The νEYE (new eye) Neutrino Telescope

K-Neutrino Symposium 2025
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Chung-Ang University

Eunil Won
Korea University, June 26, 2025

NEWS | 30 May 2024

Disputed dark-matter claim to be tested by new lab in South Korea

A multi-million dollar facility is hoping to put a 21-year-old debate about dark matter to rest.

Yemilab "LSC hall" can host O(2) kilo tonne detector

Two posters

- νEYE physics
- νEYE detector

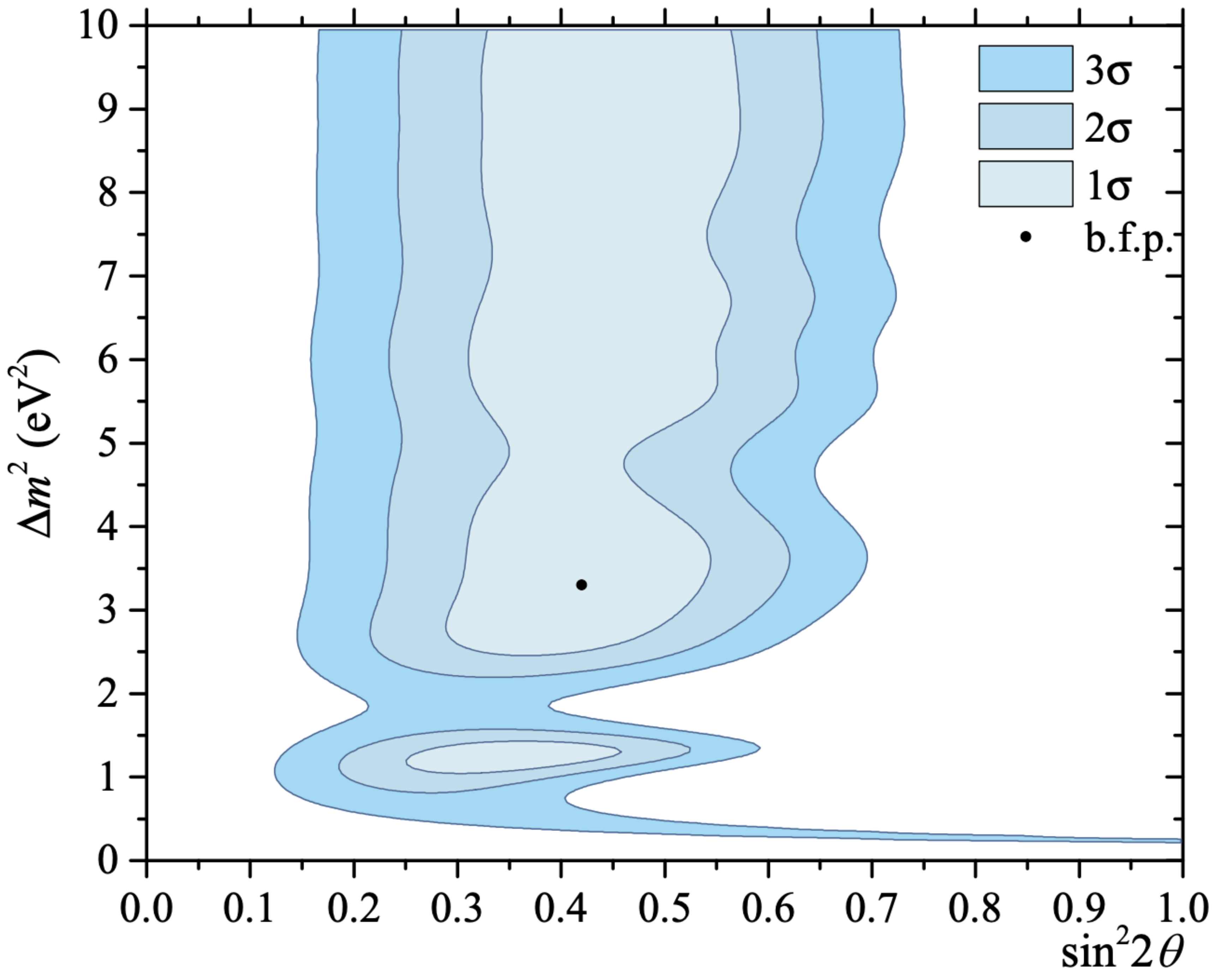
Selected Physics Cases

Summary of sterile neutrino search over the last 20 years

Since the LSND anomaly, a lot of efforts went into the search for the sterile neutrino.

- KARMEN (neutron spallation) did not confirm LSND.
- MiniBooNE ($\nu_e + \bar{\nu}_e$) compatible with LSND but with low energy excess.
- μBooNE disfavors MiniBooNE and LSND (not rule out completely).
- Daya Bay, RENO found deficit but likely due to flux calculation issue.
- NEOS, STEREO, PROSPECT, DANSS, SOLID: no evidence, Neutrino4 found arguable 3σ signal ($\Delta m^2 = 7\ eV^2$).

- SAGE, GALLEX (solar ν_e disappearance) found Gallium anomaly.
- Most recently BEST experiment claimed 4σ signal (3.4 MCi ^{51}Cr source, radiochemical method)

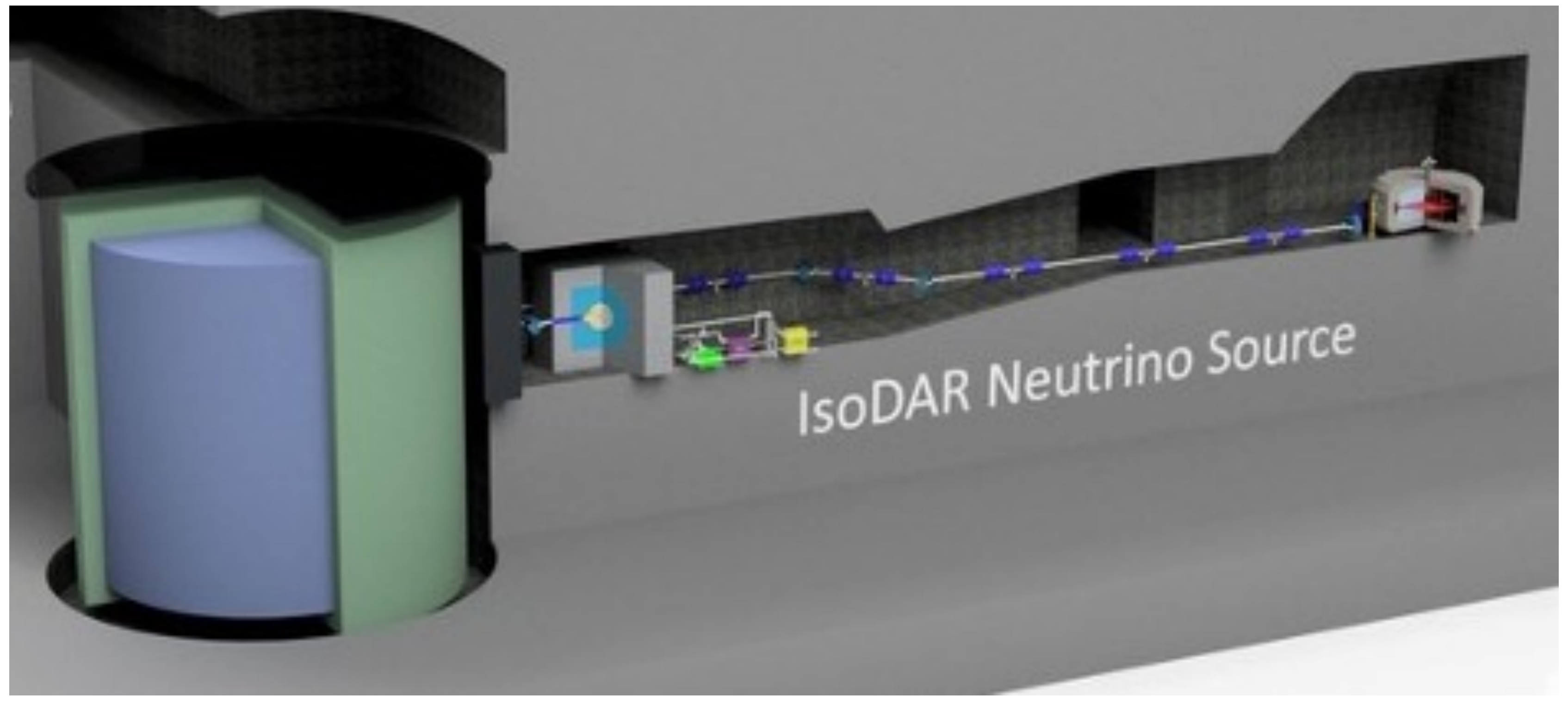


Baksan Experiment on Sterile Transitions (BEST)

Phys. Rev. Lett. 128, 232501 (2022)

