The GENIUS (Germanium in Liquid Nitrogen Underground Setup) project has been proposed in 1997 as first third generation double beta decay project, with a sensitivity aiming down to a level of an effective neutrino mass of $< m > \sim 0.01 - 0.001$ eV. Such sensitivity has been shown to be indispensable to solve the question of the structure of the neutrino mass matrix which cannot be solved by neutrino oscillation experiments alone. It will allow broad access also to many other topics of physics beyond the Standard Model of particle physics at the multi-TeV scale. For search of cold dark matter GENIUS will cover almost the full range of the parameter space of predictions of SUSY for neutralinos as dark matter. Finally, GENIUS has the potential to be the first real-time detector for low-energy (pp and $^{7}$Be) solar neutrinos. A GENIUS-Test Facility has just been funded and will come into operation by end of 2001.
Figure 1. Present situation, 2000, and expectation for the future, of the most promising $\beta\beta$ experiments. Light parts of the bars: present status; dark parts: expectation for running experiments; solid and dashed lines: experiments under construction or proposed experiments. For references see [12].

experiment for the next years, the time of the small smart experiments is over.

The requirements in sensitivity for future experiments to play a decisive role in the solution of the structure of the neutrino mass matrix are shown in Fig.2. Shown are the expectations for the effective neutrino mass (the observable in $\beta\beta$ decay) from the present experimental status of all existing neutrino oscillation experiments in the different presently experimentally favored neutrino mass models.

It can be seen that a sensitivity down to $<m_\nu> \approx 0.001$ eV as it may be reached only by the GENIUS project will be able to test all neutrino scenarios allowed by the oscillation experiments, except for one, the not favoured hierarchical LOW solution. For details see [8].

To reach this level of sensitivity $\beta\beta$ experiments have to become large. A source strength of up to 10 tons of enriched material touches the world production limits. At the same time the background has to be reduced by a factor of 1000 and more compared to that of the HEIDELBERG-MOSCOW experiment.

Table 1 lists some key numbers for GENIUS, and of the main other proposals made after the GENIUS proposal. Their potential is shown also in Fig.2. It is seen that not all of these proposals fully cover the region to be probed. Among them is also the recently presented MAJORANA project.

In the GENIUS project a reduction by a factor of more than 1000 down to a background level of 0.1 events/tomme y keV in the range of $0\nu\beta\beta$ is reached by removing all material close to the detectors, and by using naked Germanium detectors in a large tank of liquid nitrogen. It has been shown that the detectors show excellent performance under such conditions.

For technical questions and extensive Monte Carlo simulations of the GENIUS project for its application in double beta decay we refer to.
Figure 3. WIMP-nucleon cross section limits in pb for scalar interactions as function of the WIMP mass in GeV. Shown are contour lines of present experimental limits (solid lines) and of projected experiments (dashed lines). Also shown is the region of evidence published by DAMA. The theoretical expectations are shown by a scatter plot (from [4]) and by the grey region (from [11]).

3. GENIUS and Other Beyond Standard Model Physics

GENIUS will allow besides the major step in neutrino physics described in section 2 the access to a broad range of other beyond SM physics topics in the multi-TeV range. Already now $\beta\beta$ decay probes the TeV scale on which new physics should manifest itself (see, e.g. [10]). Basing to a large extent on the theoretical work of the Heidelberg group in the last four years, the HEIDELBERG-MOSCOW experiment yields results for SUSY models (R-parity breaking, sneutrino mass), leptoquarks (leptoquarks-Higgs coupling), compositeness, right-handed W mass, nonconservation of Lorentz invariance and equivalence principle, mass of a heavy left or right-handed neutrino, competitive to corresponding results from high-energy accelerators like TEVATRON and HERA.

The potential of GENIUS extends into the multi-TeV region for these fields and its sensitivity would correspond to that of LHC or NLC and beyond (for details see [10]).

