Snowmass2021 - Letter of Interest

The JUNO Experiment

NF Topical Groups: (check all that apply ☐/■)

■ (NF1) Neutrino oscillations
■ (NF2) Sterile neutrinos
■ (NF3) Beyond the Standard Model
■ (NF4) Neutrinos from natural sources
■ (NF5) Neutrino properties
☐ (NF6) Neutrino cross sections
☐ (NF7) Applications
☐ (NF8) Theory of neutrino physics
■ (NF9) Artificial neutrino sources
■ (NF10) Neutrino detectors
☐ (Other) *[Please specify frontier/topical group(s)]*

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Abstract: The Jiangmen Underground Neutrino Observatory (JUNO) is a multi-purpose liquid scintillator detector under construction in Kaiping, South China. With a total target mass of 20 ktons, and an unprecedented energy resolution of 3% at 1 MeV, JUNO will be the largest and most precise liquid scintillator detector ever built. The experiment will be located in an underground hall with a 700 m overburden at a distance of 53 km from 8 nuclear reactor cores. Thanks to its unique location and properties, JUNO will feature a rich physics program beginning in 2022 that is complementary to the neutrino program pursued by the United States. The experiment will be able to determine the neutrino mass hierarchy at the $\sim 3\sigma$ level independently from CP violation effects and the θ_{23} octant ambiguity within 6 years of running. It will also be able to determine three oscillation parameters, Δm^2_{21}, $\sin^2 2\theta_{12}$, and $|\Delta m^2_{31}|$, to unprecedented sub-percent precision. JUNO will also pursue an observational program with neutrinos from natural sources, with excellent sensitivity to the Diffuse Supernova Neutrino Background (DSNB) and the geoneutrino flux. Finally, the experiment will conduct very sensitive searches for new physics, such as proton decay in the $K^+\bar{\nu}$ mode.

Key words: mass ordering, mass hierarchy, precision oscillation parameters, geoneutrinos, supernova neutrinos, proton decay, solar neutrinos, atmospheric neutrinos, JUNO.

The JUNO Experiment

The Jiangmen Underground Neutrino Observatory (JUNO) is a multipurpose neutrino experiment located at a strategic distance of 53 km from two nuclear power plants in the southeast of China, Yangjiang and Taishan. A schematic of the main detector is shown on the left panel of Fig. 1. The central detector consists of a 35.4 m diameter acrylic sphere containing 20 ktons of undoped liquid scintillator (LS). This sphere is immersed in an ultrapure water volume containing around 18,000 20-inch and 25,600 3-inch inward-facing photomultiplier tubes (PMTs) that provide $\sim 75\%$ photocathode coverage. A 35 kton ultrapure water volume, optically decoupled from the central detector and instrumented with about 2,400 20-inch PMTs, serves as a water Cherenkov detector to tag cosmic ray muons, as well as a buffer against natural radioactivity and neutrons from cosmic rays. A top-tracker consisting of 3 layers of plastic scintillator panels provide additional coverage and precision tracking information. More information about the design of the JUNO experiment can be found in Refs. [1, 2].

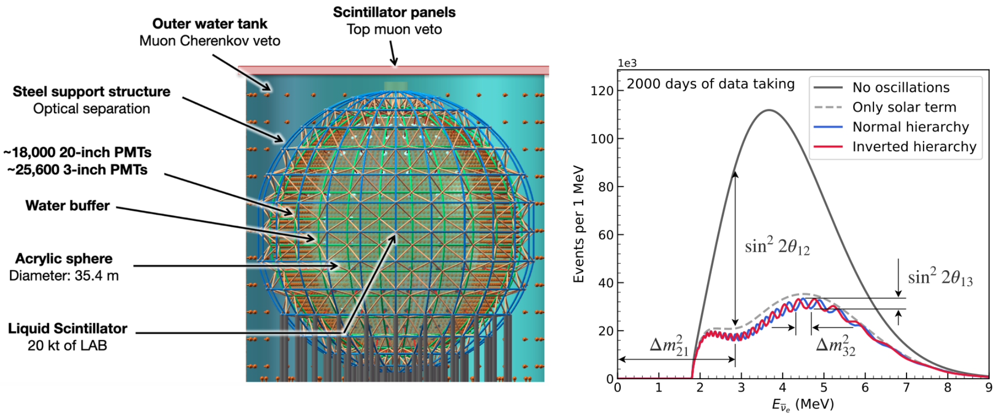

Figure 1: Left: schematic of the JUNO experiment, as described in the text. Right: oscillated and unoscillated spectrum at JUNO with infinite statistics and energy resolution, for the normal ordering (NO) and the inverted ordering (IO).

