Single Pion Production in Neutrino Reactions

To cite this article: Monireh Kabirnezhad 2017 *J. Phys.: Conf. Ser.* **888** 012122

Single Pion Production in Neutrino Reactions

Monireh Kabirnezhad

National Center for Nuclear Research

E-mail: `monireh.kabirnezhad@ncbj.gov.pl`

Abstract. An accurate model for single pion production should include single pion produced in resonant and non-resonant interactions as well as the interference contribution between them. The main effect of this correction can be visible in pion angular distributions that is represented in this work.

1. Introduction

The charged-current quasielastic (CCQE) interaction is the dominant CC process for neutrino-nucleon interactions around $E_\nu \sim 1GeV$ which is the relevant neutrino energy for current LBL neutrino oscillation experiments. CCQE events with no pion in the final state, is measured to reconstruct the neutrino energy with two body kinematics from the outgoing muon. Neutrino-induced single pion production (SPP) has significant contribution at low energies (Fig.1) and is the main background for CCQE events if the pion is missing (mainly due to pion absorbtion in medium) among final state particles. Therefore having a good model that can predict the production rate of the outgoing pions through the single pion production processes is very crucial for neutrino oscillation experiments.

An accurate model for single-pion production in neutrino-nucleon reaction should include resonant and non-resonant interactions, calculated in a common framework (Fig.2) in order

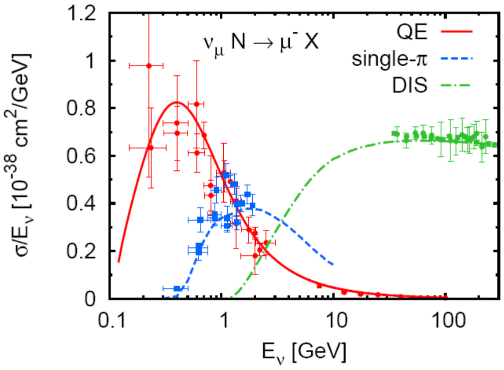

Figure 1. Neutrino interaction contributions in terms of neutrino energy.

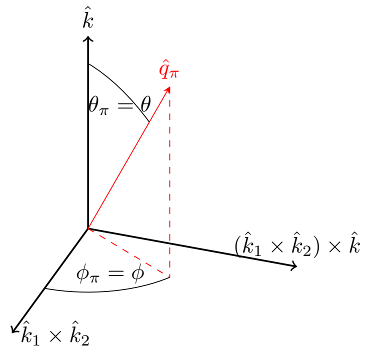

Figure 2. Adler or πN center of mass frame. Momentum transfer is at $\hat{z}$ direction.

to include the interference effects. Main concern in theoretical discussions of weak Single pion Production is the description of non-resonant background model and its interference with resonant interactions that is missing in neutrino Monte Carlo generators like NEUT [9](the primary neutrino interaction generator used by T2K experiment). In this letter first a short description for new model is given and then the effect of nonresonant interactions and its interference with resonances on angular distribution will be presented.

2. Single Pion Production Model

Pions can be produced either by decay of nucleon resonances, or directly by non-resonant interaction. Resonant interactions can be described by the Rein-Sehgal(RS) model [2]. NEUT prediction for single pion production is based on the RS model, however, a model for non-resonant interaction is missing.

This work represents an extension of the single pion production model proposed by D. Rein [1]. Rein's original model consists of resonant and nonresonant-background contributions in the helicity basis, where the latter is described with three Born diagrams. In this extension, lepton mass effects are included, and the nonresonant background has been updated with a new model[4].

Resonant interaction is described by RS model [2] which is based on helicity amplitudes derived in a relativistic quark model. The helicity amplitudes depend on the spin projection of the initial nucleon and final hadrons. In the original RS model the mass of charged lepton is neglected, and the contribution from resonances with $W < 2$ GeV, are added coherently.

Nonresonant interaction is defined by a set of Feynman diagrams (Fig.3) with pseudovector $NN\pi$ vertices determined by HNV model [4]. It is an effective chiral field theory based on nonlinear σ model. Helicity amplitudes in RS model are calculated in πN rest frame (Fig.2),

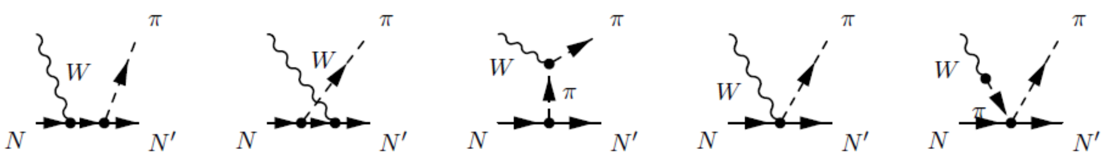

Figure 3. nonresonant single-pion production diagrams

therefore the helicity amplitudes of nonresonant interaction should be calculated in the same frame. The full model consists of the RS model based on the Berger Sehgal paper [3] for the resonance contribution, and the five diagrams based on the nonlinear σ model for nonresonance contributions are the model predictions for this work.

