The Water Cherenkov Detector of JUNO

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(On Behalf of the JUNO Collaboration)

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List of members

= 74 institutes

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Brazil	UEL	China	USTC	Italy	INFN di Frascati
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Chile	UNAB	China	Wuhan U.	Italy	INFN-Milano Bicocca
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China	CAGS	China	Zhengzhou U.	Italy	INFN-Roma 3
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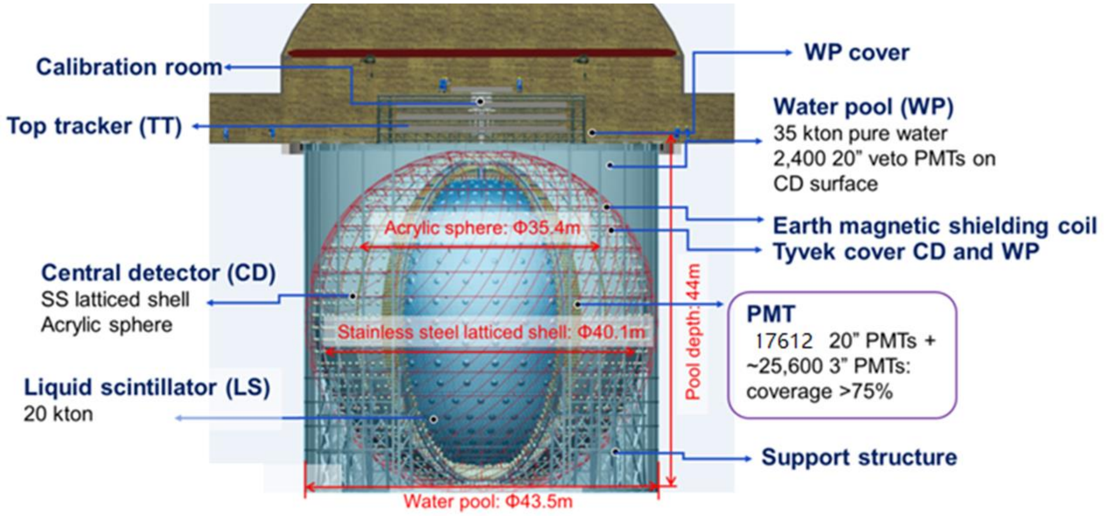
China	Shanghai JT U.	Germany	U. Hamburg	USA	UC Irvine
China	IGG-Beijing	Germany	FZJ-IKP		

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
- **Water Cherenkov Detector (veto):**
  - 2400 20-inch PMTs
  - 35 ktons ultra-pure water
- **Compensation coils:**
  - Resident earth magnetic field <0.05Gs
  - Necessary for 20” PMTs
- **Top Tracker (veto):**
  - 3 plastic scintillator layers
  - Covering half of the top of the water pool
  - Precision muon tracking



