Direct Observation of Mantle Geoneutrinos: Overview of the Ocean Bottom Detector (OBD)

Neutrino Geoscience 2026, Zhuhai, China
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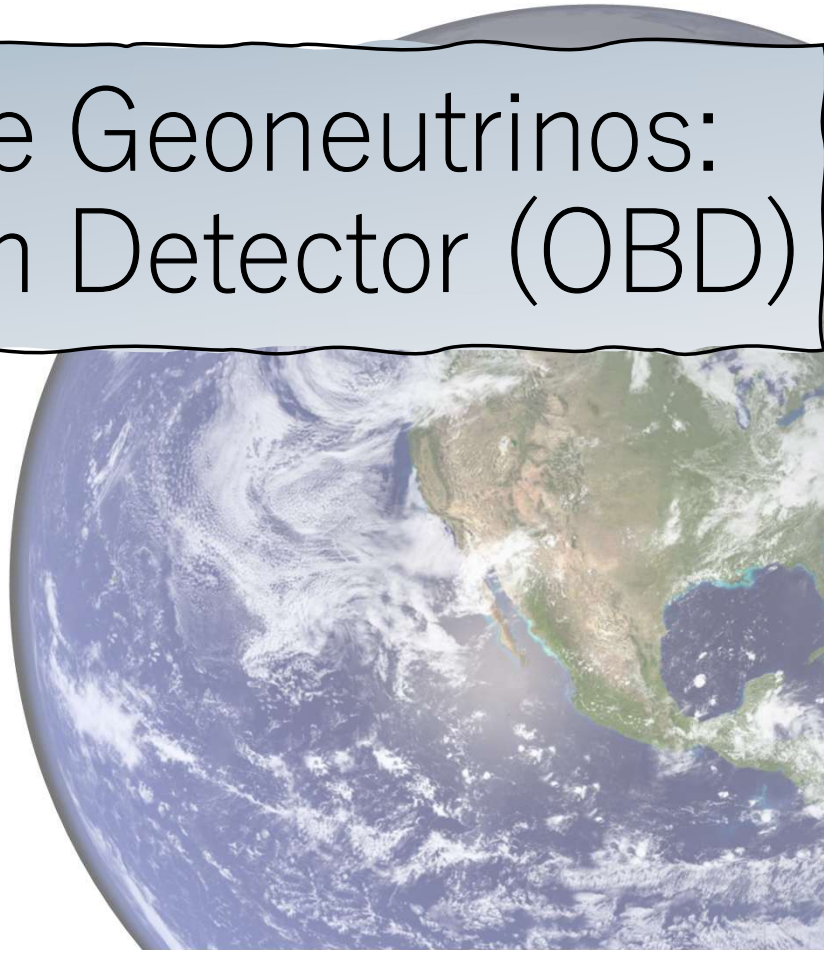

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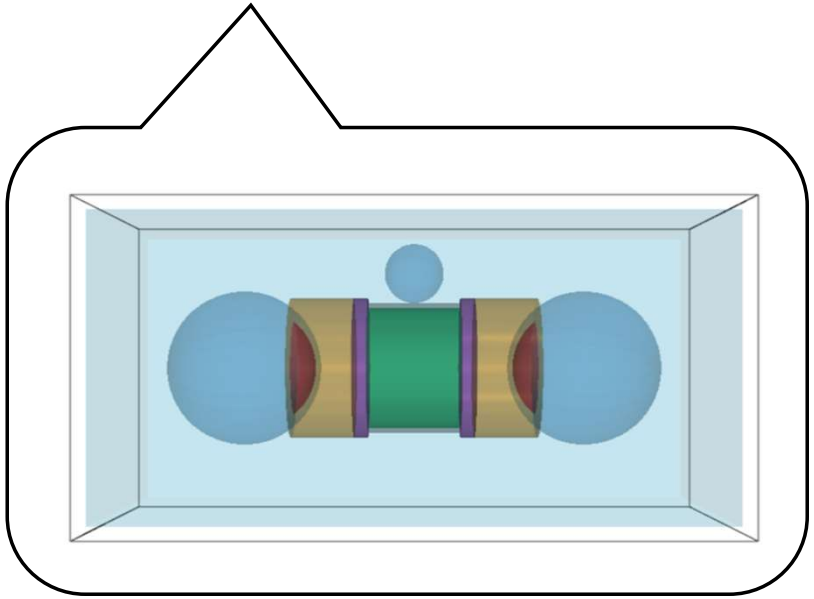
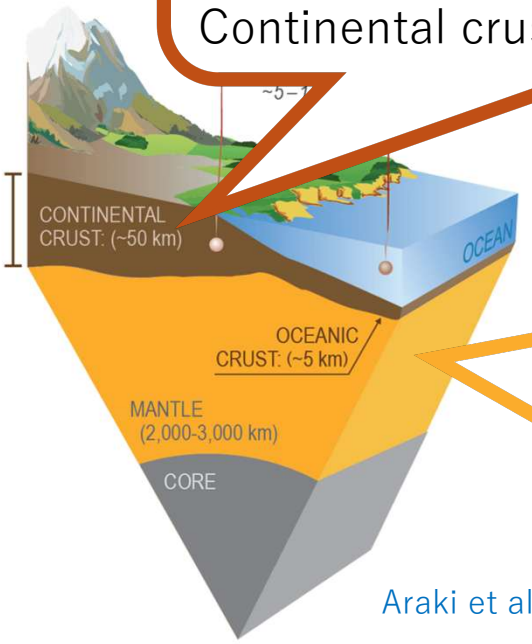


1. Motivation

Observation result of geoneutrinos

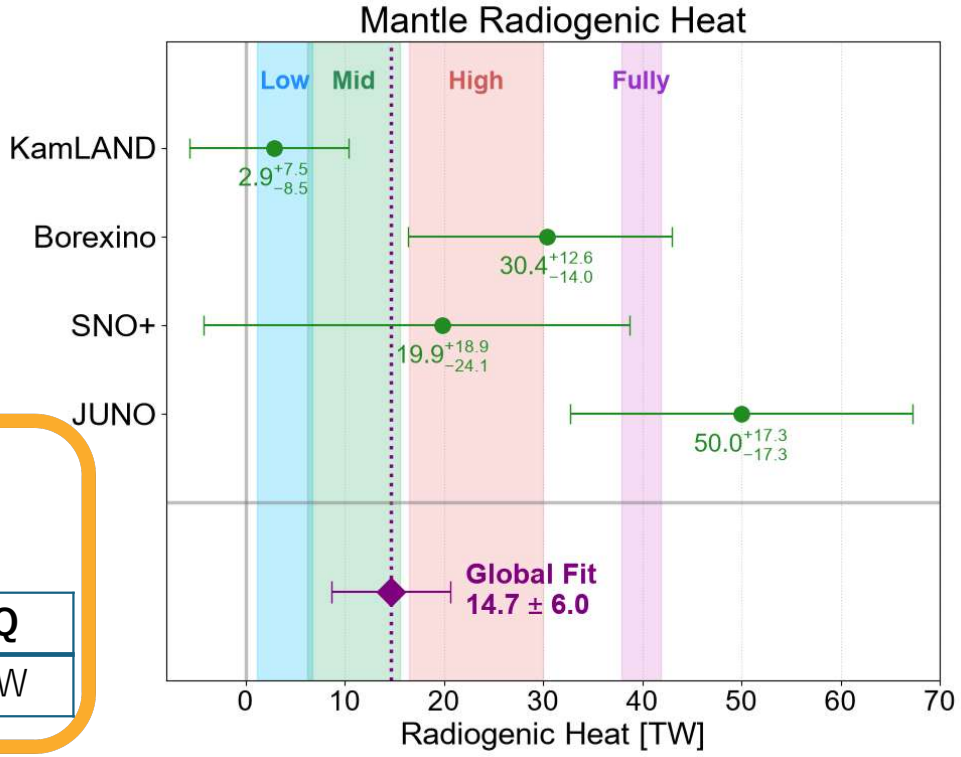
Crust
~ 7 ± 1 TW
Smaller uncertainty
Oceanic crust: ~5 km, less HPEs
Continental crust: ~ 35 km, much HPEs



Mantle
Competing models

Low-Q	Middle-Q	High-Q
10-15 TW	17-22 TW	> 25 TW

Araki et al.(2026)



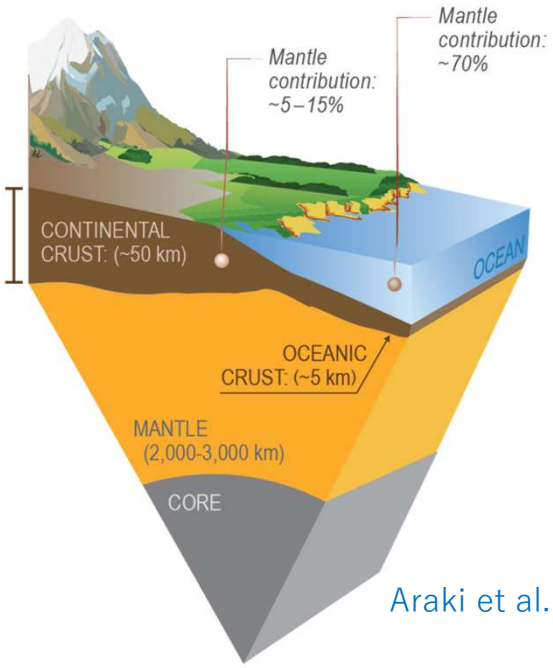
Ground experiments have large error
→Cannot decide mantle model

Why Ocean Bottom?

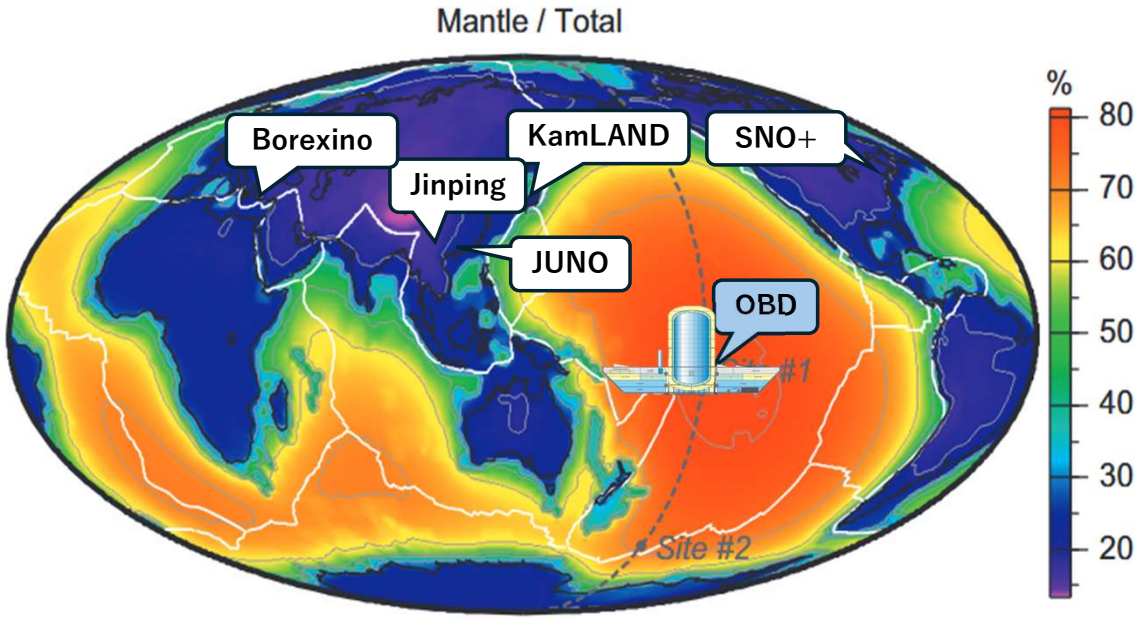
1. Above the oceanic crust

Oceanic crust: thin and low HPE abundances

→ Reduce the crust geoneutrinos



Araki et al.(2026)



