Determination of $\sin^2\theta_W$ using $\nu(\bar{\nu})$-Nucleus scattering

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Introduction

NuTeV collaboration has reported the value of $\sin^2\theta_W$ 3σ above the global fit. To resolve this discrepancy, explanations within and outside the standard model of electroweak interactions have been looked for. We study the impact of nuclear effects and nonisoscalarity corrections on the extraction of the weak-mixing angle $\sin^2\theta_W$ using (anti-)neutrino nucleus scattering. The calculations have been performed in a theoretical model using relativistic nuclear spectral functions which incorporate Fermi motion, binding energy and nucleon correlations. We have also included the pion and rho meson cloud contributions calculated from a microscopic model for meson-nucleus self-energies. The details of the model are given in Refs. [1-3].

Paschos and Wolfenstein(PW) demonstrated that for an isoscalar target the ratio of neutral current to charged current cross sections is given by:

$$R_{PW} = \frac{\sigma(\nu_\mu N \to \nu_\mu X) - \sigma(\bar{\nu}_\mu N \to \bar{\nu}_\mu X)}{\sigma(\nu_\mu N \to \mu^- X) - \sigma(\bar{\nu}_\mu N \to \mu^+ X)} = \frac{1}{2} - \sin^2\theta_W$$

This relation is also valid for the differential scattering cross section in isoscalar target.

Formalism

The differential cross section for charged current neutrino (antineutrino) interaction with a nucleus is written as [2]:

$$\frac{d^2\sigma_{CC}^{\nu(\bar{\nu})A}}{dE'\,d\Omega'} = \frac{G_F^2}{(2\pi)^2}\frac{|\vec{k}'|}{|\vec{k}|}\left(\frac{m_W^2}{q^2-m_W^2}\right)^2 L_{\nu,\bar{\nu}}^{\alpha\beta} W_{\alpha\beta}^{\nu(\bar{\nu})A}$$

$$L_{\nu,\bar{\nu}}^{\alpha\beta}(k,k') = k^\alpha k'^\beta + k'^\alpha k^\beta - g^{\alpha\beta}(k\cdot k') \mp i\epsilon^{\alpha\beta\mu\nu}k_\mu k'_\nu$$

In the local-density approximation the nuclear hadronic tensor $W_{\alpha\beta}^{\nu(\text{anti-}\nu)A}$ can be written as a convolution of the nucleonic hadronic tensor with the hole spectral function. For an N≠Z nucleus like ^{56}Fe or ^{208}Pb, we have considered separate distributions of Fermi sea for protons and neutrons:

$$W_{\alpha\beta}^{\nu(\bar{\nu})A} = 2\left\langle \int_{-\infty}^{\mu_p} dp^0\, S_h^p(p^0,\mathbf{p},k_{F,p})\, W_{\alpha\beta}^{\nu(\bar{\nu})p}\right\rangle + \left\langle 2\int_{-\infty}^{\mu_n} dp^0\, S_h^n(p^0,\mathbf{p},k_{F,n})\, W_{\alpha\beta}^{\nu(\bar{\nu})n}\right\rangle,$$

where the factor of 2 is for the two spin degrees of freedom of the nucleons. S_h^p and S_h^n are the two different spectral functions, each one of them normalized to the number of protons or neutrons in the nuclear target and are functions of Fermi momentum of protons and neutrons respectively which are given by $k_{F,p}=(3\pi^2\rho_p)^{1/3}$ and $k_{F,n}=(3\pi^2\rho_n)^{1/3}$ and $\langle\ \rangle = \int d^3r \int \frac{d^3p}{(2\pi)^3}\frac{M}{E(\vec{p})}\cdots\cdots$

PW ratio for nonisoscalar nucleus(R_{NI}^{PW}) in our model may be written in terms of PW ratio for the isoscalar nucleus(R_I^{PW}) and the correction due to nonisoscalarity(δR_{NI}):

$$R_{NI}^{PW} = R_I^{PW} + \delta R = \frac{1}{2} - \sin^2\theta_W + \delta R_{NI}$$

where $\delta R_{NI} = \delta R_1 + \delta R_2 + \delta R_3$

$$\delta R_1 = \frac{1}{D}\frac{1}{3}\sin^2\theta_w \times \left\langle \frac{\delta}{2V}\frac{\pi^2}{k_F^2}\int_{-\infty}^{\mu} dp^0 \frac{\partial S_h(p^0,\vec{p},k)}{\partial k}\Big|_{k=k_F}\frac{2}{\gamma}\frac{p_0\gamma - p_z}{p_0 - p_z\gamma}(u_v - d_v)\right\rangle$$

