WIND
Water In Neutrino Detectors

Kim Siyeon
Chung-Ang University

for

IAEA Technical Meeting 2025

Seoul, Korea

Water In Neutrino Detectors

- WbLS into RENO Detectors

  - Kilo-ton Scale Detector R&D

  - GeV-scale neutrino detection
    - 300-ton DUNE FD4 Prototype
    - Atmospheric neutrinos

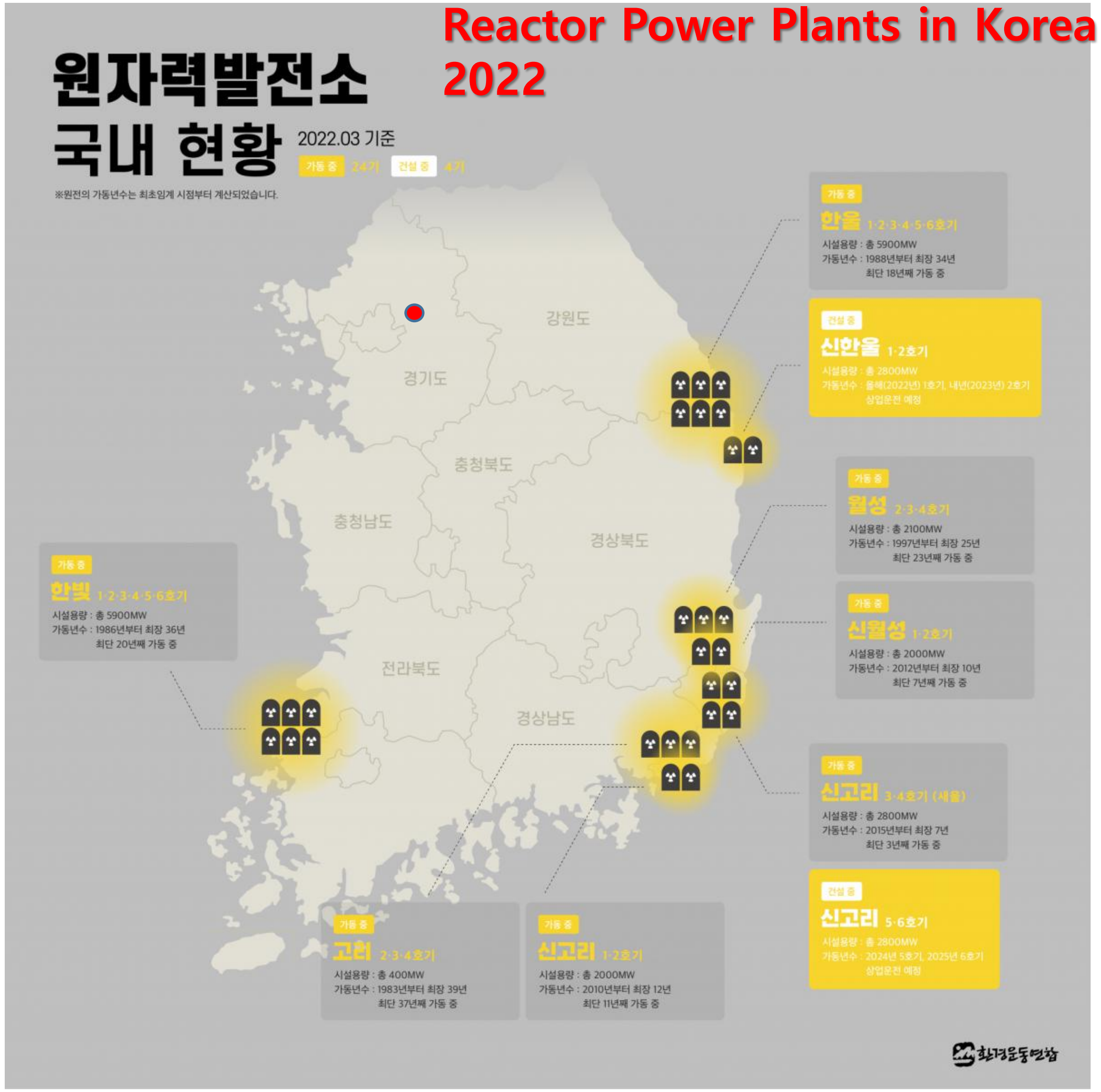
  - MeV-scale neutrino detection
    - Solar / SN neutrinos
    - Reactor Antineutrino Detection
      - Spectrum near 5-Mev with water target
      - Monitoring for non-proliferation

RENO

Reactor No.	Near Detector (m)	Far Detector (m)
1	667.9	1556.5
2	451.8	1456.2
3	304.8	1395.9
4	336.1	1381.3
5	513.9	1413.8
6	739.1	1490.1

Table 1.2: Distances of the reactor cores from the near and far detectors.

