DOUBLE BETA DECAY

Ettore Fiorini

Dipartimento di Fisica G.Occhialini dell' Universita' di Milano-Bicocca e Sezione di Milano dell' INFN, via Celoria 16, 20133 Milan (Italy)
Ettore.Fiorini@mi.infn.it

1. Introduction

Double beta was first proposed, as a very rare event, by Maria Goeppert Mayer in 1935, just one year after Fermi theory of weak interactions. It can occur in three channels (we refer here only to negative beta decays):

$$(A,Z) \longrightarrow (A,Z+2) + 2e^- + 2\bar{\nu}_e \qquad (1)$$

$$(A,Z) \longrightarrow (A,Z+2) + 2e^- + \chi \qquad (2)$$

$$(A,Z) \longrightarrow (A,Z+2) + 2e^- \qquad (3)$$

The first channel, the so called two-neutrino double beta decay, is allowed by the Standard Model and has been actually found for ten different nuclei. The second implies the emission of one or more Goldstone bosons, named "majorons" and violates the lepton number. The third, normally called "neutrinoless" double beta decay, a term which also applies in fact to channel (2), also violates by two the lepton number. Since the nuclear recoiling energy is negligible the two electrons share the total transition energy with the two neutrinos and with one or more majorons in processes (1) and (2), respectively (Fig.1). The neutrinoless process is experimentally very appealing since a peak, widened only by the energy resolution, should appear in the spectrum of the sum energy of the two electrons in correspondence to the total transition energy E_0. In addition its rate would be strongly enhanced with respect to the two neutrino channel by phase space. As a consequence neutrinoless double beta decay provides a powerful tool to investigate even tiny violations of the lepton number, as expected from a non-zero neutrino mass and/or the presence of right handed currents.

I will report here the present experimental status of the searches for double beta decay, taking advantage of the excellent recent reviews by A. Morales [1] and by J. Suhonen and O. Civitarese [2] . Details and references to the various double beta decay processes can be found in [3].

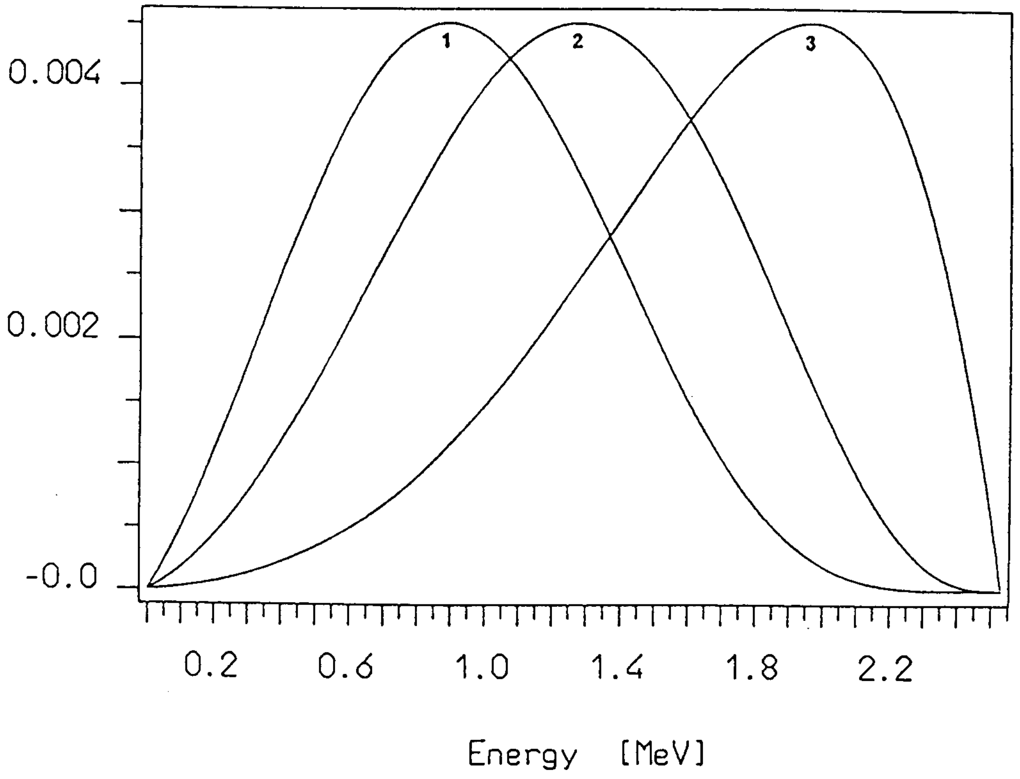

Fig.1: Spectra for two neutrino double beta decay (1) and for neutrinoless double beta decay accompanied by two (2) and one (1) majorons

2. Naïve Theoretical Introduction by an Experimentalist

The rate for two neutrino double beta decay is given by:

$$\frac{1}{\tau_{2\nu}} = G_{2\nu}(E_0, Z)\, M_{2\nu}^2 \qquad (4)$$

where M is the nuclear matrix element .

The rate for neutrinoless double beta decay with emission of one or more majorons is more majorons is :

$$\frac{1}{\tau_{0\nu\chi}} = G_{0\nu\chi}(E_0, Z)\, M_{0\nu\chi}^2 < g_{\nu\chi} >^{2m} \qquad (5)$$

Dipartimento di
N

Double beta was 1
1935, just one year aft
(we refer here only to

(A, Z) ⟶ (A, Z

(A, Z) ⟶ (A, Z

(A, Z) ⟶ (A, Z

The first channel,
Standard Model and h
the emission of one or
number. The third, no
applies in fact to chan
recoiling energy is ne
two neutrinos and wi
(Fig.1). The neutrinole
only by the energy res
electrons in correspon
strongly enhanced wi
consequence neutrinol
tiny violations of the
the presence of right h
I will report here
decay, taking advanta
Suhonen and O. Civit
processes can be founc

where $M_{0\nu\chi}$ is the corresponding nuclear matrix elements, $<g_{\nu\chi}>$ is the neutrino-majoron coupling and m is the number of emitted majorons.

