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Reducing DRIFT backgrounds with a submicron aluminized-mylar cathode

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ABSTRACT

Background events in the DRIFT-IId dark matter detector, mimicking potential WIMP signals, are predominantly caused by alpha decays on the central cathode in which the alpha particle is completely or partially absorbed by the cathode material. We installed a 0.9 μm thick aluminized-mylar cathode as a way to reduce the probability of producing these backgrounds. We study three generations of cathode (wire, thin-film, and radiologically clean thin-film) with a focus on the ratio of background events to alpha decays. Two independent methods of measuring the absolute alpha decay rate are used to ensure an accurate result, and agree to within 10%. Using alpha range spectroscopy, we measure the radiologically cleanest cathode version to have a contamination of 3.3 ± 0.1 ppt ^{234}U and 73 ± 2 ppb ^{238}U. This cathode reduces the probability of producing an RPR from an alpha decay by a factor of 70 ± 20 compared to the original stainless steel wire cathode. First results are presented from a texturized version of the cathode, intended to be even more transparent to alpha particles. These efforts, along with other background reduction measures, have resulted in a drop in the observed background rate from 500/day to 1/day. With the recent implementation of full-volume fiducialization, these remaining background events are identified, allowing for background-free operation.

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1. Introduction

The properties of dark matter continue to be among the greatest outstanding mysteries in cosmology and particle physics. The evidence for non-Baryonic dark matter is extensive [1], and a Weakly Interacting Massive Particle (WIMP) is a well-motivated candidate [2]. A convincing direct detection, which would both conclusively confirm the existence of WIMP dark matter and provide valuable information about its properties, proves to be elusive. Some recent [3] and older [4] experimental results are suggestive of dark matter-like signals. These signals, despite being consistent with dark matter, have been called into question, demonstrating the need for a more convincing dark matter signature such as the sidereal modulation of the direction of incoming WIMP particles [5,6]. The Directional Recoil Identification From Tracks (DRIFT) dark matter experiment is the world's leading directional dark matter detector and is designed to provide an unambiguous detection of dark matter. DRIFT has demonstrated directionality down to 40 keVr [7,8] and set a spin-dependent limit (WIMP on proton) of 1.1 pb for a 100 GeV/c^2 WIMP [9]. The main challenge for DRIFT over the past 8 years has been radon progeny recoils (RPRs) from the central cathode, which have resulted in background rates as large as 500 events/day [10].

Two major advances have eliminated these backgrounds, resulting in essentially background-free operation for DRIFT. The first advance has been the development of a thin film cathode that has contributed to a two-order-of-magnitude reduction in the background rate. The backgrounds and their reduction by the thin

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film cathode are the subject of this work. The second was the discovery of a method for fiducialization along the drift direction [11], which enabled events near the cathode to be excluded as dark matter candidates. This method was implemented underground in the DRIFT-IId detector and demonstrated to work [12,9].

This paper begins with a description of the DRIFT detector (Section 2) and how alpha-decays at the cathode produce dark matter backgrounds in DRIFT. This will be followed (Section 3) by a description of the analysis techniques based on alpha range spectroscopy that identify both the isotopes and their location. This analysis was a critical tool in providing quantitative feedback on the efficacy of the different versions of the thin film cathode in reducing the backgrounds. Section 4 shows how the thin film cathode is expected to reduce the backgrounds in DRIFT-IId. These analysis tools were used to measure the radioactive contamination of the thin-film central cathode down to the ppt level (Section 5) and use this information to build a newer, cleaner version (Section 6). Finally, we quantify improvements made by two versions of the thin film cathode, which has culminated in a background rate of ≈ 1 event/day.

2. The DRIFT-IId detector

The DRIFT-IId Dark Matter detector is a 1 m^3 negative-ion time projection chamber (NITPC) which, while collecting data presented here, is operated at a pressure of 40 Torr [13]. The bulk of the gas was 30 Torr of CS_2, an electronegative gas which captures ionized electrons, producing negative ions [14]. These negative ions drift 10^3 times slower than electrons and with minimum (at the thermal limit) diffusion [15,16]. The remaining 10 Torr of gas was CF_4, chosen for its high content of ^{19}F providing spin-dependent sensitivity [17].

The DRIFT-IId detector (Fig. 1) contains two 50-cm deep detection volumes that share a single central cathode plane. During the data collection runs analyzed in this document, the cathode plane was at $-30{,}242$ V which, together with a wire field cage, defines a uniform drift field of $E = 550$ V/cm in each volume. Each volume was terminated by a 1 m^2 Multi-Wire Proportional Chamber (MWPC) which is composed of three parallel planes separated by 1 cm. The middle anode plane was originally built from 20 μm stainless steel wires at ground potential. The two outer grid planes use 100 μm wires oriented perpendicular to the anodes and held at -2731 V. This voltage difference provides gas amplification with a gain of ~ 1000.