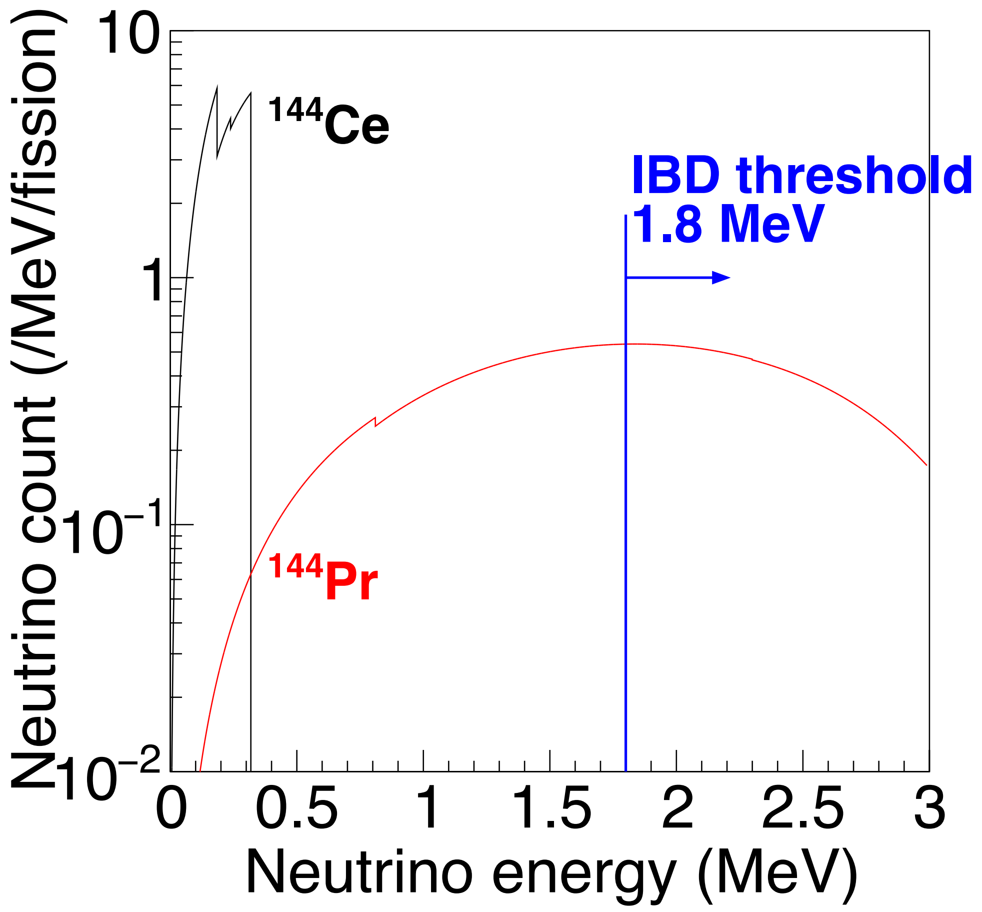
Sterile neutrino search with νEYE

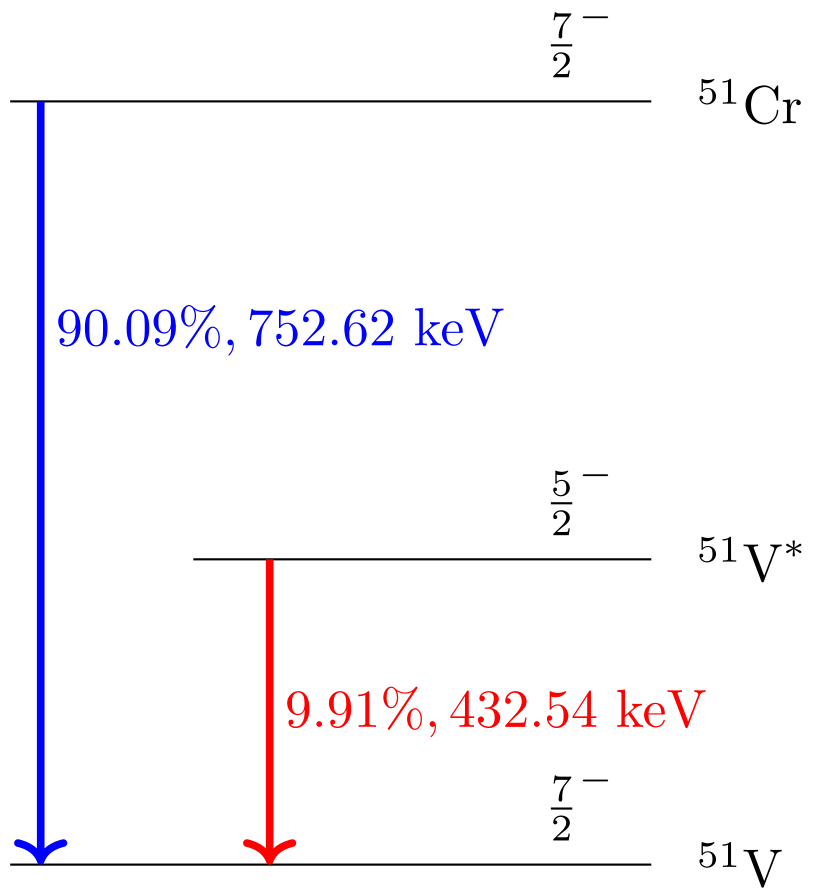
Option 1: Generation of neutrinos with high-intensity accelerator (IsoDAR).

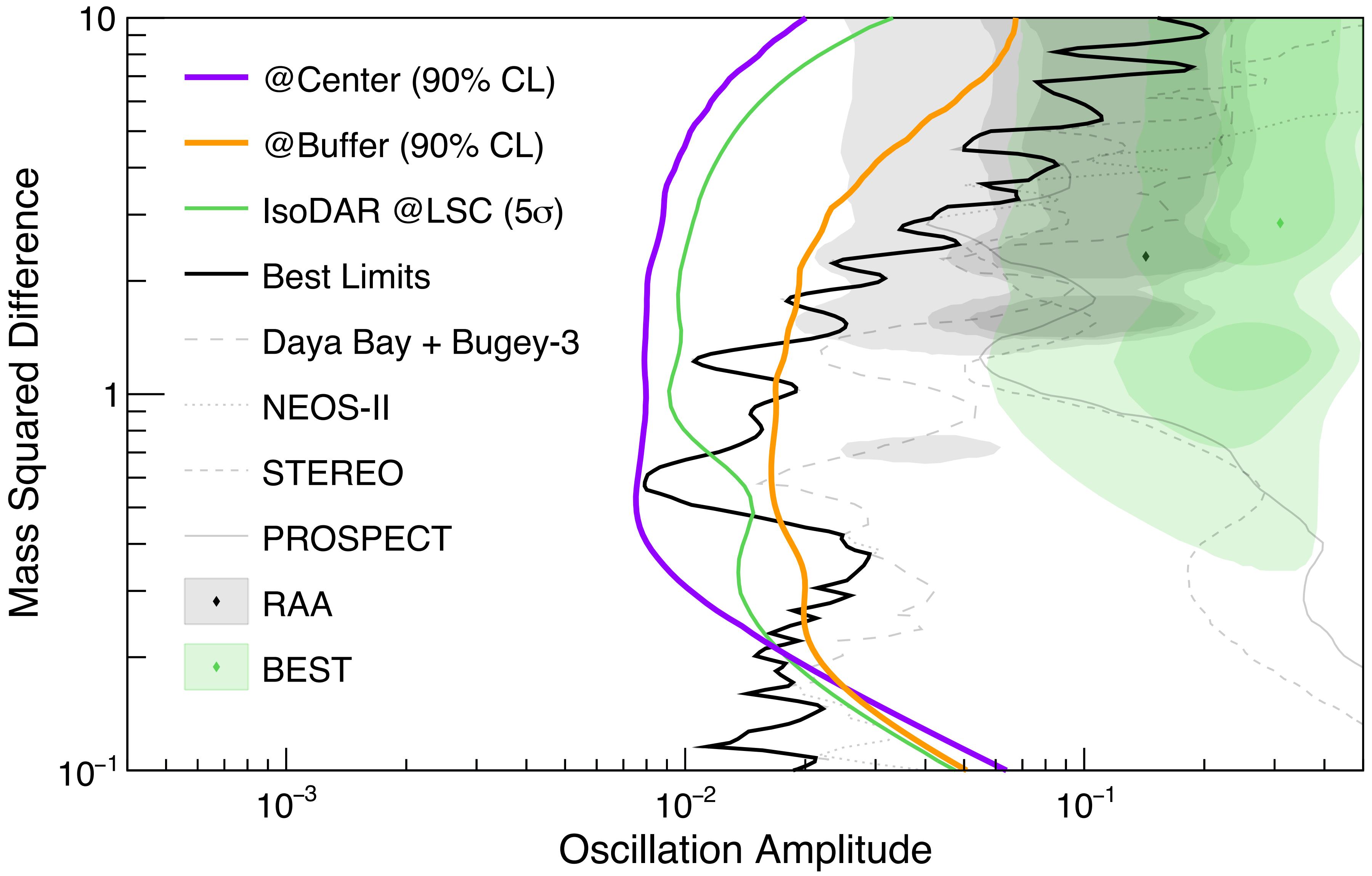


(Isotope Decay-At-Rest)

Option 2: use high activity radioactive source + in situ detection of signal.





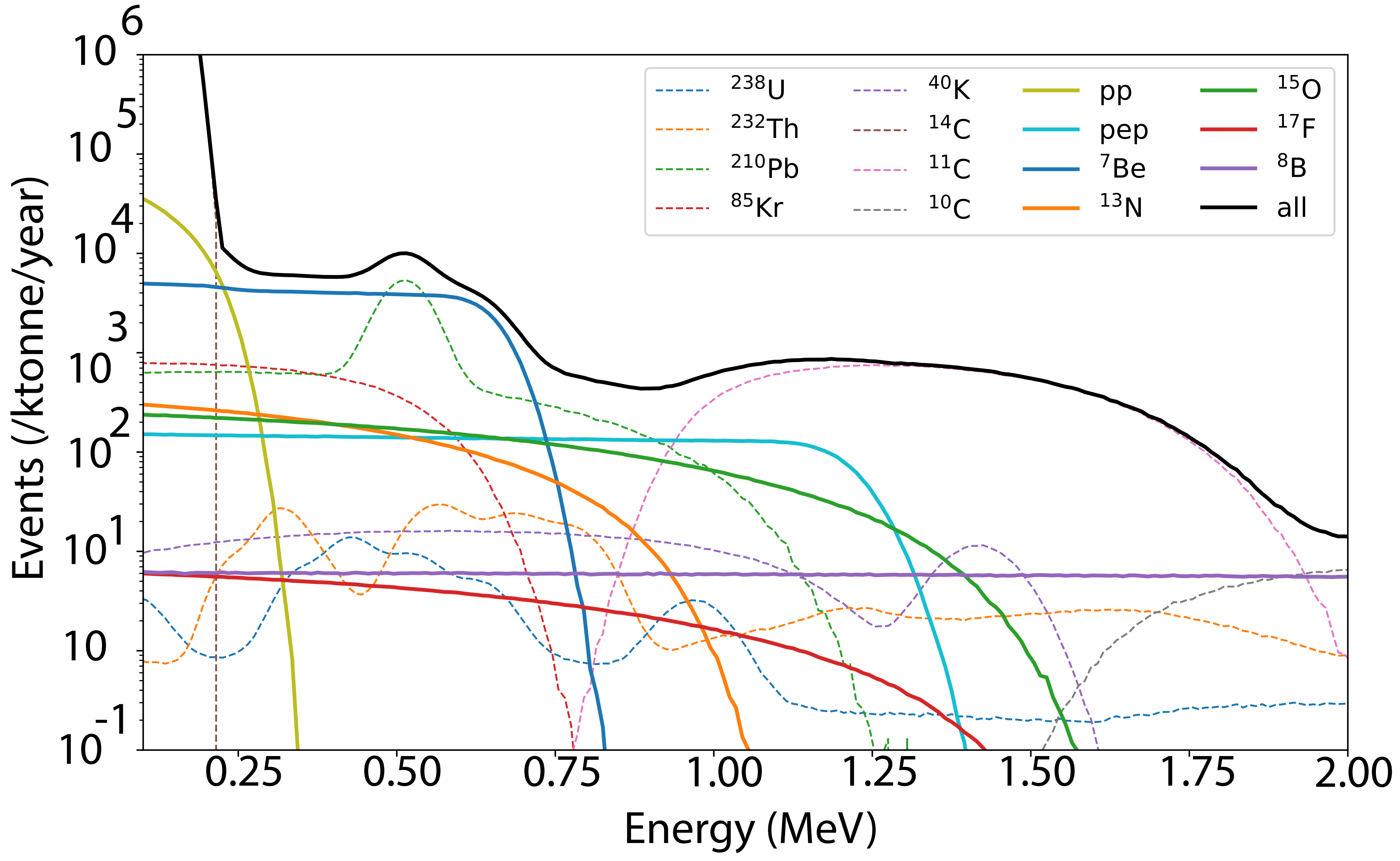


Both options allow us to confirm or rule out BEST result.

