EDELWEISS detectors: from R&D to dark matter search

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Abstract. Cryogenic Ge detectors used within the EDELWEISS experiment are subject to constant improvement with respect to the rejection capabilities against non WIMP interactions. These are driven by the performances obtained at a given step. A summary of the evolution of the ”InterDigit” detectors with interleaved electrodes will be given with new possible solutions to improve the heat channel, with the ultimate goal of defining a building piece for the EURECA detector array.

1. Introduction

One of the key ingredients for the current cosmological concordance model is the existence of a dark, matter-like fluid ruling the dynamics of structures from the current galactic scales to the largest scales at early cosmic times. Weakly Interacting Massive Particles (WIMPs) are a generic class of dark matter particles with particularly appealing features. They appear in several extensions of the current Standard Model of particle physics, where thermal production mechanisms for such particles in the Big Bang naturally yield the order of magnitude for the observed cosmic abundance [1]. A vast effort is currently dedicated to the direct detection of WIMPs from the Milky Way halo through the coherent elastic scattering on nuclei constituting a terrestrial detector. A roughly exponential nuclear recoil spectrum is expected with typical energies of a few tens of keV. Theoretical models predict a wide range of WIMP-nucleon scattering cross sections. Current searches are approaching sensitivities for rates of a few $10^{-3}$ evts/kg/day, corresponding to cross sections for spin-independent interactions at the level of a few $10^{-8}$ pb. Since we are dealing with very rare event searches, the dedicated detectors must therefore achieve a low energy threshold combined with high background rejection capabilities.

2. The EDELWEISS experiment

EDELWEISS is a direct WIMP search experiment, where nuclear recoils induced by collisions with WIMPs from the galactic halo are detected using germanium detectors working at very low temperatures with the simultaneous measurement of ionization and phonon signals [2]. The comparison of the two signals makes possible to separate on an event-by-event basis the nuclear recoils from the electron recoils induced by $\beta$ and $\gamma$ radioactivity that constitute the major source of background in most present-day direct WIMP searches. The detectors are operated at the Underground Laboratory of Modane in the Frejus Tunnel under the French-Italian Alps. The 1780 rock overburden (4800 m water equivalent) results in a muon flux of about $4 \mu/m^2/day$ in the experimental hall and the neutron flux above 1 MeV is $10^{-6}n/cm^2/s$. Each detector is
a cylindrical absorber made of a HPGe single crystal equipped with sputtered Al electrodes. The thermal sensor is a Neutron Transmutation Doped Ge (NTD) thermistor glued on the absorber with Araldite epoxy. In the following sections we will review the different phases of this experiment from the detector point of view, underlining all the progresses done in terms of sensitivity, rejection capability and fiducial mass.

2.1. EDELWEISS-I: the starting point
The first phase of the experiment, EDELWEISS-I [3], has been characterized by three heat and ionization Ge bolometers (320 g each - 70 mm in diameter and 20 mm in height with edges beveled at an angle of 45°) operating simultaneously in a low background dilution cryostat running at a regulated temperature of 17 mK. Detectors were individually housed in separate 1 mm thick Cu casings, the distance between the Ge surfaces being 13 mm. For the heat measurement, a NTD-Ge thermometric sensor was glued on each detector. For the ionization measurement, detectors were equipped with two Al electrodes. One was segmented to define two regions, a central part and a guard ring, the applied collection voltage being of a few V/cm. The evaluated fiducial volume was \( \sim 57\% \).

The final analysis of the EDELWEISS-I data covers a total fiducial exposure of 62 kg·d. The limits on the neutralino scattering cross-section were obtained from the observation of 40 nuclear recoil candidates with recoil energies between 15 and 200 keV, of which 3 are between 30 and 100 keV. The limits were obtained without the subtraction of any background, although the presence of a coincidence between two detectors and the study of charge collection distributions suggested that at least some of these events are due to a neutron background and surface interactions of electrons. In the preparation of the second phase of the experiment, it was necessary to perform a thorough investigation of all the events in EDELWEISS-I before the nuclear recoil selection, in order to better assess their origin and devise means to remove as many background components as possible for EDELWEISS-II [4]. It is clear that this first phase has been very useful to point out the main limiting factor for such a kind of experiment: the background coming from surface electron-recoil events. In fact for an interaction that takes place near the surface of the detector, the charge collection is incomplete and difficult to control. In particular, the local radioactivity from residual \(^{210}\)Pb, a daughter of Radon which is present on all surfaces, generates such events that can create signals leaking down into the nuclear recoil band, where WIMP signals are expected.

