Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Nuclear Instruments and Methods in Physics Research A 516 (2004) 406–413
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A
www.elsevier.com/locate/nima

Low energy alphas in the drift detector

D.P. Snowden-Ifft[a,*], T. Lawson[b], N.J.C. Spooner[b], N. Villaume[a]

[a] *Physics Department, Occidental College, 1600 Campus Rd., Los Angeles, CA 90041, USA*
[b] *UKDMC-Department of Physics and Astronomy, University Sheffield, Hounsfield Rd., Sheffield S3 7RH, UK*

Received 4 June 2003; received in revised form 4 September 2003; accepted 5 September 2003

Abstract

The Directional Recoil Identification From Tracks project is a US–UK endeavor to build and operate a low pressure negative ion TPC (NITPC) to search for weakly interacting massive particles (WIMPs) thought to make up the dark matter in our Galaxy. Low energy ($\sim$10 keV) alpha events from U and Th decays within the walls and wires of the detector can enter the active volume of the detector and be confused for WIMP interactions. This paper presents data on and a model of low energy alphas in a NITPC operated at 40 Torr CS_2 with the aim of understanding and removing this potentially serious background. A comparison of the data to this model reveals good agreement with range predictions of *SRIM2000* and allows us to calculate the energy dissipation per ion pair, $W = 19.0 \pm 0.5$ eV for low energy alphas in CS_2.

PACS: 29.40.Cs; 29.40.Gx; 95.35.+d

Keywords: Range; Ionization; Dark matter; Negative ion

1. Introduction

The Directional Recoil Identification From Tracks (DRIFT) detector concept is based on the possibilitiy of using a low pressure Negative Ion TPC (NITPC) to detect Weakly Interacting Massive Particles (WIMPs), a prime dark matter candidate. A description of the capabilities of a low pressure NITPC for WIMP detection can be found in Ref. [1]. A collaboration of US and UK groups (Occidental College, Temple University and the UKDMC) has been formed to exploit this idea and currently operates a large ($\sim 1\,m^3$) NITPC, called DRIFT-I, at the Boulby Underground Laboratory to search for WIMP dark matter. The NITPC technique relies on the drifting of negative ions, instead of electrons, to reduce diffusion in all dimensions eliminating the need for a large magnet. This idea has been thoroughly validated in Refs. [2,3]. A DRIFT prototype was exposed to neutrons from a ^{252}Cf source to calibrate the response of the detector to recoiling C and S ions [4]. As discussed in Ref. [1] alphas from radioactive decay of U and Th which lose most of their energy in, for instance, the wires of the MWPC can emerge into the sensitive volume of a DRIFT detector with an energy which will produce ionization identical to the $\sim$keV/amu

*Corresponding author. Tel.: +1-323-259-2793; fax: +1-323-259-4858.
E-mail address: ifft@oxy.edu (D.P. Snowden-Ifft).

0168-9002/$ - see front matter
doi:10.1016/j.nima.2003.09.032

recoils produced by WIMPs and are therefore a worrisome background. Several methods of fiducializing the events in a DRIFT detector away from, for instance, the wires are under consideration by the collaboration. Until this is successfully demonstrated some other parameter must be found to discriminate low energy alpha events from WIMP recoils. As discussed in Ref. [1] low energy alphas have much larger ranges than typical WIMP recoils but this is often not apparent because of the contorted paths taken by the relatively low mass alpha particles in a typical gas. This paper presents data on and a model of low energy alphas in a NITPC with the aim of understanding and removing this potentially serious background.

