SuperNEMO double beta decay experiment

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Abstract. SuperNEMO is a next-generation double beta decay experiment based on the successful tracking plus calorimetry design approach of the recently stopped NEMO3 experiment. SuperNEMO can study a range of isotopes, but the baseline isotope is $^{82}$Se. The total isotope mass will be 100–200 kg. A sensitivity to a $0\nu\beta\beta$ half-life greater than $10^{26}$ years can be reached which gives access to Majorana neutrino masses of 50–100 meV. Having successfully completed R&D stage the SuperNEMO Collaboration has commenced the construction of the first module, the Demonstrator. The present status of SuperNEMO program and plan for the nearest future are discussed.

1. Introduction

During $\sim 9$ years (2002-2010) NEMO3 detector was operated in the Modane underground laboratory (LSM) in the Frejus tunnel between France and Italy. Seven different isotopes have been studied in NEMO3 and very interesting and important results for $2\nu$- and $0\nu$-decay modes have been obtained for $^{100}$Mo [1, 2], $^{82}$Se [1, 2], $^{150}$Nd [3], $^{96}$Zr [4], $^{130}$Te [5], $^{116}$Cd [2], and $^{48}$Ca [2]. The tracking plus calorimetry technique employed in NEMO3 provides an accurate and efficient identification of useful and background events. And we have decided to use this very well known technique for new (SuperNEMO) experiment. Main advantages of the NEMO technique are the following:

- full event reconstruction;
- clear event signature;
- excellent background rejection;
- new physics studies using event topology (mass mechanism, RHC, excited states,...) [6].

In addition we plan to use planar geometry (instead cylindrical in NEMO3), to use modular system and improve some characteristics of the detector (energy resolution, efficiency, purity of the source, etc.). This report will focus on the present status of SuperNEMO experiment, main recent achievements and plans for the nearest future.

2. SuperNEMO

SuperNEMO aims to extend and improve the successful NEMO3 technology. It will extrapolate NEMO3 by one order of magnitude by studying about 100-200 kg of $\beta\beta$ isotope(s). The detector’s ability to measure any $\beta\beta$ isotope and reconstruction of the topological signature of the decay are distinct features of SuperNEMO. The baseline isotope choice for SuperNEMO is $^{82}$Se. However other isotopes are possible. In particular, $^{150}$Nd and $^{48}$Ca are being looked at. Detector will be able to measure individual electron tracks, vertices, energies and time of
flight, and to reconstruct fully the kinematics and topology of an event. Particle identification of gamma and alpha particles, as well as distinguishing electrons from positrons with the help of a magnetic field, form the basis of background rejection. An important feature of NEMO3 which is kept in SuperNEMO is the fact that the double beta decay source is separate from the detector, allowing several different isotopes to be studied. SuperNEMO will consist of about twenty identical modules, each housing around 5-7 kg of isotope. The project is completing a 3 year design study and R&D phase with much progress towards the first prototype Demonstrator module. The R&D program focuses on four main areas of study: isotope enrichment, tracking detector, calorimeter, and ultra-low background materials production and measurements. The expected improvement in performance of SuperNEMO compared to its predecessor NEMO3 is shown in Table 1 which compares the parameters of the two experiments. The most important design study tasks are described in the sections that follow.

| Isotope     | NEMO3  | SuperNEMO |
|-------------|--------|-----------|
| Isotope     | $^{100}$Mo | $^{82}$Se |
| mass        | 7 kg   | 100-200 kg |
| signal efficiency | 18%   | > 30%  |
| $^{208}$Tl in foil | < 20 µBq/kg | < 2 µBq/kg |
| $^{214}$Bi in foil | < 300 µBq/kg | < 10 µBq/kg |
| energy resolution at 3 MeV | 8% (FWHM) | 4% (FWHM) |
| Sensitivity to half-life | $\sim 10^{24}$ yr | $\sim (1-2) \times 10^{26}$ yr |
| sensitivity to neutrino mass | $\sim (0.3-0.9)$ eV | $\sim (0.05–0.1)$ eV |

Figure 1 shows two renderings of the SuperNEMO Demonstrator module. The source is a thin (~ 40 mg/cm) foil inside the detector. It is surrounded by a gas tracking chamber followed by calorimeter walls. The tracking volume contains more than 2000 wire drift chambers operated in Geiger mode, 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 photo multiplier tubes (PMT).

![Figure 1. Preliminary design of the SuperNEMO detector. Left-hand side: An exploded view showing the tracking chamber and calorimeter modules. Right-hand side: A view showing the configuration of the calorimeter modules with dimensions.](image-url)
2.1. Calorimeter R&D
SuperNEMO aims to improve the calorimeter energy resolution to 7%/\(E\) at FWHM (4% at the \(Q_{\beta\beta}\) energy). To reach this goal, several studies have been completed on the choice of calorimeter parameters such as scintillator material (organic plastic or liquid), and the shape, size and coating of calorimeter blocks. These are combined with dedicated development of PMTs with low radioactivity and high quantum efficiency. The feasibility to reach the required resolution of 7–8%/\(\sqrt{E}\) (MeV) with a large (26x26x15 cm\(^3\)) block has been experimentally demonstrated with PVT-based scintillators coupled to a low radioactive high-QE 8” R5912MOD Hamamatsu PMT. The remaining challenge is to demonstrate that the achieved energy resolution can be maintained at the mass production scale. The large scale construction will start in 2012.

