The FUNK search for Hidden Photon Dark Matter in the eV range

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Abstract. We give a brief update on the search for Hidden Photon Dark Matter with FUNK. The experiment uses a large spherical mirror, which, if Hidden Photon Dark Matter exists in the accessible mass and coupling parameter range, would yield an optical signal in the mirror’s center in an otherwise dark environment. After a test run with a CCD, preparations for a run with a low-noise PMT are under way and described in this proceedings.

1. Holding a mirror up to Hidden Photon Dark Matter

There is compelling evidence for Dark Matter, except that we do not know what its constituents are. The possibility of ‘heavier’ Dark Matter is under investigation by a large number of direct detection experiments. The possible signature of (possibly annihilating) Dark Matter is investigated in astrophysical settings or with direct production at colliders, e.g. at the LHC. For a recent review, see [1]. For very light-weight Dark Matter fewer experiments exist, see, e.g., [2] for a brief review. Most prominently, a growing number of experiments are hunting after axionic Dark Matter [3]. Recently, it was suggested that also ultra-light extra ‘hidden’ gauge bosons make up viable Dark Matter, either through a misalignment mechanism [4, 5] (similarly to axions), or sourced by inflationary fluctuations [6].

In the experiment described here, the relevant signature for the presence of Hidden Photon Dark Matter comes from a possible photon-to-hidden-photon coupling, \( \sim \chi F^{\mu\nu} X_{\mu\nu} \), with visible and ‘hidden’ electromagnetic field-strengths \( F^{\mu\nu} \) and \( X^{\mu\nu} \), respectively. Their coupling strength is parameterized by the kinetic mixing parameter \( \chi \), see, e.g. [7] for a review on this physics. Additionally, the Hidden Photon should have a mass \( m \) through a Higgs or Stückelberg mechanism.

The FUNK (Finding U(1)s of a Novel Kind) experiment [8] is based on the technique described in [9]: Hidden Photon Dark Matter can induce radiation emitted off a metallic surface due to its
kinetic mixing with photons (which yields an effective coupling to the electrons in the surface). In our experiment, this mirror is composed of $6 \times 6$ mirror elements originally produced for the fluorescence detector of the Pierre Auger Observatory. The total surface area of this ‘FUNK mirror’ is about $14 \text{ m}^2$, see Fig. 1.

Note that as Dark Matter, the Hidden Photons are almost at rest with respect to the mirror. In effect, the electrons in the conducting mirror surface see a very small oscillating electric field (strength downscaled through $\chi$) and the electrons can oscillate in phase and therefore emit a wave mostly perpendicular to the mirror. Thus, the signal is expected in the radius point $R$, not the focal point which makes measuring a potential signal considerably easier. A small angular offset from the rectangular emission is determined by the relative velocity of the Hidden Photons with respect to the mirror.

Such an experiment is sensitive to all Hidden Photon masses whose associated wavelength $\lambda = 2\pi/m$ can be: (1) reflected from the mirror (the induced emissivity is related to the reflectivity), (2) properly concentrated in the focal plane (wavelength longer than typical imperfections) and (3) detected by a detector in the center of the sphere.

An experiment also using this technique, albeit a smaller mirror (diameter of 50 cm with a focal length of 1 m), is based in Tokio, and has recently published first results [10] in the optical. Another dish configuration there is used to study the microwave regime [11].

2. Brief update on the ‘PMT run’
The first measurements with FUNK were done using a readily available ‘Sensicam’ CCD whose characteristics are not sufficient to reach un-tested Dark Matter parameter space. The reason is the huge amount of pixels illuminated by a potential signal and the correspondingly large dark noise contribution, see [12] for results and details.

For FUNK, due to careful alignment, the 90 % spot radius of the mirror elements was reduced to $\sim 2 \text{ mm}$ as described in [12]. The signal spot induced by Hidden Photon Dark Matter will also have a finite size due to the velocity distribution of the Dark Matter $\Delta v = 10^{-3}$ (in natural units). Following [13], the spot-radius for the DM- induced spot will be $\Delta d \sim \Delta v R \sim 1 \text{ mm} (R/m) = 3.4 \text{ mm}$, where now $R = 3.4 \text{ m}$ denotes the radius of curvature of the mirror for FUNK. The effective movement of the signal spot due the earth’s movement with respect to the Dark Matter is of a similar size.

Our results of the test run with the CCD were reported recently, see [12], and we will therefore not detail on them herein.
For the subsequent measurements in the optical, we decided to procure a photomultiplier tube (PMT) from ET Enterprise, model 9107QB [14] with an active diameter of 25 mm to safely accommodate the full potential signal spot and its movement. The spectral coverage ranges from about 200-550 nm at peak efficiencies of 28%.

The choice was mainly based on the favorable behavior of the multiplier series reported on in [15, 16, 17] for the '9893/350B type' with an active diameter of 8 mm.

This series of PMTs can be installed in a ‘FACT50’ housing that is designed to cool the PMT up to −50°C beneath room temperature while regulating itself. The behavior of the PMT in the cold is not specified by the vendor, but one reported Dark Count rate at −20°C is 0.35 ± 0.02 Hz in 30000s of acquisition time, see [17]. With a customized blind-flange that can be attached to the FACT50 housing or a ‘dark box’ the PMT can be tested under light-tight conditions.

In order to set the most suitable working point for the photo-tube in single-photon counting mode several characterization measurements need to be done. A crucial feature of the individual photomultiplier is the so called plateau range and especially its onset. Figure 2 shows the count rates at various low light levels depending on the high voltage applied.

Figure 2. Rates over threshold for 9107QB in the FACT50 housing as function of applied high voltage at a temperature of −12°C. The three measurements correspond to different light levels of an LED. Lowermost (blue curve) is a ‘dark’ environment, middle (green) and lower (red) increasing LED currents.

1 For the non-customized options, the other option ‘9893/350B’ would have been 8mm diameter which is too small in this setup.

2 The PMT is originally sensitive at 52 mm diameter but the sensitive area is internally limited to 8 mm diameter.
For a high voltage slightly above this onset of the plateau, the single electron response of the PMT is currently being studied. This allows us to later set lower and upper trigger thresholds in order to minimize further non-single photon signals.

After the PMT characterization is finalized, we will mount it on a linear translation stage in the mirror center that can shift the PMT laterally for signal and background measurements, respectively (see Figure 1, where in that picture in the radius point a milk glass is mounted).

3. Summary
After alignment and a test run of the FUNK experiment (reported on in [12]), we are preparing for running with a low-noise PMT that is expected to be sensitive to un-charted Hidden Photon Dark Matter space in the eV region.

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