Latest results from a search for neutrinoless double beta decay with NEMO3 and plans for SuperNEMO

X. Garrido

LATEST RESULTS FROM A SEARCH FOR NEUTRINOLESS DOUBLE BETA DECAY WITH NEMO3 AND PLANS FOR SUPERNEMO

X. GARRIDO for the SuperNEMO Collaboration
LAL, Université Paris-Sud 11, CNRS/IN2P3, Orsay, France

The NEMO3 experiment is devoted to the search for neutrinoless double beta decay, as well as for accurate measurement of two-neutrino double beta decay. The detector has been taking data in the Modane Underground Laboratory since 2003 up to the end of 2010. The latest NEMO3 results for seven $\beta\beta$ isotopes are presented for both decay modes. The status of SuperNEMO, the next generation experiment that will exploit the same experimental technique to extend the sensitivity of the current search, is discussed.

1 Introduction

Experimental search for the neutrinoless double beta decay ($0\nu\beta\beta$) is of major importance in particle physics because if observed, it will reveal the Majorana nature of the neutrino ($\nu \equiv \bar{\nu}$) and may allow an access to the absolute neutrino mass scale. The decay violates the lepton number and is therefore a direct indication for physics beyond the Standard Model. The existence of this process may be related to right-handed currents in electroweak interactions, supersymmetric particles with R-parity nonconservation, and massless Goldstone bosons, such as majorons.

2 The NEMO3 Experiment

The NEMO3 experiment has been taking data from 2003 to 2010 in the Modane Underground Laboratory located in the Frejus tunnel (4800 m water equivalent depth). The detector [1] has a cylindrical shape and is protected by pure iron, wood and borated water shielding. It contains almost 9 kg of seven different $\beta\beta$ isotopes in the form of thin foils. It provides direct detection of electrons from the double beta decay by the use of a tracking device based on 6180 open Geiger drift cells and a calorimeter made of 1940 plastic scintillator blocks coupled to low-radioactive photomultipliers (PMTs). For 1 MeV electrons the timing resolution is 250 ps and the energy resolution (full width at half maximum) is about 15%. A 25 Gauss magnetic field surrounding the detector provides identification of electrons by the curvature of their tracks. In addition to the electron and photon identification through tracking and calorimetry, the calorimeter measures the energy and the arrival time of these particles while the tracking chamber can measure the time of delayed tracks associated with the initial event for up to 700 μs.

When searching for rare processes, the background estimation is paramount as it will limit the final sensitivity of the experiment. An exhaustive program of work has been carried out to measure the very large number of sources of background present in the NEMO3 detector [2]. There are three categories of background: the external background, originating from radioactivity outside the tracking chamber; the tracking volume background, which includes radon in the tracking gas and the drift cell wire contamination; and the internal background due to radioactive impurities inside the source foils whose dominant isotopes are ^{40}K, ^{234m}Pa, ^{210}Bi, ^{214}Bi and ^{208}Tl. The different background contributions are estimated by measuring independent event topologies by identifying e^-, e^+, γ and α particles.

Table 1: NEMO3 results of the $2\nu\beta\beta$ half-life measurements.

Isotope	Mass [g]	$\mathcal{Q}_{\beta\beta}$ [keV]	S/B	$\mathcal{T}_{1/2}$ [10^{19} years]
^{100}Mo	6914	3034	76	0.717 ± 0.001 (stat.) ± 0.054 (syst.)
^{82}Se	932	2995	4	9.6 ± 0.1 (stat.) ± 1.0 (syst.)
^{130}Te	454	2529	0.25	$70\ ^{+10}_{-8}$ (stat.) $^{+10}_{-9}$ (syst.) [4]
^{116}Cd	405	2805	10.3	2.88 ± 0.04 (stat.) ± 0.16 (syst.)
^{150}Nd	37.0	3368	2.8	0.920 ± 0.025 (stat.) ± 0.063 (syst.) [5]
^{96}Zr	9.40	3350	1.0	2.35 ± 0.14 (stat.) ± 0.16 (syst.) [6]
^{48}Ca	6.99	4274	6.8	$4.4\ ^{+0.5}_{-0.4}$ (stat.) ± 0.4 (syst.)

