Recent results from the EDELWEISS-III WIMP search experiment

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The EDELWEISS experiment is dedicated to the direct detection of Dark Matter. The current setup (EDELWEISS-III) aims at exploring a spin-independent WIMP-nucleon cross section down to the 10^9 *pb* range, and extend the coverage for masses below 20 GeV. Since July 2014, the experiment is taking data with 24 state-of-the-art cryogenic FID800 Germanium detectors installed in the radio pure environment of the Modane underground laboratory - the deepest of its kind in Europe. These proceedings present the current status of the EDELWEISS-III experiment and show first preliminary results highlighting our new low WIMP mass analysis and the current background budget.

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1. Introduction

The existence of an unknown non baryonic matter is the best way to explain the cosmological observations. This matter, called Dark Matter, represents a large fraction of Universe's mass. Many candidates exist and a large amount of them can be gathered in a generic class of particle called the WIMP, for Weakly Interactive Massive Particle. They are non-relativistic particles, originally in thermal equilibrium with usual matter, with which they form the galaxies. Our galaxy is therefore embedded in a WIMP halo.

Dark matter can be discovered in many ways, by creating it in high energy colliders, by detecting its annihilation products coming from high dark matter density region of the Universe, or by detecting directly the WIMP from the galactic halo using coherent elastic scattering on a nucleus of different targets. Original technologies are used in this purpose, and the EDELWEISS experiment has chosen to use ionization and heat measurement in germanium bolometers.

The experimental setup will be described in the next section, and section 3 will present the data selection and the radioactive background. The section 4 is devoted to the experimental results for the low mass WIMP search.

2. Experimental setup

2.1 The detector shielding

The EDELWEISS detector is located under the Alps, inside the LSM (Laboratoire Souterrain de Modane). The rock overburden is equivalent to 4800 m of water and reduces the muon flux to 5 μ/m^2/day[1]. Inside the laboratory, the neutron flux above 1 MeV is 10^{-6}n/cm^2/s [2]. The cryostat is then protected by 20 *cm* of lead (including archeological lead) and 50 cm of polyethylene. An additional protection is achieved by flowing deradonized air (< 10 mBq/m^3) around the cryostat. Moreover, a muon veto built with scintillator bars surrounds the detector, with 98% coverage, is used to tag muon-induced neutrons. A sketch of the setup is shown in figure 1.
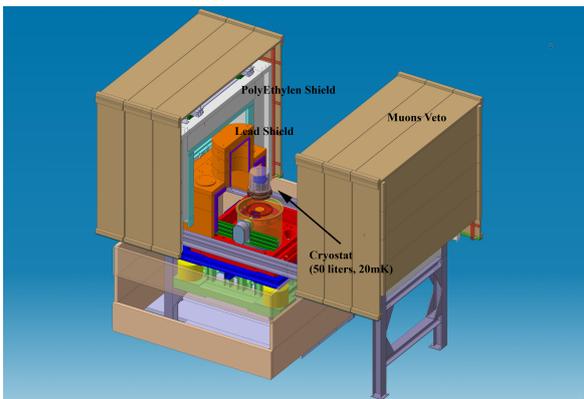
Figure 1: Sketch of the EDELWEISS setup with the various shielding, the VETO system, and the cryostat.
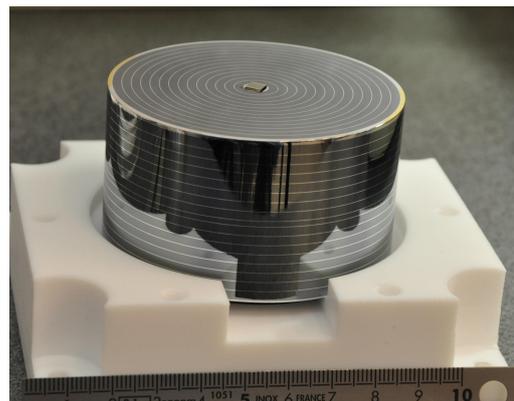
Figure 2: Picture of a bolometer, showing the interdigitized electrodes and on top the NTD sensor.
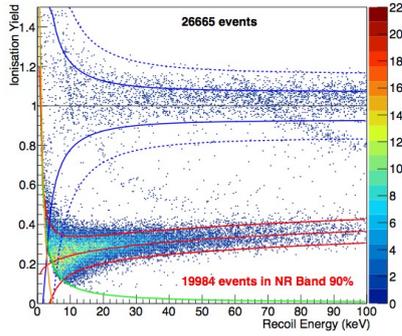
Figure 3: Ionisation yield as a function of recoil energy for an AmBe calibration (neutron plus gamma). Gamma interactions are located on a band arround 1, and neutron on the bottom band.
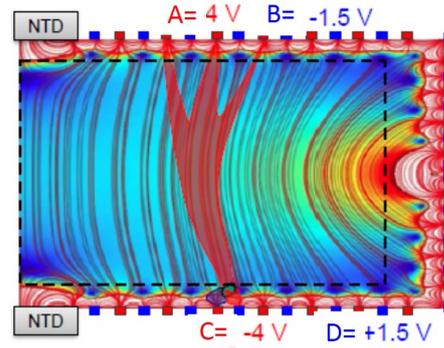
Figure 4: Electric field simulation inside the FID Detector showing the fiducial volume. Surface events will be seen by the electrodes on one side, while bulk events are detected by the electrodes on both sides.