2. Experimental procedure and data

The experiment was performed in a cylindrical vacuum chamber approximately 1 m in diameter and 0.5 m deep shown in Fig. 1. It was evacuated to $\sim$100 mTorr and then backfilled to a pressure of 40 Torr with CS_2 and sealed for the duration of the run. A thin $\sim$0.1 μCi ^{210}Po alpha source provided 5.3 MeV alphas. These were collimated by a 6.35 mm diameter and 15.35 mm deep hole and then energy degraded by a 3.4 mg/cm^2 Al foil. Further, variable, energy degradation was achieved through the 40 Torr CS_2 by moving the source relative to the detector on a moveable rod (see Fig. 1). Background runs were performed by rotating this rod so that the alphas did not enter the detector. The NITPC detector was identical to that described in Ref. [4] and will not be discussed in detail here. The detector was oriented "on its side" relative to the exposure described in Ref. [4]. This allowed alphas from a ^{210}Po source to enter the fiducial volume of the NITPC through the drift cathode. As described in Ref. [4] this cathode was made of 100 μm 304 stainless steel wires spaced at 2 mm making it highly transparent. The data acquisition system which read out the anode plane is described in detail in Ref. [4] and was identical to the setup used for this experiment (see Fig. 2). All runs were done with the Ortec 855 amplifier gain set to 100. In summary, alphas from a ^{210}Po source were slowed through various absorbers to low energies and then allowed to enter a NITPC through a transparent drift cathode. There they produced ionization which was rapidly captured by CS_2 molecules (see Ref. [3] for limits on capture distance under these conditions). The ionization was then drifted to the anode plane where an avalanche produced ionization on anode wires which were read out with a data acquisition system

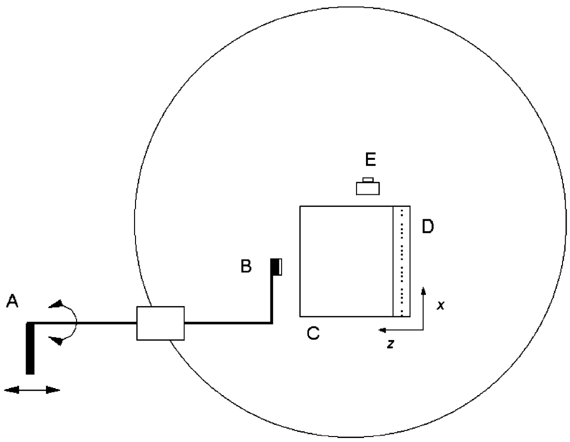

Fig. 1. Diagram of the experimental setup. The rod (A) had the ^{210}Po source and foil (B), shown in the 'on' position, attached to the end. It could be rotated and moved in and out to select different alpha energies. The alphas entered the drift region (C) through a transparent drift cathode. The electrons produced by ionization and then captured by the electronegative CS_2 gas drift towards the MWPC (D). The ^{55}Fe holder (E) was used for gas calibration.

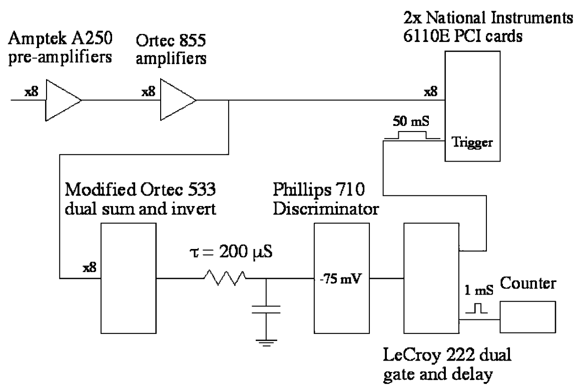

Fig. 2. Schematic of the electronics used in the exposure. More details about this setup can be found in Ref. [4].

capable of digitizing the signals on up to eight different wires. The rate of triggers was monitored by a counter.

As noted in Ref. [1] the energy scale of alphas that would mimic WIMP recoils is about 10 keV. This is well within the energy straggling of a 5.3 MeV ^{210}Po alpha [5]. The moveable rod was therefore positioned so that the alphas ranged out near the drift cathode. The energy straggling provided a spread of appropriate energies to look at. The distribution of these energies is crucial to the interpretation of the results so careful measurements were made of the count rate as a function of distance between the source and the drift cathode. These measurements are shown in Fig. 3.