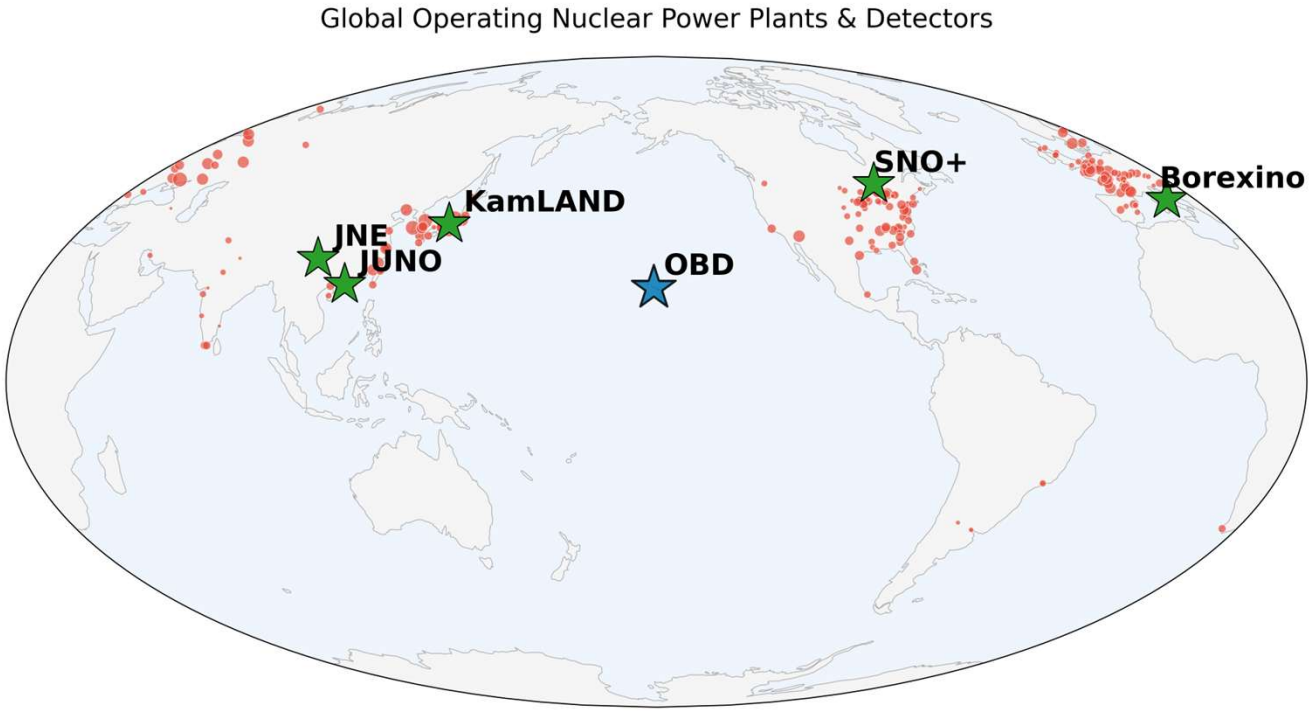
Šrámek et al (2013)

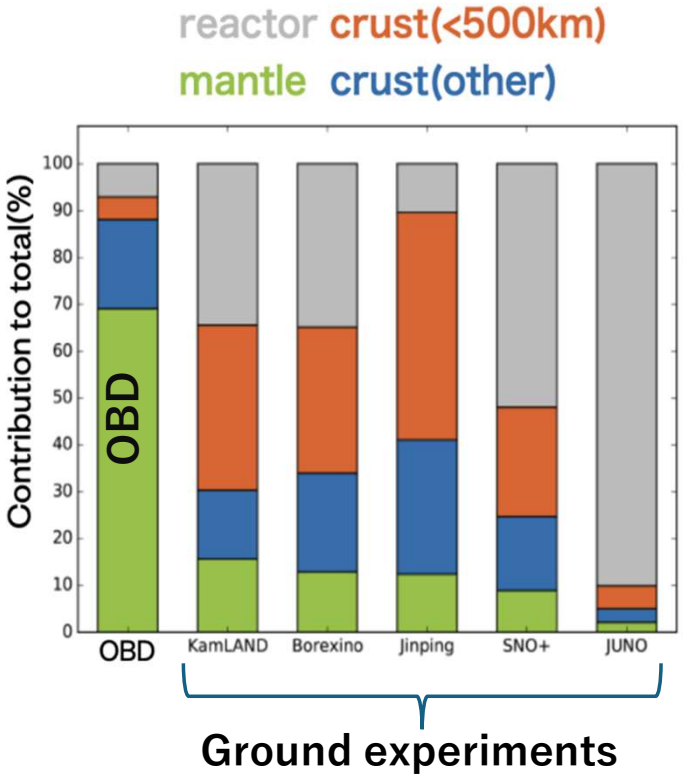
1. Motivation

Why Ocean Bottom?

2. Far away from Nuclear Power Plant

→ Reduce indistinguishable BG



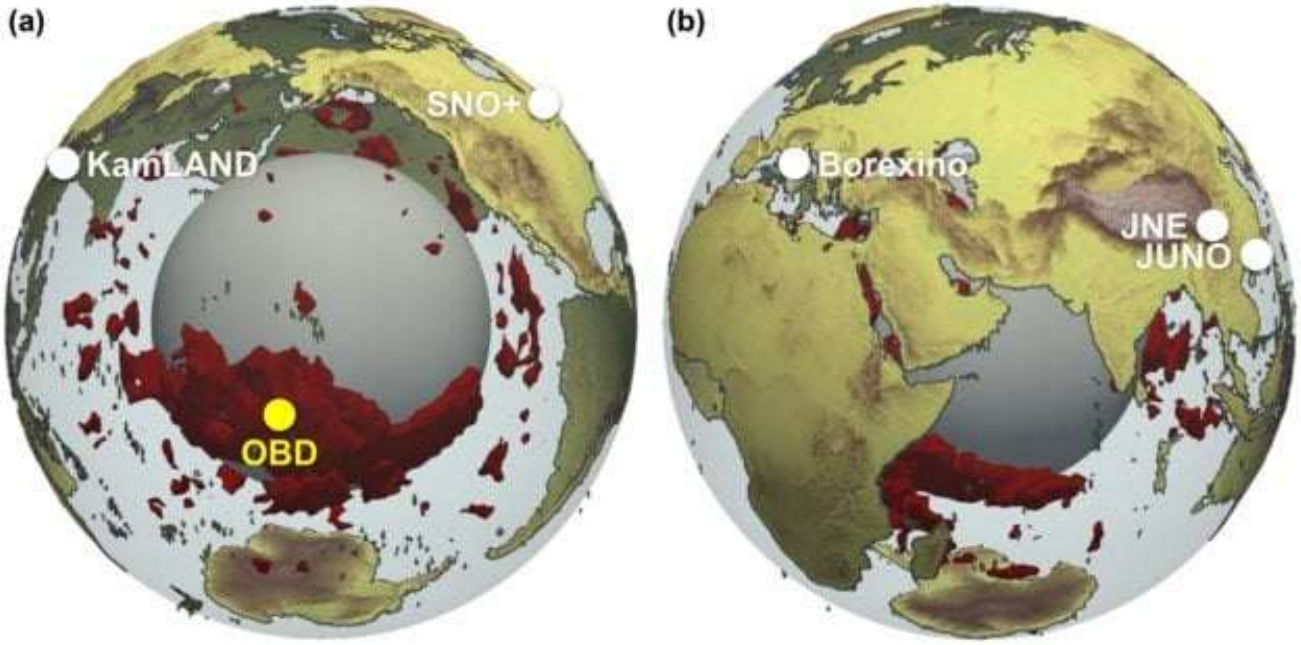


Ondřej Šrámek et al.(2016)

Why Ocean Bottom?

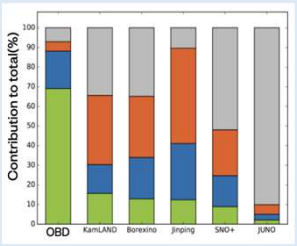
3. Above the LLVP

→ detect the signals from unusual structure



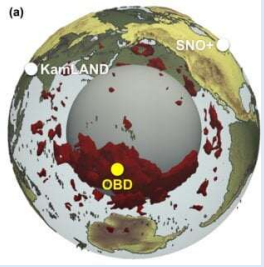
1. Above the oceanic crust
2. Far away from NPP

Detect mantle geoneutrino sufficiently (~70%)



3. Above the LLVP

Advance our understanding of mantle structure

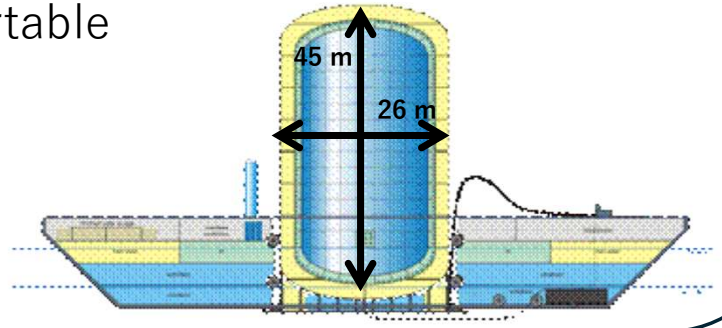


Idea of the Ocean Bottom Detector

Didn't materialize

Hanohano

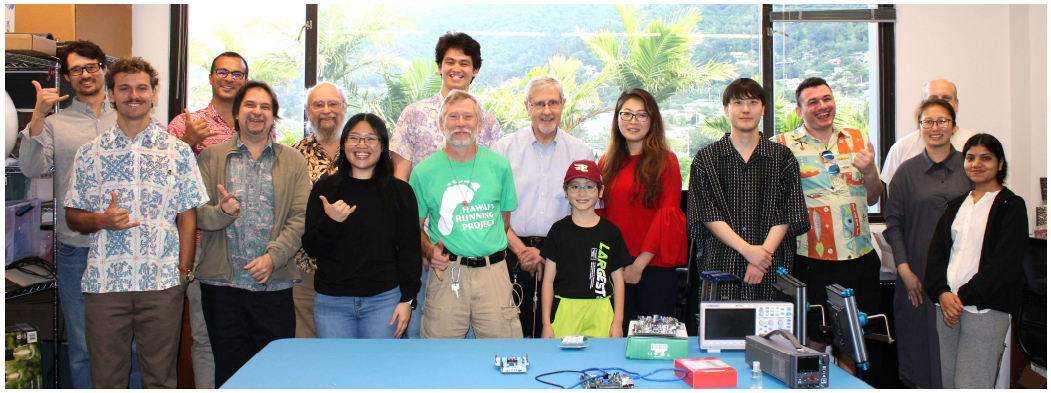
- Conceived at U.Hawaii
- 10 kt liquid scintillation detector
- deploy in the deep ocean (3-5 km)
- Portable



