SuperNEMO Project Status

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Abstract. The SuperNEMO experiment aims to reach a sensitivity up to 10^{26} years on the half-life of neutrinoless double beta decay. The chosen way is to build a "tracko-calo" detector with at least 100 kg of betabeta isotope. The current status of the main R&D tasks will be presented: enrichment and production of source foil, radiopurity control, tracker and calorimeter.

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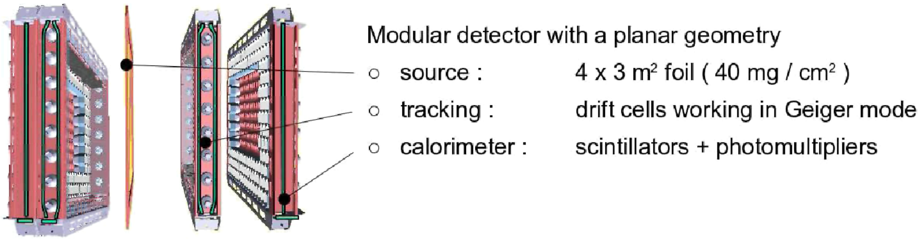
INTRODUCTION

Neutrinoless double beta decay is the best process to study the nature of the neutrino (Dirac or Majorana) and to have access to its mass scale. The signal of this decay, which is forbidden by the Standard Model, is the emission of two electrons carrying out all the released energy $Q_{\beta\beta}$. One way to highlight such an event is to associate a tracker with a calorimeter and to place a thin source foil inside. The tracker allows a clear identification of the 2 electrons coming from the source foil and the calorimeter measures both their kinetic energy and time of flight.

This technique has been well investigated by the running NEMO 3 detector [1–3] and it will reach a sensitivity of 1.4 10^{24} years on the half-life of the $\beta\beta0\nu$ process ($T^{0\nu}_{1/2}$) in 2010. The NEMO 3 / SuperNEMO collaboration has started a Research & Development phase in February 2006 to design a NEMO 3 successor. The goal is to improve the sensitivity on $T^{0\nu}_{1/2}$ by two orders of magnitude, probing the region of $\sim$ 50 meV effective neutrino mass.



Modular detector with a planar geometry
- source : 4 x 3 m² foil (40 mg / cm²)
- tracking : drift cells working in Geiger mode
- calorimeter : scintillators + photomultipliers

FIGURE 1. Schema of a SuperNEMO module

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SUPERNEMO DETECTOR CHARACTERISTICS

The SuperNEMO experiment will be part of new generation detectors for double beta decay experiments. It will contain a hundred kilograms of $\beta\beta$ isotope, divided into around twenty planar modules of 5 – 7 kg each (cf. Figure 1). Critical components of the R&D tasks for SuperNEMO are the production of such a large quantity of source foil with a high radiopurity level, the optimization of a large tracking detector and the improvement of the calorimeter resolution up to 4 % FWHM for 3 MeV electrons. The SuperNEMO specifications compared to its predecessor NEMO 3 are shown in Table 1.

TABLE 1. Comparison of NEMO 3 and SuperNEMO characteristics

	NEMO 3	**SuperNEMO**
$\beta\beta$ Isotope	^{100}Mo	^{82}Se or ^{150}Nd or ^{48}Ca
Mass	7 kg	100 – 200 kg
Energy Resolution at 3 MeV	8 % FWHM	4 % FWHM
Signal Efficiency	18 %	30 %
Foil Radiopurity :		
- in ^{208}Tl	$< 20\ \mu$Bq/kg	$< 2\ \mu$Bq/kg
- in ^{214}Bi	$< 300\ \mu$Bq/kg	$< 10\ \mu$Bq/kg
Half-Life Sensitivity $T^{0\nu}_{1/2}$	1.4 10^{24} years	1.0 – 1.5 10^{26} years
Effective Neutrino Mass Sensitivity	390 – 810 meV	43 – 145 meV*

* sensitivity with ^{82}Se

RESULTS ON THE MAIN R&D TASKS

Source foils production

The first specification for a double beta decay experiment is the choice of the $\beta\beta$ isotope, dominated by the physics criteria: i) the highest possible $Q_{\beta\beta}$ is required (at least higher than 2.6 MeV, highest gamma ray of the natural radioactive background) to reject most of the background, ii) a high natural abundance and an easy enrichment possibility are clearly critical for a 100 kg isotope detector, iii) due to the calorimeter resolution, the $\beta\beta2\nu$ process constitutes a significant background for the $\beta\beta0\nu$ search, so its half-life $T^{2\nu}_{1/2}$ must be as high as possible to minimize this ultimate background. The best candidates for SuperNEMO are ^{48}Ca , ^{82}Se and ^{150}Nd .

The isotope ^{82}Se with a high natural abundance $\sim$ 10 % and a high $\beta\beta2\nu$ half-life (9.0 10^{19} years) has been chosen for the baseline design. Inside the SuperNEMO collaboration, more than 5 kg of ^{82}Se has been currently enriched. One kilogram of ^{nat}Se has been purified by a chemical technique to validate this method. A purification by distillation has been processed for the first time to one kilogram of enriched ^{82}Se pure.

