Recent Results from RENO

NUFACT2014

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Seoul National University

KNRC
Korea Neutrino Research Center

New Results from RENO

- New measured value of θ_{13} from rate-only analysis using ~800 days of data

- Rate-only analysis with neutron capture on Hydrogen using ~400 days of data

- Observation of new reactor neutrino component at ~5 MeV

- Shape analysis (progress report)

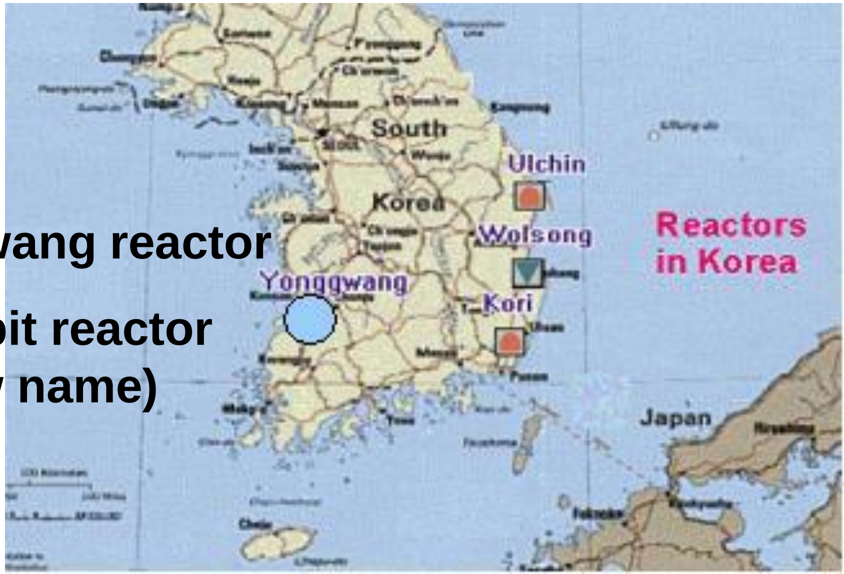
RENO Collaboration

Reactor Experiment for Neutrino Oscillation

<u>11 institutions and 40 physicists</u>

- Chonbuk National University
- Chonnam National University
- Chung-Ang University
- Dongshin University
- GIST
- Gyeongsang National University
- Kyungpook National University
- Sejong University
- Seoul National University
- Seoyeong University
- Sungkyunkwan University

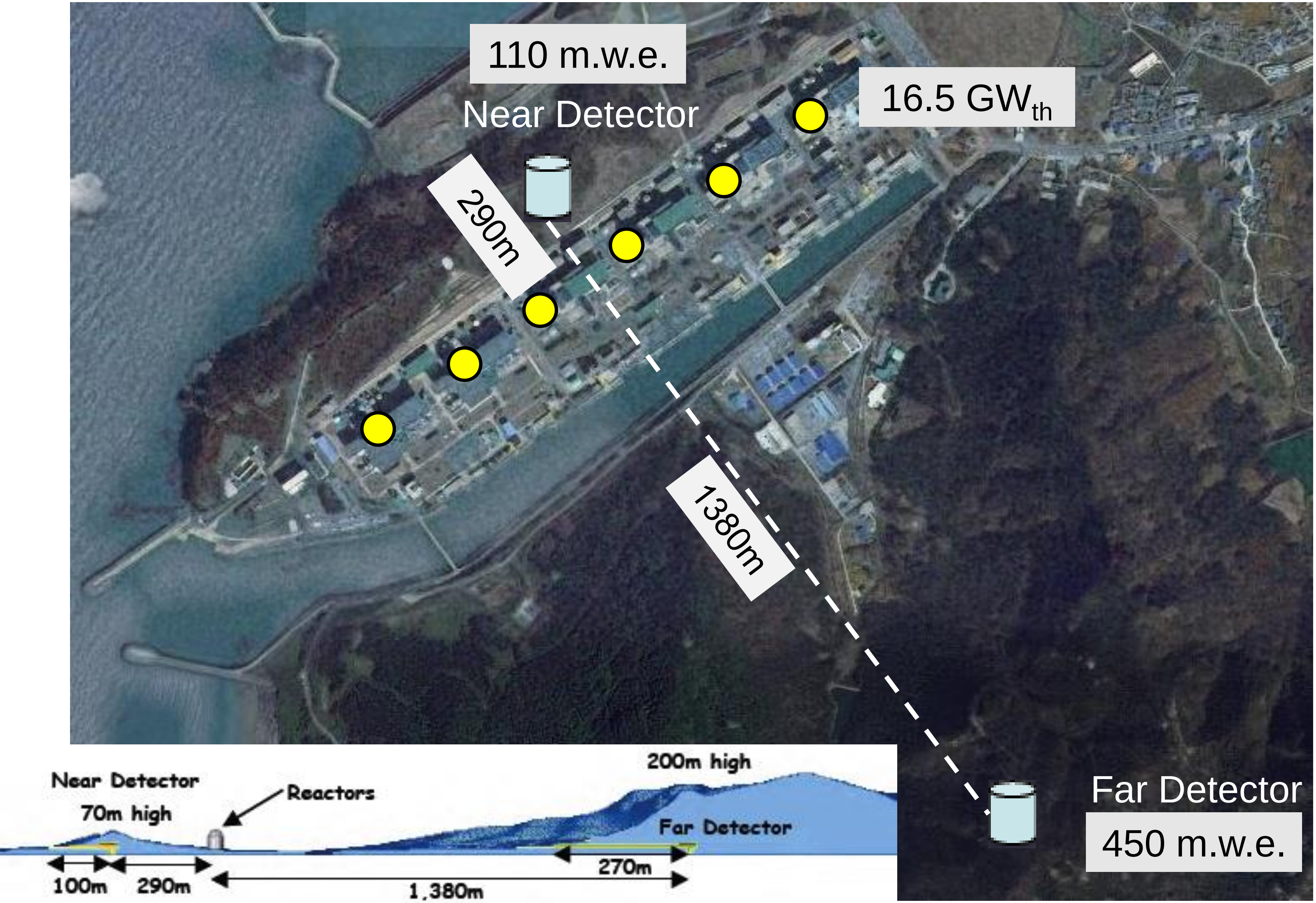
- Total cost : $10M
- Start of project : 2006
- The first experiment running with both near & far detectors from Aug. 2011



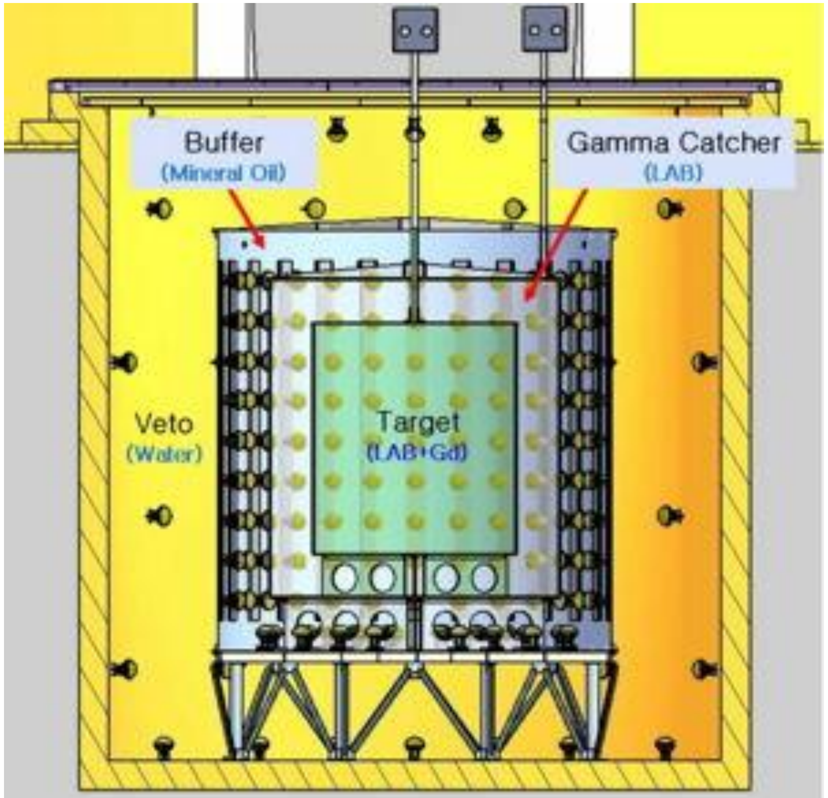
Yonggwang reactor

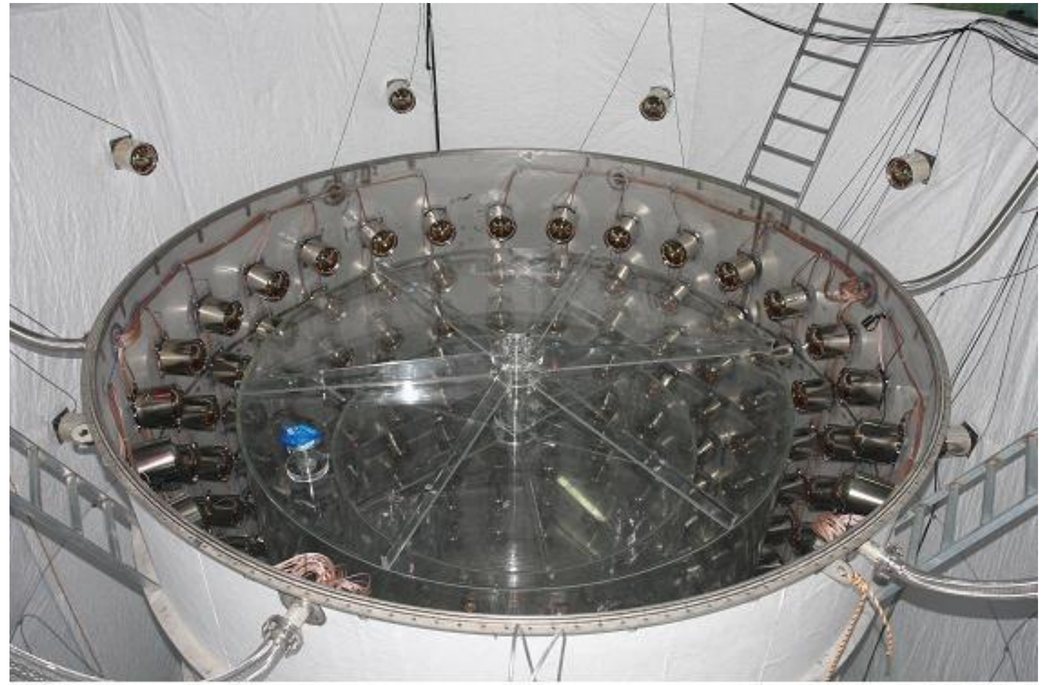
→ Hanbit reactor (new name)

