SEARCH FOR DOUBLE BETA DECAY AT THE GOTTHARD UNDERGROUND LAB

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Abstract

A search for double beta decay in ^{76}Ge using a Ge detector array is presently being performed at the Gotthard underground lab. Results obtained after the first 1900 h of data taking on 0ν, 2ν and χ^0 double beta decay are presented.

1 Introduction

The Caltech-Neuchâtel-SIN collaboration is engaged in a program to search for double beta decay. The most exciting sought-after mode is neutrinoless (0ν) double beta decay, which will occur if neutrinos are massive Majorana particles [1]. The observation of double beta decay with emission of a Majoron χ^0 would also signal new physics and has been carefully looked for. The allowed two neutrino (2ν) decay mode is not of fundamental importance, but it allows, to a point, to check the nuclear physics calculations necessary to translate the measured half lives into more fundamental quantities, like the neutrino mass [2].

The experiments are all performed in the Gotthard underground lab at a depth of 3000 m.w.e. where the cosmics backgrounds, direct or induced, are minimal. In a first step ^{76}Ge was studied with a 90 cc Ge detector [3]. This part of the experimental program is finished. A second experiment, conceptually very similar but using a much larger Ge detector array is running now. Preliminary results are available [4] and will be presented in the following. A third experiment is in preparation. It will use a TPC filled with Xe.

2 The Ge detector array

The Ge detector array (fig. 1) consists of eight crystals of 140 cc active volume each inside one cryostat. The total energy deposited is measured. Natural Ge contains 7.7% ^{76}Ge. The released energy in this nucleus is 2040.6 ± 0.5 keV. This detector was made, like the 90 cc one, from carefully selected low activity materials to achieve a low background. Copper was chosen for the cryostat. No anti-Compton detector is used. No anti-cosmic veto is necessary. The detector is shielded against local activities by 20 cm of Cu and 20 cm of Pb. Data accumulated during a total of 1900 h, corresponding to 1.30 $kg \cdot y$ have been analyzed so far. The energy resolution is 2.2 keV at 1.460 MeV. The total energy spectrum is shown in fig. 2. The continuous background above 0.7 MeV is rather low and these data are particularly sensitive to 2ν decay, which would give rise to a broad two electron spectrum peaking at 0.7 MeV, and to χ^0 decay, the two electron spectrum of which has a maximum around 1.5 MeV. To obtain meaningful limits the known backgrounds, essentially due γ and e^+ activities, must be subtracted.

The γ background is thought to come primarily from three sources:

i) activity from the ^{232}Th and ^{238}U chains, and from ^{40}K,

ii) long lived n activation of the detector and the shielding, from when they were above ground ($^{63}Cu(n,\alpha)^{60}Co$, $^{70}Ge(n,\alpha 2n)^{65}Zn$...),

iii) and, below 0.7 MeV artificial activity (^{134}Cs, ^{137}Cs,...).

The strength of these backgrounds is obtained from the total counts in the observed peaks. The location of the ^{238}U and ^{232}Th contaminations can be estimated from the measured intensity ratios of the peaks in the chains, since the absorption of γ's through matter is energy dependent. It turns out that the ^{238}U is distributed more or less homogeneously throughout the detector and shielding, while the ^{232}Th is close to the Ge crystals. The ^{40}K spectrum has a single peak only, but it is fairly strong, and the peak to continuum ratio can be determined directly. It shows that this contamination is nearby the crystals. The nuclei produced cosmogenically in

Cu must be everywhere in the cryostat and the shielding, those in Ge are inside the crystals. Using these informations the total continuous background associated with the peaks was calculated by Monte-Carlo, taking into account Compton and photo effect, pair creation and annihilation, wall effects, and bremsstrahlung.

The e^+ background comes from ^{68}Ge (Q=1.9 MeV) produced above ground in the n activation of ^{70}Ge in the Ge crystals themselves:

$$^{70}Ge(n,3n)^{68}Ge \quad \xrightarrow[288d]{EC} \quad ^{68}Ga \quad \xrightarrow[68m]{e^+(86\%)} \quad ^{68}Zn$$

The shape of this background, which decreases with time, can be reliably calculated. Its strength was determined from the measured intensity of the X-rays emitted after the electron capture in ^{68}Ge, and from the observed decrease in time of the continuous background above 1 MeV.