The NEMO3 experiment is in the unique position to perform high statistics measurements of $2\nu\beta\beta$ decays, $(A,Z) \rightarrow (A,Z+2) + 2e^- + 2\nu$. These measurements [3] improve the understanding of the $2\nu\beta\beta$ process which is the ultimate background in the $0\nu\beta\beta$ search. Its contribution can only be reduced by improving the energy resolution. Furthermore, the measured $2\nu\beta\beta$ rates help to constrain nuclear models and nuclear matrix element (NME) calculations which are currently a source of large uncertainty when translating the $0\nu\beta\beta$ half-lifes into an effective Majorana neutrino mass. Table 1 summarizes latest NEMO3 measurements of $2\nu\beta\beta$ decays. The most precise measurement is for the main isotope ^{100}Mo because of the high mass and the high signal to background ratio due to a low $\mathcal{T}^{2\nu}_{1/2}$ half-life. The $2\nu\beta\beta$ half-life of ^{130}Te is the first direct observation with a 7.7σ significance [4]. It provides a reference value to a long-standing mystery due to the wide range of measurements using geochemical sources [7].

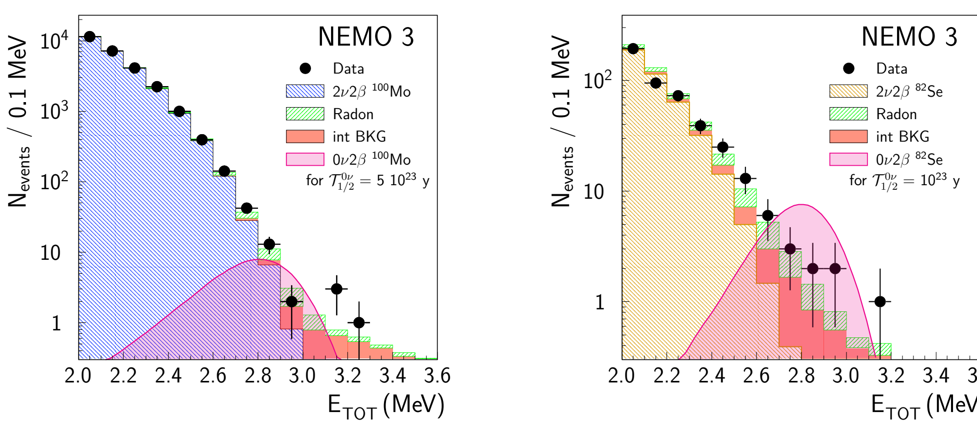

Figure 1: Total energy spectra of 2 electrons events observed in NEMO3 after 4.5 years for ^{100}Mo on the left and ^{82}Se on the right. For ^{100}Mo, 18 events have been observed between 2.8 and 3.2 MeV for 16.4 ± 1.4 expected. For ^{82}Se, 14 events have been observed between 2.6 and 3.2 Mev for 11.3 ± 1.3 expected. For illustration, the magenta shape represents what a $0\nu\beta\beta$ signal would look like with a given half-life.

