New Results from RENO & Future RENO-50 Project

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Heavy Quarks and Leptons

Virginia Tech

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KNRC

Korea Neutrino Research Center

RENO Collaboration

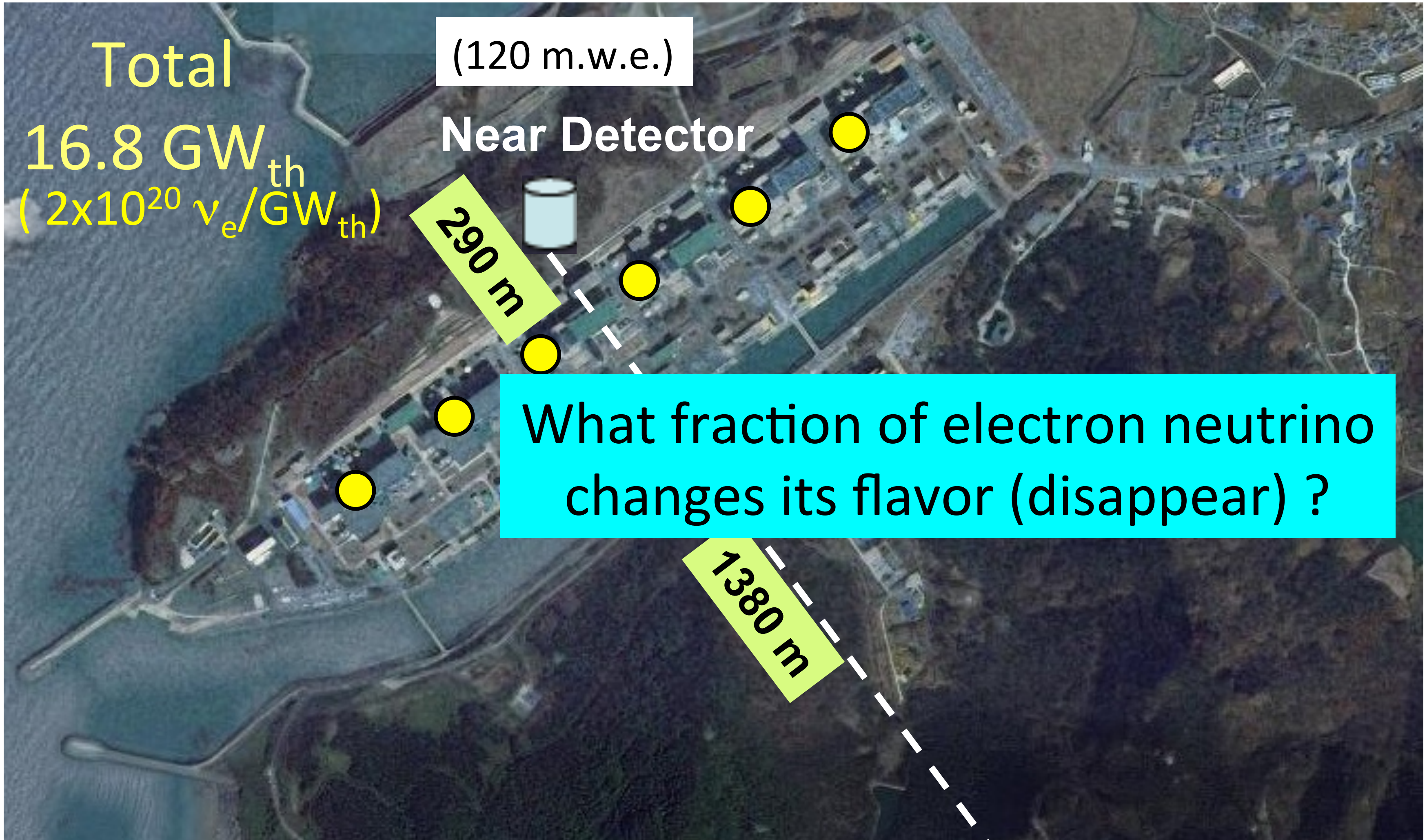
Reactor Experiment for Neutrino Oscillation

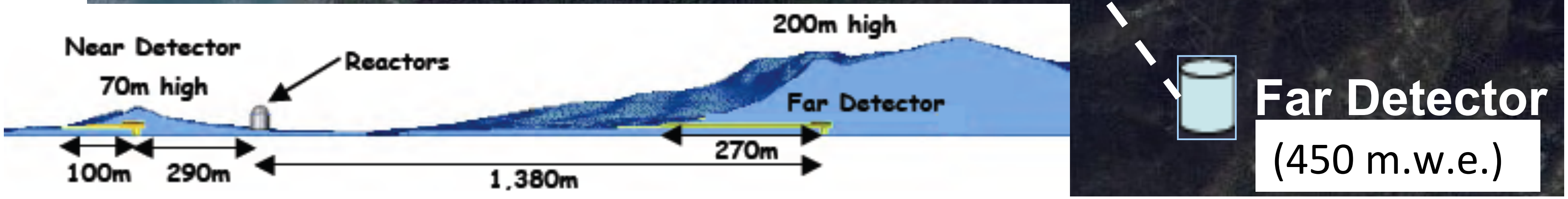
(~30 members in 10 institutions)

- Chonnam National University
- Dongshin University
- GIST
- Gyeongsang National University
- IBS
- Kyungpook National University
- Sejong University
- Seoul National University
- Seoyeong University
- Sungkyunkwan University

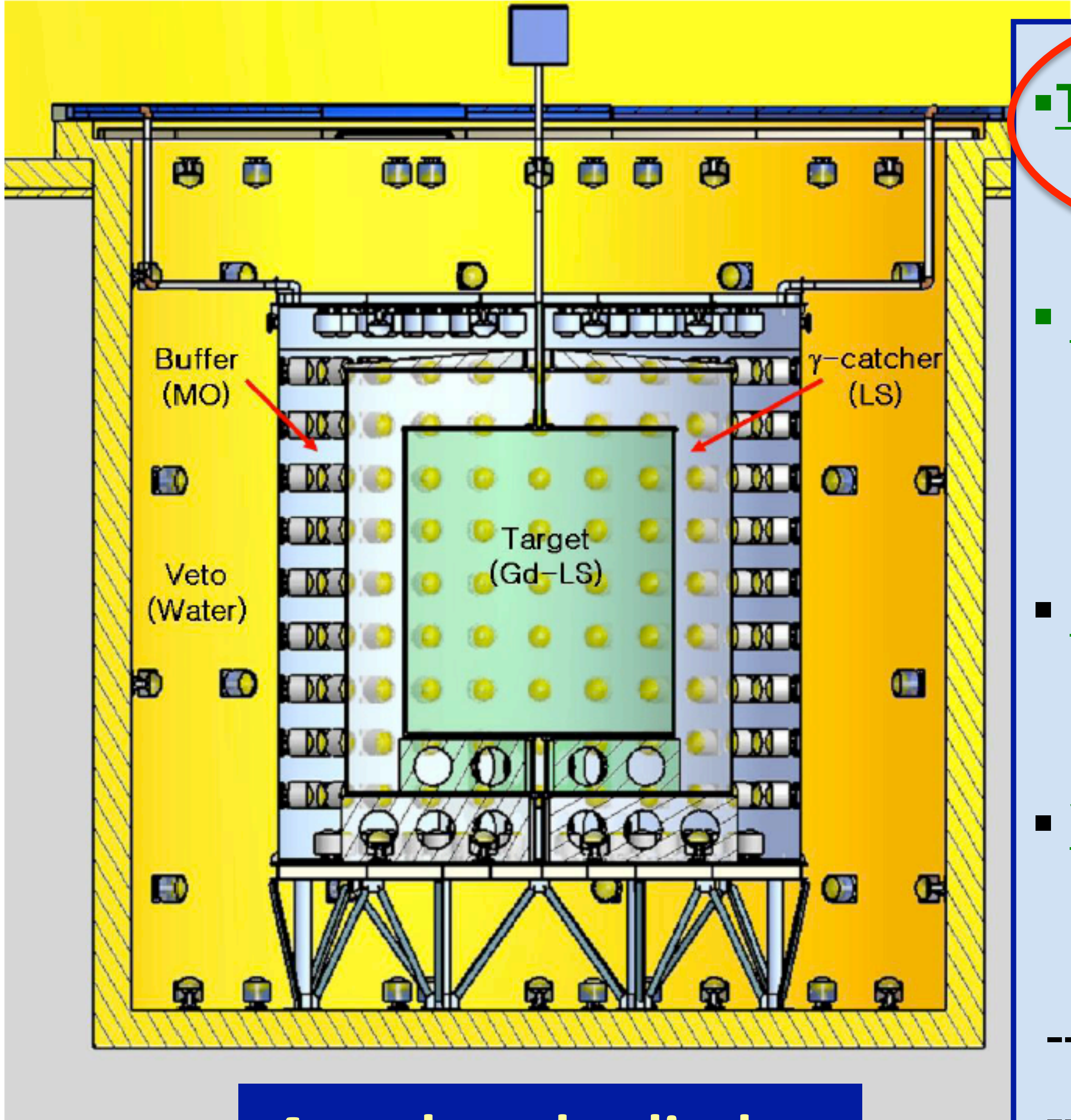
- Total cost : $10M
- Start of project : 2006
- The first reactor experiment running with both near & far detectors from Aug. 2011

RENO Experimental Setup





The RENO Detector



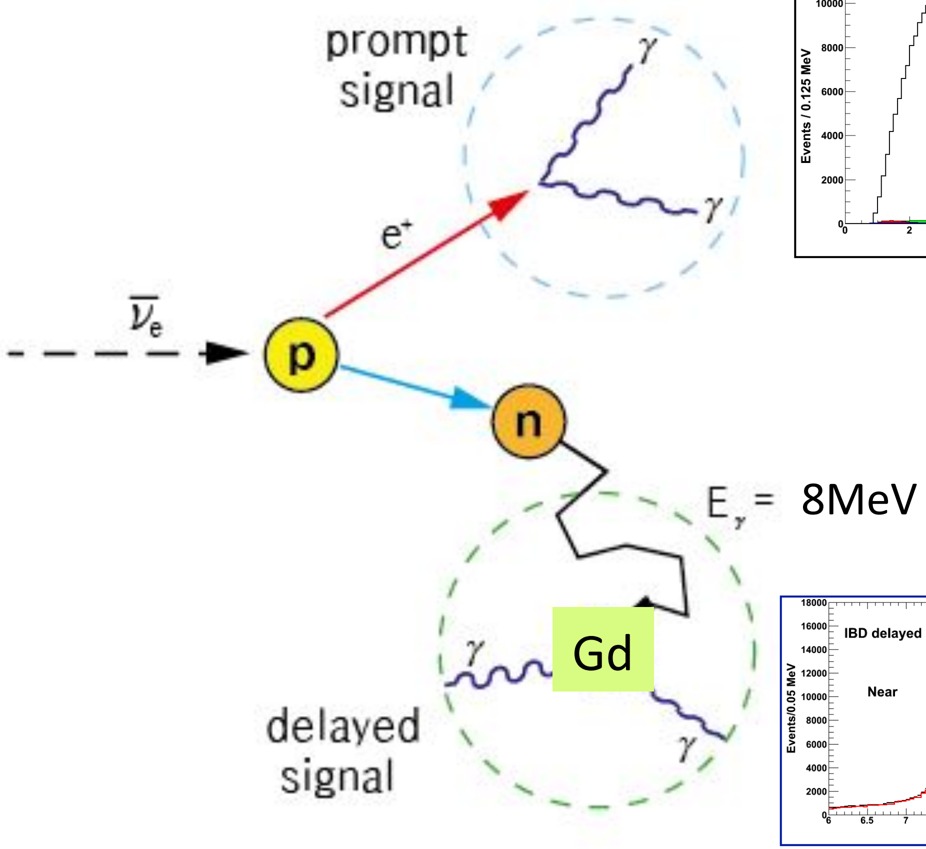
4 enclosed cylinders

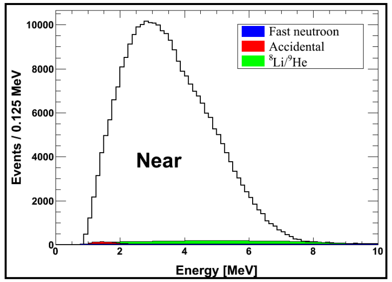
- **Target : 16 ton Gd-LS**
  (R=1.4m, H=3.2m)
- **Gamma Catcher :**
  30 ton LS
  (R=2.0m, H=4.4m)
- **Buffer :** 65 ton mineral oil
  (R=2.7m, H=5.8m)
- **Veto :** 350 ton water
  (R=4.2m, H=8.8m)

