EDELWEISS Dark Matter Search Update

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Abstract

We provide an update on the status of the EDELWEISS dark matter search. The first phase has confirmed its previously published sensitivity thanks to more data. It has also served as a test-bed for the second phase, which aims to gain two orders of magnitude in sensitivity by means of a larger, improved setup. One of the main issues which must be addressed for EDELWEISS II is the neutron background.

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1 Introduction

The problem of dark matter remains unsolved since Fritz Zwicky pointed it out in 1933 based upon observations made from Mount Wilson [1]. Much evidence suggests the dark matter may be made out of weakly interacting, massive particles (WIMPs), perhaps of supersymmetric nature [2]. Experiments have been trying to detect the elastic scattering of these relic particles off nuclei since the mid-nineteen-eighties. The challenge is that the expected events deposit little energy in the detectors (the recoil energy spectra fall off exponentially with average energies in the keV to tens of keV range) and that they are rare compared to the ambient radioactivity (at most a few events per day and kilogram of detector). The most sensitive experiments now employ semi-conducting cryogenic detectors in which a simultaneous measurement of charge and phonons allows a powerful reduction of the main radioactive background due to photons and electrons down to low energies. EDELWEISS (Expérience pour Détecter les WIMPs en Site Souterrain) [3] is one such experiment.

2 Status of EDELWEISS I

2.1 Experimental setup and detectors

EDELWEISS is located in the Modane underground laboratory (LSM) beneath the Franco-Italian Alps. The rock coverage, equivalent to 4500 m of water, reduces the cosmic muon flux to 4.2 /m²/d through a horizontal surface. The first stage of the experiment, EDELWEISS I, used a dilution fridge surrounded by 20 cm of lead and copper as shielding against photons and 30 cm of paraffin to moderate the fast neutron background (1.6 × 10⁻⁶ /cm²/s unshielded). The fridge housed up to three detectors at a temperature of 17 mK. Each detector weighs 320 g and has an absorber consisting of a high purity germanium single crystal [4]. The phonon signal is read by an NTD thermistor glued on the crystal. After a correction for the Luke-Neganov effect [5], the phonon signal provides the energy deposit in the crystal. The charge signal is read by 70 nm thick aluminum electrodes sputtered on two faces of the crystal. Bias voltages of a few Volts are applied to collect the charges. The ionization signal being several orders of magnitude faster than the thermal phonon signal, it was used as trigger unless otherwise mentioned. For a given energy deposit, electrons and photons ionize more so than do neutrons and WIMPs, both of which scatter off nuclei. The electromagnetic background can thus be separated from the expected WIMP signal — and the neutron background.

Detectors of this type initially suffered from the fact that the charge of some
surface photon or electron events was not totally collected and hence resembled neutron or WIMP events [6]. This problem has been greatly alleviated thanks to the use of amorphous Si or Ge surface treatments about 60 nm thick [7]. Moreover, the electrodes are segmented in two concentric areas. This defines an inner, fiducial, volume quantified as \( \approx 55\% \) of the crystal volume [8].

Energy scales of the detectors are calibrated with a $^{57}$Co source. Response of the detectors to uniform Compton photon interactions is established with $^{137}$Cs; neutrons from $^{252}$Cf are used for the response to nuclear recoils.

### 2.2 Results on WIMPs

A single such detector functioning in 2001 with a 30 keV threshold yielded 4 kg.d of data with no nuclear recoils [9]. In 7.4 kg.d of data taken in early 2002 with a similar detector and a 20 keV threshold, the only nuclear recoil was at 119 keV, an energy irrelevant for WIMP masses below 10 TeV [3]. No background subtraction was thus performed on the 2001+2002 data used to set limits in terms of WIMP cross-section vs. mass (Fig. 1). The limits were derived from the experimental data using the standard assumptions on the astrophysics of the WIMPs (e.g. a local density of 0.3 GeV/cm$^3$) and their particles physics (namely a coherent $A^2$ coupling to nuclei).

After October 2002, three similar detectors were operated yielding an extra fiducial exposure of \( \approx 20 \) kg.d. Recoil energy thresholds were 20 keV for one detector and 30 keV for the others. They are chosen for a detection efficiency greater than 99\% and a rejection of the gamma background greater than three standard deviations. Two low-energy nuclear recoils appeared near the thresholds. The small number of these events has so far prevented their definitive
identification as neutron events. The events are therefore retained conservatively when establishing limits on WIMPs (Fig. 1). The greater ≈ 30 kg.d exposure with two low-energy events confirm the 2001+2002 limits [10].

