$0\nu\beta\beta$ with νEYE

- νEYE Detector Concept
- $0\nu\beta\beta$ with νEYE

Workshop on the Opportunity of Locating nEXO at Yemilab

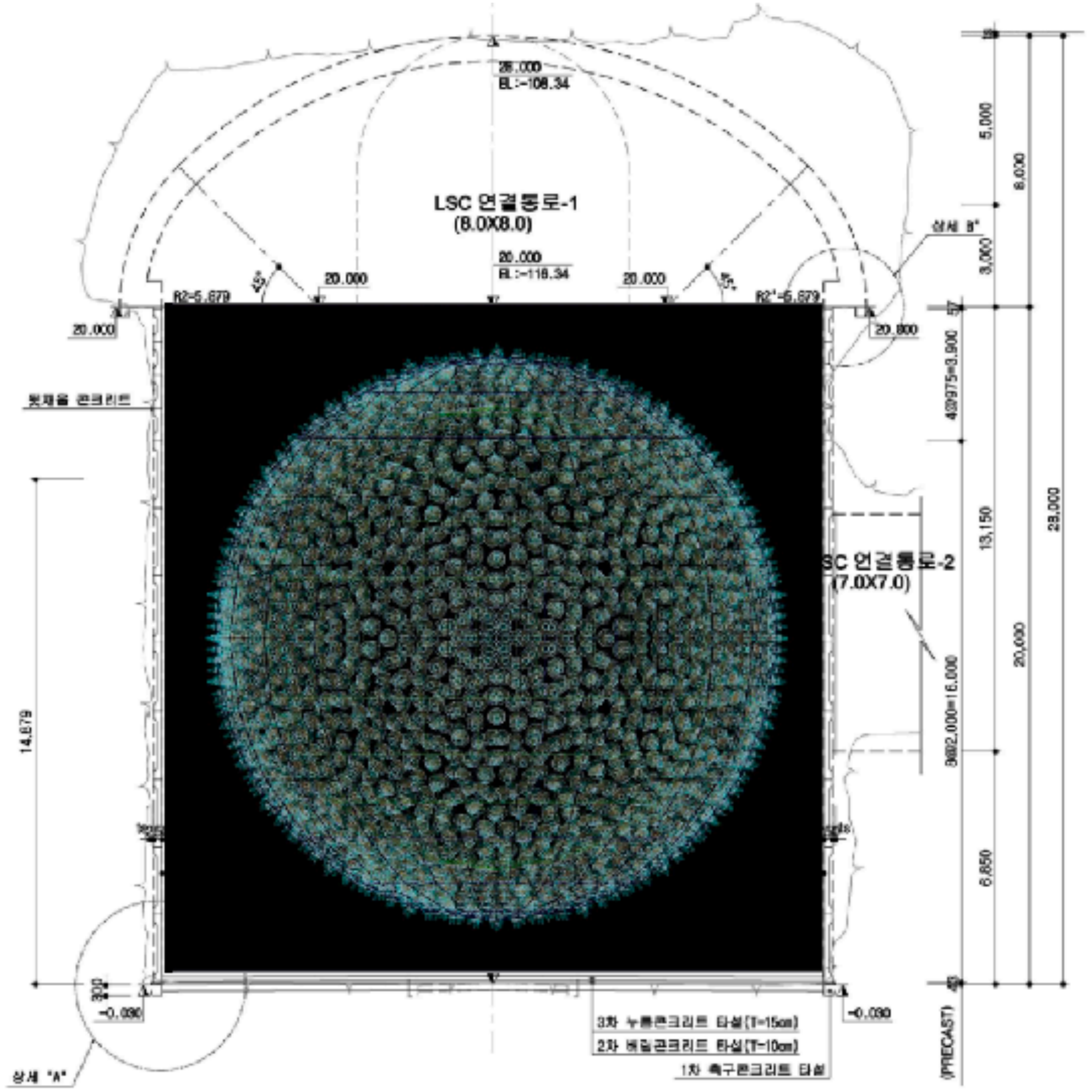
Aug. 31, 2026, IBS Headquarters (B109)

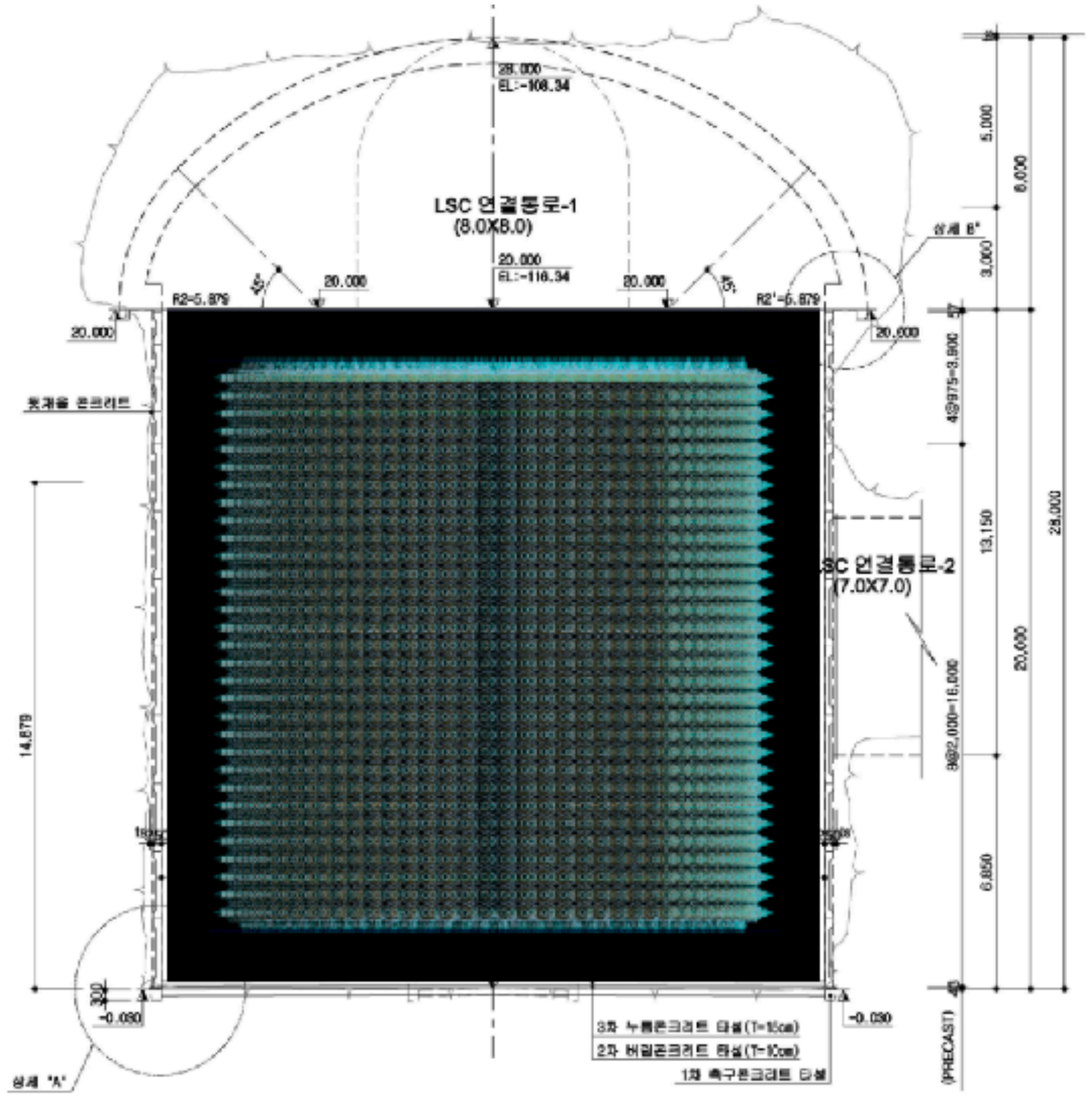
Korea University, Eunil Won

νEYE detector concept (proposal submitted in 2026)

νEYE detector: A $\mathcal{O}(2)$ kilo tonne liquid scintillator.
At this moment, we consider two options: **spherical** or **cylindrical**.

νEYE CDR: arXiv:2601.12569

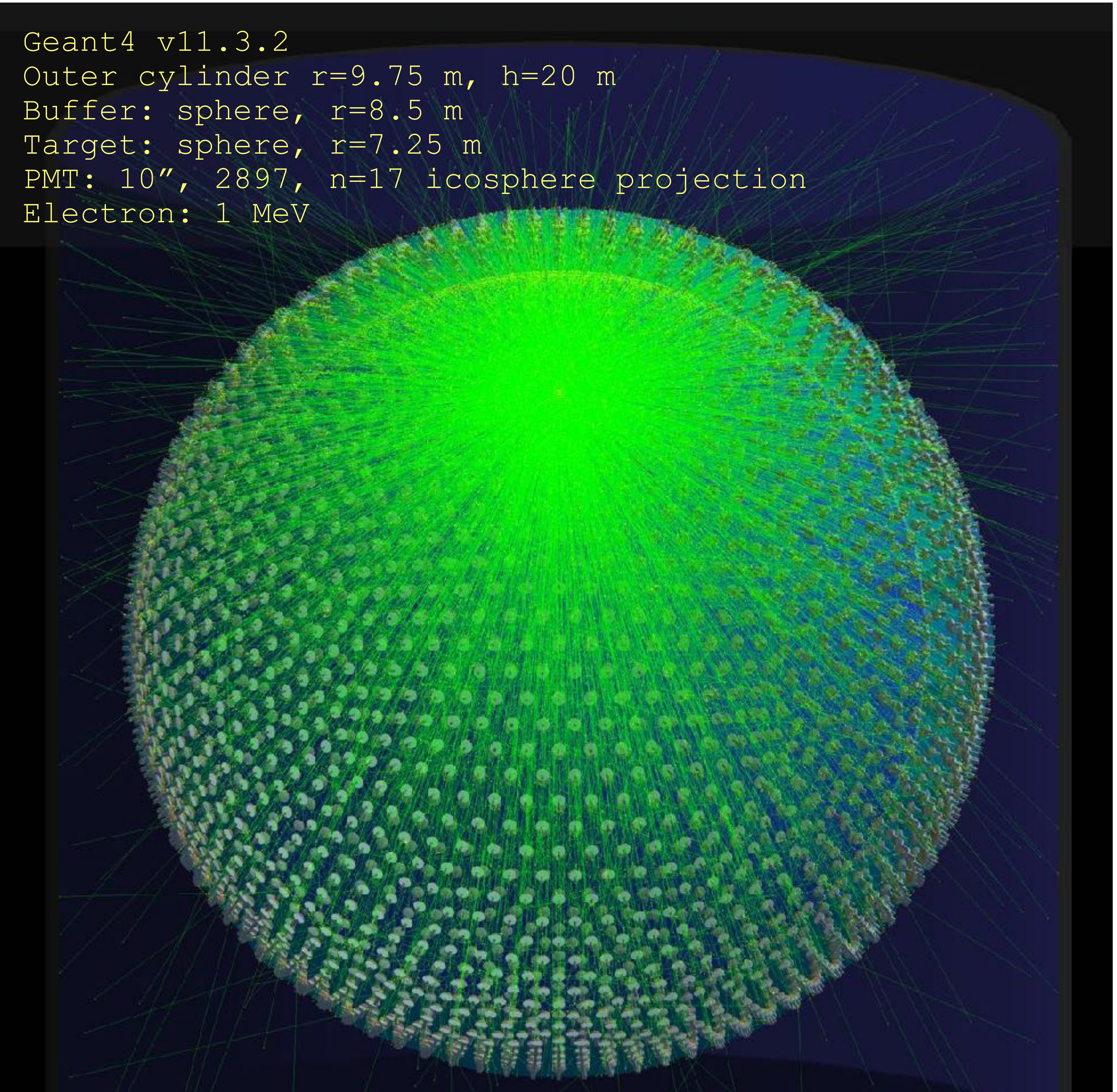




Shape	Cylindrical	Spherical
Radius (m)	7	7.25
Height (m)	14.5	-
Volume (m^3)	2232	1596
Mass (kg)	1920	1373
Number of PMTs	3700	3000

Size of buffer volume is under optimization.

Spherical Detector Option : Double spherical structure



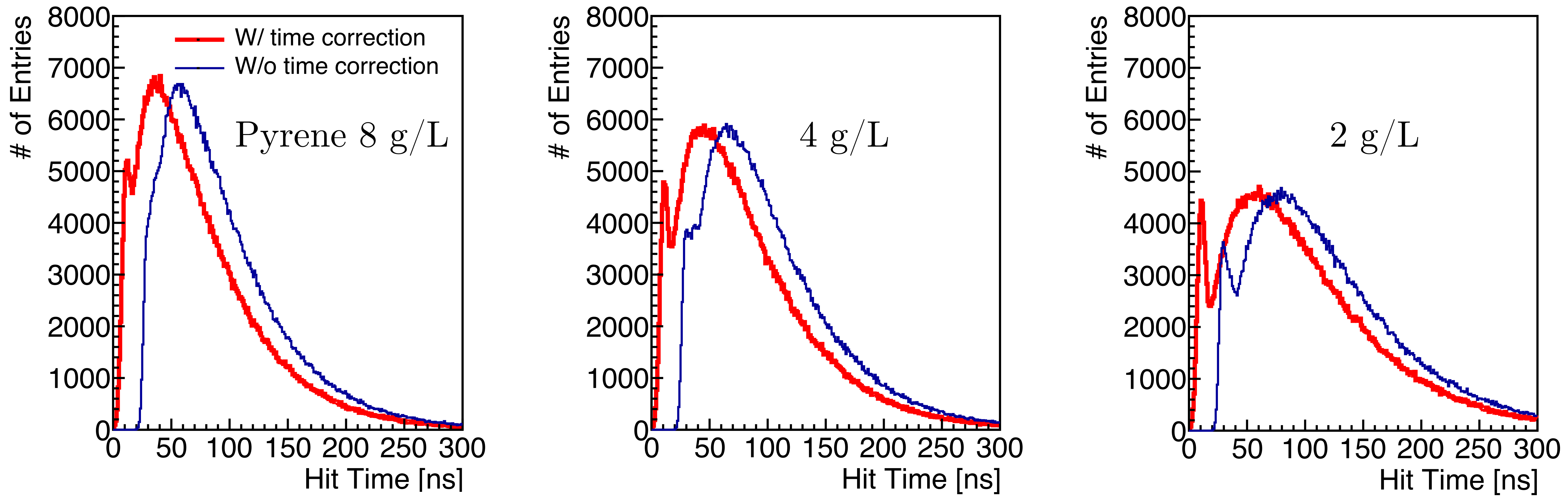
- 2897 PMTs
- Buffer: Water
- Target: LAB+PPO+Bis-MSB ("the standard")

- Geant4 simulation
  - 1 MeV electron to LS

Target liquid scintillator R&D

Slow fluors for effective separation of Cherenkov light in liquid scintillators
NIMA 972, 164106 (2020)

