RECODE
高纯锗反应堆中微子相干散射实验

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OUTLINE

1、 CEvNS

2、 RECODE Program

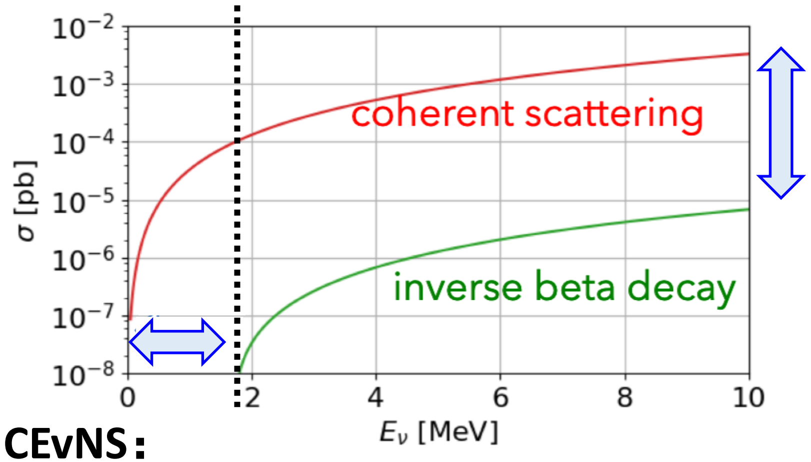
3、 Recent status

4、 Prospects and summary

CEvNS:

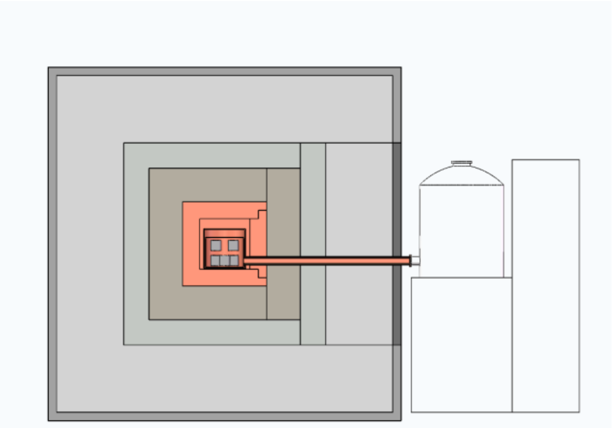
- **Accurate Testing of SM**
  - **Measurement of CEvNS scattering cross-section;**
  - **weak mixing angle under low momentum transfer…**
- **Explore new physics beyond SM**
  - **Neutrino Non-standard interaction;**
  - **Neutrino anomalous magnetic moment…**
- **Experimental Features**
  - **Larger cross section (than traditional IBD), realize the miniaturization of the detector**
  - **No Neutrino energy threshold limit**