Solar neutrino physics with νEYE

Among possible topics, so called **observation of the "up-rise"** seems the most important.

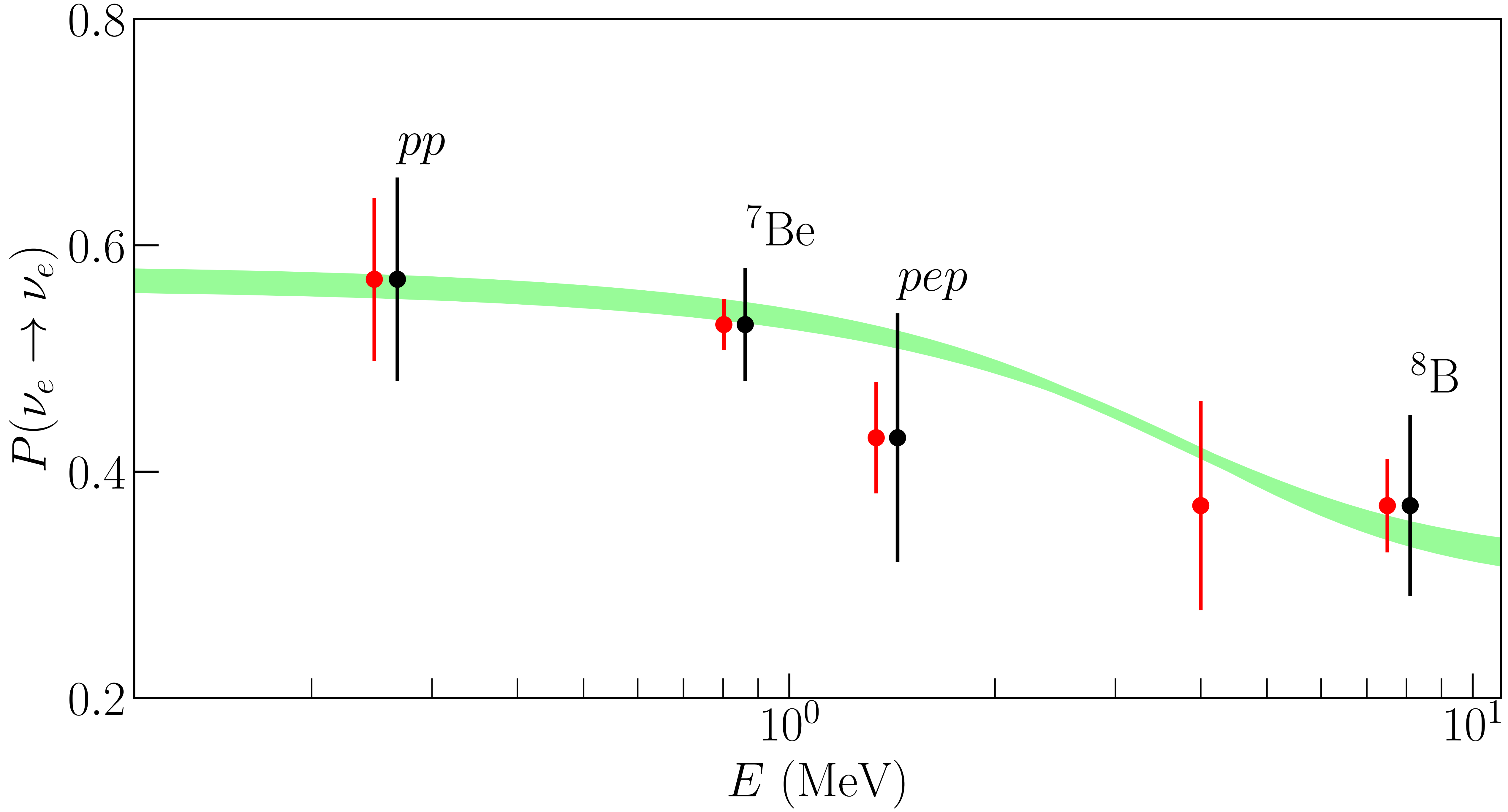
- Radio-purification is required.



Detailed understanding of signal/background (reduction of background) is critical.

For pp, error doesn't scale with $1/\sqrt{N}$ due to pile up of ^{14}C.

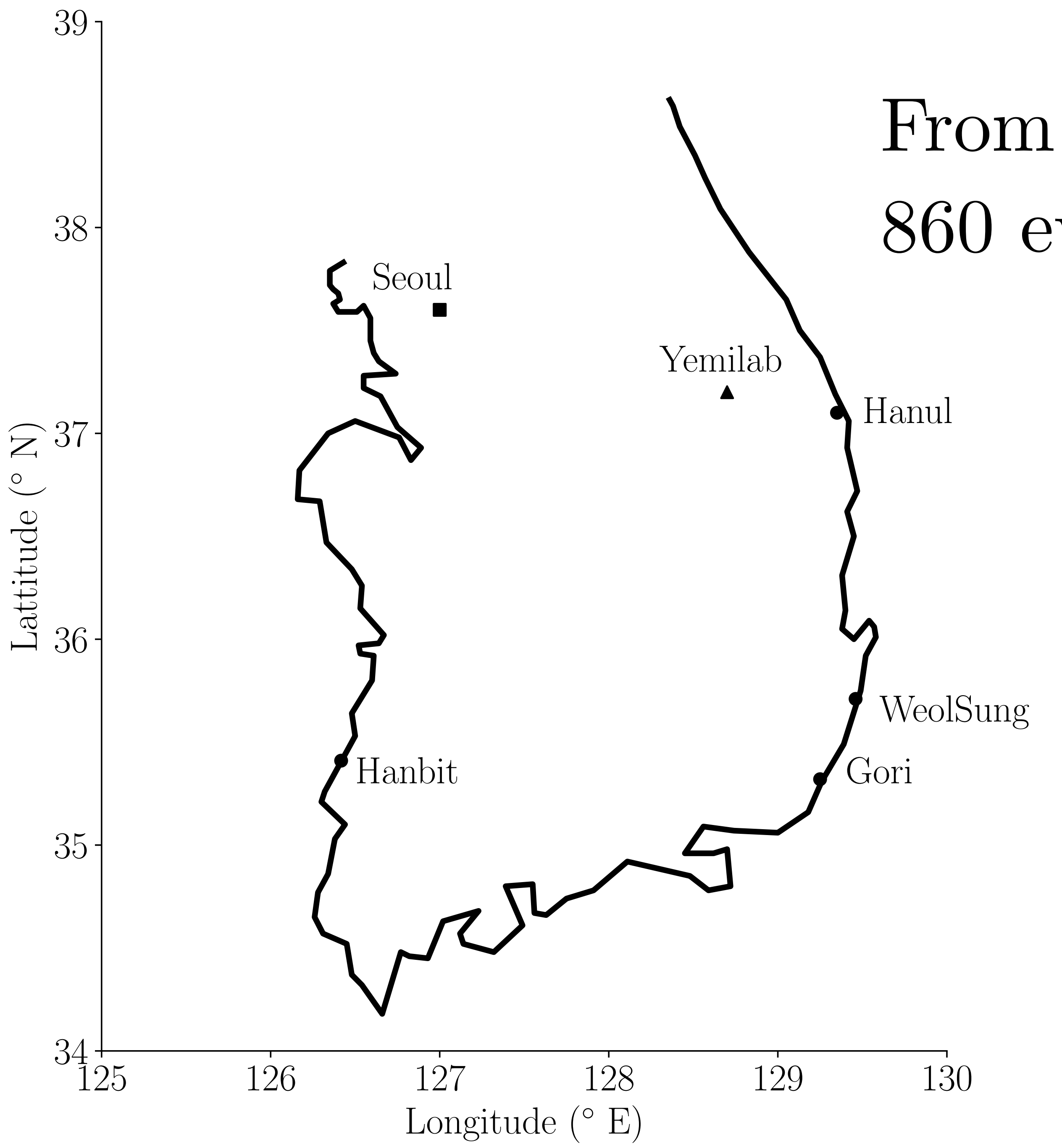
Red: νEYE
Black: Borexino



νEYE can provide points in this region.

Reactor neutrino with νEYE

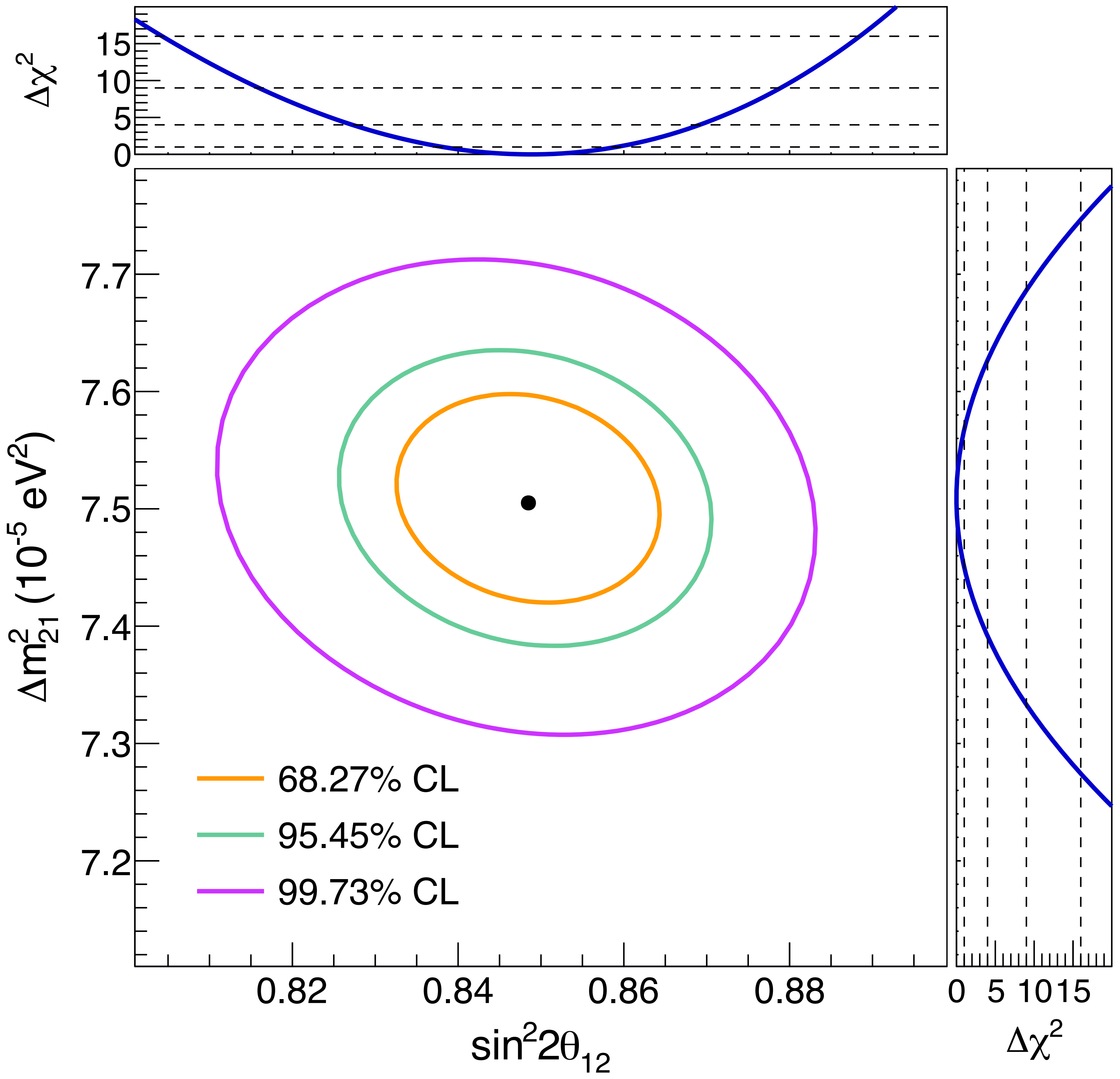
The JUNO experiment will measure 3-ν oscillation parameters with high precision.
But JUNO findings **need to be validated**: the νEYE is also at the first minimum.



