

Gamma and neutron background in the Edelweiss-II dark matter experiment

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Abstract. The Edelweiss-II collaboration has completed a search for WIMP dark matter using 400-g cryogenic Ge detectors and 384 kg·d of effective exposure. The next phase aims to probe the range of spin-independent WIMP-nucleon cross-sections between 10^{-8} and 10^{-9} pb. We present the study of gamma and neutron background coming from radioactive decays in the set-up and shield materials based on GEANT4 Monte Carlo simulations combined with measured radioactivity levels of all components. The results of these background studies have been useful to design the changes in the Edelweiss set-up to further reduce the background events in the next phase of the experiment.

1. Introduction

The reduction and discrimination of the background is one of the most important tasks in any dark matter experiment, as the signal rate expected from dark matter is extremely low. Edelweiss-II is a direct dark matter search experiment based on cryogenic Ge detectors. The combined measurement of the ionization and heat deposit in a particle interaction allows the rejection of the gamma background at the level of $(3\pm1)\times10^{-5}$ [1]. Near-surface interactions are efficiently rejected, 6×10^{-5} [3], thanks to the interleaved electrodes [2]. Using a total mass of 4 kg Edelweiss-II has recently published the final WIMP search result [1]. A cross-section of 4.4×10^{-8} pb is excluded at 90%CL for a WIMP mass of 85 GeV.

To reach the sensitivity goal of WIMP-nucleon cross-sections between 10^{-8} and 10^{-9} pb in the next phase of the experiment, the background reduction and discrimination is crucial. The sources of background in Edelweiss-II are neutrons, gamma-rays and surface beta contaminants. We present in this paper studies of the gamma-ray and neutron background coming from radioactive decays in the set-up and shield materials. Extensive Monte Carlo simulations have been performed and combined with radiopurity measurements of all components. These background studies are used for optimization of the next phase experiment, Edelweiss III.

2. Experimental set-up and simulations

Edelweiss-II is located in the Laboratoire Souterrain de Modane at 4800 m.w.e ($4 \mu\text{/m}^2\text{/day}$). The environmental gamma-ray flux dominated by natural radioactivity in the cavern walls has been reported in [4] and [5]. The neutron flux above 1 MeV is $10^{-6} \text{ n/cm}^2\text{/s}$ [6].

The Edelweiss-II experiment uses Ge detectors installed in the 10 mK chamber. Each detector is supported by PTFE holders inside individual casings made of copper of type CuC2. The

detectors are arranged on plates supported by three vertical bars. The plates, the bars, the 10 mK thermal screen and the 10 mK plate (10 mK parts) are made of copper CuC1.

To simulate the response of the detectors to various type of particles, the complete set-up has been implemented in the GEANT4 package [7] as shown in Fig. 1.

Below the 10 mK plate, at 1K, a 14 cm thick lead plate shields the detectors from the gamma-rays induced by the radioactivity in the cold electronics, the dilution unit and other cryogenic parts. Five thermal screens at 1K, 4.2K, 40K, 100K and 300K, made of copper which has not been specially selected for its ultra-low radioactivity, complete the cryostat. Edelweiss is using coaxial cables from the detectors to room temperature. Passive resistances together with electrical connectors are installed at the 1K stage below the lead shielding. The warm electronics is all integrated in a single room-temperature module which is directly screwed on the cryostat. A 18 cm-thick outer layer of modern lead with a 2 cm-thick inner roman lead layer shields the cryostat against ambient gamma background. An outer 50-cm thick polyethylene shielding is used against ambient neutrons. The shields are mounted on a mild steel structure with rails. In addition a 100 m² plastic scintillator active muon veto [8] surrounds the polyethylene.