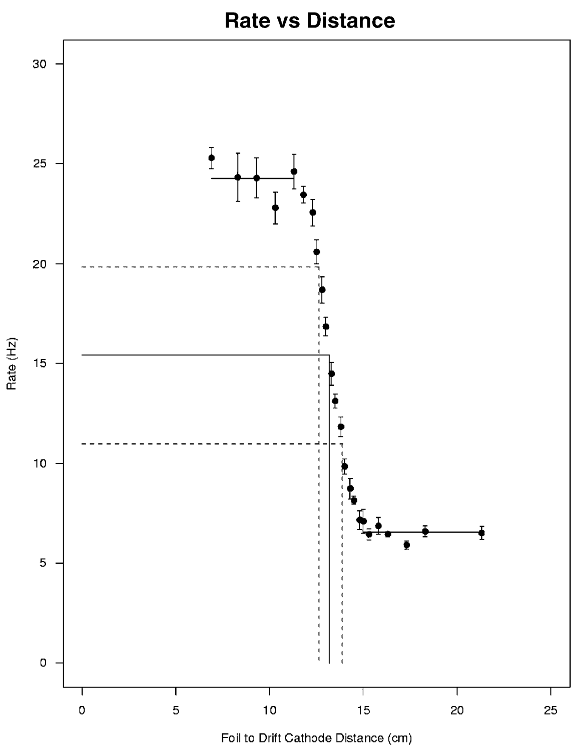

Fig. 3. Rate vs. distance. The rate is the rate observed on the counter shown in Fig. 2. The horizontal axis is the distance between the Al foil and the drift cathode. The horizontal lines extending to the rate axis show the 25%, 50% (solid), and 75% rates between the background and the saturated signal. The corresponding vertical lines show the mean (solid) and the FWHM (difference of dashed lines).

Data was taken with the foil 13.0 cm from the drift cathode. At this position 60% of the alphas made it into the detector and the distribution of ionization produced by these events appeared well matched to the amount of ionization expected from WIMP recoils. The rod was rotated so that the alphas were being shot perpendicular to the drift cathode and centered on it. In this orientation a data "run" was completed. A run consists of several "cycles" of calibration data and alpha data. Calibrations were carried out using a 100 μCi ^{55}Fe source mounted on the end of a long throw solenoid ~30 cm away from the center of the detector. During calibration cycles the rate was observed to increase to ~300 Hz swamping any alpha or background signal. For the alpha run 5 alpha data cycles of 2000 events each were taken with six accompanying calibration cycles with 500 events each. The rod was then rotated so that the alphas did not enter the chamber and a background run was completed. The background run consisted of four background cycles with an accompanying five calibration cycles. The total live time for the alpha run was 0.48 h compared to 0.43 h for the background run.

3. Data analysis

Figs. 4(a) and (b) shows two typical events. A detailed description of how this type of data can be reduced can be found in Ref. [4]. The analysis of this alpha data was performed using techniques very close to those adopted in Ref. [4]. For completeness an overview is given here with notes as to where the analyses differed. As in Ref. [4] the anode wires of the MWPC were summed so that the 1st wire was connected to the 9th, 17th, 25th wires and so on while the 2nd wire was connected to the 10th, 18th, 26th wires and so on. Thus for each triggered event (see Ref. [4] for a definition of triggering) eight channels were digitized simultaneously. These eight channels are displayed for each event in Fig. 4. Channels whose voltage fell below a software threshold, shown as a horizontal line in Fig. 4, had 14 statistics calculated. The most important of these were $t_{\min}$ and $t_{\max}$, the beginning and end of the event on that line (these

