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Performance of BDX-MINI veto systems

M. Spreafico [a,b,*], M. Battaglieri [a,c], M. Bondí [d], A. Celentano [a], P.L. Cole [e], M. De Napoli [d], R. De Vita [a], L. Marsicano [a], N. Randazzo [d], E.S. Smith [c], D. Snowden-Ifft [f], M. Wood [g]

[a] Istituto Nazionale di Fisica Nucleare, Sezione di Genova, 16146 Genova, Italy
[b] Universitá degli Studi di Genova, 16126 Genova, Italy
[c] Thomas Jefferson National Accelerator Facility, 23606, Newport News, VA, USA
[d] Istituto Nazionale di Fisica Nucleare, Sezione di Catania, 95125 Catania, Italy
[e] Lamar University, 4400 MLK Boulevard, P.O. Box 10046, Beaumont, TX 77710, USA
[f] Occidental College, Los Angeles, CA 90041, USA
[g] Canisius College, Buffalo, NY, 14208, USA

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ABSTRACT

This paper describes the veto system of the BDX-MINI detector installed at Jefferson Lab (US). The BDX-MINI experiment is the first electron beam-dump experiment specifically designed to search for Light Dark Matter (LDM) particles in the MeV-GeV mass range. The core of the BDX-MINI detector is a lead-tungstate electromagnetic calorimeter, for a total volume of 4 dm^3. The calorimeter is surrounded by a multi-layer veto aimed at rejecting cosmic background: the innermost layer of the veto is made by a passive tungsten shielding for low energy radiation, while plastic scintillators make the middle and outer layers for charged cosmic particles rejection. Being located about 20 m downstream, the dirt between the beam dump and the detector provides sufficient shielding from the beam-related background. In 2019–2020, BDX-MINI was exposed for about six months to weakly interacting particles (neutrinos and, if existing, DM) produced by a 2.176 GeV electron beam incident on the beam dump of experimental Hall-A at Jefferson Lab.

1. Introduction

Light Dark Matter (LDM) is a new compelling hypothesis that identifies Dark Matter with new sub-GeV "Hidden Sector" states. In the most popular model, LDM particles χ interaction with SM is mediated by a massive vector boson called A' ("Dark Photon"). The Dark Photon can kinematically mix with the Standard Model hypercharge field, resulting in SM-DM interactions.

Many experimental techniques can be used to probe Light Dark Matter [1,2]. Among those, Beam Dump Experiments offers unique possibilities in probing different LDM models.

In Beam Dump Experiments DM is produced by an intense beam impinging on a thick target (beam dump). DM can be produced in the beam dump beside the great number of Standard Model (SM) particles. A sizable shielding located downstream the dump absorbs all SM particles (except neutrinos), filtering a secondary DM beam. LDM particles are detected in a downstream electromagnetic calorimeter through χ scattering with detector electrons.

BDX-MINI is a Beam Dump eXperiment searching for DM particles in the MeV-GeV mass range produced by the interaction of Jefferson Lab (JLab) high intensity electron beam impinging on experimental Hall-A beam dump. It used a 2.176 GeV e^--beam, with current up to 150 μA. The detector was located in a well 26 m downstream the dump at beamline height. The entire setup was located inside a sturdy field tent.

BDX-MINI ran for 6 months in 2019–2020, accumulating a total charge of about 2.56×10^{21} EOT.

2. BDX-MINI detector

BDX-Mini detector is composed of an electromagnetic calorimeter (ECal) surrounded by a multi-layer veto system.

BDX-Mini ECal is composed of 44 parallelepiped $PbWO_4$ crystals for a total active volume of $\sim 4 \times 10^{-3}$ m^3 (Fig. 1.A). The crystals scintillation light is read by 6×6 mm^2 Hamamatsu MPPCs (S13360-6025PE) yielding 1 p.e./MeV deposited.

The hermetic veto is composed of three layers. The innermost layer is a passive tungsten shielding 0.8 cm thick (Fig. 1.B and C). The middle (Fig. 1.D) and outer (Fig. 1.E) layer of the veto are made plastic scintillator, with an octagonal and cylinder shape, respectively, each 0.8 cm thick. The Octagonal Inner Veto is composed by 8 scintillator paddles coupled with optical glue; the top and bottom are covered by two octagonal scintillator caps. The Cylindrical Outer Veto is composed of a single cylindrical scintillator tube; two round scintillator caps cover

* Corresponding author at: Universitá degli Studi di Genova, 16126 Genova, Italy.
E-mail address: marco.spreafico@ge.infn.it (M. Spreafico).

