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The NEXT experiment in the new Canfranc underground laboratory.

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Neutrinos are the least understood and the most elusive of the known fundamental particles in the Standard Model of particle physics, though they are the second most abundant in the universe. Neutrino oscillation experiments have shown that neutrinos have finite rest mass, but their absolute mass scale is still unknown. The observation of neutrinoless double beta decay could elucidate the nature of these particles (Dirac or Majorana), but this observation depends of what effective neutrino mass region could be explored. Next generation of experiments aims to explore the inverted hierarchy, which corresponds to an effective neutrino mass up to $\sim$50 meV.

The aim of the NEXT collaboration is to build a 100 kg high-pressure Xe gas TPC (HPGXe) enriched in ^{136}Xe for the search of neutrinoless double beta decay in the new LSC (Canfranc Underground Laboratory) in the Spanish Pyrenees. The high pressure TPC offers an excellent energy resolution and a background rejection power provided by the topological information of the electron tracks obtained by a photosensor array (SiPMs or APDs) detecting the electroluminescence signal. The collaboration also has R&D projects considering the use of a conventional gain TPC, based on a Micromegas plane, that would simultaneously measure tracking and energy. Here the experiment is presented and especially the results of the first generation of prototypes studying both the electroluminescence signal and the charge amplification signal with Micromegas in pure HPGXe.

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1. Introduction

Neutrinoless double beta decay ($0\nu\beta\beta$) can shed light on essential questions about neutrinos like its nature (Dirac or Majorana), hierarchy and absolute mass scale [1, 2, 3, 4]. Promising results obtained in the last decades by some of this kind of experiments about the neutrino effective mass, have encouraged the appearance of new generation experiments. These new generation experiments have as main objective the exploration of the inverted neutrino hierarchy region, which corresponds to an effective neutrino mass of $m_{\beta\beta}$ ~50–200 meV, and to determine the Majorana nature of this particle.

To have the needed sensitivity to reach this goal, all these experiments should satisfy common requirements. High mass of double beta decay (DBD) emitter, good energy resolution and detection efficiency and low background level in the transition energy ($Q_{\beta\beta}$) region are mandatory. But, independently of these common features, several DBD emitters and detection techniques have been considered to develop some of these experiments [5].

The NEXT (Neutrino Experiment with a Xenon TPC) collaboration is at present composed by fourteen institutions from six different countries and aims to study the $0\nu\beta\beta$ decay of ^{136}Xe by using a high pressure enriched Xe time projection chamber (TPC) placed at the Canfranc Underground Laboratory (LSC) [6]. A brief description of the experiment concept and the present status (mainly related to R&D programs trying to obtain conclusions to fix the final phase design) are presented here, together with prospects for further phases of the experiment.

2. The experiment

As mentioned before, The NEXT experiment aspires to study the $0\nu\beta\beta$ decay of ^{136}Xe by using a high pressure enriched Xe gas TPC (HPXeTPC). At present a Xe TPC is being used in several experiments of Rare Event searches [7] due to the interesting features that this kind of setup offers not only for $0\nu\beta\beta$ experiments, but also for dark matter searches.

Focused on $0\nu\beta\beta$, in the study of ^{136}Xe decay, with a $Q_{\beta\beta}$=2457.83 keV [8], the background level coming from natural radioactive chains that could entangle the expected signal, is mainly reduced to ^{214}Bi and ^{208}Tl contributions. Furthermore, the half life of the $2\nu\beta\beta$ decay mode for this isotope, although it has not been measured yet, is supposed to be long ($T^{2\nu}_{1/2} \sim 10^{22}$–$10^{23}$ y), which limits the contribution of this mode to the total background if good energy resolution is achieved.

In addition, an experiment using enriched ^{136}Xe gas could reach high masses of emitter since Xe gas is not too difficult to enrich and could be purified and reused during data taking.

The final phase of the experiment expects to operate 100 kg of enriched Xe at 10 bars in the mentioned high pressure vessel. The experiment will be placed at Canfranc Underground Laboratory, located in the Spanish Pyrenees at 2500 m.w.e. depth, in order to avoid background induced by cosmic rays and to operate the experiment in a controlled atmosphere.

To obtain the highest sensitivity levels, the readout installed inside this vessel has to be capable to register the energy and the track of each event with the best possible energy and spatial resolution respectively. Schematic view of the experimental setup, including the position of the readout is shown in Fig. 1.