IBD energy threshold

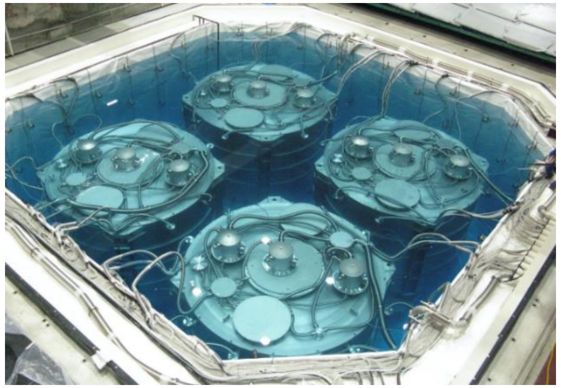


Large cross-sections helps achieve miniaturization of detectors

CEvNS：
No energy threshold



CEvNS: tens of kilograms

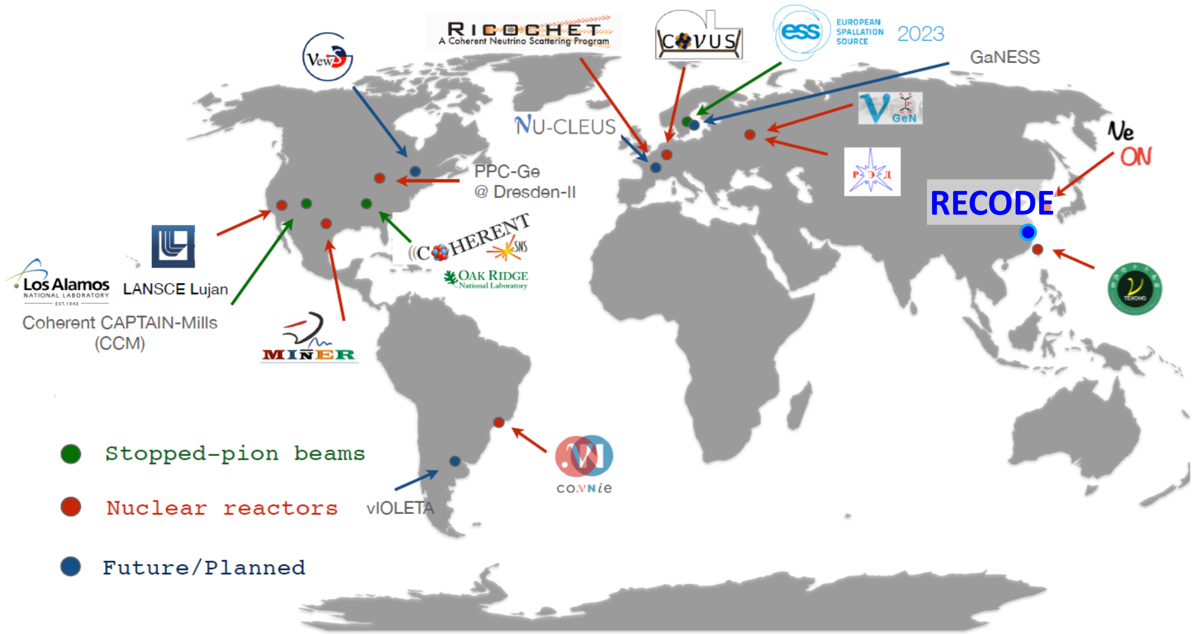


IBD: hundred tons level

CEvNS measurement with HPGe: physical needs

$$\sigma \propto N^2$$

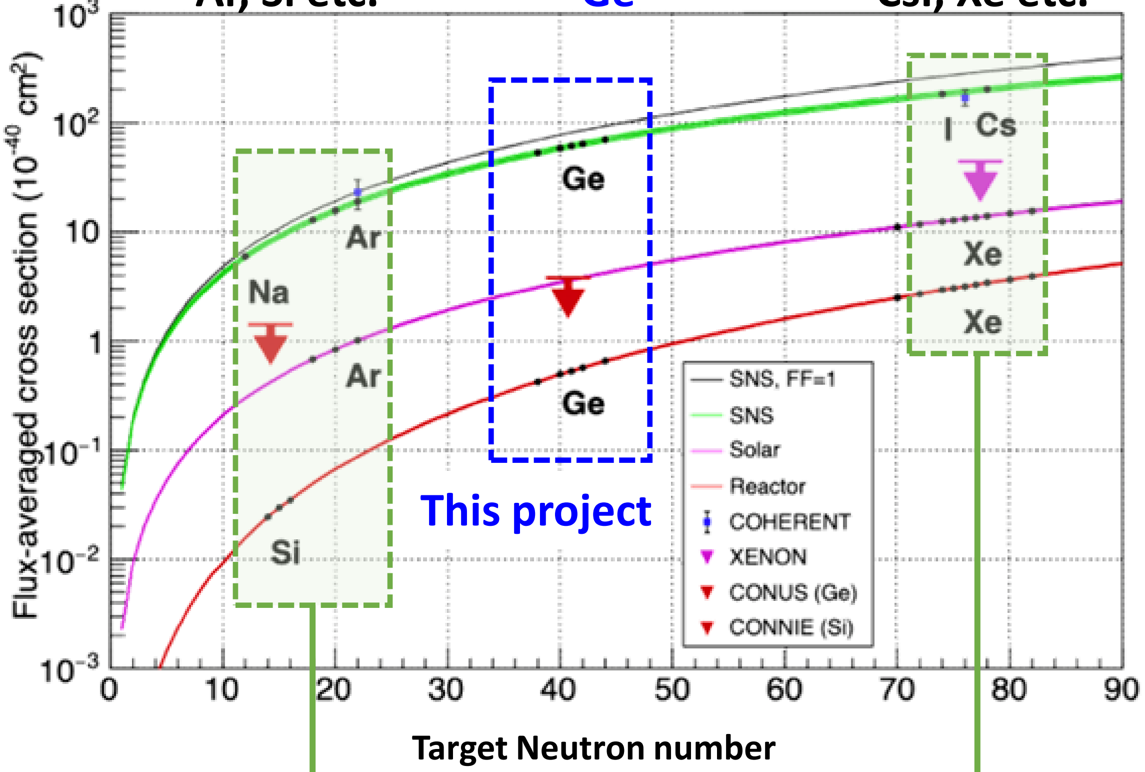
- Both Ar (light nucleus) and CsI (heavy nucleus) results are from the high-energy neutrino beam of accelerator;
- Reactor neutrino CEvNS has not been successfully mea sured in experiments to date;
- Ge (middle mass region) has advantages in measuring reactor neutrino CEvNS;



Light nucleus Ar, Si etc.

Medium mass Ge

Heavy nucleus CsI, Xe etc.



Light region, Ar	PRL 126, 012002 (2021) , 3.5σ
Heavy region, CsI	Science 357, 1123 (2017) , 6.7σ
	PRL 129, 081801 (2022), 11.6σ

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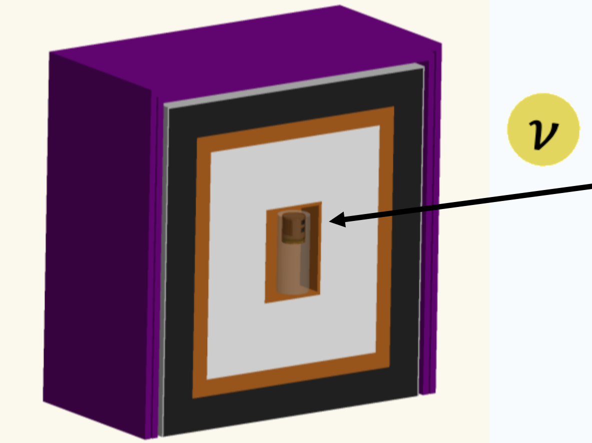
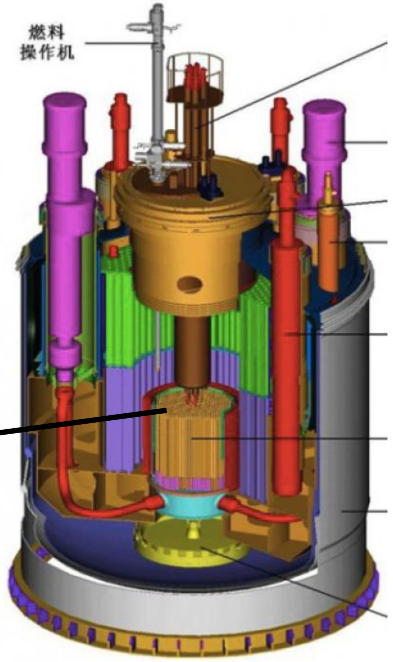
RECODE

- RECODE（**REactor neutrino COherent scattering Detection Experiment**）
- **Low threshold PPCGe detectors**, and related technology come from CDEX experiment

Project goals：

- Two Ge arrays（Far Site + Near Site /Very Near Site, ~10kg in total）
- Energy threshold ~1 keVnr (~160eVee)
- Joint measurement and analysis to reduce the systematical uncertainty





Reactor

Neutrino flux ~$10^{13}/cm^2/s$

CEvNS measurement with HPGe: technical features

- Reactor neutrino beam: high intensity (10^{12}/cm^2/s), but low energy (several MeV);
- Detector requirements: low energy threshold, low background, long-term stability and grou nd operation;