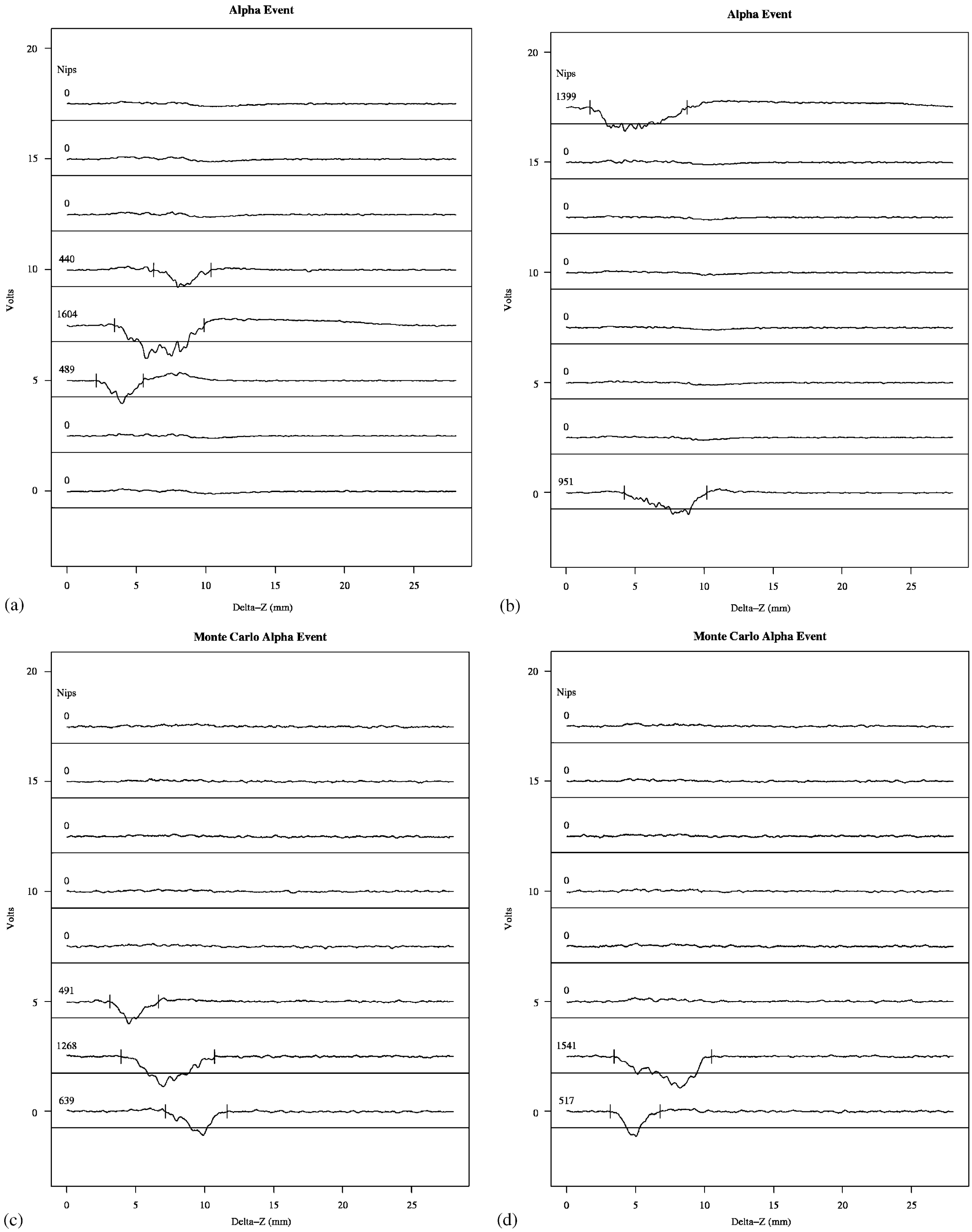

Fig. 4. Some examples of events. (a) and (b) are events from the data. (c) and (d) are from the Monte Carlo model. A constant voltage was added to each line to allow them to be printed on the same graph. Negative voltages from these baselines indicate charge depositing on the anode wires. Lines are arranged sequentially from bottom to top. The horizontal axis is time (1 ms full scale) multiplied by the drift speed.

