The JUNO Experiment

Abstract

The Jiangmen Underground Neutrino Observatory (JUNO), a 20 kton multipurpose underground Liquid Scintillator detector, was proposed for the determination of the neutrino mass hierarchy (MH) as a primary physics goal. The excellent energy resolution and the large fiducial volume anticipated for the JUNO detector offer exciting opportunities for addressing many important topics in neutrino and astroparticle physics.

The detection of antineutrinos generated by a cluster of nuclear power plants will allow the determination of the neutrino MH at a 3–4 σ significance with about six years data taking. The measurement of antineutrino spectrum with excellent energy resolution will also lead to the precise determination of the neutrino oscillation parameters $\sin^2\theta_{12}$, Δm^2_{12}, and $|\Delta m^2_{ee}|$ to an accuracy of better than 1%. The θ_{12} precise measurement will play a crucial role in the future unitarity test of the PMNS matrix and in the prediction of neutrinoless double-beta decays.

The JUNO detector is capable of observing not only antineutrinos from the power plants, but also neutrinos/antineutrinos from terrestrial and extra-terrestrial sources, including geoneutrinos, atmospheric neutrinos, solar neutrinos, supernova burst neutrinos and diffuse supernova neutrino background. A neutrino burst from a typical core-collapse supernova at a distance of 10 kpc would lead to ∼5000 inverse beta-decay events, ∼2000 all-flavour neutrino–proton ES events and 300 neutrino–electron ES events in JUNO, which are of crucial importance for understanding the mechanism of supernova explosions and for exploring novel phenomena such as collective neutrino oscillations. Detection of neutrinos from all past core-collapse supernova explosions in the visible universe would further provide valuable information on the cosmic star-formation rate and the average core-collapse neutrino energy spectrum. Antineutrinos originating from the radioactive decay of uranium and thorium in the Earth can be detected in JUNO with a rate of ∼400 events per year, significantly improving the statistics of existing geoneutrino event samples. Atmospheric neutrino events can provide independent inputs for determining the MH and the octant of the θ_{23} mixing angle. Detection of the ^{7}Be and ^{8}B solar neutrino events would shed new light on the solar metallicity problem and examine the transition region between the vacuum and matter dominated neutrino oscillations. Sterile neutrinos with $10^{-5}<|\Delta m^2_{41}|<10^{-2}$ eV^2 and a sufficiently large mixing angle θ_{14} could be identified through a precise measurement of the reactor antineutrino energy spectrum. In a later stage, JUNO can also provide excellent opportunities to test the eV-scale sterile neutrino hypothesis using either the radioactive neutrino sources or a cyclotron-produced neutrino beam. The JUNO detector is also sensitive to several other beyond the-standard-model physics. Examples include the search for proton decay via the p → K+ν decay channel, search for neutrinos resulting from dark-matter annihilation in the Sun, search for violation of Lorentz invariance via the sidereal modulation of the reactor neutrino event rate, and search for the effects of non-standard interactions. In addition, this detector could also be upgraded for neutrinoless double-beta decay searches by loading Xe or Te into the liquid scintillator.

The proposed construction of the JUNO detector will provide a unique facility to address many outstanding crucial questions in particle and astrophysics in a timely and cost-effective fashion. It holds the great potential for further advancing our quest to understanding the fundamental properties of neutrinos, one of the building blocks of our Universe.

The JUNO experimental site is under construction since end 2014. The detector installation will start end 2019 and the data taking period will begin in 2021.

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JUNO Collaboration

Introduction

The JUNO experiment[1] is driven by an international collaboration. It will take place in the south of China starting taking data by the end of 2021.

After the measurement of θ_{13} in 2012, which has been found to be relatively large, it came out that, not only the observation of a CP violation in the leptonic sector became possible, but also the determination of the neutrino mass hierarchy (MH), or ordering, using nuclear reactors. The principle aim of JUNO is indeed the MH extraction after six years data taking with a significance higher than 3 σ. Together with this measurement, JUNO will precisely measure three of the neutrino oscillation parameters. Thanks to the large volume of its detector, JUNO also has a rich astro-particle physics program together with geo-neutrino studies.

Although JUNO experiment will not take place in Europe, this Collaboration has a very strong and active European component, offering to the experiment human and financial resources. Also, the expected results will influence other European and non-European projects. For these reasons, and because the European participating institutes need European support, in this document we would like to bring to the European Strategy Group all physics performance of JUNO in order to take this into account during the elaboration of the European Particle Physics Roadmap.

