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High voltage system for the Double Chooz experiment

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Abstract

The Double Chooz experiment, which is dedicated to a measurement of the mixing angle \( \theta_{13} \), adopts 468 photomultiplier tubes (PMTs) to observe the scintillation light generated by neutrino and background signals. The high voltage (HV) system for the PMTs is important for the detector, in order to ensure the stability of the PMT gain. We make use of HV frames and modules produced by CAEN, and have developed the online control and monitoring systems. In order to obtain good correspondence between output and monitoring voltage, the HV modules have been calibrated using a special module developed by CAEN. We confirmed good accuracy and stability of HV for the physics analysis.

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1. Introduction

In neutrino physics, the measurement of neutrino mixing angle \( \theta_{13} \) is very important because it might open a way to unveiling CP violation in the leptonic sector. In recent days, measurement of \( \theta_{13} \) is moving ahead to an important period. The T2K experiment published results which indicate a non-zero \( \theta_{13} \) value [2]. The Double Chooz experiment [1] is a reactor neutrino experiment which aims to measure the neutrino mixing angle \( \theta_{13} \). Reactor neutrino experiment such as Double Chooz, DayaBay, or Reno, will measure the disappearance of anti-neutrino flux from the reactor. This kind of experiment is taking an important role in \( \theta_{13} \) measurement, since which has the advantage of being a pure \( \theta_{13} \) measurement as contrasted with accelerator based measurement which depends on a number of unknown parameters such as \( \delta_{CP} \). We aim to improving the CHOOZ [3] result by means of an increase of statistics and a reduction of systematic errors. Construction of the far detector finished in 2010. Physics data taking was started in 2011 after detector commissioning. The main goal is to improve the limit on \( \sin^2 2\theta_{13} \) from 0.2 to 0.03 in 5 years running.

Figure 1 shows a schematic view of the Double Chooz detector. In Double Chooz, two neutrino detectors [4] of identical structure are placed undergrounds of near (L ~ 400 m) and far (L ~ 1050m) location from the CHOOZ reactors. The near detector measures the neutrino flux and spectrum with high statistics while the effect of neutrino oscillation is small. The far detector measures deficit of event rate and the distortion

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of the neutrino energy spectrum with respect to those of the near detector. Taking this manner, most of the uncertainties associated with neutrino flux and spectrum, detector response and efficiencies are cancelled out. The detector consists of four concentric cylindrical tanks. From the innermost volume, there are two different types of liquid scintillator regions and mineral oil layer called “neutrino target”, ”gamma catcher” and “buffer”, respectively. They are separated by transparent acrylic vessels. In the buffer tank, 390 low background 10-inch PMTs (Hamamatsu R7081MODASSY [5]), are arranged on the stainless steel vessel with 13% photocathode coverage. Combined those three regions are called ”inner detector” (ID). At the outermost, there is a different liquid scintillator region optically separated from the ID, called ”inner veto” (IV) to veto background muons. In this region, 78 8-inch PMTs, Hamamatsu R1408 [5], have been installed. Each PMT has a single cable to reduce the dead volume inside the detector. Hence this single cable carries both signals and HV. A splitter circuit is developed and manufactured by CIEMAT to separate the signals from the high voltage. On the HV side, the voltage is applied individually to give a gain of $10^7$ which corresponds for a single photoelectron to approximately 6 mV. On the other side, the signal reaches a custom front-end electronics. Then the front-end electronics output amplified analog signals to the FADC and stretcher signals to the trigger system.

For the reactor neutrino oscillation experiment, not only deficit of the anti-neutrino but also distortion of the energy spectrum are important information for the precise measurement. Hence the precise reconstruction of the neutrino energy spectrum is required. Stability of the HV is important for the energy reconstruction because the gain of a PMT mainly depends on the supplied high voltage value. In the Double Chooz detector, there are 468 ID/IV-PMTs (390 ID + 78 IV-PMTs), hence the number of high voltage channels as same as PMTs are needed. We adopt a universal multichannel power supply system manufactured by CAEN [6].

![Fig. 1. A schematic view of Double Chooz detector.](image-url)
2. Hardware

Figure 2 shows pictures of a SY1527LC crate and an A1535P module. Two SY1527LC crates are used in one Double Chooz detector. This main frame has 16 slots for housing modules. RS232C and Ethernet are available for network interfaces between those main frames and computers. We use an Ethernet interface to control and monitor HV systems from other computers placed outside of the experimental site.

The A1535P module has 24 positive output HV channels via a Radiall 52-pin connector. The maximum output voltage is 3.5 kV and the maximum output current is 3 mA. The maximum limit of output voltage can be set by both hardware and software side. The hardware limit for each module is set by a potentiometer in front of the module. We set 2100 V as the maximum voltage because hardware limit of PMT is 2200 V. On the other hand, the software limit can be set for each channel. We have set it to 2000 V in the HV control software. The maximum current is also set on software side. When the output current goes over this maximum limit, i.e. HV is tripped, the voltage of the channel will be ramped down. In this section, some hardware properties of the high voltage system are presented.

![Image](image.png)

Fig. 2. CAEN High Voltage power supply. HV crate SY1527LC and HV module A1535P [6].

