The NEXT double beta decay experiment

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Abstract. NEXT (Neutrino Experiment with a Xenon TPC) is a neutrinoless double-beta ($\beta\beta0\nu$) decay experiment at Laboratorio Subterráneo de Canfranc (LSC). It is an electroluminescent Time Projection Chamber filled with high pressure ^{136}Xe gas with separated function capabilities for calorimetry and tracking. Energy resolution and background suppression are the two key features of any neutrinoless double beta decay experiment. NEXT has both good energy resolution ($< 1\%$ FWHM) and an extra handle for background identification provided by track reconstruction. We expect a background rate of 4×10^{-4} counts keV^{-1} kg^{-1} yr^{-1}, and a sensitivity to the Majorana neutrino mass of between 80–160 meV (depending on NME) after a run of 3 effective years of the 100 kg scale NEXT-100 detector. The initial phase of NEXT-100, called NEW, is currently being commissioned at LSC. It will validate the NEXT background rate expectations and will make first measurements of the two neutrino $\beta\beta2\nu$ mode of ^{136}Xe. Furthermore, the NEXT technique can be extrapolated to the tonne scale, thus allowing the full exploration of the inverted hierarchy of neutrino masses. These proceedings review NEXT R&D results, the status of detector commissioning at LSC and the NEXT physics case.

1. Introduction

The NEXT experiment seeks to observe neutrinoless double beta decay ($\beta\beta0\nu$) in ^{136}Xe. The detector will operate at the Laboratorio Subterráneo de Canfranc (LSC) located 2500 m.w.e below the spanish pyrenees. In order to maximise signal to background in the region of $Q_{\beta\beta}$, the collaboration has developed a detector technology which splits energy and tracking measurements which allows for the reconstruction of event topology using a dense array of SiPMs and a low noise measurement of the energy of events using an array of radiopure PMTs.

2. Development of the detector technology

The NEXT detectors are high pressure xenon TPCs which employ in-gas amplification using proportional electroluminescence (EL) and read out the charge using light sensors. The Separated Optimized Functions (SOFT) concept (illustrated in figure 1) allows for reconstruction of event topology using the forward-going light detected by an array of SiPMs directly behind the anode while performing the reconstruction of the event energy using the backward-going and reflected light detected by PMTs positioned behind the cathode. In this way both measurements can be optimised using appropriate technologies as well as using their interplay to further improve key measurements. The technologies have been studied in detail using two prototype detectors: NEXT-DEMO and NEXT-DBDM. NEXT-DBDM operated at between 10-15 bar of natural xenon and focused on the measurement of energy resolution for gamma interactions as well as

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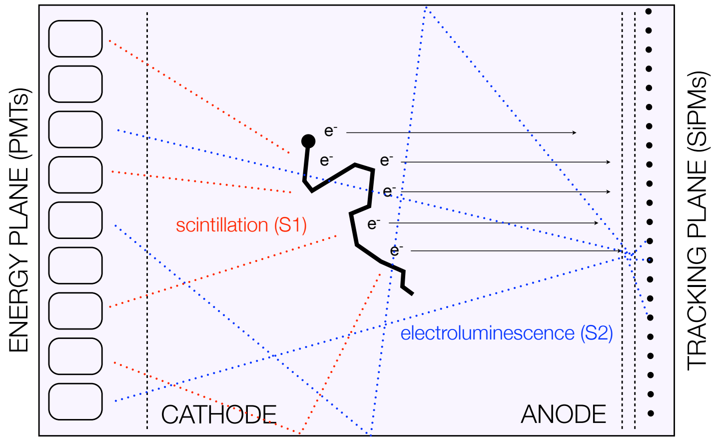

Figure 1. The design of NEXT, implementing the *Separate, Optimized Functions TPC* (SOFT) concept: EL light generated at the anode can be recorded in the photosensor plane right behind it and used for tracking; or recorded in the photosensor plane behind the transparent cathode and used for a precise energy measurement.

