PROCEEDINGS OF SCIENCE

PoS(NuFact08)063

Experimental studies of neutral current pion production at low energy

---

HIDEKAZU TANAKA[*]
Columbia University / MIT
E-mail: `thide@fnal.gov`

The unknown neutrino mixing angle θ_{13} is one of the most important goals in current neutrino experiments. For the next generation of long baseline neutrino oscillation experiments, T2K and NOvA, the precise measurement of neutrino-nucleus cross sections in the few GeV energy range is an essential ingredient in the interpretation of neutrino oscillation signals. Neutral current neutral-pion production is a major background for ν_e appearance search.

This documents discusses briefly the current status and recent progress with high statistics and precision measurements of neutral current pion production at low energies.

10th International Workshop on Neutrino Factories, Super beams and Beta beams
June 30 - July 5 2008
Valencia, Spain

---

[*] Speaker.

1. Neutral current pion production at low energy

Pion production in neutral current (NC) neutrino-nucleus interaction cans be categorized into three processes; 1) Resonant: $\nu + N \to \nu + N^* \to \nu + N' + \pi^{\pm,0}$, 2) Coherent: $\nu + A \to \nu + A + \pi^0$, 3) Deep inelastic scattering: $\nu + N \to \nu + \pi^{\pm,0} + X$, where N indicates the target nucleon and N^* is a nucleon in an excited state, A denotes target nucleus and X is final state hadrons. In the few GeV neutrino energy range, the resonant process (such as $\Delta(1232)$) is the predominant reaction. Neutrinos can also produce pions by interacting *coherently* with the nucleons forming the target nucleus. The cross section for this process is expected to be smaller than resonant pion production.

2. Past measurements on NC pion production

While the charged current (CC) single pion cross section are fairly well know, the knowledge of NC reactions is limited. Most of the present knowledge of neutrino cross sections come from bubble chamber experiments. Almost all of the available experimental data on neutral current single pion production exists in the form of NC/CC cross section ratio [1, 2, 3, 4, 5]. One set of measurements not in the form of NC/CC cross section ratio is from an experiment at CERN in the mid 1970s using the Gargamelle bubble chamber [4, 6, 7] and also from the Aachen spark chamber [8]. These data provide important constraints for simulation of neutrino-nucleus interactions, which is presently used in various neutrino experiments, although those results were obtained with low statistics (100s events) and scarce knowledge on neutrino flux. And those experiments used light nucleus targets, e.g. hydrogen, deuterium.

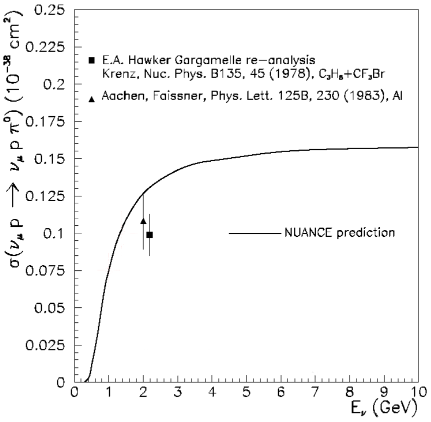

Figure 1: Experimental measurements [4, 8] of the per nucleon cross section for the neutrino resonant reaction, $\nu_\mu p \to \nu_\mu p \pi^0$. Also plotted is the prediction from the NUANCE Monte Carlo simulation [9]. Figure from [13].

3. Recent measurements of NC pion production

Recent results of NC pion production are reported mainly from the neutrino oscillation experiments, K2K and MiniBooNE experiments. These results are of NC single π^0 production (NC-1π^0) with Cherenkov detectors since NC-1π^0 events are one of the major backgrounds for ν_e appearance search. A NC-1π^0 event can mimic a ν_e signal event when, for example, one of the two photons associated with $\pi^0 \to \gamma\gamma$ decay is not detected or if the two photons have a small opening angle between them.

The next generation of neutrino oscillation experiments needs precise knowledge of NC-1π^0 cross section and also its π^0 momentum dependence is important. New neutrino data on NC-1π^0 are available that have order of magnitude higher statistics than previous measurements. K2K and

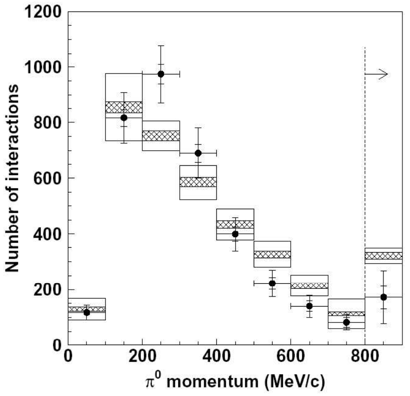

Figure 2: The momentum distribution of NC-1π^0 events. Black dots are data and the box histogram is predicted distribution by the neutrino Monte Carlo simulation (NEUT [10]). Figure from [11].

