R&D Progress of the Jinping Neutrino Experiment

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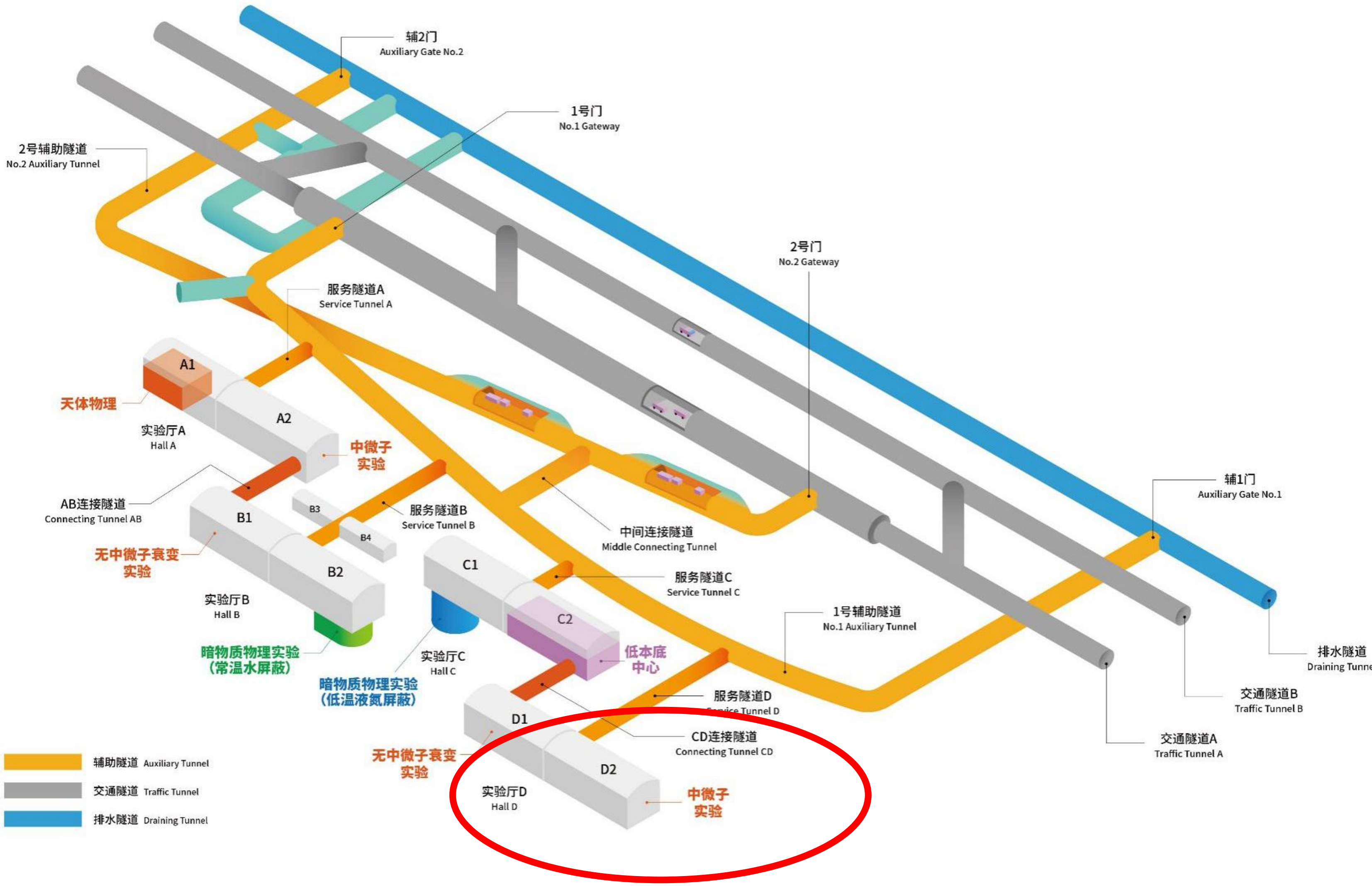
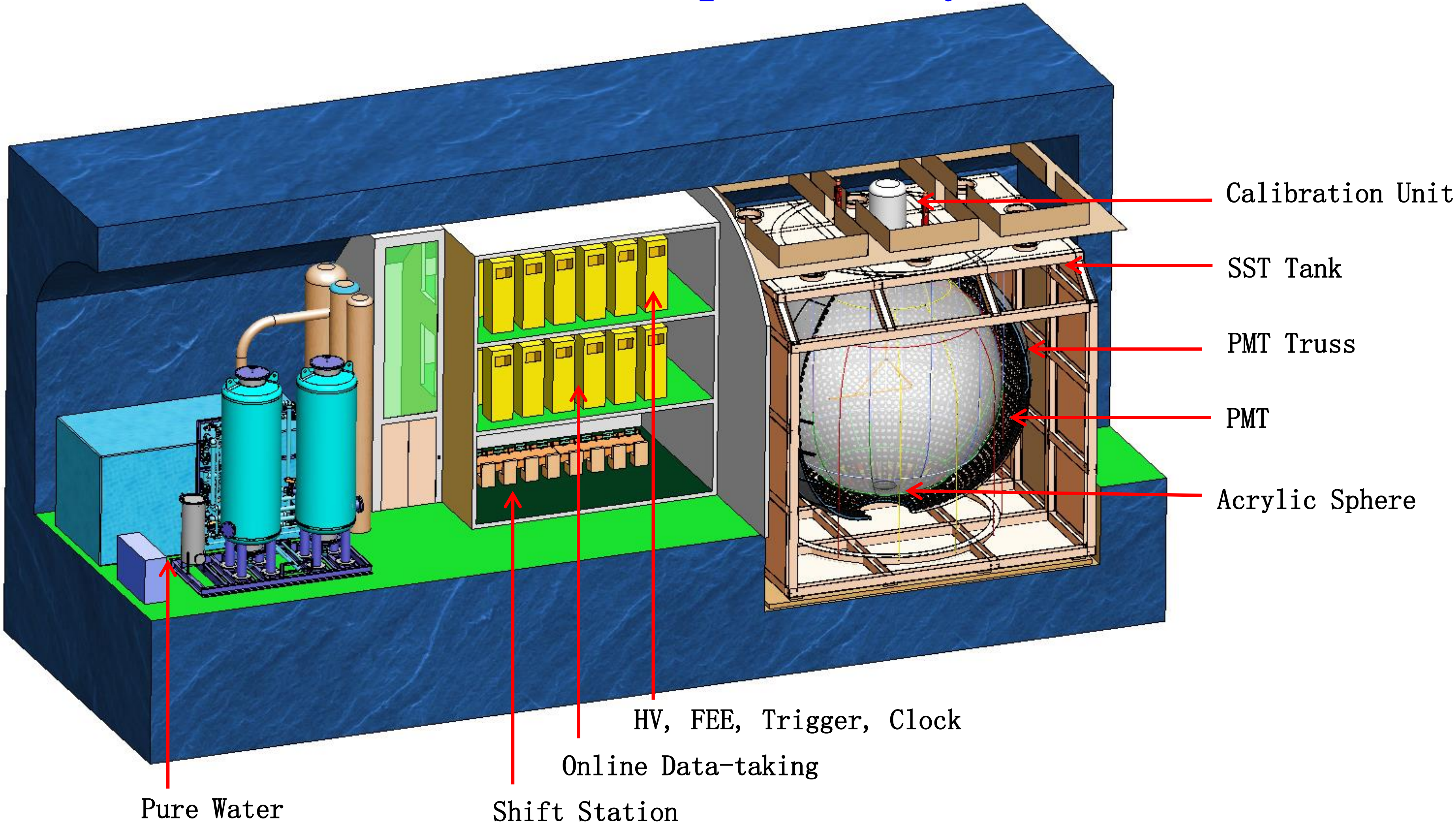
(On behalf of the research group
包括华中科技大学, 合肥工业大学, 北京工业大学, 南京大学, 等等)

