Proceedings of the 30th International Cosmic Ray Conference
Rogelio Caballero, Juan Carlos D'Olivo, Gustavo Medina-Tanco,
Lukas Nellen, Federico A. Sánchez, José F. Valdés-Galicia (eds.)
Universidad Nacional Autónoma de México,
Mexico City, Mexico, 2008
Vol. 5 (HE part 2), pages 1271–1274

30TH INTERNATIONAL COSMIC RAY CONFERENCE

Status of Super-Kamiokande and early data from SK-III

MAKOTO MIURA[1] FOR THE SUPER-KAMIOKANDE COLLABOLATION
[1]*Kamioka Observatory, ICRR, University of Tokyo*
miuram@icrr.u-tokyo.ac.jp

Abstract: Full reconstruction works of Super-Kamiokande, a large water Cherenkov detector, has was carried out in 2006 and data taking has been started from July 6th, 2006 as SK-III. Calibration works have been successfully done. Now we are in the analysis stage. This paper reports the status of SK-III.

Introduction

Super-Kamiokande is a large water Cherenkov detector located in Kamioka mine, Gifu prefecture, Japan, under the peak of Mt. Ikenoyama , providing a rock overburden of 2,700 m.w.e. The main purposes of Super-Kamiokande are to observe neutrinos produced in the sun, in the Earth's atmosphere by cosmic-rays, or during a supernova, and to search for proton decays. The Super-Kamiokande consists of two concentric, optically separated water Cherenkov detectors contained in a stainless steel tank with 42 m in height and 39.3 m in diameter, holding a total mass of 50,000 tons of pure water. The inner detector (ID) is comprised of Hamamatsu R3600 20 inch PMTs viewing a cylindrical volume of pure water 16.9 m in radius and 36.2 m in height. The ID is surrounded by the outer detector (OD), a cylindrical shell of water with 2.6 to 2.75 m thickness including 55 cm dead space, instrumented with outward-facing Hamamatsu R1408 8 inch PMTs .

The Super-Kamiokande started observation (SK-I) in 1996 with 11,146 20-inch PMTs and 1,885 8-inch PMTs after. The SK-I data gave us very important information about neutrino oscillations. In 1998, the Super-Kamiokande collaboration found the first evidence of the neutrino oscillation in the world from observation of atmospheric neutrinos [1]. In 2001, they, together with SNO experiment, found the solar neutrinos are also oscillating [2]. Furthermore, in K2K long baseline experiment, the Super-Kamiokande played important role as a far detector and the K2K experiment confirmed the neutrino oscillation observed in atmospheric neutrinos [3].

After 5 years data acquisition, several hundred dead PMTs were replaced in summer of 2001. An accident happened during filling water and 6,777 20-inch PMTs were destroyed. In order to restart observation as soon as possible, it was decided that the survived 20-inch PMTs were distributed uniformly in the tank with cases made of acrylic and FRP, which prevent propagation of shock waves produced by brow-up of 20-inch PMT inside of the case. The Super-Kamiokande restarted observation from 2002 (SK-II) less energy resolution than SK-I due to about half number of PMTs.

During SK-II, about 6,000 new 20-inch PMTs were manufactured. SK-II data acquisition was finished in October of 2005 and full reconstruction was started.

Full reconstruction for SK-III

Assembling 20-inch PMTs into the case made of acrylic and FRP has been started in July 2005. At first, PMTs in wall part were assembled and they were stored in the mine. In October, the SK tank was opened and water in the tank was drained till lower than the top of ID, and the top PMTs were installed. Then some 'floating floor' made of thick Styrofoam were formed on the surface of water, and PMT installation in the wall part were carried out on the floating floor. After one layer finished, the water level was lowered during the night, and the installation work moved to next layer. When the water level arrived at the bottom of the ID layer, the water in the tank was completely drained and installation of the bottom PMTs was started. The PMT installation work was finished in April, 2006 and the tank was filled by pure water until July. The first physics run started on 12th July, 2006.

Calibrations of SK-III

After filling the pure water, several calibration works were carried out.

