The EDELWEISS Dark Matter search program

V. Kozlov[1] *on behalf of the EDELWEISS Collaboration*

[1]Karlsruhe Institute of Technology, Institut für Kernphysik, Postfach 3640, 76021 Karlsruhe, Germany

DOI: http://dx.doi.org/10.3204/DESY-PROC-2013-04/kozlov_valentin

The EDELWEISS experiment is a direct Dark Matter search experiment with a primary goal to detect Weakly Interacting Massive Particles (WIMPs). The setup is installed in the Modane underground laboratory (LSM, France) in French-Italian Alps. The second phase of the experiment was completed in 2011 and results are published setting new limits on the spin-independent WIMP-nucleon scattering cross-section and excluding most of the parameter space favored in some recent experimental hints. Currently the upgrades of the setup towards better sensitivity are being finalized and new detectors are being installed. The scientific goals of EDELWEISS-III program will be presented, including improvements of the background, data-acquisition and measurements with a subset of the forty 800-g detectors. Ongoing installation works of the EDELWEISS-III setup and further plans for a next generation experiment, EURECA, are discussed.

1 Dark Matter search with Edelweiss

The EDELWEISS experiment searches for the WIMP dark matter by means of germanium bolometers with an improved background rejection, thanks to an *interdigitized electrode design* (ID) [1]. Once these detectors are cooled to about 18 mK, one can simultaneously measure phonon and ionization signals after an energy deposit in the germanium crystal. The ratio of the two signals, called the Q-value or *ionization yield*, is different for nuclear and electron recoils with nuclear recoils having Q$\sim$0.3 when normalized to Q=1 for electron recoils. This separation in the ionization yield allows a powerful γ/β-background rejection. Additional rejection power arises from the special electrode arrangement (Fig. 1), called interdigitized electrode design, which provides rejection of *surface events* [1]. Aluminum electrodes evaporated onto the Ge crystal are used to collect electrons and holes. The temperature increase is measured by the use of neutron-transmutation-doped germanium (NTD) as a temperature sensor. The ID detectors used in the second phase of the experiment, EDELWEISS-II, had a mass of 400 g each with interleaved electrodes only on top and bottom surfaces, which limited the fiducial volume to about 40%, or 160 g per detector [2]. For the EDELWEISS-III phase the bigger detectors of 800 g with interleaved electrodes also on the lateral surface (Fig. 1) were developed, called *fully interdigitized* (FID) bolometers. This increased the fiducial volume to about 75%, or 600 g per detector. The experimental setup (Fig. 2) is located in the Laboratoire Souterrain de Modane (LSM), an underground lab in the Fréjus road tunnel in the French-Italian Alps. The laboratory profits from a shielding of 4850 m.w.e., which reduces the muon flux down to about 5 μ/m^2/day. A general overview of the setup is shown in Fig. 2: The central part of the experiment is a dilution cryostat which can host up to 40 kg of detectors. A lead layer of 20 cm shields the bolometers against an external γ/β-background while 50 cm of polyethylene is used to moderate neutrons. An additional layer of polyethylene is installed between the bolometers and the lead layer in the EDELWEISS-III setup to further reduce the neutron background. A muon veto system (>98% coverage) consisting of 100 m^2 of plastic scintillator to tag remaining cosmic muons completes the installation [3]. In addition, a continuous control of the Rn level is performed near the cryostat, and a ^{3}He-gas detector is installed inside the shields to monitor the thermal neutron flux. A neutron counter system based on 1 m^3 of Gd-loaded liquid scintillator [4] was used during year 2009-2012 to study the muon-induced neutron background. The EDELWEISS-II phase is now finished, and the upgrade to EDELWEISS-III is ongoing (Sec. 3). The scientific goal of EDELWEISS-III is to reach a sensitivity of a few 10^{-9} pb for the WIMP-nucleon spin-independent (SI) cross-section by 2014-2015.

