THE PADME EXPERIMENT

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1 Introduction

The PADME experiment at INFN's Laboratori Nazionali di Frascati is a positron-on-fixed-target experiment operating in the center-of-mass (CoM) energy range of $14 < \sqrt{s} < 23$ MeV [1]. The positron beam is provided by the BTF facility of the LNF [2] [3]. The PADME initial goal is the search for an hypothetical particle, dubbed as "dark photon" (A'), mediator of a new type of interactions between ordinary and dark matter. The collaboration has carried out two data taking campaigns in 2018-19 and 2020 (RUN I, RUN II) with the purpose of observing the A', with null result.

In the fall of 2022 the Collaboration has dedicated its data taking (Run III) to the search of the so called "X17" particle. The postulated existence of the X17 comes as a consequence of the anomaly in the angular spectrum of internal pairs produced in the de-excitation of nuclear states observed by the ATOMKI Collaboration [4, 5, 6] in Debrecen, Hungary.

For the purpose, the cross sections of the processes $e^+e^- \to e^+e^-$ and $e^+e^- \to \gamma\gamma$ in the energy range $16.5 < \sqrt{s} < 17.5$ MeV were measured. In fact, if the X17 exists, the e^+e^- production rate is expected to be enhanced by an amount that depends on the particle's coupling with the electromagnetic current g_{ve}:

$$\mathcal{L} \supset g_{ve} X_{17}^{\mu} \bar{e} \gamma_{\mu} e, \tag{1}$$

for values of the energy corresponding to the X17 mass [7].

2 Activity of the PADME group in 2025: Run III analysis

Figure 1 shows a scheme of the apparatus used to perform the Run III data taking. The setup consists of:

- a low divergence positron beam, impinging on a diamond, thin active target, capable of monitoring the beam spot dimensions and intensity;
- a vacuum chamber to avoid particle's spurious interactions;
- a dipole magnet, instrumented on both sides with 2 arrays of plastic scintillator tiles, meant to deflect and measure charged particles, during Run-III it was switched off;
- a finely-segmented, high-resolution e.m. calorimeter (ECal). ECal has in the center, a square hole to allow the non interacting particles and high frequency Bremsstrahlung photons to pass through. During 2022 data taking, it had to detect e^+e^- pairs from X_{17} decay. To distinguish them from photons, a new detector (ETagger) was installed. It consists of an array of plastic scintillator slabs placed in front each row of ECal crystals. Lepton/photon separation is performed combining the signals of the 2 detectors in coincidence/anticoincidence;

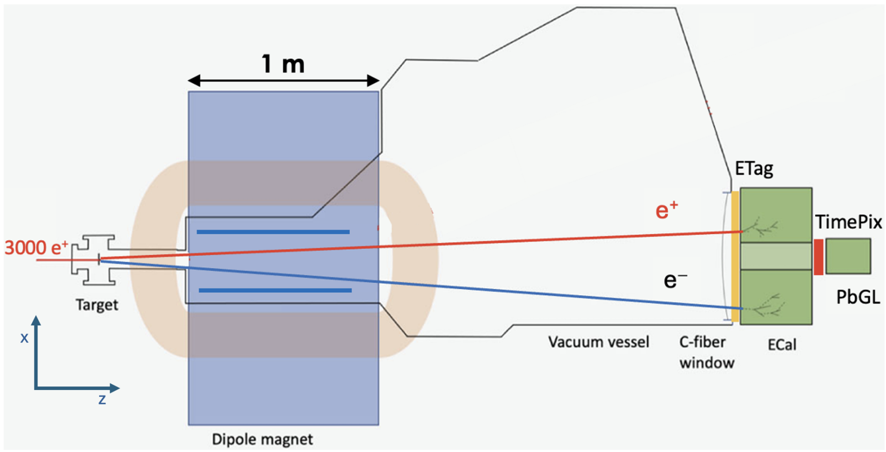

Figure 1: *The layout of the PADME experiment. During Run-III, dedicated to the X_{17} study, some changes were implemented to the experimental setup: the magnetic field was switched off and the veto detectors were not used; to allow lepton/photon separation an array of plastic scintillators was mounted in front of the main electromagnetic calorimeter (ETagger); a LeadGlass crystal was installed in place of the SAC behind the main calorimeter's hole, to be used as an online beam monitor; the solid state beam monitor (TimePix3) was moved upstream the LeadGlass.*

A change implemented to the experimental setup for Run III regards the Small Angle Calorimeter (SAC) whose original purpose was to detect Bremsstrahlung photons in coincidence with the veto detectors. Since these last were off in 2022, the SAC was replaced by a LeadGlass crystal aimed at monitoring online beam energy. A more precise evaluation of beam energy was obtained offline processing the signals of the solid state beam monitor detector. It consists of an array (6×2) of Timepix3 chips able to record either the time-of-arrival (ToA) and the energy of the incident particles providing excellent energy and time resolutions.

