The JUNO LNF group

G. Felici, A. Mengucci (Tec.), A. Paoloni (Resp.),
M. Spinetti (ospite), M. Ventura (Tec.), L. Votano (Ass.)

in collaboration with

LNF-SEA: M. Gatta, G. Papalino

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.

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.

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 Struss (SSS) of 40 m diameter, and instrumented by 18000 20-inch PMTs covering more than 75 % of the SSS area. 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.

The civil engineering works are proceeding: the digging of the eperimental hall will start in March and will be finished by the end of the year; the water pool will be excavated during the next year. The tenders for the PMTs have been finalized. 15000 20-inch PMTs will be acquired from NNVT, while 5000 (with better time performances needed for position measurements) from Hamamatsu. The 3-inch PMTs will be acquired from HZC Photonics. Up to now, 4000 PMTs from NNVT and 2000 from Hamamatsu have been already delivered in the test facility located in ZhongShan. The read-out electronics for the PMTs of the central detector is under finalization, as well as the installation procedures. According to the present schedule, the detector installation will start in January 2020 and the data taking in the middle of 2021.

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 and the JINR Dubna groups. The JUNO Top Tracker will be 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.

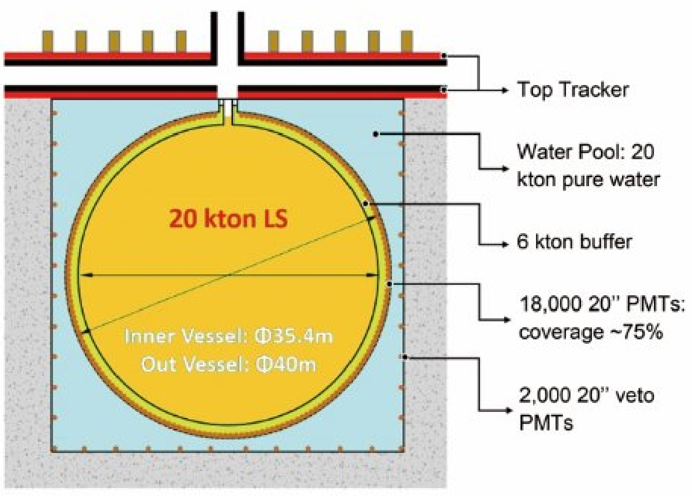

Figure 1: *JUNO detector concept.*

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 through a sample-and-hold technique. The Hold is issued by the RO board. Two options are possible, to use the internal MAROC3 Wilkinson ADC or to multiplex in output analogic signals (OutQ) proportional to the charge and convert them using 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

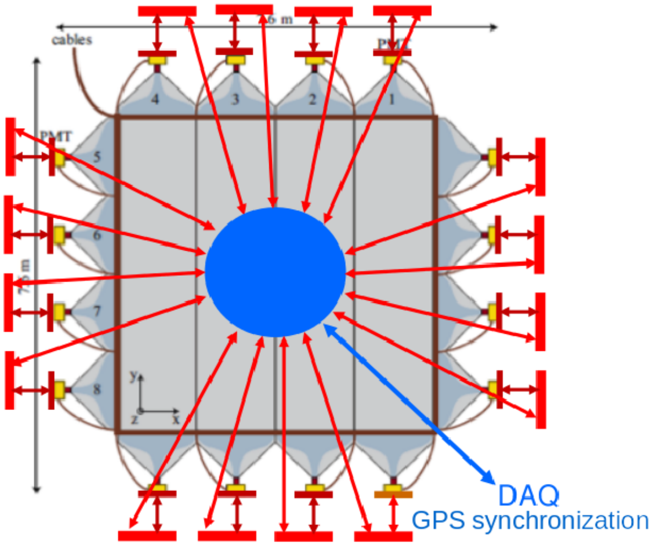

Figure 2: *Scheme of the acquisition system of one Top Tracker wall.*

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 first prototypes of the FE card and of the RO board, installed inside a Top Tracker module, is shown in figure 3. The two prototypes have been successfully tested during 2017. The first prototype of the concentrator is expected in the second half of this year.

2.2 ROB prototype tests

To finalize the design of the two boards, tests of the FE card together with the RO Board have been performed both at Strasbourg university and at Frascati laboratories during 2017.

At LNF a charge is injected in the PMT connector of the FE Card sending a squared signal on a 10 pF capacitor. The injected charge is estimated as the product of the square signal amplitude times the capacitance.

