“Precise prediction of the neutrino flux in T2K”

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T2K (Tokai-to-Kamioka) [1] (Fig. 1) is a long baseline neutrino oscillation experiment. T2K uses a neutrino beam produced in the conventional way at J-PARC. The beam axis is directed 2.5° off-axis to the far detector Super-Kamiokande (Super-K) which locates 295 km away from J-PARC (a distance L is 295 km). This configuration produces a narrow band ν_μ beam [2] tuned at the first oscillation maximum $E_\nu = |\Delta m_{23}| L/(2\pi) \sim 0.6$ GeV, reducing backgrounds from higher energy neutrino interactions. Figure 2 shows the expected neutrino flux at Super-K.

The main physics goals are precise measurement of the neutrino oscillation parameters, Δm^2_{23} and θ_{23} with precision of $\delta(\Delta m^2_{23}) \sim 10^{-4}$eV^2 and $\delta(\sin^2 2\theta_{23}) \sim 0.01$ via the ν_μ disappearance studies, and search for the $\nu_\mu \to \nu_e$ appearance via the mixing angle θ_{13} with a factor of about 20 better sensitivity compared to the θ_{13} measurement of the CHOOZ experiment [3]. In addition to the neutrino oscillation studies, the T2K neutrino beam (with $E_\nu \sim 1$ GeV) will enable a rich fixed-target physics program for the ν_μ neutrino interaction studies.

Precise prediction of the neutrino beam flux is necessary for the neutrino oscillation analysis and the neutrino interaction studies. Uncertainty in the neutrino flux is due to several error sources. The dominant error arrises from the uncertainty of the production of the hadrons which are parents of the neutrinos. We can reduce this flux uncertainty by optimizing our neutrino beam simulation using the data from the dedicated NA61 measurement [4] and other external hadron experiments. Another error arrises from the uncertainty of the proton beam condition. When the proton beam center deviates from the target center, the beam axis deviates from the original one and the neutrino flux changes We measured the actual proton beam optics parameter at the target with beam monitors and controlled the proton beam well. Also, we confirm the neutrino beam direction with a measurement of the neutrinos at an on-axis detector 280 m away from the target. In T2K, the neutrino beam direction must be controlled within 1 mrad to achieve the physics goals. This level of stability is achieved during the whole data collection period (Fig. 3). Figure 4 shows the assigned fractional flux uncertainty in the current situation.

In the T2K oscillation analysis, we extrapolate the near detector measurements to Super-K based on the neutrino beam production simulation. Some of the beam uncertainties from neutrino flux and neutrino interaction can cancel in this method. The systematic error in the ν_e appearance analysis arising from the neutrino flux is about 16% without the near-to-far extrapolation, while that with the extrapolation is 8.5%.[5].

This poster will describe the method for the precise prediction of the neutrino flux in T2K.

[1] Y. Itow et al. (T2K Collaboration), (2001), arXiv:hep-ex/0106019
[2] D. Beavis, A. Carroll, I. Chiang, et al. (E889 Collaboration), Physics Design Report BNL 52459 (1995).
[3] M. Apollonio et al. (Chooz Collaboration), Eur. Phys. J. C27, 331 (2003), hep-ex/0301017.
[4] NA61/SHINE Collaboration (N Abgrall et al.) CERN-PH-EP-2011-005, Feb 2011. 27pp. Published in Phys.Rev.C84:034604,2011. e-Print: arXiv:1102.0983 [hep-ex]
[5] Phys. Rev. Lett. 107, 041801 (2011)