The positron beam energy was varied in the range between 269 and 296 MeV, with energy spacing between points fixed to less than half of the expected width of the resonance's line shape. The beam performance for Run III data has been discussed in a dedicated paper [8]: the beam energy and its relative spread are under control even beyond the required specifications.

A careful analysis of the acquired data sample has been carried out along the entire years 2023-2024, paying particular attention to minimizing all possible systematic effects. Uncertainties below 1% per point were achieved. A blind analysis has been performed, as discussed in the paper [9].

Upper limits on the coupling strength of the hypotetical particle have been set on a previously unexplored region of the available parameters space. An excess of events over the predicted background expectation is observed for an X17 mass of 16.90 Mev/c^2, with a local and global significance of 2.5 and 1.8±0.2 standard deviations, respectively (see figure 2). Very importantly, the location of this excess is consistent with the average value of the results reported by the ATOMKI experiment.

This exciting result has been communicated for the first time at a topical conference in Genoa in April 2025 and subsequently published in [10]. It has also been reported in several seminars and conferences worldwide.

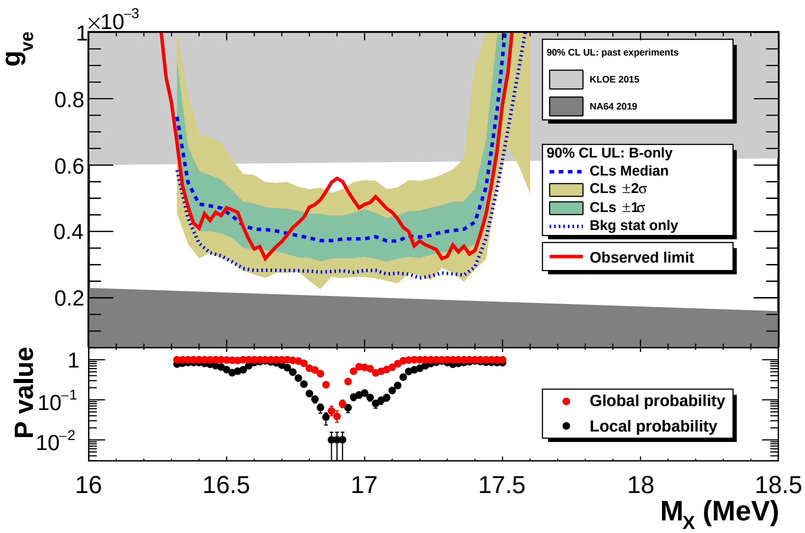

Figure 2: *Exclusion upper limits as a function of M_x at 90% CL. The solid red line is the observed limit curve, and the green and yellow bands are the 1σ and 2σ local envelopes around the median expected curve (dashed blue line) for the B-only hypothesis. The gray filled areas are the excluded regions at 90% CL from the KLOE and NA64 experiments. The bottom panel shows the probability values corresponding to the observed upper limits. Black and red dots denote local and global probabilities, respectively. Figure taken from* [10].

3 Activity of the PADME Group in 2025: Run IV

Figure 3: *: Picture of the PADME Micromega chamber.*

The primary limitations in the analysis of RUN III were identified as the exact determination of the number of positrons on target and the systematic uncertainties on the acceptance of the two-cluster events.

These challenges can be mitigated by separating the charged and neutral final states and measuring the ratio of the two corresponding cross sections. Due to the similar event topology, acceptance-related effects cancel out, and no absolute normalization with respect to the incoming positrons flux is required. On the other hand, due to the relatively low cross section of the $\gamma\gamma$ channel, a larger luminosity per point is needed.

Following these considerations, a new data taking (RUN IV) was planned for 2025, with a few modifications to the experimental apparatus and the data taking strategy:

1. The diamond target was moved downstream by ∼30 cm, consequently increasing the acceptance for two-body events by a factor ∼2.

2. A Micromegas-based detector, featuring a central anode plane and two signal readout planes with an innovative "diamond layout", was built during 2024 and installed in front of the ECAL in early 2025, see figure 3.

