Δ Production Calculations With Nuclear Effects

S.K.Singh[a] S. Ahmad[a] and M. Sajjad Athar[a]

[a]Department of Physics, A. M. U., Aligarh-202 002, India.

Calculation of nuclear effects in neutrino induced Δ production from deuteron relevant to the BNL experiment is presented. The inclusive production of Δ from nuclei is studied in a local density approximation which takes into account the modification of Δ properties in the nuclear medium. We also present the results for the coherent production of pions from ^{16}O induced by neutral current.

1. INTRODUCTION

The excitation of delta from nucleon and nuclear targets is the dominant mechanism to produce pions in the intermediate energy regions relevant to atmospheric neutrinos. While there is considerable work on the electromagnetic excitation of delta from the nuclear targets [1–8], the work in weak excitation of Δ has been limited to the analyses of very few earlier bubble chamber experiments done with neutrino beams [9–11].

The present interest in understanding the pion production from nuclear targets relevant to the neutrino oscillation experiments being done with atmospheric neutrinos has emphasized the need to re-examine these processes over a wide range of neutrino energies [12–14]. The calculation of Δ production from free nucleons is done in the standard model using delta nucleon transition matrix elements. The weak transition form factors entering these matrix elements are not known accurately and have to be determined from a model and/or experimental data whenever available [15–20]. There is an additional model dependence when the Δ production is considered in nuclei due to strong interaction of Δ in the medium. The modification in the Δ properties like its mass and width in the nuclear medium has been studied in the case of electromagnetic excitation and the results are used to calculate the weak production of delta. The delta resonsce once produced in the nucleus, decays into pions which travel through the nucleus and undergo various rescattering and absorption before they are observed. The pions thus produced leave the nucleus either in its ground state or in an excited state. The pion production processes are classified as coherent and incoherent depending upon the state of the final nucleus. In coherent production, the nucleus stays in the ground state and the lepton energy transfer is carried by the pion. While in incoherent production the nucleus could be in excited state decaying further into a final nucleus and other particles.

The nuclear effects in the Δ production are important to study the pion production from nuclei. These nuclear effects are better understood theoretically if a deuteron target is used. Deuterium filled bubble chambers have been used to study the quasielastic neutrino reactions on neutron targets. This experimental set up has also been used to study the exclusive pion production from proton and neutron using deuteron target and provide high statistics data on this process. While the nuclear effects arising because of deuteron as target has been studied for the quasielastic process, not much attention has been paid to calculate these effects for the pion production processes. The pion production data has been analysed in absence of such corrections [9,10]. A reanalysis of BNL experiment is being done[21] and it is desirable that these corrections are calculated keeping in mind the requirements of the experimental analysis.

Here we first describe the delta production processes on nucleons and deuterons in Section-2 and take up the nuclear excitation of Δ resonance in Section-3. The coherent production of pions is taken up in Section-4.

2. Δ PRODUCTION FROM NUCLEONS AND DEUTERON

The matrix element for the process $\nu p \rightarrow \mu^- + \Delta^{++}$ is written as

$$M = \frac{G_F}{\sqrt{2}} cos\theta_c l_\alpha J^\alpha \quad (1)$$

with

$$l_\alpha = \bar{u}(k)\gamma_\alpha(1-\gamma_5)u(k) \quad (2)$$

and the weak $N-\Delta$ transition matrix element is written as[17,18]

$$< p'|J^\alpha|p >=< p'|V^\alpha|p > - < p'|A^\alpha|p > \quad (3)$$

$$\begin{aligned} < p'|V^\alpha|p > = \sqrt{3}\bar{\Psi}_\mu(p') \Big[& \frac{C_3^V}{M}(g^{\mu\alpha} \not{q} - q^\mu \gamma^\alpha) \\ & + \frac{C_4^V}{M^2}(g^{\mu\alpha} q \cdot p' - q^\mu p'^\alpha) \\ & + \frac{C_5^V}{M^2}(g^{\mu\alpha} q \cdot p - q^\mu p^\alpha)\Big] \gamma_5 u(p) \end{aligned} \quad (4)$$

$$\begin{aligned} < p'|A^\alpha|p > = \sqrt{3}\bar{\Psi}_\mu(p') \Big[& \frac{C_3^A}{M}(g^{\mu\alpha} \not{q} - q^\mu \gamma^\alpha) \\ & + \frac{C_4^A}{M^2}(g^{\mu\alpha} q \cdot p' - q^\mu p'^\alpha) \\ & + C_5^A g^{\mu\alpha}\Big] u(p) \end{aligned} \quad (5)$$

where M is the nucleon mass, $\Psi_\mu(p')$ and u(p) are the Rarita Schwinger and Dirac spinors for Delta and nucleon of momenta p' and p, q is the four momentum transfer $(= p' - p = k - k')$.

