THE TEXONO LOW ENERG NEUTRINO PHYSICS PROGRAM

JIN LI Physics Center, IHEP
Beijing,100049, P.R.China

The TEXONO collaboration focus on the study of low energy reactor neutrino physics . A laboratory was built at a distance of 28 meters from the reactor core of the Kuo-Sheng(KS) Nuclear Power Plant at Taiwan at a depth of 12 m below sea level with about 25 meter-water-equivalent of overburden. The detectors of both the HPGe and CsI(Tl) crystals in the shielding were placed. Main physics are: 1,The search of neutrino magnetic moment at 10-60 kev:2,The measurement of total cross section for reaction $\overline{\nu_e}$ -e and $\sin^2\theta_W$ at 3MeV-10MeV; 3, The ultra low threshold Ge detector HPGe were used for measurement of coherent scattering and dark matter search. The paper described the results of measurement of neutrino magnetic moment; the situation of the measurement of total cross section for reaction $\overline{\nu_e}$ -e and the progress of coherent scattering and dark matter search.

1,The laboratory and detector of TEXONO

Results from recent neutrino experiments strongly favor neutrino oscillations which imply neutrino masses and mixings [1]. 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.

The focus of the TEXONO collaboration is on the study of low energy reactor neutrino physics [2]. A laboratory was built at a distance of 28 meters from the reactor core of the Kuo-Sheng(KS) Nuclear Power Plant at Taiwan at a depth of 12 m below sea level with about 25 meter-water-equivalent of overburden. The mean thermal power output of the reactor core is 2.9GW. The laboratory is equipped with an outer 50-ton shielding which consists of, from outside in, 2.5 cm plastic scintillators for cosmic ray veto, 15 cm of lead ,5 cm of stainless steel support structure ,25 cm of boron-loaded polyethylene, and 5 cm of oxygen-free high-conductance copper. The innermost room for detector has dimension of (100×80×75)cm^3 where both the HPGe and CsI(Tl) detectors and inner shielding were placed

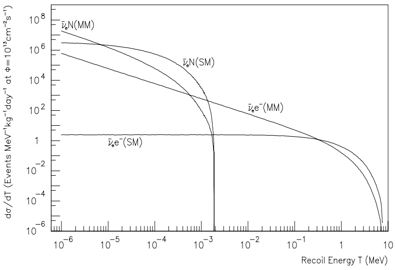

Figure1. Differential cross section basing on Standard Model and due to a neutrino magnetic moment of $10^{-10}\ \mu_B$ **, for** $\overline{\nu_e}$ **-e and coherent** $\overline{\nu_e}$ **-N scattering, at a reactor neutrino flux of** $10^{13} cm^{-2} s^{-1}$

The measure-able nuclear and electron recoil spectra due to reactor ν_e are depicted in Figure 1, showing the effects due to Standard Model ν_e e(SM) and magnetic moment ν_e e-(MM) in ν_e -electron scatterings σ, as well as ~~in~~ neutrino coherent scatterings on the nuclei ν_e N (SM) and ν_e N(MM) , respectively. The uncertainties in the low energy part of the reactor neutrino spectra require that experiments to measure ν_e e-(SM) should focus on higher electron recoil energies (T>1.5MeV), while MM searches should base on measurement~~s~~ with T<100keV [3]. Observation of ν_e N (SM) would require detectors with sub-keV sensitivities.

2, Low energy neutrino physics at TEXONO collaboration

2.1 The search of neutrino magnetic moment at 10-60 kev

Fig2 shows the setup of HPGe detector. It's a coaxial germanium detector with an active target mass of 1.06 Kg.