1 Scientific Context

Neutrino oscillations is now a well-established Quantum Mechanics mechanism. These oscillations induce a higher than zero neutrino mass and by the same way physics beyond the Standard Model (SM). Since the first neutrino observation in 1956 using nuclear reactors, neutrinos always revealed "anomalies" which at the end, with more precise measurements, ended to be confirmed as new phenomena.

Presently, many questions in neutrino physics are still open as the existence of a matter-antimatter difference (CP violation) and the neutrino MH. The existence of sterile neutrinos is also a significant open question. Precision measurement of the neutrino oscillation parameters will also allow unitarity tests of the PMNS neutrino mixing matrix.

Long baseline experiments having as main goal a possible CP violation observation in the leptonic sector are expected to start running before the end of next decade. Meantime, JUNO experiment will try to determine the neutrino MH, independent to the CP phase, by using nuclear reactor neutrinos and measure precisely three of the oscillation parameters.

2 Objectives

The objectives of JUNO experiment are the following[1]:

- **Neutrino Mass Hierarchy determination**: The determination of the neutrino MH is of great importance in neutrino physics, since it provides a crucial input for future searches of neutrinoless double beta decays, observation of supernova neutrino bursts, cosmological probe of neutrino properties and model building of the neutrino masses and flavour mixing. This determination is expected to be done by JUNO with a significance higher than 3 σ. The thermal power of the two nuclear power plants is

[1] F. An *et al.* [JUNO Collaboration], "Neutrino Physics with JUNO", J. Phys. G 43 (2016) no.3, 030401, doi:10.1088/0954-3899/43/3/030401, [arXiv:1507.05613 [physics.ins-det]].

expected to be between 26 GWth and 35 GWth by the beginning of next decade. JUNO plans to collect 100 k IBDs over 6 years to determine the neutrino MH. The MH sensitivity can be improved by including a measurement of the effective mass-squared difference in the long-baseline muon-neutrino disappearance experiments due to flavour dependence of the effective mass-squared differences.

- **Precision measurement of oscillation parameters**: JUNO will be the first experiment to simultaneously observe the neutrino oscillation driven by both atmospheric and solar neutrino mass-squared differences (Figure 3). The pronounced dip around 3 MeV corresponds to the solar Δm^2, while the rapid oscillations correspond to the atmospheric Δm^2. With the same statistics as for the mass hierarchy determination, JUNO will precisely measure the oscillation parameters Δm^2_{21} and Δm^2_{ee}, but also θ_{12}. The expected precision to be achieved for each parameter is 0.6% (2.3%), 0.5% (4%) and 0.7% (6%), respectively (in parenthesis the present achieved resolution is indicated). It has to be underlined that on top of precisely measuring the oscillation pattern in a model-independent way this also is very important for probing new physics beyond the SM. In particular, precision measurement of the fundamental parameter θ_{12} will play a crucial role in the future unitarity test of the PMNS mixing matrix. It will also significantly reduce the uncertainty of the allowed parameter space for neutrinoless double-beta decays.
- **Supernova (SN) burst neutrinos**: A high-statistics detection of neutrinos from a galactic SN will provide us with precious information about the explosion mechanism and intrinsic properties of neutrinos themselves. For a galactic SN at a distance of 10 kpc, there will be detected by the JUNO detector around 5000 events in the IBD channel, 2000 events for elastic neutrino-proton scattering and 300 events for elastic neutrino-electron scattering. The time evolution, energy spectra and flavour contents of SN neutrinos can in principle be established and used to verify or disprove the neutrino-driven explosion mechanism. With these experimental observations, many interesting questions in astronomy, astrophysics and particle physics, such as the early warning of SNe, the SN location, SN nucleosynthesis, absolute neutrino masses and neutrino MH, can hopefully be revised or addressed.
- **Diffuse supernova neutrino background (DSNB)**: Large Liquid Scintillator detectors are probably the most powerful approach to measure the long-sought DSNB. Despite its shallow depth, the relatively small size and the large atmospheric NC background, the superior detector properties of JUNO may be able to provide a DSNB detection at the 3 σ level. If no signal is detected, significant limits in the plausible parameter space can be achieved, improving on the existing limits from Super-Kamiokande which has approximately a 50% larger fiducial mass for DSNB detection. In case the gadolinium upgrade of Super-Kamiokande is fully implemented, it will have a realistic chance of measuring the DSNB. Adding the measurements of the two detectors will roughly double the overall statistics while reducing systematic uncertainties due to the differences in background and detection uncertainties. A combined analysis will either provide a more significant detection or more restrictive limits for the DSNB. Such an observation would give us confidence in theoretical expectations of SN neutrino emission parameters, strongly improving on the sparse SN 1987A data. JUNO will play a leading role in pushing the low-energy frontier of this exciting field and may be the first instrument ever to measure low-energy neutrinos from the edge of the visible universe.

