Dark Matter Search at Boulby Mine

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Abstract. A status report of the UK Dark Matter Search at Boulby mine is presented. We plan to continue the search for *WIMP*s using pulse shape discrimination in *NaI* crystals as well as expanding the programme to include *Xe* as a dark matter target. *Xe* offers a more powerful means of background rejection than can be achieved by pulse shape discrimination in *NaI*.

1. Introduction

The UK Dark Matter Collaboration has been conducting direct searches for *WIMP*s inside Boulby mine (depth $1100m$), a working salt and potash

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mine in the north east of England. The mine is operated by the 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 $200kVA$ of secure power, lighting, telephone, and fast internet link. For shielding a $200tonnes$ tank of purified water and a number of lead-copper castles have been built.

The search requires a means of discriminating $WIMP$ signal from a much higher gamma background. Until recently the main thrust of our collaboration has been in the use of NaI crystals as a $WIMP$ target. Pulse shape discrimination is used to extract any possible signal from the collected data. The available underground space has recently been increased to allow expansion of the programme. Our current and future plans include both the NaI and Xe targets to cover the $WIMP$ mass range $10-1000GeV$.

2. Dark Matter search with NaI

2.1. Detector improvements

Subsequent to the publication of Dark Matter limits from a $5kg$ crystal [1] the stability and resolution of the detector was improved by installing larger photomultiplier tubes, shorter light guides, reducing and stabilising the operating temperature ($10 \pm 0.1°C$). A total of 4000 hours, between August 1996 and October 1997, excluding calibration periods has been analysed.

2.2. Anomalous events

The improved resolution increased event rate sensitivity by a factor ~ 8 and revealed a small population of pulses with a shorter time constant ($\tau_{mean} \sim 230ns$) in a $5kg$ NaI crystal. These are distinct from Compton events ($\tau_{mean} \sim 360ns$) and close to that observed for nuclear recoils due to neutron scattering (Figure 1a).

The absence of shorter pulses during the periods of Compton calibration (Figure 1b) suggest that they were not caused by data analysis. Further confirmation has been obtained by observing a similar population of short pulses in a second $5kg$ NaI crystal, and a higher resolution $2kg$ crystal. In all other respects these pulses appear to be normal in shape (exponential), with photoelectrons distributed equally between photomultiplier tubes. The total number of unidentified events appears much larger than would be expected from photodisintegration of I by gammas, and αs from U/Th in the MeV range. Neutron contamination would be excluded by the water shielding and the low muon flux at $1100m$ depth.
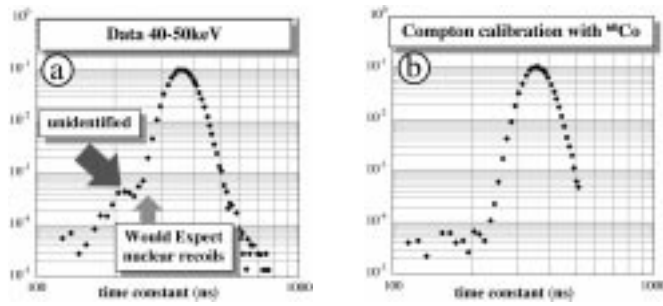
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Figure 1: Time constant distributions (normalised to unity) for a 5*kg NaI* crystal: (a) background data showing population of shorter pulses; (b) Compton calibration data.

At the time of writing there is no explanation for the presence of these events. Data runs are being made with different size crystals to establish whether the spectrum and *(Number of events)/(Crystal mass)* is similar in all crystals.

As an aside it is interesting that the data is showing a significant summer-winter variation. In the $20 - 60keV$ energy range there are approximately 700 *events* in 70 *days* during the summer, while in winter the number of events over the same length of time falls to 600. This variation, only too clearly, shows the care necessary in analysing any annual modulation effect. A spurious signal might easily produce a variation over the period of some months.

3. Liquid *Xe* programme

3.1. Discrimination in liquid Xe

Interaction of radiation with a liquid *Xe* target produces both scintillation and ionisation. The potential advantage gained in discrimination between signal and background is obtained by utilising both mechanisms.

Figure 2: Scintillation pulse shape differences in liquid *Xe*.

