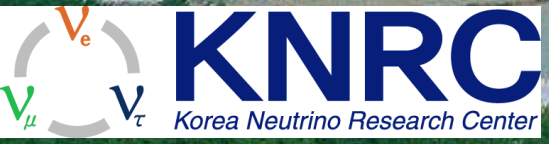
RENO Reactor Neutrino Experiment

"RENO/RENO-50"

RENO = Reactor Experiment for Neutrino Oscillation

(On behalf of RENO Collaboration)



K.K. Joo
Chonnam National University
August 13, 2015

NuFact15@CBPF, Rio de Janeiro, Brazil

Outline

1st part

RENO

- Improvements in data analysis
- Latest result of θ_{13} from RENO

2nd part

RENO-50

- Future project RENO-50
- Physics with RENO-50

RENO Collaboration

RENO
ν θ_{13}

10 institutions and 40 physicists in Korea

- 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 since **Aug. 2011**

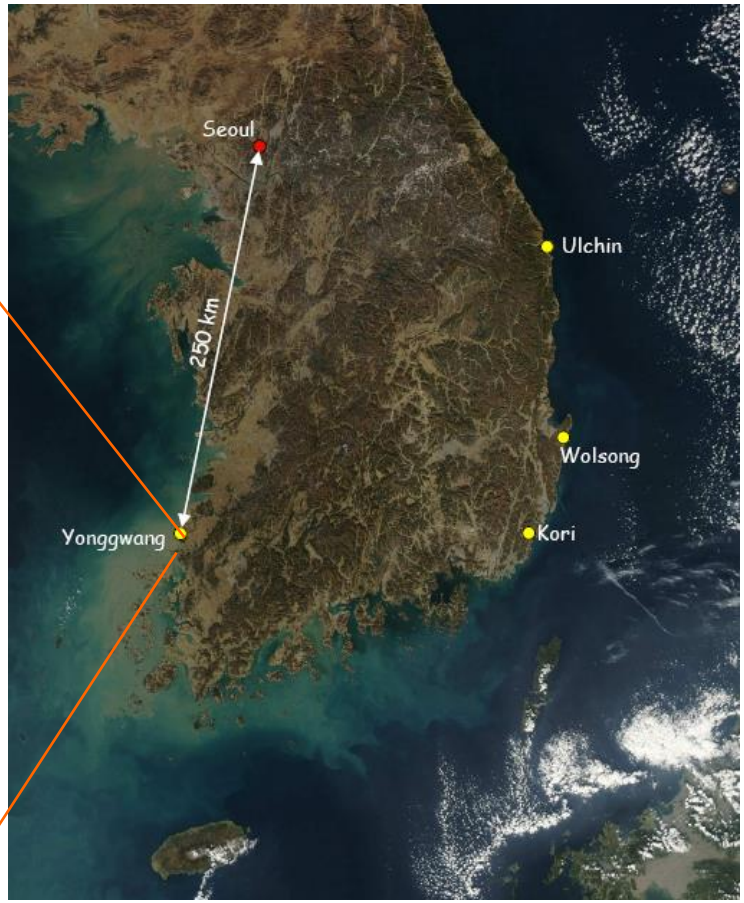
YongGwang (靈光) :

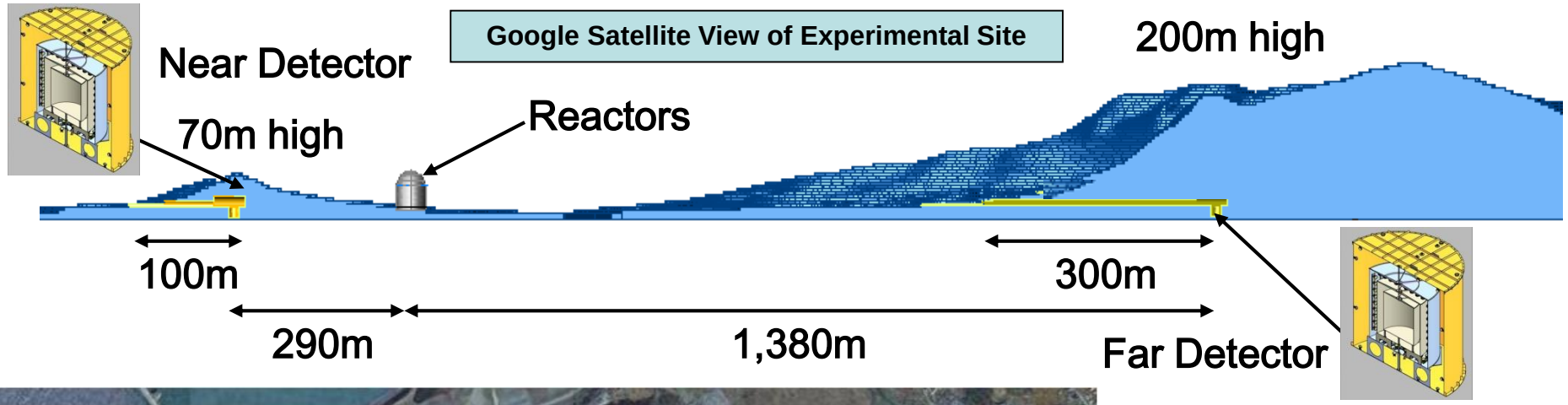
Reactor **E**xperiment for **N**eutrino **O**scillation

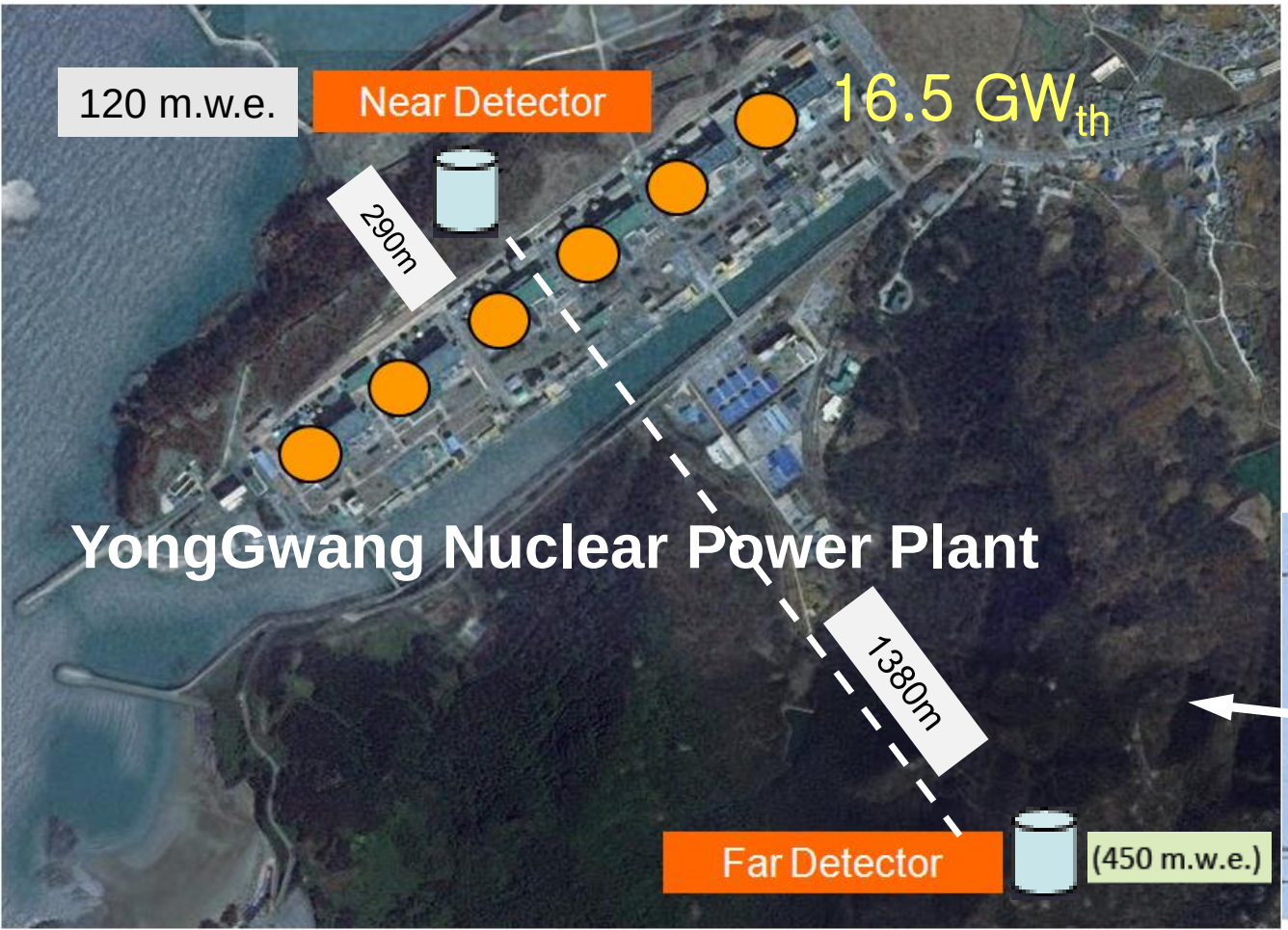
YongGwang Nuclear Power Plant

- Located in the west coast of southern part of Korea
- ~300 km from Incheon international airport
- 6 reactors are lined up in roughly equal distances and span ~1.3 km
- Total average thermal output ~16.7GW_{th} (2^{nd} largest in the world)