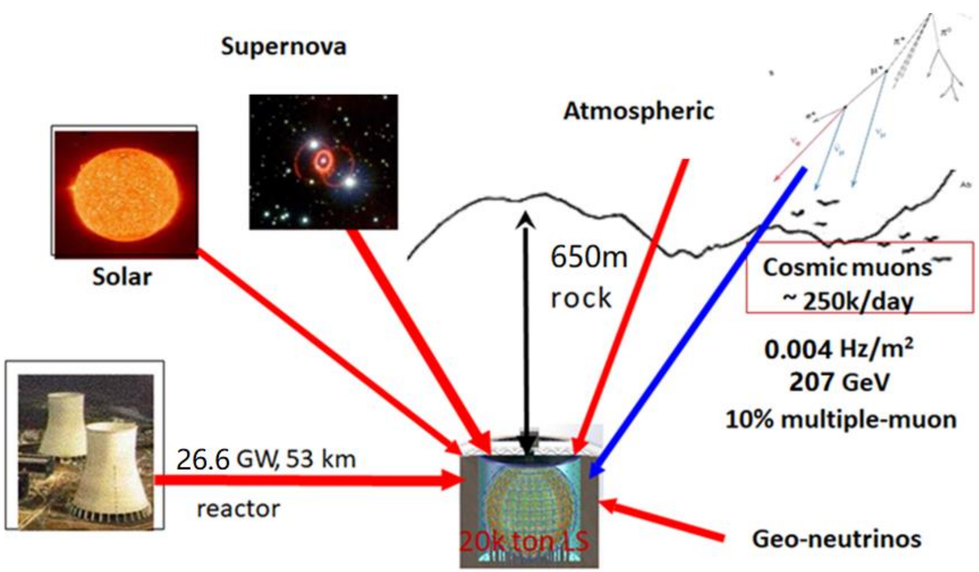
Challenging detector

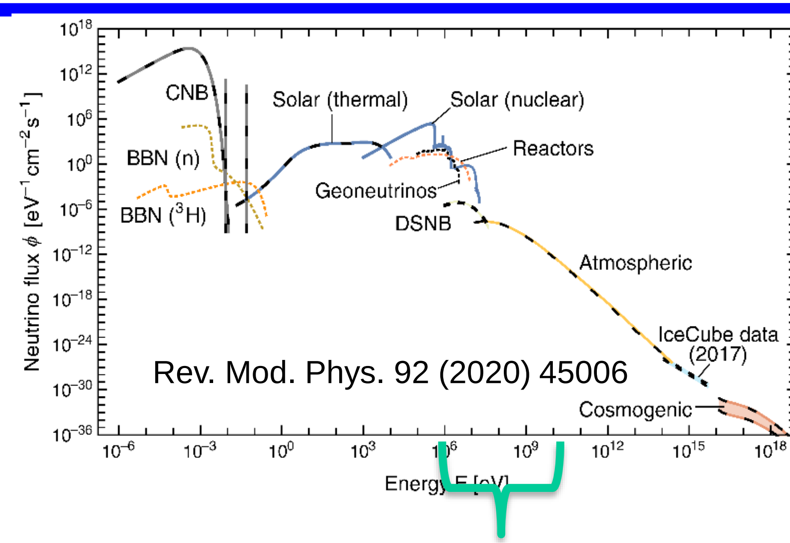
- Detector requirement
  - Large statistics
    - Large target mass;
    - Powerful nuclear power plants (NPPs)
  - Very good energy resolution
    - Very high PMT coverage + High transparency of LS+ High PMT efficiency
  - Cosmic muon induced background reduction
    - ~650 m rock overburden+ Veto system with >99.5% 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%

JUNO physics

A multi-purpose observatory





JUNO: *from~MeV to tens of GeV*

Research	Expected signal	Energy region	Major backgrounds
Reactor antineutrino	60 IBDs/day	0–12 MeV	Radioactivity, cosmic muon
Supernova burst	5000 IBDs at 10 kpc	0–80 MeV	Negligible
	2300 elastic scattering		
DSNB (w/o PSD)	2–4 IBDs/year	10–40 MeV	Atmospheric ν
Solar neutrino	hundreds per year for ^{8}B	0–16 MeV	Radioactivity
Atmospheric neutrino	hundreds per year	0.1–100 GeV	Negligible
Geoneutrino	$\sim$ 400 per year	0–3 MeV	Reactor ν

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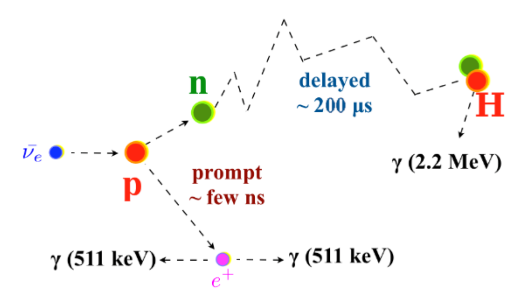
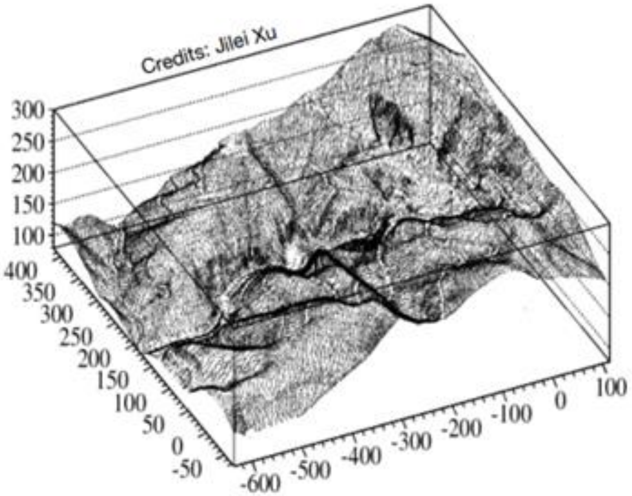
- **Inverse Beta Decay reaction(IBD)**

