$\nu_\mu(\bar{\nu}_\mu)-{}^{208}$Pb deep inelastic scattering

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In the present work, we study nuclear medium effects on the weak structure functions $F_2(x,Q^2)$ and $F_3(x,Q^2)$ in lead in the deep inelastic reactions induced by (anti)neutrino, treating lead to be a non-isoscalar nuclear target. Our study has been performed using a relativistic nucleon spectral function, used to describe the momentum distribution of nucleons in the nucleus and we define everything within a field-theoretical approach where nucleon propagators are written in terms of this spectral function. The spectral function has been calculated using the Lehmann's representation for the relativistic nucleon propagator and nuclear many body theory is used for calculating it for an interacting Fermi sea of nuclear matter. A local-density approximation is then applied to translate these results to finite nuclei. We have assumed the Callan-Gross relationship for the nuclear structure functions ${F_1}^A(x,Q^2)$ and ${F_2}^A(x,Q^2)$. The contributions of the pion and rho meson clouds are taken into account in a many-body field-theoretical approach. We have taken into account the target mass correction (TMC), which has a significant effect at low Q^2, and at moderate and high Bjorken x. We have also taken into account the shadowing effect, which is important at low Q^2 and low x, and which modulates the contribution of pion and rho cloud contributions. The details are given in Refs. [1, 2]. The expressions for $F_2^A(x)$ and $F_3^A(x)$ are given by [1]:

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

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

where

$$\gamma = \frac{q_z}{q^0} = \left(1+\frac{4M^2x^2}{Q^2}\right)^{1/2}, x_N = \frac{Q^2}{2(p^0q^0-p_zq_z)}.$$

Here $F_{2,3}^p$ and $F_{2,3}^n$ are the dimensionless structure functions for the free proton and the free neutron respectively. 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 the Fermi momentum of the protons and the neutrons and which are given by $k_{F,p}=(3\pi^2\rho_p)^{1/3}$ and $k_{F,n}=(3\pi^2\rho_n)^{1/3}$ respectively. For the proton and the neutron densities in lead, we have used two-parameter Fermi density distribution.

The differential cross section in terms of the nuclear structure functions $F_2^A(x)$ and $F_3^Ax)$, is given by:

$$\frac{d^2\sigma_{CC}^{\nu(\bar{\nu})A}}{dx_A\, dy_A} = \frac{G_F^2 M_A E_\nu}{\pi}\left(\frac{m_W^2}{Q^2+m_W^2}\right)^2\left[y_A^2 x_A F_1^{\nu(\bar{\nu})A}\right.$$
$$+ \left(1-y_A-\frac{M_A x_A y_A}{2E_\nu}\right)F_2^{\nu(\bar{\nu})A}$$
$$\pm \left. x_A y_A\left(1-\frac{y_A}{2}\right)F_3^{\nu(\bar{\nu})A}\right] \qquad (3)$$

where

$$Q^2=-q^2;\quad x_A=\frac{Q^2}{2P_A\cdot q};\quad \nu_A=\frac{P_A\cdot q}{M_A};\quad y_A=\frac{P_A\cdot q}{P_A\cdot k}$$

where P_A is the momentum of the nucleus A and $q^2=(k-k')^2$ is the square of the four-momentum transfer. x_A is the natural Bjorken variable in the nucleus and $x_A \in$

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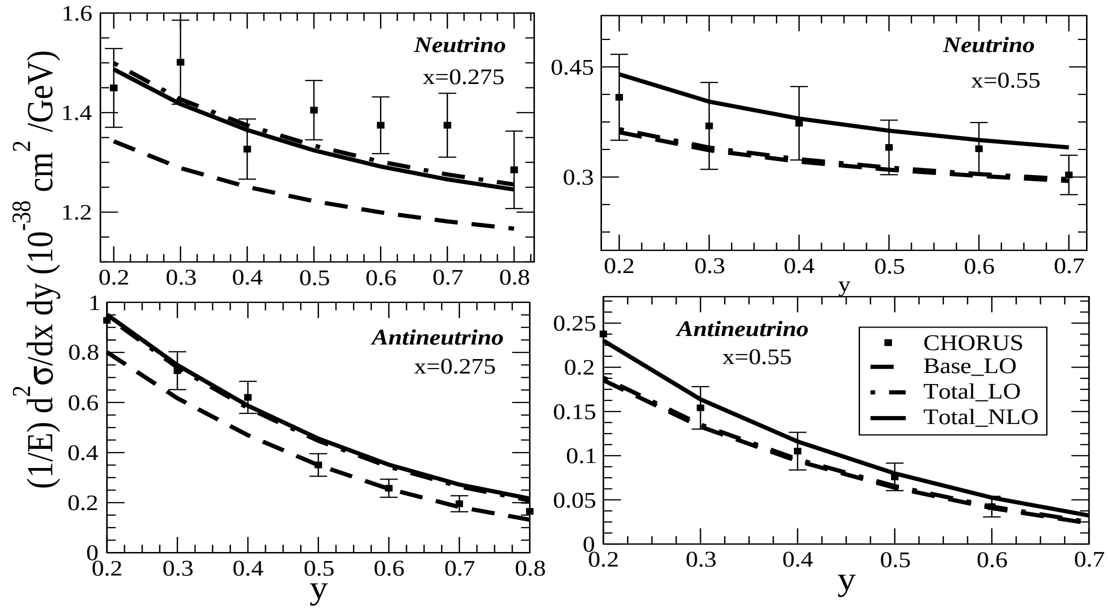

FIG. 1: $\frac{1}{E}\frac{d^2\sigma}{dxdy}$ vs y at different x for $\nu(\bar{\nu}_\mu)$-induced (E_{ν_μ} = 70 GeV) reaction in ^{208}Pb.

$[0, 1]$; y_A is the inelasticity. The variables x_A and y_A are related to the nucleonic ones via:

$$x_A = \frac{x}{A}; \quad \text{where} \quad x = \frac{Q^2}{2Mq^0} \quad \text{and} \quad y_A = \frac{q^0}{E_\nu} = y$$

where x is the Bjorken variable for neutrino-nucleon interaction expressed in the rest frame of the nucleon. We can see that $x \in [0, A]$, though for $x > 1$ the nuclear structure functions are negligible. The variable y_A varies between the following limits:

$$0 \leq y_A \leq \frac{1}{1 + \frac{M_A x_A}{2E_\nu}} \approx \frac{1}{1 + \frac{Mx}{2E_\nu}},$$

therefore, for sufficiently high neutrino energy we have $0 \leq y_A \leq 1$.

In Fig.1, we show our results for $\frac{1}{E}\frac{d^2\sigma}{dxdy}$ in ^{208}Pb at E_{ν_μ}=70 GeV for $\nu(\bar{\nu})$ induced processes. The calculations for the double differential cross sections have been performed for $Q^2 > 1$ GeV^2. While doing the numerical calculations first we obtain results by including Fermi motion, Pauli blocking and target mass corrections(TMC) and call it our base(Base) result. Then we include pion and rho cloud contributions in F_2^A and shadowing corrections in F_2^A and F_3^A, and this we call as full calculation (Total). These results are presented for our base and full calculations at LO and the full calculation at NLO. We find that the results improve (in comparison to the experimental CHORUS data) when we add the contribution of mesonic degrees of freedom to the base calculation and even more when we perform the calculation at NLO. Thus we find that the effect of nuclear medium is important in the studied regions of x and Q^2. The present study of nuclear medium effects would be a good test when data from MINERνA and the other planned experiments become available.

References

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