EDELWEISS-II : Status and Future

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The EDELWEISS experiment is dedicated to the WIMPs direct search using heat-and-ionization Ge cryogenic detectors. We present the final results obtained by the first stage of the experiment, EDELWEISS-I which used three 320 g bolometers, corresponding to 62 kg.d. We describe EDELWEISS-II which commissioning runs have already started. This second stage of the experiment involves 10 to 40 kg of detectors with a better shielding in the aim to improve the sensitivity by two orders of magnitude.

1. Introduction

Recent cosmological observations of the CMB show that the main part of the matter in our Universe is dark and non baryonic \cite{1}. If non baryonic Dark Matter is made of particles, they must be stable, neutral and massive: WIMPs (Weakly Interactive Massive Particles). In the MSSM (Minimal Supersymmetric Standard Model) framework, the WIMP could be the LSP (Lightest Supersymmetric Particle) called neutralino. It has a mass between few tens and few hundreds of GeV/c\(^2\), and a scattering cross section with a nucleon below \(10^{-6}\) pb.

The EDELWEISS experiment is dedicated to the direct detection of WIMPs. The direct detection principle (used also by other experiments like DAMA \cite{2}, CDMS \cite{3} and CRESST \cite{4}) consists in the measurement of the energy released by nuclear recoils produced in an ordinary matter target by the elastic collision of a WIMP from the galactic halo.

2. EDELWEISS-I

2.1. Experimental set-up

The EDELWEISS experiment is located in the Modane Underground Laboratory (LSM) in the Fréjus tunnel connecting France and Italy under \(~1800\) m of rock (~4800 mwe). In the laboratory, the muon flux is \(4\ \mu/m^2/d\) and the fast neutron flux has been measured to be \(~1.6\times 10^{-6}\ \text{cm}^2/s\) \cite{5}.

The detectors used in the experiment are cryogenic bolometers with simultaneous measurement of phonon and ionization signals. They are made of a cylindrical Ge crystal with Al electrodes to collect ionization signals and a NTD heat sensor glued onto one electrode to collect the phonon signal \cite{6}. The top electrode is segmented in a central electrode and an annular guard ring to define a fiducial volume corresponding to \(57 \pm 2\%\) of the total volume \cite{7}. On four of the five detectors used in EDELWEISS-I an amorphous layer (either of Ge or Si) was deposited under the electrodes to improve charge collection of near surface events \cite{8}.

The detectors were operated in a dilution cryostat with a regulated temperature of \(17 \pm 0.01\) mK. The cryostat could not house more than \(3 \times 320\) g Ge detectors. A passive shielding made of paraffin (30 cm), lead (15 cm) and copper (10 cm) surrounded the experiment \cite{9,10,11}.

The simultaneous measurement of both heat and ionization signals provides an excellent event by event discrimination between nuclear recoils (induced by WIMP or neutron scattering) and electron recoils (induced by \(\beta\) or \(\gamma\)-radioactivity).
The ratio of the ionization and heat signals depends on the recoiling particle, since a nucleus produces less ionization in a crystal than an electron does.

The heat and ionization responses to gamma rays were calibrated using $^{57}$Co and $^{137}$Cs radioactive sources and the response to nuclear recoils was measured using a $^{252}$Cf source. A summary of the bolometer baselines, resolutions and energy thresholds can be found in [12]. Typically with the EDELWEISS detectors it is possible to reject more than 99.9 % of electron recoils down to 15 keV.

2.2. Final results

During the EDELWEISS-I stage (2000-2003), four physics runs have been performed with five detectors. In the three first runs, the trigger was the fast ionization signal. For the last run, the trigger was the phonon signal. Thanks to a better resolution and the absence of quenching factor on the phonon signal, the phonon trigger improves the efficiency at low energy for nuclear recoils. The overall trigger efficiency at 15 keV for the entire EDELWEISS-I data set is 50% [12] for events in the fiducial volume.

The low-background physics data recorded in the phonon trigger configuration are shown in Figure 1. Considering the entire 62 kg.d data set, 60 events compatible with nuclear recoils have been recorded above a recoil energy of 10 keV. Only 3 events have an energy between 30 and 100 keV and this provides a strong constraint on a possible WIMP rate. The corresponding energy spectrum is shown in Figure 2 compared with simulations of theoretical spectrum for different WIMP masses, taking into account the recoil energy dependence efficiency of all experimental configurations. The overall shape of the experimental spectrum is incompatible with WIMP masses above 20 GeV/c². Considering all the events with $E_R > 15$ keV as possible WIMP interactions and taking into account the efficiency versus recoil energy function of each run, a conservative upper limit on the WIMP-nucleon cross-section as a function of the WIMP mass has been derived with the Optimum Interval Method [13]. This method allows to compute an exclusion limit in the presence of an unknown background without any subtraction. Figure 3 shows the 90 % C.L. EDELWEISS-I spin-independent exclusion limits compared with that of other running experiments. Because of the observed counts, the new limit is consistent with the previous one, obtained with a smaller exposure [16]. The best sensitivity for EDELWEISS-I is $1.5 \times 10^{-6}$ pb at 80 GeV/c² [12]. To explore more interesting supersymmetric models, a gain in sensitivity of a factor 100 is needed. This is the goal of the EDELWEISS-II experiment. This gain in sensitivity depends on improvements on the background reduction and rejection and on the increase of the detector mass.