Timing calibration

Time information of a PMT is determined when the signal comes up more than threshold, and there exists 'time walk' effect depending on the charge information. To correct the time-walk effect, we put a diffuser ball at the center of the tank and flashed by a laser through an optical fiber, and took data with various light intensities to get correction function. When we calculated time for one charge bin, we took a mean value of the time distribution. But this method was affected by reflection light from surfaces of acrylic case, PMTs, or black sheet. To avoid this effect, we made new method in which we take peak time for a charge bin. This method improves time response in the corner region between wall and top or bottom. The improvements were confirmed in Cf+Ni wire gamma ray source run.

PMT gain calibration

To determine HV value for each PMT, we use a scintillator ball which was put at the center of the tank and was flashed by a Xe lamp. It was a light source with stable and uniform intensity. We have PMTs, which have been already calibrated within 1 % before installation and they are located almost on X and Y axis in the top, bottom, and wall part. The PMTs in top and bottom parts were divided into 8 groups with same radius and wall part was divided into 17 layers. The expected charge was calculated by pre-calibrated PMTs in each group and HV of other PMTs were decided to adjust to the expected charge. The observed charges were proportional to quantum efficiency (QE) times gain of each PMT, and RMS of the ratio of the expected charge and the observed charge has been adjusted to better than 2 % (Figure 1).

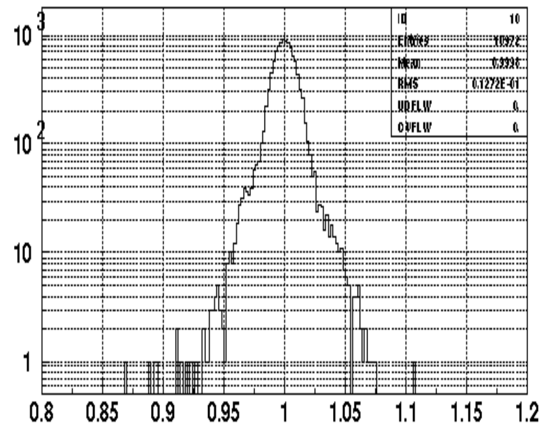

Figure 1: Horizontal axis shows the target charge divided by the observed charge and vertical axis is number of entry. RMS of the distribution is 0.013.

After HV adjustment, an overall correction factor which converts pico Coulomb to photoelectrons (pe) were determined by using 9MeV γ-ray from Cf+Ni source run, which provides 1 pe signals to PMTs. In order to take account signals, which were smaller than threshold of electronics (mostly photons which pass through the first dynode), HV values were increased so that the gains become double and lower the threshold by half. Obtained signal shape for all PMTs were integrated and normalized to one.

We used laser ball to obtain relative gain for each PMT. In multi-photon detection, the charge of individual PMTs is proportional to QE time gain of each PMT. On the other hand, hit rate with weak light source (~1 pe) is proportional to QE. We can estimate relative gain for each PMT by taking ratio of charge in multi-photon data and hit rate in low light intensity data, canceling water attenuation and so on. The fluctuation of relative gain was estimated to be 5.9 %, and top-bottom asymmetry was less than 1 %.

The charge observed by PMT is converted to pe and corrected by relative gain. The QE table of each PMT is installed to MC to reproduce the data.

Water quality

Water quality is important because charges observed by PMT are corrected by light attenuation length in momentum determination. The water quality is monitored by cosmic ray muons, which enter from top and exit from the bottom of the tank. A track of the muon is determined by top and bottom PMT information and number of photons produced in unit track length regards as constant, then distances between photon emitting points and a PMT, and charge observed by the PMT shows the light attenuation length in the water. The attenuation length reached 90 m at the end of 2006 and is still getting better because the water is circulating between the tank and water filtering system by 35 ton/hour.
Detail optical parameters are necessary to make detector simulation of SK-III. We injected laser light to obtain those parameters. The injected photons were detected by PMT directly, or after scattering in water, or after reflection from surface of PMT, acrylic case, and black sheet. The direct and scattered and reflected light can be resolved by timing information. The angular distribution of scattering light gives us fraction of symmetric Rayliegh scattering and asymmetric Mie scattering. Those informations are integrated in the detector simulation to reproduce real data.

