The EDELWEISS-III Dark Matter Search: Status and Perspectives

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DOI: http://dx.doi.org/10.3204/DESY-PROC-2014-04/235

EDELWEISS is a direct Dark Matter search program looking for WIMPs in the GeV-TeV mass range. For that purpose, an array of cryogenic Ge mono-crystals read out simultaneously by NTD thermal sensors and by surface electrodes is installed in the Modane underground laboratory. We present a summary of EDELWEISS-II results including limits on axion couplings. For EDELWEISS-III a major upgrade of the setup was undertaken. 36 new FID800 Ge bolometers are currently installed, as well as a new DAQ system and improved shielding to lower the background.

1 The EDELWEISS experiment

1.1 Experimental setup at LSM

The EDELWEISS experiment is situated in the deepest underground laboratory in Europe, the *Laboratoire Souterrain de Modane* (LSM). A 4800 mwe rock overburden reduces the cosmic muon flux by a factor of $O(10^6)$ to only $5\,\mu/\mathrm{m}^2/\mathrm{day}$ [1]. In the LSM, the experiment is housed in a clean room with a deradonized air supply and a remaining activity from Rn-decay of a few tens of $\mathrm{mBq/m}^3$. The surrounding active muon veto system of 48 plastic scintillator modules and $100\,\mathrm{m}^2$ with a geometric coverage of $>98\,\%$ tags throughgoing muons. Next is a 50 cm thick polyethylene (PE) layer to moderate the neutron flux, followed by 20 cm lead for the suppression of γ-activity. Inside is a dilution copper cryostat which cools down several tens of kg of detectors to stable cryogenic temperatures of a few mK.

1.2 Cryogenic bolometer detectors

The detectors used in EDELWEISS are germanium mono-crystal bolometers (see Fig. 1 left). Particles can interact with the Ge atoms via elastic scattering on either the nucleus or the electron shell and thereby produce both $\mathrm{e}^-/\mathrm{h}^+$-pairs and phonons. By comparing the ionization yield Q, the fraction of created charge vs. heat energy, it is possible to discriminate *Electronic Recoils* (ER) from *Nuclear Recoils* (NR) on an event-by-event basis. *ER*s from β's and γ's have $Q = 1$ by definition while *NR*s from neutrons and expected from WIMPs produce significantly less charge with $Q \approx 0.3$. This allows to efficiently reject background radiation from possible WIMP candidate events. To read out the two signals, the cylindrical detectors are equipped with phonon sensors and electrodes on the surface. At an operating temperature of $T = 18\,\mathrm{mK}$ the

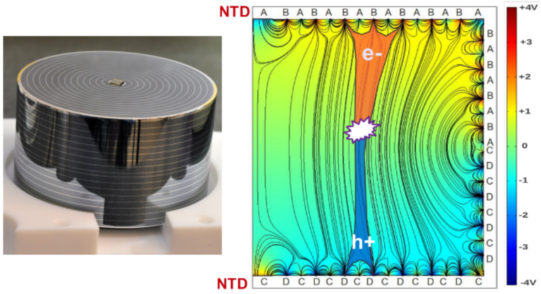

Figure 1: Left: FID800 detector with concentric ring electrodes and NTD phonon sensor. Width = 7 cm and height = 4 cm. Right: Axial symmetric electric field map with the charges of a fiducial event drifted to electrode sets B and D.

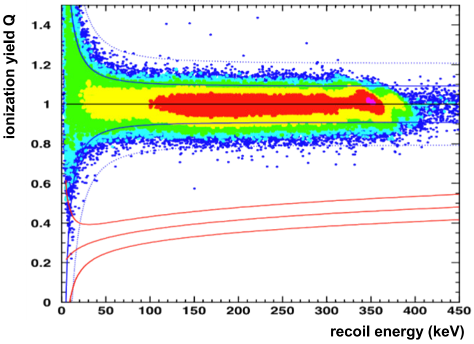

Figure 2: ^{133}Ba calibration data with electron recoils from $>400,000\,\gamma'$s. No event above 20 keV populates the 90 % C.L. nuclear recoil band.

Neutron Transmutation Doped (NTD) germanium transistors measure a minuscule temperature increase of $\approx 1\,\mu$K for a 10 keV recoil. Concentric rings of Al electrodes are connected such, that interleaved rings form two different sets on top and bottom [2]. These sets are biased with different voltages $O(1\,\mathrm{V})$, drifting charges to top and bottom of the detector and along the surface (see Fig. 1 right). The set of *fiducial electrodes* (here B and D) has the higher potential difference and collects charges from the inner bulk volume of the crystal, while a signal on the *veto* electrodes (A,C) efficiently rejects events near the surface. Detectors used in EDELWEISS-II had masses of 400 g and a so called *InterDigit* (ID) design with ring electrodes only on top and bottom, while the outer sides had planar electrodes. The resulting electric field configuration led to an inner *fiducial mass* of 40 % or 160 g. For the 800 g crystals used in EDELWEISS-III a *Fully InterDigit* (FID) design with ring electrodes also on the sidewalls leads to a much higher fiducial mass of 75 % or 600 g, while at the same time improving the rejection of surface events due to better charge collection.

2 Results from the EDELWEISS-II phase

Phase II of the EDELWEISS experiment was running under stable low temperature conditions from April 2009 to May 2010, for a continuous data taking of more than 400 days. Installed were 10 ID-detectors with masses around 400 g each.

