PROCEEDINGS OF SCIENCE

# New Results from RENO

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RENO (Reactor Experiment for Neutrino Oscillation) is the reactor neutrino experiment which has been taking data from August 2011 with two identical near and far detectors at Hanbit Nuclear Power Plant, Yonggwang, Korea. Using 2,200 days of data, $\sin^2 2\theta_{13}$ and $|\Delta m^2_{ee}|$ are precisely measured based on spectral shape of reactor antineutrinos events with delayed neutron captured by Gd : $\sin^2 2\theta_{13} = 0.0896 \pm 0.0048(\text{stat.}) \pm 0.0047(\text{syst.})$ and $|\Delta m^2_{ee}| = 2.68 \pm 0.12(\text{stat.}) \pm 0.07(\text{syst.})(\times 10^{-3}\text{eV}^2)$. Another independent measurement is carried out via antineutrino events with delayed neutron captured by hydrogen based on rate-only information : $\sin^2 2\theta_{13} = 0.085 \pm 0.008(\text{stat.}) \pm 0.012(\text{syst.})$. We also observe a fuel $^{235}$U dependent variation of reactor antineutrino yield with 6.7 $\sigma$ and 2.6 $\sigma$ significant hint of the correlation between 5 MeV excess and $^{235}$U fission fraction.

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## 1. Introduction

RENO observes the reactor neutrinos via inverse beta decay (IBD) using Gd loaded liquid scintillation detector and has measured $\sin^2 2\theta_{13}$ and $|\Delta m^2_{ee}|$, successfully. RENO is located in Hanbit nuclear power plant which consists of six reactor cores placed linearly with equal spacing and provides a total thermal power of 16.8 $\mathrm{GW_{th}}$ in full operation mode. There are two identical detectors located at near and far sites at 294 m and 1,383 m from the center of the reactor array. More details on the RENO experimental setup and the detector are found in Ref. [1].

## 2. New results of $\sin^2 2\theta_{13}$ and $|\Delta m^2_{ee}|$

We observe a clear energy dependent disappearance of reactor $\bar{\nu}_e$ in the far detector [Figure 1]. For determination of $|\Delta m^2_{ee}|$ and $\theta_{13}$ simultaneously, a $\chi^2$ with pull parameter terms of systematic uncertainties is constructed using the spectral ratio measurement and is minimized by varying the oscillation parameters and pull parameters as described in Ref. [2]. We obtain $\sin^2 2\theta_{13} = 0.0896 \pm 0.0048(\text{stat.}) \pm 0.0047(\text{syst.})$ and $|\Delta m^2_{ee}| = 2.68 \pm 0.12(\text{stat.}) \pm 0.07(\text{syst.})(\times 10^{-3}\text{eV}^2)$ based on spectral shape of reactor antineutrinos. And $\sin^2 2\theta_{13}$ is measured via antineutrino events with delayed neutron captured by hydrogen based on rate-only information independently and measured to be $0.085 \pm 0.008(\text{stat.}) \pm 0.012(\text{syst.})$.

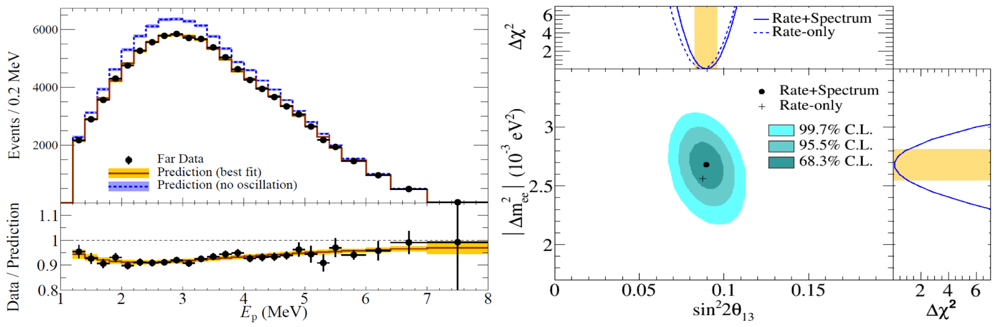


**Figure 1:** Left top: comparison of the observed IBD prompt spectrum in the far detector (dots) with the no-oscillation prediction (blue shaded histogram) obtained from the measurement in the near detector. Left bottom: ratio of IBD events measured in the far detector to the no-oscillation prediction (dots) and the ratio from the MC simulation with best-fit results folded in (shaded band). Errors include the statistical and background subtraction uncertainties. Right: allowed regions of the $|\Delta m^2_{ee}|$ and $\sin^2 2\theta_{13}$ . The $\Delta\chi^2$ distribution for $\sin^2 2\theta_{13}$ and $|\Delta m^2_{ee}|$ are also shown with an 1 $\sigma$ band.

