The radon and radium concentrations in water measurement systems for JUNO's Water Cherenkov Detector

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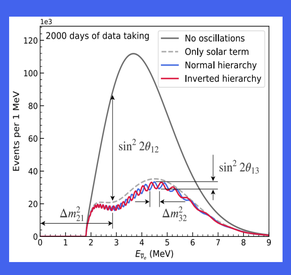
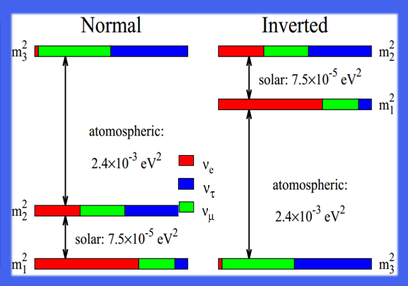
JUNO: A multi-purpose neutrino experiment [1]

- Sources: reactor neutrinos, 26.6 GW_{th} total thermal power;
- Detector: 20 kton liquid scintillator with 17612 20'' photomultiplier tubes (PMTs) and 25600 3'' PMTs.
- Detecting method: inverse beta decay reaction;
- Baseline: 53 km;
- Location: 700 m underground；

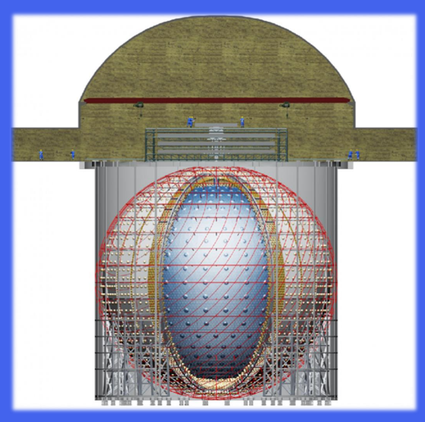
JUNO location

Physics Goals





- Determine neutrino mass ordering (major goal);
- Precise measurements of three neutrino oscillation parameters;
- Study supernova neutrinos, solar neutrinos, atmospheric neutrinos, geo-neutrinos;
- Exotic searches, proton decay;



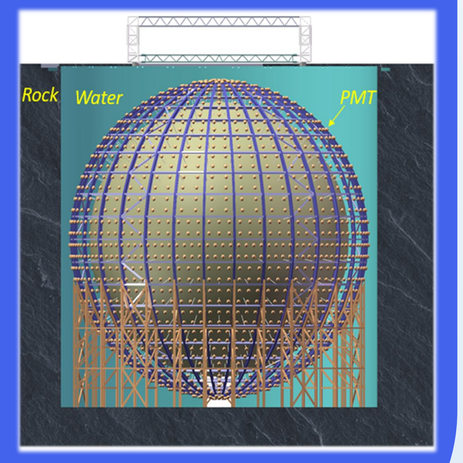
JUNO detector

The Veto detector

- JUNO will be equipped with two veto systems providing both an efficient background reduction towards the environmental radioactivity and the residual cosmic muon flux crossing the detector.
- Composition of the veto detector:
  - ✓ The Water Cherenkov detector (WCD): A pool filled with 35 kton of ultrapure water and instrumented with 2400 Microchannel Plate Photomultipliers;
  - ✓ The top tracker detector: Plastic scintillator detector supplied by OPERA;

