



New results of reactor $\bar{\nu}_e$ oscillation using 3800 days of RENO data

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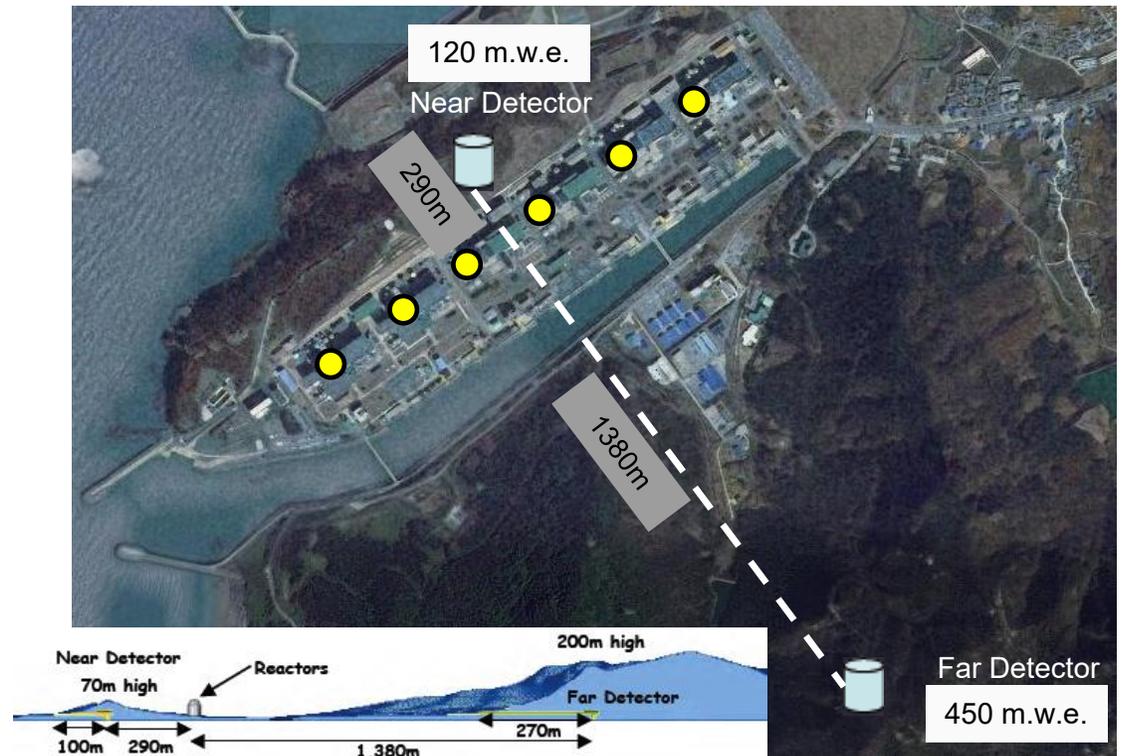


RENO



- Reactor Experiment for Neutrino Oscillation
- reactor $\bar{\nu}_e$ oscillation at Hanbit Nuclear Plant
- 9 institutions and 40 physicists

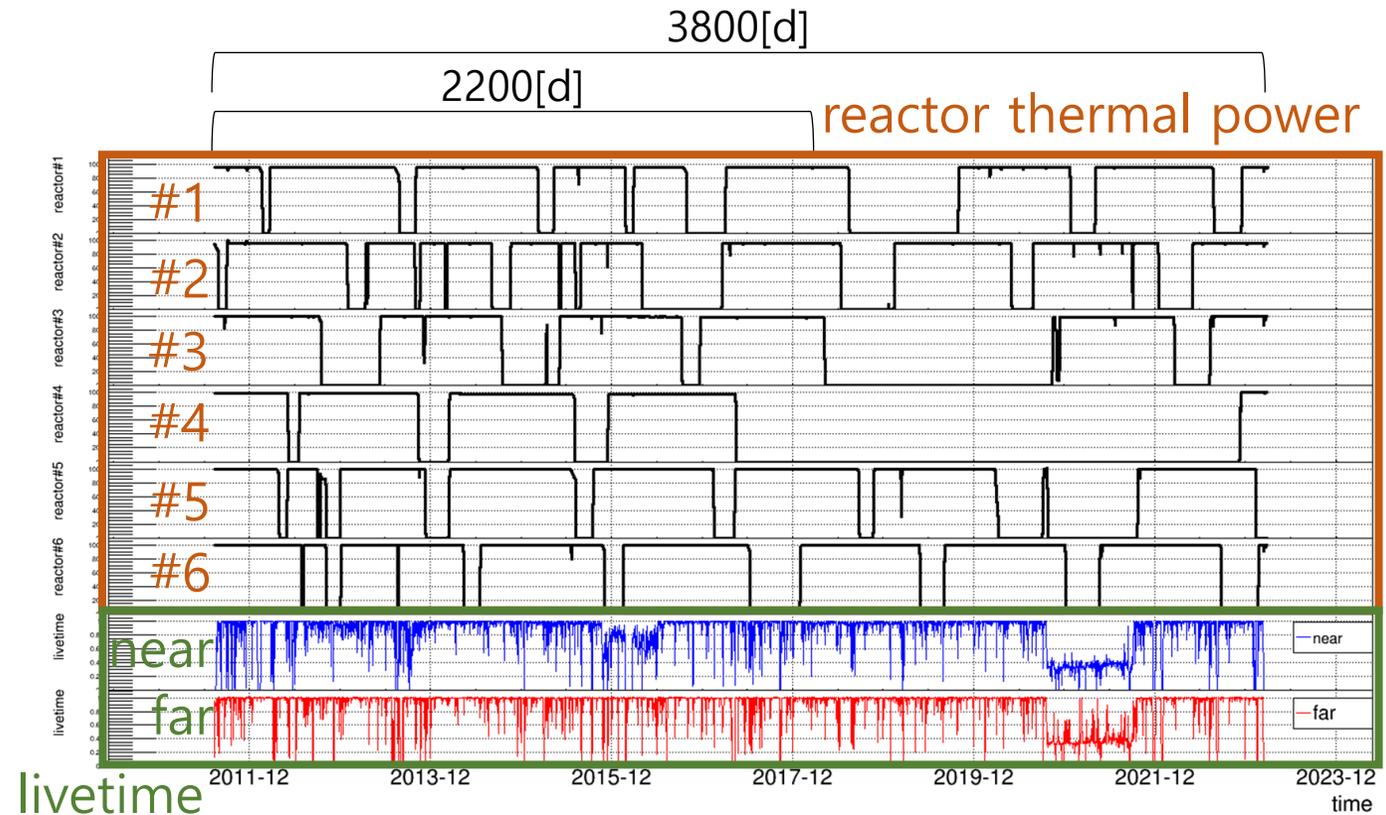
- Total cost : \$10M
- Start of project : 2006
- The first experiment running with both near & far detectors from **Aug. 2011**