$$\delta R_2 = -\left(\frac{1}{2} - \sin^2\theta_W\right)\frac{y}{2-y}\frac{1}{D}\left\langle \frac{\delta}{2V}\frac{\pi^2}{k_F^2}\int_{-\infty}^{\mu} dp^0 \frac{\partial S_h(p^0,\vec{p},k)}{\partial k}\Big|_{k=k_F}\left[2 + \frac{p_x^2}{(p\cdot q)}4x_N\right](u_v - d_v)\right\rangle$$

$$\delta R_3 = -\left(\frac{1}{2} - \sin^2\theta_W\right)\frac{1 - y - \frac{Mxy}{2E_\nu}}{xy\left(1-\frac{y}{2}\right)}\frac{1}{D}\left\langle \frac{\delta}{2V}\frac{\pi^2}{k_F^2}\int_{-\infty}^{\mu} dp^0 \frac{\partial S_h(p^0,\vec{p},k)}{\partial k}\Big|_{k=k_F} G\, x_N\,(u_v - d_v)\right\rangle$$

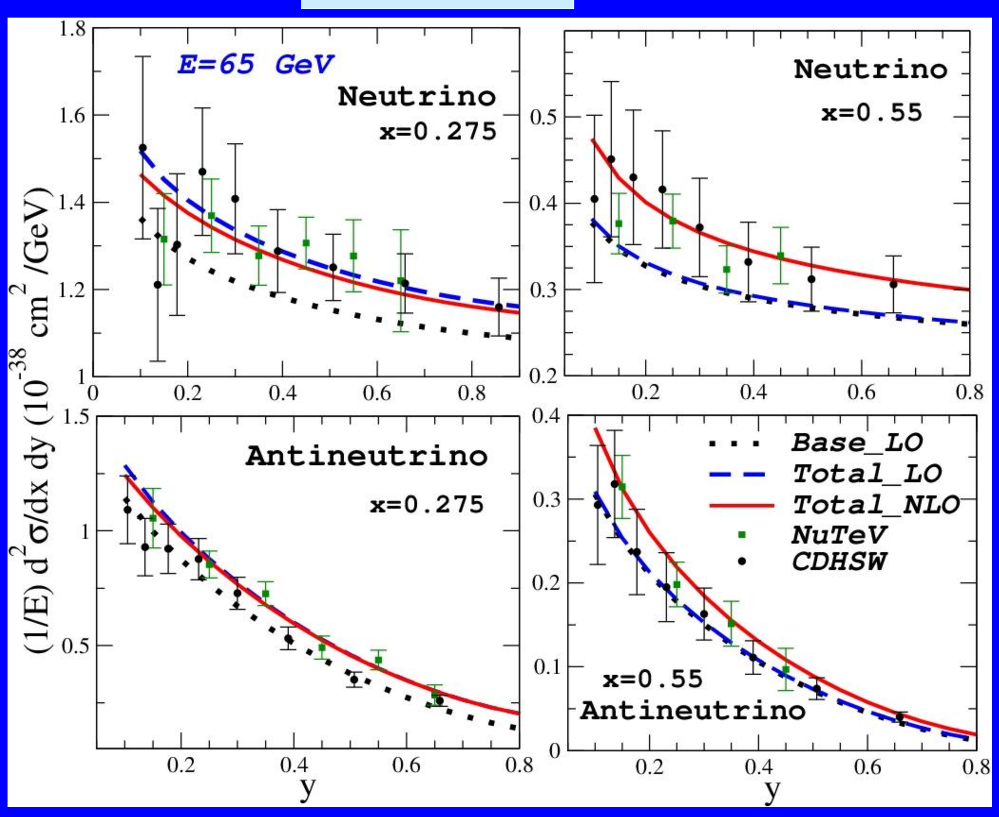
$\delta/V=(N-Z)/V=\rho_n(r)-\rho_p(r)$

$$G(p^0,\vec{p}) \equiv \frac{q^0\left[q^2(\vec{p}^2 + 2(p^0)^2 - p_z^2) - 2(q^0)^2\left((p^0)^2 + p_z^2\right) + 4p^0q^0p_z\sqrt{(q^0)^2 - q^2}\right]}{2M\left(q^2 - (q^0)^2\right)\cdot(p\cdot q)}$$

$$D = \left\langle \int_{-\infty}^{\mu} dp^0\, S_h(p^0,\vec{p},k)\,\frac{2}{\gamma}\frac{p_0\gamma - p_z}{p_0 - p_z\gamma}(u_v + d_v)\right\rangle$$

