Study of the intrinsic $\nu_e$ component in the T2K neutrino beam with the near detector

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The T2K experiment

Flux spectrum peaks at:

- survival min/oscillation max ($\nu_\mu \rightarrow \nu_\mu$)  
  \[ \rightarrow \theta_{23} \]

- oscillation max for ($\nu_\mu \rightarrow \nu_e$)  
  \[ \rightarrow \theta_{13} \text{ and } \delta_{CP} \]

J-PARC $\rightarrow$ Near Detector (ND280) $\rightarrow$ Super Kamiokande (SK)
The importance of $\nu_e$ measurements in ND280

Measure intrinsic $\nu_e$ component of the beam

$\nu_e$ are the **signal** in the search for $\nu_\mu \rightarrow \nu_e$ (\textit{$\nu_e$ from oscillation})

$\nu_e$ are also the largest **background** (\textit{intrinsic $\nu_e$ component of beam})

Measure $\nu_e$ cross-section: **Current data is scarce**

Previous T2K measurement: $\nu_e$ CC inclusive cross-section

- At the moment only $\nu_\mu$ data is used to constrain systematic uncertainties at SK
- $\nu_e$ cross-section approximated to be the same as $\nu_\mu$
- $\nu_e$ data can provide a check for $\nu_\mu$ flux and cross-section measurements
- Difference between $\nu_\mu$ and $\nu_e$ cross-section important as sensitivities increase

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ND280
T2K off-axis near detector

- 280m from source
- Same off-axis angle as SK
  → oscillation effects negligible

2x Fine Grained (scintillator) Detectors (FGDs)
- active target mass, vertex reconstruction

3x Time Projection Chambers (TPCs) in an applied magnetic field
- momentum reconstruction
- charge identification
- Particle Identification (PID) using energy deposited as a function of distance (dE/dx)

Electromagnetic Calorimeters (ECals) surrounding the inner sub-detectors
- energy containment, further PID
In charged current (CC) interactions, Neutrino flavour can be determined by identifying the lepton.

**Charged Current Quasi-Elastic (CCQE)**

\[ \nu_e + N \rightarrow e^- + N' \]

**Charged Current non Quasi-Elastic (CCnonQE)**

\[ \nu_e + N \rightarrow e^- + N' + \text{pions} \]
Selecting $\nu_e$ CC events in ND280

- **Data quality** checks and **timing** compatibility
- Select **Highest Momentum Negative (HMN) Track** starting in FGD fiducial volume (FV)
  - Momentum $> 200$ MeV/c
  - Good quality track in the TPC
  - TPC Particle identification (PID) to select $e^-$
  - If the track enters the ECal $\rightarrow$ perform **ECal PID** to select $e^-$
  - **Reject pair production** ($\gamma \rightarrow e^+ e^-$) events by looking for a positron, and cutting on the invariant mass
  - **Veto cuts** in sub-detectors reject background causing **upstream activity**.
Splitting $\nu_e$ CC events into $\nu_e$ CC 0$\pi$ and $\nu_e$ CC other sub-samples

We can only detect particles which leave the nucleus
Final state interactions (FSI), e.g. a pion could be absorbed in the nucleus
→ Better to define samples according to the topology
  i.e. the particles that exit the nucleus

$\nu_e$ CC 0$\pi$
→ No pions exiting nucleus
  • No Michel electrons
  • No 'extra' tracks
  • No 'extra' ECal activity

$\nu_e$ CC other
→ Any $\nu_e$ CC that is not CC 0$\pi$
  • One or more of the following:
    Michel electron
    1+ extra tracks

'Extra' track – any track that starts in the FGD and is not the selected track
Selection improvements

'Extra' tracks

- $\nu_e$ CC $0\pi$
- No Michel electrons
- No 'extra' tracks
- No 'extra' ECal activity

Cut designed with this situation in mind:
- Lepton ejected

Sometimes the proton is ejected into the TPC and the track is reconstructed (improved reconstruction capabilities)

New approach to the 'extra' track

In the case of only one extra FGD-TPC track
→ perform some PID
→ pass only if the track is proton-like