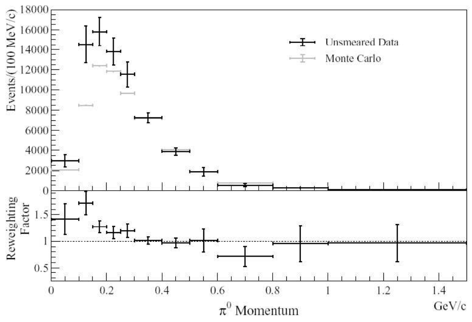

Figure 3: Momentum distribution of selected NC-1π^0 candidates (top). The dark points show data and light points show predicted distribution by the neutrino Monte Carlo simulation (NUANCE [9]). The bottom plot shows the ratio of the two distributions. Figure from [12]

MiniBooNE experiment provide the largest sample to date of π^0 produced in NC neutrino-nucleus interactions at low energy.

K2K-1KT [11]

K2K-1KT detector is a 1000 ton water Cherenkov detector used as a near detector of the K2K long baseline neutrino experiment. The K2K-1KT group reported NC-1π^0 measurement with a mean neutrino energy of 1.3 GeV, which is first measurement of NC-1π^0 in a H_2O target. In the final sample, after applying several corrections and background subtraction, $(3.61 \pm 0.07 \pm 0.36) \times 10^3$ events were obtained. Using the final sample, the relative cross section of NC-1π^0 to ν_μ-CC is obtained to be $\sigma(NC - 1\pi^0)/\sigma(CC) = 6.4 \pm 0.1(stat) \pm 0.7(sys)\%$ besides the NEUT [10] Monte Carlo prediction is 0.065 and they are in good agreement. While the predicted number of NC-1π^0 events agree well with the measurement, the π^0 momentum distribution is not in perfect agreement as shown in Fig 2.

MiniBooNE [12]

The MiniBooNE detector is a 800 ton mineral oil Cherenkov detector and has collected data with the FNAL Booster Neutrino Beam. The experiment reported a measurement of the momentum distribution of π^0s produced in mineral oil (CH_2) and the first observation of coherent production off carbon at low energy. After all the event selection criteria, the MiniBooNE data set consists of 28,000 NC-1π^0 candidate events. The π^0 momentum distribution of the selected NC-1π^0 candidates is shown in Fig 3. As shown in the plot, the neutrino Monte Carlo prediction disagrees with the measurement. The data and Monte Carlo ratio in Fig 3 (bottom plot) is used to scale Monte Carlo π^0 event as a function of true momentum. Integrated over the MiniBooNE neutrino flux, the sum of NC coherent scattering off carbon and diffractive production on hydrogen is found to be $(19.5 \pm 1.1(stat) \pm 2.5(sys))\%$ of all exclusive NC π^0 production. The coherent fraction predicted by the NUANCE generator is 30%.

As we have seen above, recent high statistics measurements reveal that current knowledge on neutrino interactions is not sufficient to describe data. Especially measured momentum spectrum

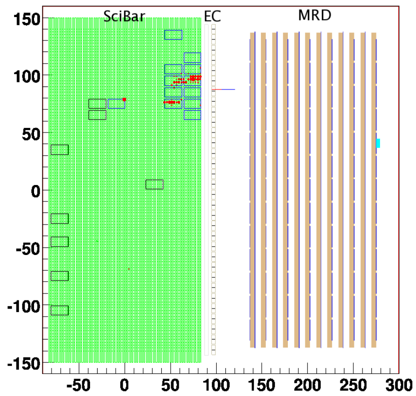

Figure 4: Event display of a typical NC-1π^0 event candidate in SciBooNE data. The neutrino beam runs from left to right in this figure, encountering SciBar, the EC and MRD, in that order. The circles on SciBar and the EC indicate ADC hits for which the height of the bar is proportional to the energy deposition in that channel.

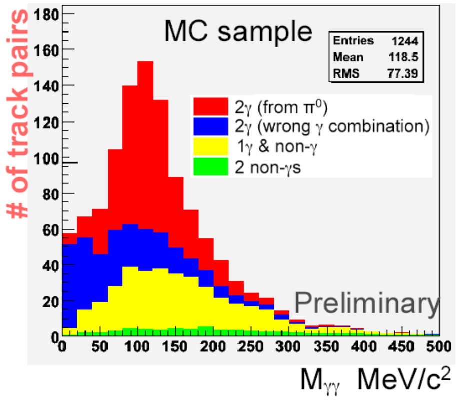

Figure 5: Reconstructed invariant mass distribution from SciBooNE Monte Carlo simulation (NEUT [17]). Histogram filled in red is right combination of two γs, blue histogram indicates wrong combination of two γs, yellow histogram denotes one γ and non-γ, e.g. proton, combination.

of π^0 events disagrees with Monte Carlo predictions in both experiments as seen in Fig. 2 and 3. One possible interpretation is that these results are effects of final state interactions, so-called *nuclear effect*, which can modify the number of particles, momenta, direction and charge state of produced particles during traversal of nuclear matter. It is known that nuclear effect is one of major systematic uncertainties in oscillation experiment. Therefore, efforts to achieve a better understanding of neutrino interactions, including nuclear effects, must be pursued with new data. There exist two dedicated neutrino scattering experiments, SciBooNE and MINERvA, which use a fine-grained detector that can detect all particles produced in the final states, which cannot be done with Cherenkov detectors.