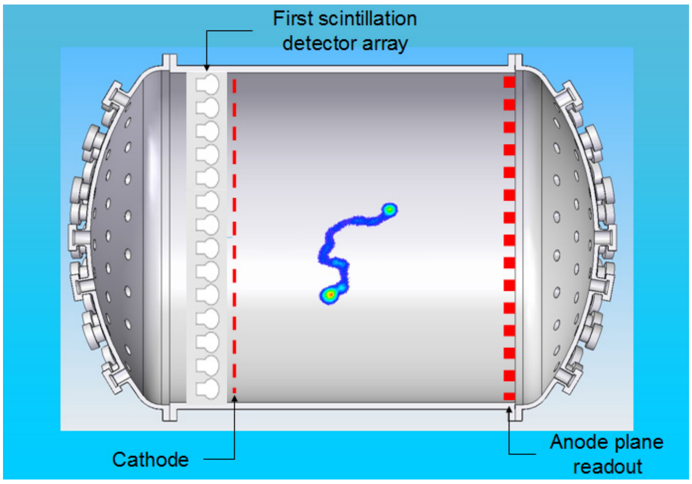

Figure 1: Conceptual design of the NEXT experiment vessel, including the location of the different readout.

Registering the energy and track of each event the application of different analysis techniques to discriminate $0\nu\beta\beta$ events from background ones becomes possible. Apart from a fixed energy ($Q_{\beta\beta}$), a $0\nu\beta\beta$ event is composed by two electrons emitted from the same point with a determined angular correlation. For this reason, these events have a well defined topological signature: two electron tracks starting from the same point (event vertex) and finishing in a big energy deposition (called *blobs*).

On the other hand, background events affecting the $Q_{\beta\beta}$ region of interest, will be mainly produced by bremsstrahlung or multi-Compton events, which have different topology than the typical *2 tracks + 2 blobs* of the $0\nu\beta\beta$ events. Due to these differences in the event tracks, the application of a pattern recognition to the events seems to be the most powerful tool to eliminate background events, reducing background level while keeping high percentages of identification of $0\nu\beta\beta$ ones, which implies high detection efficiency values and therefore improving the sensitivity of the experiment.

For the energy measurement, the main idea is to detect the electroluminescence light by an array of photosensors placed after the cathode. Photomultipliers tubes (PMTs) have been chosen to carry out these measurement due to the excellent energy resolution that could be achievable using these detectors, since it is necessary to obtain energy resolution values around or below 1% FWHM at $Q_{\beta\beta}$ to reach the expected sensitivity. Photomultipliers tubes (PMTs) have been considered as the main option to make these measurements since it has been demonstrated their capability to reach the required energy resolution. Avalanche photodiodes (APDs) or an array of these APDs placed on a common Si substrate and working in Geiger mode (usually called SiPMs in the literature) could be a possible alternative to PMTs.

For the tracks register, it is necessary to have information of the three dimensions. Placing a readout plane at the anode two–dimensions information is obtained. For the third one, measurement of primary scintillation light and further calculation of time difference with secondary signal (produced when the drifted charges reach the readout plane) is necessary. The mentioned readout plane must have a pixelization that allows to produce the event track with a good level of accuracy (a 1×1 cm^2 should be taken as reference value). For this task SiPMs as main option, and alternatively APDs, are considered, while the primary scintillation measurement be be carried out by PMTs, as it was mentioned.

As alternative option for the readout, the utilization of last generation of micromesh gas amplification structures (microbulk Micromegas) [9] has been also considered to register the energy and the track of each events. Using these detectors, only the placement of some PMTs to detect the primary scintillation is also necessary. Micromegas detectors have been successfully used in several experiments for tracking purposes and new generation of these detectors are expected to be suitable for calorimetry measurements having acceptable energy resolution values [10] (although at present not as good as obtained with PMTs), apart from the intrinsic radiopurity of these detectors [11], which favors their utilization for Rare Event searches.

3. Present status

In order to check the features of all the different detectors considered to be used in the experiment, as well as some other elements to improve the high pressure vessel design and the handling and purification of the enriched Xe; several R&D projects are being currently ongoing. These projects focus an important part of the current work of the collaboration. Next, brief description and main results achieved are summarized:

3.1 NEXT-0 EL

This prototype has been designed to carry out first tests of PMTs with Xe, although other detectors like SiPM boards could also be implemented (Fig 2a). Chamber dimensions allow to make tests with one PMT and different drift configurations. In a first phase, primary scintillation was measured using 2 cm length drift and a PMT Hamamatsu R8520-06SEL. In a second phase, tests were focused in the secondary scintillation using 3 cm length drift and 0.5 cm scintillation region. In first measurements using this configuration and ^{55}Fe source, an energy resolution of 8.9 % FWHM at 5.9 keV was reached with the same PMT [12], which indicates that really good energy resolution could be reached with this system at the $Q_{\beta\beta}$ region of interest. Repeat the measurements at different pressures to see the dependance with the signal is the main test to be done using this prototype.

