Neutrino Interactions in the T2K WAGASCI Detector and Combining Measurements With Multiple Neutrino Fluxes

John Nugent (Tohoku University) on behalf of the T2K Collaboration

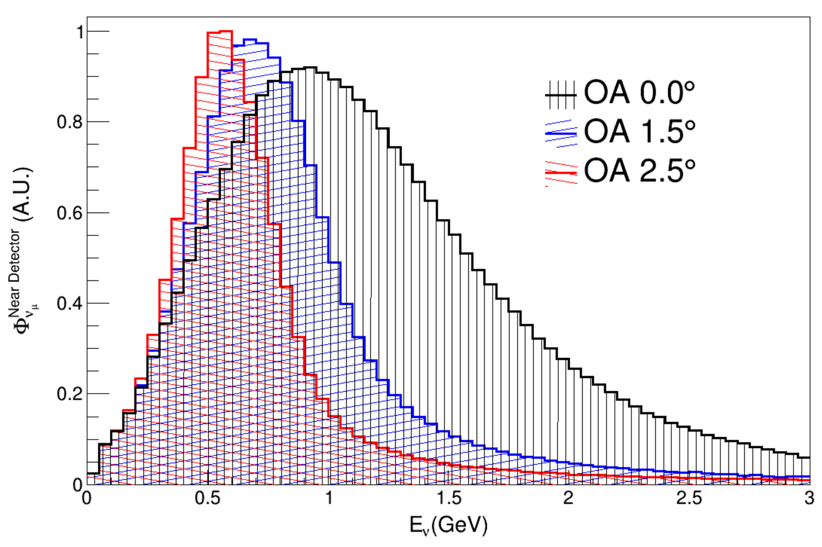
Department of Experimental Particle Physics

T2K

T2K is a long base line neutrino experiment in Japan with a 295 km base line between the JPARC facility, which produces the neutrino beam, and the Super-Kamiokande water Cherenkov far detector

Joint analysis

Figure: ν flux at on & off axis positions



- Proposal is for joint measurement using ND280 near detector, at 2.5 degree off-axis position, and WAGASCI, at 1.5 degree off-axis
- Combined cross sections analysis using data at both off-axis angles offers the unique ability to better constrain the flux and cross sections than either data set can accomplish individually
- Also will incorporate new water target data from WAGASCI

