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Progress report from the UK Dark Matter Search at Boulby Mine

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The UK Dark Matter Collaboration is currently running a series of scintillation devices at the Boulby mine in North Yorkshire to search for the neutralino, the hypothetical WIMP solution to the dark matter problem. Results of the current NaI(Tl) detector array will be discussed, illustrating a population of events of unknown origin. Diagnostic tests performed to investigate the origin of these anomalous events will be outlined, including alpha, beta and neutron calibrations.

1. Introduction

The UK Dark Matter Collaboration has been conducting a direct search for WIMP inside Boulby mine, a working salt and potash mine in the north-east of England. The mine is operated by Cleveland Potash Ltd. The management of the company has provided the use of several disused tunnels and caverns as a permanent location for the UK underground physics programme. The underground caverns have been equipped with 200 kVA of secure power, lighting, telephone, and fast internet link.

The search requires a means of discriminating WIMP signal from a much higher gamma background. Pulse shape discrimination was therefore applied to reject background events. The available underground space has recently been increased and we are expanding underground programme. Our current and future plans include both NaI and Xe targets to cover the WIMP mass range 10 to 10^3GeV.

2. Dark Matter search with NaI(Tl)

Detectors are based on NaI(Tl) scintillator crystals, 2-10 kg in mass. The scintillation light is observed by two photomultiplier tubes coupled to the crystals through silica light guides. All detector materials have been selected for lowest radioactivity possible. For shielding a 6 m tank of purified water and a number of lead and copper castles have been built. The depth of the experimental site (1100 m in rock corresponding to 3000 m water equivalent) ensures a low flux of cosmic ray muons.

The detection relies on elastic interactions between WIMP and the nuclei of NaI(Tl). Sensitivity is limited by the background due to interactions in the crystal of neutrons and gammas from the surrounding environment and the components of the detector itself. Neutron flux is reduced by shielding and using pure materials for the construction of the detector. The gammas are discriminated out using pulse shape discrimination techniques [1], [2].

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2.1. Anomalous events

Subsequent to the previously published limits the stability and resolution of current detectors was improved by installing larger photomultiplier tubes, shorter light guides, reducing and stabilising the operating temperature ($10 \pm 0.1°C$). A total of 11.6 kg years has been analysed, between August 1996 and November 1999, excluding calibration periods.

The improved resolution revealed a small population of pulses (Figure 1) with a shorter time constant (mean $\sim$ 230 ns), quite distinct from the time constant from Compton events (mean $\sim$ 360 ns) and close to the time constant observed for nuclear recoils induced by neutrons [3], [4].

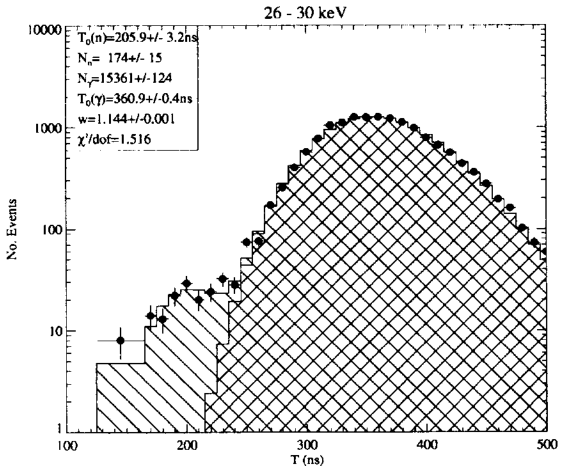

Figure 1. Examples of anomalous events in one energy bin contrasted with Compton calibration data.

A similar population of short pulses has been observed in other NaI crystals. Figure 2 illustrates energy spectra of these events. In all other respects these pulses appear to be normal in shape with photoelectrons distributed equally between photomultiplier tubes.

Similar events have been seen by the Saclay group operating at the Modane site [5]. This finding rules out manufacturing process as a possible culprit, as these crystals have been provided by a different supplier; nor can they be caused by data analysis, because independent techniques have been employed.

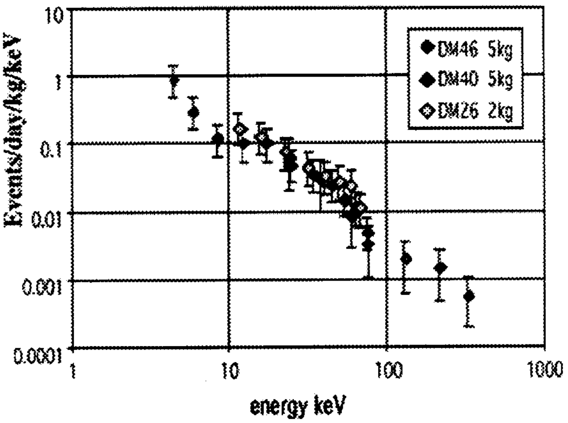

Figure 2. Energy spectra of anomalous events. Data from several crystals is shown to be consistent.

