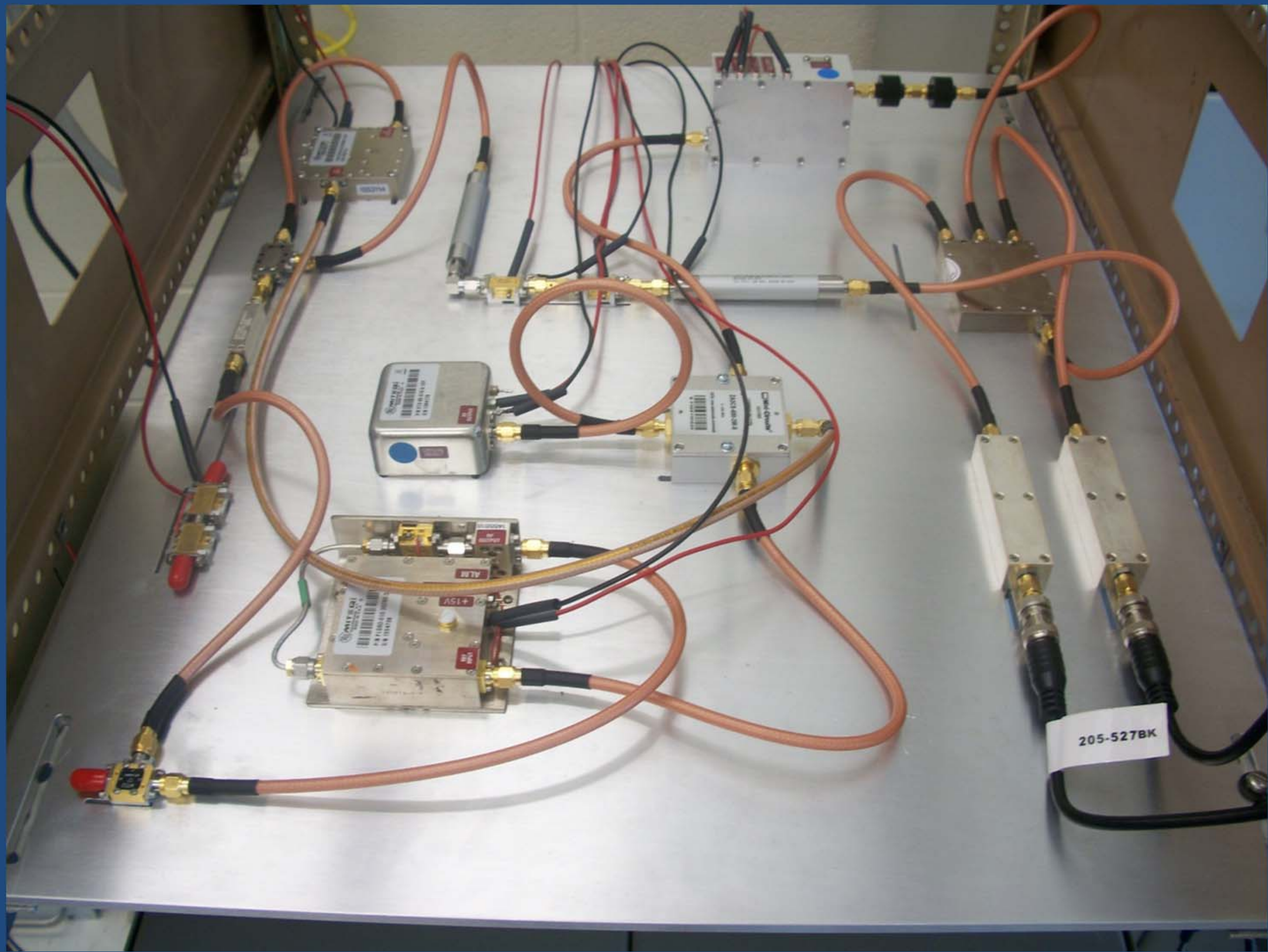


Microwave Receiver

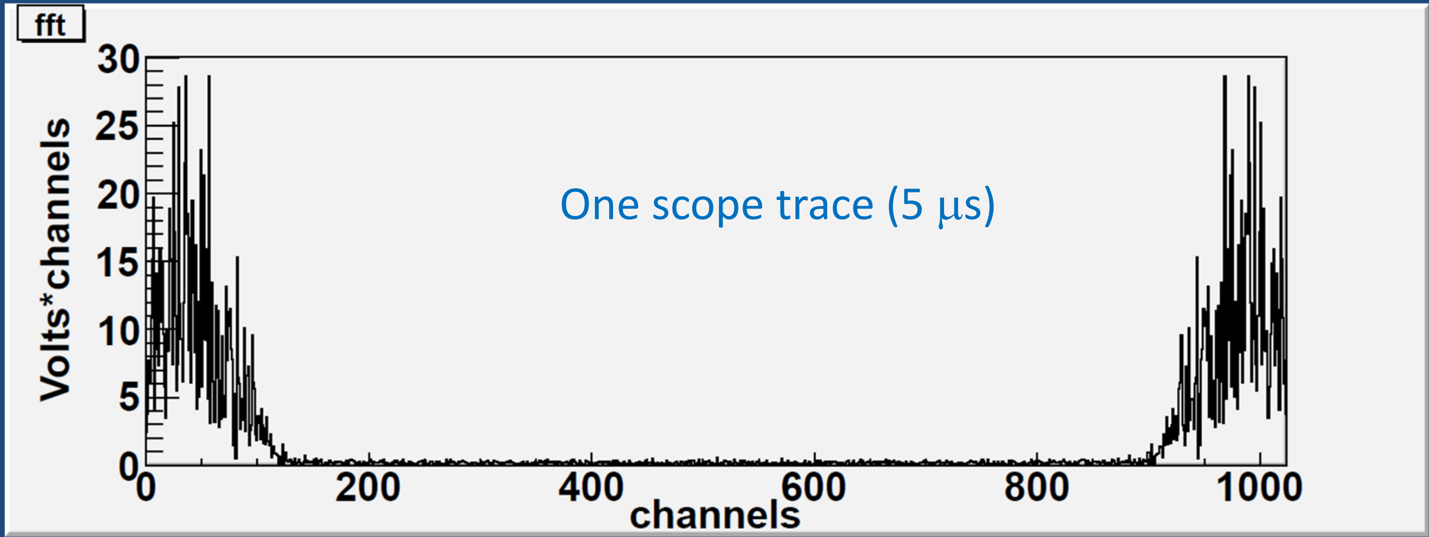


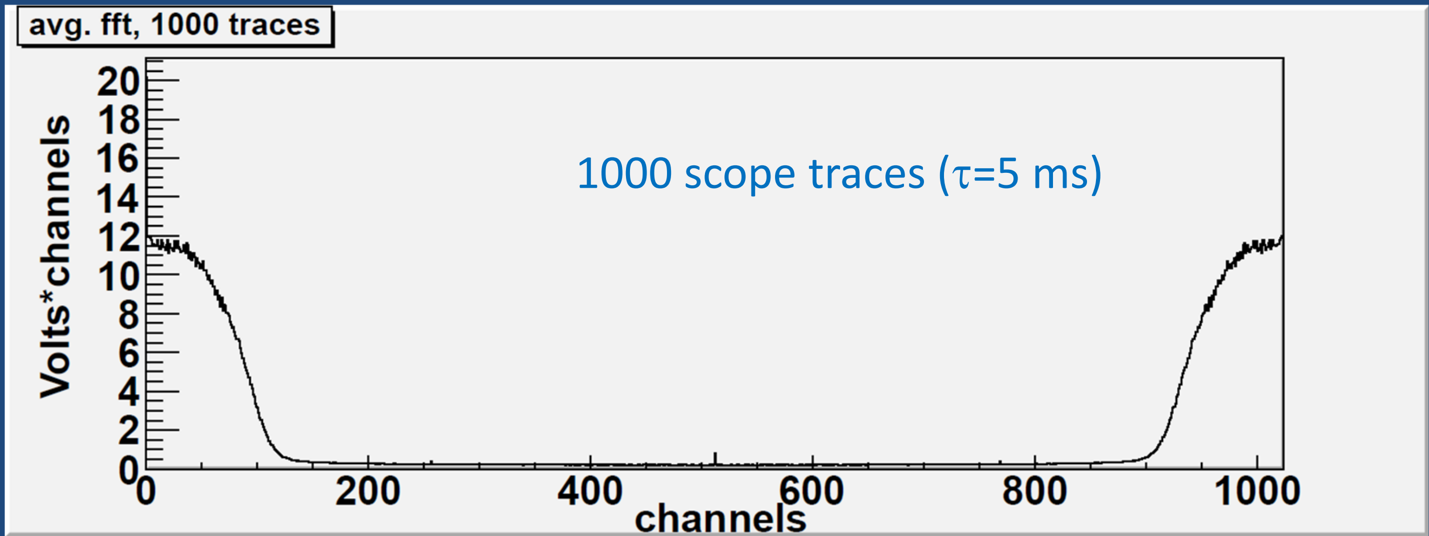
W. Guinon, private communication

Receiver Layout

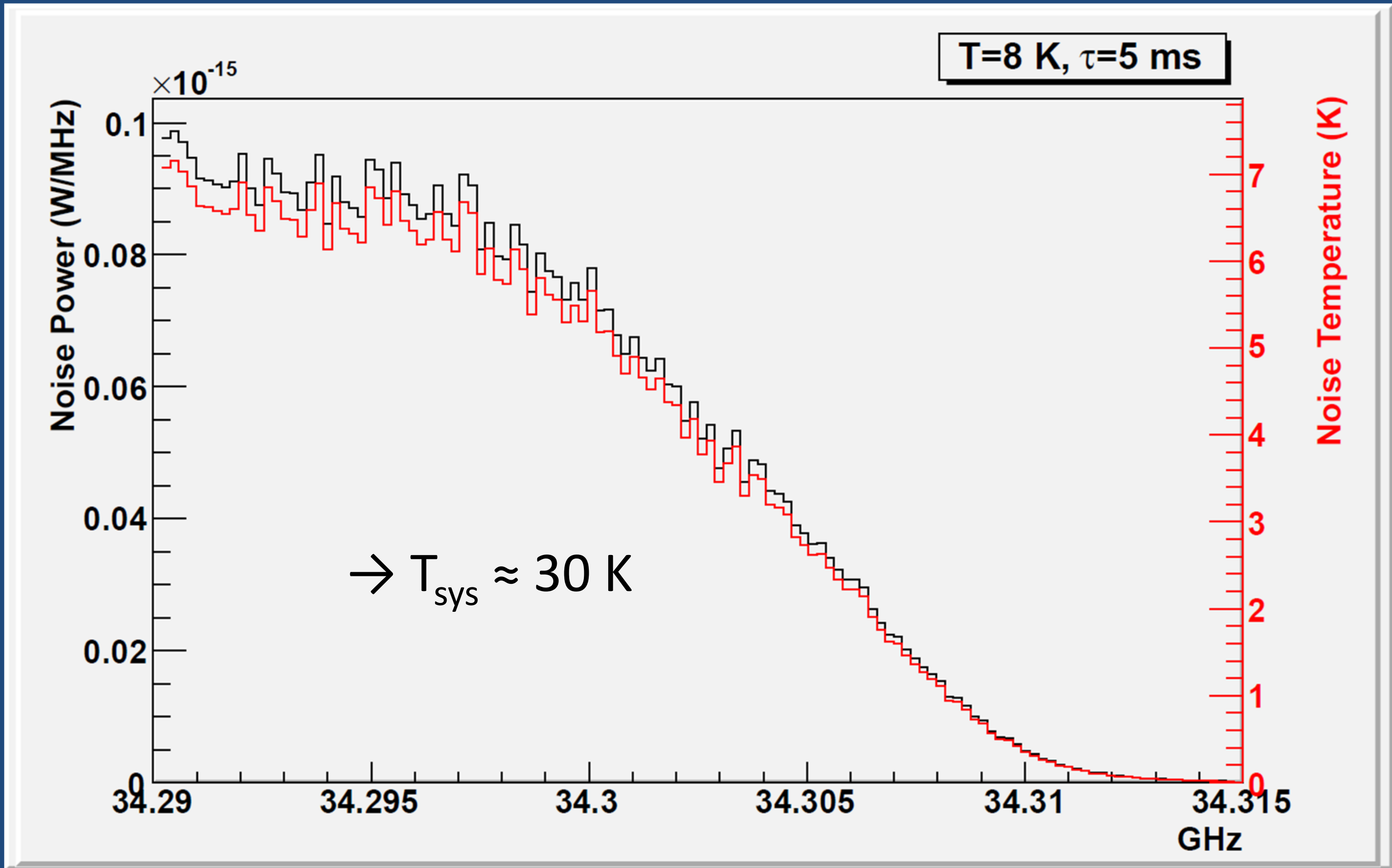


FFT of Oscilloscope Trace





Noise Power Density From Cold 50 Ω Terminator



Sensitivity of Result

Dicke radiometer equation:

$$5\sigma_T = 5\frac{T_{sys}}{\sqrt{\Delta\nu_{RF}\tau}}.$$

$T_{sys} = T_{cavity} + T_{hemt} = 32$ K

$\Delta\nu_{RF} = 1$ MHz, $\tau = 1$ s

⇨ $P_{min} = 2 \times 10^{-18}$ W

Field Overlap Integrals

Galactic halo ALPs

$$C_{lmn} \equiv \frac{1}{V}\left(\int_V d^3\mathbf{x}\hat{\mathbf{B}}_{ext}\cdot\mathbf{B}_{cav}\right)^2$$

ALPs generated in LSW experiment

$$G \equiv \omega_0^2 \int_{V'}\int_V d^3\mathbf{x}d^3\mathbf{y}\frac{exp(ik|\mathbf{x}-\mathbf{y}|)FF}{4\pi|\mathbf{x}-\mathbf{y}|}$$

