SEARCH FOR NEUTRINOLESS DOUBLE BETA DECAY WITH NEMO-3 USING ^{150}ND

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The NEMO-3 detector looks for neutrinoless double beta decay from 10 kg of enriched $\beta\beta$ emiters. Using 440 days of data, background measurements give activities from each contribution from Neodinium foil. During the same period of data acquisition, preliminary study gives the half-life of the $2\nu\beta\beta$ process : $T_{1/2}(2\nu) = (9.75 \pm 0.35(stat.) \pm 0.85(syst.))10^{18} years$. Up to now, no evidence of lepton number violation has been observed. A limit on the half-life of the neutrinoless process has been obtained : $T_{1/2}(0\nu) > 8.0 \quad 10^{21}$ y at 90% CL.

1 Neutrinoless double beta decay

The goal of the NEMO-3 (Neutrino Ettore Majorana Observatory) detector is to search for evidence of lepton number violation in neutrinoless double beta decay ($0\nu\beta\beta$):

$$(A, Z) \rightarrow (A, Z + 2) + 2e^- \tag{1}$$

The decay may be explained by the exchange of a light massive Majorana neutrino. Also (V+A) coupling or Majoron emission could describe the $0\nu\beta\beta$ decay. These processes, forbidden in the framework of the standard model, are the only experimental opportunity to prove the Majorana nature of the neutrino.

The half-life of the $0\nu\beta\beta$ process by light Majorana neutrino exchange can be written as :

$$(T^{0\nu}_{1/2})^{-1} = G^{0\nu}(Z, Q_{\beta\beta})|M^{0\nu}_{GT} - (\frac{g_V}{g_A})^2 M^{0\nu}_F|^2 \langle m_{\beta\beta}\rangle^2 \tag{2}$$

Where $G^{0\nu}(Z, Q_{\beta\beta})$ is the phase space factor proportional to the $Q^5_{\beta\beta}$, $M^{0\nu}_\chi$ are the nuclear matrix elements (NME) and $\langle m_{\beta\beta}\rangle$ is the effective mass of neutrino given by :

$$< m_{\nu_{\beta\beta}} >= |\cos^2\theta_{13}(|m_1|\cos^2\theta_{12} + |m_2|e^{2i\phi_1}\sin^2\theta_{12}) + |m_3|e^{2i\phi_2-\delta}\sin^2\theta_{12}| \tag{3}$$

Isotopes	$Q_{\beta\beta}$ (keV)	Mass d'isotope (g)
$^{130}Te \rightarrow {}^{130}Xe$	2533±4	454
$^{116}Cd \rightarrow {}^{116}Sn$	2802±4	405
$^{82}Se \rightarrow {}^{82}Kr$	2995±6	932
$^{100}Mo \rightarrow {}^{100}Ru$	3034±6	6914
$^{96}Zr \rightarrow {}^{96}Mo$	3350±3	9,4
$^{150}Nd \rightarrow {}^{150}Sm$	3367±2	37
$^{48}Ca \rightarrow {}^{48}Ti$	4271±4	6,99

Table 1: $\beta\beta$ emitters in the NEMO-3 detector.

The measurement of the $0\nu\beta\beta$ process half-life, given the NME, determines the absolute Majorana neutrino scale.

2 Searching for golden events in the NEMO-3 detector

The NEMO-3[1] detector is designed to detect and identify neutrinoless double beta decays using 10 kg of enriched $\beta\beta$ emiters (Cf. table 1).

Isotopes are spread on thin foils at the center of a drift chamber formed by 6180 open Geiger cells to reconstruct charged particles tracks. An ultra pure calorimeter made of 1940 plastic scintillators encloses the drift chamber to measure energy and time of flight of particles coming from the source foils. NEMO-3 is able to identify $0\nu\beta\beta$ candidate events (golden events) with some dedicated criteria.