2.2 The bolometers

The EDELWEISS bolometers are made of about 800 g of high purity germanium. In order to measure ionization, they are instrumented with interdigitized concentric electrodes on all the bolometer surfaces, as shown on the bolometer picture in figure 2. The heat elevation is measured using two thermal Ge-NTD (Neutron Transmutation Doping) sensors glued on each side of the bolometers, also visible in figure 2.

The EDELWEISS cryostat is able to maintain up to 40 kg of germanium at 18 mK. For the current run, 36 bolometers have been produced and installed inside the cryostat, and 24 among them are fully cabled.

3. Analysis scheme

3.1 Event selection

Interactions between the WIMPs and the bolometer produce nuclear recoils, while the gammas from radioactivity interact with the electronic cloud. Therefore, the EDELWEISS bolometers have been designed to distinguish these two types of interactions. They use the fact that the ionization yield (energy measured by ionization divided by the recoil energy) is different for nuclear and electron recoils. It is computed using the energy measured by the heat sensor (E_{heat}), and the one measured by the electrodes (E_{ioni}). Figure 3 shows this yield as a function of the recoil energy for an AmBe calibration that produces gammas and neutrons. By calibration, it is equal to one for the electronic recoil, while it is around 0.3 for the nuclear recoil. We can clearly see the gamma and the neutron bands. The ^{133}Ba calibration gives a rejection factor $< 5.6 \ 10^{-6}$ [3].

3.2 Surface event rejection

Events occurring near the surface will suffer a bad charge collection on the signal electrodes. Furthermore, the surface will be polluted by alphas and betas coming from the natural radioactivity.

Volume	Fiducial	total
Copper	7.3	12.8
brass screws	21.6	33.2
Connectors	39.7	69.3
Others	4.8	8.6
Total MC	78	125
Data	70	128

Table 1: Gamma background budget simulated and measured, for $20 keV < E_{ioni} < 200 keV$ (evt/kg.d).

Neutrons originating from	Single neutron between $[20\ keV - 200\ keV]$
Cryostat and electronics	$1.7\ 10^{-4}$
Shielding and supports	$4.6\ 10^{-4}$
Cavern walls	$5.2\ 10^{-5}$
total	$6.8\ 10^{-4}$

Table 2: Neutron background simulation, for $20 keV < E_{ioni} < 200 keV$ (evt/kg.d).

Bulk event are selected using a set of 4 electrodes alternatively polarized with +4 V and -1.5 V on one side, and with -4 V and +1.5 V on the other side, and creating inside the bolometer the electric field shown in figure 4. With this polarization, surface events will be mostly collected on one side, between the $\pm 4\ V$ and $\mp 1.5\ V$ electrodes, while bulk event will be collected by +4 V and -4 V electrodes. A ^{210}Pb calibration demonstrates that surface event rejection is better than $5 \cdot 10^{-5}$ for a recoil energy greater than 15 keV [4, 5].

3.3 Background from natural radioactivity

The radioactivity contamination of each material composing the detector has been measured using a high sensitivity germanium detector located in the LSM, and called Gentiane. A Geant 4 [6] based simulation has been performed for the ^{238}U and the ^{232}Th radioactive chain and for ^{137}Cs, ^{60}Co and ^{40}K contamination. The main background contributions are listed in table 1 for the fiducial and the total volume of the detectors. We can see that almost half of the background comes from the connectors, that are a very little component. This is due to the presence of Beryllium for the socket-pin elasticity. Results are compatible with data [7], and are sufficiently low to be rejected by the rejection factor achieved via the different ionization yield.

Neutrons produce nuclear recoil inside the bolometers, and therefore mimic the WIMP interaction, if only one bolometer is hit by the neutron. The number of single neutrons have been estimated using the same simulation program, using the neutron spectra calculated with the SOURCE package. Results are reported in table 2. They are typically 10 times better than for EDELWEISS II.

4. Low mass WIMP analysis

EDELWEISS-III took first data between July 2014 and April 2015, with 36 detectors installed inside the cryostat, and 24 detectors cabled, representing more than 14 kg of Germanium. A new run restarted in June 2015.

