Comparison Study of Counting and Fitting Methods in the Search for Neutrinoless Double Beta Decays

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Abstract

In neutrinoless double-beta decay (0 $\beta\beta$) experiments, common methods for sensitivity calculations include the counting method and the spectrum fitting method. This study compares the differences in sensitivity between these methods for energy resolutions ranging from 1% to 7% at 1 MeV in a liquid scintillator detector. Additionally, the performance of high- and low-Q-value 0 $\beta\beta$ isotopes is compared. The results of this research could provide guidance on the selection of sensitivity calculation methods, energy resolution, and $0\nu\beta\beta$ isotopes for future 0 $\beta\beta$ experiments.

Full Text

Comparison Study of Counting and Fitting Methods in the Search for Neutrinoless Double Beta Decays

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In neutrinoless double beta decay (0 $\beta\beta$) experiments, sensitivity calculations commonly employ either the counting method or the spectrum fitting method. This study compares the differences in sensitivity between these two approaches across energy resolutions ranging from 1% to 7% at 1 MeV in a liquid scintillator detector. Additionally, we compare the performance of high and low Q-value

$0\ \beta\beta$ isotopes. Our results provide guidance for future $0\ \beta\beta$ experiments on the selection of analysis methods, energy resolution requirements, and isotope choices.

Keywords: Neutrinos, Neutrinoless double-beta decay, MC simulation, Analysis and statistical methods

Introduction

Neutrinoless double beta decay ($0\ \beta\beta$), (A, Z) $\rightarrow$ (A, Z + 2) + $2e^-$, is a hypothetical decay process that could occur in certain nuclides if neutrinos are Majorana particles [1]. The investigation of $0\ \beta\beta$ plays a significant role in exploring physics beyond the Standard Model [2]. The half-life of $0\ \beta\beta$ could provide crucial information for determining the neutrino mass hierarchy, since the effective mass of Majorana neutrinos $m\beta\beta$ is highly related to the half-life. The existence of $0\ \beta\beta$ decay would demonstrate that neutrinos are Majorana fermions.

Currently, there is no confirmed experimental evidence for neutrinoless double beta decay, though extensive experimental efforts are dedicated to the search [3-13]. These studies typically employ two methods to estimate sensitivity to the $0\ \beta\beta$ half-life. The counting method involves statistical analysis of events within a selected region of interest (ROI), relying solely on the number of events in that region. The fitting method utilizes spectrum fitting to calculate sensitivity and, despite requiring detailed background characterization, can leverage information from events outside the ROI. This research examines the differences in sensitivity between these two methods.

The best results in $0\ \beta\beta$ experiments have come from the KamLAND-Zen experiment using a liquid scintillator detector [12], which offers the advantage of high exposure to $0\ \beta\beta$ nuclei. In this study, we simulate a liquid scintillator detector as an example case. Detector simulations were performed with an energy resolution δ (defined by the standard deviation σE at 1 MeV as $\delta = \sigma E/1\text{MeV}$) ranging from 1% to 7%, making our conclusions applicable to other detector types within this energy resolution range, such as time projection chamber (TPC) detectors.

Furthermore, we selected ^{150}Nd and ^{130}Te as representative isotopes, corresponding to high Q-value (approximately 3.37 MeV) and low Q-value (approximately 2.53 MeV) cases, respectively. The purpose of this research is to provide guidance for future experiments using various isotopes in selecting appropriate methods for sensitivity calculations.

Section II describes the simulation setup. Section III presents the background considerations. Section IV provides a detailed description of the counting and fitting methods, together with a comparison of their results. Section V presents a discussion, and Section VI concludes.

Detector Setup and Simulation

Detector Setup

The geometry of the liquid scintillator detector used in this research is similar to JUNO [14]. The general structure of the multi-hundred-ton detector is shown in Fig. 1 [Figure 1: see original paper]. The main body of the detector is a 500-ton liquid scintillator enclosed in a 5-meter-radius acrylic sphere. The acrylic sphere is immersed in mineral oil, with a stainless steel support frame for the photomultiplier tubes (PMTs) at a radius of 6 meters. Thousands of 8-inch PMTs are placed on the support frame, and the outer layer is a cubic water tank with a side length of 12 meters.

In this research, the liquid scintillator is loaded with 0 $\beta\beta$ isotopes by a specific mass fraction set to 1% for natural Nd and Te [15–18], corresponding to a mass of 0.285 ton for ^{150}Nd and 1.71 ton for ^{130}Te.