4. Dedicated neutrino scattering experiments

SciBooNE [13]

SciBooNE started operation in June 2007 and collected data with neutrino and anti-neutrino beams in the FNAL Booster Neutrino Beam line (BNB). The experiment is carried out by installing the K2K-SciBar [14] in the FNAL BNB. The SciBooNE detector consists of three detector components; SciBar, Electromagnetic Calorimeter [15] (EC) and Muon Range Detector [16] (MRD). Figure 4 shows a typical NC-1π^0 candidate in SciBooNE data.

The analysis starts with selection of event topology (no muon track, two or more isolated tracks (two photons and proton tracks) in a event), and applies particle identification (PID) based on dE/dx information for rejecting background events, such as CC events and NC charged-pion events. Additionally, for CC event rejection, low energy muon which is fully stopped inside the SciBar detector is identified by detecting electron from muon decay using SciBar multi-hit TDC information. After applying a series of event selection criteria, the purity of NC-1π^0 events in the selected sample is $\sim$70% according to the NEUT [17] prediction. Figure 5 shows the reconstructed invariant mass distribution (MC sample). Note that the vertical axis of the figure is “number of track pairs” meaning there can be two or more entries from an event since the event can contain two γ tracks and a recoiled proton. As shown in the figure, a clear peak around the π^0 mass can be seen for right combination of two photons while wrong combination of tracks, e.g. photon and proton tracks, does not make π^0 mass peak. The result with data will be released soon[1].

MINERvA [18]

MINERvA is a neutrino scattering experiment which uses the NuMI beamline at FNAL, which covers wide neutrino energy range. The possible peak neutrino energy ranging from 3 to 12 GeV allows an energy scan of neutrino interactions over the energy range. The experiment will also use several types of nuclear targets, He, C, Fe, Pb, allowing a detailed study of nuclear effects with A-dependence. MINERvA is currently detector construction stage, the first detector module was completed in early 2006. The experiment plans to begin taking data in 2009.

These next generation experiments are expected to provide essential improvements on understanding neutrino-nucleus interactions in coming years.

5. Acknowledgments

The author would like to thank the organizing committee for their invitation to the conference. The author is supported by the JSPS Postdoctoral Fellowship for Research Abroad, Columbia University and MIT.

References

[1] S. J. Barish *et al.*, Phys. Rev. Lett. **33** (1974) 448.
[2] M. Derrick *et al.*, Phys. Rev. D **23** (1981) 569.
[3] G. L. Fogli and G. Nardulli, Nucl. Phys. B **165** (1980) 162.
[4] W. Krenz *et al.* Nucl. Phys. B **135** (1978) 45.
[5] W. Y. Lee *et al.*, Phys. Rev. Lett. **38** (1977) 202.
[6] W. Lerche *et al.*, Phys. Lett. B **78** (1978) 510.
[7] S. Ciampolillo *et al.* Phys. Lett. B **84** (1979) 281.
[8] H. Faissner *et al.*, Phys. Lett. B **125** (1983) 230.
[9] D. Casper, Nucl. Phys. Proc. Suppl. **112** (2002) 161
[10] Y. Hayato, Nucl. Phys. Proc. Suppl. **112** (2002) 171.
[11] S. Nakayama *et al.* [K2K Collaboration], Phys. Lett. B **619** (2005) 255
[12] A. A. Aguilar-Arevalo *et al.* [MiniBooNE Collaboration], Phys. Lett. B **664** (2008) 41
[13] A. A. Aguilar-Arevalo *et al.* [SciBooNE Collaboration], arXiv:hep-ex/0601022.
[14] K. Nitta *et al.*, Nucl. Instrum. Meth. A **535** (2004) 147
[15] C. Giganti [SciBooNE Collaboration], AIP Conf. Proc. **967** (2007) 301.
[16] J. Walding, AIP Conf. Proc. **967** (2007) 289.
[17] G. Mitsuka, AIP Conf. Proc. **981** (2008) 262.
[18] D. Drakoulakos *et al.* [Minerva Collaboration], arXiv:hep-ex/0405002.

---

[1] The results have been presented in Neutrino Oscillation Workshop (Otranto, Lecce, Italy) September 6-13, 2008.