The neutrinoless double beta decay search was performed on the NEMO3 data from 2003 to the end of 2009. The distribution of the energy sums, E_{TOT}, of the two electrons is used to search for neutrinoless double beta decay. A signal would correspond to an excess at $E_{\mathrm{TOT}} \simeq \mathcal{Q}_{\beta\beta}$, smeared out by the energy resolution of the calorimeter. No evidence for neutrinoless double beta decay has been observed in ^{100}Mo nor in ^{82}Se (see Fig. 1). Therefore, 90% CL lower limits on the half-lives have been set: $\mathcal{T}_{1/2}^{0\nu} \geq 1.0\,10^{24}$ yr for ^{100}Mo and $\mathcal{T}_{1/2}^{0\nu} \geq 3.2\,10^{23}$ yr for ^{82}Se. The corresponding limits on the effective Majorana neutrino mass are respectively $\langle m_\nu \rangle \leq 0.31 - 0.96$ eV and $\langle m_\nu \rangle \leq 0.94 - 2.6$ eV, according to the most recent NME calculations used by NEMO3 [8].

3 The SuperNEMO Experiment

SuperNEMO is the next-generation $0\nu\beta\beta$ experiment based on the technique of tracking and calorimetry of the NEMO3 detector [9]. It will consist of 20 identical modules, each housing 7 kg of source isotope (^{82}Se is the baseline choice). The SuperNEMO experiment increases by two orders of magnitude the NEMO3 $0\nu\beta\beta$ half-life sensitivity (see Table 2) by improving the radiopurity of detector components, the energy resolution and the selection efficiency.

Table 2: A comparison of the main NEMO 3 and SuperNEMO parameters.

	NEMO3	**SuperNEMO**
Mass	7 kg	100 kg
Isotope	^{100}Mo	^{82}Se
Foil density	60 mg/cm^2	40 mg/cm^2
Energy resolution (FWHM)		
@ 1 MeV	15 %	7 %
@ 3 MeV	8 %	4 %
Sources contaminations		
$\mathcal{A}(^{208}\text{Tl})$	$< 20\ \mu$Bq/kg	$< 2\ \mu$Bq/kg
$\mathcal{A}(^{214}\text{Bi})$	$< 300\ \mu$Bq/kg	$< 10\ \mu$Bq/kg
Radon (^{222}Rn)	~ 5.0 mBq/m^3	~ 0.1 mBq/m^3
Efficiency	18 %	30 %
Sensitivity	$\mathcal{T}_{1/2}^{0\nu} \geq 10^{24}$ y	$\mathcal{T}_{1/2}^{0\nu} \geq 10^{26}$ y
	$\langle m_\nu \rangle < 0.31 - 0.96$ eV	$\langle m_\nu \rangle < 40 - 100$ meV

During a 4 years R&D program, a tracker prototype has been instrumented and tested, reaching the target space resolution ($\sigma_{\mathrm{T}} \simeq 0.7$ mm and $\sigma_{\mathrm{L}} \simeq 1$ cm); a dedicated wiring robot is used for mass production of drift cells. For the calorimeter, the R&D program aims to reach an energy resolution of 7% FWHM at 1 MeV. Energy resolution of 7.3% has been measured with Eljen PVT blocks coupled to 8 inches Hamamatsu PMTs. As for radiopurity, the troublesome contamination from ^{208}Tl and ^{214}Bi that decay with high energy release, can be monitored by the so-called BiPo process (emission of an electron followed by a delayed α particle). The dedicated BiPo1 detector [10] is running since 2008 to measure the surface radiopurity of the source foils. A larger detector, BiPo3, will be installed in Canfranc underground laboratory in 2012 and will qualify the radiopurity of SuperNEMO foils with the required sensitivity in 6 months.

A demonstrator module with all the components of the final design will be ready for competitive physics measurement by the end of 2012. Its main objectives is to confirm R&D program on a large scale mass production and to measure backgrounds especially Radon issues. The sensitivity on the effective Majorana neutrino mass will be $\langle m_\nu \rangle < 200 - 400$ meV reaching Klapdor's claim by 2015 (see Fig. 2).

