Latest results from the EDELWEISS WIMP search

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Abstract. The latest results obtained by the EDELWEISS WIMP (Weakly Interacting Massive Particles) direct detection experiment using three heat-and-ionisation 320 g germanium bolometers are presented. Presently the most sensitive WIMP Direct Detection experiment for WIMP mass > 30 GeV, EDELWEISS-I is testing a first region of SUSY models compatible with accelerator constraints. The status and main characteristics of EDELWEISS-II, involving in a first stage 28 germanium bolometers, and able to accommodate up to 120 detectors, are briefly presented.

1 Introduction: motivations

The case for non baryonic dark matter has become compelling over the last few years. After the recent satellite WMAP precision measurements of the CMB background [1], the precision on the universe density is now a few percent and $\Omega \sim 1.02 \pm 0.02$. On the other hand, the recent apparition in the cosmological landscape of a non zero cosmological constant or some other quintessential component has brought some uneasiness to an emerging Standard Model: our Universe appears to be a strange mixture of 2/3 of some cosmological repulsive component, 1/3 of exotic matter, with only a few percent of ordinary matter:

95% of the universe content is unkown. The baryonic density, Ω_{baryon}, is impressively constrained by primordial nucleosynthesis [2] and cosmological constraints to be $\sim 4.4 \pm 0.2\%$, implying that matter is composed at nearly 85% of a mostly unobserved and non interacting component.

Although we have now good evidence that neutrinos are indeed massive, the sensitivity reached by present searches excludes that neutrinos can fill the gap: experimental constraints impose that they contribute at most to 10% of the missing mass. Generically predicted by supersymmetric (SUSY) theories, Weakly Interacting Massive Particles (WIMPs) then provide the best motivated candidate to solve the missing matter enigma while, for the first time, direct and indirect detection experiments are beginning to test regions of supersymmetric model parameter space compatible with cosmological and accelerator constraints.

In the following, we will summarize the strategy and main results obtained by the EDELWEISS-I experiment in the direct detection of dark matter, using heat-and-ionization cryogenic Ge detectors. The experiment, which has been described elsewhere [3], is set in the low-background environment of the Modane Underground Laboratory (LSM), which reduces the muon cosmic background by a factor $\sim 2 \times 10^6$ compared to the flux at sea level. The neutron flux originating from the rock has been measured to be $\sim 1.4 \times 10^{-6}$ cm^{-2} s^{-1}. In the present EDELWEISS-I setup, this neutron flux, in the MeV range, is strongly attenuated and degraded in energy by a paraffin shielding of thickness $\sim$ 30 cm. During the last four years, a series of data takings using several 320 g Ge detectors have allowed EDELWEISS to achieve the best sensitivity to WIMP interactions for all WIMP mass > 30 GeV.

2 Experimental results

The Ge detectors presently used in the EDELWEISS experiment are described in Ref. [4,5]. These detectors have a cylindrical geometry (70 mm diameter and 20 mm thickness) and their edges are beveled at an angle of 45 degrees to improve charge collection near free lateral detector surfaces. Two distinct Al electrodes, a central and a guard ring electrode, are used for charge collection. The thermal sensor is a Neutron Transmutation Doped Germanium crystal (Ge-NTD) of few mm^3 glued onto the guard ring. Four out of a total of seven 320 g bolometers were equipped with an additional 60nm thick Ge or Si amorphous layer providing improved charge collection efficiency for near surface events [6]. Since January 2002, three 320 g detectors have been simultaneously operated in the EDELWEISS-I cryostat, all the signals being numerically filtered and triggered online. The quality of the LSM experimental site combined with copper, lead and paraffin shielding of the cryostat as well as material selection in the close vicinity of the detectors [7] reduces the γ-ray background down to typically 1.2 events/(keV $\times$ kg $\times$ day) before background rejection. The residual neutron background after these shieldings is estimated to be 0.03 events/(kg $\times$ day) above 20 keV [8].

