Study of neutrino properties at TEXONO

M. K. Singh[1, 2], V. Sharma[1, 2], L. Singh[1, 2], M. K. Singh[1, 2], V. Singh[1*], H. T. Wong[2]
[1.] *Physics Department, Institute of Science, Banaras Hindu University, Varanasi-221005, INDIA*
[2.] *Institute of Physics, Academia Sinica, Nankang, Taipei - 11529, TAIWAN*
*email: venkaz@yahoo.com

1. Introduction

With the help of detectors having good energy resolution, very low background and fewer thresholds one can search / study the rare physics processes. In the present scenario, various rare physics processes are still far away from the experimental reach such as dark matter physics, search for existence of Majorana neutrino, sterile neutrino, neutrino mass hierarchy, cross section measurement of neutrino nucleus coherent scattering etc. Study of neutrino properties can lead us to see such physics which is beyond the standard model physics [1-2].

The **T**aiwan **Ex**periment **O**n **N**eutrin**o** (TEXONO) collaboration is aimed to study such rare and unexplored properties of neutrino. The Ultra-Low-Energy and Ultra-Low-Background High Purity Germanium detectors are able to provide such facility which we require to search for neutrino and Astroparticle Physics [2]. Therefore, such detectors are able to open a new window for the search of dark matter physics. The TEXONO uses reactor neutrinos produced at the Kuo-Sheng (KS) Nuclear Power Plant for the study of neutrino properties and their interactions in the low energy region [3]. The schematic view of the Kuo-Sheng nuclear Power Plant experiment is shown in Figure 1. It is the first particle physics experiment in Taiwan. The electron antineutrino flux is 6.4×10^{12} cm^{2}s^1 at the Kuo-Sheng Nuclear Power Plant.

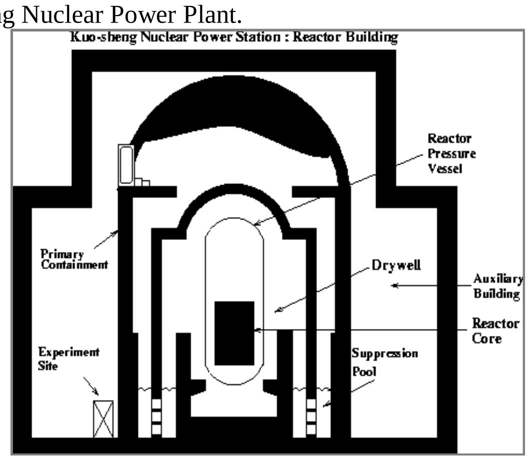

FIG. 1: Schematic side view of the Kuo-Sheng Nuclear Power Plant Building, indicating the experimental site. The reactor core-detector distance is about 28 m [2].

To study the rare physics processes in principle zero background is required. To achieve such low background we use different types of shielding around the detector. At KS, experimental target volume is 100 cm × 80 cm × 75 cm after shielding where various types of detectors can be placed for various physics goals. The shielding material and its design is already discussed in detail in Ref. [2-3].

2. Detector and electronics

For different scientific aims, TEXONO has heavily exploited the HPGe detectors, mass ranging from 5g to 1000g, and various designs starting from coaxial to point-contact. Because common High purity germanium detectors have high background in the range of 2 to 10 keV due to microphonic noise, electronics noise and leakage current TEXONO uses ULE HPGe detector in ionization mode and has achieved a detection threshold of 200 eV [1]. It has also studied 100 crystals of CsI(Tl), each crystal is single crystal having 2 kg mass and 40 cm long.

The output of detector is readout by using very versatile electronics and DAQ systems [4] consist of 8-channel 60MS/s-16 bit FADC module, 8-channel-20MS/s-16 bit, FADC module, 2-channel-12-bit-200MS/s FADC module and 2 channel-8 bit-20MS/s FADC modules. The readout is capable to record all relevant pulses and also the timing information (a few ms after the initial trigger) [4]. Produced data (obtained after regular monitoring) are stored and accessed for further analysis [2].

