PROCEEDINGS OF SCIENCE

The PADME Detector

Pinna F.[a,b,*] **for the PADME Collaboration**[§]

[a] *INFN - Sezione di Torino, via Pietro Giuria 1, Torino, Italy*

[b] *DISAT, Politecnico di Torino, corso Duca degli Abruzzi 24, Torino, Italy*

E-mail: federico.pinna@to.infn.it, federico.pinna@polito.it

The Positron Annihilation into Dark Matter Experiment (PADME) aims to search for a dark photon (A') produced in the process $e^+e^- \to \gamma A'$. It uses the positron beam provided by the DAΦNE LINAC, maximum energy 550 MeV, at the Frascati National Laboratory of INFN. The aim of the experiment is to evaluate the missing mass of single-photon final states following positron annihilation on the electrons of a thin target. To measure such a reaction, the PADME apparatus has been built. It consists of a small-scale detector composed of the following parts:

- a diamond active target, to measure position and intensity of the beam in each single bunch;
- a beam monitor system consisting of two different silicon-pixel detectors;
- a spectrometer, to measure the charged particle momenta in the range 50-400 MeV;
- a dipole magnet, to deflect the primary positron beam out of the spectrometer and calorimeter and to allow momentum analysis;
- a finely segmented, high resolution electromagnetic calorimeter, to measure 4-momenta and/or veto final state photons.

Each element has specific requirements that are stringent and sometimes at the limit of present technology.

**** Particles and Nuclei International Conference - PANIC2021 ****
**** 5 - 10 September, 2021 ****
**** Online ****

PoS(PANIC2021)079

[§] A.P. Caricato, M. Martino, I. Oceano, F. Oliva, S. Spagnolo (INFN Lecce and Dip. di Matematica e Fisica, Università del Salento), G. Chiodini (INFN Lecce), F. Bossi, B. Buonomo, R. De Sangro, C. Di Giulio, D. Domenici, G. Finocchiaro, L.G. Foggetta, M. Garattini, A. Ghigo, F. Giacchino, P. Gianotti, I. Sarra, B. Sciascia, T. Spadaro, E. Spiriti, C. Taruggi, E. Vilucchi (INFN Laboratori Nazionali di Frascati), V. Kozhuharov (University of Sofia "St. Kl. Ohridski" and INFN Laboratori Nazionali di Frascati), G. Georgiev, S. Ivanov, R. Simeonov (University of Sofia "St. Kl. Ohridski"), F. Ferrarotto, E. Leonardi, F. Safai Tehrani, P. Valente (INFN Roma1), E. Long, G.C. Organtini, G. Piperno, M. Raggi (INFN Roma1 and Dip. di Fisica, "Sapienza" Università di Roma), S. Fiore (ENEA centro ricerche Frascati and INFN Roma1), V. Capirossi, F. Iazzi, F. Pinna (Politecnico di Torino, INFN Torino), B. Liberti (Dip. di Fisica, Università di Roma "Tor Vergata", INFN Laboratori Nazionali di Frascati), M. Martini Università G. Marconi and INFN Laboratori Nazionali di Frascati), J. Alexander, A. Frankenthal (Dep. of Physics Cornell University).

[*] Speaker

1. Introduction

Since the early 20^{th} century, astronomical observations hint the existence of something that cannot be directly observed, yet its presence affects the motion of the entire universe. That "something" has been called Dark Energy and Dark Matter. Despite making up to 26.8% of the universe mass (another 68% can be ascribed to Dark Energy), the elusive Dark Matter does not interact with electromagnetic radiation, making it extremely hard to detect.
The Positron Annihilation into Dark Matter Experiment (PADME) [1] is currently looking for the detection of a Dark Matter particle named Dark Photon (DP, indicated with A'), which could act as a portal between the Standard Model Sector and another sector, named Hidden Sector. In this picture, the DP is the mediator of a new force associated to a further U(1) symmetry added to the SM gauge; a key aspect of this mechanism is that the DP weakly couples with leptons and mixes with the standard photon through a parameter ϵ.
In positron-electron interactions, meson decay, Bremsstrahlung, and annihilation are the three main production mechanisms for an A'; among them, PADME exploits $e^+e^- \rightarrow \gamma A'$ reaction, which is achieved by irradiating a diamond target with a e^+ beam at energies lower than 550 MeV. The γ is collected in a calorimeter, and by knowing the energy of the e^+ it is possible to infer the A' mass by using the missing mass method $m^2_{A'} = (P_{e^+} + P_{e^-} - P_\gamma)^2$, where P_{e^+}, P_{e^-}, and P_γ are the four-momenta of the positron, the electron, and the photon, respectively.
In PADME's conditions, the maximum detectable mass for A' is 23.7 MeV.