October 31, 2023 @ Symposium of Frontiers of Underground Physics

Jinping Neutrino Experiment at CJPL-II, hall D2



Hall D and Experiment Layout

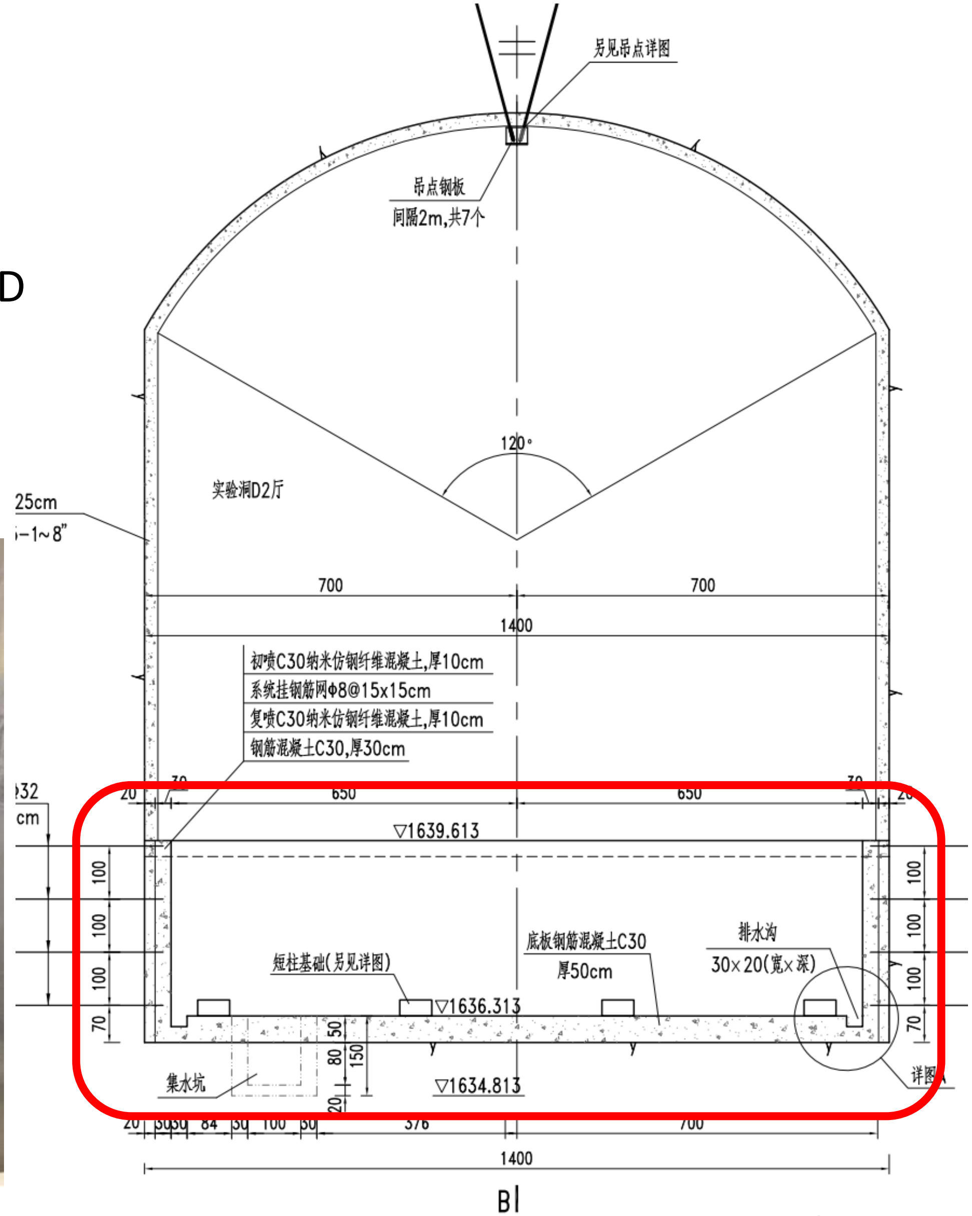


500 cubic meter target volume

Pit for Detector

Construction of the pit is finished 2023 summer

1. Designed by Huadong Engineering Corporation Limited
2. Constructed by Sinohydro Bureau 5 Co. LTD
3. Onsite management: Yalong Hydro CJPL Administration Bureau



Detector Design

Stainless steel tank:

14.5 m (L)*12.9 m (W)*13.2 m (H)

SST PMT truss:

12.16 m (Diameter)

Acrylic vessel:

9.96 m (Diameter), 0.05 m (Thickness)

500 cubic meter

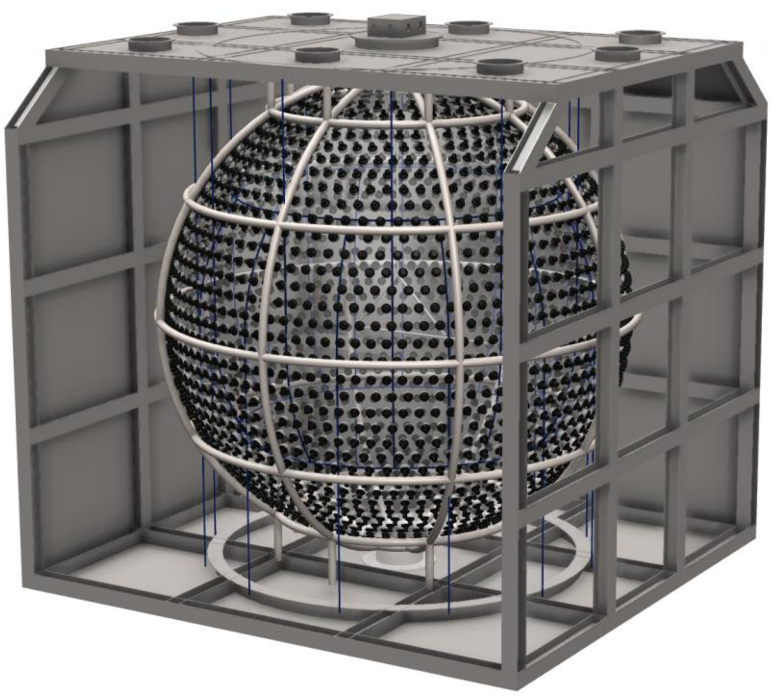
Rope network:

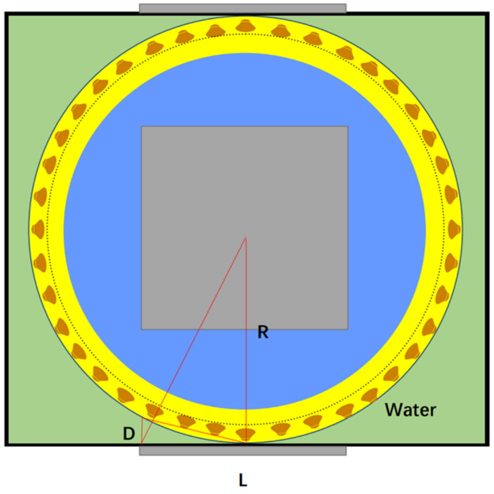
holding-up and holding-down

(Allow a detection material heavier or lighter than water with 20% density difference.)

Shieling material:

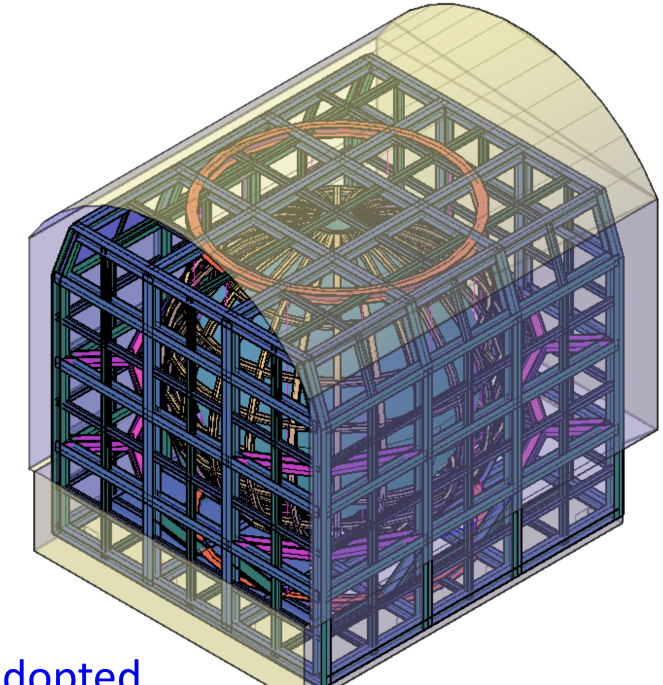
Water and SST (or lead)





