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JUNO detector design and status

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The Jiangmen Underground Neutrino Observatory (JUNO) is a next generation multipurpose liquid scintillator detector being built in China. It will address a wide range of topics in neutrino physics: the determination of the neutrino mass ordering and the sub-percent measurement of three oscillation parameters from reactor neutrino oscillations, detection of solar, atmospheric and supernova neutrinos as well as the search for physics beyond the Standard Model. The JUNO detector design is optimised towards the determination of the neutrino mass ordering by reaching an unprecedented energy resolution and a low background. The experimental hall, which was recently successfully dug out, is located under about 700 m of granite overburden. The center of the instrument consists of a 35.4-meter diameter acrylic vessel containing 20 kt of LAB-based liquid scintillator, making it the largest liquid scintillator detector in the world. The spherical detector is submerged in a water pool shielding doubling as a water Cherenkov detector which, along with a top tracker above it, serves to precisely reconstruct and veto atmospheric muons. Surrounding the vessel are 17612 20" photomultiplier tubes (PMTs) and 25600 3" PMTs, which will collect the light induced by neutrinos interacting in the detector. This document presents the detector design and construction status of JUNO, which is expected to start taking data in 2023.

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1. Introduction

The JUNO detector is under construction in China with the main goal of determining the Neutrino Mass Ordering (NMO) [1, 2]. The path towards the NMO determination was opened with the non zero value of the mixing angle θ_{13} neutrino oscillation parameter reported by the Daya Bay [3], RENO [4] and Double Chooz [5] experiments, and yet remains a mystery in neutrino physics. Its measurement will give important clues towards the formulation of a theory of flavour beyond the standard model. The NMO has an effect on the electron anti neutrino energy spectrum coming from the nuclear reactors, situated at about 53 km from the detector, that will be observed by JUNO. Moreover, JUNO will perform world leading precision measurements on the other mixing parameters ($sin^2\theta_{12}, \Delta m^2_{12}$, Δm^2_{31} and Δm^2_{32}). Reactor neutrinos will interact in the detector via inverse beta decay ($\overline{\nu}_e + p \rightarrow n + e^+$), producing a double coincident signal. First, the positron deposits its energy and annihilates into two 511 keV photons, producing a prompt signal. After 200 μs on average, a delayed signal is emitted as the neutron, once thermalised, is captured by a proton, releasing a 2.2 MeV γ. This prompt-delayed signal coincidence in space and time is a key background suppressor. The expected daily number of reactor anti-neutrino events detected in JUNO is around 80. In order to be sensitive to the NMO, three requirements are needed: high event statistics, the energy resolution should better than 3% at 1 MeV, and the energy scale uncertainty should be less than 1%. Those requirements have been key for the JUNO detector design.

2. JUNO detector design

JUNO is a medium baseline reactor neutrino experiment, located 700 m underground. It measures the anti electron neutrino flux from 8 reactor cores dispatched in two nuclear power plants at 53 km distance. A schematic view of the instrument is given in Fig. 1. JUNO has been designed in order to fulfill the requirements described in the introduction, allowing it to reach its main physics goal: measuring the NMO in JUNO at 3σ level within six years of data taking. JUNO is the largest ever built liquid scintillator detector and has an impressive PMT coverage (>40.000 PMTs).

The central detector (CD) of JUNO consists of an acrylic sphere filled with 20 kton of liquid scintillator (LS), which will measure the light induced by the interaction of particles with the LS with two systems: the large 20 inch PMT and the small 3 inch PMT systems. The large and small PMTs will be disposed in the detector as to maximise the photocatode area. Thanks to its large LS volume and high LS light yield, together with the high PMT coverage and efficiency, JUNO will have larger event statistics than any previous detector of that kind. Concerning the energy resolution requirement, an uncertainty below 3% is ensured with the double calorimetry system (combining the small and large PMT systems), and four complementary calibration subsystems, detailed in section 2.2. An energy scale uncertainty below 1% can be achieved in JUNO thanks to the high transparency of the LS, a satellite detector near the reactor neutrino source (see section 2.3), and also the calibration plays an important role for that. Surrounding the central detector, there is a water pool which will act as a Cherenkov detector for vetoing atmospheric muons. In addition, the so called top-tracker detector will be used to veto and sample muons, to evaluate their reconstruction performance and their contamination in the CD.

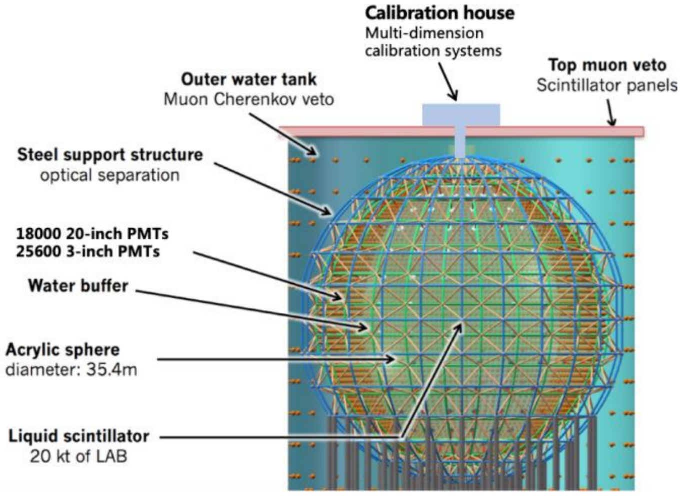

Figure 1: Schematic view of the JUNO detector.

