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Measurement of the ^{136}Xe $\beta\beta2\nu$ half-life with NEXT-White

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The NEXT (Neutrino Experiment with a Xenon TPC) collaboration aims at the sensitive search of the neutrino-less double beta decay ($\beta\beta0\nu$) of ^{136}Xe at the Laboratorio Subterraneo de Canfranc (LSC). The observation of such a lepton-number-violation process would prove the Majorana nature of neutrinos, providing also handles for an eventual measurement of the neutrino absolute mass. A first large-scale prototype of a high-pressure gas-Xenon electroluminescent TPC, NEXT-White, has been operating at the LSC since 2016. This 5-kg radiopure detector has already proven the outstanding performance of the NEXT technology in terms of the energy resolution (<1% FWHM at 2.6 MeV) and the topology-based background rejection. NEXT-White has also measured the relevant backgrounds for the $\beta\beta0\nu$ search using both ^{136}Xe-depleted and ^{136}Xe-enriched xenon. In this paper, the measurement of the half-life of the two neutrino mode of the double beta decay ($\beta\beta2\nu$) will be presented. For this measurement, two novel techniques in the field have been used: 1) a Richardson-Lucy deconvolution to reconstruct the single and double electron tracks, boosting the background rejection, and 2) a direct subtraction of the $\beta\beta$ backgrounds, measured with ^{136}Xe-depleted data. These techniques allow for background-model-dependent and background-model-independent results, demonstrating the robustness of the $\beta\beta2\nu$ half-life measurement and the unique capabilities of NEXT. The physics program of NEXT-White will be completed in late 2021, when the construction of the NEXT-100 detector at the LSC starts. Holding 100 kg of ^{136}Xe and with a background index below 5×10^{-4} counts/keV/kg/year, this detector will perform the first competitive $\beta\beta0\nu$ search within the NEXT roadmap. As validated with NEXT-White, NEXT-100 will reach a sensitivity to the half-life of 6×10^{25} y after 3 years of data taking, paving the way for future ton-scale phases.

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1. Introduction

NEXT is a neutrinoless double beta decay experiment located at the Canfranc Underground Laboratory in Spain. Divided in various stages, each one is carried out by a different detector improving the features of previous detectors and incorporating them into following stages.

The detection concept is the same for all NEXT detectors. Most consist in a chamber containing ^{136}Xe-enriched gas (90%) at high pressure (10-15bar), a SiPM plane, a PMT plane, and 2 electric fields: drift field (moderate intensity) created by an anode and a cathode, and a more intense field located in the electroluminescence region called EL field, which produces ~500 γ per ionisation e- without causing avalanches affecting the energy resolution.

The latest stage involved the NEXT-White radiopure detector, contained 5kg of Xe gas and has proven the outstanding performance of the NEXT technology in terms of the energy resolution (<1% FWHM at 2.6 MeV) and the topology-based background rejection. It has also measured the relevant backgrounds for the $\beta\beta0\nu$ search using both ^{136}Xe-enriched and depleted xenon used in this analysis for the measurement of the half-life of the $\beta\beta2\nu$.

2. Data

For this analysis, two data-taking periods have been used: a 271.6 day period using ^{136}Xe-enriched (RunV) and a 208.9 day period with ^{136}Xe-depleted (RunVI). For both, NEXT-White took data under the same operation conditions of gas pressure, drift and EL fields. Although the operation conditions remained the same, the time evolution of the temperature and gas density were monitored, with the largest source of variability of the latter being the re-filling of the detector between RunV and RunVI. Consequently, to compare the rates for each data-taking period some corrections on the gas density, selection efficiencies and DAQ livetime have been applied.

3. Richardson-Lucy deconvolution

The diffusion of ionisation electrons when traveling in the drift direction towards the anode along with the spread of light produced in the electroluminescence process are two effects that degrade the topology of events [1]. The aforementioned produce blurred images deteriorating one of the main features of the NEXT experiment. The introduction of the Richardson-Lucy (RL) deconvolution in the reconstruction has proven to revert this effect, producing highly refined images of events, leading to a significant upgrade in the signal/background discrimination.

This RL deconvolution algorithm applies a 2D interpolation over corrected hits and takes advantage of the variation of the Point Spread Function (PSF) in the drift direction applying an iterative procedure that provides a sharper representation of the event. Fig. 1 shows the same event before and after the deconvolution process revealing a much more faithful reconstruction of the true event. On the extreme points of the track, a sphere of 18 mm radius is traced from the center and the energy of all the hits inside it will accounted to form the so-called “blobs”. If the energy of a blob exceeds a certain threshold, it will be considered a Bragg peak. Hence this procedure allows distinguishing events with one or two Bragg peaks, i.e., single or double-electron

