Monte Carlo studies towards a Measurement of the ν_μ Induced Neutral Current π^0 Production Cross-section in the NOvA Near Detector

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Introduction

Neutrino-nucleus interactions have been studied intensively for decades. ν_μ induced NC interactions with a π^0 in the final state represents the main background for the NOvA (NuMI Off-axis ν_e Appearance) experiment's ν_μ to ν_e oscillation studies as the photons produced in the π^0 decay can fake the ν_e appearance signal. Therefore a complete understanding of Neutral Current (NC) neutral pion production is very important.

At present, few measurements of neutrino induced π^0 production have been performed. Most of these are in the form of ratios so as to reduce the systematics. There also exists the absolute cross-section measurements around 1 GeV for incoherent π^0 production and an inclusive cross-section measurement from the MiniBooNE experiment [1].

1. Experiment Description

NOvA is an off-axis long-baseline experiment designed to study neutrino oscillations with two detectors. The Near Detector (ND) is located at Fermilab, 1 km from the primary target station. The Far Detector (FD) is located 810 Km away in northern Minnesota. The detectors are functionally identical tracking calorimeters so as to cancel the systematics effects and are exposed to a narrow- band beam of muon neutrinos peaked at 2 GeV in energy.

Due to its proximity to the target source, the NOvA ND has high statistics and thus provides an excellent opportunity for the measurement of various neutrino interactions mainly cross-section measurements.

2. Monte-Carlo Study

The analysis is performed on a Monte Carlo (MC) dataset (developed for the NOvA neutrino oscillation program) corresponding to 2.81e21 POTs. The distributions presented here are scaled to 4.0e20 POTs, the data available at the NOvA ND. We select and study ν_μ NC interaction in the ND with the production of at-least one π^0 with kinetic energy above 0.5 GeV. The signal composition is shown in Table 1.

Table 1: Percentage of signal events for various interaction types from MC study

Interaction type	%
NC Deep Inelastic	80.9
Resonance	13.1
NC Coherent	5
NC Quasi Elastic	< 1

The main background consists of the ν_μ Charged Current (CC) interactions and NC interactions without a π^0 in final state or with π^0 below the energy threshold. Another source of background is intrinsic beam ν_e contamination since electrons create an electromagnetic shower that can be mistaken for the photons of the π^0 decay.

A first pre-selection requires the reconstructed vertex to be inside fiducial volume of the detector and all reconstructed showers be contained. The distribution of the number of 3-D prongs reconstructed for the signal events is shown in the left plot of Fig.1, which

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shows that the majority of signal events has only 1-prong which can be due to the merging of 2-photon showers. Here, we focus on 2-prong (25%) and 3-prong (15%) events, where in principle a reconstructed π^0 mass can be used as a discriminant.

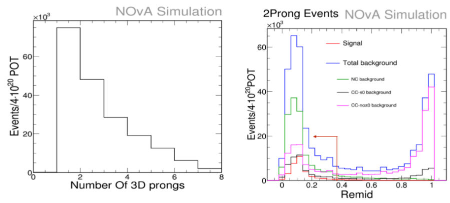

FIG. 1: **Left**: Number of reconstructed 3D prongs in signal events. **Right**: ReMID distribution.

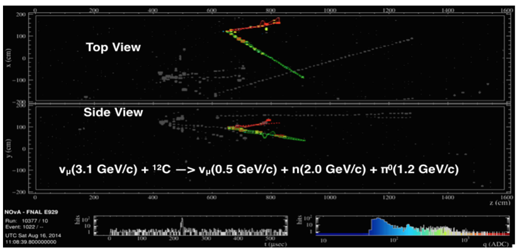

FIG. 2: Event display of a simulated 2-prong signal event

After pre-selection, the Reconstructed Muon Identification (ReMID) PID [2] is used to reject most of the CC background. ReMID uses track length, dE/dx and scattering information to select the reconstructed tracks originating from the muons. ReMID value < 0.36 (Right panel of Fig. 1) maximizes the Figure Of Merit (S/$\sqrt{(S+B)}$, S is signal and B is background events) by rejecting 37% of the background. Further, we use information from events and prong variables such as prong length, width, energy, gap from the vertex to start of the shower/prong and dE/dx variable to discriminate signal from the background.

For the 2-prong case, the signal to background ratio improves by 91% and for 3-prong case it improves by 138% w.r.t pre-selection events. Event display in Fig.2 shows a 2-prong signal event as simulated in the NOvA ND.

3. Results and Conclusions

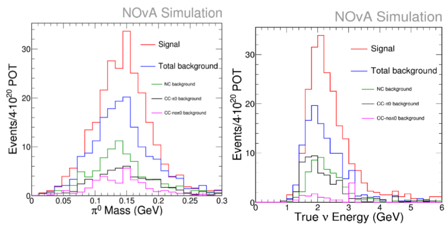

FIG. 3: **Left**: Reconstructed π^0 mass (GeV) **Right**: True neutrino Energy (GeV) for the 3-prong events.

After applying the selection cuts, π^0 mass distribution and true neutrino energy distribution (Fig. 3) are made which show the separation between signal and background. The selected signal and background events can then be used to calculate a cross-section.

$$\sigma = \frac{N_{sel} - N_{bkg}}{\varepsilon \times N_{Target} \times \Phi} \quad (1)$$

where, N_{sel} and N_{bkg} is number of selected signal and background events. ε is efficiency of signal selection. N_{Target} is number of target nucleons. Φ is the neutrino flux. From this study we found that 13 % of the selected signal events constitute of 2 π^0 events in the final state, but only in 5 % of cases both have kinetic energy above 0.5 GeV. Similarly, 57% of the selected background constitute 2 π^0 events where in 39% of the cases both have kinetic energy above threshold.

This is the current status of the analysis, where we present the first studies to differentiate signal from background. We are now studying how to improve signal efficiency using Multivariate techniques and PID training specific for π^0s.

References

[1] J.A. Formaggio, G.P. Zeller, From eV to EeV: Neutrino Cross Sections Across Energy Scales, arXiv:1305.7513 [hep-ex].

[2] Nicholas J. Raddatz, Reconstructed Muon Identification, nova docdb 11206-v1.