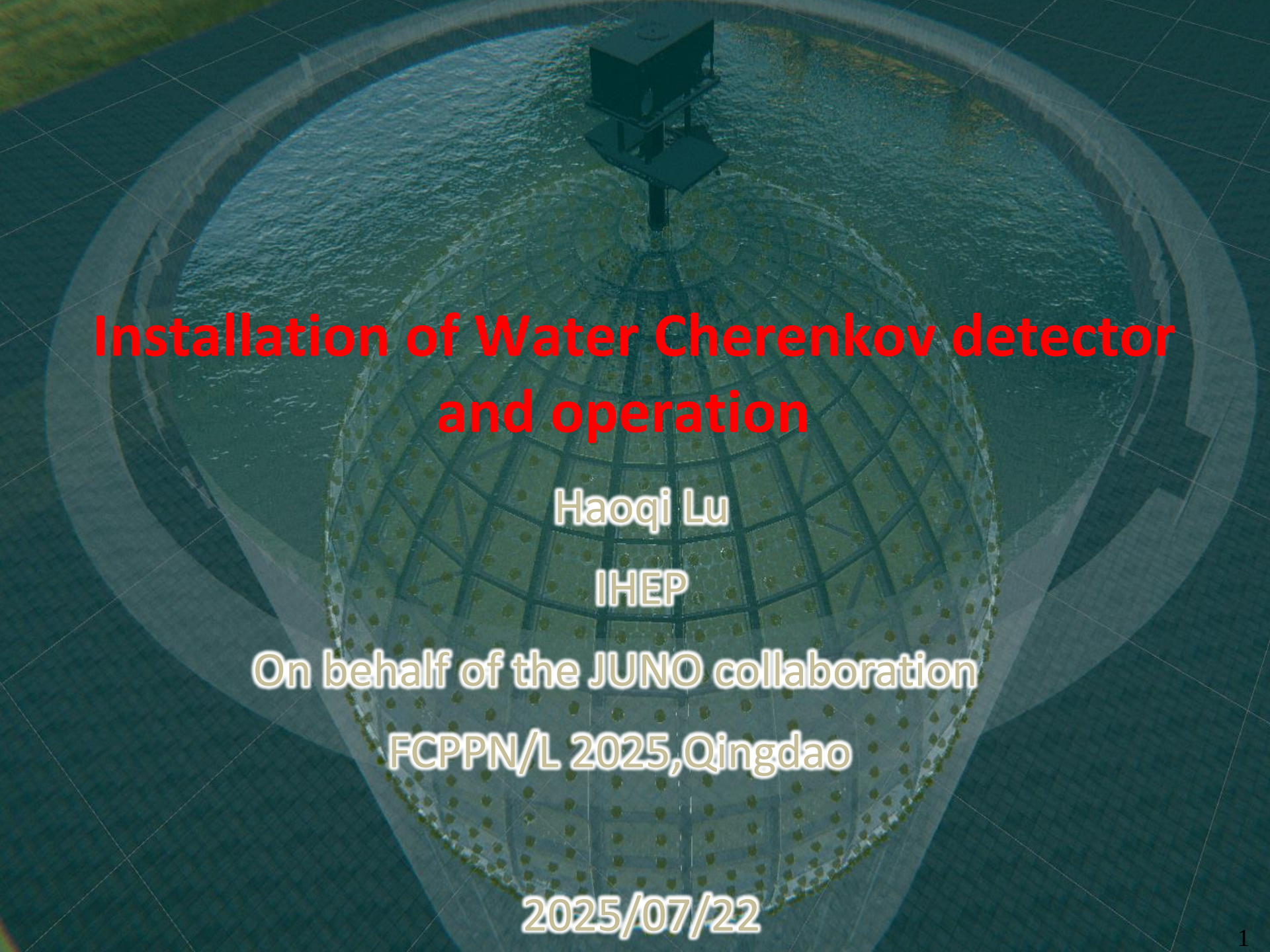


Installation of Water Cherenkov detector and operation

Haoqi Lu

IHEP

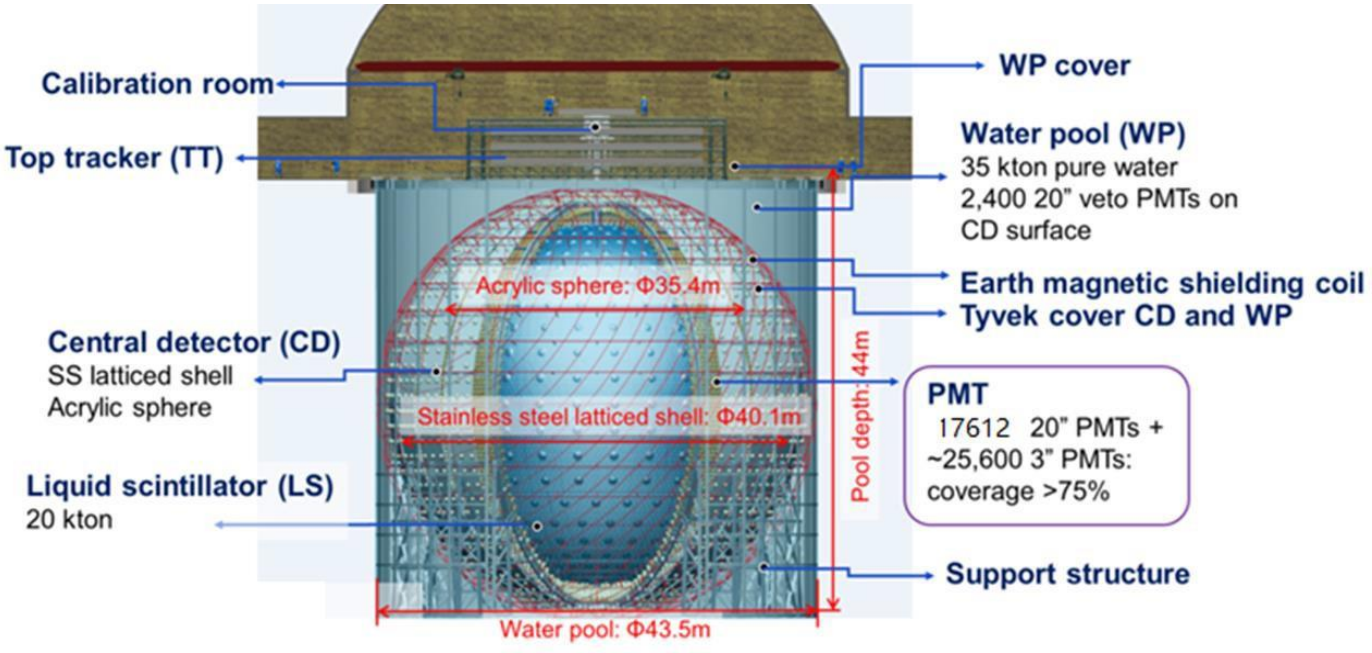
On behalf of the JUNO collaboration

FCPPN/L 2025,Qingdao

2025/07/22

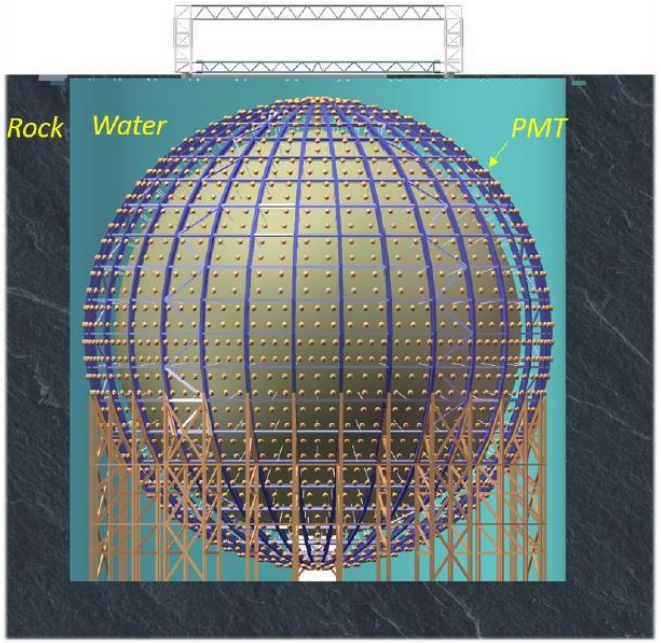
JUNO Detector overview

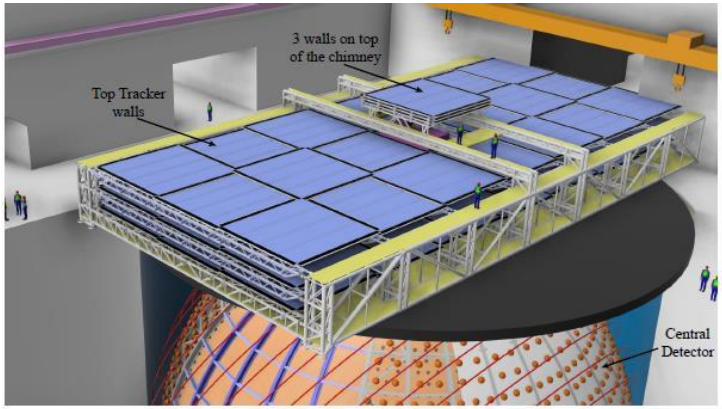
- **Central detector:**
  - Acrylic vessel with liquid scintillator
  - 17612 large PMTs (20-inch)
  - 25600 small PMTs (3-inch)
  - ~ 78% PMT coverage
  - PMTs in water buffer
- **Veto detector for cosmic muon detection and background reduction.**
  - **Water Cherenkov Detector :**
  - **Top Tracker**



The veto system

- **Water Cherenkov Veto:**
  - Muon event tagging.
    - Outer of the detector;
    - 35 kton ultrapure water as medium;
    - Fast neutrons background rejection
      - Muon tagging+ passive shielding;
  - Radioactivity from rock
    - Passive shielding by water
  - **Compensation coils:**
    - Compensates Earth's magnetic field (~0.45 Gs), which otherwise reduces PMT efficiency by ~60%.
    - Ensures uniform magnetic shielding;
  - **Tyvek reflector**: increase light collection for PMT
- **Top tracker(detail see JP's talk):**
  - On top of water pool, cover ½ of pool;
  - A precise muon track reconstruction;
  - Cosmogenic muon induced isotopes reduction (^{9}Li/^{8}He and other isotopes).





Challenging for detector

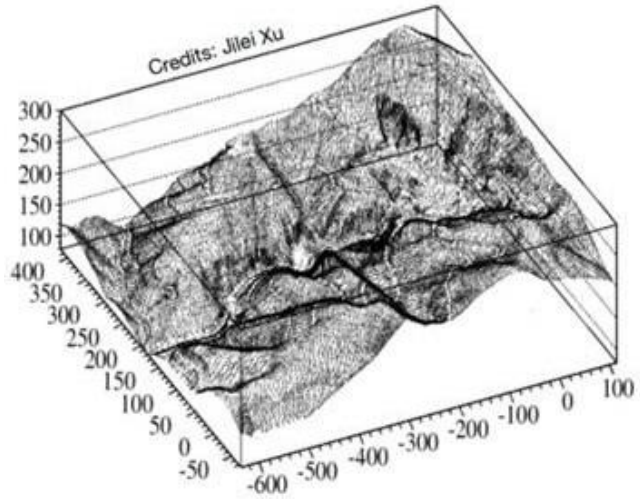
- Detector requirement
  - Large statistics
    - Large target mass;
    - Powerful nuclear power plants (NPPs)
  - Very good energy resolution
    - Very high PMT coverage + High transparency of LS+ High PMT efficiency
  - Cosmic muon induced background reduction
    - ~700 m rock overburden+ Veto system with >99% efficiency