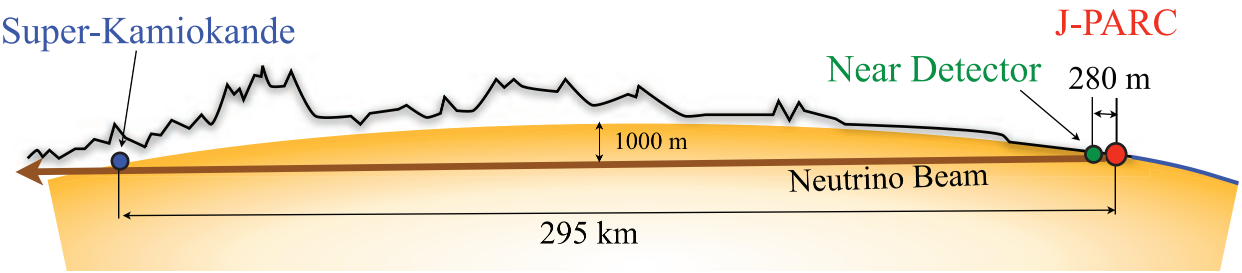

Figure 1: A schematic of a neutrino's journey from the neutrino beamline at J-PARC, through the near detectors which are used to determine the properties of the neutrino beam, and then 295 km underneath the main island of Japan to Super-Kamiokande (Super-K).

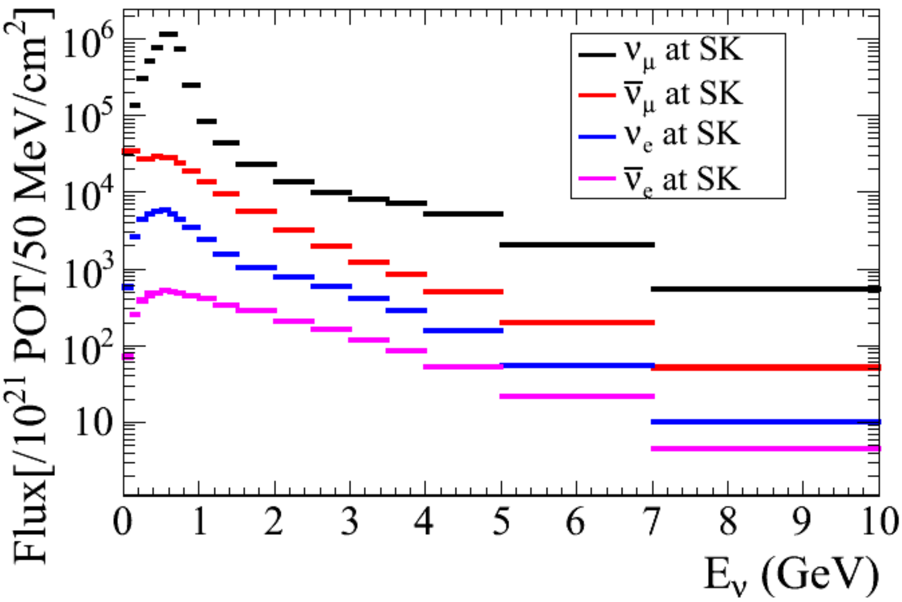

Figure 2: The expected T2K neutrino flux energy spectrum at Super-K for each neutrino flavor.