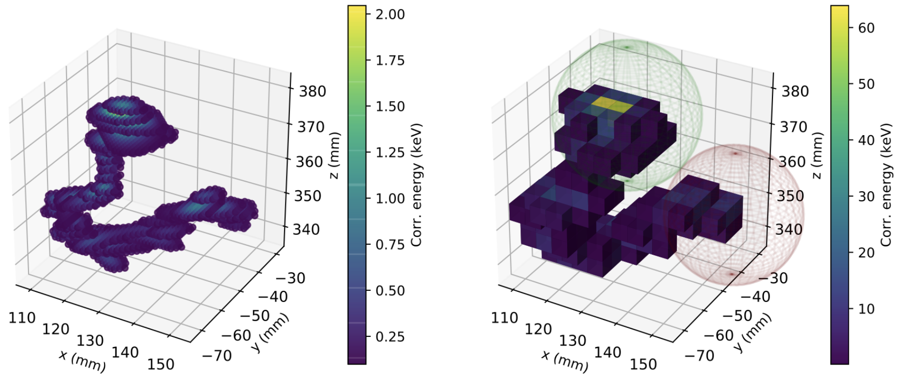

Figure 1: Left: XYZ representation of the deconvoluted hits. Right: Voxelized track for the same event with the blob candidates illustrated. This event would be classified as a single electron event (i.e. background), since only the green blob will be considered as Bragg peak due to its blob energy values.

events. The improvement in the signal acceptance over background rejection obtained using the RL deconvolution has been successful. Due to topology related inconveniences the discrimination between single and double-electron events deteriorates for energies below 1MeV.

4. Selection cuts

Selection cuts are fundamental to improve the relation between signal over background by rejecting the maximum amount of background without throwing away many signal events. Moreover, the different cuts will provide us four data subsamples to test each of the fitting strategies approached in this analysis.

The first selection is the **background selection** which rejects events with multiple Compton scatters and several energy depositions produced by Bremsstrahlung radiation of the electrons and avoids surface backgrounds with the fiducial cuts. Another selection labeled as **no overlap selection** provides a subsample where the blob candidates do not have any hits in common. Finally, we perform two more selections, named **single (β)** and **double electron selections ($\beta\beta$)** classifing the events in one and two Bragg peak events by setting a certain threshold for the blob energy.

5. Measurement of $T_{1/2}^{2\nu}$

Two different analysis have been performed in order to obtain the $T_{1/2}^{2\nu}$ of ^{136}Xe: a background-model dependent fit and a background-model independent one. The background-model dependent fit was performed on the $\beta\beta$ subsample which boosts the signal/background ratio and therefore improves the precision in the $T_{1/2}^{2\nu}$ measurement. The best-fit values for the 4 background contributions (one per isotope) are extracted along with the $\beta\beta2\nu$ ^{136}Xe rate, which is translated into a best-fit value for the half-life of $T_{1/2}^{2\nu}$ = (2.14±0.80) × 10^{21} y. On the other hand, having two data-taking periods allows a direct background subtraction from the ^{136}Xe-enriched data of the ^{136}Xe-depleted gas data sample that will constitute the background model independent fit. The background-model dependent result acts as a cross-check for the background-model independent

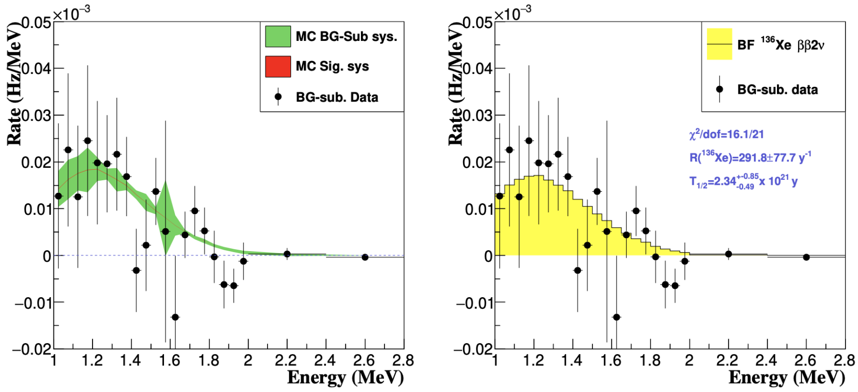

Figure 2: Background-subtracted energy fit. Left: background-subtracted energy spectrum superimposed to the nominal MC expectation relying on the EXO-200 measurement of the $\beta\beta2\nu$ half-life. Right: background-subtracted energy spectrum superimposed to the best-fit $\beta\beta2\nu$ MC.

analysis. Two consistent background-subtraction $\beta\beta2\nu$ fits are proposed considering different observables and subsamples (the $\beta\beta$ and no overlap, separately). The first is mostly data driven as the MC is only used to estimate the ratio between single and double-electron events in the background. In order to derive the half-life of the ^{136}Xe $\beta\beta2\nu$ from the background subtracted energy spectrum, a fit is performed to the corresponding MC expectation. The pre-fit distributions and the fit outcome are shown in Fig. 2. The best-fit rate corresponds to a $T^{2\nu}_{1/2} = (2.34^{+0.85}_{-0.49}) \times 10^{21}$ y. A second background-subtraction fit has been performed on the RunV and RunVI no-overlap data samples. The idea is to fit the less energetic blob energy distribution of the rate excess, as opposed to cut on this variable as done in the $\beta\beta$ selection. With this approach a consistent half-life value has been obtained.

These results are consistent and assess the robustness of the $\beta\beta2\nu$ analysis performed with the NEXT-White data. Although the obtained precision on the measurement is limited by the small amount of ^{136}Xe mass, it is worth noticing that the NEXT-White results are compatible with the values provided by EXO-200 [2] and KamLAND-Zen400 [3]. The analysis relies on two unique capabilities of the NEXT technology, namely the topological signature of the events and the direct subtraction of backgrounds. This background subtraction technique, novel in the field, offers results with very small dependence on the Monte Carlo assumptions.

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