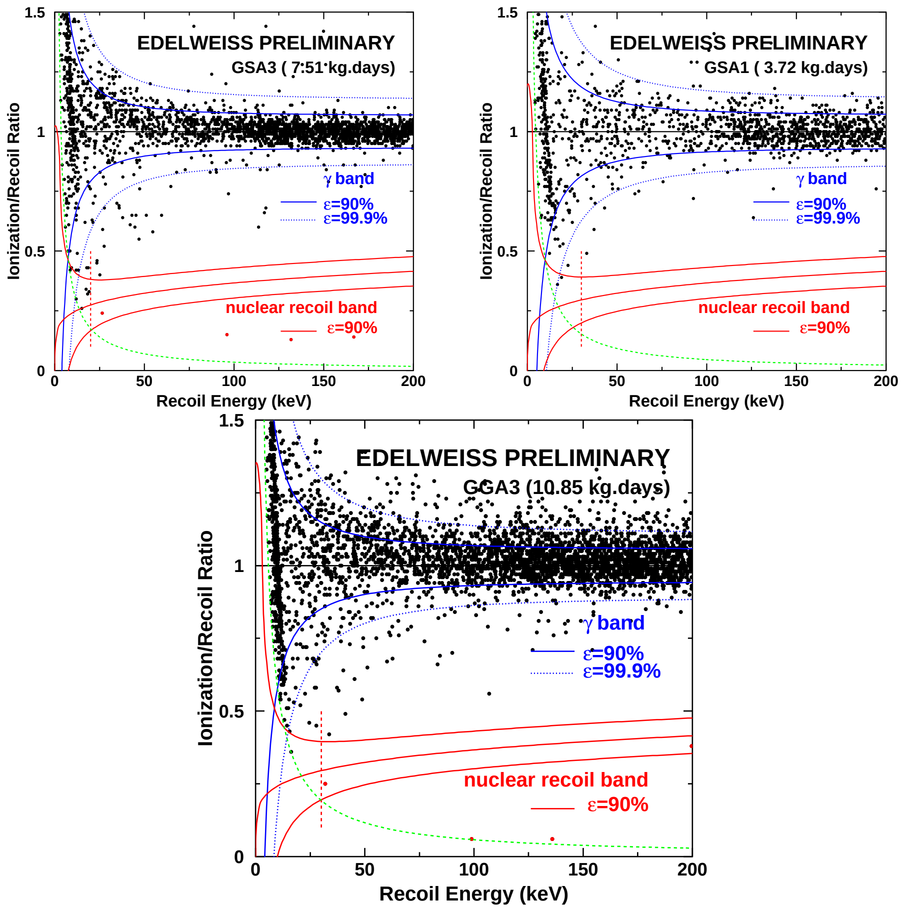

Fig. 1. Distribution of the quenching factor versus recoil energy for the 2003 low background data using three 320 g Ge bolometers.

3 Detector calibration

The heat and ionization responses to γ-ray particles were calibrated using ^{57}Co, ^{60}Co and ^{137}Cs sources. Ionization baseline resolutions are better than 1.5 keV FWHM for all detectors, and the heat baseline FWHM resolution range from 0.4 keV to 1keV depending on the detector. The recoil energy threshold using ionization triggering was 20 keV for the GSA3 detector, and 30 keV for the GGA3 and GSA1 detectors ($>$ 99% efficiency). A summary of the bolometers baselines, resolutions and thresholds are given in Ref. [5].

Owing to the simultaneous measurement of heat and ionization, the major part of the background signal in these detectors can be rejected. Indeed, nuclear recoils induced by neutrons and WIMPs are less ionizing than electron recoils induced by γ-rays. The separation efficiency between electron and nuclear recoils is a very important feature for this type of detectors. It is regularly controlled by measuring the quenching factor Q (ratio of the ionization to recoil energy) during γ-ray calibrations. In particular, surface electron recoil events are associated with incomplete charge collection, and give a lower Q factor, which could make them confused with nuclear recoil events. We observe that charge collection efficiency for surface events is much better for detectors equipped with amorphous Si or Ge layers, and have measured that $< 0.03\%$ of events found in the recoil band during γ-ray calibrations.

4 Results and discussion

Three periods of low background data have been realized using different bolometers. During the 2000 and 2002 runs, a total of 11.6 kg $\times$ days of data were accumulated using the GeAl6 and GGA1 detectors [9,10]. We will focus here on a new 2003 data taking period, which accumulated an additional set of 18.9 kg $\times$ days, based on three new detectors, GGA3, GSA1 and GSA3. The corresponding Q versus recoil energy diagrams are plotted in Fig. 1. The three detectors show very similar behavior with only two events lying into the neutron recoil band. These two events, together with three events at very low quenching factors, all arrived within a few days of each other. Conservatively, these two events are considered as real nuclear events. Under this conservative hypothesis, the spin-independent exclusion limit for WIMP-nucleon cross section derived from these data is almost identical to and confirms the sensitivity reached in the 2000-2002 data takings, with a cumulated statistics of 30.5 kg $\times$ day and using three new detectors. Fig. 2 presents the present EDELWEISS sensitivity, together with the constraints of the presently most sensitive experiments. In particular, the WIMP cross-section associated with the best fit to the DAMA annual modulation candidate [11,12], assuming standard halo parameters [33], is excluded at a 99.998% confidence level.

