New Results from RENO

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GIST, Korea

NuFact 2018

Blacksburg, Virginia, Aug. 13-18, 2018

KNRC

Korea Neutrino Research Center

RENO Collaboration

Reactor Experiment for Neutrino Oscillation

(8 institutions and 30 physicists)

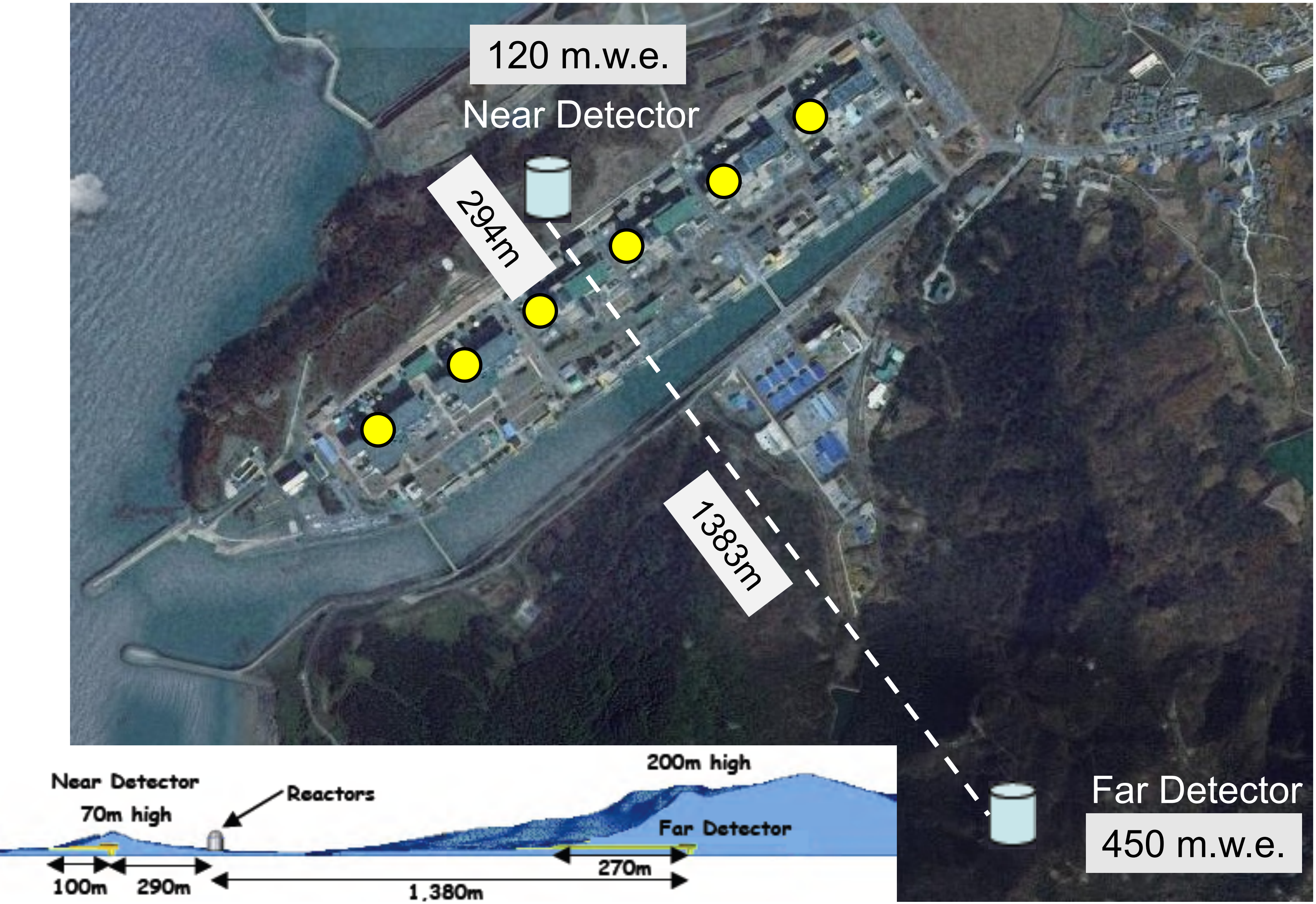
- Chonnam National University
- Dongshin University
- GIST
- KAIST
- Kyungpook National University
- Seoul National University
- Seoyeong University
- Sungkyunkwan University

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

Hanbit nuclear power plant in YongGwang :

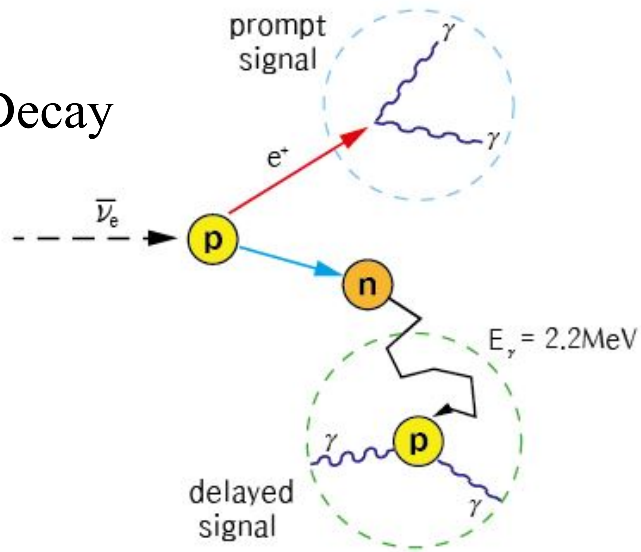
16.8 GW (6 reactors)

RENO Experimental Set-up

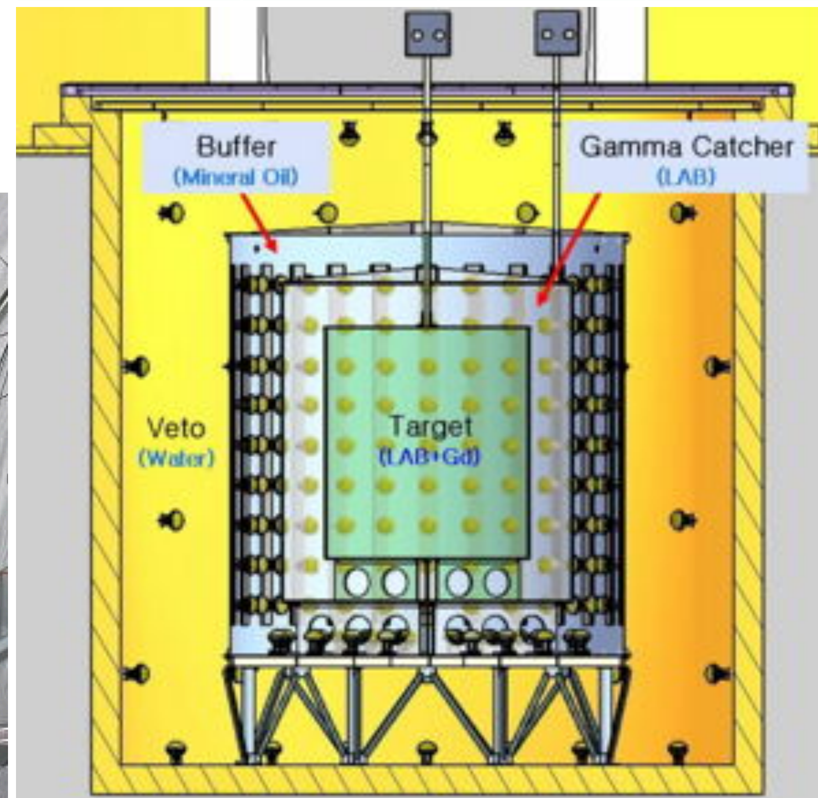


Detection of Anti-neutrino

Invers Beta Decay (IBD)



Inner Detector			Outer Detector
354 10" PMTs			67 10" PMTs
(Target) Gd-LS 16.5 tons	(γ Catcher) LS 30 tons	(Buffer) Mineral Oil 65 tons	(Veto) Water 350 tons



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)

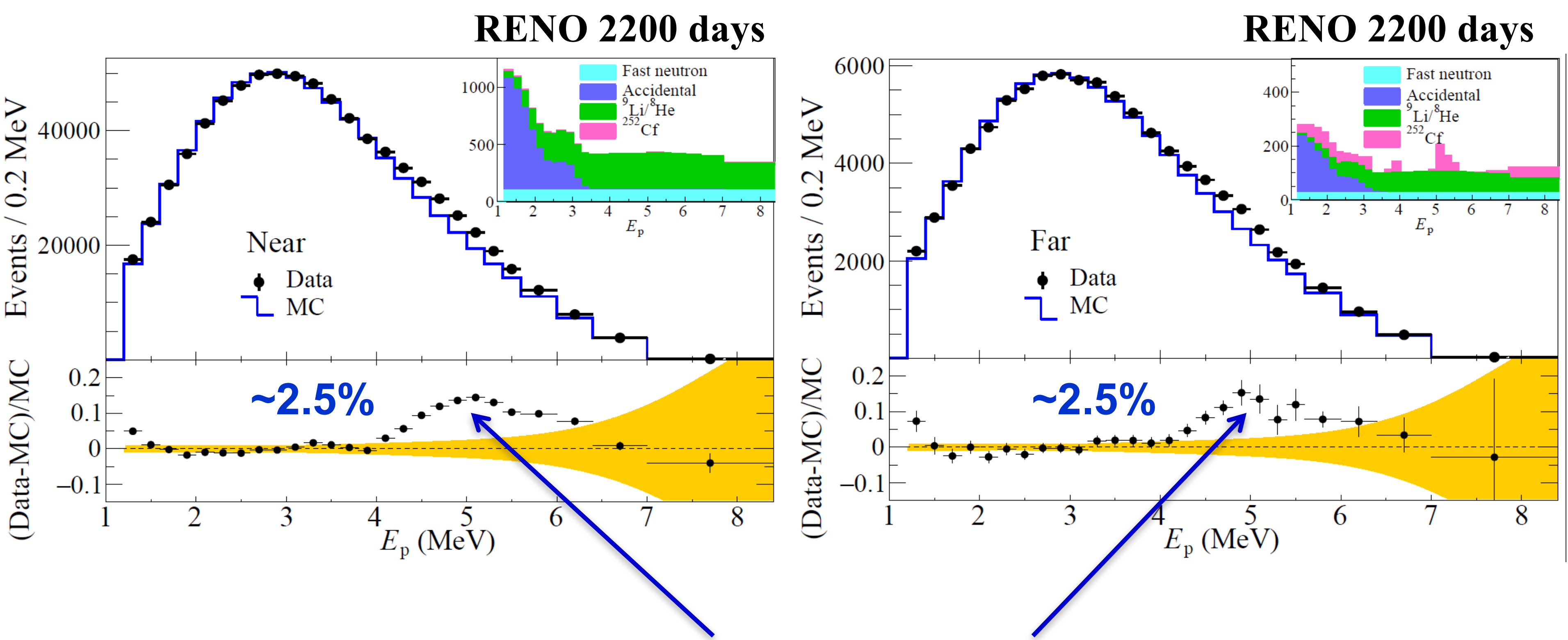
■ Fuel-composition dependent reactor antineutrino yield →
"Fuel-composition dependent reactor antineutrino yield and spectrum at RENO" → submitted to PRL (arXiv: 1806.00574)