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

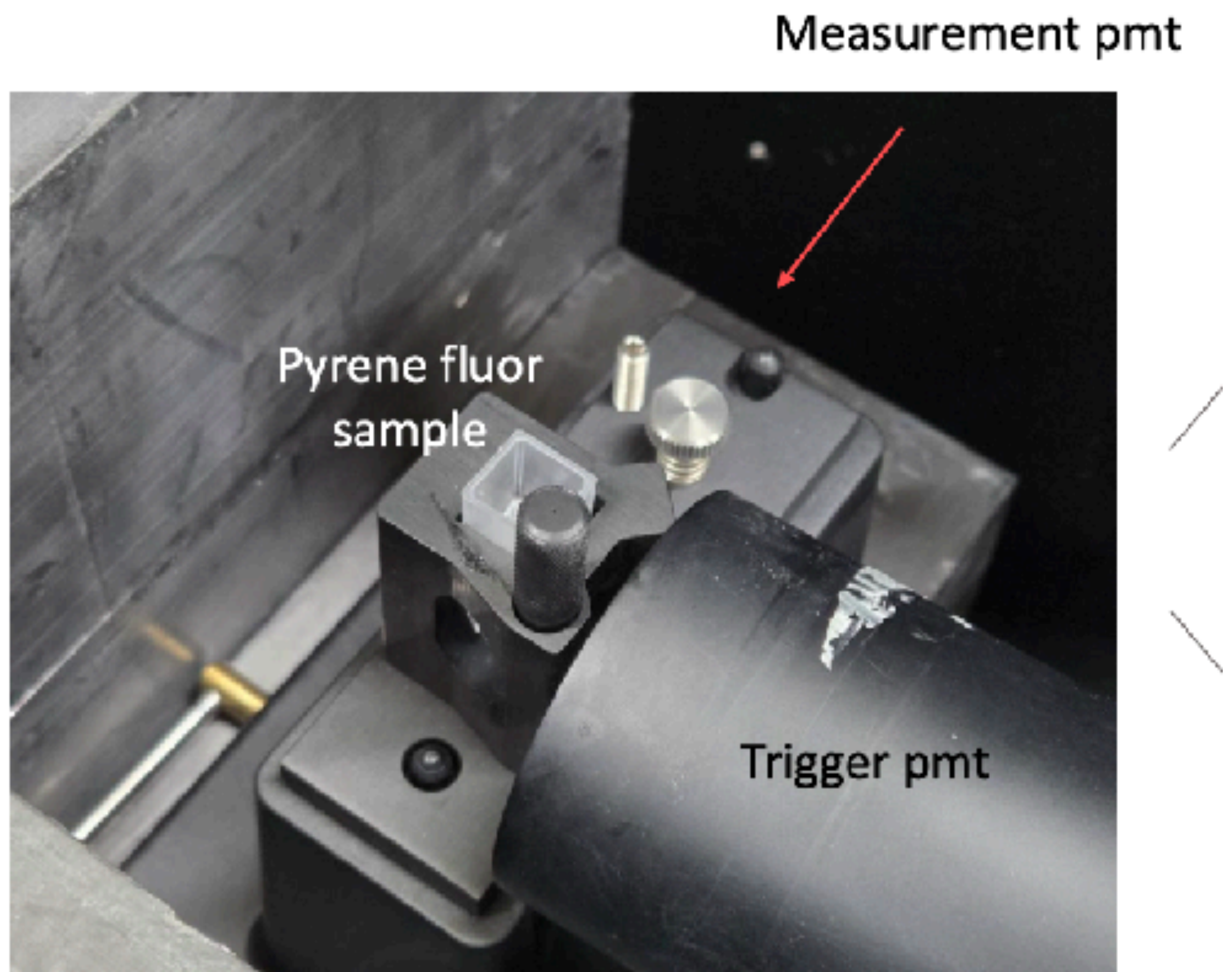


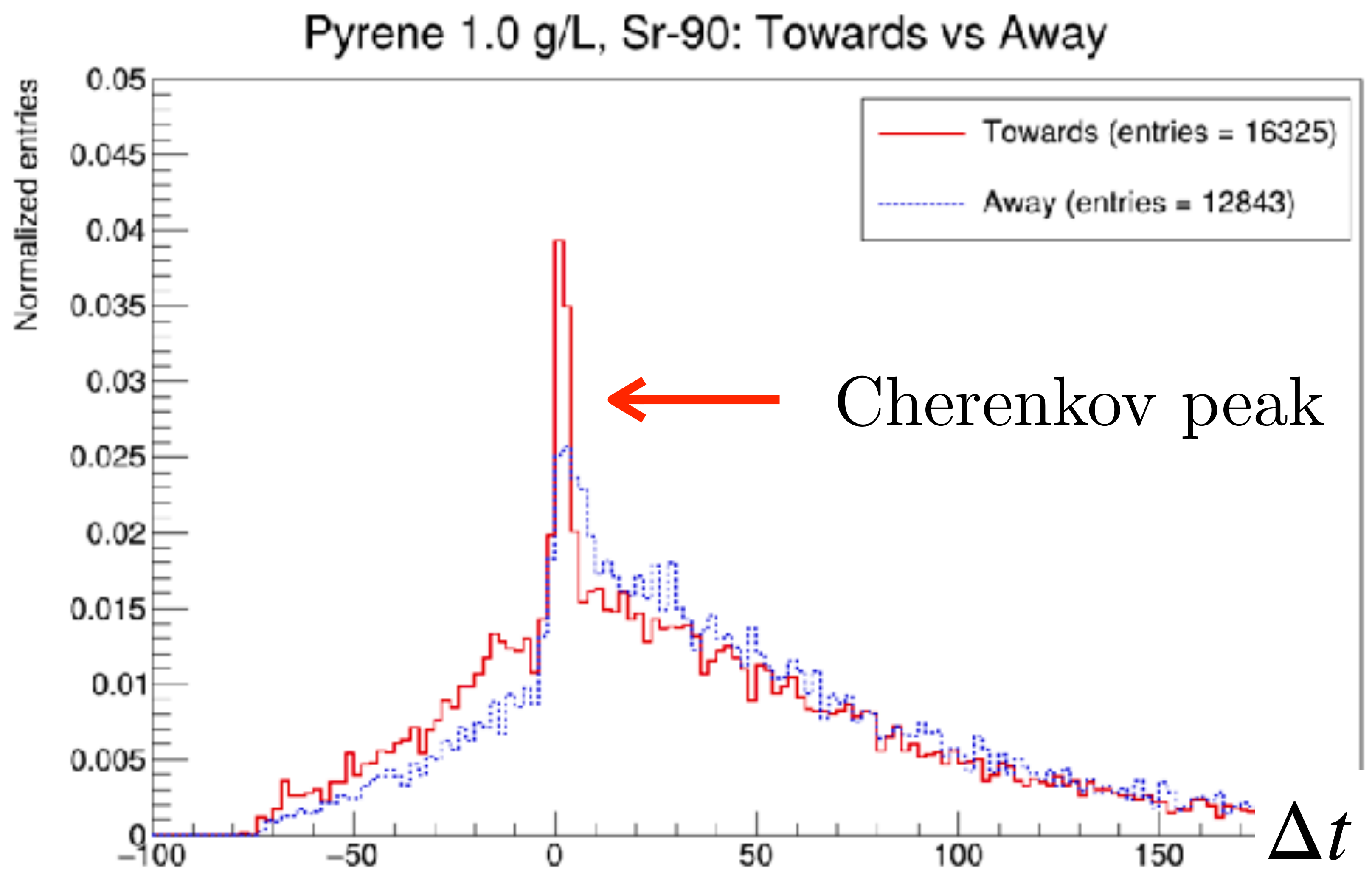
Hit time from Geant4 simulation

Cherenkov separation is enhanced with 2 g/L option.

Detailed R&D status can be found from

: https://sites.google.com/korea.ac.kr/the-nueye-telescope/pubpresentations





$\Delta t = t_{meas} - t_{trig}$

Real data with pyrene (DAQ:ADC)

Future DAQ with TDC (under calibration) expected.

Photodetector

Our primary choice for the photodetector is **photomultiplier** technology.
Another possible option: LAPPD - complication of readout, cost issues have to be resolved.
(https://sites.google.com/korea.ac.kr/the-nueye-telescope/pubpresentations)

In the market, we have three major options.

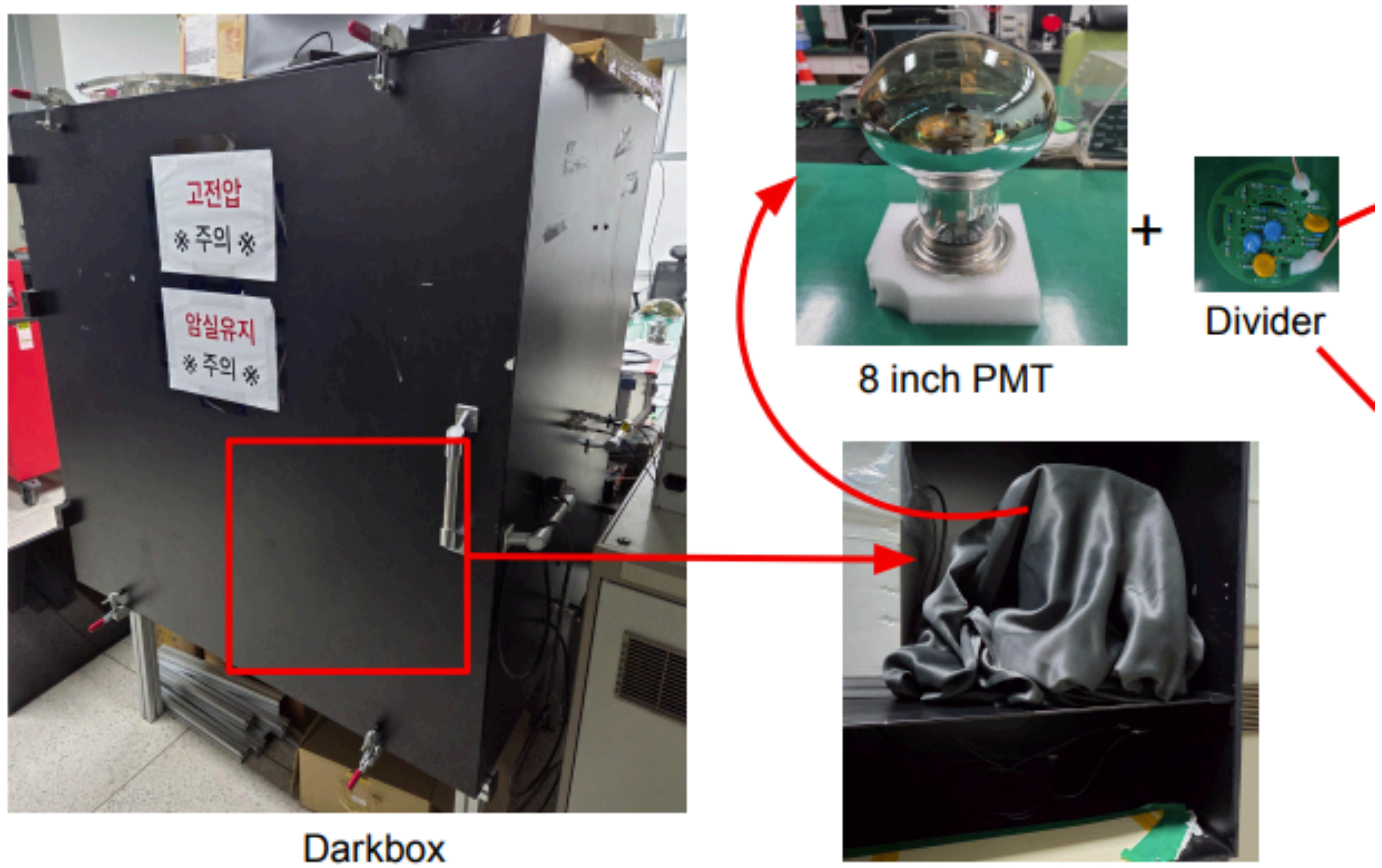
- R12860: business class (~100 M USD)
- N6082: economy class (~40 M USD)

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

All well studied by community:

We have samples of all and R&D is underway.

8 inch MCP PMT Test setup to see Dark



Darkbox

Inside darkbox

A prototype νEYE (1 tonne, 1/2,000 scale) construction

Volume : 1.2 m x 1.2 m acrylic tank: $\mathcal{O}(1)$ tonne of LS.
Buffer : pure water ~~or mineral oil~~.
PMTs : 31 PMTs of 10" R7081 (from RENO).

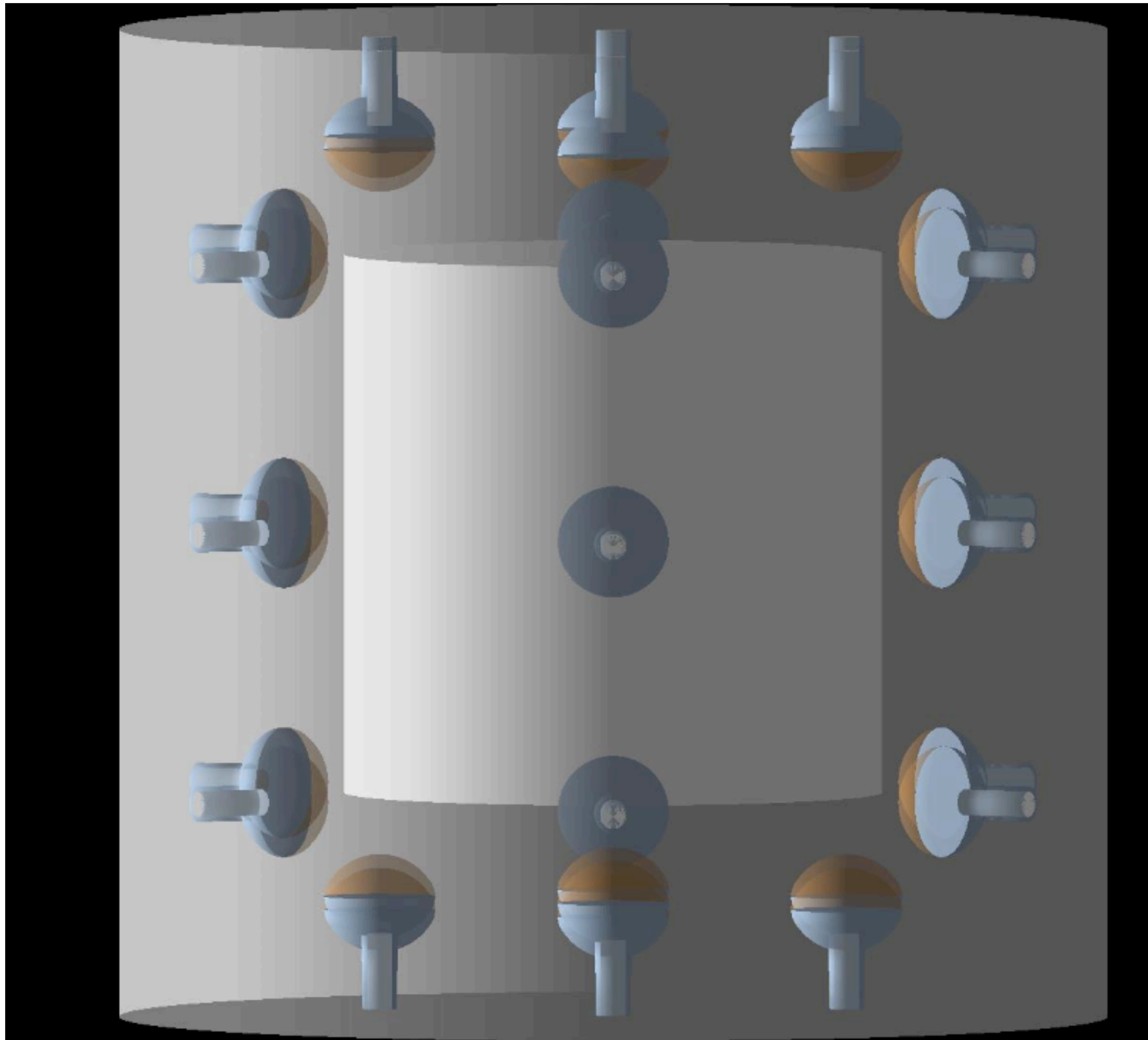
DAQ and HV
FADC: 500 MHz (from Notice Korea).
CAEN A7435SP

Purpose

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

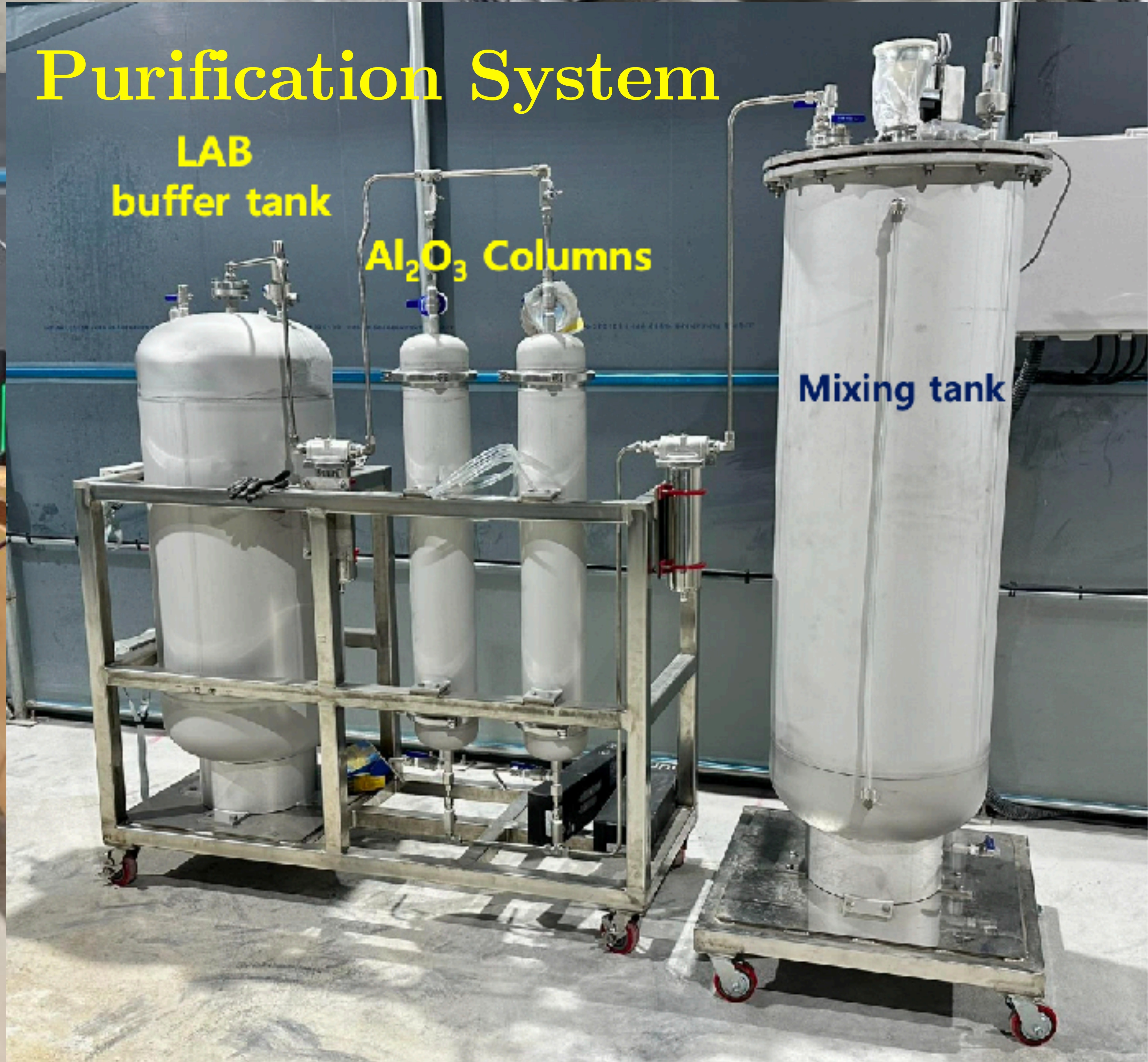
To provide feedback to full scale νEYE detector.
Optimize and validate the Geant4 simulation.

Construction started from summer of 2025.