2.1 The JUNO electronics system

The JUNO electronics, sketched in Fig. 2, are divided into the wet (inside water) and dry (outside water) systems. The wet electronics consist on the large and small PMT systems, which readout the signals, and the Global Control Units (GCUs), which process them. The dry electronics host the backend electronics [10], the Data Acquisition System (DAQ) and the trigger, to filter the data. The GCUs are connected to the dry electronics trough one synchronous link to trigger, and trough an asynchronous link for the data acquisition and the slow control of the PMTs. Both systems communicate via various lenght (max. 80 m) ethernet cables.

2.2 The calibration system of JUNO

The four different subsystems conforming the JUNO calibration strategy are the following: the Automated Calibration Unit (ACU), the Guide Tube system (GT), the Cable Loop System (CLS), and the Remotely operated (under-LS) vehicle (ROV). More details can be found in [6].

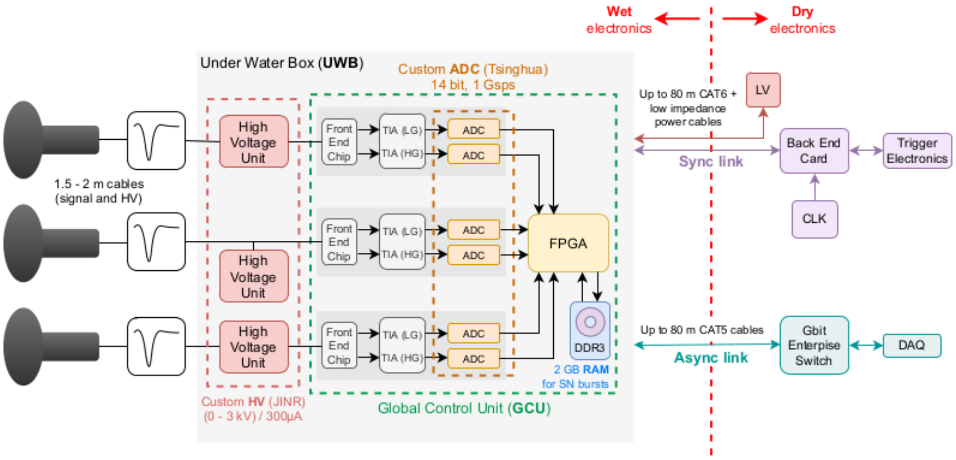

Figure 2: Schema of the electronics system of JUNO.

The ACU is the subsystem in charge to do calibration along the central vertical axis of the CD. The ACU will be used to monitor the stability of the energy scale during the data taking, as well as to partially monitor the position non-uniformity. Different sources (neutron, gamma or laser) can be deployed in the ACU. The GT is a tube that is placed along a longitudinal circle outside of the acrylic sphere. Within the tube, a radioactive source is driven, providing a positioning precision of 3 cm. The CLSs will be installed in the two opposite half-planes, with sources at off-axis positions. On each CLS, two cables forming a loop are attached to the source, allowing to deliver and retract it. Different sources can be interchanged on the CLS. It might also be important to access locations other than the CLS plane, to evaluate any significant local effects or azimuthal dependence present during data taking. These effects can be studied using physical backgrounds, such as spallation neutrons. In addition, JUNO will have a ROV capable of deploying a radioactive source in almost the entire LS volume. Both the CLSs and the ROV will work with an ultrasonic positioning system.

2.3 The JUNO satellite detector: TAO

TAO will be a satellite detector of JUNO. It will be filled with 1 ton of LS and located 30 m from one of the Taishan cores [11]. The TAO detector will be used for a precise an independent measurement of the reactor neutrino spectrum. Its high event statistics due to the close distance to the source, will allow to reduce the reactor flux systematics, as well as the uncertainty on the energy scale. It will also serve for monitoring and safeguard of the reactor.

3. Status of the detector construction

In this section we present the status of JUNO, highlighting the latest achievements. First, about the civil construction: the experimental cavern dug is ready for detector installation, the water pool concrete has been finished and the equipment for the power supply is already in position. For what concerns the central detector, the acrylic sphere had been produced and the pre-assembly, and the tests and stress measurements are ongoing. The stainless steel structure has also been produced and pre-assembled. All the large and small PMTs have been produced, potted and tested. In summary, all detector components are now produced or in the production stage, and will be ready in time for the installation. The detector installation will take place in 2022, and data taking will start in 2023.

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