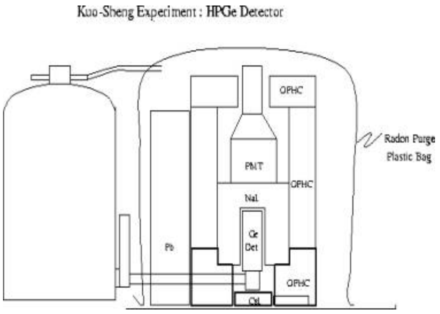

Fig.2. ULB-HPGe detector & Compton Veto

The HPGe was surrounded by an anti-Compton detector system made up by 5 cm thick NaI(Tl) in barrel part and 4 cm thick CsI(Tl) at the bottom. The anti-Compton detector were read out by photo-multipliers (PMTs).. All of detectors were surround by 3.7 cm of OFHC copper inner shielding and another 10 cm of lead provided additional shielding against the liquid nitrogen Dewar and pre-amplifier electronics. The whole system was covered by a plastic gad connected to the exhaust pipe of the Dewar, serving as a purge for the radioactive radon gas. The HPGe detector is optimal for magnetic moment search because of its low threshold, excellent energy resolution and robust stability.

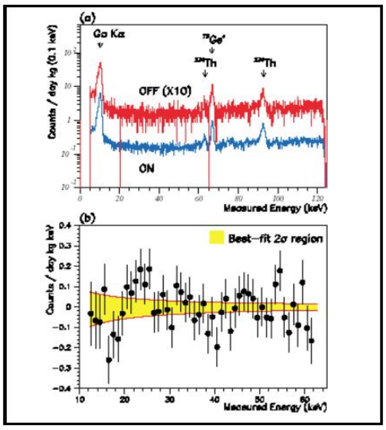

Fig.3a.The energy spectra for single events of HPGe detector

3b The residual of the ON spectrum over the OFF background, ON/OFF data taking.

The energy spectra for single events of HPGe detector from 4712/1250 live time hours of reactor ON/OFF data [4] are displayed in Fig 3a. The ON data were taken in 1282 and 3430 hours of run time before and after OFF period, respectively. The events selection includes the anti-Compton veto, cosmic-ray veto and pulse shape analysis. The total event selection efficiency is 94%. ..Fig3b shows the residual of the ON spectrum over the OFF background, from 4712/1250 live hours of reactor ON/OFF.

Based on the fitting of the ON spectrum to the relation ϕOFF+ε(ϕSM+κe2ϕμ-10), where ε is efficiency of 94%, ϕSM and ϕμ-10 are the electron recoil spectra from SM and magnetic interaction at μνe= 10-10μB, respectively. The best-fit value of κe2=-0.4±1.3(stat.)±0.4(syst.) and χ2=48/49 was obtained. Adopting the unified approach, the limit on the νe magnetic moment of μνe< 1.3×10-10μB at 90% C.L was .derived.

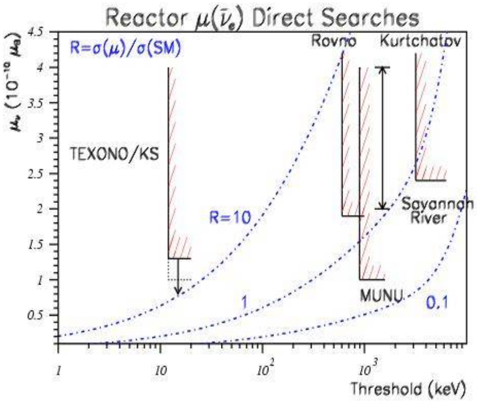

Fig.4 The results from different reactor experiments on neutrino magnetic moment

Fig.4 shows the results for μνe from different reactor experiments on neutrino magnetic moments [5]. The dotted lines denote the R=σ(μ)/σ(SM) ratio at a particular (T, $\mu_{\nu e}$). TEXONO experimental result has been obtained at mush lower threshold of 12 keV compared to the other measurements. The large R values imply that the TEXONO results are robust against the uncertainties in the SM cross sections.

