New results from RENO and Future RENO-50 Project

June Ho Choi (Dongshin University) "International Nuclear Physics Conference" Adelaide, Australia, 11-16 September 2016"



RENO Collaboration



Reactor Experiment for Neutrino Oscillation

(9 institutions and 40 physicists)

- Chonnam National 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



RENO Experimental Set-up



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 (R=2.7m, H=5.8m)
- Veto : 350 ton water (R=4.2m, H=8.8m)

RENO Data-taking Status



New Results from RENO

• Observation of energy dependent disappearance of reactor neutrinos to measure Δm_{ee}^2 and θ_{13} using ~500 days of data (Aug. 2011 ~ Jan. 2013)

"Observation of Energy and Baseline Dependent Reactor Antineutrino Disappearance in the RENO Experiment" (PRL 116, 211801, 2016)

- PRD to be submitted soon for details

Measurement of absolute reactor neutrino flux

 Observation of an excess at ~5 MeV in reactor neutrino spectrum using ~1400 days of data

• Independent measurement of θ_{13} with n-H for a delayed signal (additional background reduction achieved)

Measured Spectra of IBD Prompt Signal



New θ_{13} Measurement by Rate-only Analysis

Rate-only new result



The 5 MeV Excess is there !

RENO

Double Chooz

Daya Bay







In 2014, RENO showed the 5 MeV excess comes from reactors.

Observation of an excess at 5 MeV



The measured near spectrum is compared with prediction using χ^2 -square test.

(Preliminary)

Fraction of 5 MeV excess: **2.46 ± 0.27 (%)**

Significance of the 5 MeV excess: ~**9**σ

Correlation of 5 MeV Excess with Reactor Power



Correlation of 5 MeV excess with ²³⁵U isotope fraction

(Preliminary)

²³⁵U fraction corresponds to freshness of reactor fuel



Measurement of Absolute Reactor Neutrino Flux

R (data/prediction) = 0.946 ± 0.021 (500 days)

- The flux prediction is with Huber + Mueller model
- Flux weighted baseline at near : 411 m



*Prediction is corrected for three flavor neutrino oscillation

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



Results from Spectral Fit



Observed L/E Dependent Oscillation

PRL 116, 211801, 2016





n-H IBD Analysis

Motivation:

- 1. Independent measurement of θ_{13} value.
- 2. Consistency and systematic check on reactor neutrinos.





θ_{13} Measurement with n-H

(Preliminary, 500 days)♪

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\sin^2 2\theta_{13} = 0.086 \pm 0.012 (\text{stat.}) \pm 0.015 (\text{syst.})
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Overview of RENO-50

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

- Goals : Determination of neutrino mass ordering High procision measurement of A Am² and Am²
 - High-precision measurement of θ_{12} , Δm_{21}^2 and Δm_{ee}^2 - Supernova neutrinos, Geo neutrinos, Sterile neutrino search,
- Budget : \$ 100M for 6 year construction (Civil engineering: \$ 15M, Detector: \$ 85M)
- Schedule : 2016 ~ 2021 : Facility and detector construction 2022 ~ : Operation and experiment



Geological Survey for Undergro und Facility

Conceptual Design of REN O-50 Detector



Cost estimation for RENO-50 undergr ound facility (in progress)

 Geological survey for design of tun nel and experimental hall
Cost estimation to be obtained soo n



RENO-50 detector (MC)



RENO-50 R&D Status in Progress

(1) Development of DAQ electronics is on-going.

(2) Develop techniques of LS purification is on-going.

(3) Mechanical design of detector is on-going.

(4) Measurement of radioactivity for detector material is on-going.

(5) Upgrade of measurement device for absolute LS attenuation length is on-going.

Current status

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 are on-going.

Summary of RENO/RENO-50

- Various measurements done
 - Update on θ₁₃ value
 - 5 MeV excess with reactor thermal power
 - First measurement of Δm_{ee}^2
 - Absolute antineutrino flux measurement
 - Independent measurement of θ_{13} with n-H
 - Sterile neutrinos search
- RENO will continue data-taking for next 3 more years, reaching its sensitivity limit, in order to obtain a precise measurement of θ_{13}
- RENO-50: various R&D in progress

Thanks for your attention!

