Neutrino Astroparticle Physics at Boulby Mine

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Thanks to new funding, the Boulby Mine Underground Laboratories are undergoing a significant expansion. These improvements have been designed primarily to meet the requirements of the Dark Matter programme, but future plans for the facility also include the possible installation of neutrino detectors. In this contribution, we describe the new facility and review the Boulby neutrino astrophysics programme.

1. THE BOULBY UNDERGROUND FACILITY

Boulby Mine is a working salt and potash mine located on the North English coast, about 10 miles north of Whitby. It has provided underground space for the UKDMC programme for more than ten years. The laboratories are situated at a depth of 1100 m (giving a 10^6 reduction in cosmic muon flux) in a halite stratum (low in backgrounds from U and Th). Also the low Rn levels ($\sim$5 Bq/m^3) makes it a competitive underground site of international standards.

A recently awarded Joint Infrastructure Fund (JIF) grant has enabled a major upgrade of the underground facilities. A new area of 2500 m^2 has been excavated (figure 1). Parts of it have already been built, housing the DRIFT Dark Matter detector. The existing facilities have been improved, housing the ZEPLIN-1 and NaIAD detectors, as well as a materials testing. The funding also provided a surface building, comprising workshop, lab and office space. The Boulby Dark Matter programme is reported by S.P. Hart in these proceedings[1]. This contribution concentrates on the neutrino programme.

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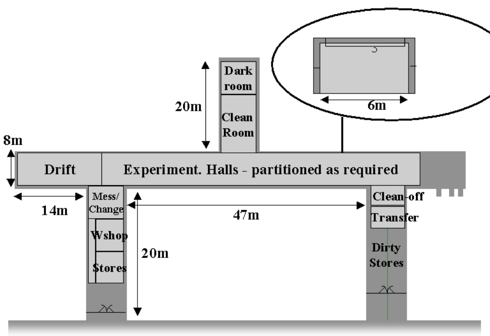

Figure 1. Plan of the new JIF-area. The design is based on an array of progressively cleaner areas from roadway to the experimental halls; it will include a workshop and a clean room.

2. SIREN: A SOLAR NEUTRINO EXPERIMENT

Until recently, the discrepancy at a level of 20σ between measured and predicted solar neutrino fluxes has been one of the most intriguing puzzles of fundamental particle physics. Resolution of this incompatibility was only possible by introducing ν-flavor oscillation[2]. With the SNO[4] and the SK results[5], compelling evidence now exists for these oscillations to occur. Nevertheless, the precise ν-flavor oscillation scenario remains uncertain. Due to their high thresholds, both SK and SNO measure only part of the spectrum (figure 2). Existing low threshold experiments (Homestake, Gallex, Sage) do not have the energy resolution needed to identify the source reaction, whereas Borexino will not be able to specify the ν-flavor. Therefore, there is a strong need for gathering detailed spectroscopic information below 1 MeV[3].

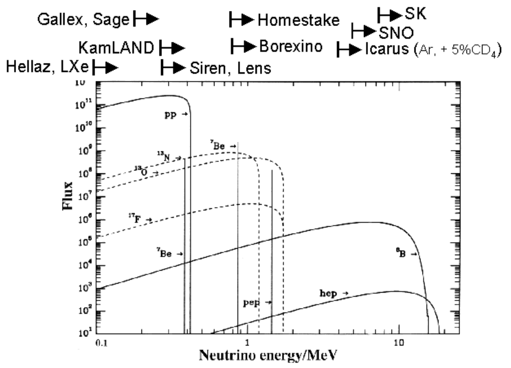

Figure 2. Solar neutrino spectrum according to the Standard Solar Model. The threshold of experiments is also shown.

The SIREN detector (Solar Neutrino Interactions by Real time Excitation of Nuclei) is based on the concept of sub-MeV ν_e-capture to a relatively long-lived excited level such as occurs in ^{82}Se, ^{115}In, ^{160}Gd or ^{176}Yb[6]. This idea is also investigated by the LENS collaboration, which is currently studying the possibility to use ^{115}In[7], while SIREN concentrate on ^{160}Gd. In each case the capture happens through charge current excitation. Its distinctive real-time signature consists (for ^{160}Gd) of a prompt e^- in coincidence with a delayed (80 ns) mono-energetic γ (75 keV). The total energy shed by the excited nucleus is simply related to the energy of the incident ν_e. We expect the energy resolution to be sufficient to distinguish between the different oscillation modes (figure 3). Furthermore, the real-time facility would be sensitive to day-night (studies of matter oscillation induced by the Earth) and seasonal effects (Earth-Sun distance modulation).

