PROCEEDINGS OF SCIENCE

Mass testing of Large-PMT electronics at Kunshan for the JUNO experiment

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The Jiangmen Underground Neutrino Observatory (JUNO) [1] is a neutrino medium baseline experiment under construction in southern China, expecting to be completed in 2023. The experiment has been proposed with the main goals of determining the neutrino mass ordering and measuring three oscillation parameters with sub-percent precision. To reach these goals, JUNO is located about 52.5 km from two nuclear power plants and will detect electron antineutrinos from reactors through inverse beta decay. Furthermore, an unprecedented energy resolution of 3% at 1 MeV is required [2]. The JUNO detector consists of 20 kton of liquid scintillator contained in a 35.4 m diameter acrylic vessel, which is instrumented with a system of about 17,612 20-inch Large-PMTs and 25,600 3-inch small-PMTs, with a total photocoverage greater than 75% [3].

The front-end electronics for the Large-PMT system consists of a Global Central Unit (GCU), which performs the analog-to-digital conversion of the waveforms a few meters away from the PMT, thus providing good performance in terms of signal-to-noise ratio.

The mass production of the Large-PMT electronics was carried out in a dedicated facility in Kunshan, China. At the production site, several tests were performed to assess the integrity and the performances of the GCUs; the integration with the back-end electronics was also tested.

This contribution will focus on the test protocol that has been developed for the mass testing of the Large-PMT electronics at Kunshan. Results of the tests will also be presented.

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1. The JUNO experiment

The Jiangmen Underground Neutrino Observatory (JUNO) [1] is a 20 kton multi-purpose underground Liquid Scintillator (LS) detector, currently under construction in South China. The experiment was proposed with the main goal of determining the Neutrino Mass Ordering (NMO), by analyzing the oscillation pattern of $\overline{\nu}_e$ produced by the 52.5 km distant Yangjian and Taishan Nuclear Power Plants. JUNO is expected to resolve the NMO at 3σ significance within 6 years of data taking and will also provide a measurement of three oscillation parameters with sub-percent world-leading precision. Beside its main goal, JUNO's physics program is extensive and includes neutrinos from the sun, the atmosphere, supernovae, the Earth. In order to fulfill its ambitions, JUNO aims to reconstruct the deposited energy in the LS with a 3% energy resolution at 1 MeV and a good linearity response (non-linearity $\leq$ 1%). This resolution is achieved with two PhotoMultiplier Tubes (PMTs) systems consisting of 17,612 20-inch Large-PMTs and 25,600 3-inch Small-PMTs, resulting in a 78% photon sensor coverage [3].

2. JUNO Large-PMT electronics

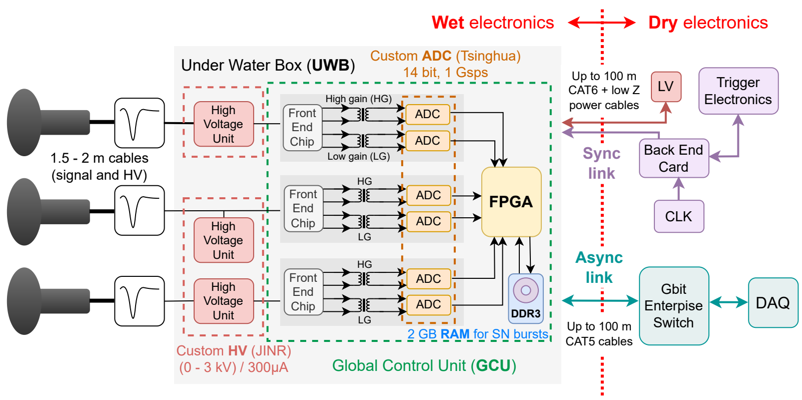

Figure 1: JUNO Large-PMTs readout electronics scheme.

A scheme of the JUNO Large-PMT electronics is given in Figure 1: this is an optimization of previous developments [3].

The JUNO Large-PMTs readout electronics is composed of two parts: the Front-End Electronics (FEE, or *wet* electronics) and the Back-End Electronics (BEE, or *dry* electronics). The FEE will be located very close to the PMTs and will be submerged in the water pool. Groups of three PMTs are connected via a 1.5 m coaxial cable to an Under Water Box (UWB), namely a water-tight stainless steel box containing three High Voltage Units (HVUs) and the Global Control Unit (GCU) board. The GCU integrates the FE and the readout electronics, an FPGA and a 2 GBs DDR3 SDRAM as a larger memory buffer. The Xilinx Kintex-7 FPGA has the tasks of buffering the data, reconstructing the charge and generating the trigger. Each of the three GCU channels is equipped with a *test pulse generator* circuit, that is used to check that a channel is working and to calibrate it. Moreover, the GCU is connected to the BEE via a CAT6 cable (*synchronous* link). The main active element of the BEE is the Back-End Card (BEC) with the Trigger and Time Interface Mezzanine

(TTIM). Groups of 48 GCUs are then connected via Ethernet CAT5 cable (*asynchronous* link) to a Gbit Enterprise Switch and eventually to the Data AcQuisition (DAQ). More details on the JUNO Large-PMT electronics can be found in [3].

