Current Status of RENE Experiment

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On behalf of RENE collaboration

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21st International conference on neutrino physics at ICISE, Quy Nhon, Vietnam
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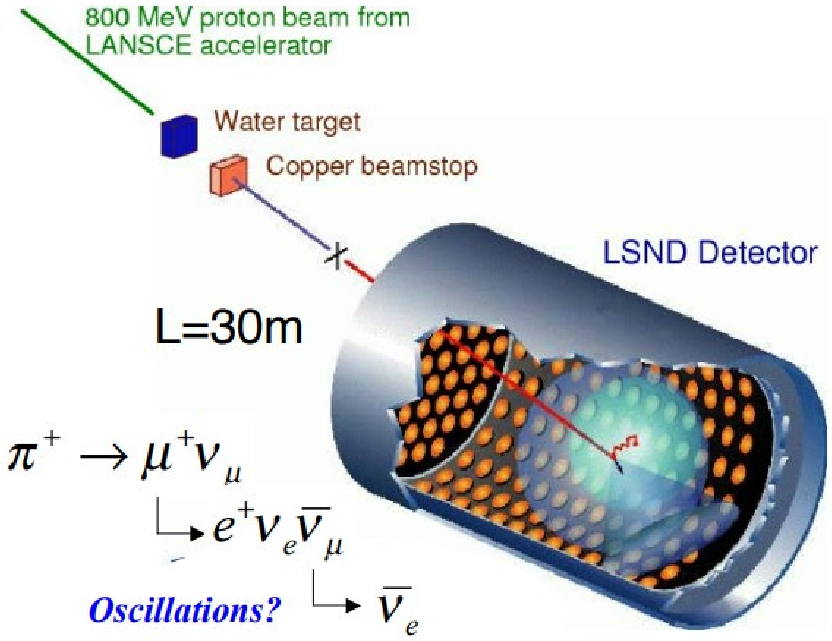
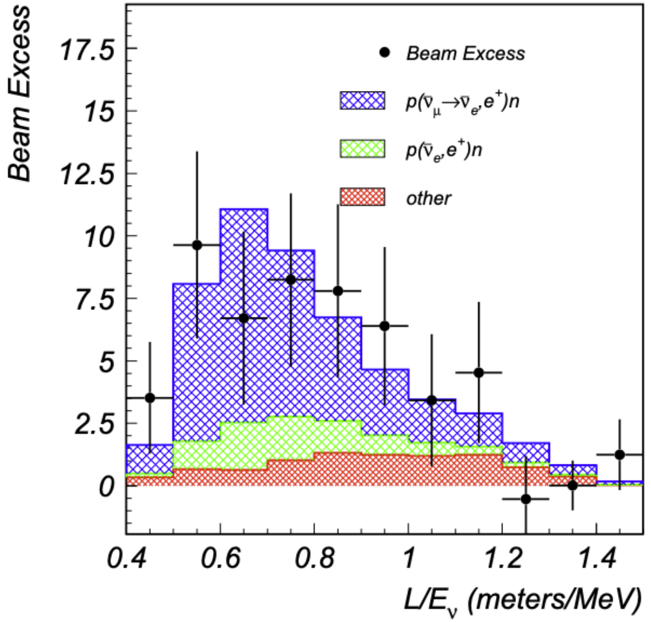
Contents

1 Motivation

- The Liquid Scintillator Neutrino Detector (LSND) experiment provided one of the first key hints
  - Observing a significant 3.8σ $\bar{\nu}_e$ signal excess from a μ^+ decay-at-rest beam
  - This hinted at a $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillation over a 30 m baseline, corresponding to $\Delta m^2 \approx 1\ eV^2$
  - This led to the hypothesis of a fourth, “sterile” neutrino to explain the LSND anomaly



LSND $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ signal (appearance)



(Right)
- μ^+ decay-at-rest experiment
- Very low $\bar{\nu}_e$ contamination
- Liquid scintillator detector
- Low background: inverse β-decay detection

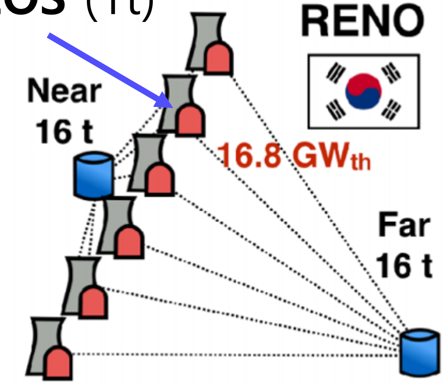
(Left)
- Excess events: $87.9 \pm 22.4 \pm 6.0$
- With an oscillation probability of $(0.264 \pm 0.67 \pm 0.045)$ %
- 3.8σ evidence for $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$

PRD **64** (2001) 112007

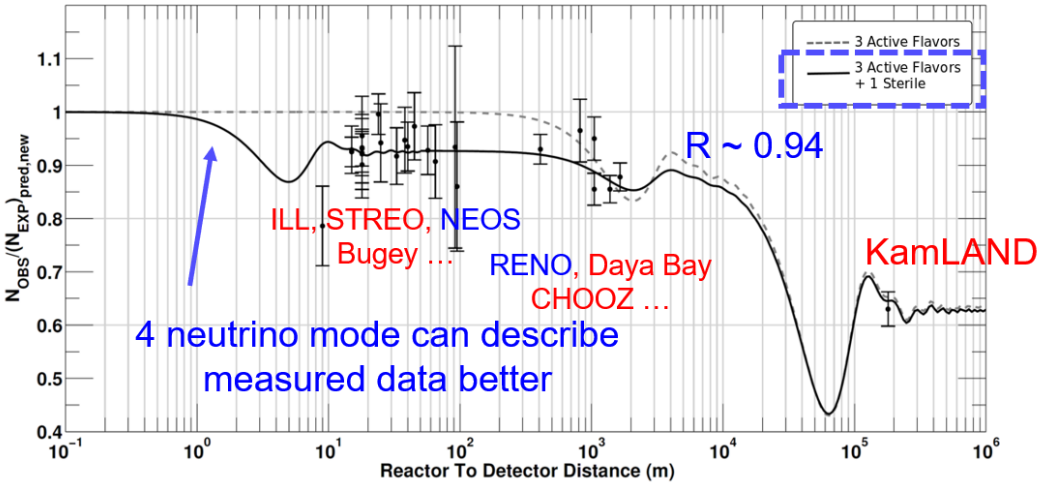
- The Reactor Antineutrino Anomaly (RAA)
  - A re-evaluation of predicted reactor $\bar{\nu}_e$ flux (by Muller et al. and Huber) in 2011 resulted in a ~ 3 % increase.
  - Leading to a common deficit observed across many short-baseline reactor neutrino experiments (at distances < 100 m)
  - The ratio of measured-to-predicted flux was found to be $\frac{R_{experiment}}{R_{theory}} = 0.943 \pm 0.023$, indicating a ~ 6 % deficit
  - This discrepancy, known as the RAA, can also be explained by oscillations into a sterile neutrino with $\Delta m^2 \sim 1\ eV^2$

The puzzle:
- While the RAA hinted at sterile neutrinos, the exact oscillation parameters remained unclear

The key players in Korea:
- RENO (long-baseline) and NEOS (short-baseline), located at the same reactor site, offered a unique opportunity for a combined analysis.