In progress

Ocean Bottom Detector

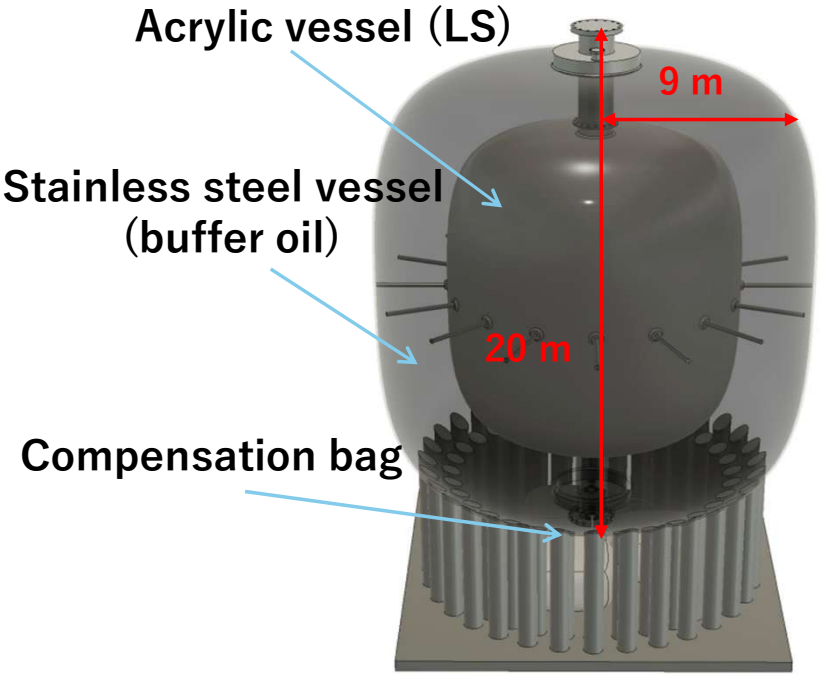
- Carry out by Tohoku.U, U.Hawaii and LLNL



2005 — 2019 — 2026

Overview of the OBD





Ocean Bottom Detector (OBD)

- Size: 1.5kt LS detector
- Goal: detect the mantle geoneutrinos
- Method: Inverse Beta Decay
- Site: 4km depth off Hawaii

To veto cosmic muons

Under high P(40 MPa) & low T (2-4℃),
The properties may change



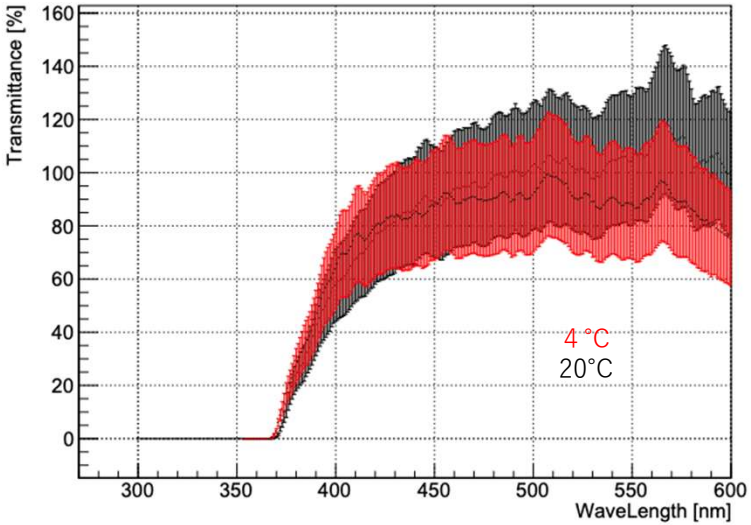
Research on property



Liquid scintillator

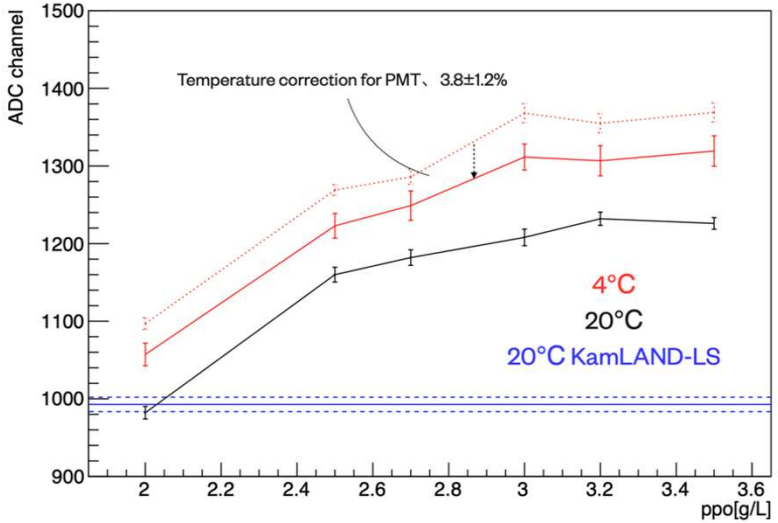
- Transmittance @7m

No significant change @ 4°C



- Light yield

increase 8.6%, @20°C→4°C





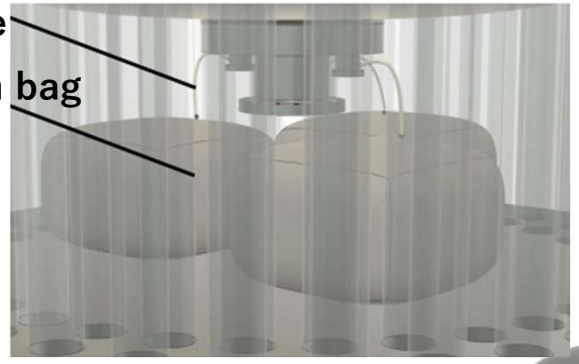
We can use LS under <u>low temperatures</u> in good condition

Research on property



Compensation bag

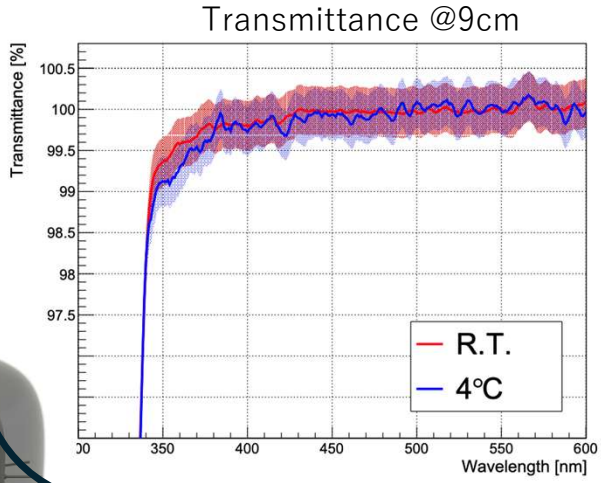
Volume of LS changes (~73 kL)
→Need to compensate the liquid volume

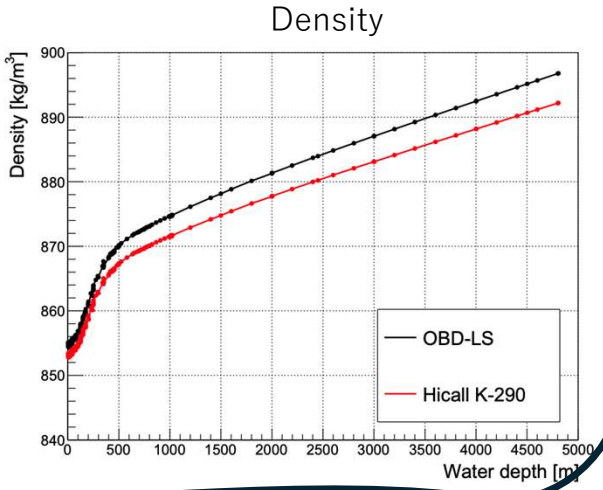




Buffer oil

Transmittance: no significant change @4°C
$\Delta\rho$(LS-BO)= 4.3 kg/m^3 @4km depth





Research on properties are in progress!!

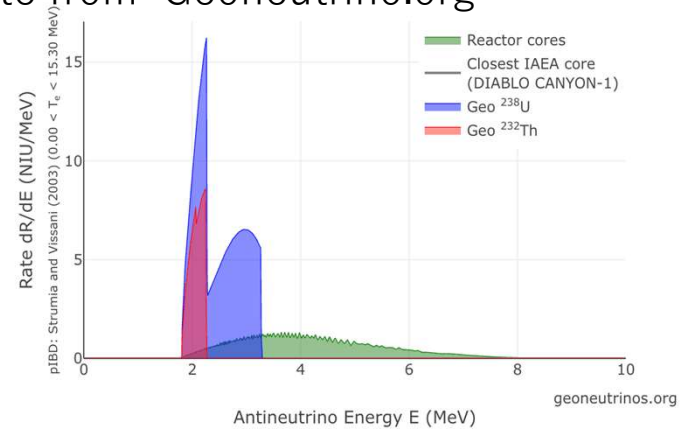
2. Ocean Bottom Detector



Expected events

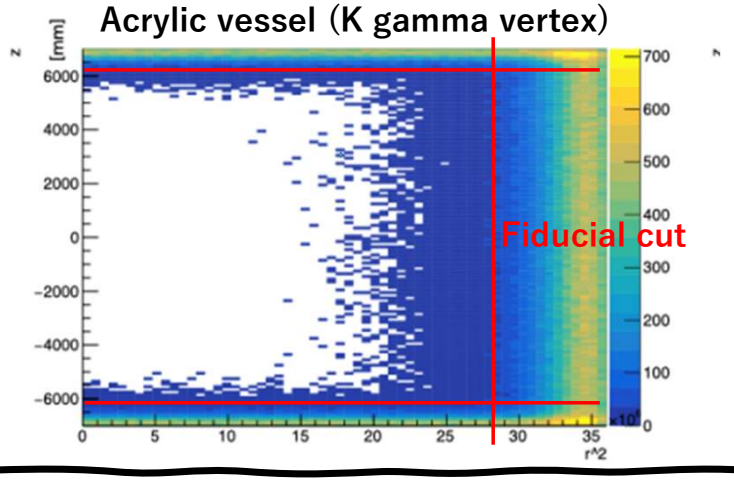
Geoneutrino /Reactor

・Cite from Geoneutrino.org



Accidental

・Originates from detector components
・Assume the radioactive impurity in KL/JUNO



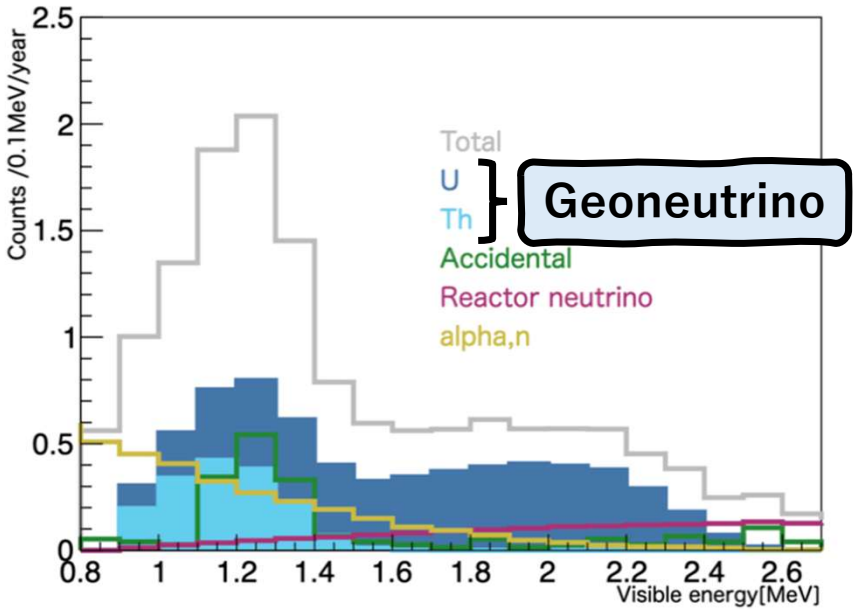
(α,n)

