Double beta decay is indispensable to solve the question of the neutrino mass matrix together with $\nu$ oscillation experiments. Recent analysis of the most sensitive experiment since nine years - the HEIDELBERG-MOSCOW experiment in Gran-Sasso - yields a first indication for the neutrinoless decay mode. This result is the first evidence for lepton number violation and proves the neutrino to be a Majorana particle. We give the present status of the analysis in this report. It excludes several of the neutrino mass scenarios allowed from present neutrino oscillation experiments - only degenerate scenarios and those with inverse mass hierarchy survive. This result allows neutrinos to still play an important role as dark matter in the Universe. To improve the accuracy of the present result, considerably enlarged experiments are required, such as GENIUS. A GENIUS Test Facility has been funded and will come into operation by early 2003.

**Keywords:** Beta decay, double beta decay; Neutrino mass and mixing; Weak-interaction and lepton (including neutrino) aspects.

1. Introduction

Double beta decay is the most sensitive probe to test lepton number conservation. Further it seems to be the only way to decide about the Dirac or Majorana nature of the neutrino. Observation of $0\nu\beta\beta$ decay would prove that the neutrino is a Majorana particle and would be another clear sign of beyond standard model physics. Recently atmospheric and solar neutrino oscillation experiments have shown that neutrinos are massive. This was the first indication of beyond standard model physics. The absolute neutrino mass scale, however, cannot be determined from oscillation experiments alone. Double beta decay is indispensable also to solve this problem.

The observable of double beta decay is the effective neutrino mass

$$\langle m \rangle = |\sum U_{ei}^2 m_i| = |m_{ee}^{(1)}| + e^{i\phi_2} |m_{ee}^{(2)}| + e^{i\phi_3} |m_{ee}^{(3)}|,$$

with $U_{ei}$ denoting elements of the neutrino mixing matrix, $m_i$ neutrino mass eigen-
states, and $\phi$, relative Majorana CP phases. It can be written in terms of oscillation parameters
\[ |m^{(1)}_{ee}| = |U_{e1}|^2 m_1, \]
\[ |m^{(2)}_{ee}| = |U_{e2}|^2 \sqrt{\Delta m_{21}^2 + m_1^2}, \]
\[ |m^{(3)}_{ee}| = |U_{e3}|^2 \sqrt{\Delta m_{32}^2 + \Delta m_{21}^2 + m_1^2}. \]

The effective mass $\langle m \rangle$ is related with the half-life for $0\nu\beta\beta$ decay via
\[ \left( \frac{T_{1/2}^{0\nu}}{1/2} \right)^{-1} \sim \langle m_\nu \rangle^2, \]
and for the limit on $T_{1/2}^{0\nu}$ deducible in an experiment we have
\[ T_{1/2}^{0\nu} \sim a \sqrt{\frac{Mt}{\Delta EB}}. \]

Here $a$ is the isotopical abundance of the $\beta\beta$ emitter; $M$ is the active detector mass; $t$ is the measuring time; $\Delta E$ is the energy resolution; $B$ is the background count rate and $\epsilon$ is the efficiency for detecting a $\beta\beta$ signal. Determination of the effective mass fixes the absolute scale of the neutrino mass spectrum.

In this paper we will discuss the status of double beta decay search. Although in the HEIDELBERG-MOSCOW experiment we also have the highest statistics ($\sim 147,000$ events) for $2\nu\beta\beta$ decay (see [5] and [6]) we shall concentrate in this paper on the neutrinoless decay mode. We shall, in section 2, discuss the recent evidence for the neutrinoless decay mode, from the HEIDELBERG-MOSCOW experiment, and the consequences for the neutrino mass scenarios which could be realized in nature. In section 3 we discuss the possible future potential of $0\nu\beta\beta$ experiments, which could improve the present accuracy.

2. Evidence for the Neutrinoless Decay Mode

The status of present double beta experiments is shown in Fig. 1 and is extensively discussed in [7]. The HEIDELBERG-MOSCOW experiment using the largest source strength of 11 kg of enriched $^{76}$Ge (enrichment 86%) in form of five HP Ge-detectors is running since August 1990 in the Gran-Sasso underground laboratory [9,11,16,30,32] and is since nine years now the most sensitive double beta experiment worldwide.

