PROCEEDINGS OF SCIENCE

NEXT, a neutrinoless double beta decay experiment.

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The NEXT experiment searches for the neutrinoless double beta decay in ^{136}Xe using a series of detectors based on the high pressure xenon gas time projection chamber (HPXeTPC) technology. The previous stage of this family of detectors was NEXT-White, the first radiopure detector of the NEXT series, with 5 kg of Xe. Its goals were a detailed assessment of the backgrounds for ^{136}Xe double beta decay searches, the measurement of the ^{136}Xe $2\beta\beta\nu$ half-life and the characterisation of the detector performance at energies close to the ^{136}Xe decay energy. Since its decommissioning in 2021, NEXT has entered its current stage, with the construction of the NEXT-100 detector. NEXT-100 will hold up to 100 kg and is estimated to start running by the beginning of 2024. This detector will perform NEXT's first sensitive neutrinoless double beta decay search in ^{136}Xe. Both NEXT-White and NEXT-100 are hosted by the Laboratorio Subterráneo de Canfranc, located in the Spanish Pyrenees. R&D has also started for next-generation NEXT detectors beyond NEXT-100, which may enable for the first time the detection of the daughter ^{136}Ba^{2+} ion produced in the ^{136}Xe decay. In this talk we will discuss the latest results of the experiment brought by NEXT-White, including NEXT's first search for the $0\beta\beta\nu$, the status of NEXT-100 construction and R&D prospects towards future tonne scale detectors.

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1. Introduction.

The $2\nu\beta\beta$ decay is a radioactive process first suggested by M. Goeppert-Mayer in 1935 [1], consisting of the simultaneous β^- decay of two neutrons in the same nucleus. In practice, the $2\nu\beta\beta$-decay of a nucleus is only observable for 35 isotopes in which the β-decay is energetically forbidden or strongly suppressed because of a large change of spin. It has only been observed for 14 isotopes which have very long half-lives in the range: $T^{2\nu}_{1/2} \sim 10^{18} - 10^{21}$ yr.

In contrast, $0\nu\beta\beta$-decay (analogous process with no neutrinos in the final state) is considered the most promising way to find if neutrinos are Majorana particles. This process, proposed by W.H. Furry in 1939 [2], has typically even longer half-lives $T^{0\nu}_{1/2} > 2.3 \times 10^{26}$ yr being the best limit for ^{136}Xe provided by the KamLAND Collaboration [3]. Moreover, this disintegration is forbidden in the Standard Model as it violates lepton number conservation.

A continuous energy spectrum ranging from 0 to $Q_{\beta\beta}$ is observed for the $2\nu\beta\beta$, as opposed to the monoenergetic line at $Q_{\beta\beta}$ expected for $0\nu\beta\beta$. On the one hand, the $0\nu\beta\beta$ signal inevitably overlaps with the $2\nu\beta\beta$ signal, effect that can be mitigated via the improvement of the energy resolution. On the other hand, $0\nu\beta\beta$ is also affected by other contributions which must be taken into consideration such as the radiogenic and cosmogenic backgrounds. These backgrounds can be reduced with a number of techniques as screening campaigns, muon veto installation among others.

2. NEXT experiment.

NEXT (Neutrino Experiment with a Xenon TPC) is an experiment that searches for the $0\nu\beta\beta$ process in ^{136}Xe gas used both as a detection medium and the source of the decays. It is located at the Canfranc Underground Laboratory (LSC) in the Spanish Pyrenees, an underground facility reached through the Somport tunnel connecting Spain and France.

2.1 Detection concept.

The NEXT technology is based in a high pressure Xe gas with electroluminiscence time projection chamber (HPGXe-EL TPC), consisting in an asymmetric field cage enclosed between two planes: an energy plane (EP) with an array of low-radioactivity PMTs, and a tracking plane (TP) with a SiPM array. Concerning the field cage, the cathode and the gate create an intense electric field across the active volume. On the other side, we have the electroluminescence (EL) region, located between the gate and the anode, where an even more intense electric field is created, as shown in Fig. 1.