4. GENIUS and Cold Dark Matter Search

Already now the HEIDELBERG-MOSCOW experiment is the most sensitive Dark Matter experiment worldwide concerning the raw data. GENIUS would already in a first step, with 100 kg of natural Ge detectors, cover a significant part of the MSSM parameter space for prediction of neutralinos as cold dark matter (Fig. 3). For this purpose the background in the energy range < 100 keV has to be reduced to $10^{-2}$ events/kg y keV, which is possible if the detectors are produced and handled on Earth surface under heavy shielding, to reduce the cosmogenic background produced by spallation through cosmic radiation (critical products are tritium, $^{68}$Ge, $^{63}$Ni, ...) to a minimum. For details we refer to [5]. Fig. 3 shows together with the expected sensitivity of GENIUS predictions for neutralinos as dark matter by two models, one basing on supergravity [11], another starting from more relaxed unification conditions [4].

The sensitivity of GENIUS for Dark Matter corresponds to that obtainable with a 1 km$^3$ AMANDA detector for indirect detection (neutrinos from neutralino annihilation at the Sun). Interestingly both experiments would probe different neutralino compositions: GENIUS mainly gaugino-dominated neutralinos, AMANDA mainly neutralinos with comparable gaugino and Higgsino components. It should be stressed that, together with DAMA, GENIUS will be the only future Dark Matter experiment, which would be able to positively identify a dark matter signal by the seasonal modulation signature. This cannot be achieved, for example, by the CDMS experiment.

5. GENIUS and Low-Energy Solar Neutrinos

Gallex and Sage measure $\text{pp + }^7\text{Be + }^8\text{B}$ neutrinos (60 + 30 + 10%) down to 0.24 MeV, the
Figure 4. Simulated cosmogenic background during detector production. Assumptions: 30 days exposure of material before processing, 1 d activation after zone refining, 3 y deactivation underground (see [12]).

Chlorine experiment measured $^7\text{Be} + ^8\text{B}$ neutrinos (80% $^8\text{B}$) above $E_\nu = 0.817$ MeV, all without spectral, time and detection information. No experiment has separately measured the pp and $^7\text{Be}$ neutrinos and no experiment has measured the full pp $\nu$ flux. BOREXINO plans to measure $^7\text{Be}$ neutrinos, the access to pp neutrinos being limited by $^{14}\text{C}$ contamination (the usual problem of organic scintillators). GENIUS could be the first detector measuring the full pp (and $^7\text{Be}$) neutrino flux in real time.

Extending the radius of GENIUS to 13 m and improving some of the shielding parameters as described in [12], the background can be reduced to a level of $10^{-3}$ events/ kg y keV (Fig. 4) (see also [12]). This will allow to look for the pp and $^7\text{Be}$ solar neutrinos by elastic neutrino-electron scattering with a threshold of 11 keV or at most 19 keV (limit of possible tritium background) (Fig. 5) which would be the lowest threshold among other proposals to detect pp neutrinos, such as HERON, HELLAZ, NEON, LENS, MOON, XMASS.

The counting rate of GENIUS (10 ton) would be 6 events per day for pp and 18 per day for $^7\text{Be}$ neutrinos, i.e. similar to BOREXINO, but by a factor of 30 to 60 larger than a 20 ton LENS detector and a factor of 10 larger than the MOON detector.

6. GENIUS - Test Facility

Construction of a test facility for GENIUS - GENIUS-TF - consisting of ~ 40 kg of HP Ge detectors suspended in a liquid nitrogen box has been started. Up to end of 2000, three detectors each of ~ 2.5 kg and with a threshold of as low as ~ 500 eV have been produced.

Besides test of various parameters of the GENIUS project, the test facility would allow, with the projected background of 4 events/kg y keV in the low-energy range, to probe the DAMA evidence for dark matter by the seasonal modulation signature within about one year of measurement with 95% c.l.. Even for an initial lower mass of 20 kg the time scale would be not larger than three years (for details see [13,14]). If using the enriched $^{76}\text{Ge}$ detectors of the HEIDELBERG-MOSCOW
experiment in the GENIUS-TF setup, a background in the $0\nu\beta\beta$ region a factor 30 smaller than in the HEIDELBERG-MOSCOW experiment could be obtained, which would allow to test the effective Majorana neutrino mass down to 0.15 eV (90\% c.l.) in 6 years of measurement. This limit is similar to what much larger experiments aim at, at much larger time scale (see Table 1.).

