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The NEMO 3 and SuperNEMO experiments

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Abstract
NEMO 3 is a double beta decay experiment. A part of the new low background data was analysed and improved lower limits on neutrinoless decay were obtained: $T^{0\nu}_{1/2}(^{100}\text{Mo}) > 5.8 \times 10^{23}$ years and $T^{0\nu}_{1/2}(^{82}\text{Se}) > 2.1 \times 10^{23}$ years (90% CL). SuperNEMO project R&D has started.

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1. Introduction

Neutrinoless double decay ($\beta\beta_{0\nu}$) is the most sensitive process for the search of lepton number violation and its discovery would prove that the neutrino is a massive Majorana particle. This process may occur through several mechanisms. In particular, the existence of the $\beta\beta_{0\nu}$ decay by light neutrino exchange would allow us to determine the mass scale of the neutrinos [1].

NEMO 3 is a double beta decay experiment running in the Frejus Underground Laboratory (4800 m w.e.) in Modane, France. Its major goal is to look for neutrinoless double beta decay of ^{100}Mo and ^{82}Se, as well as to measure two neutrino decay, $\beta\beta_{2\nu}$, of five other isotopes: ^{116}Cd, ^{150}Nd, ^{96}Zr, ^{48}Ca and ^{130}Te. A radon background reduction facility was completed in October 2004. About a year of low background data was recorded since then.

Apart from this an R&D programme on the new SuperNEMO project has been started. It will use the NEMO like tracker plus calorimeter technique to study 100 kg of isotopes. It is planned to reach a sensitivity $\sim 1\text{–}2 \times 10^{26}$ years for neutrinoless mode of the decay.

2. The NEMO 3 detector

NEMO 3 is a tracking experiment. It means that electrons from $\beta\beta$ decay are registered in the tracking device and their energies are measured in the calorimeter. This provides excellent signature of the event, and helps to reduce and control background.

The detector has the form of a cylinder. A thin source ($\sim 50\,\text{mg cm}^{-2}$) is situated between two tracking volumes restricted by walls of plastic scintillator blocks coupled to photomultipliers (PMT). There are about 10 kg of isotopes: 6.9 kg of ^{100}Mo, 0.93 kg of ^{82}Se, 0.4 kg of ^{116}Cd, 0.45 kg of ^{130}Te, 37 g of ^{150}Nd, 9 g of ^{96}Zr and 7 g of ^{48}Ca.

The tracking chamber consists of 6180 drift cells operating in Geiger mode and provides track vertex resolution of about 1 cm. The calorimeter has 1940 blocks with an energy resolution at FWHM of $14\text{–}17\%/\sqrt{E}$. Its time resolution (250 ps) allows excellent suppression of crossing electron background with time of flight analysis.

There is a vertical magnetic field of 25 G to reject e^+e^- pair production in the source. The whole detector is covered with 18 cm thick iron passive shielding and 30 cm thick tanks with boron water solution as neutron shield.

The detector is capable to detect e^-, e^+, γ and α particles. A detailed description of the detector is presented in [2].

2.1. Background model

Background in NEMO 3 can be classified into three types: external, from incoming γ, radon in the tracker and internal radioactive pollution of the source. All sources of background were estimated with event topologies other than e^-e^- (i.e. e^-, $e^-\gamma$, $e^-\gamma\gamma$).

To control the background, a blank Cu foil (621 g) was installed in the detector. In figure 1(a), a spectrum of $\beta\beta$ events measured in Cu as well as the MC prediction according to the model is shown. It is an important check of our understanding of the background in the experiment.

