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

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Abstract. A laboratory has been constructed by the TEXONO Collaboration at the Kuo-Sheng Reactor Power Plant in Taiwan to study low energy neutrino physics. A limit on the neutrino magnetic moment of $\mu_\nu(\bar{\nu}_e) < 7.2 \times 10^{-11}\ \mu_B$ at 90% confidence level has been achieved from measurements with a high-purity germanium detector, as well as the electron neutrinos (ν_e) produced from nuclear power reactors has been studied. Other research program at Kuo-Sheng are surveyed.

Keywords: Neutrino Magnetic Moments; Reactor Neutrino; Neutrino scattering
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INTRODUCTION

The TEXONO Collaboration[1]. has been built up since 1997 to pursue an experimental program in Neutrino and Astroparticle Physics[2]. The “flagship” program is on reactor-based low-energy low-background in Neutrino and Astrophysics Physics[7] at the Kuo-Sheng (KS) Power Plant in Taiwan[3]. The TEXONO Collaboration is the first research collaboration among scientists from Taiwan and China[4].

Results from recent neutrino experiments strongly favor neutrino oscillations which imply neutrino masses and mixings[5, 6]. 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.

KUO-SHENG NEUTRINO LABORATORY

The “Kuo-Sheng Neutrino Laboratory”[3] is located at a distance of 28 m from the core #1 of the Kuo-Sheng Nuclear Power Station at the northern shore of Taiwan. The facilities of the laboratory are described in ref.[8]. The measure-able 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.

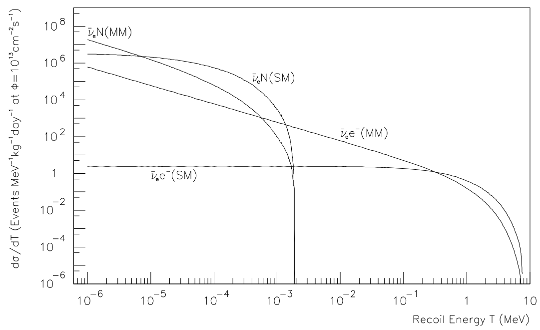


FIGURE 1. Differential cross section showing the recoil energy spectrum in $\bar{\nu_e}$-e for the Standard Model [$\bar{\nu}_{\rm e}{\rm e}^-({\rm SM})$] and magnetic moment [$\bar{\nu}_{\rm e}{\rm e}^-({\rm MM})$][9] ,as well as in neutrino coherent scatterings on the nuclei $\bar{\nu}_{\rm e}{\rm N}({\rm SM})$ and $\bar{\nu}_{\rm e}{\rm N}({\rm MM})$, respectively at a reactor neutrino flux of 10^{13} cm^{-2}s^{-1}, due to a neutrino magnetic moment (MM) of 10^{-10} μ_B.