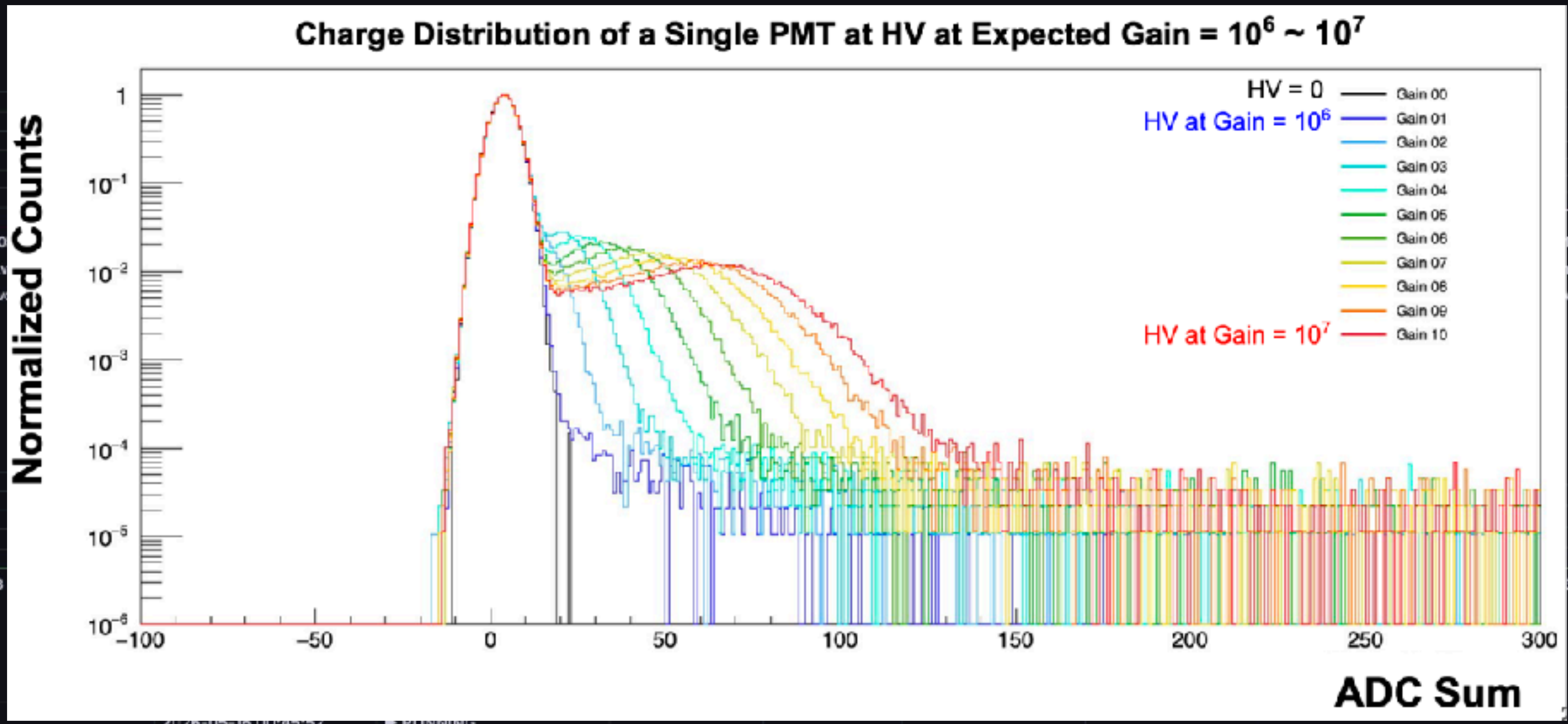


- 1 tonne prototype preparation

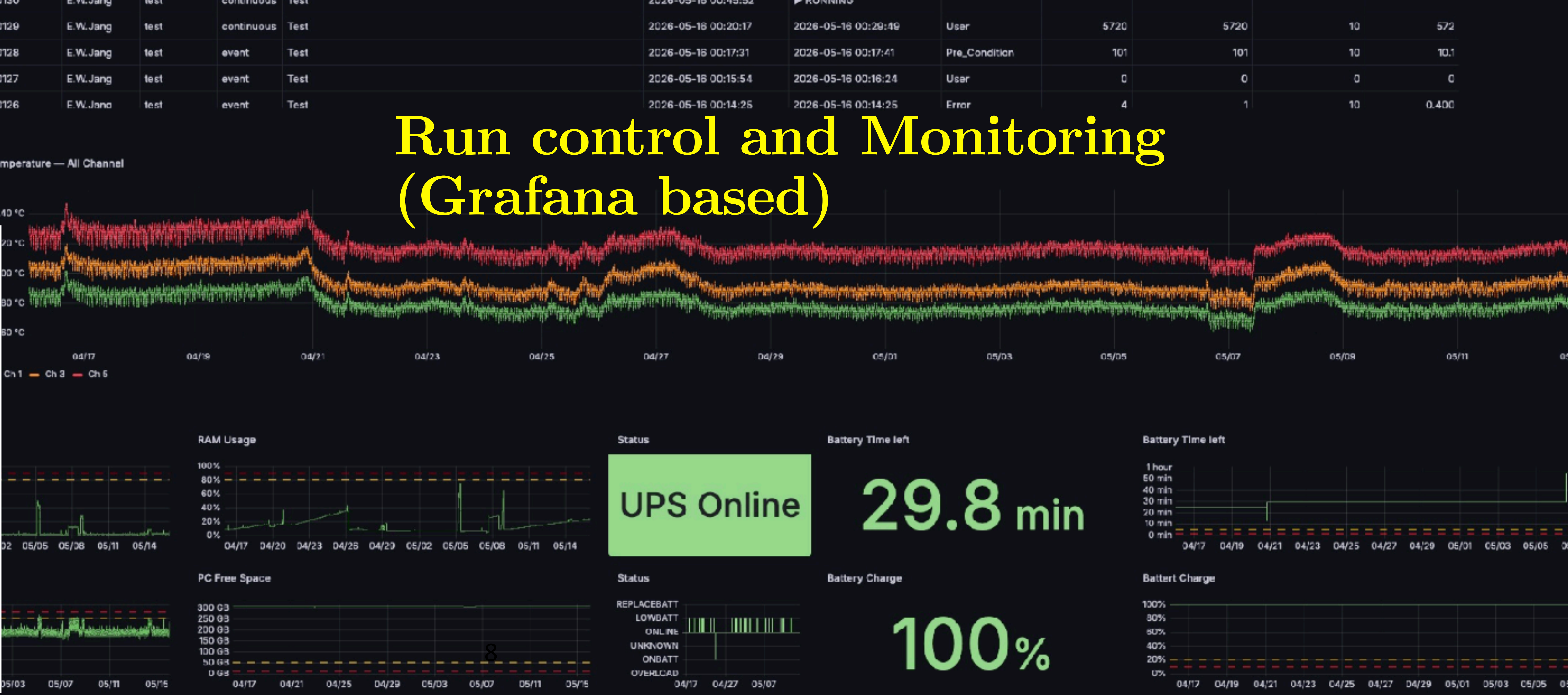
Tent, outer/iner containers
Purification system
Readout/DAQ all prepared.

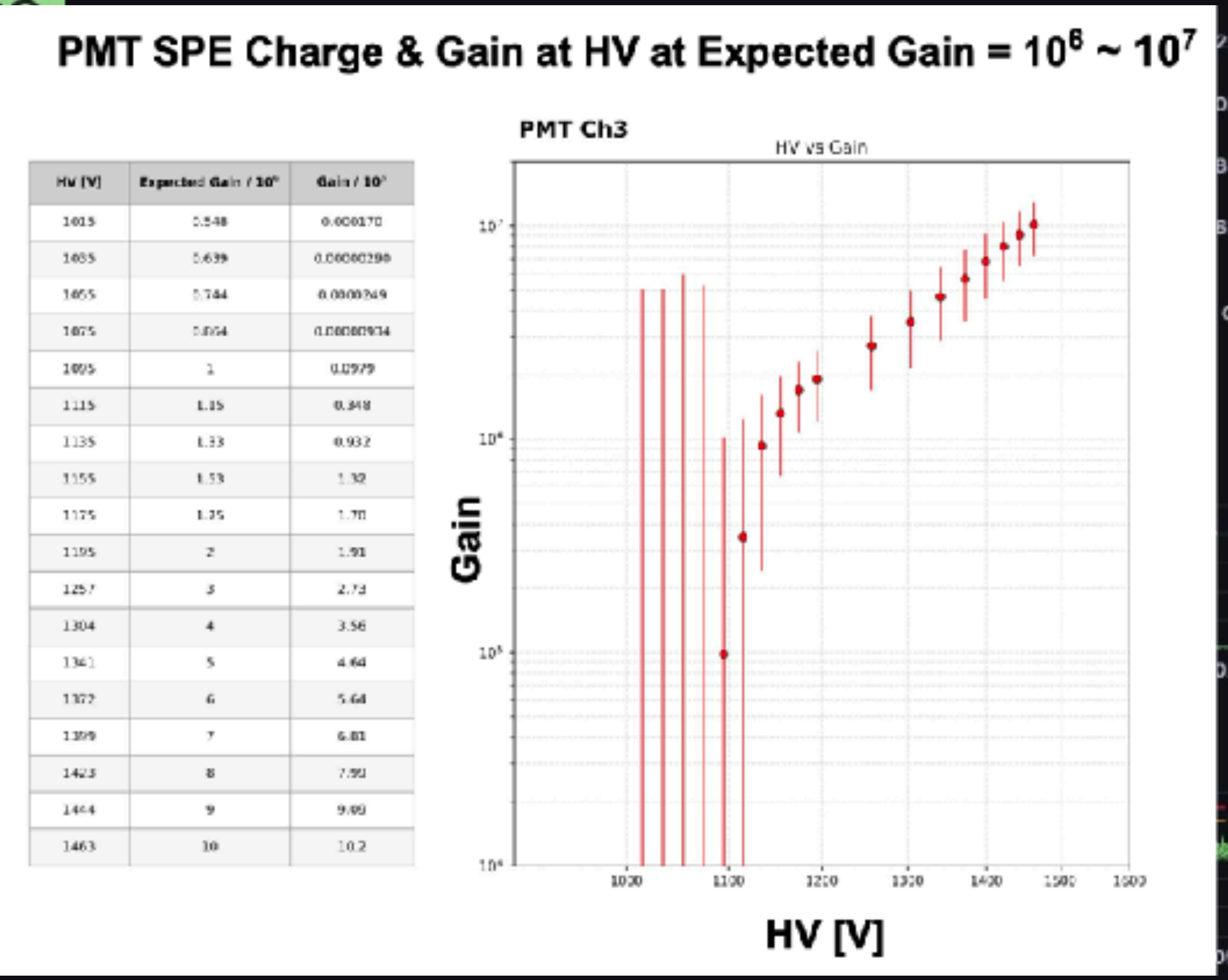


- 1 tonne prototype dry run: May 2026
- Water fill on June 15
- Expect to fill LS (LAB based) on Oct. (TBC)



Run control and Monitoring (Grafana based)





Contents

CDR - arXiv:2601.12569

Uploaded in Jan. 2026

Important for future!

νEYE web: https://sites.google.com/korea.ac.kr/the-nueye-telescope

νEYE The NuEYE Telescope

Home Science Detector CDR Pub/Presentations Contact us

The NuEYE Experiment at Yemilab

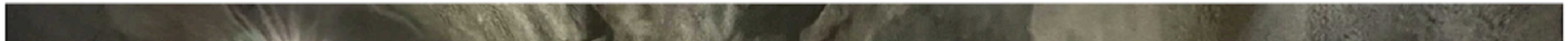
In September 2022, a new underground laboratory, Yemilab, was completed in Jeongseon, Gangwon Province in South Korea, with a depth of 1,000 m. In the laboratory, the largest site is the LSC Hall, combining a square dome measuring 22 m (width) by 22 m (length) by 8 m (height) on top, with a cylindrical pit having a diameter and depth of 20 m. The pit has a volume of 6,200 m^3 and serves as a multipurpose space for detectors. For a liquid type, about a 2 kilo-tonne detector can be hosted as an expample. The NuEYE experiment is a new proposed underground neutrino telescope at Yemilab for a multi-purpose neutrino science.

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.

By Gemma Conroy



$0\nu\beta\beta$ with νEYE

0νββ

Roughly, there are "two" types of 0νββ experiments:

Classification	Characteristics	Experiments
Almost background free	**Very little background in ROI.** Topology and/or energy resolution reject backgrounds	**nEXO**, LEGEND...
Background limited	Sensitivity is limited by radioactive background. **Large volume of LS.**	**νEYE**, SNO+, KamLAND(2)-Zen...

For **νEYE**, **careful choice of isotope** (Q, abundance, radioactive isotope contamination) and **radio-purification** of LS are key elements.

$0\nu\beta\beta$

- **SNO+**

Vessel: 780 tonnes (of LS: LAB + PPO)

Isotope: ^{130}Te ($Q = 2.527$ MeV)

Abundance: 34.1% (Loading 0.5% of natural Te or 1300 kg of ^{130}Te)

Sensitivity: 2×10^{26} years (3 years of running)

Backgrounds in ROI (highest to lower)

^{8}B solar neutrino:	**irreducible** (unless with directionality)
Internal Th:	**reducible**
$2\nu\beta\beta$:	energy resolution
External gamma:	fiducial cut
Internal U:	**reducible**
Cosmogenic:	small
^{13}C(α,n):	small

$0\nu\beta\beta$

- **KamLAND-Zen**

Isotope: ^{136}Xe ($Q = 2.458$ MeV)

Load 745 kg of enriched Xe

Half-life limit: $T^{0\nu}_{1/2}(^{136}\mathrm{Xe}) > 3.8 \times 10^{26}$ years

PRL 135, 262501

For ^{136}Xe, backgrounds are different (see Neutrino2026)

KamLAND2-Zen aims to reach 2×10^{27} years

$0\nu\beta\beta$

- νEYE ?

CDR: At the end of the νEYE operation for ν physics, we plan to load an isotope to do $0\nu\beta\beta$ experiment.

Q: Isn't it too late for νEYE, given the importance of the experiment?

A: Even next gen. exp. such as LEGEND-1000 - full run in 2035.

$\longrightarrow$ **nEXO@Yemilab is therefore critical!**

■ In the CDR (2601.12569), we mentioned ^{124}Sn (Q = 2.2 MeV, abundance 5.8 %) and ^{130}Te.

> One possible candidate isotope is Tin-124 (^{124}Sn) with Q=2.2 MeV. It has abundance of 5.79% but shows high solubility in aromatic solvent in the form of organo-tin such as tetramethyltin (TMSn) or tetrabutyltin (TBSn), and the loaded LS demonstrates relatively small light quenching according to a pioneering study (Astroparticle Phys. 6, 412, 2009).
>
> Another possible choice is ^{130}Te that has a Q = 2.54 MeV. It has relatively high natural abundance of 34.1%. We plan to have a long-term R&D for double beta candidates, and loading methods into LS, in order to reach the half-life time sensitivity of order 10^{28} years.

■ ^{136}Xe ?

: anything forces not to think about it in νEYE ?

$0\nu\beta\beta$

- **νEYE ?**

^{136}Xe option:

Simple scaling up from KamLAND-Zen for 1 kilo tonne fiducial volume:

KamLAND-Zen $T^{0\nu}_{1/2} < 3.8 \times 10^{26}$ yr $\leftarrow$ $Mt \sim 2.1$ tonne yr

νEYE: $M(^{136}\mathrm{Xe}) = 27.3$ tonne (90% enrichment), $T^{0\nu}_{1/2} \propto \sqrt{Mt}$

νEYE: $Mt \sim 27.3 \times 5 = 136.5$ tonne yr $\rightarrow$ $T^{0\nu}_{1/2} < 3.8 \cdot \sqrt{136.5/2.1} \times 10^{26} \underline{= 3.1 \times 10^{27}}$ yr

(This is assuming similar backgrounds as in KamLAND-Zen. May not be quite reasonable?)

$\Rightarrow$ Possible improvements based on our previous discussions?

- Adding ^{131}Xe directly to the target LS ?
- Melting H_3BO_3 (Boric Acid, powder) to the buffer water? (optically colorless)
- And/or Boron shielding (BPE, opaque solid) outside the buffer?

$\Rightarrow$ **Study in detail needed.**

$^{10}\mathbf{B} + n \rightarrow {}^{7}\,\mathbf{Li} + \alpha$

Summary

$0\nu\beta\beta$ is becoming more and more interesting subject.

νEYE should also look at $0\nu\beta\beta$.

- Cleaver choice of the isotope for ***ν*EYE** is needed (^{124}Sn, ^{130}Te, ^{136}Xe...).
- Different isotopes have somewhat different backgrounds to worry.
- It would be nice to reach 10^{27} years, aiming for 10^{28} !
- ^{136}Xe?

  : can we distinguish two electron $0\nu\beta\beta$ topology from single electron solar neutrino in νEYE with "slow LS" ?

  Probably not easy...

New physics program with IsoDAR + νEYE

Intense beams of **nuclei, mesons, e^+, e^-, γ** allow **competitive new physics programs.**

Dark photon (A'): spin-1 massive gauge boson, kinetic mixing with SM photons.

Production: Meson decay (ex: $\pi^0 \to \gamma A'$), proton brem. ($p + N \to p + N + A'$), annihilation ($e^+e^- \to \gamma A'$)

Decay: $A' \to e^+e^-$, $A' \to \chi\bar{\chi}$ (χ: dark matter)

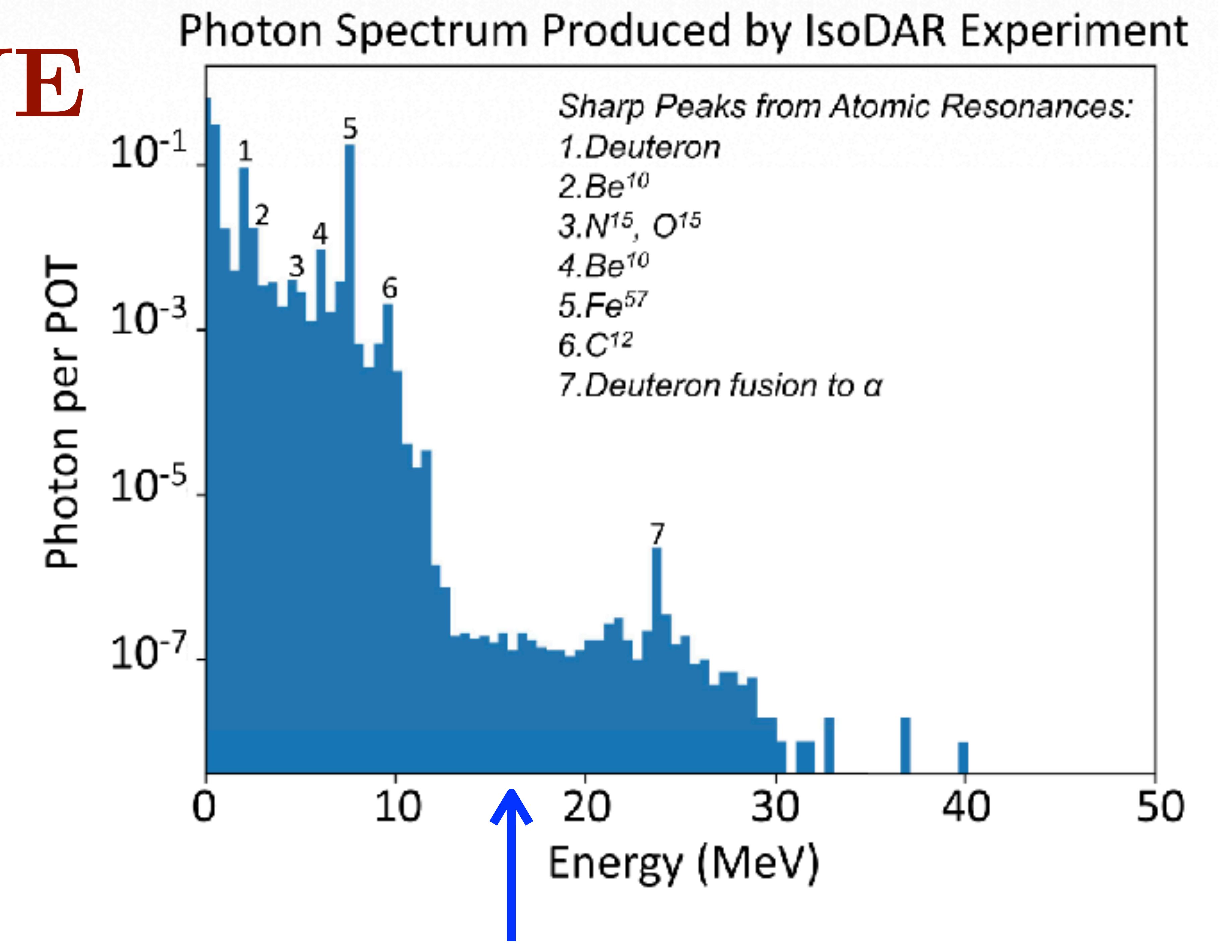
Axion Like Particle: light pseudoscaler, 10^{-22} eV - GeV.

Production: Primakoff production ($\gamma + N \to a + N$), meson decay (ex: $\pi^0 \to \gamma a$), electron brem.

Decay: $a \to \gamma\gamma$, $a \to e^+e^-$

PRD **105** 052009 (2022)

New physics program with IsoDAR + νEYE



Atomki anomaly region

X boson (low mass mediator) decay to $\nu_e\bar{\nu}_e$ (ex: $N^* \to NX \to \nu_e\bar{\nu}_e$).