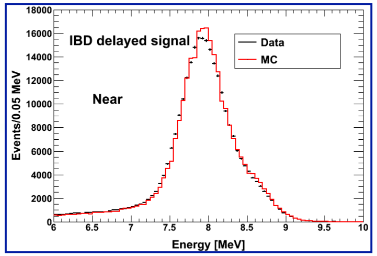
-- 354 ID 10 " PMTs

-- 67 OD 10" PMTs

Detection Principle of Reactor Neutrinos







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

IBD process

or

Gd capture	**H capture**
Delayed signal	**Delayed signal**
~30 μs	**~200 μs**
~8 MeV	~**2.2** MeV

- 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** in ~30 μs
  or 2.2 MeV " by H in ~200 μs

RENO Data-taking Status

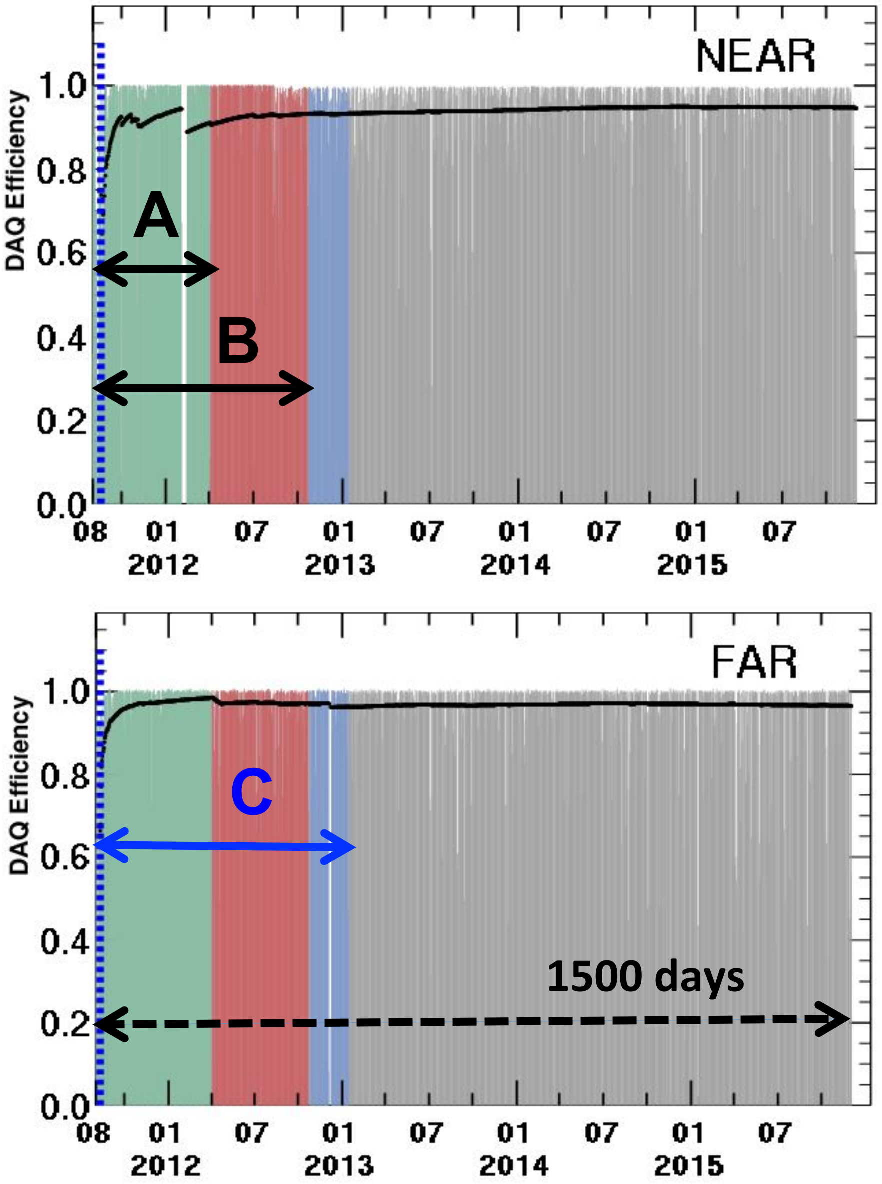
- Data taking began on Aug. 1, 2011 with both near and far detectors.
  (DAQ efficiency : ~95%)

- **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

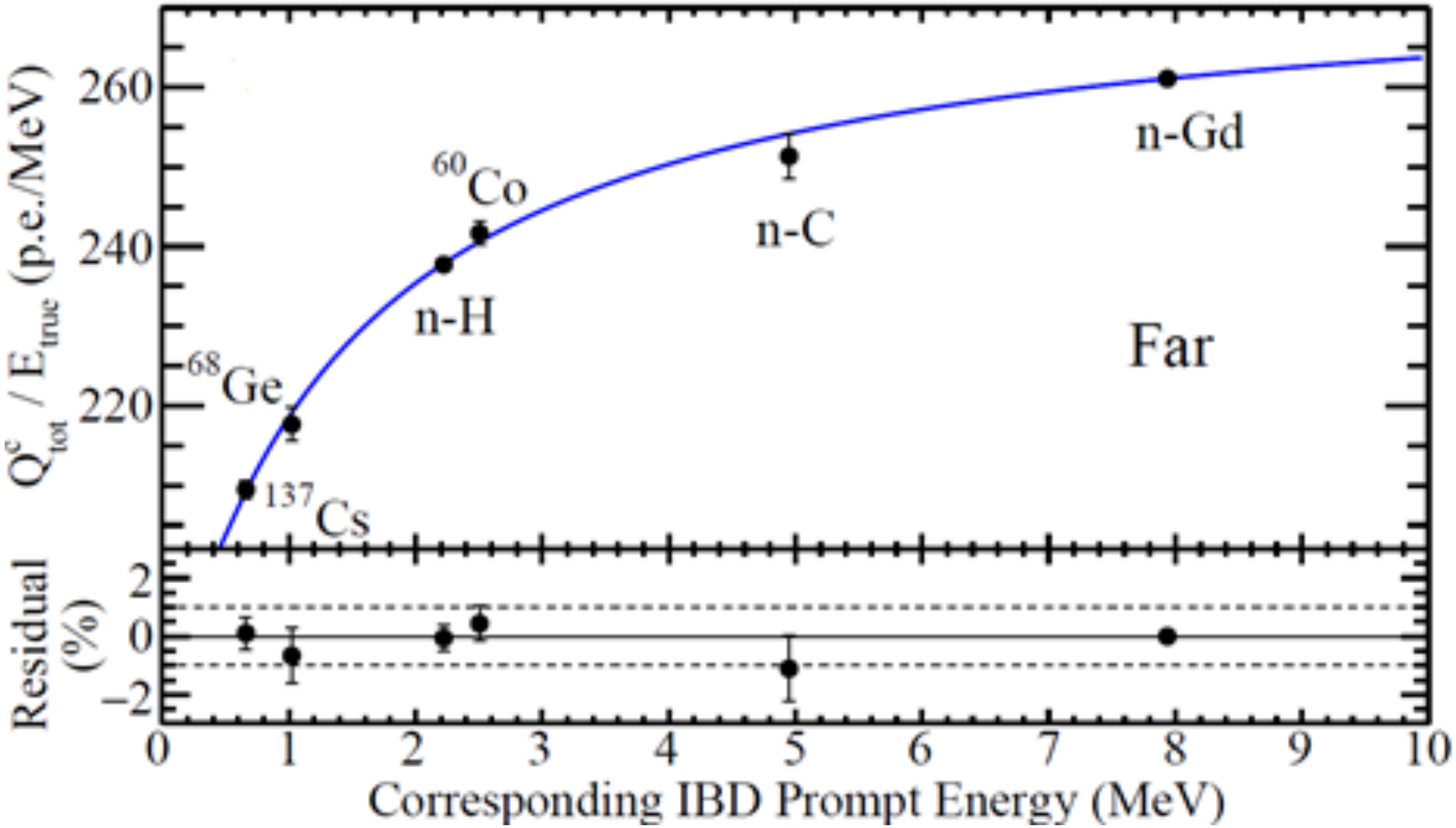
- **C (~500 days)** : **New result**
  Shape+rate analysis (**θ_{13} and $|\Delta m_{ee}^2|$**)
  [11 Aug, 2011~21 Jan, 2013]
  → Sterile neutrino search in progress,
  n-H analysis in progress

- Total observed reactor neutrino events as of today (1500 days):
  ~ 1.5M (Near), **~ 0.15M** (Far)