2.2 The measurement of total cross section for reaction $\bar{\nu}_e$ -e and sin^{2}θ$_w$ at 3MeV-10MeV.

Fig.5 shows the array of CsI(Tl) scintillation crystal [6]. The total mass of 186 kg crystal was running. The geometry of the CsI(Tl) crystal modules is a 40-meter-long hexagonal prism with a cross section of 2 cm sides. Every module is a single crystal or for a few cases, consisted of two 20-meter glued ones that are placed at the peripheral places of the detector array. PMTs are mounted at both ends of the crystal as photon-electron converters. Signals retrieved from the two PMTs are used to reconstruct the energy information and the longitude position of the events[3].

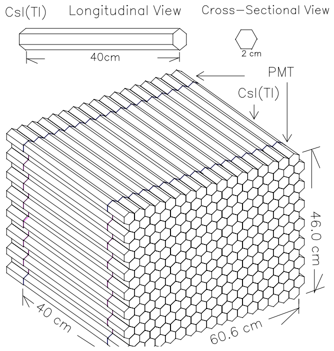

Fig.5 Configuration of CsI(Tl) scintillation detector array

The goal is to perform the first measurement on the ν_e -e cross-sections at the MeV momentum transfer range. Data taking and analysis are under way. Fig 6 shows the distribution of Q_l versus Q_r from two ends of one crystal which provides both energy and position measurements. It can be seen that ^{137}Cs band is uniform along the crystal, implying ^{137}Cs isotope resides evenly inside the crystals, while the other two bands: ^{40}K and ^{208}Tl attenuate with increasing depth originated from ambient radioactivity. Meanwhile, the concentration of the events along the two edge of the profile shows that the bulk of the background is external to the crystal such that they can be effectively rejected by a thickness cut. Figure 7 shows the background energy spectrum measured by CsI(Tl)crystal array after event selection

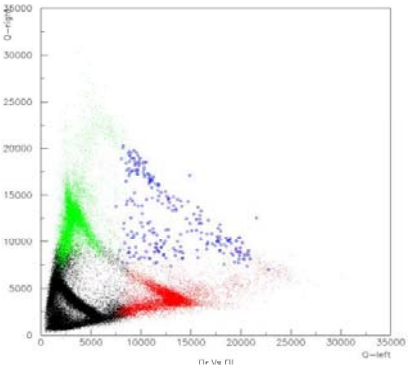

Fig.6 the distribution of Q_l versus Q_r after event reconstruction.

which includes both single-hit and pulse shape requirements. It can be seen that the background is very low at energy larger than 3 MeV.

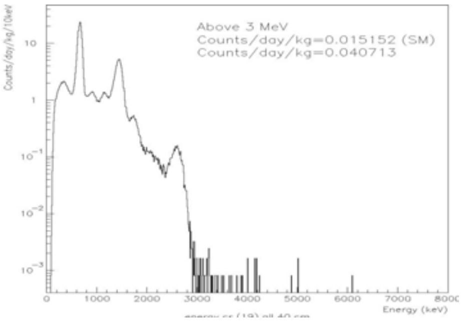

Fig 7 The energy spectrum of background measured by CsI(Tl) crystal array after event selection

2.3 **The ultra low threshold Ge detector HPGe for coherent scattering and dark matter search.**

A prototype "Ultra-Low-Energy" HPGe detector with mass 5 g has been constructed as an R&D program towards the goal of the first observation of neutrino-nuclei coherent scattering as well as searches for the Weakly Interactive Massive Particles (WIMPs). The mass of such detector concept can easily be upgraded to the 1 kg range in array form. Figure 8 shows the calibration spectrum using low energy X-ray sources. The KX-rays of Ti (4.5keV and 4.9keV) and KX-rays of Mn (5.9keV and 6.5keV) are readily measured. PSD method has also been used to process the experimental data. The output signal of HPGe detector is digitized by a 20MHz FADC (Flash Analog-to-Digital Converter). The average time ($\bar{t}$) was used for event identification [7]. The scattered plot of $\bar{t}$ vs. Energy is shown in Figure 9 at the energy range below 1 keV. It can be seen that the noise and electron signals can be separated down to 100eV or less.