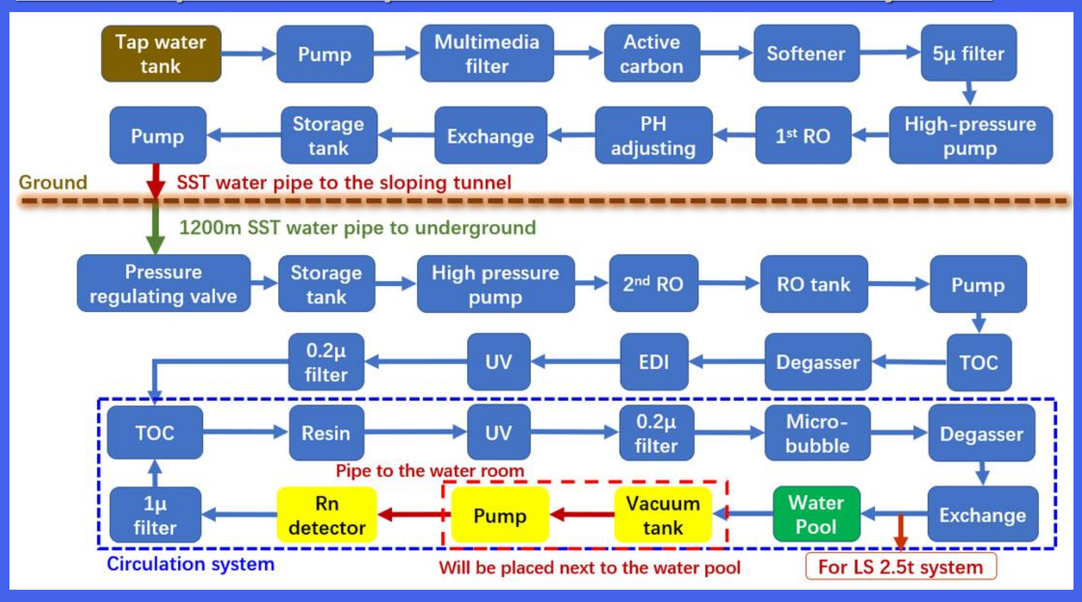
The water Cherenkov detector

- The muon tagging efficiency of WCD is larger than 99% and the fast neutron background from muon spallation can be reduced to ~0.1 event/day.
- An online water system will be used to provide ultra-pure water for the WCD.
- Main functions and requirements for the water system are:
  - ✓ Keep the overall detector temperature stable (21±1℃);
  - ✓ Keep the water quality good:
    - To get a long attenuation length;
  - ✓ Keep the intrinsic background low:
    - U/Th concentration should be less than 10^{-14} g/g;
    - The ^{222}Rn concentration should be less than 10 mBq/m^3;
    - The ^{226}Ra concentration should be less than 10 mBq/m^3.



JUNO veto detector

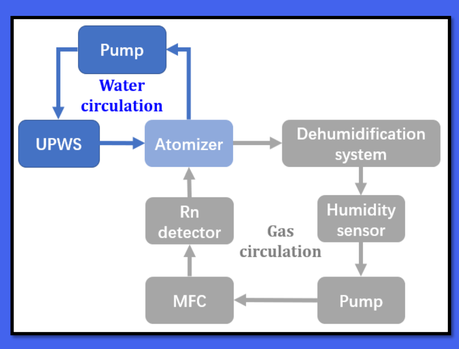
The ultrapure water production and circulation system



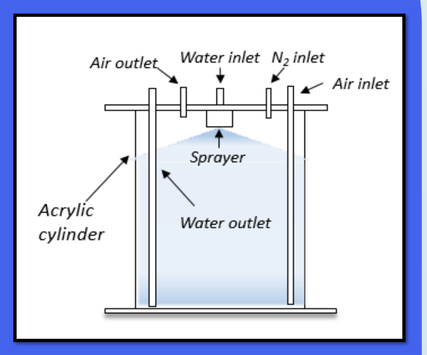
- RO: Reverse Osmosis, can be used to remove the dissolved ions as well as the suspended species in water, including bacteria;
- TOC: Total Organic Carbon, this device can be used to remove the organic matters in the water;
- EDI: Electrode ionization, can separate the dissolved ions from the water ;
- Resin: Removes the dissolved ions ;
- Micro-bubble： Loads gas into water for radon removal;
- Degasser: Removes the gas from water, including oxygen, nitrogen, radon and so on.

The ^{222}Rn concentration in water measurement system[2]

Radon concentration in water measurement system



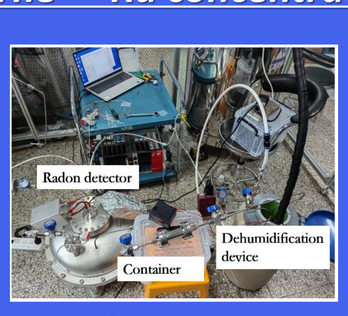
Schematic diagram of the measurement system



Schematic diagram of the atomizer

- Radon concentration measurement:
  - ✓ A semi-automatic measurement system for radon concentration in water has been developed;
  - ✓ Electromagnetic valves are used in the system;
  - ✓ Software has been developed for remote operating;
  - ✓ The atomizer can transfer radon from water into gas;
  - ✓ A radon detector based on electrostatic collection is used for radon concentration determination;
  - ✓ The sensitivity of the system is ~1 mBq/m^3;

The ^{226}Ra concentration in water measurement system[3]



Rn emanation measurement system

Mn-fiber

Extraction column

Emanation chamber

- Radium concentration measurement:
  - ✓ Mn-fiber is used to extract radium from water, Mn-fiber is polyurethane fiber with MnO_2 attached;
  - ✓ The background of Mn-fiber is：~20 μBq/g;
  - ✓ ^{226}Ra activity is determined by its gaseous daughter ^{222}Rn;
  - ✓ The amount of water treated by the Mn-fiber and the adsorption efficiency of Ra were calibrated with a ^{226}Ra solution:
  - ✓ 5 g Mn-fiber can extract radium from 10 m^3 of water;
  - ✓ The Ra extraction efficiency is ~88%;
  - ✓ The sensitivity of the system is ~13 μBq/m^3;

Summary

- JUNO is a multi-purpose neutrino experiment and its main physics goal is to determine neutrino mass ordering;
- A water Cherenkov detector is used as passive shielding and muon veto;
- Several sub-systems have been developed to realize its physical functions;
- To lower the accidental background in the center detector, the radioactivity of the water should be well controlled;
- Two setups for measuring ^{222}Rn (^{226}Ra) concentration in water with a sensitivity of 1 mBq/m^3 (13 μBq/m^3) have been developed;
- The installation of the sub-systems is steadily progressing;

References

[1] JUNO physics and detector, PPNP 123 (2022) 103927;

[2]Y.P. Zhang, et al., The development of ^{222}Rn detectors for JUNO prototype, RDTM(2018)2:5;

[3] L.F. Xie, et al., Developing the radium measurement system for the water Cherenkov detector of the Jiangmen Underground Neutrino Observatory, NIM A 976 (2020) 164266;