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Title

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Authors

Chen, Ye
Liang, Zuo-tang
Sichtermann, Ernst
et al.

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Ye Chen[a], Zuo-tang Liang[a], Ernst Sichtermann[b], Qing-hua Xu[a,b] and Shan-shan Zhou[a]

[a] *Department of Physics, Shandong University, Jinan, Shandong 250100, China*

[b] *Nuclear Science Division, MS 70R0319,*

Lawrence Berkeley National Laboratory, Berkeley, CA 94720

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Abstract

We study the longitudinal polarization of the $\bar{\Sigma}^-$, $\bar{\Sigma}^+$, $\bar{\Xi}^0$ and $\bar{\Xi}^+$ anti-hyperons in polarized high energy pp collisions at large transverse momenta, extending a recent study for the $\bar{\Lambda}$ anti-hyperon. We make predictions by using different parametrizations of the polarized parton densities and models for the polarized fragmentation functions. Similar to the $\bar{\Lambda}$ polarization, the $\bar{\Xi}^0$ and $\bar{\Xi}^+$ polarizations are found to be sensitive to the polarized anti-strange sea, $\Delta\bar{s}(x)$, in the nucleon. The $\bar{\Sigma}^-$ and $\bar{\Sigma}^+$ polarizations show sensitivity to the light sea quark polarizations, $\Delta\bar{u}(x)$ and $\Delta\bar{d}(x)$, and their asymmetry.

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I. INTRODUCTION

The self spin-analyzing parity violating decay [1] of hyperons and anti-hyperons provides a practical way to determine the hyperon and anti-hyperon polarization by measuring the angular distributions of the decay products. The polarizations have been used widely in studying various aspects of spin physics in high energy reactions [2, 3, 4, 5, 6, 7]. The discovery of transverse hyperon polarization in unpolarized hh and hA collisions in the 1970s led to many subsequent studies [8]. Phenomenological studies of longitudinal hyperon polarization may be found in Refs. [9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25]. The main themes of these studies can be categorized as follows. On the one hand, one aims to study spin transfer in the fragmentation process. On the other, one aims to get insight in the spin structure of the initial hadrons. Experimental data are available from e^+e^--annihilation at the Z-pole [2, 3], deep-inelastic scattering with polarized beams and targets [4, 5, 6, 7], and hyperon production in pp collisions [26].

The study of anti-hyperon polarization is topical since COMPASS data [7] indicate a difference between Λ and $\bar{\Lambda}$ polarization, a recent study for $\bar{\Lambda}$ polarization in pp-collisions [25] shows sensitivity to the anti-strange quark spin contribution to the proton spin, and the pp spin physics program at the Relativistic Heavy Ion Collider (RHIC) has come online [27]. In this paper, we evaluate the longitudinal polarization of the $\bar{\Sigma}^-$, $\bar{\Sigma}^+$, $\bar{\Xi}^0$ and $\bar{\Xi}^+$ anti-hyperons in pp collisions at large transverse momenta p_T. Section II contains the formalism and discusses the current understanding of the parton distribution and fragmentation functions. The contributions to the anti-hyperon production cross sections are discussed in Section III, followed by the polarizations in Section IV and a short summary in Section V.

II. FORMALISM

The perturbative techniques to evaluate the longitudinal polarization of high p_T hyperons and anti-hyperons in high energy pp collisions are described in Refs. [11, 15, 16, 17, 18, 19, 20]. For self-containment we briefly summarize the key elements and emphasize the aspects that are specific to anti-hyperons.

A. Definitions and general formulae

We consider the inclusive production of high p_T anti-hyperons ($\bar{H}$) in pp collisions with one of the beams longitudinally polarized. The longitudinal $\bar{H}$ polarization is defined as,

$$P_{\bar{H}}(\eta) \equiv \frac{d\sigma(p_+p \to \bar{H}_+X) - d\sigma(p_+p \to \bar{H}_-X)}{d\sigma(p_+p \to \bar{H}_+X) + d\sigma(p_+p \to \bar{H}_-X)} = \frac{d\Delta\sigma}{d\eta}(\vec{p}p \to \bar{H}X)/\frac{d\sigma}{d\eta}(pp \to \bar{H}X), \quad (1)$$

where η is the pseudo-rapidity of the $\bar{H}$, the subscripts $+$ and $-$ denote positive and negative helicity, and $\Delta\sigma$ and σ are the polarized and unpolarized inclusive production cross sections. We assume that p_T is high enough so that factorization is expected to hold. In this case, the produced $\bar{H}$'s are the fragmentation products of high p_T partons from $2 \to 2$ hard scattering ($ab \to cd$) with one initial parton polarized.

The polarized inclusive production cross section is given by,

$$\frac{d\Delta\sigma}{d\eta}(\vec{p}p \to \bar{H}X) = \int_{p_T^{min}} dp_T \sum_{abcd} \int dx_a dx_b \Delta f_a(x_a) f_b(x_b) D_L^{\vec{a}b\to\vec{c}d}(y) \frac{d\hat{\sigma}}{d\hat{t}}(ab \to cd) \Delta D_c^{\bar{H}}(z), \quad (2)$$

where the $\bar{H}$ transverse momentum is integrated above a threshold p_T^{min}; the sum concerns all subprocesses; $\Delta f_a(x_a)$ and $f_b(x_b)$ are the polarized and unpolarized parton distribution functions in the proton, x_a and x_b are the momentum fractions carried by partons a and b, $D^{\vec{a}b\to\vec{c}d}(y) \equiv d\Delta\hat{\sigma}/d\hat{\sigma}$ is partonic spin transfer factor in the elementary hard process $\vec{a}b \to \vec{c}d$ with cross section $\hat{\sigma}$, $y \equiv p_b \cdot (p_a - p_c)/p_a \cdot p_b$ is defined in terms of the four momenta p of the partons a–d, and $\Delta D_c^{\bar{H}}(z)$ is the polarized fragmentation function. It is defined by,

$$\Delta D_c^{\bar{H}}(z) \equiv D_c^{\bar{H}}(z,+) - D_c^{\bar{H}}(z,-), \quad (3)$$

in which the argument z is the momentum carried by $\bar{H}$ relative to the momentum of the fragmenting parton c, and the arguments $+$ and $-$ denote that the produced $\bar{H}$ has equal or opposite helicity as parton c. The scale dependencies of the parton distribution and fragmentation functions have been omitted for notational clarity. Intrinsic transverse momenta in the proton and in the fragmentation process are neglected.

The unpolarized inclusive production cross section, $d\sigma/d\eta$, is given by an analogous expression with unpolarized parton distribution and fragmentation functions.

