

Status of the RENO Experiment

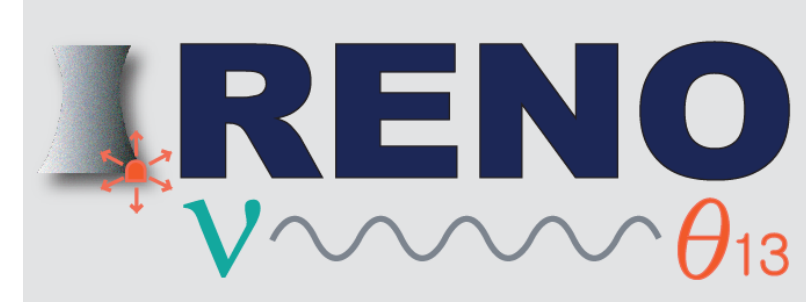
Sanghoon Jeon for the RENO Collaboration
Seoul National University

The 24th International Workshop on Neutrinos From Accelerators
21th ~ 26th Aug.

NuFACT 2023

The 24th International Workshop on Neutrinos from Accelerators
August 21 ~ 26, 2023 at Seoul National University, Seoul, Korea

RENO Collaboration



- Reactor Experiment for Neutrino Oscillation

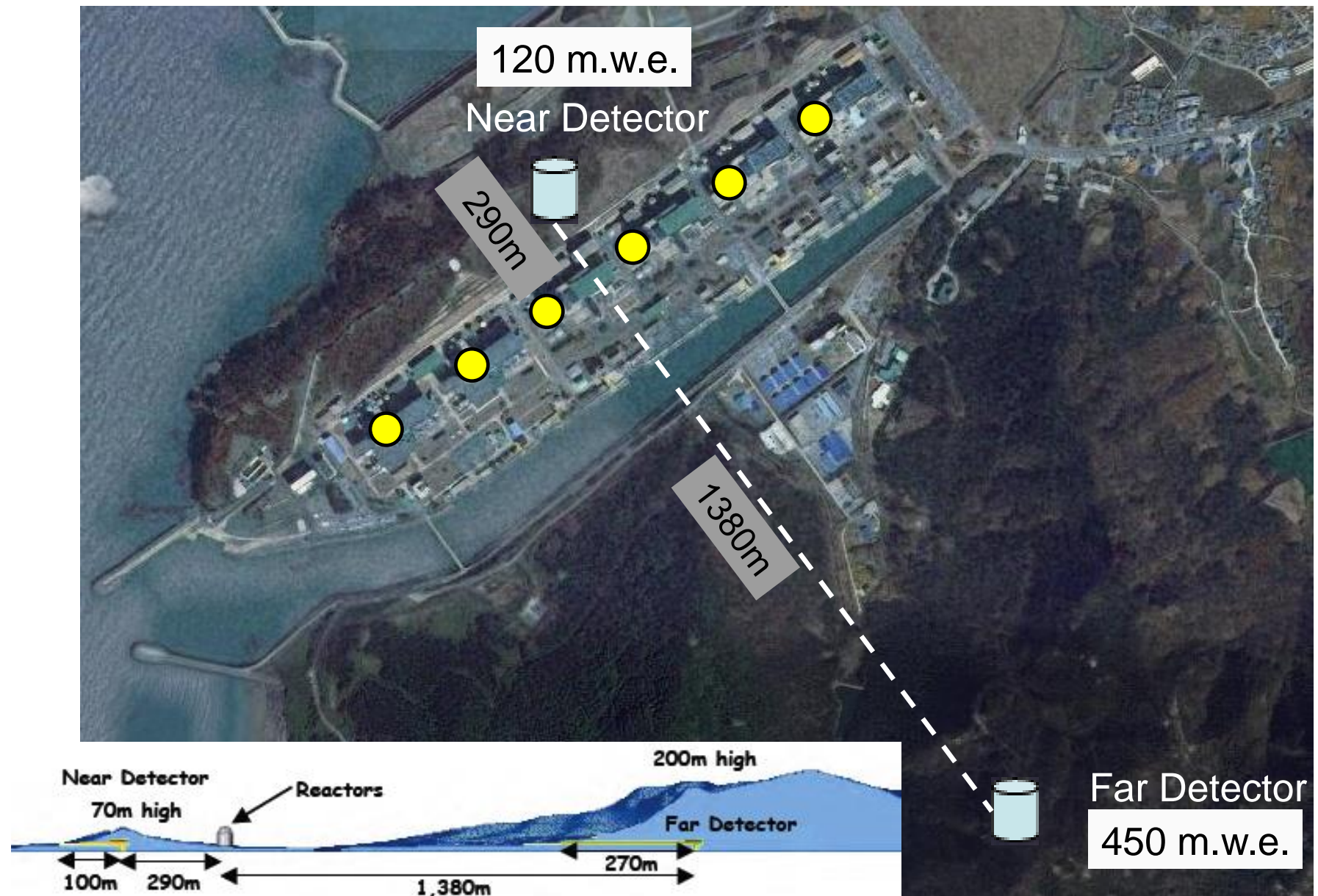
- 9 institutions and 40 physicists
 - Chonnam National University
 - Dongshin University
 - GIST
 - Gyeongsang National University
 - KAIST
 - Kyungpook National University
 - Seoul National University
 - Seoyeong University
 - Sungkyunkwan University

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

YongGwang (靈光) :



