First results of the K2K long baseline experiment and the atmospheric neutrino problem

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Abstract. The first accelerator-based long baseline neutrino oscillation experiment, K2K, has been launched in the beginning of this year. We report results obtained in the run until June, 1999. So far, we have accumulated 3.5×10^{18} protons on target. One neutrino interaction is observed in Super Kamiokande detector fiducial volume, while expected number of interactions without oscillation is 5.5 ± 1.6.

1. Introduction

Last year, the Super Kamiokande (SK) group announced that an evidence of neutrino oscillation is found in the atmospheric neutrino observation. The result is the first implication of physics which can not be explained by the standard model. Therefore to definitely establish the existence of neutrino oscillation is of great importance and an urgent task.

The K2K experiment is the first accelerator-based long baseline neutrino oscillation experiment. The purpose is to look for neutrino oscillation using well defined ν_μ beam and to confirm the SK results. Figure 1 shows region allowed by SK [1] and sensitive region of K2K. Most part of the allowed region can be tested. Primary search mode of the experiment is $\nu_\mu \to \nu_x$ disappearance.

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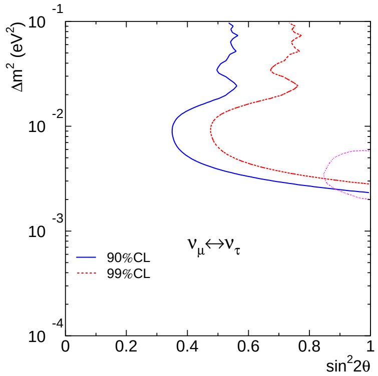

Figure 1. Oscillation parameter region allowed by SK [1] and sensitive region of K2K. The solid and dashed lines are sensitive area of K2K experiment at 90% and 99% confidence level, respectively. The dotted line is 90% CL allowed region by SK.

2. Experiment

The strategy of the experiment is (1) measure absolute ν_μ flux at front neutrino detectors (FDs), $\Phi_{FD}(E_\nu)$, as a function of neutrino energy E_ν, (2) estimate ratio of ν_μ flux at SK to that at FDs, $R(E_\nu) \equiv \Phi_{SK}(E_\nu)/\Phi_{FD}(E_\nu)$, using momentum and angle distribution of secondary pions measured by a pion monitor (πM), (3) multiply $\Phi_{FD}(E_\nu)$ and $R(E_\nu)$ to obtain absolute flux at SK, $\Phi_{SK}(E_\nu)$, (4) compare $\Phi_{SK}(E_\nu)$ with observed one.

Here experimental setup is briefly described. Refer [2] for more detail.

The 12 GeV pulsed proton beam is extracted from KEK proton synchrotron and hits an Al target. The pulse width is 1 μsec and rate is once per every 2.2 sec. The intensity of the beam reached 4.5×10^{12} protons on target per pulse. The secondary pions are focused by two electromagnetic horns [3]. The horns are designed to be operated at 250 kA peak current. Pions decay in the subsequent decay tunnel of 200 m length. Beam Monte-Carlo (MC) simulation predicts that mean neutrino energy is 1.4 GeV and the intensity is uniform within radius of 1 km at SK [2].

We have several secondary particle monitors. The πM is a gas Čerenkov detector placed at just downstream of the second horn. The schematic view of the πM is shown in fig. 2. It measures a slice of Čerenkov ring by an array of photomultiplier tubes. Muon monitors (MMs) are installed behind the beam dump at 200 m from the target. Two types of detectors are prepared: strip ionization chamber and Si pads. The purposes of the

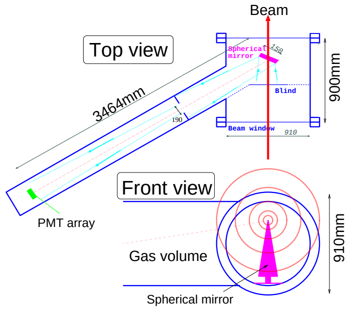

Figure 2. Pion monitor.

MMs are to monitor beam profile and intensity pulse by pulse basis.