PLB 829 (2022) 137054, PRD 83 (2011) 073006

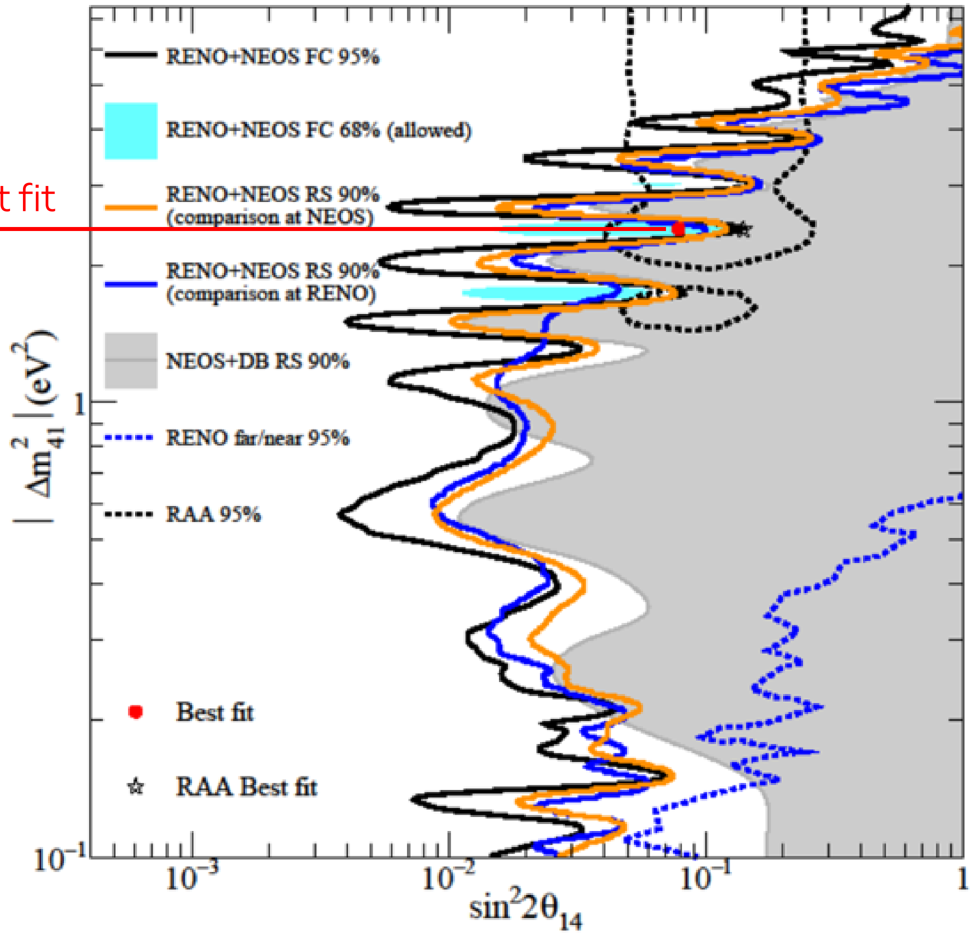


RENO and NEOS Joint Analysis

- A joint analysis of RENO's and NEOS's data was conducted to significantly constrain the parameter space for sterile neutrinos
  - This combined analysis significantly improved the constraints on the sterile neutrino oscillation parameters, $|\Delta m^2_{41}| = 2.41\ eV^2, \sin^2 2\theta_{14} = 0.08$

Best fit

PRD 105 (2022), L111101



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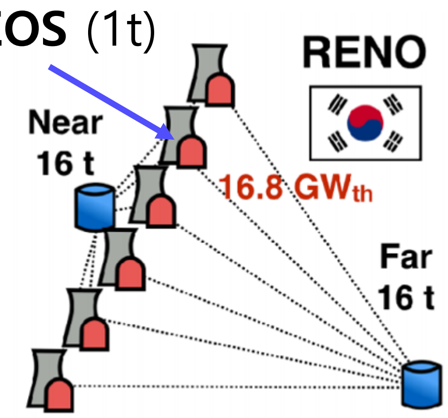
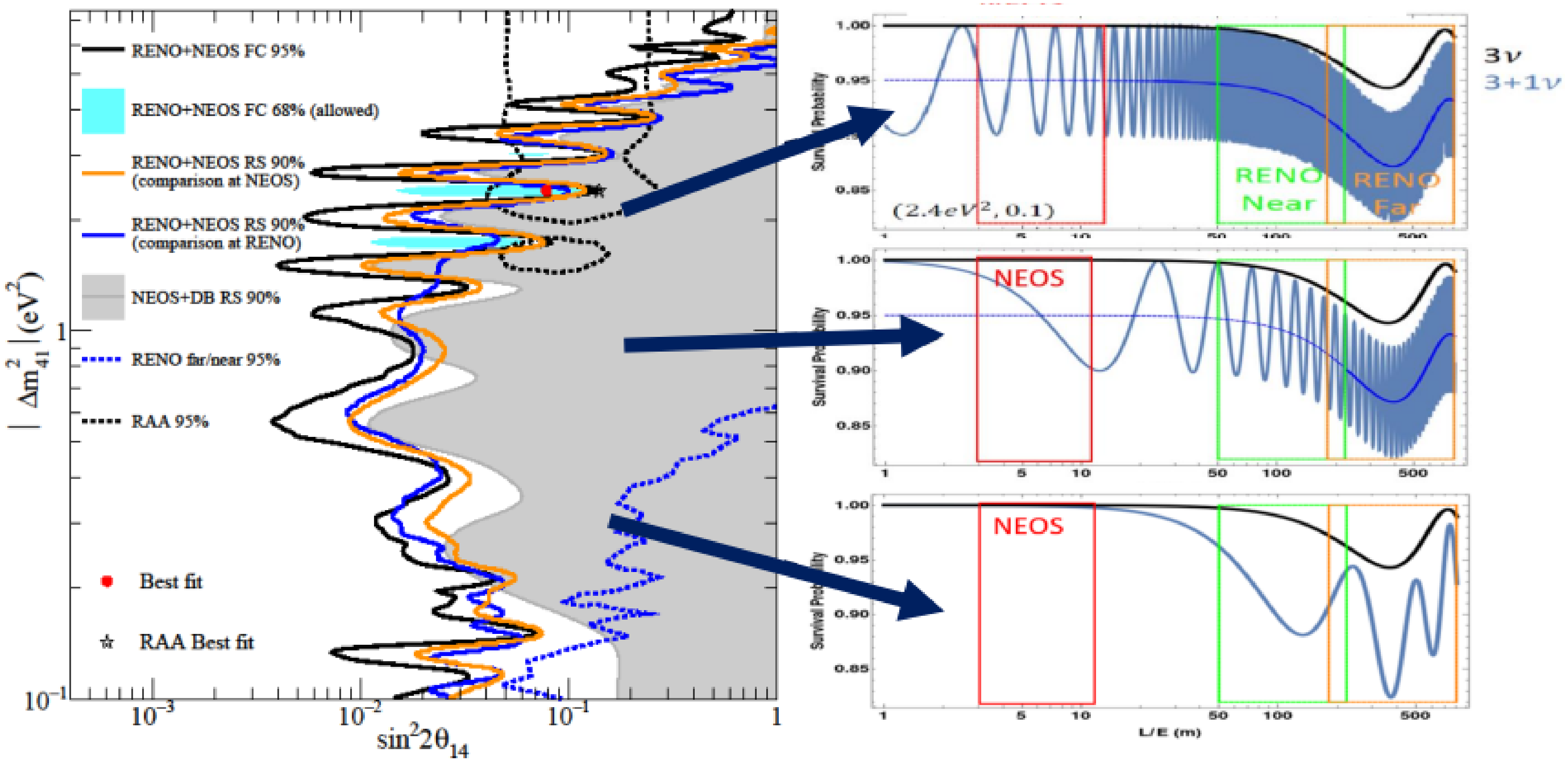


