PROCEEDINGS OF SCIENCE

JUNO's physics prospects

Jie Cheng[a,1,*]

[a] *North China Electric Power University,*
Beijing, China

E-mail: `chengjie@ncepu.edu.cn`

The 20 kton liquid scintillator detector of the Jiangmen Underground Neutrino Observatory (JUNO) is under construction in an underground laboratory in South China. The JUNO detector construction is expected to be completed by 2023. With an excellent energy resolution and large detector volume and excellent background control, JUNO is expected to determine the neutrino mass ordering, and provide precise measurements on the neutrino oscillation parameters $\sin^2\theta_{12}$, Δm^2_{21}, and $|\Delta m^2_{32}|$. As a multi-purpose neutrino observatory, JUNO also has world competitive potential on the searches for diffuse supernova neutrino background, core-collapse supernova neutrinos, solar neutrino, atmospheric neutrinos, geo-neutrinos, nucleon rare decays and other new physics beyond the Standard Model. In this paper, the latest evaluations on the prospects of JUNO's physics goal are presented.

41st International Conference on High Energy physics - ICHEP2022
6-13 July, 2022
Bologna, Italy

PoS(ICHEP2022)571

---

[1] on behalf of the JUNO Collaboration
[*] Speaker

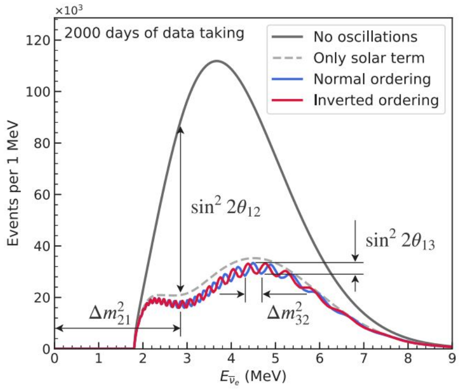

Figure 1: The expected antineutrino energy spectrum weighted by IBD cross-section at JUNO [3].

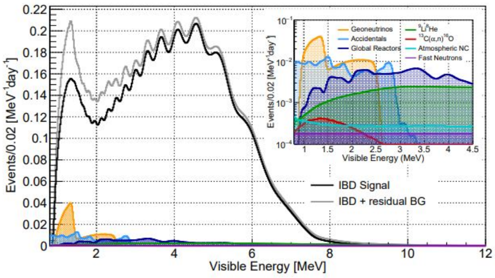

Figure 2: The expected reactor antineutrino IBD signal and background spectra at JUNO [3].

1. Introduction

The Jiangmen Underground Neutrino Observatory (JUNO), a 20 kton multi-purpose liquid scintillator (LS) detector with an expected energy resolution of $3\%/\sqrt{(E[\mathrm{MeV}])}$, is currently under construction in a laboratory around 700 meters underground and would be the largest LS detector ever built. The detector assembly and installation are in progress and are scheduled to be completed by 2023. The JUNO experiment is located at Jiangmen in Guangdong province, China, with the primary goals of determining the neutrino mass ordering (NMO) [1, 2] and the precision measurement of oscillation parameters [3] with reactor antineutrinos, together with other physics program, including studies of neutrinos from the Sun [4], the planet Earth [2], the atmosphere [5], and the supernova [6, 7] as well as the exploration of physics beyond the Standard Model [1]. This paper provides an updated evaluation on the prospects of JUNO's physics goal [1].

2. Physics with JUNO

2.1 Reactor antineutrino

The antineutrinos from the reactors near JUNO serve as the primary signal for determining the NMO and providing precise measurements on the neutrino oscillation parameters $\sin^2\theta_{12}$, Δm^2_{21}, and $|\Delta m^2_{32}|$. Most reactor antineutrinos in JUNO will originate from two and six cores in the Taishan and Yangjiang nuclear power plants (NPPs), respectively. Both plants are located at a baseline of about 53 km, which was optimized for the NMO sensitivity. They have a combined nominal thermal power of 26.6 $\mathrm{GW_{th}}$. JUNO measures the reactor antineutrino using the inverse-beta-decay (IBD) reaction channel on free proton (~ 99%) or carbon (~ 1%). The energy characteristics, time correlation, and spatial correlation between the prompt and delayed signals allow for significant reduction in background events.

Fig. 1 shows the reactor antineutrino spectrum without (black) and with (grey, blue and red) the effect of neutrino oscillation in the JUNO location, assuming 6 years of data-taking. As shown in Fig. 1, the energy spectrum will be distorted by a low frequency oscillation driven by Δm^2_{21} and modulated by $\sin^2\theta_{12}$, as well as a high frequency oscillation driven by Δm^2_{31} and modulated by

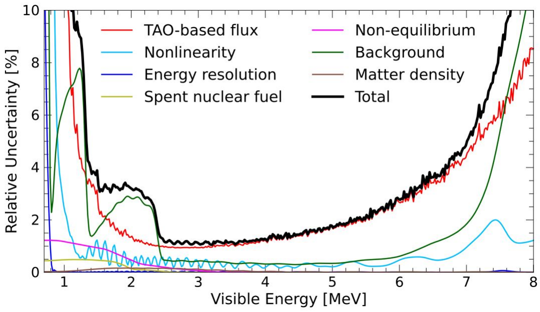

Figure 3: Shape uncertainties relative to the number of events in each bin [2].