From Hanul, we expect 860 events per year.

	Hanul	Wolsong	Gori	Hanbit
Thermal Power (GW)	20.8	11.8	21.3	16.9
Baseline (km)	65	180	216	282

νEYE sensitivity on Δm^2_{21} and $\sin^2 2\theta_{12}$



$\Delta m^2_{21} = (7.51 \pm 0.06) \times 10^{-5}$ eV^2 and $\sin^2 2\theta_{12} = 0.848 \pm 0.010$ (all statistical error only)

Neutrinoless double beta decay with νEYE

At the end of the experiment, the νEYE telescope can be loaded with metal to allow a neutrino-less double beta decay experiment.

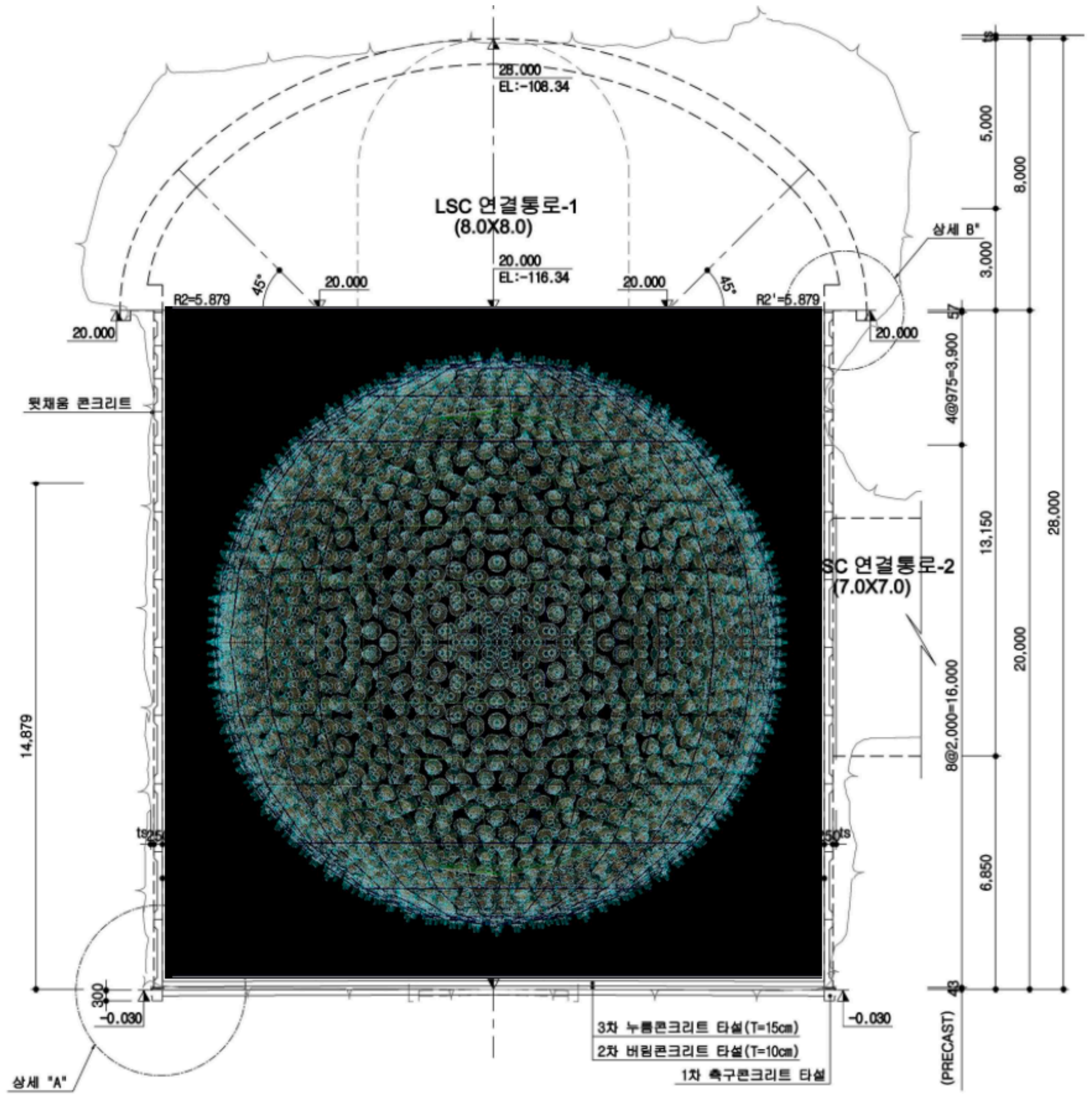
One possible candidate isotope is Tin-124 (Q=2.2 MeV). Another possible choice is ^{130}Te that has a $Q = 2.54$ MeV. It has relatively high natural abundance of 34.1%. Our target half-life time sensitivity is of order 10^{28} years.

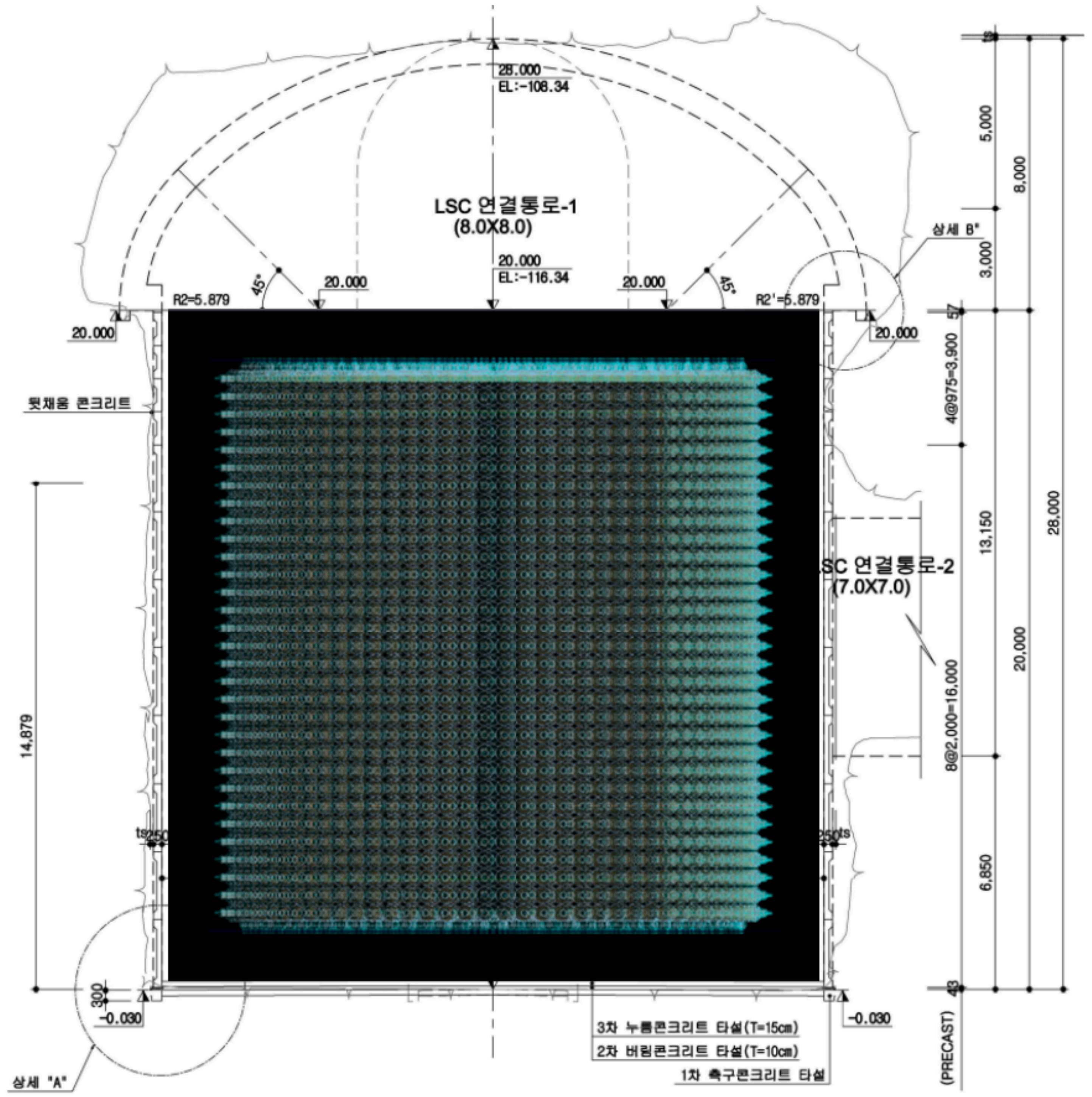
This topic requires a long-term R&D on the loading issues.

Detector Design

Detector concept

A 2 kilo tonne liquid scintillator (the actual target-mass is smaller).
At this moment, we consider two options: **spherical** or **cylindrical**.



