RENO Reactor Neutrino Experiment

RENO & RENO-50

RENO = Reactor Experiment for Neutrino Oscillation

(On behalf of RENO Collaboration)

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Chonnam National University
March 15, 2013

2013 ICRR Neutrino Workshop @ Kashiwa campus

Past Efforts for Finding θ_{13}

- Chooz (2003) & Palo Verde (2000): No signal

$\sin^2(2\theta_{13}) < 0.12$ at 90% C.L.

- T2K : 2.5 σ excess (2011)

$0.03 < \sin^2(2\theta_{13}) < 0.28$ at 90% C.L. for N.H.

$0.04 < \sin^2(2\theta_{13}) < 0.34$ at 90% C.L. for I.H.

- MINOS : 1.7 σ excess (2011)

$0 < \sin^2(2\theta_{13}) < 0.12$ at 90% C.L. for N.H.

$0.04 < \sin^2(2\theta_{13}) < 0.19$ at 90% C.L. for I.H.

- Double Chooz : 1.7 σ measurement (2011)

$\sin^2(2\theta_{13}) = 0.086 \pm 0.041(\text{stat.}) \pm 0.030(\text{syst.})$

- Daya Bay (03. 08. 2012)

5.2 σ observation

$\sin^2(2\theta_{13}) = 0.092 \pm 0.016(\text{stat.}) \pm 0.005(\text{syst.})$

RENO Result

- **Last result on PRL:**

Ahn et al (RENO collab.), PRL 108, 191802 (2012)

$$\sin^2 2\theta_{13} = 0.113 \pm 0.013(stat.) \pm 0.019(syst.)$$

- For the **New result**

<u>Statistics:</u>

-- about twice more data

<u>Systematics:</u>

-- Improved background estimation/reduction

(Li/He background, fast N, flasher removal)

-- Improved energy scale calibration

Outline

RENO

- Introduction
- Experimental setup & detector
- Data-taking & data set
- Improvements in data analysis
- Results
- Summary

RENO-50

- Introduction
- Physics with RENO-50
- Summary

Neutrino Mixing Parameters

In 1962 Z. Maki, M. Nakagawa, and S. Sakata considered neutrino flavor oscillations: neutrinos of different flavors can be transformed to each other

Matrix Components:
- 3 Angles (θ_{12}; θ_{13}; θ_{23})
- 1 CP phase (δ)
- 2 Mass differences

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

$$U = \underbrace{\begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix}}_{\text{atmospheric SK, K2K}} \begin{pmatrix} c_{13} & 0 & s_{13}e^{i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{-i\delta} & 0 & c_{13} \end{pmatrix} \underbrace{\begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}}_{\text{SNO, solar SK, KamLAND}}$$

The Next Big Thing?

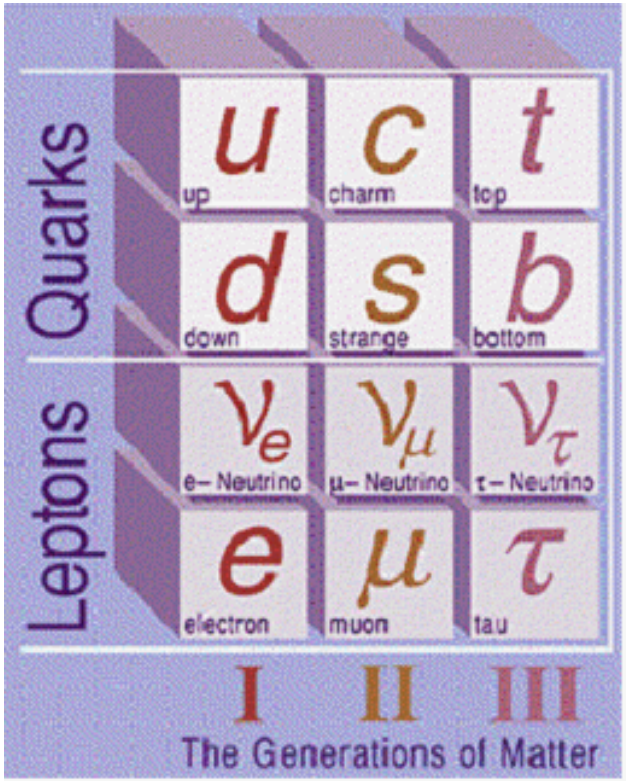
$\theta_{23} \approx \theta_{atm} \approx 45^\circ$

Large and maximal mixing!

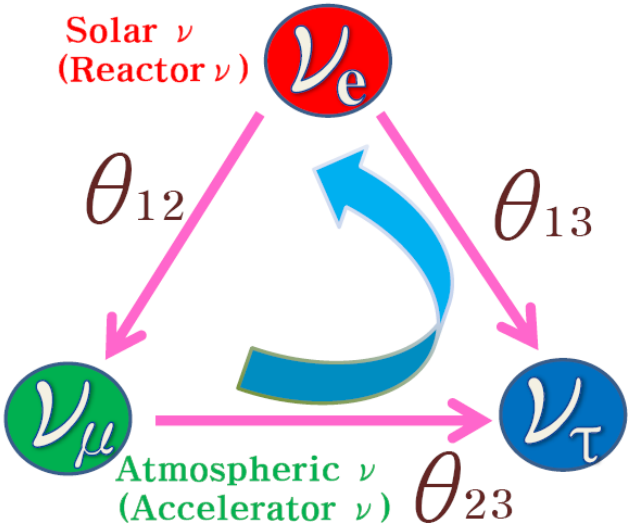
$\theta_{12} \approx \theta_{sol} \approx 32^\circ$

Neutrino Oscillation

Neutrino: elementary particle



Three types of neutrinos exist & mixing among them



Oscillation parameters

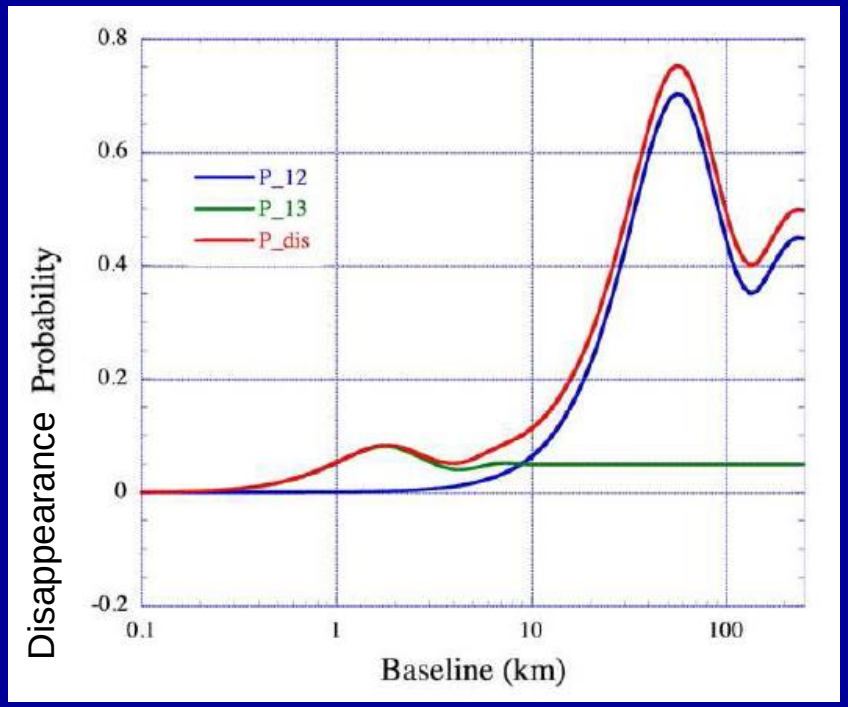
$(\theta_{12}, \theta_{23}, \theta_{13})$

Trying to measure precisely

Reactor Antineutrino Oscillation

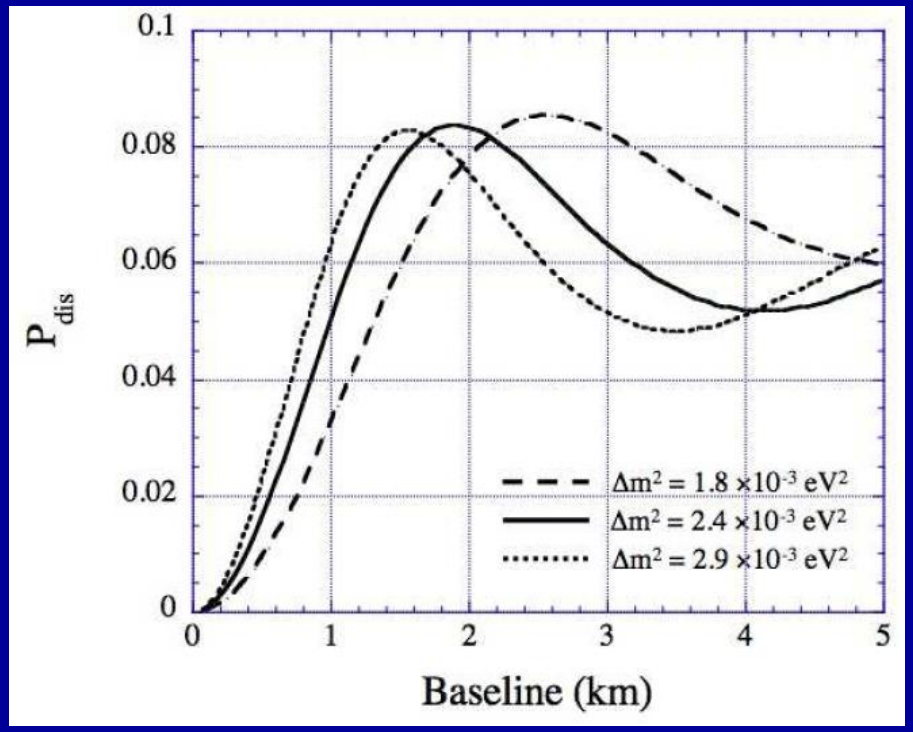
$$P(\bar{\nu}_e \to \bar{\nu}_e) \approx 1 - \sin^2 2\theta_{13} \sin^2\left(\frac{1.27\Delta m_{13}^2 L}{E_\nu}\right)$$

Reduction of reactor neutrinos due to oscillations



$$\sin^2 2\theta_{13} = 0.10,$$

$$\theta_{12} = 34^\circ, \quad \Delta m^2_{21} = 7.9 \times 10^{-5}\mathrm{eV}^2, \quad \Delta m^2_{31} = 2.5 \times 10^{-3}\mathrm{eV}^2$$

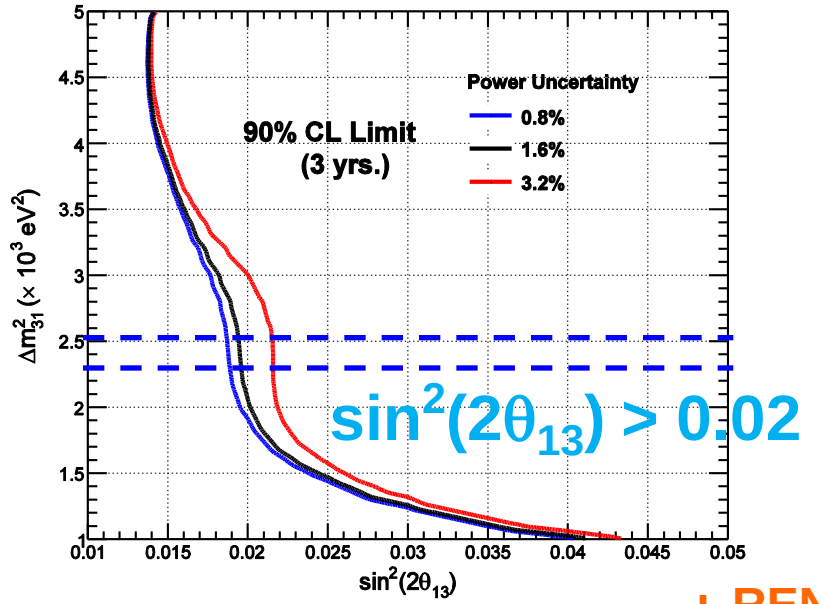


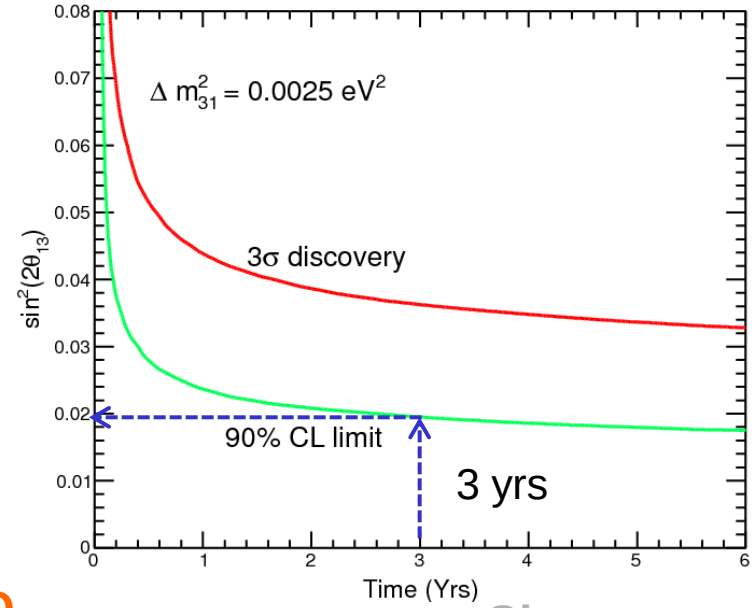
Reactor neutrino disappearance Prob. due to θ_{13} with the allowed 2σ range in Δm_{23}^2

- $\sin^2 2\theta_{13} > 0.01$ with 10 t •14GW •3yr ~ 400 t•GW•yr
  (400 t•GW•yr: a 10(40) ton far detector and a 14(3.5) GW reactor in 3 years)

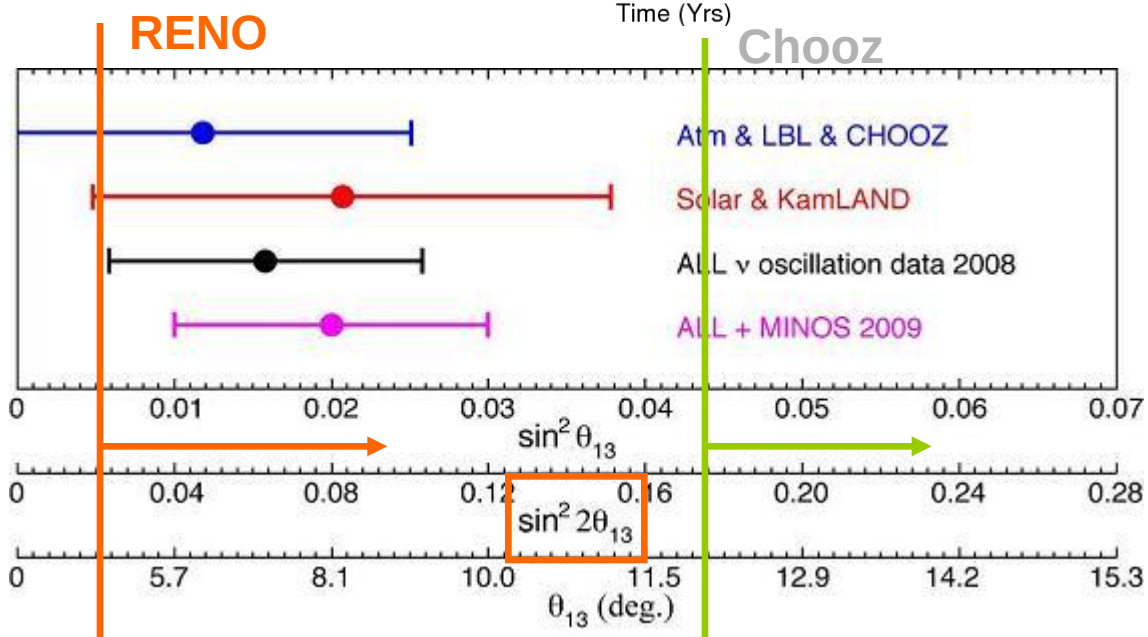
RENO Expected Sensivity

90% CL Limits





- **10 times better sensitivity than the current limit**



G. Fogli *et al.* (2009)

RENO Collaboration

(12 institutions and 40 physicists)

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

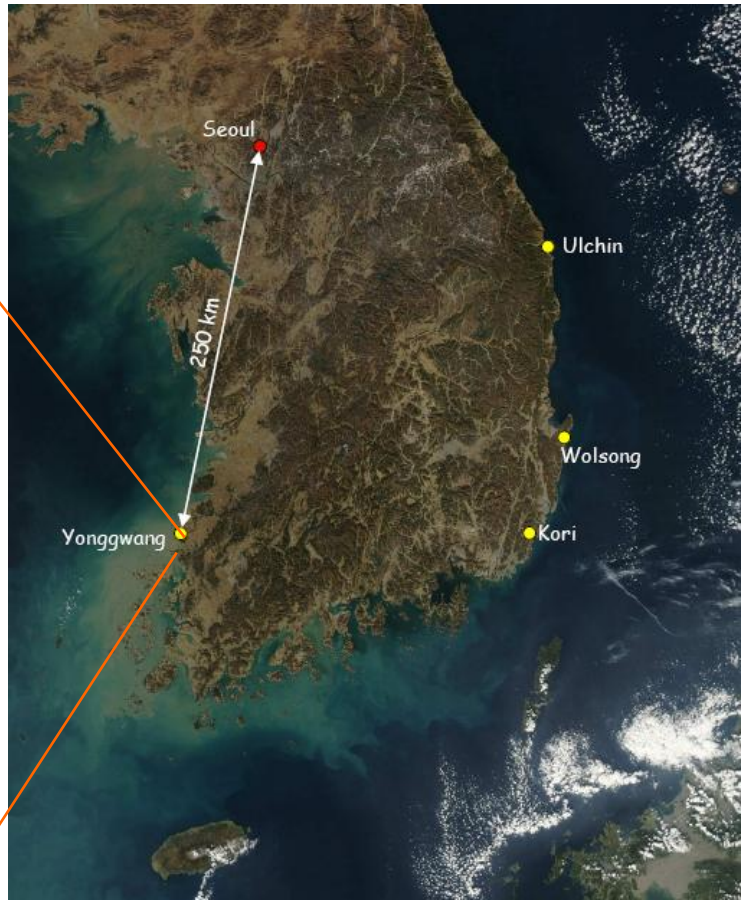
- Total cost : $10M
- Start of project : 2006
- The first experiment running with both near & far detectors from Aug. 2011

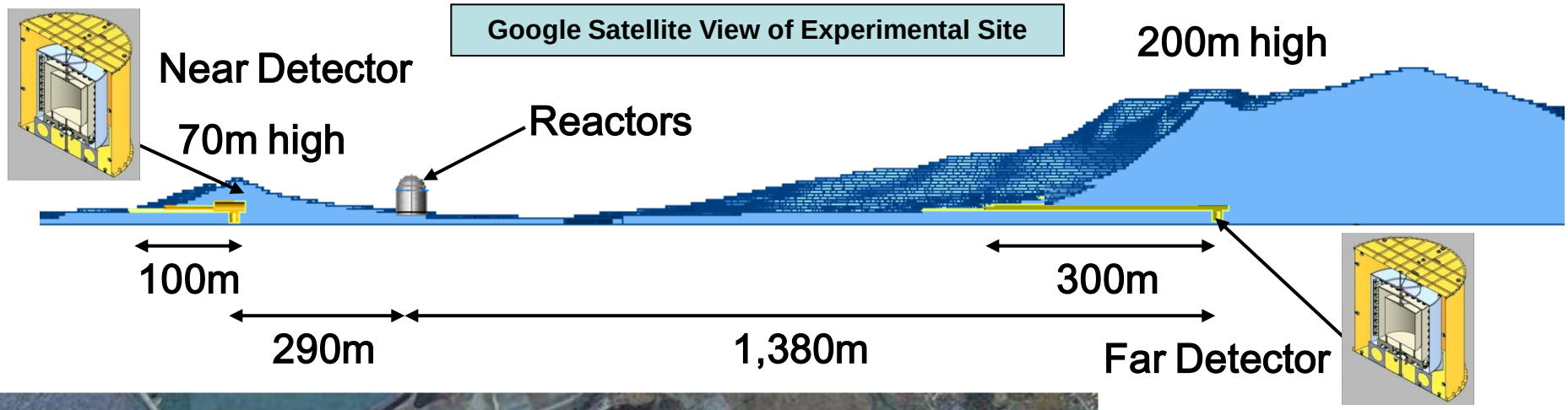
+++ http://reno01.snu.ac.kr/RENO

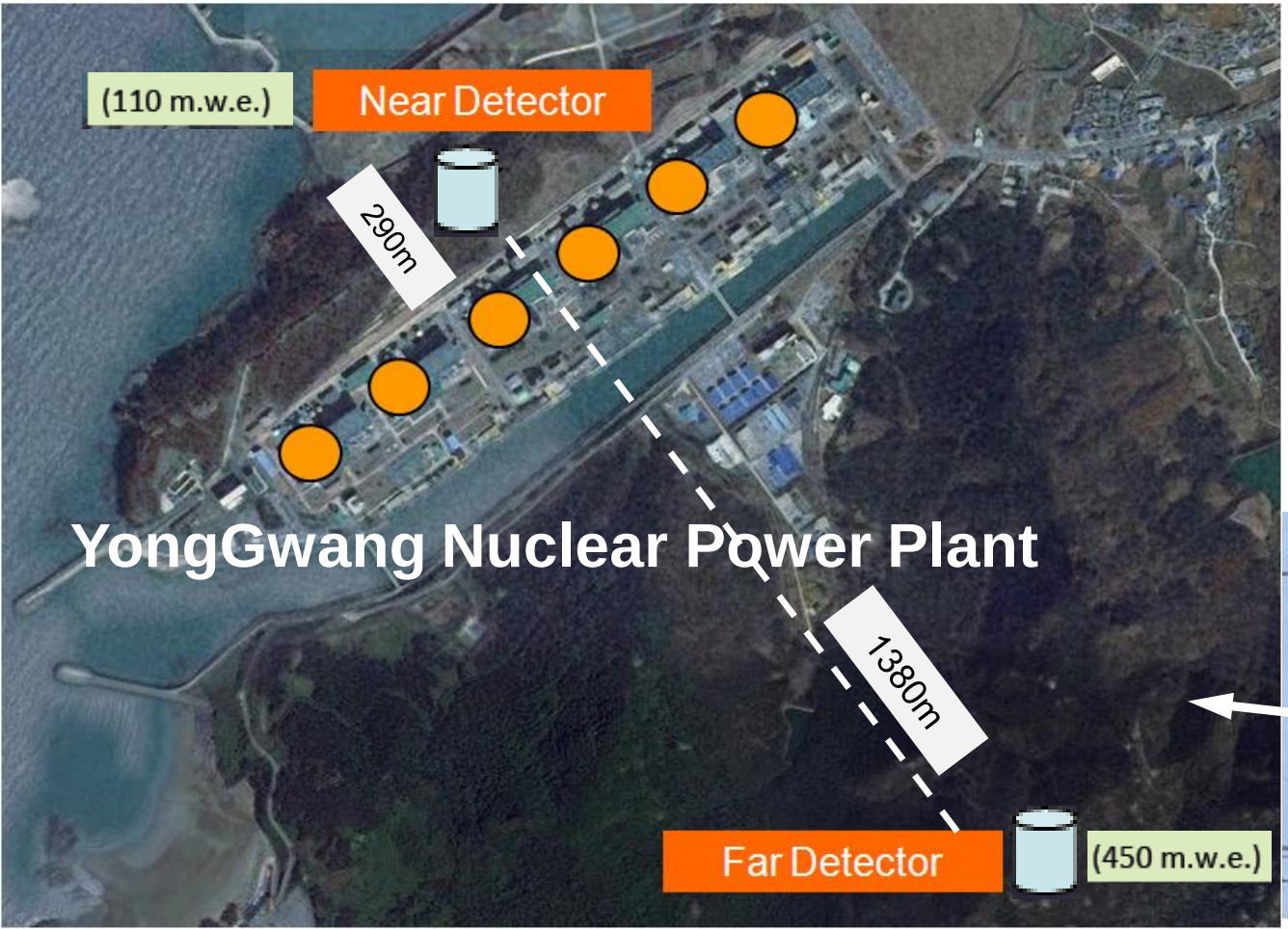
YongGwang Nuclear Power Plant

- Located in the west coast of southern part of Korea
- ~400 km from Seoul
- 6 reactors are lined up in roughly equal distances and span ~1.3 km
- Total average thermal output ~16.4GW$_{th}$ (2nd largest in the world)

