PROCEEDINGS OF SCIENCE

JUNO detector design and status

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The Jiangmen Underground Neutrino Observatory (JUNO) is the state-of-the-art liquid-scintillator-based neutrino physics experiment under construction in South China. Thanks to the 20 ktons of ultra-pure liquid scintillator (LS), JUNO can perform innovative and ground-breaking measurements like determining neutrino mass ordering (NMO). The experiment is being constructed in a 650 m underground laboratory (1800 m.w.e.), about 52 km from the Taishan and Yangjiang nuclear power plants. The JUNO Central Detector (CD) will be equipped with 17,612 20-inch and 25,600 3-inch photomultiplier tubes (PMTs), respectively. JUNO CD energy resolution is expected to be better than 3% at 1 MeV and to have an absolute energy scale uncertainty better than 1% over the whole reactor antineutrino energy range. In addition, the JUNO experiment also has a satellite detector, the Taishan antineutrino observatory, to measure the reactor antineutrino energy spectrum with high precision. Beyond NMO, JUNO will measure the three neutrino oscillation parameters with a sub-percent precision. Moreover, the JUNO experiment is also expected to have important physics reach with solar neutrinos, supernova neutrinos, geoneutrinos, and atmospheric neutrinos, and searches for physics beyond the Standard Model such as nucleon decay. This paper will present the detector design and installation status of the different JUNO subsystems.

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1. Introduction

The Jiangmen Underground Neutrino Observatory (JUNO), a 20 kton multi-purpose underground liquid scintillator (LS) detector, was proposed with the determination of the neutrino mass ordering as a primary physics goal [1]. The JUNO detector is capable of observing not only antineutrinos from the nuclear power plants (NPPs), but also neutrinos/antineutrinos from terrestrial and extra-terrestrial sources, including supernova burst neutrinos, diffuse supernova neutrino background, geo-neutrinos, atmospheric neutrinos, and solar neutrinos [1].

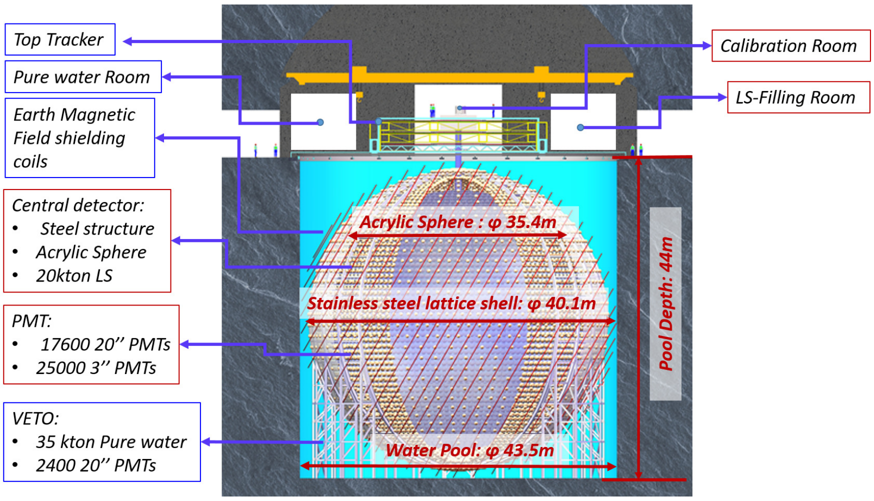

Figure 1: The scheme of the JUNO detector.

Fig. 1 shows the scheme of the JUNO detector [2]. The 20 kton Ultra-pure LS is contained in a spherical acrylic vessel and the light emitted by LS is watched by photomultiplier tubes (PMTs). The entire LS detector is submerged in a water Cherenkov detector (WCD). On the top of the WCD, a top tracker (TT) will be installed to measure the muon directions. Multiple calibration sources and multiple dimensional scan systems will be developed for detector calibration. To eliminate the model dependence of JUNO for NMO determination, a satellite detector named Taishan Antineutrino Observatory (TAO), will be built to precisely measure the reactor antineutrino spectrum [3].

2. The JUNO detector

2.1 Central detector

The Central Detector (CD) is a 20 kton LS detector with a designed energy resolution equal or better than 3% at 1 MeV. The LS is contained in a 12 cm thick acrylic vessel with a diameter of 35.4 m. The acrylic vessel is supported by a Stainless Steel (SS) structure via connecting bars. On the inner surface of the SS structure, 17612 20-inch PhotoMultiplier Tubes (PMTs) and 25600 3-inch PMTs are installed. The total photo-cathode coverage of CD is 77.9%.