RENO Experimental Setup



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 Status

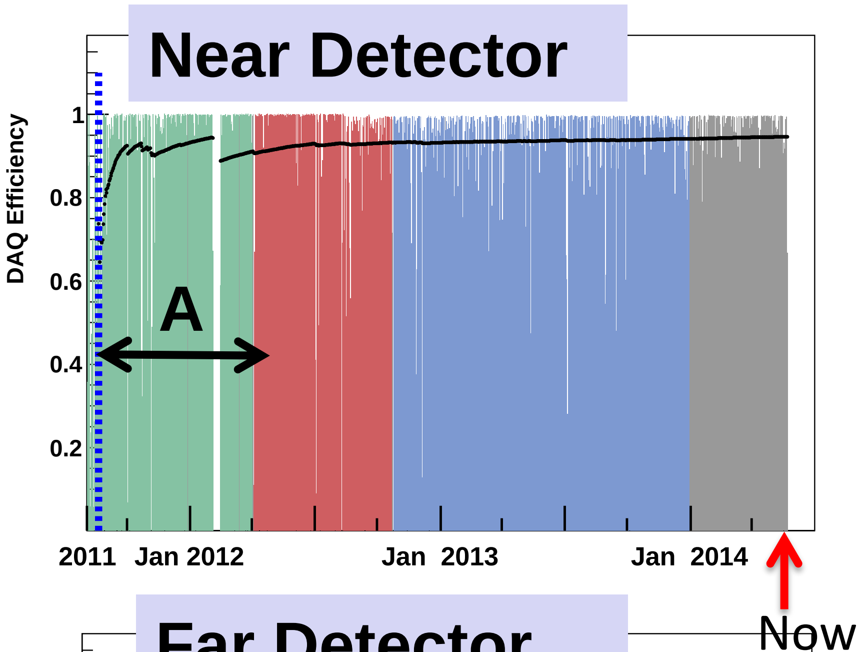
- Data taking began on Aug. 1, 2011 with both near and far detectors.
  (DAQ efficiency : ~95%)

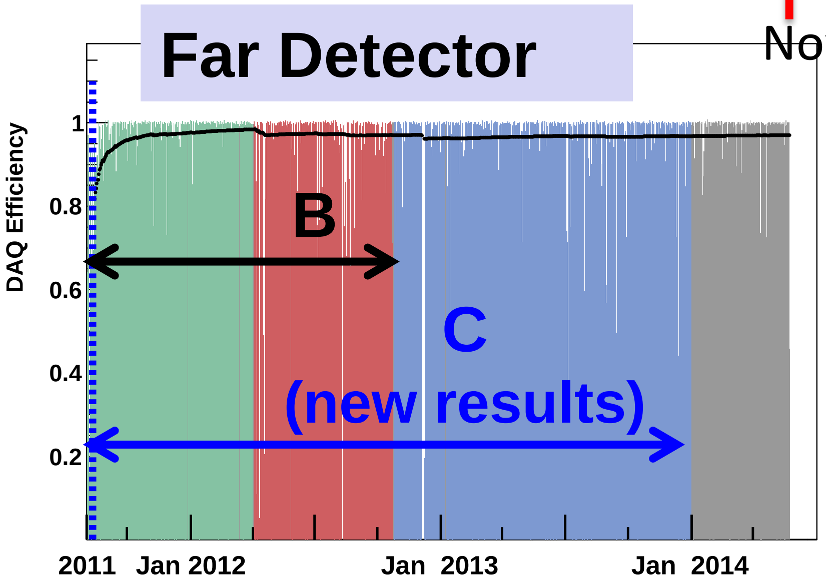
- **A** (220 days) : **First θ_{13} result**
  [11 Aug, 2011~26 Mar, 2012]
  PRL 108, 191802 (2012)

- **B** (403 days) : **Improved θ_{13} result**
  [11 Aug, 2011~13 Oct, 2012]
  NuTel 2013, TAUP 2013, WIN 2013

- **C** (~800 days) : New **θ_{13} result**
  Shape+rate analysis (in progress)
  [11 Aug, 2011~31 Dec, 2013]

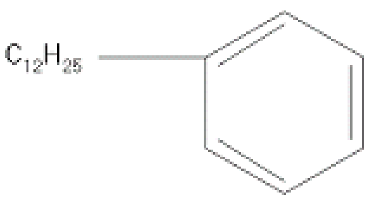
- Total observed reactor neutrino events as of today : ~ 1M (Near), ~ 0.1M (Far)
  → Absolute reactor neutrino flux measurement in progress
  [reactor anomaly & sterile neutrinos]





Detection of Reactor Antineutrinos

C_nH_{2n+1}-C_6H_5 (n=10~14)



Linear Alkyl Benzene (LAB)

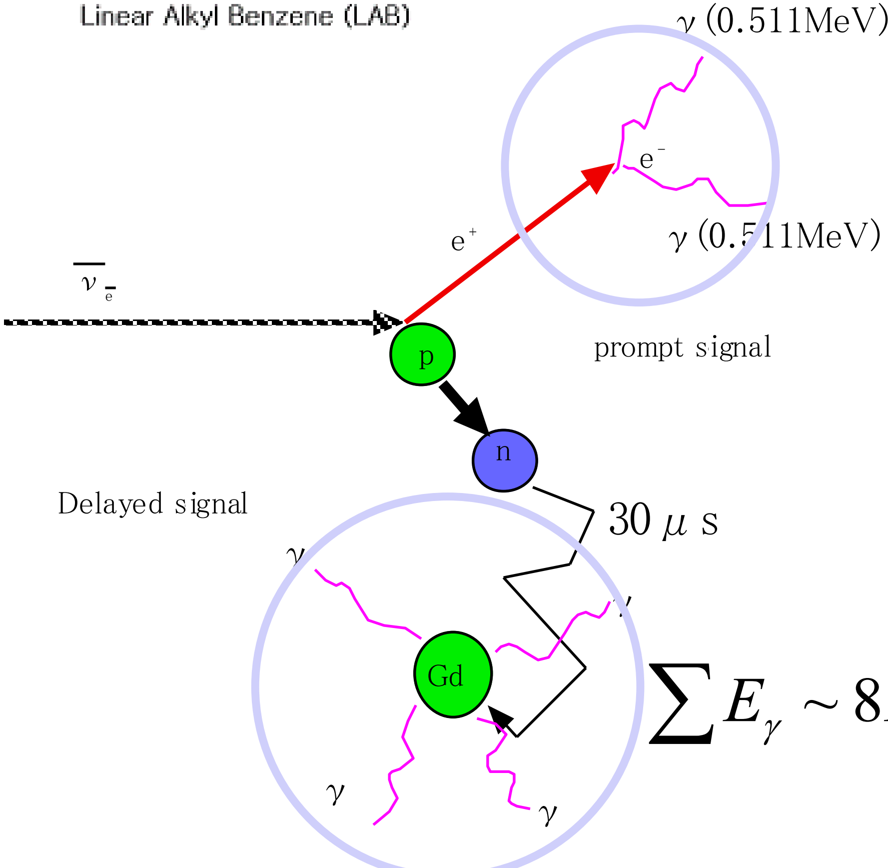
(prompt signal)

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

(delayed signal)

~180 μs: + p → D + γ (2.2 MeV) — **H capture**

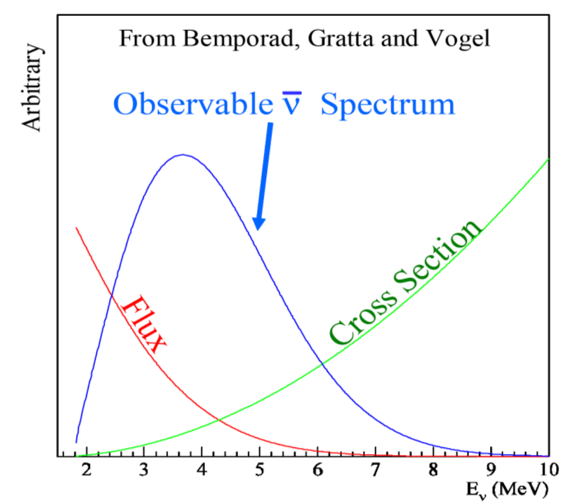
~28 μs (0.1% Gd): + Gd → Gd + γ's (8 MeV) — **Gd capture**



$$\sum E_\gamma \sim 8MeV$$

- **Neutrino energy measurement**

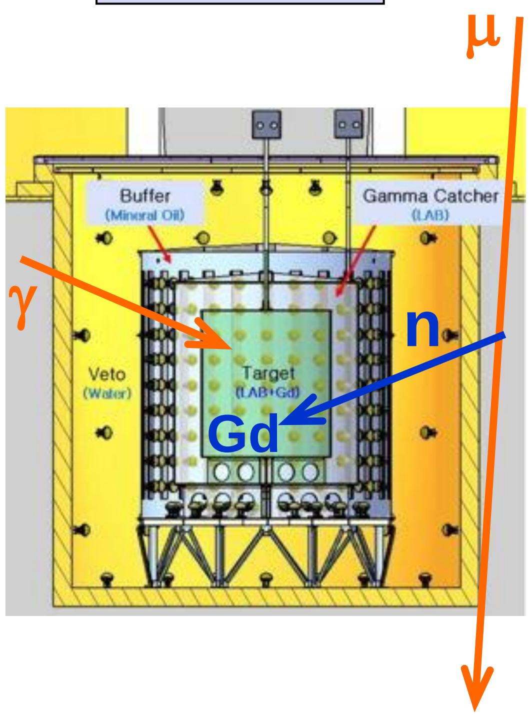
$$E_{\bar{\nu}} \cong T_{e^+} + \underbrace{T_n}_{10\text{-}40\ keV} + \underbrace{(M_n - M_p) + m_{e^+}}_{1.8\ MeV}$$



