

The DRIFT Project: Searching for WIMPS with a Directional Detector

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Abstract. A low pressure time projection chamber for the detection of WIMPs is discussed. Discrimination against Compton electron background in such a device should be very good, and directional information about the recoil atoms would be obtainable. If a full 3-D reconstruction of the recoil tracks can be achieved, Monte Carlo studies indicate that a WIMP signal could be identified with high confidence from as few as 30 detected WIMP-nucleus scattering events.

To identify a WIMP signal, conventional searches rely mainly on searching for an annual modulation in the rate of nuclear recoils in the detector. This arises from the varying combined velocity vectors of the Earth's orbital motion and the Galactic rotation [?]. Because this is only a 5% effect, and existing detectors generally have a large background from Compton electrons, many WIMP-nucleus scattering events are needed to identify a WIMP signal statistically. Therefore emphasis has mainly been placed on

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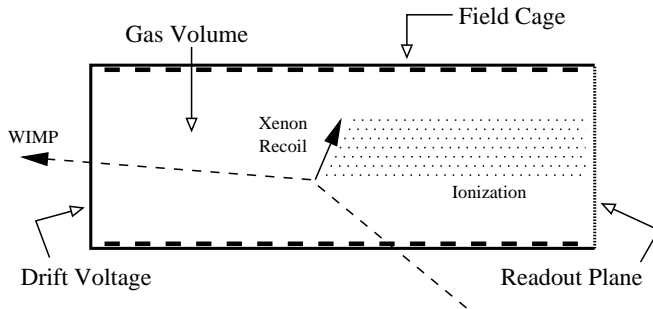


Figure 1. Schematic of TPC.

using very large mass detectors to increase the event rate, and great long-term system stability is required. In this paper, we present an alternative technique which, although it has a very low total target mass, has a strong signature for WIMPs and excellent background rejection capabilities.

The DRIFT experiment (Directional Recoil Identification From Tracks) is the successor to a project begun at UC San Diego [?]. The detector is a Time Projection Chamber (TPC), consisting of a target gas volume in a strong electric field (see figure 1). A nuclear recoil in the target volume will ionize the gas as it loses energy. A low pressure gas is used to extend the ranges of these ionization tracks to a few mm for typical WIMP-induced recoil energies (~ 100 keV). In the UCSD detector scheme, the ionized electrons were then drifted by the electric field to an optically imaged Parallel Plate Avalanche Chamber (PPAC) in the end cap. The entire detector was placed in a 4.5 kG large bore superconducting magnet to suppress the diffusion of the electrons as they drifted through the gas. This was necessary in order to maintain the resolution of the original track [?]. The need for the magnet made a large scale-up of the project impractical and prohibitively expensive, so a new method of suppressing the diffusion was needed.

A breakthrough was made when it was realized that a slightly electronegative gas admixture (in this case, CS_2) would reversibly attach the ionized electrons [?]. The resulting negative ions then drift to the high field gain region where they release the electrons and avalanche on the anodes. It was expected that the diffusion of the ions would be much less than that of the electrons; this has now been verified [?, ?]. There is the added advantage that the longitudinal diffusion is suppressed as well as the transverse diffusion, which is not the case for electrons in a magnetic field. The timing of the ions arriving at the readout plane therefore carries valuable information about the drift-direction extension of the tracks.

Along with the transverse position, a three dimensional reconstruction of the track becomes possible when only two (transverse) dimensions were available using the magnetic field technique. Our preliminary measurements [?, ?] show that sub-millimeter resolution can be maintained after drifting 1 m in 20 torr of a Xe-CS₂ (50:50) mixture, and it is hoped that further investigation will show that even longer drift distances are possible.

After the ions are drifted to the end of the chamber, the timing and spatial distributions must be determined in order to reconstruct the track. In the UCSD work, an optically imaged PPAC was used, but there were difficulties in achieving the necessary resolution. Other readout schemes are being investigated, including multiwire proportional chambers, pads, microdots, microstrips, and GEMMs. In the end we hope to achieve the sensitivity required to accurately determine the recoil direction (both its axis and the sense of the motion) and energy for tracks longer than 2 mm. This corresponds to an energy threshold of about 100 keV. This resolution should allow virtually all Compton electrons to be rejected, since the electron range at given total ionization is predicted to be many times longer than for a Xenon recoil. Measurements to confirm the electron rejection efficiency will soon be undertaken at the University of Sheffield Neutron Beam Facility and at Occidental College. Background due to alpha-emitting contaminants in the gain-producing electrodes (wires, grids or strips) can also be rejected with good efficiency using total ionization and tracking cuts [?]. This superior background rejection allows this detection scheme to be competitive with conventional techniques with much larger target masses. In the gas detector method, background events are rejected on an event-by-event basis, while other methods rely on a statistical subtraction of background which introduces larger uncertainties and thus lowers the overall sensitivity.