The weak form factors C_i^V(i=3-6) are obtained using the conserved vector current(CVC) hypothesis, which requires $C_6^V = 0$. The remaining three form factors are related to the various amplitudes in the photo and electroproduction of the Δ resonance.

From the experimental data on these processes, the following values of the vector form factors are obtained, which are used in the analysis of the neutrino scattering experiments[18–20]:

$$C_5^V = 0, \quad C_4^V = -\frac{M}{M_\Delta} C_3^V, \quad (6)$$

with

$$C_3^V(q^2) = \frac{2.05}{(1 - q^2/0.54GeV^2)^2}. \quad (7)$$

The values of the axial form factors most often used in the analyses of the neutrino experiments are[9,10]

$$C_{i=3,4,5}^A(q^2) = C_i^A(0)\left[1 - \frac{a_i q^2}{b_i - q^2}\right]\left(1 - \frac{q^2}{{M_A}^2}\right)^{-2} \quad (8)$$

and

$$C_6^A(q^2) = {C_5}^A \frac{M^2}{{m_\pi}^2 - q^2} \quad (9)$$

with $C_3^A(0) = 0, C_4^A(0) = -0.3, C_5^A(0) = 1.2, a_4 = a_5 = -1.21, \ b_4 = b_5 = 2GeV^2$ and M_A is treated as a free parameter. For our present purpose, we take $M_A = 1.28GeV$.

With these matrix elements the differential cross section is calculated to be

$$\frac{d\sigma}{dq^2 dk'_0} = \frac{{G_F}^2 Cos^2\theta_c}{128\pi^2}\frac{M}{M_\Delta}\frac{1}{(s-M^2)^2} \times L_{\alpha\beta}J^{\alpha\beta}\frac{\frac{\Gamma_\Delta(W)}{2}}{(W-M_\Delta)^2 + \frac{\Gamma_\Delta(W)^2}{4.}} \quad (10)$$

$s = (p+k)^2$, $L_{\alpha\beta}$ is the Leptonic tensor and $J^{\alpha\beta}$ is the Hadronic tensor and Γ_Δ is the width of Δ resonance.

When the reaction takes place in the deuteron i.e. $\nu(k) + d(p) \rightarrow \mu^- + \Delta^{++}(p'_1) + n(p'_2)$, the differential cross section in the impulse approximation is derived to be[22]

$$\frac{d\sigma}{dq^2 dk'_0} = \frac{{G_F}^2 Cos^2\theta_c}{128\pi^2}\frac{M_d^2}{M_\Delta(s-M_d^2)^2}L_{\alpha\beta}J^{\alpha\beta} \times \int \frac{d^3p_2}{(2\pi)^3 p_2'^0}\frac{\Gamma_\Delta(W)}{(W-M_\Delta)^2 + \frac{\Gamma_\Delta(W)^2}{4.}}\tilde{\phi}^2(p_2) \quad (11)$$

where M_d is the deuteron mass and $\tilde{\phi}_d(p_2)$ is the Fourier transform of $\phi_d(\mathbf{r})$, the deuteron radial wave function. This expression is derived assuming the neutron to be spectator, and neglecting meson exchange currents and final state interactions. Using the above equation we have calculated the differential cross section for the reaction $\nu + d \rightarrow \mu^- + \Delta^{++} + n$ for various deuteron wave functions corresponding to Hulthen [23], Paris[24] and Bonn[25] potentials.

In Fig.1, we show the effect of deuteron structure using the various wave functions. We find that these effects give a reduction in $\frac{d\sigma}{dq^2}$ of $5-10\%$ in the region of low q^2 depending upon the wave functions used for the deuteron. Furthermore, it was found that, in this model, the reduction is very weakly dependent on q^2. This is in contrast to the ealier experimental analysis[9], where a strong reduction is found around $q^2 \approx 0$. The present theoretical results do not include the meson exchange current effects which may be important specially at low q^2.

In earlier analyses of Δ production from deuteron, S wave decay width for Δ resonance has been used by many authors [10,18]. It is more appropriate to use a P wave decay width for the Δ resonance given by:

$$\Gamma_\Delta(W) = \frac{1}{6\pi}(\frac{f_{\pi N\Delta}}{m_\pi})^2 \frac{M}{W} |\mathbf{q_{CM}}|^3 \Theta(W - M - m_\pi) \quad (12)$$

where the step function Θ denotes the fact that the width is zero for the invariant masses below the $N\pi$ threshold, W is the Δ invariant mass and $\mathbf{q_{CM}}$ the pion momentum in the rest frame of the resonance.