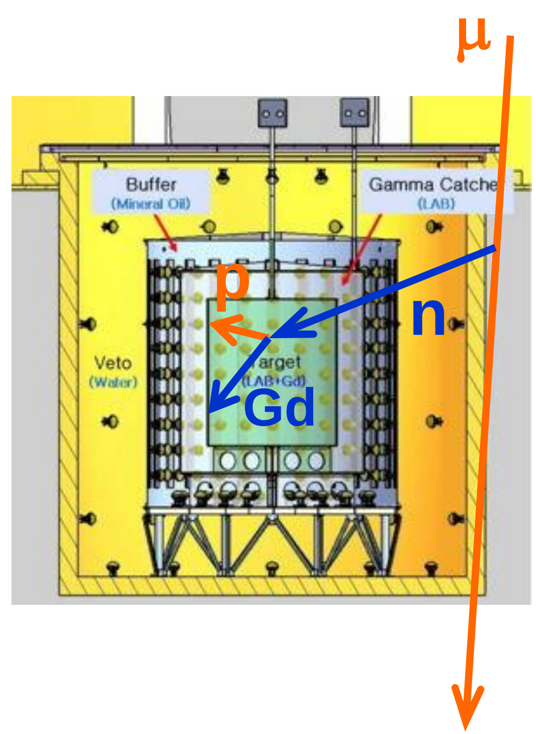
Backgrounds

- 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

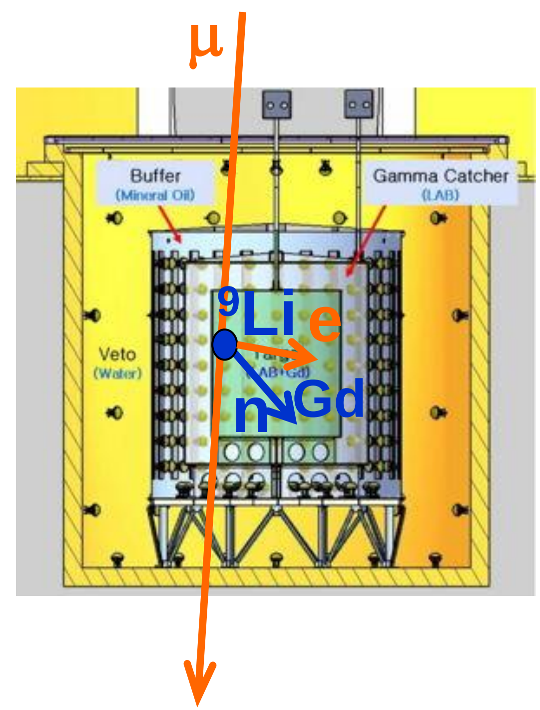
Accidentals



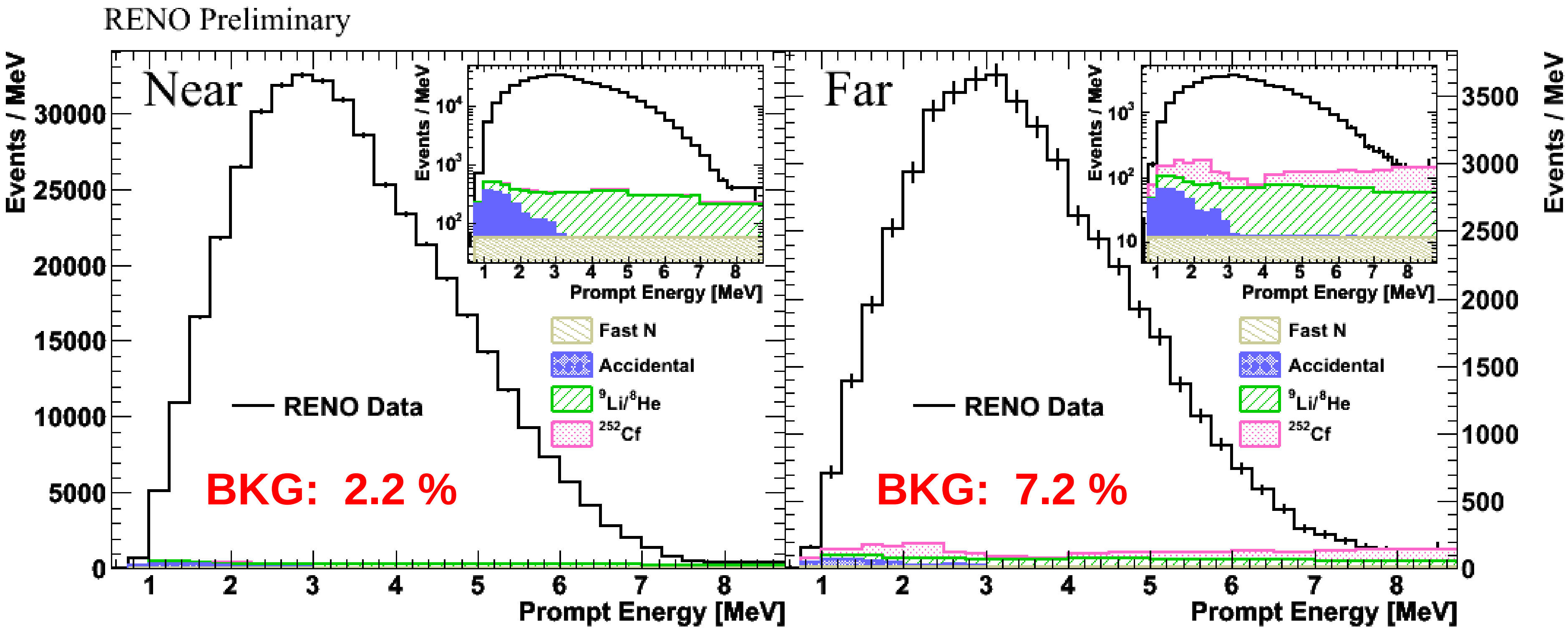
Fast neutrons



^{9}Li/^{8}He β-n followers



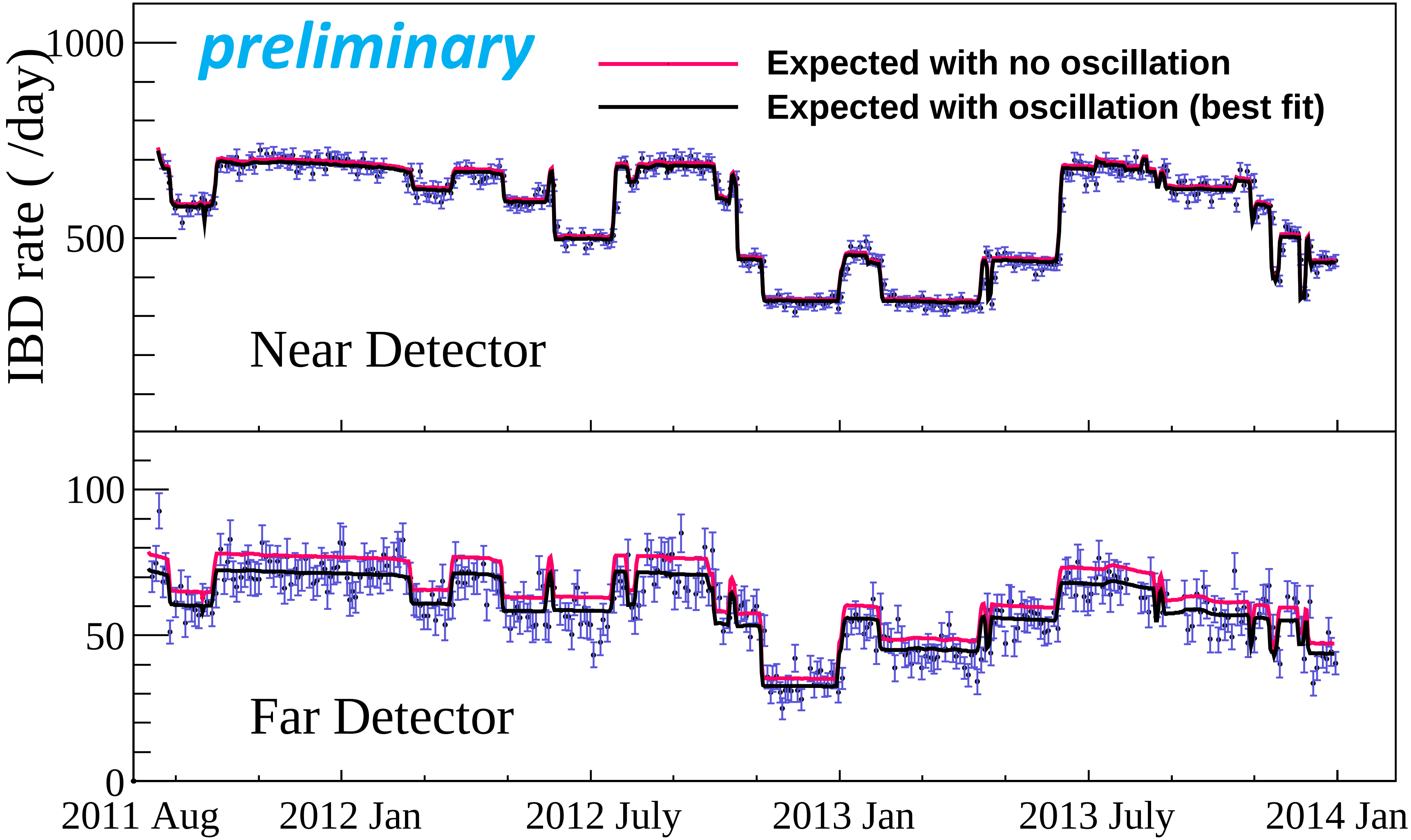
Measured Spectra of IBD Prompt Signal



Near Live time = 761.11 days
# of IBD candidate = 433,196
# of background = 9499 (2.2 %)