YongGwang(靈光):
= glorious[splendid] light (~spirited)
New name: Hanbit







RENO

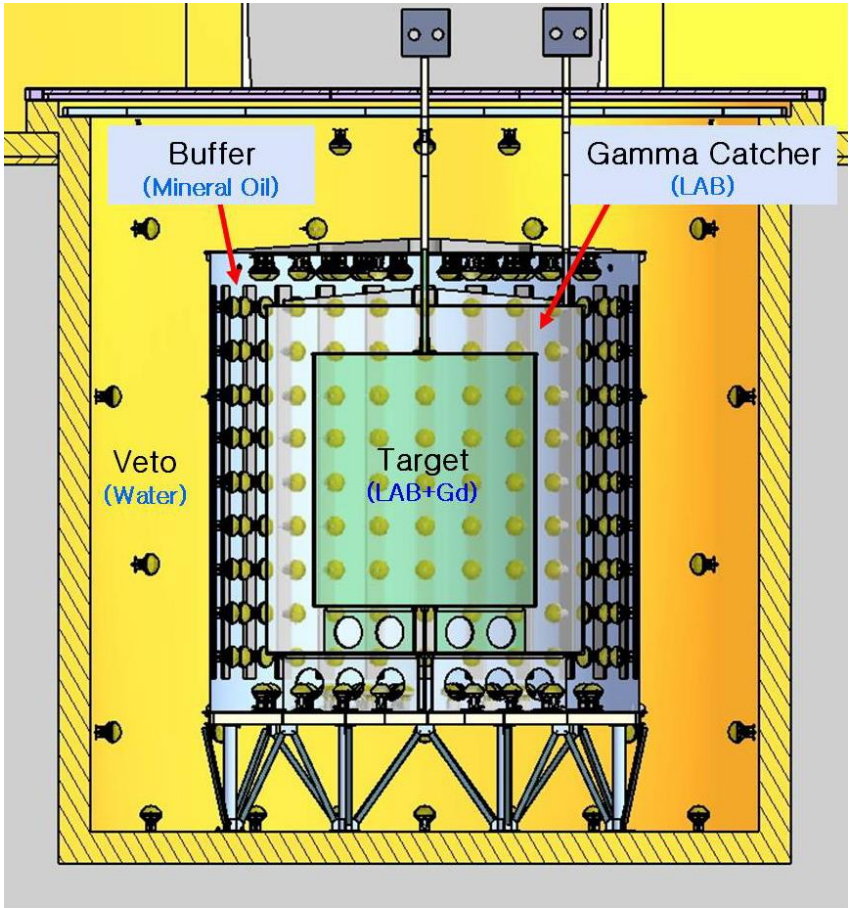
ν θ_{13}

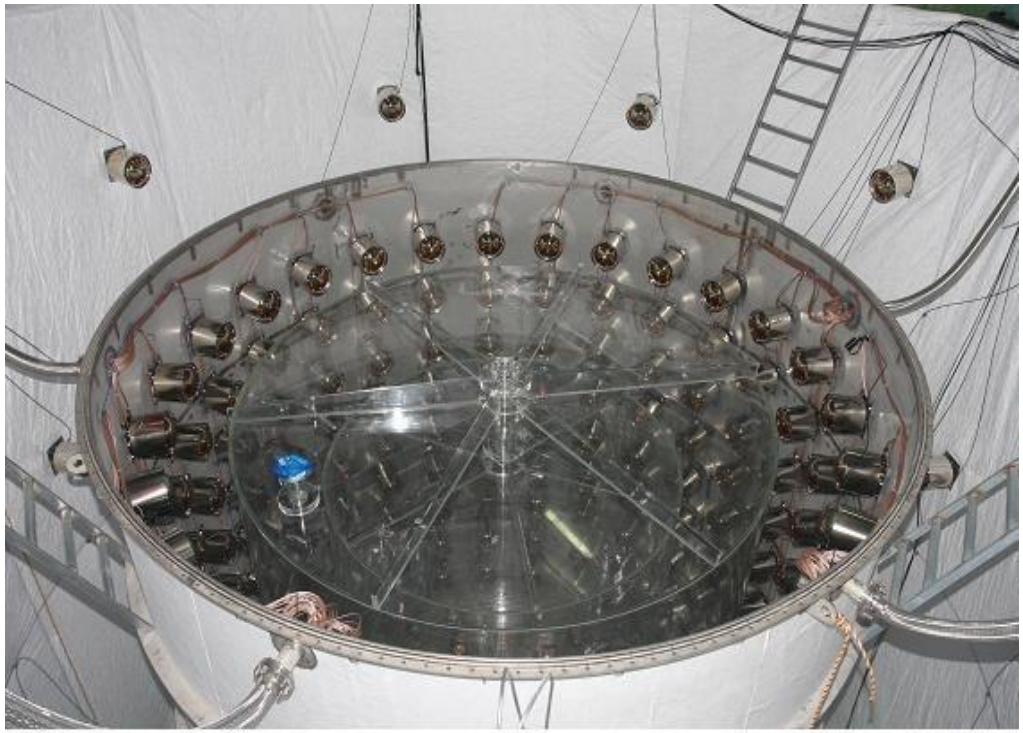
ν_e ν_μ ν_τ

KNRC

Korea Neutrino Research Center

RENO Detector



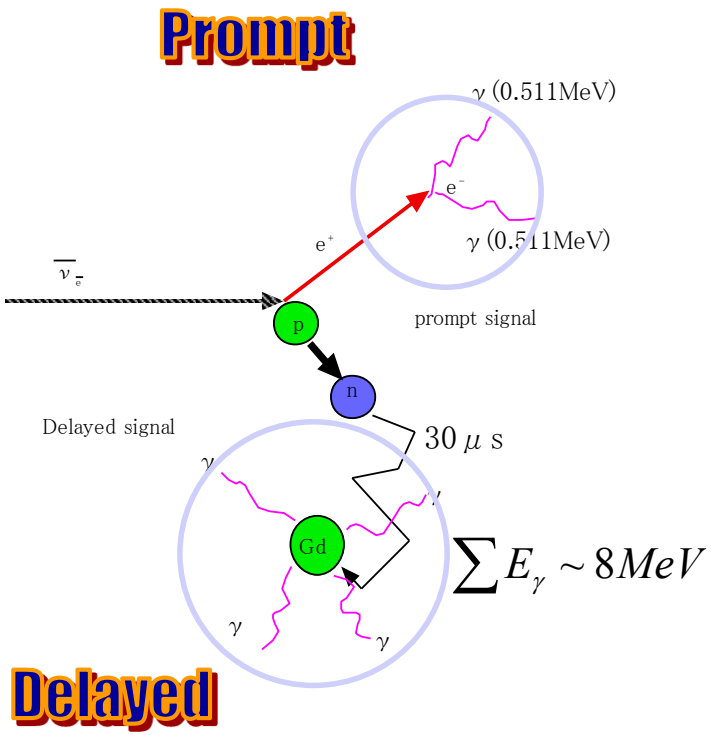


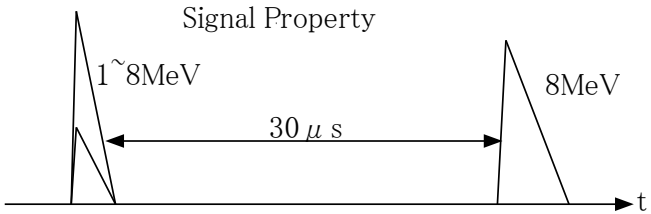
- Target : **16.5 ton** Gd-LS
  (R=1.4m, H=3.2m)
- Gamma Catcher : 30 ton LS
  (R=2.0m, H=4.4m)
- Buffer : 65 ton mineral oil (MO)
  (R=2.7m, H=5.8m)
- Veto : 350 ton water (R=4.2m, H=8.8m)

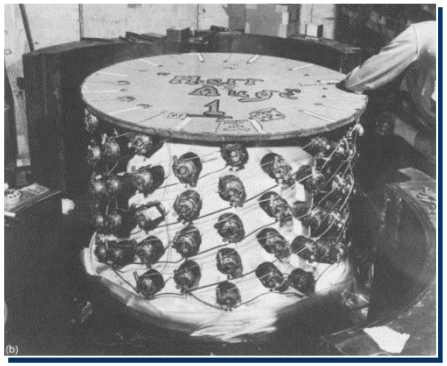
total ~460 tons

- **Inner PMTs: 354 10” PMTs**
  - solid angle coverage = ~14%
- **Outer PMTs: ~ 67 10” PMTs**

Detection of Reactor Antineutrinos







- Use inverse beta decay ($\bar{\nu}_e + p \rightarrow e^+ + n$) reaction process
- Prompt part:
  subsequent annihilation of the positron to two 0.511MeV γ
- Delayed part:
  neutron is captured
  ~200μs w/o Gd
  ~ 30μs w Gd
  Gd has largest n absorption cross section & emits high energy γ
- Signal from neutron capture
  ~2.2MeV w/o Gd
  ~ 8MeV w Gd
- Measure prompt signal & delayed signal
- "Delayed coincidence" reduces backgrounds drastically

RENO Data Taking Status

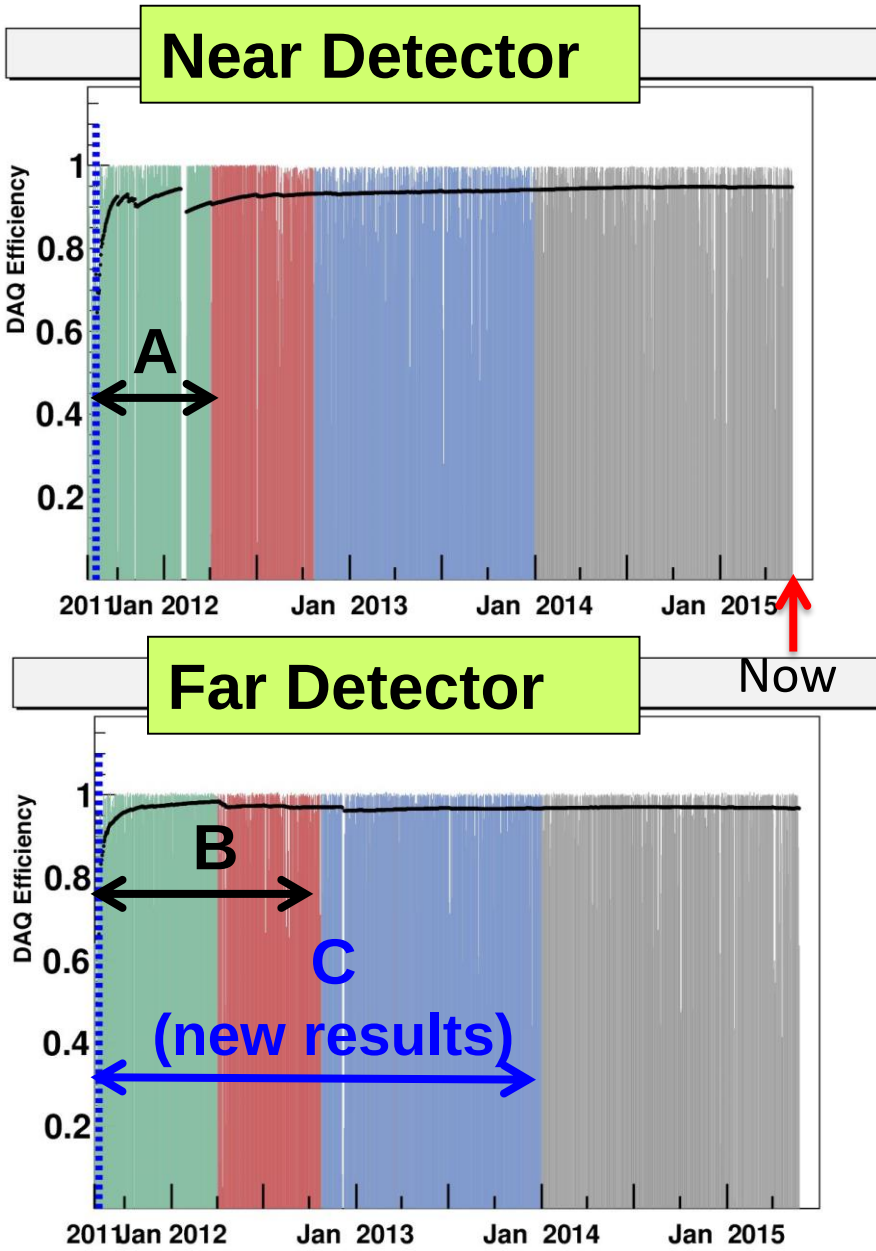
- Data taking began on Aug. 1, 2011 with both near and far detectors.
  (DAQ efficiency : ~95%)

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

- **B** (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 : **~ 1.5M** (Near), **~ 0.15M** (Far)
  → Absolute reactor neutrino flux measurement in progress
  [reactor anomaly & sterile neutrinos]



Quick Overview

- ~800 days of data
- New measured-value of θ_{13} from rate-only analysis
- Observation of an excess at 5 MeV in reactor neutrino spectrum

Improvements after Neutrino 2014

- Relax Q_{max}/Q_{tot} cut : 0.03 → 0.07

  - allow more accidentals to increase acceptance of signal and minimize any bias to the spectral shape

- More precisely observed spectra of Li/He background

  - reduced the Li/He background uncertainty based on an increased control sample

- More accurate energy calibration

  - best efforts on understanding of non-linear energy response and energy scale uncertainty

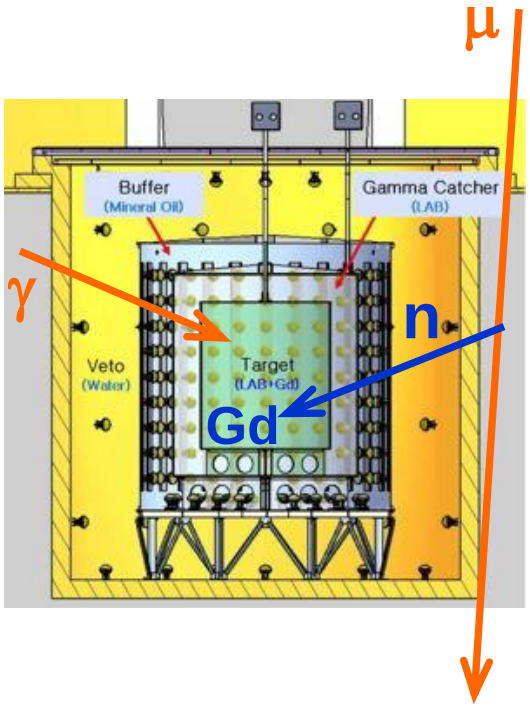
- Elaborate study of systematic uncertainties on a spectral fitter

  - estimated systematic errors based on a detailed study of spectral fitter in the measurement of Δm_{ee}^2

