The JUNO Water Cherenkov Veto system

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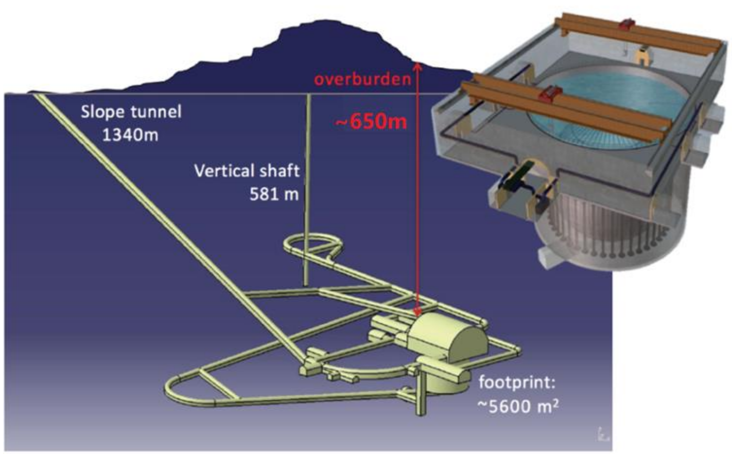
Experiment location

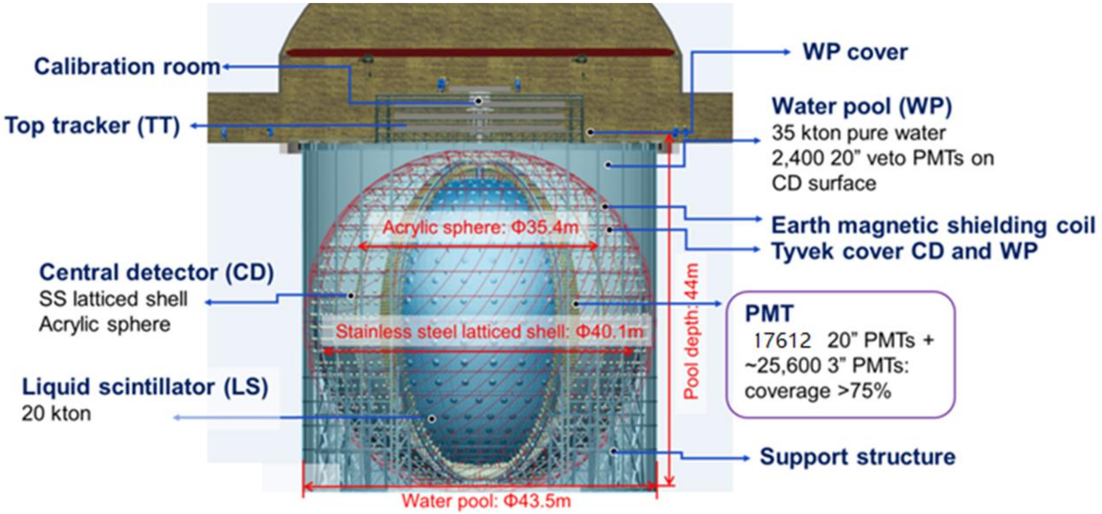
- Location: Jiangmen, Guangdong Province,China
- Powerful source: 8 nuclear reactors
  - All six 2.9 GW_{th} cores in Yangjiang NPP and two 4.6 GW_{th} cores in Taishan NPP are in operation now.
  - Baseline : 53km
  - Background reduction: Under ~650 m(1800 m.w.e.) deep underground for muon flux reduction.



Cores	YJ-1	YJ-2	YJ-3	YJ-4	YJ-5	YJ-6	TS-1	TS-2	DYB	HZ
Power (GW)	2.9	2.9	2.9	2.9	2.9	2.9	4.6	4.6	17.4	17.4
Baseline(km)	52.74	52.82	52.41	52.49	52.11	52.19	52.77	52.64	215	265