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



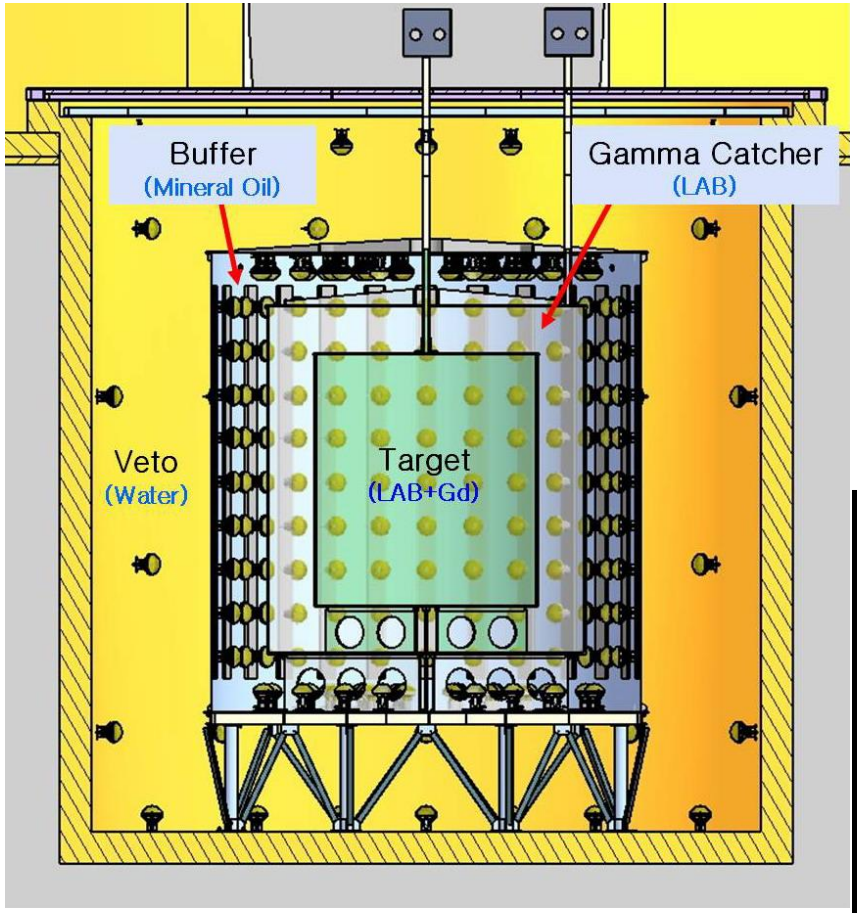


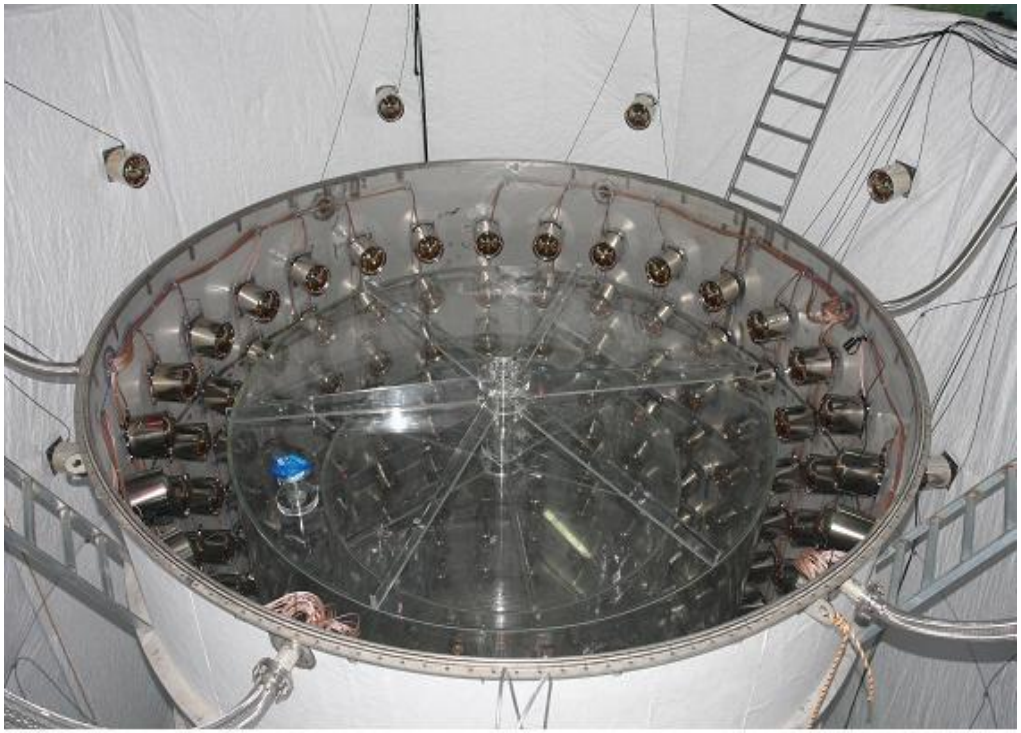


RENO

KNRC
Korea Neutrino Research Center

RENO Detector





	Thick (cm)	vessel	Material	Mass (tons)
Target	140	Acrylic (10mm)	Gd(0.1%) +LS	15.4
Gamma catcher	60	Acrylic (15mm)	LS	27.5
Buffer	70	SUS(5mm)	Mineral oil	59.2
Veto	150	Steel (15mm)	water	354.7

total ~460 tons

- **Inner PMTs: 342 10" PMTs**
  - solid angle coverage = 12.6%
- **Outer PMTs: ~ 60 10" PMTs**

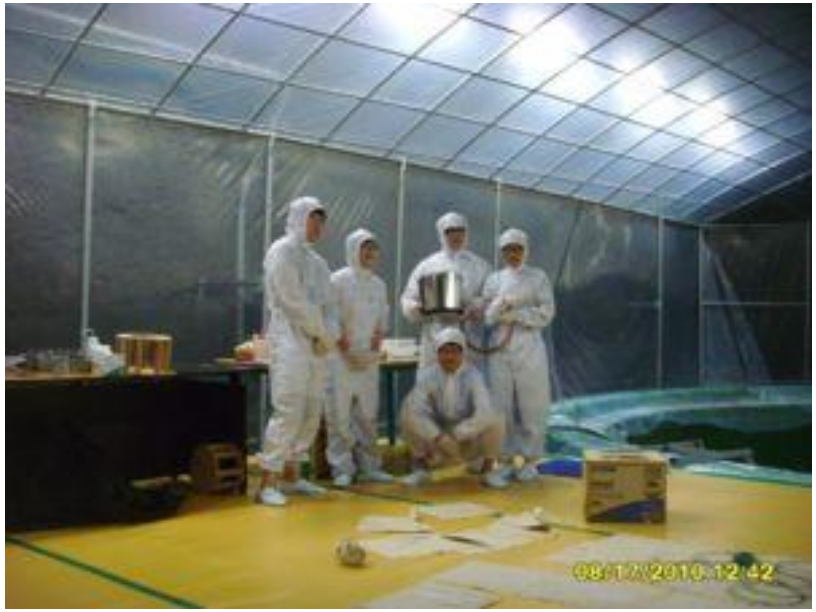
Summary of Detector Construction

- 2006. 03 : Start of the RENO project
- 2008. 06 ~ 2009. 03 : Civil construction including tunnel excavation
- 2008. 12 ~ 2009. 11 : Detector structure & buffer steel tanks completed
- 2010. 06 : Acrylic containers installed
- 2010. 06 ~ 2010. 12 : PMT test & installation
- 2011. 01 : Detector closing/ Electronics hut & control room built
- 2011. 02 : Installation of DAQ electronics and HV & cabling
- 2011. 03 ~ 06 : Dry run & DAQ debugging
- 2011. 05 ~ 07 : Liquid scintillator production & filling
- 2011. 07 : Detector operation & commissioning
- 2011. 08 : Start data-taking

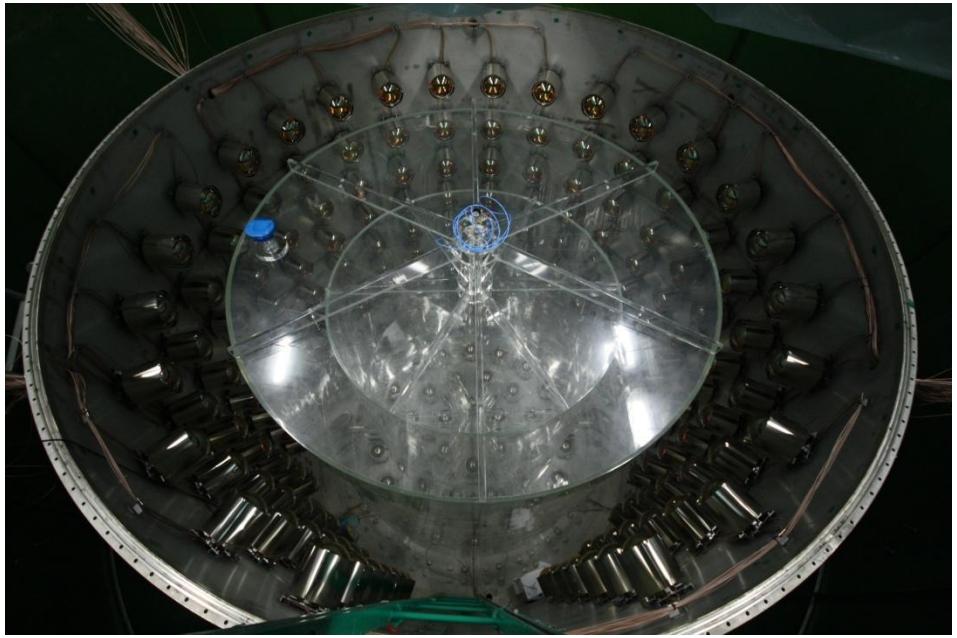
by KOATECH Co. Korea

(2009.7~2010.6)

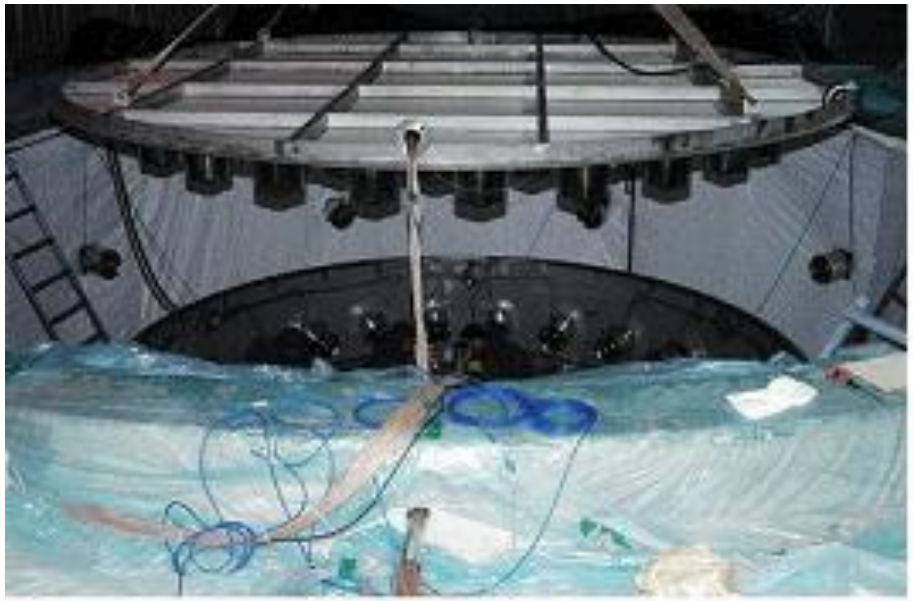
PMT Mounting (2010. 8~10)

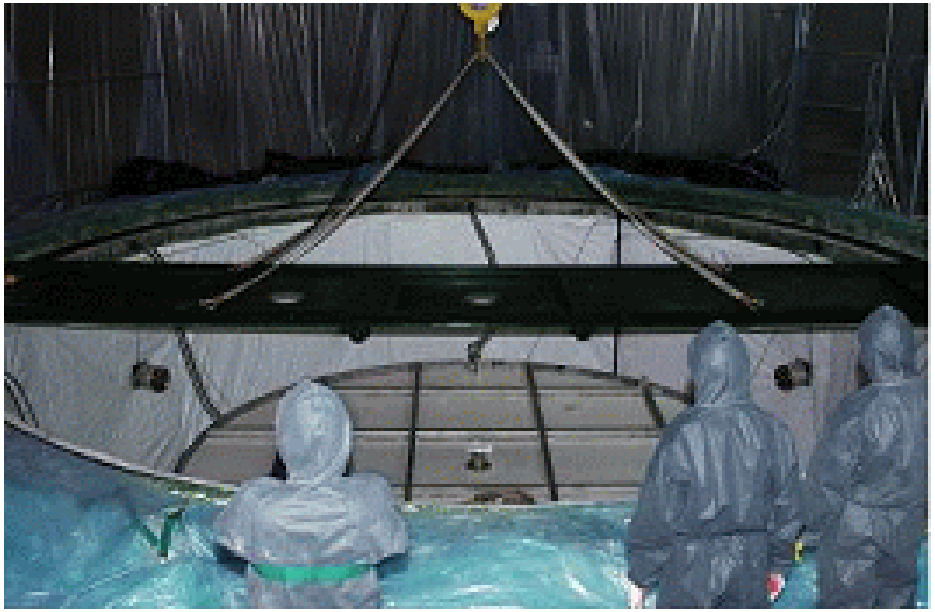


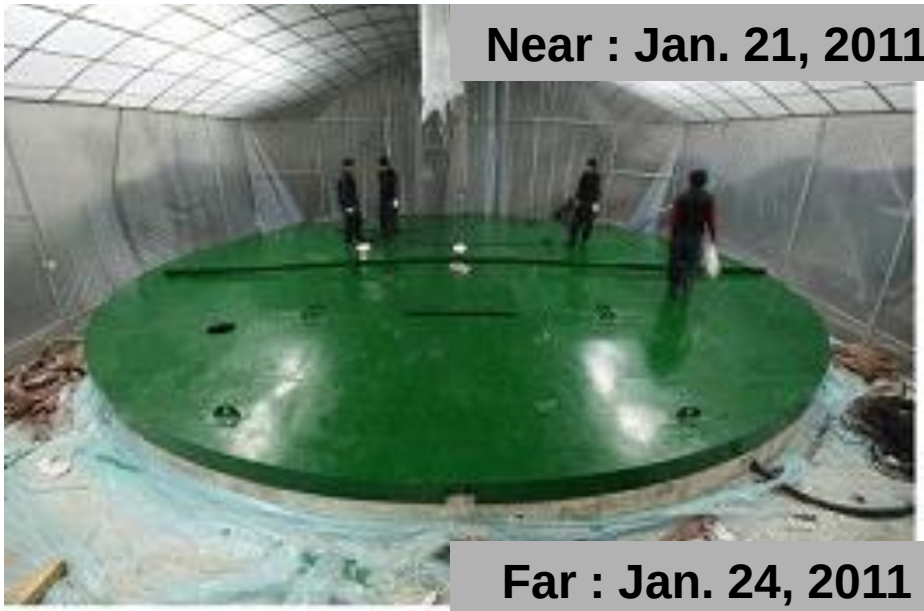
PMT Mounting (2010. 8~10)



Detector Closing (2011. 1)



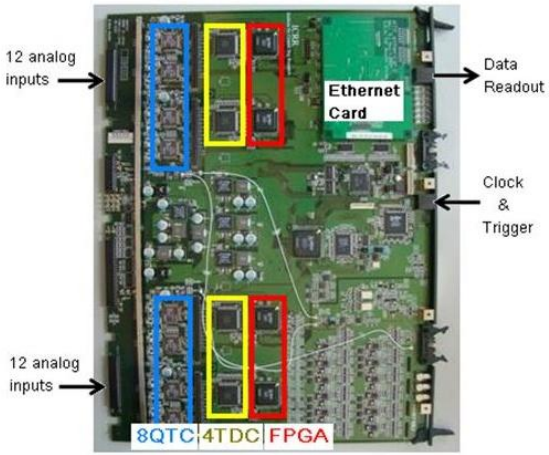




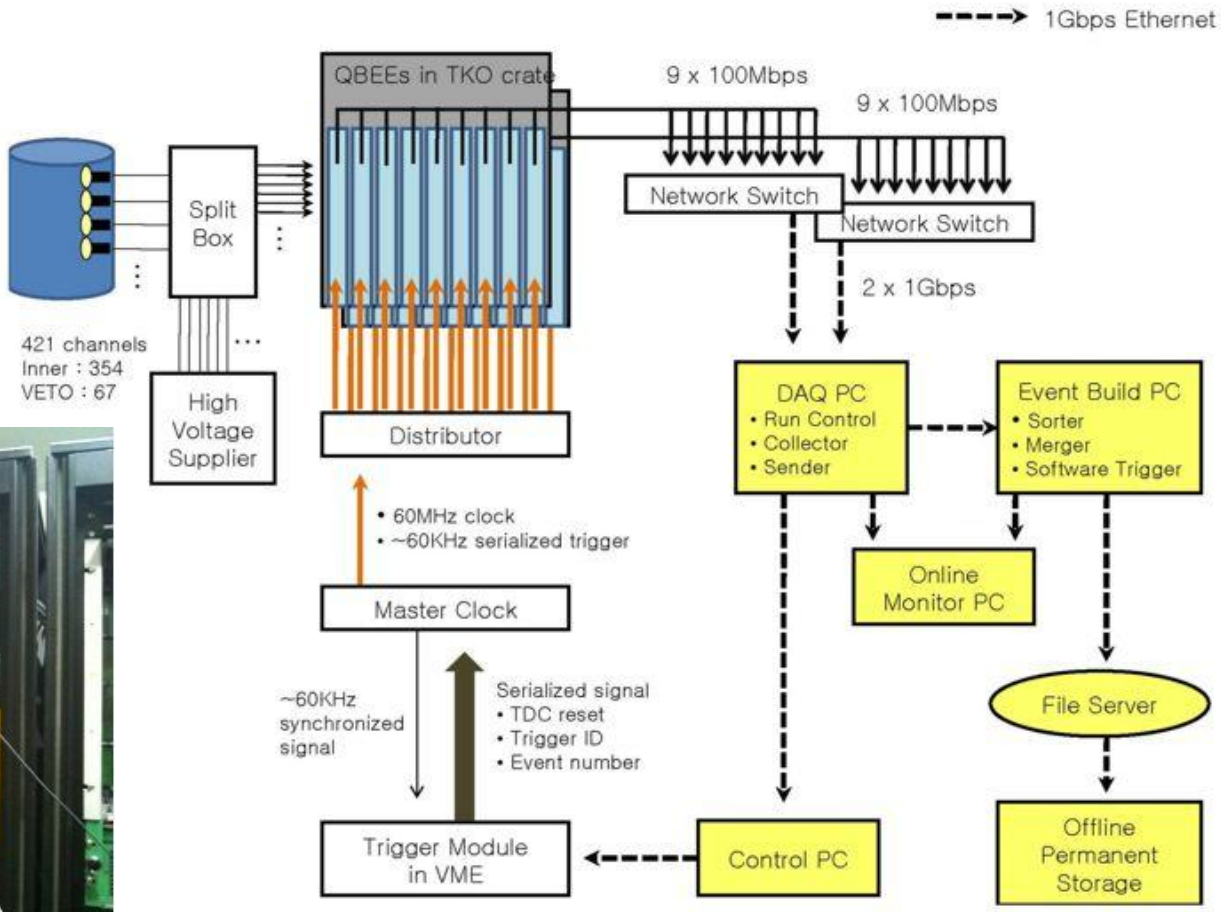
Near : Jan. 21, 2011

Far : Jan. 24, 2011

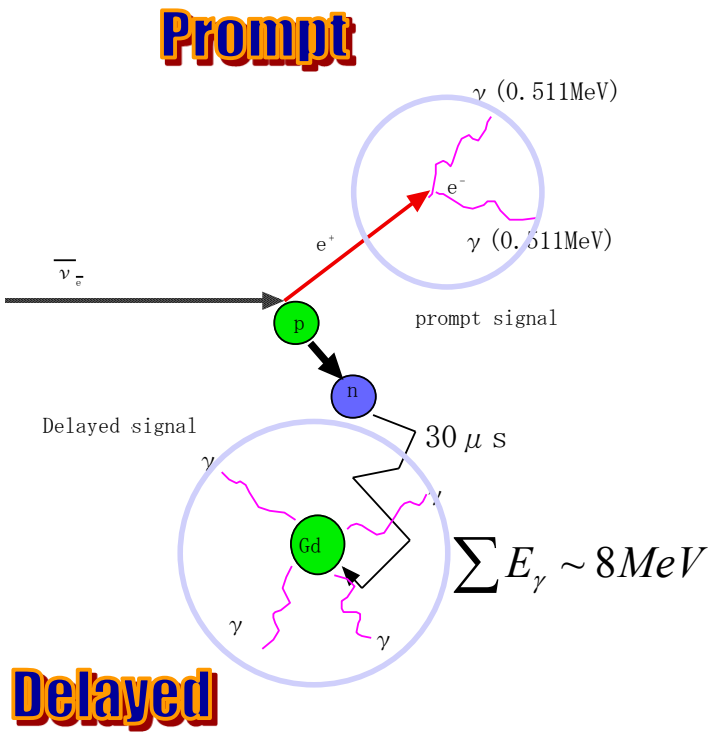
Data Acquisition System

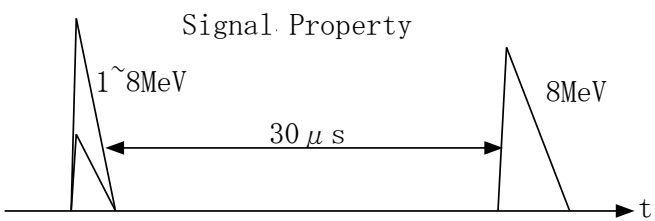


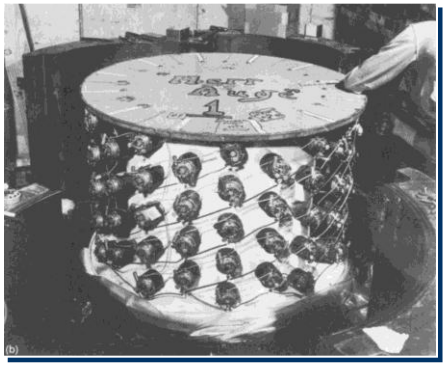
- 24 channel PMT input to ADC/TDC
- 0.1pC, 0.52nsec resolution
- ~2500pC/ch large dynamic range
- No dead time (w/o hardware trigger)
- Fast data transfer via Ethernet R/W



