Development of an optical simulation for the SuperNEMO calorimeter

Arnaud Huber on behalf of the SuperNEMO collaboration
CENBG, Université de Bordeaux, CNRS/IN2P3, F-33175 Gradignan, France
E-mail: huber@cenbg.in2p3.fr

Abstract. The SuperNEMO double beta decay project is a modular tracker-calorimeter based experiment. The aim of this project is to reach a sensitivity of the order of $10^{26}$ years concerning the neutrinoless double beta decay half-life, corresponding to a Majorana neutrino mass of 50-100 meV. The main calorimeter of the SuperNEMO demonstrator is based on 520 Optical Modules made of large volume plastic scintillators (10L) coupled with large area photomultipliers (Hamamatsu R5912-MOD and R6594). The design of the calorimeter is optimized for the double beta decay detection and allows gamma tagging for background rejection. In large volumes of scintillators, a similar deposited energy by electrons or photons will give different visible energy and signal shapes due to different interactions inside the scintillator. The aim of the optical simulation, developed for SuperNEMO, is to model the Optical Module response on the energy and time performances, regarding the particle type.

1. The SuperNEMO demonstrator
The SuperNEMO project [1] is a next generation neutrinoless double beta decay experiment based on the successful NEMO-3 tracker-calorimeter design [2]. It will consist of 20 identical modules containing 5 kg of $^{82}$Se each. The first module of SuperNEMO, named demonstrator (Figure 1), is under construction at the underground laboratory of Modane (LSM) and should start taking data in 2017. The source foil of $\beta\beta$-isotope ($^{82}$Se baseline and possibly $^{150}$Nd in a second phase) is suspended in the middle of a tracking chamber surrounded in turn by a calorimeter. The tracker is composed by 2034 drift cells working in Geiger mode and calorimeter walls are made off 712 optical modules, 520 for the main walls and 192 for the side and top walls. Each optical module consists of a large volume (10L) plastic scintillator manufactured by NUVIA directly coupled to low radioactivity 8” photomultipliers (R5912-MOD) and 5” photomultipliers (R6594) from Hamamatsu. The objective of SuperNEMO is to achieve a background-free energy region of interest to reach a half-life sensitivity of $T_{1/2}^{0\nu} > 10^{26}$ years on the $\beta\beta$ process corresponding to an effective Majorana neutrino mass of $\langle m_{\beta\beta}\rangle < 0.04–0.10$ eV in the case of a light Majorana exchange mechanism.

2. Optical Module modelization response
The sensibility on the $0\nu\beta\beta$ process is related to the equation (1).

$$T_{1/2}^{0\nu} > \frac{\ln 2 N_A \epsilon}{K_{C.L.} A} \sqrt{\frac{mt}{N_{bkg} R[keV]}}$$  (1)
where $N_A$ is the Avogadro number, $\epsilon$ the $\beta\beta$0$\nu$ detection efficiency, $k_{C.L.}$ the confident level, $mt$ the exposure ($kg\cdot an$), $A$ the atomic mass of isotope, $N_{bkg}$ the background event rate ($keV^{-1}kg^{-1}an^{-1}$) and $R$ the energy resolution ($keV$) at the $Q_{\beta\beta}$ value.

A good energy resolution and a precision better than 1% on the energy measurement are required to reach the expected sensitivity. The visible energy has to be reproduced with high accuracy by the simulation. Due to some geometric or non-uniformity effects, the light collection from the scintillation will depend on the type of particles (electrons or gammas) and their different interaction points inside the scintillator. An optical simulation has been developed based on the GEANT4 framework with the addition of some dedicated classes to simulate all the optical photon processes taking into account the optical properties of the materials [3]. The two main issues of the simulation concerns the light emission and propagation in the scintillator and the collection properties of the photomultiplier.

Concerning the scintillator, primary emission done by the pTP dopant and absorption re-emission process due to the POPOP wavelength-shifting molecule are taking into account. The reflective properties of the different surfaces are included in the simulation particularly for the Teflon (Lambertian reflection) and Mylar (specular reflection) used to wrap the scintillators.

Concerning the photomultiplier, the aim is to reproduce the quantum efficiency spectrum and the collection efficiency of large photocathode where it exists a non uniformity in the photoelectron collection.

The next section presents the different results obtained with the optical simulation.

3. Results

The main goal of this simulation is to provide a correction factor to apply into the GEANT4-based SuperNEMO software. This correction will transform the deposited energy into the real visible energy. In order to validate our model, we tested different measurement configurations using a $^{207}$Bi source (electrons of 976 keV) located on different points of the optical module (central position on the front face, corner position on the front face and top position near the photocathode). The corner and central configurations allow to test the geometric effects on the light propagation whereas the top position near the photocathode tests the non uniformity of the light collection. According the different results (Figure 2) these different effects have to be corrected with the help of the optical simulation.

The optical simulation leads to the production of a scintillator map giving the correction factor to apply to the deposited energy to obtain the visible energy. With these corrections, the single rate spectrum induced by the radioactive contaminations of each optical module components at LSM has been simulated. According to the different locations of the contaminations (PMT,
coupling, Mylar, Teflon, scintillator) and particle types, different spatial distribution of energy deposition are tested (Figure 3 [right]). This measurement confirms as well that the energy correction factor is required to reproduce the experimental spectrum (Figure 3 [left]).

**Figure 3.** Comparison of experimental single rate of one SuperNEMO optical module (black) with simulations taking into the deposited energy only (blue) or the energy correction from optical simulation (red).

### 4. Conclusion
An optical simulation dedicated to the SuperNEMO experiment has been developed to understand and predict all the optical processes in the calorimeter. This simulation provides corrections on the deposited energy to reproduce the measured energy in the data.

### References
[1] R. Arnold et al., European Physical Journal, C 70 (2010) 927
[2] R. Arnold et al., Nuclear Instruments and Methods in Physics Research, A 536 (2005) 79
[3] J. Argyriades et al., Nuclear Instruments and Methods in Physics Research, A 625 (2011) 20