CEvNS Technical Challenges

Challenge	Requirement
Rare event rate	Low background
Low energy transfer	Low threshold
ON/OFF measurements	stability
Near Reactor core	Ground operation

Considering the influence of high flux
Cosmic ray

Obtained long-term verification in DM exp. →

Solid state det. flexibility →

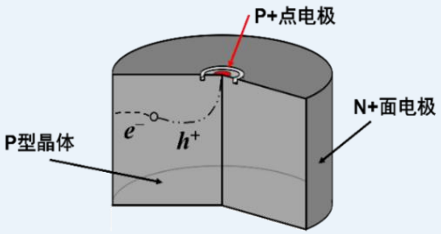
Technical advantages of HPGe

Excellent resolution （< 0.12%）

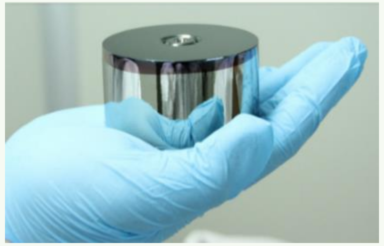
Low threshold （< 200 eV）

Low internal bkg （纯度~13个9）

Long-term stability （数十年）



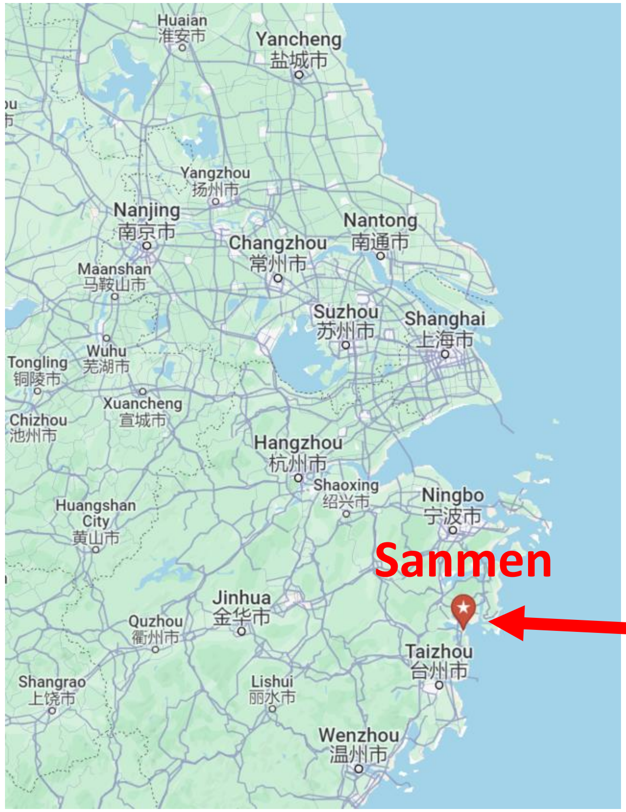
High density,
small volume （ϕ6cm*H6cm）
Bkg control in confined spaces



Sanmen Reactor Neutrino Laboratory

Sanmen Nuclear Power Plant (AP1000) @ Taizhou, Zhejiang, China

- Thermal power 3.4 GWth, ~22m /11m /7m from the core
- Neutrino flux > 1.4 $\times$ 10^{13} $cm^{-2}s^{-1}$

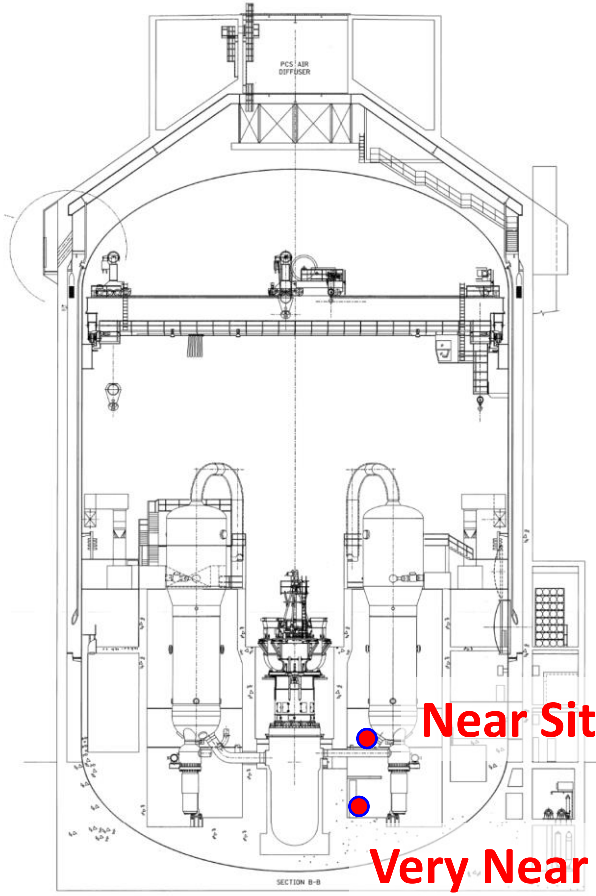


Project Location

Large volume

water shielding:

10m(L)*6.5m(W)*6m(H)



Outside of reactor containment

Inside of reactor containment
（NS: 11m; VNS: 7m）

Solid combination shielding:
copper, lead, polyethylene, etc.