YongGwang (靈光) :

RENO Status & Data Taking

- RENO DAQ running
 - Aug. 2011 ~ Mar. 2023.
- ~3800[days] livetime
- Recent re-operation of the near DAQ
 - => **RENE** experiment (sterile neutrino search)

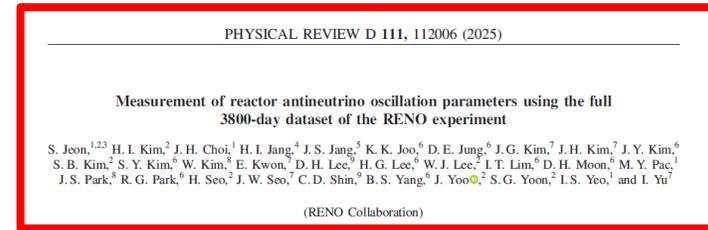


period	live time	result
Aug. 2011 ~ Feb. 2018	2200 [days]	2018 PRL
Aug. 2011 ~ Mar. 2023	3800 [days]	new result

Major Results from RENO & Future

- Precise measurement of $|\Delta m_{ee}^2|$ and θ_{13} with n-Gd capture

- Phys. Rev. Lett. 108, 191802 (2012) - 229[d]
- Phys. Rev. Lett. 116, 211801 (2016) - 500[d]
- Phys. Rev. D 98, 012002(2018) - 500[d]
- Phys. Rev. Lett. 121, 201801 (2018) - 2200[d]
- Phys. Rev. D 111, 112006 (2025) - 3800[d]



finished with 3800[d] analyses.

- Measurement of θ_{13} with n-H capture

- JHEP 04 029 (2020) - 1500[d]
- 2800[d] days of data -> being extended to 3800[d]

- reactor neutrino yield & spectrum

- Phys. Rev. Lett. 122, 232501 (2019) - 1800[d]
- Phys. Rev. D 104, L111301 (2021) - 2900[d]

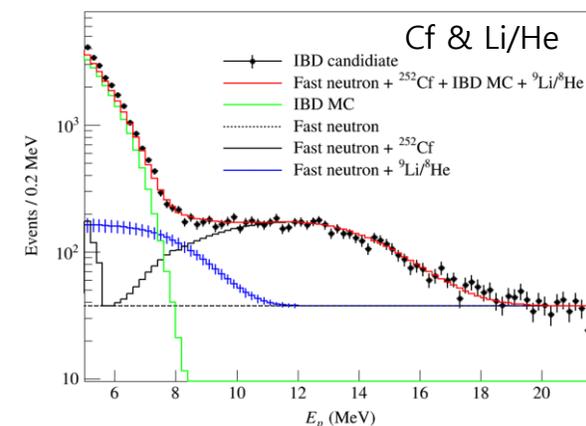
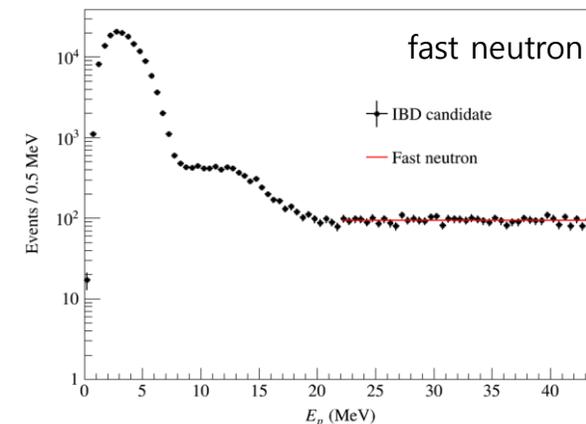
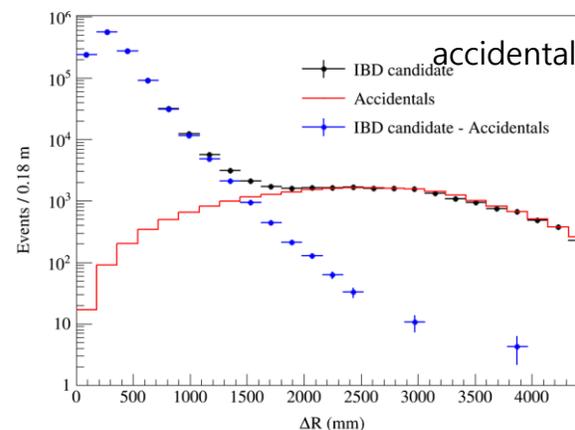
will be continued beyond 3800[d] analyses according to re-operation of the near detector.