Shieling SST (or lead) planes

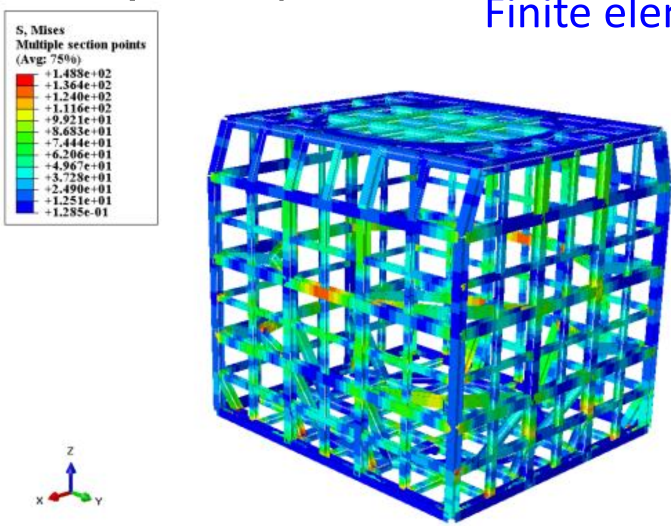
Water Tank



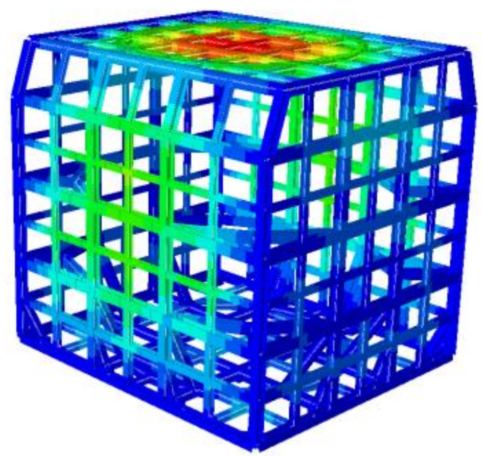
Requirement for the stainless steel tank:

1. Hold the water and all inside structures (14.5 m*12.9 m*13.2 m)
2. Hold all equipment on the top the tank (calibration and other electronics)
3. Hold the shielding materials (SST or lead plates)

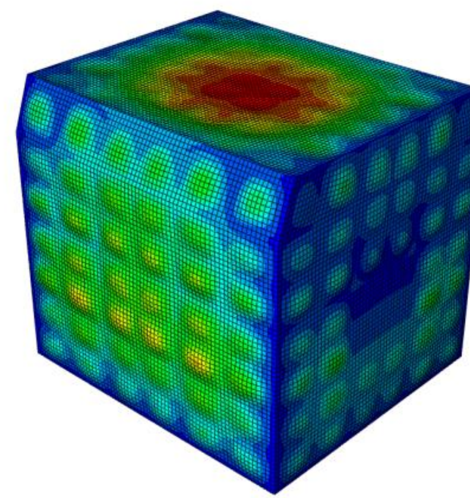
Finite element software ABAQUS is adopted



Stress contour diagram

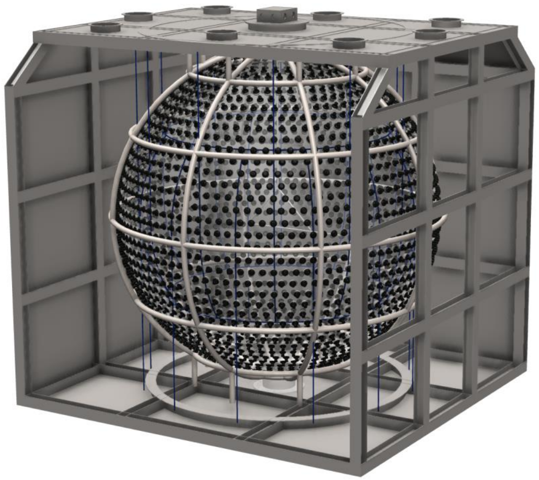


Displacement contour diagram



Stress contour diagram with covering SST plates

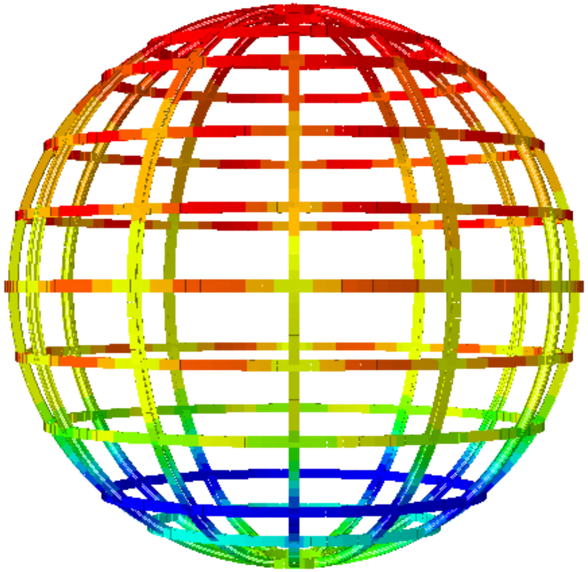
PMT Truss



Requirement for the PMT truss:

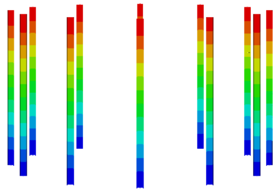
1. Hold 4000 PMTs

Structure



Axial force contour diagram for the sphere

Finite element software ABAQUS is adopted

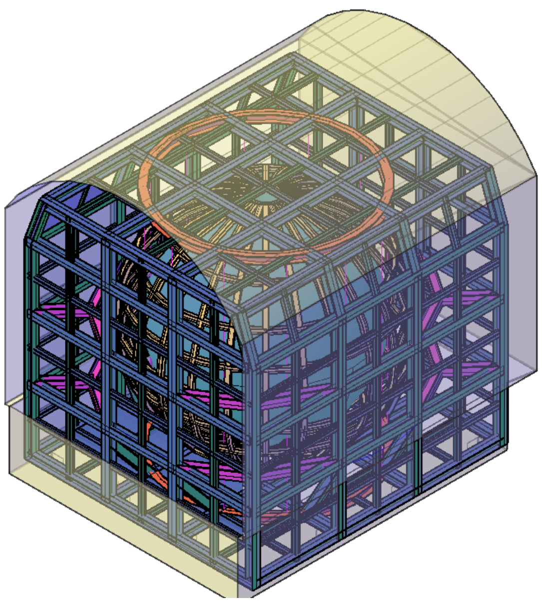


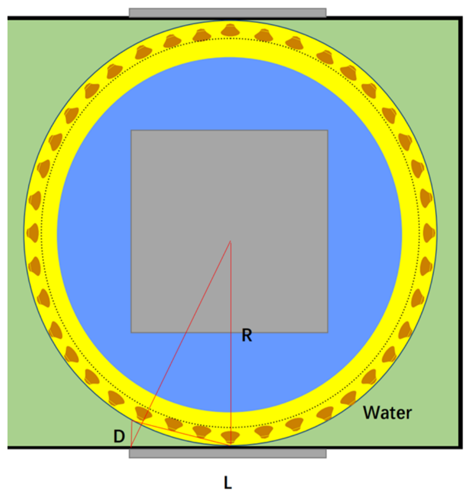
Axial force contour diagram for the legs

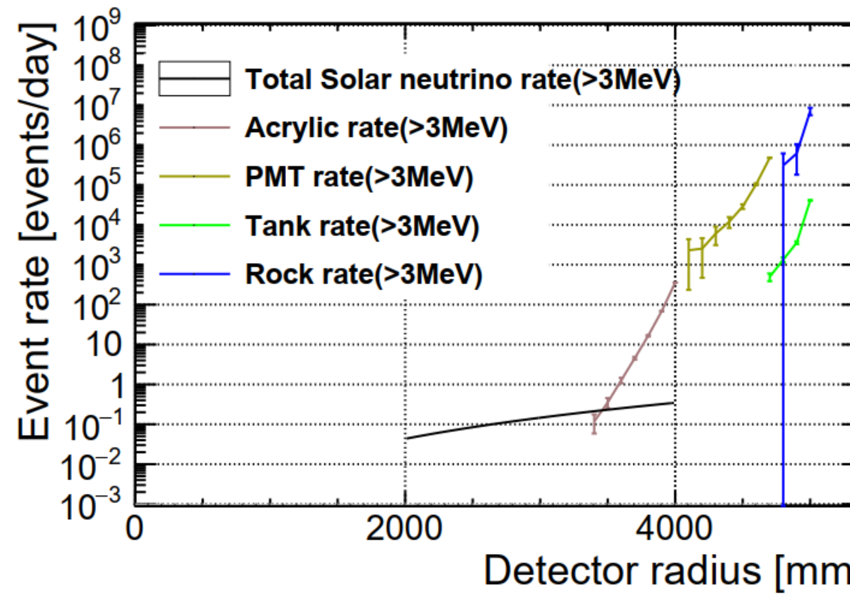
Shielding Plates

Requirements for Shield Plates

1. Shield concrete/rock background to 1 meter water equivalent
2. 7 m*7 m*20 cm steel (or lead) plates, 76 ton, on each side