$\bar{\nu} + p \to n + e^+$ E_ν>1.8 MeV



Cosmogenic background

Digitalized mountain profile of JUNO site



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

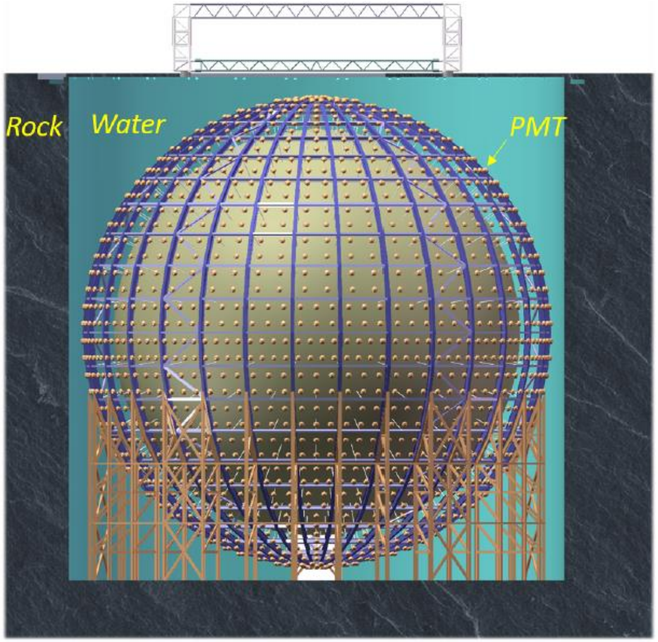
- Cosmic muons
  - ~650m rock overburden(1800 m.w.e);
- **Muon related background**
  - $^{9}Li/^{8}He$ unstable isotopes produced by muon spallation on ^{12}C and decay beta-neutron;
  - ~127 ^{9}Li+40 ^{8}He isotope/day(IBD signal ~60/day);
  - Untagged muon induced fast neutron background.
  - Reduce the background to low level:
    - Good veto detector are required;
  - **With current veto strategy, muon induced background**
    - ^{9}Li+ ^{8}He ->0.8/day;
    - Fast neutron->0.1/day

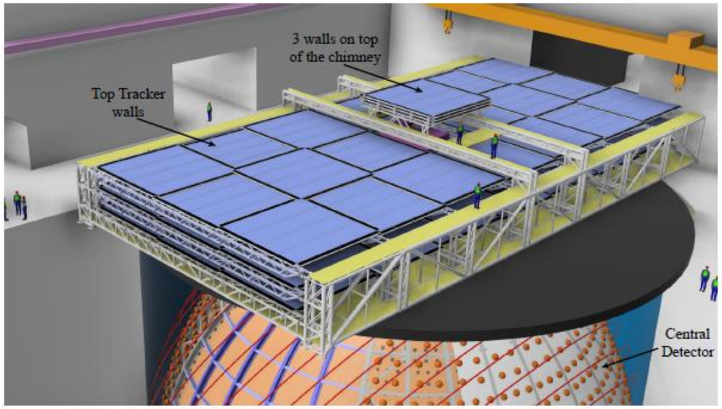
Background	Rate (day^{-1})
Geoneutrinos	1.2
World reactors	1.0
Accidentals	0.8
$^{9}Li/^{8}He$	0.8
Atmospheric neutrinos	0.16
Fast neutrons	0.1
$^{13}C(\alpha,n)^{16}O$	0.05

The veto system

Two veto detectors for cosmic muon detection and background reduction.

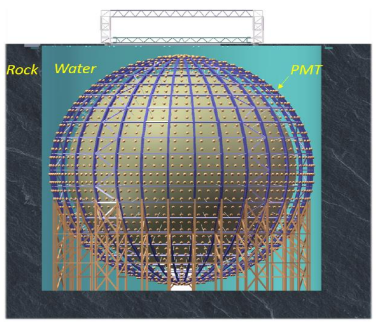
- **Water Cherenkov Veto:**
  - Muon event tagging.
    - Outer of the detector;
    - 35 kton ultrapure water as medium;
    - Fast neutrons background rejection
      - Muon tagging+ passive shielding;
  - Radioactivity from rock
    - Passive shielding by water
- **Top tracker:**
  - On top of water pool, cover ½ of pool;
  - A precise muon track reconstruction;
  - Cosmogenic muon induced isotopes reduction (^{9}Li/^{8}He and other isotopes).

