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First Results from the DRIFT-I Detector

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DRIFT-I is the world's first WIMP dark matter detector with sensitivity to the direction of nuclear recoils. This article discusses the DRIFT-I detector, and presents some preliminary data from underground engineering runs.

1. Introduction

DRIFT (**D**irectional **R**ecoil **I**dentification **F**rom **T**racks) is a low pressure Negative Ion Time Projection Chamber (NITPC) designed to detect WIMP dark matter. In addition to it's ability to measure the energy of WIMP-induced nuclear recoils DRIFT has the unique capability of measuring components of their range. This directionally sensitivity offers significant advantages in positively identifying a WIMP signal compared with other techniques such as annual modulation. Whilst several prototype directional detectors based on phonon anisotropy in BaF_2 crystals [1] or roton anisotropy in liquid He [2] have been tested, low pressure gas detectors with Ar,Xe or other gases offer the best prospects for a workable detector. The DRIFT project is a collaboration between the United Kingdom Dark Matter Collaboration (UKDMC: Sheffield University, Rutherford Appleton Laboratory, Imperial College), Occidental College, Temple University, and Lawrence Livermore National Laboratory with the purpose of constructing and operating low pressure NITPC for WIMP dark matter detection. This article discussed the DRIFT-I detector and presents some preliminary data from underground engineering runs.

2. Directional Detectors - Theory

The standard isotropic sphere model of the WIMP halo believed to surround our Galaxy predicts it to be non-rotating with a Maxwellian velocity distribution of mean speed $270kms^{-1}$. In contrast, the solar system is orbiting the galactic center at a speed of $220kms^{-1}$. The closeness of the mean WIMP and solar system speeds means that the WIMP velocity distribution in the Earth's frame is strongly peaked in the direction of the solar system's motion. In consequence, the distribution of recoil directions will be strongly peaked in the opposite direction. Thus a detector capable of measuring the directions of these recoils can positively identify a WIMP signal from two distinct signatures.

As shown in Figure 1, a detector fixed on the Earth will see the mean recoil direction rotate from downwards to southwards and back again over one sidereal day. Alternatively, one can transform the recoil directions to the galactic frame and look at the resultant direction distribution for deviations from isotropy. Monte Carlo

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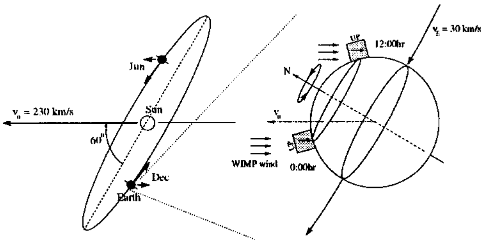

Figure 1. Geometry of the Earth's motion through the Galactic WIMP halo.

simulations indicate an asymmetry of 20% giving a 90% confidence level detection after only ≈ 140 events [3] A further advantage of these directional signatures is that they cannot be mimicked by background signals.

3. Directional Detectors - Realisation

The sub-100keV energy scale of WIMP induced nuclear recoils means that their ranges are very short (of order a few hundred Angstroms) in solids and liquids rendering directional detection nearly impossible. DRIFT therefore utilizes a gas at low pressure to extend the recoil range to a few millimetres.

Of course in order for DRIFT to see a signal background must also be suppressed. Fortunately DRIFT's ability to visualize the range also allows for excellent background rejection. As shown in Figure 2 below, the difference in range between electrons, alphas and recoils at a given ionisation is such that rejection efficiencies of at least 99.9% are possible at $6keV$ [4]. This allows a $1m^3$ detector operating with Ar at a pressure of 40torr to produce a limit competitive with DAMA and CDMS-I, see Figure 3.