It is found that the results for $\frac{d\sigma}{dq^2}$ are within 5% when S wave or P wave decay width for Δ resonance is used. However, neglecting Δ width as done by Hemmert et al.[26] to obtain a value of $C_5^A(0)$ while analysing these experiments gives a very high value of $\frac{d\sigma}{dq^2}$ in the region of low q^2.

3. Δ PRODUCTION IN NUCLEI

Weak production of Δ has been studied in order to calculate the pion production from nuclei. The detailed calculation of Fogli and Narduli[27] does not give a quantitative description of the nuclear effects. The effect of nuclear medium has been recently calculated in a relativistic mean field approximation[28,29]. In this approximation, a modified mass for the nucleon and delta has been used but a constant decay width for the Δ has been employed to calculate the pion production. In the nuclear medium the mass and decay width of Δ are both modified due to strong interactions. We present the results of the nuclear effects on the delta production in nuclei in the local density approximation(LDA)[30,31] which takes into account the modification of mass and decay width. The method has been used in past to calculate some electromagnetic and strong reactions in nuclei in the region of Δ dominance[2–7]. In this approximation the incoming neutrino interacts with the nucleon moving inside the nucleus of density $\rho(r)$ with the corresponding momentum $\mathbf{p_N}$ which is constrained to be within Fermi sea and is therefore bounded by the local Fermi momentum $p_F(r) = \left[\left(\frac{3\pi^2}{2}\rho(r)\right)^{\frac{1}{3}}\right]$.

The Δ's however have no restriction on their momentum. These delta particles once produced may decay through $\Delta N \rightarrow NN$ and $\Delta \rightarrow N\pi$ channels in the nucleus. The nucleons produced in these decay processes are Pauli blocked and therefore the mass(M) and width(Γ) of Δ in the nuclear medium are modified. This has been studied in detail in electromagnetic and strong interactions[2,3]. These modifications are parameterised by making density dependent changes in M and Γ. These are done by replacing $M_\Delta \rightarrow \tilde{M_\Delta} = M_\Delta + Re\Sigma_\Delta$ and $\Gamma \rightarrow \Gamma_{eff} = \tilde{\Gamma} - 2Im\Sigma_\Delta$, where $\tilde{\Gamma}$ is the Pauli blocked width of Δ and Σ_Δ is the self energy of the delta in the nuclear medium. The Pauli blocked decay width $\tilde{\Gamma}$ is given by

$$\tilde{\Gamma} = \frac{1}{6\pi}\left(\frac{f_{\pi N\Delta}}{m_\pi}\right)^2 \frac{M|\mathbf{p'}_{cm}|^3}{\sqrt{s}} F(E_F, E_\Delta, K_\Delta)$$

where $\mathbf{p'}_{cm}$ is the momentum of the nucleon in the final πN center of mass frame and $F(E_F, E_\Delta, k_\Delta)$, the Pauli correction factor is written as

$$F(E_F, E_\Delta, K_\Delta) = \frac{k_\Delta|\mathbf{p'_{cm}}| + E_\Delta E'_{p_{cm}} - E_F\sqrt{s}}{2k_\Delta|\mathbf{p'}_{cm}|}$$

The imaginary part of the Δ-self energy is parametrized as:

$$-Im\Sigma_\Delta = C_Q\left(\frac{\rho}{\rho_0}\right)^\alpha + C_{A2}\left(\frac{\rho}{\rho_0}\right)^\beta + C_{A3}\left(\frac{\rho}{\rho_0}\right)^\gamma \quad (13)$$

and is determined mainly by the one pion interactions in the nuclear medium. This includes the two body, three body absorption and the quasi-elastic absorption contributions for the produced pions in the nucleus.

The coefficients C_Q, C_{A2}, C_{A3} are prameterised in the range $80 < T_\pi < 320 MeV$, where T_π is the pion kinetic energy, as [2,3]

$$C(T_\pi) = ax^2 + bx + c, \qquad x = \frac{T_\pi}{m_\pi}$$

.

where C stands for all the coefficients i.e. $C_Q, C_{A2}, C_{A3}, \alpha$ and $\beta(\gamma = 2\beta)$.

The coefficients a,b,c and α, β are given in Table-1. For $T_\pi > 320 MeV$, the coefficients corresponding to $T_\pi = 320 MeV$ are taken. This is an approximation which needs further study in this approach.

