The SuperNEMO neutrinoless double beta decay experiment

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Abstract. SuperNEMO is an experiment currently in the construction phase with the aim of searching for neutrinoless double beta decay, a beyond the standard model lepton number violating process. It employs the same strategy as its predecessor NEMO-3, with a tracker and calorimeter surrounding a thin foil of source isotope. Twenty modules are planned, yielding 100 kg of $^{82}$Se as source, with a sensitivity to a half-life of $10^{26}$ years. The first module is intended to demonstrate the very stringent radiopurity requirements, with no background counts being expected in the region of interest of the decay for 2.5 years of data taking. It will hold 7 kg of $^{82}$Se, giving it a sensitivity to a half-life of $6.5 \times 10^{24}$ years. The tracking detector is essential for background discrimination and its construction and commissioning are being undertaken in the U.K., primarily at UCL, MSSL (UCL) and The University of Manchester.

1. Introduction

Neutrinoless double beta decay ($0\nu\beta\beta$) is a second order weak process where two nucleus-bound neutrons decay into two protons and two electrons. This process can only occur if neutrinos are Majorana particles and have a finite mass [1].

Majorana neutrinos play a crucial role in see-saw mechanisms which offer an explanation for the smallness of neutrino masses. Lepton number violating processes such as the one being discussed help to elucidate the matter/antimatter asymmetry in the universe [2].

In the simplest case the decay proceeds through the exchange of a light neutrino. Given the chiral nature of the weak interaction this requires a spin-flip of the neutrino, which gives the decay rate a dependence on the mass of the neutrino.

Given the absence of neutrinos in the final state, the distribution of the sum of the electrons’ energies is a peak at the Q-value for the decay. An irreducible background for this process is double beta decay with the emission of two neutrinos ($2\nu\beta\beta$), which is allowed by the Standard Model and produces a tail up to the region of interest around the Q-value.

2. SuperNEMO

SuperNEMO is an experiment currently under construction. It employs the strategy proven by the series of NEMO experiments (most notably NEMO-3 [3]) of having a tracker, calorimeter and source as separate entities. NEMO-3 produced the best measurements of $2\nu\beta\beta$ for 7 double beta decay isotopes.
The tracker and calorimeter approach allows for particle identification and measurement of their kinematics. This is used to greatly reduce backgrounds by selecting signal-like event topologies and to generate a number of control channels with alternative event topologies which give accurate measurements of the activities of background sources. This technique also gives SuperNEMO its unique capability to search for alternative $0\nu\beta\beta$ decay mechanisms (e.g., right-handed currents and Majoron emission).

The experiment will consist of several modules. Through an increase in the source mass, an extensive R&D programme and stringent background requirements it is planned to have a sensitivity to $0\nu\beta\beta$ two orders of magnitude better than NEMO-3 (Table 1).

| Source          | $^{82}$Se ($^{150}$Nd, $^{48}$Ca) | $^{82}$Se |
|-----------------|----------------------------------|----------|
| Source mass     | 100 kg                           | 7 kg     |
| Energy resolution | 4 % @ 3 MeV (FWHM)               |          |
| $^{222}$Rn activity in tracker volume | $< 0.15$ mBq/m$^3$ |          |
| Sensitivity to $0\nu\beta\beta$ (90 % CL) | $T^{1/2} > 10^{26}$ years | $T^{1/2} > 6.6 \times 10^{24}$ years |
|                 | $m_{\beta\beta} < 40 - 100$ meV  | $m_{\beta\beta} < 200 - 400$ meV |

Table 1. Experimental parameters and $0\nu\beta\beta$ sensitivity for the SuperNEMO experiment and its Demonstrator module.

3. The Demonstrator Module

The first SuperNEMO module (the Demonstrator, Figure 1) is now in an advanced stage of construction. Its main objective is to demonstrate the feasibility of achieving the very low background requirements imposed on SuperNEMO. As such it is expected to be the experiment with the lowest background count in the $0\nu\beta\beta$ region of interest for 2.5 years of running.

The detector will take NEMO-3’s place in the Modane Underground Laboratory (LSM) and underground commissioning is due to start in late 2014.

Figure 1. Exploded view drawing of the Demonstrator module. From left to right: calorimeter wall; tracker section; source foil frame; tracker section; calorimeter wall.
4. Source foil
The double beta decay source for the Demonstrator will consist of thin strips of enriched $^{82}\text{Se}$. A mechanical support material is needed for depositing the source isotope. It is important that the mass of this material is minimised to reduce the background level and minimise energy losses of electrons as they traverse the source. Backing materials such as perforated films and meshes in various materials are currently under study.

A system was designed and is currently under testing which allows for calibration sources to be deployed in the source plane between strips, with minimal additional material inside the detector volume.

5. Calorimeter
The main calorimeter for the first SuperNEMO module consists of 520 plastic scintillator blocks wrapped in PTFE and aluminised mylar, directly coupled to 8” Hamamatsu photomultiplier tubes. These are assembled into eight-block “bricks” which provide mechanical support, magnetic shielding and gas seal.

An extensive R&D programme led to an optimised scintillator block geometry, scintillator material and photomultiplier selection. This resulted in an energy resolution two times better than that of NEMO-3.

6. Tracker
The tracker for the Demonstrator consists of an array of 2034 cells operating in Geiger mode. Each cell contains a central anode wire which is set to $\sim$1.5 kV and is surrounded by 12 grounded field wires in an approximately cylindrical structure 3 m long and 4.4 cm in diameter. Copper rings are placed at both ends of each cell on which a pulse is induced by the arrival of the avalanche. The time difference between an external trigger (from the calorimeter) and a pulse on the anode wire gives the hit’s radial distance with an error of 0.7 mm, and the time difference between an anode pulse and pulses on the copper rings gives the longitudinal position of the hit with 1 cm resolution.

The tracker is being assembled in quarters, each quarter containing 504 cells. Each frame is populated with calorimeter modules which enclose the tracking volume. These modules are built with recommissioned NEMO-3 photomultipliers. Tracker quarters will be commissioned at surface at the Mullard Space Science Laboratory, before being shipped to LSM for integration with the rest of the detector and underground commissioning.

7. Conclusion
The SuperNEMO experiment is now at an advanced stage of construction. The first quarter of the tracker has been assembled and populated with calorimeter blocks. Tracker cells are in full production and their insertion in the tracker frame is imminent. The emanation of $^{222}\text{Rn}$ into the tracker volume is being measured at each stage of construction. The calorimeter modules for the main calorimeter are in production. The collaboration is in possession of most of the source required for the Demonstrator, with 5.5 kg of $^{82}\text{Se}$ enriched.

The UK has an important role in this phase of the experiment, having undertaken the construction and commissioning of the tracker.

References
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