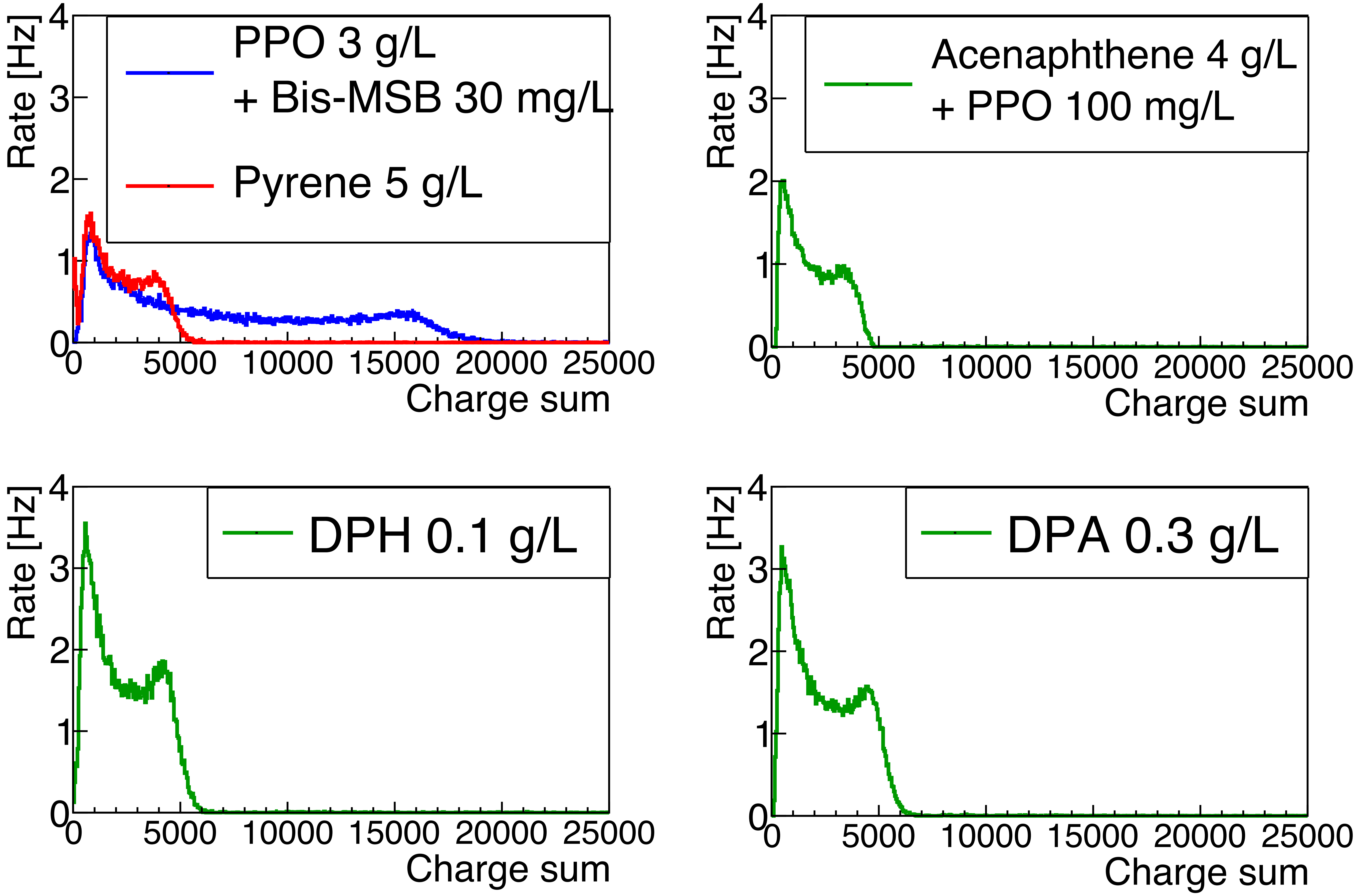


Shape	Cylindrical	Spherical
Radius (m)	7	7.25
Height (m)	14.5	-
Volume (m^3)	2232	1596
Mass (kg)	1920	1373
Number of PMTs	3700	3000

Size of buffer volume is under optimization.

Target liquid scintillator

Our primary choice is “**slow scintillator**”, to separate Cherenkov from scintillation.
A chemical lab is constructed to initiate this R&D @ Yemilab.



Light yield (LY) measurements.

- PPO + Bis-MSB shows the largest LY.
- Others show similar LY.

Photodetector

Our primary choice is **photomultiplier** technology.
Another possible option: LAPPD - complication of readout, cost issues have to be resolved.

In the market, we have three major choices.
- To reduce the cost, our primary choice becomes N6082 (8 inch) + "light concentrator".

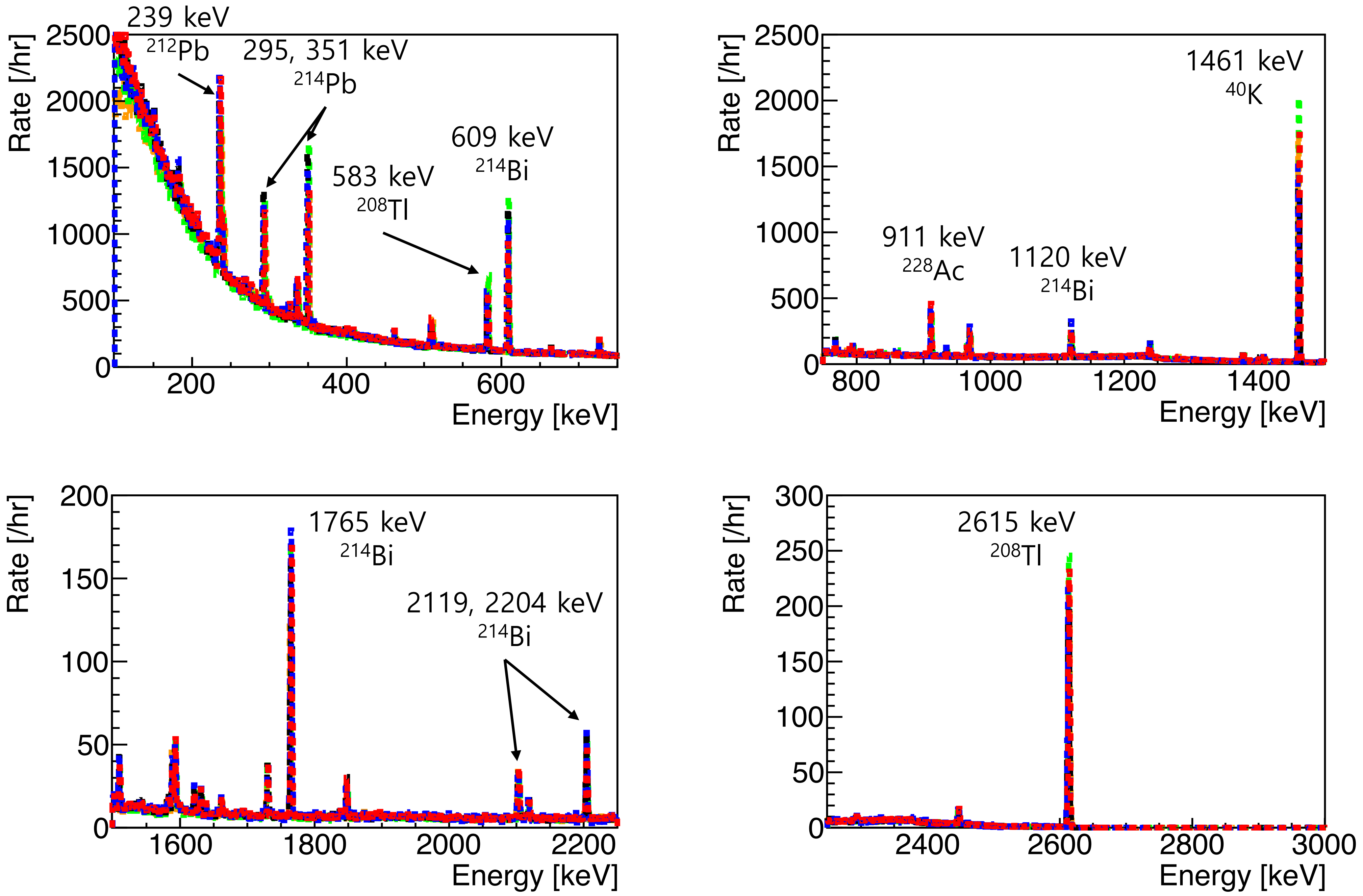
Model	R12860	N6203	N6082
Size (inch)	20	20	8
Peak wavelength (nm)	420	380	380
HV (V)	2000	1900	1750
Q.E. (%)	30	30	30
TTS (ns)	2.4	5	1.6
Supplier	Hamamatsu	NVT	NVT

Environmental backgrounds @ Yemilab

At the Yemilab site, HPGe is used to measure the radioactive background from rocks.

Bq/kg

	^{238}U	^{40}K	^{232}Th
Shotcrete	16.7 ± 0.6	447 ± 16	25.3 ± 0.6
Rock # 1	19 ± 2	618 ± 69	22 ± 2
Rock # 2	18 ± 2	872 ± 98	26 ± 2
Rock # 3	13 ± 1	561 ± 63	15 ± 1

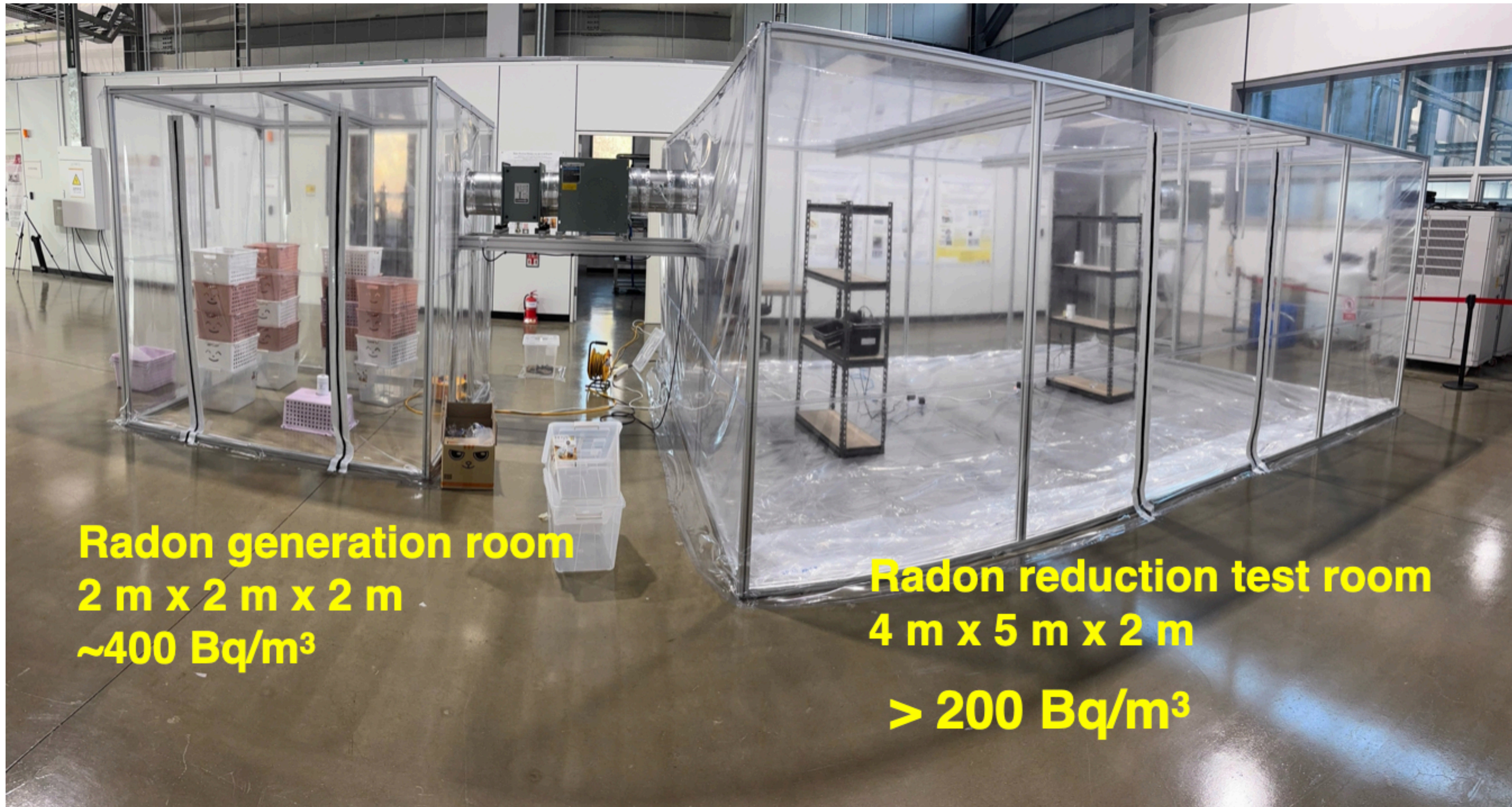


Measured Radon activity

Location	Radon level (Bq/m^3)
Up	68 ± 14
Middle	84 ± 19
Middle (opposite)	118 ± 12
Middle (low)	125 ± 21
Hall center	148 ± 17

Dedicated Radon reduction system is required.

