Multi-ring charged current $\nu 1\pi^+$ samples at T2K far detector

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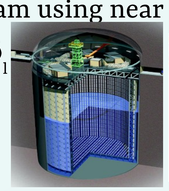
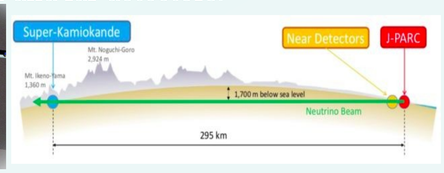
Weak Interactions and Neutrinos conference, 2021

- T2K experiment measures neutrino oscillation parameters via the observation of disappearance of $\nu_\mu(\bar{\nu}_\mu)$ and appearance of $\nu_e(\bar{\nu}_e)$ from a $\nu_\mu(\bar{\nu}_\mu)$ beam using near and far detectors.
- In the far detector Super-Kamiokande (SK) ν_l & $\bar{\nu}_l$ interaction products produce Cherenkov rings.





- Most dominant interaction at T2K flux: peak - charged current quasi–elastic (CCQE)
- interaction of ν and $\bar{\nu}$: $\nu_l + n \rightarrow l^- + p$; $\bar{\nu}_l + p \rightarrow l^+ + n$.
- Second dominant channel - resonant single pion production:

$$\nu_l\, p \rightarrow l^-\, p\, \pi^+ \;;\; \bar{\nu}_l\, p \rightarrow l^+\, p\, \pi^-$$
$$\nu_l\, n \rightarrow l^-\, n\, \pi^+ \;;\; \bar{\nu}_l\, n \rightarrow l^+\, n\, \pi^-$$
$$\nu_l\, n \rightarrow l^-\, p\, \pi^0 \;;\; \bar{\nu}_l\, p \rightarrow l^+\, n\, \pi^0$$

3 charged current resonant single pion production channels →

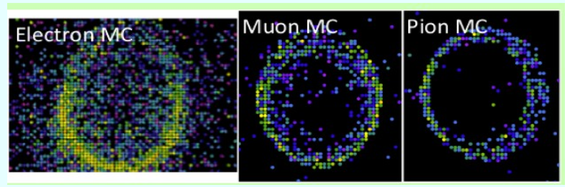
Event samples currently used in T2K analyses

- 1 ring μ–like and e–like events in both ν and ν̄ modes
- 1-ring ν_e CC1π^+ sample with π^+ below Cherenkov threshold

This study : To add CC1π+ dominant sample in the neutrino mode, to oscillation analysis to improve statistics and hence the constraints on oscillation parameters.

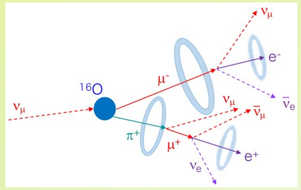
Reconstruction of events in SK

- A maximum likelihood reconstruction algorithm **fiTQun** reconstructs the events at SK.
- Depending on the charge profile, various event topology hypotheses (e-, μ-, and π^+- like) and their likelihood functions are formed.



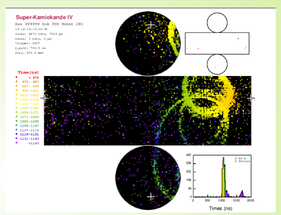
- Position, time, direction, momentum and energy loss of tracks are reconstructed.
- Multi-ring hypotheses are tested by sequentially adding e-like and π^+ like rings.
- The expected charge of 1-ring hypotheses are summed upto 6 rings.

Charged Current $\nu_\mu 1\pi^+$ events

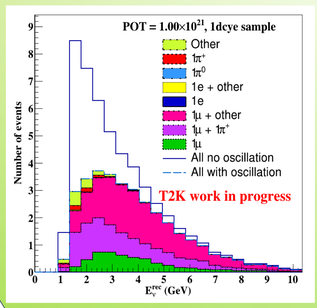


- Inclusion in oscillation analysis is expected to improve the sensitivity to θ_{23} and $|\Delta m^2_{32}|$.
- Events selected for neutrino mode running only.
- Two categories of events - with 1 decay electron and 2 decay electrons.
- Selection is optimized based on a simple figure of merit S/√(S + B), where S = signal and B = background.

