SuperNEMO project

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Abstract.
    The neutrinoless double beta decay ($\beta\beta0\nu$) is the most sensitive process for the search of lepton number violation and its discovery would prove the neutrino is a massive Majorana particle. Based on the experience of the NEMO 3 detector construction and its data analysis, the SuperNEMO collaboration has been formed and started the feasibility study to construct next stage detector for the $\beta\beta$ experiment with a mass of at least 100 kg enriched $\beta\beta$ isotpes. The goal of the sensitivity is to reach $\beta\beta0\nu$ half-life limit of a few 10^{26} years and 50 meV of the effective Majorana neutrino mass.

1. Introduction

The absolute neutrino mass scale is recognized as one of the most fundamental questions to be solved experimentally. Recent experimental results of neutrino oscillations suggest important information related to the small absolute neutrino mass scale. However neutrino oscillations are only sensitive to the squared mass difference between two flavor mass eigenstates. Therefore neutrinoless double beta decay ($\beta\beta0\nu$), which process is beyond the standard model with lepton number violation, is the only practical way to do the most precise laboratory measurement of absolute Majorana neutrino mass.

The present experiments, for example NEMO 3 [1] and CUORICINO, are searching for neutrino mass in Sub-eV region. On the other hand, recent analysis of neutrino oscillations combined with the inverted neutrino mass hierarchy hypothesis strongly suggests the $\sim$50 meV effective $< m_{\beta\beta} >$ region. So the sensitivity of the next stage experiment should be improved one order of magnitude.

Experimental techniques of $\beta\beta$ decay measurements are mainly divided by two methods. One is experiment using pure calorimeter, as Ge semi-conductor diodes or bolometer detector. Here the $\beta\beta$ source is used as the detector and the measured quantity is the total deposited energy. Second technique is "tracko-calo" detector. It is not only the summed energy measurement but also available tracking reconstruction technique to identify the two emitted electrons.

The main advantage of pure calorimeter experiment is the good energy resolution and detection efficiency. The disadvantage is that there is no direct signature of the two electrons and the origins of the backgroud signals are more dificult to identify. On the contrary, "tracko-calo" experiment has less energy resolution but the capability to identify the two electron emissions and to reject background signals with higher efficiency than calorimeter experiment. It also measure individual energy for each of the two electrons and their angular distribution, which allows distinguishing $\beta\beta0\nu$ decay mechanisms in detail. Another advantage is that the detector

Table 1. From NEMO 3 to SuperNEMO

NEMO 3		SuperNEMO
^{100}Mo $T_{1/2}(\beta\beta2\nu) \sim 7{\cdot}10^{19}$ y	Choice of isotope	^{82}Se (or ^{150}Nd) $T_{1/2}(\beta\beta2\nu) \sim 10^{20}$ y
7 kg	Isotope Mass	100 - 200 kg
$\epsilon(\beta\beta0\nu) \sim 8\%$	Efficiency	$\epsilon(\beta\beta0\nu) \sim 30\%$
^{214}Bi < 300 μBq/kg ^{208}Tl < 20 μBq/kg (^{208}Tl, ^{214}Bi) ~ 1 evt/7kg/y $\beta\beta2\nu \sim 2$ evt/7kg/y	Background	^{214}Bi < 10 μBq/kg ^{214}Tl < 2 μBq/kg (^{208}Tl, ^{214}Bi) ~ 1 evt/100 kg/y $\beta\beta2\nu \sim 1$ evt/100 kg/y
$\sim 8\%$ @ 3 MeV (FWHM)	Energy Resolution	$\geq 4\%$ @ 3 MeV (FWHM)
$T_{1/2}(\beta\beta0\nu) > 2{\cdot}10^{24}$ y $< m_\nu > < 0.3$ - 1.3 eV	Sensitivity	$T_{1/2}(\beta\beta0\nu) > 10^{26}$ y $< m_\nu > < 50$ meV

is independent from $\beta\beta$ source foils, which allows to select best $\beta\beta$ isotope or to measure different $\beta\beta$ isotopes at the same time.

Thus, based on the good experience of the typical "tracko-calo" detector of NEMO 3 detector, the SuperNEMO collaballation has been formed and started the feasibility study to construct next stage detector with a mass of at least 100kg of enriched $\beta\beta$ isotope in order to reach the sensitivity of $\beta\beta0\nu$ half-life limit a few 10^{26} years and 50 meV of the effective Majorana neutrino mass.

2. From NEMO 3 to SuperNEMO
The performance characteristics to improve from NEMO 3 to SuperNEMO are summarized in Table 1.

