Neutrino-Electron Scattering Cross-Section Measurement with CsI(Tl) Crystal Array at the KS Nuclear Power Reactor

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Introduction

In recent years, strong evidence of neutrino (ν) oscillations has been shown from the reactor, atmospheric as well as long baseline accelerator and solar neutrino measurements that implies $m_\nu \neq 0$ and mixings [1]. But their physical origin and experimental consequences are not yet fully understood. More experimental studies using different techniques on the ν properties and interactions are crucial because they can shed light to these fundamental questions and may provide hints or constraints to models on new physics.

This article reports on a study of ν-e^- scattering using reactor neutrinos at the Kuo-Sheng Nuclear Power Station with a CsI(Tl) scintillating crystal array. This scattering has been studied with several generations of experiments at the accelerator using mostly ν_μ ($\bar{\nu}_\mu$) [2]. It is a pure leptonic process and therefore provides a clean test to Standard Model (SM). The typical 4-momentum transfer is $Q^2 \sim 10^{-2}$ GeV^2 and the electroweak angle $\sin^2\Theta_W$ were probed to an accuracy of ±3.6%.

Using electron-neutrinos as probe, the interaction ν_e ($\bar{\nu}_e$) + $e^- \rightarrow \nu_e$ ($\bar{\nu}_e$) + e^- has been studied at medium energy accelerators as well as at the power reactors. It is also an important channel in the detection of solar neutrinos. This process are among a few of the SM interactions which proceed via charge current (CC), neutral current (NC) as well as their interference (Int) term as shown in figure 1.

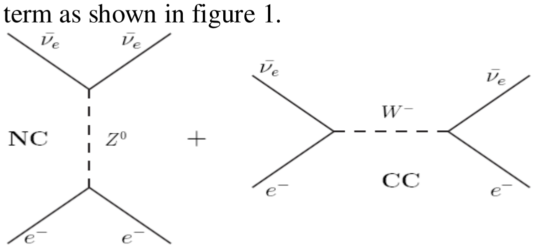

FIG.1: Interactions of e^- with electron via the SM-allowed CC & NC channels. There is an additional interference effect between them.

Experimental Detail

A research program on low energy neutrino physics [3] is being pursued by the TEXONO Collaboration at the KSNL. Details about the experimental set up are described in ref. [4]. The evaluation of the reactor neutrino flux and spectra has been discussed in details in ref. [5]. It is well established that the reactor $\bar{\nu}_e$ spectrum can be accurately evaluated to ≤5% uncertainties for E_ν>3 MeV [6]. A total flux of $\bar{\nu}_e$ is about 6.4 x 10^{12} cm^{-2}s^{-1} at KSNL. The laboratory is equipped with a 50-ton shielding structure of less radioactive materials.

Results

The experimentally measured rates for neutrino events ($R_{expt}(\nu)$) is given by $R_{H1}(ON)=R_{expt}(\nu) - R_{H1}(Bkg)$, where $R_{H1}(ON)$ is the measured H1 spectra for reactor ON data and $R_{H1}(Bkg)$ is the background derived from the statistical average of three measurements: (a) Reactor OFF data (b) ^{208}Tl associated H1 background and (c) cosmic-ray induced H1 background. Data used for this results were from 29882(7369) kg-days of fiducial mass exposure during reactor ON(OFF), respectively. The analysis energy window is 3 – 8 MeV spread out uniformly over (N_{bin}=) 10 energy bins. The cross section ratio ζ= [$R_{expt}(\nu)$] / [$R_{SM}(\nu)$] were derived with best-fit with χ^2. As cross check, identical procedures were applied to the combined reactor OFF data, where the contributions to $R_{H1}(Bkg)$ from ^{208}Tl and cosmic-rays were included. The result ζ(OFF)= – 0.52±0.70(stat) at χ^2/dof=9.1/9 demonstrates good overall systematic control. The residual spectrum is shown in figure 2. With the combined reactor ON and OFF data set and adopting the systematic uncertainties calculated, the ratio ζ=1.18±0.29 (stat) ±0.08 (sys) was derived. The results represent a probe to SM at

$Q^2 \sim 3 \times 10^{-6}$ GeV^2 and improve over those from previous reactor neutrino experiments. The weak mixing angle was derived from $[(d\sigma/dT)\ \bar{\nu}_e e]_{SM} = G^2_F m_e/2\pi\{4\sin^2\Theta_W{}^2[1+\{1-(T/E_\nu)^2 - m_eT/E^2_\nu\}]$

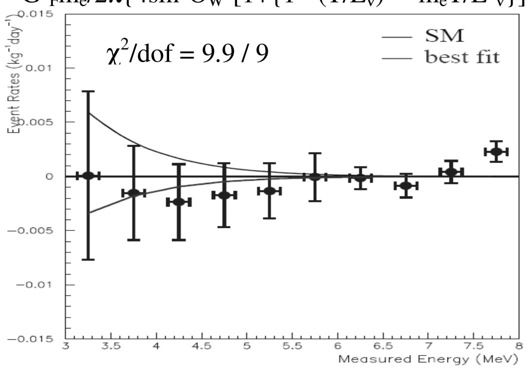

FIG.2: The combined residue spectrum for R(OFF) – R(OFF_{pred}) for all reactor OFF periods showing the best fit consistent with zero.

