PROCEEDINGS OF SCIENCE

JUNO's sensitivity to ^{7}Be, *pep*, and CNO solar neutrinos

Apeksha Singhal[1,2,*] **for the JUNO collaboration**

[1] *Institut für Kernphysik, Forschungszentrum Jülich, 52425 Jülich, Germany*

[2] *III. Physikalisches Institut B, RWTH Aachen University, 52062 Aachen, Germany*

E-mail: a.singhal@fz-juelich.de

The multipurpose JUNO Experiment located in China, whose central detector uses 20 kt liquid scintillator, is on the track to completion of its construction in 2023. Its primary goal is to determine the Neutrino Mass Ordering by leveraging its large target mass and the excellent energy resolution of 3% at 1 MeV. The unique properties of JUNO position it to have a large potential for the real-time solar neutrino measurements. A sensitivity study is performed by considering all potential sources of backgrounds at various radiopurity levels, along with a full simulation of the detector response using reconstructed variables. Our results indicate that for the most of the background level scenarios, JUNO will be able to improve the current best measurements of ^{7}Be, *pep*, and CNO solar neutrino fluxes. Furthermore, JUNO has a potential to measure individually for the first time the rate of the two main components of the CNO neutrino flux, namely the ^{13}N and ^{15}O solar neutrinos. This article summarizes the strategy used for the estimation of the JUNO's sensitivity to ^{7}Be, *pep*, and CNO solar neutrinos above 0.45 MeV and presents the final results.

The European Physical Society Conference on High Energy Physics (EPS-HEP2023)
21-25 August 2023
Hamburg, Germany

[*]Speaker

PoS(EPS-HEP2023)193

1. Introduction

The two distinct sets of hydrogen-to-helium fusion reactions that power our Sun, are classified as the proton-proton (*pp*) chain and the Carbon-Nitrogen-Oxygen (CNO) cycle. The *pp* chain is the dominant process in the Sun, contributing about 99% of the solar energy. Several types of solar neutrinos, the carriers of information about the energy production mechanism in the Sun's core and its chemical composition, are emitted in these processes. In the *pp*-chain, the *pp*-ν, ^{7}Be-ν, *pep*-ν, ^{8}B-ν, and hep-ν are emitted, while the ^{13}N, ^{15}O, and ^{17}F neutrinos (collectively referred as the CNO-ν) are produced in the CNO cycle. There has been a longstanding problem in the solar physics, the *solar metallicity puzzle* [1], which still remains unsolved. The next generation experiments such as the JUNO (Jiangmen Underground Neutrino Observatory) could provide insights to this problem by precisely measuring the solar neutrino fluxes.

JUNO is the first multi-kiloton (20 kt) liquid scintillator (LS) experiment, currently under construction in southern China [2]. It features unprecedented energy resolution of ~3% at 1 MeV and large photocathode coverage (~78%). The primary goal of JUNO is the determination of neutrino mass ordering (NMO) by measuring reactor anti-neutrinos. It also provides further opportunities for the studies in various topics of the neutrino and astroparticle physics, thanks to its excellent properties. JUNO's potential to detect ^{8}B-ν has already been studied in [3]. In this article, we summarize the sensitivity of JUNO to ^{7}Be, *pep*, and CNO solar neutrinos, considering various possible experimental conditions such as the background levels and the exposure.

2. Solar neutrinos and backgrounds in JUNO

In JUNO, the solar neutrinos are detected by elastic scattering off electrons. The energy of recoiled electron is deposited in LS and the dominant scintillation photons are produced isotropically, which are then detected by PMTs. The visible energy (E_{vis}) spectrum is obtained for the recoiled electrons from all the solar-ν sources. Here, we study the sensitivity to solar neutrinos in an energy range 0.45 MeV<E_{vis} <1.6 MeV, to avoid ^{14}C and its pile-up, which are dominant at the low energies. In this energy range, the decay of radioactive isotopes such as ^{40}K, ^{85}Kr, the ^{232}Th chain, the ^{238}U chain and the ^{210}Pb chain, present inside LS cause background events. We have assumed 4 scenarios of their concentration levels:

High Background scenario: This is the minimum requirement for the NMO studies.

