Search for sterile neutrinos at RENO

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On behalf of the RENO collaboration

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RENO Collaboration

Reactor Experiment for Neutrino Oscillation

(9 institutions and 30 physicists)

- Chonnam National University
- Dongshin University
- Gwanju Institute of Science and Technology
- Gyeongsang National University
- Korea Advanced Institute of Science and Technology
- Kyungpook National University
- Seoul National University
- Seoyeong University
- Sungkyunkwan University

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

16.8GW (6 reactors)
RENO experimental site

Near Detector
(120 m.w.e.)

Hanbit Nuclear Power Plant
6 reactor array
2.8GW$_{th}$/reactor

Far Detector
(450 m.w.e)
Search for **light sterile neutrino**

- **Light sterile neutrino**: A promising solution to explain experimental anomalies (RAA, Gallium, LSND & MiniBooNE)

- Sterile neutrino gives an explanation for the origin of extremely light neutrino mass. (Albeit we need to extend the standard *see-saw* mechanism a bit to include both light and heavy sterile neutrino)

- However, sterile neutrino models currently fail to account for all of anomalies simultaneously.
Sensitivity for sterile neutrino search

✓ 3+1 active - sterile neutrino mixing

\[ P_{\nu_e \rightarrow \bar{\nu}_e} \approx 1 - \sin^2 2\theta_{13} \sin^2 (1.27 \Delta m^2_{31} \frac{L}{E}) - \sin^2 2\theta_{14} \sin^2 (1.27 \Delta m^2_{41} \frac{L}{E}) \]

✓ L/E determines the sensitivity

<table>
<thead>
<tr>
<th>Detectors</th>
<th>Baselines (m)</th>
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<tbody>
<tr>
<td>Near</td>
<td>R1 660, R2 445, R3 302, R4 339, R5 520, R6 746</td>
</tr>
<tr>
<td>Far</td>
<td>R1 1564, R2 1461, R3 1398, R4 1380, R5 1409, R6 1483</td>
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L (m)
- Reactor to NEOS : \(~24m\)
- Reactor to RENO (near) : \(~400 m\)
- Reactor to RENO (far) : \(~1400 m\)

E (MeV)
Neutrino spectrum : 1.8 ~ 10 MeV
Expected sensitivity of RENO’s sterile neutrino search

- **Long L** (Reactor 1, 2, 5 and 6)
- **Low E** (1.2~3 MeV)
- **Medium L**
- **Medium E**
- **Short L** (Reactor 3 and 4)
- **High E** (3~8 MeV)

![Graph showing RENO's expected sensitivity for sterile neutrino search](image-url)
Results: **Sub-eV sterile neutrino search at RENO**

- 2200 days of RENO far / near data
- Excluded $10^{-4} \lesssim |\Delta m_{41}^2| \lesssim 0.5 \text{ eV}^2$
- No significant evidence for a sterile neutrino oscillation ($\Delta \chi^2 = 1.4$, p-value = 0.87)

We share the same reactor source but have different detector response.
✓ **Spectral shape comparison** to see the possible shape distortion due to active - sterile neutrino oscillation

✓ *(Ingredient 1)* RENO prompt -> neutrino spectrum -> expected prompt spectrum at NEOS

✓ *(Ingredient 2)* Measured spectrum of NEOS

✓ Vise versa gives equivalent results
Unfolded spectrum (Using Iterative Bayesian Unfolding)

- Using the Bayesian formula, IBU iteratively updates the prior neutrino spectrum according to the data.
- Systematic uncertainties are considered with the covariance matrix.
- Energy scale is the most dominant error source.
Spectral-only comparison

✓ RENO expected prompt spectrum at NEOS vs. measured prompt spectrum at NEOS

\[ \chi^2 / \text{NDF} = 47.45 / 58 \]

RENO expected prompt spectrum at NEOS

Best fit \( \chi^2 / \text{NDF} \) = 47.45 / 58

\( \chi^2 / \text{NDF} \)

with 3ν (flat ratio)

