Quark Distributions of Octet Baryons from SU(3) Symmetry

Bo-Qiang Ma\textsuperscript{a}, Ivan Schmidt\textsuperscript{b}, Jacques Soffer\textsuperscript{c}, and Jian-Jun Yang\textsuperscript{b,d}

\textsuperscript{a}Department of Physics, Peking University, Beijing 100871, China
\textsuperscript{b}Departamento de Física, Universidad Técnica Federico Santa María, Casilla 110-V, Valparaíso, Chile
\textsuperscript{c}Centre de Physique Théorique, CNRS, Luminy Case 907, F-13288 Marseille Cedex 9, France
\textsuperscript{d}Department of Physics, Nanjing Normal University, Nanjing 210097, China

Abstract

SU(3) symmetry relations between the octet baryons are introduced in order to connect both the unpolarized and polarized quark distributions of the octet baryons with those of the nucleon. Two different parametrizations of the nucleon quark distributions are used. A new scenario of quark flavor and spin structure of the Λ is found and compared with two other models: a perturbative QCD based analysis and a quark diquark model. The $u$ and $d$ quarks inside the Λ are predicted to be positively polarized at large Bjorken variable $x$ in the new scenario. By using an approximate...
relation connecting the quark fragmentation functions with the quark distributions, the hadron polarizations of the octet baryons in $e^+e^-$-annihilation, polarized charged lepton deep inelastic scattering (DIS) processes, and neutrino (antineutrino) DIS processes are predicted. The predictions for Λ polarizations in several processes are compatible with the available data at large fragmentation momentum fraction $z$, and support the prediction of positively polarized $u$ and $d$ quarks inside the Λ at large $x$. Predictions for Drell-Yan processes from $\Sigma^\pm$ and $\Xi^-$ beams on an isoscalar target are also given and discussed.

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1 Introduction

Quark distributions are important basic physical quantities containing the information of the underlying structure of the nucleon, and they can be precisely measured by combining various deep inelastic scattering (DIS) \[1\] and Drell-Yan processes \[2\]. After more than three decades of experimental studies, our knowledge of the quark distributions for the nucleon is more or less clear concerning the bulk features of momentum, flavor and helicity distributions, although there are still a number of uncertainties concerning the flavor and helicity structure of the sea quarks and also of the valence quarks at large Bjorken variable \(x \rightarrow 1\). High precision experiments on nucleons could in principle explore these regions, and therefore eliminate these uncertainties. However, it is also meaningful if we can find a new domain where the same physics concerning the quark distributions of the nucleon can manifest itself in a way that is easy and clean to be detected and studied. Indeed, the quark structure of the \(\Lambda\) hyperon has become a new area to study the quark structure of hadrons, and there has been continuous progress in this direction recently \[3-23\]. There are also proposals to study the quark structure of \(\Sigma\) and \(\Xi\) hyperons \[19, 24, 25\]. Therefore it is timely to study the quark distributions of other baryons, in addition to those of the nucleon.

In principle, the precise knowledge of quark distributions of the other baryons should be measured from experiments, and then compared with theoretical predictions. There have been a number of predictions on the quark distributions of \(\Lambda\) via fragmentation processes \[12, 13, 17, 18, 19\], and on quark distributions of \(\Sigma\) and \(\Xi\) through Drell-Yan processes \[24\]. All of these predictions suffer, to some extent, from theoretical uncertainties. In fact, the quark distributions of the octet baryons should be related to each other from theoretical considerations, but the precise form of this relation is not known. The purpose of this paper is to study the quark distributions of the other octet baryons by connecting them with the quark distributions of the nucleon using SU(3) symmetry relations. For the quark distributions of the nucleon we do not use theoretical calculations, instead, we use available parametrizations. In this way we are able to make realistic predictions concerning the bulk features of
physical quantities related to the quark distributions of the other baryons. If these theoretical predictions disagree with future experimental measurements, then we will be able to modify our approach in two possible ways. First, to change the relations used for connecting the quark distributions between different baryons. For example, we can consider SU(3) breaking effects between the quark distributions of different baryons, and we should be able to study and extract these SU(3) breaking effects with more experimental data of quark distributions for different baryons. Second, to use the experimental results of the quark distributions of other baryons to constrain the uncertainties of quark distributions of the nucleon. For example, the discrepancies between predictions and experiments may come from improper assumptions in the quark distributions of the nucleon, and the effects of these assumptions lead to incorrect behaviors of the quark distributions of the other octet baryons. Therefore we can use the quark distributions of the other baryons as a laboratory to test the quark distributions of the nucleon.