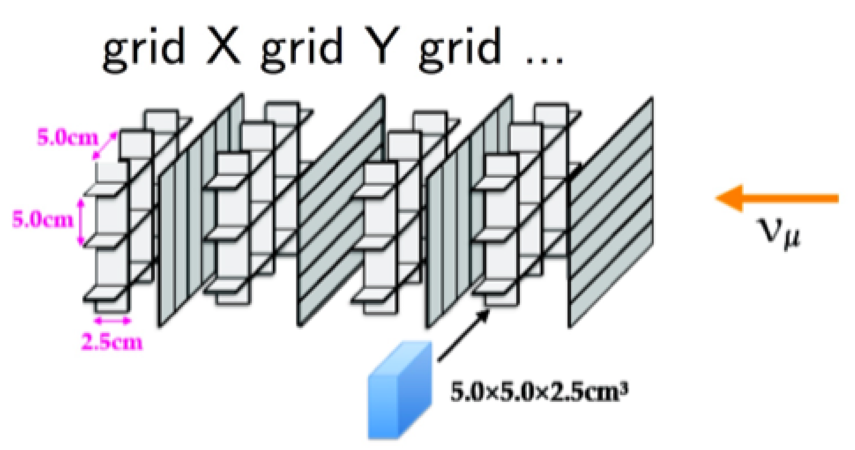
WAGASCI

Figure: The WAGASCI detector

WAGASCI offers a unique opportunity to measure neutrino interactions

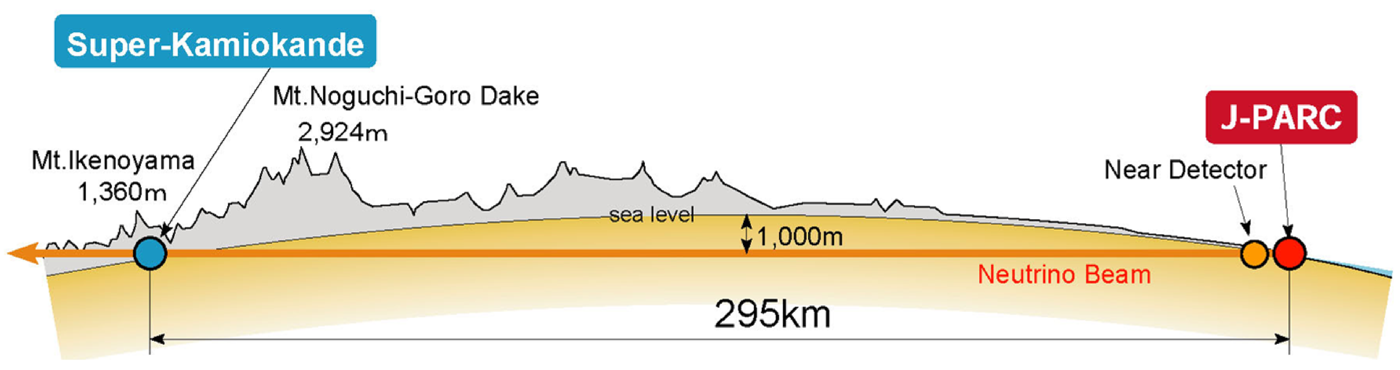
- Tank of 600l of H_2O, same neutrino target as far detector
- Large angular acceptance to match SK FD
- First WAGASCI only analysis already completed, a publication is in preparation

Figure: Grid and Bar scintillators of WAGASCI



Long Base Line Experiment

Figure: Schematic of T2K Experiment



Super-Kamiokande

- Located in the Kamioka mine, 295 km from ν source
- Tank of 50 kTon of ultrapurified water
- Instrumented with 13,000 PMTs
- Outer tank to reject background events
- Sensitive to accelerator and atmospheric νs

JPARC Accelerator

Source of νs for the T2K experiment

- Main Ring is 30 GeV synchrotron
- Synchrotron protons are incident on graphite target
- π produced decay to ν that leave beam line and travel in direction of SK
- Near Detectors (ND) measures ν flux before oscillation

Sample Selection

The different NDs of T2K are located at different off-axis positions hence they measure a different ν flux

- Event selection is already well developed for both existing ND280 samples and for the newest samples from WAGASCI

Figure: ND280 ν_μ CC0π selection [1]