PRL 125 (2020) 191801

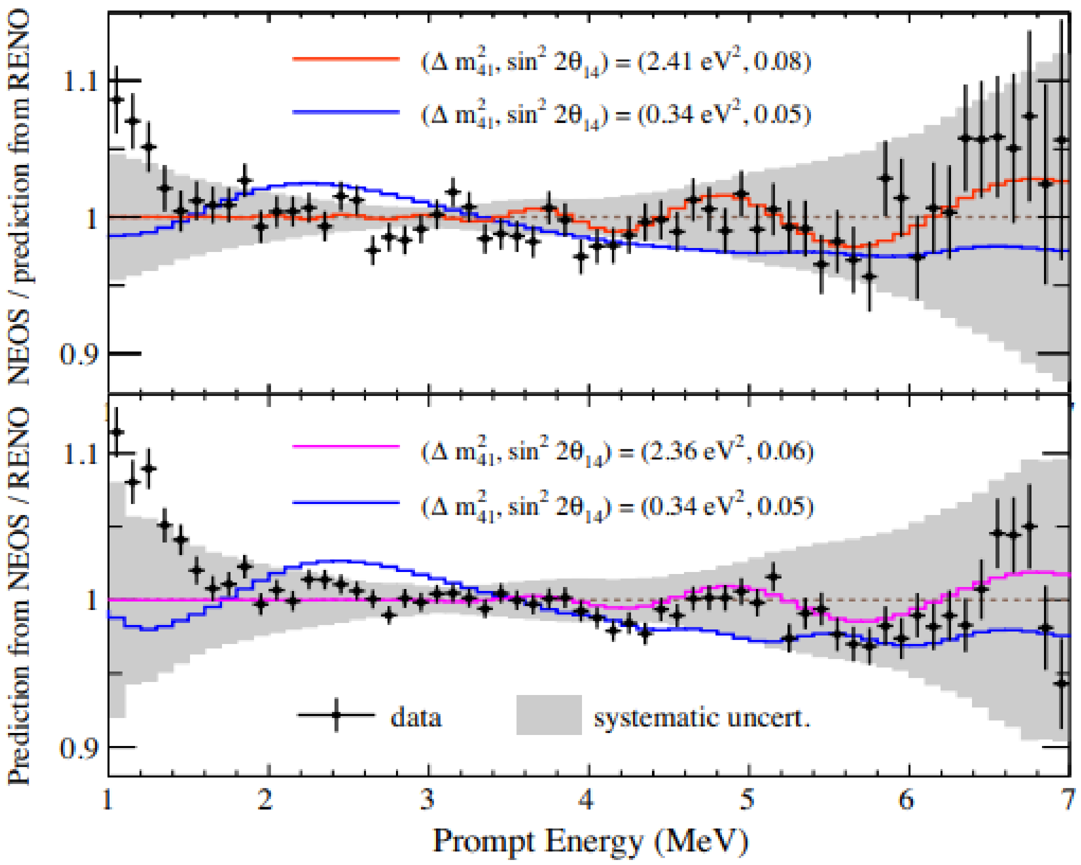
RENO and NEOS Joint Analysis

- The analysis revealed a statistical tension between **the 3+1** and the 3-neutrino hypothesis, with a p-value of 8.2%



PRD 105, L111101 (2022) RENO+NEOS

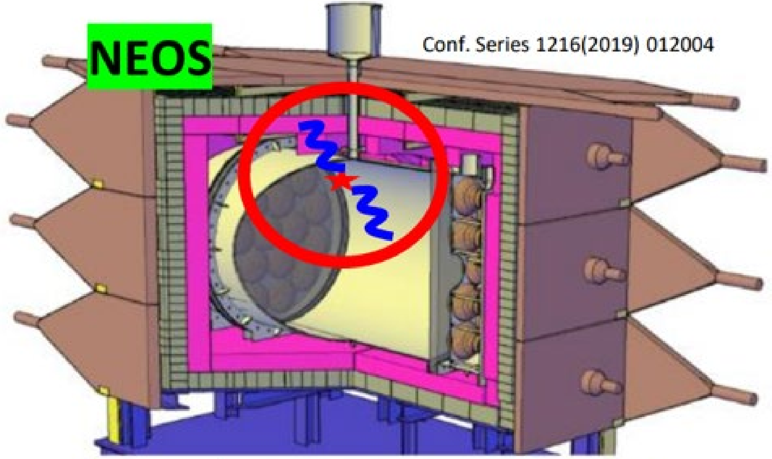
- A joint analysis of RENO's and NEOS's data was conducted to significantly constrain the parameter space for sterile neutrinos
  - The analysis continues to indicate a statistical discrepancy between the 3+1 model and the data provided
  - This result strongly motivates a dedicated experiment to confirm or rule out this specific region, leading directly to our new short-baseline project (later officially named RENE)

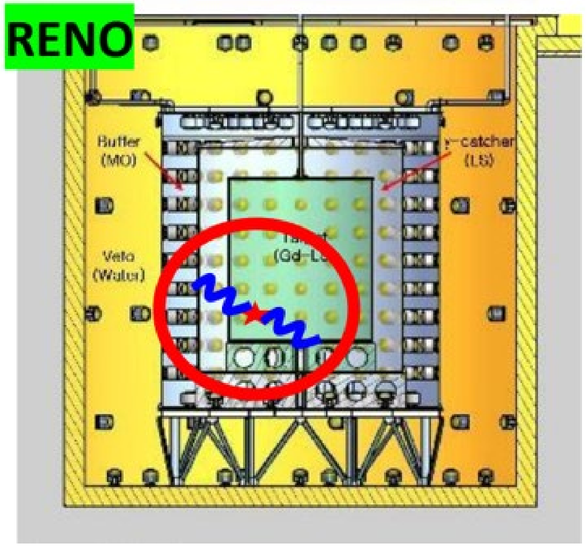


PRD 105, L111101 (2022) RENO+NEOS

Improving Energy Resolution by Mitigating γ-ray Escape

- Precise measurement of the prompt energy spectrum is crucial for sterile neutrino search
  - NEOS, with its target-only design, suffered from escaping gamma rays from positron annihilation
  - This led to degraded energy resolution, creating low-energy tails and secondary peaks in the energy spectrum
- The key design strategy for our new short-baseline project is to overcome this limitation by surrounding the target with a γ-catcher, significantly improving the resolution

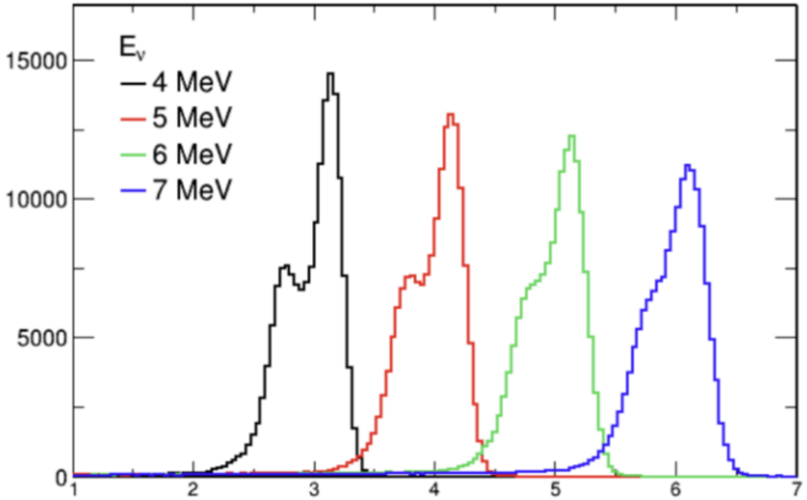




Improving Energy Resolution by Mitigating γ-ray Escape

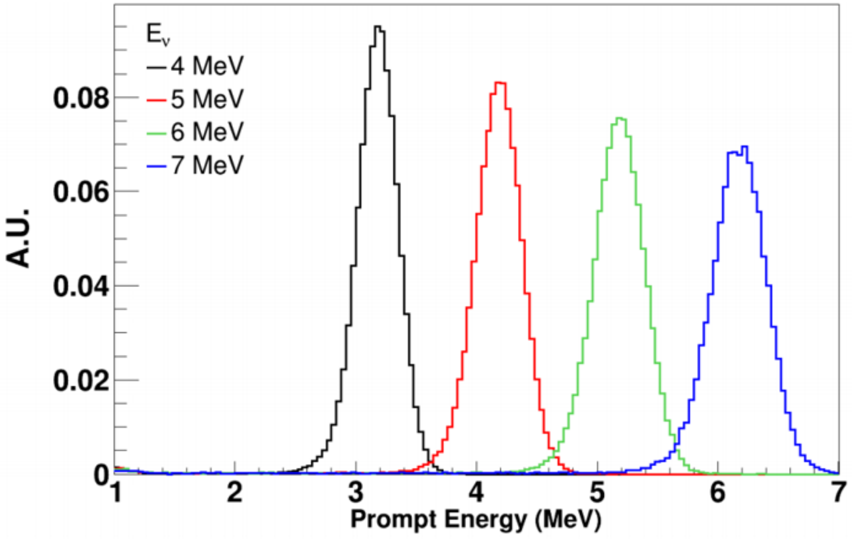
- This led to degraded energy resolution, creating low-energy tails and secondary peaks in the energy spectrum
- The key design strategy for our new short-baseline project (RENE) is to overcome this limitation by surrounding the target with a γ-catcher, significantly improving the resolution

