The PADME Experiment at INFN CNAF

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Abstract. The PADME experiment at the DAΦNE Beam-Test Facility (BTF) in Frascati is designed to detect dark photons produced in positron on fixed target annihilations decaying to dark matter ($e^+e^-\to\gamma A'$) by measuring the final state missing mass. The collaboration completed the construction of the experiment in September 2018 and the first data acquisition run lasted from October 2018 to March 2019. This report, after a brief introduction of the experiment and its physics goals, describes the PADME data analysis model and the first data acquisition run with specific information on the use of computing facilities at INFN CNAF.

1. Introduction

The long standing problem of reconciling the cosmological evidence of the existence of dark matter with the lack of any clear experimental observation of it, has recently revived the idea that the interaction of the new particles with the Standard Model (SM) gauge fields is not direct but occurs through "portals", connecting our world with new "secluded" or "hidden" sectors. One of the simplest models introduces a single U(1) symmetry, with its corresponding vector boson, called Dark Photon or A'. In the most general scenario, the existence of dark sector particles with a mass below that of A' is not excluded: in this case, so-called "invisible" decays of the A' are allowed. Moreover, given the small coupling of the A' to visible SM particles, which makes the visible rates suppressed by ε^2 (ε being the reduction factor of the coupling of the dark photon with respect to the electromagnetic one), it is not hard to realize a situation where the invisible decays dominate. There are several studies on the searches of A' decaying into dark sector particles, recently summarized in [1,2].

At the end of 2015 INFN formally approved a new experiment, PADME (Positron Annihilation into Dark Matter Experiment) [3,4], to search for invisible decays of the A'. Aim of the experiment is to detect the non-SM process $e^+e^-\to\gamma A'$, with A' undetected, by measuring the final state missing mass, using a 545 MeV positron beam from the improved Beam-Test Facility (BTF) of the DAΦNE Linac at the INFN Frascati National Laboratories (LNF) [5]. The PADME collaboration completed the construction of the detector in September 2018 and in October of the same year started the first physics run, which ended in March 2019 after collecting a total of 270 TB of raw data. The final goal of the experiment is to collect a total in excess of 10^{13} positrons on target, in order to reach a $\varepsilon \sim 10^{-3}$ sensitivity up to a dark photon mass of $M_{A'} \sim 24$ MeV/c^2.

The experiment, shown in figure 1, is composed of a thin active diamond target, to measure the average position and the intensity of the positrons during a single beam pulse; a set of charged particle veto detectors immersed in the field of a 0.5 Tesla dipole magnet to detect positrons losing their energy due to Bremsstrahlung radiation; and a calorimeter made of BGO crystals, to measure/veto final state photons. As the rate of Bremsstrahlung photons in its central region is too high, the calorimeter has a hole covered by a faster photon detector, the small angle calorimeter (SAC). Finally, a silicon pixel detector measures the time and spatial distributions of the outgoing beam. The apparatus is inserted into a vacuum chamber, to minimize unwanted interactions of primary and secondary particles that might generate extra photons. The maximum repetition rate of the beam pulses from the DAΦNE Linac is 50 Hz.