  - Radioactivity background(reactor neutrinos, solar neutrinos)
    - Material background control + Installation procedure & clean environment control
  - Precise reference spectra of NPPs
    - Satellite detector → JUNO-TAO

Experiment	Daya Bay	Borexino	KamLAND	JUNO
Target mass [tons]	8 x 20	~300	~1,000	20,000
Photo electron[p.e./MeV]	~160	~500	~250	>1345
Energy resolution	~8.5%	~5%	~6%	~3%
Photocathode coverage	12%	34%	34%	~78%
Energy calibration uncertainty	0.5%	1%	2%	<1%

Cosmogenic background

- Cosmic muons
  - ~700m rock overburden;
- Muon related background
  - ^{9}Li/^{8}He unstable isotopes produced by muon spallation on ^{12}C and decay beta-neutron;
  - ~127 ^{9}Li+40 ^{8}He isotope/day(IBD signal ~60/day);
  - Untagged muon induced fast neutron background.
  - Reduce the background to low level:
    - Good veto detector are required;
  - With the current veto strategy, the muon-induced background
    - ^{9}Li+ ^{8}He ->0.8/day;
    - Fast neutron->0.1/day

Digitalized mountain profile of JUNO site

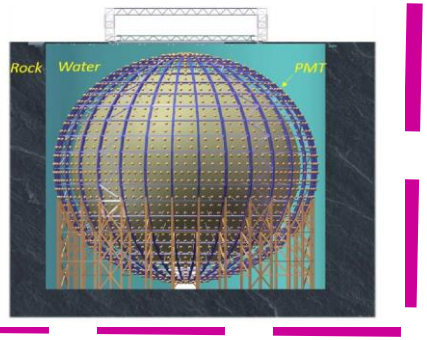


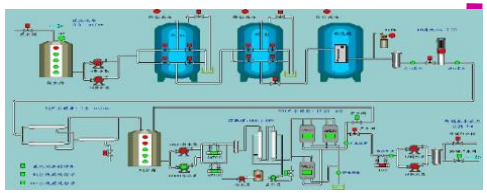
R_μ = 4 Hz in LS, $< E_\mu >$ = 207 GeV

Background	Rate (day^{-1})
Geoneutrinos	1.2
World reactors	1.0
Accidentals	0.8
^{9}Li/^{8}He	0.8
Atmospheric neutrinos	0.16
Fast neutrons	0.1
^{13}C(α,n)^{16}O	0.05

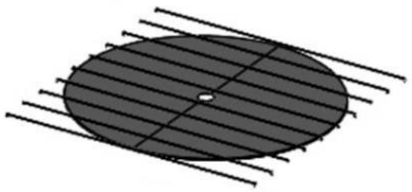
Water veto sub-systems/components

- **Sub-systems/components**
  - **PMTs**:2400 20-inch PMTs
  - **EMF coils**: shielding the detector to ensure the 20 inch PMT performance
  - **Water system**: 100 t/h water system
  - **Pool lining**: covering the pool wall as Rn barrier
  - **Tyvek reflector**: increase light collection for PMT
  - **Cover**: light/gas tight cover for the detector
  - **Support structure**