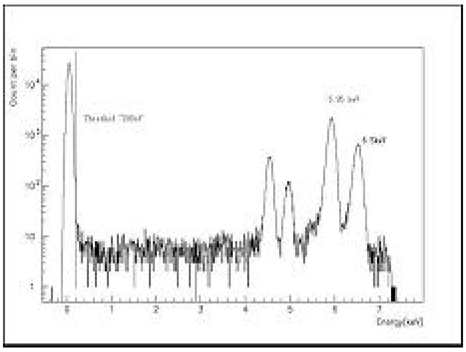

Figure 8 The energy spectrum of HPGe detector calibrated by X-ray sources

The sensitivities were estimated for WIMPs-nucleon cross-section limits as a function of the WIMPs mass for spin-independent interaction, based on Ge-detector with 100eV energy threshold and 5g mass, and a Quenching Factor of 0.25. Levels of different background level in unit of cpd (count/keV·kg·day) , and detector mass were shown and compared to other experiments [8]. Figure10 shows the estimation of WIMPs-nucleon cross section limits of our experimental projection and results from other experiments.

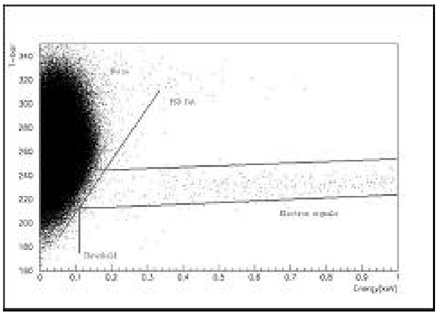

Figure 9 The scatter plot of $\bar{t}$ vs. Energy for different events

3. Summary

A laboratory has been constructed by the TEXONO collaboration at the Kuo-Sheng Reactor Power Plant in Taiwan for study of low energy neutrino physics. A limit on the neutrino magnetic moment of μν< 1.3 10-10μb at 90% confidence level has been achieved from measurements with a high-purity germanium detector. The data analysis of CsI(Tl) crystal array are being pursued and will provide measurements of the total cross section of $\bar{\nu}_e$-e scattering and sin2θw. An ultra low threshold HPGe prototype detector has been built and will be used to study neutrino coherent scattering and to search for WIMPs in the Yangyang underground laboratory in Korea. TEXONO will continue to make contributions in neutrino physics and dark matter search in the future.

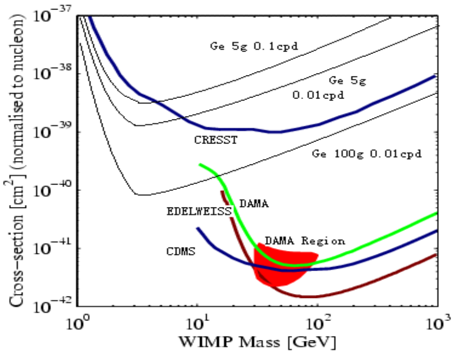

Figure 10 The WIMPs-nucleon cross section limits of our experimental projection and results from other experiments

Reference:

1. See the respective sections in Review of Particle Physics, Particle Data Group, Phys. Lett. B 592 (2004), for details and references.
2. H.T.Wong, Mod. Phys. Lett. {\bf A 19}, 1207 (2004).
3. H.B.Li and H.T.~Wong, J. Phys. {\bf G 28}, 1453 (2002).
4. H.B.Li et al., TEXONO Coll., Phys. Rev. Lett. {\bf 90}, 131802 (2003), and references therein.
5. H.T.Wong, hep-ex/0409003 (2004), and referenecs there in.
6. H.B.Li et al., TEXONO Coll., Nucl. Instrum. Methods {\bf A 459}, 93 (2001); Y.~Liu et al., TEXONO Coll., Nucl. Instrum. Methods {\bf A 482}, 125 (2002).
7. S.C. Wu et al., Nucl. Instrum. Methods A 523, 116 (2004).
8. CDM Review