3. About twice the data with respect to RUN III were acquired to reduce the statistical uncertainty.

4. More no-target data were acquired, to study in detail the beam-induced background.

Several beam tests have beam performed to state the performance of the new detector, and the results were compliant with Run IV requests in terms of resolution, rate capability and efficiency. A second, smaller, Micromega detector was also installed at the end of the beam line for beam monitoring purposes.

RUN IV has started in May 2025 and ended in November 2025. In total, 39 data points were taken, 36 around the supposed resonance, 3 far from it for calibration purposes. About 2×10^{10} POT per point were collected, a substantial increase with respect to what taken during RUN III.

Data analysis of RUN IV data is ongoing. The main challenge is that of being able to correctly reconstruct the tracks of charged particles in the Migromega detector, in events with high contamination of beam-induced background. First results are expected by the end of 2026.

4 List of Conference Talks presented by LNF Speakers in Year 2025

Below is the list of conference presentations given by LNF PADME members in 2025:

1. T. Spadaro,"PADME Run III preliminary results", talk at the *Dark Matter at Accelerators Conference*, Genova, 8 - 11 Apr. 2025.

2. T. Spadaro,"PADME Run III preliminary results", *LNF General Seminar*, Frascati, 15 Apr. 2025.

3. T. Spadaro,"Search for a new 17 MeV resonance via e^+e^- annhilation with the PADME experiment", *CERN EP Seminar*, Geneva, 3 Jun. 2025.

4. M. Mancini, "Search for the X17 particle with the PADME detector", talk at the *International Conference for New Frontiers in Physics*, Crete, 17 - 31 Jul. 2025.

5. E. Di Meco, "Search for the X17 particle with the PADME experiment", talk at the *Lepton Photon 2025*, Madison (USA), 25 - 29 Aug. 2025.

6. E. Di Meco, "The PADME experiment", talk at the *Cosmic Whispers Coast Action*, Sofia, 12 - Sep. 2025.

7. M. Antonelli, "Search for a 17 MeV resonance via e^+e^- annhilation with the PADME experiment", talk at the *Light Dark World 2025*, Madrid, 16 - 19 Sep. 2025.

8. M. Mancini,"PADME run III results on X17 search", talk at the *Congresso Nazionale SIF 2025*, Palermo, 22 - 26 Sep. 2025.

9. E. Di Meco, "Hunting X17 at PADME", talk at the *Munich Dark Matter Meeting*, Munich, 14 Oct. 2025.

10. C. Arcangeletti, “Results from PADME experiment”, talk at the *Workshop Italiano della Fisica ad Alta Intensità (WIFI 2025)*, Bari, 11 - 14 Nov. 2025.

For the complete list of presentations to conferences given by the PADME collaborators, please refer to `http://padme.lnf.infn.it/talks/`.

5 List of Publications by LNF Authors in Year 2025

Below is the list of papers published by LNF PADME members in 2025:

1. S. Bertelli *et al.*, “Blind unblinding procedure for the PADME X17 data sample ”, JHEP 06 (2025) 01, 040.
2. K. Dimitrova *et al.*, “New light particles searches with PADME ”, Acta.Phys.Polon.Supp. (2025) 4,4-A3.
3. F. Bossi *et al.*, “Search for a new resonance in e+e- annhilations with the PADME experiment”, JHEP 11 (2025) 007.

The complete list of papers published by the PADME collaboration can be found here `http://padme.lnf.infn.it/papers/`.

References

1. M. Raggi and V. Kozhuharov, Rivista del Nuovo Cimento 38 no. 10 (2015). DOI 10.1393/ncr/i2015-10117-9.
2. B. Buonomo *et al.*, arXiv:2308.03058
3. L. Foggetta *et al.*, doi:10.18429/JACoW-IPAC2021-THPAB113
4. A. J. Krasznahorkay *et al.*, Phys. Rev. Lett. 116 (2016) 042501.
5. A. J. Krasznahorkay *et al.*, Phys. Rev. C 104 (2021) 044003.
6. A. J. Krasznahorkay *et al.*, Phys.Rev.C 106 (2022) L061601.
7. L. Darmé, M. Mancini, E. Nardi and M. Raggi, Phys. Rev. D 106 no. 11 (2022) 115036.
8. S. Bertelli *et al.*, JHEP **08** (2024), 121 doi:10.1007/JHEP08(2024)121 [arXiv:2405.07203 [hep-ex]].
9. S. Bertelli *et al.*, JHEP **06** (2025), 007 doi:10.1007/JHEP06(2025)040 [arXiv:2503.05650 [hep-ex]]
10. F. Bossi *et al.*, JHEP **11** (2025), 040 doi:10.1007/JHEP11(2025)007 [arXiv:2505.24797 [hep-ex]]