- sterile neutrino search

- Phys. Rev. Lett. 125, 191801 (2020) - 2200[d]
- Phys. Rev. D 105, L111101 (2022) - 2500[d] x NEOS 180[d]

IBD Candidate Sample & Background Estimation

- 1,211,995(144,667) $\bar{\nu}_e$ candidate events observed for near(far).
- The total background rates :
 - near : 9.08 ± 0.18 [events/day] (2.5%)
 - far : 2.06 ± 0.13 [events/day] (5.3%)

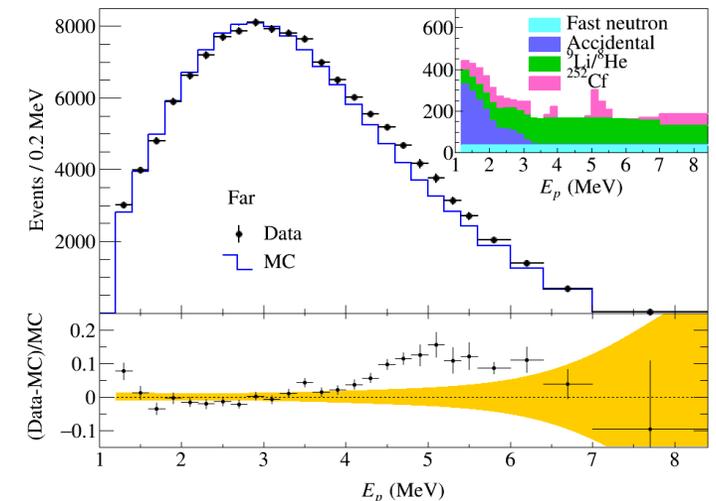
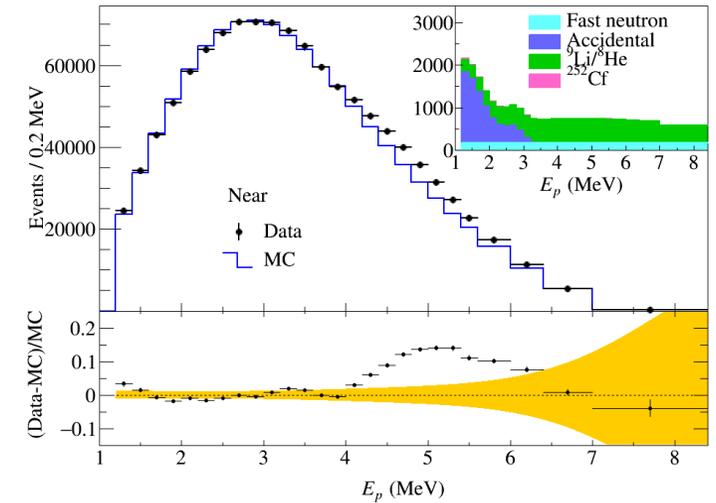


Detector	Near	Far
IBD rate	366.47 ± 0.33	38.70 ± 0.10
after background subtraction	357.39 ± 0.38	36.64 ± 0.16
total background rate	9.08 ± 0.18	2.06 ± 0.13
live time [days]	3307.25	3737.85

measured IBD and estimated background rates with $1.2 < E_p < 8.0$ [MeV], given per day

IBD Prompt Spectrum

- A shape comparison between the observed IBD prompt spectrum and the prediction from a reactor $\bar{\nu}_e$ model
 - data : observed IBD prompt spectrum after background subtraction
 - MC : prediction with best-fit oscillation
- The fractional difference between data and prediction in the lower panel
- A clear discrepancy between the observed and the predicted spectral shapes in the region of 5 [MeV]