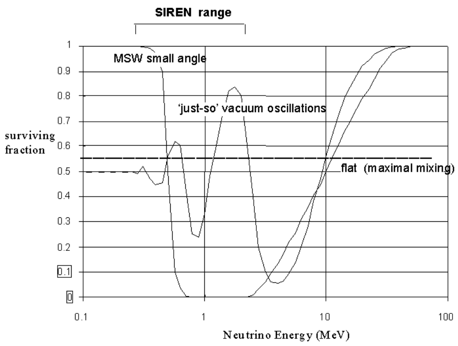

Figure 3. Neutrino signal attenuation due to oscillation for different modes. The SIREN sensitivity range is also shown.

SIREN relies on the use of Gd-loaded liquid scintillator as target medium. Because of the required target mass (10^4 kg), commercially available scintillators (with typically 0.2% loading) are not suitable. An important part of the R&D has been dedicated to the development of high-loaded and high-flashpoint, non-toxic (as Boulby is a working mine) liquid scintillator. Loadings of 5-10% have been achieved while maintaining an satisfactory light yield. Study of their characteristics (such as pulse shape) is in progress, while a test-module of 50 litre for background studies is in construction and will be installed underground next year.

While uncorrelated background will be minimized by the use of pulse shape discrimination and by the segmentation of the detector volume (with small module sizes < 0.1 m^3), the correlated background (eg. the $\beta\gamma$ coincidence from ^{231}Th-^{231}Pa) may be decreased by using purification techniques similar to the ones used by Borexino. In the first stage however, these events will be very useful for sensitivity studies by simulating the ^{160}Gd-ν_e capture signals.

3. NEUTRINOS FROM SUPERNOVA

Recently, a number of groups have expressed interest in using heavy elements (such as Pb, Fe) as targets for supernova neutrino detection[8]. The ν-target interaction occurs through nuclear excitation which results in the release of 0,1 or 2 neutrons, depending on the neutrino energy and on whether the transition is CC or NC induced. The cross-section has been estimated as being one order of magnitude bigger than the ν_e-e^- process commonly used for the same purpose. The greater sensitivity to 'high-flavor' (ν_μ, ν_τ) neutrinos makes an experiment based on nuclear excitation complementary to the existing, predominantly $\overline{\nu_e}$ sensitive detectors. As neutron detector medium, a simple commercially available Gd-loaded liquid scintillator could be used.

The potential of a detector based on this technique (OMNIS, Observatory for Multiflavour Neutrino Interactions from Supernova) is reviewed in detail in ref. [8]. The time profile of a supernova ν-burst would be significantly distorted by non-zero mass down to $\sim$10 eV/c^2. Even if smaller masses are suggested by ν-mixing experiments, the arrival signals still provide information on ν-mixing parameters and supernova models. Another issue is the galactic supernova rate: while observations of extra-galactic supernova suggests a rate of 3$\pm$1 per century, the historic records of visible supernovae indicate a rate of 6$\pm$1 per century. A compilation based on a variety of astrophysical methods shows a range as large as 2-10 per century.

Funding for a dedicated OMNIS experiment is being pursued in the US, however funding for a dedicated UK detector has been deferred. Low cost alternatives lie in combining it with other projects. One option envisaged is a SIREN-OMNIS combination (figure 4). OMNIS-like modules combined with Pb-shielding could also be used as a muon veto for low background experiments (eg. advanced Dark Matter detectors). Other combinations (eg. with a long-baseline far detector) have been suggested[9].

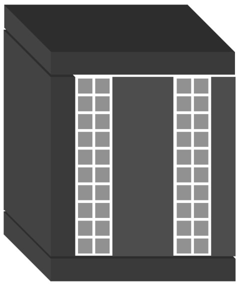

Figure 4. SIREN-OMNIS combined detector: the SIREN Pb shielding acts as an OMNIS target, while the Gd ν target is also a neutron absorber.

4. ACKNOWLEDGEMENTS

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