Detector overall

- **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



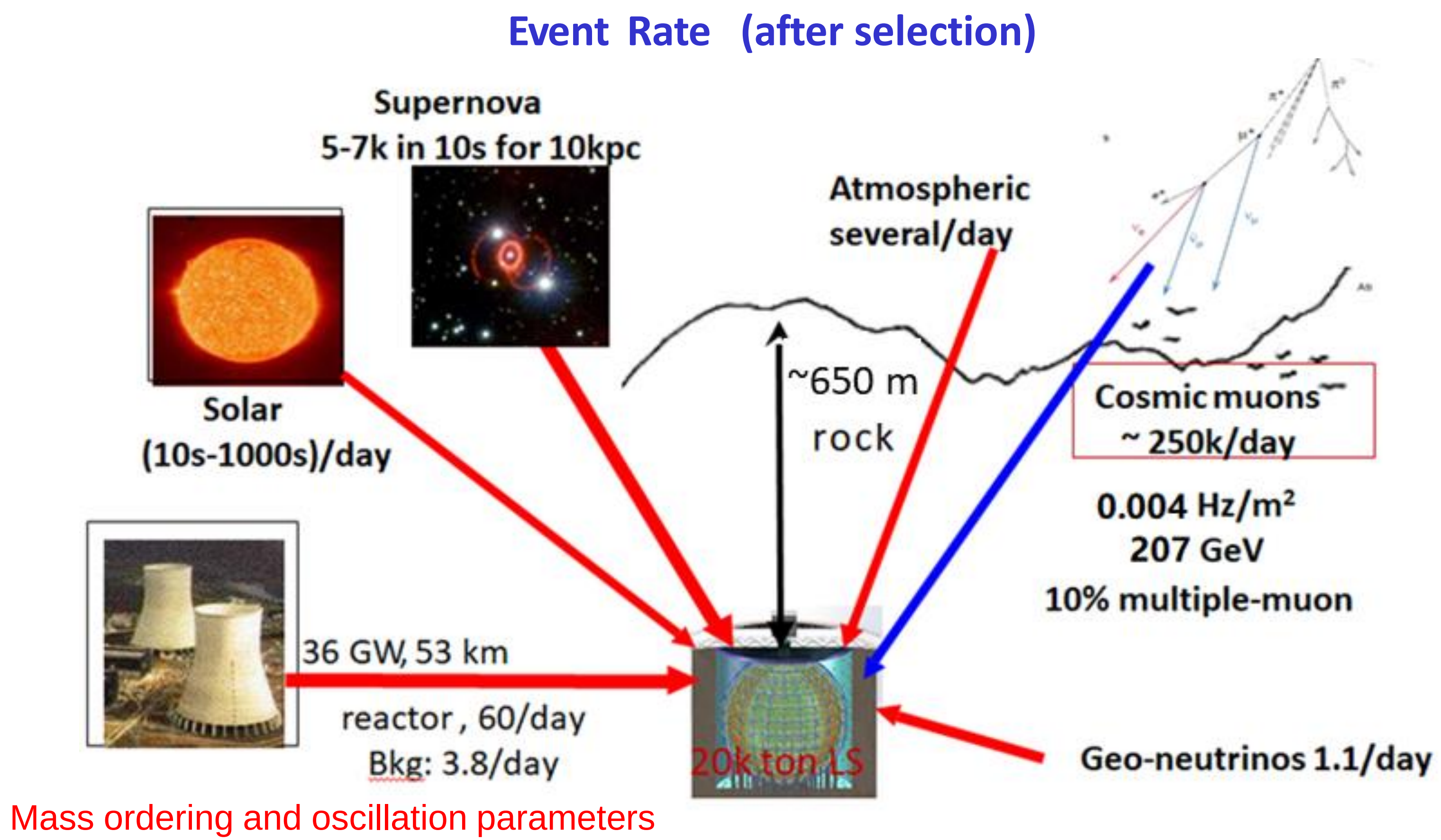
Detector challenging

- **Detector requirement:**
  - 3% @ 1 MeV energy resolution, very high energy resolution
  - High transparency Liquid Scintillator (>20m@430nm)
  - High coverage of PMTs (>75%)
  - Low backgrounds(reactor neutrinos, solar neutrinos)

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%

The most challenging design in the reactor neutrino experiments throughout the world.

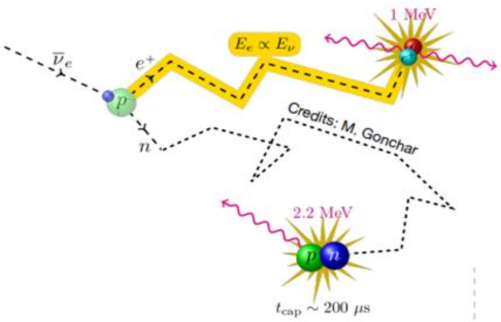
Rich physics program of JUNO

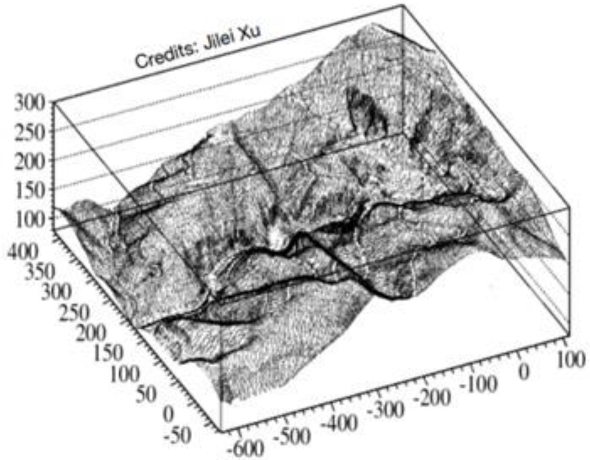


J. Phys. G43:030401 (2016)

Cosmogenic background

- Reactor neutrinos detected via inverse beta decay(IBD)
- Cosmic muons
  - Mean muon energy at experiment hall ~207Gev;
  - Rate in central detector 4Hz.
- Muon related background
  - $^{9}Li/^{8}He$ unstable isotopes produced by muon spallation on ^{12}C and decay beta-neutron;
  - Untagged muon induced fast neutron background.