The intermediate nucleon feels a single particle potential influenced by all the other nucleons in the nucleus. This effect can be taken into account in the form of the real part of the delta self-energy. This effect modifies the delta mass in the medium by

$$M_\Delta \to \tilde{M}_\Delta = M_\Delta + Re\Sigma_\Delta \ ,$$

The real part of the Δ-self energy is associated with the medium corrections and is approximated as [3]

$$Re\Sigma_\Delta = 40.0\frac{\rho}{\rho_0} MeV \, .$$

With these modifications the differential cross section for production of a Δ in a nuclear medium is written as[32]

$$\frac{d^2\sigma}{d\Omega_{k'} dE_{k'}} = \int \frac{d\mathbf{r}}{(4\pi)^3}\frac{k'}{E_\nu} \times \frac{\frac{\tilde{\Gamma}}{2} - Im\Sigma_\Delta}{(W - M - Re\Sigma_\Delta)^2 + (\frac{\tilde{\Gamma}}{2.} - Im\Sigma_\Delta)^2} \times (\rho_n(\mathbf{r}) + 3\rho_p(\mathbf{r}))L_{\alpha\beta}J^{\alpha\beta} \quad (14)$$

where $\rho_n(\mathbf{r})$ and $\rho_p(\mathbf{r})$ are the neutron and proton densities of the nucleus and

$$L_{\alpha\beta} = k_\alpha k'_\beta + k'_\alpha k_\beta - g_{\alpha\beta} k.k' + i\epsilon_{\alpha\beta\gamma\delta}k^\gamma k'^\delta$$

and

$$J_{\alpha\beta} = \bar{\sum}\sum J^\dagger_\alpha J_\beta$$

.

For antineutrino reactions we replace $\rho_n \to \rho_p$ and change the sign of the antisymmetric term in the leptonic tensor $L_{\alpha\beta}$.

It should be noted from the above equation that the ImΣ_Δ term in the numerator gives the particle hole excitation and $\frac{\tilde{\Gamma}}{2}$ term gives the Δs which produce pions.

These pions once produced inside the nucleus suffer rescattering and absorption on their way out. A calculation of the absorption coefficient to estimate the reduction in pion flux has been done in the eikonal approximation. The energy dependent mean free path has been taken from ref.[33].

We have used in our calculations the three parameter Fermi density[34].

$$\rho(r) = \rho_0 \frac{(1 + \frac{wr^2}{c^2})}{1 + exp(\frac{r - C_1}{C_2})} \quad (15)$$

with $C_1 = 2.608 fm$, $C_2 = 0.513 fm$ and $w = -0.051$.

In Fig.2, we have shown the results for $\frac{d\sigma}{dE'_e}$ for $E_\nu = 750 MeV$. The effect of the medium modification of strong interaction properties of the Δ results in an over all reduction of $\frac{d\sigma}{dE'_e}$ by $20-25\%$ in the peak region, shown by the dotted line as compared to the free Δ (solid line). However, only $\approx 80\%$ of these Δ's produce pions (shown by long-dashed line) and the rest produce particle hole excitations. These pions once produced, suffer reabsorption giving a reduction of about $15-20\%$ which has been shown by the dash-dotted line in Fig.2. Similar calculations have been done in the relativistic mean field theory of the nucleus by Kim et al.[28,29]. In this calculation a constant decay width has been used for the Δ resonance. Our results agree qualitatively with these calculations when we neglect the energy dependence of the decay width and its modification in the nuclear medium as discussed in Section-3. As a result of these modifications the calculated value of $\frac{d\sigma}{dE'_e}$ are further reduced and are smaller than the results of Kim et al.[28,29]. A study of pion spectrum in this model will be very useful from the experimental point of view.

4. COHERENT PION PRODUCTION IN NUCLEI

4.1. Differential Cross Sections

The coherent pion production is the process in which the nucleus remains in the ground state. The study of such processes in electromagnetic interactions has shown that these are dominated by Δ-excitation in the energy region of atmospheric and K2K neutrino beams. In this energy region the coherent pion production induced by neutrinos has been studied by Kelkar et al.[35] in a non-relativistic approach and by Kim et al.[28] in a relativistic mean field theory of the nucleus. At very high energies, the coherent pion production has been studied using PCAC and the Adler's theorem for forward production and extrapolating it to non-zero Q^2 [36].

In this section we present the calculation of coherent pion production from nuclei in the local density approximation using a relativistic description of Δ resonance. The corresponding scattering diagram is shown in Fig.3. The cross section correponding to this diagram is given by

$$\sigma = \int \frac{d^3k'}{(2\pi)^3} \int \frac{d^3p}{(2\pi)^3} \frac{1}{2E_\pi} \times \Pi_f \frac{2m_f}{2E_f} \sum \bar{\sum} |T|^2 2\pi \delta(q^0 - p^0) \tag{16}$$

In writing this expression the recoil of the nucleus has been neglected. In a seperate calculation we checked that the recoil of the nucleus gives only a few percent ($< 3-4\%$)correction in the energy range considered here.

