The active diamond target of the PADME experiment

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Abstract
PADME (Positron Annihilation into Dark Matter Experiment) at the Laboratori Nazionali di Frascati of the INFN is an experiment that searches for the gauge boson of the dark sector, the dark photon A´, produced in the annihilation between a positron of a beam with an electron of a target. The PADME Lecce group designed and assembled the active diamond target, the heart of the experiment that is working since September 2018 in the beamline in vacuum in stable conditions, without any external interventions.

Keywords: Design of experiments, Dark matter, Solid-state detectors.

1. INTRODUCTION

The existence of dark matter is inferred by cosmological and gravitational observations, but currently there are no experimental evidences of its nature. This motivated the speculative idea of the existence of a dark sector which interacts with ordinary matter only by a neutral portal. One of the most compelling dark sector model introduces an additional symmetry U´(1) to describe the interactions between the dark particles [1].
The corresponding gauge boson is called dark photon and different experiments are searching for it in both, invisible and visible decay mode.
The PADME experiment [2] searches for the dark photon A´ in the annihilation process $e^+e^- \to \gamma A'$ using the missing mass method, totally independent from the decay mode. In this case, the mass of the hypothetical dark photon could be calculated with the formula:

$$M^2{}_{miss} = (P_{e^+} + P_{e^-} - P_\gamma)^2 \qquad (1.1)$$

where $P_{e^+}, P_{e^-}, P_\gamma$ are the quadri-momenta of the beam positron, of the target electron and of the photon, respectively.

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PADME is located at the Beam Test Facility (BTF) of the Laboratori Nazionali di Frascati (LNF) of INFN and it uses a positron beam of 550 MeV of energy in bunches with a rate of 50 Hz coming from the LINAC.
The experiment can explore the region of sensitivity for the mass of the dark photon $M_{A'} \leq 23.7$ MeV/c^2 and for the mixing parameter above $\varepsilon^2 > 10^{-6}$ for $4 \cdot 10^{13}$ Positrons On Target (POT).
The PADME detector is made of a diamond target, a magnetic dipole, which bends the beam outside the experimental acceptance, a high resolution electromagnetic calorimeter (ECAL), a small angle electromagnetic calorimeter (SAC) and a charged particle veto system. A signal event is represented by a ECAL cluster, due to the photon produced in association with the dark photon, which is not correlated in time with signals in the charged particle veto system. The scheme of the experiment is shown in Fig. 2.1.