RENO Experimental Set-up



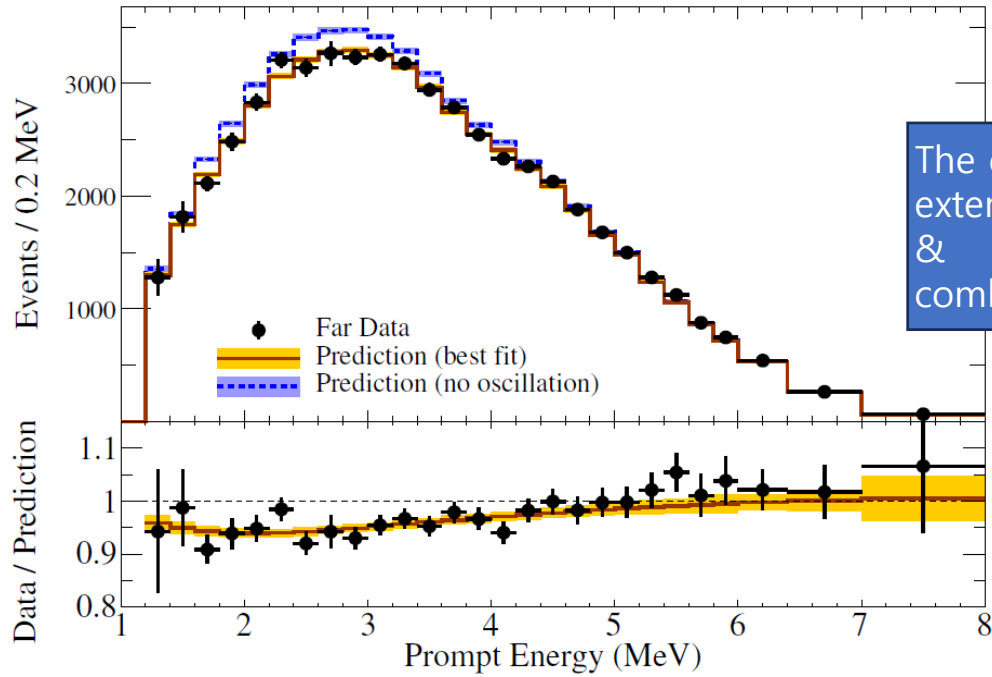
Results in RENO

- Precise measurement of $|\Delta m_{ee}^2|$ and θ_{13} using ~ 2200 days of data (Aug. 2011 – Feb. 2018)
 - “Measurement of Reactor Antineutrino Oscillation Amplitude and Frequency at RENO” (Phys. Rev. Lett. 121, 201801 (2018. 11. 15))
- Fuel-composition dependent reactor antineutrino yield
 - “Fuel-composition dependent reactor antineutrino yield at RENO” (Phys. Rev. Lett. 122, 232501 (2019. 06. 12))
- Measurement of θ_{13} with nH capture using ~ 1500 days of data
 - “Observation of reactor antineutrino disappearance using delayed neutron capture on hydrogen at RENO” (JHEP 04 029 (2020. 04. 06))
- Results from sterile neutrino search
 - “Search for Sub-eV Sterile Neutrino at RENO” (Phys. Rev. Lett. 125, 191801 (2020. 11. 06))

