NEUTRAL CURRENT SINGLE PION PRODUCTION OFF THE NUCLEON

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Introduction

We built a model for Neutral Current weak pion production off the nucleon induced by (anti-) neutrino. The salient features of our(Ref. [1]) model are:

- Contribution from non-resonant background terms use inputs from chiral Lagrangian, with phenomenological form factors to extend the model for higher energy(momenta).
- Dominant $\Delta(1232)$ resonance vector form factors are tuned from photo- and electro-production data, and for axial couplings we rely on Goldberger-Treiman Relation (GTR) together with PCAC and pion pole dominance.
- Resonances from the Second-Resonance Region(SRR) such as: $P_{11}(1440)$, $D_{13}(1520)$, $S_{11}(1535)$, $S_{11}(1650)$ and $P_{13}(1720)$, which helps us to extend the model to higher invariant mass and hence to higher neutrino energies. The vector form factors for the SRR are obtained from Helicity Amplitudes provided by MAID Ref. [2]. For axial form factor, we rely again on GTR and PCAC.
- We obtained the total as well as differential cross section for all possible $\nu(\bar{\nu})$-channel and compared their results.

Formalism

- Neutral current single pion production reactions may be written as

$$Z^0(q) + N(p, M) \to \pi(k_\pi, m_\pi) + N'(p', M) \quad (1)$$

where four momenta with their masses are show in parenthesis.

- The differential cross section for the above process is given by,

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

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:

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

Where, G_F is the Fermi-coupling constant ($1.1663787 \times 10^{-5} GeV^{-2}$), and V_{ud} accounts for Cabibbo mixing.

- The leptonic tensor is trivial, the hadronic tensor $\mathcal{J}_{\mu\nu}$ is written

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

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

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

- In the second-resonance region(SRR), we include the contribution from resonances shown in Table. 1.

Resonances	M_R (MeV)	Isospin	Spin	Parity	Width (MeV)
$\mathbf{P_{33}(1232)}$	1232	3/2	3/2	+	117
$\mathbf{P_{11}(1440)}$	1440	1/2	1/2	+	350
$\mathbf{D_{13}(1520)}$	1515	1/2	3/2	−	110
$\mathbf{S_{11}(1535)}$	1530	1/2	1/2	−	150
$\mathbf{S_{11}(1650)}$	1650	1/2	1/2	−	125
$\mathbf{P_{13}(1720)}$	1720	1/2	3/2	+	250

Table 1: Resonance parameters taken from PDG Ref. [3]

