Proceedings of the DIS'2004, Štrbské Pleso, Slovakia

EFFECTS OF $\Delta G(X)$ ON THE π^0 SPIN ASYMMETRY AT RHIC

M. HIRAI* AND K. SUDOH†

*Institute of Particle and Nuclear Studies, KEK
1-1, Ooho, Tsukuba 305-0801, JAPAN

†Radiation Laboratory, RIKEN (The Institute of Physical and Chemical Research),
Wako, Saitama 351-0198, JAPAN

We investigate behavior of the polarized gluon distribution for the π^0 double spin asymmetry measured by the PHENIX. We suggest that the data might impose a change on the polarized gluon distribution.

The polarized gluon distribution $\Delta g(x)$ plays an important role in describing the spin structure of the nucleon. So far, a number of parametrizations of the spin-dependent parton distribution functions (PDFs) have been already obtained. However, the $\Delta g(x)$ has still large uncertainties, and the behavior of $\Delta g(x)$ is not known well.

Recently, a longitudinal double spin asymmetry for inclusive π^0 production was measured by the PHENIX [1] at center of mass energy $\sqrt{s} = 200$ GeV and transverse momentum $p_T = 1 \sim 5$ GeV. The data suggest significant negative asymmetry at moderate p_T, while most of theoretical predictions are positive asymmetry.

In this work, we investigate behavior of the π^0 spin asymmetry by modifying $\Delta g(x)$ within its uncertainty. The asymmetry at low p_T has been studied in Ref. [2] in which the slight negative asymmetry is demonstrated in the framework of perturbative QCD (pQCD). We focus on behavior of the asymmetry especially in large p_T region ($p_T > 8$ GeV). We suggest that the asymmetry in the region is more sensitive to the functional form of $\Delta g(x)$.

The longitudinal double spin asymmetry is defined by

$$A_{LL}^{\pi^0} \equiv \frac{[d\sigma_{++} - d\sigma_{+-}]/dp_T}{[d\sigma_{++} + d\sigma_{+-}]/dp_T} = \frac{d\Delta\sigma/dp_T}{d\sigma/dp_T}, \tag{1}$$

where $d\sigma_{hh'}$ denotes the spin-dependent cross section with definite helicity h and h' for incident protons. The cross section can be written by the following convolutions:

$$\frac{d\Delta\sigma}{dp_T} = \sum_{a,b,c} \int d\eta \int dx_a \int dx_b \int dz\ \Delta f_a(x_a, Q^2) \Delta f_b(x_b, Q^2) \frac{d\Delta\hat{\sigma}}{dp_T d\eta} D_c^{\pi^0}(z, Q^2), \tag{2}$$

where the sum is over the partonic processes $a + b \to c + X$ associated with π^0 production. $\Delta\hat{\sigma}$ describes the polarized partonic cross section. The long distance factors $\Delta f_i(x_i, Q^2)$ and $D_c^{\pi^0}(z, Q^2)$ are the polarized PDFs for parton i with momentum fraction x_i and the (unpolarized) fragmentation function decaying into pion ($c \to \pi^0$) with momentum fraction z, respectively. The pseudo-rapidity η is integrated in the range $|\eta| \leq 0.35$ in the PHENIX acceptance.

The asymmetry is discussed in leading order level. In numerical calculations, we adopt the AAC set [3] as the polarized PDF and the Kretzer's fragmentation functions [4]. We choose the scale $Q^2 = p_T^2$.

For the partonic subprocesses, main contribution to the polarized cross section comes from gluon-gluon (gg) and quark-gluon (qg) fusion processes. With conventional PDFs, the gg contribution dominates in low p_T region and steeply decreases with p_T increases. The qg process consequently becomes dominant contribution in larger p_T region. The spin asymmetry must be sensitive to $\Delta g(x)$, since the cross section for the both processes are proportional to $\Delta g(x)$ quadratically or linearly.

The fragmentation function associates with the π^0 production not only in polarized pp collisions but also in unpolarized pp collisions. The unpolarized cross section was already measured by the PHENIX, and agrees with pQCD calculation with good accuracy [5]. Therefore, we can consider that the pQCD approach is applicable to the π^0 production in polarized pp collisions, and the asymmetry does not strongly affected by the fragmentation function even though the fragmentation function has some uncertainties. In terms of the polarized quark distribution functions $\Delta q(x)$, the π^0 production is flavor blind reaction for the initial state. The cross section depends on only the sum $\Delta q(x) + \Delta \bar{q}(x)$ which is well determined by the polarized DIS. We can neglect the ambiguity from $\Delta q(x)$. These facts imply that the main uncertainty comes from $\Delta g(x)$.