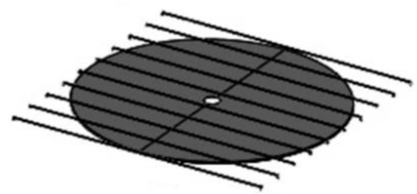




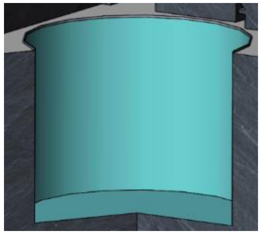
Water veto sub-systems/components

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

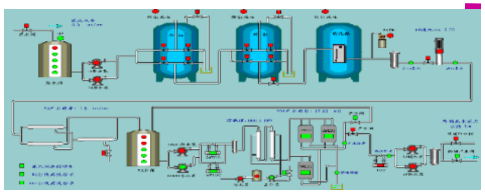




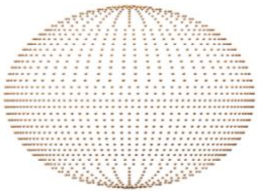
Cover & rail



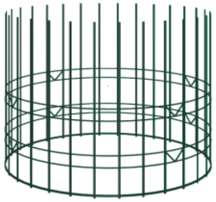
Pool liner



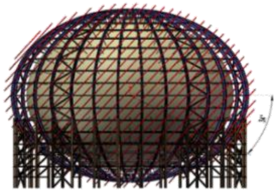
Pure water system, flow rate: ~100t/h



PMTs & Tyvek reflection film



Bird cage &Tyvek reflection film



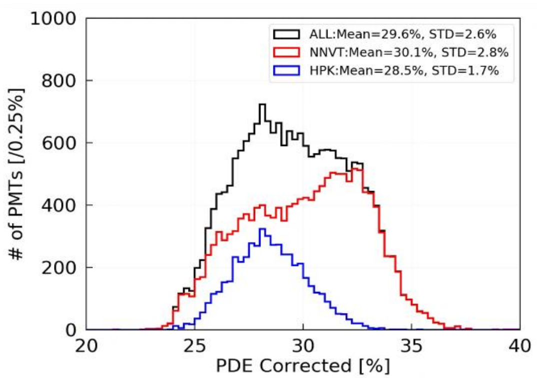
EMF coils

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**

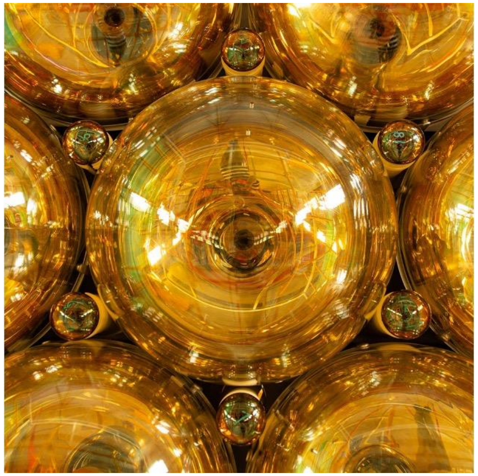
20012 20-inch PMTs (17612 CD + 2400 veto)

Photon Detection Efficiency



Acrylic cover

SS cover

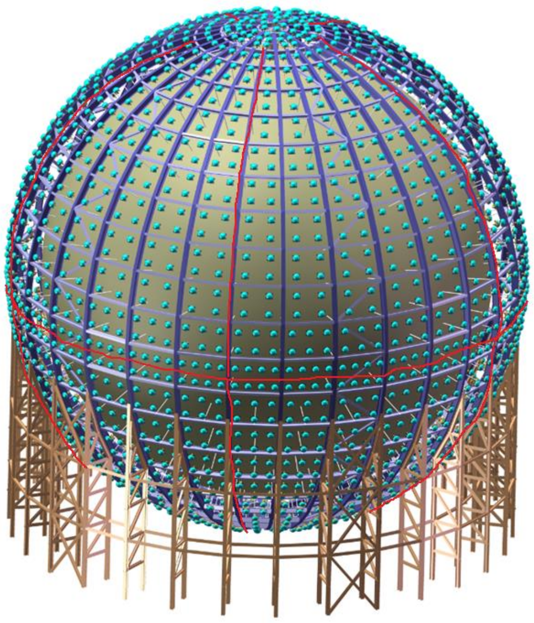


- All PMTs are produced, tested;
- ~1/3 of PMTs are transported on site for detector installation.

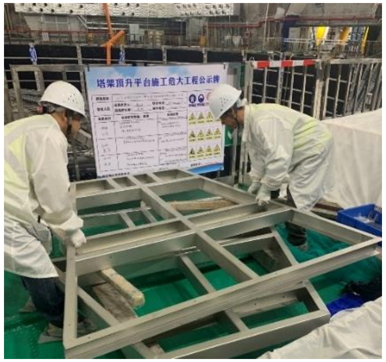
PMT placement in water veto

- 2400 20 inch MCP-PMT used for veto system;
    - PMTs put on the surface of the sphere and facing outside;
- 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;
  - The PMT will be affected by the magnetic field by the coils/EMF;
- Move PMTs on the sphere of the stainless frame to get better performance.

- Trigger & efficiency
  - Divide the detector into 10 pieces for local trigger;
  - Detector efficiency is expected to reach 99.5%.
- Fast neutron background
  - With the high muon tagging efficiency, the fast neutron background is anticipated to be <0.1/day.