Figure 3: *Picture of the FE card and RO board prototypes installed inside a Top Tracker module.*

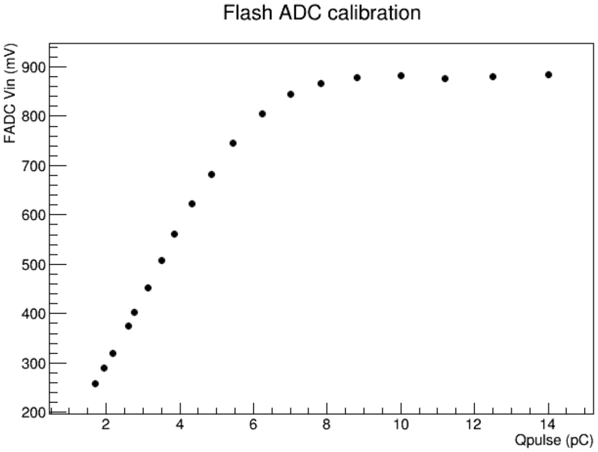

Figure 4: *OutQ amplitude as a function of the injiected charge. 1 V bias has been subtracted.*

The preamplifiers of the MAROC3 have been set with gain equal to one, while the shapings both of the digital and of the analogic sectors of the chip have been chosen according to OPERA experience: in particular we want a rise time in the sample-and-hold chain as short as possible. The Hold signal issued by the ROB has been verified to have a maximum jitter of 2.5 ns, and its delay optimized in order to maximize the charge read out by the internal Wilkinson ADC.

The OutQ signal has been measured as a function of the injected charge, and it is shown in figure 4, after subtraction of 1 V bias. The buffer in the RO board for the digitization of the OutQ signal has been carefully designed and it is shown in figure 5.

The calibration curves of the internal Wilkinson ADC and of the Flash ADC in the RO board are shown in figure 6. A resolution on the charge measurement better than 1%, dominated by the time jitter of the Hold signal, is obtained in the bench tests, using either of the ADCs. The response uniformity on 64 channels is 2.4%.

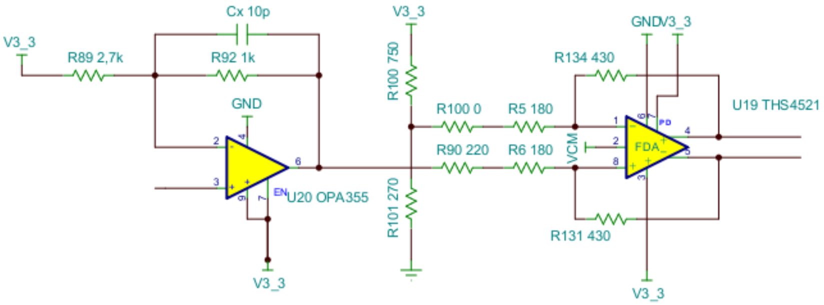

Figure 5: *Final design of the buffer circuit for the digitazion of the OutQ in the RO board.*

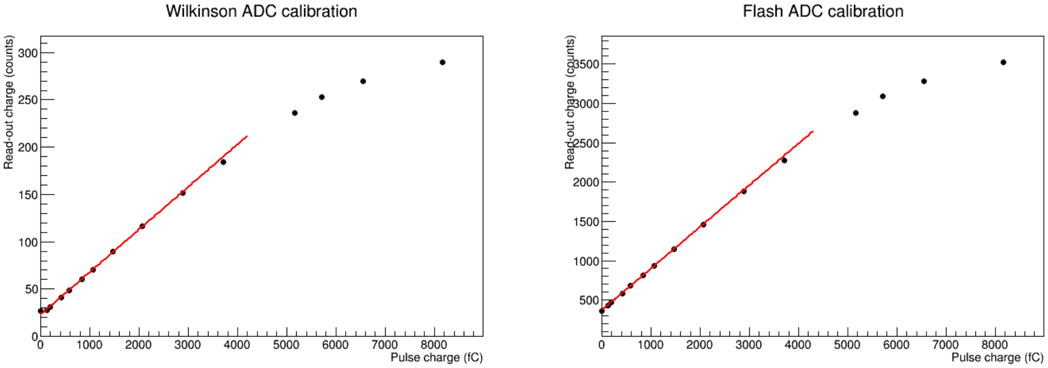

Figure 6: *Calibration curves of the Wilkinson (left) and of the Flash ADC (right).*

The functionality of the HV control and of the test pulse have also been verified in the RO board prototype. The board design will be frozen after the tests with the concentrator prototype.

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.

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.