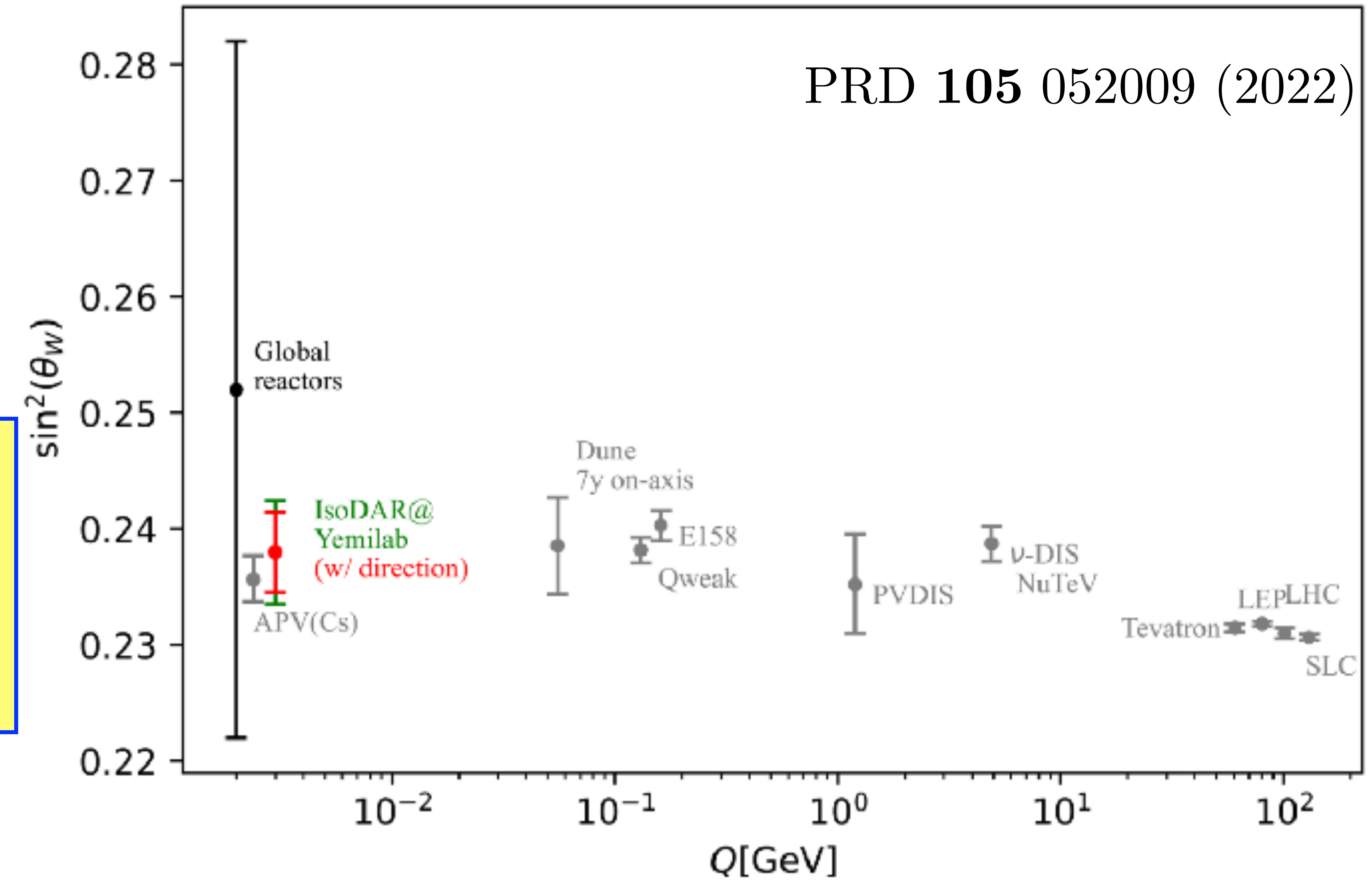
Atomki anomaly: reported excess of e^+e^- pairs from 18 MeV Be* in ^{7}Li$(p,n)^8$Be* - PRL **116**, 042501 (2016).

5 MeV bump?

If Huber-Mueller of reactor is incorrect, Li should not see it.

If IsoDAR@Yemilab sees it, can be from ^{13}C$(\bar{\nu},\bar{\nu}')^{12}$C* :PRD 99, 055045 (2019).

* Seodong. Shin, PRD 112, 055046 (2025)



$\bar{\nu}_e - e^-$ scattering

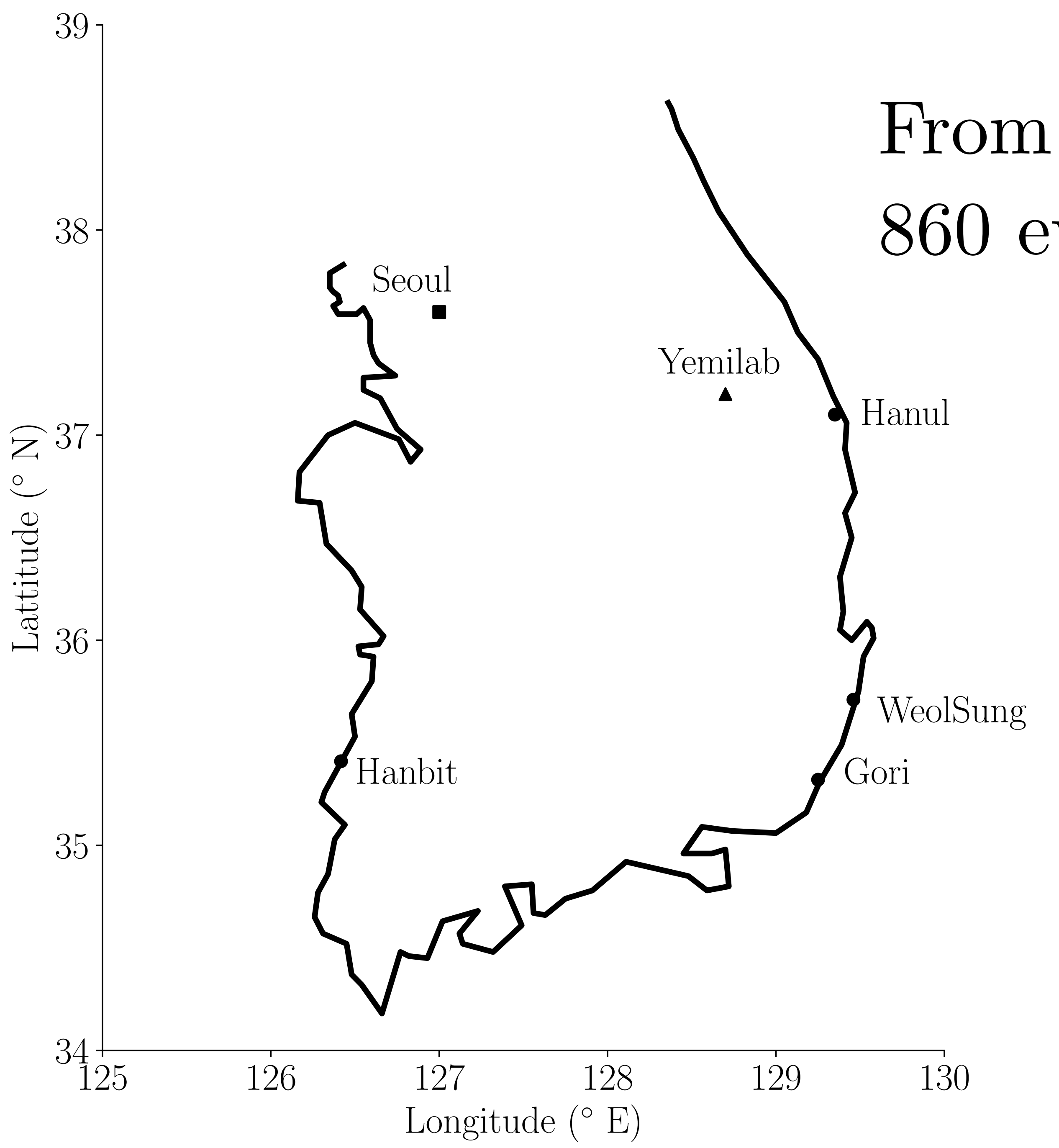
Non Standard Interactions in weak mixing angle:

Similar study with source in progress (Both $\bar{\nu}_e$ and ν_e available)

More on new physics cases in PRD **105** 052009 (2022)

Reactor neutrino with νEYE

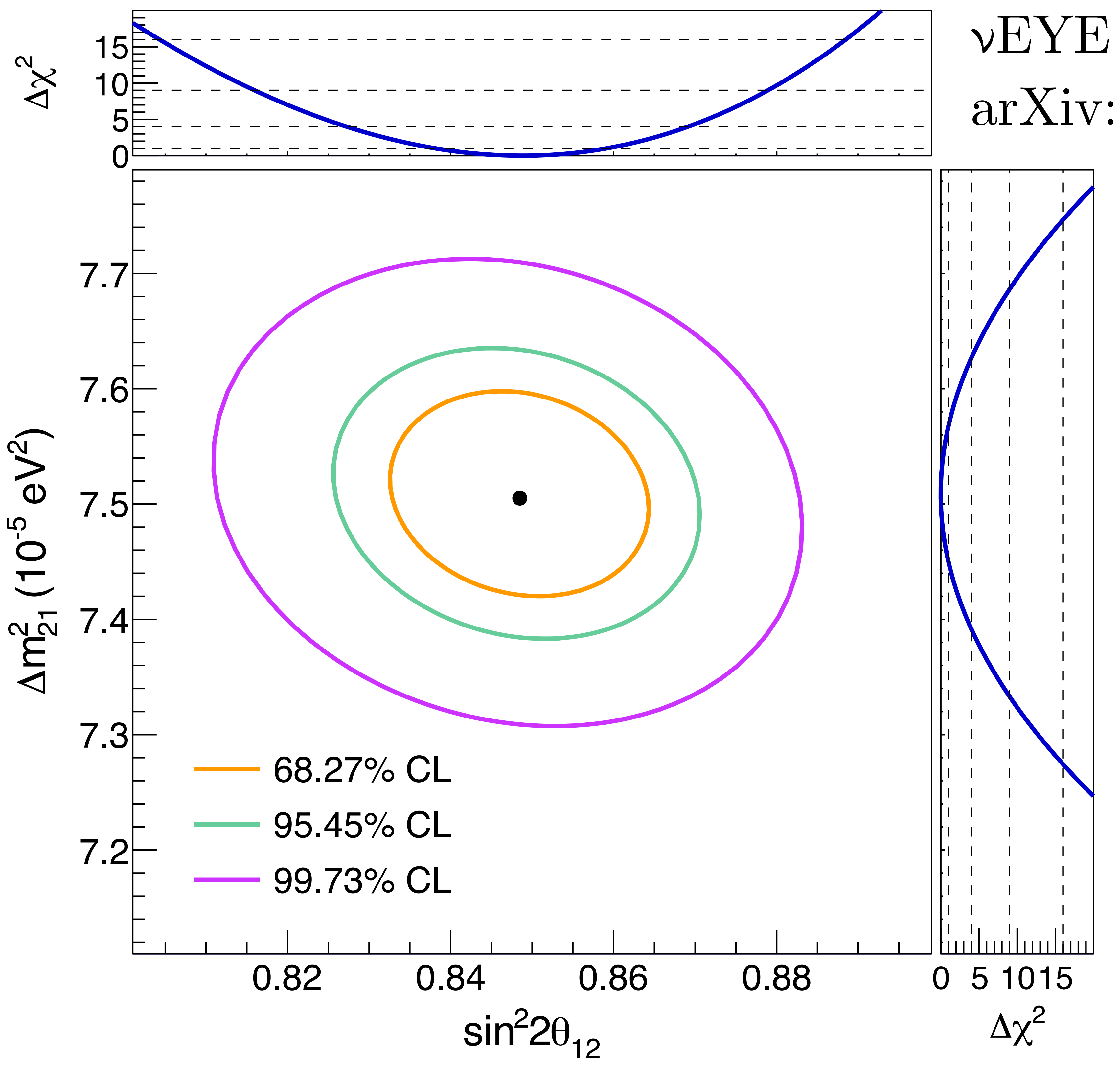
The JUNO experiment will measure 3-ν oscillation parameters with high precision.
But JUNO findings **need to be validated**: the νEYE is also at the first minimum.



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 $\sin^2 2\theta_{12}$



νEYE CDR:
arXiv:2601.12569

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

Radio-purification (for one tonne)

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 impurities

Metal & Oxide, U/Th, K, Bi, Po/Pb

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

Now @ Yemilab

Glove box (see the picture on the right)

Other components are being purchased.

Budget breakdown

Unit: 1 billion KRW (1 억원) = 0.1 Billon KRW

Catagory	Item	Unit price	Qty	Total	Notes
1. PMT	PMT	0.07	3000	210.0	PMT 0.07
	HV	0.005	3000	15.0	Power & Mainframe
	Readout	0.01	3000	20.0	FADC/Fronend 0.01 Misc 0.01
	Misc	0.01	3000	20.0	Cables, Connectors, Mounts
	Muon Veto			70.0	Plastic/RPC ??
	Sum			335.0	
2. 데이터 처리	Trigger/Global			10.0	Trigger & Global Timing System
	Online DAQ			10.0	Online DAQ & Networking
	Storage			50.0	Data Storage & Computing (Offline Analysis)
				70.0	
3. LS	LS production			60.0	LS production (Raw Materials)
	Handling System			40.0	Storage/mixing Tanks, Transfer Pumps, Piping
	Purification System			100.0	Distillation, Gas Stripping, Water Extraction
	Sum			200.0	
4. Construction & Infracture					
Detector Structure	Acrylic Target Vessel			80.0	
	SS Buffer Frame			60.0	PMT Support structure
	Veto System			60.0	Waterproofing Linear 등
Lab Infra	Clean Rm & HVAC			50.0	Clean room & HVAC System (Class 100)
	Utility			50.0	전력 보강, 급/배수
				300.0	
5. Human	Scientists			200.0	
	Postdoc			100.0	
	Technitian			50.0	
	Students			50.0	
	Sum			400.0	
6. R&D				50.0	Scope, measurements, material, design
7. Operation/Travel				50.0	
8. Radioactive Source	51Cr / 144Ce			100.0	Borexino input + inflation
Total Budget		22		1505.0	약 1500 억원

Selected Physics Cases

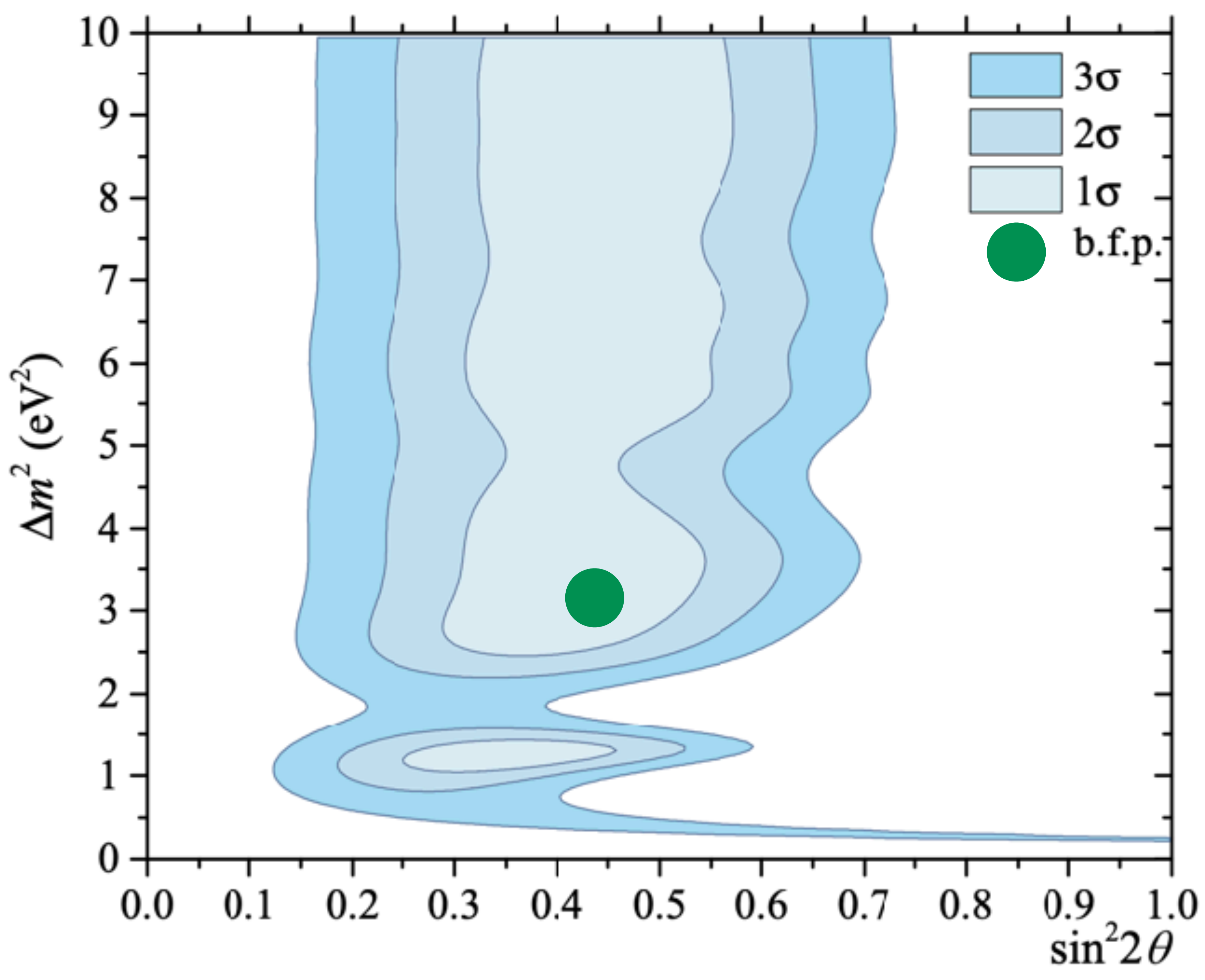
Summary of sterile neutrino search over the last 20 years

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**)
- Recent µBooNE result, Nature 648, 64–69 (2025) disfavors a single sterile neutrino state.

Reactor
Accelerator
Radioactive source



Baksan Experiment on Sterile Transitions (BEST)

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

Sterile neutrino? (Example: two talks in Neutrino2024)

June 21, 2024 (v1) Presentation Open

Sterile ν: review of positive hints

Gorbunov, Dmitry

Plenary talk at the Neutrino 2024 conference. Session 14: Re

(Talks)

ber 13, 2024

35 45

accel.: $\nu_\mu \to \nu_s$

source/reactor: $\nu_e \to \nu_s$

Mixing angle parameters are different.

Discrepancy between source and accelerator based expo?

June 21, 2024 (v1) Presentation Open

Sterile ν: review of negative hints

Danilov, Mikhail

Plenary talk at the Neutrino 2024 conference. Session 14: Reactor neutrinos.

