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Neutrino magnetic moment results at the Kuo-Sheng Nuclear Power Plant

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Abstract. A search of neutrino magnetic moment was carried out at the Kuo-Sheng Nuclear Power Station at a distance of 28 m from the 2.9 GW reactor core. With a high purity germanium detector of mass 1.06 kg surrounded by scintillating NaI(Tl) and CsI(Tl) crystals as anti-Compton detectors, a detection threshold of 5 keV and a background level of 1 $\mathrm{kg^{-1}keV^{-1}day^{-1}}$ at 12-60 keV were achieved. Based on 4712 and 1250 hours of Reactor ON and OFF data, respectively, the limits on the neutrino magnetic moment of $\mu_{\bar{\nu}_e} < 1.3(1.0) \times 10^{-10}\ \mu_B$ at 90(68)% confidence level were derived. Indirect bounds of the $\bar{\nu}_e$ radiative lifetime of $m_\nu^3\ \tau_\nu > 2.8(4.8) \times 10^{18}\ \mathrm{eV^3 s}$ can be inferred. The present status and future plans are discussed.

1 Introduction

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

Results from recent neutrino experiments strongly favor neutrino oscillations which imply neutrino masses and mixings [4,5,6]. 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 [7]. The results can constrain theoretical models which will be necessary to interpret the future precision data. In addition, these studies could also explore new detection channels to open up new avenues of investigations.

2 Kuo-Sheng Neutrino Laboratory

The "Kuo-Sheng Neutrino Laboratory" 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 [2]. A schematic view is depicted in Fig. 1.

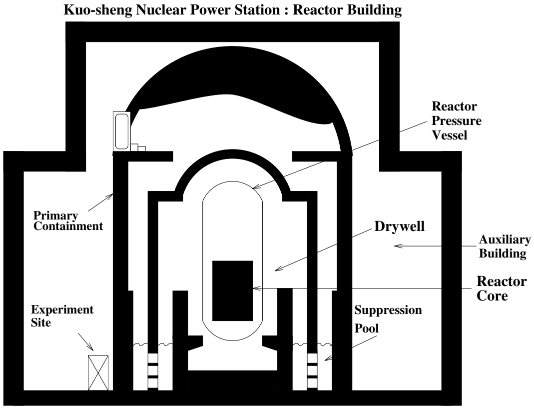

Fig. 1. Schematic side view, not drawn to scale, of the Kuo-Sheng Nuclear Power Station Reactor Building, indicating the experimental site

A multi-purpose "inner target" detector space of 100 cm ×80 cm×75 cm is enclosed by 4π passive shielding materials which have a total weight of 50 tons. The shielding provides attenuation to the ambient neutron and gamma background, and consists of, from inside out, 5 cm of OFHC copper, 25 cm of boron-loaded polyethylene, 5 cm of steel, 15 cm of lead, and cosmic-ray veto scintillator panels. The schematic layout of one side is shown in Fig. 2.

Different detectors can be placed in the inner space for the different scientific goals. The detectors are read out by a versatile electronics and data acquisition systems [8] based on 16-channel, 20 MHz, 8-bit Flash Analog-to-Digital-Convertor (FADC) modules. The readout allows full recording of all the relevant pulse shape and timing information for as long as several ms after the initial trigger. Software procedures have been devised to extend the effective dynamic range from the nominal 8-bit measurement range provided by the FADC [9]. The reactor laboratory is connected via telephone line to the home-base laboratory

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[1] **T**aiwan **EX**periment **O**n **N**eutrin**O**

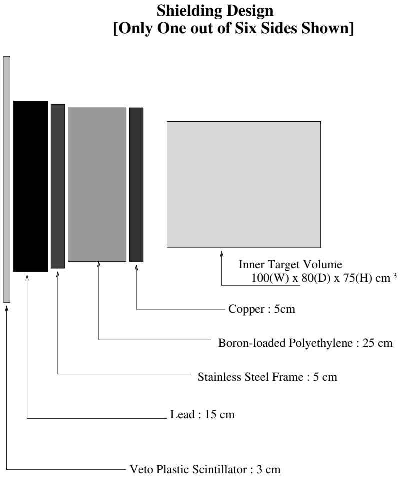

Fig. 2. Schematic layout of the inner target space, passive shieldings and cosmic-ray veto panels. The coverage is 4π but only one face is shown

