Dark Matter Experiments At Boulby Mine

M.J.Carson[1] for the Boulby Dark Matter Collaboration
(1) Department of Physics and Astronomy, University of Sheffield, Sheffield S3 7RH, UK. Email: m.j.carson@sheffield.ac.uk

abstract

The status of galactic dark matter searches currently underway at Boulby mine in the UK is reviewed. These experiments are searching for the elusive Weakly Interacting Massive Particles (WIMPs) and utilise both scintillator and low pressure gas detectors. NaIAD and ZEPLIN are scintillator based experiments. The DRIFT experiment uses a low pressure gas TPC to detect recoils due to WIMP events. Recent results from both NaIAD and ZEPLIN are presented and our future programme is discussed.

1. Introduction

The UK Dark Matter Collaboration (UKDMC) has been operating NaI(Tl) detectors at the Boulby Mine underground site for several years [1]. Limits on the flux of weakly interacting massive particles (WIMPs), that may constitute up to 90% of the mass of the Galaxy, have been recently set using the data from the first NaIAD detectors [2]. In recent years emphasis has shifted toward the operation of liquid Xe based detectors (the ZEPLIN program) and TPCs (DRIFT). These are potentially more senstive to WIMP signatures and, in the case of DRIFT, can provide directional information on the WIMP flux. ZEPLIN I is a liquid Xe scintillation detector and is currently one of the most sensitive dark matter detectors in operation.
The initial goal of each experiment is to determine a WIMP event rate (or to put an upper limit on this rate) measured in number of events per kg per day. WIMP events are expected to produce nuclear recoil events in the detector. Scintillation pulses due to nuclear recoils have a shorter mean time-constant than those associated with electron recoils (electron recoils are due to the gamma-ray background). The mean time-constant therefore allows us to discriminate between background and any potential signal.

pp. 1693–1696

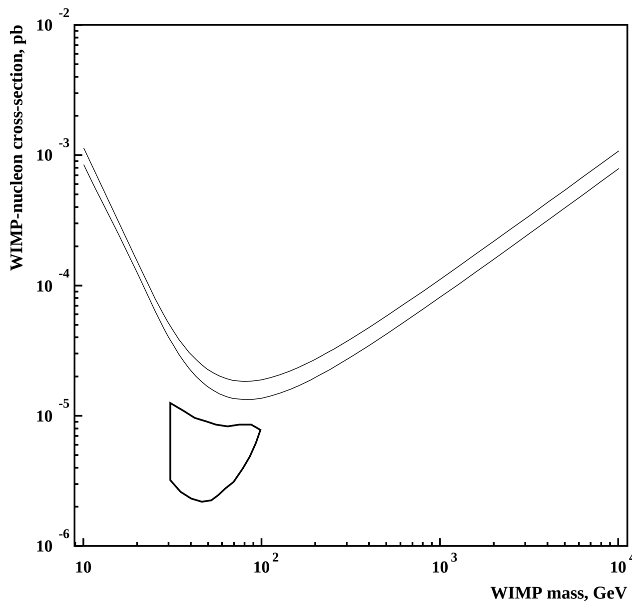

Fig. 1. Limit curves for WIMP-nucleon spin-independent cross-section. The upper and lower curves are the NaIAD 2002 and 2003 90% confidence limits respectively. The enclosed curve is the DAMA allowed region [3].

2. The NaIAD Experiment

The NaIAD (NaI Advanced Detector) array is operational in the UK Boulby Mine laboratory (North Yorkshire) at a vertical depth of 2800 mwe. The array consists of 7 NaI crystals with a total mass of 55 kg. Two detectors contain encapsulated crystals, while 5 other crystals are unencapsulated. To avoid degradation due to air humidity, the unencapsulated crystals have been sealed in copper boxes filled with dry air. Each crystal is mounted in a 10 mm thick solid PTFE reflector cage and is coupled to two 4-5 cm light guides at either end. The light guides are also mounted in the PTFE cages and are coupled to two 5 inch diameter low background photomultiplier tubes (PMTs) of the type ETL 9390UKB. Low background materials are used throughout. PMT signals are digitised using an Acqiris cPCI based DAQ system.
Our standard procedure of data analysis involves fitting a single exponential to each scintillation pulse. The time constants of these pulses follow a log-normal distribution with a mean time which increases with increasing energy for electron recoils but is practically constant for nuclear recoils. Electron and nuclear recoils

