# GENIUS - A New Facility of Non-Accelerator Particle Physics

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The GENIUS (Germanium in Liquid Nitrogen Underground Setup) project has been proposed in 1997 [1] 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 [2]. 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 [3,4]. Finally, GENIUS has the potential to be the first real-time detector for low-energy (pp and $^7Be$) solar neutrinos [6,5]. A GENIUS-Test Facility has just been funded and will come into operation by end of 2001.

## 1. Introduction

Underground physics can complement in many ways the search for New Physics at future colliders such as LHC and NLC and can serve as important bridge between the physics that will be gleaned from future high energy accelerators on the one hand, and satellite experiments such as MAP and PLANCK on the other [7]. The first indication for beyond SM physics indeed has come from underground experiments (neutrino oscillations from SK), and this type of physics will play an even large role in the future.

Concerning neutrino physics, without double beta decay there will be no solution of the nature of the neutrino (Dirac or Majorana particle) and of the structure of the neutrino mass matrix. Only investigation of $\nu$ oscillations *and* double beta decay together can lead to an absolute mass scale.

Concerning the search for cold dark matter, even a discovery of SUSY by LHC will not have proven that neutralinos form indeed the cold dark matter in the Universe. Direct detection of the latter by underground detectors remains indispensable. Concerning solar neutrino physics, present information on possible $\nu$ oscillations relies on 0.2% of the solar neutrino flux. The total pp neutrino flux has not been measured and also no real-time information is available for the latter.

The GENIUS project proposed in 1997 (see [1, 7]) as the first third generation $\beta\beta$ detector, could attack all of these problems with an unpredented sensitivity.

## 2. GENIUS, Double Beta Decay and the Light Majorana Neutrino Mass

Present double beta experiments are not able to reach a limit for the (effective) neutrino mass below $\sim$ 0.1 eV. The most sensitive experiment is *since eight years* the HEIDELBERG-MOSCOW experiment using the world's largest source strength of 11 kg of 86% enriched $^{76}Ge$ in form of 5 high-purity Ge detectors, run in the Gran Sasso Underground laboratory. The limits reached after 37.24 kg y of measurement $T^{0\nu}_{1/2} > 3.5(2.1) \cdot 10^{25}y$ and $< m_\nu >< 0.26(0.34)eV$, 68% and 90% c.l., respectively.

The status and potential of other experiments are shown in Fig. 1.

With the era of the HEIDELBERG-MOSCOW experiment which will remain the most sensitive

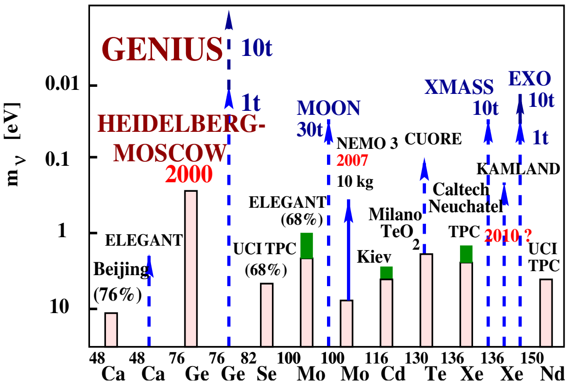


Figure 1. Present situation, 2000, and expectation for the future, of the most promising $\beta\beta$ experiments. Light parts of the bars: present status; dark parts: expectation for running experiments; solid and dashed lines: experiments under construction or proposed experiments. For references see [12].