Resulting improvement (run2):

- CC $0\pi$ purity: $50.6\% \rightarrow 51.4\%$
- CC $0\pi$ efficiency: $28.4\% \rightarrow 35.1\%$

NOTE: T2K work in progress
Final selections (FGD1 + FGD2)

Run1, run2, run3, run4 → ~6x10^{20} POT

$\nu_e$ CC 0\pi

Purity: 48.8%

Efficiency: 36.7%

$\nu_e$ CC other

Purity: 45.9%

Efficiency: 26.4%

'\gamma' background' → Parent is a photon, and selected track is e+ or e-

'\mu' background' → Selected track is a muon
Planned cross-section measurement: $\nu_e$ CC $0\pi$

Previous T2K measurement:
$\nu_e$ CC inclusive ($\nu_e$ CC $0\pi + \nu_e$ CC other) on carbon

Planned measurement:
$\nu_e$ CC $0\pi$ on carbon (FGD1)

- **Increased statistics** from two most recent T2K runs
  - allows a measurement on the more constrained sub-sample
- $\nu_e$ CC $0\pi$ better for **kinematic reconstruction**
Planned cross-section measurement: $\nu_e$ CC $0\pi$

Background

**Biggest background** comes from pair production
- photon converts into $e^+e^-$ pair in the FGD
- largely from NC $\pi^0$ interactions … $\pi^0$ production has large uncertainties

→ 'gamma selection' selects pair production events with a purity $\sim 99$
→ can use this to **constrain the background**
Summary

Motivation

- $\nu_e$ cross-section data is scarce
- Intrinsic $\nu_e$ is the biggest background in $\nu_\mu \rightarrow \nu_e$ oscillation

ND280

- constrain flux and cross-section parameters for SK measurement
- perform $\nu_e$ cross-section measurement in energy region of interest for long-baseline neutrino oscillation experiments

Implementation / progress

- $\nu_e$ CC selection in ND280 is performing well
- Cross-section measurement plans are under way
Thanks for listening
Major neutrino-producing decay modes in the decay volume:

For a neutrino beam

\[ \pi^+ \rightarrow \mu^+ + \nu_\mu \]

\[ K^+ \rightarrow \mu^+ + \nu_\mu \]

\[ K^+ \rightarrow \pi^0 + \mu^+ + \nu_\mu \]

\[ K^+ \rightarrow \pi^0 + e^+ + \nu_e \]

\[ \mu^+ \rightarrow e^+ + \nu_e + \nu_\mu \]
Signal definitions

$\nu_e$ CC $0\pi$
- in FV
- parent is $\nu_e$ or $\bar{\nu}_e$
- $\nu_e$ CC interaction
- none of the following particles
  $\pi^0$, $\pi^-$, $\pi^+$, $\eta$, $\rho^0$, $K^0$, $K^+$, $K^-$

$\nu_e$ CC other
- in FV
- parent is $\nu_e$ or $\bar{\nu}_e$
- nuCC interaction
- NOT $\nu_e$ CC $0\pi$
PID Paths

Only use Ecal PID if track exits TPC with momentum >300 MeV/c

Energy < 1 GeV → MIP EM
Energy > 1 GeV → EM Energy
Gamma tracker analysis

Cuts

-------- List of cuts for branch 0: #cuts = 9 --------
0: event_quality --> event quality
1: himom --> Highest Momentum Track Momentum cut
2: secondary --> Secondary Track
3: quality --> # TPC nodes
4: distance.closer --> Pair Distance Cut
5: Minv.closer --> Invariant Mass Cut
6: PID --> Electron PID
7: veto_p0d --> P0D Veto
8: veto_ecal --> ECal Veto

-------- List of cuts for branch 1: #cuts = 7 --------
0: event_quality --> event quality
1: himom --> Highest Momentum Track Momentum cut
2: secondary --> Secondary Track
3: quality --> # TPC nodes
4: distance.closer --> Pair Distance Cut
5: Minv.closer --> Invariant Mass Cut
6: PID --> Electron PID