In Section 2 we will use SU(3) symmetry to connect the quark distributions of the other octet baryons with those of the nucleon. Using two available parametrizations of unpolarized and polarized nucleon quark distributions, we find a new scenario for the quark flavor and spin structure of the Λ, different from two models already known: a perturbative QCD based analysis and a quark spectator diquark model. In Section 3 we will make predictions of various quark to octet baryon fragmentations in several processes, by using an approximate relation to connect the quark distributions with fragmentation functions. It will be shown that the predicted Λ polarizations in several processes are consistent with available data at large fragmentation momentum fraction \( z \), and predictions for other octet baryon polarizations are also made. In Section 4, we present our predictions for the cross sections in Drell-Yan processes induced by \( \Sigma^\pm \) and \( \Xi^- \) beams. The quark distributions of the \( \Sigma^\pm \) and \( \Xi^- \) hyperons are directly used in the calculations, therefore these processes are most suitable to explore the sea quark content of the octet baryons and the SU(3) relations between octet baryons. Section 5 is devoted to some discussions and summary.
There have been a number of parametrizations of the unpolarized \cite{26,27,28} and polarized \cite{29,30,31,32,33} quark distributions of the nucleon. In Section 3 we will study the baryon polarization in quark fragmentation, and for this purpose we need both the unpolarized and polarized quark distributions of the baryons. We choose two sets of parametrizations for both the unpolarized and polarized quark distributions of the nucleon \cite{27,28,29,30}, in order to illustrate our procedure for extending the quark distributions from the nucleon to other octet baryons, by using SU(3) symmetry relations. Although the quark-antiquark pairs in the baryon may have non-trivial behaviors, such as quark-antiquark asymmetry \cite{34}, it is still common practice to assume quark-antiquark symmetry, in the available standard parametrizations of quark distributions. Therefore we will assume the following symmetry relations for the sea quark distributions in the baryon $B$

\begin{equation}
q_s^B(x) = \overline{q}^B(x), \quad \Delta q_s^B(x) = \Delta \overline{q}^B(x),
\end{equation}

where $q_s^B(x)$ means the sea quark distribution of $B$ and $\overline{q}^B(x)$ means the antiquark distribution of the baryon sea. The valence quark distribution of the baryon is then defined as

\begin{equation}
q_v^B(x) = q^B(x) - \overline{q}^B(x), \quad \Delta q_v^B(x) = \Delta q^B(x) - \Delta \overline{q}^B(x),
\end{equation}

where $q^B(x)$ means the quark distributions of both valence and sea quarks with flavor $q$ in $B$. In the parametrizations of quark distributions of the nucleon, only the relations $q_v = q_v^p$ and $\overline{q} = \overline{q}^p$ for unpolarized, and $\Delta q_v = \Delta q_v^p$ and $\Delta \overline{q} = \Delta \overline{q}^p$ for polarized ones, are needed for a whole set of quark distributions.

The SU(3) symmetry relations between the quark distributions of $p$, $n$, $\Sigma^\pm$, $\Xi^-$,
and \( \Xi^0 \) can be simply obtained by permutations between \( u \rightarrow d \rightarrow s \) and \( \overline{u} \rightarrow \overline{d} \rightarrow \overline{s} \)

\[
\begin{align*}
u^p &= d^n = u^{\Sigma^+} = d^{\Sigma^-} = s^{\Xi^-} = s^{\Xi^0} = u; \\
d^p &= u^n = s^{\Sigma^+} = s^{\Sigma^-} = d^{\Xi^-} = u^{\Xi^0} = d; \\
s^p &= s^n = d^{\Sigma^+} = u^{\Sigma^-} = s^{\Xi^-} = d^{\Xi^0} = s; \\
\overline{\pi}^p &= \overline{d}^n = \overline{u}^{\Sigma^+} = \overline{d}^{\Sigma^-} = \overline{s}^{\Xi^-} = \overline{s}^{\Xi^0} = \overline{u}; \\
\overline{d}^p &= \overline{u}^n = \overline{s}^{\Sigma^+} = \overline{u}^{\Sigma^-} = \overline{d}^{\Xi^-} = \overline{d}^{\Xi^0} = \overline{s}; \\
\overline{s}^p &= \overline{s}^n = \overline{d}^{\Sigma^+} = \overline{s}^{\Sigma^-} = \overline{u}^{\Xi^-} = \overline{u}^{\Xi^0} = \overline{d}. \\
\end{align*}
\]

For \( \Sigma^0 \) we notice the relation

\[
\Sigma^0 = \frac{1}{2}(\Sigma^+ + \Sigma^-),
\]

therefore we get

\[
\begin{align*}
u^{\Sigma^0} &= \frac{1}{2}(u^{\Sigma^+} + u^{\Sigma^-}) = \frac{1}{2}(u + s); \\
d^{\Sigma^0} &= \frac{1}{2}(d^{\Sigma^+} + d^{\Sigma^-}) = \frac{1}{2}(u + s); \\
s^{\Sigma^0} &= \frac{1}{2}(s^{\Sigma^+} + s^{\Sigma^-}) = d; \\
\overline{u}^{\Sigma^0} &= \frac{1}{2}(\overline{u}^{\Sigma^+} + \overline{u}^{\Sigma^-}) = \frac{1}{2}(\overline{u} + \overline{s}); \\
\overline{d}^{\Sigma^0} &= \frac{1}{2}(\overline{d}^{\Sigma^+} + \overline{d}^{\Sigma^-}) = \frac{1}{2}(\overline{u} + \overline{s}); \\
\overline{s}^{\Sigma^0} &= \frac{1}{2}(\overline{s}^{\Sigma^+} + \overline{s}^{\Sigma^-}) = \overline{d}. \\
\end{align*}
\]