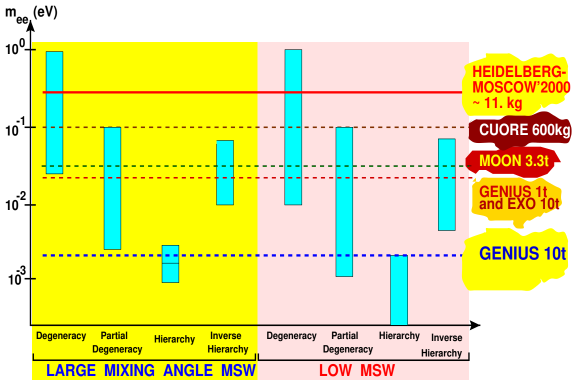


Figure 2. Values expected from $\nu$ oscillation experiments for $m_{ee} \equiv (< m_\nu >)$ in different schemes. The expectations are compared with the present neutrino mass limits *obtained* from the HEIDELBERG-MOSCOW experiment as well as the *expected* sensitivities for the CUORE, MOON, EXO proposals and the 1 ton and 10 ton proposal of GENIUS [8]. For references and more details about the different experiments see [7,12].

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 [2,8].

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 [2,8,9].

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/tonne 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 [5].

For technical questions and extensive Monte Carlo simulations of the GENIUS project for its application in double beta decay we refer to [5].

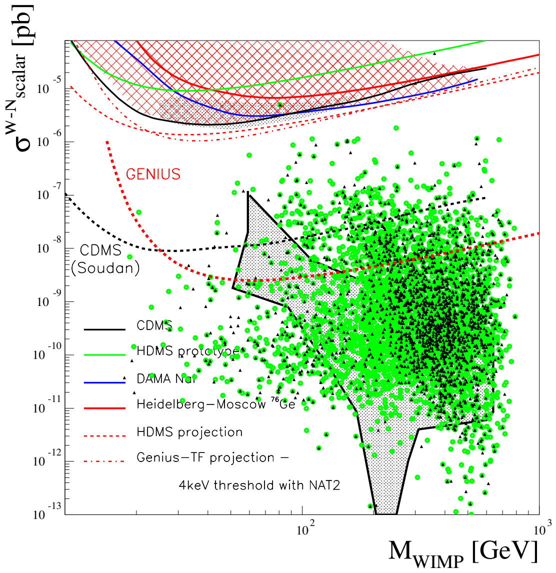


Figure 3. WIMP-nucleon cross section limits in pb for scalar interactions as function of the WIMP mass in GeV. Shown are contour lines of present experimental limits (solid lines) and of projected experiments (dashed lines). Also shown is the region of evidence published by DAMA. The theoretical expectations 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. [1,10]). 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 righthanded 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 [7,10]).

## 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 pp + $^7Be$ + $^8B$ neutrinos (60 + 30 + 10%) down to 0.24 MeV, the

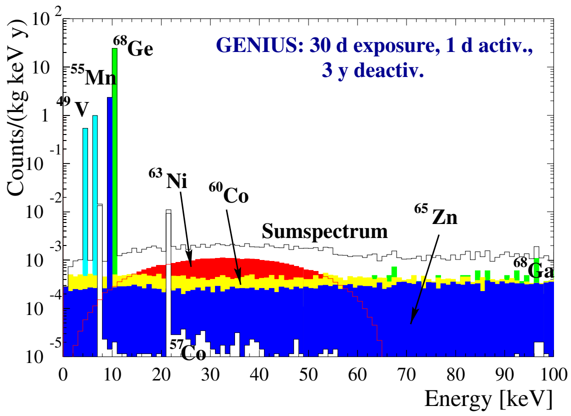


Figure 4. Simulated cosmogenic background during detector production. Assumptions: 30 days exposure of material before processing, 1 d activation after zone refining, 3 y deactivation underground (see [12]).

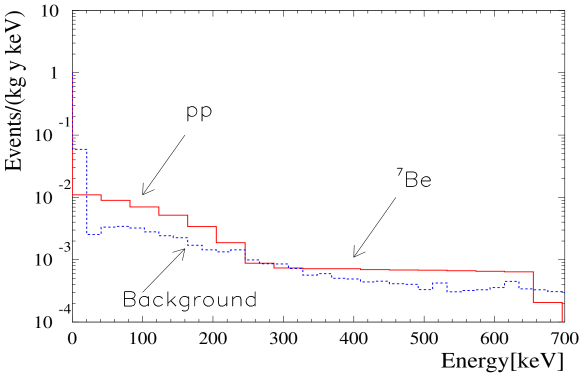


Figure 5. Simulated spectrum of low-energy solar neutrinos (according to SSM) for the GENIUS detector (1 tonne natural or enriched Ge) (from [6]).