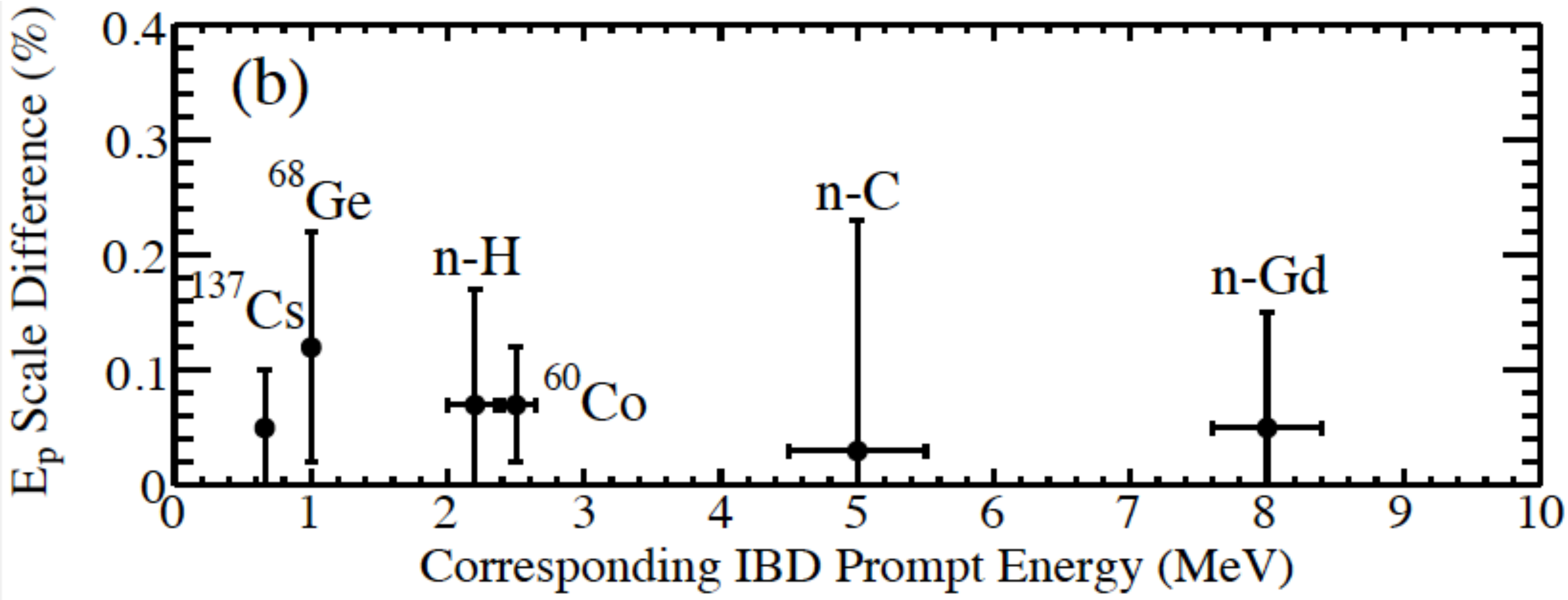
Energy Calibration from γ-ray Sources

- Non-linear resonse of the scintillation energy is calibrated using γ-ray sources.
- The visible energy from γ-ray is corrected to its corresponding positron energy.



Fit function : $E_{vis}/E_{true} = a - b/(1 - \exp(-cE_{true} - d))$

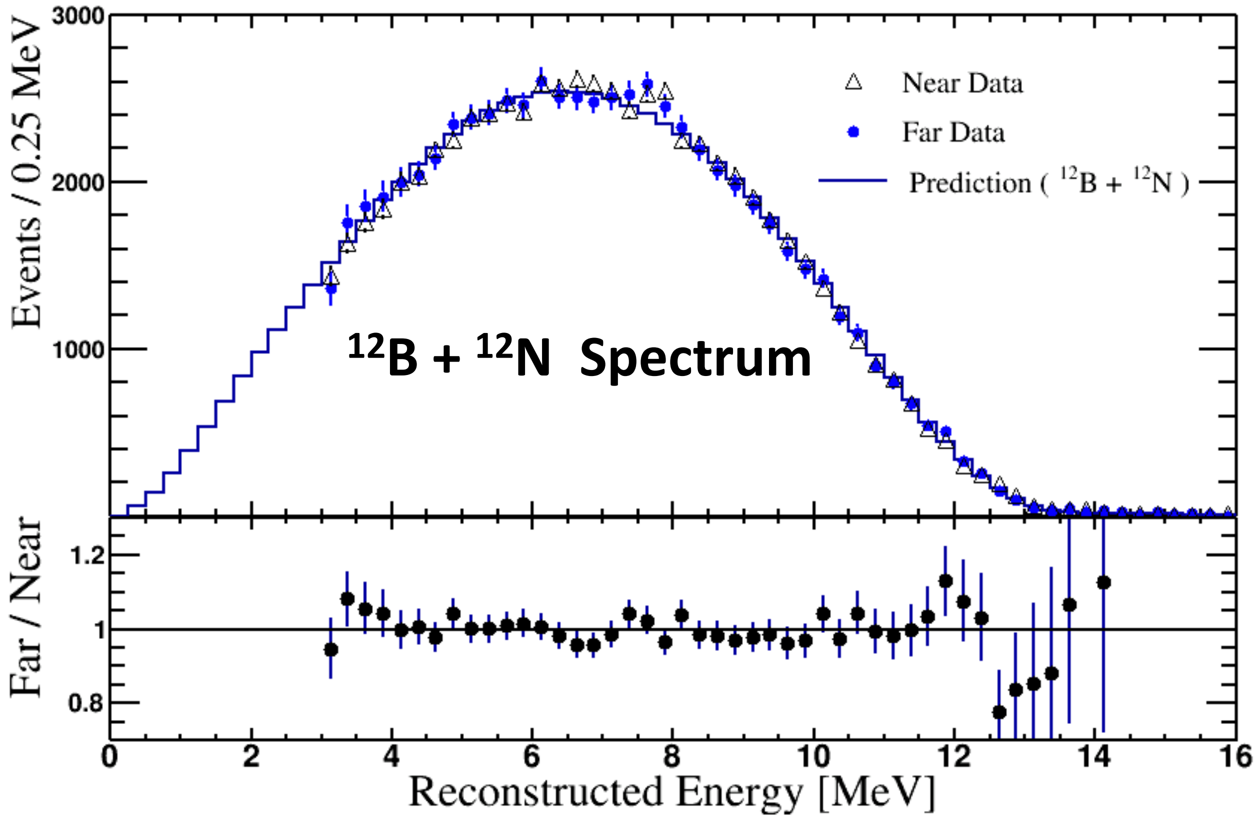
Energy Scale Difference between Near & Far



Energy scale uncertainty: < 0.15 %

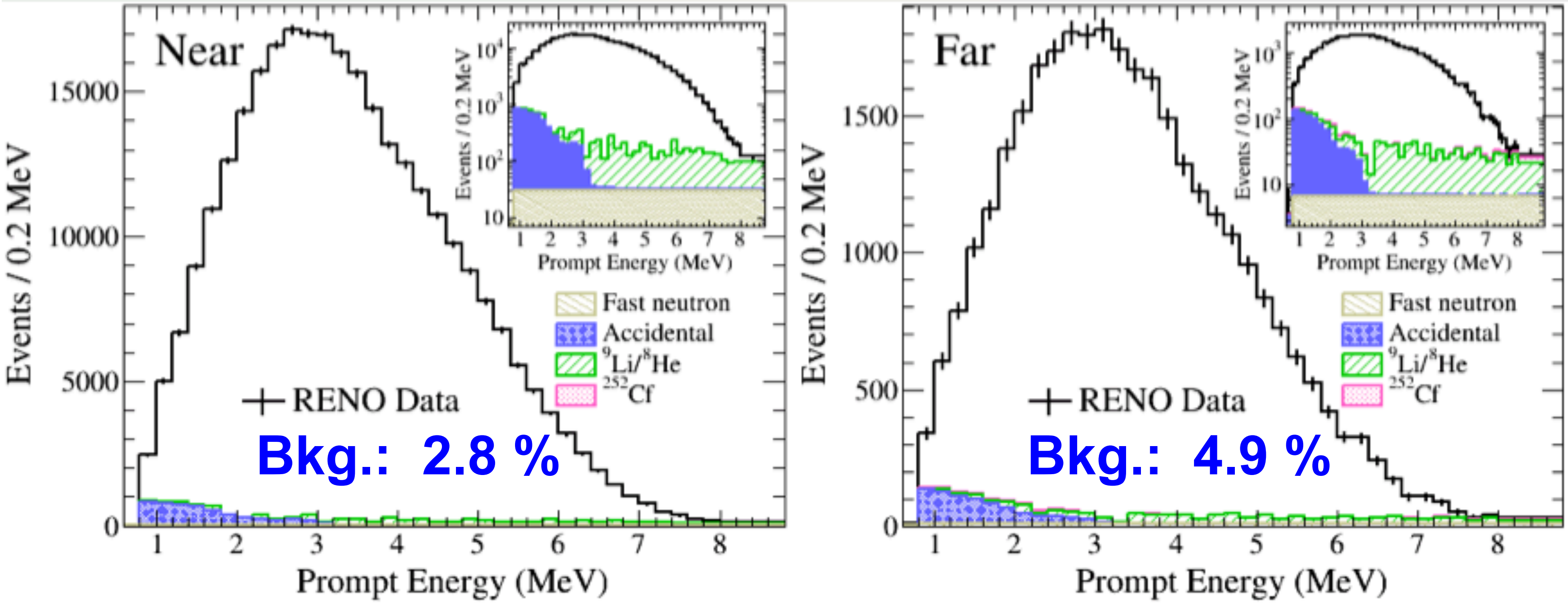
^{12}B Energy Spectrum

- Electron energy spectrum from β-decays from ^{12}B and ^{12}N, which are produced by cosmic-muon interactions.



Good agreement between data and MC spectrum!

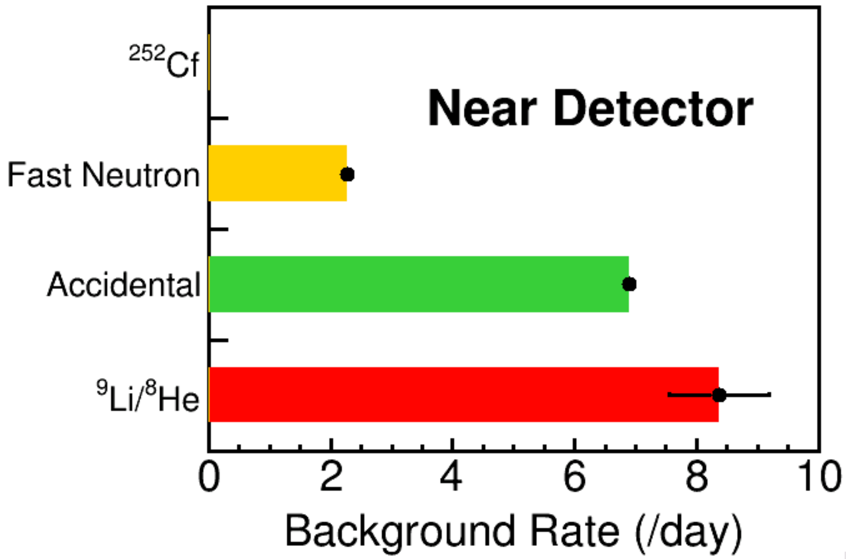
Prompt Energy Spectra of IBD Candidates

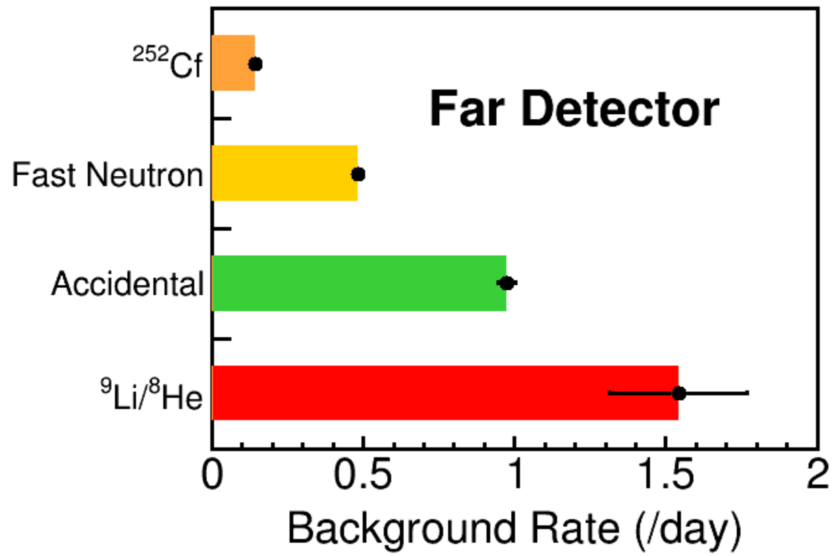


Near Live time = 458.49 days
# of IBD candidate = 290,775
# of background = 8,041 (2.8 %)