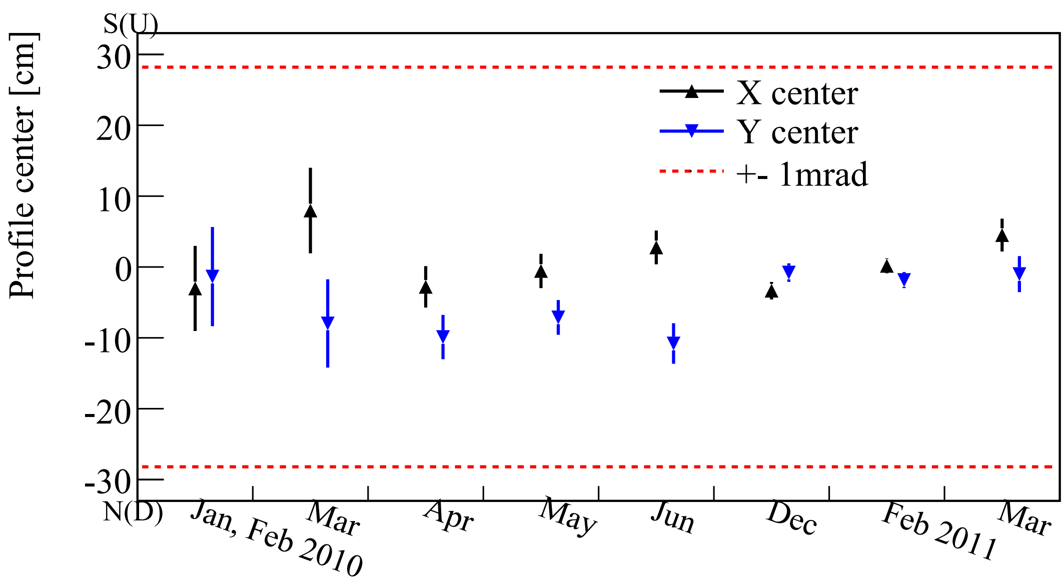

Figure 3: Measured neutrino beam center by the on-axis neutrino beam monitor. X/Y correspond to horizontal / vertical direction. Error bars are only statistics error. Red doted line shows 1 mrad difference from the beam axis. Beam direction is stable within 1 mrad.

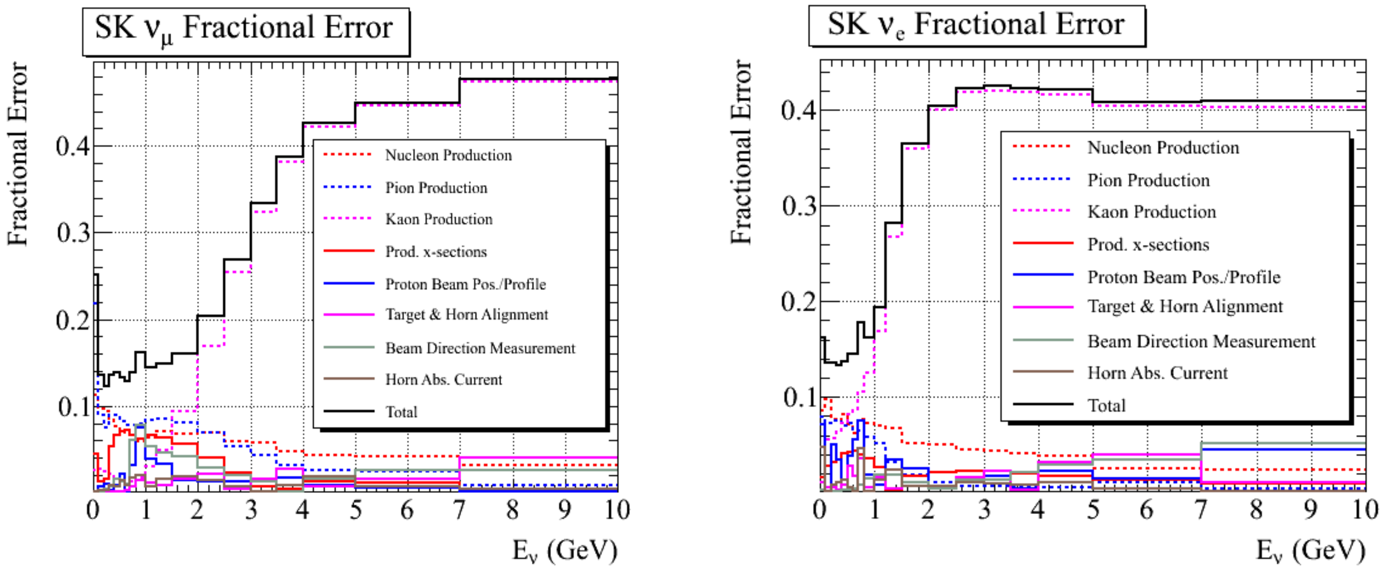

Figure 4: The fractional flux uncertainty for the ν_μ / ν_e neutrino flux at Super-K. "Nucleon Production", "Pion Production", "Kaon Production" and "Prod x-section" are each uncertainty of the production of parent hadrons. "Proton Beam Pos./ Profile" is due to the uncertainty of the proton beam optics. "Beam Direction Measurement" is due to off-axis uncertainty. "Horn Abs. Current" is due to the uncertainty of the current of the focusing horns.