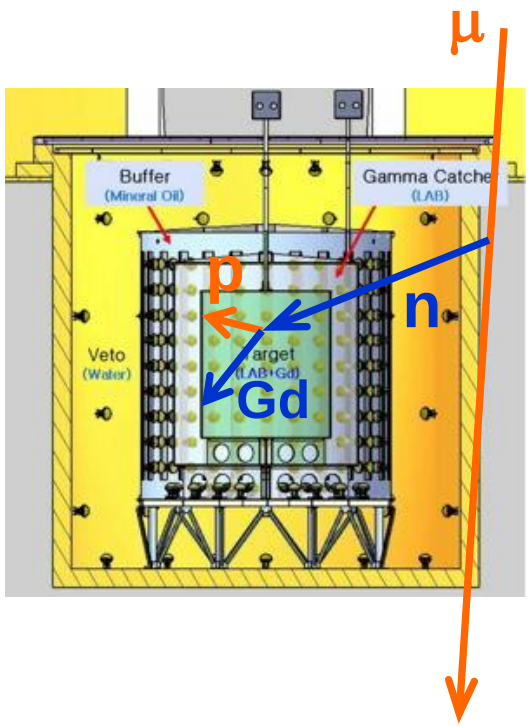
Backgrounds

- 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

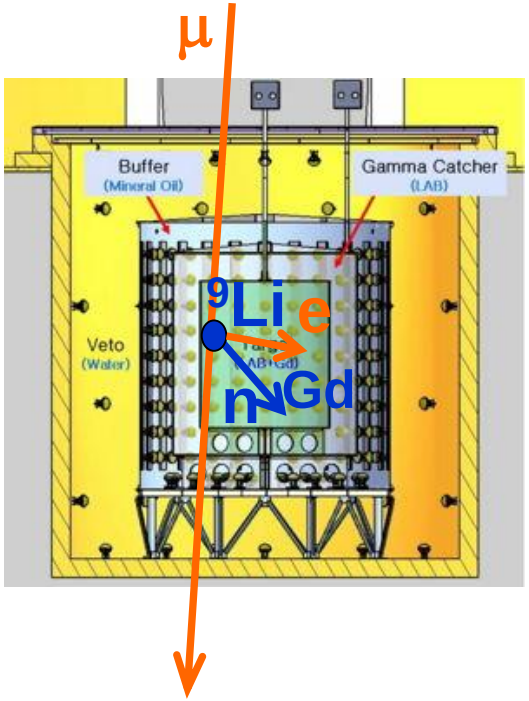
Accidentals



Fast neutrons



^{9}Li/^{8}He β-n followers



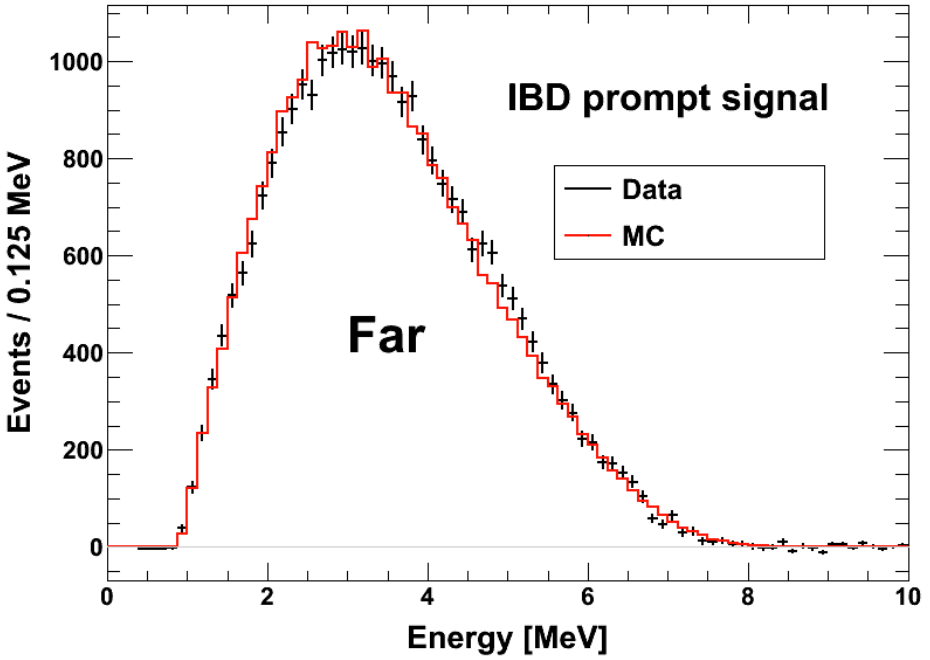
Signature of Reactor Neutrino Event (IBD)

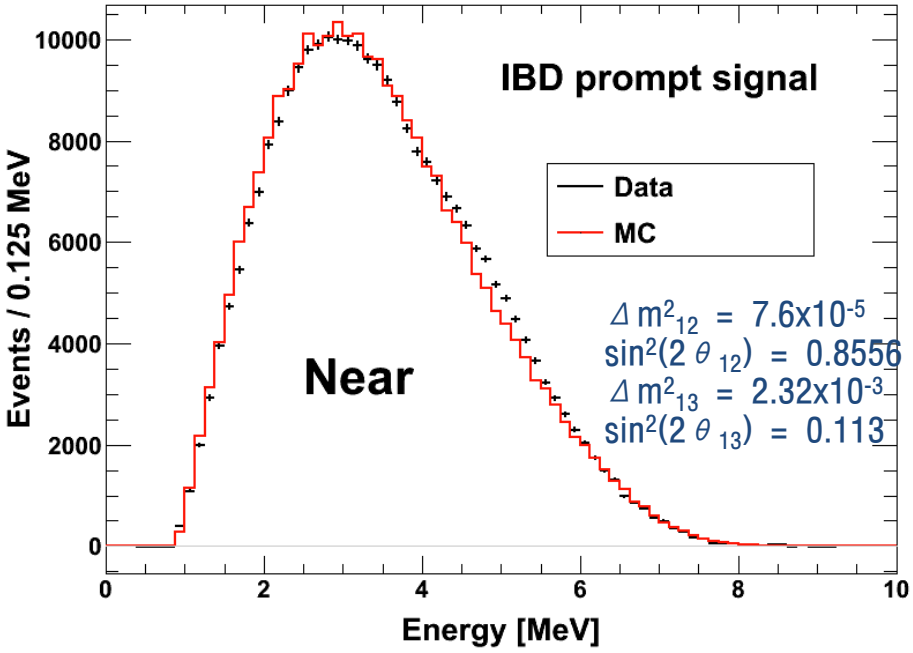
$$\bar{\nu}_e + p \rightarrow e^+ + n$$

- Prompt signal (e^+) : 1 MeV 2γ's + e^+ kinetic energy (E = 1~10 MeV)
- Delayed signal (n) : 8 MeV γ's from neutron's capture by Gd

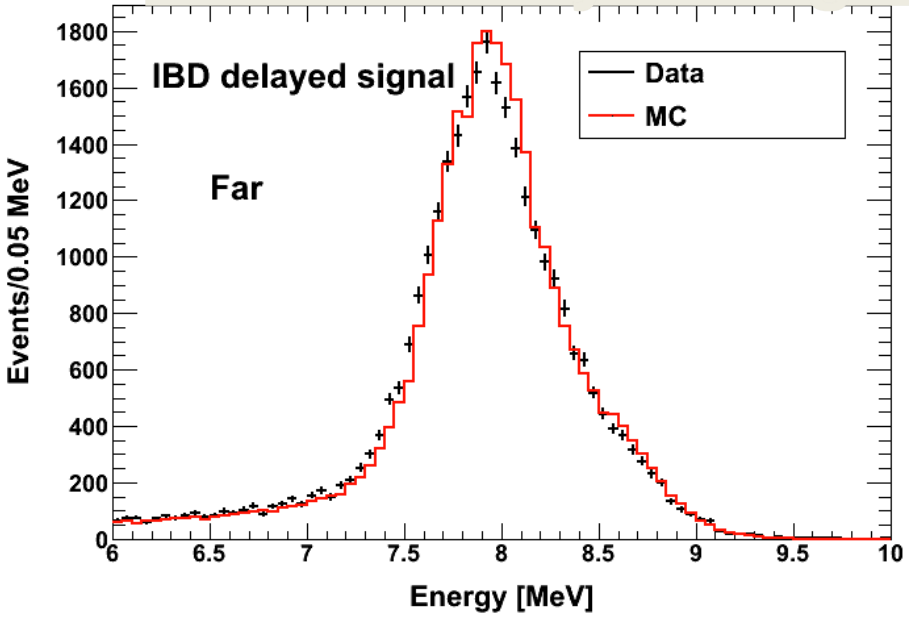
~26 μs (0.1% Gd) in LS

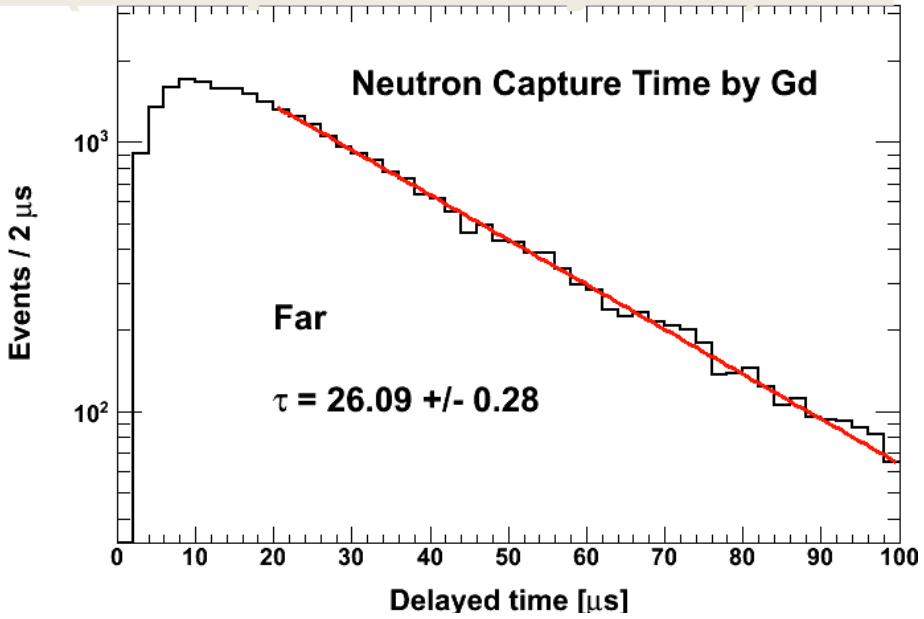
Observed spectra for Prompt Signal

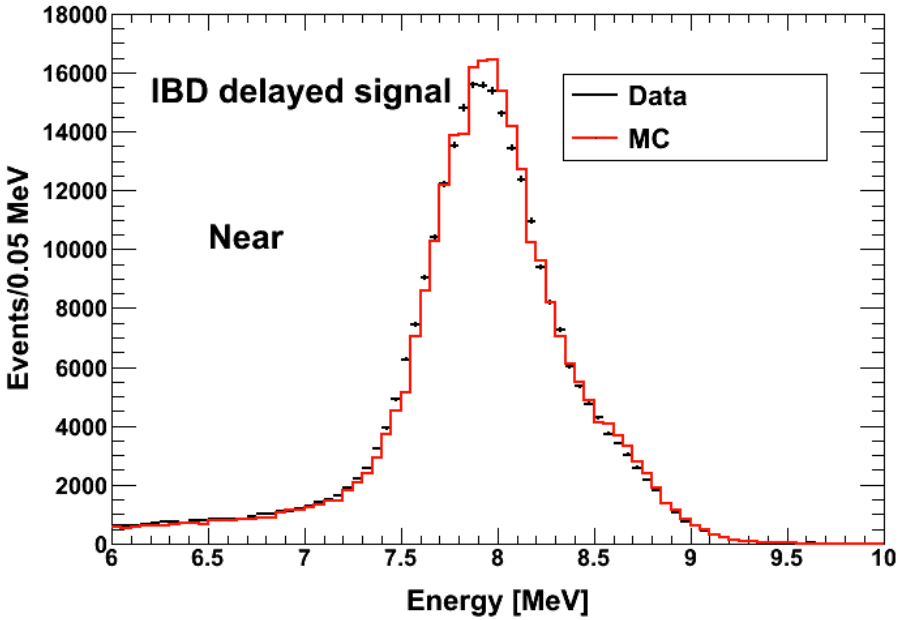


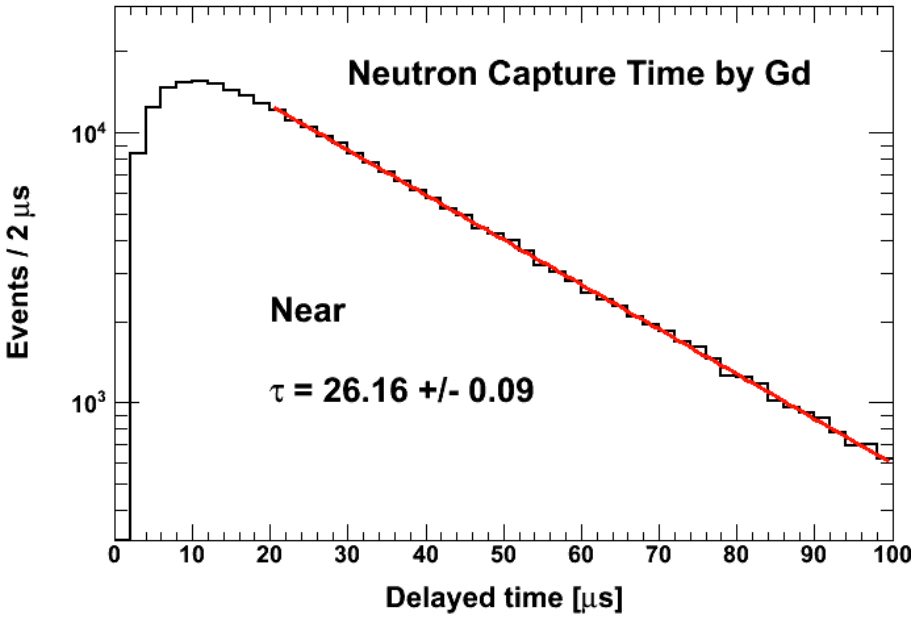


Observed Spectra for Delayed Signal (n captured by Gd)