Far Live time = 489.93 days
# of IBD candidate = 31,541
# of background = 1540(4.9 %)

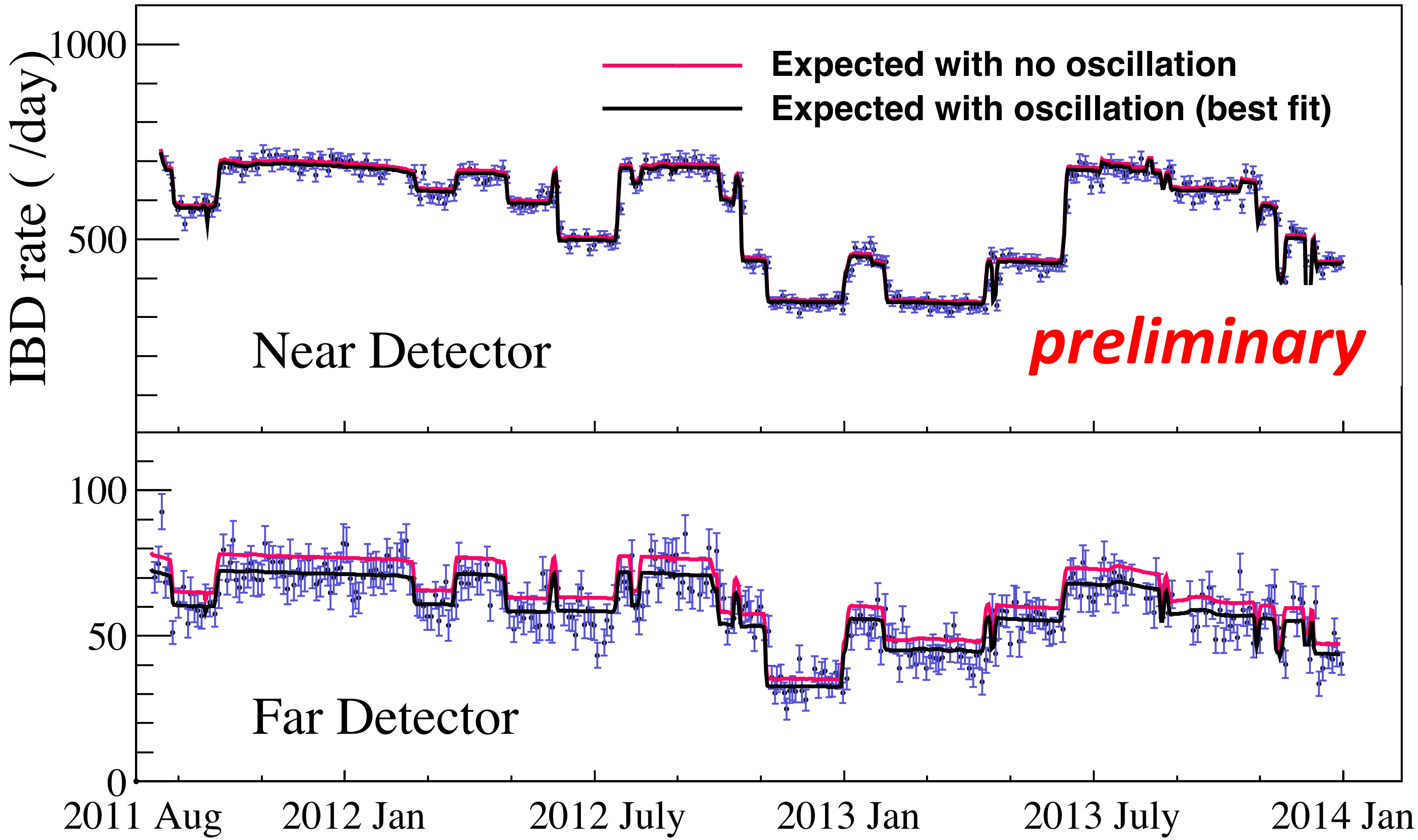
IBD Candidates & Background





	Near	Far
DAQ live time [days]	458.49	489.93
IBD candidates	290755	31541
Total BKG rate [/day]	17.54 ± 0.83	3.14 ± 0.21
IBD rate [/day] after BKG subtraction	616.67 ± 1.44	61.24 ± 0.42

Observed Daily Averaged IBD Rate



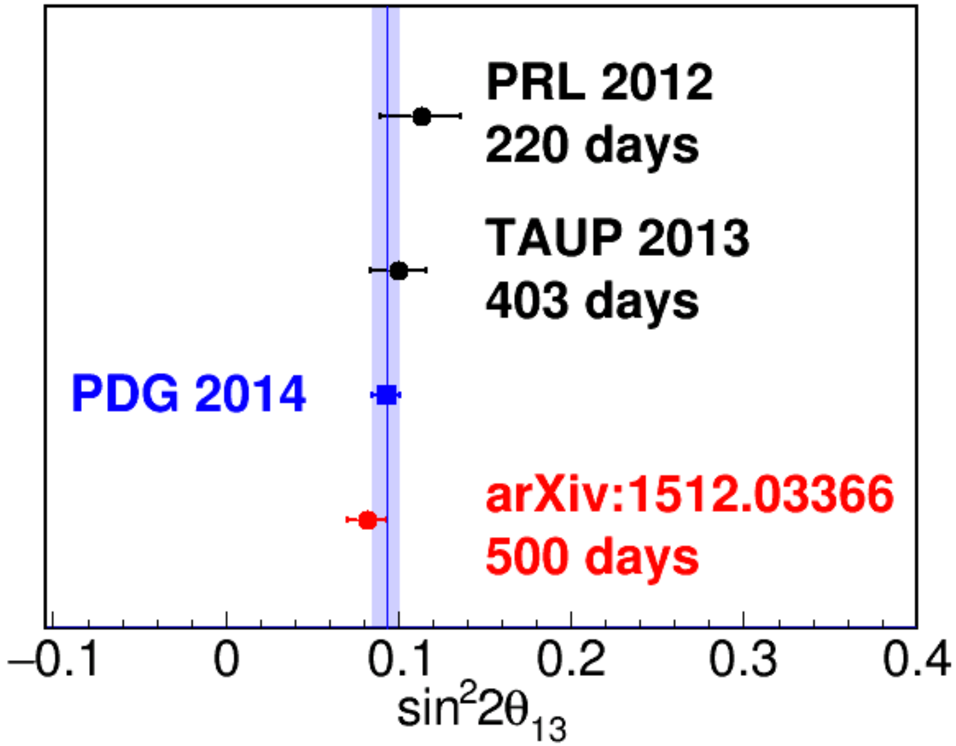
- Good agreement with observed rate and prediction.
- Accurate measurement of thermal power by reactor neutrinos

New θ_{13} Measurement by Rate-only Analysis

Rate-only new result

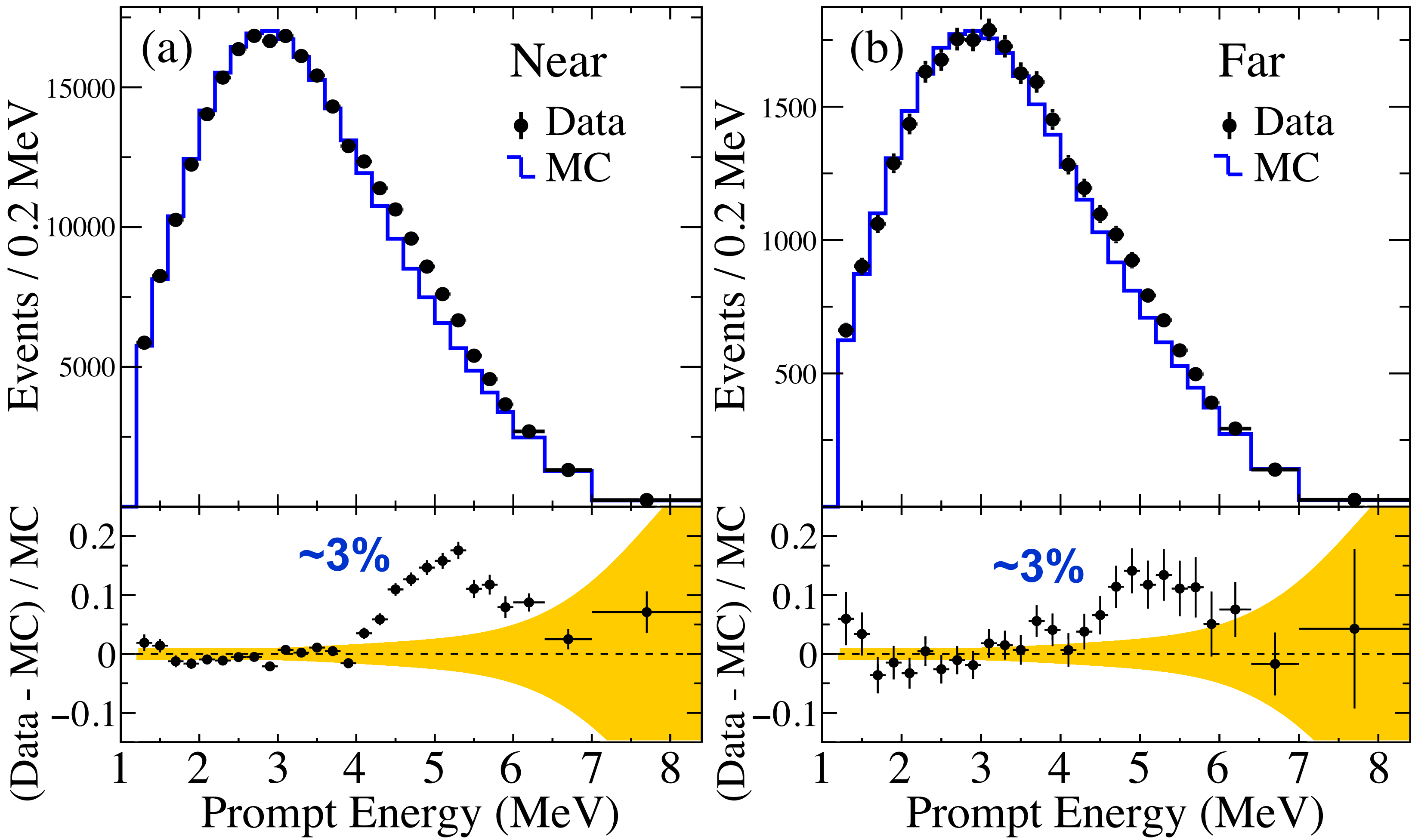
$$\boxed{\sin^2 2\theta_{13} = 0.087 \pm 0.009(\text{stat.}) \pm 0.007(\text{syst.})}$$

By minimizing $\chi^2 = \frac{\left(O^{F/N} - T^{F/N}\right)^2}{\left(U\right)^2} + Pull\_Terms$

