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Abstract. In dark matter studies, the absence of experimental evidences other than the astrophysical observations, has triggered new approaches. Nowadays, many particle physics experiments at accelerators are trying to contribute by looking for signals of hidden particles postulated by different theoretical extensions of the Standard Model. This results in a vaste hunting for new particles with a wide range of properties with the intention to also give reason to other unexplained particle physics phenomena. Within this scenario is inserted the Positron Annihilation into Dark Matter Experiment (PADME) ongoing at the Laboratori Nazionali di Frascati of INFN that is looking for signals of hidden particles by studying the annihilations of a positron beam with the electrons of a fixed target. PADME had, up to now, two data taking periods devoted to the search of a dark photon signal, but its setup turned out to be also suited to explore the existence of a protophobic new boson of mass 17 MeV/c^2 postulated to explain an anomalous effect observed by a Hungarian group while studying nuclear excited states. In this paper it is reported an overview of the PADME experiment and of the modifications implemented to allow a dedicated data taking at 282 MeV beam energy, meant to produce the new particle at resonance.

1. Introduction

The anomaly observed in the distribution of the opening angle of e^+e^- pairs produced in the decays of excited ^{8}Be, ^{4}He and ^{12}C nuclei [1–3] can be interpreted with the creation and decay of an intermediate bosonic state of mass approximately 17 MeV/c^2 which has been called X_{17} [4,5]. Along the years, several light particles have been postulated by theoretical extensions of the Standard Model (SM) with a wide range of properties, in the attempt of justifying some unexplained phenomena like the (g-2)$_\mu$ anomaly or the nature of the dark matter. Up to now, none of these new feebly interacting particles has ever been observed. The existence of the X_{17} boson, if confirmed, will then represent a real breakthrough in the search of physics phenomena beyond the Standard Model.

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The Positron Annihilation into Dark Matter Experiment (PADME) ongoing at the Laboratori Nazionali di Frascati of INFN, is searching for dark sector candidates by studying the annihilations of the local positron beam, with a maximum energy of 550 MeV, with the electrons of a fixed target [6]. The PADME physics program includes, together with the dark photon search, Axion-Like-Particles (ALPs), proto-phobic X bosons and Dark Higgs investigations. Furthermore, thanks to its peculiar center of mass energy range, PADME has an unmatchable potential in ruling out or confirming the existence of the X_{17}. In fact, by properly setting the energy of the positron beam, the new boson might be produced via the resonant annihilation process: $e^+e^- \to X$ [7] and then identified through its decay via e^+e^-. This paper reports an overview of the PADME detector modifications and of the beam-line optimization performed to allow a dedicated data taking at 282 MeV beam energy, meant to produce the X_{17} at resonance.

2. The PADME detector

The PADME detector was designed to investigate the associated production of a dark photon A' together with an ordinary photon. The positron beam from the Beam Test Facility of the National Laboratories of Frascati (LNF) impinges on a 100 μm thick active diamond target that allows to measure the beam intensity and impact position. In the positron-target interaction, the production of a dark photon can actually occur via different mechanisms: resonant production, associated production, and "A' -sstrahlung" - similar to Bremsstrahlung, but with the SM photon replaced by the A'. PADME is studying associate production by selecting events where a single SM photon is detected by the a BGO Electromagnetic Calorimeter (ECAL – consisting of an array of 616 crystals) and nothing else is present in the other detectors, as shown in Figure 1.

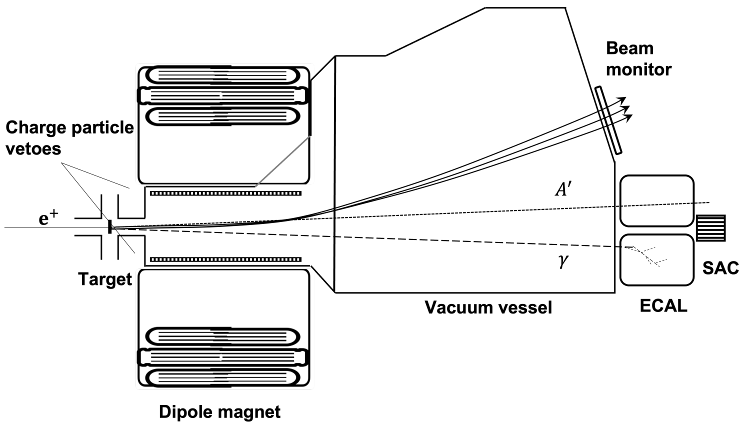

Figure 1. Layout of the PADME detector.

The mass $M_{A'}$ would possibly emerge as a peak in the invariant mass distribution of this process. The main source of background is represented by Bremsstrahlung that produces photons emitted at low angles to the beam. This is why the ECAL was built with a central hole, behind which is the Small Angle Calorimeter (SAC – made of PbF_2 crystals). The SAC information, having a faster response time than BGO, combined with that of the Charged Particle Vetoes, enables to cut out the high flux of Bremsstrahlung photons. This last detector consists of two stations of plastic scintillator sticks located along the walls of the vacuum vessel within the 0.5 T dipole. The experimental setup is completed by a TimePix3 [8] beam monitor located on the outgoing path of not interacting positrons. More details about the PADME detector can be found in [9].

3. The X17 hypotesis

While studying the de-excitation, via internal pair conversion (IPC), of ^{8}Be nucleus, it was announced in 2016 by an Hungarian group of the ATOMKI Institute of Debrecem, the presence of a 6.8 σ anomaly in the opening angle of the measured electron and positron pairs [1]. The attempt to explain this observation triggered a lot of theoretical speculation. Among others, Feng *et al.* put forward the possibility that the effect could be an indication of a protophobic new particle of mass approximately 17 MeV/c^2 [4]. In the following years, the ATOMKI group continued to study other de-excitation transitions via IPC of ^{4}He [2] and more recently of ^{12}C [3] producing new and more convincing evidences of this anomaly. All the observed excesses are compatible with a new particle (now named the "X_{17}") of mass roughly 17 MeV/c^2 decaying to e^+e^- that can indicate the existence of a new force of nature.

