Physics Letters B 687 (2010) 294–298

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

First results of the EDELWEISS-II WIMP search using Ge cryogenic detectors with interleaved electrodes

EDELWEISS Collaboration

E. Armengaud [f,*], C. Augier [g], A. Benoît [a], L. Bergé [b], O. Besida [f], J. Blümer [c,d], A. Broniatowski [b], A. Chantelauze [d], M. Chapellier [b], G. Chardin [b], F. Charlieux [g], S. Collin [b], X. Defay [b], M. De Jesus [g], P. Di Stefano [g,1], Y. Dolgorouki [b], J. Domange [b,f], L. Dumoulin [b], K. Eitel [d], J. Gascon [g,*], G. Gerbier [f], M. Gros [f], M. Hannawald [f], S. Hervé [f], A. Juillard [g], H. Kluck [d], V. Kozlov [d], R. Lemrani [f], P. Loaiza [i], A. Lubashevskiy [h], S. Marnieros [b], X.-F. Navick [f], E. Olivieri [b], P. Pari [e], B. Paul [f], S. Rozov [h], V. Sanglard [g], S. Scorza [g], S. Semikh [h], A.S. Torrento-Coello [f], L. Vagneron [g], M.-A. Verdier [g], E. Yakushev [h]

[a] CNRS-Néel, 25 Avenue des Martyrs, 38042 Grenoble Cedex 9, France
[b] CSNSM, IN2P3-CNRS, Université Paris XI, bat 108, 91405 Orsay, France
[c] Karlsruhe Institute of Technology, Institut für Experimentelle Kernphysik, Gaedestr. 1, 76128 Karlsruhe, Germany
[d] Karlsruhe Institute of Technology, Institut für Kernphysik, Postfach 3640, 76021 Karlsruhe, Germany
[e] CEA, Centre d'Etudes Saclay, IRAMIS, 91191 Gif-Sur-Yvette Cedex, France
[f] CEA, Centre d'Etudes Saclay, IRFU, 91191 Gif-Sur-Yvette Cedex, France
[g] IPNL, Université de Lyon, Université Lyon 1, CNRS/IN2P3, 4 rue E. Fermi 69622 Villeurbanne Cedex, France
[h] Laboratory of Nuclear Problems, JINR, Joliot-Curie 6, 141980 Dubna, Moscow region, Russia
[i] Laboratoire Souterrain de Modane, CEA-CNRS, 1125 route de Bardonnèche, 73500 Modane, France

ARTICLE INFO

Article history:
Received 3 December 2009
Received in revised form 7 March 2010
Accepted 17 March 2010
Available online 20 March 2010
Editor: M. Doser

Keywords:
Dark matter
Cryogenic Ge detectors
WIMP searches

ABSTRACT

The EDELWEISS-II Collaboration has performed a direct search for WIMP dark matter with an array of ten 400 g heat-and-ionization cryogenic detectors equipped with interleaved electrodes for the rejection of near-surface events. Six months of continuous operation at the Laboratoire Souterrain de Modane have been achieved. The observation of one nuclear recoil candidate above 20 keV in an effective exposure of 144 kg d is interpreted in terms of limits on the cross-section of spin-independent interactions of WIMPs and nucleons. A cross-section of 1.0×10^{-7} pb is excluded at 90% CL for a WIMP mass of 80 GeV/c^2. This result demonstrates for the first time the very high background rejection capabilities of these simple and robust detectors in an actual WIMP search experiment.

1. Introduction

The existence of Weakly Interacting Massive Particles (WIMPs) is a likely explanation for the various observations of a dark matter component from the largest scales of the Universe to galactic scales [1]. WIMPs are predicted by several extensions of the Standard Model of particle physics. WIMPs distributed in the Milky Way halo may be detected through coherent, elastic scattering on nuclei constituting a terrestrial detector [2]. The expected nuclear recoils have a quasi-exponential energy distribution with typical energies of a few tens of keV. Current searches [3–5] set upper limits on the interaction rate at the level of $\sim 10^{-2}$ event per kg and per day (evt/kg/d). Minimal extensions of the Standard Model with Supersymmetry where the WIMP is the lightest neutralino predict a particularly interesting range of parameters where their spin-independent scattering cross-section on nucleons lies between 10^{-8} and 10^{-10} pb, corresponding to rates of 10^{-3} to 10^{-5} evt/kg/d. As a consequence, experiments dedicated to the direct detection of WIMPs require large masses of detectors and long exposure times. The radioactive background is the main obstacle to measure such extremely low rates. Provision of passive rejection, such as the use of shieldings and radiopure materials in a deep underground site, must be complemented by a detector technology that enables a clear identification of single nuclear recoils with respect to other types of interactions.

* Corresponding authors.
E-mail address: gascon@ipnl.in2p3.fr (J. Gascon).
[1] Present address: Department of Physics, Queen's University, Kingston, ON, K7L 3N6, Canada.

0370-2693 © 2010 Elsevier B.V. Open access under CC BY license.
doi:10.1016/j.physletb.2010.03.057

Cryogenic Germanium detectors [3,6] constitute a leading technology in direct detection of dark matter. Event discrimination is provided by the comparison of the ionization signals to the bolometric measurement of the deposited energy. A long-standing issue with these detectors is the reduction of the charge collection efficiency for interactions occurring close to their surface, which can impair significantly the discrimination between nuclear and electron recoils. The CDMS Collaboration addresses it by adding a discrimination based on the time structure of their athermal phonon signals [3], obtaining with this the best published sensitivity for WIMPs of masses above $\sim$40 GeV/c^2. Recently, the EDELWEISS Collaboration deployed an alternative solution based on a new detector design with interleaved electrodes [7], named ID in the following. In Ref. [8], we demonstrated a rejection factor greater than 10^4 for low-energy surface events induced by electrons emitted from ^{210}Pb source. Combined with a comparable factor for the rejection of bulk electronic recoils, this technology, and the low-background environment achieved in the EDELWEISS-II setup [9], should enable to reach the required sensitivity to probe WIMP-nucleon cross-sections well below 10^{-8} pb. This new technology is also considered for application in more ambitious searches in the 10^{-10} pb range such as in the EURECA project [10].