Simulation

The detector simulations used a package named Jinping Simulation and Analysis Package (JSAP). JSAP is based on GEANT4 and includes features such as event generation, detector simulation, dark noise and pre-trigger effects, waveform generation, and trigger logic. Details of JSAP are described in [19].

Neutrinoless Double Beta Decay Experiment Backgrounds

The backgrounds in 0 $\beta\beta$ experiments have various sources, including two-neutrino double beta decay (2 $\beta\beta$), solar neutrinos, and radioactive and cosmogenic backgrounds. These can mask the 0 $\beta\beta$ signals. Our simulations are based on the China Jinping Underground Laboratory (CJPL), where the cosmic ray flux and cosmogenic background are one-thousandth of those in the KamLAND-Zen experiment [20, 21], making them negligible. Therefore, we consider only the 2 $\beta\beta$, solar neutrino, and radioactive backgrounds.

Two-Neutrino Double Beta Decay Background

The 2 $\beta\beta$ process is an intrinsic background in 0 $\beta\beta$ experiments. Similar to 0 $\beta\beta$, the 2 $\beta\beta$ reaction $(\mathrm{A}, \mathrm{Z}) \rightarrow (\mathrm{A}, \mathrm{Z}+2) + 2\mathrm{e}^- + 2$ generates background through the energy deposition of the two final-state electrons. Since the antineutrinos can carry away energy, the total kinetic energy of the two electrons forms a continuous spectrum with its endpoint at the reaction' s Q-value. This energy spectrum can be approximately given by [22]:

$$\frac{dN}{dK} \approx (K-Q)^5 \left(1 + 2K + \frac{K^2}{2} + \frac{K^3}{6} + \cdots\right)$$

where K is the total kinetic energy of the two final-state electrons and Q is the reaction' s Q-value. This equation neglects double Fermi transitions and uses the Interaction Boson Model with the closed approximation, while the Fermi factor is computed using the Primakoff-Rosen approximation [23].

Fig. 2 [Figure 2: see original paper] shows the 2 $\beta\beta$ and 0 $\beta\beta$ two-electron total kinetic energy spectra with an energy resolution of 3%/√E(MeV) for ^{150}Nd. The ratio of the half-life of 2 $\beta\beta$ to the half-life of 0 $\beta\beta$ is set to 1:1.06 $\times$ 10^7, based on the ratio of the half-life of 2 $\beta\beta$ to the lower limit of the half-life of 0 $\beta\beta$ in the KamLAND-Zen experiment [11, 24].

Solar Neutrino Background

Solar neutrinos are produced through nuclear fusion processes in the Sun' s core. For most nuclides of interest in 0 $\beta\beta$ experiments, the Q-value falls within the region above 2.4 MeV [2]. Within this energy range, only the ^{8}B and hep neutrinos exhibit significant contributions [25]. Since the ^{8}B component is approximately hundreds of times higher than the hep component, we ignore the hep contribution in this research.

Neutrino-Electron Elastic Scattering The primary mechanism by which solar neutrinos contribute to the background in 0 $\beta\beta$ experiments is through elastic scattering (ES). Theoretical studies provide the survival probabilities of solar neutrinos reaching Earth [26]. The flux of solar neutrinos dϕ (E), where i = e, , τ, can be calculated using these survival probabilities. By combining this flux with the neutrino-electron elastic scattering cross-sections dσ (Ee, E) [27], the recoil electron spectrum can be derived as:

$$\frac{dN_e}{dE_e} = N_0 \times t \times \sum_i \int d\phi_i(E_\nu) \frac{d\sigma_i}{dE_e}(E_e, E_\nu)$$

where N_0 is the number of electrons in the target and t is the measuring time. The resulting ^{8}B recoil electron spectrum with √E(MeV) energy resolution is shown in Fig. 3 [Figure 3: see original paper]. We validated this background calculation by reproducing the ^{8}B neutrino ES energy spectra reported in the KamLAND-Zen and Borexino experiments [28, 29].