positions are shown on the voltage traces in Fig. 4 with a vertical hash mark) and Σ which is the integral of the voltage with respect to time between t_{min} and t_{max} multiplied by -1. On the basis of these statistics 10 cuts are made on the data to remove sparks, hits to ground, ringers and other unwanted events (see Ref. [4]). Further analysis of events which pass all of these cuts proceeds as follows. Using the ^{55}Fe calibrations the parameter Σ is converted into number of ion pairs produced (*Nips*) by the alpha particle. The variation in the ^{55}Fe peaks, i.e. the gain of the system, was less than 6%. The gas gain was calculated to be 625. Using the number of wires hit (i.e. with non-zero *Nips* values) and the difference between t_{min} and t_{max} multiplied by the drift velocity in this TPC the two-dimensional projection of the range $R2$ (see Ref. [4]) was calculated.

As discussed in Ref. [4] it is convenient to raise the software threshold (more negative) to eliminate low energy electron events. An analysis identical to that described in Ref. [4] was applied to this data set. Increasing the software threshold from 25 *DFNips* (for Delta Function Nips and physically the instantaneous deposition of *Nips* to a wire necessary to achieve the software threshold voltage) to 75 *DFNIPs* reduced the number of low energy electron events by a factor of ~ 20 but left the number of alpha events statistically unchanged. Further increases produced losses in both populations. In Ref. [4] the threshold for neutrons was set at 150 *DFNips* with no significant loss of neutron events. Here such a large threshold would produce a factor of ~ 3 loss of alpha events. Physically this is due to the fact that the ionization in a NITPC falls onto the wires over a timescale which is long compared to the shaping time of the amplifiers. The presence of a threshold to trigger the analysis of the event therefore selects events with large ionization density. As discussed in Ref. [1] electron and alpha events have lower ionization densities than neutron or WIMP recoil events, due to their longer ranges, and therefore are more susceptible to being cut by this effect. In this detector imposing a software (or hardware) cut of 150 *DFNips* reduces gamma events by a factor of several hundred [4] and reduces alpha events by a factor of ~ 3 while preserving nearly unit efficiency for triggering on neutron or WIMP recoil events. Thus the threshold can be used as a low level discriminant of neutron or WIMP events in a NITPC detector. Plots of *Nips* vs. $R2$ for the background and alphas runs with a 75 *DFNip* threshold are shown in Figs. 5(a) and (b).

4. The model

Modeling alphas is difficult due to the contorted paths they follow at low energy. Fig. 6 shows a *SRIM2000* [5] simulation of 20 alpha tracks in 40 Torr CS_2 each of 20 keV. Obviously the straight line approximation used in Ref. [4] is not going to work here. The output from the *SRIM2000* simulation can be used to simulate these events but before doing so it is crucial to establish the validity of *SRIM2000*. In particular *SRIM2000* comes with many disclaimers about its ability to model ions in gases.

To this end a full *SRIM2000* simulation of this experiment was set up and run. The output of *SRIM2000* containing the alpha energy and *xyz* coordinates of alpha collisions with atoms in the gas and foil, the COLLISON.TXT file, was used for this analysis. It is the x and y coordinates of these collisions that are plotted in Fig. 6. The alphas in the simulation were started at the origin pointing in the x direction. Random alphas were selected from the COLLISON.TXT file and the largest value of x was recorded. The distance between the source and the foil was subtracted to obtain a measure of the distance between the foil and the cathode. The mean of these ‘‘largest values of x’’ was found to be 13.59 cm and the full-width-at-half-maximum (FWHM) of the distribution was found to be 1.13 cm. These numbers can be directly compared to the data taken on counts vs. distance and shown in Fig. 3. From this data one finds a mean value of 13.2 ± 0.2 cm with a FWHM of 1.3 ± 0.1 cm. The theoretical mean differs from the measured value by $3 \pm 2\%$ and the theoretical FWHM differs from the measured value by $12 \pm 9\%$. The FWHM comparison is important as this is a measure of the ability of *SRIM2000* to predict the energies and ranges associated with the low energy alphas used in this experiment. With

