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Supernova neutrinos detection in JUNO(*)

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Summary. — JUNO is the acronym for Jiangmen Underground Neutrino Observatory, an underground neutrino observatory located close to Kaiping city, South China. It will be the largest detector to use a liquid scintillator to detect neutrinos. JUNO will use 20 ktons of liquid scintillator and will be equipped with 17612 20-inch photomultipliers and 25600 3-inch photomultipliers to capture the light emitted during the scintillation. JUNO will be able to detect neutrinos and antineutrinos emitted by various sources including those emitted during stellar explosions. In particular, it will be possible to study both the diffuse supernova neutrino background and the neutrinos emitted by a Supernova that occurred during the active life of the Observatory. By exploiting the different detection channels, the high energy resolution (3% at 1 MeV), and the ability to detect neutrinos of all lepton families, JUNO will have a leading role in studying these phenomena. In this regard, a trigger system focused on multi-messenger astronomy has been developed specifically for JUNO. The potential of JUNO to detect neutrinos produced by supernovae will be presented and discussed in this manuscript.

1. – Introduction

The Jiangmen Underground Neutrino Observatory (JUNO) is a liquid scintillator-based neutrino detector under construction in China. JUNO, with its unique characteristics, in particular the high energy resolution and low systematic uncertainty on neutrino energy, will play an important role in the discovery of the correct neutrino mass hierarchy [1]. To enhance JUNO's discovery potential a second detector, the Taishan Antineutrino Observatory (named TAO or JUNO-TAO), is under development [2, 3]. The main goal of JUNO is to determine the correct neutrino mass hierarchy and provide the most precise measurement of the Δm^2_{31}, Δm^2_{21}, $\sin^2\theta_{12}$, and $\sin^2\theta_{13}$ using reactor antineutrinos. Besides its main goals, JUNO has a full list of topics in neutrino physics that can play a leading role. JUNO is sensitive to neutrinos coming from different sources. In addition to the neutrinos produced by the nuclear reactors of the Yangjian and Taishan power plants, JUNO can detect neutrinos emitted by the interaction of primary cosmic

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rays in the atmosphere (atmospheric neutrinos), neutrinos produced in the Sun (solar neutrinos), neutrinos emitted in the decay of ^{40}K, ^{232}Th and ^{238}U and neutrinos emitted during the Core-Collapse SuperNova (CCSN).

2. – JUNO detector

The JUNO detector will be deployed in an underground laboratory, 650 m overburden, in the South of China. The main JUNO detector is shown in fig. 1. The primary antineutrino target of 20 kton of liquid scintillator is contained in a transparent 12-cm thick acrylic sphere 35.4 m in diameter. This constitutes the largest detector of this kind. The acrylic sphere is surrounded by 17612 large 20-inch photomultiplier tubes (PMTs), referred to as LPMTs, and 25600 small 3-inch PMTs, referred to as SPMTs. The main detector is fully surrounded by a water pool filled with 35 kton high-purity water and instrumented with 2000 20-inch PMTs. This water pool works as an ultra-pure water Cherenkov detector that serves as both an active veto for cosmic muons and a passive shield against external radioactivity and neutrons from cosmic rays. The muon cosmic veto system is completed by a muon tracker, placed on the top of the pool, consisting of three layers of plastic scintillator repurposed from the OPERA experiment. The liquid scintillator composition is optimized for JUNO needs and is composed of: LAB (Linear Alkyl Benzene), 2 g/L diphenyloxazole (PPO), and 1 mg/L p-bis-(o-methylstyryl)-benzene (bis-MSB). JUNO is a liquid scintillator detector that detects the electron antineutrinos mainly via Inverse Beta Decay (IBD) using the following reaction:

$$\overline{\nu}_e + p \rightarrow e^+ + n$$

The coincidence of the prompt scintillation generated by the positron with the delayed neutron capture provides a distinctive signature for events generated by $\overline{\nu}_e$. To achieve its important physic goals, JUNO has set stringent upper limits of 10^{-15} g/g on the contamination level of the LS for uranium and thorium chain isotopes and 10^{-17} g/g for solar neutrinos [4]. To achieve these radiopurity requirements an extensive purification program needs to be performed on the liquid scintillator before filling the acrylic vessel. The Online Scintillator Internal Radioactivity Investigation System (OSIRIS) will verify the efficiency of the purification plants and monitor the radiopurity of the produced LS for the filling of the JUNO Central Detector. Non-uniformity and non-linearity could compromise the measurement of the antineutrino energy spectrum. To reduce these effects, a calibration system was developed. The calibration system is composed of three sub-systems: the Automatic Calibration Unit (ACU), the Guide Tube System (GT), and the Cable Loop System (CLS) [5]. The ACU is developed to perform calibration along the central vertical axis using a neutron source (AmC), a gamma source (^{40}K), and a pulsed UV laser source. The GT is a tube looped outside of the acrylic sphere along a longitudinal circle. Within the tube, a radioactive source with cables attached to both ends gets driven around with a positioning precision of 3 cm allowing to calibrate the central detector non-uniformity at the boundary. The CLS will deploy different sources to off-axis positions. To reach positions not covered by the CLS a Remotely Operated Vehicle (ROV) was developed. It is capable of deploying a radioactive source in almost the entire LS volume.

