Results from RENO

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Lake Louise Winter Institute 2018

Chateau Lake Louise, AB, Canada, February. 18-24, 2018

RENO Collaboration

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

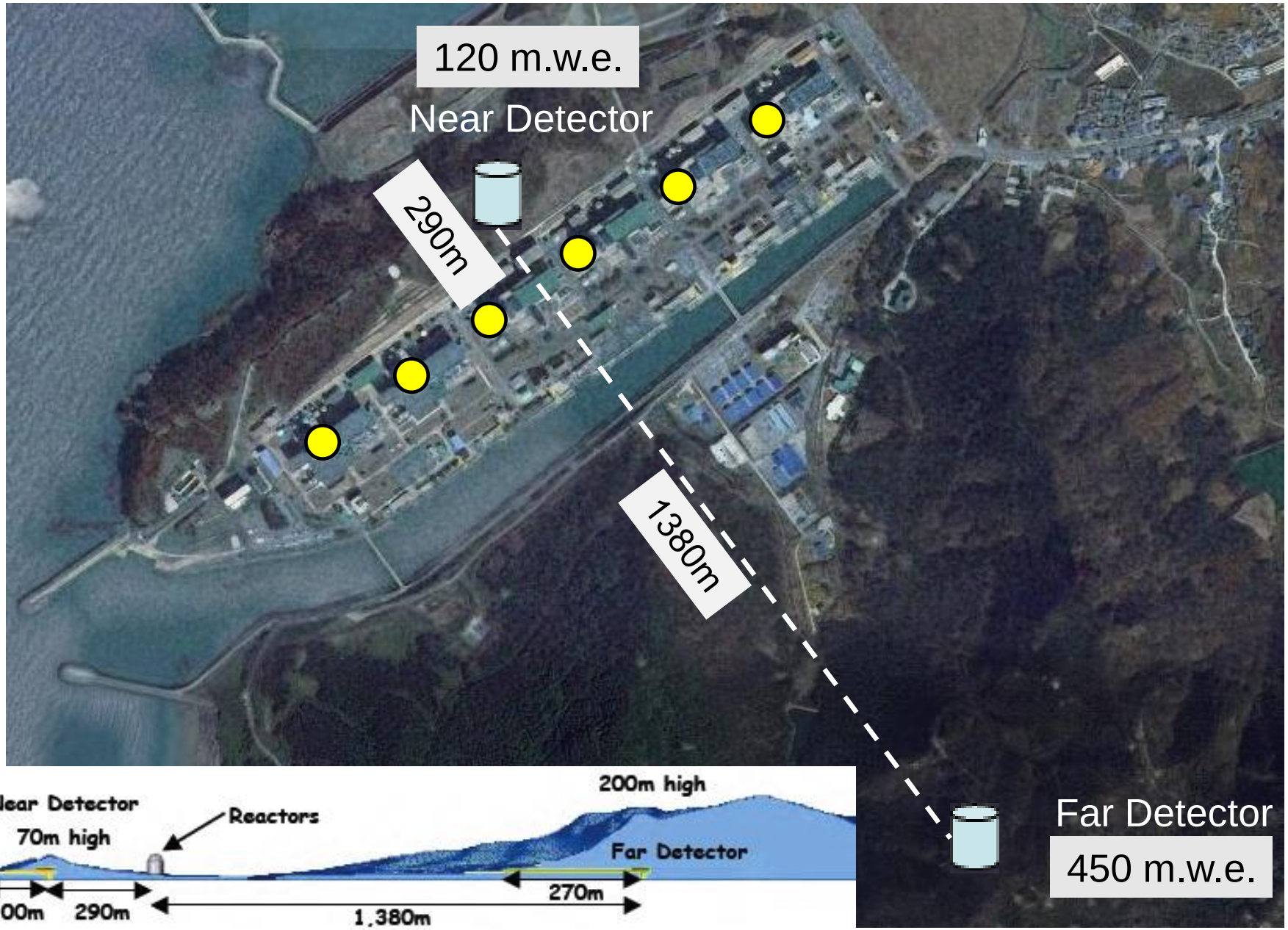
(8 institutions and 40 physicists)

- Chonnam National University
- Dongshin University
- GIST
- Gyeongsang National University
- 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



New Results from RENO

- Observation of energy dependent disappearance of reactor neutrinos to measure Δm_{ee}^2 and θ_{13} using 1500 live days of data (Aug. 2011 ~ Sep. 2015)

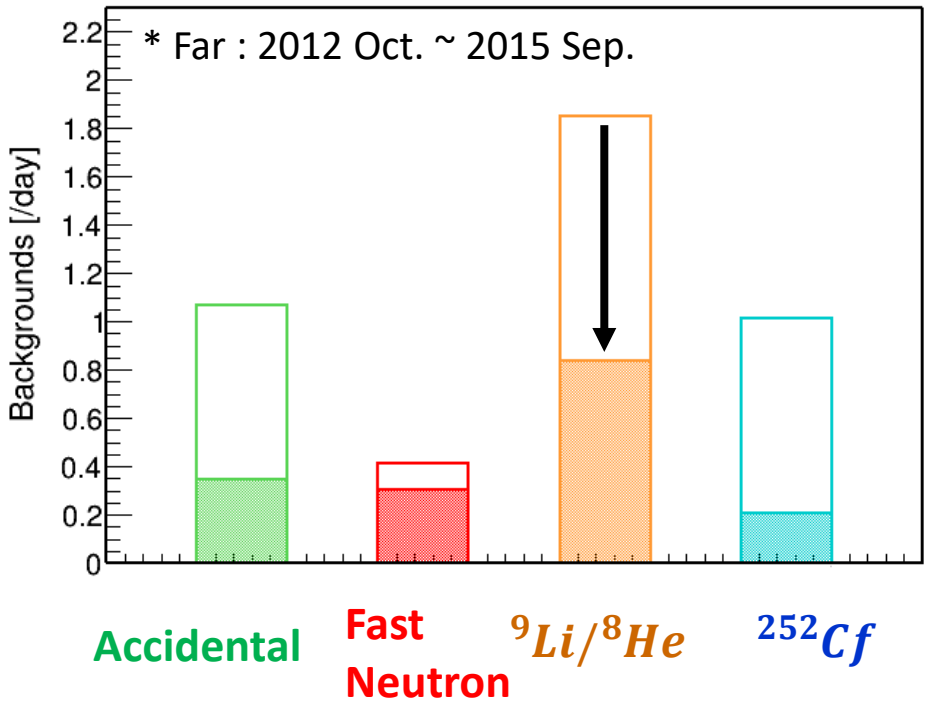
- Observation of an excess at ~5 MeV in reactor neutrino spectrum using 1500 days of data