The DAMA group has contested this contradiction, invoking the uncertainty in the WIMP halo parameters. But Copi and Krauss [13] have recently shown that the contradiction remains model-independent when the relative sensitivity of both experiments is considered, unless unconventional couplings are used. A mixture of spin-dependent and spin-independent couplings has also been proposed to reconcile the conflicting experimental results between EDELWEISS and CDMS on the one hand, and DAMA on the other. But Kurylov and Kamionkowski [14] have shown that, except in a very small region in phase space in the WIMP-proton/WIMP-neutron plane, it seems impossible to reconcile the DAMA result with the EDELWEISS and CDMS negative results for all WIMP mass > 18 GeV.

5 Compared sensitivities of EDELWEISS and indirect detection experiments

Despite their small interaction cross–section with ordinary matter, WIMPs can be captured by celestial bodies, such at the Sun or the Earth [15]. Using the neutrino signal emitted during WIMP annihilations may constitute a powerful signature as the signal is directional and sources opaque for γ-ray emission can be observed. Three main potential sources have been studied: the Earth, the Sun and the Galactic Center region. The overwhelming muon background

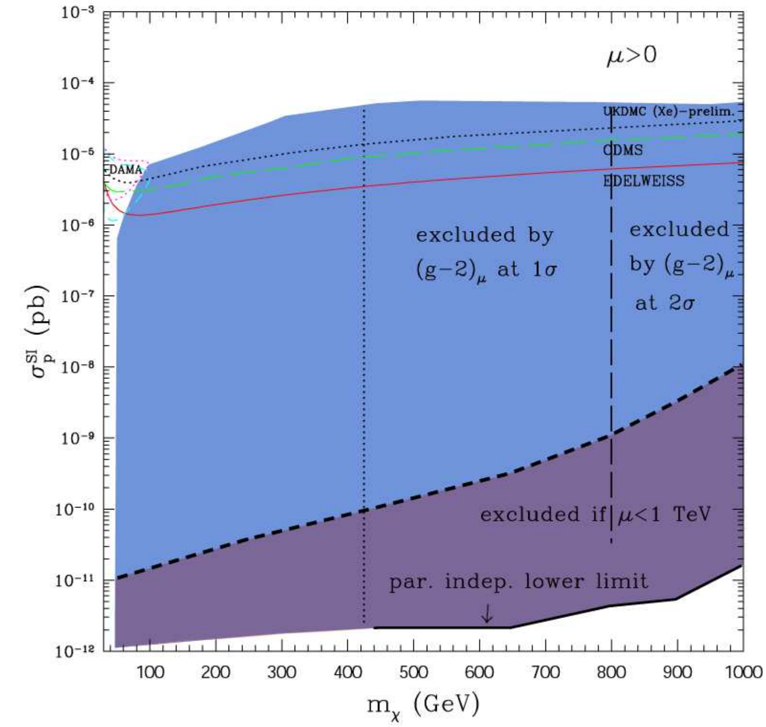

Fig. 2. Experimental sensitivities of the present most sensitive WIMP direct detection experiments (from Ref. [19]). The EDELWEISS result, without background subtraction, excludes the full 3-σ zone of the DAMA signal (upper left corner) compatible with accelerator constraints, independently of the WIMP halo model parameters. The parameter independent lower limit on the WIMP-p cross-section can be seen to be $\sim 10^{-12}$ pbarn.

coming from the above horizon hemisphere imposes to have a detector with directional capabilities, to distinguish upward going muons, associated with neutrino interactions, from the huge background of down–going cosmic–ray remnants. Cerenkov detectors provide an elegant solution to this experimental challenge, with large and unexpensive target mass. Indirect detection experiments include Baksan [21], Macro [22], now dismantled, and SuperKamiokande [23] for the deep underground detectors, together with AMANDA [24] and Baikal [25] for, respectively, under-ice and underwater detectors.

The AMANDA [24], Baksan [21], MACRO [22] and Super-Kamiokande [23] underground experiments have published sensitivity limits to WIMP disintegrations derived from the observation of high-energy neutrino interactions. The presently most sensitive indirect search experiment for spin–independent WIMP interactions is SuperKamiokande, using a 3.5 years data sample and a 50 kiloton target. AMANDA–B and Baksan are reaching somewhat lesser but similar sensitivities. The degraded sensitivity of AMANDA at lower energies can be attributed to its higher energy threshold. Figures 3 and 4 compare the sensitivities reached by EDELWEISS and the indirect detection experiments.