If the recombination of ionised charge takes place the discrimination can still be achieved purely by the difference in pulse shapes induced by nuclear and electron recoils. This is evident from Figure 2. However, recombination can be inhibited with
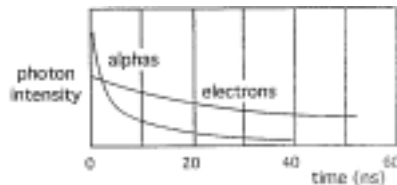
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an electric field. Drifting these electrons in a uniform electric field and detecting the current, via proportional scintillation and/or induced electrical pulses, would offer a more powerful method of background rejection than pulse shape discrimination alone. In the case of proportional scintillation. Primary pulse S_1 is followed, a few μsec later, by a secondary proportional pulse S_2.
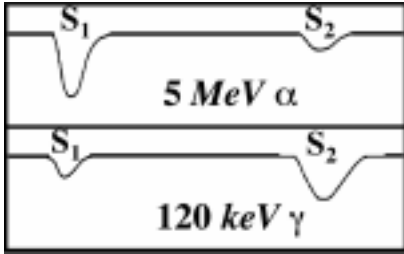

Figure 3: Primary and proportional scintillation in liquid Xe.

A small liquid Xe test chamber has been built and operated at CERN by the ICARUS group. Their results suggest that the average of S_1/S_2 is in the range $0.1 - 0.3$ and $1 - 10$ for nuclear and electron recoils respectively (Figure 3) [2].

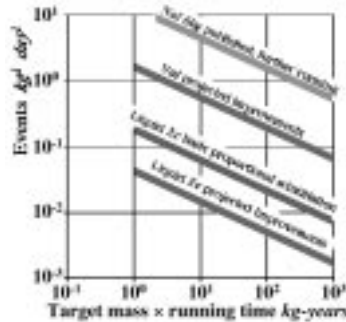Further work with liquid Xe involving the construction of a $2kg$ chamber has continued at CERN. The ICARUS group made measurements of the discrimination factor for Xe recoils from neutron scatterings. It was shown that after the removal of noise pulses the use of the S_1/S_2 ratio for discrimination resulted in the overlap of 0.1% for gammas at $22keV$ [3]. Figure 4 shows a comparison between estimated efficiencies for different methods of detection. The assumed quenching factor for liquid Xe is $\sim 50\%$ [4].

3.2. ZEPLIN-0

The UK Dark Matter Collaboration, in co-operation with UCLA and Torino groups, is proposing the construction of a liquid Xe *WIMP* detector of $20 - 30kg$ target mass. The detector to be located inside the Boulby mine facility. The acronym for this programme is *ZEPLIN* (*Z*oned *P*roportional scintillation in *LI*quid *N*oble gases).

As part of our *ZEPLIN* programme we are currently in the final construction stage of a $5kg$ target mass liquid Xe detector. This preliminary design will employ pulse shape discrimination only to achieve background rejection. Furthermore, this will

Figure 4: Comparison of the predicted sensitivity between several detection methods.
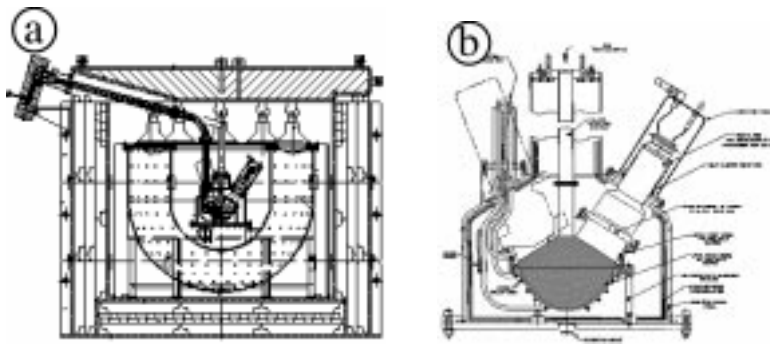
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Figure 5: Engineering drawing of the *ZEPLIN-0* detector. (a) detector includes the veto showing shielding and cryogenics pipes. (b) detector itself, shaded region indicates active volume.

be a test-bed for further detector development studies finally leading to a scale-up utilising proportional scintillation as means of background rejection. The detector will be surrounded by a liquid scintillator Compton veto. Monte Carlo studies indicate that for a $30 - 100 keV$ threshold, 90% of the low energy background can be rejected.

The detector is shown in Figure 5. It is machined from low background copper. The bowl holding the active volume of liquid Xe is lined with *PTFE* to improve reflection of light. The target used for this detector is the natural occurring unenriched Xe. In the future a specific isotope may be used to investigate spin-dependent and spin-independent *WIMP* interactions.

4. Future programme

In addition to improvements to liquid Xe detectors, we are considering Xe gas in a *TPC* configuration to achieve directionality [5]. The Boulby programme may also be expanded to include neutrino astrophysics projects.

References

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[2] Benetti P *et al* 1993 *Nucl. Instrum. Methods A* **327** 203

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