When a charged particle interacts in the active volume, it excites and ionizes the gas producing primary scintillation light (S1 signal) detected by the PMTs in the EP, allowing to determine the initial time of the event (t_0). These ionization charge carriers are drifted towards the EL region, where they are accelerated and secondary VUV scintillation light (S2 signal) is produced. The S1 and S2 signal combination will allow obtaining the position of the event along the drift axis. The backward-emitted EL light detected by the EP will provide the energy measurement; and the forward-emitted EL light detected by the TP will provide the topology of the event.

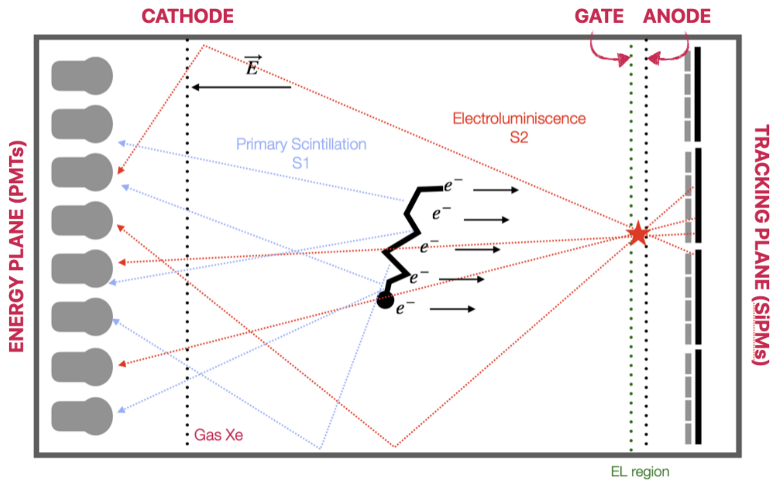

Figure 1: Graphical representation of the NEXT asymmetric HPGXe-EL TPC.

3. NEXT-White.

NEXT-White (named after Prof. James White) was the first radiopure detector of NEXT, located in the Hall A of the LSC holding up to ~ 3.4 kg of xenon gas at 10 bar. It started its commissioning in October 2016, and started taking data in March 2017 until the end of its life in Summer 2021. Its main goals were the demonstration of the scalability of the technology in combination with the characterisation of the backgrounds and the measurement of the mode half-life. It also demonstrated an energy resolution less than 1% FWHM at 2615 keV [4].

The NEXT technology in this detector offered the capability of obtaining a measurement of the $2\nu\beta\beta$ mode half-life by means of a direct background subtraction. This was achieved with 2 low background data-taking periods: the first one of 271.6 days with ^{136}Xe-enriched gas and the second one of 208.9 days with ^{136}Xe-depleted gas. The radiogenic background was found to be consistent in both periods.

To each data sample an event selection was applied to filter the 2 blob like events, satisfying the following conditions: having single tracks fully contained in the fiducial volume, with not overlapping blobs, blob energy above a certain threshold and a total event energy over 1 MeV.

The rate of both periods was subtracted to obtain a $T_{1/2}^{2\nu}$ measurement of $2.34^{+0.85}_{-0.49} \times 10^{21}$ yr. As a validation, a background-model-dependent fit of the event energy was performed obtaining $T_{1/2}^{2\nu} = 2.14^{+0.80}_{-0.46} \times 10^{21}$ yr [5]. Both measurements are compatible with the measurements of EXO-200 [6] and KamLAND-Zen400 [7] as shown in Fig. 2.

Despite not being the original goal of this detector, limits to the $0\nu\beta\beta$ mode were obtained. Analogous to the $2\nu\beta\beta$ measurement, both strategies were applied, using the same data sample and including the model for cosmogenic-induced backgrounds derived from MC simulations. We obtained two lower limits: $T_{1/2}^{0\nu} > 1.3 \times 10^{24}$ yr at 90% CL for the novel direct-background-subtraction technique and $T_{1/2}^{0\nu} > 5.5 \times 10^{23}$ yr for the background-model-dependent approach [8].