Digitalized mountain profile of JUNO site

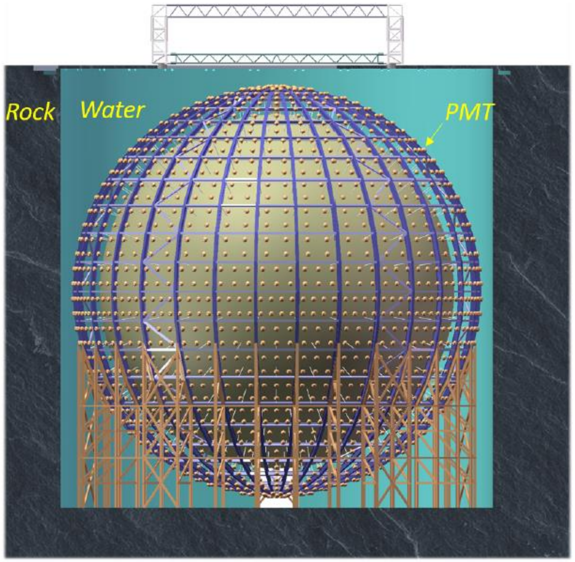
By good veto detector design and veto strategy , muon induced background anticipation as shown in the following table(red square frame).

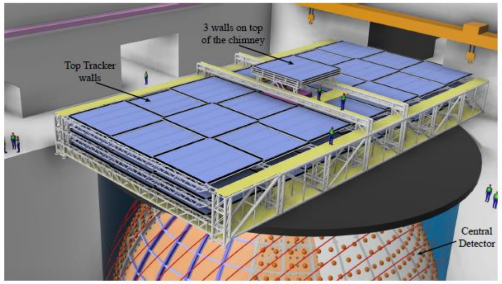
Background	Rate (day^{-1})
Geoneutrinos	1.2
World reactors	1.0
Accidentals	0.8
$^{9}Li/^{8}He$	0.8
Atmospheric neutrinos	0.16
Fast neutrons	0.1
$^{13}C(\alpha,n)^{16}O$	0.05

The veto system

Two veto systems for cosmic muon detection and background reduction.

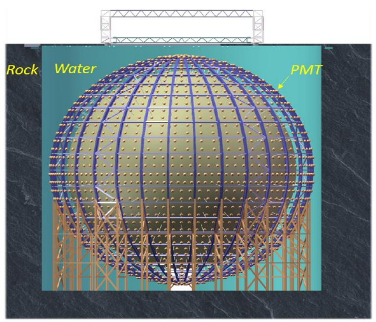
- **Water Cherenkov Veto:**
  - Muon event tagging.
    - Outer of the detector;
    - 35 kton ultrapure water as medium;
    - Fast neutrons background rejection
      - Muon tagging+ passive shielding
  - Radioactivity from rock
    - Passive shielding by water
- **Top tracker:**
  - On top of water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

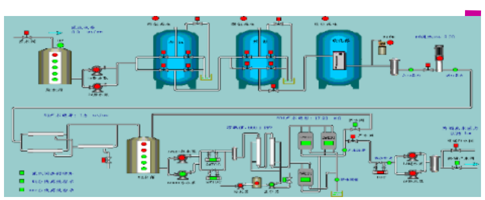




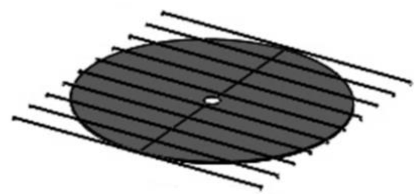
Water veto sub-systems/components

- **Sub-systems/components**
  - PMTs:2400 20 inch PMTs
  - Water system: 100ton/h water system
  - EMF coils: shielding the detector to ensure the 20 inch PMT performance
  - 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