The rate of neutrinoless double beta decay can be expressed in function of the "average" neutrino mass $<m_\nu>$ and of the right-right (η) and left-right (λ) current parameters :

$$\frac{1}{\tau_{0\nu}} = C_{mm}\left(\frac{<m_\nu>}{m_e}\right)^2 + C_{\eta\eta} <\eta\eta>^2 + C_{\lambda\lambda} <\lambda\lambda>^2 + \qquad (6)$$

$$C_{m\eta}\left(\frac{<m_\nu>}{m_e}\right) <\eta> + + C_{m\lambda}\left(\frac{<m_\nu>}{m_e}\right) <\lambda> + C_{\eta\lambda} <\eta><\lambda>$$

I would like to note that double beta decays to the excited 2^+ and 0^{+*} have been also theoretically and experimentally investigated.

The main difficulty in the calculations of the various double beta decay rates comes from the evaluation of the relevant nuclear matrix elements. In the first very simple theoretical approach by Primakoff and Rosen all the two neutrino and neutrinoless double beta decay nuclear matrix elements have been assumed to be equal to a constant value of 0.1.

The first detailed nuclear calculations for individual nuclei, based on the shell model, gave reasonable results for the prediction of the double decay rates of ^{48}Ca . The measurements carried out in geochemical experiments led however to lifetimes for double beta decay of ^{82}Se , ^{128}Te and ^{130}Te, much larger than predicted theoretically. This was accounted for by theories based on the Quasi Particles Random Phase Approximation (QRPA) , where the suppression of the nuclear matrix elements due to the particle-particle interaction is introduced. The sensitivity of this suppression to the particle-particle interaction strength (g_{pp}) leads however to very large uncertainties in the evaluation of the nuclear matrix elements , particularly for the two neutrino channel. The important role played by the 1^+ intermediate state, was first considered by A. Morales (1), while measurement of "real" reactions connecting the intermediate nucleus to nuclei (A,Z) and (A,Z+2) have been carried out mainly in Osaka.

3. Experimental Approaches

I will review here the main experimental approaches to search for double betata decay in the lepton conserving and non conserving channels [3].

3a. *Radiochemical or "milking" experiments*

This approach consists in storing a suitable amount of material containing the double beta active nucleus underground in order to shield it against the background due to cosmic rays. After a reasonably long time the stored material is "milked" to extract the daughter nucleus produced by double beta decay , which should be radioactive in order to detect it with a sufficient sensitivity. A typical example is the successful search for two neutrino double beta decay of ^{238}U into ^{238}Pu , a nucleus which decay by emission of an α particle with a lifetime of 87.7 days. Unfortunately there is obviously no way to distinguish in these experiments among two neutrino, majoron and neutrinoless double beta decays to the ground or excited states, apart from the comparison with the predicted rates, which are, as mentioned before, quite uncertain.

3b. *Geochemical Experiments*

These experiments are based on the search for an abnormal isotopic abundance of the nucleus (A,Z+2) produced in geological times by double beta decay in a rock containing the "grandfather" nucleus (A,Z). These experiments present the obvious advantage of the extremely long "duration", but do not allow to distinguish directly among the various lepton conserving and non-conserving channels. Evidence for double beta decay has been achieved for ^{82}Se, ^{96}Zr, ^{128}Te and ^{130}Te . Many efforts have been devoted to the theoretical evaluation of neutrinoless rates from the ratio of the ^{128}Te and ^{130}Te lifetimes. They are however somewhat spoiled by the fact that there is no "a priori" reason to assume equality of the corresponding nuclear matrix elements. In addition it has been found in Berkeley [4] that the cross section on these two nuclei for reactions of cosmic ray protons, which could mimic double beta decay, are different. In addition some difficulty could arise from the evaluation of the age of the rock and from the possibility (deeply investigated,however) that the nucleus (A,Z+2) (which is in gaseous form for all daughters apart ^{96}Mo) could have escaped from the rock. In fact, while there is a reasonable agreement among the lifetime evaluated in geochemical experiments for the ^{82}Se - ^{82}Kr transitions, the measured lifetimes range from (1.5 ± .2) to (7.7 ± .4) x 10^{24} years, and from (.7 ± .2) to (2.8 ± .3) x 10^{21} years for for ^{128}Te and for ^{130}Te, respectively.

I have to mention here a recent and provocative question by A. Barabash [5]: does the weak interaction constant change with time? He is stimulated in this possibility by the comparison of the various geochemical results obtained with rocks of different ages with those from the direct experiments. I believe however that that uncertainties on the geochemical experiments are still too severe to support this possibility. The direct cryogenic experiments on ^{130}Te (see later) will definitely answer this question.

3.c *Direct experiments*

These experiments are based on the direct detection and measurement of the two electrons. At present they are all carried out underground and under heavy shields to reduce the background due to cosmic rays and environmental radioactivity. Two different approaches have been implemented. The former one is the detection of the electrons emitted by a passive double beta decay source (source≠detector approach). In

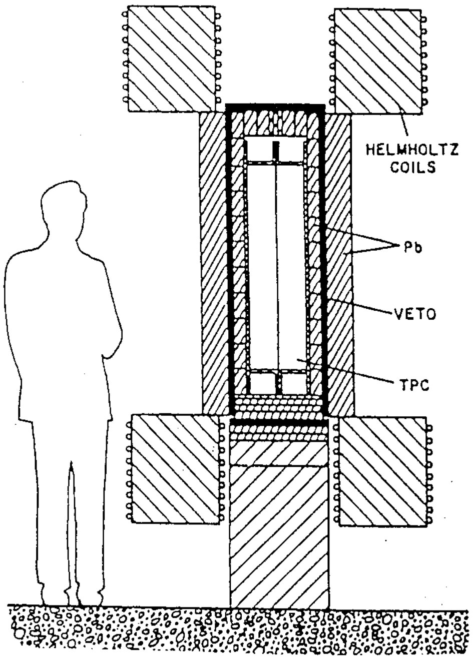

Fig.2a: The pioneering experiment carried out with a Time Projection Chamber by the Irvine group on double beta decay of ^{82}Se

