PROCEEDINGS OF SCIENCE

JUNO-TAO design, prototype and its impact for JUNO physics

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The JUNO-TAO detector is a satellite detector of the Jiangmen Underground Neutrino Observatory (JUNO) and it will be placed near the core of the Taishan nuclear power plant. It is a liquid-based scintillator that will precisely measure the nuclear antineutrino spectra, improving the sensitivity of JUNO on the correct mass ordering studies. Furthermore, JUNO-TAO will provide benchmark tests on the nuclear database. TAO will be installed in the Taishan nuclear power plant at a distance from one of the reactor cores about 30 m. The target of the TAO central detector is a 2.8-ton Gd-doped LS contained in a spherical acrylic vessel and viewed by about 4000 SiPMs corresponding to a coverage of 94%. The central detector will be operated at -50 °C to reduce the dark noise rate of SiPMs. This manuscript will present JUNO-TAO's design, the status of its R&D program, and its physics potential.

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Table 1: Event rates of the IBD signal and backgrounds

Source	Type	Radiation
IBD signal	2000 evts/day	
Muon rate	70 Hz/m^2	
Singles from radioactivity	<100 Hz	
Fast neutron background after veto	<200 events/day	
Accidental background rate	<190 events/day	
^{8}He/^{9}Li background rate	~54 events/day	

1. Introduction

Jiangmen Underground Neutrino Observatory (JUNO) is a neutrino detector under construction in China and, thanks to its most accurate determination of neutrino energy, will play an important role in the discovery of the correct neutrino mass hierarchy[1]. To enhance JUNO's discovery potential, a robust research and development program was launched, culminating in a second detector, the Taishan Antineutrino Observatory (named TAO or JUNO-TAO)[3]. TAO is a liquid scintillator detector placed 30 m away from a reactor core of the Taishan Nuclear Power Plant (4.6 GW). It aims to measure the reactor antineutrino spectrum with sub-percent energy resolution. The measurement of the unoscillated energy spectrum of the anti-electron neutrinos is important to eliminate model dependencies of determination of the neutrino mass ordering related to possible yet uncovered fine structures in the reactor antineutrino energy spectrum but also will provide a test benchmark for the nuclear database, will search for sterile neutrinos and will be used to monitor the status of the reactor[4].

2. JUNO-TAO detector

The Central Detector consists of 2.8 ton gadolinium-doped liquid scintillator (LS) contained in a spherical acrylic vessel of 1.8 m in inner diameter. To fully contain the energy deposition of gammas from the Inverse Beta Decay (IBD) positron annihilation, a 25-cm selection cut will be applied for the positron vertex from the acrylic vessel, resulting in 1 ton fiducial mass and 2000 events per day. To collect photons emitted in the scintillation process, ~4500 per MeV, 4000 SiPM tiles are installed on the inner surface of a spherical copper shell of 1.8 m inner diameter. The copper shell is installed in a cylindric stainless steel tank filled with Linear Alkylbenzene (LAB), the solvent of the GdLS, which serves as the buffer liquid to shield the radioactivity of the outer tank. The stainless steel tank is insulated with 20 cm thick Polyurethane (PU). The central detector will operate at -50○C to reduce the dark noise of SiPMs to $\sim\ 100Hz/mm^2$. TAO will work at ground level. To reduce the ambient radioactivity, the central detector is surrounded by a water tank and 1 m High-Density Polyethylene (HDPE) on the top. The water tank is equipped with photomultipliers to identify cosmic muons working together with a plastic scintillator on the top. The schematic drawing of the TAO detector is shown in Fig. 1. The expected rates of the IBD signal and the residual backgrounds passing the IBD selection cuts are summarized in table 1.