B. The partonic spin transfer factors $D^{\vec{a}b\to\vec{c}d}(y)$ in the hard scattering

The partonic spin transfer factor $D^{\vec{a}b\to\vec{c}d}(y)$ is determined by the spin dependent hard scattering cross sections. At high p_T the spin transfer factors $D^{\vec{a}b\to\vec{c}d}(y)$ are calculable using perturbative QCD. At leading order they are functions only of y, defined above. The results for quarks are tabulated in Ref. [17]. Here, we are particularly interested in anti-quarks. By using charge conjugation, a symmetry which is strictly valid in QCD, one obtains

$$D_L^{\vec{\bar{q}}_1 q_2\to\vec{\bar{q}}_1 q_2}(y) = D_L^{\vec{q}_1 q_2\to\vec{q}_1 q_2}(y), \tag{4}$$

$$D_L^{\vec{\bar{q}}_1 g\to\vec{\bar{q}}_1 g}(y) = D_L^{\vec{q}_1 g\to\vec{q}_1 g}(y), \tag{5}$$

etc. Next-to-leading order calculations are available [28, 29], but should be used consistently with the polarized parton distribution and fragmentation functions. In view of the current knowledge of the polarized fragmentation functions, we consider only the leading order.

C. The parton distribution functions

The unpolarized parton distributions $f(x)$ are determined with high accuracy from unpolarized deep inelastic scattering data and can be evaluated conveniently using parton distribution function libraries [30]. Many parametrizations exist also for the polarized parton distribution functions $\Delta f(x)$, e.g. GRSV2000, BB, LSS, GS, ACC, DS2000, and DNS2005 [31, 32, 33, 34, 35, 36, 37]. However, they are less well constrained by data and large differences exist in particular for the parametrizations of the polarized anti-sea distributions. This is illustrated in Fig. 1, showing the anti-sea distributions from the GRSV2000 and DNS2005 parametrizations.

D. The polarized fragmentation functions $\Delta D_c^{\bar{H}}(z)$

The polarized fragmentation function $\Delta D_c^{\bar{H}}(z)$ is defined in Eq. (3) and can in general be expressed as the sum of contributions from directly produced and from decay $\bar{H}$,

$$\Delta D_c^{\bar{H}}(z) = \Delta D_c^{\bar{H}}(z;\text{direct}) + \Delta D_c^{\bar{H}}(z;\text{decay}). \tag{6}$$

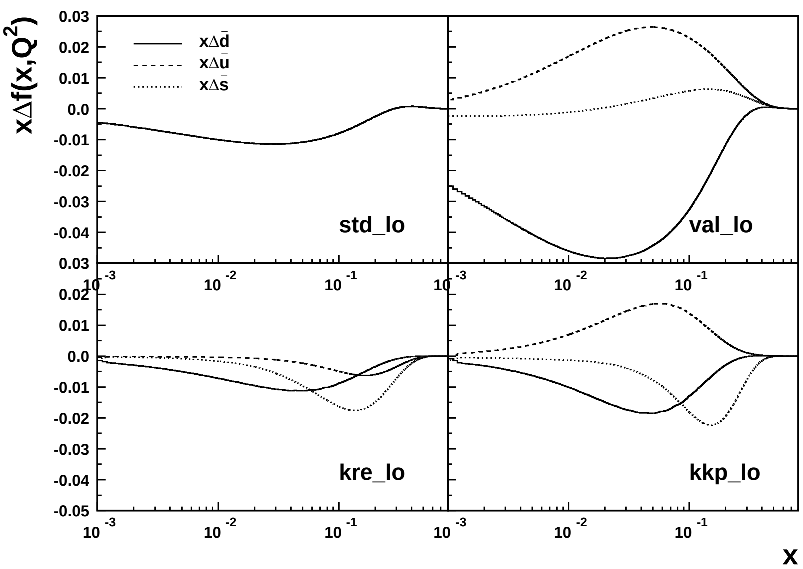

FIG. 1: Polarized anti-sea quark distributions from the leading order GRSV2000 (upper) and DNS2005 (lower) parametrizations evaluated at a scale $Q = 10\,\mathrm{GeV}$.

The decay contribution $\Delta D_c^{\bar{H}}(z;\mathrm{decay})$ is given by a sum over parent anti-hyperons $\bar{H}_j$ and involves kinematic convolutions,

$$\Delta D_c^{\bar{H}}(z;\mathrm{decay}) = \sum_j \int dz' t^D_{\bar{H},\bar{H}_j} K_{\bar{H},\bar{H}_j}(z,z') \Delta D_c^{\bar{H}_j}(z'), \tag{7}$$

in which the kernel function $K_{\bar{H},\bar{H}_j}(z,z')$ is the probability for the decay of the parent $\bar{H}_j$ with a fractional momentum z' to produce $\bar{H}$ with fractional momentum z, and $t^D_{\bar{H},\bar{H}_j}$ is the spin transfer factor in the decay process. If charge conjugation is a good symmetry for the decay process, $K_{\bar{H},\bar{H}_j}(z,z') = K_{H,H_j}(z,z')$ and $t^D_{\bar{H},\bar{H}_j} = t^D_{H,H_j}$. We assume also the validity of charge conjugation symmetry for the fragmentation functions, so that $\Delta D_c^{\bar{H}}(z) = \Delta D_{\bar{c}}^{H}(z)$.

The kernel function $K_{H,H_j}(z,z')$ is easily calculated for a two body decay of an *unpolarized* $H_j \to HM$. In this case, the momentum of H is known and isotropically distributed in the rest frame of the parent H_j. A Lorentz transformation to the moving frame of H_j gives,

$$K_{H,H_j}(z,\vec{p}_T;z',\vec{p}_T{}') = \frac{N}{E_j} Br(H_j \to HM)\delta(p\cdot p_j - m_j E^*), \tag{8}$$

where $Br(H_j \to HM)$ is the decay branching ratio, N is a normalization constant, and E^* is the energy of H in the rest frame of H_j, which depends on the parent mass m_j and on the masses of the decay products.

The calculation of $K_{H,H_j}(z,z')$ for a *polarized* H_j is more involved since the angular decay distribution can be anisotropic in the case of a weak decay and each decay process needs to be dealt with separately. However, since the E^* is usually small compared to the momentum of H_j in the pp center of mass frame, the anisotropy can be neglected and Eq.(8) forms a good approximation. This makes it possible to use an unpolarized Monte-Carlo event generator such as PYTHIA [38] to do the calculations.

The unknowns are thus the $\Delta D_c^H(z,\mathrm{direct})$, which are determined by the hadronization mechanism and by hadron structure. Present data do not sensitively constrain parametrizations of the polarized fragmentation functions, which thus have to be modeled [10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24].