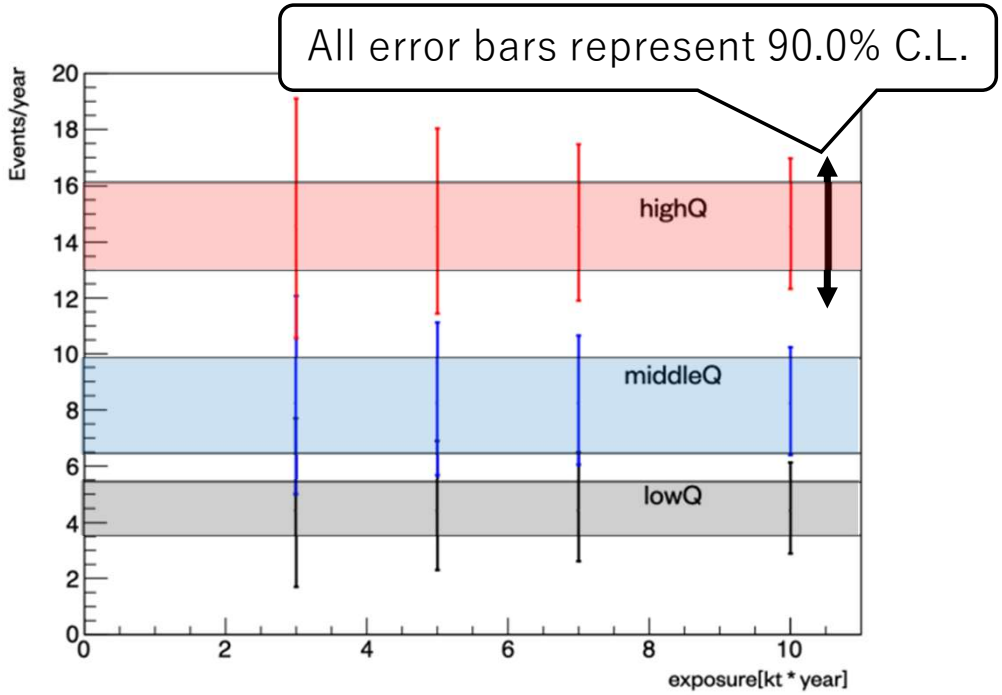
・Induced by Po-210
・Assume the Po-210 abundance in KL

	Geoneutrino	reactor	accidental	(α,n)
All region	8.23 /year	4.13 /year	1.92 /year	3.88 /year
geo$\bar{\nu}_e$ region		1.53 /year	1.90 /year	2.96 /year

Expected signals @ pacific ocean

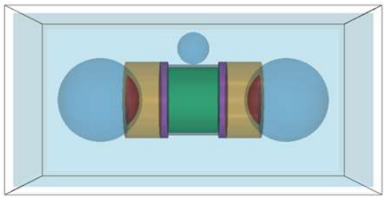






Mantle geoneutrino: ~ 6 event/year

Distinguish each models in 10 years @ 99.5% C.L.



Motivation of the prototype detector

Challenges of OBD

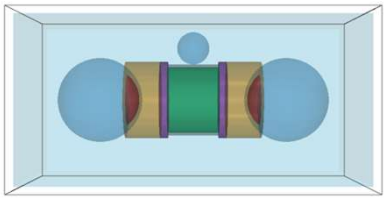
→Extreme deep sea environment

- Develop an LS detector operational under low T (2-4°C) and high P (40 MPa)
- Establish an end-to-end operational sequence

To verify these requirements

OBD prototype is essential !!

Overview of the OBD prototype



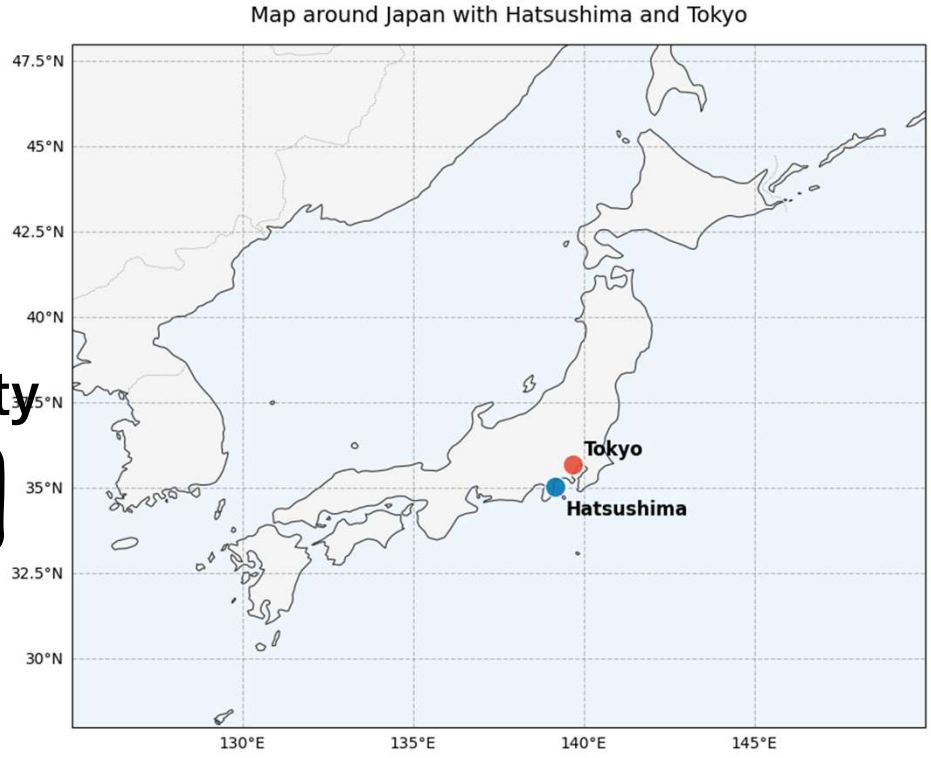
OBD prototype

- Size: 20 kg LS detector
- Time: several months
- Goal:
  - **monitor the stability** of LS detector
    +
    measure the **environmental radioactivity**

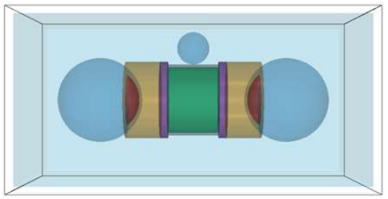
New

Physic + Geoscience→interdisciplinary

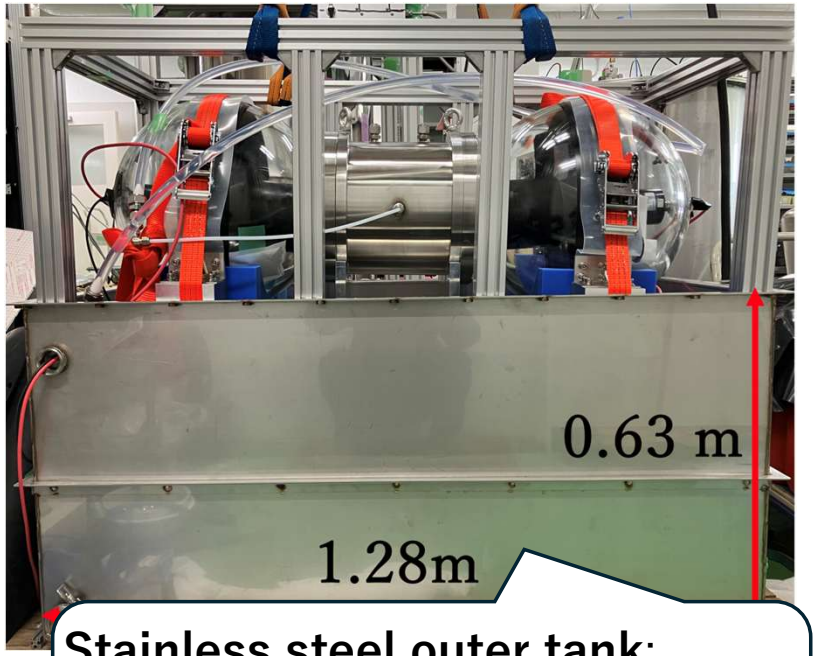
- Method: detect the gamma ray
- Site: Hatsushima observatory, Japan



Structure of the OBD prototype



Overall view

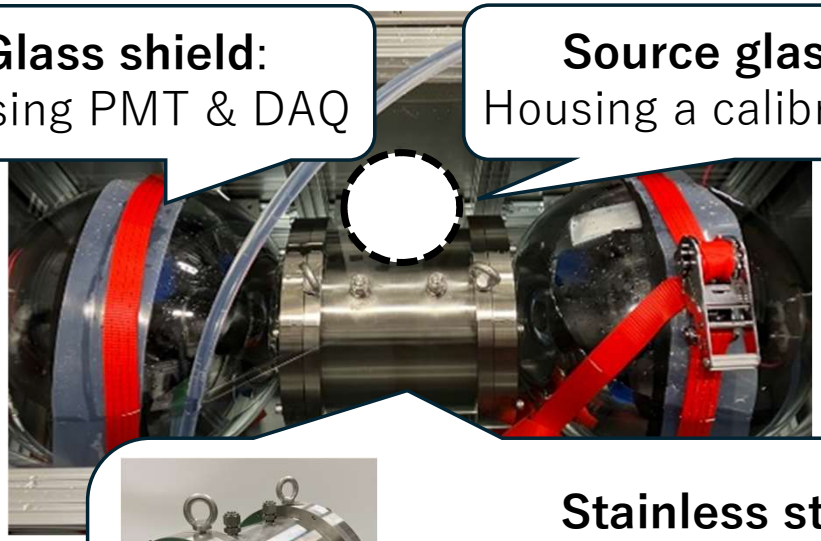


Stainless steel outer tank:
Housing all internal components
Filled with water

Internal view

Glass shield:
Housing PMT & DAQ

Source glass shield:
Housing a calibration source

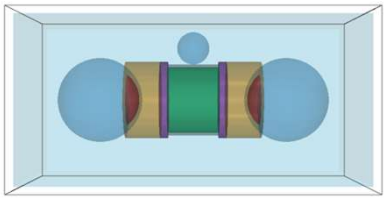




Stainless steel vessel:
Filled with LS

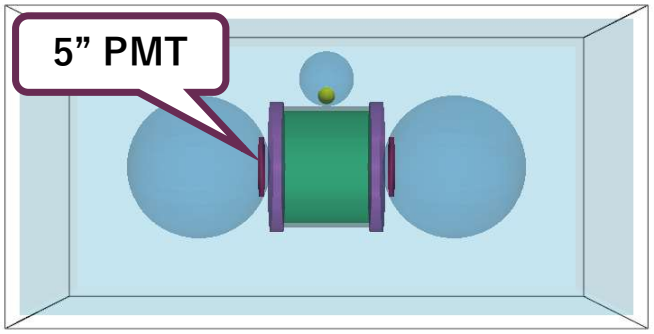
Acrylic window:
For observing scintillation light

