Evaluation of Longitudinal Double Spin Asymmetry By Bag Model

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The longitudinal double-spin asymmetry was evaluated in the range of $(1GeV/c < p_t < 11GeV/c)$ and compared with the existing data. The gluon spin contribution to the proton spin is studied in the longitudinally polarized proton collisions. Experimental results for the measurements of the double-spin asymmetry (A_{LL}) inclusive jet production at midrapidity in polarized proton-proton collisions at $\sqrt{s} = 200GeV$ of STAR data and at $\sqrt{s} = 62.4GeV$ of PHENIX data were analyzed. The evaluated results provide significant new constraints on the gluon spin contribution to nucleon spin through the comparison of predictions derived from one global fit to polarized deep-inelastic scattering measurements.

1. Introduction

Deep Inelastic Scattering (DIS) experiments with polarized leptons and polarized nucleons have found that the quark and anti-quark spin contribution account for only about 25% of the nucleon spin [1] leads our focusing on contribution from gluons. The gluon helicity distribution and orbital angular momenta are thus essential to the understanding of the nucleon spin crisis. DIS experiments have placed constraints on the polarized gluon distribution function $\Delta g(x)$, based on the scale dependence of the inclusive nucleon spin structure function [2] and on recent semi-inclusive data [3]. Measurements taken from collisions of longitudinally polarized protons provide sensitivity to the polarized gluon spin distribution at leading order through quark-gluon and gluon-gluon scattering contributions to the cross section. Measurements of high P_t hadron pairs and charm mesons resulting from the Photon-gluon fusion process in DIS have provided additional but limited constraints. In Contrast to DIS, hadronic interaction provide direct, leading order access to both the quark and gluon polarized parton distribution functions (PDFs) via detection of the jets of particles fragmenting from the scattered partons.

Interesting Channels include gluon mediated processes in semi-inclusive polarized deep inelastic scattering and hard QCD processes in high energy polarized proton-proton collisions at RHIC. According to Altarelli et al., [4] the polarized glue makes a scaling contribution to the first moment of g_1, ($\alpha_s \Delta g \approx$ constant), means that gluon polarization is not necessarily small and must become large at very high momentum scales. Previous NLO QCD motivated fits to the inclusive g_1 data were suggested that, the net polarized glue might be positive but more direct measurements involving glue sensitive observables which are needed to really extract the magnitude of Δg and the shape of $\Delta g(x, Q^2)$ including any possible nodes in the distribution function.

Experimentally high P_t particles are used instead of charm to access Δg . This leads to samples with large statistics, but these have larger background contributions, from QCD Compton processes and fragmentation that one has to control. The hope and expectation is that because of the large invariant mass of the charged hadron pairs, the underlying QCD subprocesses can still be described using perturbative QCD even if the virtuality of the incident photon is small or zero. The measurement of Δg using high P_t charged particles is at the limit of where a perturbative treatment of the data can be expected to be valid, but the result is interesting $\Delta g/g$ = 0.41±0.18±0.03 at an average $< x_g >$ = 0.17 [5]. The present measurement of the longitudinal double-spin asymmetry A_{LL} using thermodynamical bag model is at the center of mass energies of $\sqrt{s} = 200GeV$ and $\sqrt{s} = 62.4GeV$. In pQCD the polarized jet cross section involves a convolution of polarized quark and gluon distribution functions

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and the polarized hard partonic scattering cross section [6] and the similar technique is valid for unpolarized case also. We use quark distribution based calculations, to support their use in constraining the polarized gluon distribution through the measurement of $A_{LL.}$

2. Thermodynamical Bag Model

Thermodynamical Bag Model (TBM) developed by Devanathan et al., [7] considers the nucleon in the infinite momentum frame. Here the quarks are treated as fermions and gluons as bosons at temperature T [8]. The quark density is expressed as,

$$n_q - n_{\bar{q}} = \frac{\mu T^2}{6} + \frac{\mu^3}{6\pi^2} \quad (1)$$

In this equation, the chemical potential μ is a function of temperature T and the quark density $n_q - n_{\bar{q}}$. It is positive quantity for quarks with positive helicity.

In this model, statistical distribution function [9] has been utilized and modulated with the structure of the hadronic current, while deriving the quark distribution function. Non-interacting Fermi particles are governed by the distribution function and this feature is adopted for the interacting quarks emitting gluons and quark-antiquark pairs (sea quarks). The distribution function is governed by the Bjorken variable x and the four momentum transfer Q^2 . These determine the invariant mass of the final hadronic state which in turn measure the temperature T of the excited bag. This model remarkably explains the abundant experimental data of both polarized and unpolarized nucleon structure functions and its asymmetries. This model is used not only for getting the quark distribution functions which include the effect of quark interactions but also for the estimation of asymmetries. The thermal equilibrium of the model is utilized only for the above purpose and meant for explanation of the process involved in the interaction between lepton and nucleon.