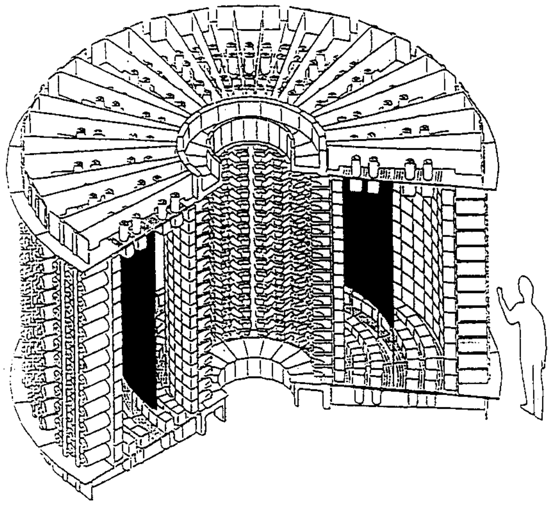

Fig.2b: the NEMO III set-up, presently under construction

the latter [6] (source=detector or calorimetric) the detector is made by a material which contains the double beta active nucleus and acts therefore also as a double beta decay source.

A great variety of detecting techniques have been and are used to search for double beta decay in the source≠detector approach. Visual techniques like cloud chambers and nuclear emulsions were used. Presently [3] double beta decay experiments employ ionization, proportional and Geiger counters, drift and Time Projection Chamber, scintillators and solid state counters. The double beta decay source , normally in form of a thin sheet or of wires, is placed inside the detecting region (Fig.2). The source≠detector approach is very powerful in the detection and measurement of two neutrino double beta decay since it often allows to follow the two electron tracks and sometime even to determine their charge, with a consequent strong reduction of the background. On the other hand the resolution could be affected by auto absorption in finite thickness of the source, with a consequent loss in sensitivity in the search for the neutrinoless channel.

One approach in the source=detector approach is the use of scintillators containing the double beta decay active nucleus in enriched or natural form. Experiments have been and are being carried out with $^{48}CaF_2$ and $^{116}CdWO_4$ and even with large CaF_2 crystals with natural calcium. Another approach is to use Xenon in ionization, proportional, and Time Projection Chambers, and even as scintillator to search for double beta decay of ^{136}Xe [7].

The technique of Ge semiconductor detectors as source=detector of double beta decay of ^{76}Ge [8] has been widely applied, and strong constraint on the neutrinoless channel have been obtained recently by the Heidelberg-Moscow[3,9] and IGEX [3,10] experiments.

A very wide choice of nuclei can be investigated in the source=detector approach by the technique of cryogenic detectors, suggested almost 15 years ago [11] which is still in its infancy. The principle is to operate at very low temperature a diamagnetic and dielectric crystal. The heat capacity is in this case proportional to the cube of the ratio between the operating and Debye temperatures. As a consequence in the region of tens of millikelvin it can become so low that even the tiny energy produced by a double beta decay event occurring inside the crystal can be revealed and measured by means of a suitable thermal sensor. The only experiment being performed so far with this technique is a search on double beta decay of and ^{130}Te carried out with an array of 20 crystals of and TeO_2 of 340 gram each. Neutron Transmutation Doped thermistors glued in thermal contact with them [12] are used to produce the thermal pulses. This experiment, presently operating in the Gran Sasso Underground Laboratory, is also going to search for two neutrino double beta decay. This search will be based on the comparison between the spectra obtained with two crystals of 340 grams enriched in and ^{130}Te with those from two similar crystals enriched in ^{128}Te placed in the same dilution refrigerator.

An excellent candidate for thermal detection of double beta decay would be and ^{150}Nd in a $^{150}NF_2$ crystal. Test measurements carried out by the Milano and Santa Barbara groups have however encountered considerable difficulty to cool to low temperatures these crystals , probably due to the paramagnetic properties of Neodimium. Another excellent candidate for neutrinoless double beta decay would be a crystal of and $^{48}CaF_2$ operated at the same time as thermal and scintillator detector. One has to note in fact that , due to the very large transition energy of ^{48}Ca (4272 keV), the background in the region of neutrinoless double beta decay is dominated by degraded α particles which have a poor scintillating yield. As a consequence a coincidence between the thermal and scintillation pulses would allow a very efficient suppression of the background. A small scintillating bolometer has been constructed and successfully operated by the Milano group [13]. The only , but severe, difficulty for this experiment lies in the difficulty and cost to provide a reasonable amount of and ^{48}Ca sufficiently free from radioactive contamination.

4. Results

Some recent experimental results on the various channels of $\beta^-\beta^-$ decay are reported in Table I . Also reported in the Table are the ranges of theoretical predictions on the lifetimes and the limits that can be extracted on the average neutrino mass and on the neutrino-majoron coupling. The spectra in the region of neutrinoless double beta decay by the Heidelberg-Moscow [9] and IGEX [10] experiments are shown in Fig.3 and Fig.4. The results of the theoretical calculations are somewhat surprising. Its seems in particular peculiar that, while there is a large uncertainty in the evaluation of the predicted lifetimes for neutrinoless double beta decay, there is on the contrary a reasonable agreement for the evaluation of two neutrino double beta decays , at least for the specific nuclei where this process has been experimentally found. This seems in disagreement with the expectations that uncertainties should be larger for the two neutrino with respect to the neutrinoless channels.

