IL NUOVO CIMENTO **47 C** (2024) 115
DOI 10.1393/ncc/i2024-24115-y

Colloquia: IFAE 2023

Looking for X_{17} at PADME(*)

E. Di Meco for the PADME Collaboration(**)
INFN, Laboratori Nazionali di Frascati - Via Enrico Fermi 54, 00054 Frascati, Italy

received 13 February 2024

Summary. — The ATOMKI collaboration has recently confirmed the existence of the so-called "^{8}Be anomaly" also in the decay via Internal Pair Creation (IPC) of ^{4}He and ^{12}C. This anomaly can be seen as the creation and decay of a ~ 17 MeV intermediate particle called X_{17}. PADME Run III goal was to determine the existence and nature (whether it is a vector or pseudo-scalar) of X_{17}. The PADME experiment, located at the Frascati National Laboratories of INFN, can indeed generate X_{17} through positron annihilation with the electrons of a fixed thin diamond target. During Run II in 2020, PADME already collected data at a fixed center-of-mass energy of 20 MeV to search for a dark photon signal. On the contrary, the recently concluded Run III was performed at the center of mass energies around the expected mass value of X_{17}, with the aim of observing an enhancement in the e^+e^- pairs produced. Indeed, by analyzing the finely scanned data acquired around $\sqrt{s} = 17$ MeV, it will be possible to clearly identify any significant increases in cross-section induced by the production of a particle not predicted by the Standard Model.

1. – Introduction

The observed anomaly in the distribution of the opening angle of e^+e^- pairs, arising from the decays of excited ^{8}Be, ^{4}He and ^{12}C, finds an interpretation in terms of an intermediate bosonic state with a mass of approximately 17 MeV, referred to as X_{17} [1]. Over the years, various light particles have been theorized within extensions of the Standard Model (SM) to account for unexplained phenomena such as the $(g\text{-}2)_\mu$ anomaly and the nature of dark matter. Despite these theoretical propositions, none of

(*) IFAE 2023 - "Poster" session
(**) S. Bertelli, F. Bossi, R. De Sangro, C. Di Giulio, E. Di Meco, D. Domenici, G. Finocchiaro, L. G. Foggetta, M. Garattini, P. Gianotti, M. Mancini, I. Sarra, T. Spadaro, E. Spiriti, C. Taruggi, E. Vilucchi, V. Kozhuharov, K. Dimitrova, S. Ivanov, Sv. Ivanov, R. Simeonov, G. Georgiev, F. Ferrarotto, E. Leonardi, P. Valente, A. Variola, E. Long, G. C. Organtini, M. Raggi and A. Frankenthal.

these hypothesized particles has been experimentally observed up to now. Confirming the existence of the X_{17} boson would thus mark a significant advancement in the exploration of physics phenomena beyond the Standard Model.

The Positron Annihilation into Dark Matter Experiment (PADME), based at the Laboratori Nazionali di Frascati of INFN, aims to identify potential candidates in the dark sector by investigating the annihilations of a positron beam, with a maximum energy of 550 MeV, with electrons of a fixed target. The PADME physics program covers the exploration of dark photon candidates, Axion-Like-Particles (ALPs), protophobic X bosons, and Dark Higgs. Because of its center of mass energy range, PADME has the possibility to either validate or dismiss the existence of the X_{17} . Specifically, by precisely tuning the energy of the positron beam, the resonant annihilation process $e^+e^- \to X_{17}$ may lead to the production of the new boson, subsequently identified through its decay into e^+e^- .

2. – The PADME experiment

The Positron Annihilation Into Dark Matter Experiment (PADME) is a fixed target experiment that takes place at the Frascati National Laboratories of INFN. PADME, in fig. 1 (left), was designed to search a dark photon signal by studying the missing-mass spectrum of single photon final states resulting from 550 MeV positrons annihilations with the electrons of a 100 μm-thin active diamond target. In the e^+e^- interaction, the generation of a dark photon can take place through various mechanisms: resonant production, associated production, and a process analogous to Bremsstrahlung but involving the substitution of the standard model photon with the A'. The first two runs of PADME aimed to specifically investigate associated production by focusing on events in which a solitary standard model (SM) photon is identified by the BGO Electromagnetic Calorimeter (ECAL, comprising 616 crystals) and no other particles are detected in the remaining detectors. These two data taking underlined a much larger beam induced background than expected resulting in the necessity to develop a full simulation of the beamline of the Frascati Beam Test Facility [6] and also to use different beamline configurations during the two runs. The main result achieved using the collected datasets consists in the measurement of the cross section of the two-photon annihilation. Using the tag-and-probe method presented in [4], the cross-section was found to be:

$$\sigma(e^+e^- \to \gamma\gamma)_{\mathrm{PADME}} = 1.977 \pm 0.018\ (stat) \pm 0.119\ (syst)\ \mathrm{mb}$$

which agrees with QED at next to leading order, as calculated by Babayaga [5],

$$\sigma(e^+e^- \to \gamma\gamma)_{\mathrm{Theory}} = 1.9478 \pm 0.0005\,(stat) \pm 0.0020\,(syst)\ \mathrm{mb}$$

within the experimental errors. The result is shown along with other measurements at a comparable energy scale in fig. 1 (right).

