

Search for Hidden Sector Photons in a Microwave Cavity Experiment

Rhys Povey¹, John Hartnett¹, Mike Tobar¹

¹Frequency Standards and Metrology Group, University of Western Australia, Perth, Australia

DOI: http://dx.doi.org/10.3204/DESY-PROC-2009-05/tobar_mike

In this proceeding we report the first results of a microwave cavity search for hidden sector photons. Using a pair of isolated resonant cavities we look for ‘light shining through a wall’ from photon - hidden sector photon oscillations. Our prototype experiment consists of two cylindrical, copper cavities stacked axially inside a single vacuum chamber. At a hidden sector photon mass of $39.58 \mu\text{eV}$ we place an upper limit on the kinetic mixing parameter χ at 7.8×10^{-6} . Whilst this result is inside already established limits our experiment has great scope for improvement.

1 Introduction

Many theories beyond the standard model predict an extra ‘hidden sector’ of particles which only very weakly interact with standard model matter [1, 2]. The hidden photon is thought to be massive, although very light in the sub-eV range, and able to kinetically mix with the standard photon thereby allowing oscillations between the photon and hidden sector photon [3]. Experimental searches for the hidden sector photon typically employ the ‘light shining through a wall’ (LSW) technique of indirect observation. As its name suggests this approach attempts to detect light passing through an impenetrable wall via a photon - hidden sector photon - photon oscillation. Until now this has only been carried out with lasers [4–13] but here we report the first LSW experiment using microwaves based on the proposal by Jaeckel and Ringwald [14].

2 Theory

To carry out microwave LSW we require two isolated cavities, an emitter cavity and detector cavity, at matched resonance frequencies. The emitter cavity is excited by a signal generator at its resonance frequency and a detection system attached to the detector cavity looks for a signal. The probability of transmission is given by [14]

$$\begin{aligned} P_{\text{trans}} &= \frac{P_{\text{det}}}{P_{\text{emit}}} = \chi^4 Q_{\text{emit}} Q_{\text{det}} \left(\frac{m_{\gamma'} c^2}{\hbar \omega_{\gamma}} \right)^8 |\mathcal{G}|^2 \\ &= \chi^4 Q_{\text{emit}} Q_{\text{det}} \left(1 - \frac{k_{\gamma'}^2}{k_{\gamma}^2} \right)^4 |\mathcal{G}|^2 \end{aligned} \quad (1)$$

where $\mathcal{G}$ is a dimensionless function encoding the geometric setup of the cavities,

$$\mathcal{G}\left(\frac{k_{\gamma'}}{k_{\gamma}}\right) = k_{\gamma}^2 \iiint_{V_{\text{emit}}} \iiint_{V_{\text{det}}} \frac{\exp(i k_{\gamma'} |\mathbf{x} - \mathbf{y}|)}{4\pi |\mathbf{x} - \mathbf{y}|} \mathbf{A}_{\text{emit}}(\mathbf{y}) \cdot \mathbf{A}_{\text{det}}(\mathbf{x}) d^3\mathbf{y} d^3\mathbf{x},$$

and P_{det} and P_{emit} are the power in and out of the respective cavities, χ is the kinetic mixing parameter, Q is the quality factor, $m_{\gamma'}$ is the hidden sector photon mass, ω_{γ} is the angular (and resonance) frequency of the photons, k_{γ} is the photon wavenumber, $k_{\gamma'}$ is the hidden sector photon wavenumber and $\mathbf{A}$ is the normalized spatial part of the resonant electromagnetic gauge field inside the cavities. Calculations of this six dimensional integral had to be carried out numerically. As might be expected $\mathcal{G}$ scales roughly to the reciprocal of separation distance between the two cavities. In our investigation of the probability of transmission and $\mathcal{G}$ for axially stacked cylinders we found that increasingly higher order axial and radial modes were in most cases better but increasingly higher order azimuthal (whispering gallery) modes were worse. To maximize $\mathcal{G}$ in the accessible X-band (8 – 12 GHz) frequency range for our experiment we chose to use the TE_{011} (fundamental transverse electric) cavity mode.