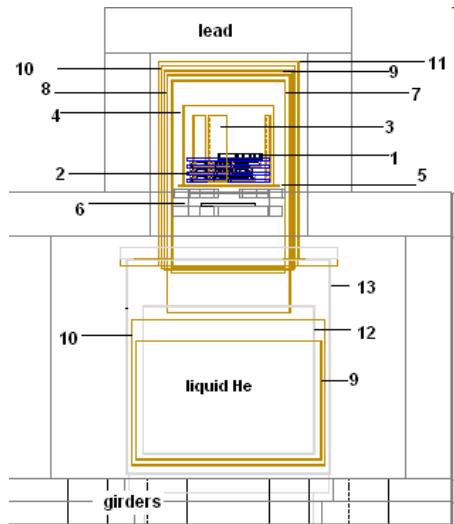


Figure 1. The GEANT4 geometry of the Edelweiss-II set-up. 1- germanium detectors with copper casings, 2- 10 mK copper plates, 3- support bars for the copper plates (10 mK) 4- 10 mK thermal screen, 5- 10 mK plate, 6- internal roman lead shielding, 7- 1K thermal screen, 8- 4.2K thermal screen, 9- 40K thermal screen, 10- 100K thermal screen, 11- 300K thermal screen, 12- stainless steel liquid He reservoir, 13- stainless steel pot. The outer polyethylene shielding and the muon veto are not shown.

All materials used in the construction have been measured to assess their radioactive contaminations. The results will be presented in [9].

3. Gamma-background

Figure 2 shows the gamma-background in the fiducial volume of the Edelweiss-II detectors compared to the GEANT4 MC simulation results. Details on the MC model will be given in [9]. The decays of ²²⁶Ra, ²²⁸Ra, ⁶⁰Co, ⁴⁰K, ⁵⁴Mn and ²¹⁰Pb were simulated in the most important set-up materials, including all components shown in Fig. 1. In addition, the cosmogenically induced isotopes ⁶⁸Ge and ⁶⁵Zn in germanium crystals were considered. Radiopurity measurements are used to calculate the gamma contributions of each component. As only upper limits were obtained for CuC1 copper and the copper of the screens, a χ^2 minimization with 10 free parameters was used to determine those contaminations, where the upper limits in the radioactive levels are taken as upper bounds for the fitting procedure.

The contributions to the gamma background in the low-energy region are presented in Table 1 for two fitting results, corresponding to the minimum and maximum contributions of the cryostat screens. The components which are not shown in Table 1 produce a negligible number of gamma events. The primary source of gamma background are the U/Th descendants and ⁶⁰Co

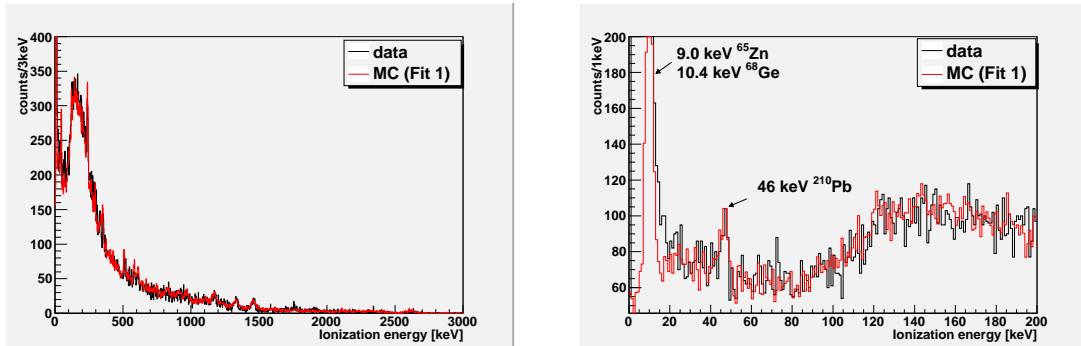


Figure 2. The background ionization energy spectrum in the fiducial volume of the Edelweiss-II detectors from measured data (black line) and Monte Carlo simulation (red line) for 185 kg d.

in the copper from the cryostat screens and 10mK parts, which represent between 39% and 52% of the total gamma-background. The second most important source (between 27% and 37%) is a pollution at 300K which must be introduced to match the data, which might be due to radioactivity in cryogenic pipes, warm electronics, radon or uncontrolled impurities on the 300K screen. The third most important gamma background source is the ^{210}Pb surface pollution on the detector casings (17%).

Table 1. Gamma-background sources in [20-200] keV. Rate in fiducial volume.

