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New results from RENO

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The Reactor Experiment for Neutrino Oscillation (RENO) has been taking reactor antineutrinos data from the six reactors at Hanbit Nuclear Power Plant in Korea using two identical near and far detectors since August, 2011. The smallest neutrino mixing angle θ_{13} has been successfully measured by observing the disappearance of reactor antineutrinos. In 2016, RENO has published an updated value of θ_{13} and its first measurement of Δm^2_{ee} based on energy dependent disappearance probability using 500 live days of data taken until January. RENO has accumulated more data to obtain more precise values of θ_{13} and Δm^2_{ee}. A study has been on progress to find changes in the observed reactor antineutrino flux with respect to the reactor fuel evolution. In this talk, we present newly measured values of θ_{13} and Δm^2_{ee} and results on the evolution of observed reactor antineutrino yields.

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1. Introduction

RENO has measured the smallest neutrino mixing angle θ_{13} in 2012 [1]. An updated value of θ_{13} and its first measurement of $|\Delta m^2_{ee}|$ based on energy dependent disappearance probability using 500 days of data has been published in 2016 [2]. The detailed description has been also published to PRD [3]. RENO has accumulated more data to obtain more precise values of θ_{13} and Δm^2_{ee}. A study has been on progress to find changes in the observed reactor antineutrino flux with respect to the reactor fuel evolution. We report newly measured values of θ_{13} and Δm^2_{ee} and results on the evolution of observed reactor antineutrino yields.

2. Experimental setup

RENO detects antineutrinos from the six reactors at Hanbit Nuclear Power plant in Yonggwang, Korea. The six pressurized water reactors with each maximum thermal output of 2.815 GW_{th} (reactors 3, 4, 5 and 6) or 2.775 GW_{th} (reactors 1 and 2) are lined up in roughly equal distances and span $\sim$1.3 km. Two identical antineutrino detectors are located at 294 m and 1383 m, respectively, from the center of reactor array. The far (near) detector is beneath a hill that provides 450 m (120 m) of water equivalent rock overburden to reduce the cosmic backgrounds. The far-to-near ratio of antineutrino fluxes measured in the two identical detectors considerably reduce systematic uncertainties coming from the reactor neutrino flux, target mass, and detection efficiency. The reactor-flux weighted baseline is 410.6 m for the near detector, and 1445.7 m for the far detector. The detail of detection methods and setup of the RENO experiment can be found elsewhere [4].

3. Measurement of θ_{13} and Δm^2_{ee}

Oscillation amplitude and frequency of neutrino survival probability are measured based on the information of the observed reactor neutrino rate and spectra. $|\Delta m^2_{ee}|$ and $\sin^2 2\theta_{13}$ are determined by comparing measured far-to-near ratio of IBD prompt spectra to that of prediction.

Figure 1 shows the observed spectrum at the far detector compared to the one expected with no oscillation and the one expected with the best-fit oscillation at the far detector. The expected spectrum with no oscillation is obtained by weighting the spectrum observed at the near detector. The lower panel of the Figure 1 shows the ratio of reactor $\overline{\nu}_e$ events measured in the far detector to the no-oscillation prediction (points). We have observed a clear energy dependent deficit of reactor $\overline{\nu}_e$ in the far detector. The best-fit values obtained from the rate and spectral analysis are $\sin^2 2\theta_{13}$ = 0.0896 $\pm$0.0048 (stat.) $\pm$0.0047 (syst.) and $|\Delta m^2_{ee}|$ = [2.68 $\pm$0.12 (stat.) $\pm$0.07 (syst.)] $\times$ $10^{-3} eV^2$.

4. Fuel-composition dependent reactor antineutrino yield

A study has been on progress to find changes in the observed reactor antineutrino flux with respect to the reactor fuel evolution. Through this study, we test reactor antineutrino model and find possible source of reactor antineutrino anomaly [5]. Left hand side plot in Figure 2 shows a measured IBD yield per fission $\overline{y}_f$ as a function of the effective fission fraction. We observe a clear dependence of the IBD yield per fission on the effective fission fraction. This result rules out no

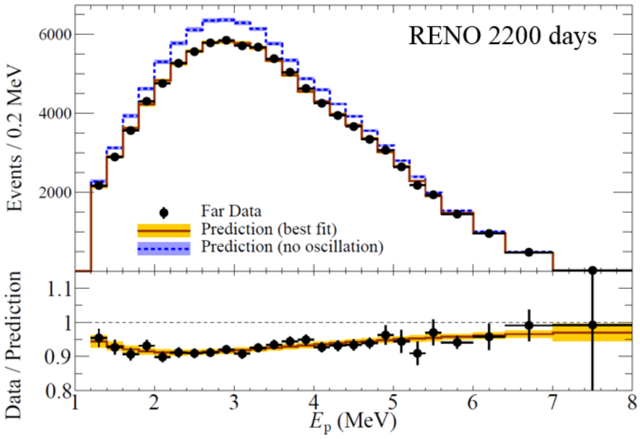

Figure 1: Top: Comparison of the observed IBD prompt spectrum in the far dectector with the no-oscillation prediction (blue shaded histogram) derived from the measurement in the near detector. The prediction from the best-fit oscillation is also shown (yellow shaded histogram). Bottom: ratio of reactor $\overline{\nu}_e$ events measured in the far detector to the no-oscillation prediction (points) and the best-fit prediction (yellow shaded band). Errors are statistical uncertainties only.

fuel-dependent variation of IBD yield per fission at 6.7 σ. The observed slope of the IBD variation over fission fraction is not inconsistent with that of Huber-Mueller (HM) model prediction [6, 7]. y_{235} and y_{239} denoting IBD yield per fission for individual isotope ^{235}U and ^{239}Pu, respectively, are determined using the eight data points of the left hand side plot of Figure 2 by a χ^2 fit with pull parameters of systematic uncertainties. Right hand side plot of Figure 2 shows the result of the measurements of y_{235} and y_{239}. The contours are allowed regions, the dot is the best fit and the cross is the HM prediction. The measured y_{235} is smaller than the HM prediction at 3.5 σ while measured y_{239} is smaller than the HM prediction only at 1.2 σ. This suggests the reactor antineutrino anomaly can be largely understood by incorrect prediction of y_{235}. However, it is hard to rule out ^{239}Pu as a contributor to the reactor antineutrino anomaly because error of y_{239} is large.