2.2. EDELWEISS-II: ID detectors - a big improvement thanks to surface event rejection with interleaved electrodes
Given the experience acquired with EDELWEISS-I, a new design of a cryogenic germanium detector for dark matter search was required, taking advantage of the coplanar grid technique of event localization to improve the background discrimination and mainly to reject surface events [5]. The new-generation detectors called ID (InterDigit) method are essentially a variation of the coplanar grid technique, in which interleaved concentric strips are substituted for the classical disk-shaped collection electrodes. The depth of an event relative to the surfaces can be inferred from a comparison of the ionization signals on the different strips, making possible a rejection of energy deposits at the detector surfaces. This phase consisted of ten hyperpure germanium crystals of cylindrical shapes with a diameter of 70 mm and a height of 20 mm. Five of these detectors had their edges bevelled at an angle of 45° with a mass of 360 g. The mass of the other five detectors was 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. A total effective exposure of 384 kg·d has been achieved, mostly coming from fourteen months of continuous operation. Five nuclear recoil candidates are observed above 20 keV, while the estimated background is 3.0 events. The result
is interpreted in terms of limits on the cross-section of spin-independent interactions of WIMPs
and nucleons. A cross section of $4.4 \times 10^{-8}$ pb is excluded at 90\% CL for a WIMP mass of 85
GeV [6].

Here below the main detector properties are summarized:

- Detector mass: 400 g
- FWHM baseline: 1.2 keV for the heat signal
- FWHM baseline: 0.9 keV for the fiducial ionizing signal
- NTD sensitivity: 60 nV/keV
- Analysis threshold: 20 keV
- Fiducial mass: 160 g ($\sim$ 50\% fiducial volume)

2.3. EDELWEISS-III: the FID800 detector - the new strategy

To go beyond the EDELWEISS-II sensitivity and to be competitive with other experiments, a
third phase of this experiment is foreseen. The EDELWEISS-III project consists in an upgrade
of both the current EDELWEISS setup and detectors to reach a sensitivity to WIMP-nucleon
cross-section of the order of $5 \times 10^{-9}$ pb in a short term requiring an exposure of 3000 kg·d.
For the reduction of the $\beta$ and $\gamma$ backgrounds, the development of an improved detector design,
named Full InterDigit (FID) has been pursued. 800 g crystals are equipped with two NTD
heat sensors, and are covered by interleaved electrodes on all their surface. There is therefore
no guard region anymore inside the crystal volume. Both the increase of crystal mass and
the removal of guard regions increase strongly the fiducial mass for each individual detector.
In addition, simulations have shown that Compton interactions spanning the fiducial and low-
field guard regions may induce fake WIMP candidates. Large-statistics gamma-ray calibration
of the first FID detectors have indeed shown improved rejection performances relative to ID
detectors. The plan is to install 40 FID800 detectors in 2012. Infrastructure upgrades (cabling,
cold electronics, cryogenics and acquisition) are necessary to host these new detectors, to reduce
microphonic noise and hence the analysis threshold, and will also reduce the neutron budget
within the cryostat. In addition, an inner polyethylene shield will be installed to reduce the
flux of fast neutrons coming from outside the cryostat. Fig.1 shows a picture of a FID detector:
interleaved electrodes are visible on all its surface and also the NTD sensor is appreciable on
the top surface. Fig.2 represents a sketch of the electric field lines inside the crystal resulting in
a 75\% of fiducial volume ($\sim$ 640g).

3. Conclusions and Perspectives

Important progresses have been done with cryogenic Ge detectors in the EDELWEISS
experiment during last years. There is still a comfortable space for detector improvements
including also larger masses. In addition, thanks to the big versatility of these detectors, they
can be adapted to lower thresholds; at this purpose the collaboration is working on the heat
channel with the development of new innovative heat sensors, called "$\text{NbSi superconductive}
resistive meanders$", that have the potentiality to decrease the threshold improving also the
energy resolution.

For the near future, new data in the coming year will contribute to clarify the present situation
at low mass, a hot topic at nowadays, with the possibility to test the DAMA/CoGeNT/CRESST
signals. In the next future, EURECA [7], a Ton scale Dark matter experiment, will search for
WIMP interactions down to $\sigma \sim 10^{-10}$ pb corresponding to a rate of $\sim$1 event/ton/year. It is
clear that to achieve this further step different present limitations should be overcome.
Figure 1. Picture of a FID detector of 800 g in its copper holder. Interleaved electrodes are visible on all its surface and also the NTD sensor is appreciable on the top surface.

Figure 2. Sketch of the electric field lines inside the crystal.

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