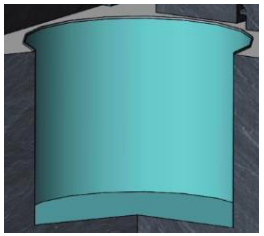




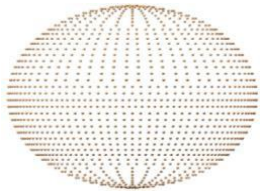
Pure water system, flow rate: ~100t/h



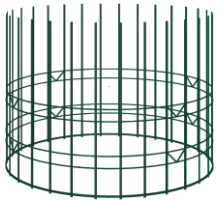
Cover & rail



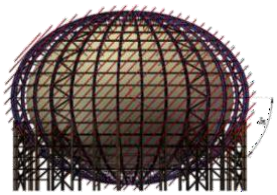
Pool liner



PMTs & Tyvek reflection film



Bird cage &Tyvek reflection film



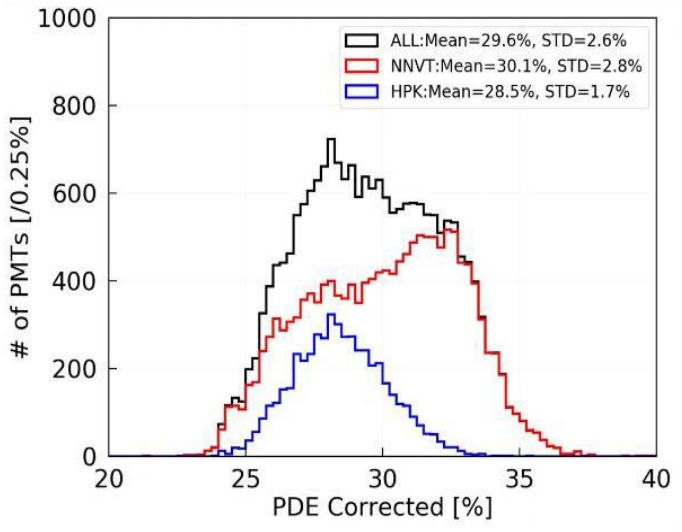
EMF coils

PMTs

- Three types of PMTs used in JUNO
  - Central detector
    - 17612 large PMTs (20-inch)
      - 12612 MCP-PMTs from NNVT
      - 5000 dynode PMTs from Hamamatsu
    - 25600 small PMTs (3-inch) from HZC
  - **Water veto**
    - **2400 MCP-PMTs from NNVT**

- 20012 20-inch PMTs (17612 CD + 2400 veto)

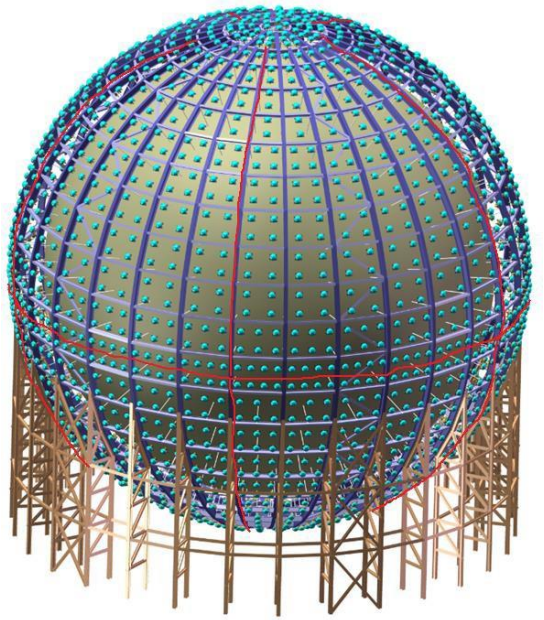
Photon Detection Efficiency



PMT placement in water veto

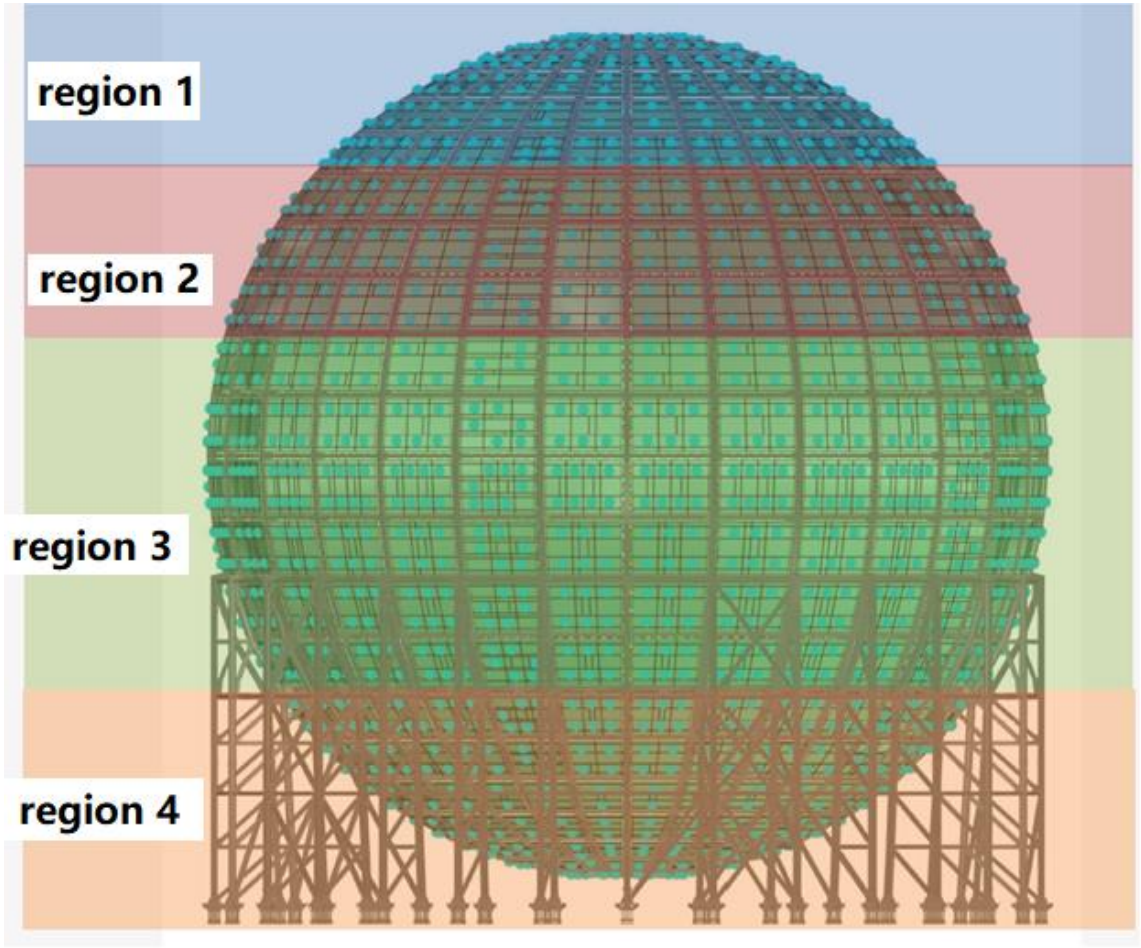
- **Optimized PMT placement**
- Original design had some PMTs in wall/floor pointing inwards;
  - In this case, PMTs facing muon exiting CD in lower part of detector
  - Positions are too close to the compensation coils/outside the coils;
    - effected by the magnetic field by the EMF coil;
- Move PMTs on the sphere of the stainless
  - PMTs put on the surface of the sphere and facing outside to get better performance.

- Trigger & efficiency
  - Divide the detector into 10 pieces for local trigger;
  - Detector efficiency is expected to reach >99.0%.
- Fast neutron background
  - With the high muon tagging efficiency, the fast neutron background is anticipated to be <0.1/day.

