Results on the Search of Neutrino Magnetic Moments at the Kuo-Sheng Reactor Neutrino Experiment

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A laboratory has been set up at the Kuo-Sheng Nuclear Power Station in Taiwan at a distance of 28 m from the 2.9 GW reactor core to study low energy neutrino physics. Data were taken with a high purity germanium detector of mass 1.06 kg and 46 kg of CsI(Tl) crystal scintillator array operating in parallel. A threshold of 5 keV has been achieved for the germanium detector, and the background level is comparable to those of underground Dark Matter experiments. Based on 185/49 days of Reactor ON/OFF data, limits on the neutrino magnetic moment of $\mu_{\bar{\nu}_e} < 1.4(1.0) \times 10^{-10}$ μ_B at 90(68)% confidence level were derived. Indirect bounds of the $\bar{\nu}_e$ radiative lifetime can be inferred.

1. OVERVIEW

The TEXONO collaboration [1] has been built up among scientists from Taiwan and China to pursue an experimental program in neutrino and astro-particle physics. It is the first large scale collaborative efforts in basic research among scientists from the two regions.

The flagship efforts have been the study of low energy neutrino physics at the Kuo-Sheng (KS) Power Reactor Plant in Taiwan. As depicted in Figure 1, the KS laboratory is located at a distance of 28 m from the reactor core, having a $\bar{\nu}_e$ flux of 5.6×10^{12} $cm^{-2}s^{-1}$. It is equipped with flexibly-designed shieldings, cosmic veto systems, electronics and data acquisition systems [2] which can operate with different detector schemes. The physics theme is to study standard and anomalous neutrino interactions and properties [3,4] at the unexplored keV$-$MeV range.

Period I data were taken between June 2001 and April 2002 with a 1.06 kg high purity germanium (HPGe) detector and 46 kg of CsI(Tl) crystal scintillator array operating in parallel. The set-up of the HPGe sub-system and the associated inner shieldings are displayed schematically in Figure 2.

2. NEUTRINO MAGNETIC MOMENTS

The strong and positive evidence of neutrino oscillations implies the existence of neutrino masses and mixings [3], the physical origin, structures and experimental consequences of which are still not thoroughly known and understood. Experimental studies on the neutrino properties and interactions can shed light to these fundamental questions

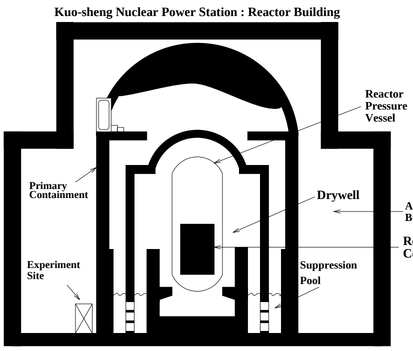

Figure 1. Schematic diagram of the Kuo-Sheng Neutrino Laboratory within the reactor building

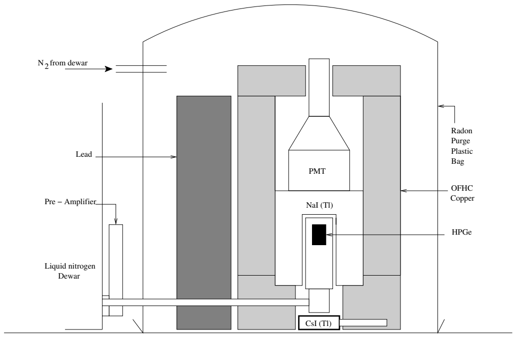

Figure 2. Schematic diagram of the the germanium sub-system with its anti-Compton detectors and shieldings.

and/or to constrain theoretical models on the possible sub-leading contributions which will be necessary for the interpretations of future precision measurements [4]. The coupling of neutrino with the photons are consequences of non-zero neutrino masses. Two of the manifestations of the finite electromagnetic form factors for neutrino interactions [5] are neutrino magnetic moments and radiative decays.

The searches of neutrino magnetic moments are performed in experiments on neutrino-electron scatterings [6]: $\nu_{l_1} + e^- \rightarrow \nu_{l_2} + e^-$. The experimental observable is the kinetic energy of the recoil electrons(T). The dependence of magnetic scattering(MS) cross-section on neutrino energy E_ν is given by [5]:

$$(\frac{d\sigma}{dT})_{MS} = \frac{\pi \alpha_{em}^2 {\mu_l}^2}{m_e^2} [\frac{1 - T/E_\nu}{T}] \ . \tag{1}$$

The ν-γ couplings probed by ν-e scatterings are the same as that giving rise to the neutrino radiative decays [7]: $\nu_j \rightarrow \nu_k + \gamma$ between ν_j and ν_k. The decay rate Γ_{jk} is related to μ_{jk} by:

$$\Gamma_{jk} = \frac{\mu_{jk}^2}{4\pi} \frac{[m_j^2 - m_k^2]^3}{m_j^3} \tag{2}$$

where m_j is the mass of ν_j and $\Delta m_{jk}^2 = m_j^2 - m_k^2$. Neutrino flavor conversion induced by resonant or non-resonant spin-flip transitions in the Sun via its transition magnetic moments has been considered to explain the solar neutrino measurements [5], and were recently shown [4] to be consistent with the existing data.