For \( \Lambda \), the SU(3) relation connecting its valence quarks with those of the proton \[19\] is

\[
\begin{align*}
u^\Lambda &= d^\Lambda = \frac{1}{6}u_v + \frac{4}{6}d_v; \\
s^\Lambda &= \frac{2}{3}u_v - \frac{1}{3}d_v.
\end{align*}
\]

We also know from the baryon-meson fluctuation picture of the intrinsic sea quark-antiquark pairs \[34\], that \( \Lambda \) should have a similar sea structure as \( \Sigma^0 \), therefore we use

\[
\begin{align*}
\overline{\nu}^\Lambda &= \overline{d}^{\Sigma^0} = \frac{1}{2}(\overline{u} + \overline{s}); \\
\overline{d}^\Lambda &= \overline{s}^{\Sigma^0} = \frac{1}{2}(\overline{u} + \overline{s}); \\
\overline{s}^\Lambda &= \overline{u}^{\Sigma^0} = \overline{d}. \\
\end{align*}
\]

Although there might be some model-dependence in the above relations for the sea of \( \Lambda \), such relations can be investigated and checked by looking at the quark distributions of \( \Lambda \) at small \( x \). Nevertheless, this will not affect much our predictions for the \( \Lambda \).
polarization in quark fragmentation, since these predictions are only reliable at large \( x \), a region depending mainly on the valence structure of the \( \Lambda \) (see Section 3). Therefore we have all the necessary relations for extending the quark distributions of the nucleon to those of the other members of the octet baryons, and we list the above results in Table 1. The formulae for the polarized quark distributions can be simply obtained by adding \( \Delta \) in front of the unpolarized ones. We notice that \( s - \bar{s} = 0 \) in the standard quark distributions with a quark-antiquark symmetric sea.

Table 1  The quark distributions of the octet baryons from SU(3) symmetry

| Baryon | \( u^B \) | \( d^B \) | \( s^B \) | \( \bar{\nu}^B \) | \( \bar{\tau}^B \) | \( \bar{\pi}^B \) |
|--------|-------|-------|-------|--------|--------|--------|
| \( p \) | \( u_v \) | \( d_v \) | \( s - \bar{s} \) | \( \bar{\nu} \) | \( \bar{\tau} \) | \( \bar{\pi} \) |
| \( n \) | \( d_v \) | \( u_v \) | \( s - \bar{s} \) | \( \bar{\nu} \) | \( \bar{\tau} \) | \( \bar{\pi} \) |
| \( \Sigma^+ \) | \( u_v \) | \( s - \bar{s} \) | \( d_v \) | \( \bar{\nu} \) | \( \bar{\tau} \) | \( \bar{\pi} \) |
| \( \Sigma^0 \) | \( u_v \) | \( s - \bar{s} \) | \( d_v \) | \( \bar{\nu} \) | \( \bar{\tau} \) | \( \bar{\pi} \) |
| \( \Sigma^- \) | \( s - \bar{s} \) | \( u_v \) | \( d_v \) | \( \bar{\nu} \) | \( \bar{\tau} \) | \( \bar{\pi} \) |
| \( \Lambda^0 \) | \( u_v \) | \( s - \bar{s} \) | \( d_v \) | \( \bar{\nu} \) | \( \bar{\tau} \) | \( \bar{\pi} \) |
| \( \Xi^- \) | \( s - \bar{s} \) | \( d_v \) | \( u_v \) | \( \bar{\nu} \) | \( \bar{\tau} \) | \( \bar{\pi} \) |
| \( \Xi^0 \) | \( \bar{u}_v \) | \( s - \bar{s} \) | \( \bar{d}_v \) | \( \bar{\nu} \) | \( \bar{\tau} \) | \( \bar{\pi} \) |

In fact, the results in Table 1 can be applied to any set of parametrized nucleon quark distributions, in order to get the quark distributions of other octet baryons. As an example of the application, we will choose two sets of parametrizations for both the unpolarized and polarized quark distributions of the nucleon.

The Set-1 unpolarized and polarized nucleon quark distributions are taken from Ref. [27] (with ISET=2, NLO, MS-Scheme) and Ref. [29] (with ISET=1, NLO, MS-Scheme), respectively. The Set-2 unpolarized and polarized nucleon quark distributions are taken from Ref. [28] (With Mod=1, Set=COR01, central gluon and \( \alpha_s \)) and Ref. [30] (with Iflag=0, gluon set A), respectively.