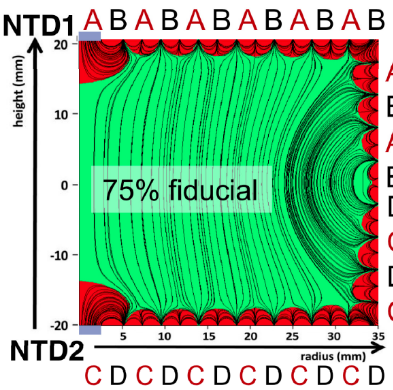

Figure 1: (color online) The electrode scheme of an FID detector (to be used in EDELWEISS-III). The detectors have a radius of 3.5 cm and a height of 4 cm (FID800). In this example, the top and bottom fiducial electrodes are B and D, while the surface veto electrodes are A and C.

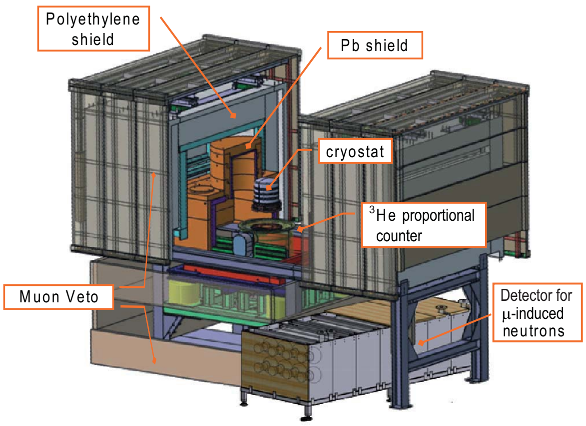

Figure 2: (color online) The EDELWEISS setup layout: in the center is the cryostat able to host up to 40 kg of detectors and surrounded by the passive and active (muon-veto) shields. Auxiliary detectors: ^{3}He proportional counter for thermal neutrons and liquid scintillator detector to measure muon-induced neutrons.

2 Results of the Edelweiss-II phase

In the second phase of the experiment the EDELWEISS collaboration successfully operated ten 400-g ID detectors over a period of 14 months from April 2009 to May 2010 and in addition two detectors during an initial run between July and November 2008. Here we summarize the main results of this measurement period.

2.1 WIMP search for $M_\chi > 50$ GeV

The analysis was optimized to maximize the exposure in a recoil energy range where the behavior of all of the ten detectors was homogeneous and well understood. It resulted in a 384 kg·day total effective exposure. Five nuclear recoil candidates were observed above *a priori* set threshold of 20 keV. In the background conditions of Edelweiss-II (see Sec. 2.4), the result was interpreted in terms of limits on the cross-section of spin-independent interactions of WIMPs and nucleons. A cross-section of $4.4{\cdot}10^{-8}$ pb is excluded at 90% C.L. for a WIMP mass of 85 GeV (Fig. 4). New constraints were also set on models where the WIMP-nucleon scattering is inelastic [2]. As both Edelweiss and CDMS experiments use the same target material, germanium, the two collaborations decided to combine their results. This allowed an increase of the total data set to 614 kg·day equivalent exposure and an improvement of the upper limit on the WIMP-nucleon spin-independent cross-section [5], e.g. a value of $3.3{\cdot}10^{-8}$ pb was excluded at 90% C.L. for a WIMP mass of 90 GeV where the combined analysis is most sensitive (Fig. 4). Chosen methods of combination and further details of the work can be found in Ref. [5].

2.2 Analysis for low-mass WIMPs

The direct detection of low-mass (∼10 GeV or lower) WIMPs is challenging because the recoil energies generated by the elastic scattering on nuclei of such low-mass particles are close to the experimental thresholds of existing detectors; for WIMPs with a mass of about 10 GeV, the highest expected recoil energy is of the order of 10 keV. This is why in this analysis a restricted data set was used, selected on the basis of detector thresholds and backgrounds, for which a low-background sensitivity to nuclear recoils down to 5 keV could be achieved. The data quality cuts resulted in only four out of the ten detectors were used, and the total exposure reduced to 113 kg·day [6]. For WIMPs of 10 GeV mass, one event was observed in the WIMP search region, which lead to a 90% C.L. limit of $1.0{\cdot}10^{-5}$ pb on the spin-independent WIMP-nucleon scattering cross-section (Fig. 4) [6]. This extended the sensitivity of Edelweiss-II down to WIMP masses below 20 GeV and constrained the parameter space associated with the findings reported by the CoGeNT, DAMA and CRESST experiments. Ref. [6] provides all details of this analysis.