3.2 NEXT-0 & 0.5 APD

The APDs test bench, both for tracking and electroluminescence, are these two prototypes. The small one (NEXT-0 APD, Fig 2c) was used to make the first electroluminescence measurements using a Hamamatsu 5×5 mm^2 APD with a 1.5 cm drift length and 0.7 cm scintillation region. From some calibrations with a ^{109}Cd source, an energy resolution of 10 % FWHM at 22 keV was obtained, leading to think that required energy resolution at $Q_{\beta\beta}$ region of interest is reachable. Next step is the implementation of 25 APDs and 2 PMTs in the NEXT-0.5 APD prototype (Fig 2d). In this detector, with a total length of 30 cm, APDs will be used to measure electroluminescence light, while primary scintillation will be measured by the PMTs, which will allow to register the energy and the track of the events. In addition, the chamber will be connected to a gas system permitting the purification and recirculation of the gas. This prototype is expected to be operative before the end of 2010.

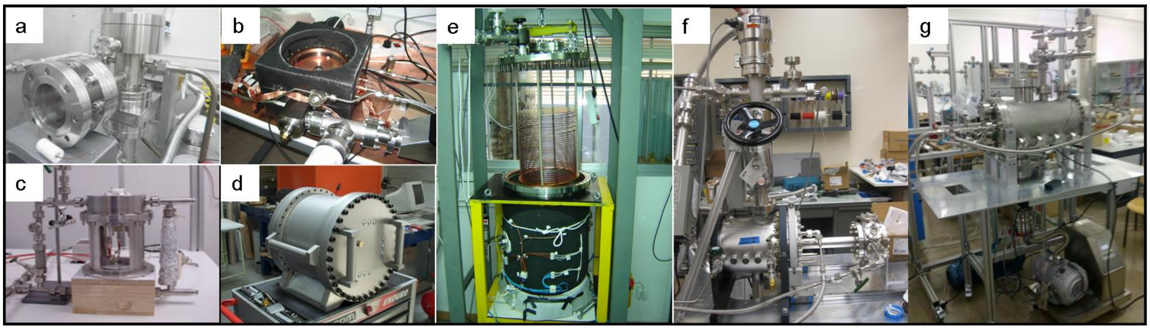

Figure 2: Pictures of the NEXT experiment prototypes: NEXT-0 EL (a), NEXT-0 μM (b), NEXT-0 APD (c), NEXT-0.5 APD (d), NEXT-I μM (e), NEXT-I LBNL (f) and NEXT-I EL (g).

3.3 NEXT-0 μM

First tests about the use of Micromegas detectors for energy and tracking acquisition have been carried out in this prototype (Fig 2b), which has as main objective the operation of a microbulk Micromegas in pure Xe. The vessel, with ultra high vacuum (UHV) specifications and capable to hold up to 10 bar pressure, was designed to have 6 cm length drift. This prototype is also connected to a gas system that allows the purification of the gas to be placed inside the vessel. Routine calibrations with an ^{241}Am source (emitting 5.5 MeV alphas and 59.5 keV gammas) using Xe up to 8 bars showed a best resolution of 7.81% FWHM at 59.5 keV and 2 % FWHM at 5.5 MeV. These values let to be optimistic about the resolution achievable at $Q_{\beta\beta}$ region of interest, covering the requirements needed to reach the expected sensitivity. Although big size pixelized microbulk Micromegas was already installed inside the vessel registering energy and tracks, which cover an important milestone for this prototype, to test different kind of Micromegas detectors or to improve the quality of gas to obtain better resolution values, are the next works to carry out with it. Some of these results are presented in more detail in Ref. [13].

3.4 NEXT-1 μM

To follow the tests performed in NEXT-0 μM prototype, this one has been built with the same specifications about vacuum and high pressure, but bigger enough to hold 1 kg of Xe gas at 10 bar in the sensitive volume (with a drift length of 35 cm and 30 cm diameter readout area, see Fig 2e). After the full equipment of the vessel, implementing it in the same gas system that NEXT-0 μM, first measurements using a 1200 pixel bulk Micormegas and Ar-iC_4H_{10} (2 %) gas have been carried out being capable to acquire energy and tracks from muons and 5.5 MeV alphas coming from a Rn source. The utilization of Xe and other detectors (like new generation microbulk Micromegas), and the tuning of DAQ to improve the quality of tracks acquired and energy resolution are ongoing as next steps to make using this prototype.

