Low Energy Neutrino Physics at the Kuo-Sheng Reactor Laboratory in Taiwan

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Abstract. The TEXONO Collaboration has been pursuing a research program on low energy neutrino physics at the Kuo Sheng Reactor Neutrino Laboratory in Taiwan. We focus on the final results of our studies on neutrino magnetic moments and radiative decay lifetimes with a high-purity germanium detector. Limits of $\mu_e(\bar{\nu}_e) < 7.4 \times 10^{-11} \, \mu_B$ at 90% confidence level were derived at a physics threshold of 12 keV and a background level of 1 keV$^{-1}$kg$^{-1}$day$^{-1}$, comparable to underground dark matter experiments. The other programs at Kuo-Sheng are described.

1. Introduction
The TEXONO Collaboration [1] has been built up since 1997 to pursue an experimental program in Neutrino and Astroparticle Physics. The “flagship” program is on reactor-based low-energy low-background in Neutrino and Astrophysics Physics at the Kuo-Sheng (KS) Power Plant in Taiwan [2].

Results from recent neutrino experiments strongly favor neutrino oscillations which imply neutrino masses and mixings [3]. Their physical origin and experimental consequences are not fully understood. There are strong motivations for further experimental efforts to shed light on these fundamental questions by probing standard and anomalous neutrino properties and interactions. The results can constrain theoretical models necessary to interpret the future precision data or may yield surprises which have been the characteristics of the field. In addition, these studies will also explore new neutrino sources and novel detection channels to provide new tools for future investigations.

2. Kuo-Sheng Neutrino Laboratory
The “Kuo-Sheng Neutrino Laboratory” is located at a distance of 28 m from the 2.9GW reactor core of the Kuo-Sheng Nuclear Power Station at the northern shore of Taiwan. The measurable nuclear and electron recoil spectra due to reactor $\bar{\nu}_e$ are depicted in Figure 1. An ultra low-background high purity germanium (ULB-HPGe) detector started data taking since June 2001, while 200 kg of CsI(Tl) crystal scintillators were added from January 2003.

3. Search of Neutrino Magnetic Moments at Kuo-Sheng
An overview on the particle physics aspects of neutrino magnetic moments can be referred to a recent review [5] and the references therein. The neutrino electromagnetic vertex can be parametrized by terms corresponding to interactions without and with its spin, identified
Figure 1. Differential cross section showing the recoil energy spectrum in $\bar{\nu}_e$-$e$ for the Standard Model [$\bar{\nu}_e e^-$ (SM)] and magnetic moment [$\bar{\nu}_e e^-$ (MM)] [4], as well as in neutrino coherent scatterings on the nuclei $\bar{\nu}_e N$(SM) and $\bar{\nu}_e N$(MM), respectively at a reactor neutrino flux of $10^{13}$ cm$^{-2}$ s$^{-1}$, due to a neutrino magnetic moment (MM) of $10^{-10}$ $\mu_B$.

as the “neutrino charge radius” and “neutrino magnetic moments’, respectively. With an ULB-HPGe of mass 1.06kg surrounded by NaI(Tl) and CsI(Tl) crystal scintillators as anti-Compton detectors, the low energy spectrum of Figure 2 is relevant to the studies of neutrino magnetic moments. A detector threshold of 5 keV and a backgound level above 12 keV at the range of 1 keV$^{-1}$kg$^{-1}$day$^{-1}$ were achieved. Based on the measured spectra for 570.7/127.8 days of Reactor ON/OFF data [6], at an average Reactor ON electron anti-neutrino flux of $6.4 \times 10^{12}$ cm$^{-2}$s$^{-1}$, shows no excess in Figure 3 and limits of the neutrino magnetic moment $\mu_\nu(\bar{\nu}_e) < 7.4 \times 10^{-11}$ $\mu_B$ at 90% confidence level (CL) were derived.

Figure 2. Both Reactor ON and OFF spectra after all the selection criteria were applied are separately displayed for the range below 120 keV. Key $\gamma$-lines were identified.

Figure 3. The residual plot on the Reactor ON data of all periods combined over the background spectra.

Depicted in Figure 4 is the summary of the results in $\mu_\nu(\bar{\nu}_e)$ searches versus the achieved threshold in various reactor experiments [6]. The neutrino-photon couplings probed by $\mu_\nu$ searches in $\nu$-$e$ scatterings are related to the neutrino radiative decays ($\gamma_\nu$) [7]. Indirect bounds on $\gamma_\nu$ can be inferred and are displayed in Figure 5.
4. Other Programs at Kuo-Sheng

Nuclear fission at reactor cores also produce electron neutrino ($\nu_e$) through the production of unstable isotopes. A realistic neutron transfer simulation has been performed to estimate the flux and physics analysis on the $\mu_\nu$ and $\gamma_\nu$ for $\nu_e$ will be performed [8]. In addition, studies of neutrino-induced nuclear transitions, as well as searches for possible reactor-produced axions [9], are pursued. The physics goal for the CsI(Tl) scintillating crystal array is to measure the Standard Model neutrino-electron scattering cross sections, and thereby to provide a measurement of $\sin^2\theta_W$ at the untested MeV range.

Our future goal of developing a ultra-low-energy germanium (ULE-HPGe) detector is to reach a 100-eV threshold, a background level of $1 \text{keV}^{-1}\text{kg}^{-1}\text{day}^{-1}$, target size of the 1 kg mass range, for neutrino-nucleus coherent scattering and dark matter searches [10].

References

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