PROBING FOR WIMP INTERACTION RATES BELOW 10/kg/day AT BOULBY MINE.

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The current UK Dark Matter Collaboration programme is reviewed with emphasis on the Pulse-Shape Discrimination techniques used to produce WIMP interaction limits below 10/kg/day. Prospects for future improvements are discussed, with reference to both the scale-up of current NaI detectors and the use of new detectors with enhanced discrimination.

1 Introduction

The UK Dark Matter Collaboration has been using scintillation detectors for galactic WIMP Dark Matter searches since 1991 at the Boulby Mine (3600 mwe). New limits have recently been published from analysis using Pulse-Shape Discrimination (PSD) techniques on 173 days of data from a 5.8 kg NaI crystal [1]. The PSD process relies upon the difference in mean pulse time constant τ between signal (nuclear recoil) events and background (electron recoil) events, with the former having the shorter mean τ. At the low recoil energies considered here the discrimination provided by this technique is statistical but

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nevertheless enables considerable improvements to be made on previous results obtained without background rejection [2].

2 Experimental Considerations

The detector consists of a cylindrical NaI crystal mounted within a 3 mm thick OFHC copper cylinder suspended inside a 160 ton tank of ultra-pure water. The crystal is wrapped circumferentially in PTFE tape and coupled to two PMTs (Electron Tubes 9625A) via cylindrical silica lightguides of length 30 cm. Low-background materials are used throughout. The detector temperature is monitored to correct for variations in τ due to temperature fluctuations. Coincident signals from the PMTs which satisfy the trigger threshold of 2.4 pe per channel are digitised by a Lecroy DSO and passed to custom DAQ software.

3 Analysis and Limits

The analysis procedure [1] fits each digitised scintillation pulse to a single exponential function $A(1 - exp((t_0 - t)/\tau))$, where the free parameters are the time constant τ, the pulse amplitude A and the pulse start-time t_0. The fitted parameters for each pulse are used to construct event histograms of E vs. τ in narrow energy bands ΔE. These and distributions from gamma and neutron tests are fitted to a gaussian function of $\ln(\tau)$. This allows the extraction of the best fit mean τ values and the elimination of fast noise events, since the distribution of these is not governed by the fitted function. The total number of events keV^{-1} kg^{-1} day^{-1} (dru) is shown in Figure 1 both before (curve (a)) and after (curve (b)) subtraction of noise.

A small admixture of signal events in the data would lead to a shift δ_n of the fitted τ away from the gamma calibration distribution and towards the shorter mean τ given by neutron calibration data. The degree to which this shift can be excluded within the statistics allows limits on the WIMP flux to be set. The values of δ_n may contain errors from statistical variation in the fitted mean time constant for data and calibration events and from variations in the detector temperature, which can also effect the mean τ. The errors are estimated by using respectively the standard deviations in the fitted mean τ values for data and calibrations and a temperature correction error estimated by observing the time variation of the mean data τ. These errors are added in quadrature to give the combined 1σ uncertainty in mean time constant, σ_C.

The quantities δ_n and σ_C are used to derive a signal fraction g_n and its standard error $\sigma(g_n)$, for each energy band ΔE. These values are multiplied

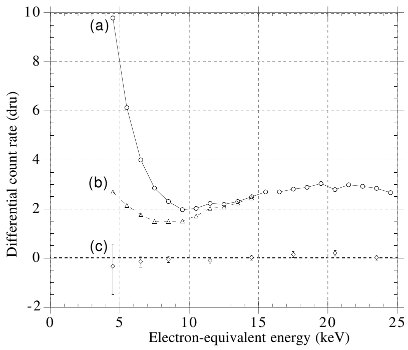

Figure 1: Background differential spectra: (a) total rate before noise subtraction; (b) total rate after noise subtraction; (c) 2σ limits on nuclear recoil signal.

by the data event distribution in curve (b) of Figure 1 to give a limit (c) on nuclear recoil signal events for each ΔE. Corrections for Poissonian statistics and the rejection of low-energy events by the trigger threshold are included in these limits. Note that errors bars in Figure 1 represent 2σ errors.

Taking into account the expected WIMP recoil spectrum, nuclear form factors and the recoil efficiency of the target nuclei within the crystal [1] it is possible to extract from curve (c) a limit on WIMP interaction rate $(R_0/r)_{k,M}$ (tru) and error $\sigma_{k,M}$ for each energy bin k and WIMP mass M. Limit curves for each energy bin may then be combined to give an overall limit R_0/r and error σ, as shown in Figure 2. In the absence of an identifiable signal all offsets of the limits from zero are assumed to be consistent with this value and a 90% confidence limit of 1.3σ is assigned to each WIMP mass bin.