7. Conclusion

The GENIUS project is - among the projected or discussed other third generation double beta detectors - the one which exploits this method to obtain information on the neutrino mass to the ultimate limit. Nature is extremely generous to us, that with an increase of the sensitivity by two orders of magnitude compared to the present limit, down to $< m_\nu > \sim 10^{-3}$ eV, indeed essentially all neutrino scenarios allowed by present neutrino oscillation experiments can be probed.

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.

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Table 1
Some key numbers of future double beta decay experiments (and of the HEIDELBERG-MOSCOW experiment). Explanations: \( \triangledown \) - assuming the background of the present pilot project. \( ** \) - with matrix element from [Sta90*-II], [Tom91**-I], [Hax84**-I], [Wu91*-II], [Wu92*-II] (see Table II in [HM99*-III]). \( \bigtriangleup \) - this case shown to demonstrate the ultimate limit of such experiments. For details see [7].

| \( \beta\beta \)-Isotope | Name                  | Status   | Mass (tonnes) | Assumed backgr. \( \uparrow \) events/kg y keV, \( \downarrow \) events/kg y FWHM, \( \ast \) events/yFWHM | Running Time (tonn.years) | Results limit for \( 0\nu\beta\beta \) half-life (years) | \( <m_{\nu}> \) (eV) |
|--------------------------|-----------------------|----------|---------------|-------------------------------------------------|-------------------------|----------------------------------------------------------------|------------------|
| 76Ge                     | HEIDELBERG MOSCOW     | running  | 0.011 (enriched) | \( \uparrow 0.06 \) \( \downarrow 0.24 \ast 2 \) | 35.5 kg y               | \( 1.9 \cdot 10^{25} \) < 0.34 \( 90\% \) c.l. \( 3.1 \cdot 10^{25} \) < 0.26 \( 68\% \) c.l. NOW !! | \( \bigtriangleup \) |
| 100Mo                    | NEMO III [NEM2000]    | under constr. | \( \sim 0.01 \) (enriched) | \( \uparrow 0.0005 \) \( \downarrow 0.2 \ast 2 \) | 50 kg y 10^{24–25} 0.3–0.7 | \( \bigtriangleup \) |
| 130Te                    | CUORE [Gu1998*-]VI   | Proposal  | 0.75 (natural) | \( \uparrow 0.5 \) \( \downarrow 4.5 \ast 1000 \) | 5 9 \cdot 10^{24} 0.2–0.5 | \( \bigtriangleup \) |
| 136Xe                    | EXO Proposal [Dan2000a] | 1 * 0.6 | 10 8.3 \cdot 10^{26} 0.05–0.14 | \( \bigtriangleup \) |
| 76Ge                     | GENIUS Proposal [Kla97**-VI] | 1 (enrich.) | \( \uparrow 0.04 \cdot 10^{-3} \) \( \downarrow 0.15 \cdot 10^{-3} \ast 1.5 \ast 1.5 \) | 1 5.8 \cdot 10^{27} 0.02–0.05 | \( \bigtriangleup \) |
| 76Ge                     | GENIUS Proposal [Kla97**-VI] | 10 (enrich.) | \( \uparrow 0.15 \cdot 10^{-3} \) | 10 6 \cdot 10^{28} 0.006–0.016 | \( \bigtriangleup \) |

* \( \ast \) events/kg y FWHM, \( \ast \) events/yFWHM

For details see [7].
Elsevier instructions for the preparation of a 2-column format camera-ready paper in \LaTeX

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1.1. Spacing

We normally recommend the use of 1.0 (single) line spacing. However, when typing complicated mathematical text \LaTeX automatically increases the space between text lines in order to prevent sub- and superscript fonts overlapping one another and making your printed matter illegible.

