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Performance of the PADME Calorimeter prototype at the DAΦNE BTF

M. Raggi [c,d,*], V. Kozhuharov [a,b], P. Valente [d], F. Ferrarotto [d], E. Leonardi [d], G. Organtini [c,d], L. Tsankov [b], G. Georgiev [a,b], J. Alexander [e], B. Buonomo [a], C. Di Giulio [a], L. Foggetta [a], G. Piperno [a]

[a] Laboratori Nazionali di Frascati, Frascati (RM) 00044 Italy
[b] Faculty of Physics, University of Sofia "St. Kl. Ohridski", 5 J. Bourchier Blvd., Sofia 1164, Bulgaria
[c] Sapienza Università di Roma, Piazzale Aldo Moro 5, Rome 00185, Italy
[d] INFN sezione di Roma, Piazzale Aldo Moro 5, Rome 00185, Italy
[e] Cornell University, Ithaca, NY 14853, USA

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ABSTRACT

The PADME experiment at the DAΦNE Beam-Test Facility (BTF) aims at searching for invisible decays of the dark photon by measuring the final state missing mass in the process $e^+e^- \to \gamma + A'$, with A' undetected. The measurement requires the determination of the 4-momentum of the recoil photon, performed using a homogeneous, highly segmented BGO crystals calorimeter. We report the results of the test of a 5×5 crystals prototype performed with an electron beam at the BTF in July 2016.
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1. Introduction

A possible solution to the dark matter problem postulates that dark matter interacts with Standard Model (SM) particles through a new force mediated by a "portal". If the new force has a U(1) gauge structure, the "portal" is a massive photon-like vector particle, 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 Standard Model 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 A' decaying into dark sector particles (χ), recently summarized in [1].

The aim of the PADME experiment is to detect the non SM process $e^+e^- \to \gamma + A'$, A' undetected, by measuring the missing mass in the final state [2,3], using 550 MeV positrons from the improved Beam-Test Facility (BTF) of the Frascati LINAC [4]. The experiment is composed of a thin (100 μm in the baseline design) active diamond target [5], 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 dipole magnet, to detect the positrons losing their energy due to Bremsstrahlung radiation, and a calorimeter, to measure/veto final state photons. The apparatus is inserted into a vacuum chamber, to minimize unwanted interactions of primary and secondary particles that might generate extra photons. The rate in the central part of the calorimeter is too high due to Bremsstrahlung photons. For this reason the calorimeter has a central hole covered by a faster photon detector, the Small Angle Calorimeter (SAC). The maximum repetition rate of the beam pulses is 49 Hz. In the following sections we describe the PADME BGO calorimeter, the 5×5 cells prototype being tested, and the results on the prototype performance obtained during a test with electrons at BTF in July 2016.

2. The PADME calorimeter

The PADME calorimeter is a homogeneous crystal calorimeter with an approximately cylindrical shape, with a diameter of ~600 mm, depth of 230 mm, and with a central 100×100 mm^2 square hole (see Fig. 1). The active volume will be composed by 616 $21\times21\times230$ mm^3 BGO crystals, obtained by machining the

* Corresponding author at: INFN sezione di Roma, Piazzale Aldo Moro 5, Rome 00185, Italy.
E-mail address: mauro.raggi@roma1.infn.it (M. Raggi).

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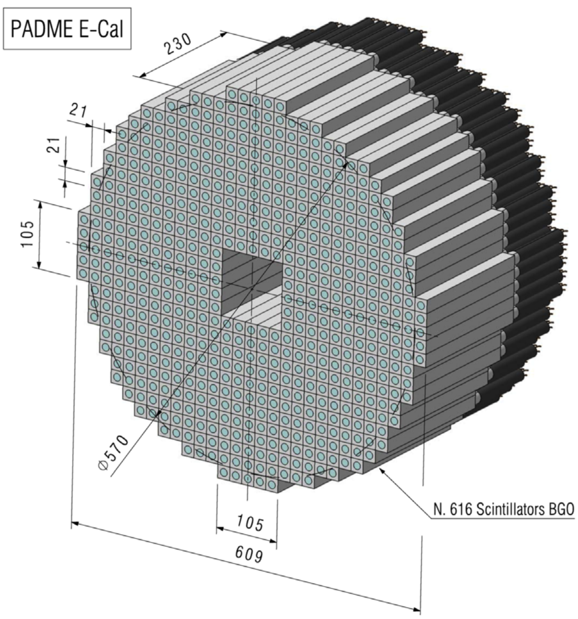

Fig. 1. The PADME BGO crystal calorimeter.

