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Status of the JUNO reactor anti-neutrino experiment

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Abstract

The Jiangmen Underground Neutrino Observatory (JUNO) is a reactor antineutrino experiment with the aim to determine the neutrino mass hierarchy. The detector will be filled with 20 kilotons of liquid scintillator and instrumented with 18000 20-inch PMTs to achieve an unprecedented energy resolution of 3%@1 MeV. A 35.4 m diameter acrylic sphere will be built as a liquid scintillator vessel.The detector will be constructed in a 700-m-deep-underground laboratory to reduce cosmogenic muon flux. An external veto cosisting of a water Cherenkov detector and a top tracker will be used for cosmogenic muon detection and background reduction. The mass hierarchy sensitivity is expected to reach 3-4σ after 6 years of data taking. Civil construction and detector R&D are underway. Data taking is expected to start in 2020.

Keywords: neutrino, JUNO, mass hierarchy

1. Introduction

In the past few decades, it has been proven that the observed neutrino oscillations can be described by a 3-flavor active neutrino framework, using a parameterization of the standard Pontecorvo-Maki-Nakagawa-Sakata (PMNS) matrix to describe the unitary transformation relating the neutrino mass and flavor eigenstates [1, 2]. The matrix contains the three mixing angles (θ_{23}, θ_{12}, and θ_{13}) and one charge-parity(CP)-violating phase. θ_{23} is determined by atmospheric and accelerator neutrino experiments [3, 4], while θ_{12} is determined by solar and reactor neutrino experiments [5, 6]. The last angle θ_{13} was first measured by the Daya Bay Reactor Neutrino Experiment in 2012 [7]. Many future generation experiments will focus on the determination of the mass hierarchy (MH) and the measurement of the CP Phase.

Using reactor antineutrinos to determine the mass hierarchy allows us to choose a medium baseline (50 km) and to study an oscillation probability that is independent of CP phase and θ_{23}. Observing a distortion of the energy spectrum (Figure 1) will allow to discriminate between two different neutrino MHs [8, 9, 10, 11]. JUNO is such a type of reactor neutrino experiment.

2. The JUNO experiment

The Jiangmen Underground Neutrino Observatory (JUNO) is located at Kaiping, Jiangmen City, Guangdong Province, China [12]. The detector will use 20 ktons of liquid scintillator aiming at a 3% energy resolution (at 1MeV). The detector will be constructed underground to reduce the background induced by cosmogenic muons, with an overburden of about 700 m of rock. As shown in Figure 2, the detector is located 53 km away from the Yangjiang and Taishan nuclear power plants,which is an optimized baseline length. According

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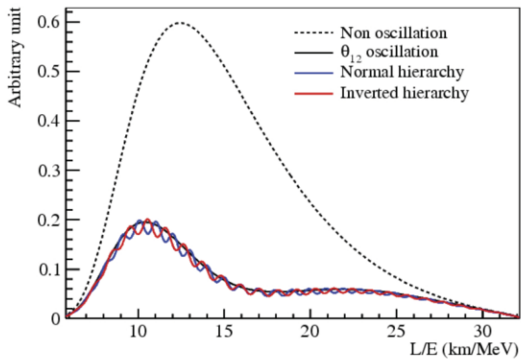

Figure 1: The relative shape difference of reactor antineutrino energies by different neutrino MHs.

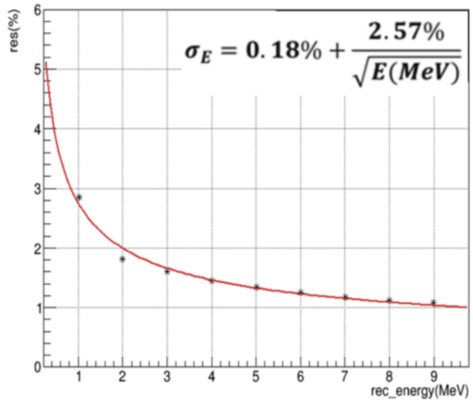

Figure 3: Detector energy resolution from simulation

to the reactors construction plan, 26.6 GW will be available by 2020, while the total power of 36 GW will be eventually available.The main goal of JUNO is to determine the mass hierarchy by precisely measuring of the anti-neutrino energy spectrum distortion.

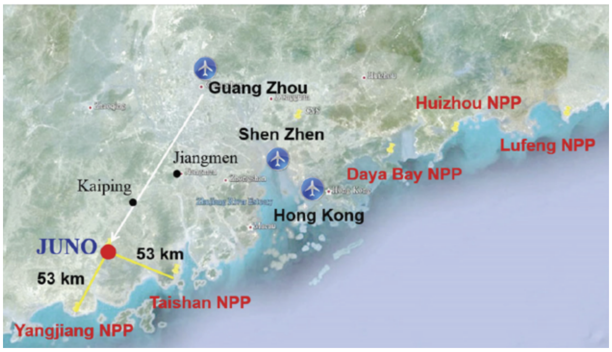

Figure 2: JUNO experimental site location. The Taishan and Yangjiang reactor complexes will be used by JUNO.

In order to reach such an unprecedently high energy resolution for liquid scintillator detectors, the experiment will use high QE (max.35%) PMTs with a coverage of PMTs close to 75%. The attenuation length of the liquid scintillator will be larger than 20 meters at 430 nm. Figure 3 shows the energy resolution expected from simulation; the results are based on the total charge-based energy reconstruction with an ideal vertex reconstruction.

JUNO will measure antineutrino induced events via the inverse beta decay (IBD) reaction $\bar{\nu}$+ p $\rightarrow e^+$ + n. The IBD reaction is characterized by two time correlated signals, a prompt one from the production and subsequent annihilation of the positron, and a delayed one from the neutron capture in the liquid scintillator. The expected background includes the geo-neutrinos, accidental coincidences, cosmogenic muon induced backgrounds and so on. After event selection, the anticipated IBD signal rate is about 60/day and the background rate is about 3.8/day.

To estimate the JUNO mass hierarchy sensitivity, a chi-squared method is constructed to fit the antineutrino spectrum assuming the normal MH or inverted MH [13]. The difference of the minima is proportional to the MH sensitivity.The discriminator of the MH can be defined as

$$\Delta\chi^2 = |\chi^2_{min}(N) - \chi^2_{min}(I)|. \quad (1)$$

For the ideal case, as shown by Figure 4, the $\Delta\chi^2 is >$ 16 (4σ) with 6 years of data. If we take into account the spread of reactor cores, uncertainties from energy non-linearity, etc, the mass hierarchy sensitivity with 6 years of data-taking can reach $\Delta\chi^2 > 9$ (3σ) with a relative measurement and $\Delta\chi^2 > 16$ with an absolute $\Delta m_{\mu\mu}$ measurement from accelerator neutrino experiments.

JUNO is a multipurpose experiment that can also measure neutrino oscillation parameters [14]. The precision of three parameters(Δm^2_{21},Δm^2_{ee},$\sin^2\theta_{12}$) will reach the sub-percent level, several times improved compared with the current precision.

The detector concept of JUNO is shown in Figure 5. The central detector is an acrylic sphere filled with 20 ktons of liquid scintillator. There are around 18,000 20-inch PMTs installed in the central detector, combined with 36,000 3-inch PMTs as a redundant calorimeter. The outer part is filled with ultrapure water and equipped with more than 2,000 20-inch PMTs to serves as a water Cherenkov detector for cosmogenic muon de-