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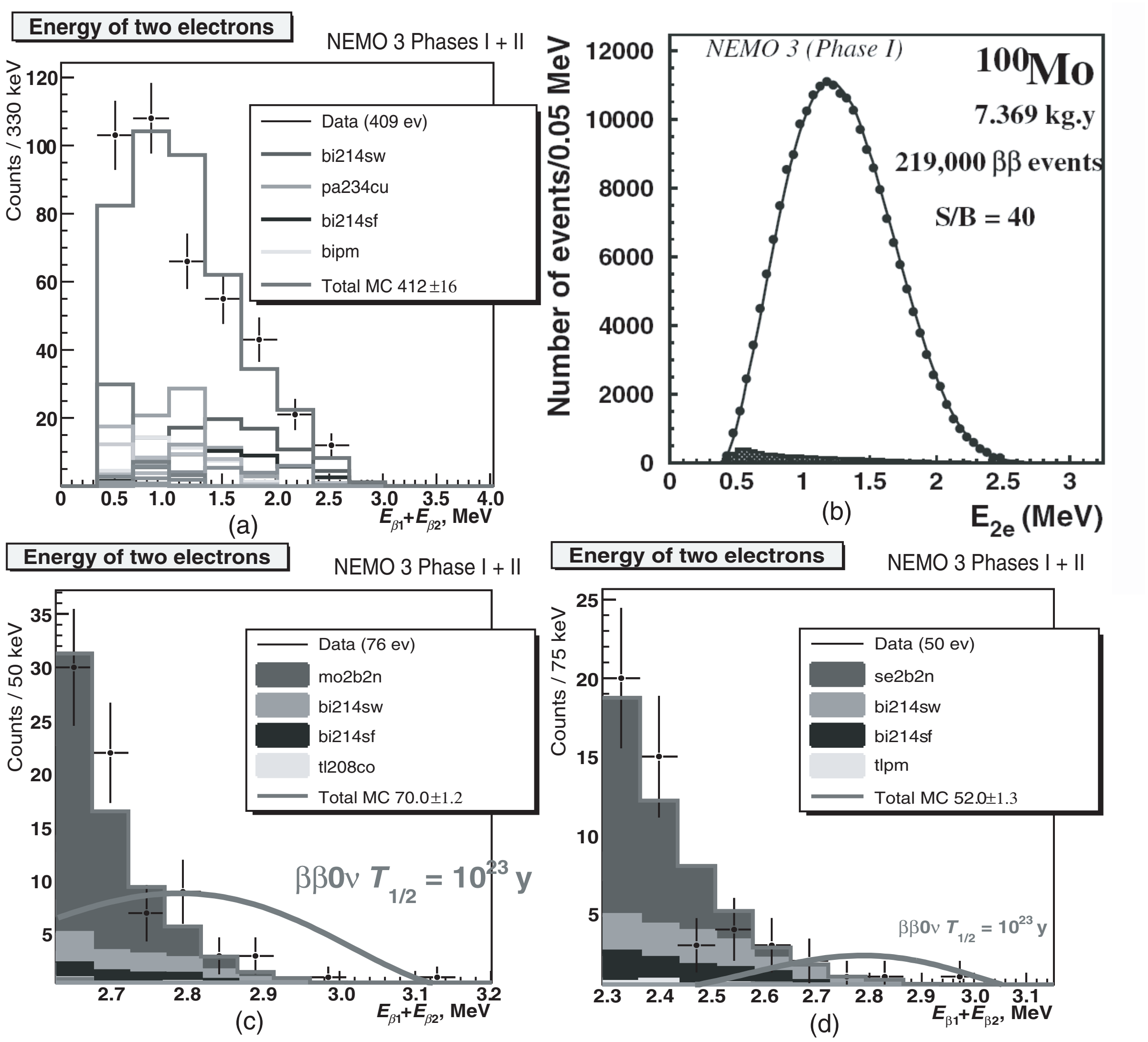

Figure 1. (a) Background $\beta\beta$ spectrum in Cu foil; (b) ^{100}Mo Phase-I $\beta\beta_{2\nu}$ spectrum; (c) ^{100}Mo Phase I and II $\beta\beta_{2\nu}$ spectrum at $Q_{\beta\beta}$; (d) ^{82}Se Phase I and II $\beta\beta_{2\nu}$ spectrum at $Q_{\beta\beta}$.

