The NEXT experiment

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Abstract. Neutrinoless double beta decay measurements are the most promising experiments both to reveal the Majorana nature of the neutrino and to set a value for its mass. The NEXT project propose to build a High pressure Xenon TPC in the Canfranc Underground Laboratory (Huesca, Spain) to measure double-beta decay of ^{136}Xe, both normal and neutrinoless, with a source mass of 100 kg of enriched xenon.

1. Introduction

The neutrino nature is one of the problems of Physics still unsolved. There exist experimental evidence that neutrinos oscillate [1], which imply they are massive. Mass differences between the different neutrino flavours are extracted from neutrino oscillation data. However, the mass of the lightest neutrino is still unknown, and only an upper limit of about 500 meV is established by different experiments and cosmological considerations. Double beta decay is a rare decay process which can be observed only if the corresponding single beta decays are energetically forbidden [2]. Only a few isotopes fulfill this condition. Normal double beta decay ($\beta\beta2\nu$) occurs as a two-step process of ordinary beta decay, and produces a continuous energy spectrum of the electron pair, as the one shown in Fig. 1. However, massive neutrinos could be Majorana particles, which

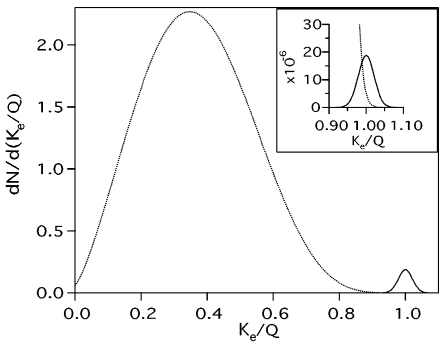

Figure 1. Double beta decay spectrum. The continuous part is the spectrum of the $\beta\beta 2\nu$ process and the peak to the right correspond to the $\beta\beta 0\nu$ process. The inset illustrates how the $\beta\beta 2\nu$ process contribute as a background for the $\beta\beta 0\nu$ peak for finite energy resolution. Taken from Ref.[3]

implies they are identical to their corresponding antineutrinos. In this case, double beta decay could take place without emission of neutrinos and the ideal energy spectrum would be a spike at the $Q_{\beta\beta}$ value. The half-lives of double beta decay can be written for the neutrinoless and two neutrino cases as,

$$T^{0\nu}_{1/2}{}^{-1} = G_{0\nu}(Q_{\beta\beta}, Z)\,[M_{0\nu}]^2\, m^2_{\nu\nu} \tag{1}$$

$$T^{2\nu}_{1/2}{}^{-1} = G_{2\nu}(Q_{\beta\beta}, Z)\,[M_{2\nu}]^2 \tag{2}$$

where $G_{0\nu} and G_{2\nu}$ are exactly calculable phase space factors, $M_{0\nu} and M_{2\nu}$ nuclear matrix elements, at present strongly model dependent, and $m_{\nu\nu}$ the electronic neutrino mass. The measurement of neutrinoless double-beta decay ($\beta\beta 0\nu$) by any of the current or future experiments could show the Majorana nature of the neutrino and provide the value of its mass at the same time. However, to observe the $\beta\beta 0\nu$ peak, one has to avoid any background in the $Q_{\beta\beta}$ energy region, including the $\beta\beta 2\nu$ spectrum. In practice, this requires not only to work in a deep underground laboratory, and with very low levels of radioactivity in all the components the detector is made of, but also to measure electron energies with a resolution good enough to make the $\beta\beta 2\nu$ background negligible in the region of the $\beta\beta 0\nu$ peak.

Different double-beta decay experiments have been carried out during the past four decades [4], without any observation of $\beta\beta 0\nu$ events up to the date (with the exception of the controversial data of the Heidelberg-Moscow collaboration known as Klapdor claim [5]), but have established more stringent limits to the neutrino mass. Double-beta decay detectors can be classified into two different types: calorimeters and track-calorimeters. The experiments of the calorimeter type measure the total kinetic energy of both electrons with state of the art resolutions. To these kind of experiments belong those based on Ge and bolometers. They have excellent energy resolution, which in any case is an essential characteristic of this method in order to separate true events from the different sources of background. As the source isotope belongs to the detector material, these detectors have better efficiency than detectors with an external source, due to the absence of windows and backscattering.

