DRIFT: Background Reduction and Spin-Dependent Limits

Daniel Walker on behalf of the DRIFT collaboration

Department of Physics and Astronomy, University of Sheffield, S3 7RH, UK

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The DRIFT (Directional Recoil Identification From Tracks) collaboration operates a $1m^3$ directional dark matter search experiment, based on a low pressure gaseous negative ion time projection chamber (NI-TPC) in the Boulby Underground Laboratory. Recent progress includes the addition of CF_4 to the target volume, and a series of background reduction work. A preliminary limit on the spin-dependent WIMP-proton interaction cross-section is presented from a non-blind analysis of 47.2 days live time with a $0.8m^3$ 30 Torr CS_2 - 10 Torr CF_4 target. The preliminary limit has a minimum of 1.1pb for a 100GeV WIMP.

1 Introduction

Dark matter halo models suggest that WIMPs may exist in the form of an isothermal sphere encompassing the Milky Way, providing an explanation for flat galactic rotation curves [1]. The interaction of WIMPs with baryonic matter is expected to be such that particle detectors of sufficient sensitivity should be able to detect the rare low energy nuclear recoils that would result ($\sim$ 1 keV at $<$ 1 event/kg/day). The basis of directional detection lies in the assumption of a finite Galactic orbital velocity of our Solar System, $\sim$ 220kms^{-1} relative to the WIMP velocity distribution in the Galactic halo. There is hence a WIMP 'wind' experienced for a detector in the Solar System, with a preference for nuclear recoils with velocities opposite to the orbital motion through the Galaxy. This WIMP 'wind' will have both an annual and a sidereal variation as shown in Figure 1. Over the course of a sidereal day the direction of this will oscillate, a very powerful signature that will be difficult for any terrestrial background to mimick [2]. The DRIFT collaboration is attempting to utilise this powerful discriminant against terrestrial backgrounds through the development of a directionally sensitive dark matter detector.

2 DRIFT Overview

The DRIFT-II detector is described in detail in [3]. DRIFT-II is a $1m^3$ low pressure gaseous negative ion time projection chamber (NI-TPC). WIMP-nucleon interactions in the 40 Torr CS_2-CF_4 target gas are expected to create ionisation tracks a few millimetres in length. The orientation of these tracks would be biased in the direction opposite to that of the incoming WIMPs [4]. In DRIFT, the drifted tracks are negative ions, which reduces diffusion up to drift

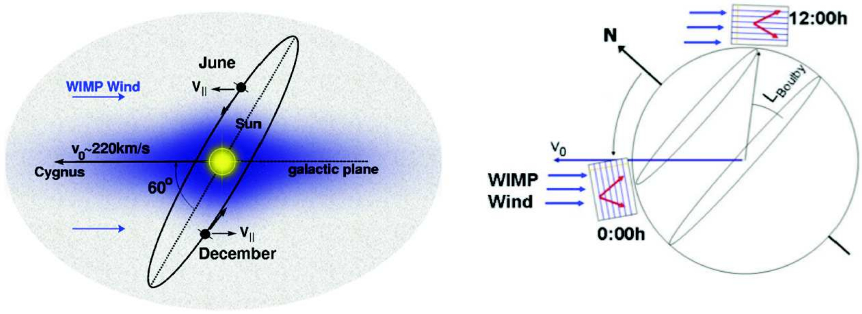

Figure 1: The WIMP 'Wind' and its annual (left) and sidereal (right) variation.

distances of 50 cm. CS_2 is electronegative, thus primary ionisation electrons quickly attach to CS_2 molecules producing a track of negative CS_2 ions. Compared with electrons drifted alone these heavy ions give far less diffusion, down to thermal levels. This preserves the track's directional information.

3 Backgrounds

The current dominating background in the underground DRIFT-II detector is from events termed radon progeny recoils (RPRs). Radon gas (^{222}Rn and ^{220}Rn) is present in the DRIFT detector target volume, emitted from trace levels of U and Th in the detector components. ^{222}Rn is unstable and decays to ^{218}Po, emitting a 5.49 MeV alpha particle, which gives an ionisation track in the detector volume of length $\sim$ 400mm. Because of the long track length, these events can be discriminated with high efficiency, and hence have negligible effect. $\sim$ 80% of the time, the decay product is $^{218}Po^{+}$, an unstable, charged atom. In the electric field this drifts to the surface of the 20μm stainless steel central cathode wires [5]. The $^{218}Po^{+}$ atom then decays via emission of a 6.11 MeV alpha particle. In stainless steel this has a range of 14μm, and hence due to the geometry of the wire, this gives a 37% chance of the alpha becoming embedded in the cathode wire, with only the recoil atom (^{218}Po) being detected in the fiducial volume. The detection of a nuclear recoil of energy $\sim$ 100keV can potentially mimick the signal expected from a WIMP nuclear recoil. In addition, the radon decay chain results in ^{210}Pb plating out onto the surface of the cathode wires. Being unstable, with a half life of 22.3 years, this can be a further source of RPR background events, even after any radon inside the detector volume has been eliminated.