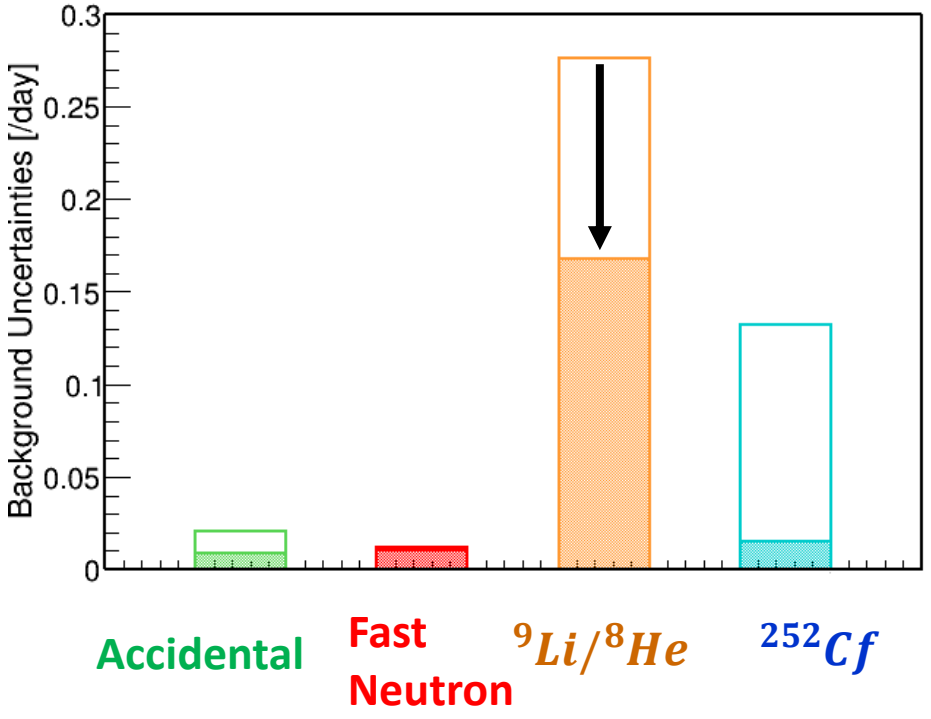
- Measurement of absolute reactor neutrino flux using 1500 d ays of data

- Fuel dependent variation of reactor antineutrino yield and sp ectrum (progress report)

Reduction of background rates & uncertainties

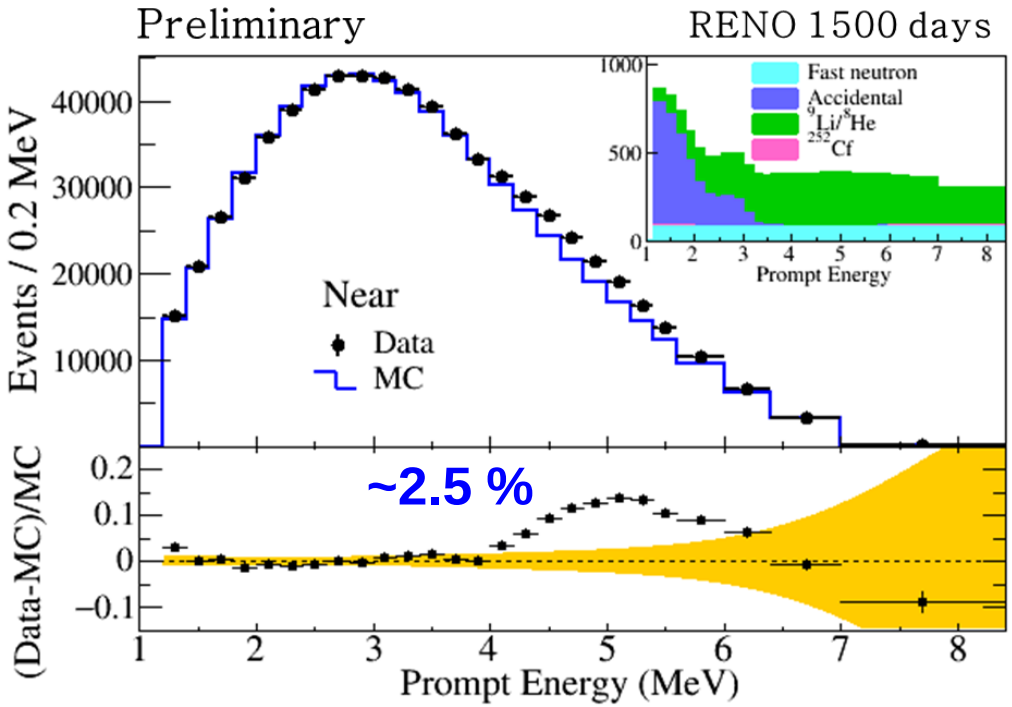
Allows precise measurements of $sin^2 2\theta_{13}$ and Δm^2_{ee}