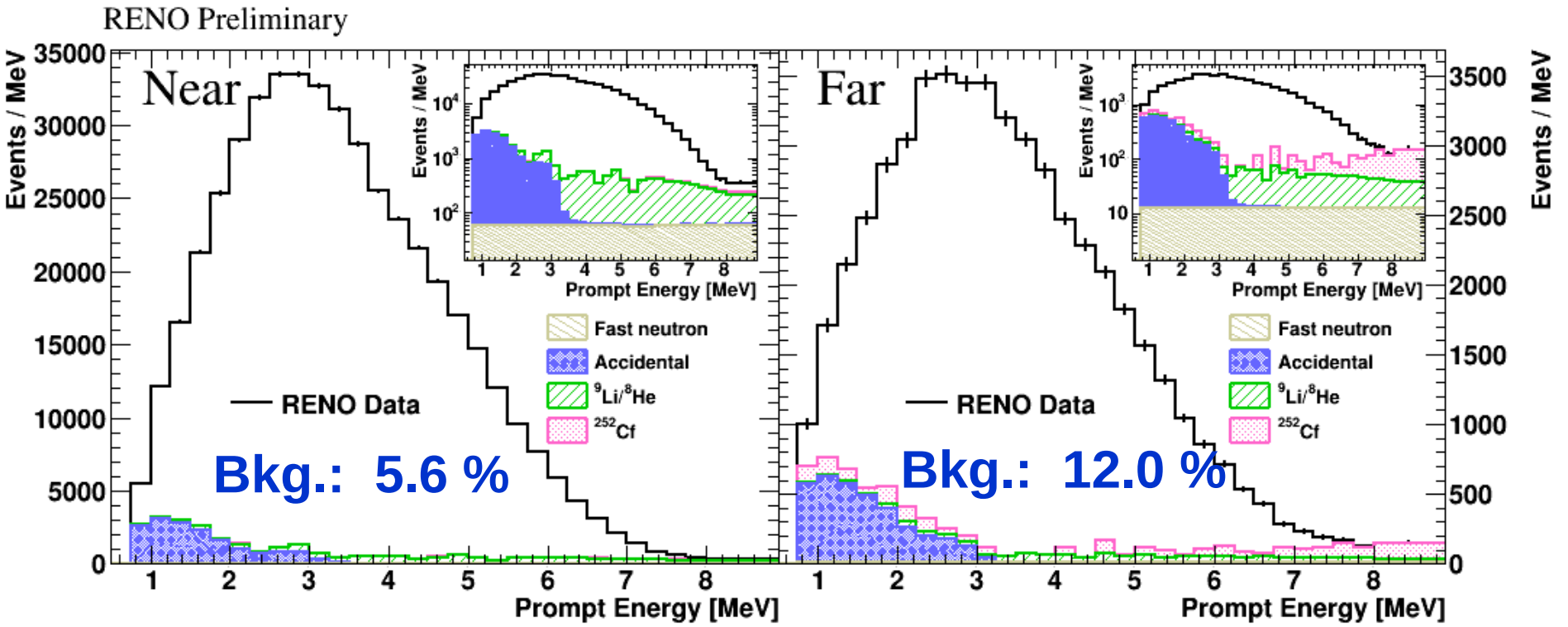








Measured Spectra of IBD Prompt Signal



Near Live time = 761.11 days
# of IBD candidate = 470,787
# of background = 26,375 (5.6 %)

Far Live time = 794.72 days
# of IBD candidate = 52,250
# of background = 6,292 (12.0 %)

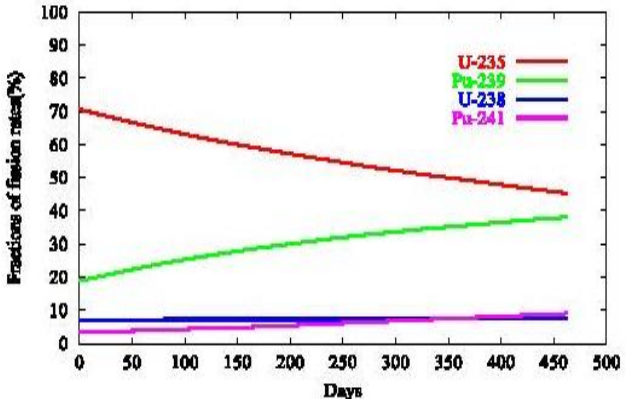
Expected Reactor Antineutrino Fluxes

- Reactor neutrino flux

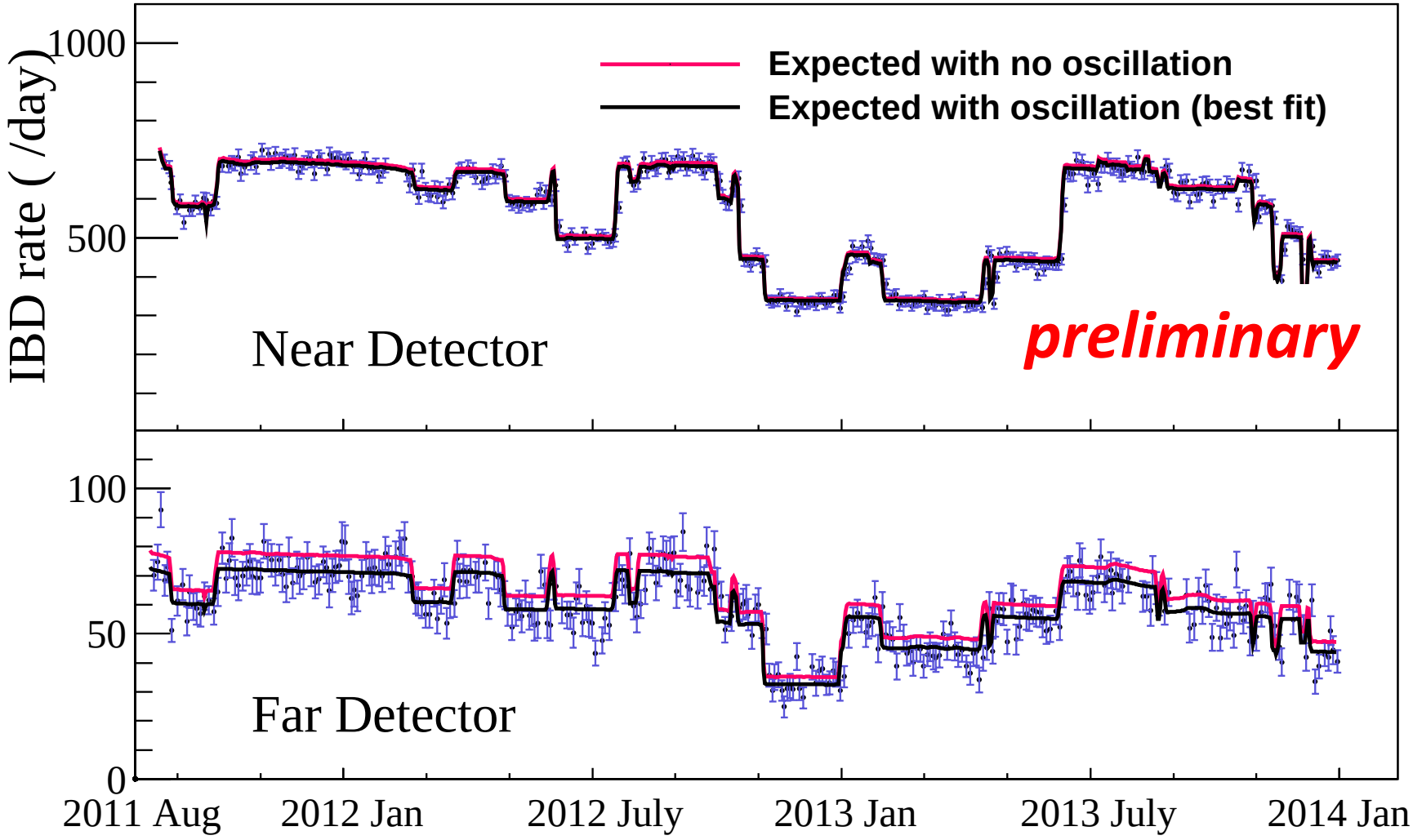
$$\Phi(E_\nu) = \frac{P_{th}}{\sum_{i}^{isotopes} f_i \cdot E_i} \sum_{i}^{isotopes} f_i \cdot \phi_i(E_\nu)$$

- P_{th} : Reactor thermal power provided by the YG nuclear power plant
- f_i : Fission fraction of each isotope determined by reactor core simulation of Westinghouse ANC
- $\phi_i(E_\nu)$: Neutrino spectrum of each fission isotope
  [* P. Huber, Phys. Rev. C84, 024617 (2011)
  T. Mueller *et al*., Phys. Rev. C83, 054615 (2011)]
- E_i : Energy released per fission
  [* V. Kopeikin *et al*., Phys. Atom. Nucl. 67, 1982 (2004)]

Isotopes	James	Kopeikin
^{235}U	201.7±0.6	201.92±0.46
^{238}U	205.0±0.9	205.52±0.96
^{239}Pu	210.0±0.9	209.99±0.60
^{241}Pu	212.4±1.0	213.60±0.65

