The JUNO LNF group

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1 The JUNO experiment

Despite the great progress accomplished in the last decades, a number of fundamental questions concerning the nature of neutrino and their interactions remains. These elusive particles are among the least understood in the Standard Model. The fascinating and well-established phenomenon of neutrino oscillation has clearly shown that neutrino do have masses but as its sensitive only to the differences in the squared masses, the absolute mass of neutrinos has not yet been determined. Likewise it is not known how masses are ordered, i.e. if the mass of the neutrino mass eigenstate m3 is heavier or lighter than the m1 m2 pair. The two possible options are known as normal or inverted mass hierarchy (MH). Moreover there are considerable doubts that the recently discovered Higgs-mechanism, supposed to explain the masses of all elementary particles could apply also to neutrinos, thought as massless in the Standard Model. We also must ask why neutrinos are so light, the heaviest neutrino being at least 11 orders of magnitude lighter than the top quark. Finally it is not known if the CP-symmetry is violated in neutrino oscillations and if there are other generations of neutrinos beyond the standard three.

The neutrino MH is then among the most important issues in the future neutrino oscillation program, and its also crucial for the interpretation of the results of the experiments on CP-violation in neutrino oscillations and the neutrino-less double-beta experiments looking at Majorana neutrinos. The Jiangmen Underground Neutrino Observatory (JUNO) is an experiment designed to determine the neutrino mass hierarchy at the 3-4 σ significance level as a primary physics goal, by detecting reactor anti-neutrinos from two power plants at 53 km distance. The measurement of the anti-neutrino spectrum will also lead to the precise determination of three out of the six oscillation parameters to an accuracy of better than 1 %.

Mass hierarchy can be determined in JUNO exploiting an interference effect between the 3-flavour oscillations in the disappearance of electron anti-neutrino emitted from nuclear power reactors at the medium baseline. The interference manifests itself in a rapid oscillation pattern superimposed on the solar oscillation. The oscillation amplitude and the frequency of the pattern depend on the mass hierarchy. The determination of the neutrino mass spectrum hierarchy, however, will require an unprecedented level of detector performance and collected statistics, as well as the control of several systematics at (sub)percent level.

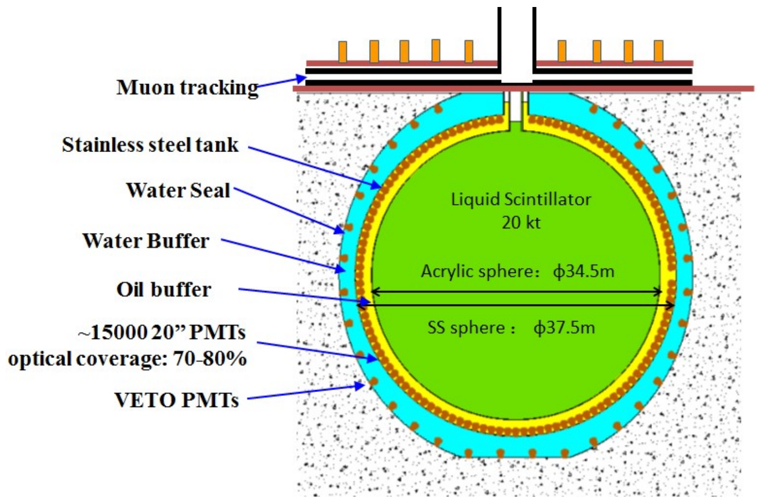

Figure 1: *JUNO detector concept.*

The JUNO experiment will also be able to observe neutrinos from terrestrial and extra-terrestrial sources, i.e. supernova neutrinos, diffuse supernova background, atmospheric neutrinos and neutrinos from the annihilation of dark matter particles in our galaxy. JUNO can then be defined as a multipurpose experiment able to explore the neutrino nature as well as to perform neutrino astronomy and astrophysics. It is the only next generation experiment presently fully funded and it is scheduled to start data taking in middle 2021.