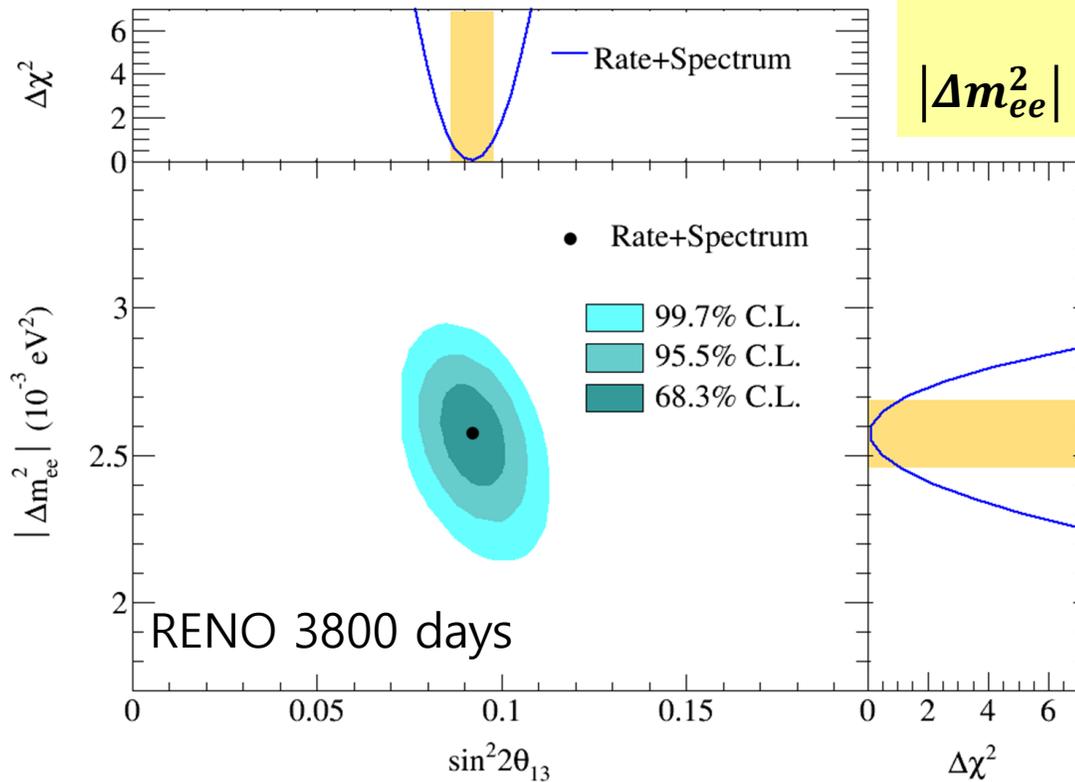


Results of $|\Delta m_{ee}^2|$ and θ_{13}

Based on the measured far-to-near ratio of prompt spectra from the 3800[d] sample,

$$\sin^2 2\theta_{13} = 0.0920^{+0.0044}_{-0.0042} (\text{stat.})^{+0.0041}_{-0.0041} (\text{syst.}) \quad (6.4\% \text{ precision})$$

$$|\Delta m_{ee}^2| = 2.57^{+0.10}_{-0.11} (\text{stat.})^{+0.05}_{-0.05} (\text{syst.}) [\times 10^{-3} eV^2] \quad (4.5\% \text{ precision})$$



source of the systematic uncertainty

	Δm_{ee}^2 [$10^{-3} eV^2$]	$\sin^2 2\theta_{13}$ []
reactor	-	± 0.0003
detection efficiency	-	± 0.0032
energy scale	± 0.05	± 0.0009
backgrounds	± 0.02	± 0.0015

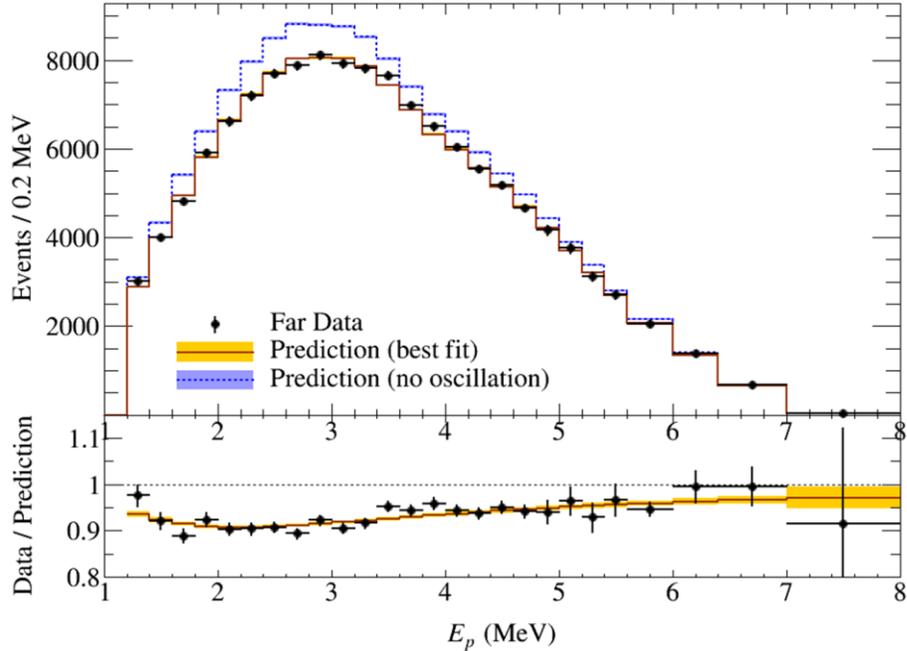
(reference) 2018 PRL

$$\sin^2 2\theta_{13} = 0.0896 \pm 0.0048(\text{stat.}) \pm 0.0047(\text{syst.})$$