2.1. Data from the HEIDELBERG-MOSCOW Experiment

The data taken in the period August 1990 - May 2000 (54.9813 kg y, or 723.44 mol-years) are shown in Fig. 2 in the section around the $Q_{\beta\beta}$ value of 2039.006 keV [18,19]. Fig. 2 is identical with Fig. 1 in [1] except that we show here the original energy binning of the data of 0.36 keV. These data have been analysed [24] with various statistical methods, with the Maximum Likelihood Method and in particular also with the Bayesian method (see, e.g. [13]). This method is particularly suited for low counting rates, where the data follow a Poisson distribution, that cannot be
Fig. 1. Present sensitivity, and expectation for the future, of the most promising $\beta\beta$ experiments. Given are limits for $\langle m \rangle$, except for the HEIDELBERG-MOSCOW experiment where the recently observed value is given (95% c.l. range and best value). Framed parts of the bars: present status; not framed parts: future expectation for running experiments; solid and dashed lines: experiments under construction or proposed, respectively. For references see 9, 2, 4, 39, 50.

Fig. 2. The spectrum taken with the $^{76}\text{Ge}$ detectors Nr. 1, 2, 3, 4, 5 over the period August 1990 - May 2000 (54.9813 kg y) in the original 0.36 keV binning, in the energy range 2000 - 2100 keV. Simultaneous fit of the $^{214}\text{Bi}$ lines and the two high-energy lines yield a probability for a line at 2039.0 keV of 91%.
approximated by a Gaussian. Details and the results of the analysis are given in [1-4].

![Graph](image.png)

Fig. 3. Top: Probability K that a line exists at a given energy in the range of 2000-2080 keV derived via Bayesian inference from the spectrum shown in Fig. 2. Bottom: Result of a Bayesian scan for lines as in the left part of this figure, but in an energy range of ±5σ around Q_{ββ}.

Our peak search procedure (for details see [2,4]) reproduces (see [1,2,4]) γ-lines at the positions of known weak lines from the decay of $^{214}$Bi at 2010.7, 2016.7, 2021.8 and 2052.9 keV [17]. In addition, a line centered at 2039 keV shows up (see Fig. 3). This is compatible with the Q-value [18,19] of the double beta decay process. The Bayesian analysis yields, when analysing a ±5σ range around Q_{ββ} (which is the usual procedure when searching for resonances in high-energy physics) a confidence level (i.e. the probability K) for a line to exist at 2039.0 keV of 96.5 % c.l. (2.1 σ) (see Fig. 3). We repeated the analysis for the same data, but except detector 4, which had no muon shield and a slightly worse energy resolution (46.502 kg y). The probability we find for a line at 2039.0 keV in this case is 97.4% (2.2 σ) [12,14].

Fitting a wide range of the spectrum yields a line at 2039 keV at 91% c.l. (see Fig. 3).

We also applied the Feldman-Cousins method [14]. This method (which does not use the information that the line is Gaussian) finds a line at 2039 keV on a confidence level of 3.1 σ (99.8% c.l.). In addition to the line at 2039 keV we find candidates for lines at energies beyond 2060 keV and around 2030 keV, which at
Important further information can be obtained from the *time structures* of the individual events. Double beta events should behave as single site events (see Fig. 4 top), i.e. clearly different from a multiple scattered $\gamma$-event (see Fig. 4 bottom). It is possible to differentiate between these different types of events by pulse shape analysis. We have developed three methods of pulse shape analysis\,[10,11,12] during the last seven years, one of which has been patented and therefore only published recently.

![Graph 1](image1.png)

![Graph 2](image2.png)

*Fig. 4.* Top: Shape of one candidate for $0\nu\beta\beta$ decay classified as SSE by all three methods of pulse shape discrimination. Bottom: Shape of one candidate classified as MSE by all three methods.

Installation of Pulse Shape Analysis (PSA) has been performed in 1995 for the four large detectors. Detector Nr.5 runs since February 1995, detectors 2,3,4 since November 1995 with PSA. The measuring time with PSA from November 1995 until May 2000 is 36.532 kg years, for detectors 2,3,5 it is 28.053 kg y.

In the SSE spectrum obtained under the restriction that the signal simultaneously fulfills the criteria of *all three* methods for a single site event, we find again indication of a line at 2039.0 keV (see Figs. 5, 6).
Fig. 5. Scan for lines in the single site event spectrum taken from 1995-2000 with detectors Nr. 2,3,5, (Fig. 6), with the Bayesian method. Top: Energy range 2000 -2080 keV. Bottom: Energy range of analysis ± 4.4σ around Q_{ββ}. 

