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First 10 kg of naked germanium detectors installed in liquid nitrogen in GENIUS Test-Facility in GRAN-SASSO

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Abstract. The GENIUS Test Facility has come into operation in Gran Sasso on May 5, 2003 with its first ten kg of naked Ge detectors in liquid nitrogen. This is the first time that this novel technique for extreme background reduction in search for rare decays is applied under the background conditions of an underground laboratory. GENIUS-TF has the potential to check the DAMA evidence for cold dark matter by modulation, and possibly, to improve the accuracy of the recently observed first signal for neutrinoless double beta decay.

PACS. 95.35d Dark matter search – 95.55.Vj WIMPs – 14.60.Pq Neutrino mass – 23.40.Bw Low-background measurements – 12.60.Jv High-purity Ge detectors

1 Introduction

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 (see Fig. 1). 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 in Fig. 2.

GENIUS-TF will allow to improve the limits on WIMP-nucleon cross sections (see Fig. 4) with respect to our results with the HEIDELBERG-MOSCOW and HDMS experiments [22], and allow for a test of the claimed evidence for WIMP dark matter from the DAMA experiment [38]. 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 seasonal modulation of the event rate [20]. 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 [1,2,4]. A detailed description of GENIUS-TF project is given in [19,21,23].

From the HEIDELBERG-MOSCOW experiment it was found [1,2,3,4,18], that for ^{76}Ge the half-life for neutrinoless double beta decay is

$$T^{0\nu}_{1/2} = (0.8 - 18.3) \times 10^{25}\mathrm{y} \quad (95\% c.l.) \qquad (1)$$

with best value of $T^{0\nu}_{1/2} = 1.5 \times 10^{25}\ y$. Double beta decay is the slowest nuclear decay process observed until now in nature. Assuming the neutrino mass mechanism to domi-

Fig. 1. *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

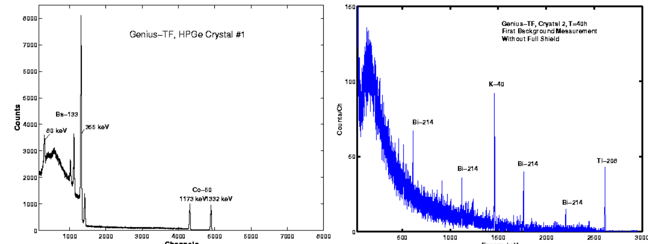

Fig. 2. A first spectrum measured with detector 1 with a ^{60}Co source outside, and the ^{133}Ba source inside the setup (*left*), and background spectrum measured with detector 2 over 40 h without shield of the setup to the top (*right*).

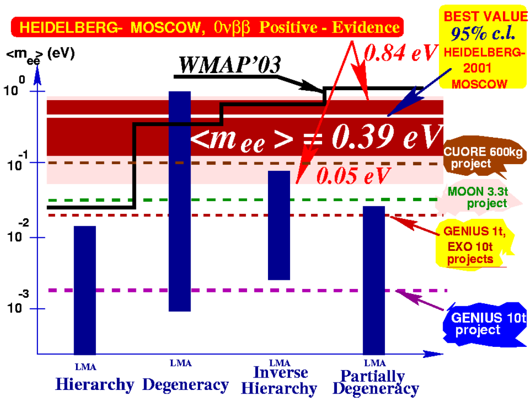

Fig. 3. Best value of effective neutrino mass $\langle m \rangle$ from the HEIDELBERG-MOSCOW experiment, and range of 95% c.l. The vertical bars correspond to expectations for $\langle m \rangle$ in different neutrino mass scenarios (from [12])

nate the decay amplitude, we can deduce

$$\langle m_\nu \rangle = (0.11 - 0.56)\, eV \quad (95\% c.l.) \tag{2}$$

This value we obtain using the nuclear matrix element of [14]. Allowing for an uncertainty of ±50% of the matrix elements (see [4,11]), this range widens to

$$\langle m_\nu \rangle = (0.05 - 0.84)\, eV \tag{3}$$

The result (2) and (3) determines the neutrino mass scenario to be degenerate [7,12]. The common mass eigenvalue follows then to be

$$m_{com} = (0.05 - 3.2)\, eV \quad (95\%) \tag{4}$$

If we allow for other mechanisms (see [9,10,11,8], the value given in (2),(3) has to be considered as an upper limit. In that case very stringent limits arise for many other fields of beyond standard model physics.

Of course it would be important to reduce the error bars of the measured half-lifes (and effective neutrino mass), in particular also in view of the recent information from other experiments.

Table 1 shows that the $0\nu\beta\beta$ result is supported by the neutrino masses required for the Z-burst scenarios of high-energy cosmic rays [31,24]. It is consistent with a (g-2) deviating from the standard model expectation [25]. It is consistent also with the limit from the tritium decay experiments [37] but the allowed 95% confidence range extends down to a range which cannot be covered by future tritium experiments.