Decay Nuclide Capture Background Neutrinos can be captured by nuclides in the detector through a charged current (CC) process. Ref. [30, 31] indicates that 0 $\beta\beta$ nuclides would capture neutrinos and then undergo single β decay (SB) to release an electron (and possibly photons):

$$\mathrm{CC}: (A, Z-1) + \nu \to (A, Z) + e^- + \gamma(s) + Q_\nu$$
$$\mathrm{SB}: (A, Z) \to (A, Z+1) + e^- + \gamma(s) + Q_\beta$$

This research follows the calculations from [30, 31] to obtain the energy spectrum of β or β + γ. For example, ^{150}Nd undergoes the CC process to become

^{150}Pm, which subsequently undergoes SB to the ground state or excited states of ^{150}Sm, emitting an electron and possibly de-excitation photons. The calculation considers all decay paths of ^{150}Pm with a branching ratio greater than 1% and sets the lower limit of the branching ratio for the ground state at 10%, resulting in a total branching ratio of 99.7%. The β decay energy spectrum is approximately given by [32]:

$$\frac{dN}{dE_e} \approx (E_0 - E_e)^2 E_e p_e F(Z, E_e)$$

where E_0 is the β decay endpoint energy, Ee and pe are the energy and momentum of the final-state electron, and F(Z, Ee) is the Fermi function. ^{130}Te follows a similar process, transforming via CC into ^{130}I, which then undergoes SB to become ^{130}Xe. Fig. 4 [Figure 4: see original paper] shows the total energy spectra of neutrino capture by ^{150}Nd and ^{130}Te, with an energy resolution of 3%/√E(MeV).

Radioactive Background

Radioactive isotopes in materials emit α, β, and γ particles that can deposit energy in the detector, contributing to the radioactive background. The primary contributors are isotopes from the ^{238}U and ^{232}Th decay chains, along with ^{40}K. High-energy γ rays from these sources, such as the 2.61 MeV γ from ^{208}Tl, can penetrate detector materials and reach the detector center, depositing energy to form background events. Table 1 shows the radioactive purity for various materials in the simulation. We assume radiative equilibrium of the U/Th series since radon leakage is suppressed by multiple shielding layers and a continuous nitrogen purging system, as detailed in [33].

Simulation for Backgrounds

This research used the Monte Carlo (MC) method to simulate 0 $\beta\beta$ signals and 2 $\beta\beta$, solar neutrino, and radioactive backgrounds. Monte Carlo events are generated through sampling where the energy spectrum of each background component serves as the probability density function (PDF). The effect of energy resolution δ (ranging from 1%/√E(MeV) to 7%/√E(MeV)) on the spectral shapes is incorporated by convolving with a Gaussian function N($=0$, σ = E(MeV) $\times$ δ).

For radioactive backgrounds, we first obtain their visible energy (electron equivalent energy, unit MeVee) spectra. This requires detector simulation to record energy deposition in the liquid scintillator. For decays occurring in the liquid scintillator, we consider the ^{238}U decay chain, the ^{232}Th decay chain, and ^{40}K. For decays outside the liquid scintillator, we simulate only specific nuclei: ^{210}Tl, ^{214}Bi, and ^{234}Pa from the ^{238}U chain; ^{208}Tl, ^{212}Bi, and ^{228}Ac from the ^{232}Th chain; and ^{40}K. Nuclei undergoing α decay are not considered since α particles quench in liquid scintillator and produce low visible energy (<1.5 MeVee). Additionally, nuclei with visible energies below 1.5 MeVee are excluded as they fall outside the fitting range (1.5–4.8 MeV). A Bi-Po tagging selection is applied to reduce ^{214}Bi and ^{212}Bi backgrounds inside the liquid scintillator.

With these radioactive background spectra, MC simulations can be performed. As an example, Fig. 5 [Figure 5: see original paper] shows the radioactive background energy spectra in the liquid scintillator (5-meter-radius sphere) with an energy resolution of 3%/√E(MeV). The peaks in the U/Th series background primarily arise from γ rays produced during radioactive decay. For instance, the peak in the U series at 2.45 MeV originates from 2.45 MeV γ rays (1.5% branching ratio) emitted during ^{214}Bi decay, while the peak in the Th series at 3.2 MeV mainly originates from the combined 0.58 MeV + 2.61 MeV γ rays (49% branching ratio) emitted by ^{208}Tl decay in the acrylic shell.

Fig. 6 [Figure 6: see original paper] shows a sample of simulated background spectra for 1% natural Nd-loading with an energy resolution of 3%/√E(MeV). As illustrated, the shape of the radioactive background energy spectrum varies with the fiducial volume because the fiducial volume cut selects events based on their deposited energy centroid. When the fiducial volume radius decreases, the external radioactive background from outside the liquid scintillator decreases exponentially, whereas the background from the interior does not. This differential reduction leads to variation in the spectral shape.

