ν_μ CC$\pi°$ reaction in the Tracker of the ND280 detector in the T2K experiment

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Abstract. A good knowledge of both inclusive and exclusive neutrino interaction cross sections is one of the key issues for a precise determination of the neutrino oscillation parameters in the T2K experiment. These studies are performed at the near detector (ND280). Its central tracker part equipped with a water target is used, among others, to study the ν_μCC$\pi°$ reaction. At the energies of the T2K neutrino beam its contribution to the total cross section is relatively large, so the reaction is a potential source of the background for the quasi-elastic ν_μCC reaction. Two different production mechanisms contribute to ν_μCC$\pi°$: single pion resonance production and Deep Inelastic Scattering (DIS). In addition, Final State Interactions (FSI) have to be considered. Thus, the analysis of the ν_μCC$\pi°$ reaction aims also at a better tuning of the Monte Carlo (MC) models used to describe neutrino interactions in T2K.

This paper describes selection criteria leading to the determination of the inclusive and exclusive cross sections for the $\pi°$ production in the ν_μCC interactions.

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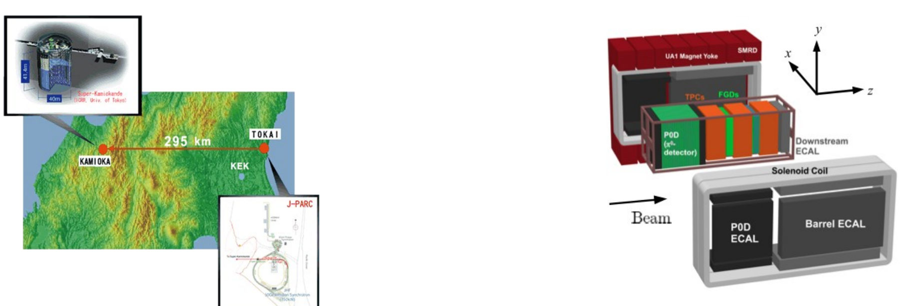
T2K EXPERIMENT AND ND280 NEAR DETECTOR

The T2K experiment [1] is a long baseline neutrino oscillation experiment. An intense muon neutrino beam is produced in the J-PARC accelerator complex in Tokai. The neutrino flux is measured before the oscillations by the system of two detectors: INGRID and ND280 situated at a distance of 280 m from the neutrino beam source (target). Then the beam is sent to the SuperKamiokande (SK) detector located in Kamioka, 295 km away from J-PARC, where muon neutrino disappearance and electron neutrino appearance are studied.

T2K is the first experiment which uses an off-axis neutrino beam. One of the near detectors, ND280, and the far detector SK are positioned 2.5° away from the beam axis. Such positioning helps to obtain a narrower neutrino energy peak at the 600 MeV. For this energy the far detector is in the first oscillation minimum for the ν_μ disappearance and the charge current quasi elastic (CCQE) reaction dominates.

The tracker part of the ND280 detector consists of two scintillating detectors (Fine Grain Detectors – FGD) located among three Time Projection Chambers (TPC). The tracker is surrounded by the electromagnetic calorimeter (TECal) and a magnet generating a homogeneous magnetic field of 0.2 T.



(a) *(b)*

FIGURE 1. Overview of the T2K experiment (a) and the Near Detector ND280 (b)

INCLUSIVE $\nu_\mu CC\pi°$ EVENT SELECTION

Signal and background definition

Due to FSI (secondary interactions inside the nucleus) the products of the primary neutrino interaction can differ from the particles going out of the nucleus [2]. Only the latter can be observed in the detector, leading to the following definitions of reactions.

Signal reactions in the FGD Fiducial Volume (FV) contributing to the inclusive π° production in the ν_μCC interactions (inclusive $\nu_\mu CC\pi°$, Figure 2):

$$\begin{array}{lll} 1. CC1\pi^0: & \nu_\mu + N & \rightarrow \mu^- + N's + \pi^0 \\ 2a. CC\pi^0 + X: & \nu_\mu + N & \rightarrow \mu^- + N's + \pi^0 + other, other\ can\ be\ \pi^0 \\ 2b. CC\ Sec\ \pi^0 (secondary\ \pi^0): & \nu_\mu + N & \rightarrow \mu^- + N's + other, \\ & & other\ is\ not\ \pi^0, but\ decays\ into/produces\ \pi^0 \end{array}$$

Background reactions:

$$\begin{array}{lll} CCQE: & \nu_\mu + N & \rightarrow \mu^- + N's \\ CC + X: & \nu_\mu + N & \rightarrow \mu^- + N's + other, other \neq \pi^0 \\ NC1\pi^0: & \nu_\mu + N & \rightarrow \nu_\mu + N's + \pi^0 \\ NC\pi^0 + X: & \nu_\mu + N & \rightarrow \nu_\mu + N's + \pi^0 + other, other\ can\ be\ \pi^0 \\ NC + X: & \nu_\mu + N & \rightarrow \nu_\mu + N's + other, other \neq \pi^0 \end{array}$$

$\bar{\nu}_\mu$, ν_e and $\bar{\nu}_e$ reactions are divided into the same categories, but they are all background reactions.

