Progress report on DRIFT-II

Mark Pipe for the DRIFT collaboration
Department of Physics and Astronomy, University of Sheffield, Sheffield S3 7RH, UK
E-mail: m.pipe@sheffield.ac.uk

Abstract. We present recent progress from the DRIFT (Directional Recoil Identification From Tracks) collaboration. We summarise recent work demonstrating 1) directional sensitivity to a neutron source in a 1 m$^3$ DRIFT-II detector in all 3 dimensions at energies of 50 keV 2) first measurements of the head-tail effect in $\sim$keV/amu nuclear recoils using a DRIFT-II detector. We also summarise results of measurements of W-value, mobility and gas gain in CS$_2$-CF$_4$ gas mixtures from a single proportional counter experiment that suggest the potential of the DRIFT-II detector as a spin-dependant dark matter detector.

1. Introduction

Weakly Interacting Massive Particles (WIMPs) remain a particularly well-motivated candidate for cold dark matter. As discussed in [1], WIMP dark matter may form an isothermal sphere encompassing our galaxy, resolving the problem of flat galactic rotation curves. An observer on Earth would perceive a WIMP wind of several hundred $\text{km} \cdot \text{s}^{-1}$, reflecting the motion of the Earth’s surface with respect to the galactic rest frame. DRIFT is pioneering operation of a directionally sensitive WIMP detector in a low-background, deep underground site, which is potentially capable of using the WIMP wind as a powerful discriminant between true astrophysical signals and laboratory based noise.

The DRIFT-II detector (described in detail in [2]) is a 1 m$^3$ low pressure gaseous negative ion time projection chamber (NI-TPC). WIMP-nucleon interactions in the drift region (0.8 m$^3$ of CS$_2$ at 40 Torr - 134 g target mass) would create tracks of ionisation a few mm in length, and with an orientation biased in the direction of the incoming WIMPs [3]. Electrons liberated by the primary nuclear recoil bind to electronegative CS$_2$ molecules resulting in a track of negative CS$_2$ ions. These heavy ions drift with far less diffusion than electrons drifted alone, making it feasible to scale-up the drift region to meter dimensions whilst retaining the ability to reconstruct the direction and charge distribution in the original track. There are currently two, essentially identical, DRIFT-II modules in operation. DRIFT-IIId is located at a depth of 2805 m.w.e. at the Boulby Underground Laboratory, UK. DRIFT-IIic is located in a surface laboratory at Occidental College, Los Angeles, CA, USA.

2. Directional studies on DRIFT-IIc

A 202$\mu$Ci $^{252}$Cf source was used to produce nuclear recoils similar to those expected from WIMP interactions. The source was placed on each of the principle dimensions of the detector at a distance of 3.31 m so that the angular spread of the neutron beams was collimated to $\sim$ 10% (excluding scattering). Range components of the nuclear recoils were calculated, with $\Delta x$ and $\Delta y$ calculated from charge deposition on the two perpendicular wire planes of the MWPC,
and $\Delta z$ coming from timing information. For each source position, it is found that the range component is largest for the axis on which the neutron source is placed [4]. This effect is greatest for the $\Delta z$ component derived from timing, and least for the $\Delta y$ component derived from signals on the MWPC grid wires, leading to an optimal orientation choice where the anode wires run parallel to lines of fixed latitude on the Earth's surface and the normal to the MWPC readout plane points to the zenith.

3. Head-tail effects in nuclear recoils

It has been shown that being able to determine the full vector of a WIMP-induced nuclear recoil, compared to the scaler direction, can reduce the number of events required for positive detection by an order of magnitude [5]. The differential ionisation of low energy ($\sim$keV/amu) nuclear recoils expected from a WIMP-nucleon interaction is unclear [6]. Determining whether these low energy recoils produce a head-tail effect, and whether this effect can be detected in a 1m$^3$ DRIFT-II detector are critical.

An experimental setup similar to that used for the directional measurements was used [7]. Analysis defined a head-tail asymmetry parameter derived from the ratio of charge deposited in the first and second half of ionisation tracks from nuclear recoils. Using this asymmetry parameter it is shown that the ionisation density was higher close to the primary collision than at the far end of the recoil track. Figure 1 shows that this head-tail effect increases with larger energy recoils and remains significant down to energies of 50 keV ($\sim$1.5 keV/amu).