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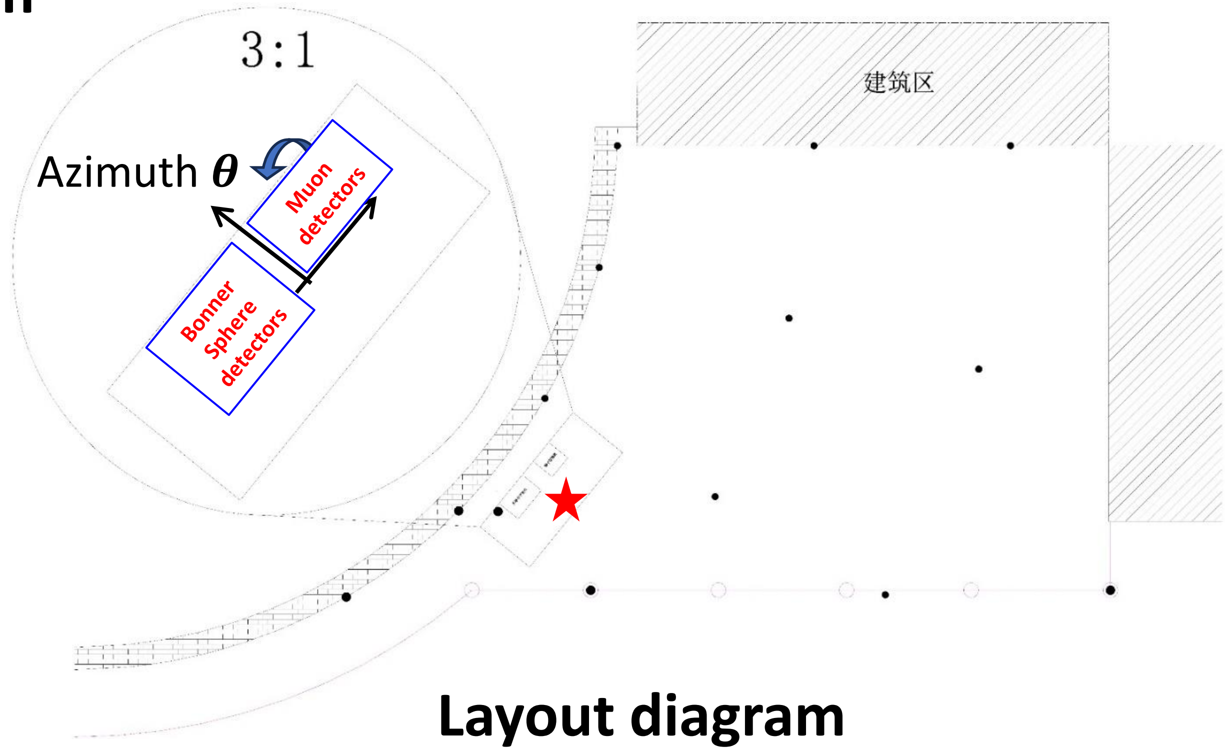
Environmental background measurement @Sanmen

- A series of environmental background measurement technologies have been developed in CJPL, which can be directly applied to the **environmental background measurement near the reactor**, providing key inputs for the shield design;

- **Cosmic ray muon measurement system**

- **Bonner Sphere detectors**

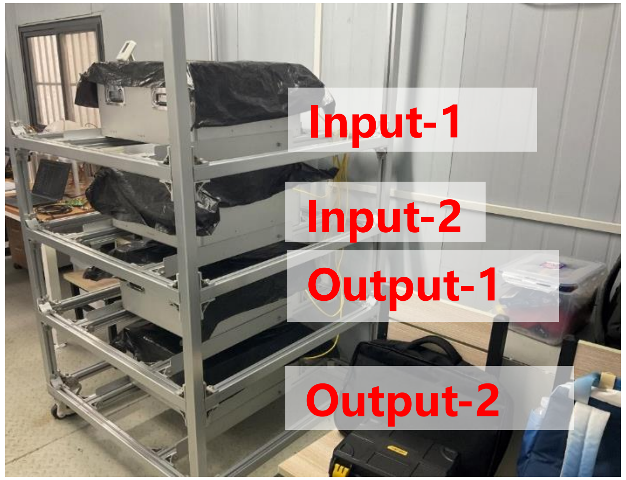


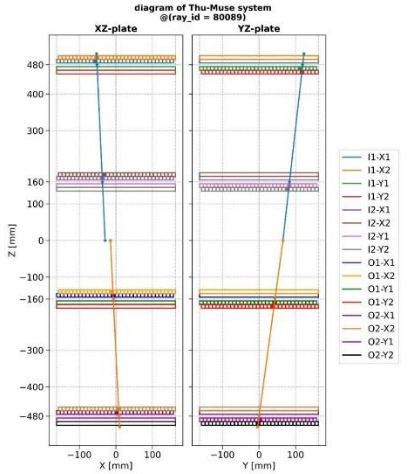
Layout diagram

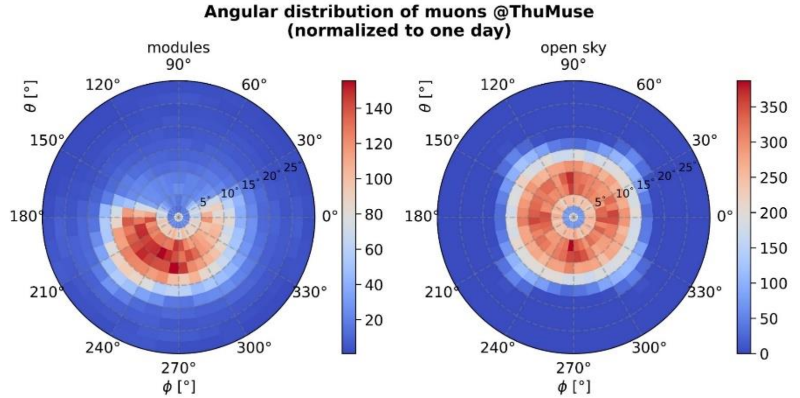
Environmental background measurement @Sanmen

Neutron measurement: Bonner Sphere detectors

- **Preliminary results [Neutron spectrum analysis is in progress]:**
- Neutron flux @10MeV:
  10^{-4}-10^{-3} [1/cm²/s]
- Neutron flux for thermal neutron-20MeV:
  4.92×**10^{-3} [1/cm²/s]**
- Surrounding dose equivalent rate magnitude
  [nSv/h]