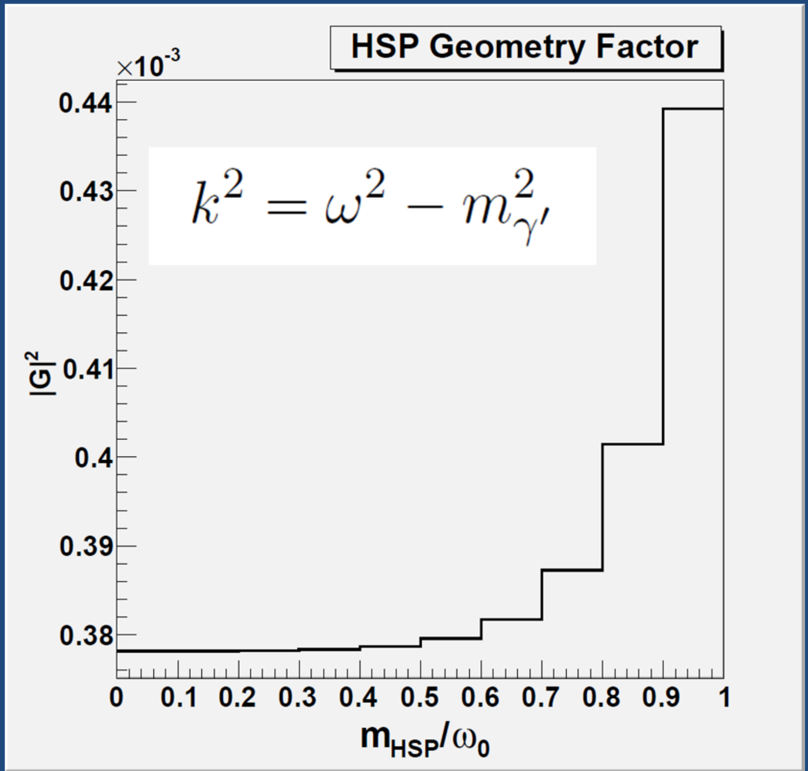
Hidden sector photons in LSW experiment

$$G_{HSP} \equiv \omega_0^2 \int_{V'}\int_V d^3\mathbf{x}d^3\mathbf{y}\frac{exp(ik|\mathbf{x}-\mathbf{y}|)A(\mathbf{y})A'(\mathbf{x})}{4\pi|\mathbf{x}-\mathbf{y}|},$$

H. Peng et al., Nucl. Inst. Meth. A 444, 569 (2000), J. Jaeckel and A. Ringwald, Phys. Lett. B 659 (3) 509, 2008.

Geometry Factor* – hidden photons

$$G_{HSP} \equiv \omega_0^2 \int_{V'} \int_V d^3\mathbf{x} d^3\mathbf{y} \frac{exp(ik|\mathbf{x}-\mathbf{y}|)A(\mathbf{y})A'(\mathbf{x})}{4\pi|\mathbf{x}-\mathbf{y}|},$$



$$k^2 = \omega^2 - m_{\gamma'}^2$$

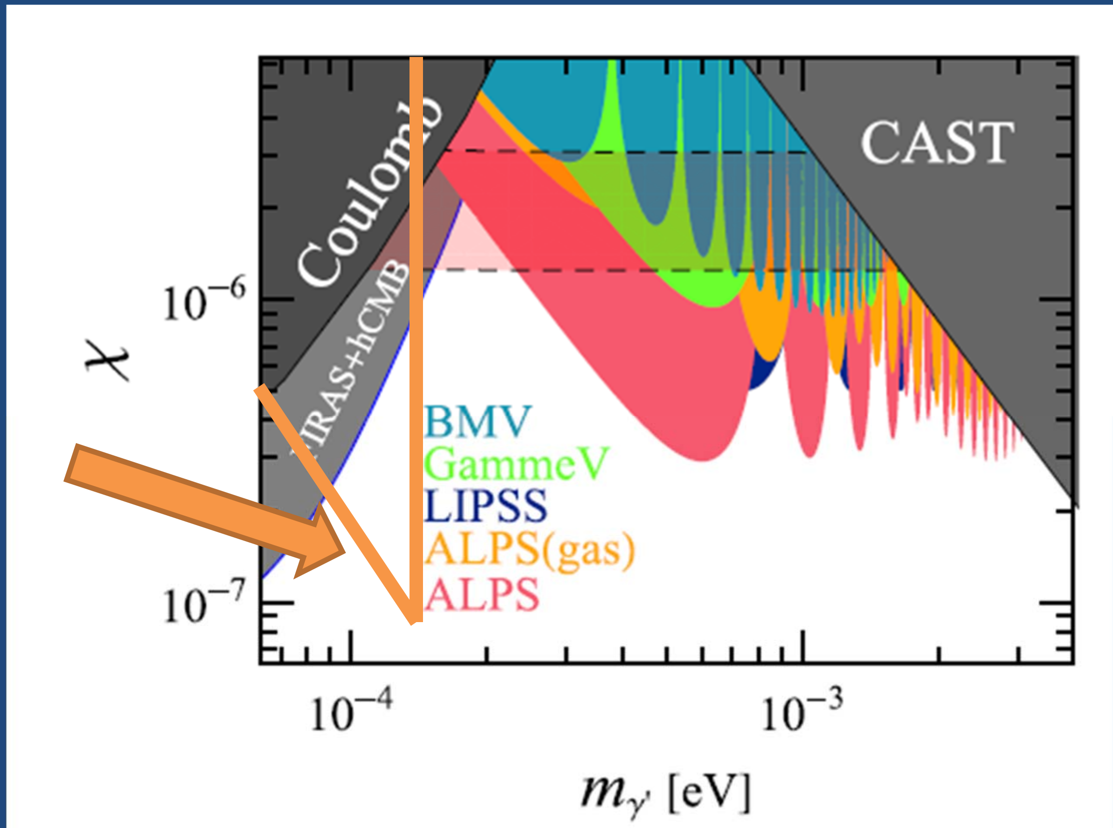
Separates geometry information (e.g. cavity fields and their overlap) from the remainder of the calculation*.

