Proceedings of the DIS'2004, Štrbské Pleso, Slovakia

# LONGITUDINAL GLUON POLARIZATION IN RHIC DOUBLE-SPIN ASYMMETRIES

BARBARA JÄGER AND MARCO STRATMANN
*Institut für Theoretische Physik, Universität Regensburg, D-93040 Regensburg, Germany*

STEFAN KRETZER AND WERNER VOGELSANG
*Physics Department, Brookhaven National Laboratory, and RIKEN-BNL Research Center, Upton, New York 11973, USA*

Recent preliminary PHENIX data are consistent with a negative longitudinal double-spin asymmetry $A_{\rm LL}^{\pi}$ for $\pi^0$ production at moderate transverse momentum $p_\perp \simeq 1 \div 4\,\mathrm{GeV}$ and central rapidity. By means of a systematic investigation of the relevant degrees of freedom we show that the perturbative QCD framework at leading power in $p_\perp$ produces at best a very small negative asymmetry in this kinematic range.

## 1 Introduction

The determination of the nucleon's polarized gluon density is a major goal of current experiments with longitudinally polarized protons at RHIC [1]. It can be accessed through measurement of the spin asymmetries

$$A_{\rm LL} = \frac{d\Delta\sigma}{d\sigma} = \frac{d\sigma^{++} - d\sigma^{+-}}{d\sigma^{++} + d\sigma^{+-}} \tag{1}$$

for high transverse momentum ($p_\perp$) reactions. In Eq. (1), $\sigma^{++}$ ($\sigma^{+-}$) denotes the cross section for scattering of two protons with same (opposite) helicities. Such reactions can be treated in pQCD via factorization into parton densities, hard scattering cross sections and, eventually, fragmentation functions. Hadronic reactions have the advantage over DIS that the partonic Born cross sections involve gluons in the initial state . They may therefore serve to examine the gluon content of the colliding longitudinally polarized protons. We will here consider [2] the spin asymmetry $A_{\rm LL}^{\pi}$ for high-$p_\perp$ $\pi^0$ production, for which very recently the PHENIX collaboration has presented first data [3] at a c.m.s. energy $\sqrt{S} = 200$ GeV and central rapidity.

## 2 Hard-Scattering calculation

We may write the polarized high-$p_\perp$ pion cross section as

$$\frac{d\Delta\sigma^{\pi}}{dp_\perp d\eta} = \sum_{a,b,c} \int dx_a \int dx_b \int dz_c \; \Delta a(x_a,\mu)\, \Delta b(x_b,\mu) \times \frac{d\Delta\hat{\sigma}^{c}_{ab}(p_\perp,\eta,x_a,x_b,z_c,\mu)}{dp_\perp d\eta}\, D_c^{\pi}(z_c,\mu) \;, \tag{2}$$

 

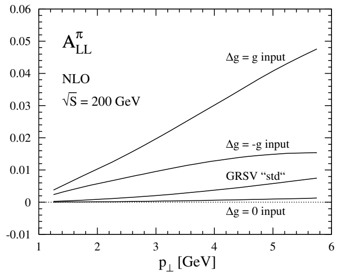


Figure 1. NLO predictions for $A_{\rm LL}^{\pi}$.

where $\eta$ is the pion's pseudorapidity. The $\Delta a, \Delta b$ $(a, b = q, \bar{q}, g)$ are the polarized parton densities; for instance,

