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THE PADME EXPERIMENT AT LNF

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Abstract

Among the theoretical models addressing the dark matter problem, the category based on a secluded sector is attracting increasing interest. 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. This 'dark photon' is weakly coupled to the photon of the Standard Model, and it provides an experimental signature for one of the simplest implementations of the dark sector paradigm. The DAΦNE Beam-Test Facility of LNF provides a high intensity, mono-energetic positron beam impacting on a low Z target. The PADME detectors are designed to measure with high precision the momentum of a photon, produced along with A' boson in e^+e^- annihilation in the target, thus allowing to measure the A' mass as the missing mass in the final state. This technique, particularly useful in case of invisible decays of the A' boson, is adopted for the first time in a fixed target experiment. Simulation studies predict a sensitivity on the interaction strength (ϵ^2 parameter) down to 10^6, in the mass region 1 MeV $< M_{A'} <$ 22.5 MeV, for one year of data taking with a 550 MeV beam. In Winter 2018-2019 the first run took place, providing useful data to study the detector performance, along with the beam and background conditions. Intense activity is taking place to deliver preliminary results on the PADME data quality. This talk will review the status of the experiment and the prospects.

1 Introduction

The observation of cosmological phenomena (e.g., gravitational lensing or anisotropies in the Cosmic Microwave Background) suggests the existence of a new kind of matter, which interacts at least gravitationally with particles of the Standard Model (SM). In the last decades, many experiments tried to detect this kind of matter, commonly known as Dark Matter (DM). The extremely difficult detection of DM could be explained if SM particles and DM particles would live in two separate sectors, connected by a portal. The simplest model for this theory introduces a $U(1)$ symmetry, acting as a portal, between these two sectors [1]. The vector boson mediator of this interaction could be massive, and is called dark photon (marked as A'), in analogy with SM photon. We can think three main ways to produce a dark photon using electron and/or positron interactions:

1. annihilation $e^+e^- \to \gamma A'$
2. Bremsstrahlung $e^{+,-}N \to e^{+,-}A'$
3. meson decay (in which mesons are produced by e^+, e^- interactions) $\pi^0, \eta, ... \to \gamma A'$

Dark photon decay depends on DM mass properties. If only DM particles with $m_{DM} > m_{A'}/2$ exist (where m_{DM} is DM mass and $m_{A'}$ is dark photon mass respectevely), then dark photon will decay in SM particles (visible decay). Otherwise, if $m_{DM} \leq m_{A'}/2$, dark photon will predominantly decay in DM particles (invisible decay).

2 The PADME experiment

2.1 The experimental technique

The PADME experiment [2], [3] will search for a dark photon exploiting the annihilation $e^+e^- \to \gamma A'$ of a positron beam on a target making the hypothesis of invisible decay channels of A'. If the positron beam energy is known and target is at rest, the detection of the SM photon in the final state allows to close the kinematic of the process, and to search for the dark photon as a peak in the missing mass distribution:

$$m^2_{miss} = (P_{e^+} + P_{e^-} - P_\gamma)^2 \tag{1}$$

with P_i 4-momentum of the positron, the electron and the SM photon, depending on the index.

The only assumption the experiment makes is that A' couples to leptons. Since the invisible decay of A' is considered, no restrictions on the decay time of A' are needed: the signature of the experiment is a single photon in the electromagnetic calorimeter. Moreover, the experiment can set new limits on the coupling for any kind of particles that can be produced in e^+e^- annihilations.

2.2 Description of the detector

PADME is installed at the Beam Test Facility of the Laboratori Nazionali di Frascati [4]. The experiment (see fig. 1 for a scheme of the detector) is using a 550 MeV positron beam (20k e^+ per bunch, 200 ns duration, 49 Hz), which allows to reach dark photon masses up to 22.5 MeV. The beam hits an active diamond target where the annihilation process takes place. The target is made of a $20\times20\times0.1$ mm^3 policrystalline diamond: 16 x graphitic strips on one side, and 16 y graphitic strips on the other provide information about beam position and multiplicity [5]. The low Z of carbon and the small thickness (100 μm) of the target minimize multiple scattering and background from Bremsstrahlung.

