The SuperNEMO light injection and monitoring system

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Abstract. SuperNEMO is the successor of the NEMO-3 experiment and will search for the hypothetical process of $0\nu\beta\beta$ by combining tracking and calorimetric measurements. The SuperNEMO calorimeter consists of 712 optical modules made of scintillator blocks directly coupled to photomultiplier tubes. $^{207}$Bi sources will be used to calibrate the energy scale of the calorimeter in dedicated calibration runs separated by a few weeks. In between these runs, a Light Injection (LI) system will guarantee the stability of the calorimetric response to 1%. The LI system injects pulsed LED light into each scintillator block via optical fibers. A reference optical module is used to monitor the light level against a $^{241}$Am source. The details of the LI system and its performance are presented.

1. Introduction
The search for the neutrinoless double beta decay ($0\nu\beta\beta$) is one of the most active field in neutrino physics [1]. The $0\nu\beta\beta$ observation will prove the Majorana nature of the neutrino and will give us informations about their absolute mass scale. In the framework of a Majorana neutrino, the total lepton number is not conserved and could be linked to the asymmetry between matter and antimatier in Universe. In the easier case, where the $0\nu\beta\beta$ is due to the exchange of a light Majorana neutrino, the half-life of the process can be written as :

$$[T_{1/2}^{0\nu}(A, Z)]^{-1} = g_A^4 G_{0\nu}(Q_{\beta\beta}, Z) |M_{0\nu}(A, Z)|^2 \left| \frac{\langle m_\nu \rangle}{m_e} \right|^2$$

(1)

where $g_A$ is the axial coupling constant, $G_{0\nu}$ the kinematical phase space, $M_{0\nu}$ the nuclear matrix element and $\langle m_\nu \rangle$ the effective neutrino mass, related with some of the neutrino oscillation parameters. According the isotope, the half-life can vary over several orders of magnitude.

2. The SuperNEMO demonstrator
Based on the well-known NEMO-3 technique [2], the SuperNEMO detector [3] combines tracking and calorimetric measurements to search for the hypothetical $0\nu\beta\beta$ process. In its final design SuperNEMO will consist of 20 identical modules containing each 5 kg of $^{82}$Se. Its goal is to reach a sensitivity on the half-life $T_{1/2}^{0\nu} > 10^{26}$ years which corresponds to an effective mass
of \( \langle m_\nu \rangle < 0.04 - 0.10 \) eV. The first module called demonstrator, shown in Figure 1, is under construction at Laboratoire Souterrain de Modane (LSM). A thin foils of \(^{82}\)Se is suspended in the middle of the detector surrounded by a tracking chamber consisting of 2034 drift cells working in Geiger mode. Calorimeter walls consisting of 520 optical modules enclose the source foil and the tracker volume. By adding 2 x-walls and 2 \( \gamma \)-veto to cap the sides, the top and the bottom of the detector, a total of 712 optical modules compose the calorimeter. Each optical module consists of a plastic scintillator block directly coupled to a low-radioactivity PMT.

![Figure 1. Schematic view of the SuperNEMO demonstrator module.](image)

3. The light injection system
To control and monitor the response of the calorimeter over the lifespan of the experiment, two complementary systems have been developed by the collaboration. A first system allows the deployment of \(^{207}\)Bi calibration sources inside the detector volume to provide an absolute energy calibration at two values: 482 keV and 976 keV.

A second system called Light Injection system (LI) will inject pulsed UV light into each optical module via optical fiber to control and monitor the response of the calorimeter between the calibration runs. The aim of the LI system is to guarantee the stability of the calorimetric response within 1%. The LI system consists of 20 UV-LED illuminating 1500 optical fibers routed to optical module. Each LED illuminates a bundle of 75 fibers. To avoid time difference and to simplify the system, the length of all the fibers are the same about 20 meters. A reference optical module is used to monitor the light level for an \(^{241}\)Am source. Charge spectra collected by the ADC for each PMT is shown in Figure 2.

![Figure 2. Charge spectra.](image)
To verify the ability of the LI system to monitor the response within 1%, the position of the $^{207}$Bi peak at 976 keV is predicted using LED peak, $^{241}$Am peak and the formula:

$$\text{Bi}_{\text{pred}}(t) = \text{Bi}(t=0) \times \frac{\text{LED}_{\text{calo}}(t=0)}{\text{LED}_{\text{calo}}(t)} \times \frac{\text{LED}_{\text{mon}}(t)}{\text{LED}_{\text{mon}}(t=0)} \times \frac{\text{Am}(t=0)}{\text{Am}(t)}$$

(2)

The ratio between the predicted and the measured peak position for the 976 keV $^{207}$Bi is shown in Figure 3, it does not deviate more than 1% represented by the red bounding lines.

![Figure 3. Ratio of the predicted to measured peak position for the $^{207}$Bi at 976 keV. The red lines represents a deviation at 1%. The discontinuities in the data correspond to changes in high voltage on the 8-inch PMT.](image)

In order to realize linearity tests, the light received by the PMT has to be uniform. The uniformity of the light has been improved by slightly cutting the tip of the LED. Before cutting 83% of the fibers are considered as usable. After cutting, 98% of the fibers can be used. Many performance tests have been realized as the measure of the attenuation length: $9.7 \pm 0.1$ m for the UV-LED ($\lambda = 385$ nm). A fiber of 15 m loses about 79% of the initial light.

4. Conclusion

A light injection system has been developed to control and monitor the 712 optical modules of the SuperNEMO calorimeter. The LI system will work between the absolute calibration runs. The system has been shown to be able to monitor a test optical module at the 1% level. SuperNEMO demonstrator is under construction and physics data taking is expected to start by 2017.

References

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