Fig. 6. Sum spectrum of single site events, measured with the detectors Nr. 2,3,5 operated with pulse shape analysis in the period November 1995 to May 2000 (28.053 kg.y), summed to 1 keV bins. Only events identified as single site events (SSE) by all three pulse shape analysis methods have been accepted. The curve results from Bayesian inference in the way explained in sec.3. When corrected for the efficiency of SSE identification (see text), this leads to the following value for the half-life: T^{0ν}_{1/2}=(0.88 - 22.38) \times 10^{25} y (90\% c.l.).
We find 9 SSE events in the region 2034.1 - 2044.9 keV ($\pm 3\sigma$ around $Q_{\beta\beta}$). Bayes analysis of the range 2032 - 2046 keV yields a signal of single site events, as expected for neutrinoless double beta decay, with 96.8% c.l. at the $Q_{\beta\beta}$ value. The Feldman-Cousins method gives a signal at 2039.0 keV of 2.8 $\sigma$ (99.4%).

The analysis of the line at 2039.0 keV before correction for the efficiency yields 4.6 events (best value) or (0.3 - 8.0) events within 95% c.l. (2.1 - 6.8) events within 68.3% c.l.). Corrected for the efficiency to identify an SSE signal by successive application of all three PSA methods, which is 0.55 $\pm$ 0.10, we obtain a $0\nu\beta\beta$ signal with 92.4% c.l. The signal is (3.6 - 12.5) events with 68.3% c.l. (best value 8.3 events). Thus, with proper normalization concerning the running times (kg.y) of the full and the SSE spectra, we see that almost the full signal remains after the single site cut (best value), while the $^{214}$Bi lines (best values) are considerably reduced. We have used a $^{238}$Th source to test the PSA method. We find the reduction of the 2103 keV and 2614 keV $^{228}$Th lines (known to be multiple site or mainly multiple site), relative to the 1592 keV $^{228}$Th line (known to be single site), shown in Fig. 7. This proves that the PSA method works efficiently. Essentially the same reduction as for the Th lines at 2103 and 2614 keV and for the weak Bi lines is found for the strong $^{214}$Bi lines (e.g. at 609.6 and 1763.9 keV (Fig. 7)).

The possibility, that the single site signal is the double escape line corresponding to a (much more intense!) full energy peak of a $\gamma$-line, at 2039+1022=3061 keV is excluded from the high-energy part of our spectrum.

![Fig. 7. Relative suppression ratios: Remaining intensity after pulse shape analysis compared to the intensity in the full spectrum. Right: Result of a calibration measurement with a Th source - ratio of the intensities of the 1592 keV line (double escape peak, known to be 100% SSE), set to 1. The intensities of the 2203 keV line (single escape peak, known to be 100% MSE) are strongly reduced (error bars are $\pm 1\sigma$. The same order of reduction is found for the strong Bi lines occurring in our spectrum - shown in this figure are the lines at 609.4 and 1763.9 keV. Left: The lines in the range of weak statistics around the line at 2039 keV (shown are ratios of best fit values). The Bi lines are reduced compared to the line at 2039 keV (set to 1), as to the 1592 keV SSE Th line.](image)
A very careful simulation of the different components of radioactive background in the Heidelberg-Moscow experiment has been performed recently by a new Monte Carlo program basing on GEANT4. This simulation uses a new event generator for simulation of radioactive decays basing on ENSDF-data and describes the decay of arbitrary radioactive isotopes including $\alpha$, $\beta$ and $\gamma$ emission as well as conversion electrons and X-ray emission. Also included in the simulation is the influence of neutrons in the energy range from thermal to high energies up to 100 MeV on the measured spectrum. Elastic and inelastic reactions, and capture have been considered, and the corresponding production of radioactive isotopes in the materials of the setup. The neutron fluxes and energy distributions were taken from published measurements performed in the Gran Sasso. Also simulated was the influence of the cosmic muon flux measured in the Gran Sasso, on the measured spectrum.

The simulation gives no indication that the signal at 2039 keV comes from a known background line. In particular, the simulation shows, that e.g. decays of $^{77}\text{Ge}$, $^{76}\text{Ga}$ or $^{228}\text{Ac}$, should not lead to signals visible in our measured spectra near the signal at $Q_{\beta\beta}$. For details we refer to 6.