■ Measurement of absolute reactor neutrino flux and spectrum

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

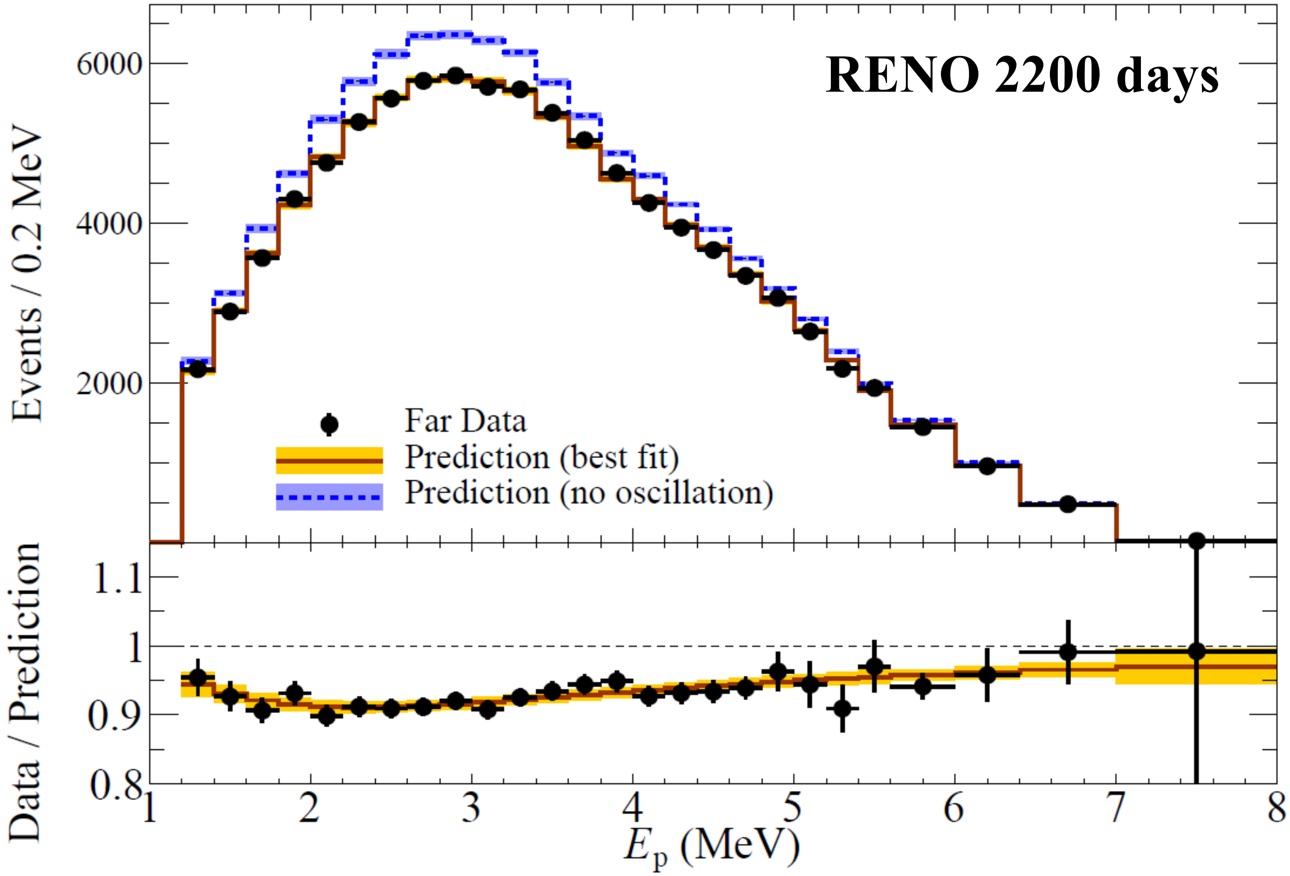
Measurement of $|\Delta m_{ee}^2|$ and θ_{13}