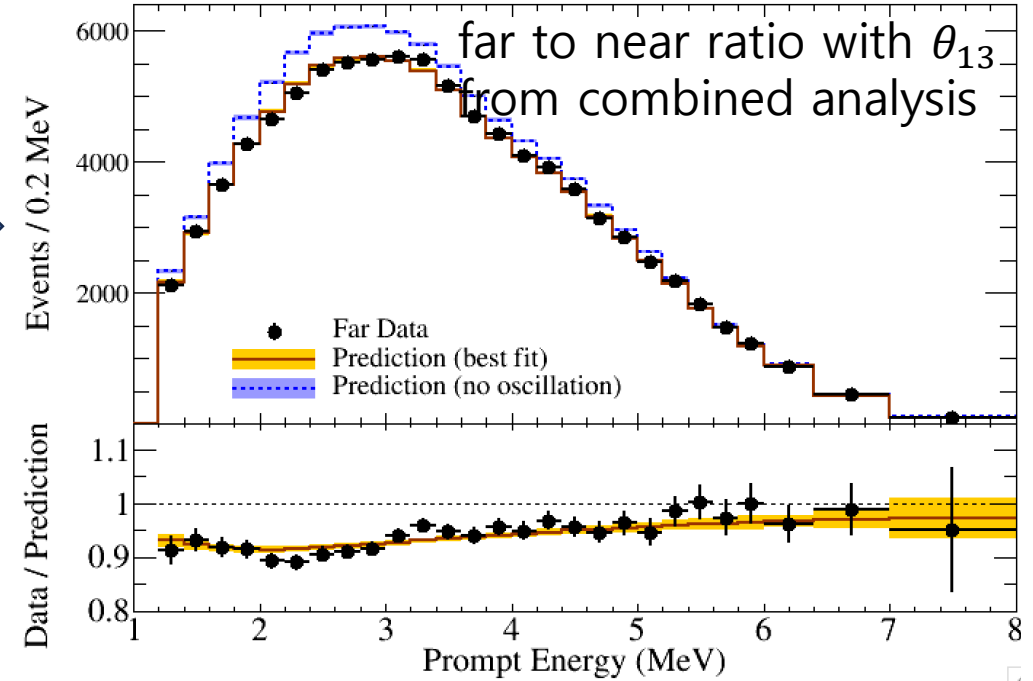
Results in RENO

- Reactor Neutrino Spectrum
 - "Measurement of reactor antineutrino flux and spectrum at RENO" (Phys. Rev. D 104, L111301 (2021. 12. 09))
- Sterile neutrino search from joint analysis by RENO & NEOS
 - "Search for sterile neutrino oscillation using RENO and NEOS data" (Phys. Rev. D 105, L111101 (2022. 06. 08))
- Measurement of ${}^9\text{Li}/{}^8\text{He}$ production
 - "Measurement of cosmogenic ${}^9\text{Li}$ and ${}^8\text{He}$ production rates at RENO" (Phys. Rev. D 106, L012005 (2022. 07. 20))
- Reactor Neutrino Spectrum
 - "Measurement of Reactor Antineutrino Spectra from ${}^{235}\text{U}$ and ${}^{239}\text{Pu}$ Fission at RENO" => poster
- Measurement of θ_{13} with nH capture using ~2800 days of data
 - "Combined Measurement of θ_{13} using reactor antineutrino events rates with neutron capture on hydrogen and Gadolinium at RENO" => poster

Measurement of θ_{13} with nH capture



The data sample has been extended to 2800 [d] & combine nGd&nH



From 1500 [d] of data,
 $\sin^2 2\theta_{13} = 0.086 \pm 0.008(\text{stat.}) \pm 0.014(\text{syst.})$

“Observation of reactor antineutrino disappearance using delayed neutron capture on hydrogen at RENO” (JHEP 04 029 (2020. 04. 06))

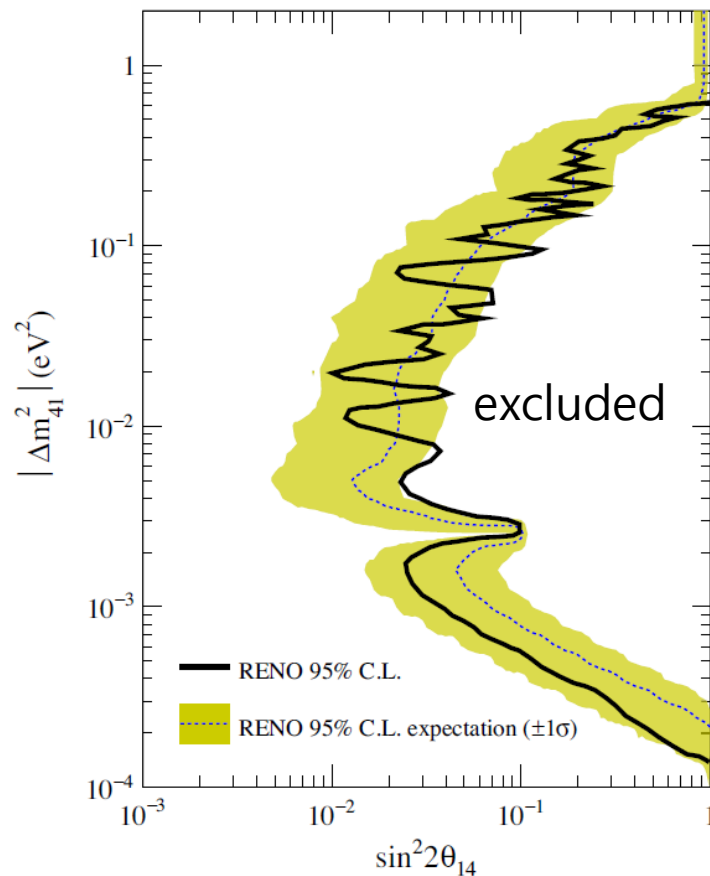
From 2800 [d] of data combined with nGd,
 $\sin^2 2\theta_{13} = 0.0871 \pm 0.0040(\text{stat.}) \pm 0.0045(\text{syst.})$

details in the poster session : “Combined Measurement of θ_{13} using reactor antineutrino events rates with neutron capture on hydrogen and Gadolinium at RENO”