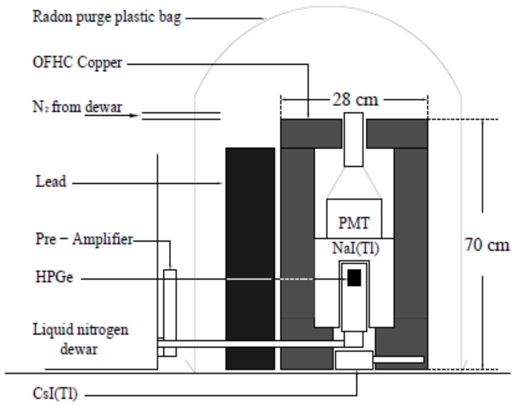

FIG. 2: Schematic drawings of the ULB-HPGe detector with its anti-Compton scintillators and passive shielding [2].

Figure 2 shows the complete experimental setup including detectors and shielding placed inside the Kuo-sheng (KS) nuclear Power Plant. Here ULB-HPGe detector is almost 4π covered with the NaI (Tl) and CsI (Tl) crystal scintillators which are acting as the anti-Compton detectors [3].

3. Physics highlights

A. Neutrino Magnetic moment

On the basis of current experimental results obtained from Super-Kamiokande and Sudbury Neutrino Observatory (SNO), it has been confirmed that the neutrino do oscillations and hence due to their oscillation they possess mass too. This makes very clear that neutrinos have magnetic moment. But its value might be very small and it depends whether the neutrino mass is of Majorana or Dirac.

The upper limits of neutrino magnetic moment obtained from TEXONO [4] using Kuo-Sheng reactor neutrinos is $\mu_\nu < 7.4 \times 10^{-11}\ \mu_B$ at 90% confidence level.

B. Neutrino Electron elastic scattering

Neutrino electron elastic scattering is a very simple and purely leptonic weak process which is capable of testing the standard model (SM) of electroweak interactions. This can also be used in measuring the electromagnetic properties of neutrinos, such as neutrino magnetic moment.

$$\nu_e(\bar{\nu}_e) + e^- \rightarrow \nu_e(\bar{\nu}_e) + e^-$$

Using reactor neutrinos of energy range $3.0<E_\nu<8.0$ and with a CsI(Tl) scintillating crystal array having a total mass of 187 kg, TEXONO has achieved the ratio of experimental to the SM cross sections as [1.08 ± 0.21 (stat) ± 0.16 (sys)] [5]. Constraints on the electroweak parameters (g_V, g_A) were placed, corresponding to a weak mixing angle measurement of $\sin^2\theta_W = 0.251 \pm 0.031$ (stat) ± 0.024 (sys). Destructive interference in the SM $\bar{\nu}_e$-e process was verified.

C. Neutrino Coherent Scattering

Coherent neutral - current (NC) neutrino - nucleus scattering (CENNS) was first predicted theoretically in 1974 [6] but has never been observed experimentally. To know the physics beyond the standard model, coherent neutrino-atom and neutrino-nucleus scattering play a very crucial role [6]. From this scattering process one of the most important out come observed is the cross section. Not only this, it will shed light on the facts that neutrinos can scatter coherently with the nucleons as well as with the atom itself.