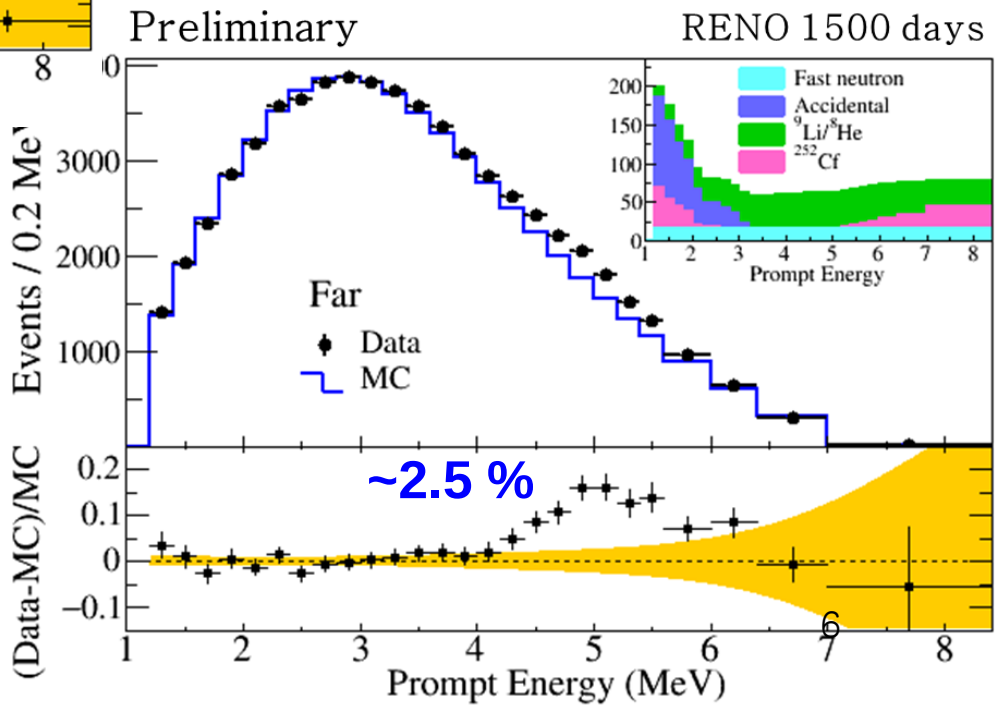
- Accidentals : Additional cuts and improved flashing-PMT removal algorithms
- Cosmogenic $^9Li/^8He$: Optimized muon veto criteria
- ^{252}Cf contamination : Improved multiple-neutron removal algorithms