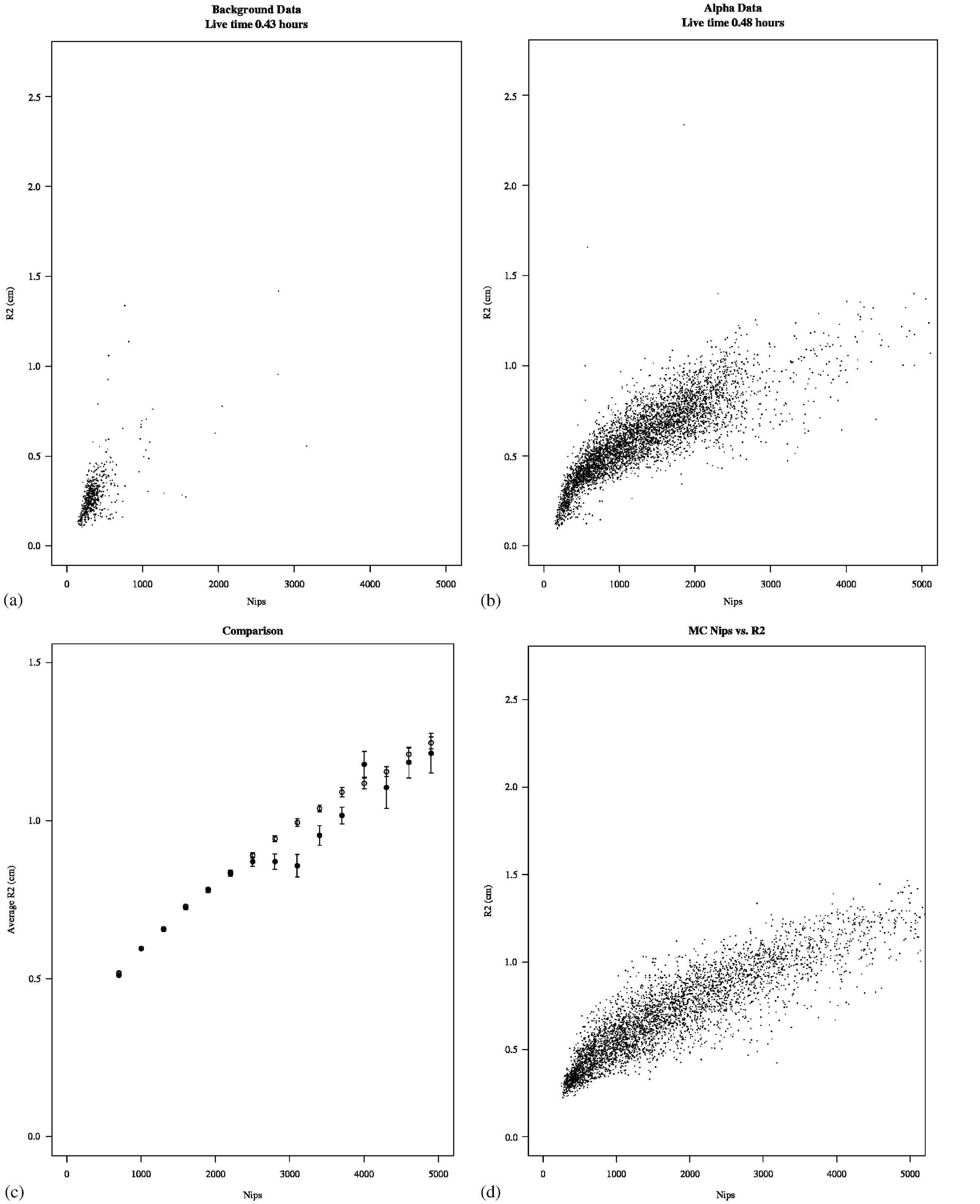

Fig. 5. (a) and (b) *Nips* vs. *R*2 for the background and alpha data with a 75 *DFNip* threshold. (c) shows the mean *R*2 values for various *Nip* windows for both the data (solid circles) and the output of *AlphaMC* (open circles) for $W = 19\,\mathrm{eV}$.(d) shows the *Nips* vs. *R*2 for the *AlphaMC* "data" for $W = 19\,\mathrm{eV}$.

