New Results from RENO

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Korea Neutrino Research Center

RENO Collaboration

Reactor **E**xperiment for **N**eutrino **O**scillation

(8 institutions and 40 physicists)

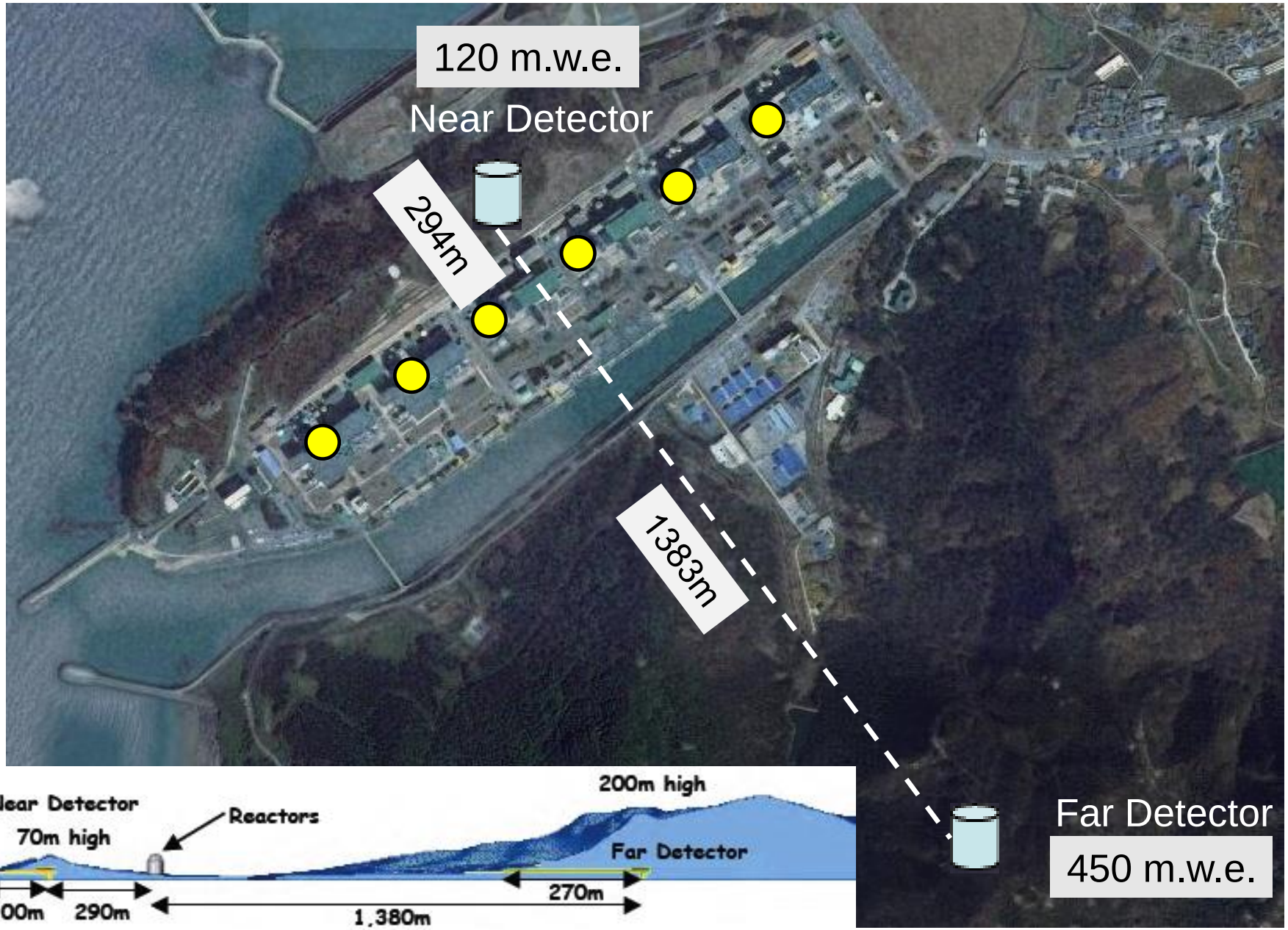
- Chonnam National University
- Dongshin University
- GIST
- KAIST
- Kyungpook National University
- Seoul National University
- Seoyeong University
- Sungkyunkwan University

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

YongGwang (靈光) :

16.8 GW (6 reactors)

RENO Experimental Set-up



New RENO Results

■ 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" → submitted to PRL (arXiv:1806.00248)

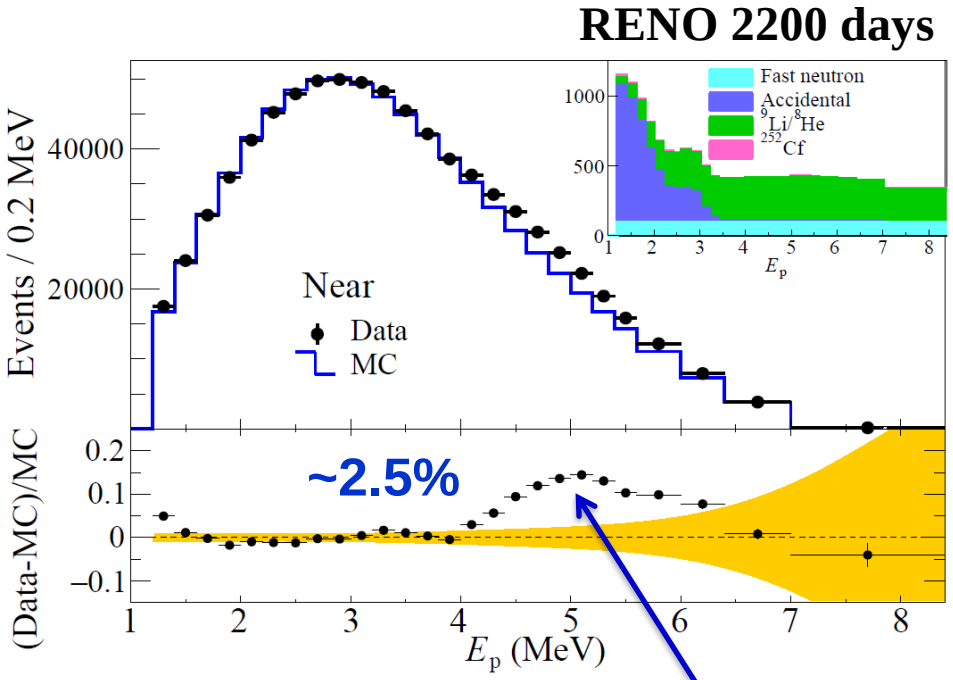
■ Fuel-composition dependent reactor antineutrino yield →
"Fuel-composition dependent reactor antineutrino yield and spectrum at RENO" → submitted to PRL (arXiv: 1806.00574)

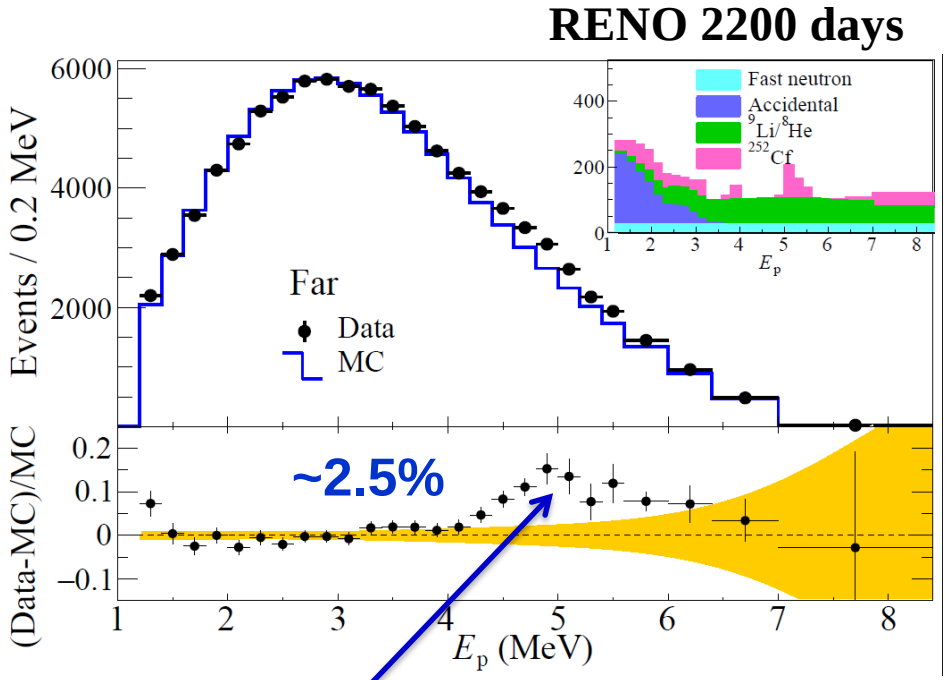
■ Measurement of absolute reactor neutrino flux and spectrum

■ Independent measurement of $|\Delta m_{ee}^2|$ and θ_{13} with delayed n-H signals