2.1 Standard WIMP analysis

The standard analysis [3], optimized for WIMPs of masses $O(100\,\mathrm{GeV})$, used a total effective exposure of 384 kg.days after all cuts. In the 90 % C.L. nuclear recoil band [20, 200 keV] (the WIMP search region), 5 candidate events were observed, which was compatible with the expected background of 3.0 events. This result was interpreted in terms of a spin-independent WIMP-nucleon scattering cross section, leading to $\sigma_{\mathrm{SI}} < 4.4 \times 10^{-8}$ pb (90 % C.L.) for a WIMP mass of 85 GeV. Constraints were also set on scenarios with inelastic scattering mechanisms.

Due to their similarities, the results of EDELWEISS-II and the CDMS experiment could be combined and the two collaborations published an exclusion limit of $\sigma_{\mathrm{SI}} < 3.3 \times 10^{-8}$ pb for a WIMP mass of 90 GeV, derived from a combined exposure of 614 kg.days [4].

2.2 Low mass WIMP analysis

A dedicated analysis was performed on a reduced data set to search for low mass WIMPs between 7 and 30 GeV [5]. The 4 ID detectors with the best resolutions were used and stronger quality cuts allowed to lower the analysis threshold to $5\,\mathrm{keV_{nr}}$, therefore making the experiment sensitive to low WIMP masses. With an upper recoil energy limit set to 20 keV, the results are independent from the standard WIMP analysis. For a reduced effective exposure of 113 kg.days a maximum of 3 candidate events (depending on the WIMP mass) were found, which was compatible with the expected background from neutrons and γ's of 2.9 events. At a WIMP mass of 10 GeV and with only one candidate event, the resulting limit derived with Poisson statistics is $\sigma_{\mathrm{SI}} < 1.0 \times 10^{-5}$ pb (90 % C.L.) which significantly constrains a possible CoGeNT signal and excludes signals reported by DAMA/LIBRA and CRESST.

2.3 Search for Axions and ALPs

Complimentary to WIMP search in nuclear recoil events, the search for axions in EDELWEISS-II was performed on data of electron recoils only [6]. Axions and *Axion Like Particles* (ALPs) could lead to such recoils after producing photons via the Primakoff effect (enhanced by Bragg diffraction in the mono-crystals) or electrons via the axio-electric effect. For these type of events the surface rejection with the ID design provided very low backgrounds down to 0.3 evts/kg/day/keV and energy thresholds down to $2.5\,\mathrm{keV_{ee}}$, in a data set with 484 kg.days exposure. For 3 different solar production mechanisms and the assumption of an axion Dark Matter halo limits could be set on axion-photon and axion-electron couplings to exclude mass ranges of $0.92\,\mathrm{eV} < m_{\mathrm{A}} < 80\,\mathrm{keV}$ for DFSZ axions and $5.78\,\mathrm{eV} < m_{\mathrm{A}} < 40\,\mathrm{keV}$ for KSVZ axions.

3 Improvements for EDELWEISS-III

The EDELWEISS-II sensitivity goal was reached in 2010 with the experiment eventually limited by backgrounds. To probe spin-independent cross sections down to $\sigma_{\mathrm{SI}} \approx 10^{-9}$ pb, EDELWEISS-III will employ a higher exposure at a significantly reduced background level.The 36 FID 800-g detectors currently installed in the cryostat do not only increase the fiducial mass from 1.6 kg in EDELWEISS-II to > 20 kg, but also have reduced background due to their improved design. The rejection of γ's was shown to be 5× better than for ID400 detectors. This was measured with calibration data from a ^{133}Ba γ-source (see Fig. 2). Out of $> 4 \times 10^5\ \gamma's$ no event leakage into the 90 % C.L. nuclear recoil band above 20 keV was observed, giving a rejection factor of $< 6 \times 10^{-6}$ NRs/γ. Rejection of surface events was also improved: With a ^{210}Pb source implanted in its copper casing, a detector was exposed to 10^5 α's, β's and γ's of the Pb decay chain. Only one event in the 90 % C.L. NR-band above 15 keV was observed after the fiducial volume cut, giving a rejection of 4×10^{-5} misidentified evts/kg.day. Both improvements are attributed to the better charge collection due to the additional electrode rings, which decreases the misreconstruction of double scatter events.

Enhancements were also made to the experimental setup. Within the cryostat additional PE at the 1 K stage has been added between detectors and cold electronics, while new PE pieces outside the shield against the warm electronics. Coaxial cabling in the cryostat has been replaced with more radiopure Kapton cabling. New thermal screens for the cryostat itself are now made from NOSV copper with higher radiopurity. The combined neutron suppression compared to EDELWEISS-II improved by a factor of 100. In order to reduce microphonic noise, the pulse tubes close to the cryostat have been replaced by GM thermal machines outside the complete shielding, which are connected by a cryoline. To avoid Johnson noise, resistors in the electronics have been removed and the active feedback system was replaced by a relay system. Altogether these changes lead to improvements of $\approx 30\,\%$ in resolutions, lowering the average FWHM baselines of the ionization channels from 900 eV to 600 eV and from 1.2 keV to 1.0 keV for the heat channel. Multiple R&D efforts are currently ongoing to improve the sensitivity of the experiment: Replacing the JFET based amplifiers with a HEMT readout could improve the resolution on the ionization channel down to 300 eV, with a significant benefit for low mass WIMP search. The recent installation of an integrated DAQ system is accompanied by tests with an event triggered 40 MHz readout of the ionization channel, which gives additional spatial information on the z-axis of the detector. The channel upscaling due to the new DAQ system is a crucial requirement for the next phase after EDELWEISS-III, the proposed cryogenic 1-ton scale multi-target experiment EURECA [7].
With the 36 FID800 detectors installed, EDELWEISS-III is currently on the way to take a first data set of 3000 kg.days exposure, expected to be background free. The final goal is then an exposure of 12 000 kg.days which should reach a sensitivity of $\sigma_{\mathrm{SI}} \approx 10^{-9}$ pb with background limitation setting in.

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

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