A frequently used approach is to evaluate $\Delta D_f^H(z)$ according to the origin of H [10, 11, 15, 16, 17, 18]. In this approach, the produced hyperons are divided into the following four categories: (A) directly produced hyperons that contain the initial quark q of flavor f; (B) decay products of heavier polarized hyperons; (C) directly produced hyperons that do not contain the initial q; (D) decay products of heavier unpolarized hyperons. We thus write,

$$D_f^H(z;\mathrm{direct}) = D_f^{H(\mathrm{A})}(z) + D_f^{H(\mathrm{C})}(z), \tag{9}$$

$$\Delta D_f^H(z;\mathrm{direct}) = \Delta D_f^{H(\mathrm{A})}(z) + \Delta D_f^{H(\mathrm{C})}(z), \tag{10}$$

and assume that,

$$\Delta D_f^{H(\mathrm{C})}(z) = 0, \tag{11}$$

and

$$\Delta D_f^{H(\mathrm{A})}(z) = t_{H,f}^F D_f^{H(\mathrm{A})}(z), \tag{12}$$

where $t_{H,f}^F$ is referred to as the fragmentation spin transfer factor. If the quarks and antiquarks produced in the fragmentation process are unpolarized, consistent with Eq.(11), then $t_{H,f}^F$ is a constant given by,

$$t_{H,f}^F = \Delta Q_f / n_f, \tag{13}$$

where ΔQ_f is the fractional spin contribution of a quark with flavor f to the spin of the hyperon, and n_f is the number of valence quarks of flavor f in H.

An advantage to this approach is that the different kinds of contributions, including the decay contributions, are taken into account explicitly. In Feynman-Field like fragmentation models $D_f^{H(A)}(z)$ is the probability to produce a first rank H with fractional momentum z.

It is usually denoted by $f^H_{q_f}(z)$, so that $D^{H(C)}_f(z) = D^H_f(z;\text{direct}) - f^H_{q_f}(z)$, and $f^H_{q_f}(z)$ is well determined by unpolarized fragmentation data. The z-dependence of ΔD is thus obtained from the unpolarized fragmentation functions in this model, which are empirically known, and only the constant $t^F_{H,q}$ is unknown. Expectations based on the SU(6) quark-parton wave function and on polarized deep-inelastic scattering data are discussed in Ref. [15].

Experimentally, polarized fragmentation functions can be studied in e^+e^--annihilation, polarized deep-inelastic scattering, and high p_T hadron production in polarized pp collisions by measuring the polarization of the produced hyperons. The accuracy of present data [2, 3, 4, 5, 6, 7, 26] does not allow one to distinguish between the expectations for $t^F_{H,f}$ based on SU(6) and on deep-inelastic scattering, the so-called SU(6) and DIS pictures, but the z-dependence obtained from the model seems to agree well with the available data on Λ polarization [15].

An alternative approach [14, 22] to $\Delta D^H_f(z)$ makes use of the Gribov relation [39], a proportionality relating $D^H_f(z) \propto q^H_f(z)$ and $\Delta D^H_f(z) \propto \Delta q^H_f(z)$ where $q^H_f(z)$ and $\Delta q^H_f(z)$ are the parton distributions in the hyperon. Other alternative approaches to $\Delta D^H_f(z)$ found in the literature [12, 13] are in essence different combinations or approximations of the aforementioned approaches.

In this paper, we will evaluate $\Delta D^H_f(z)$ according to the origin of H. It is supported by data and the constant $t^F_{H,f}$ can be obtained from the SU(6) or the deep-inelastic scattering picture for the spin structure of the nucleon [15]. The longitudinal polarization of $\bar{H}$ in pp collisions with one of the beams longitudinally polarized is evaluated using several parametrizations of the polarized parton distribution functions $\Delta f(x)$, and both SU(6) and deep-inelastic scattering as model inputs for the polarized fragmentation functions $\Delta D^{\bar{H}}_c(z)$.

III. ANTI-HYPERON PRODUCTION

The longitudinal polarization of high p_T anti-hyperons produced in pp collisions is determined by the polarization of the initial partons taking part in the hard scattering, the partonic spin transfer factor, and the spin transfer in the fragmentation process. Since the up, down, and strange quark and anti-quark polarizations in the polarized proton are different and the spin transfer in the fragmentation process for a given type of anti-hyperon is flavor dependent as well, the contributions to $\bar{H}$ production from the fragmentation of different quark flavors and gluons need to be studied. These contributions are independent of polarization and have been determined in multi-particle production data in high energy reactions. An impressive body of data has been collected over the past decades and the contributions can thus be considered to be known accurately and to be well-modeled in Monte-Carlo event generators.

We have used the PYTHIA generator [38], version 6.4 without initial state radiation but otherwise with default parameter settings, to evaluate the contributions to the production of the $\bar{\Sigma}^-$, $\bar{\Sigma}^+$, $\bar{\Xi}^0$ and $\bar{\Xi}^+$ anti-hyperons. The flavor compositions of these anti-hyperons lead us to expect a large contribution to the production of $\bar{\Sigma}^+(\bar{d}\bar{d}\bar{s})$ from $\bar{d}$-fragmentation, a large contribution to $\bar{\Sigma}^-(\bar{u}\bar{u}\bar{s})$ production from $\bar{u}$-fragmentation, and a large contribution to $\bar{\Xi}$-production from $\bar{s}$-fragmentation.