Measured Spectra of IBD Prompt Signal

Clear excess at 5 MeV

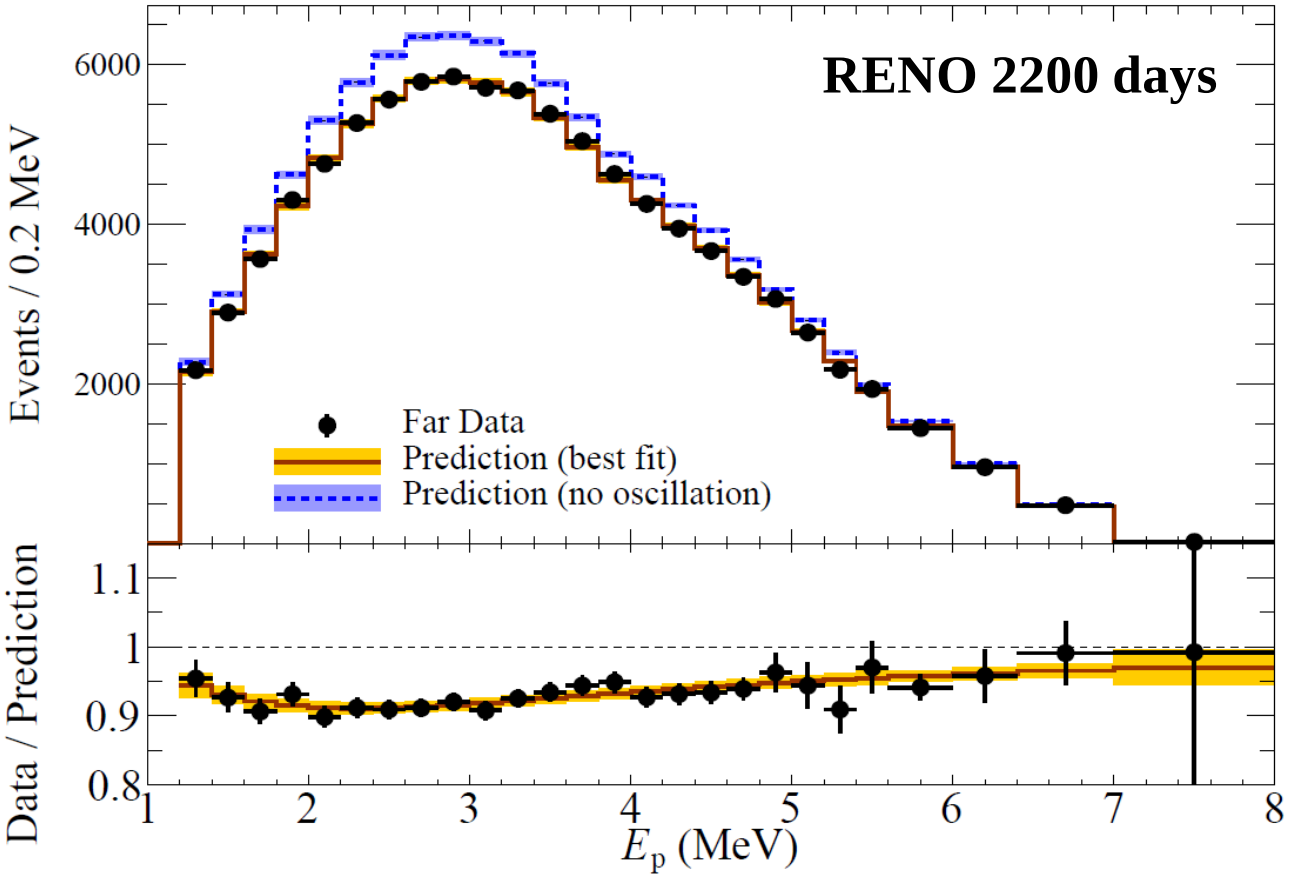




In 2014, RENO showed the 5 MeV excess comes from reactors.

Far/Near Shape Analysis

Energy-dependent disappearance of reactor antineutrinos

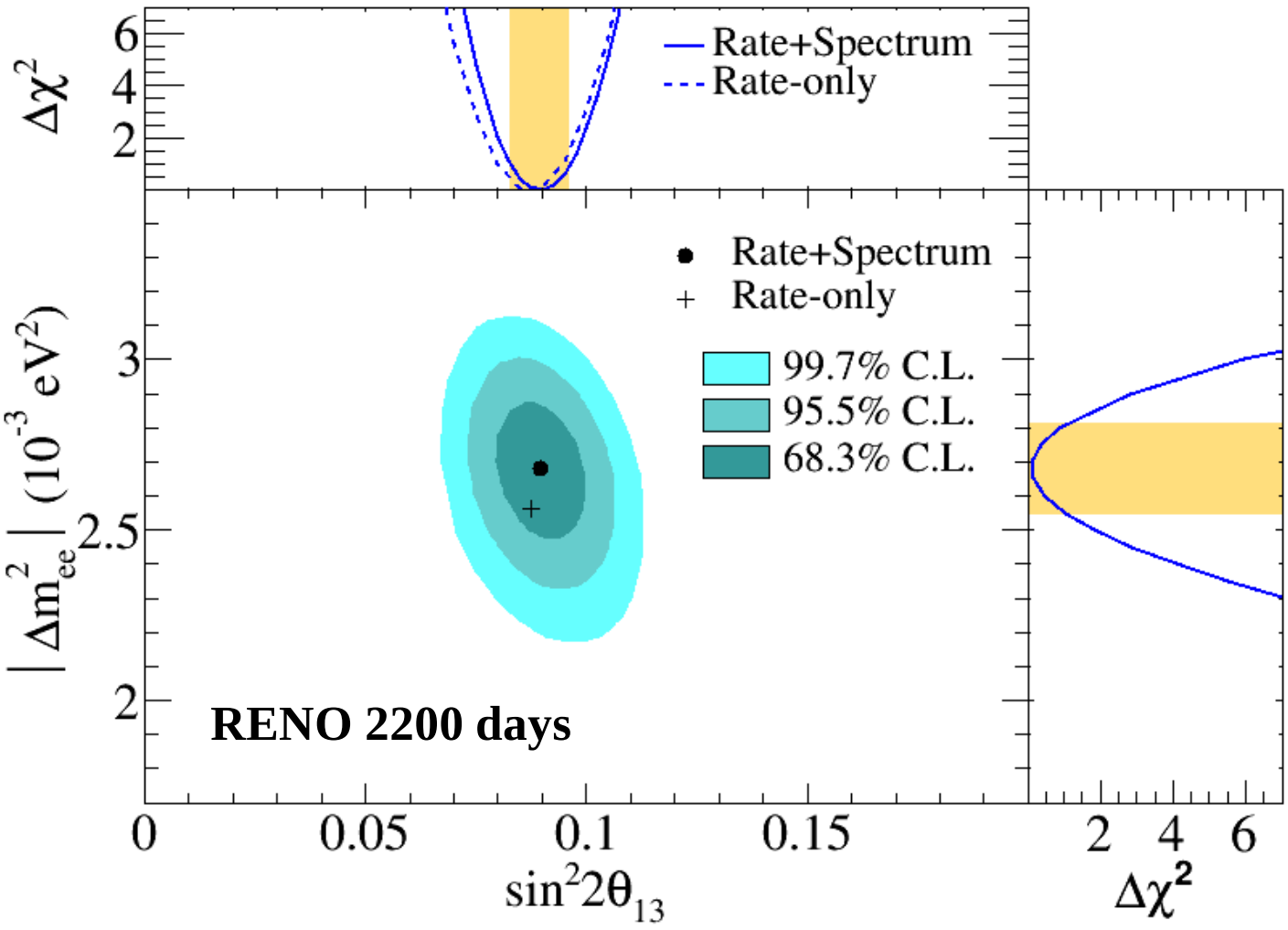


$$\sin^2 2\theta_{13} = 0.0896 \pm 0.0048(\text{stat.}) \pm 0.0047(\text{syst.})$$ (± 7.6%)

$$|\triangle m_{ee}^2| = 2.68 \pm 0.12(\text{stat.}) \pm 0.07(\text{syst.}) \ (\times 10^{-3}\ \text{eV}^2)$$ (± 5.2 %)

Poster Presentation "Precise measurement of Δm_{ee}^2 and θ_{13} at RENO" by D. H. Lee (# 569)

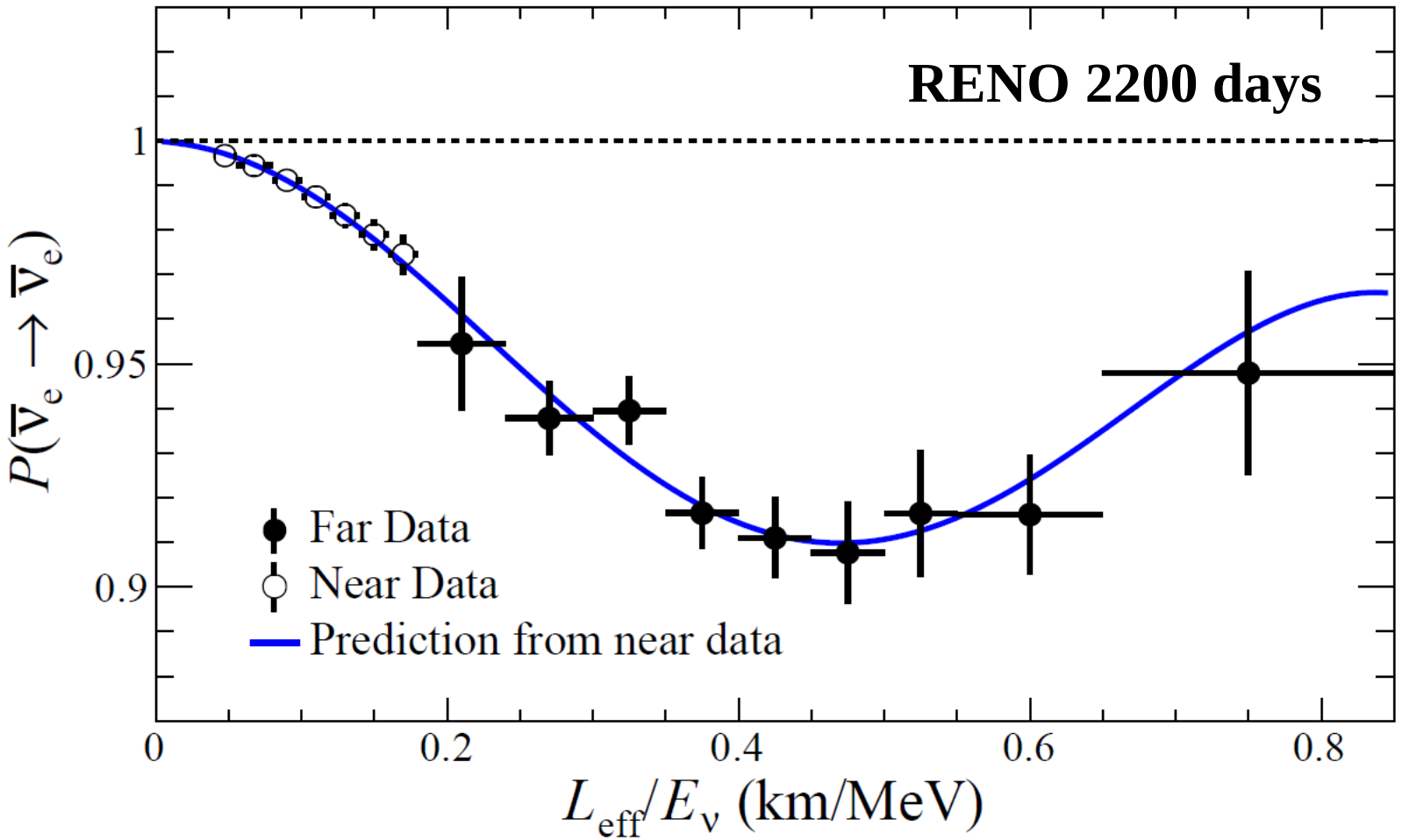
Results of θ_{13} and $|\Delta m^2_{ee}|$