JUNO's primary detection channel will be the inverse beta-decay reaction, $\bar{\nu}_e + p \rightarrow e^+ + n$. The experiment is designed to achieve an energy resolution of 3% at 1 MeV and an energy scale uncertainty of 1%, enabled through an aggressive calibration program. Construction is ongoing, and data taking is expected to begin in 2022.

Physics with JUNO

A detailed list of JUNO's physics prospects can be found in Ref. [2]. These are some of the main highlights:

Oscillation Physics with Reactor Antineutrinos: a schematic showing the oscillated spectrum expected at JUNO is shown on the right panel of Fig. 1, illustrating the small effect that the choice of mass ordering has on the subdominant "fast" oscillations (modulated by $\sin^2 2\theta_{13}$) running on top of the "slow" oscillations (modulated by $\sin^2 2\theta_{12}$). With an energy resolution of 3% at 1 MeV, JUNO will be able to discriminate between these two scenarios to 3σ or higher with 6 years of data. The precise measurement of the oscillated neutrino spectrum will also allow to determine $\sin^2 2\theta_{12}$, Δm^2_{21}, and $|\Delta m^2_{32}|$ to significantly better than 1%. These measurements are largely complementary to the worldwide neutrino program and can be expected to have a strong impact on other experiments, model building, and unitarity tests of the neutrino mixing matrix.

Physics with Neutrinos from Natural Sources: an average core-collapse supernova at a distance of 10 kpc will allow to collect about 5000 IBD events and 2000 all-flavor neutrino-proton elastic scattering events with an unparalleled energy resolution and a very low threshold ($\sim$0.1 MeV). Furthermore, with an expected detection significance of 3-5σ after 10 years depending on the model considered, JUNO will have a leading sensitivity to the DSNB created by past core-collapse supernovae. This measurement will provide valuable information on quantities such as the cosmic supernova (SN) rate and the average SN neutrino spectrum.

JUNO will collect geoneutrinos at an unprecedented rate of about 400 per year, which amounts to almost double the total sample existing to date [3, 4] yearly. Despite the large reactor antineutrino background, the geoneutrino flux will be determined with a precision of $\sim$5% after 10 years. This will likely constitute the most precise measurement of this kind for a long time, and will help place important constrains on the composition and heat budget of our planet. Moreover, atmospheric neutrinos in JUNO will provide complementary information for the determination of the mass hierarchy and the octant of the θ_{23} mixing angle. ^{7}Be and ^{8}B solar neutrinos will shed new light on the solar metallicity problem and on the transition region between the vacuum and matter dominated neutrino oscillations [5]. JUNO will also be able to explore the tension observed in the measurements of Δm^2_{21} between reactor and solar neutrino experiments [6, 7] within the same detector.

Searches for New Physics: JUNO has a particular advantage for proton decay searches in the $p \to \bar{\nu} + K^+$ channel, thanks to the K^+ signal being visible in the LS and forming a triple coincidence with the subsequent μ^+ and e^+ signals. The experiment will also be a good ground to search for other exotic physics, such as neutrinos caused by dark matter annihilation in the Sun and Lorentz invariance violation. Sterile neutrinos in a wide range of masses could also be sought for with radioactive sources or a cyclotron-produced beam.

Reactor Antineutrino Physics: JUNO will also deploy a satellite detector called the Taishan Antineutrino Observatory (TAO) at a distance of roughly 30 m from one of the cores of the Taishan Nuclear Power Plant. The details about this detector, as well as its physics program, are covered in a separate LOI [8].

Complementarity with Worldwide Neutrino Program

There is a high level of complementarity between JUNO and the neutrino program being pursued in the United States and the rest of the world.

For the foreseeable future, JUNO will be the only experiment addressing the neutrino mass ordering via reactor antineutrino disappearance. This channel is unaffected by CP violation effects and the ambiguity in the θ_{23} octant, and can be combined with long-baseline measurements to achieve a definitive answer for the realized mass ordering [9, 10]. No other upcoming experiment will be able to determine Δm^2_{21} and $\sin^2 2\theta_{12}$ to a comparable precision. JUNO will likely also produce the most precise determination of $|\Delta m^2_{32}|$, although next-generation accelerator experiments are expected to achieve a comparable precision at the $< 0.5\%$ level [11, 12]. JUNO's oscillation measurements will thus provide unique information to the community that will allow to characterize and test the three neutrino framework well beyond current limits.

Moreover, JUNO has an edge for low-energy neutrino detection. Simply put, no other experiment combines the low-threshold, large size, and exquisite energy resolution of JUNO. Its measurements with neutrinos from reactors and natural sources will provide the community with complementary and in some cases unique information compared to what can be learned in other experiments.

Finally, there is potential for turning JUNO into a world-class facility to search for $0\nu\beta\beta$ decays. For more information about this exciting possibility, please refer to the corresponding LOI [13].

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