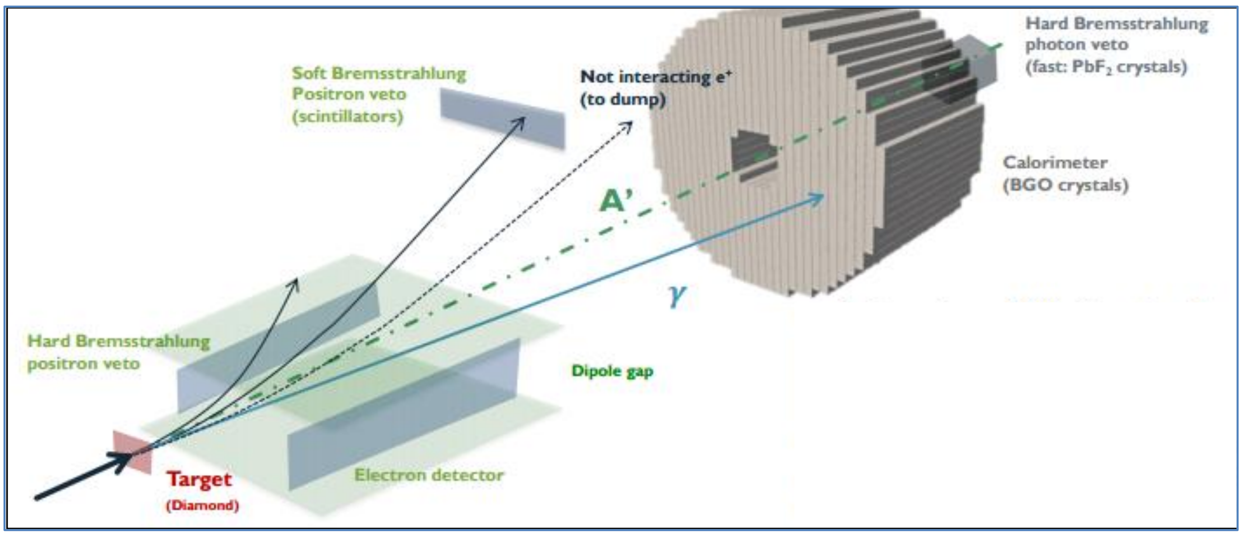

Figure 2.1: scheme of the PADME detector.

The target of the experiment has to be active because the resolution of the measured missing mass improves with the spatial resolution of the beam position for a narrow beam. The diamond active target was the final choice thanks to its low atomic number (Z=6), that limits the Bremsstrahlung interactions ($\propto Z^2$), main source of background, with respect to annihilation ($\propto Z$).

2. THE ASSEMBLY OF THE ACTIVE DIAMOND TARGET

The active diamond detector was fully realized by the PADME Lecce group starting from a Chemical Vapor Deposition (CVD) polycristalline diamond film provided by the Applied Diamond (USA) [3] of 2 x 2 cm^2 area and 100 µm thickness.
The ohmic graphitic contacts were realized in the L3 Laboratory of Lecce by means of an excimer laser ArF (λ = 193 nm) [4]. The graphitics strips, nineteen on both sides, were realized on the two sides, in the X and Y direction, with a pitch of 1 mm, in order to have a good spatial resolution and to allow the beam reconstrution for both views.
The detector was precisely positioned with a micrometric XYZ and Θ handling system to a printed circuit board (inner board) and mechanically connected by spots of Araldite glue using a syringe belonging to a dispensing system.

The electrical contacts on the back side were realized using a bi-component conductive glue and monitoring the electrical resistance. On the front side the electric contacts were made at INFN Perugia by wire bonding. In Fig. 2.1 the PADME diamond target is shown.

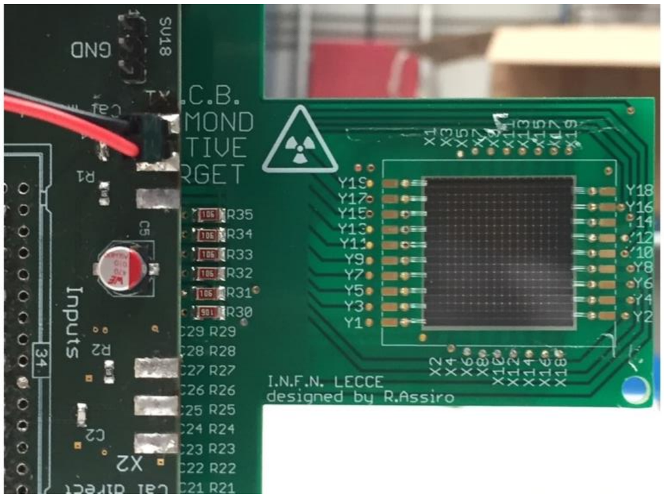

Figure 2.1: PADME Diamond detector with 19x19 graphitic strips, 2x2 cm^2 area and 100 µm thickness. In this picture the wire bonding between each strip and the gold pad is visible.

The X and Y strips were readout by two evaluation boards of Amadeus chip [5], for a total of 16 +16 electronic channels.
The detector was installed in September 2018 with all the electronics under vacuum.
In Fig. 2.2 the vacuum cross that hosts the diamond in the beam line of the experiment is shown.
All PADME detector signals were digitized by CAEN V1742 modules with 12 bit ADC reading 1024 samples of the signal at a rate changing from 1 to 5 GS/s, according to the detector type. The active diamond target signals were sampled at 1GS/s.