These quark distributions may not fully match at large \( x \), because from the lack of data in this region, the behaviors for \( x \rightarrow 1 \) are not well determined, so that the relations between the unpolarized and polarized parametrizations are not well con-
Figure 1: The quark ratios of the proton in the two sets of quark distributions: (a) $d(x)/u(x)$; (b) $\Delta u(x)/u(x)$; (c) $\Delta d(x)/d(x)$.

trolled. The unpolarized nucleon quark distributions are well constrained by a large amount of data, so that different sets of quark distributions should be in close agreement. However the difference between different sets of polarized quark distributions can be larger, since at the $x \to 1$ end-point, the flavor structure of the polarized quark distributions is still not well known experimentally. The flavor and helicity structure of the two sets of nucleon quark distributions is reflected in the ratios $d(x)/u(x)$, $\Delta u(x)/u(x)$, and $\Delta d(x)/d(x)$, shown in Fig. 1. We notice that $d(x)/u(x) \to 0$ as $x \to 1$, in agreement with the quark-diquark model prediction [35, 36, 37]. However, $\Delta u(x)/u(x) < 0.8$ as $x \to 1$ in the two sets of nucleon quark distributions, with some difference from both the quark-spectator-diquark (quark-diquark) model [37] and the perturbative QCD based analysis [38, 39], which both predict $\Delta u(x)/u(x) \to 1$ as $x \to 1$. We also notice that $\Delta d(x)/d(x)$ in the range $[-0.4, -0.2]$ as $x \to 1$ for the two sets and this is inconsistent with the perturbative QCD analysis, which predicts $\Delta d(x)/d(x) \to 1$ as $x \to 1$ [38, 39], but roughly consistent with the quark-diquark model, which predicts $\Delta d(x)/d(x) \to -1/3$ as $x \to 1$ [37]. At large $x$, say $x \sim 0.9$, the behavior of Set-2 for $\Delta u(x)/u(x)$ and of both Set-1 and Set-2 of $\Delta d(x)/d(x)$ seem to be consistent with the quark-diquark model. Nevertheless large uncertainties remain for the parametrizations of polarized quark distributions for $x \sim 1$, due to the absence of data.

It has been suggested that the $\Lambda$ quark distributions at large $x$ are sensitive to different predictions of the flavor and helicity structure of the nucleon quark distri-
butions. By using the SU(3) relations in Table 1, we can get the quark distributions of the Λ from those of the nucleon, and we present the ratios \( \frac{u^\Lambda(x)}{s^\Lambda(x)} \), \( \Delta s^\Lambda(x)/s^\Lambda(x) \), and \( \Delta u^\Lambda(x)/u^\Lambda(x) \) in Fig. 3. It is interesting to remark that we have \( \frac{u^\Lambda(x)}{s^\Lambda(x)} = 0.25 \) at \( x \to 1 \), and this is different from both the quark-diquark model prediction of 0 and the perturbative QCD prediction of 0.5 \([12, 13, 19]\). This feature can be easily understood since at large \( x \to 1 \)

\[
\frac{u^\Lambda(x)}{s^\Lambda(x)} \approx \frac{u^\Lambda_v(x)}{s^\Lambda_v(x)} = \frac{u_v + 4d_v}{4u_v - 2d_v} = \frac{1 + 4d_v/u_v}{4 - 2d_v/u_v} = \begin{cases} 
\frac{1}{4} & \text{for } \frac{d_v}{u_v} = 0; \\
\frac{1}{2} & \text{for } \frac{d_v}{u_v} = \frac{1}{5}.
\end{cases} \tag{8}
\]

The above result of \( \left. \frac{u^\Lambda_v(x)}{s^\Lambda_v(x)} \right|_{x=1} = 1/4 \) for \( d_v/u_v = 0 \) comes from the SU(3) symmetry relations. We know that the quark-diquark model predicts \( \left. \frac{u^\Lambda_v(x)}{s^\Lambda_v(x)} \right|_{x=1} = 0 \), although it also predicts \( \left. \frac{d_v(x)}{u_v(x)} \right|_{x=1} = 0 \) \([12, 13, 19]\). The difference between the above two different scenarios is due to the fact that the quark-diquark model breaks SU(3) symmetry, and this breaking comes from the use of different quark and diquark masses. In the perturbative QCD analysis, the helicity aligned distributions (+) is dominant over the helicity anti-aligned (-), and therefore SU(6) is broken to SU(3)+×SU(3)-, which is a different symmetry from the usually flavor SU(3) that we are considering here. Therefore we arrive at the conclusion that the flavor structure of the Λ hyperon at large \( x \) is also sensitive to the SU(3) symmetry between different baryons, and it is therefore an important region to test different conjections and theories. The behavior of \( \Delta u^\Lambda(x)/u^\Lambda(x) \) at large \( x \) is also interesting, since the SU(3) symmetry relations predict also positively polarized \( u \) and \( d \) quark distributions at large \( x \), as can be seen from Fig. 3 (b), and this coincides with the predictions of both the quark-diquark model and the perturbative QCD analysis. From the recent progress on Λ production in various quark fragmentation processes, we know that the prediction of positively polarized \( u \) and \( d \) quarks inside the Λ is supported by all of the available data \([12, 13, 17, 18, 19]\). In the next section, we will present our predictions for baryon polarizations in various quark fragmentation processes using the above SU(3) relations for the quark distributions of baryons.
Figure 2: The quark ratios of the Λ in the two sets of quark distributions:
(a) $u^Λ(x)/s^Λ(x)$; (b) $Δu^Λ(x)/u^Λ(x)$; (c) $Δs^Λ(x)/s^Λ(x)$.

