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Background Rejection in DRIFT

Eric MILLER[*]
University of New Mexico
E-mail: `ehmiller@unm.edu`

On behalf of the DRIFT Collaboration

The DRIFT dark matter detector is a 1 m^3 scale TPC with direction sensitivity to WIMP recoils operating in the Boulby Mine in England. Our primary backgrounds are from low-energy nuclear recoil events due to radon progeny plated out on the detector's wire central cathode. Here we describe a large background reduction resulting from the installation of a new thin-film central cathode. We also describe a new technique which promises to fully fiducialize the chamber, potentially eliminating this source of background entirely.

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[*] Speaker.

The detection and identification of dark matter is one of the most important persuits in astrophysics today[1]. Founded on a host of independent observations, current astrophysics and particle physics models suggest that the best candidate for dark matter is a Weakly Interacting Massive Particle (WIMP)[2]. Observations suggest that these particles exist in "halos" surrounding galaxies including our own and, therefore, they pass through our solar system allowing direct detection with experiments in earth-based laboratories[3]. While direct detection in laboratory experiments is the most robust evidence for dark matter particles, their slow speed and weak interactions with ordinary matter lead to exceedingly rare and feeble events inside detectors. Moreover, there exist large backgrounds due to naturally occurring radiation that can mimic the dark matter signal. In particular, the background from $\sim$MeV neutrons is nearly indistinguishable from WIMPs.

Fortunately, there exist a number of unique dark matter signatures that can be used to separate the background from the dark matter signal and positively identify it. The largest and most robust signature is the "day-night" variation of the directionality of WIMP recoils at Earth[4][5][6]. This diurnal modulation could be used to distinguish between a dark matter signal and background with a few tens of events[7]. The Directional Recoil Identification From Tracks (DRIFT) experiment has the capability to measure the scattered nuclear recoil direction and thereby infer the incoming WIMP direction, enabling it to be sensitive to this variation[8].

The DRIFT dark matter detector is a low-pressure negative ion TPC in which two drift volumes share a central cathode. Operating at 40 Torr, a nuclear recoil is long enough that the track can be resolved and a direction measured. DRIFT currently operates with a 30-10 mixture of CS_2-CF_4. Because CS_2 is electronegative it is the negative ions that drift rather than electrons, which results in less diffusion and better track resolution[9]. The inclusion of CF_4 provides DRIFT with spin-dependent wimp on proton sensitivity via ^{1}9F.

The detector consists of two 50 cm drift volumes in which the electric field is defined by an instrumented MWPC and a shared central cathode (See Figures 1 and 2). Each MWPC has two planes of instrumented readout wires. The wires of each plane are perpendicular and provide two dimensions of track information, called x and y. The outermost wires of each plane are veto wires and serve to fiducialize these two axes. Measurement along the drift direction (z) is obtained by sampling the readout wire voltages at 1 MHz. This axis provides the best resolution. See [10] for a more detailed description of the DRIFT detector.

The DRIFT technology, which is based on range vs. energy, provides excellent discrimination between nuclear recoils, electron recoils, and alpha particles. The detector itself is 1 km underground in the Boulby mine to reduce cosmogenic backgrounds and the vacuum vessel is surrounded on all sides with plastic shielding to eliminate any external neutron background. Nevertheless, the experiment is currently dominated by a large number of nuclear recoils whose source is described below.

1. Background

The dominant backgrounds in the DRIFT detector are due to Radon Progeny Recoils (RPRs)[11]. The process begins with ^{222}Rn emanating from materials in the vacuum vessel and diffusing into the detection volume. When this atom decays, an alpha particle travels 38 cm through the gas[12] and a ^{218}Po atom recoils several mm in the opposite direction, typically losing some or all of its

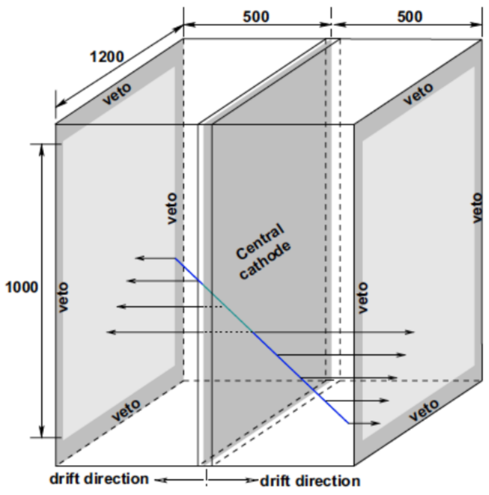

Figure 1: A schematic of the DRIFT detector, described in the main text.

