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Prospects of oscillation physics with JUNO

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The Jiangmen Underground Neutrino Observatory (JUNO) is a 20 kton liquid scintillator detector that will study reactor antineutrinos emitted from two nuclear power plants in the south of China at a baseline of about 53 km. Thanks to its two photon detection systems (17612 20-inch PMTs and 25600 3-inch PMTs), JUNO will achieve an unprecedented 3% energy resolution at 1 MeV along with an energy scale calibration uncertainty of 1%. Such powerful detector performances will allow to resolve, for the first time, the interference pattern between the solar and atmospheric oscillation modes. Therefore, the primary physics goals of JUNO include the determination of the neutrino mass ordering at a 3-sigma confidence level and the measurement of three neutrino oscillation parameters, $\sin^2\theta_{12}$, Δm^2_{21} and Δm^2_{32}, with sub-percent precision. This talk will cover the oscillation physics potential of JUNO, also showing the impact of JUNO future results within the global neutrino framework.

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1. Introduction

Neutrino oscillations have become a precision science in the last decades thanks to a new generation of experiments that have allowed the compilation of new data from long-baseline accelerators and nuclear reactors. These oscillations are governed by six independent parameters: 3 mixing angles θ_{12}, θ_{23} and θ_{13}, two mass squared differences Δm^2_{21} and $\Delta m^2_{31}/\Delta m^2_{32}$ and a δ_{CP} phase responsible for the CP-violation. However there are still open challenges, as the value of δ_{CP} or the sign of Δm^2_{31}, the latter giving rise to the so-called neutrino mass ordering (NMO) problem.

The Jiangmen Underground Neutrino Observatory (JUNO) is a multi-purpose reactor neutrino experiment which aims to determine the NMO and measure the oscillation parameters with sub-percent precision [1]. The JUNO detector, under construction, is located at equal distances of ~53 km from the Yangjiang and the Taishan nuclear power plants and has been optimized to have the best sensitivity for determining the NMO. JUNO, depicted in Fig.1, consists of a neutrino target mass of a 20 kton liquid scintillator (LS) sphere, surrounded by 17.612 large 20-inch photomultiplier tubes, referred to as LPMTs, and 25.600 small 3-inch PMTs or SPMTs, yielding 77.9% photo-cathode coverage. The intrinsic dual-calorimetry of JUNO is crucial to achieve an unprecedented energy resolution better than 3% at 1 MeV, required for the NMO determination [2].

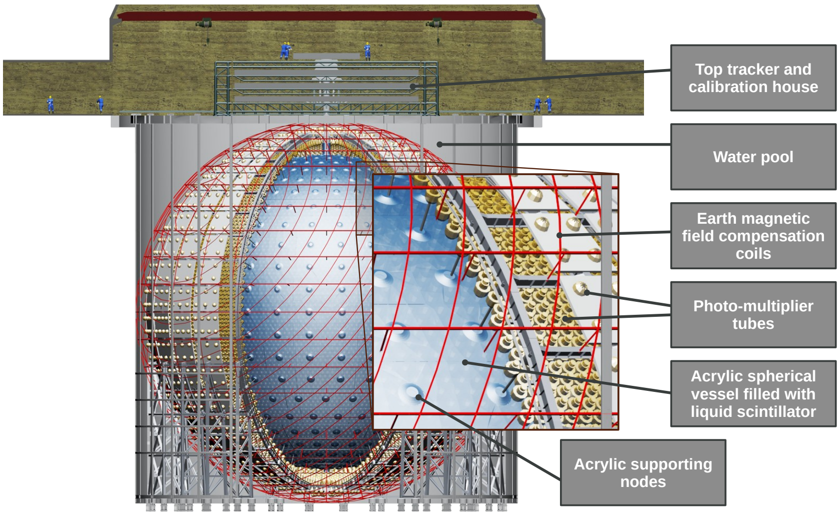

Figure 1: Schematic view of the JUNO detector.