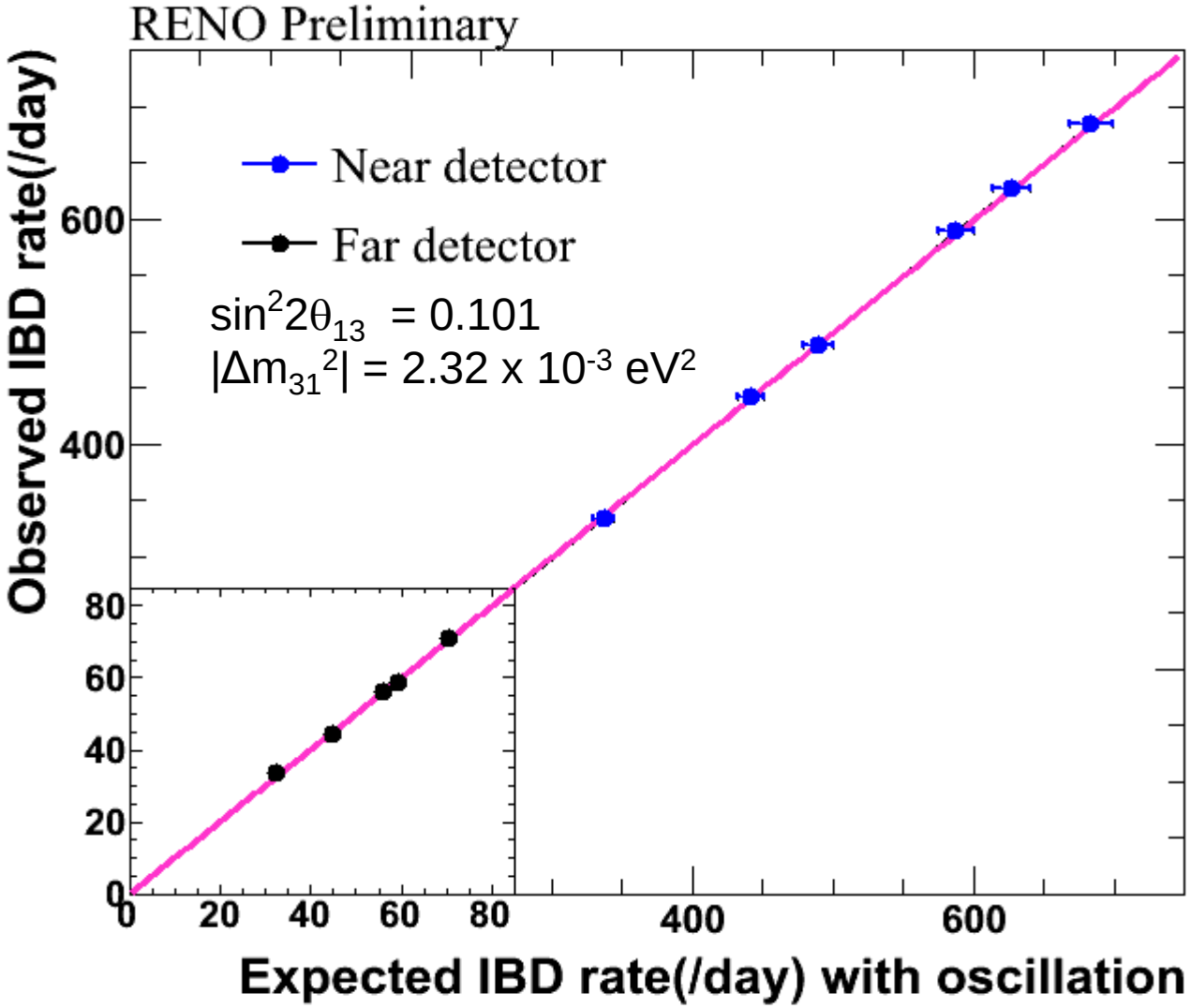


Observed Daily Averaged IBD Rate



- 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

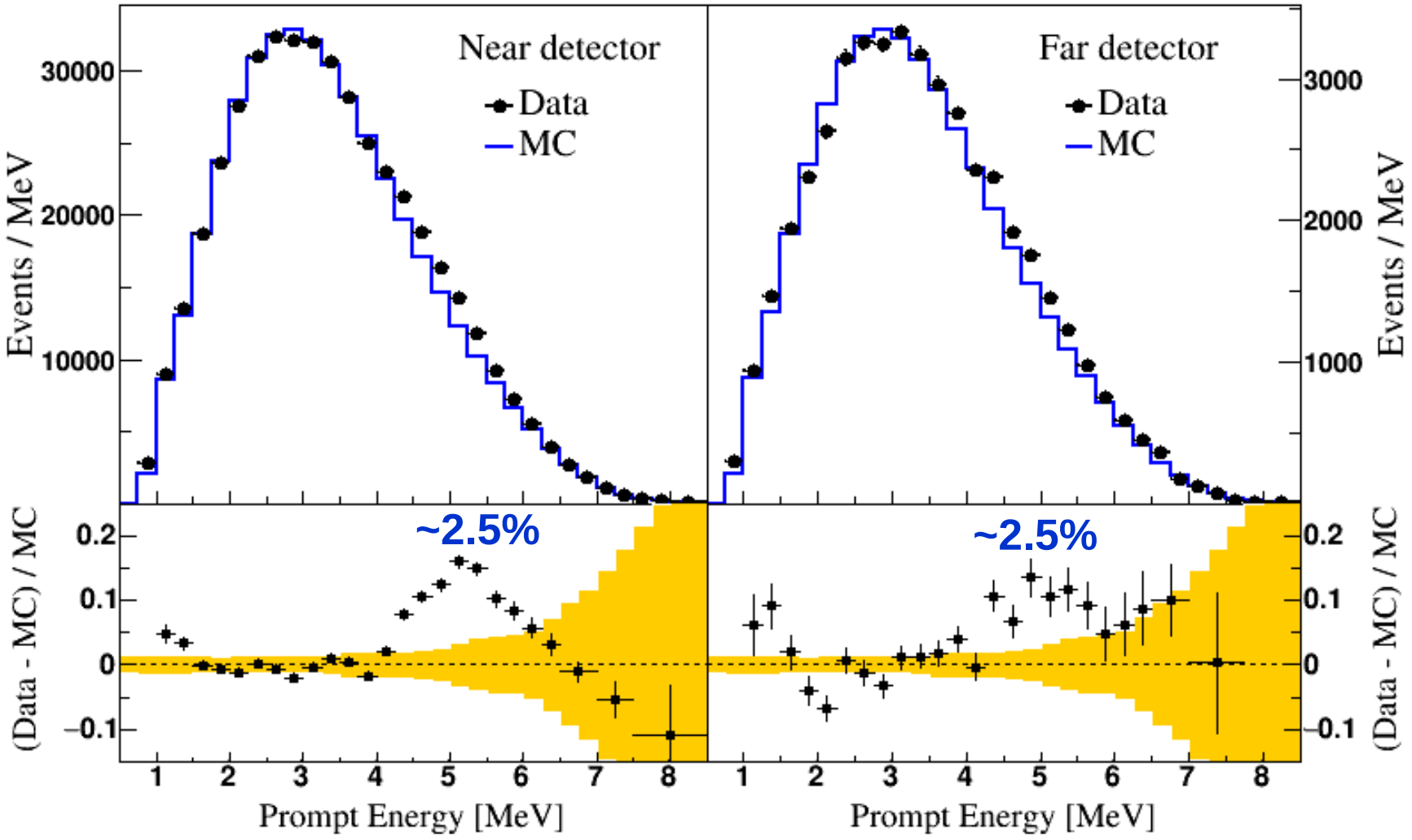
New θ_{13} Measurement by Rate-only Analysis

(Preliminary)

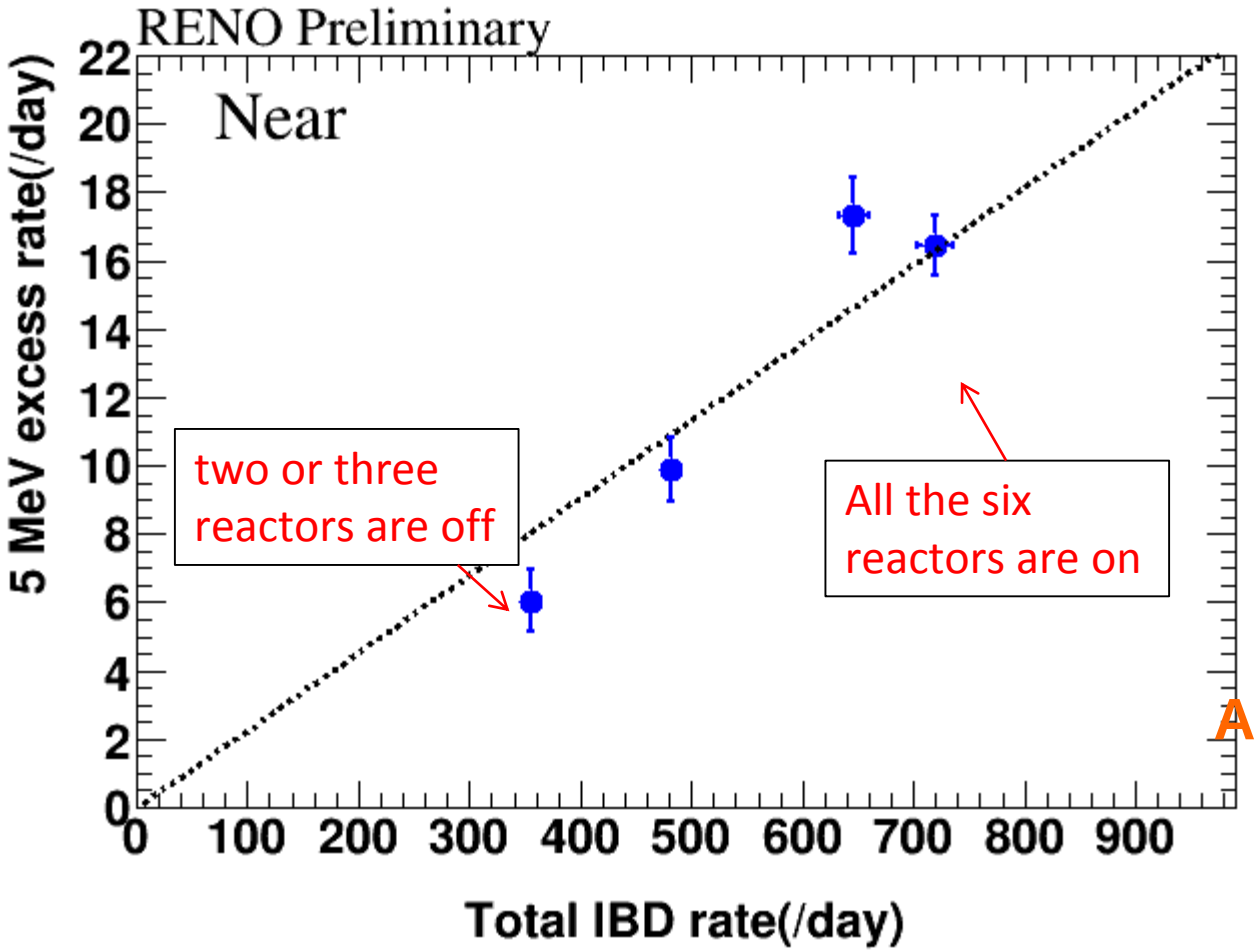
$$\sin^2 2\theta_{13} = 0.087 \pm 0.008(\text{stat}) \pm 0.008(\text{syst})$$

Uncertainties sources	Uncertainties (%)
Statistics (near) (far)	0.21 % 0.54 %
Systematics (near) (far)	0.94% 1.06%
Reactor	0.9 %
Detection efficiency	0.2 %
Backgrounds (near) (far)	0.14 % 0.51 %

Observation of an excess at 5 MeV



Correlation of 5 MeV Excess with Reactor Power



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

A new reactor neutrino component !!

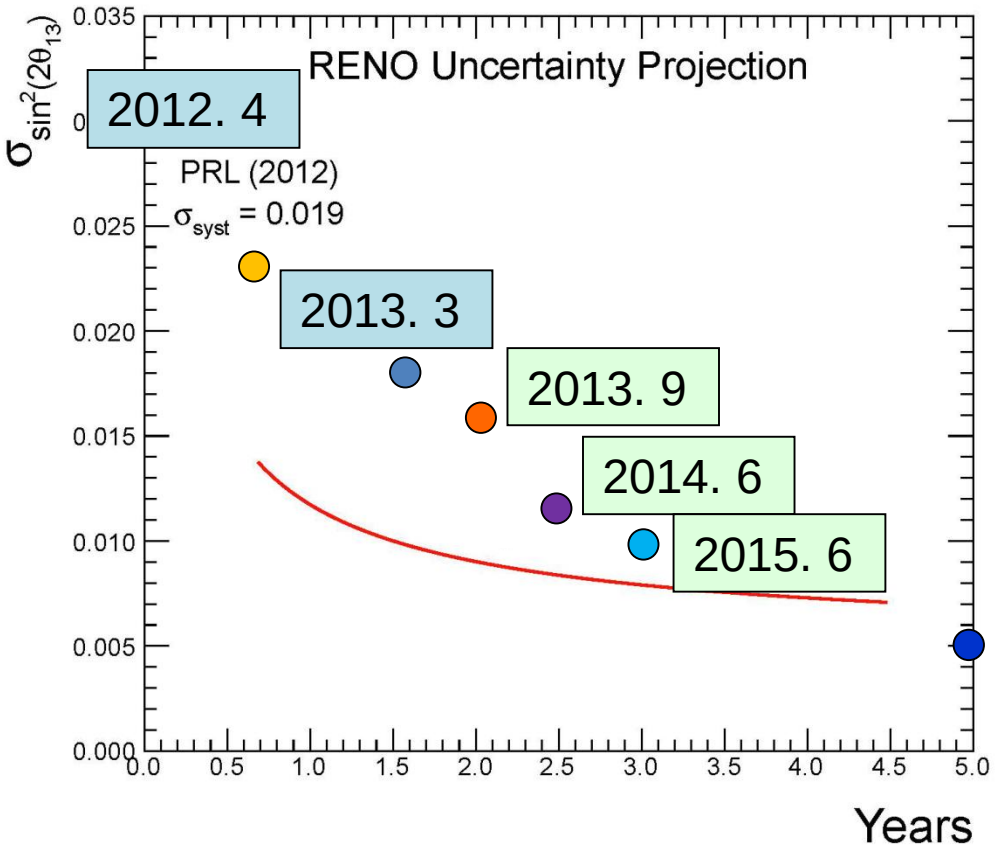
** Recent ab initio calculation [D. Dwyer and T.J. Langford, PRL 114, 012502 (2015)] :

- The excess may be explained by addition of eight isotopes, such as ^{96}Y and ^{92}Rb

Projected Sensitivity of θ_{13}

(Preliminary) $\sin^2 2\theta_{13} = 0.087 \pm 0.011$ (~800 days)