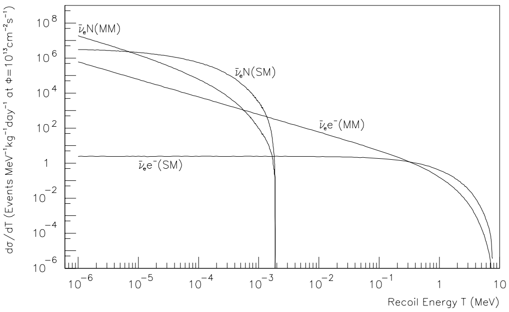

Fig. 3. Differential cross section showing the recoil energy spectrum in $\bar{\nu}_{\rm e}$-e and coherent $\bar{\nu}_{\rm e}$-N scatterings, at a reactor neutrino flux of 10^{13} cm^{-2}s^{-1}, for the Standard Model (SM) processes and due to a neutrino magnetic moment (MM) of 10^{-10} $\mu_{\rm B}$

at AS, where remote access and monitoring are performed regularly. Data are stored and accessed via the PC IDE-bus from a cluster of multi-disks arrays each with 800 Gbyte of memory.

The measure-able nuclear and electron recoil spectra due to reactor $\bar{\nu}_{\rm e}$ are depicted in Fig. 3, showing the effects due to Standard Model [$\bar{\nu}_{\rm e}$e$^-$(SM)] and magnetic moment [$\bar{\nu}_{\rm e}$e$^-$(MM)] in $\bar{\nu}_{\rm e}$-electron scatterings [10], as well as the Standard Model [$\bar{\nu}_{\rm e}$N(SM)] and magnetic moment [$\bar{\nu}_{\rm e}$N(MM)] neutrino coherent scatterings on the nuclei. It was recognized recently [11] that due to the uncertainties in the modeling of the low energy part of the reactor neutrino spectra, experiments to measure $\sigma[\bar{\nu}_{\rm e}{\rm e}^-({\rm SM})]$ with reactor neutrinos should focus on higher electron recoil energies (T>1.5 MeV), while μ_ν searches should base on measurements with T<100 keV. Observation of $\bar{\nu}_{\rm e}$N(SM) would require detectors with sub-keV sensitivities.

Accordingly, data taking were optimized for with these strategies. An ultra low-background high purity germanium (ULB-HPGe) detector was used for Period I (June 2001 till May 2002) data taking, while 186 kg of CsI(Tl) crystal scintillators were added in for Period II. Both detector systems operate in parallel with the same data acquisition system but independent triggers. The target detectors are housed in a nitrogen environment to prevent background events due to the diffusion of the radioactive radon gas.

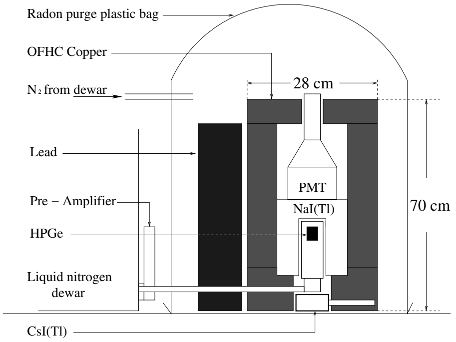

Fig. 4. Schematic drawings of the ULB-HPGe detector with its anti-Compton scintillators and passive shieldings

3 Neutrino magnetic moment searches with low background germanium detector

As depicted in Fig. 4, the ULB-HPGe is surrounded by NaI(Tl) and CsI(Tl) crystal scintillators as anti-Compton detectors, and the whole set-up is further enclosed by another 3.5 cm of OFHC copper and lead blocks.

After suppression of cosmic-induced background, anti-Compton vetos and convoluted events by pulse shape discrimination, the measured spectra for 4712/1250 hours of Reactor ON/OFF data in Period I [12] are displayed in Fig. 5a. Background at the range of 1 keV^{-1}kg^{-1}day^{-1} and a detector threshold of 5 keV are achieved. These are the levels comparable to underground Dark Matter experiment. Comparison of the ON and OFF spectra shows no excess and limits of the neutrino magnetic moment $\mu_{\bar{\nu}_{\rm e}} < 1.3(1.0) \times 10^{-10}$ $\mu_{\rm B}$ at 90(68)% confidence level (CL) were derived. The residual plot together with the best-fit regions are depicted in Fig. 5b.