3 Baryon Polarizations in Quark Fragmentations

Although the quark structure of the Λ has some significant features which can be
used to distinguish between different predictions, it is difficult to measure the quark
distributions of the Λ directly, since the Λ is a charge neutral-particle which cannot
be accelerated as incident beam and its short lifetime makes it also difficult to be used
as a target. However, there have been attempts to connect the quark distributions
with the quark fragmentation functions, so that one can use hadron productions from
quark fragmentations to check the quark structure of hadrons. The connection is the
so called Gribov-Lipatov (GL) relation \[40\]

$$D^h_q(z) \sim z q_h(z),$$

where $D^h_q(z)$ is the fragmentation function for a quark $q$ splitting into a hadron $h$
with longitudinal momentum fraction $z$, and $q_h(z)$ is the quark distribution of finding
the quark $q$ carrying a momentum fraction $x = z$ inside the hadron $h$. The GL
relation should be considered as an approximate relation near $z \to 1$ at an input
energy scale $Q^2_0$ \[41\], \[42\]. It is interesting to note that such a relation provided
successful descriptions of the available Λ polarization data in several processes \[12\],
\[13\], \[7\], \[18\], \[19\], based on quark distributions of the Λ in the quark diquark model
and in the pQCD based counting rule analysis. Thus we still use (9) as an Ansatz
to relate the quark fragmentation functions to the corresponding quark distributions.
This may be understood as a phenomenological method to parametrize the quark
fragmentation functions, and then we can check and improve these fragmentation functions by comparing the predictions with experimental observations. To reduce the uncertainties in the GL relation, we will only predict the baryon polarizations, rather than the absolute values of cross sections.

### 3.1 Baryon Polarizations in $e^+e^-$ Annihilation

In the standard model of electroweak interactions, the quarks and antiquarks produced in unpolarized $e^+e^-$-annihilation near the Z pole should be polarized due to the parity-violating coupling of the fermions, and this leads to the polarizations of the hadrons produced in quark fragmentations. The hadron polarization in $e^+e^-$-annihilation can be written as

$$P_h = -\frac{\sum_q A_q[\Delta D^h_q(z) - \Delta D^b_q(z)]}{\sum_q C_q[D^h_q(z) + D^b_q(z)]},$$

where $A_q$ and $C_q$ are determined by the standard model. Explicit expressions can be found in Refs. [12, 19]. $D^h_q(z)$ and $\Delta D^h_q(z)$ are the unpolarized and polarized fragmentation functions for the quark with flavor $q$ splitting into hadron $h$. Using the GL relation, we can then calculate the hadron polarizations for the octet baryons with the two sets of octet baryon quark distributions described in the last section. Uncertainties in the absolute magnitude of fragmentation functions can be reduced, since the hadron polarization (10) only involves ratios between different fragmentation functions. In Fig. 3 we present our predictions for the longitudinal hadron polarizations of the octet baryons in $e^+e^-$-annihilation at two energies: LEP I at the Z resonance $\sqrt{s} \approx 91$ GeV and LEP II at $\sqrt{s} \approx 200$ GeV. The available experimental data of the $\Lambda$ are taken at the Z resonance [43, 44, 45], and from the figure we find that the calculated results are compatible with the data. This supports the prediction of positively polarized $u$ and $d$ quarks inside the $\Lambda$ at large $x$, similar to the results in Refs. [12, 19]. More experimental data for the octet baryon polarizations in $e^+e^-$-annihilation are necessary in order to check different predictions.
Figure 3: The predictions of the longitudinal hadron polarizations for the octet baryons in $e^+e^-$-annihilation at two energies: LEP I at $Z$ resonance $\sqrt{s} \approx 91$ GeV (thick curves) and LEP II at $\sqrt{s} \approx 200$ GeV (thin curves), with the input fragmentation functions from the SU(3) symmetry of quark distributions for the octet baryons by the Gribov-Lipatov relation [40]. The solid curves and the dashed curves correspond to the Set-1 and Set-2 quark distributions of the nucleon, respectively. The experimental data are taken from Refs. [43, 44, 45].
3.2 Baryon Polarizations in Charged Lepton DIS Process