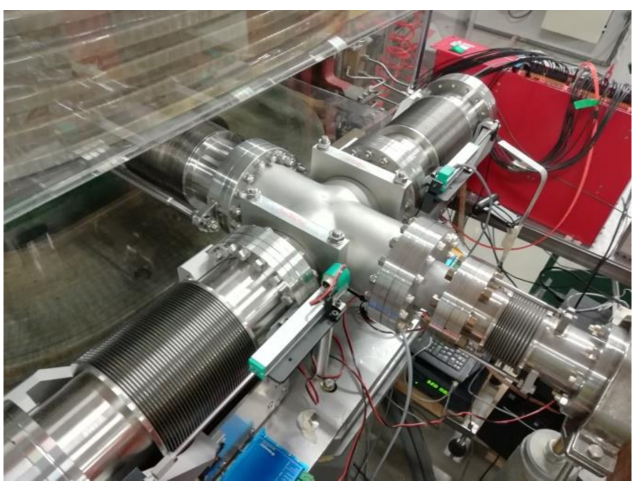

Figure 2.2: PADME vacuum cross, where the target with the readout electronics is located.

3. PRELIMINARY TARGET RESULTS

Before starting taking data, the bias voltage to apply to the diamond detector was chosen studying the collected charge in the X and Y direction. The chosen value was 250 V, that corresponds to a region of charge saturation.

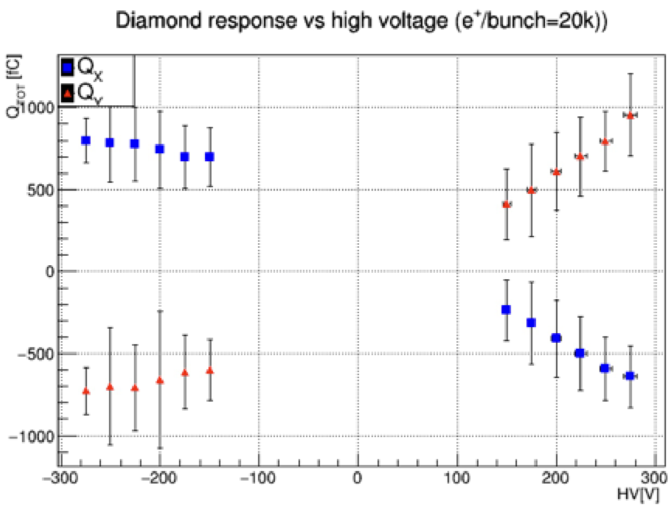

Figure 3.1: Diamond response to different bias voltage applied.
Multiplicity of the bunch ~20000 positrons on target, Beam Energy = 545 MeV.

The diamond target worked in stable conditions for all the whole run I from September 2018 to March 2019 with a constant bias voltage of 250 V, without suffering any discharges, providing important informations per bunch such as beam profiles and bunch multiplicity.
The detector provided the beam reconstruction for the X and Y directions for single bunch, which corresponds to a positron multiplicity on target of ~20000 particles.
Only one strip out to 32 failed the contact; the collected charge of the unconnected strip was evaluted intepolating linearly the adjacent strips.
A distribution of the beam multiplicity for almost 30000 events with BTF trigger (bunch of positrons with a rate of 50 Hz) is shown in Fig. 3.2. The value of the mean of the gaussian fit is 17910 ± 652 positrons per bunch.

