Longitudinal double-spin asymmetries of inclusive jet and dijet production at STAR

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Abstract

At the STAR experiment, the gluon helicity distribution $\Delta g(x,Q^2)$ can be accessed through the double-spin asymmetries A_{LL} of inclusive jet and dijet production in collisions of longitudinally polarized protons. These proceedings report on recently published results of A_{LL} for inclusive jets and dijets at $\sqrt{s} = 200$ GeV and $\sqrt{s} = 510$ GeV in mid-pseudorapidity ($|\eta| < 1$) and preliminary results for dijets in intermediate pseudrapidity ($-0.8 < \eta < 1.8$). The mid-pseudorapidity jet and dijet measurements are sensitive to $\Delta g(x,Q^2)$ for gluon momentum fractions x from $\simeq 0.5$ down to $\simeq 0.015$; the sensitivity region for dijets in intermediate pseudorapidity at 510 GeV extends to even lower x. The measurements are in good agreement with previous STAR results and recent theoretical evaluations of prior world data.

1 Introduction

How is the spin of the proton distributed among its quark, anti-quark, and gluon constituents? Decades of polarized Deep Inelastic Scattering experiments show that only about 25-30% of the proton's spin comes from the spins of quarks and anti-quarks [1–5]. The rest must originate from the the spins of the gluons and the orbital angular momenta of the quarks and gluons. The Solenoidal Tracker at Relativistic Heavy Ion Collider (STAR) experiment is addressing this fundamental question about the origin of the proton spin using collisions of high-energy polarized protons. Since gluon-gluon and gluon-quark scatterings dominate jet production at $\sqrt{s} = 200$ GeV and $\sqrt{s} = 510$ GeV at STAR, measurements of the double-spin asymmetries of inclusive jet and dijet production in longitudinally polarized proton collisions provide access to the gluon spin contribution to the proton spin.

STAR results on inclusive jet production at mid-pseudorapidity using 200 GeV p+p data collected in 2009 [6], when included in perturbative QCD (pQCD) analysis of global data, provide evidence for positive gluon polarization for the momentum fraction $x > 0.05$ at a scale $Q^2 = 10$ GeV^2 [1, 2]. The measurements of dijet A_{LL} based on the same data [7, 8] provide more information about the initial state kinematics and further constrain the x-dependence of the gluon polarization as shown in [3]. Perturbative QCD analyses at the next-to-leading order [1, 2] using the available world data show that spins of gluons with momentum fractions $x > 0.05$ contribute approximately 40% of the total proton spin at $Q^2 = 10$ GeV^2, with

a relative uncertainty of about 30%. The corresponding unpolarized differential jet and di-jet production cross sections at STAR, including recent preliminary results for inclusive jets at $\sqrt{s} = 200$ GeV and 510 GeV [9, 10], are well described by next-to-leading order pQCD calculations. Further reduction on the uncertainty of $\Delta g(x, Q^2)$ at $x > 0.05$ calls for measurements with improved statistics at $\sqrt{s} = 200$ GeV, while improvements in the lower x region can be achieved with measurements at a higher center-of-mass energy $\sqrt{s} = 510$ GeV and more forward pseudorapidity up to $\eta \simeq 1.8$ at STAR.

2 Experiment and Data Analysis

In the inclusive jet and dijet A_{LL} measurements at STAR, the Time Projection Chamber [11] with a 0.5 T solenoidal magnetic field is used to measure charged particle tracks in $|\eta| < 1.3$ and full range of the azimuthal angle. Barrel (BEMC) [12] and Endcap Electromagnetic Calorimeters (EEMC) [13] measure the electromagnetic energy deposition in $|\eta| < 1$ and $1.09 < \eta < 2$, respectively, in full range of the azimuthal angle. The calorimeters are also used for jet triggers that require minimal transverse energy deposition in fixed $\Delta\eta \times \Delta\phi = 1 \times 1$ regions. Moreover, information from the Vertex Position Detectors [14] and the Zero Degree Calorimeters [15], covering $4.2 < |\eta| < 5.2$ and $|\eta| > 6.6$, respectively, is used to calculate the relative luminosities for different helicity configurations of the colliding beams.