- **NEOS**

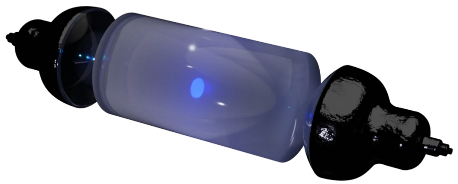


Neutrino Experiment Oscillation at Short Baseline – Yoomin Oh, @The 39th ISNP (2017)

- **RENO**

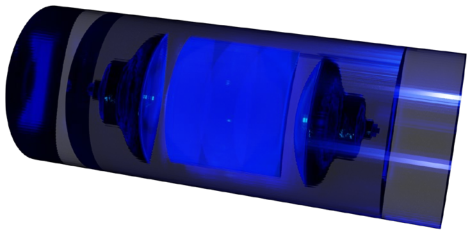


Target-only design (NEOS)



Optimized target + γ-catcher design (RENE)

Large target and γ-catcher design (RENO)

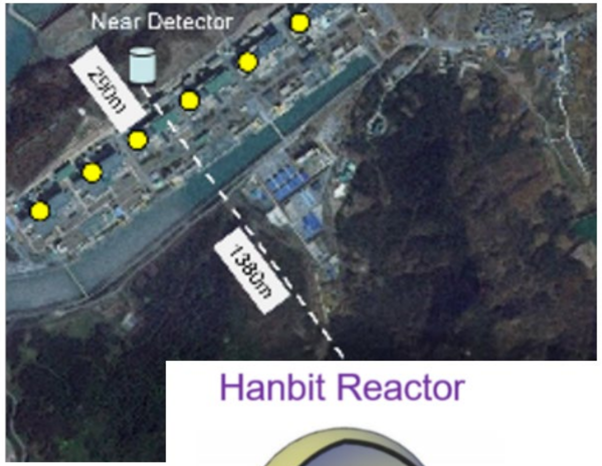


Simple cartoons

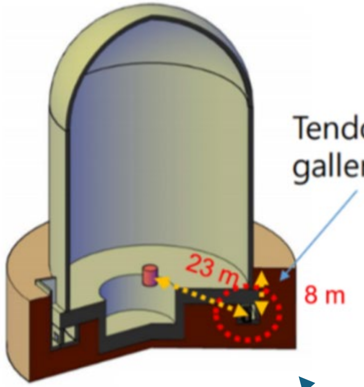
2

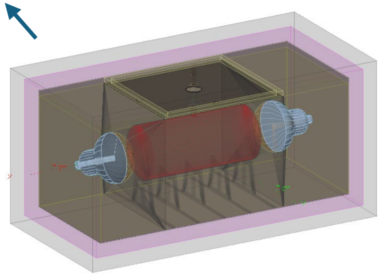
Status

- RENE is a new short-baseline experiment in South Korea, which started in 2022
  - Primary Goal: To investigate the sterile neutrino oscillation hint from the RENO-NEOS joint analysis in the $\Delta m^2_{41} \sim 2\ eV^2$ region.
  - Secondary Goal: To provide precise measurements of the reactor $\bar{\nu}_e$ flux and spectrum, which can help understand the "5 MeV excess"
  - Location: To be installed in the tendon gallery of a reactor at Hanbit Nuclear Power Plant, Yeonggwang, at a baseline of ~23 meters



Hanbit Reactor





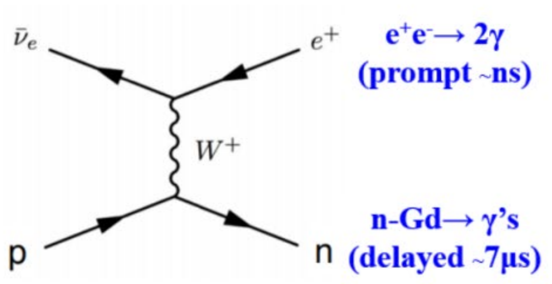
RENE Collaboration

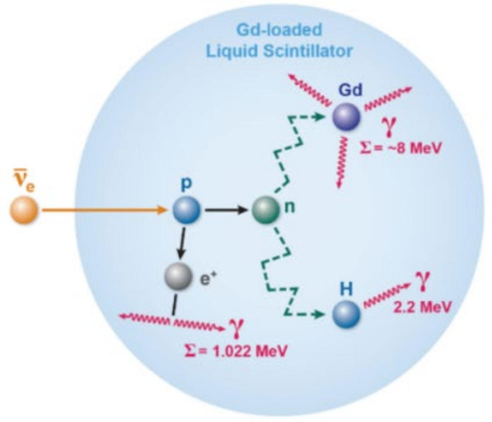
- RENE project is driven by a strong collaboration of ~30 members from 12 institutions across South Korea

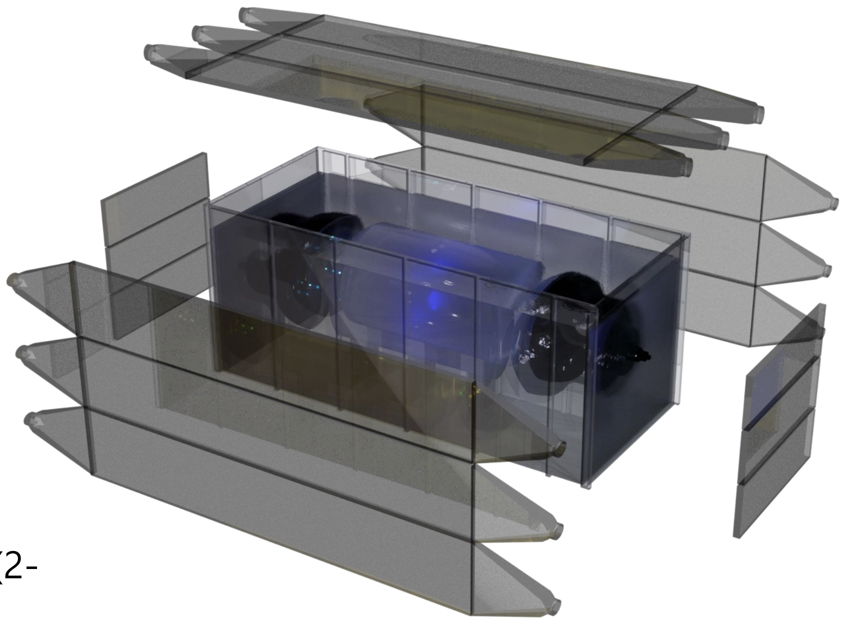
RENE Detector : Overall Design

- Detection channel: Inverse beta decay (IBD)
- The design concept
  - Target (Gd-LS):
    - a Gd-loaded liquid scintillator (Gd-LS) target to maximize the IBD interaction and neutron capture signal
  - γ-catcher (LS):
    - Liquid scintillator (LS) surrounds the target to catch escaping γ-rays, ensuring high energy resolution
  - Veto system (PS):
    - an outermost layer of plastic scintillator (PS) to reject cosmic muon-induced backgrounds