- **Solar neutrinos**: The JUNO detector has many advantages in performing solar neutrinos measurements compared with previous detectors. Being a Liquid Scintillator detector similar to Borexino and KamLAND, it has the benefit of high light yield and, therefore, very high energy resolution and low energy threshold. Being a massive 20 kton detector it will have large statistics comparable to the Super-Kamiokande water Cherenkov detector. This makes JUNO an attractive detector to further improve the measurement precision of various components of the solar neutrino flux, shed light on the solar metallicity problem, and probe the transition region between the vacuum-dominated and MSW-dominated neutrino oscillations. However, the solar neutrino measurements demand challengingly low level of radio-impurities and accurate determination of cosmogenic backgrounds. Since JUNO is optimized for reactor antineutrino measurements with relatively tolerant background requirements, dedicated efforts to realize the low background phase for solar neutrino measurements are necessary.
- **Atmospheric neutrinos**: Still ongoing studies shows that the JUNO's MH sensitivity can reach 0.9 σ for a 200 kton-years exposure and $\sin^2\theta_{23}$ =0.5, which is complementary to the JUNO reactor neutrino results. The wrong θ_{23} octant could be ruled out at 1.8 σ (0.9 σ) for the true normal (inverted) hierarchy and θ_{23} ~ 35°.
- **Geoneutrinos**: JUNO represents a great opportunity to measure geoneutrinos. Its unprecedented size and sensitivity will allow the detection of 300-500 geoneutrino interactions per year. In approximately six months JUNO would match the present world sample of recorded geoneutrino interactions, which is less than 150 events (KamLAND, Borexino). The geoneutrino signal in JUNO has to be extracted from the considerable background of reactor antineutrinos and other non-antineutrino sources. This will be done using a well constrained reactor signal and reasonable estimates of the non-antineutrino sources. With this observation JUNO can study for example the radiogenic heating in the mantle, which is closely related to the mantle geoneutrino signal, a critical geological significance study. Moreover, the statistical power of the geoneutrino signal enables a measurement of the thorium to uranium ratio, which provides valuable insight to the Earth's origin and evolution. In summary, this contribution reveals the unprecedented opportunity to explore the origin and thermal evolution of the Earth by recording geoneutrino interactions. There is an experienced and dedicated community of neutrino geoscientists in JUNO Collaboration that is eager to take advantage of this unique opportunity.
- **Sterile neutrinos**: The JUNO detector has multiple advantages in searching for light sterile neutrinos, including its large dimensions, unprecedent energy resolution and excellent position accuracy. Placing in a second stage of the experiment a 50-100 kCi source of antineutrinos extracted from spent reactor fuel, inside or outside the detector for a 1.5-year run, JUNO is sensitive to the entire global analysis region for electron-flavour disappearance in the 3+1 scheme, at a more than 3 σ confidence level. It has the greatest sensitivity for 0.1-10 eV^2-scale sterile neutrinos among all current and planned experiments with various proposed sources. Using a ^{8}Li antineutrino source produced from a 60 MeV/amu cyclotron accelerator (IsoDAR@JUNO[1]) located 5 m away from the detector would provide sensitivity to 1 eV^2-scale sterile neutrinos. Assuming 5 years of data-taking, the sensitivity curve of IsoDAR@JUNO covers the allowed reactor anomaly region, the 3+1 scheme global analysis region for electron-flavour disappearance, and the global electron anti-neutrino appearance region (i.e.,

all present anomaly regions) at a greater than 5 σ confidence level. In addition to the excellent sensitivity to 1 eV^2-scale light sterile neutrinos, the JUNO experiment can search for super-light sterile neutrinos at the Δm^2 scale of the order of 10^{-5} eV^2 using reactor antineutrinos. With a total of 100 k IBD events from reactors collected over 6 years of full-power running, the most sensitive region is $10^{-5}<|\Delta m^2_{41}|<10^{-2}$ eV^2. Combined with the sterile neutrino exclusion region of the DYB experiment, the JUNO experiment will have good sensitivity across the entire range of light sterile neutrino searches $10^{-5}<|\Delta m^2_{41}|<0.3$ eV^2, about seven orders of magnitude in $|\Delta m^2_{41}|$, when using antineutrinos both from sources and reactors.