3.5 NEXT-1 LBNL

This prototype was designed to hold a readout plane composed by 19 PMTs and operate 10 liters of Xe from 10 to 20 bar, which implies from 0.5 to 1 kg (Fig 2f). The main objective is to obtain an energy resolution at the level of 1% FWHM at 511 keV using a tagged source (since it emits two back-to-back 511 keV photons from e^+ annihilation), and to measure the dependance of the energy resolution with the drift field in Xe. To achieve it, the vessel is connected to a gas system allowing the recirculation and purification of Xe. In addition, some experience with HV feedthroughs and DAQ will be also obtained. All the elements of the prototype (vessel, readout, field cage...) are already manufactured and assembled together, expecting to have first results before the end of 2010.

3.6 NEXT-1 EL

To measure the energy of an event using PMTs and its track using SiPMs, in a medium-size sensitive volume, this prototype has been commissioned (Fig 2g). With 30 cm drift length and 20 cm diameter readout surface, it is possible to operate up to 0.5 kg of Xe at 10 bar. The main objective of this prototype is to develop the light detection using different detectors paying special attention to the energy resolution improvement. Vessel, field cage and readout planes have been commissioned or built and it is expected that the system will operate before the end of 2010.

3.7 Other tasks

Apart from working in all the prototypes described above, several tasks more related with the final phase of the experiment are also ongoing. Some projects about gas system or shielding design, software for data acquisition and electronics development, simulations of background and signal events for further performance of the analysis methods or radiopurity measurements of the materials suitable to be used in final setup, are some of the tasks where the collaboration is involved at present. It is expected that experience and conclusions obtained for all these tasks will lead to the best choices for the final phase of the experiment.

4. Prospects and conclusions

The NEXT experiment is intended to operate a HPGXe TPC with 100 kg of enriched Xe at 10 bar for $0\nu\beta\beta$ study. This experiment will be inside of the group of the so-called new generation DBD experiments. By registering energy and track of each event, NEXT experiment claims to have enough discrimination capability to identify signal events from background ones in order to reach the required level of sensitivity to explore neutrino effective masses around 50 meV.

The initial plan is to install it at the LSC during 2013. To reach this aim, several R&D studies using different prototypes are ongoing trying to obtain as much information as possible about the features of all the detectors considered to be installed in the final setup (PMTs, SiPMs, APDs or microbulk Micromegas). Apart from the work with these prototypes, different projects have been also defined to fix all the features of the experiment (vessel materials, shielding, DAQ...). It is expected that the final decision about detector definition, as well as complete conceptual design of the final phase of the experiment, will be ready during 2011. Starting of the construction of the vessel and shielding for the final setup are scheduled for 2012.

5. Acknowledgments

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References

[1] A. Morales, Nucl. Phys. B (Proc. Suppl.) 77 (1999) 335.

[2] S. R. Elliot and P. Vogel, Ann. Rev. Nucl. Part. Sci. 52 (2002) 115-151.

[3] S.R. Elliott and J. Engel, J.Phys. G 30 (2004).

[4] H. V. Klapdor-Kleingrothaus, “Sixty Years of Double Beta Decay: From Nuclear Physics to Beyond Standard Model Particle Physics”, World Scientific, 2001.

[5] F. T. Avignone III et al, Rev. Mod. Phys. 80 (2008) 481.

[6] Letter of Intent to the Canfranc Underground Laboratory, NEXT collaboration, arXiv:0907.4054 [hep-ex].

[7] E. Aprile, T. Doke, Rev. Mod. Phys. 82 (2010) 2053.

[8] M. Redshaw et al, Phys. Rev. Lett. 98 (2007) 053003.

[9] S. Andriamonje et al, JINST 5 (2010) P02001.

[10] T. Dafni et al, Nucl. Instrum. and Meth. A 608 (2009) 259–266.

[11] S. Cebrián et al, Astropart. Phys. (2010) doi:10.1016/j.astropartphys.2010.09.003

[12] L.M.P. Fernandes et al, JINST 5 (2010) P09006.

[13] S. Cebrián et al, JCAP 10 (2010) 010.