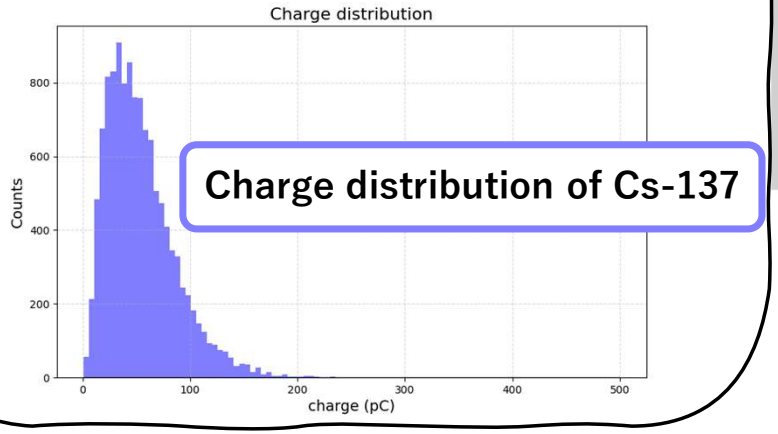
Optimization of structure



Motivation: Improve energy resolution to identify environmental signals

Before optimization



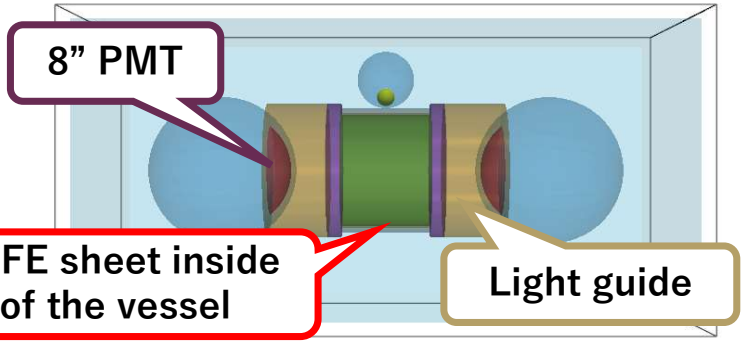


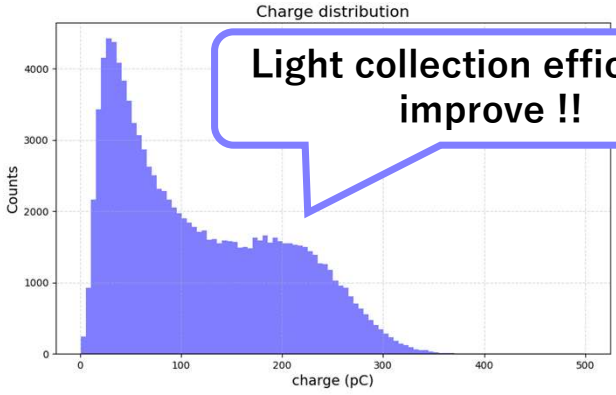
Charge distribution of Cs-137

Changes
- PMT 5”→8”.

Add
- Lightguide
- PTFE sheet

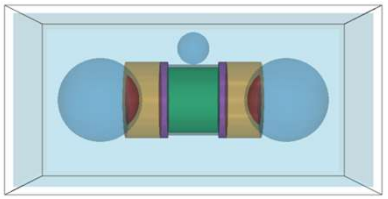
After optimization





Light collection efficiency improve !!

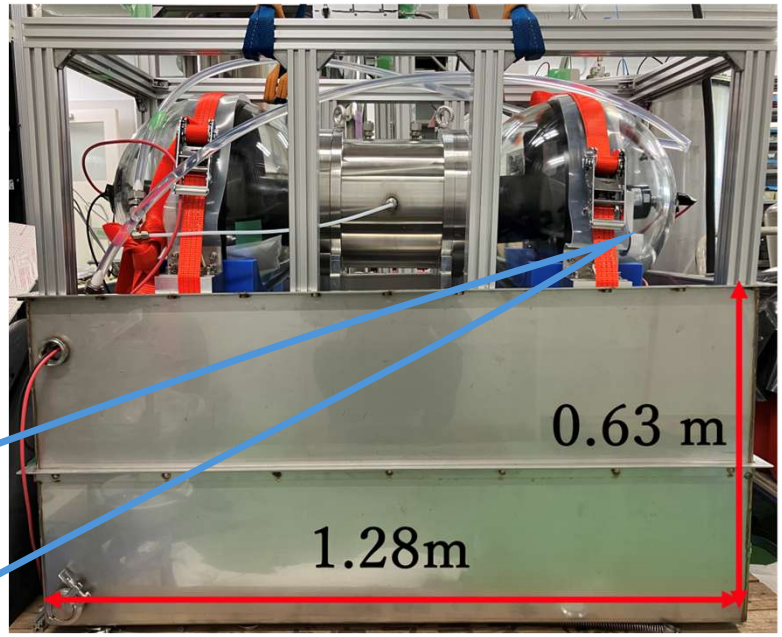
Research on property



Pressure compensation system

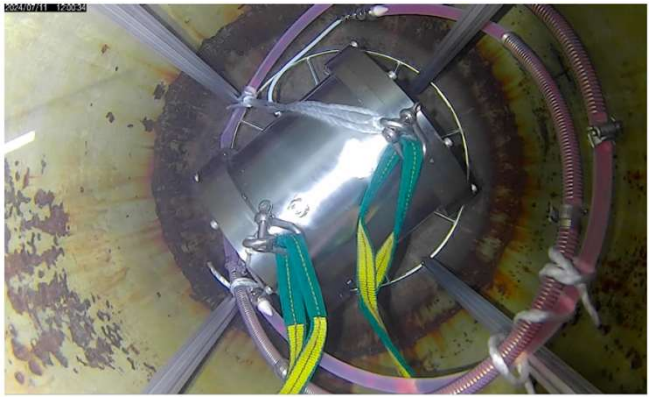
Tube-like compensator was developed

- passed the leak test under high pressure
- liquid injected into the tank under high pressure



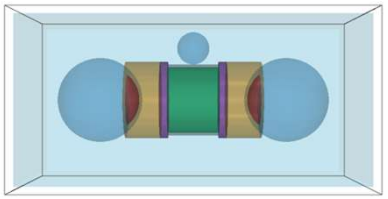


Overall view



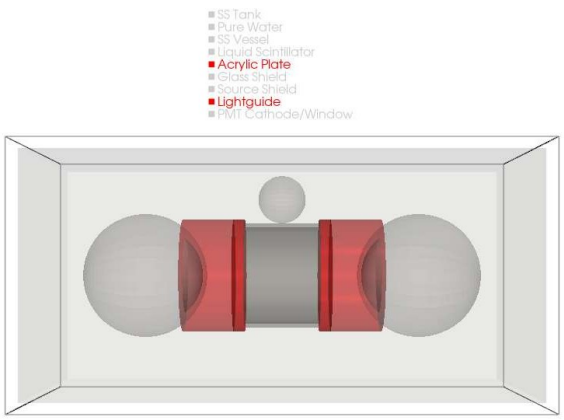
picture of pressure test

Expected events



- **Detector BG**

Acryl

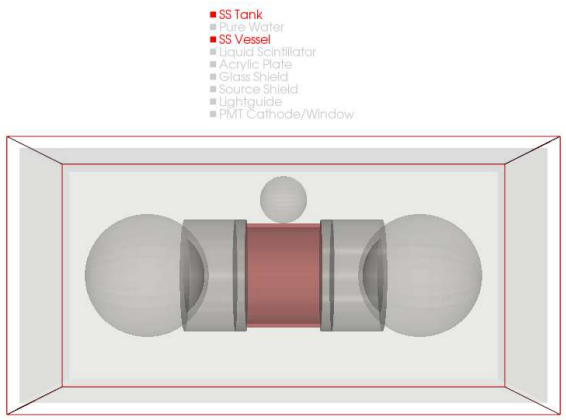


Assume values from JUNO

U-238	Th-232	K40
1.0×10^{-11} g/g	1.0×10^{-11} g/g	1.0×10^{-11} g/g

F. An et al.(2016)

Stainless steel

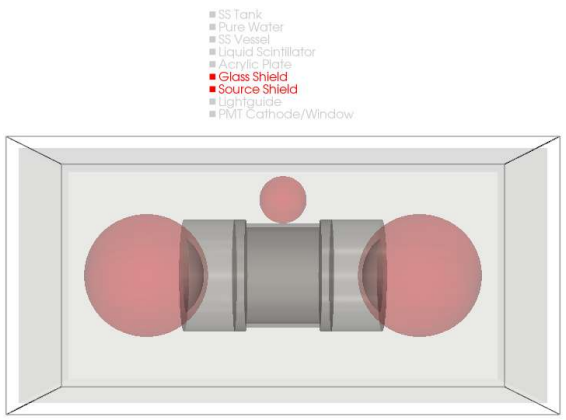


Assume typical values from literature

U-238	Th-232	K40	Co60
1.0 mBq/kg	1.0 mBq/kg	1.0 mBq/kg	19.0 mBq/kg

W. Maneschg et al.(2008)

Glass

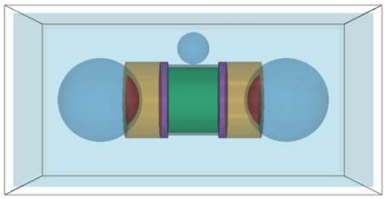


Assume values from D-egg module

U-238	Th-232	K40
5.20 Bq/kg	1.16 Bq/kg	1.0 Bq/kg

R. Abbasi et al.(2023)

Expected events

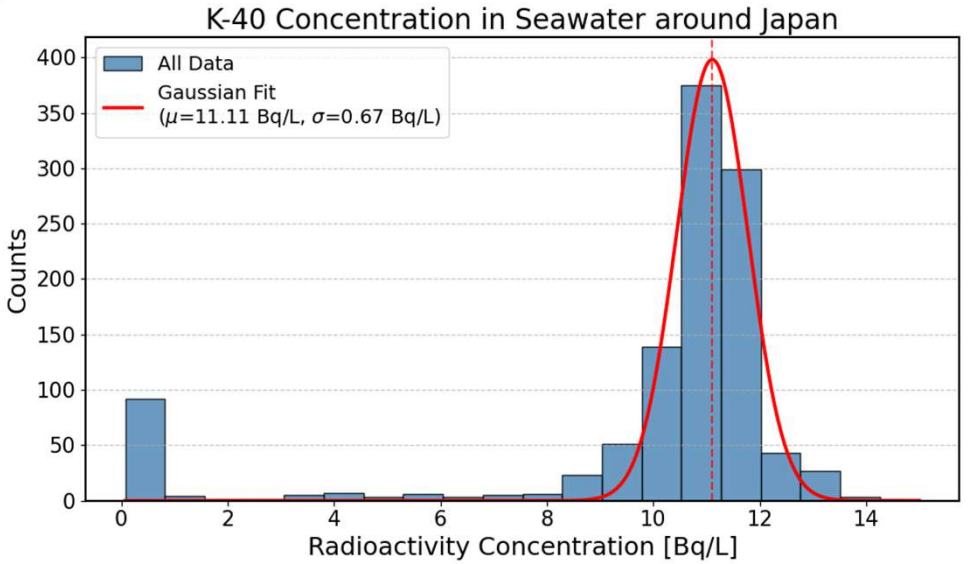


- **Cs-137**:

calibration source

- **Sea K-40**:

uniformly distributed, **11.1 Bq/L**



- **Sediment**:

