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 DAΦNE LINAC [2]. Its first goal is the search for an hypotetical particle, dubbed as "dark photon" (A'), mediator of a new type of iteractions between ordinary and dark matter. The A' can be produced in reactions of the type

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

The observation of an excess of events for a specific energy of the emitted photon over the expected SM distribution would signal the existence of the A'.

As a consequence of the observed anomaly in the angular spectrum of internal pairs produced in the de-excitation of nuclear states by the ATOMKI Collaboration [3, 4, 5] and the postulated existence of a particle with mass M_X around 17 MeV (the "X17" particle), the Collaboration has dedicated its data taking in the fall of 2022 (Run III) to an independent search of the X17.

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}:

$$\mathcal{L} \supset g_{ve} X_{17}^{\mu} \bar{e} \gamma_\mu e, \tag{2}$$

for values of the energy corresponding to the X17 mass [6].

2 Run III apparatus

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 sticks, meant to deflect and measure charged particles, during Run-III it was switched off;
- a finely-segmented, high-resolution e.m. calorimeter (ECal), with the main purpose to detect the single SM photon of reaction 1. ECal has in the center, a square hole to allow high

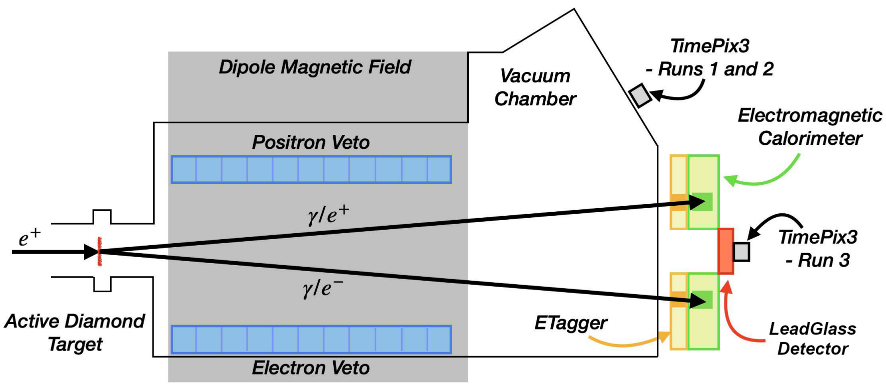

Figure 1: *The layout of the PADME experiment. During Run-III, dedicated to the X_{17} study, some changes were implemented to the experimental setup: the magnetic field was switched off and the veto detectors were not used; to allow lepton/photon separation an array of plastic scintillators was mounted 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 behind the LeadGlass.*

frequency Bremsstrahlung photons to pass through. During 2022 data taking, it had also 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;

A change implemented to the experimental setup 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 in 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.

3 Activity of the PADME Group in 2024

PADME Run III collected data can be divided in 3 samples:

- *on resonance*, 47 points collected in the energy range 263-299 MeV. For each energy value $\sim 10^{10}$ POT were recorded;
- *below resonance*, 5 points collected in the energy range 205-211 MeV with the same statistics, for each energy value, of on resonance points. They are necessary to define the analysis method;
- *above resonance*, 5 different runs of $\sim 0.4 \times 10^{10}$ POT collected all at the same energy, 402 MeV, but at different times to check stability and reproducibility of the apparatus response.

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. There was a certain number of optics adaptations along the run, which can be taken into account at the analysis level. The proposed mass scan region in Ref. [7] was considered large enough to allow for meaningful signal-free regions under the hypothesis that positrons annihilate against at-rest target electrons. However, after the realization that the electron motion significantly broadens the CoM energy of the collisions [9] and consequently the distribution of the potential X17 enhancement over the collected data sample, this approach had to be abandoned. The uncertainty on the X17 mass reported by the ATOMKI Collaboration and the broadening of the X17 production enhancement caused by the atomic electron motion leave no significant regions in which contributions from X17 production can be safely excluded.

For this reason a simple sideband subtraction method cannot be applied to Run III data and a specific procedure had to be developed to enable an accurate assessment of the data quality and of the expected systematic uncertainties, whitout unblinding the analysis [10].

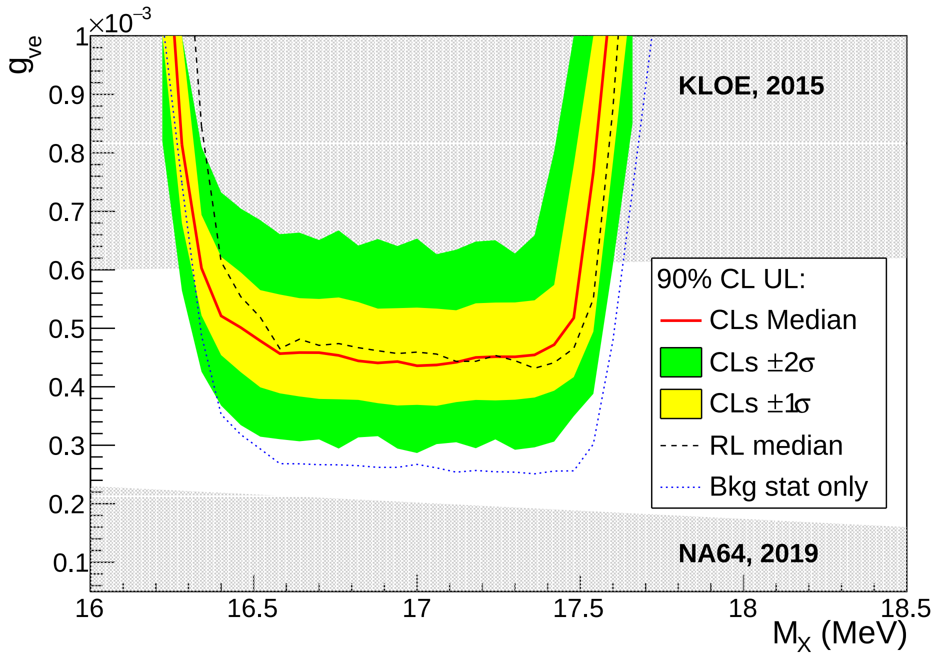

Figure 2: *Expected 90% confidence level upper limits in absence of an X_{17} signal from the PADME Run III data sample, as a function of the X_{17} coupling g_{ve} and mass M_X. The median upper limit is shown in red. The $\pm 1\sigma$ and $\pm 2\sigma$ upper limit coverages are shown in yellow and green, respectively. The regions excluded by past searches are shown in grey.*