Reactor Power Plants in Korea 2022

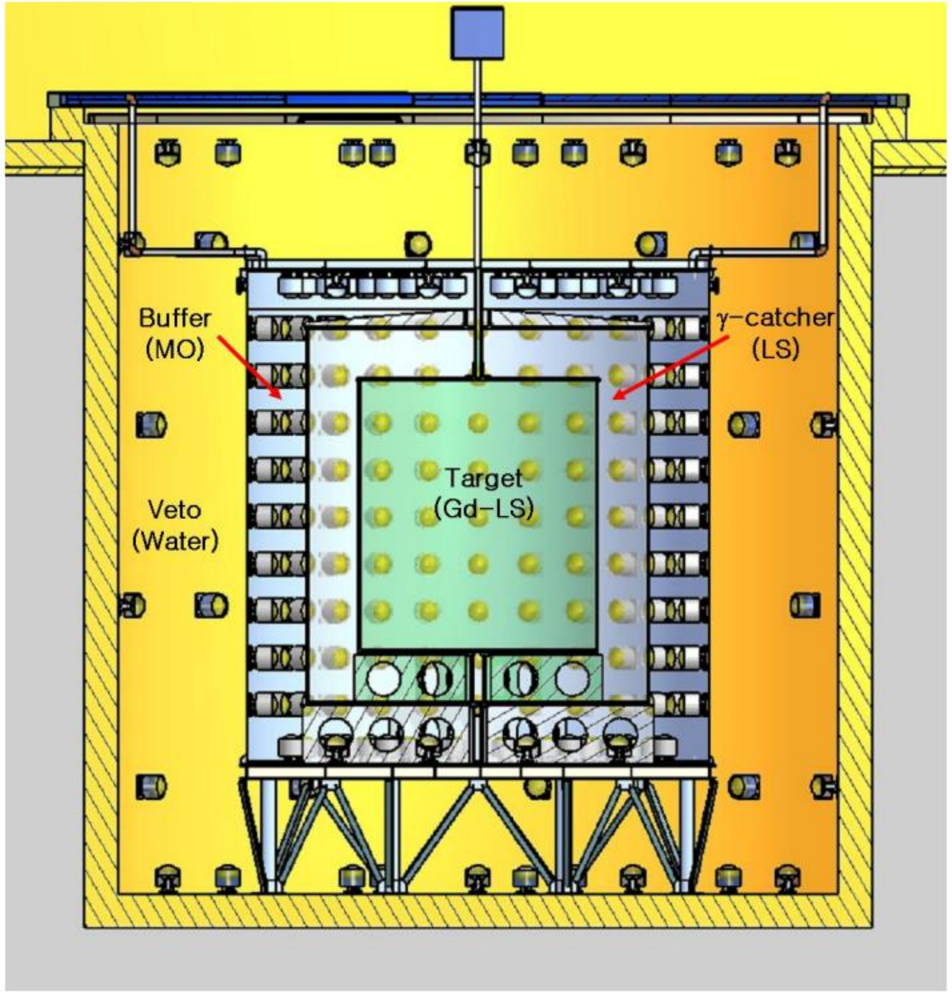


RENO

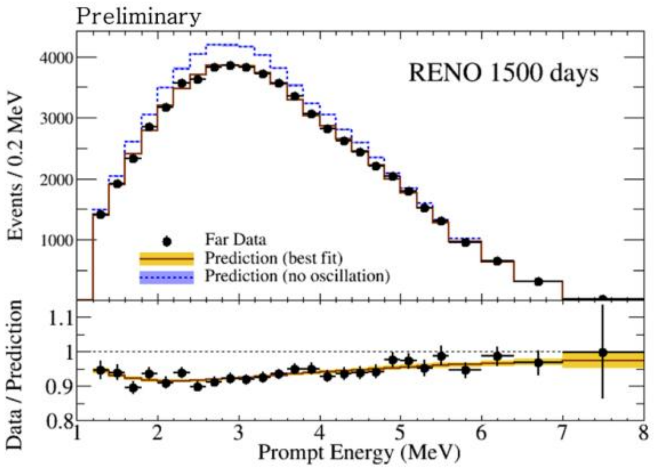
- Overburden: ND 120 m.w.e.
  FD 450 m.w.e.
- Target: 16-ton Liquid Scintillator with 0.1% Gd
- PMT: 354 10-inch Hamamatsu (R7081)
- 14% photo-sensitive surface area coverage
- IBD rate per day without background :
  FD 46.8 / ND 464 for 1.2 MeV<E_p<8 MeV

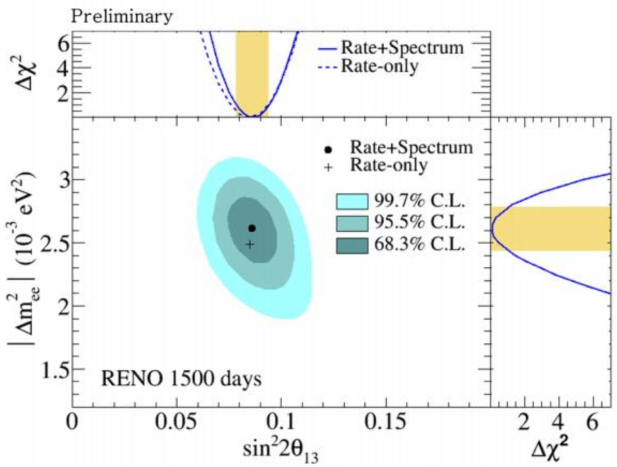
Detector Component	Outer Diameter(mm)	Outer Height(mm)	Thickness (mm)	Material	Volume (m^3)	Mass (tons)
Target	2750	3150	–	Gd-loaded LS	18.70	16.08
Target Vessel	2800	3200	25	Acrylic	0.99	1.18
γ-catcher	3940	4340	570	LS	33.19	28.55
γ-catcher Vessel	4000	4400	30	Acrylic	2.38	2.83
Buffer	5388	5788	694	Oil	76.46	64.22
Buffer Vessel	5400	5800	6/12*	SUS	1.05	8.39
Veto	8400	8890	1500	Water	354.84	354.84

Table 3.1: Dimensions of the mechanical structure of the detector. (*)The buffer vessel thickness is 6 mm for the top and barrel sections and 12 mm for the bottom section.



RENO





$$\sin^2 2\theta_{13} = 0.086 \pm 0.006(\text{stat.}) \pm 0.005(\text{syst.})$$

$$|\Delta m^2_{ee}| = 2.61 + 0.15 - 0.16(\text{stat.}) \pm 0.09(\text{syst.}) (\times 10^{-3} \text{eV}^2)$$

- Accomplishment: The first measurement of theta_13 with Daya Bay, 2012
- Hanbit Nuclear Power Plant in Yong Gwang
- 2009-2011 Construction and Commissioning of 2 identical detectors
- August 2011, RENO began collecting data.
- March 2023, Data taking was concluded after about 3800 live days.

WbLS basic performance

Slide of
Dr. G. Yang

Brookhaven
National Laboratory

- Developed and characterized a variety of WbLS formulas for multiple frontiers.
- In the context of neutrino physics, Cherenkov and Scintillation light separation is a key feature.

In general:

- Scintillation light yield proportional to WbLS concentration
- Scintillation light later than Cherenkov light
- Scintillation light with a narrower wavelength distribution than Cherenkov light
- Scintillation light generated isotropically

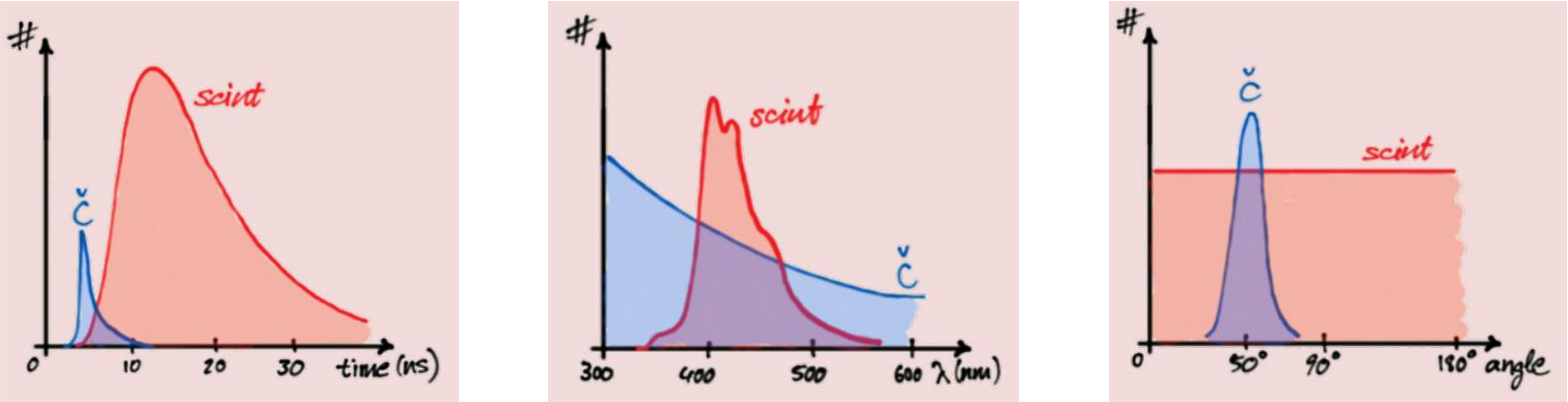


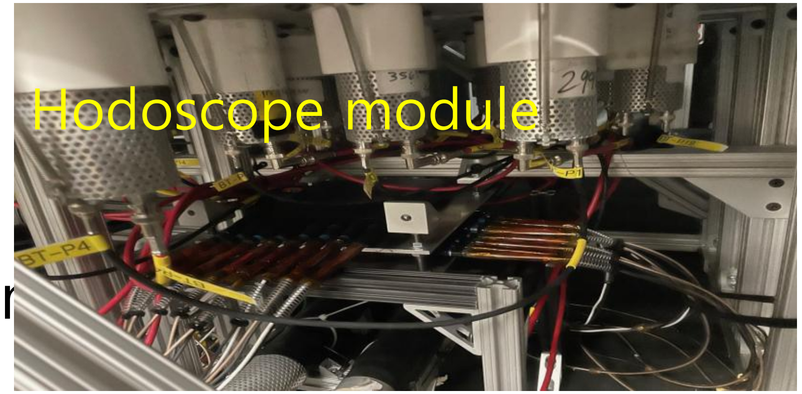
Figure 4. A wide angle view of the 1-ton testbed facility at BNL.

