PROCEEDINGS OF SCIENCE

Status of SuperNEMO Demonstrator

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The SuperNEMO experiment is looking for the neutrinoless double beta decay process ($0\nu\beta\beta$) with a Tracker-Calorimeter technique. The aim of the experiment is to reach a sensitivity of 10^{26} y equivalent to a Majorana effective mass of a 50-100 meV with ~100 kg of enriched isotopes. A first module called Demonstrator is under construction at the Laboratoire Souterrain de Modane (LSM) at 4800 m.w.e. depth. It will host 7 kg of ^{82}Se isotope ($Q_{\beta\beta}$=2.99 MeV) divided in thin foils of 40-60 mg/cm^2 thickness. The goal of this first phase is to reach a zero background level in the region of interest of $0\nu\beta\beta$ in order to demonstrate the feasibility of the full SuperNEMO experiment. The radiopurity strategies and the performances achieved are described as well as the status of the construction and integration of the Demonstrator module.

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1. Introduction

SuperNEMO is a next generation experiment based on the same successful NEMO3 tracking and calorimetric technology. This technique is able to strongly suppress backgrounds and to disentangle different mechanisms of $0\nu\beta\beta$ decay by reconstructing the full topology and kinematics of $\beta\beta$ events, including the measurements of individual electron energies and angle between the two electrons [1]. The goal of SuperNEMO is to reach a sensitivity on the Majorana effective neutrino mass of 50-100 meV with an exposure of 500 kg.y by using $\sim$100 kg of enriched double beta isotopes, like ^{82}Se (baseline isotope), ^{150}Nd or ^{48}Ca. To do so, the radiopurity of the source foils must be at the level of few μBq/kg for ^{208}Tl and ^{214}Bi and the energy resolution of the detector a the level of 3.4% (σ) at 1 MeV in order to reduce the contribution of the backgrounds in the region of interest to few 10^{-5} cts.keV^{-1}.kg^{-1}.y^{-1}.

2. The SuperNEMO Demonstrator

A Demonstrator module has been designed with 7 kg of ^{82}Se isotope in order to demonstrate a 'zero' background level in the region of interest and to reach a sensitivity on the half-life of 6×10^{24} years. The ^{82}Se is a good candidate due to its large $Q_{\beta\beta}$ value (2.99 MeV), above most of the natural backgrounds, especially the 2.6 MeV gamma from the natural radioactive chains, and its large enrichment factor up to 97%. The SuperNEMO demonstrator module has a planar geometry of 6x4x2 m^3 (see Fig.1 on the left). The 7 kg of enriched source is divided in thin foils of 40-60 mg/cm^2 thickness in order to minimize the energy loss of the electrons. A wire chamber, composed of 2034 cells running in Geiger mode and filled with a gas mixture (95% He, 4% ethanol, 1% Ar), is surrounding the source foils in order to track the two electrons emitted as illustrated on Fig.1 (right). A coil producing a 25 G magnetic field will be installed to curve their trajectory and to disentangle electrons and positrons. A Calorimeter module is placed after the tracking chamber in order to measure precisely the energy of the electrons with a resolution of 3.4% σ at 1 MeV electrons (8% FWHM) but also to tag the gammas. It hosts 712 Optical Modules (OM) composed of plastic scintillator (mainly Polystyrene) coupled to radiopure 8" and 5" PMTs.

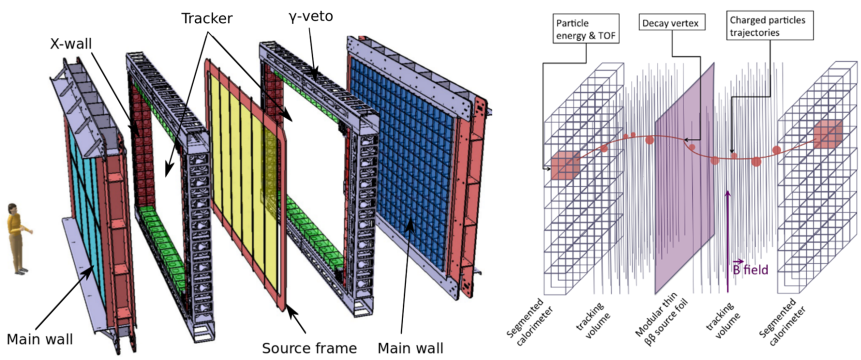

Figure 1: Exploded views of a SuperNEMO module. Left: mechanical design. Right: sketch of a $\beta\beta$ event with two electrons emitted from the source foil, curved by the magnetic field, tracked by the wire chamber and detected by two optical modules of the segmented calorimeter with energy and time measurements.

3. Radiopurity strategies

The requirements of the SuperNEMO experiment in terms of radiopurity are by order of importance: the radiopurity of the source foils at the level of 2 and 10 μBq/kg for ^{208}Tl and ^{214}Bi respectively, the radiopurity of the gas of the tracking chamber in term of Radon (^{222}Rn) at the level of 0.15 mBq/m^3 and the radiopurity of all the components surrounding the foils at the level of few mBq/kg. The first two backgrounds are called internal background and the last one external. Detailed simulations have demonstrated that $\sim$0.1 event in the ROI [2.8-3.2 MeV] is expected for a 17.5 kg.y exposure of the SuperNEMO Demonstrator taking into account the required internal backgrounds (Tl, Bi and Radon) and the $2\nu2\beta$ half-life of ^{82}Se with a 8% FWHM energy resolution [2]. We will describe in the next subsections the strategies adopted in order to fulfill these requirements.