2. The PADME Detector

The PADME detector is composed of several sub-detectors: a diamond active target, MIMOSA and TimePix beam monitors, ECAL and SAC calorimeters, and charged particle vetoes. A scheme of the whole apparatus is shown in figure 1.

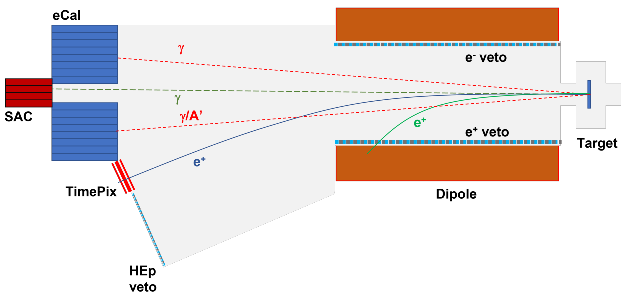
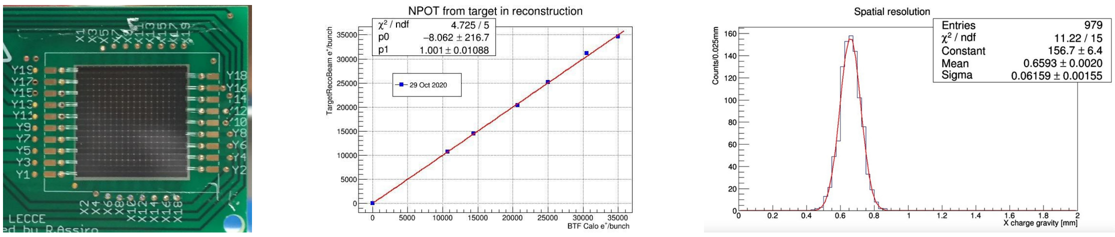


Figure 1: Scheme of the PADME detector, showing the position of the sub-detectors (MIMOSA detector not shown here). The photons/A' produced by annihilation are depicted as red dotted lines; a slowed positron and the emitted Bremsstrahlung photon are shown in green; the non-interacting beam is shown as a solid blue line. The whole apparatus is about 4 m in lenght.

2.1 Diamond Active Target

The target used in PADME (figure 2a) is a 100 μm thick, 2 x 2 cm^2 large diamond, grown by Chemical Vapour Deposition (CVD), which serves both as target and as detector. The low atomic number of C helps in reducing the importance of the main background source, i.e. Bremsstrahlung (cross section $\propto Z^2$), with respect to the annihilation signal (cross section $\propto Z$). The beam profile and its multiplicity are measured using 32 graphite strips (16 per side, strips on one side are orthogonal to those on the other side), etched directly on the target surface by an excimer laser. This allows for online monitoring of the two quantities during data taking. The multiplicity reading in particular proved to be reliable up to 35k e^+/bunch (figure 2b), despite being designed for 5k e^+/bunch [2] (currently, data is taken at 20k-30k e^+/bunch). The detector's spatial resolution is 0.06 mm, significantly better than the experimental upper limit of 1 mm needed for the interaction point assessment.