Spectral shape of observed and expected IBD prompt signal



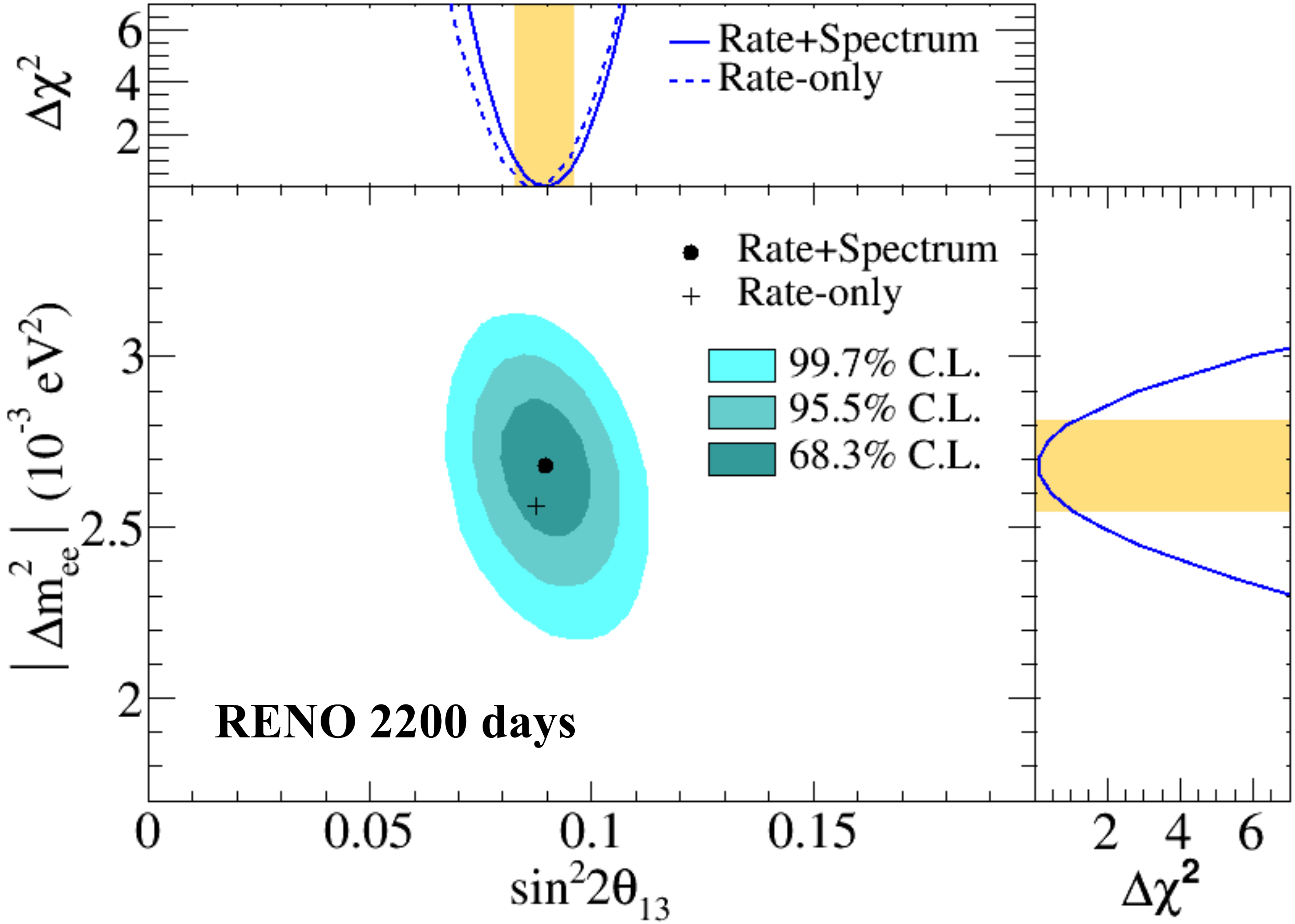
Clear excess at 5 MeV

Spectral shape of Far / Near



Energy-dependent disappearance of reactor antineutrinos

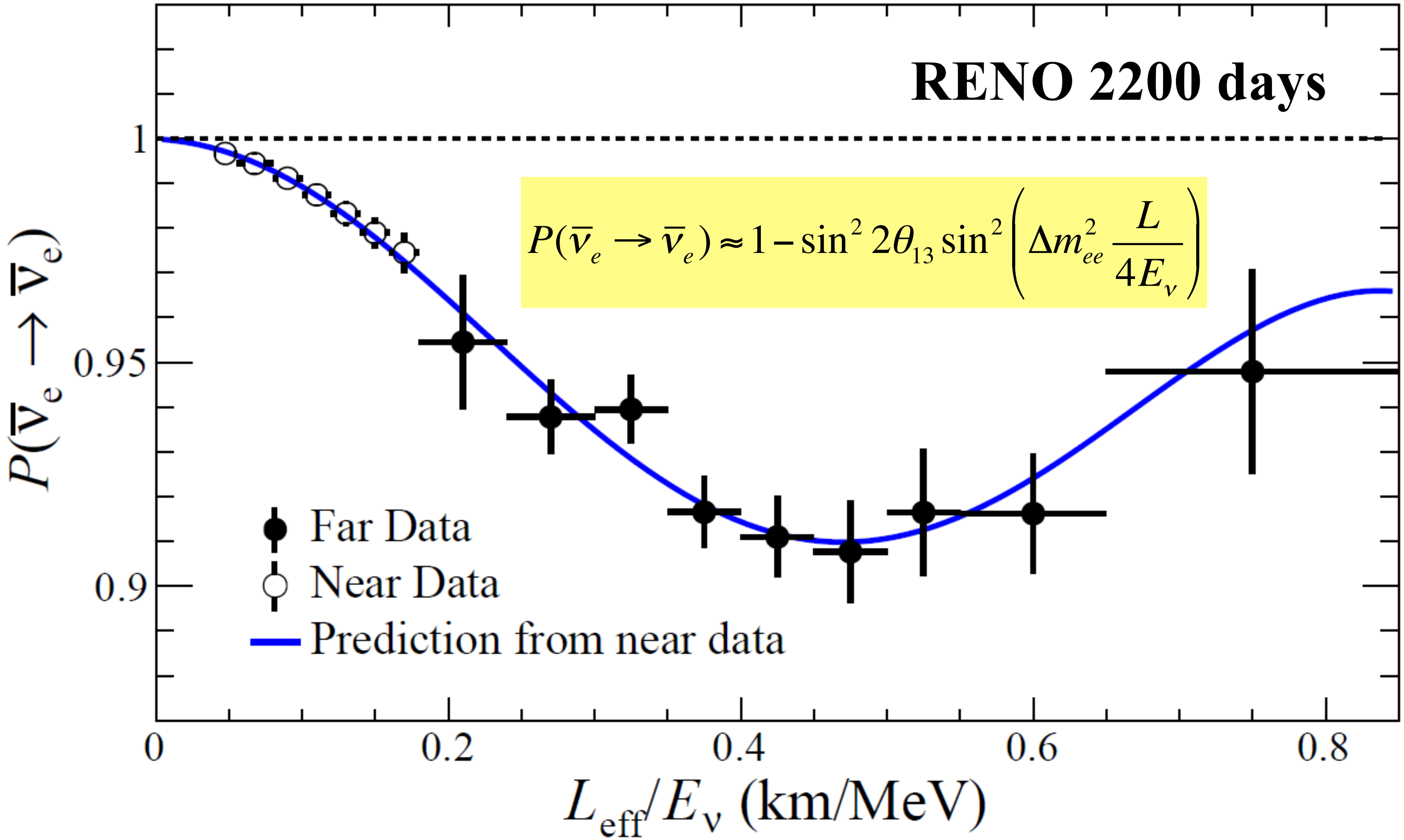
Allow regions for θ_{13} and $|\Delta m^2_{ee}|$



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

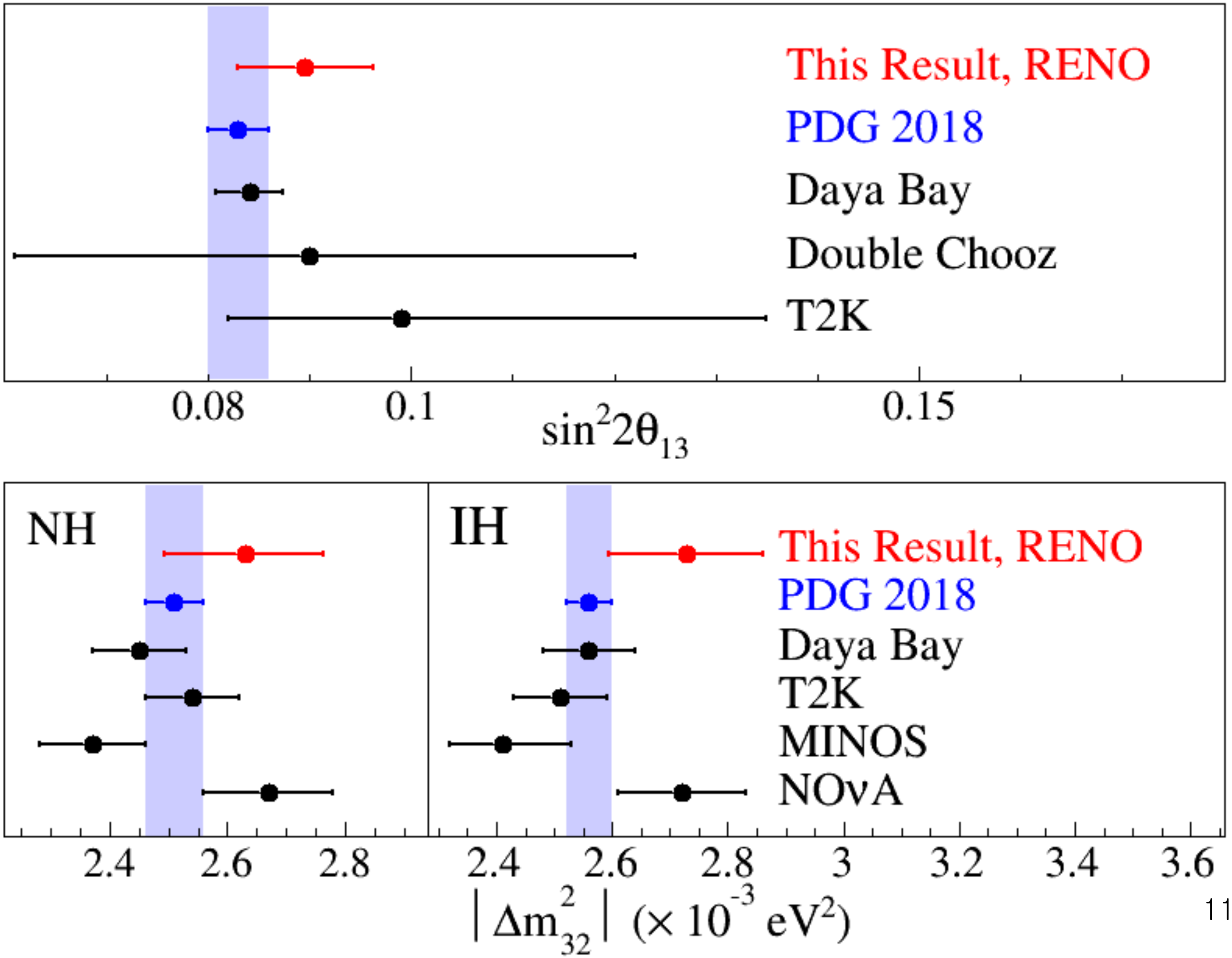
$|\Delta m_{ee}^2| = 2.68 \pm 0.12(\text{stat.}) \pm 0.07(\text{syst.})$ ($\times 10^{-3}$ eV^2) (± 5.2 %)

Survival probability of reactor antineutrinos



Clear L/E-dependent disappearance of reactor antineutrinos

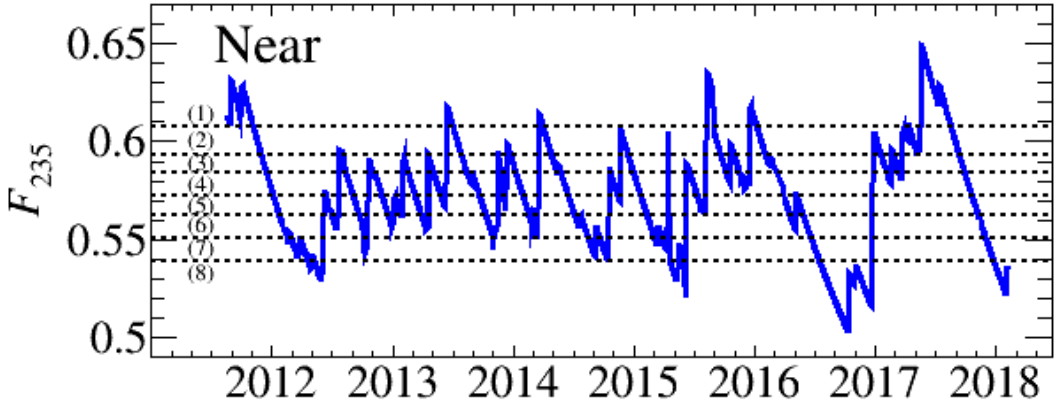
Comparison of θ_{13} and $|\Delta m^2_{ee}|$

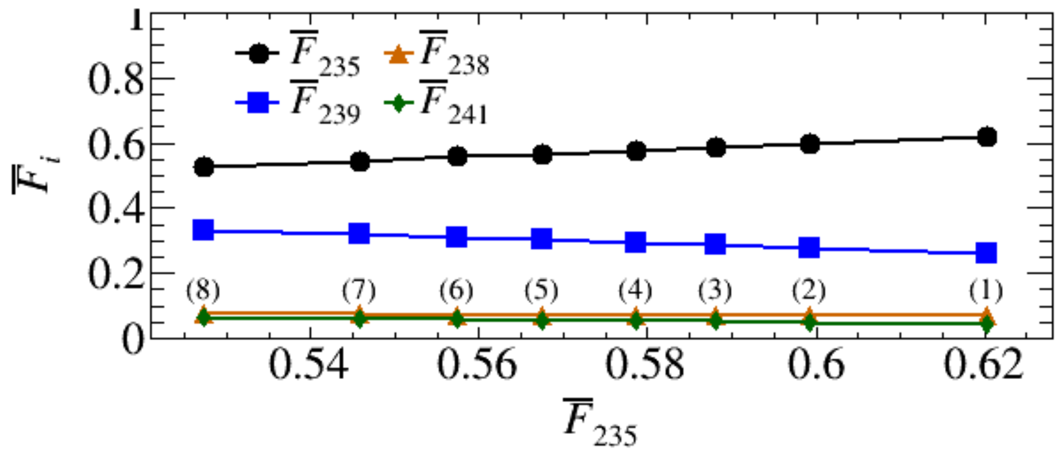


Fuel composition dependent anti-neutrino yield

Evolution of Fuel Isotope Fraction

Fission fraction data of each reactor core, is provided by the Hanbit nuclear power plant and average fission fraction of 6 reactors is used for this study.