Measured Spectra of IBD Prompt Signal

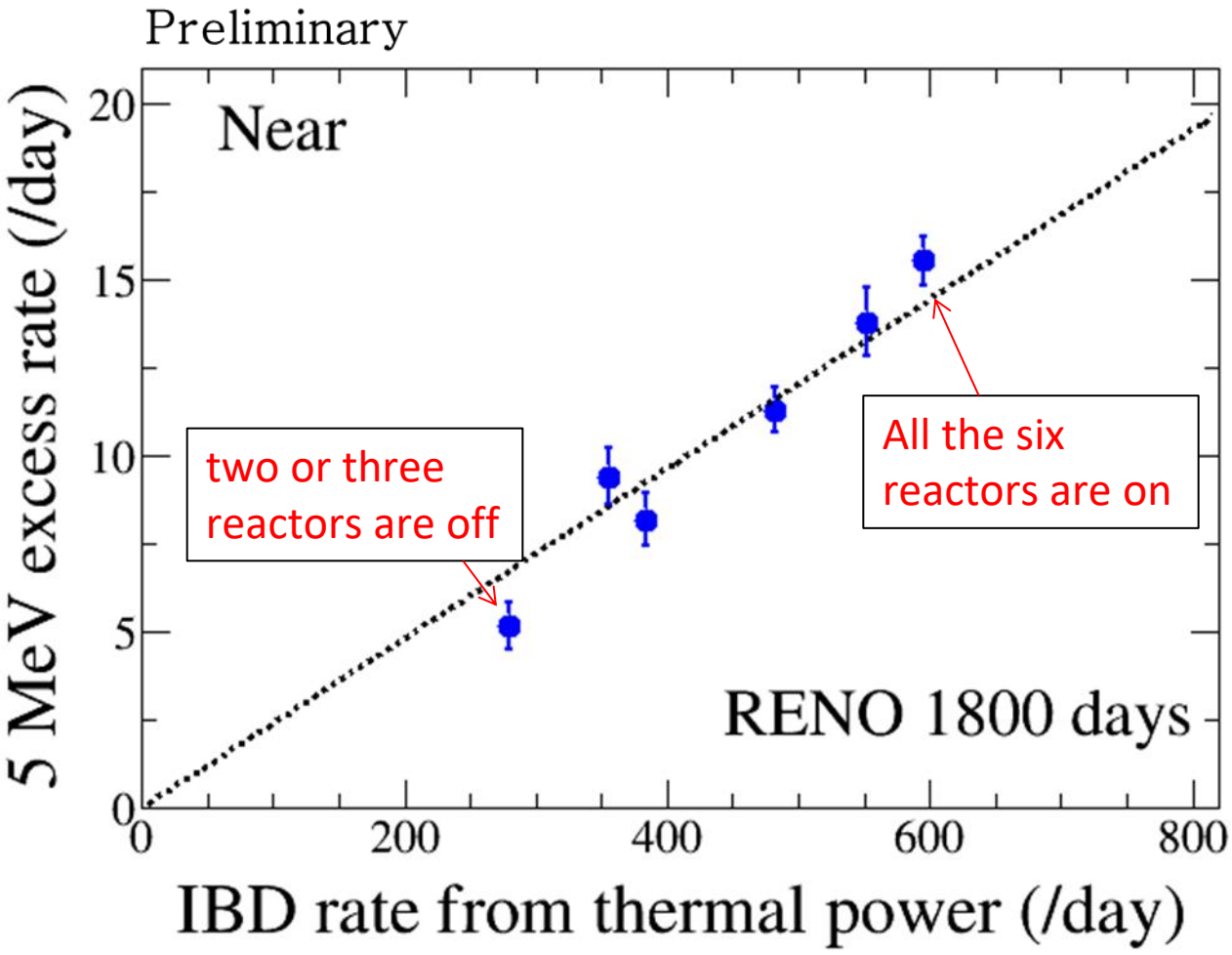


RENO's observation of 5 MeV excess

Clear excess at 5 MeV



Correlation of 5 MeV Excess with Reactor Power

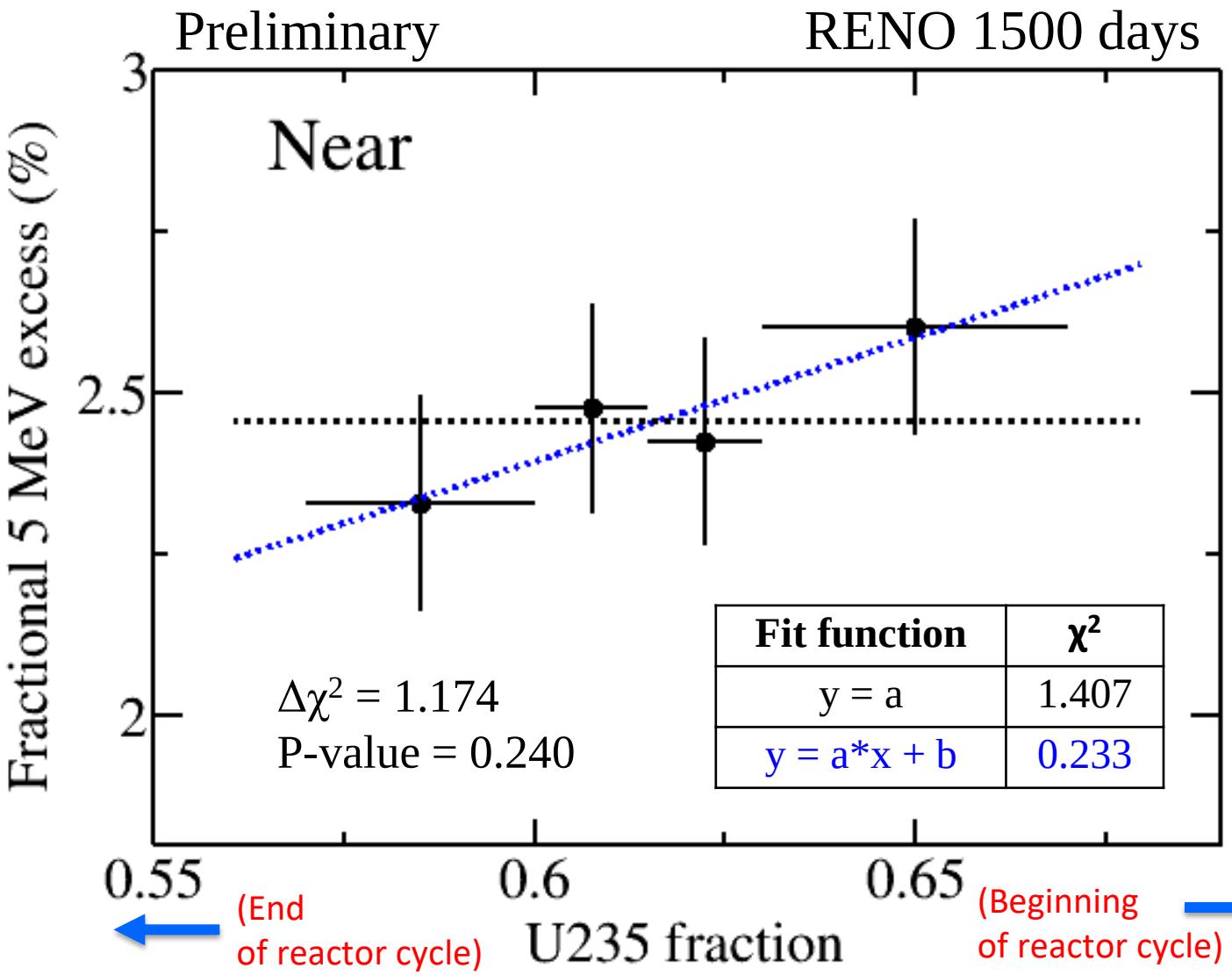


5 MeV excess has a clear correlation with reactor thermal power !

The 5 MeV excess comes from reactors!