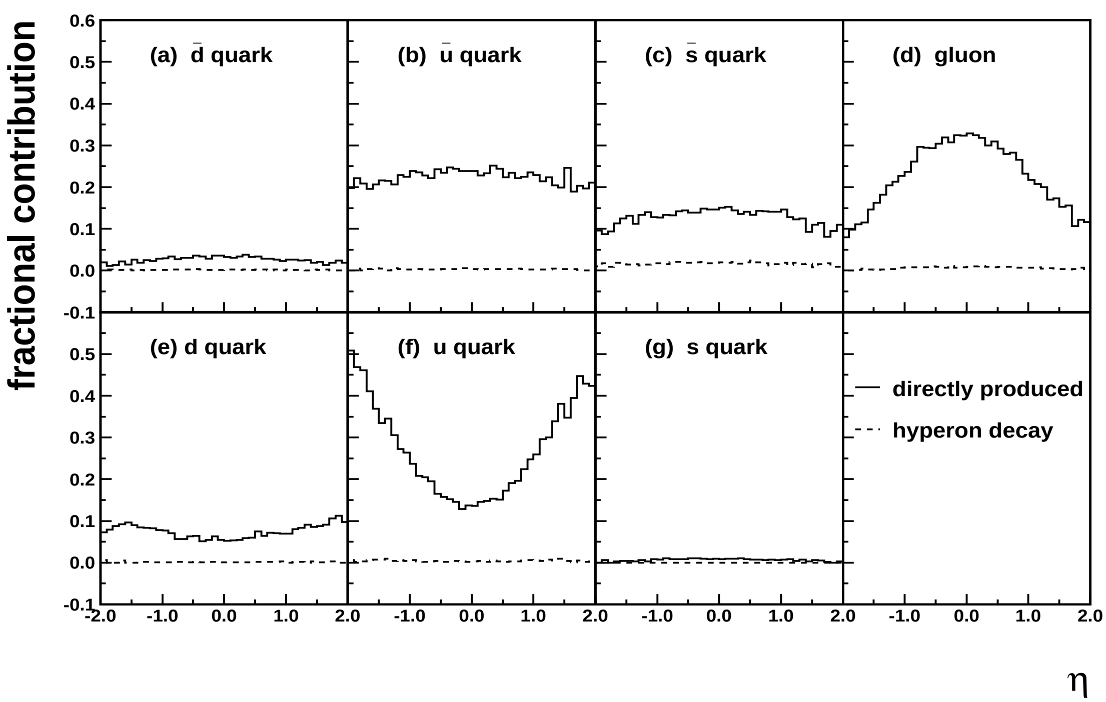

FIG. 2: Contributions to $\bar{\Sigma}^-(\bar{u}\bar{u}\bar{s})$ production with $p_T \geq 8$ GeV/c in pp collisions at $\sqrt{s} = 200$ GeV. The continuous and dashed lines are respectively the directly produced and decay contributions.

Fig. 2 shows the results for the fractional contributions to $\bar{\Sigma}^-$ production from the fragmentation of anti-quarks/quarks of different flavors and of gluons in pp collisions at $\sqrt{s} = 200\,\text{GeV}$ for hyperon transverse momenta $p_T > 8\,\text{GeV}$ versus pseudo-rapidity η. The

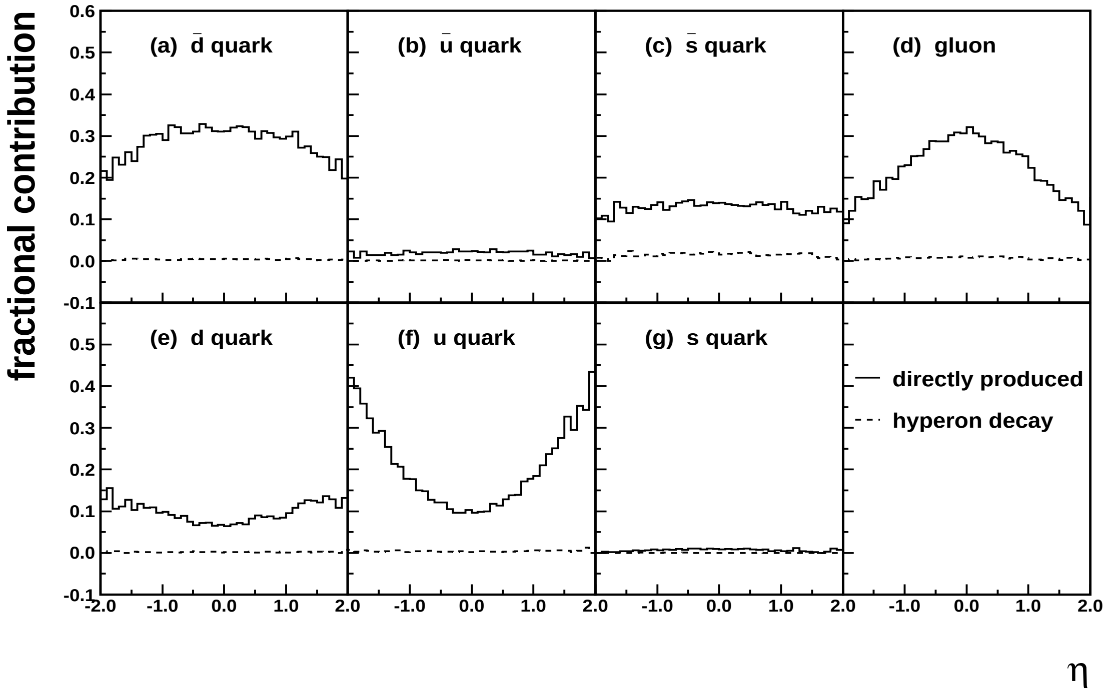

FIG. 3: Contributions to $\bar{\Sigma}^+(\bar{d}\bar{d}\bar{s})$ production with $p_T \geq 8$ GeV/c in pp collisions at $\sqrt{s} = 200$ GeV. The continuous and dashed lines are respectively the directly produced and decay contributions.

decay contribution to $\bar{\Sigma}^-$ production is seen to be negligibly small. This is different than for $\bar{\Lambda}$ production and implies that its polarization measurement will reflect more directly the spin structure of the nucleon and the polarized fragmentation function. The results are symmetric in $\eta \leftrightarrow -\eta$ since pp collisions are considered. The $\bar{d}$-quark and s-quark fragmentation contributions originate from second or higher rank particles in the fragmentation and have similar shapes since both are sea quarks (anti-quarks). The increasingly large u-quark contribution with increasing $|\eta|$ originates from valence quarks. Only the $\bar{u}$-quark and $\bar{s}$-quark give first rank fragmentation contributions. These contributions are sizable. Most important for the production of $\bar{\Sigma}^-$ with $p_T > 8\,\mathrm{GeV}$ and $|\eta| < 1$ are $\bar{u}$ and gluon fragmentation. Since the $\bar{\Sigma}^-$ spin is carried mostly by the $\bar{u}$-quark spins, this implies that the $\bar{\Sigma}^-$ polarization in singly polarized pp collisions should be sensitive to $\Delta\bar{u}(x)$, the $\bar{u}$-quark polarization distribution in the polarized proton.

The results for $\bar{\Sigma}^+$, shown in Fig. 3, are similar to those for $\bar{\Sigma}^-$ when $\bar{u}$ and $\bar{d}$ are interchanged. The small difference between the fractional contribution of the $\bar{u}$-quark to

$\bar{\Sigma}^-$ production and of the $\bar{d}$-quark to $\bar{\Sigma}^+$ production reflects the asymmetry of the light sea density in the proton, $\bar{d}(x)>\bar{u}(x)$, which is built into the parton distribution functions. The large $\bar{d}$-quark fragmentation contribution to $\bar{\Sigma}^+$ production and the large $\bar{d}$-quark spin contribution to the $\bar{\Sigma}^+$ spin lead us to expect that $\bar{\Sigma}^+$ polarization measurements in pp collisions are sensitive to $\Delta\bar{d}(x)$.