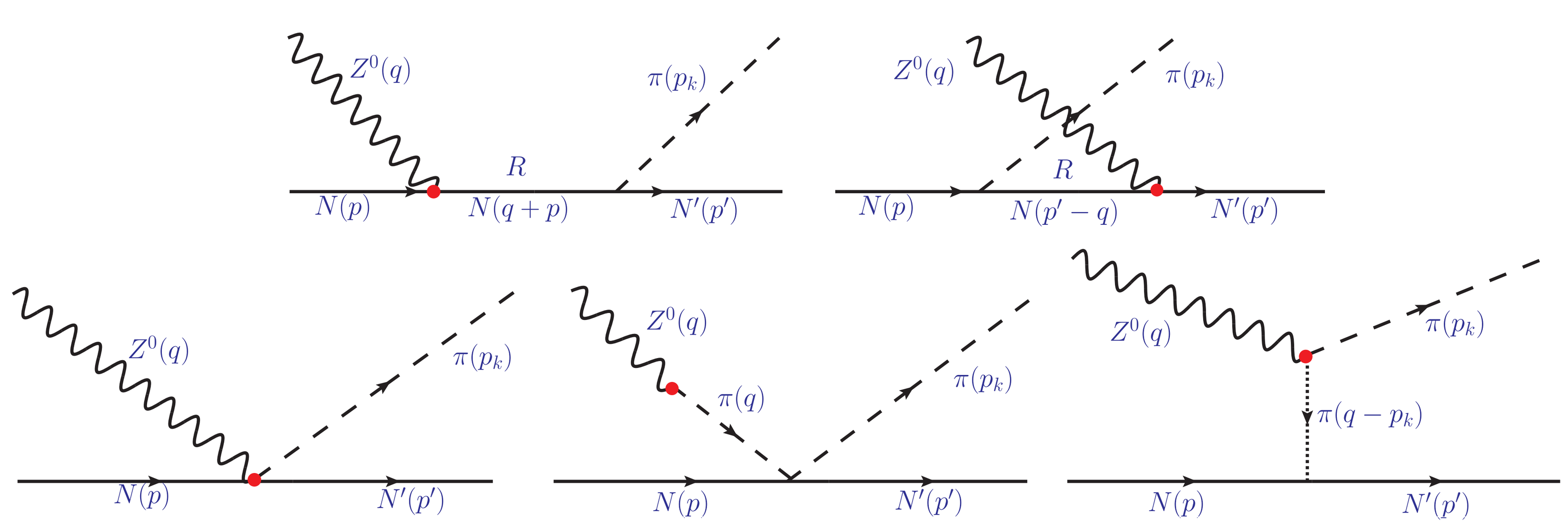

Figure 1: Feynman Diagrams for the $Z^0N \to N'\pi$ reaction consist of seven diagrams: Direct(s) and Crossed(u) Resonance and Nucleon pole terms, Contact, Pion pole and Pion-in-flight term.

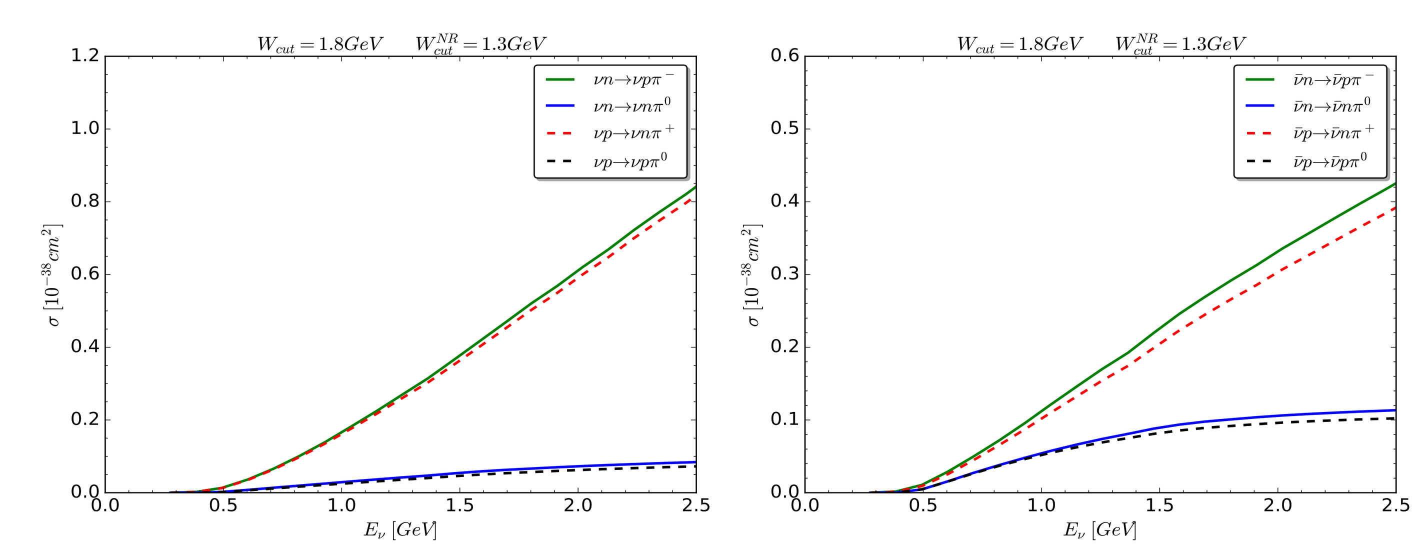

Figure 2: Preliminary results of total cross section for various possible $\nu(\bar{\nu})$-induced NC processes with $w_{cut} = 1.8GeV$