The quark distribution *q(x)* obtained in the infinite momentum frame of this model, being a function of chemical potential μ and temperature T, can be expressed as,

$$q(x) = \frac{4VM^2Tx}{(2\pi)^2} \ln\left[1 + \exp\left\{\left(\frac{1}{T}\right)\left(\mu - \frac{Mx}{2}\right)\right\}\right] \quad (2)$$

It is found that the partons are moving freely and independently at certain temperature T within the restricted volume V. The antiquark distribution can be obtained by replacing μ by $-\mu$. The quarks distribution and structure function explained the nuclear medium effects (EMC), which is the significant feature of this model [10]. In the infinite momentum frame *q(x)dx* gives the probability of finding a quark carrying the momentum fraction between x and $x+dx$ of the nucleon momentum and $u_v(x), d_v(x)$ denote the unpolarized up and down valence quark distributions in a bag.

3. Evaluation of Double Spin Longitudinal Asymmetry

In RHIC experiment, spin is achieved using polarized proton-proton collisions at 200GeV of centre of mass energy with approximately 60% polarization. Experiments using the STAR and PHENIX detectors are investigating polarized glue in the proton. The data from STAR [11] and PHENIX [12] are compared with our evaluated values using TBM. The RHIC spin program and the PHENIX detector configuration have made the double helicity asymmetry for production of neutral pions with large transverse momentum with best probe of the gluon polarization in PHENIX [13]. Charged pion asymmetries will provide complementary sensitivity to gluon polarization. The mid-rapidity cross section for neutral pions at STAR is in good agreement with QCD based TBM calculations [10]. This represents an important stepping stone for future neutral pion and direct photon asymmetry measurements, probing Δg . Photon-jet correlations will provide information on the kinematics of the partonic scattering.

The COMPASS semi-inclusive data suggest that the gluon polarization is small or that it has a node in it around $x_g \sim 0.1$, whereas the NLO QCD fits to the inclusive g_1 data suggest modest gluon polarization. The PHENIX and STAR data are consistent with modest gluon polarization. Nevertheless, the tentative conclusion is that the gluon polarization may be small. The Polarized gluon distribution function $\Delta g(x)$ can be extracted from the measured asymmetry A_{LL} over a wide and resolved kinematic range $0.01 < x < 0.3$. The gluon spin contribution to the proton spin [14] is expected to be determined to a precision better than 0.5. In polarized proton collisions, assuming a partonic interaction a + b → c + x, where a, b and c are quarks or gluons, we can define a double longitudinal spin asymmetry [15] using the parton distribution function (PDF) as,

$$A_{LL} = D\left[A_1^p + \eta A_2^p\right] \tag{3}$$

Here $A_1^p = \dfrac{g_1^p - \gamma^2 g_2^p}{F_1^p}$ and $A_2^p = \dfrac{\gamma\left[g_1^p + g_2^p\right]}{F_1^p}$

g_1^p, g_2^p are the polarized first and second moment proton structure function and F_1^p is the unpolarized proton structure function. γ and η are the kinematic factors, 'D' is the depolarization factor of the virtual photon.

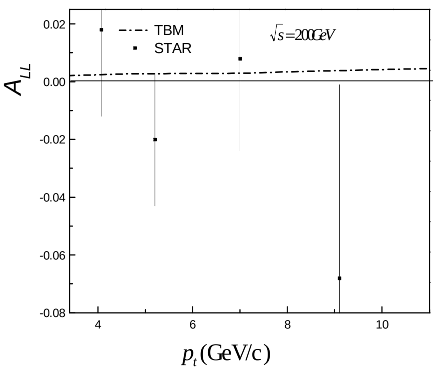

Fig.1

Taking the center of mass energies $\sqrt{s} = 200GeV$ for STAR data and $\sqrt{s} = 62.4GeV$ for PHENIX data, the longitudinal double spin asymmetry was calculated by our theoretical model, which is compared with the existing data. In Fig.1, TBM calculation of longitudinal double-spin asymmetry is compared with inclusive π^0 production at midrapidity in $p + p$ collisions at $\sqrt{s} = 200GeV$ of STAR [11]. In Fig. 2, TBM calculation of longitudinal double-spin asymmetry is compared with inclusive π^0 production at midrapidity in $p + p$ collisions at $\sqrt{s} = 62.4GeV$ of PHENIX [12].

