NEXT: The Electroluminescence Readout

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Abstract. NEXT 100 is a neutrinoless double beta decay search experiment scheduled for installation at the Laboratorio Subterráneo de Canfranc (LSC) in 2013. The NEXT 100 detector is a Time Projection Chamber (TPC) utilizing the default technology solution of a electroluminescence signal amplification. NEXT 1 EL is an important milestone in the development of NEXT 100 which aims to demonstrate large size EL amplification and long track drift in 10 bar pressure Xe gas.

1. Introduction

Neutrinos, unlike the other Standard Model fermions, could be Majorana particles, that is, truly neutral particles indistinguishable from their antiparticles. The existence of Majorana neutrinos may have very deep physics implications. For example, they provide a natural explanation for the smallness of neutrino masses, the so-called seesaw mechanism [1]-[4]. Furthermore, Majorana neutrinos, through leptogenesis, could have induced the baryon asymmetry of the Universe. The only practical way to establish experimentally that neutrinos are their own antiparticles is the detection of neutrinoless double beta decay ($\beta\beta^0\nu$). This is a hypothetical, very slow nuclear transition in which a nucleus with $Z$ protons decays into a nucleus with $Z + 2$ protons and the same mass number $A$, emitting two electrons that carry essentially all the energy released ($Q_{\beta\beta}$). Such a process occurs if and only if neutrinos are massive, Majorana particles. Also, $\beta\beta^0\nu$ violates lepton number conservation, and is therefore forbidden in the Standard Model. Any source of lepton number violation (LNV) can induce $\beta\beta^0\nu$ and contribute to its amplitude. If we assume, nevertheless, that the dominant LNV at low energies is the Majorana mass term for the neutrino, the rate of $\beta\beta^0\nu$ is proportional to the effective Majorana mass of the $\nu_e$

$$m_{\beta\beta} = \left| \sum_i m_i U_{ei}^2 \right|$$

where $m_i$ are the neutrino mass eigenstates and $U_{ei}$ are elements of the neutrino mixing matrix. Measuring the decay rate of ($\beta\beta^0\nu$) process would provide direct information on neutrino masses. The most sensitive limit to date was set by the Heidelberg-Moscow (HM) collaboration [5]. They claimed to have observed neutrinoless double beta decay in $^{76}Ge$ and measured $T_{1/2}^{0\nu} \geq 1.9 \times 10^{25}$ years.

This result has been criticized [6]. However, together with the observation of neutrino oscillations [8] (which proves that neutrinos have a non-zero mass, which is an essential condition
for the neutrinoless double beta decay to exist) have revived the interest in neutrinoless double beta decay searches, and several new experiments with sensitivity for $m_{\beta\beta}$ 100$meeV$ are presently under design and construction. NEXT 100 is a 100 kg (enriched $^{136}$Xe) Time Projection Chamber neutrinoless double beta decay detector scheduled for installation at the Laboratorio Subterreneo de Canfranc (LSC) in 2013. Electroluminescence readout default technology solution for NEXT 100 [7].

2. Methodology

Double beta decay experiments are, in general, calorimeters searching for a small peak at $Q_{\beta\beta}$ in their energy spectrum. This is a challenging task: backgrounds from natural radioactivity are abundant in this region of energies and can easily overwhelm the signal peak. Good energy resolution is therefore very important, because increases the signal-to-noise ratio, but it is not enough by itself. Indeed, experiments based on germanium diodes (such as HM), devices with excellent energy resolution, have been background-limited. Consequently, all new-generation experiments try to exploit other signatures, such as event reconstruction, to further discriminate between signal and background.

A high-pressure xenon gas (HPXe) TPC can provide both good energy resolution and event topological information for $\beta\beta0\nu$ searches. Double beta decay events have a distinctive topological signature in HPXe that can be used to reject backgrounds: a ionization track, of about 30 cm long at 10 bar, tortuous due to the multiple scattering, an with larger deposition (blobs) in both ends (see Figure 1). The Gotthard experiment [9], consisting in a small xenon TPC (5 kg) operated at 5 bars, proved the utility of this signature, achieving an impressively low background rate of about 0.01 counts/keV/kg/year. However, the detector suffered of a modest energy resolution, 6.6% FWHM at $Q_{\beta\beta}$, probably due to the the use of conventional avalanche amplification in a wire plane, and to the addition of methane (4%) to the xenon (in order to increase the drift velocity and to suppress diffusion), that quenched the primary signals. Measurements in other small HPXe systems [10, 11] have shown that optimal energy resolution, $<0.5$% FWHM at $Q_{\beta\beta}$, is possible using electroluminescence (EL) for the amplification of the signals: the charges from primary ionization are accelerated by a moderate electric field (3-4 kV/cm/bar), producing a proportional emission of UV light with sub-poissonian fluctuations. This performance seems independent of the gas pressure below some 50 bar.

Xenon is the only noble gas that has a $\beta\beta$-decaying isotope, $^{136}$Xe. Its $Q_{\beta\beta}$-value is high enough (2458 keV) to be used in a $\beta\beta0\nu$ experiment. The natural abundance of the isotope is 9%, but it can be enriched by centrifugation at a reasonable cost. In addition, xenon does not have any other long-lived radioactive isotopes, and being a noble gas, it can be easily purified.