In figure 1-(b) a partial top view of the detector shows a $0\nu\beta\beta$-like event in NEMO-3 detector. There are two β tracks with negative curvature with a common vertex on the source foil. The time of flight is compatible with an event coming from the foil ($\delta t_{TOF} \approx 0$). The total energy deposit in the calorimeter is equal to 3222 keV ($Q_{\beta\beta}$=3367 keV for ^{150}Nd and energy resolution : 14 % at 1 MeV). This event from 37 g of ^{150}Nd is a typical golden event (ΔL=2 process).

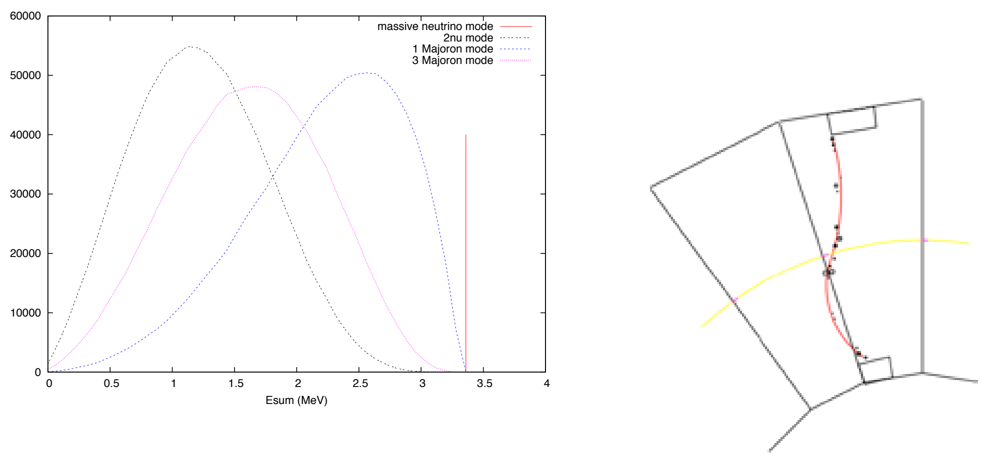
3 Analysis and results

The golden event showed in figure 1-(b) is simulated from possible background contribution. Each process which is able to produce two electrons with a total energy around $Q_{\beta\beta}$ is considered as a dangerous background for the neutrinoless double beta decay investigation. For example, a $\beta\beta$-like event can be generated by a $\beta - \gamma$ emiter, the second electron being produced by Compton or photoelectric effect.

Typically the most important background comes from natural radioactive chain (^{238}U and ^{232}Th). That brings to light the crucial importance of the extreme radio-purity one needs to achieve in order to reach a sensitivity to the half-life of up to 10^{24-25} years. The NEMO-3 detector is hosted in the Frejus underground laboratory under 4800 m.w.e. to reduce the cosmic ray flux. More the allowed process ($2\nu\beta\beta$) is the ultimate background which cannot be suppressed due to the energy resolution (Cf. figure 1-(a)).

3.1 Background studies

The so-called *tracko-calo* technology used in NEMO-3 is able to measure and control the background sources using dedicated channels and to localize possible contaminations. The channels of interest are defined by the decay scheme from natural radioactive isotopes (Cf figure 2).



(a) Theorical spectrum of the total energy for $\beta\beta$ processes in ^{150}Nd. The standard model allowed process ($2\nu\beta\beta$) is observed in NEMO-3. Due to the energy resolution, the continuous energy spectrum is a significant source of background for the $0\nu\beta\beta$ search.

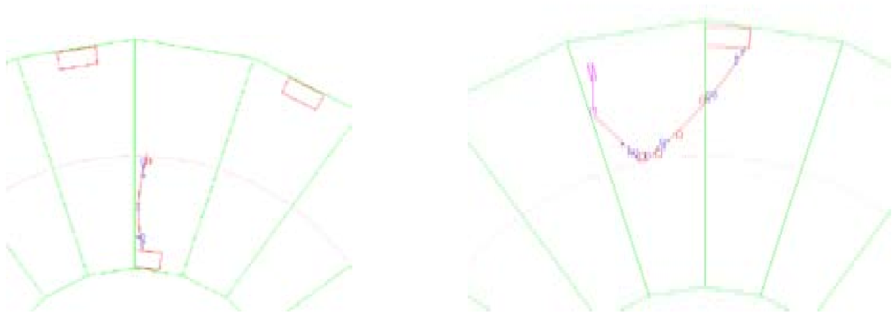
(b) Top view of a typical $0\nu\beta\beta$ event in NEMO-3 from ^{150}Nd.

