The water system and radon measurement system of Jiangmen Underground Neutrino Observatory

Cong Guo Yongpeng Zhang Jinchang Liu , On behalf of the JUNO collaboration

Institute of High Energy Physics, Chinese Academy of Science

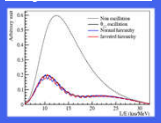
The Jiangmen Underground Neutrino Observatory (JUNO) is a 20 kton liquid scintillator detector with multi-purpose measurements. The detector will be built in 700m deep underground laboratory with primary physics goal the neutrino mass hierarchy determination. Due to low background requirement of the experiment, a multi-veto system for cosmic muon detection is required for background reduction.

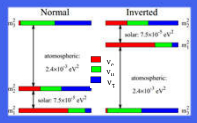
JUNO: A reactor anti-neutrino experiment [1]

- Sources: reactor neutrinos, 6+4 cores (Yangjiang and Taishan NPP, under construction)
- Detecting method: inverse beta decay reaction
- Baseline : 53km
- Under 700 m deep underground for muon flux reduction.
- Detector: 20-kton liquid scintillator with 17k 20'' photomultiplier tubes (PMTs) + 25k 3'' PMT

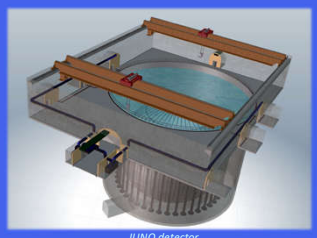
JUNO location

Physics Goals





- JUNO will determine the neutrino mass hierarchy. The energy resolution can reach 3% at 1 MeV for spectrum measurement. In addition, the experiment offers a rich program in neutrino physics (solar neutrino, geo neutrino, atmospheric, ...) and will perform precision measurements concerning the PMNS mixing matrix elements at the percent level and will open the door to unitary tests.



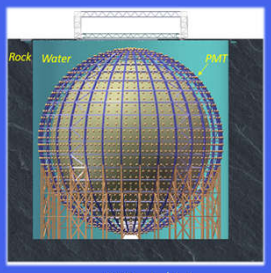
JUNO detector

The Veto detector

- In order to reduce the experimental backgrounds, the neutrino detector must be placed in deep underground and a veto system is used to tag muons.
- The composition of the veto detector:
  - ✓ The Water Cherenkov detector: A pool filled with 40ktons of ultrapure water and instrumented with 2400 MCP-PMTs;
  - ✓ The top tracker detector: Plastic scintillating detector supplied by OPERA;

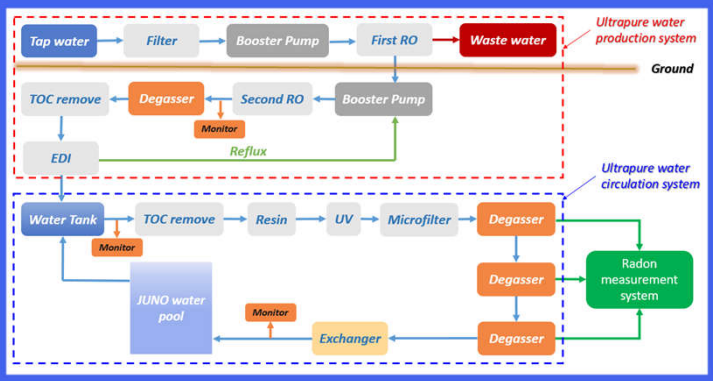
The ultrapure water system

- For the JUNO water Cherenkov detector, it requires ultrapure water for high muon detection efficiency, it is necessary to build a reliable ultrapure water production, purification and circulation system.
- The requirements for the water system:
  - ✓ Keep the overall detector temperature stable;
  - ✓ Keep the water quality good:
    - The attenuation length longer than 30m;
    - The resistivity larger than 17MΩ*cm;
  - ✓ Keep the intrinsic background low:
    - The radon concentration should be less than 0.2Bq/m^3.



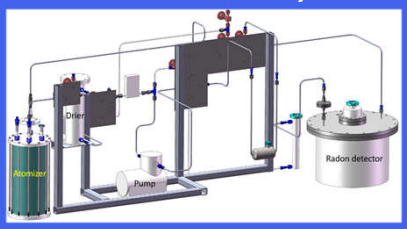
JUNO veto detector

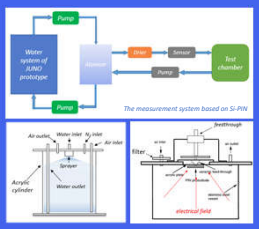
The ultrapure water production and circulation system



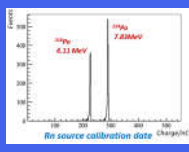
- RO: Reverse Osmosis, can be used to remove the dissolved and suspended species in water, including bacteria;
- TOC remove: TOC is short for total organic carbon, this device can be used to remove the organic matters in the water;
- EDI: Electrode ionization, can separate the dissolved ions from the water ;
- Resin: Remove the dissolved ions ;
- UV: used to sterilized;
- Degasser: Used to remove the gas in the water, including oxygen, nitrogen, radon and so on.