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

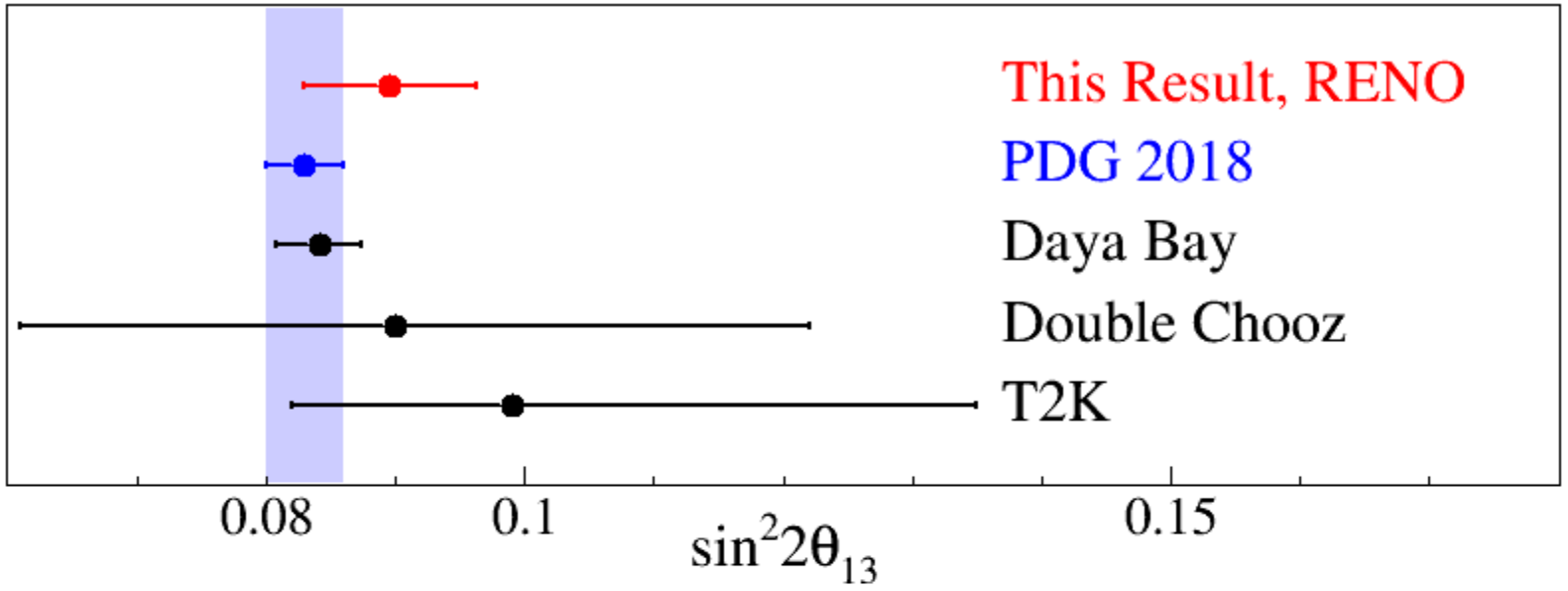
$$|\triangle m_{ee}{}^2| = 2.68 \pm 0.12(\text{stat.}) \pm 0.07(\text{syst.}) \ (\times 10^{-3}\ \text{eV}^2)$$

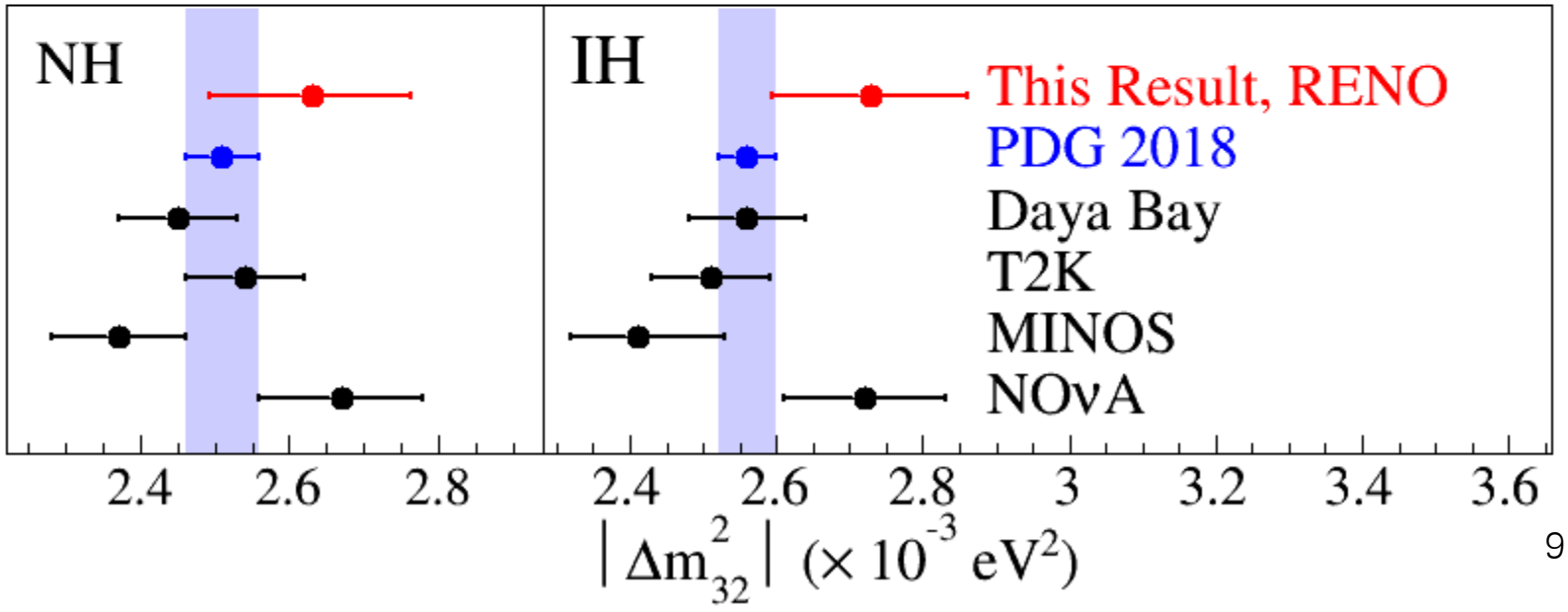
Observed L/E Dependent Oscillation



$$P(\bar{n}_e \to \bar{n}_e) \approx 1 - \sin^2 2q_{13} \sin^2\left(\Delta m^2_{ee} \frac{L}{4E_n}\right)$$

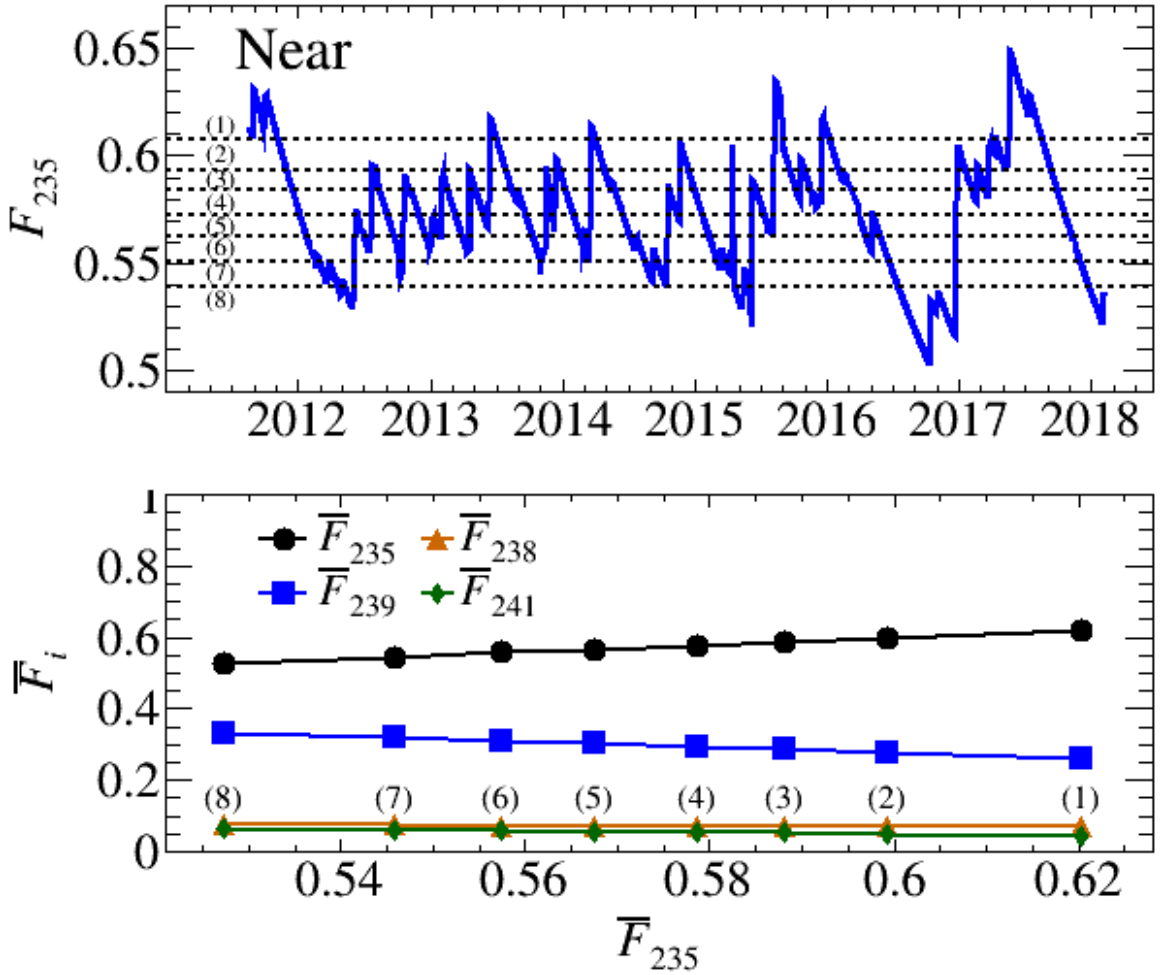
Comparison of θ_{13} and $|\Delta m^2_{ee}|$





