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NEXT: searching for the neutrinoless double beta decay with a gas-xenon TPC

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Abstract. Although different techniques are used to search for the neutrinoless double beta decay, the common challenges for all the existing or planned experiments are to achieve a good energy resolution and large background rejection factors. The NEXT collaboration addresses these two challenges with a high-pressure gas-Xenon TPC. Natural Xenon consists of almost 9% of ^{136}Xe , a $\beta\beta^{0\nu}$ candidate emitter, and can be easily enriched. When used as a calorimeter, ^{136}Xe yields an excellent energy resolution. This fact, combined with the expected long life of the $\beta\beta^{2\nu}$ mode, accounts for negligible intrinsic backgrounds up to masses of 1 ton. Furthermore, external backgrounds can be rejected with high efficiency by means of the electron tracking capabilities of the TPC. A detector containing about 100 kg of enriched Xenon is expected to be installed at Canfranc Underground Laboratory (LSC) within the next 5 years, with the twofold aim of exploring the degenerated hierarchy of the neutrino mass and providing deep understanding of the experimental techniques which allow extrapolation to larger detectors.

1. Introduction

Results of oscillation experiments in the past few years have demonstrated that neutrinos are massive particles and that individual lepton numbers are not conserved. A direct consequence is the renewed interest in the double beta ($\beta\beta$) decay experiments. $\beta\beta$ decay is a nuclear transition in which two neutrons bound in a nucleus are simultaneously transformed into two protons plus two electrons. The decay mode in which two neutrinos are emitted ($\beta\beta^{2\nu}$) has been observed in many nuclei. However, if neutrinos are massive Majorana particles, the neutrinoless $\beta\beta$ ($\beta\beta^{0\nu}$) decay may be also possible. The detection of the $\beta\beta^{0\nu}$ process would prove the Majorana nature of neutrinos, providing also a measurement of the so-called *neutrino effective mass* $\langle m_\nu \rangle$.

In the search for the $\beta\beta^{0\nu}$ process two main detector capabilities are requested. The first one is to achieve a good energy resolution; the second one is to provide extra handles to reject backgrounds in the energy region around $Q_{\beta\beta}$. The NEXT collaboration aims at finding a good compromise between these two requirements by using a gas ^{136}Xe TPC. So far, there is no clear signal of the $\beta\beta^{0\nu}$ process, although a group of the Heidelberg-Moscow [1] experiment has claimed to observe this decay in ^{76}Ge . To confirm or refute this result, next generation of $\beta\beta$ experiments is meant to reach sensitivities around $\langle m_\nu \rangle = 50$ meV and to develop the techniques that will allow further improvement in case no signal is detected. These are the two main goals of the NEXT collaboration, along with the measurement of the $\beta\beta^{2\nu}$ decay lifetime, which is not known yet.

2. The NEXT TPC

NEXT stands for Neutrino Experiment with a Xenon TPC. The TPC is defined to operate with gaseous xenon at high pressure (HPGXe), as done in the Gotthard experiment [2]. Xenon is the only noble gas that has a $\beta\beta$ -decaying isotope (^{136}Xe) and no other long-lived radioactive isotope. ^{136}Xe natural abundance is almost 9% and further enrichment can be easily achieved by centrifugation. Its $Q_{\beta\beta}$ value is relatively high (2480 keV) and the $\beta\beta^{2\nu}$ decay mode, not measured yet, may be as long as 10^{22} - 10^{23} years. All these characteristics make ^{136}Xe to be a suitable isotope for the search of the $\beta\beta^{0\nu}$ process. A xenon TPC provides both primary scintillation light and ionization electrons when charged particles interact in the TPC volume. The scintillation determines the start-of-event t_0 time when detected with a photosensor device. Although a liquid xenon TPC is a much more compact device than a gas xenon TPC, its tracking capabilities are quite limited. Given the density of the liquid xenon (3 g/cm^3), electrons from a $\beta\beta$ decay deposit all their energy in a single blob. On the contrary, electrons can be easily tracked in the gas: a gas xenon TPC operating at 10 bar is able to track $\beta\beta$ electrons with path lengths of about 15 cm. In addition, the ionization of liquified noble gases is accompanied by larger fluctuations, thus leading to a worse energy resolution [3].