- **Proton decay**: Being a large Liquid Scintillator detector deep underground, JUNO is in an excellent position to search for nucleon decays. In particular, in the SUSY-favoured decay channel $p \rightarrow K+\nu$, JUNO will be competitive with or complementary to those experiments using either water Cherenkov or Liquid Argon detectors. Today's best limit is $\tau(p \rightarrow K+\nu)>5.9\times10^{33}$ yrs at 90% C.L. reported by the Super-Kamiokande collaboration. The tagging efficiency for the proton decay can be largely improved due to the large scintillation signal created by the K^+ itself, invisible in a water Cherenkov detector. The JUNO sensitivity to the proton lifetime is expected to be $\tau> 1.9\times10^{34}$ yrs after 10 years data taking. This represents a factor of three improvement over today's best limit from the Super-Kamiokande experiment and starts to approach the region of interest predicted by some GUT models.
- **Neutrinos from Dark Matter (DM)**: DM can be detected indirectly by looking for a neutrino signature from DM annihilation or decays in the galactic halo, the Sun or the Earth. In particular, the search for the DM-induced neutrino signature from the Sun has given quite tight constraints on the spin dependent DM-proton scattering cross section. The sensitivities of the JUNO detector to DM-proton scattering have been studied by focusing on the neutrino signature from the Sun. The sensitivities are calculated based upon the excess of neutrino events beyond the atmospheric background. These studies are focused on muon neutrino events resulting from DM annihilation channels $\chi\chi \rightarrow \tau\tau$ and $\chi\chi \rightarrow \nu\nu$. It is found that JUNO sensitivity to the spin dependent DM-proton scattering is much better than the current direct detection constraints. In the case of spin independent DM-proton scattering, JUNO is competitive with direct detection experiments for $m_\chi < 7$ GeV.
- **Exotic searches**: Among different possibilities, Non-Standard Interactions (NSI) and Lorentz invariance violation (LIV), are of particular importance at JUNO. High-dimensional operators from the new physics contributions can affect the neutrino oscillation in the form of NSI, which emerge as effective four fermion interactions after integrating out the heavy particles beyond the SM. NSI can modify both the neutrino production and detection processes and induce shifts for both the mixing angles and mass-squared differences at reactor antineutrino oscillations. LIV is an indication for quantum gravity. The low energy phenomena of LIV can be systematically studied in the framework of the standard model extension. In reactor antineutrino experiments, LIV can be tested in terms of both the spectral distortion and sidereal variation effects.

3 Methodology

The survival probability of electron anti-neutrinos is approximated to the following formula:

$$P\left(\bar{\nu}_e \rightarrow \bar{\nu}_e\right) \approx 1 - \cos^4\theta_{13}\sin^2 2\theta_{12}\sin^2\left(\frac{\Delta m_{21}^2 L}{4E_\nu}\right) - \sin^2 2\theta_{13}\sin^2\left(\frac{\Delta m_{31}^2 L}{4E_\nu}\right)$$

$$-\sin^2\theta_{12}\sin^2 2\theta_{13}\sin^2\left(\frac{\Delta m_{21}^2 L}{4E_\nu}\right)\cos\left(\frac{2\left|\Delta m_{31}^2\right| L}{4E_\nu}\right)$$

$$\pm\frac{\sin^2\theta_{12}}{2}\sin^2 2\theta_{13}\sin\left(\frac{2\Delta m_{21}^2 L}{4E_\nu}\right)\sin\left(\frac{2\left|\Delta m_{31}^2\right| L}{4E_\nu}\right)$$

The ± at the fourth term is for Normal (+) and Inverted hierarchy (-). The experiments must be placed at a distance to maximise the contribution of this last term in order to be significantly sensitive to the neutrino mass hierarchy. It has to be noted that this probability doesn't depend on the CP violation parameter δ_{CP}, also the matter effect for the considered baseline is negligible. It comes out that the distance to place the detector form nuclear reactors must be around 50-60 km.

