Direct Dark matter search with the Edelweiss experiment

Valentin 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-2014-03/kozlov_valentin

The EDELWEISS experiment searches for Dark Matter particles by means of Ge-bolometers with a powerful rejection of background. 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. The same data set was also analyzed to search for axion-induced electron recoils down to 2.5 keV. We set new limits on ALP parameters for different scenarios, some of which provide one of the best bounds for direct axion searches. Recently the setup was upgraded towards significantly higher sensitivity and 36 new Ge-detectors of 800 g each were installed. The detector background rejection capabilities and performances, and improvements of the background will be presented. The status and scientific goals of the current EDELWEISS program will be described as well as further plans for a next generation experiment, EURECA.

1 Overview of the Edelweiss experiment

The primary goal of the EDELWEISS experiment is a direct search for the WIMP dark matter. As the expected rate of events is below 10^{-3}/kg/day, the experiment is located in the underground laboratory in Modane (France), which provides a very good shielding against cosmogenic background down to 5 μ/m^2/day. To reduce further the radioactive background the muon veto, external polyethylene and lead shields, and recently introduced internal polyethylene shield, are used in the experimental setup (Fig. 1). The volume inside the shields is flushed with de-radonized air to even more reduce the influence of the ambient background. Another important reduction of the background is possible due to the ability of the detectors to distinguish between nuclear recoils (expected from the WIMP interaction) and electron recoils (originate from ambient sources of background). The experiment uses bolometers of ultra pure germanium: Once these detectors are cooled to about 18 mK, both phonon and ionization signals can be simultaneously measured. The ratio of the two signals, called *ionization yield*, is different for nuclear and electron recoils allowing to separate these two types of recoils. Additional rejection power arises from the special electrode arrangement, called *interdigitized electrode design* (ID), which provides vetoing of *surface events* [1]. The EDELWEISS experiment finished its second phase (Sec. 2), and the upgrade to EDELWEISS-III is nearly completed (Sec. 3). The scientific goal of EDELWEISS-III is to reach a sensitivity of about 10^{-45} cm^2 for the WIMP-nucleon spin-independent (SI) cross-section by 2015-2016 (Fig. 2).

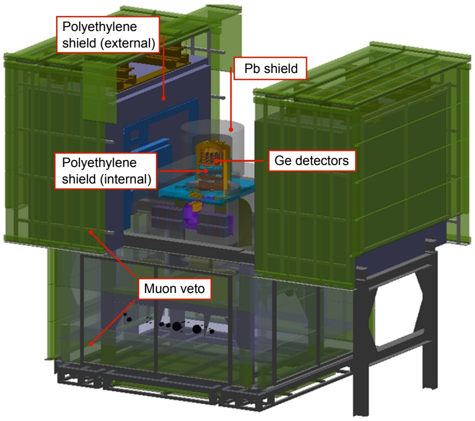

Figure 1: The EDELWEISS setup layout: in the center is the dilution refrigerator able to host up to 40 kg of detectors. The passive lead and polyethylene shields followed by the active muon-veto system protect the detectors against various backgrounds.

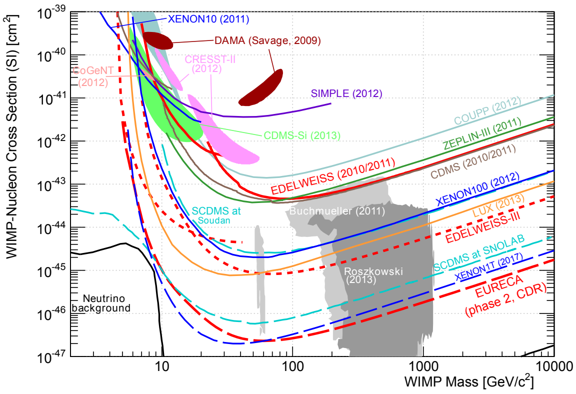

Figure 2: The upper limits on the WIMP-nucleon spin-independent cross-section as a function of WIMP mass. The EDELWEISS-II data are marked with thick solid red lines and correspond to Refs. [2, 3]. As dashed red lines are shown EDELWEISS-III projections for two cases: the standard WIMP, 12000 kg·day, and low-mass WIMP analysis, 1200 kg·day, HEMT-based front-end electronics. The EURECA projection, phase 2, is shown as the red long dashed line. The shaded areas correspond to theoretical SUSY predictions.

