The PADME experiment at Laboratori Nazionali di Frascati

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Abstract

The PADME experiment will search for the invisible decay of Dark Photons produced in interactions of positron from the DAΦNE Linac on a target. The collaboration aims at reaching a sensitivity of $\sim 10^{-3}$ on the coupling constant for values of Dark Photon masses up to 23.7 MeV.

1 Introduction

The problem of the elusiveness of the Dark Matter (DM) can be solved speculating that it interacts with particles and gauge fields of the Standard Model (SM) only by means of portals that connect our world to the dark sector. The simplest model adds a U(1) symmetry and its vector boson A': SM particles are neutral under this symmetry, while the new boson couples to the SM with an effective charge εe and for this reason it is called Dark Photon (DP). [1, 2]

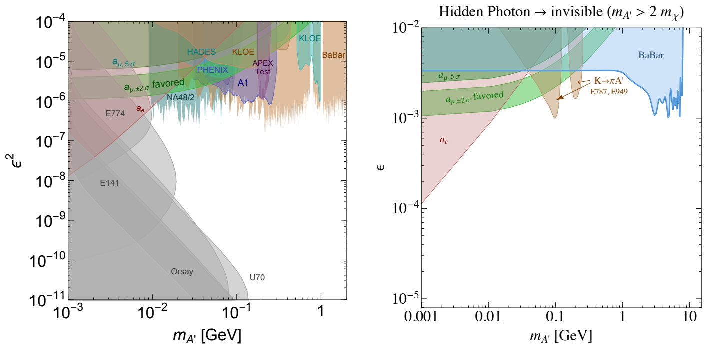

Figure 1: Current DP search status: on the left for visible decays (adapted from [4]), on the right for the invisible ones (adapted from [5]). Typical DP exclusion plot have the A' mass on the x-axis and the coupling constant (squared) on the y-axis. In both cases the 2σ anomalous muon magnetic moment favored band is indicated.

In addition, it has been pointed that the existence of an A' with a mass $m_{A'}$ in the range $[1\,\mathrm{MeV}, 1\,\mathrm{GeV}]$ and a coupling constant $\varepsilon \sim 10^{-3}$, might be responsible for the discrepancy currently observed between the theoretical expectation, based on the SM, and the measurement of the muon anomalous magnetic moment $(g-2)_\mu$. [3]

If there are no particles in the hidden sector with mass smaller than one half of A', it can only have SM decays (visible decays). Currently, the region of the ε, $m_{A'}$ plane favored by $(g-2)_\mu$ discrepancy, is excluded for an A' decaying into SM (see Fig.1 left).

In the most general case the A' can decay into DM (invisible decays). In this scenario, there are still unexplored regions in the $(g-2)_\mu$ favored band, as shown in Fig.1 right.

A comprehensive overview of the experimental programs of this field is presented in [6].

2 The PADME experiment

The PADME (Positron Annihilation into Dark Mediator Experiment) experiment is designed to detect invisible decaying DPs that are produced in the reaction $e^+ e^- \rightarrow A'\gamma$, where the e^+ are accelerated from the DAΦNE to 550 MeV and the e^- belongs to a fixed target. [7, 8]

2.1 The Frascati Beam Test Facility

PADME will be hosted in the newly redesigned hall of the Beam Test Facility (BTF), a transfer-line from the DAΦNE linac of the Laboratori Nazionali di Frascati (LNF). [9] BTF is able to provide up to 50 bunches/s with a maximum energy of 550 and 800 MeV, for positrons and electrons respectively, and with duration (at constant intensity) from 1.5 to 40 ns. The energy spread is 0.5%, while the beam spot size can vary by orders of magnitude: $[0.5, 25]$ mm (vertical) $\times$ $[0.6, 55]$ mm (horizontal). The number of particles that can be provided per bunch goes from 1 to 10^{10}.

2.2 The detector

The detector is designed to identify events with a single photon emerging from the e^+/e^- annhilation and to measure the missing squared invariant mass of the final state, by exploiting energy-momentum conservation and the fully constrained initial state: e^+ beam (known momentum and position) on an active fixed target. The A' squared invariant mass M^2_{miss} can be estimated as:

$$M^2_{miss} = \left(\vec{P}_{e^-} + \vec{P}_{beam} - \vec{P}_{\gamma}\right)^2,$$

where $\vec{P}_{e^-} = \vec{0}$ and $P_{beam} = 550\,\text{MeV}$ along the initial beam direction, are the e^- and the e^+ momentum respectively and $\vec{P}_{\gamma}$ is the photon final state.

The detector, shown Fig.2, consists of different components: [7]

- Diamond active target. It allows to measure the beam intensity and position (precision of ≈ 5 mm) by means of graphite perpendicular strips. The low Z of diamond is needed to reduce the bremsstrahlung process. The area is $2 \times 2\,\text{cm}^2$ and the small thickness ($50\,\mu$m or $100\,\mu$m) is to reduce the probability of e^+ multiple interactions.

- Dipole magnet. Located 20 cm after the target, it is designed to deflect exhaust beam out of the detector and send the positrons that lost part of their energy (mainly through bremsstrahlung) towards the vetoes. The field is 0.5 T over a gap of 23 cm for 1 m of length.