* J. Jaeckel and A. Ringwald, Phys. Lett. B 659 (3) 509, 2008.

Sensitivity to hidden photons

$$P_{trans} = \chi^4 Q Q' \frac{m_{\gamma'}^8}{\omega_0^8} |G_{HSP}|^2.$$

Expected result



* J. Jaeckel and A. Ringwald, Phys. Lett. B 659 (3) 509, 2008.

Sensitivity to scalar halo ALPs

$$P_a = g^2 V B_0^2 \rho_a C_{lmn} Q$$

$$C_{lmn} \equiv \frac{1}{V} \left(\int_V d^3\mathbf{x} \hat{\mathbf{B}}_{ext} \cdot \mathbf{B}_{cav} \right)^2$$

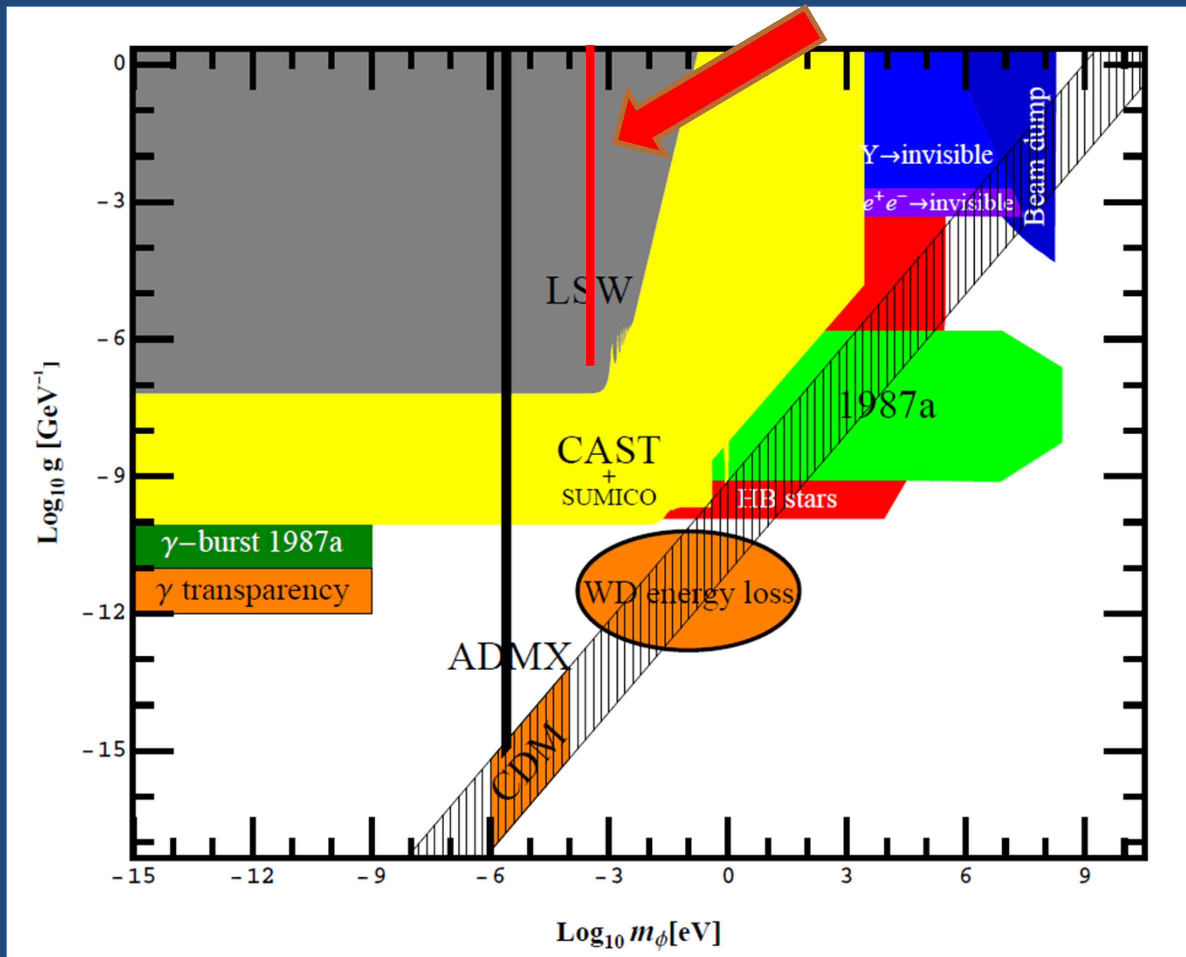
$$\int_V d^3\mathbf{x} (E_{cav}^2 + B_{cav}^2) = 1.$$