These proceedings report on a first demonstration analysis, using only one bolometer (FID837) representing an exposure of 35 kg.d. This bolometer is used to tune the analysis, and to build data driven background models. Then, this analysis has been blindly applied to more bolometers [9]. This analysis is devoted to the WIMP search with a mass below 25 GeV. Since the previous run, the

performances at low energies have been improved, largely due to new electronics [3]. The plot of figure 5 shows the ionization energy versus the heat energy for a gamma calibration using a ^{133}Ba source, and a neutron calibration using an AmBe source. We can see the neutrons in the grey band. A gamma/neutron discrimination at 4σ is possible for $E_{ioni} > 1keVee$ and $E_{heat} > 3keV\,nr$.
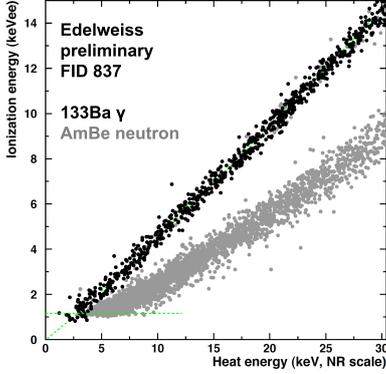
Figure 5: E_{ioni} as a function of E_{heat} for a ^{133}Ba (black point) and AmBe (grey point) Calibration with FID837.
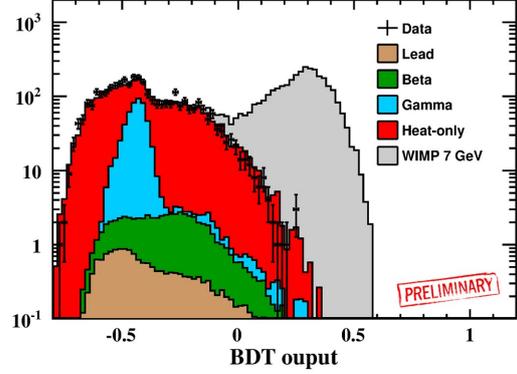
Figure 6: Output discrimination variable of the Boosted Decision Tree for a WIMP mass of 7 GeV.

Fiducial events, where only one bolometer have been hit and where $0 < E_{ioni} < 15keVee$ and $1.5 < E_{heat} < 15keVee$ are selected for this analysis.

The background are modeled using data in the region without signal, and using calibration. Most of the background comes from heat only events (*i.e.* event caused by microphony, that didn't produce an ionization signal). Then come surface events and miss-identified gamma events. The WIMP signal is modeled using a Monte Carlo simulation. And finally, a Boosted Decision Tree (BDT) algorithm is used for event discrimination. This is a multivariate method which combines several inputs into a single discriminating variable ranging between -1 (background like events) and +1 (signal like events). This output variable is shown in figure 6 for a WIMP with a mass of 7 GeV. A cut is applied on this variable, its value is derived from simulations by maximizing the signal over noise ratio, effectively rejecting all backgrounds (< 1 background event expected). A BDT was trained for each WIMP mass. The resulting limit is shown in figure 7.

Even with a small exposure, the results are competitive with most of the comparable experiments. This analysis has been reported in [8]

5. Conclusion

EDELWEISS has collected data during 10 months with 24 bolometers, and already analyzed a small fraction of the data set showing competitive results. Forthcoming results will use 8 more bolometers of the same quality than the one already analyzed, and thresholds will be lowered, leading to further improvements of sensitivity [9].

Furthermore, the EDELWEISS collaboration is involved in two R&D programs. The first one is devoted to the High Electron Mobility Transistor that should allow us to lower the ionization threshold. The second one studies the possibility of increasing the bias voltage to amplify the Luke-Neganov effect. Together with a reduction of heat only events of a factor 100, this will help
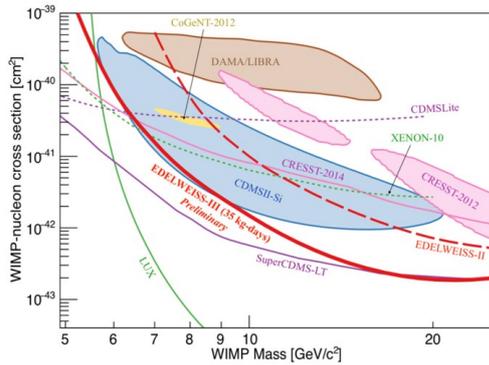
Figure 7: Exclusion plot obtained by EDEL-WEISS for an exposure of 35 kg.d, and compared with other results.
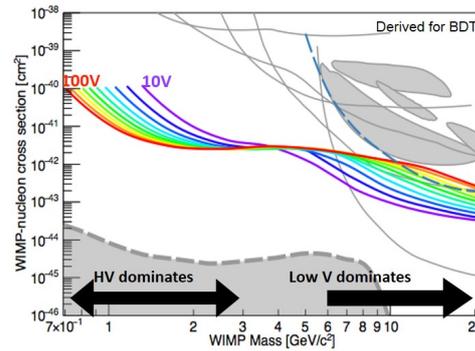
Figure 8: Projection for further developments using different voltage to use a boosted luke-neganov effect.

to lower the ionization and heat threshold down to 100 eV. Figure 8 shows the projection for the different voltage. The improvement is significant for very low mass WIMP.

6. Acknowledgments

References

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