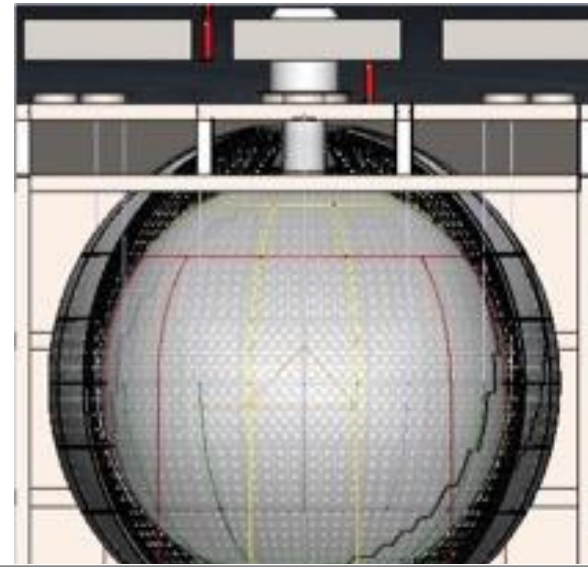




Narrow Hall D and all occupied.

Shield concrete and rock background

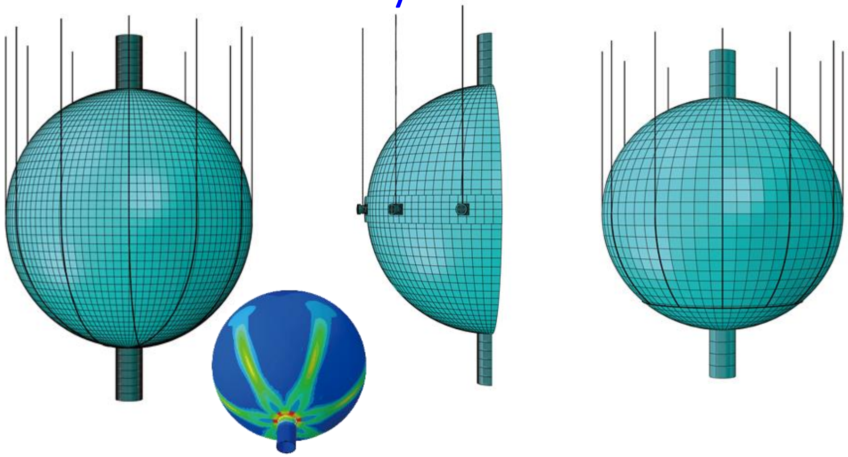
Acrylic Vessel



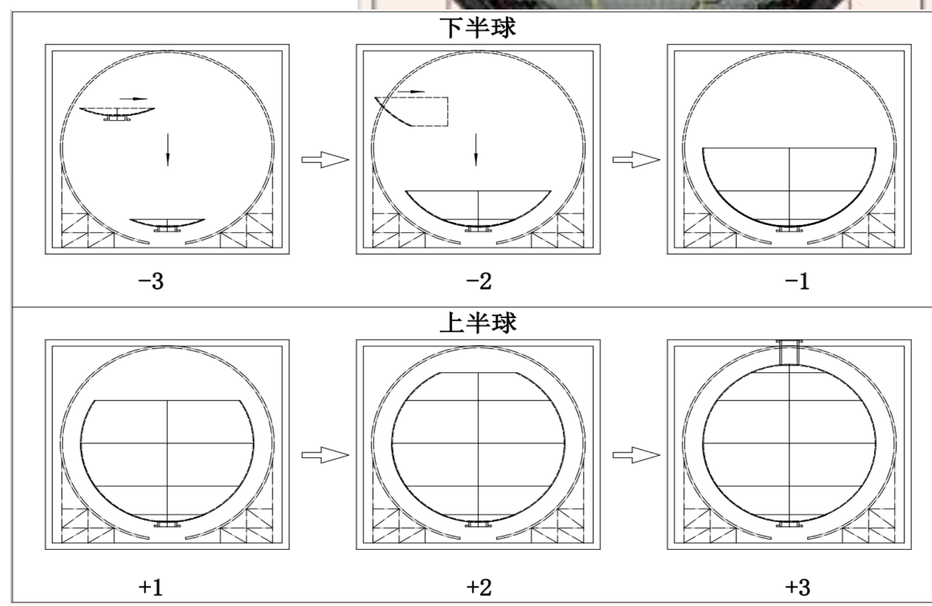
Requirement for the PMT truss:

1. Contain detection material
   Water, LS, or Doped LS
   Density difference to water: $\pm$20%
2. Low background

Plan to use JUNO acrylic. The same design team for JUNO acrylic test.



Compared 3 holding designs
Last one presents least stress on acrylic

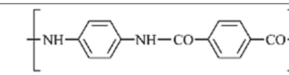
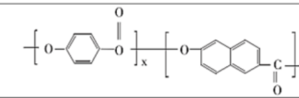
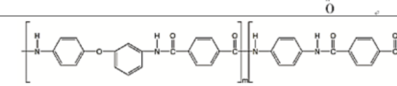


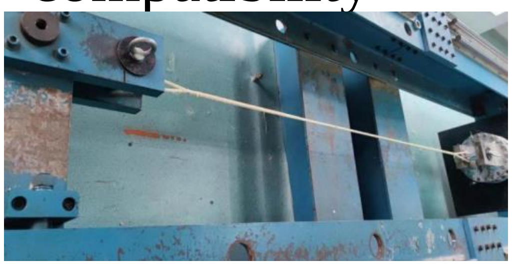
Preliminary installation plan
Division, bonding, and cleaning

Ropes

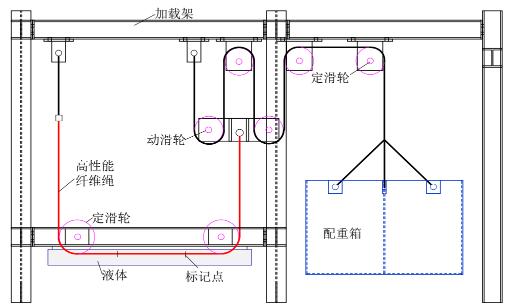
Requirement for the Ropes:

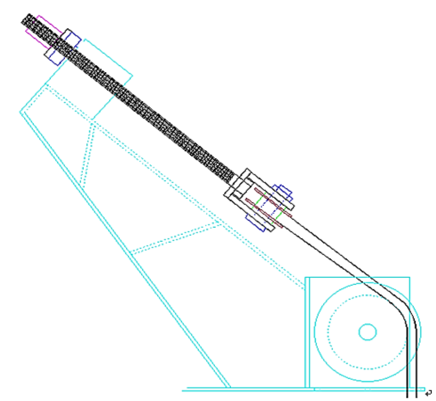
1. Hold acrylic sphere
   Water, LS, or Doped LS
   Density difference to water: ±20%
2. Low background
3. High strength, low creeping, water compatibility

品种	化学式
UHMWPE 纤维	$H_3C-[CH_2-CH_2]_n-CH_3$
Kevlar 纤维	
Vectran 纤维	
Technora 纤维	



Breaking experiments





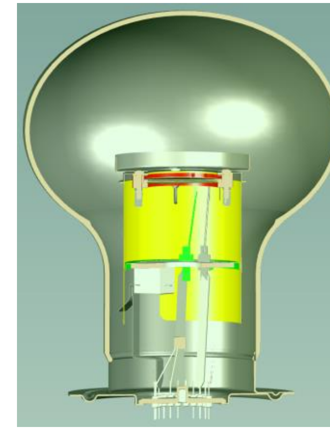
Preparing for chemical analysis

Creeping experiments

Tension monitor and length adjustment

MCP-PMT

Material control

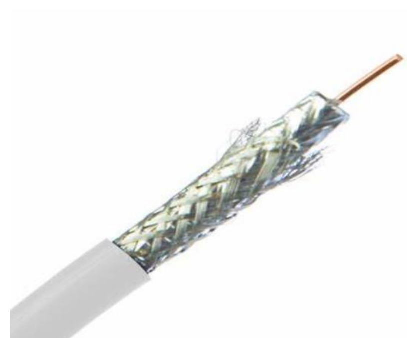


Structure

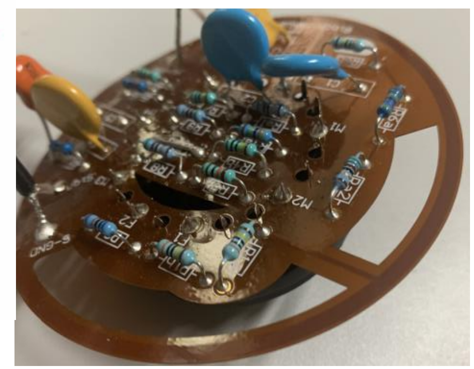
New 8-inch MCP PMTs

1. U、Th: <4E-8 g/g
2. K-40: <4e-9 g/g
3. High QE: 30%
4. Good timing: TTS<1.8 ns

400 produced.