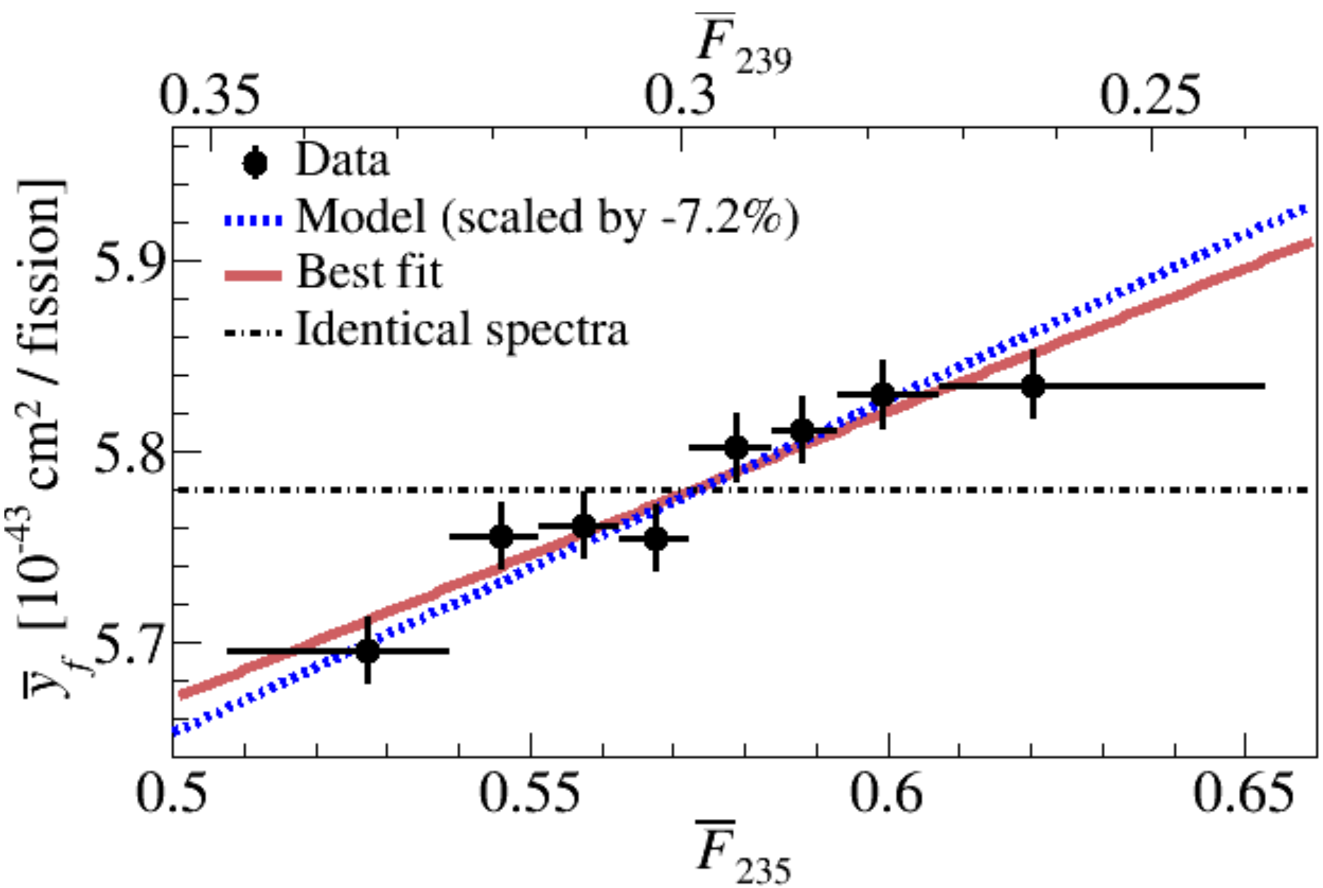




Average fission fraction

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

Fuel-Composition Dependent Reactor Neutrino Yield



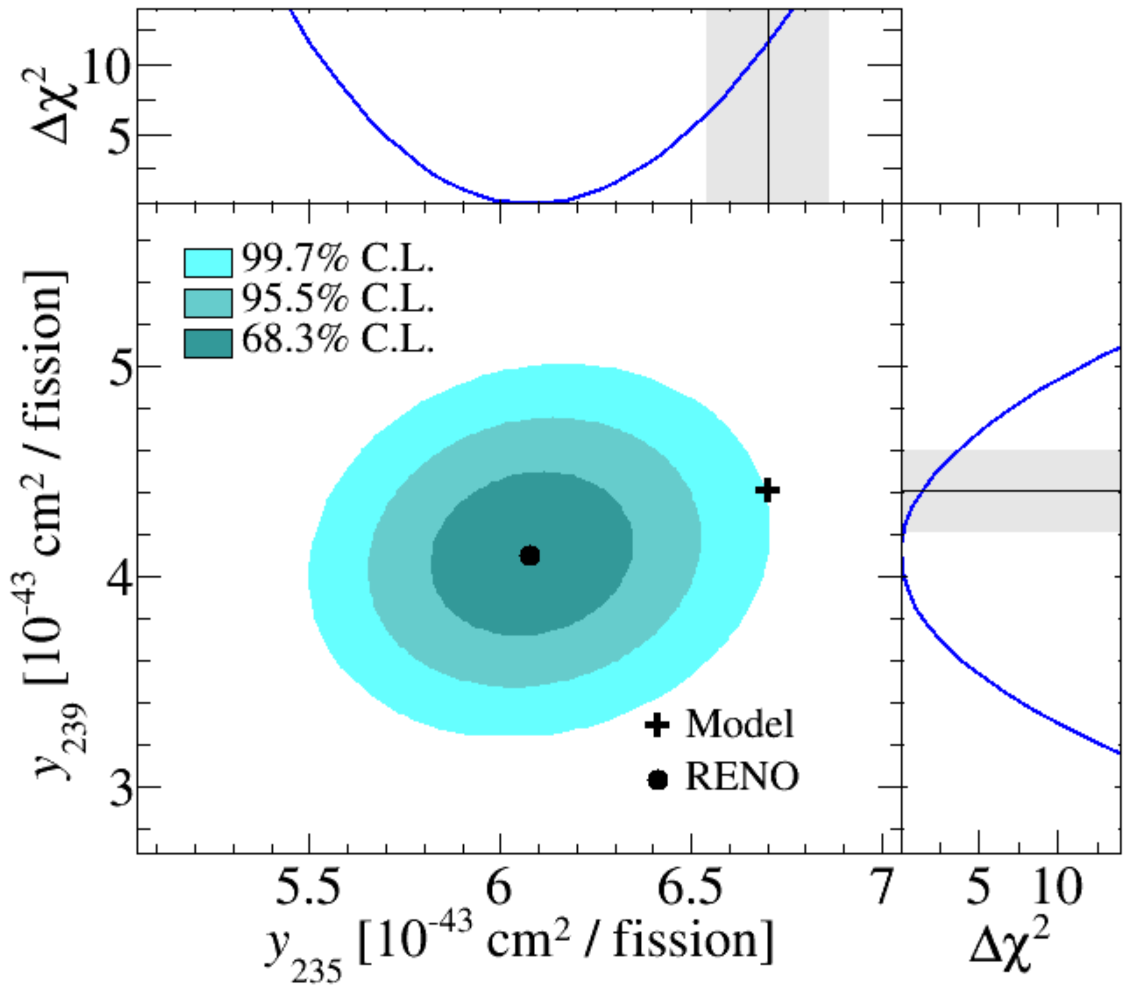
Average of IBD yield per fission

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

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

No fuel-dependent variation of IBD yield per fission is ruled out with 6.7 σ

Best-fit result of IBD yields per fission of ^{235}U (^{239}Pu)