Evolution of Fuel Isotope Fraction

8 groups of near IBD samples with different ^{235}U isotope fraction



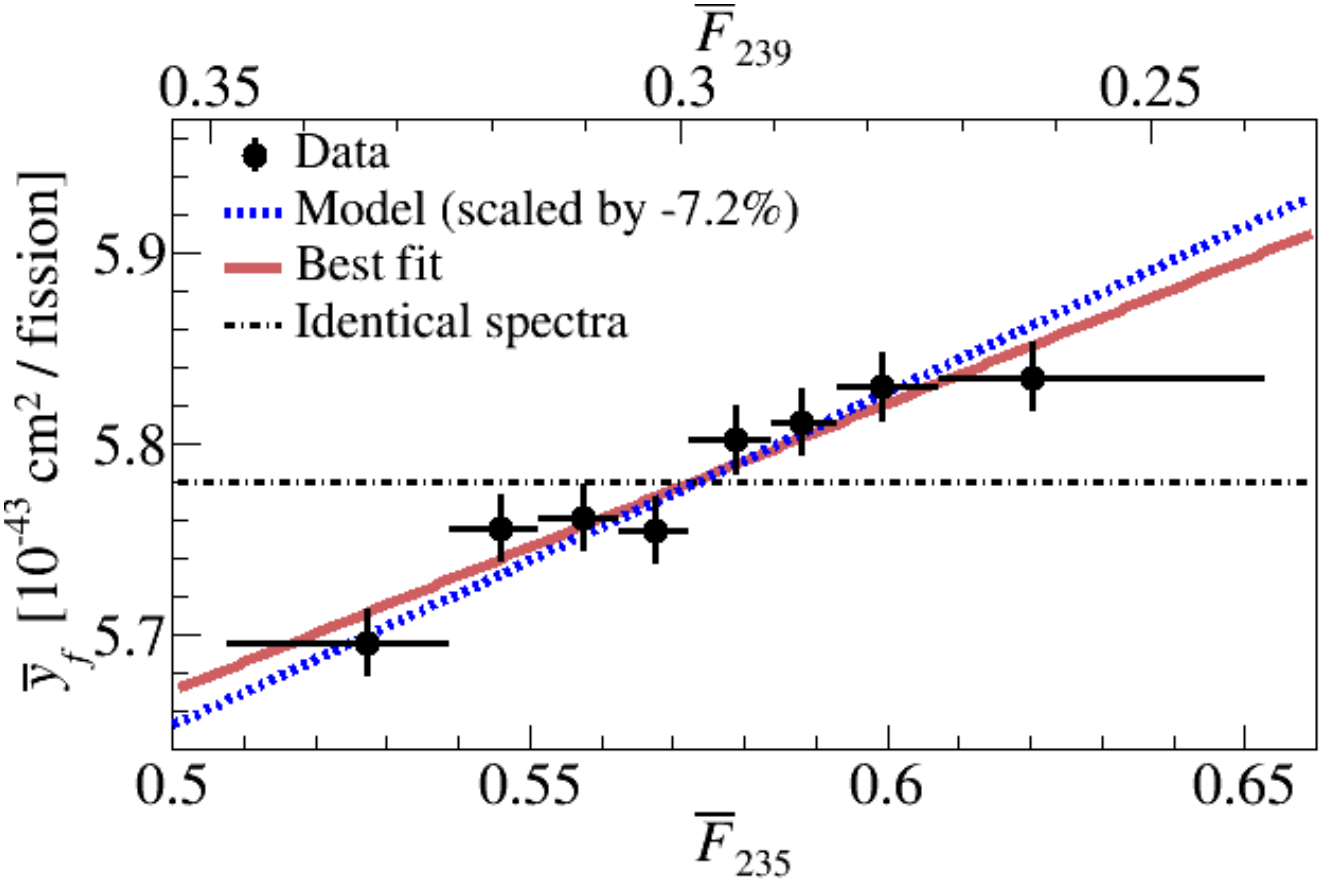
Average fission fraction

f_{235}: f_{239}: f_{238}: f_{241}= 0.573 : 0.299 : 0.073 : 0.055

Fuel-Composition Dependent Reactor Neutrino Yield

Observation of fuel(energy)-dependent variation in IBD yield

→ 6.7σ rejection of identical reactor antineutrino spectra between 4 main fuel isotopes



IBD yield per fission

$$y = \int \sigma(E_\nu)\phi(E_\nu)dE_\nu$$

$\phi(E_\nu)$: energy spectrum

$$\overline{y}_f = \sum \overline{F}_i y_i$$

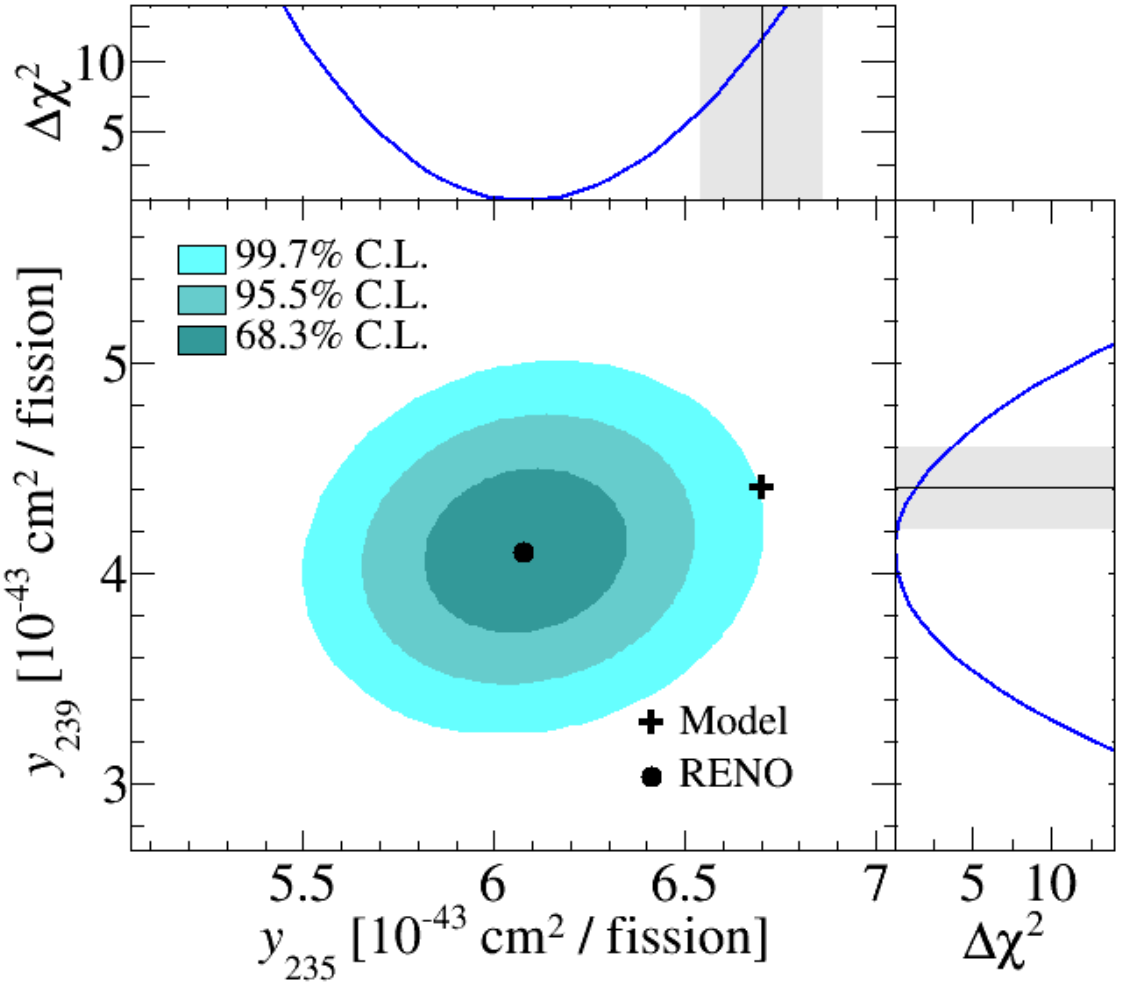
$\overline{F}_i$: time averaged fission fraction of isotope i

Reactor Antineutrino Yield per ^{235}U vs. ^{239}Pu Fission

The best-fit measured yields per fission of ^{235}U (^{239}Pu)

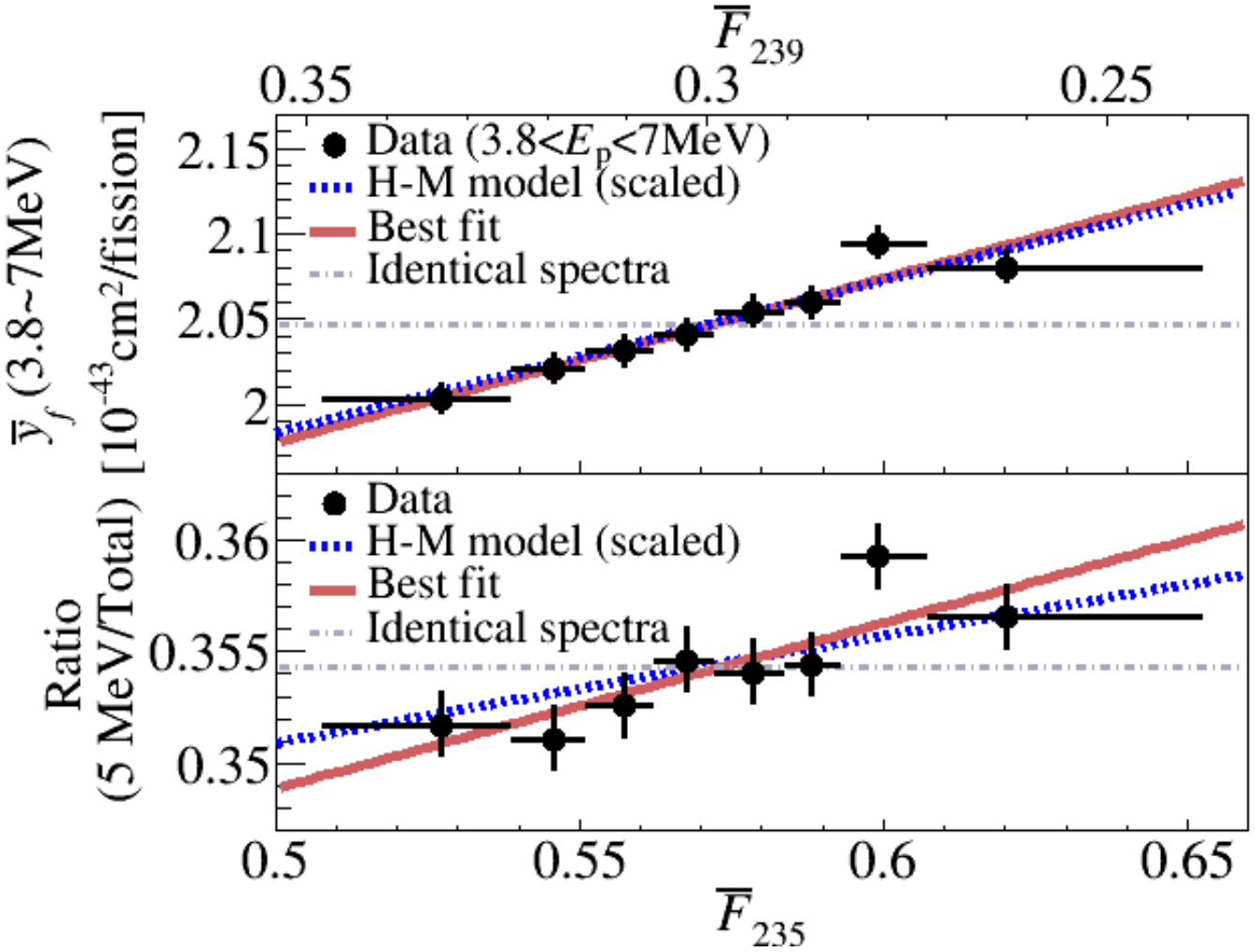
→ ^{235}U: 3.5σ deficit relative to Huber-Mueller (H-M) prediction

