WISP Hunting - some New Experimental Ideas

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We present several new ideas on how to search for weakly interacting sub-eV particles in laboratory experiments. The first experiment is sensitive to minicharged particles. It exploits that in strong electric fields particle - antiparticle pairs are produced by the Schwinger mechanism. The charged particles move along the lines of the electric field and generate a current that can be measured. The other two experiments are designed to search for hidden-sector photons. They are based on photon - hidden photon oscillations and resemble classic light shining through a wall experiments. One uses (nearly) constant magnetic fields instead of the laser light. Photon - hidden photon mixing would allow these magnetic fields to leak through superconducting shielding which would ordinarily eliminate all magnetic fields. The other one replaces the laser light with microwaves inside cavities. The latter can achieve much higher quality factors than optical cavities increasing the sensitivity.

1 Introduction

Over the last few years it became increasingly clear that low energy experiments can provide a powerful tool to explore hidden sectors of particles which interact only very weakly with the ordinary standard model particles. Such hidden sectors appear in many extensions of the standard model. In fact, it may be exactly those hidden sectors that give us crucial information on how the standard model is embedded into a more fundamental theory as, e.g., string theory.

The key observation from the viewpoint of low energy experiments is that, due to their feeble interactions with the standard model particles, the hidden sector particles are relatively unconstrained allowing them to be light possibly even in the sub-eV range. This opens the possibility for observable effects in low energy but high precision experiments.

In this note we will focus on two particular classes of such light 'hidden-sector' particles: minicharged particles and hidden sector photons. The former are particles interacting with the ordinary electromagnetic field via the usual minimal coupling induced by the covariant derivative,

$$D_\mu = \partial_\mu - \mathbf{i} Q_f e A_\mu \tag{1}$$

where Q_f is the electric charge of the particle of a particle f. For example if f is a fermion the interaction term reads $Q_f e \bar{f} \not{A} f$.

The crucial point for a minicharged particle is now simply that the charge is much smaller than 1,

$$Q_f \ll 1. \tag{2}$$

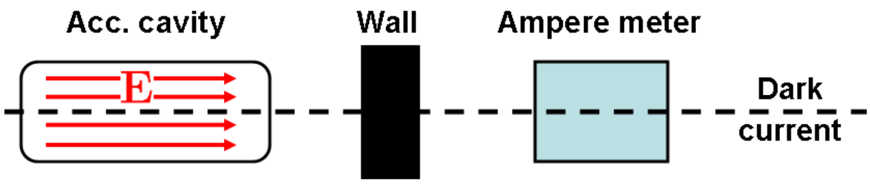

Figure 1: Schematic illustration of an *accelerator cavity dark current* (AC/DC) experiment for searching minicharged particles.

In particular it is not necessarily integer. Indeed it does not even have to be a rational number. Minicharges can arise in theories with kinetic mixing [1] (see also below) but also in scenarios with extra dimensions [2]. Typical predicted values, e.g., in realistic string compactifications range from 10^{-16} to 10^{-2} [2, 3].

The second class of particles we are concerned with in this note are massive hidden sector photons. These are extra U(1) gauge bosons which can mix with the ordinary electromagnetic photons via a so-called kinetic mixing term [1] in the Lagrangian,

$$\mathcal{L} = -\frac{1}{4}F^{\mu\nu}F_{\mu\nu} - \frac{1}{4}X^{\mu\nu}X_{\mu\nu} - \frac{1}{2}\chi\, F^{\mu\nu}X_{\mu\nu} + \frac{1}{2}m_{\gamma'}^2 X_\mu X^\mu + j_\mu A^\mu, \tag{3}$$

where $F_{\mu\nu}$ is the field strength tensor for the ordinary electromagnetic $\mathrm{U}(1)_{\mathrm{QED}}$ gauge field A^μ, j^μ is its associated current (generated by electrons, etc.) and $X^{\mu\nu}$ is the field strength for the hidden-sector $\mathrm{U}(1)_{\mathrm{h}}$ field X^μ. The first two terms are the standard kinetic terms for the photon and hidden photon fields, respectively. Because the field strength itself is gauge invariant for U(1) gauge fields, the third term is also allowed by gauge and Lorentz symmetry. This term corresponds to a non-diagonal kinetic term, the kinetic mixing [1]. This term is a renormalizable dimension four term and does not suffer from mass suppressions. It is therefore a sensitive probe for physics at very high energy scales. Kinetic mixing arises in field theoretic [1] as well as in string theoretic setups [2, 3] and typical predictions for its size range between 10^{-16} and 10^{-2}. The second to last term is a mass term for the hidden photon. This could either arise from a Higgs mechanism or it could be a Stückelberg mass term [4].

