GENIUS-Test-Facility Started Operation in GRAN SASSO - with First Ten kg of Naked Germanium Detectors in Liquid Nitrogen

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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.
The GENIUS-TF experiment, aims to search for the annual modulation of the Dark Matter signal using 40 kg of naked-Ge detectors in liquid nitrogen. It should be able to confirm the DAMA result within two or three years of measuring time.

1. Introduction

The present status of further 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) project in 1997 [1, 2, 3, 4, 5, 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 radiactivity.

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, 16], which is the most sensitive double beta experiment

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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 $\sim$ 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 [18, 19] thus allowing for a test of the claimed evidence for WIMP dark matter from the DAMA experiment [20, 23]. 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 [21] 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, 9, 10, 16]. A detailed description of the 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, 6), the first four detectors have been installed in liquid nitrogen on May, 5 2003 and have started operation. This has been reported in [14] and [15].

Figure 1: Location of GENIUS-TF is the building on the right (car in front), opposite to the HEIDELBERG-MOSCOW experiment building (left side) (see also Fig. 6).

Figure 2: The sucssesful team after installation of the first four detectors on May 5, 2003. From left to right: Irina Krivosheina and Claudia Tomei, Hans Volker Klapdor-Kleingrothaus, Oleg Chkvoretz and Herbert Strecker.

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 briefly we demonstrate the potential of GENIUS-TF to probe the DAMA signal for cold dark matter by looking for the expected modulation signal.

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. 3 shows the contacted crystals after taking them out of the transport dewars, in the holder made from high-purity PA5 (a type a 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. Fig. 2 shows the sucessesful team after installation of the first four detectors on May 5, 2003.

The liquid nitrogen (in total $\sim$ 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 ($\sim$300 kg) forming the first highly efficient shield of the Ge detectors (see Fig. 5).

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. 5 shows the geometry of the setup. Fig. 4 shows the setup in the status of

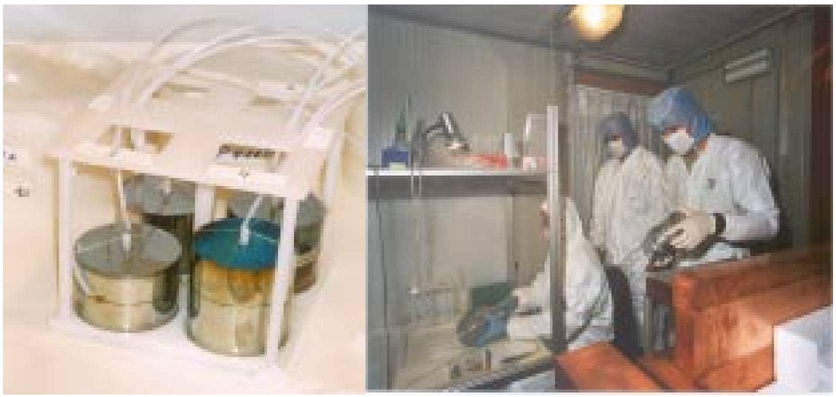

Figure 3: Right: Taking out the crystals from the transport dewars and fixing the electrical contacts in the clean room of the GENIUS-TF building - from left to right: Herbert Strecker, Hans Volker Klapdor-Kleingrothaus, Oleg Chkvorets. Left: The first four contacted naked Ge detectors before installation into the GENIUS-TF setup.

Figure 4: View of GENIUS-TF in the Gran Sasso Underground Laboratory in Italy. Left: The setup with detectors inside, but shielding only partly mounted. In front the preamplifier system. Status May 5, 2003. Right: The full shielding of GENIUS-TF, status December 2, 2003.

not yet fully closed copper and lead shields, and the fully closed setup (status December 2, 2003). 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 m^3/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. 6. For the experimentally measured strong reduction of Rn by the cryogenic column adsorption see [17].