Scalar coupling to B_z in cavity (not B_r).

→ $g > 3 \times 10^{-7}$/GeV

P. Sikivie, Phys. Rev. Lett. 51, 1415 (1983).

Axion-like particles

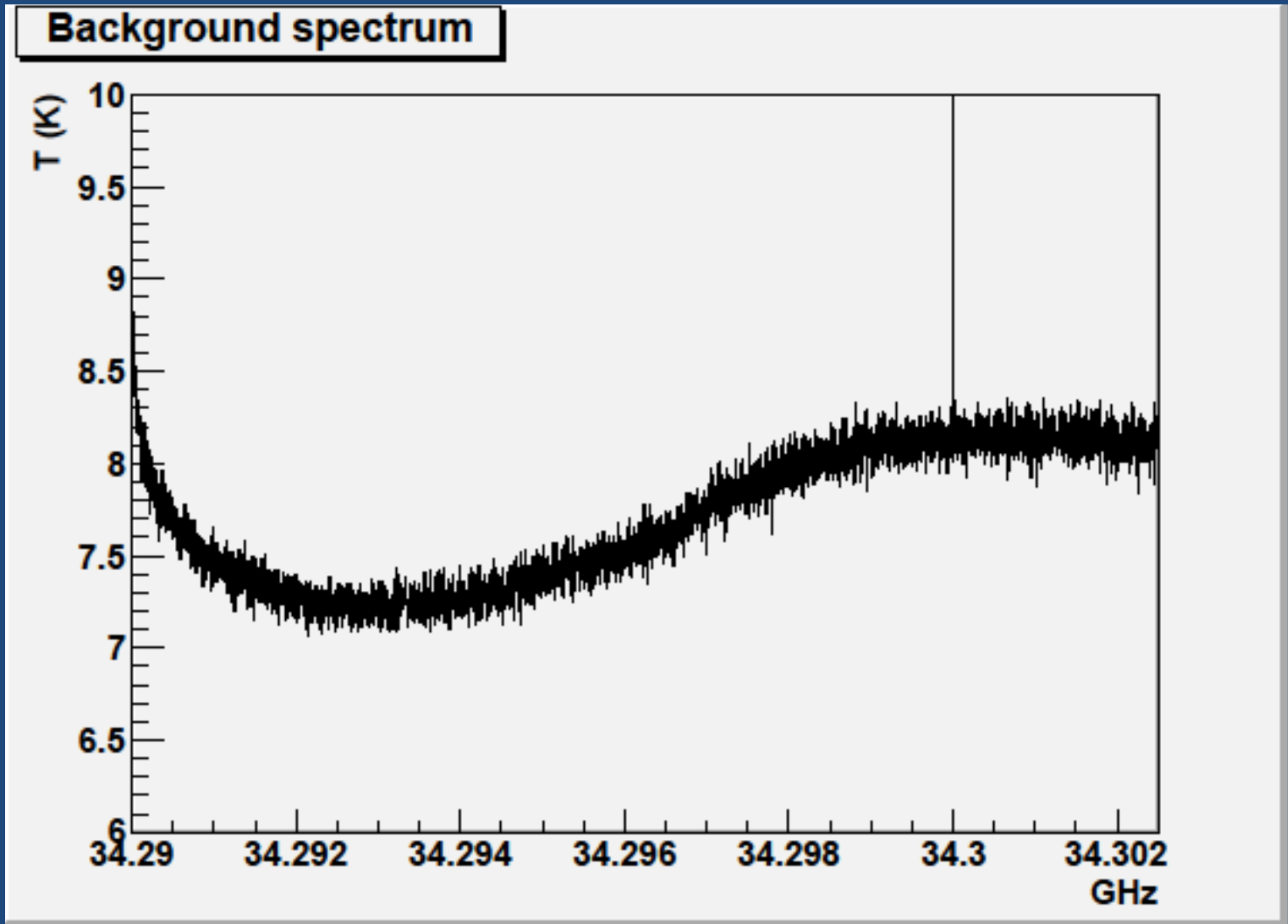


J. Jaeckel and A. Ringwald, Ann. Rev. of Nuc. and Particle Sci., 60, 405, 2010.