Table I

DECAY	Isotopic ab.(%)	E_o (keV)	Decay mode	Lifetime (years)	Theoret. prediction
^{48}Ca-^{48}Ti	.187	4272	$2\nu\ (0^+-0^+)$	$4.3^{+3.4}_{-1.5}\times10^{19}$	$(3-27)\times10^{19}$y
			$0\nu\ (0^+-0^+)$	$>9.5\times10^{21}$	$<m_\nu>$ $<(12-55)$ eV
			$0\nu\chi\ (0^+-0^+)$	$>7.2\times10^{20}$	
			$0,2\nu\ (0^+-2^+)$	$>1\times10^{21}$	$\sim10^{25}$
			$0,2\nu\ (0^+-0^{+*})$	$>8\times10^{18}$	
^{76}Ge-^{76}Se	7.44	2039	$2\nu\ (0^+-0^+)$	$(1.1-1.8)\times10^{21}$	$(8-9)\times10^{20}$
			$0\nu\ (0^+-0^+)$	$>1.3\times10^{25}$	$<m_\nu>$ $<(0.3-1.3)$ eV
			$0\nu\chi\ (0^+-0^+)$	$>3.9\times10^{22}$	$<g_{\nu\chi}>$ $<(1-5)\ 10^{-4}$
			$0\nu\ (0^+-2^+)$	$>8.2\times10^{23}$	
			$0\nu\ (0^+-0^{+*})$	$>2\times10^{22}$	
			$0\nu2\chi\ (0^+-0^+)$	$>5.9\times10^{21}$	
			$0,2\nu\ (0^+-2^+)$	$>1.4\times10^{21}$	$\tau_{2\nu}=(6-800)\times10^{22}$
			$0,2\nu\ (0^+-0^{+*})$	$>1.7\times10^{21}$	$\tau_{2\nu}=(6-800)\times10^{22}$
^{82}Se-^{82}Kr	8.73	2995	geochemical	$(1.1-1.7)\times10^{21}$	
			$2\nu\ (0^+-0^+)$	$(7-14)\times10^{19}$	$(1-15)\times10^{19}$
			$0\nu\ (0^+-0^+)$	$>5\times10^{21}$	$<m_\nu>$ $<(11-24)$ eV
			$0\nu\ (0^+-2^+)$	$>3.4\times10^{21}$	
			$0\nu\chi\ (0^+-2^+)$	$>2\times10^{21}$	$<g_{\nu\chi}>$ $<(2-6)\times10^{-4}$

Table I (continued)

DECAY	Isot. Ab.(%)	E_o (keV)	Decay mode	Lifetime (years)	Theoret. prediction
^{96}Zr-^{96}Mo	2.8	3350	geochemical	$(3.9\pm.9)x10^{19}$	
			$2\nu\ (0^+-0^+)$	$(2\pm1)x10^{19}$	$(6\text{-}1100)x10^{17}$y
			$0\nu\ (0^+-0^+)$	$>8x10^{20}$	$<m_\nu>$ $<(28\text{-}186)$ eV
			$0\nu\chi\ (0^+-0^+)$	$>3x10^{20}$	$<g_{\nu\chi}>$ $<(7\text{-}47)\ 10^{-4}$
			$0,2\nu\ (0^+-2^+)$	$>4.1x10^{19}$	$\tau_{2\nu}=(3-7x10^5)$ $x10^{20}$
			$0,2\nu\ (0^+-0^{+*})$	$>8x10^{18}$	$\tau_{2\nu}=(2-150)$ $x10^{20}$
^{100}Mo-^{100}Ru	9.63	3035	$2\nu\ (0^+-0^+)$	$(9\text{-}12)x10^{18}$	$(2\text{-}32)x10^{18}$
			$0\nu\ (0^+-0^+)$	$>5.2x10^{22}$	$<m_\nu>$ $<(1.4\text{-}264)$ eV
			$0\nu\chi\ (0^+-0^+)$	$>5.4x10^{21}$	$<g_{\nu\chi}>$ $<(1\text{-}130)\ 10^{-4}$
			$0\nu2\chi\ (0^+-0^+)$	$>5.3x10^{19}$	
			$0,2\nu\ (0^+-2^+)$	$>2.3x10^{21}$	$\tau_{2\nu}=(5-1x10^6)$ $x10^{22}$
			$0,2\nu\ (0^+-0^{+*})$	$(8\pm2)x10^{21}$	$\tau_{2\nu}=(5-500)$ $x10^{19}$

Table I (continued)

DECAY	Isot. Ab.(%)	E_o (keV)	Decay mode	Lifetime (years)	Theoret. prediction
^{116}Cd-^{116}Sn	8.73	2995	$2\nu\ (0^+-0^+)$	$(2.6\text{-}3.8)\times10^{19}$	$(4\text{-}10)\times10^{19}$
			$0\nu\ (0^+-0^+)$	$>2.9\times10^{22}$	$<m_\nu>$ $<(4\text{-}13)$eV
			$0\nu\ (0^+-2^+)$	$>4.4\times10^{21}$	
			$0\nu\chi\ (0^+-0^+)$	$>1.2\times10^{21}$	$<g_{\nu\chi}>$ $<(2\text{-}11)\times10^{-4}$
			$0\nu2\chi\ (0^+-0^+)$	$>2.6\times10^{20}$	
			$0,2\nu\ (0^+-2^+)$	$>2.4\times10^{21}$	$\tau_{2\nu}=(1-80)$ $\times10^{24}$
			$0,2\nu\ (0^+-0^{+*})$	$>2.1\times10^{21}$	$\tau_{2\nu}=(1-100)$ $\times10^{22}$
^{124}Sn-^{124}Te	5.79	2287	$2\nu\ (0^+-0^+)$	$>1\times10^{17}$	$(8\text{-}2\times10^5)\times10^{19}$
			$0\nu\ (0^+-0^+)$	$>2.4\times10^{17}$	$<m_\nu>$ <2600 eV
			$0\nu\chi\ (0^+-0^+)$	$>1\times10^{17}$	
			$0,2\nu\ (0^+-2^+)$	$>4.1\times10^{19}$	$\tau_{2\nu}\sim6\times10^{26}$
			$0,2\nu\ (0^+-0^{+*})$	$>2.2\times10^{18}$	$\tau_{2\nu}\sim3\times10^{21}$
^{128}Te-^{128}Xe	33.8	867	geochemical	$(1.4\text{-}7.7)\times10^{24}$	$\tau_{2\nu}=(6-380)10^{26}$
			$0\nu\ (0^+-0^+)$	$>2.1\times10^{22}$	$<m_\nu>_{\text{geoch}}$ $<(1\text{-}10)$ eV $<m_\nu>$ (19-85)eV
			$0,2\nu(0^+-0^+)$	$>4.7\times10^{21}$	$\tau_{2\nu}=$ $(2\text{-}4000)\times10^{30}$

