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Determination of gluon polarization from deep inelastic scattering and collider data

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Abstract

We investigate impact of π^0-production data at Relativistic Heavy Ion Collider (RHIC) and future E07-011 experiment for the structure function g_1 of the deuteron at the Thomas Jefferson National Accelerator Facility (JLab) on studies of nucleonic spin structure, especially on the polarized gluon distribution function. By global analyses of polarized lepton–nucleon scattering and the π^0-production data, polarized parton distribution functions are determined and their uncertainties are estimated by the Hessian method. Two types of the gluon distribution function are investigated. One is a positive distribution and the other is a node-type distribution which changes sign at $x \sim 0.1$. Although the RHIC π^0 data seem to favor the node type for $\Delta g(x)$, it is difficult to determine a precise functional form from the current data. However, it is interesting to find that the gluon distribution $\Delta g(x)$ is positive at large x (> 0.2) due to constraints from the scaling violation in g_1 and RHIC π^0 data. The JLab-E07-011 measurements for g_1^d should be also able to reduce the gluon uncertainty, and the reduction is comparable to the one by RUN-5 π^0-production data at RHIC. The reduction is caused mainly by the error correlation between polarized antiquark and gluon distributions and by a next-to-leading-order (NLO) gluonic effect in the structure function g_1^d. We find that the JLab-E07-011 data are accurate enough to probe the NLO gluonic term in g_1. Both RHIC and JLab data contribute to better determination of the polarized gluon distribution in addition to improvement on polarized quark and antiquark distributions.

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1. Introduction

Quark and gluon contributions to the nucleon spin are described by polarized parton distribution functions (polarized PDFs) and their first moments. It became clear that only a small fraction of nucleon spin is carried by quarks and antiquarks. Therefore, a large gluon polarization or effects of orbital angular momenta should be possible sources for explaining the origin of the nucleon spin. The gluon polarization is expected to be clarified in the near future, whereas it would take time to determine the effects of the orbital angular momenta.

Polarized PDFs have been investigated by global analyses of data on polarized lepton–nucleon deep inelastic scattering (DIS) and proton–proton collisions [1–6]. Polarized quark distributions are determined relatively well; however, the polarized gluon distribution $\Delta g(x)$ is not accurately determined. Here, x is the Bjorken scaling variable, and $\Delta g(x)$ is the difference between the gluon distribution with helicity parallel to that of parent nucleon and the one with helicity antiparallel.

The gluon distribution contributes to the structure function g_1 as a higher-order effect in the expansion by the running coupling constant α_s of quantum chromodynamics. The unpolarized gluon distribution has been determined primarily by the Q^2 dependence of F_2 at small x, where Q^2 is defined by the momentum transfer q by $Q^2 = -q^2$ in lepton scattering. The kinematical range of x and Q^2 is still limited for g_1 in determining $\Delta g(x)$ by the scaling violation, so that the determination of $\Delta g(x)$ is difficult from the scaling violation. Nonetheless, it is noteworthy that there are Q^2 differences between the COMPASS and HERMES data for g_1 in the range of $x \sim 0.05$. Such Q^2 differences could be used for constraining a gluon polarization at large x as pointed out in Ref. [5]. However, this idea should be tested by future measurements on the scaling violation in g_1 because the Q^2 differences could originate also from higher-twist effects [3].

Other types of measurements are needed to improve the situation of $\Delta g(x)$. There were measurements on $\Delta g(x)$ in lepton–nucleon scattering by observing high-p_T hadrons [7–9] and open-charm events [10]. These data provided constraints on the gluon polarization at $x \sim 0.1$. They indicated that the ratio $\Delta g(x)/g(x)$ is small although experimental errors are still large. Measurements at Relativistic Heavy Ion Collider (RHIC) are also important for constraining the gluon polarization. For example, π^0 and jet-production data [11,12] in polarized proton–proton collisions are valuable for the determination of $\Delta g(x)$. In fact, we showed that the π^0 data play an important role in reducing the uncertainty of $\Delta g(x)$ by a global analysis including the π^0 data in addition to the DIS data [5]. Certain fragmentation functions are used in the analysis of π^0-production processes. We should be careful that gluon and light-quark fragmentation functions have large uncertainties at small Q^2 or small p_T [13].

In order to determine the polarized PDFs including the gluon polarization, precise measurements are needed also in DIS. After our previous analysis [5], new DIS data are reported by the CLAS [14], HERMES [15], and COMPASS [16] Collaborations. In future, the structure function g_1 for the deuteron will be accurately measured at the Thomas Jefferson National Accelerator Facility (JLab) by the proposed experiment E07-011 [17,18]. The measurements at JLab should be valuable for reducing large uncertainties of the polarized antiquark and gluon distributions because they cover a large-x region at small Q^2.

In this work, we determine the polarized PDFs by global analyses of the data for spin asymmetries A_1 in polarized lepton–nucleon DIS and double spin asymmetries A_{LL} of the π^0 production