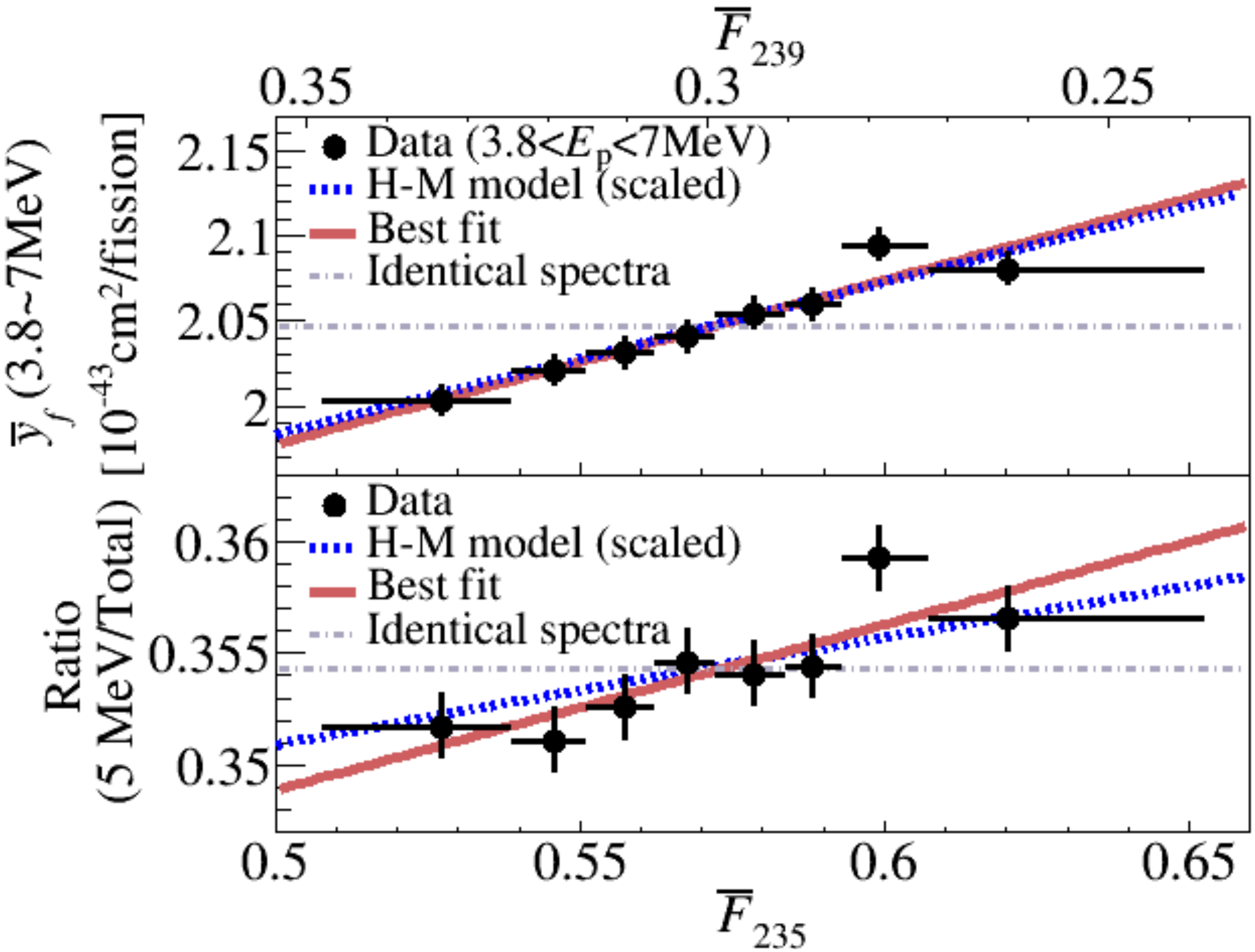


^{235}U: 3.5σ deficit relative to Huber-Mueller (H-M) prediction

^{239}Pu: 1.2σ deficit

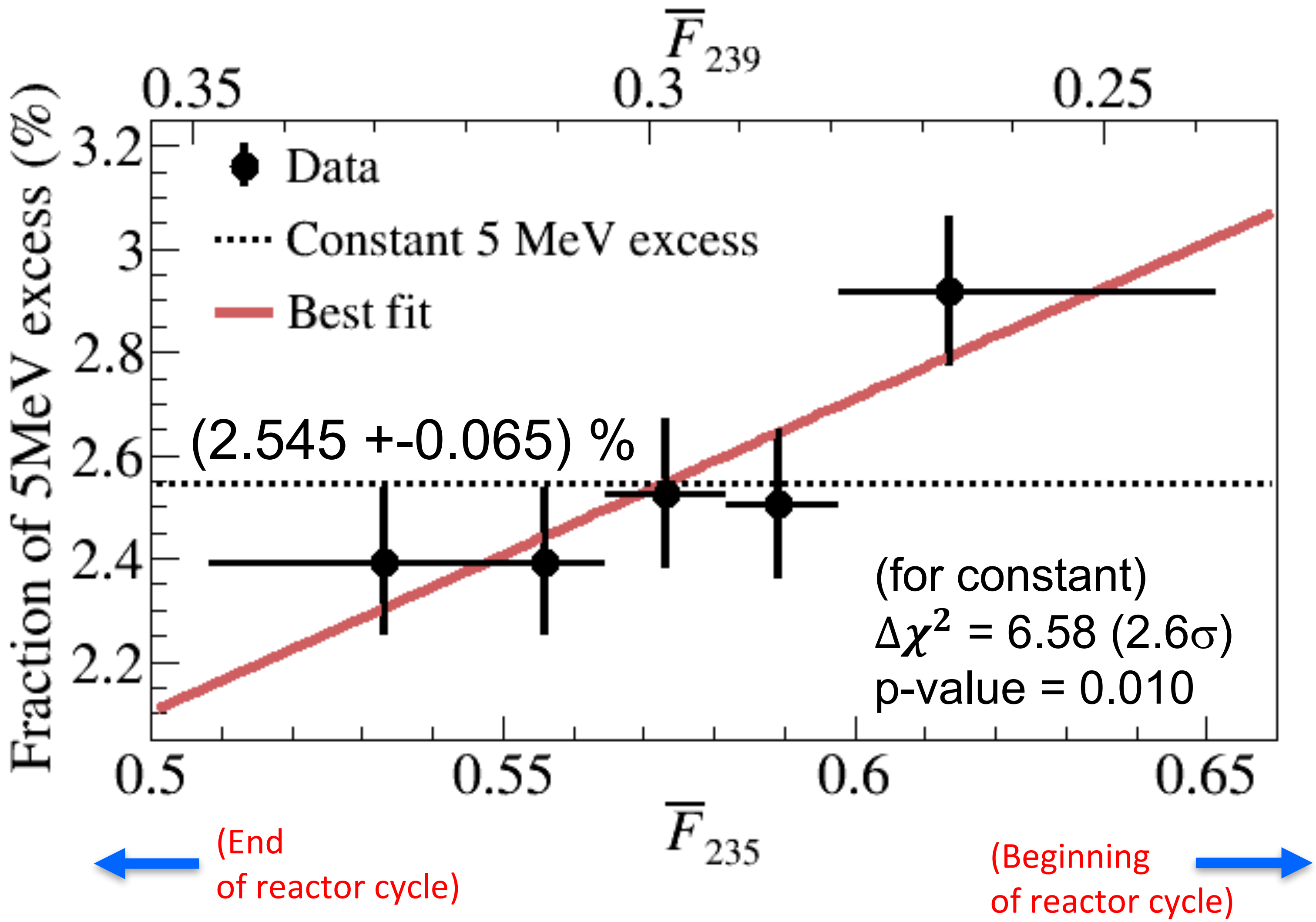
Fuel composition dependent 5 MeV excess

IBD Yield Variation of 5 MeV Excess Region



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



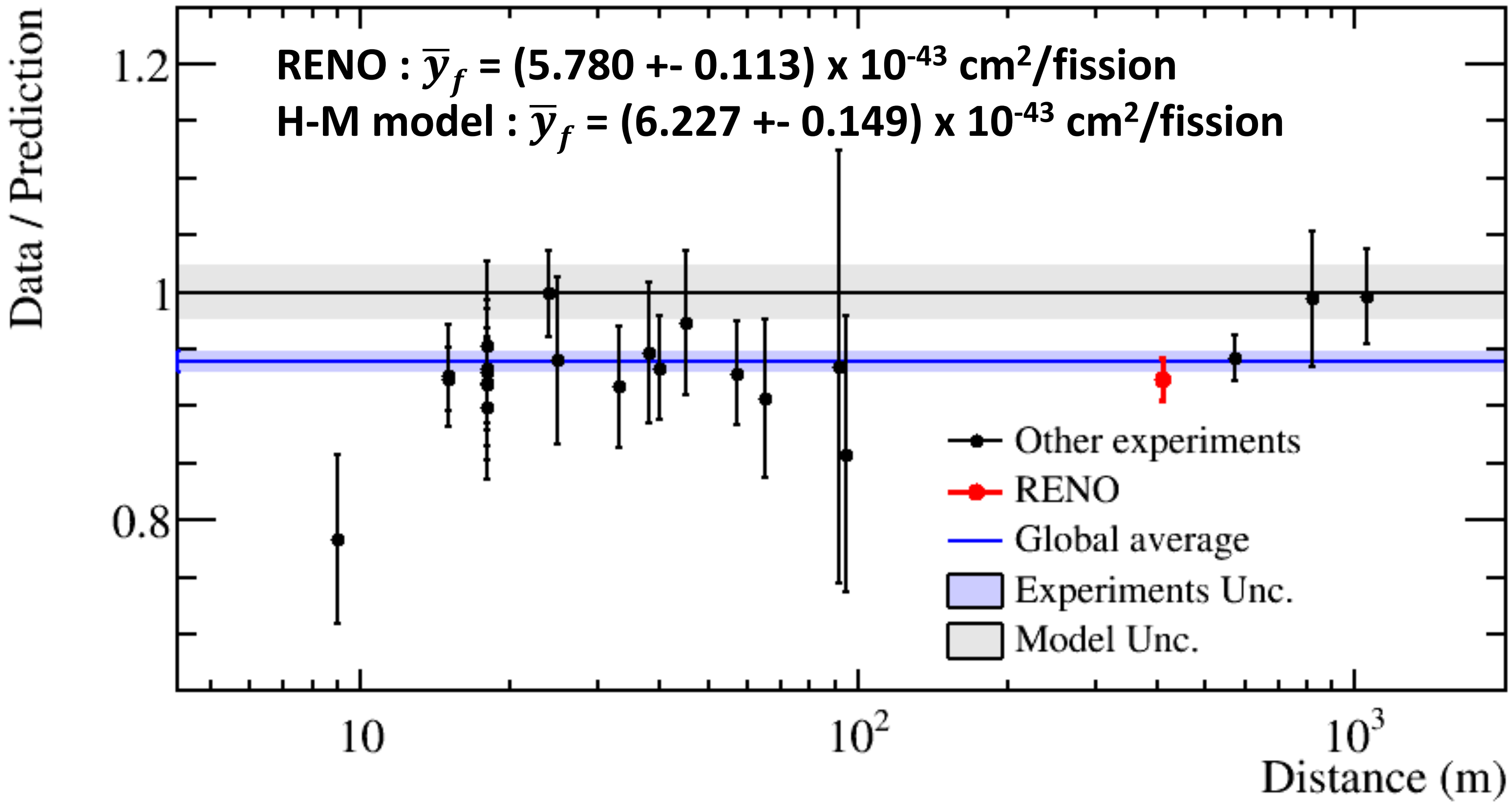
2.6σ indication of 5 MeV excess coming from ^{235}U fuel isotope fission

Absolute reactor neutrino flux and spectrum

Measurement of Absolute Reactor Neutrino Flux

Cross section calculation
- Fayans 85 formalism
- τ_n= 880.2s (PDG2017)

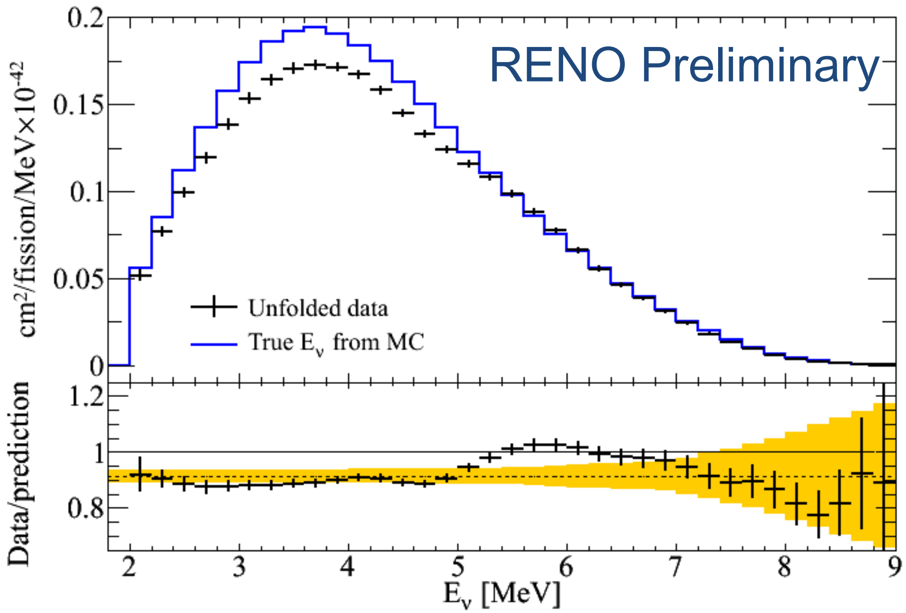
Data / Prediction, RENO 2200 days at near detector
0.924 +- 0.018 (for Huber + Mueller model) 0.966 +- 0.019 (for ILL + Vogel model)