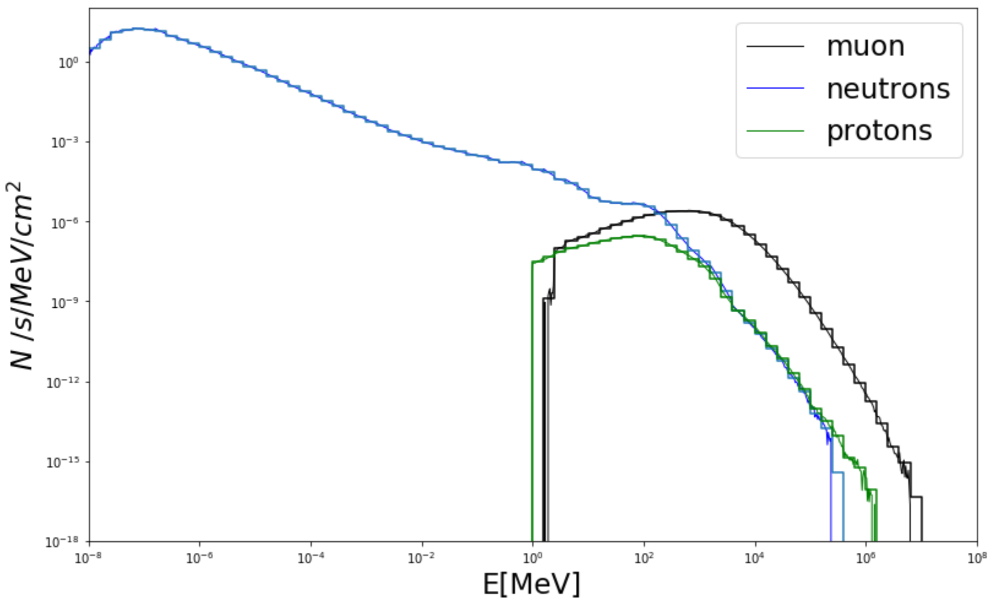


Measured zenith angle-azimuth distribution | **Simulated distribution in open scenes**

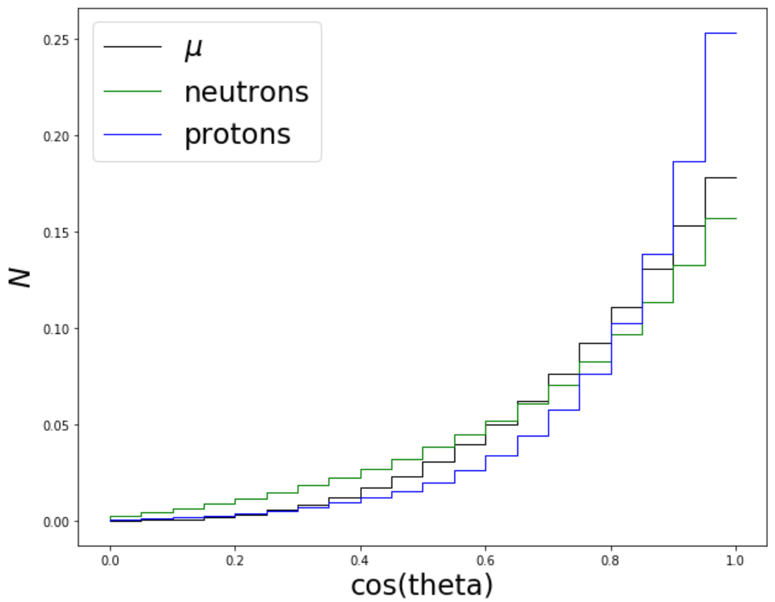
- **Measured zenith angle-azimuth distribution is consistent with the experimental site conditions: low muon flux near the Reactor Concrete Containment side, ~1/3 of muons can be shielded**

Cosmic ray simulation

- The cosmic rays that travel through the atmosphere can produce a variety of radiati on particles, such as neutrons, protons, gammas, and pions...
- In addition to the muon, we should also consider the **high-energy cosmic-ray neutr ons**, which can easily pass through the shield and deposit energy in the detector;
- Cosmic-ray Shower Library (CRY) to calculate their flux;



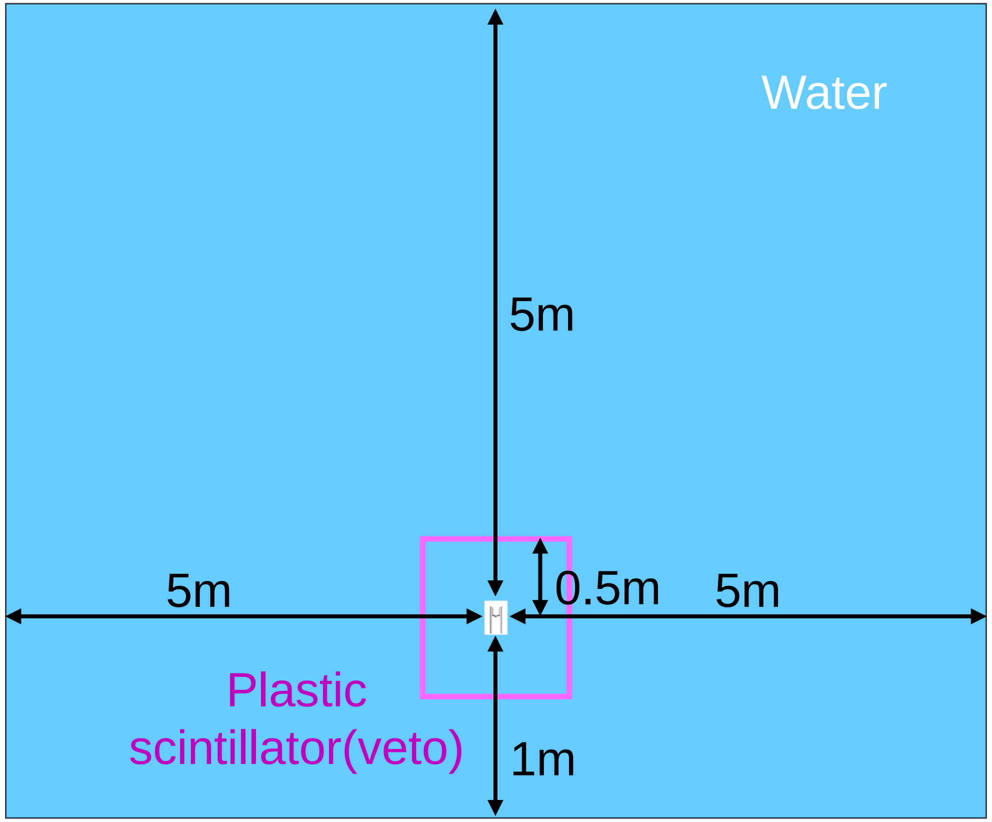
Spectra of cosmic-ray neutrons, protons, and muons at Sanmen sea level