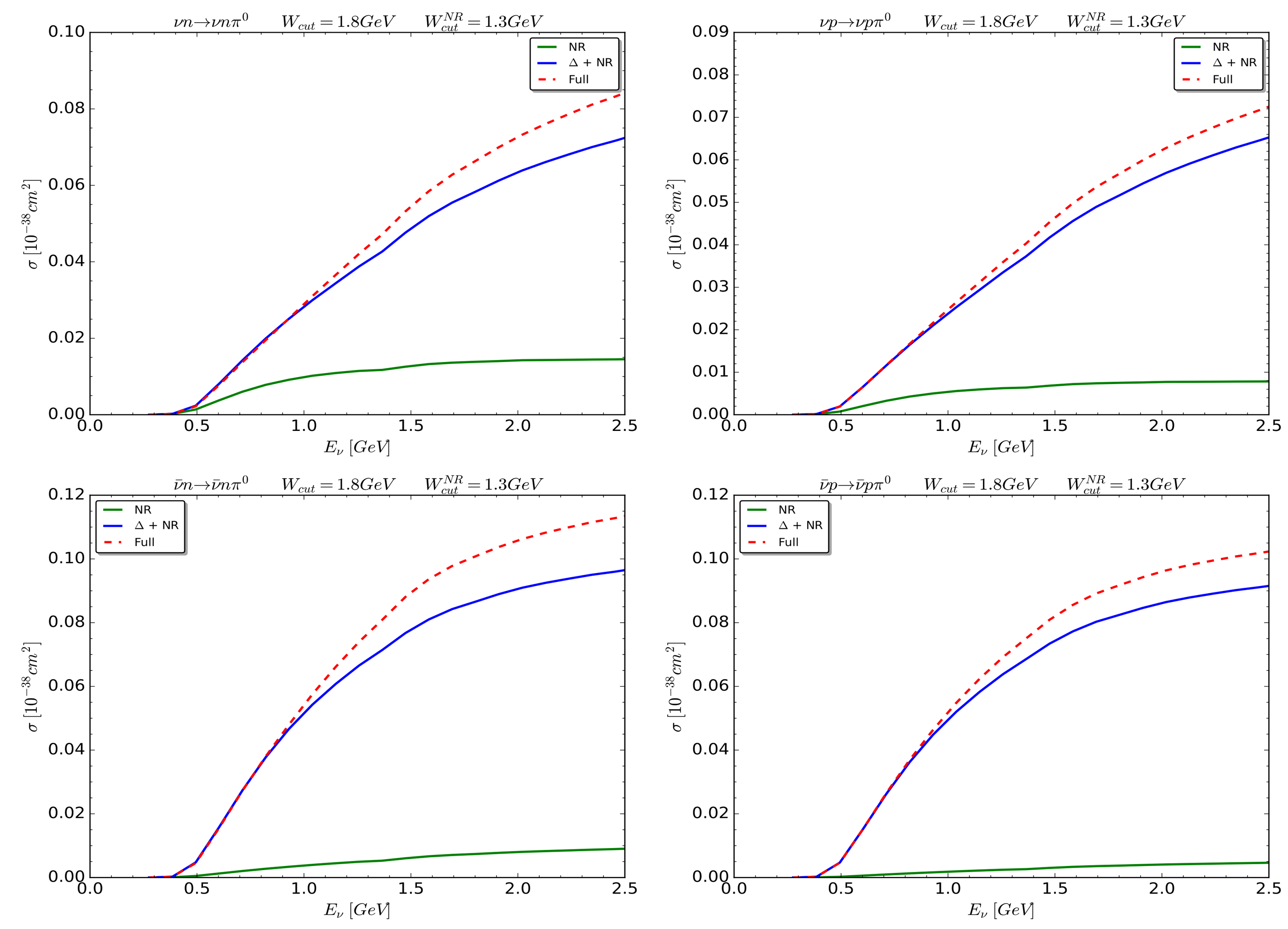

Figure 3: Preliminary results of total cross section for ν(above) and $\bar{\nu}$(below)-induced NC processes of Δ, Non-Resonant(NR) and Full(NR+Δ+SRR) channels.