The track-calorimeter detectors measure both the energy of the electrons and some tracking information of the β particles. This tracking information provides a topological signal characterizing two electron events, allowing to discriminate these events from other background events like e-γ events. This is the case of the NEMO3 detector[6] which combines exclusive measurement of electron energies with tracking information sufficiently good to measure angular distributions[7]. In this detector, source isotope and calorimeter material are different. To avoid

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critical loss of efficiency through backscattering of the electrons in the calorimeter, NEMO3 (and its possible extension SuperNEMO) is limited to calorimeters of very low Z, which in practice means the use of plastic scintillators, characterized by a poor energy resolution (8% at best).

As the topological signal given by tracking information can produce a background suppression of about two orders of magnitude, the ideal detector should combine an energy resolution good enough to avoid $\beta\beta2\nu$ background under the $\beta\beta0\nu$ peak and a reasonable tracking information, allowing to reject background produced by non $\beta\beta$ events. Another important issue is scalability. If the $\beta\beta0\nu$ decay is not found in current experiments, detectors of larger masses (multiton) may need to be built. To obtain full advantage ofan eventual increase of mass, it is essential that background be proportionally reduced [4]. This is only possible when the source isotope is a volume which can be produced and kept along its running life in extraordinary conditions of radio-purity. A continuous purification system can be implemented only for liquids and gases.

2. The Canfranc Underground laboratory

The Canfranc Underground Laboratory (LSC) is a new underground facility located in the Spanish part of the Somport road tunnel connecting Spain and France. It is managed by a consortium of the University of Zaragoza, the Gobierno de Aragón (local government of the Aragón Spanish autonomous community) and the Spanish Ministry of Science and Innovation (MICINN). Its depth and cosmic muon flux relative to other underground laboratories is given in Fig. 2. In Fig. 3 the experimental hall A is shown.

The physics at LSC has been supported by the MICINN in the framework of the program CONSOLIDER-INGENIO, with the approval of the project CUP (Canfranc Underground Physics) in the 2008 opening of that program.

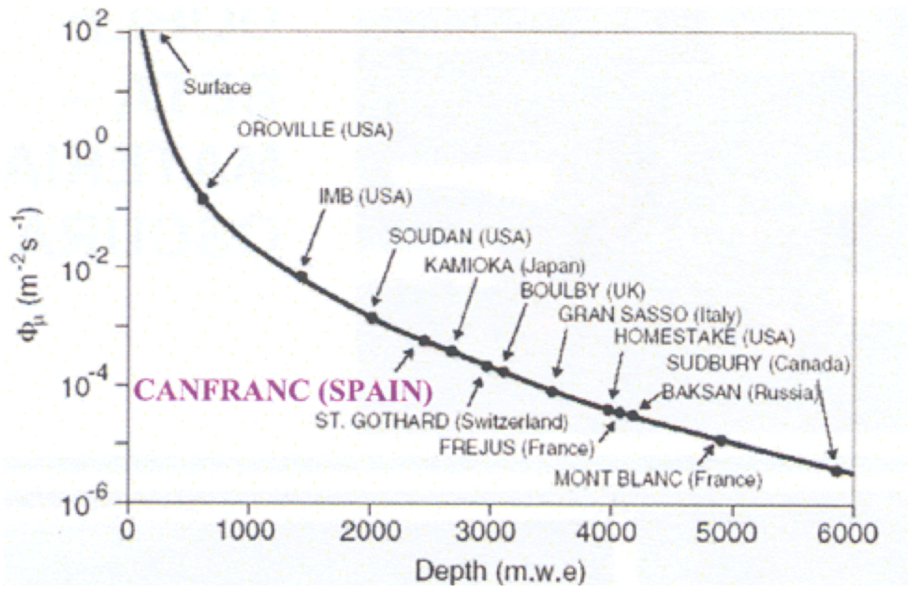

Figure 2. Dependence of the muon flux with the depth of different underground facilities, including the LSC.

3. The NEXT Experiment

The NEXT (Neutrino Experiment with a Xenon TPC) experiment is one of the proposals of CUP (in fact the main one) and has as a goal the design and construction of a High Pressure Xenon

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Figure 3. Hall A of the LSC

TPC enriched in ^{136}Xe to measure its double beta decay both with neutrinos and neutrinoless. None of these modes have been observed yet. The NEXT collaboration is integrated at present by the Spanish universities of Girona, Santiago de Compostela, Politécnica de Valencia, Valencia and Zaragoza, and the research institutions CIEMAT (Madrid), Coimbra (Portugal), CSIC, IFAE (Barcelona), Saclay (France) and LBL (USA). Other institutions may join in the future.