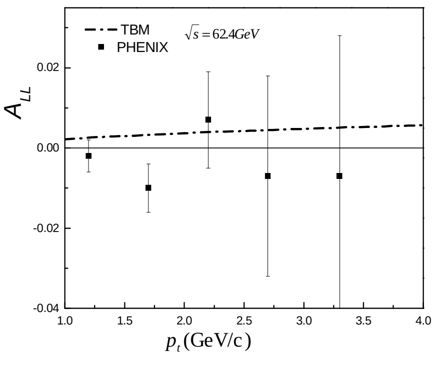

Fig.2

4. Gluon Polarization

The gluon distribution is accessed via the Photon-Gluon Fusion (PGF) process, whereby a virtual photon couples to a gluon via a quark-antiquark pair. The two different selections of the PGF are the open charm and high P_t hadron production. Both have been successfully used to directly measure the unpolarized gluon distribution. PGF events comprising the production of light quark pair are enhanced by the selection of hadron pairs with high transverse momenta relative to the virtual photon [16]. Compared to the selection of PGF via open charm production these so-called high P_t events are much more abundant. The process that allows for high P_t hadrons [17] is the QCD-Compton process, in which the scattered quark emits a gluon in analogy to Compton scattering with emission of a photon. Besides the hard scattering, there are two other possible sources of transverse momentum, the intrinsic transverse momentum of the quarks inside the nucleon and the transverse momentum with respect to the initial quark direction obtained in the fragmentation process [18]. Since there is practically no charm inside the nucleon and charm production in hadronisation may be suppressed. The intricacy of the problem becomes larger at low Q^2, where processes involving resolved photons dominate.

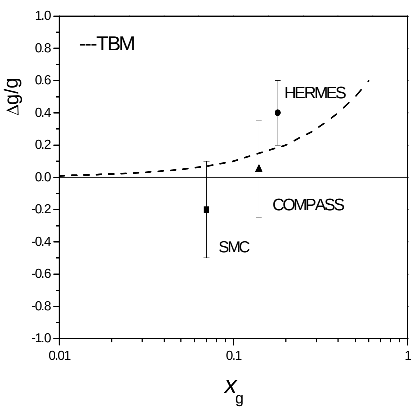

Fig.3

The gluon polarization Δg is evaluated using the Thermodynamical Bag Model at $Q^2 > 1GeV^2$ and is compared with the experimental results of HERMES [19], SMC [20] and COMPASS [21]. Experimentally, for $Q^2 > 1GeV^2$ it would be necessary to analyze high P_t hadron pairs and consider the contribution from the three processes, Photon-Gluon Fusion (PGF), QCD Compton and leading DIS process. Apart from DIS experiments, measurements of the gluon polarization can be carried out in polarized Proton-Proton reaction. The Proton-Proton collisions pave the ways to extract $\Delta g/g$. Using the quark distribution functions the Gluon polarization is evaluated as,

$$\Delta g = \left[\left\{ \left(\frac{-16V}{4\pi^2} \right) M^2 T x^2 \ln\left(1 - \exp\left(\frac{-Mx}{2T} \right) \right) \right\} \right] \quad (4)$$

Here the gluon polarization Δg is expressed as x times of g. In Fig. 3, $\Delta g / g$ Measurements from HERMES [19], SMC [20] and COMPASS [21] results are compared with the TBM (Dotted lines). Our theoretical evaluations are in fair accuracy with the SMC and COMPASS than the results from HERMES. The evaluation is also compatible with all parametrization obtained from the best fit within the error. To gain deeper insight into the polarization of the gluon inside the nucleon and to better constrain QCD-fits to the data it is desirable to map the gluon polarization for different values of x_g. The gluon helicity contribution to the nucleon can be determined by direct measurements of $\Delta g/g$, and this is measured by HERMES, SMC and COMPASS. Within the present statistical accuracy this value is consistent with QCD-fits to the present data from inclusive and semi-inclusive polarized deep inelastic scattering experiments. This result indicated that the gluon polarization is small. For better constraint of gluon polarization it would be necessary to map a larger region of the gluon momentum fraction x_g. To understand the spin structure of the nucleon more precisely, the measurement of gluon polarization by HERMES, SMC and COMPASS are presented here. The nucleon spin can be decomposed conceptually into the angular momentum contributions of its constituents (quarks and gluons). Based on our evaluation for Δg , we conclude that, if the gluon momentum fraction is extended for larger values, the gluon polarization Δg results will be better towards the contribution to the nucleon spin.

5. Results and Discussions

In Fig. 1, our calculated values are in consistent with the STAR data [11] at $\sqrt{s} = 200GeV$. The double longitudinal asymmetry reaches small positive values at large P_t. Similarly in Fig. 2, our theoretical evaluation agrees with the PHENIX data [12] at $\sqrt{s} = 62.4GeV$. Here A_{LL} also reaches small positive values at large P_t.