3.1 The BiPo-3 detector

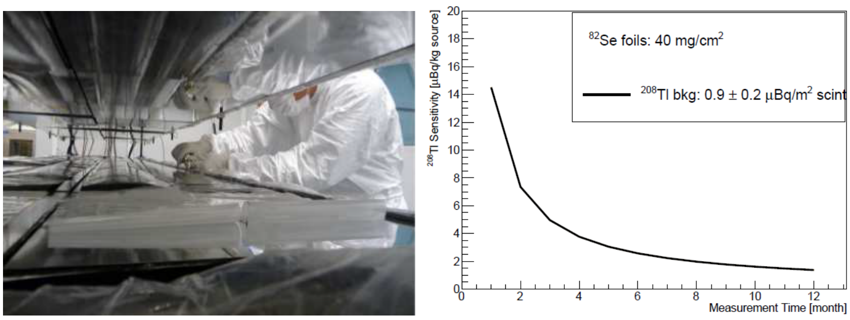

Figure 2: Left: picture of the the BiPo-3 detector hosting ^{82}Se foils. Right: sensitivity achieved for ^{208}Tl in μBq/kg with measurement time.

The SuperNEMO collaboration has developed a dedicated detector called BiPo-3 in order to qualify the thin foils of ^{82}Se at unprecedented levels of few μBq/kg for ^{208}Tl (Th serie) and ^{214}Bi (U serie). In the case of ^{208}Tl, the principle of the measurement consists in detecting the so-called ^{212}BiPo cascade, i.e. an electron from β decay of ^{212}Bi followed by a delayed α of 8.8 MeV from ^{212}Po with a typical half-life of 300 ns. A successful R&D has been conducted in 2006-2010 with two prototypes that have demonstrated the proof of principle of such a detector to reach very low backgrounds [3]. A bigger detector called BiPo-3 has been designed and built in 2012 in order to measure the final ^{82}Se foils for the SuperNEMO Demonstrator with a total sensitive area of 3.6 m^2 [4]. It is divided in two modules, each of them hosting 20 pairs of optical sub-modules, composed of thin polystyrene scintillators coupled to 5" low background PMTs. The BiPo-3 detector is in operation since 2013 at the Canfranc Underground Laboratory (see Fig.2 left). A very low surfacic background has been achieved for ^{208}Tl at the level of 0.9$\pm$0.2 μBq/m^2. Taking into account the radiopurity of the materials used in the fabrication of the source foils (PVA and raw/irradiated mylar), the simulations demonstrate that the level of 2 μBq/kg for ^{208}Tl can be achieved with a ^{82}Se foil of 3.6 m^2 (1.4 kg) in 6-8 months of measurement (see Fig.2 right).

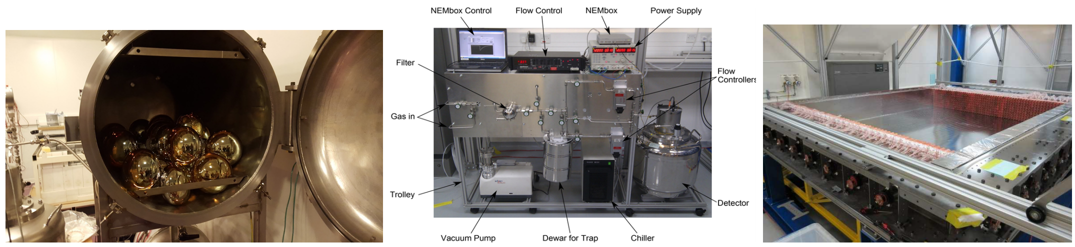

Figure 3: Left: picture of the large emanation chamber hosting 30×8" PMTs. Middle : picture of the Radon Concentration Line (RnCL) used to measure the Radon in quarter tracker at the level of 0.15 mBq/m^3. Right: picture of one of the quarter tracker fully populated with drift cells.