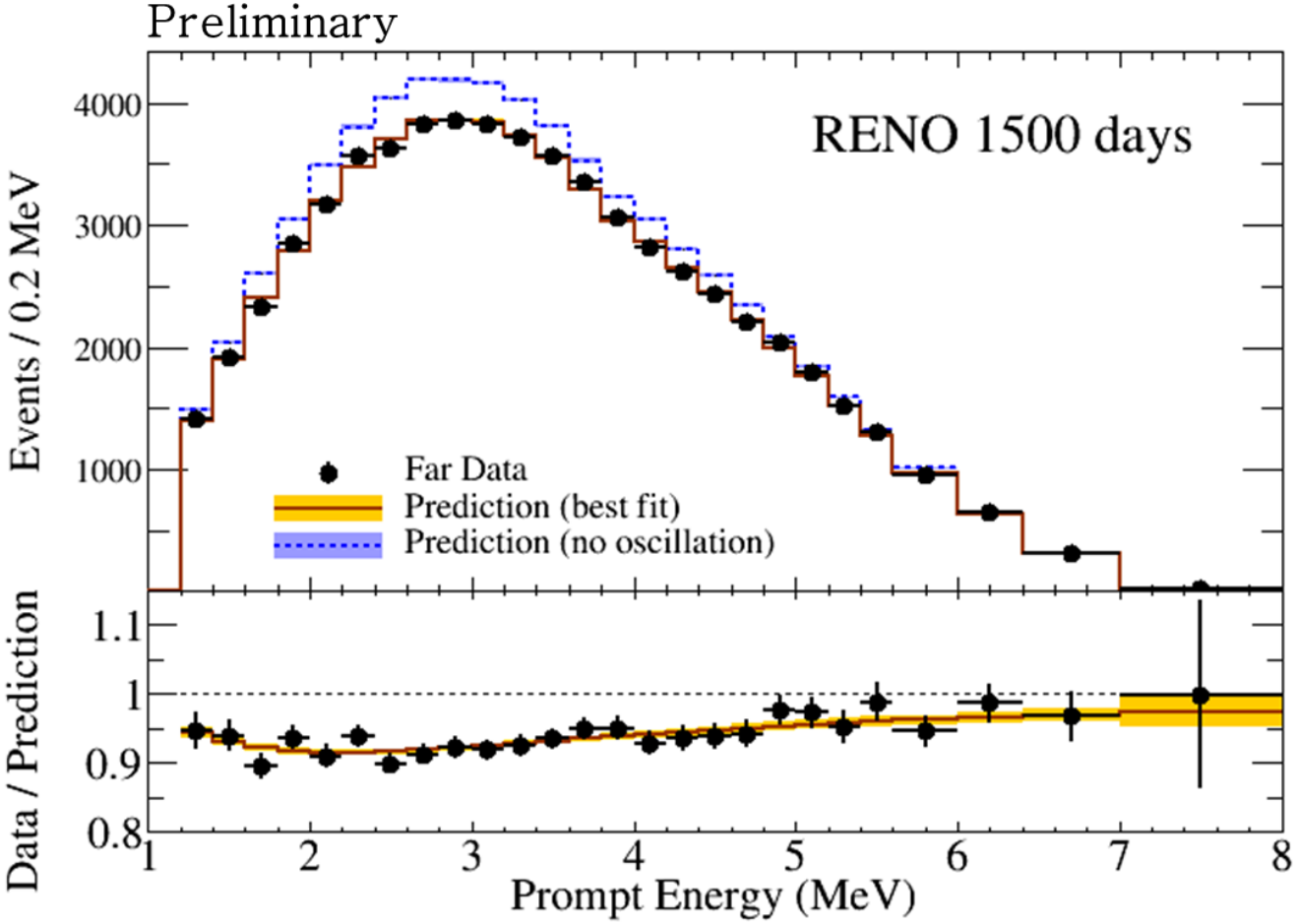
Correlation of 5 MeV excess with ^{235}U isotope fraction

^{235}U fraction corresponds to freshness of reactor fuel



Results from Spectral Fit

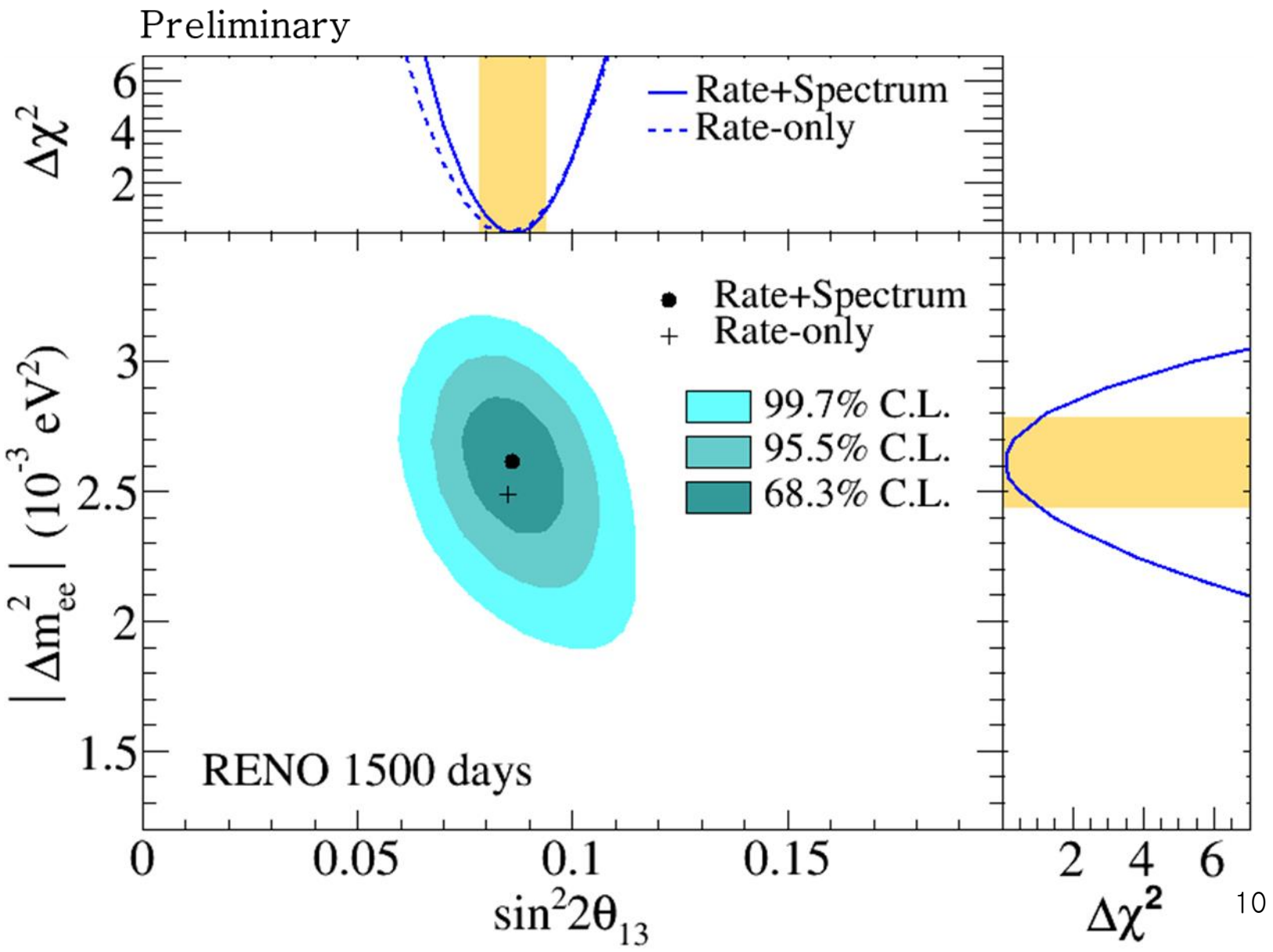
Energy-dependent disappearance of reactor antineutrinos