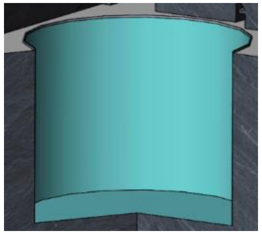




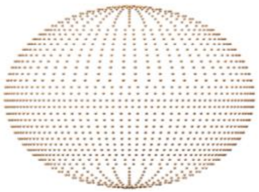
Pure water system, flow rate: ~100t/h



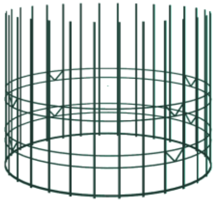
Cover & rail



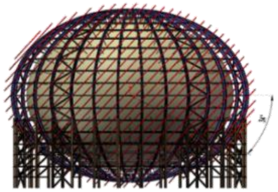
Pool liner



PMTs & Tyvek reflection film



Bird cage &Tyvek reflection film

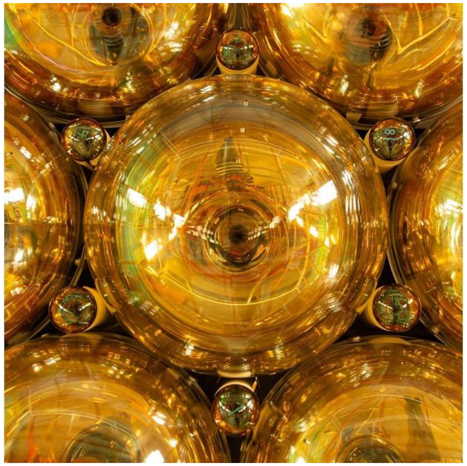


EMF coils

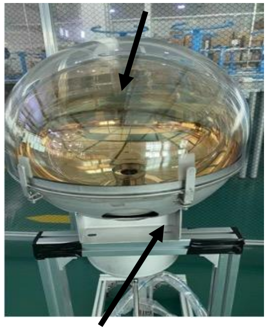
PMTs

- 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)

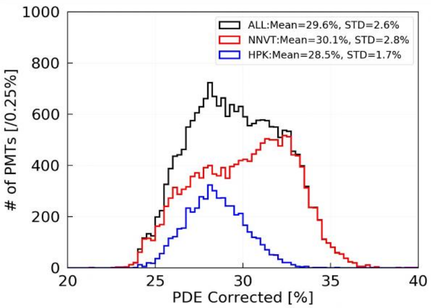


Acrylic cover

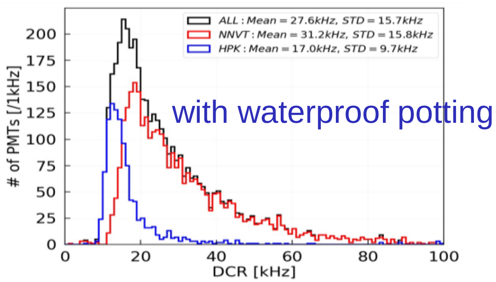


SS cover

Photon Detection Efficiency



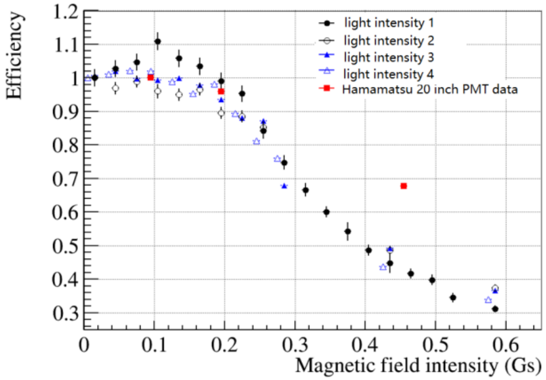
Dark count rate

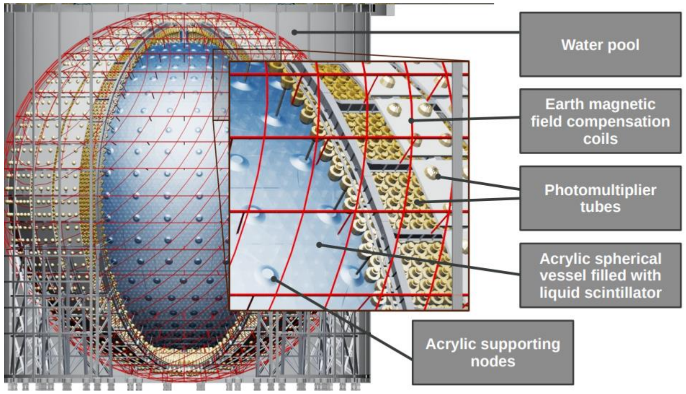


All PMTs are produced, tested, and instrumented with waterproof potting.