After the interaction point, a magnetic field ($\sim$0.5 T) in a vacuum chamber (10^{-6} bar) bends positrons and electrons towards the charged particles veto system of the experiment. The system consists of three veto stations, each made of $1.1\times1\times17.8$ mm^3 plastic scintillating bars coupled to optical fibers and SiPMs [6]. 90 bars are placed on the left side (beam point of view) of the vacuum chamber and work as positrons veto (PVeto), while 90 bars are place on the right side, working as electrons veto (EVeto). 16 bars are placed to the left side of the calorimeters, working as high energy positrons veto (HEPVeto).

Photons fly unhindered to the Electromagnetic Calorimeter (ECal), and to the Small Angle Calorimeter (SAC). The SM Bremsstrahlung radiation rate would not fit with the long decay time (300 ns) of BGO crystals, "blinding" the calorimeter most of the time. For this reason, ECal has a central hole of $\sim$105 mm side, which allows radiation to reach the faster SAC. ECal is made of 616 $21\times21\times230$ mm^3 BGO crystals, coupled to HZC Photonics XP1911 photomultipliers (readout sampling: 1 GHz, 1024 samples) [7]. The scintillating units are arranged in a cylindrical shape (radius $\sim$ 300 mm).
SAC consists of 25 $30\times30\times140$ mm^3 PbF_2 Cherenkov crystals, coupled to Hamamatsu R13478UV photomultipliers (readout sampling: 2.5 GHz, 1024 samples) [8]. PbF_2 time resolution ($\sim$ 100 ps) allows us to reconstruct Bremsstrahlung events. The distance between the target and ECal is approximately 3.45 m, while between ECal and the SAC front faces is $\sim$ 50 cm. A TimePix3 silicon pixels detector monitors the exhausted beam. The detector consists of 12 sensors, each made of a 256×256 pixels matrix. With a 8.4×2.8 cm^2 surface, it's the biggest TimePix3 array used so far in particle physics.

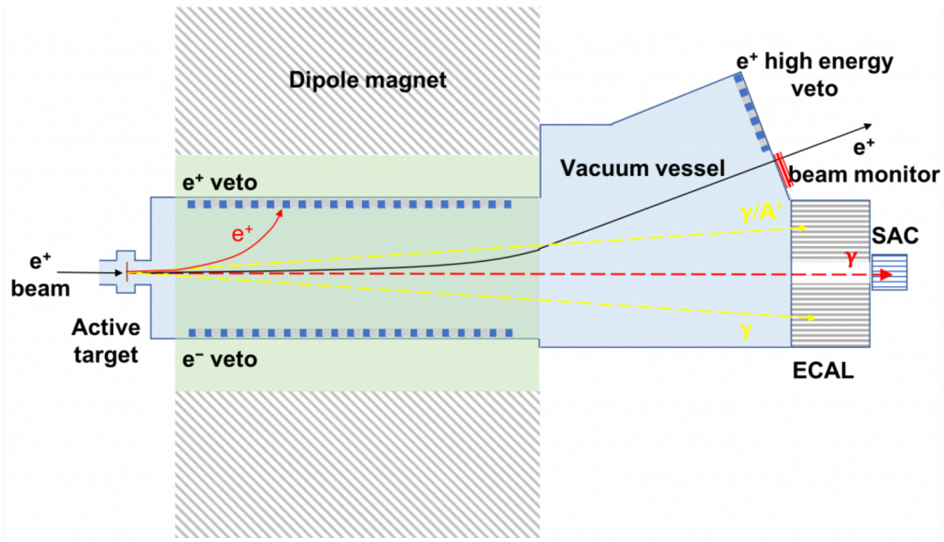

Figure 1: A schematic of PADME. The positron beam hits the target, where the annihilation happens; charged particles are deflected in vacuum by the magnetic field towards the vetoes, while photons arrive to the calorimeters (see text for more details).