The FDs are located at 300 m from the target. Figure 3 shows the FDs. They consists of two independent detectors, front water Čerenkov detector (FWC) and fine grained detector(FGD). The purposes of the FDs are to measure $\Phi_{FD}(E_\nu)$, beam profile and ν_e contamination. The FGD

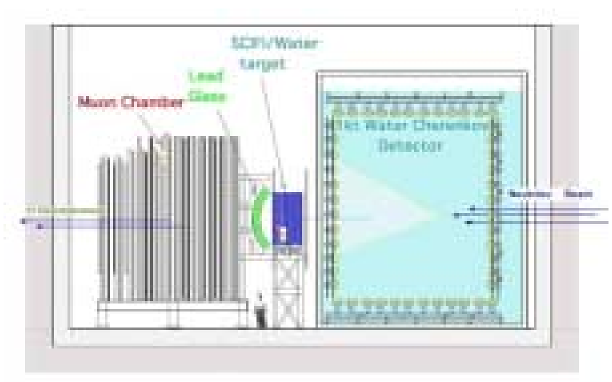

Figure 3. Front neutrino detector.

consists of scintillation fiber tracker(SFT), lead glass detector and muon chamber(MUC). Specialty of FGD is a good position resolution of SFT which enables precise determination of fiducial mass. The SFT is a stack of the water containers and sheets of staggered fibers. The position resolution of the SFT is measured to be 1.1 mm by in situ cosmic-ray measurement. The MUC is a stack of 10- or 20-cm thick, 8×8 m^2 iron plates and layers of drift chambers.

For the $\Phi_{FD}(E_\nu)$ measurement, events with single muon track are used. Assuming quasi elastic interaction $\nu_\mu + n \rightarrow \mu^- + p$, the neutrino energy E_ν

is calculated using muon energy and angle. Main background is inelastic pion productions. Contamination is estimated to be about 30% by MC.

The SK is located at 250 km from KEK. In order to identify the events induced by neutrinos from KEK, time of every beam spill start(T_{spl}) and every SK event trigger (T_{SK}) are recorded by using global positioning system [4]. We expect $0 \leq T_{Diff} \equiv T_{SK} - T_{spl} - TOF \leq 1$ μsec, where TOF is time of flight of neutrino from KEK to Kamioka.

The experiment started January 1999 as scheduled. Until March, we had engineering runs. Physics runs were performed from April to June. In May horn current dependence was measured. In June, horn current of 200 kA was chosen for safety. Then we entered summer shutdown. During the shutdown, horn endurance test at 250 kA is being done.

3. Results

Čerenkov light from pions was successfully observed by the πM as demonstrated in fig. 4. Analysis of the data to obtain $R(E_\nu)$ is in progress. Figure 4 also shows typical muon profile measured by MMs. They show

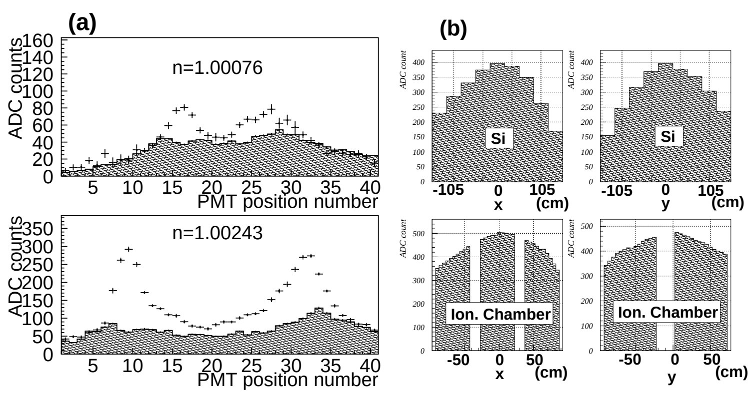

Figure 4. (a) Čerenkov light distribution measured by the πM. Points are data and histograms are background from electromagnetic components estimated by MC. n means refractive index. (b) Muon profile measured by MMs.

that the beam is centered within 20 cm which corresponds to 1 mrad. The fluctuation of the center is measured to be less than 5 cm (RMS).

In FDs, all the detector components have been working. The neutrino profile measured by the FWC is shown in fig. 5(a). The profile is peaked at center and spread a few m. It is in good agreement with MC prediction.

Figure 5(b) is the reconstructed neutrino energy E_ν^{rec} spectrum of the ν_μ events occurred in SFT. Studies to estimate the background contamination is in progress. Also we analyzed ν_μ events occurred in MUC iron plates (νFe events). In fig. 5, horn current dependence of the νFe event rate is shown. The event rate is 5.6/100 spill at 250 kA in 445 ton fiducial mass and it decreases with horn current. The νFe events are useful to monitor neutrino beam intensity and profile because of its high rate and coverage of large area.