Table I (continued)

DECAY	Isot. Ab.(%)	E_o (keV)	Decay mode	Lifetime (years)	Theoret. prediction
^{130}Te-^{130}Xe	33.8	2528	Geochemical	$(7\text{-}27)\text{x}10^{20}$	$\tau_{2\nu}$= $(2.6–26)\ \text{x}10^{20}$
			$2\nu\ (0^+–0^+)$	$>4\text{x}10^{20}$	$(2.6–26)\ \text{x}10^{20}$
			$0\nu\ (0^+–0^+)$	$>1\text{x}10^{23}$	$<m_\nu>$ $<(2\text{-}5)$eV
			$0\nu\chi\ (0^+–0^+)$	$>1.4\text{x}10^{21}$	$<g_{\nu\chi}>$ $<(2.5\text{-}7)\text{x}10^{-4}$
			$02\nu\chi\ (0^+–0^+)$	$>1\text{x}10^{21}$	
			$0,2\nu\ (0^+–2^+)$	$>1.6\text{x}10^{22}$	$\tau_{2\nu}=(3–300)\ \text{x}10^{22}$
			$0,2\nu\ (0^+–0^{+*})$	$>5\text{x}10^{21}$	$\tau_{2\nu}=(3–7)\ \text{x}10^{20}$
^{136}Xe-^{136}Ba	8.9	2468	$2\nu\ (0^+–0^+)$	$>5.6\text{x}10^{20}$	$(1\text{-}8)\text{x}10^{20}$
			$0\nu\ (0^+–0^+)$	$>4.2\text{x}10^{23}$	$<m_\nu>$ $<(2\text{-}5)$ eV
			$0\nu\chi\ (0^+–0^+)$	$>1.1\text{x}10^{22}$	$<g_{\nu\chi}>$ $<(1.5\text{-}6)\text{x}10^{-4}$
^{150}Nd-^{150}Sm	5.64	3368	$2\nu\ (0^+–0^+)$	$(1.7\pm1)\text{x}10^{19}$	$\sim3\text{x}10^{18}$
			$0\nu\ (0^+–0^+)$	$>2.1\text{x}10^{21}$	$<m_\nu>$ $<(4\text{-}16)$ eV
			$0\nu\chi\ (0^+–0^+)$	$>5.3\text{x}10^{20}$	$<g_{\nu\chi}>$ $<(1\text{-}4)\text{x}10^{-4}$
			$0,2\nu(0^+–2^+)$	$>4.7\text{x}10^{21}$	
			$0,2\nu(0^+–0^+)$	$>4.7\text{x}10^{21}$	$\tau_{2\nu}$ = $(2\text{-}4000)\text{x}10^{30}$