The election of ^{136}Xe as source isotope has several obvious advantages: 1) ^{136}Xe has a large abundance in natural Xe (8.9%) and can be easily enriched by centrifuging; 2) Xe gas has no radioactive natural isotope and can be continuously purified by standard gas systems and kept to negligible levels of radioactivity; 3) xenon responds with a scintillation light ($\lambda = 175$ nm) to the passage of fast charged particles, which can be used as a trigger signal to measure double-beta decay events; 4) a TPC can work with pure xenon avoiding all the complications associated with gas mixtures; the failure to observe $\beta\beta2\nu$ decay by the Gotthard experiment [8] indicates that this process is suppressed by an unknown mechanism in ^{136}Xe and so produces a small background in the region of the $\beta\beta0\nu$ peak; and 5) $Q_{\beta\beta} = 2.4578$ MeV [9] for ^{136}Xe, which is a value reasonably high to have a reduced background.

The election of high pressure Xe TPC has the advantage over of liquid Xe TPCs, as those of the XENON [10] and EXO [11] experiments, the possibility of recording tracking information. The electron energies are deposited in a small region in the case of liquid Xe. In the case of gaseous Xe, the energy is deposited in a track of length dependent on the gas pressure. Simulations indicate that at a pressure of about 10 bars, a good compromise is obtained between efficiency and sufficient tracking length to provide a topological signature allowing to reject effectively background. At higher pressures, energy deposition tracks are too short to be used for background rejection. Also, the energy resolution may be better in gas than in liquid Xe.

The NEXT collaboration aims to reach mass of enriched Xe of 100 kg in a time schedule of about 5 years from this writing. Previous to the building of this detector, called NEXT-100, a smaller detector of about 10 kg of mass, called NEXT-10, will be build to check all the relevant issues: radiopurity, readout system, gas purification, electronics and data acquisition. NEXT-10 I is foreseen to be built in a time schedule of 3 years.

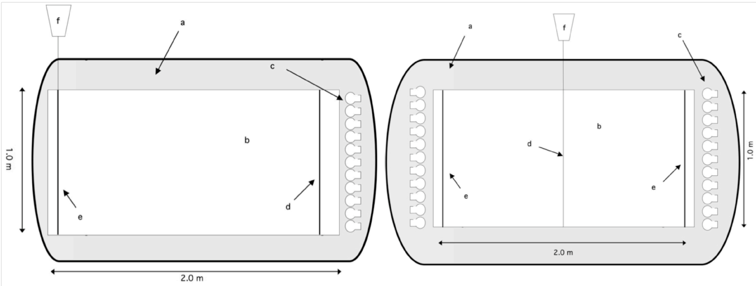

Figure 4. Concept of NEXT: A TPC of about 2 m length and 1 m diameter. The lamps indicate a readout system.

In Fig. 4 the concept of NEXT-100 is shown. The TPC will be a cylinder of about 2 m length and 1 m diameter. The cathode can be placed in one side or in the middle. This second option would allow to read on both sides. This could be necessary if different readout methods are used for energy and tracking readouts. For example, it could be possible to read the energy signal with photomultiplier tubes (PMT) on one side and the tracking pattern with silicon photomultipliers or Micromegas detectors on the other side.

The topological signal produced by two electron tracks is a kind of rope with two balls at its ends, as shown in the left part of Fig. 5. This track reminds the boleadoras employed to hunt by ancient natives of South America like the one depicted in the right part of the picture. The blobs are produced by the Bragg peak of the electrons as they are stopped in the gas. The track is not a rectilinear path but a zigzagging track due to Coulomb scattering. For this reason, no information about angular distributions can be obtained from tracking information. However, this topological signal is essential to distinguish two electron tracks from other kind of events, like the one electron track shown on the left part of Fig. 5. The tracking system finally selected should have a granularity high enough to distinguish the Bragg blobs produced by electrons stopping in the gas.