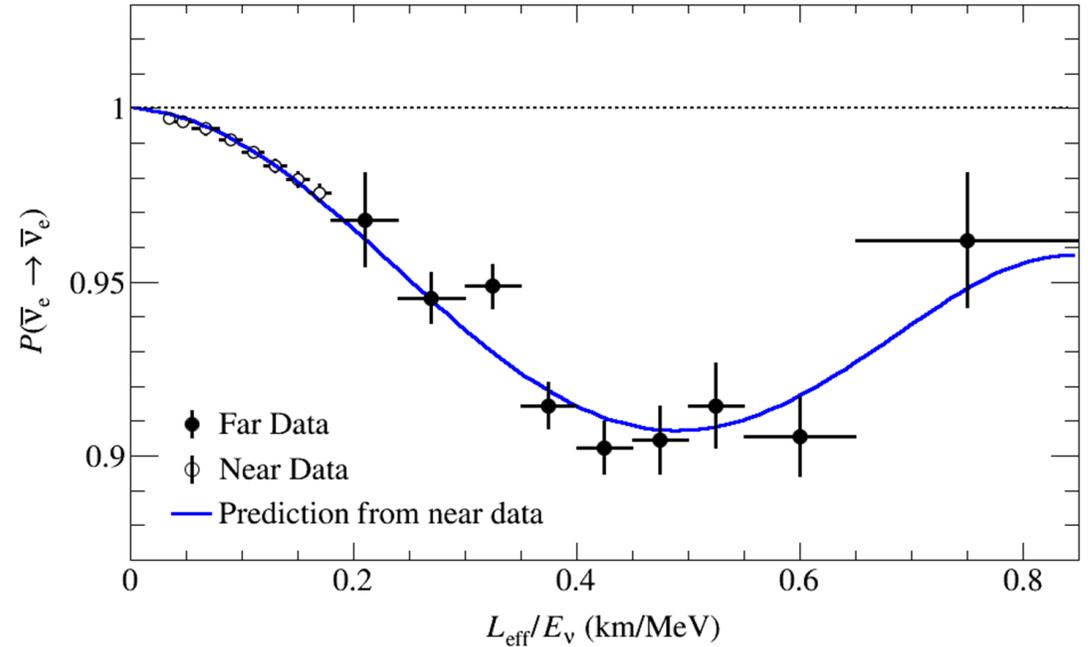
$$|\Delta m_{ee}^2| = 2.68 \pm 0.12(\text{stat.}) \pm 0.07(\text{syst.}) [\times 10^{-3} eV^2]$$

Energy & L/E Dependent $\bar{\nu}_e$ Oscillation

Energy-dependent disappearance of reactor $\bar{\nu}_e$



observed L/E dependent oscillation

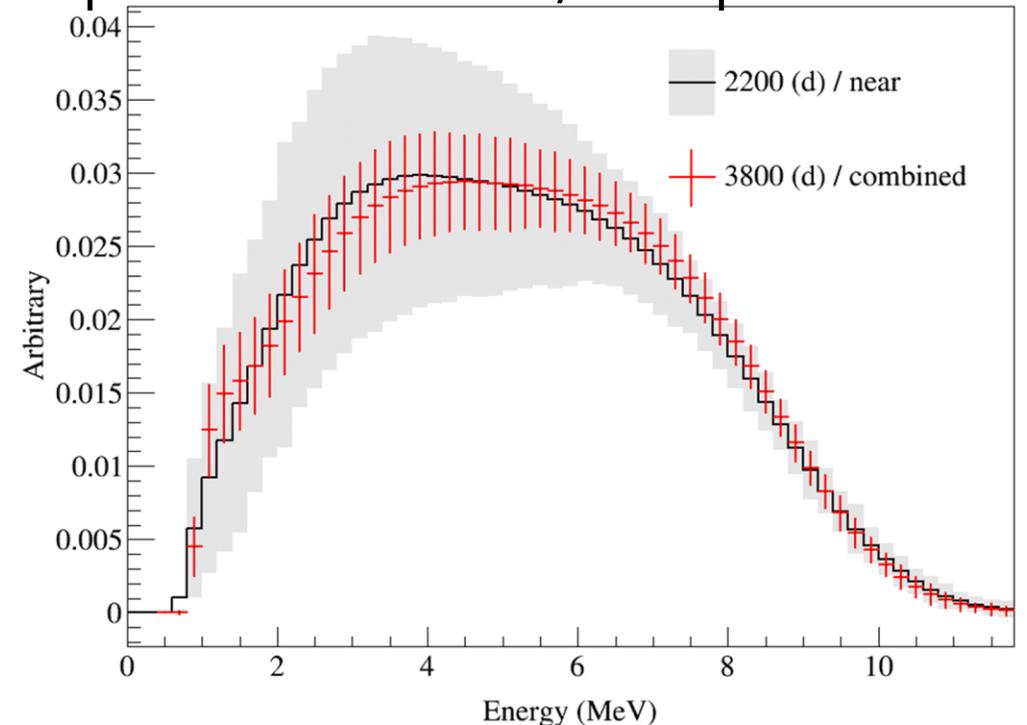


$$P(\bar{\nu}_e \rightarrow \bar{\nu}_e) \approx 1 - \sin^2 2\theta_{13} \sin^2 \left(\Delta m_{ee}^2 \frac{L}{4E_\nu} \right)$$