Brookhaven National Laboratory

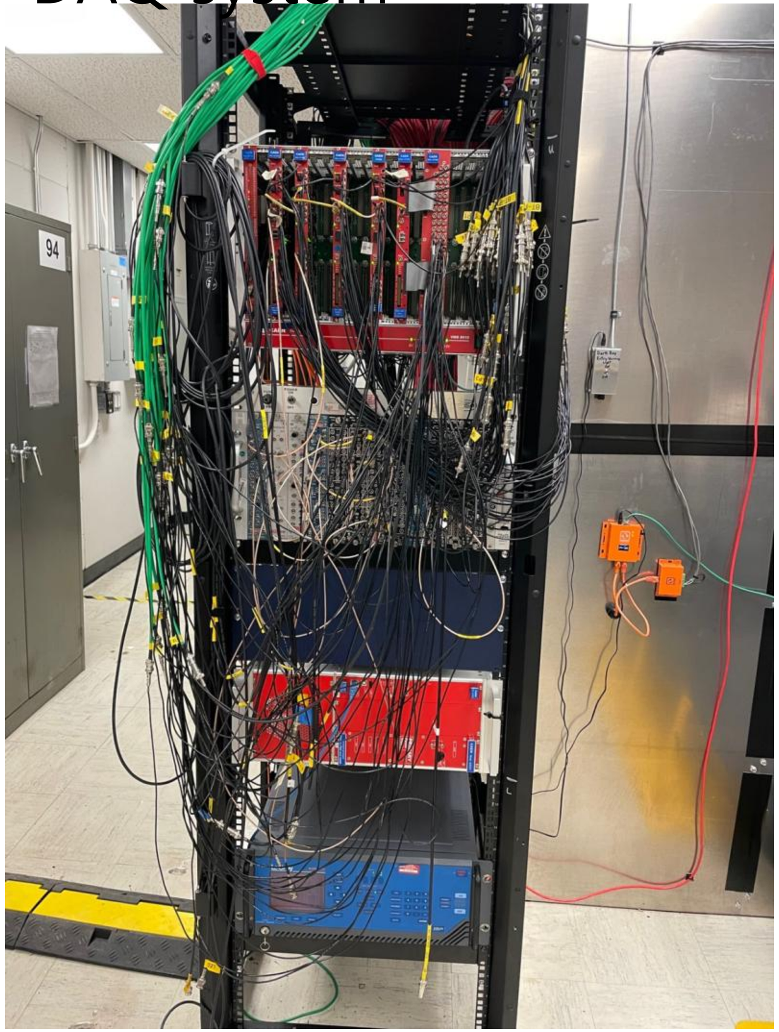
Slide of
Dr. G. Yang

BNL 1T detector

Nano-filteration system



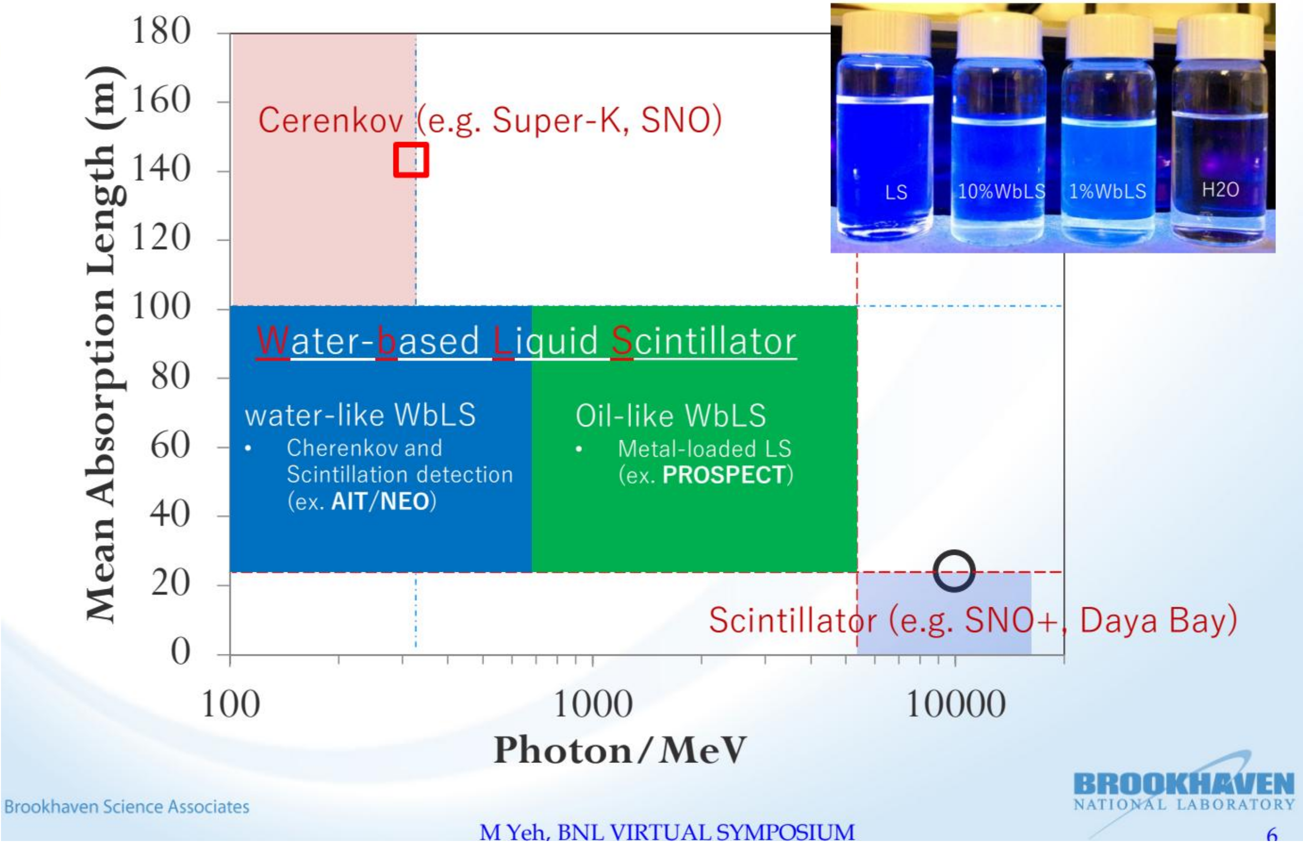
DAQ system



30 2″ PMTs on the bottom
28 3″ PMTs on the side
2 16-channel hodoscope modules

1ton under UV

Slide of
Dr. G. Yang



Operation of 1-ton WbLS, arXiv:2403.13231

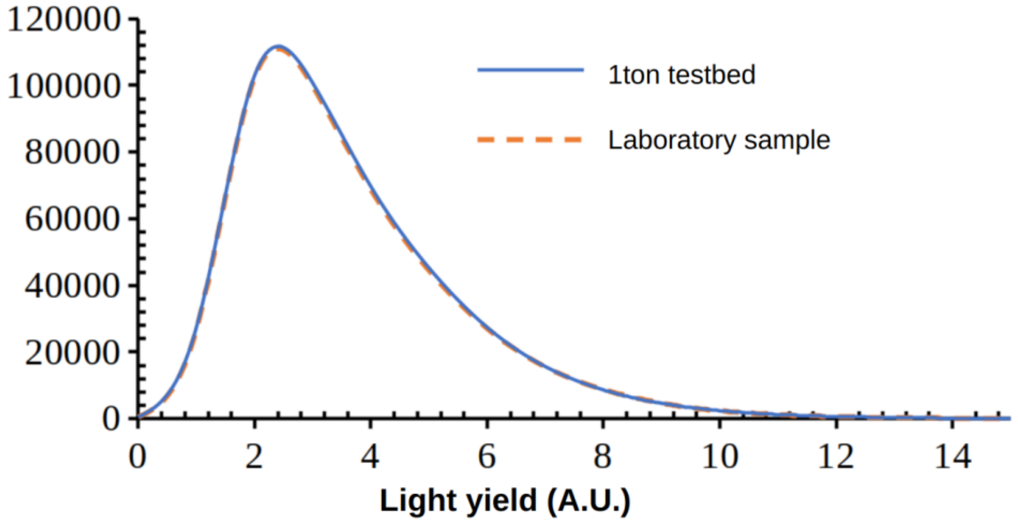


Figure 6. The relative light yield of WbLS from the 1-ton system compared to laboratory samples.

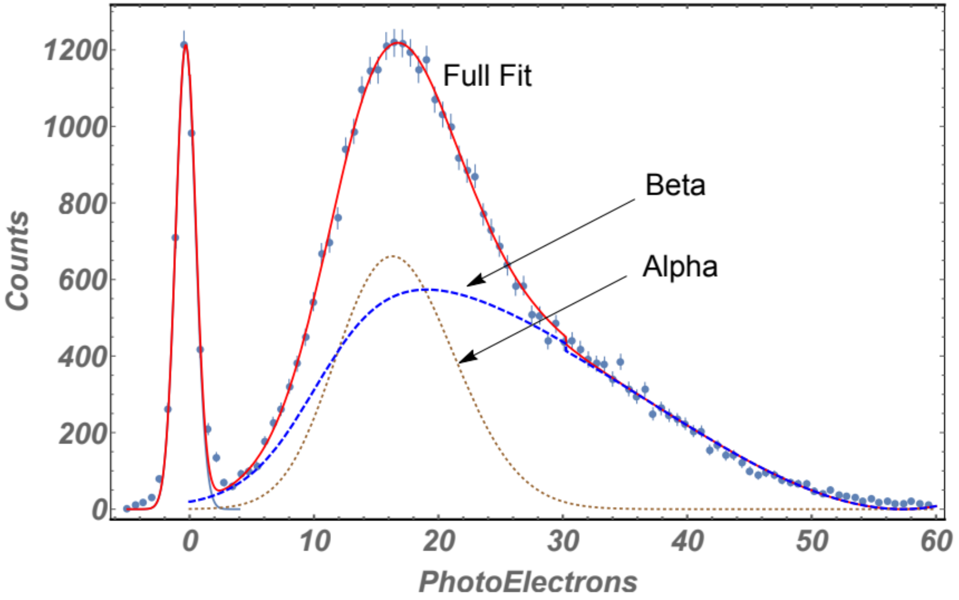


Figure 9. The total photoelectron yield from a single day of data from the calibration source with a model for α and β components. The yield was obtained by summing the signals over all PMTs. The pedestal at zero is due to accidental triggers. The alpha (peak at 16 pe) and beta (tail extending to 60 pe) components in the spectrum are separated with a model that includes a rising threshold at 10 pe. The red curve is the total spectrum including all components, and the blue dashed curve is the beta component.