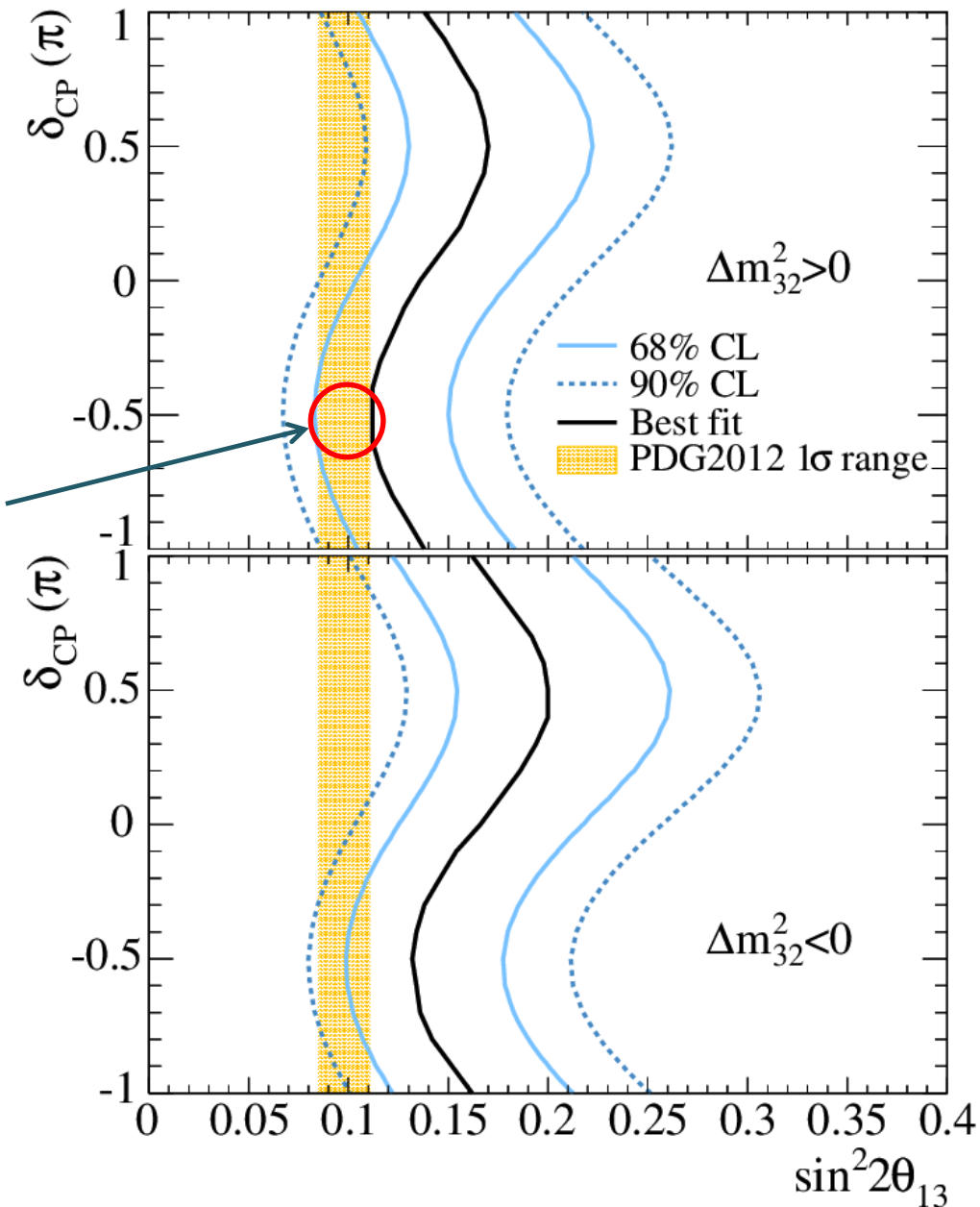
± 0.005 (5 % precision) (5 years of data)



(5 % precision)

(sensitivity goal of θ_{13})

θ_{13} from Reactor and Accelerator Experiments



First hint of δ_{CP} combining Reactor and Accelerator data

Best overlap is for Normal hierarchy & $\delta_{CP} = -\pi/2$

Is Nature very kind to us?
Are we very lucky?
Is CP violated maximally?

Strong motivation for anti-neutrino run and precise measurement of θ_{13}

(T2K: PRL 112, 061802, 2014)

Summary (1st part)

- Observed an excess at 5 MeV in reactor neutrino spectrum
- New measurement of θ_{13} by rate-only analysis

$$\sin^2 2\theta_{13} = 0.087 \pm 0.008(\text{stat}) \pm 0.008(\text{syst})$$

(preliminary)

Work in progress

- ❑ Shape analysis for Δm^2 is almost finalized… (stay tuned)
- ❑ Measurement of θ_{13} from on n-H IBD analysis

- ❑ $\sin^2(2\theta_{13})$ to 5% accuracy within 3 years

RENO-50

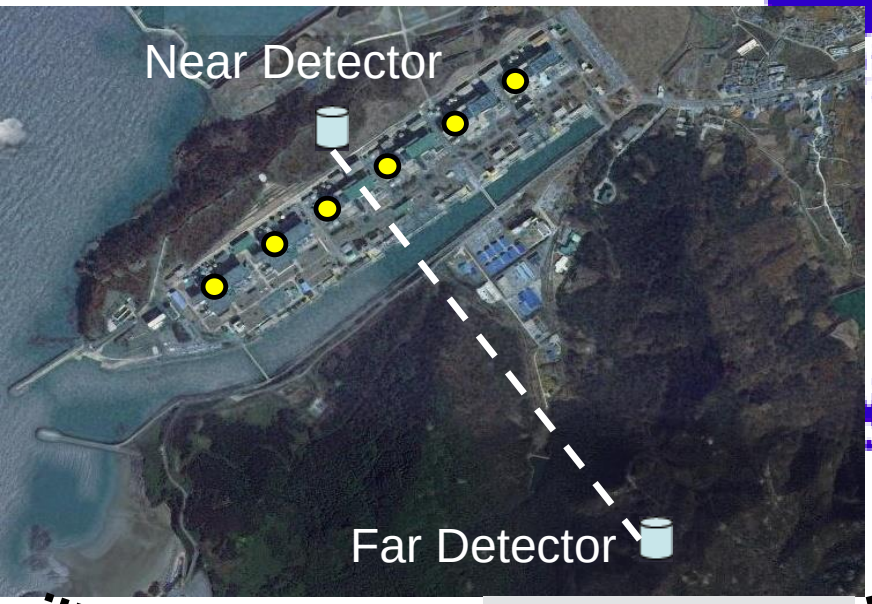
Overview of Future RENO-50

- **RENO-50** : An underground detector consisting of 18 kton ultra-low-radioactivity liquid scintillator & 15,000 20” PMTs, at ~50 km away from the Hanbit(Yonggwang) nuclear power plant

- **Goals** : - Determination of neutrino mass hierarchy
  - High-precision measurement of θ_{12}, Δm^2_{21} and Δm^2_{31}
  - Study neutrinos from reactors, the Sun, the Earth, Supernova, and any possible stellar objects

- **Budget** : $ 100M for 6 year construction
  (Civil engineering: $ 15M, Detector: $ 85M)

- **Schedule** : 2015 ~ 2020 : Facility and detector construction
  2021 ~ : Operation and experiment



(NEAR Detector)

RENO

ν θ_{13}

(FAR Detector)

RENO-50

18 kton LS Detector
~47 km from YG reactors

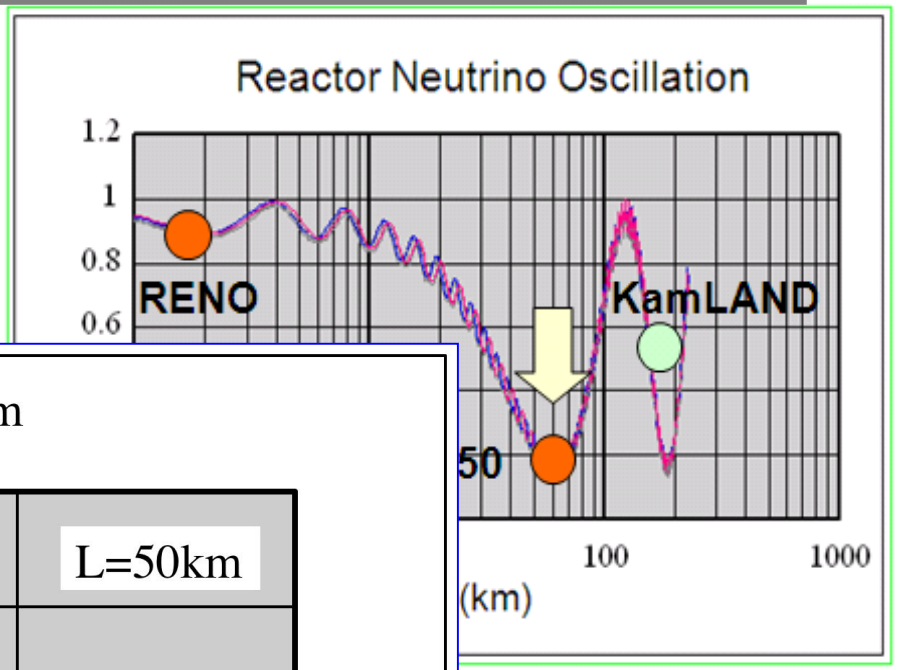
Mt. Guemseong (450 m)
~900 m.w.e. overburden

