NEW LIMITS TO INTERACTION RATES FROM THE UK DARK MATTER EXPERIMENT

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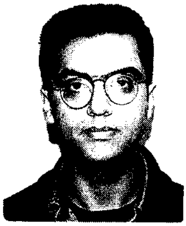

ABSTRACT

Direct detection of Weakly Interacting Massive Particles (WIMP's) is possible if they have a scattering cross-section with nucleons comparable to that of a neutrino. Low background underground detector searches are underway worldwide and we report here on an improvement of an order of magnitude in our published limits to the spin-dependent dark matter interaction rate. A 2σ upper limit to the rate of 0.14 events/kg.keV.day (at 7-10 keV equivalent photon energy) is achieved by use of event time profile information to reject most of the radioactive background.

Recent results from the microlensing community appear to show that <30% of the Galactic halo can be baryonic[1]. Thus the motivation for a non-baryonic dark matter search remains as strong as ever and is discussed elsewhere in these proceedings. Many groups worldwide are engaged on this quest and we presented our first results from a room temperature NaI scintillator experiment at a previous Moriond conference[2]. We report here an order of magnitude improvement over our latest published result[5] in the upper limit to the interaction rate achieved by using event profile information to reject background noise.

Experimental Details

The experiment is located at a depth of 1100m (3000 mwe) underground in a working mine near Boulby, England. Passive shielding is effected by means of lead and copper castles or by lowering the detector inside a pure copper vessel into a 6m diameter, 6m deep tank of recirculating pure water. All shielding materials have been stored underground for many years.

The results discussed are from data acquired over a 6 month run with a 6.2 kg NaI(Tl) crystal located in the water tank. The scintillation event readout using 2 low-noise EMI 9625A photomultipliers viewing opposite crystal faces through 30 cm silica light guides. Each coincident event is digitised and recorded from both PMTs. The photoelectron yield in this configuration was measured to be ~1.7/keV. A real time environmental monitoring system allows us to record the detector temperature.

The resulting low energy background spectrum is shown in fig1. Note that a rate of ~1.7 counts/keV/kg/day is measured for the 7-10 keV equivalent photon energy interval. Since this energy range represents a minimum in the background versus energy loss curve of fig1 and is near the detector threshold, we can obtain a best dark matter limit from this point on the curve.

Calibration

We expect a WIMP event signal to be similiar in its time decay characteristics to that produced by a neutron scattering in the crystal. Experimentally we observe two distinct event decay time constant distributions for neutrons and gamma rays with the separation diverging towards higher energy. As the residual neutron activity is negligable in the proximity of the experiment, it is possible to detect statistically the presence of a small fraction of dark matter

recoil events in the presence of a beta and gamma background by using an event decay time discrimination scheme.
Calibration runs in the water tank with a ^{252}Cf source emitting gammas and neutrons and a ^{57}Co source emitting gammas only yielded the two time constant distributions for the 7-10 keV energy range shown in fig2. A separation of the mean decay time constant between the two species of ~26ns can be seen. All time constants have been determined by a least-squares-fit of the event profile to a single exponential.

Results and Limits

We can compare a time constant distribution derived from the measured spectrum of fig1 with the calibration curves shown in fig2 for the 7-10 keV energy range. Corrections have been applied to the background spectrum for Poisson statistics of photoelectron generation and the probability of coincidentally triggering both PMT channels. In addition a correction for a secular reduction in light collection efficiency amounting to 2.5%/month and an empirical time constant temperature coefficient of 1.3%/degree K for a ±1K temperature drift have been made.
In fig2 data from the observed background spectrum is shown plotted and a near coincidence with the gamma calibration spectrum is seen. To 90% C.L. the difference between the means of these time constant distributions is 2ns, thus only 2/26 (0.008) of the observed 1.7 events/keV/kg/day count rate could be due to dark matter particles (see[3][4]). The resultant 0.14 events/keV/kg/day is taken to represent the upper limit to dark matter interactions arising from this experiment.

We can relate the observations to a differential event rate/keV/kg/day by[5];

$$dR/dE_R = (R_o/E_o r)(\pi^{0.5}/4y)\ [\mathrm{erf}(x+y)-\mathrm{erf}(x-y)]\ [F(E_R)]^2 \qquad (1)$$

where F is the form factor, R_o is the reduced total event rate in counts/kg/day, $E_o=1/2M_d(v_o)^2$, M_d and M_t is the mass of the dark matter particle and the target nucleus respectively, $x=(E_R/E_o)$, $y=(v_E/v_o)$, $r=4(M_dM_t)/(M_d+M_t)^2$.
By using the 90% C.L. experimental limit in equation 1 we can solve for the normalised rate R_o/r. The resulting limit as a function of the particle mass is shown in fig3 for the spin dependent interaction. Also shown are our previous results for a 1.3kg detector[5] and the Germanium (~8% ^{73}Ge isotope) limit[6-9].

