Role of nuclear medium in the determination of $\sin^2\theta_W$

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Paschos and Wolfenstein(PW) [1] derived a relationship between cross sections which is known as Paschos-Wolfenstein(PW) relation and is given by

$$R_{PW} = \frac{\sigma(\nu_l\ N \to \nu_l\ X)\ -\ \sigma(\bar{\nu}_l\ N \to \bar{\nu}_l\ X)}{\sigma(\nu_l\ N \to l^-\ X)\ -\ \sigma(\bar{\nu}_l\ N \to l^+\ X)}$$

For an isoscalar target and ignoring the contributions from heavy quark flavors the above ratio R_{PW} is related to the weak mixing angle $sin^2\theta_W$ as

$$R_{PW} = \frac{1}{2}\ -\ \sin^2\theta_W. \tag{1}$$

NuTeV collaboration [2] performed an experiment with neutrino & antineutrino beams using iron target and found $\sin^2\theta_W$ to be inconsistent with the values obtained from a global standard model fits. In their analysis the ratios R^ν(for neutrino) and $R^{\bar{\nu}}$(for antineutrino) defined for neutral current to charged current total cross sections were measured to obtain

$$\begin{aligned} R_{PW} &= \frac{\sigma(\nu_\mu\ N \to \nu_\mu\ X)\ -\ \sigma(\bar{\nu}_\mu\ N \to \bar{\nu}_\mu\ X)}{\sigma(\nu_\mu\ N \to \mu^-\ X)\ -\ \sigma(\bar{\nu}_\mu\ N \to \mu^+\ X)} \\ &= \frac{\frac{\sigma(\nu_\mu\ N\to\nu_\mu\ X)}{\sigma(\nu_\mu\ N\to\mu^-\ X)} - r\ \frac{\sigma(\bar{\nu}_\mu\ N\to\bar{\nu}_\mu\ X)}{\sigma(\bar{\nu}_\mu\ N\to\mu^+\ X)}}{1 - \frac{\sigma(\bar{\nu}_\mu\ N\to\mu^+\ X)}{\sigma(\nu_\mu\ N\to\mu^-\ X)}} \\ &= \frac{R^\nu\ -\ r\ R^{\bar{\nu}}}{1-r} \end{aligned} \tag{2}$$

with $r = \frac{\sigma(\bar{\nu}_\mu\ N\to\mu^+\ X)}{\sigma(\nu_\mu\ N\to\mu^-\ X)} \sim \frac{1}{2}$ [2]. Using R_{PW} from Eq.(2) in Eq.(1), $\sin^2\theta_W$ was determined. NuTeV collaboration [2] made isoscalar correction as ^{56}Fe is a non-isoscalar target. In addition to this correction effects like Fermi motion, binding energy corrections, nuclear shadowing effects and pion and rho cloud contributions are also important. These are effective in the different regions of the Bjorken scaling variable x. These nuclear medium effects modify the charged and neutral current structure functions. In this work we have performed the calculations for neutrino/antineutrino nucleus scattering cross section by taking ^{56}Fe and ^{208}Pb nuclear targets which are presently being used in the various oscillation experiments. We have taken medium modification effects into account to see the effect of nuclear medium on the Paschos-Wolfenstein(PW) relation. The details of the formalism are given in Refs. [3]-[4].

We have studied the effect of nuclear medium in the determination of nuclear structure functions $F_2^A(x,Q^2)$ and $F_3^A(x,Q^2)$ and using these structure functions the differential scattering cross section $\frac{d^2\sigma_{CC,NC}^{\nu(\bar{\nu})A}}{dx_A\ dy_A}$ has been obtained by using the expression

$$\begin{aligned} \frac{d^2\sigma_{CC,NC}^{\nu(\bar{\nu})A}}{dx_A\ dy_A} &= \rho^2\frac{G_F^2 M_A E_\nu}{\pi}\left(\frac{m_W^2}{Q^2+m_W^2}\right)^2 \\ &\left(y_A^2 x_A F_1^{\nu(\bar{\nu})A} + \left\{1 - y_A - \frac{M_A x_A y_A}{2E_\nu}\right\}\right. \\ &\left. F_2^{\nu(\bar{\nu})A} \pm x_A y_A\left\{1-\frac{y_A}{2}\right\}F_3^{\nu(\bar{\nu})A}\right) \end{aligned} \tag{3}$$

where ρ is 1 for charged current reaction and is $\frac{M_W^2}{cos^2\theta_W\ M_Z^2}$ for neutral current reaction. Also for the neutral current reaction M_W is replaced by M_Z. +(-) sign is for $\nu(\bar{\nu})$. We have used Callan-Gross relation $F_2 = 2xF_1$ and the expressions for $F_2^A(x)$ and $F_3^A(x)$ for non-isoscalar nuclear targets are obtained as [5]:

$$\begin{aligned} F_2^A(x_A,Q^2) &= 2\int d^3r\int\frac{d^3p}{(2\pi)^3}\frac{M}{E(\mathbf{p})}\left[\int_{-\infty}^{\mu_p}dp^0\right. \\ & S_h^p(p^0,\mathbf{p},k_{F,p})F_2^p(x_N,Q^2) + \int_{-\infty}^{\mu_n}dp^0\ S_h^n(p^0,\mathbf{p},k_{F,n}) \\ & \left. F_2^n(x_N,Q^2)\right]\frac{x}{x_N}\left(1+\frac{2x_N p_x^2}{M\nu_N}\right) \end{aligned} \tag{4}$$