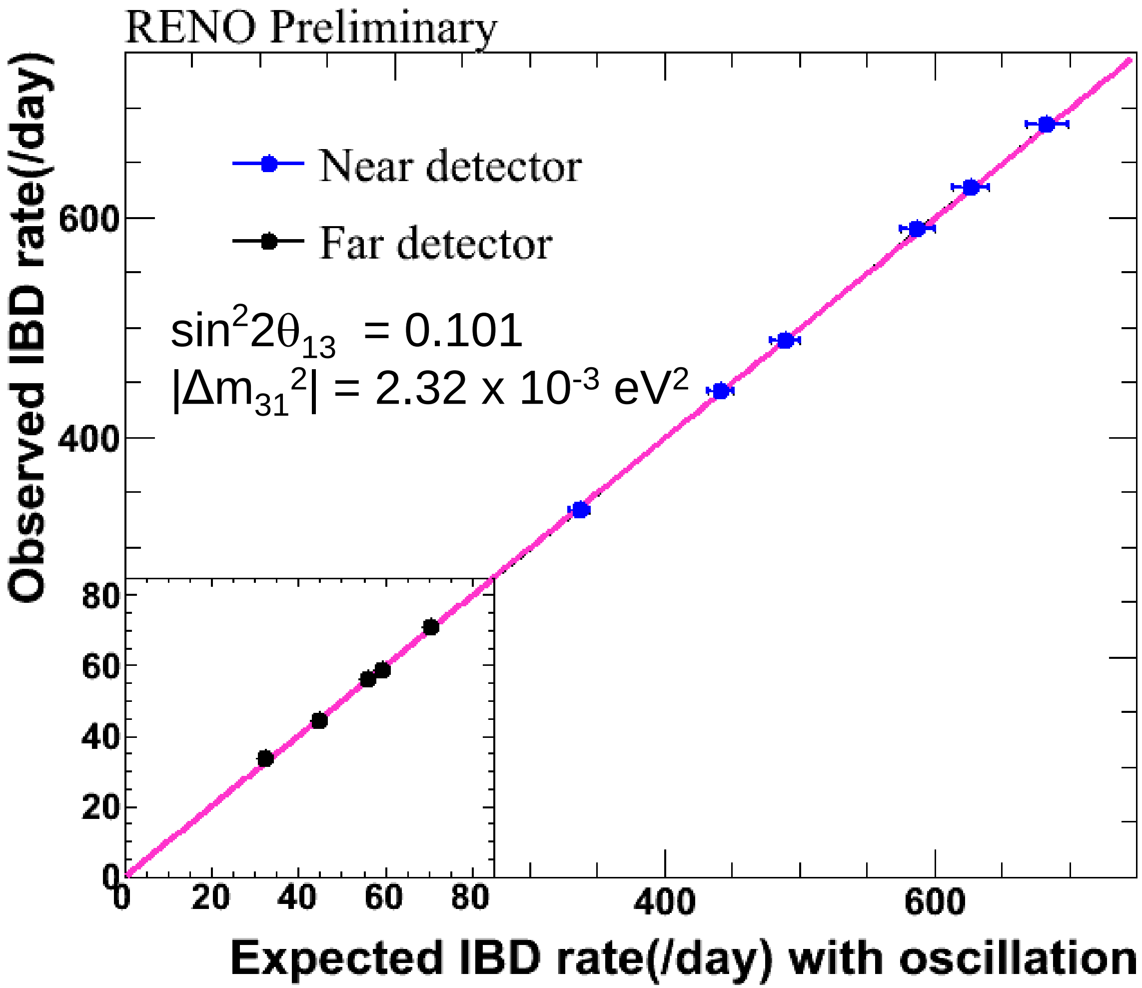
Far Live time = 794.72 days
# of IBD candidate = 50,750
# of background = 3672 (7.2 %)

Observed Daily Averaged IBD Rate



- Good agreement with observed rate and prediction.
- Accurate measurement of thermal power by reactor neutrinos

Observed vs. Expected IBD Rates



- Good agreement between observed rate & prediction
- Indication of correct background subtraction

New θ_{13} Measurement by Rate-only Analysis

C data set (~800 days)

Preliminary result

$\sin^2(2\theta_{13}) = 0.101 \pm 0.008\,(\text{stat.}) \pm 0.010\,(\text{sys.})$

$\sin^2 2\theta_{13} = 0.113 \pm 0.023$ 4.9 σ (Neutrino 2012)

→ 0.100 ± 0.016 6.3 σ (TAUP/WIN 2013)

→ 0.101 +/- 0.013 7.8 σ (Neutrino 2014)

Analysis for Neutron Capture on Hydrogen

Why n-H IBD Analysis?

Motivation:

1. Independent measurement of θ_{13} value

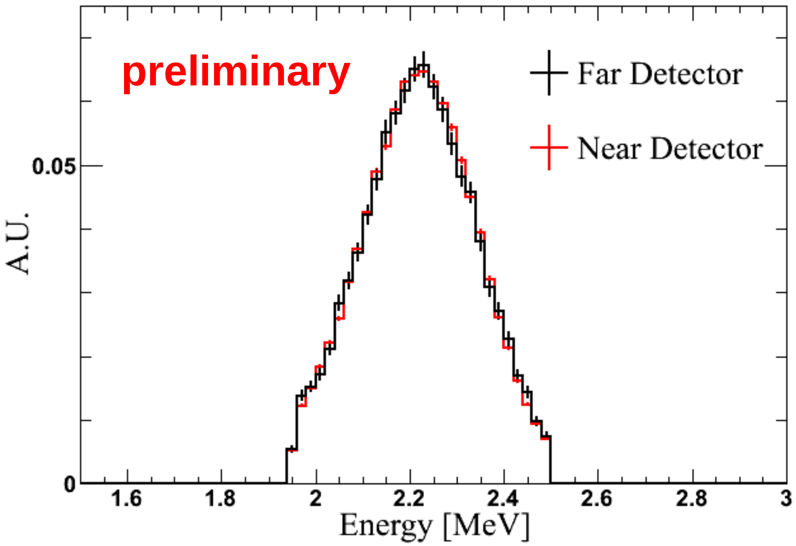
2. Consistency and systematic check on reactor neutrinos

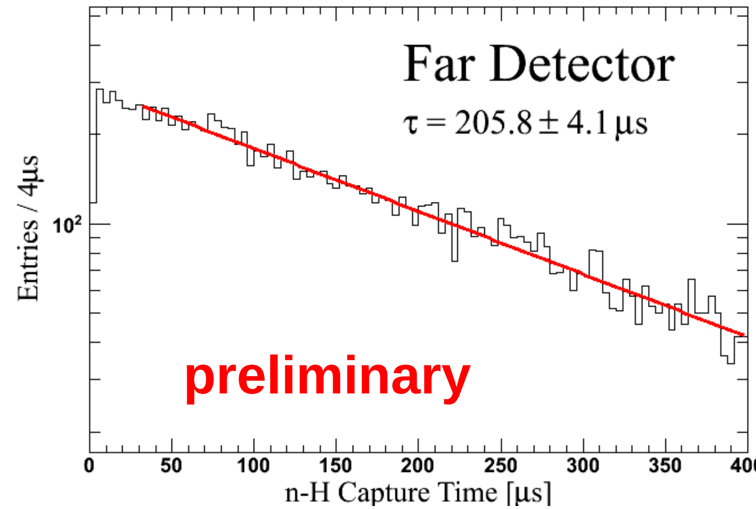
RENO's low accidental background makes it possible to perform n-H analysis

-- low radio-activity PMT

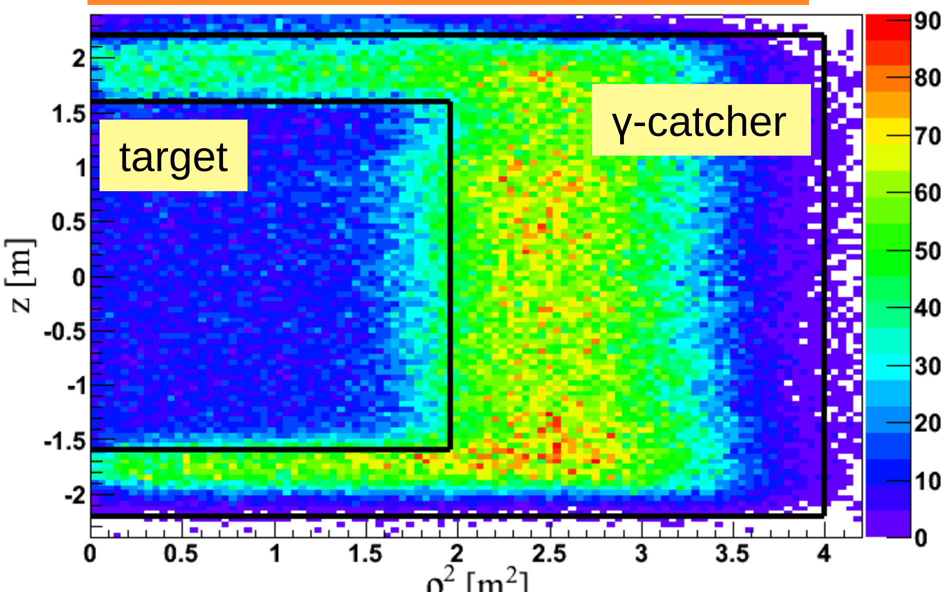
-- successful purification of LS and detector materials

n-H IBD Analysis (I)





n-H IBD Event Vertex Distribution



Neutron−H Capture cut criteria	
Prompt Energy	0.7 ~ 12 MeV
Delayed Energy	1.95~2.50 MeV
deltaT	2 ~ 400 us
deltaR	< 50 cm
Qmax/Qtot	< 0.08
Muon Veto time	1 ms
Shower Muon Veto time	700 ms
Additional Trigger veto time cuts	

n-H IBD Analysis (II)

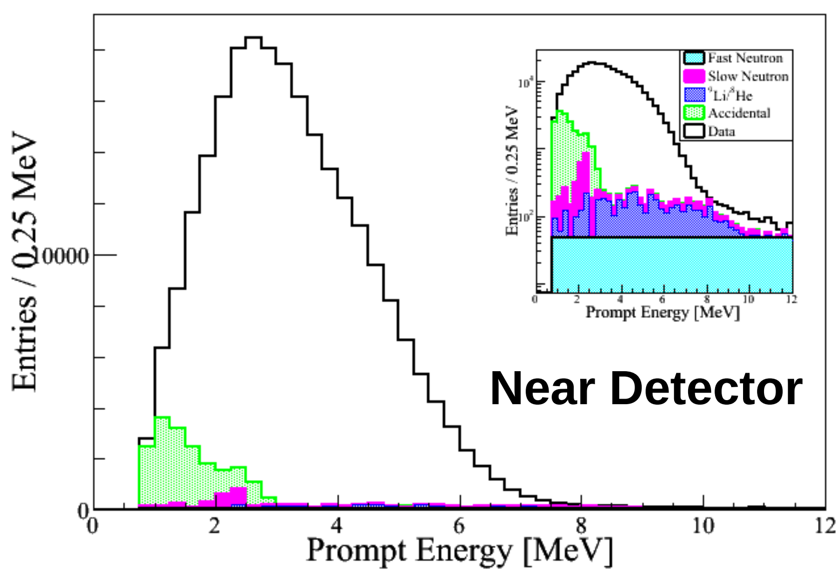
	Near	Far
Live time(day)	379.663	384.473
IBD Candidate	245,281	55,545
IBD(/day)		
Accidental (/day)	40.87+-1.74	72.69+-0.83
Fast Neutron(/day)	5.63+-0.09	1.28+-0.10
Soft Neutron(/day)	6.42+-0.35	1.04+-0.47
LiHe(/day)	7.24+-0.92	3.17+-0.35