In order to calculate σ, the matrix element is calculated using the Feynman diagrams shown in Fig.4 and is given by

$$T = \frac{G_F}{\sqrt{2}} \bar{u}(k') \gamma^\mu (1-\gamma_5) u(k) \times J^\mu F(\mathbf{q} - \mathbf{p}_\pi) \tag{17}$$

where

$$F(\mathbf{q} - \mathbf{p}_\pi) = \int d^3r (a\rho_p(\mathbf{r}) + b\rho_n(\mathbf{r})) e^{i(\mathbf{q}-\mathbf{p}_\pi).\mathbf{r}} \tag{18}$$

and a and b are the numerical factors and depend upon the charge state of pion produced in charge or neutral processes.

J^μ is given by

$$J^\mu = \frac{f_{\pi N \Delta}}{m_\pi} \frac{1}{2} \sum_s \bar{u}^s(p') \left[p_{\pi_\sigma} \Delta^{\sigma\lambda} O_{\lambda\mu} + p_{\pi_\sigma} O^{\sigma\lambda} \Delta_{\lambda\mu} \right] u^s(p) \tag{19}$$

where the first term in the bracket is for the direct diagram and the second term for the crossed diagram as shown in Fig.4.

$\Delta_{\mu\nu}$ is the on mass shell Δ-propagator and is written as

$$\Delta_{\mu\nu} = \frac{\not{P} + M_\Delta}{P^2 - M_\Delta^2 + i\Gamma M_\Delta} \times \left\{ g_{\mu\nu} - \frac{1}{3}\gamma_\mu\gamma_\nu - \frac{2P_\mu P_\nu}{3M_\Delta^2} + \frac{P_\mu\gamma_\nu - \gamma_\mu P_\nu}{3M_\Delta} \right\}, \tag{20}$$

The most general form of $O^{\sigma\lambda}$ effective vertex is given by equation (4 & 5.)

Using these expressions the following form of the double differential cross section for pion production is obtained

$$\frac{d^2\sigma}{d\Omega_\pi dE_\pi} = \frac{1}{8} \frac{1}{(2\pi)^5} \frac{(E_\nu - E_\pi)}{E_\nu} |\mathbf{p}_\pi| \sum |T|^2 \tag{21}$$

where $|T|^2$ is obtained by squaring the terms given in equation(17). Similar expressions are derived for the lepton and/or pion differential spectrum for the process induced by the charged currents.

4.2. Nuclear Effects and the Pion absorption

The nuclear medium effect in the coherent pion production is incorporated by modifying the mass and width of Δ by including the real and imaginary Σ_Δ as described in section-3. The nuclear form factor $F(\mathbf{q} - \mathbf{p}_\pi)$ as it appears in equation (18) describes the pion as plane wave. In order to describe the pion distortion we use an eikonal approximation which has been used successfully in the case of pion photoproduction. In this approximation the nuclear form factor $F(\mathbf{q}-\mathbf{p}_\pi)$ is replaced by a modified $\tilde{F}(\mathbf{q}-\mathbf{p}_\pi)$ given by [7]

$$\tilde{F}(\mathbf{q}-\mathbf{p}_\pi) = \int d^3\mathbf{r}\rho(\mathbf{r})e^{i(\mathbf{q}-\mathbf{p}_\pi).\mathbf{r}} \times$$
$$exp[-i\int_0^\infty \frac{1}{2p_\pi}\prod(\rho(r'))dl] \qquad (22)$$

where $\prod(\rho)$ is the pion self energy as a function of the nuclear density

$$\prod(\rho) = \frac{4}{9}(\frac{f^*}{m_\pi})^2\frac{M^2}{s}\mathbf{p}_\pi{}^2\rho G_{\Delta h}(s,\rho)$$

$$\mathbf{r}' = \mathbf{r} + \frac{\mathbf{p}_\pi}{|\mathbf{p}_\pi|}\mathbf{l}$$

and

$$G_{\Delta h}(s,\rho(\mathbf{r}) = \frac{1}{\sqrt{s}-M_\Delta+\frac{1}{2}i\tilde{\Gamma}(s,\rho(\mathbf{r}))-\Sigma_\Delta(s,\rho(\mathbf{r}))} \qquad (23)$$

It should be noted that we have taken the nonrelativistic expression for $G_{\Delta h}$ to describe the pion distortion. We take $\rho(r)$ to be the density of the nucleus.