Veto PMT/electronics installation

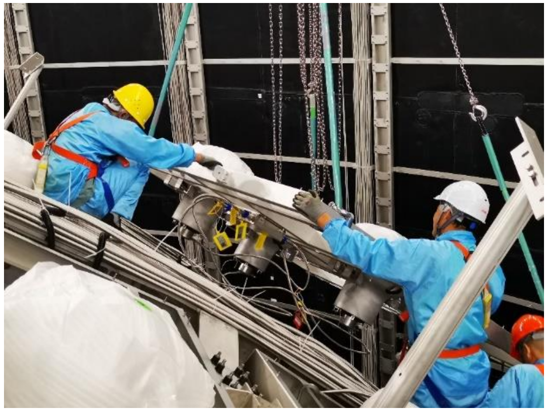


Veto module structure

Install PMT/electronics box

Veto module assemble

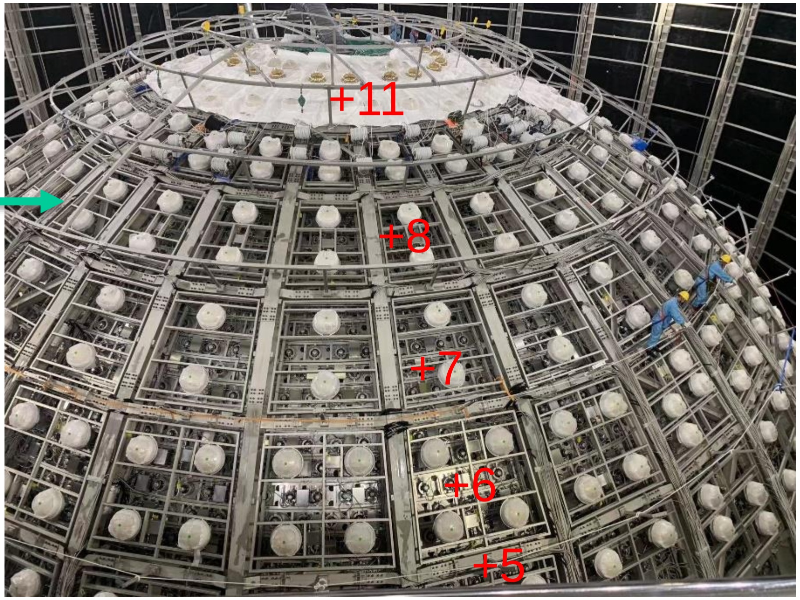
Lifting



Module fixation

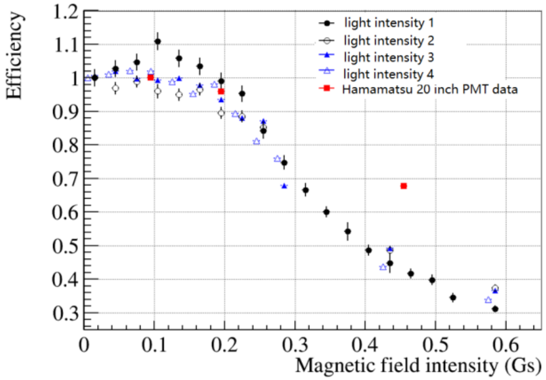
~500 veto PMTs installed

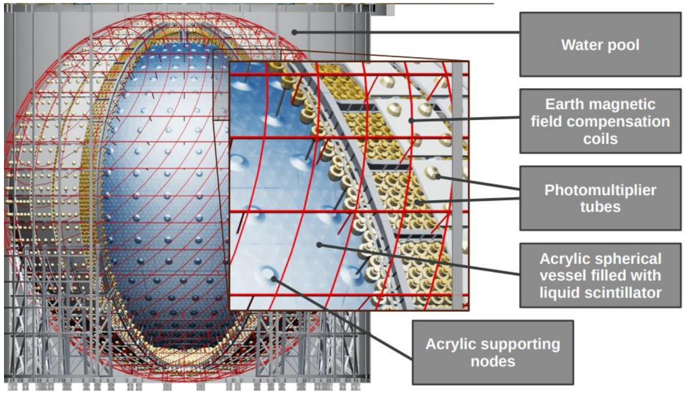
(~20% of PMT) ;



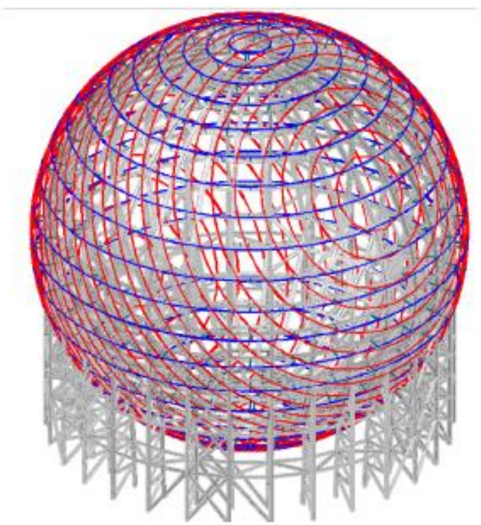
Compensation coils system

- **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.**



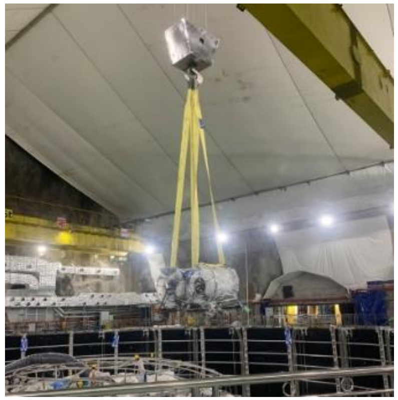


- **Use one set of coils to generate the opposite direction of the geomagnetic field to compensate it.**
  - **32 coils scheme;**
  - **Coils's uniformity in CD<0.05G.**
- EMF direction change effect
  - The EMF direction change every year(<0.2deg/y).
  - Set a compensation angle when the coils are installed.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