Result using ~400 days of data

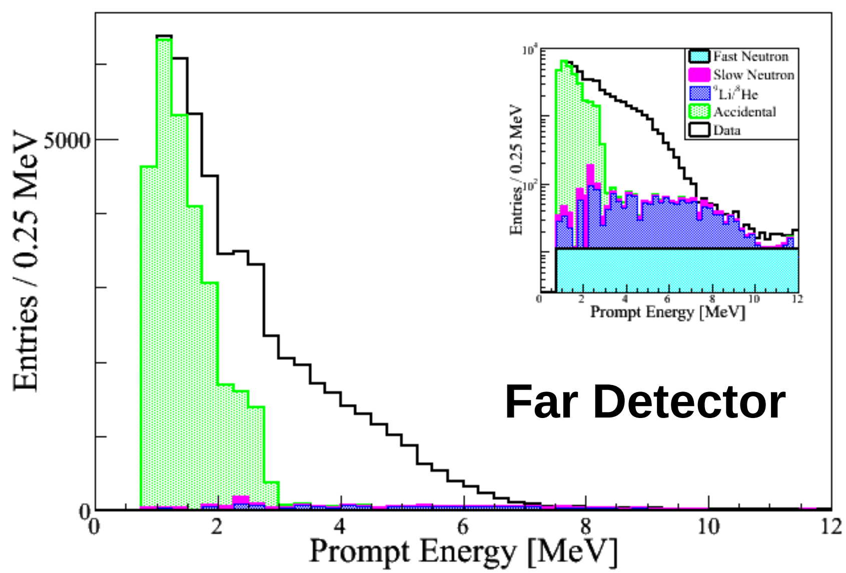
$\sin^2(2\theta_{13}) = 0.095 \pm 0.015$ (stat.) ± 0.025 (sys.)