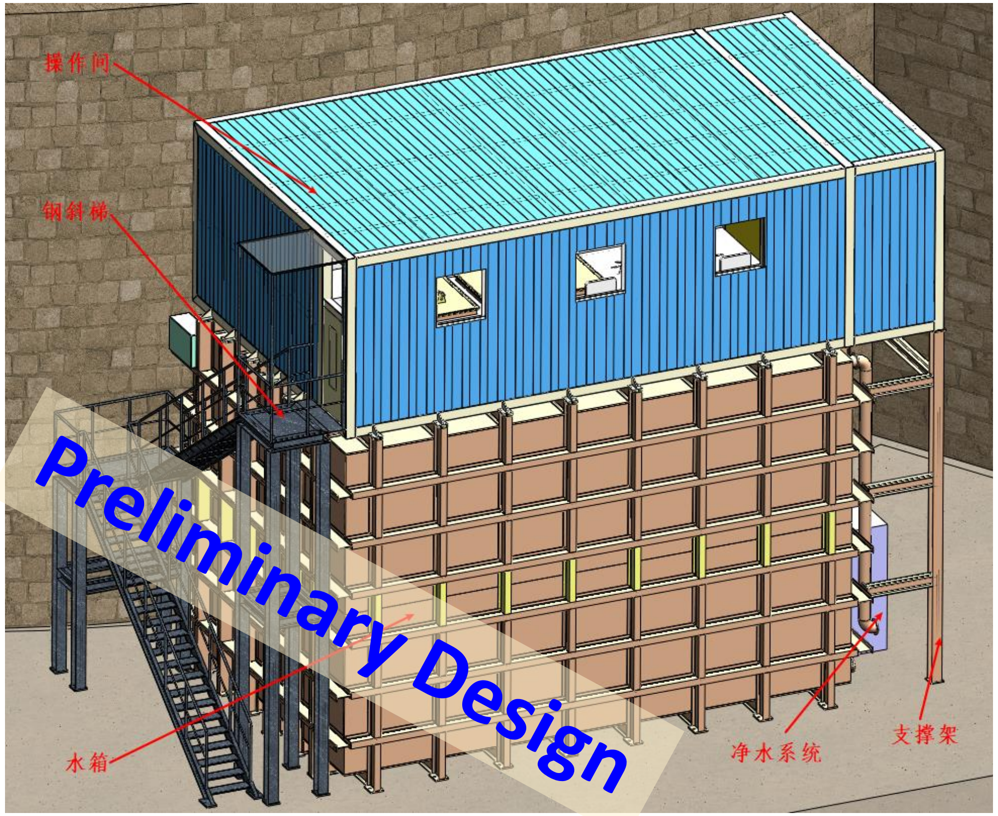


Angular distribution of cosmic-ray at Sanmen sea level

Water shield simulation design

- 5 m water shield on top can suppress the cosmic-ray neutron-induced backgroun d to a controlled level;
- Water tank (inner): 10m(L)*6.5m(W)*6m(H); The detector is placed in the water t ank on the side close to the reactor concrete containment.

