THE PHYSICS PROGRAM OF THE PADME EXPERIMENT*

P. Gianotti

on behalf of the PADME Collaboration†

Laboratori Nazionali di Frascati dell'INFN, Via E. Fermi 54, 00044 Frascati, Italy

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Massive photon-like particles are predicted in many extensions of the Standard Model as possible portals toward a hidden sector where dark matter is secluded. They are vector bosons mediating the interaction between ordinary and dark matter and can be produced in different processes through a dim mixing to the photon. The PADME experiment searches for a signal of a dark photon A' in the $e^+e^- \to \gamma A'$ reaction in a positron-on-target experiment. For this purpose, the missing mass spectrum is analysed for final states with a single photon, produced in the annihilation of the positron beam of the DAΦNE Beam-Test Facility, at Laboratori Nazionali di Frascati of INFN, on the electrons of a diamond target. By collecting 10^{13} positron-on-target, a sensitivity on the interaction strength down to 0.001 is achievable in the mass region $M(A') < 23.7$ MeV/c^2. The scientific program of the experiment and its current status are here illustrated.

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1. Introduction

The nature of dark matter (DM) is nowadays an open problem that connects particle physics and cosmology. From astrophysical observations, something different from ordinary baryonic matter should exist with an abundance 5 times larger than Standard Model particles and there are no reasons why this new entity cannot be produced at particle accelerators.

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† A.P. Caricato, G. Chiodini, M. Martino, I. Oceano, F. Oliva, S. Spagnolo (INFN LE and Univ. Salento), F. Bossi, B. Buonomo, R. De Sangro, D. Domenici, G. Finocchiaro, L.G. Foggetta, M. Garattini, A. Ghigo, F. Giacchino, P. Gianotti, B. Liberti M. Martini, I. Sarra, B. Sciascia, T. Spadaro, E. Spiriti, C. Taruggi, E. Vilucchi (INFN LNF), F. Ferrarotto S. Fiore, E. Leonardi, E. Long, G.C. Organtini, G. Piperno, M. Raggi, F. Safai Tehrani, P. Valente (INFN Roma1 and Univ. Sapienza) J. Alexander, A. Frankenthal (Cornell Univ.) S. Ivanov, V. Kozhuharov, R. Simeonov (Univ. Sofia).

DM could live in a hidden sector and the link with ordinary matter might be realized via sub-GeV mediators of new forces. Some theoretical models postulate the existence of a new Abelian broken gauge symmetry $U_D(1)$ mediated by massive dark photon (DP) A', interacting with ordinary photons via a kinetic mixing $\frac{\epsilon}{2}F^{\mathrm{QED}}_{\mu\nu}F^{\mu\nu}_{D}$ with $\epsilon \ll 1$ being the dimensionless strength of the mixing [1]. The search for DP signals can be carried out at particle accelerators by means of low-cost, high-impact experiments and thus it has become the main goal, or the side product, of many particle physics experiments [2]. The Positron Annihilation into Dark Matter Experiment (PADME), taking place at the Laboratori Nazionali di Frascati (LNF) of INFN, occupies a special role within this panorama. It has the special characteristic of requiring only that the new boson couples to the electromagnetic field and, therefore, it poses very few constraints on its nature. In the following sections, an overview of the experiment and of the present status of the activities is reported.

2. The PADME experiment

The main goal of the PADME experiment is to search for a DP produced by the annihilation of a positron beam with the electrons of a thin active diamond target at rest [3].

The process under study is

$$e^+e^- \to A'\gamma \,. \tag{1}$$

By measuring the interaction point of the incoming positron and the recoil four-momentum of the outgoing photon, the mass of the missing state (A') can be obtained through the formula

$$M^2 = \left(P_{e^+} + P_{e^-} - P_\gamma\right)^2 \,, \tag{2}$$

where $P_{e^+}, P_{e^-}, P_\gamma$ are positron, electron, and photon four-momenta. The information on the photon energy and divergence is determined by measuring its impact position with respect to the positron interaction point. These requirements have driven the design of the experimental setup, whose main components are:

— a thin (100 μm) active diamond target, able to measure on-line the multiplicity and the average position of the beam, thanks to orthogonal graphitic strips realized on its opposite faces;

— a dipole magnet, producing a field of about 0.5 T, to deflect any non-interacting positrons out of the detector acceptance and to divert any charged particle produced in the target interaction toward charged particle veto detectors;

— three charged particle veto stations, to reject background reactions. They are arrays of plastic scintillator sticks, consisting of 96, 90 and 16 elements, respectively (pVeto, eVeto, HepVeto);

— a vacuum chamber, to avoid as much as possible interactions with air of primary and secondary particles in their travel in the apparatus;

— a BGO Electromagnetic Calorimeter (ECAL), to measure and/or veto final-state photons. It has a central square hole to let Bremsstrahlung radiation to pass through and hit the SAC;

— a PbF_2 fast Small Angle Calorimeter (SAC), to veto photons emitted at small angle with respect to the primary positron beam;

— a solid state beam monitor detector.