2.2. Comparison with earlier results

We applied the same methods of peak search as used in our analysis to the spectrum, measured in the Ge experiment by Caldwell et al. more than a decade ago. These authors had the most sensitive experiment using natural Ge detectors (7.8% abundance of $^{76}\text{Ge}$). With their background being a factor of 9 higher than in the present experiment, and their measuring time of 22.6 kg y, they have a statistics for the background larger by a factor of almost 4 in their (very similar) experiment. This allows helpful conclusions about the nature of the background.

The peak scanning finds indications for peaks essentially at the same energies as in Fig. 3. This shows that these peaks are not fluctuations. In particular it sees the 2010.78, 2016.7, 2021.6 and 2052.94 keV $^{214}\text{Bi}$ lines. It finds, however, no line at $Q_{\beta\beta}$. This is consistent with the expectation from the rate found from the HEIDELBERG-MOSCOW experiment. About 16 observed events in the latter correspond to 0.6 expected events in the Caldwell experiment, because of the use of non-enriched material and the shorter measuring time.

The first experiment using enriched (but not high-purity) $^{76}\text{Ge}$ detectors performed by Kirpichnikov and coworkers, because of their low statistics of 2.95 kg y would expect 0.9 counts. Their result is consistent with this expectation. Another Ge experiment (IGEX) using 8.8 kg of enriched $^{76}\text{Ge}$, but collecting since beginning of the experiment in the early nineties till shutdown in end of 1999 only 8.8 kg y of statistics could expect, according to our result, about 2.6 events. The result of that measurement is also consistent with the expectation.
Fig. 8. Peak scanning of the spectrum measured by Caldwell et al. [21], with the Maximum Likelihood method (upper part), and with the Bayesian method (lower part) (as in Figs. 3, 6) (see 4).

2.3. Proofs and Disproofs

The result described in section 2.1 has been questioned in some papers (Aalseth et al., hep-ex/0202018; Feruglio et al., Nucl. Phys. B 637(2002)345; Zdesenko et al., Phys. Lett. B 546(2002) 206). We think that we have shown in a convincing way that these claims against our results are incorrect in various ways. In particular the estimates of the intensities of the $^{214}$Bi lines in the first two papers do not take into account the effect of true coincidence summing, which can lead to drastic underestimation of the intensities. A correct estimate would also require a Monte Carlo simulation of our setup, which has not been performed in the above papers. All of these papers, when discussing the choice of the width of the search window, seem to ignore the results of the statistical simulations we published in 2, 3, 4. For details we refer to 3, 4.

2.4. Half-Life and Effective Neutrino Mass

Having shown that the signal at $Q_{\beta\beta}$ consists of single site events and is not a $\gamma$-line, we translate the observed number of events into half-lifes. We obtain $T^{0\nu}_{1/2} = (0.8 - 18.3) \times 10^{25}$ y (95% c.l.) with a best value of $1.5 \times 10^{25}$y. Assuming that the $0\nu\beta\beta$ amplitude is dominated by the neutrino mass mechanism, we obtain,
with the nuclear matrix element from \textsuperscript{15} an effective mass of $\langle m_\nu \rangle = (0.11 - 0.56) \text{ eV} \ (95\% \ c.l.)$.

The result obtained is consistent with all other double beta experiments - which still reach less sensitivity. The most sensitive experiments following the HEIDELBERG-MOSCOW experiment are the geochemical $^{128}\text{Te}$ experiment with $T_{1/2}^{0\nu} > 2(7.7) \times 10^{24} \text{ y} \ (68\% \ c.l.)$, \textsuperscript{24} the $^{136}\text{Xe}$ experiment by the DAMA group with $T_{1/2}^{0\nu} > 1.2 \times 10^{24} \text{ y} \ (90\% \ c.l.)$, \textsuperscript{25} a second $^{76}\text{Ge}$ experiment with $T_{1/2}^{0\nu} > 1 \times 10^{24} \text{ y}$ \textsuperscript{22} and a $^{nat}\text{Ge}$ experiment with $T_{1/2}^{0\nu} > 1.44 \times 10^{23} \text{ y} \ (90\% \ c.l.)$. Other experiments are already about a factor of 100 less sensitive concerning the $0\nu\beta\beta$ half-life: the Gotthard TPC experiment with $^{136}\text{Xe}$ yields $T_{1/2}^{0\nu} > 4.4 \times 10^{23} \text{ y} \ (90\% \ c.l.)$ and the Milano Mibeta cryodetector experiment $^{138}T_{1/2}^{0\nu} > 1.44 \times 10^{23} \text{ y} \ (90\% \ c.l.)$.