2. JUNO physics with reactor antineutrinos

Around 60 reactor antineutrinos $\bar{\nu}_e$ per day, major signal of the JUNO experiment, are detected through their interaction via the inverse beta decay (IBD) with a proton of the LS: $\bar{\nu}_e + p \longrightarrow e^+ + n$. Reactor neutrino experiments use IBD to detect $\bar{\nu}_e$ due to two major reasons: the charged current interaction has a larger interaction cross section for $\bar{\nu}_e$ with energy of a few MeV than any other processes, and the final state particles (positron and neutron) can be detected in coincidence, which largely suppresses backgrounds compared with the single signal detection. After applying the IBD selection criteria to suppress any radiogenic or cosmogenic events, as well as any possible geoneutrinos, JUNO will be able to detect 47 $\bar{\nu}_e$ per day, with a selection efficiency of ~82%.

At the JUNO experimental site, the neutrino energy spectrum will be distorted by a slow (low frequency) oscillation driven by Δm^2_{21} and modulated by $\sin^2\theta_{12}$, as well as a fast (high frequency) oscillation driven by Δm^2_{31} and modulated by $\sin^2\theta_{13}$. JUNO will be the first experiment to observe these two modes of oscillation simultaneously. Fig.2 shows the $\bar{\nu}_e$ spectrum expected in JUNO.

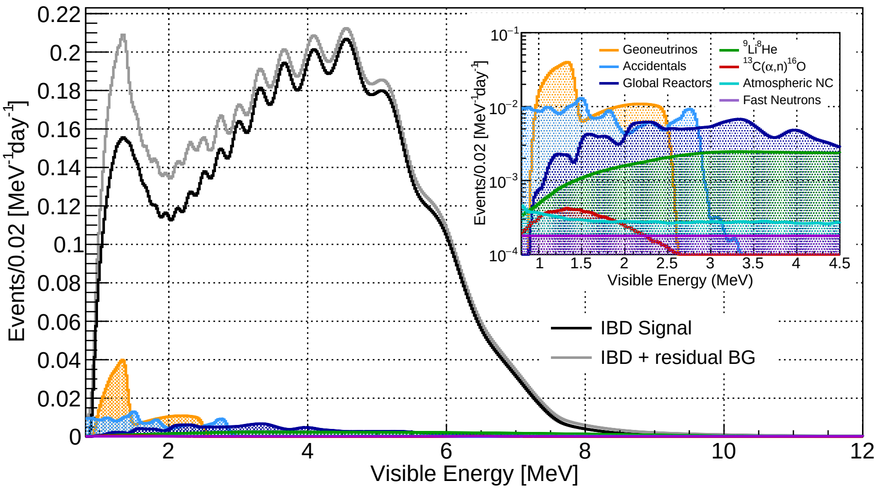

Figure 2: Visible energy spectrum and background spectra expected in JUNO detector.

In order to eliminate any possible model dependance on the reactor antineutrino spectrum, the Taishan Antineutrino Observatory (TAO) [3] is proposed as a satellite experiment. It will be located 30 m from one of the Taishan reactor cores and provide the $\bar{\nu}_e$ energy spectrum with an energy resolution better than 2% at 1 MeV, helping in addition to reduce the reactor flux shape uncertainty.

2.1 NMO determination

As previously mentioned, disentangling the two oscillation modes (normal and inverted) requires the detector to have the ability to measure the fast atmospheric oscillations. The sensitivity of JUNO to the NMO is calculated using an Asimov sample. The positron spectrum is fitted assuming normal or inverted ordering with the χ^2 method and the correct ordering is then determined by constructing the estimator $\Delta\chi^2_{\rm NMO} = |\chi^2_{\rm min}({\rm NO}) - \chi^2_{\rm min}({\rm IO})|$.