2.3 Phonon trigger runs

One way to lower the threshold is to trigger on the slower but more sensitive phonon channel rather than on the ionization channel. This was implemented in autumn 2003 [11]. Trigger efficiency has been studied using neutron calibrations. Neutrons from a $^{252}$Cf source, of 2 MeV average energy, have a mean free-path of a few centimeters in Ge and thus are likely to provide coincident events in several of the detectors. By comparing the ratio of events that triggered a given detector over the number of events that triggered any detector, one can reconstruct the trigger efficiency as a function of energy. Thresholds 100% efficient down to 10 keV have been achieved in some detectors. An additional 30 kg.d of fiducial data in this configuration are under analysis.

2.4 Winter 2003-2004 tests

Several tests were carried out over the winter of 2003-2004. Apart from mundane ones such as testing new detector holders, a series was completed on new detectors to improve rejection of surface events [12]. They use NbSi thin films rather than NTDs as phonon sensors. Such films are sensitive to athermal phonons as well as thermal ones. When films are placed on opposite sides of the Ge crystal, the ratio of athermal to thermal pulse components provides an indication of the interaction depth. Results of these tests are being studied.

As of the end of April 2004, EDELWEISS I has been terminated and dismantled to make room for the next phase of the experiment.

3 Status of EDELWEISS II

3.1 Setup

To gain two orders of magnitude in sensitivity and reach 0.002 events/day/kg, EDELWEISS is being upgraded. A new cryostat has been built and tested down to 10 mK. It has a reversed geometry, pulse-tubes to dispense with liquid nitrogen, and a reliquefier to reduce helium consumption. Its experimental volume is 100 l. Initially, the cryostat will house 21 320 g Ge detectors with
3.2 Background considerations

Assuming surface events can be dealt with through a combination of lower radioactivity environment, surface treatment and position sensitivity, the next background will come from neutrons, which cannot be rejected by their charge-to-energy ratio. In LSM, the main neutron flux has been measured [13] and comes from the natural radioactivity of the rock. Its typical energy of a few MeV means it can be moderated by polyethylene (PE). The 50 cm of PE around EDELWEISS II should reduce the rate of these neutrons in the detectors by 3 orders of magnitude to $5 \times 10^{-4}$ evts/d/kg above a 10 keV threshold.

Another contribution comes from muon-induced neutrons [14]. The rare muons making it to LSM (mean energy 300 GeV) may hit a heavy element in the surrounding rock, or a heavy element such as the Pb in the 30 tonne shielding right around the cryostat. This releases high-energy neutrons which are difficult to moderate. Preliminary simulations show that the neutrons from the lead shielding contribute $10^{-2}$ evts/d/kg. They can be dealt with by a muon tagger around the experiment with at least a 95% efficiency. This tagger will be made up of large (2–3 m$^2$) plastic scintillator panels obtained from the KARMEN experiment and readout with photomultipliers. These 5 cm thick modules with a total surface of 140 m$^2$ will cover EDELWEISS with some minor gaps for rails, pumping lines and tubes. Simulations using the muon distribution at LSM [15] show that the geometrical coverage of the tagger is sufficient. To achieve the required muon detection efficiency, it is paramount to know the response of each individual scintillator to muons. A muon telescope, the Modane Muon Measurement (M3) [14], has thus been fashioned from two scintillators and run underground to study their response and threshold. About 250 days of data are being analyzed. These data and further simulations show that a tagger threshold of 6 MeV is low enough to reach a muon tagging efficiency greater than 98% but high enough to avoid too great a count rate from other sources. Simulations are underway to understand the contribution of the harder-to-tag neutrons from muons in the surrounding rock.

Other possibilities to reduce the neutron background include having a large and dense enough total detector volume to see coincidences from neutrons. Another is to exploit the fact that unlike fast neutron cross sections, WIMP cross sections depend strongly on target nucleus mass. With sufficient statistics, comparison of rates on light targets to those on heavy ones could allow subtraction of the neutron contribution, as shown by the CDMS experiment [16].
4 Conclusion

Previous EDELWEISS limits constraining the phase space of WIMPs and obtained with a single detector are confirmed using multiple detectors and a greater exposure. EDELWEISS I has now been dismantled to make way for the next phase of the experiment. EDELWEISS II intends to gain two orders of magnitude in sensitivity thanks to more and improved detectors as well as better shielding. The fast ambient neutron background will be moderated by polyethylene, while the rare cosmic muons interacting in the experimental area and inducing higher energy neutrons will be tagged by scintillators. Upgraded cryogenic experiments such as EDELWEISS II, CDMS II and CRESST II [16] are poised to start exploring supersymmetric phase space seriously.

References

G. Angloher et al, ibid, 108.