PROCEEDINGS OF SCIENCE

Search for sterile neutrinos at RENO

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The RENO experiment was designed to measure a neutrino mixing angle, θ_{13}, by detecting electron antineutrinos emitted from the Hanbit nuclear reactors in Korea, and succeeded to measure θ_{13} from the disappearance mode in three neutrino frame. We investigate the possibility of sterile neutrinos existence at RENO experiment and compare data with Monte Carlo generated in four neutrino frame. In this talk, we present some recent results using chi-square analysis method. The probability deficit curve as a function of an effective baseline and the excluded contour plot in $\sin^2(2\theta_{14}) - \Delta(m_{41})^2$ space will be shown.

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1. Introduction

There has been large process of understanding about the neutrino oscillation phenomenon due to determination of the last mixing parameter θ_{13}, which is measured by reactor anti-neutrino experiments. Therefore, three-neutrino parameter scheme are almost known, but there are several neutrino oscillation anomalies. Thus, 3+1 neutrino scheme which includes the additional neutrino called sterile neutrino is proposed for explaining these anomalies. Especially, the past short baseline experiments with anti-electron neutrinos from a reactor is reinterpreted because of the update of reactor neutrino flux and neutrino cross section of inverse beta decay recently. These results show the possibility of the existence of sterile neutrino, and we need more studies

When combined with experimental data at baselines between 10-100 m these recent calculations suggest a ~6% difference between the measured and expected reactor antineutrino flux with a 3 sigma significance when taking into account all correlations. This is called the reactor anomaly. (Figure 1)

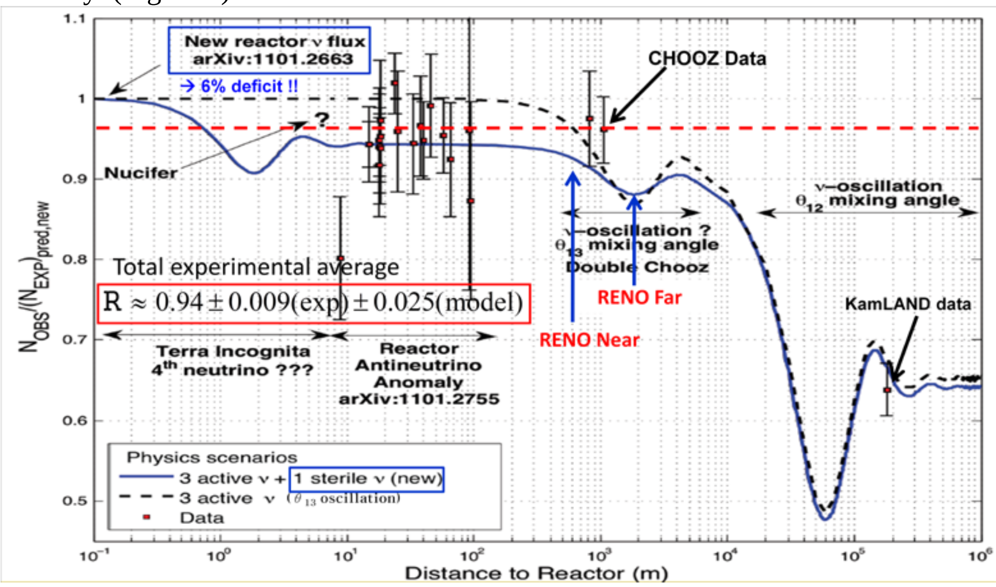

Figure 1. Results of short baseline experiments

2. Spectral analysis using Far/Near ratio

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The χ^2 for the rate + shape analysis is also based on the pull method described in Ref.[1], and is written as

$$\chi^2 = \sum_{P=before,After} \left\{ \sum_{i=1\sim N_b} \frac{\left(\frac{N_{obs}^{F,P,i}}{N_{obs}^{N,P,i}} - \frac{N_{Exp}^{F,P,i}}{N_{Exp}^{N,P,i}} \right)^2}{(U_i)^2} \right\} + Pull\ term \qquad \textbf{-(1)}$$