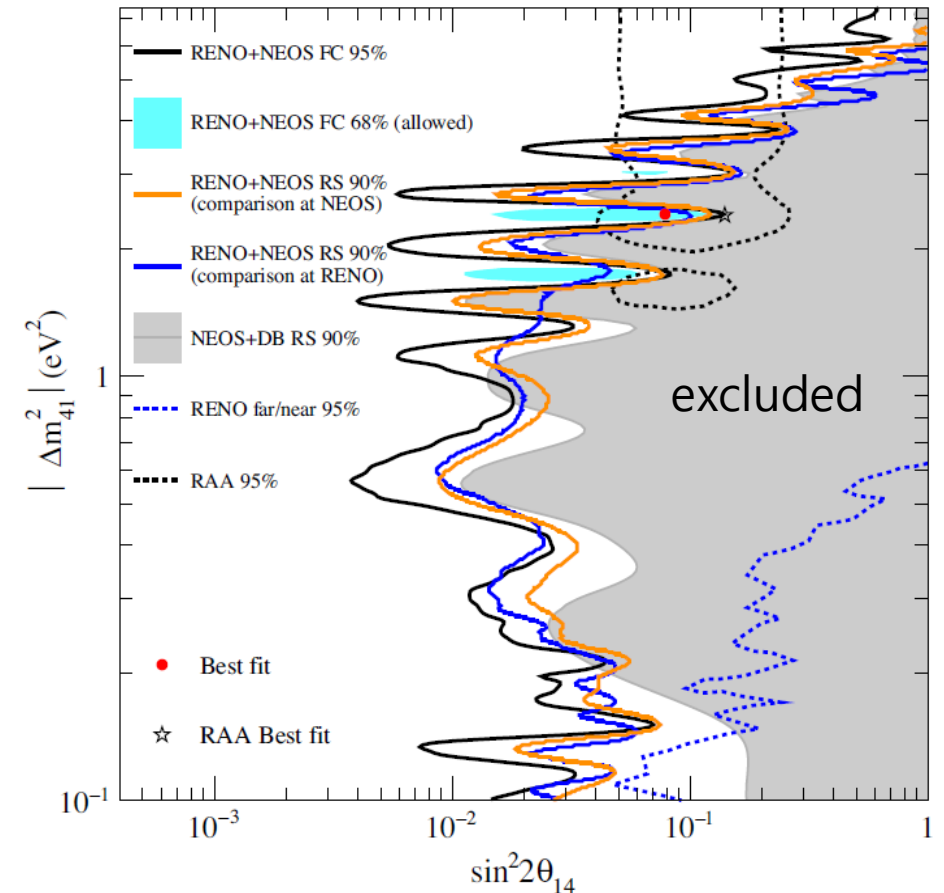
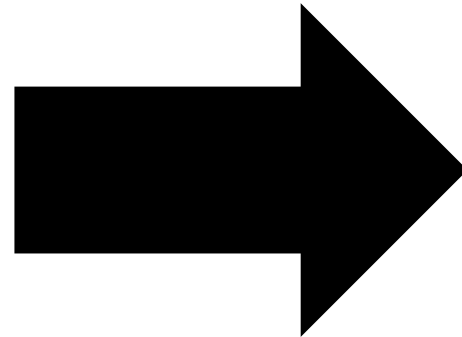
Light Sterile Neutrino Search

- RENO 2200 [d]
- using spectral distortion => reactor model independent
- consistent with standard 3-flavor neutrino oscillation model
- able to set stringent limits in the region $10^{-3} < \Delta m_{41}^2 < 0.1 \text{ eV}^2$

- RENO x NEOS joint
- at same reactor complex (Hanbit Nuclear Power Plant)
- spectral distortion
- exclusion at $0.1 < \Delta m_{41}^2 < 7 \text{ eV}^2$

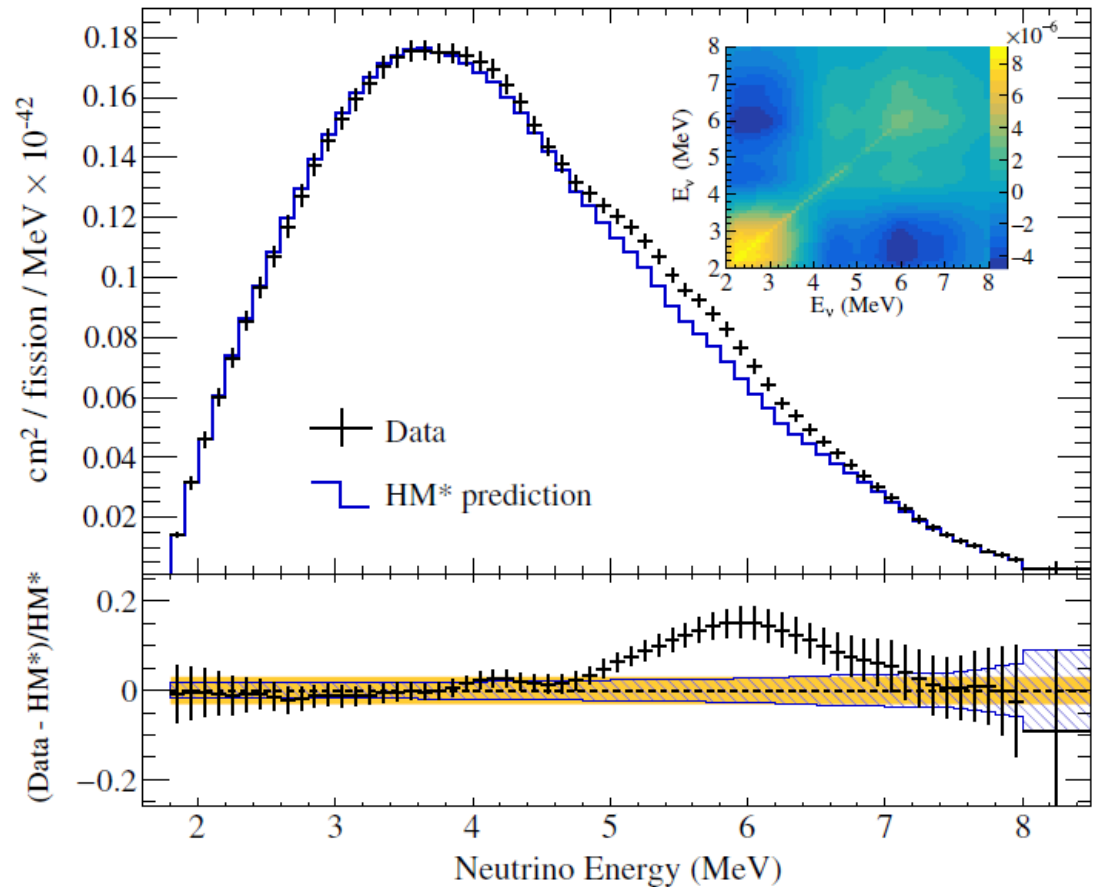


"Search for Sub-eV Sterile Neutrino at RENO"
(Phys. Rev. Lett. 125, 191801 (2020. 11. 06))