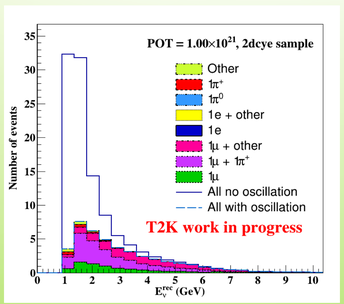
- Cuts on fiducial volume, number of decay electrons and ratios of log likelihoods of different hypotheses are applied.
- For 1 decay electron sample an extra cut on the sum of the energy loss of two rings by fiTQun 2-ring $\pi^\pm\pi^\pm$ is applied to remove NC1π ± background.



1 decay electron sample



2 decay electron sample



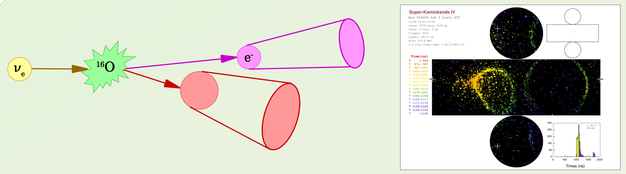
Reconstructed neutrino energy (GeV)

1.00×10²¹ POT	ν_μ CCQE	ν_μ CC1π⁺	ν_μ CC other	$\bar{\nu}_\mu$ CC	$\nu_e+\bar{\nu}_e$ CC	NC	Signal Purity
1R μ like	143.34 (Signal)	18.41	7.45	11.43	0.05	5.49	76.99%
Signal Efficiency	83.84%						
MR 1 decay e	8.93	11.15 (signal)	9.26	2.38	0.088	1.83	33.14%
Signal efficiency		52.02%					
MR 2 decay e	2.85	23.97 (signal)	11.86	0.732	0.011	1.76	58.20%
Signal efficiency		86.28%					

T2K work in progress

Selection efficiency and purity of ν_μ signal events in neutrino mode with a POT of 1.00 X 10^{21}. The signal efficiency is calculated w.r.to events passing the fully contained and fiducial volume cuts. Signal purity is the fraction of signal events passing the final selection cut, out of all events Passing the same cut.

Charged Current $\nu_e 1\pi^+$ events



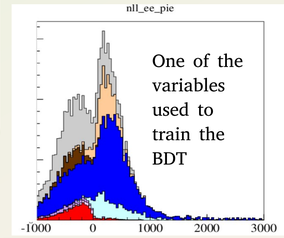
- Inclusion in oscillation analysis will improve the sensitivity to leptonic δ_{CP}. A 12% increase in ν_e signal events is predicted.
- Event selection involves cuts on reconstructed variables and a cuts from training a boosted decision tree (BDT) on Monte Carlo (MC) events.

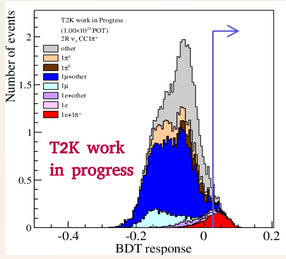
- Pre-BDT cuts: events have to be in the fiducial volume of SK and should have 1 decay electron from $\pi^+ \rightarrow \mu^+ \rightarrow e^+$.
- Reconstructed ν energy should be < 1.5 GeV.
- BDT uses likelihood ratios of different ring hypotheses and reconstructed kinematic variables from various fits.

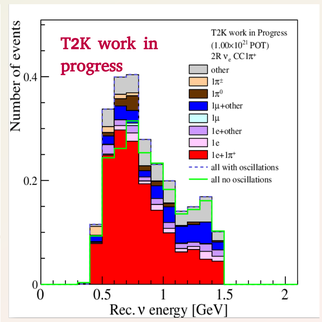
1.00×10²¹ POT	ν_e CCQE	ν_e CC1π⁺	ν_e CC other	$\bar{\nu}_e$ CC	$\nu_\mu+\bar{\nu}_\mu$ CC	NC	Signal purity
Existing 1 ring elike 0 dcye sample	39.892 (signal)	3.347	0.884	0.482	0.201	2.771	83.85%
Signal efficiency	76.65%						
MR e like BDT sample	0.027	1.647	0.134	0.007	0.328	0.388	65.07%
Signal efficiency		9.64%					

T2K work in progress

Selection efficiency and purity of ν_e signal events in neutrino mode with a POT of 1.00 X 10^{21}. The signal efficiency is calculated w.r.to events passing the fully contained and fiducial volume cuts. Signal purity is the fraction of signal events passing the final selection cut, out of all events passing the same cut.







Reconstructed Neutrino Energy(GeV)

Acknowledgements: This research is supported by NCN grant no: UMO-2018/30/E/ST2/00441. Many thanks to T2K collaboration; members of Warsaw Neutrino Group; Kamioka computing facility and the organisers of WIN 2021 conference.

References:

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