Depicted in Fig. 6a is the summary of the results in $\mu_{\bar{\nu}_{\rm e}}$ searches versus the achieved threshold in reactor experiments. The dotted lines denote the ${\rm R} = \sigma(\mu)/\sigma({\rm SM})$ ratio at a particular (T,$\mu_{\bar{\nu}_{\rm e}}$). The KS(Ge) experiment has a much lower threshold of 12 keV compared to the other measurements. The large R-values imply that the KS results are robust against the uncertainties in the SM cross-sections. The neutrino-photon couplings probed by μ_ν-searches in ν-e scatterings are related to the neutrino radiative decays ($\varGamma_\nu$) [13]. Indirect bounds on $\varGamma_\nu$ can be inferred and displayed in Fig. 6b for the simplified scenario where a single channel dominates the transition. It corresponds to $\tau_\nu {\rm m}_\nu^3 > 2.8(4.8) \times 10^{18}$ eV^{3}s at 90(68)% CL in the non-degenerate case. It can be seen that ν-e scatterings give much more stringent bounds than the direct approaches.

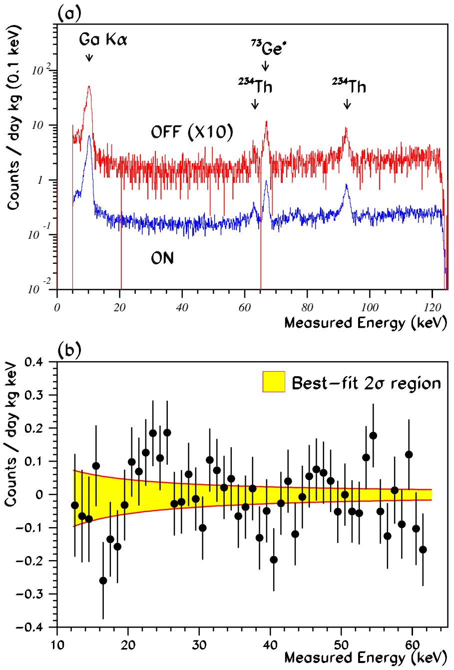

Fig. 5. a The ON and OFF spectra after all identifiable background suppressed, for 4720 and 1250 hours of data, respectively. **b** The residual of the ON spectrum over the OFF background, with the 2-σ best-fit region overlaid

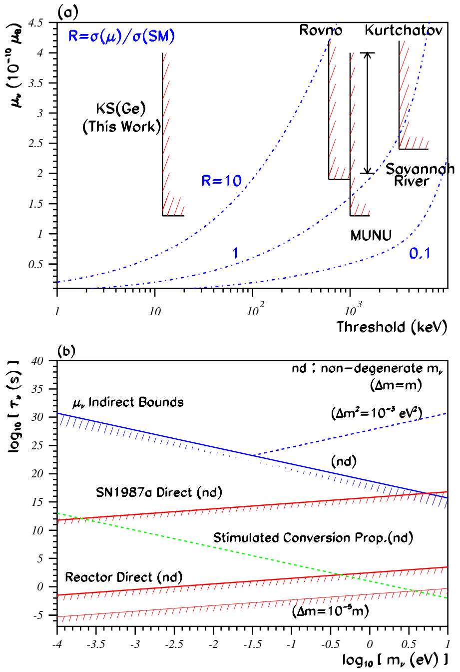

Fig. 6. Summary of the results in **a** the searches of neutrino magnetic moments with reactor neutrinos, and **b** the bounds of neutrino radiative decay lifetime

4 Status and plans

Data taking continues at the Kuo-Sheng Neutrino Laboratory. An array with a total of 186 kg of CsI(Tl) [14] have been commissioned for the Period II data taking, which started in January 2003. The main physics goal is the measurement of the Standard Model neutrino-electron scattering cross sections. The strategy [11] is to focus on data at high (>2 MeV) recoil energy. The large target mass compensates the drop in the cross-sections at high energy.

In addition, various R&D projects [15] are pursued in parallel to the KS reactor neutrino experiment. In particular, an ultra-low-energy germanium prototype detector is being studied, where the potential applications of Dark Matter searches and neutrino-nuclei coherent scatterings. are being investigated. A hardware energy threshold of better than 300 eV has been achieved, while advanced software pulse shape techniques are expected to further suppress the electronic noise to reduce this threshold. It is technically feasible to build an array of such detectors to increase the target size to the 1 kg mass range.

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