2.3 Axion search

Edelweiss is primarily a direct WIMP search experiment. However, the fact that germanium bolometers are also sensitive to low-energy electron recoils allows a search for such recoils potentially induced by solar or dark matter axions to be performed. The same data set was therefore analyzed to probe scenarios involving different hypotheses on the origin and couplings of axions. The extensive study has been presented at this conference [7]. Here we merely summarize that by combining all obtained results we exclude the mass range 0.91 eV $< m_A <$ 80 keV for DFSZ (Dine-Fischler-Srednicki-Zhitnitskii) axions and 5.73 eV $< m_A <$ 40 keV for KSVZ (Kim-Shifman-Vainstein-Zakharov) axions [7], which is a prominent result for a direct axion search from a single dataset.

2.4 Background studies

In order to interpret any result of a direct WIMP search, one has to properly evaluate all possible background components. We have carried out Monte-Carlo simulations based on Geant4 for

Background	EDELWEISS-II (event/kg·day)	EDELWEISS-III (event/kg·day)
Gamma rate	82	14 - 44
Ambient neutrons	$<8.1\cdot10^{-3}$	$(0.8 - 1.9)\cdot10^{-4}$
Muon-induced neutrons	$<2\cdot10^{-3}$	$<4\cdot10^{-4}$

Table 1: Levels of background achieved in EDELWEISS-II and improvements expected for the EDELWEISS-III. When the limits are given, they at 90% C.L.

the complete EDELWEISS-II setup to study the gamma and neutron background coming from radioactive decays in the setup and shielding, and normalized the expected background rates to the measured material radiopurity (or upper limits) of all components [8]. The expected gamma-ray event rate in EDELWEISS-II at 20 - 200 keV agrees with the observed rate of 82 events/kg·day within the uncertainties in the measured concentrations. The neutron rate from radioactivity was estimated to be less than 3.1 event at 90% C.L. at 20 - 200 keV and for an effective exposure of 384 kg·days, or $< 8.1\cdot10^{-3}$ event/kg·day. The rate of muon-induced neutrons was deduced in the dedicated study [3] and resulted in < 0.72 events (90% C.L.) for the EDELWEISS-II total effective exposure, i.e. less than $2\cdot10^{-3}$ event/kg·day. However, the main contribution was dominated by a short period of malfunctioning muon veto. The contribution of misidentified gammas, taking into account the gamma-rejection power of the ID detectors deduced in ^{133}Ba calibrations, was estimated to be less than 0.9 events, while the surface event contribution is less than 0.3 for EDELWEISS-II effective exposure of 384 kg·days. The overall background was calculated to be less than 5.02 event and does not contradict the five observed events in nuclear recoil band.

The simulation framework was extended to the EDELWEISS-III configuration with 800-g crystals, better cryostat material purity and additional neutron shielding inside the cryostat. The results of the background studies showed that it is possible to upgrade the existing setup to further reduce the expected rate of background events (Tab. 1) and improve the sensitivity of the experiment by another order of magnitude. These results also helped to select higher purity components and improve shielding of the experiment.

