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The JUNO experiment and its electronics readout system

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Abstract: The main goal of the Jiangmen Underground Neutrino Observatory (JUNO) under construction in China is to determine the neutrino mass hierarchy. The detector consists of 20 ktons of liquid scintillator instrumented by 17612 20-inch photo-multiplier tubes, and 25600 3-inch small PMTs, with photo-cathode coverage of 77%. The electronics system is separated into two main parts. The front- end system, sitting under water, performs analog signal processing. The back-end electronics system, sitting outside water, consists of the DAQ and the trigger. The design of the electronics system as well as the current production status will be reported in the presentation.

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Contents

1 Introduction

The non zero value of the θ_{13} neutrino oscillation parameter measured the Daya Bay [2], RENO [9] and Double Chooz [1] experiments, opened the path to the determination of the neutrino mass hierarchy. The Mass hierarchy measurement will give important clues for the quest of the neutrino nature (Dirac or Majorana mass terms) towards the formulation of a theory of flavour. One fundamental aspect in the lepton sector of the standard model neutrino Mass Hierarchy (NMH) can be distinguished between the Normal Mass Hierarchy (NH) and the Inverted Mass Hierarchy (IH). In the NH the neutrino mass m1 with the highest electron flavor con

m1m2the format is not same

le m_3 with the least electron flavor content is the heaviest. In the IH, m_3 changes its position to be the lightest mass, while the ordering between $m1$ and $m2$ remains. The NMH has a effect on the electron anti neutrino energy spectrum coming from the nuclear reactor. The major goal of JUNO is the determination of the NMH using electron anti-neutrinos from the nearby nuclear reactors situated at a distance of about 53 km. JUNO will also allow better measurement on the other mixing parameter ($\sin^2\theta_{12}$, $|\Delta m^2_{13}|$ and Δm^2_{21}).

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2 Detector

The detector will be located at 700 m underground. JUNO experiment [5] uses 20 ktons of liquid scintillator contained in a 35 m as central detector. The liquid scintillator has similar composition as the Daya Bay, it will be doped with 3 g/L 2.5-diphenyloxazole (PPO) as the fluor and 15 mg/L p-bis-(omethylstyryl)-benzene (bis-MSB) as the wavelength shifter. The acrylic sphere is ~~instrumented~~ by 18000 20-inch photo-multiplier tubes (PMT) and 25600 3-inch PMTs [3]. The 3” PMTs will be installed in the gap between large PMTs. This design will improve the non stochastic term of the energy resolution. The large volume of the central detector and its high photo-cathode coverage

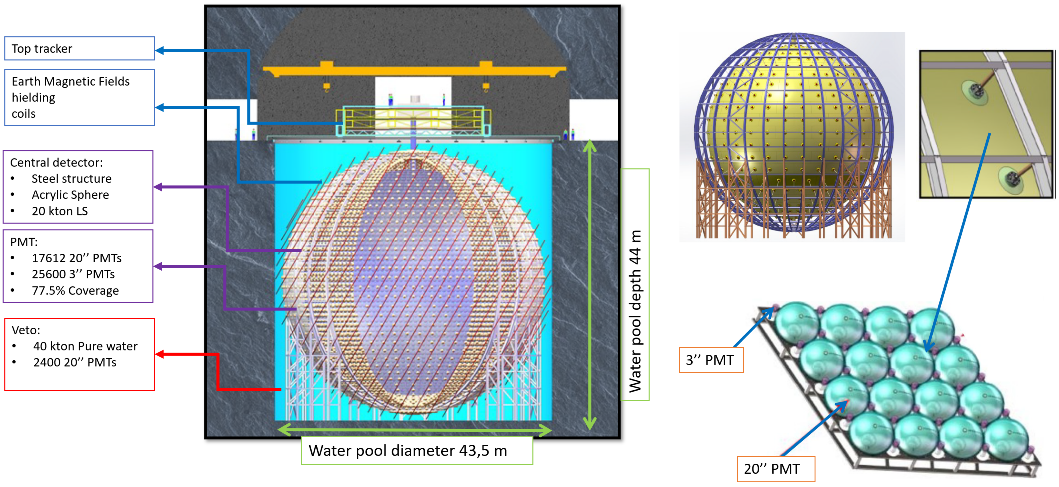

Figure 1. Caption

were designed to improve the gaining statistics and energy resolution as it is a important factor to achieve precise measurements on the neutrino parameters.

