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The investigation on the dark sector at the PADME experiment

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ABSTRACT

The PADME experiment, at the Laboratori Nazionali di Frascati (LNF) of INFN, is designed to be sensitive to the production of a low mass gauge boson A' of a new $U(1)$ symmetry holding for dark particles. The DAΦNE Beam-Test Facility of LNF is providing a high intensity, mono-energetic positron beam impacting on a low Z target to provide e^+e^- annihilations, where the dark photon can be produced along with an ordinary photon. Simulation studies predict a sensitivity on the interaction strength (ε^2 parameter) down to 10^{-6}, in the mass region 1 MeV/c^2 <$M_{A'}$ <23.7 MeV/c^2, for one year of data taking with a 550 MeV beam. In 2018 the first run will take place, and early data will give the opportunity to compare the detector performance with the design parameters. Right now, an intense activity is taking place to install and commission the PADME experimental apparatus on site.

Contents

1. Introduction

The nature of Dark Matter (DM) is one of the more intriguing open issues of fundamental research. Some theoretical approaches suggest that, in addition to gravity, DM particles can have interactions with ordinary matter through a new force, mediated by a massive vector boson that then take the name of dark photon A' [1]. The A' is thus the manifestation of a new abelian gauge symmetry $U(1)$ which interacts with ordinary matter only through kinetic mixing $\frac{\varepsilon}{2}F_{\mu\nu}F'^{\mu\nu}$ with the Standard Model (SM) photon. The PADME experiment, on the way to start data taking at the Laboratori Nazionali di Frascati (LNF) of INFN, aims at testing this theoretical picture [2] with a complete model-independent approach.

2. The PADME technique

The main goal of the PADME experiment is to search for dark photons produced in the annihilation of a positron beam with the electrons at rest in a thin active diamond target. The 550 MeV positron beam of the Frascati Beam Test Facility (BTF) [3] interacting with the electrons of the target can generate a dark photon through the reaction:

$$e^+e^- \rightarrow \gamma A' \tag{1}$$

up to mass of 23.7 MeV/c^2. In the hypothesis that the A' decay products are not detected, the resulting final state of the reaction (1) is represented by a single SM photon. Therefore, the PADME detector must be able to measure accurately the energy and the angle of the recoiling photon, in order to evaluate precisely the missing mass of the

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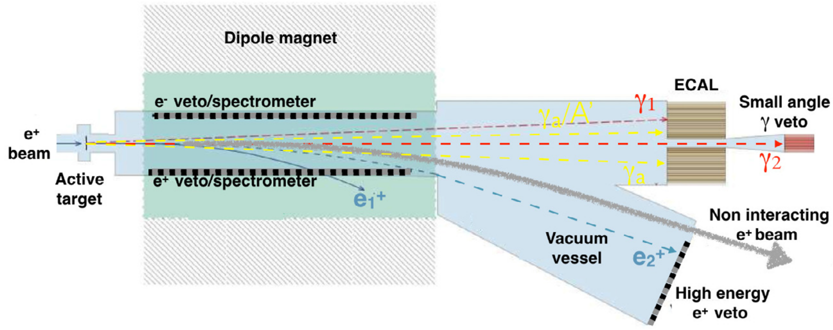

Fig. 1. Schematic view of the PADME detector (see text for more details).

reaction and get, in the end, a signal of the A'. The strategy for the A' identification requires also the capability to efficiently reject the background that is mainly represented by Bremsstrahlung photons, 2 and 3γ events. These final states are rejected by requiring only one cluster in the main electromagnetic calorimeter (ECAL). The reconstructed cluster position should fall inside a fiducial range to improve the resolution on the missing mass, reducing the energy leakage in the ECAL. By selecting a cluster energy interval optimised for the A' mass hypothesis, Bremsstrahlung ($E_\gamma > E_{min}$) and pile-up ($E_\gamma < E_{max}$) can be efficiently cut out. A charged particle veto system should not have in-time signals with the ECAL (within 2 ns). Finally, there should be no cluster in the Small Angle Calorimeter (SAC) with energy above 50 MeV. This last requirement removes most of the residual 3γ events, when only one falls inside the ECAL acceptance.