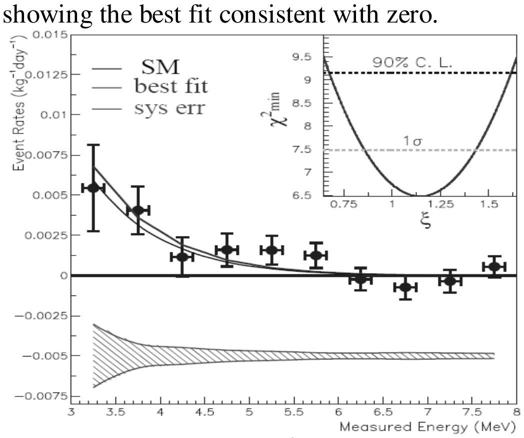

FIG.3: The best fit and χ^2 test of the measured cross section at 10 points in 3 – 8 MeV energy region. The upper and lower lines correspond to the SM expectations and to the best fit of the data, respectively. For better clarity, systematic error's region is shown below in the figure.

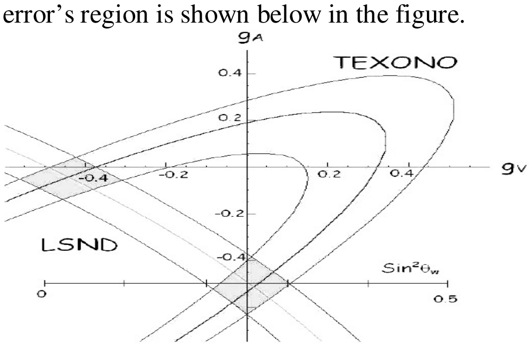

FIG.4: Allowed region in $g_V - g_A$ space and in the $\sin^2\Theta_W$ axis, from this experiment on ν_e-e^- and from the results from LSND on ν_e-e^-.

$+ 4\sin^2\Theta_W [(1-T/E_\nu)^2 - (m_eT/2E^2_\nu)] + (1-T/E_\nu)^2\}$ giving $\sin^2 \Theta_W = 0.26 \pm 0.04(stat) \pm 0.01(sys)$ in excellent agreement with the SM value of $sing^2\Theta_W(SM) = 0.23867 \pm 0.00016$ at this low Q^2 ($<10^{-4}$ GeV^2) range. The results improve over previous results those from accelerator ν_e experiments due to enhancement factors favoring $\bar{\nu}_e$.

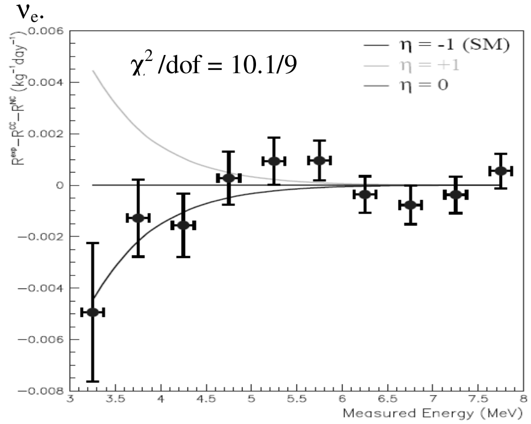

FIG.5: The measurement of interference term from the best fit in 3 – 8 MeV. Below curve and straight lines correspond to theoretical SM expectations and upper curved line corresponds to the best fit.

The interference term was probed using $R_{expt} = R_{CC} + R_{NC} + \eta.R_{Int}$, where the three components (R_{CC}: R_{NC}: R_{Int}) are in the ratios of $R_{SM}(\bar{\nu}e) \rightarrow$ (0.77: 0.92: 0.69) present work and $R_{SM}(\nu e) \rightarrow$ (1.83: 0.17: 0.99). The best fit value the sign-parameter η is = –0.80 ±0.40 (stat) ±0.21 (sys). The residual spectrum showing ($R_{expt} - R_{CC} - R_{NC}$) is displayed in figure 5, with expected spectra for η=0, ±1 overlaid. The results verified destructive interference in the SM $\bar{\nu}_e$-e^- interactions. These results will be presented.

References

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