In order to optimise the spatial resolution of such a detector, the diffusion of charge in the particle tracks must be minimised. Cost, size and power requirements rule out the use of a magnet in an underground experiment. Instead, DRIFT uses CS$_2$ as an electronegative target gas to capture the ionisation electrons. The resultant neg-

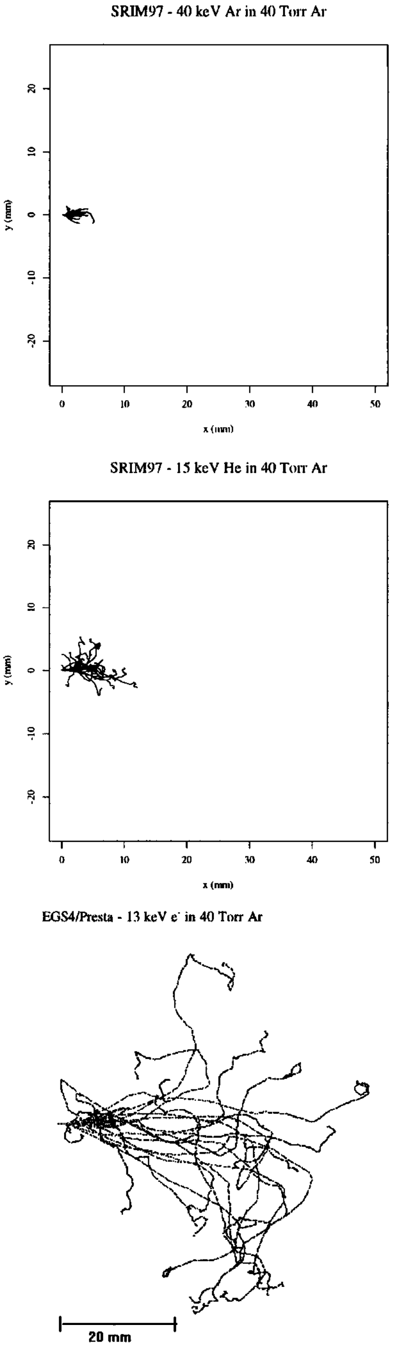

Figure 2. Simulations of 500NIP recoil, alpha and electron tracks in 40torr Ar.

ative ions are drifted to the readout plane, reducing diffusion to the thermal level. Experiments have shown that the diffusion can be reduced to $0.5mm$ over drift lengths of $50cm$ using CS_2 gas [5].

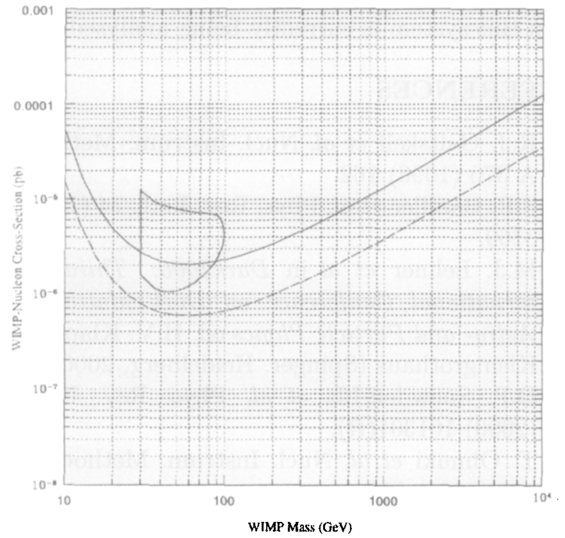

Figure 3. Sensitivity of a DRIFT detector using 40torr Ar for 1 year's exposure [4]. Also shown is a representative DAMA region.

4. The DRIFT-I Detector

DRIFT-I is the first full scale DRIFT detector to be operated underground. It consists of a $1m^3$ fiducial volume detector contained within a large stainless steel vacuum vessel.