In spite of the recent progress in the calculation methods for the nuclear matrix elements, these calculations are always too uncertain and nuclear theory is not yet able to predict the best candidate from the point of view of nuclear matrix element. In order to reduce the background coming from the $\beta\beta2\nu$ decay, a good criterion for isotope selection would be to choose an isotope with a half-life $T_{1/2}(2\nu)$ longer than 10^{20} years and higher $Q_{\beta\beta}$ value. Higher $Q_{\beta\beta}$ value gives larger phase space factor and exceeds crucial energies of β and γ decays of ^{238}U and ^{232}Th daugter nuclei, which are major background sources to the $\beta\beta0\nu$ experiment.

^{82}Se is one of the best candidate with $T_{1/2}(2\nu) \sim 10^{20}$ y and $Q_{\beta\beta} = 2.992$ MeV. Using the actual enrichment factories, the production of an order of 100 kg is feasible in a few years with a reasonable cost. Already R&D program of the production of 2 kg source for the study of radiopurity, chmical purification, souce foil making process etc. is in progress.

There is an interesting isotope candidate ^{150}Nd, which has 8 times larger phase space factor than ^{82}Se and enough $Q_{\beta\beta}$ value (3.368 MeV). However, it is very difficult to enrich an order of 100 kg quantities by known methods including a conventional centrifugal method. Recently an alternative method of atomic vapor laser ion separation (AVLIS) technology is discussed to be effective for ^{150}Nd isotope enrichment and the possibilities of the reuse of the MENPHIS facility in France is considered. If the facility will be available, ^{150}Nd will be another good candidate of the SuperNEMO $\beta\beta$ source.

The contribution from $\beta\beta2\nu$ high energy tail to the concerned peak region of $\beta\beta0\nu$ is directly related to the detector energy resolution. The SuperNEMO detector is required to the calorimeter resolution better than 4% (FWHM) at 3 MeV ($\beta\beta0\nu$ peak region) to achieve the sensitivity goal. The collaboration has been studying various possibilities to keep the NEMO 3 techniques but improving plastic scintillator (including the use of liquid scintillator option etc.), PMT properties and so on.
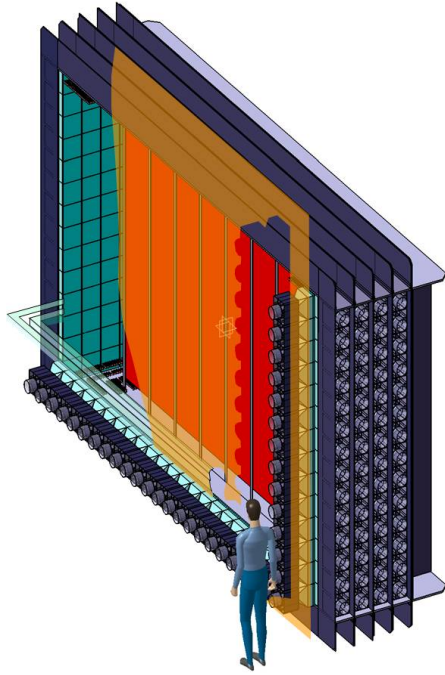
Figure 1. View of a possible one SuperNEMO module

To reach sensitivity goal, radiopurity levels of the source foils of ^{214}Bi and ^{208}Tl have to be lower than 10μ Bq/kg and 2μ Bq/kg, which means reduction factor 10 to the present NEMO 3 experiment. It is necessary to develope new methods to measure radiopurity levels for ^{214}Bi and ^{208}Tl as low as 10μ Bq/kg and 2μ Bq/kg, respectively. "Bi-Po" detector project has been developing to the detection before source installations using delayed coincidence of Bi-Po sequential decays related series of the radioactive decay.

The R&D program of the tracking detector is also important to improve its transparency by optimizing the length, diameter, wire materials etc. to keep the better efficiency.

The first start point of the design of the SuperNEMO detector would be composed of several identical modules for example 20 modules with 5 kg $\beta\beta$ source. The size of the source plane would be, for example, 4 m long, 3 m high and 40 mg/cm^3 (see fig. 1).

After three years various R&D programs to achieve the requirements from NEMO 3 to SuperNEMO, a detailed technical design proposal for SuperNEMO will be written by the end of 2008.

References
[1] Arnold R et al., 2005 *Nucl. Instr. Meth.* A **536** (2005) 79, Arnold R et al., 2005 *Phys. Rev. Lett.* **95** 182302