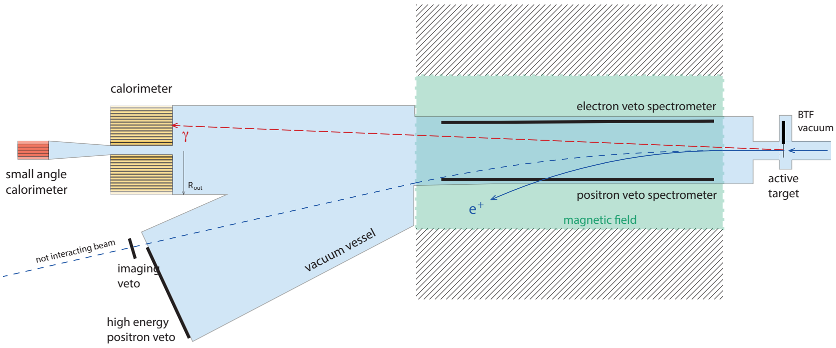

Figure 2: PADME detector layout. From right to left: the active target, the e^+e^- vetoes inside the magnetic dipole, the high energy e^+ veto near the exhaust beam exit, the ECAL and the SAC. The distance between the ECAL and the target is 3 m.

- Positrons/electrons veto. It is divided into two parts: one inside the dipole for positrons and electrons and one, near the beam exit, for high energy positrons that lost only a small part of their energy, typically for bremsstrahlung. It is composed of $1 \times 1 \times 16\,\text{cm}^3$ bars of plastic scintillators. The arrays inside the magnet are ≈ 1 m long, while the high energy positron one is ≈ 0.5 m long.

- Electromagnetic calorimeter (ECAL). Made of 616 $2 \times 2 \times 22\,\text{cm}^3$ BGO crystals and placed at 3 m from the target. Energy resolution is foreseen to be $\sim \frac{(1-2)\%}{\sqrt{E}}$. The shape is cylindrical (30 cm radius) with a central hole (a square of 10 cm side) to allow the bremsstrahlung radiation to pass and impinge on the Small Angle Calorimeter. This is necessary because of the BGO decay time of 300 ns: the ECAL would be continuously "blinded" by the bremsstrahlung rate. The angular coverage is $(20, 93)$ mrad.

- Small Angle Calorimeter (SAC). It consists of 49 $2 \times 2 \times 20\,\text{cm}^3$ lead glass SF57 and its goal is to veto events with a bremsstrahlung photon. The lead glass decay time of 4 ns makes it a good candidate for this task, being fast enough for the expected rate. The angular coverage is $(0, 20)$ mrad.

Hence the DP signature is a single γ in the ECAL and no particles in the vetoes. Being $E_{beam} = 550$ MeV, the largest A' reachable mass is 23.7 MeV.

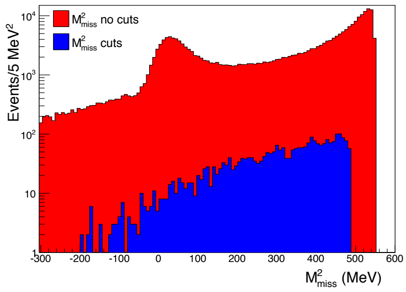

Figure 3: Background before (red) and after (blue) good events selection.

2.3 Backgrounds and sensitivity

The SM physical processes that take place when the e^+ beam hits the target are: bremsstrahlung and e^+/e^- annihilation in 2 or 3 γs. [7] The probability that they mimic a DP production event can be reduced through an optimization of the ECAL geometry and granularity and of the system of vetoes. The beam intensity plays an important role through the pileup: clusters cannot be resolved in time by the calorimeter if they are temporally too close each other. [7] Fig.3 shows the background reduction obtained requiring only one cluster in the ECAL, no hits in vetoes, no γs in the SAC with energy $> 50\,\mathrm{MeV}$ and an energy of the cluster in a range optimized depending on $m_{A'}$.

The DP sensitivity calculation is based on $2.5 \cdot 10^{10}$ GEANT4 simulated 550 MeV positrons on target extrapolated to 10^{13} e^+. This number of particles can be obtained running PADME for 2 y at 60% efficiency with 5000 e^+ per bunch (40 ns) at a repetition rate of 50 Hz. The obtained result for a DP decaying to invisible particles is shown in Fig.4 for different bunch durations: favored $(g-2)_\mu$ region can be explored in a model independent way (the only hypothesis on the DP is the coupling to leptons) up to masses of 23.7 MeV. [7] Single Event Sensitivity (SES) refers to the sensitivity in absence of background.

3 Conclusions

Theoretical models with a DP provide a solution to the DM puzzle. Additionally a DP with mass in the [1 MeV, 1 GeV] interval and coupling constant

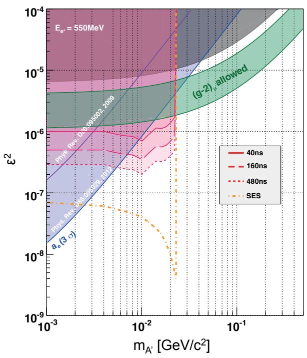

Figure 4: PADME sensitivity to $A' \to invisible$. Increasing bunch length it is possible to explore smaller ε. SES refers to sensitivity in absence of background.

$\varepsilon \sim 10^{-3}$, can justify the muon anomalous magnetic moment discrepancy.

PADME will perform a model independent search for an invisible decaying DP, using the accelerator complex present at the LNF. The collaboration aims at reaching a sensitivity on ε of $\sim 10^{-3}$ for DP with masses up to 23.7 MeV.

References

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