Journal of Physics: Conference Series

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Searching for leptonic number non-conservation with NEMO-3 and SuperNEMO

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Abstract.
The NEMO 3 experiment is devoted to the search for the neutrinoless double beta decay, a leptonic number violating second order weak process which is still to be discovered. The detector has been taking data in the LSM laboratory since 2003. Latest NEMO 3 results for several double beta decay emitters are presented here. The next generation SuperNEMO project, which aims to improve sensitivity to double beta decay by two orders of magnitude using NEMO 3 technique is also briefly described.

1. Introduction
Neutrinoless double beta decay ($0\nu\beta\beta$) (A,Z) $\rightarrow$(A,Z+2) + 2e$^-$ is a leptonic number violating process. It has been intensely searched for the last three decades but has not been discovered yet. The observation of such a process, interpreted through the exchange of a light Majorana neutrino (the *mass mechanism* [1]), would indicate the nature of the neutrino and give access to its absolute mass scale.

The NEMO collaboration aims to investigate the $0\nu\beta\beta$ process using a specific experimental technique briefly described in this paper. The NEMO 3 detector is currently running in the Fréjus underground laboratory (LSM, Modane, France). The SuperNEMO project is the next generation experiment that will improve the NEMO 3 sensitivity by two orders of magnitude.

2. The NEMO 3 detector
The NEMO 3 detector has been designed for the direct detection of electrons from neutrinoless double beta decay at the sensitivity of $T_{1/2}^{0\nu\beta\beta} \simeq 10^{24}$ y. It accomodates a 20 m^2 thin source foil made of 7 kg of ^{100}Mo, 1 kg of ^{82}Se for $0\nu\beta\beta$ search, together with smaller amounts of ^{116}Cd, ^{150}Nd, ^{96}Zr, ^{48}Ca and ^{130}Te used to measure two-neutrino double beta decay (A,Z) $\rightarrow$(A,Z+2) + $2e^-$ + $2\bar{\nu}_e$ ($2\nu\beta\beta$). The $\beta\beta$ source is surrounded by a tracking chamber composed of 6400 drift cells working in the Geiger regime and a calorimeter made of 1940 plastic scintillator blocks coupled with low radioactive photomultiplier tubes. A full description of the detector can be found in [2]. The use of such a technique enables the measurement of the total electron energy, the energy of each electron and angular distribution between the electrons. Thanks to its ability to reconstruct the full kinematics of $2\nu\beta\beta$ decays, the NEMO 3 detector also gives very valuable constraints for double-beta decay nuclear models. More, the reconstruction of the topology of beta decays and gamma emission from natural radioactivity is possible and allows to model

all sources of background events that would mimic $0\nu\beta\beta$ decays [3]. This feature makes the NEMO 3 detector an unique tool to investigate very rare $\beta\beta$ decays in a ultra low radiactivity environment.

Two-neutrino double beta decay measurements for several isotopes after 3.85 years of data collection are presented in table 1. ^{100}Mo $2\nu\beta\beta$ decays to 0^+ excited state of ^{100}Ru has been measured thanks to NEMO 3 hability to reconstruct $2e2\gamma$ topology: the half-life is $T_{1/2} = [5.7^{+1.3}_{-0.9}$ (stat)$\pm$ 0.8 (syst)] 10^{20} y [4]. More, the analysis of the shape of the single electron energy spectrum in ^{100}Mo $2\nu\beta\beta$ decay strongly supports the single state dominance mechanism hypothesis (SSD) [5].