We study the dependence of $\Delta g(x)$ on the spin asymmetry by preparing three functional forms for $\Delta g(x)$. In the left panel in Fig. 1, solid curve represents $\Delta g(x)$ by the global analysis with the polarized DIS data. In addition, dashed and dot-dashed curves are artificially modified $\Delta g(x)$ which are obtained within the $\Delta g(x)$ uncertainty by the AAC analysis. For the sample-1 $\Delta g(x)$ which has a node, there is a possibility to make gg contribution be negative due to the opposite sign of polarization at x_a and x_b. If the node exists between x_a and x_b, then the product $\Delta g(x_a) \cdot \Delta g(x_b)$ must be negative. However, the absolute value $x_a - x_b$ is small in the PHENIX acceptance. It requires that the slope must be steeper to obtain sizable gg contribution. The sample-2 is a small negative $\Delta g(x)$. In this case, the gg contribution is positive while the qg contribution is negative. As mentioned above, the gg contribution dominates in low p_T, whereas the qg contribution dominates in large p_T regions. Therefore, if we take $\Delta g(x)$ to be small in low x and to be large in high x, we might have sizable negative contribution through the qg process. The $\Delta g(x)$'s shown here, of course, have the Q^2 dependence and are evolved by the DGLAP equation.

The right panel in Fig. 1 shows the spin asymmetry A_{LL} with different sets of $\Delta g(x)$. We find that A_{LL} for the AAC $\Delta g(x)$ is positive in the whole p_T region and increases with p_T. Although A_{LL} for sample-1 indicates slight negative asymmetry at low p_T, it becomes positive in larger p_T region as well as A_{LL} for the AAC. This is because that both gg and qg processes represent positive contributions in large p_T region. When p_T becomes large, the node rapidly shifts to low x direction by the Q^2 evolution and then the polarization of $\Delta g(x)$ has same signs at x_a and x_b. On the contrary, A_{LL} for sample-2 is negative in the whole p_T region. The absolute value of A_{LL} is very small at low p_T due to a cancellation between gg and qg contributions. Since the qg process dominates in large p_T region, the asymmetry

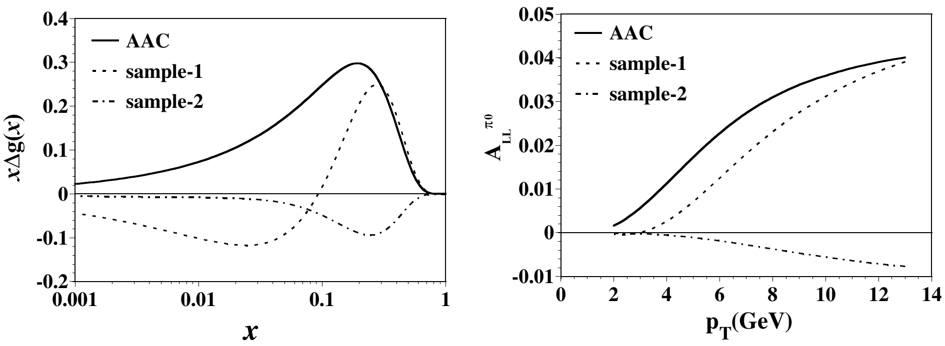

Figure 1. Several polarized gluon distributions $\Delta g(x)$ at $p_T = 2.5$ GeV (left panel) and corresponding asymmetries for π^0 production (right panel).

becomes negative and decreases with p_T increases.

In any case, there is no way to derive large negative asymmetry of a few percent levels at low p_T, even though PDFs are controllable. However, the difference of asymmetries might be remarkable in the large p_T region. The asymmetry in this region is strongly affected by the medium-x behavior of $\Delta g(x)$. As shown in A_{LL} with sample-2 $\Delta g(x)$, if future experiments measure the negative asymmetry, $\Delta g(x)$ has the potential of the negative distribution. The data over a wide p_T region is required to determine $\Delta g(x)$.

Next, we consider effects of the π^0 data on the $\Delta g(x)$ determination. The left panel in Fig. 2 shows a comparison the asymmetry uncertainty with statistical errors of the PHENIX data [1]. This uncertainty mainly comes from the $\Delta g(x)$ uncertainty. We find that the uncertainty almost corresponds to the experimental errors. This fact indicates that the present π^0 data have the same constraint on the $\Delta g(x)$ as the polarized DIS data. The π^0 production would be a good probe for the $\Delta g(x)$ determination by future precise data.