Improvement

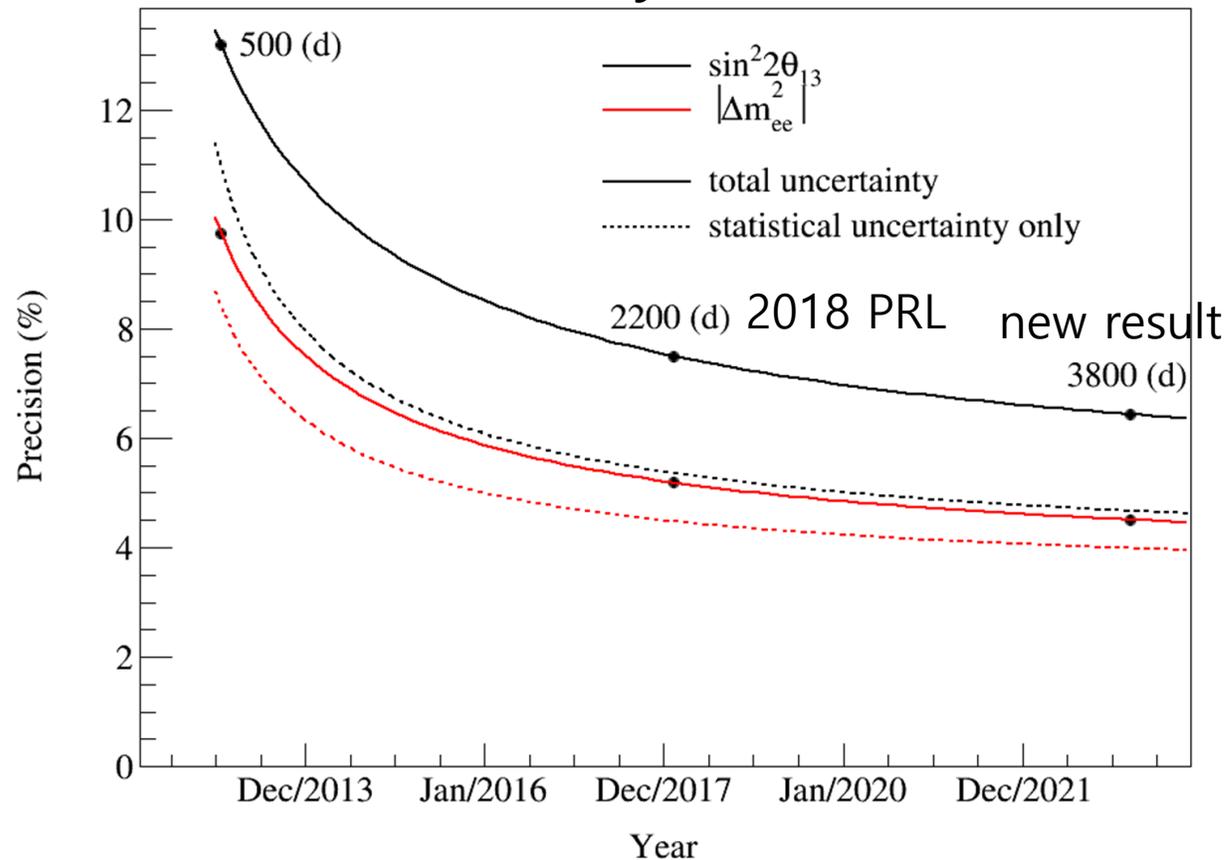
- Li/He Background Spectrum
 - extension of dataset
 - combined far & near spectrum
- reactor-related uncertainties
 - decomposition of detector-correlated & detector-uncorrelated components
 - only detector-uncorrelated component can be considered for far-to-near ratio analysis.

comparison of the Li/He spectrums



New Result(3800[d]) vs 2018 PRL(2200[d])

Precision of oscillation measurement in the RENO's analyses



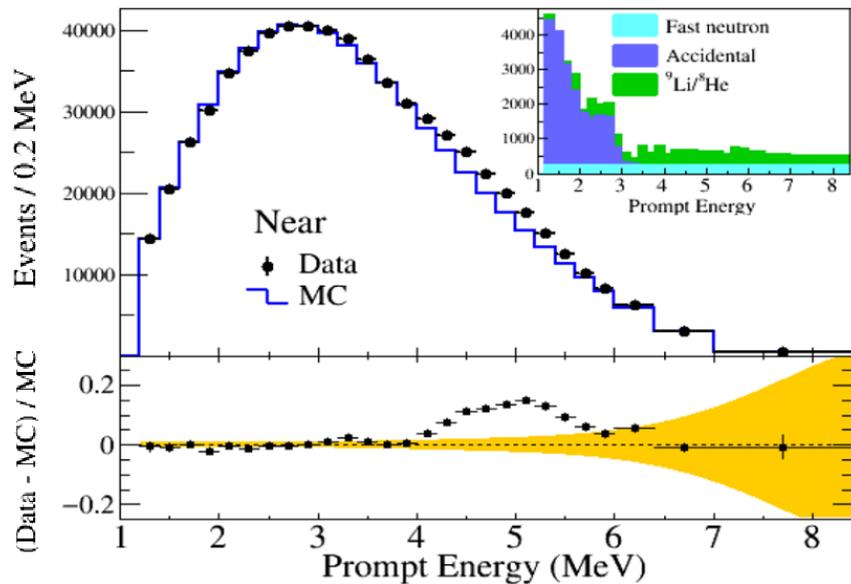
	live time	precision	
		$\sin^2 2\theta_{13}$	Δm_{ee}^2
2018 PRL	2200 [d]	7.5%	5.2%
new result	3800 [d]	6.4%	4.5%