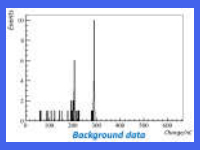
The radon measurement system[2]





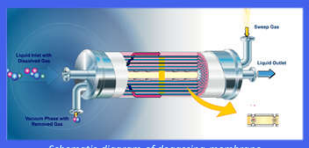
- The atomizer is used to transfer the radon from water into air, when they are at equilibrium state, the ratio of radon concentration in air and water follows $a = 0.105 + 0.405e^{-0.0502T}$ [3];
- Determine the Rn concentration by detecting the α decayed from ^{214}Po and ^{218}Po with Si-PIN(Hamamatsu S3204-09) ;
- 90% of the radon daughters(^{214}Po and ^{218}Po) are positive, the drier is used to keep the relative humidity below 3%;
- A gas flow solid radon source is used to calibrate the detector;
- The sensitivity of the radon detector is calculated *with* L_{LC} *=4.6sqrt(N_b)*[4], based on the background level, the sensitivity is 11.6mBq/m^3.





Rn concentration in water measurement and Rn removal

- The Liquid-cel degasser membrane is used to remove the radon in water;
- Degasser membrane uses microporous hollow fibers to degassing liquids[5];
- The Rn removal efficiency is correlated with the gas concentration in the water and the inlet pressure of the water;



Schematic diagram of degassing membrane

Measuring results

Case 1 Rn concentration in water of JUNO water prototype system

Condition	Counts/h	Results (Bq/m^3)	Concentration (Bq/m^3)
Degasser "OFF"	101.40 ± 7.80	0.96 ± 0.093	0.88 ± 0.096
One stage degasser "ON"	36.00 ± 4.65	0.34 ± 0.048	0.26 ± 0.053
Degasser "ON"	24.00 ± 3.79	0.23 ± 0.039	0.15 ± 0.045

Case 2 Rn concentration in water of the small steel vessel

Condition	Counts/h	Results (Bq/m^3)	Concentration (Bq/m^3)
Degasser "OFF"	498.65 ± 20.11	4.73 ± 0.34	4.65 ± 0.34
Degasser "ON"	25.80 ± 3.93	0.24 ± 0.039	0.16 ± 0.045
Degasser "ON" and CO_2	10.20 ± 2.47	0.097 ± 0.024	0.012 ± 0.033

Case 3 Rn concentration in water of the wate system in the Dayabya hall 5

Condition	Counts/h	Results (Bq/m^3)	Concentration (Bq/m^3)
Degasser "OFF"	2574.00 ± 124.27	24.39 ± 1.86	24.31 ± 1.86
Degasser "ON"	15.00 ± 3.00	0.14 ± 0.029	0.056 ± 0.037

- Case 1: 0.15MPa inlet water pressure;
- Case 2: 0.15MPa inlet water pressure with CO_2 loading;
- Case 3: 0.35MPa inlet water pressure;

Real picture of the degassing membrane

Summary

- The main goal of JUNO is to determine the neutrino mass hierarchy and the cosmic ray muon induced background is the main background;
- The water Cherenkov detector can be used as passive shielding and muon veto;
- The ultrapure water production and circulation system has been designed to meet the requirements of JUNO;
- The Si-PIN radon detector has been developed for radon concentration measurement of JUNO and the sensitivity of it is 11mBq/m^3; which can meet the needs of JUNO veto detector;
- The Liquid-cel degassing membrane is used to remove the radon in the water;
- Loading CO2 into the water and increase the inlet water pressure could help to increase the efficiency of the degassing membrane and the radon concentration can be reduced to around 10mBq/m^3, which can satisfy the requirement of JUNO.

Reference

- [1] Neutrino Physics of JUNO, arXiv:1507.05613;
- [2] The development of 222Rn detectors for JUNO prototype, RDTM(2018)2:5;
- [3] http://durridge.com/documentation;
- [4] Experimental methods of nuclear physics, Zhihua Wu, et al., Atomic energy press(1997)339-345;
- [5] http://www.liqui-cel.cn/.

Thanks for your attention!