Operation of 1-ton WbLS, arXiv:2403.13231

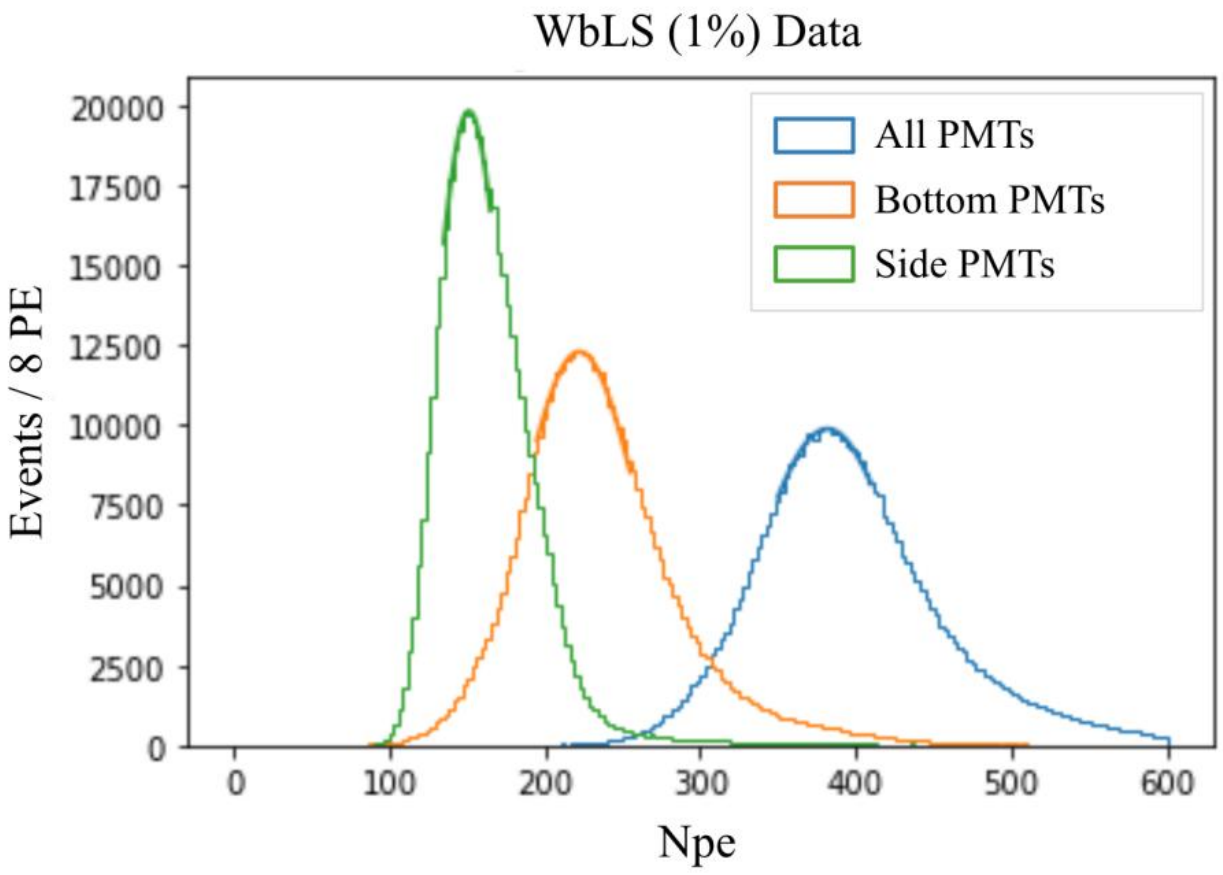
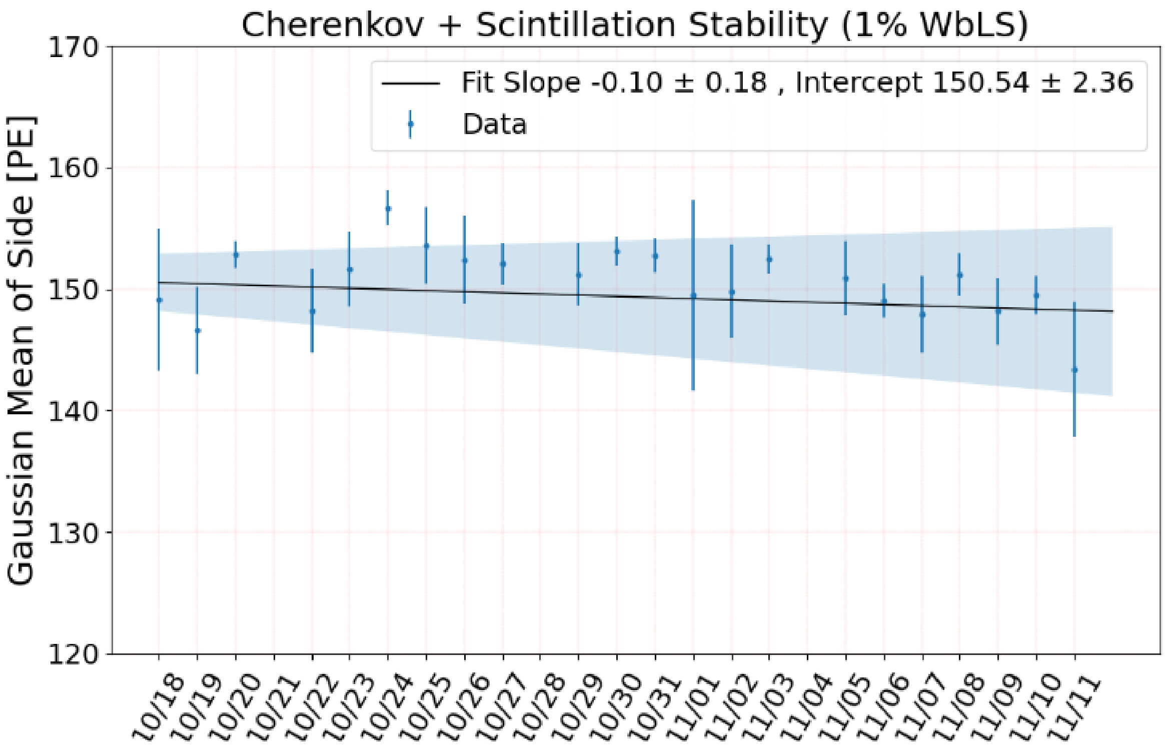
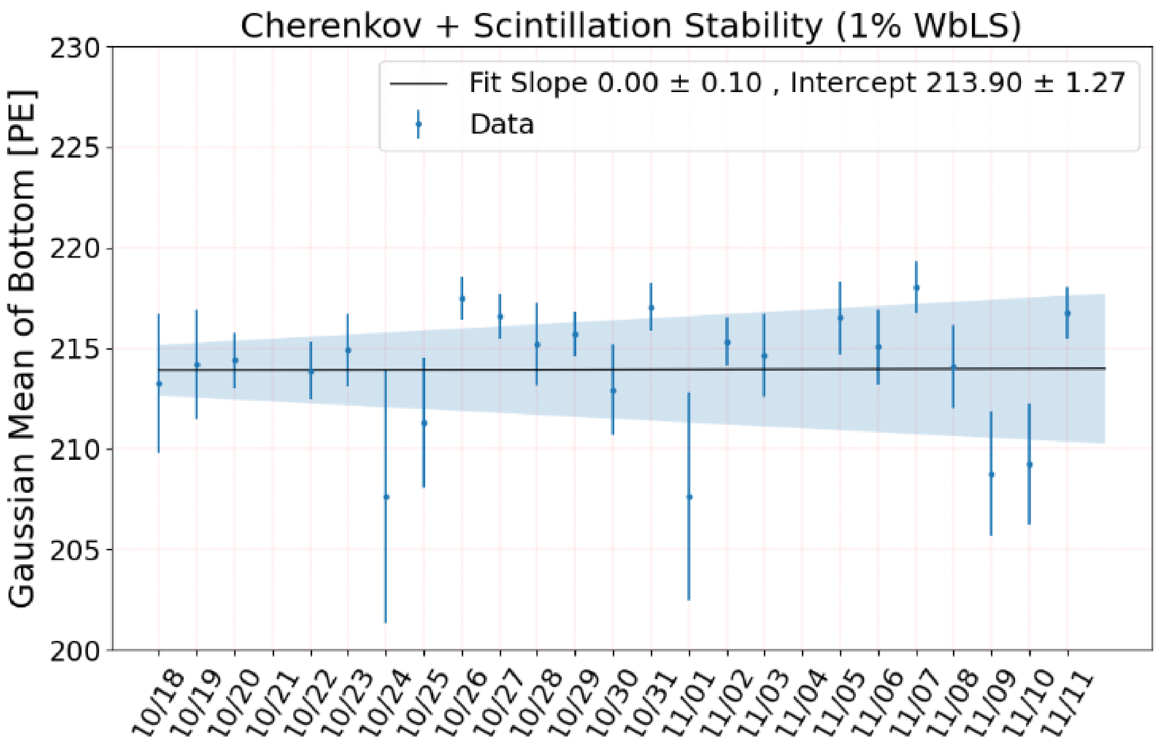