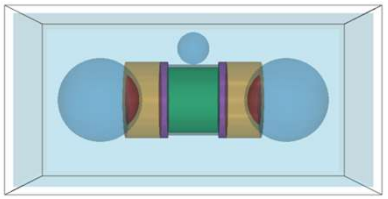
location dependent, **fit the concentrations!!**

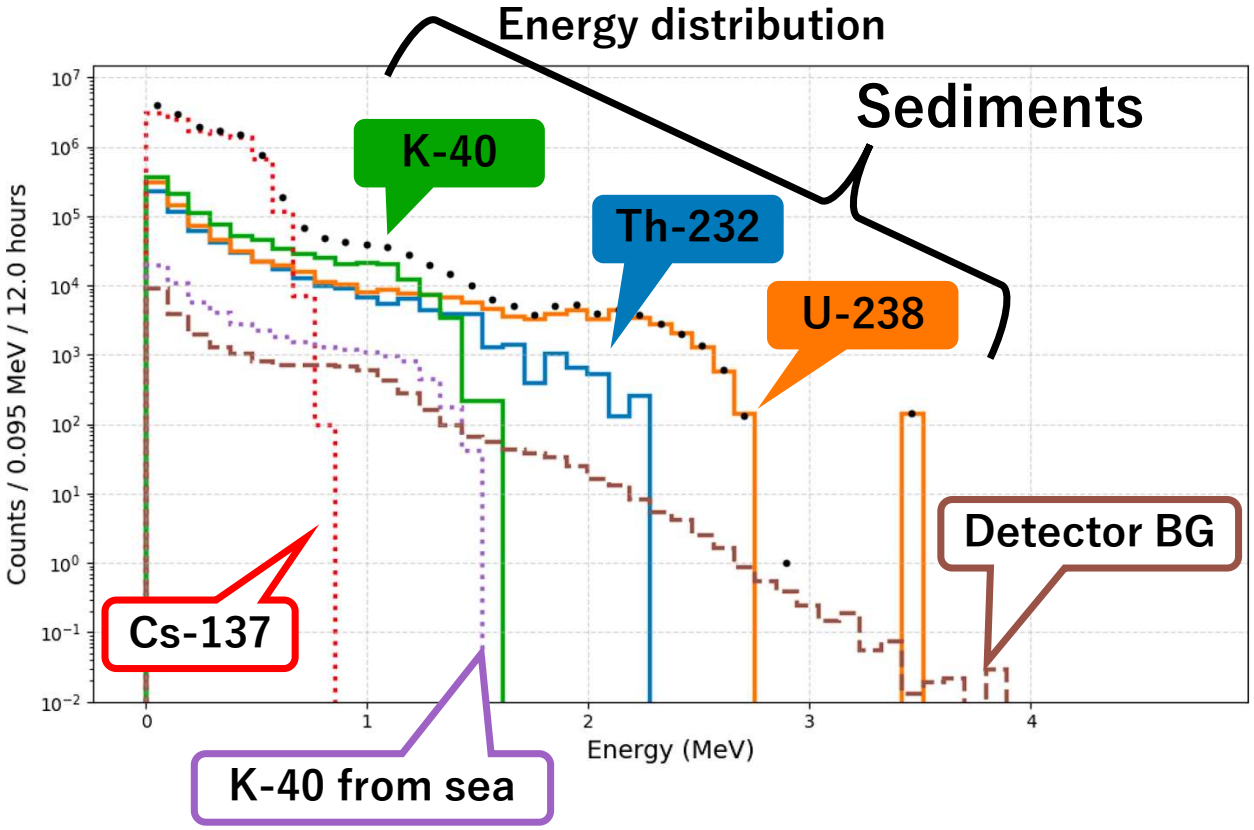
U-238 (ppm)	Th-232 (ppm)	K-40 (ppm)
2-12	1-20	10000-22000

Range of radioactive element concentrations in the sediments

H. H. Veeh. (1967)
N. Khaustova et al.(2021)
H. Takahashi et al.(2023)
C. T. Hayes.(2024)
D. Heye.(1969)
J. G. Ryan and C. Chauvel.(2014)

Detection simulation results



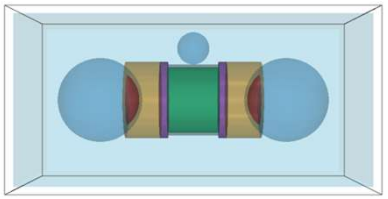


Fit results of sediment concentration (12h simulation)

HPEs for the sediments	Fitted values (ppm)	Input values (ppm)
U-238	2.94 ± 0.07	3
Th-232	10.07 ± 0.07	10
K-40	2.24 ± 0.02	2.2

Concentrations in the sediment can be estimated w/ relative error of 2.5%

Future works

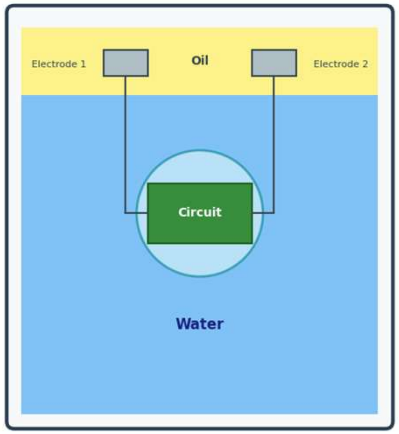


Oil leak detect system

Method: Capacitance measurement

- $\varepsilon_{water} = 80$
- $\varepsilon_{oil} = 2$

→ we can detect the oil leak



Optical module

- 13” glass shield
- 8“ PMT from Hamamatsu
- DAQ circuit

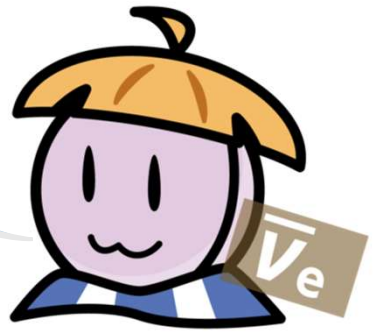
Carried out in Collaboration w/ Chiba U.



Summary

- OBD is a **deep-sea detector to observe mantle geoneutrinos directly**
- 1.5 kt OBD can distinguish **three mantle models** in 10 years @ **99.5% C.L.**
- The prototype detector can **estimate the concentrations of HPEs in the sediment**
- OBD development is ongoing at Tohoku U with international cooperation.

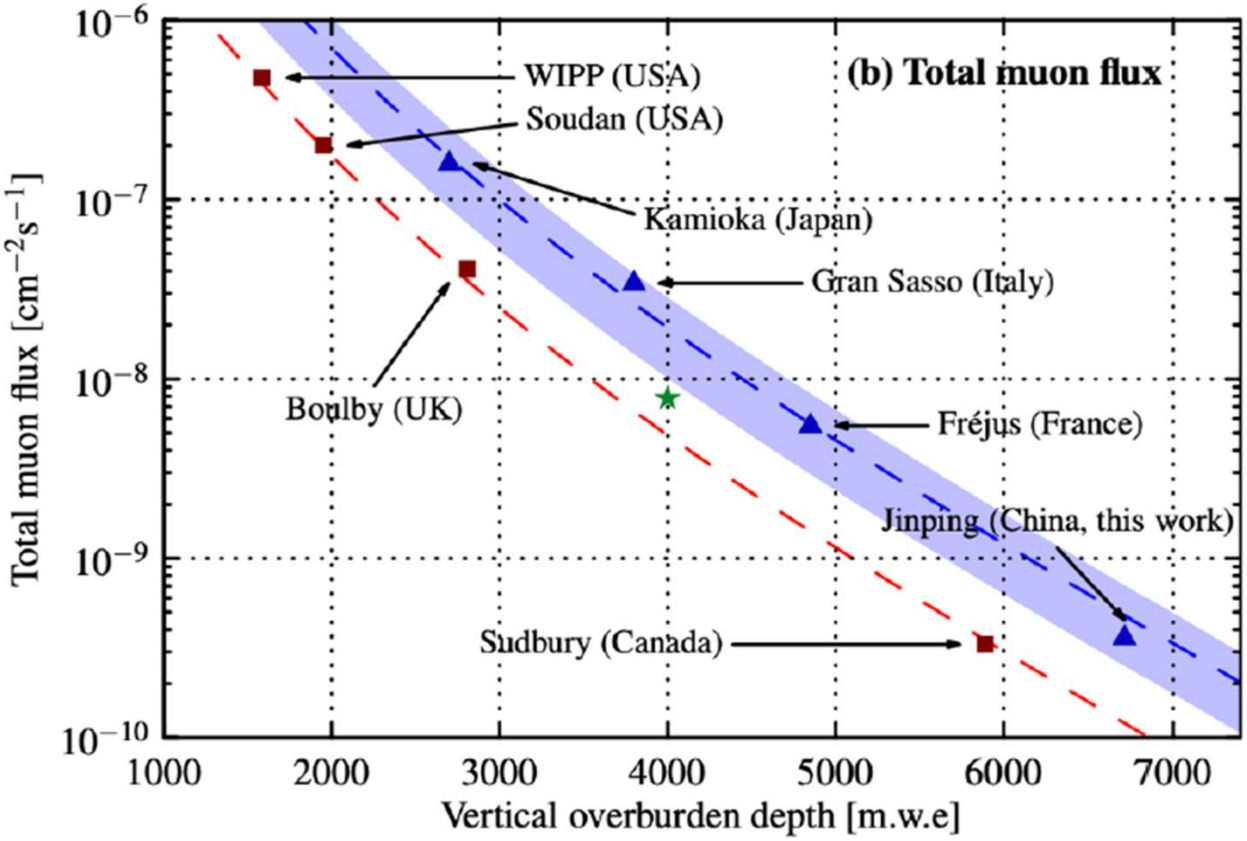
Thank you for your attendance!!