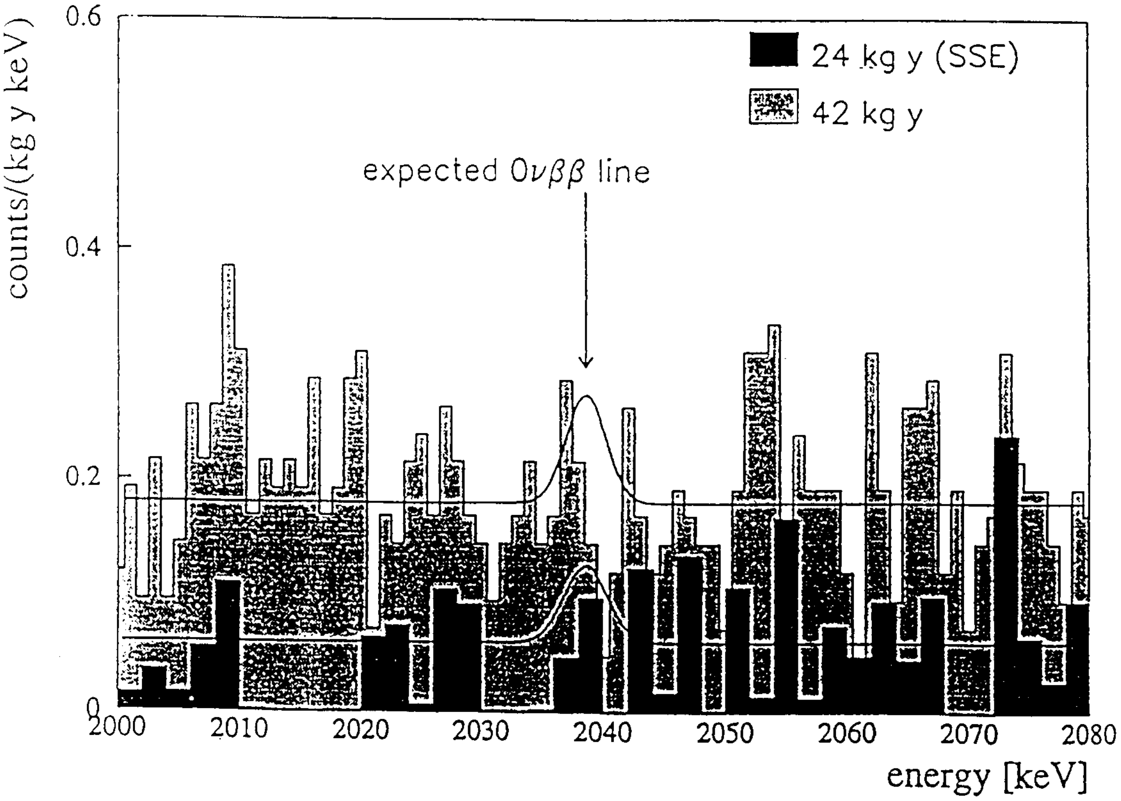

Fig.3 : Recent results from the Heidelberg-Moscow experiment

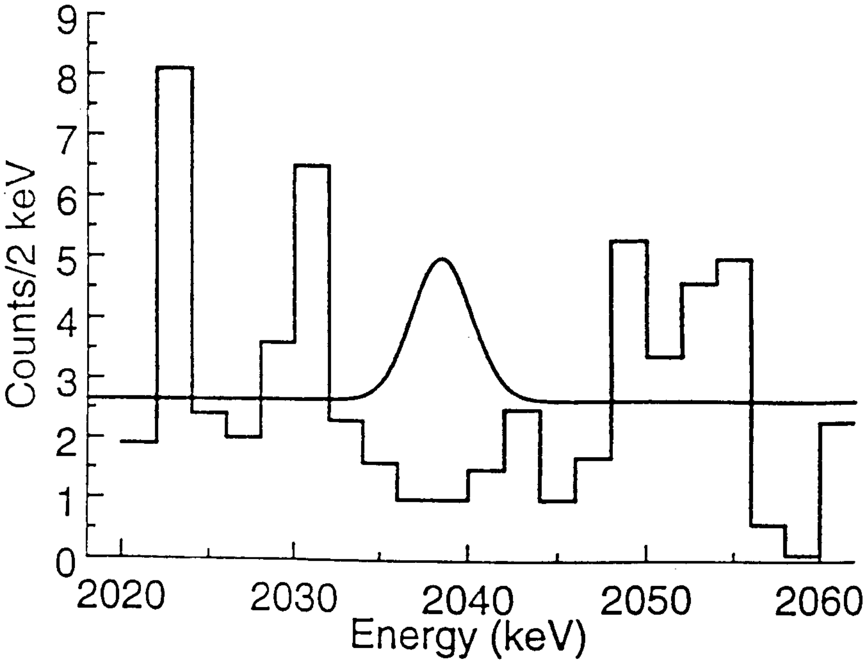

Fig.4: Recent results from the IGEX experiment

4. The future

New technical approaches have been suggested to search for double beta decay, but none of them have been actually implemented. Among the more interesting ones I would like to quote:

- The Resonant Ionization Spectroscopy (to detect for instance the double beta decay of ^{82}Se)
- The chemical separation of the daughter isotope (suggested for instance for the ^{136}Xe-^{136}Ba transition)
- The above mentioned scintillation+heat approach for double beta decay of ^{48}Ca
- Dissolution of ^{136}Xe in Borexino [14]

For future developments one has to note that the sensitivity for a double beta decay can be roughly written as follows:

$$S=4.17 x 10^{26} x \left(\frac{\text{isot.ab}}{A}\right)\sqrt{\frac{m(kg)\, t(years)}{\text{Backgr}(c.\ keV^{1}\ y^{-1}\ kg^{1})\,\Delta}}\ x\,\varepsilon \qquad (7)$$

where ε is the efficiency of detection of the event and Δ the energy resolution in keV. And the consequence sensitivity on the average neutrino mass would be:

$$<m_{\nu}> = K m^{1/4}\ t^{1/4}\ \text{Back}^{-1/4}\ \Delta^{-1/4}\ \text{isot.ab}^{1/2}\ m^{1/4}\ \varepsilon \qquad (8)$$

As a consequence the efforts to improve the present sensitivity should be addressed to:

- increase the source=detector mass
- run for the longer possible time with a suitable stability of the detector
- reduce the radioactive background (e.g. by pulse discrimination or by the scintillation vs. heat technique)
- improve the energy resolution
- chose an element with a large isotopic abundance of the double beta active nuclide (e.g. 34% for ^{130}Te) or use isotopically enriched samples.

Two large projects have been presented

GENIUS (for Germanium in liquid Nitrogen Underground Setup)

It would consist [15] in an array of about 300 semiconductor detectors of Germanium enriched in ^{76}Ge with a total mass of about a ton. The detectors would be suspended in a tank filled with liquid Nitrogen which would provide at the same time cooling and shielding against external radioactivity (15). For an efficient shielding the tank should therefore be very large with linear dimensions of 12 m, which could imply some