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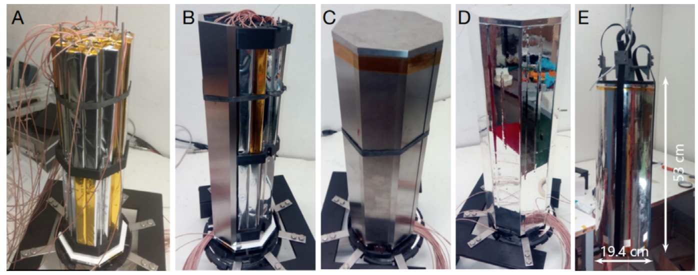

Fig. 1. The different components of BDX-Mini detector are shown. A. The two modules that constitute the ECal. B and C. Tungsten Shielding D. Inner Veto. E. Outer Veto.

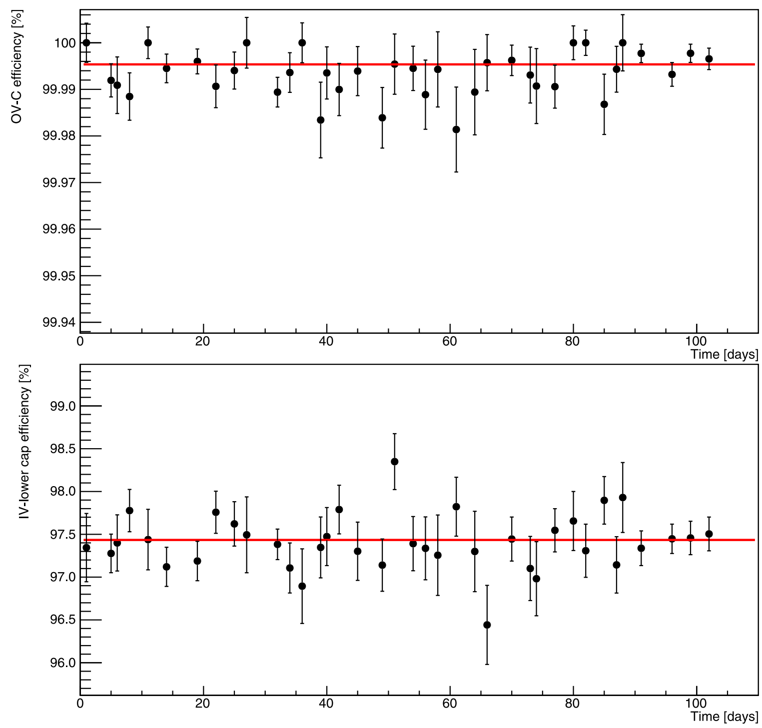

Fig. 2. Response of the OV-Cylinder (upper panel) and IV lower cap (bottom panel) as a function of time. The red line represents the average efficiency. The response of OV-Cylinder was measured selecting muons leaving a signal in both IV-O, OV-C and two adjacent caps. The response of IV lower cap was evaluated selecting muons leaving a signal in all caps.

the top and bottom. The scintillation light is collected by Wavelength Shifter Fibers inserted in grooves on the scintillator and read by 3×3 mm^2 Hamamatsu S13360-3075CS SiPMs. For each veto there are 10 readout channels, 8 for the lateral surface and 2 for the bases.

The front-end electronics and data acquisition system was installed outside the well at ground level. Each SiPM was connected via an 8-m long coaxial cable to a custom front-end circuit that provided the bias voltage and amplified the signal from photosensors. For each event, all channel were digitalized by a 250 MHz fADC and the corresponding waveform was saved on disk.

For a more detailed review of BDX-MINI experimental setup see Ref. [3]

3. Detector performance

Since BDX-MINI ran inside a field tent for several months, it was of paramount importance to monitor its performance over all measurement period.

In particular, considering the veto systems have a key role in the cosmic background rejection, it is mandatory to check and, in case, correct any possible response variation over time. The performance of each veto system was studied using cosmic-ray data collected during the accelerator down period. In Ref. [3], the analysis of beam-off data accumulated in over 30 days showed that requiring the anti-coincidence with the veto yields a very high suppression of the cosmic background.

To check the long-term stability of each component, the response of the veto to well defined trajectories produced by cosmic muons was studied as a function of time. For each cap, vertical muons were selected by requiring a significant deposited energy (corresponding to >5 p.e.) in other caps than the one under study and no activity in the other veto channels. The event selection to study the Inner Veto Octagon (Outer Veto Cylinder) performance required hits (at least one SiPM with a signal >5 p.e.) in the cylinder veto (octagon veto) and either the two upper or lower caps. Fig. 2 shows the response as function of time (each point represents a data-taking run) of the OV-Cylinder (upper panel) and Bottom IV cap (bottom panel). The results indicate that the response of each veto component was stable better than 1% for the whole data taking period.

4. Conclusions

BDX-Mini was the first modern electron beam dump experiment aimed specifically at Light Dark Matter search. Its detector was optimized for DM searches at accelerators, having the ECal surrounded by a highly hermetic multi layer veto. The veto demonstrated to have a very high rejection capability. In this paper, we report the performance of each veto system component investigated using cosmic ray data. This study demonstrated that the response of the veto system was extremely stable during the whole data taking period, although the experiment was performed inside a sturdy field tent.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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