New Results

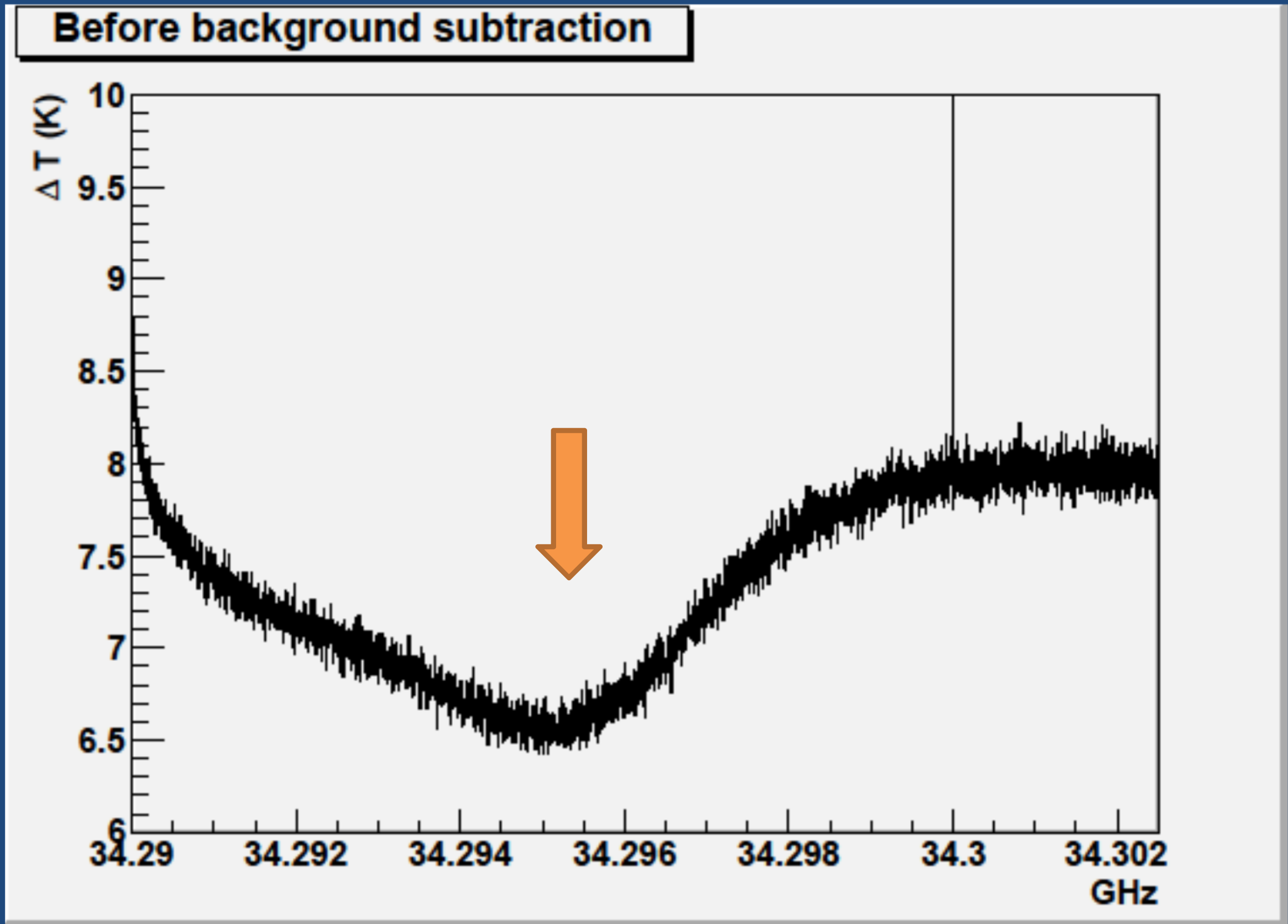
- We have taken our first batch of halo axion data < 1 month ago
- T_{cav} ~ 4.2 K
- B = 7 T
- 2.5 MHz steps 34.2775 – 34.3025 GHz
- Analysis is ongoing

