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Evaluation of unpolarized neutron structure function and ratio of F_2^n / F_2^p by Thermodynamical Bag Model

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Abstract:

We evaluate the unpolarized neutron structure function and the ratio F_2^n / F_2^p in the kinematic region $0.2 < x < 0.8$ at $Q^2 > 1$ GeV^2 using Thermodynamical Bag Model (TBM). The evaluated results are compared with CLASS experimental data. It is found that evaluated results show similar trend as that of experimental data in the entire kinematic range of interest.

Keywords: DIS, Nucleon structure function, TBM

Introduction:

The measurement of structure function in high energy lepton nucleon scattering plays unavoidable in the modern history of nuclear and particle physics. Quantum Chromo Dynamics (QCD) is most acceptable theory for describing the strong interaction [1]. In earlier, the structure function is demonstrated from deep inelastic scattering (DIS) experiments at SLAC, the quarks are constituents of proton and neutron [2] and is interpreted in terms of quark and gluon momentum distributions which gives the internal picture of the nucleon [3-4]. In the past four decades, the DIS experimental programs are done by SLAC, CERN and DESY. These experiment results give the investigation of parton distribution functions (PDFs) over a wide kinematic range x region and Q^2. Moreover, other experiments for the purpose of probing the structure function of nucleon were demonstrated by Drell-yan, W-boson and jet production at Fermi lab [5-6]. The structure functions reflect the QCD features, asymptotic freedom at short distance and quark confinement at long distance scale. It provides the strong constraints on the quark and gluon momentum distribution functions of the nucleon.
Baillie [7] presented the first measurement of unpolarized neutron structure function using the spectator tagging technique gives high precision data from which we studied the information about the neutron structure function. Barik[8] using independent

quark model, the unpolarized structure function of nucleon with use of certain assumption in the Bjorken limit. Amaudruz [9] presented the Gottfried sum rule with use of ratio F_2^n / F_2^p which yields simple quark-parton model prediction of 1/3. In parton picture, unpolarized structure function ratio of neutron to proton is high sensitive for the ratio of d/u quark distribution particularly in the high x region. In earlier many experiments are done on F_2^n / F_2^p at SLAC[10, 11] and CERN[12]. A better knowledge of neutron structure function in the resonance region is needed to help untravel the full region contributions to the cross-section as well as to provide the critical input for interpreting inclusive polarization measurements. In our present work, the neutron structure function Q^2=4GeV^2 and the ratio F_2^n / F_2^p in the region of $0.2 < x < 0.8$ at $Q^2 > 1$ GeV^2. are evaluated and the results are compared with CLASS[13] experiment.

Thermodynamical Bag Model

In TBM, the excited nucleon is described as a statistical thermodynamical bag. Consdering the nucleon [14-17] to be Infinite Momentum Frame (IMF), the quarks and gluons are treated as fermions and bosons respectively. The equations of state are obtained as,

$$W^2 = M^2 + 2M\nu - Q^2 \tag{1}$$

$$6(n_u - n_{\bar{u}}) = \mu_u T^2 + \frac{\mu_u^3}{\pi^2} \tag{2}$$

$$6(n_d - n_{\bar{d}}) = \mu_d T^2 + \frac{\mu_d^3}{\pi^2} \tag{3}$$

At any temperature using equations (2) and (3), we obtain the chemical potentials of up and down quarks. Here W is invariant mass of the nucleon, M is mass of the nucleon, ν is the energy transfer, μ_u and μ_d are the chemical potentials of up and down quarks respectively. The energy density of the system is equal to the sum of quarks, antiquarks and gluons are given by

$$\varepsilon(T) = 6(\varepsilon_u + \varepsilon_{\bar{u}}) + 6(\varepsilon_d + \varepsilon_{\bar{d}}) + 16\varepsilon_g \tag{4}$$

