The NEXT experiment for neutrinoless double beta decay searches

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Abstract. NEXT is an experiment to search for the neutrinoless double beta decay of 136Xe using a high pressure xenon gas time projection chamber. This detector technology has several key advantages, including excellent energy resolution, powerful event classification based on track topology, and favorable mass scalability. The current stage of the experiment, NEXT-White, has been taking data at the Canfranc Underground Laboratory (LSC) in Spain since late 2016. In this talk, we will review recent results from NEXT-White after the first year of low-background operations with both 136Xe-depleted and 136Xe-enriched xenon gas. Background measurements will be shown as well as preliminary results on the two-neutrino mode double beta decay.

1. Introduction
The NEXT Collaboration is using an asymmetric high pressure xenon gas (HPGx) time projection chamber (TPC) with electroluminiscent (EL) amplification to search for 0νββ decays. The detector NEXT-100 will have 100kg of isotopically enriched 136Xe and will start to be built at the Laboratorio Subterráneo de Canfranc (LSC) by the end of 2019. Since October 2016, a 1:2 scale detector, NEXT-White is operating at LSC. This detector uses the same materials and photosensors as the first phase of NEXT-100 and can be used to characterize the backgrounds at LSC and to measure the two neutrino mode of double beta decay.

The NEXT-White detector uses two dedicated readout planes, one behind the cathode with photo-multiplier tubes (PMTs) to measure the energy of events and the other one behind the anode with silicon photo-multipliers (SiPMs) for the tracking. EL amplification is essential to achieve an excellent energy resolution thanks to the linear gain. In this way, HPGXe technology offers an excellent energy resolution (0.5-0.7% FWHM at Q_{ββ} = 2458 keV) and tracking capabilities fundamental to distinguish signal and background events.

2. Detector calibration
The NEXT-White detector has been characterized both at low and high energies. For the low energy calibration a 83Rb source is inserted into the gas system, decaying into 83mKr radioactive atoms that will diffuse through the detector’s active volume, producing low energy electrons uniformly distributed that will be observed as point-like 41.5 keV events. Using these events two x-y correction maps can be constructed: one for the electron attachment due to the impurities in the xenon gas, and another for the geometrical corrections due to the solid
Figure 1. Energy spectrum from calibration data with $^{228}$Th and $^{137}$Cs sources

angle covered by PMTs, internal reflections, etc. Using these corrections, the energy resolution measured for $^{83m}$Kr is $4.553 \pm 0.010$ (stat.) $\pm 0.324$ (sys.)%, which is extrapolated as $1/\sqrt{E}$ to $0.5916 \pm 0.0014$ (stat.) $\pm 0.0421$ (sys.)% at $^{136}$Xe $Q_{\beta\beta}$ [1].

For the high energy calibration two $^{228}$Th sources has been placed in the upper ports of the detector and a $^{137}$Cs source in the lateral one. The $^{137}$Cs source provides a 661.6 keV gamma, while $^{228}$Th decays into $^{208}$Tl, which provides a 2614.5 keV gamma and also the double-escape peak resulting from $e^+e^-$ pair production interactions of the gamma in which the two 511 gammas escape. The energy spectrum is shown in Figure 1. The resolutions obtained are $1.20 \pm 0.02$% FWHM at 662 keV, $0.98 \pm 0.03$% at 1592 keV and $0.91 \pm 0.12$% FWHM at 2615 keV [2, 3]. This means NEXT-White is the xenon-based detector with the best energy resolution in the world, less than 1% FWHM at $Q_{\beta\beta}$.

3. Topological signal

One of the salient features of NEXT technology is that it can reconstruct particle tracks and use their topology to improve signal-background discrimination. This procedure has been tested with data taken from the NEXT-White detector during January 2019 with a $^{228}$Th source. $e^+e^-$ events from $^{208}$Tl double-escape has been used as signal while Compton events from 2615 keV $^{208}$Tl gammas with the same deposited energy as the double-escape peak, are used as background [4].

Applying a threshold on the energy of the ends of the tracks, most of the background can be removed while keeping the signal. The optimal value for that threshold is $265.9 \pm 0.6_{\text{sys}}$ keV, giving an efficiency for signal-like events of $71.6 \pm 1.5_{\text{stat}} \pm 0.3_{\text{sys}}$% for a $22.3 \pm 0.4_{\text{stat}} \pm 0.5_{\text{sys}}$% background [4]. The same cut applied to Monte Carlo data gives a signal efficiency of $73.4 \pm 1.2_{\text{stat}} \pm 3.0_{\text{sys}}$% for a background acceptance of $22.3 \pm 0.4_{\text{stat}} \pm 0.5_{\text{sys}}$%, in agreement with data.