1.2. Fonts

These instructions have been produced using a 10 point Computer Modern Roman. Other recommended fonts are 10 point Times Roman, New Century Schoolbook, Bookman Light and Palatino.

2. PRINTOUT

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The printout submitted should be an original; a photocopy is not acceptable. Please make use of good quality plain white A4 (or US Letter) paper size. The dimensions shown here should be strictly adhered to: do not make changes to these dimensions, which are determined by the \LaTeX document class. The document class leaves at least 3 cm at the top of the page before the head, which contains the page number.

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\textsuperscript{*}Footnotes should appear on the first page only to indicate your present address (if different from your normal address), research grant, sponsoring agency, etc. These are obtained with the \texttt{\textbackslash thanks} command.
3. TABLES AND ILLUSTRATIONS

Tables should be made with \LaTeX{}; illustrations should be originals or sharp prints. They should be arranged throughout the text and preferably be included on the same page as they are first discussed. They should have a self-contained caption and be positioned in flush-left alignment with the text margin within the column. If they do not fit into one column they may be placed across both columns (using \texttt{\begin{table*}} or \texttt{\begin{figure*}} so that they appear at the top of a page).

3.1. Tables

Tables should be presented in the form shown in Table 1. Their layout should be consistent throughout.

Horizontal lines should be placed above and below table headings, above the subheadings and at the end of the table above any notes. Vertical lines should be avoided.

If a table is too long to fit onto one page, the table number and headings should be repeated above the continuation of the table. For this you have to reset the table counter with \texttt{\addtocounter{table}{-1}}. Alternatively, the table can be turned by 90° (‘landscape mode’) and spread over two consecutive pages (first an even-numbered, then an odd-numbered one) created by means of \texttt{\begin{table*}} without a caption. To do this, you prepare the table as a separate \LaTeX{} document and attach the tables to the empty pages with a few spots of suitable glue.

3.2. Useful table packages

Modern \LaTeX{} comes with several packages for tables that provide additional functionality. Below we mention a few. See the documentation of the individual packages for more details. The packages can be found in \LaTeX{}'s \texttt{tools} directory.

array Various extensions to \LaTeX{}’s \texttt{array} and \texttt{tabular} environments.

longtable Automatically break tables over several pages. Put the table in the \texttt{longtable} environment instead of the \texttt{table} environment.

\begin{table}[h]
\centering
\begin{tabular}{cccccc}
\hline
\multicolumn{3}{c}{The next-to-leading order (NLO) results without the pion field.} \\
\multicolumn{3}{c}{\L\ (MeV)} & \multicolumn{3}{c}{Exp.} \\
140 & 150 & 175 & 200 & 225 & 250 \\
\hline
\hline
$\Lambda$ & 1.972 & 1.974 & 1.978 & 1.983 & 1.987 & 1.996(7) \\
$\rho_d$ & 0.259 & 0.268 & 0.287 & 0.302 & 0.312 & 0.321 \\
$Q_d$ & 2.32 & 2.83 & 6.14 & 9.90 & 1.23 & 0.847 \\
$P_d$ & 0.878 & 0.895 & 0.937 & 1.185 & 1.570 & 2.156 \\
$\mu_d$ & 4.887 & 4.881 & 4.864 & 4.846 & 4.827 & 4.810 \\
$\delta_{\text{VP}}$ & 0.867 & 0.864 & 0.855 & 0.845 & 0.834 & 0.823 \\
$\delta_{\text{C2:C}}$ & 0.03 & 0.03 & 0.03 & 0.03 & 0.03 & 0.03 \\
$\delta_{\text{C2:N}}$ & 0.03 & 0.03 & 0.03 & 0.03 & 0.03 & 0.03 \\
\hline
\end{tabular}
\end{table}

The experimental values are given in ref. [4].
Table 1
The next-to-leading order (NLO) results without the pion field.

