# WP3: Status of MEC analysis 

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## Neutrino interactions

- Neutrino may interact with matter through various channels
- What we detect in the experiment are Charged Current $v$ interactions
- The well known processes of $v$ interactions occur on single nucleon:


Pion production


Inelastic scattering


- We are trying to measure interactions on correlated nucleon pairs:


2 particle - 2 hole interaction (2p2h) or
Meson Exchange Current (MEC)

## Why 2p2h are important

- CCQE puzzle - measurements from other experiments suggests to large value of $\mathrm{M}_{\mathrm{A}}$ ~1.2-1.35, but there are experiments which suggest that 2 p 2 h solve the problem.
- Topology of 2p2h interactions seen in the detector can be same as for quasi-elastic interactions.
- Measurements performed by the near detector of T2K suggest that 2p2h contribute to neutrino interaction processes as predicted by simulation.

In oscillation analysis reconstruction of neutrino energy is based on CCQE selection $\rightarrow$ therefore the measurement is disturbed by the 2p2h background.

Systematics of oscillation measurement is dominated by v interaction uncertainty in Super-Kamiokande detector, mainly 2p2h.

## Data samples

- We use large sample of data accumulated by the Near Detector of T2K.
- We use sample of CC muon neutrino interactions, where no pions were produced


Define sub-samples depending on number of reconstructed proton tracks


FGD1 FGD2


FGD1 FGD2


FGD1 FGD2
$\mu$ TPC-Np
TPC1 TPC2 TPC3


FGD1 FGD2

## Kinematic variables

NEUT simulation

Variables using reconstructed tracks of muon and proton $\cos \theta \mu-p$ and transverse variables.

(a)


(b)


## Target neutron momentum

Calculate longitudinal target neutron momentum F

$$
p_{L}=\frac{\left(M_{A}+k_{L}^{\prime}+p_{L}^{\prime}-E^{\prime}-E_{p^{\prime}}\right)^{2}-p_{T}^{2}-M_{A-1}^{* 2}}{2\left(M_{A}+k_{L}^{\prime}+p_{L}^{\prime}-E^{\prime}-E_{p^{\prime}}\right)}
$$

Reconstructed target neutron momentum

$$
p=\sqrt{p_{T}^{2}+p_{L}^{2}}
$$



Study of selection cuts:

| Cut value | 2p2h purity | 2p2h efficiency | Efficiency $\times$ purity |
| :---: | :---: | :---: | :---: |
| $p_{\mu}<400 \mathrm{MeV} / \mathrm{c}$ | 0.18 | 0.30 | 0.05 |
| $p_{n}>300 \mathrm{MeV} / \mathrm{c}$ | 0.21 | 0.88 | 0.18 |
| $\delta p_{T}>300 \mathrm{MeV} / \mathrm{c}$ | 0.22 | 0.72 | 0.16 |
| $\delta \phi_{T}>1$ | 0.26 | 0.51 | 0.13 |
| $\cos \theta_{\mu-p}>0.6$ | 0.21 | 0.49 | 0.10 |

## Vertex Activity - definition

## FGD detector

Calorimetric measurement of energy deposited by charged particles near neutrino interaction vertex


VA 1x1

$3 \times 3$


5x5


7x7




As well reconstructed tracks as low momentum particle leave energy deposit near the vertex.
Contribution from reconstructed tracks can be subtracted.

## Vertex Activity - distributions





Events with reconstructed muon and proton track only



Events where additional low momentum proton is present in the interaction

## Analysis using $\mathbf{P}$

## neutron

Selection of 2p2h enhanced signal region by applying cut $p_{n}>300 \mathrm{MeV} / \mathrm{c}$


| Interaction |  |  |  |
| :--- | :---: | :---: | :---: |
| mode | . TTPC-pTPC | Background region <br> $p_{n}<300$ | Signal region <br> $p_{n}>300 \mathrm{MeV} / \mathrm{c}$ |
| CCQE | 0.54 | 0.83 | 0.31 |
| RES+DIS | 0.28 | 0.12 | 0.40 |
| 2p2h | 0.13 | 0.03 | 0.21 |
| Other | 0.05 | 0.02 | 0.08 |

# Vertex Activity and 2p2h fit 



Signal region,


Large energy deposition suggests presence of low momentum protons

Goal: Fit fraction of 2 p 2 h events in MC to the data
Test: Can we explain signal region just with RES+DIS, but without introducing 2 p 2 h ? Answer is that, we can not. The RES+DIS fraction would be enlarged so much, that it would cause large disagreement for sample with reconstructed charged pion track - CC1 $\pi$.

## Fit results

How big is contribution of 2 p 2 h interactions?

- The Nieves model predicts $21 \%$ contribution of 2 p 2 h in given sample.
- The fit results to Vertex Activity distributions gives 18+-2\%


The predicted 2p2h cross section based on Nieves model for T2K $v$ beam is:

$$
\sigma_{2 p 2 h}^{\text {Nieves }}=5.47 \times 10^{-40} \mathrm{~cm}^{2}
$$

Obtained fit results leads to:

$$
\sigma_{2 p 2 h}^{\text {tuned }}=[4.81 \pm 0.45(\text { stat. })] \times 10^{-40} \mathrm{~cm}^{2} .
$$

## Summary

- analysis done for Run1-4 data

MSc thesis

- writing of technical note in progress
will contain also many other tests
- plan to include Run 8 (double the statistics) for the deliverable