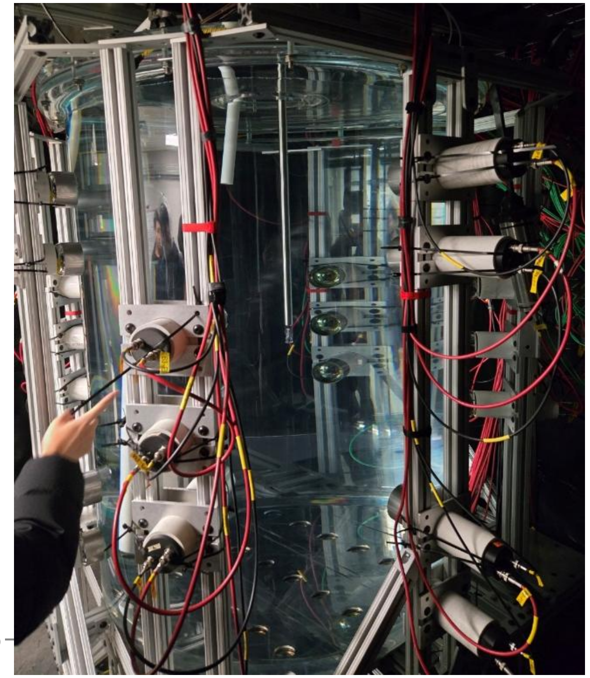
Figure 11. The PE distributions for side, bottom, and all PMTs with a requirement of the sum of photoelectrons for the bottom two rows of PMTs between 65 and 140.