IBD : $\overline{\nu}_e + p \rightarrow n + e^+$



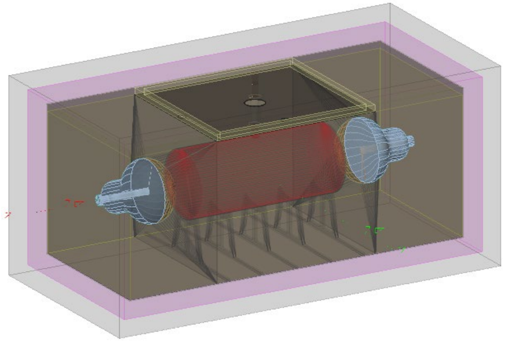


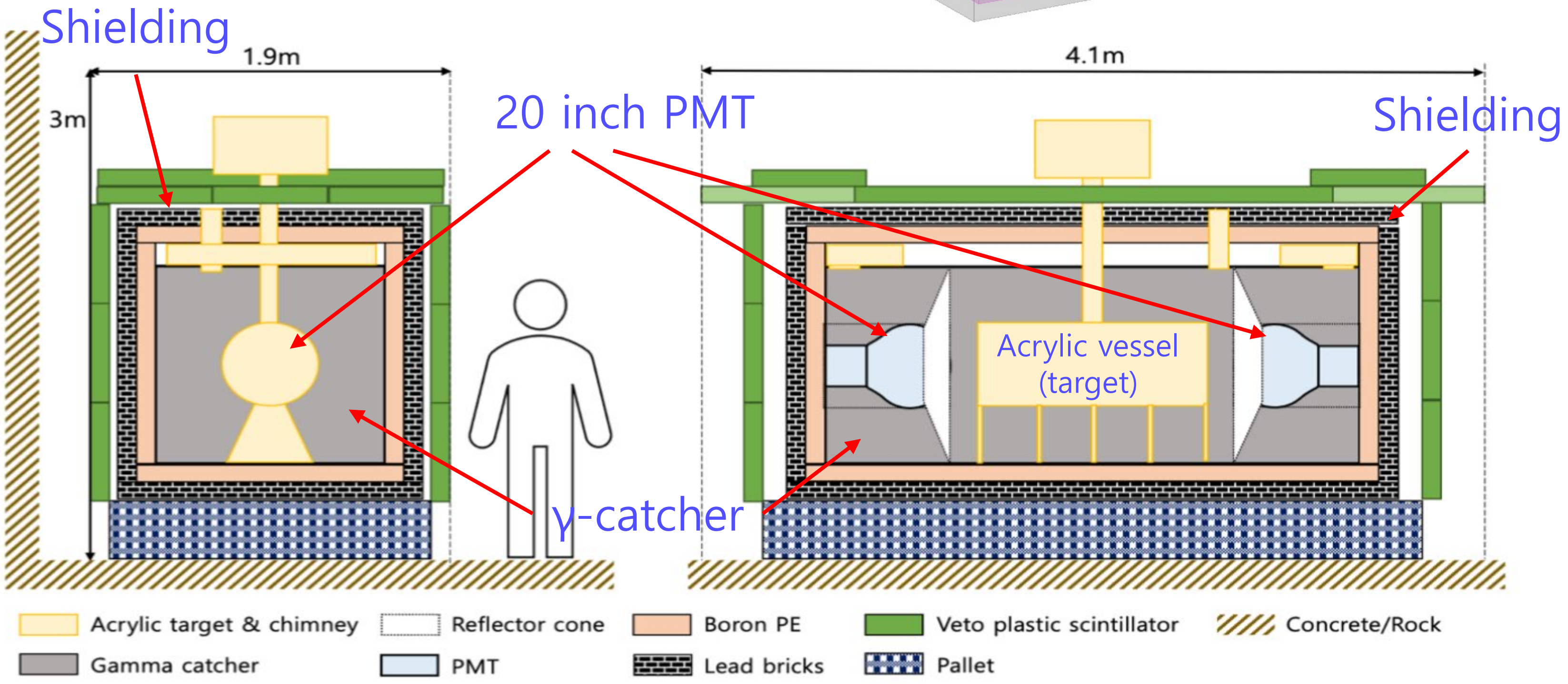


Our LS components: linear alkylbenzene (LAB) + 2,5-diphenyloxazole (PPO) +1,4-bis(2-methylstyryl)benzene (bis-MSB)

RENE Detector : Design

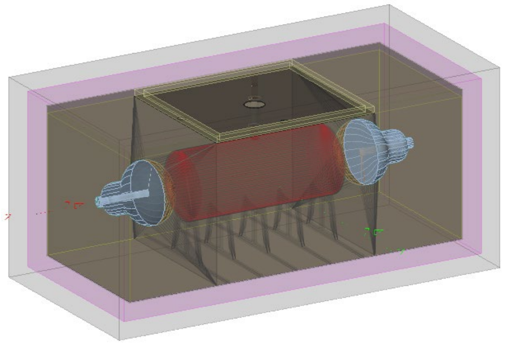
- Cylindrical acrylic target filled with 0.5% Gd-LS.
- 10% di-isopropylnaphthalene (DIN), a commercial LS (EJ-309), will be added for pulse shape discrimination (PSD)
- Box-shaped stainless steel γ-catcher filled with unloaded LS
- Reflector cones to maximize light collection efficiency