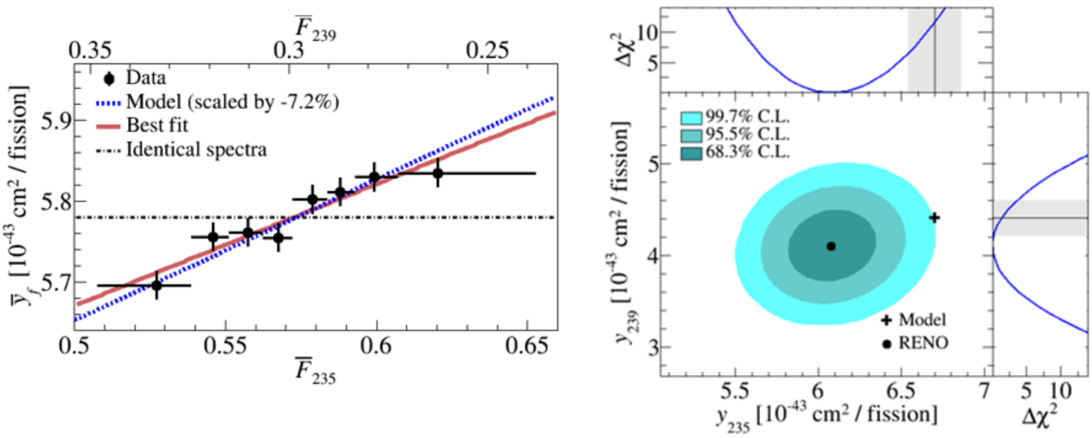

Figure 2: Left: IBD yield per fission $\overline{y}_f$ as a function of the effective fission fraction. The black dots are measured values, blue dotted line is the scaled Huber-Mueller model prediction and red solid line is the best fit of the data. The horizontal errors of the data indicate the range of effective fission fraction. Errors of $\overline{y}_f$ are statistical uncertainties only. Right: measurement of IBD yield per fission for individual isotope ^{235}U and ^{239}Pu. The contours are allowed regions, the dot is the best fit and the cross is the Huber-Mueller model prediction.

5. Summary

RENO has observed a clear energy dependent disappearance of reactor $\overline{\nu}_e$ at far detector and updated the result of $\sin^2 2\theta_{13}$ and $|\Delta m^2_{ee}|$ measurement based on far-to-near ratio analysis using 2200 days of data. RENO is going to take data until the end of 2018 and expect to measure $sin^2 2\theta_{13}$ and $|\Delta m^2_{ee}|$ with 6% accuracy and it will provide an important information on determination of the leptonic CP phase if combined with a result of an accelerator neutrino beam experiment [8]. RENO also report a fuel-dependent IBD yield using 1807.9 days of RENO near data. Hypothesis of no fuel-dependent IBD yield is ruled out at 6.7 σ. The measured IBD yield per ^{235}U fission is smaller than the Huber-Mueller model at 3.5 σ. So we conclude the reactor antineutrino anomaly can be understood by reevaluation of the ^{235}U IBD yield prediction. However we do not rule out ^{239}Pu as a contributor to the reactor antineutrino anomaly because error of measured ^{239}Pu IBD yield is large.

References

[1] J.K.Ahn *et al*. (RENO Collaboration), *Observation of Reactor Electron Antineutrinos Disappearance in the RENO Experiment*, Phys.Rev.Lett. **108**, 191802 (2012).

[2] J.H.Choi *et al*. (RENO Collaboration), *Observation of Energy and Baseline Dependent Reactor Antineutrino Disappearance in the RENO Experiment*, Phys.Rev.Lett. **116**, 211801 (2016).

[3] S.H.Seo *et al*. (RENO Collaboration), *Spectral Measurement of the Electron Antineutrino Oscillation Amplitude and Frequency using 500 Live Days of RENO Data*, Phys.Rev.D. **98**, 012002 (2018).

[4] J.K.Ahn *et al*. (RENO Collaboration), *RENO: An Experiment for Neutrino Oscillation Parameter* θ_{13} *Using Reactor Neutrinos at Yonggwang*, arXiv:1003.1391.

[5] G.Mention *et al*., Phys.Rev.D. **83**, 073006 (2011).

[6] Th.A.Mueller *et al*., *Improved predictions of reactor antineutrino spectra*, Phys. Rev. C **83**, 054615 (2011).

[7] P.Huber, *Determination of antineutrino spectra from nuclear reactors*, Phys. Rev. C **84**, 024617 (2011).

[8] K. Abe *et al*. (T2K Collaboration), *Evidence of electron neutrino appearance in a muon neutrino beam*, Phys.Rev.D. **88**, 032002 (2013); K. Abe *et al*,. (T2K Collaboration), *Observation of Electron Neutrino Appearance in a Muon Neutrino Beam*, Phys.Rev.Lett. **112**, 061802 (2014).