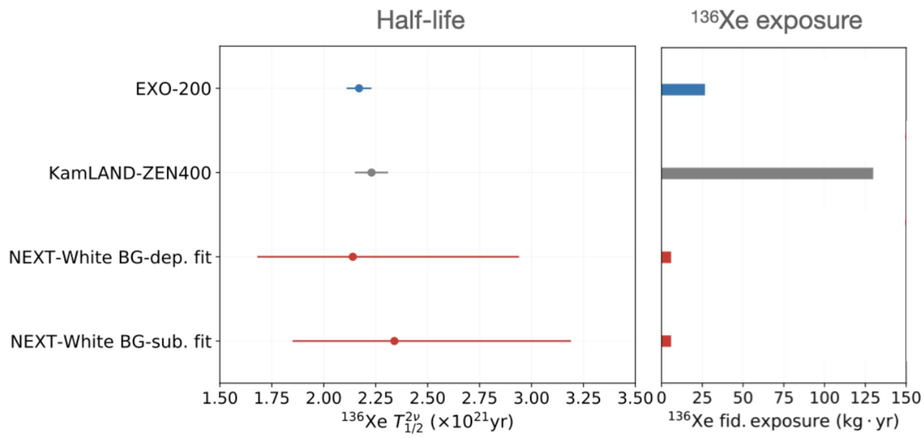

Figure 2: Comparison of $T^{2\nu}_{1/2}$ and exposures of NEXT-White, EXO-200 and KamLAND-Zen400.

4. NEXT-100.

The current stage of the NEXT experiment is NEXT-100, described to be a 1:2 scale NEXT-White, is currently under construction. It will contain 100 kg of Xe gas at 15 bar with 3584 SiPMs and 60 PMTs. Expecting to start operating at the beginning of 2024, it's main goals are to further prove the scalability of the technology in preparation for the tonne scale detectors and demonstrate less than a background event per year, which will eventually lead to a limit in $0\nu\beta\beta$ searches.

Over the summer of 2023 the TPC assembly was completed as observed in Fig. 3. This part of the detector has major differences with respect to NEXT-White. Tensioned hexagonal meshes (made from photochemical etching) as the ones in Fig. 4 were placed for the cathode, gate and anode. This solution was preferred over the implemented in the previous stage due to the need to tension the meshes to avoid deflection, as well as being strong against HV discharges, with more stored electrical energy than in the NEXT-White EL. In the case of the anode, the replacement of the quartz plate with the mesh also accounted for an improvement in the xenon gas circulation in the chamber.

Another main difference with the previous design is the SiPM size, in this case we use 1.3×1.3 mm^2 sensors as opposed to the 1×1 mm^2 used in NEXT-White. Additionally, the distance between consecutive SiPMs (pitch) has increased to 15 mm. The teflon masks, originally installed over the SiPMs for light collimation purposes, have now rectangular holes instead of circular ones and are coated with TPB, as a consequence of replacing the quartz anode with a mesh grid.

Finally, in order to demonstrate about one background event expected per year as shown in Fig. 5, all the materials integrated in NEXT-100 underwent and exhaustive screening campaign using different techniques depending on the analyzed material.

5. Tonne-scale detectors.

In parallel to the construction of NEXT-100, the Collaboration is undertaking R&D on possible future modules both with and without barium tagging, both at the ton-scale and beyond.

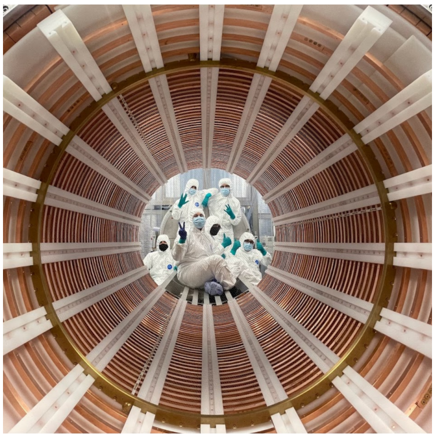

Figure 3: Assembled NEXT-100 TPC.

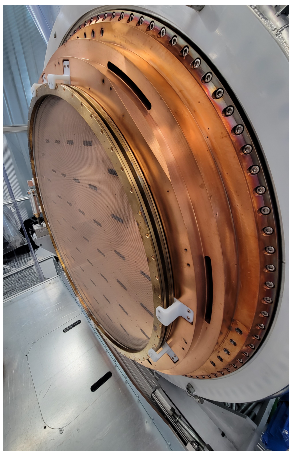

Figure 4: NEXT-100 EL meshes.