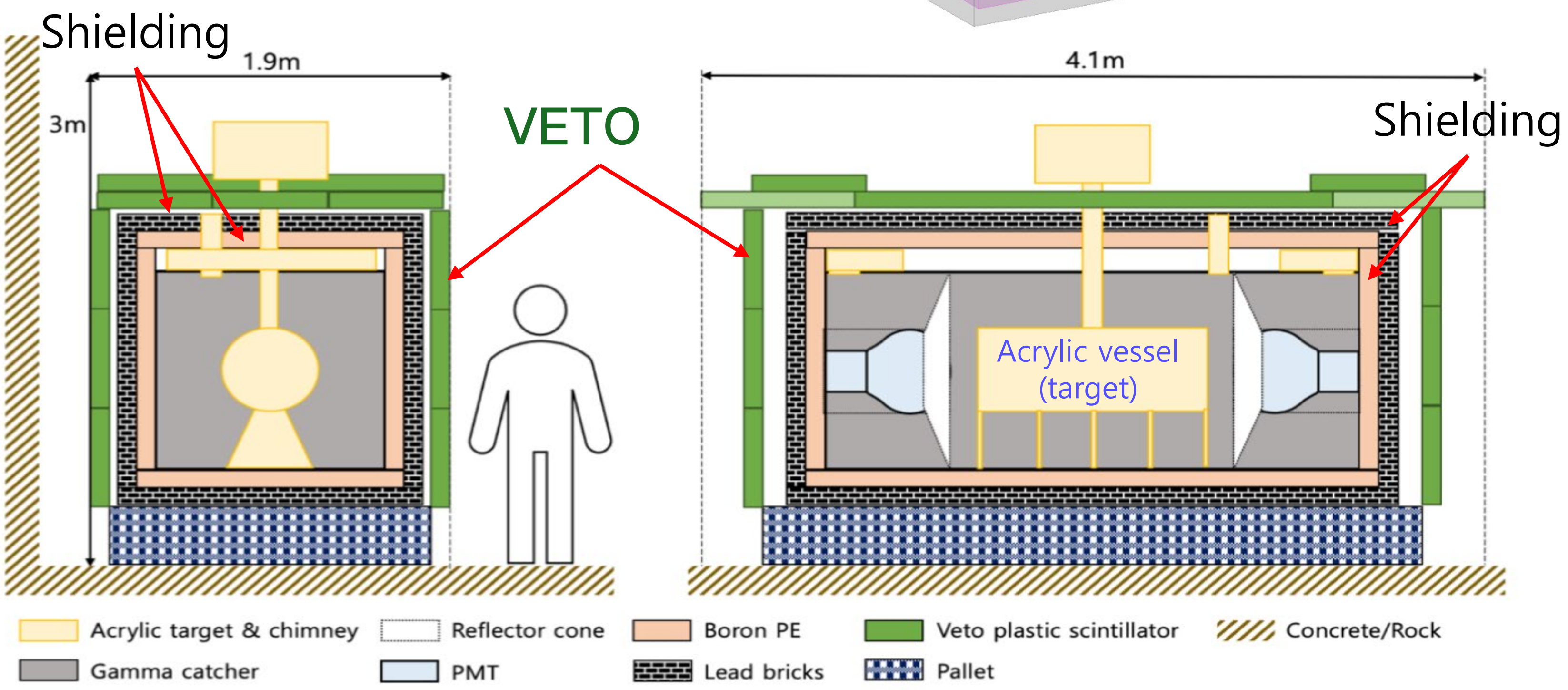




RENE Detector : Design

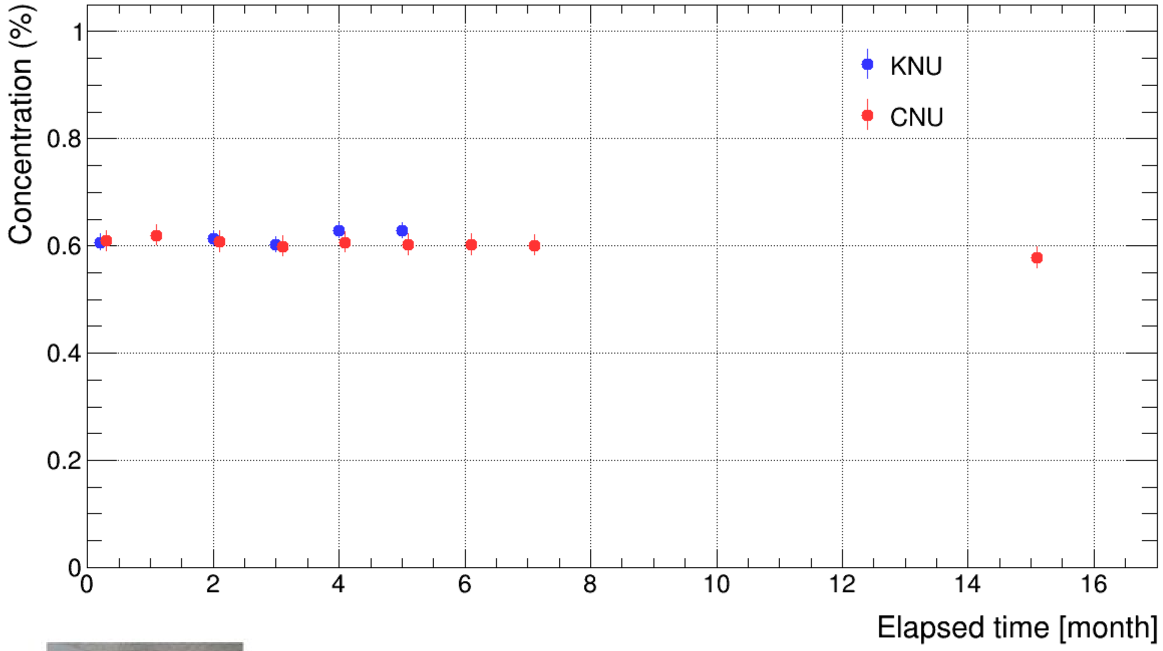
- Two 20-inch PMTs on left and right
- 20-inch PMT holder with Mu-metal shielding
- Passive shielding
  - Boronated and high-density polyethylene plates, and lead bricks
- Veto detectors
  - 15 PS (EJ-200) panels
  - 30 2-inch PMTs for veto detector

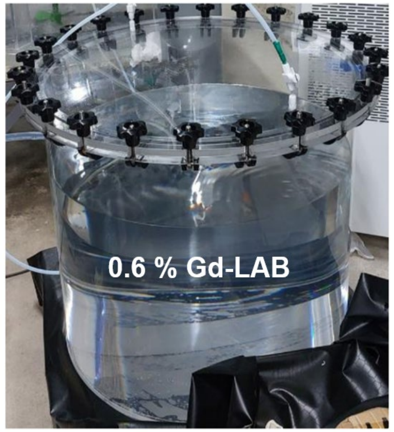




RENE Detector : Components (Gd-LS)

- Total 240 L of 0.6 % Gd-LAB solution is ready
- The final Gd-LS will be synthesized on-site by mixing this Gd-LAB concentrate with the main liquid scintillator during deployment.
- The Gd-LAB and Gd's concentrations have remained stable for over one year
- To enhance PSD, 10% (by weight) of a commercial scintillator (EJ-309) will be added.



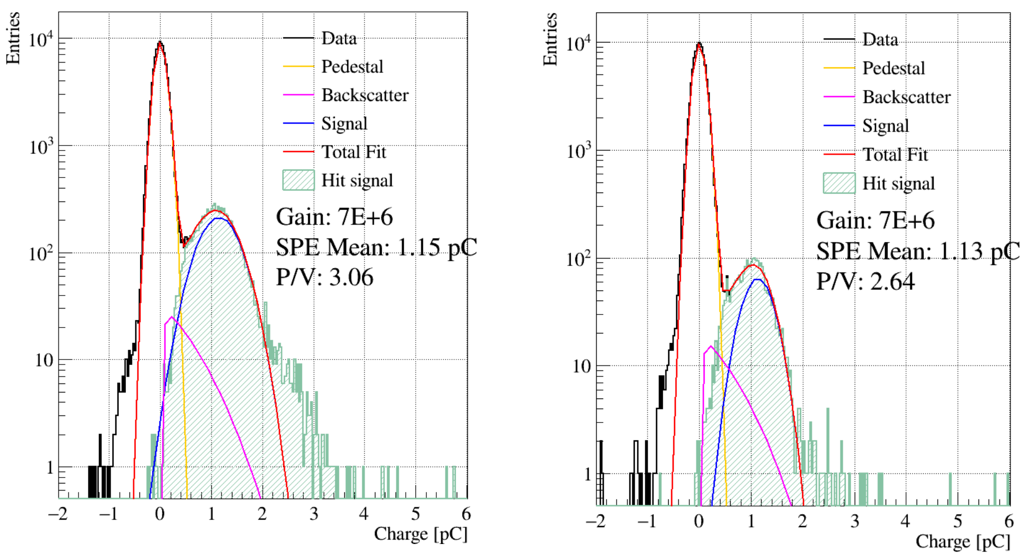


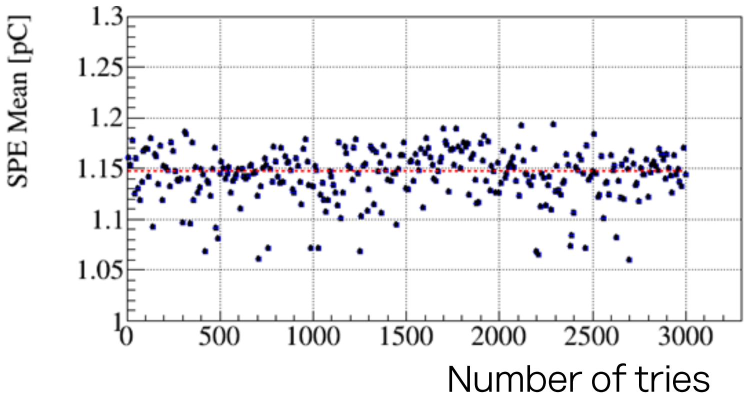
- Our LS ingredients : linear alkylbenzene (LAB) + 2,5-diphenyloxazole (PPO) +1,4-bis (2-methylstyryl) benzene (bis-MSB)
- Gadolinium-loaded linear alkylbenzene: Gd-LAB
- Gd-LS: Gd-LAB + LS

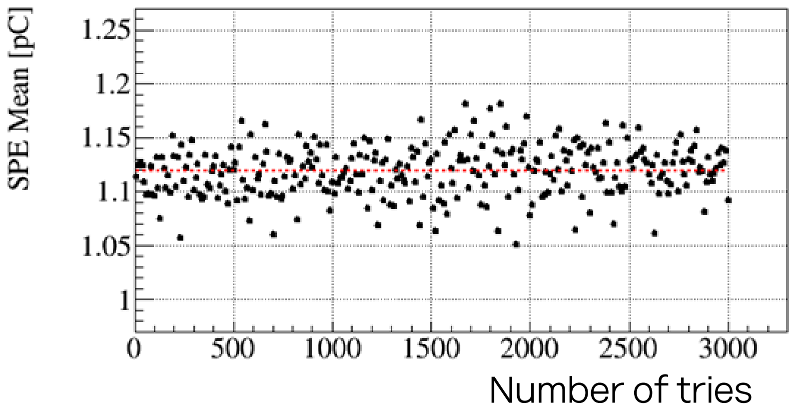
RENE Detector : Components (20-inch PMT)

- Hamamatsu R12660 (Ref. Hamamatsu handbook)
  - Fast time response and high stability (TTS ~ 2 ns)
  - 30% quantum efficiency
- Characterized in a dark box using a pico-pulse laser
- Clear single photoelectron (SPE) peak and good afterpulse discrimination
- Position dependence test completed (center vs. edge).