The limits obtained here for spin-dependent interactions are ~ 50 times lower than the original Ge limits for WIMPs with masses > 10 GeV. The coherent limits for WIMP masses > 50 GeV also represent significant improvements but are matched by recent gains using the Ge technique [4].

4 Improvements and New Techniques

Planned improvements to the current technique include enhancements to light output, background event rate and discrimination. Alternative growth and doping techniques may improve the intrinsic scintillation efficiency of the crys-

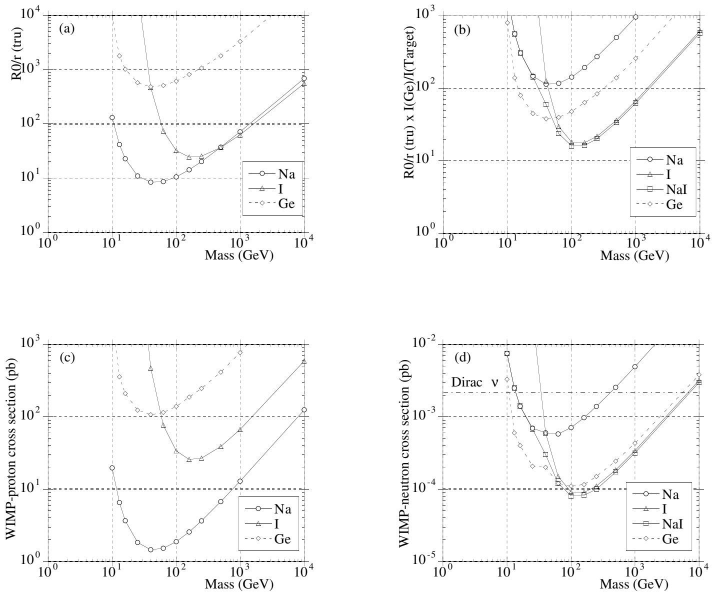

Figure 2: WIMP interaction limits: (a) spin-dependent rate; (b) coherent rate; (c) spin-dependent cross-section; (d) coherent cross-section.

tals, while optimised geometries for crystals and lightguides, unencapsulated crystals and larger PMTs improve the light collection efficiency. We are experimenting with chemical radio-purification of raw NaI powder and have recently implemented a system to maintain detectors at a constant optimised temperature ($\Delta T < \sim 0.1$ K) so as to improve the PSD efficiency. There are indications from tests run at energies higher than those considered here that the NaI pulse-shape may contain additional components (Figure 3) leading to improved discrimination when use is made of more complex pulse fitting-functions. These techniques are under consideration for use on scaled-up NaI detectors intended to probe lower WIMP event-rates by increasing target mass.

Further benefits may be obtained by using undoped NaI crystals operated at cryogenic (160 K) temperatures [3]. The scintillation pulse contains two components, the relative amplitudes of which are dependent upon whether the event is due to nuclear or electron recoil. In connection with this technique

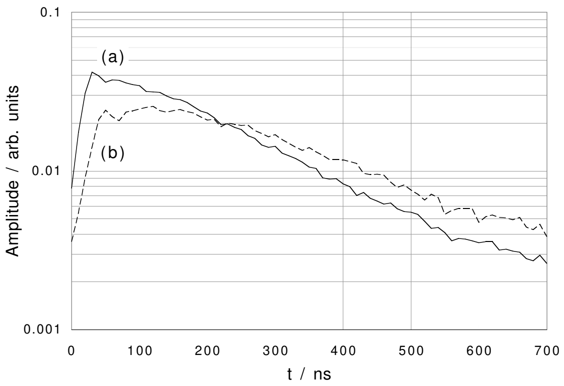

Figure 3: Mean differential pulse-shapes for (a) nuclear recoil events and (b) electron recoil events (AmBe source, 30 - 60 keV energy range).

we are investigating the replacement of PMTs with low-background Avalanche Photodiodes, which have the potential for Quantum Efficiencies > 50%.

An alternative scintillation target for WIMP Dark Matter is Liquid Xenon. This has the advantage of isotopes with high atomic mass and / or non-zero nuclear spin and potentially better discrimination. The UK collaboration has plans to develop a LXe detector in conjunction with UCLA, whose own research in this field is described elsewhere in these proceedings [5].

5 Conclusions

The UK Dark Matter Collaboration has applied a statistical PSD technique to data from a 5.8 kg NaI crystal installed at the Boulby Mine. This has enabled new WIMP interaction limits a factor 50 better than the original Ge limits to be derived for spin-dependent interactions.

References

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