Counting and Fitting Methods

We describe here the mathematical principles of the counting and fitting methods, the fiducial volumes defined for both methods, and the ROI selection for the counting method.

Counting Method

The counting method' s mathematical principles are described in Section IV A 1, while the fiducial volume and ROI selection are detailed in Section IV A 2.

Mathematical Principles of Counting Method Based on the total number of events NROI observed in the ROI, the upper limit Slimit for the signal count at a given confidence level (C.L.) can be defined as P(Slimit > S) $\geq$ 1 - α, where 1 - α is the confidence level value.

For experiments with large background event counts in the ROI, the Poisson distribution of NROI (i.e., $\pi(\lambda$ = B+S)) can be approximated as a normal distribution: N(= B+S, σ^2 = B+S), where B and S are the expected numbers of background and signal events in the ROI, respectively. Assuming B is known, the one-sided confidence interval for the signal estimate Ŝ can be obtained as [37]:

$$S_{limit} = N_{ROI} - B + n_\sigma \sqrt{N_{ROI}}$$

where nσ corresponds to the confidence level. For example, a 90% confidence level ($\alpha = 0.1$) corresponds to nσ = 1.28.

When signal counts are much lower than backgrounds, this can be further approximated as:

$$S_{limit} = n_\sigma \sqrt{N_{ROI}} = n_\sigma \sqrt{M \cdot t \cdot B \cdot \Delta}$$

where M is the detector mass, t is the run time, B is the background index per unit mass, time, and energy, and Δ is the ROI width.

For a specific 0 $\beta\beta$ isotope, the upper limit Slimit can be converted to a lower limit on the 0 $\beta\beta$ half-life as follows [37]:

$$T_{1/2}^{limit} = \frac{N_A \times \ln 2 \times \epsilon \times M \cdot t \times x \times \eta}{A_{iso} \times S_{limit}}$$

where NA is Avogadro' s number, x is the loading mass fraction of the 0 $\beta\beta$ nuclides, is the isotopic abundance, Aiso is the atomic number of the isotope, and is the detection efficiency.

Fiducial Volume and ROI Searching Selecting appropriate fiducial volume and ROI range can enhance the counting method' s sensitivity. To determine suitable parameters, we tested various values as described below.

The radius was varied to optimize the fiducial volume using forty values ranging from 1.1 to 5.0 meters in 0.1-meter steps. As the fiducial volume reduced, we observed an exponential decrease in radioactive background from outside the liquid scintillator because the scintillator outside the fiducial volume acts as a buffer layer. This reduction also changes the spectral shape for different fiducial volumes, as shown in Fig. 6. Therefore, we individually studied the spectral shape for each fiducial volume condition by simulating radioactive backgrounds.

ROI selection requires determining an appropriate width and center position. To select a suitable width, we divided the ROI width ΔER (ranging from 0.02 to 1 MeV) into fifty values with 0.02 MeV steps. For the center position, we tested three configurations: [Q - 0.5ΔER, Q + 0.5ΔER], [Q - 0.25ΔER, Q + 0.75ΔER], and [Q, Q + ΔER], since 2 $\beta\beta$ backgrounds are not symmetric near the Q-value.

We searched for the optimal counting method condition using an MC data set; Fig. 7 [Figure 7: see original paper] shows sample results. For specific energy resolutions and isotopes, we selected the fiducial volume radius and ROI corresponding to the highest 90% C.L. sensitivity. Table 2 presents the fiducial volume and ROI selection results for the counting method.

The fiducial volume for ^{130}Te is smaller than that for ^{150}Nd because radioactive backgrounds near the Q-value of ^{130}Te are much higher, requiring a smaller fiducial volume to exclude them.

Fitting Method

The fitting method requires detailed background characterization and can utilize events outside the ROI. This research uses the Chi-squared (^{2}) fitting method, with the ^{2} function form described in Section IV B 1 and mathematical principles in Section IV B 2.