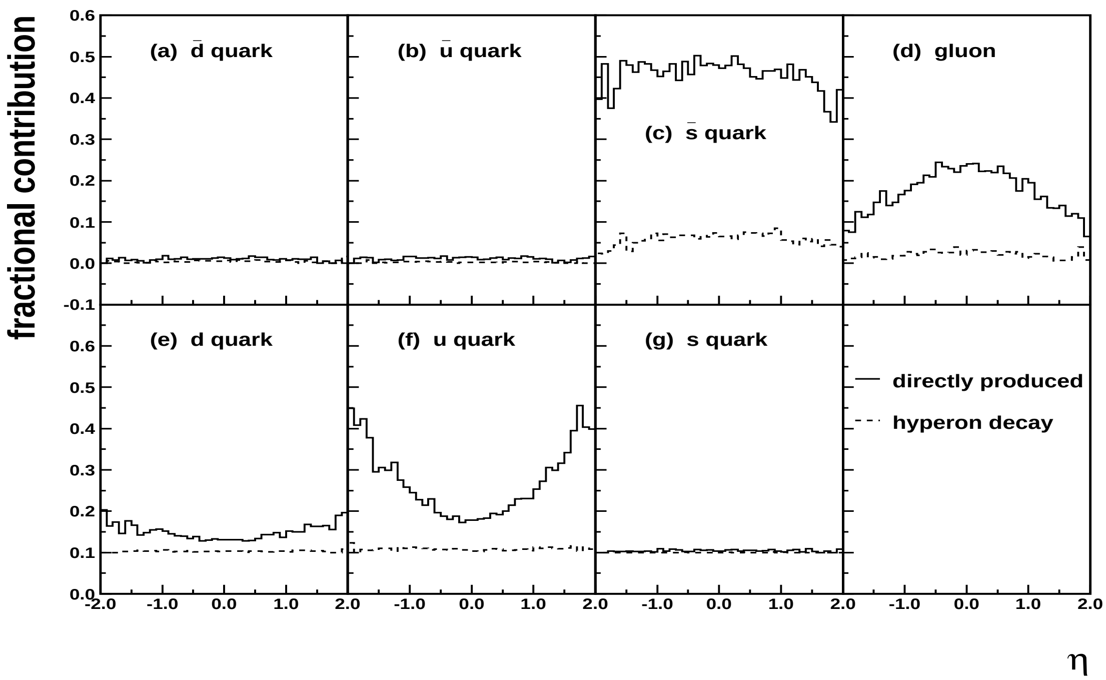

FIG. 4: Contributions to $\bar{\Xi}^0(\bar{u}\bar{s}\bar{s})$ production with $p_T \geq 8$ GeV/c in pp collisions at $\sqrt{s} = 200$ GeV. The continuous and dashed lines are respectively the directly produced and decay contributions.

Figs. 4 and 5 show the fractional contributions for $\bar{\Xi}^0$ and $\bar{\Xi}^+$ production, respectively. The dominant contribution originates from $\bar{s}$-quark fragmentation. It amounts to almost half the $\bar{\Xi}$ production, and is larger than the $\bar{d}$-quark fragmentation contribution to $\bar{\Sigma}^+$ production and the $\bar{u}$-quark fragmentation contribution to $\bar{\Sigma}^-$ production. This results from strange suppression, which reduces the relative contributions from $\bar{u}$ and $\bar{d}$-quark fragmentation to $\bar{\Xi}$ production. We thus expect that $\bar{\Xi}$ polarization measurements are sensitive to $\Delta\bar{s}(x)$ in the nucleon. They are thus complementary to polarization measurements of the $\bar{\Lambda}$ [25], which has a larger production cross section but also larger decay contributions.

In Fig. 6 we show the p_T dependence of the fractional fragmentation contributions for

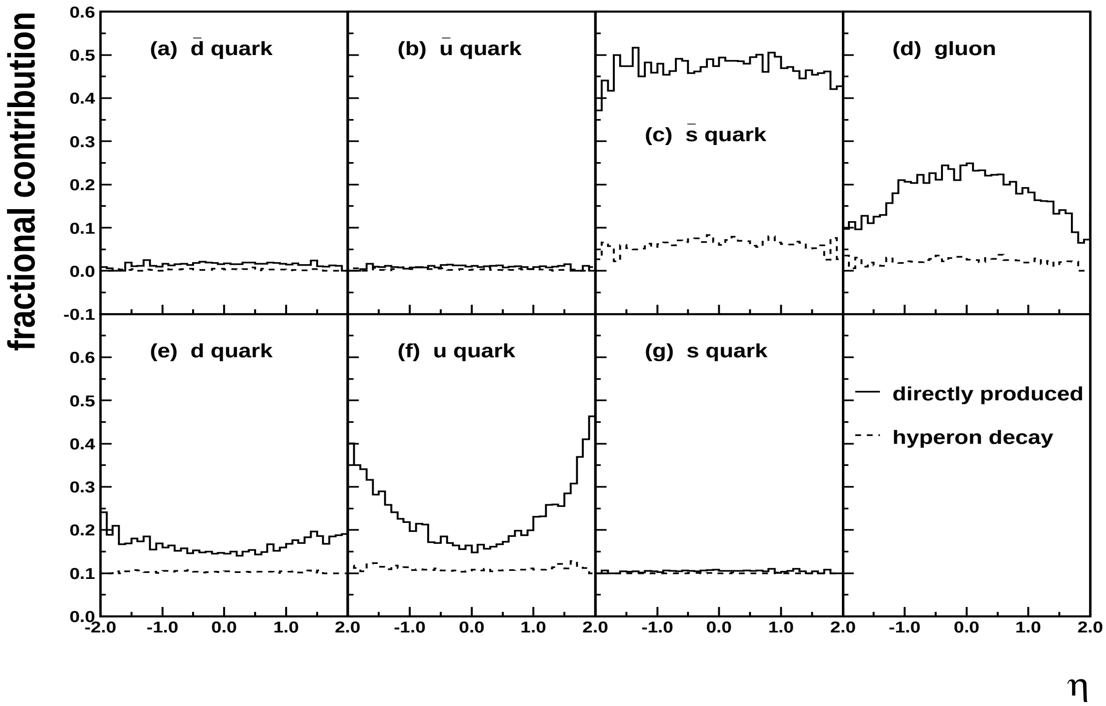

FIG. 5: Contributions to $\bar{\Xi}^{+}(\bar{d}\bar{s}\bar{s})$ production with $p_T \geq 8$ GeV/c in pp collisions at $\sqrt{s} = 200$ GeV. The continuous and dashed lines are respectively the directly produced and decay contributions.

