NEXT: double beta decay experiment

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The discovery of neutrino oscillation has reactivated the search of the elusive neutrino-less double beta decays ($\beta\beta0\nu$). The goal of the next generation of experiments is to cover values of effective neutrino mas down to 20meV, the so-called inverse hierarchy region. Several experiments are looking for this disintegration using different techniques. The challenges of these experiments are an excellent energy resolution and large background rejection factor. The Xenon is naturally enriched with $\beta\beta0\nu$ candidate emitter, ^{136}Xe, and shows excellent energy resolution when used as a calorimeter. In gaseous phase, the electrons can be tracked reducing considerable external backgrounds. The NEXT collaboration is designing a pressurized gaseous enriched Xenon detector of about 100 kg to be operated at the Canfranc Underground Laboratory in Huesca (Spain).

1. Introduction

Neutrino oscillation experiments have shown that neutrinos have masses and mix[1]. Neutrinos are also the only known elementary neutral fermions. Neutrinos might be the same as their antiparticles, Majorana Neutrinos, contrary to the case of charged fermions where particles and antiparticles are different, Dirac particles. In the case of Majorana neutrinos, the lepton number is not conserved. At present, most theoretical efforts trying to explain the small mass of the neutrinos requires Majorana neutrinos. The fact that the neutrinos have mass opens also the possibility of detecting this phenomena via the process called neutrino-less double beta decay process ($\beta\beta0\nu$). Double beta decay is a rare transition between two nuclei with the same mass number, A, that changes the nuclear charge, Z, by two units emitting two electrons. The disintegration can be accompanied by two neutrinos ($\beta\beta2\nu$) in the final state, conserving the lepton number. This process has been measured for several nuclei with lifetimes of the order of 10^{18}-10^{21} years. There might be also a process without neutrinos in the final state ($\beta\beta0\nu$). In this case the lepton number is violated by two units and it requires massive Majorana neutrinos. Many experiments have searched for the $\beta\beta0\nu$ process in the past. The decay was never observed, except for a disputed claim[2], setting lifetime limits of the order of 10^{23}-10^{25} years depending on the isotope. These limits corresponds to values of the effective neutrino mass of the order of 250-1000 meV. The next generation of experiments is aiming at reducing this limits to values of 50meV. To accomplish this goal, detectors with large masses (order of 50-100 kg) and improved energy resolution and background rejections are being designed and constructed. Two approaches are being explored at the moment: calorimeters with excellent energy resolution[3–5] and tracking detectors with reduced resolution but tracking capabilities to reduce background contamination[6]. A new experiment, NEXT, will explore the best of both solutions to build a detector competitive using existing technology.

2. NEXT experiment

NEXT stands for "Neutrino Experiment with a Xenon TPC". NEXT experiment is being design in two phases. One with 10 kg Xe pressurized TPC to prove the operation and construction principle and capable of measuring the $\beta\beta2\nu$

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lifetime of ^{136}Xe. The second phase aims at a 100 kg pressurize Xe TPC searching for $\beta\beta0\nu$ decay expected in 2014. A very intense R&D has been started to accomplish these goals in a relative short period of time. The experiment has been already approved at the Laboratorio Subterraneo de Canfranc (LSC) in Huesca (Spain) for the first and second phases.

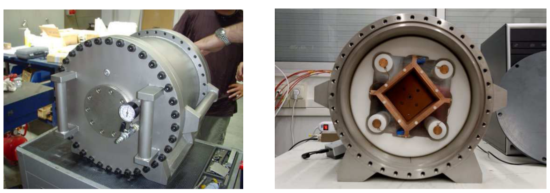

Figure 1. Left picture shows the aluminum pressure vessel of the TPC. Right picture shows the inner structure of the TPC can be seen.

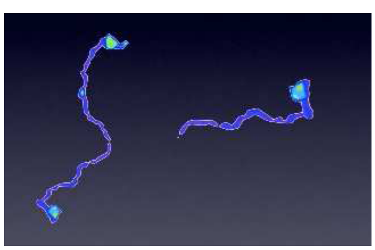

Figure 2. Figure illustrate the difference between signal on the left and single electron background on the right. In both case, the cord represents the electron as a minimum ionizing particle and the final blobs the high ionization before stopping.

A gaseous Xenon based TPC offers very good performance both in energy resolution[7] and tracking performance[8]. Xenon as a noble gas can be used as source and detector simultaneously, it does not have any other radioactive isotope and it can be easily recirculated and continuously purified. The interesting isotope is almost 10% of natural Xenon and it can be enriched by rather inexpensive methods like centrifugation. The $Q_{\beta\beta}$ is rather high (2480 keV) and the $\beta\beta2\nu$ mode has a lifetime larger than 10^{22} years reducing the impact of this intrinsic background.

