First Ten kg of Naked Germanium Detectors in Liquid Nitrogen installed in the GENIUS-Test-Facility

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Abstract

The first four naked high purity Germanium detectors were installed successfully in liquid nitrogen in the GENIUS-Test-Facility (GENIUS-TF) in the GRAN SASSO Underground Laboratory on May 5, 2003. This is the first time ever that this novel technique aiming at extreme background reduction in search for rare decays is going to be tested underground. First operational parameters are presented.

1 Introduction

The present status of cold dark matter search, of investigation of neutrinoless double beta decay and of low-energy solar neutrinos all require new techniques of drastic reduction of background in the experiments. For this purpose we proposed the GENIUS (GErmanium in liquid NItrogen Underground Setup)

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The project in 1997 [1–6]. The idea is to operate ‘naked’ Ge detectors in liquid nitrogen, and thus, by removing all materials from the immediate vicinity of the Ge crystals, to reduce the background considerably with respect to conventionally operated detectors. The liquid nitrogen acts both as a cooling medium and as a shield against external radioactivity.

That the removal of material close to the detectors is the crucial point for improvement of the background, we know from our experience with the HEIDELBERG-MOSCOW double beta decay experiment [10], which is the most sensitive double beta experiment for 10 years now. Monte Carlo simulations for the GENIUS project, and investigation of the new physics potential of the project have been performed in great detail, and have been published elsewhere [5,7]. Already in 1997 it has been shown experimentally in our Heidelberg low-level facility (shielding ~ 10 mwe) that the techniques of operating ‘naked’ Ge detectors in liquid nitrogen is working and we were the first to show that such device can be used for spectroscopy [5].

A small scale version of GENIUS, the GENIUS-Test-Facility has been approved by the Gran Sasso Scientific Committee in March 2001. The idea of GENIUS-TF is to prove the feasibility of some key constructional features of GENIUS, such as detector holder systems, achievement of very low thresholds of specially designed Ge detectors, long term stability of the new detector concept, reduction of possible noise from bubbling nitrogen, etc.

Additionally the GENIUS-TF will improve the limits on WIMP-nucleon cross sections with respect to our results with the HEIDELBERG-MOSCOW and HDMS experiments [15,16] thus allowing for a test of the claimed evidence for WIMP dark matter from the DAMA experiment [17]. The relatively large mass of Ge in the full scale GENIUS-TF compared to existing experiments would permit to search directly for a WIMP signature in form of the predicted [18] seasonal modulation of the event rate [13]. Introducing the strongly ‘cooled down’ enriched detectors of the HEIDELBERG-MOSCOW $\beta\beta$-experiment into the GENIUS-TF setup, may allow, in a later stage, to improve the present accuracy of the effective Majorana neutrino mass determined recently [8–10]. A detailed description of GENIUS-TF project is given in [11].

After installation of the GENIUS-TF setup between halls A and B in Gran Sasso, opposite to the buildings of the HEIDELBERG-MOSCOW double beta decay experiment and of the DAMA experiment (Figs. 1, 5), the first four detectors have been installed in liquid nitrogen on May, 5 2003 and have started operation.

This is the first time ever, that this novel technique for extreme background reduction in search for rare decays is tested under realistic background conditions in an underground laboratory.
In section 2 we will describe the actual setup, including the measures taken for producing high-purity nitrogen, the measurement system of the liquid nitrogen level, the new digital data acquisition system [12], and will present first measured spectra. In section 3 we give a short Summary.

2 Description of Setup and of Present Performance

On May 5, 2003 the first four naked Ge detectors were installed under clean-room conditions into the GENIUS-TF setup. Fig. 2 shows the contacted crystals after taking them out of the transport dewars, in the holder made from high-purity PA5 (a type of teflon), in which they then are put into liquid nitrogen. Each detector has a weight of 2.5 kg. The depth of the core of the detectors was reduced to guarantee a very low threshold, estimated by ORTEC to be around 0.5-0.7 keV, with only marginal deterioration of the energy resolution.

The liquid nitrogen (in total ~ 70 l) is kept in a thin-walled (1 mm) box of high-purity electrolytic copper of size 50x50x50 cm$^3$. Inside this copper box, i.e. also inside the liquid nitrogen, is installed another box with walls of 5 - 10 cm monocristalline Ge bricks (~300 kg) forming the first highly efficient shield of the Ge detectors (see Fig. 3).

The copper box is thermally shielded by 20 cm of special low-level styropor, followed by a shield of 10 cm of electrolytic copper (15 tons) and 20 cm of low-level (Boliden) lead (35 tons). Fig. 3 shows the geometry of the setup, and also
Fig. 2. Right: Taking out the crystals from the transport dewars and fixing the electrical contacts in the clean room of the GENIUS-TF building - from left to right: Herbert Strecker, Hans Volker Klapdor-Kleingrothaus, Oleg Chkvorez. Left: The first four contacted naked Ge detectors before installation into the GENIUS-TF setup.

The setup in the status of not yet fully closed copper and lead shields. The setup will finally by shielded against neutrons with 10 cm Boronpolyethylene plates.