^{239}Pu: 1.2σ deficit



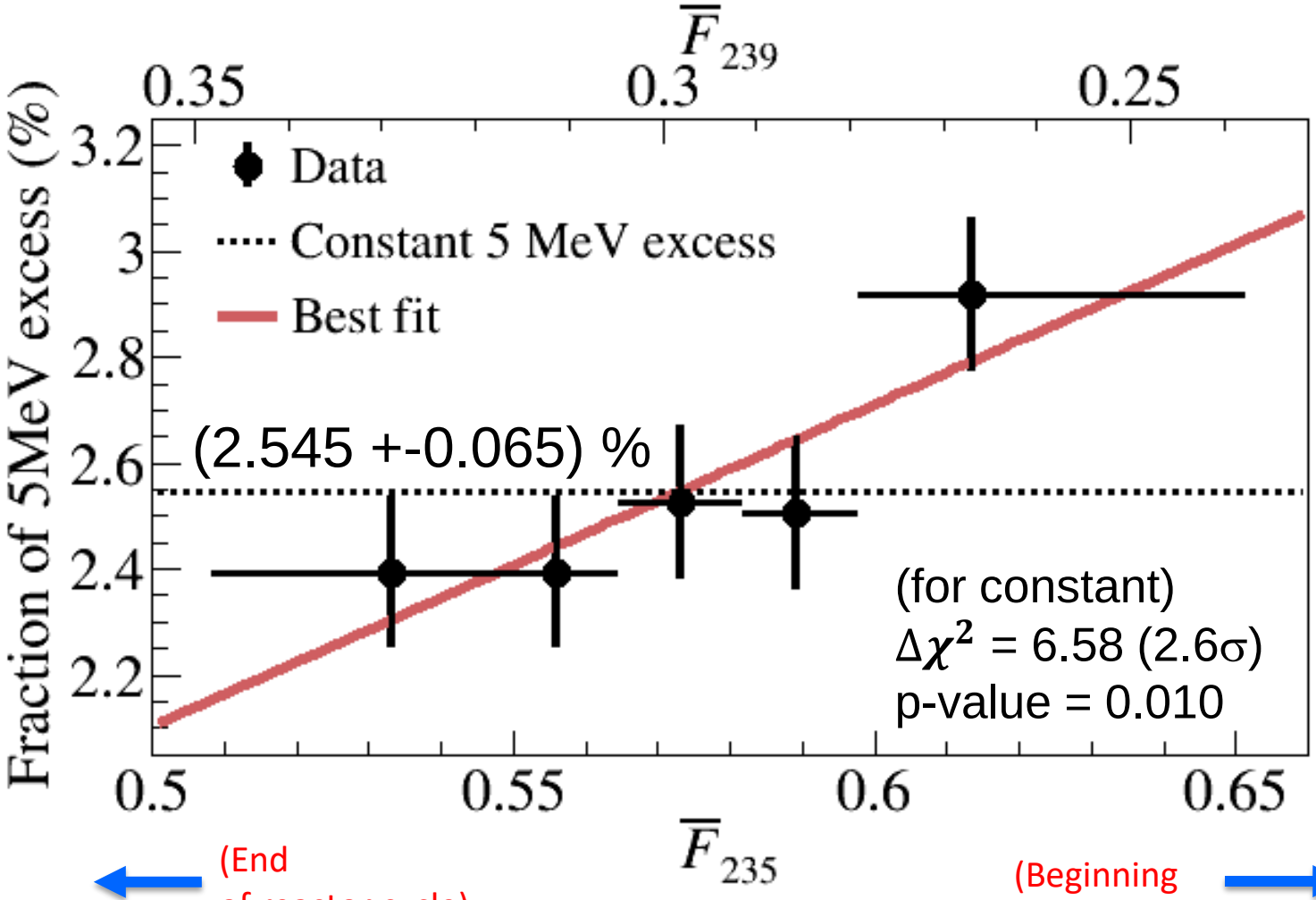
IBD Yield Variation of 5 MeV Excess Region

Ratio of IBD yield per fission between “5 MeV excess region” and “total” → Weak indication of enhanced yield in 5 MeV excess region due to ^{235}U isotope fraction increase….



Correlation of 5 MeV excess with ^{235}U isotope fraction

2.6σ indication of 5 MeV excess coming from ^{235}U fuel isotope fission !!

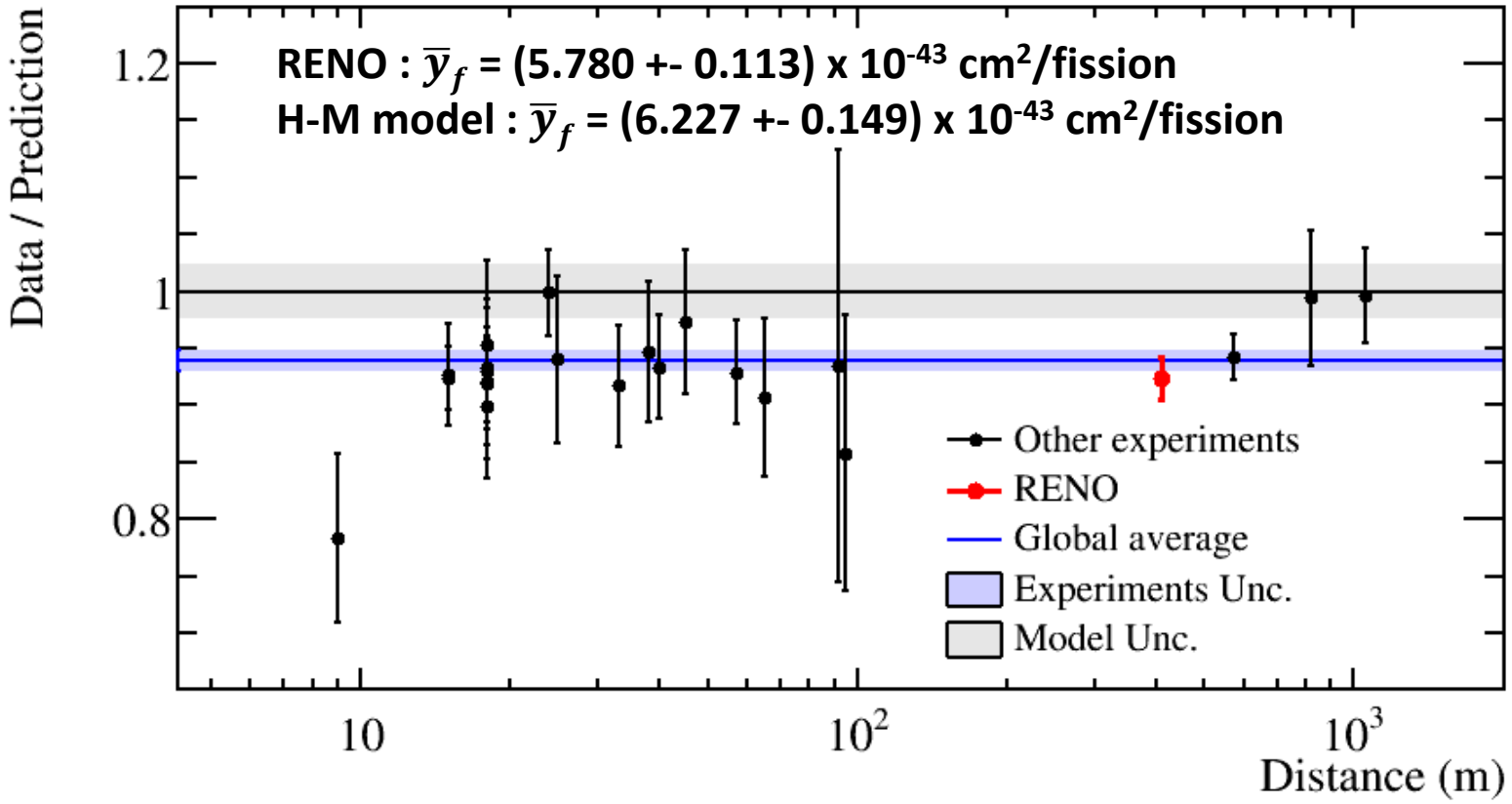


Measurement of Absolute Reactor Neutrino Flux

Cross section calculation
- Vogel 84 formalism
- τ_n = 880.2s (PDG2017)

Data / Prediction, RENO 2200 days at near detector

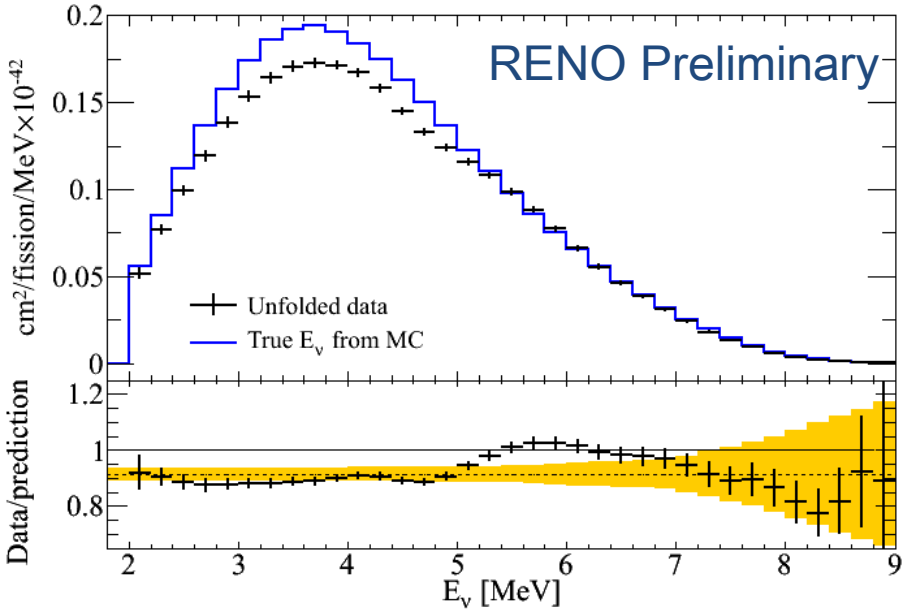
0.924 +- 0.018 (for Huber + Mueller model)
0.966 +- 0.019 (for ILL + Vogel model)



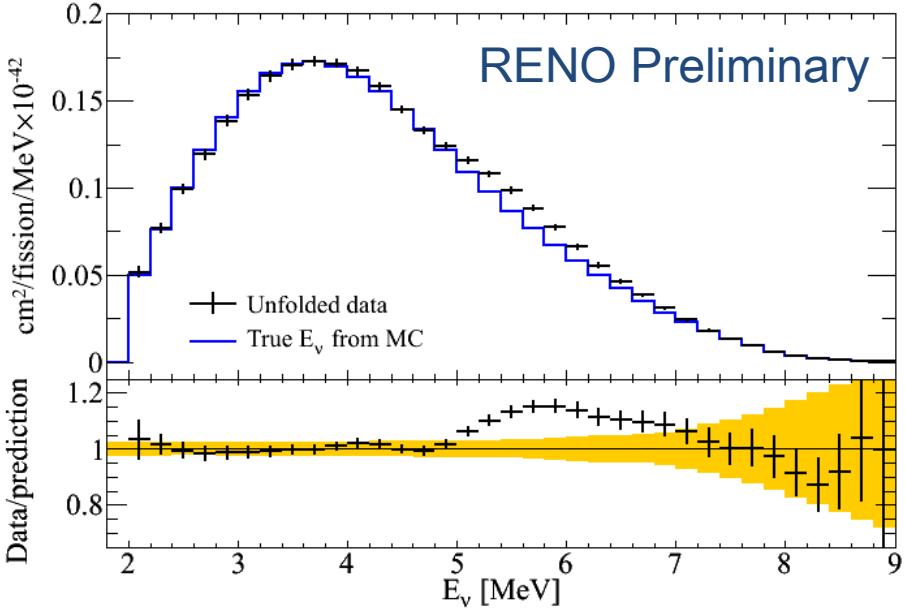
Deficit of observed reactor neutrino fluxes relative to the prediction (Huber + Mueller model) indicates an overestimated flux or possible oscillation to sterile neutrinos

