GammeV: Search for WISPs at Fermilab

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The GammeV experiment has searched for Weakly Interacting Slim Particles (WISPs) and has previously published exclusion plots for axion-like particles and a first exclusion of chameleons that couple to photons. Recently, a new experiment, GammeV-CHASE, has obtained improved preliminary results in the search for chameleons. Members of the collaboration are also involved in R&D in long baseline optical cavities that might be required for a photon resonnant regeneration experiment or a search for holographic noise.

1 Introduction

Physics beyond the Standard Model might include Weakly Interacting Slim Particles (WISPs) that would address fundamental questions such as what is the nature of dark matter or even shed insight into the underlying nature of dark energy. WISPs are a general class of particles that include axions, axion-like particles, hidden sector photons, milli-charged particles, chameleons etc. The GammeV experiment originated in 2007 in order to test an anomalous axion-like particle signal by the PVLAS experiment [1] which was not evident in subsequent data [2]. The GammeV experiment utilized a laser and an accelerator magnet in a light shining through a wall (LSW) [3] configuration where a photon propagating in a magnetic field could oscillate into a WISP, traverse an opaque barrier, and have a small probabilty for reconverting back into a detectable photon. GammeV excluded the WISP interpretation of the anomalous result. Beyond this result, it has been found that the parameter space of a variety of other WISP candidates is both largely unexplored and is accessible by modest experiments employing lasers and possibly accelerator magnets. GammeV data has also been used to set limits on possible hidden sector photons [4]. Further work by the GammeV team has focused on a reconfiguration of the apparatus to be sensitive to chameleon particles including a new result presented here. In order to extend sensitivity for searches beyond what has been achieved, new techniques employing optical cavities are under development.

2 Axion-like particle search

The GammeV apparatus consists of a 3W pulsed Nd:YAG laser frequency doubled to 532 nm shown into the warm bore of a Tevatron dipole magnet operating at 5 T. Two novel aspects have been employed in order to increase sensitivity over the region of interest. A plunger is

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constructed so that it can place the "wall" either in the middle or toward one end of the magnet in order to remove regions of insensitivity of mass where the oscillation probability vanishes. The second aspect is to utilize time correlated single photon counting techniques in order to have high efficiency for signal and very low noise. The chance of a random PMT pulse being in time with a laser pulse is very small compared with the possible rate of regenerated photons. No signal above background is observed and 3σ exclusion limits for the coupling of scalar and pseudoscalar axion-like particles to photons in milli-eV mass region have been published [6] and are consistent with the results obtained by other experiments [7].

Figure 1(a) shows an enhanced LSW experiment that employs phased locked optical cavities on both the generation and regeneration side of the wall [9]. The "**R**esonnantly **E**nhanced **A**xion **P**hoton **R**egeneration" (REAPR) possible project is in an R&D phase to develop the phase locking scheme between the cavities and to explore the achievable finessee, $\mathcal{F}$, of long baseline cavities. The sensitivity to the $g_{a\gamma\gamma}$ coupling constant scales as the fourth root of the product of the two $\mathcal{F}$'s and linearly with the magnetic field length. With at least 12 Tevatron magnets in length and $\mathcal{F} \sim 10^5$, a sensitivity of $g_{a\gamma\gamma} < \sim 10^{-11}$ would be achievable, exceeding current experimental bounds on the coupling of axion-like particles to photons.

R&D on long baseline optical cavities is expected to continue for the next couple of years at Fermilab. During this time, clarification on the required infrastructure to support a long magnet string will be obtained. In the meantime, design work for optical feedback and control for the two phased matched cavities will continue with collaborators at the University of Florida. The R&D on long baseline optical cavities is also relevant at Fermilab for a laser interferometer experiment that might be sensitive to "holographic noise" [10] - a possible jitter in space-time due to Planck scale effects. The status is that a 40m long vacuum system is being constructed in an otherwise unused and vacant beam tunnel at Fermilab. Two service vacuum vessels are connected by valves, bellows, and about 40m of vacuum tubes with a diameter of 6 inches. Baffles have been developed that will reduce the clear apparature to about 4 inches but will greatly reduce the chance of scattered light from adding phase noise into the cavity. A laser table will allow for the launch of a laser beam into one service vessel where the light in vacuum will then move through a power recycling mirror, through one end mirror, down the 40m of length, and reflect upon the end mirror on the far service vessel. Sensitive photodiodes will be employed for monitoring and feedback of the cavity. Specially coated optics with small losses have been ordered. The piezo actuated control system including using a Pound-Drever-Hall locking scheme is also being developed. First results on the achievable finesse of this cavity are expected in early 2011.

3 Chameleon search

Chameleons are WISPs that usually take the form of a scalar particle coupled to the stress energy tensor in a potential such that their properties depend on their environment. In particular, a chameleon acquires an effective mass proportional to its local matter density. The original GammeV apparatus was reconfigured such that a laser is shown through the chamber (no wall) with photons that might oscillate into chameleons and reflect off of the exit vacuum windows or vacuum walls estenially building up a gas of chameleon particles within the vacuum region. The laser is turned off and the PMT is turned on to look for an expontential signal decay above background as chameleons reconvert back into photons resulting in a detectable afterglow.