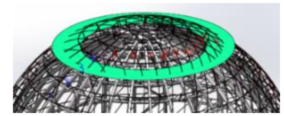


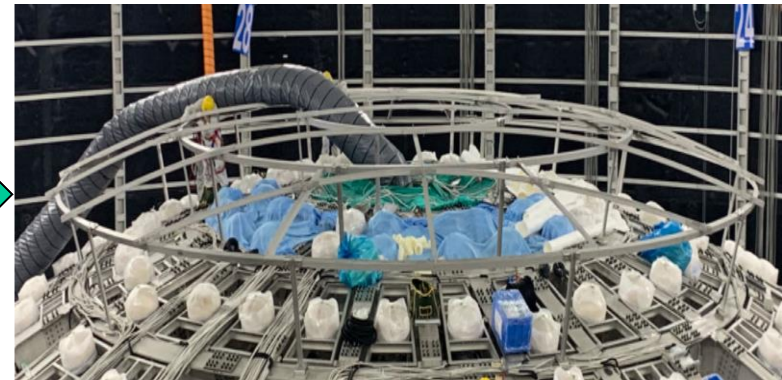
Compensation coils installation

coils



Lifting





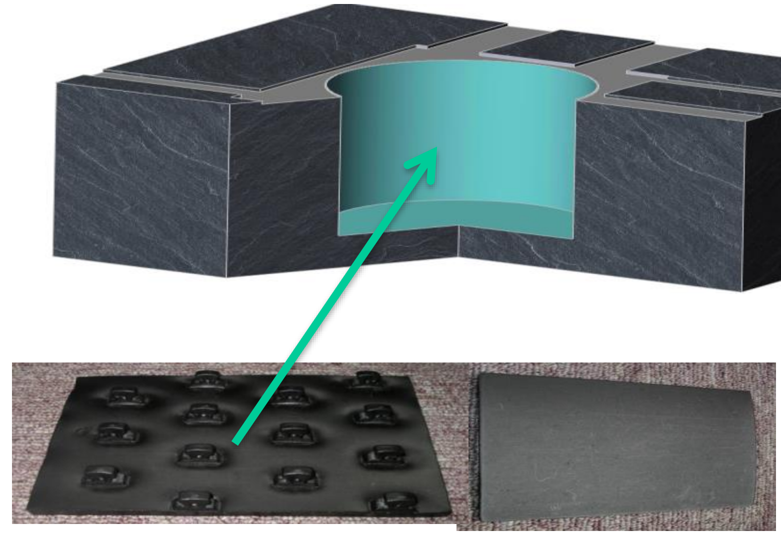
EMF coils support structure installation

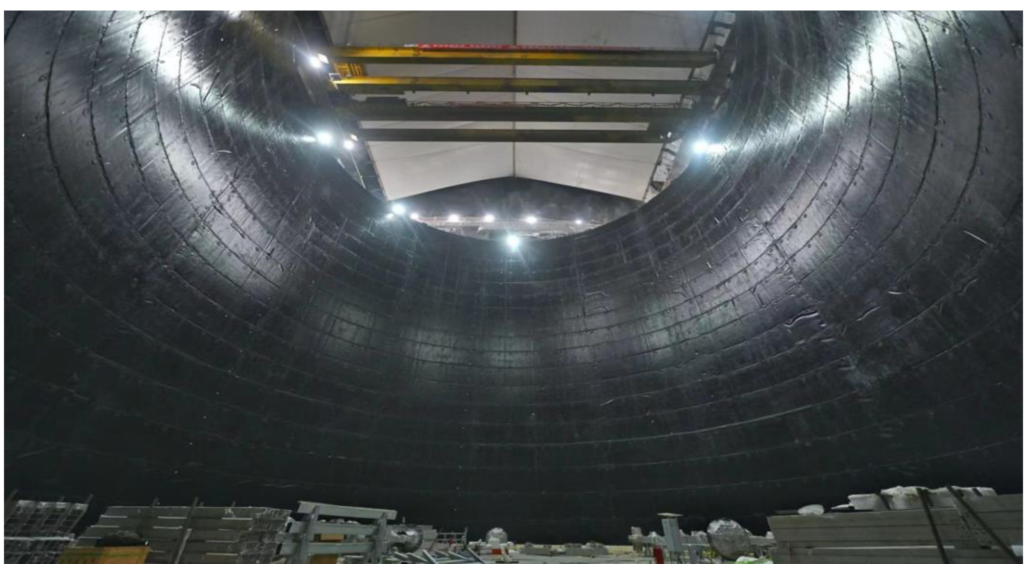
- **Earth magnetic compensation coils**
  - **7 coils installed (32 coils in total);**

Coils fixation and spool placement

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 was finished.