To determine the sensitivity with the above assumptions, a Monte Carlo simulation was run in which WIMP-nucleus scattering events were generated in a Xe-CS₂ (50:50) mixture and the ranges of the recoils were estimated using a software package entitled SRIM [?]. (SRIM calculations in low pressure gases are known to be off by as much as a factor of two, and because this will dominate the uncertainty of these results, no diffusion or straggling effects were included in the simulation. A range-energy calibration is planned for early next year using the Sheffield neutron beam.) The number of recoils above threshold was recorded and the detection efficiency as a function of WIMP mass was determined. A plot of the sensitivity of such a detector is shown in figure 2. The curves shown are the upper limits on rate that could be set if no nuclear recoils were detected at various exposures. Note that the limits would be stronger than the current UKDMC NaI limits [5], even though the density of the Xenon targets is only 0.07 kg/m³. This attests to the fact that high sensitivity can indeed be achieved

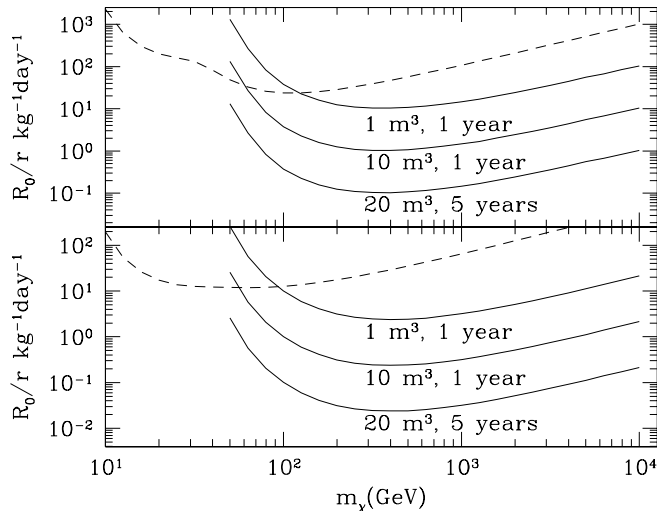


Figure 2. Upper limits (95% c.l.) on rate, normalized to Ge, that may be achieved for coherent (top) and spin dependent (bottom) WIMP-Xenon interactions at different exposures, assuming zero background. Also shown with the dashed lines are the current UKDMC NaI limits.

with a very low target mass if the backgrounds can be sufficiently reduced.

However, more important than the ability to set an upper limit is the sensitivity for an actual positive WIMP signal detection. This is where the ability to determine the recoil axis and direction would give a significant advantage. Spergel [6] has shown the WIMP interaction rate as a function of recoil energy and angle (in the Galactic frame) to be

$$\frac{dR}{dE_R d\cos\gamma} \propto \exp\left[\frac{-(v_\odot \cos\gamma - v_{\min})^2}{v_{\text{halo}}^2}\right] \quad (1)$$

where $v_{\min}^2 = (m_N + m_\chi)^2 E_R / 2m_N m_\chi^2$ and $v_{\text{halo}}^2 = 3v_\odot^2/2$. This equation is used in the Monte Carlo simulation to generate the recoil angle spectrum as well as to determine the detection efficiency. Figure 3 shows typical recoil angle spectra for 30 random WIMP events with axis and direction determination. Note the resemblance to the true spectra even at these statistics. Kolmogorov-Smirnov tests indicate that the signals shown are inconsistent with an isotropic background at the 99% c.l. Thus in the absence of background, such a detector could discover a WIMP signal with high confidence from only 30 detected events. Even with zero background, more than 12,000 events would be needed to detect a 5% annual modulation

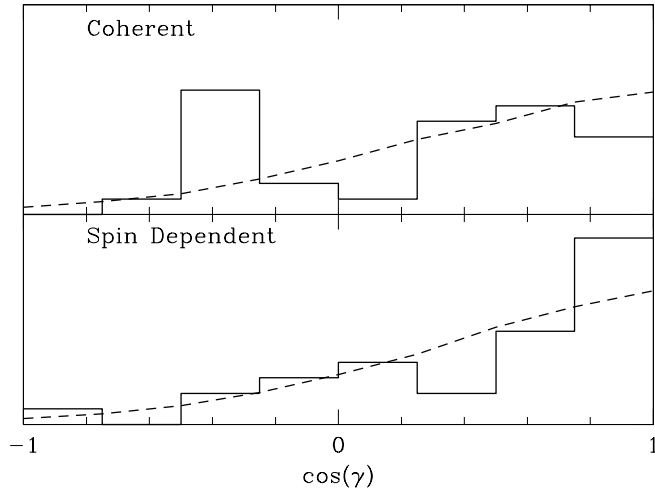


Figure 3. Histograms of recoil angles in Galactic frame (direction of sun through the Galaxy is at 180°) for 30 WIMP-Xenon interactions. Also shown in the dashed lines are the distributions for large numbers of events.

at the same confidence level.

Plans for the project begin with imaging readout tests with the UCSD prototype (0.18 m^3) in negative ion drift mode, and operation of a 0.03 m^3 prototype at Occidental College. At the same time a 1 m^3 detector will be constructed. By the year 2001 we hope to have a 20 m^3 detector operating in Boulby mine, which after 5 years of running would allow a positive WIMP detection at rates above $0.3 \text{ events/kg/day}$ for a 1000 GeV WIMP.