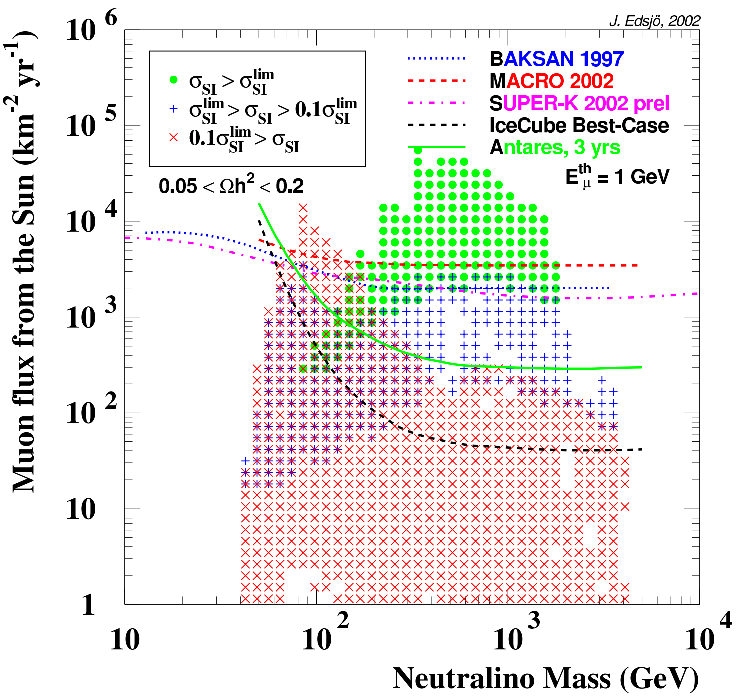

Fig. 3. Sensitivities of the present and future indirect searches using interactions of neutrinos produced in WIMP annihilations in the Sun (from Ref. [26]) compared with the sensitivity obtained by the EDELWEISS direct search (noted SI (spin-independent), region represented by full grey dots). Improvement in the sensitivity of direct detection experiments by a factor 10 will allow to sample the region marked with + symbols. The target sensitivities of the future ICECUBE and ANTARES experiments are also presented on the figure as the two lower curves.

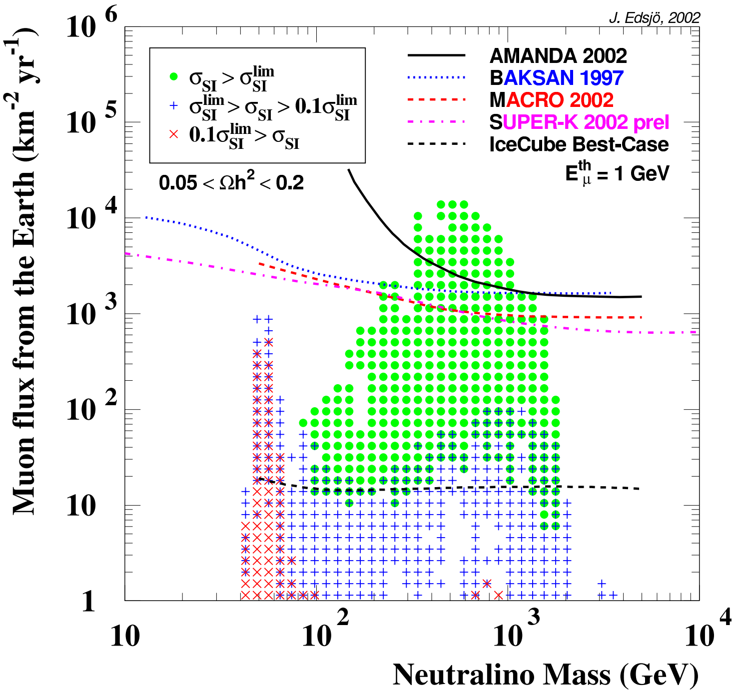

Fig. 4. Sensitivities of the present and future indirect searches using interactions of neutrinos produced in WIMP annihilations in the Earth (from Ref. [26]) compared with the sensitivity obtained by the EDELWEISS direct search (noted SI (spin-independent), region represented by full grey dots). Improvement in the sensitivity of direct detection experiments by a factor 10 will allow to sample the region marked with + symbols. The target sensitivities of the future ICECUBE experiment is also presented on the figure as the lower dotted curve.