Principle of Neutrino Detection



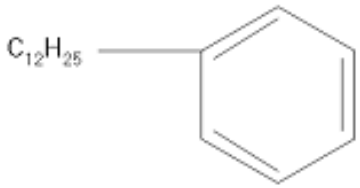




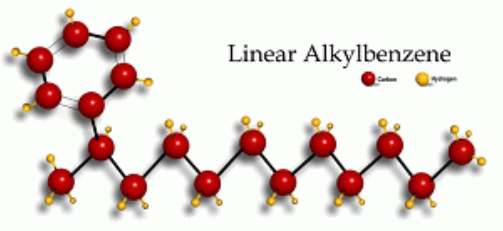
- Use inverse beta decay ($\bar{\nu}_e + p \rightarrow e^+ + n$) reaction process
- Prompt part:
  subsequent annihilation of the positron to two 0.511MeV γ
- Delayed part:
  neutron is captured
  ~200μs w/o Gd
  ~ 30μs w Gd
  Gd has largest n absorption cross section & emits high energy γ
- Signal from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

Gd Loaded Liquid Scintillator

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



Linear Alkyl Benzene (LAB)

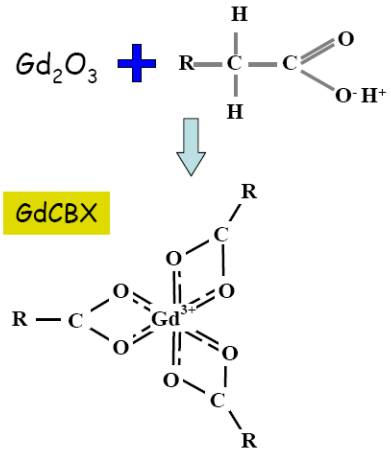


❑ Recipe of Liquid Scintillator

Aromatic Solvent & Flour	WLS	Gd-compound
LAB	PPO + Bis-MSB	0.1% Gd+TMHA (trimethylhexanoic acid)

- High Light Yield : not likely Mineral oil (MO)
- replace MO and even Pseudocume (PC)
- Good transparency (better than PC)
- High flash point : 147°C (PC : 48°C)
- Environmentally friendly (PC : toxic)
- Components well known (MO : not well known)
- Domestically available: Isu Chemical Ltd.

Carboxylic acids



❑ Solvent-solvent extraction method

$$RCOOH + NH_3 \cdot H_2O \rightarrow RCOONH_4 + H_2O$$
$$3RCOONH_4(aq) + GdCl_3(aq) \rightarrow Gd(RCOO)_3 + 3NH_4Cl$$

❑ 0.1% Gd compounds with CBX (Carboxylic acids; R-COOH)

- CBX : TMHA (trimethylhexanoic acid)

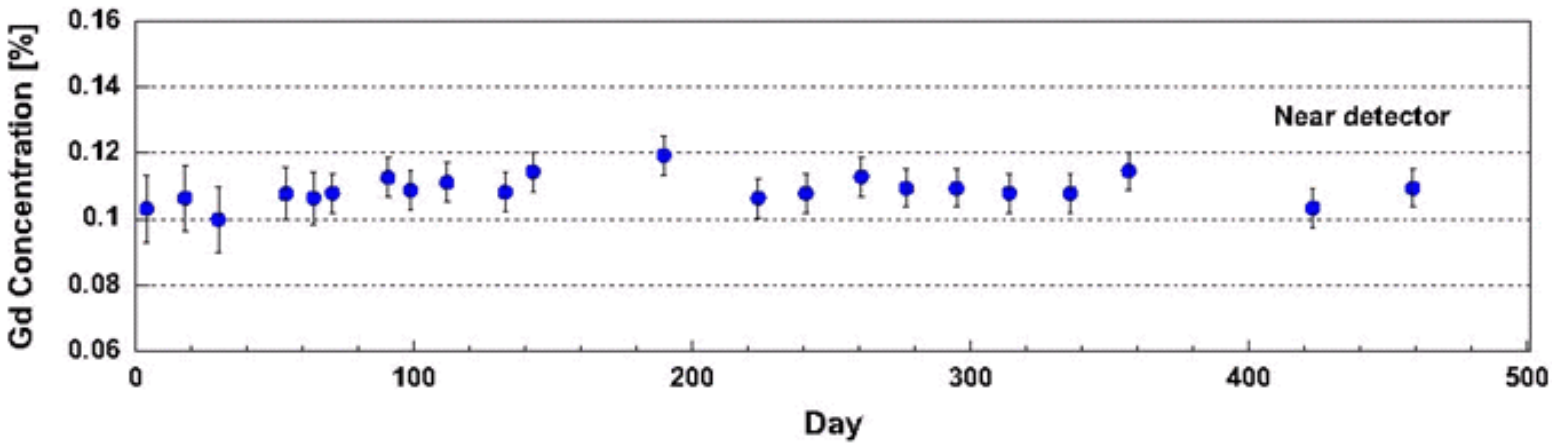
Liquid Production System (2010. 11~2011. 3)

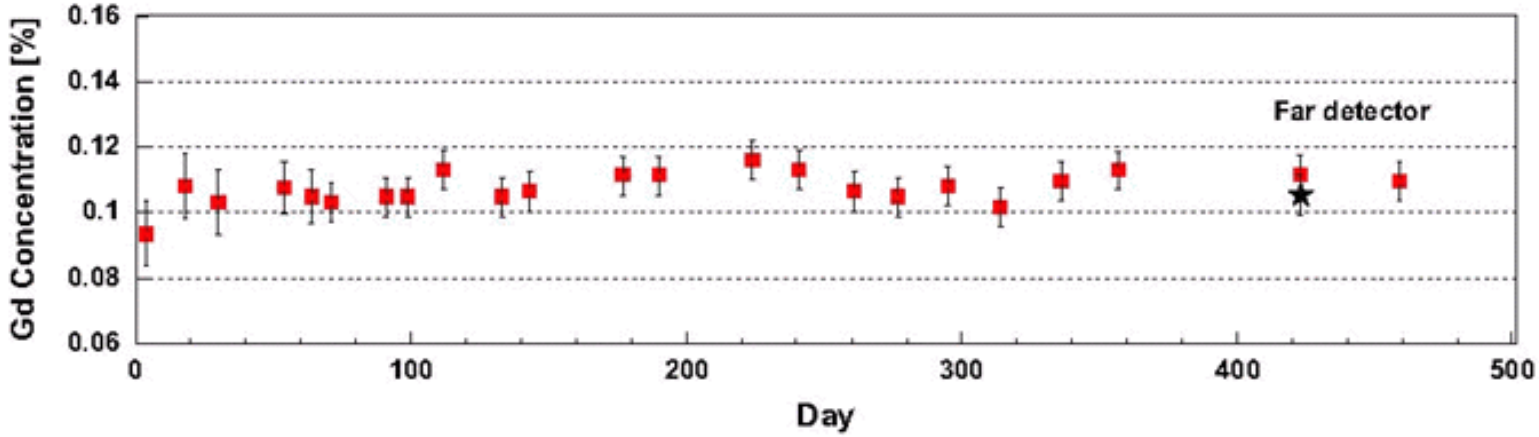
Stability of Gd Concentration

* Stable light yield : ~250 pe/MeV

* Stable Gd concentration (0.11%)

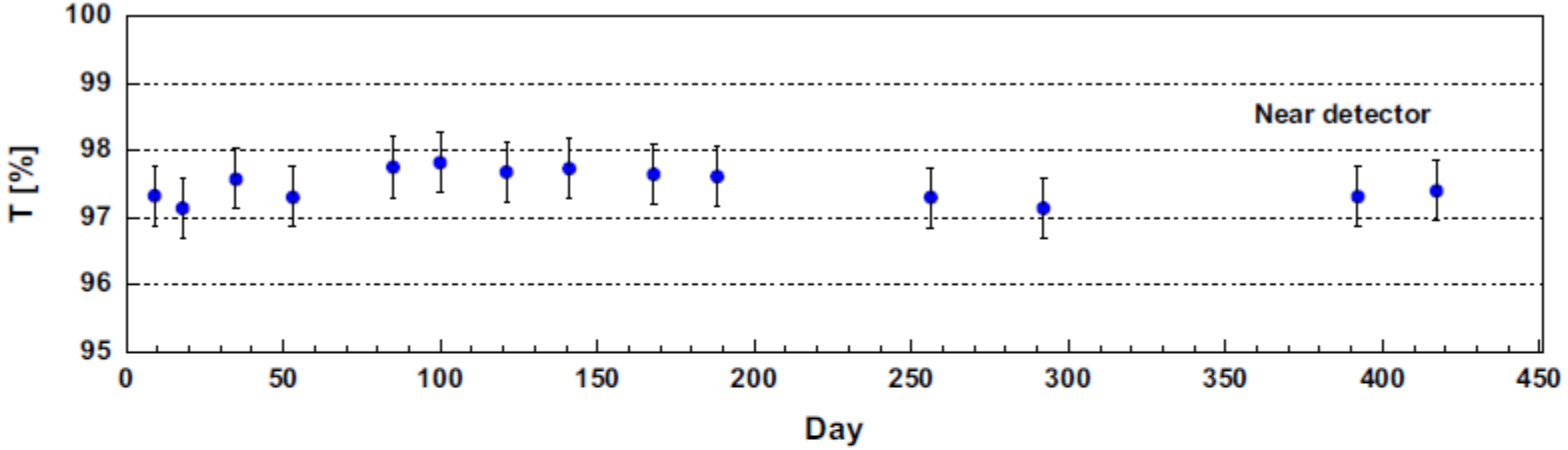
Nuclear Instruments and Methods in Physics Research A, 707, 45-53 (2013. 4. 11)

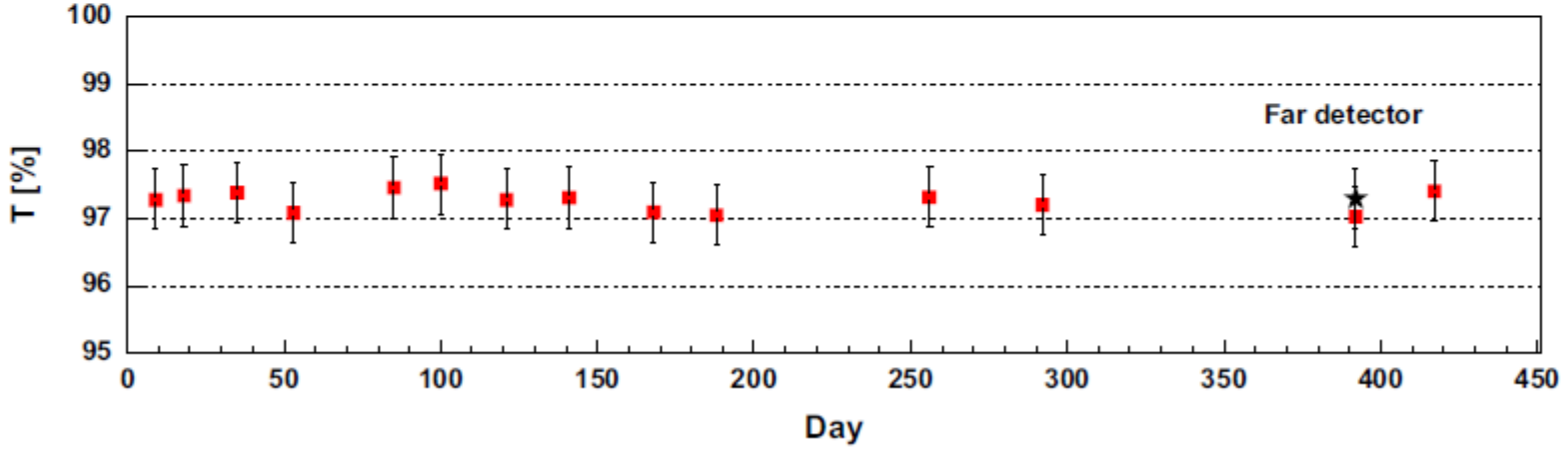




Stability of Transmittance [T]

* Shimadzu UV-1800 spectrophotometer



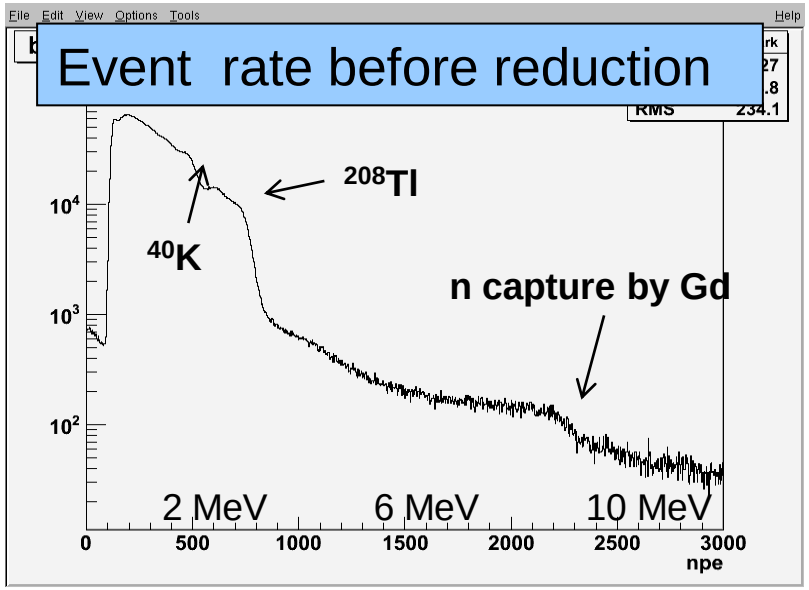


* Stable transparency at 430 nm

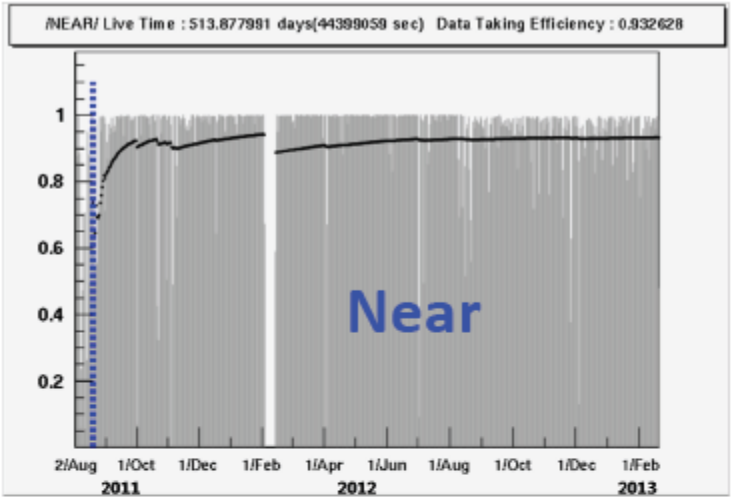
* Stable : ~450 days (2011.09 ~ present)

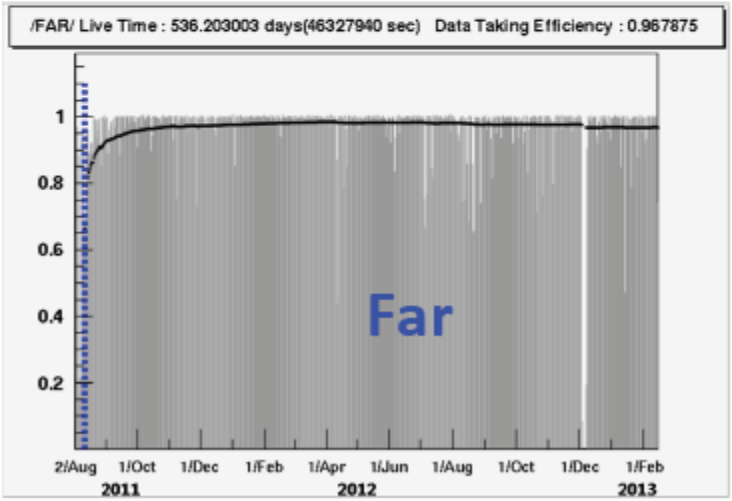
Data-Taking & Data Set

- Data taking began on Aug. 1, 2011 with both near and far detectors.
- Data-taking efficiency > 90%.
- Trigger rate at the threshold energy of 0.5~0.6 MeV : 80 Hz @ FD
- Data-taking period : > 510 days Aug. 11, 2011 ~ present



- Data-taking efficiency



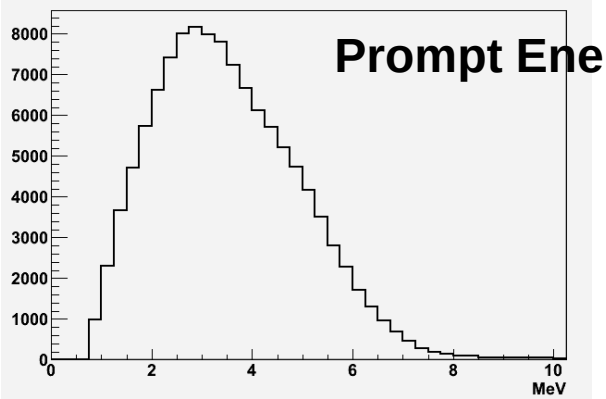


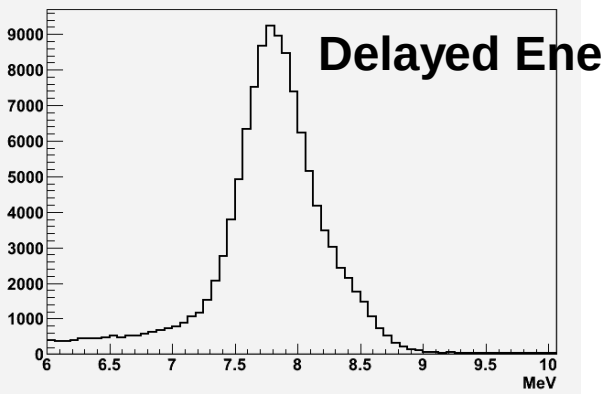
IBD Event Signature and Backgrounds

❑ IBD Event Signature

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

- 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





❑ Backgrounds

- Accidental backgrounds which mimic IBD Event
- ^{9}Li/^{8}He β-n followers produced by cosmic muon spallation
- Fast neutrons produced by muons, from surrounding rocks and inside detector (n scattering : prompt, n capture : delayed)

Improvements in Data Analysis

- Better estimation of Li/He background :

$$2.59 \pm 0.75 / day \rightarrow 3.61 \pm 0.60 / day \quad \text{(far)}$$

$$12.45 \pm 5.93 / day \rightarrow 13.73 \pm 2.13 / day \quad \text{(near)}$$

(more improvement soon on the errors…)