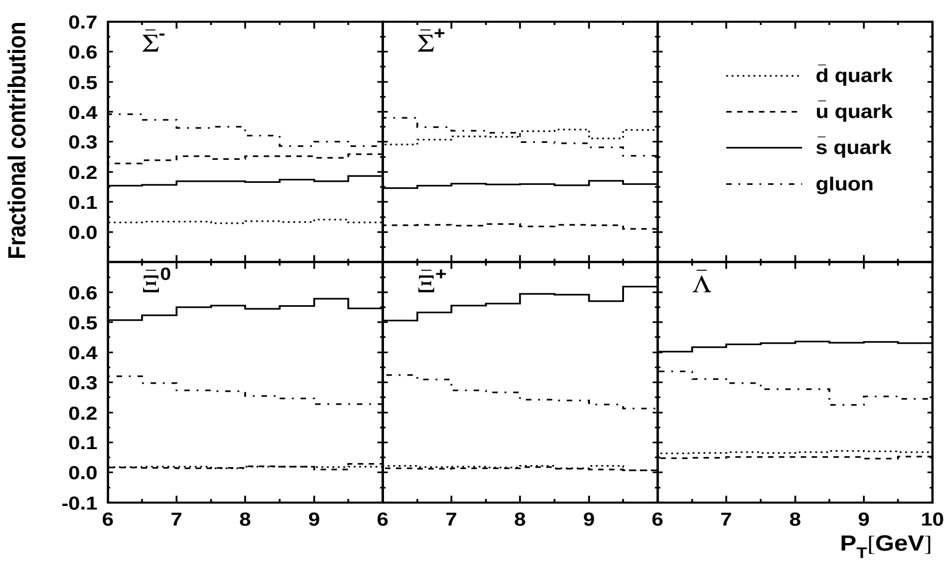

FIG. 6: Contributions to $\bar{\Sigma}^{-}(\bar{u}\bar{u}\bar{s})$, $\bar{\Sigma}^{+}(\bar{d}\bar{d}\bar{s})$, $\bar{\Xi}^{0}(\bar{u}\bar{s}\bar{s})$ and $\bar{\Xi}^{+}(\bar{d}\bar{s}\bar{s})$ production for $|\eta| < 1$ in pp collisions at $\sqrt{s} = 200$ GeV versus transverse momentum p_T.

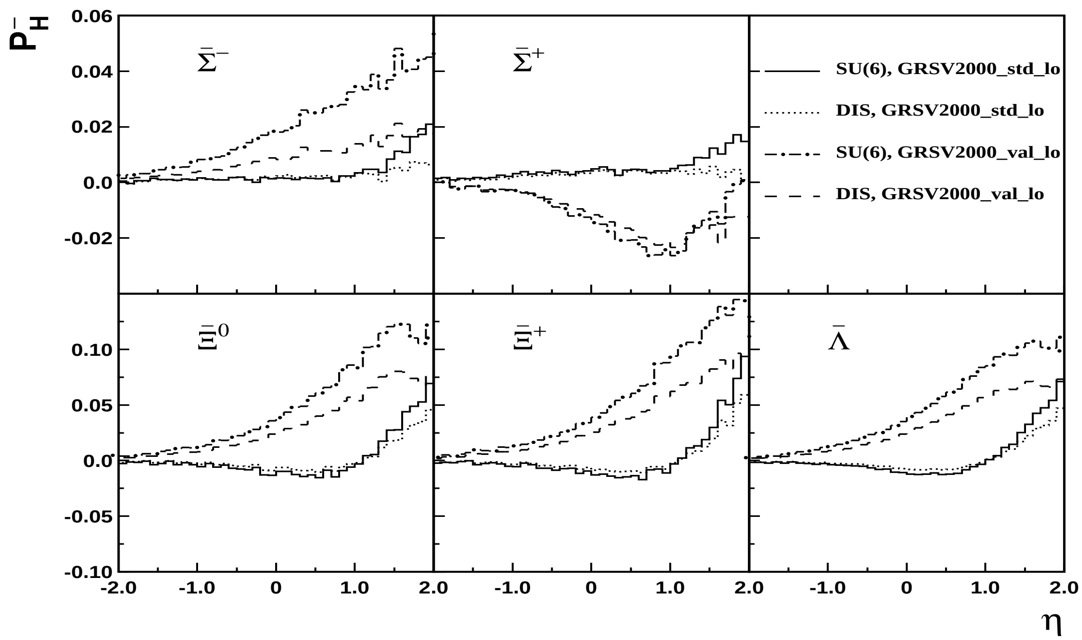

FIG. 7: Longitudinal polarization for anti-hyperons with transverse momentum $p_T \geq 8$ GeV/c in pp collisions at $\sqrt{s} = 200$ GeV with one longitudinally polarized beam versus pseudo-rapidity η. Positive η is taken along the direction of the polarized beam.

the mid-rapidity region, $|\eta| < 1$, for the $\bar{\Sigma}^-$, $\bar{\Sigma}^+$, $\bar{\Xi}^0$, $\bar{\Xi}^+$, as well as the $\bar{\Lambda}$. The anti-quark contributions generally increase with increasing p_T, and the gluon contributions decrease.

IV. RESULTS AND DISCUSSION

We have evaluated $P_{\bar{H}}$ for the $\bar{\Sigma}^-$, $\bar{\Sigma}^+$, $\bar{\Xi}^0$, and $\bar{\Xi}^+$ anti-hyperons as a function of η for $p_T \geq 8$GeV and $\sqrt{s} = 200\,$GeV using different parametrizations for the polarized parton distributions and using the SU(6) and DIS pictures for the spin transfer factors $t^F_{H,q}$ in the fragmentation. In all cases, the unpolarized parton distributions of Ref. [40] were used. The results using the polarized parton distributions of Ref. [31] are shown in Fig. 7, together with our previous results for $P_{\bar{\Lambda}}$ [25]. The main characteristics are:

- the size of the polarization increases in the forward direction with respect to the polarized proton beam and can be as large as 10% ($\bar{\Xi}^0$, $\bar{\Xi}^+$) at $\eta = 2$,

- the differences between the $\bar{H}$ polarizations obtained for different parametrizations of the polarized parton distribution functions are generally larger than the differences between the results for different models for the spin transfer in fragmentation,
- the size of the polarizations for the $\bar{\Sigma}^-$ and $\bar{\Sigma}^+$ hyperons is smaller than for the $\bar{\Lambda}$ and $\bar{\Xi}$ hyperons because of the lower fractional contributions from $\bar{u}$ and $\bar{d}$ fragmentation to $\bar{\Sigma}^-$ and $\bar{\Sigma}^+$ production than from $\bar{s}$ fragmentation to the $\bar{\Lambda}$ and $\bar{\Xi}$ production,
- the results for $\bar{\Sigma}^-$ and $\bar{\Sigma}^+$ for the GRSV2000 valence distributions differ in sign because of the sign difference in $\Delta\bar{u}(x)$ and $\Delta\bar{d}(x)$, and in size and shape because of flavor-symmetry breaking in the unpolarized and this polarized parton distribution scenario,
- the $\bar{\Xi}^0$ and $\bar{\Xi}^+$ polarizations are similar to each other because of the dominance of $\bar{s}$-fragmentation; they are somewhat larger than the $\bar{\Lambda}$ polarization because of the smaller decay contributions and their sensitivity to $\Delta\bar{s}$ is thus more direct.