The detector, whose concept is shown in figure 1, will be placed in a 700 m deep underground laboratory, presently under excavation, located at Jiangmen (Guangdong province) in South China, 53 km away from the Taishan and Yangjiang reactor complexes. The central detector consists of a 20-kiloton of Linear Alkyl-Benzene (LAB) liquid scintillator contained inside a 12 cm thick and 35.4 m wide acrylic ball, supported by a stainless-steel structures, and instrumented by more than 17000 20-inch PMTs covering more than 75 % of the surface area of the sphere. In addition, up to 25000 3-inch PMTs will fill the gaps among the large PMTs in order to improve the energy and vertex resolutions. To achieve the primary goal of the MH determination, an unprecedented energy resolution of 3 % at 1 MeV is a critical parameter which requires the total photocathode coverage bigger than 75%, a large PMT quantum efficiency (35%) and the LS attenuation length bigger than 20 m at 430 nm. The central detector is immersed in a 44 m-high, 43.5-wide ultrapure water Cherenkov pool, instrumented by about 2000 20-inch PMTs that will tag events coming from outside the neutrino target. It will also act as a passive shielding for gammas and neutrons induced by cosmic rays in the surrounding rock. A muon tracker, composed of three layers of plastic scintillator strips, will be installed on top of the detector in order to tag cosmic muons and validate the muon track reconstruction.

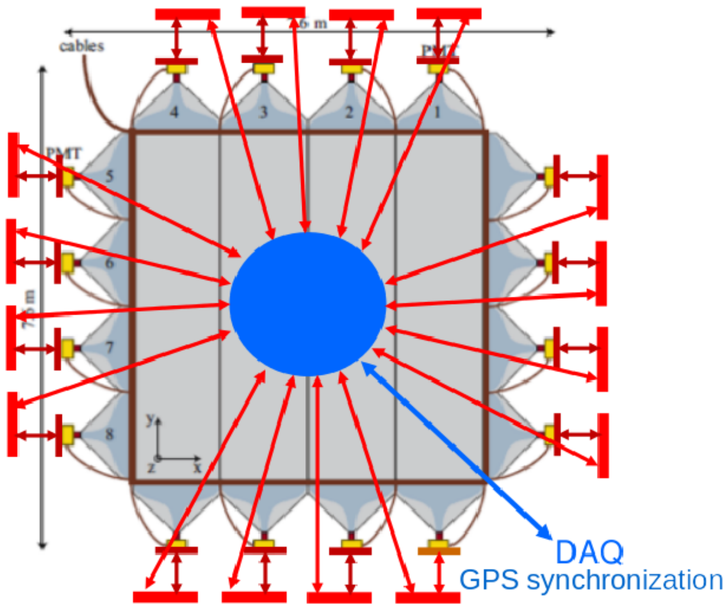

Figure 2: *Scheme of the acquisition system of one Top Tracker wall.*

2 Activities of the LNF group

The LNF group is responsible for the design and the construction of the Top Tracker electronics, in cooperation with the IPHC Strasbourg, the LLR Paris and the JINR Dubna groups. The JUNO Top Tracker will used to select a golden sample of cosmic events in order to estimate the cosmogenic background for anti-neutrino detection and to monitor the performances of the central detector. The 62 walls constituting the OPERA Target Tracker [3] will be used and disposed into three layers on top of JUNO experiment. Each wall is made by 256+256 crossed scintillator strips, 2.6 cm wide; the light, collected by wavelength shifting fibers glued on the strips, is read-out on both fiber ends by 64 channel H7546 Multi-anode PhotoMulTipliers (MaPMT). Each wall contains therefore 16 MaPMTs.

2.1 Description of the Top Tracker acquisition system

Due to the environment (rock) radioactivity, counting rates of up to 50 kHz/MaPMT are expected, therefore the electronics of the OPERA experiment needs to be replaced because of the increased rate. A scheme of the acquisition of one wall is shown in figure 2. Like in OPERA, each MaPMT is served by two electronic boards, the Front-End (FE) board and the Read-Out (RO) board. The 16 RO boards are connected to the Concentrator board, located in the middle of the wall, to equalize the cable length.

The FE board contains a 64 channel MAROC3 chip [4], performing the discrimination of the 64 analog signals at 1/3 photo-electron (pe), the OR of the discriminated signals and the charge measurement by an internal Wilkinson ADC; a multiplexed analog output permits also to acquire the charge with an external ADC. The 64 digital outputs are multiplexed in an 8 channel output connection by a FPGA.

The RO board contains a Cyclone5 GX FPGA. It configures the MAROC3 chip in the FE board and in presence of a signal in the MAROC, delivers the OR to the Concentrator board and starts the acquisition of the digital pattern and further of the charges of the fired strips (both options are possible, to use the internal MAROC3 ADC or a 12 bit FADC located in the RO board). In absence of a coincidence between the x and y strips, performed in the Concentrator, a reset of the started MAROC3 acquisition is performed. The RO board also hosts an HV module (the MaPMT works at 800 V with a current of about 500 μA) and a test pulse unit for calibration purposes: the latter is recoverable from the OPERA experiments, while for the HV module we plan to use a CAEN A7505N power supply module.

