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Spin Dependent Structure Function and Asymmetry of Neutron at Q² >1 Gev² Using Thermodynamical Bag Model

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ABSTRACT

Spin dependent structure function and asymmetry of neutron are evaluated at $W > 1GeV$ and $Q^2 > 1GeV^2$ using Thermodynamical Bag Model (TBM). The model in which incorporated QCD corrections for the evaluation of quark distributions. Evaluated xg_1^n increases with increasing x in negative values and A_1^n decreases with increasing W. The evaluated results are good agreement with CLAS experimental data.
Key words : DIS, Spin Dependent Structure Function, Asymmetry, TBM

I. INTRODUCTION

Towards the understanding of the nucleon spin, its vital that constituent quarks and gluon is a long-standing mission. After the discovery of the spin puzzle by EMC[1], Deep inelastic electron and muon scattering(DIS), Semi-Inclusive Deep Inelastic Scattering(SIDIS), Deeply Virtual Compton Scattering(DVCS) and proton-proton collisions have been used to examine the internal structure of the nucleon and inclusive polarized lepton scattering remains the criteria for the study of longitudinal nucleon spin.

In DIS, nucleon structure is suitably parameterized by the unpolarized structure functions and polarized structure functions depend upon Q² is the negative square of the four momentum transferred in the scattering interaction and x is the Bjorken variable which leading order in the infinite momentum frame equal to the fraction of the nucleon momentum carried by the struck quark. The total nucleon spin can be written by the sum of quark and gluon spins and their orbital angular momentum given by

$$\frac{1}{2}\Delta\sum + \Delta G + L_q + L_g = \frac{1}{2}$$

Where $\Delta\sum$ and ΔG are the quark and gluon helicities, L_q and L_g are quark and gluon orbital angular momentum.

Various theoretical model approaches foretell that $A_1^n = 1$ as $x \to 1$. In relativistic quark model calculations, generally assume that SU(6) symmetry is broken and final results the struck quark carries the nucleon spin[2]. In leading order pQCD, the valence quark orbital angular momentum assumed to be insignificant at high x and Q², thus leading hadron helicity conservation[3]. Our former works[4], $A_1^n = 1$ as $x \to 1$ and A_1^n has zero crossing mere at x = 0.5 with target mass correction. In the current work, we evaluate the Q² dependence of neutron spin dependent structure function and asymmetry using TBM and theoretical results are compared with CLAS experimental data[5].

Thermodynamical Bag Model:

Thermodynamical Bag Model (TBM) is altered form of MIT bag model [6-10] considering the nucleon to be in the Infinite Momentum Frame (IMF), where the quarks and gluons are treated as fermions and bosons respectively. The invariant mass(W) of the final hadron and the equation of states are

$$[\varepsilon(T)V + BV]^2 = W^2 + 2M\nu - Q^2 \qquad (1)$$

$$6(n_\mu - n_{\bar{\mu}}) = \frac{2}{V} = \mu_u T^2 + \frac{\mu_u^3}{\pi^2} \qquad (2)$$

$$6(n_d - n_{\bar{d}}) = \frac{1}{V} = \mu_d T^2 + \frac{\mu_d^3}{\pi^2} \qquad (3)$$

Where ε(T) is the energy density of the system at a temperature T, V is the volume of bag, B is the bag constant, W is the invariant mass of excited nucleon at T, ν is the energy transfer, Q^2 is square of four momentum transfer, M is the mass of the nucleon at ground state, $6(n_u - n_{\bar{u}})$ is number density of up quark, $6(n_d - n_{\bar{d}})$ is the number density of down quark, μ_u is the chemical potential of up quark and μ_d is the chemical potential of down quark.

The total energy density ε(T) of the bag can be written by the sum of energy densities of up quark, down quark and gluon is given by

$$\varepsilon(T) = d_q(\varepsilon_u + \varepsilon_{\bar{u}}) + d_q(\varepsilon_d + \varepsilon_{\bar{d}}) + d_g\varepsilon_g \qquad (4)$$

Where dq= 6 and dg=16 denotes the degeneracy of quarks and gluon orderly.

The statistical Parton Distribution Functions are revealed as

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

(5)

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

(6)

μ_i is the chemical potential of quark with the flavour 'i'. Here 'i' denotes either u or d quark. In order to relate the PDF's with Λ_{QCD}, which is quark gluon coupling parameter, we introduce the strong quark gluon coupling constant. The experimental fit could be made by considering only with the QCD corrections. The quark and anti-quark distributions are altered along with QCD parameters as,

$$q_i'(x,Q^2) = q_i(x,Q^2)\left(1 - \frac{\alpha_s(Q^2)}{2\pi}\right) \qquad (7)$$

$$\bar{q}_i'(x,Q^2) = \bar{q}_i(x,Q^2)\left(1 - \frac{\alpha_s(Q^2)}{2\pi}\right) \qquad (8)$$

The strong running coupling constant (α_s) for various Q^2 is evaluated using the Next to Leading Order (NLO) solution.