| Λ (MeV) | 140  | 150  | 175  | 200  |
|---------|------|------|------|------|
| r_d (fm) | 1.973 | 1.972 | 1.974 | 1.978 |
| Q_d (fm^2) | 0.259 | 0.268 | 0.287 | 0.302 |
| P_D (%) | 2.32  | 2.83  | 4.34  | 6.14  |
| μ_d | 0.867 | 0.864 | 0.855 | 0.845 |
| M_{M1} (fm) | 3.995 | 3.989 | 3.973 | 3.955 |
| M_{GT} (fm) | 4.887 | 4.881 | 4.864 | 4.846 |
| δ_{VP} (%) | -0.45 | -0.45 | -0.45 | -0.45 |
| δ_{C2:C}^{1B} (%) | 0.03  | 0.03  | 0.03  | 0.03  |
| δ_{C2:N}^{1B} (%) | -0.19 | -0.19 | -0.18 | -0.15 |

The experimental values are given in ref. [4].

3.3. Line drawings
Line drawings should be drawn in India ink on tracing paper with the aid of a stencil or should be glossy prints of the same; computer prepared drawings are also acceptable. They should be attached to your manuscript page, correctly aligned, using suitable glue and not transparent tape. When placing a figure at the top of a page, the top of the figure should be at the same level as the bottom of the first text line.

All notations and lettering should be no less than 2 mm high. The use of heavy black, bold lettering should be avoided as this will look unpleasantly dark when printed.

3.4. PostScript figures
Instead of providing separate drawings or prints of the figures you may also use PostScript files which are included into your \LaTeX file and printed together with the text. Use one of the packages from \LaTeX’s graphics directory: graphics, graphicx or epsfig, with the \usepackage command, and then use the appropriate commands (\includegraphics or \epsfig) to include your PostScript file.

The simplest command is:
\includegraphics{file}, which inserts the PostScript file file at its own size. The starred version of this command:
\includegraphics*{file}, does the same, but clips the figure to its bounding box.

With the graphicx package one may specify a series of options as a key–value list, e.g.:
\includegraphics[width=15pc]{file}
\includegraphics[height=5pc]{file}
\includegraphics[angle=90,width=20pc]{file}
\includegraphics[angle=90, width=20pc]{file}

See the file grfguide, section “Including Graphics Files”, of the graphics distribution for all options and a detailed description.

The epsfig package mimicks the commands familiar from the package with the same name in \LaTeX2.09. A PostScript file file is included with the command \psfig{file=file}.

Grey-scale and colour photographs cannot be included in this way, since reproduction from the
3.5. Black and white photographs
Photographs must always be sharp originals (not screened versions) and rich in contrast. They will undergo the same reduction as the text and should be pasted on your page in the same way as line drawings.

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Sharp originals (not transparencies or slides) should be submitted close to the size expected in publication. Charges for the processing and printing of colour will be passed on to the author(s) of the paper. As costs involved are per page, care should be taken in the selection of size and shape so that two or more illustrations may be fitted together on one page. Please contact the Technical Editor in the Camera-Ready Publications Department at Elsevier for a price quotation and layout instructions before producing your paper in its final form.

4. EQUATIONS
Equations should be flush-left with the text margin; \texttt{\LaTeX} ensures that the equation is preceded and followed by one line of white space. \texttt{\LaTeX} provides the package \texttt{fleqn} to get the flush-left effect.

\[ H_{\alpha\beta}(\omega) = E^{(0)}(\omega)\delta_{\alpha\beta} + \langle \alpha|W_{\pi}|\beta \rangle \]  

You need not put in equation numbers, since this is taken care of automatically. The equation numbers are always consecutive and are printed in parentheses flush with the right-hand margin of the text and level with the last line of the equation. For multi-line equations, use the \texttt{eqnarray} environment. For complex mathematics, use the \texttt{AMSLaTeX} package.

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References should be collected at the end of your paper. Do not begin them on a new page unless this is absolutely necessary. They should be prepared according to the sequential numeric
system making sure that all material mentioned is generally available to the reader. Use \cite to refer to the entries in the bibliography so that your accumulated list corresponds to the citations made in the text body.

Above we have listed some references according to the sequential numeric system [1–4].