$\sin^2\theta_{13}$. JUNO will simultaneously measure these two oscillation modes. The NMO information is contained in the small oscillation peaks in the oscillated antineutrino spectrum. For the JUNO's primary physics goals, where energy resolution and spectral shape uncertainty are two key points, having a comprehensive understanding of spectral shape is crucial.

Based on the measurement and simulation, we have predicted the spectra and rates of reactor antineutrino signal and backgrounds, as shown in Fig. 2. Several updates have impacted the spectra and rates of signal and background, with corresponding impacts to the NMO analysis and precise oscillation parameter measurements since the Ref. [1]. For example, only two of the four original Taishan NPP reactor cores were constructed, leading to a lower signal rate. On the other hand, the measured light yield and photomultiplier tube quantum efficiency were higher than the estimates in the Ref. [1]. The light yield in detector center is about 1345 PEs/MeV [8], resulting in an energy resolution of 3% at 1 MeV. It should be noted that according to the recent analysis, an increase of up to 20% of the light level is possible.

In addition to the changes mentioned above, there is a satellite detector named the Taishan Antineutrino Observatory (TAO) [9]. TAO Liquid Scintillator will operate at a temperature of -50 °C with an energy resolution of roughly $2\%/\sqrt{(E[\mathrm{MeV}])}$ and is located about 30 m from one of the Taishan reactor cores. Thanks to larger statistics and high energy resolution of TAO, we can measure the unoscillated reactor spectrum with unprecedented precision, which allow us to constrain the shape uncertainty of the reactor antineutrino energy spectrum close to the assumption in the Ref. [1], as shown in Fig. 3.

2.1.1 Neutrino mass ordering

To obtain the JUNO sensitivity, an Asimov data set was generated using the processes described above under either the normal ordering (NO) or inverted ordering (IO) hypothesis. Fitting an Asimov data set with the assumptions of both NO and IO yielded a chi-square, and the difference of minima in $\Delta\chi^2_{\mathrm{NMO}} = |\chi^2_{\mathrm{min}}(\mathrm{NO}) - \chi^2_{\mathrm{min}}(\mathrm{IO})|$, was used to calculate NMO sensitivity [1, 2], where $\chi^2_{\mathrm{min}}(\mathrm{NO})$ and $\chi^2_{\mathrm{min}}(\mathrm{IO})$ are the minima of the chi-square function under the NO and IO hypothesis, respectively. With only reactor antineutrino data, the median sensitivity of JUNO in determining the NMO would be 3σ after 6 years of data-taking. Note that the NMO sensitivity is further enhanced by combining with atmospheric neutrinos, and work on this is ongoing.

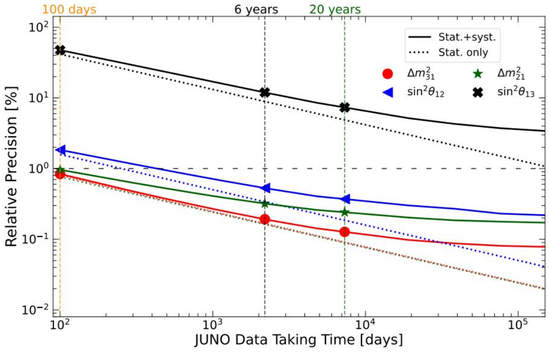

Figure 4: Relative precision of the oscillation parameters as a function of JUNO data taking time [3].

2.1.2 Precision measurement of oscillation parameters

Thanks to a large number of reactor antineutrinos and excellent detector performance, JUNO will be able to measure the neutrino oscillation parameters $\sin^2\theta_{12}$, Δm^2_{21}, and $|\Delta m^2_{32}|$ to an unprecedented precision of better than 1%. The time evolution of the JUNO precision sensitivity is illustrated in Fig. 4, which shows that after roughly a year of JUNO data-taking, the precision of oscillation parameters will reach the sub-percent era.

2.2 Supernova neutrinos

2.2.1 Neutrinos from supernova burst

JUNO's 20 kton LS provides excellent detection of all flavors of $\mathcal{O}$(10 MeV) neutrinos from supernova (SN) burst using multi-channels, such as IBD, the elastic neutrino–electron scattering and the elastic neutrino–proton scattering. JUNO will be able to detect ~7300 SN neutrinos [2] for a typical galactic distance of 10 kpc and typical SN parameters.