2.2. Radon background reduction

After starting the experiment, a small amount of radon was detected inside the tracking chamber. It was demonstrated that its major part was coming from laboratory air through small leaks. To solve the problem, a tight tent surrounding the detector was built. The tent is fed with radon free air, coming from the purification facility. The core of this facility is a charcoal tank operating at −50°C. Radon is trapped inside the charcoal and decays while diffusing through it. So no regeneration is needed.

A reduction factor of 100 was achieved for the radon in the air inside the tent. Radon level in the tracking chamber dropped from 20–30 mBq m^{-3} to 4–5 mBq m^{-3}. It was shown that it is not any more dependent on amount of radon in the tent, thus its major source now is detector components degassing.

Thus there are two data sets: Phase I data corresponding to higher radon background, and Phase II with low background conditions.

Table 1. Main results on $\beta\beta_{2\nu}$ decays. S/B is a signal to background ratio.

Nuclei	S/B	$T_{1/2}$ (years)
^{100}Mo	40	7.11 ± 0.02(stat) ± 0.54(syst) $\times 10^{18}$
^{82}Se	4.0	9.6 ± 0.3(stat) ± 1.0(syst) $\times 10^{19}$
^{116}Cd	7.5	2.8 ± 0.1(stat) ± 0.3(syst) $\times 10^{19}$
^{150}Nd	2.8	9.7 ± 0.7(stat) ± 1.0(syst) $\times 10^{18}$
^{96}Zr	1.0	2.0 ± 0.3(stat) ± 0.2(syst) $\times 10^{19}$
^{48}Ca	∼10	3.9 ± 0.7(stat) ± 0.6(syst) $\times 10^{19}$

3. NEMO 3 results

3.1. ^{100}Mo *results*

A measurement of $\beta\beta_{2\nu}$ decay was done with Phase I data, see table 1 and figure 1(b) [3]. With the biggest statistics collected in the world (219 000 events) and a signal to background ratio (S/B) of 40 single state dominance (SSD) mechanism [4] of the decay was demonstrated. Also ^{100}Mo $\beta\beta_{2\nu}$ decay to excited 0^+ state of ^{100}Ru was measured with a half-life of

Table 2. Constraints on $T_{1/2}$ in years for exotic processes from NEMO 3 data (90% CL). λ is a (V+A) Lagrangian parameter, g is a majoron to neutrino coupling strength; nuclear matrix elements calculations from [5] were used. See [6] for explanation of n.

Nuclei	(V+A) current	$n = 1$	$n = 2$	$n = 3$	$n = 7$
^{100}Mo	$>3.2 \times 10^{23}$ $\lambda < 1.8 \times 10^{-6}$	$>2.7 \times 10^{22}$ $g < (0.4–1.8) \times 10^{-4}$	$>1.7 \times 10^{22}$	$>1.0 \times 10^{22}$	$>7.0 \times 10^{19}$
^{82}Se	$>1.2 \times 10^{23}$ $\lambda < 2.8 \times 10^{-6}$	$>1.5 \times 10^{22}$ $g < (0.7–1.9) \times 10^{-4}$	$>6.0 \times 10^{21}$	$>3.1 \times 10^{21}$	$>5.0 \times 10^{20}$

$T_{1/2} = 5.7^{+1.3}_{-0.9}(\text{stat}) \pm 0.8(\text{syst}) \times 10^{20}$ years. All these results are important input for nuclear physics theory. They allow us to validate nuclear model for further $\beta\beta_{0\nu}$ matrix elements calculations.

As for $\beta\beta_{0\nu}$ decay search, no signal was found (figure 1(c)). The results for Phase I and Phase II data were combined. A preliminary counting analysis shows 14 events in the window of interest (2.78–3.20) MeV, the expected background is 13.4 events, and $\beta\beta_{0\nu}$ efficiency is 8.4%. The effective time analysed is 13 kg year yielding a lower limit on the half-life of $T_{1/2} > 5.8 \times 10^{23}$ years (90% CL), corresponding to the effective neutrino mass $\langle m_\nu \rangle <$ 0.6–1.0 eV [5].