Another experiment with enriched $^{76}\text{Ge}$, which has stopped operation in 1999 after reaching a significance of 8.8 kg y, yields (if one believes their method of ‘visual inspection’ in their data analysis), in a conservative analysis, a limit of about $T_{1/2}^{0\nu} > 5 \times 10^{24} \text{ y} \ (90\% \ c.l.)$. The $^{128}\text{Te}$ geochemical experiment yields $\langle m_\nu \rangle < 1.1 \text{ eV} \ (68\% \ c.l.)$ \textsuperscript{24} the DAMA $^{136}\text{Xe}$ experiment $\langle m_\nu \rangle < (1.1 - 2.9) \text{ eV}$ \textsuperscript{25} and the $^{130}\text{Te}$ cryogenic experiment yields $\langle m_\nu \rangle < 1.8 \text{ eV}$ \textsuperscript{48}.

Concluding we obtain, with about 95\% probability, first evidence for the neutrinoless double beta decay mode. As a consequence, at this confidence level, lepton number is not conserved. Further the neutrino is a Majorana particle. If the $0\nu\beta\beta$ amplitude is dominated by exchange of a massive neutrino the effective mass $\langle m_\nu \rangle$ is deduced to be $\langle m_\nu \rangle = (0.11 - 0.56) \text{ eV} \ (95\% \ c.l.)$, with best value of 0.39 eV. Allowing conservatively for an uncertainty of the nuclear matrix elements of $\pm 50\%$ (for detailed discussions of the status of nuclear matrix elements we refer to \textsuperscript{9, 4, 16} and references therein) this range may widen to $\langle m_\nu \rangle = (0.05 - 0.84) \text{ eV} \ (95\% \ c.l.)$.

Assuming other mechanisms to dominate the $0\nu\beta\beta$ decay amplitude, the result allows to set stringent limits on parameters of SUSY models, leptoquarks, compositeness, masses of heavy neutrinos, the right-handed $W$ boson and possible violation of Lorentz invariance and equivalence principle in the neutrino sector. For a discussion and for references we refer to \textsuperscript{9, 27, 38, 40, 50}.

With the limit deduced for the effective neutrino mass, the HEIDELBERG-MOSCOW experiment excludes several of the neutrino mass scenarios allowed from present neutrino oscillation experiments (see Fig. \textsuperscript{9}) - allowing only for degenerate and inverse hierarchy mass scenarios \textsuperscript{8}.

Assuming the degenerate scenarios to be realized in nature we fix - according to the formulae derived in \textsuperscript{7} - the common mass eigenvalue of the degenerate neutrinos to $m = (0.05 - 3.4) \text{ eV}$. Part of the upper range is already excluded by tritium experiments, which give a limit of $m < 2.2 - 2.8 \text{ eV} \ (95\% \ c.l.)$ \textsuperscript{32}. The full range can only partly (down to $\sim 0.5 \text{ eV}$) be checked by future tritium decay experiments, but could be checked by some future $\beta\beta$ experiments (see, e.g., next section). The deduced best value for the mass is consistent with expectations from experimental
Fig. 9. The impact of the evidence obtained for neutrinoless double beta decay in this paper (best value of the effective neutrino mass $\langle m \rangle = 0.39$ eV, 95% confidence range (0.05 - 0.84) eV – allowing already for an uncertainty of the nuclear matrix element of a factor of ± 50%) on possible neutrino mass schemes. The bars denote allowed ranges of $\langle m \rangle$ in different neutrino mass scenarios, still allowed by neutrino oscillation experiments (see 8). Hierarchical models are excluded by the new $0\nu\beta\beta$ decay result. Also shown are the expected sensitivities for the future potential double beta experiments CUORE, MOON, EXO and the 1 ton and 10 ton project of GENIUS 9, 38, 51, 29.

$\mu \to e\gamma$ branching limits in models assuming the generating mechanism for the neutrino mass to be also responsible for the recent indication for an anomalous magnetic moment of the muon 55. It lies in a range of interest also for Z-burst models recently discussed as explanation for super-high energy cosmic ray events beyond the GKZ-cutoff 53, 54, 57. A recent model with underlying $A_4$ symmetry for the neutrino mixing matrix also leads to degenerate neutrino masses consistent with the present result from $0\nu\beta\beta$ decay 56. The range of $\langle m \rangle$ fixed in this work is, already now, in the range to be explored by the satellite experiments MAP and PLANCK 31 (see Fig. 10).

