

K2K and T2K

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Abstract. K2K is the first accelerator experiment to investigate neutrino oscillation in the Δm^2 region of atmospheric neutrinos. The observed energy dependent disappearance of ν_μ leads, with a preliminary analysis of the full statistics, to the determination of $\sin^2 2\theta = 1.19 \pm 0.23$ and $\Delta m^2 = (2.55 \pm 0.40) \times 10^{-3} \text{ eV}^2$. The T2K experiment, follow-up of K2K, will start data taking in 2009. T2K will use the new high intensity muon neutrino beam now under construction at J-PARC. Neutrino interactions will be detected, as for K2K, in SuperKamiokande at a distance of 295 km. Main goals of the experiment are a high sensitivity search for ν_e appearance and a study of ν_μ with precision $\delta(\Delta m_{23}^2) \sim 1 \times 10^{-4} \text{ eV}^2$ and $\delta(\sin^2 2\theta_{23}) \sim 0.01$.

1. Introduction

The oscillation of atmospheric neutrinos was first established by SuperKamiokande (SK) in 1998 [1]. The KEK to Kamioka K2K experiment is the first accelerator experiment investigating neutrino oscillation in the Δm^2 region of atmospheric neutrinos. K2K has found evidence for an energy dependent ν_μ disappearance, interpreted as an oscillation with mixing close to maximum [2]. It becomes now of the greatest interest to improve the precision on the oscillation parameters for disappearance, and to search for the sub-dominant oscillation mode, i.e. for ν_e appearance at the atmospheric Δm^2 , a phenomenon related to a non-zero θ_{13} mixing angle and to a possible CP violation in the lepton sector. These issues will be addressed by the T2K experiment which will start data taking in 2009. T2K will use the new high intensity muon neutrino beam, now under construction at the J-PARC complex in Tokai. A brief description of K2K and T2K is given in the following.

2. K2K

The K2K experiment has collected data from 1999 to 2004. The almost (98%) pure ν_μ beam was produced at KEK by the 12 GeV PS. The beam of 1.3 GeV mean energy was directed towards SuperKamiokande, the 50 Kton water Cherenkov detector, at 250 km from KEK.

The experiment also includes a set of near detectors, located 300 m downstream from the proton target. The near detectors are used to monitor the non oscillated beam in direction, intensity, energy, and composition, and to study the characteristics of neutrino interactions. The near detectors consisted of a 1 Kton water Cherenkov detector, and a scintillating fiber plus water target (SCIFI), followed by a lead glass calorimeter and a muon range detector. In the last phase of data taking the lead glass calorimeter was replaced by SCIBAR, a new fully active fine grained detector made of 14848 strips of extruded scintillator read out by wavelength shifting fibers.

The final statistics of the experiment corresponds to 0.92×10^{20} Protons On Target (POT). Evidence for oscillation is obtained from a disappearance analysis based on the deficit in the total number of

neutrino interactions detected in SK, and on the distortion of the neutrino energy spectrum, measured for the restricted sample of fully contained single-ring muon-like events (1R μ -like).

Evidence for ν_μ disappearance is obtained from a comparison of the observed number of events in SK with the number expected in absence of oscillation. The total number of fully contained events in SK, selected in coincidence with the beam spill, is 112. The number of events expected in SK in absence of oscillation is computed using the events collected in the near 1 Kt water Cherenkov detector, where neutrino cross-sections are the same as in SK, and detection efficiencies can be reliably scaled to those of SK. The expected number of events, without oscillation, is 156^{+12}_{-10} (sys).

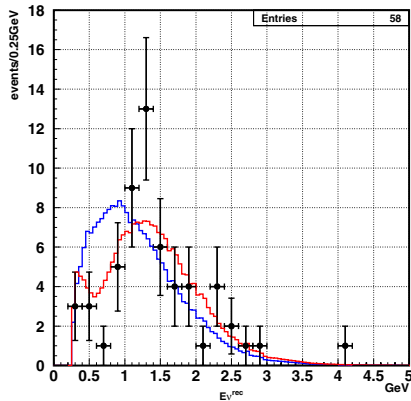


Figure 1. K2K - E_ν spectrum from 1R μ -like events (points with error bars), compared with oscillation best fit (curve with a dip), and with the spectrum without oscillation.

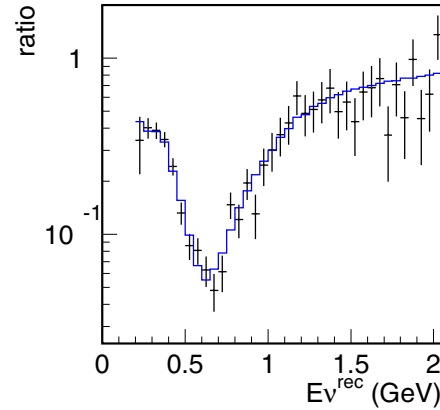


Figure 2. T2K - 1R μ -like events - Ratio of the observed E_ν spectrum to the one predicted in absence of oscillation (simulated experiment: $\sin^2 2\theta_{23} = 1.$, $\Delta m^2 = 2.7 \times 10^{-3} \text{ eV}^2$).

The neutrino energy spectrum at SK is computed using the 58 candidates of the restricted sample of 1R μ -like events. E_ν is computed with the kinematics of the quasi elastic (q.e.) $\nu_\mu n \rightarrow \mu^- p$ scattering, with the angle and the energy of the muon derived from the measurements of the Cherenkov ring. The resulting spectrum is shown in figure 1. An extensive study of neutrino interactions in the near detectors is used to compute the expected spectrum, with and without oscillation. The pattern of neutrino interactions measured in SCIFI, and more recently with even more detail in SCIBAR, is used to determine the characteristics of 1 and 2 tracks events and hence to better control the inference of the E_ν spectrum from the measurement of the 1R μ -like events.