- Improved flasher removal : reduction of accidental background

- Reduction of fast neutron background :

$$0.97 \pm 0.06 / day \rightarrow 0.68 \pm 0.04 / day \quad \text{(far)}$$

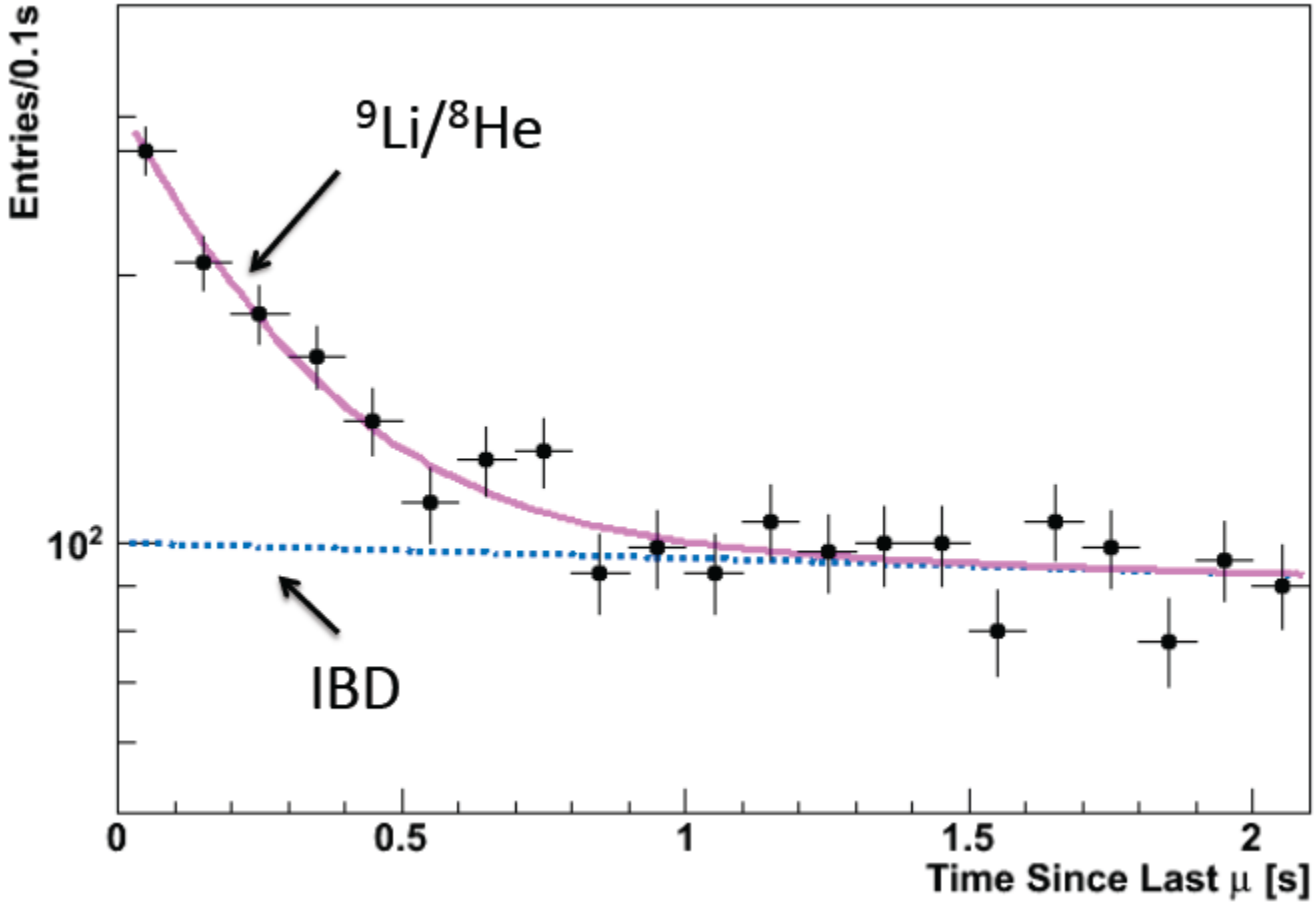
$$5.00 \pm 0.13 / day \rightarrow 3.14 \pm 0.09 / day \quad \text{(near)}$$

- Major efforts on energy calibration : accurate energy scale

- Selection of clean data sample

$^{9}Li/^{8}He$ β-n Backgrounds

$^{9}Li/^{8}He$ are unstable isotopes emitting (β,n) followers and produced when muon interact with carbon in the LS.



Flasher Characteristics

"Flasher PMT" event

Normal event

Anti-isolation variable R

$$R_n = \frac{\overline{n}_n}{n_{max}}$$

$$\overline{n}_n \equiv \frac{\sum n_i}{N_{nb}}$$

$\sum n_i$ ← Sum of NPEs in the neighbouring PMTs

N_{nb} ← Number of neighbouring PMTs

→ Smaller R value for flasher events.

Effectively we can remove sparking backgrounds

Cf Contamination

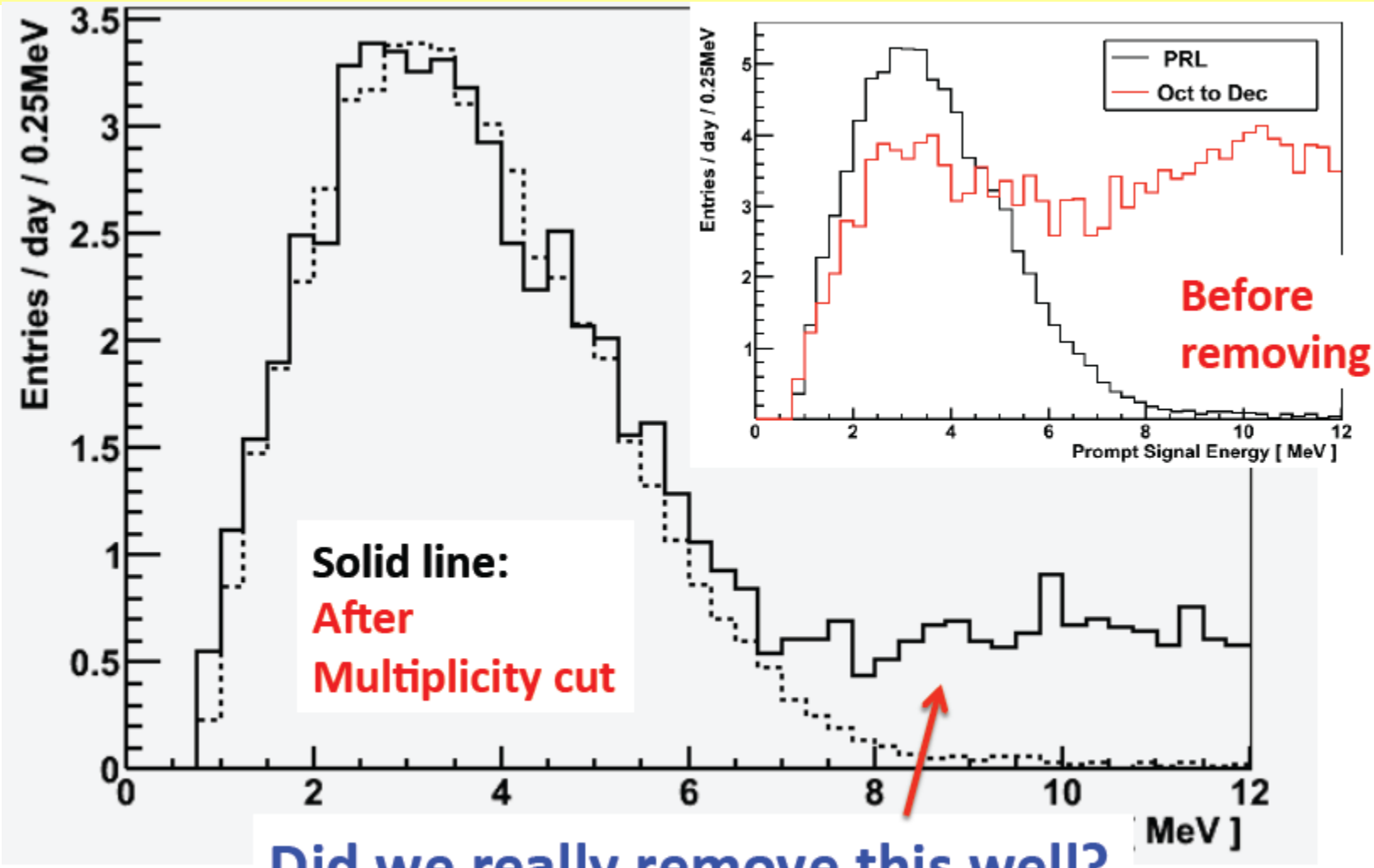
- Tiny fraction of Cf calibration source dissolved into Gd-LS after Oct. 13, 2012 :

  - Loose O-ring in the source container → LS into the container → Cf contamination on gloves and the container surface → dissolved into LS

  - Cf at the bottom of target (confirmed by event vertex)

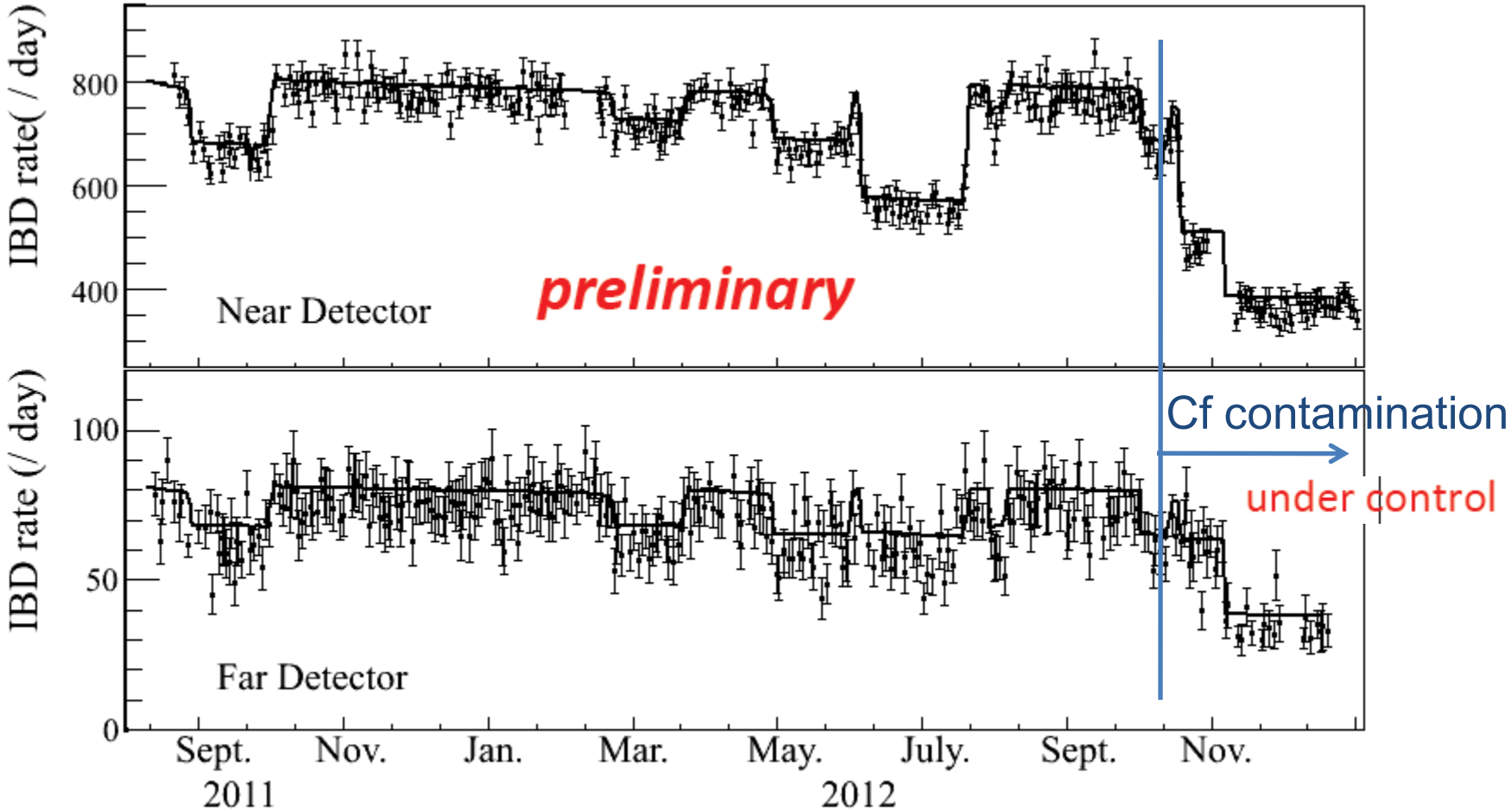
Cf Contamination

Most of Cf events were removed by a multiplicity cut and remained Cf events in IBD events were estimated by its energy shape.



Did we really remove this well?

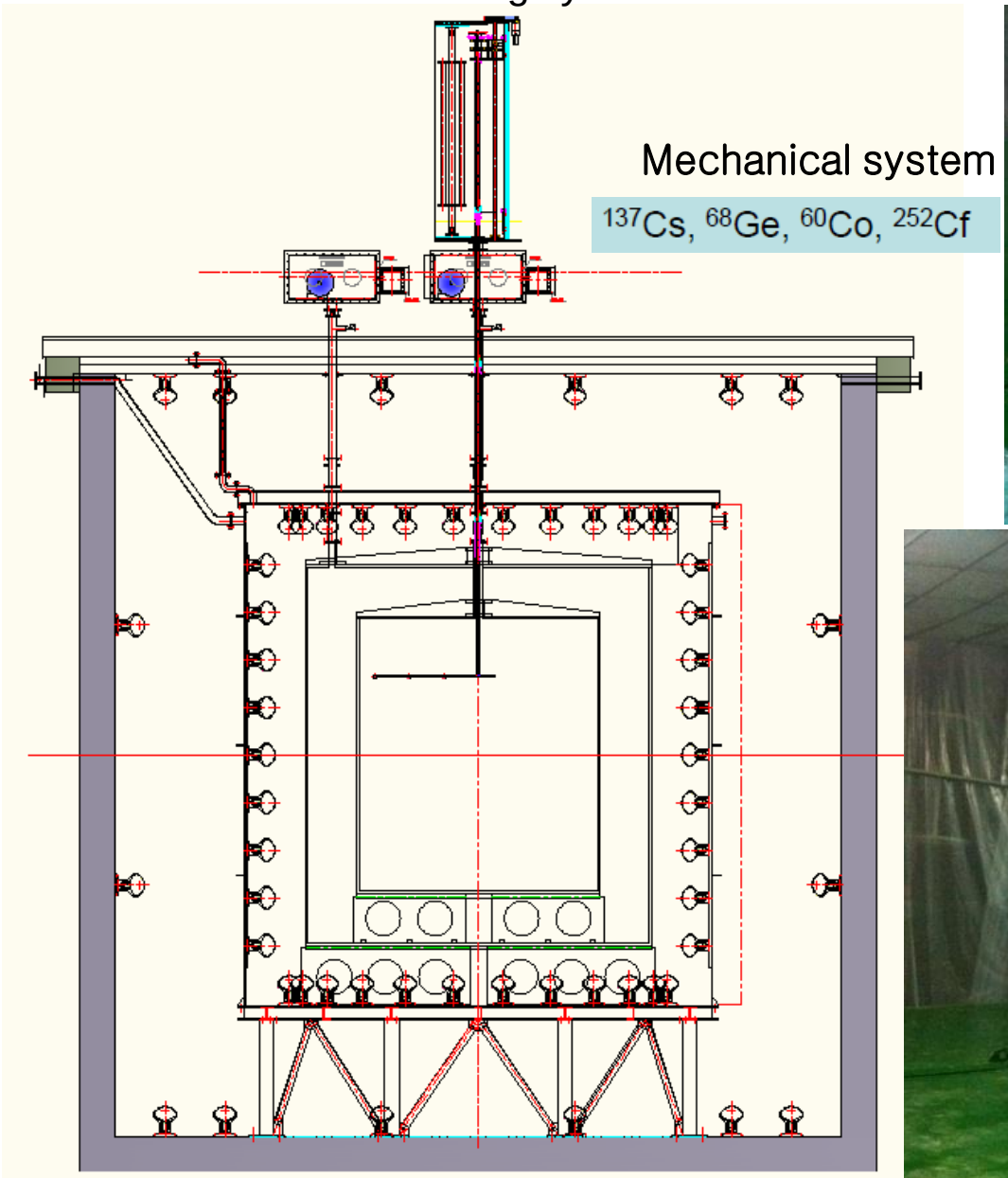
Observed Daily IBD Rate



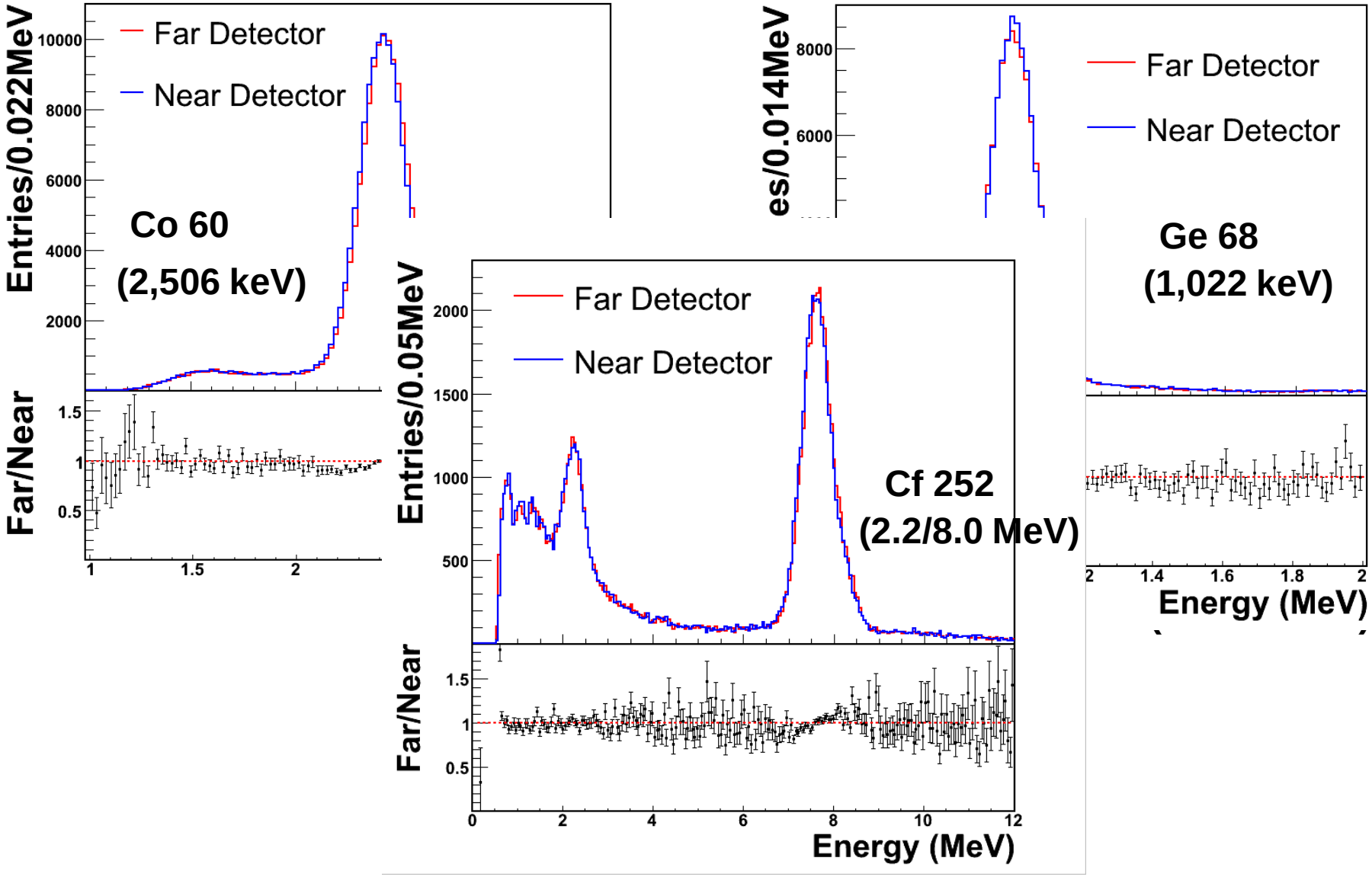
- Solid line is predicted rate from the neutrino flux calculation.
- Observed points have very good agreement with prediction.
- It's the accurate flux measurement.