Fig. 8 shows the polarizations in the pseudo-rapidity range $0 < \eta < 1$ versus transverse momentum p_T. The polarizations are sensitive mostly to the polarized anti-quark distributions for momentum fractions $0.05 < x < 0.25$ and the p_T-dependences are consequently not very strong. Only a modest variation is expected also with center-of-mass energy. To illustrate this, we have repeated the calculations for $\sqrt{s} = 500$ GeV. Fig. 9 shows the η-dependence for $p_T > 10\,\mathrm{GeV}$. Apart from differences expected from phase-space, the results are seen to be very similar to those in Fig. 7.

Last, we have estimated the precision with which $\bar{H}$ polarization measurements could be made at RHIC [27]. For an analyzed integrated luminosity of $\mathcal{L} \simeq 300\,\mathrm{pb}^{-1}$ and a proton beam polarization of $P \simeq 70\%$, we anticipate that e.g. $P_{\bar{\Xi}}$ could be measured to within $\sim$0.02 uncertainty. Measurements of $\bar{H}$ polarization at RHIC are thus worthwhile in view of the presently limited knowledge of $\Delta\bar{q}(x)$ in the nucleon, as evidenced in particular by the large differences between the parametrization sets of Ref. [31].

V. SUMMARY

In summary, we have evaluated the longitudinal polarizations of the $\bar{\Sigma}^-$, $\bar{\Sigma}^+$, $\bar{\Xi}^0$, and $\bar{\Xi}^+$ anti-hyperons in highly energetic collisions of longitudinally polarized proton beams. The results show sensitivity to the anti-quark polarizations in the nucleon sea. In particular,

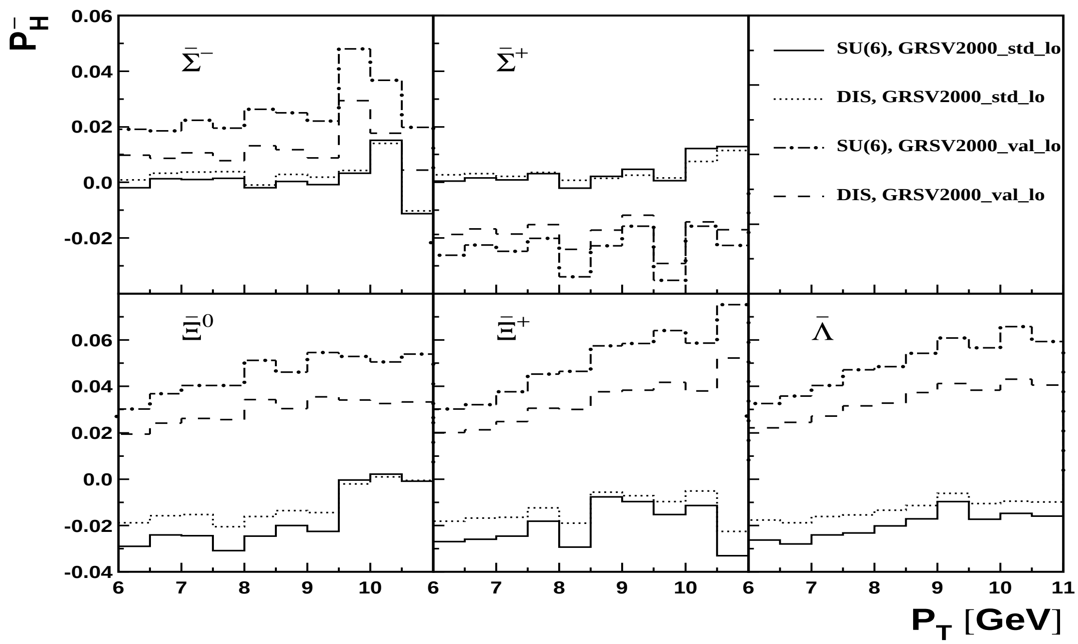

FIG. 8: Longitudinal polarization for anti-hyperons with pseudo-rapidity $0 < \eta < 1$ in pp collisions at $\sqrt{s} = 200$ GeV with one longitudinally polarized beam versus transverse momentum p_T. Positive η is taken along the direction of the polarized beam.

the $\bar{\Sigma}^-$ and $\bar{\Sigma}^+$ polarizations are sensitive to the light sea quark polarizations, $\Delta\bar{u}(x)$ and $\Delta\bar{d}(x)$. The $\bar{\Xi}^0$ and $\bar{\Xi}^+$ polarizations are sensitive to strange anti-quark polarization $\Delta\bar{s}(x)$. Precision measurements at the RHIC polarized pp-collider should be able to provide new insights in the sea quark polarizations in the nucleon.

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[1] T. D. Lee and C. N. Yang, Phys.Rev.108, 1645 (1957); T.D. Lee, J. Steinberger, G.Feinberg, P.K. Kabir, and C.N. Yang, Phys. Rev. 106, 1367 (1957).

[2] D. Buskulic *et al.* [ALEPH Collaboration], Phys. Lett. B **374**, 319 (1996).

[3] K. Ackerstaff *et al.* [OPAL Collaboration], Eur. Phys. J. C **2**, 49 (1998).

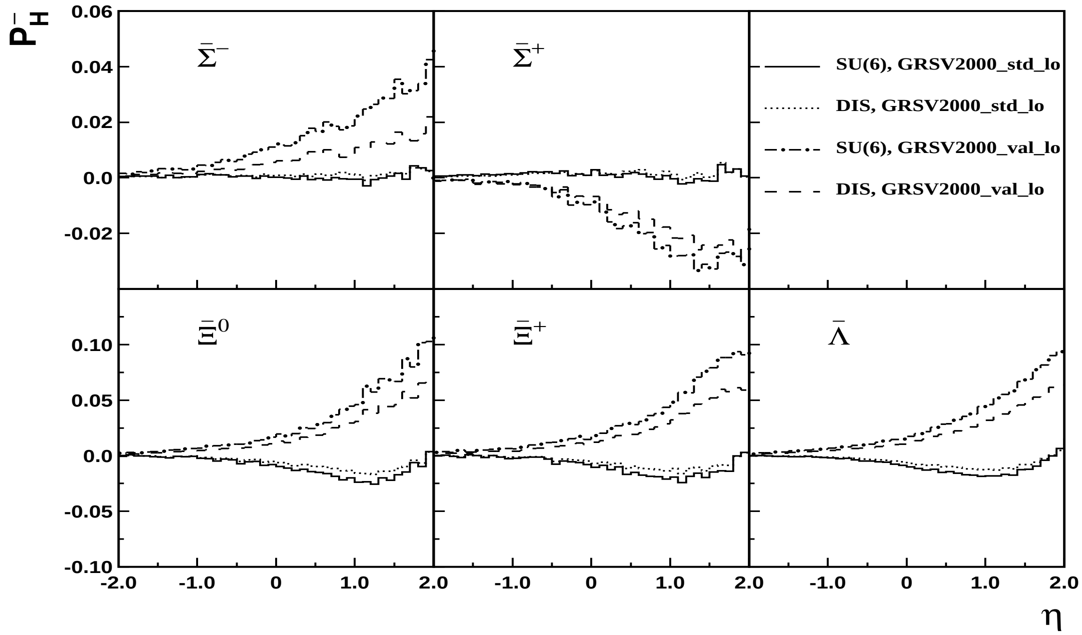

FIG. 9: Longitudinal polarization for anti-hyperons with $p_T > 10$ GeV as a function of the pseudo-rapidity η in pp collisions at $\sqrt{s} = 500$ GeV with one longitudinally polarized beam. Positive η is taken along the direction of the polarized beam.