Unfolded Reactor Antineutrino Spectrum

Measured spectrum vs. H-M prediction



Spectral comparison



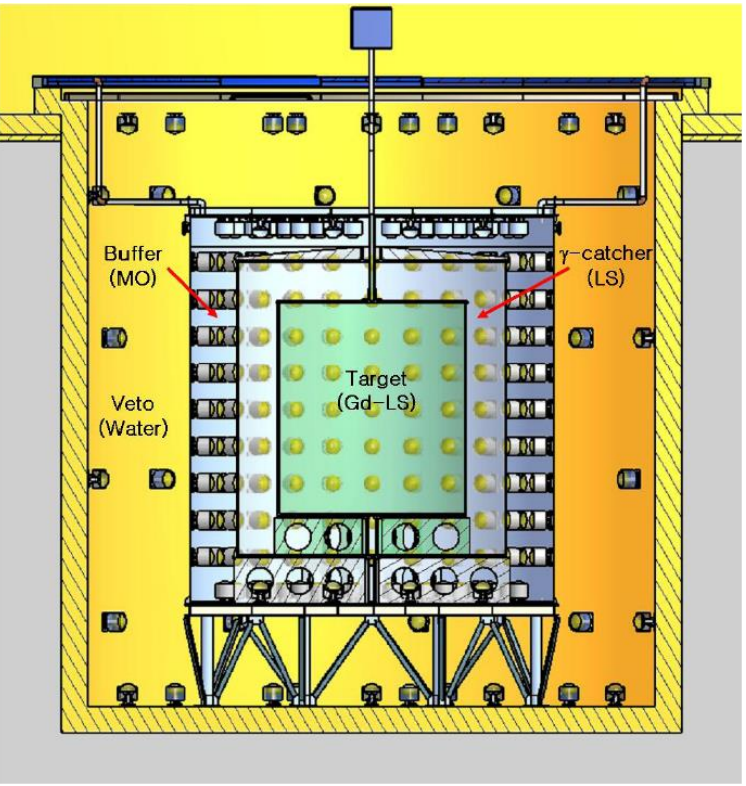
* MC is normalized to data in the region excluding $3.6 < E_p < 6.6$ MeV

- Unfolding using iterative method in *RooUnfold*

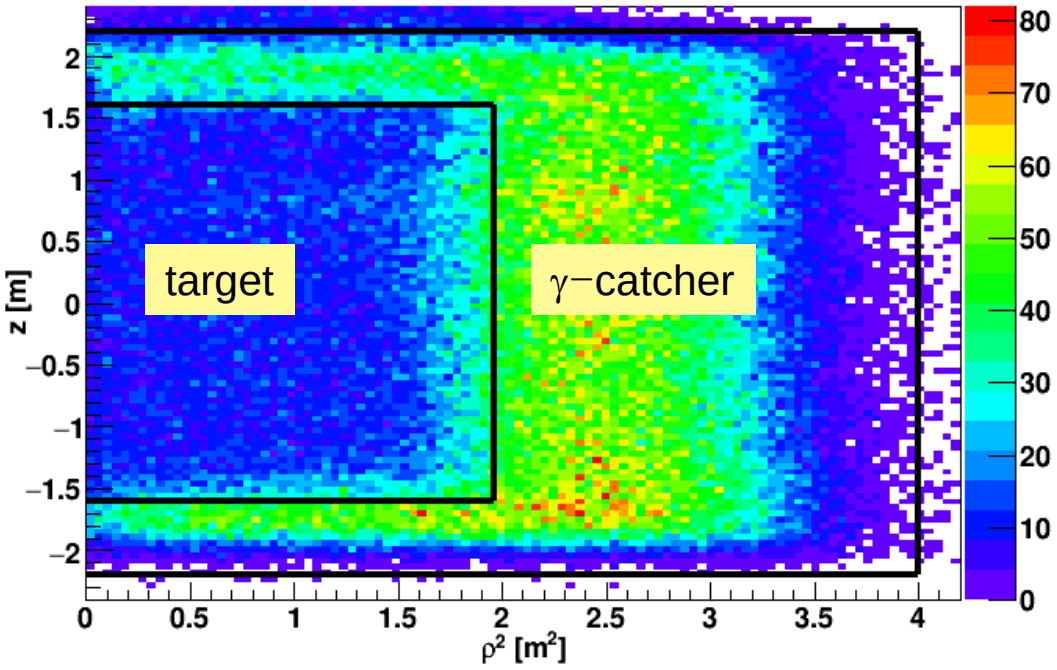
n-H IBD Analysis

Motivation:

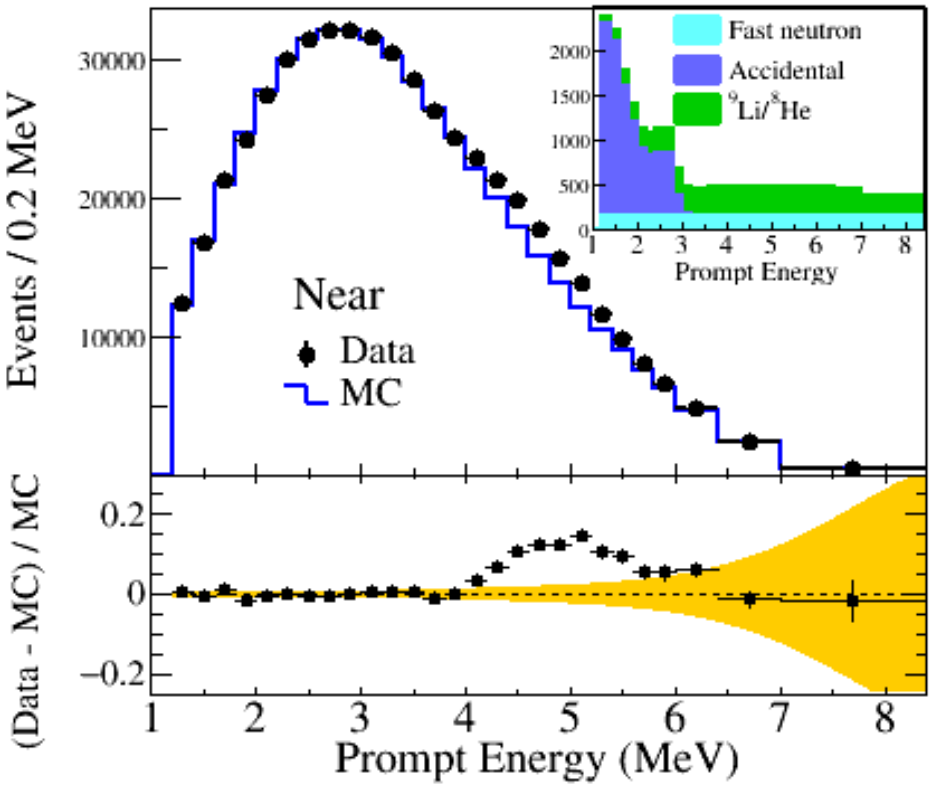
1. Independent measurement of θ_{13} and $|\Delta m_{ee}^2|$.
2. Consistency and systematic check on reactor neutrinos.