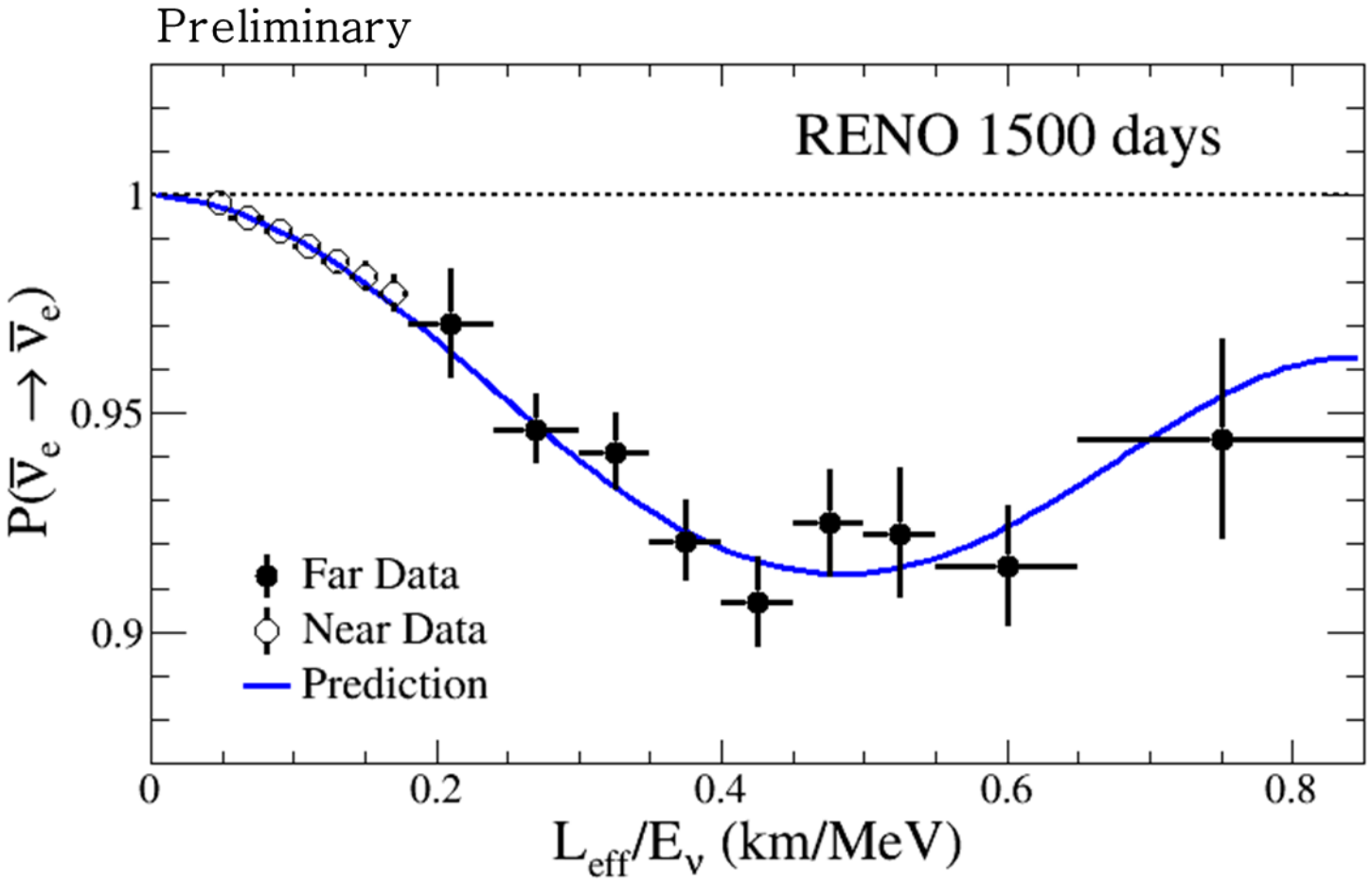
$$\sin^2 2\theta_{13} = 0.086 \pm 0.006(\text{stat.}) \pm 0.005(\text{syst.})$$ (± 9 %)

$$\left|\Delta m^2_{ee}\right| = 2.61^{+0.15}_{-0.16}(\text{stat.})^{+0.09}_{-0.09}(\text{syst.}) \ (\times 10^{-3}\text{eV}^2)$$ (± 7 %)