3.1. Readout technologies

At present, three different readout technologies are being considered. On one side, charge amplification readout by Micromegas is being developed by the Zaragoza and Saclay groups. Excellent energy resolution has been obtained with different gas mixtures, but further investigations are needed to be able to operate Micromegas in pure xenon at high pressure. On the other side, readout of scintillation light produced by electroluminiscence is being studied both with avalanche photodetectors (APD) and photomultiplier tubes. Both PMT and APD have been shown to deliver signals with excellent energy resolution (better than 1%) [11, 12]. Moreover, both APD and PMT can be produced with very good radiopurity levels. In the R&D phase we are going to use the PMT R8520 from Hamamatsu Photonics, already selected and tested by the XENON collaboration. These PMT do not stand pressures higher than 5 bar. In some prototypes, the PMT will be placed outside the TPC, and will read the scintillation light through quartz windows with high transparency in the $\lambda = 175$ nm region, and thick enough to stand 10 bar of pressure.

Different prototypes are going to be built to investigate the performance of each technology for high pressure pure xenon. The final decision will be taken in function of the tracking and energy resolution obtained, without forgetting the necessity of producing the different components with the required level of radiopurity. In Fig. 6, a prototype of a TPC read out by 16 PMT placed in side box is shown. The prototypes will work coupled to a vacuum system able to reach 10^{-7} torr, to clean all the impurities that could produce attachment in the gas. Once the vacuum is reached,

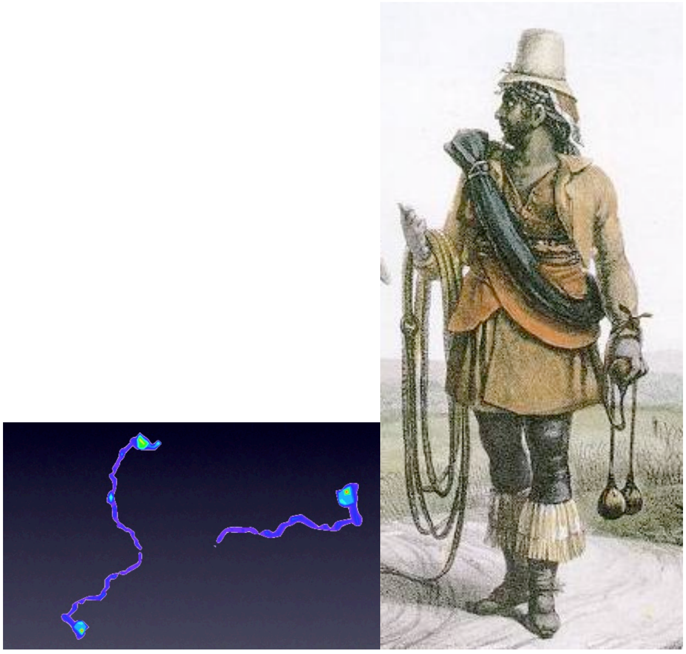

Figure 5. Topological characteristics of 2 electrons and 1 electron tracks. Two electron tracks are characterized by a boleadoras pattern (a rope with two balls like those carried by the indian native to the right)

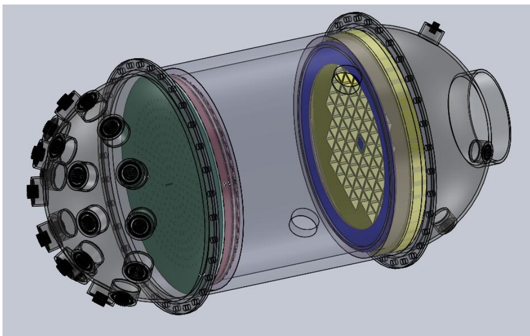

Figure 6. Prototype to test the read energy with PMT and tracking with SiPMTs

the gas system sketched in Fig. 7 enters into work.

3.2. Electronics

Although no decision has be taken yet concerning electronics and data acquisition, going fully digital seems the best option. Continuous sampling by flash ADC avoids the use of triggers, which always have an efficiency less than unity. As an additional advantage, a more stable electronics running is obtained. The big amount of data recorded can be reduced to reasonable amount by modern techniques of data compressing like those employed by the ICE CUBE collaboration. All the sampled values less than a given threshold are set to 0, and a zero suppression technique is applied. For the small prototypes, and probably for NEXT-10, commercial VME flash ADC available from CAEN will be used. For NEXT-100, the adaptation of one of the available chips is under study.

