ν-induced weak kaon production from nucleons and nuclei

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The study of weak nuclear reactions induced by neutrinos and anti-neutrinos in the energy region of a few GeV has become quite important due to the role played by these processes in the analysis of various neutrino oscillation experiments being done with atmospheric and accelerator neutrinos. In this energy region processes in which pions, kaons and hyperons are produced also become important. There exists very few calculations for the neutrino production of kaons from nucleons. In principle, their cross sections are smaller than for the pionic processes but in the era of precision neutrino oscillation experiments their knowledge could be important for the data analysis [2].

In this paper, we present the results of the cross sections for the neutrino induced kaon production from nucleons. This has been obtained using a microscopical model based on the SU(3) chiral Lagrangian. The basic parameters of the model are f_π, the pion decay constant, Cabibbo's angle, the proton and neutron magnetic moments and the axial vector coupling constants for the baryons octet, D and F, that are obtained from the analysis of the semileptonic decays of neutron and hyperons. The basic reaction for the neutrino induced charged current kaon production is

$$\nu_l(k) + N(p) \rightarrow l(k') + N'(p') + K(p_k), \quad (1)$$

where $l = e, \mu$ and $N\&N'$=n,p, $\bar{\Sigma}\Sigma|\mathcal{M}|^2$ is the square of the transition amplitude matrix element averaged(summed) over the spins of the initial(final) state and amplitude $\mathcal{M}$ is given by,

$$\mathcal{M} = \frac{G_F}{\sqrt{2}} j_\mu^{(L)} J^{\mu\,(H)} \quad (2)$$

where $j_\mu^{(L)}$ and $J^{\mu\,(H)}$ are the leptonic and hadronic currents respectively, G_F is the Fermi coupling constant. Feynman diagrams contributing to the amplitude are given in Fig.1. The structure of the hadronic current and details of the formalism are given in Ref. [1]. The expression of the cross section corresponding to reaction (1) is given by,

$$\sigma = \frac{1}{32}\frac{1}{(2\pi)^4}\int_{T_{Kaon}^{min}}^{T_{Kaon}^{max}} dT_{Kaon} \int_{k^l_{min}}^{k^l_{max}} dk_l \times \int_0^{2\pi} d\phi_{Kq} \int_{-1}^{1} dcos\theta_{\nu l} \frac{|\vec{k}'|^2}{M_N E_\nu E_l\ |\vec{q}|} \bar{\Sigma}\Sigma|\mathcal{M}|^2$$

where q $(k - k')$ is the momentum transfer.

In Fig.2, we have presented the results of the cross section for $\nu_\mu p \rightarrow \mu^- K^+ p$ channel, and we find that the contact term is the most dominant, followed by the u-channel diagram with a Λ intermediate state and the π exchange term. The curve labeled as Full Model has been calculated with a global dipole form factor with a mass of 1 GeV. The band corresponds to changing up and down this mass by a 10 percent. A similar effect is found in the other channels.

As most of the neutrino experiments are being performed using nuclear targets, therefore, when the reaction (1) takes place inside the nucleus, like ^{40}Ar, ^{56}Fe, etc., role of nuclear medium effects come into play. The effects of nuclear medium and final state interaction have been found out to be quite large in the case of pion production processes, however, this is expected to be small in the case of kaon

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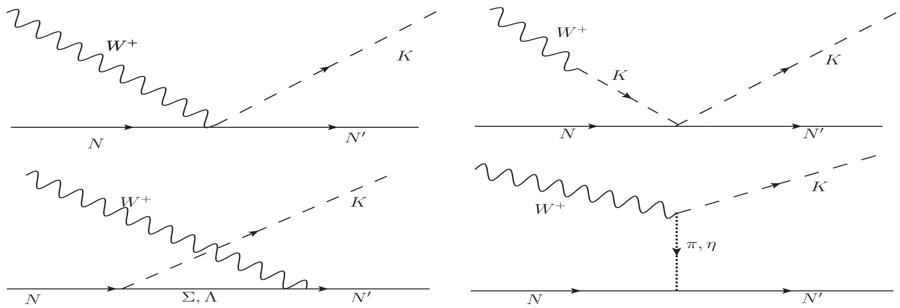

FIG. 1: Feynman diagrams for the process $\nu N \to l N' K$. From left to right; First row : contact term, Kaon pole; Second row: u-channel diagram and Pion(Eta) in flight.

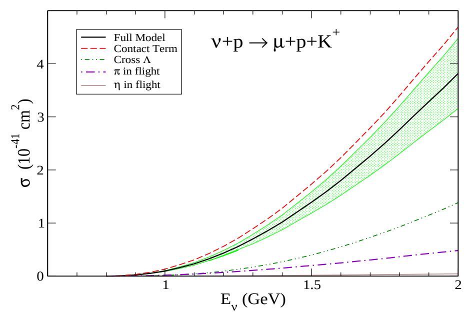

FIG. 2: Contribution of the different terms to the total cross section for the $\nu_\mu p \to \mu K^+ p$ reaction.

production process due to the absence of resonant diagram as well as the absence of final state interaction effect.

We evaluate the cross section for the process (1) inside a nucleus, in a local density approximation(LDA), where the cross section is evaluated as a function of local Fermi momentum, $p_F(r)$ and integrated over the whole nucleus. In a nucleus, the neutrino scatters from a nucleon whose local density in the medium is $\rho_N(r)$, and the corresponding local Fermi momenta for neutrons and protons are given by

$$p_{F_n} = [3\pi^2 \rho_n(r)]^{1/3}; p_{F_p} = [3\pi^2 \rho_p(r)]^{1/3} \quad (3)$$

$\rho_n(r)$ and $\rho_p(r)$ are the local density of neutrons and protons respectively.

The cross section for the scattering taking place inside the nucleus σ_A is given in terms of the free neutrino nucleon cross section σ as $\sigma_A = \int_0^\infty \rho_N(r)\, d^3r\, \sigma$.

In a symmetric nuclear matter, each nucleon occupies a volume of $(2\pi)^3$. However because of two possible spin orientations of nucleons, each unit cell in configuration space is occupied by two nucleons. Thus the number of protons or neutrons in a certain volume is $N = 2V \int^{p_F} \frac{d^3p}{(2\pi)^3}$ and $\rho = \frac{N}{V} = 2 \int \frac{d^3p}{(2\pi)^3} n_N(p,r)$, where $n_N(p,r)$ is the occupation number of proton or neutron.

Thus the cross section in the LDA is given by

$$\sigma_A = 2 \int_0^\infty d^3r \int_0^{k_F(r)} \frac{d^3p}{(2\pi)^3}\, \sigma(\nu N \to l N' K), \quad (4)$$

The details of the results will be presented in the symposium.

References

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