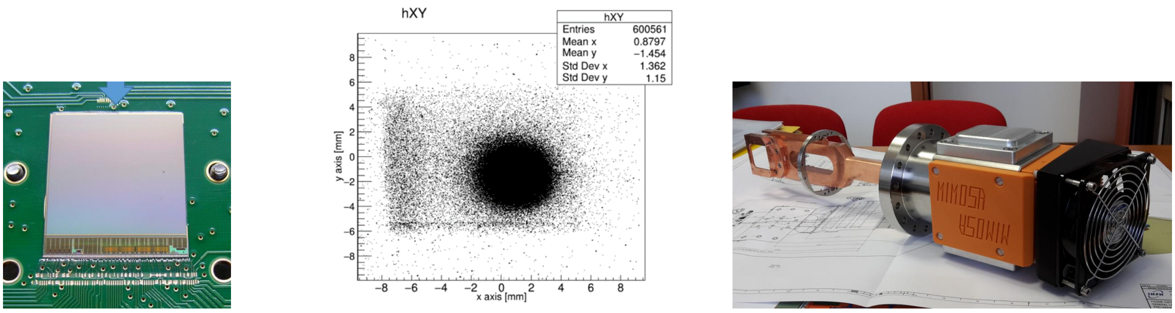


(a) **(b)** **(c)**

Figure 2: a) Picture of the diamond target and the graphite strips along the x and y axis; b) Plot of the target multiplicity count, which is linear up to 35k e^+/bunch; c) Spatial resolution of the active target.

2.2 MIMOSA

The MIMOSA-28 is a monolithic sensor, 19.9 x 19.2 mm^2 in area (figure 3a), used to characterize the shape, position, angle, and divergence of the beam (for the latter two quantities at least a series of 2 sensors is required). The sensor is composed of a matrix of 960 x 928 pixels ($\sim$ 0.9 million pixels), 20.7 μm in pitch, which have a spatial resolution of 3 μm, which gives an extremely refined map of the beam (figure 3b).



(a) **(b)** **(c)**

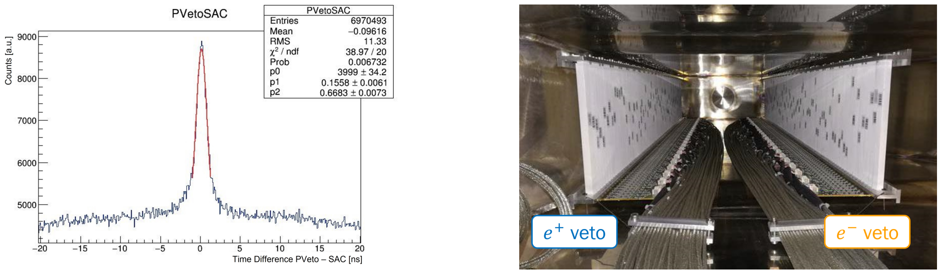
Figure 3: a) picture of the MIMOSA sensor; b) beam profile detected by the MIMOSA, clearly distinguished from background; c) the MIMOSA step motor and cooling copper frame.

The readout time is 200 μs, which limits the maximum beam multiplicity to about 1000 e^+/bunch (higher values would quickly saturate the detector). For this reason, and for the degradation of the beam energy definition, the MIMOSA and the target cannot be used simultaneously.

PoS(PANIC2021)079

2.3 Charged Particle Vetoes and Magnetic Dipole

The vetoes for charged particles are composed of 212 scintillating plastic bars 1x1x17.8 cm^3 in dimension, coupled with SiPM S13360 from Hamamatsu. The e^+ veto is formed of 90 bars on the left hand side of the beam axis, while the e^- veto is made of 96 bars placed symmetrically to the e^+ veto (figure 4b). The high energy positron veto (HEPVeto) is formed of 16 bars placed at the beam exit on the left hand side of the detector [3].
The former two are inside a dipole magnetic field of 0.45 T, which is used to bend the positron beam and lower energy particles (mainly e^+ that lose energy while crossing the target) away from the main calorimeter ECAL. The position in which slowed positrons hit the veto provides an estimate of their momentum within a 2% error. Bremsstrahlung events are identified thanks to a time calibration with the SAC, the coincidence time resolution is less than 0.7 ns, as shown in figure 4a (the upper limit for a successful identification is 1 ns).