Isotope	$T^{2\nu\beta\beta}_{1/2}$ (y)
^{100}Mo	$[7.11 \pm 0.02(stat) \pm 0.54(syst)]\times 10^{18}$ (SSD favored)
^{100}Mo(0^+_1)	$[5.7^{+1.3}_{-0.9}(stat) \pm 0.8(syst)] \times 10^{20}$
^{82}Se	$[9.6 \pm 0.3(stat) \pm 1.0(syst)]\times 10^{19}$
^{116}Cd	$[2.8 \pm 0.1(stat) \pm 0.3(syst)]\times 10^{19}$
^{130}Te	$[6.9 \pm 0.9(stat) \pm 1.0(syst)]\times 10^{20}$ *
^{150}Nd	$[9.20^{+0.25}_{-0.22}(stat) \pm 0.73(syst)] \times 10^{18}$ *
^{96}Zr	$[2.35 \pm 0.14(stat) \pm 0.19(syst)]\times 10^{19}$ *
^{48}Ca	$[4.4^{+0.5}_{-0.4}(stat) \pm 0.4(syst)] \times 10^{19}$ *

Table 1. Two-neutrino double beta decay measurements after 3.85 years of data collection with NEMO 3 (* preliminary results).

Concerning the neutrinoless double beta decay, data up to the end of 2008 show no evidence for leptonic number violation; 90% CL lower limits on the $0\nu\beta\beta$ decays half-live for ^{100}Mo [6] and ^{82}Se are set and upper limits on the Majorana neutrino effective mass are derived using recent calculations of nuclear matrix elements [7, 8, 9]:

^{100}Mo: $T^{0\nu\beta\beta}_{1/2} > 1.1\ 10^{24}$ y and $< m_\nu > < 0.45$–0.93 eV

^{82}Se: $T^{0\nu\beta\beta}_{1/2} > 3.6\ 10^{23}$ y and $< m_\nu > < 0.89$–1.61 eV

No evidence for $0\nu\beta\beta$ processes via V+A current or Majoron [10] emission have been proved and the corresponding derived limits are shown on table 2. More details can be found in [11, 12].

	V+A	Majoron(s) emission			
Isotope	$T^{0\nu\beta\beta}_{1/2}$ (y)	n=1	n=2	n=3	n=7
^{100}Mo	$> 5.7\ 10^{23}$ $\lambda < 1.4\ 10^{-6}$	$> 2.7\ 10^{22}$ $g_{ee} < (0.4-1.8)10^{-4}$	$> 1.7\ 10^{22}$	$> 1.0\ 10^{22}$	$> 7\ 10^{19}$
^{82}Se	$> 2.4\ 10^{23}$ $\lambda < 2.0\ 10^{-6}$	$> 1.5\ 10^{22}$ $g_{ee} < (0.7-1.9)10^{-4}$	$> 6\ 10^{21}$	$> 3.1\ 10^{21}$	$> 5\ 10^{20}$

Table 2. Limits on neutrinoless double beta decay throug V+A current and Majoron emission mechanisms (nuclear matrix elements has been taken from [13, 14]).

3. The SuperNEMO project

The SuperNEMO experiment is being designed to search for $0\nu\beta\beta$ at the sensitivity for the half-life $T^{0\nu\beta\beta}_{1/2} \simeq 2\ 10^{26}$ years, corresponding to $< m_\nu > \sim 50$ meV, for a typical ^{82}Se 500 kg.y exposure. Following NEMO 3 experimental technique, it will accomodate $\sim$ 100 kg of a ^{82}Se source. A three-year R&D phase started in 2006 and a technical design report is due in 2009. A first demonstrator module with 5 kg of ^{82}Se will be constructed in 2010. After validation, 19 more similar modules will be completed to start data collection in 2012. The SuperNEMO R&D program concentrates on the following critical points [15, 16, 17]:

- the making of 100 kg of ultra pure enriched source of ^{82}Se, including experimental validation of the required radiopurity level of the final thin source foils thanks to a dedicated BiPo detector [18],
- the selection and control of the materials used in the construction of the detector to ensure a very low radioactivity level,
- the design of a radon-free highly optimized tracking chamber, including the technology for automated mass production of drift cells,
- the design of the PVT plastic scintillator based calorimeter with required energy, time and spatial resolution, together with a high quality calibration survey procedure.

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