Medium Background scenario: It represents concentration levels with a factor of 10 improvement compared to the high background scenario for all isotopes.

Low Background scenario: It represents concentration levels with a factor of 10 improvement compared to the medium background scenario for all isotopes, except the ^{210}Pb and ^{285}Kr with improvement factor of 5.

Very Low Background scenario: This is the radiopurity levels reached by the Borexino experiment in Phase-III [4, 5] period.

The cosmogenic isotopes such as ^{11}C, ^{10}C, and ^{6}He, created by the cosmic muon spallation on carbon atoms inside the LS, also contribute in the chosen energy range. The so-called Three-Fold-Coincidence (TFC) algorithm [6] is used to identify the cosmogenic events by finding the space-time coincidence between the spallation reaction by parent muon, the cosmogenic decay, and a neutron capture. Using the TFC, the dataset is split into 2 complementary samples: TFC-tagged (enriched in cosmogenic events) and TFC-subtracted (depleted in cosmogenic events). Its performance is given by: *Tagging power (TP)*: the percentage of correctly identified cosmogenic events; *Subtracted exposure (SE)*: the remaining exposure in TFC-subtracted dataset. Their values chosen in the analysis are TP = 0.9 and SE = 0.7, similar to working values in Borexino. Using Monte Carlo (MC) simulations, we found that using a spherical fiducial volume (FV) with radius of 14 m, external backgrounds (^{208}Tl, ^{214}Bi, and ^{40}K) have negligible contribution in the analysis.

3. Sensitivity extraction strategy and results

In JUNO, the solar-ν events are generally indistinguishable on an event-by-event basis from the backgrounds' events. So, we perform a fit of the energy distributions of detected events (sum of neutrino and background contributions) in the FV with the corresponding probability density functions (PDFs) from JUNO MC simulations. The two datasets, TFC-tagged and TFC-subtracted energy spectra, are created by randomly sampling the PDFs for each component according to the given exposure and radiopurity scenario. The fit is based on the maximisation of binned Poissonian likelihood function, where the rates of each species are left free to vary, otherwise indicated. By performing 10,000 pseudo-experiments, the distribution of relative statistical error of each solar-ν is obtained. The quoted central value of sensitivity is the median, and the left as well as the right errors are estimated by the distance between median and 34% C.L. band extremes.

Using this approach, we find that after a few years of data-taking, JUNO can reach and overcome the current best result on ^{7}Be-ν rate from Borexino [4] in all radio-purity scenarios as shown in Figure 1. For longer data-taking, JUNO will measure ^{7}Be-ν rate with unprecedented precision: from ~1.0% in the High Background scenario to ~0.15% in the Very Low Background case. The critical backgrounds for ^{7}Be-ν rate measurements are ^{226}Ra, ^{210}Po, and ^{85}Kr and the measured ^{7}Be-ν rate precision worsens as a function of increased backgrounds levels.

For the first time, the *pep*-ν flux can be measured by JUNO without using the constraint on the CNO-ν rate, which was necessary in Borexino to break spectral degeneracy [4]. After 2 years of data-taking (except for the High background level) JUNO will exceed the current best result from Borexino [4] as shown in Figure 1. For the long data-taking, JUNO will obtain competitive statistical errors by exceeding the Borexino's best result in all radio-purity scenarios. An investigation on the impact of TFC performance on the sensitivity to *pep*-ν has also been performed, since ^{11}C is the crucial background for the *pep* analysis. Except in the High background scenario, TP plays a central role with respect to SE.

After data-taking period of >6 years, JUNO will measure the CNO-ν rate with relative statistical error of ~10%, ~12%, and ~15% for the Very Low, Low, and Medium Background scenarios, respectively. These results would pave the way for measuring the solar metallicity using solar neutrinos. These results have been obtained by constraining *pep*-ν rate but without constraining ^{210}Bi background in the spectral fit for the first time. Without using *pep*-ν constraint, JUNO will measure CNO rate with comparable precision to that of Borexino [5] after two years in the Very Low and Low background scenarios. JUNO also has the potential to measure individually for the first time the rate of the two main components of the CNO flux, ^{13}N and ^{15}O neutrinos, except in the case of the High background level.