Allowed regions in $|\Delta m_{ee}^2|$ and $\sin^2 2\theta_{13}$



Observed L/E Dependent Oscillation



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

More precise measurement of θ_{13} and $|\Delta m_{ee}^2|$

PRL 116, 211801 (2016), Submitted to PRD (arXiv:1610.04326)

500 days	Mean	Stat.	Sys.	Precision
$\sin^2 2\theta_{13}$	0.082	+0.009 -0.009	+0.006 -0.006	12 %
$\|\Delta m_{ee}^2\|$ ($\times 10^{-3}$ eV^2)	2.62	+0.21 -0.23	+0.12 -0.13	10 %

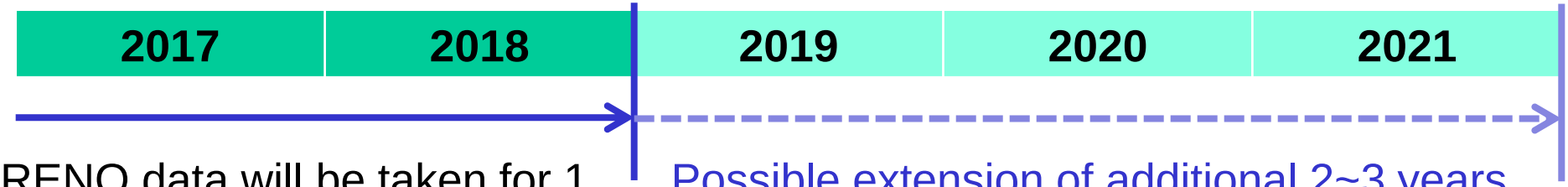
New results (preliminary)

1500 days	Mean	Stat.	Sys.	Precision
$\sin^2 2\theta_{13}$	0.086	+0.006 -0.006	+0.005 -0.005	**9 %**
$\|\Delta m_{ee}^2\|$ ($\times 10^{-3}$ eV^2)	2.61	+0.15 -0.16	+0.09 -0.09	**7 %**

Systematic errors are reduced due to background reduction and larger statistics of control samples

RENO : Plan and Prospects

Plan for RENO data taking



RENO data will be taken for 1 more years from now and it will take 2 additional years for the analysis.

Possible extension of additional 2~3 years

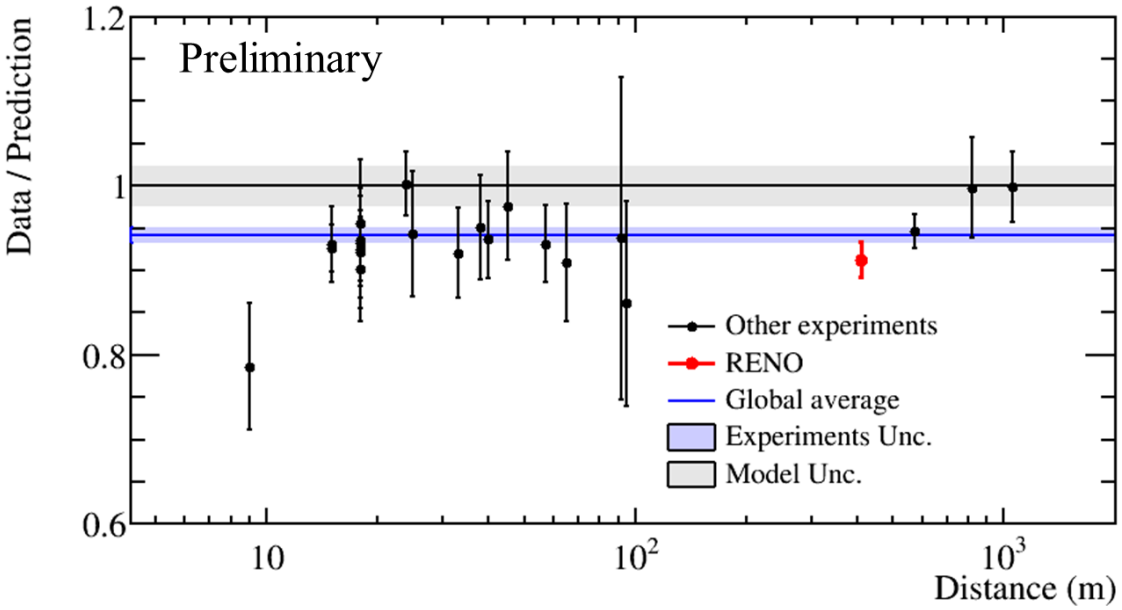
According to our recent study, the systematic error of $|\Delta m_{ee}^2|$ is smaller than the statistical error.

$\sin^2 2\theta_{13}$ and $|\Delta m_{ee}^2|$ will approach to **~6% precision** (our design goal).