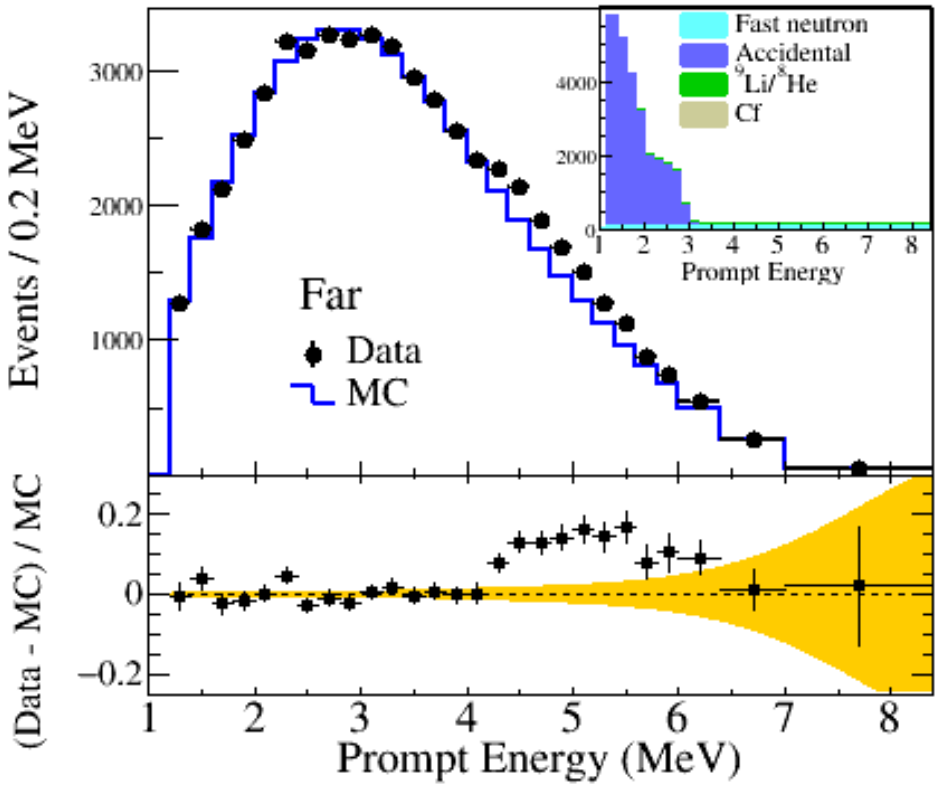


n-H IBD Event Vertex Distribution



θ_{13} Measurement with n-H

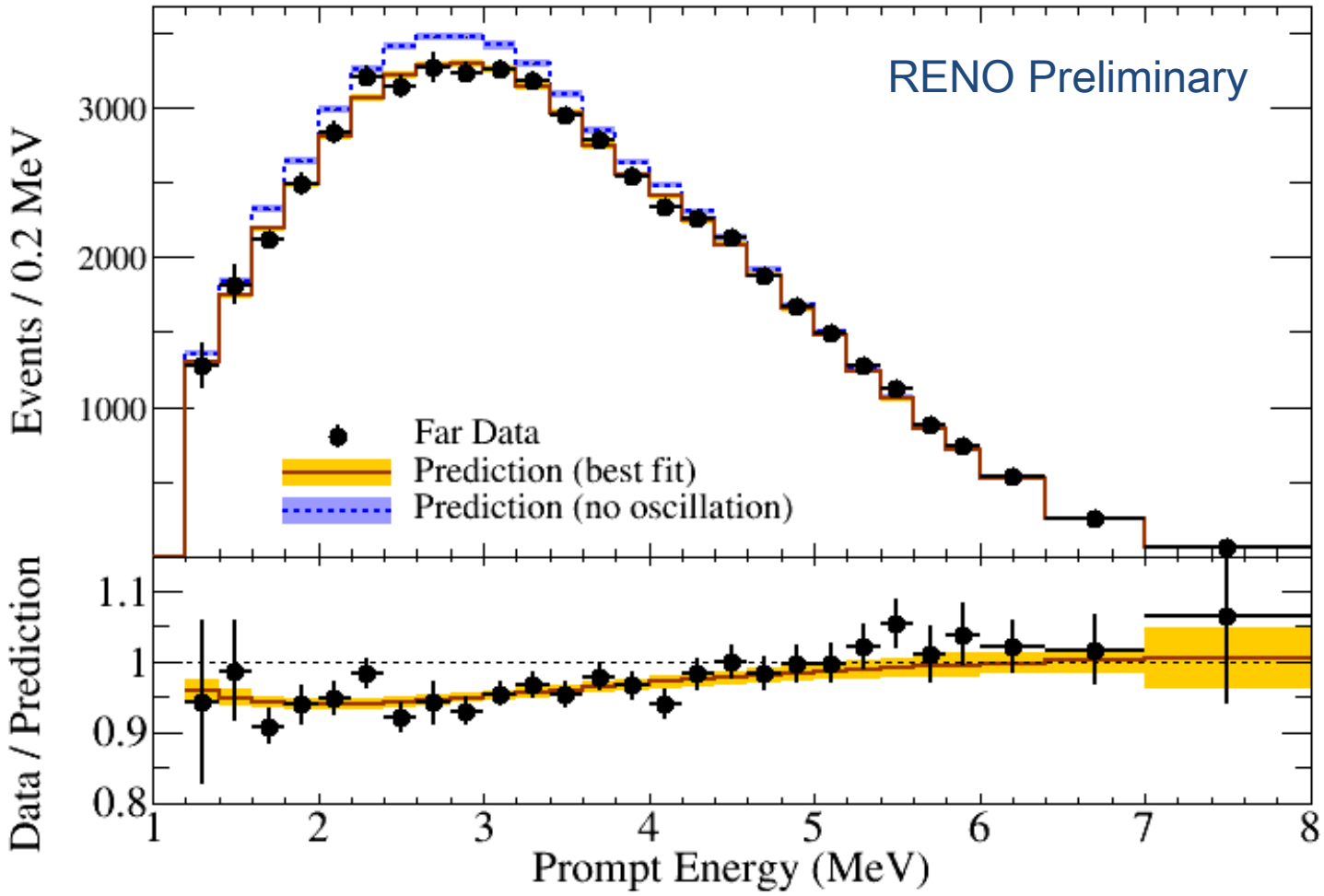




$$\sin^2 2\theta_{13} = 0.085 \pm 0.008(\text{stat.}) \pm 0.012(\text{syst.})$$

Poster Presentation "Measurement of θ_{13} in the reactor neutrino events with neutron captures on Hydrogen at RENO" by C. D. Shin (# 425)

θ_{13} and $|\Delta m^2_{ee}|$ Measurement with n-H



$$\sin^2 2\theta_{13} = 0.094^{+0.012}_{-0.010}(\text{stat}) \pm 0.009(\text{syst})$$

$$|\Delta m^2_{ee}| = 2.53^{+0.25}_{-0.28}(\text{stat.})^{+0.13}_{-0.16}(\text{syst.}) \ (\times 10^{-3}\text{eV}^2)$$

Summary

- More precise measurement of $|\Delta m_{ee}^2|$ and θ_{13} using 2200 days of data

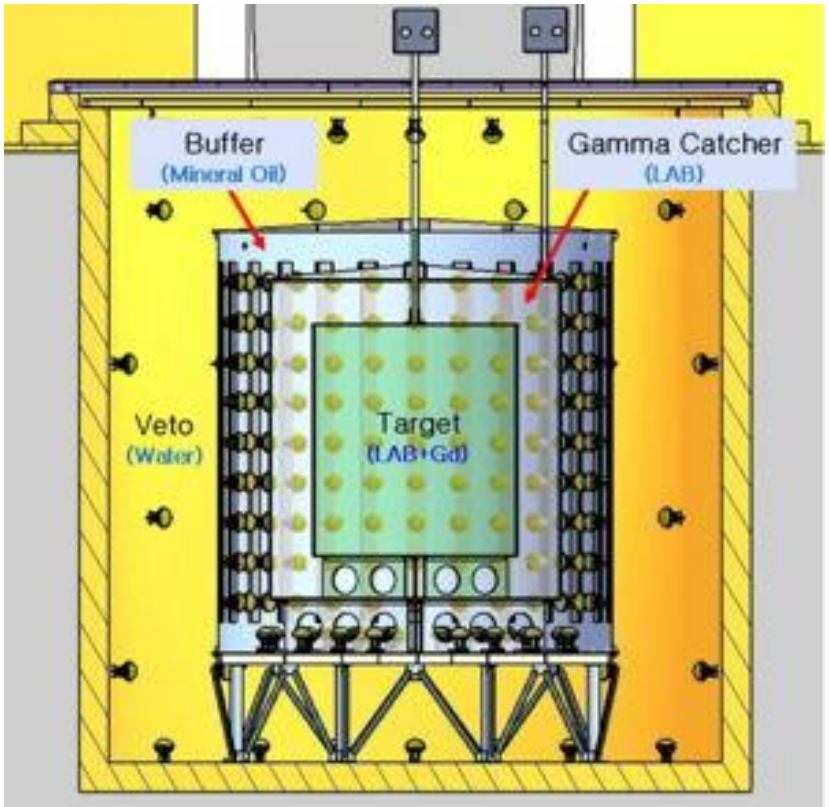
$\sin^2 2\theta_{13} = 0.0896 \pm 0.0048(\text{stat.}) \pm 0.0047(\text{syst.})$ ± 0.0068 7.6 % precision

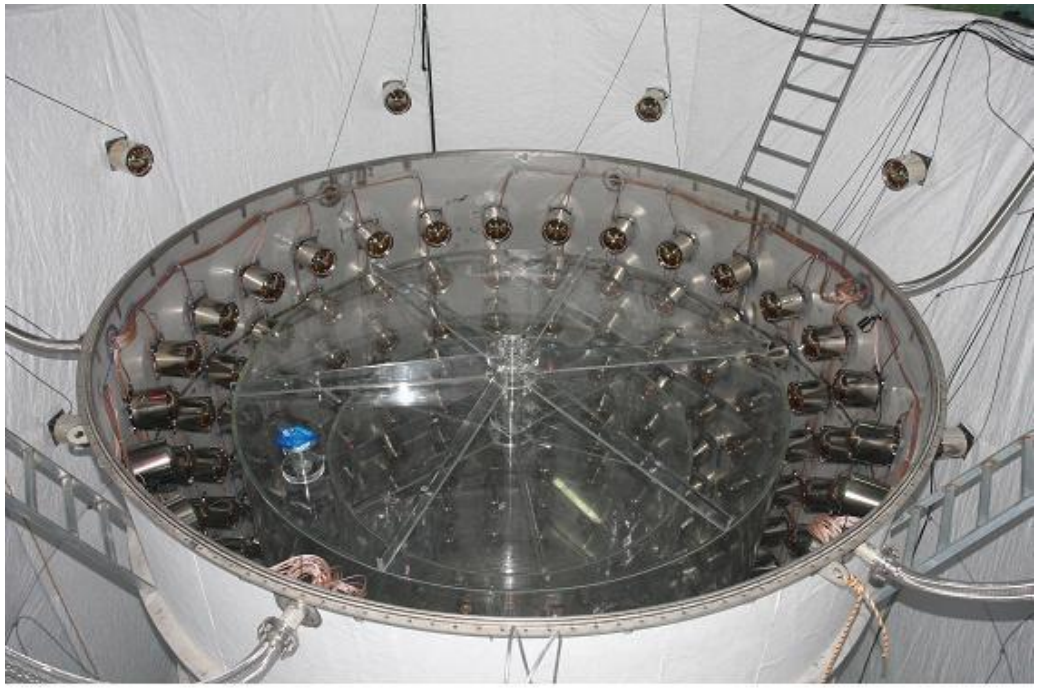
$|\triangle m_{ee}^2| = 2.68 \pm 0.12(\text{stat.}) \pm 0.07(\text{syst.}) \ (\times 10^{-3}\ \text{eV}^2)$ ± 0.14 5.2 % precision

- First hint for correlation between 5 MeV excess and ^{235}U fission fraction
- Measured absolute reactor neutrino flux : R= 0.924±0.018 (H-M)
- Measurement of $|\Delta m_{ee}^2|$ and θ_{13} using n-H IBD analysis
- additional 2~3 years of data taking under consideration to improve Δm_{ee}^2 accuracy and the fuel dependent IBD yield.

Thanks for your attention!

RENO Detector





- 354 ID +67 OD 10” PMTs
- Target : 16.5 ton Gd-LS, R=1.4m, H=3.2m
- Gamma Catcher : 30 ton LS, R=2.0m, H=4.4m
- Buffer : 65 ton mineral oil, R=2.7m, H=5.8m
- Veto : 350 ton water, R=4.2m, H=8.8m