The NEXT TPC is being designed according to the *SOFT* (Separated-Optimized Function for tracking) concept, based on ideas by D. Nygren [4]: separated and optimized technical solutions for energy and tracking measurements are being explored. Electroluminescence (EL) will be used to amplify the ionization signal, allowing to measure both scintillation and ionization signals with the same photosensors. The readout plane devoted to perform the energy function (and t_0) will be an array of Hamamatsu R8520-06SEL PMTs, currently under development. According to [3], the target for the energy resolution has been set to 1% FWHM at 2480 keV. On the other hand, three main approaches are under study to implement the tracking function. Multi-pixel photon counters (MPPC) and large area avalanche photodiodes (LAPD) could provide tracking information by reading the same EL light used for the energy measurement. Alternatively, Micromegas [5] could perform a charge amplification of the primary ionization and read out the charge.

3. Physics case

The physics case of any $\beta\beta$ experiment can be described in terms of the background rates populating the energy region around the $Q_{\beta\beta}$ value of the isotope under study. In the NEXT experiment, background coming from the tail of the $\beta\beta^{2\nu}$ spectrum is expected to be negligible given the long life of the $\beta\beta^{2\nu}$ decay mode of ^{136}Xe . Furthermore, external backgrounds can be also suppressed down to a negligible value by means of shielding. Therefore, the dominant background comes from ^{214}Bi and ^{208}Tl decays, from the ^{238}U and ^{232}Th chains respectively, taking place in detector materials. A photon of 2614.5 keV is emitted in the ^{208}Tl decay with 100% intensity, along with the β particle and other photons. In addition, ^{214}Bi has two β decays with endpoints above 2480 keV (2663 keV with 1.7% intensity and 3272 keV with 18.2% intensity) and a γ of 2447.8 keV (1.5% intensity). All these decay channels can lead to secondary electrons via Compton and photoelectric interactions.

$\beta\beta$ events have a distinctive topological signature in a HPGXe TPC: an ionization track, of about 30 cm length at 10 bar, tortuous because of multiple scattering, and with larger depositions or *blobs* in both ends corresponding to the two stopping electrons (see Figure 1). This signature is different from that one of a single electron, as only one energy blob is produced. Thereby, the tracking capabilities of the TPC provide a major handle to reject background events when searching for $\beta\beta$ decays. In addition, the specific signature of each physics process allows the measurement of the backgrounds operating the detector on site.

In order to reject backgrounds, three main selection cuts can be applied in the analysis of the data, all of them taking advantage of the topology of the events. First, events with energy

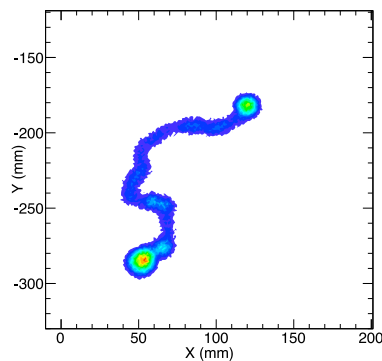


Figure 1. XY projection of a 3D $\beta\beta$ track simulated in ^{136}Xe at 10 bar.

depositions close to the vessel are rejected. Second, only events with one reconstructed track fully contained in the fiducial volume are selected. Finally, the reconstructed track is requested to end up in two blobs of high energy. A full Monte Carlo study has been developed to estimate the background suppression factors according to the above selection cuts. It has been found that a rejection factor of the order of 10^{-7} (10^{-6}) is achieved for ^{214}Bi (^{208}Tl) background events, when only the two first selection cuts are taken into account. According to the results of the Gotthard experiment [2], an additional reduction in the background levels of at least one order of magnitude is expected due to the topology signature. Assuming typical radiopurity levels for the detector materials, it has been concluded that background rates will be less than 10^{-3} count/keV/kg/year, leading to a sensitivity to the $\beta\beta^{0\nu}$ lifetime around 2×10^{23} years at 90% C.L. (below 100 meV in terms of $\langle m_\nu \rangle$) for an exposure of 500 kg · year.

4. The NEXT project

NEXT is an international collaboration already partially funded by the Spanish Ministry of Science and Innovation. NEXT aims at the operation of a 100 kg fiducial volume HPGXe TPC at LSC, by 2018. A Letter of Intent has been already submitted to the LSC Scientific Committee [6] and the project has been approved. The project is divided into three well defined stages. In the first stage, several small prototypes are being built and operated to prove the feasibility of the technologies (energy resolution with PMTs, tracking with photosensors and operation of Micromegas in xenon at high pressure). From 2011 to 2013, a second stage will be devoted to the construction and commissioning of a radiopure HPGXe TPC containing 10 kg of xenon (NEXT-10), to be installed at LSC. Finally, from 2013 to 2018, the ultimate NEXT detector (NEXT-100) containing 100 kg of ^{136}Xe will be built and operated at LSC.

5. Acknowledgments

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