In deep inelastic scattering of a longitudinally polarized charged lepton on an unpolarized nucleon target, the scattered quark will be polarized and its spin will be transferred to the baryon produced in the fragmentation of this quark. The longitudinal spin transfer to the outgoing hadron \( h \) is given in the quark-parton model by

\[
A^h(x, z) = \frac{\sum_q e^2_q q^N(x, Q^2) \Delta D^h_q(z, Q^2) + (q \rightarrow \overline{q})}{\sum_q e^2_q [q^N(x, Q^2) D^h_q(z, Q^2) + (q \rightarrow \overline{q})]},
\]

where a detailed description of the quantities in the above formula can be found in Refs. [6, 12, 17, 18]. We can also calculate the spin transfers for the octet baryons with the two sets of quark distributions as input, and we present our predictions in Figs. 4 and 5. The final detected hadron could be either a baryon or an antibaryon, and a combination of both data provide information of quark and antiquark to hadron fragmentations. Therefore we present our predictions of the spin transfers for both baryons and antibaryons respectively. There is some preliminary data by the HERMES Collaboration [46] on \( \Lambda \) production, and by E665 Collaboration [47] on \( \Lambda \) and \( \overline{\Lambda} \) productions. The E665 data are too rough, and mainly focused on the small \( z \) region where the GL relation is not expected to work well. Our calculated results based on the SU(3) relations of quark distributions are consistent with the HERMES point, and this supports the prediction of positively polarized \( u \) and \( d \) quarks inside the \( \Lambda \). However, the \( \Xi^0 \) (and \( \Xi^0 \)) polarizations are predicted to be negative at large \( z \), and this differs from either the quark-diquark model and the perturbative QCD analysis, as can be seen by compare Figs. 4(e) and 5(e) with Figs. 2(e) and 3(e) in Ref. [19]. There are several reasons for negative \( \Xi^0 \) (and \( \Xi^0 \)) polarizations. First, \( u \rightarrow \Xi^0 \) is a dominant fragmentation chain as a result of the dominant \( u \) quarks of the target and the squared charge factor of \( 4/9 \). Second, the \( u \) quarks are negatively polarized inside the \( \Xi^0 \) and also the ratio \( u \Xi^- (x) / s \Xi^- (x) = 1/4 \) is not negligible when \( x \rightarrow 1 \). Thus \( \Xi^0 \) and \( \Xi^0 \) polarizations in polarized DIS process are sensitive physical quantities that can distinguish between different scenarios concerning the flavor and helicity structure of the octet baryons at large \( x \) (For similar and detailed discussions,
3.3 Baryon Polarizations in Neutrino DIS Process

As has been pointed out in Refs. [11, 17], the DIS scattering of a neutrino beam on a hadronic target provides a source of polarized quarks with specific flavor structure, and this makes it an ideal system to study the flavor dependence of quark to hadron fragmentation functions, especially in the polarized case. For the production of any hadron $h$ from neutrino and antineutrino DIS processes, the longitudinal polarization of $h$ in its momentum direction, for $h$ in the current fragmentation region, can be expressed as [11, 17],

$$P_h^\nu(x, y, z) = -\frac{d(x) + \omega s(x)[\Delta D_h^u(z) + \omega \Delta D_h^d(z)]}{[d(x) + \omega s(x)]D_h^u(z) + (1 - y)^2\bar{u}(x)[D_h^d(z) + \omega D_h^s(z)]},$$  \hspace{1cm} (12)

$$P_h^\bar{\nu}(x, y, z) = -\frac{(1 - y)^2u(x)[\Delta D_h^d(z) + \omega \Delta D_h^s(z)] - [\bar{d}(x) + \omega \bar{s}(x)]\Delta D_h^u(z)}{(1 - y)^2u(x)[D_h^d(z) + \omega D_h^s(z)] + [\bar{d}(x) + \omega \bar{s}(x)]D_h^u(z)},$$  \hspace{1cm} (13)

where the terms with the factor $\omega = \sin^2 \theta_c / \cos^2 \theta_c$ ($\theta_c$ is the Cabibbo angle) represent Cabibbo suppressed contributions. The beam can be either neutrino or antineutrino, and the produced hadron can be either baryon or antibaryon. Therefore we have four combinations of different beams and fragmented baryons, and they can provide different information on the flavor dependence of quark fragmentation functions. We present in Figs. 6-13 the longitudinal polarizations in the four different combinations of beams and produced hadrons for each member of the octet baryons. For $\Lambda$ production in neutrino DIS process, there have been preliminary results by the NOMAD collaboration [48, 49] which seem to support a positively polarized $u$ and $d$ quarks inside the $\Lambda$ [50]. We notice that our prediction for the $\Lambda$ polarization is compatible with the data [49] at large $z$, although there is one experimental point at rather low $z$ that does not seem to be consistent with our results, as can be seen in Fig. 6. Further studies are needed, both theoretically and experimentally, concerning the detailed features of $\Lambda$ production in neutrino DIS processes. More precise measurements of $\Lambda$ ($\bar{\Lambda}$) polarization in neutrino and antineutrino DIS processes seem hard to perform.
Figure 4: The predictions of the $z$-dependence for the hadron spin transfers of the octet baryons in polarized charged lepton DIS process on the proton target. The input fragmentation functions are from the SU(3) symmetry of quark distributions for the octet baryons by the Gribov-Lipatov relation \[40\]. The solid curves and the dashed curves correspond to the predictions using the Set-1 and Set-2 quark distributions of the nucleon.
Figure 5: The predictions of $z$-dependence for the anti-hadron spin transfers of the octet antibaryons in polarized charged lepton DIS process on the proton target. The others are the same as Fig. 4.
Figure 6: The predictions of $z$-dependence for the hadron and anti-hadron polarizations of $\Lambda$ in the neutrino (antineutrino) DIS process. The input fragmentation functions are from the SU(3) symmetry of quark distributions for the octet baryons by the Gribov-Lipatov relation. The solid curves and the dashed curves correspond to the predictions using the Set-1 and Set-2 quark distributions of the nucleon, for the proton target $Q^2 = 4$ GeV$^2$ with the Bjorken variable $x$ integrated over $0.02 \rightarrow 0.4$ and $y$ integrated over $0 \rightarrow 1$.