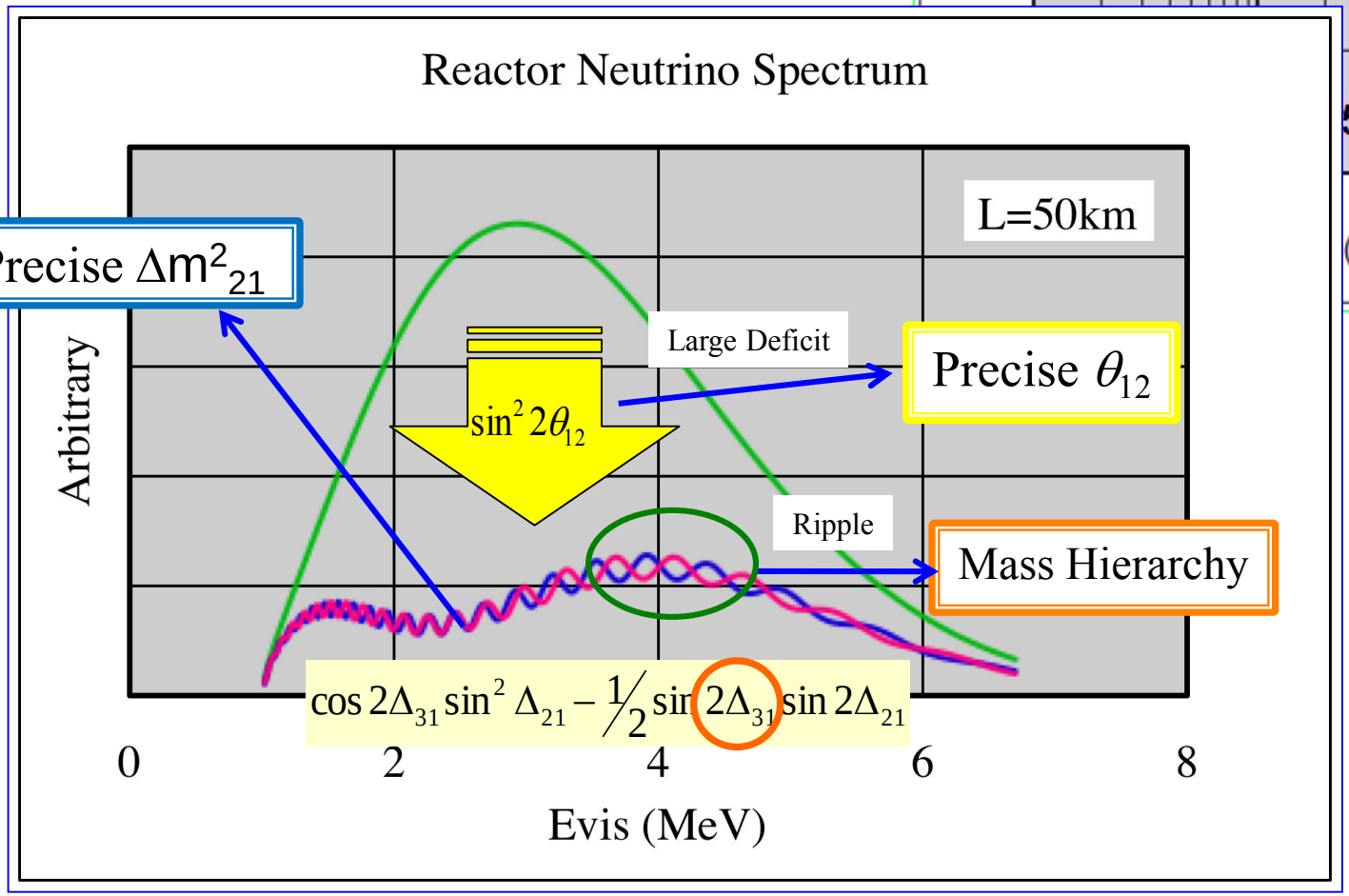
RENO-50 Candidate Site

RENO-50 Candidate Site

Reactor Neutrino Oscillations at 50 km

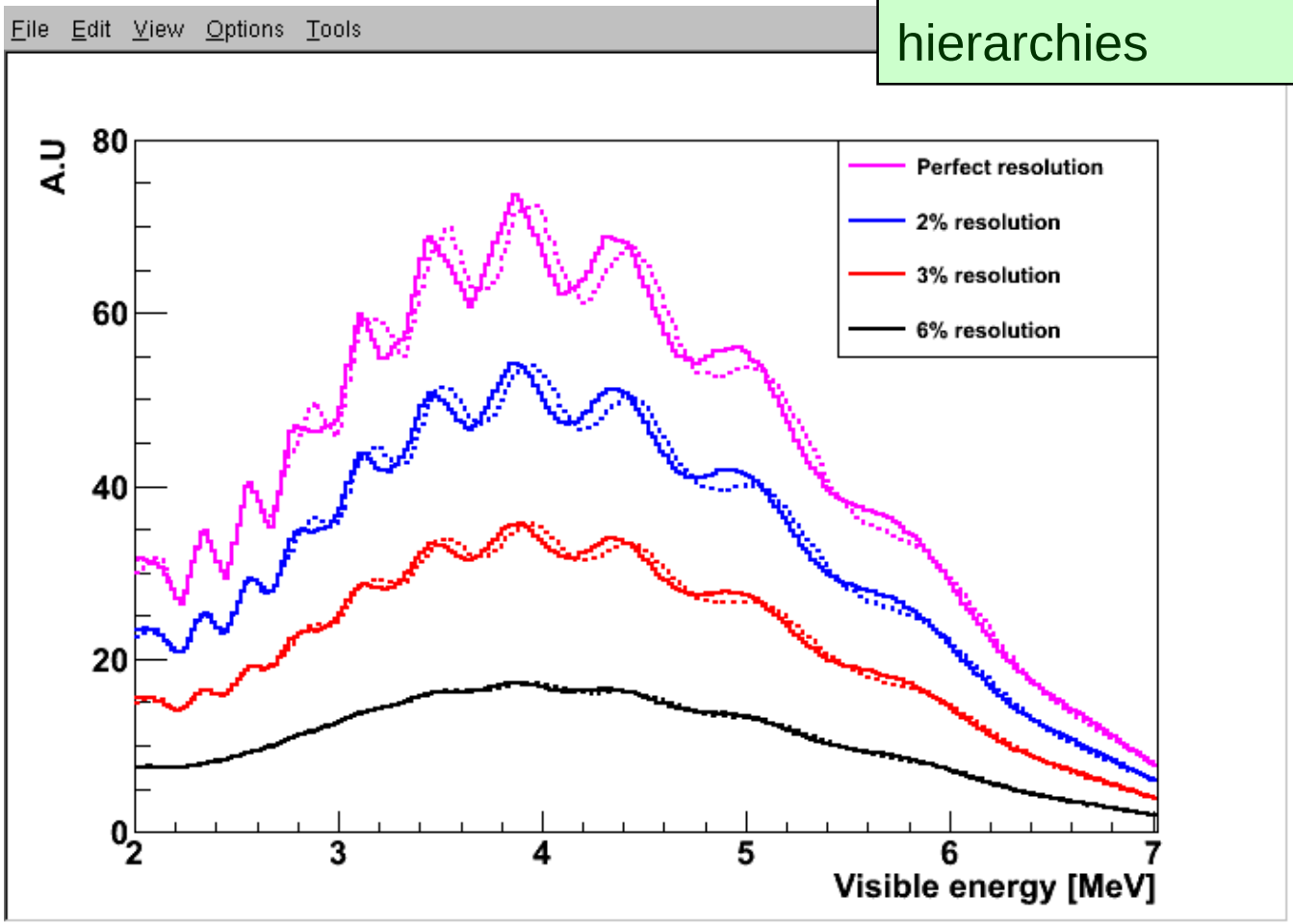
Neutrino mass hierarchy (sign of Δm^2_{31})
+ precise values of θ_{12}, Δm^2_{21} & Δm^2_{31}





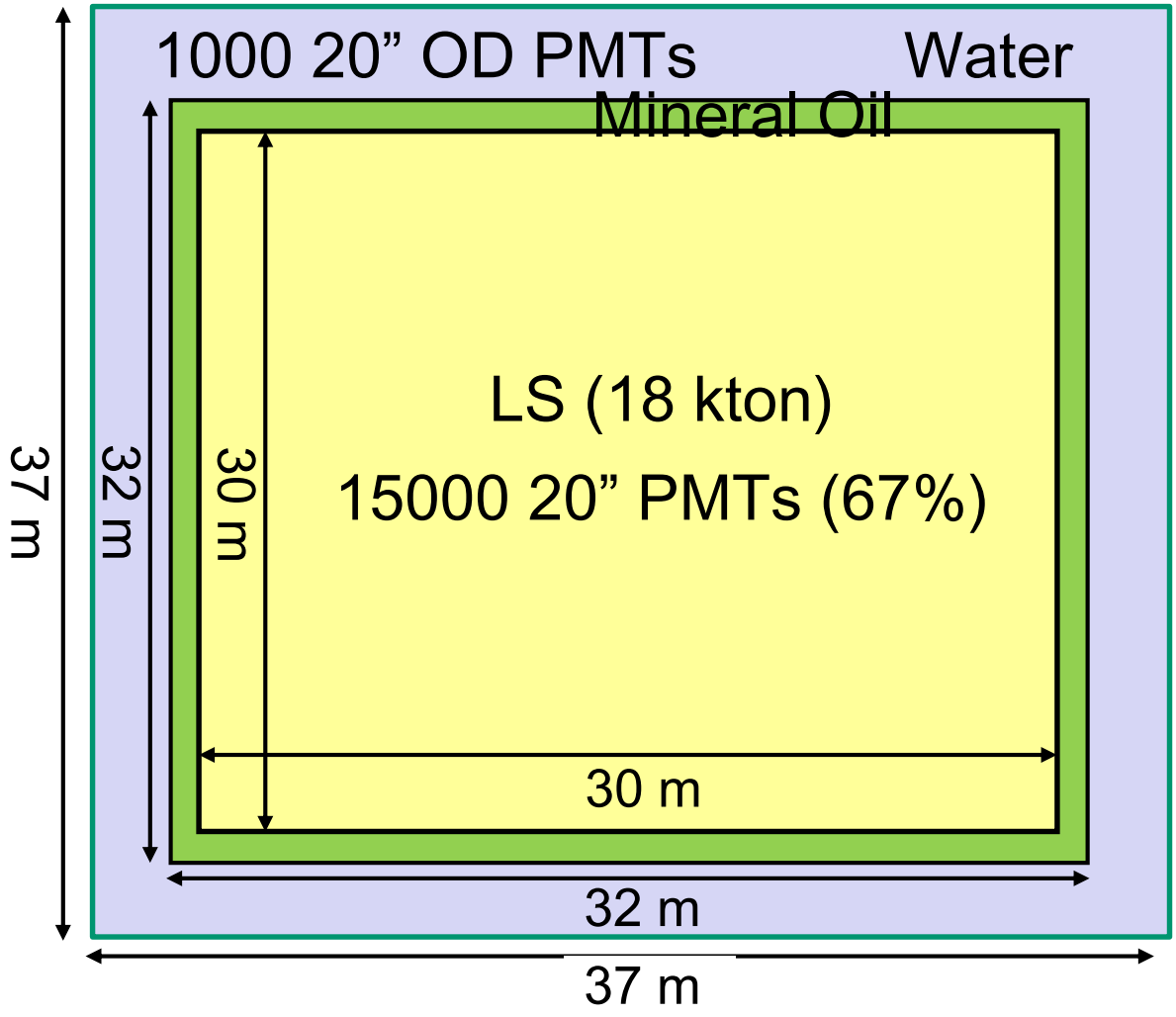
Energy Resolution for Mass Hierarchy

3% energy resolution essential for distinguishing the oscillation effects between normal and inverted mass hierarchies



Conceptual Design of RENO-50

- 18 ktons ultra-low-radioactivity Liquid Scintillation Detector



Technical Challenges

	KamLAND	RENO-50
LS mass	~1 kt	18 kt
Energy resolution	6.5%/√E	3%/√E
Light yield	500 p.e./MeV	>1000 p.e./MeV
LS attenuation length	~16 m	~25 m

- R&D for 3% energy resolution :
  - High transparency LS : 15 m → 25 m (purification & better PPO)
  - Large photocathode coverage : 34% → 67% (15,000 20” PMT)
  - High QE PMT : 20% → 35% (Hamamatsu 20” HQE PMT)
  - High light yield LS : ×1.5 (1.5 g/ℓ PPO → 5 g/ℓ PPO)

2012 Particle Data Book

LEPTONS

Neutrino Mixing

$\sin^2(2\theta_{12}) = 0.857 \pm 0.024$ (±2.8%)

$\Delta m^2_{21} = (7.50 \pm 0.20) \times 10^{-5}$ eV^2 (±2.7%)

$\sin^2(2\theta_{23}) > 0.95$ [i] (±3.1%)

$\Delta m^2_{32} = (2.32^{+0.12}_{-0.08}) \times 10^{-3}$ eV^2 [i] (+5.2-3.4%)

$\sin^2(2\theta_{13}) = 0.098 \pm 0.013$ (±13.3%)

$\sin^2\theta_{12} = 0.312 \pm 0.017$ (±5.4%)

$\Delta m_{21}^2 / |\Delta m_{31(32)}^2| \approx 0.03$

- Precise measurement of θ_{12}, Δm^2_{21} and Δm^2_{32}

$$\frac{\delta \sin^2\theta_{12}}{\sin^2\theta_{12}} < 1.0\%(1\sigma) \quad (\leftarrow 5.4\%)$$

$$\frac{\delta \Delta m^2_{21}}{\Delta m^2_{21}} < 1.0\%(1\sigma) \quad (\leftarrow 2.7\%)$$

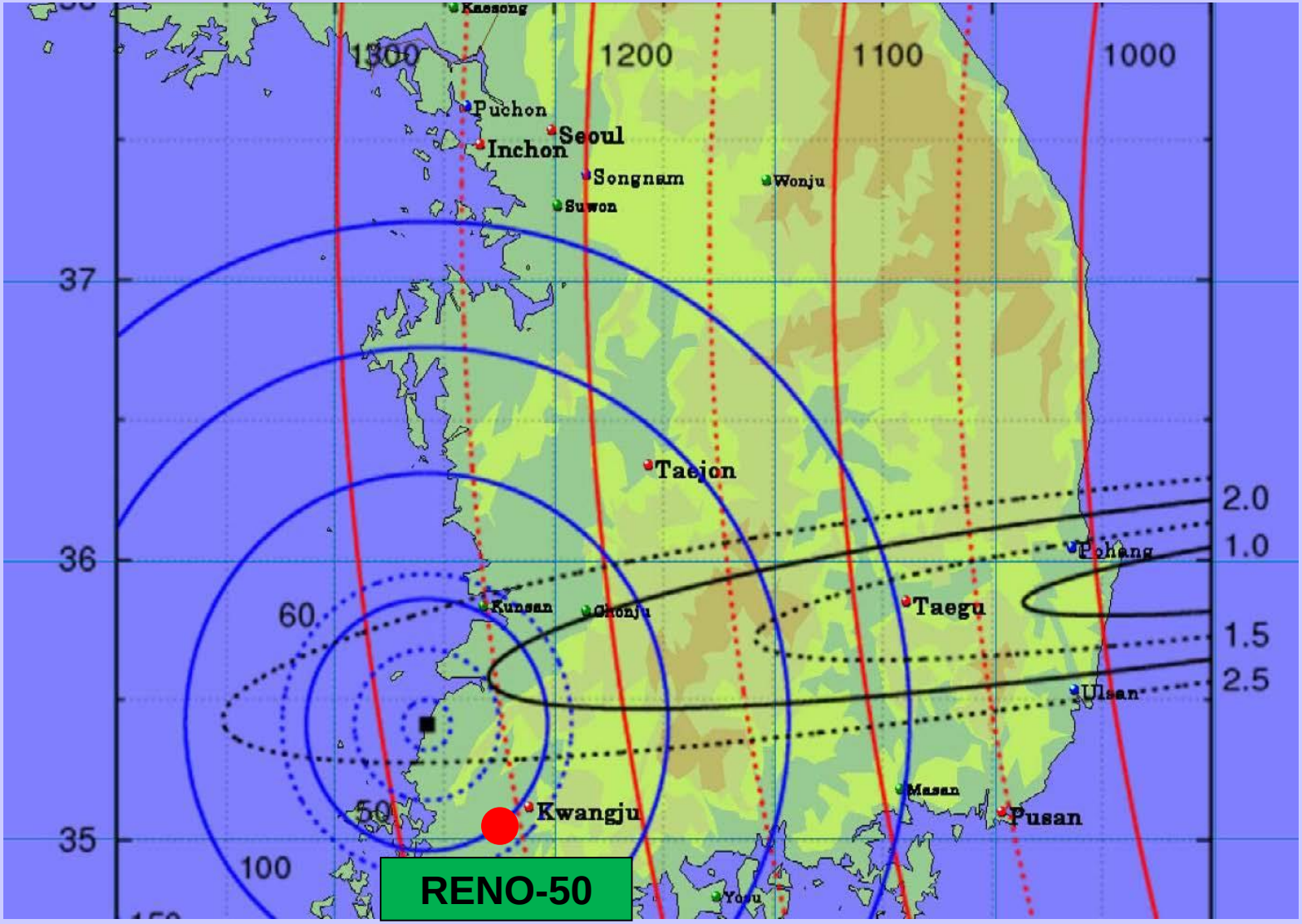
$$\frac{\delta \Delta m^2_{32}}{\Delta m^2_{32}} < 1.0\%(1\sigma) \quad (\leftarrow 5.2\%)$$