1D/3D Calibration System (2010. 8 ~ 2011. 7)

Two identical source driving systems at the center of TARGET and one side of GAMMA CATCHER

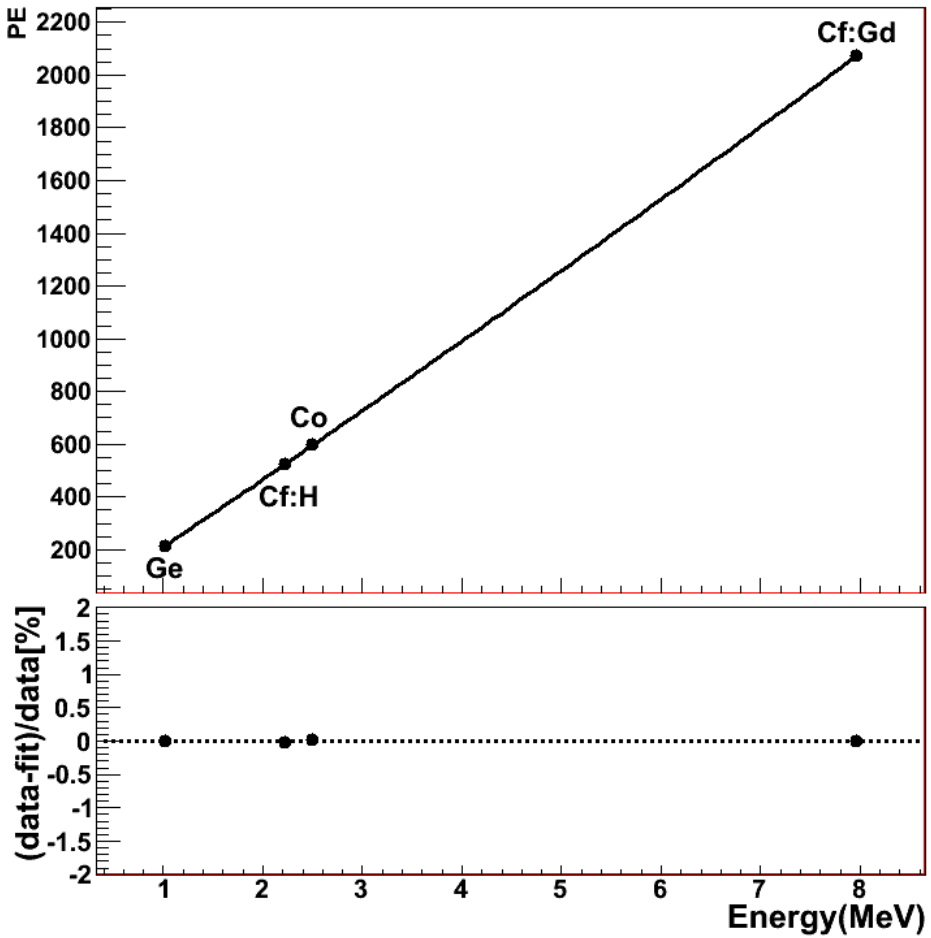


Energy Scale Calibration

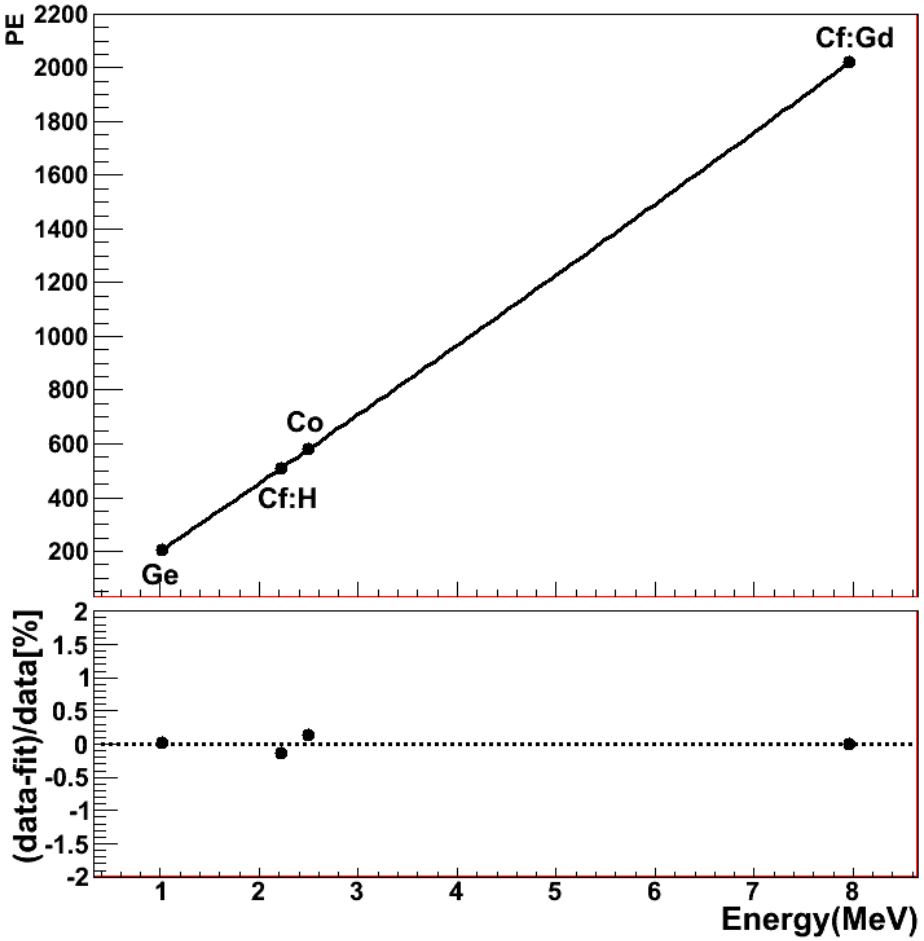


Energy Scale Calibration

Far Detector



Near Detector



IBD Event Selection

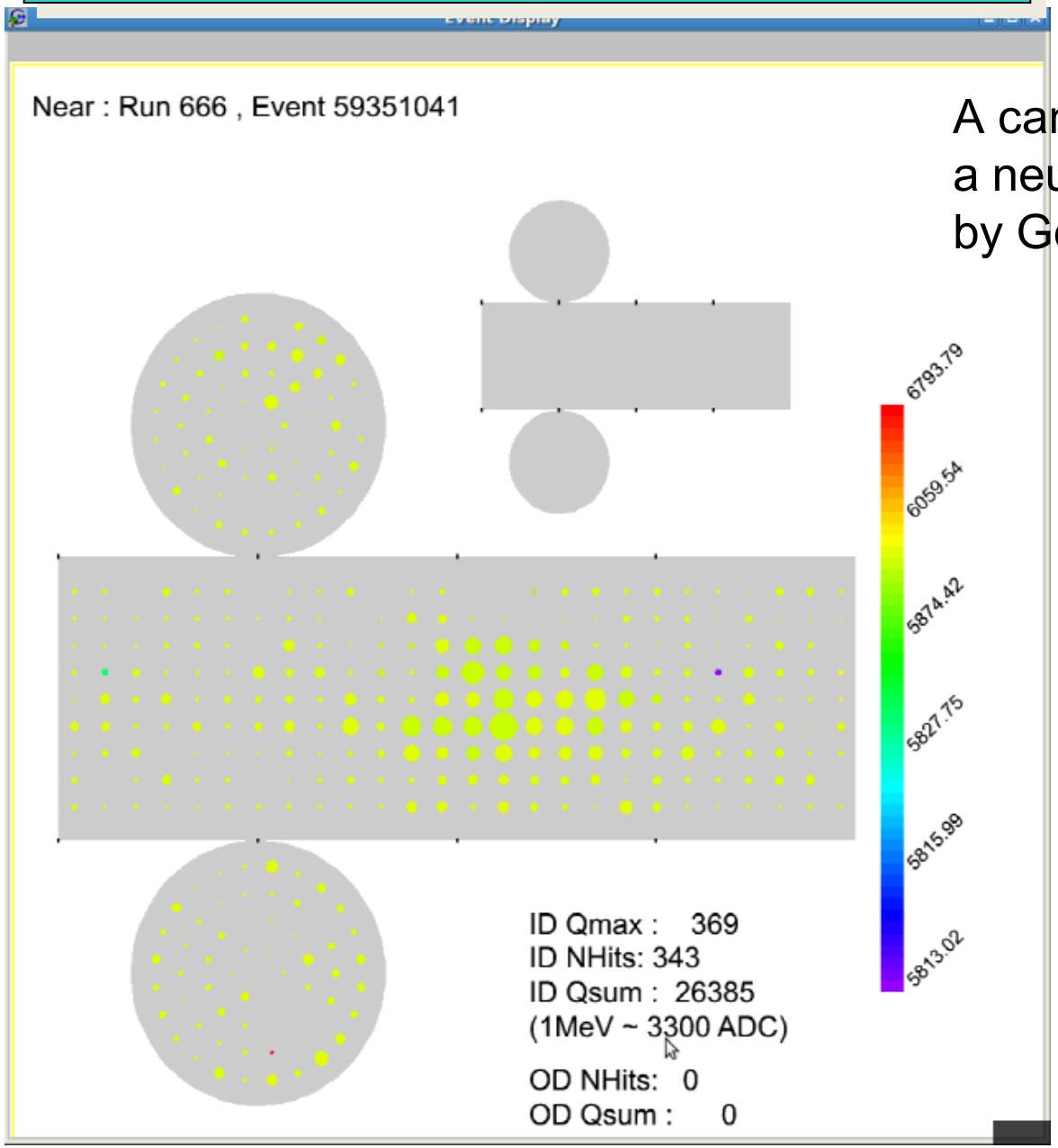
- Reject flashers and external gamma rays : $Q_{max}/Q_{tot} < 0.03$
- Muon veto cuts : reject events after the following muons

  (1) 1 ms after an ID muon with E > 70 MeV, or with 20 < E < 70 MeV and OD NHIT > 50

  (2) 10 ms after an ID muon with E > 1.5 GeV
- Coincidence between prompt and delayed signals in 100 μs

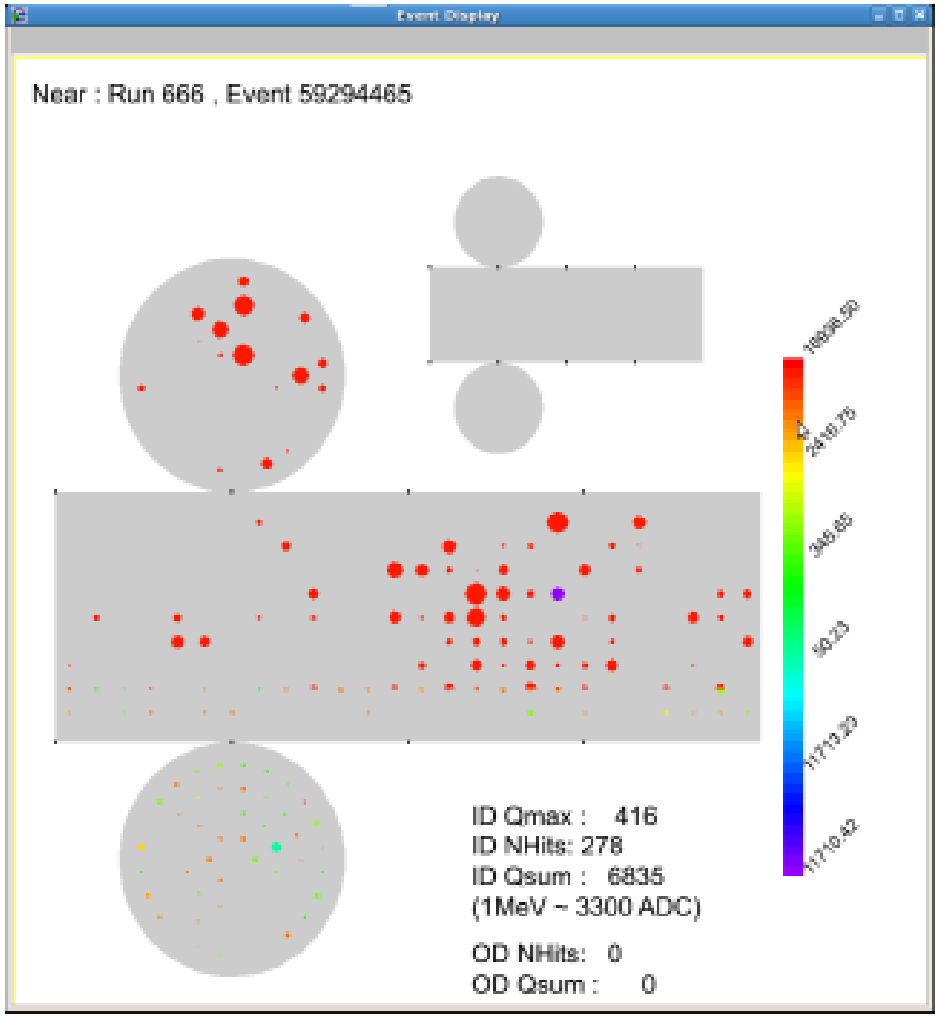
  - E_{prompt} : 0.7 ~ 12.0 MeV, $E_{delayed}$: 6.0 ~ 12.0 MeV
  - coincidence : 2 μs < Δt_{e+n} < 100 μs
- Multiplicity cut : reject pairs if there is a trigger in the preceding 100 ms window

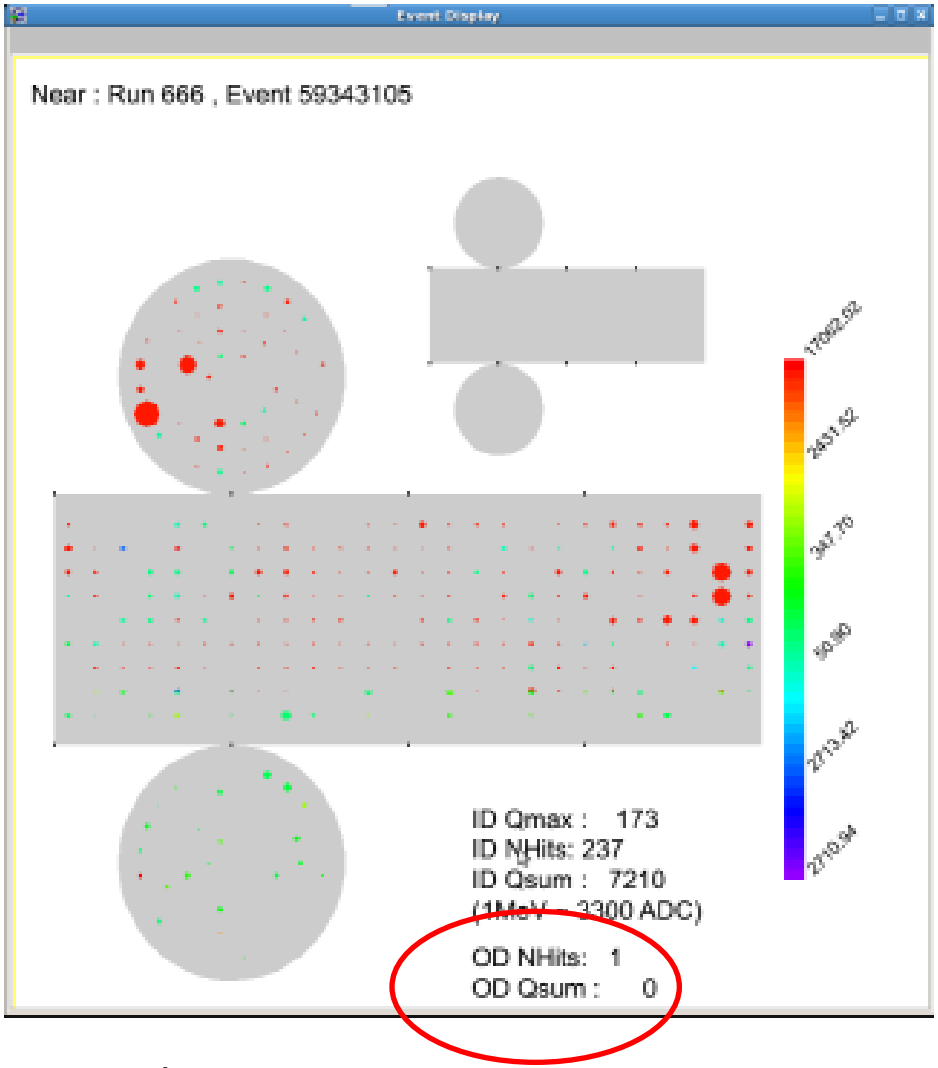
IBD Candidate Event



A candidate for
a neutron captured
by Gd

Background Events



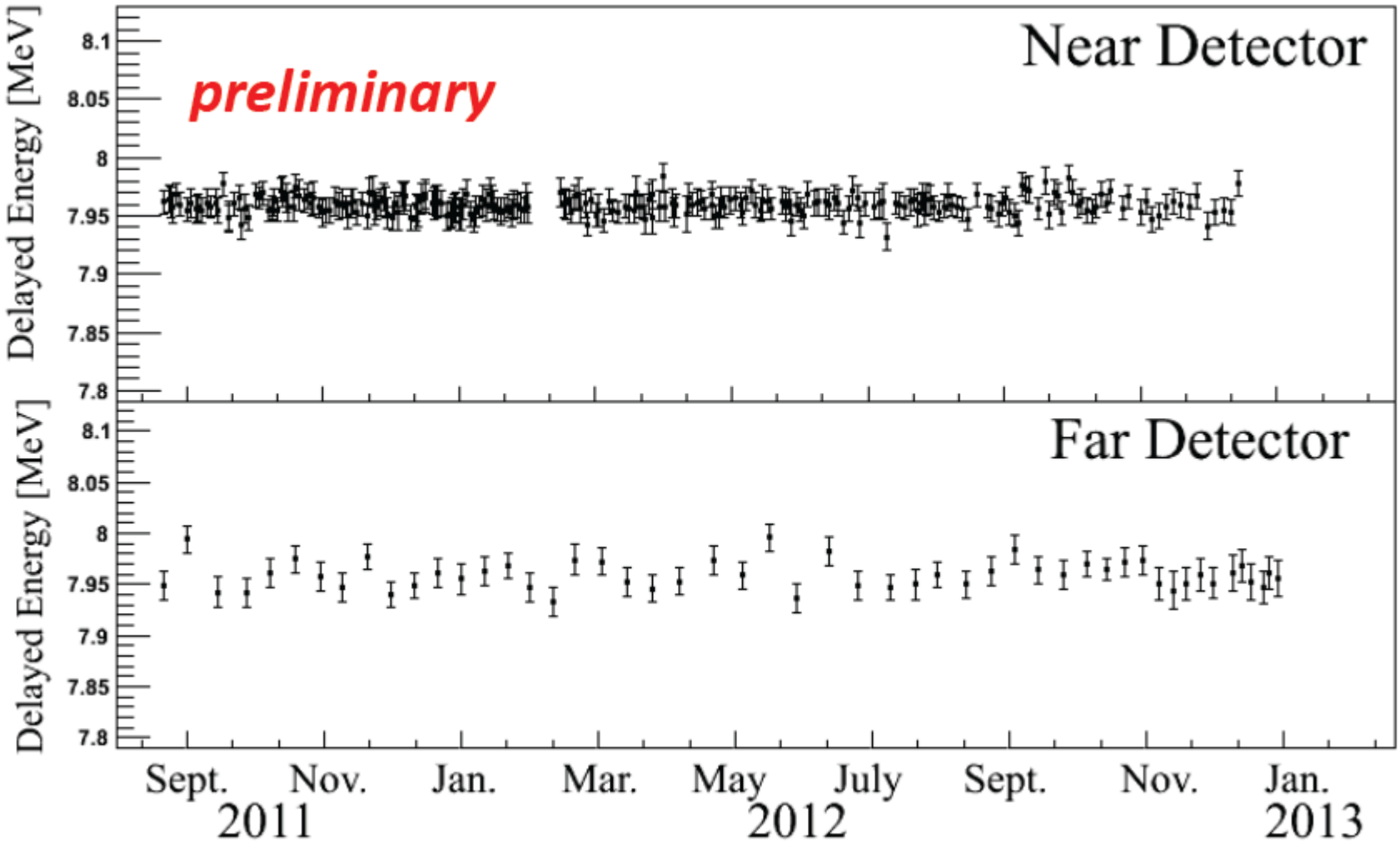


Event time (S1, S2) is not satisfied

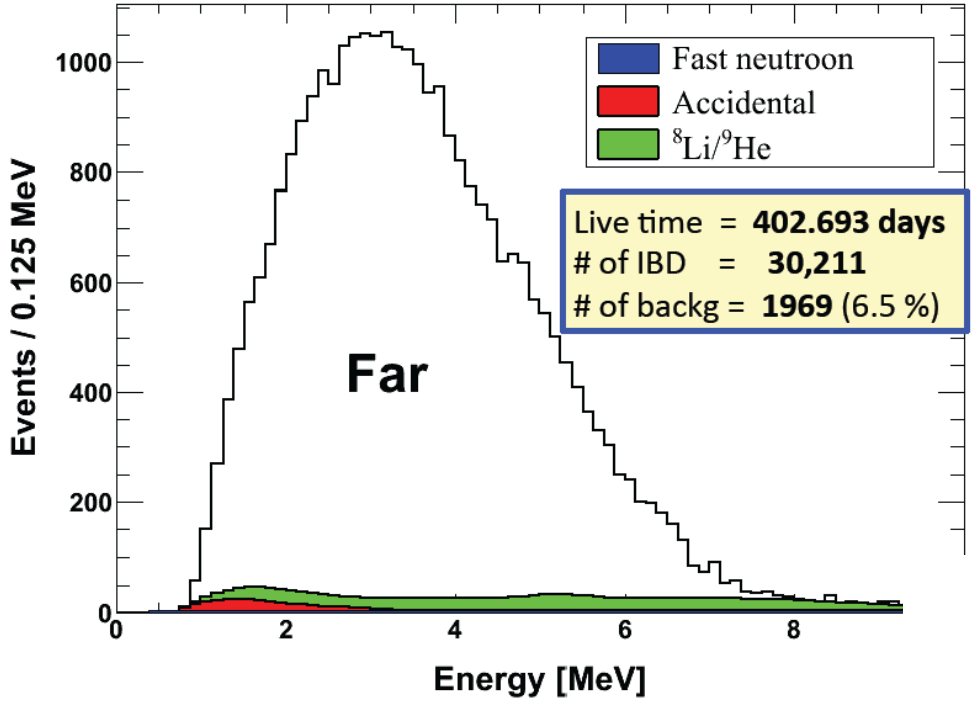
Veto hit exists

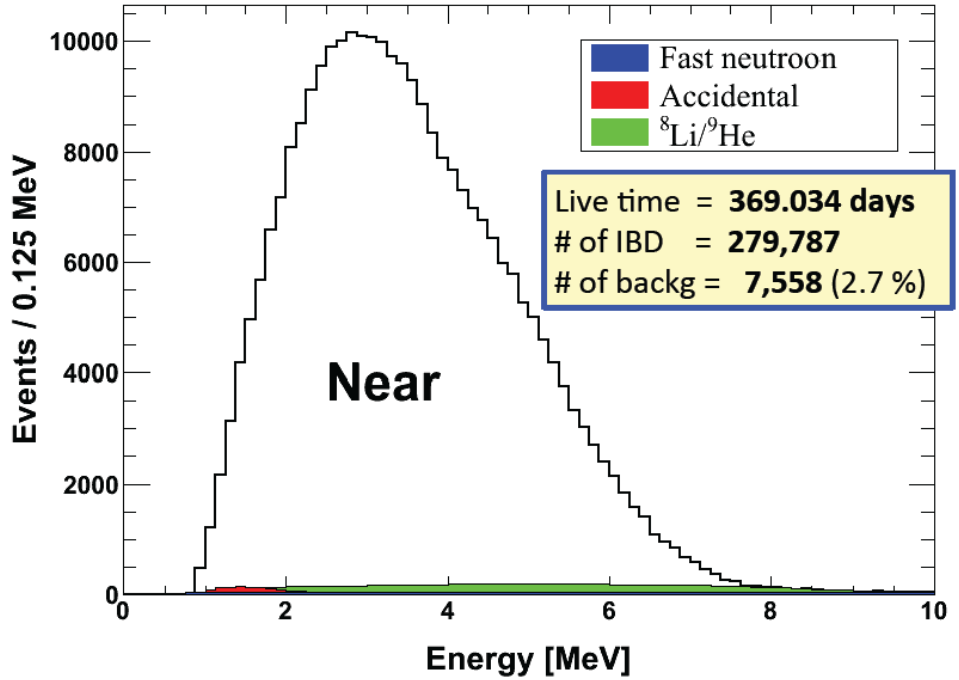
Detector Stability of Energy Scale

- IBD candidate's delayed signals (capture on Gd)