"Search for sterile neutrino oscillation using RENO and NEOS data"
(Phys. Rev. D 105, L111101 (2022. 06. 08))

Reactor Neutrino Spectrum

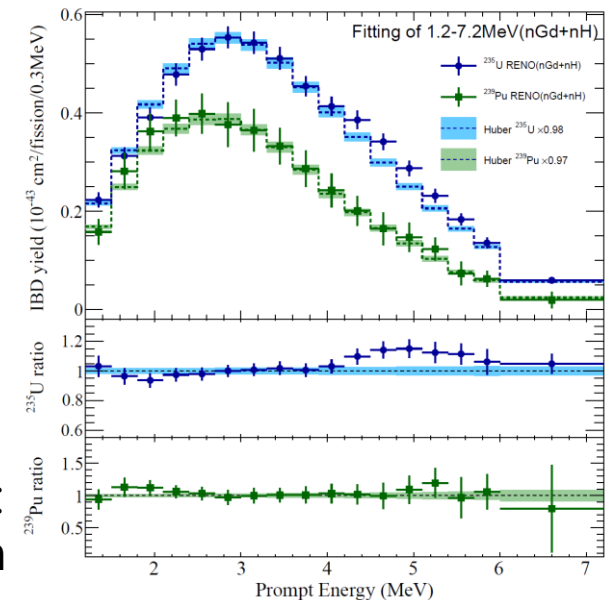
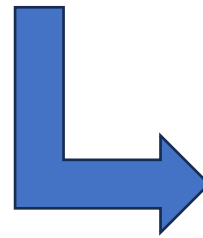


For precise study of reactor neutrino physics, it is important to understand the neutrino spectrum. From the RENO data, the neutrino spectrum from Hanbit Nuclear Reactors.