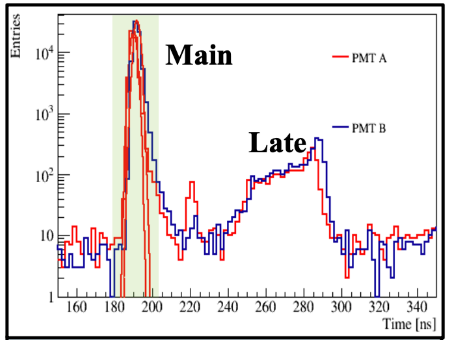
Charge distribution at gain = 0.7×10^6







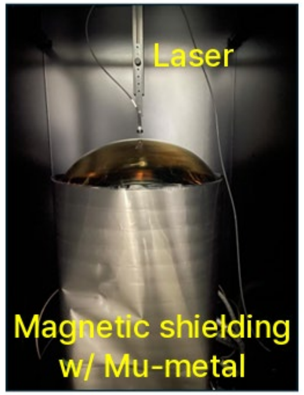
Time response



- Main Time response (A): **189 ± 0.0078 ns**
- Main Time response (B): **191 ± 0.0072 ns**
- Late Time response: **Main + 100 ns**
- Transit Time Spread **(TTS) ≈ 2 ns**

*Time response: Trigger time – PMT falling time

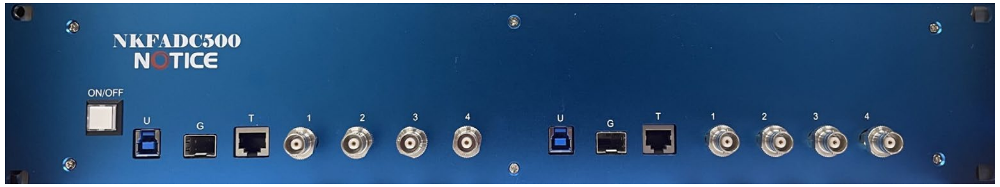
Dark box



RENE Detector : Components (data acquisition system)

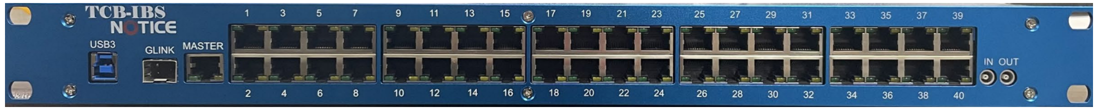
- Custom data acquisition (DAQ) system developed by a domestic Korean company
- The main (20-inch PMT) detector signals are digitized by a FADC (NKFADC500) enabling offline PSD
  - 12-bit resolution, ± 2.5 V_{pp} dynamic range, 4+4 channel, sampling rate = 500MS/ch/s, 4+4Gb DRAM
- Veto (2-inch PMT) detector signals are handled by a 32-channel ADC (M64ADC)
  - 12-bit resolution, ± 2 V_{pp} dynamic range, 32 channe, sampling rate = 62.5 MS/ch/s, 4Gb DRAM
- A Trigger Control Board (TCB) synchronizes the entire system.

NOTICE NKFADC500

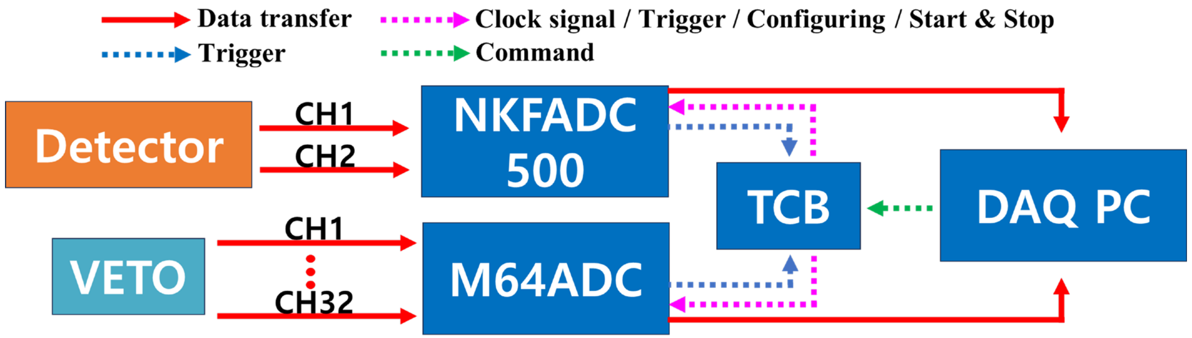


NOTICE M64ADC

NOTICE TCB



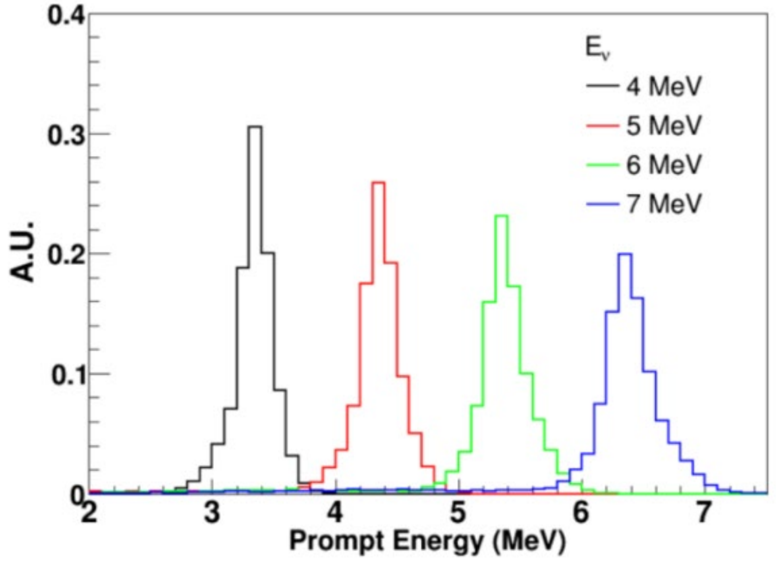
DAQ Schematic.