Cable

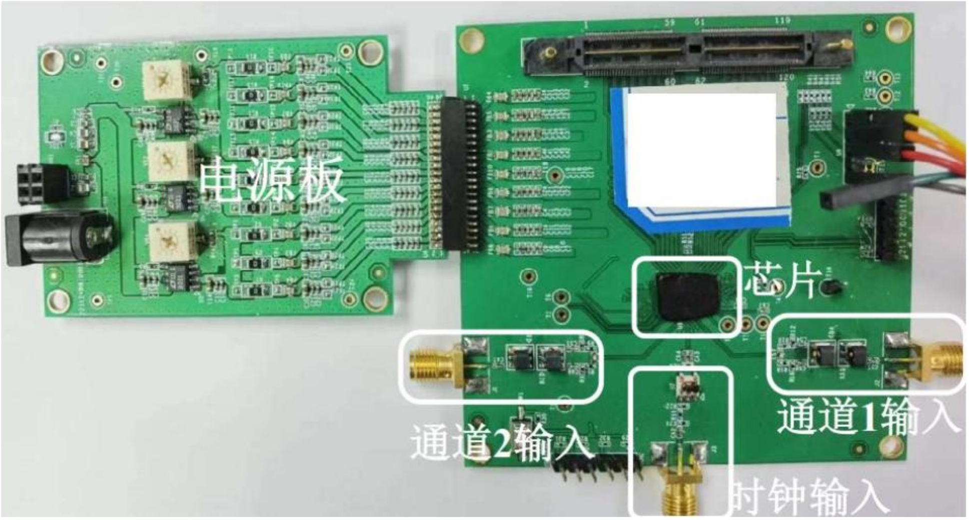


HV divider

FADC and Readout

FADC for PMT waveform readout

350 mW, 12 bit, 1 GSps
(based on the development for JUNO, but with even lower power consumption than 800 mW)

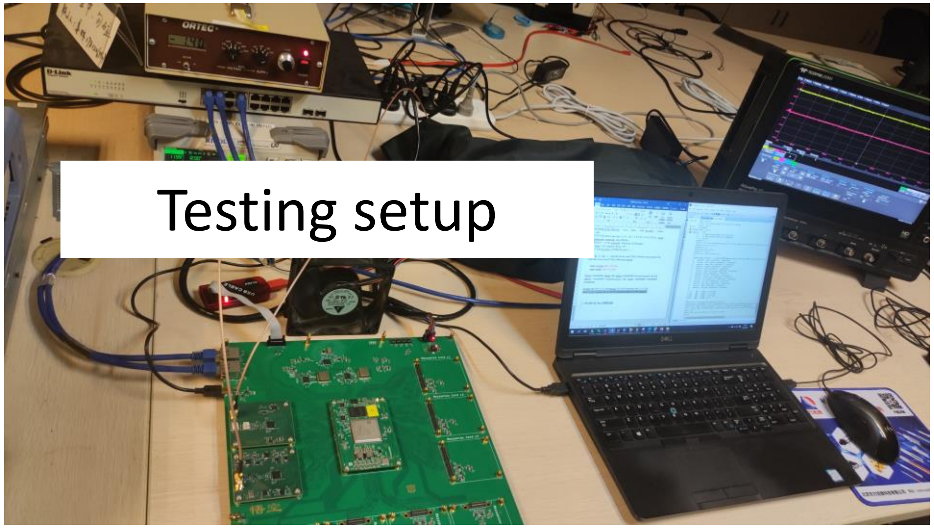


Readout board

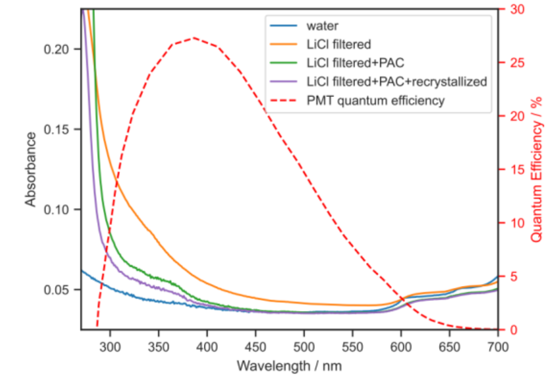
Bandwidth 300 MHz, 40Gbps

Testing setup

The whole system will be tested on the one-ton prototype this year.



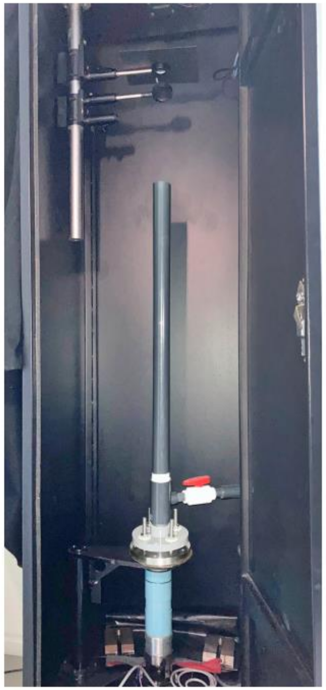
LiCl Water Solution



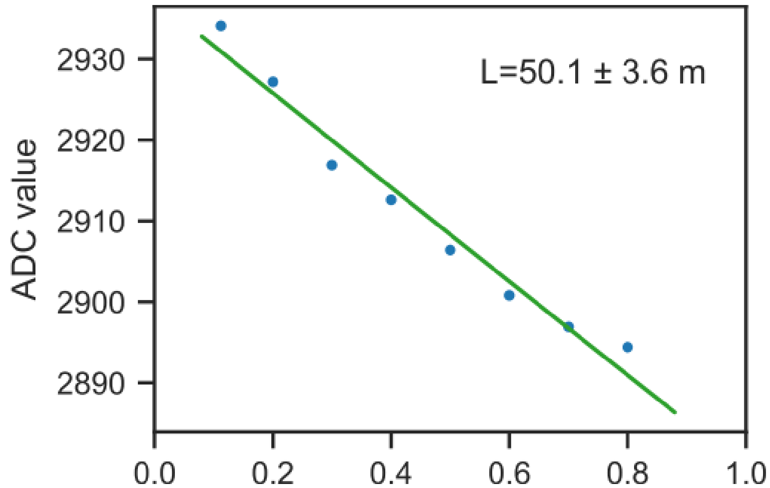
LiCl water solution

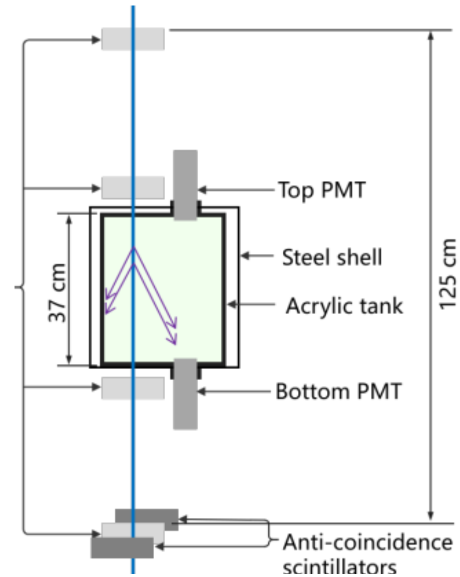
Ideal for solar neutrino upturn effect study

1. Attenuation length at 430 nm is greater than 50 meters
2. C124 can be added to enhance light yield



(b)