4. X17 production at PADME

The PADME detector, with a slightly modified setup, has the unique opportunity to investigate the existence of X_{17} anomaly by studying e^+e^- pairs resulting from positron-electron annihilations. The signature of the resonant production of this new particle would manifest with an increase of the produced e^+e^- pairs when the positron beam energy is such that $\sqrt{s} = M_X$. The main background to this measurement is represented by the Bhabha electron-positron scattering. This exhibits two contributions: the t-channel showing a peak at high energies for the scattered positron, and the s-channel more insidious having the same kinematics than the signal. The detection of the e^+e^- pairs will be performed combining ECAL signals to those of a new charge particles tagger. In fact, the PADME Charged Particle Vetoes cannot be used to constrain e^+e^- vertices not coming from the target. Therefore, it has been decided to switch off the PADME dipole and to add a new detector. This will be used combined with ECAL to disentangle electron-positron pairs form $\gamma\gamma$ events. It consists of an array of scintillators (5 mm thick) placed in front of ECAL. The vertical size of each bar is 4 cm allowing to stand the rate while covering the fiducial region of the calorimeter with a reasonable number of channels. The detector was commissioned in July 2022 during a test data taking aimed at tuning the beam line.

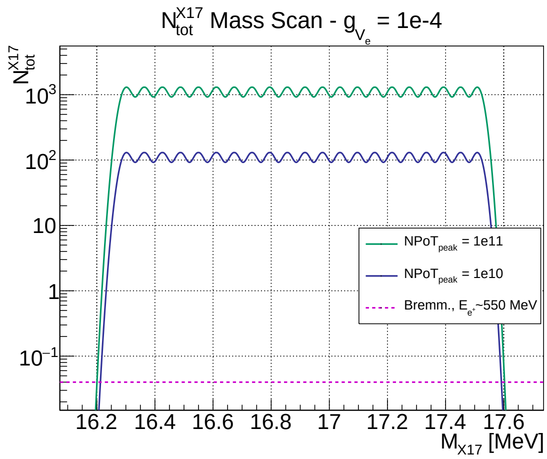

Figure 2. Number of expected X_{17} as function of M_X, under the hypothesis of a coupling constant $g_{ve} = 10^{-4}$. The green and blue curves represent 10^{11} and 10^{10} PoT for each beam energy value, respectively. The dotted horizontal line correspond the level of irreducible background [10].

The PADME data taking for searching the X_{17} will consist in counting the e^+e^- pairs produced at various beam energies to fully cover the interesting mass range. The X_{17} width is expected to be much smaller than the beam energy spread, therefore the existence of the new particle will contribute to the measured $e^+e^- \to e^+e^-$ rate in mostly a single bin of the scan. Using ECAL and measuring simultaneously $e^+e^- \to e^+e^-$ and $e^+e^- \to \gamma\gamma$ the evaluation of the ratio of the two processes for each energy bin will allow to identify any deviation from SM cross-sections. This strategy will allow to reduce systematic effects, since both, luminosity and acceptance measurements, cancel in the ratio.

Figure 2 shows the number of expected X_{17} as a function of the mass value explored for two different statistics of Positron-on-Target collected for each energy point: 10^{11} and 10^{10}, respectively. The value of the coupling constant considered is $g_{ve} = 10^{-4}$. The picture also shows the expected irreducible backgrounds.

5. Conclusion

The PADME experiment has the unique opportunity to confirm/disprove, in a complete model independent way, the existence of a new particle of mass ~ 17 MeV/c^2 predicted to explain an anomalous effect observed in nuclear reactions. A slightly modified setup of the detector has been commissioned in July 2022 and will performe an energy scan of the M_X mass region starting in Autumn 2022.

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References

[1] Krasznahorkay A J *et al.* 2016 *Phys. Rev. Lett.* **116** 042501 (*Preprint* 1504.01527)
[2] Krasznahorkay A J, Csatlós M, Csige L, Gulyás J, Krasznahorkay A, Nyakó B M, Rajta I, Timár J, Vajda I and Sas N J 2021 *Phys. Rev. C* **104** 044003 (*Preprint* 2104.10075)
[3] Krasznahorkay A J *et al.* 2022 (*Preprint* 2209.10795)
[4] Feng J L, Fornal B, Galon I, Gardner S, Smolinsky J, Tait T M P and Tanedo P 2016 *Phys. Rev. Lett.* **117** 071803 (*Preprint* 1604.07411)
[5] Feng J L, Fornal B, Galon I, Gardner S, Smolinsky J, Tait T M P and Tanedo P 2017 *Phys. Rev. D* **95** 035017 (*Preprint* 1608.03591)
[6] Raggi M and Kozhuharov V 2014 *Adv. High Energy Phys.* **2014** 959802 (*Preprint* 1403.3041)
[7] Darmé L, Mancini M, Nardi E and Raggi M 2022 (*Preprint* 2209.09261)
[8] Frojdh E, Campbell M, Gaspari M D, Kulis S, Llopart X, Poikela T and Tlustos L 2015 *JINST* **10** C01039
[9] Albicocco P *et al.* 2022 *JINST* **17** P08032 (*Preprint* 2205.03430)
[10] Mancini M 2022 *Hunting X17 using the resonant production at PADME* Master's thesis Tor Vergata Università degli studi di Roma