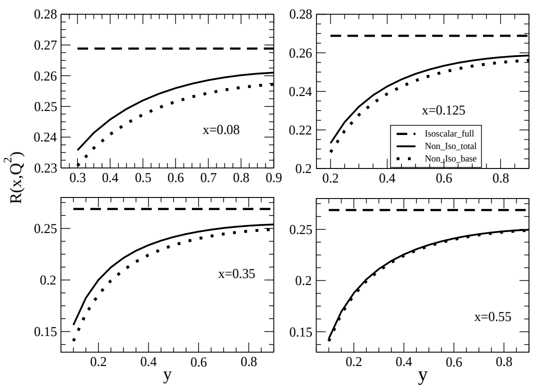

FIG. 1: Paschos and Wolfenstein ratio $R(x,Q^2)=\frac{\frac{d^2\sigma(\nu_\mu \; N\rightarrow\nu_\mu \; X)}{dxdy} - \frac{d^2\sigma(\bar\nu_\mu \; N\rightarrow\bar\nu_\mu \; X)}{dxdy}}{\frac{d^2\sigma(\nu_\mu \; N\rightarrow\mu^- \; X)}{dxdy} - \frac{d^2\sigma(\bar\nu_\mu \; N\rightarrow\mu^+ \; X)}{dxdy}}$ in iron for isoscalar and non-isoscalar cases. Dotted(Solid) line is for base(full) calculation for nonisoscalar case. Dashed line is plotted for isoscalar case.

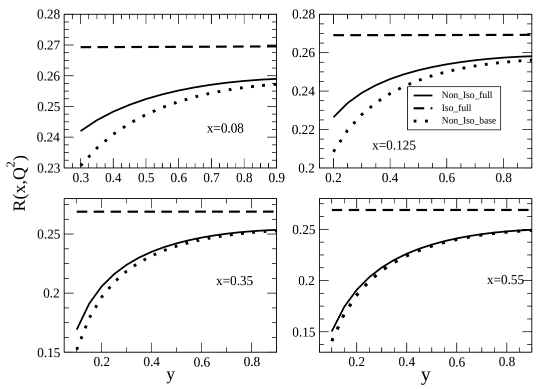

FIG. 2: Paschos and Wolfenstein ratio R(x,Q^2) in lead. Lines has same meaning as in Fig.1

$$F_3^A(x_A,Q^2) = 2\int d^3r \int \frac{d^3p}{(2\pi)^3}\frac{M}{E(\mathbf{p})}\left[\int_{-\infty}^{\mu_p} dp^0 \right.$$
$$S_h^p(p^0,\mathbf{p},k_{F,p})F_3^p(x_N,Q^2) + \int_{-\infty}^{\mu_n} dp^0 \; S_h^n(p^0,\mathbf{p},k_{F,n})$$
$$\left. F_3^n(x_N,Q^2)\right] \frac{p^0\gamma - p_z}{(p^0-p_z\gamma)\gamma} \qquad (5)$$

where S_h^p and S_h^n are the spectral functions for protons and neutrons respectively. $k_{F,p}$ ($k_{F,n}$) is the Fermi momentum for proton(neutron), for details see ref.[6, 7]. $\gamma = \frac{q_z}{q^0} = \left(1+\frac{4M^2x^2}{Q^2}\right)^{1/2}$ and $x_N = \frac{Q^2}{2(p^0q^0-p_zq_z)}$.

$F_{2,3}^N$ are the nucleon structure functions which are determined in terms of parton distribution functions for quarks and antiquarks [8]. Using Eqs.4 and 5 in Eq.3 we obtain the differential scattering cross section in iron and lead for isoscalar and nonisoscalar cases. The results obtained by using Fermi motion and binding energy corrections in Eq.3, we call it as our base results and when pion and rho cloud contributions, shadowing and antishadowing effects are also taken into account we call it the results with full calculations. In Figs.1 and 2, we have presented the ratio(R(x,Q^2)) of neutral current to charged current differential scattering cross section in iron and lead at E_ν=25GeV for some values of x. If we treat iron and lead to be isoscalar then the results for the PW-ratio obtained by using base results or with full calculations are the same. The result with our base calculations and with full calculations have also been shown by treating iron and lead as nonisoscalar targets. We find that the difference between the results of isocalar and nonisoscalar cases is around 10-12% in PW-ratio at low y which becomes smaller (around 3-4%) at mid and high y for all values of x. Detail of the results would be presented in the symposium.

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