The EDELWEISS Experiment: Status and Outlook

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Abstract. The EDELWEISS Dark Matter search uses low-temperature Ge detectors with heat and ionisation read-out to identify nuclear recoils induced by elastic collisions with WIMPs from the galactic halo. Results from the operation of 70 g and 320 g Ge detectors in the low-background environment of the Modane Underground Laboratory (LSM) are presented.

1 Introduction

The EDELWEISS experiment is a direct WIMP search, where nuclear recoils induced by collisions with WIMPs from the galactic halo are detected using Germanium detectors with simultaneous measurement of ionisation and phonon signals. The comparison of the two signals makes possible to separate on an event-by-event basis the nuclear recoils from the electron recoils induced by β- and γ- radioactivity that constitute the major source of background in most present-day direct WIMP searches.

The detectors are operated in the Laboratoire Souterrain de Modane in the Fréjus Tunnel under the French-Italian Alps. The 1780 rock overburden (4800 m water equivalent) results in a muon flux of about 4 m−2 day−1 in the experimental hall and the flux of neutrons in the 2-10 MeV range has been measured to be 4±1×10−6 cm−2 s−1 [1].
The EDELWEISS-I phase consists in the operation of one to three Ge detectors in the current one-litre cryostat, their number being limited by the small volume. In the year 2002, the program will enter a second phase with the installation of a 100-litre cryostat currently under construction, allowing the use of up to 100 detectors. In the mean time, the data-taking with the present-day cryostat is devoted to the development of the detectors and to setting improved limits on a possible WIMP signal.

Outside the LSM, this activity is accompanied by an intensive research and development program aimed at improving the detector designs and our understanding of their physical properties. This includes work on phonon heat sensors using NbSi thin films as Anderson insulators, and the development of a facility to calibrate detector responses to nuclear recoils using a neutron beam and an array of NE213 scintillators to measure event-by-event the actual nuclear recoil energy.

2 The EDELWEISS detectors

Important considerations in the design of heat-and-ionisation detectors are size and performance in terms of charge collection. The imperfect charge collection of an electron recoil can be mislead for the reduced ionisation yield of a nuclear recoil. This must be avoided, e.g. by a careful electrode design or by means of identification of events where the charge has been deposited close to the detector surface. A large detector size is clearly advantageous in terms of event rate and surface-to-volume ratio. However how this affects space-charge build-up and trapping (affecting the ionisation signal) and how the increased heat capacity affects the heat phonon signal requires thorough investigations. For these reasons, the EDELWEISS collaboration has tested detectors with different sizes and electrode designs.

Two detector sizes have been tested: 70 g (48 mm diameter, 8 mm thick cylindrical Ge monocrystals) and 320 g (70 mm diameter, 20 mm thick). The edges have been bevelled at an angle of 45°.

The plane surfaces and wedges have been metallised for ionisation measurement. Two types of metallisation have been tested. In the first one, the electrodes are boron and phosphorus implanted, yielding a p-i-n structure. In the second one, 100 nm Al layers are sputtered onto the surfaces after etching. In one of the 320 g prototypes the top electrode is divided in a central part and a guard ring, electrically decoupled for radial localisation of the charge deposition.

The thermal sensor consists of a Neutron Transmutation Doped germanium crystal (NTD) of a few mm³ glued to the surface of the detector.

3 Results with 70 g detectors

The first results of the EDELWEISS collaboration obtained in 1997 in its first test of a 70 g Ge detector without the Roman lead shielding and radon removal have been published recently. Resolutions of about 1 keV FWHM
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Fig. 1. Scatter diagram of the recoil energy vs. charge amplitude for a 70 Ge detector (1.17 kg-day exposure). The four shaded areas correspond to the populations of events attributed to (from left to right:) nuclear surface, nuclear volume, electron surface and electron volume events.

have been measured on both ionisation and heat channels. The ionisation trigger threshold was approximately 5 keV. Fig. 1 shows the scatter diagram of the recoil energy versus the ionisation energy of events measured with an exposure of 1.17 kg-day. As expected from calibrations with gamma and neutron sources, electron recoil events appear along the diagonal and the ionisation yield of nuclear recoil events is relatively suppressed by a factor ~3.5. Electron recoil events with incomplete charge collection fill the gap between the first two regions. These events are attributed to interactions close to the surface of the detector (mostly β contamination and X rays) where approximately half of the initially produced ionisation is lost. There is no clear separation between the populations of nuclear recoils and electron surface events.

A fourth population is observed: nuclear events with incomplete charge collection, attributed to surface contamination from alpha emitters.

The total event rate before electron recoil rejection is 30 events/kg/day/keV in the 20 to 100 keV recoil energy range. After rejection, the upper limit on the nuclear recoil event rate in that range is 0.6 event/kg/day/keV at 90% C.L.