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Measurement of absolute reactor neutrino flux

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Obtained results from a sterile neutrinos search

Delayed Signals from Neutron Capture by Gd



Coincidence of prompt and delayed signals



IBD Candidates & Backgrounds

		Near♪	Far				
DAQ live time♪ (days)♪	4	58.49⊅	489.93♪				
IBD candidates	2	90755	31541				
Total BKG rate (/day)	17.	54± 0.83	3.14± 0.21 ♪				
IBD rate (/day)61after BKG subtraction		.67± 1.44 ♪	61.24± 0.42 ♪				
²⁵² Cf - Near Detector Fast Neutron		²⁵² Cf - Fast Neutron	Far Detector				
Accidental - ⁹ Li/ ⁸ He		Accidental - ⁹ Li/ ⁸ He					
Background Rate (/day) Background Rate (/day)							

Observed Daily Averaged IBD Rate



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

Reactor Neutrino Oscillations



Correlation of 5 MeV excess with ²³⁵U isotope fraction

(Preliminary)

²³⁵U fraction corresponds to freshness of reactor fuel



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.



B12 Energy Spectrum (Near & Far)

 Electron energy spectrum from β-decays from ¹²B and ¹²N, which are produced by comic-muon interactions.



Good agreement between data and MC spectrum!

Energy Scale Difference between Near & Far

Look Poster #1034



Energy scale difference < 0.15%

RENO New Results

	Rate-	only	Rate+shape
Data set	220 days (2012) days(2015)	500	500 days (2015)
<mark> ∆m_{ee}² </mark> [x10 ⁻³ eV²]	2.32 (PDG 2010)	2.49 (PDG 2014)	$2.62_{-0.23}^{+0.12}$ (stat.) $_{-0.13}^{+0.12}$ (syst.)
sin²(2θ ₁₃)	0.113	0.087	0.082
Stat. error	0.013	0.009	0.009
Syst. error	0.019	0.007	0.006
Total error	0.023	0.011	0.011
Significance ⁹ Li/ ⁸ He BKG u	4.9 σ uncertainty redu	7.9 σ ced greatly !	7.5 σ

Near:	12.45 ± 5.93/day (48	%)		Near:	8.36 ± 0.82/days	(10%)
Far:	2. 59 ± 0.75/day (29	%)		Far	1.54 ± 0.23/day	(15%)
	(220 days)	Se	eminar @ CEF	RND	(500 days)	36

Delayed Spectrum and Capture Time



Light Sterile Neutrino Search Results

Look Poster #614

(Preliminary)

• All 500 days of RENO data



Summary

- Observation of energy dependent disappearance of reactor neutrinos and our first measurement of Δm_{ee}^2

 $\sin^2 2\theta_{13} = 0.082 \pm 0.009(\text{stat}) \pm 0.006(\text{syst}) \pm 0.010$ 12 % precision

 $\left|\Delta m_{ee}^{2}\right| = 2.62_{-0.23}^{+0.21} (\text{stat.})_{-0.13}^{+0.12} (\text{syst.}) (\times 10^{-3} \text{eV}^{2}) \pm 0.26$ 10 % precision

- Measured absolute reactor neutrino flux : R= 0.946±0.021
- Observed an excess at 5 MeV in reactor neutrino spectrum
- Measurement of θ_{13} using n-H IBD analysis : 0.086±0.019
- Obtained an excluded region from a sterile neutrino search
- $sin(2\theta_{13})$ to 6% accuracy Δm_{ee}^2 to 0.15×10⁻³ eV² (6%) accuracy for final sensitivity

Various Physics with RENO-50

- Determination of neutrino mass ordering
 - 3σ sensitivity with 10 years of data
- Precise (~0.5%) measurement of θ_{12} , Δm_{21}^2 and Δm_{ee}^2
 - An interesting test for unitarity & essential for the future discoveries
- Neutrino burst from a Supernova in our Galaxy
 - ~5,600 events (@8 kpc)
 - Study the core collapsing mechanism with neutrino cooling
- Geo-neutrinos : ~ 1,500 geo-neutrinos for 5 years
 - Study the heat generation mechanism inside the Earth
- Solar neutrinos
 - MSW effect on neutrino oscillation

Sterile neutrino search : reactor / radioactive sources / IsoDAR

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

RENO-50 Candidate Site