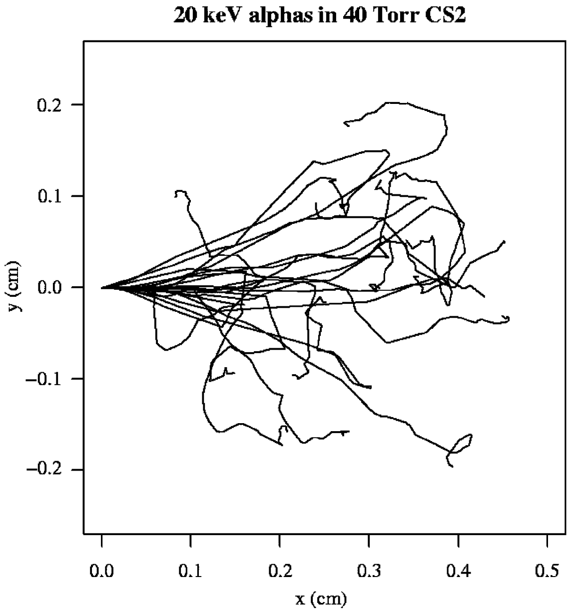

Fig. 6. Output of the *SRIM2000* code for 20 20 keV alphas headed initially in the x direction.

one small exception the model developed below assumed that *SRIM2000* correctly predicted the ranges and energies of alphas in 40 Torr CS_2. Possible errors introduced by this assumption are less than $\sim 10\%$ as indicated by these measurements.

The model achieved concrete form in a C program (actually several programs working in concert) called *AlphaMC*. Many of the functions used by *AlphaMC*, to produce for instance avalanches on wires, are identical to ones used in the Monte Carlo code described in Ref. [4], called *NeuRec* for *Neu*tron *Rec*oil. *AlphaMC* begins with randomly selected tracks in the COLLISON.TXT file. These tracks are followed for a user specified distance representing the distance between the source and the drift cathode. If a track reaches this distance the alpha energy, y and z coordinates are interpolated for this user specified x and the remainder of the track is passed on for further processing. It was at this point that the small exception noted above entered. Instead of choosing the measured distance this user specified distance was chosen to match observed 60% transmission rate. The distance from foil to drift cathode used as input for *AlphaMC* was 13.465 cm as opposed to 13.0 ± 0.2 cm indicated by the data. It is felt that this 3.6%"normalization" of the model reflects the $3 \pm 2\%$ difference between the theoretical and experimental means discussed above and better reflects the physical situation. The "chopped" tracks are then handled in the following way. For each segment of the track the difference in energy between the beginning and end of the segment was calculated. This energy loss was then divided by a user input energy dissipation per ion pair (W-value) to get the number of ion pairs produced along the segment. It was assumed that the W-value was independent of energy, an assumption justified by low energy electron data [6]. The electrons were uniformly distributed along the track segment. Care was taken to properly handle fractional numbers of electrons per segment. The result was an array of xyz coordinates for the electrons produced by ionization of the alpha particle. The only difference between this array of ionization produced in *AlphaMC* and that produced in *NeuRec* was that the latter had only one segment while the former, typically, included many. The electrons were then drifted to the anode wires assuming thermal diffusion in all dimensions as in Ref. [4]. They were then avalanched onto an anode wire as described in Ref. [4] except with a gain of 625 instead of 650, and voltages on wires produced in exactly the same way as described in Ref. [4]. Some examples are shown in Figs. 4(c) and (d). This Monte Carlo "data" was then analyzed in exactly the same way that the real data was for various values of the W parameter and *Nips* vs. $R2$ plots generated.

