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Results of NEMO 3 and Status of SuperNEMO

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The NEMO 3 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 LSM laboratory since 2003 and the latest NEMO 3 results for seven $\beta\beta$ isotopes are presented here for both decay modes. The SuperNEMO project aims to extend the NEMO technique to a 100 – 200 kg isotope experiment with the target half-life sensitivity of $1 - 2 \times 10^{26}$ y. The current status of the SuperNEMO R&D programme is described.

1. Introduction

The currently running NEMO 3 experiment [1] (NEMO = Neutrino Ettore Majorana Observatory) is devoted to the search for neutrinoless double beta decay ($0\nu\beta\beta$) and to the accurate measurement of two-neutrino double beta decay ($2\nu\beta\beta$) by means of the direct detection of the two electrons. $0\nu\beta\beta$ decay is a process beyond Standard Model because of the violation of lepton number conservation by two units. Detection of this process is the best experimental test for Majorana character of neutrinos. This kind of decay constrains also the type of mass spectrum hierarchy and the absolute mass of the neutrinos.

2. NEMO 3 detector

The NEMO 3 detector is located in the Modane underground laboratory (LSM) in the Fréjus tunnel in France at the depth of 4800 m w.e. The set-up is cylindrical in design, it is divided into twenty equal sectors and combines two detection techniques – particle identification provided by a wire tracking chamber and energy and time measurements of particles with a calorimeter. Thus, NEMO 3 is able to identify e^-, e^+, photons, and α-particles which allows recognition of different $\beta\beta$ decay modes, measurement of internal and external backgrounds, as well as good discrimination between signal and background.

The tracking detector is made of 6180 open octagonal drift cells operated in Geiger mode and providing a three-dimensional measurement of the charged particle tracks by recording the drift time and the two plasma propagation times. The calorimeter, which surrounds the wire chamber, consists of 1940 plastic scintillators coupled to very low-radioactivity PMTs and gives an energy resolution of $14-17\%/\sqrt{E}$ FWHM at 1 MeV and the time resolution of 250 ps.

Seventeen sectors of NEMO 3 accommodate almost 10 kg of enriched $\beta\beta$ isotopes (see Table 1) in the form of thin foils. Three sectors are also used for external background measurement and are equipped with pure Cu and natural Te.

The detector is surrounded by a solenoidal coil generating magnetic field of 25 Gauss for the e^-/e^+ recognition, and is covered by two types of shielding against external γ-rays and neutrons.

3. Event selection and background

A candidate for a $\beta\beta$ decay is a two-electron event which is selected by requiring two reconstructed tracks with a curvature corresponding to the negative charge and coming from the same vertex in the source foils. Each track has to be associated with a fired scintillator, energy of each e^- measured in the calorimeter should be higher than 200 keV and the time-of-flight has to correspond to the case of two electrons emitted at the same time from the common vertex in the foils.

A complete study of background in the $0\nu\beta\beta$ window has been performed. The level of each background component has been directly measured from data using different analysis chan-

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nels. The background can be classified in three groups: 1) internal radioactive contamination of the source, 2) external background from incoming γ-rays and 3) radon inside the tracking volume.

The dominant background during the first running period from February 2003 to September 2004 (Phase I) was due to radon diffusion into the wire chamber through tiny air leaks. The radon level inside NEMO 3 during the second running period after installation of the radon trapping facility in November 2004 (Phase II) has been reduced by a factor of ten. Remaining low radon activity inside NEMO 3 is due to detector component degassing.

4. NEMO 3 results

Measurements of the $2\nu\beta\beta$ decay half-lives have been performed for all the seven $\beta\beta$ isotopes in NEMO 3. The obtained half-lives, combining new preliminary results for ^{150}Nd, ^{130}Te, ^{96}Zr, and ^{48}Ca with higher statistics (Phase I and II data) and previous results for ^{100}Mo and ^{82}Se (Phase I data), are given in Table 1.

No evidence was found for the $0\nu\beta\beta$ decay of ^{100}Mo, ^{82}Se, ^{150}Nd, ^{96}Zr, and ^{48}Ca. The $0\nu\beta\beta$ decay half-life limits and limits on the effective Majorana neutrino mass $\langle m_\nu \rangle$ have been derived and are summarised in Table 2.

5. SuperNEMO detector design

SuperNEMO aims to extend and improve the experimental techniques use by the current NEMO 3 experiment in order to search for $0\nu\beta\beta$ decay with a target half-life sensitivity of $1-2\times 10^{26}$ year, which corresponds to the effective neutrino mass sensitivity $\langle m_\nu \rangle$ of $40-100$ meV, depending on nuclear matrix elements (NME) used. The SuperNEMO project is a $\sim 100-200$ kg source experiment and is currently in a three year design study and R&D phase.

Like NEMO 3, SuperNEMO will combine calorimetry and tracking. This technological choice allows the measurement of individual electron tracks, event vertices, energies and time-of-flight, and thus provides the full reconstruction of kinematics and topology of an event. SuperNEMO will consist of about twenty identical modules, each housing around $5-7$ kg of isotope in the form of thin foil (~ 40 mg/cm^2). The tracking volume contains more than 2000 wire drift cells operated in Geiger mode (Geiger cells), which are arranged in nine layers parallel to the foil. The calorimeter is divided into ~ 1000 blocks, which cover most of the detector outer area and are read out by low background PMTs.