3.2 The Radon facilities

The Radon 222, a noble gas progenitor of ^{214}Bi, can diffuse through materials from the outside, emanate from materials containing ^{226}Ra impurities or be present in the input gas of the SuperNEMO tracker. Thus, several strategies have been adopted in order to minimize the Rn activity down to 0.15 mBq/m^3 in the wire chamber. Firstly, an apparatus to measure the Rn diffusion coefficient D of various thin materials have been developed with a sensitivity of few 10^{-16} m^2.s^{-1} in order to select the most tight materials. For example, this setup has been of crucial help to validate the use of a nylon film located between the Tracking chamber and the Calorimeter module [5]. We developed also small and large chambers built with radiopure stainless steel in order to measure the Rn emanation from the most critical materials. These facilities are complementing each other. The large setup with a 0.7 m^3 volume chamber is well-adapted to large volume samples (see Fig.3 left) or films with large surfaces up to 80 m^2 with a typical sensitivity 3 mBq [6]. The small setups with a few liters volume are well-adapted to smaller samples with a much higher sensitivity of 0.2 mBq. All the materials in contact with the gas have been screened with these facilities. Finally, a Radon Concentration Line (RnCL) has been developed in order to measure the final volumic activity of the Tracker itself at the level of 0.15 mBq/m^3. It is composed of an electrostatic Radon detector coupled to a trap containing activated carbon which is cooled to -50 Celsius degrees (see Fig.3 middle). The principle of the measurement consists in flushing pure nitrogen in each quarter tracker (see Fig.3 right) and to transfer it to the RnCL in order to estimate the level of Radon emanation from the internal materials. Three of the four quarter trackers have been tested and a small activity of Radon has been measured at the level of few mBq [7]. Assuming a replacement rate of 2 m^3/h during the running of SuperNEMO, the level of 0.15 mBq/m^3 can be achieved.

3.3 The Germanium facilities

All the materials of the Demonstrator module have been screened by low-background gamma spectrometry using High Purity Germanium detectors (HPGe) from various platforms. Their acceptation or rejection has been based on their activity compared to the total activity of the glass of the 8" PMTs, which is the dominant source of external gammas [8]. The rule consists in having an activity much lower than 10% of the glass activity in ^{40}K, ^{238}U, ^{214}Bi and ^{208}Tl. Depending on their locations and their total mass in the demonstrator, they have been accepted with typical activity levels from few 0.1 mBq/kg to few 100 mBq/kg.

4. Status of the construction and integration of the SuperNEMO Demonstrator

4.1 Status of the Source production

The 7 kg of ^{82}Se will be divided in 36 strips of 270x13.5(12.5) cm^2 each with 250 μm thickness. These strips are produced with a mixture of Selenium and PVA (Polyvinyl Alcohol) sandwiched by two raw or irradiated mylar foils [9]. Up to now, 11 strips (1.43 kg) have been produced for SuperNEMO with the technique using irradiated mylar. Ten of them have been qualified with the BiPo-3 detector at the level of [9-44] μBq/kg (90% C.L.) in ^{208}Tl. The other 25 strips are under fabrication with raw mylar: 4 of them have been already produced and will be qualified with BiPo-3. All the selenium foils will be installed in a radiopure source frame at LSM in spring 2017.

4.2 Status of the Tracker construction

The wire chamber is divided in quarter tracker parts called C-sections. It is composed of 2034 drift cells (40 mm diameter, 2.7 m long) running in Geiger modes. The construction and assembly have been performed in ultraclean conditions. Commissionning of the first three tracker C-sections has been performed using cosmic muons and has demonstrate that 99% of the 1512 tested cells will be fully operationnal under LSM conditions. The production of all the cells have been completed in October 2016 and the last C-section is about to be fully populated. Half of the Tracker is already installed at LSM and the second half will be sent before the end of 2016.

4.3 Status of the Calorimeter construction

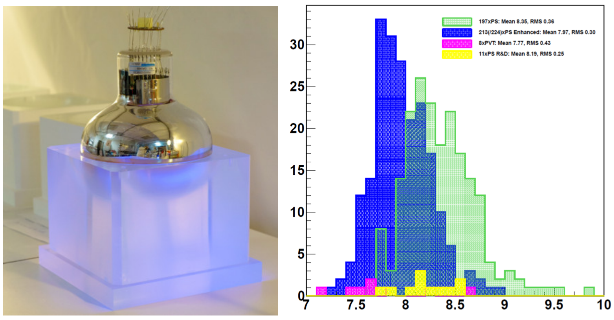

Figure 4: Left: picture of an Optical Module (OM) equipped with a 8” PMT. Right: distribution of the energy resolution for the 440 OM of the Main Walls with a mean value of 8.3% and 8% FWHM for normal (green) and enhanced (blue) Polystyrene composition respectively.

The Calorimeter module is composed of three different parts. The most important part consists in two Main Walls located vertically in front of the source foils. They host 440 Optical modules (OM) equipped with 8” PMTs (illustrated on the left part of the Fig.4) and 80 OM with 5” PMTs. The production of these modules has been completed in July 2016 and sent to LSM. The Fig. 4 (right) shows the energy resolution distribution of the 440 OM. With a mean value of 8.0-8.3% FWHM, the goal for SuperNEMO has been reached thanks to a successfull R&D based on detailed optical simulations to optimize the performances [10]. A calibration system has been also developped to maintain an energy stability better than 1%.

5. Conclusion

Figure 5: Left: picture of the first calorimeter Main Wall during its integration at LSM. Right: final coupling of half of the detector with the Tracker (left) and the first Calorimeter Main Wall (right).

The SuperNEMO Demonstrator module is currently under integration at the Laboratoire Souterrain de Modane, as it is illustrated on Figure 5. Half of the detector is ready to be commissionned. The other half will be integrated beginning of 2017. The source and source frame will be installed in spring with a final closure of the detector planned by mid of 2017. Data taking will start in the second half of the year to measure the level of background achieved.

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