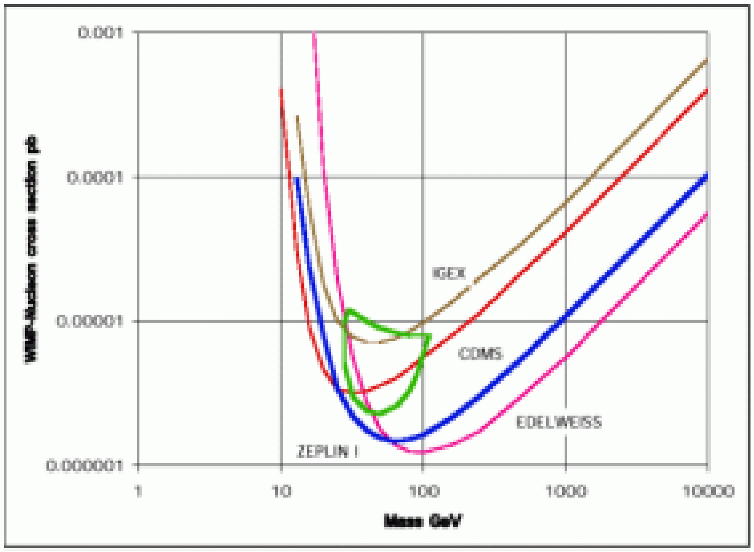

Fig. 2. ZEPLIN I limit (preliminary) with limits from other experiments

give rise to two populations with different mean times and so we can discriminate between them. Data from 9.7 kg×years have been analysed to produce the (preliminary) limit curve shown in Figure 1. This represents an improvement of about 50% over the previous limit.

3. The ZEPLIN I Experiment

The ZEPLIN I (Zoned Proportional scintillation in LIquid Noble gases) detector consists of 3.1 kg fiducial mass of liquid Xe incased in a copper vessel and viewed by 3 PMTs through silica windows. The detector istelf is enclosed in a 0.93 tonne active Compton veto, its function being to veto gamma events from the PMTs and the surroundings. ZEPLIN has better sensitivity than NaIAD due to its improved discrimination and lower energy threshold. As with NaIAD, background discrimination is possible due to the difference in time constant between nuclear and electron recoils. The 90% C.L. on the number of nuclear recoils in each 1 keV energy bin is extracted and this is then used to calculate the WIMP-nucleon cross-section as a function of WIMP mass. The preliminary limit on the spin-independent WIMP-nucleon cross-section from 230 kg×days of data is shown in Figure 2. in comparison with other world-best limits.

4. The DRIFT Experiment

The DRIFT (Directional Recoil Identification From Tracks) detector adopts a different approach to identifying a potential WIMP signal. DRIFT I uses a low

pressure CS_2 gas Time Projection Chamber capable of measuring the components of recoil track ranges in addition to their energy. It consists of two $0.5\,\text{m}^2$ fiducial volumes defined by 0.5 m long field cages mounted either side of a common anode plane consisting of 512 $20\,\mu$m stainless steel wires. Particle tracks are read out with two 1 m long MWPCs, one at either end of the field cages. The difference in track range between electrons, alpha particles and recoils is such that rejection efficiencies as high as 99.9% at 6 keV are possible. After 1 year of operation DRIFT I is expected to reach a sensitivity of $\sim 10^{-6}$ pb.
The power of DRIFT comes from its ability to determine the direction of a WIMP induced nuclear recoil. The Earth's motion around the galactic centre means that the Earth experiences a WIMP "wind". As the Earth rotates through this wind the nuclear recoil direction is modulated over a period of 12 sidereal hours, making it a strong signature of a galactic WIMP signal [4]

5. Conclusions and Prospects

Work is now underway on ZEPLINs II, III and ZEPLIN MAX. The latter should have a sensitivity to WIMP-nucleon spin-independent interactions down to 10^{-10} pb. ZEPLIN II is a two phase detector with a target mass of about 30 kg and a sensitivity to WIMP-nucleon cross-section down to 10^{-7} pb. In ZEPLIN II events produce both excitation and ionisation. Electron recoils produce more ionisation, while for nuclear recoils excitation is more important. This provides ZEPLIN II with greater discrimination power over ZEPLIN I. ZEPLIN III aims to increase background discrimination and with a fiducial mass of 6 kg should achieve similar sensitivities as ZEPLIN II. DRIFT II is proposed to have 30-50 times the sensitivity of DRIFT I through an increase in the volume and gas pressure. A higher gas pressure means that the recoil range will be shorter requiring higher spatial resolution. Alternative read-out schemes are currently being investigated including Gas Electron Multipliers and a MICROMEGAS microstructure detector.

References

[1] P. F. Smith et al. *Physics Reports*, 307 (1998) 275.

[2] B. Ahmed et al. to appear in *Astroparticle Physics*, hep-ex/0301039.

[3] R. Bernabei et al. *Physics Letters B*, 480 (2000) 23.

[4] M. J. Lehner et al. in *2nd International Conference on Dark Matter in Astro and Particle Physics (DARK98)*, 767-771, Heidelberg, Germany, 20-25 Jul 1998.