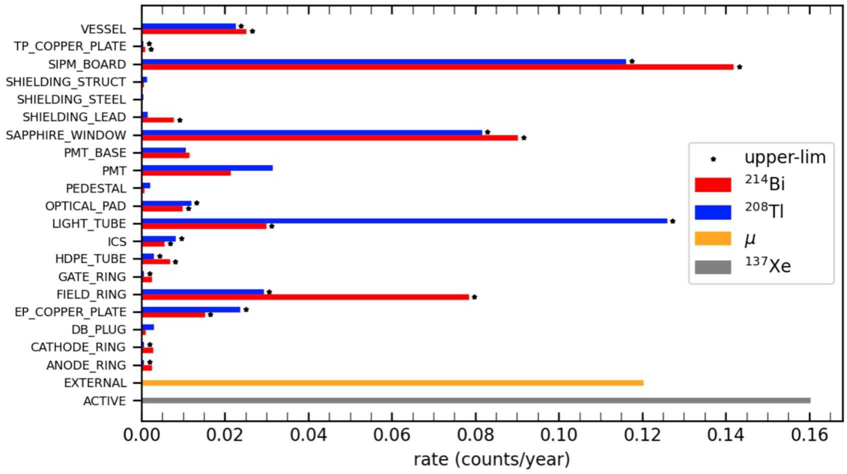

Figure 5: Background contribution of each volume of the detector NEXT-100.

One phase will be NEXT-HD which stands for High Definition. It would be a scaled up version of NEXT-100, hosting 1 T of Xe gas. Due to the complexity of operating PMTs in a high pressure chamber these will be substituted by a SiPM array, resulting in a vertical symmetric TPC. This design will reduce diffusion as the drift length is shortened and provide high definition tracks with the combination of the reduction of the SiPM pitch to 5mm. In this detector, the energy of the events will be extracted from the TPC with an optical fiber barrel that will guide the detected light to an external sensor. In order to reduce the backgrounds NEXT-HD will be installed in a water tank and the addition of ^{3}He is being considered to mitigate the cosmogenic contributions.

The other tonne scale detector will be NEXT-BOLD (barium iOn Light Detection). Barium ions are not produced by natural radioactivity, taking advantage of this fact, these ions could be tagged in order to obtain a background free experiment. The barium must be detected in coincidence with the $2e^-$ signal of the $0\nu\beta\beta$ ^{136}Xe disintegration, making $2\nu\beta\beta$ our main contributor to the background. Several detection approaches are being considered such as Sensor-to-ion (the sensor moves towards the ions position), Ion-to-sensor (the sensor would move to the sensor), RF-carpets for Ba++ transportation in the gas, and single molecule fluorescent imaging (FBIs) techniques to tag the ions such as bi-color indicators and ON/OFF fluorescence molecules. It is still to be determine which combination of all of them will be installed in the future detector. An example would be the combination of sensor-to-ion and FBIs: in this case, the $^{136}Ba^{2+}$ produced from the $0\nu\beta\beta$ ^{136}Xe decay will drift towards the cathode while the ionization electrons will drift towards the anode. The barycenter of the track will be reconstructed triggering the sensor to move to the position where the $^{136}Ba^{2+}$ will be deposited over a monolayer of molecules. These molecules will shift their light emision in combination with the $^{136}Ba^{2+}$ giving us the barium detection signal. This, together with the electron tracks will conform our delayed coincidence signal.

6. Summary.

The NEXT Collaboration has proven our high pressure TPCs designs are successful. NEXT-White has given compatible results with KamLAND and EXO for the $2\nu\beta\beta$ half-life with very little exposure. Currently, the Collaboration is devoted to the construction of NEXT-100 which will start operating in less than 6 months and eventually provide a competitive search for neutrinoless double beta decay. Parallelly, there is a big effort targeted to the R&D towards the tonne scale detectors, that will enable to explore the inverted ordering region and improving significantly our half-life sensitivity.

References

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