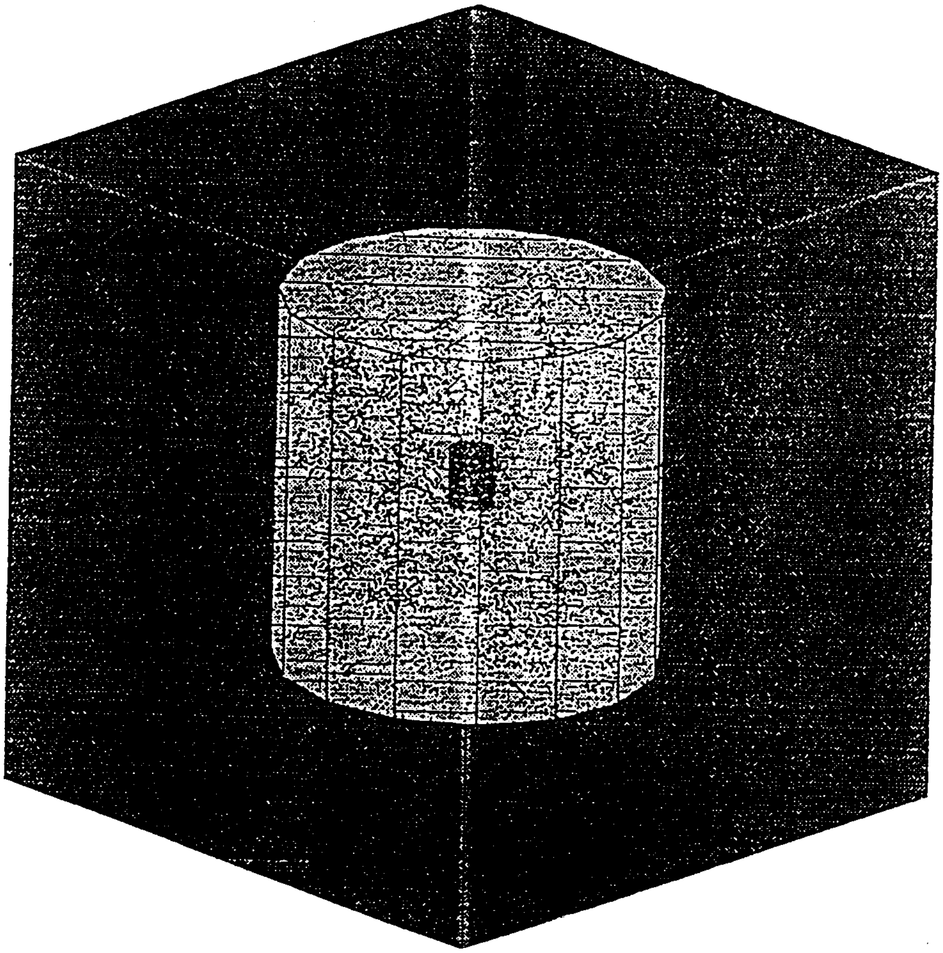

Fig.5: The GENIUS proposal

difficulty in finding a sufficiently ample underground location. Germanium detectors have been already successfully tested in liquid Nitrogen and a very detailed Monte Carlo code has been implemented to evaluate the sensitivity of the experiment to double beta decay and Dark Matter searches.

A preliminary proposal has been presented for an array of 40 crystals of natural germanium for a total mass of 100 kg. This array , obviously aiming in itself only to search for Dark Matter, should be operated in the same tank as GENIUS to test the predictions on the background reduction. It is near to be funded , but some difficulty exists in finding a suitable underground location. The main problem for GENIUS is the cost , mainly due to the enrichment in ^{76}Ge whose natural abundance is of 7.44 % only. A figure of at least 100 Million dollars seem at present realistic.

CUORE (for Cryogenic Underground Observatory for Rare Events)

This cryogenic set-up would consist [16] in 17 towers , each containing 15 planes of 4 cubic crystals of 5 cm side of TeO_2. It would be housed in a single specially constructed dilution refrigerator , shielded with Roman and normal lead and operated in the Gran Sasso Underground Laboratory. Due to its compact structure (Fig.6) it could be housed in one the presently available spaces, pending obviously the approval by the Gran Sasso Scientific Committee. The total mass of sensitive material is of about 800 kg. Two of these 5x5x5 cm^3 TeO_2 have been already tested, With a new suspension which minimize microphonics a resolution of 3.8 keV has been obtained, very near to those of Germanium diodes and superior to that of the present 20 detectors array. Other materials, like $PbWO_4$ made with Roman lead, can be also considered for searches on Dark Matter and have been preliminarily tested.