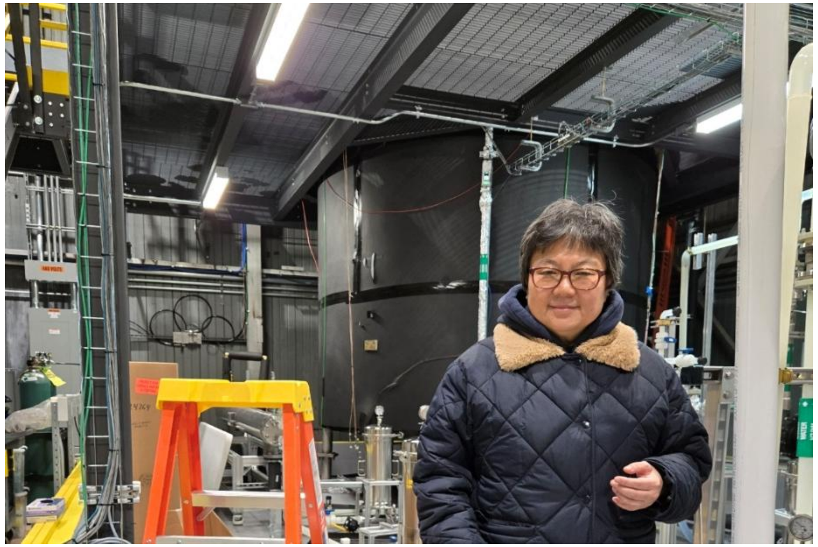
BNL 1T performance - Stability





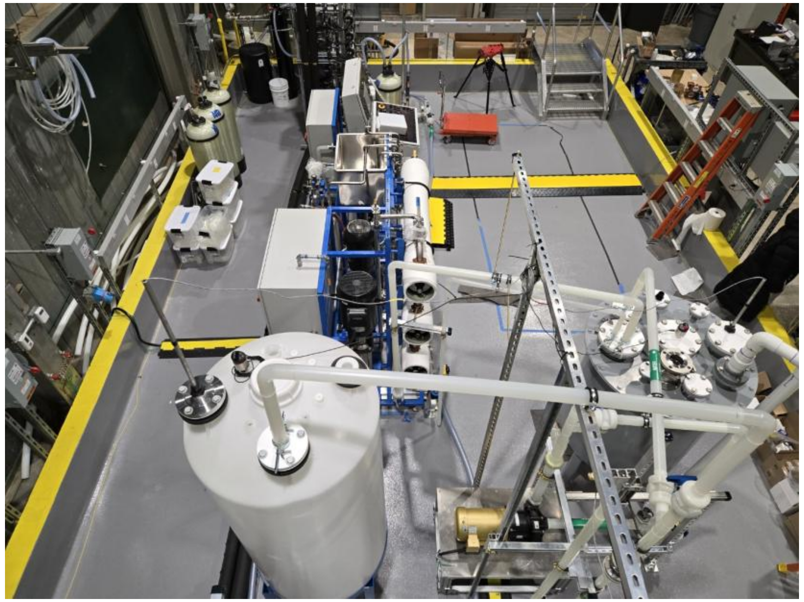
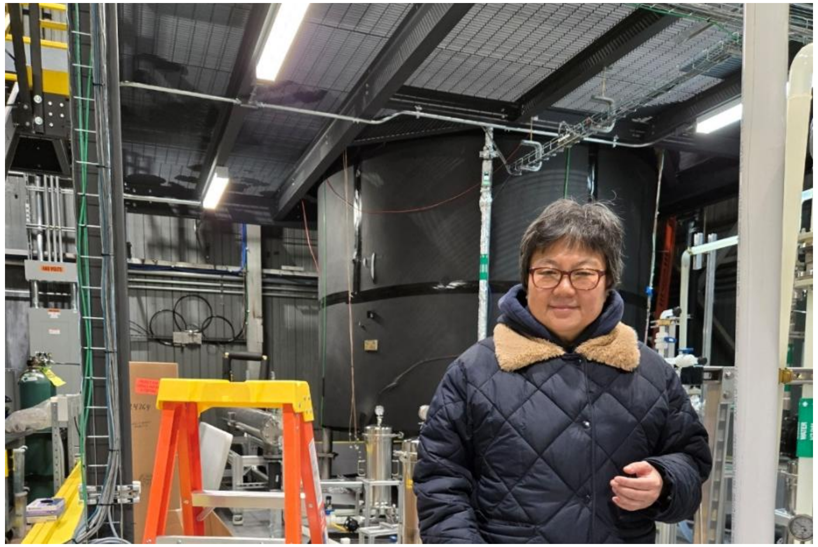
Cooperation of CAU Nula and BNL WbLS Group





BNL WbLS 30 ton



Projects of Water-Based Liquid Scintillator

Project	Size	Purpose	Status
BNL 1-ton WbLS	1 ton	- Study light yield, timing, and scaling potential	Operation
BNL 30-ton WbLS	30 ton	- To characterize the properties of WBLS as prototype for large-scale neutrino experiments - Aiming to evaluate the scalability and stability - Testbed for refining WbLS formulations, purification techniques, and deployment methods.	Operation Mixing LS
EOS (UC Berkeley)	4 ton	- 240 PMT - The separation of Cherenkov and scintillation at a multi-ton scale. - Directional Resolution with beta sources. - Advanced photodetector technologies, e.g., fast-timing PMTs and Dichroic filters for spectral photon sorting. - Expecting insights for the design of larger-scale detectors	Commissioning
Theia-25 Theia-100	25 kton 100 kton	DUNE FD4 Neutrinoless Double Beta Decays	Conceptual Design

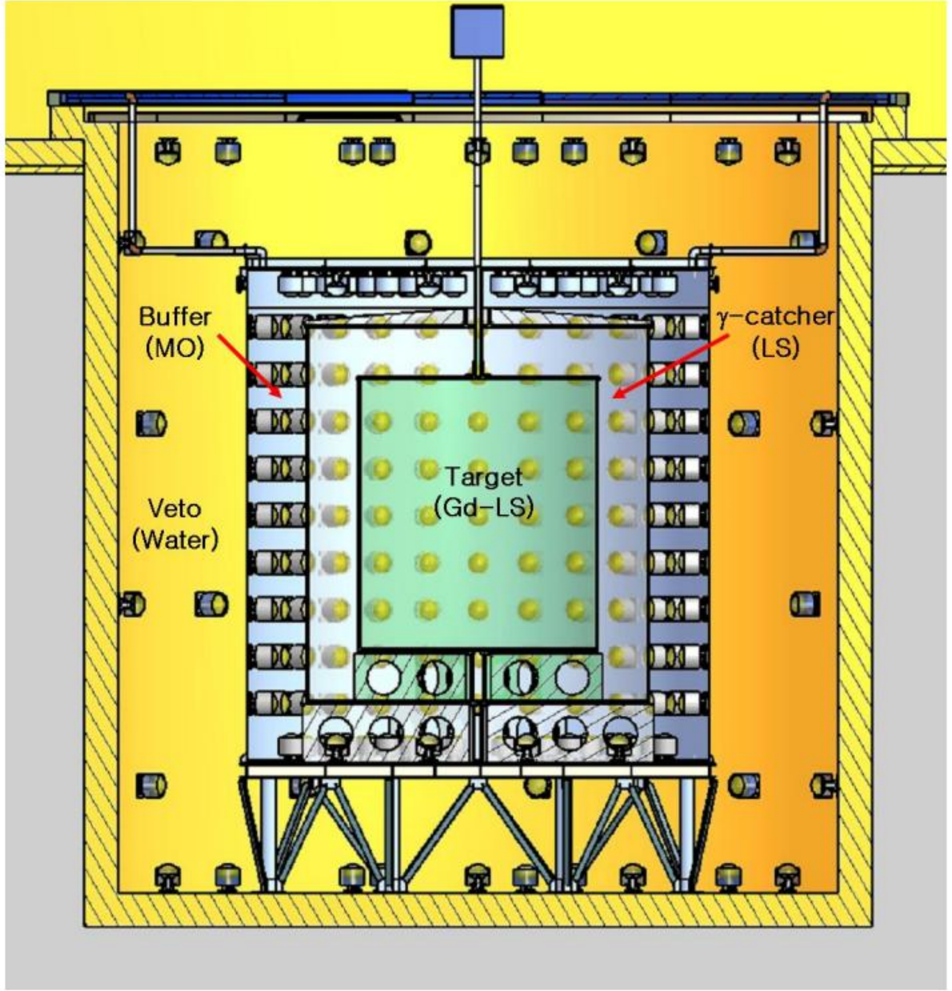
Projects of Water-Based Liquid Scintillator