4. Gas measurements with a proportional counter

A proportional counter experiment was set up such that UV photons from a xenon flashlamp were used to liberate single photoelectrons on the inner cathode wall of the proportional counter. This was used for measurements of W-value, mobility and gas gain for a variety of CS$_2$-CF$_4$ gas mixtures [8].

Measurements of W-value (mean energy required to create an ion pair) were made by using an $^{55}$Fe source to produce X-rays of known energy (5.9 keV) in the proportional counter volume. Measuring the mean pulse size from X-ray events and combining this with the mean pulse size of single electron events provides a measure of the mean number of ion pairs produced in a 5.9 keV event, and hence the mean energy required to create a single ion pair. W-values were measured as (CS$_2$-CF$_4$ Torr): 24.9±0.8 (40-0), 25.2±0.6 (30-10), 29.2±1.0 (20-20) and 33.0±1.0 eV (10-30). The implication of this result for the operation of a 1 m$^3$ DRIFT-II detector with CS$_2$-CF$_4$ gas mixtures is that as CF$_4$ concentration increases relative to CS$_2$ the detector will become less sensitive to low energy events.

Mobility, $\mu$, is defined by $v = (\mu E)/p$, where $v$ is drift velocity, $E$ is electric field and $p$ is gas pressure. The drift velocity is deduced experimentally by measuring the average difference in time between excitation of a photoelectron on the cathode and arrival of charge at the anode. The average mobility was measured as (CS$_2$-CF$_4$ Torr): 0.54 ± 0.02 (40-0), 0.60 ± 0.02 (30-10), 0.69 ± 0.02 (20-20) and 0.81 ± 0.03 cm$^2$ atm V$^{-1}$ s$^{-1}$ (10-30). At concentrations of CF$_4$ above 75% drift times fluctuate substantially, indicating fluctuating electron capture path lengths. This would result in large diffusion of ionisation before the negative ion track is formed, leading to loss of directional information. However, the measurements show that for concentrations up to 10-30 Torr CS$_2$-CF$_4$ negative ion drift is preserved, and the average mobility increases as CF$_4$ content is increased.

Gas gain (the charge multiplication that occurs in the avalanche region of the proportional counter) was calculated by measuring the ionisation produced by single electron events through an amplification chain of known gain. Figure 2 shows the gas gain curves for various CS$_2$-CF$_4$ mixtures as a function of applied voltage and shows that gas gain increases as CF$_4$ concentration is increased. The maximum applied voltage was reduced with increasing CF$_4$ concentration in
order to prevent electrical breakdown in the proportional counter. These results show that increased gain, and hence improved signal-to-noise, is expected with the addition of CF$_4$ to the DRIFT-II detector, but that high-voltage stability will be reduced and lower MWPC operating voltages will be required for stable running.

5. Summary
The results from the directional and head-tail studies demonstrate key features of the DRIFT-II detectors. They are however, non-optimal. An upgrade of the detector electronics and DAq to a system with lower noise and less aggressive pulse shaping is in progress, expected to lower the energy threshold of the detector and increase sensitivity to the head-tail asymmetry. Improved parameterisation and track reconstruction techniques could also amplify these effects. The prospect of refining these techniques and combining these signals suggests DRIFT as a powerful tool for identification of WIMPs and further study of their properties.

The work with CS$_2$-CF$_4$ mixtures demonstrates the flexibility of the DRIFT-II detectors and offers an opportunity to run the detectors in a spin-dependent mode with the addition of CF$_4$. DRIFT-IId at the Boulby mine has been upgraded with a new gas mixing system that allows the continuous flow of CS$_2$-CF$_4$ gas mixtures (required to maintain gas purity in the 1.5m$^3$ stainless steel vacuum vessel). Stable running has been achieved with a 30-10 CS$_2$-CF$_4$ mixture. Data is currently being collected.

![Figure 1. Pulse asymmetry parameter as a function of S recoil energy (blue circles optimal, brown triangles anti-optimal).](image1)

![Figure 2. Gas gain as a function of applied voltage for CS$_2$-CF$_4$ gas mixtures.](image2)

References
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