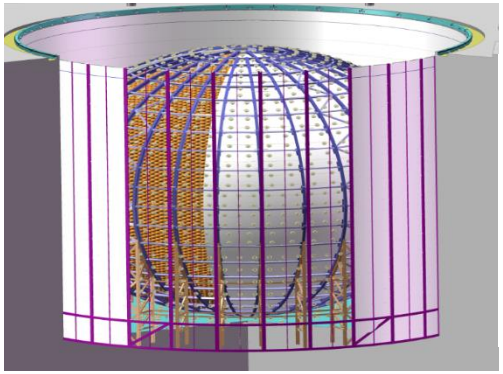
- Dimension:43.5 m diameter*44m height;
- >6000 m^2 lining.

Tyvek reflector

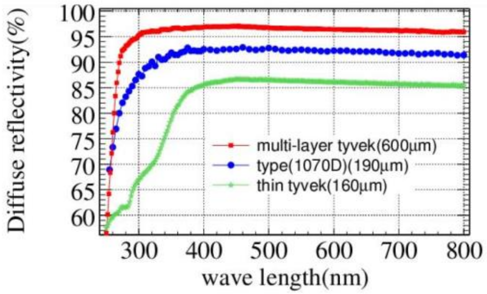
Tyvek reflection film

To be installed on

- Surface of the SS latticed shell;
- Pool wall, bottom and top;
- Cover the whole inner surface of the pool to improve light collection.
- Tyvek reflector production finished.
- **Tyvek installation started.**