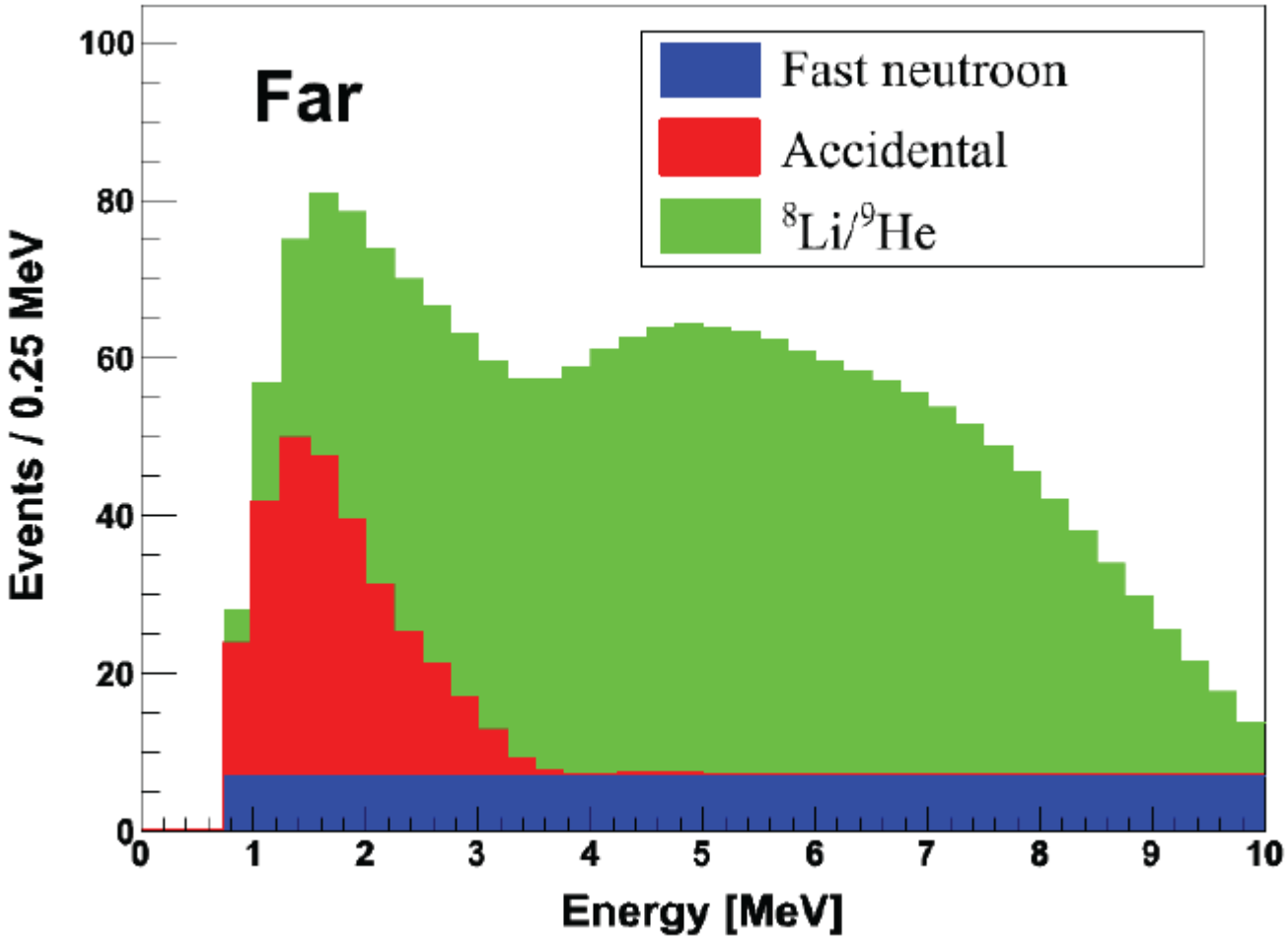
Measured Spectra of IBD Prompt Signal



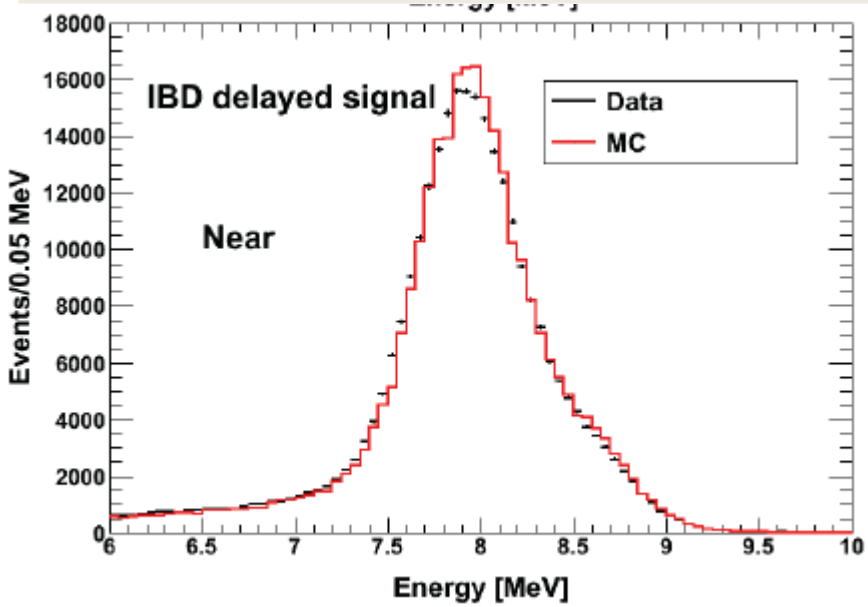


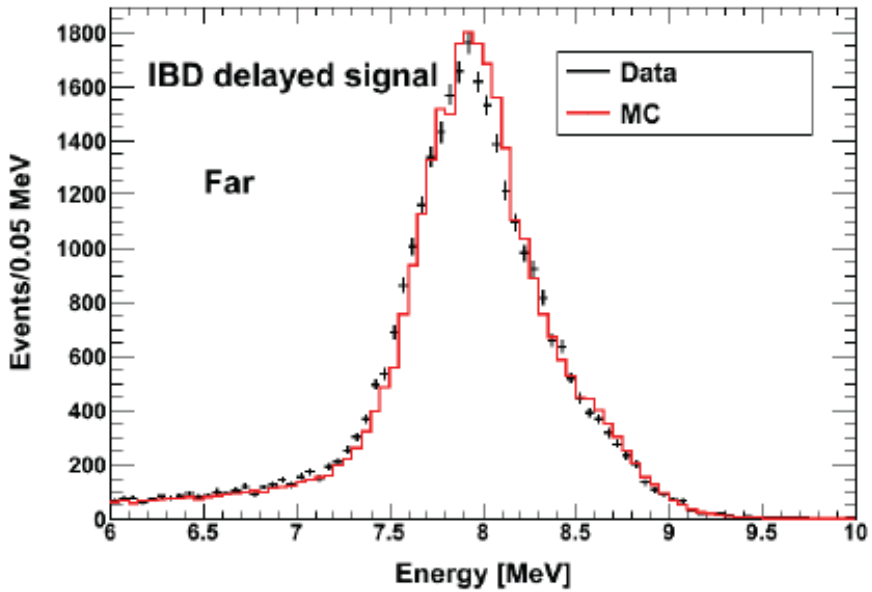
Backgrounds

- Backgrounds shape & rates are well understood
- Total 6.5% background at Far & 2.7% background at Near

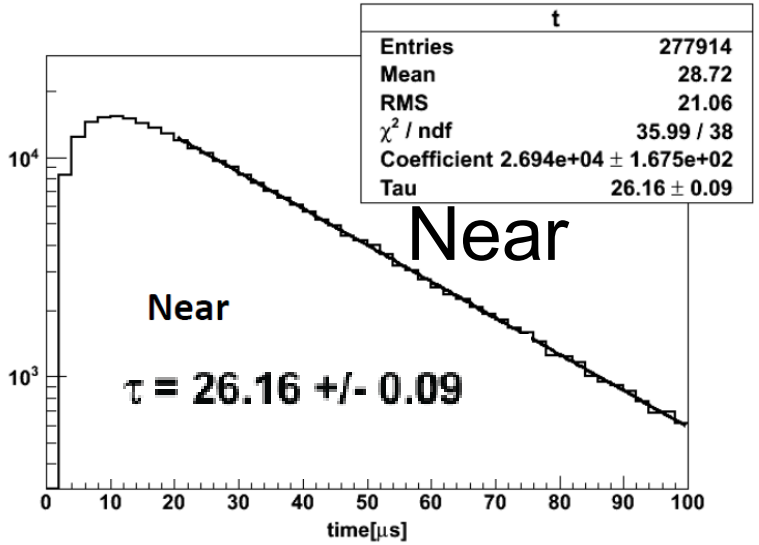


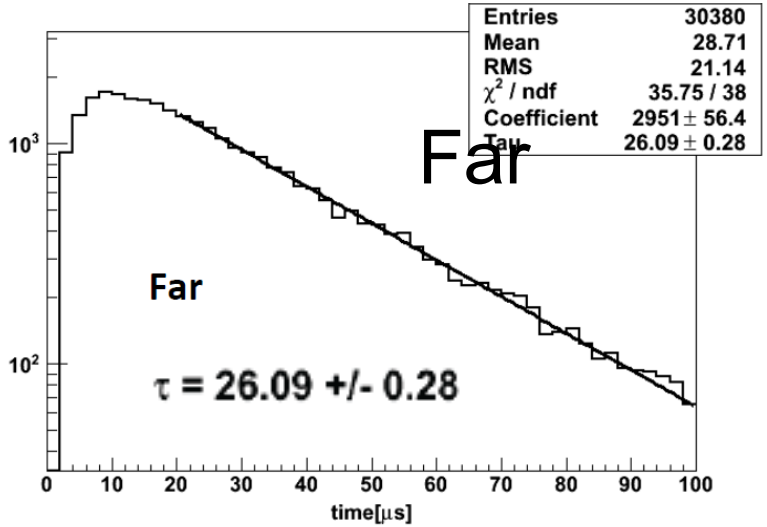
Spectra & Capture Time of Delayed Signals





Neutron Capture Time by Gd





New Results

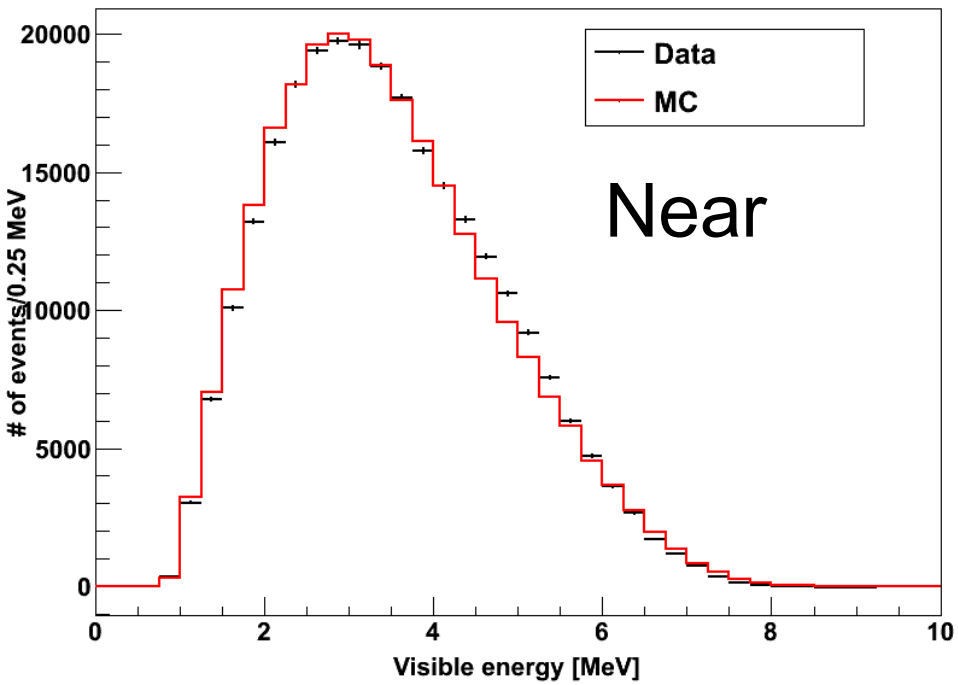
preliminary

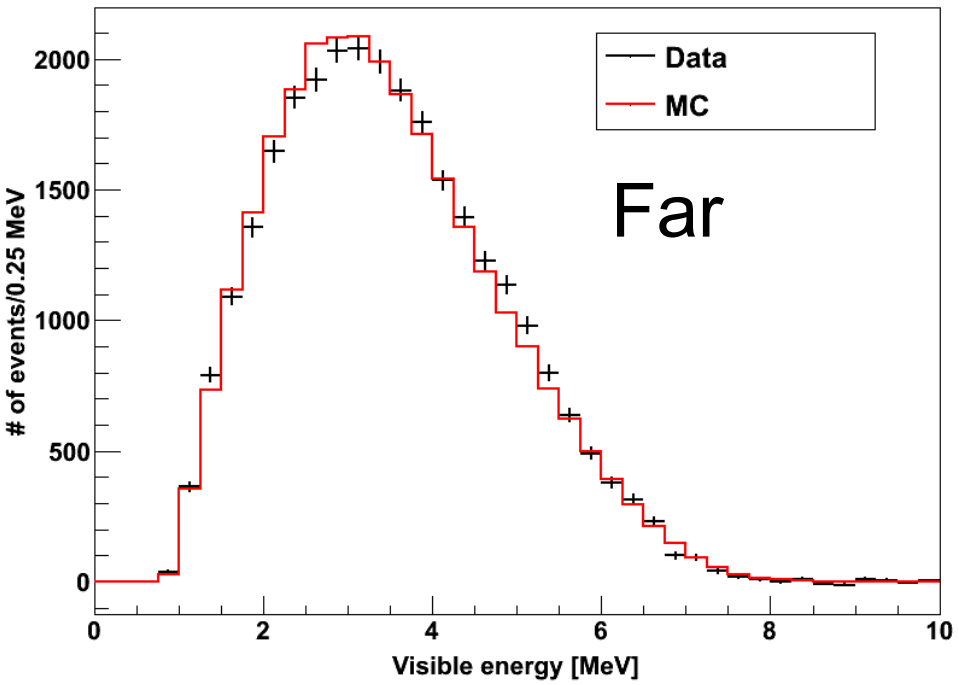
	Near (PRL)	Near (New)	Far (PRL)	Far (New)
# of IBD events	153,807	279,787	17,062	30,211
Total Background rate (/day)	21.73 +- 5.93	20.48 +- 2.13	4.3 +- 0.75	4.89 +- 0.60
Accidental backgr ound (/day)	4.30 +- 0.06	3.61 +- 0.05	0.68 +- 0.03	0.60 +- 0.03
Fast neutron backg round (/day)	4.98 +- 0.16	3.14 +- 0.09	1.03 +- 0.07	0.68 +- 0.04
Li/He background (/day)	12.45 +- 5.93	13.73 +- 2.13	2.59 +- 0.75	3.61+- 0.60
DAQ Live-time (days)	192.42	369.034	222.06	402.693
Detector efficiency (%)	64.7 +- 0.14	61.99 %	74.5 +- 0.14	71.37 %

Observed Spectra for Prompt Signal (e^+)

Neutrino energy measurement

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

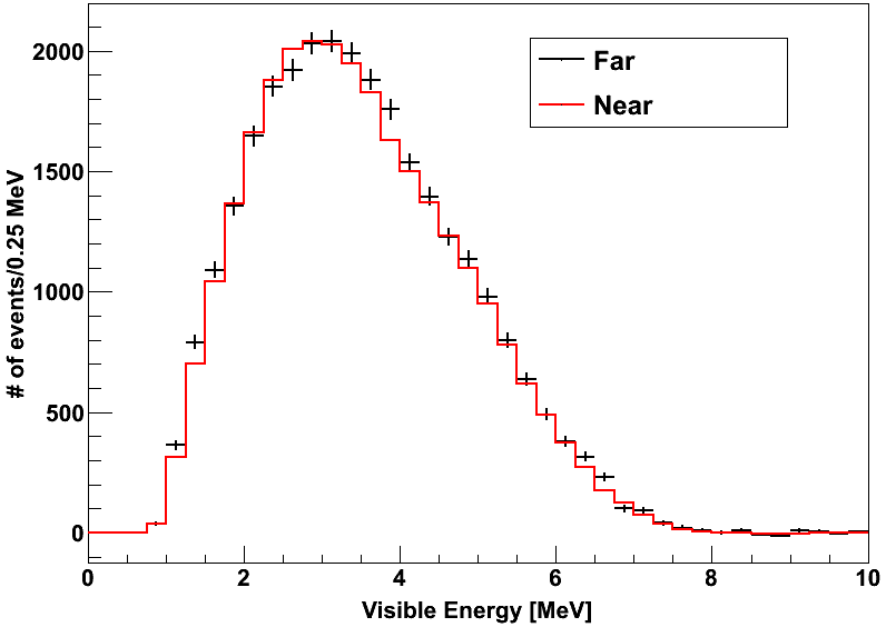


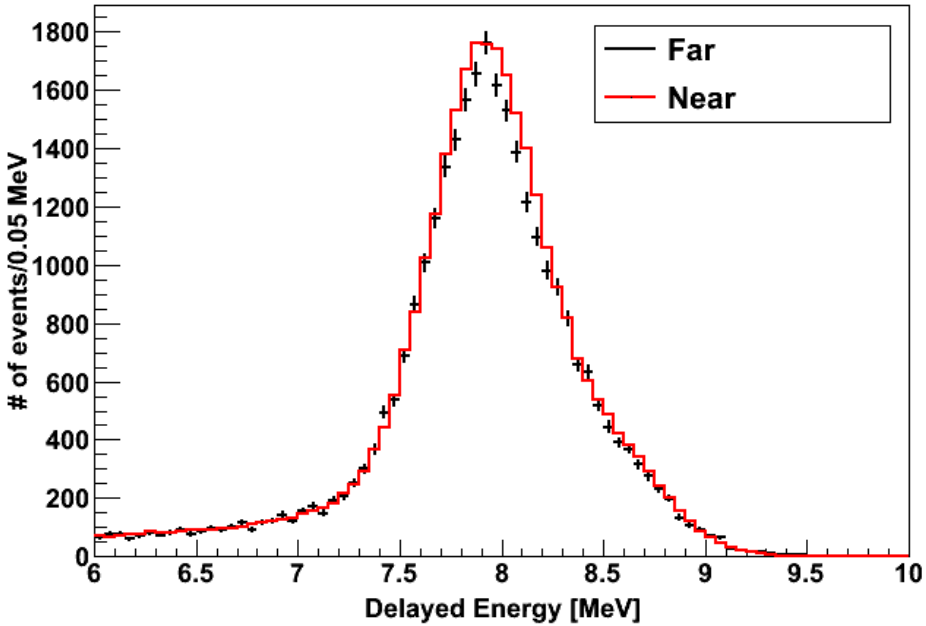


Data & MC match very well !

Comparison of Observed Spectra

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





Finally, we can compare the number of reactor anti-neutrino events observed in our detector with the expectation from the reactor.