Very preliminary
Rate-only result

preliminary

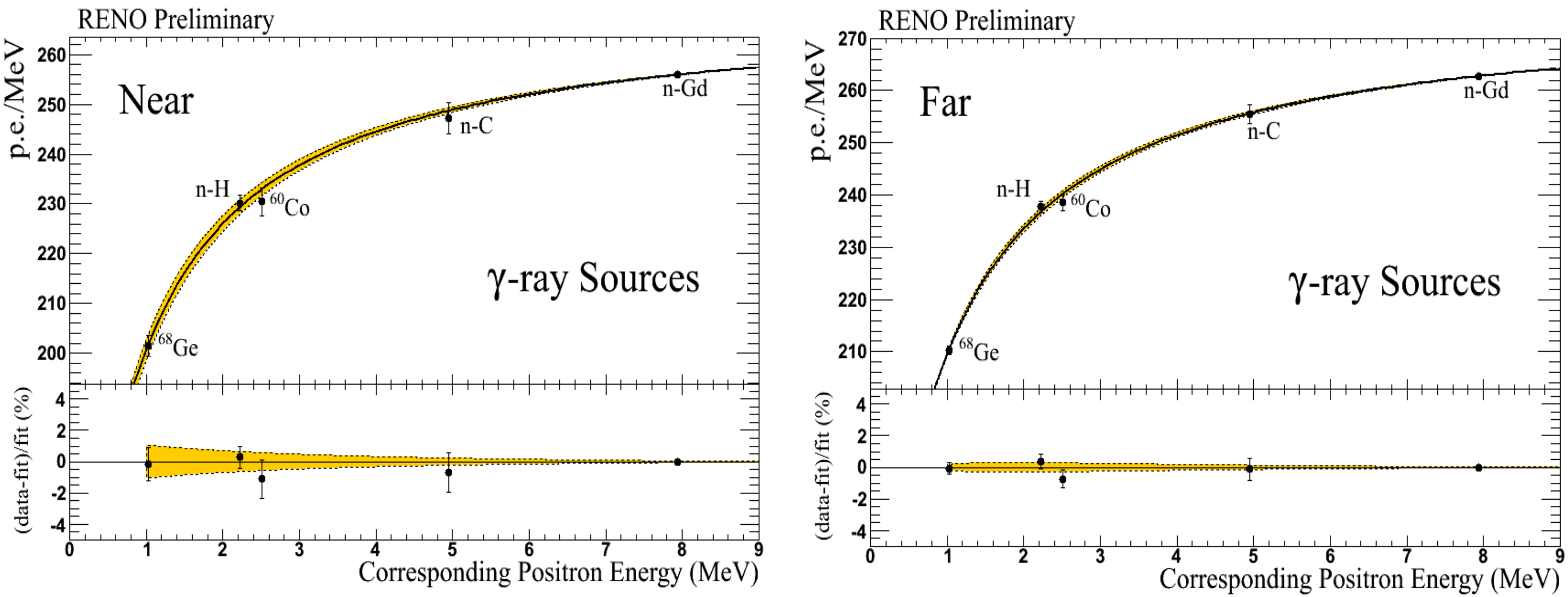


preliminary



Shape Analysis

Energy Calibration from γ-ray Sources

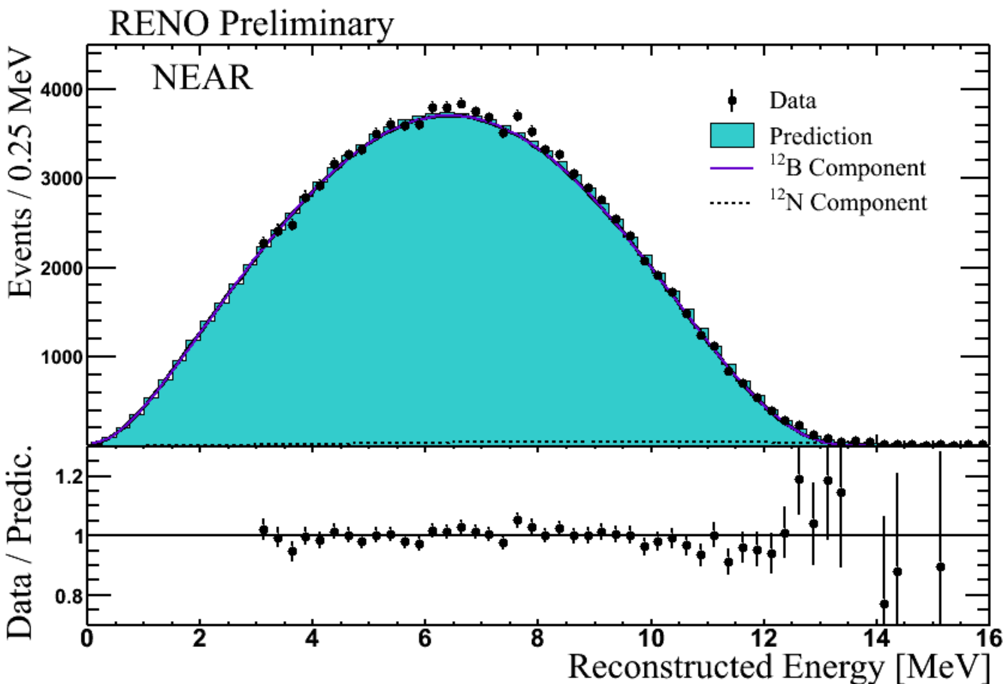


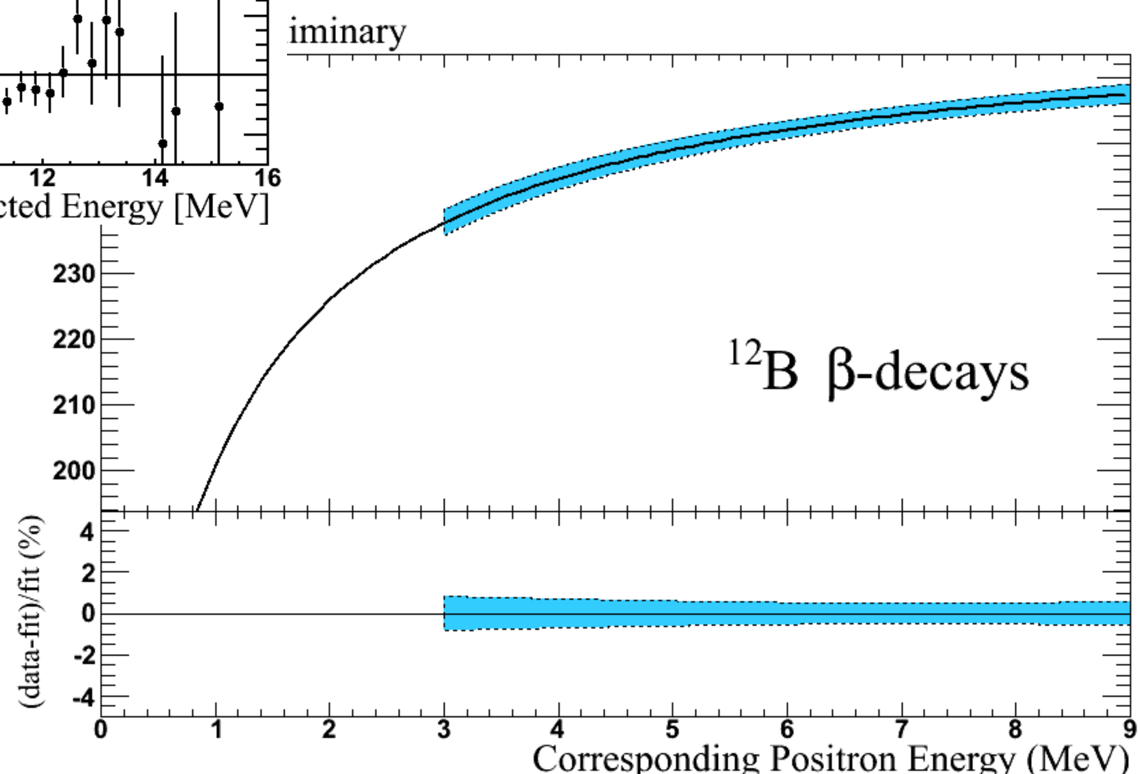
p.e. → MeV conversion function

Fitting accuracy is within 1% level

Energy Calibration from B12 β-decays

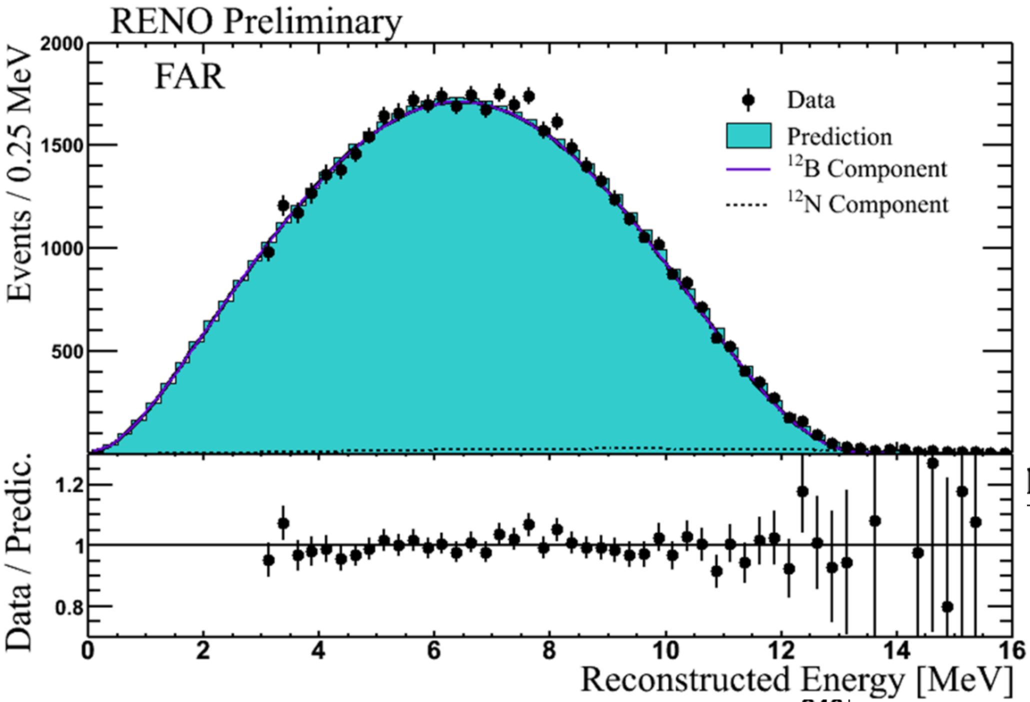
Near detector

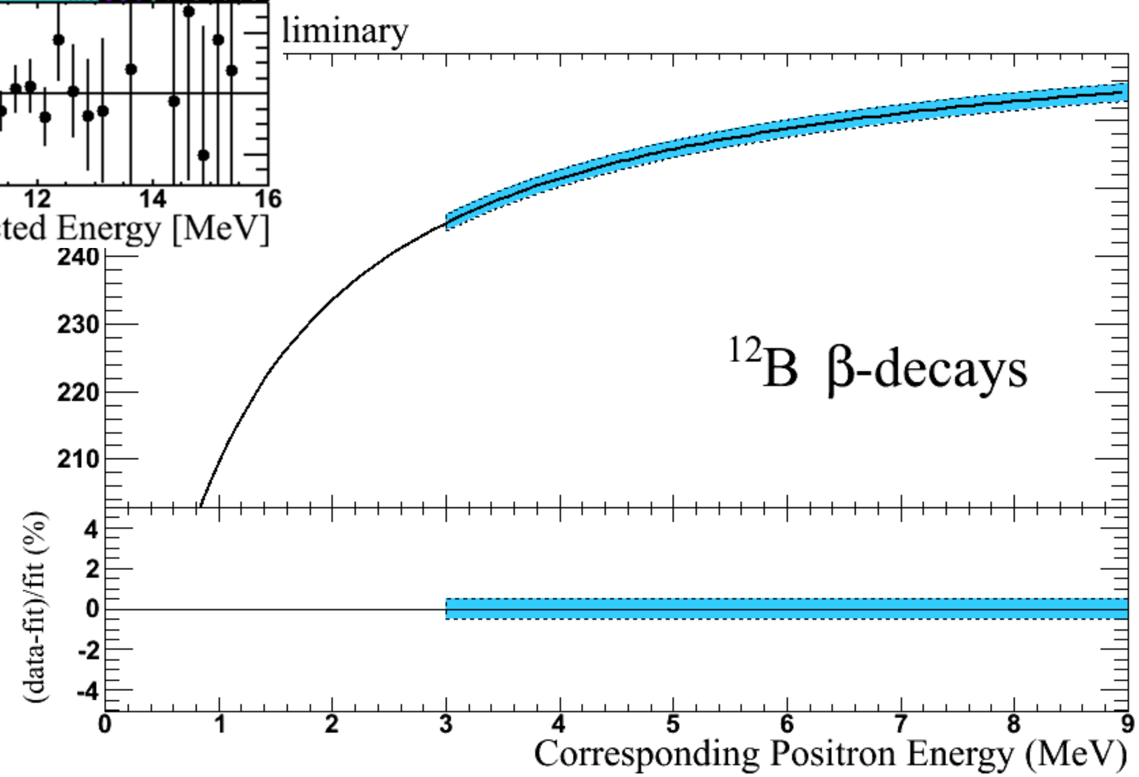




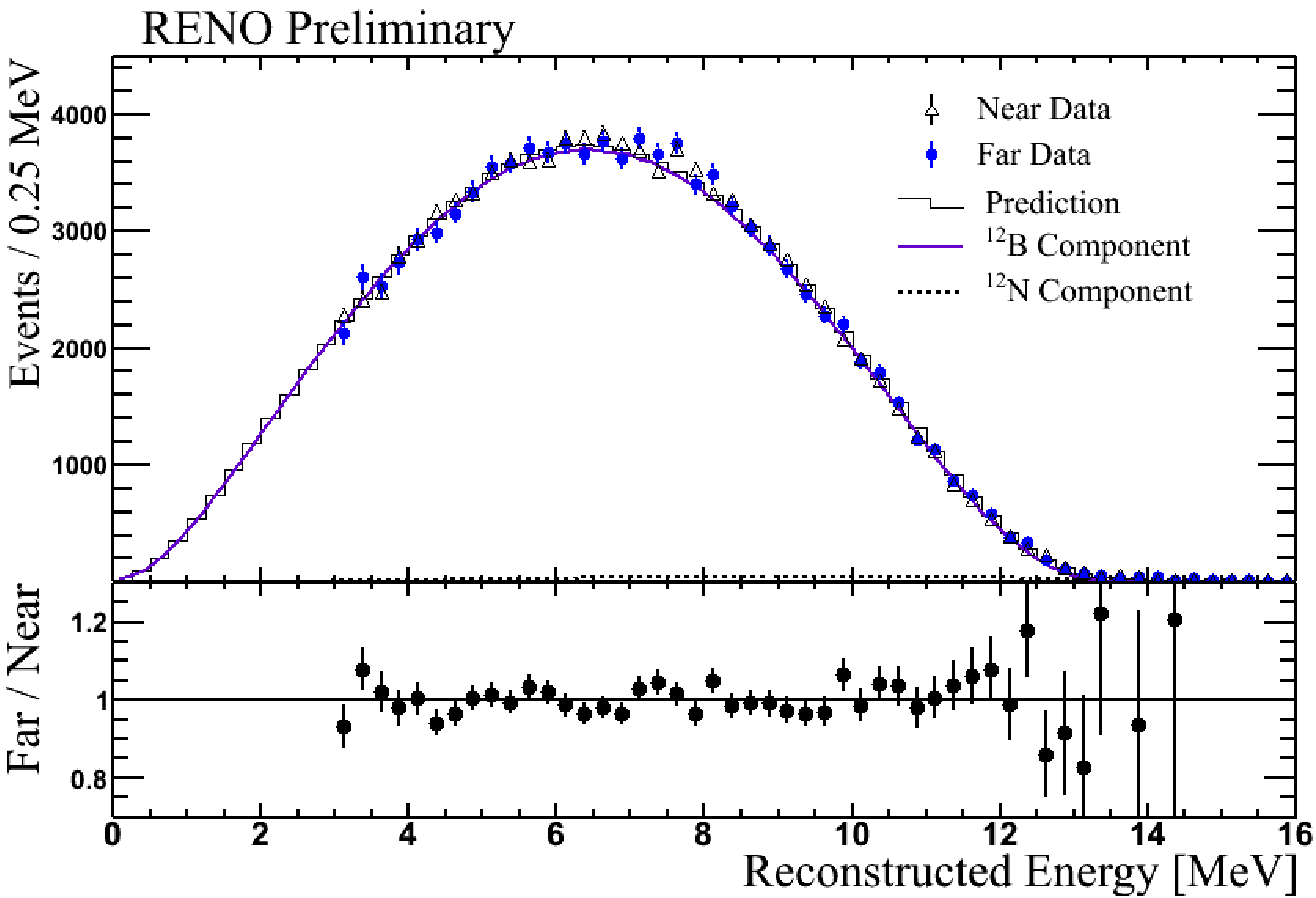
Energy Calibration from B12 β-decays

Far detector



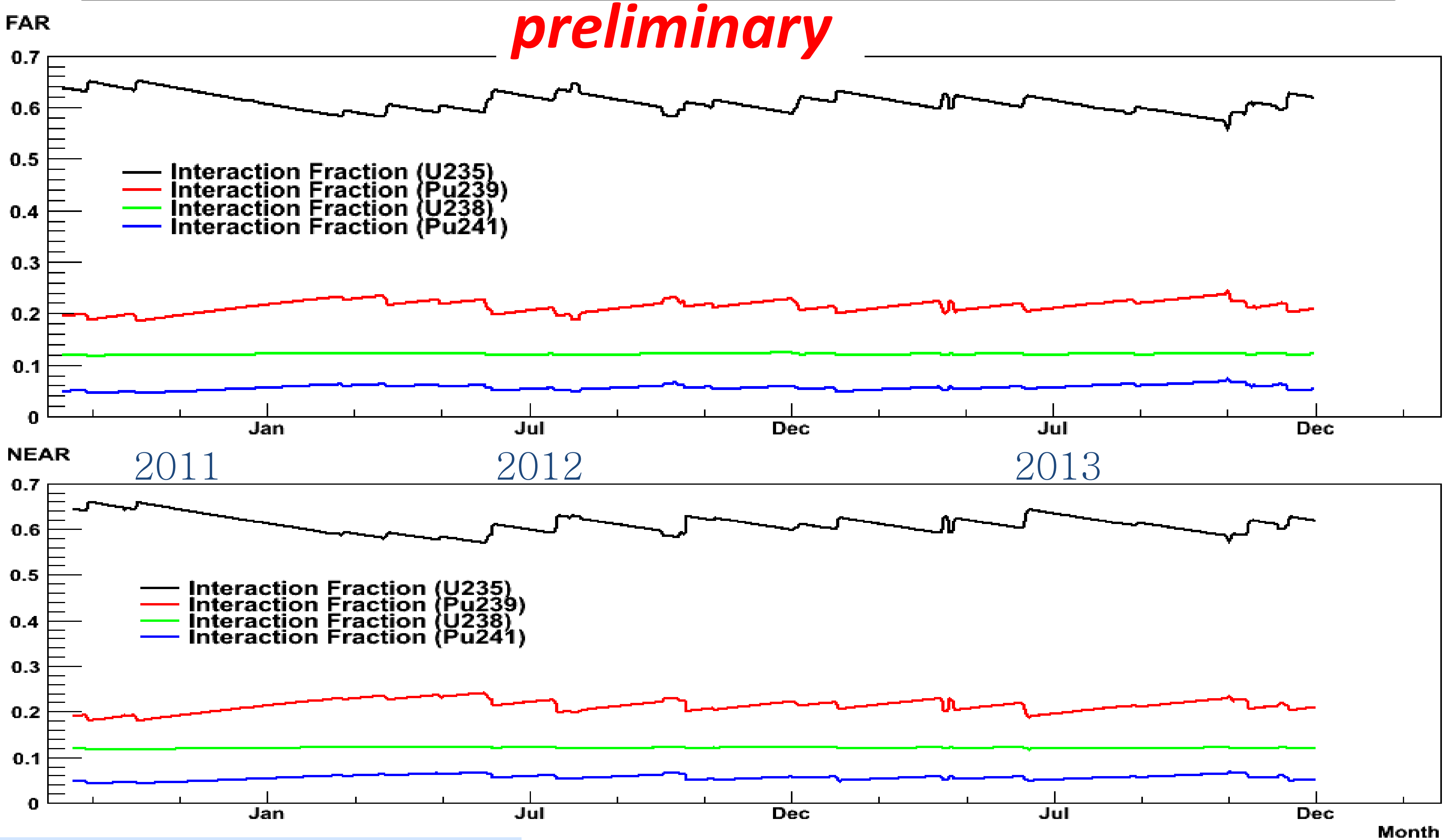


