Improved performances of a 320g Ionization-Heat Cryogenic Germanium Detector for Dark Matter search

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Abstract

EDELWEISS is a WIMP direct detection experiment using 320g ionization-heat cryogenic Ge detectors operated in the very low-background environment of the Frejus Underground Laboratory (French Alps). EDELWEISS has presently the best sensitivity for all WIMPs with a mass greater than 35 GeV. For these ionization-heat Ge detectors, the rejection of incomplete charge collection events represents the main challenge. New results on the rejection power of our detectors will be presented. On the other hand, detectors design has been studied to reduce the energy threshold and then to be more sensitive to WIMP interactions.

Key words: Bolometer; Germanium; Dark Matter; WIMP

1. Introduction

The Edelweiss experiment, located in the Laboratoire Souterrain de Modane in the Frejus Tunnel, has obtained an increased sensitivity for WIMP (Weakly Interacting Massive Particle) direct detection [1] [2]. For the first time, a region of realistic Supersymmetric models is excluded at 90 % CL.

In this paper, we present the calibration results of the new 320g Ge ionization-heat detectors that have been used for this type of Dark Matter search.

2. New 320g ionization-heat detectors and set-up

The strong interest of cryogenic detectors measuring ionization and heat simultaneously is the high discrimination power between nuclear and electron recoil interactions. As neutrons, Wimps induce nuclear recoils which generate less ionization than X, gammas and betas.

Three new detectors were put in operation in the beginning of year 2002. They have been subject to significant improvements relative to GeAl-6, the detector used for WIMP search in 2000 and 2001.

Two of the new three, GeAl-9 and GeAl-10 are constituted of germanium cylindrical single-crystals (70 mm diameter and 20 mm thickness) with beveled edge and sputtered aluminum electrodes for ionization measurement. The top electrode is divided in a central part and a guard ring, electrically decoupled for radial localization of the charge deposition.

For the third one, GGA-1, a hydrogenated amorphous germanium layer was deposited below the electrodes in order to reduce the charge collection problems associated with surface events, as suggested by [4] [7] [8] and to passivate the non-metallic surfaces.

The ionization signal was obtained by collecting charge under a low bias (1 to 4 Volts) in order to reduce the amplitude of the Luke effect (amplification of the heat signal due to ionization measurement) [6], [5].

The heat signal is measured with a Neutron Transmutation Doped Germanium (NTD) close to the metal-insulating transition [3]. The size of the NTD sensors has been changed in order to increase by a factor from 2 to 8 the the surface of exchange between

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the absorber and the sensor.

The reliability of electrical contacts and heat links has been improved by ultrasonic bonding of gold wires (diameter 25 microns) on gold pads. Given the consequent thickness of those pads, their heat capacity becomes not negligible compared to the heat capacity of the absorber (around 1nJ/K) and care was taken to ensure their thermalization at the temperature of the bath. The heat link is then controlled by the Kapitza resistance between the gold pads and the aluminum electrodes. A thermal analysis of the detector will be published latter.

For these new detectors, the NTD sensor is coupled to the Ge absorber by a layer of only 20 micrometer-thick electrical insulating glue. The large heat capacity of the previous silvered epoxy glue is suppressed.

3. Calibration

The ionization, heat measurements and discrimination efficiency between electron recoils and nuclear recoils were calibrated using ^{57}Co and ^{60}Co sources.

A completely new wiring with low capacitance coaxial cables from 300K to the detectors and selected cold FETs were installed in the dilution cryostat. The baseline resolutions were thus improved relative to GeAl-6 : less than 1.5 keV for all ionization channels and 1.3, 0.5 and 0.4 keV for the heat channel in GGA-1, GeAl-9 and GeAl-10. The resolutions at 122 keV of the detectors (2-3 keV) remained close to GeAl-6 ones.

The energy threshold has been lowered to 20 keV for nuclear recoils within 1 % of full efficiency (30 keV for GeAl-6), and 4 keV for electron recoils. The sensitivity for the heat signal was approximately of 50nV/keV for GGA-1 and 100nV/keV for GeAl-9 and GeAl-10.

The fiducial volume was measured using neutron calibrations to be 57 % of the total volume.

Discrimination efficiency has been studied using the usual Q factor defined as the ratio of the ionization signal over the heat signal normalized to one for the electronic recoils. The Q distributions obtained for each detector are shown in figure 1. The calibrations of GeAl-9 and GeAl-10 show a large fraction of events at low Q, indicating a deficient charge collection. As a consequence, the low background data taken with these two detectors presented a flat tail in the Q distribution, which rendered them so far inappropriate for the purpose of this experiment. On the other hand, GGA-1 discrimination is much higher with only 2 events found for Q less tan 0.5 in a statistics of 11537 events. The amorphous layer does appear to reduce incomplete charge collection and allowed to obtain with GGA1 the best world sensitivity for WIMP detection [1], [2].

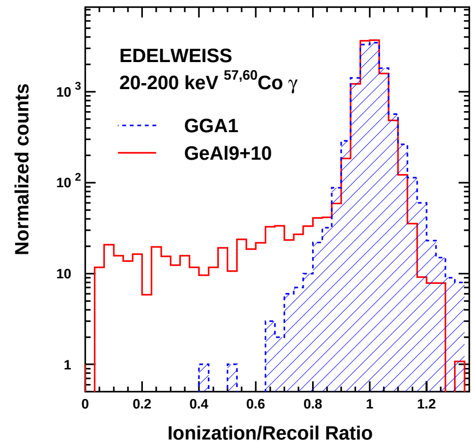

Fig. 1. Distributions of the Q factor (see text) obtained by exposing the detectors to ^{57}Co and ^{60}Co sources. The electronic recoils are at Q=1 by construction while the nuclear recoils are expected at Q around 0.3. GGA1 shows a much better discrimination than GeAl9 and GeAl10.

4. Conclusion

The calibrations of three 320g detectors have clearly shown two types of behavior for charge collection of surface events and indicate the way to obtain an efficient rejection of these events. The new design of the NTD-Ge sensors and the thermalization has led to unprecedented sensitivities with such a thermal sensor.

A new detector with amorphous layer is in operation and will be used with GGA-1 for data taking until the end of this year. A series of detectors of each type are going to be produced to study the reproducibility of the performances. This study should allow us to finalize the technical specifications for the 21 detectors of the EDELWEISS-II experiment in 2004.

This work has been partially funded by the EEC Network program under contract ERBFMRXCT980167.

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