The recent information from investigation of the cosmic microwave radiation by WMAP, and from Large Scale Structure observations is, concerning the neutrino mass consistent with the result from $0\nu\beta\beta$ decay [33,34,35, 36] (see Fig. 3). The limitations of the information from WMAP, in particular the missing power to discriminate between different mass scenarios, are seen in Fig. 3 (see also in [4,7]), thus results of PLANCK are eagerly awaited.

The results from solar and atmospheric neutrino oscillations already yield, assuming degenerate neutrinos, a

Table 1. Recent support of the neutrino (degenerate ν's) mass deduced from $0\nu\beta\beta$ decay [1,2,4,6,5], by other experiments, and by theoretical work

Experiment	References	m_ν(eV)
$0\nu\beta\beta$	[1,2,4,6,5]	0.05 - 3.2
WMAP	[33,34]	< 0.23, or 0.33, or 0.50
CMB	[32]	< 0.7
CMB+LSS +X-ray gal. Clust.	[35]	∼0.2 eV
Z - burst	[24,31]	0.08 - 1.3
g-2	[25]	> 0.2
Tritium	[37]	<2.2 - 2.8
ν oscillation	[27,28]	> 0.04
Theory:		
A_4-symmetry	[29]	> 0.2
identical quark and ν mixing at GUT scale	[30]	> 0.1

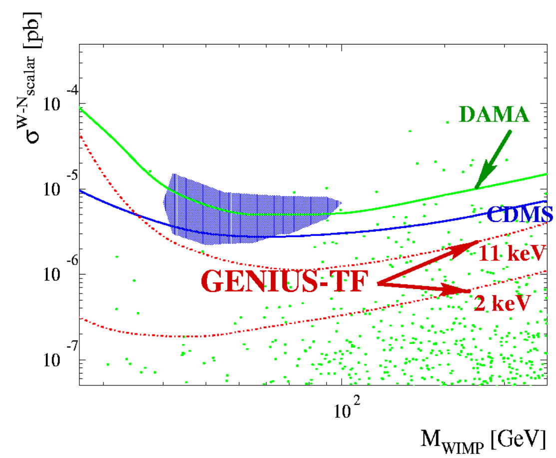

Fig. 4. Perspectives of GENIUS-TF for cold dark matter search [19,23,20,22,11]

lower limit of the common mass eigenvalue of > 0.04 keV [12,36].

As mentioned already in [13], the results from double beta decay and WMAP *together* may indicate that the neutrino mass eigenvalues have indeed the same CP parity, as required by the model of [30].

Concerning theory, a recent model with underlying A_4 symmetry for the neutrino mixing matrix also leads to degenerate neutrino masses > 0.2 eV, consistent with the present result from $0\nu\beta\beta$ decay [26,29]. Starting with the hypothesis that quark and lepton mixing are identical at or near the GUT scale, Mohapatra et al. [30] show that the large solar and atmospheric neutrino mixing angles can be understood purely as result of renormalization group evolution, if neutrino masses are quasi-degenerate (with the same CP parity). The common Majorana neutrino mass then must be, in this model, larger than 0.1 eV.

Coming to the expected sensitivity of GENIUS-TF for cold dark matter (CDM), this is shown for different assumptions on the threshold in Fig. 4. The detectors are expected to have a threshold of 500-700 eV. The figure shows that even in a very conservative case, assuming a threshold of only 11 keV, the experiment should be able to probe the claim of DAMA by the modulation signal (see [38]). This will be the first and main scientific motivation for GENIUS-TF.

Concluding, GENIUS-TF was originally planned to investigate some constructional and operational parameters for the GENIUS-project, which we proposed now six years ago [15,16,17]. This project aimed at huge improvement of sensitivity in search for $0\nu\beta\beta$ decay, cold dark matter search and low-energy solar neutrinos, at a time when there was *no* indication for the first two topics, and the solar ν problem was not solved. Now after *six years* the situation has changed completely and history may have overcome the necessity of the full GENIUS project. The solar ν problem seems to be solved by KAMLAND and SNO, there is a 6.4σ signal for cold dark matter and, with the improved confidence level for $0\nu\beta\beta$ decay from our additional three years of data until 2003 from the HEIDELBERG-MOSCOW experiment, the full GENIUS project *may not be needed anymore*.

Concerning $0\nu\beta\beta$ decay an independent observation of this process with *another* isotope, would probably the most reasonable choice - requiring, however, that such experiment (*in contrast*, e.g., to CUORICINO, CUORE) should be able to differentiate between β and γ-events, or to see the tracks of the fundamental process. This would require an experimental approach, different from all *what is pursued at present*.

Probably the most important task is to see CDM in an *independent* experiment by the *modulation signal*. This is the only model-independent check - and this can be done in a foreseeable future *only* by GENIUS-TF, which in this way turns from an original Test-Facility to an independent pioneering experiment of its own scientific significance.

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