Figure 1 shows the experimental setup with the main detector components outlined: in the picture, the thin grey/red tracks correspond to a Bremsstrahlung event, and the thick grey/yellow ones to a $\gamma\gamma$ reaction. These final states represent the major source of physics background for the PADME measurement.

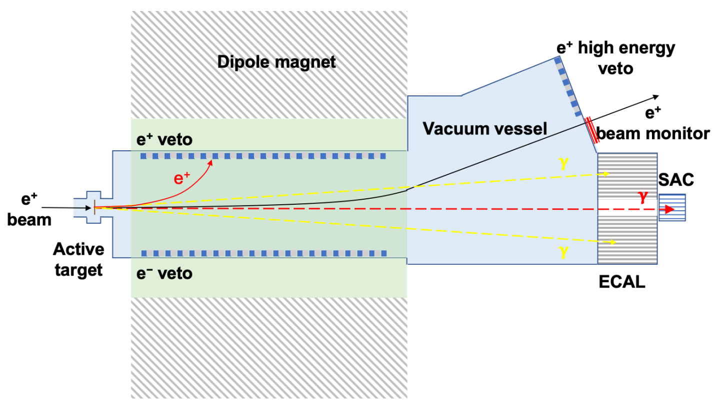

Fig. 1. (Colour on-line) Schematic, top view of the PADME experiment. Main detector components are indicated together with the tracks corresponding to a Bremsstrahlung event (thin grey/red) and a $\gamma\gamma$ event (thick grey/yellow).

The physics potential of the PADME experiment extends beyond DP search. The built detector is sensitive to any new light particle, including scalars and pseudo-scalars that are produced in the positron-on-target interaction. An estimate of the physics potential of PADME to search for axion-like particles as well as other exotic states is ongoing [4]. In addition, it will be possible to perform measurements of the differential cross sections for Bremsstrahlung emission for positrons in the $O(100\text{ MeV})$ energy range and to evaluate the multi-photon annihilation cross sections.

Recent observations of the decays of excited ^{8}Be have shown an anomalous yield of electron–positron pairs production, which might be explained by the existence of a new vector particle, labelled X-boson, of mass ~ 17 MeV [5]. As pointed out in [6], setting the positron beam energy at ~ 282 MeV would allow PADME to produce this state resonantly. The idea is to perform a beam-dump measurement and to look for an enhancement of the cross section of the interacting beam with a 10 cm W target, when approaching the production threshold.

The PADME positron beam is provided by the LINAC present at LNF on a beam transfer-line optimized for the transport of positrons or electrons in a wide range of intensity, energy, beam spot dimensions and divergence. Each of the 50 pulses accelerated by the LINAC can be either driven to a small ring for emittance damping (and from there injected into the DAΦNE collider rings), or to the Beam Test Facility (BTF) line where the PADME experiment is installed. Positrons can be accelerated up to 550 MeV after being generated in the LINAC on a W–Re converter of 2 X_0 (positron converter) located after the first electron accelerating sections (primary positron beam). Alternatively, a secondary positron beam of slightly higher energy can be produced by a primary electron beam of 750 MeV hitting a Cu converter of selectable X_0 (1.7, 2, or 2.3) (BTF target) located before a 1 m thick concrete wall that separates the LINAC from the BTF experimental hall. An energy selection system and collimators on the BTF transfer-line define momentum, spot size, and intensity of the beam. Figure 2 shows the details of the PADME beam line.

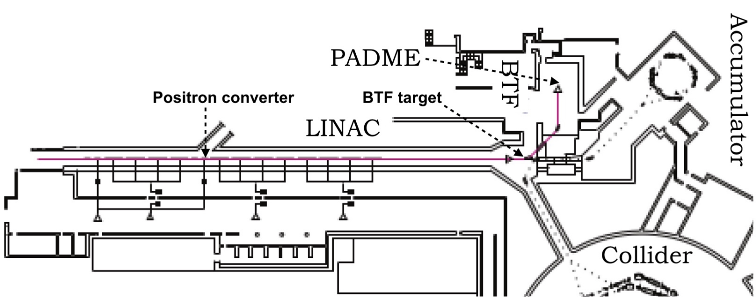

Fig. 2. Layout of the PADME beam line.

