GammeV: Laser Experiments at Fermilab for WISPs and Other Effects

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The GammeV and GammeV-CHASE experiments have searched for Weakly Interacting Slim Particles (WISPs) and have published exclusion plots for axion-like particles and chameleons that couple to photons. R&D continues in long baseline optical cavities that might be required for a axion 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 address 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 (**Gam**ma to **m**illi-**eV**) experiment originated in 2007 in order to test a positive anomalous axion-like particle interpretation of the PVLAS experiment which was not evident in subsequent data [1, 2]. The experiment was also motivated as it was realized that the milli-eV scale appears naturally in a see-saw between the electroweak and Planck scales, neutrino mass differences, the dark energy density, and the possible mass for certain dark matter candidates. GammeV excluded both a scalar and pseudoscalar axion-like particle interpretation of the anomalous PVLAS result setting a limit of around 3.1×10^{-7} GeV^{-1} on the coupling to photons for low mass scalar axion-like particles.

Further work by the GammeV team has focused on a reconfiguration of the apparatus to be sensitive to possible chameleon particles. Chameleons are scalar (or pseudoscalar) particles that couple to the stress energy tensor in a potential such that their properties depend on their environment. In particular, a chameleon acquires an effective mass which increases with local matter density, ρ. For a certain class of such potentials, the chameleon field has properties that might explain dark energy [3]. GammeV set the first limits on the coupling of chameleons to photons. A dedicated follow-up experiment, GammeV-CHASE, (**CH**ameleon **A**fterglow **SE**arch), has also been performed and sets limits on both photon and some model dependent matter couplings as a function of an effective chameleon mass.

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2 Experimental setup

The GammeV and GammeV-CHASE apparati are shown in Fig. 1. Both experiments were conducted at the Fermilab Magnet Test Facility that allowed for high field operation of Tevatron magnets. Both experiments used a 3W pulsed Nd:YAG laser frequency doubled to 532 nm shown into the bore of a Tevatron dipole magnet operating at 5 T. The GammeV experiment used a light shining through a wall (LSW) [4] configuration where a photon propagating in a magnetic field could oscillate into an axion-like particle, traverse an opaque barrier, and have a small probabilty for reconverting back into a detectable photon. Two novel aspects were employed in order to increase sensitivity over the region of interest. A "plunger" was constructed so that the wall could be placed 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 utilized time correlated single photon counting techniques in order to reject noise from an already relatively low-noise photomultiper tube (PMT). An *a priori* 10 ns wide search window was established using a calibration run where laser photons were attenuated by approximately 19 orders of magnitude (i.e. no wall) and allowed to be recorded by the PMT.

For GammeV-CHASE, a "particle trapped in a jar" afterglow technique was employed [5, 6]. The configuration improved many different experimental aspects from the first look by GammeV to extend sensitivity. Laser photons converting into chameleons would remain trapped in the vacuum system until possibly reconverting back into photons that could leave the vacuum system through an optical window and hit the PMT. Similar to the plunger, GammeV-CHASE divided the magnetic field region into three separate regions providing sentivity to different effective chameleon masses. A small residual ~ 1 Hz rate of photons from an ion pump and a long-lived luminescence of orange photons similar to known phosphorescence of vacuum grease [7] provided calibration of the experiment's sensitivity.

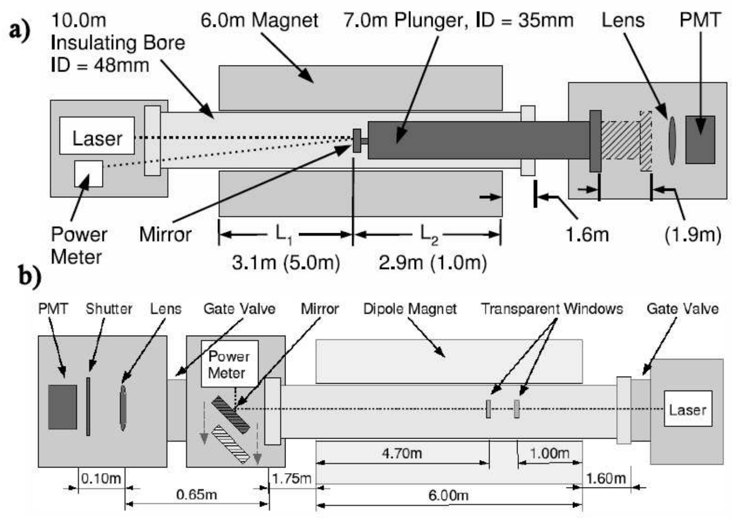

Figure 1: (a) Schematic diagram of the (a) GammeV experimental apparatus and (b) GammeV-CHASE experimental apparatus. The laser, spare Tevatron magnet, phototubes, and data acquition electronics were used by both experiments.

