論文の内容の要旨

Sterile neutrino oscillation studies with the T2K far detector Super-Kamiokande
(T2K実験におけるスーパーカミオカンデ遠地検出器を用いたステライルニュートリノ振動の研究)

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There are interesting hints from experiments, like LSND and Daya Bay, which suggest a third mass splitting $\Delta m^2 \sim 1\text{eV}^2$ in neutrino oscillation. Such results might be explained by the existence of sterile neutrinos, which are present in many extensions of the Standard Model. Sterile neutrinos are neutral singlet fermions which do not participate in the weak interaction, making direct detection difficult. But if eV-scale sterile neutrinos exist, they can affect the oscillation spectra through mixing with the three active neutrinos.

In the T2K experiment, the high intensity neutrino beam produces large statistics of neutrino events which are useful in searching for sterile neutrino. We utilize the oscillation samples in the far detector Super-Kamiokande (SK) to constrain the sterile mixing parameters under the 3+1 sterile neutrino model (3 active neutrinos + 1 sterile neutrino). In particular, we include the neutral current (NC) interaction samples in the oscillation analysis for the first time to enhance the sterile sensitivity.

The sterile mixing parameters have different effects on the oscillation spectra. T2K is mostly sensitive to the sterile mixing angles θ_{24} and θ_{34}. We modify the T2K official fitter to include the sterile oscillation probability and NC oscillation samples. A joint analysis with both the standard charged current (CC) oscillation samples and new NC samples is performed to constrain θ_{24} and θ_{34} for a range of Δm^2_{41}. The standard CC samples, ν_μ disappearance samples (FHC/RHC 1Rμ) and ν_e appearance samples (FHC/RHC 1Re, FHC ν_eCC1π^+), are sensitive to θ_{24}. The new NC samples, FHC/RHC 2Rπ^0 samples (mainly NC1π^0 resonant production) and FHC NCγ de-excitation sample (mainly neutral current quasi-elastic (NCQE) events), measure the NC interaction rates of all three active neutrinos, and give us sensitivity on θ_{24} and θ_{34}.

Most systematic parameters inherit from the standard 3-flavor analysis. Two cross-section errors and twelve SK detector errors are added to describe the uncertainties on the newly added NC samples. The SK detector uncertainties are calculated based on separate studies, with final state interaction and secondary interaction model uncertainties handled by a reweighting software package.

The fit goodness is described by a joint likelihood function for all samples:

$$\mathcal{L}(\vec{N}_{\text{obs}}, \vec{N}_{\text{pred}}, o, f) = \mathcal{L}_{sample}(\vec{N}_{\text{obs}}, \vec{N}_{\text{pred}}(o, f)) \times \mathcal{L}_{\text{syst.}}(f),$$

where $\mathcal{L}_{sample}$ is the binned Poisson likelihood between the number of observed events $\vec{N}_{\text{obs}}$ and the number of predicted events $\vec{N}_{\text{pred}}$ calculated with oscillation parameters o and systematic parameters f. The systematic penalty $L_{\text{syst.}}$ is evaluated with the input covariance matrix.

An Asimov data set (event rates predicted without any statistical or systematic fluctuations) is generated assuming T2K-SK Run1-8 protons on target (POT), with no sterile mixing (except NCγ de-excitation sample, only Run1-4). The expected sensitivity of the sterile mixing parameters are evaluated by fitting the Asimov data.

Data fits are performed in two sterile parameter planes: $\sin^2\theta_{24}$ vs Δm^2_{41}, and $\sin^2\theta_{24}$ vs $\sin^2\theta_{34}$. The data fit results are consistent with the Asimov sensitivity. Our constraint on $\sin^2\theta_{24}$

is better than existing results for $\Delta m_{41}^2 < 0.003\text{eV}^2$. However we are not competitive for larger Δm_{41}^2 values, or in the $\sin^2\theta_{34}$ constraint. We exclude $\sin^2\theta_{24} > 0.1$ and $\sin^2\theta_{34} > 0.5$ at 90% limit for $\Delta m_{41}^2 > 0.1\text{eV}^2$.

The current analysis is still statistically limited, and future T2K data will definitely improve our results. On the other hand, the newly added NC cross-section errors (NC1π and NCQE) turn out to be the greatest systematic limitations in the fit. Future cross-section analysis from T2K (or other experiments) might help reduce these errors. Development of additional oscillation samples is in progress, and would provide extra sensitivity upon implementation.