Updated $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ Oscillation Search at T2K

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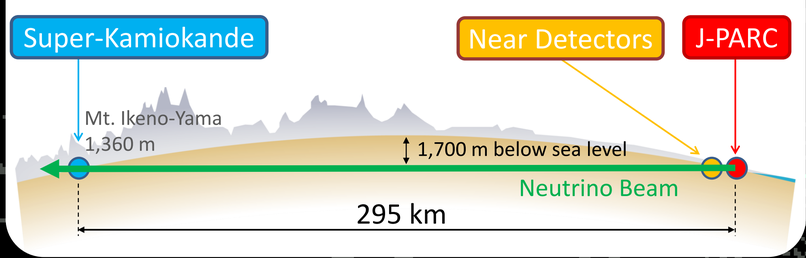
1) Introduction

T2K is a long-baseline ν oscillation experiment located in Japan, which aims to measure $\nu_\mu \rightarrow \nu_e$ oscillations and the not yet observed $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillations to determine the parameters of the PMNS matrix.

Super-K event samples:
- ν mode 1-ring μ-like
- $\bar{\nu}$ mode 1-ring μ-like
- ν mode 1-ring e-like
- ν_e CC1π^+-like
- $\bar{\nu}$ mode 1-ring e-like

(control samples)



2) Overview

To search for $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillations a statistical test of the significance for any observed signal is constructed in the following way:

Modify the oscillation probability with a new parameter, β

$$P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e) \rightarrow \boldsymbol{\beta} \cdot P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$$

Null hypotheses

a) No $\bar{\nu}_e$ appearance ($\beta = 0$) b) PMNS $\bar{\nu}_e$ appearance ($\beta = 1$)

Two test statistics for each hypothesis
- Number of $\bar{\nu}$ mode 1-ring e-like events: rate-only analysis
- $\Delta\chi^2 = \chi^2(\beta = 0) - \chi^2(\beta = 1)$: rate+shape analysis

(χ^2 values calculated by marginalising all systematic and oscillation parameters)

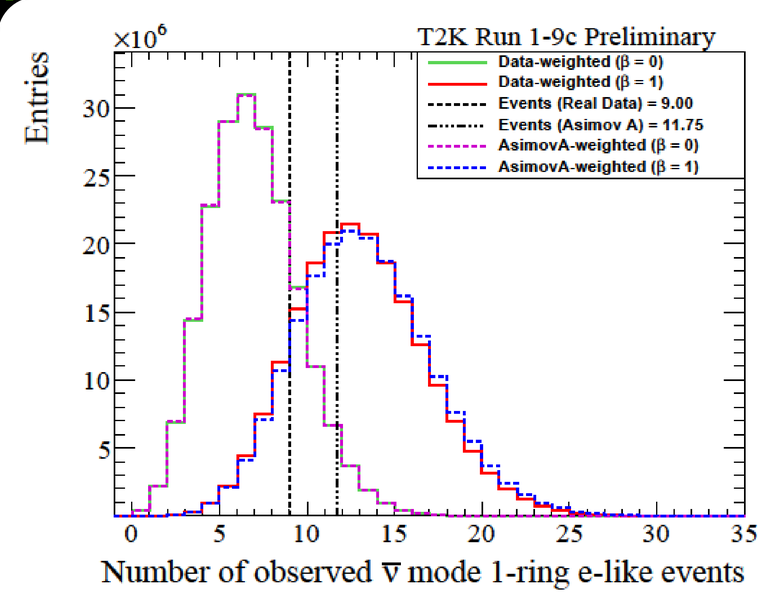
3) Method

- Generate 20k pseudo-data sets by sampling the control sample (see sec. 1) oscillation parameter space around the maximum likelihood to constrain the oscillation and systematic model parameters
- Calculate test statistics for each pseudo-data set
- Make distributions of each test statistic for each hypothesis
- Compare to the data test statistic to obtain p-values

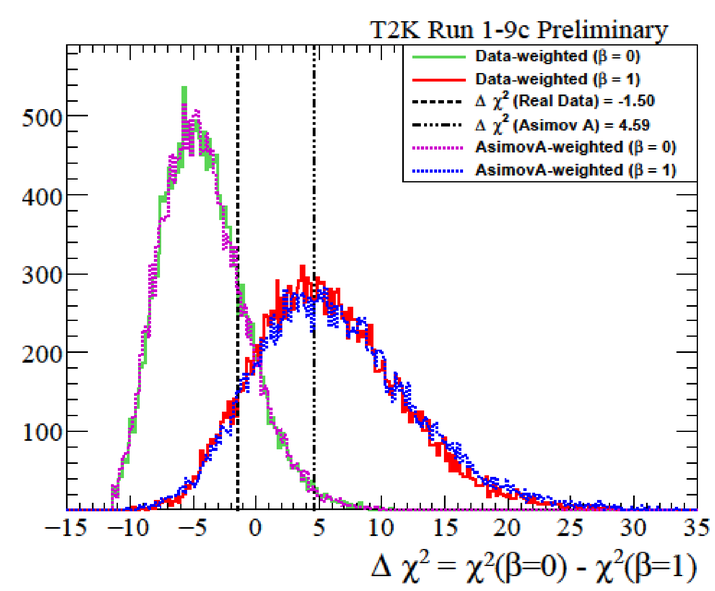
4) Sensitivity to $\bar{\nu}_e$ Appearance

Expected sensitivities are generated using an Asimov dataset in place of the data. This uses oscillation parameters close to the normal hierarchy PDG values with $\sin^2(\theta_{23}) = 0.528$, $\sin^2(\theta_{13}) = 0.0219, \delta_{CP} = -1.601$ and $\beta = 1$.