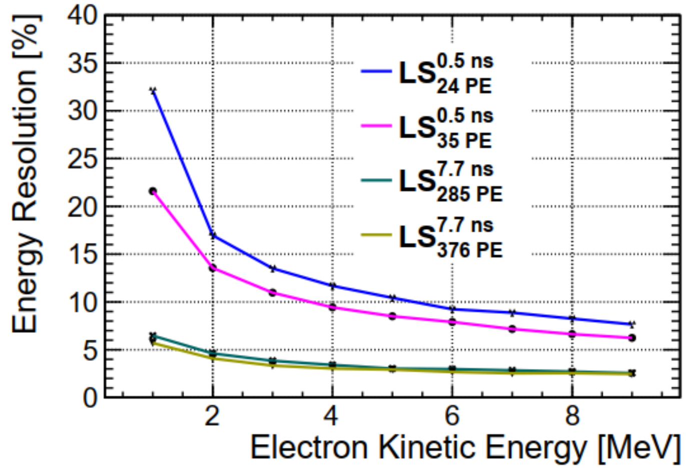
	Top PMT PEs	Bottom PMT PEs
Water	0.76 ± 0.08	15.8 ± 1.5
Saturated LiCl solution	0.54 ± 0.08	17.2 ± 1.5
Saturated LiCl solution with 1 ppm C-124	3.7 ± 0.4	16.0 ± 1.6

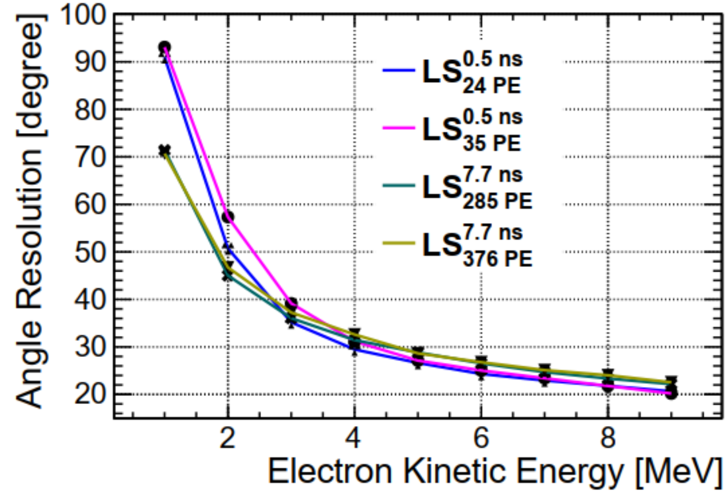
Cherenkov Liquid Scintillator Reconstruction

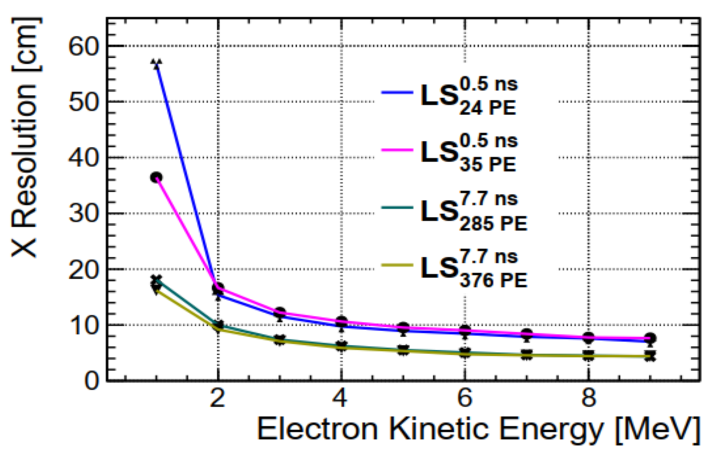
Reconstruct both Cherenkov light and scintillation light

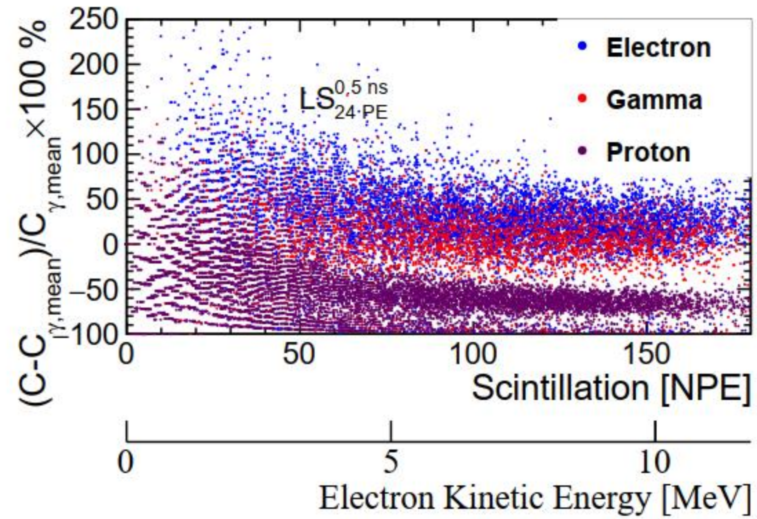
1. Energy; 2. Direction; 3. Position; 4. **Particle identification**

Guide liquid scintillator development









Physics program

The construction and testing running of the detector is expected at 2027. Physics runs follow...

1. **Solar neutrino upturn effect, oscillation parameter measurement**
2. **Geoneutrino measurement, Tibet crust geoneutrinos**
3. **Supernova relic neutrinos**
4. **Double beta decay**
5. **Others: sterile neutrino, neutrino cross-section, nuclear physics, etc.**

Solar Neutrino Physics with LiCl Solution

1. **CC process for ν_e:**

$$\nu_e + {}^7\text{Li} \rightarrow {}^7\text{Be} + e^- (+\gamma)$$

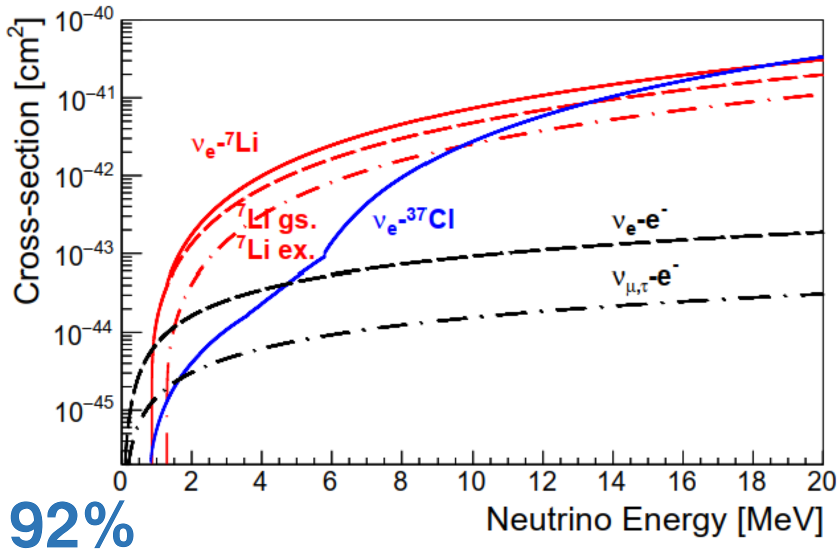
   Measure neutrino energy

2. **High cross–section:**

   ν_e-Li7: 60 times of ν_e-e elastic scattering for solar B8 neutrinos

3. **High natural abundance of Li7: 92%**

4. **High solubility: 80 g LiCl in 100 g water**



	^{7}Li	^{37}Cl	All CC	e^-
Molarity (mol/L)	11	2.9	NA	610
Event rate (No Osci)	305	22.7	328	271
Event rate (Osci)	101	7.28	108	124
Event rate (Osci & >4 MeV)	94.5	7.24	102	48.0
Event rate (Osci & >5 MeV)	87.3	7.17	94.4	34.5