Background Spectra



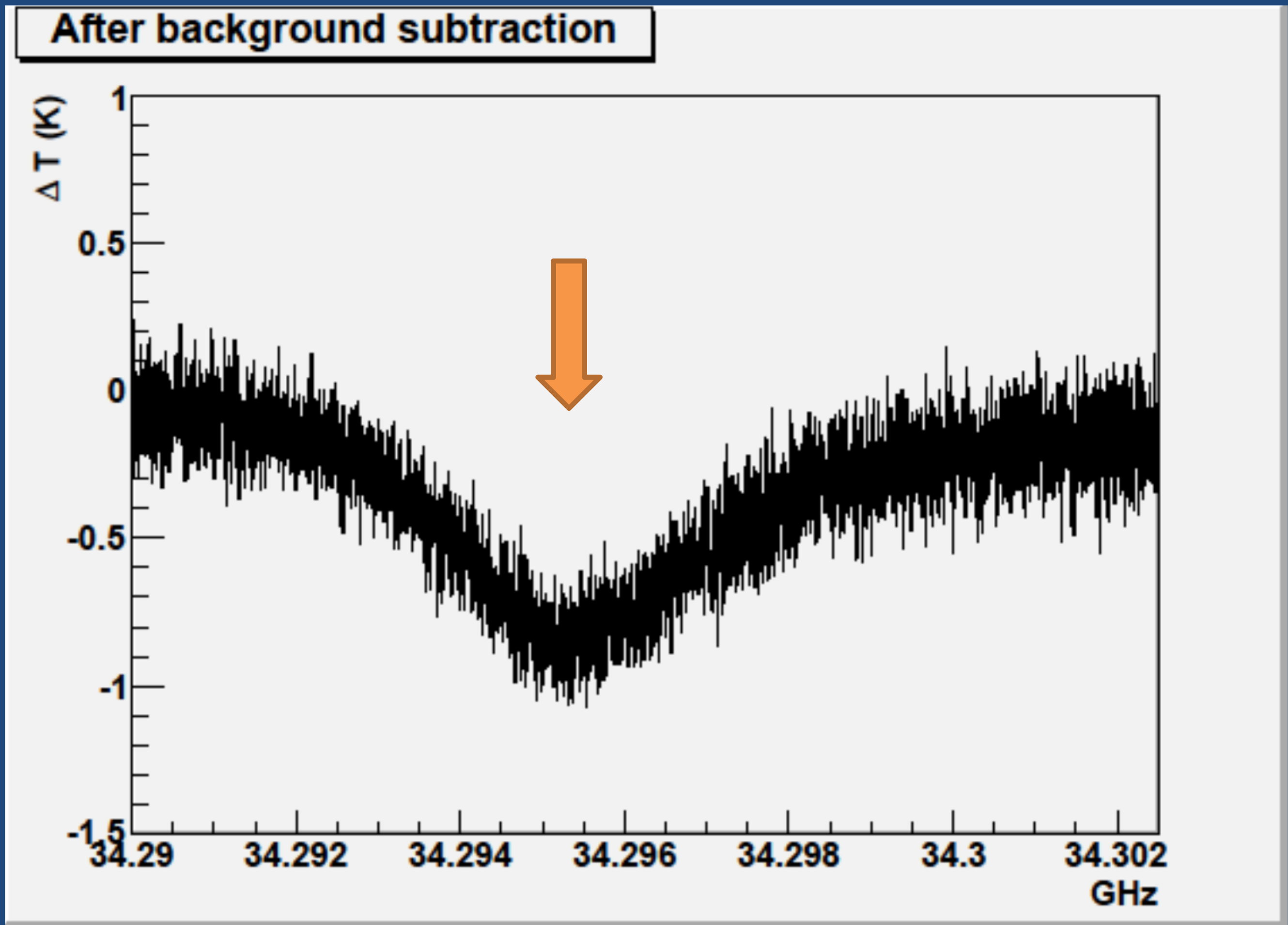
Cavity tuned to 34.37 GHz

Raw Spectrum



Cavity tuned to 34.2850 GHz

Background Subtracted



Cavity tuned to 34.37 GHz

Up Next for Halo Axions

- Take B=0 runs for background subtraction
  - Difference should be flat
- Need better thermal stability
  - Disconnect cryostat space from inside waveguides
  - Run with liquid helium in cryostat
- Finish analysis

Mid-Term Future

- Run with Magnicon for LSW data
  - HSP
  - Scalar axion measurement
- Build TM_{010} cavities
  - Do pseudoscalar axion LSW
  - Improve halo axion sensitivity
- Add the ability to tune the receiver
  - Allows us to widen the halo axion coverage

Summary

- Currently working on the first batch of data for halo axions
- Know how to do first LSW experiments
- TM010 cavity will make halo axion searches more powerful and pseudoscalar axion LSW search possible
- Know how to widen the search range for halo axions

Acknowledgments

The authors are grateful to the ONR for supporting this project.