GammeV searched for chameleons and no afterglow was observed. Fig. 2 shows the exclu-

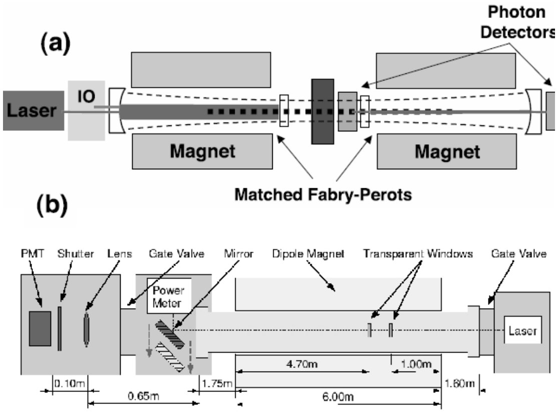

Figure 1: Schematic of the (a) resonnant regeneration light shining through a wall proposal and (b) the GammeV-CHASE experiment.

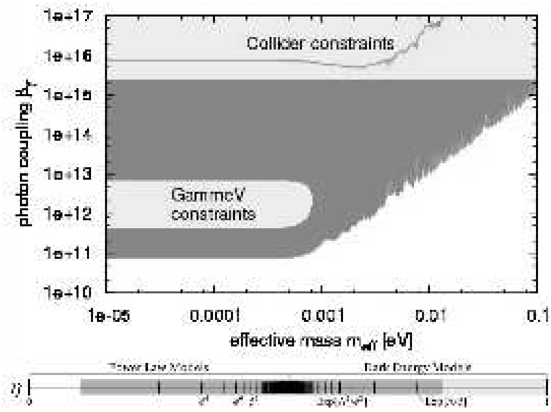

Figure 2: (a) The exclusion region of the coupling normalized to the Planck mass to photons versus the effective chameleon massas published for the GammeV reconfiguration (small region) and the results from GammeV-CHASE.

sion region in the chameleon coupling to photons vs effective chameleon mass obtained under the assumption that the chameleon potential had a characteristic mass dependence on matter density $m_{eff} \propto \rho^{\alpha}$ with $\alpha > 0.8$ [11].

A new effort, **GammeV - CHASE** (**CH**ameleon **A**fterglow **SE**arch), has been mounted during the past year. In this reincarnation, shown in Fig. 1(b), improvements to the original chameleon search have been addressed. Data taking at reduced magnetic field allows for a probe for very strong chameleon couplings to photons. A lower noise PMT helps improve the sensitivity for weak couplings. A "dish rack" that holds optical windows such that the 6 m magnetic field region is divided into regions of approximately 4.7 m, 1.0 m, and 0.3 m, probes higher effective masses. Finally, removing a mechanical pump and utilitizing very low vacuum enabled by cryopumping allows for sensitivity of an extended range of $\alpha > 0.1$ such that potentials consistent with various chameleon dark energy models can be probed [12].

For both scalar and pseudoscalar configurations, data was recorded at magnetic fields from 0.05 T to 5 T in science runs. A laser-on time of 10 minutes was followed by a rapid transition using gate valves and shutters to a laser-off period when the PMT was exposed to the apparatus to search for afterglow. During this $\sim$ 15 min period, the shutter was alternatively opened and closed in $\sim$ 15s periods to allow for a background subtraction. For small couplings to photons, longer runs at the maximum field strength were employed. Two runs for each of the polarizations consisted of approximately 5 hours of filling and 45 minutes of data collection. Calibration runs are acquired before and after science runs. These runs have no magnetic field and showed two systematic effects. The first was a 1.15 ± 0.08 Hz of photons present in the shutter open data which is thought to be dominated by small light given off of ion pumps (note ion gauges, which give off quite a bit of light, are turned off during the data collection periods). This small effect demonstrates the ability of the apparatus to be sensitive to a small rate of photons at a level of $\sim$ 1 Hz. The second systematic effect has been dubbed "orange glow" as it appears when using several 40nm-wide orange wavelength filters. The glow is observed as a steeply falling rate of excess photons present shortly after the laser is turned off. The excess rate after the laser is turned off has most of the rate disappearing after a few 10s of seconds; however, a small residual amount lasts beyond 120s. The rate depends heavily on temperature with an initial amplitude of several hundred Hz when the magnet and cold bore are near 4K, a few 10s of Hz when the magnet is cooled to liquid N_2 temperatures, and just a few Hz when the magnet is at room temperature. The working assumption is that impurities in the dish rack windows get optically excited or other phosphoresent contaminates are present despite no evidence in RGA scans of our vacuum. Further investigation will continue and since this observation at no magnetic field is not consistent with a chameleon, limits are derived from a non-observation of excess rate after these two systematics are subtracted. Figure 2 shows the preliminary exclusion region for the photonic coupling versus effective mass. An exclusion region of the matter coupling versus photonic coupling for a variety of potential models has also been obtained [13].

4 Conclusions

A new research program at Fermilab has obtained published results for axion-like particle and chameleon searches. Next generation experiments have started or are undergoing R&D. The possibility that WISPs or other phenomenon might be observable using relatively inexpensive experimental optical set-ups allows for searches of physics beyond the Standard Model. Who knows, such crazy experiments might just reveal a new weirdness of nature.

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