Project	Size	Purpose	Status
ANNIE (Accelerator Neutrino Neutron Interaction Experiment)	366 liters	- Neutron yields from nu-nucleus interaction - Fermilab - Neutron tagging in a beam environment	Operation
CHESS (Cherenkov and Scintillation Separation)	~liters	- Tabletop scale - To study the separation of Cherenkov and scintillation light in WbLS operation	R&D
WATCHMAN (WATer Cherenkov Monitor for Anti-Neutrinos)	1 kton	- Under consideration for AIT-NEO (Advanced Instrumentation Testbed-Neutrino Expt. One) - The feasibility of remote monitoring of nuclear reactors via antineutrino detection. - To utilize WbLS to improve sensitivity to antineutrino signals - USA and UK	Under Development

WATCHMAN for Non-Proliferation

- 1100-m Boulby Underground Laboratory
- 1-kton WATCHMAN
- 30-ton BUTTON (Boulby Underground Technology Testbed for Observing Neutrinos)
  >> Button1000
- Hartlepool Reactor
  - 26 km from Boulby
  - 2 cores of 1.5 GWth
- Heysham Reactor
  - 148 km from Boulby
  - 4 cores of 1.5 GWth

RENO Detector



	U-235	U-238	Pu-239	Pu-241
Fission Fraction	57.4%	7.3%	29.8%	5.5%
Released Energy [MeV]	202.36	205.99	211.12	214.26

Phys. Rev. D **104**, L111301

Phys. Rev. C **88**, 014605

$$\langle Y_{IBD} \rangle = 5.891 \times 10^{-43}\ \mathrm{cm^2/fission}$$

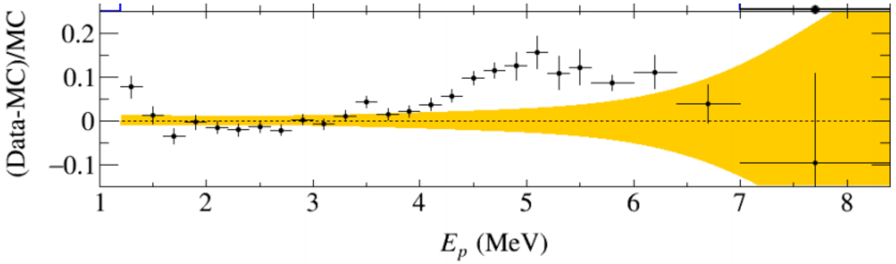
RENO's average IBD yield

Phys. Rev. D **104**, L111301

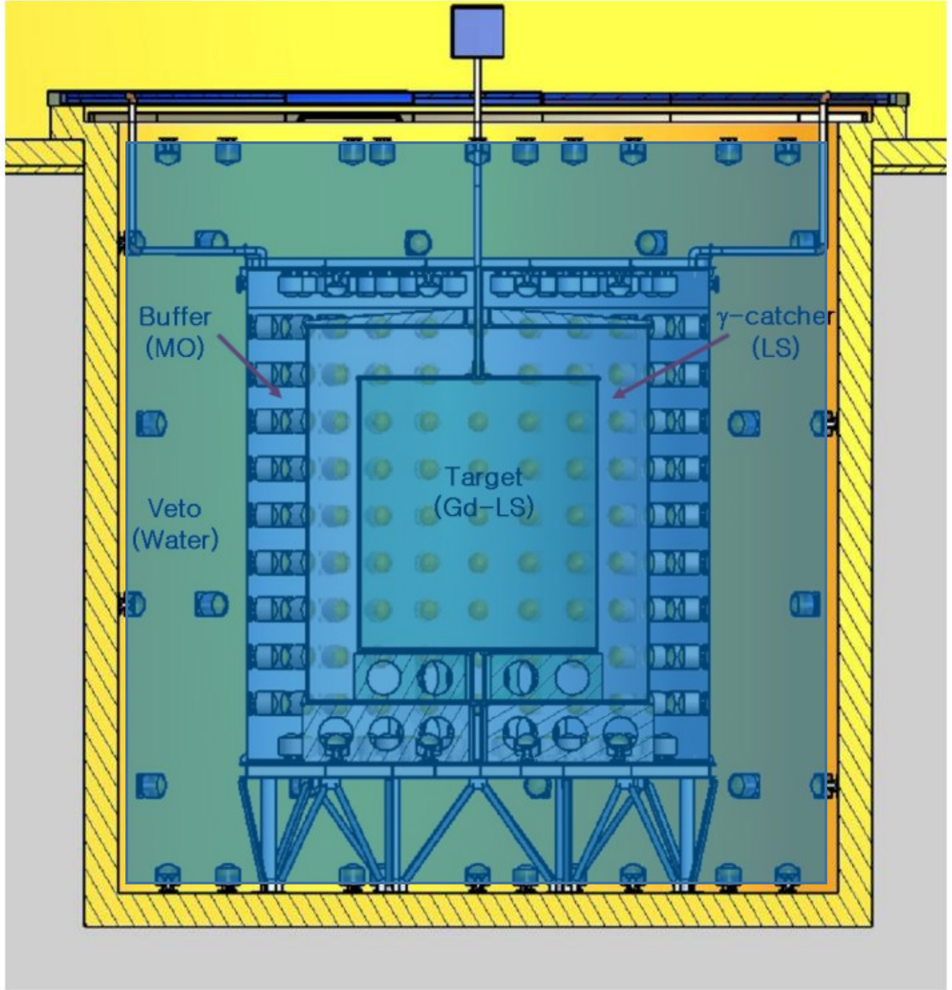
From Yang's Slide "RENO"

- 1,211,995(144,667) $\bar{\nu}_e$ candidate events observed for near(far).