3 Limits on 2ν and χ^0 double beta decay

The total known background is then subtracted from the measured data, leaving a spectrum consistent with zero (fig. 2). There is no indication of 2ν or χ^0 double beta decay. Lower limits on the half lives were obtained from the upper limit of the integral rate, in the region from 1.5 to 2 MeV for χ^0 decay and from 0.7 to 2 MeV for 2ν decay, yielding:

$$T_{1/2}^{2\nu} > \begin{array}{ll} 5.0 \cdot 10^{20} y & (68\% CL) \\ 2.0 \cdot 10^{20} y & (90\% CL) \end{array}$$

$$T_{1/2}^{\chi^0} > \begin{array}{ll} 1.0 \cdot 10^{21} y & (68\% CL) \\ 0.8 \cdot 10^{21} y & (90\% CL) \end{array}$$

The 2ν limit cuts into the range $T_{1/2}^{2\nu} = (1.5 - 13) \cdot 10^{20} y$ allowed by the calculation of Engel, Vogel and Zirnbauer, when using input data from ordinary beta decay [5]. This is consistent with the trend observed in other double beta decay candidates like ^{130}Te, ^{128}Te and ^{82}Se, where the measured half lives are systematically longer than the predicted ones [2]. The nuclear physics parameters in the Engel, Vogel and Zirnbauer calculation can however, without dramatic change, be adapted to reproduce these measured half lives. The predicted range for ^{76}Ge is then $T_{1/2}^{2\nu} = (1.5 - 30) \cdot 10^{21} y$, quite a bit higher than our measured value. The calculations by Civitarese, Faessler and Tomoda [6] ($T_{1/2}^{2\nu} > 6 \cdot 10^{19} y$) and Muto and Klapdor [7] ($T_{1/2}^{2\nu} > 3.1 \cdot 10^{20} y$) give lower limits which are less stringent, and are in full agreement with our result.

Our limit for χ^0 decay does not rely on any assumption on the shape of the background. It is somewhat worse, but maybe somewhat safer, than our previous result ($T_{1/2}^{\chi^0} > 1.2 \cdot 10^{21} y$ ($90\% CL$)) from data obtained with our 90 cc *Ge* detector under the assumption of a smooth background [3]. It should be stressed here however that the smoothness assumption is reasonable. All possible background sources we can think of are smooth in the energy region considered. In particular we have verified by calculations and measurements with a source that the spectrum of cosmogenically produced ^{60}Co in the Cu shielding above 1.5 MeV has no kinks which could mask the bump from the χ^0 decay, as claimed by Avignone and coworkers [8]. In any events our results exclude double beta decay with χ^0 emission with a half life comparable to that reported by the PNL-USC collaboration ($T_{1/2}^{\chi^0} = (6 \pm 1) \cdot 10^{20} y$)[9]. The UCSB-LBL collaboration, which operates a detector system of size comparable to ours, reached a similar conclusion [10].

4 Limit on 0ν double beta decay

Neutrinoless double beta decay from the initial 0+ state to the final 0+ state would manifest itself as a peak at the full decay energy of 2040.6 ± 0.5 keV. Around that energy our resolution is 2.7 keV FWHM, and the continuous background is 3 $counts \cdot keV^{-1} \cdot kg^{-1} \cdot y^{-1}$. No obvious peak is present (fig. 3). To be more quantitative χ^2 values were computed for various hypothesis. A form of χ^2 valid even when the number of counts per channel is low had to be used [4], [11]. The best χ^2 calculated for a flat free background is not significantly worse than the one computed with, in addition, a gaussian peak of known position and resolution, but a free height. Upper limits on the number of counts in the peak were derived by varying the height of the peak until a significant increase of the χ^2 was obtained. They correspond to the following limits on the half life:

$$T_{1/2}^{0\nu}(0+ \rightarrow 0+) > \begin{array}{ll} 3.0 \cdot 10^{23} y & (68\% CL) \\ 1.9 \cdot 10^{23} y & (90\% CL) \end{array}$$

This result is not as good as the one of the UCSB-LBL collaboration [10], essentially because our data set still is limited. Nevertheless it is interesting to see what it means in terms of the neutrino mass m_ν. At $68\% CL$ the limit using the Engel, Vogel, Zirnbauer calculation normalized to ordinary beta decay becomes: $m_\nu < 9 - 22\ eV$. The same calculation normalized to double beta decay gives limits lower by a factor of 2 roughly [2]. The limit using the Civitarese, Faessler and Tomoda calculations is not too different: $m_\nu < 3.1\ eV$. Majorana neutrinos with masses larger than say 10 eV thus appear unlikely.

It is also interesting to look for 0ν decay to the 2+ first excited state. In 30% of the cases the 559 keV deexcitation γ ray can escape from our crystals without interacting, giving rise to events with total energy deposition 1482 keV. There is no indication of a peak at that energy. Using the formalism described above we find the limits:

$$T_{1/2}^{0\nu}(0+ \rightarrow 2+) > \begin{array}{ll} 7 \cdot 10^{22} y & (68\% CL) \\ 3 \cdot 10^{22} y & (90\% CL) \end{array}$$

Our data do not confirm the indication found by the Bordeaux-Zaragoza collaboration for this decay [12].