= 56.24 / 60

PRELIMINARY
RENO+ NEOS excluded & allowed region

Preliminary

Best fit at $(0.08, 2.4eV^2)$

$4\nu$ Minimum $\chi^2 : 47.45 / 58$

$3\nu (\sin^2 2\theta_{14} = 0) \chi^2 : 56.24 / 60$

$\Delta\chi^2 = 8.8$

P-value : 8.5%

- Feldman and Cousins method excludes more space than raster scan method except near the best-fit parameter
- Best-fit parameter is consistent with RAA allowed region
Sterile neutrino search using RENO and NEOS data

- Best fit \((\Delta m_{41}^2 = 2.4 eV^2, \sin^2 2\theta_{14} = 0.08)\) is consistent with the RAA allowed region
- 95% excluded limit: \(10^{-3} eV^2 < \Delta m_{41}^2 < 7 eV^2\) (p-value \(\sim 8.5\%\))

Summary and Conclusion

- Search for sub-eV sterile neutrino at RENO gives a null result
  - Excluded \(10^{-4} \lesssim |\Delta m_{41}^2| \lesssim 0.5 eV^2\)
RENO and NEOS joint analysis for sterile neutrino search is launched!

RENO & NEOS collaboration list

- Chonnam National University
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- Kyungpook National University
- Seoul National University
- Seoyeong University
- Sungkyunkwan University
- Start of project: 2006

NEOS Collaboration

- Neutrino Experiment for Oscillation at Short baseline
- 20 Researchers from 8 institutes in Korea
  - Chonnam National University
  - Chung-Ang University
  - Institute for Basic Science (IBS)
  - Korea Research Institute of Standard and Science (KRISS)
  - Korea Atomic Energy Research Institutes (KAERI)
  - Kyungpook National University
  - Sejong University
  - University of Science and Technology
- Project launched in 2012
Thank you!
Back up slides
There are three ways of comparisons

1. NEOS prompt

RENO prompt -> RENO neutrino -> RENO prompt (NEOS response) VS NEOS prompt

2. RENO prompt

RENO prompt VS NEOS prompt -> NEOS neutrino -> NEOS prompt (RENO response)

3. Neutrino

RENO prompt -> RENO neutrino VS NEOS prompt -> NEOS neutrino

※ Sterile neutrino search using both neutrino spectrum requires caution because we imposed smooth function constraint when unfolding. It is safe to compare in prompt spectrum to test the hypothesis.
Ratio comparisons

1. NEOS prompt VS

2. RENO prompt VS

3. Neutrino VS

Preliminary
Exclusion contour (with other experiments)

Preliminary

- Best fit at $(0.08, 2.4eV^2)$
- $4\nu$ Minimum $\chi^2: 47.45/58$
- $3\nu (\sin^2 2\theta_{14} = 0) \chi^2: 56.24/60$
- $\Delta \chi^2 = 8.8$
- P-value: 8.5%

- Best-fit parameter is consistent with RAA allowed, but it has tension with recent STERO result.

- Feldman and Cousins method exclude more space than raster scan method except near the best-fit parameter.
Previous version of excluded and allowed region

Best fit: $\Delta m^2_{41} = 2.37 \pm 0.03 \text{ eV}^2$, $\sin^2 2\theta_{14} = 0.09 \pm 0.03$

- P-value (assuming 3ν with MC) $\sim 13\%$
- Weak hint for the sterile neutrino oscillation
- The best fit is compatible with the RAA allowed region

$\chi^2_{4\nu, \text{min}} / \text{NDF} = 23.2/57 \quad \chi^2_{3\nu} / \text{NDF} = 34.9/59$

Fast algorithm to find the global minimum for FC simulation

1. Picking up the extreme values with fixed $\sin^2 2\theta_{14}$

2. Finding the local minimum for fixed $\Delta m_{41}^2$

3. Picking up the most smallest local minimum among candidates $\Delta m_{41}^2$ -> Check one more if that point is local minimum by varying $\Delta m_{41}^2$

Calculation speed is boosted $\sim \times 40$
+ It is still fast even if the grid is dense because it just pick up the extreme value, where the number of extreme value is fixed no matter how dense the grid is. (more accurate)
Critical $\Delta \chi^2$ distribution

$\chi^2(2DOF)$
$\chi^2(5DOF)$

$\Delta \chi^2 (95\%) = 6.35$

$\Delta \chi^2 (95\%) = 10.15$
P-value test

\[ \Delta \chi^2 = 8.8 \]

P-value : 8.5%