Previously published results on inclusive jet and dijet production at $\sqrt{s} = 200$ GeV [6–8] are based on 2009 data corresponding to an integrated luminosity of $\mathcal{L} = 20$ pb^{-1}. The recent results of the inclusive jet and dijet A_{LL} measurements at $\sqrt{s} = 200$ GeV and mid-pseudorapidity [16] presented in these proceedings are based on the longitudinally polarized data collected in 2015 with an approximately twice larger figure of merit, $\mathcal{L}P^4$, than 2009 data. It corresponds to an integrated luminosity of $\mathcal{L} \simeq 52\,\text{pb}^{-1}$ and average beam polarizations of $P_B \simeq 52\%$ and $P_Y \simeq 57\%$ for the RHIC "blue" (B) and "yellow" (Y) beams, respectively. The presented results at $\sqrt{s} = 510$ GeV [17] are based on the data collected in 2012 with an integrated luminosity $\mathcal{L} \simeq 82$ pb^{-1} and beam polarizations of about $P_B \simeq 54\%$ and $P_Y \simeq 55\%$.

The double spin asymmetries are evaluated according to the following formula:

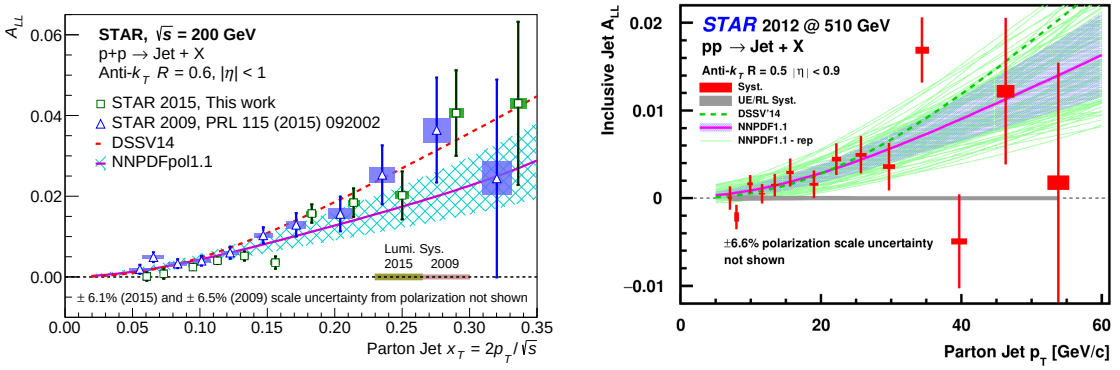
$$A_{LL} = \frac{\sum_{\text{runs}} P_B P_Y (N^{++} - r N^{+-})}{\sum_{\text{runs}} P_B^2 P_Y^2 (N^{++} + r N^{+-})}, \tag{1}$$

where P_B and P_Y are the measured beam polarizations, N^{++} and N^{+-} are the yields of inclusive jets or dijets from colliding beam bunches with equal or opposite helicities, respectively, and r is the relative luminosity for collisions with these helicity configurations.

The details about the event selection, jet reconstruction, and systematic uncertainty estimation can be found in [16, 17]. One of the main improvements of the presented results with respect to previous STAR measurements [6, 7] is the jet-by-jet underlying-event correction. Jet p_T and dijet invariant mass, M_{inv}, are corrected for underlying-event contributions using the off-axis method from [18].