6. SuperNEMO R&D

The R&D programme focuses on four main areas of study: (i) calorimeter, (ii) isotope enrichment, (iii) tracking detector, and (iv) ultra-low background materials and measurements.

SuperNEMO aims to improve the calorimeter energy resolution to $7\%/\sqrt{E}$ FWHM at 1 MeV. To reach this goal, several ongoing studies are investigating the choice of calorimeter parameters such as scintillator material (plastic or liquid) and the shape, size and coating of calorimeter blocks [9]. These are combined with dedicated development of PMTs with very low radioactivity and high quantum efficiency. The collaboration expects to make the final decision on the calorimeter design in mid-2009.

The tracking detector design study has for its goal optimisation of the wire chamber parameters to obtain high efficiency and resolution in measuring the trajectories of electrons from $\beta\beta$ decay, as well as of α-particles for the purpose of background rejection. The first 9-cell prototype was successfully operated demonstrating propagation efficiency close to 100% over a wide range of voltages [10]. Recently, a 90-cell prototype has been set in operation.

The main candidate $\beta\beta$ isotopes for SuperNEMO are ^{82}Se and ^{150}Nd. A sample of 4 kg of ^{82}Se has been enriched and is currently undergoing purification. The SuperNEMO collaboration is investigating the possibility of enriching large amounts of ^{150}Nd via the atomic vapour laser isotope separation (AVLIS) method.

In order to reach required sensitivity, SuperNEMO has to maintain ultra-low levels of background (one order lower than for NEMO 3). Contamination of sources has to be less than

Table 1
$\beta\beta$ isotopes installed in NEMO 3 and results for $2\nu\beta\beta$ decay half-life measurement.

Isotope	Mass (g)	$Q_{\beta\beta}$ (keV)	$T_{1/2}^{2\nu}$ (y)	S/B
^{100}Mo	6914	3034	$[7.11 \pm 0.02(stat) \pm 0.54(syst)] \times 10^{18}$ [2]	40
^{82}Se	932	2995	$[9.6 \pm 0.3(stat) \pm 1.0(syst)] \times 10^{19}$ [2]	4.0
^{150}Nd	37.0	3367	$[9.11^{+0.25}_{-0.22}(stat) \pm 0.63(syst)] \times 10^{18}$ [3]	2.8
^{130}Te	454	2529	$[7.6 \pm 1.5(stat) \pm 0.8(syst)] \times 10^{20}$	0.25
^{116}Cd	405	2805	$[2.8 \pm 0.1(stat) \pm 0.3(syst)] \times 10^{19}$	7.5
^{96}Zr	9.4	3350	$[2.3 \pm 0.2(stat) \pm 0.3(syst)] \times 10^{19}$	1.0
^{48}Ca	7.0	4272	$[4.4^{+0.5}_{-0.4}(stat) \pm 0.4(syst)] \times 10^{19}$	6.8

Table 2
NEMO 3 results: $0\nu\beta\beta$ decay half-life limits at 90% C.L.

Isotope	$0\nu\beta\beta$ mode	$T_{1/2}^{0\nu}$ limit (90% C.L.)		NME
^{100}Mo	(V − A)	$> 5.8 \times 10^{23}$ y [2]	$\langle m_\nu \rangle < 0.8 - 1.3$ eV	[4, 5]
	(V + A)	$> 3.2 \times 10^{23}$ y [2]		
^{82}Se	(V − A)	$> 2.1 \times 10^{23}$ y [2]	$\langle m_\nu \rangle < 1.4 - 2.2$ eV	[4, 5]
	(V + A)	$> 1.2 \times 10^{23}$ y [2]		
^{150}Nd	(V − A)	$> 1.80 \times 10^{22}$ y [3]	$\langle m_\nu \rangle < 3.7 - 5.1$ eV	[6]
	(V + A)	$> 1.07 \times 10^{22}$ y [3]		
^{96}Zr	(V − A)	$> 8.6 \times 10^{22}$ y	$\langle m_\nu \rangle < 7.4 - 20.1$ eV	[4, 7]
^{48}Ca	(V − A)	$> 1.3 \times 10^{22}$ y	$\langle m_\nu \rangle < 29.6$ eV	[8]

2 μBq/kg for ^{208}Tl and less than 10 μBq/kg for ^{214}Bi. In order to evaluate these activities, a dedicated BiPo detector is being developed. The first prototype, BiPo1, installed in the LSM laboratory in February 2008, reached the background level of < 7.5 μBq/kg for ^{208}Tl (90% C.L.) [11]. Another prototype, BiPo2, was installed in the LSM in July 2008.

7. Conclusion

The NEMO 3 detector has been routinely taking data since 2003. The $2\nu\beta\beta$ decay half-lives of seven isotopes have been measured with high statistics and with better precision than in previous measurements. No evidence for the $0\nu\beta\beta$ decay has been found in data and the $T_{1/2}$ and $\langle m_\nu \rangle$ limits have been set. The next generation experiment SuperNEMO will extrapolate the NEMO technique of calorimetry plus tracking to 100 – 200 kg of $\beta\beta$ isotope scale experiment. Due to its modular design, SuperNEMO can start operation in stages, with the first module installed in 2011 and all the modules running by 2014.

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