TOWARDS PRECISION ENERGY CALIBRATION IN THE SUPERNEMO DEMONSTRATOR: UNCOVERING UNACCOUNTED ENERGY LOSSES

Ya. Ye. Kozina[1], M. Macko[2], O. A. Bezshyyko[1], L. O. Golinka-Bezshyyko[1]

[1]*Physics Faculty, Taras Shevchenko National University of Kyiv, Ukraine*
[2]*Astrocent, Polish Academy of Sciences, Poland*

The SuperNEMO experiment is an international collaboration focused on double-beta-decay studies and searching for neutrinoless double-beta decay – a hypothetical process whose observation would prove the Majorana nature of neutrinos, establish lepton number violation, and enable a direct measurement of the effective Majorana neutrino mass, thus revealing physics beyond the Standard Model.

The SuperNEMO Demonstrator module consists of ^{82}Se double-beta decay source foils placed in the center of the detector, a tracking detector, surrounding the source foils on both sides, a segmented calorimeter, composed of 712 optical modules (OMs) enclosing the tracker, and a ^{207}Bi-based energy calibration system, consisting of 42 sources inserted into gaps between the ^{82}Se source foils. Each calibration source is a droplet of ^{207}Bi solution sandwiched between two thin Mylar foils and sealed within a rectangular frame made of radiopure copper, providing conversion electrons (among others) with energies 482, 976 and 1682 keV. Electrons emitted from the ^{207}Bi sources traverse the tracker before reaching the calorimeter walls, where their energy is measured [1-3]. The unique tracker-calorimeter design allows full reconstruction of each electron's trajectory from the source to the calorimeter, which is essential for applying trajectory-dependent energy loss corrections in the calibration procedure.

As neutrinoless double-beta decay is expected to be an extremely rare process (with a half-life exceeding 10^{25}-10^{28} years [1,4]), precise and reliable energy calibration of the calorimeter is crucial. To ensure high-quality calibration, all detector effects that influence the behaviour of calibration electrons, hence, the shape of the calibration spectrum and the extracted calibration constants, must be identified and accounted for. Understanding the physical origin of such effects is of utmost importance, as it provides the foundation for any future improvements to the calibration procedure. In this work, we investigate such effects within the framework of the calibration model developed by Filip Koňařík [2], which applies energy corrections accounting for optical non-linearities and electron energy losses in the detector materials traversed before reaching the calorimeter. While this model provides a working calibration procedure, certain spectral features remain unexplained, motivating the present investigation.

Examination of the experimental calibration spectra reveals that the 976 keV energy peak is not symmetrical, forming a broad plateau between approximately 600 and 800 keV, located between the two main calibration peaks at 482 and 976 keV, which is not accounted for by the calibration model [2]. Examination of the experimental spectrum accounting for the angular distribution of the electrons (performed on a dataset of 285 runs each consisting of around 18 000 selected events) shows that the number of events forming the plateau increases, the more parallel to the calibration source electrons are emitted – they face additional energy losses of around 300-350 keV on average. This feature is shown to be inconsistent with tracker-gas energy losses alone: such losses would produce a narrow Landau-distributed contribution. This points to an additional energy loss mechanism associated with the geometry of the calibration source itself.

The effect is attributed to electrons from the 976 keV conversion line that lose a substantial fraction of their energy in the copper frame of the calibration source. Depending on the emission angle, electrons traverse different effective thicknesses of copper, producing a wide distribution of energy losses that populates precisely this inter-peak region. This interpretation was confirmed by examination of simulated events (performed on 100 datasets with around 17 000 of ^{207}Bi decay selected events each) with a nonzero energy deposit in the copper frame, which are concentrated in the 600-800 keV region (see Fig. 1). Simulated trajectories show that electrons belonging to the energy window 600-800 keV enter the copper frame and undergo multiple scatterings within it, resulting in energy losses of around 300-350 keV on average.

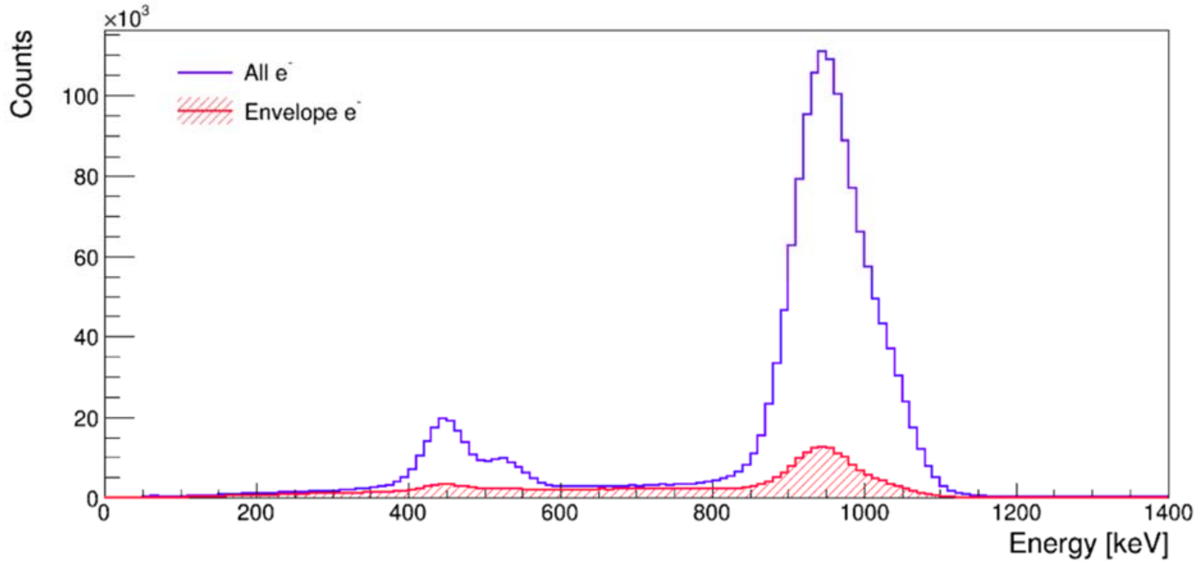

Fig. 1. Simulated ^{207}Bi electron energy spectrum showing all electrons (violet) and the subset that traversed the copper calibration source frame (red). Copper-frame electrons populate the broad plateau between the 482 keV and 976 keV conversion peaks, confirming the proposed interpretation of the observed spectral feature.

The identified effect of energy losses in the copper frame is shown to be responsible for the broad inter-peak plateau, providing a physical explanation of its origin. Moreover, the simulated spectrum of electrons traversing the copper frame yields a characteristic spectral template of this contribution, opening a potential path toward its subtraction from the measured spectrum and a consistent fit of the full calibration spectrum. This, however, requires further dedicated study and development of the calibration model.

1. G. Adhikari et al. (nEXO Collaboration). J. Phys. G: Nucl. Part. Phys. 49 (2022) 015104.
2. F. Koňařík. Development of a script for calibration of individual optical modules in the segmented calorimeter of the SuperNEMO experiment. Master thesis (Czech Technical University in Prague, Prague, 2024).
3. R. Arnold et al. (SuperNEMO Collaboration). J. Instrum. 16 (2021) T07012.
4. R. Arnold et al. (SuperNEMO Collaboration). Eur. Phys. J. C 70 (2010) 927.