Early data from SK-III

Atmospheric neutrino data

To check data quality, we analyzed SK-III data from July 2006 to March 2007 (live time 166 days) with the same reduction and reconstruction tools as SK-II except obvious changes such as number of PMTs. The obtained event rates of fully contained (FC) and partially contained (PC) atmospheric neutrino candidates are 8.31$\pm$0.22 (stat. error) and 0.57$\pm$0.06 event/day, respectively. These values are consistent with SK-II within statistical errors (8.22 event/day for FC and 0.54 event/day for PC). For upward going muon, we have not subtracted background yet, but we obtained 0.32$\pm$0.04 event/day for stopping muon (0.28 event/day for SK-II) and 1.05$\pm$ 0.07 event/day for through going muon (1.07 event/day for SK-II). Figure 2 shows the zenith angle distributions of FC and PC samples with MC predictions in which the neutrino oscillation is not taken account. Even though preliminary results, the distortion due to the neutrino oscillation can be seen in the zenith angle distributions of mu-like events.

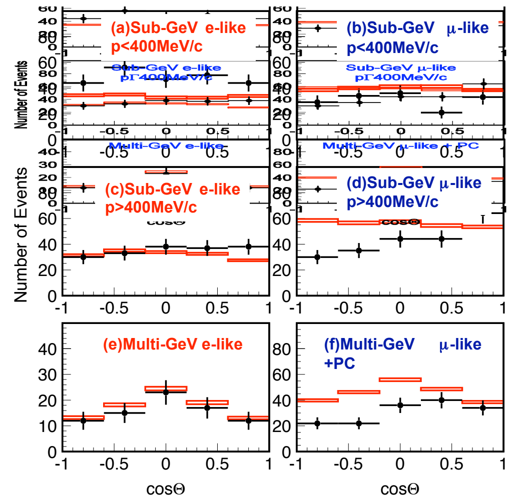

Figure 2: Preliminary results of zenith angle distributions of each -sample: (a) sub-GeV e-like, p < 400 MeV/c, (b) sub-GeV mu-like, p < 400 MeV/c, (c) sub-GeV e-like, p > 400 MeV/c, (d) sub-GeV mu-like, p > 400 MeV/c, (e) multi-GeV e-like, (f) multi-GeV mu-like + PC . Black dots correspond to observed data and red boxes are MC without oscillation.

Solar neutrino data

SK-III data taking started with two triggers; one is for high energy and another is for low energy (LE trigger). The background level was getting lower and the 3rd trigger called super low energy (SLE) trigger has been installed since 24th January 2007. Figure 3 shows efficiency of LE and SLE trigger. The SLE trigger efficiency is 100 % at 5 MeV and 50 % at 4.2 MeV, which is comparable with SK-I. Details of solar neutrino analysis for SK-III are described in another talk (Id: 213)

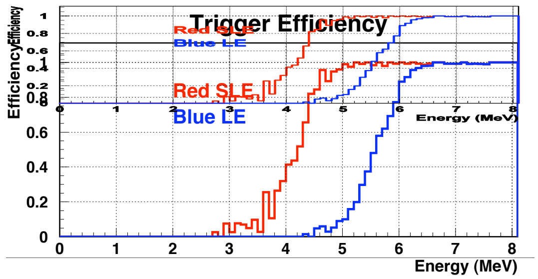

Figure 3: Efficiency curve for LE and SLE triggers.

Summary

From October 2005 to April 2006, full reconstruction of the Super-Kamiokande detector was carried out. We have started data taking as SK-III from July 2006. Several calibration works has been done. The early data of SK-III are checked and found that it is promising the same data quality as before. We are ready to analyze SK-III data and to observe neutrinos from J-PARC.

Acknowledgement

A part of the present work was supported by the Grant-in-Aid in Scientific Research of JSPS.

References

[1] The Super-Kamiokande Collaboration, Phys. Rev. D 72, 052007 (2005).
[2] The Super-Kamiokande Collaboration, Phys. Rev. D 73, 112001 (2006).
[3] The K2K collaboration, M. H. Ahn et al, Phys. Rev. D 74, 072003 (2006).