3 Status and goals of Edelweiss-III

Since it was realized that it is possible to upgrade the setup in order to significantly improve the EDELWEISS sensitivity, the EDELWEISS-III phase of the experiment was started. The actual changes concern all aspects of the experiment. New copper thermal screens were produced out of higher radiopurity copper, which reduces the intrinsic gamma background. A new polyethylene shield was installed inside the cryostat between the detectors and the lead castle (Fig. 2) to protect against neutrons. There were installed additional modules of the muon veto, and further optimization of its operation is ongoing in order to improve its efficiency. The analog front-end electronics has been upgraded such that DAC-controlled mechanical relays are used instead of feedback resistors of charge sensitive preamplifiers [9]. The use of relays is expected to avoid Johnson noise contributions from resistances and thus improve the low frequency noise level. It also allows the electronics to be moved further away, and thus reduce its radioactive influence on the detectors. A new DAQ has been implemented to read up to 60 bolometers and includes the readout of the muon veto timing. The new design reduces the continuous data flow processed by acquisition computers for triggering and data storage. This is a highly scalable system

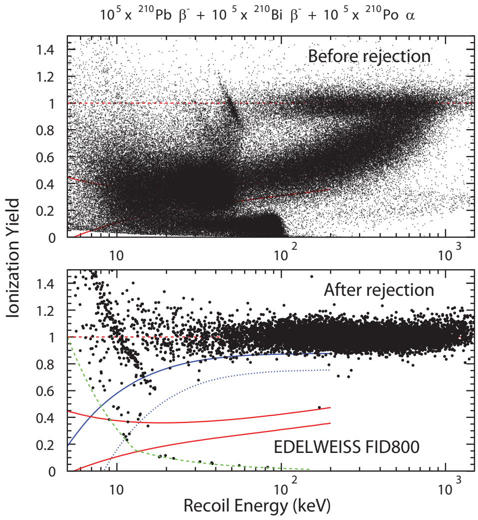

Figure 3: (color online) *Top*: Ionization yield versus energy for two 800-g FID detectors for an exposure to 10^5 ^{210}Pb decays. *Bottom*: same data after rejection of events which had sufficient signals on the veto electrodes (A,C on Fig. 1) and non-equal signals on fiducial electrodes (B,D on Fig. 1), so-called *fiducial cut*. Solid red lines represent the nuclear recoil band (90% region), while the full and dashed blue lines indicate the 90% and 99.99% regions for electron recoils, respectively. Only one event remains in the nuclear recoil band above 15 keV threshold on the recoil energy.

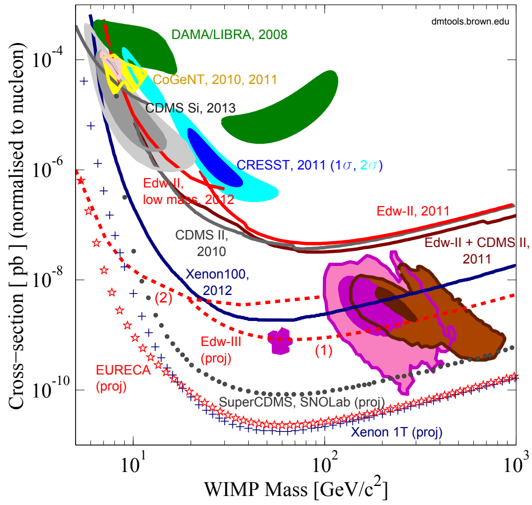

Figure 4: (color online) The upper limits on the WIMP-nucleon spin-independent cross-section as a function of WIMP mass. The EDELWEISS-II only data are marked with thick solid red lines and correspond to Refs. [2, 6]. Combined data of the EDELWEISS-II and CDMS-II experiments [5] are indicated as "Edw-II + CDMS II". As dashed red lines are shown EDELWEISS-III projections for two cases: (1) - the standard WIMP, 12000 kg·day, and (2) - low-mass WIMP analysis, 1200 kg·day, HEMT-based front-end electronics. The EURECA projection is shown as red stars. The magenta and brown shaded areas correspond to theoretical SUSY predictions.