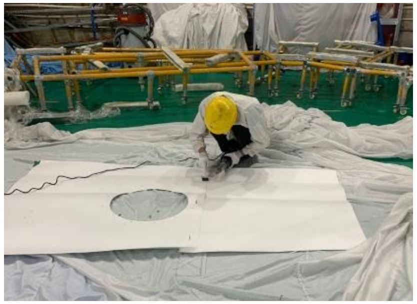


Tyevk Reflectivity

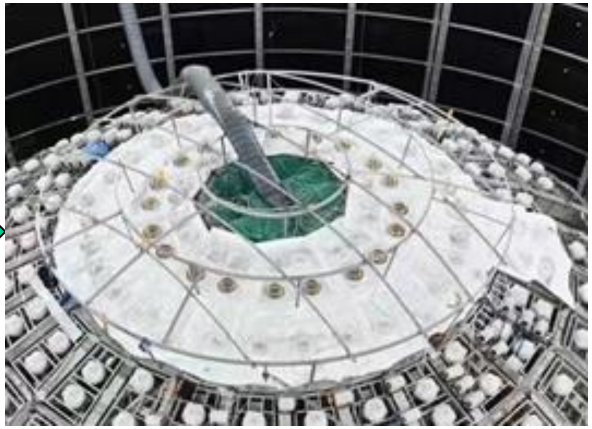


Reflectivity larger than 95% for wavelengths > 300nm

Tyvek



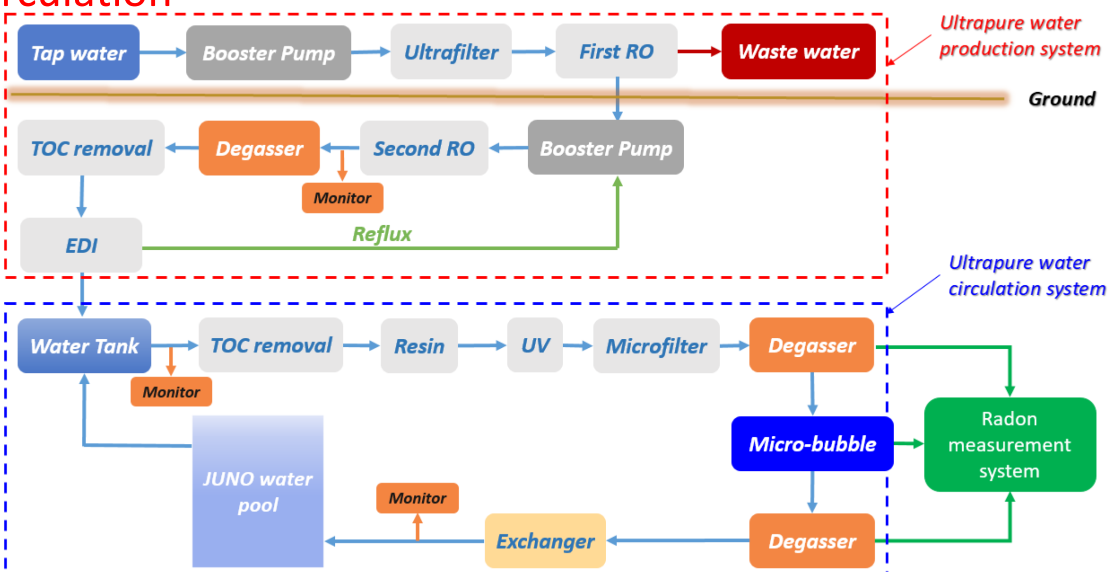
Welding



Installation

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



Water system status

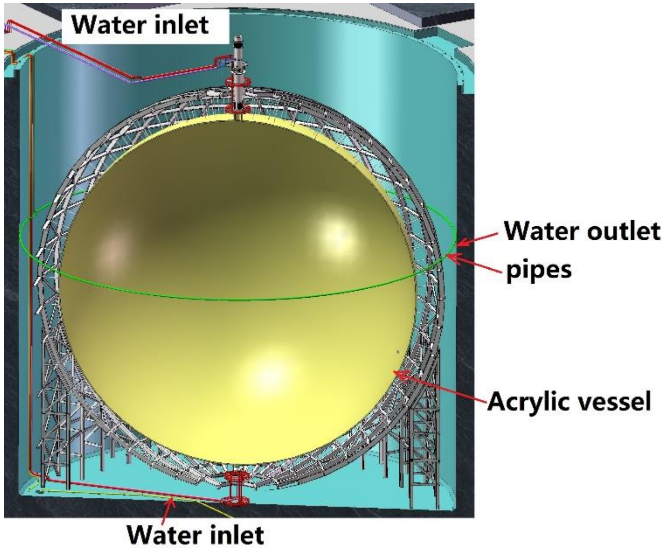
- **Water system(Ground)**

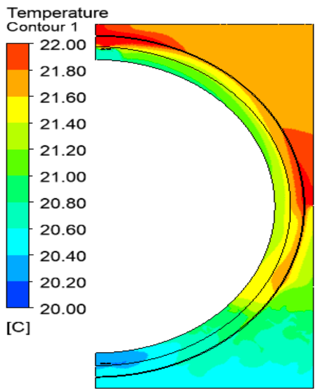
- **Water system(Underground)**

- **Status:**
  - Both ground and underground system installation are finished.
  - **Ready for tunning and commissioning.**

Detector temperature control

- **Keep temperature control within (21±1)℃ around the acrylic vessel**
  - Important for acrylic safety;
  - Keep the detector's mechanical stability.
- A lot of studies and optimizations were done to achieve this goal.
- The circulation schema:
  - Top and bottom of the pool have inlet pipes;
  - Outlet pipes at the equator of the detector;
  - Top and bottom pipes have distributors to make the circulation more uniform;
  - The temperature distribution around the acrylic vessel is anticipated: 20℃< T <22℃.





Temperature distribution around the acrylic vessel

Radon removal in water

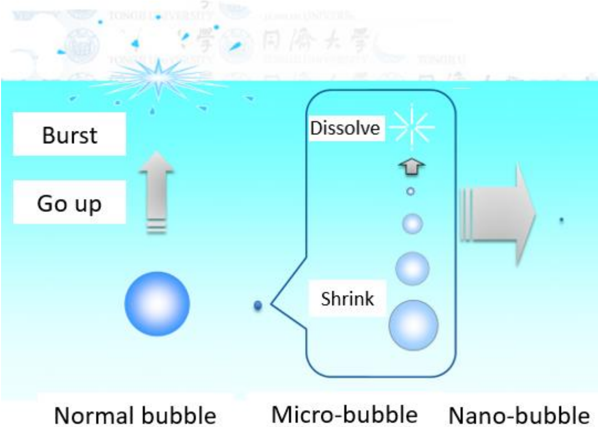
- Water buffer between the central detector acrylic vessel and PMTs.
  - **Requirement for radon concentration in water<10 mBq/m^3**
- Liquid-cel degassing membrane is used to remove radon from water.

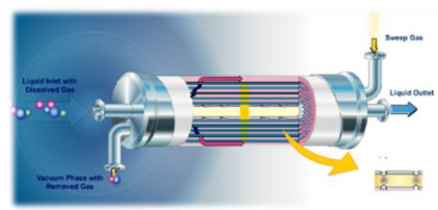
➢ Micro-bubble device used

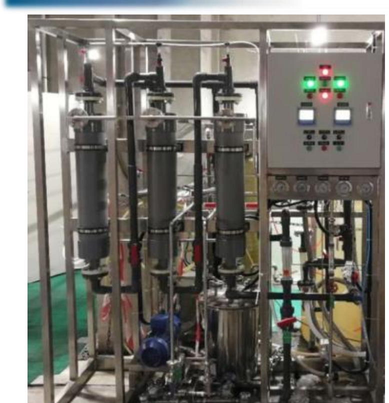
- The Rn removal efficiency is correlated with the gas content in water;
- Generate bubbles at a scale of nm/μm to greatly increase the gas content in water;
- Installed after the first stage of degasser to load gas into the water.

➢ Micro-bubble device + degassing membrane

- The radon concentration in water was reduced to ~5mBq/m^3;
- These devices will be combined into water system.







Summary

- JUNO will measure neutrino mass ordering(3 σ with 6 years data taking) and three oscillation parameters to <1% level.
- JUNO also has 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 progressing smoothly.
  - Plan to finish the detector installation and starting filling next year.

Thanks!