In Fig. 2, the expected 90% confidence level exclusion limit in the absence of signal is shown. The red line is the median upper limit, while the yellow (green) bands represent the $\pm 1\sigma$ ($\pm 2\sigma$) quantiles.

The final result of the analysis is expected by Spring 2025.

4 Preparation for RUN IV

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 normaliation 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.

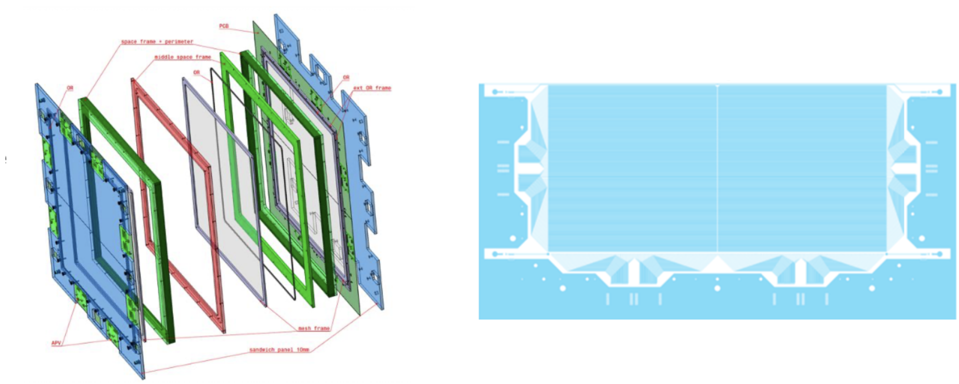

Figure 3: *Left panel: A sketch of the new PADME Micromegas chamber. Right panel: the innovative diamond layout of the PADME Micromega chamber.*

In order to be able to perform the above measurement, tracking capabilities must be added to the apparatus. Therefore a new Micromegas-based detector has been built during 2024, featuring a central anode plane and two signal readout planes with an innovative "diamond layout". It will be installed in front of the ECAL in early 2025. Several beam tests have beam performed to state the performance of the detector, and the results were compliant with Run IV requests in terms of resolution, rate capability and efficiency.

RUN IV is scheduled to start in the Spring of 2025 and is expected to last for about 6 months.

5 List of Conference Talks presented by LNF Speakers in Year 2024

Below is the list of conference presentations given by LNF PADME members in 2024:

1. M. Mancini,"The X17 resonant research at PADME", poster at the *International Winter Meeting on Nuclear Physics*, Bormio, 22 - 26 Jan. 2024.

2. E. Di Meco, "Il bosone X17 a PADME", talk at the *Incontri di Fisica delle Alte Energie 2024*, Firenze, 3 - 5 Apr. 2024.

3. P. Gianotti, "Search for Light-Feebly Interacting Particles with the PADME experiment", talk at the *International Research Network (IRN) Terascale*, Frascati, 15 - 17 Apr. 2024.

4. M. Mancini,"The X17 search with the PADME experiment", talk at the *15th International Workshop on the Identification of Dark Matter*, L'Aquila, 8 - 12 Jul. 2024.

5. E. Di Meco, “Cornering the X17 at PADME”, talk at the *Workshop Italiano della Fisica ad Alta Intensità (WIFI 2024)*, Bologna, 12 - 15 Nov. 2024.

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

6 List of Publications by LNF Authors in Year 2024

Below is the list of papers published by LNF PADME members in 2024:

1. S. Bertelli *et al.*, “Beam diagnostics with silicon pixel detector array at PADME experiment”, JINST 19 (2024) 01, C01016.
2. S. Bertelli *et al.*, “Design and performance of the front-end electronics of the charged particle detector of the PADME experiment”, JINST 19 (2024) 01, C01051.
3. E. Di Meco, “Looking for X17 at PADME”, Nuovo Cim. C47 (2024) 3,115.
4. S. Bertelli *et al.*, “Characterization of the positron beam for the PADME experiment”, JHEP 08 (2024) 121.
5. P. Gianotti, “Investigating the dark sector with the PADME experiment”, Nuovo Cim.C47 (2024) 4,241.
6. M. Mancini *et al.*, “Searching for the X17 using resonant production at PADME”, Nuovo Cim. C47 (2024) 5,254.

The complete list of papers published by the PADME collaboration in 2024 can be find here `http://padme.lnf.infn.it/papers/`.

References

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7. E. Nardi *et al.*, Phys. Rev. D 97 no. 9 (2018) 095004.
8. S. Bertelli *et al.* [PADME], JHEP **08** (2024), 121 doi:10.1007/JHEP08(2024)121 [arXiv:2405.07203 [hep-ex]].
9. F. Arias-Aragon *et al.*, Phys. Rev. Lett. 132 no. 26 (2024) 261801
10. S. Bertelli *et al.*, arXiv:2503.05650 [hep-ex] (2024)