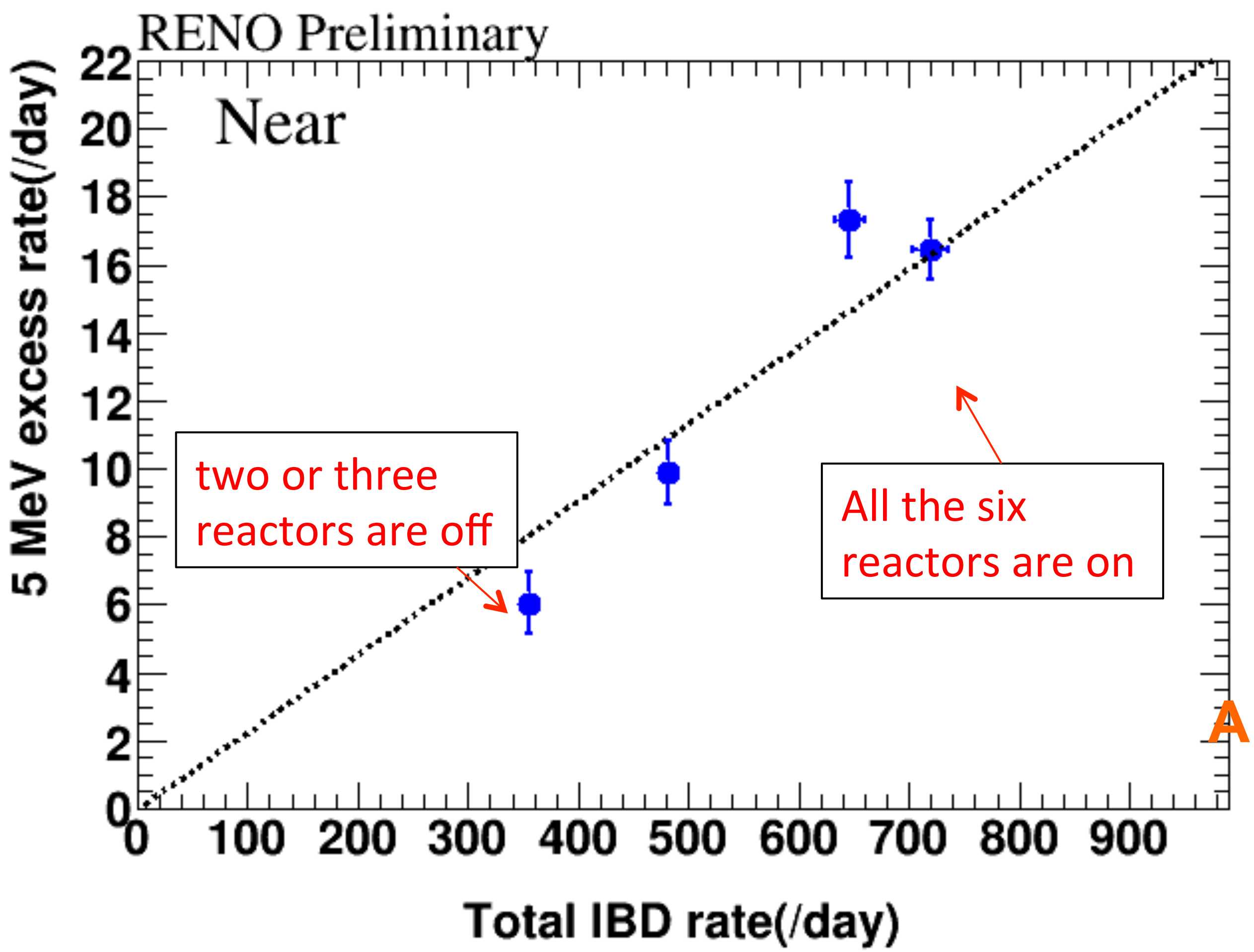


Observation of an excess at 5 MeV

arXiv:1511.05849.v2



Correlation of 5 MeV Excess with Reactor Power



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

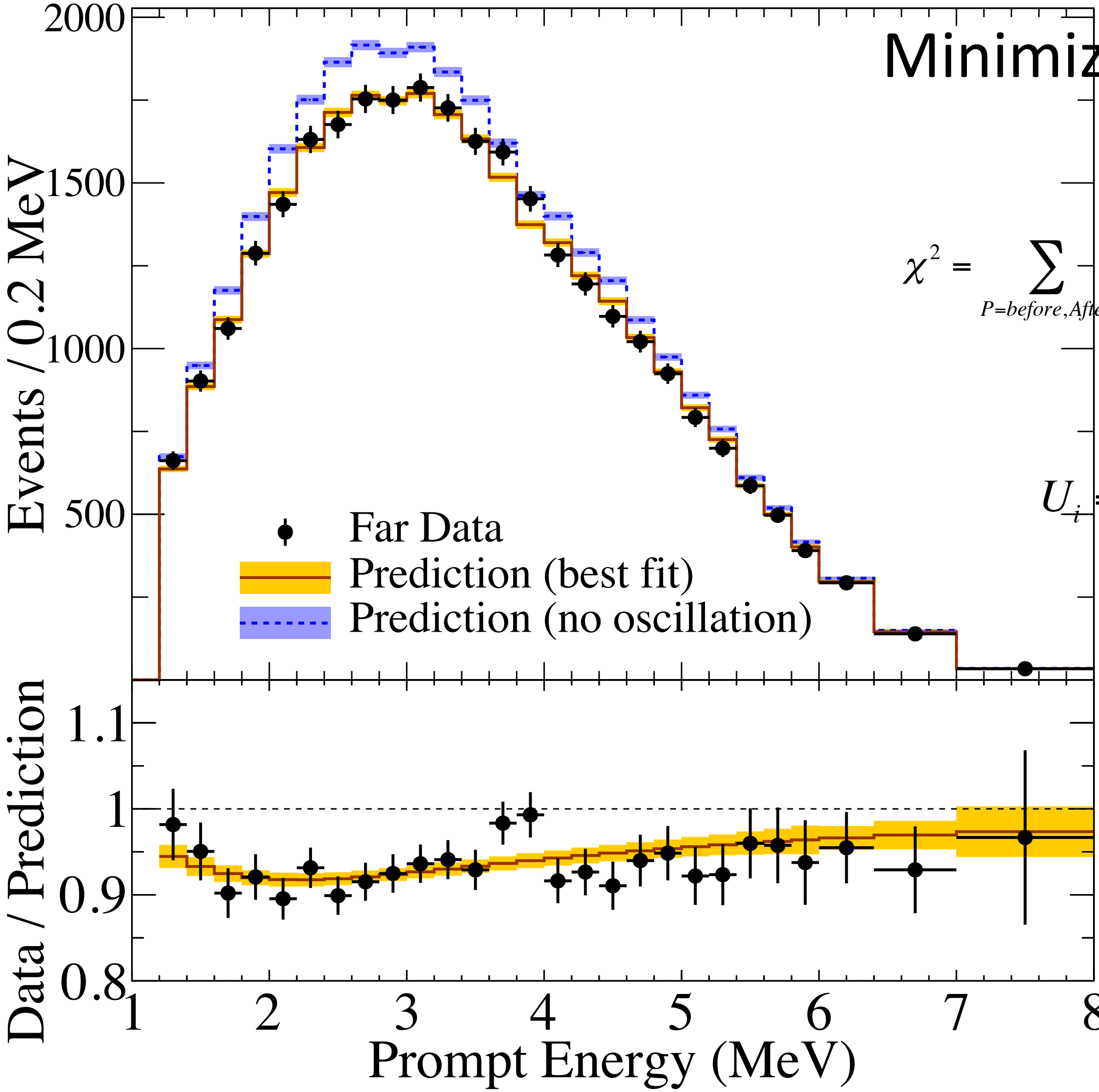
A new reactor neutrino component !!

** 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

Far/Near Shape Analysis for $|\Delta m_{ee}^2|$

arXiv:1511.05849.v2

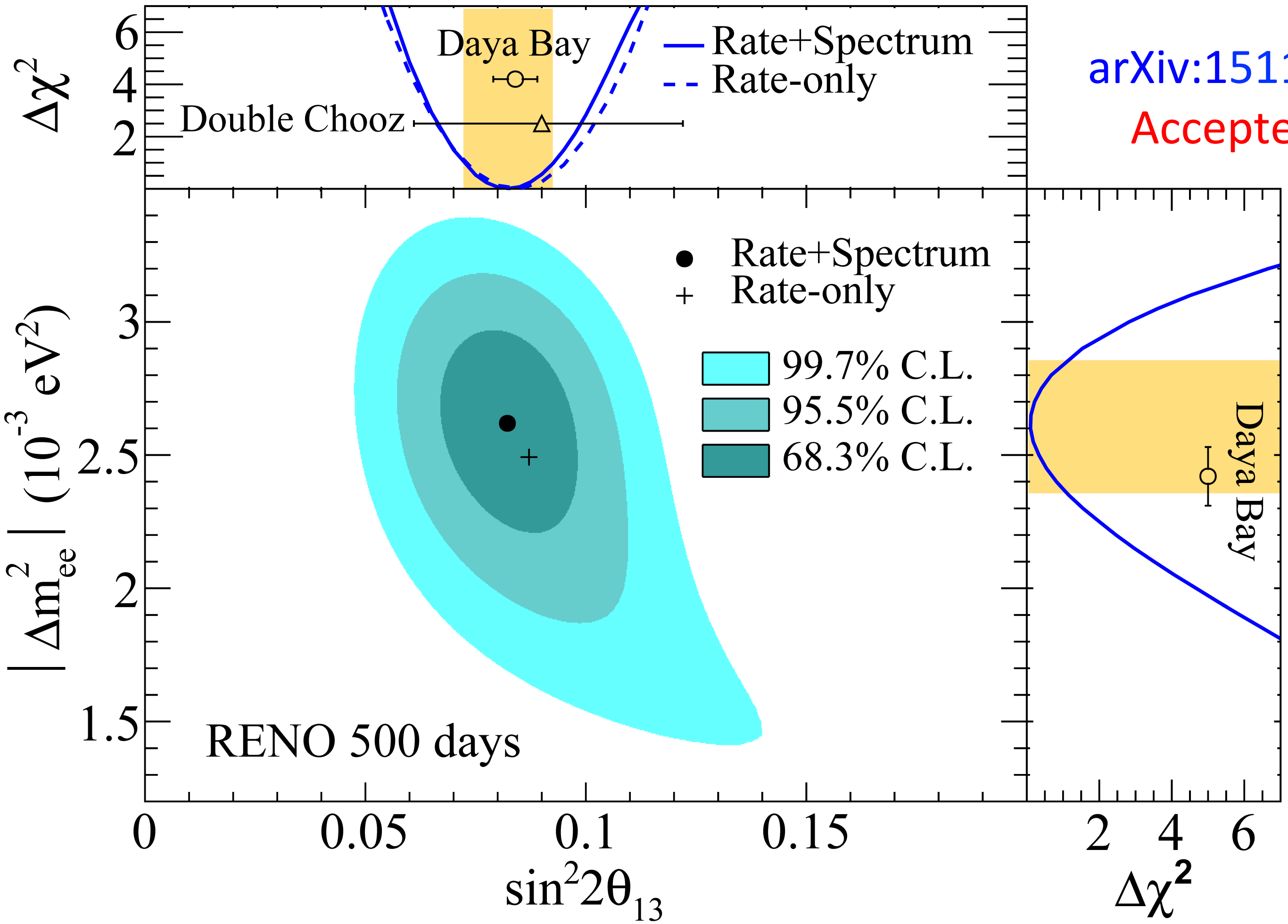


Minimize X^2 Function

$$\chi^2 = \sum_{P=before,After} \left\{ \sum_{i=1\sim N_b} \frac{\left(\frac{N_{obs}^{F,P,i}}{N_{obs}^{N,P,i}} - \frac{N_{Exp}^{F,P,i}}{N_{Exp}^{N,P,i}} \right)^2}{(U_i)^2} \right\} + Pull\_Terms$$

$$U_i = \frac{N_{obs}^{F,i}}{N_{obs}^{N,i}} \cdot \sqrt{\frac{N_{obs}^{F,i} + N_{bkg}^{F,i}}{(N_{obs}^{F,i})^2} + \frac{N_{obs}^{N,i} + N_{bkg}^{N,i}}{(N_{obs}^{N,i})^2}}$$

