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The Sensitivity of the nEXO Experiment to Majorana Neutrinos

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Abstract. The nEXO Collaboration is performing R&D towards a detector with \( \sim 5 \) t of enriched liquid \(^{136}\text{Xe}\) to search for neutrinoless double-beta decay. The experiment is based on the success of the EXO-200 detector, an ultra-low background time projection chamber with collection of both scintillation light and ionization charge from xenon. The projected sensitivity of the nEXO detector will probe the inverted hierarchy of neutrino masses.

1. Introduction to the nEXO Experiment
Neutrinoless double-beta decay \((0\nu\beta\beta)\) can only occur if neutrinos are Majorana particles [1]. The double-beta decay mode with two neutrinos \((2\nu\beta\beta)\) of \(^{136}\text{Xe}\) has a Q-value of 2.458 MeV and is the longest and most precisely known double-beta decay to date, with half-life of \(2.165 \pm 0.016(\text{stat.}) \pm 0.059(\text{syst.}) \times 10^{25}\) yr measured by the EXO-200 experiment [2].

Using an exposure of 100 kg·yr, EXO-200 has achieved a half-life sensitivity of \(1.9 \times 10^{25}\) yr at 90% confidence level (CL) [3]. It has also demonstrated an energy resolution \(\sigma/E < 1.5\%\) and an ultra-low background index. The nEXO Collaboration will extend the effort of this state-of-the-art liquid enriched \(^{136}\text{Xe}\) (LXe) double-beta decay experiment. It is envisaged as a monolithic time projection chamber (TPC) filled with \( \sim 5 \) t of LXe that collects charge and light from interactions. Xenon’s ease to purify combined with an expected energy resolution of \(\sigma/E = 1\%\) result in backgrounds dominated by radioactivity from external sources.

The next generation of \(0\nu\beta\beta\) experiments are expected to extend the experimental sensitivity by about two orders of magnitude, and thus to possible new physics such as the lepton number violation. Using nuclear models, this can be related to a sensitivity to the effective Majorana mass, which is limited by \(\sim 15\) meV for the inverted hierarchy of neutrino masses (figure 1). In order to achieve this goal, the nEXO Collaboration is pursuing R&D in various fronts based on experience acquired with EXO-200. Among others, nEXO is planned to sustain higher electric field and electron lifetime because of the longer drift length. The improved energy resolution will be achieved primarily with large photo-coverage by silicon photo-multipliers placed along the TPC barrel (figure 2). The fine granularity of the charge readout is expected to provide better separation between single-site signal-like events (primarily \(\beta\) or \(\beta\beta\) decays) and multiple-site backgrounds (primarily \(\gamma\) interactions).

2. nEXO Backgrounds and Sensitivity to Majorana Neutrinos
The expected types and amounts of background events in the nEXO detector must be well understood for an accurate determination of its physics potentials. The contribution from each
detector component due to radioactive contaminants is obtained by appropriately combining its mass, interaction probability, as well as the activity and half-life of the isotope in consideration.

MC simulations of the physics interactions and the detector response are used to obtain the probability density functions (PDFs) of each detector component. A GEANT4-based software [4], that shares the same physics used in the EXO-200 analysis, with the baseline concept of the nEXO geometry, simulates energy deposits in LXe. These deposits are then grouped into clusters based on the event topology, before other detector effects such as energy threshold and fiducial volume cut are applied. The final energy spectra are consistent with those obtained by the EXO-200 detector, but with an improved background rejection that reaches 90% in the region-of-interest (ROI). This separation power is determined from dedicated simulations of the nEXO charge readout response.

nEXO background projections used to compute the sensitivity are solidly grounded on existing EXO-200 and radioassay data. A detailed representation of the current nEXO concept is implemented in the MC and uses realistic amounts of materials for which actual radioassay data exists [5].

The self-shielding feature of the LXe contributes to an exponential reduction of the rate of such background events with LXe depth, providing an almost background-free inner detector. This effect is utilized in the analysis to better determine background rates accounted for by the standoff-distance, the smallest distance between all clusters in an event and the nearest detector component. In particular, amounts of $^{214}$Bi, that has a $\gamma$-line at 2.448 MeV, are well determined by this approach.

An analysis similar to that established by EXO-200 [3] is used to evaluate the sensitivity of the nEXO experiment. The simulated PDFs for all of the detector components are scaled by the corresponding count expectations to generate toy data. A 2-dimensional negative log-likelihood on energy and standoff-distance is minimized with SS-fractions and LXe radon contamination constrained to their MC values. The upper limit of the $0\nu\beta\beta$ counts at 90% CL is used to evaluate limits of the corresponding half-life.

The sensitivity is calculated under the inclusion of zero $0\nu\beta\beta$ (signal) events, while the
discovery potential evaluation follows a similar procedure with non-zero signal events. An interpolation is used to obtain the number of signal events required for a discovery at the 3σ level. The results are presented in figure 3.

Figure 3. Projected nEXO sensitivities to 0νββ half-life as a function of the detector livetime.

3. Discussion and Conclusions
As discussed above, with viable improvements over the EXO-200 detector, nEXO will reach sensitivities to the Majorana neutrino mass that covers the inverted hierarchy. After 10 years of data, the projected half-life sensitivity is greater than $9.5 \times 10^{27}$ yr at 90% CL (figure 3).

Acknowledgments
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