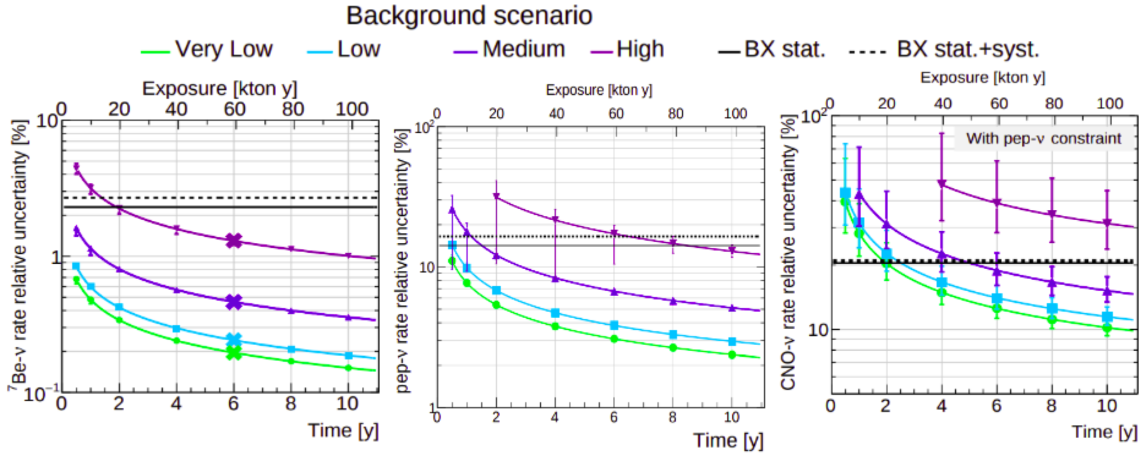

Figure 1: The relative errors of ^{7}Be (left), *pep* (middle) and CNO (right) solar-ν as a function of exposure. The *pep*-ν rate constraint is applied to extract the relative error of CNO solar-ν rate. The Very Low, Low, Medium, and High Background scenarios are shown respectively in green, light blue, blue, and purple solid lines. The best Borexino results, with and without the systematic uncertainty are reported as black dotted and solid lines respectively [7].

4. Conclusions

To conclude, JUNO will be able to measure the solar-ν rates with uncertainties highly competitive to the current state-of-the-art in the solar-ν field. After few years, JUNO will measure the ^{7}Be-ν with unprecedented errors in all radio-purity scenarios. The errors on *pep* measurement will also be significantly improved with respect to the current measurements after >6 years in all background levels. JUNO will also be able to provide the first simultaneous ^{7}Be, *pep*, and CNO measurement in case of optimistic radio-purity scenarios. Without using the ^{210}Bi rate constraint, JUNO will also be highly competitive for the CNO measurements for long data-taking periods. The first separation of ^{13}N and^{15}O neutrinos is also possible in JUNO [7].

References

[1] N. Vinyoles et. al., 2017 ApJ 835 202.

[2] A. Abusleme et. al (JUNO collaboration), Prog. Part. Nucl. Phys. 123 (2022) 103927.

[3] A. Abusleme et. al (JUNO collaboration), Chin. Phys. C 45 (2021) 023004. J. Zhao et. al (JUNO collaboration), arXiv:2210.08437 (2022).

[4] M. Agostini et. al. (Borexino Collaboration), Nature 562 (2018) 505.

[5] M. Agostini et. al. (Borexino Collaboration), Nature 587 (2020) 577; S. Appel et al. (Borexino Collaboration), Phys. Rev. Lett. 129 (2022) 252701.

[6] M. Agostini et. al. (Borexino Collaboration), Eur. Phys. J. C 81, 1075 (2021).

[7] A. Abusleme et. al.(JUNO collaboration), JCAP10(2023)022.