Results from Spectral Fit



arXiv:1511.05849.v2

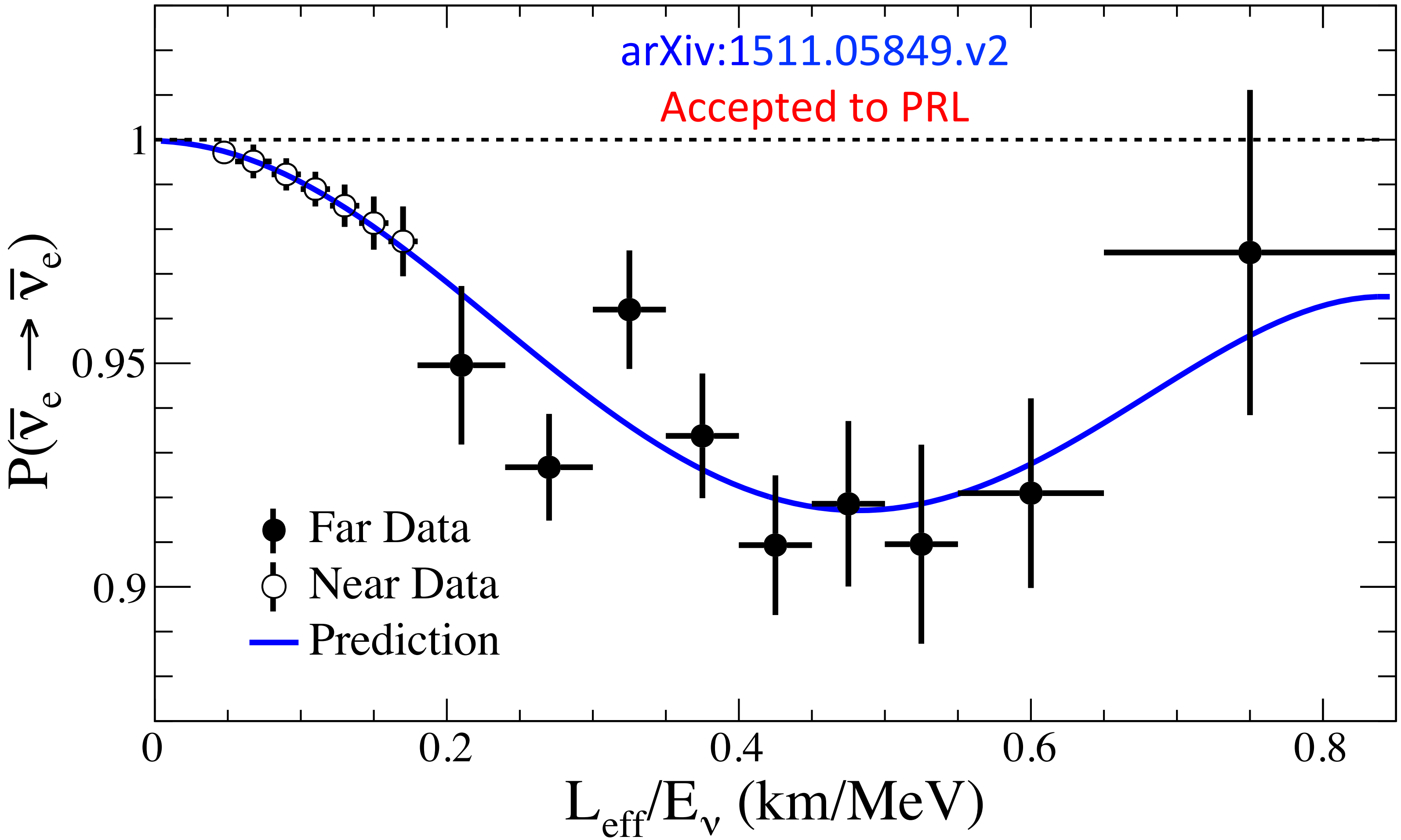
Accepted to PRL

Rate+shape new results

$$\sin^2 2\theta_{13} = 0.082 \pm 0.009(\text{stat.}) \pm 0.006(\text{syst.})$$

$$\left|\Delta m^2_{ee}\right| = 2.62^{+0.21}_{-0.23}(\text{stat.})^{+0.12}_{-0.13}(\text{syst.}) \ \ (\times 10^{-3}\, eV^2)$$

L/E Plot



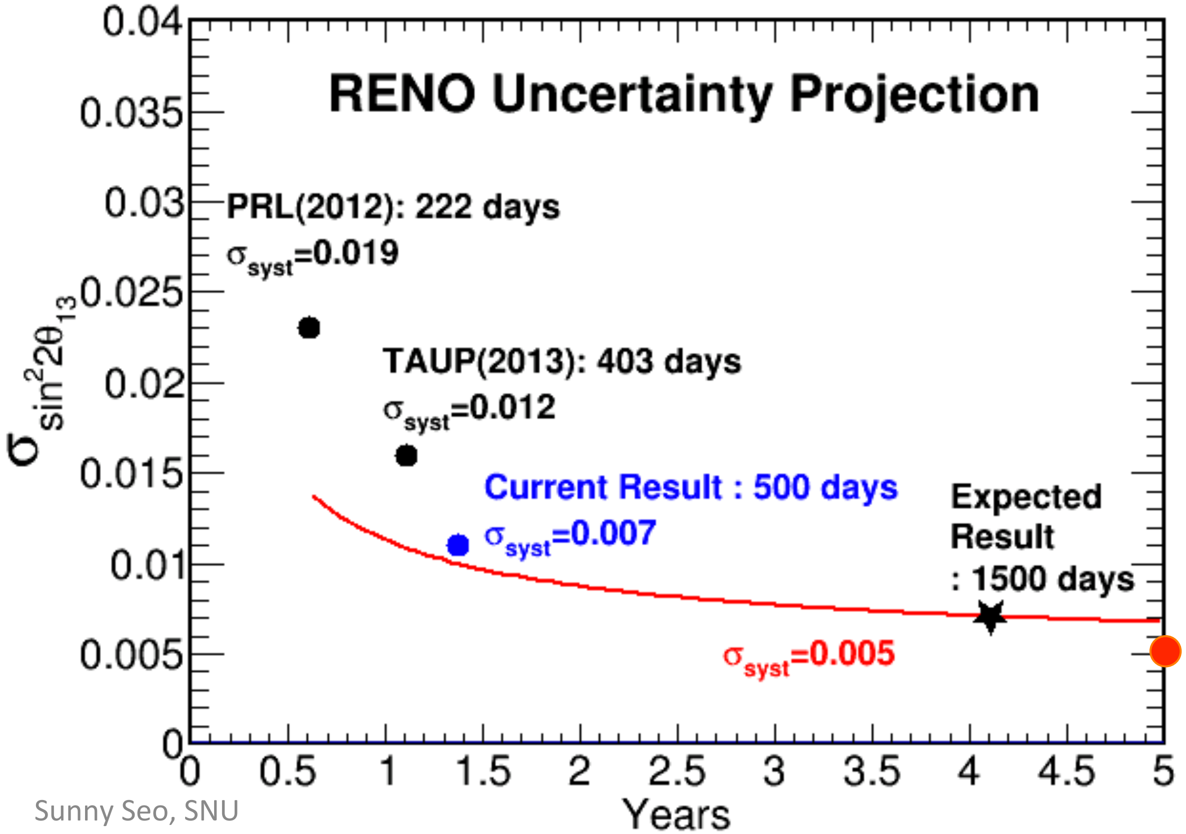
$$P(\bar{\nu}_e \rightarrow \bar{\nu}_e) \approx 1 - \sin^2 2\theta_{13} \sin^2\left(\Delta m^2_{ee} \frac{L}{4E_\nu}\right)$$

Projected Sensitivity of θ_{13} & $|\Delta m_{ee}^2|$

$\sin^2 2\theta_{13} = 0.082 \pm 0.010$ (13% precision) (~500 days)

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

* Expected precision of $|\Delta m_{ee}^2|$: ~ 0.1×10^{-3} eV^2 (4% precision)



(5 % precision)

(sensitivity goal of θ_{13})

RENO Summary

- We obtained new results by rate+shape analysis (500 days).

$$\sin^2 2\theta_{13} = 0.082 \pm 0.009(\text{stat}) \pm 0.006(\text{syst})$$

$$\left|\Delta m^2_{ee}\right| = 2.62\,^{+0.21}_{-0.23}(\text{stat.})\,^{+0.12}_{-0.13}(\text{syst.})\ \ (\times 10^{-3}\,eV^2)$$

Accepted to PRL (issue of May 27, 2016)

- Observed an excess at 5 MeV in reactor neutrino spectrum

- Measurement of θ_{13} from n-H IBD analysis

$$\sin^2 2\theta_{13} = 0.103 \pm 0.014(\text{stat}) \pm 0.014(\text{syst})$$

(preliminary)

- Sterile neutrino search result will be available soon.