3. – X_{17} anomaly and PADME RUN-III

The ATOMKI collaboration in Debrecen, Hungary, in 2016 observed an unusual occurrence in the decay processes of different nuclei, also known as "X_{17} anomaly". This anomaly was initially detected in the angular distribution of e^+e^- pairs produced during the decay of ^{8}Be nucleus. A notable statistical significant peak in the angular spectrum was indeed observed, corresponding to the decay of a particle with an estimated mass of

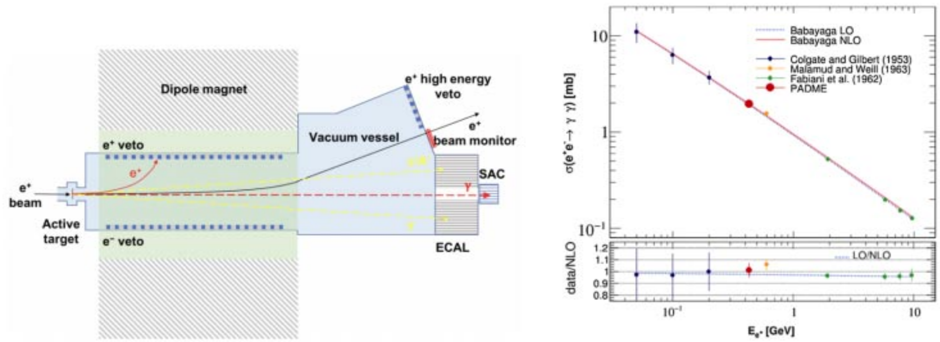

Fig. 1. – Left panel: PADME original setup. Right panel: $\sigma(e^+e^- \to \gamma\gamma)$ measurements at the <10 GeV energy scale. The measurement from PADME Run II is represented by the red marker while QED predictions are indicated by the line.

approximately 17 MeV [1]. Subsequently, the experiment was repeated with an improved experimental setup [2, 3], focusing on the decay processes of ^{4}He and ^{12}C nuclei.

The results of these follow-up experiments revealed that the X_{17} anomaly persisted in the decays of both ^{4}He and ^{12}C nuclei. In the case of ^{4}He, three different excited states were investigated, all of which exhibited significances exceeding 6σ for a particle with a mass of approximately 17 MeV decaying into e^+e^- pairs [3]. For ^{12}C, four distinct states were studied, with significance levels of 3σ, 3σ, 7σ, and 8σ, respectively [2].

PADME approach allows to look for any new particle produced in e^+e^- collisions through a virtual off-shell photon such as long lived ALPs, proto-phobic X bosons, Dark Higgs. Applying some minor changes to the experimental setup it was possible to explore the resonance X_{17} production, by finely tuning the beam energy to a center of mass value that matched the expected mass of X_{17} . The experimental signature of X_{17} would be the observation of a excess in the number of the detected e^+e^- pairs within a narrow beam energy interval, consistent with the particle mass constraints. The scanning procedure around the expected mass value was performed collecting data for a total of 47 different energy values around the X_{17} resonance, each with 10^{10} Positron on Target (PoT) collected, 6 points out of resonance (5 below, 1 above), to be compared with Monte Carlo data in order to asses the systematics, and 3 points without target (for background and beam energy spread studies). Considering the two viable options for X_{17} , vector and pseudoscalar, the expected 90% confidence level sensitivity of PADME RUN-III to the vector coupling ($g_{\nu e}$) and pseudo-scalar coupling (g_{ae}) is presented in fig. 2 [7].

4. – Preliminary results

Data analysis started from the below-resonance data. Figure 3 (left) illustrates the energy distribution of two-clusters events in the ECal as a function of the theta angle relative to the beamline. Owing to kinematic constraints, particles originating from target vertices should be confined within the red-highlighted box. The time difference between the two clusters for events belonging to the red-box region is also presented in fig. 3 (right) and shows a gaussian distribution with $\sigma \sim 1.5$ ns, demonstrating that the experiment is not dominated by background either from out-of-trajectory beam particles or from pile-up events.