Future experiments include ICECUBE [27], a km^2 extension of the AMANDA-B detector, together with ANTARES [28], a European collaboration in the Mediterranean sea. NESTOR and NEMO are two other projects based in the Mediterranean sea, with sensitivities similar to ANTARES. ANTARES, in its 0.1 km^2 version, plans to increase the present indirect detection sensitivity by a factor $\sim$ 3 and ICECUBE is expected to increase the ANTARES sensitivity by a further factor $\sim$ 5, at least for high WIMP mass. This experiment benefits from a larger detection area, in the km^2 range, but the diffusion of Cerenkov photons in the ice is expected to lead to a degraded angular resolution at low muon energies. The target sensitivities of the ICECUBE and ANTARES experiments are shown on Figures 4 and 3. It can be seen on these figures that even ICECUBE can hardly compete with the present EDELWEISS sensitivity using neutrino emission from the Earth. The situation is more interesting for the constraints which can be derived from observations of neutrino emission from the

Sun. Here, indirect searches remain competitive even when compared to the next generation of direct searches, such as EDELWEISS-II, CDMS-II, CRESST-II or ZEPLIN-II, and can observe significant muon fluxes for models inaccessible to direct detection methods, due to their better sensitivity for predominantly axial, or spin-dependent, couplings.

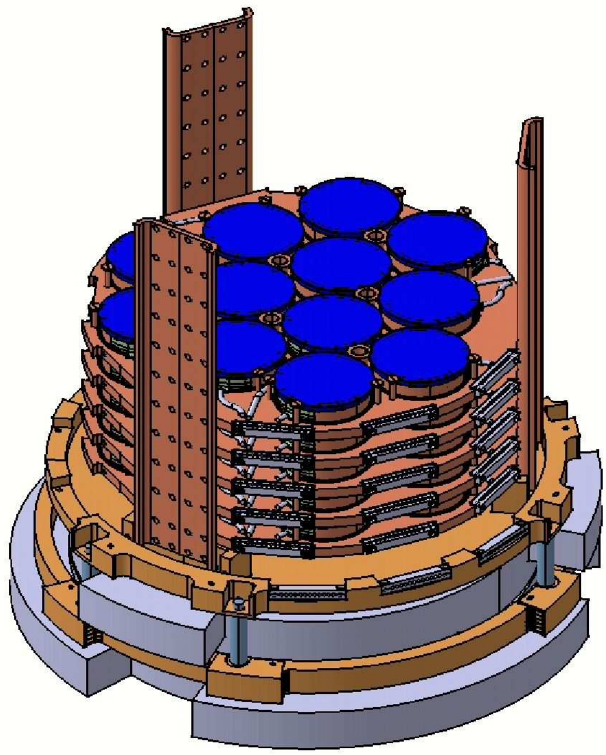

Fig. 5. Drawing of the EDELWEISS-II detector set-up. Up to 120 Ge detectors of mass 320 g (the blue plates) can be accomodated in a compact hexagonal arrangement at 10 mK. The grey plate, made of ultra-pure archeological lead, shields the detectors from the radioactivity of the dilution cryostat (not shown).

6 Towards EDELWEISS-II and further detector developments

An improved acquisition system with very low energy threshold has been realized in the EDELWEISS-I experiment and data have been accumulated with close to 100% detection efficiency at E_{recoil} = 10 keV. By the end of 2003, the present EDELWEISS-I run will be stopped and installation of the EDELWEISS-II experiment will take place. The goal is an increased sensitivity by a factor of 100 in terms of WIMP cross section exclusion limit. A new very low radioactivity cryostat able to cool 120 detectors down to 10mK is presently tested in the CRTBT laboratory of Grenoble (Fig. 5). In addition to 21 NTD-Ge equiped 320g bolometers, the first stage of EDELWEISS II will include seven 400g detectors, based on NbSi thin film thermistors capable of identifying near-surface events [30,29]. Furthermore, implementation of charge pulse shape analysis on both type of detectors will allow event localization and greatly improve control of space-charge creation [31,32]. An improved polyethylene 50 cm thick shielding combined with the installation of a muon veto around the Pb shielding of the cryostat will further reduce the neutron background of the bolometers at a level below 0.01 event/kg/day. EDELWEISS-II should then be able to probe much more deeply the region of allowed SUSY models and, hopefully, to detect WIMP candidates.

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