2 AC/DC an experiment to search for minicharged particles

The basic setup [5] is depicted in Fig. 1. In a strong electric field a vacuum pair of charged particles gains energy if the particles are separated by a distance along the lines of the electric field. If the electric field is strong enough (or the distance large enough) the energy gain can overcome the rest mass, i.e. the virtual particles turn into real particles. This is the famous Schwinger pair production mechanism [6]. After their production the electric field accelerates the particles and antiparticles according to their charge in opposite directions. This leads to an electric current (dashed line in Fig. 1). If the current is made up of minicharged particles the individual particles have very small charges and interact only very weakly with ordinary matter. Therefore, they can pass even through thick walls nearly unhindered. An electron current, however, would be stopped. After passage through the wall we can then place an ampere meter to detect the minicharged particle current.

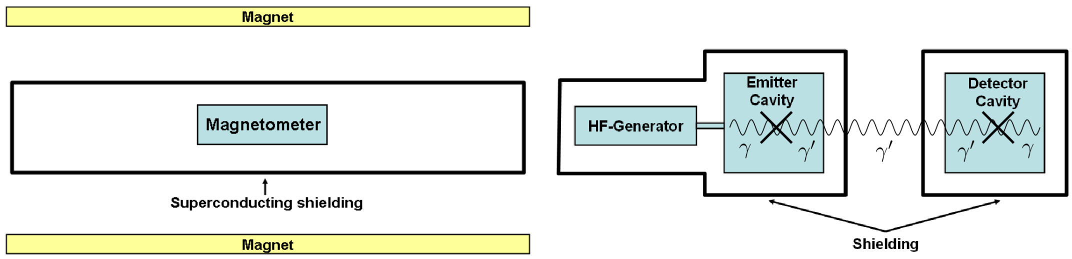

Figure 2: **Left panel:** Sketched setup for the *superconducting box* experiment. **Right panel:** Schematic illustration of a *microwaves permeating through a shielding* experiment for the search for massive hidden sector photons mixing with the photon (a high-frequency (HF) generator drives the emitter cavity).

Typical accelerator cavities achieve field strengths of $\gtrsim 25\,\mathrm{MeV/m}$ and their size is typically of the order of 10s of cm. Precision ampere meters can certainly measure currents as small as μA and even smaller currents of the order of pA seem feasible. Using the Schwinger pair production rate we can then estimate the expected sensitivity for such an experiment to be

$$\epsilon_{\mathrm{sensitivity}} \sim 10^{-8} - 10^{-6} \quad \text{for } m_\epsilon \lesssim \mathrm{meV}. \tag{4}$$

Therefore such an experiment has the potential for significant improvement over the currently best laboratory[1] bounds [9, 10], $\epsilon \lesssim$ few 10^{-7}.

3 Searching hidden photons inside a superconducting box

The basic idea [11] of the proposed experiment is very similar to a classic *light shining through a wall experiment* [12]. However, instead of light it uses a static magnetic field and the wall is replaced by superconducting shielding (cf. Fig. 2). Outside the shielding we have a strong magnetic field. Upon entering the superconductor the ordinary electromagnetic field is exponentially damped with a length scale given by the London penetration depth λ_{Lon}. Yet, due to the photon – hidden photon mixing a small part of the magnetic field is converted into a hidden magnetic field. After the superconducting shield is crossed the mixing turns a small fraction of the hidden magnetic field back into an ordinary magnetic field that can be detected by a magnetometer. Since the magnetometer measures directly the field (and not some probability or power output) the signal is proportional to the transition amplitude and therefore to the mixing squared, χ^2, instead of being proportional to χ^4.

High precision magnetometers can measure fields of the order of 10^{-13} T and even tiny fields of a few 10^{-18} T seem feasible. The expected sensitivity is shown as the blue area in Fig. 3.