The EDELWEISS data can also put constraints on models where spin-dependent interactions dominate [17]. This is because natural Ge is made of 7.8 % of $^{73}$Ge with a spin of 9/2. Figure 4

\[ \text{Figure 1. Distribution of the ratio of the ionization energy to the recoil energy as a function of the recoil energy collected in the fiducial volume of three EDELWEISS detectors in the last run for 2003 [12].} \]
shows the constraints established for different experiments in the \((a_p,a_n)\) plane, where \(a_{p,n}\) are the effective WIMP-proton (-neutron) couplings. Experiments with Ge detectors are the most sensitive to \(a_n\), but optimistic models are still a factor 100 below the present limits \[17\].

### 2.3. Background studies

Although the EDELWEISS-I limits of Figure 3 are derived assuming all events as possible WIMP candidates, the experimental data reveals some clues as to the nature of possible backgrounds. From the simulation of the neutron flux in the laboratory \[5\], we expect 2 nuclear recoils in 62 kg.d with \(\sim 10\%\) being coincidences. One two-detector coincidence of nuclear recoils has been recorded. This event is very likely a neutron-neutron coincidence, indicating that a certain fraction of events in Figure 2 could be due to single hits by neutrons. The measurement is statistically consistent with the prediction but does not provide a strong constraint on the single rate. Miscollected charge events, as indicated by the few events lying between electronic and nuclear recoil bands in Figure 1 are another possible source of background. But with the present statistics, largely limited by the number of detectors, it is not possible to conclude any further.

The gamma ray background is well understood. It results from the copper shielding present around the cryostat. Most of the rate observed at high and intermediate energy can be explained by the measured contamination in U and Th of our copper shielding which will be removed for the future experiments. The contributions of \(\alpha\)-emitters and their daughters was investigated by studying high energy events. A peak appeared at a recoil energy of 5.3 MeV with a quenching factor of 0.3. This is attributed to alpha decays from \(^{210}\)Po near the detector surface. It seems very likely that these events are due to \(^{210}\)Pb contamination on the surface of Cu facing detectors, because no peak at 100 keV from the lead recoils has been observed \[18\]. By removing the Cu cover, these events should disappear.
3. EDELWEISS-II

EDELWEISS-II is the second stage of the experiment which installation is achieved in November 2005. The first phase consists in 28 detectors with NTD or NbSi sensors. The expected sensitivity of this second phase is 0.002 evt/kg/d. Specific improvements are aimed at reducing the possible background sources, that may have limited the sensitivity of EDELWEISS-I.

To reduce the radioactive background in the cryostat all the materials are tested for radiopurity in a HPGe dedicated detector, with very low radon level. A clean room surrounds the experiment and air flow is available.

Concerning the low energy neutron background, due to the radioactive surrounding rock, it is attenuated by more than three orders of magnitude thanks to a 50 cm polyethylene shielding. In addition, a muon veto [19] surrounding the experiment will tag muons interacting in the lead shielding. The increased number of detectors, up to ∼110 in a compact arrangement, will improve the possibility of detecting multiple interactions of neutrons.

One important limitation for the EDELWEISS-I sensitivity is the presence of surface events, namely interactions near electrodes. Because of diffusion, trapping and recombination, the charge in surface events is miscollected and can mimic nuclear recoils. Two solutions exist. First, the passive rejection in improving the charge collection of surface events with amorphous layer or with thick electrodes. And second, the active rejection in identifying the surface events with the pulse shape analysis or NbSi sensors. One of the R&D goals in EDELWEISS is the event-by-event identification of these miscollected events and their active rejection. A new generation of detectors has been developed with NbSi thin film sensors (instead of the NTD heat sensors for present detectors). They consist in a Ge crystal with two NbSi sensors acting also as electrodes for charge collection. These thin film sensors are sensitive to the athermal component of the phonon signal, acting as near-surface interaction tag [20]. Several tests have been made in the EDELWEISS-I setup with three 200 g Ge detectors showing an improvement of a factor 20 of the rejection and only a reduction of 10% of the fiducial volume. With these very encouraging results, seven 400 g Ge detectors are being prepared for the first stage of EDELWEISS-II.

In January 2006 a first cryogenic run has been recorded. Presently, the experiment is in commissioning run in different configurations with 8 bolometers to valid a lot of items: cryogeny, detectors, microphony, new electronic and acquisition system, ...

4. Conclusion

EDELWEISS-I experiment has reached its limit sensitivity near 10^{-6} pb, allowing the exclusion of some optimistic SUSY models. The presence of two possible backgrounds have been observed, neutrons and surface events. The goal for the future with EDELWEISS-II is to gain a factor 100 in sensitivity thanks to an improved setup. EDELWEISS is pursuing its R&D on the detectors with NbSi or NTD sensors to permit the identification of surface events. EDELWEISS-II will prepare the next generation of detector in...
the 100 kg to one ton scale with the EUECA project [21].

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