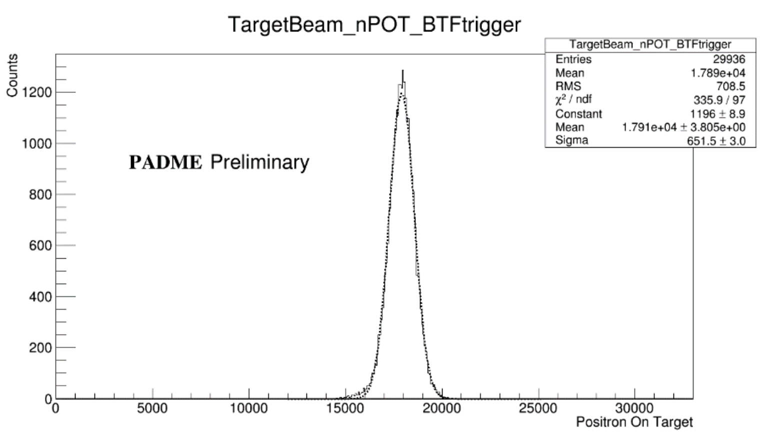

Figure 3.2: Positron On Target, BTF Trigger (50 Hz), ~30000 events.
Energy of the beam 545 MeV.

The charge response of the diamond detector to different bunches multiplicity, obtained using a Cherenkov lead-glass calorimeter of the BTF, was studied. The detector shown a good charge linearity; in Fig. 3.3 it is possible to observe the distribution of the collected charge in both directions, X and Y. Every peak corresponds to a different multiplicity; data was collected in step of 2000 particles.
This calibration also allowed to obtain a preliminary value of the charge collection distance (CCD)

of the diamond detector.
The CCD is a figure of merit of a polycristalline diamond and it could be defined as:

$$CCD = \frac{q_c}{q_g} d \sim 12\ \mu m, \qquad (3.1)$$

where d is the thickness of the detector, while q_c and q_g are respectively the charge collected and the charge generated by a minimum ionizing particle (MIP).

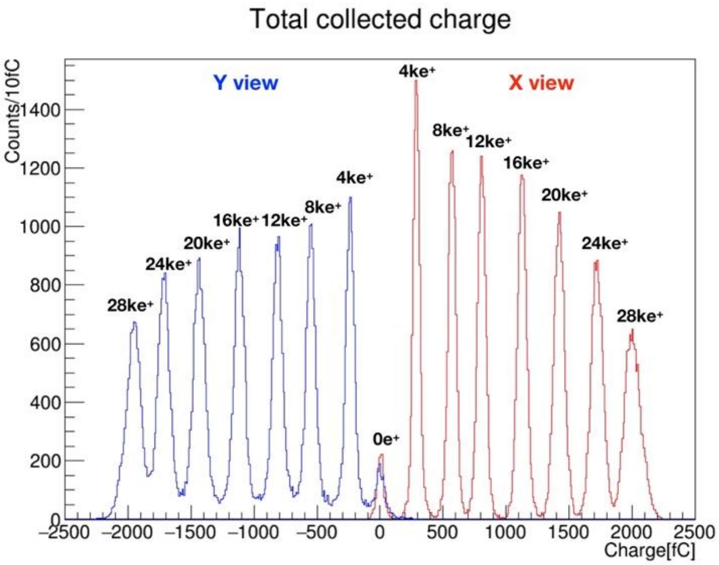

Figure 3.3: distribution of the charge for both X and Y view, in response to different bunches multiplicity, obtain with a Cherekov lead glass calorimeter.

A preliminary value of the spatial resolution of the detector was also obtained studying the beam center of gravity distribution in the X direction for about 1000 event, with a positron beam multiplicity of ~20000 positrons and energy 545 MeV.
The sigma value of the gaussian fit superimposed gives a first estimate of the spatial resolution (σ_x=0.06 mm) and it is in agreement with the spatial resolution request for the PADME target (< 1 mm).

4. CONCLUSIONS

The diamond detector for the PADME experiment was realized and operated by the Lecce group and it worked in stable conditions for the whole Run I, from September 2018 to March 2019. The target precisely provided the beam X and Y profiles and the bunch multiplicity per event.
The PADME group is now working on the analysis of the collected data and a new physics run is scheduled for the end of 2019.

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