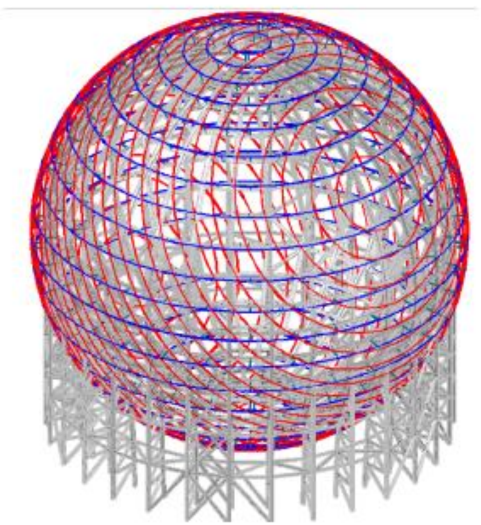
Compensation coils system

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



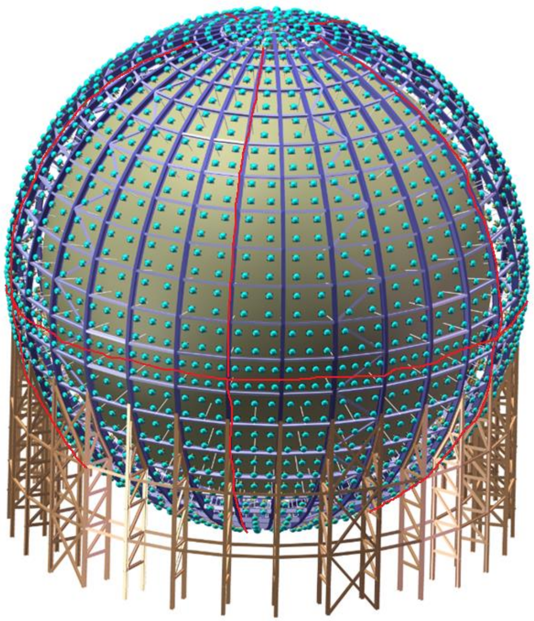


- Use one set of coils to generate the opposite direction of the geomagnetic field to compensate.
  - 16 pairs shielding coils scheme;
  - Coils's uniformity in CD<0.05G.
- EMF direction change effect
  - The EMF direction change every year(<0.2deg/y).
  - Set a compensation angle when the coils are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



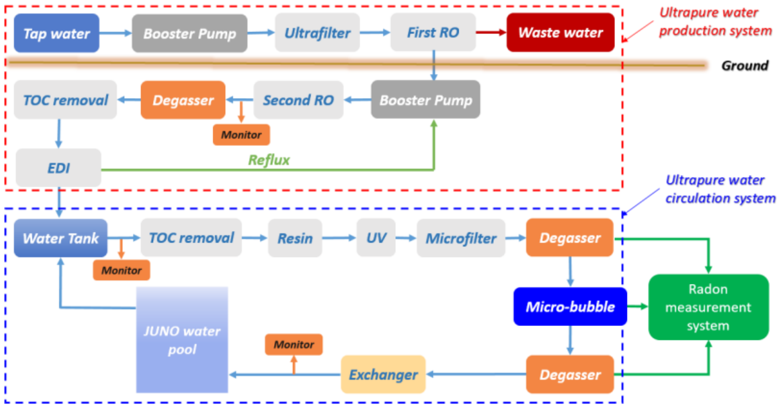
PMT placement in water veto

- 2400 20 inch MCP-PMT used for veto system;
  - PMTs put on the surface of the sphere and facing outside;
- No PMT on the bottom and side of the wall.
  - 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.



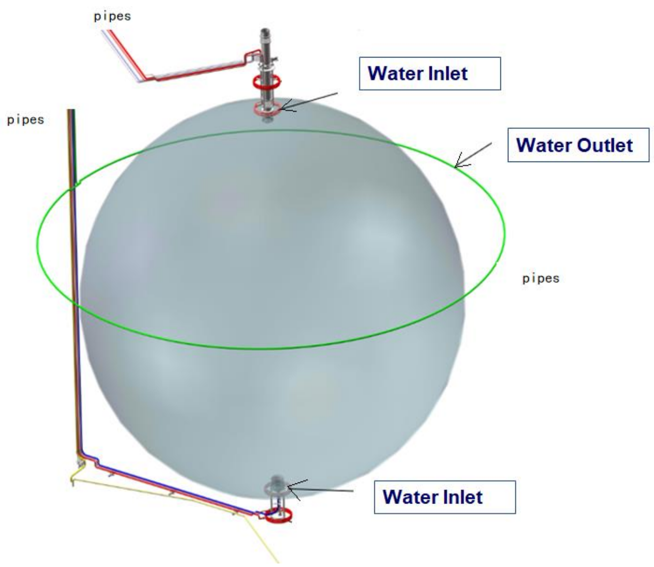
The ultrapure water production and circulation system

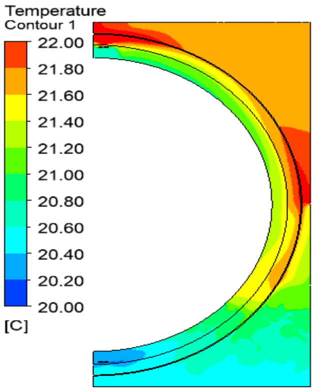
- **Water system**
  - Keep water quality with good transparency for detector performance
  - Flow rate: ~100 t/hour
  - Ground system:
    - Water production
  - Underground system:
    - Purification and circulation;
  - Connection ground and underground system by 1300 stainless steel pipe in slope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



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℃.