Reactor neutrinos provide a sensitive probe for "laboratory" searches of $\mu_{\bar{\nu}_e}$, taking advantages of the high $\bar{\nu}_e$ flux, low E_ν and the better experimental control via the reactor ON/OFF comparison. A finite $\mu_{\bar{\nu}_e}$ would manifest itself as excess events in the ON over OFF periods, where the energy spectra have an 1/T profile. The existing results [8] are summarized in Figure 4a.

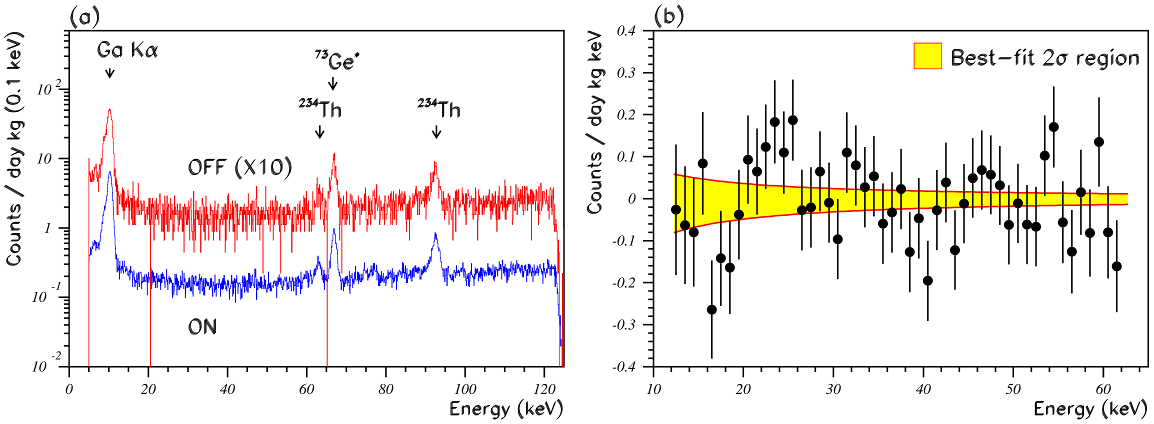

Figure 3. (a) The energy spectra for lone events, and (b) The residual of the Reactor ON recoil spectrum over $\phi_{\rm OFF}$, from 185/49 live time days of Reactor ON/OFF data taking.

3. KUO-SHENG RESULTS

The search of neutrino magnetic moment was performed using the KS HPGe data [9]. The germanium detector is optimal for magnetic moment searches [1,10] with its low detection threshold, excellent energy resolution, and robust stability. The strategy is to focus on energy <100 keV [11] where the Standard Model(SM) background are negligible at the 10^{-10} $\mu_{\rm B}$ range considered here.

Scatterings of $\bar{\nu}_{\rm e}$-e inside the Ge target would manifest as "lone-events" uncorrelated with other detector systems. The lone-event spectra from for 185/49 live time days of reactor ON/OFF data are displayed in Figure 3a. A detector threshold of 5 keV and a background of $\sim$1 keV^{-1}kg^{-1}day^{-1} above 12 keV, comparable to those in underground Cold Dark Matter experiments, were achieved. The OFF spectrum was fitted to a smooth 4th-degree polynomial function $\phi_{\rm OFF}$, giving an excellent χ^2/dof of 80/96. The function $\phi_{\rm OFF}$ and its uncertainties were then used as input to the fit of the ON spectrum to $\phi_{\rm OFF} + \epsilon(\phi^{\rm SM} + {\kappa_{\rm e}}^2\ \phi^{\rm MS}_{-10})$, where $\phi^{\rm SM}$ and $\phi^{\rm MS}_{-10}$ are the recoil electron spectra for SM and MS at 10^{-10} $\mu_{\rm B}$, respectively, $\kappa_{\rm e} = \mu_{\bar{\nu}_{\rm e}}/(10^{-10}\ \mu_{\rm B})$ and $\epsilon = 0.96$ is the analysis efficiency. A best-fit value of ${\kappa_{\rm e}}^2 = -0.48 \pm 1.38({\rm stat.}) \pm 0.36({\rm sys.})$ at χ^2/dof of 48/49 was obtained. The limits on the $\bar{\nu}_{\rm e}$ magnetic moment of $\mu_{\bar{\nu}_{\rm e}} < 1.4(1.0){\rm X}10^{-10}\mu_{\rm B}$ at 90(68)% CL were derived. The residual plot with the ON spectra over $\phi_{\rm OFF}$ and the best-fit 2σ region are depicted in Figure 3b.