B12 Energy Spectrum (Near & Far)



Daily Isotope Fraction

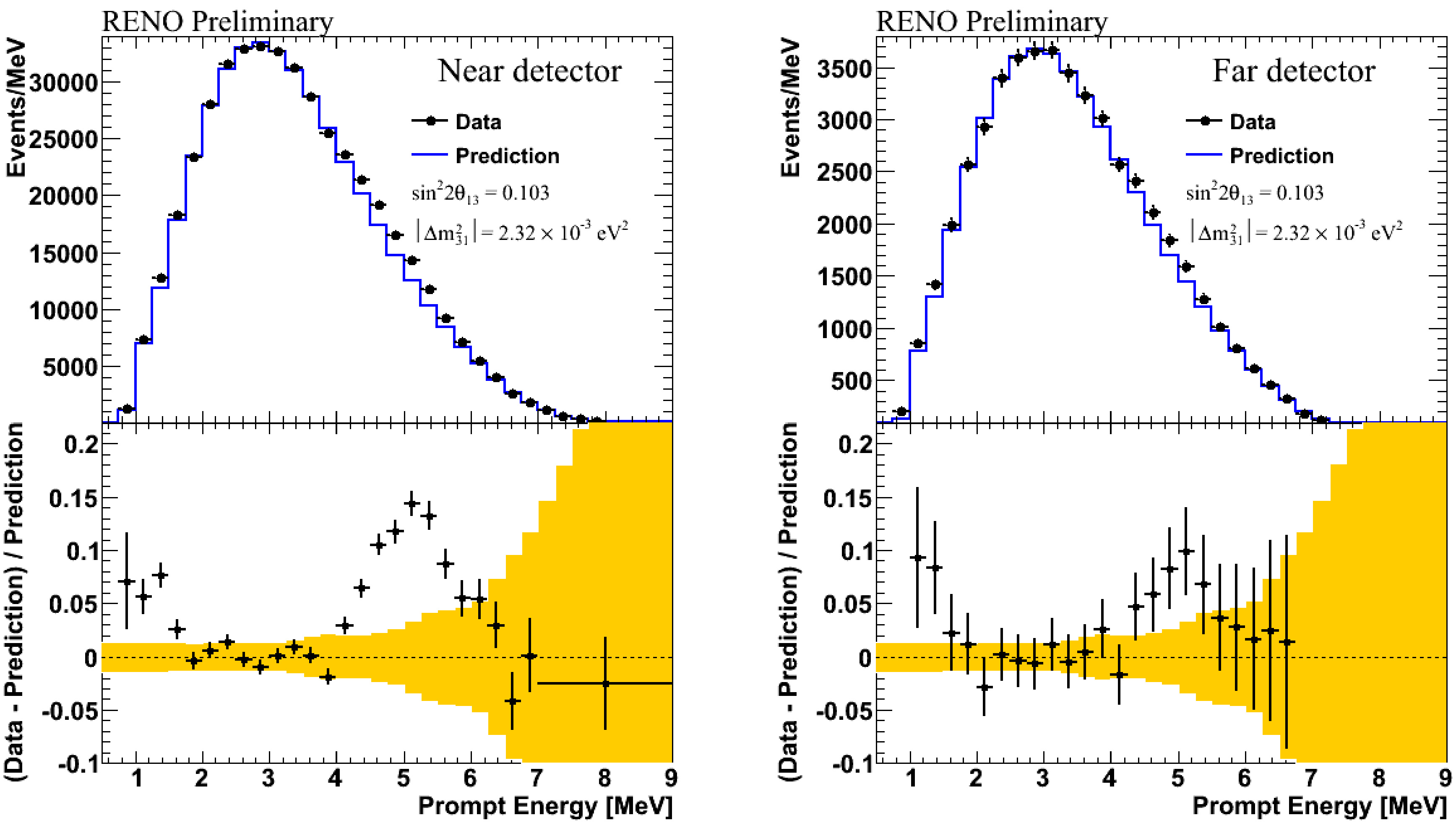
preliminary



Spectral shape depends on isotope fraction.

We considered daily isotope fraction in the expected n spectrum & flux.

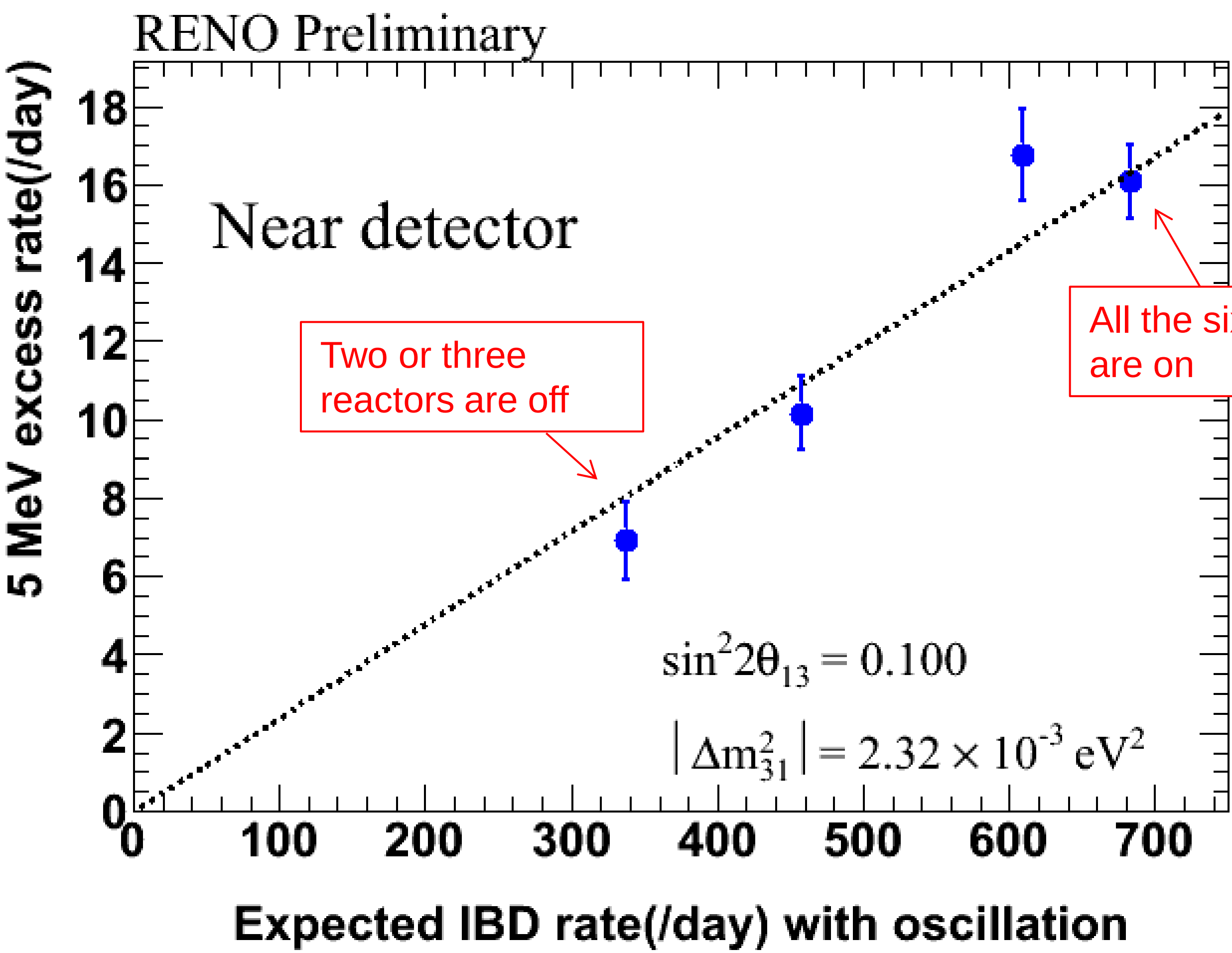
Observation of new reactor ν component at 5 MeV



<u>Fraction of 5 MeV excess (%) to total expected flux</u>

- Near : 2.303 +/- 0.117 (stat.) +/- 0.395 (sys.) +/- 0.492 (expected shape error)
- Far : 1.468 +/- 0.390 (stat.) +/- 0.499 (sys.) +/- 0.482 (expected shape error)