3 Experiment

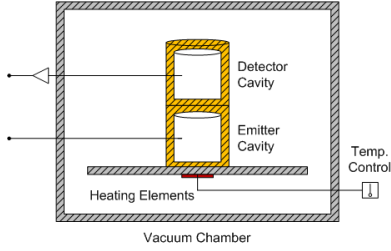


Figure 1: Schematic of the experimental setup.

Our experiment uses two cylindrical, copper cavities with an internal radius of approximately 2 cm and internal length of approximately 4 cm. A single loop probe was inserted in the middle of the side wall of each cavity and aligned and adjusted to maximize coupling to the TE_{011} resonance mode. Operating in the TE_{011} mode the cavities have quality factors of 9060 and 8370, resonance frequencies of 9.58806 GHz and 9.58794 GHz, and resonance bandwidths of 1.01 MHz and 1.17 MHz. The difference in resonance frequencies between the two cavities is 0.12 MHz, well within their resonance bandwidth of ~ 1 MHz.

The cavities were stacked axially on top of each other inside a vacuum chamber and temperature controlled to maintain the resonance frequency match. They were clamped down to provide good thermal contact. Isolation between the cavities was provided only by their individual cavity walls with no extra shielding being employed. As expected microwave leakage was a major problem in this simple setup. A diagram of the cavities in the vacuum chamber is shown in Figure 1.

To excite the emitter cavity a signal generator is used at its resonance frequency. To measure the resulting signal in the detector cavity the microwave circuit shown in Figure 2 is used. The output of the detector cavity passes through a low noise amplifier and is then mixed against a second signal generator set a few MHz off the cavity resonance frequency. This provides a signal at the offset frequency which is put through a low pass filter and preamplifier before being measured by a spectrum analyzer. A diagram of the full system is shown in Figure 2.

Operating the experiment, the detector cavity power output was measured to be 120.35 ± 1.50 dB below the power input of the emitter cavity. This relatively huge signal is most likely

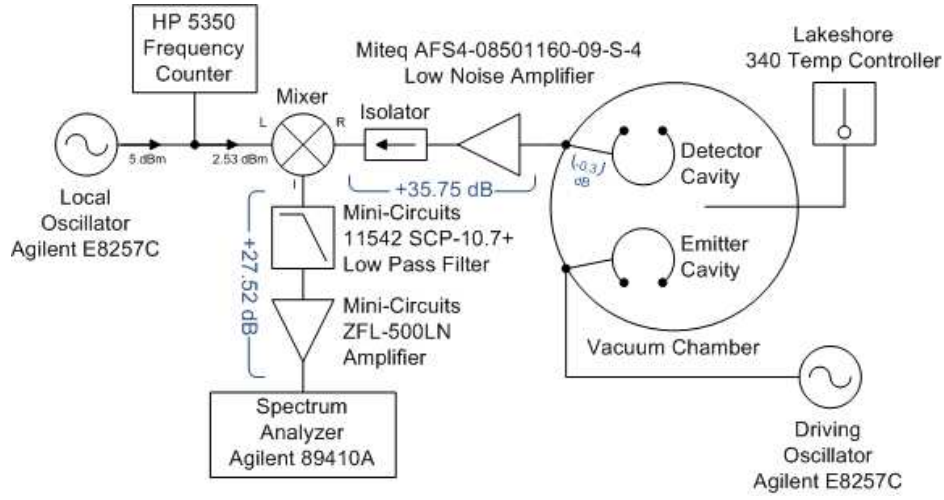


Figure 2: Diagram of the microwave circuit used in our cavity experiment.

due to microwave leakage inside the common vacuum chamber, probably predominately through the necessary pinhole in each cavity for vacuum pumping. Nevertheless by equation (1) we are able to place an upper limit on the kinetic mixing parameter χ from this experiment which is depicted in Figure 3.