$$\Delta g(x, \mu) \equiv g_{+}(x, \mu) - g_{-}(x, \mu) \ , \tag{3}$$

(the sign referring to the gluon helicity in a proton of positive helicity) is the polarized gluon distribution. These parton cross sections start at $\mathcal{O}(\alpha_s^2)$ in the strong coupling with the QCD tree-level scatterings: (i) $gg \to gg$, (ii) $gg \to q\bar{q}$, (iii) $gq(\bar{q}) \to gq(\bar{q})$, (iv) $q\bar{q} \to q\bar{q}$, $q\bar{q} \to gg$, $qq \to qq$, $qq' \to qq'$, $q\bar{q} \to q'\bar{q}'$. The transition of parton $c$ into the observed $\pi^0$ is described by the (spin-independent) fragmentation function $D_c^{\pi}$. All next-to-leading order [NLO, $\mathcal{O}(\alpha_s^3)$] QCD contributions to polarized parton scattering are known [4]. Corrections to Eq. (2) itself are down by inverse powers of $p_\perp$ and are thus expected to become relevant if $p_\perp$ is not much bigger than typical hadronic mass scales. Fig. 1 shows NLO predictions for $A_{\rm LL}^{\pi}$, for various gluon polarizations $\Delta g$ [5]. Despite the fact that the $\Delta g$'s used in Fig. 1 are all very different from one another, none of the resulting $A_{\rm LL}^{\pi}$ is negative in the $p_\perp$ region we display. We find it interesting to investigate the question whether this observation is accidental or systematic and what one could learn from a possible violation of the apparent positivity of $A_{\rm LL}^{\pi}$.

## 3 Basic observations

We first focus on the partonic cross sections. Among the reactions (i)-(iii) listed above that have gluons in the initial state, process (ii) has a negative *partonic* spin asymmetry $\hat{a}_{\rm LL} \equiv -1$, while (i) and (iii) both have $\hat{a}_{\rm LL} > 0$ [1]. A first guess is, then, to attribute a negative $A_{\rm LL}^{\pi}$ to the negative $gg \to q\bar{q}$ cross section. However, this expectation is refuted by the numerical hierarchy in the partonic cross sections: at $\hat{\eta} = 0$ in the partonic c.m.s., which is most relevant for the PHENIX data, channel (i) is (in absolute magnitude) larger than (ii) by a factor of about 160. We therefore exclude that the $gg \to q\bar{q}$ channel is instrumental in making $A_{\rm LL}^{\pi}$ negative, and we thus have to investigate possibilities within $\Delta g$ itself, and its involvement in $gg \to gg$ and $qg \to qg$ scattering.

## 4 A lower bound on $\mathbf{A}_{\mathrm{LL}}^{\pi}$

We consider the LO cross section integrated over all rapidities $\eta$. It is then convenient to take Mellin moments in $x_T^2$ of the cross section,

$$\Delta\sigma^{\pi}(N) \equiv \int_0^1 dx_T^2 \left(x_T^2\right)^{N-1} \frac{p_\perp^3 d\Delta\sigma^{\pi}}{dp_\perp} . \tag{4}$$

One obtains (we suppress the scale $\mu$ from now on):

$$\Delta\sigma^{\pi}(N) = \sum_{a,b,c} \Delta a^{N+1}\, \Delta b^{N+1}\, \Delta\hat{\sigma}_{ab}^{c,N}\, D_c^{\pi,2N+3} , \tag{5}$$

where the $\Delta\hat{\sigma}_{ab}^{c,N}$ are the $\hat{x}_T^2$-moments of the partonic cross sections and, as usual, $f^N \equiv \int_0^1 dx\, x^{N-1} f(x)$ for the parton distribution and fragmentation functions. We now rewrite Eq. (5) in a form that makes the dependence on the moments $\Delta g^N$ explicit:

$$\Delta\sigma^{\pi}(N) = \left(\Delta g^{N+1}\right)^2 \mathcal{A}^N + 2\Delta g^{N+1}\mathcal{B}^N + \mathcal{C}^N . \tag{6}$$

Here, $\mathcal{A}^N$ represents the contributions from $gg \to gg$ and $gg \to q\bar{q}$, $\mathcal{B}^N$ the ones from $qg \to qg$, and $\mathcal{C}^N$ those from the (anti)quark scatterings (iv) above; in each case, the appropriate combinations of $\Delta q$, $\Delta\bar{q}$ distributions and fragmentation functions are included. Being a quadratic form in $\Delta g^{N+1}$, $\Delta\sigma^{\pi}(N)$ possesses an extremum, given by the condition

$$\mathcal{A}^N \Delta g^{N+1} = -\mathcal{B}^N . \tag{7}$$

The same equation may also be derived by finding the stationarity condition along a variational approach. In the following we neglect the contribution from the $gg \to q\bar{q}$ channel which, as we discussed above, is much smaller than that from $gg \to gg$ for the $p_\perp$ we are interested in. The coefficient $\mathcal{A}^N$ is then positive, and Eq. (7) describes a minimum of $\Delta\sigma^{\pi}(N)$, with value

$$\Delta\sigma^{\pi}(N)\Big|_{\min} = -\left(\mathcal{B}^N\right)^2/\mathcal{A}^N + \mathcal{C}^N . \tag{8}$$