β	Analysis	p-value	σ
0	Rate-only	0.036	2.1
	Rate+shape	0.0128	2.5
1	Rate-only	0.386	0.9
	Rate+shape	0.426	0.8



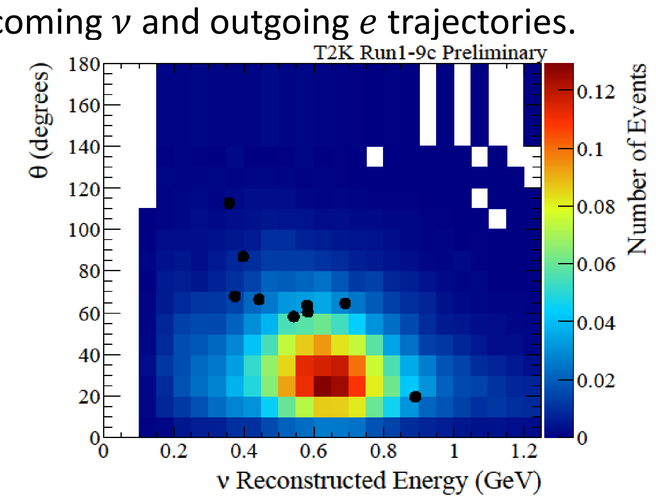
Rate-only analysis



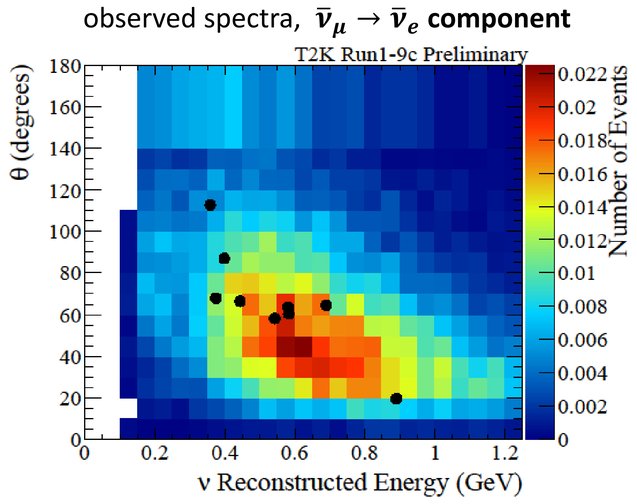
Rate+shape analysis

5) Signal/Background Separation with Charged Lepton Kinematics

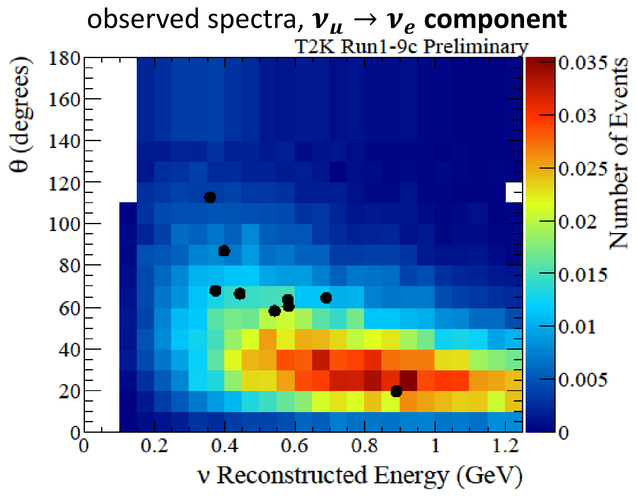
Spectra have been produced using T2K data obtained in period 2010 – Dec. 2017 (T2K Run 1-9c) at an exposure of 1.49×10^{21} Protons On Target (POT) in ν mode and 1.12×10^{21} POT in $\bar{\nu}$ mode. θ is the angle between the incoming ν and outgoing e trajectories.



$\bar{\nu}$ mode 1-ring e-like expected and observed spectra, $\boldsymbol{\bar{\nu}_\mu \rightarrow \bar{\nu}_e}$ **component**



$\bar{\nu}$ mode 1-ring e-like expected and observed spectra, $\boldsymbol{\nu_u \rightarrow \nu_e}$ **component**



$\bar{\nu}$ mode 1-ring e-like expected and observed spectra, $\boldsymbol{\nu_e}$ & $\boldsymbol{\bar{\nu}_e}$ **intrinsic beam components**

11.75 events were expected (6.47 background + 5.28 signal), but only 9 events were observed. The data are more consistent with the $\nu_\mu \rightarrow \nu_e$ and ν_e & $\bar{\nu}_e$ intrinsic beam backgrounds than the $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ signal.

6) Data Results

With the current statistics, T2K is unable to exclude either no $\bar{\nu}_e$ appearance or PMNS $\bar{\nu}_e$ appearance. More antineutrino data is currently being collected, potentially providing a stronger constraint on $\bar{\nu}_e$ appearance.

β	Analysis	p-value	σ
0	Rate-only	0.209	1.3
	Rate+shape	0.215	1.2
1	Rate-only	0.210	1.3
	Rate+shape	0.092	1.7