From the production plant the liquid nitrogen is transported by 200 l vessels to the

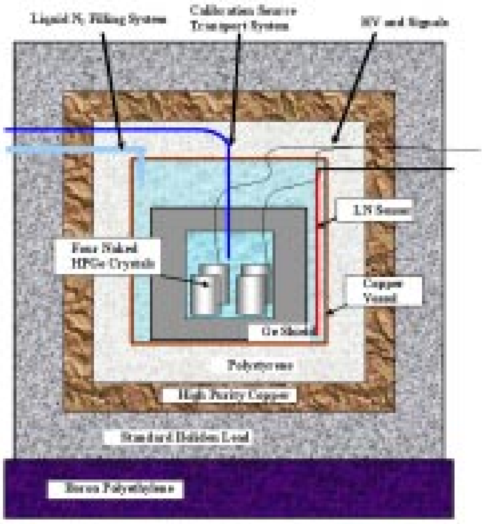

Figure 5: Cross section of the setup.

Figure 6: 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 200 l vessels to the GENIUS-TF building (lower right).

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.

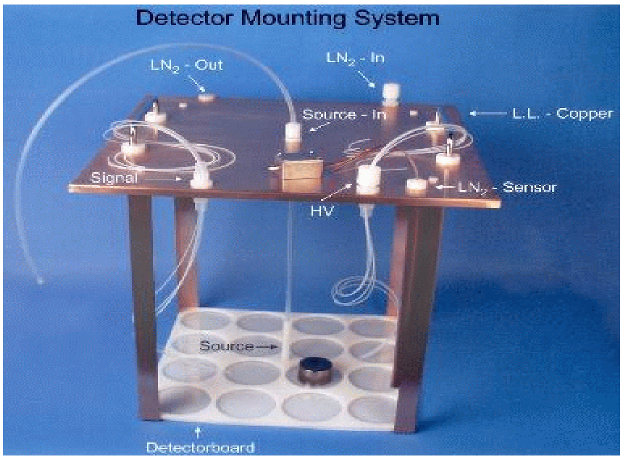

Figure 7: Connections of electronics, liquid nitrogen, source and LN_2 sensor to the inner part of GENIUS-TF.

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

The data acquisition system we developped recently for GENIUS-TF and GENIUS is decribed in detail in [12]. It uses multichannel digital processing technology with FLASH ADC modules with high sampling rates of 100 MHz and resolution of 13 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. 8 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. 9, 10 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. 9. The resolution at this moment (two days after installation) is 3 keV in the 1330 keV region.

Fig. 10 shows the background, measured with the still *open* setup to the top. When

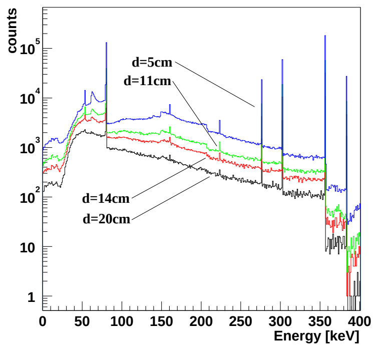

Figure 8: Monte Carlo simulation of GENIUS-TF calibration measurements with a movable ^{133}Ba source, for different source-detector distance, with GEANT4. **d** is the vertical distance of the source from the plane, on which the detectors are sitting (from [15]).

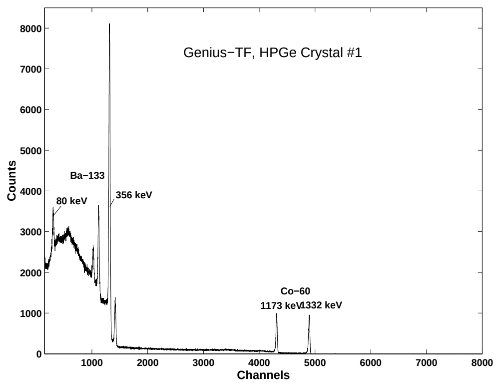

Figure 9: A first spectrum measured with detector 1 with a ^{60}Co source outside, and the ^{133}Ba source inside the setup (see [15]).

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.

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. Searching for the Annual Modulation of Dark Matter signal with the GENIUS-TF experiment.