ν_e CC, ES, and $\bar{\nu}_e$ detection

1. **CC process for ν_e:**

$$\nu_e + {}^7\mathrm{Li} \to {}^7\mathrm{Be} + e^-(+\gamma)$$

Measure neutrino energy

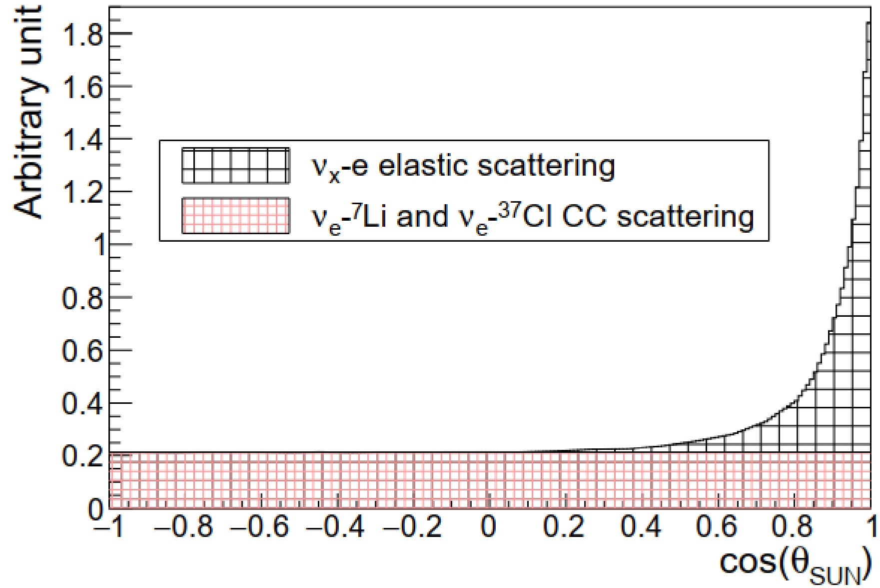
1. **Elastic scatter on e^-:**

2. **Delayed coincidence for $\bar{\nu}_e$**

$$\bar{\nu}_e + p \to n + e^+$$

with neutron capture on H, Li6, and Cl35

measure $\bar{\nu}_e$ energy



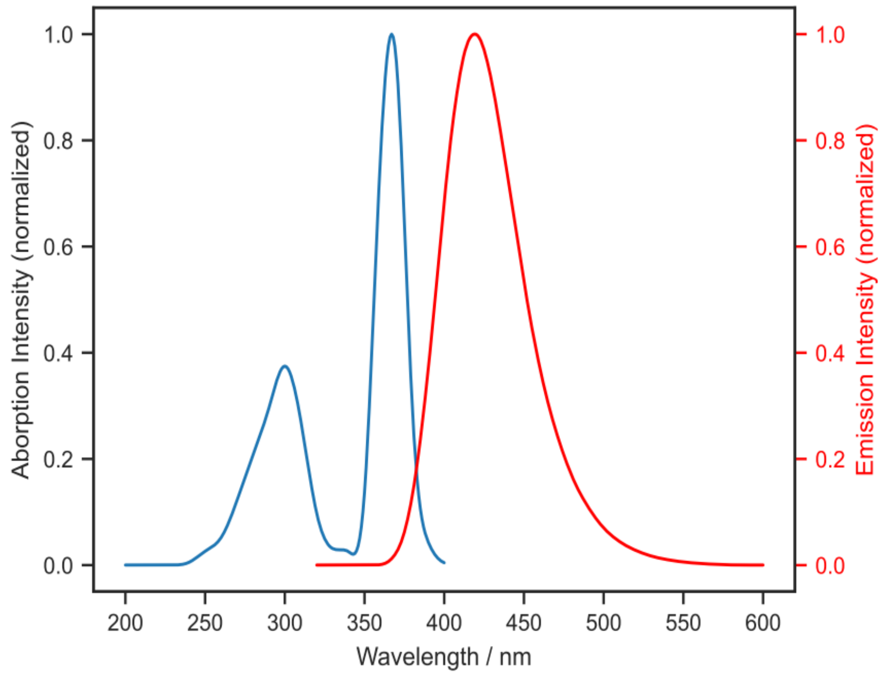
Spectrometer for ν_e and $\bar{\nu}_e$

Good chance for solar, geo, and supernova neutrinos

LiCl aqueous solution with carbostyril 124

Adding 1 ppm C124 to LiCl aqueous solution

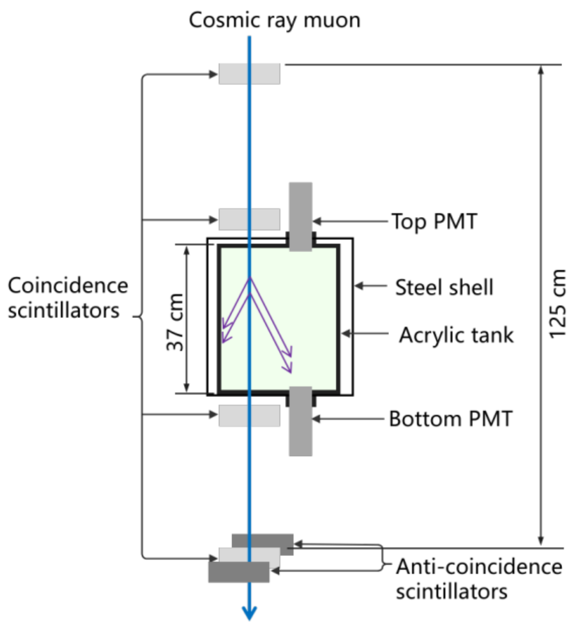
1. Convert short wavelength UV to longer wavelength
2. Convert short attenuation length UV to long attenuation length visible light

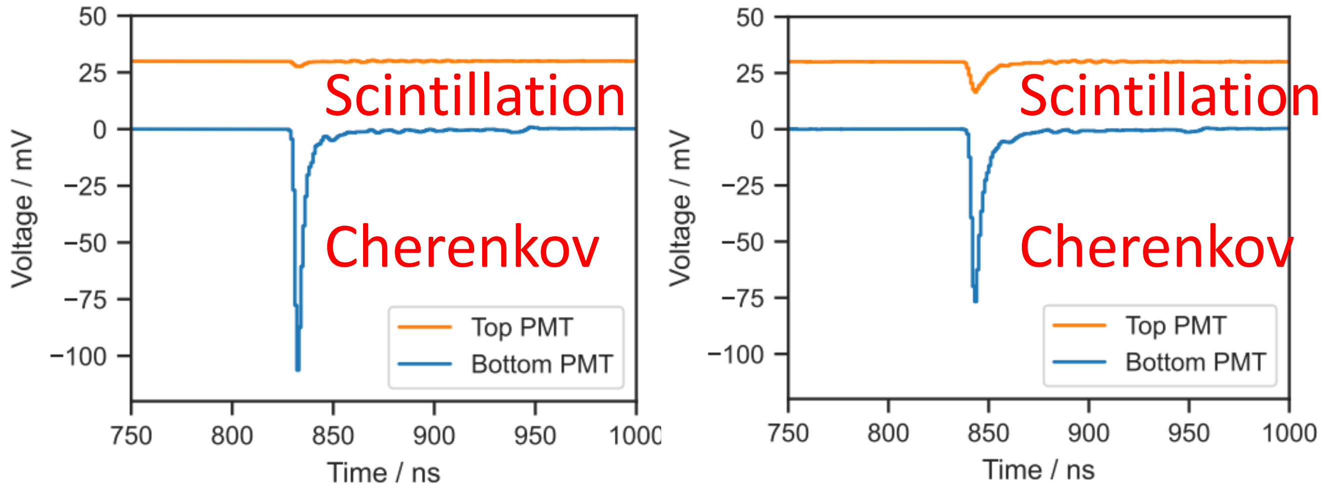


C124 absorption and emission spectra

LiCl aqueous solution with carbostyril

Light yield verification with a muon telescope





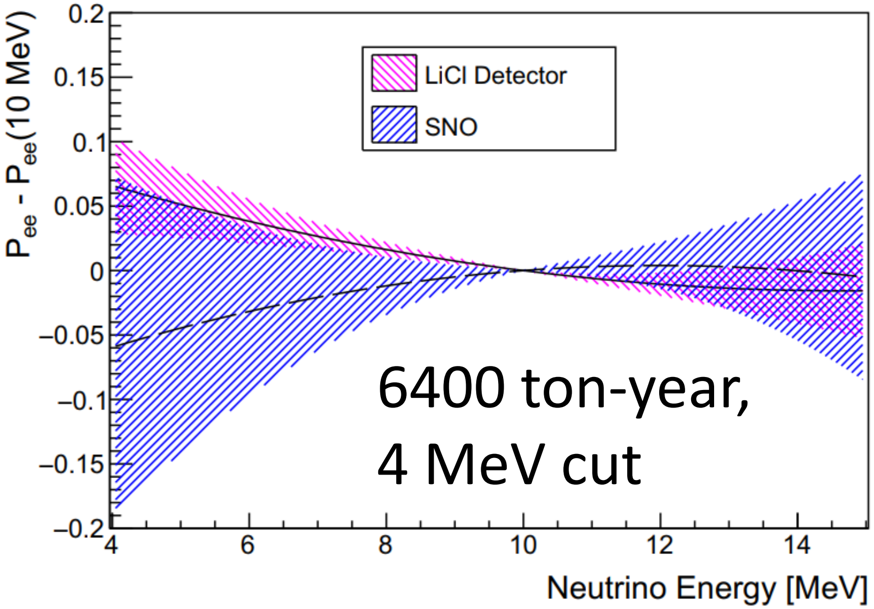
(a) LiCl → (b) LiCl with 1 ppm C-124

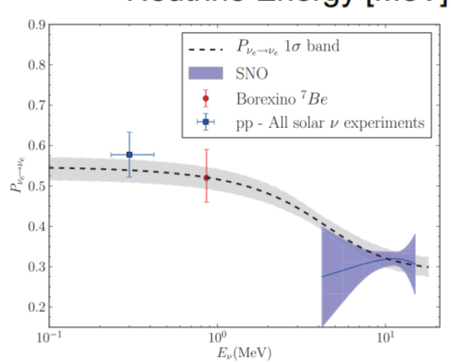
3.7 PE detected from isotropic scintillation