Correlation of 5 MeV Excess with Reactor Power

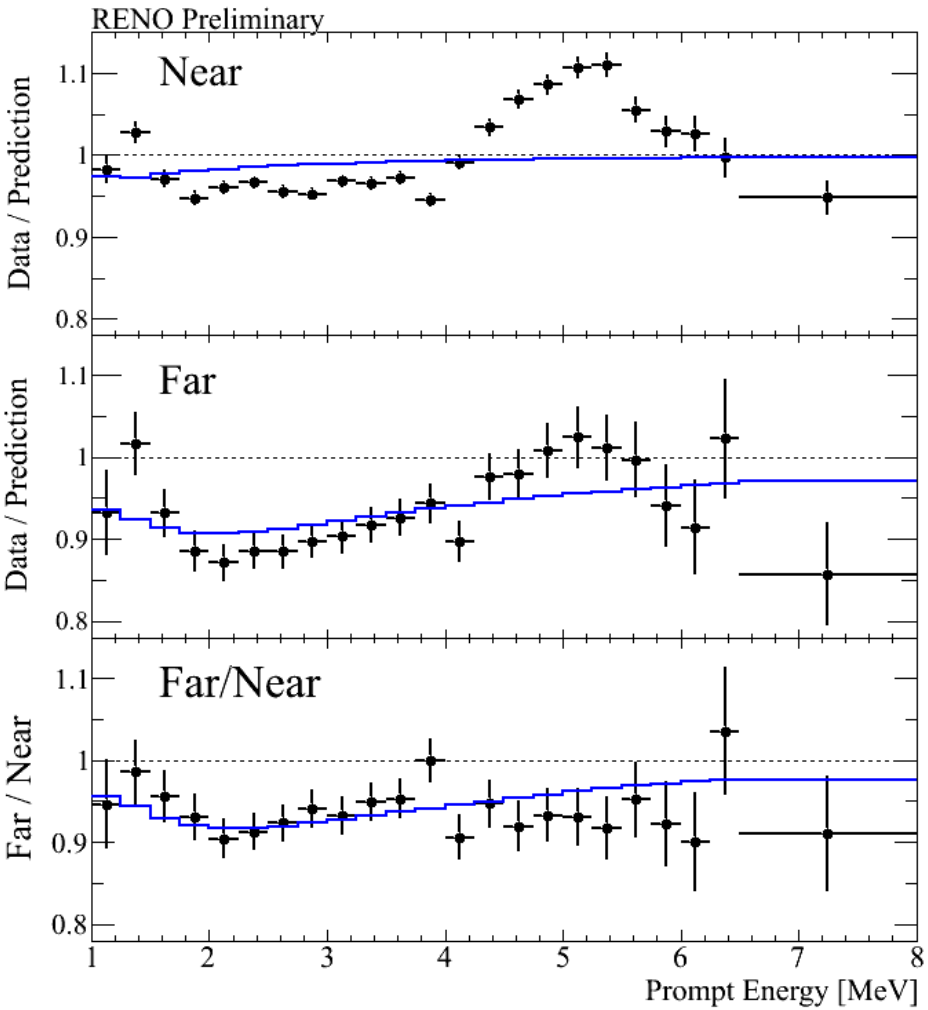


5 MeV excess has a clear correlation with reactor thermal power !

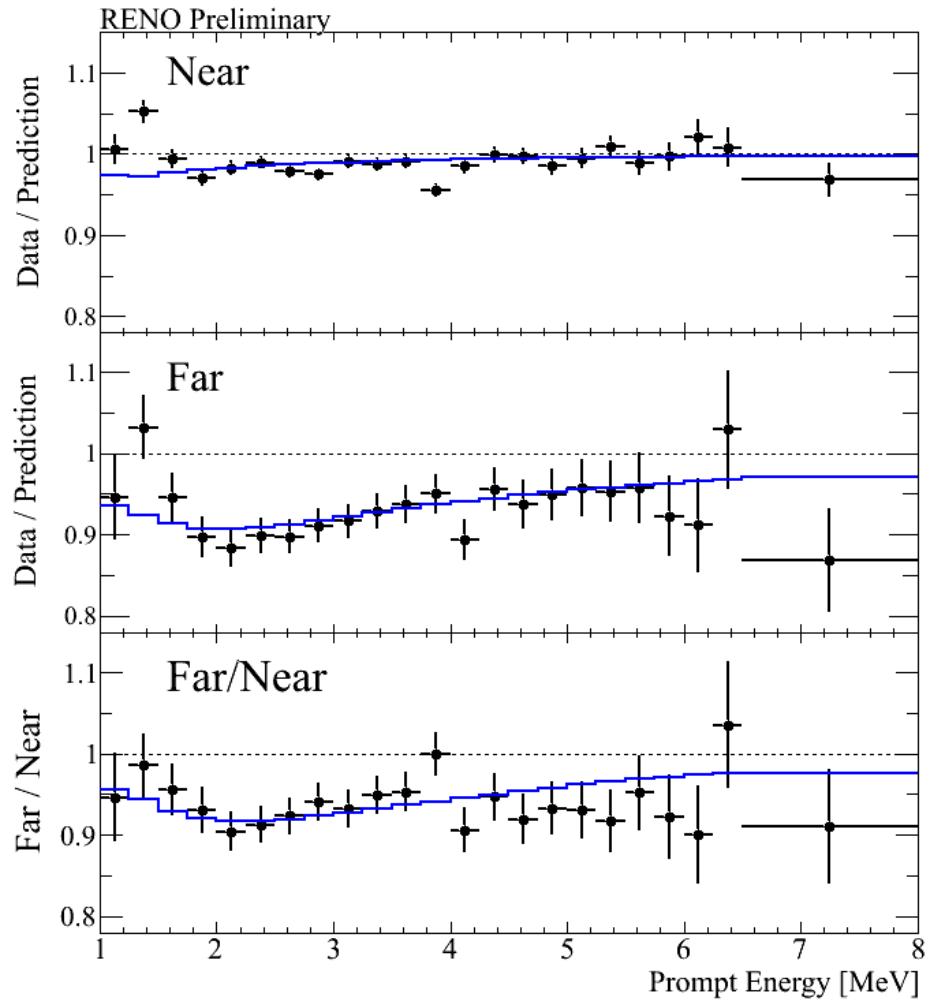
Shape Analysis for Δm_{ee}^2

In progress…. Stay tuned…

Without 5 MeV excess



With 5 MeV excess

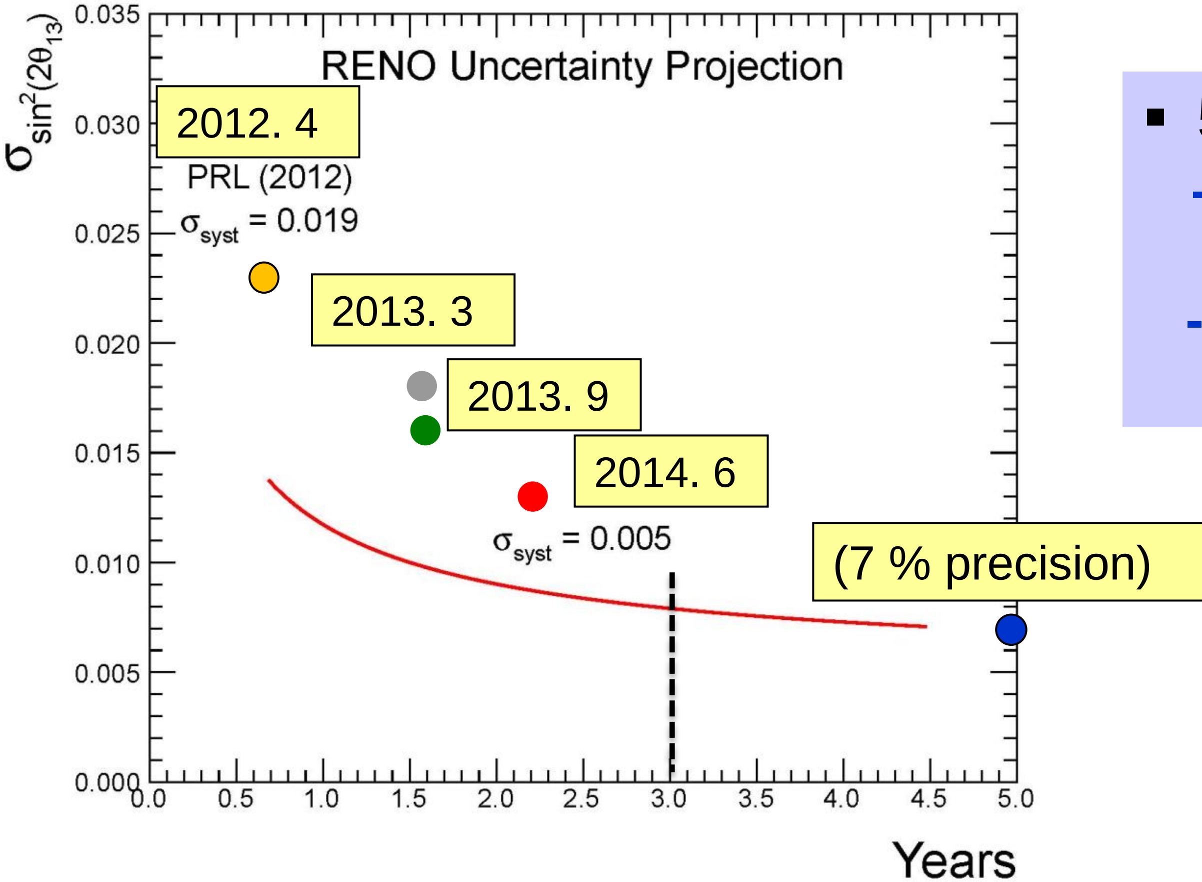


RENO's Projected Sensitivity of θ_{13}

$$\sin^2 2\theta_{13} = 0.101 \pm 0.008(stat.) \pm 0.010(syst.)$$

(~800 days) 0.101 ± 0.013 (7.8 σ) → ± 0.007 (14 σ) (in 3 years)

(13 % precision) (7 % precision)



- 5 years of data : 7 %
  - **stat. error :**
    $\pm 0.008 \rightarrow \pm 0.005$
  - **sys. error :**
    $\pm 0.010 \rightarrow \pm 0.005$

Summary

- New measurement of θ_{13} by rate-only analysis (preliminary)

$$\sin^2(2\theta_{13}) = 0.101 \pm 0.008 \text{ (stat.)} \pm 0.010 \text{ (sys.)}$$

- First result on n-H IBD analysis (very preliminary)

$\sin^2(2\theta_{13}) = 0.095 \pm 0.015$ (stat.) ± 0.025 (sys.)

- We observed new reactor neutrino component at 5 MeV (3.6 σ)

- Shape analysis for Δm^2 in progress… (stay tuned)

- $\sin^2(2\theta_{13})$ to 7% accuracy within 3 years
  $\rightarrow$ will provide the first glimpse of $\delta_{CP.}$
  If accelerator results are combined