PROCEEDINGS OF SCIENCE

New results from RENO

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The Reactor Experiment for Neutrino Oscillation (RENO) started data-taking since August, 2011 and has successfully measured the smallest neutrino mixing angle θ_{13} in 2012 using 220 days of data by observing the disappearance of reactor antineutrinos. Antineutrinos from the six reactors at Hanbit Nuclear Power Plant in Korea are detected and compared by the two identical detectors located at the near and far distances from the reactor array center. In 2016, RENO has published 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. In this talk, we present precise measurement of θ_{13} and $|\Delta m^2_{ee}|$ using more data and improved systematic uncertainties. In addition, the 5 MeV excess of reactor antineutrino spectrum will be reported.

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1. Introduction

RENO has published the result of its first measurement of 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 in 2016 [2]. The detail description has been submitted to PRD [3]. RENO has accumulated about 1500 live days of data as of September 2015. We report updated results of θ_{13} and $|\Delta m^2_{ee}|$ measurements with improved systematic uncertainties using the 1500 live days of data and the observation of an excess at ∼5 MeV in reactor antineutrino spectrum.

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 ∼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. Rate and Spectrum Analysis

Figure 1 shows a spectral comparison between the observed IBD prompt spectrum and the prediction from a reactor neutrino model [5, 6] and the best-fit oscillation results. A clear spectral discrepancy is observed in the region of 5 MeV in both detectors. The MC predicted energy spectra are normalized to the observed events out of the excess range $3.6 < E_p < 6.6$ MeV. The excess of events is estimated as about 2.5% of the total observed IBD events in both detectors. The fractional difference is also shown in the lower panel. Furthermore, the 5 MeV excess is observed to be proportional to the reactor thermal power. Figure 2 shows a clear correlation between the 5 MeV excess rate and the total IBD rate that is proportional to the reactor thermal power. This indicates that the 5 MeV excess comes from reactors.

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. The following χ^2 equation is constructed to extract the best fit oscillation parameters using rate and spectral information [7].

$$\chi^2 = \sum_{i=1}^{N_{bin}} \left\{ \frac{\frac{N^{F,i}_{obs}}{N^{N,i}_{obs}} - \frac{N^{F,i}_{exp}}{N^{N,i}_{exp}}}{U^i} \right\}^2 + \left(\frac{\xi}{\sigma_\xi}\right)^2 + \sum_{d=F,N} \left(\frac{b^d}{\sigma^d_{bkg}}\right)^2 + \sum_{r=1}^{6} \left(\frac{f_r}{\sigma_{f_r}}\right)^2 + \left(\frac{e}{\sigma_{scale}}\right)^2 \tag{3.1}$$

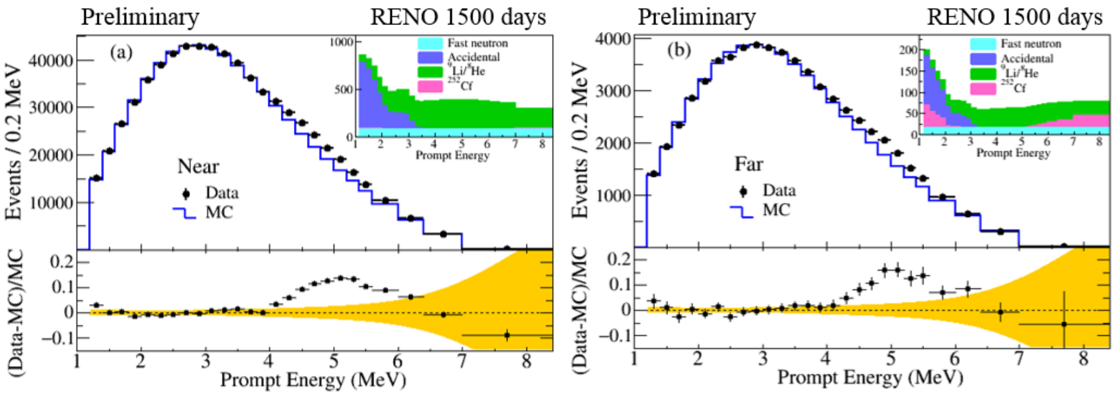

Figure 1: Comparison of observed and expected IBD prompt energy spectrum in the near (a) and far (b) detectors. The expected distributions are obtained from the best-fit oscillation results. The excess at around 5 MeV is clearly seen. A spectral-only comparison is made by normalizing the MC predicted energy spectra to the observed events out of the excess range $3.6 < E_p < 6.6$ MeV.

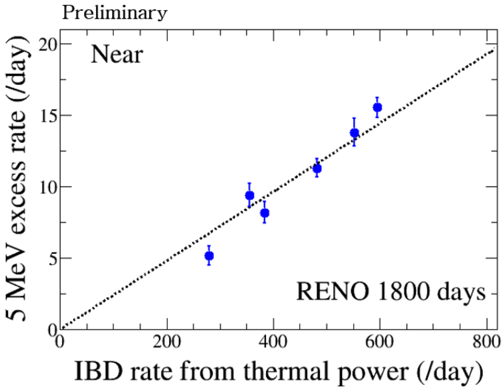

Figure 2: Correlation between the 5 MeV excess rate and the total IBD rate. The IBD rate is proportional to the reactor thermal power. This indicates that the 5 MeV excess comes from reactors.

where $N^{d,i}_{obs}$ is the number of observed IBD events (d = detector (FAR, NEAR)) in the i-th energy bin, $N^{d,i}_{exp}$ is the number of expected IBD events (d = detector (FAR, NEAR)) and U^i is the statistical uncertainty. ξ, b^d, f_r and e are pull parameters of detection efficiency, background, reactor antineutrino flux and energy scale, which are systematic uncertainty sources. σ_ξ, σ^d_{bkg}, σ_{f_r} and σ_{scale} are their systematic uncertainties.

Figure 3 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 3 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 $sin^2 2\theta_{13}$ = 0.086 ±0.006 (stat.) ±0.005 (syst.) and $|\Delta m^2_{ee}|$ = $[2.61^{+0.15}_{-0.16}$ (stat.) $^{+0.09}_{-0.09}$ (syst.)$]\times 10^{-3} eV^2$.

4. Summary and Prospects

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

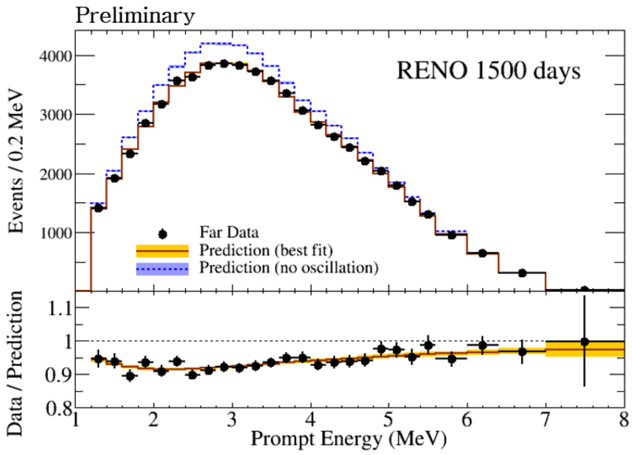

Figure 3: Top: Comparison of the observed IBD prompt spectrum in the far dectector with the no-oscillation prediction (blue shaded histogram) derived from the measurement in the near detector. The prediction from the best-fit oscillation is also shown (yellow shaded histogram). Bottom: ratio of reactor $\overline{\nu}_e$ 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.

1500 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].

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