The neutrino mass deduced leads to $0.002 \geq \Omega_{\nu}h^2 \leq 0.1$ and thus may allow neutrinos to still play an important role as hot dark matter in the Universe 37.

3. Future of $\beta\beta$ Experiments - GENIUS and Other Proposals

With the HEIDELBERG-MOSCOW experiment, the era of the small smart experiments is over. New approaches and considerably enlarged experiments (as discussed,
Fig. 10. Double beta decay observable $\langle m \rangle$ and oscillation parameters: The case for degenerate neutrinos. Plotted on the axes are the overall scale of neutrino masses $m_0$ and mixing $\tan^2 \theta_{12}$. Also shown is a cosmological bound deduced from a fit of CMB and large scale structure, and the expected sensitivity of the satellite experiments MAP and PLANCK. The present limit from tritium $\beta$ decay of 2.2 eV would lie near the top of the figure. The range of $\langle m \rangle$ fixed by the HEIDELBERG-MOSCOW experiment is, in the case of small solar neutrino mixing, already in the range to be explored by MAP and PLANCK.

E.g. in (9,31,12,29,38) will be required in future to fix the neutrino mass with higher accuracy.

Since it was realized in the HEIDELBERG-MOSCOW experiment, that the remaining small background is coming from the material close to the detector (holder, copper cap, ...), elimination of any material close to the detector will be decisive. Experiments which do not take this into account, like, e.g. CUORE and MAJORANA, will allow at best only rather limited steps in sensitivity. Furthermore there is the problem in cryodetectors that they cannot differentiate between a $\beta$ and a $\gamma$ signal, as this is possible in Ge experiments.

Another crucial point is - see eq. (4) - the energy resolution, which can be optimized only in experiments using Germanium detectors or bolometers. It will be difficult to probe evidence for this rare decay mode in experiments, which have to work - as result of their limited resolution - with energy windows around $Q_{\beta\beta}$ of several hundreds of keV, such as NEMO III, EXO, CAMEO.

Another important point is (see eq. 4), the efficiency of a detector for detection of a $\beta\beta$ signal. For example, with 14% efficiency a potential future 100 kg $^{82}\text{Se}$ NEMO experiment would be, because of its low efficiency, equivalent only to a
10 kg experiment (not talking about the energy resolution).

In the first proposal for a third generation double beta experiment, the GENIUS proposal,\cite{27,28,30,51,29,51} the idea is to use 'naked' Germanium detectors in a huge tank of liquid nitrogen. It seems to be at present the only proposal, which can fulfill both requirements mentioned above - to increase the detector mass and simultaneously reduce the background drastically. GENIUS would - with only 100 kg of enriched $^{76}\text{Ge}$ - increase the confidence level of the present pulse shape discriminated $0\nu\beta\beta$ signal to 4\sigma within one year, and to 7\sigma within three years of measurement (a confirmation on a 4\sigma level by the MAJORANA project would at least need \~330 years, the CUORE project would need (ignoring for the moment the problem of identification of the signal as a $\beta\beta$ signal) 3700 years). With ten tons of enriched $^{76}\text{Ge}$ GENIUS should be capable to investigate also whether the neutrino mass mechanism or another mechanism (see, e.g.\cite{9}) is dominating the $0\nu\beta\beta$ decay amplitude. A GENIUS Test Facility is at present under construction in the GRAN SASSO Underground Laboratory\cite{41,40}.

4. Conclusion
The status of present double beta decay search has been discussed, and recent evidence for a non-vanishing Majorana neutrino mass obtained by the HEIDELBERG-MOSCOW experiment has been presented. The latter opens a new era in space-time structure\cite{52}. It has been shown\cite{52} that the Majorana nature of the neutrino tells us that spacetime does realize a construct that is central to construction of supersymmetric theories.

Future projects to improve the present accuracy of the effective neutrino mass have been briefly discussed. The most sensitive of them and perhaps at the same time most realistic one, is the GENIUS project. GENIUS is the only of the new projects which simultaneously has a huge potential for cold dark matter search, and for real-time detection of low-energy neutrinos (see\cite{27,33,35,38,42,39,50}).

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