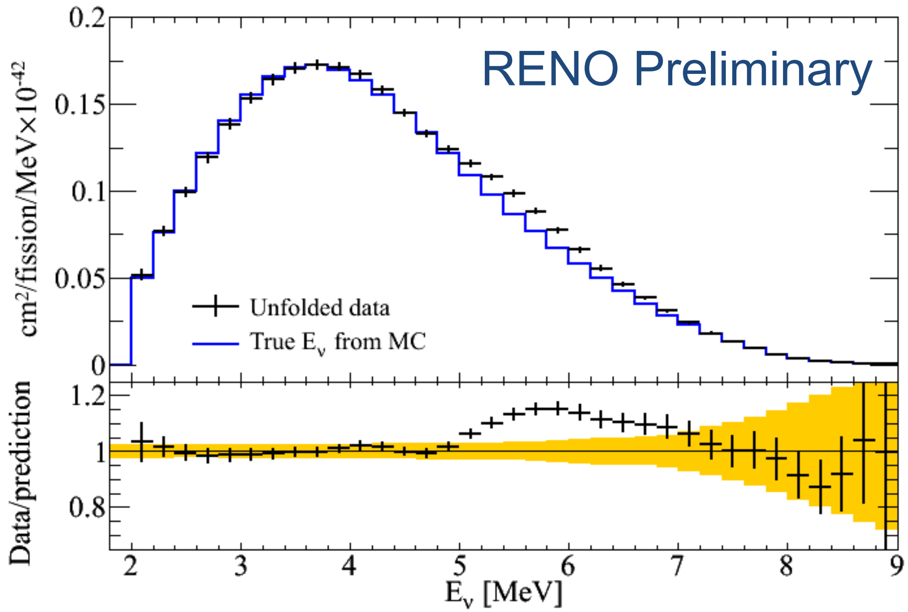
Deficit of observed reactor neutrino fluxes relative to the prediction (Huber + Mueller model) indicates an overestimated flux or possible oscillation to sterile neutrinos

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

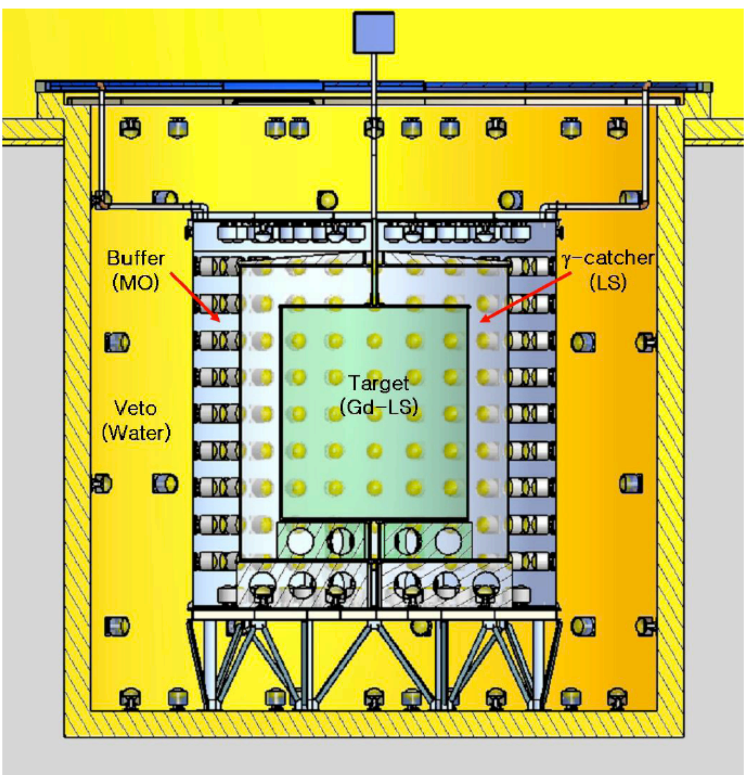
- Unfolding using iterative method in *RooUnfold*

IBD events with delayed neutron captured by Hydrogen

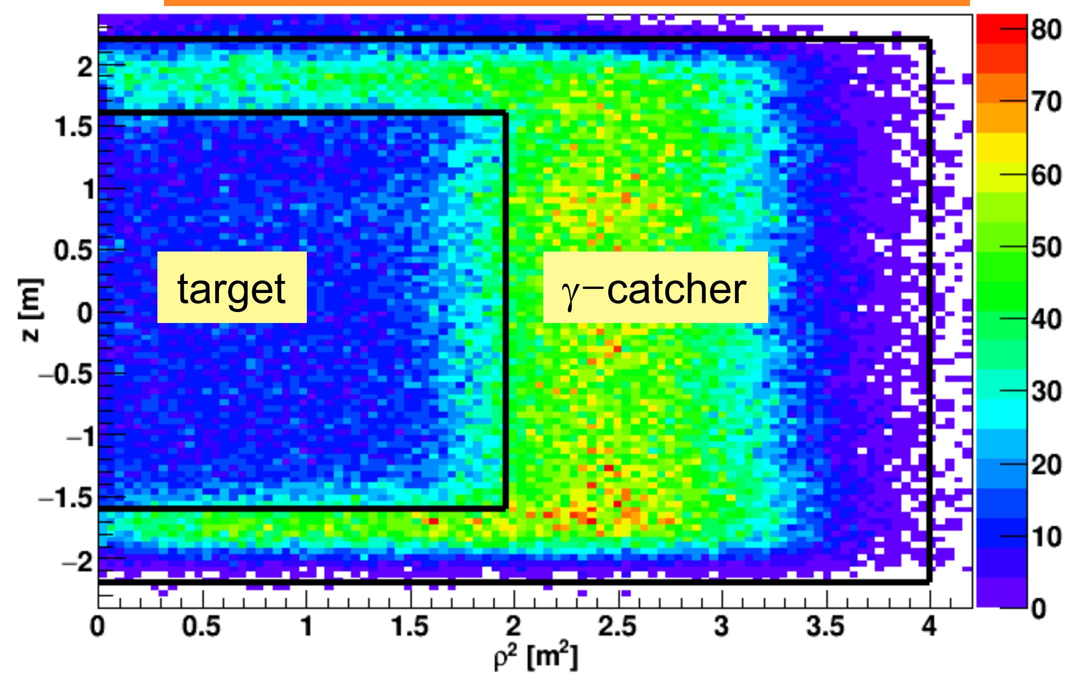
n-H IBD Analysis

Motivation:

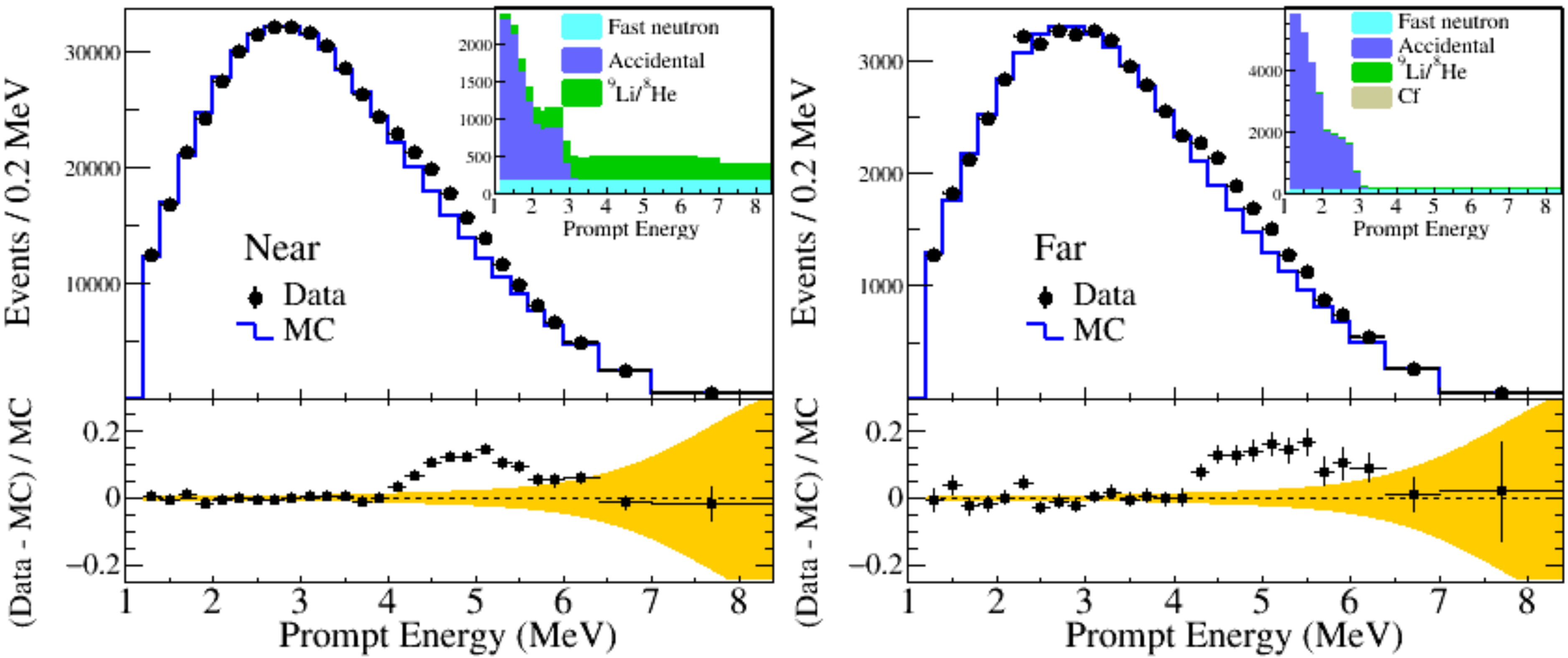
1. Independent measurement of θ_{13} and $|\Delta m_{ee}^2|$.
2. Consistency and systematic check on reactor neutrinos.