It is generally assumed that our galaxy is embedded in a halo of dark matter particles (WIMPs) with energy density $\rho \simeq 0.3$ GeV/cm^3 and velocities distributed according to

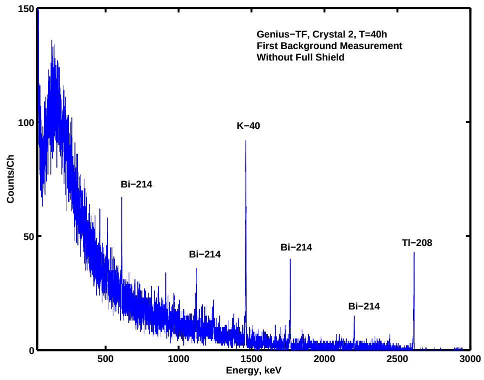

Figure 10: The first background spectrum measured with detector 2 over 40 hours without shield of the setup to the top (see [15]).

a Maxwellian distribution with parameter v_0 (defined as $\sqrt{(\frac{2}{3})}\ v_{\rm rms}$) and cut-off velocity equal to the escape velocity in the Galaxy ($v_{\rm esc} \simeq 650$ km/s).

The recoil spectrum produced by WIMP-nucleus scattering in a target detector is expected to show the so-called annual modulation effect, due to the Earth's motion around the sun [22].

We have investigated the potential of GENIUS-TF for searching for this modulation effect [13]. Fig. 11 shows the expected WIMP rate in Ge for different masses. Fig. 12 shows the result, which can be obtained after two years of measurement if a WIPM exists as claimed by DAMA [20].

4. Conclusions

The annual modulation, due to the motion of the earth with respect to the galactic halo, is the main signature of a possible WIMP signal. A positive indication of this modulation has been found over the past years by the DAMA experiment and it would be of great importance to look for the same effect with another experiment, expecially in the region of the WIMP parameter space indicated by the DAMA results.

The GENIUS-TF experiment [15, 11], a prototype for the GENIUS experiment with a mass of 40 kg and a background of 4 counts/(kg y keV), can be used to look for Dark Matter, not only through the direct detection of WIMP-induced nuclear recoils, but also through the annual modulation of the experimental rate. GENIUS-TF will be - in addition to DAMA [25] - the *only* experiment which will be able to probe the annual modulation signature in a foreseeable future (see Figs: 11, 12). The at present much discussed cryo detector experiments, such as CDMS [26], CRESST [27], EDELWEISS [28] have at present no chance to do this because the mass projected to be in operation in these experiments is by far too low (see also [24]).

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.

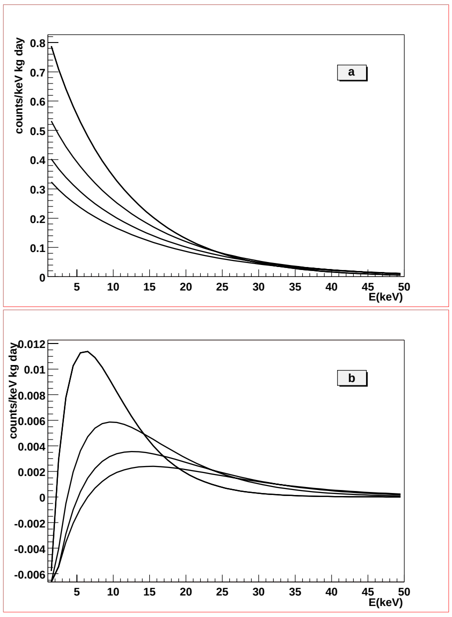

Figure 11: Expected WIMP rate in Ge for m_W= 40, 60, 80, 100 GeV (from top to bottom) and $\sigma_{Ge} = 10^{-34}$ cm^2: a) time-independent component of the signal (S_0) ; b) amplitude of the modulated component ($S_{\rm m}$) (from [13]).

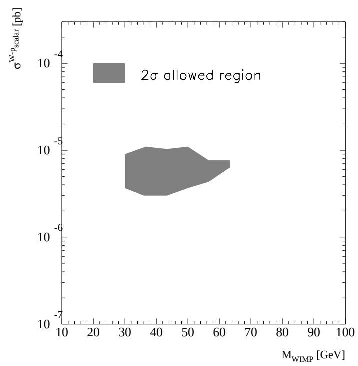

Figure 12: Allowed region at 2σ C.L. corresponding to the best-fit values of $m_W = (39.9 \pm 5.6)\, GeV$, and $\sigma_p = (7.0 \pm 1.6) \cdot 10^{-6}$ (see for details [13]). The region is calculated (see [13]) and has to be interpreted as the result that can be given by GENIUS-TF after two years of measurement if a WIMP exists with the properties assumed so far (from [13]).

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 [20, 23].

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