Back up

Muon veto




(b) Total muon flux
WIPP (USA)
Soudan (USA)
Kamioka (Japan)
Gran Sasso (Italy)
Boulby (UK)
Fréjus (France)
Jinping (China, this work)
Sudbury (Canada)
Total muon flux [cm^{-2}s^{-1}]
Vertical overburden depth [m.w.e]
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
1000
2000
3000
4000
5000
6000
7000

Strength verification of acrylic vessel

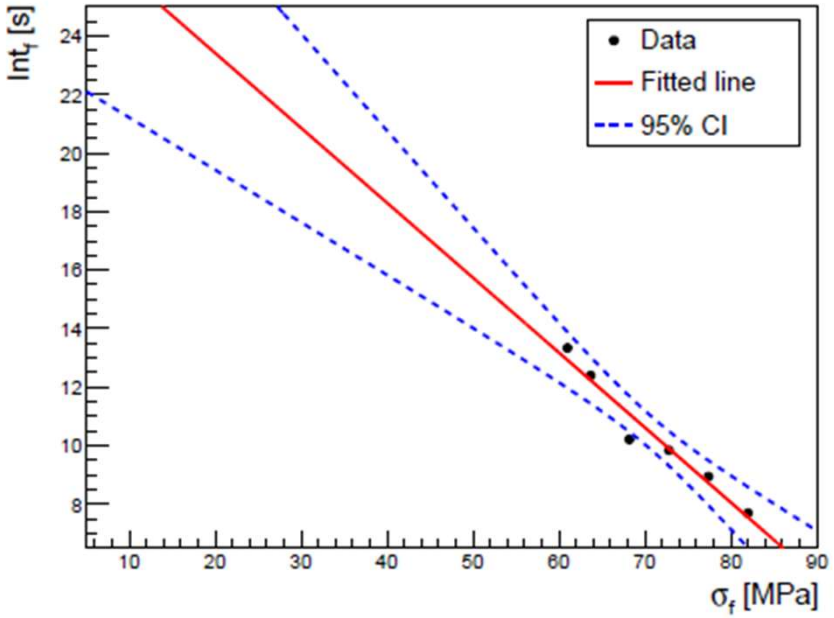


Creep test

$$\ln t_f = A + B \ln \sigma_f$$

→Maximum stress is 19.2 MPa @10y

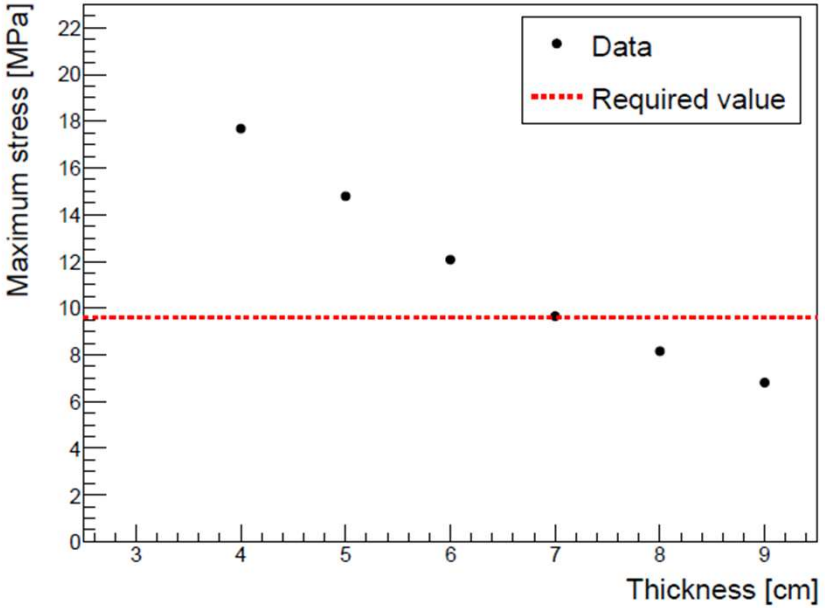




CAD result

Allowable stress w/ safety factor 2

→9.6 MPa



Compensation bag

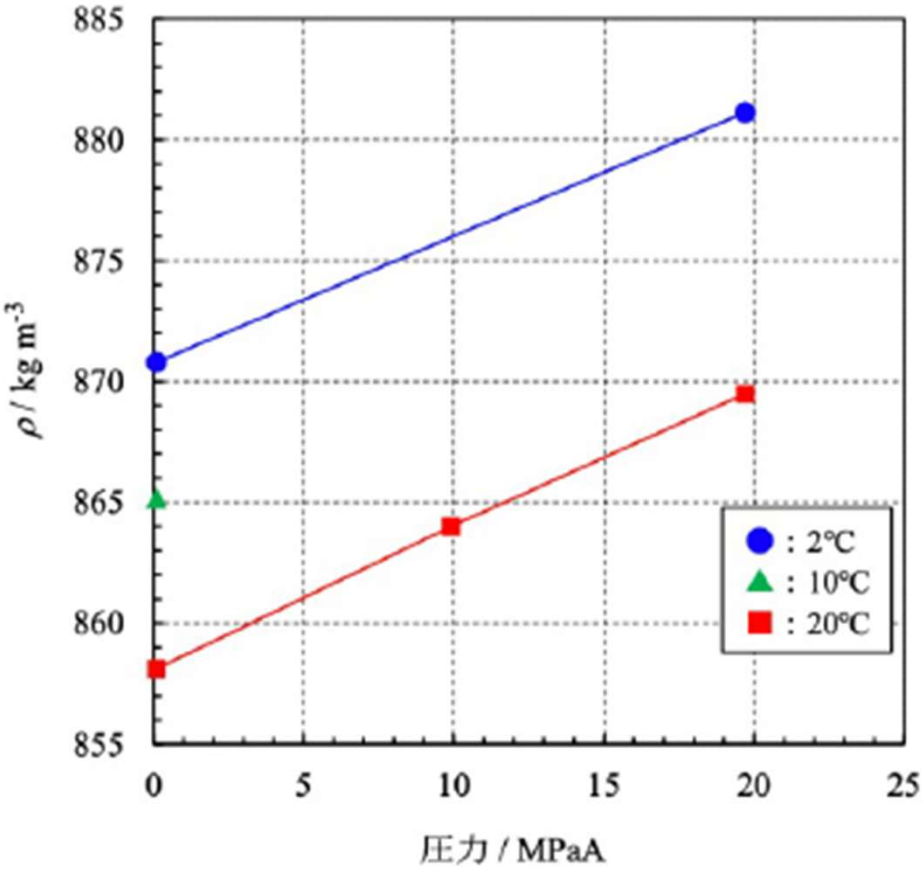


Density difference

- 0.1 MPa → 10 MPa @20°C
  $\Delta\rho \sim 0.7\%$
- 20°C → 2°C @0.1 MPa
  $\Delta\rho \sim 1.5\%$

For 1.5 kt detector,

Volume decreases 4.2 %(73 kL)