4 A cavity experiment to search for hidden photons

Our final proposal [13] (see [14] for a similar proposal for axions [2]) is another setup searching for signatures of photon – hidden photon oscillations which resembles a classic *light shining through*

[1] Astrophysical bounds are much stronger [7] but are also somewhat model dependent [8].

[2] The only change necessary for an axion search is that one applies an additional magnetic field which allows for the usual photon–axion conversion inside magnetic fields. One might be worried that in this case one cannot

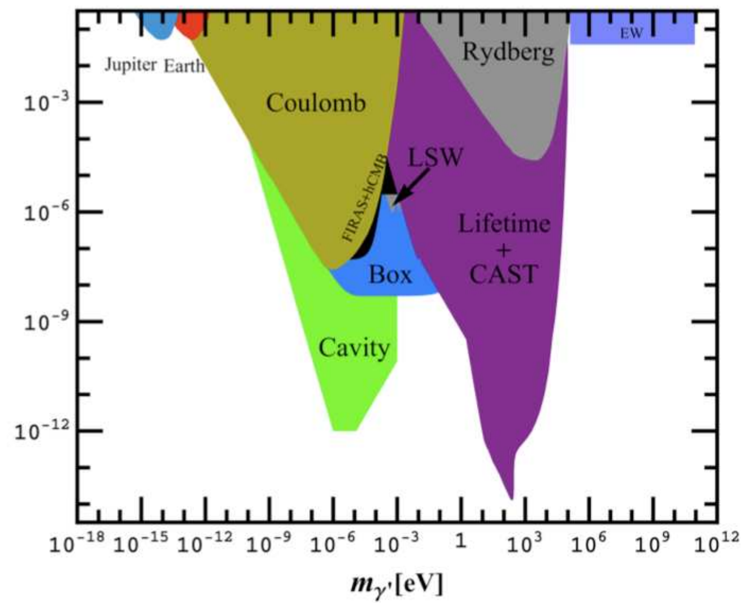

Figure 3: Current bounds on hidden-sector photons (cf., e.g., [16] and references therein). The *superconducting box* experiment could probe the blue region (Box). The estimated sensitivity for the *microwaves permeating through a shielding* is shown in green (Cavity). For details on the respective setups see [11, 13].

a wall [12] experiment, more precisely a resonant setup [15]. It consists of two microwave cavities shielded from each other (cf. Fig. 2). In one cavity, hidden photons are produced via photon – hidden photon oscillations. The second, resonant, cavity is then driven by the hidden photons that permeate the shielding and reconvert into photons. Due to the high quality factors achievable for microwave cavities (superconducting ones can reach $Q \sim 10^{11}$) and the good sensitivity of microwave detectors $\sim 10^{-26} - 10^{-20}$ W such a setup will allow for an unprecedented discovery potential for hidden sector photons in the mass range from μeV to meV (green area in Fig. 3).

5 Conclusions

We have presented several ideas for small scale laboratory experiments to search for weakly interacting sub-eV particles predicted in many extensions of the standard model. For minicharged particles an *accelerator cavity/dark current* experiment promises improvement over current laboratory bounds. Both the *superconducting box* and the *microwaves permeating through a shielding* experiment have the potential to improve not only upon the current laboratory but

use superconducting cavities because a magnetic field applied from outside the cavity cannot permeate through the superconductor to the inside of the cavity where it is needed for the conversion. This would allow only normal conducting cavities which have somewhat smaller Q. However, this may not be the case if one uses type II superconductors which allow for magnetic field penetration (via flux tubes) while maintaining their superconducting properties. Nevertheless, the magnetic field (and the flux tubes) can increase the surface resistance, again limiting the Q factor. Further investigation is needed to determine if one can achieve high Q with a strong magnetic field on the inside of the cavity.

also beyond existing astrophysical and cosmological bounds, thereby having significant discovery potential for new physics. Searching for extremely weakly interacting particles at small masses that would be missed in conventional colliders all these experiments provide for a new, complementary probe of fundamental physics.

Finally, we would like to point out that an experiment of the *microwaves permeating through a shielding* type is already in an initial stage [17] and will also be used to search for axions and axion-like particles.

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