2.3 Data taking run I and future prospects

The first run of the experiment lasted from October 2018 to March 2019. Priorities for first run has been set to:

1. the development of an online monitor system for the experiment, in order to have reliable information about the experiment during data taking
2. calibrations studies for every detectors, a crucial point for the events reconstruction, performed with beam (target and veto) and cosmic rays (ECal and SAC)
3. finding the best beam configuration, moving from a secondary beam, where beam positrons are obtained by the collision of accelerated electrons on a target, to a primary beam, where positrons are accelerated after the production

4. performing background studies, in order to compare them to the Montecarlo of the experiment
5. providing information about the number of positrons arriving on target
6. collect a sample of 10^{12} positrons on target (POT): a preliminary estimate on the result we obtained gave us $\sim 7 \cdot 10^{12}$ POT for the first run, but we must include uncertainty to this number.

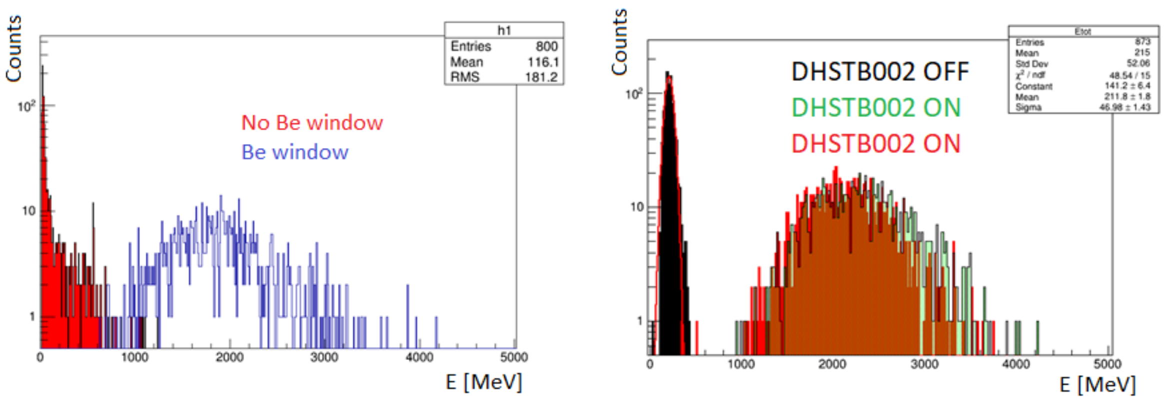

Figure 2: On the left, the total energy distribution of the Montecarlo of the experiment, with and without the beryllium window; on the right, the total energy distribution of the collected data (DHSTB002 is the last dipole of the transfer line before the target).

One of the most important task was to better understand the beam-induced background of the experiment. In first place, a 3 times smaller background has been obtained switching from secondary to primary beam. In second place, data analysis suggested that the main cause for this kind of background was due to the beam hitting the beryllium window separating BTF vacuum from PADME vacuum. The addition of the beam line and of the beryllium window to the Montecarlo of the experiment provided us a more reliable simulation of the collected data. In fig. 2 it's possible to note the similar behaviour of the total energy distribution in the Montecarlo and in data, once the beryllium window is added to the simulation.
A second calibration tool is going to be placed on ECal: it will use a ^{22}Na source, that will be moved in front every scintillating units also to monitor the performance of the calorimeter during data taking. Promising results on beam background decrease have been obtained with a different beam configuration, and the shift of the beryllium window should guarantee further improvements. The collaboration asked for a second physics run in order to reach 10^{13} positrons on target.

3 Conclusions

The PADME experiment at Laboratori Nazionali di Frascati started its search for the possibile mediator A' of a new interaction between dark matter and standard matter. The particle, called "dark photon" in analogy with the Standard Model photon, will be searched as a peak in the missing mass distribution of the annihilation process $e^+e^- \to \gamma A'$. A first run of the experiment was performed from October 2018 to March 2019, allowing the study the background of the experiment and to perform calibration studies of the detectors. We collected 10^{12} positrons on target during Run I, and the collaboration asked for additional time to reach the goal of 10^{13}.

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