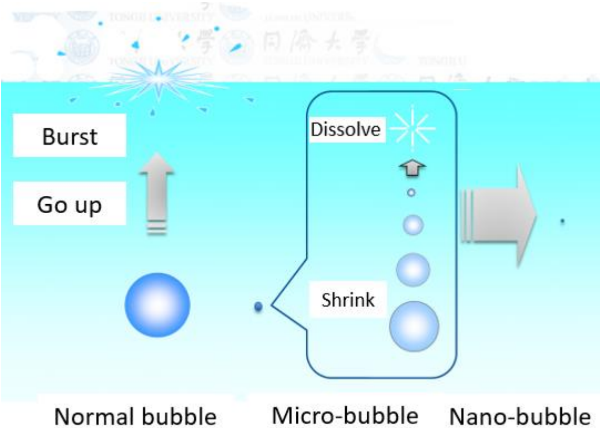
Temperature distribution around the acrylic vessel

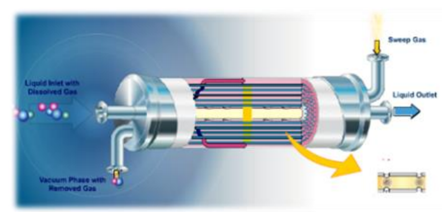
Radon/radium removement in water

- 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.

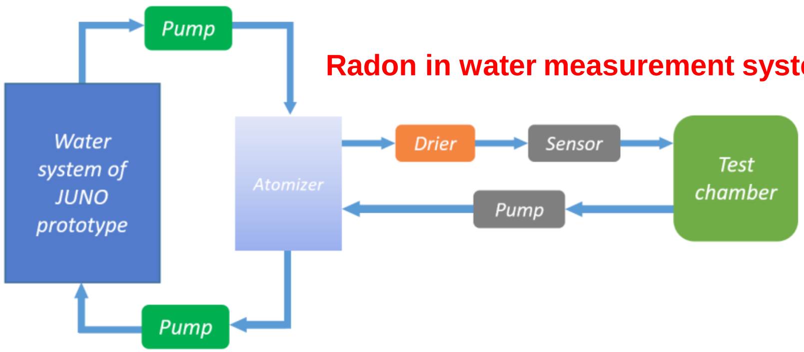
➢ Micro-bubble device used
  - The Rn removal efficiency is correlated with the gas content in water;
  - Generate bubbles at a scale of nm/μm to greatly increase the gas content in water;
  - Installed after the first stage of degasser to load gas into the water.

➢ Micro-bubble device + degassing membrane
  - The radon concentration in water was reduced to ~5mBq/m^3;
  - These devices will be combined into water system.



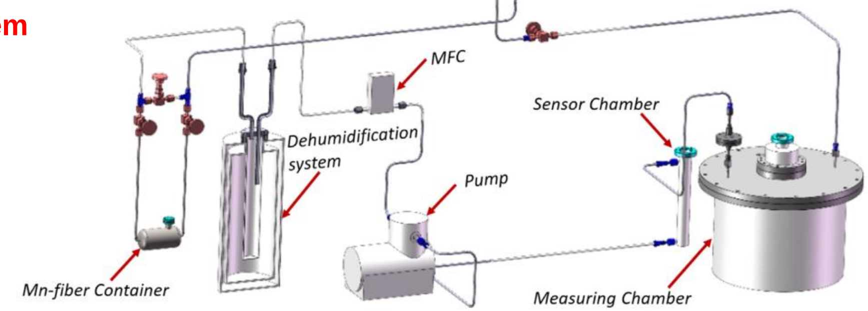


The Rn/Ra concentration measurement system



Radon in water measurement system

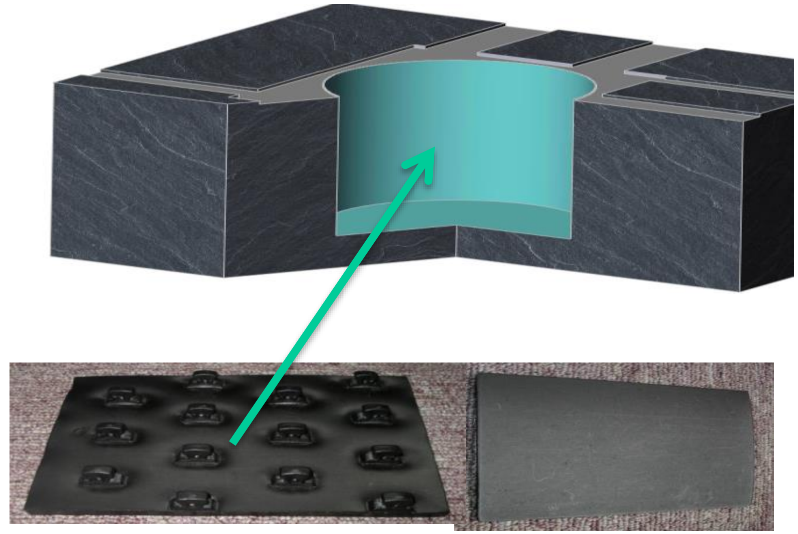
Radium measurement system



- Rn concentration:
  - By detecting the αs from ^{214}Po and ^{218}Po decay with a Si-PIN (Hamamatsu S3204-09) ;
  - The sensitivity is ~0.7mBq/m^3 for one day measurement.
- ^{226}Ra
  - The progenitor of ^{222}Rn;
  - Mn-fiber extract radium from water;
  - A radon emanation measurement system to measure the activity of ^{226}Ra;
  - The sensitivity of the radium concentration in water ~0.1mBq/m^3.