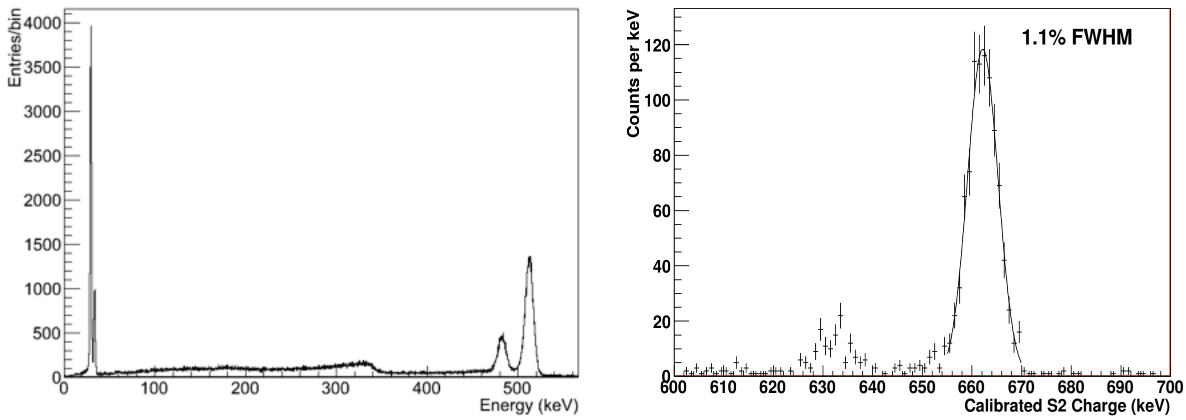

Figure 2. Spectra obtained for source gamma energy reconstruction in the NEXT prototypes. Left, ^{22}Na spectrum in DEMO [4] and, right, ^{137}Cs spectrum in DBDM [1].

studying the separation of nuclear and electron recoils [1, 2]. NEXT-DEMO implemented a small scale version of the NEXT design and operated at 10 bar of natural xenon. Operation has been used to aid development of the NEXT simulation and the data taken has been used to study the effectiveness of the technology [3], to study energy resolution and detector calibration [4], to study alpha particle interactions [5], and to benchmark the basic topological background rejection using source data [6]. Energy reconstruction measurements performed using data from ^{137}Cs and ^{22}Na sources in the prototype detectors led to spectra including those shown in figure 2. Extrapolation of the calculated energy resolutions for the principal peaks of these spectra predict resolution at $Q_{\beta\beta}$ of 0.5–0.7% FWHM [1, 4].

The ability to distinguish between the topologies of double electrons and those left by single electrons induced by radioactive isotopes in the detector materials and environment is key to the NEXT proposal. NEXT-DEMO data has been used to study the rejection power of the basic cuts which were proposed as the baseline analysis in the NEXT LOI [7]. Modelling signal with pair production events where the annihilation gammas both escape the detector (double escape peak, 1.592 MeV) and background with the 1.275 MeV gamma from the ^{22}Na source, datasets of signal-like and background-like events were collected in NEXT-DEMO and simulated in the NEXT Monte Carlo. As described in Ref. [6], the data and Monte Carlo are found to agree on key parameters related to the reconstruction. Moreover, the proportion of those events which reach the key 'two-blob' cut (illustrated in figure 3) entering the final sample is consistent with that predicted by the Monte Carlo and, hence, with the projections for NEXT-100.

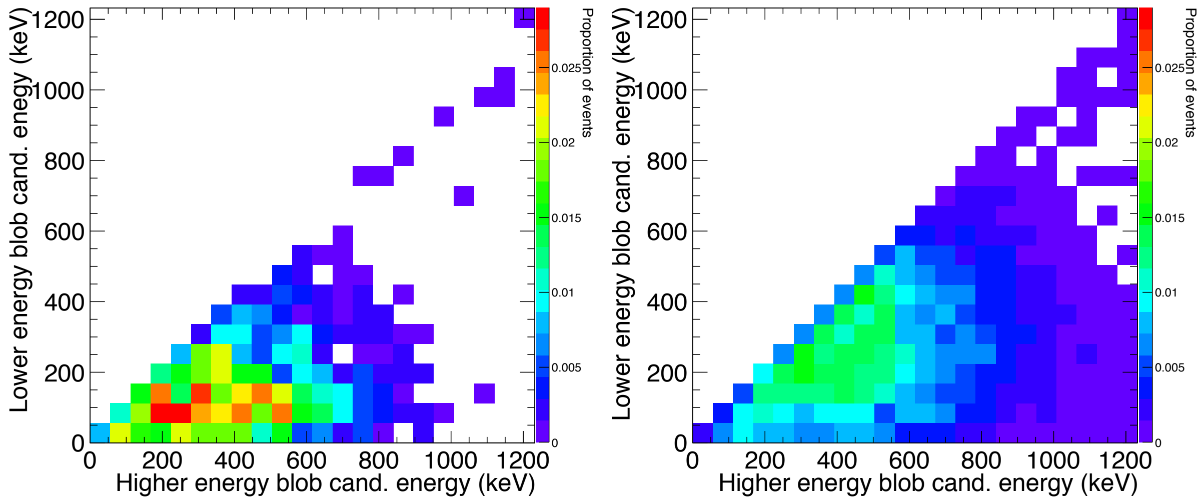

Figure 3. Energy distribution at the end-points of the tracks coming from ^{22}Na decay (left) and those coming from the ^{208}Tl decay (right) for 2 cm radius blob candidates (plot from [6]).