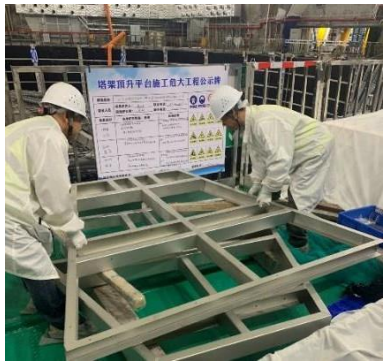


Detector installation

Total 4 regions for the whole detector installation



Veto PMT/electronics installation(region 1, 2)



Veto module structure

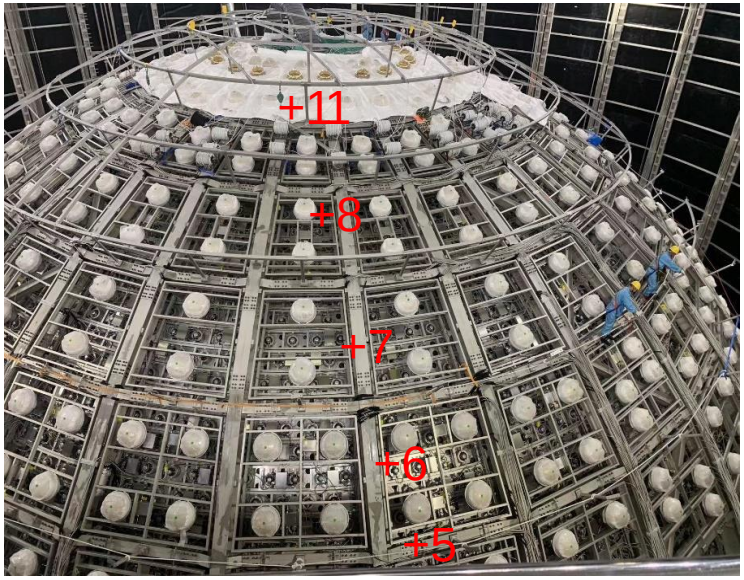
Install PMT/electronics box

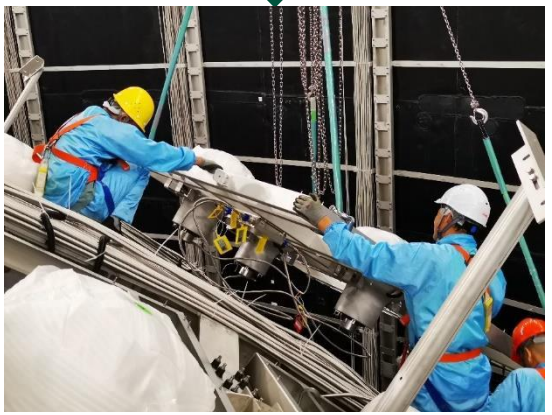
Veto module assemble

Lifting

Top half detector installation；

- PMT/module assemble in Exp. Hall.
- The module is mainly lifted by crane.



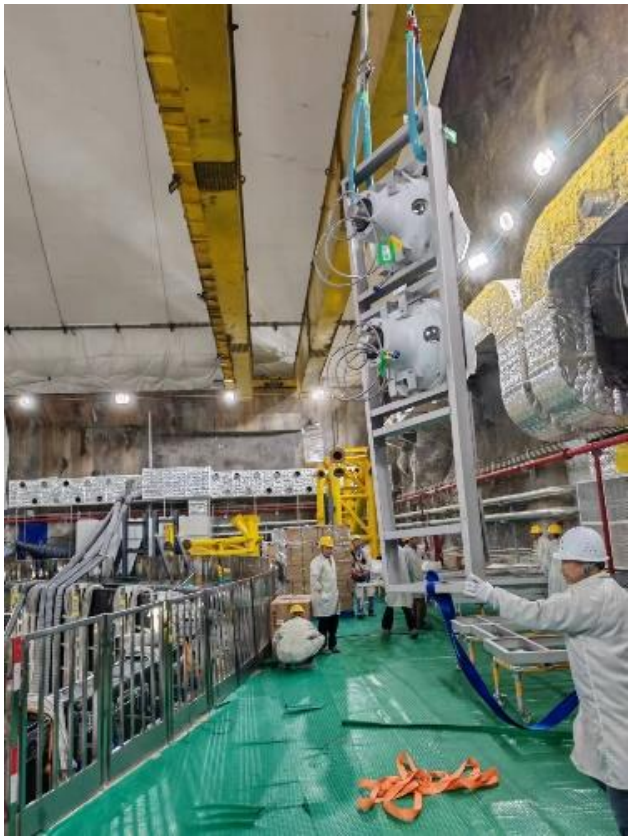


Module fixation

PMT module Installation(region 3)

- Lower hemisphere -3, -4(S3,S4) layer installation;
- Difficulty in installing slanted support window;
  - Large window changed to 2 small windows;
  - Small window PMT first, large window module, and then PMT installed.

S3,S4(installation)

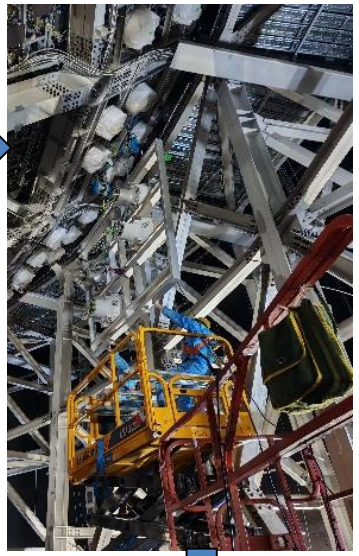


The bottom half sphere installation(region 4)

Module

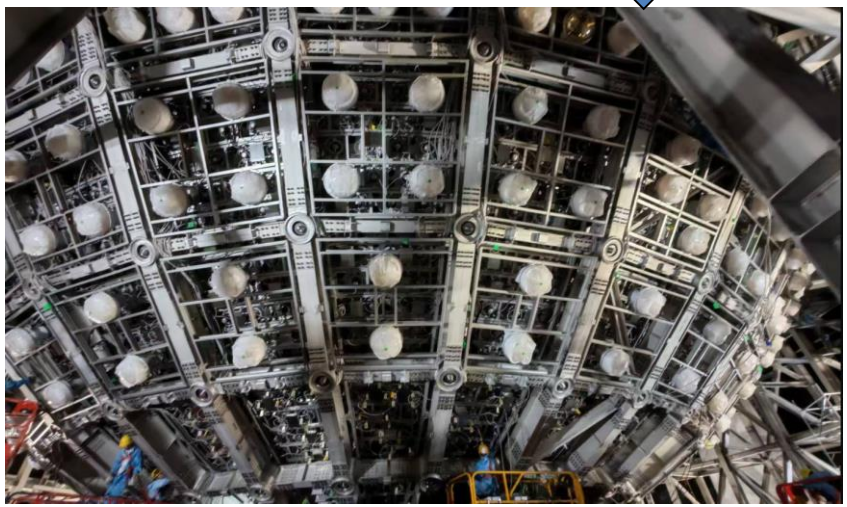
Install PMTs

S5-S11 installation



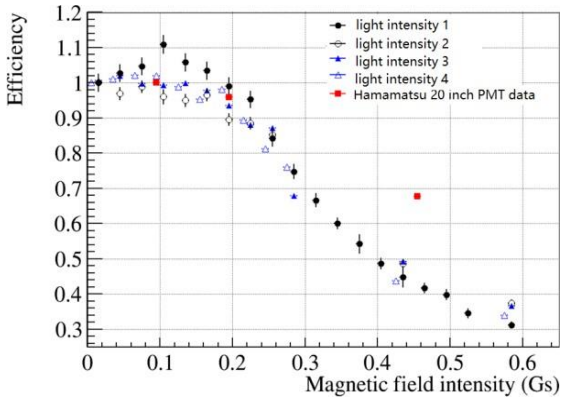
- Lower Hemisphere-5 -11 vetoPMT/Module installation:
- Initial Installation Options Scaffolding solution:
  - time consuming, inefficient installation.
- Final solution:
- Lift truck + winch :
  - Speed boosted installation of 20 modules/shift;
  - greatly improving installation efficiency and completing the task on time.