and allows an inclusion of even more detectors in the future. Additionally, an increase in the sampling rate on the ionization channel from 10 kSamples to 40 MSamples has been studied. The higher resolution on timing of the ionization signal would improve further the discrimination power between fiducial and surface events [1]. Ongoing R&D on the HEMT-based front-end readout should allow us to lower the recoil energy threshold down to 3 keV and thus improve the low-mass WIMP search (Fig. 4). In order to handle a significantly increased data flow, a multi-tiered data structure, analysis toolkit and data processing management system has been constructed [10]. Finally, new FID detectors with twice the mass (800 g) and increased fiducial volume ($\sim$600 g) have been developed (Fig. 1). These detectors are confirmed to have a better rejection of γ-events comparing to the previous ID400 detectors, e.g. out of $4{\cdot}10^5$ γ-events recorded in ^{133}Ba calibration, none leaked into the region-of-interest, i.e. nuclear recoil band between 20 keV and 200 keV. Recently two of these detectors were also tested for rejection of surface events (Fig. 3) and showed a slightly better rejection power of $4{\cdot}10^{-5}$ above 15 keV recoil energy (90% C.L.) compared to that previously measured for ID bolometers of $6{\cdot}10^{-5}$ above 20 keV.

The plan of the fully funded EDELWEISS-III project is to acquire an exposure of 3000 kg·day within a half year of operation and to reach in 2014 a WIMP-nucleon scattering cross-section sensitivity of a few 10^{-9} pb. It is foreseen to continue further to achieve larger exposure and better sensitivity in case of no background (Fig. 4). The ongoing research builds a good ground for the EURECA project [11], a next generation dark matter experiment with a multi-nuclei target of up to 1000 kg mass. EURECA is supported by different European dark matter groups and a closer collaboration with the SuperCDMS experiment is foreseen. EURECA will probe in its 1-tonne phase a WIMP-nucleon SI interaction down to 10^{-11} pb (Fig. 4).

4 Acknowledgments

The help of the technical staff of the Laboratoire Souterrain de Modane and the participant laboratories is gratefully acknowledged. The EDELWEISS project is supported in part by the German ministry of science and education (BMBF Verbundforschung ATP Proj.-Nr. 05A11VK2), by the Helmholtz Alliance for Astroparticle Phyics (HAP) funded by the Initiative and Networking Fund of the Helmholtz Association, by the French Agence Nationale pour la Recherche, by Science and Technology Facilities Council (UK) and the Russian Foundation for Basic Research (grant No. 07-02-00355-a).

5 Bibliography

References

[1] A. Broniatowski *et al.*, Phys. Lett. B **681**, 305 (2009) [arXiv:0905.0753 [astro-ph.IM]].

[2] E. Armengaud *et al.*, Phys. Lett. B **702**, 329 (2011) [arXiv:1103.4070 [astro-ph.CO]].

[3] B. Schmidt *et al.*, Astropart. Phys. **44**, 28 (2013) [arXiv:1302.7112 [astro-ph.CO]].

[4] V. Yu. Kozlov *et al.*, Astropart. Phys. **34**, 97 (2010) [arXiv:1006 [astro-ph.IM]]; and in AIP Conf. Proc. **1549**, 231 (2013).

[5] Z. Ahmed *et al.*, Phys. Rev. D **84**, 011102 (2011) [arXiv:1105.3377 [astro-ph.CO]].

[6] E. Armengaud *et al.* [EDELWEISS Collaboration], Phys. Rev. D **86**, 051701(R) (2012) [arXiv:1207.1815 [astro-ph.CO]].

[7] E. Armengaud *et al.* [EDELWEISS Collaboration], arXiv:1307.1488 [astro-ph.CO]; and C. Nones *et al.* in these proceedings, *Patras 2013.*

[8] E. Armengaud *et al.*, Astropart. Phys. **47**, 1 (2013) [arXiv:1305.3628 [physics.ins-det]].

[9] B. Censier *et al.*, J. Low Temp. Phys. **167**, 645 (2012).

[10] G. A. Cox *et al.*, Nucl. Instr. and Meth. A **684**, 63 (2012).

[11] H. Kraus *et al.*, Nucl. Phys. B, (Proc. Suppl.) **173**, 168 (2007).