We are developing a new method: silver-ion exchanged zeolite @ Korea U. (PTEP 2024 023C01)



- Early study: K. Lee et al, J. Korean Phys. Soc. **85**, 381–388 (2024), arxiv.org/abs/2401.13215

Software developments initiative

νOscillation

νOscillation: a software package for computation and simulation of neutrino propagation and interaction

Seong-hyeok Jang,[1] Eun-Ju Jeon,[2] Youngju Ko,[2] Kyungmin Lee,[1] and Eunil Won[1]

Physics, Korea University, Seoul 02841, Korea

hysics, Institute for Basic Science, Daejeon 34047, Korea

only phenomenon that cannot be explai
sterious neutrino interactions observed
nd ongoing or planned neutrino experi
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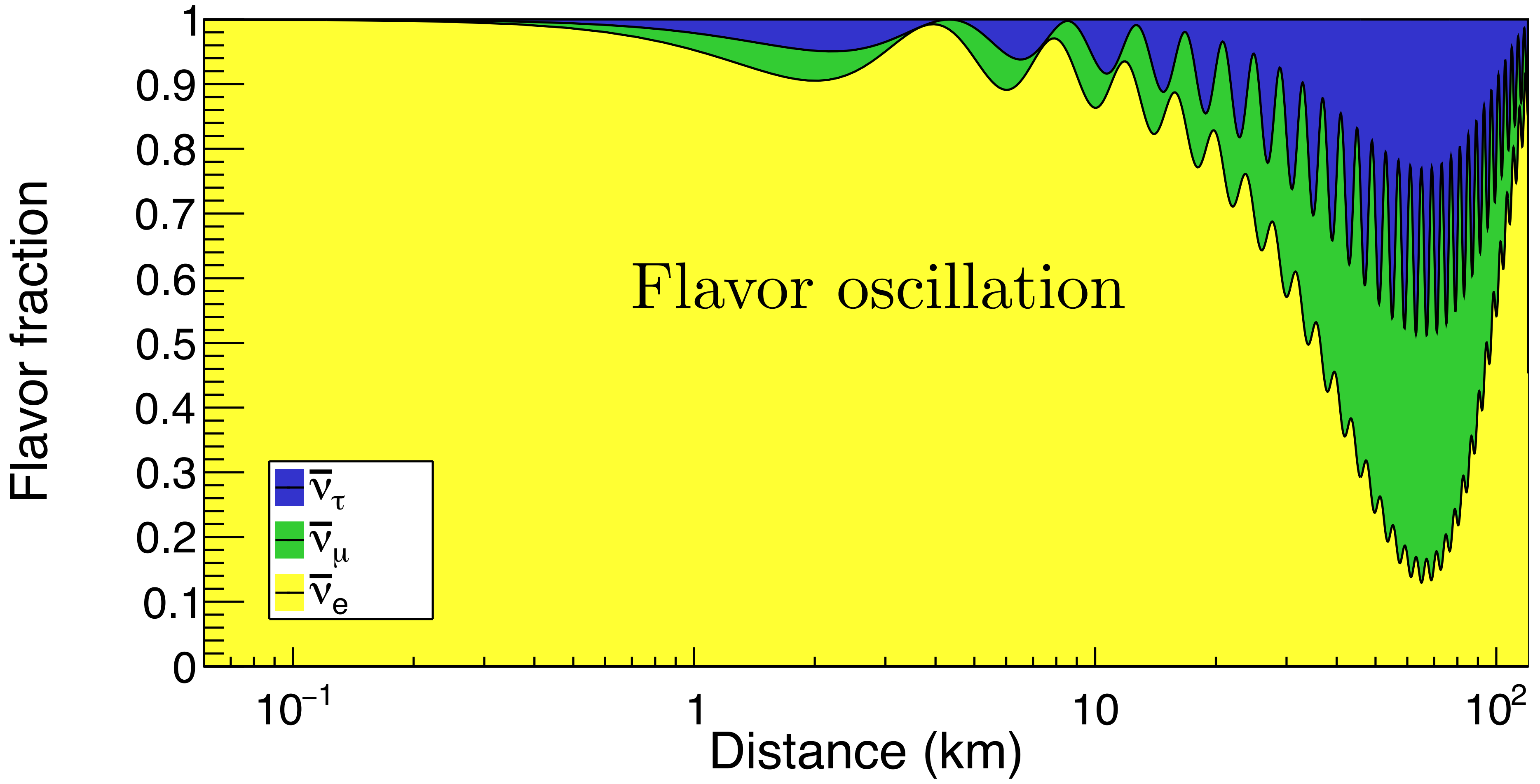

from the sun, and the oscillation of

the neutrino oscillation with assuming a reactor located at 53 km away from the detector.