Where

$$\varepsilon_u + \varepsilon_{\bar{u}} = \left(\frac{1}{8\pi^2}\right)\mu_u^4 + \left(\frac{1}{4}\right)\mu_u^2 T^2 + \left(\frac{7\pi^2}{120}\right)T^4 \tag{5}$$

$$\varepsilon_d + \varepsilon_{\bar{d}} = \left(\frac{1}{8\pi^2}\right)\mu_d^4 + \left(\frac{1}{4}\right)\mu_d^2 T^2 + \left(\frac{7\pi^2}{120}\right)T^4 \tag{6}$$

$$\varepsilon_g = \frac{\pi^2 T^4}{30} \tag{7}$$

The statistical Parton distribution functions (PDFs) are expressed as,

$$q_j(x,Q^2) = \left(\frac{6V}{4\pi^2}\right)M^2 Tx \ln\left[1 + \exp\left\{\left(\frac{1}{T}\right)\left(\mu_j - \frac{Mx}{2}\right)\right\}\right] \tag{8}$$

$$\bar{q}_j(x,Q^2) = \left(\frac{6V}{4\pi^2}\right) M^2 Tx \ln\left[1+\exp\left\{\left(\frac{1}{T}\right)\left(-\mu_j - \frac{Mx}{2}\right)\right\}\right] \quad (9)$$

Where μ_j is the chemical potential of quark with flavor j=u or d. In order to relate PDFs for Λ_{QCD}=250 MeV, quark and antiquark distributions are modified by including QCD correction,

$$q_j'(x,Q^2) = q_j(x,Q^2)\left(1-\frac{\alpha_s(Q^2)}{2\pi}\right) \quad (10)$$

$$\bar{q}_j'(x,Q^2) = \bar{q}_j(x,Q^2)\left(1-\frac{\alpha_s(Q^2)}{2\pi}\right) \quad (11)$$

The strong coupling constants (α_s) for different Q^2 is evaluated using Next to Leading Order (NLO) solution,

$$\alpha_s(Q^2) = \frac{4\pi}{\beta_0 \ln(Q^2/\Lambda^2)}\left[1-\frac{\beta_1 \ln(\ln(Q^2/\Lambda^2)}{\beta_0^2 \ln(Q^2/\Lambda^2)}\right] \quad (12)$$

Where $\beta_0 = 11-(2n_f/3)$ and $\beta_1 = 102-(38n_f/3)$

Unpolarized structure function:

In the Quark Parton Model (QPM), the nucleon is composed of three quarks. From the quantum number of these quarks, all the quantum number of the nucleon should be reproduced. In QPM, these quarks are called valence quarks. The structure functions F_1 and F_2 related by Callon-Gross equation[18] is given by

$$2xF_1(x) = F_2(x) = \sum_i e_i^2 x q_i(x) \quad (13)$$

Here e_i is the electric charge of a quark of flavor i. q_i is proportional to the density probability of binding a parton of a flavouri with a function x of the nucleon momentum. The unpolarized structure function of proton and neutron are calculated with use of quark distribution functions and given by

$$F_2^p(x) = x\left\{\frac{4}{9}[u(x)+\bar{u}(x)]+\frac{1}{9}[d(x)+\bar{d}(x)]\right\} \quad (14)$$

$$F_2^n(x) = x\left\{\frac{1}{9}[u(x)+\bar{u}(x)]+\frac{4}{9}[d(x)+\bar{d}(x)]\right\} \quad (15)$$