Figure 1 presents the oscillated neutrino energy spectrum versus L/E for the two hierarchies compared to the unoscillated one. It can be clearly seen that a very good energy resolution is needed to discriminate the two cases.

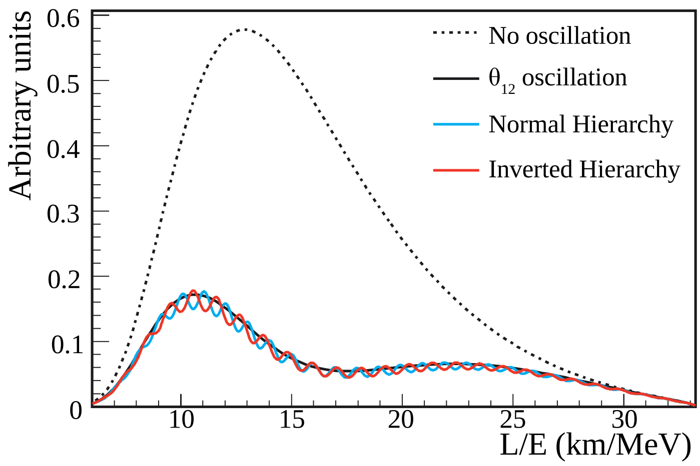

Figure 1: Neutrino energy spectrum for both hierarchies compared to the unoscillated spectrum.

After measuring the last unmeasured neutrino oscillation parameter θ_{13}, it came out that this last term could be measurable provided that the neutrino detector would have a very good energy resolution. In order to discriminate the two neutrino possible mass hierarchies, ~3%/√E energy resolution has to be reached. JUNO experiment proposes to exploit this effect using a large 20 kt Liquid Scintillator detector.

Thanks to the size of this detectors, other physics subjects can be treated together with the reactor neutrino program, as mentioned above.

3.1 Energy Resolution

In order to achieve the required energy resolution, compared to present and previous experiments, JUNO detector must be able to detect more than 1200 photoelectrons per deposited MeV. To achieve this, three axes are followed:

1. Increase the photon light yield and the attenuation length of the Liquid Scintillator: A strategy has been developed by JUNO aiming to obtain an optimal admixture of solvent

and solutes in optical and radio-active terms. A pilot distillation plant has been installed in one of the Liquid Scintillation halls of the Daya Bay experiment in China to test the quality of the proposed JUNO scintillator. An attenuation length of more than 20 m is required for JUNO that is already achieved.

2. Better photocathode coverage: Using ~18000 20" PMTs in the JUNO central detector, a photocathode coverage of more than 75% can be reached.
3. High detection efficiency of the used photomultipliers: A PMT detection efficiency of the order of 30% has already been achieved compared to the one of the Super-Kamiokande PMTs which is of the order of 15%.

On top of the optimisation of the above parameters, JUNO will use a very performant calibration system.

3.2 The JUNO Detector

The JUNO central detector[2] will be spherical compared to the cylindrical shape of Super-Kamiokande. A schematic view of the JUNO detector is depicted by Figure 2. The neutrino interactions will occur inside an acrylic sphere (12 cm thick) immersed in water, containing the liquid scintillator and having a diameter of 35.4 m. Outside this sphere a mechanical structure will support all 20'' PMTs (about 20000 including those for muon veto). In between the 20'' PMTs, small PMTs (3'') will be placed to mainly increase the energy dynamic range of the whole system and serve as an independent energy calorimeter.
All the surrounding water will be used as Water Cherenkov veto detector with about 2000 PMTs (20''). In order to compensate the earth magnetic field significantly degrading the PMT detection performance, magnetic coils will be placed inside the veto detector. On top of the central detector, a muon tracker (Top Tracker) will be placed in order to well study the cosmogenic background. This Top Tracker based on plastic scintillator strips consists of a recycling of the OPERA Target Tracker.