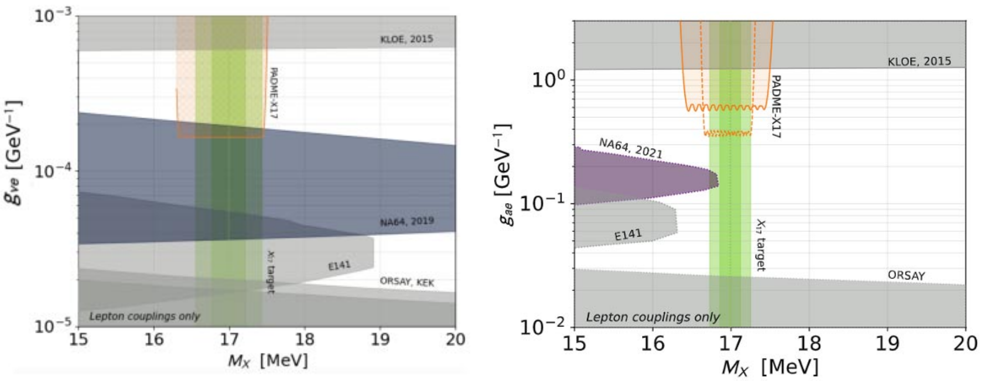

Fig. 2. – Current constraints on X_{17} [7] for vector (left) and pseudoscalar (right) models. The targeted parameter space for PADME Run III is shown in orange while the green band represent the constraint on X_{17} mass coming from the ATOMKI measurements.

5. – Conclusions

PADME was designed to investigate dark photons through the e^+e^- annihilation process. In 2022, the collaboration achieved a significant milestone by publishing its inaugural physics measurement. This study revealed that the cross-section for $e^+e^- \to \gamma\gamma$ aligns well with the predictions of the Standard Model at the next-to-leading order. Subsequently, the collaboration shifted its focus towards the X_{17} anomaly, identified at the ATOMKI collaboration. Hence a dedicated data-taking was executed, specifically targeting the on-resonance production of the X_{17} . From data quality first checks, it appears that the dataset is not prominently influenced by background. This indicates that the data will allow conducting a comprehensive analysis of the X_{17} anomaly.

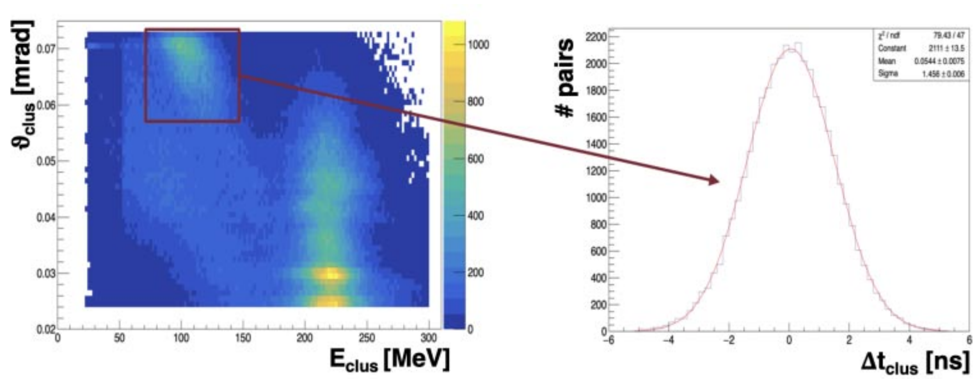

Fig. 3. – Left panel: energy of two-clusters events in ECal *vs.* theta angle to beamline. Right panel: Time difference of cluster pairs within red box.

REFERENCES

[1] Krasznahorkay A. J. *et al.*, *Phys. Rev. Lett.*, **116** (2016) 042501.
[2] Krasznahorkay A. J. *et al.*, *Phys. Rev. C*, **106** (2022) L061601.
[3] Krasznahorkay A. J. *et al.*, *Phys. Rev. C*, **104** (2021) 044003.
[4] Bossi F. *et al.*, *Phys. Rev. D*, **107** (2023) 012008.
[5] Carloni Calame C. M., Montagna G., Nicrosini O. and Piccinini F., *Nucl. Phys. B: Proc. Suppl.*, **131** (2004) 48.
[6] Buonomo B., Di Giulio C., Foggetta L. G. and Valente P., *The Frascati LINAC Beam-Test Facility (BTF) Performance and Upgrades*, in *5th International Beam Instrumentation Conference, TUPG29* (2023).
[7] Darmé Luc, Mancini Marco, Nardi Enrico and Raggi Mauro, *Phys. Rev. D*, **106** (2022) 115036.