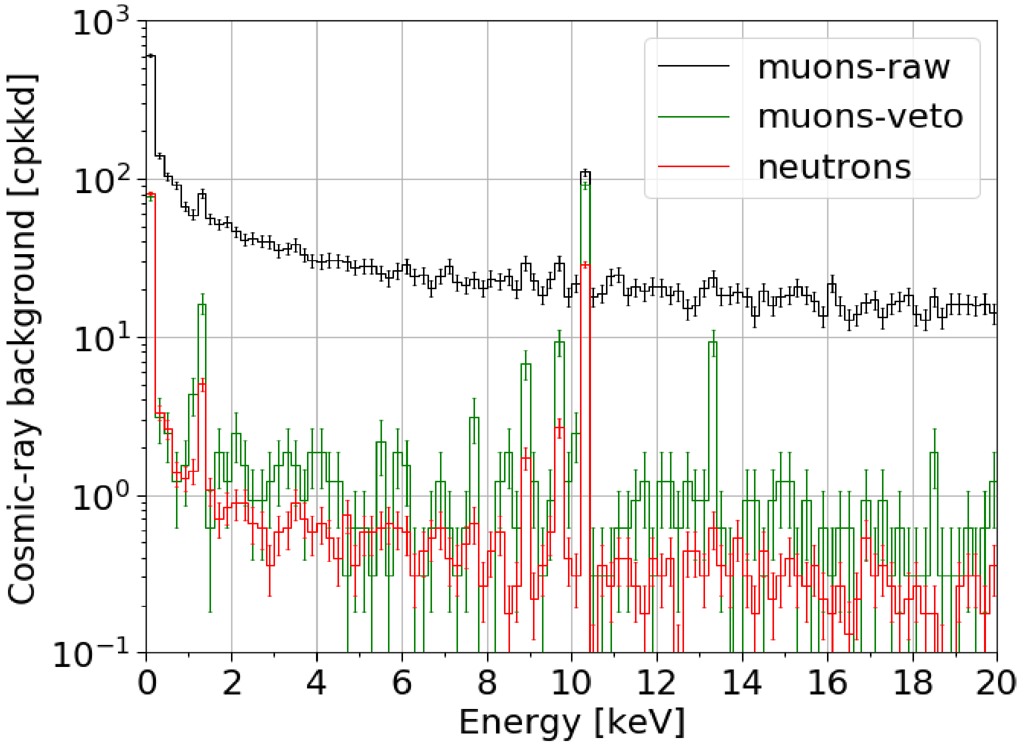




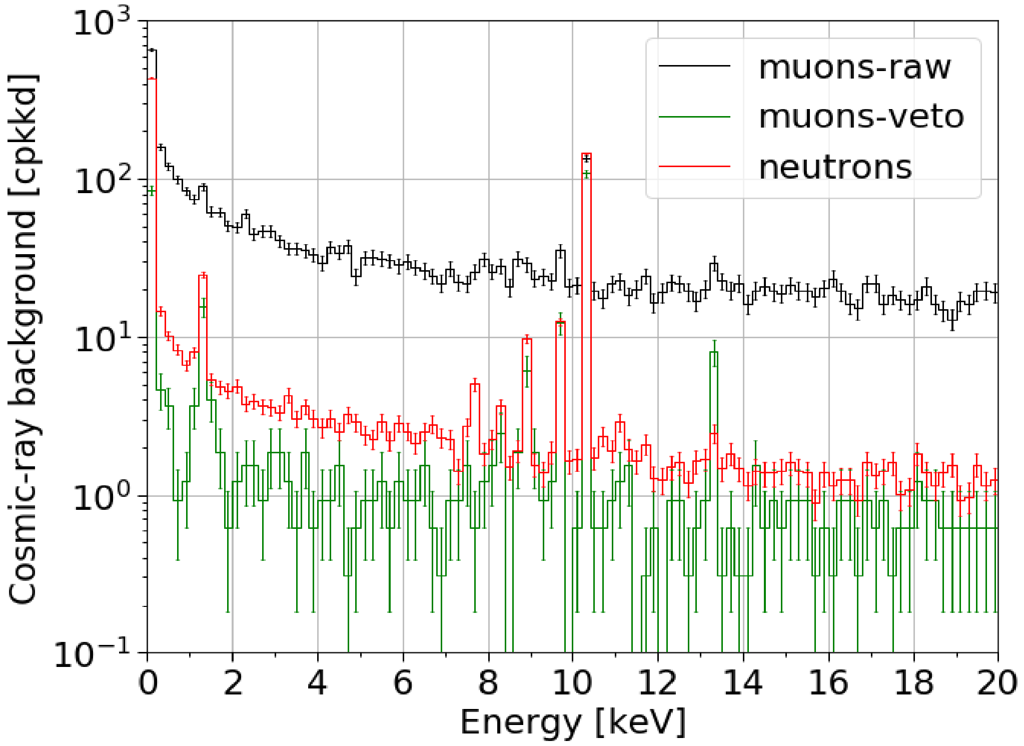
Water shield simulation design

- The size of the water tank has been optimized based on the MC simulation, espe cially the **cosmic-ray neutrons**, to satisfy the requirement of CEvNS detection;
- 5 m water shield on top can suppress the cosmic-ray neutron-induced backgroun d to a controlled level.

Water thickness 5m

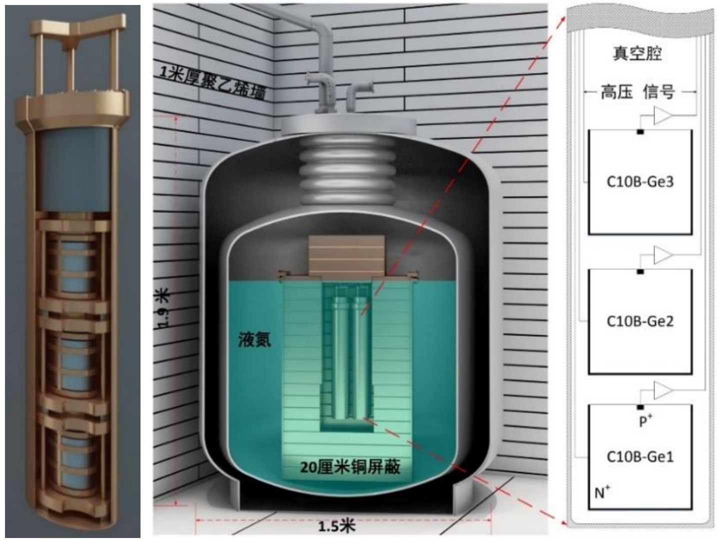


Water thickness 3m

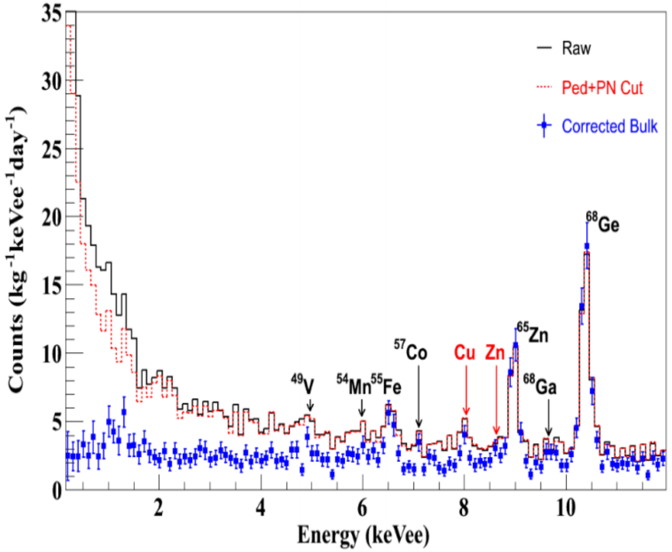


RECODE Far Site (based on CDEX-1/10)