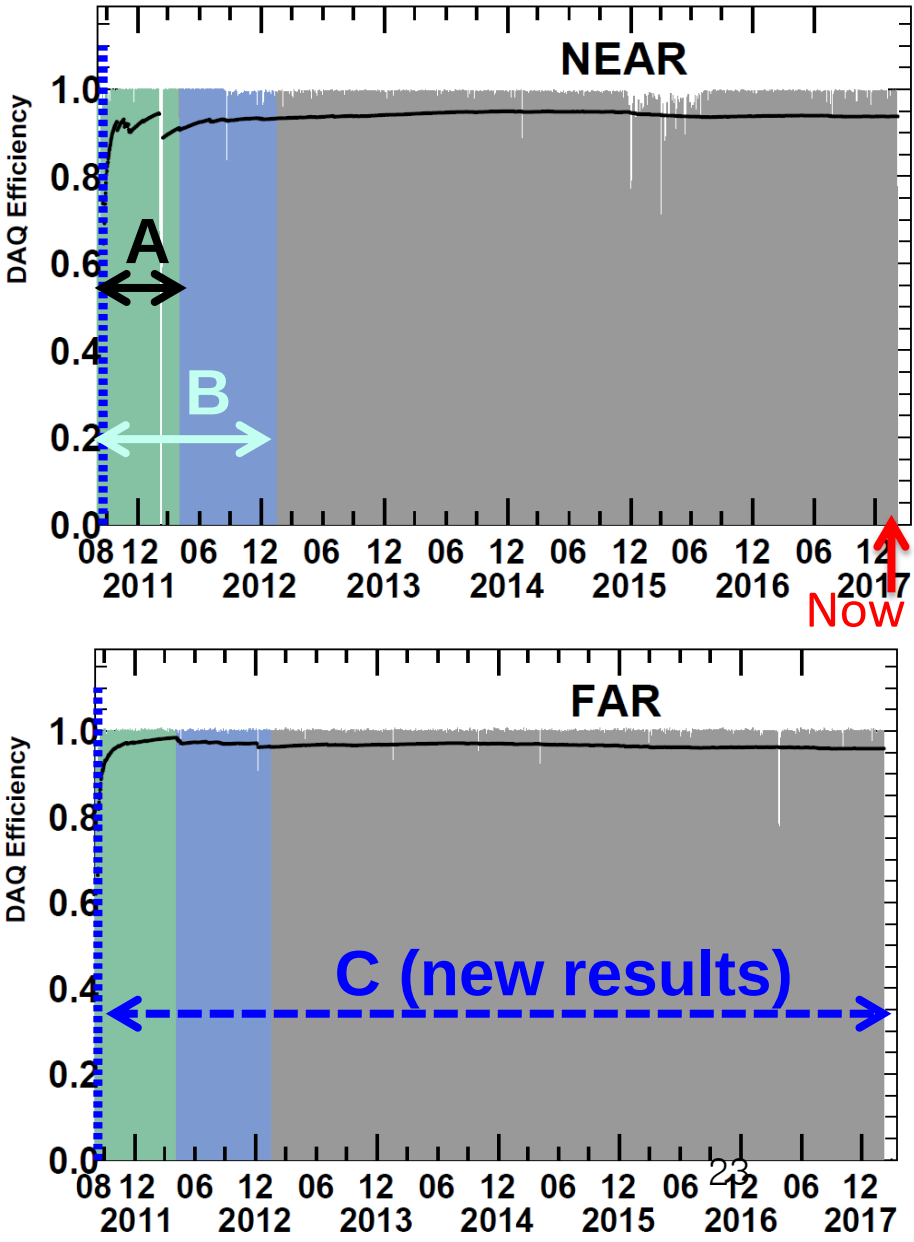
RENO Data-taking Status

- Data taking began on Aug. 1, 2011 with both near and far detectors.
  (DAQ efficiency : ~95%)

- **A (220 days)** : **First θ_{13} result**
  [11 Aug, 2011~26 Mar, 2012]
  PRL 108, 191802 (2012)

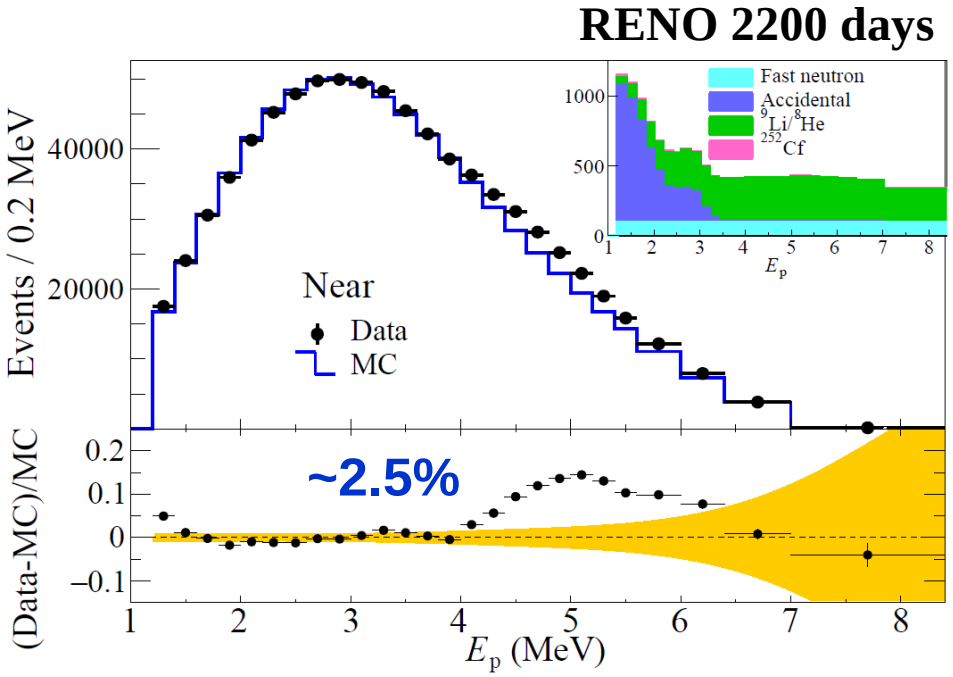
- **B (~500 days)** : **Recent results**
  Rate+shape analysis (θ_{13} **and** $|\Delta m^2_{ee}|$)
  [11 Aug, 2011~21 Jan, 2013]
  → PRL 116, 211801 (2016)
  accepted to PRD (arXiv:1610.04326)

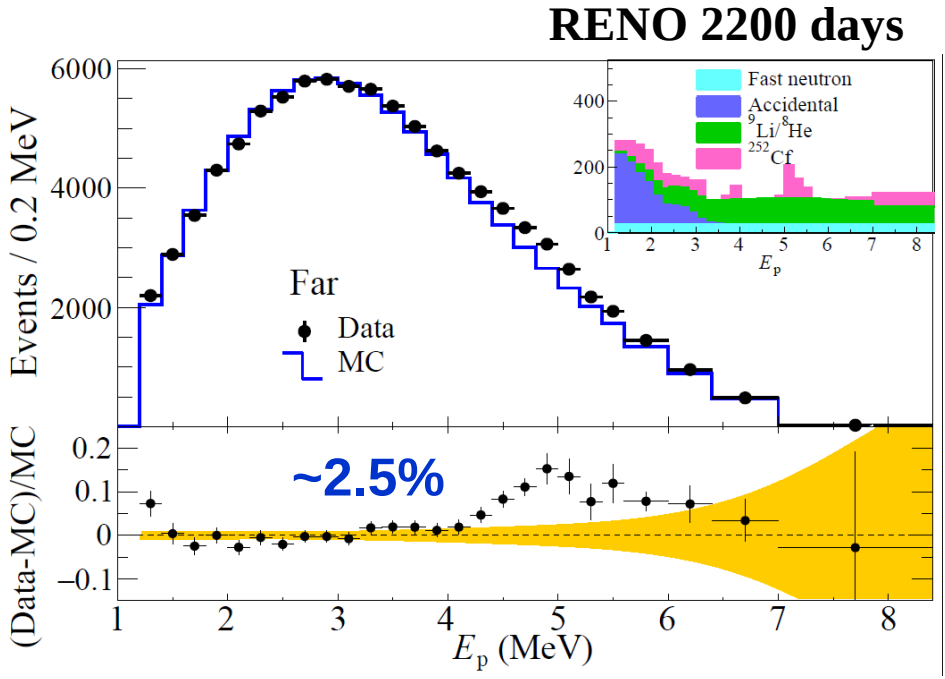
- **C (~2200 days)** : **New results**
  Rate+shape analysis (θ_{13} **and** $|\Delta m^2_{ee}|$)
  [11 Aug, 2011~7 Feb, 2018]
  → submitted to PRL (arXiv:1806.00248)



Measured Spectra of IBD Prompt Signal

Clear excess at 5 MeV

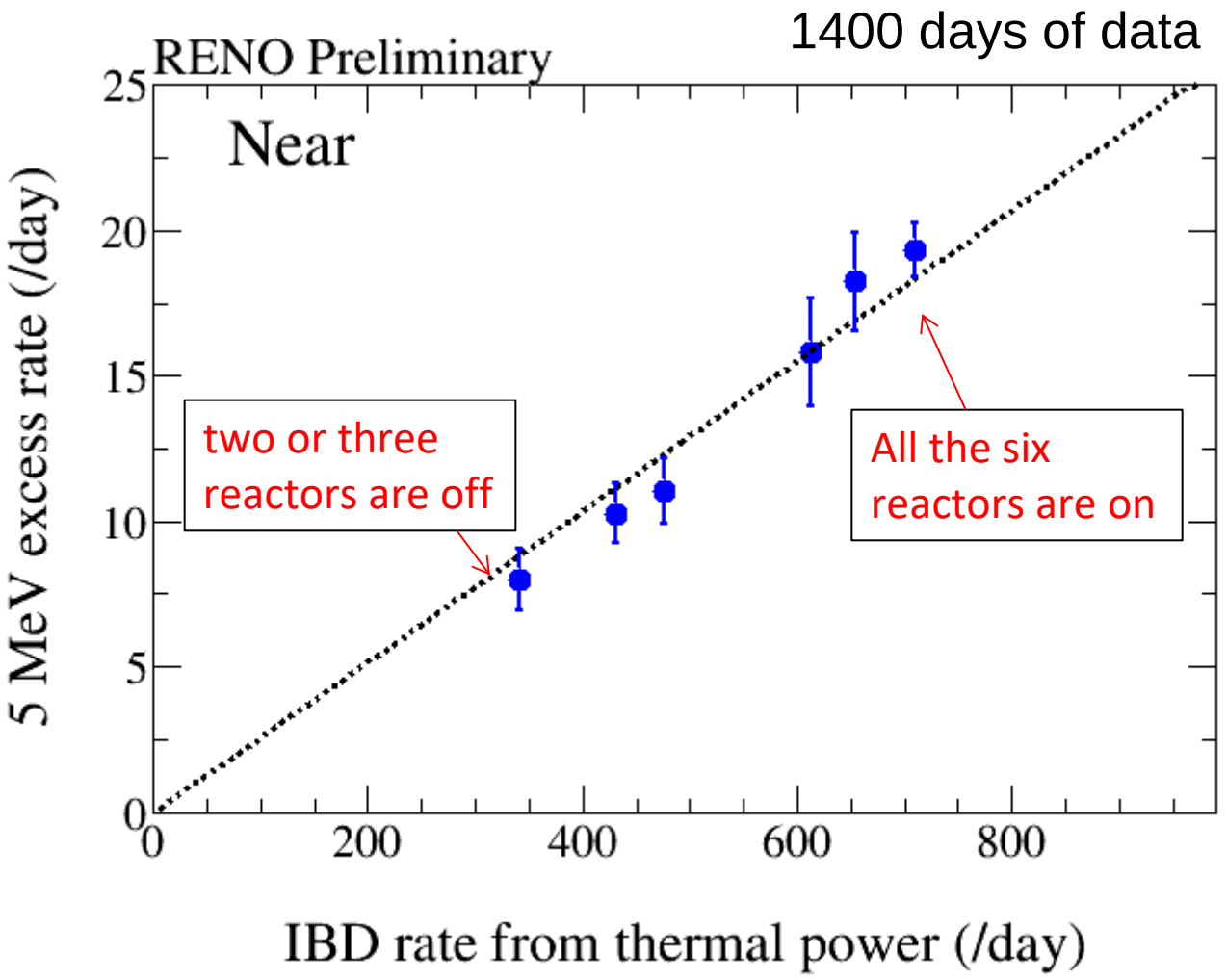




Near Live time = 1807.88 days
# of IBD candidate = 850,666
# of background = 17,233 (2.0 %)

Far Live time = 2193.04 days
# of IBD candidate = 103,212
# of background = 4,879 (4.8 %)

Correlation of 5 MeV Excess with Reactor Power



5 MeV excess has a clear correlation with reactor thermal power !

The 5 MeV excess comes from reactors!