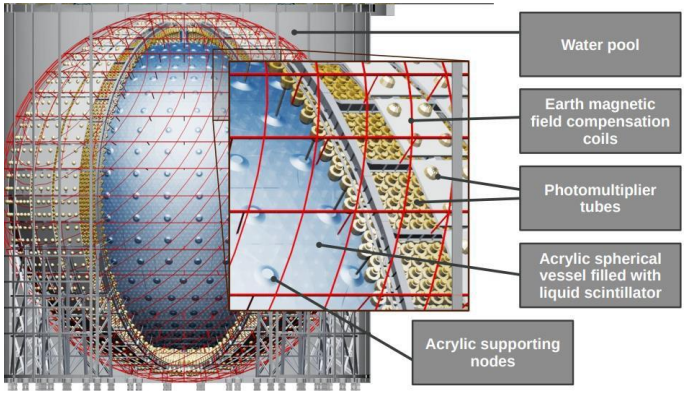
Fixed on the SS frame



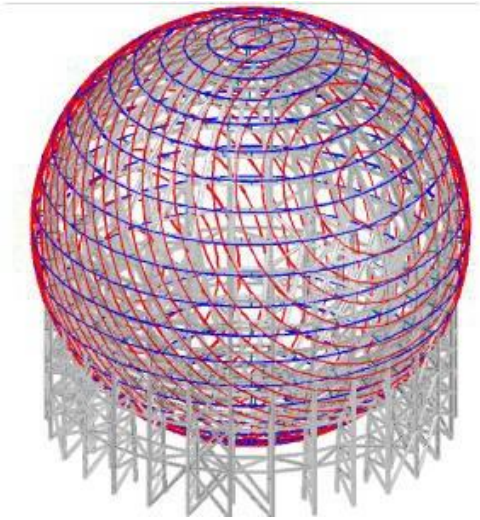
Compensation coils system

- Earth Magnetic Field(EMF) intensity at JUNO site
  - Intensity ~0.45Gs
    - Big negative effect on the 20 inch PMT performance;
  - Need a shielding system for compensation EMF.

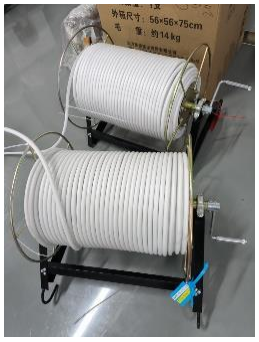




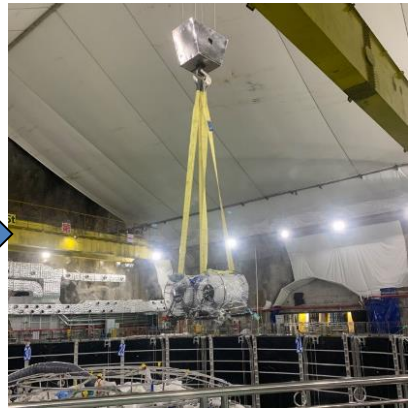
- **Use one set of coils to generate the opposite direction of the geomagnetic field to compensate it.**
  - **32 coils scheme;**
  - **Coils's uniformity in CD~0.05G.**
- EMF direction change effect
  - The EMF direction change every year(<0.2deg/y).
  - Set a compensation angle when the coils are installed.
  - Make the angle change < 1 degree within 10 years.



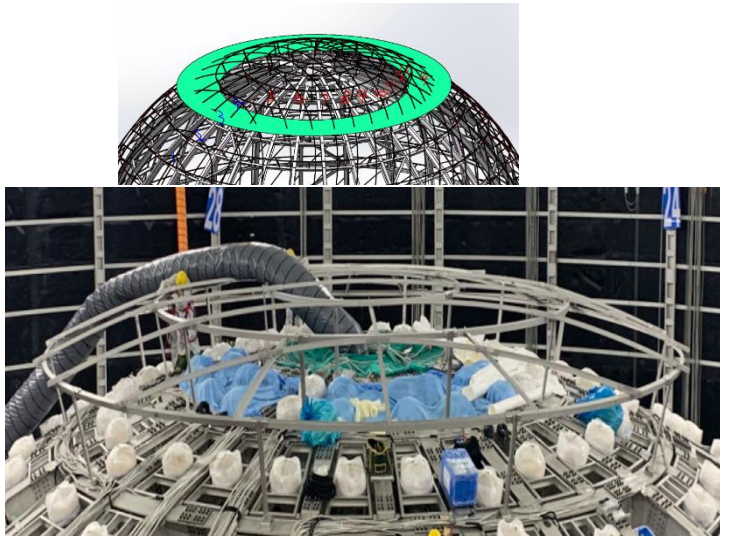
EMF shield coils installation(I)



Cable winding in SAB clean room



Lifting for installation



EMF coils support structure installation

Coils fixation and spool placement

- **EMF coils installation**
  - Winding coils is done in the SAB clean room, the length of the wire is numbered, and resistance is tested;
  - Lifts spools of cable by crane for installation.

EMF shield coils installation(II)

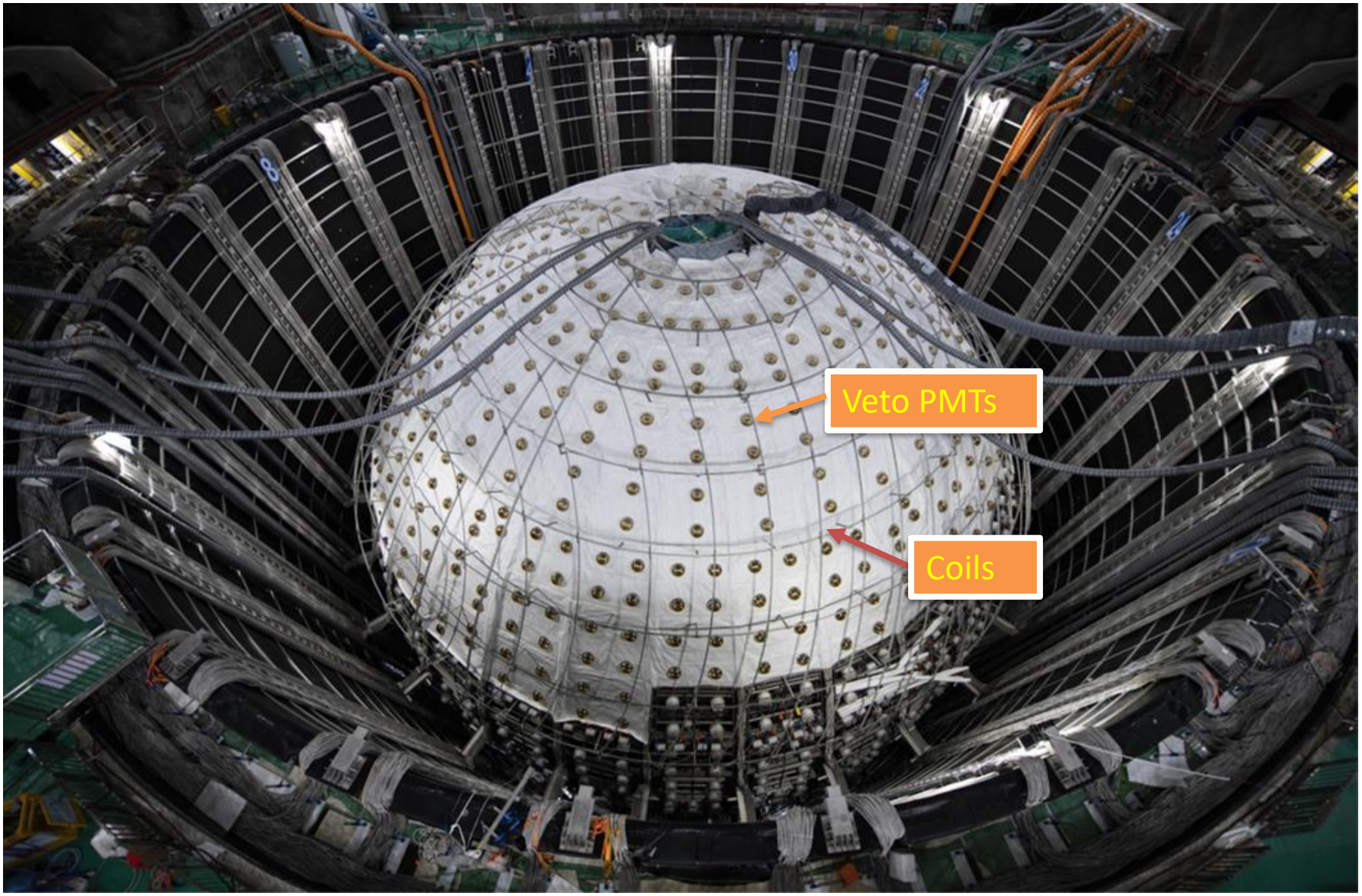
- **EMF coils and support structure installation：**
  - Top half sphere EMF colis structure installation and coil installation.
  - Mainly depend on crane;