(a) **(b)**

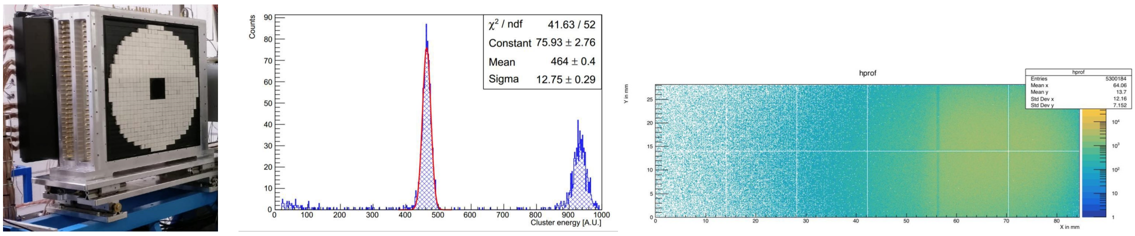
Figure 4: a) time difference between the veto and SAC signals; b) the portion of the scattering chamber immersed in the dipole field, presenting the e^+ veto on the left side and the e^- veto on the right.

2.4 Small Angle Calorimeter

The Small Angle Calorimeter is located about 3.4 meters downstream from the target, covering the angle [0,18.9] mrad, and collects Bremsstrahlung photons, typically emitted at a small angle with respect to the beam axis. It is an assembly of 5 x 5 Cherenkov Lead Fluoride (PbF_2) scintillators, 30 x 30 x 140 mm^3, coupled with fast Hamamatsu R13478UV PMT. The SAC is a fast detector, and having a dead time of ~2 ns is able to sustain the high rate of Bremsstrahlung events (around 100 MHz). Using a sampling frequency of 2.5 GHz, the SAC is able to detect around 50 γ/bunch, with a time resolution of 86 ps [4]. The detector has been calibrated using both the beam and cosmic rays.

2.5 Electromagnetic Calorimeter

The electromagnetic calorimeter ECAL is composed of 616 Bismuth Germanate (BGO) crystals, arranged to form a cylinder around the SAC and covering the angle within [15,84] mrad (figure 5a). Each crystal is 21x21x230 mm^3, the whole detector has a diameter of about 60 cm. The detector is slower than the SAC, having a dead time of 300 ns, and the readout is performed by using XP1911 PMT from HZC; the energy resolution of the whole object is $\sigma(E)/E$ ~2.7%. Finally, two scintillating plates are placed above and below the ECAL, and are used as cosmic ray trigger. Cosmic rays are in fact used for online calibration of the ECAL, as well as for evaluating its efficiency (≥ 98% for more than 99.1% of the channels) [5].



(a) **(b)** **(c)**

Figure 5: a) The assembled e.m. calorimeter; b) Energy of clusters in ECAL, peaked around the beam energy with a $\sigma(E)/E$ of 2.7%; c) Distribution of non-interacting positrons on the TimePix3 detector.

2.6 TimePix3

The TimePix3 is a detector used as beam monitor and particle tracker, composed of a matrix of 6 x 2 sensors; each sensor is a matrix of 256 x 256 pixels, 55 μm in pitch. It is located between the HEPVeto and the ECAL, where the non-interacting portion of the e^+ beam arrives after being bent by the magnetic dipole. The group of sensors covers an area of 8.4 x 2.8 cm^2, which allows to measure the beam divergence on the y-axis and the beam energy definition along the x coordinate (figure 5c). Every incoming particle's position, energy, and time are measured.

3. Conclusion

The PADME experiment is currently searching for an intermediate mass Dark Photon, a dark matter particle able to interact with leptons and therefore bridge the Hidden Sector and the SM sector. The DP (and regular photons) is produced by annihilation between the electrons of a diamond target and a e^+ beam ($e^+e^- \rightarrow \gamma A'$). The detectors described in this work proved to be reliable and to perform within the experimental requirements, and the collected data during the runs performed in 2019 and 2020 are being used to further improve their performances and reduce the background.

References

[1] M. Raggi and V. Kozhuarov, Adv. High Energy Phys., 2014, (2014), 959802.

[2] F. Oliva and PADME collaboration, Nuclear Inst. and Methods in Physics Research A, 958, (2019), 162354.

[3] F. Oliva and PADME collaboration, Nuclear Inst. and Methods in Physics Research A, 936, (2019), 259–260

[4] A. Frankenthal et al., Nuclear Inst. and Methods in Physics Research A, 919, (2019) 89–97

[5] P. Albicocco et al., Journal of Instrumentation, 15, (2020), T10003