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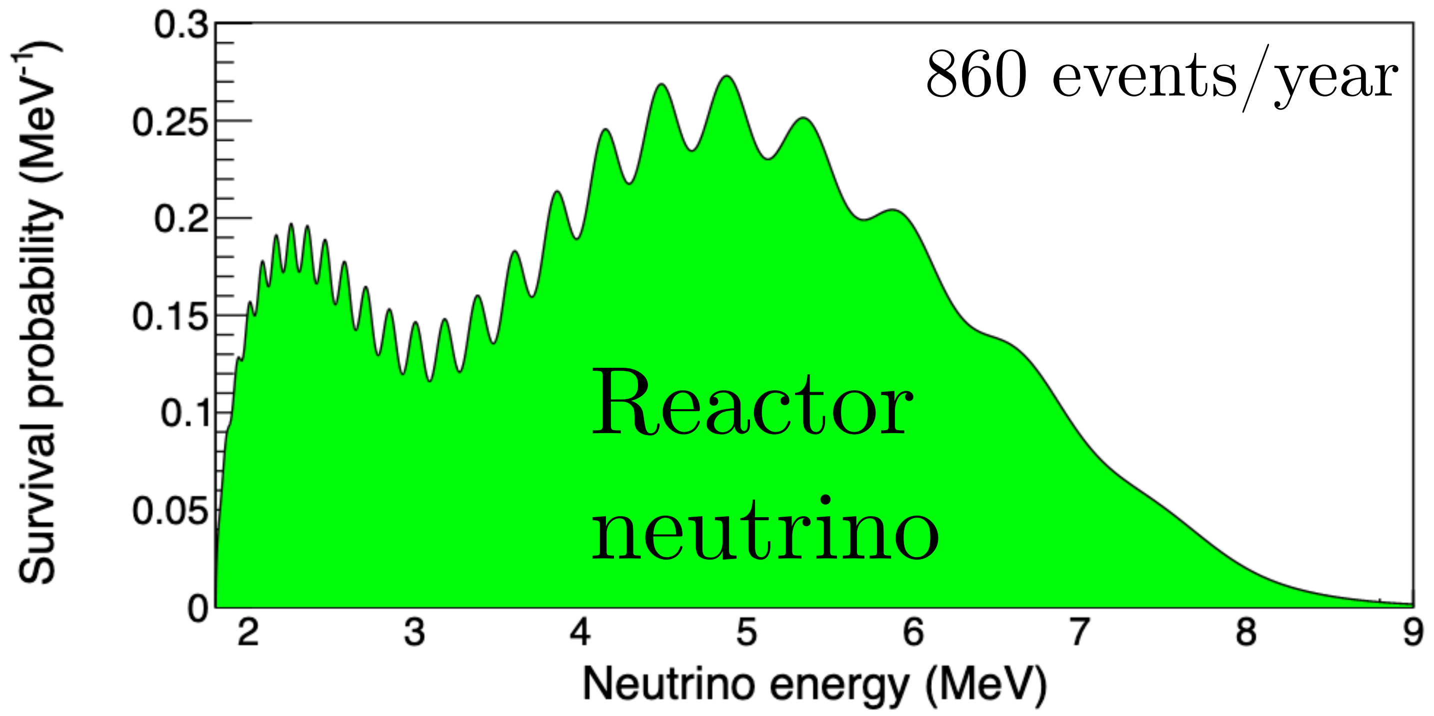
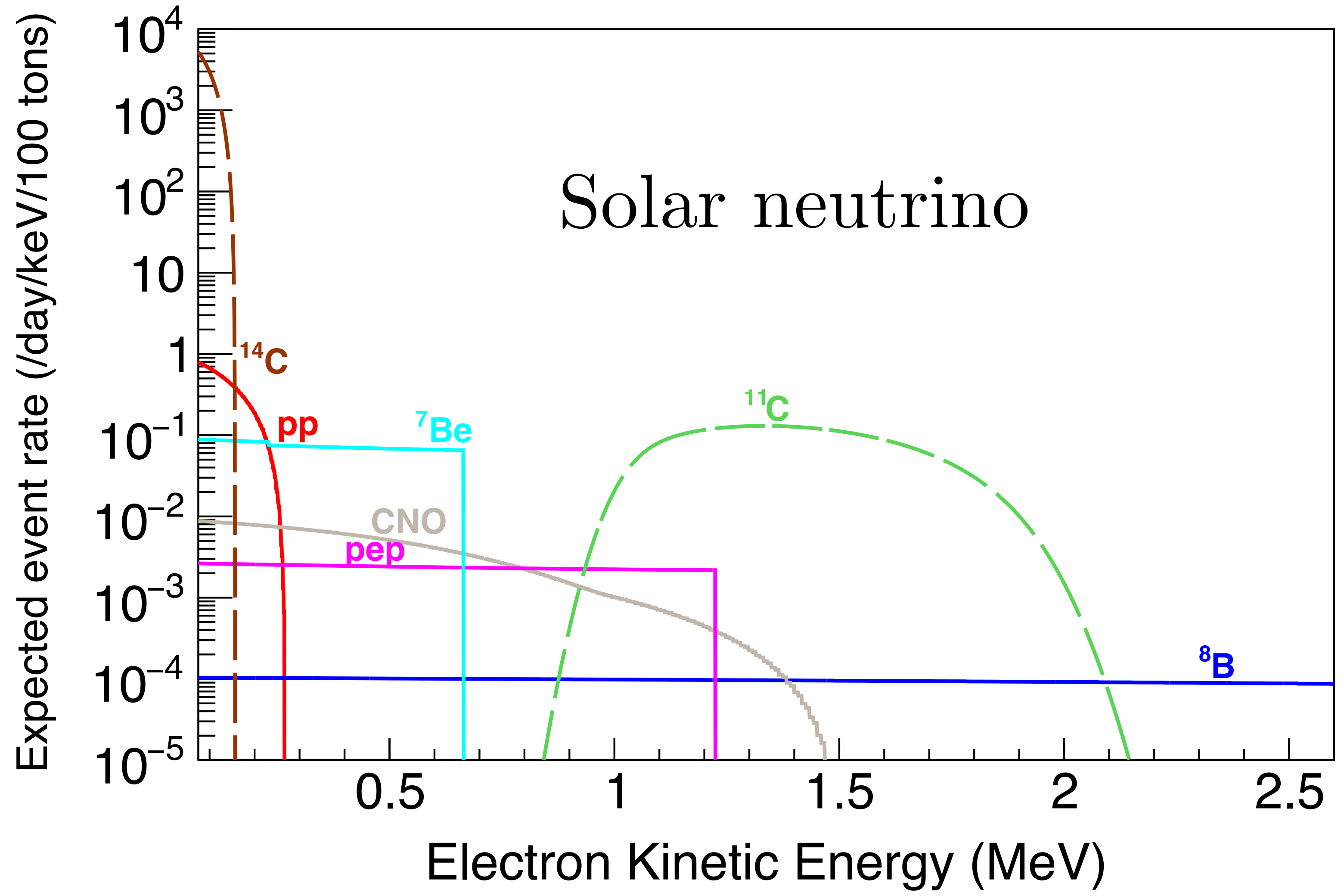
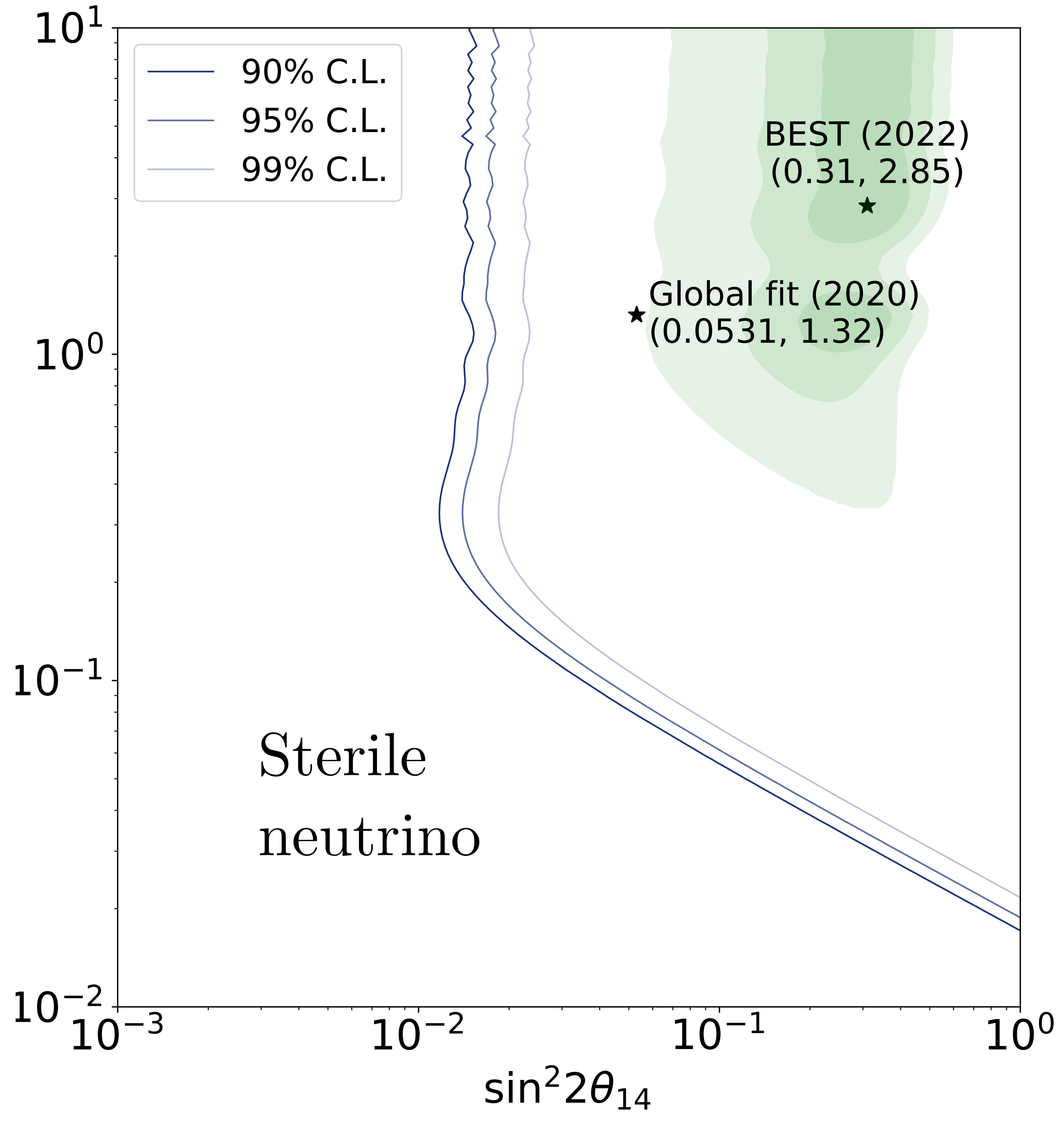


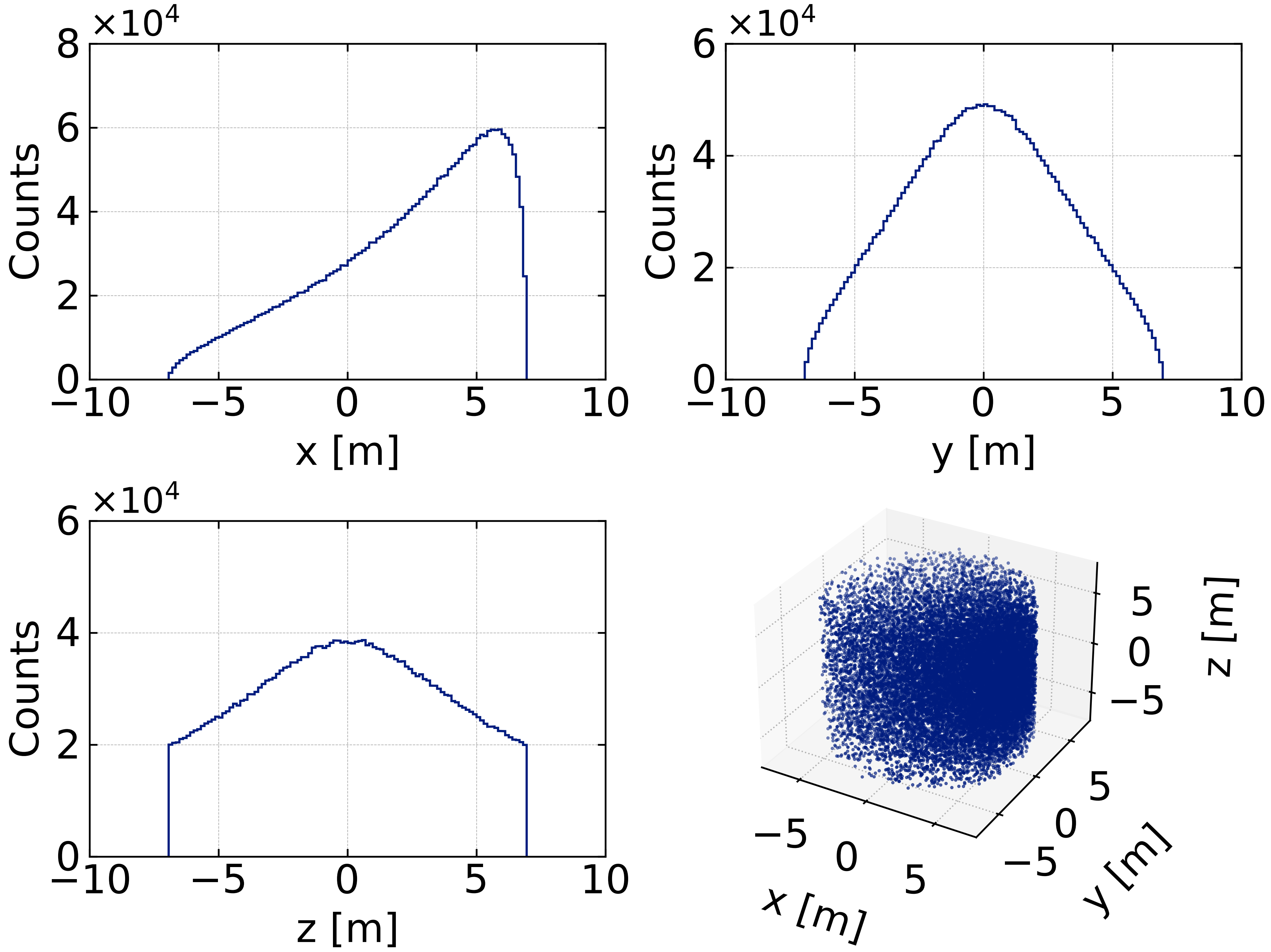




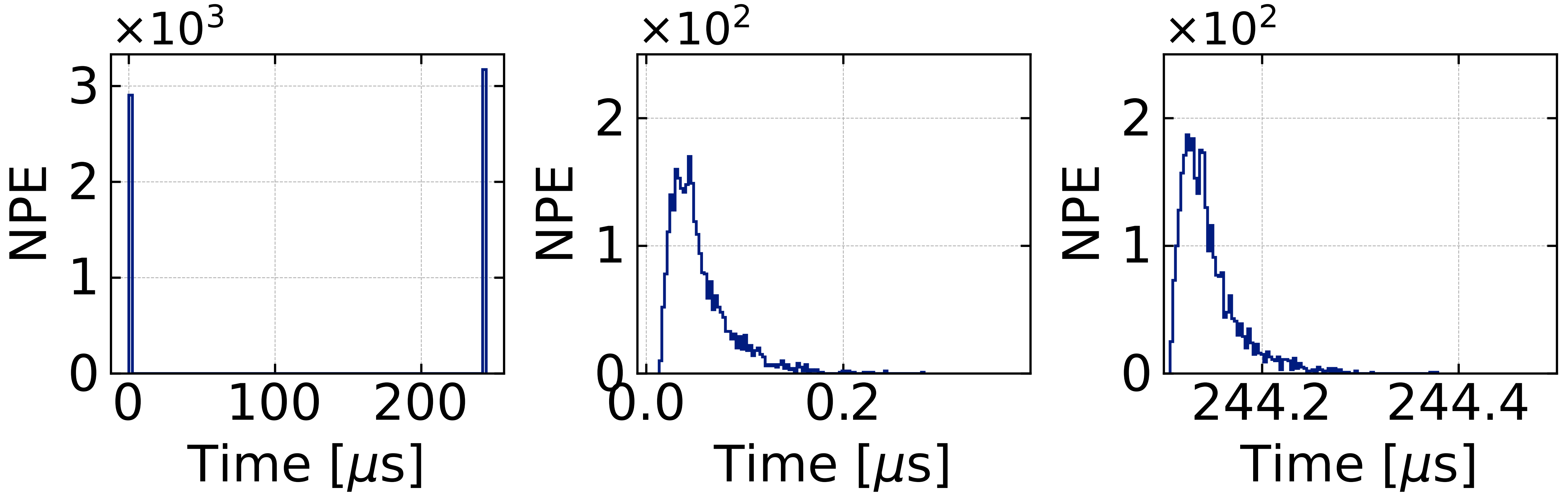
Software developments with Geant4

^{144}Ce $\bar{\nu}_e$ production simulation (Geant4) and reconstruction of inverse beta decays (IBD)