4.3. RESULTS AND DISCUSSION

In Figs. 5 and 6, we present the results for $\frac{d^2\sigma}{d\Omega_\pi dE_\pi}$ vs E_π at $\theta_{\pi q}=0$ and $\frac{d^2\sigma}{d\Omega_\pi dE_\pi}$ vs $\theta_{\pi q}$ at $E_\pi = 300MeV$ as calulated from equation(21) for $E_\nu = 1GeV$. The modification of Δ properties in the medium through M_Δ and $\tilde{\Gamma}_\Delta$ as discussed in the text leads to a strong reduction in $\frac{d^2\sigma}{d\Omega_\pi dE_\pi}$ (not shown in the figure). There is a further reduction due to pion absorption as calculated in the eikonal approximation through the modification of $\tilde{F}(q-p_\pi)$ (see equation 22). In Figs.7 and 8, we present the results for the angular distribution $\frac{d\sigma}{dcos\theta_{\pi q}}$ and the momentum distribution $\frac{d\sigma}{dp_\pi}$. The strong reduction due to nuclear medium effects and pion absorption in these distributions is quite large.

The results presented in Figs.5-8, are in quantitative agreement with the results of Kelkar et al[35] done for the coherent pion induced charged current lepton production. We find that the relativistic effects leads to a very small ($<5\%$) increase of the cross sections as compared to the nonrelativistic case. The vector contribution which is neglectd in the nonrelativistic calculation found to give very small ($<2-3\%$) contribution in the relativistic description.

REFERENCES

1. D.Drechsel,L.Tiator,S.S.kamalov and S.N.Yang, Nucl. Phys.A660 423(1999); J.M.Laget, Nucl. Phys.A481 765(1988); B.Korfgen, F.Osterfeld and T.Udagawa, Phys.Rev.C50 1637(1994).; J.H.Koch and N.Ohtsuka, Nucl.Phys.A435 765(1985).
2. E.Oset and L.L.Salcedo, Nucl. Phys. A468 631(1987).
3. C.Garcia Recio, E.Oset, L.L.Salcedo, D. Strottman and M.J.Lopez, Nucl. Phys. A526 685(1991).
4. J.Nieves,E.Oset and C.Garcia Recio, Nucl. Phys. A443 570(1985).
5. E.Oset,H.Toki and W.Weise, Phys. Rep.83 282(1982)
6. H.Hirenzaki,J.Nieves,E.Oset and M.J.Vicente Vacas, Phys. Letts. B304 198(1993).
7. R.C.Carrasco,J.Nieves and E.Oset, Nucl.Phys.A565 797(1993).
8. W.Peters,H.Lenske and U.Mosel, Nucl. Phys.A640 89(1998).
9. T.Kitagaki et al., Phys.Rev. D42 1331(1990); ibid 34 (1986)2554.
10. S.J.Barish et al., Phys. Rev. D19 (1979) 2521; G.M.Redecky et al., Phys. Rev.D25 1161(1982).
11. P.Allen et al., Nucl.Phys.B176 269(1979); J.Bell et al., Phys.Rev.Lett.41 1008(1978); W.Lee et al., Phys. Rev.Lett.38 202(1977).
12. C.Mauger, Nucl. Phys.B(Proc.Suppl.)112 146(2002).
13. M.Sakuda, Nucl. Phys.B(Proc.Suppl.)112 109(2002).
14. E.A.Paschos, Nucl. Phys.B(Proc.Suppl.)112 89(2002); E.A.Paschos,L.Pasquali and J.Y.Yu, Nucl.Phys.B588 263(2000); E.A.Paschos and J.Y.Yu, Phys.Rev. D65

Table 1
Coefficients of eq.13 for the interpolation of ImΣ_Δ

	C_Q(MeV)	C_{A2}(MeV)	C_{A3}(MeV)	α	β
a	-5.19	1.06	-13.46	0.382	-0.038
b	15.35	-6.64	46.17	-1.322	0.204
c	2.06	22.66	-20.34	1.466	0.613