- Goals: ~5% accuracy within 2 years for both $\sin(2\theta_{13})$ and $|\Delta m_{ee}^2|$

Overview of RENO-50

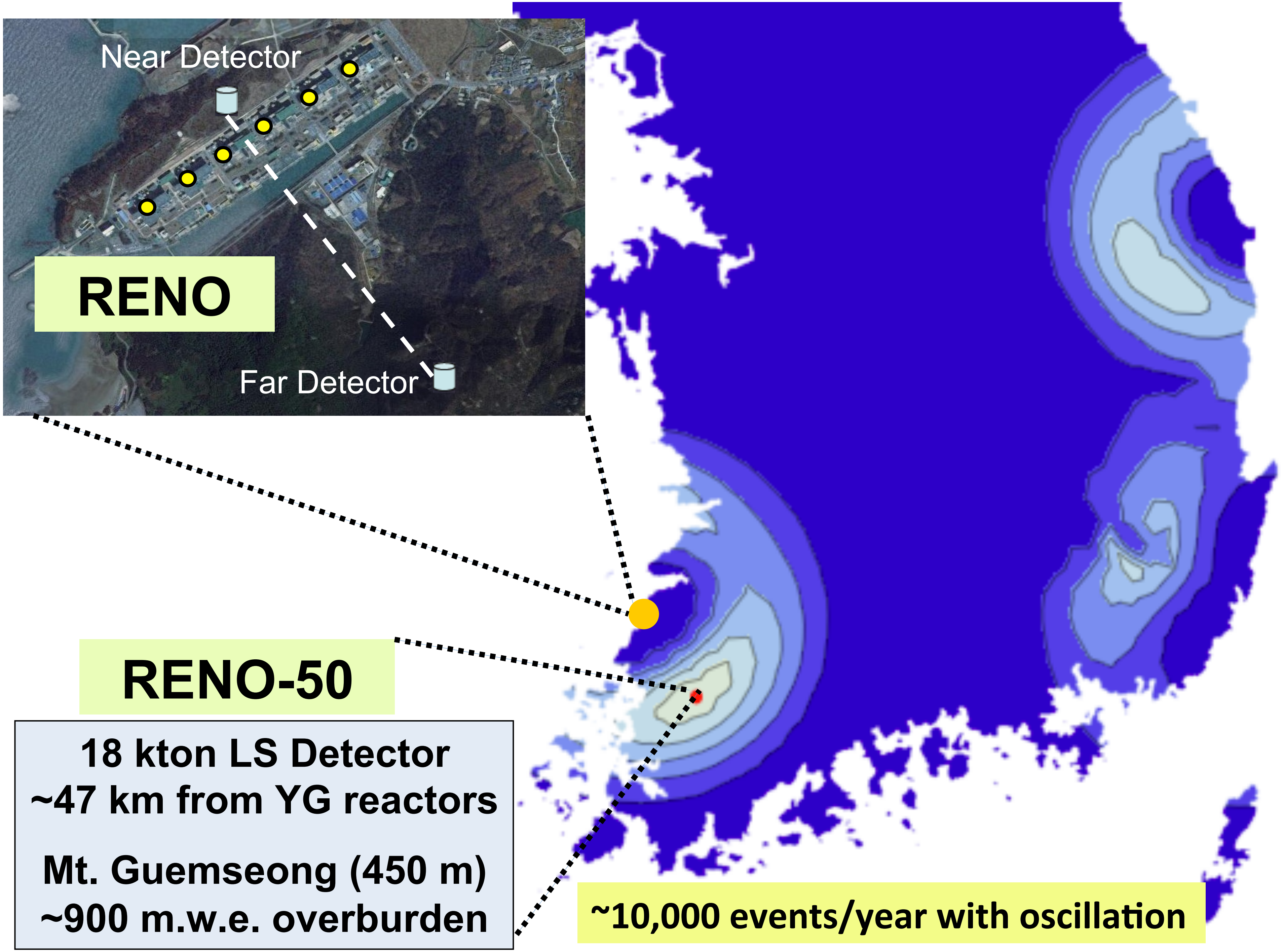
- **RENO-50** : An underground detector consisting of 18 kton ultra-low-radioactivity liquid scintillator & 15,000 20" PMTs, at 50 km away from the Hanbit(Yonggwang) nuclear power plant

RENO can be used as Near detector for RENO-50 (reduce sys. error)

- **Goals** : - Determination of neutrino mass hierarchy
- High-precision measurement of θ_{12}, Δm^2_{21} and Δm^2_{ee}
– Neutrino astronomy, Geo ν, sterile ν search, etc.

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

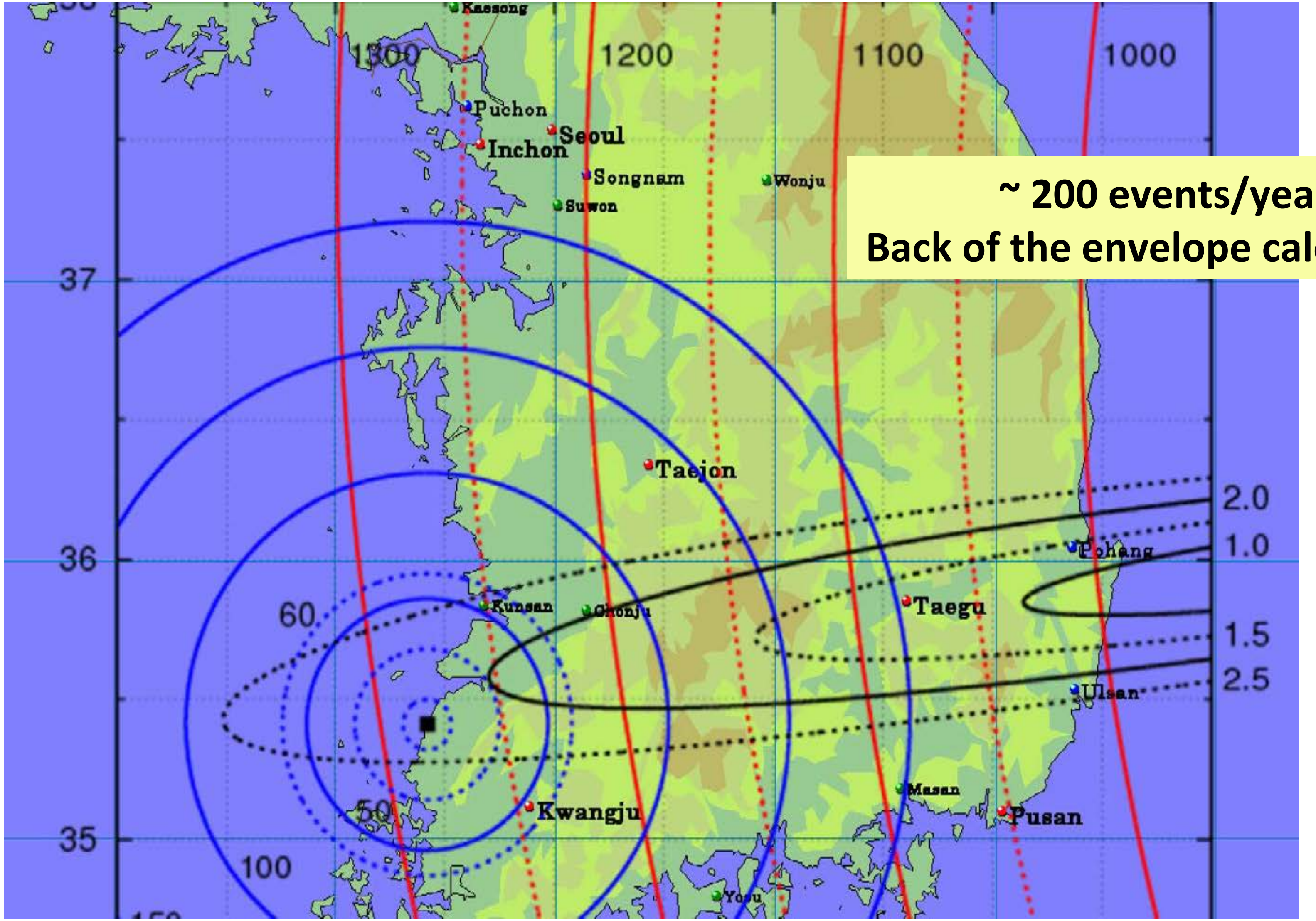
- **Schedule** : 2016 ~ 2021 : Facility and detector construction
2022 ~ : Operation and experiment



Near Detector
RENO
Far Detector
RENO-50
18 kton LS Detector
~47 km from YG reactors
Mt. Guemseong (450 m)
~900 m.w.e. overburden
~10,000 events/year with oscillation

J-PARC neutrino beam

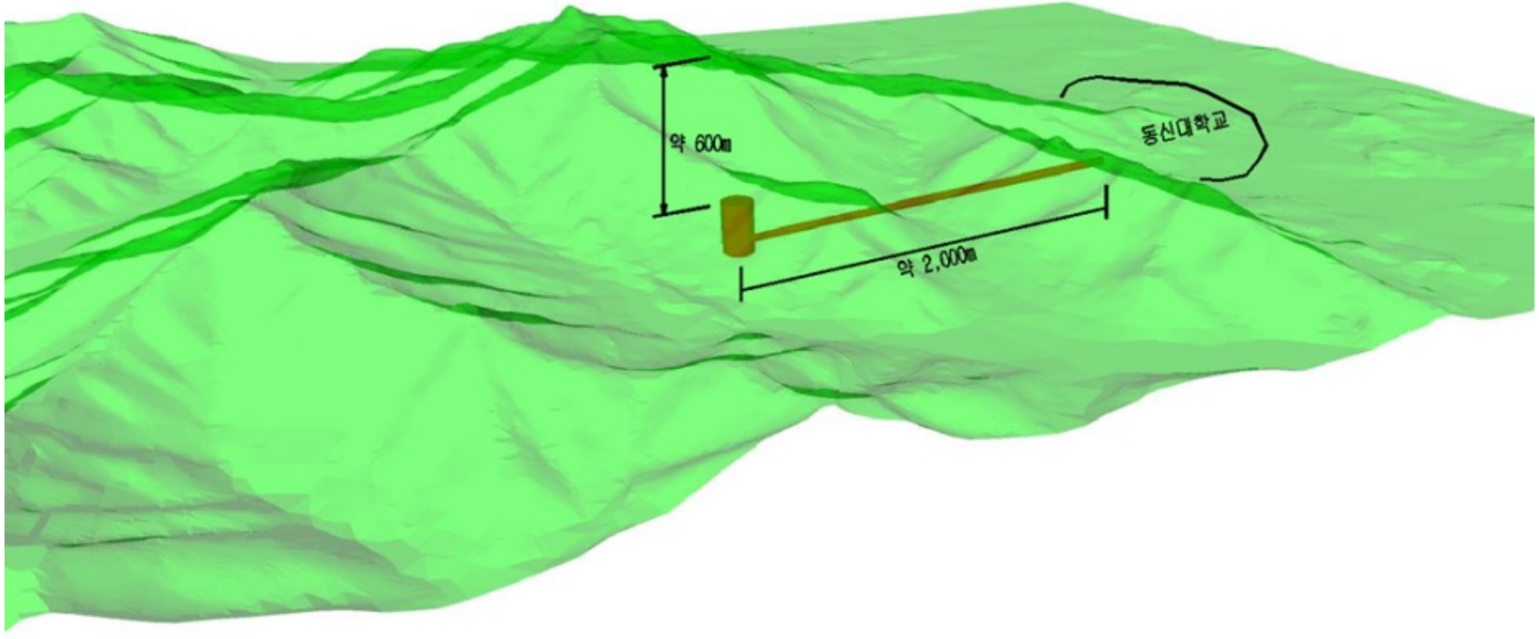
Dr. Okamura & Prof. Hagiwara



~ 200 events/year

Back of the envelope calculation

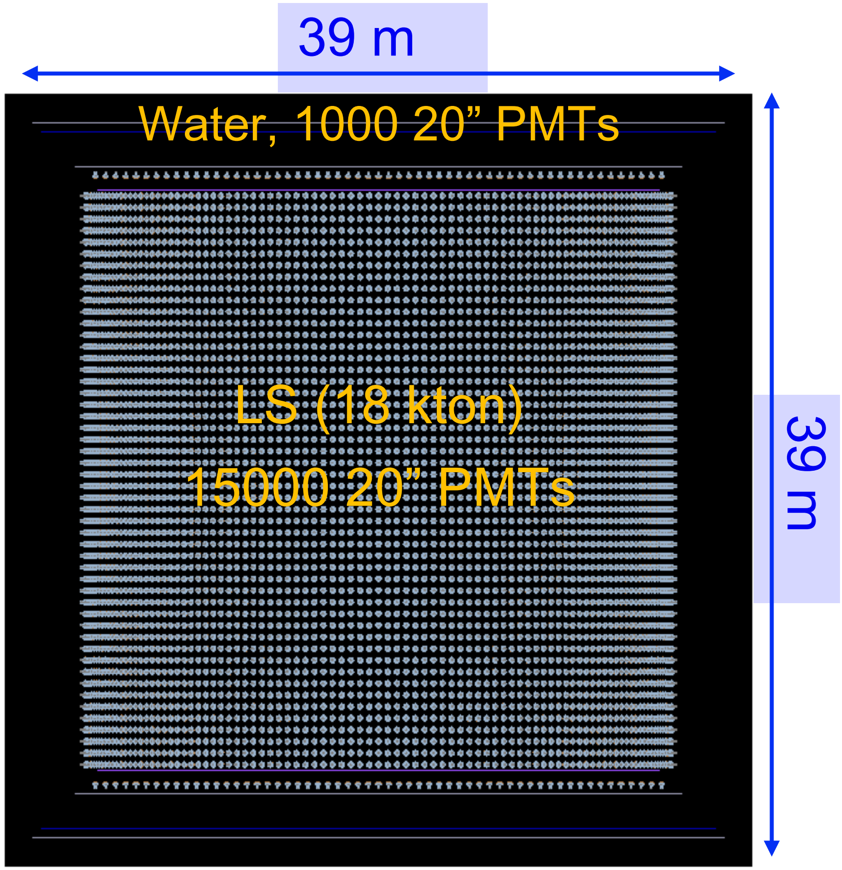
Geological Survey for Underground Facility