3. The PADME detector

A schematic drawing of the PADME setup can be seen in Fig. 1. The positron beam enters from the left of the picture and impinges on a polycrystalline diamond target [4]. A vacuum chamber, inserted inside the gap of a dipole magnet, providing a magnetic field of 0.5 T, in order to avoid unwanted interactions of the e^+e^- reaction products. Charged particle veto systems, made of plastic scintillator bars, are installed inside and outside the vacuum chamber, to veto Bremsstrahlung events [5]. To measure energy and direction of the ordinary photons, a cylindrical BGO calorimeter (ECAL) is used. It foresees a central squared hole (100×100 mm^2) to allow the passage of high energy photons that would overload the calorimeter and that instead are vetoed by the SAC placed just behind [6]. The SAC consist of a 5×5 PbF_2 crystal matrix readout by fast photomultipliers.

4. The PADME sensitivity

To evaluate the experiment sensitivity for the invisible dark photon decays, Monte Carlo simulations with GEANT4 have been performed. These assumed beam bunches of 40 ns length, each containing 5000 positrons of 550 MeV energy with a spread of 1%, an angular divergence of ~ 1 mrad, and a Gaussian beam spot with $\sigma_{x,y}$ 1 mm. With these input parameters, an integrated luminosity of 1×10^{13} positron on target will be integrated in 2 years of data taking, assuming an overall efficiency of 50%. Nevertheless, an intense consolidation work has been performed recently on the Frascati LINAC. This lets to stretch the positron bunches up to ~ 200 ns allowing to reduce significantly the experiment running time. The results of this simulation work are shown in Fig. 2.

Thanks to the capability to detect photons and charged particles, the PADME experiment will also be able to explore other types of dark sector mediators such as Axion Like Particles, proto-phobic X bosons [9], and Dark Higgs.

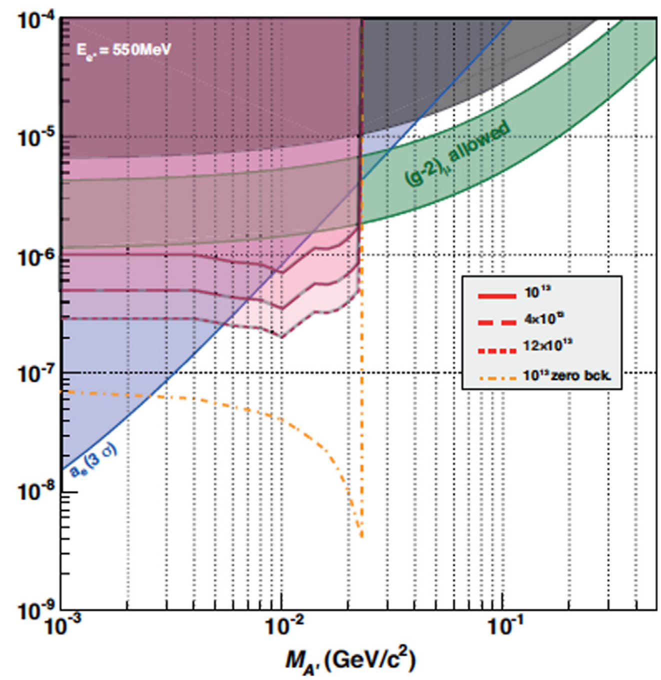

Fig. 2. Expected sensitivity of the PADME experiment to the coupling of the new force for different integrated luminosities. The yellow dot-dashed curve represent the ultimate goal in case of zero background. Also shown are the $(g-2)_\mu$ excluded region (grey area), the preferred values to explain $(g-2)_\mu$ (green band) [7], and the constrain fixed by $(g-2)_e$ (blue area) [8]. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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