Since JUNO sensitivity is based on the vacuum oscillations, the NMO determination has no dependence on the unknown CP-violating phase and the θ_{23} octant, adding unique information when combined with other neutrino experiments. Fig. 3 depicts that after 6 years of data taken, 26.6 GW of exposure, the expected sensitivity would be larger than 3σ by fitting JUNO's data alone. The improvement on the energy resolution (from 3% to 2.9% at 1 MeV) is embedded in this result [4]. By using an external 1% constraint from ν_μ disappearance measurements, the NMO sensitivity can be improved to 4σ [5]. Furthermore the combined sensitivity of JUNO together with accelerator experiments has the potential to yield the first resolved ($\geq 5\sigma$) measurement of the NMO [6].

2.2 Precision Measurement of Oscillation Parameters

Besides the determination of the NMO, JUNO is expected to give a precise measurement of $\sin^2\theta_{12}$, Δm^2_{21} and $\Delta m^2_{31}/\Delta m^2_{32}$. The precision measurement of these parameters is a powerful tool

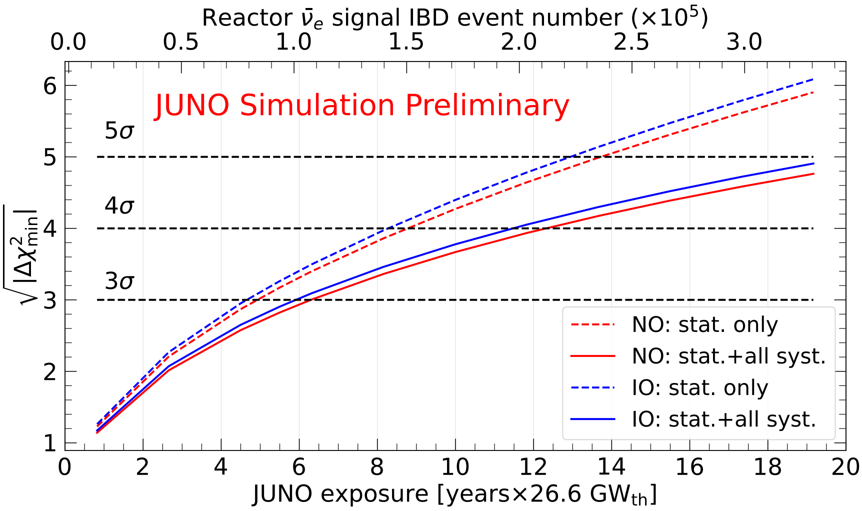

Figure 3: The NMO discriminator $\Delta\chi^2_{min}$ as a function of JUNO exposure time for both normal (red) and inverted (blue) ordering Asimov data set.

to test the standard three-flavor neutrino picture and discover physics beyond the Standard Model.

To extract the neutrino oscillation parameters, the expected spectrum that JUNO will measure, illustrated in Fig. 2, is compared against the hypothesis model obtained using the nominal oscillation parameters from [7]. JUNO is expected to improve today's precision by measuring three out of six neutrino oscillation parameters to the per mile precision, as shown in table 1. In fact, JUNO will dominate the world precision on those parameters with only about 100 days of data taking [8].

	Central Value	PDG2020	100 days	6 years	20 years
Δm^2_{31} ($\times 10^{-3}$ eV^2)	2.5283	±0.034 (1.3%)	±0.021 (0.8%)	±0.0047 (0.2%)	±0.0029 (0.1%)
Δm^2_{21} ($\times 10^{-5}$ eV^2)	7.53	±0.18 (2.4%)	±0.074 (1.0%)	±0.024 (0.3%)	±0.017 (0.2%)
$\sin^2\theta_{12}$	0.307	±0.013 (4.2%)	±0.0058 (1.9%)	±0.0016 (0.5%)	±0.0010 (0.3%)
$\sin^2\theta_{13}$	0.0218	±0.0007 (3.2%)	±0.010 (47.9%)	±0.0026 (12.1%)	±0.0016 (7.3%)

Table 1: Precision levels for the oscillation parameters. The current knowledge (PDG2020 [7]) is compared with 100 days, 6 years and 20 years of JUNO data taking. No external constraint on $\sin^2\theta_{13}$ is applied.

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