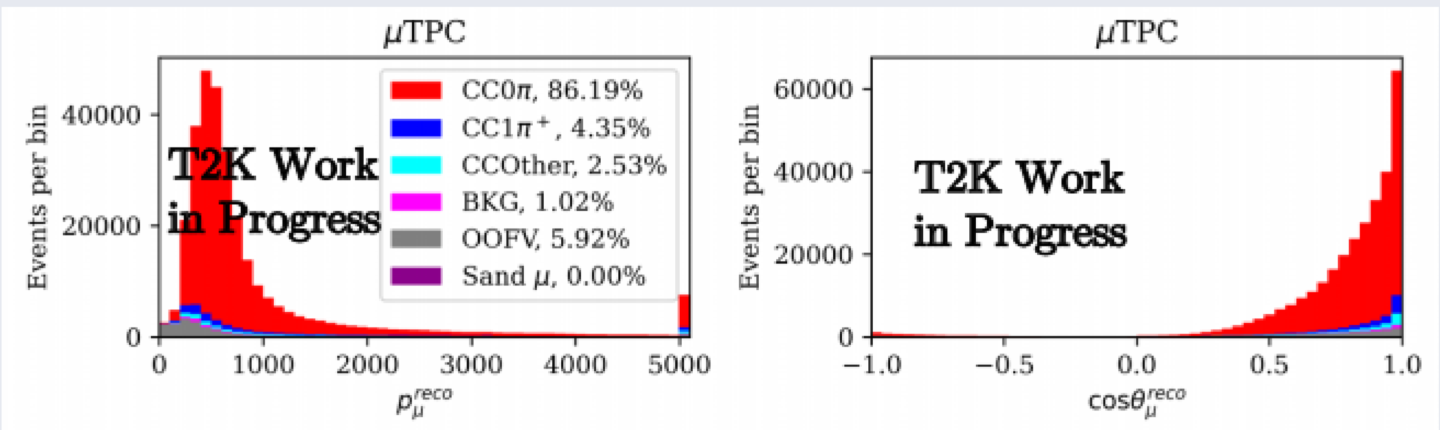
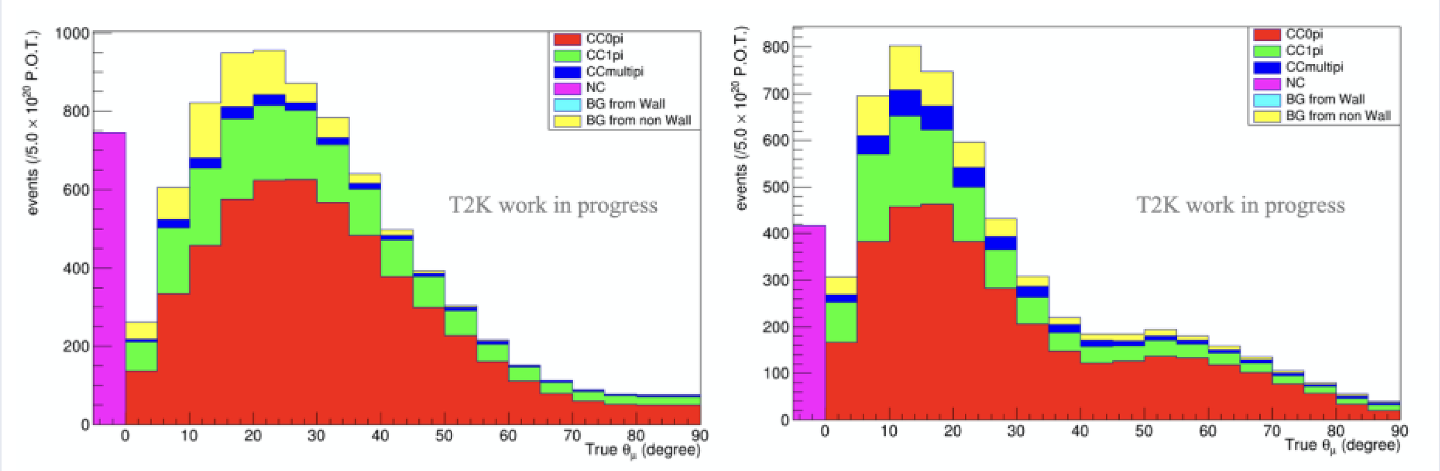


Figure: WAGASCI ν_μ CC0π selection, currently being refined [2]