Part of Neutrino 2024 (Talks)

Uploaded on September 13, 2024

46 46

High Energy Physics – Experiment

[Submitted on 14 Jan 2025]

Experiment BEST-2 with 58Co neutrino source

V.N. Gavrin, V.V. Gorbachev, T.V. Ibragimova, V.A. Matveev

The article describes a new experiment with an artificial neutrino source 58Co on a gallium target GGNT (SAGE). The goal of the experiment is to study the gallium anomaly. The experiment makes it possible to find the parameters of oscillation transitions of electron neutrinos to sterile states in a wide range of parameters. Including the parameter {\Delta}m2, the experimental determination of which usually causes significant difficulties. An important feature of the experiment is the possibility of identifying the dependence of the gallium anomaly on the neutrino energy.

Radiochemical method:

- Not in-situ method

Sterile neutrino or not ?

BEST results are to be confirmed.

Sterile neutrino search with νEYE

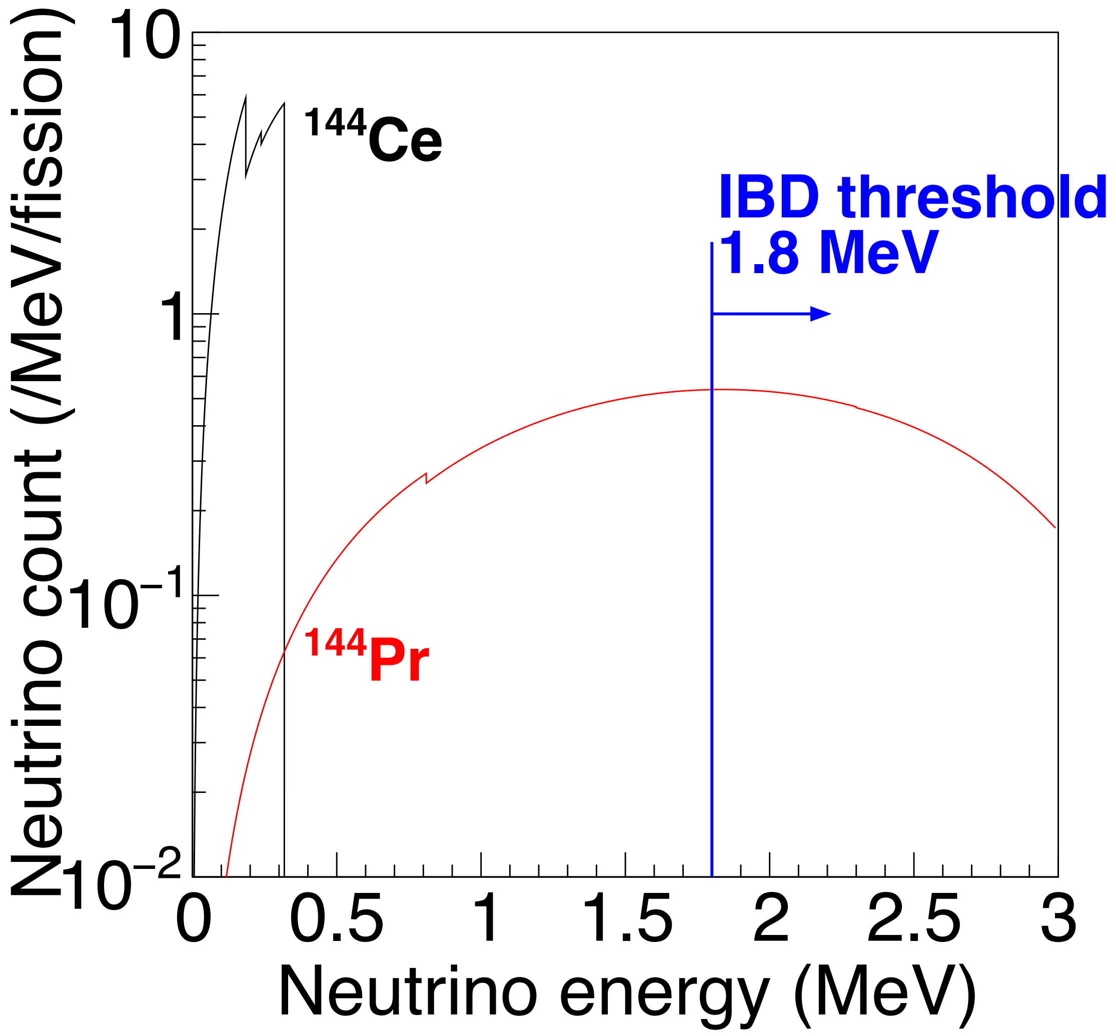
Will be the first of its kind in the world!

Use high activity radioactive source (^{144}Ce or ^{51}Cr) + **in situ** detection of signal w/ νEYE.

Radiochemical method not needed!

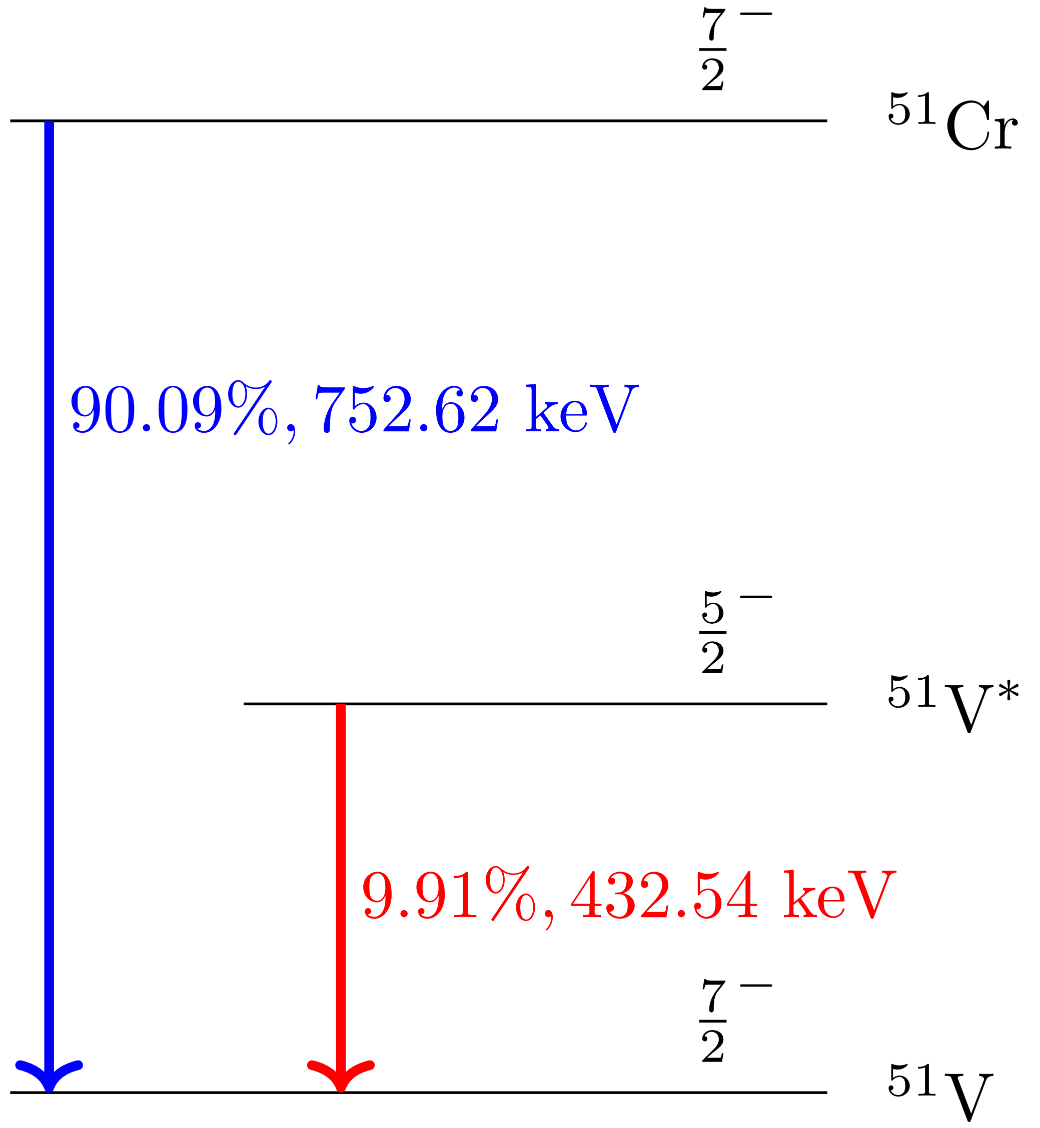
Both sources show similar sensitivity (purple) to confirm or rule out BEST result.

^{144}Ce

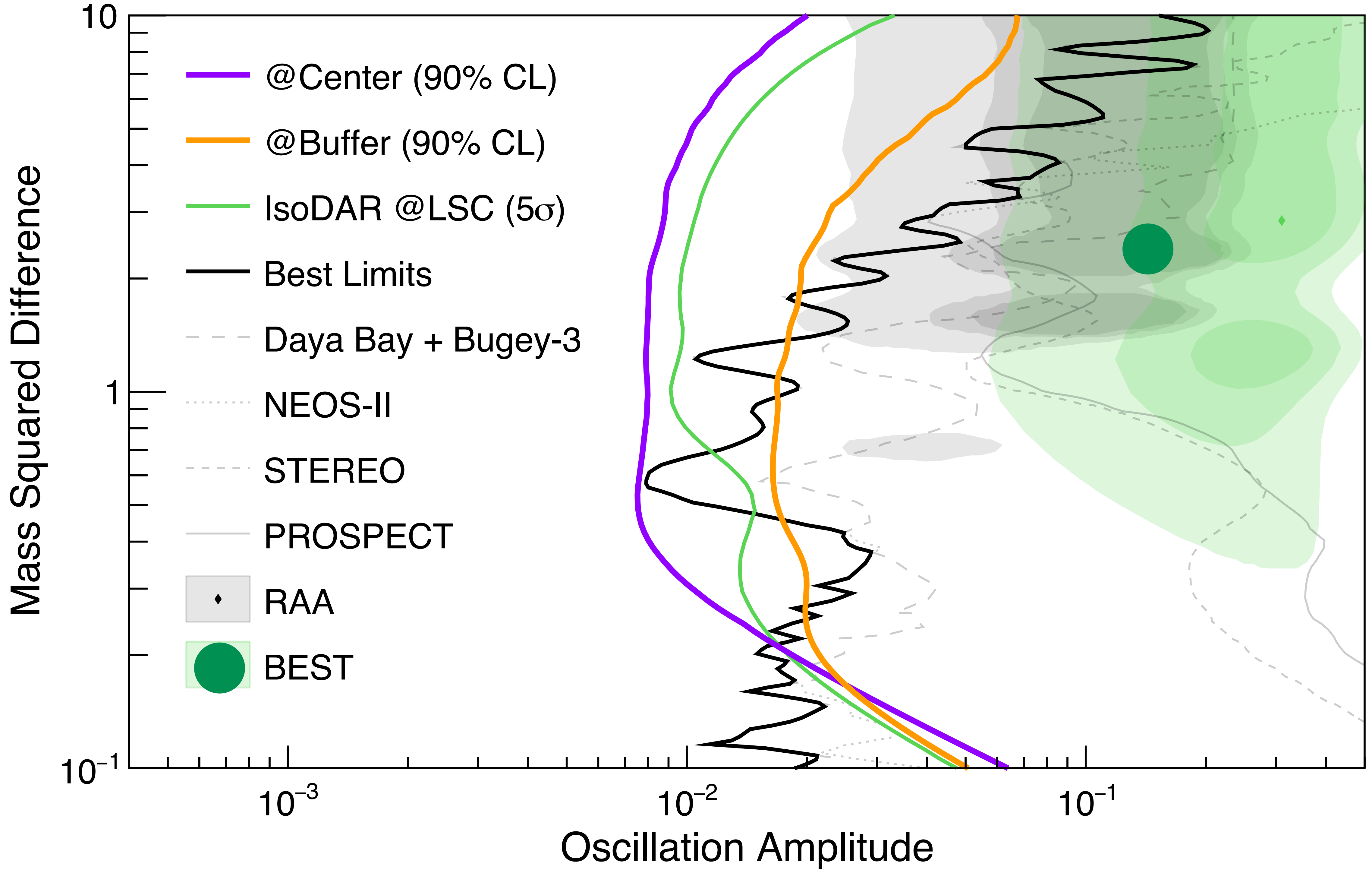


$\overline{\nu}_e$ source

^{51}Cr



ν_e source

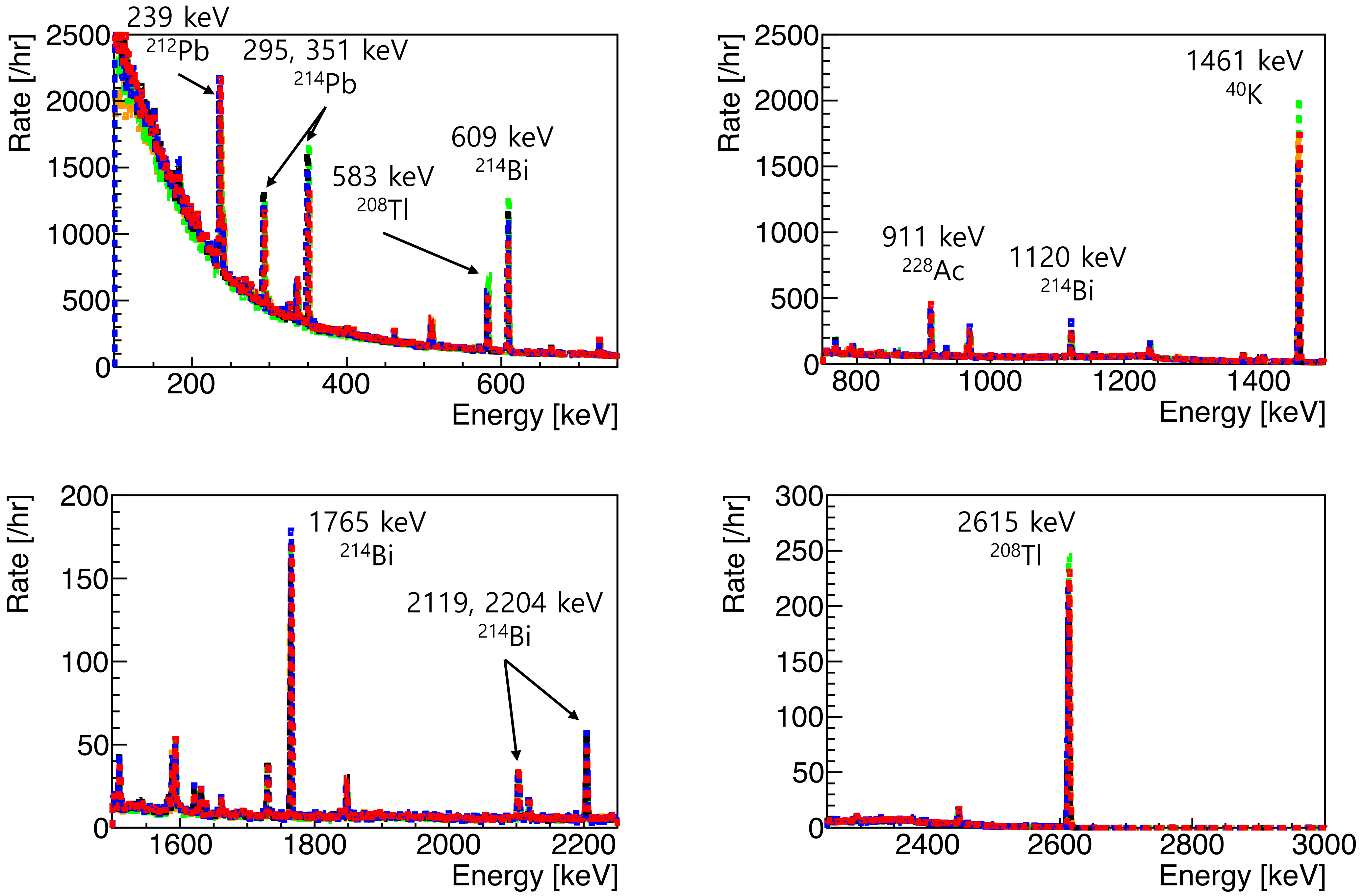


Environmental backgrounds @ Yemilab

At the Yemilab site, HPGe is utilized, 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

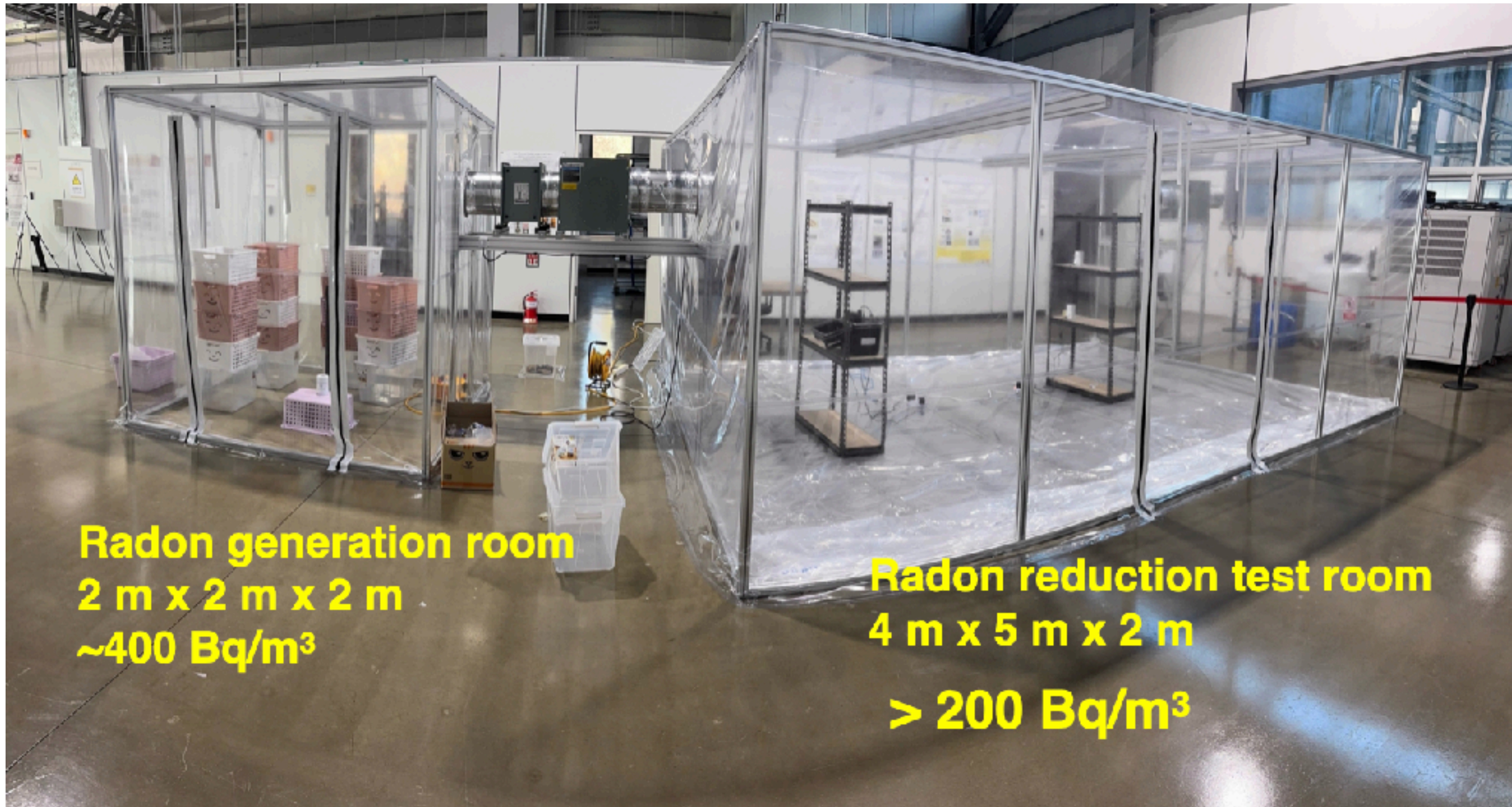


Measured Radon activity

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 exploring a new method: silver-ion exchanged zeolite (PTEP 2024 023C01) @ Korea U Sejong campus.