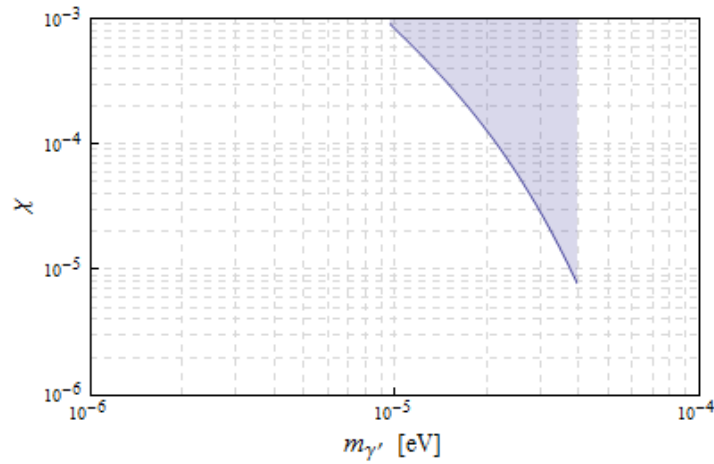


Figure 3: Hidden sector photon parameter space $(m_{\gamma'}, \chi)$ with the blue/gray shaded region excluded by this experiment. The peak occurs at 3.958×10^{-5} eV with $\chi = 7.8 \times 10^{-6}$.

4 Future work

Our results from this prototype experiment are not a betterment on previous hidden sector photon bounds [2, 15, 16], but do show promise for the future of microwave cavity LSW. Great improvements on this experiment can be made and a reduction in the χ limit by multiple orders of magnitude is possible. The two main areas for improvement are microwave leakage suppression and higher Q cavities. By separating our cavities into individual vacuum chambers we can greatly reduce the amount of leakage and hence be able to place a tighter limit on the mixing parameter. This extra separation comes at the cost of reducing $\mathcal{G}$ but this should be outdone by a greater reduction in leakage. We can also use higher Q emitter and detector cavities to improve our sensitivity to χ . However if a moderate Q detector cavity is maintained whilst using a high Q emitter cavity we can avoid the challenge of frequency matching two narrow bandwidth resonant cavities.

References

- [1] S. A. Abel, M. D. Goodsell, J. Jaeckel, V. V. Khoze, and A. Ringwald, JHEP **07**, 124 (2008), arXiv:0803.1449.
- [2] M. Goodsell, J. Jaeckel, J. Redondo, and A. Ringwald, (2009), arXiv:0909.0515.
- [3] L. B. Okun, Sov. Phys. JETP **56**, 502 (1982).
- [4] R. Cameron *et al.*, Phys. Rev. D **47**, 3707 (1993).
- [5] G. Ruoso *et al.*, Zeitschrift fr Physik C Particles and Fields **56**, 505 (1992).
- [6] C. Robilliard *et al.*, Physical Review Letters **99**, 190403 (2007).
- [7] M. Ahlers, H. Gies, J. Jaeckel, J. Redondo, and A. Ringwald, Physical Review D (Particles and Fields) **76**, 115005 (2007).
- [8] A. S. Chou *et al.*, Physical Review Letters **100**, 080402 (2008).
- [9] M. Ahlers, H. Gies, J. Jaeckel, J. Redondo, and A. Ringwald, Physical Review D (Particles and Fields) **77**, 095001 (2008).
- [10] A. Afanasev *et al.*, Physical Review Letters **101**, 120401 (2008).
- [11] M. Fouché *et al.*, Physical Review D (Particles and Fields) **78**, 032013 (2008).
- [12] A. Afanasev *et al.*, Physics Letters B **679**, 317 (2009).
- [13] K. Ehret *et al.*, Resonant laser power build-up in ALPS - a “light-shining-through-walls” experiment, 2009, arXiv:0905.4159v1 [physics.ins-det].
- [14] J. Jaeckel and A. Ringwald, Physics Letters B **659**, 509 (2008).
- [15] E. R. Williams, J. E. Faller, and H. A. Hill, Phys. Rev. Lett. **26**, 721 (1971).
- [16] D. F. Bartlett and S. Lögl, Phys. Rev. Lett. **61**, 2285 (1988).