3. Pion angular distributions

Polar (θ) and azimuthal (ϕ) angles are shown in the Adler or $N\pi$ rest frame in Figure 2. The interference between resonant and non-resonant interactions has its main effect on the pion polar angle. In terms of pion angles, NEUT [9] only has the contribution from Δ resonance, and missing the other resonances as well as the non-resonance effects.

Figure 4 shows the differential cross-sections in terms of polar angle, and the comparison between RS model and the new model. To show the difference between NEUT prediction (only shape) and the model, the contribution from dominant Δ resonance is also added to the Figure (4).

According to [5], ϕ angle is a good observable to extract form-factors. The ϕ distribution (only shape) is almost unaffected by nuclear effects, therefore experiments with heavy target can also be a good probe to extract form-factors in the neutrino-nucleon models, while bubble chamber data is not precise enough to distinguish different models. For RS model and resonant

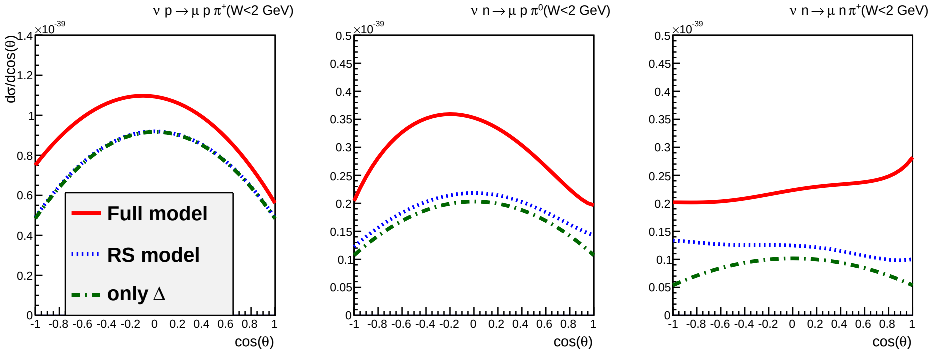

Figure 4. The differential cross-section averaged over T2K flux in terms of the polar angle. The blue doted curve shows the RS model, i.e. all resonances (up to $W = 2GeV$) and their interference, while the Green (dashed) curve is only for the dominant Δ resonance. The Red (solid) curve shows the full model.

interactions there are two different form-factors on the market i.e. the dipole (RS) form-factors from the original RS model [2], and the form-factors introduced by Graczyk and Sobczyk (GS) [6]. Figure (5) shows the significantly different distributions for different models with different form-factors.

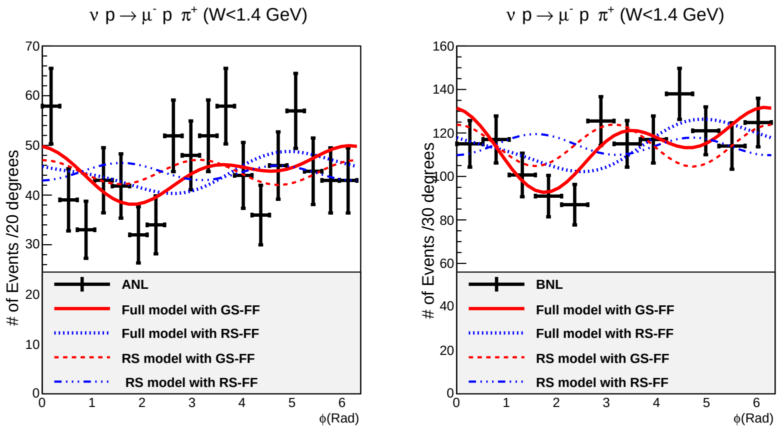

Figure 5. ANL and BNL distribution of events in the pion azimuthal angle in πN rest frame with $W < 1.4GeV$ for $\mu^- p\pi^+$ final state. Curves are flux-averaged, area-normalized prediction of the model for $d\sigma/d\phi$.

References

[1] D. Rein, Z. Phys. C **35** (1987) 43.
[2] D. Rein and L. M. Sehgal, Annals Phys. **133** (1981) 79.
[3] C. Berger and L. M. Sehgal, Phys. Rev. D **76** (2007) 113004
[4] E. Hernandez, J. Nieves and M. Valverde, Phys. Rev. D **76** (2007) 033005
[5] F. Snchez, Phys. Rev. D **93** (2016) no.9, 093015
[6] K. M. Graczyk and J. T. Sobczyk, Phys. Rev. D **77** (2008) 053001 Erratum: [Phys. Rev. D **79** (2009) 079903]
[7] G. M. Radecky *et al.*, Phys. Rev. D **25** (1982) 1161 [Phys. Rev. D **26** (1982) 3297].
[8] T. Kitagaki *et al.*, Phys. Rev. D **34** (1986) 2554.
[9] Y. Hayato, Acta Phys. Polon. B **40** (2009) 2477.