CDEX-1B (1kg PPCGe),
cooled with the cooling finger
and LN2 Dewar



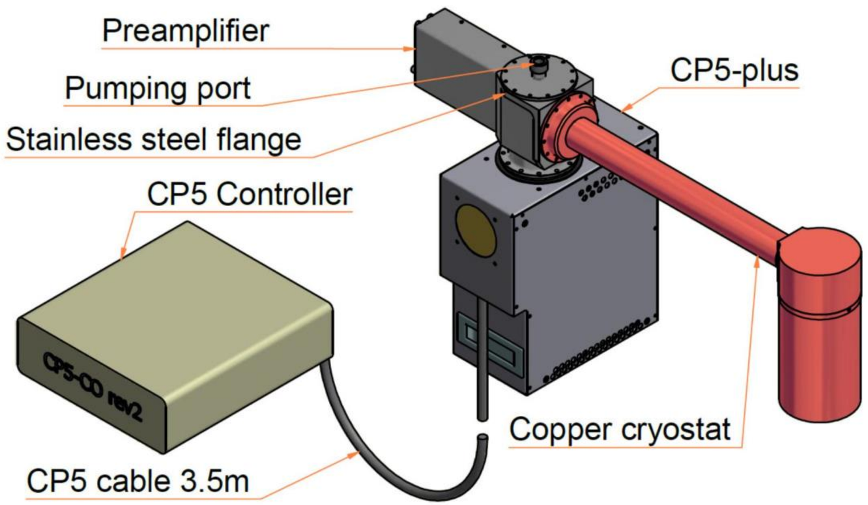
CDEX-10 (9*1kg PPCGe),
cooled with the vacuum cryos
tat directly immersed into LN2



CDEX-10 measured spectrum@CJPL,
~2 cpkkd@2keV, threshold 160 eVee

RECODE Near Site/Very Near Site

From HT Wong



Electric cooled HPGe

Mass (g)	Pulsar FWHM (eV_{ee})	Threshold (eV_{ee})
500	70	200
900	70	~230
1430	~60	~160
1430	70	200

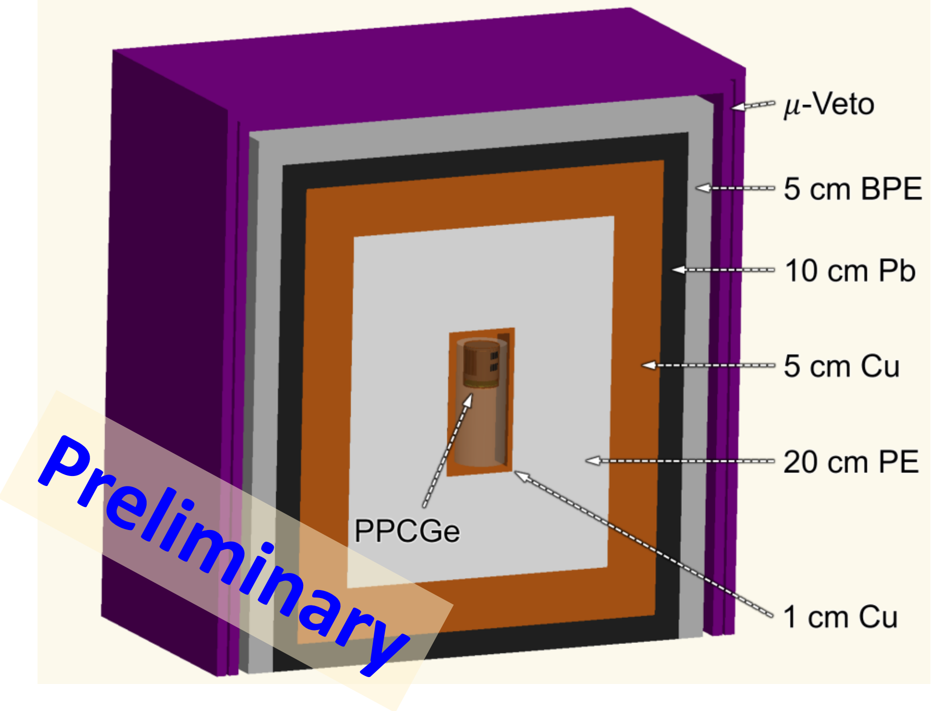
Advantages of electrical cooled HPGe:

- ✓ No need to regularly replenish liquid nitrogen
- ✓ Controllable crystal temperature
- ✓ Real-time monitoring of Refrigerator performance
- ✓ Good long-term stability

Preliminary Design of the shielding (Near Site)

- **Shielding design and optimization (Near Site)**
  - Anti coincidence efficiency of Cosmic ray:>99%
  - Gamma current strength: reduced by 5 orders of magnitude
  - Neutron current intensity: reduced by 3 orders of magnitude

- **From outer to inner (Preliminary):**
  - ✓ Muon veto detector
  - ✓ Boron doped polyethylene (BPE)
  - ✓ Lead (Pb)
  - ✓ Coper (Cu)
  - ✓ Polyethylene (PE)
  - ✓ Coper (Cu)



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Schedule

2023	2024	2025	2026
✓ On site environmental background measurement/estimation ✓ Design, production, and processing of various subsystems	✓ Subsystem independent testing ✓ Joint testing work	✓ Transport to NPP, installation, testing ✓ First physics run	✓ Second physics run ✓ Data analysis

Subsystems testing @CJPL and ground, Sanmen Laboratory preparation (2023–2024)

Physics Run (FS, NS, VNS) @Sanmen NPP (2025–2026)

Summary

- **Two layouts (Far, Near) with three sites (FS, NS + VNS):**
  - **Far Site** (22m distance to reactor core, outside of Containment, no overburden)
  - **Near Site** (11m, overburden>15m.w.e, Maintainable during reactor operation)
  - **Very Near Site** (7m, overburden>20m.w.e., Not maintainable during operation)
  - **Far-Near Joint analysis**: reduce systematic uncertainty, improve the sensitivity
- **Shielding for FS/NS, according to the overburden:**
  - Far Site: 400 tons of pure Water shielding, 10m(L) X 6.5m(W) X 6m(H)
  - Near Site: composite shielding with Lead, Copper, and Polyethylene…
- **HPGe technologies from CDEX:**
  - low energy threshold, low background
  - Liquid nitrogen cooling (FS), Electric cooling (NS/VNS)

谢谢！