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.



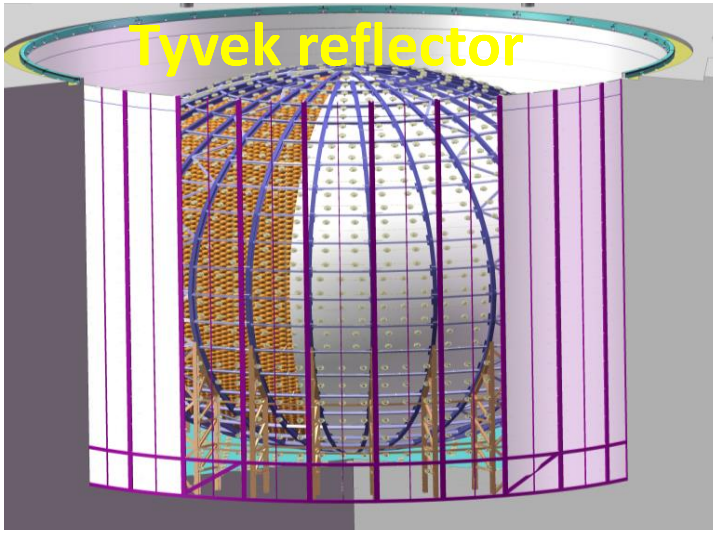
- Dimension:43.5 m diameter*44m height;
- >6000 m^2 lining.

Tyvek reflector

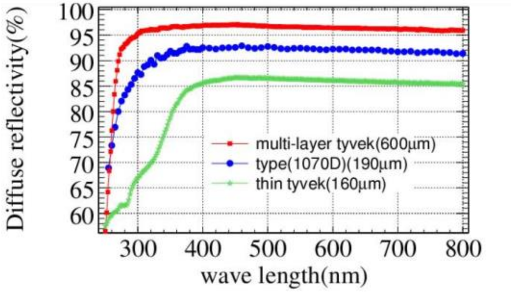
Tyvek reflection film

To be installed on

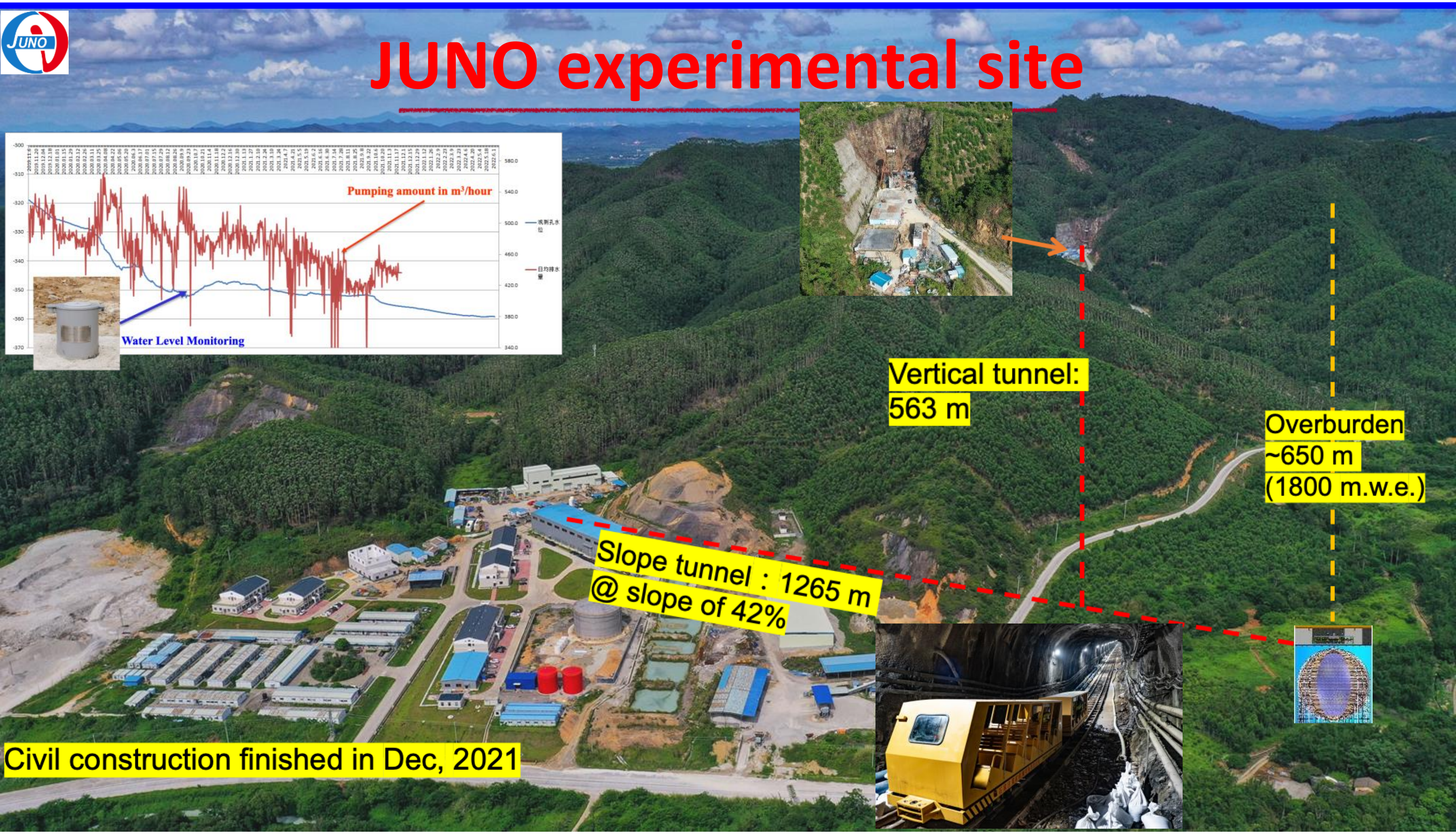
- Surface of the SS latticed shell;
- Pool wall, bottom and top;
- Cover the whole inner surface of the pool to improve light collection.
- **Tyvek reflector production finished.**