3. Status and perspectives

The PADME experiment was commissioned in September 2018 and took data until the end of February 2019. Almost all of the collected data (about 7.5×10^{12} POT) were acquired with the positrons produced at BTF target, while a few days of data at the end of February 2019 were instead collected with the primary positron beam. These data were very useful to set up the beam line, to calibrate the detector components, and to establish the running conditions for the real physics run foreseen for 2020. Figure 3 shows the online response of the PADME apparatus.

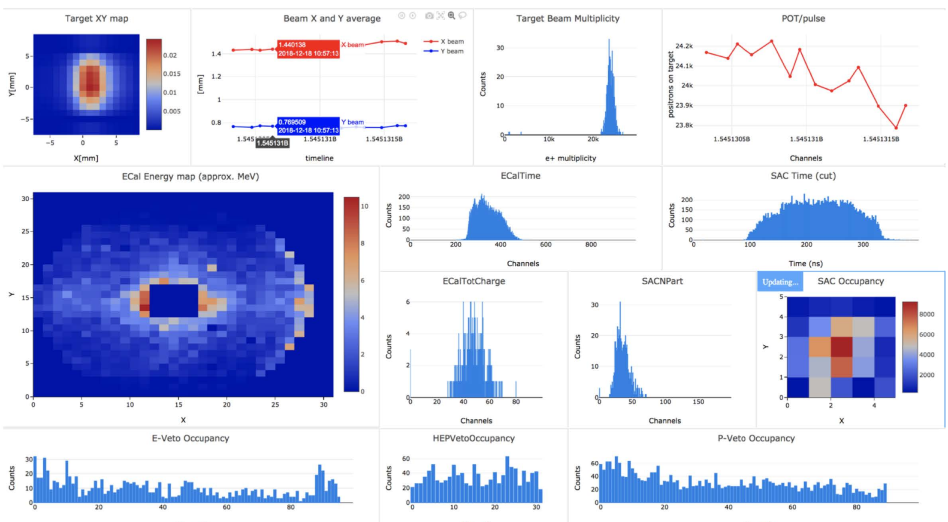

Fig. 3. Screenshot of the PADME on-line monitor. All main information from each detector is available in a single web page to control running conditions. High levels of backgrounds are visible in ECal, above all around the central hole.

One of the main objectives of the ongoing data analysis is the precise determination of the background level that is crucial to achieve the experimental goal. Two different background components are present: beam-induced and physics backgrounds. The beam component first comes from the Be window used to separate the accelerator vacuum from the detector vacuum. This produces scattering of beam positrons, creating secondary particles which are not collinear with the beam trajectory and can potentially reach the ECAL. Furthermore, the beam has an energy spread, and positrons with an energy different from the nominal energy leave the magnet that steers the beam from the injection point into the PADME target at an angle, hitting other parts of the detector and showering further secondary particles into the ECAL. To reduce beam-induced background, the forthcoming PADME data taking will see a completely new beam line. The Be window will be removed and the two different vacuum regions will be separated by the use of a thinner Mylar window placed more upstream. This will also help to reduce the presence of off-energy particles.

The physics background comes from standard multi-photon e^+e^- annihilations and Bremsstrahlung events. The apparatus has, therefore, been designed specifically to reduce this background. Two/three photon final states are easily identified by the highly segmented ECAL detector that exhibits both an excellent angular (~ 1 mrad) and energy ($\sim 2\%/\sqrt{E}$) resolution. The rate of Bremsstrahlung photons is 4000 time higher than the rate of annihilation and the angular distribution of Bremsstrahlung radiation is sharply peaked toward small angles. To prevent these photons from compromising the measurement of single photon final states, the ECAL has been built with a central hole that let them pass through and hit the SAC. The SAC is a matrix of Cherenkov counters with a fast response that allows the individual identification of Bremsstrahlung photons, despite their high rate [7]. By performing an in-time correlation between the pVeto and the SAC signals, Bremsstrahlung events are tagged and rejected.

4. Conclusions

PADME is the first experiment searching for a dark photon signal using the missing mass technique on an extracted positron beam. During the experiment conditioning run, the detector collected 7.5×10^{12} POT and demonstrated that the design performance has been reached. The next steps for the collaboration are to finalize the absolute calibration of the detector, and to measure Bremsstrahlung and $\gamma\gamma$ annihilation cross sections with the collected data. At the same time, studies of the beam background are ongoing in order to fix the best conditions for a physics run in 2020, with the aim to collect 10^{13} POT. This will permit the experiment to probe the existence of a dark photon with a coupling $\epsilon\ O(10^{-3})$ in a mass range below 23.7 MeV/c^2.

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