The limit obtained with our pulse shape discrimination scheme clearly represents an improvement on previous results.
We can also relate R_O/r to a total interaction cross section and an equivalent cross section for a single proton by using the appropriate spin factors for Na and H[3]. This yields a value of ~3pb in the 7-10 keV range.

Conclusion

We have demonstrated an order of magnitude improvement on our previous published spin-dependent limits by noise rejection using event decay time characteristics. A detailed statistical analysis of all the energy bins in the background spectrum yielding a small improvement on the above limit is in preparation[4].
We envisage further gains in sensitivity will be achieved by scaling up the detector size and with longer running times. We have initiated a development programme to produce large area photon-counting avalanche photodiodes. Deployment of these will result in an increased light collection efficiency, lower energy threshold and with a segmented array geometry, provide a further discrimination channel. In addition alternative routes to our goal including cooled NaI and liquid xenon are under investigation.

Acknowledgements

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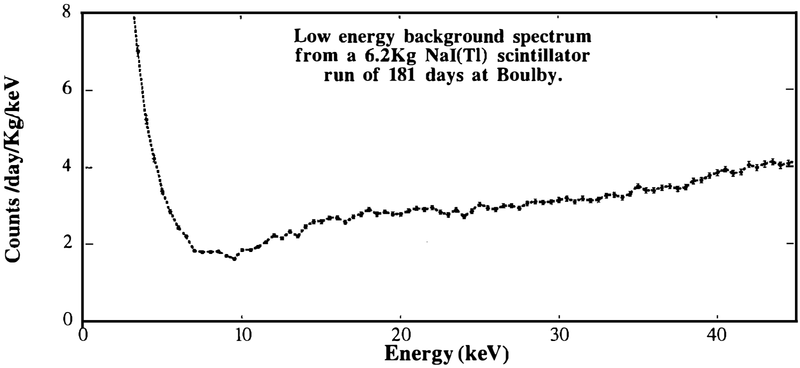

Figure 1: Low energy pulse height spectrum from a 6.2kg NaI(Tl) crystal

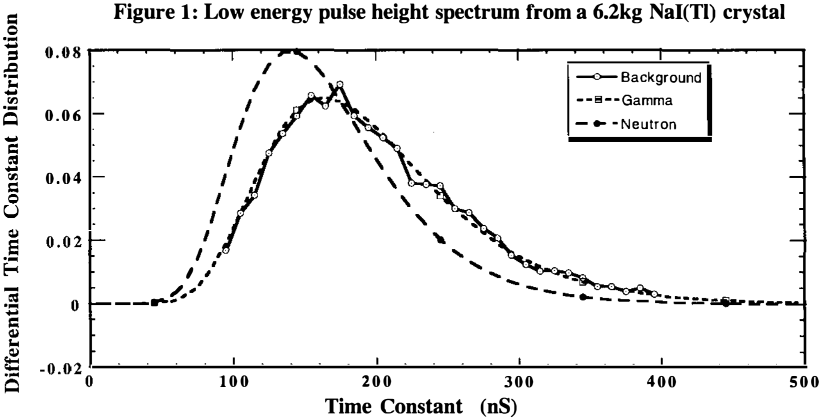

Figure 2: Normalised differential time-constant distributions for the 7-10 keV energy loss interval

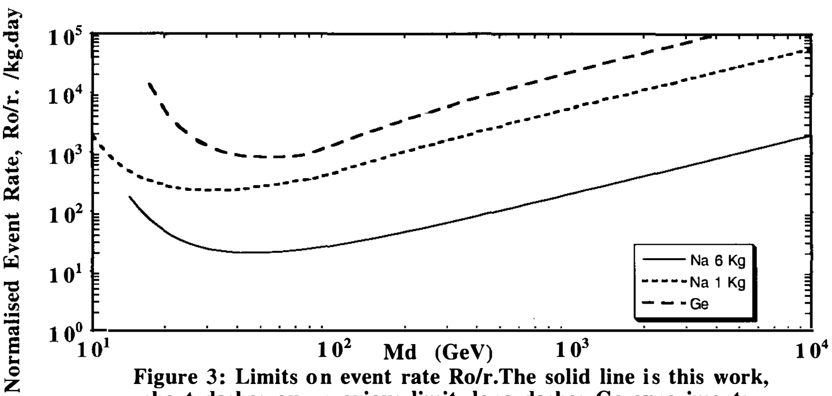

Figure 3: Limits on event rate Ro/r.The solid line is this work, short dashes our previous limit, long dashes Ge experiments