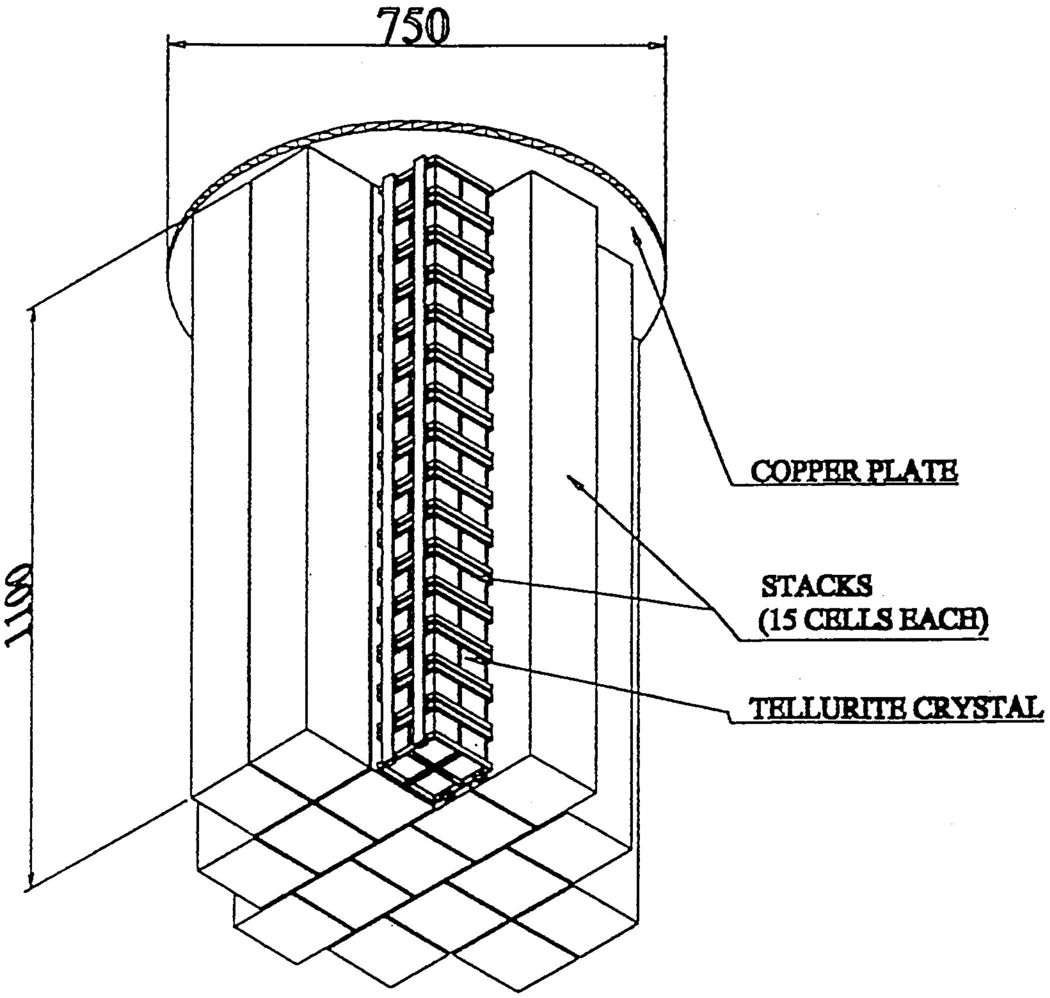

Fig.8: Scheme of the CUORE proposal. A single tower roughly corresponds to CUORICINO

A proposal has been presented and approved for CUORICINO, consisting practically in one of the towers of CUORE (Fig.6) . This very simple structure can be housed in a dilution refrigerator presently operating in the Gran Sasso. CUORICINO could start taking data in 2001.

The cost of CUORE (about 10 Million dollars for natural tellurium) seems accessible to an international collaboration. Due to the larger natural abundance (34%) of the double beta candidate ^{130}Te the cost of an "enriched" CUORE should not exceed 20 millions dollars.

6. Conclusions

No evidence for neutrinoless double beta decay has been found so far in any of the presently running experiments and this leads to the most constraining limit on the conservation of the total lepton number. Very restrictive limits on the "average' neutrino mass (less than one eV in the Heidelberg-Moscow and IGEX experiments) can be extracted from these data , but they are subject to the uncertainties in the calculation of the nuclear matrix elements. The same is true for the possible presence of right handed components in weak interactions. As a consequence a large number of double beta decay candidate nuclei should be investigated, and the thermal technique seems very suitable for this aim in the source=detector approach.

More stringent constraints on neutrinoless double beta decay (or, better, evidence for it!) would come from the approved NEMO 3 experiment and from the proposed GENIUS and CUORE set-ups. A comparison between these two large experiments can only be based on the very questionable assumption that the nuclear matrix elements for ^{76}Ge and ^{130}Te be equal or at least similar. Under this assumption the larger number of moles of ^{76}Ge in GENIUS is balanced in the "non enriched" CUORE by the larger available phase space for the decay of ^{130}Te. The comparison of the background is very difficult: GENIUS present the obvious suppression of pulse- shape analysis; CUORE could efficiently apply the anti-coincidence procedure since there is practically no material between two adjacent crystals. Even assuming that the intrinsic background will be less in GENIUS , CUORE in its "enriched" version, anyway much cheaper than GENIUS, could have a similar sensitivity.

Due to the uncertainty of the nuclear matrix elements both experiment seem to me worth to be done .

The preliminary experiments on CUORICINO have been funded in part by the TMR CEE program, under Contract FMRX-CT98-0167

REFERENCES

[1] A. Morales : Review of Double Beta Experiments and Comparison with Theory, Invited talk at the XVIII International Conference on Neutrino Physics and Astrophysics, Neutrino 98 , in Tokayama (Japan) , June 1998, to appear in Nucl. Phys.B (Proc.Suppl)

[2] J. Suhonen and O. Civitarese , Physics Reports 300 (1998) 123

[3] V.I.Tretyak and Yu.Zdesenko, Atomic Data and Nuclear Data Tables 61 (1995) 43 and references therein

[4] M.T.F. da Cruz, et al: Thick-target yields of iodine isotopes from proton interactions in Te, and the double-beta decay of 128Te, , Presented at the Twenty Third International Cosmic Ray Conf. ,Calgary (Canada) July 19-30,1993

[5] A. S. Barabash, JEPT Letters 68 (1998) 1

[6] G.F. Dell' Antonio and E. Fiorini, Suppl.Nuovo Cim. 17 (1960) 132

[7] R.Luescher et al, Phys.Lett. B 434 (1998) 407

[8] E.Fiorini,A.Pullia,G.Bertolini,F.Cappellani and G.Restelli, Phys.Lett.25B, 602 (1967)

[9] L. Baudis et al, Phys.Lett. B 407 (1997) 219, and private communication by L. Baudis

[10] C.E. Aalseth et al; Phys.Rev.C 59 (1999) 1

[11] E.Fiorini and T.O.Niinikoski, Nucl.Instrum.and Meth. 224 (1984) 83

[12] O. Cremonesi : Thermal Detectors, Invited talk at the XVIII International Conference on Neutrino Physics and Astrophysics, Neutrino 98 , in Tokayama (Japan) , June 1998, to appear in Nucl. Phys.B (Proc.Suppl)

[13] A. Alessandrello et al, Phys.Lett. B 420 (1998) 109

[14] B. Caccianiga and M.G. Giammarchi: Double beta decay with 136Xe in Borexino and CTF2- Borex report - 30 November 1998

[15] L. Baudis et al, Phys.Rep. 307 (1998) 301, and private communications by L.Baudis and H. Klapdor-Kleingrothaus

[16] E.Fiorini, Phys.Rep. 307 (1998) 309