3 Results

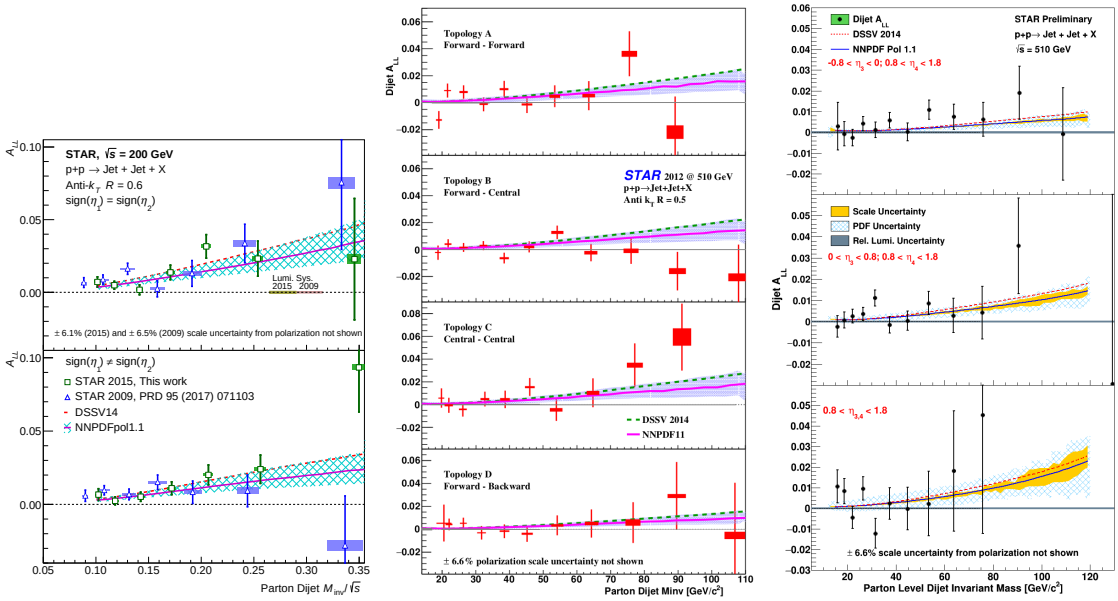
The inclusive jet A_{LL} for $\sqrt{s} = 200$ GeV and $\sqrt{s} = 510$ GeV are presented in Fig. 1. Figure 1a shows the recent results at $\sqrt{s} = 200$ GeV and $|\eta| < 1$ based on 2015 data [16] together with the results using 2009 data [6]. The first results at $\sqrt{s} = 510$ GeV and $|\eta| < 0.9$ using 2012 data [17] are shown in Fig. 1b.



(a) (b)

Figure 1: (a) A_{LL} for inclusive jets with $|\eta| < 1.0$ versus x_T at the parton level at 200 GeV. The square markers show the 2015 data from [16], whereas the triangle markers show the 2009 data from [6]. (b) A_{LL} for inclusive jets with $|\eta| < 0.9$ versus parton jet p_T based on 2012 data at 510 GeV [17]. The error bars show the size of the statistical uncertainties, whereas the boxes indicate the size of the systematic uncertainties. The yellow, pink and gray bands represent the common relative luminosity uncertainty. The curves show the expected A_{LL} values for the DSSV14 [2] and NNPDFpol1.1 [1] with the blue uncertainty band for the latter. The green curves in Fig. (b) show predictions from the 100 equally probable NNPDFpol1.1 replicas.