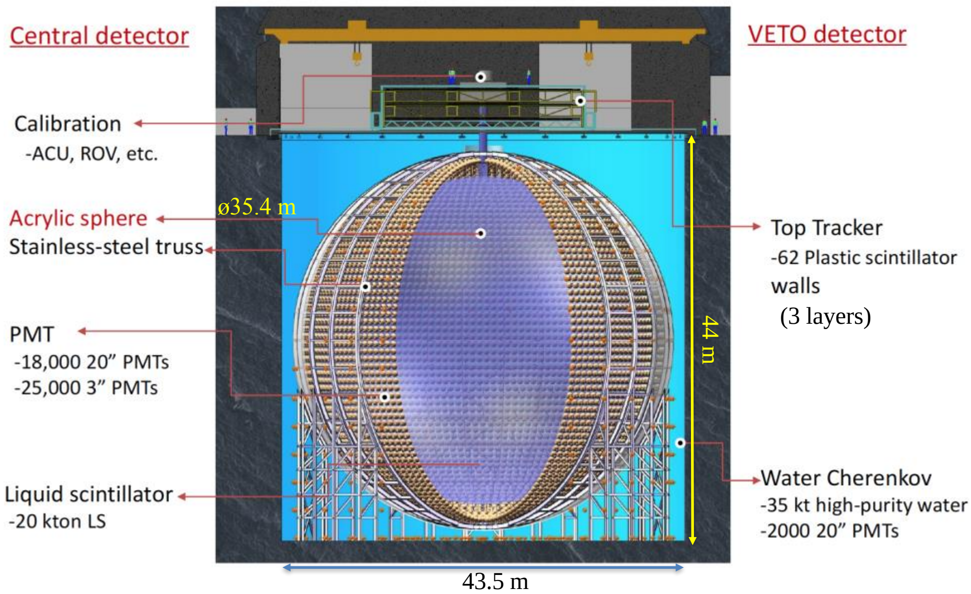

Figure 2: Schematic view of the JUNO detector.

[2] JUNO Conceptual Design Report, JUNO Collaboration, Aug 28, 2015, 329 pp., e-Print: arXiv:1508.07166 [physics.ins-det]

Taking the experience from Daya Bay, JUNO has elaborated a very extensive calibration program to well calibrate all the detector positions at various energies. This includes displacement of radioactive sources with ultrasonic positioning system for energy calibration, and fast 1 ns laser system for timing calibration.

The JUNO detector will be place in an underground laboratory with an overburden of the order of 2000 mwe. A sloped tunnel (1266 m) will provide a direct access to transport material in the underground JUNO experimental hall, while a vertical shaft (564 m) will be used for personnel transportation.
After 6 years of data taking and accumulating 100 k IBD events, the energy distribution of Figure 3 is expected to be observed including background contribution. The background sources are indicated in the figure.

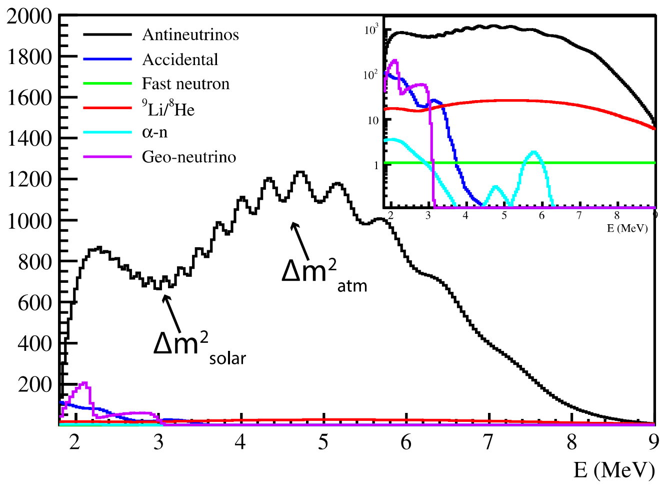

Figure 3: Neutrino energy spectrum with main background contributions.

3.3 The JUNO Reference Detector

In order to well measure the IBD spectrum with a resolution better than the JUNO detector, the JUNO Collaboration has decided to construct a high energy resolution reference detector placed in a short distance to one of the Taishan reactors. This JUNO reference detector to well measure the IBD spectrum is called JUNO-TAO (Taishan Antineutrino Observatory). The requirement is that its energy resolution must be better than the JUNO one, i.e., <3%/√E. The proposed detection technique uses Gd-loaded Liquid Scintillator readout by SiPM. Placed at 40 m of one of the Taishan reactors, this detector will record about 700 k IBD events per year. The design of the detector and some R&D are ongoing. The expected energy resolution is of the order of 1.5%/√E.

