Search for the Dark Photon with the PADME Experiment at LNF

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Massive photon-like particles are predicted in many extensions of the Standard Model with a hidden sector where dark matter is secluded. They are vector bosons mediating the interaction between dark matter particles and can be produced in scattering of ordinary particles through a faint mixing to the photon. Most of the present experimental constraints on this "dark photon" (A') rely on the hypothesis of dominant decays to lepton pairs. The PADME experiment will search for the $e^+e^- \rightarrow \gamma A'$ process in a positron-on-target experiment, assuming a decay of the A' into invisible particles of the hidden sector. The positron beam of the DAΦNE Beam-Test Facility, at Laboratori Nazionali di Frascati of INFN, will be used. A fine-grained, high-resolution calorimeter will measure the momentum of the photon in events with no other activity in the detector, thus allowing to measure the A' mass as the missing mass in the final state. In about one year of data taking, a sensitivity on the interaction strength (ε^2 parameter) down to 10^{-6} is achievable in the mass region $M_{A'} < 23.7$ MeV. The experiment is currently under construction and it is planned to take data in 2018. The status of PADME and its physics potential will be reviewed.

1 Introduction

The PADME experiment [1], hosted in the DAΦNE [2] Beam-Test Facility (BTF) [3] at Laboratori Nazionali di Frascati (LNF) of INFN, is designed to search for the dark photon by using an intense positron beam hitting a light target. The A' can be observed by searching for an anomalous peak in the spectrum of the missing mass measured in events with a single photon in the final state. The measurement requires the precise determination of the 4-momentum of the recoil photon, performed by an homogeneous electromagnetic calorimeter.

The collaboration aims to complete the design and construction of the experiment by the end of 2017 and to collect $\sim 10^{13}$ positrons on target by the end of 2018.

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A comprehensive review of the dark sector, along with a summary of the ongoing experimental programs addressing the theoretical hypotheses motivating the search for the dark photon, can be found in Ref. [4].

2 The PADME Detector

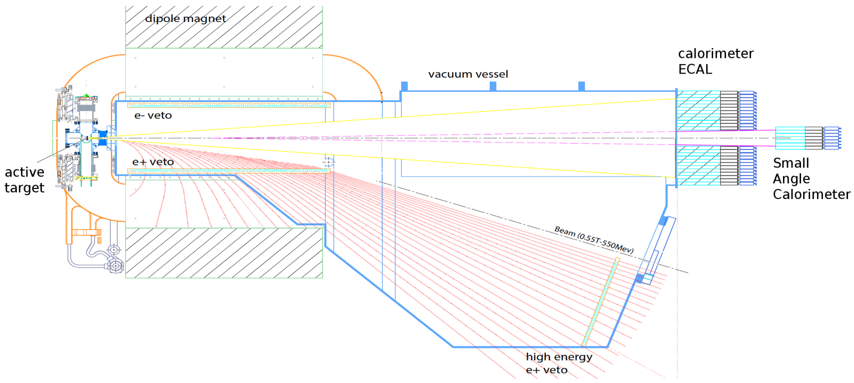

Figure 1: Layout of the PADME detector: the active target, the veto detectors inside the dipole magnet, the HEPVeto near to the non-interacting beam exit, the ECAL and the SAC.

In its baseline configuration, PADME will use the positron beam of 550 MeV energy delivered by the LINAC of the DAΦNE. The time structure of the pulsed beam is a sequence of bunches with a controllable positron population (from single particle to about 10^4) of constant intensity in a time span of 40 ns and a maximum repetition rate of 50 Hz. The experimental apparatus, whose layout is shown in Fig. 1, consists of:

- a 2×2 cm^2 polycrystalline CVD diamond active target [5, 6], aimed at measuring the beam intensity and position (with a precision of a few mm) by means of perpendicular conductive strips. The low Z helps to reduce the occurrence of Bremsstrahlung processes. The small thickness (100 μm) reduces the probability of e^+ multiple interactions.
- a dipole magnet, located 20 cm down-stream of the target, designed to deflect non-interacting beam particles out of the detector and to direct the positrons that lost part of their energy towards veto detectors. The field is 0.5 Tesla over a gap of 23 cm for 1 m length.
- a system of $1 \times 1 \times 18$ cm^3 bars of plastic scintillators used as veto detector for charged particles divided in 3 parts: two arrays of scintillator fingers on the left and right internal walls of the dipole act as positron and electron veto, and another one near the beam dump detects high energy positrons having lost a small part of their energy (mainly through Bremsstrahlung processes).
- a highly segmented electromagnetic calorimeter of cylindrical shape (ECAL) [7] with axis on the beam line located at about 3 m from the target. Its final design implements an active volume of 616 $2 \times 2 \times 23$ cm^3 BGO crystals covering the angular region $20 \div 83$ mrad. The expected energy resolution is $\sim \frac{(1 \div 2)\%}{\sqrt{E}}$ for < 1 GeV electrons and photons.