Fiducial cut

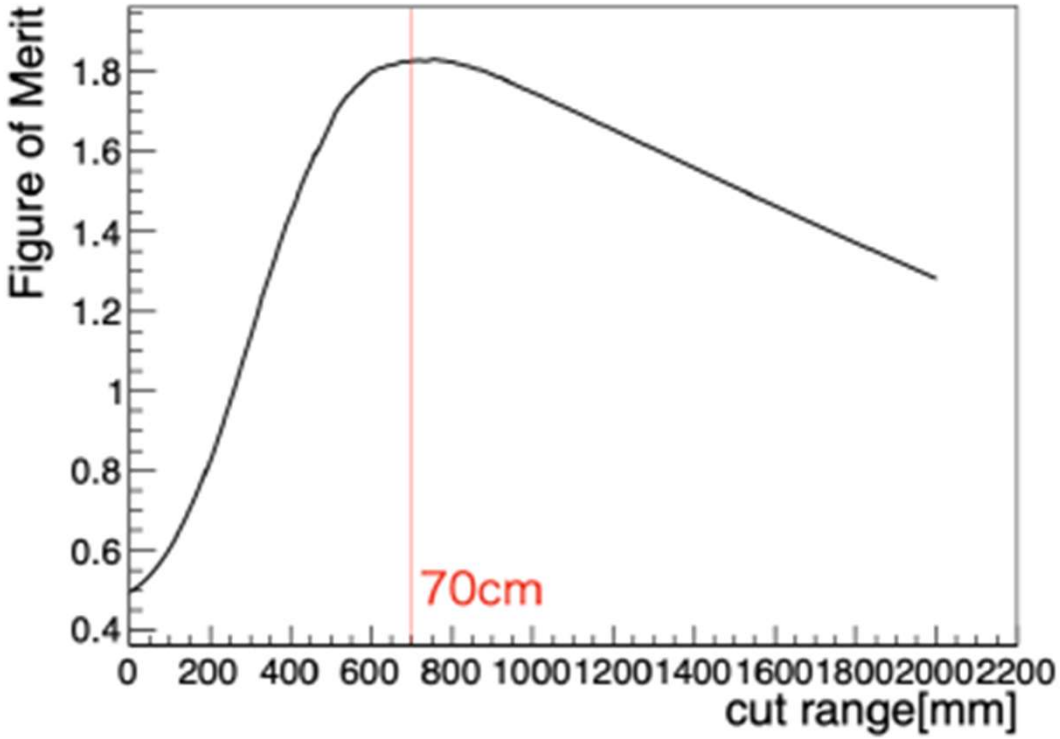


Figure of Merit

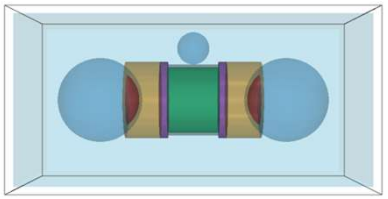
$$FOM = \frac{S}{\sqrt{(S+B)}}$$

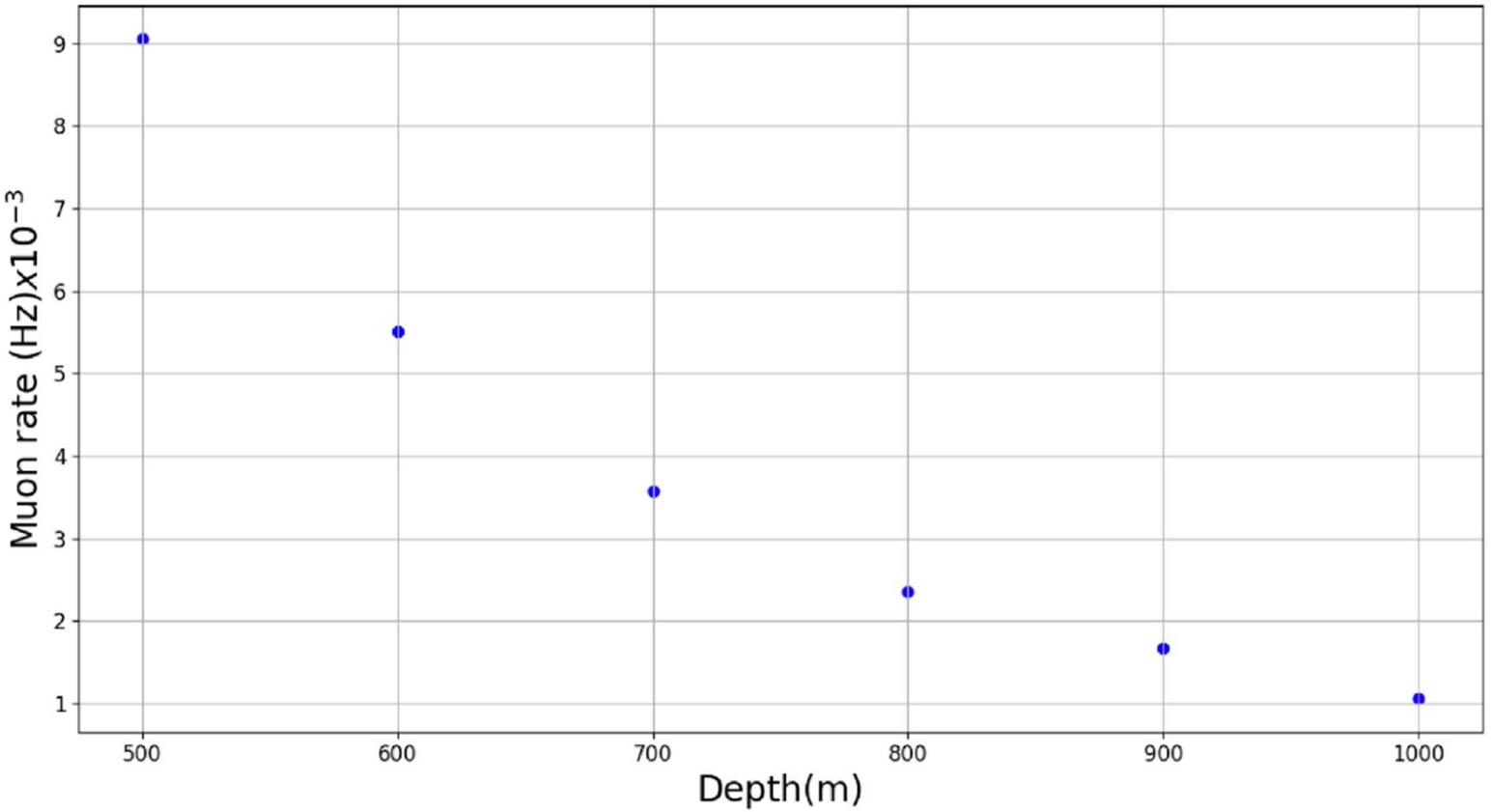
S: number of geoneutrino signals

B: Number of all BGs



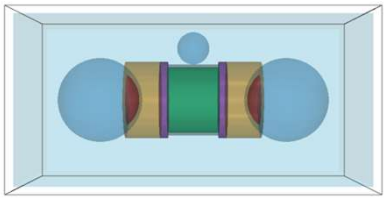
Muon veto





Energy reconstruction

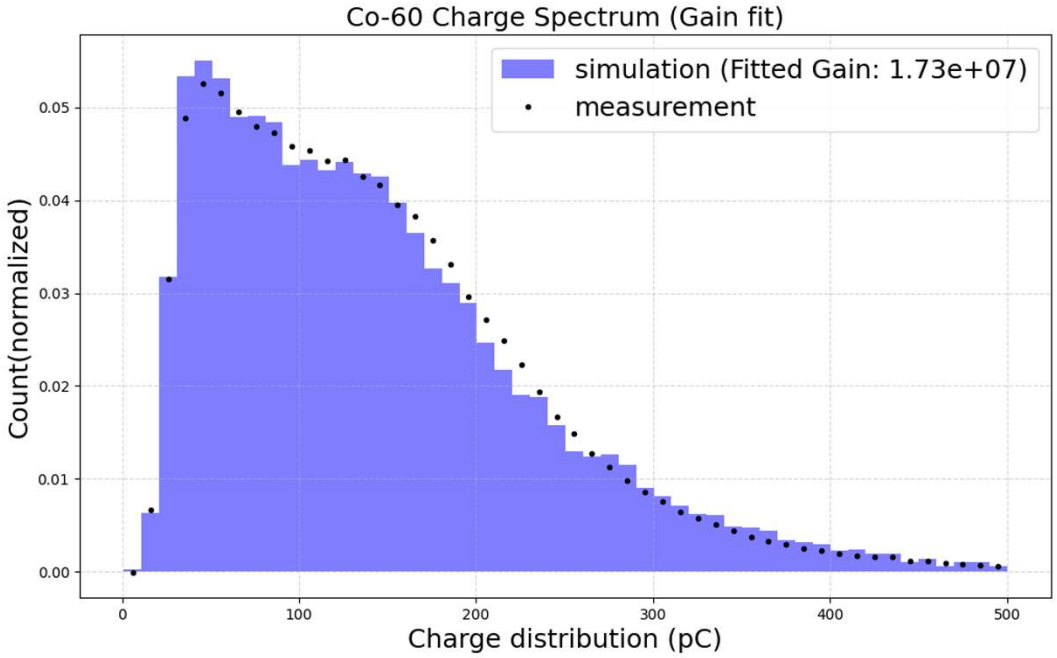
Convert charge to energy

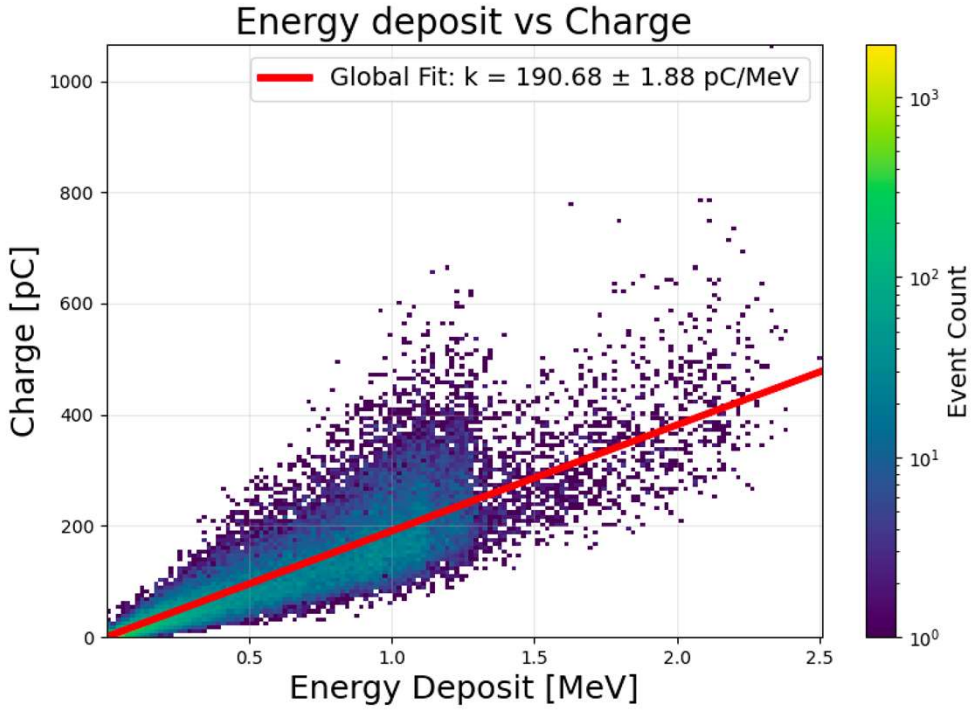


1. **Adjust the PMT gain** in the simulation to fit the measured data

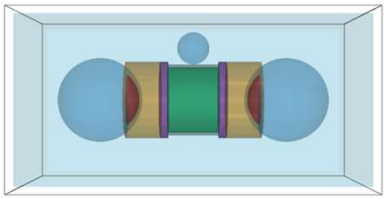
2. **Plot the simulation result** as Energy vs. Charge using the adjusted PMT gain

3. **Fit** the data to obtain the **conversion factor**

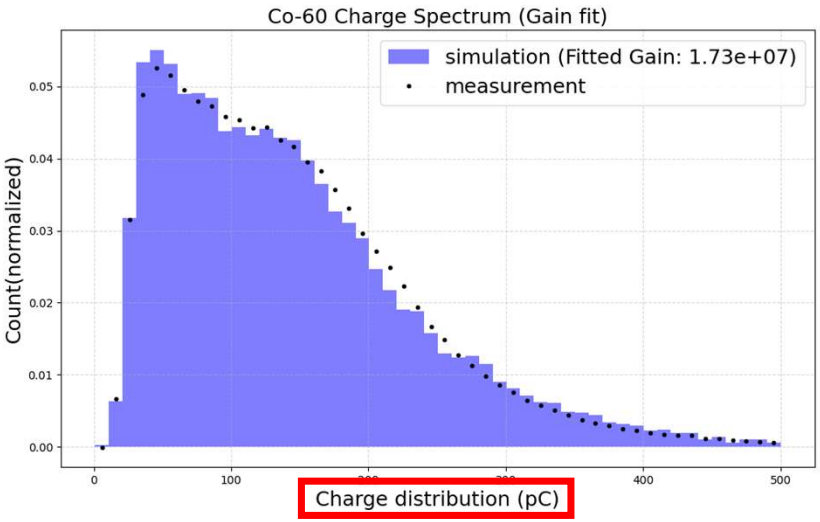




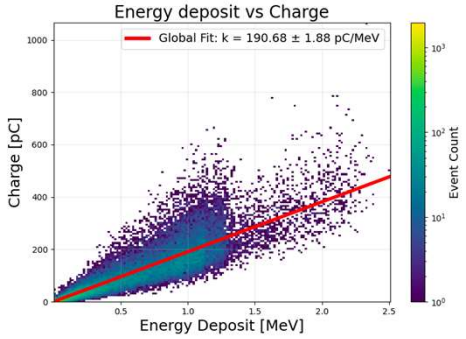
Energy reconstruction



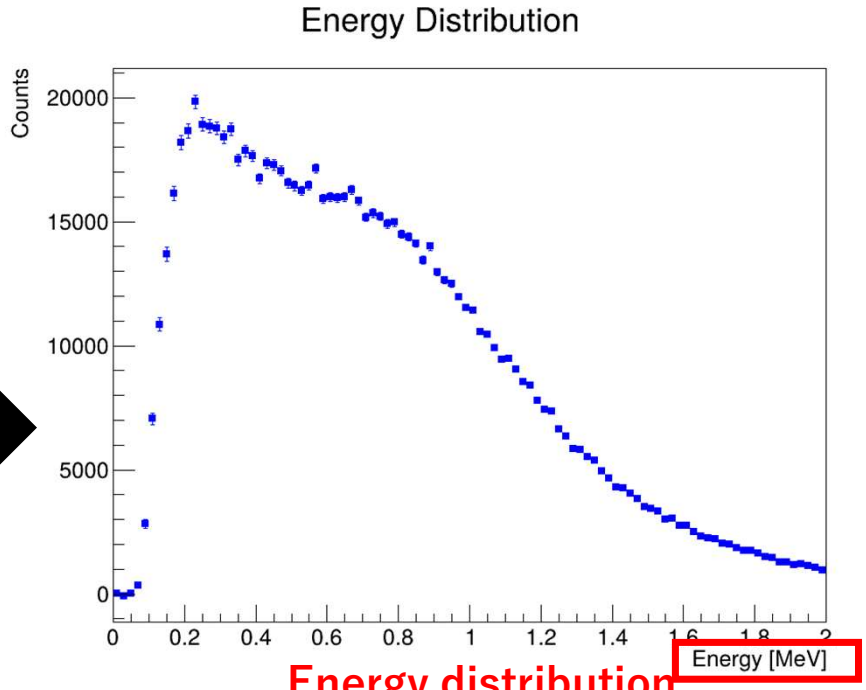
4. **Convert the measured spectrum** using the conversion factor



Charge distribution



$k = 190.89 \pm 1.89\ [pC/MeV]$



Energy distribution