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JUNO potential for SN, solar, and atmospheric neutrinos

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JUNO (Jiangmen Underground Neutrino Observatory) will be the first multi-kton liquid scintillator detector. Its construction is currently under completion in South China. The active mass of the experiment will consist of 20 kton of organic liquid scintillator. Thanks to its huge volume, an unprecedented energy resolution and a great radiopurity of all its components, JUNO will be one of flagship neutrino experiments in the next decades: it will be able to detect and study neutrinos from different artificial and astronomical sources. In this contribution I will focus on JUNO potential for solar, supernova, and atmospheric neutrinos.

In case of good radiopurity of the liquid scintillator, JUNO will be very competitive in performing precision measurements of ^{7}Be, *pep*, and CNO solar neutrinos fluxes. Furthermore, the first model independent measurement of ^{8}B solar neutrino flux since SNO will be performed. JUNO will also be able to detect supernova neutrinos in case of a supernova explosion in our galaxy (or in the near proximity). Finally, JUNO will become the first liquid scintillator experiment to measure atmospheric neutrinos.

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1. The JUNO experiment

JUNO (Jiangmen Underground Neutrino Observatory) will be a multipurpose neutrino physics experiment. It is located in south China under a vertical overburden of ~ 650 m. Its Central Detector is composed of 20 kton of organic liquid scintillator (LS), placed inside an acrylic sphere of radius $r = 17.7$ m. The light will be detected by a set of 43212 photomultiplier tubes (PMTs) [1]. The main goal of JUNO is to determine the Neutrino Mass Ordering (NMO) with $\sim 3\,\sigma$ significance in $6 - 7$ years of data-taking through reactor antineutrinos [2]. However, thanks to its huge active volume, an unprecedented energy resolution of 3% at 1 MeV, and the great radiopurity of all its component, JUNO will also be able to detect and study neutrinos from astrophysical sources and to perform exotic searches. In this contribution I will focus on JUNO's potentials for solar, supernova, and atmospheric neutrinos.

2. Solar neutrinos in JUNO

Solar neutrinos are produced in the Sun through fusion reactions that constantly take place inside its core. Solar neutrinos with energy < 2 MeV (*pp*, *pep*, ^{7}Be, and CNO-ν) can be detected in JUNO only through elastic scattering (ES) reactions with LS electrons:

$$\nu_x + e^- \rightarrow \nu_x + e^- \qquad x = e, \mu, \tau \qquad \sigma(\nu_e)/\sigma(\nu_{\mu,\tau}) \sim 1/6.$$

Since the reaction does not produce multiple events in temporal coincidence, the decay of any radioactive isotope will mimic a solar neutrinos event. A statistical separation of signal and background events can be performed exploiting the different energy spectra of the species. The amount of radioactive nuclei inside the LS will drive the sensitivity to solar neutrinos. Since the exact levels of contamination of the LS are still unknown, four progressively worse radiopurity scenarios are studied: Very Low, Low, Medium and High scenarios. JUNO can improve the current best results (all set by Borexino) on ^{7}Be, *pep* and CNO neutrinos [3]. For ^{7}Be-ν, 2 years of data-taking will be needed (see left panel of Fig. 1); for *pep*-ν, 2 years will be needed as well, unless the radiopurity scenario will be the most pessimistic. Finally, for CNO-ν, constraining *pep*-ν, a data taking of $2 - 6$ years will be needed unless the radiopurity scenario will be the High one (see right panel of Fig. 1).

Since ^{8}B solar neutrinos are more energetic (endpoint of ~ 15MeV), two additional interaction channels (charged and neutral current interactions, CC and NC) on ^{13}C open up:

$$\nu_e + {}^{13}\mathrm{C} \rightarrow e^- + {}^{13}\mathrm{N}.$$

$$\nu_x + {}^{13}\mathrm{C} \rightarrow \nu_x + {}^{13}\mathrm{C}^* \qquad x = e, \mu, \tau \qquad \sigma(\nu_e) = \sigma(\nu_\mu) = \sigma(\nu_\tau).$$

The NC channel allows a model independent measurement of $\Phi(^8\mathrm{B})$, whereas the ES and CC rates depend on both neutrino flux and survival probability. Hence, a simultaneous measurement of $\Phi(^8\mathrm{B})$, $\sin^2\theta_{12}$, Δm^2_{21} can be performed. After 10 years of data-taking, JUNO is expected to reach a precision of $\sim 5\%$, $\sim 9\%$, $\sim 20\%$ on $\Phi(^8\mathrm{B})$, $\sin^2\theta_{12}$, Δm^2_{21} respectively [4]. These two oscillations parameters will also be measured through reactor antineutrinos. A significant discrepancy between the two sets of measurements would imply beyond-Standard Model physics [5].