## 3. Fuel-composition dependent reactor antineutrino yield

Based on multiple fuel cycles from August 2011 to February 2018, we observe a fuel $^{235}$U dependent variation of measured IBD yields. Figure 2 shows the IBD yield per fission $\bar{y}_f$ as a function of the $^{235}$U effective fission fraction. No variation of measured IBD yield as a function of the fission fraction is ruled out with 6.7 $\sigma$. In spectral shape of IBD prompt events, the excess around 5 MeV is observed and the deviation from the expectation near 5 MeV is larger than the uncertainty of an expected spectrum from the reactor antineutrino model in Figure 3. The correlation between 5 MeV excess and $^{235}$U fission fraction is observed with 2.6 $\sigma$.

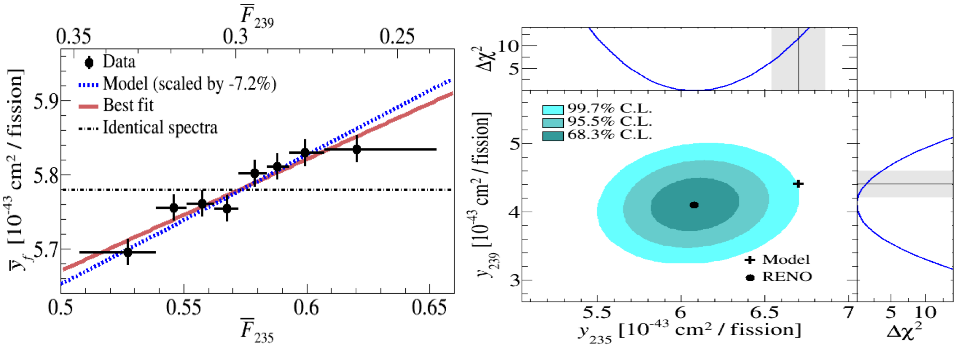


**Figure 2:** Left: IBD yield per fission $\bar{y}_f$ as a function of the $^{235}$U effective fission fraction. The measured values (black dots) are compared to the scaled Huber-Mueller model prediction (blue dotted line) and the best fit of the data (red solid line). Detail description is in Ref. [3]. Right: combined measurement of $y_{235}$ and $y_{239}$. The cross shows the prediction of the Huber-Mueller model. The top and right side panels show one dimensional $\Delta\chi^2$ profile distributions for $y_{235}$ and $y_{239}$ while the grey shaded bands represent the model predictions.

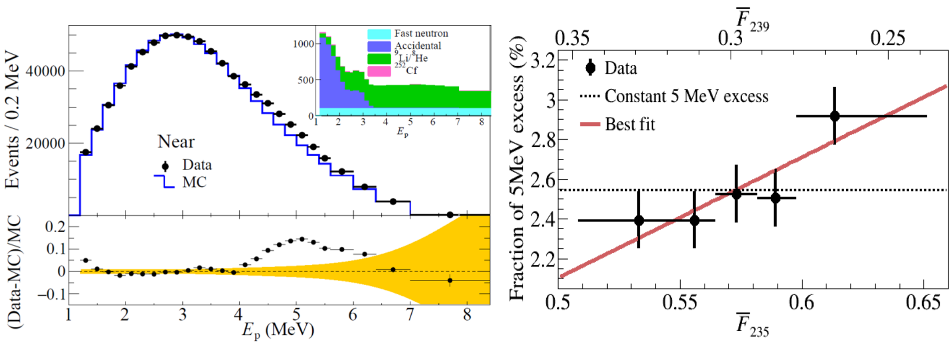


**Figure 3:** Left: Comparison of observed and expected IBD prompt energy spectrum in the near detector. Right: Fraction of the 5 MeV excess as a function of $\bar{F}_{235}$. The red line is the best fit to the data and the dotted line represents no correlation of 5 MeV excess fraction with $\bar{F}_{235}$.

## 4. Conclusion

The value of $\sin^2 2\theta_{13}$ and $|\Delta m^2_{ee}|$ are measured with 7.6 % and 5.2 % precision using 2,200 days of data. Then, another consistent result for $\sin^2 2\theta_{13}$ via antineutrino events with delayed neutron captured by hydrogen is also obtained. We observe a fuel 235 U dependent variation of reactor antineutrino yield with 6.7 $\sigma$ and the first hint of the correlation between 5 MeV excess and $^{235}$U fission fraction is observed. Through the additional 2 or 3 years of data taking, we expect to improve the $|\Delta m^2_{ee}|$ accuracy and the result of fuel dependent IBD yield.

## References

[1] G. Bak et al. (RENO collaboration), Phys. Rev. Lett. 121, 201801 (2018).

[2] J. H. Choi et al. (RENO Collaboration), Phys. Rev. Lett. 116, 211801 (2016).

[3] G. Bak et al. (RENO collaboration), arXiv:1806.00574v3 (2018).