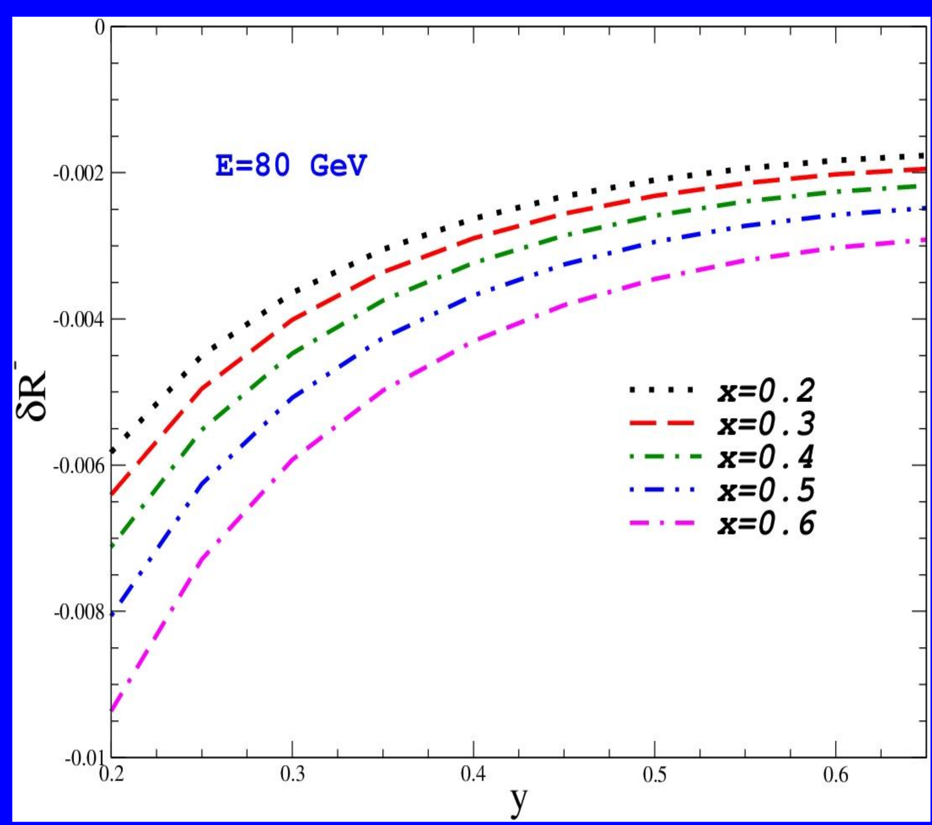
Results and Discussion

FIGURE 1



In Fig. 1 we have presented the results for anti(neutrino) induced differential scattering cross section for different values of x at E= 65 GeV at LO and NLO in iron. The numerical results have been compared with NuTeV and CDHSW data. We observe that results are in better agreement at NLO.

FIGURE 2



To see the effect of non-isoscalarity in the iron target, we have plotted δR^- vs y for different values of x at E= 80 GeV in Fig. 2 We find that the effect of non-isoscalarity is large at low y and high x which decreases with the increase in the value of y. This effect is smaller at low values of x.