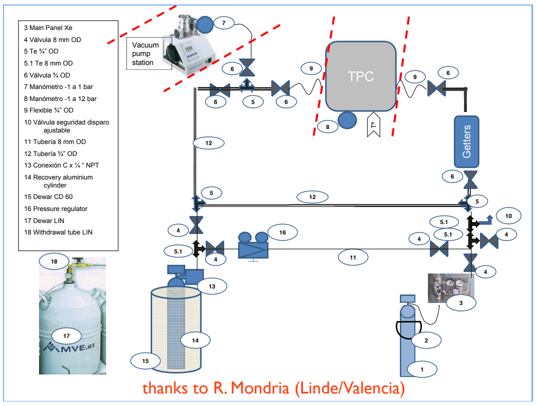

Figure 7. Sketch of the gas system at IFIC-Valencia

3.3. Background, Shielding and Radiopurity program

The most concerning background events for the NEXT experiment are electrons and gamma rays (which produce Compton electrons) with an energy above the Q_{energy}, 2.48 MeV. Most of these particles are originated from the ^{238}U and ^{232}Th chains coming from detector components and from the laboratory natural radioactivity. ^{208}Tl produced in the ^{232}Th chain, emits a photon of 2614.5 keV in the 99% of the decays, never alone, but together with several photons and electrons. To enter into the ROI this photon has to lose a fraction of its energy by bremsstrahlung radiation of the electrons produced in photoelectric absorption, which escapes the detector, or successive Compton scatterings in which low energy gamma rays escape from the detector. In the ^{238}U chain, two beta decays with Q_{max} above 2.48 MeV are produced: 2662.68 keV (1.7% of intensity) and 3272 keV (18.2% of intensity) from ^{214}Bi, ionizing always a few millimeters near the vessel surface, and a photon of 2447.8 keV (with an intensity of 1.57%) which follows a beta decay with Q_{max}=824.3 keV. Another concerning contamination is radon gas. It can be translated into ^{214}Bi, for the ^{222}Rn, or into ^{208}Tl, for the ^{220}Rn, their only decay products affecting the experiment through deposition on the surface of the readout system. Thanks to the use of la 15 cm lead shielding and muon veto, we can get external background reductions of the order of 10^{-5}. An active veto will also eliminate any event depositing its energy in the first centimeter of the vessel surface. Moreover, NEXT has excellent capabilities to get further reductions due to its good energy resolution (a FWHM=1% will eliminate the disturbing double beta contamination and part of the gamma contribution) and, very important, thanks to a good spatial resolution. The possibility to reconstruct electron tracks will eliminate multiple events, as those caused by multiple Compton interactions, and some single electron event (a reduction of the order of 10^{-2} according to Gotthard experiment). Monte Carlo simulations show that after a complete off-line analysis, we could easily, at this preliminary study, reach contamination levels below 0.01 counts keV^{-1} kg^{-1} year^{-1} (Gottard final level, with FWHM of 5.2% at 2480 keV, to be compared to the expected 1% for NEXT) which implies around 25 counts per year for 100 kg of ^{136}Xe, still a large number. The selection of high radio-pure materials, and an improvement of pattern recognition may quickly decrease this number.

The main contaminants that could fake the $\beta\beta$ signal are γ rays of energy higher than the $Q_{\beta\beta}$ value for ^{136}Xe. Gamma rays of these energies can be produced by one of the few cosmic rays reaching the Canfranc experimental hall by different mechanisms, in particular by spallation of rock materials and subsequent capture of the neutrons produced. This mechanism is particularly dangerous if neutrons reach the inner part of the detector and are captured there, because, in this case, pair converted γ rays in the energy window of $\beta\beta$ events cannot be distinguished of true events. External γ rays may also convert in the detector, but they can be strongly suppressed with moderate lead or iron shielding. Neutron shielding is more troublesome, requiring a big volume of hydrogen rich material like water. Calculation of the shielding needed, taking into account the LSC muon flux of $5{\cdot}10^{-3}$ μ cm^{-2}s^{-1} are being carried out by the U. of Zaragoza group.

4. Summary

The NEXT project is already approved by the Scientific Committee of the LSC and partially funded. In three years from now, a 10 kg detector working with natural xenon, NEXT-10, will be built. This detector will allow us to check all the technological issues and radioactive backgrounds. In 5 years a 100 kg detector working with xenon enriched in ^{136}Xe is intended be built. This NEXT-100 detector offers a new physics potential, since none of the double beta decay modes of ^{136}Xe has been measured up to now. The technology seems scalable to much larger masses, and in case the $\beta\beta0\nu$ process has not been discovered by then, a detector housing a mass of 1 ton or more enriched xenon could be envisaged.

Acknowledgments

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