The overall analysis in terms of two flavors oscillation is made with likelihood fits to the total number of events and to the energy spectrum. The best fit energy spectrum with oscillation is shown in figure 1 (curve with a dip), together with the spectrum expected in absence of oscillation, normalized to the 1R μ -like sample. The measured parameters (preliminary results for the full statistics) are:

$$\sin^2 2\theta = 1.19 \pm 0.23, \quad \Delta m^2 = (2.55 \pm 0.40) \times 10^{-3} \text{ eV}^2, \text{ or,} \\ 1.88 \times 10^{-3} \cdot \Delta m^2 \cdot 3.48 \times 10^{-3} \text{ eV}^2 \text{ at } 90\% \text{CL, when imposing } \sin^2 2\theta = 1.$$

3. T2K

Since 2001, the construction of a new accelerator complex, including a very high intensity 40 GeV PS, has started at the Japan Atomic Research Institute (JAERI) in Tokai, at 100 km from Tokyo. The 40 GeV proton beam will be used to provide a neutrino beam to the Tokai to Kamioka (T2K) experiment. The approval of T2K in December 2003 has given start to the construction of the neutrino beam, and the experiment is expected to start data taking in April 2009. The neutrino beam will hit (off-axis) the fully reconstructed SK detector at 295 km from Tokai. The high intensity of this “super-beam”,

coupled to the performance of SK, will open a new phase in the measurements of neutrino oscillation in the domain of the atmospheric Δm^2 .

The neutrino beam now under construction will have an off-axis configuration, yielding a quasi monochromatic energy spectrum matching the Δm^2 of the oscillation ($\theta_{\text{off-axis}} = 2.5^\circ$, and $\langle E_\nu \rangle = 0.7$ GeV is the baseline choice). After a period of test, the beam power will steadily increase, with different options still under study for the power upgrade. Following the most likely scenario, the power will reach values around 1.3 MW by the end of 2012. T2K expects to collect, starting from April 2009, 5×10^{21} POT in 5 years of data taking (50 times the number of POT of the complete K2K experiment). We refer to this statistics in the following summary of the goals of the T2K experiment.

The high sensitivity search for ν_e appearance will be performed by looking for single ring electron-like events in SK, mainly corresponding to the q.e. interaction of ν_e . The appearance of ν_e is to be compared with the 4800 ν_μ q.e. candidates (1R μ -like) which would be expected in SK in the absence of oscillations, illustrating that the sensitivity can reach the per mill region. The expected efficiency for ν_e CC interactions is around 40%, and the expected background is of the order of 20 events. The background, to be predicted with 10% precision, equally comes from the small (0.4%) original ν_e contamination in the beam, and from single π^0 events produced in neutral current interactions of ν_μ . The reach of T2K is given by the 90% sensitivity to $\sin^2 \theta_{13}$ for $\Delta m^2 = 2.5 \times 10^{-3} \text{ eV}^2$: $\sin^2 2\theta_{13} = 0.008$ (at $\delta_{\text{CP}} = 0$); a value about 20 times smaller than the best present limit due to CHOOZ [3].

The high statistics collected by T2K will also be crucial for the precision measurements in the ν_μ disappearance mode. The 1R μ -like events in SK will allow to reconstruct the energy spectrum of the neutrino at SK. Figure 2 shows the result of a simulated experiment with $\Delta m^2_{23} = 2.7 \times 10^{-3} \text{ eV}^2$ and $\sin^2 2\theta_{23} = 1$. The quantity in the plot is the ratio of observed to expected (in absence of oscillation) neutrino energy spectrum. The plot suggests the precision that T2K will achieve on the measurement of the parameters of the oscillation: $\delta(\Delta m^2_{23}) \sim 1 \times 10^{-4} \text{ eV}^2$ and $\delta(\sin^2 2\theta_{23}) \sim 0.01$.

The success of the measurements at SK relies on a good knowledge of the beam and of the characteristics of neutrino interactions. In T2K the beam direction will be monitored spill by spill by measuring high energy muons from π decay directly after the beam dump, and by measuring the neutrino beam profile with an array of “on-axis” iron/scintillator detectors, located in a station at 280m from the production target. This station will also host a sophisticated “off-axis” detector operating in a uniform magnetic field. It will perform accurate studies of the ν_e contamination in the beam, and of the π^0 production, both essential in the search for ν_e appearance. It will also provide detailed information on the neutrino processes related to the 1R μ -like events of SK used in the ν_μ disappearance study. The 280 m detectors are under construction, and will be in operation at the beginning of the experiment, in April 2009. It is also being planned, for a somewhat later stage, the construction of an experimental area at 2 km from the production target, designed to host a 1 Kton water Cherenkov detector, together with a high resolution 150 tons Liquid Argon TPC. At the 2 km location the effects of the finite size of the neutrino source are negligible, and the use of a water Cherenkov detector similar to SK simplifies the measurements of signal and background reactions. The 2 km measurements will therefore further reduce the uncertainties on the extrapolation to SK of beam and backgrounds.

We conclude by mentioning that T2K is also exploring longer term plans to exploit at best the final 4 MW power of the beam, probably available from year 2015. Some of these plans were discussed in other talks at this Conference.

References

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