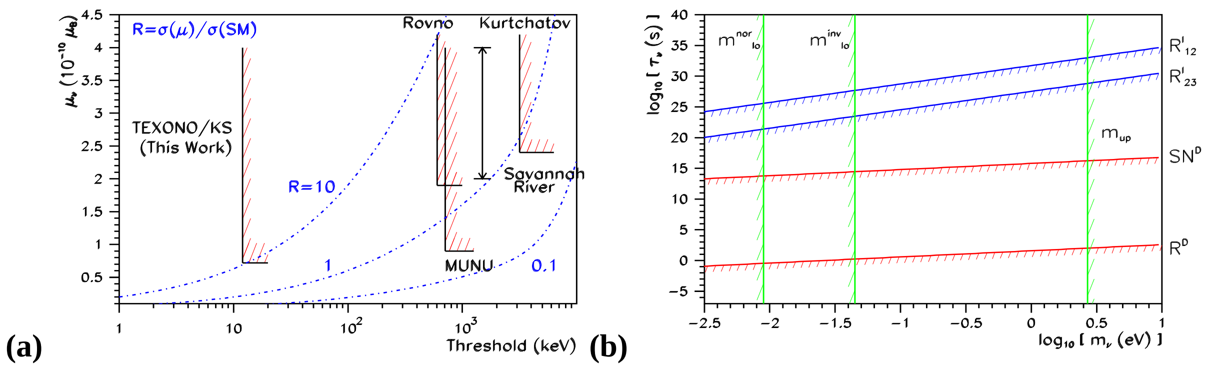
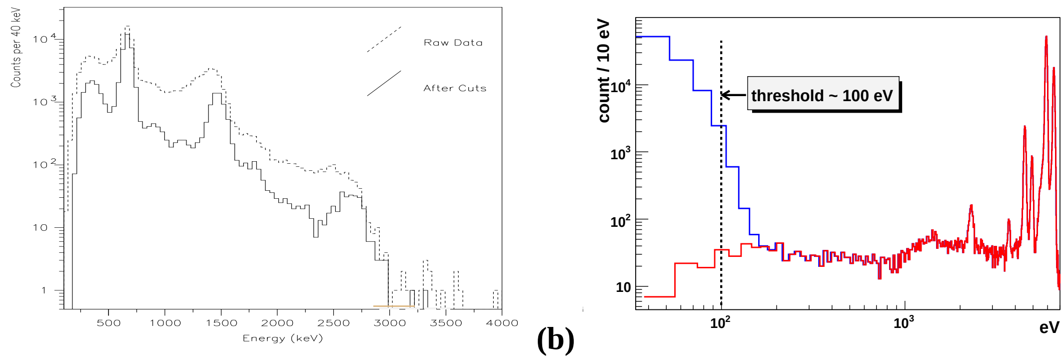


FIGURE 2. Summary of the KS results in (a) the searches of neutrino magnetic moments with reactor neutrinos, and (b) the excluded parameter space on neutrino radiative decay lifetime from $\bar{\nu_e}$ measurements.

RESEARCH PROGRAM AT KUO-SHENG

Neutrino magnetic moments characterize the neutrino electromagnetic couplings which involve the spin-interactions[11]. With an ULB-HPGe of mass 1.06kg surrounded by NaI(Tl) and CsI(Tl) crystal scintillators as anti-Compton detectors, a backgound level at 20 keV at the range of 1 keV^{-1}kg^{-1}day^{-1} and a detector threshold of 5 keV were achieved. Comparison of the measured spectra for 570.7/127.8 days of Reactor ON/OFF data[12] shows no excess and limits of the neutrino magnetic moment $\mu_\nu(\bar{\nu}_{\rm e}) < 7.2 \times 10^{-11}$ $\mu_{\rm B}$ at 90% confidence level (CL) were derived. Depicted in Figure 2(a) is the summary of the results in $\mu_\nu(\bar{\nu}_{\rm e})$ searches versus the achieved threshold in various reactor experiments[12]. The neutrino-photon couplings probed by μ_ν searches in ν-e scatterings are related to the neutrino radiative decays (γ_ν)[13]. Indirect bounds on γ_ν can be inferred and are displayed in Figure 2(b).

Nuclear fission at reactor cores also produce electron neutrino (ν_e) through the production of unstable isotopes. A realistic neutron transfer simulation has been performed



(a) (b)

FIGURE 3. (a) The raw and the "single-hit" energy spectra from 14 kg-day of data taking with he CsI(Tl) array, represented by the dashed and solid histograms, respectively. (b) Measured energy spectra with ^{55}Fe source and X-rays from Ti by the ULE-HPGe prototype. After the PSD selection, the threshold of <100 eV[10] is achieved.

to estimate the flux and physics analysis on the μ_ν and γ_ν for ν_e will be performed[14]. In addition, studies of neutrino-induced nuclear transitions, as well as searches for possible reactor-produced axions, 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. The raw and "single-hit" spectra from 14 kg-day of data are displayed in Figure 3(a).

A prototype ultra-low-energy germanium (ULE-HPGe) detector of 5 g mass is being studied. A hardware energy threshold of better than 100 eV has been achieved, as illustrated in Figure 3(b). The ULE-HPGe has collected data inside the shieldings at the KS laboratory for the first-ever background studies at the sub-keV energy range. It is technically feasible to build an array of such detectors to the target size of the 1 kg mass range. Such detectors can potentially be adopted for Dark Matter searches and to observe neutrino-nucleus coherent scatterings[3].

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