The central detector is contained into a ultra-pure water pool of 43.5 m by 44m. The ultra-pure water Cerenkov pool around the central detector instrumented by 2000 20-inch PMTs will tag events coming from outside the neutrino target. It will also act as a passive shielding for neutrons and gammas. In addition, a muon tracker using the OPERA tracker layers, will be installed on top of the detector (top muon veto) in order to tag cosmic muons. It will study the muon track reconstruction and background contamination of in the central detector due to cosmogenic isotope of $^{9}Li/^{8}He$ and the radioactivity from rock. The veto system play a role of a shield against the radioactivity from rock by water. Steel

The calibration of JUNO is also a big challenge due to the large size of the detector and the high photo-cathode coverage. The calibration system include 4 different system: the Automatic Calibration Unit (vertical scan of the central detector), two Cable Loop Systems (complete vertical plane), the Guide Tube (vertical plane scanning but from outside of the acrylic), and the Remotely Operated Vehicle (to transport a source at any place in the liquid scintillator). This system will use neutron sources, positron sources and gamma sources.

3 Electronics readout system

The JUNO electronics system [4] can be separated into two main parts:

1. the front-end electronics system, performing analog signal processing (the underwater electronics).

2. the back-end electronics system, sitting outside water, consisting of the DAQ and the trigger. The back-end electronics system is connected to the front-end electronics system through 100 m cables.

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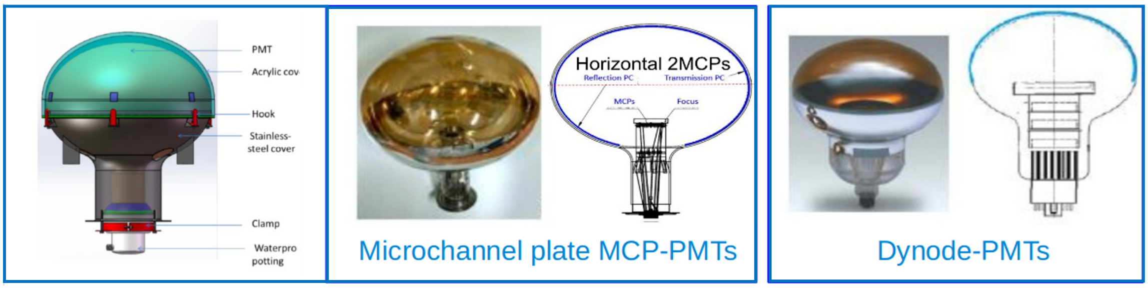

Figure 2. Caption

3.1 20-inch PMT readout system

To be able to discriminate between the two NMH, nominal experimental setup must have a energy resolution 3% at 1 MeV which correspond to photon-electron statistics of 1200 p.e./MeV . To achieve this goal with the central detector size and specifications, the photo-cathode total coverage of JUNO will be above 77%, and the Photo-detection efficiency greater than 25%. In a second time, an excellent photon arrival time measurement is needed for good vertex reconstruction and muon track reconstruction/isolation in the central detector. A large dynamic range (for atm-, geo-, and solar neutrinos) and negligible dead-time (for supernova events lasting up to few seconds) is also asked to the readout system. As a significant par of the electronics will stand underwater, the reliability of the underwater electronics is a main concerns. The objective is to have less than 1% PMT and underwater electronics failure over 6 years of data taking.

3.1.1 20-inch PMTs

For the 20" photo-multipliers system, JUNO made the choice to use two different technologies: the classical dynodes PMTs, and a new development PMTs (conducted and patented by the IHEP laboratory) based on a Muti-Channel Plate (MCP) PMT. More than 20,000 photo-multipliers will be produce to instrument the CD and the veto system. 15,000 MCP-PMTs will produced by NNVT and 5,000 dynodes-PMTs by Hamamatsu Photonics. The MCP-PMT will be used for the CD and the veto-system while the dynodes PMTs will be use exclusively for the central detector. All the PMT have already been delivered and tested. The mean Photon Detection Efficiency (PDE) on all the PMTs achieved is 29.6 %. More specifically, the mean PDE of 30% was achieved for MCP-PMT and 28.4% for dynode PMTs. With the technical improvement from NNVT, the quantum efficiency of MCP-PMT has increased to 35%(HQE-MCP-PMT) [10] while the typical quantum efficiency of DyNode-PMT is 30%. what's more, the collection efficiency of MCP-PMT is 99.9% higher than dynode-PMT of 93.3%[6]. Thereforee the detection efficiency of HQE-MCP-PMT is better than Dynode-PMT.