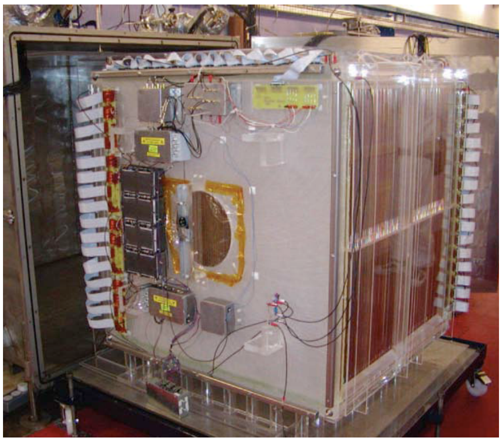

Figure 2: The DRIFT-IId underground in the Boulby mine, showing the detector outside of the vacuum vessel.

electrons. This first decay is easily recognized and vetoed by the long alpha track. The now-positively charged ^{218}Po ion drifts down the electric field lines, eventually plating out onto the central cathode. With a half-life of 3 minutes, it undergoes an alpha decay into ^{214}Pb. Most of the time, the alpha travels through the gas and again is easily identified; however approximately 40% of the time the alpha, with a range of 14 μm in steel, is fully absorbed by the 20 μm steel wires that make up the cathode. When this occurs, the recoiling ^{214}Pb nucleus enters the detection volume and is identified as a nuclear recoil, similar to one from a dark matter interaction.

One distinguishing feature of these background events is that they all come from the central cathode, whereas a true WIMP signal would be uniformly distributed throughout the detection volume. DRIFT is currently capable of estimating the drift distance of an event by measuring the track size; for short nuclear recoils, this is dominated by diffusion. Events with smaller spacial extent (or RMST) tend to occur farther away from the cathode and closer to the MWPC. Figure 3 shows the distribution of RMST as a function of energy for a background run (black) and neutron calibration runs (red). The neutron events, expected to occur uniformly within the detection volume, have RMST values between 11 and 17 μs. The RMST of background events is instead clustered, with some spread in the distribution, around 16 μs. This suggests that the background events experience a maximal drift and are coming from the cathode, as expected from RPRs produced at the cathode.

DRIFT presently defines a cut in the RMST vs. energy parameter space to exclude the majority of the RPRs[13]; however this cut significantly reduces DRIFT's signal region and, therefore, sensitivity to WIMPs. Eliminating this background will increase the detector's sensitivity by an order of magnitude.

2. Radiation-Transparent Cathode

DRIFT's primary background, RPRs, exist because alpha particles from Polonium decays range out in the material of the central cathode, leaving only the recoiling Lead nucleus to mimic a

WIMP event. If the central cathode was transparent to alphas, then the long (∼40 cm) alpha track would be visible and provide a signature with which to veto the RPR background events. Table 1 lists the current cathode (20 μm steel wire) and possible alternatives, along with the fraction of surface alphas that are expected to be absorbed.

Cathode Type	Fraction Lost (%) Po 214 (7.69 MeV)	Fraction Lost (%) Po 218 (6 MeV)	Fraction Lost (%) Po 210 (5.3 MeV)
20 micron steel wire	37	41	
2 micron mylar sheet	1.8 (1.6)	2.7 (2.5)	3.2 (3.1)
0.9 micron mylar sheet	0.8	1.2	1.5

Table 1: The chance that an alpha particle emitted from the surface of the cathode is completely absorbed by the cathode, determined for various potential cathode materials. Values are determined by geometric calculations. Values in parenthesis are results of SRIM simulations[14].

The most transparent cathode material we could acquire and handle is the 0.9 μm aluminized mylar. According to geometric calculations, between 0.8% and 1.5% of the alphas in the radon chain that result in RPRs would be fully absorbed within the film. This is roughly a factor 40 fewer than we expect from the normal wire cathode, which should correspond to a reduction in RPRs by a factor of 40.