2.2.2 Diffuse supernova neutrino background [7]

Large underground neutrino detectors, such like JUNO, are expected to detect the diffuse supernova neutrino background (DSNB), which is the integrated neutrino signal from all SN explosions in the Universe. Depending on the DSNB model, we expect about 2-4 IBD events per year in the energy range above the reactor antineutrino signal. The results in the Ref. [1] significantly improve when the latest DSNB signal predictions, more realistic background evaluation, the pulse shape discrimination efficiency optimization, and additional triple coincidence cuts are used [7]. As shown in Fig. 5, JUNO would reach the significance of 3σ for 3 years of data taking. In the pessimistic scenario of non-observation, JUNO can be set the world-leading best limits of DSNB $\bar{\nu}_e$ flux.

2.3 Solar neutrinos

JUNO as an LS detector with a much larger mass, has the potential to significantly advance our knowledge of solar neutrinos. JUNO can make a high-statistics measurement of the flux and spectral shape of ^{8}B solar neutrinos by using the elastic scattering (ES) interaction on electrons with an energy threshold of around 2 MeV. The data can also be used to independently measure the oscillation parameters Δm^2_{21} to 20% precision and $\sin^2\theta_{12}$ to 8% precision [4]. Aside from

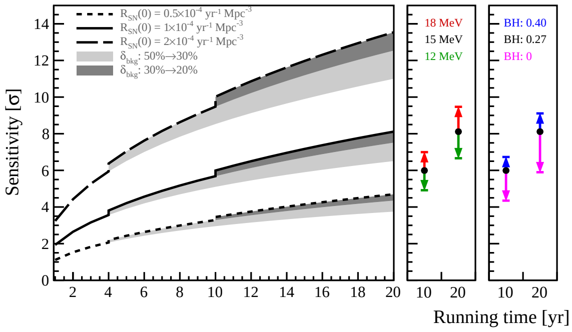

Figure 5: DSNB discovery potential (σ) at JUNO as a function of the running time [7].

the high statistics measurement in the ES channel, the presence of a large mass of the ^{13}C nuclei ($\sim$ 0.2kt) allows for the detection of ^{8}B solar neutrinos via charged-current (CC) and neutral-current (NC) interactions on ^{13}C. It has been discovered through a combined analysis of all three detection channels that it is possible to measure the ^{8}B solar neutrino flux with a 5% precision [10].

Thanks to its unprecedented energy resolution and lower energy threshold, JUNO can simultaneously measure ^{7}Be, pep, and CNO solar neutrinos. It should be noted that the relative uncertainty of the measurement is highly dependent on the final radioactivity level.

2.4 Other physics topics

In addition to the physics discussed above, JUNO with a 20 kton LS is sensitive to atmospheric neutrinos, geo-neutrinos, nucleon decays and other new physics, as detailed in the Ref. [1, 2].

3. Conclusion

JUNO is 20 kton LS detector, under construction in an underground laboratory in South China. An excellent energy resolution and a large fiducial volume offer the potential to address a wide range of important topics in neutrino and astro-particle physics. The detector construction will be completed by 2023.

References

[1] F. An *et al.* [JUNO Collaboration], "Neutrino Physics with JUNO," J. Phys. G **43**, 030401 (2016).

[2] A. Abusleme *et al.* [JUNO], "JUNO Physics and Detector," Prog. Part. Nucl. Phys. **123**, 103927 (2022).

[3] A. Abusleme *et al.* [JUNO], "Sub-percent Precision Measurement of Neutrino Oscillation Parameters with JUNO," Chin. Phys. C **46**, no.12, 123001 (2022), [arXiv:2204.13249 [hep-ex]].

[4] A. Abusleme *et al.* [JUNO], "Feasibility and physics potential of detecting ^{8}B solar neutrinos at JUNO," Chin. Phys. C **45**, no.2, 023004 (2021).

[5] A. Abusleme *et al.* [JUNO], "JUNO sensitivity to low energy atmospheric neutrino spectra," Eur. Phys. J. C **81**, 10 (2021).

[6] J. S. Lu, Y. F. Li and S. Zhou, "Getting the most from the detection of Galactic supernova neutrinos in future large liquid-scintillator detectors," Phys. Rev. D **94**, no.2, 023006 (2016).

[7] A. Abusleme *et al.* [JUNO], "Prospects for detecting the diffuse supernova neutrino background with JUNO," JCAP **10**, 033 (2022)

[8] A. Abusleme *et al.* [JUNO], "Calibration Strategy of the JUNO Experiment," JHEP **03**, 004 (2021)

[9] A. Abusleme *et al.* [JUNO], "TAO Conceptual Design Report: A Precision Measurement of the Reactor Antineutrino Spectrum with Sub-percent Energy Resolution," [arXiv:2005.08745 [physics.ins-det]].

[10] A. Abusleme *et al.* [JUNO], "Model Independent Approach of the JUNO ^{8}B Solar Neutrino Program," [arXiv:2210.08437 [hep-ex]].