Charge Current Single Pion Production off the Nucleon

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Introduction

A precise knowledge of $\nu(\bar{\nu}) - N$ cross sections is essential for minimizing the systematic errors in analyzing $\nu(\bar{\nu})$ oscillation experiments. These experiments use Monte Carlo event generators (MC-gen) to calculate event rates, where $\nu(\bar{\nu}) - N$ cross-sections are taken as input. Most of these experiments are running or planned in the $\nu(\bar{\nu})$ energy $E_\nu \approx 0.5-2$ GeV. Experiments like MiniBooNE and T2K etc., have peaked around these energies. In this intermediate energy region, the major contribution to $\nu(\bar{\nu}) - N$ cross-section comes from the Inelastic channel dominated by single pion production(SPP). Additionaly, weak pion production offers a unique opportunity to learn about the axial properties, and helps in understanding the Standard Model(SM).

Here, we study Charge Current single pion production off the nucleon. The model is derived from the model developed in Ref. [1], which consists of non-resonant terms and Δ plus higher resonant terms. Unlike Ref. [1], the resonance parameters are tuned with electro– and photo–production data for a wide energy region. The work is in progress, and we present preliminary results.

Formalism

Charged current single pion production reactions may be written as

$$W^{\pm}(q) + N(p, M) \rightarrow \pi(k_\pi, m_\pi) + N'(p', M) \tag{1}$$

where in parenthesis, the four momenta with their masses are shown. The differential cross section for the above process is given by,

$$\frac{d\sigma}{dQ^2 dW} = \frac{W}{2^9\pi^4}\frac{1}{M^2 E_\nu^2 |\vec{q}|}\int dE_\pi \int d\phi_{q\pi} \overline{\Sigma}\Sigma|\mathcal{M}|^2 \tag{2}$$

with $W(=\sqrt{(p+q)^2})$ is the invariant mass and E_ν is the neutrino beam energy. The square of the transition matrix element:

$$\overline{\Sigma}\Sigma|\mathcal{M}|^2 = \frac{G_F^2}{2}\frac{1}{2}\, V_{ud}^2\, \mathcal{L}_{\mu\nu}\, \mathcal{J}^{\mu\nu}.$$

Where, G_F is the Fermi-coupling constant $(1.1663787 \times 10^{-5} GeV^{-2})$, and V_{ud} accounts for Cabibbo mixing. While the leptonic tensor is trivial, the hadronic tensor $\mathcal{J}_{\mu\nu}$ is written

$$\mathcal{J}_{\mu\nu} = \mathbf{Tr}\left[\mathrm{J}^\mu(\not{p} + \mathrm{M})\tilde{\mathrm{J}}^\nu(\not{p}' + \mathrm{M})\right], \tag{3}$$

with the help of hadronic current J^μ, which takes contribution from non-resonant as well as from resonant terms:

$$J^\mu \equiv J^\mu_{NR} + J^\mu_{s-\Delta} + J^\mu_{u-\Delta} + J^\mu_{s-R} + J^\mu_{u-R}.$$

While it is well known that the single pion production($CC1\pi$) channels get most of the contribution from $\Delta(1232)$ resonance [2], the non-resonant background [2] and higher resonances may also be crucial for some channels(especially I=1/2) in a specific kinematic range. The present work is primarily based on Ref. [1], where non-resonant terms are taken in a model-independent way using chiral perturbation theory (χPT) and gauge-invariance. While for $\Delta(1232)$, we use phenomenological Lagrangian where the weak $n-\Delta$ form factors are constrained using the EM data and PCAC with Goldberger-Trieman relation. In the second-resonance region(SRR), we include the contribution from resonances: $P_{11}(1440, +)$,

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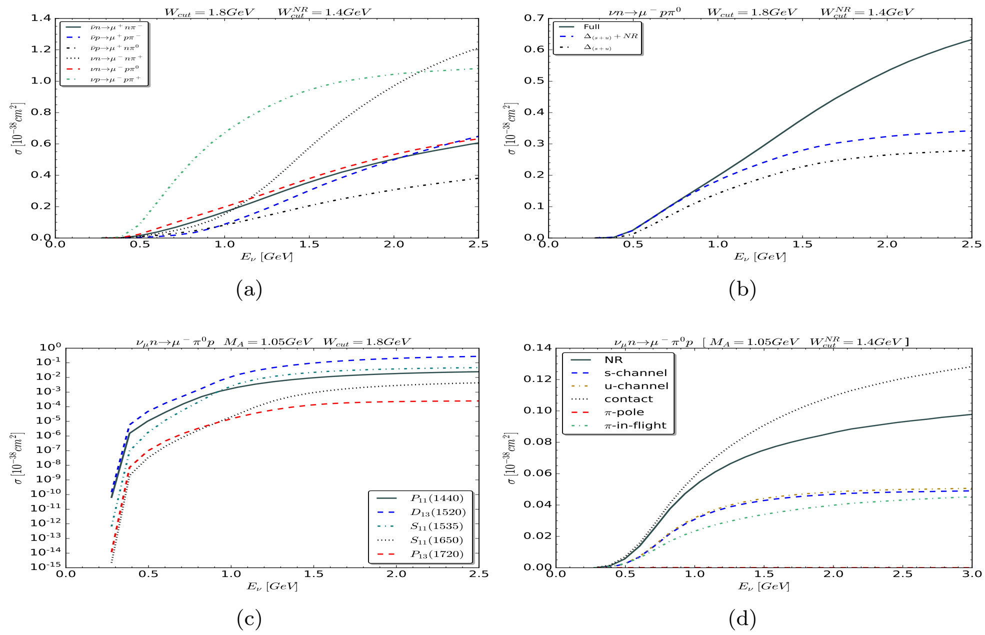

FIG. 1: Cross section for various possible $\nu(\bar{\nu})$-induced CC processes.

$D_{13}(1520, -)$, $S_{11}(1535, -)$, $S_{11}(1650, -)$ and $P_{13}(1720, +)$, where Breit–Wigner mass and parity are given in parenthesis. See Ref. [3], for detailed properties. While for SRR, the vector form factors are taken from the helicity amplitudes [4], for the axial form factors, we rely on PCAC and GTR.

Results and Discussion

In Fig. 1, we show the total cross-section σ for neutrino energies using Eq. (2). In Fig. 1(a), we compare the cross-section of different channels, while in Fig. 1(b-d), we show the strength of the constituent Feynman diagrams for one of the channels, $\nu_\mu n \to \mu^- \pi^0 p$. One can see the dominance of pure $I = \frac{3}{2}$ states, $\nu_\mu p \to \mu^- p\pi^+$, and $\bar{\nu}_\mu n \to \mu^+ n\pi^-$ channels; the contribution of $I = \frac{1}{2}$ states may also be significant in some kinematic regions. Finally, We apply invariant mass cut ($W \leq 1.8\ GeV$) to avoid the effects due to higher resonances. Further, since the NR terms are obtained within the framework of χPT, we impose an additional cut($W \leq 1.4\ GeV$) on NR terms to limit the phase space such that the higher order terms in chiral expansion do not contribute. While, the contribution of NR and $\Delta(1232)$ is taken from the works of Ref. [2], however, the $\Delta(1232)$ parameters are slightly modified to match electro- and photo- data. For the remaining higher resonances, we use the helicity amplitudes [4] for vector and the axial part we rely on partial conservation of axial current with Goldberger-Trieman relation.

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