  - Bottom half sphere EMF colis structure/coils installation and coil installation.
    - More difficult with no crane;

Put the coils on the right coils structure position

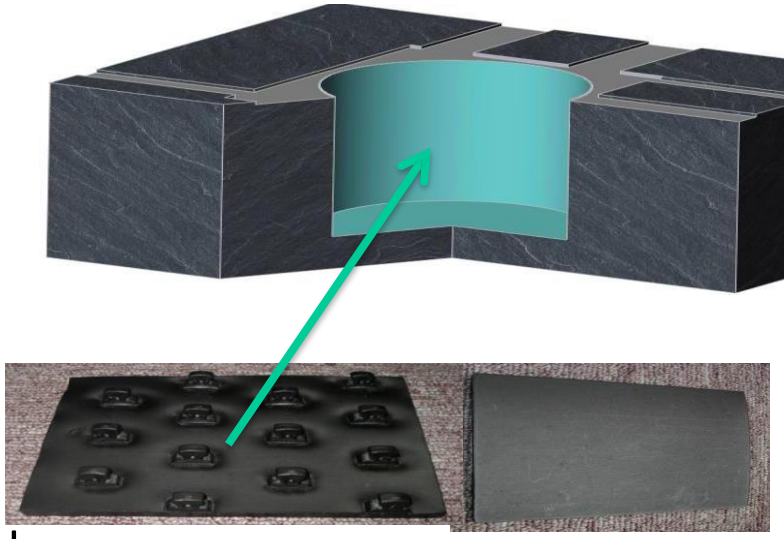
Fixed to the structure

Final installation finished.

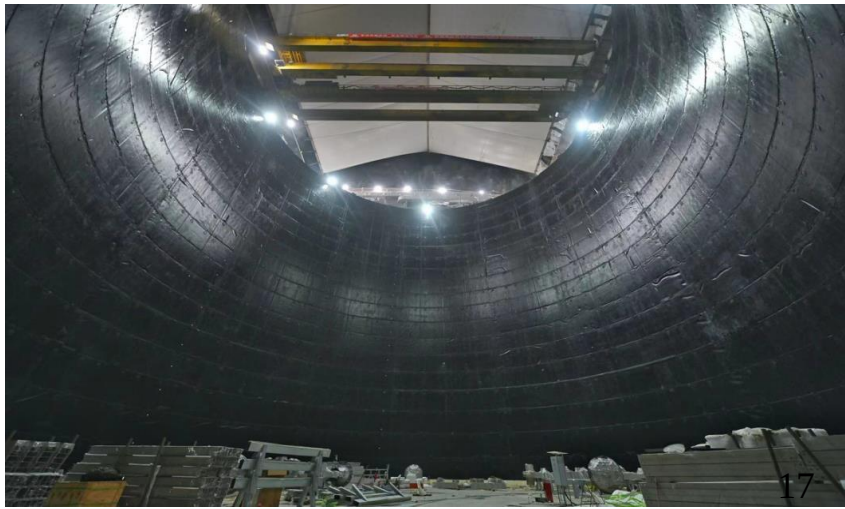

Veto PMTs
Coils

Pool lining

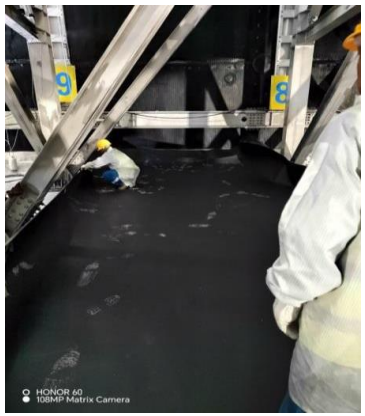
- **High Density Polyethylene (HDPE)**
  - To separate pure water from the rock
  - To prevent rock radon from diffusing into the pool.
  - Two kinds of HDPE plate, with and without nails.
    - Thickness 5 mm.
  - The side wall lining installation is combine with civil wall construction.
  - The bottom HDPE film is installed at last stage.



- Dimension:43.5 m diameter*44m height;
- >6000 m^2 lining.