These results encouraged the pursuit of the project with the construction of a neutron shield and improving the radiopurity of the detector environment. A new implantation scheme for the p-i-n electrodes was also tested on a new 70 g detector. The cryostat was acoustically insulated from the rest of the underground laboratory, with a copper mesh on the floor for better grounding. An automatic system was set up to inverse at regular interval for short periods the
polarity on the electrodes of the Ge, in order to free the trapped electrons that create undesirable residual fields within the detector volume. The protection against the radioactive background has also been strengthened. A clean room was installed for handling the detectors. A 30 cm thick paraffin shielding against neutrons was installed. Pure Nitrogen was circulated around the cryostat in order to reduce radon accumulation. All electronic components were moved away from the detector and hidden behind the archeological lead shields. A thorough selection of all materials entering the experimental setup was instigated, using the low-background counting facilities at the LSM.

![Fig. 2. Ratio of the ionisation yield to the recoil energy for events with recoil energies between 20 and 100 keV. The electron recoil yield has been normalised to 1 using γ-ray calibration sources and is expected to be approximately 0.3 and 0.5 for nuclear and surface electron recoils, respectively. The data set, normalised to 1 kg·day, are: (line) 1.8 kg·day exposure for a 70 g detector in the 1997 configuration; (dashed) 2.0 kg·day exposure for a 70 g detector in the 2000 configuration and (hatched histogram) 3.1 kg·day exposure in the center fiducial region of a 320 g detector with guard ring.](image-url)

Tests with this new configuration were performed in 1999-2000. A reduction of the overall background rate (before electron recoils rejection) by a factor of ten was achieved, as illustrated in fig. 2. This figure shows the distribution of the ratio of the ionisation yield to the recoil energy for recoil energies between 20 and 100 keV range measured in 1997 (full line) and in a 1.97 kg·day run with the new configuration (dashed line). This reduction is observed for electron
recoils with both complete (arrow labeled $\gamma$ on fig. 2, with ionisation/recoil ratio $\sim 1$) and incomplete charge collection (labeled $\beta$, ratio $\sim 0.5$).

The efficiency-corrected rate of nuclear recoils in the 20-100 keV range is $11 \pm 3$ counts/kg/day. It is only a factor two better than in the 1997 configuration, yielding an upper nuclear recoil rate of 0.25 nuclear counts/kg/day/keV in the 20-100 keV range (90% C.L.). The subsequent test of a 320 g detector has proven that this rate is essentially due to electron recoils with improper charge collection. The factor ten reduction of the rate observed for events with a ionisation/recoil ratio close to 0.5 does not apply for events with significantly worse charge collection (ratios $<0.3$).

4 Results with a 320 g detector

An important breakthrough came with the operation of 320 g Ge heat-and-ionisation detectors in the LSM, the largest of this type of detectors in operation in the world. So far two detectors have been tested and up to three should be installed at the end of the present run.

The most interesting results have been obtained with a detector equipped with a guard ring electrode. Work is still in progress in reducing the microphonic noise on the ionisation and heat channels. So far baseline resolutions of 2 keV on both channels have been achieved. The ionisation trigger threshold was kept under 7 keV over an exposure time of 6.3 kg-day, and consequently the data analysis has been restricted to nuclear recoils above 30 keV, a conservative estimate of the effective threshold for these recoils. The data taking is still under way.

The fiducial region defined by rejecting events with a significant signal on the guard electrode has been estimated using a neutron calibration source and it represents approximately 50% of the total volume. The distribution of the ratio of the ionisation yield to the recoil energy obtained so far with an equivalent exposure of 3.1 kg-day is shown in Fig. 2 as a hatched histogram. The overall rate before the rejection of electron recoils with complete charge collection is comparable to the best performance of the 70 g detectors. More importantly, the rate of events with incomplete charge collection is significantly reduced. So far no nuclear recoils are observed in the 30 to 100 keV recoil energy range, resulting in the preliminary exclusion contour shown in fig. 3. It should be noted that this limit is obtained without any neutron background subtraction, and can be expected to improve as data taking is progressing.

5 Perspectives and Conclusions

The present EDELWEISS 320 g detector is already setting interesting WIMP limits. As the limitation of the detectors have not been reached yet, foreseeable improvements should come with the increase of statistics in the current run.
Other improvements should arise with the better understanding of the microphonics and other effects affecting the energy resolution and threshold. Before the end of 2001 the full 3×320 g detector setup should be installed.

In 2002 will start the installation of the 100-litre EDELWEISS-II cryostat presently built in the CRTBT laboratory in Grenoble. It will be able to accommodate up to 100 detectors and their electronics, providing the opportunity to increase the sensitivity to a WIMP signal by more than two orders of magnitude.

Acknowledgements

The help of the technical staff of the Laboratoire Souterrain de Modane and the participating laboratories is gratefully acknowledged. This work has been partially funded by the EEC Network program under contract ERBFMRXCT980167.

References

1. V. Chazal et al.: Astropart. Phys. 9, 163 (1998)
2. P. Di Stefano et al.: Astropart. Phys. 14, 329 (2001)
3. A. Benoit et al.: Phys. Lett. B 479, 8 (2000)
4. X.F. Navick et al.: Nucl. Instr. Meth. A 444, 361 (2000)
5. R. Bernabei et al.: Phys. Lett. B 450, 448 (1999)
6. R. Abusaidi et al.: Phys. Rev. Lett. 84, 5699 (2000)
7. L. Baudis et al.: Phys. Rev. D 59, 022001 (1999)