The Concentrator board perform the coincidence between the 16 MaPMT OR signals coming from x and y strips of the wall; a rate of about 10 kHz/wall is expected, assuming a 100 ns shaping for the discriminated signals, dominated by random coincidences. In presence of a coincidence, an FPGA based TDC perform the measurement of the time difference between the coincidence inputs and the shaped trigger signal. In addition the digital patterns and the charges are collected from the 16 RO boards, and a global UTC timestamp is given to the trigger signal, in order to reconstruct tracks in the Top Tracker and to synchronize its acquired data with the Water Cerenkov VETO and the Liquid Scintillator Central Detector. In addition the Concentrator collects also slow control data and set different data taking modes: normal, calibration (LED pulsers are used to measure pedestals and single pe charge), debugging (counting rates are measured for each strip, to find eventual light leaks). A maximum data flow of few Mbit/sec is expected for each Concentrator. A data reduction is foreseen, either based on a software algorithm running on a dedicated machine, or performed with a second level trigger board.

A picture of the prototype of the FE board, developed by the IPHC Strasbourg group, and a graphic sketch of the RO board prototype, presently under assembling, are shown in figure 3. The two prototypes will be tested during Spring 2017, while the finalization of the Concentrator board is expected in the second half of the same year.

2.2 Detector prototype tests at LNF

To test the full electronic chain, a prototype of the detector made of two layers of 64 scintillator strips 2.6 cm wide, has been installed at LNF laboratories. The set-up is shown in figure 4.

Since the RO board prototype is not yet ready, we started testing the pulser board using a $\times 10$ Front-End amplifier developed by the LNF electronic workshop. The pulser board is based on an AD8036 limiting amplifier producing an output signal driven by a 20 ns shaped LVDS logical signal and regulated by a voltage V_c, ranging from 0 to 4 V. In figure 5 the typical LED light output, as measured with a power meter, is shown as a function of V_c; a good linearity is obtained above 1 V. Integrating more than one light pulse, a good linearity is measured for pulsing frequencies up to 100 kHz with no pile-up.

The analog signal of 16 MaPMT channels are acquired through a CAMAC C205 ADC. In figure 6 the charge measured for a sample channel is shown for different V_c values from 0 to 1.6 V

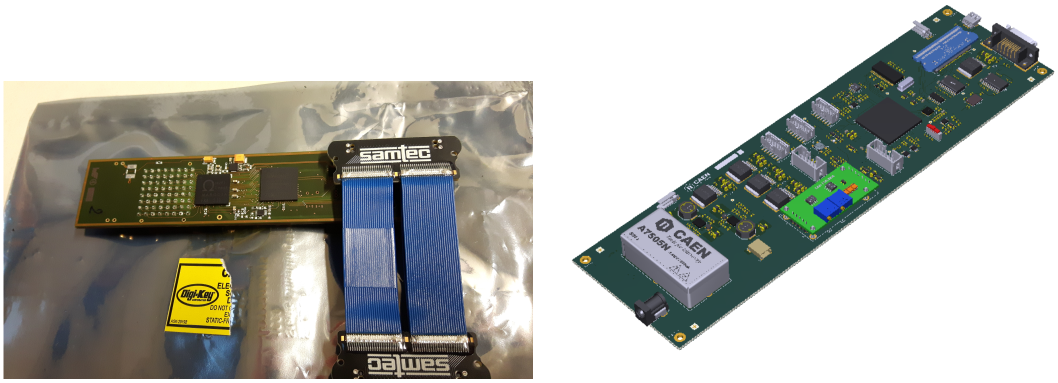

Figure 3: *Picture of the FE board prototype (left) and graphic sketch of the RO board (right).*