Fig. 2. The PADME 5×5 BGO crystal prototype.

crystals recovered from one of the end-caps of the electromagnetic calorimeter of the dismantled L3 experiment at LEP [6]. According to the tests performed by the L3 collaboration [7], the expected energy resolution lies in the interval $(1-2)\%/\sqrt{E}$ for <1 GeV electrons and photons.

Early tests aimed at evaluating the best readout technology showed that avalanche photodiodes (APDs), even with a (relatively large) area of $10 \times 10\ \text{mm}^2$, have a gain, and consequently a total collected charge, that is insufficient to perform a high resolution energy measurement in the energy interval relevant to PADME, that is from a few to a few hundred MeV. The readout system will therefore be based on 19 mm diameter photo-multiplier tubes.

3. The Frascati Beam test Facility

The Beam Test Facility (BTF) of the DAΦNE LINAC [8] at the Frascati National Laboratory of INFN (LNF), is a beam line which delivers electrons or positrons pulses, diverted from the DAΦNE LINAC injection line, in a dedicated experimental hall. The beam can be used for detector test/calibration purposes or to study physics phenomena at the energy scale of O(100 MeV) [2].

BTF can deliver the LINAC primary beam (nominal energy 510 MeV, 10 ns pulse) for high intensity measurement (one pulse per second, fixed energy, up to 3×10^{10} particles/s), or a secondary one, up to 49 pulses of e^+/e^- per second, with energy in the range from $\simeq$30 MeV to the primary one; the intensity is in this case energy dependent. In dedicated beam time, energy up to 750 MeV for e^- and 550 MeV for e^+ can be reached, while the pulse length can be adjusted from 1.5 ns up to 150 ns.

During the PADME July beam-test the BTF was operated in electron mode and the average number of particles per pulse was kept close to one, in order to study the response of the PADME calorimeter prototype. Two different beam setups with energies of 250 and 450 MeV were used. The typical size of the beam spot was kept by the BTF optics below 2 mm^2 RMS while the energy spread of the beam was estimated at the level of 1%.

4. The PADME calorimeter prototype

The prototype was composed of 25 BGO crystals arranged in a 5×5 matrix (Fig. 2). The geometry was obtained by machining original L3 crystals to get a parallelepiped of $20 \times 20 \times 220\ \text{mm}^3$, very close to the final dimensions for the experiment. The crystals were wrapped with teflon sheets and the scintillation light was detected by 19 mm diameter photo-multipliers (15 mm diameter active area) by HZC Photonics,[1] model XP1912, coupled to the crystals using optical grease.

The prototype was placed on the BTF remotely movable table, and was adjusted so that the beam impinged onto the central crystal of the matrix. The photo-tubes were operated at $\sim$1100 V, corresponding to an equalised gain of $\sim 5 \times 10^5$, according to the HZC Photonics specifications. BTF hall temperature is controlled by an air conditioning system and continuously monitored using temperature sensors. The typical temperature variation in short time scales (days) is below 0.5 °C therefore no temperature control system was implemented on the prototype. The effect of temperature variation on the calorimeter response is expected to be below -0.5% due to crystal response variation (-0.9%/C) [6].

The 25 channels of the prototype were fed into a CAEN V1742 high-speed digitizer [9], based on the DRS4 chip, set to a sampling speed of 1 GS/s (1 ns/sample). The digitizer was operated in sampling mode providing 12 bit measurement of the input amplitude for the 1024 sample, corresponding to an integration window of $\approx 1\ \mu$s. The trigger was based on an external NIM signal from the BTF timing system, which allowed to record the waveforms of all the readout channels for every single pulse. The timing with respect to the actual arrival of electrons at the BTF beam exit was adjusted by means of the BTF programmable digital delay. The data were transferred to a readout PC through optical fibers by a dedicate control program and stored in binary format for further analysis. A scheme of the test beam setup is shown in Fig. 3.

The presented results are based on the data sample collected during one week test run at BTF in July 2016.

5. Charge reconstruction

The offline data contained the recorded waveforms in a window of 1024 ns (1024 amplitude measurements every 1 ns for each event). The typical BGO signal has a duration of $\sim 1\ \mu$s due to

[1] http://hzcphotonics.com/

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