This shows that at increasing P_t values the longitudinal asymmetry also increases with our calculation based on quark and gluon distributions. The data agree with our evaluation. The parameterized calculation based on GRSV [22] assuming $\Delta g = 0$ is also consistent with our evaluation. By measuring A_{LL} for different center of mass energies, the x range can be extended. Data at different $\sqrt{s}$ can be compared using x_t defined as,

$$x_t = \frac{2p_t}{\sqrt{s}} \quad (5)$$

In our model, A_{LL} is evaluated for both center of mass values. Interpretation of this result requires that the data is described by pQCD. Therefore, it is important to check that π^0 cross section is described by pQCD at $\sqrt{s} = 62GeV$. This analysis is ongoing, and upon completion, will allow further discussion of this A_{LL} result by comparing it with the pQCD calculations. The calculations are performed for jets composed of NLO partons which do not include effects due to hadronization. The majority of the published polarized PDFs utilize forms similar to TBM for $\Delta g(x)$ at the initial scale.

The STAR jet asymmetries are consistent with our theoretical evaluations based on the assumption that the gluons in the nucleon are maximally polarized. Our theoretical evaluations are in good agreement with DSSV [23] and GS-C global analyses that includes semi-inclusive and inclusive DIS data, as well as results obtained by the PHENIX [24] and STAR [25] experiments. The GS-C [26] analyze the polarized gluon distribution function has a large positive gluon polarization at low x, a node near $x \approx 0.1$, and a negative gluon polarization at large x. A maximal positive gluon polarization, which has a total gluon contribution $\Delta g = \int_0^1 \Delta g(x)dx = 1.26$ at an initial scale of 0.4GeV^2 [27,28]. The small statistical uncertainty regarding our model with the data shows that the distributions of qq, qg and gg pairs comprise the inclusive measurement. The consequence of this change for A_{LL} also depends on the true value of the gluon helicity distribution. The evaluated value of A_{LL} shows small positive values at high P_t due to the fact that virtual photon energy has small increased values when the values of four momentum transfer is increased. This tends to make the result of the A_{LL} as such. Our evaluated results are in consistent with the presented data.

Our theoretical evaluations are in fair accuracy with the SMC and COMPASS than the results from HERMES. The evaluation is also compatible with other parametrization obtained from the best fit within the error. SMC shows negative gluon polarization, while COMPASS and HERMES shows positive gluon polarization. COMPASS shows small positive gluon polarization at $x \approx 0.15$, while HERMES shows gluon polarization at $x \approx 0.18$. Our theoretical evaluated values are consistent with SMC and COMPASS but deviates from the results of HERMES due to the large positive value of gluon polarization at low x ($x \approx 0.18$). To gain deeper insight into the polarization of the gluon inside the nucleon and to better constrain QCD-fits to the data, it is desirable to map the gluon polarization for different values of $x_{g.}$

5. Conclusion

A precise measurement of Δg is crucial for a full understanding of the proton spin problem. HERA has shown that large centre of mass energy allows several processes to be used to extract the unpolarized gluon polarization. These include jet and high P_t hadron production, charm production both in deep inelastic scattering and photoproduction, and correlations between multiplicities of the current and target hemisphere of the events in the infinite momentum frame. This measurement has the potential to contribute to future fragmentation studies. The asymmetry A_{LL} was measured in the hard scattering regime at $3.7 < P_t < 11$GeV/c and this also found to be in consistent with NLO pQCD calculations utilizing polarized quark and gluon distributions from inclusive and semi-inclusive DIS data and from polarized proton data. Our evaluations based on QCD improved quark distribution of TBM for double longitudinal spin asymmetries is compared with the first preliminary measurements of the double longitudinal spin asymmetries in mid-rapidity inclusive jet production in polarized proton-proton interactions at $\sqrt{s} = 200GeV$ and $\sqrt{s} = 62.4GeV$. The results are consistent with the data based on deep inelastic scattering experiments for the gluon polarization in the nucleon, and disfavor large positive values of gluon polarization.

The evaluated results of the longitudinal double-spin asymmetry A_{LL} for inclusive jet production with transverse jet momenta of $3.5GeV/c < p_t < 11GeV/c$ at $\sqrt{s} = 200GeV$ and $1GeV/c < p_t < 4GeV/c$ at $\sqrt{s} = 62.4GeV$ had an improved precision compared to the experimental data of STAR and PHENIX. The asymmetries A_{LL} are consistent with quark distribution based calculations of TBM model utilizing polarized quark and gluon distribution from inclusive DIS analyses and disfavor at 98%, large positive values of gluon polarization in the polarized nucleon.

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Received: 20 September, 2010
Accepted: 03 March, 2011