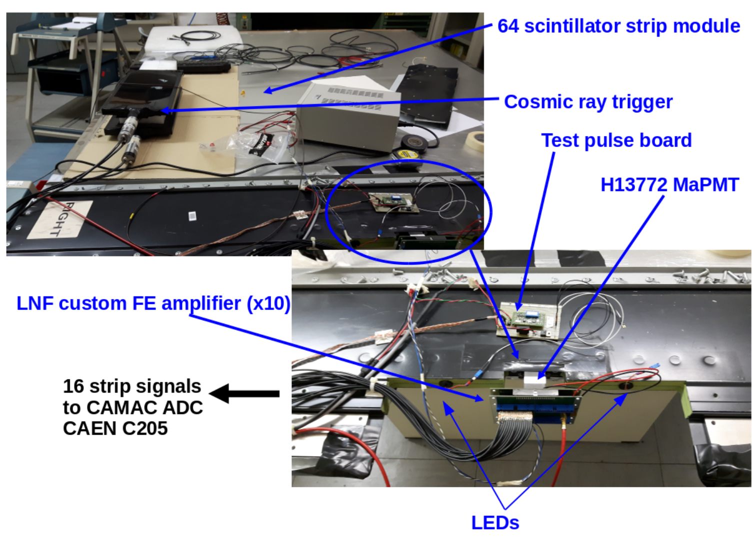

Figure 4: *LNF test stand set-up.*

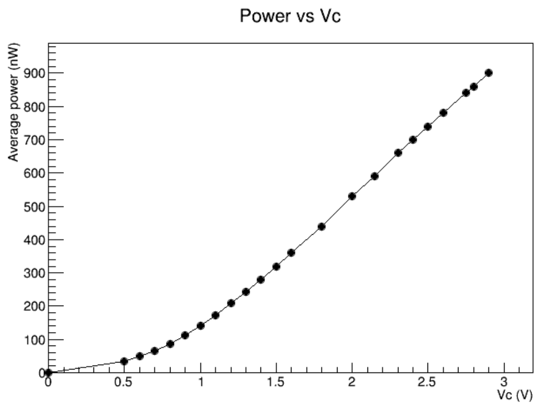

Figure 5: *Typical LED light output power as a function of* V_c.

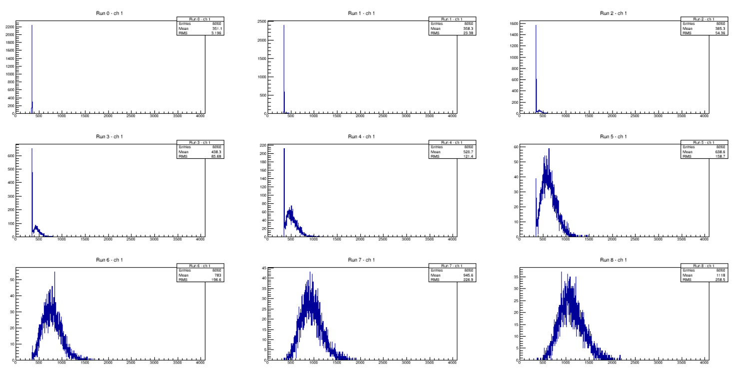

Figure 6: *Measured charge spectrum (before pedestal subtraction) for a single MaPMT channel as a function of* V_c *running from 0 (top left) to 1.6 V (bottom right) with 0.2 V steps. The charge is measured in ADC counts.*

before pedestal subtraction. From the plot it is evident that $V_c = 0.8V$ is a suitable voltage for calibrations, allowing to measure both the pedestal and the single pe charge. Finally in figure 7 the single pe charge measured for 32 channels out of 64 is shown (including a $\times 10$ amplification). A disuniformity of about 10 % is observed. With the MAROC3 it is possible to equalize the single pe charge regulating the amplification channel by channel.

3 Publications

1. The JUNO Collaboration, Conceptual Design Report, ArXiv:1508.07166.

2. The JUNO Collaboration, J. Phys. G: Nucl. Part. Phys. 43 (2016) 030401.

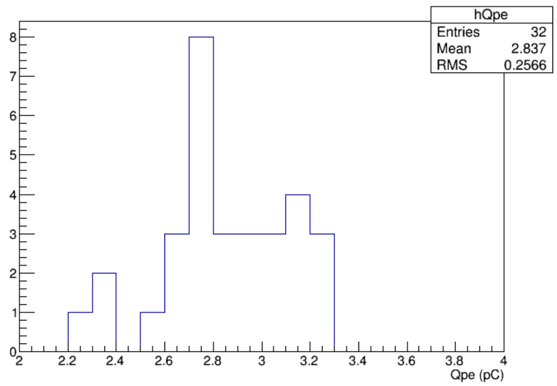

Figure 7: *Distribution of the single pe charge measured for 32 channels of the MaPMT.*

References

1. The JUNO Collaboration, Conceptual Design Report, ArXiv:1508.07166.
2. The JUNO Collaboration, J. Phys. G: Nucl. Part. Phys. 43 (2016) 030401.
3. T. Adam *et al.*, Nucl. Instrum. Meth. A577 (2007) 523.
4. http://omega.in2p3.fr/index.php/products/maroc-front-end-chip.html.