⇒ 0.941 ± 0.015 of HM

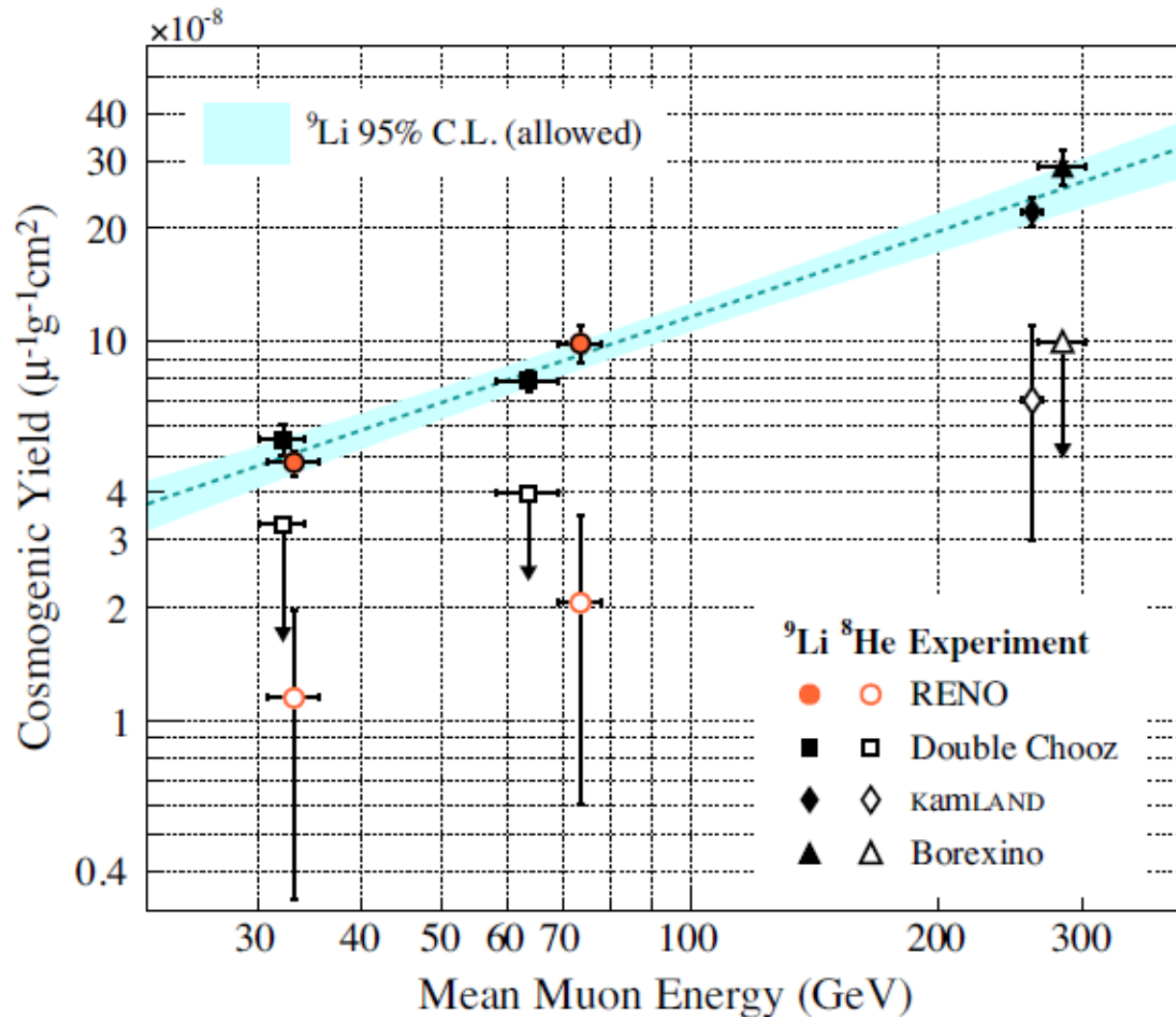
⇒ 6 [MeV] excess

“Measurement of reactor antineutrino flux and spectrum at RENO” (Phys. Rev. D 104, L111301 (2021. 12. 09))



Study for decomposed spectrum for each fuel component will be presented in the poster session : “Measurement of Reactor Antineutrino Spectra from ^{235}U and ^{239}Pu Fission at RENO”

Measurement of ${}^9\text{Li}/{}^8\text{He}$ production



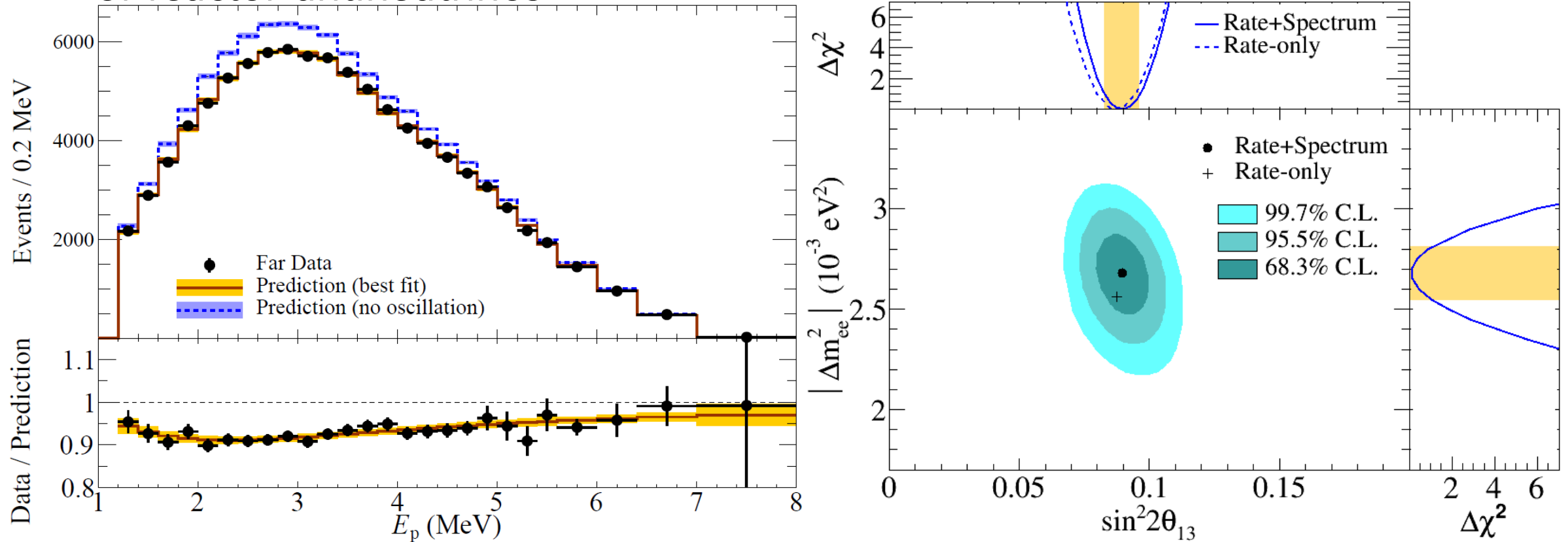
${}^9\text{Li}/{}^8\text{He}$ is one of the dominant background produced by cosmic muon spallation on ${}^{12}\text{C}$.

Result for production rate & yield of ${}^9\text{Li}/{}^8\text{He}$

“Measurement of cosmogenic ${}^9\text{Li}$ and ${}^8\text{He}$ production rates at RENO” (Phys. Rev. D 106, L012005 (2022. 07. 20))

Precise measurement of $|\Delta m_{ee}^2|$ and θ_{13} (2018)