2.2. Tracker design
The SuperNEMO tracker consists of octagonal wire drift cells operated in Geiger mode. Each cell is around 4 m long and has a central anode wire surrounded by 8–12 ground wires, with cathode pickup rings at both ends. Signals can be read out from the anode and/or cathodes to determine the position at which the ionizing particle crossed the cell. The tracking detector design study looks at optimizing its parameters to obtain high efficiency and resolution in measuring the trajectories of double beta decay electrons, as well as of alpha particles for the purpose of background rejection. The tracking chamber geometry is being investigated with the help of detector simulations to compare the different possible layouts. In addition, several small prototypes have been built to study the drift chamber cell design and size, wire length, diameter and material, and gas mixture [7]. The first 9-cell prototype was successfully operated with three different wire layouts, demonstrating a plasma propagation efficiency close to 100% over a wide range of voltages [7]. In addition, a 90-cell prototype has recently been constructed. Measurements of cosmic ray tracks in a 90-cells prototype have been demonstrated the required space resolution (0.7 mm radial and 1 cm longitudinal). A SuperNEMO module will contain several thousand drift cells with 8–12 wires each. The large total number of wires requires an automated wiring procedure, thus a dedicated wiring robot is being developed for the mass production of drift cells.

2.3. Choice of source isotope
The choice of isotope for SuperNEMO is aimed at maximizing the neutrinoless signal over the background of two-neutrino double beta decay and other background events. Therefore the isotope must have a long two-neutrino half-life, and high endpoint energy and phase space factor. The enrichment possibility on a large scale is also a factor in selecting the isotope. The main candidate isotopes for SuperNEMO have emerged to be \(^{82}\)Se (\(E_{\beta\beta} = 2995\) keV). A sample of 5 kg of \(^{82}\)Se has been enriched and is currently undergoing purification.

2.4. Radiopurity of the source
SuperNEMO will search for a very rare process, therefore it must maintain ultra-low background levels. The source foils must be radiopure, and their contamination with naturally radioactive elements must be precisely measured. The most important source contaminants are \(^{208}\)Tl and \(^{214}\)Bi, whose decay energies are close to the neutrinoless double beta decay signal region. SuperNEMO requires source foil contamination to be less than 2 \(\mu\)Bq/kg for \(^{208}\)Tl and less than 10 \(\mu\)Bq/kg for \(^{214}\)Bi. In order to evaluate these activities, a dedicated BiPo detector was developed which can measure the signature of an electron followed by a delayed alpha particle. The first BiPo prototype (BiPo1) was installed in the Modane Underground Laboratory in February 2008 and is currently running with 20 modules (with a 0.8 m\(^2\) of sensitive surface). The objective for this prototype is to measure the backgrounds and surface contamination of the prototypes plastic scintillators [8]. A medium-size BiPo-3 detector with a 3.25 m\(^2\) sensitive
surface and using the same techniques developed in the BiPo-1 prototype is under construction (see Fig. 2). The goal of the BiPo-3 detector is to measure the first double beta decay source foils of the SuperNEMO Demonstrator in the year 2012. Required SuperNEMO sensitivity will be reached in six months of measurement.

Figure 2. Schematic view of BiPo-3 capsule (left) and one of two modules (right).

3. SuperNEMO Demonstrator and schedule outline
Having successfully completed the R&D stage the SuperNEMO collaboration has commenced the construction of the first module, the Demonstrator. The main goals of the Demonstrator are: to demonstrate feasibility of mass production of detector components under ultra-low background conditions; to measure backgrounds especially from radon emanation; to finalize the detector design; to produce a competitive physics result. To accomplish the latter goal on a competitive time scale the Demonstrator module will house 5–7 kg of the $^{82}\text{Se}$ isotope. The construction and commissioning of the Demonstrator will be completed in 2013 with data taking expected to commence in the second half of 2013. The module will be located in the LSM (in the existing cavern). The sensitivity of the Demonstrator after 17 kg×yr of exposure is $6.5 \times 10^{24}$ yr (90% CL) (sensitivity to effective Majorana neutrino mass is $\sim 0.2$-$0.5$ eV). The modular design of SuperNEMO makes it possible to proceed with construction and data taking in parallel. The full detector construction is expected to start in 2014 (in parallel with the Demonstrator running). The 500 kg×yr exposure will be reached in $\sim 2019$ pushing the sensitivity to the effective Majorana neutrino mass down to 50-100 meV.

4. Conclusion
Based on the successful experience of the NEMO detectors, the extensive and intensive SuperNEMO R&D program is finishing with construction of the Demonstrator started in 2010. Construction and commissioning of the first module (Demonstrator) will be completed in 2013 for a possible full detector construction starting in 2014 reaching its sensitivity of $\sim 10^{36}$ yr on $0\nu\beta\beta$ decay of $^{82}\text{Se}$ in $\sim 2019$. The unique technique of the SuperNEMO detector could provide the possibility to study the origin of $0\nu\beta\beta$ decay in the case of its discovery.

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