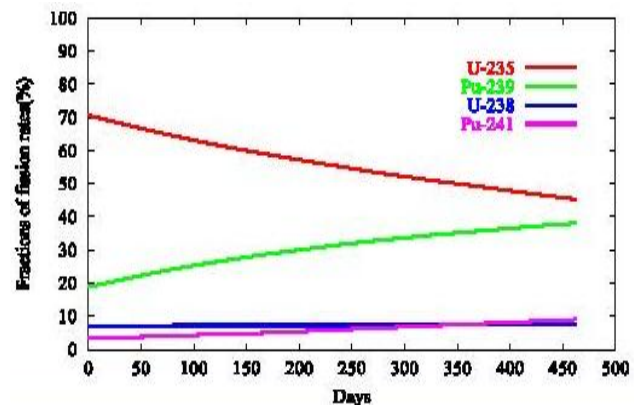
Expected Reactor Antineutrino Fluxes

- 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



Detection Efficiency & Systematic Uncertainties

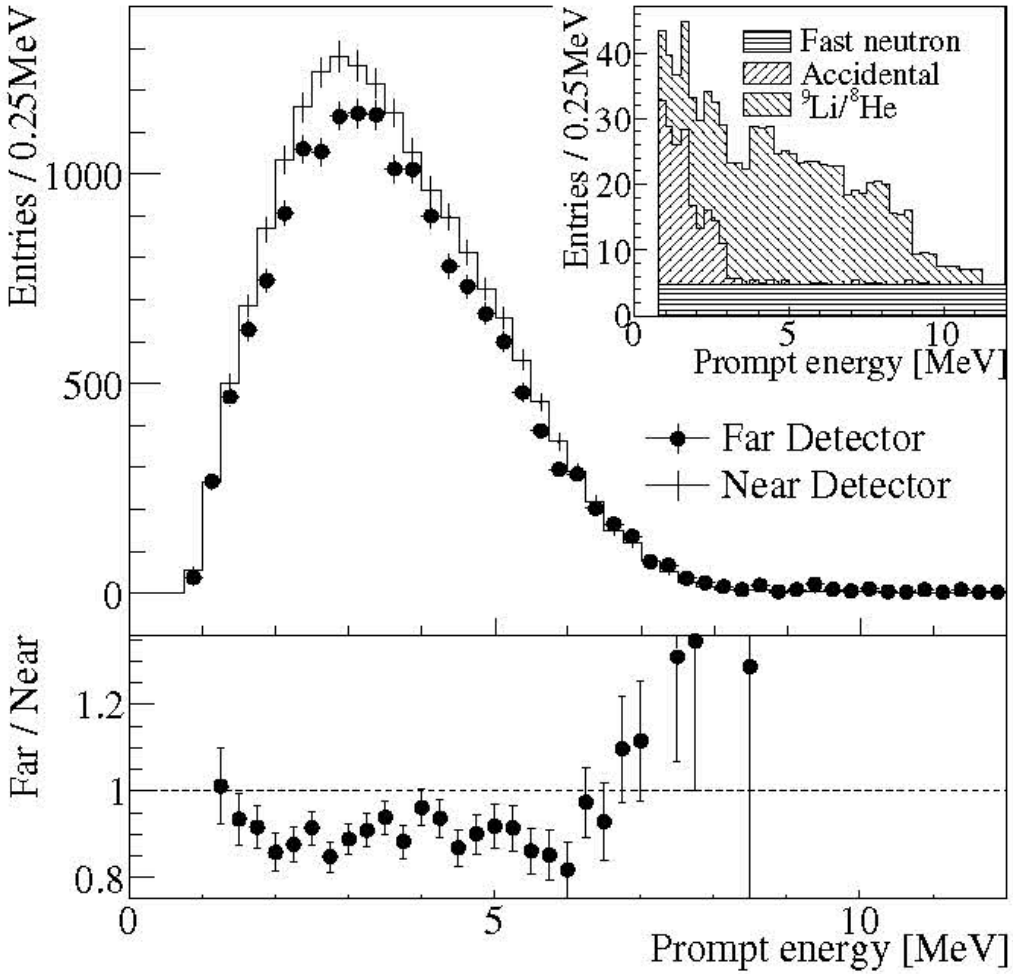
Criteria	Detection efficiency (%)
The fraction of neutron captures on Gd	86.52 ± 0.7
Flasher cut & Prompt energy cut	96.19 ± 0.11
The 6.0Me	95.22 ± 0.46
Time coin	
The spill-i	
Common	
Muon vet	
Multiplicit	
The total	

Reactor	Uncorrelated(%)	Correlated(%)
Thermal power	0.5	-
Fission fraction	0.7	-
Fission reaction cross section	-	1.9
Reference energy spectra	-	0.5
Energy per fission	-	0.2
Combined	0.9	2.0

Detection	Uncorrelated(%)	Correlated(%)
IBD cross section	-	0.2
Target protons	0.10	0.5
Prompt energy cut	0.01	0.1
Flasher cut	0.01	0.11
Gd capture ratio	0.10	0.7
Delayed energy cut	0.10	0.46
Time coincidence cut	0.01	0.44
Spill-in	0.08	0.71
Muon veto cut	0.02	0.02
Multiplicity cut	0.04	0.06
Combined	0.20	1.31

Reactor Antineutrino Disappearance

$$R = \frac{\Phi^{Far}_{observed}}{\Phi^{Far}_{expected}} = 0.929 \pm 0.006(stat.) \pm 0.009(syst.)$$

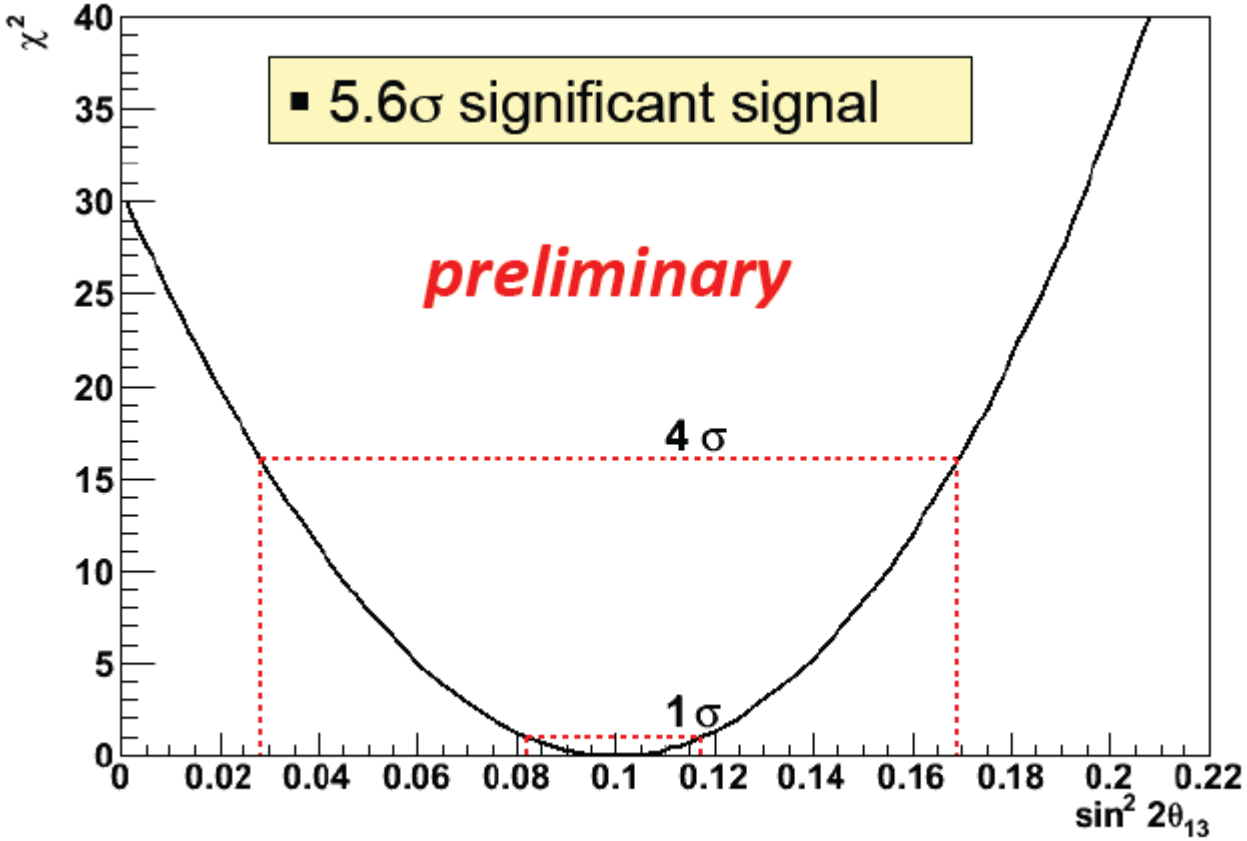


preliminary

- A clear deficit in rate (7.0% reduction)
- Consistent with neutrino oscillation in the spectral distortion

Definitive Measurement of θ_{13}

$$\sin^2 2\theta_{13} = 0.100 \pm 0.010(stat.) \pm 0.015(syst.)$$



Summary

- RENO was the first experiment to take data with both near and far detectors, from August 1, 2011.

- RENO has collected about 502 live days of neutrino data so far & improved systematic uncertainties and energy calibration

- RENO observed a clear disappearance of reactor antineutrinos.

$$R = 0.929 \pm 0.006(stat.) \pm 0.009(syst.)$$

- RENO measured the last, smallest mixing angle θ_{13}

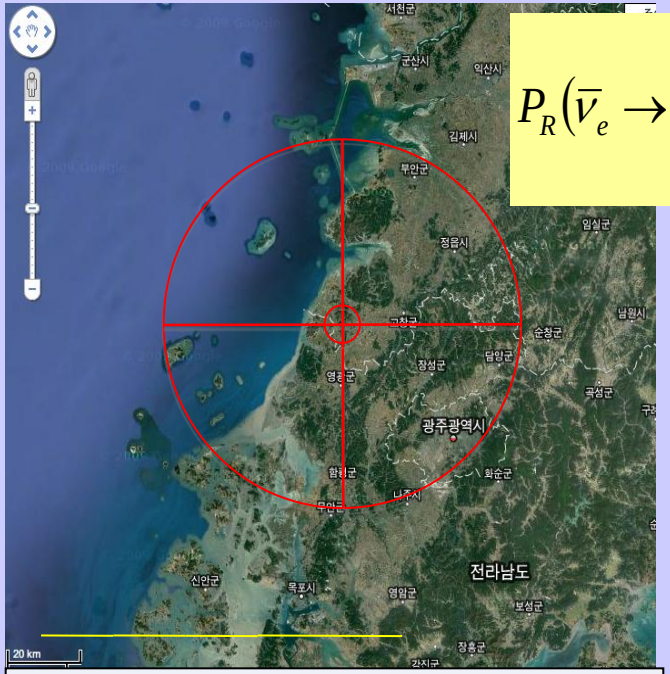
$$\sin^2 2\theta_{13} = 0.100 \pm 0.010(stat.) \pm 0.015(syst.)$$

- There is a room to improve sys. Error (to be improved soon)

RENO-50

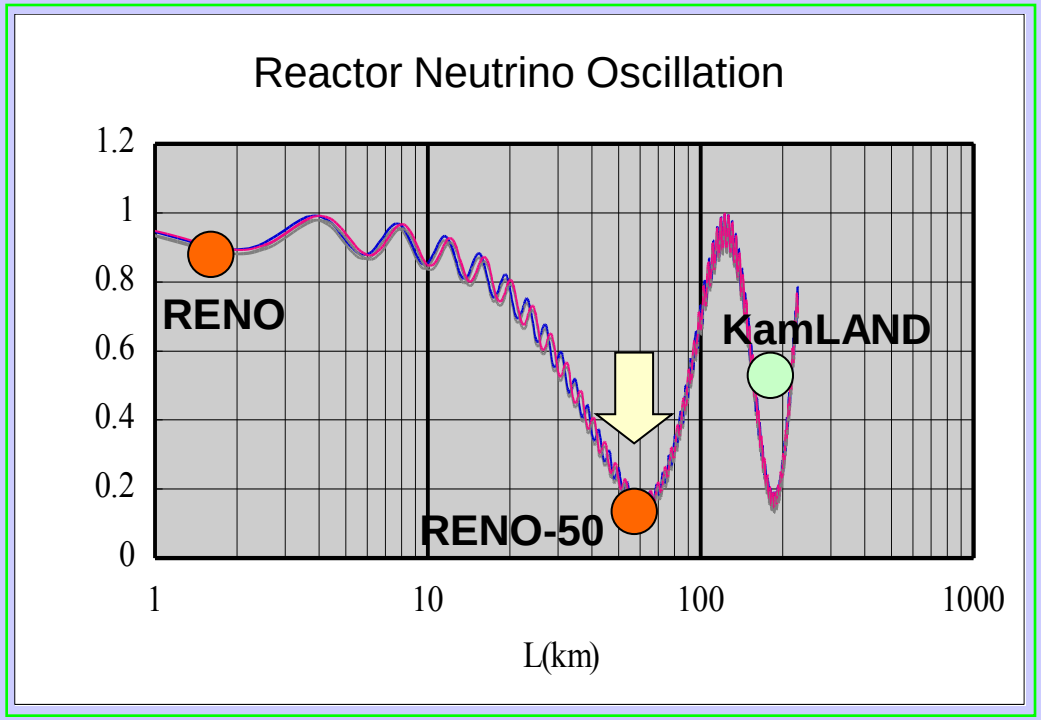
RENO-50

- Large θ_{12} neutrino oscillation effects at 50 km + 5kton liquid scintillator detector
- RENO can be used as near detectors. → Precise reactor neutrino fluxes
- Negligible contribution from other nuclear power plants.



$$P_R(\bar{\nu}_e \to \bar{\nu}_e) = 1 - \left\{ \begin{array}{l} \cos^4\theta_{13}\sin^2 2\theta_{12}\sin^2\Delta_{21} \\ +\sin^2 2\theta_{13}\sin^2\theta_{12}\left(\cos 2\Delta_{31}\sin^2\Delta_{21} - \frac{1}{2}\sin 2\Delta_{31}\sin 2\Delta_{21}\right) \end{array} \right\}$$

L~50km experiment could be a natural extension of current RENO θ_{13} experiment. (2018 ~)



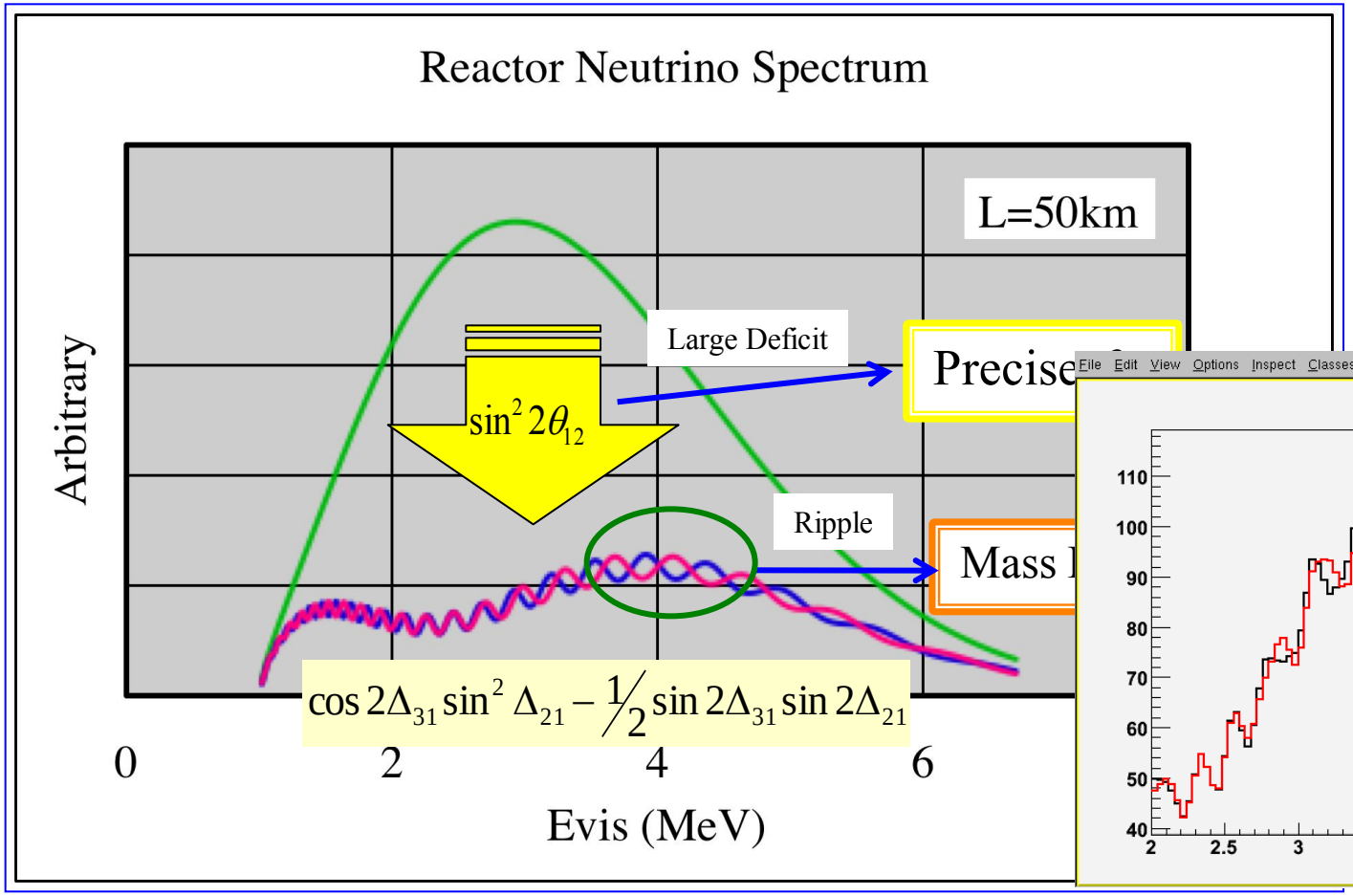
RENO-50 vs. KamLAND

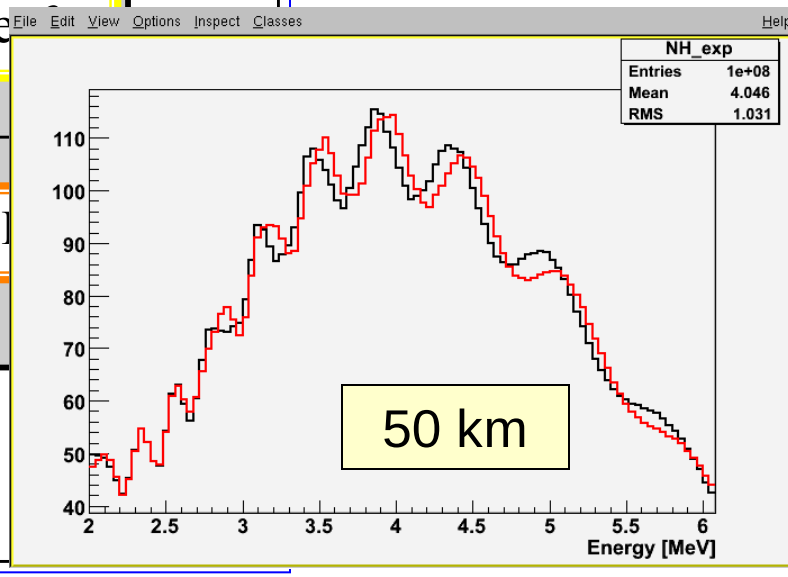
- RENO-50 is dedicated to the YG power plant. (negligible contribution from the other nuclear power plants)
- RENO can be used as near detectors.
- Precise reactor neutrino fluxes : systematic error from ~3% to ~0.1%

- KamLAND uses the entire Japanese nuclear power plants as a source.

1st Δm^2_{21} Maximum (L~50km) ; precise value of θ_{12} & Δm^2_{21} + mass hierarchy (Δm^2_{31})

$$P_R(\bar{\nu}_e \to \bar{\nu}_e) = 1 - \left\{ \begin{array}{l} \cos^4\theta_{13}\sin^2 2\theta_{12}\sin^2\Delta_{21} \\ +\sin^2 2\theta_{13}\sin^2\theta_{12}\left(\cos 2\Delta_{31}\sin^2\Delta_{21} - \tfrac{1}{2}\sin 2\Delta_{31}\sin 2\Delta_{21}\right) \end{array} \right\}$$

