Coherent pion production in ν-Nucleus interaction

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Introduction

The neutrino interaction with matter in intermediate energy range gets contribution from many processes which include Quasi Elastic Scattering (QES), interaction via Resonance Production (RES) and Deep Inelastic Scattering (DIS). In the neutrino nucleus interaction, coherent pion production is an important process where the nucleus interact as a whole with neutrino and remain in the same quantum state as it was initially when the neutrino arrived. This process helps in constrainig the nuclear effects in neutrino interaction with matter. The neutral current coherent pion production gives π^0 which decays into photon which mimics an electron and thus it becomes a critical background for neutrino oscillation experiments searching for ν_e. In this work, we calculate the differential and total cross section of the cohrent pion production in neutrino nucleus scattering using KPG [1] and KM [2] formalisms. Both of these formalisms use Adler's Partially Conserved Axial Current (PCAC) theorem which relates the neutrino induced coherent pion production to the pion-nucleus elastic scattering.

Pion production in ν-Nucleus interaction

In the KPG formalism [1] charged current coherent pion production cross section of a ν-nucleus interaction can be written as [1]

$$\frac{d\sigma(\nu_\mu + A \to \mu^- + \pi^+ + A)}{dQ^2\ d\nu\ dt} = \frac{G_F^2\ |V_{ud}|^2\ \nu}{2\ (2\pi)^2 E_\nu^2}$$
$$\left\{\frac{f_\pi^2}{Q^2}\left[\tilde{L}_{00} + \tilde{L}_{ll}\Big(\frac{m_\pi^2}{Q^2+m_\pi^2}\Big)^2 + 2\ \tilde{L}_{l0}\right.\right.$$
$$\left.\left.\frac{m_\pi^2}{Q^2+m_\pi^2} - 2(Q^2+m_\mu^2)\right]\frac{d\sigma(\pi^+ + A \to \pi^+ A)}{dt}\right\}$$

Here G_F is the Fermi coupling constant, V_{ud} is the matrix element in CKM matrix, f_π is the pion decay constant, E_ν is the energy of the incoming neutrino, ν is the difference in the energies of incoming neutrino and out going lepton i.e. (E_ν - E_μ) and $Q^2 = -q^2$ is the four-momentum transfer. The relevant matrix elements are give by

$$\begin{aligned}
\tilde{L}_{00} &= \frac{2\left[Q^2\ (2\ E_\nu - \nu) - \nu\ m_\mu^2\right]^2}{Q^2\ \vec{q}^2}, \\
\tilde{L}_{ll} &= 2\ m_\mu^2\ \Big(\frac{m_\mu^2}{Q^2}\ + 1\Big), \\
\tilde{L}_{l0} &= \frac{2\ m_\mu^2\left[Q^2\ (2\ E_\nu - \nu)\ -\ \nu\ m_\mu^2\right]}{Q^2\ |\vec{q}|}.
\end{aligned}$$

The $d\sigma(\pi^+ + A \to \pi^+ A)/dt$ repersent the pion-nucleus total elastic cross section.
In the KM formalism [2] the differential cross section of charged pion production in neutrino nucleus interaction is given by

$$\frac{d\sigma(\nu_\mu + A \to \mu^- + \pi^+ + A)}{dQ^2\ dy\ dt} = \frac{G_F^2 |V_{ud}|^2 f_\pi^2}{2\pi^2}$$
$$\frac{E_\nu}{|\mathbf{q}|}u\ v\left[\Big(G_A - \frac{1}{2}\frac{Q^2_{min}}{(Q^2+m_\pi^2)}\Big)^2 + \frac{y}{4}\right.$$
$$\left.(Q^2 - Q^2_{min})\frac{Q^2_{min}}{(Q^2+m_\pi^2)^2}\right]\frac{d\sigma(\pi^+ A \to \pi^+ A)}{dt}$$

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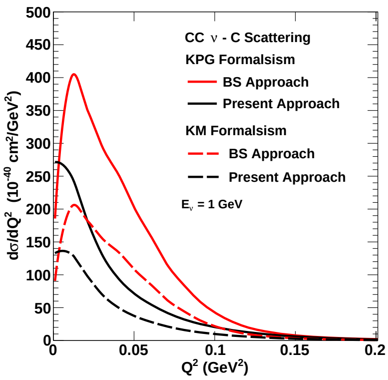

FIG. 1: differential cross section, $d\sigma/dQ^2$ for cohrent pion production as a function of momentum transfer square, Q^2.

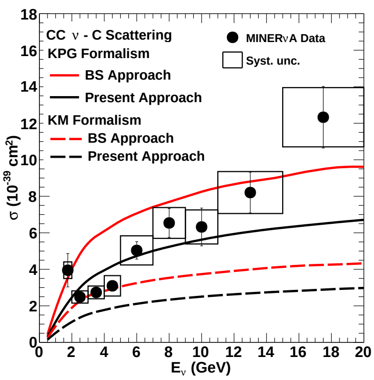

FIG. 2: Total coherent pion production cross section, σ as a function of neutrino energy, E_ν.

Here the kinematic factors u and v are given by $u, v = \Big(E_\nu + E_\mu \pm |\mathbf{q}|\Big)/(2\,E_\nu)$. We use two approaches to calculate total cross section for pion-carbon elastic scattering, i) the Berger-Sehgal (BS) model [3] ii) approach based on Glauber model (Present Model) [4, 5].

Results and discussions

Figure 1 shows differential cross section, $d\sigma/dQ^2$ for cohrent pion production as a function of momentum transfer square, Q^2. We use both KM and KPG formalism along with both methods of pion-carbon elastic scattering cross section calculation. Berger-Sehgal (BS) model [3] gives higher cross section at lower Q^2 for both the formalism. Figure 2 shows total coherent pion production cross section, σ as a function of neutrino energy, E_ν. The calculations are persented for all the four cases and compared with the data recorded by MINERνA experiment [6]. The cross section calculated in KPG formalism is always greater than the cross section calculated in KM formalism. At lower energies ($E_\nu \leq 5$ GeV) both the formalism are compatible with the data. For higher energy ($E_\nu \geq 6$ GeV) the data clearly favours the KPG formalism.

Conclusion

We have calculated the differential and total cross section of the cohrent pion production in neutrino carbon scattering using the popular Kopeliovich Marage(KM) and KPG formalism. The neutrino-carbon elastic scattering cross section is calculated using BS approach and Glauber model. These cross sections are then used with both the above mentioned approches. Both the formalism are compatible with the data at lower neutrino energies while KPG gives better description at higher energy. The advantage with the Glauber approach is we can extend the calculations for predicting the cross section for any nucleus without requiring pion nucleon elastic scattering cross section.

References

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