Additional Physics with RENO-50

- Neutrino burst from a Supernova in our Galaxy
  - ~5,600 events (@8 kpc)
  - A long-term neutrino telescope
- Geo-neutrinos : ~ 1,000 geo-neutrinos for 5 years
  - Study the heat generation mechanism inside the Earth
- Solar neutrinos : with ultra low radioacitivity
  - MSW effect on neutrino oscillation
  - Probe the center of the Sun and test the solar models
- Neutrinoless double beta decay search : possible modification like KamLAND-Zen
- Detection of J-PARC beam : ~200 events/year

J-PARC neutrino beam

Dr. Okamura & Prof. Hagiwara



Schedule

- 2015 : Group organization
  Detector simulation & design
  Geological survey
- 2016 ~ 2017 : Civil engineering for tunnel excavation
  Underground facility ready
  Structure design
  PMT evaluation and order,
  Preparation for electronics, HV, DAQ & software tools,
  R&D for liquid scintillator and purification
- 2018 ~ 2020 : Detector construction
- 2021 ~ : Data taking & analysis

Summary (2nd part)

- Longer baseline (~50 km) reactor experiments is under pursuit to determine the mass hierarchy in 3σ for 5 years of data-taking, and to perform high-precision (<1%) measurements of θ_{12}, Δm^2_{21}, & Δm^2_{31}

- Domestic and international workshops held in 2013 to discuss the feasibility and physics opportunities

- An R&D funding (US $ 2M in next 3 years) is given by the Samsung Science & Technology Foundation.

➡ SNU (Prof SB Kim) & CNU start doing various R&D works

- A proposal have been submitted to obtain full funding.

Thanks for your attention!

Reactor Neutrino Oscillations

$$P_{\bar{\nu}_e \to \bar{\nu}_e} = 1 - \sin^2 2\theta_{13} \sin^2\left(\Delta m^2_{ee} \frac{L}{4E}\right) - \sin^2 2\theta_{12} \cos^4 2\theta_{13} \sin^2\left(\Delta m^2_{21} \frac{L}{4E}\right)$$

Short Baseline

Long Baseline

$$\sin^2(\Delta m^2_{ee} \tfrac{L}{4E}) \equiv \cos^2\theta_{12} \sin^2(\Delta m^2_{31} \tfrac{L}{4E}) + \sin^2\theta_{12} \sin^2(\Delta m^2_{32} \tfrac{L}{4E})$$

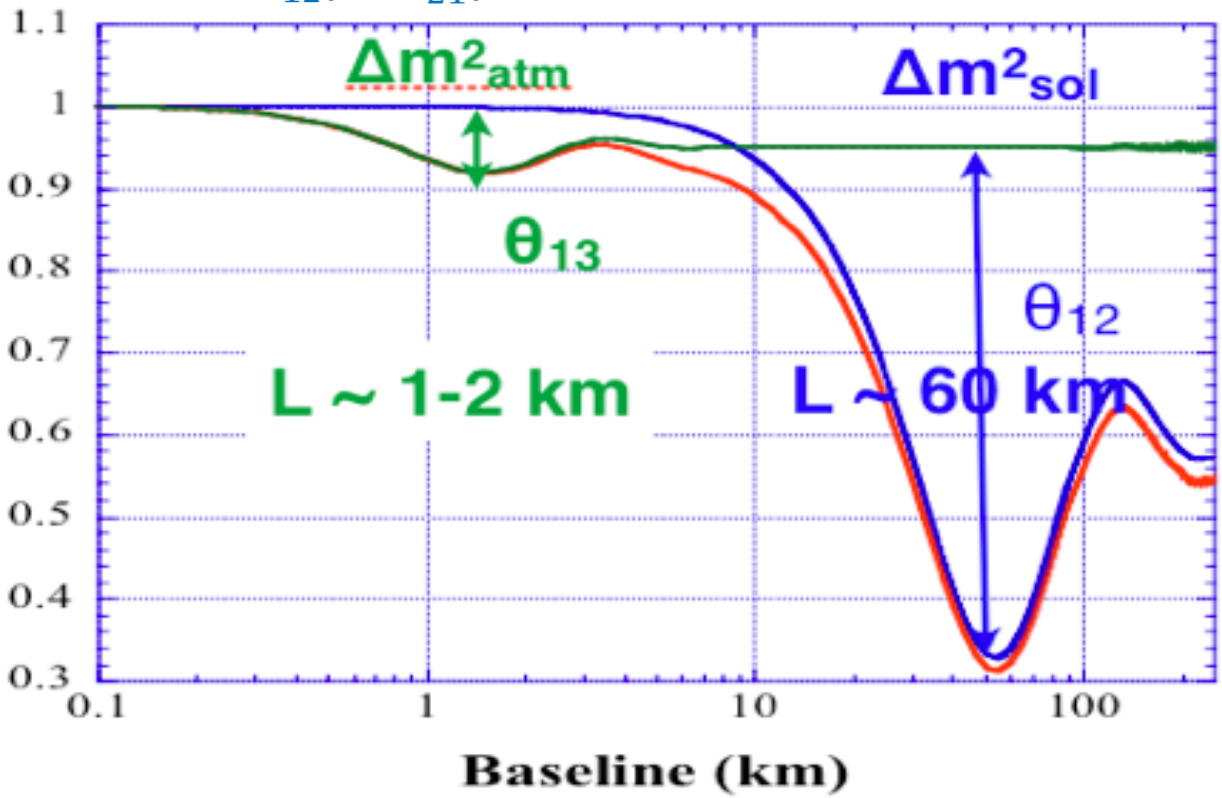
$$|\Delta m^2_{ee}| \simeq |\Delta m^2_{32}| \pm 5.21 \times 10^{-5} \mathrm{eV}^2$$

+: Normal Hierarchy

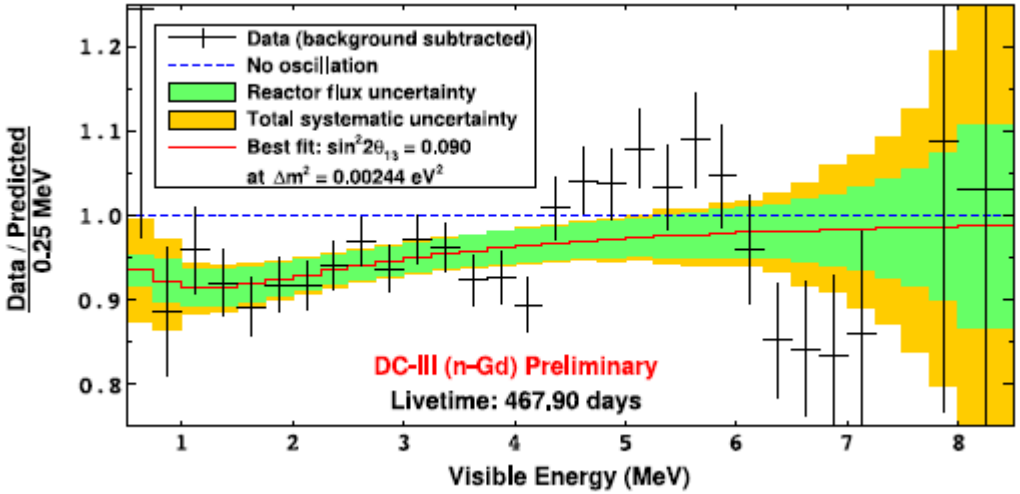
−: Inverted Hierarchy

[Nunokawa & Parke (2005)]

$\cos^2\theta_{12}|\Delta m^2{}_{21}|$

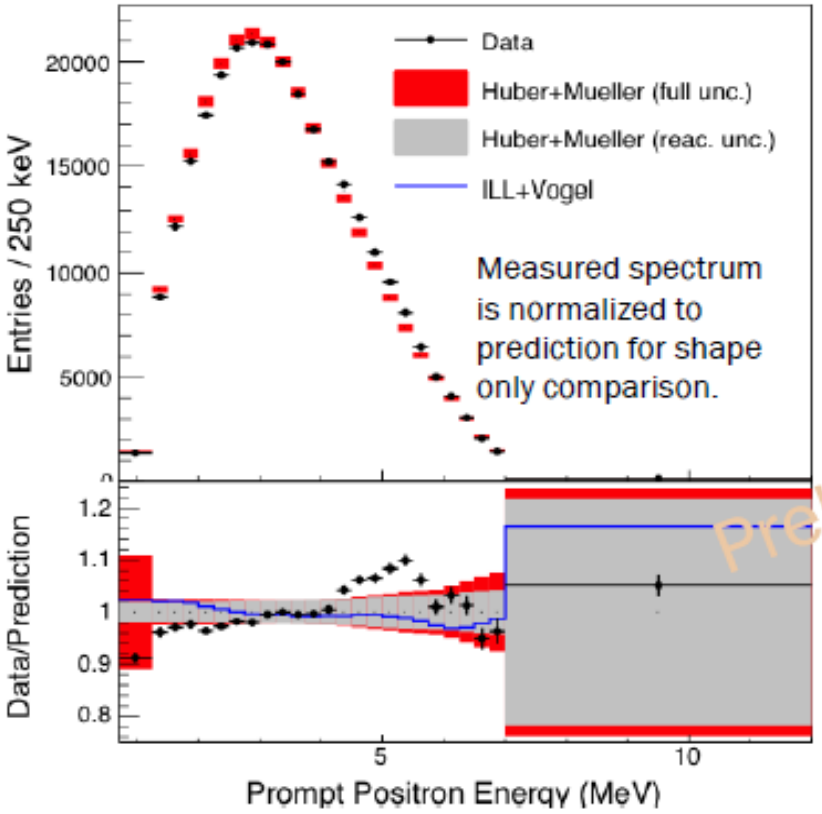


The 5 MeV Excess Seen at Double-Chooz and Daya Bay



Double-Chooz, Neutrino 2014

Daya Bay, ICHEP 2014



RENO-50 vs. KamLAND

	Oscillation Reduction	Reactor Neutrino Flux	Detector Size	Syst. Error on ν Flux	Error on $\sin^2\theta_{12}$
RENO-50 (50 km)	80%	$13 \times 6 \times \phi_0$ [6 reactors]	18 kton	~ 0.3%	< 1%
KamLAND (180 km)	40%	$0.6 \times 55 \times \phi_0$ [55 reactors]	1 kton	3%	5.4%
Figure of Merit	×2	×2.4	×18	×10	

$(50\ \text{km} / 180\ \text{km})^2 \approx 13$

Observed Reactor Neutrino Rate

- RENO-50 : ~ 15 events/day
- KamLAND : ~ 1 event /day

⇒ Determination of mass ordering:
~ 3σ with 5 year data