2.2. Excluded causes of anomalous events

The absence of shorter pulses during the periods of Compton calibration suggests that they were not caused by the analysis procedures. Also the total number of events appears much larger than would be expected from photodisintegration of I by gammas above 2.6 MeV. Neutron contamination would be excluded by the water shielding and low muon flux at 1100 m depth. Alpha contamination from fission of U/Th impurities in the crystal has been ruled out on the basis of observed gamma flux being too low for this to be contributing.

A study designed to characterise alphas, gamma and nuclear recoil pulses arising in NaI(Tl) crystal at the energy range 10-100 keV has been conducted in order to ascertain further possible causes of observed fast events [6]. Pulses initiated by X-rays (via photoelectric effect close to the surface of the crystal) were found not to differ from those produced by γ-rays. However, pulses produced by alpha particles (degraded from an external MeV source) were found to be $\sim$ 10% faster than those of nuclear recoils, but insufficiently fast to account for the anomalous events (Figure 3).

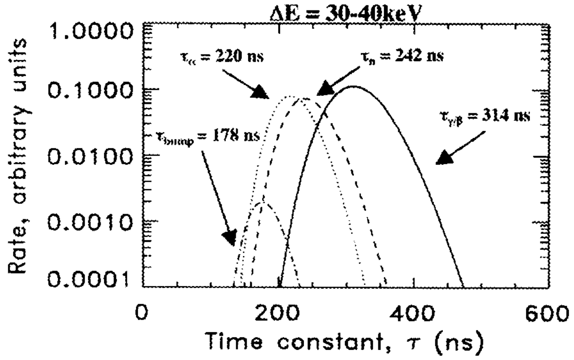

Figure 3. Example of tests conducted to characterise recoils initiated by different sources in a NaI(Tl) crystal. Only one energy range is shown.

2.3. Possible causes of anomalous events not yet excluded

Recoils from alpha particles emitted from a thin surface (0.1-0.2 μm) layer would give the observed energy spectrum. However, such a scenario would require a rather high level contamination during manufacture ($\sim$ 0.1ppm of U/Th or $\sim 10^{-2}$ decay $\sec^{-1}$ g^{-1} of Rn) [7].

It is also possible that as yet unknown lattice events may be contributing to this phenomenon [8].

3. Sensitivity and Limits

The observation of anomalous events precludes lower Dark Matter limits being set. Only experimental sensitivity can be determined (Figure 4). Once the nature of the anomalous events has been understood further progress can be made.

4. Future work

Investigation into the causes of the anomaly is continuing.

The NaI component of the programme is being upgraded to a total target mass of 100 kg with improved energy resolution. A liquid, single phase Xe detector is in the final stages of assembly and testing, scheduled for instillation early in 2000.

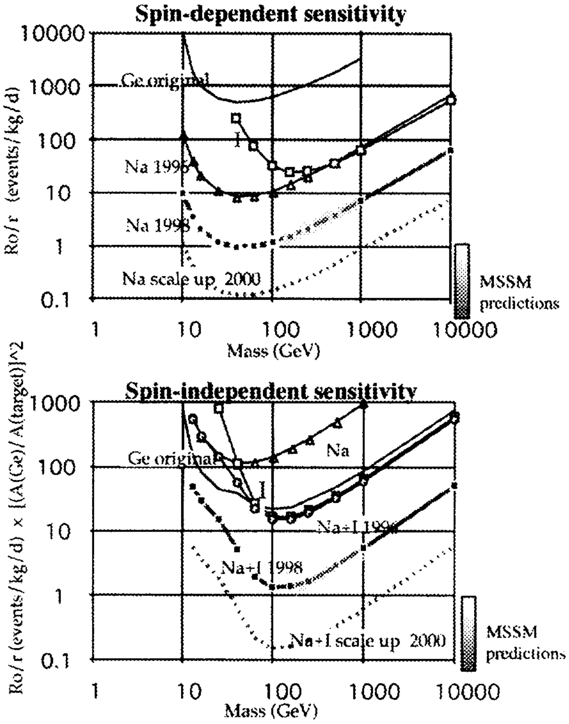

Figure 4. Achieved Dark Matter limits, current and projected sensitivity. Shaded area represents the region of the observed anomaly.

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