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

(9)

Where β_0 = 11-(2 N_f /3) and β_1 = 102-(38 N_f /3).

Theoretical evaluation of neutron asymmetry:

The structure function F_1 and F_2 are related by Callon-Gross relation

$$2xF_1(x) = F_2(x) = \sum_i e_i^2 x q_i(x) \qquad (10)$$

In above relation, structure functions F_1 and F_2 are depend only on x. This means that the lepton scatters on particles which do not involve any scale i.e. on point-like particles. Scattering discovered at SLAC [11] was the experimental validation for the parton model as the structure function does not depend on Q^2. The unpolarized structure function of proton and neutron are evaluated with the inclusion of up and down anti-quarks,

$$F_2^p = x\left[\frac{4}{9}(u'(x) + \bar{u}'(x)) + \frac{1}{9}(d'(x) + \bar{d}'(x))\right] (11)$$

$$F_2^n = x\left[\frac{4}{9}(d'(x) + \bar{d}'(x)) + \frac{1}{9}(u'(x) + \bar{u}'(x))\right] (12)$$

The spin structure function $g_1(x)$ is interpreted as the difference between two probabilities $q_i^{\uparrow}(x)$ and $q_i^{\downarrow}(x)$ averaged over the quark flavor charges.

$$g_1(x) = \frac{1}{2}\sum_i e_i^2 \Delta q_i(x)$$

Where $\Delta q_i(x)$ = $\left[q_i^{\uparrow} + \bar{q}_i^{\uparrow}\right]$ - $\left[q_i^{\downarrow} + \bar{q}_i^{\downarrow}\right]$. It measures the electric charge weighted difference between quarks with spins parallel and antiparallel to the nucleon spin. Hence spin dependent structure function of proton and neutron are given by

$$g_1^p = 0.5\left[\frac{4}{9}\Delta u'(x) + \frac{1}{9}\Delta d'(x)\right] \qquad (13)$$

$$g_1^n = 0.5\left[\frac{4}{9}\Delta d'(x) + \frac{1}{9}\Delta u'(x)\right] \qquad (14)$$

Where $\Delta u'(x), \Delta d'(x)$ are the spin distribution function of up and down quark with anti-quarks given by

$$\Delta u'(x) = \left[(u'(x) + \bar{u}'(x)) - \frac{2}{3}(d'(x) + \bar{d}'(x))\right]\cos 2\theta \qquad (15)$$

$$\Delta d'(x) = \left[-\frac{1}{3}(d'(x) + \bar{d}'(x))\right]\cos 2\theta \qquad (16)$$

Where

$$\cos 2\theta(x) = \frac{1}{1 + \left(\frac{H_0}{\sqrt{x}}(1-x)^2\right)}$$

is known as the spin dilution factor[12]. Spin dilution factor is not obtained from first principle, so the same is not adjusted to satisfy the Bjorken sum rule which is the basic guiding principle of QCD. From the above equation, valence quark distribution could be determined very clearly. Here H_0 is a free parameter chosen 0.075 to satisfy the Bjorken sum rule.

Neutron asymmetry is expressed by the ratio between spin dependent structure function and unpolarized structure function of neutron. Since g_1 and F_1 are evaluated at same Q^2 in leading order QCD. A_1 is expected to vary slowly with Q^2.

$$A_1^n(x, Q^2) = \frac{g_1^n(x, Q^2)}{F_1^n(x, Q^2)} \qquad (17)$$

II. RESULTS AND DISCUSSION

The theoretical results obtained from the study are that the spin dependent structure function and asymmetry of neutron are evaluated using TBM based on quark distribution in four different Q^2 regions and these results are compared with CLAS experimental data. Figure 1 shows that xg_1^n as a function of x and four Q^2 regions. In $1.3 < Q^2 < 1.9$ region, xg_1^n attains maximum value with x. further increasing x value, it becomes decrease. Similar behavior observed in $1.9 < Q^2 < 2.7$, $2.7 < Q^2 < 3.8$ and $3.8 < Q^2 < 5.4$