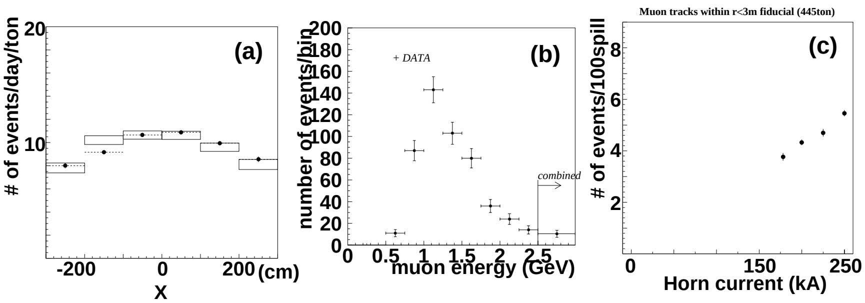

Figure 5. Results of FDs. (a) Horizontal profile measured by FWC. Points are data and boxes are MC prediction. (b) E_ν^{rec} spectrum by SFT. (c) Horn current dependence of νFe event rate.

At the SK, we have accumulated 3.5×10^{18} protons on target (POT) during physics runs from April to June. Figure 6(a) shows the T_{Diff} distribution of fully contained events. We observed 4 candidate events in the signal time window. One event out of them fall in our analysis fiducial volume where distance from the wall is more than 2 m. The event display of the event is shown in fig. 6. There are two prompt rings and 1 decay electron ring.

Expected number of events at SK N_{SK}^{expt} without neutrino oscillation is estimated as follows;

$$N_{SK}^{expt} = \frac{N_{FD}^{obs}}{\varepsilon_{FD}} \times R_{int} \times \varepsilon_{SK} \quad (1)$$

where N_{FD}^{obs} is number of selected ν_μ events in one of the front detectors, ε_{FD} is the detection efficiency of the detector, R_{int} is the ratio of number of interactions in SK to FD and ε_{SK} is the detection efficiency of SK events. Eventually, R_{int} should be extracted from πM results but, for now, is estimated using beam MC. We obtained $N_{SK}^{expt} = 5.5 \pm 1.6$. Major source of the error is difference of R_{int} between hadron production models used in the beam MC. The value is very preliminary and studies to reduce the systematic errors need to be done.

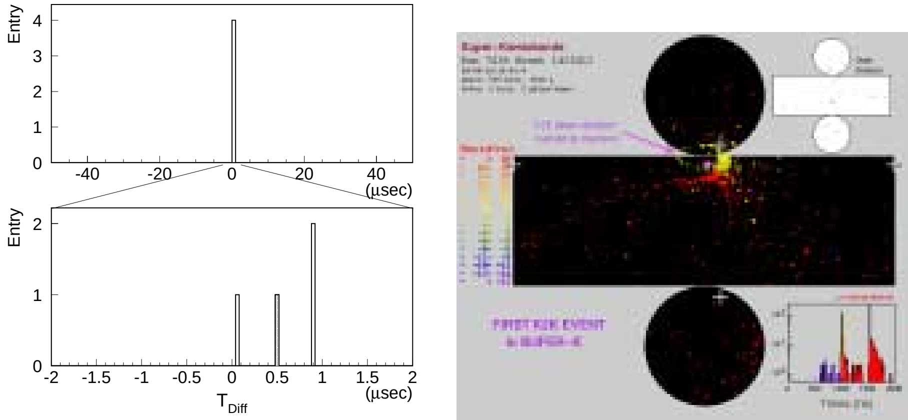

Figure 6. T_{Diff} distribution of SK events and event display of the first event in the fiducial volume. Histogram in the event display shows PMT hit timing.

4. summary

The K2K experiment has been started in January 1999 as scheduled. The proton beam intensity of 4.5×10^{12} on target per pulse is achieved. Accumulated POT during physics runs is 3.5×10^{18}. All detector components start working well. We observed 1 SK event in fiducial volume. The expected number of events without oscillation is 5.5 ± 1.6. Studies to predict neutrino flux at SK more precisely are going on. The physics run will resume in October 1999 at the design horn current of 250 kA.

References

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