In March of 2010 the wire central cathode of the DRIFT-IId detector in Boulby was replaced with a thin-film cathode. This new cathode consisted of four side-by-side strips of 0.9μm thick mylar, aluminized on both sides. DRIFT-IId has been collecting blinded data using this thin-film central cathode since then. A few days of unblinded performance monitoring data are available, and an initial comparison is shown in figure 3. These data provide a background rate of 6 ± 2 events

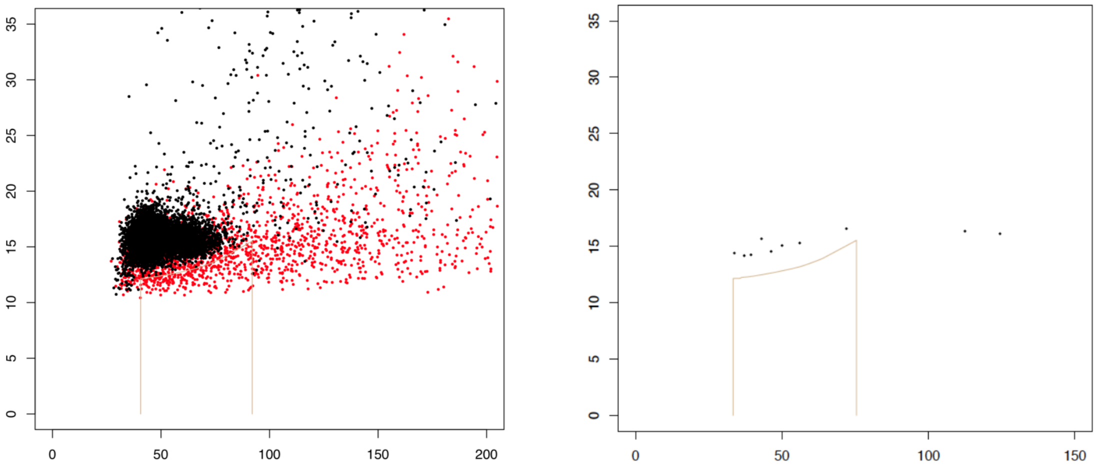

Figure 3: Signal RMST (μs) vs. event energy (keV). RMST is a measure of the size of the event's ionization cloud when it is detected by the MWPC, which is dominated by diffusion for these low-energy nuclear recoils. The background-free signal region is shown as a tan box in both plots. LEFT: Data from Neutron calibration runs in red; Data from background runs in black. The background rate is 130 ± 2 events/day, and these are clustered around 15 μs RMST. RIGHT: Background data using thin-film cathode, showing 6 ± 2 events/day.

per day, compared with the previous rate of 130 ± 2 events per day. This corresponds to a reduction in background by a factor of 20. We are currently investigating why the improvement is only half of what we expected.

3. Z-Fiducialization

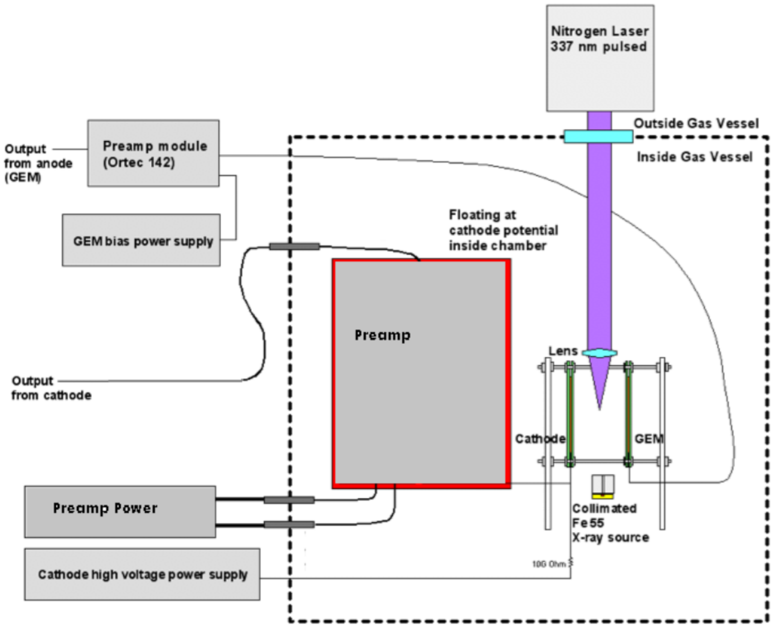

Figure 4: Hardware configuration for cathode sensitivity measurements for very low amplitude events. Variable amplitude ionizing events were produced by a pulsed nitrogen laser. Calibration of the laser generated events was accomplished by using a GEM to amplify the low level ionization events using an ^{55}Fe source as a reference and varying the intensity of the laser pulses to produce the desired number of generated ion pairs. After the laser was calibrated to produce the desired amount of ionization, the GEM was powered down to eliminate interference with the cathode electronics.