Material	Gamma event rate (evts/kg day) [20-200] keV						Fit 2 Total (%)
	^{226}Ra	^{228}Ra	^{60}Co	^{40}K	Others	Total (%)	
Ge crystals	0	0	0	0	^{68}Ge : 1.6	1.6 (2)	1.6 (2)
Detector casings (CuC2 copper)	1.2	1.	1.	0	^{210}Pb : 11	14 (17)	14 (18)
10 mK parts (CuC1 copper)	0.2	1	5	0.3	^{57}Co : 0.7, ^{54}Mn : 2.3	9.5 (12)	13.5 (17)
Cryostat screens (Cu)	12	15	3.	2	^{57}Co : 0.2, ^{54}Mn : 0.3	32.5(40)	17 (22)
Pollution 300K	8	14	0	0	0	22 (27)	29 (37)
Pb boliden	0	2.6	0	0	0	2.6 (3)	4 (5)
Total MC	21	33.6	9	2.3	16	82	79
Total data						82	82

4. Neutron background

Details on the GEANT4 model used for the simulation of the neutron background will be given in [9]. To check the accuracy of the model, simulations of neutrons from an Am-Be source placed inside the lead shielding have been compared to the measured rate and energy spectrum of nuclear recoils. The ratio of measured-to-simulated event rates above 20 keV after all cuts, corrected for the dead time and averaged over all crystals, has been found to be 0.94 ± 0.20 , where the error is given at 68% CL. The ratio is consistent with 1 within errors, proving the validity of the geometrical model of the detector and neutron phycsic in GEANT4.

To estimate the event rate due to neutrons in the data reported in [1] representing a total exposure of 384 kg d, the components detailed in the first column in Table 2 have been considered as potential sources of neutrons. The radiopurity data for the materials have been taken from radioactivity measurements. The maximum number of neutron events from the walls given in Table 2 takes into account the uncertainties in the U/Th concentration, in the neutron transport in polyethylene and in the environmental neutron flux. For the components located

inside the lead shielding, the uncertainty due to neutron transport and geometry model should not exceed 20% (as follows from the agreement between simulations and data with a neutron source positioned within the shielding), and is taken into account in the values in Table 2. The neutron background is potentially dominated by neutrons from materials inside the shields, specially cables and electronics.

Table 2. Number of background events due to neutrons in Edelweiss-II in the run detailed in [1]. The column "Material" refers to the material in each source which contributes most to neutron production. The same cuts as for data have been applied to the simulated events.

Source	Material	Neutron events (384 kg d) [20-200] keV
Hall walls	Rock	<0.01
Hall walls	Concrete	<0.1
Shielding	Polyethylene	<0.05
Shielding	Lead	<0.08
Support	Stainless steel	<0.01
Support	Mild steel	<0.04
Thermal screens, 10mK plates, 10mK bars (cryostat)	Copper	<0.03
1K connectors	Al, plastics	<0.4
Coaxial cables	PTFE	<0.65
Crystal holders	PTFE	<0.01
Electrodes	Aluminium	<0.01
Total		<1.4

Simply summing up the upper values from the materials considered in Table 2 yield less than 1.4 neutron events expected above 20 keV in the data in [1] where 5 nuclear recoil candidates are observed. Current investigations indicate that the number of neutron events from warm electronics is (1.0 ± 0.5) adding up to the sources detailed in Table 2.

5. Conclusion and future improvements

An extensive study of the gamma and neutron background have been performed, based on MC simulations combined with radiopurity data. The primary source of gamma background in Edelweiss-II is the copper from the cryostat screens and 10 mK parts. The neutron background is potentially dominated by neutrons produced by α -n reactions in materials inside the shields, specially cables and electronics. The background studies performed in the present work have fostered progresses for the next stage of the experiment. New cryostat screens and 10mK parts will be built from ultra-pure copper and an inner polyethylene shield against neutrons from materials inside the shields will be installed. With these improvements and the coming increase by an order of magnitude of the detector mass, the goal is to soon probe the physically interesting range of spin-independent WIMP-nucleon cross-sections between 10^{-8} and 10^{-9} pb.

References

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