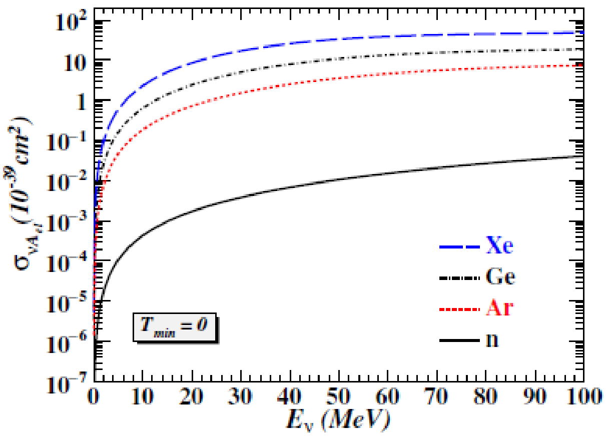

FIG. 3: The total cross section (σ_ν A_{el}) at T_{min}= 0 as a function of Eν. The nuclei (n, Ar, Ge, Xe) are selected for illustrations.

The condition of coherence requires sufficiently small momentum transfer Q to the nucleon so that the waves of scattered nucleons in the nucleus are all in phase and contribute coherently i.e. the Q must be smaller than the inverse of nucleus or atomic size ($QR \leq 1$). Neutrinos having energies in the range from MeV to GeV have coherent interaction properties. Neutrinos with energies less than 50 MeV are most favorable, as they largely fulfill the coherence condition in most target materials with nucleus recoil kinetic energy of tens of keV. It is found that solar, supernovae, reactor and artificial sources of neutrino follow this condition very strictly [6].

This is also one of the very challenging tasks, which physicists from all over the world must solve, in order to probe the physics beyond the standard model. TEXONO collaboration has also been trying to understand the experimental and theoretical aspects of CENNS. In this direction, several nuclei with experimental interest and having different mass ranges, (neutron, Ar, Ge, Xe) at Z = (0; 18; 32; 54), are selected for studies as shown in Figure 3, and also indicated that they will be able to make improvements in the limits of neutrino magnetic moment (NMM).

4. Summary

In understanding the fundamentals of physics and the laws of nature, study on neutrino have played a very important role. In this study, reactor neutrinos are the experimental initiative. Using the reactor neutrinos, many serious and long standing questions have been answered. In this direction the TEXONO has made significant contribution. Using ULE-HPGe detector it has been probed to a limit on neutrino magnetic moment measured the neutrino electron elastic scattering cross section and involved in detecting the neutrino nucleus coherent scattering. Detailed quantitative studies on the search strategies and potential reaches of different BSM models with νA_{el} interactions, as well as the sensitivity constraints due to decoherency effects, are subjects of future research.

Acknowledgment

This work is fully supported by the Academia Sinica and the Ministry of Science and Technology, Taiwan. Authors are thankful to the TEXONO Collaboration.

Reference

[1] V. Singh et al., Proc. DAE Symp. Nucl. Phys. **60**, 1004 (2015).

[2] M.K. Singh et al., Proc. DAE Symp. Nucl. Phys. **60**, 904 (2015); H.T. Wong, Nucl. Phys. **B138**, 333 (2005).

[3] H.T. Wong and J. Li, Mod. Phys. Lett. **A15**, 2011 (2000); W.P. Lai et al., NIM **A465**, 550 (2001).

[4] H.T. Wong et al., Phys. Rev. **D75**, 012001 (2007); H.B. Li et al., Phys. Rev. Lett. **90**, 131802 (2003); H.T. Wong, Nucl. Phys. **A721**, 495 (2003).

[5] M. Deniz, et al. Phys. Rev. **D81**, 072001 (2010); M. Deniz et al., Phys. Rev. **D82**, 033004 (2010); S. Bilmis et al., Phys. Rev. **D92**, 033009 (2015); S. Bilmis et al., Phys. Rev. **D85**, 073011 (2012).

[6] R.G. Arns, Phys. Perspect. **3**, 314 (2001); D.Z. Freedman, Phys. Rev. **D9**, 1389 (1974); Y.V. Gaponov and V.N. Tikhonov, Sov. J. Nucl. Phys. **26**, 31 (1977); L.M. Sehgal and M. Wanninger, Phys. Lett. **B171**, 107 (1986); J. Barranco, et al., JHEP **0512**, 021 (2005).