With appropriate shielding from external sources of backgrounds, the remaining sources are limited to those originating from the detector material itself. This is the case for the RPR background present in DRIFT, as described above. These are typically removed by defining an inner fiducial volume sufficiently far from the inner surface of the detector. DRIFT fiducializes along the x and y axes by using veto wires as described above. However, there is currently no mechanism for fiducializing along the z axis.

We are developing the technology to fully fiducialize the DRIFT detector by instrumenting the cathode to detect drifting positive ions. One timing marker is obtained when the negative ions are amplified in the MWPC, and a second timing marker is obtained by detecting the positive ions' arrival at the cathode. The z position of the event occurred is then given by $(t_1 - t_2) * v_{drift}/2$, where $v_{drift} = 60$ m/s is the drift velocity of ions in the chamber. The difficulty is in obtaining that second timing marker. For the RPR events in the DRIFT detector, this requires correctly extracting the timing marker of a 1000 ion signal off of the -32kV cathode.

The first tests were performed using a small mockup of DRIFT using a drift distance of 6 cm and 7 cm by 7 cm cathode and anode (See Figure 3 for schematic). The cathode was a wire plane similar to the old DRIFT cathode and the anode was an unpowered Gas Electron Multiplier, or GEM[15]. The cathode was read out by an Amptek A250. We produced ionization within the detection volume by focusing a pulsed Nitrogen laser down to a point[16]. Attenuating the beam provided a method to vary the amplitude of the signal, which we calibrated against an ^{55}Fe x-ray source[17].

Using this setup, we were able to generate events with a known timing marker and an amplitude of 950 ion-pairs. Despite significant noise reduction efforts, our signal/noise ratio for events of this amplitude was still around 0.8. In order to detect signals under these circumstances, we used the technique of cross-correlation with a known signal waveform. Looking only within a ±1ms time window (corresponding to the maximum drift time), we were able to correctly extract the timing marker of the event 84% of the time (see Figure 3).

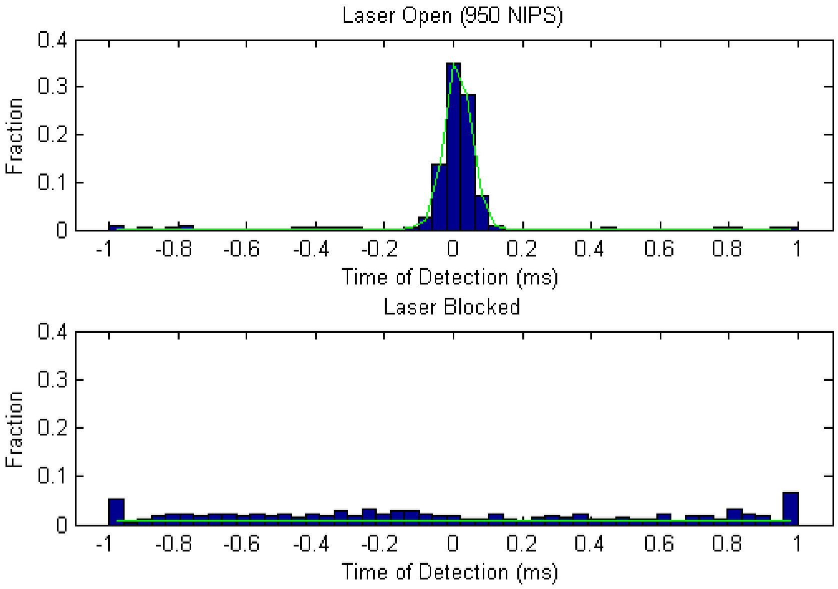

Figure 5: Histograms of extracted timing markers compared with known timing markers. A result of 0 ms corresponds to an exactly correct detection; the search window is limited to ±1ms by the maximum drift time in the system. TOP: This run was calibrated to 950 ± 210 ion pairs. 84% of the 283 signals fell under the curve of a fitted gaussian, shown in green. The width of this fit, measuring precision of a fiducialization system, corresponds to half of a centimeter. BOTTOM: This run was set up identically to the above run, but the laser path was physically blocked. The flatness of the resulting distribution confirms that we are not observing false signals induced by the laser electronics.

4. Future Work

We are currently implementing the successful cathode readout scheme in a DRIFT-II module. This is a challenging task because scaling up from the small prototype detector used to demonstrate the cathode readout to the full-scale DRIFT detector introduces new sources of noise. For example, a major new noise source comes from microphonics, and their origins may differ greatly between the small prototype and the full sized DRIFT detector. Much of our current efforts are now targetted toward noise reduction with a particular focus on microphonics.

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