The work presented in this Letter confirms these results in the conditions of an actual WIMP search, and in particular demonstrates the detector reliability and efficiency over long periods of time. We report on the results of a WIMP search carried out over a period of six months with an array of ten 400 g cryogenic germanium ID detectors. These data are combined with a smaller set recorded during the validation run of the first two ID 400 g detectors and interpreted in terms of limits on the spin-independent WIMP-nucleon cross-section. The reliability and efficiency of the ID technology will be assessed, together with its prospect for a significant improvement of the sensitivity for WIMP detection. These results will be compared to those of other leading WIMP searches.

2. Experimental setup

The experimental setup is described in detail in Ref. [9]. It is located in the Laboratoire Souterrain de Modane (LSM). The rock overburden of 4800 mwe reduces the cosmic muon flux to 4 μ/m^2/day. The flux of neutrons above 1 MeV is 10^{-6} n/cm^2/s [11]. The cryostat housing the detectors is protected from the ambient γ-rays by a 20 cm lead shield. This is surrounded by a 50 cm thick polyethylene shield, covered by a muon veto system with 98% geometric efficiency for thoroughgoing muons. The remaining rate of single nuclear recoils from energetic neutrons induced by muons is less than 10^{-3} evts/kg/day according to GEANT4 simulations of the experiment with its shields and the active rejection of muon-tagged events [12].

The detectors are made from ten hyperpure germanium crystals (less than 10^{10} impurities per cm^3) of cylindrical shapes with a diameter of 70 mm and a height of 20 mm. Five of these detectors have their edges bevelled at an angle of 45° and have a mass of 360 g. The mass of the other five detectors is 410 g. The detectors are in individual copper casings, stacked in towers of two to three ID detectors. During the entire data-taking periods, a dilution refrigerator maintains the detectors at a stabilized temperature of 18 mK.

For each interaction in a detector, two types of signals are recorded: an elevation of temperature and a charge signal. The temperature increase for each event is measured using neutron transmutation doped (NTD)-Ge thermometric sensors glued on each detector, as was the case in the previous EDELWEISS detectors [6]. The charge is collected by electrodes, the design of which and polarization scheme are described in details in Ref. [8]. Basically, the flat surfaces are covered with concentric aluminium ring electrodes of 2 mm pitch, and biased at alternating potentials. Each side has thus two sets of electrodes, each connected to its next but one neighbor through ultra-sonically bonded wires. The biases are chosen as to produce an axial field in the bulk of the detector, while the field close to the surface links two adjacent ring electrodes and is therefore approximately parallel to the surface.

Bulk events are thus identified by the collection of electrons and holes on the set of electrodes with the largest difference of potential across the detector, called *fiducial electrodes* in the following. The two other electrodes act as a veto for surface events. Typical biases for the fiducial and veto electrodes are ± 4 V and ∓ 1.5 V respectively. Two additional plain guard electrodes, typically biased at ± 1 V, cover the outer edges of the crystal. The fiducial volume of the detector is defined as the region for which the charge is collected entirely by the two fiducial electrodes.

The heat and the six charge signals of each detector are digitized continuously at a rate of 100 kHz, using a common clock for all channels. After online filtering, a threshold trigger is applied to each of the heat channels. The value of that threshold is updated continuously within the data acquisition on the basis of the noise level, aiming to keep the trigger rate below a fraction of a Hz. For each event, the raw heat and ionization data of all detectors in the corresponding tower are stored to disk. Triggers detected on more than one detector on the same tower are tagged online as coincidences. The data from detectors that did not participate to the trigger are used to monitor systematically the baseline resolutions as a function of time.

The muon veto has an independent read-out system. Each of the 42 plastic scintillation modules is equipped with 8 photomultipliers, 4 added at each end. A signal is recorded as a veto hit once a coincidence of the 2 ends of a module occurs within a 100 ns wide coincidence window. With a low trigger threshold deliberately chosen as to optimize the muon veto efficiency, the muon veto rate of $\sim$0.2 events/sec is dominated by environmental background. Each muon veto event is tagged with the corresponding time on the common clock used for the cryogenic detector readout. The coincidences between muon veto events and those in the detector towers are identified offline by comparing the respective time tags.

3. Detector performance and fiducial acceptance

After an initial cool-down of the cryostat in March 2009, the bulk of the data presented here was recorded over the following period of six months from April to September. An additional data set was recorded with two detectors during an initial run performed between July and November 2008.

In the six-month running period, the data acquisition was running 80% of the time. Half of the losses are accounted for by regular maintenance operations and the other half by unscheduled stops. The fraction of running time devoted to detector calibration with γ and neutron sources is 6%. Among the 70 read-out channels, only five were defective or too noisy for use: four guards and one veto. Extensive calibrations performed in 2008 have shown that a signal on one of the guards is almost invariably accompanied by another one on either the other guard or a veto electrode, or by an imbalance in the charge collected on the fiducial electrodes. Relying on this redundancy is sufficient to attain high rejection factors even in the absence of a guard channel. Three detectors with one deficient guard signal are thus kept for the WIMP search. One detector had one deficient guard and one deficient veto electrode. In the absence of evidence that this particular combination of two missing channels can be efficiently compensated by the existing