Figure 2 left panel shows protection surrounding the 20-inch PMTs. An acrylic protective cover which reduces the shock wave to prevent a chain implosion of the tubes in JUNO, ass it append to Super-Kamiokande in 2001.

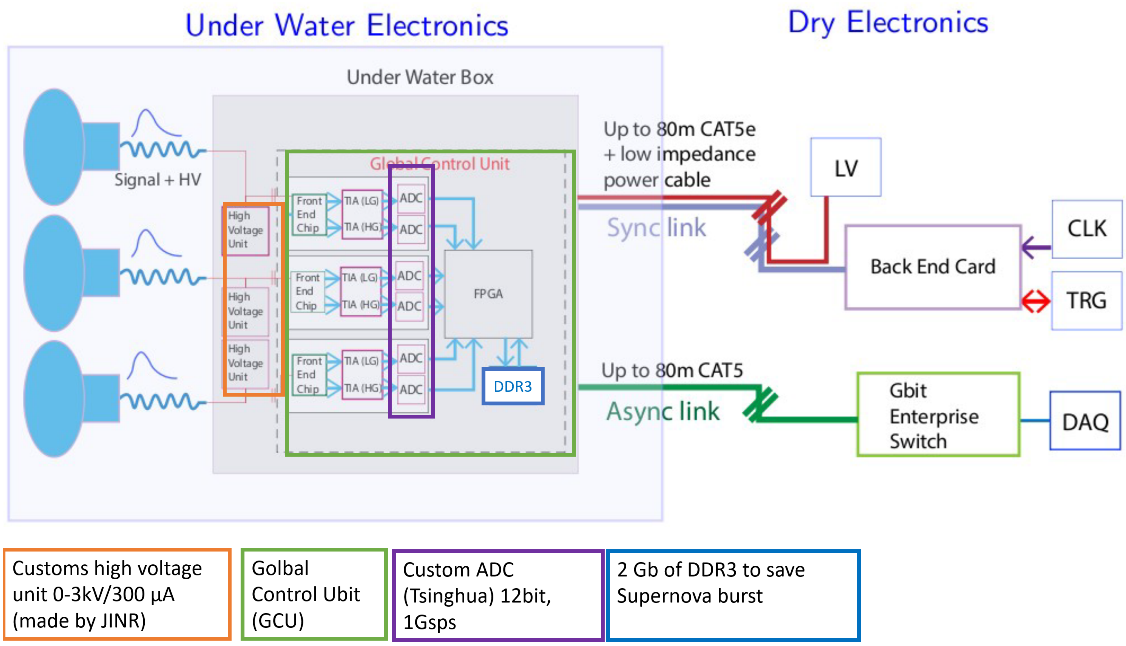

Figure 3. Caption

3.1.2 Underwater electronics

The PMT current signal is conditioned, duplicated into two streams and converted to a voltage value (low-gain and high-gain TIAs) as follows: for the low gain (8:1) in the case of 0-1000 pe, and for the high gain (1:1) in the case of 1-128 pe. Each stream is digitized with a 14-bit 1 Gsample/s custom designed ASIC, developed by Tsinghua University. The digital signal is then processed in the FPGA (Field-Programmable Gate Array). The FPGA used is a Xilinx kintex7. The reconstructed (timestamp, charge) and the digitized waveforms are then stored locally (2 GB DDR RAM). All the Global Control Units (GCUs), about 7000, are synchronised in a time window lower than 16 ns. See Refs. [7, 8] for more details on the GCUs and the clock system, and on the timing synchronisation, respectively.

3.1.3 Dry electronics

As shown in Figure **??**, the BEC can be seen as a concentrator board. The links for the data exchange between the underwater electronics and the back-end electronics are performed through Ethernet cables (represented as a blue line in Figure **??**). Ethernet cable was chosen due to it's high reliability and low cost.

3.2 3-inch PMTs readout system

4 Conclusion

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