The detector itself consists of two back to back field cages either side of a central cathode plane consisting of 512 $20\mu m$ stainless steel wires. Both the field cages and cathode plane frame are constructed from Lucite to ensure a low U/Th contamination and hence background rate. Tracks are read out with two $1m^2$ MWPCs, one at each end of the $0.5m$ long field cages. The MWPCs are made up of an anode plane instrumented with 512 $20\mu m$ stainless steel wires at a pitch of $2mm$, with grid planes of $100\mu m$ stainless steel wires either side. As with the other detector components, the MWPC frames are constructed from Lucite. Although these MWPCs only permit a 2D projection of the track to be measured, rejection efficiencies $> 99.9\%$ are still possible by measuring the two dimensional projection of the range. The detector is housed within a large stainless steel vacuum vessel.

Full engineering runs were performed above ground during spring of 2001 before installation at the Boulby underground site. Various calibration tests were carried out with gamma (^{55}Fe) and neutron (^{252}Cf) sources during this period, and many cosmic ray induced neutrons were observed. DRIFT-I was fully installed at Boulby Mine during September/October of 2001, followed by several months of engineering runs to ensure stability of operation.

5. Preliminary Engineering Data

The initial DAQ system for DRIFT-I multiplexed every eighth MWPC anode wire together over both top and bottom detectors. Events were sampled at a rate of $2.5MHz$ with the output being in the form of traces of the voltage across each of the eight wires. These traces can then be analysed as described in Snowden-Ifft [6] to determine the primary ionisation in the events, NIPs, and the two dimensional projection of the range, R2.

Initial underground runs concentrated on acquiring data with a ^{252}Cf neutron source. The resultant plot of R2 versus NIPs after cuts are applied is shown in Figure 4.

Typical voltage pulses from this system are well above the noise level. A characteristic neutron recoil event is shown in Figure 5.

In early February of 2002, a new DAQ system was installed that allows each wire to be read out individually. This allows vetoing of events that occur close to the walls of the chamber. Data analysis of calibration runs with ^{55}Fe gamma and ^{252}Cf neutron sources, together with dark matter

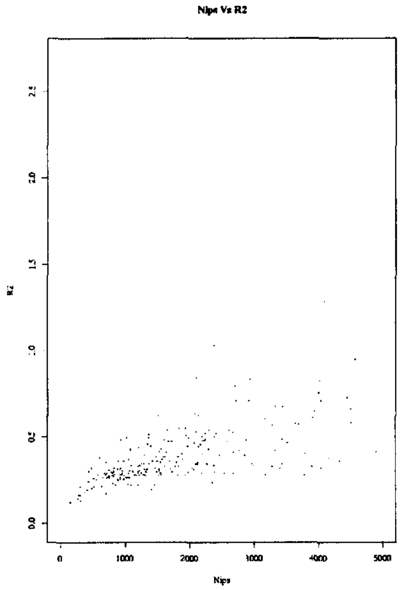

Figure 4. Neutron data from DRIFT-I Results.

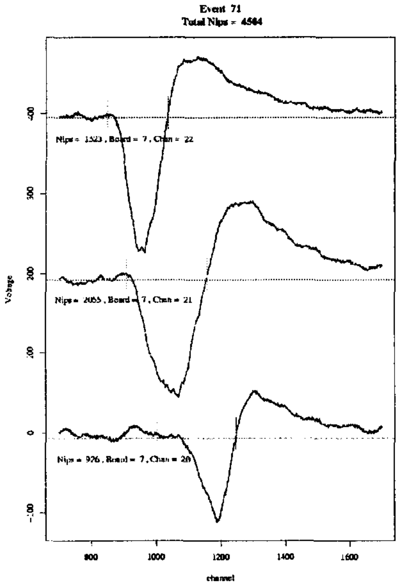

Figure 5. Voltage pulses of a typical neutron event in DRIFT-I.

runs is now underway.

6. Conclusions

DRIFT-I has now been operating stably underground for over six months . Neutron and gamma source calibration runs have shown the detector to work as expected. A new DAQ system has been installed in the last few months and data from this system is currently being analysed.

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