2.1. Splitter circuit and Noise reduction

Noise produced by the high voltage system has approximately 30-40 mVpp pulse height (Fig 4). This noise is too large comparing with single photo electron signal. The splitter circuit, which is a simple combination of a high-pass and a low-pass filters, is used to separate signals from the high voltage and also used for noise reduction. In Figure 3, schematic diagram of the signal splitter circuit is shown. The high voltage noise has been evaluated using a dummy PMT load. The noise level on the signal cable is required to be less than 1 mVpp, since the pulse height of 1 p.e. signal is a few mV. Figure 5 shows the noise signal after the splitter circuit. We confirmed that the noise from the high voltage system almost vanishes after passed through the splitter circuit.

2.2. HV module calibration

In order to calibrate output voltage from the high voltage modules, we have to measure the output voltage values for given input by a high voltage probe, and make measurements for different values of high voltage. Then fit these measured points by some appropriate functions.

A special high voltage calibration module which can perform the whole calibration sequence is manufactured by CAEN. A picture of this module and the calibration flow are shown in Fig 6. The calibration module which has 24 digital voltmeters in itself can be inserted in the CAEN high voltage crate. Those voltmeters read actual output voltage values then send it back to the high voltage crate. From the output voltage measured by the calibration module, the main crate calibrates the output and monitored voltage by changing calibration constants stored in the HV modules. Calibration constants can be stored and rewritten by ourselves. It takes about one minute for one module calibration. Those processes were done automatically by
some commands once calibration module is connected to the high voltage module by a cable. Figure 7 and 8 shows the calibration result. We checked output voltage value and the monitored value, before and after the calibration. The discrepancy from the set value shows narrow distribution after the calibration.

3. Control and Monitoring

Due to limitation of accessibility to the detector, all electronics including the high voltage system must be controlled and monitored from outside the laboratory since the location of the detector is in the control area of the nuclear power station. Driver and low level interfaces for accessing the HV system is provided by CAEN. The HV server which performs control and monitoring is written in C++ and control/monitoring-GUI is developed with Java. Shifters can perform several operations such as ON/OFF, set the HV value, store the current setting value, through the control-GUI. Figure 9 shows the structure of HV-related software.

MySQL database is commonly used in Double Chooz and two tables to store the ”setting” and ”monitoring” HV values are prepared. The setting table store the individual high voltage values which give a gain of \( 10^7 \) determined in advance [7]. The HV server can put the voltages to PMTs individually by reading the setting table. Moreover, HV server reads the voltage and current values from HV crate then stores them to
the monitoring database, and sends them to the online monitor server every two minutes.

HV monitor system is developed based on the Double Chooz online monitoring system framework[8] which consists of "DAQ subsystems", "Monitor Server" and "Monitor Viewer". DAQ subsystems create and send monitoring information as collections of histograms, named "Histogram packages". Monitor Server collects and stores temporarily monitoring information then transfers them to Monitor Viewers. Two types of Monitor Viewers were developed. One is a Java based viewer which accesses Monitor Server directly by TCP sockets. The other version is based on web browser technologies such as HTML and Java script accessing Monitor Server through web server by HTTP. Alert system which delivers notification from each online system is implemented and we can immediately find the problem by warning massage from the alert system server. All networks between HV server and other systems are connected by TCP/IP communication.

4. Performance

In Double Chooz, precise measurement of neutrino energy is essential to improve the sensitivity and to realize the detection of $\theta_{13}$. The neutrino energy is reconstructed from the charge of signals from PMTs,

Fig. 6. Calibration module and calibration flow. The module calibration performs to uniform $V_{\text{set}}$, $V_{\text{mon}}$, and $V_{\text{out}}$ values from the calibration module.

Fig. 7. Discrepancy between setting value and HV module monitoring value before (dashed line) and after (solid line) calibration.

Fig. 8. Discrepancy between setting value and measured value using dummy PMT load and HV probe before (dashed line) and after (solid line) calibration.
hence the high voltage which directly determines PMT gain is taking an important role in the experiment.

As presented in Sec. 3, the monitored voltages, currents, and times are stored in a MySQL database. The temperature of high voltage modules is also monitored which is approximately 21°C. These values are analysed at the offline level, then the quality of high voltage is validated to determine whether data taken during specific period can be used for physics analyses. An automatic analysing system is developed using the high voltage database and the run control database. Several plots to show history and quality of high voltage during DAQ runs are available on the Web interface using LAMP (Linux, Apache, MySQL and PHP) technologies.

Figure 10 and 11 show examples of stability plots for about two months. In the two months, the high voltage values has been stable within 0.15 percent for all 468 channels. A 0.15 percent deviation corresponds to 1.2 percent of PMT gain variation. This deviation is should be smaller than the systematic uncertainties expected from the other sources. Therefore, the high voltage system is not a major source of systematic uncertainty in Double Chooz.
5. Summary

Double Chooz is a reactor neutrino experiment which aims to measure the neutrino mixing angle $\theta_{13}$. The far detector construction was completed by the end of 2010, and physics data taking started in 2011 after the detector commissioning. CAEN high voltage power supply SY1527LC crates and A1535P modules are used to supply high voltages for 468 PMTs in the detector. Control and monitoring softwares have been developed and are working properly.

To achieve precise measurement of $\theta_{13}$, high voltage system is important for the reconstruction of antineutrino energy spectrum and must be stable. In this paper, we have evaluated several important properties of the high voltage system, the noise level, the precision of output voltages, and the stability. The high voltage system shows good performance to be used in the experiment and is very stable since its installation to the far detector.

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References