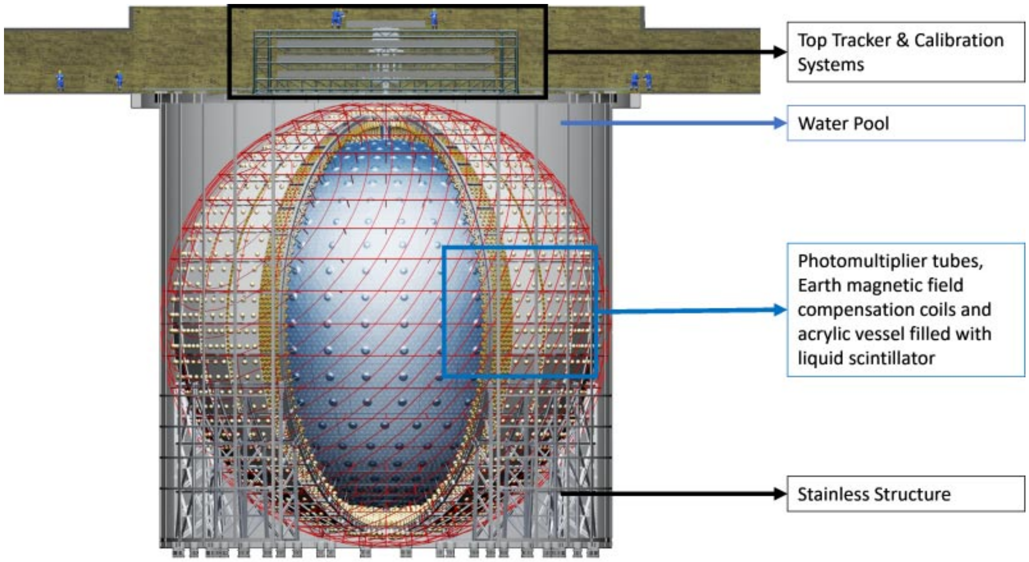

Fig. 1. – Schematic view of the JUNO detector, consisting of a Central Detector (CD), the outer shielding and veto system. The veto is composed of a water pool equipped with ~ 2000 LPMTs, working as a Cherenkov detector, and by a plastic scintillator on the top of the pool. The calibration systems are inside the top tracker. The Acrylic sphere filled with the liquid scintillator is sustained by a stainless structure and surrounded by 17612 20-inch PMTS and 25600 3-inch PMTs (yellow dots in the figure).

3. – SuperNova detection with JUNO

JUNO has good capability for the CCSN neutrino observation because of its large target mass, low background, and multiple-flavor detection channels. The neutrino burst during a Core Collapse SuperNova explosion could be registered with full flavors in LS via different channels: inverse beta decay, neutrino-proton elastic scattering, neutrino-electron elastic scattering, as well as neutral-current and charge-current interactions of neutrinos on carbon nuclei. For a SN at 10 kpc and typical SN parameters, JUNO will register ~ 5000 IBD events, ~ 300 eES events, ~ 2000 pES events, and ~ 500 events on ^{12}C [1]. Pre-supernova neutrinos, detectable via the IBD and eES channels, could provide an early warning for the optical observations of core-collapse SNe. The real-time CCSN monitor system in JUNO was developed to provide early alerts for the next galactic or nearby galactic CCSN and record CCSN-related data as much as possible [6]. The IBD candidates for Pre-SN Monitor (pre-SN IBD) are preliminarily selected with fiducial volume cut and specific requirements on energy and time. The IBD candidates for SN are selected with the same pre-SN IBD criteria except for a different prompt energy cut. Since SN burst neutrinos last only for a few seconds, the muon veto system and the calibration systems are switched off to not reduce the active volume of JUNO and to not contaminate the data collected respectively. Furthermore, the short duration of the neutrino burst and the high number of expected events allow us to consider SuperNova events quasi-background-free. The real-time monitoring system consists of prompt monitors on the trigger boards and online monitors at the DAQ stage to ensure both alert speed and alert coverage of progenitor stars. The JUNO front-end electronics will feature real-time waveform processing by FPGAs. The processed signal will be sent to the data acquisition (DAQ) in triggerless mode, while the raw waveforms will be sent to DAQ once validated by the global trigger electronics. This configuration limits the chance of data loss even in the face of the very high event rate expected for a nearby supernova. Furthermore, a dedicated multi-messenger trigger system is under design to achieve an ultra-low detection threshold of the order of about 10 keV. This system will enable JUNO to act as a powerful machine for broad-band multi-messenger observation and connect to the global network of multi-messenger observatories. JUNO can be expected to become a major player in the next-generation Supernova Early Warning System (SNEWS2.0) [7].

4. – Conclusion

JUNO can detect neutrinos from different sources, in particular, neutrinos produced from a massive star before and during core collapse form a burst of the pre-SN and SN neutrinos, respectively. The early and prompt detection of the pre-SN and SN neutrinos provides a unique opportunity to realize the multi-messenger observation of the CCSN events. In the case of SN-alert, provided or received by SNEWS, JUNO will acquire data in triggerless mode to maximize the physical events collected. In this way, JUNO will provide deep insights into the supernova burst mechanism, and with 10 years of data, it is expected to provide 5σ evidence of the Diffuse Supernova Neutrino Background (DSNB) signal.

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