5. Comparison between model and data

The model and the data were compared in the following way. First in order to avoid background, only events greater than 700 *Nips* (see Fig. 5(a)) were considered. Then $R2$ values were averaged for events within *Nip* windows 300 *Nips* wide extending from 700 *Nips* up to 4900 *Nips*. The solid circles in Fig. 5(c) show these values with errors. *AlphaMC* runs were performed with various values of W and compared to the data with a χ^2 test. The best fit, shown in Fig. 5(c) with open circles has a W of 19 eV. Fig. 5(d) shows a *Nips* vs. $R2$ plot for the *AlphaMC* run with $W = 19$ eV. A comparison of the *Nips* vs. $R2$ plot for the data in Fig. 5(b) and the *Nips* vs. $R2$ plot for the output from *AlphaMC* reveal differences. While the FWHM of the *Nips* are nearly identical for these distributions, coinciding with the convergence of values for rate vs. distance data discussed above to 10%, the shape of the distributions are quite different. This could be a problem with the *SRIM2000* code or a problem with, for instance, the assumption that W is fixed for all energies. Furthermore there is a dip in the data around 2800 *Nips*, shown in Fig. 5(c) which is not represented in the model. We believe that the dip in the data is caused by a second population of ionizing events, probably carbon knock-ons, which enter the detector volume from the outside. As discussed in Ref. [4] it is in this region of the plot that carbon recoils are expected. The population can be seen below 2800 *Nips* but it cannot affect the average $R2$ because of the overwhelming number of alpha events. Only when the number of alpha events falls dramatically after 2800 *Nips* does this population begin to affect the average $R2$. Finally, subtracting background only 4% of the data lie above 2800 *Nips* so whatever the source of these events they are a small part of the data to be analyzed. Therefore analyzing only data between 700 and 2800 *Nips* we find a reduced χ^2 of 0.3 for $W = 19.0 \pm 0.5$ eV. It is interesting to note that this value of W is identical to the value found for low energy electrons [7].

As a final test of the model we can compare the behavior of the model with respect to changes in the threshold level to that of the data. Increasing the threshold from -75 *DFNips* to -150 *DFNips* decreases the number of events passing all the cuts from 4148 to 1464 a ratio of 2.83. Increasing the threshold on the "data" from *AlphaMC* yields a ratio of $4336/1377 = 3.15$–10% different from the data.

6. Conclusion

In conclusion, low energy alpha range information from this experiment agreed well ($\sim 10\%$) with an *SRIM2000* simulation. A one parameter fit was performed between a model, based *SRIM2000*, and the data and good agreement was reached when $W = 19 \pm 0.5$ eV. As an independent check of the model the threshold for detection was changed in both the data and the model and good agreement found. As discussed this points to an easy and low level way of discriminating WIMP recoils from alpha particles. The success of the model will allow full simulations of the response of DRIFT detectors to the serious backgrounds posed by low energy alphas.

Acknowledgements

This work was supported by the National Science Foundation and Occidental College. We thank PPARC for providing a studentship grant for T. Lawson. Correspondence should be addressed to D.P. Snowden-Ifft.

References

[1] D.P. Snowden-Ifft, C.J. Martoff, J.M. Burwell, Phys. Rev. D 61 (2000) 1.
[2] C.J. Martoff, D. Snowden-Ifft, T. Ohnuki, N. Spooner, M. Lehner, Nucl. Instr. and Meth. A 440 (2000) 355.
[3] T. Ohnuki, C.J. Martoff, D.P. Snowden-Ifft, Nucl. Instr. and Meth. A 463 (2001) 142.
[4] D.P. Snowden-Ifft, T. Ohnuki, E.S. Rykoff, C.J. Martoff, Nucl. Instr. and Meth. A 498 (2003) 155.
[5] J.P. Biersack, L. Haggmark, Nucl. Instr. and Meth. 174 (1980) 257.
[6] L. Rolandi, W. Blum, Particle Detection with Drift Chambers, Springer, Berlin, Germany, 1994, p. 6.
[7] Unpublished.