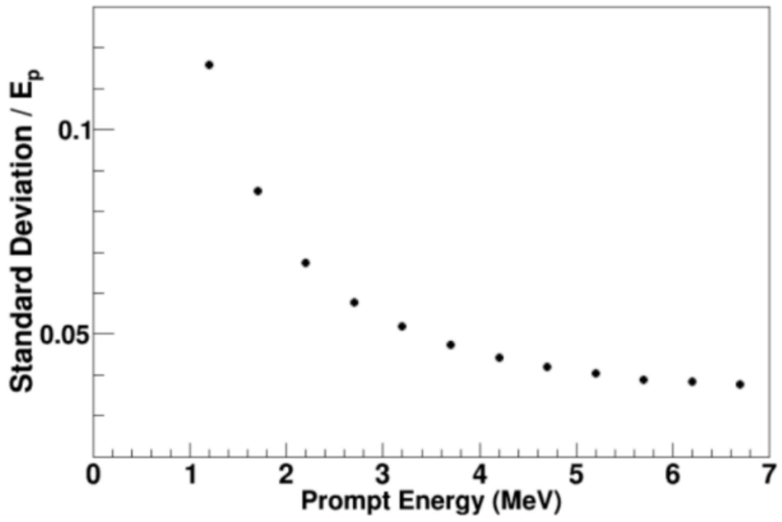


Expected Performance

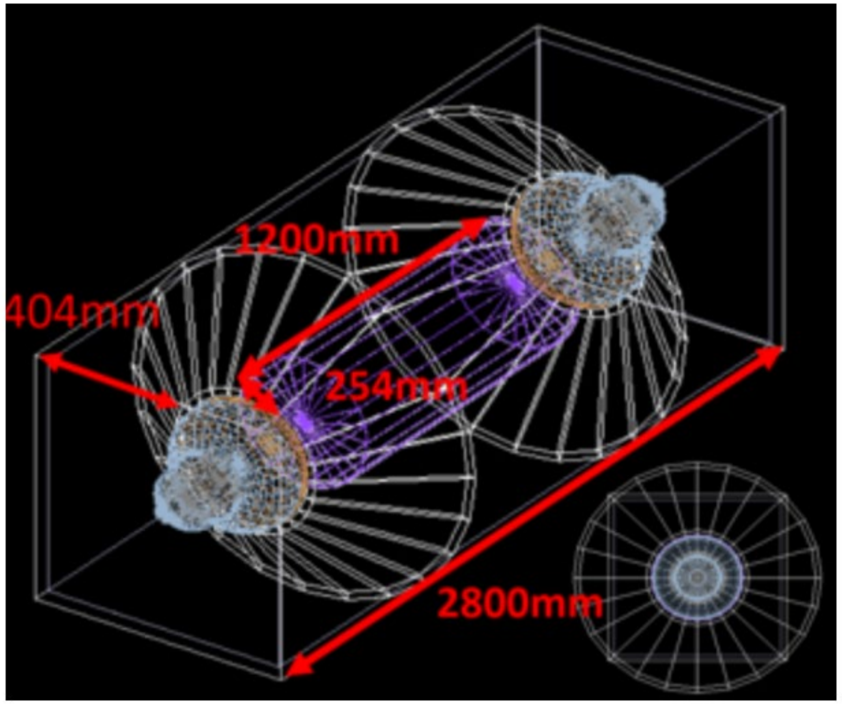
- Simulation toolkit: GLG4Sim
- Energy resolution was evaluated using positrons from IBD events
- Energy resolution is defined as standard deviation over the corresponding energy
- Expected ~ 300 IBD events per day

For simplicity, only positrons with energies of 4, 5, 6, and 7 MeV are shown.



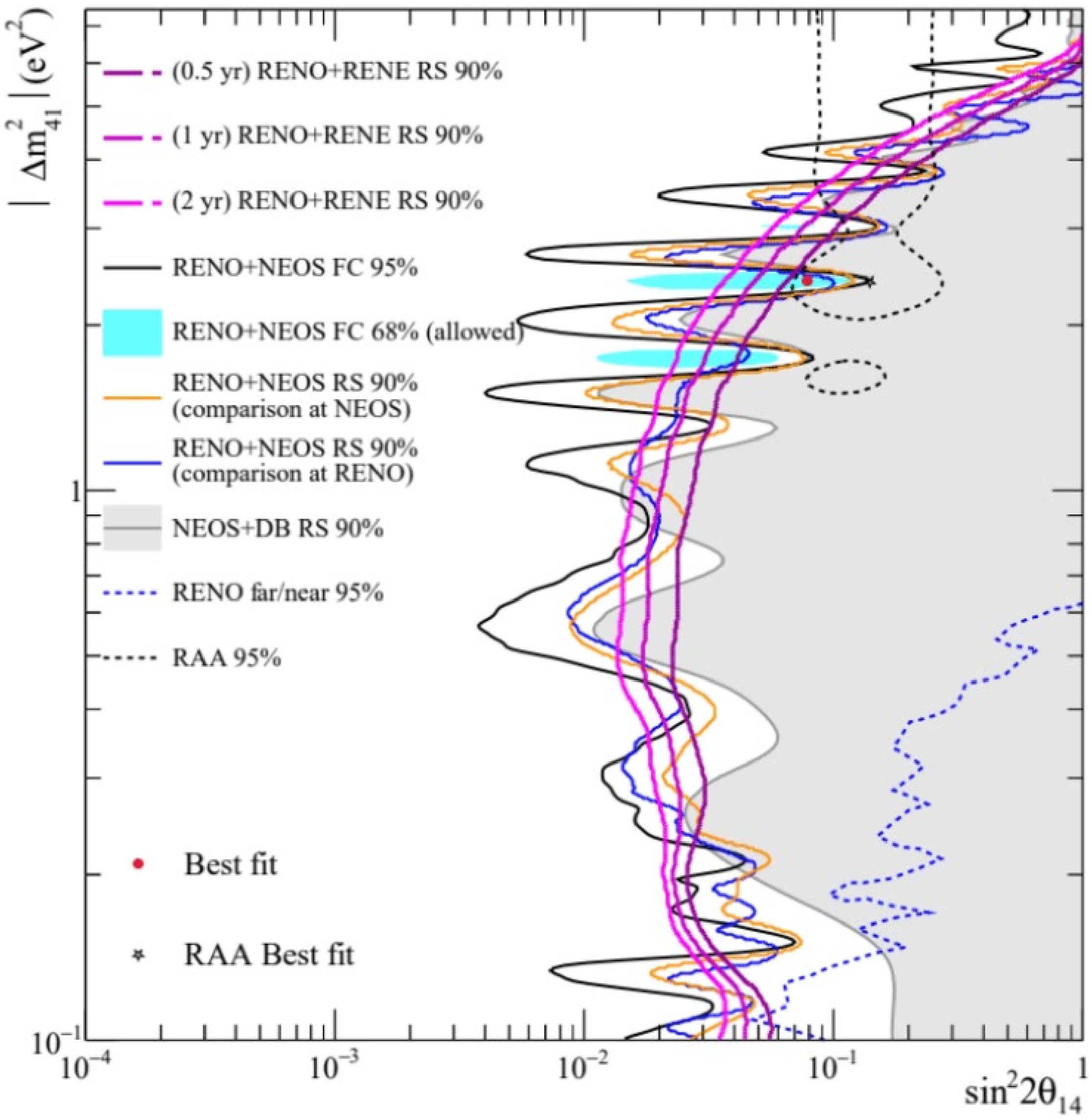


Schematic view of the RENE detector in MC



Expected Performance

- Simulation toolkit: GLG4Sim
- Expected ~ 300 IBD events per day
  - The expected event rate is scaled from previous estimates based on RENE's ~ 0.5-ton target mass
- The sensitivity plot was estimated for 0.5, 1, and 2 years of future data taking.
  - The parameter estimation was based on χ^2 test with quadratic forms
- The analysis combines RENE's projected data with existing RENO near detector data.



Project Timeline

Year	2022				2023				2024				2025			
Month	1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12
Collaboration Start																
Design																
Simulation																
Gd-LS and LS																
DAQ																
PMT																
Construction																
DAQ Commissioning (CNU site)																
RENE Data-taking																

: RENE started

We are in the detector commissioning phase at Chonnam National University (CNU)

A paper detailing the RENE technical design report is currently undergoing the peer-review process, with publication expected soon.

3

Summary and outlook

Summary

- Inspired by the hint of RENO-NEOS joint analysis, RENE is designed to search for the sterile neutrino around $\Delta m^2 \sim 2\ eV^2$
- Detector commissioning is ongoing at CNU
- Deployment is pending regulatory approval of installation in the tendon gallery of the Hanbit reactor
- Stay tuned for future results from RENE