3 Results

Both GammeV and GammeV-CHASE observed no significant WISP signal above background [8], [5], [10], [11]. Fig. 2 shows the exclusion regions of the coupling to photons versus the (effective) mass for axion-like particles (3σ) and chameleons (95% C.L.). For GammeV, data was recorded in two polarizations for two configurations of the position of the wall with each of these runs consisting of approximately 20 hours of magnet time. The non-observation of a signal has also been reported by other experiments worldwide [9]. For GammeV-CHASE, multiple runs were recorded with 10 hours to reach the smallest couplings of photons to chameleons. Shorter runs were recorded at reduced magnetic field to cover larger couplings of photons to chameleons.

The reach of the GammeV and GammeV-CHASE essentially was an energy scale of a 3×1000 TeV and 3×10000 TeV respectively. These high scales are made accessible by the intense photon beam (incident photons were a few $\times 10^{23}$) from which a small regenerated photon signal could be identified above background.

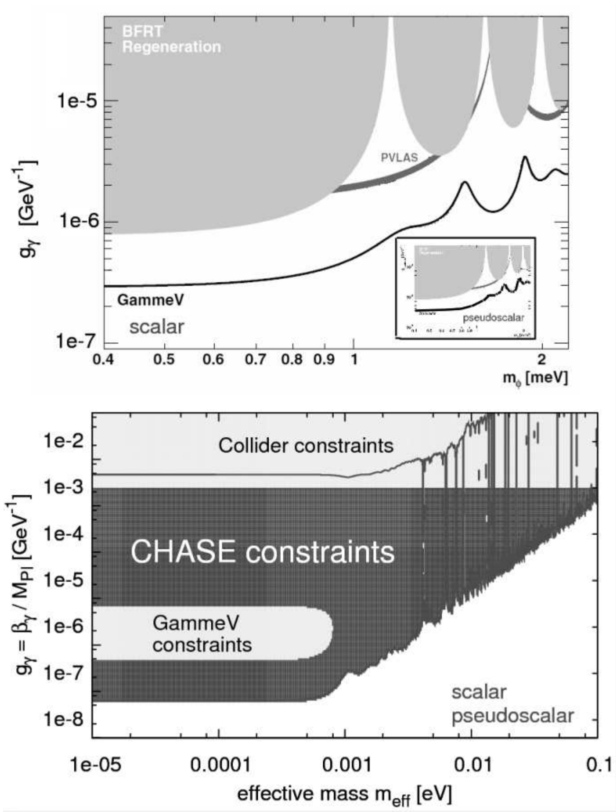

Figure 2: Published exclusion regions of photon coupling versus effective mass obtained (a) by GammeV for scalar and pseudoscalar (inset) axion-like particles at 3σ and (b) by GammeV and GammeV-CHASE for chameleon particles at 95% C.L. where the GammeV and GammeV-CHASE regions are valid for $\eta > 0.8$ and 0.1 respectively when expressing $m_{eff} > \rho^{\eta}$.

4 Future Plans

The future plans include extending the GammeV region of sensitivity from a few $\times$ 10^{-7} GeV^{-1} to possibly the 10^{-12} GeV^{-1} level. Such an effort has been called REAPR [12], **R**esonnantly **E**nhanced **A**xion-**P**hoton **R**egeneration." There is on-going R&D on long baseline optical cavities in conjuction with the Holometer [13] experiment.

There are ideas of extending the search region for chameleons as well as hidden sector photons. Before an experiment is proposed, careful consideration will be given to the increase in sensitivity compared with other experimental results and the motivation for and effort that it would take to obtain that sensitivity.

5 Conclusions

A 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.

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