Software developments

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

νOscillation

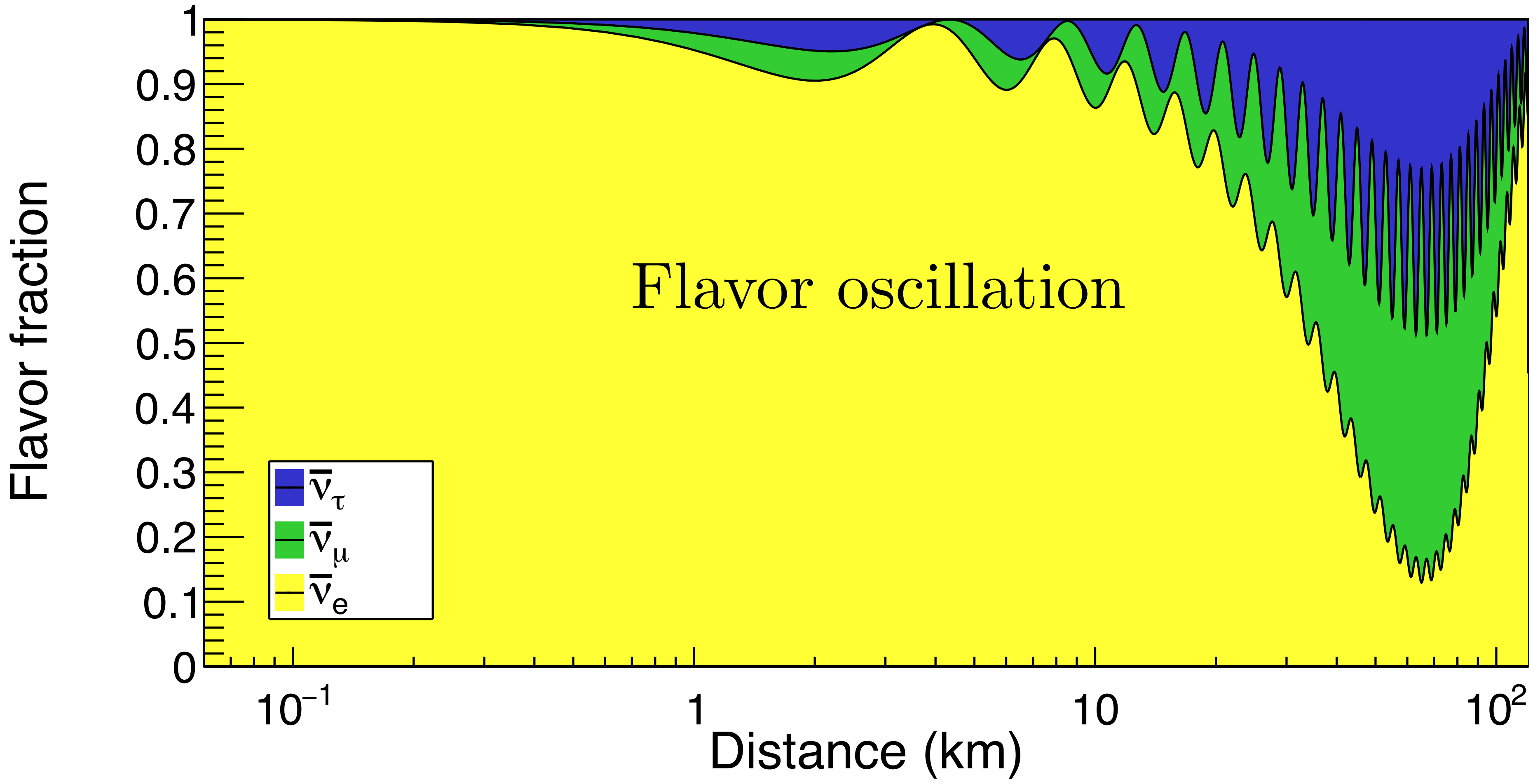
νOscillation: a software package for computation and simulation of neutrino propagation and interaction

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

Physics, Korea University, Seoul 02841, Korea

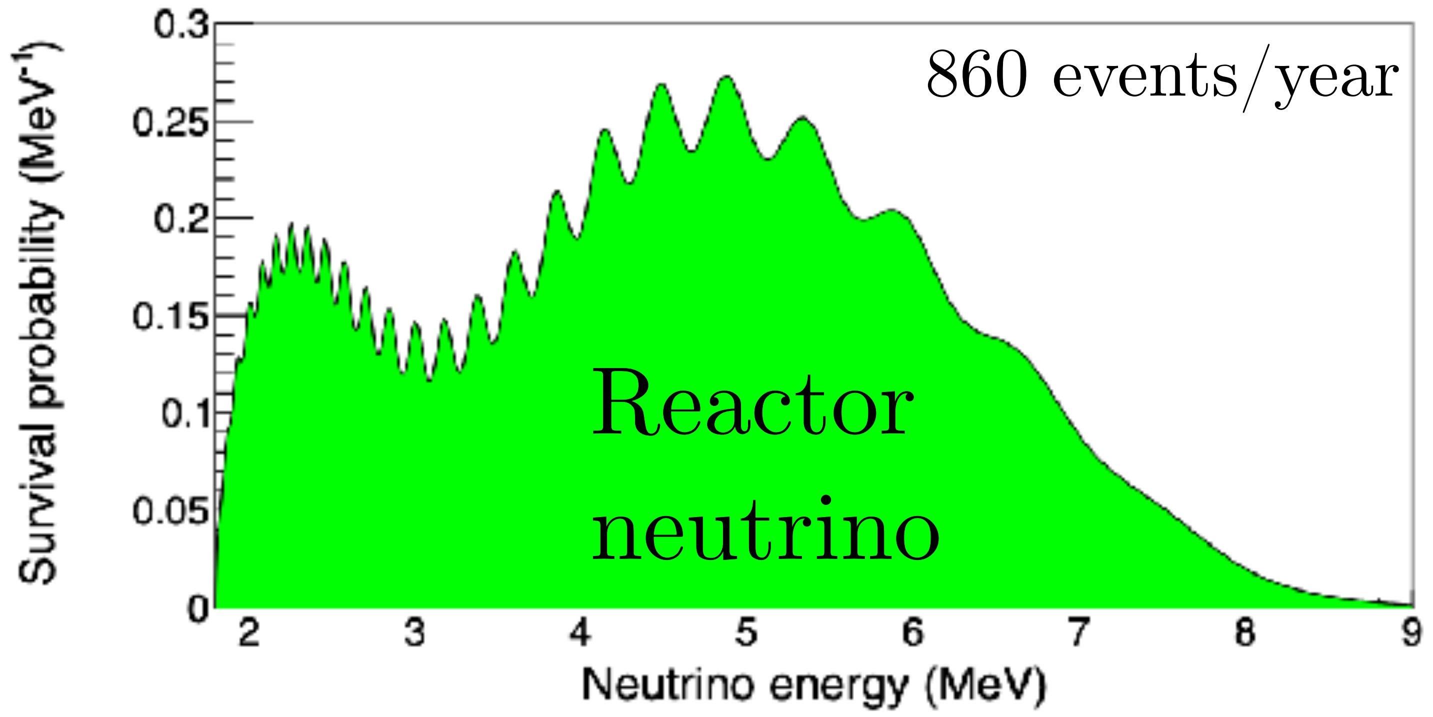
hysics, Institute for Basic Science, Daejeon 34047, Korea

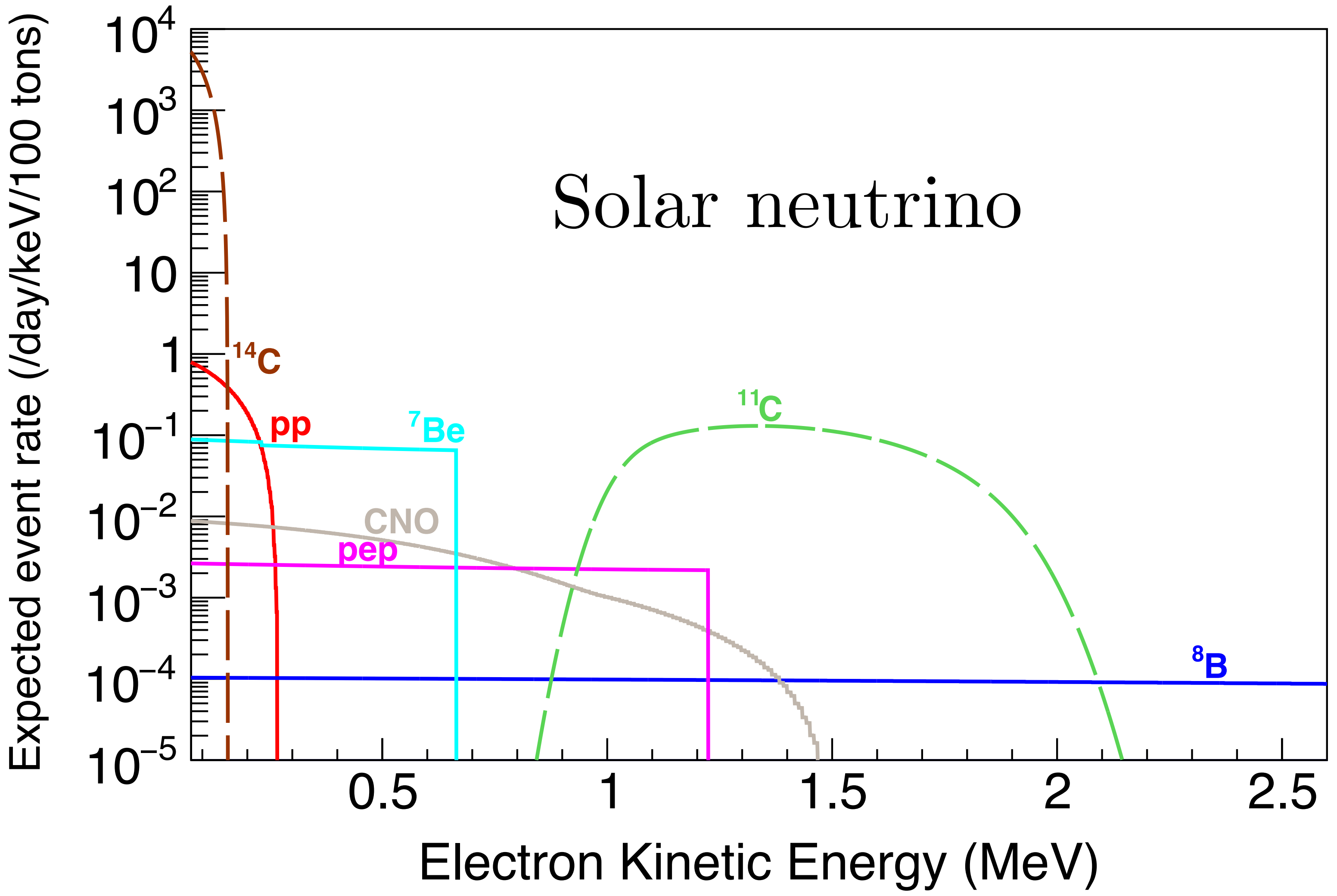
only phenomenon that cannot be explai
sterious neutrino interactions observed
nd ongoing or planned neutrino experi
ely on precise computations of neutrino