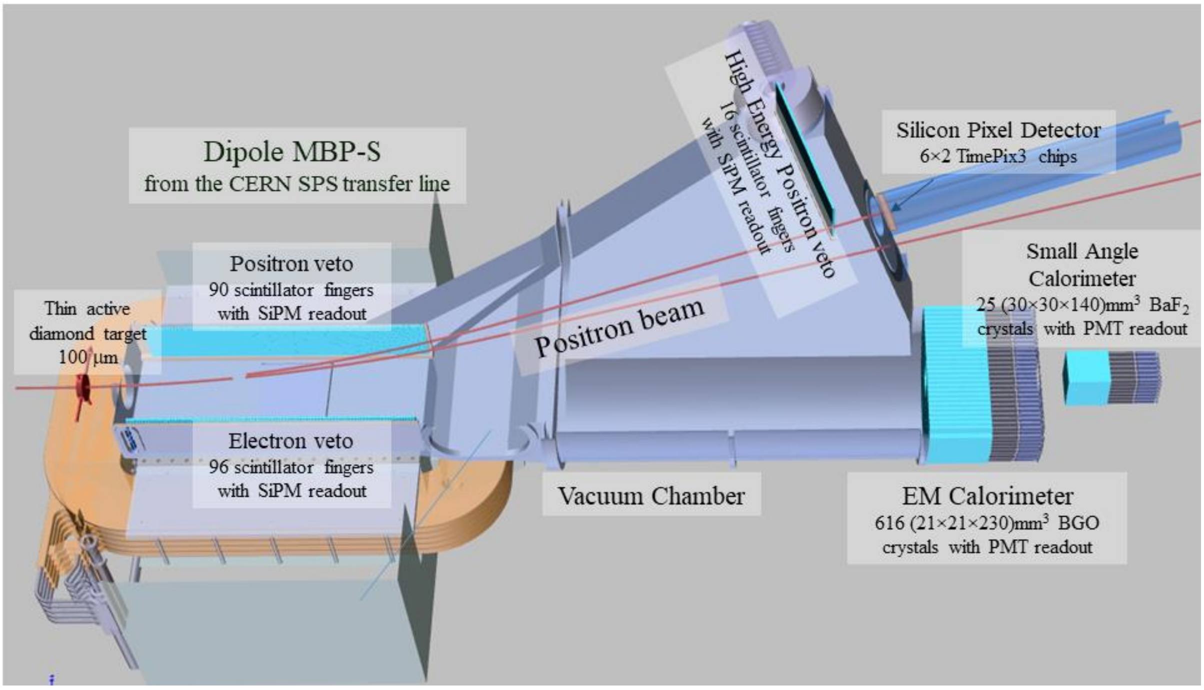

Figure 1. The PADME experiment as seen from above. The positron beam travels from left to right.

2. The PADME Run1 data model

The beam delivered to the BTF consists in particle bunches of O(2×10^4) 545 MeV positrons distributed over 250 ns and with a repetition rate of 50 Hz. After each bunch, analogue signals from all 900 channels of the experiment are digitized and merged into a single data structure that is written to file using a PADME-specific ROOT data format [6]. The average total data rate during PADME Run1 was of 70 MB/s.

All data coming from the on-line DAQ were written to local disk servers and from there copied to the CNAF tape library and to the LNF Tier2 disk system. As a disaster recovery measure, all data stored in the CNAF tape library were replicated to the KLOE tape library at LNF. A total of 270 TB of raw data were collected during PADME Run1. Using the copy on the LNF Tier2 disk system, the collaboration is now in the process of reconstructing the events for physics analysis using the LNF and CNAF computing facilities.

To optimize the experimental layout in terms of signal acceptance and background rejection, the full experiment was modelled with the GEANT4 simulation package [7,8]. Production of MC events started in 2017 to continue for the whole duration of the experiment, thus producing an amount of simulated data of the same order of the real data.

The simulation of MC events and the reconstruction and analysis of both real and simulated data will require a substantial amount of CPU power which will be provided by GRID-based resources. Between 2017 and 2019 INFN Committee 1 financed a total of 6500 HEP-SPEC of CPU power for MC event production and for event (both real and MC) reconstruction and analysis. The acquired

CPUs are distributed between the PADME Tier2 site at LNF and the general purpose farm at INFN Tier 1.

3. CNAF resources for PADME

3.1. CPU Resources
As previously mentioned, INFN Committee 1 financed a total of 6500 HEP-SPEC of CPU power to support all off-line computing activities of the collaboration: of these, 2600 HEP-SPEC were allocated at CNAF. These resources are fully integrated into the PADME off-line computing system and are used for MC events production. The remaining CPU resources were installed at LNF and are mainly dedicated to event reconstruction and analysis.