- a Small Angle fast Calorimeter (SAC) made of $492 \times 2 \times 20\text{cm}^3$ lead glass (SF57) bars with angular coverage $0 \div 20$ mrad, placed behind the central hole of the main calorimeter, thus instrumenting the region of maximum flux of Bremsstrahlung photons produced in the target, mainly aimed at suppressing background from $3\,\gamma$ events.

The target and all veto detectors will be hosted in a vacuum chamber to minimize the interactions of the beam with the atmosphere.

3 Signal and Background

The detector will identify events with a single photon generated in the e^+e^- annihilation taking place in the interaction of the positron beam with the target. The dominant Standard Model processes expected to occur are Bremsstrahlung and $e^+\ e^- \to \gamma\gamma(\gamma)$. The probability that their kinematics will mimic a dark photon production event in the PADME detector can be reduced through an optimization of the ECAL geometry and granularity and of the veto system. The thin target and the adjustable beam intensity play a crucial role in reducing events pile-up.

A signal event is satisfying the following requirements: one cluster in the ECAL fiducial volume (with energy in a range optimized depending on $M_{A'}$), no hits in the vetoes, and no photons with energy larger than 50 MeV in the SAC.

The sensitivity estimation is based on GEANT4 simulations extrapolated to 10^{13} e^+ positrons on target. This number of particles can be obtained by running PADME for 2 years at 50% efficiency with 5000 e^+ per 40 ns bunch at a repetition rate of 49 Hz. The obtained result for A' decaying into invisible particles is shown in Fig. 2. Smaller values of the coupling constant ϵ can be explored by increasing the bunch length. The favored $(g\text{-}2)_\mu$ region can be explored in a model independent way (the only hypothesis on the A' is the coupling to leptons) up to masses of 23.7 MeV [7].

4 Status and Perspectives

The PADME experiment is pioneering for the first time the missing mass technique to constrain directly the A' invisible decay in the parameter region preferred by the $(g\text{-}2)_\mu$ and also to investigate other phenomena, not mentioned here, such as Axion Like Particles (ALPs) [9], Dark Higgs [10] and the fifth force [11]. Early Monte Carlo studies applied to dark photon invisible decay modes demonstrated that PADME can reach a sensitivity down to the level of $\epsilon^2 \sim 1 \cdot 10^{-6}$ in the mass range $M_{A'} < 23.7$ MeV.

The PADME experiment is expected to run in early 2018 and the preparation of the several detector components proceeds according to the schedule. In particular, the dipole magnet is ready and only the mechanical support for final integration must be prepared. In addition, the prototypes of calorimeters and charged veto detector systems have been finalized and tested. All the crystals and scintillator bars are ready for final assembly. A prototype diamond detector has been successfully tested and the final active diamond target is under construction. The readout and digitizing system ($1 \div 5$ Gs/s and 12bit ADC for about 1000 channels) is also available.

An upgraded pulsing system has been recently commissioned, allowing to deliver beam pulses of increasing length, up to $5\,\mu$s, so that, after having optimized the RF power and phases and the magnetic focusing in the LINAC, electron or positron beams could get accelerated close

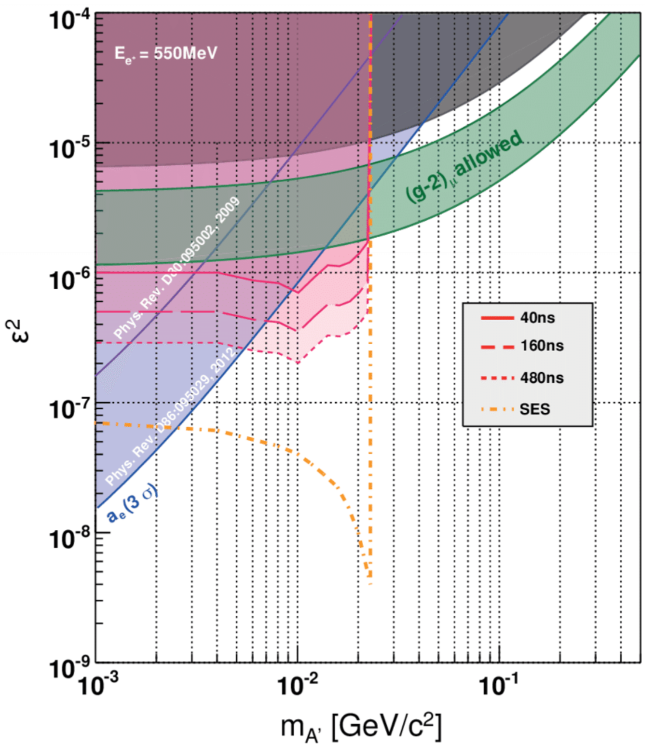

Figure 2: PADME estimated sensitivity for A' decaying into invisible particles for different values of the bunch length. The SES curve refers to single event sensitivity (no background).

to the maximum energy, with a width of several hundreds of ns. An upgrade of the DAΦNE LINAC energy up to 1 GeV has been also proposed [3]. This will extend the parameter space to lower values of ϵ and increase the A' mass range to $M_{A'} < 32$ MeV.

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