Figure 1:

- ^{208}Tl from the ^{232}Th chain is a β emiter with Q_β at 4.99 MeV. The most efficient signature to study this background consists in the measurement of one electron and several photons from dexecitation from the daughter nucleus. The corresponding channel is defined by an electron in coincidence with at least γ rays. The ^{208}Tl activity in ^{150}Nd foil using such techniques has been measured at 17 μBq.

- ^{214}Bi from ^{238}U chain is a β emiter at Q_β=3.27 MeV followed by the α ($T_{1/2}$=164 μs) from ^{214}Po decay in ^{210}Pb. Dedicated electronics have been developped to identify the delayed α particle in the tracking chamber. The main channel to measure the BiPo cascade contamination is a prompt β decay in coincidence with a delayed α. ^{214}Bi contamination has been measured on the Nd foil at the level of 90 μBq.

These results are compatible with independant measurements using HPGe detector.



(a) (b)

Figure 2: Vizualisation of some channels studied to measure background contamination in NEMO-3 detector. a) Typical event in the $e\gamma\gamma$ channel used to identify the ^{208}Tl contamination. b) Typical event in the $e\gamma\alpha$ channel used in case of ^{214}Bi contamination.

3.2 Double beta decay analysis

The total energy spectra from two internal electron channel is split into two main parts. The [0-3] MeV region is used to measure the $2\nu\beta\beta$ process and the [3-3.6] MeV energy range is used to search for $0\nu\beta\beta$ signal. Contaminations of this channel are ^{214}Bi and ^{208}Tl (and other isotopes from natural radioactive chains) . The contamination level has been studied to determine the background contribution in the $\beta\beta$ candidate signal from the Neodinium foil .

Preliminary results for a total time acquisition of 10560 hours give 756 $\beta\beta$-like events with signal over background ratio $\frac{S}{B}$=3.4 in the [400-3600] keV full spectra. The half-life of the $2\nu\beta\beta$ process is :

$$T_{1/2}(2\nu) = (9.75 \pm 0.35(stat.) \pm 0.85(syst.))10^{18} years \tag{4}$$

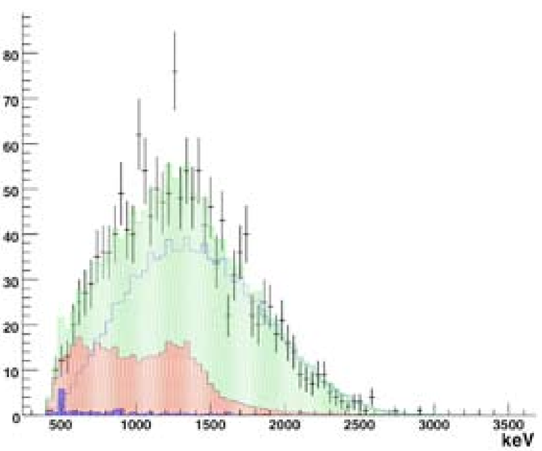


Figure 3: Total energy spectra in the two internal electron channel. Dots are real data. Blue/red histograms represent the expected contamination from external/internal background. The blue line is the $2\nu\beta\beta$ contribution. The green histogram represents the sum of all contributions mentioned previously.

There is no expected background event in the [3-3.6] MeV energy range. No $0\nu\beta\beta$ candidate event have been observed in the 10560 hours data sample from ^{150}Nd foil. The limit obtained is $T_{1/2}(0\nu) > 8.0 \quad 10^{21}$ y at 90% CL for the light majorana exchange hypothesis. Up to now there is no lepton number violation evidence using ^{150}Nd data in the NEMO-3 detector.

References

1. NEMO Coll.,Technical design and performance of the NEMO-3 detector *Nucl. Instrum. Methods* A **536** 2005