n-H IBD Event Vertex Distribution

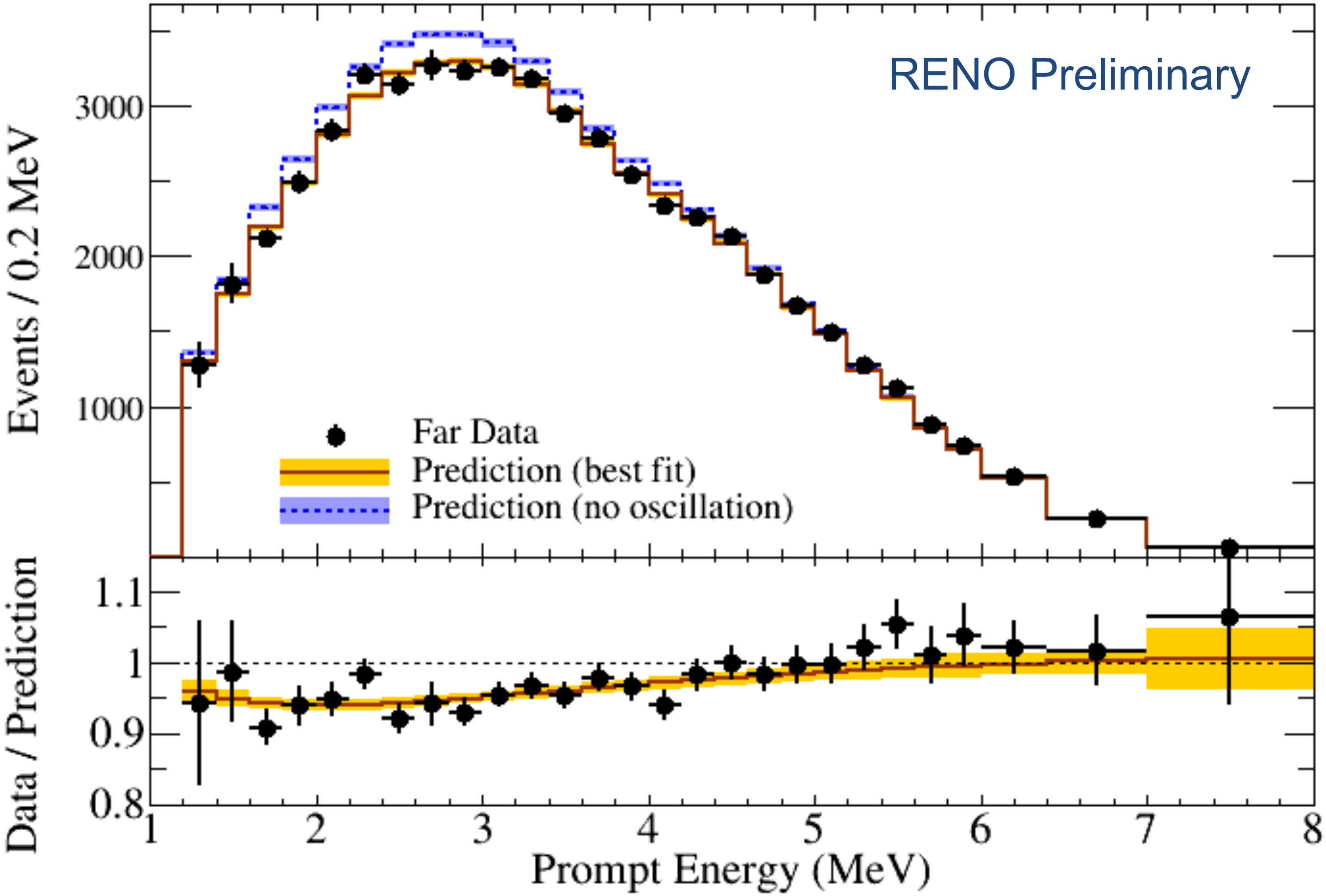


θ_{13} Measurement with n-H



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

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

- Fuel composition dependent reactor antineutrino yield : No fuel dependent IBD yield is ruled out at 6.7 σ

- 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.

Backup

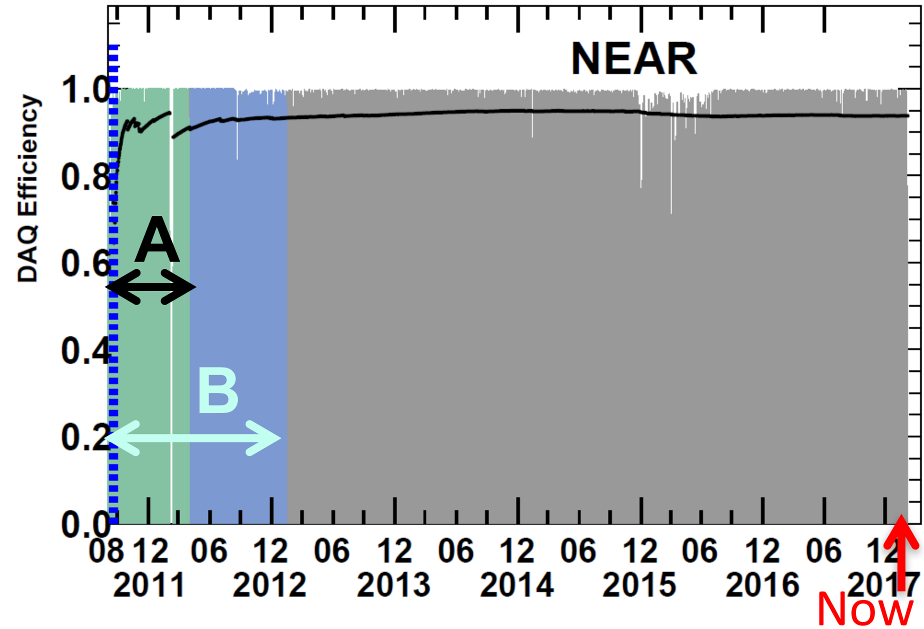
RENO Data-taking Status

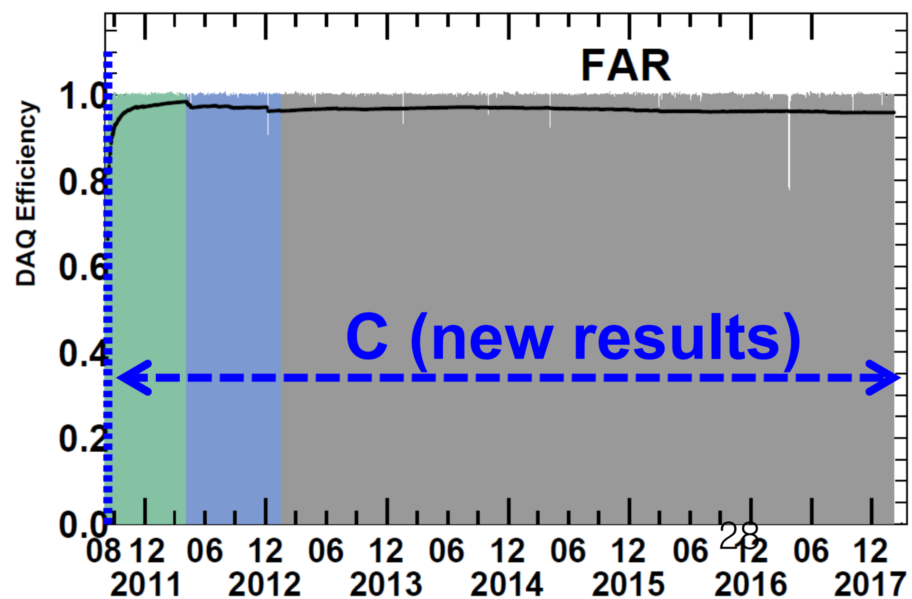
- Data taking began on Aug. 1, 2011 with both near and far detectors.
  (DAQ efficiency : ~95%)

- **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 $|\Delta m_{ee}^2|$**)
  [11 Aug, 2011~21 Jan, 2013]
  → PRL 116, 211801 (2016)
  accepted to PRD (arXiv:1610.04326)

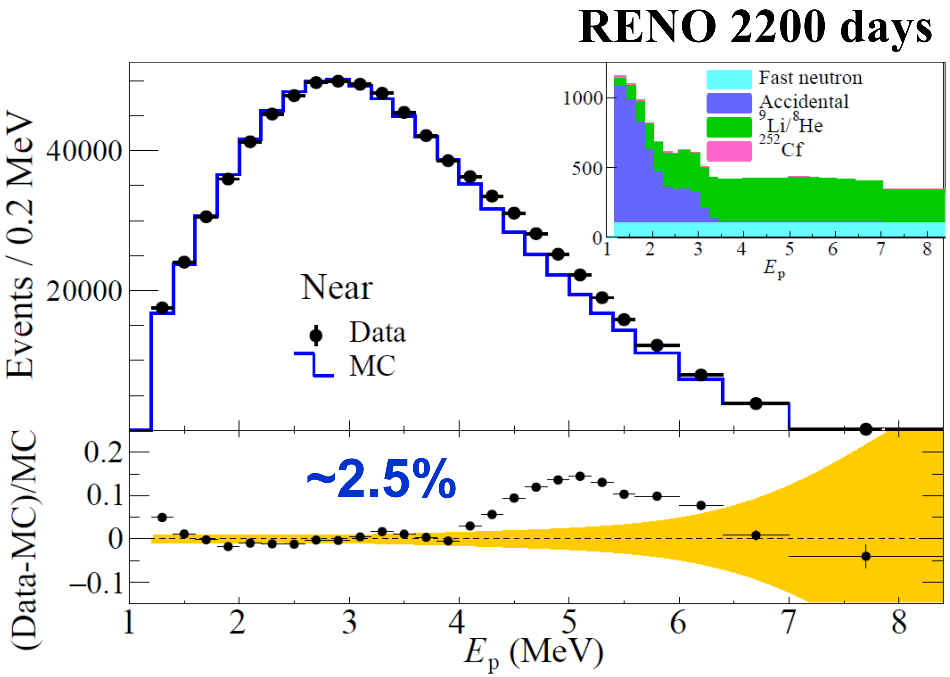
- **C (~2200 days)** : **New results**
  Rate+shape analysis (**θ_{13} and $|\Delta m_{ee}^2|$**)
  [11 Aug, 2011~7 Feb, 2018]
  → submitted to PRL (arXiv:1806.00248)