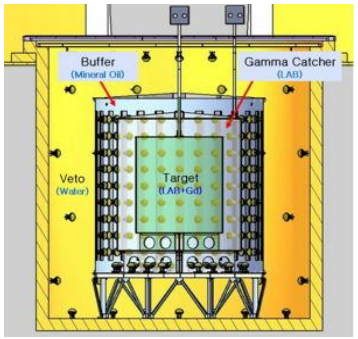




RENO-50

- 5000 tons ultra-low-radioactivity Liquid Scintillation Detector

RENO

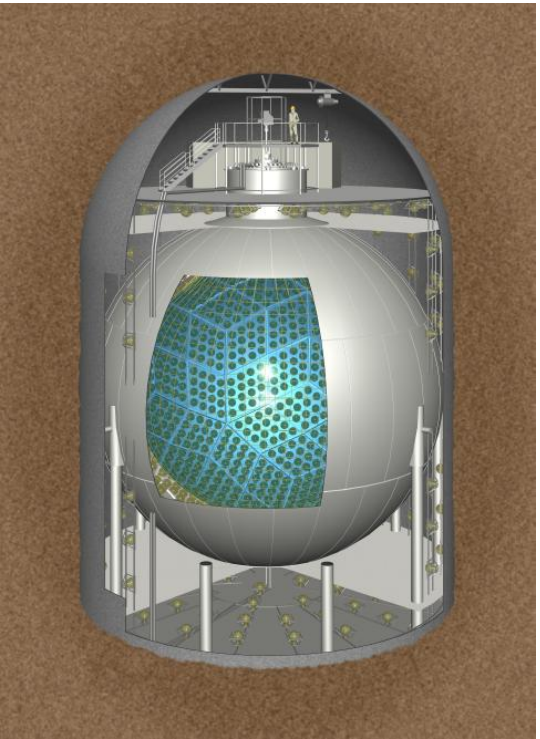


8.8 m

5.8 m

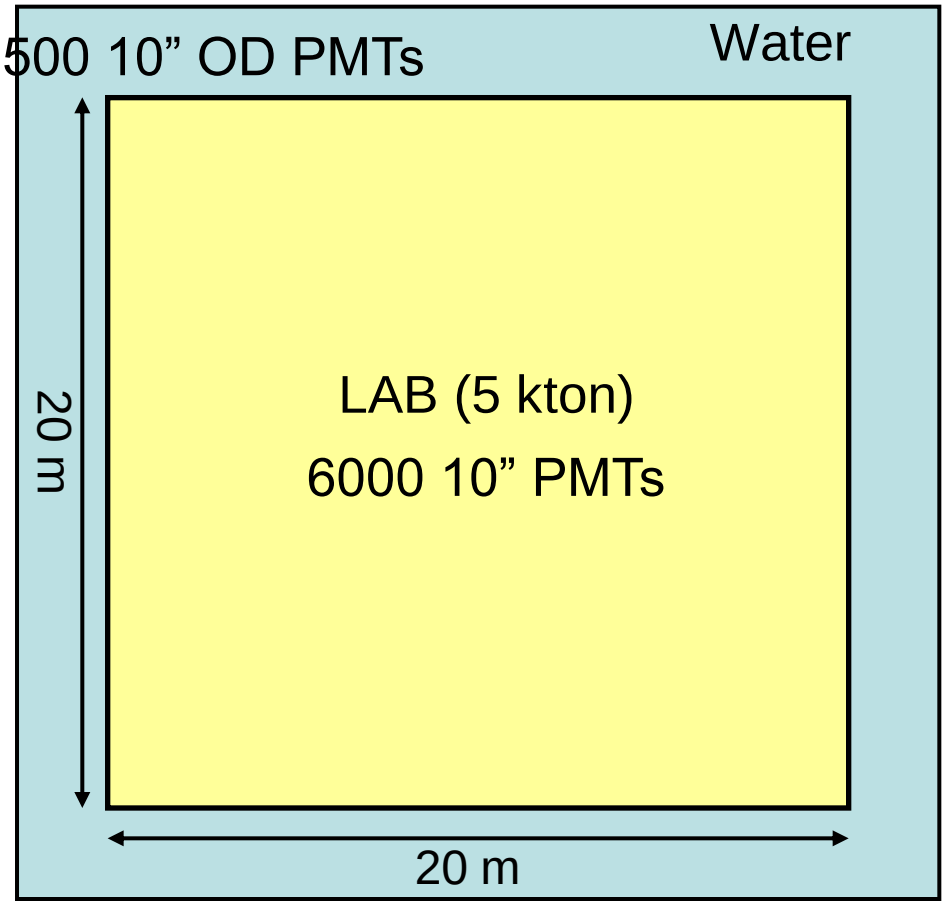
5.4 m

8.4 m



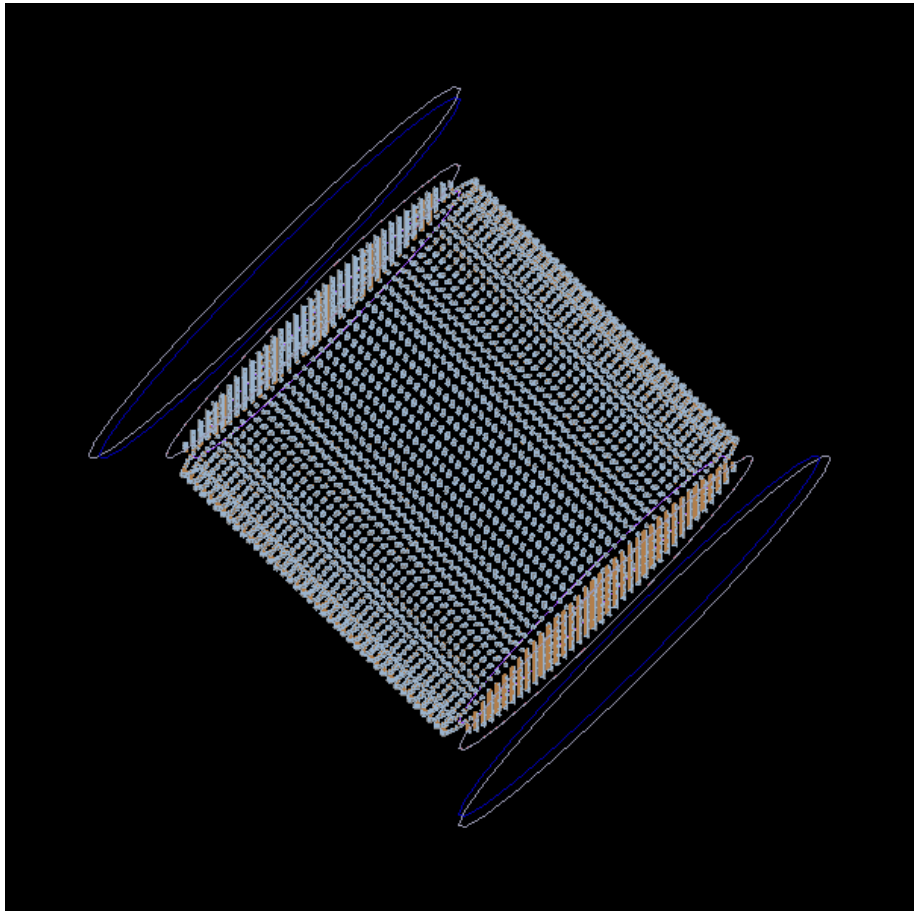
KamLAND

RENO-50

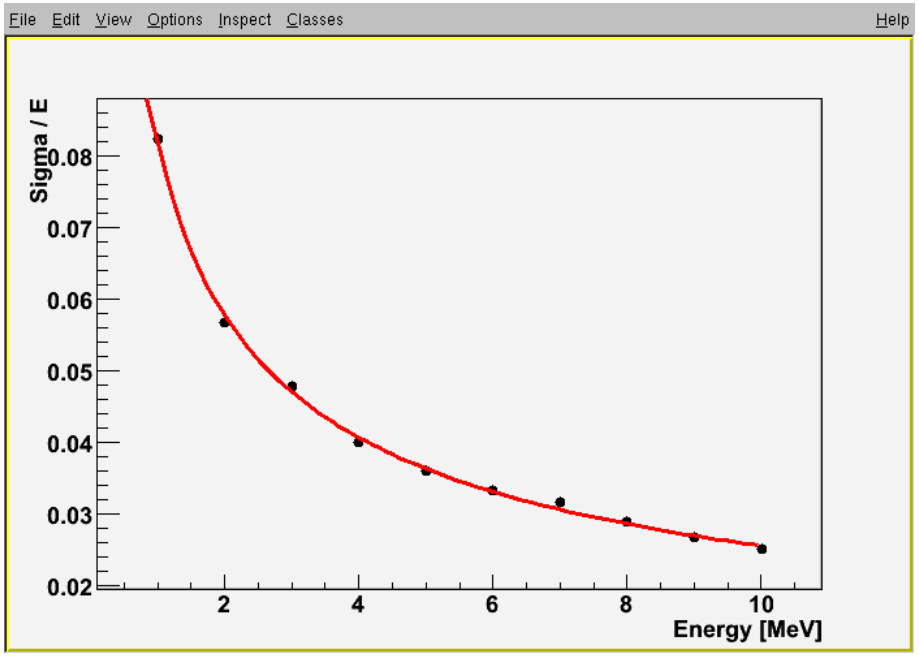


Site Survey for RENO-50

MC Simulation for RENO-50



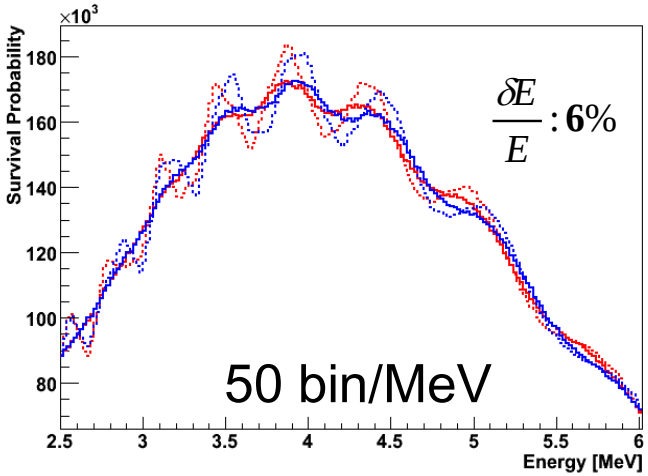
- Energy Resolution

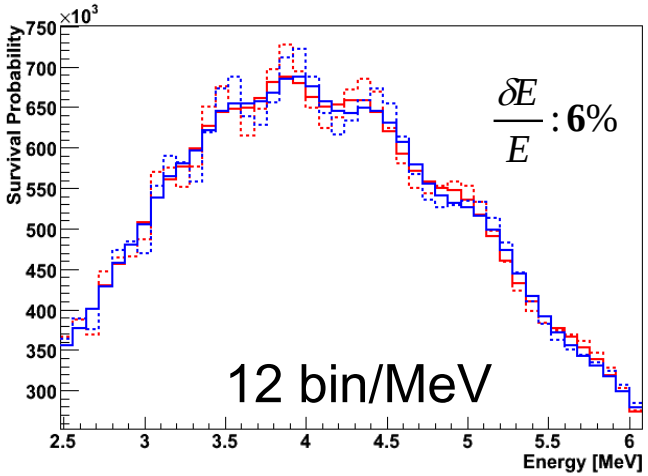


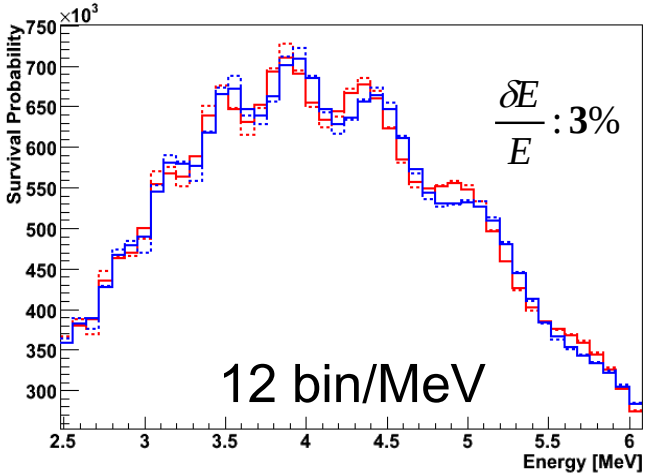
- Also GloBES study is under way

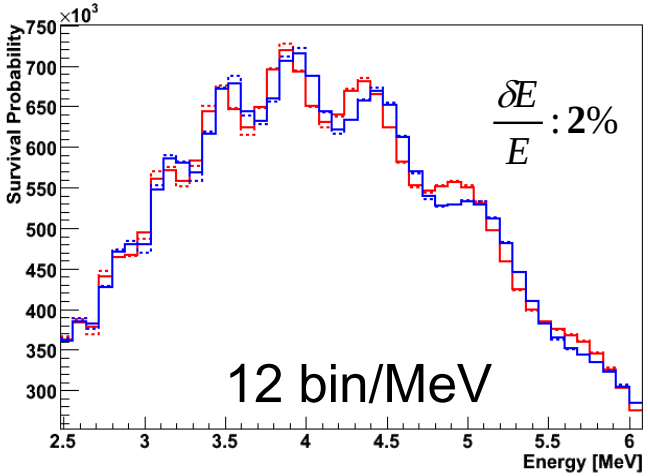
MC Study of Mass Hierarchy at RENO-50

- **Bin size effect of determining mass hierarchy**
- **At least 3% energy resolution is needed to distinguish NH and IH (@ ~5 MeV : 12 bin/MeV)**









MC Study of Mass Hierarchy at RENO-50

▪ χ^2 calculation test

□ χ^2 calculation test RENO-50 expects to observe ~1500 events / year.
- Include oscillation effects and assume 70% detection efficiency.

□ Generate for NH and calculate χ^2 based on hypotheses of NH or IH.
- χ^2 value decreases rapidly with energy resolution.
- 3σ determination : 60000 events (40 years) for RENO-50.
[10 years for a 20 kton detector]

▪ Conclusion

□ A large (> 20 kton) detector with 3% energy resolution is needed (25% PMT coverage) to determine neutrino mass hierarchy.
- 10 years of data taking.
- Modular detector components necessary because of ~25m attenuation length.

□ RENO-50 needs an alternative solution for the mass hierarchy.

□ The solution will be reported soon….

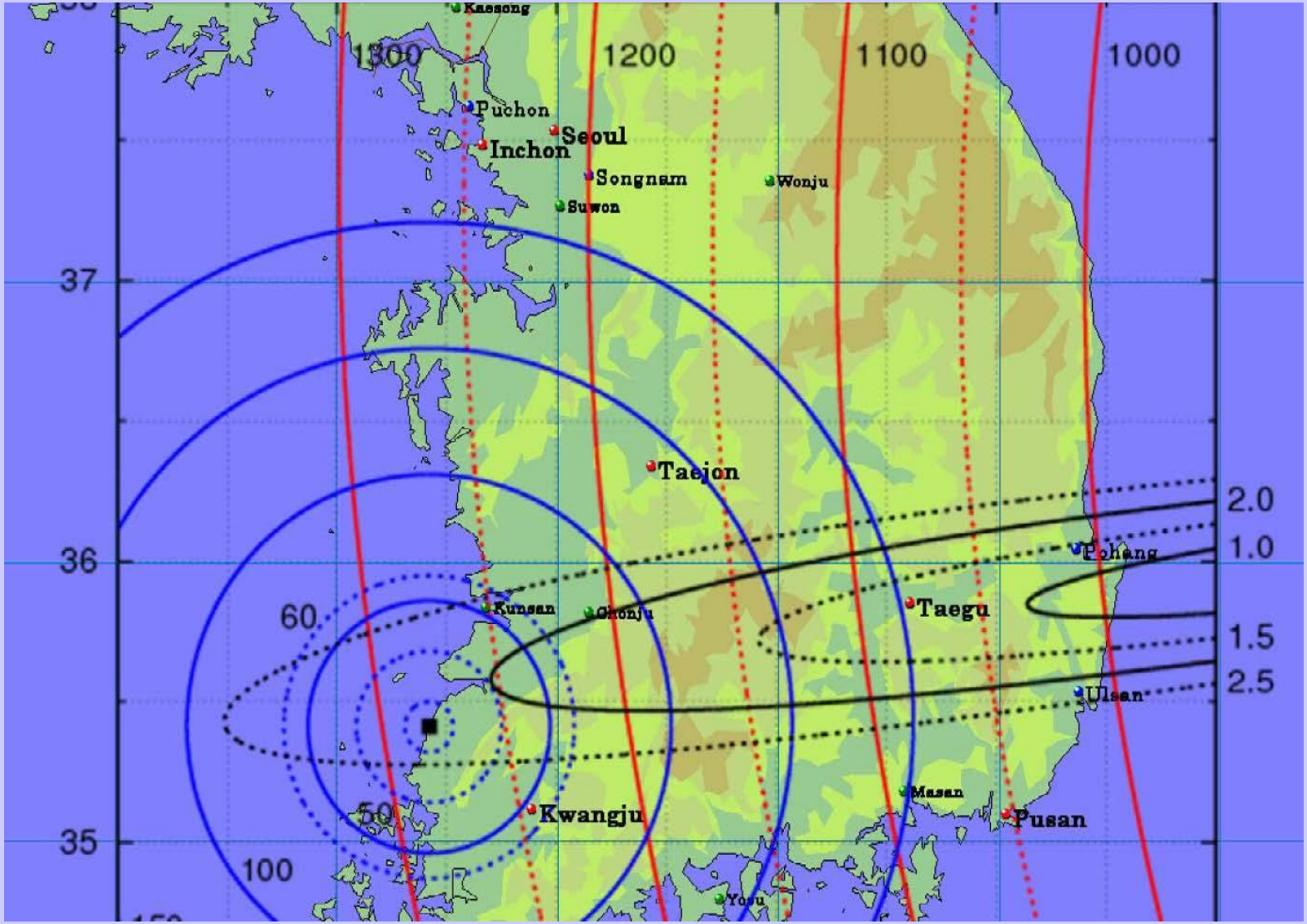
RENO-50 vs. KamLAND

	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]	5 kton	~ 0.3%	~1%
KamLAND (180 km)	40%	$53 \times \phi_0$ [53 reactors]	1 kton	3%	5.4%
Figure of Merit	$\times 2$	$\times 1.5$	$\times 5$	$\times 10$	

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

J-PARC neutrino beam

Dr. Okamura & Prof. Hagiwara



Physics with RENO-50 (1)

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

$$\frac{\delta \sin^2\theta_{12}}{\sin^2\theta_{12}} \sim 1.0\%(1\sigma)$$ in a year (← 5.4%)

$$\frac{\delta \Delta m^2_{21}}{\Delta m^2_{21}} \sim 1.0\%(1\sigma)$$ in 2~3 years (← 2.6%)

- Determination of mass hierarchy (sign of Δm^2_{31} or Δm^2_{32})

  - Quite challenging : requires extremely good energy resolution

  - Plan B : an additional 1000 ton detector at ~10 km

  (L : 300 m + 1.4 km + 10 km + 50 km)

- Neutrino burst from a Supernova in our Galaxy

  - ~1500 events (@8 kpc)

  - A long-term neutrino telescope

Physics with RENO-50 (2)

- Geo-neutrinos : ~ 300 geo-neutrinos for 5 years

  - Study the heat generation mechanism inside the Earth

- Solar neutrinos : with ultra low radioacitivity

  - Matter effects on neutrino oscillation
  - Probe the center of the Sun and test the solar models

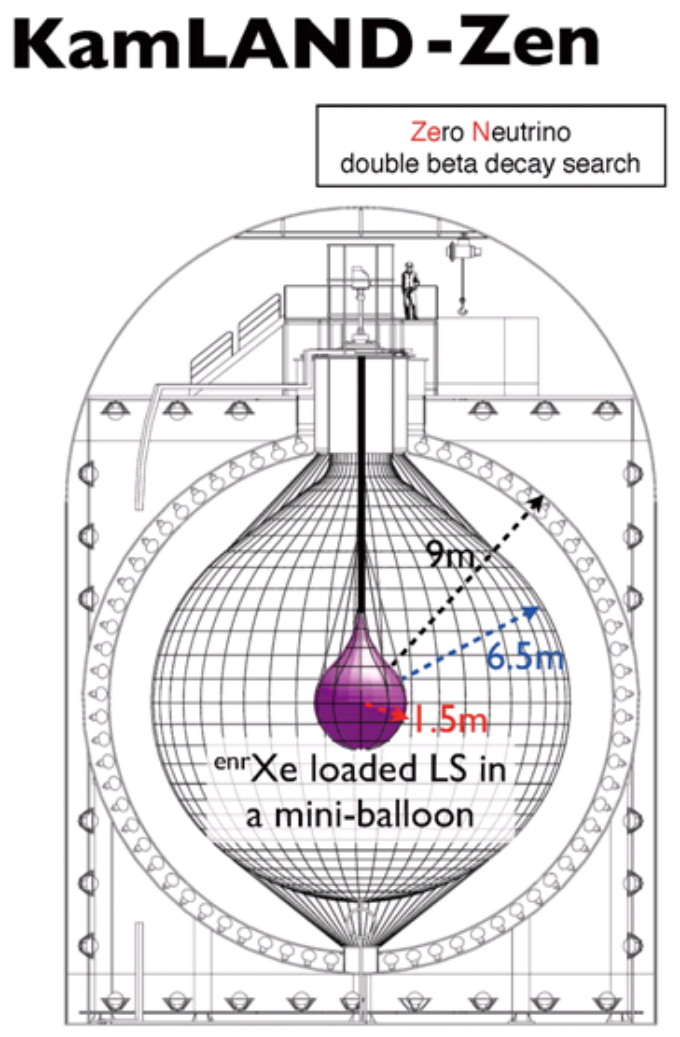
- Reactor physics : non-proliferation

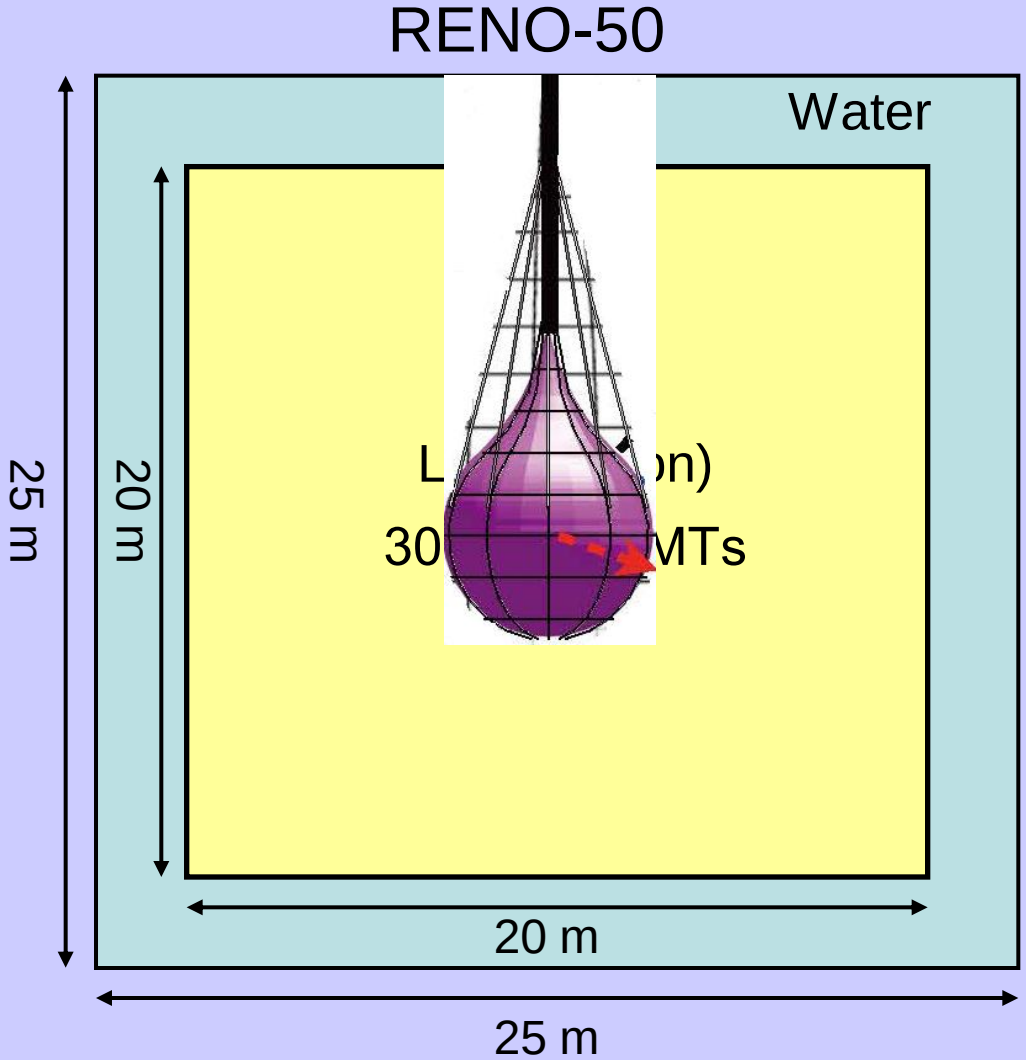
- Detection of J-PARC beam : ~120 events/year

- Test of non-standard physics : sterile/mass varying neutrinos

Physics with RENO-50 (3)

- Search for neutrinoless double beta decay





Closing Remarks

- RENO, the first Korean neutrino detector, observed a clear disappearance of reactor antineutrinos, and performed a definitive measurement of θ_{13} with both near and far detectors in operation.

- A surprisingly large value of θ_{13} will strongly promote the next round of neutrino experiments to find the CP phase and determine the mass hierarchy.

- RENO will continue data-taking for next 3~4 more years, reaching its sensitivity limit, in order to obtain a precise measurement of θ_{13}.

- Korean reactors can be used as an intense neutrino source to study the neutrino properties. RENO-50, a multi-purpose neutrino detector, is pursued to perform high-precision measurements of θ_{12} and Δm^2_{21}, determine the mass hierarchy, and detect neutrinos from the astrophysical sources.

RENO-50 Workshop @Seoul

KNRC
Korea Neutrino Research Center

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International Workshop on "RENO-50" toward Neutrino Mass Hierarchy

13-14 June 2013, Seoule National University, Korea

Overview

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Dear colleagues,

We would like to call your attention to an international workshop on RENO-50 that will be held at Seoul National University, Seoul in Korea on June 13-14, 2013.

The recent measurement of a rather large neutrino mixing angle theta_13 has promoted the opportunities to determine the neutrino mass hierarchy and the leptonic CP phase. Reactor neutrinos have been demonstrated to be a valuable source to measure neutrino mixing angles, and possibly to determine the mass hierarchy.

After the successful RENO experiment, we plan to build a next large liquid scintillator detector to determine the neutrino mass hierarchy and make an unprecedentedly accurate measurement of the mixing angle

http://home.kias.re.kr/MKG/h/reno50/

- When: June 13 – 14, 2013
- Where: Seoul National University, Seoul, Korea

Please register & join!