The first step in reducing this background is the removal of radon from the detector volume. It was found from radon emanation tests that RG58 coaxial cables (PVC coated) and ribbon cables (also PVC coated) were the dominant source of radon emanation. As suitable replacements, PTFE coated coaxial signal cables and FEP coated ribbon cables were found. After these replacements, the total number of Rn atoms per second emitted by all detector components was found to have been reduced from 0.95 ± 0.06 to 0.09 ± 0.03.

In a further step to remove any radon, in March 2008 the 1m^2 central cathode was etched in nitric acid to remove long lived radon progeny (^{210}Pb). Subsequent analysis of data from before and after this procedure showed that the level of background events was reduced further by a factor of 6.7 ± 1.0.

4 Spin-Dependent WIMP-Proton Limit

In order to set a limit for spin-dependent WIMP interactions, a target material of 30 Torr CS_2 - 10 Torr CF_4 was chosen. This maximises the fluorine content, which has nuclei of spin 1/2 [6]. Negative ion drift and detector stability is maintained via this mixture [7]. A total of 47.2 days live time data with a continuous flow of this gas mixture was taken, this flow being to minimise radon in the gas. This yields 1.47 kg·days of fluorine fiducial mass. Preliminary limits on the SD WIMP-proton cross-section were produced using the zero background signal region and the WIMP detection efficiency. These limits are shown in Figure 2. Note that this analysis is not blind, as the signal region was chosen after an analysis of the data and background study. A fully blind analysis is planned with further data that is currently being taken.

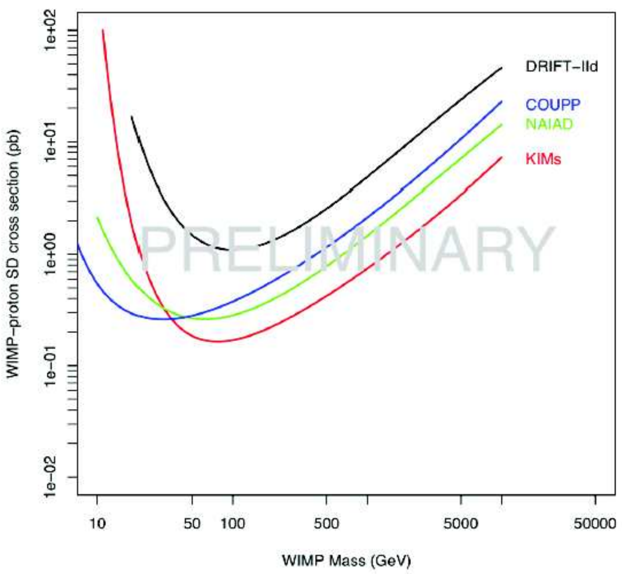

Figure 2: Preliminary limits on spin-dependent WIMP-proton coupling from 47.2 days live time with a $0.8m^3$ fiducial volume of 30 Torr CS_2 - 10 Torr CF_4 in the DRIFT-IId detector underground at Boulby Mine.

5 Thin Film Cathode

The RPR background discussed above results from unstable radon progeny on the surface of the central cathode wires that recoil into the fiducial volume. The alpha that should easily distinguish this event from signal becomes embedded in the central cathode wire. One way to reduce this background is to make the cathode more transparent to alphas in order to reject these events via detection of this alpha.

Several potential cathodes were modelled, and a 0.9μm mylar sheet, evaporation coated with aluminium was found to be a suitable material. It was expected that $\sim 1\%$ of decays on the surface would result in a recoil that would be indistinguishable from a WIMP recoil, compared with 37% of radon progeny decays on the wire cathode. This suggests a potential reduction in background by a factor of ~ 40.

After testing at Occidental College, a 1m^2 cathode was installed on the detector at Boulby mine in March 2010. Preliminary analysis of data taken shows a reduction in background by a factor ~ 15, suggesting there may be other backgrounds within the RPR region introduced by the thin film cathode. A study is currently underway to understand these backgrounds for the proposed blind analysis.

Acknowledgments

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References

[1] J. D. Vergados, "Theoretical directional and modulated rates for direct supersymmetric dark matter detection," Phys. Rev. D **67**, 103003 (2003).

[2] B. Morgan, A. M. Green, and N. J. C. Spooner, "Directional statistics for realistic weakly interacting massive particle direct detection experiments," Phys. Rev. D **71**, 103507 (2005).

[3] G. J. Alner, et al., "The DRIFT-II dark matter detector: Design and commissioning," Nucl. Instrum. Meth. A **555**, 173 (2005).

[4] D. P. Snowden-Ifft, C. J. Martoff, and J. M. Burwell, "Low pressure negative ion time projection chamber for dark matter search," Phys. Rev. D **61**, 101301 (2000).

[5] S. Burgos, et al., "Track reconstruction and performance of DRIFT directional dark matter detectors using alpha particles," Nucl. Instrum. Meth. A, **584**, 114 (2008).

[6] J. Ellis, and R. A. Flores, "Elastic supersymmetric relic-nucleus scattering revisited," Phys. Lett. B **263**, 259 (1991).

[7] K. Pushkin, and D. P. Snowden-Ifft, "Measurements of W-value, mobility and gas gain in electronegative gaseous CS2 and CS2 gas mixtures," Nucl. Instrum. Meth. A **606**, 569 (2009).