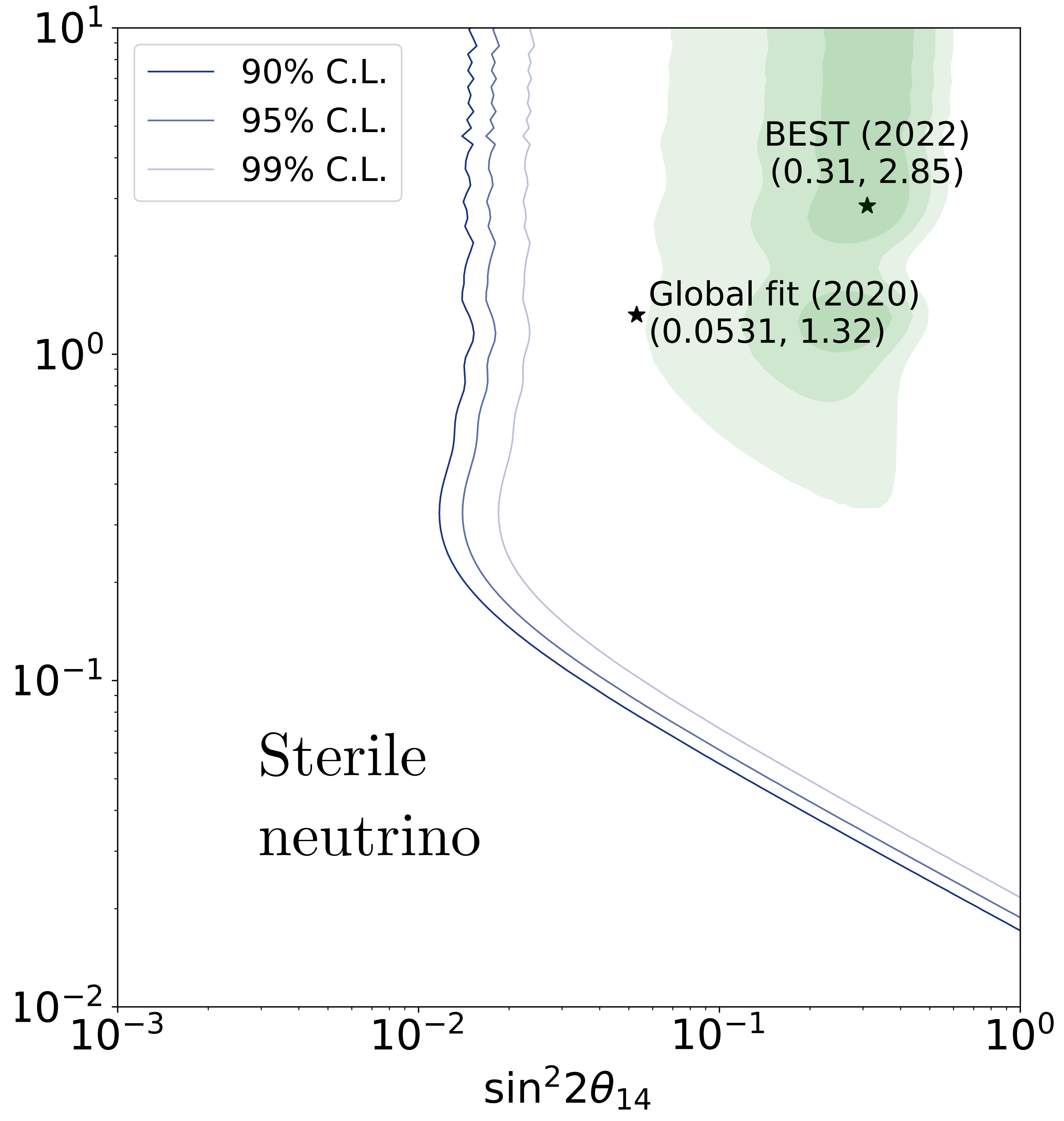


from the sun, and the oscillation of

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





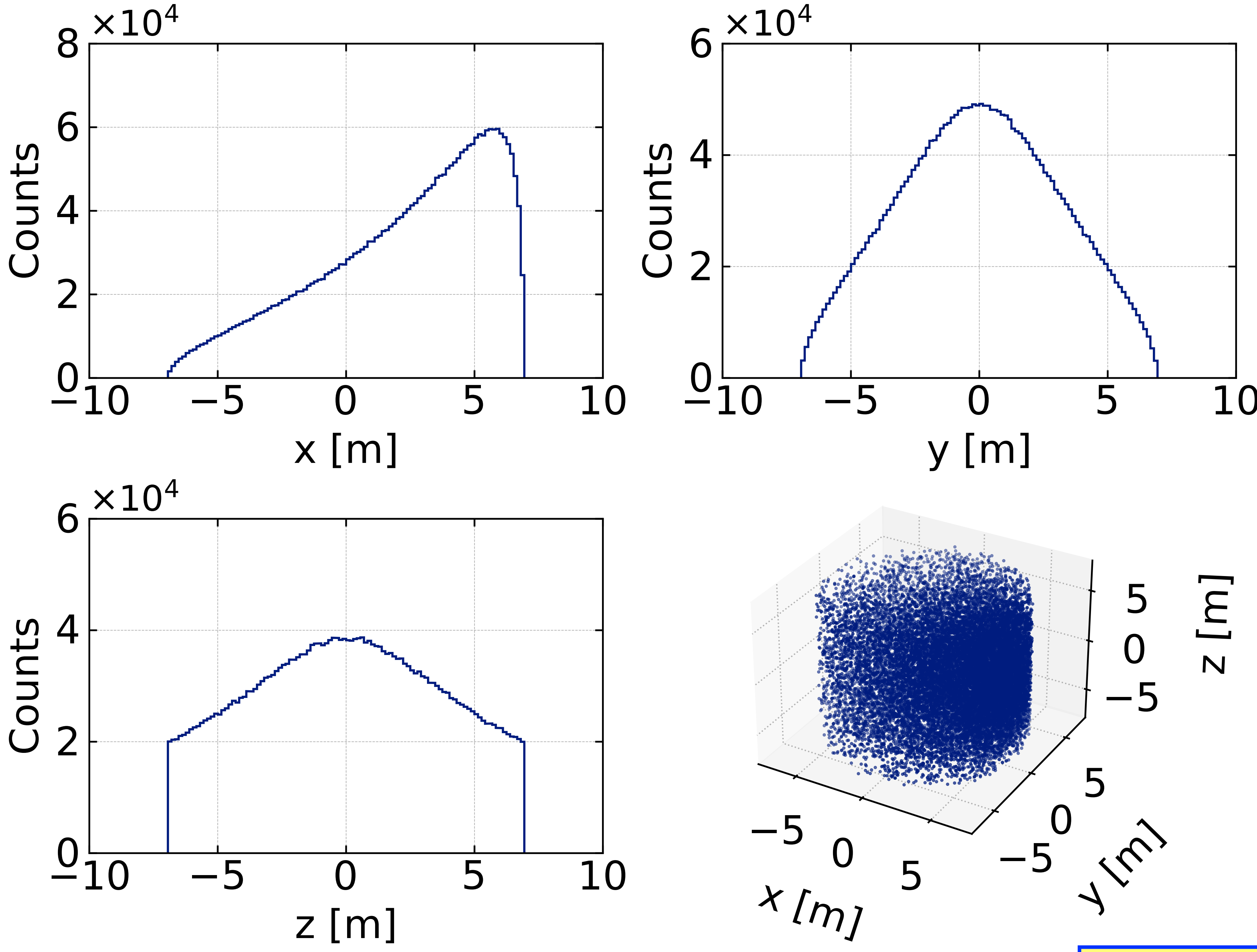


Software developments with Geant4

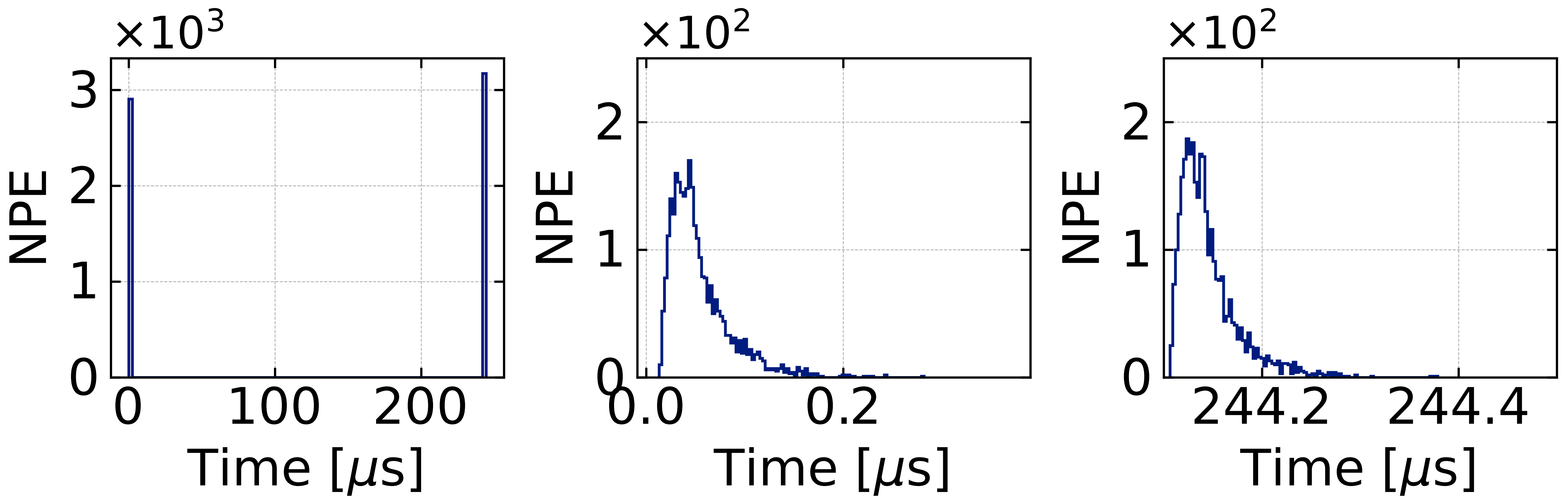
^{144}Ce $\bar{\nu}_e$ production simulation (Geant4) and reconstruction of inverse beta decays (IBD)

νEYE CDR: arXiv:2601.12569

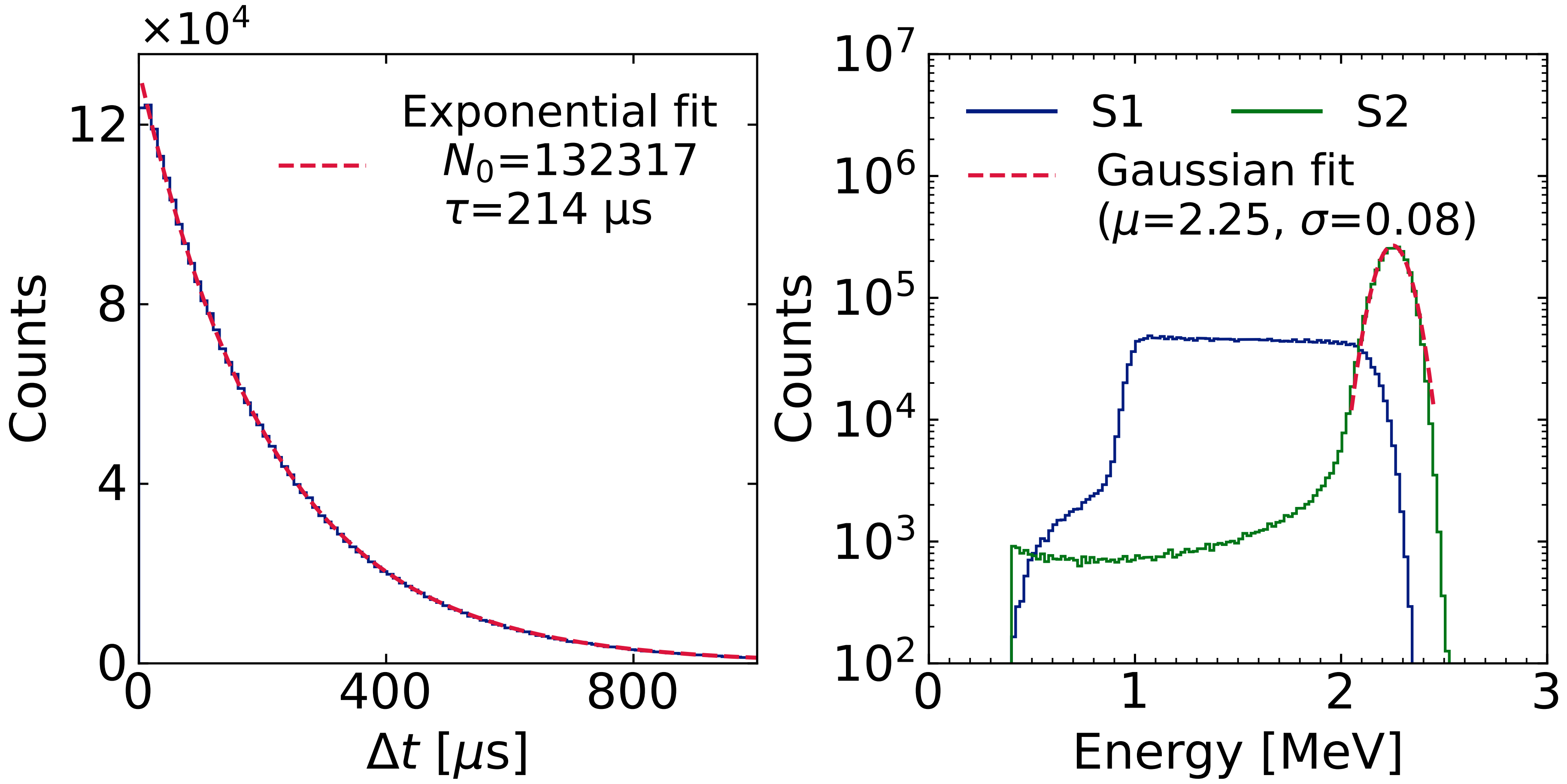
^{144}Ce at (9,0,0) m



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



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



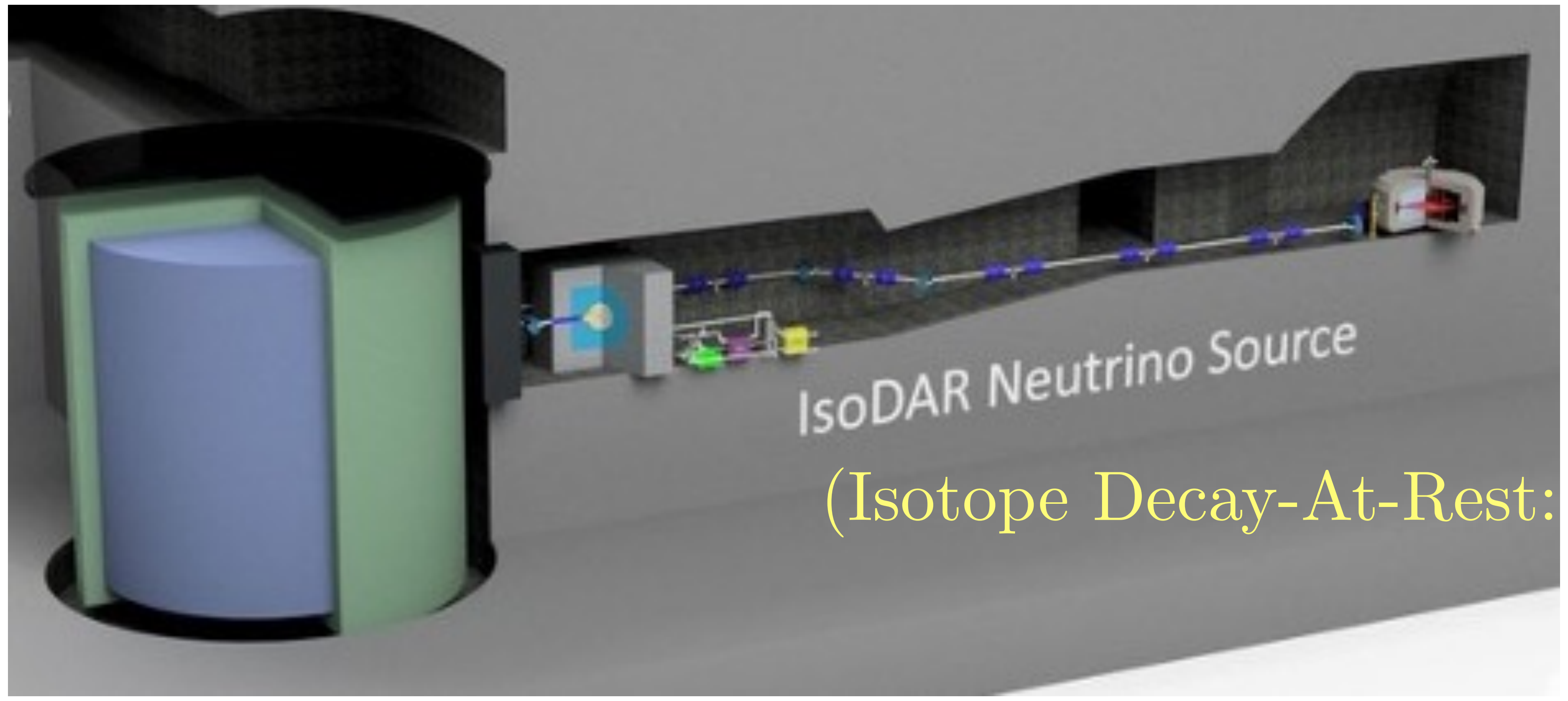
No issues with IBD reconstruction

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)

Optionally, with a high-current accelerator:

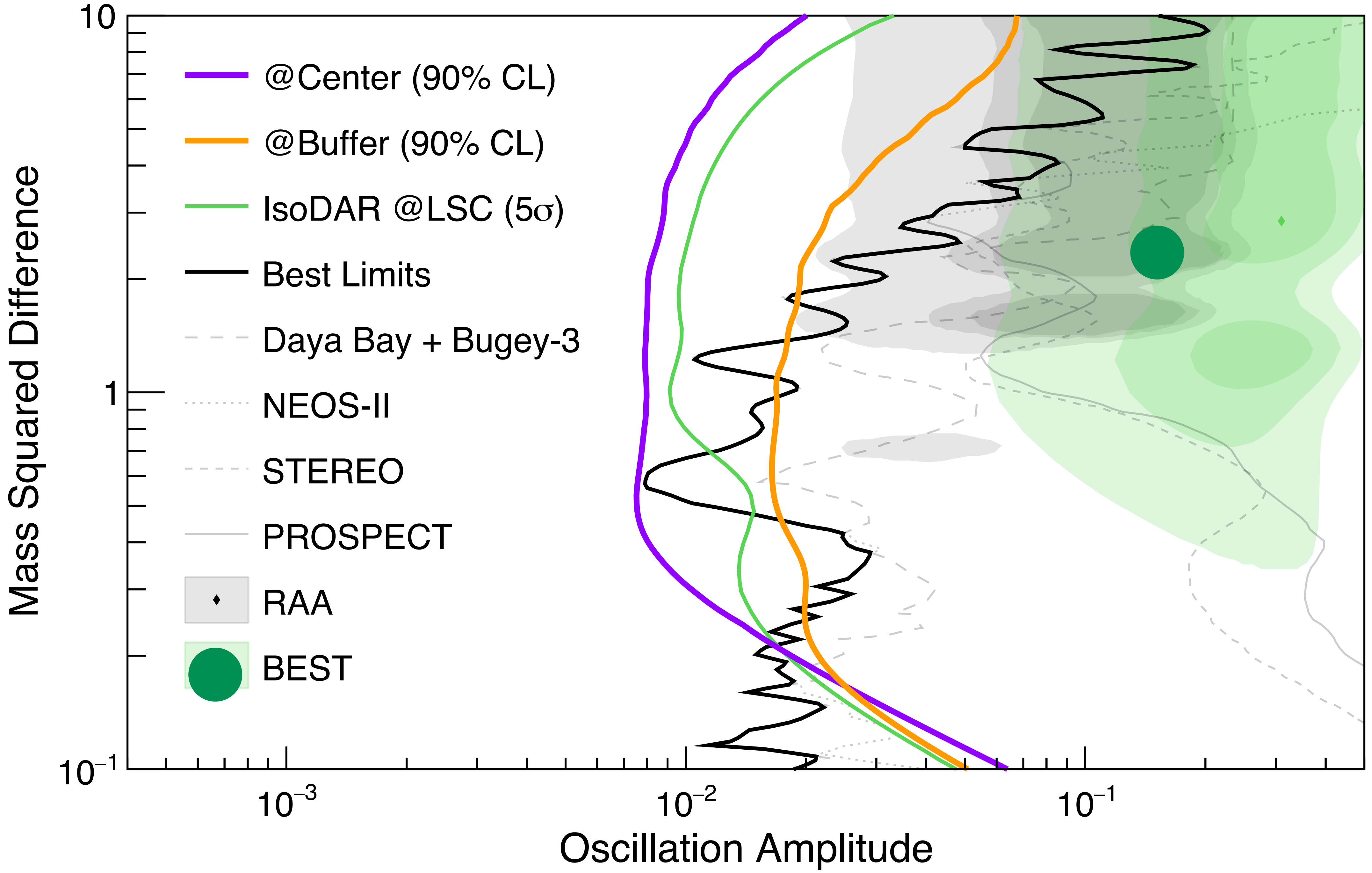
If IsoDAR is available: Generation of neutrinos with high-intensity accelerator.



(Isotope Decay-At-Rest: **US project**)

$$^{7}\mathrm{Li}(n,\gamma)^{8}\mathrm{Li}^{*},\ ^{8}\mathrm{Li} \rightarrow ^{8}\mathrm{Be}^{*} + e^{-} + \bar{e}_{\nu}$$

Both source and accelerator (green) allow us to confirm or rule out BEST result.



Massachusetts Institute of Technology

Janet Conrad
Professor of Physics

Building 26, Room 537
77 Massachusetts Avenue
Cambridge, Massachusetts
02139–4307

Email conrad@mit.edu

To whom it may concern,

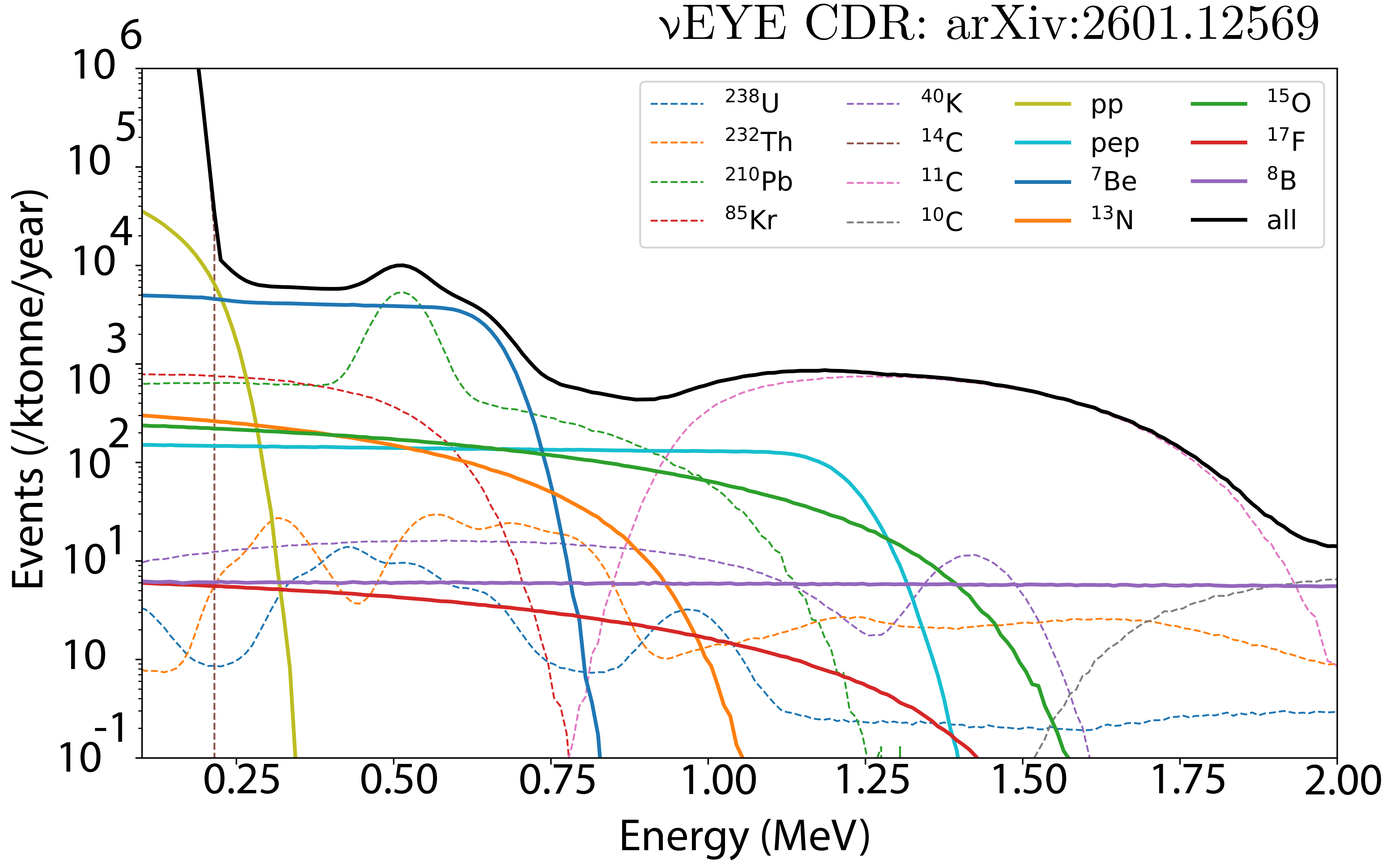
As a scientist who has worked in the field of neutrino studies for more than 25 years, and has served as co-spokesperson of the MiniBooNE and IsoDAR collaborations, I am writing this letter to express my strongest support for the construction of the νEYE detector at Yemilab. νEYE is a crucial project for the international particle physics community, and my group at MIT intends to actively participate in the experiment. My own interest is in coupling νEYE with an underground accelerator, IsoDAR, that we are developing and would bring to the project, that opens up a program of physics that cannot be explored at any other site in the world. The area of high-intensity, accelerator-based underground physics has enormous potential for discovery, and IsoDAR@Yemilab would be first-of-its-kind.