In a Monte Carlo sample in the $0\nu\beta\beta$ region (2435-2481 keV) with the same cuts, a threshold 266.5 keV gives a signal efficiency of $71.5 \pm 0.1_{\text{stat}} \pm 0.3_{\text{sys}}$%, for a background acceptance of $13.6 \pm 1.1_{\text{stat}} \pm 0.7_{\text{sys}}$%. There is an improvement when cutting background at higher energies due to the fact that the tracks are longer and, therefore, easier to separate at their end points. Larger improvements are expected with a better reconstruction, in that direction several algorithms, such as Lucy-Richardson deconvolution, Deep Neural Networks and Maximum-Likelihood Expectation Maximization are being explored [5, 6]. A preliminary analysis using convolutional neural networks for $0\nu\beta\beta$ selection yields $\sim 92$% signal efficiency for $\sim 8$% background rejection. The discrimination is also expected to improve by having a gas mixture with reduced transverse diffusion [7, 8, 9, 10].
4. NEXT-White Backgrounds

NEXT-White has taken more than 3 months of data (Run-IV) with depleted xenon (<3% of $^{136}$Xe) with the goal of measuring the background levels. Thanks to the radon abatement system NEXT-White has a virtually airborne radon-free environment. The last period of Run-IV, Run-IVc, has been performed in the conditions as Run-V, devoted to the $2\nu\beta\beta$ half-life measurement. The fiducial background rate measured is $2.78 \pm 0.03^{\text{stat}} \pm 0.03^{\text{syst}}$ mHz above 600 keV.

The background model has been compared with Run-IVc data in [12]. This model, built using GEANT-4, includes 4 isotopes ($^{60}$K, $^{40}$K, $^{214}$Bi, $^{208}$Tl) and 22 detector volumes. All materials activities has been screened [13, 14, 15] and the internal Rn expectation is taken from [11].

The comparison with the background measurement is done for $E > 1000$ keV, obtaining a rate of $0.84 \pm 0.02$ mHz in the data, while the prediction is $0.489 \pm 0.002^{\text{stat}} \pm 0.004^{\text{syst}}$ mHz, yielding a ratio of $1.71 \pm 0.04$. A measurement of each isotope can be obtained by fitting the energy and $z$ distributions: $R(^{60}\text{Co})=(0.23 \pm 0.02)$ mHz, $R(^{40}\text{K})=(0.13 \pm 0.02)$ mHz, $R(^{214}\text{Bi})=(0.22 \pm 0.04)$ mHz, $R(^{208}\text{Tl})=(0.27 \pm 0.02)$ mHz. Given the sensitivity of the fit to the spatial origin of the backgrounds, most of the excess with respect to the model comes from the anode region.

After applying a set of topological cuts (see Figure 2), the background rate is $(0.248 \pm 0.010)$ mHz for the data and $(0.244 \pm 0.001^{\text{stat}} \pm 0.008^{\text{syst}})$ mHz for the MC. The best-fit background model has been used to estimate the $2\nu\beta\beta$ half-life sensitivity in NEXT-White, which is found to be $(3.5 \pm 0.6)\sigma$ after one year of data taking. The expected background in a 200 keV window around $^{136}$Xe $Q_{\beta\beta}$ is $0.75 \pm 0.12^{\text{stat}} \pm 0.02^{\text{syst}}$ in 37.9 days, while one event is observed in Run-IVc. Therefore, the background model is validated in the $0\nu\beta\beta$ energy range.

A preliminary analysis of 78 days of Run-V data with $\sim 3$ kg of $^{136}$Xe yields a half-life of $(1.47 \pm 1.05) \times 10^{21}$yr for the $2\nu\beta\beta$ decay of $^{136}$Xe. This is compatible with the EXO-200 measurement of $(2.17 \pm 0.06) \times 10^{21}$yr [20]. The error on the measurement will quickly get smaller when more data are analyzed.

5. Future and prospects

The NEXT-White detector is a 1:2 scale version of NEXT-100, which will have a drift length of 1300 mm, 97 kg of xenon gas enriched at 90% in $^{136}$Xe at 15 bar [16]. The energy plane is composed of 60 PMTs, while the tracking plane has 5600 SiPMs. NEXT-100 is fully funded and operations will begin at 2020. The background rate expected is $4 \times 10^{-4}$ counts keV$^{-1}$ kg$^{-1}$ yr$^{-1}$, yielding a projected background in the ROI of NEXT-100 of <0.7 counts yr$^{-1}$ [17]. NEXT-100
can explore up to a $m_{\beta\beta} < 70 - 130$ meV, depending on the nuclear matrix element, at 90% confidence level with 5 years of data. NEXT-100 is expected to be a virtually background-free experiment at the 100 kg scale and will serve as a demonstrator for the tonne scale technology.

With the aim of exploring the inverted hierarchy, the NEXT collaboration is intensely working on the design and development of a tonne scale detector with a two phase approach [18]. In the first one, named NEXT-HD, incremental improvements over NEXT-100 will be done such as: replacing PMTs with SiPMs as they are the main background source, operate at lower temperatures to reduce dark noise and use a low diffusion gas mixture to improve the performance of the topological signature. The second phase, NEXT-BOLD, will be a detector capable of doing barium tagging, that is, detecting with high efficiency the presence of the Ba$^{++}$ ion produced in the $^{136}$Xe $0\nu\beta\beta$ decay [19]. This could imply a background-free detector.

6. Conclusions
The results of the NEXT-White detector demonstrate the performance of the detector technology and sufficiently low background levels for NEXT-100. The physics campaign is ongoing with more data being taken to make a good measurement of the two-neutrino mode of the $\beta\beta$ decay. That data will also be analyzed to put a limit on the $0\nu\beta\beta$ decay. NEXT-100 operation will begin on 2020 with physics data expected for 2021. Studies for tonne scale detectors are under development with intense R&D ongoing on different fronts such as barium tagging for HPXe-TPC, low-diffusion gas mixtures, gas cooling or sensor plane upgrades.

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