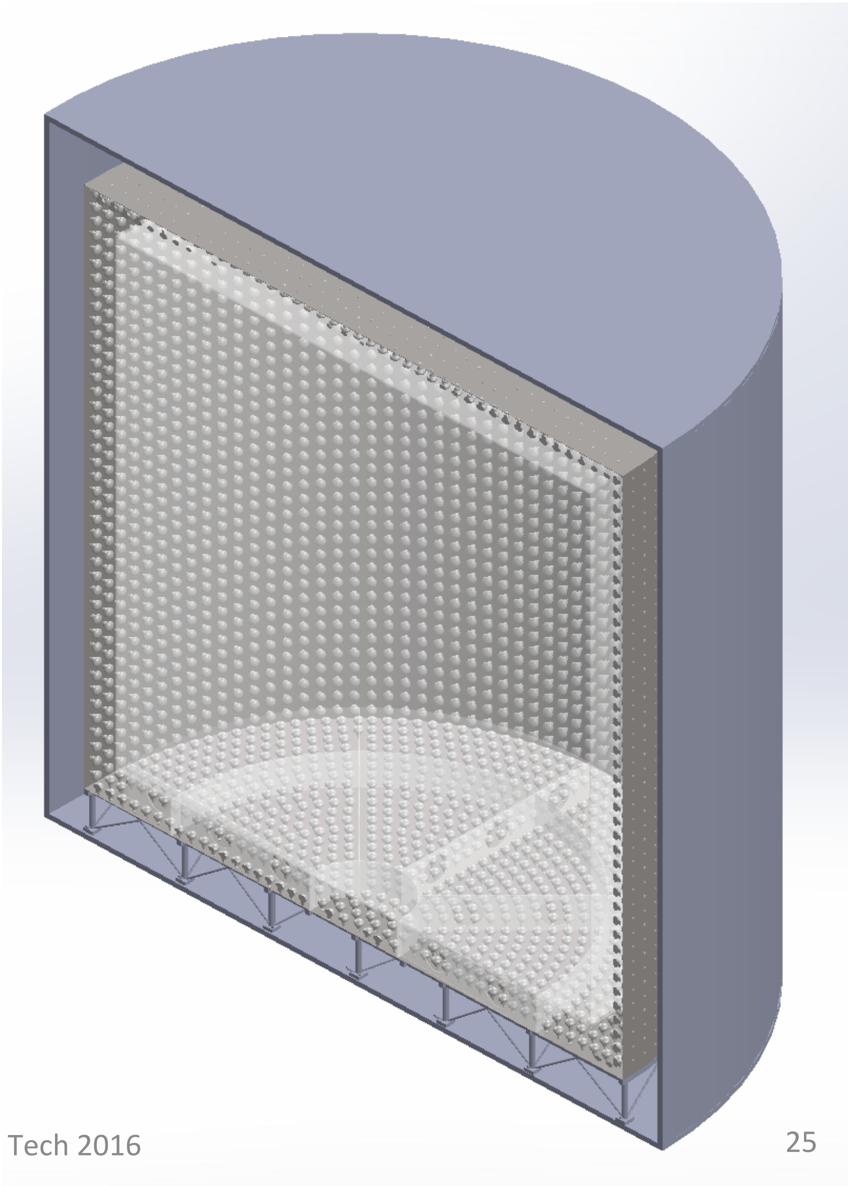
Cost estimation for RENO-50 underground facility (in progress)

- Geological survey for design of tunnel and experimental hall
- Cost estimation to be obtained soon

Conceptual Design of RENO-50 Detector



RENO-50 detector (MC)



Status of Funding and R&D

- An R&D funding (US $ 2M in 3 years, 2015~2017) is given by the Samsung Science & Technology Foundation.

- A proposal has been submitted to obtain construction funding.

→ International Neutrino community's supports will greatly enhance our opportunities !

- A domestic symposium and an international workshop were held in 2013 to discuss the feasibility and physics opportunities.

- R&D is in progress for LS, PMT, DAQ, MC and detector design, in order to prepare a Technical Design Report (TDR).

- International collaboration is expected to be formed.
You are welcome to join us for R&D and detector construction!

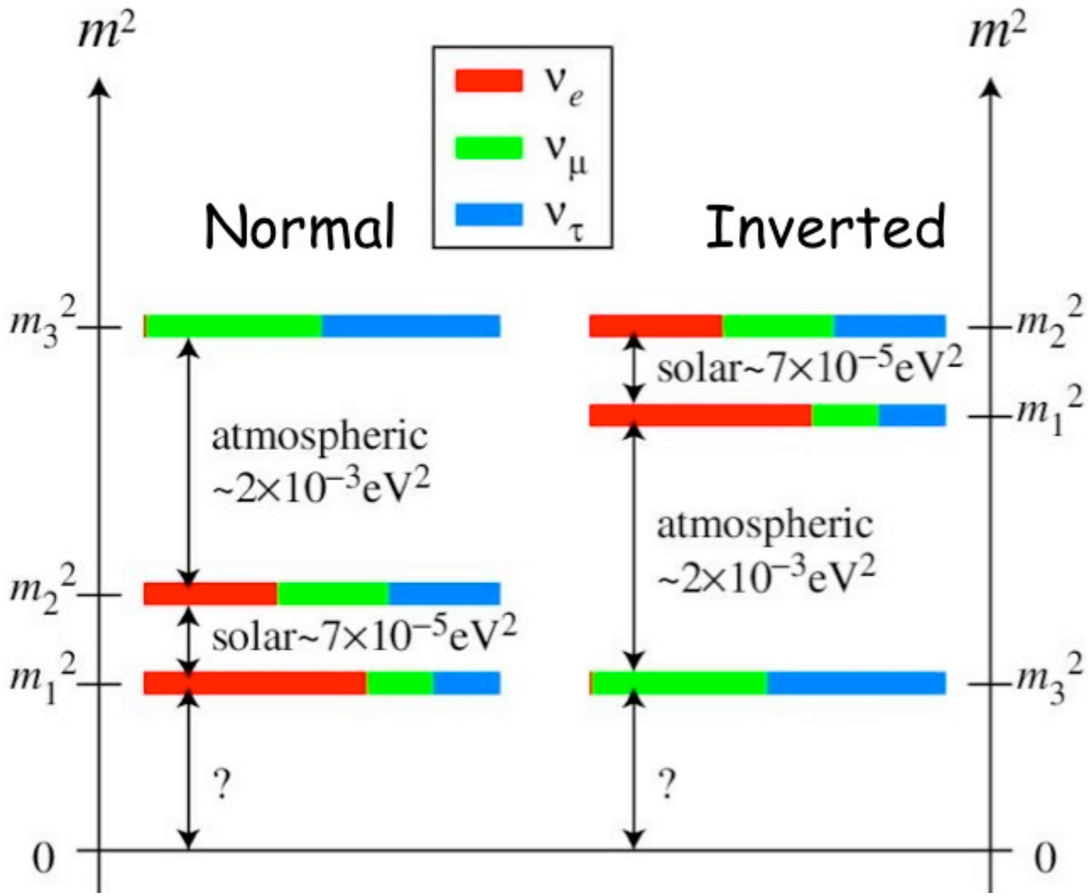
Schedule

- 2016 : Group organization
  Detector simulation & design
  Geological survey
- 2017 ~ 2018 : 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
- 2019 ~ 2021 : Detector construction
- 2022 ~ : Data taking & analysis


XIIIth International Conference on
Heavy Quarks and Leptons
May 22-27, 2016
Center for Neutrino Physics, Virginia Tech, Blacksburg, Virginia
VirginiaTech
Invent the Future®

Thank you !

What are the mass ordering of the three neutrinos ?



Reactor:

RENO-50, JUNO

Accelerator:

DUNE,

Hyper-K etc.

Atmosphere:

PINGU, ORCA

Physics Goals with RENO-50

- Determination of neutrino mass hierarchy (very challenging)

~3 σ sensitivity from ~10 years of data

- Precise measurement of θ_{12}, Δm^2_{21} and $|\Delta m^2_{ee}|$

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

$$\frac{\delta \Delta m^2_{21}}{\Delta m^2_{21}} < 1.0\%(1\sigma) \quad (\leftarrow 2.4\%)$$

$$\frac{\delta \Delta m^2_{ee}}{\Delta m^2_{ee}} < 1.0\%(1\sigma) \quad (\leftarrow 2.8\%)$$

- Neutrino burst from a Supernova in our Galaxy

~5,600 events @ 8 kpc

- Geo-neutrinos : **~ 1,500 geo-neutrinos for 5 years**

- Study the heat generation mechanism inside the Earth

- Solar neutrinos : with ultra low radioacitivity detector

- Test MSW effect on neutrino oscillation and solar models

- Sterile neutrino searches : reactor ν, radio-sources, IsoDAR ν

- Detection of J-PARC beam : **~200 events/year**

R&D in Progress

(1) Development of DAQ electronics

- Specification for *dead time free, high sensitivity and high speed signal processing*
- Prototype boards to be tested

(2) Develop techniques of LS purification

- Reduction of LS radioactivity to 10^{-16} g/g of U and Th
- Removal of LS impurities for attenuation length of ~25 m
- Several methods applied for investigation and evaluation
- Efforts on high sensitive measurement of radioactive concentration and optical parameters in LS

(3) Mechanical design of detector

- Detailed drawing of mechanical parts in progress
- MC simulation to estimate the performance

R&D in Progress

(4) Measurement of radioactivity for the detector materials

- Evaluate radioactive contamination of detector parts using a high purity Ge detector
- Estimate event rate contribution of those contaminations

(5) Measurement device for absolute LS attenuation length

- Developed a long pipe device with a laser source and a PMT
- Upgrade of the device in progress

SAMSUNG 삼성미래기술육성재단

- An R&D funding (US $2M for 3 years of 2015-2017) is given by the Samsung Science & Technology Foundation.

- Efforts on obtaining a full construction fund