12.3 PE for Cherenkov

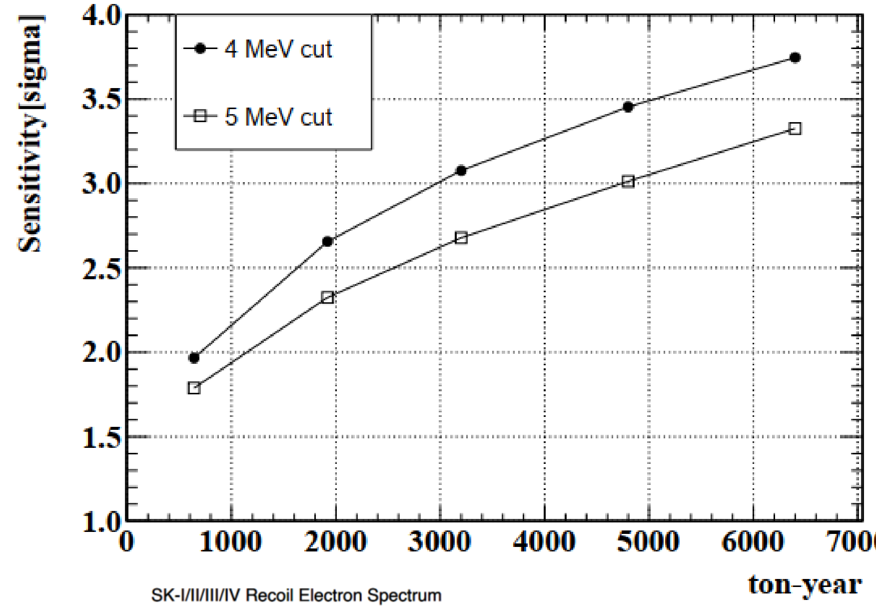
Solar Neutrino Physics with LiCl Solution

Solar neutrino survival probability-average vs energy

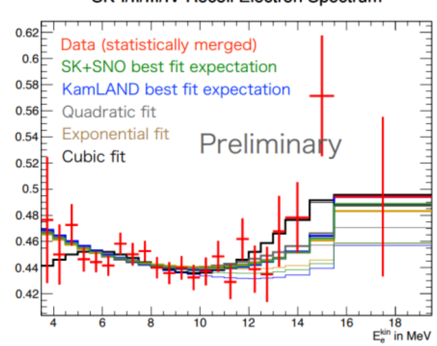




Upturn discovery sensitivity versus exposure



SK-I/II/III/IV Recoil Electron Spectrum

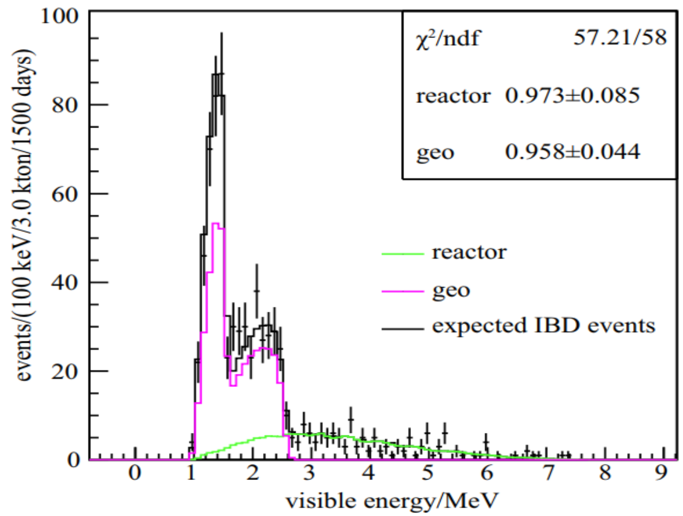


Slightly favors up-turn,
though need more data

Geo Neutrino and Supernova Relic Neutrinos

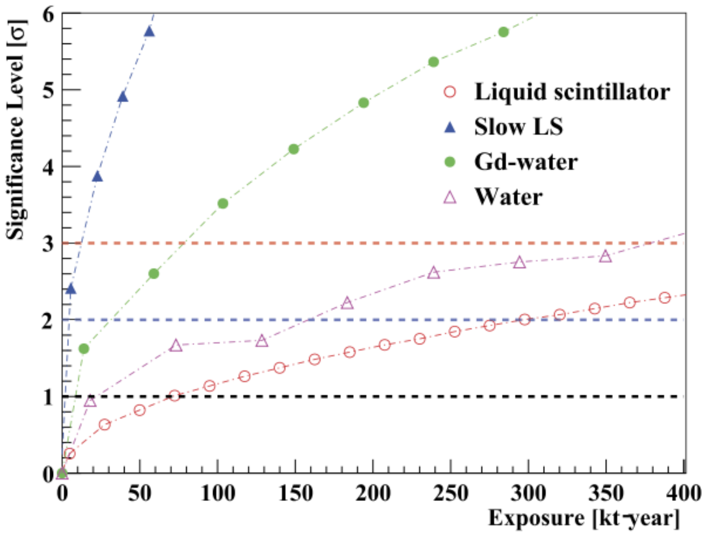
With prompt-delayed signal detection:

Expect tens of geoneutrinos in 5-10 years with the 500-ton detector →



With Cherenkov-scintillation liquid scintillator:

Expect a few golden candidate supernova relic neutrinos in 5-10 years with the 500-ton detector →



Expect an improvement better than this figure. Work in progress.

Summary

1. **500 hundred-ton neutrino detector at CJPL II**
    a. Detector design and construction
    b. Replaceable detection media, allowed density range ± 20% wrt water, oil- or water- based liquid scintillator
2. **New MCP-PMT, Low background, fast, high QE**
3. **ADC chips and waveform readout electronics under design and testing**
    a. AD chips, 12 bit, GSPS, 350mW
    b. waveform readout, 300 Mz, 40Gbps
4. **LiCl aqueous solution for solar neutrinos**
5. **Supernova relic and geoneutrinos**
6. **Working on improving liquid scintillators**

Looking for new collaborations...

Thank you. Stay tuned.

Related publications

1. Wenhui Shao, et al., The potential to probe solar neutrino physics with LiCl water solution, Eur. Phys. J. C 83 (2023) 799.
2. John F. Beacom, et al., Physics prospects of the Jinping neutrino experiment, Chinese Physics C 41 (2017) 023002.
3. Hanyu Wei, Zhe Wang, Shaomin Chen, Discovery potential for supernova relic neutrinos with slow liquid scintillator detectors, Physics Letters B 769 (2017) 255.
4. Aiqiang Zhang, et al., Performance evaluation of the 8-inch MCP-PMT for Jinping Neutrino Experiment, Nucl.Instrum.Meth.A 1055 (2023) 168506.
5. Ye Liang, et al., Optical property measurements of lithium chloride aqueous solution for a novel solar neutrino experiment, JINST 18 (2023) P07039.
6. D.C. Xu, et al., Towards the ultimate PMT waveform analysis, JINST 17 (2022), P06040.
7. Wentai Luo, et al., Reconstruction algorithm for a novel Cherenkov scintillation detector, Journal of Instrumentation, 2023, 18(02): P02004.
8. Wei Dou, et al., Reconstruction of Point Events in Liquid-Scintillator Detectors Subjected to Total Reflection, ArXiv:2209.10993.
9. Ziyi Guo, et al., Muon Flux Measurement at China Jinping Underground Laboratory, Chin.Phys.C 45 (2021) 2, 025001.
10. [] Lin Zhao, et al., Measurement of Muon-induced Neutron Production at China Jinping Underground Laboratory, Chin.Phys.C 46 (2022) 2, 025001.
11. [] Yiyang Wu, et al., Performance of the 1-ton Prototype Neutrino Detector at CJPL-I, Nucl.Instrum.Meth.A 1054 (2023) 168400.