As depicted in Fig. 4a, the achieved sensitivity level improves over previous experiments and is comparable to the on-going MUNU experiment. The bounds for the radiative decay lifetime are displayed in Fig. 4b. This indirect limit is much more stringent than those from direct searches [12] with neutrinos from reactor and supernova SN1987a.

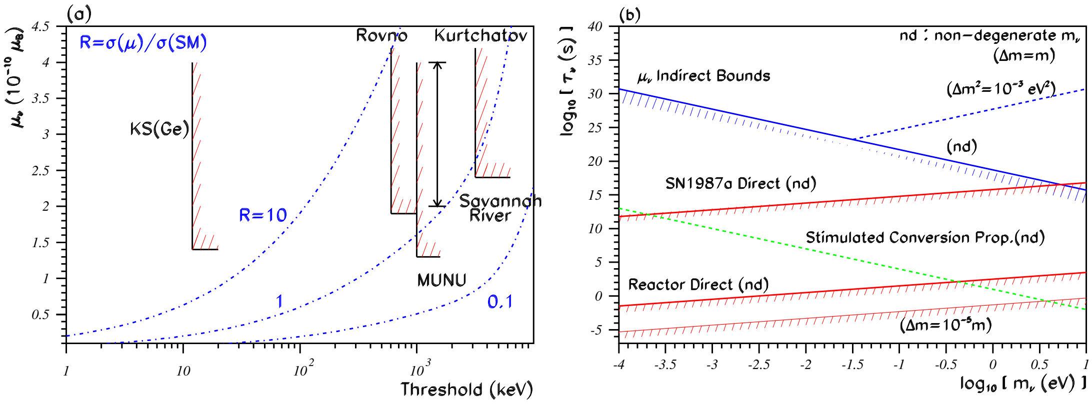

Figure 4. Summary of the results in (a) the searches of neutrino magnetic moments with reactor neutrinos and (b) the bounds in radiative decay lifetime of the neutrino.

4. STATUS AND PLANS

The KS experiment continues data taking in 2002-03 using HPGe with improved shieldings and 186 kg of CsI(Tl) crystals. Besides improving the $\mu_{\bar{\nu}_e}$ sensitivities, the goals are to perform a measurement of the $\bar{\nu}_e$-e cross-section at the MeV range, and to study various standard and anomalous neutrino interactions. Various R&D projects are being pursued, including one on the study of a prototype HPGe detector with sub-keV threshold.

REFERENCES

1. H.T. Wong and J. Li, Mod. Phys. Lett. **A 15**, 2011 (2000); H.B. Li et al., Nucl. Instrum. Methods **A 459**, 93 (2001).
2. W.P. Lai et al., Nucl. Instrum. Methods **A 465**, 550 (2001).
3. For the recent status, see *Proc. of the XX Int. Conf. on Neutrino Phys. & Astrophys., Munich*, eds. F. von Feilitzsch et al. (2002).
4. J. Valle, in Ref. [3], and references therein (2002).
5. P.Joel and J.Engel, Phys. Rev. **D 39**, 3378 (1989), and references therein.
6. B. Kayser et al., Phys. Rev. **D 20**, 87 (1979).
7. G.G. Raffelt, Phys. Rev. **D 39**, 2066 (1989).
8. F. Reines, H.S. Gurr and H.W. Sobel, Phys. Rev. Lett. **37**, 315 (1976); G.S. Vidyakin et al, JETP Lett. **55**, 206 (1992); A.I. Derbin et al., JETP Lett. **57**, 769 (1993); J.-L. Vuilleumier, in Ref. [3] (2002).
9. TEXONO Collaboration, complete paper in preparation (2002).
10. A.G. Beda, E.V. Demidova, and A.S. Starostin, Nucl. Phys. **A 663**, 819 (2000).
11. H.B. Li and H.T. Wong, J. Phys. **G 28**, 1453 (2002).
12. L. Oberauer, F. von Feilitzsch and R.L. Mössbauer, Phys. Lett. **B 198**, 113 (1987); J. Bouchez et al., Phys. Lett. **B 207**, 217 (1988); E.L. Chupp, W.T. Vestrand, and C. Reppin, Phys. Rev. Lett. **62**, 505 (1989); M.C. Gonzalez-Garcia, F. Vannucci and J. Castromonte, Phys. Lett. **B 373**, 153 (1996).