Finally, we discuss the asymmetry for charged pion production, π^+ and π^-. We show asymmetries with the AAC $\Delta g(x)$ and sample-2 $\Delta g(x)$ for each particles in the right panel in Fig. 2. In asymmetries with the AAC $\Delta g(x)$, we can see differences in large p_T region where the qg process dominates. The asymmetry in the region is proportional to the following factor:

$$A_{LL}^{\pi} \propto \frac{\Delta g}{g} \cdot \frac{(\Delta u + \Delta d)D_g^{\pi} + \Delta u \cdot D_u^{\pi} + \Delta d \cdot D_d^{\pi}}{(u+d)D_g^{\pi} + u \cdot D_u^{\pi} + d \cdot D_d^{\pi}} \ , \qquad (3)$$

where there are relations among fragmentation functions as

$$D_g^{\pi^+} = D_g^{\pi^-} \ , \ D_u^{\pi^+} > D_u^{\pi^-} \ , \ D_d^{\pi^+} < D_d^{\pi^-} \ , \ D_i^{\pi^0} = (D_i^{\pi^+} + D_i^{\pi^-})/2 \ . \qquad (4)$$

For π^+ production, the contribution associated with Δu distribution is enhanced by the fragmentation function. Increasing asymmetry for π^+ production is caused by positive contribution from Δu distribution, whereas decreasing asymmetry comes

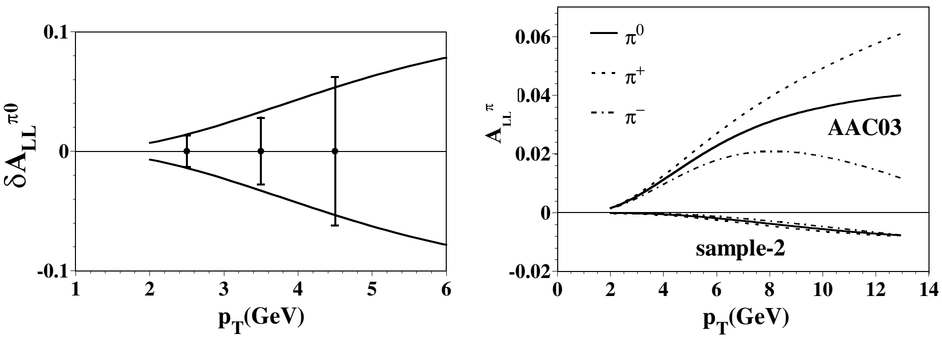

Figure 2. Comparison asymmetry uncertainties with statistical errors measured by the PHENIX (left panel). Asymmetries for neutral and charged pion productions with different $\Delta g(x)$ sets (right panel).

form negative Δd distribution for π^-. On the other hand, asymmetries are almost same in the case of the sample-2 $\Delta g(x)$. The difference among asymmetries are controlled by the magnitude of $\Delta g(x)$, since the asymmetry is proportional to $\Delta g(x)$ as written in Eq. (3). If the absolute value of $\Delta g(x)$ is small, then the asymmetry has no significance among π^0, π^+, and π^-.

In summary, we have studied a correlation between the π^0 spin asymmetry and the configuration of $\Delta g(x)$. We find that it is difficult to derive the sizable negative asymmetry at moderate p_T, though the slight negative asymmetry can be obtained. Experimental uncertainties are however large at present. It is premature to conclude that the pQCD framework is not applicable to π^0 production in polarized pp collisions. Furthermore, we have demonstrated the existence of $\Delta g(x)$ which keeps the asymmetry to be negative in the whole p_T regions. The negative asymmetry would suggest the negative polarization of $\Delta g(x)$. The PHENIX data might motivate us to modify $\Delta g(x)$ drastically. In addition, asymmetries for neutral and charged pion productions in wide p_T region will provide useful information for determining the gluon spin content.

References

1. PHENIX Collaboration, S. S. Adler *et al.*, hep-ph/0404027.
2. B. Jäger, M. Stratmann, S. Kretzer, and W. Vogelsang, Phys. Rev. Lett. **92**, 121803 (2004).
3. Asymmetry Analysis Collaboration, M. Hirai, S. Kumano, and N. Saito, Phys. Rev. D **69**, 054021 (2004).
4. S. Kretzer, Phys. Rev. D **62**, 054001 (2000).
5. PHENIX Collaboration, S. S. Adler *et al.*, Phys. Rev. Lett. **91**, 241803 (2003).