Chi-Squared Function Our fitting method utilizes binned ^{2} fitting. The test statistic ^{2} consists of two components:

$$\chi^2 = \chi^2_{energy} + \chi^2_{penalty}$$

where

$$\chi^2_{energy} = 2\sum_{i=1}^{N_{bin}}\left(n_i \log\frac{n_i}{v_i} + v_i - n_i\right)$$

is a Poisson-format ^{2} [38] and

$$\chi^2_{penalty} = \sum_{k=1}^{N_{bkg}}\frac{(v^k_{bkg} - n^k_{bkg})^2}{(\sigma^k_{bkg})^2}$$

Here, Nbin denotes the number of bins in the fitting range, ni is the observed number of events in the i-th bin, and vi = vsignal + Σk vbkg^k is the expected number of events in the i-th bin. Nbkg denotes the number of background types, vbkg^k represents the expected number of events of the k-th background, nbkg^k is its measured value, and σbkg^k is the standard deviation of the measured value. Penalty terms constrain the impact of statistical fluctuations in large-magnitude backgrounds (e.g., 2 $\beta\beta$) on the fitting procedure.

This research utilizes the TMINUIT class from the CERN ROOT [39] software package with its default optimization algorithm MIGRAD to minimize the ^{2} function. Fig. 8 [Figure 8: see original paper] shows a sample ^{2} fit with an energy resolution of 3%/√E(MeV) and a detector run time of 10 years (corresponding to exposures of 1.35 ton-year for ^{150}Nd and 1.46 ton-year for ^{130}Te).

Mathematical Principles of Fitting Method The fitting method uses binned ^{2} fitting, and the Feldman-Cousins method [40] (FC method) calculates confidence intervals. For multi-dimensional samples, constructing confidence bands requires computationally intensive calculations and is difficult to visualize.

Therefore, we employed a toy MC method called the profiled FC method [41] to address this challenge.

For a specific parameter value = s, we generate multiple toy MC samples xi, each corresponding to a particular background configuration. For each sample, we calculate:

$$\Delta\chi_j^2(x_i;\mu_s) = \chi^2(x_i;\mu_s) - \chi^2(x_i;\mu_{best})$$

where best is the best-fit result for parameter . We then derive a critical value c(s) such that 1 - α of the toy MC samples satisfy Δ 2_j(xi; s) < c(s). Repeating this process for sufficient s points yields a curve c(s), from which the confidence interval for for a specific sample x can be derived as:

$$I_\mu = \{\mu|\Delta\chi^2(x;\mu) < c(\mu)\}$$

The profiled FC method avoids constructing confidence bands in multi-dimensional x- space. However, it requires choosing nuisance parameter values during toy MC generation. One solution is pre-assigning nuisance parameter values using a predetermined function [42].

In this research, the total count of each background {Nk} and the 0 $\beta\beta$ signal Ns were set as fitting parameters, while the samples are events in each bin {ni}. The profiled FC method determines the confidence interval for the signal count Ns using equation (12). In most situations, this interval encompasses 0 and becomes an upper limit Ns|upper, allowing straightforward conversion to a lower limit on the 0 $\beta\beta$ half-life:

$$T_{1/2}^{lower} = \frac{N_A \times \ln 2 \times M_{iso} \times 10^6}{A_{iso} \times N_s|upper} \times t \times \epsilon$$

where the constants are defined as in equation (8).

We use this method to obtain the 0 $\beta\beta$ half-life sensitivity by generating toy MC samples with zero signal, calculating the lower limit for each sample, and taking the median result.

Fiducial Volume Cut for Fitting Method The fiducial volume cut searching process for the fitting method follows the same procedure as the counting method described in Section IV A 2. Fig. 9 [Figure 9: see original paper] shows a sample fiducial volume search for the fitting method with ^{150}Nd and ^{130}Te under an energy resolution of 3%/√E(MeV) and a detector run time of 10 years, where exposures change with fiducial volume radius. For specific resolutions and isotopes, we selected the fiducial volume radius corresponding to the highest 90% C.L. sensitivity. Table 3 gives the resulting fiducial volume cuts.

Comparison of Counting and Fitting Methods

We compare the counting and fitting methods using the obtained 90% C.L. sensitivities of the 0 $\beta\beta$ half-life. The comparison was performed with different isotopes (^{130}Te and ^{150}Nd) and energy resolutions, with other conditions shown in Tables 2 and 3. These half-life sensitivities were derived with optimal fiducial volume and ROI, with results shown in Fig. 10 [Figure 10: see original paper].