2 Summary of the phase II

In a period from April 2009 to May 2010 the EDELWEISS collaboration successfully operated ten 400-g ID detectors. The data set acquired during this period (with an addition of the run between July and November 2008) was analyzed for the 'standard' WIMP search, i.e. with a possible WIMP mass, m_χ, around or above 100 GeV [2], low-mass WIMP search with $m_\chi \sim$10 GeV [3], and thanks to the low-background environment and the ability to separate electron recoils out, we also searched for axion-induced signals [4].

The EDELWEISS primary goal is to search for the WIMP dark matter. However, as another possible dark matter candidate, axions, would lead to electron recoils which can be measured down to low energies because of the EDELWEISS very low background down to 2.5 keV and the ability to reject the surface events, four scenarios involving different hypotheses on the origin and couplings of axions were probed. This includes the Primakoff axion search, i.e. due to Primakoff axion production in the Sun (Fig. 3), a search for solar axions produced by Compton-bremsstrahlung and axion-recombination and deexcitation processes (C-B-RD), the search for solar axions emitted by ^{57}Fe, and the specific scenario in which the galactic dark matter halo is made of ALPs (axion like particles) with a keV-scale mass (Fig. 4). By combining all obtained results we exclude the mass range 0.92 eV $< m_A <$ 80 keV for DFSZ (Dine-Fischler-Srednicki-

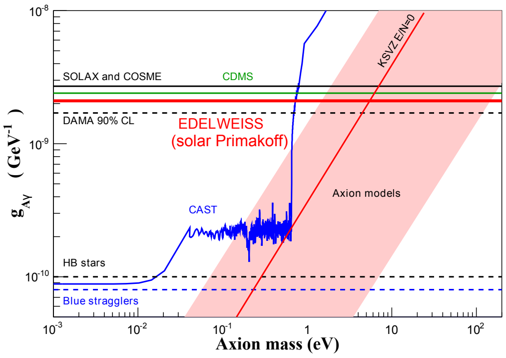

Figure 3: 95% C.L. constraint on the $g_{A\gamma}$ coupling from the solar Primakoff flux obtained by EDELWEISS-II (red thick line), compared to other crystal experiments.

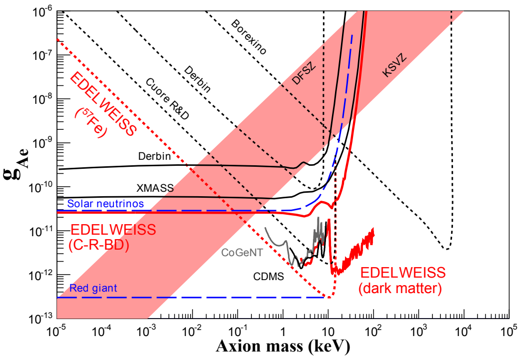

Figure 4: The limits obtained by EDELWEISS-II on the g_{Ae} axion coupling as a function of axion mass, m_A (red lines).

Zhitnitskii) axions and 5.78 eV $< m_A <$ 40 keV for KSVZ (Kim-Shifman-Vainstein-Zakharov) axions [4], which is a prominent result for a direct axion search from a single data set.

The obtained WIMP search limits are summarized on Fig. 2 (thick solid red lines): in the 'standard' WIMP search the analysis was optimized for the maximum exposure and resulted in the exclusion of the spin-independent WIMP-nucleon scattering cross-section of $4.4{\cdot}10^{-44}$ cm^2 at 90% C.L. for $m_\chi \sim$85 GeV (Fig. 2) [2]. For the low-mass WIMP search the detectors with the lowest possible thresholds and backgrounds were selected, such that the sensitivity to nuclear recoils down to 5 keV could be achieved. This leaded to a restricted data set but extended the sensitivity of EDELWEISS-II down to WIMP masses below 20 GeV (Fig. 2) [3].