3.2. Tape Library
The INFN CNAF tape library was chosen by the PADME collaboration for the long-term storage of all its data. This tape library guarantees all necessary resources, both in term of storage capacity, data access speed, and data conservation. In addition, CNAF and LNF are connected via a high-speed link, which allows a quasi-real-time transfer of all data produced by the experiment, thus reducing the requirements for local disk buffers, and a fast recovery of the same data for re-processing and analysis using distributed computing resources.
The initial 100 TB tape pool created for PADME at the end of 2016 was expanded between 2017 and 2019 to 1250 TB, thus satisfying all storage needs of the collaboration up to the PADME Run2, scheduled for the end of 2019. All data produced during the PADME Run1 of 2018-2019 and all the testbeam and MC activities of the previous years are stored on this tape pool, for a total of 270 TB of data. Since the beginning of 2017 the PADME tape pool at CNAF is accessible from all GRID nodes via a StoRM interface and is integrated, together with all other off-line storage facilities, in the automatic central data recording (CDR) system of the experiment.

3.3. GRID services
A complete GRID-based computing model requires some basic services to guarantee the correct authentication and access to the distributed resources and the automatic distribution of all needed software packages to the sites where the jobs should run.

In June 2016 CNAF created the “vo.padme.org” virtual organization (VO) which is currently hosted on the voms2.cnaf.infn.it VOMS server. This VO was registered on the EGI infrastructure and is used for authentication and role management on all GRID resources used by PADME.

In order to easily distribute all the software needed for MC production and data reconstruction and analysis to all WNs used by the collaboration, CNAF created a virtual CVMFS server, cvmfs-padme.cnaf.infn.it, hosting the /cvmfs/padme.infn.it area. Here PADME software managers can install all the experiment’s software packages which are then automatically made available to all GRID sites hosting PADME resources.

4. Conclusions
The PADME experiment will search for the dark photon A' with mass up to 24 MeV in the annihilation process $e^+e^-\to\gamma A'$, with A' undetected, using the Beam-Test Facility of the DAΦNE Linac at the INFN Frascati National Laboratories. The first run of data taking (PADME Run1) started in October 2018 and ended in March 2019, collecting a total of $O(5\times10^{12})$ positrons on target. Since the beginning of 2016, CNAF provided several important computing services to the PADME collaboration, namely access to resources on their tape library for long-term data storage and the hosting of the VOMS and CVMFS services. Since 2018 PADME has successfully been using the CNAF Tier1 facilities to support all computing and storage needs of the collaboration. In addition to this, CNAF personnel always provided us with technically savvy information and advice, effectively

helping the PADME collaboration in the delicate phase of designing and implementing a computing model, for which we are truly grateful.

5. References

[1] Raggi M and Kozhuharov V 2015 Results and perspectives in dark photon physics *Riv. Nuovo Cimento* **38** (10) 449-505

[2] Alexander J *et al.* 2016 Dark Sectors 2016 workshop: community report *arXiv:1608.08632 [hep-ph]*

[3] Raggi M and Kozhuharov V 2014 Proposal to search for a dark photon in positron on target collisions at DAΦNE Linac *Adv. High Energy Phys.* **2014** 959802

[4] Raggi M, Kozhuharov V and Valente P 2015 The PADME experiment at LNF *EPJ Web of Conferences* **96** 01025

[5] Valente P *et al.* 2016 Linear accelerator test facility at LNF conceptual design report *arXiv:1603.05651 [physics.acc-ph]*

[6] Leonardi E, Raggi M, Valente P. Development and test of a DRS4-based DAQ system for the PADME experiment at the DAΦNE BTF *J. Phys.: Conf. Ser.* **898** 032024

[7] Agostinelli S *et al.* 2003 Geant4 – A simulation toolkit *Nucl. Instrum. Methods A* **506** 250-303

[8] Leonardi E, Kozhuharov V, Raggi M and Valente P 2017 GEANT4-based full simulation of the PADME experiment at the DAΦNE BTF *J. Phys.: Conf. Ser.* **898** 042025