New methods for foil production have been tested to produce homogeneous pads with a thickness of 40 mg/cm^2 using mold casting, a coating process by rolling, or by mixing the isotope powder with an epoxy resin to obtain an auto-supporting foil.

Low radioactivity controls

The SuperNEMO detector radioactivity has to be as low as possible, especially the source foils where ultra-low background levels of 10 μBq/kg in ^{214}Bi and 2 μBq/kg in ^{208}Tl are required. Both of these contaminants have the Bipo process in their natural radioactive chain : a beta decay from the bismuth nucleus followed by an alpha decay of the polonium. The BiPo detector is being developed by the collaboration to control the radiopurity in ^{214}Bi and ^{208}Tl of the final source foils. This dedicated detector consists of a sandwich of two low radioactive sintillators enclosing the foil and it is able to detect the signature of an electron with a delayed alpha. A first BiPo prototype (BiPo1) made of 20 modules with an area of 400 cm^2 each has been installed. The goal of this prototype is to measure its own background level, exclusively coming from the contamination of scintillator surfaces. The surface background level of ^{208}Tl has been estimated at 1 μBq/m^2 and data on ^{214}Bi is currently under studies.

The next step is to build a full BiPo detector of 3.5 m^2. Assuming that its background will be the same as the BiPo1 background, one can achieve a sensitivity of 3 μBq/kg in ^{208}Tl for the SuperNEMO source foil control.

Two high purity germanium detectors are available at the Laboratoire Souterrain de Modane (LSM) to measure the radiopurity of all the other components of the detector in order to select them. To improve the sensitivity, a new detector with a larger crystal of 600 cm^3 (instead of 400 cm^3) is under development.

As a result of NEMO 3 and its background measurement, studies on radon emanation and diffusion are currently being carried out and a new radon detector is being designed to measure the radon activity in the 700 L of gas with a sensitivity of 0.1 mBq/m^3.

Tracker R&D

The SuperNEMO tracker consists of drift cells operating in Geiger mode. Tests on small prototypes have been worked out to optimize the choice of the wire material, size, diameter, configuration of wires as well as the readout. In parallel, an automated wiring robot has been developed to build the large number of wires required the SuperNEMO tracker i.e. several thousand per module. A 90-cell prototype has been built with this robot to validate it and identify possible new developments. This large tracker prototype is currently running to finalize the software reconstruction. Preliminary measurements of cosmic ray tracks have given a resolution of 0.7 mm in the transverse position and 1.3 cm for the longitudinal one.

Calorimeter R&D

The main objective of the calorimeter R&D is to reach an energy resolution of 7 % FWHM for 1 MeV electrons (equivalent to 4 % FWHM at 3 MeV) with a large size detector: a scintillator block with a thickness of at least 10 cm coupled to a 8" photomultiplier tube (PMT). A large quantity of scintillators, with various material composition, shape and wrapping have been thoroughly studied to maximize the light output. Accurate optical simulations with GEANT4 have been developed to understand these effects and improve the measurements. Concerning PMTs, companies are now able to produce photocathodes with a high quantum efficiency of up to 40 %. A strong collaboration with Photonis to develop a dedicated PMT tube (XP1886) has given an unequaled resolution of 6.7 % FWHM at 1 MeV with a large PVT block. Unfortunately Photonis decided to stop all their PMT activity. The best result obtained to date with a tube from Hamamatsu is 7.7 % FWHM at 1 MeV, which is also close to the specification.

An alternative calorimeter design with 2 m long scintillator bars is also investigated. This geometry improves the efficiency of gamma tagging, the background rejection and also reduces the number of PMT channels, but its energy resolution is around 10 % at 1 MeV compared to 7.7 % for the baseline design. Work is in progress to improve this resolution and to determine if all the bar design advantages can compensate a worse energy resolution.

In parallel new calibration procedures are also investigated, such as one photoelectron peak monitoring or a low activity alpha source embedded into a plastic scintillator to have a more accurate alternative of LASER survey.

SuperNEMO location, schedule and sensitivity

Before erecting the full SuperNEMO detector, the collaboration will build one demonstrator module to prove the feasibility of a large scale detector with the required performances. After 2 years of running with 7 kg of ^{82}Se , this demonstrator could reach a sensitivity of 6.5 10^{24} years on $T^{0\nu}_{1/2}$ so a limit on the effective neutrino mass of 210 – 570 meV [4–6]. The full BiPo detector should be ready in 2010 for radiopurity foil control. Construction and commissioning of the demonstrator is planned for 2010 – 2011, it could be in place and running in 2012 at the LSM in NEMO 3's current location. First other modules should be ready progressively from 2013. Depending on the final mass of ^{82}Se in the full detector (between 100 to 200 kg), the final target sensitivity is on $T^{0\nu}_{1/2}$ 1.0 – 1.5 10^{26} years corresponding to a sensitivity on the effective neutrino mass of 43 – 145 meV [4–6].

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