Comparing with the 2018 PRL result, the new result gives **14% and 13% improved precision** for $\sin^2 2\theta_{13}$ and Δm_{ee}^2 each.

θ_{13} Measurement with n-H capture (Preliminary)

Based on 2800[d] n-H sample,

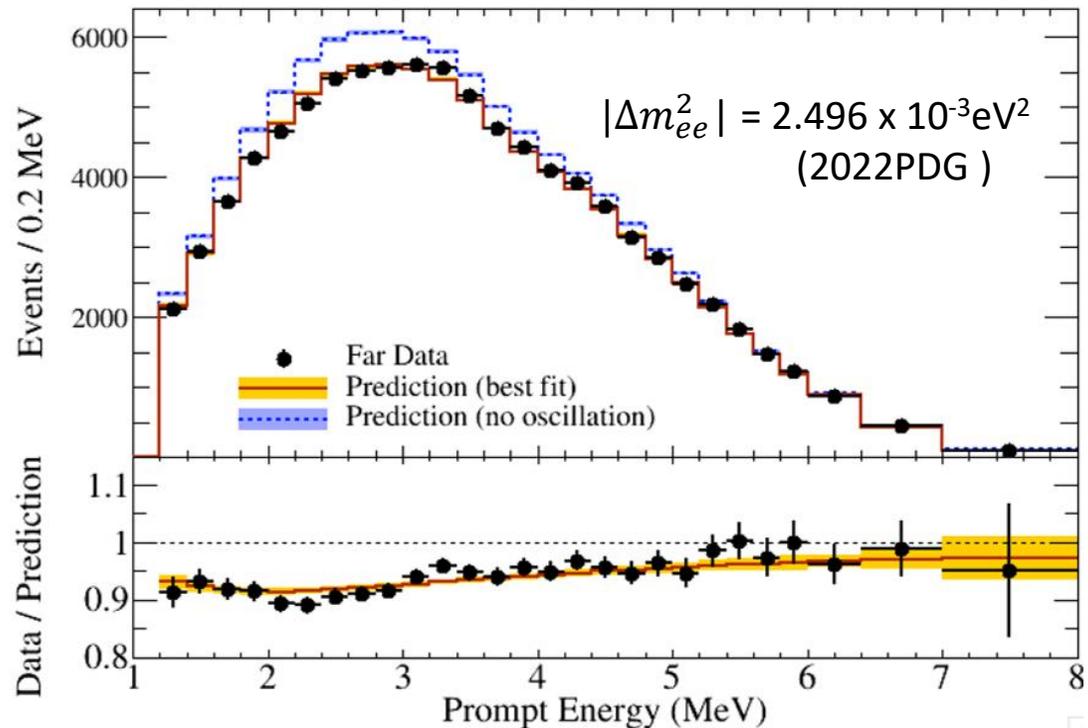
$$\sin^2(2\theta_{13}) = 0.082 \pm 0.007(\text{stat.}) \pm 0.011(\text{syst.}) \quad (15.9\% \text{ precision})$$



	Near	Far
DAQ live time (days)	2259.298	2653.297
IBD candidates & backgrounds rate	316.67 ± 0.37	61.10 ± 0.15
After background subtraction	298.60 ± 0.62	35.67 ± 0.28
Total background rate	18.06 ± 0.50	25.43 ± 0.24

(reference) 2019 JHEP with 1500[d]

$$\sin^2 2\theta_{13} = 0.086 \pm 0.008(\text{stat.}) \pm 0.014(\text{syst.})$$



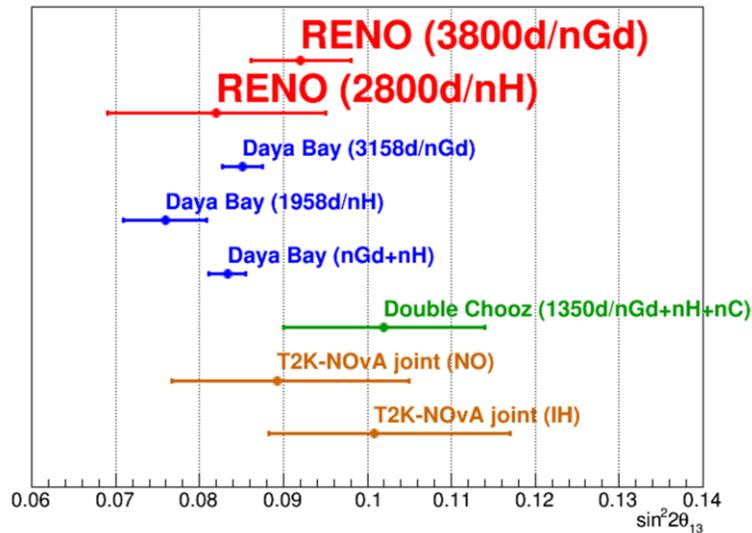
being extended to 3800[d]

Global Comparison

The new result shows good agreement with the global results.