before more intense neutrino beams or a neutrino factory \cite{51} become available. Another realistic possibility is the production of $\Lambda$ in charged current semi-inclusive DIS at HERA. We need to mention that several processes are dominated by antiquark contributions: $\Sigma^-$ and $\Xi^-$ productions in neutrino process, and $\Sigma^+$ and $\Xi^+$ productions in antineutrino process. In Figs. (9) and (11) we remove the predictions for these processes at $x > 0.6$, due to the reason that the two parametrizations have some unphysical points with $|\Delta q/q| > 1$ in this region.

From the above discussions of baryon polarizations in three different processes, we arrive at the conclusion that all of the available data of $\Lambda$ polarization support positively polarized $u$ and $d$ quarks inside the $\Lambda$ at large $x$, and are compatible with the theoretical predictions based on SU(3) symmetric quark distributions. Of course, detailed features still need further studies to confront theoretical understandings with experimental observations (For some discussions, see Refs. \cite{12, 13, 17, 18, 19, 20, 24}).
Figure 7: The same as Fig. 6, but for predictions of $z$-dependence for the hadron and anti-hadron polarizations of $\Sigma^0$ in the neutrino (antineutrino) DIS process.

Figure 8: The same as Fig. 6, but for predictions of $z$-dependence for the hadron and anti-hadron polarizations of $\Sigma^+$ in the neutrino (antineutrino) DIS process.
Figure 9: The same as Fig. 6, but for predictions of $z$-dependence for the hadron and anti-hadron polarizations of $\Sigma^{-}$ in the neutrino (antineutrino) DIS process.

Figure 10: The same as Fig. 6, but for predictions of $z$-dependence for the hadron and anti-hadron polarizations of $\Xi^{0}$ in the neutrino (antineutrino) DIS process.
Figure 11: The same as Fig. 6, but for predictions of $z$-dependence for the hadron and anti-hadron polarizations of $\Xi^-$ in the neutrino (antineutrino) DIS process.

Figure 12: The same as Fig. 6, but for predictions of $z$-dependence for the hadron and anti-hadron polarizations of $p$ in the neutrino (antineutrino) DIS process.
The above predictions of baryon polarizations in quark fragmentations rely on the GL relation connecting the fragmentation functions with the distribution functions, and such a relation has not been firmly established, especially at small $x$, although there have been some encouraging results to support the use of this relation from the available $\Lambda$ polarization data in several processes. Therefore in order to study the SU(3) symmetry relations of the quark distributions between different octet baryons, it is better to study the quark distributions directly, instead of the fragmentation functions. It has been proposed \cite{24} that the Drell-Yan process of $\Sigma^\pm$ and $\Xi^-$ beams on the isoscalar target can be used to study the quark distributions of $\Sigma^\pm$ and $\Xi^-$ hyperons. It is the purpose of this section to perform such a study by using the two sets of quark distributions for the octet baryons described in Section 2.

For the Drell-Yan process

$$\Sigma N \rightarrow l^+l^-X,$$  \hspace{1cm} (14)
the cross section can be written as
\[ \sigma(\Sigma N) = \frac{8\pi\alpha^2}{9\sqrt{\tau}} K(x_1, x_2) \sum_f e_f^2 [q^\Sigma_f(x_1)\bar{q}_f(x_2) + \bar{q}^\Sigma_f(x_1)q_f(x_2)], \]  
(15)
where \( \sqrt{\tau} = M/\sqrt{s} \), \( M \) is the mass of the dilepton pair and \( \sqrt{s} \) the total c.m. energy. The factor \( K(x_1, x_2) \) is due to higher-order QCD corrections. For an isoscalar target with nucleon number \( A \), we obtain the cross sections
\[ \sigma^\pm = \sigma(\Sigma^\pm A) = \frac{A}{2} \left[ \sigma(\Sigma^\pm p) + \sigma(\Sigma^\pm n) \right]; \]  
(16)
from which we can obtain the ratio
\[ T(x_1, x_2) = \frac{\sigma^+(x_1, x_2)}{\sigma^-(x_1, x_2)}. \]  
(17)
Thus we can calculate this ratio with the two sets of quark distributions of octet baryons. On the experimental side, it is convenient to use the variables \( \tau \) and \( y \), where \( y \) is the rapidity of the dilepton pair, instead of the variables \( x_1 \) and \( x_2 \), through the relations
\[ x_1 = e^y \sqrt{\tau}; \]
\[ x_2 = e^{-y} \sqrt{\tau}. \]  
(18)
Thus we can express the quantity \( T \) as a function of \( \tau \) and \( y \). We present our predictions for \( T \) versus three different kinematic variables in Figs. 14-16. The advantage of these calculations is the fact that we know the complete quark distributions needed in \( T \) from the two sets of quark distributions, and therefore we do not need to make the valence-dominance approximation in the calculations. We also present our calculation for \( T \) with the two sets of quark distributions by turning off the sea contributions in Eq. (17), and find a big difference at \( x_1, x_2 < 0.7 \) compared with the present calculation which contains all quark contributions. This means that the sea quarks play an important role in the Drell-Yan process and they cannot be simply neglected in the numerical evaluation for \( x_1, x_2 < 0.7 \).