Energy-dependent disappearance
of reactor antineutrinos



From 2200d of data,

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

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

DAQ Shutdown

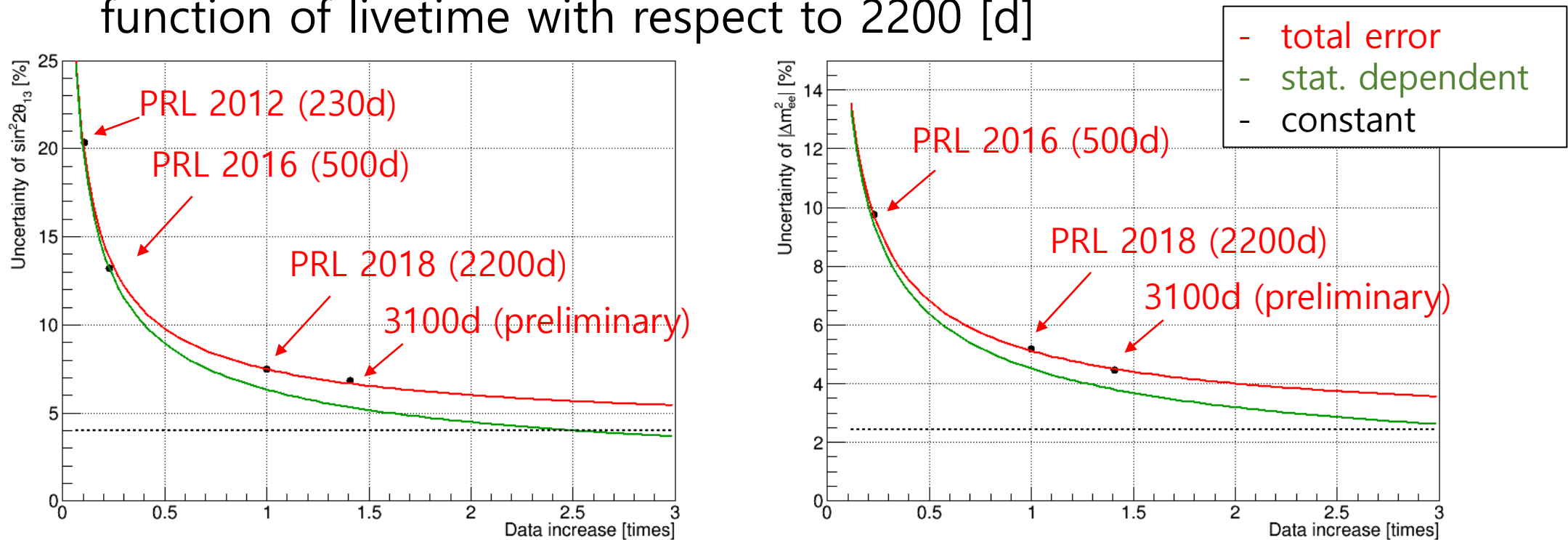
- At 16th Mar. 2023, the RENO DAQ was shut-down.
- 3800[d] of total sample had been taken, which is under analysis.

period	name	result
Aug. 2011 ~ Feb. 2018	2200d sample	2018 PRL
Aug. 2011 ~ Mar. 2023	3800d sample	under analysis

- The other systems maintaining quality of the hardware are under operation.
- We have a plan to re-operate the near detector as a reference detector for the **RENE** experiment (sterile neutrino search).

Expected Uncertainty

Uncertainty of the oscillation parameters as a function of livetime with respect to 2200 [d]



livetime	uncertainty	
	$\sin^2 2\theta_{13}$	$ \Delta m_{ee}^2 $
2200 [d]	7.6 [%]	5.2 [%]
3800 [d] (~1.7times)	6.3 [%]	4.2 [%]

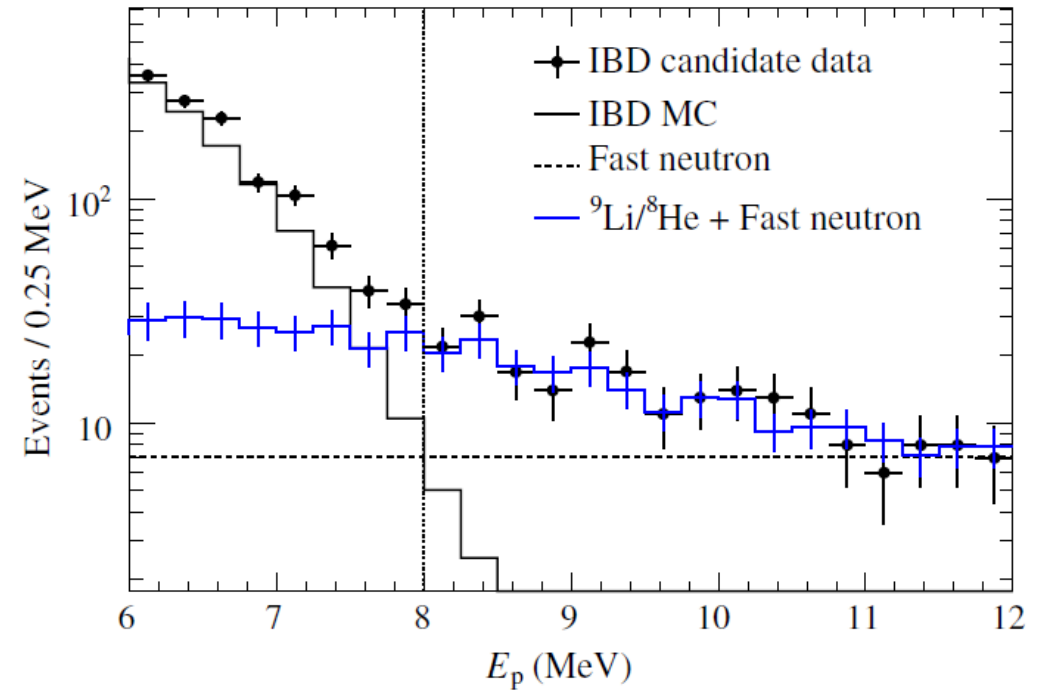


Systematic Uncertainty by ${}^9\text{Li}/{}^8\text{He}$

Detector	Near	Far
IBD rate	470.53 ± 0.51	47.06 ± 0.15
After background subtraction	461.00 ± 0.58	44.82 ± 0.18
Total background rate	9.53 ± 0.28	2.24 ± 0.10
Live time (days)	1807.88	2193.04
Accidental rate	2.54 ± 0.03	0.46 ± 0.01
${}^9\text{Li}/{}^8\text{He}$ rate	5.10 ± 0.27	0.98 ± 0.08
Fast neutron rate	1.81 ± 0.02	0.37 ± 0.01
${}^{252}\text{Cf}$ contamination rate	0.08 ± 0.02	0.43 ± 0.04