Each of these planes has 552 wires with a pitch of 2 mm. The outermost 52 (41) wires of the anode (grid) are used to identify and veto events entering the fiducial volume of the detector from the outside. The remaining 448 (459) wires in each plane, spanning a 896 mm (918 mm) fiducial length, are grouped into 8 channels such that every eighth wire is read out by the same channel; this introduces a periodicity of 16 mm in the readouts. This does not affect the WIMP search as the low energy nuclear recoils of interest have tracks that are typically less than 5 mm long. This periodicity can be seen in longer tracks, such as those from alpha particles or protons, as seen in Fig. 2. The 8 anode channels measure the track along the x-axis while the perpendicular grid channels measure the y extent of a track. The z component of the length is measured by the transit of charge into the MWPC at a known drift speed of 59.37 ± 0.15 m/s. The digitization rate of 1 MHz and fast electronics correspond to a sub-mm spatial resolution along the z- axis, so the measurement of the track along this axis is the most precise and accurate.

The detector is located in the Boulby Underground Laboratory, at 2805 m.w.e., to shield from cosmogenics [19]. It is further shielded from rock neutrons by polypropylene pellets providing at least 35 g cm^{-2} of hydrogenous shielding. This is expected to reduce backgrounds from rock neutrons to less than 1/year [10].

2.1. DRIFT backgrounds and the thin-film solution

The first studies of background events in DRIFT-II observed a prohibitively high rate of WIMP-like backgrounds; around 500/day [10]. These have been attributed primarily to Radon Progeny Recoils (RPRs) produced at the 20 μm stainless steel wires of the cathode used at the time. Production of an RPR often begins with the emanation of ^{222}Rn inside the vacuum vessel. The ^{222}Rn atom diffuses into the fiducial volume and decays, emitting a 5.49 MeV alpha particle and a ^{218}Po atom which is typically positively charged (the charged fraction and its measurement is described in Section 5.1). While this initial alpha particle track is easily identified, it is the charged ^{218}Po that has the potential to initiate the RPR backgrounds. After the ^{218}Po drifts to and electrodeposits

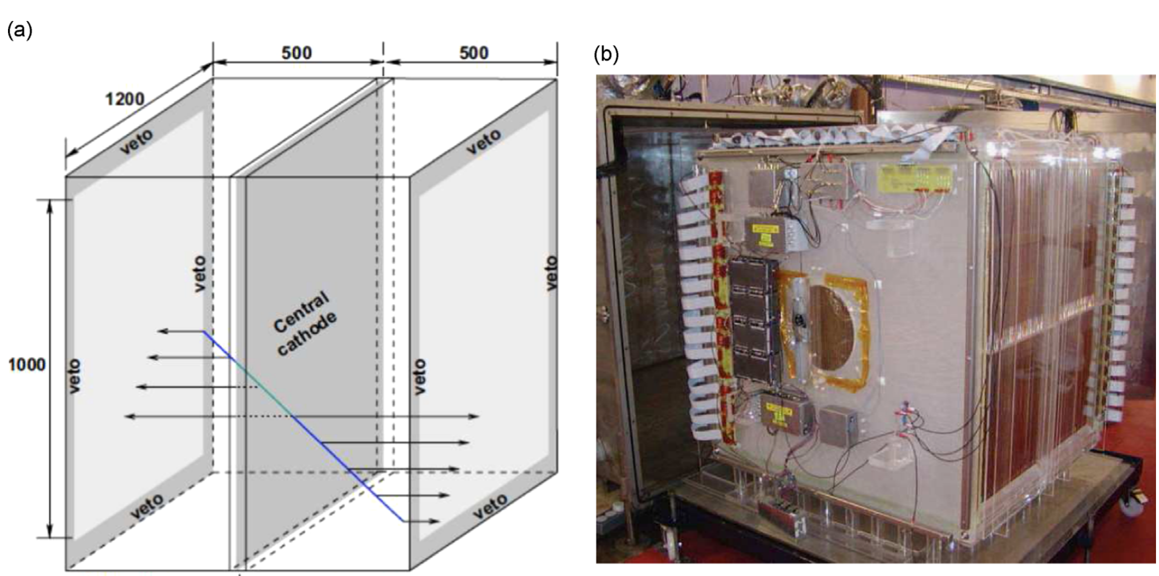

Fig. 1. The DRIFT-IId detector. (a) Schematic of the DRIFT-IId detector, showing a cathode-crossing alpha track. Lengths are in mm. Image reproduced from [18]. (b) Photograph of the DRIFT-IId detector removed from its vacuum vessel.