3. NEXT 1 EL

NEXT 1 EL is presently the largest operational Xe TPC. Operating at a designed pressure of 10 bar the TPC fits inside a chamber 600 mm long and 300 mm inner diameter. The fiducial volume consists of a hexagonal cross-section, defined by the PTFE reflector panels, 160 mm across the diagonal and 300 mm drift region. The electroluminescence region is made of two parallel grids separated by 5 mm. The maximum designed drift field is 1 kV/cm and the maximum electroluminescence field is 40 kV/cm. The optical readout is made up of a PMT plane, consisting of 19 Hamamatsu R7378A photomultiplier tubes, located 100 mm behind the cathode, and 248 SiPM located 2 mm behind the anode grid. The PMT plane gives the $t_0$ of the events and collects EL light to reconstruct the energy of the event. Figure 2 and Figure 3 show the internal view of the fiducial volume and the external view of the field cage. The field shaping rings of the field cage are made by cutting and machining aluminum pipe. The supports are manufactured from peek, a low outgassing plastic.
Figure 1. Example of a simulated double beta track. The two electrons terminate in a blob like structures due to rapid energy loss at the ends of their trajectories.

Figure 2. View inside the fiducial volume of NEXT 1 EL showing the PTFE reflector panels and the PMT holder seen in the far end of the hexagonal light tube.

Figure 3. The external view of the field cage showing the field rings, divider resistor chain. The Cathode, EL region, PMT screen and drift region are indicated.

The SiPM plane is responsible for the tracking and provides topological information on the observed event such as the simulated track shown in Figure 1. The sensors are arranged on a square grid with a 20 mm pitch. Light emission in Xe takes place at 175 nm therefore PMTs with quartz windows are being used. However, SiPMs have no sensitivity to light at this wavelength. To gain sensitivity the SiPM have been coated with tetraphenyl-butadiene (TPB) by evaporation in vacuum. TPB is a molecular wavelength shifter capable of capturing the light emitted by Xe.
with high efficiency and re-emitting in blue. As a result the UV light, emitted by Xe, is shifted into the visible region where it now can be registered by the SiPM tracking plane.

The tracking plane consist of 18 daughter boards that plug into a single motherboard mounted onto one of the end-caps. In Figures 4-5 images of the motherboard and daughter boards are shown.

The High Voltage is supplied to the Cathode and the Gate, in the electroluminescence region, through custom made HHV. These have been tested to high vacuum and 100 kV without leaking or sparking.

The side of the chamber contains 8 CF40 size nipples. One set is located in the horizontal plane while the other 135°. these contain radioactive source ports used for calibration of the TPC. The ports are made by welding a 0.5 mm blank at the end of a 12 mm liquid feedthrough. The radioactive source is then located on the outside of the detector.

3.1. Gas System
The materials used for the vessel and the readout place outgas electro-negative impurities, which degrade the performance of the detector, into the Xe gas. The role of the gas system is to remove these. This is achieved by continuously re-circulating the Xe gas through a SAES Getters (MC500). All the gas piping, save for the inlet gas hoses and Getter fittings, are 1/2 inch diameter with VCR fittings. The re-circulation loop is powered by a KNF diaphragm pump with a nominal flow of 100 standard liters per minute. At a 10 bar operating pressure of NEXT 1 EL this translates to an approximate flow of 10 liters per minute. Figure 6 and Figure 7 show the schematic and photographs of the gas system respectively. The photograph shows the main elements used in the purification of the Xe gas. The Gas system was vacuum evacuated to a pressure of $10^{-5}$ mbar and baked to a temperature of 150°C. Additionally the system was flushed with Ar gas and again evacuated and baked.

3.2. Commissioning
At the time of TPC Symposium the commissioning of the NEXT 1 EL just began. Figure 8 shows first light in NEXT 1 EL. The detector was operated at a 5 bar absolute pressure and Cathode and Gate operated at -15 kV and -8 kV respectively. A source of $^{137}$Cs positioned so as to emit gammas along the central axis of the detector. The trace give clear illustration of the
Figure 6. The schematic diagram of the NEX 1 EL gas system. The diagram shows the gas lines as well as vacuum lines used for evacuation of the system prior to use.

Figure 7. The photograph of the main elements of the gas system mounted on its frame. This was taken prior to the installation of the vacuum lines used to evacuate the system.

primary scintillation pulse which is followed by the larger electroluminescence pulse produced by the ionized track drifting into the EL region.

Figure 8. Showing first light of the NEXT 1 EL. The trace shows a clear primary scintillation pulse followed by the larger electroluminescence signal.

Figure 9. Expected sensitivity of NEXT 100 for two different energy resolution values.

4. The Future
NEXT 1 EL was an important milestone in the development of the large Electroluminescence TPC, which is presently the default solution for NEXT 100, although other technologies are under investigation[13, 14, 15] NEXT 100 is an approved and funded experiment scheduled to complete construction and installation at the Canfrac underground laboratory in 2013. The primary aim of the project is to instrument 100 kg of enriched $^{136}$Xe in order to search for the neutrinoless double beta decay. The 90% enriched gas has been obtained and is available at the
Figure 10. The assembled and operating NEXT 1 EL with the Gas system shown on the right.

Canfrac laboratory. The expected sensitivity of NEXT 100 is shown in Figure 9[12]. The plot was obtained assuming the shell model matrix element[16].

5. Acknowledgment

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