In Refs. [5] and [6] general background conditions of EDELWEISS-II were investigated, and possible improvements were pointed out. Together with significantly increased target mass this leaded to the next phase of the experiment, EDELWEISS-III.

3 Phase III and beyond

EDELWEISS-III is the upgrade of the EDELWEISS-II towards enlarged target mass, more advanced detectors and reduced background environment. New FID800 detectors have about 800 g total mass, two NTD sensors to measure phonons, all surfaces are covered with interleaved electrodes to perform the surface event rejection. The fiducial volume is also increased, i.e. it is 75%, or 600 g per detector, compared to 40%, or 160 g, in previously used ID400 detectors. As follows from tests the γ-rejection factor of the new FID800 is improved by factor 5 compared to ID400, or $< 6 \cdot 10^{-6}$, while surface-event rejection is better by 33%, or $< 4 \cdot 10^{-5}$ for the recoil energy E_R >15 keV. As of autumn 2014, 36 FID800 detectors are installed in the cryogenic setup, while 24 are cabled and used in the just started WIMP search. The cabling between the detectors and the acquisition system as well as the connectors were exchanged by new ones, using less radioactive materials. In the 1 K zone of the cryostat additional polyethylene was installed to shield the detectors from the internally generated neutrons, e.g. due to (α,n). New copper thermal screens were produced out of higher radiopurity copper to lower the intrinsic gamma background but also to fit the larger detector mass and new shielding. The cryogenic system was upgraded to reduce the microphonic noise. The analog front-end electronics placed at 100 K stage of the cryostat has been upgraded such that DAC-controlled mechanical relays are used instead of feedback resistors of charge sensitive preamplifiers [7]. A new data analysis framework improves the usability of the recorded data [8]. The EDELWEISS-III DAQ can read up to 60 bolometers and includes the readout of the muon veto timing. The system consists of a crate with FPGA based input cards which are able to do a real time analysis of the data stream in parallel for all channels. This is a highly scalable system and can be extended to include even more detectors in future. The readout electronics of one of the detectors is equipped with the prototype of a time resolved digitization card, which allows to read 2 ionization channels with a 400 times higher sampling rate of 40 MHz. The higher resolution on timing of the ionization signal would improve further the characterization of events, e.g. the discrimination between fiducial and surface events or double scattering events [1]. One more R&D is ongoing to use the HEMT-based front-end readout in order to lower the recoil energy threshold down to 3 keV and thus improve the low-mass WIMP search. The projected sensitivities of EDELWEISS-III for the 'standard' WIMP search and the low-mass case are shown on Fig. 2.

To go beyond the EDELWEISS-III sensitivity a next generation dark matter experiment, EURECA, is planned. In its 1^{st} phase EURECA will host a multi-nuclei target of about 150 kg, while in the 2^{nd} phase up to 1000 kg [9]. For the 1^{st} phase a closer collaboration with the SuperCDMS at SNOlab experiment is foreseen. EURECA in its 1-tonne version should probe a WIMP-nucleon SI interaction down to 10^{-47} cm^2 (Fig. 2).

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 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) and by the Helmholtz Alliance for Astroparticle Physics (HAP) funded by the Initiative and Networking Fund of the Helmholtz Association. R&D activities within EDELWEISS towards EURECA are also supported in part by the German ministry of science and education (BMBF Verbundforschung ATP Proj.-Nr. 05A11VK2).

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

[4] E. Armengaud *et al.*, J. of Cosm. and Astropart. Phys. **11**, 067 (2013) [arXiv:1307.1488 [astro-ph.CO]].

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

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

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

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

[9] G. Angloher*et al.*, Phys. of the Dark Univ. **3**, 41 (2014).