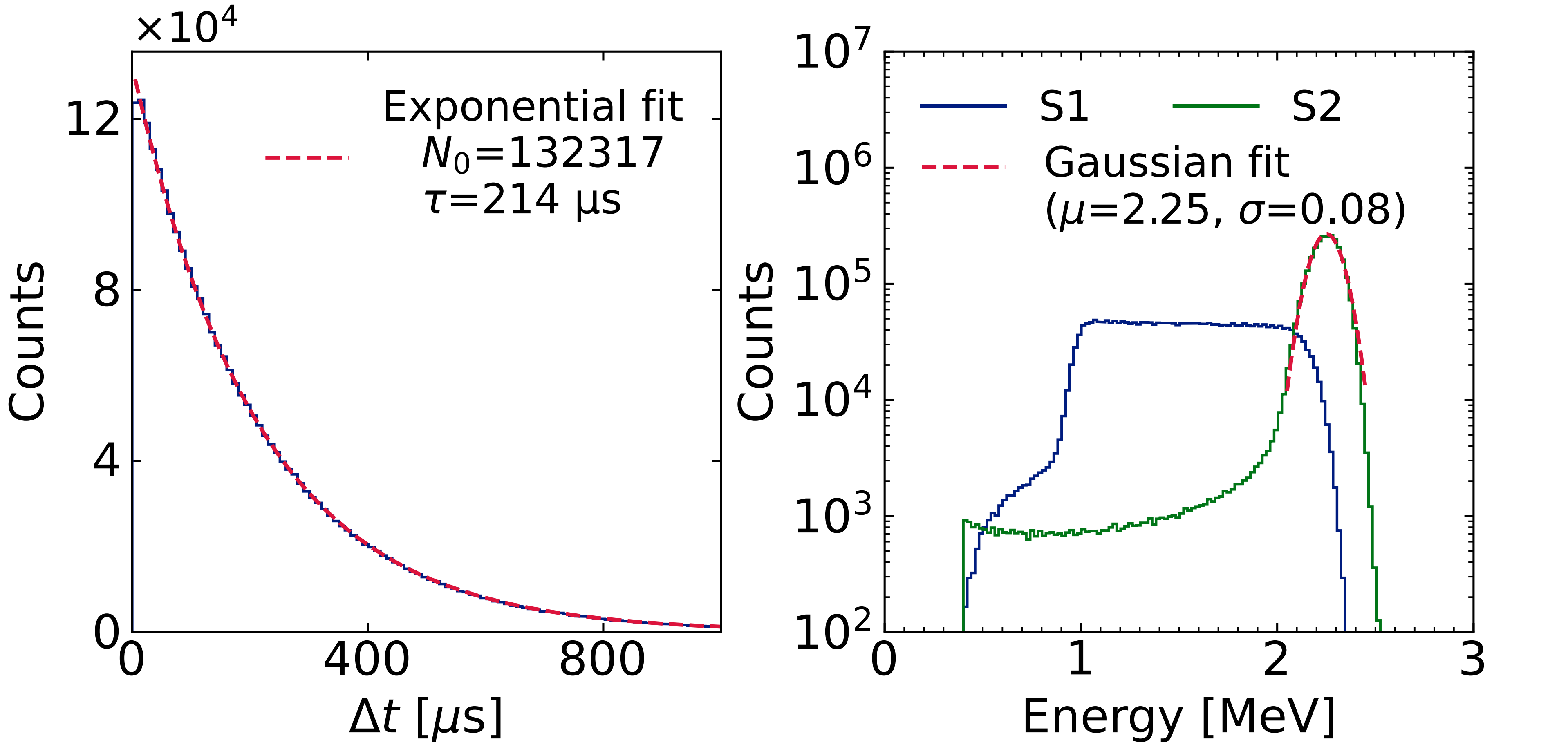
^{144}Ce at (9,5,0,0) m



Hit time distributions (S1, S2 together, S1 and S2 respectively)



Time difference btw S1 and S2 (left) and energy deposit (right)



IBD events trigger

- Require hits in 200 ns
- If NPE > 400, all hits in 500 ns constitute first cluster (S1)
- Search for the second cluster (same condition, S2)

A prototype νEYE (1 tonne) construction

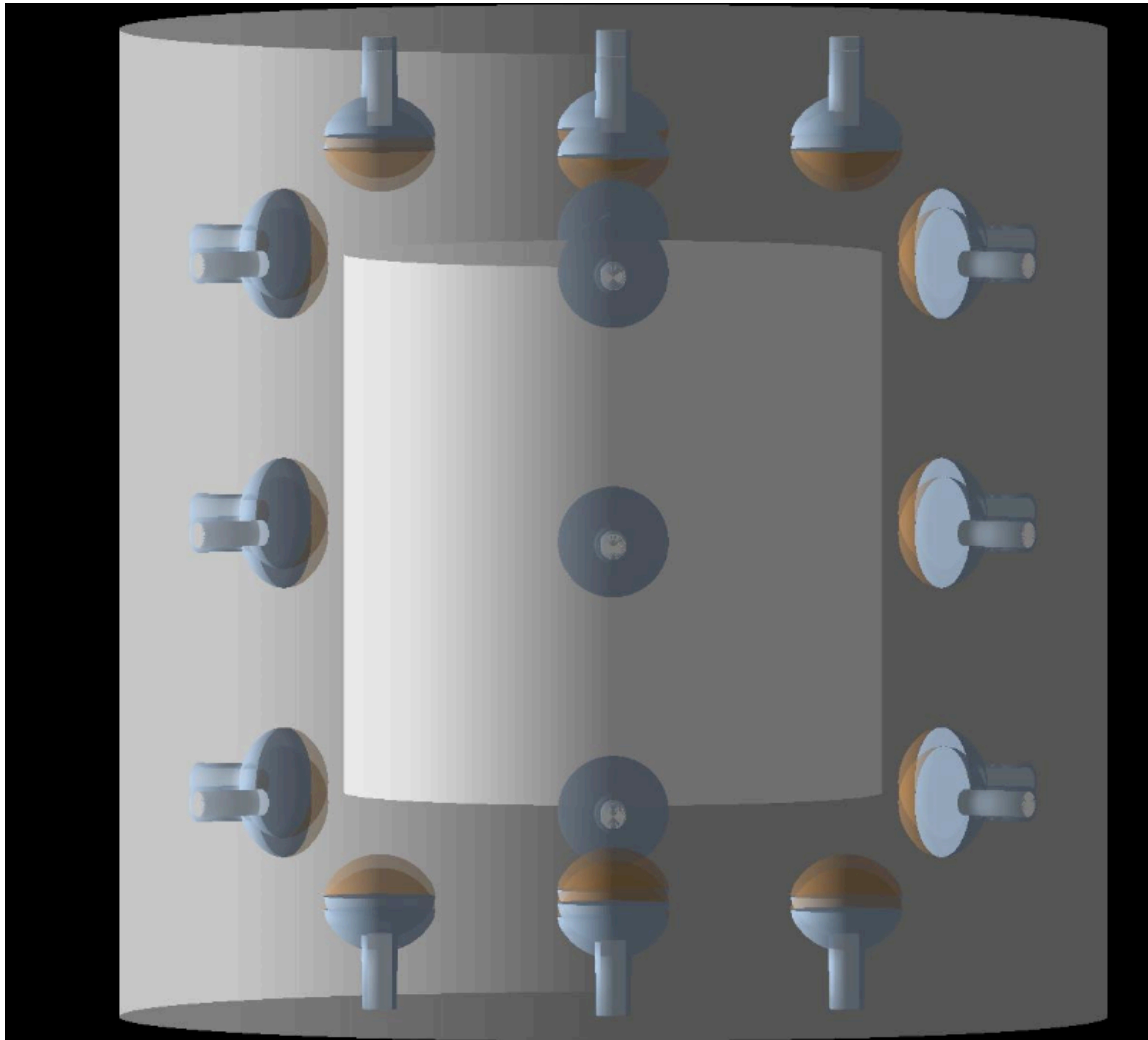
Volume : 1.2 m x 1.2 m acrylic tank: $O(1)$ tonne of LS.
Buffer : pure water.
PMTs : O(30-60) PMTs of 10" R7081, contribution from RENO (Water proof, single cable).

DAQ and HV
FADC: 500 MHz (to be purchased from Notice).
CAEN A7435SP (some has to be purchased).

Purpose
Study and optimize LS.
Measure intrinsic background : $10^{-13 \text{ or } -14}$ g/g.

To provide feedback to full scale νEYE detector.
Optimize and validate the Geant4 simulation.

Construction will start from this summer.



Radio-purification

Filtration

Removes optical impurities.

Removal of U/Th and K.

Water extraction

Removes dissolved radioactive metal ions

K, U, Th, Pb removal

Inorganic impurities

Water extraction
Custom build.

Nitrogen gas stripping

Remove dissolved gases

Vacuum Distillation

Removes high boiling point impuritie

Metal & Oxide, U/Th, K, Bi, Po/Pł

(1) Vertical-type "WEV-1001V"

Construction of prototype purification lab at Yemilab

Glove box (see the picture on the right)

Other components are being purchased.

Summary

The νEYE neutrino telescope: a 2 kilo tonne LS detector is discussed.

Selected physics cases are shown.

- Sterile neutrino search.
- Solar neutrino: up-turn.
- Reactor neutrino: Yemilab is at the first minimum of Hanul reactor.

Default designs of νEYE detector are presented.

- LS: slow LS.
- PMT: 8 inch version + light concentrator (for now at least).
- Software : IBD, generators, $e^- - \nu_e$ scattering (not discussed).

From this summer, **one tonne prototype νEYE construction** will be started.

We are looking for domestic and international collaboration.

Please join us !