NEXT collaboration is exploring charge amplification or electro-luminiscence for the readout of primary ionization. The charge amplification can use Micromegas[9] to amplify and read out the charge. The electro-luminiscence uses a parallel grid or a wire plane to accelerate the electrons below the avalanche limit producing abundant scintillation light that is detected with photosensors (PMT or APD). The Micromegas advantages are the cost and the possibility to cover large readout areas but the energy resolution is worse due to avalanche fluctuations. Secondary scintillation light has potentially an excellent energy resolution[10] at the cost of worse tracking capabilities and larger cost. Energy resolution measurements using a high pressure TPC from the Hellaz experiment readout with a 3x3 cm^2 Micromega indicate a resolution of 0.7 % (FWHM) at 4 bar for Ar-Isobutane and ^{241}Am α source (4.5% for pure Xe with 5.5 MeV α)[11]. This is the intrinsic resolution with no drift. A prototype has been constructed, Fig.1, at the IFAE in Barcelona to test the readout options with a 17 cm drift.

The NEXT signal signature is a long ionization cord ending in two large energy depositions from stopping electrons. This signature is different from a single electron in the gas where only one end shows high energy deposition, see Figure.2. γ rays entering the detector will produce normally one or more Compton interactions. Events with more that one interaction is easily detected while events with a single electron can be discarded using topological analysis of the event. This simple signature allows us to relax the tracking criteria, so we can increase the pressure in the detector to reduce the volumen and also to improve the ratio of active mass to surface originating most of the background. The NEXT TPC will be operated between 5 to 10 bars where Monte-

Carlo simulations show the optimal performance for background level and event efficiency. Recent measurements show very small degradation of energy resolution with electro-luminiscence readout[10]. A 100 kg Xenon-TPC requires a volume of 1x1x2m^3 at 10 bars that easily fits in actual underground facilities. The TPC will be equipped with photosensors (PMT or APD's) to detect the prompt scintillation light. This signal will be used to calculate the position of the disintegration along the drift direction in the gas. This allows to define a fiducial volumen in the inner gas volume away from the detector walls to eliminate charged particle background, the only significant background is expected to be neutrals.

2.1. Background considerations

The most critical backgrounds for the NEXT experiment are electrons and γ with an energy above the lower limit of the resolution window around 2.48 MeV ($Q_{\beta\beta}^{^{136}Xe}$). Most of them are originated from the ^{238}U and ^{232}Th chains coming from detector materials and laboratory walls. The electrons are reduced by defining a fiducial volume separated from detector walls. The ^{208}Tl of the ^{232}Th chain emits a photon of 2614.5 keV in the 99% of the decays together with several photons and electrons. To enter into the region of interest, the γ has to lose a fraction of its energy via undetected Bremstrahlung radiation of the photoelectric electron or via successive Compton scatterings where low energy gamma escapes the detector. In the ^{238}U chain, ^{214}Bi has two β decays with Q_{max} above 2.48 MeV (2662.68 keV with 1.7% of intensity and 3272 keV with 18.2% intensity) and a photon of 2447.8 keV (1.57% of intensity) following a β decay with Q_{max}=824.3 keV. External backgrounds are reduced to the order of 10^{-5} with 15 cm lead shielding and muon veto. An active veto will eliminate any event depositing energy close to the vessel surface. The possibility to reconstruct electron tracks will eliminate events as those caused by multiple Compton interactions, and some of the single electron event (reduction 10^{-2} from Gotthard experiment). MC simulations show that after a complete offline analysis, we could easily reach contamination levels below 0.01 $counts/keV/kg/year$ (Gotthard level for FWHM of 5.2% at 2480 to be compared to the 1% of NEXT) which implies around 25 counts per year for 100 kg of ^{136}Xe, still a big number. High radiopure materials and the improvement of pattern recognition will improve this number.

3. Outlook

A high pressure gaseous Xenon TPC (NEXT) with 100 kg offers a good compromise between the tracking detectors (SuperNemo) and calorimetric solutions (Gerda,EXO, CUORE) in the search for the $\beta\beta0\nu$ decay. The collaboration has started an ambitious R&D program to identify the technical challenges to establish operation.

REFERENCES

1. M.C.Gonzalez-Martini and M.Maltoni,Phys. Lett. B663 405 (2008).
2. H.V.Klapdor-Kleingrothaus and I.V.Krivosheina, Modern Physics Letters A Vol. 21, No. 20 1547 (2006).
3. I.abt et al. (GERDA Coll.), Letter of intent, hep-ex:04040390.
4. C. Arnaboldi et al. - Astropart. Phys. 20:91-110, (2003)
5. EXO Coll., Letter of Intent, (http://www-project.slac.standford.edu/exo/)
6. R. Arnold et al. NEMO Collaboration, PRL 95, 182302 (2005)
   Ph.Adamson et al., SuperNEMO Expression of interest, (http://nemo.in2p3.fr/supernemo/eoi_SuperNEMO.htm)
7. D.Nygren. Nucl.Instrum.Meth.A58, 632 (2007).
8. R.Luscher et al., Phys.Lett.B434, 407 (1998).
9. Y. Giomataris Ph. Rebourgeard, J. P. Robert and G. Charpak, Nucl.Instrum.Meth.A376: 29 (1996).
10. D.S.Covita et el., IEEE Transactions on Nuclear Science, Vol. 51, No. 4, August (2004).
11. F.J. Iguaz et al., talk at the 4^{th} Symposium on Large TPCs for Low Energy Rare Event Detection, to be published in Journal of Physics. Conference Series.