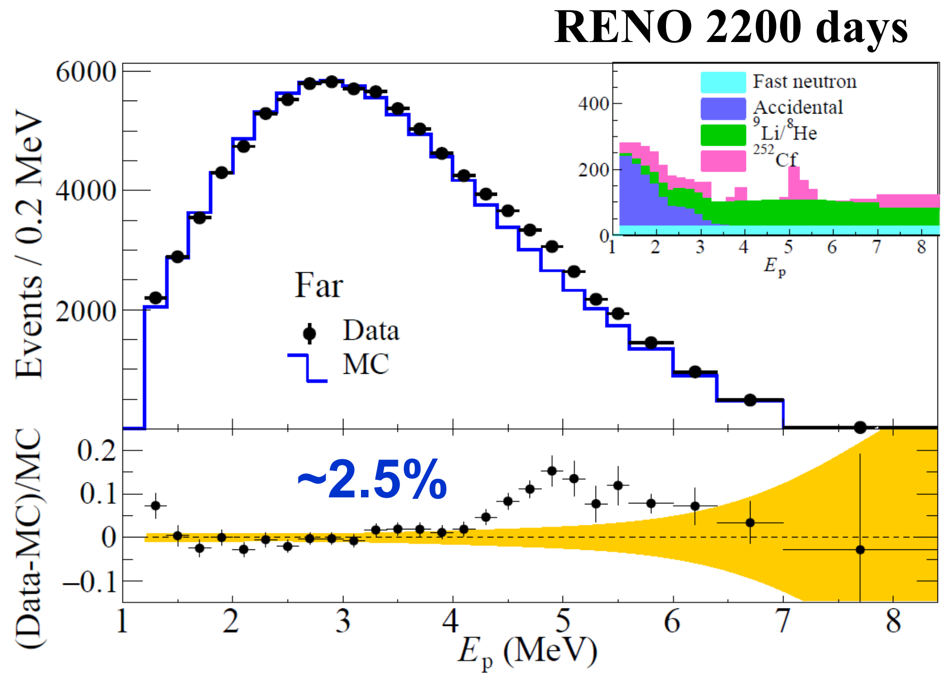




Measured Spectra of IBD Prompt Signal

Clear excess at 5 MeV





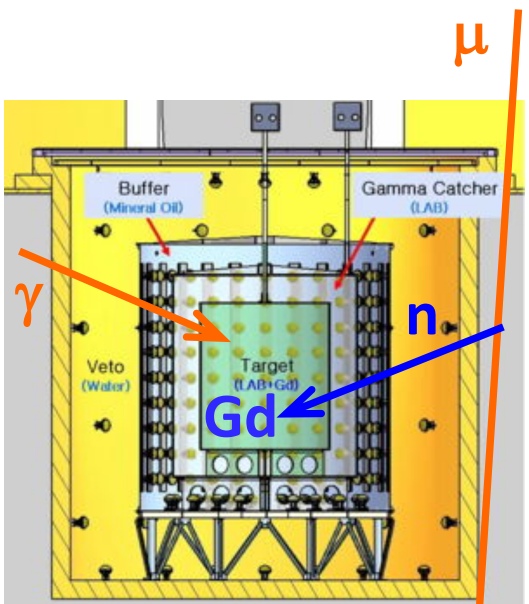
Near Live time = 1807.88 days
# of IBD candidate = 850,666
# of background = 17,233 (2.0 %)

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

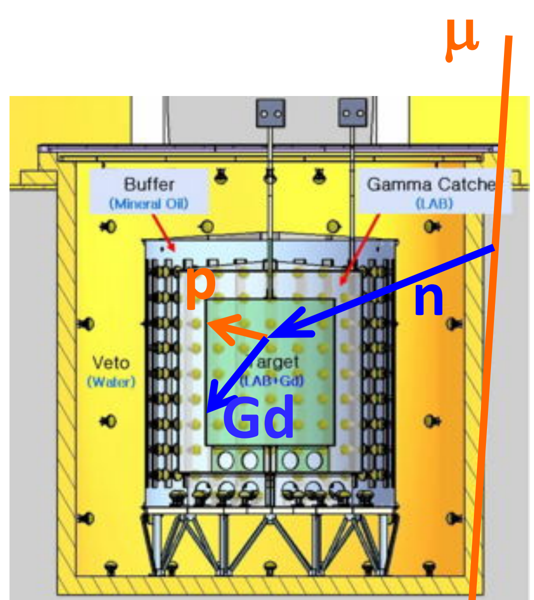
Backgrounds

- Accidental coincidence between prompt and delayed signals
- Fast neutrons produced by muons, from surrounding rocks and inside detector (n scattering : prompt, n capture : delayed)
- **^{9}Li/^{8}He** β-n followers produced by cosmic muon spallation

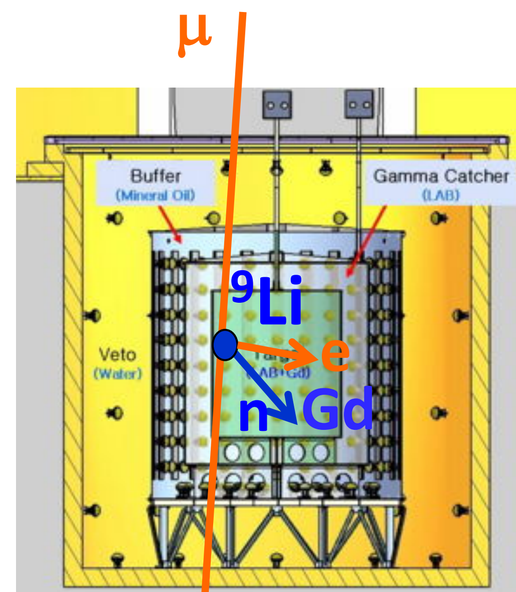
Accidentals



Fast neutrons

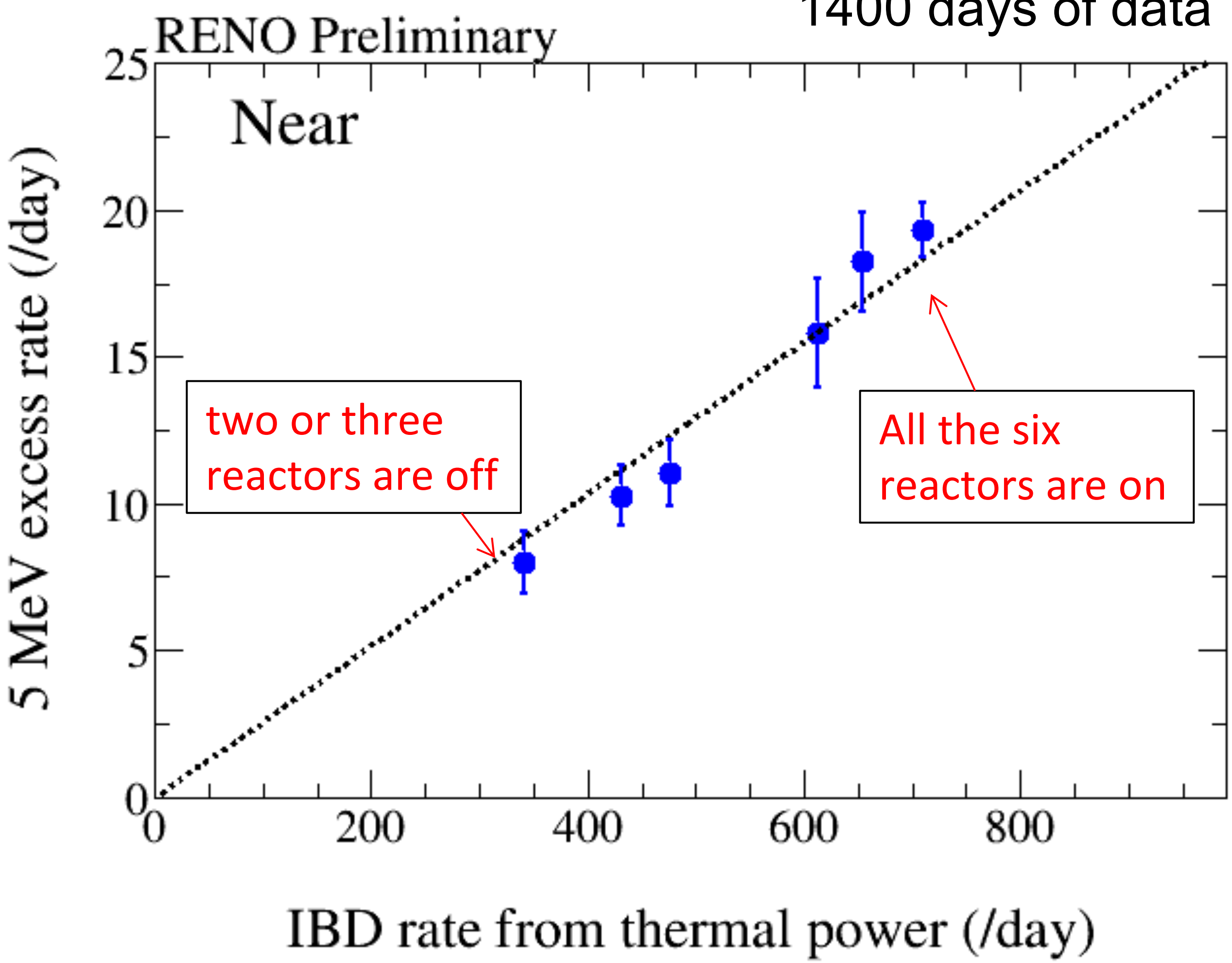


^{9}Li/^{8}He β-n followers



Correlation of 5 MeV Excess with Reactor Power

1400 days of data



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

The 5 MeV excess comes from reactors!