Pool bottom HDPE lining installation



Spread the HDPE

Fixed on injection ring

Welding on the wall

Welding

Cleaning

Leakage detection

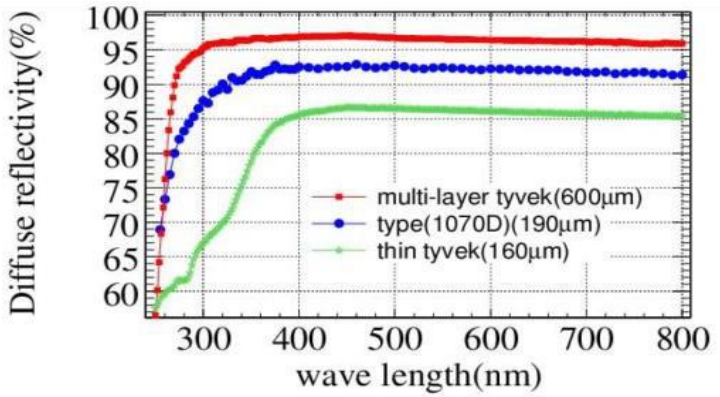
Tyvek reflector

Tyvek reflection film

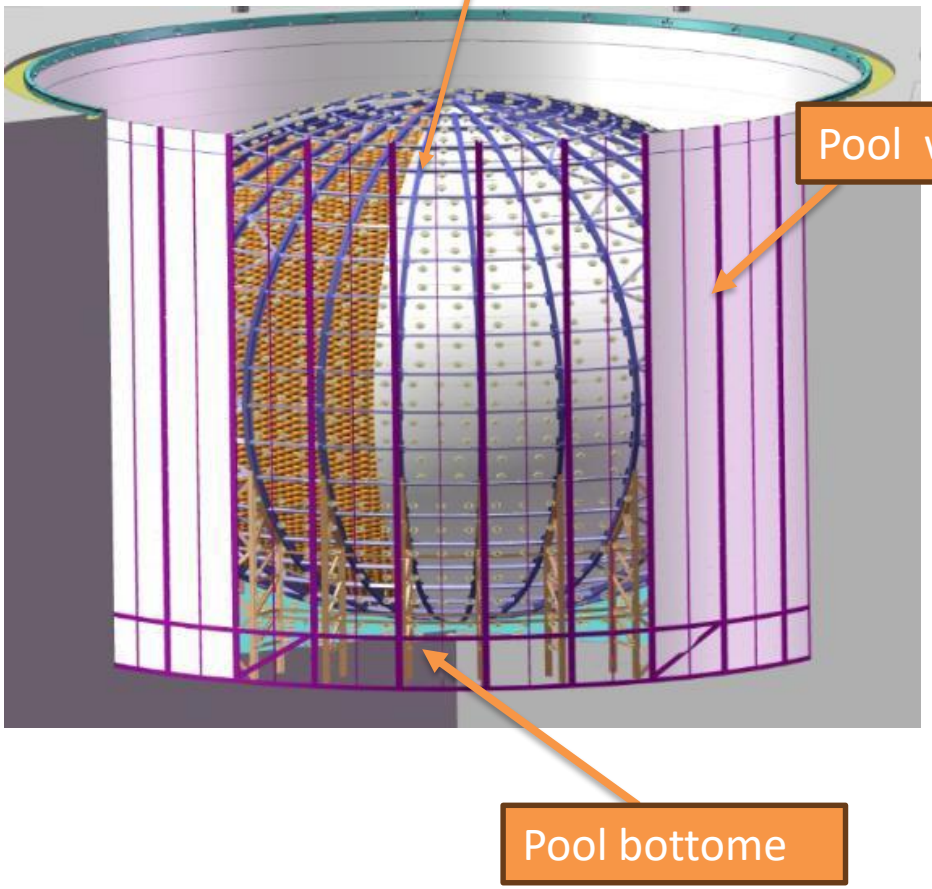
To be installed on

- Surface of the SS latticed shell;
- Pool wall, bottom;
- Cover the whole inner surface of the pool to improve light collection.

Tyevk Reflectivity



Reflectivity larger than 95% for wavelengths > 300nm

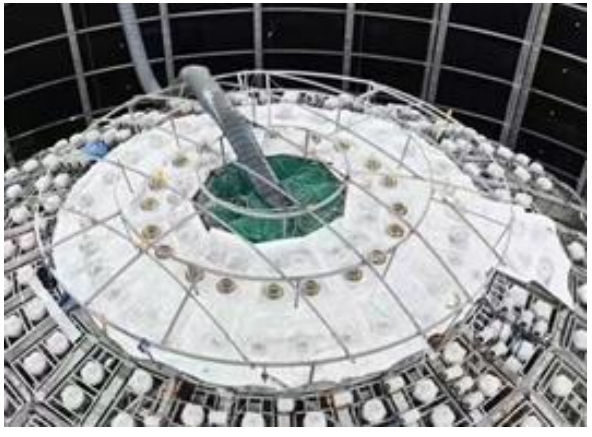


Tyvek installation

- **CD SS structure surface Tyvek installation**
  - Installed Tyvek window by window;
  - The size is to fit the veto PMT module.