Oscillation parameters are determined using far/near ratio of IBD prompt energy spectrum.
The 3+1 neutrino extension of unitary transformations from mass eigenstate to flavor eigenstate is given in terms of six mixing angles and three Dirac phases

$$U_F = R_{34}(\theta_{34})R_{24}(\theta_{24},\delta_2)R_{14}(\theta_{14})R_{23}(\theta_{23})R_{13}(\theta_{13},\delta_1)R_{12}(\theta_{12},\delta_3) \quad \text{-(2)}$$

phases where $R_{ij}(\theta_{ij})$ is the rotation of the ij block by an angle of θ_{ij} and δ_k is Dirac phases. The survival probability of the electron antineutrino from reactor is,

$$P_{th}(\bar{\nu}_e \to \bar{\nu}_e) = 1 - \sum_{i<j} 4\left|\tilde{U}_{ei}\right|^2 \left|\tilde{U}_{ej}\right|^2 \sin^2\left(\frac{\Delta m_{ij}^2 L}{4E_\nu}\right) \quad \text{-(3)}$$

It can be expressed as follows,

$$\begin{aligned} P_{th}(\bar{\nu}_e \to \bar{\nu}_e) = 1 &- c_{14}^4 c_{13}^4 \sin^2 2\theta_{12} \sin^2\left(1.27\Delta m_{21}^2 \frac{L}{E}\right) - c_{14}^4 c_{12}^2 \sin^2 2\theta_{13} \sin^2\left(1.27\Delta m_{31}^2 \frac{L}{E}\right) \\ &- c_{14}^4 s_{12}^2 \sin^2 2\theta_{13} \sin^2\left(1.27\Delta m_{32}^2 \frac{L}{E}\right) - c_{13}^2 c_{12}^2 \sin^2 2\theta_{14} \sin^2\left(1.27\Delta m_{41}^2 \frac{L}{E}\right) \\ &- c_{13}^2 s_{12}^2 \sin^2 2\theta_{14} \sin^2\left(1.27\Delta m_{42}^2 \frac{L}{E}\right) - s_{13}^2 \sin^2 2\theta_{14} \sin^2\left(1.27\Delta m_{43}^2 \frac{L}{E}\right) \end{aligned}$$

Physics data was acquired with the far and near detectors from August 2011.
The IBD candidates obtained 31541 events for a 500 day dataset in the far detector and 290775 events for a 500 day dataset in the near detector with a prompt energy range (1.2-8 MeV). To measure θ_{14} and Δm^2 41, Expected IBD templates are prepared with various oscillation parameters, as shown in Figure 2. Each template that is shown as a point in the Figure 2 represents the expected oscillated prompt spectra at the far and near detectors. The measured θ_{14} and Δm^2 41 are points in the template sets, which have minimum chi ^2 values calculated between the events observed and the expected templates. There are a total of 14448 expected templates in the region bounded by $0.001 < \theta_{14} < 0.99$ and $0.0001 < \Delta m^2\ 41 < 0.2$ eV^2.

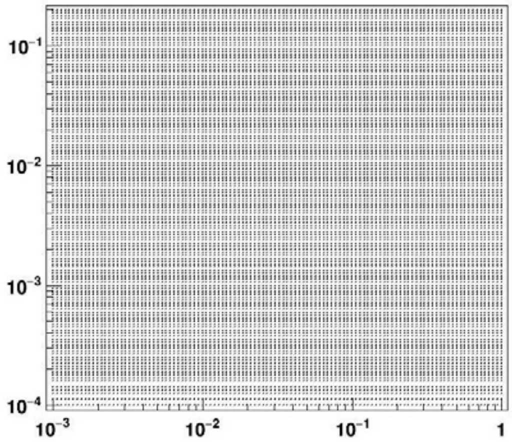


Figure 2. Oscillation parameters coordinate.

IBD expected MC template input is oscillation parameters, signal MC w/ 4 isotopes, interaction fraction, expected # of IBD, detection efficiency, dead time.

3. Summary

We used reno data of 500 days. We investigate the possibility of sterile neutrinos existence at RENO experiment and compare data with Monte Carlo generated in four neutrino frame. we present some recent results using chi-square analysis method. We was analyzed in two ways. 0ne way is fixed $\sin^2 2\,\theta_{13}$ and the other way is varying $\sin^2 2\,\theta_{13}$. we drawn Exclusion contours at 95% C.L.. (Figure 3) and We checked consistent with standard 3-flavor neutrino oscillation model. also, delta m able to set stringent limits in the region. (Figure 4) We checked about un-excluded parameters and excluded parameters.