3.2. ^{82}Se *results*

2570 $\beta\beta_{2\nu}$ events were registered during Phase I of the experiment, with a S/B ratio equal to about 4, and a half-life given in table 1.

After the preliminary analysis of 1.76 kg year of Phase I and Phase II data (see figure 1(d)), seven events were found in the window (2.62–3.20) MeV, with the expected background 6.4 events, $\beta\beta_{0\nu}$ efficiency of 14.4% yielding a lower limit on the half-life of $T_{1/2} > 2.1 \times 10^{23}$ years (90% CL), which corresponds to an upper mass limit of $\langle m_\nu \rangle <$ 1.2–2.5 eV [5].

3.3. $\beta\beta_{2\nu}$ *decay*

Phase I data for four other isotopes were analysed and their half-lives measured, see table 1 with preliminary results. This could be a very important input for nuclear theory. Since all isotopes are measured with the same device, the half-life ratio has a very small systematic uncertainty, while statistical errors will reach few per cent.

3.4. *Search for exotic processes*

Along with mass mechanism, there are other possibilities to generate $\beta\beta_{0\nu}$ decay, e.g. if there is an explicit right-handed current (V+A) term in the Lagrangian, or if there are neutrino-coupled axions (majorons). In the first case, one expects the angular and single electron energy distributions to differ from $\beta\beta_{0\nu}$ driven by the mass mechanism. Only a tracking detector like NEMO 3 can use this signature. In the second case, axions are emitted in the decay, thus forming specific energy spectrum, characterized by spectral index n [6]. One can look for deviations in the $\beta\beta_{2\nu}$ spectrum shape to restrict majoron models and NEMO 3 is one of the best experiments here, taking into account amount and purity of $\beta\beta_{2\nu}$ data collected. In table 2, results for (V+A) and majoron search are summarized.

4. SuperNEMO project

The SuperNEMO collaboration has started to study the feasibility of an extrapolation of the NEMO technique to a detector with a mass of at least 100 kg of enriched $\beta\beta$ isotope in order to reach a sensitivity of 50 MeV on the effective neutrino mass.

SuperNEMO would use the NEMO technical choices: a thin source between two tracking volumes surrounded by a calorimeter. The main features to improve comparing to NEMO 3 are the energy resolution (FWHM 7–10%/$\sqrt{E}$ depending on final design are needed), the improved $\beta\beta_{0\nu}$ detection efficiency ($\sim$ factor 2), the source radiopurity (factor $>$ 10 compared to NEMO 3) and the background rejection methods.

A 3 year R&D programme was approved in UK and France to achieve all these goals and make a detailed technical design proposal by the end of 2008. If approved, detector construction can start as early as 2009 and first data will be taken in 2010 in order to reach the planned sensitivity by 2015.

References

[1] Faessler A and Šimkovic F 1998 *J. Phys. G: Nucl. Part. Phys.* **24** 2139
Suhonen J and Civitarese O 1998 *Phys. Rep.* **300** 123
Elliot S R and Vogel P 2002 *Annu. Rev. Nucl. Part. Sci.* **52** 115
Vergados J D 2002 *Phys. Rep.* **361** 1
[2] Arnold R *et al* 2005 *Nucl. Instrum. Methods* A **536** 79
[3] Arnold R *et al* 2005 *Phys. Rev. Lett.* **95** 182302
[4] Abad J *et al* 1984 *An. Fis.* A **80** 9
Šimkovic F *et al* 2001 *J. Phys. G: Nucl. Part. Phys.* **27** 2233
[5] Šimkovic F *et al* 1999 *Phys. Rev.* C **60** 055502
Stoica S and Klapdor-Kleingrothaus H V 2001 *Nucl. Phys.* A **694** 269
Civitarese O and Suhonen J 2003 *Nucl. Phys.* A **729** 867
Suhonen J 2002 *Nucl. Phys.* A **700** 649
Aunola M and Suhonen J 1998 *Nucl. Phys.* A **463** 207
[6] Arnold R *et al* 2006 *Nucl. Phys.* A **765** 483