Similar discussions and predictions can be also extended to the case where the charged octet baryon \( \Xi^- \) is used as the beam, i.e., for the Drell-Yan process
\[ \Xi^- N \rightarrow l^+ l^- X. \]  
(19)
Figure 14: The thick curves are $T(x_1, x_2)$ in the two sets of quark distributions at fixed $x_2 = 0.3$ as a function of $x = x_1$, whereas the thin curves are the corresponding $T(x_1, x_2)$ with only valence quark contributions.

Figure 15: The thick curves are $T(x_1, x_2)$ in the two sets of quark distributions at fixed $y = 0$ as a function of $\tau$, whereas the thin curves are the corresponding $T(x_1, x_2)$ with only valence quark contributions.

In this case $s$ is the dominant valence quark and $d$ is the less dominant valence quark at large $x$ inside the $\Xi^-$, and this can provide further information to check the flavor structure of the two sets of quark distributions. We expect that the sea quarks also play an important role in this case (For detailed formulae and discussions see Ref. [24]).
Figure 16: The thick curves are $T(x_1, x_2)$ in the two sets of quark distributions at fixed $\tau = 0.02$ as a function of $y$, whereas the thin curves are the corresponding $T(x_1, x_2)$ with only valence quark contributions.

5 Discussions and Summary

We showed in this paper that one can use SU(3) symmetry relations between the octet baryons, in order to get a complete set of unpolarized and polarized quark distributions of the octet baryons from the known quark distributions of the nucleon. Thus we have a new domain to check the nucleon quark distribution parametrizations.

We found a new scenario of quark flavor and spin structure of the $\Lambda$ in comparison with two already known models of a perturbative QCD based analysis and a quark diquark model. The $u$ and $d$ quarks inside the $\Lambda$ are predicted to be positively polarized at large Bjorken variable $x$ in the new scenario. Although the new scenario and the quark-diquark model have the same ratio of $d(x)/u(x) \to 0$ for the proton at $x \to 1$, they give very different predictions of the ratio $u^\Lambda(x)/s^\Lambda(x)$ at $x \to 1$. The quark-diquark model predicts $u^\Lambda(x)/s^\Lambda(x) = 0$ whereas the SU(3) symmetry predicts $u^\Lambda(x)/s^\Lambda(x) = \frac{1}{4}$. The difference between the two scenarios is due to the fact that the quark-diquark model in fact breaks SU(3) symmetry, because it uses different quark and diquark masses. Therefore we conclude that the flavor structure of the $\Lambda$ hyperon at large $x$ is also sensitive to the SU(3) symmetry between different baryons, and it is a region with rich physics to test different models.

Using an approximate relation connecting the quark fragmentation functions with the quark distributions, we predicted the hadron polarizations of the octet baryons
in several processes. The prediction of the $\Lambda$ polarizations are compatible with the available data at large fragmentation momentum fraction $z$, and this supports the prediction of positively polarized $u$ and $d$ quarks inside the $\Lambda$ at large $x$. It is also shown that the $\Xi^0$ and $\Xi^-\bar{\Xi}^0$ polarizations in polarized DIS process are sensitive to different scenarios of the flavor and helicity structure of the octet baryons at large $x$. We also presented predictions and discussions on Drell-Yan processes for $\Sigma^\pm$ and $\Xi^-$ beams on isoscalar targets.

Our predictions can be used to check the SU(3) relations between the quark distributions of the octet baryons and/or the quark distributions of the nucleon. There are still uncertainties on the quark distributions of the nucleon concerning its sea content and the flavor and helicity structure at large Bjorken variable $x \rightarrow 1$. We have shown in this paper that one can reduce or eliminate these uncertainties by exploring the quark structure of other members of the octet baryons. Thus systematic studies of the quark distributions of the octet baryons will introduce a new direction to confront and check our understandings of the basic hadron structure by comparing theoretical predictions with experimental observations.

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