For the JUNO LS, the optimal composition is determined to be the solvent Linear Alkyl Benzene (LAB) with 2.5 g/L 2,5-diphenyloxazole (PPO), and 3 mg/L p-bis(o-methylstyryl)-benzene (bis-MSB) [4]. The LS requirement for U/Th radiopurity is 1×10^{-15} g/g for reactor antineutrino studies and 1×10^{-17} g/g for solar neutrino studies. Except for careful raw materials selection, a combined purification system, including alumina filter, distillation, water extraction, and gas stripping will be used to remove particles and radioactive impurities from the LAB or LS. The LS's final quality will be checked by the Online Scintillator Internal Radioactivity Investigation System [5].

For the acrylic vessel, by the end of July 2023, half of the 265 pieces of acrylic panels have been assembled to form the upper hemisphere. According to the measurement results, the transparency of the acrylic panel in ultrapure water is >95% and its internal U/Th radiopurity is <1 ppt.

2.2 Veto detector

The veto detector consists of a WCD and a TT. The WCD is a pool filled with 35 kton of ultrapure water and equipped with 2400 Microchannel Plate PMTs (MCP-PMTs). The WCD serves as an active veto for cosmic muons as well as a passive shield against external radio activities. The muon tagging efficiency of the WCD is >99.5% and the fast neutron background from muon spallation can be reduced to ~0.1 event/day [2]. The inner surface of the water pool is covered by 5 mm thickness High-Density Polyethylene to prevent the rock-emanated radon from diffusing into the water. Next to the wall of the water pool, there is a mechanical structure, called birdcage that acts as supporting structures. Tyvek reflective foils are used to cover the inner surface of the birdcage and the outer surface of the SS structure to increase the light collection efficiency of the WCD. An online water system will be used to provide and monitor the purity of the water as well as to remove the radioactive isotopes from the water. Furthermore, the water system also can help to keep the temperature of the acrylic sphere stabilized to 21 ± 1 °C to maintain the detector's mechanical stability.

The TT serves as a supplemented muon tagging system, which consists of three layers of plastic scintillator repurposed from the OPERA experiment. The TT will be located at the top of the WCD and covers ~60% of the surface.

2.3 Calibration system

To determine the NMO, in addition to the high requirement on the energy resolution, JUNO also requires a 1% energy linearity [6]. To address the detector's energy non-linearity and spatial non-uniformity, four subsystems have been developed. The Automatic Calibration Unit (ACU) can deploy multiple radioactive sources or a pulsed laser diffuser ball along the CD central axis. The Cable Loop System (CLS), moving on a vertical half-plane, can scan the CD vertical plane. The Guide Tube Calibration System (GTCS), which surrounds the outside of the CD and runs in a longitudinal loop, can scan the CD boundary. The Remotely Operated Vehicle (ROV), which can be deployed to any desired location inside the LS, can be used for a full-volume scan.

The ACU, CLS, and ROV systems will be moving inside the CD, so they will be installed and deployed from an air-tight stainless steel calibration house located on the top of the WCD.

2.4 JUNO-TAO

The TAO [3] detector is designed for high-precision measurement of the reactor antineutrino spectrum. With a ton-level Gadolinuim-based LS (Gd-LS) detector at ~30 m from a reactor core of the Taishan NPP, TAO will provide a reference spectrum for the determination of NMO in JUNO, as well as a benchmark measurement to test nuclear databases.

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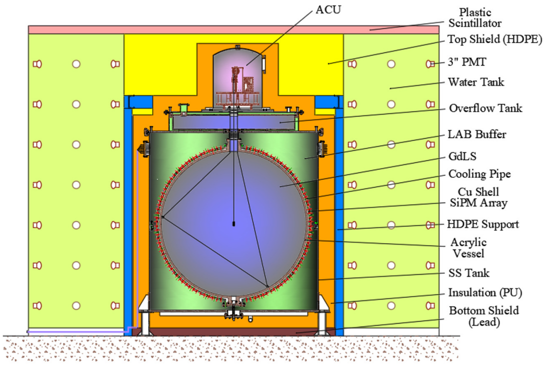

Figure 2: Scheme of the TAO detector.

Fig. 2 shows the scheme of the TAO detector. 2.8 tons of Gd-LS target is contained in a 1.8 m diameter acrylic sphere and Silicon Photomultipliers (SiPM), with a photon detection efficiency of >50%, will be used to detect the photons emitted from the Gd-LS. To lower the dark noise of the SiPM, the detector has to be operated at -50°C. The expected light yield of TAO is ~4500 photoelectrons per MeV and the energy resolution is expected to be better than 2% at 1 MeV.

3. Summary

JUNO is a multipurpose neutrino experiment and will determine NMO with 3-4σ in 6 years. The key to JUNO is the $3\%/\sqrt{E}$ energy resolution and 1% energy linearity. The JUNO detector construction is well in progress and is expected to start commissioning in 2024.

4. Acknowledgement

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