Sources of Systematic Error in Oscillation Analyses

Table: Summary of systematic errors associated with ν oscillation analysis

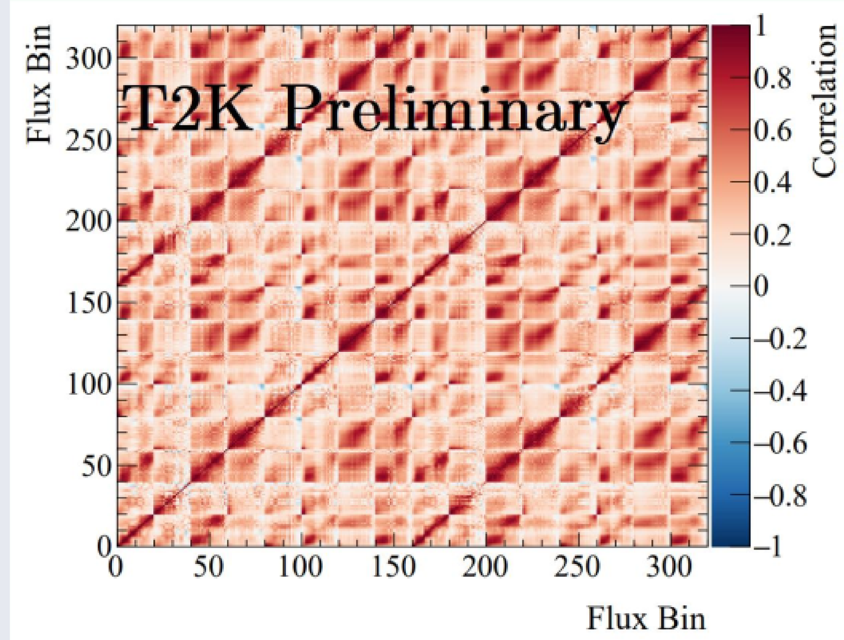
Error source	1-Ring μ FHC	1-Ring μ RHC	1-Ring e FHC	1-Ring e RHC	1-Ring e FHC 1 d.e.	FHC/RHC
Flux and (ND unconstrained)	14.3	11.8	15.1	12.2	12.0	1.2
cross-section (ND constrained)	3.3	2.9	3.2	3.1	4.1	2.7
SK Detector	2.4	2.0	2.8	3.8	13.2	1.5
SK FSI + SI + PN	2.2	2.0	3.0	2.3	11.4	1.6
Nucleon Removal Energy	2.4	1.7	7.1	3.7	3.0	3.6
$\sigma(\nu_e)/\sigma(\overline{\nu}_e)$	0.0	0.0	2.6	1.5	2.6	3.0
NC1γ	0.0	0.0	1.1	2.6	0.3	1.5
NC Other	0.3	0.3	0.2	0.3	1.0	0.2
$\sin^2\theta_{23}$ and Δm^2_{21}	0.0	0.0	0.5	0.3	0.5	2.0
$\sin^2\theta_{13}$ PDG2018	0.0	0.0	2.6	2.4	2.6	1.1
All Systematics	5.1	4.5	8.8	7.1	18.4	6.0

Cross section uncertainties are one of the leading sources of systematic error for the oscillation analysis

- To maximise sensitivity of oscillation analysis, clearly systematic error due to cross section model uncertainties will have to be reduced
- An outstanding topic is a joint measurement at different off-axis positions on both O and C, for this a study using WAGASCI data is required

Flux Correlations

Figure: Flux correlation matrix



T2K has software tools to determine flux correlations between between different neutrino types, off-axis positions and running modes

- In the final fit to extract the cross-section this covariance matrix can be used to account for flux modeling uncertainties by fitting the flux as nuisance parameters
- These tools have been extended to include the flux prediction at 1.5° off-axis, i.e., the WAGASCI position
- This allows for joint fits using the WAGASCI data, will exploit this opportunity in this analysis
- Flux correlation enter the joint fit through penalty term:

$$\chi^2_{syst} = (p - p_{prior})(V^{syst}_{cov})^{-1}(p - p_{prior}) \quad (1)$$

Conclusions

Development continuing on first joint cross-section measurement using WAGASCI and ND280 data

- Measurement will exploit flux correlations between data at different off-axis positions
- Joint analysis offers the unique opportunity to better constrain cross sections than either data set can accomplish individually
- Sample selection fully developed
- Description of systematic errors associated with measurement in progress

References

- C. Schloesser [T2K], https://www.t2k.org/docs/poster/109/postercasparschloesser
- K. Yasutome [T2K], PoS **NuFact2021** (2022), 075 doi:10.22323/1.402.0075

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john.nugent.d5@tohoku.ac.jp