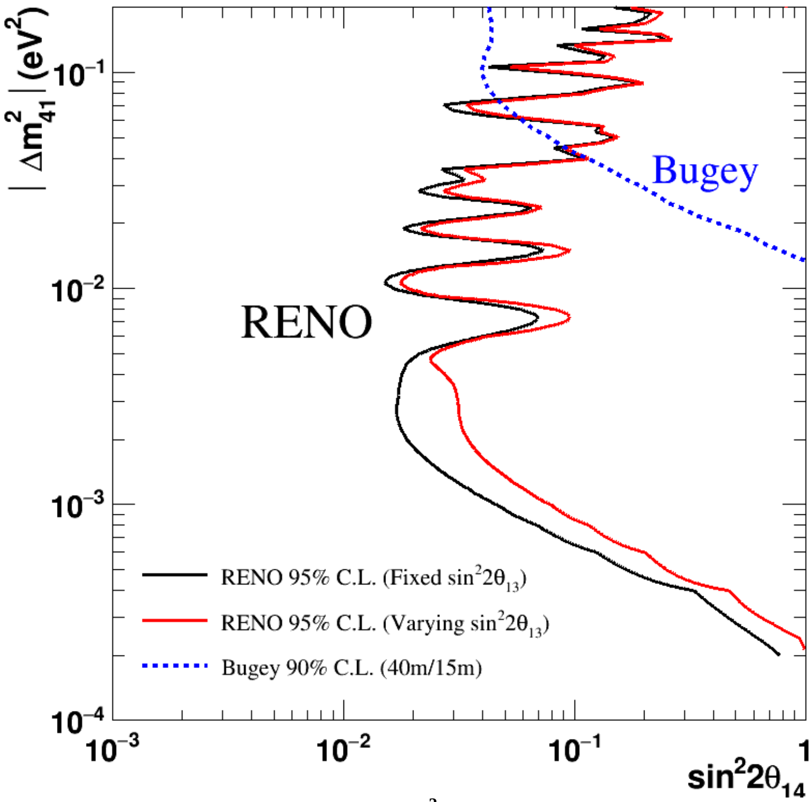
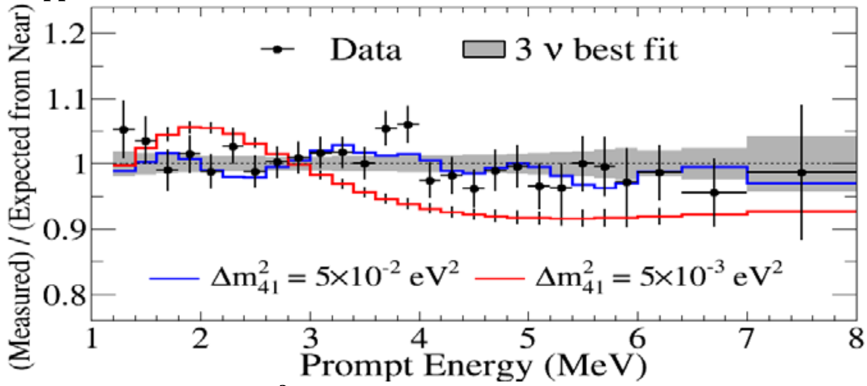


Figure 3. (Black line) The value of $\sin^2 2\ \theta_{13}$ were fixed. (Red line) The value of $\sin^2 2\ \theta_{14}$, $\sin^2 2\ \theta_{13}$, and Δm^2 41 were unconstrained. Exclusion contours for the neutrino oscillation parameters $\sin^2$ 2 θ_{14} and $\Delta m^2 41$. Normal mass hierarchy is assumed for both Δm^2 31 and Δm^2 41. The parameter space to the right side of the contours is excluded. For comparison, Bugey's 90% C.L. limit on νe disappearance is also shown as the blue dashed curve.



full curves assumes $\sin^2 2\theta_{14}$=0.1

Figure 4. (color online). Prompt energy spectra observed at far. divided by the prediction from the near spectrum with the three-neutrino best-fit oscillation parameters from the previous RENO analysis. The gray band represents the uncertainty of the three-neutrino oscillation prediction, which includes the statistical uncertainty of the near data and all the systematic uncertainties. Predictions with $\sin^2$ 2 θ_{14} = 0.1 and two representative Δm^2 41 values are also shown as the dotted and dashed curves.

References

[1] G. L. Fogli, L. Lisi, A. Marrone, D. Montanino, and A. Palazzo, Phys. Rev. D **66**, 053010 (2002).