The high-purity liquid nitrogen used, is produced by the BOREXINO nitrogen plant, which has been extended for increase of the production capacity to be able to provide enough nitrogen also for GENIUS-TF. Liquid nitrogen of standard quality (99.99% purity) is directly purified in the liquid phase by an adsorber column system, consisting of two independent columns (Low Temperature Adsorber - LTA) filled with about 2 kg of ‘activated carbon’ each. One of them we purchased to supplying GENIUS-TF. The system is designed to continuously produce about 150 l of liquid nitrogen per hour, respectively about 100 m³/h gaseous nitrogen for both experiments. During the regeneration phase of one column the other one is in use. The plant is shown in Fig. 4. For the experimentally measured strong reduction of Rn by the cryogenic column adsorption see [14].

From the production plant the liquid nitrogen is transported by 2001 vessels to the building of the experiment. Filling of the copper container with liquid nitrogen is provided by connecting them to the filling system consisting of isolated teflon tubes as shown in (Fig. 5). The nitrogen level in the detector chamber is measured by a capacitive sensor consisting of two 40 cm long isolated selected-material copper tubes, one inside the other. The change of the medium between the tubes by the entering liquid nitrogen leads to a change of the capacity, which is measured by subsequent electronics and indicated by LED’s outside of the setup. We measure the nitrogen level in ten steps be-
Fig. 3. View of GENIUS-TF in the Gran Sasso Underground Laboratory in Italy. Upper part: Cross section of the setup. Lower part: The setup with detectors inside, but shielding only partly mounted. In front the preamplifier system.

Fig. 4. Connections of electronics, liquid nitrogen, source and LN$_2$ sensor to the inner part of GENIUS-TF.
Fig. 5. BOREXINO-GENIUS-TF nitrogen purification system in GRAN SASSO (left and upper right). The left part shows the absorber column (low temperature absorber - LTA) provided by the GENIUS-TF group. The nitrogen is transported by 2001 vessels to the GENIUS-TF building (lower right).

tween 0 and 100%. GENIUS-TF has to be refilled every two days (with some reserve of one more day).

The data acquisition system we developed recently for GENIUS-TF and GENIUS is described in detail in [12]. It uses multichannel digital processing technology with FLASH ADC modules with high sampling rates of 100 MHz and resolution of 12 bits. It allows to capture the detailed shape of the preamplifier signal with high-speed ADC, and then perform digitally all essential data processing functions, including precise energy measurement over a range of 1 keV - 3 MeV, rise time analysis, ballistic deficit correction and pulse shape analysis. Thus we obtain both the energy and the pulse shape information from one detector using one channel of the Flash ADC module.

To allow for regular calibration of the detectors, a source of $^{133}$Ba fixed on a wire can be introduced through a teflon tube into the center among the detectors. The source is transported via a magnetic system. The activity of the source is 401 kBq.

Fig. 6 shows the dependence of the expected spectrum seen by the four detectors as function of the position in the setup ($d$ is the vertical distance of the source from the plane, on which the detectors are lying. For $d \sim 7$-10 cm the source is approximately on top of the detectors).

Figs. 7, 8 show two spectra measured a few days after installation. A first spectrum measured with a $^{60}$Co source outside the setup, and the $^{133}$Ba source inside, is shown in Fig. 7. The resolution at this moment (two days after
Fig. 6. Monte Carlo simulation of GENIUS-TF calibration measurements with a movable $^{133}$Ba source, for different source-detector distance, with GEANT4. $d$ is the vertical distance of the source from the plane, on which the detectors are sitting. (installation) is 3 keV in the 1330 keV region.

Fig. 7. A first spectrum measured with detector 1 with a $^{60}$Co source outside, and the $^{133}$Ba source inside the setup.

Fig. 8 shows the background, measured with the still open setup to the top. When the liquid nitrogen level decreases, the background slightly increases. This shows that the radioactive impurities seen (from $^{40}$K, and the $^{232}$Th and $^{238}$U natural decay chains) are located outside the setup. No cosmologically produced impurities in the detectors are seen on the present level of sensitivity.
Fig. 8. The first background spectrum measured with detector 2 over 40 hours without shield of the setup to the top.

The effect of microphonics from bubbling in the liquid nitrogen is as far as it can be seen now, negligible for high energies, but has to be discriminated by pulse shape analysis for low energies. This can be done by the new digital data acquisition system [12].

3 Conclusion

The first four naked Ge detectors (10 kg) have been installed in liquid nitrogen into the GENIUS-Test-Facility in the GRAN SASSO Underground Laboratory on May 5, 2003. This is the first time that this novel technique is applied under realistic background conditions of an underground laboratory. With the successful start of GENIUS-TF a historical step has been achieved into a new domain of background reduction in underground physics in the search for rare events - and at the same time, a first experimental step to GENIUS. Besides testing of constructional parameters for the GENIUS project one of the first goals of GENIUS-TF will be to test the signal of cold dark matter reported by the DAMA collaboration [17], which could originate from modulation of the WIMP flux by the moving of the Earth relative to that of the Sun.
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