It is straightforward to perform a numerical Mellin inversion of this minimal cross section:

$$\left.\frac{p_\perp^3 d\Delta\sigma^{\pi}}{\mathrm{p}_\perp}\right|_{\min} = \frac{1}{2\pi i}\int_\Gamma dN \left(x_T^2\right)^{-N} \Delta\sigma^{\pi}(N)\Big|_{\min} , \tag{9}$$

where $\Gamma$ denotes a suitable contour in complex-$N$ space. For the numerical evaluation we use the LO $\Delta q$, $\Delta\bar{q}$ of GRSV [5], the $D_c^{\pi}$ of [6], and a fixed scale $\mu = 2.5$ GeV. We find that the minimal asymmetry resulting from this exercise is negative indeed, but very small: in the range $p_\perp \sim 1 \div 4$ GeV its absolute value does not exceed $10^{-3}$. The $\Delta g$ in Eq. (7) that minimizes the asymmetry is shown in Fig. 2, compared to $\Delta g$ of the GRSV LO "standard" set [5]. One can see that it has a node and is generally much smaller than the GRSV one, except at large $x$. The node makes it possible to probe the two gluon densities in the $gg$ term at values of $x_a$, $x_b$ where they have different sign, so that $A_{\mathrm{LL}}^{\pi} < 0$ becomes just barely possible.

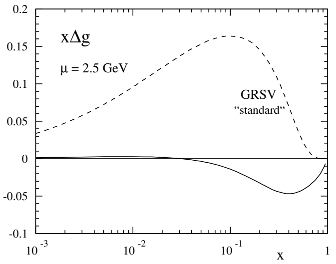


Figure 2. $\Delta g(x, \mu = 2.5\,\text{GeV})$ resulting from Eq. (7) (solid) compared to GRSV LO "standard" $\Delta g$ [5].

## 5 Conclusions

In its details, the bound in Eq. (9) is subject to a number of corrections, however, a global analysis [2], taking into account the results from polarized DIS as well confirms the somewhat idealized case, as summarized by Eqs. (8) and (9), that $A_{\rm LL}^{\pi}$ is basically positive definite $A_{\rm LL}^{\pi} \gtrsim \mathcal{O}(-10^{-3})$ in leading twist pQCD and for $p_\perp$ not largely exceeding $\sim 4$ GeV. At the same time, $A_{\rm LL}^{\pi}$ is trivially bounded from above by saturating positivity through $\Delta g(x) = g(x)$, see the corresponding curve in Fig. 1. A significantly negative $A_{\rm LL}^{\pi}$ would be indicative of power-suppressed contributions or non-perturbative effects. One possibility might be the population of low $p_\perp$ bins with statistical pions that follow a quasi-thermal exponential distribution. However, such random pions would have to realize the $J = 1$ configuration in Eq. (1) either through angular momentum of (Goldstone) pions or the spin of co-produced massive baryons, leading one to expect a positive $A_{\rm LL\,nonpert.}^{\pi} > 0$. A quantitative estimate of this effect will be given elsewhere.

### Acknowledgements

This work was supported in part by BMBF and DFG, Berlin/Bonn and by RIKEN, BNL, and the U.S. Department of Energy (contract DE-AC02-98CH10886).

### References

1. See, e.g.: G. Bunce *et al.*, Annu. Rev. Nucl. Part. Sci. **50**, 525 (2000).
2. B. Jäger *et al.*, Phys. Rev. Lett. **92**, 121803 (2004).
3. PHENIX Collab. (S.S. Adler *et al.*), `hep-ex/0404027`; and F. Bauer's contribution to these proceedings.
4. D. de Florian, Phys. Rev. **D67**, 054004 (2003); B. Jäger *et al.*, Phys. Rev. **D67**, 054005 (2003).
5. M. Glück *et al.*, Phys. Rev. **D63**, 094005 (2001).
6. B.A. Kniehl *et al.*, Nucl. Phys. **B582**, 514 (2000).