Reflectivity larger than 95% for wavelengths > 300nm

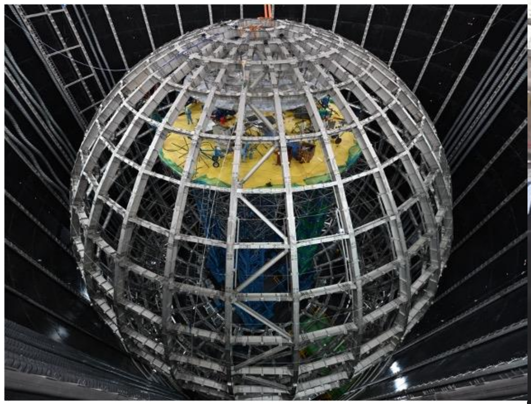


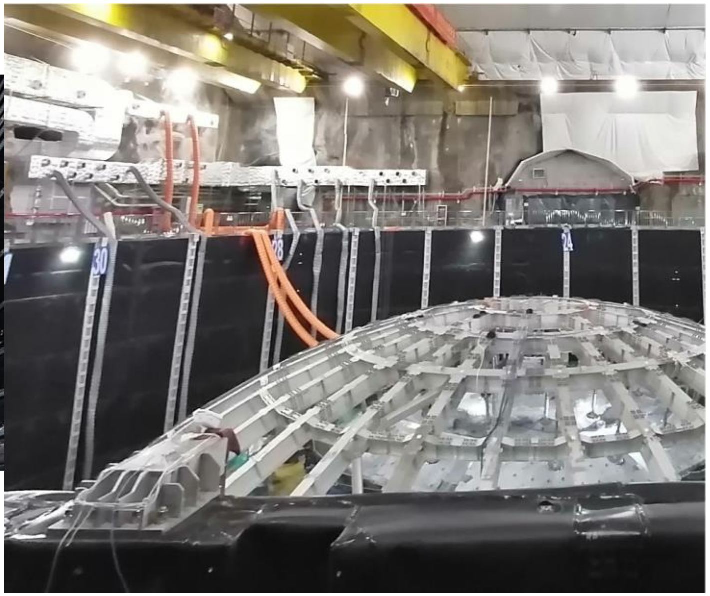
Reflectivity measurement

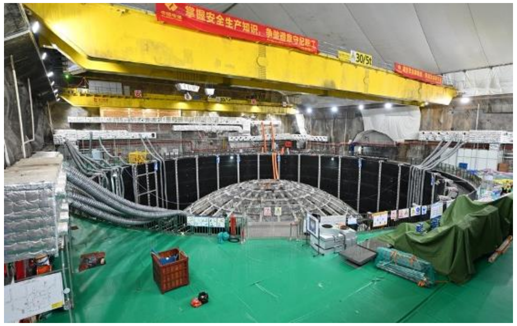


JUNO experimental site
Pumping amount in m³/hour
Water Level Monitoring
Vertical tunnel:
563 m
Overburden
~650 m
(1800 m.w.e.)
Slope tunnel：1265 m
@ slope of 42%
Civil construction finished in Dec, 2021

Detector construction/Installation progress







JUNO Timeline

2014
- International collaboration established
- Conceptual design

2015
- PMT production line setup
- CD parts R&D
- Civil construction start

2016
- PMT production start
- CD parts production start
- Yellow book published

2017
- PMT testing start
- TT arrived

2018
- PMT potting
- Start delivery of surface building
- Start production of acrylic sphere

2019-2021
- Electronics production starts
- Civil construction and lab preparation completed
- Detector construction

2022 — 2023

Complete detector construction
Data taking

Neutrino detected

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 sub-systems production/installation are well underway.
- The experiment is expected to start data taking in 2023.

Thanks!