4 Readiness and expected challenges

In order to build and operate a large detector as the JUNO one, significant human and material resources are needed. The JUNO Collaboration accounts now 77 institutes from 16 countries, among them 8 European countries accounting for more than 170 scientists. The full composition of the Collaboration is given in the Addendum. The human resources are already considered enough for the detector construction.

The JUNO underground laboratory is since end 2014 under construction. The civil engineering will be finished by the end of 2019. At that moment, the JUNO detector installation will start and will last up to end 2021 when the data taking will start. The surface buildings will be ready by mid-2019. Production reviews of important part of the detector has been accomplished.

The main biddings have already been realised and many orders to companies have been placed.

The contract for the production and assembly of the large acrylic sphere has been signed. A new production line for radioactive-pure acrylic panel was built. Measurement and R&D of mechanical and optical properties of the acrylic panel and all related design has been completed. Together with the company, a 3 m diameter prototype was built and the final assembly method was under investigation.

The design of the stainless-steel structure which supports all the instruments and the acrylic sphere has been completed, taking into accounts the effects of thermal expansion to acrylic, structure stiffness, precision and tolerance of all parts even at extreme conditions like earthquakes. Assembly process including PMT installation and cable routing has been understood. Contracts have been signed and production will start soon.

For the 20" PMTs, more than 12000/20000 tubes have already been delivered and the majority of them is already tested. The detection efficiency is still improving to reach on average 31% going up to 35% for the MCP PMTs. A final design of the PMT bases is now available based on reliability tests. For the PMT potting, 200 prototypes have been potted successfully using the final design of the system. The potting lab for mass production is almost completed. The potting is expected to start by beginning of 2019. Many tests have also been done concerning the PMT protection covers. The bidding for this part has been done and the contract has been signed. The production of the 3" PMTs has started by HZC Photonics since January 2018. Over 25000 PMTs, 9000 have already been accepted. Prototypes of electronics and underwater boxes have been made.

For the Liquid Scintillator, a successful final design review has been done for the distillation and gas stripping plants, which are now under construction. The study on the alumina filtration and water extraction plants using a Daya Bay detector is ongoing. The contract of 60 tons of PPO has been signed. Studies together with the manufacturer will start in order to lower the radioactivity level. The study on high sensitivity Rn measurement system with Rn enrichment is about to be accomplished.

Concerning the electronics system of the 20" PMTs, the main part is in a water tight box placed behind the PMTs hosting three independent ADC Units (ADU) which convert the analogue signal to a digital waveform with a 1 ns sampling rate. The ADUs are interfaced to the Global Control Unit (GCU) cards which makes a real time analysis of the digitized PMT waveforms and generate a trigger signal in case any of the PMT has photoelectrons data. Two CAT5 STP cables (up to 100 m long) connect the underwater box electronics to the JUNO electronics rooms. One of the two cables is dedicated to synchronous communication with the underwater electronics providing a reference clock and receiving back a trigger signal. One end of the cable is connected to the Back-End Card (BEC) which takes care of injecting the reference clock signal and of routing the incoming trigger signal to the trigger processing boards. The other CAT5 STP cable is used for the asynchronous communication and is connected, via commercial enterprise switches, to the DAQ computers of the experiment. All needed electronic boards are now under final design.

Concerning computing, about 12000 CPU cores and 10 PB/year disk storage will be needed during the data taking period.

For all JUNO calibration systems, the studies are well advanced and prototypes have been produced and tested.

5 Expected challenges

The first challenge already achieved was to gather enough institutes from all over the world to build and operate the JUNO detector. The following technological and physics challenges has to be faced by the JUNO Collaboration:

- Achieving $3\%/\sqrt{E}$ energy resolution in a 20 kt Liquid Scintillator detector. The way to achieve this is explained above.
- Building a 20 kt voluminous Liquid scintillator detector.
- Well understanding all systematic errors in order to achieve a mass hierarchy determination with a significance higher than 3 σ.
- Achieving the low radioactivity level mainly necessary for the solar neutrino physics program.
- Well examining the local Earth crust and JUNO sensitivity to geoneutrino detection in order to exploit the JUNO's potential to neutrino geosciences.

The construction of the reference detector JUNO-TAO to measure the IBD spectrum with a resolution significantly better than the one of the 20 kt JUNO detector will be another real challenge.