Tyvek

Welding

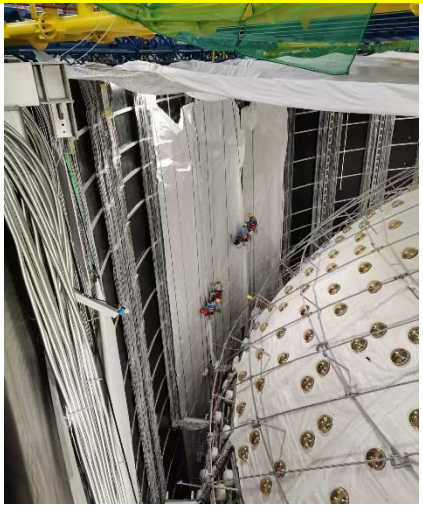


Installation

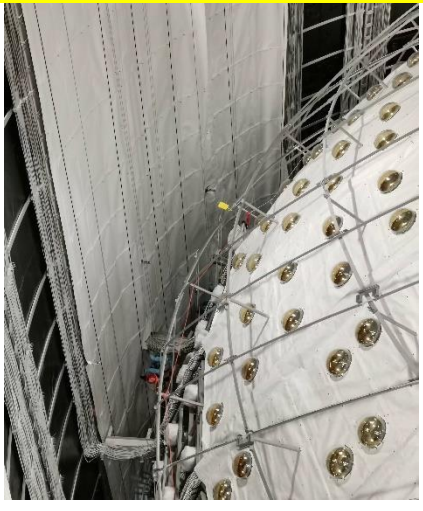
Pool wall Tyvek installation

Put a Tyvek roll by the wall

Unroll the Tyvek along the wall

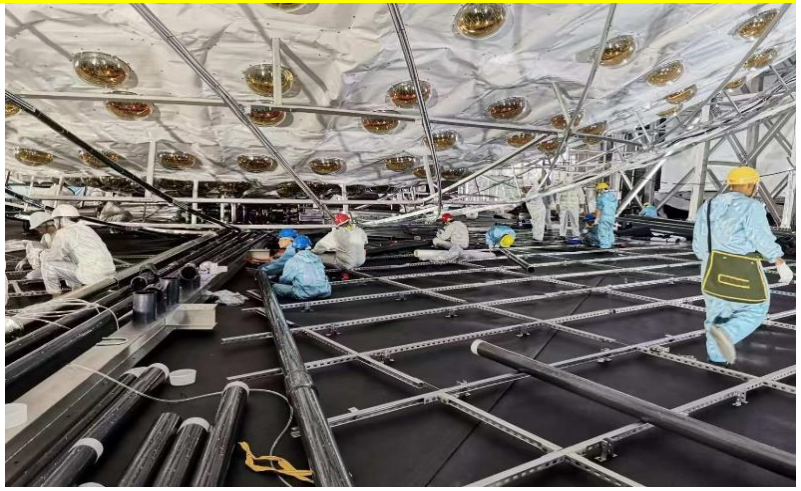


Fixing the Tyvek on the birdcage structure



Pool bottom Tyvek installation

Assembling the Unistrut support structure



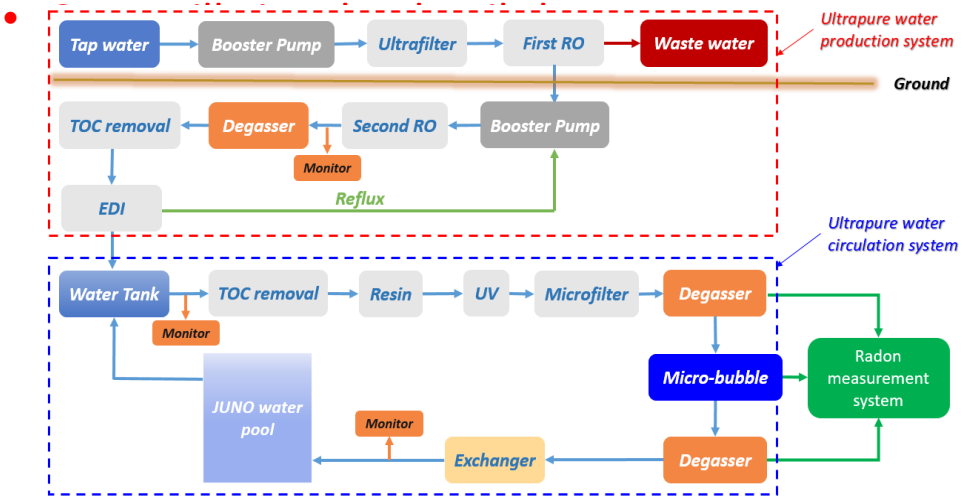
Laying the Tyvek films

Bottom Tyvek emerged in the water

The final installed

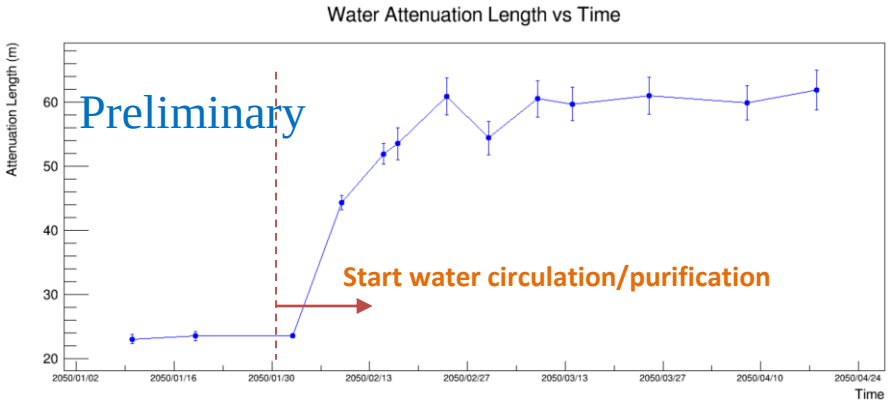
The ultrapure water production and circulation system

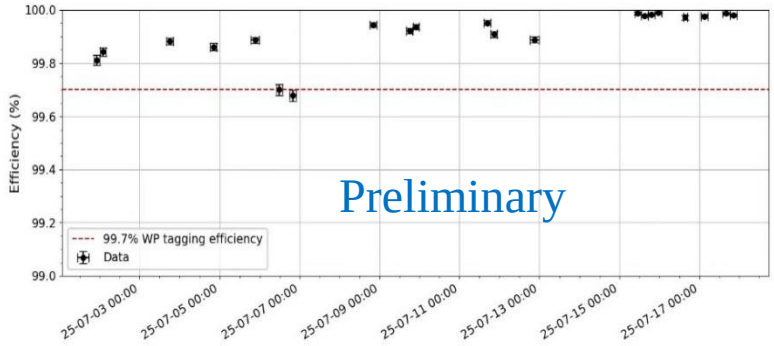
- **Water system**
  - Keep water quality with good transparency for detector performance
  - Flow rate: ~100 t/hour
  - Ground system:
    - Water production
  - Underground system:
    - Purification and circulation;
  - Connection ground and underground system by 1300 m stainless steel pipe in slope tunnel
  - Water circulation
    - 2-3 weeks one volume.



Detector operation and performance

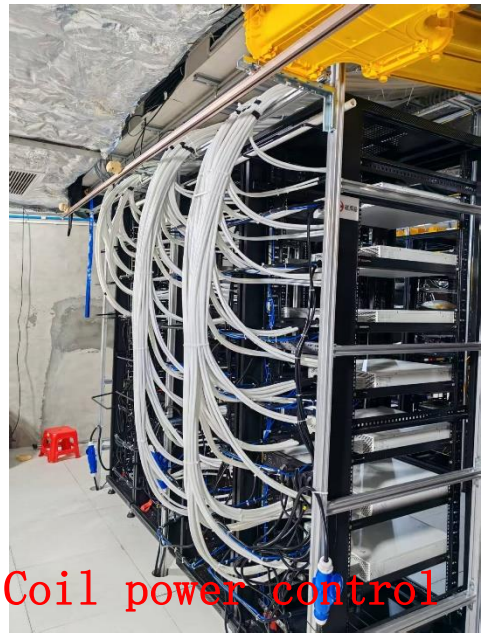
- Dec.18,2024,whole detector installation finished and detector start filling.
- Feb. 2025, the pool is full and start LS/water change and LS filing in CD.
- Water Cherenkov detector start commission and operation and tuning.
  - Threshold tunning, trigger rate, PMT HV, trigger window scan…

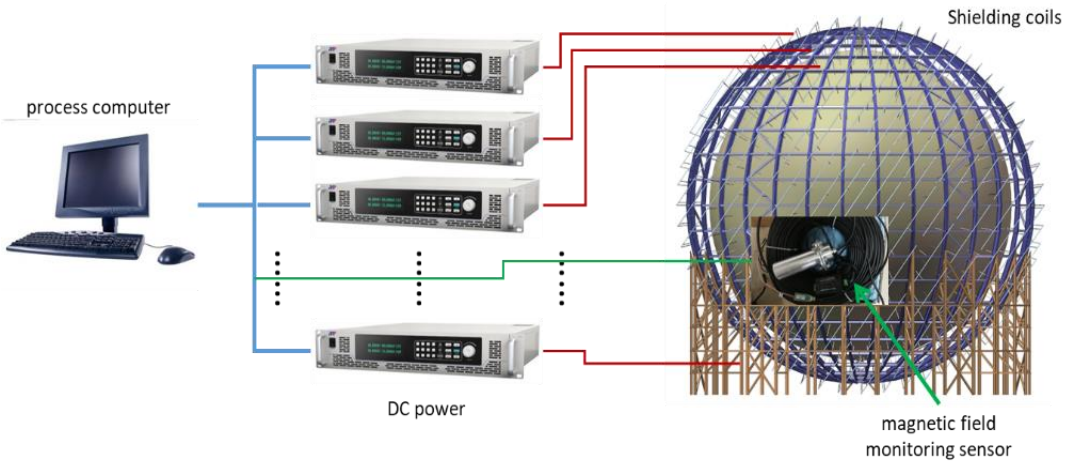


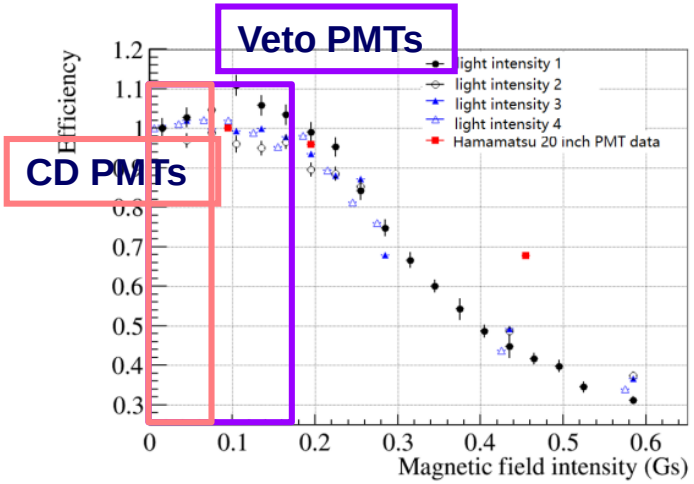


- The water attenuation length now can reach 60m;
  - Target 40m, better than anticipation.
- For CD muon detection efficiency >99.5%
- Now the detector is still under commissioning, we try to improve the WCD performance at the best condition.

Veto EMF shielding coils performance







- 32 set of EMF coils, highly effective for 20” PMT detection efficiency increase
  - Residual EMF for CD PMT: max. < 0.1 Gauss (average ~0.05 Gauss); same as anticipation.
  - Residual EMF for Veto PMT: max. < 0.2 Gauss (average ~0.1 Gauss) ; same as anticipation.

Summary

- JUNO will measure neutrino mass ordering, and a rich physics potential with supernova neutrinos, geo-neutrinos, solar neutrinos,atmospheric neutrinos and other oscillation physics such as searches for proton decay, etc.
- JUNO water Cherenkov detector is designed for muon detection and background reduction.
  - The detector assembly/installation is finished.
  - Now the detector is under commissioning and tunning.
  - The preliminary results shows that the water Cherenkov has good performance.

Thanks!