3. Mass testing at production site in Kunshan, China

A facility was set up in Kunshan (China) for the mass production and testing of the Large-PMT readout electronics. In this large-scale test facility, it is possible to simultaneously manage a total of 344 GCUs located on shelves in a dedicated testing room. During the production, the HVU and GCU are soldered and stainless steel bellows are welded to a UWB. After the assembling, each UWB is tested for 7 days. Eventually, after a leakage test, the boxes are laser welded and sent to the JUNO site. The testing of the 6900 JUNO electronics modules lasted about 10 months and were concluded in July 2022.

3.1 Test protocol

For the 7-day test, an automated procedure was developed and performed in parallel on all the GCUs, after the assembling of the components. The *test protocol* consists of: (i) a ping test; (ii) a linearity test; (iii) a stability test; (iv) a slow control monitoring.

Ping test The first step of the test protocol is the *ping test*, through which the connection of the GCUs to the network is checked. By using the Linux `ping` command, 100 56-byte packets are sent to each GCU each second and the resulting mean response time can be checked as a function of the GCU ID number (Figure 2).

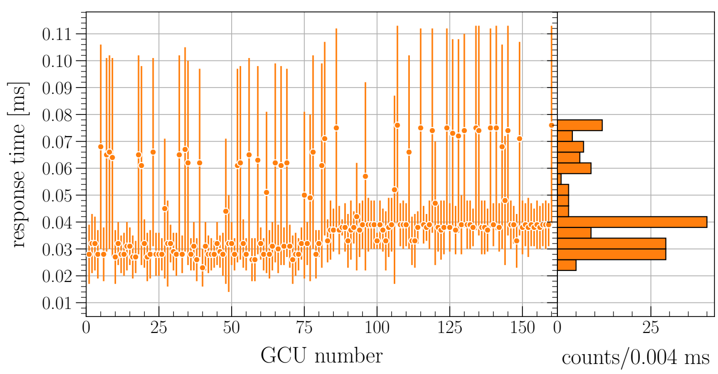

Figure 2: Ping test for a group of 140 GCUs.

Linearity test The Large-PMT signal reaching the GCU is processed by a custom Front-End Chip (FEC), which provides two outputs with low and high gain. The outputs are then digitized by two custom Flash Analog-to-Digital Converters (FADCs), providing a wide dynamic range. The *linearity test* is hence meant to test the linear response of the two FADCs and to retrieve the gain factors. The test was carried out by generating PMT-like signals with the internal calibration circuit (Section 2) and performing short runs at various test pulse amplitude values.

Stability test The *stability test* consists of checking the waveform properties over a long period of time (usually several hours), by providing to each channel a test pulse with the same amplitude over the test duration. The quantities that were monitored are: baseline, noise (baseline sigma), minimum of the waveform, position of the minimum. An example of stability test for the noise parameter is given in Figure 3: an accepted noise level lies betwen 2 and 4.5 ADC counts.

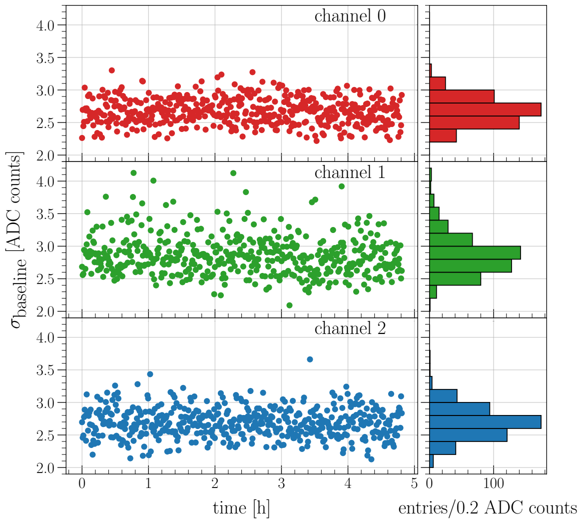

Figure 3: Time evolution of the noise in a stability run for three GCU channels.

Slow control monitoring With the *slow control monitoring*, it is possible to monitor the status of a GCU by reading the sensors installed on the board and several parameters. This is done in parallel to the DAQ. Examples of parameters are: FPGA temperature, HVU temperature, PMT high voltage and internal voltages or currents.

4. Conclusions

During the mass production of Large-PMT readout electronics modules, underwater boxes were thoroughly tested by means of a dedicated test protocol. The protocol was developed so that it could be controlled remotely and run in parallel to the production. In total, 6900 devices were tested in a time span of 10 months, with an acceptance yield of 99.1%.

References

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