Figure 2 shows recent results on dijet A_{LL} for the same datasets. The asymmetry for dijets versus $M_{inv}/\sqrt{s}$ at the parton level at $\sqrt{s} = 200$ GeV and mid-pseudorapidity are presented in Fig. 2a. It is shown for two different event topologies, $\text{sign}(\eta_1) = \text{sign}(\eta_2)$ and $\text{sign}(\eta_1) \neq \text{sign}(\eta_2)$, where 1 and 2 denote the two jets. The different topologies sample different regions of x. The same-sign events probe more asymmetric collisions with better-separated high-x and low-x distributions, while the opposite-sign events probe an intermediate-x range (see, e.g., Fig. 3 in Ref. [7]). For the 510 GeV results at mid-pseudorapidity, presented in 2b, individual jets in the dijet were sorted into the following three categories: forward ($0.3 < \eta < 0.9$), central ($|\eta| < 0.3$), and backward ($-0.9 < \eta < -0.3$). The final A_{LL} results are presented for four dijet event topologies, namely, with forward-forward jets, forward-central jets, central-central jets, and forward-backward jets. The forward-forward and forward-central configurations probe the most asymmetric collisions down to $x \simeq 0.015$. The forward-forward and central-central events probe collisions with $|\cos\theta^*|$ near zero, whereas forward-central and forward-backward events are more sensitive to larger $|\cos\theta^*|$, where θ^* is the scattering angle in the center-of-mass frame of scattering partons. The preliminary results for the measurement at 510 GeV and intermediate pseudorapidity ($-0.8 < \eta < 1.8$) [19] are shown in Fig. 2c. The results are divided into three classes based on the pseudorapidities of the jets in the dijet pair: one jet in the east half of the BEMC ($-0.8 < \eta < 0$) or the west half of the BEMC ($0 < \eta < 0.8$) and the other jet in the EEMC ($0.8 < \eta < 1.8$), or both jets in the EEMC. The last category probes the most asymmetric collisions to x even below 0.015. In all the figures presented in this section, theoretical evaluations of A_{LL} for DSSV14 [2] and NNPDFpol1.1 [1] parton distribution functions are presented for comparison.



(a) (b) (c)

Figure 2: A_{LL} as a function of parton-level invariant mass for dijets from 2012 data at 510 GeV as well as 2009 and 2015 data at 200 GeV. Figure (a) presents A_{LL} versus $M_{inv}/\sqrt{s}$ at 200 GeV for dijets with the sign(η_1) = sign(η_2) (top) and sign$(\eta_1) \neq$ sign(η_2) (bottom) event topologies. The square markers show the 2015 data from [16], whereas the triangle markers show the 2009 data from [7]. Figure (b) presents results at 510 GeV from [17] for different event topologies in BEMC as described in the text. Figure (c) shows the preliminary results at 510 GeV obtained for the east BEMC-EEMC (top), west BEMC-EEMC (middle) and EEMC-EEMC (bottom) event topologies [19]. The error bars show the size of the statistical uncertainties, whereas the boxes indicate the size of the systematic uncertainties. In Fig. (c) only statistical uncertainties are presented. The curves represent theoretical evaluations of A_{LL} for DSSV14 [2] and NNPDFpol1.1 [1] parton distribution functions with the blue uncertainty band for the latter.

4 Summary

STAR has recently published results for inclusive jet and dijet longitudinal double-spin asymmetries at mid-pseudorapidity based on data collected in 2015 at 200 GeV [16] and 2012 at 510 GeV [17]. These results build on the prior STAR measurements [6–8], with [6] providing the first evidence for positive polarization of the gluons in a polarized proton for $x > 0.05$ upon inclusion in global analyses. The recent STAR results presented in these proceedings are in good agreement with the prior STAR measurements as well as the theoretical evaluations from DSSV14 [2] and NNPDFpol1.1 [1]. The 2015 results with an approximately twice larger figure of merit and reduced systematic uncertainties compared to the prior data at $\sqrt{s} = 200$ GeV will provide one of the most stringent constraints on the magnitude and shape of the gluon helicity distribution for $x > 0.05$ when included in future global analyses of the polarized parton distribution functions. The first results at 510 GeV at mid-pseudorapidity and recent preliminary results at intermediate pseudorapidity based on 2012 data, as well as upcoming measurements based on 2013 data at 510 GeV with an integrated luminosity of $\mathcal{L} \simeq 250$ pb^{-1}, will provide further constraints on $\Delta g(x, Q^2)$, especially in the region $x < 0.05$ where $\Delta g(x, Q^2)$ is largely unconstrained in the prior global analyses. Since the Relativis-

tic Heavy Ion Collider has concluded the data taking with longitudinally polarized protons in 2015, the STAR data are anticipated to provide one of the most important insights to $\Delta g(x, Q^2)$ well into the future.

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