## 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  $\Delta m_{ee}^2$  and  $\theta_{13}$  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  $\theta_{13}$  with n-H for a delayed signal (additional background reduction achieved)

## **Measured Spectra of IBD Prompt Signal**



## New $\theta_{13}$ 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  $\chi^2$ -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 <sup>235</sup>U isotope fraction

(Preliminary)

#### <sup>235</sup>U 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  $\theta_{13}$  value.
- 2. Consistency and systematic check on reactor neutrinos.





## $\theta_{13}$ 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 Am<sup>2</sup> and Am<sup>2</sup>
  - High-precision measurement of  $\theta_{12}$ ,  $\Delta m_{21}^2$  and  $\Delta m_{ee}^2$ - 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 θ<sub>13</sub> value
  - 5 MeV excess with reactor thermal power
  - First measurement of  $\Delta m_{ee}^2$
  - Absolute antineutrino flux measurement
  - Independent measurement of  $\theta_{13}$  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  $\theta_{13}$
- RENO-50: various R&D in progress

## Thanks for your attention!

## **New Results from RENO**

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Measurement of absolute reactor neutrino flux

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

Obtained results from a sterile neutrinos search

### **Delayed Signals from Neutron Capture by Gd**



## **Coincidence of prompt and delayed signals**

![](_page_27_Figure_1.jpeg)

## **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 ♪				
<sup>252</sup> Cf - <b>Near Detector</b> Fast Neutron		<sup>252</sup> Cf - Fast Neutron	Far Detector				
Accidental - <sup>9</sup> Li/ <sup>8</sup> He		Accidental - <sup>9</sup> Li/ <sup>8</sup> He					
Background Rate (/day) Background Rate (/day)							

## **Observed Daily Averaged IBD Rate**

![](_page_29_Figure_1.jpeg)

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

## **Reactor Neutrino Oscillations**

![](_page_30_Figure_1.jpeg)

### Correlation of 5 MeV excess with <sup>235</sup>U isotope fraction

(Preliminary)

#### <sup>235</sup>U fraction corresponds to freshness of reactor fuel

![](_page_31_Figure_3.jpeg)

## **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.

![](_page_32_Figure_3.jpeg)

## **B12 Energy Spectrum (Near & Far)**

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

![](_page_33_Figure_2.jpeg)

Good agreement between data and MC spectrum!

### **Energy Scale Difference between Near & Far**

Look Poster #1034

![](_page_34_Figure_2.jpeg)

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<sub>ee</sub>² </mark> [ x10 <sup>-3</sup> eV²]	2.32 (PDG 2010)	2.49 (PDG 2014)	$2.62_{-0.23}^{+0.12}$ (stat.) $_{-0.13}^{+0.12}$ (syst.)
sin²(2θ <sub>13</sub> )	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 <sup>9</sup> Li/ <sup>8</sup> 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**

![](_page_36_Figure_1.jpeg)

## **Light Sterile Neutrino Search Results**

## Look Poster #614

(Preliminary)

• All 500 days of RENO data

![](_page_37_Figure_3.jpeg)

## Summary

- Observation of energy dependent disappearance of reactor neutrinos and our first measurement of  $\Delta m_{ee}^2$ 

 $\sin^2 2\theta_{13} = 0.082 \pm 0.009(\text{stat}) \pm 0.006(\text{syst}) \pm 0.010$  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  $\theta_{13}$  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  $\Delta m_{ee}^2$  to 0.15×10<sup>-3</sup> eV<sup>2</sup> (6%) accuracy for final sensitivity

## **Various Physics with RENO-50**

- Determination of neutrino mass ordering
  - $3\sigma$  sensitivity with 10 years of data
- Precise (~0.5%) measurement of  $\theta_{12}$ ,  $\Delta m_{21}^2$  and  $\Delta m_{ee}^2$ 
  - 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**

![](_page_40_Picture_1.jpeg)