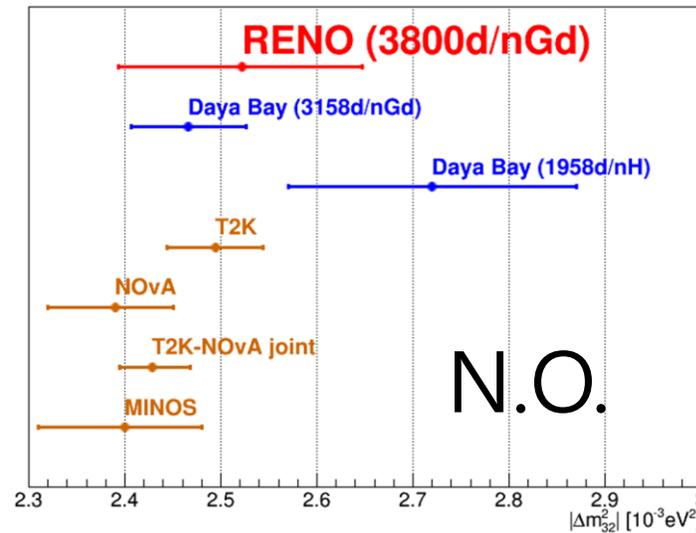
$$\sin^2 2\theta_{13}$$

Global Comparison for $\sin^2 2\theta_{13}$

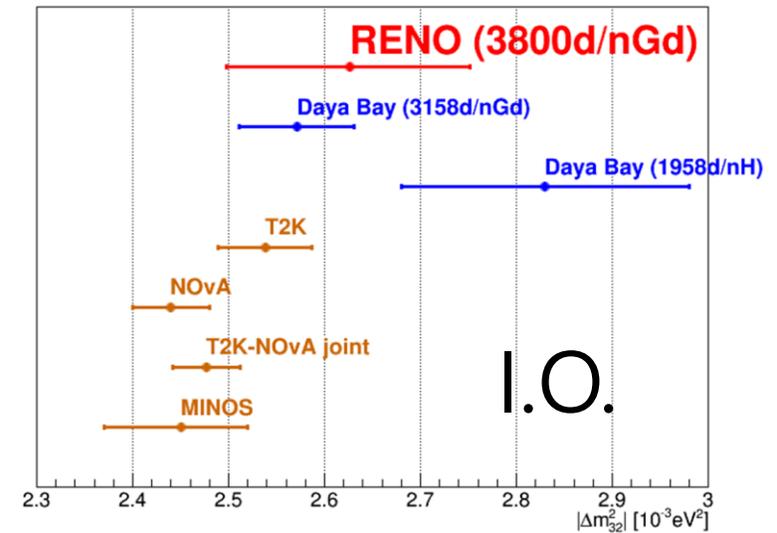


$$|\Delta m_{32}^2|$$

Global Comparison for $|\Delta m_{32}^2|$ (Normal Ordering)



Global Comparison for $|\Delta m_{32}^2|$ (Inverted Ordering)



Summary

- The RENO experiment has precisely measured the amplitude and frequency of reactor $\bar{\nu}_e$ oscillation at Hanbit Nuclear Power Plant since Aug. 2011.
- As of Mar. 2023, the RENO DAQ was shut down, and 3800[d] live time of dataset was obtained.
- From 3800[d] n-Gd sample,
 - 1,211,995(144,667) IBD candidates are observed during 3307.25(3737.85) [d] in the near(far) detector.
 - the far-to-near ratio analysis gives
 - $\sin^2 2\theta_{13} = 0.0920^{+0.0044}_{-0.0042} (stat.)^{+0.0041}_{-0.0041} (syst.)$ (7.5% -> 6.4% precision improved)
 - $\Delta m_{ee}^2 = 2.57^{+0.10}_{-0.11} (stat.)^{+0.05}_{-0.05} (syst.) [\times 10^{-3} eV^2]$ (5.2% -> 4.5% precision improved)
- In the future,
 - other analyses (n-H, $\bar{\nu}_e$ spectrum, sterile neutrino, etc.) with the 3800[d] full data set
 - further improvements expected with a re-operating near detector.

↳ Phys. Rev. D 111, 112006 (2025)

Backup

Global Comparison Reference

experiment	reference
RENO (3800d/nGd)	PRD 111, 112006 (2025)
RENO (2800d/nH)	preliminary
Daya Bay (3158d/nGd)	PRL 130, 161802 (2023)
Daya Bay (1958d/nH)	PRL 133, 151801 (2024)
Double Chooz (1350d/nGd+nH+nC)	Neutrino 2020
T2K	EPJC 83, 782 (2023)
NOvA	PRD 110, 012005 (2024)
T2K-NOvA joint	Neutrino 2024
MINOS	PRL 125, 131802 (2020)