K2K Experiment

The KEK-to-Kamioka long baseline neutrino oscillation experiment (K2K) is the first accelerator-based experiment with hundreds of km neutrino path length. The intense, nearly pure neutrino beam (98.2 % ν_μ, 1.3 % ν_e, and 0.5 % $\bar{\nu}_\mu$) has an average $L/E_\nu \sim 200 (L = 250km, < E_\nu > \sim$ 1.3 GeV). K2K focuses on the study of the existence of neutrino oscillation in ν_μ disappearance that is observed in atmospheric neutrinos, and on the search for $\nu_\mu \rightarrow \nu_e$ oscillation with well understood flux and neutrino composition in the $\Delta m^2 \geq 2 \times 10^{-3}$ eV^2 region.

In fiscal year 2001, K2K took data from April to July. The total number of protons delivered onto the pion production target (POT) since the start of the K2K in 1999 reached 5.6×10^{19}. The net POT, successfully used for the analysis of the Super-Kamiokande data, is 4.8×10^{19}. The balance is due to various reasons: tuning of the beam channel, testing of the horns, Super-Kamiokande calibration, failure of Super-Kamiokande due to power failure, etc., and failure in the online data acquisition of the beam-monitoring data. As of July, 2001, K2K is midway to the goal which is represented by 10^{20} POT.

With all the available data analyzed, 56 neutrinos coming from KEK were observed inside the central 22,500 tons of the Super-Kamiokande fiducial volume. On the other hand, from the observation in the 1000-ton water Cherenkov detector located at the KEK site, $80.6^{+7.3}_{-8.0}$ neutrino events were expected to be observed in the Super-Kamiokande detector if neutrinos do not oscillate. The expected number of events fully contained in the Super-Kamiokande fiducial volume is also calculated for the hypothesis of neutrino oscillation with the maximal mixing. Table 1 shows the results. This table also shows numbers for 1-ring μ-like and e-like events and multi-ring events.

Figure 1 shows overall arrival time of events through all runs. The horizontal axis is POT rather than the elapsed time. The uniformity of the arrival times is tested by the KS (Kolmogoroff-Smirnov) probability, which is 43.1 %, indicating satisfactorily uniform distribution.

For the oscillation analysis, the goal is to compare the observed spectrum at the far detector with the non-oscillated spectrum extrapolated from the spectrum measurement at the near detector. Figure 2 shows the reconstructed E_ν spectrum with 30 fully contained 1-ring μ-like events in the Super-Kamiokande fiducial volume. Here, kinematics of two-body quasi-elastic (QE) reaction is assumed. Therefore the observed spectrum mainly consists of the real muon neutrino energy spectrum and non-QE background. The histogram shows a preliminary spectrum extrapolated from the measurement at the near detector, assuming no neutrino oscillation. The non-QE background is taken into account by the Monte Carlo simulation for the neutrino interactions and the detector response. The systematic errors associated with this spectrum have yet to be estimated. Note, however, that neutrino oscillation with $\Delta m^2 = 3 \times 10^{-3}$ eV^2, which is consistent with the atmospheric neutrino oscillations, gives an oscillation minimum in the observed spectrum at $E_\nu \sim 600$ MeV even with the existence of the non-QE background. Although preliminary, the data seem to indicate this minimum.

On November 12, 2001, Super-Kamiokande, the far detector of the K2K experiment and operated by Institute for Cosmic Ray Research, the University of Tokyo, suffered from a sad accident in which about 60 % of both 20-inch PMTs for the in-

Table 1: The observed numbers of events fully contained in SK with the vertices located inside the 22500-ton fiducial volume are compared to the expected numbers calculated from the observation in the 1000-ton water Cherenkov detector at the KEK site for the hypotheses of no oscillation and neutrino oscillation with $\sin^2 2\theta = 1$.

			Δm^2 (eV^2)		
	$N_{\rm SK}^{\rm observed}$	Null Oscillation	3×10^{-3}	5×10^{-3}	7×10^{-3}
FC in 22500 ton	56	$80.6^{+7.3}_{-8.0}$	52.4	34.6	29.2
1-ring	32	48.4 ± 6.7	28.1	17.8	16.0
μ-like	30	44.0 ± 6.8	24.4	14.6	13.5
e-like	2	4.4 ± 1.7	3.7	3.2	3.0
Multi-ring	24	32.2 ± 5.3	24.3	16.8	12.6

ner detector and 8-inch PMTs for the outer detector were destroyed. After 5 years of operation, Super-Kamiokande had been emptied and dead PMTs were replaced with new ones since July, 2001. The accident occurred during water fill, after completion of the replacement work: the water level was about 30 m at that time. The cause of the accident was implosion of one of the PMTs at the inner bottom PMT plane. This implosion generated intense shock waves which destroyed neighboring PMTs, resulting in chain reactions and mass destruction of the PMTs. The first PMT most probably imploded due to a light damage of the PMT glass during the repair or due to strains given at the bottom replacement work.