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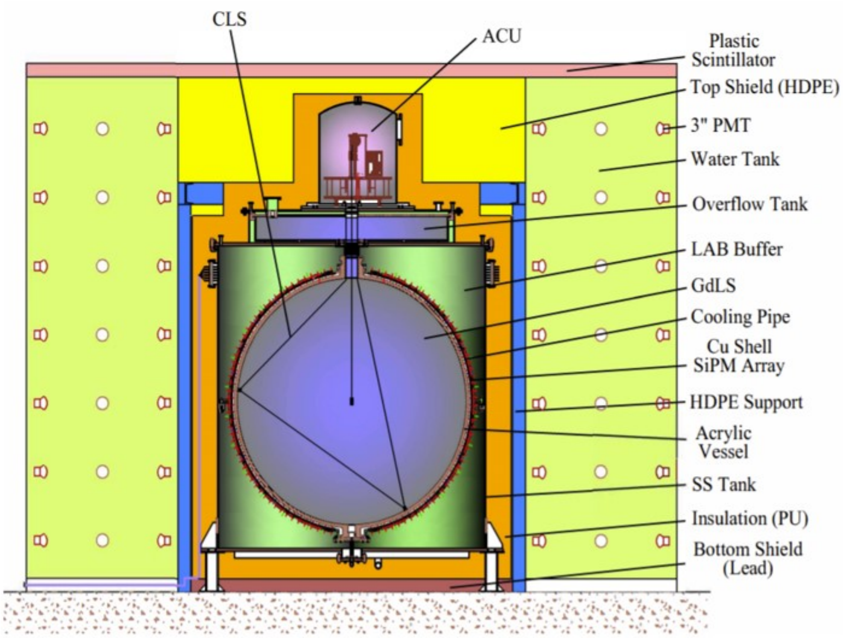

Figure 1: Schematic view of the TAO detector, consisting of a Central Detector (CD), the cryogenic system, an outer shielding, and a veto system composed by the Water Cherenkov Detector and the plastic top tracker.

3. The calibration system used in JUNO-TAO

The position dependence of the number of detected photons, caused by a variation of absorption and scattering of photons across the detector medium, photon's incident angles, and their reflections, is known as the detector nonuniformity. Both non-linearity and non-uniformity are accounted for by a dedicated calibration system [5].
TAO calibration system is composed of an Automated Calibration Unit (ACU) and a Cable Loop System (CLS)[6].
The ACU, displayed in fig. 2, can deploy three different sources inside the detector alongside the z-axis while a turntable revolves to a specific angle. In particular, the sources are:

- an ultraviolet (UV) light source;
- ^{68}Ge source;
- a combined source that contains multiple gamma sources and one neutron source.

The Cable Loop System (CLS) was designed with a single radioactive source, that can be deployed to an off-axis position. It adopts some experience from JUNO CLS[5]. The radioactive source, a ^{137}Cs, is positioned in a small area of the stainless steel cable, which is coated with Teflon along its entire length to prevent contamination of the Gadolinium doped liquid scintillator. Two anchors are glued to the inner surface and the cable is passed through the anchors. Two stepper motors can pull the cable in either direction to position the radioactive source into the detector with good positional accuracy. Thanks to ACU and CLS it will be possible to deploy different

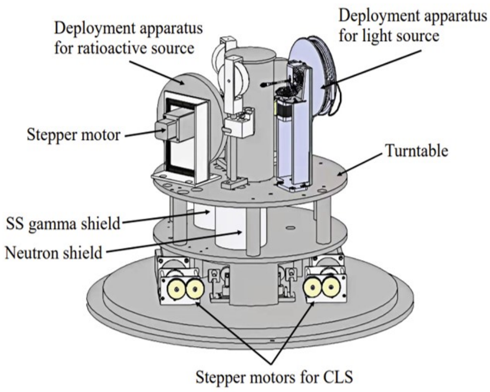

Figure 2: Schematic view of the Automatic Calibration Unit

radioactive sources on and off the central axis mapping the response of the entire detector. The energy resolution degradation and energy bias will be controlled within 0.05% and 0.3% respectively making TAO able to measure the antineutrino energy spectrum with the required precision [6].

4. Conlcusion

After a few years of R&D, a prototype of TAO is under construction in China. TAO will provide a high precision energy spectrum of reactor electron antineutrino useful for JUNO neutrino mass ordering determination and for testing the nuclear databases. Two independent calibration systems, named ACU and CLS, were developed to reach an energy resolution of 2% at 1 MeV.

References

[1] JUNO collaboration. *JUNO physics and detector*, *Progress in Particle and Nuclear Physics* **123** (2022): 103927.

[2] Abusleme A. et al. *Tao conceptual design report: a precision measurement of the reactor antineutrino spectrum with sub-percent energy resolution*, *arXiv preprint*, arXiv:2005.0874 (2020).

[3] Abusleme A. et al.. *JUNO physics and detector*, *Progress in Particle and Nuclear Physics* **123** (2022): 103927.

[4] Lombardo C. *Overview of the JUNO-TAO detector*, *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* **1048** (2023): 168030.

[5] Abusleme, A. et al. *Calibration strategy of the JUNO experiment*, *Journal of high energy physics* **2021**,4 (2021).

[6] Xu, H. et al. *Calibration strategy of the JUNO-TAO experiment*, *The European Physical Journal C* **82**,,1112 (2022).