5 Conclusion

The experiment is continuing and we hope that with increased statistics and more systematic studies we will be able to understand better the background, and improve our sensitivity to 2ν and χ^0 double beta decay of ^{76}Ge. Higher statistics will also lead to improved results on 0ν double beta decay. It seems important however, in view of the large uncertainties still afflicting the nuclear physics calculations, and the large differences which appear between nuclei, to extend the search for double beta decay to candidates other than ^{76}Ge. We thus plan to search for double beta decay in ^{136}Xe using a TPC built at Caltech and which will be installed in the Gotthard lab. It will be filled with 60% enriched ^{136}Xe at 5 atm pressure. The active volume will be 200 l.

References

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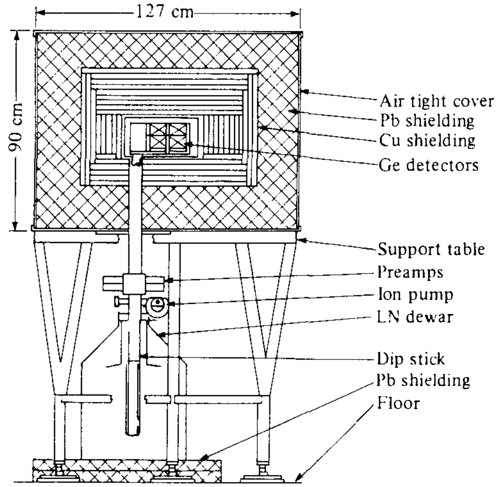

Fig. 1. The *Ge* detector array.

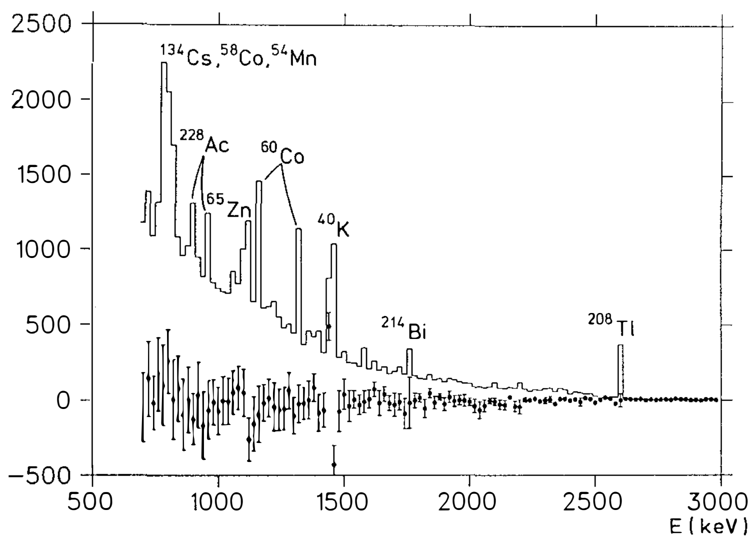

Fig. 2. The total energy spectrum of the *Ge* detector array for 1.3 $kg \cdot y$. The peaks are from the ^{232}Th chain (^{228}Ac, ^{208}Tl), the ^{238}U chain (^{214}Bi), ^{40}K and n activation (^{60}Co, ^{65}Zn, ^{54}Mn, ^{58}Co). The dots show the spectrum after subtraction of the known backgrounds.

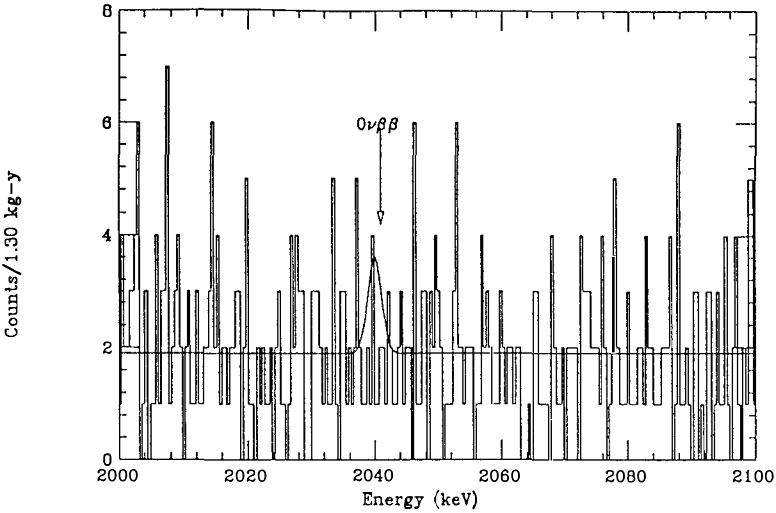

Fig.3. The region around 2040 keV, where the peak of 0ν double beta decay to the 0+ ground state would appear.