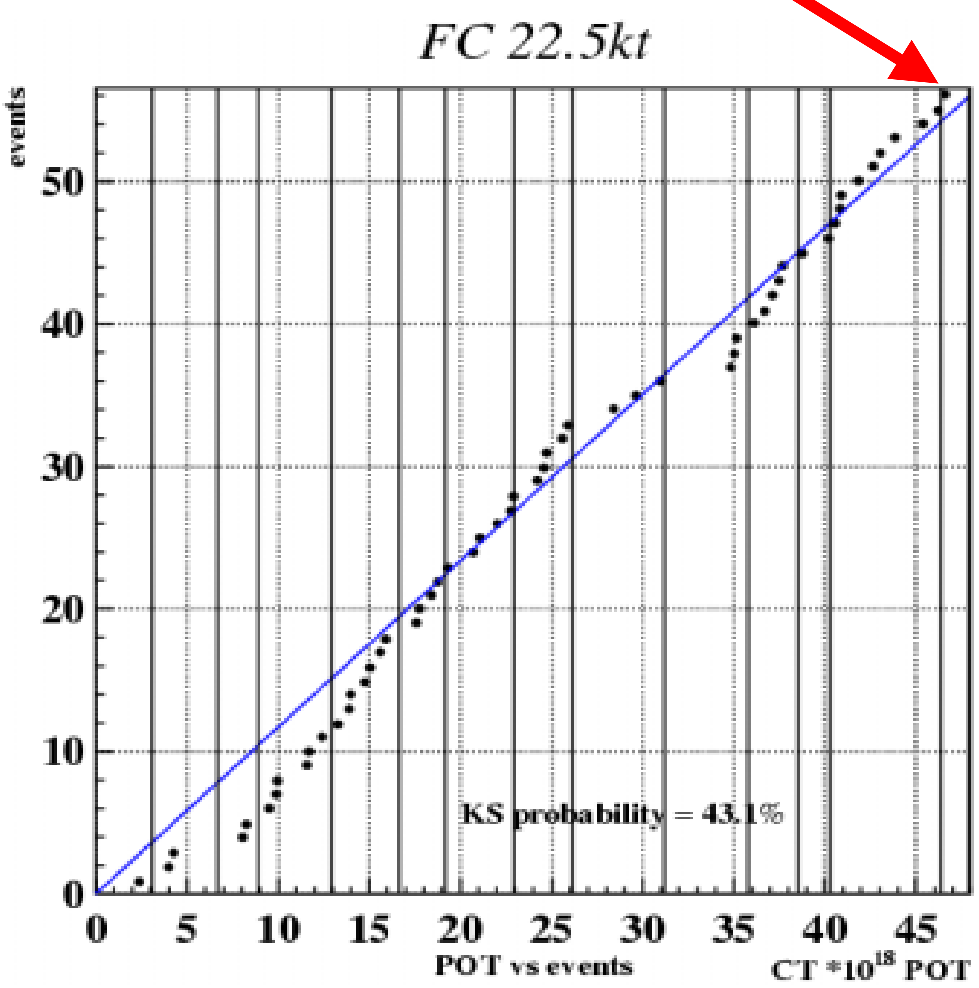
As a result, the K2K run, originally scheduled to resume in January 2002, had to be deferred. As the spokesperson of the Super-Kamiokande Collaboration, Professor Totsuka, announced immediately after the accident, the Super-Kamiokande detector will be rebuilt as quickly as possible with the PMT density reduced by about a half, in order to restart the K2K experiment. The goal may be within a year. It should be noticed that for the detection of GeV neutrinos which are shot from KEK, half PMT density will not cause any serious deterioration of the detector performance. The K2K Collaboration will fully support the recovery work of Super-Kamiokande.