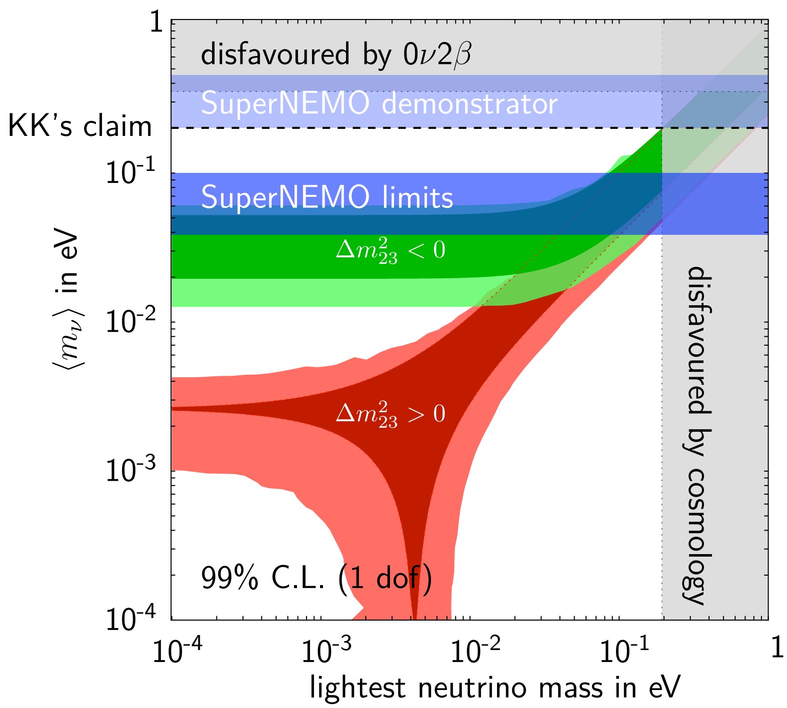

Figure 2: SuperNEMO sensitivity to neutrino mass hierarchies ($\Delta m^2_{23} < 0$ inverse hierarchy is shown in green; $\Delta m^2_{23} > 0$ normal hierarchy is shown in red).

4 Summary

The NEMO approach of using tracking plus calorimetry is unique for a $0\nu\beta\beta$ experiment and allows for excellent background rejection, choice of multiple isotopes and full kinematic reconstruction. The $2\nu\beta\beta$ decay half-lives of seven isotopes have been measured with high statistics and with better precision than in any previous measurements. No evidence for the $0\nu\beta\beta$ decay has been found in 4.5 years of data and the current limit on $\langle m_\nu \rangle$ has been set to $0.31 - 0.96$ eV. The next generation experiment SuperNEMO will extrapolate the NEMO technique to 100 kg of $\beta\beta$ isotope scale. The construction of SuperNEMO demonstrator has already started and competitive results are expected by 2015.

References

1. R. Arnold *et al*, *Nucl. Instrum. Methods* A **536**, 79 (2005).
2. R. Arnold *et al*, *Nucl. Instrum. Methods* A **606**, 449 (2009).
3. R. Arnold *et al*, *Nucl. Phys.* A **781**, 209 (2007).
4. R. Arnold *et al*, *Phys. Rev. Lett.* **107**, 062504 (2010).
5. J. Argyriades *et al*, *Phys. Rev.* C **80**, 032501 (2009)).
6. J. Argyriades *et al*, *Nucl. Instrum. Methods* A **847**, 168 (2010).
7. A. Barabash, *Czech. J. Phys.* **56**, 437 (2006).
8. M. Kortelainen and J. Suhonen, *Phys. Rev.* C **76**, 024315 (2007),
   M. Kortelainen and J. Suhonen, *Phys. Rev.* C **75**, 051303 (2007),
   F. Šimkovich *el al*, *Phys. Rev.* C **77**, 045503 (2008)
9. R. Arnold *et al*, *Eur. Phys. J. C* **70**, 927 (2010),
   F. Piquemal, *Phys. Atom. Nucl.* **69**, 2096 (2006).
10. J. Argyriades *et al*, *Nucl. Instrum. Methods* A **622**, 120 (2010).