3. NEW at LSC

The next step in the development of NEXT is the installation and operation of NEXT-NEW. NEW is constructed of the same materials selected for radiopurity for NEXT-100 and will operate in the NEXT lead castle shielding at LSC. Installation began in the summer of 2015 and the light sensors and data acquisition systems are currently being commissioned.

The next year of data taking will be dedicated to understanding the technological solutions and repeating the source based analyses developed in NEXT-DEMO at a larger scale and wider range of energies. The calibration protocol will be developed and benchmarked using a ^{83}Kr^{m} source to generate point-like interactions in the full detector volume. In this way a regular calculation of the geometric response of the detector will be used with all other data. An extended run with natural xenon will further aid the development of the background model. A final run with xenon enriched in ^{136}Xe will be used to make a first estimate of the $\beta\beta2\nu$ decay lifetime while NEXT-100 is prepared for commissioning.

4. Sensitivity of the NEXT-100 detector

Using the measurements made by the prototype detectors and the extensive radiopurity screening performed by the collaboration [8, 9] as inputs, a study of the sensitivity to the measurement of $\beta\beta0\nu$ has been made.

In order to make the most conservative prediction of NEXT-100 sensitivity within the predictions of the prototypes, the worst predicted $Q_{\beta\beta}$ energy resolution (0.75% FWHM) was assumed in the analysis and in the case of materials where only an upper limit on the

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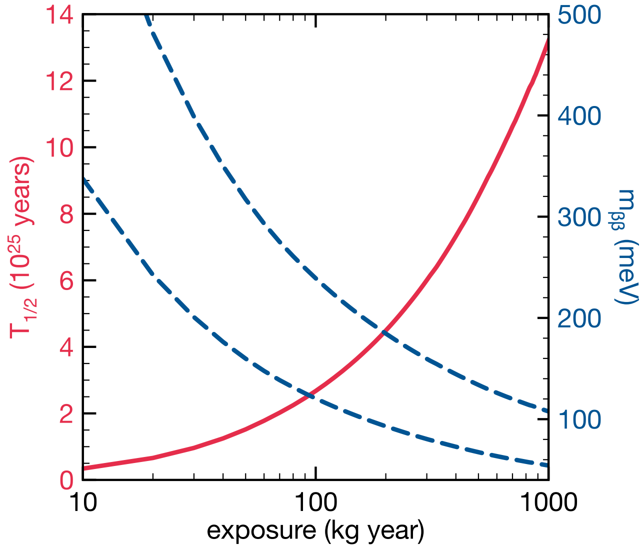

Figure 4. Sensitivity (at 90% CL) of NEXT-100 in terms of the accumulated exposure for an estimated background rate of 4×10^{-4} counts keV^{-1} kg^{-1} yr^{-1} to neutrinoless double beta decay. The (crimson) solid curves represent the half-life sensitivity, while the (blue) dashed curves correspond to the $m_{\beta\beta}$ sensitivity for the largest (EDF) and smallest (ISM) NME estimates from [11] and [12] respectively (plot from Ref. [10]).

natural activity has been determined, that upper limit was treated as if it were the mean of a measurement. Applying the standard analysis to simulated backgrounds in the detector materials and applying the predicted rates measured by the collaboration a background rate of $< 4 \times 10^{-4}$ counts keV^{-1} kg^{-1} yr^{-1} is expected. Thus for an exposure of 275 kg yr a sensitivity to the $\beta\beta0\nu$-decay half life of 6×10^{25} years is predicted [10]. Sensitivity to the effective Majorana mass depends on the nuclear matrix element calculation, as illustrated in figure 4.

5. Possible upgrade paths

Studies of possible upgrades to the analysis and detector design are running concurrently with the main effort. Analysis upgrades are focused on the improvement of track identification and the use of neural networks to optimise the use of topological information with the end to improve signal efficiency over the basic analysis used in the sensitivity studies.

Looking towards a possible 1 tonne detector using the NEXT concepts, the possibility to add molecular additives to the xenon to improve diffusion is being studied. Stable additives which reduce diffusion without seriously affecting light yield would allow for a more detailed topological reconstruction and, in principle, an improved background rejection. Additives under study for possible future application include CO_2, CH_4 and CF_4 [13]. Other possible upgrades include the use of a water tank as shielding and changes to the light sensors to remove background effects due to irreducible natural radioisotope content.

6. Summary

The NEXT experiment is entering the first stages of underground operation. The extensive R&D programme has demonstrated the power of the design and in the NEW detector final technological and background model measurements will be made. Studies using inputs from the prototype detectors and the results of material screening for radioisotopes predict a competitive sensitivity to the ^{136}Xe $\beta\beta0\nu$-decay half life.

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