	500 days Measured	1500 days Measured (preliminary)	~3500 days Expected
$\sin^2 2\theta_{13}$	12 %	9 %	6 ~ 7 %
$\|\Delta m_{ee}^2\|$	10 %	7 %	4 ~ 5 %

Measurement of Absolute Reactor Neutrino Flux

RENO at near (411 m)	Old (Neutrino 2016) λ = 1.26, no δ_{rad}	New τ_n = 880.2 s (PDG 2016)
Data / Prediction (Huber + Mueller)	0.946 +- 0.021	**0.913 +- 0.021**



In Neutrino 2016, our cross section calculation was based on Vogel-Beacom 1999 (Phys Prev D60 053003) but we had used some what old parameters and we did not apply δ_{rad}

$\lambda = g_A/g_V$, δ_{rad} : radiative correction
τ_n : neutron lifetime

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

Investigation of the reactor anomaly

- There has been some investigation on the possibility that reactor anomaly is due to miscalculation of one or more of the ^{235}U, ^{239}Pu, ^{238}U and ^{241}Pu antineutrino fluxes.

C. Giunti, Phys. Lett. B 764, 145 (2017)

- Data from 26 reactor experiments are analyzed → measured ^{235}U flux differs from prediction by 2.2 σ

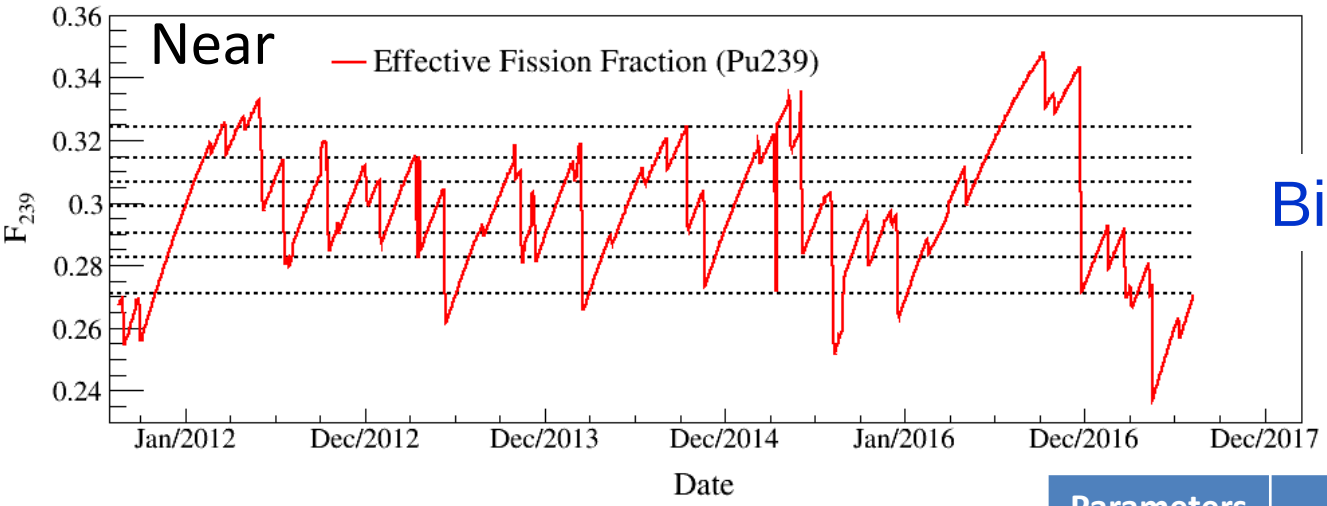
F. P. An et al. (Daya Bay Collaboration), PRL 118, 251801 (2017)

- Daya Bay data are binned into 8 groups according to effective ^{239}Pu fission fraction → analysis result indicates a preference for an incorrect prediction of the ^{235}U flux

- **RENO : measurement of IBD yield of individual isotope is in progress**

Daily effective fission fraction

Daily effective fission fraction of ^{239}Pu



Binned into 8 groups

$$F_i(t) = \sum_{r=1}^{6} \frac{W_{th,r}(t)\bar{p}_r f_{i,r}(t)}{L_r^2 \bar{E}_r(t)} \Big/ \sum_{r=1}^{6} \frac{W_{th,r}(t)\bar{p}_r}{L_r^2 \bar{E}_r(t)}$$

Parameters	Description
r, i	r : reactor, i : isotope
$W_{th,r}(t)$	Reactor thermal power
$\bar{p}_r$	Mean survival probability
$f_{i,r}(t)$	Fraction of fission from isotope i
L_r	Distance between detector center and reactor
$\bar{E}_r(t)$	$\bar{E}_r(t) = \sum_i f_{i,r}(t)\, e_i$, where e_i is average energy (MeV) released per fission

- Study on fuel dependent variation of reactor antineutrino yield and spectrum is in progress

Results will be published soon

Summary

- More precise measurements of θ_{13} and Δm_{ee}^2 by energy dependent disappearance of reactor neutrinos (1500 days of data)

(Preliminary)

$$\sin^2 2\theta_{13} = 0.086 \pm 0.006(\text{stat.}) \pm 0.005(\text{syst.})$$ ± 0.008 (9 %)

$$\left|\Delta m_{ee}^2\right| = 2.61^{+0.15}_{-0.16}(\text{stat.})^{+0.09}_{-0.09}(\text{syst.}) \ (\times 10^{-3}\text{eV}^2)$$ ± 0.18 (7 %)

(Preliminary)

- Measured absolute reactor neutrino flux : R= 0.913 ± 0.021
- Observed an excess at 5 MeV in reactor neutrino spectrum
- $\sin^2(2\theta_{13})$ and Δm_{ee}^2 to 6% accuracy after 1 more years data taking
- Study on fuel dependent variation of reactor antineutrino yield and spectrum is in progress → results will be published soon

Thanks for your attention!