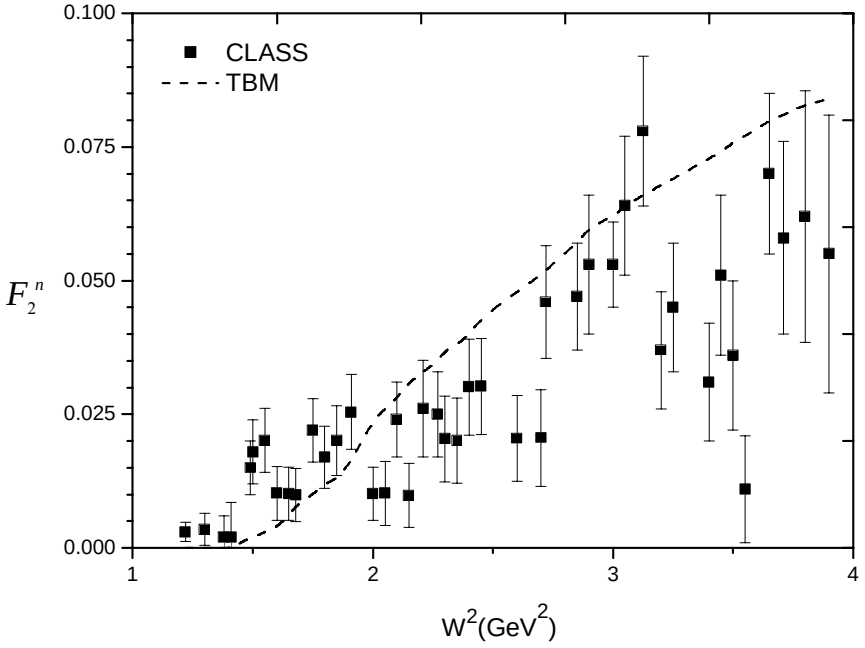

Figure I: The structure function F_2^n as a function of $W^2(GeV^2)$ and Q^2=4 GeV^2. TBM (dashed line) results are compared with CLASS data (solid squares)

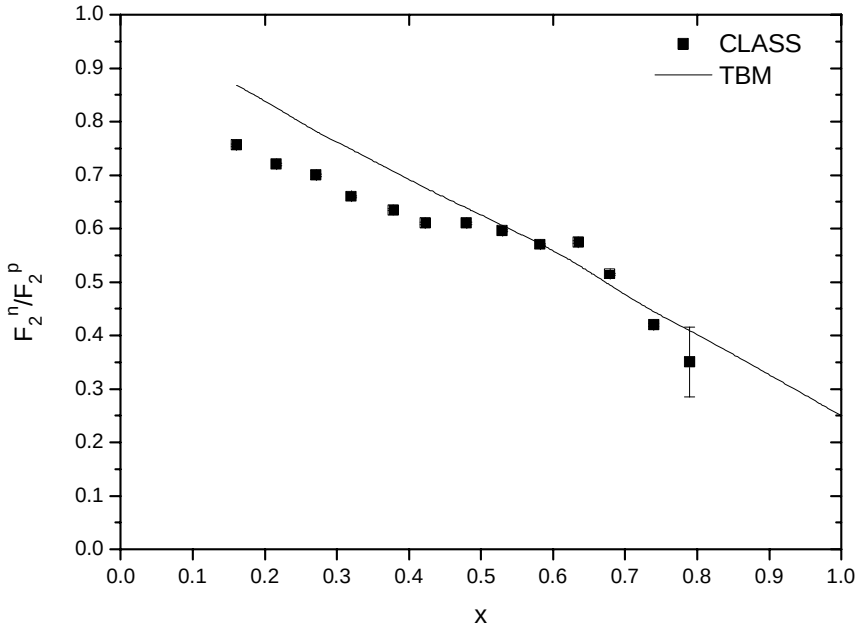

Figure II: The ratio of neutron to proton structure function at $Q^2 > 1$ GeV^2 TBM (solid line) results are compared with CLASS data (solid squares).

Results and discussions:

In the present work, the evaluated theoretical neutron structure function F_2^n and ratio F_2^n / F_2^p using thermodynamical bag model are compared with CLASS experimental results[13]. The valence quarks distribution inside a nucleon can be studied with knowledge of up and down quark distributions and corresponding their antiquarks and sea quarks. The up quark distribution is relatively well constrained by measurements of the proton structure function F_2^p in contrast the down quark distribution is poorly determined due to lack of comparable on the neutron structure function F_2^n. The evaluated neutron structure function is shown in figure I. In Figure II, the ratio F_2^n / F_2^p deviation with experimental data because of the proton structure function decreases more than the neutron structure at low x region with Q^2 whereas it increases at high x region[19]. The up quark and down quark and their antiquark distribution functions evaluated using TBM reveal the fact that at low x region the momentum distribution for neutron and proton being nearly equal and there is a greater probability of the nucleon spin parallel to the target [20]. The evaluated ratio of neutron to proton structure function is 1/4 as $x \rightarrow 1$ which is consistent with the accepted value and inconsistent with the value 3/7 from perturbative QCD. The evaluation of unpolarized structure function of neutron and theratio of neutron to proton structure function are good agreement with CLASS experimental resultsin whole measured region.

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