FIGURE 3

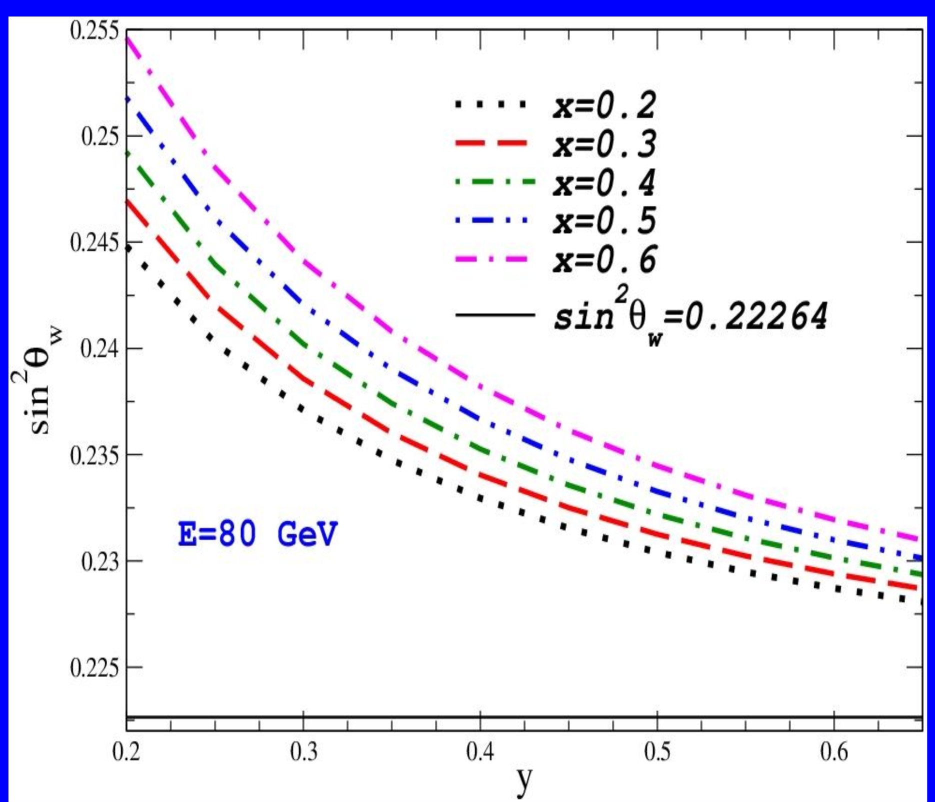
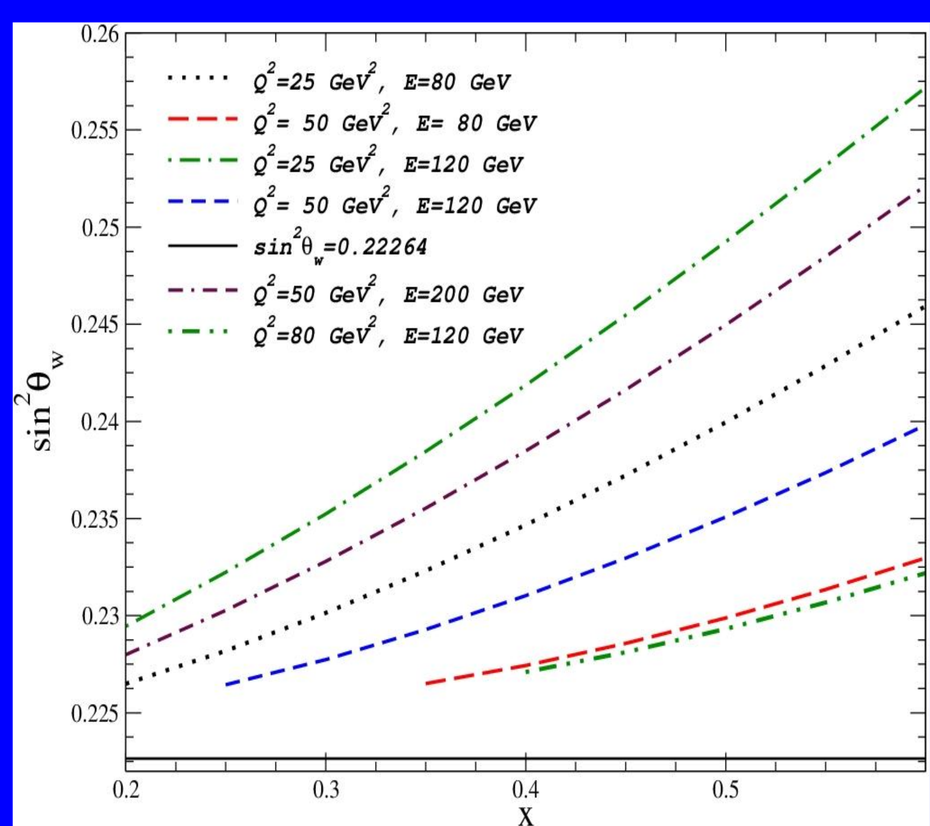


Fig. 3 is for $\sin^2\theta_W$ corrected for isoscalar target. We find that due to medium effects $\sin^2\theta_W$ is different from the global fit and this difference is 6-7% when evaluated for low value of y at x=0.2 which decreases to 1% at high values of y. This change is 8-9% when calculated for low y at x=0.6, which reduces to 2% at high values of y.

FIGURE 4



In Fig. 4 we have presented the dependence of $\sin^2\theta_W$ on E and Q^2. We observe that at low x for E=80 GeV and Q^2=25 GeV^2, $\sin^2\theta_W$ is almost close to the standard value. The value of $\sin^2\theta_W$ changes significantly with the change in E , Q^2 and x.

Conclusions

PW ratio has been studied using differential scattering cross section **in <u>iron at LO</u>** treating it to be isoscalar as well as nonisoscalar nuclear target.
Non-isoscalar corrections in iron is important for calculating the PW ratio.
There is a strong dependence on nuclear medium effects as well as non-isoscalarity corrections in the different regions of x and Q^2.
Extraction of $\sin^2\theta_w$ also depends upon the ν/anti-ν energies when evaluated for a given x and Q^2.

References

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2. H. Haider, I. Ruiz Simo, M. Sajjad Athar and M. J. Vicente Vacas, Phys. Rev. C 84 054610 (2011).
3. H. Haider, I. Ruiz Simo and M. Sajjad Athar, Phys. Rev. C 85 055201 (2012).