Construction of νEYE in combination with an internationally-funded high-intensity accelerator underground is a game-changing idea. At present, particle physicists build mas-

Solar neutrino physics with νEYE

Among possible topics, so called **observation of the "up-turn"** seems the most important.
- Radio-purification is required.

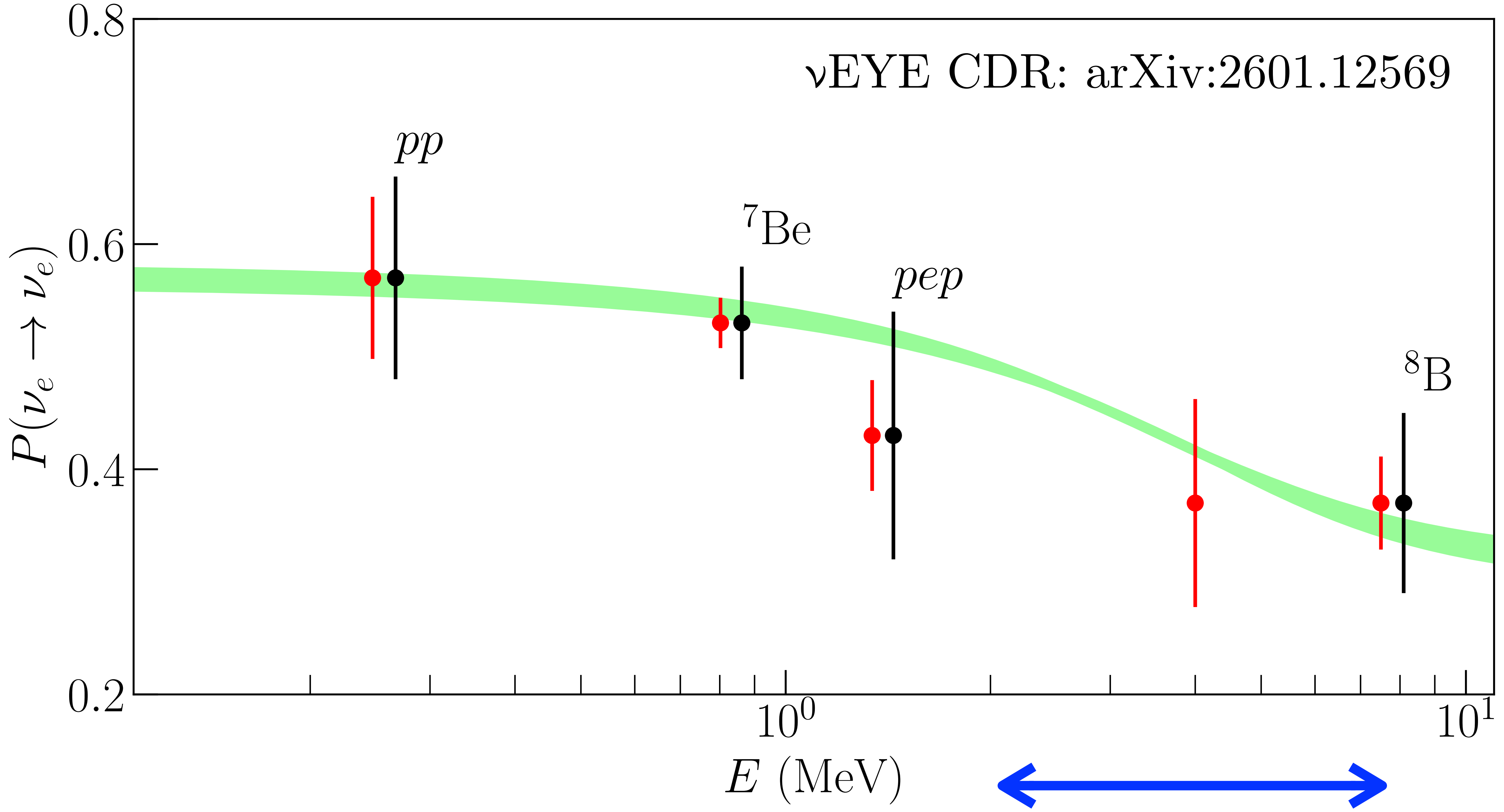
νEYE CDR: arXiv:2601.12569



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.

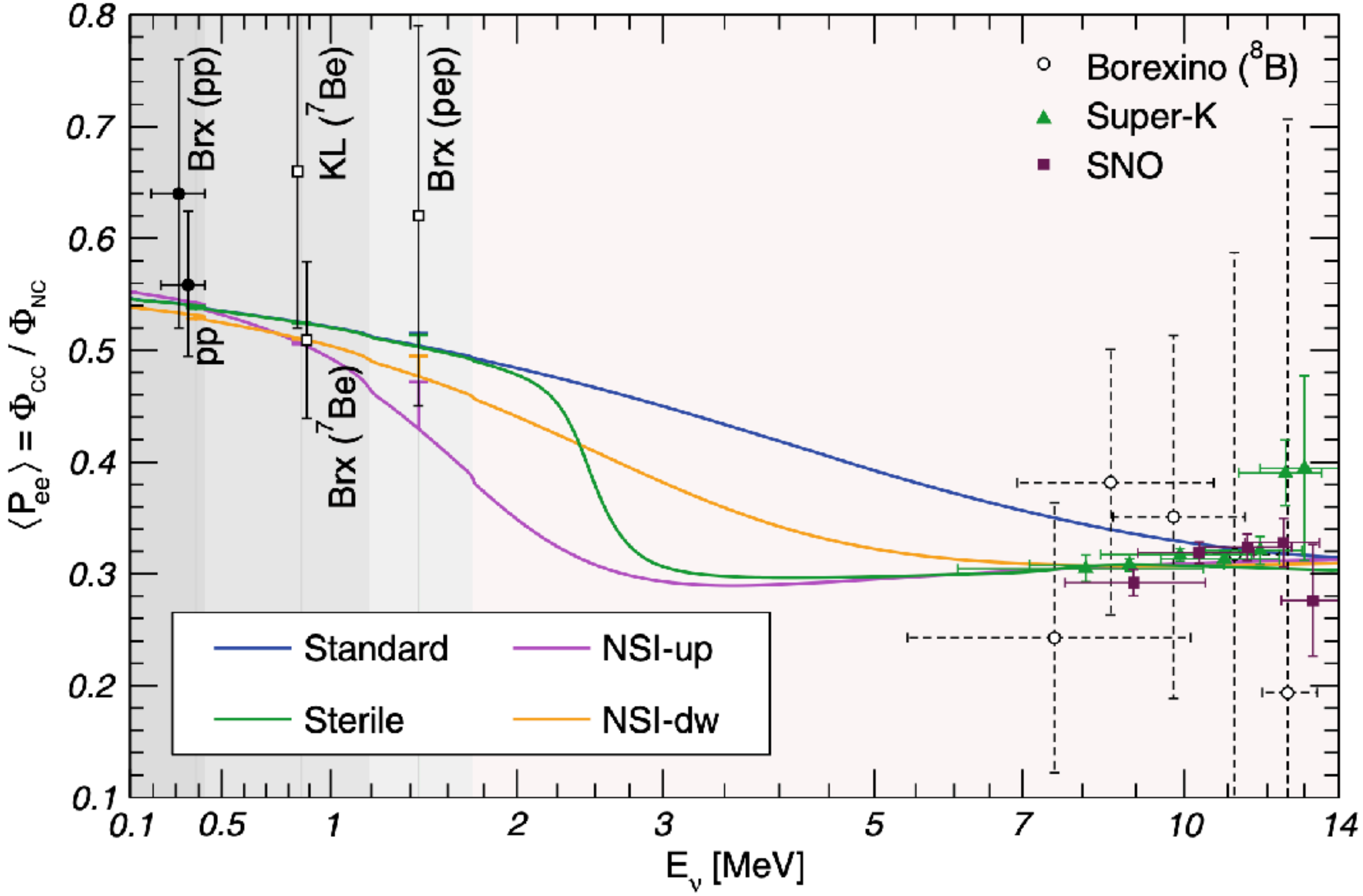
Red: νEYE
Black: Borexino



Only(*) νEYE can provide points in this region.
(5 year run here)

Solar neutrino physics with νEYE

Eur. Phys. J. A (2016) **52**: 87



Neutrinoless double beta decay ($0\nu\beta\beta$) with νEYE

At the end of the experiment, the νEYE telescope can be loaded with metal to allow a $0\nu\beta\beta$ experiment.

Candidate isotopes: Tin-124 (Q=2.2 MeV) or ^{130}Te (Q = 2.54 MeV).

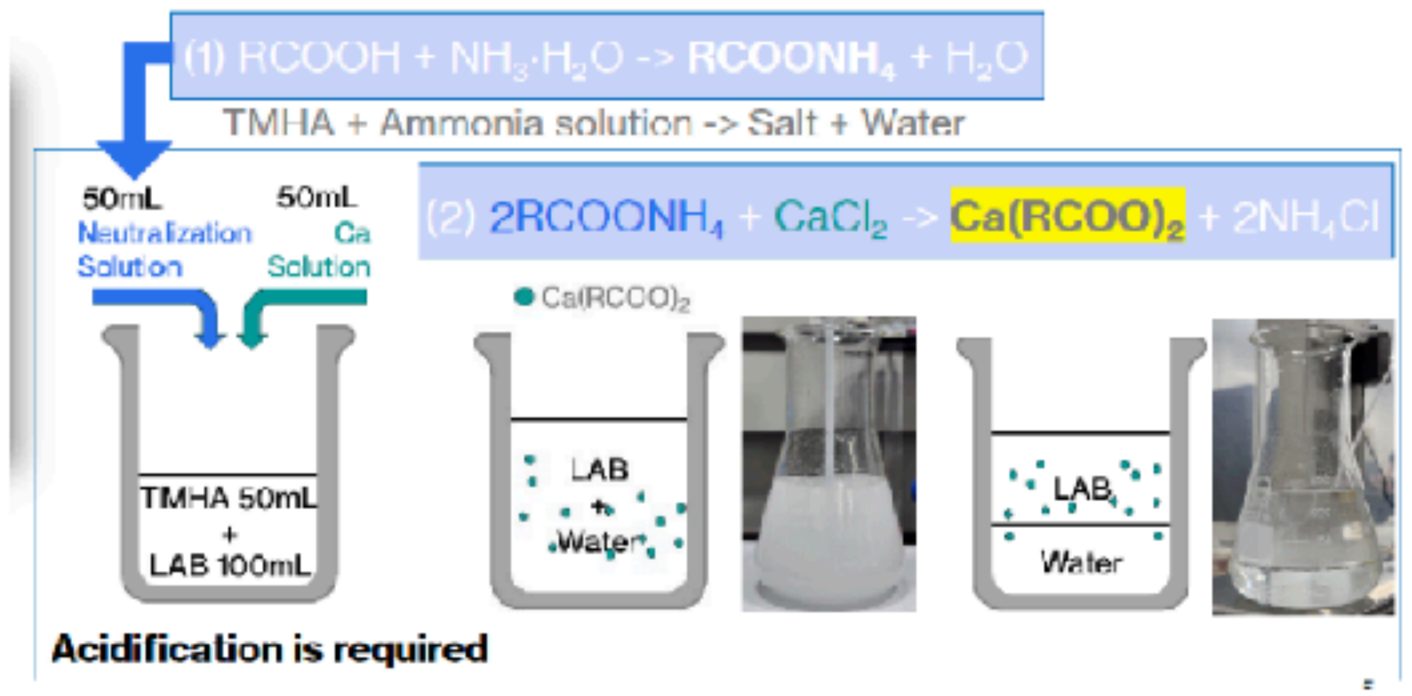
This topic requires a long-term R&D on the loading issues.

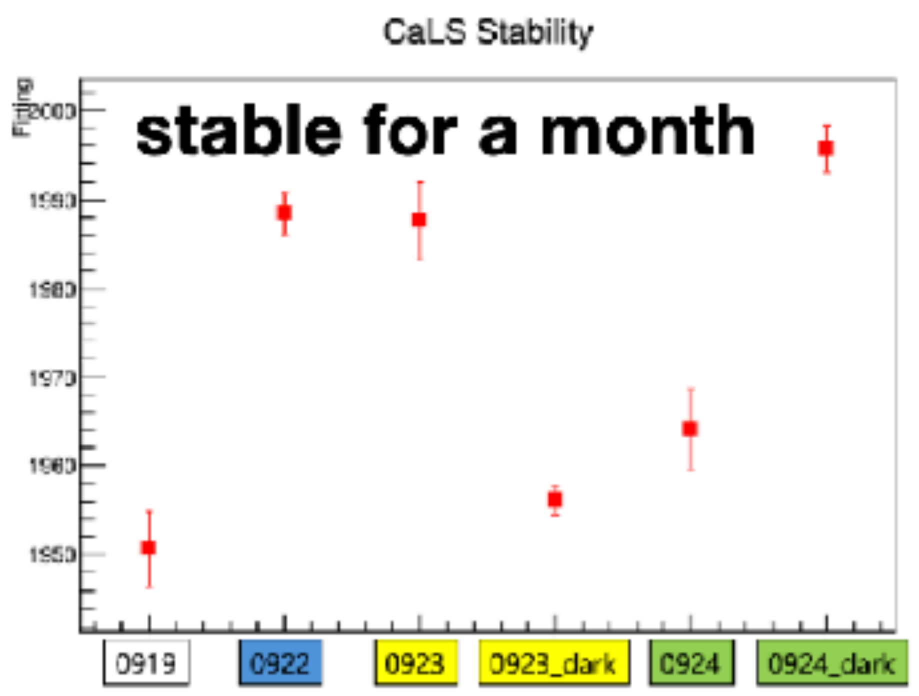
Current R&Ds and Sensitivity

Example from CPNR workshop of 2025.
Chang Hyun Ha (CNU)
Idea: Isotope loading and extraction

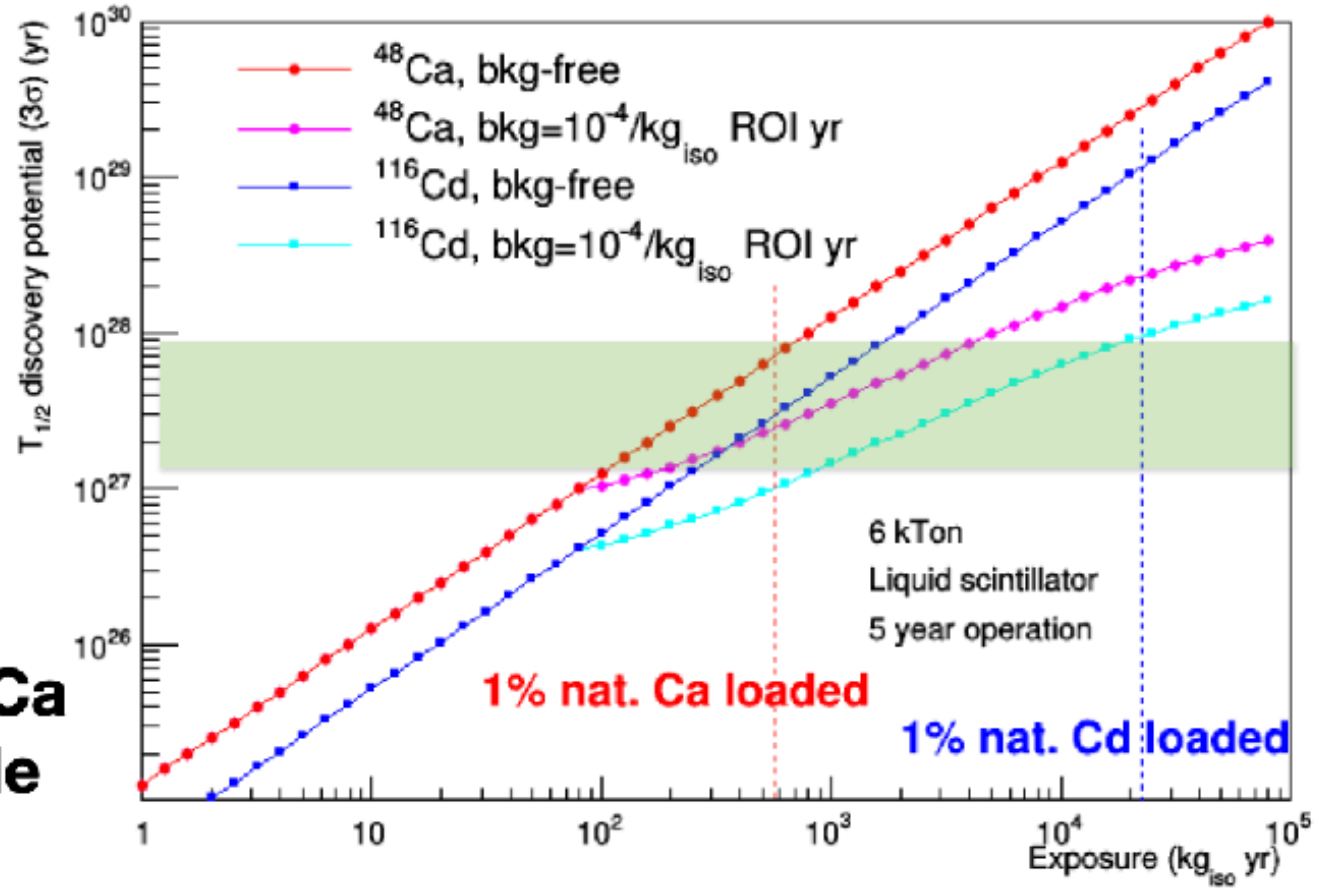
https://indico.neutrino.or.kr/event/356/timetable/#20251024.detailed

Neutrino: Dirac or Majorana particle - $0\nu\beta\beta$ 실험으로 규명 !





R&D with KNU shows 2.8 g/L Ca loading possible



1% nat. Ca loading would give us 114kg * 5yr Exposure (bkg. better, mass lower)
For Cd, 22,500 kg yr exposure (higher mass, a bit of bkg will not be competitive),
For Se and Mo, somewhere in between.