Detector	Near	Far
IBD rate	366.47 ± 0.33	38.70 ± 0.10
after background subtraction	357.39 ± 0.38	36.64 ± 0.16
total background rate	9.08 ± 0.18	2.06 ± 0.13
live time [days]	3307.25	3737.85



Water In the Neutrino Detector



- Water 450 m^3
- Inner surface 270 m^2
- 350 PMT -> photo-cathode coverage 6.5%
  1500 (2000) PMTs -> 27.8% (37.0%)

- Number of protons N_p = 3.02 x 10^{31}
- Efficiency ε= 70%
  - Cf: RENO 76.5%, Daya Bay 78.8%
- Number of neutrino events

$$N_\nu = \sum_i^6 \frac{N_p \epsilon}{4\pi L_i^2} \langle Y_{IBD} \rangle \frac{P_{th,i}}{\langle E_{rel} \rangle}$$

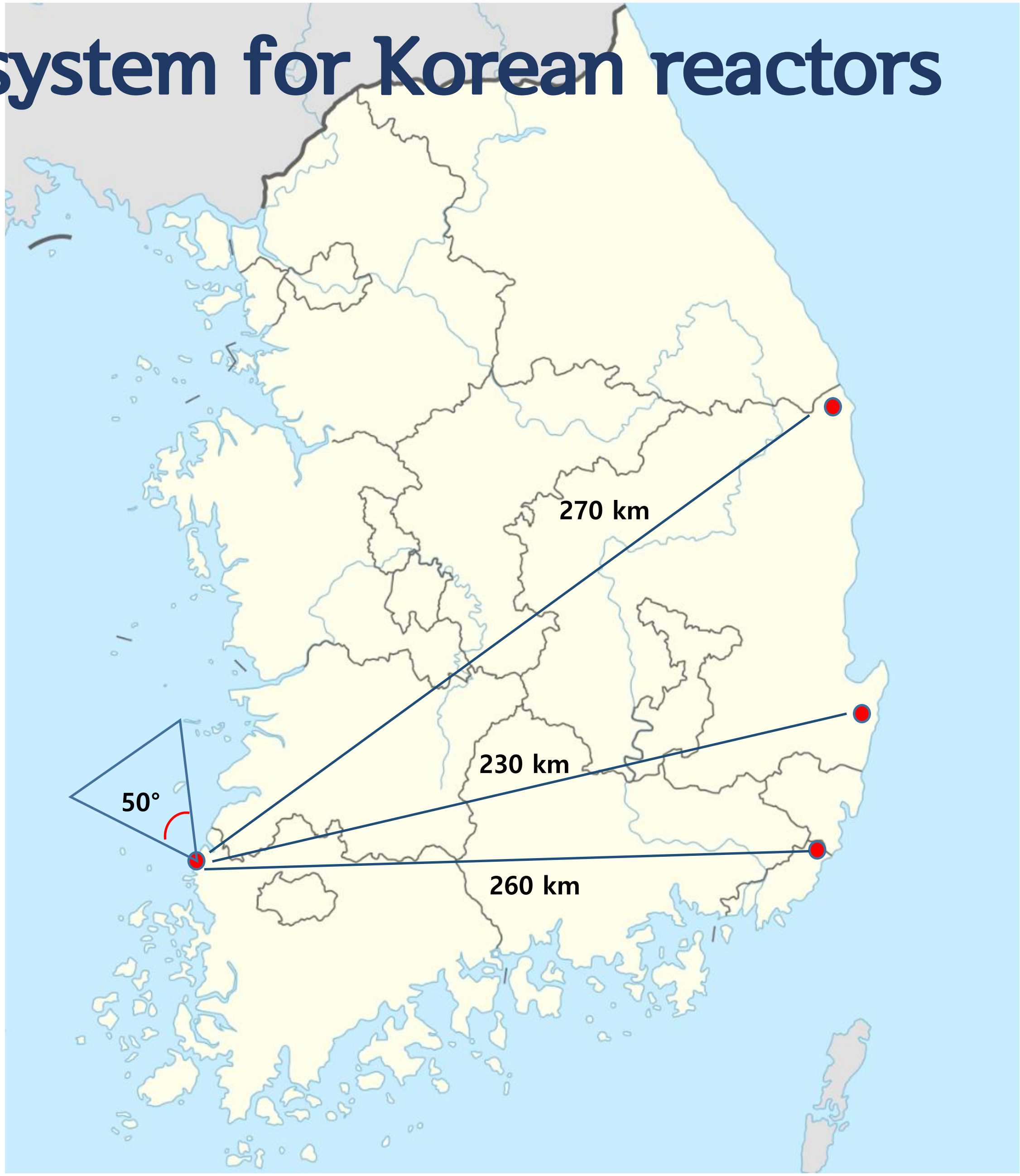
Estimated by Young Ju Ko

- 2,090 per day >>> 763,000 per year
  - Cf: RENO 144,667 / 3800 days

- Sufficient statistics for 5-MeV excess using the target H_2O.

Monitoring system for Korean reactors

Thermal Capacity (MWth)	
Hanbit	L (meters)
2787	1556
2787	1456
2825	1396
2825	
2825	
2825	
total	16.9 GWth

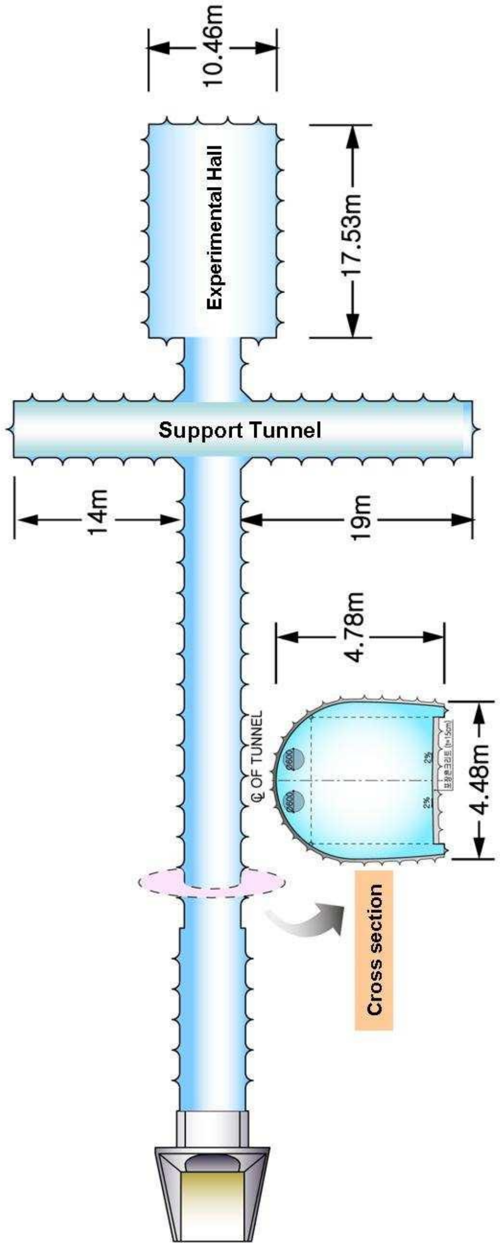


Thermal Capacity (MWth)	
Hanul	Shin-Hanul
2775	3983
2775	3983
2825	
2825	
2825	
2825	
total	24.8 GWth
Wolsong	Shin-Wolsong
~~2061~~	2825
2061	2825
2061	
2061	
total	16.0 GWth
Kori	Shin-Kori
~~1723~~	2825
1882	2825
2912	
2912	
total	13.4 GWth

From PRIS at IAEA.org

WIND Water In Neutrino Detectors

- WbLS into RENO Detectors



Concluding Remarks

WIND (WbLS in RENO FD)

WbLS is a novel type of particle detector to take advantage of both Cherenkov and scintillation light detection.
- Cherencov >> Directional info and fast timing
- Scintillation >> High LY and good energy resolution

RENO Site
- Renovate and reuse the neutrino detector hall and the well.
- Good size and distances from reactor plants in South Korea.
- Chance to validate the 5-MeV excess issue with water target.