033002(2002).
15. D.Rein, L.M.Sehgal, Nucl.Phys. B223 29(1983).
16. S.L.Adler, Ann. Phys. (N.Y.)50 189(1968).
17. C.H.Llewellyn Smith, Phys. Rep.3 261(1971).
18. P.A.Schreiner and F.Von Hippel, Nucl. Phys.B58 333(1973).
19. N.C.Mukhopadhyay et al., Nucl. Phys. A633 481(1998)
20. S.K.Singh, Nucl. Phys.B(Proc.Suppl.)112 77(2002).
21. K.Furuno, Paper presented in this Conference.
22. L.Alvarez Ruso, S.K.Singh and M.J.Vicente Vacas, Phys. Rev. C57 2693(1998).
23. L.Hulthen and M.Sugawara, Handbuch der Physik (Springer Verlag, Berlin, 1957)Vol.39.
24. M.Lacombe et al., Phys. Rev. C21 861(1980), Phys. Letts. B101 139(1981).
25. R.Machleidt et al., Phys. Rep. 1149 1(1989)
26. T.R.Hemmert, B.R.Holstein and N.C.Mukhopadhyay, Phys. Rev. D51 158(1995).
27. G.L.Fogli and G.Nardulli, Nucl. Phys. B160 116(1979); ibid 165 162(1980).
28. H.Kim, S.Schramm and C.J.Horowitz, Phys. Rev. C53 2468(1996).
29. H.Kim, S.Schramm and C.J.Horowitz, Phys. Rev. C53 3131(1996).
30. S.K.Singh and E.Oset, Phys. Rev. C48 1246(1993).
31. S.K.Singh and M.Sajjad Athar, Nucl. Phys.B(Proc.Suppl.)112 215(2002).
32. S.K.Singh, M.J.Vicente Vacas and E.Oset, Phys. Letts. B416 23(1998).
33. E.Oset and D.Strottman, Phys. Rev.C42 2454(1990).
34. C.W. de Jager, H. de Vries and C. de Vries, Atom. Data and Nucl. Data Tables 14 479(1974).
35. N.G.Kelkar, E.Oset and P.Fernandez de Cordoba, Phys. Rev. C55 1964(1997).
36. D.Rein, L.M.Sehgal, Nucl.Phys. B223 29(1983); A.A.Belkov,B.Z.Kopeliovich, Sov.J.Nucl.Phys.46 499(1987).

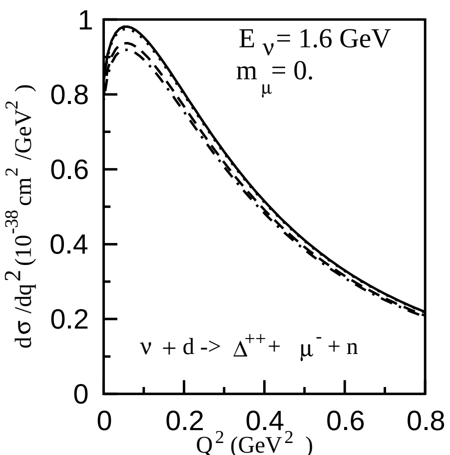

Fig.1. $d\sigma/dq^2 \sim Q^2$. The solid line is without deuteron effects, dotted, long-dashed and dash-dotted include these effects using Hulthen, Bonn and Paris deuteron wave functions.

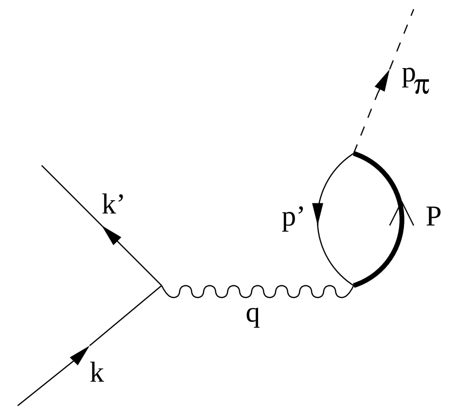

Fig. 3. Feynman diagram for Coherent pion production through delta−hole excitations. k and k' are the incoming and outgoing momenta and q is the momentum transfer.

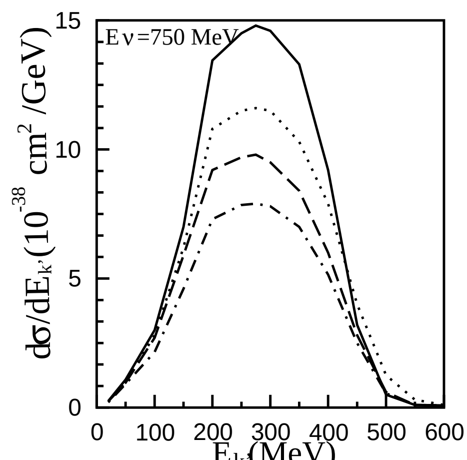

Fig. 2. $d\sigma/dE_{k'} \sim E_{k'}$ for (ν, e^-) reaction on ^{16}O without medium effects (solid) with medium effects (dotted); pion production without absorption (long-dashed) and with absorption (dash-dotted).