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

Extending the radius of GENIUS to 13 m and improving some of the shielding parameters as described in [5,6] 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 $^7Be$ 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 $^7Be$ 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 $\sim$ 40 kg of HP Ge detectors suspended in a liquid nitrogen box has been started. Up to end of 2000, three detectors each of $\sim$ 2.5 kg and with a threshold of as low as $\sim$ 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 $^{76}Ge$ 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: $\nabla$ - 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]). $\triangle$ - this case shown to demonstrate **the ultimate limit** of such experiments. For details see [7].

| $\beta\beta-$ *Isoto−* pe | *Name* | *Status* | Mass (*ton−* nes) | Assumed backgr. † events/ kg y keV, ‡ events/kg y FWHM, $*$ events /yFWHM | Run- *ning* Time (tonn. years) | Results limit for $0\nu\beta\beta$ half-life (years) | $<m_\nu>$ ( eV ) |
|---|---|---|---|---|---|---|---|
| **$^{76}$Ge** | **HEIDEL- BERG MOSCOW [Kla99e**] [HM2000*] [-III]** | **run- ning** | 0.011 (enri- ched) | † 0.06<br>‡ 0.24<br>$*$ 2 | **35.5 kg y** | **$1.9 \cdot 10^{25}$ 90% c.l. $3.1 \cdot 10^{25}$ 68% c.l. NOW !!** | **$<$ 0.34 $**$ 90% c.l. $<$ 0.26 $**$ 68% c.l. NOW !!** |
| **$^{100}$Mo** | NEMO III [NEM2000] | *under constr.* | ~0.01 (enri- -ched) | † **0.0005**<br>‡ 0.2<br>$*$ 2 | 50 kg y | $10^{24-25}$ | 0.3-0.7 |
| **$^{130}$Te** | CUORE$^{\nabla}$ [Gui99a* -VI] | Pro- posal | 0.75 (natu- ral) | † 0.5<br>‡ 4.5<br>$*$ 1000 | 5 | $9 \cdot 10^{24}$ | 0.2-0.5 |
| **$^{130}$Te** | CUORE | Pro- posal | 0.75 (natu- ral) | † 0.005<br>‡ 0.045<br>$*$ 45 | 5 | $9 \cdot 10^{25}$ | 0.07-0.2 |
| **$^{100}$Mo** | MOON [Eji99b* -VI] | idea | 10 (en- rich.)<br>100 (nat.) | ? | 30<br>300 | ? | 0.03 |
| **$^{136}$Xe**<br>**$^{136}$Xe** | EXO<br>[Dan2000a] | Pro-<br>posal | 1<br>10 | $*$ 0.4<br>$*$ 0.6 | 5<br>10 | $8.3 \cdot 10^{26}$<br>$1.3 \cdot 10^{28}$ | 0.05-0.14<br>0.01-0.04 |
| **$^{76}$Ge** | **GENIUS** [Kla97** -VI] | Pro- posal | 1 (enrich.)<br>1 | † $\mathbf{0.04 \cdot 10^{-3}}$<br>‡ $\mathbf{0.15 \cdot 10^{-3}}$<br>$*$ **0.15**<br>$*$ **1.5** | 1<br>10 | $\mathbf{5.8 \cdot 10^{27}}$<br>$\mathbf{2 \cdot 10^{28}}$ | **0.02-0.05**<br>**0.01-0.028** |
| **$^{76}$Ge** | **GENIUS** [Kla97**- -VI] | Pro-<br>posal | 10<br>(enrich.) | ‡ $\mathbf{0.15 \cdot 10^{-3}}$<br>$\mathbf{0^{\triangle}}$ | 10<br>10 | $\mathbf{6 \cdot 10^{28}}$<br>$\mathbf{5.7 \cdot 10^{29}}$ | **0.006 - 0.016**<br>**0.002 - 0.0056** |