background rate & error for the
2200[d] result in 2018 PRL

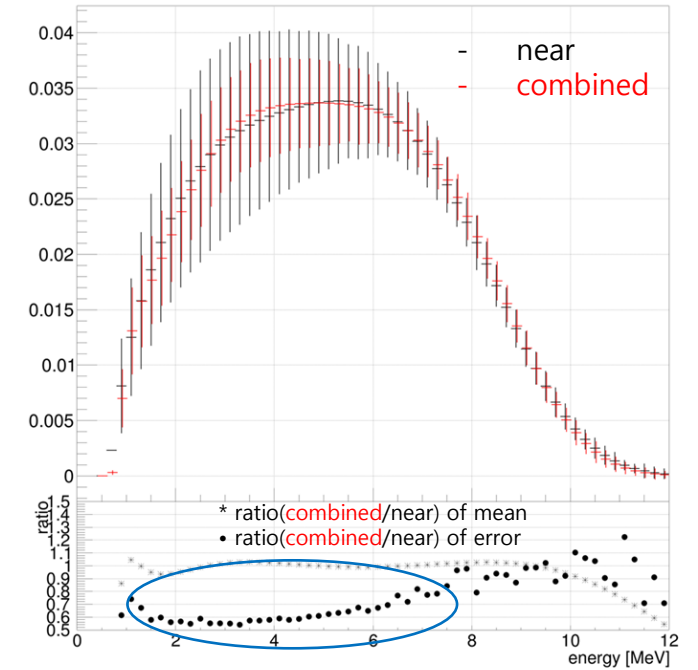
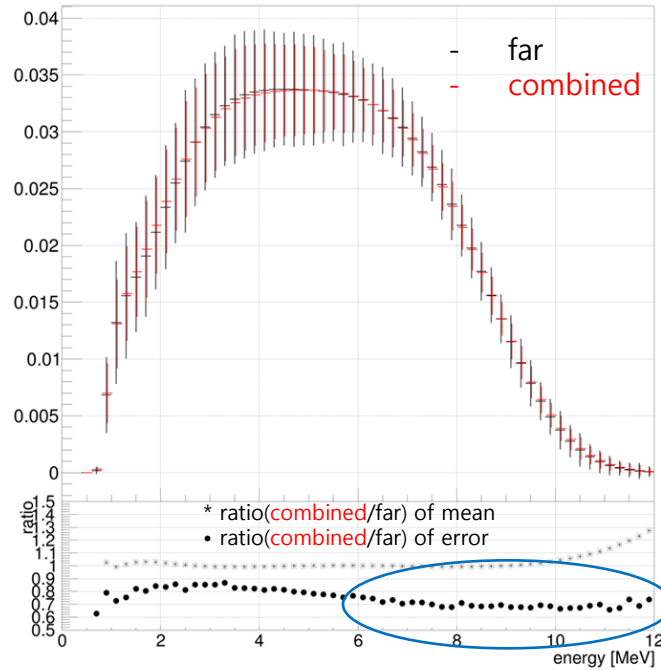
Estimation of ${}^9\text{Li}/{}^8\text{He}$ background



Precision of ${}^9\text{Li}/{}^8\text{He}$ template dominantly affects the background uncertainty, and ultimately $|\Delta m_{ee}^2|$ and θ_{13} .

Combined ${}^9\text{Li}/{}^8\text{He}$ Template

In the 2200d analysis, individual ${}^9\text{Li}/{}^8\text{He}$ template has been used in order to estimate the background rate for each far & near detector. RENO's far & near detector have "identical", so combined template can be used, which is expected to reduce background uncertainty.



frac. err.	far	near	combine	combined with 3350[d]
1.2~8 [MeV]	0.0361	0.0510	0.0295	0.0221
7~12 [MeV]	0.0514	0.0387	0.0358	0.0264

Significant reduction of systematic uncertainty in 3800d result is expected. Detail effect of the combined template on $|\Delta m_{ee}^2|$ and θ_{13} is under investigation.

Summary

- Since the result for precise measurement of $|\Delta m_{ee}^2|$ and θ_{13} was report in 2018,
 - $\sin^2 2\theta_{13} = 0.0896 \pm 0.0048(\text{stat.}) \pm 0.0047(\text{syst.})$
 - $|\Delta m_{ee}^2| = 2.68 \pm 0.12(\text{stat.}) \pm 0.07(\text{syst.}) (\times 10^{-3} \text{ eV}^2)$, ~1600 days more data has been taken. The total sample corresponds to 3800[d], which is under analysis.
 - $|\Delta m_{ee}^2|$ and θ_{13} measurement
 - reactor neutrino spectrum
 - sterile neutrino search
- The DAQ was shut down on Mar., and the near detector is planed to be re-operated to utilize for the RENE experiment (sterile search).