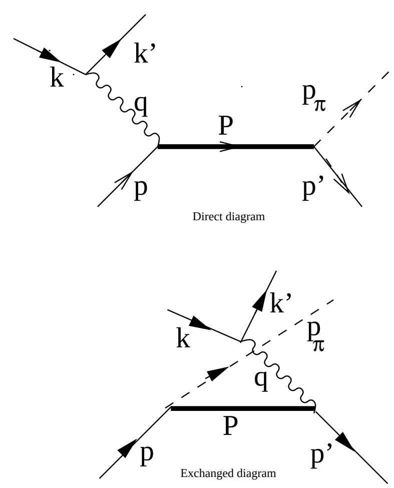

Fig.4. Feynman diagrams considered for the reaction $\nu + N \longrightarrow \nu + N + \pi^0$

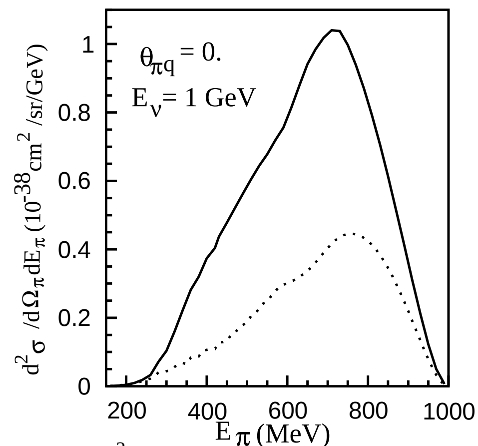

Fig. 5. $d^2\sigma /d\Omega_\pi dE_\pi \sim E_\pi$ .with medium effects , without pion absorption (solid line) and with pion absorption (dotted line).

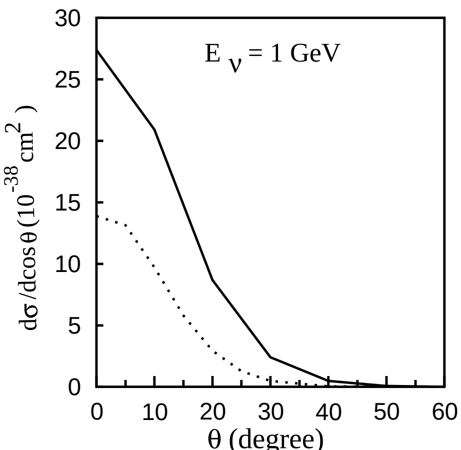

Fig. 7. $d\sigma/d(\cos\theta) \sim \theta$.with medium effects without pion absorption (solid line) and with pion absorption (dotted line).

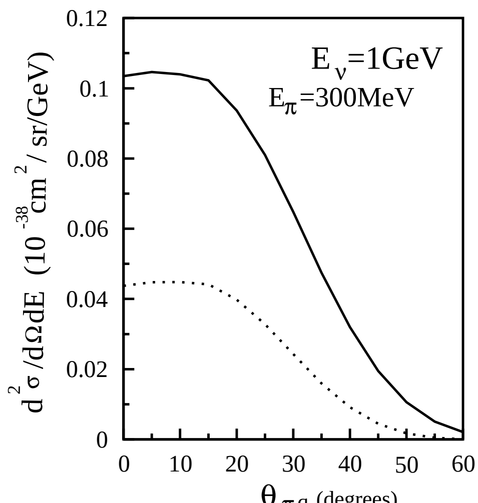

Fig. 6. $d^2\sigma/d\Omega_\pi dE_\pi \sim \theta_{\pi q}$ with medium effects , without pion absorption (solid line) and with pion absorption (dotted line).

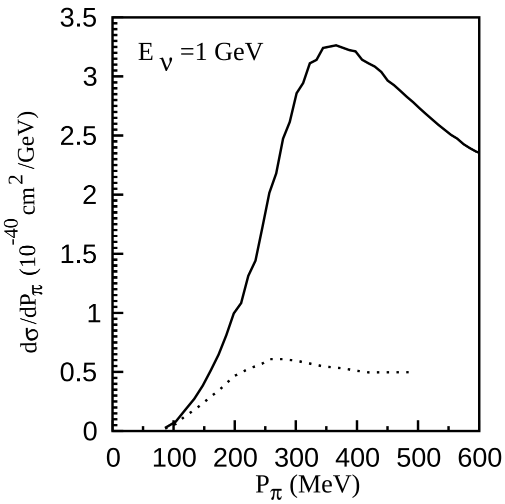

Fig. 8. $d\sigma/dP_\pi \sim P_\pi$ with nuclear effects without pion absorption (solid line) , with pion absorption (dotted line).