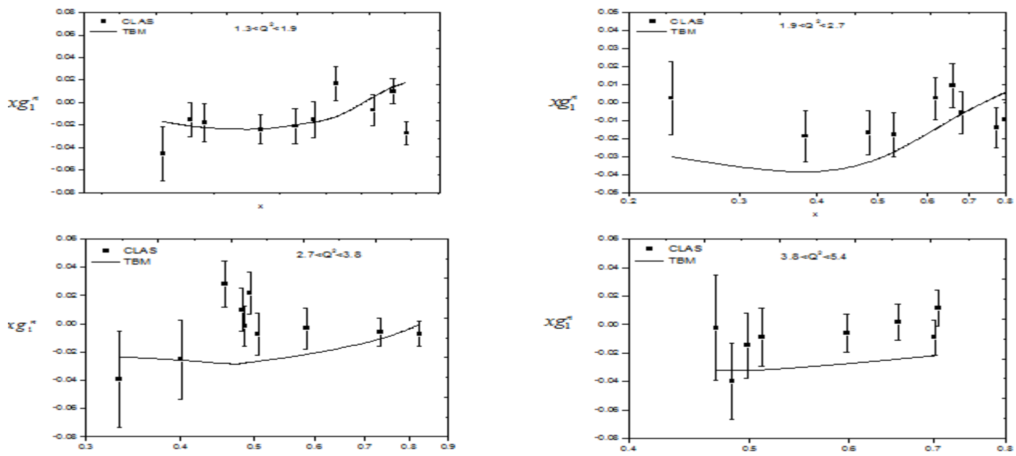

Figure 1. The variation of xg_1^n as a function of x and Q^2. TBM results are compared with CLAS experimental data

In region, is increasing with x but evaluated is negative distribution in whole x region. This is due to the distribution of down quark is more dominated over the up quark distribution.

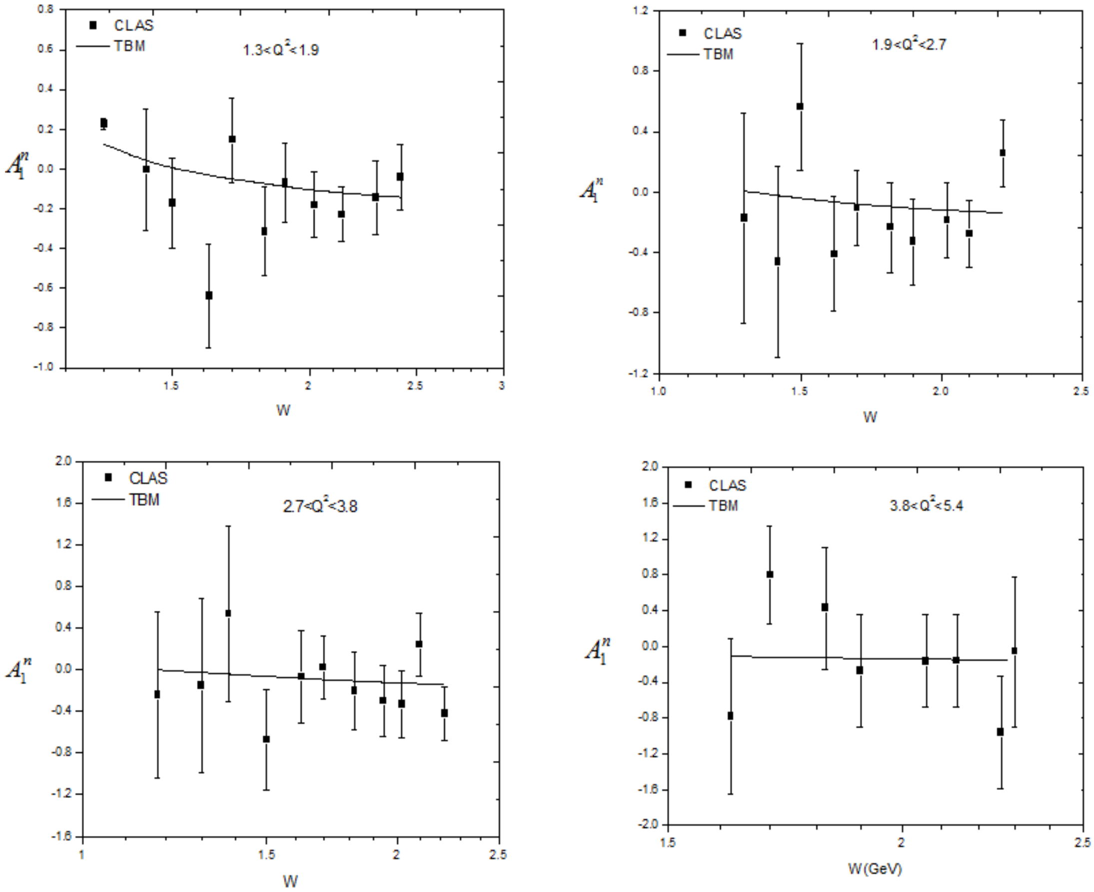

Figure 2. The variation of as a function of x and Q^2. TBM results are compared with CLAS experimental data.

Figure 2 shows that the variation of neutron asymmetry A_1^n as a function of W. The invariant mass of the nucleon of the final hadronic system increases when decreasing the Bjorken variable x and it yields to the production of sea quarks and gluons which is a natural consequency of this model. Asymmetry of A_1^n decreases with increasing W in all four Q^2 regions. Theoretical results of TBM are good agreement with CLAS experimental data.

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