Under all energy resolution conditions studied, the fitting method achieves higher sensitivity to the 0 $\beta\beta$ half-life compared to the counting method. For the fitting method, sensitivity for the high Q-value isotope (^{150}Nd) shows a sharp decline when energy resolution exceeds 6%/√E(MeV), discussed in Section V B. For the counting method, sensitivity for ^{150}Nd decreases faster than for ^{130}Te because, in our detector setup, the main background for the low Q-value isotope is radioactive background, while for the high Q-value isotope it is 2 $\beta\beta$ background. The 2 $\beta\beta$ background within the ROI increases rapidly as energy resolution deteriorates, leading to faster sensitivity degradation for ^{150}Nd.

Discussion

Comparison of Effective Neutrino Mass Obtained by Different Isotopes

For 0 $\beta\beta$ experiments, the effective neutrino mass m$\beta\beta$ is of greater interest, satisfying the relationship [43]:

$$\langle m_{\beta\beta}\rangle^2 = \frac{m_e^2}{G_{0\nu} g_A^4 |M_{0\nu}|^2 T_{1/2}^{0\nu}}$$

where gA is the coupling constant, me is the electron mass, and G0 and M0 are the phase space factor and nuclear matrix element related to the isotope, respectively. The phase space factor G0 for ^{150}Nd is approximately 4 times that of ^{130}Te [44], while the nuclear matrix element M0 has large theoretical uncertainty [45–51]. Multi-isotope 0 $\beta\beta$ experiments are critically important for constraining this theoretical uncertainty.

The 90% C.L. sensitivities of m$\beta\beta$ for ^{150}Nd are shown in Fig. 11 [Figure 11: see original paper], with G0 and M0 taken from (a) QRPA model and (b) IBM model data in Ref [44]. As a reference, the KamLAND-Zen experiment reported a published lower limit of 2.3×10^{26} years (90% C.L.) for the neutrinoless double beta decay half-life, corresponding to an effective neutrino mass of 36–156 meV [12]. Meanwhile, the SNO+ collaboration anticipates achieving a sensitivity of 1.9×10^{26} years, corresponding to an effective neutrino mass of 50.6 meV [52].

The Sharp Decline of Sensitivity When Fitting with Nd-150

The fitting method' s sensitivity with ^{150}Nd shows a sharp decline at energy resolutions worse than 6%/√E(MeV), as shown in Fig. 10. This feature arises from the 2 $\beta\beta$ background of ^{150}Nd. As energy resolution deteriorates, the 2 $\beta\beta$ background increasingly overlaps with 0 $\beta\beta$ signals, causing a significant drop in fitting performance, illustrated in Fig. 12 Figure 12: see original paper.

Fig. 12(b) shows background events in [Q - σ, Q + σ], where Q is the Q-value of ^{150}Nd and σ is the standard deviation of the ^{150}Nd 0 $\beta\beta$ signals. The background rate increases rapidly with deteriorating energy resolution, confirming that 2 $\beta\beta$ is a critical factor affecting ^{150}Nd sensitivity. This sharp decline causes ^{150}Nd' s sensitivity to fall below that of ^{130}Te at energy resolutions worse than 6%/√E(MeV), primarily because ^{150}Nd has more 2 $\beta\beta$ background that is highly sensitive to energy resolution.

Conclusion

This research focuses on comparing counting and fitting methods in 0 $\beta\beta$ experiments. Based on simulation of a 500 m^3 spherical liquid scintillator detector at CJPL, we compared 0 $\beta\beta$ half-life sensitivities obtained from both methods across energy resolutions from 1%/√E(MeV) to 7%/√E(MeV). We performed fiducial volume cuts for both methods and optimized ROI selection for the counting method. Furthermore, we selected ^{150}Nd and ^{130}Te as representatives of high and low Q-value isotopes.

Our results indicate that the fitting method obtains higher sensitivity than the counting method across all studied energy resolutions. This research provides guidance for future experiments in selecting appropriate methods for sensitivity calculations.

We chose 3%/√E(MeV) as a typical liquid scintillator detector energy resolution. Under this resolution and with exposures of 1.46 ton-year for ^{150}Nd and 0.30 ton-year for ^{130}Te, the better sensitivities from the fitting method are:

- ^{150}Nd: 6.45×10^{25} yr (90% C.L.)
- ^{130}Te: 4.60×10^{25} yr (90% C.L.)

These 0 $\beta\beta$ half-life limits correspond to effective neutrino masses m$\beta\beta$ of 42–92 meV for ^{150}Nd and 75–149 meV for ^{130}Te.

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Note: Figure translations are in progress. See original paper for figures.