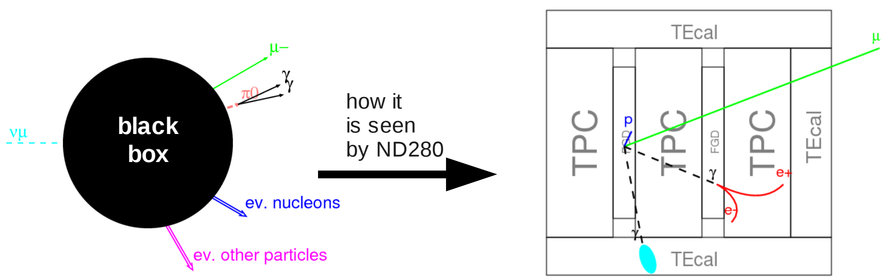


FIGURE 2. Inclusive $\nu_\mu CC\pi°$ reaction definition and its manifestation in the ND280 detector

Selection cuts

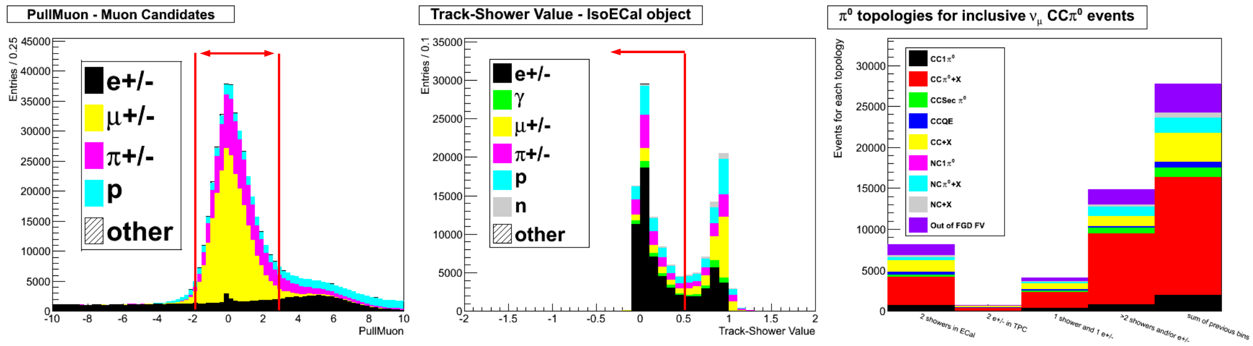
The sample used in this analysis is a minimum bias Monte Carlo corresponding to 2.25e21 protons on target (POT), which is equal to 8 times the present statistics for real data. Inclusive $\nu_\mu CC\pi°$ events selection requires a muon and at least two π° decay products.

The muon goes directly from the vertex, so the beginning of its track is assumed to be the vertex position and should be inside FGD FV. In ND280, particle identification is based upon the observed ionization in the TPC. Therefore, a good quality TPC track is required to correctly identify a particle. The identity of the particle is hypothesized using pull values, where

$$Pull_\alpha = \frac{dE/dx_{meas} - dE/dx^\alpha_{expec}}{\sigma_\alpha}, \alpha = e^\pm, \mu^\pm, \pi^\pm, p.$$

If a track has $-2 < Pull_\mu < 3$ (Figure 3(a)) and $|Pull_e| > 2$ it is muon-like. If more than one candidate passes these cuts, the highest momentum negative track is chosen. The last cut, veto in TPC1, rejects interactions from the more upstream part of ND280. These can reconstructed as happening in FGD due to track-breaking between different subdetectors. The efficiency of FGD FV ν_μCC selection is 54%, the purity is 87%. At this stage inclusive ν_μCCπ° contribution is 16%.

In an ideal situation a photon from π° is observed as a shower in the calorimeter or electron-positron pair in TPC (Figure 2). In fact, some photons do not convert at all or are invisible due to low energy, and sometimes only one particle from e^+e^- pair is visible in TPC.



(a) *(b)* *(c)*

FIGURE 3. PullMuon distribution for muon candidate (a). Track shower discriminator distribution for photon shower candidates (b). π° topologies for selected inclusive ν_μCCπ° events (c).

It is assumed that all isolated objects in the calorimeter, which are shower-like, i.e. their track-shower discriminator is below 0.5 (Figure 3(b)), are photons from π° decay. In fact, the true primary particle is π° in 40%.

Photons convert in dense matter, which is why I require $e^{\pm}$ tracks to start in the FGD or TPC outer envelope. The track should be a good quality electron-like ($|Pull_e| < 2$) TPC track. Then the proton-like positive tracks and tracks with the momentum below 50 MeV are rejected. 54% of the selected tracks come from primary π°.

Final results

In total, 27785 MC events with muon and at least two π° products were selected using the above cuts. The different topologies of the π° products are shown in Figure 3(c). 62% of the events were inclusive ν_μCCπ° with the vertex in FGD FV. Among them the signal subsamples were as follows:

1. ν_μCC1π° : 7%,

2a. ν_μCCπ°+X : 51%,

2b. ν_μCC secondary π° : 4%.

The efficiency of the selection is 32%. The analysis of the real data is currently underway and results will be published in the future.

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