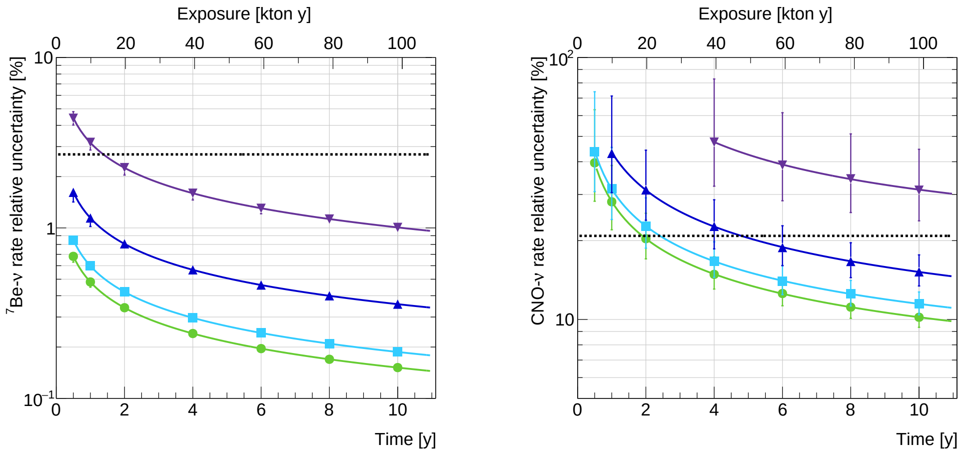

Figure 1: JUNO sensitivity to ^{7}Be (left panel) and CNO neutrinos (right panel) as a function of the data-taking time in the High (violet), Medium (blue), Low (azure), and Very Low (green) radiopurity scenarios. The horizontal dotted lines correspond to Borexino final results on such solar neutrino species.

3. JUNO sensitivity to Pre-Supernova, Supernova neutrinos and Diffuse Supernova Neutrino Background

The life of a massive star ends with a staggering emission of neutrinos and antineutrinos of all flavors. In the last hours before the collapse, the neutrino luminosity increases significantly (the so-called ’Pre-SuperNova neutrinos’, Pre-SN, are emitted). Then, during the SuperNova (SN) explosion, a burst of neutrinos is emitted in $\sim$ 10 seconds. In JUNO, the golden interaction channel to detect Pre-SN and SN neutrinos is the Inverse Beta Decay (IBD)

$$\bar{\nu}_e + p \to e^+ + n$$

thanks to its peculiar signature (prompt event: e^+ annihilation; delayed event $\Delta T \sim 200\,\mu$s: n capture) and very low backgrounds. The Pre-SN and SN neutrino bursts can be identified since they produce a sudden increase of the steady ($\sim$ 60 /day) IBD rate: an exploding star of $30 M_\odot$ at a distance of 10 kpc would cause $\sim$ 5000 IBDs in JUNO in a few seconds. Assuming a progenitor of $30 M_\odot$, JUNO is sensitive to Pre-SN neutrinos up to a distance of 1.6 kpc (0.9 kpc) in case of normal (inverted) mass ordering and to SN neutrinos up to 370 kpc (360 kpc) in case of normal (inverted) ordering [6]. Even if no closeby SN will explode during the data-taking, JUNO will measure the Diffuse Supernova Neutrino Background (DSNB). The DSNB is the integrated neutrino flux from all the past supernova explosions. It can be detected in JUNO through the IBD reaction as well. Its event rate is very low ($\sim 0.14\,\mathrm{y}^{-1}\,\mathrm{kton}^{-1}$), but the main backgrounds can be controlled through fiducial volume cuts, Pulse-shape discrimination, and Three-Fold coincidences tags. With the reference DSNB model, JUNO is expected to reach a sensitivity to DSNB of $\sim 3\sigma$ in 3 y, and of $> 5\sigma$ in 10 y [7].

4. Atmospheric neutrinos in JUNO

Atmospheric neutrinos are produced in the decays of particles in air showers initiated by cosmic rays. Their detection is important for NMO determination. In fact, if the correct NMO scenario was the normal one, neutrinos with energy ~ GeV traveling through the innermost regions of the Earth would have their oscillation probabilities $P(\nu_\alpha \to \nu_\beta)$ enhanced. On the other hand, if the correct NMO scenario was the inverted one, then the probability $P(\bar{\nu}_\alpha \to \bar{\nu}_\beta)$ would be enhanced [8]. Thanks to its huge volume, JUNO will be the first LS detector to measure and study atmospheric neutrinos. The combination of their measurements with reactor antineutrinos will boost the sensitivity to NMO. In order to achieve this goal, an excellent muon veto strategy; the selection of charged current interaction events; the reconstruction of neutrinos energy, direction, flavor and $\nu/\bar{\nu}$ discrimination will be needed. The evaluation of JUNO sensitivity to NMO with atmospheric neutrinos (and its combination with reactor antineutrinos) is currently ongoing.

5. Conclusions

Thanks to its unique features, JUNO will be able to detect neutrinos of different energy scales coming from several artificial and astrophysical sources. In particular, in case of good LS radiopurity, it will be able to overcome Borexino results on ^{7}Be, *pep*, and CNO solar neutrinos in a few years of data-taking. Regarding ^{8}B solar neutrinos, a simultaneous measurement of $\Phi(^8\text{B})$, $\sin^2\theta_{12}$, Δm^2_{21} will be possible. In particular, for the first time since SNO, the measure of $\Phi(^8\text{B})$ will be model independent. In case of nearby Supernova explosion, JUNO will be able to detect both Pre-SN and SN neutrinos. Finally, JUNO will be the first experiment to measure atmospheric neutrinos. Their combination with reactor antineutrino analysis can boost the sensitivity to NMO.

References

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