Weak interaction induced meson production from nucleons and nuclei

A. Fatima,* M. Sajjad Athar, and S. K. Singh
Department of Physics, Aligarh Muslim University, Aligarh - 202002, India

In this work, we study the neutrino and antineutrino induced meson (π, η, and K) production from the free nucleon as well as from the nuclear targets like carbon, argon, lead, etc. The meson production processes are dominated by the resonance excitations except in the threshold energy region where the non-resonant Born diagrams contribute significantly. In the numerical calculations, we have considered the different nucleon and delta resonances available in the PDG with 4-star rating and significant branching ratio to $N\pi$, $N\eta$, and YK ($Y = \Lambda, \Sigma$) decay modes. The non-resonant Born terms are determined using the non-linear sigma model involving the lowest lying baryons and mesons.

1. Introduction

Neutrino physics is entering a precision era and one of the aspects is to measure with high accuracy the neutrino oscillation parameters, to look for CP violation in the lepton sector, etc., for which the simultaneous knowledge of neutrino and antineutrino cross sections in the same energy region for a given nuclear target is required to reduce the systematics to a few percent level. In the few GeV energy region of neutrinos and antineutrinos, the contribution to the total scattering cross section comes from the quasielastic, inelastic, and deep inelastic scattering processes. The inelastic scattering region is quite intriguing as it excites various nucleon and delta resonances lying in the first and higher resonance regions starting with $P_{33}(1232)$ resonance, followed by $P_{11}(1440)$, $D_{13}(1520)$, $S_{11}(1535)$ resonances, etc. These resonances then decay to various meson-baryon channels leading to the production of mesons in the inelastic region. The inelastic meson production processes have been studied both theoretically as well as experimentally for many years in the reactions induced by photons and electrons where the contribution comes from the vector current only. However, in the weak sector, additional contribution from the axial vector current becomes important. Since the information about the axial vector nature of these resonances is very limited both experimentally as well as theoretically, therefore, in order to understand the inelastic scattering region of (anti)neutrinos, the study of meson production in the weak sector is important [1].

2. Formalism

Specifically, we study charged and neutral current induced single pion production, eta production, kaon production in the $|\Delta S| = 0$, 1 reactions from the free nucleon target as well as from the nuclear targets. The generic Feynman diagrams for the different meson production processes are shown in Fig. 1. The hadronic current receives contribution from the background terms as well as from the nucleon and delta resonance excitations. We have considered only those nucleon/delta resonances which are present in the PDG having spin $\frac{1}{2}$ and $\frac{3}{2}$ and mass in the range < 2 GeV with significant branching ratio in any particular meson decay mode. In the (anti)neutrino induced processes, the weak hadronic current is expressed in terms of the vector and axial vector currents, which contains the vector and axial vector form factors. The form factors associated with the vector current of the weak interaction are related to the electromagnetic form factors through the conserved vector current (CVC) hypothesis. While in the axial vector sector, partially conserved axial vector current (PCAC) and the Goldberger-

*Electronic address: atikafatima1706@gmail.com

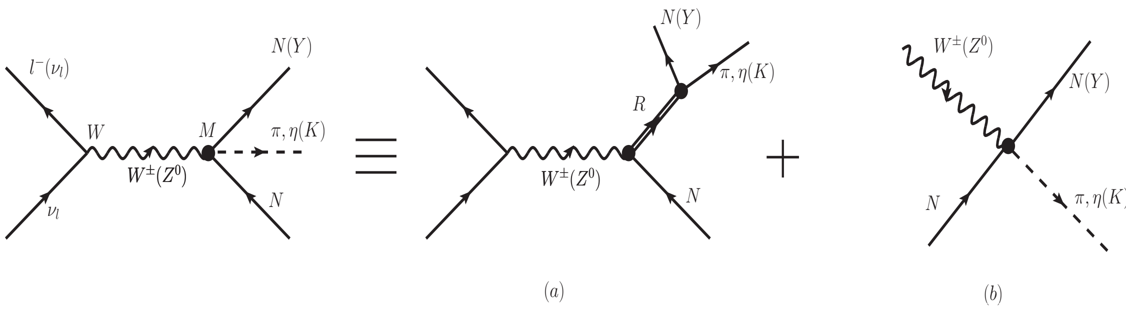

FIG. 1: Generic Feynman diagrams representing charged and neutral current induced meson production processes. In Fig. (a), R is the resonance excited by the (anti)neutrino interactions induced by $W^{\pm}(Z^0)$ intermediate vector bosons, which subsequently decays to a baryon and a meson and Fig. (b) shows the Feynman diagram corresponding to the nonresonant Born terms.

Treiman relation are used to determine the axial vector factors. The Q^2 dependence of the electromagnetic form factors, fitted from the meson electroproduction data, is used to obtain the Q^2 dependence of the weak vector form factors. Since the information about the axial vector nature of the nucleon and delta resonances is very limited, therefore, for simplicity, a dipole form factor is used to take into account the Q^2 dependence of the axial vector form factors. At the strong RNN' and RKY vertices, we have fitted the coupling constants using the meson photoproduction data, which then are used in the (anti)neutrino induced meson production processes. Thus, in our numerical calculations, we have used the inputs obtained from the fittings of photo and electroproduction processes, viz. the strong coupling constants are fitted from the experimental data available from the $N\eta$ [1] and $K\Lambda$ [2] photoproduction processes and the electromagnetic form factors are fitted from the electroproduction data.

In the case of non-resonant Born terms, an interaction Lagrangian based on the nonlinear realization of chiral SU(3) symmetry has been used to describe the interaction of nucleons and hyperons with nonstrange and strange mesons like pion, eta and kaon. At the weak vertex, the hadronic current is expressed in terms of the $N-N'$ and $N-Y$ vector and axial vector transtion form factors, which are determined using the various symmetry properties of the weak hadronic current like SU(3) symmetry, T invariance, CVC and PCAC hypotheses, etc. The strong couplings like $g_{NN\pi}$, g_{NKY}, etc. are expressed in terms of the meson decay constants and the symmetric and antisymmetric axial vector couplings D and F. The meson decay constants f_π, f_K, f_η, meson masses, and the axial vector couplings are treated as fixed parameters and their experimental values have been taken from the PDG.

The results obtained in our model shall be discussed along with the theoretical results available in the literature for the different meson production processes as well as with the recent measurements from the accelerator experiments.

Acknowledgments

We are thankful to the Department of Science and Technology (DST), Government of India for providing financial assistance under Grant No. SR/MF/PS-01/2016-AMU.

References

[1] M. Sajjad Athar, A. Fatima and S. K. Singh, Prog. Part. Nucl. Phys. (Under review), [arXiv:2206.13792].

[2] A. Fatima, Z. Ahmad Dar, M. Sajjad Athar and S. K. Singh, Int. J. Mod. Phys. E **29**, 2050051 (2020).