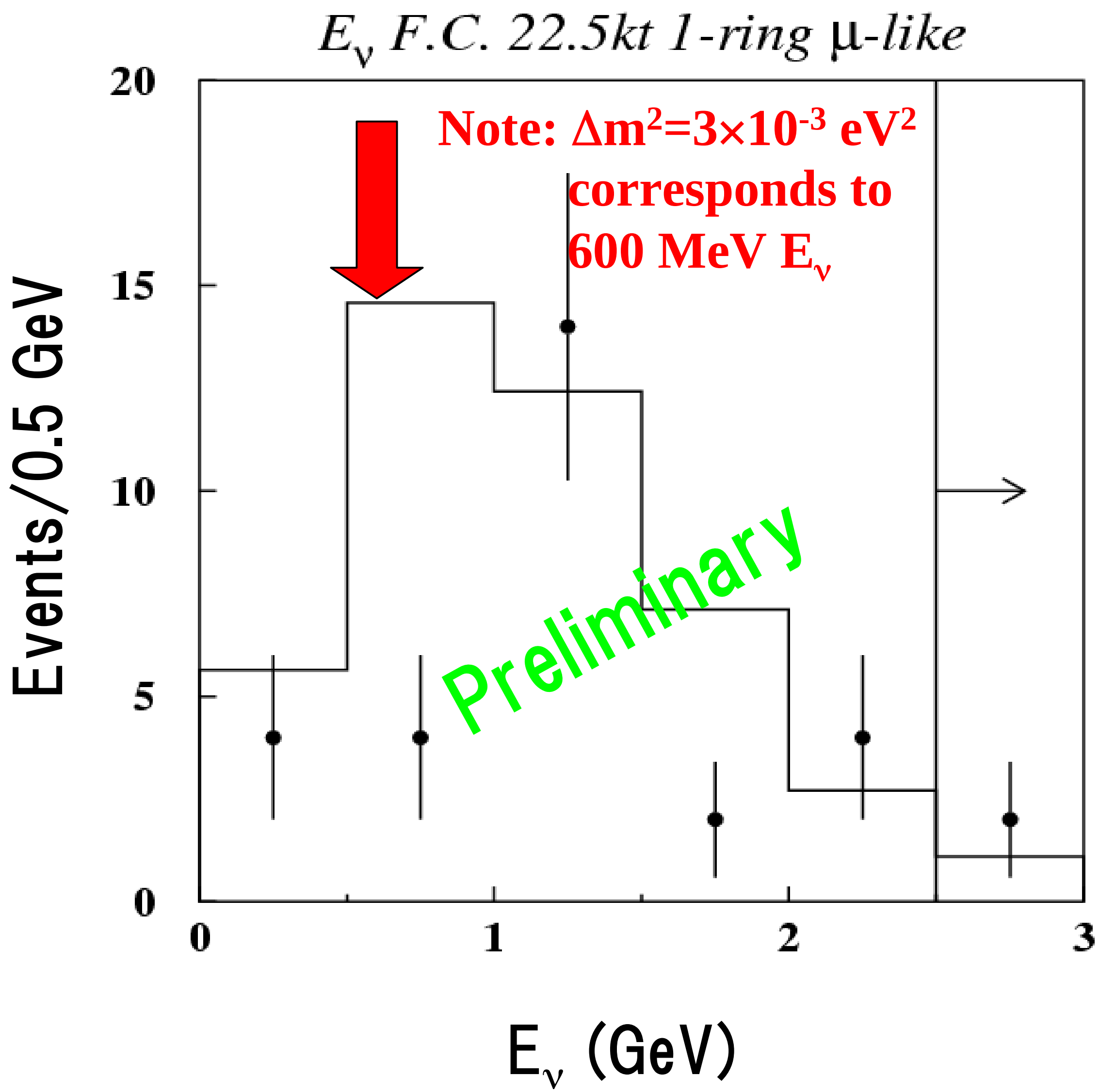
Figure Captions

Fig. 1. POT (number of protons delivered onto the target) versus accumulated number of events at Super-Kamiokande.

Fig. 2. The neutrino spectrum observed at Super-Kamiokande. The histogram shows the spectrum extrapolated from the observation at the near detector, assuming no neutrino oscillation (preliminary).

56 events @ 48 × 10^{18} POT





Eν F.C. 22.5kt 1-ring μ-like
Note: Δm²=3×10⁻³ eV² corresponds to 600 MeV Eν
Preliminary
Events/0.5 GeV
Eν (GeV)
0
5
10
15
20
0
1
2
3