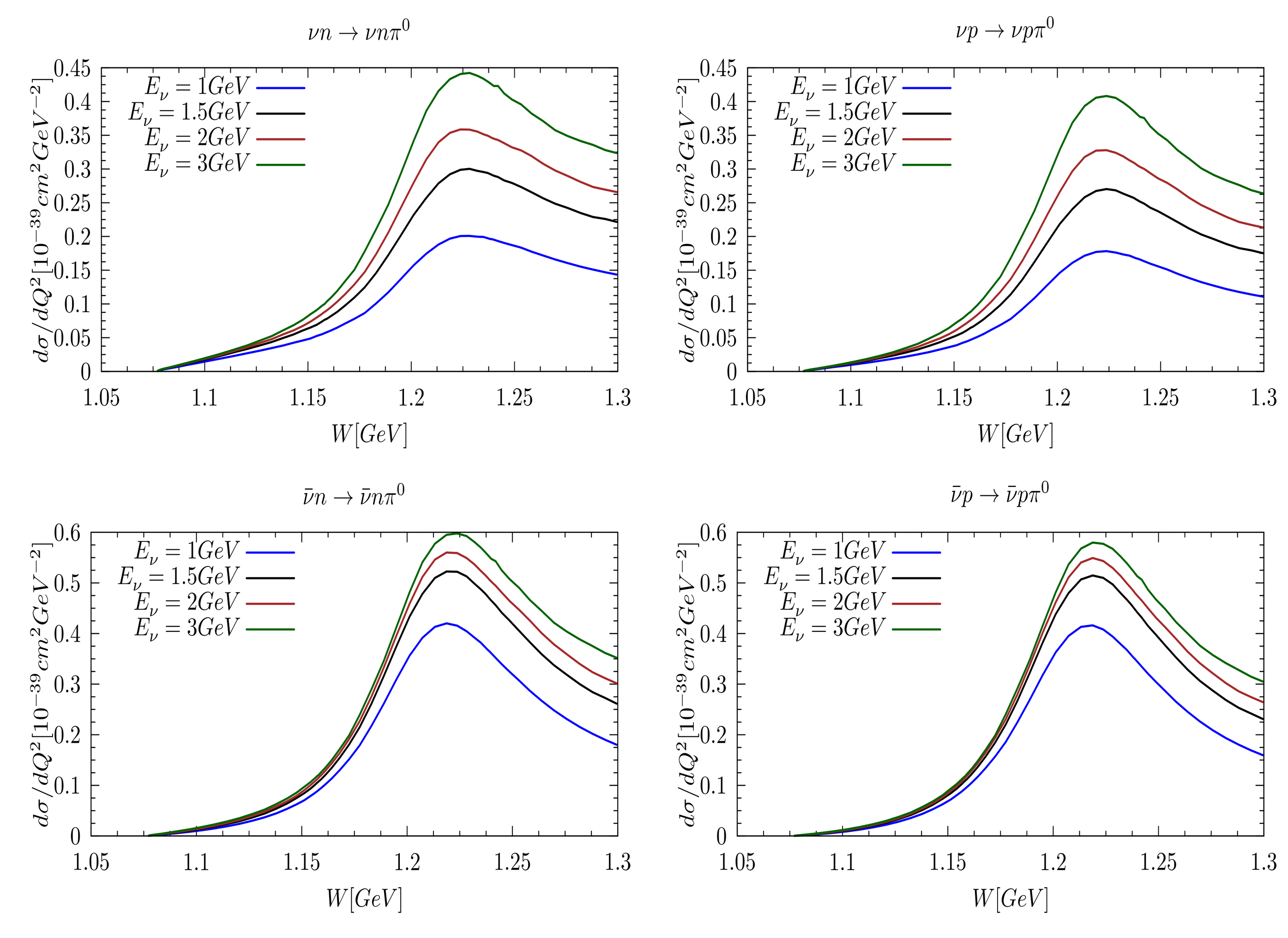

Figure 4: W-distribution for various possible $\nu(\bar{\nu})$-induced NC processes with different ν energies(E_ν).

Results and Discussion

- We show the total cross-section(σ) for neutrino energies in Fig. [2], using Eq. (2).
- In Fig. [3], we compare the NR, (Δ+NR) and full model total cross-section of different channels, while in Fig. [4], we show the W-distribution of different channels.
- One can see the dominance of pure $I = \frac{3}{2}$ states, $\nu_\mu n \to \nu_\mu p\pi^-$, and $\nu_\mu p \to \nu_\mu n\pi^+$ 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($W \leq 1.3\ GeV$) 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. [4], however, the $\Delta(1232)$ parameters are slightly modified to match electro- and photo- data.
- We are planning to tune the resonance parameters(from second resonance region) to match the electro- and photo- data and also unitarize our model using Watson's theorem.
- Next, we would like to apply the nuclear effects together with final state interactions such that the experimentalists can use our model for their analysis.

References

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