[4] P. Astier *et al.* [NOMAD Collaboration], Nucl. Phys. B **588**, 3 (2000); **605**, 3 (2001).

[5] A. Airapetian *et al.* [HERMES Collaboration], Phys.Rev. D **64**, 112005 (2001); **74**, 072004 (2006).

[6] M. R. Adams *et al.* [E665 Collaboration], Eur. Phys. J. C **17**, 263 (2000).

[7] M. G. Sapozhnikov, [COMPASS Collaboration], hep-ex/0503009 and hep-ex/0602002; also V.Yu. Alexakhin, [COMPASS Collaboration], hep-ex/0502014.

[8] A. Lesnik *et al.,* Phys. Rev. Lett. **35**, 770 (1975); G. Bunce *et al.*, Phys. Rev. Lett. **36**, 1113 (1976); K. Heller *et al.*, Phys. Rev. Lett. **41**, 607 (1978); For a review, see e.g., A. Bravar, in Proc. of the 13th International Symposium on High Energy Spin Physics, Protvino, Russia, Septmber 1998, edited by N.E. Tyurin *et al*, World Scientific, Singapore, 1999, p.167.

[9] M. Burkardt and R. L. Jaffe, Phys. Rev. Lett. **70**, 2537 (1993); R. L. Jaffe, Phys. Rev. D **54**, 6581 (1996).

[10] G. Gustafson and J. Häkkinen, Phys. Lett. B **303**, 350 (1993).

[11] C. Boros and Z. T. Liang, Phys. Rev. D **57**, 4491 (1998).

[12] A. Kotzinian, A. Bravar and D. von Harrach, Eur. Phys. J. C **2**, 329 (1998).

[13] D. de Florian, M. Stratmann, and W. Vogelsang, Phys. Rev. Lett. **81**, 530 (1998); Phys. Rev. D**57**, 5811 (1998).

[14] B. Q. Ma and J. Soffer, Phys. Rev. Lett. **82**, 2250 (1999).

[15] C. X. Liu and Z. T. Liang, Phys. Rev. D **62**, 094001 (2000).

[16] C. X. Liu, Q. H. Xu and Z. T. Liang, Phys. Rev. D **64**, 073004 (2001).

[17] Q. H. Xu, C. X. Liu and Z. T. Liang, Phys. Rev. D **65**, 114008 (2002).

[18] Z. T. Liang and C. X. Liu, Phys. Rev. D **66**, 057302 (2002).

[19] Q. H. Xu and Z. T. Liang, Phys. Rev. D **70**, 034015 (2004).

[20] H. Dong, J. Zhou and Z. T. Liang, Phys. Rev. D **72**, 033006 (2005).

[21] C. Boros, J. T. Londergan and A. W. Thomas, Phys. Rev. D **62**, 014021 (2000).

[22] B. Q. Ma, I. Schmidt and J. J. Yang, Phys. Rev. D **61**, 034017 (2000); **63**, 037501 (2001); B. Q. Ma, I. Schmidt, J. Soffer and J. J. Yang, Phys. Rev. D **62**, 114009 (2000); Eur. Phys. J. C **16**, 657 (2000); Nucl. Phys. A **703**, 346 (2002).

[23] M. Anselmino, M. Boglione and F. Murgia, Phys. Lett. B **481**, 253 (2000).

[24] J. R. Ellis, A. Kotzinian and D. V. Naumov, Eur. Phys. J. C **25**, 603 (2002); J. Ellis, A. Kotzinian, D. Naumov and M. Sapozhnikov, arXiv:hep-ph/0702222.

[25] Q. H. Xu, Z. T. Liang, and E. Sichtermann, Phys. Rev. D **73**, 077503 (2006).

[26] Q. H. Xu [STAR collaboration], hep-ex/0512058 and hep-ex/0612035.

[27] G. Bunce, N. Saito, J. Soffer and W. Vogelsang, Ann. Rev. Nucl. Part. Sci. **50**, 525 (2000).

[28] J. Babcock, E. Monsay, D. W. Sivers, Phys. Rev. Lett. **40**, 1161 (1978); Phys. Rev. D **19**, 1483 (1979).

[29] B. Jäger, A. Schäfer, M. Stratmann, W. Vogelsang, Phys. Rev. D **67**, 054005 (2003).

[30] H. Plothow-Besch, Comput. Phys. Commun. **75**, 396-416 (1993).

[31] M. Glück, E. Reya, M. Stratmann and W. Vogelsang, Phys. Rev. D **63**, 094005 (2001); Phys. Rev. D **53**, 4775 (1996).

[32] J. Blümlein and H. Böttcher, Nucl. Phys. B **636**, 225 (2002).

[33] E. Leader, A. V. Sidorov and D. B. Stramenov, Phys. Rev. **D** 73, 034023 (2006); *ibid* **D** 75, 074027 (2007).

[34] T. Gehrmann and W. J. Stirling, Phys. Rev. D **53**, 6100 (1996).

[35] M. Hirai *et al.* [Asymmetry Analysis Collaboration] Phys. Rev. D **69**, 054021 (2004); *ibid* D **74**, 014015 (2006).

[36] D. De Florian and R. Sassot, Phys. Rev. D **62**, 094025 (2000).

[37] D. De Florian, G. A. Navarro, R. Sassot, Phys. Rev. D **71**, 094018 (2005).

[38] T. Sjöstrand, S. Mrenna, P. Skands, **JHEP 0605**, 026 (2006); B. Andersson, G. Gustafson, G. Ingelman and T. Sjöstrand, Phys. Rep. **97**, 31 (1983).

[39] V. N. Gribov, and L. N. Lipatov, Phys. Lett. B **37**, 78 (1971); Yad. Fiz. **15**, 1218 (1972) [Sov. J. Nucl. Phys. **15**, 675 (1972)].

[40] M. Glück, E. Reya, and A. Vogt, Eur. Phys. J. C **5**, 461 (1998).