LONGITUDINAL DOUBLE SPIN ASYMMETRY IN JET PRODUCTION AT STAR

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We report measurements of the longitudinal double-spin asymmetry $A_{LL}$ for the inclusive production of jets at midrapidity in polarized proton-proton collisions at $\sqrt{s} = 200$ GeV. The data amount to an integrated luminosity of $3 \text{ pb}^{-1}$ and were collected with the STAR detector at the Relativistic Heavy Ion Collider. Typical beam polarizations were 50%. The $A_{LL}$ measurements cover jet transverse momenta $5 < p_T < 30$ GeV/c and provide sensitive constraints on the gluon spin contribution to the proton spin.

1 Introduction

The Relativistic Heavy Ion Collider (RHIC) is the first polarized high-energy proton-proton collider, providing collisions at $\sqrt{s} = 200$ GeV and in the future at $\sqrt{s} = 500$ GeV. One of the main objectives of the program with polarized proton beams is the measurement of the gluon spin contribution, $\Delta G$, to the proton spin. The processes under study include inclusive jet and pion production, dijets, heavy flavor, and photon-jet coincidences. The present focus is on inclusive measurements with large production cross sections. At a center-of-mass energy $\sqrt{s} = 200$ GeV production processes at midrapidity and with transverse momenta $p_T > 5$ GeV/c typically give sensitivity to the integral of $\Delta G$ over the range $0.03 \lesssim x \lesssim 0.3$ in the gluon momentum fraction. Coincidence measurements can provide the $x$ dependence of $\Delta G$. However, they require larger total integrated luminosities than have been sampled so far. Collisions at $\sqrt{s} = 500$ GeV will extend the $x$ coverage to smaller values, which are important for global analyses of the polarized parton distributions. The STAR (Solenoidal Tracker at RHIC) detector, with its large acceptance and electromagnetic calorimetry, is well suited for jet reconstruction at RHIC.

The (polarized) jet cross section has large contributions from (polarized) gluon-gluon and quark-gluon scattering, which provide direct sensitivity to $\Delta G$ in the measurements of the longitudinal double-spin asymmetry $A_{LL}$:

$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}},$$

where $\sigma^{++}$ ($\sigma^{+-}$) is the inclusive jet cross section when the colliding proton beams have equal (opposite) helicities. The gluon-gluon scattering contribution dominates up to jet $p_T \lesssim 8$ GeV/c while at higher $p_T$ in the range of the present measurements the quark-gluon scattering contribution is the largest. The quark-quark contribution is small.

First inclusive jet $A_{LL}$ and cross section results from STAR have been published. The unpolarized cross section is well described by NLO pQCD calculations for jet $p_T$, $5 < p_T < 50$ GeV/c,
motivating the application of the NLO pQCD framework to interpret the spin asymmetry results. The asymmetry $A_{LL}$ was measured for $5 < p_T < 17$ GeV/c and disfavors large positive gluon polarization in the proton. These proceedings report on new measurements of $A_{LL}$ for inclusive jet production with increased sensitivity and extended coverage in jet $p_T$.

2 Experiment and Data Analysis

The present results are based on an integrated luminosity of $\sim 3 \text{ pb}^{-1}$ and were recorded in the year 2005. The STAR detector subsystems used for jet reconstruction are the Time Projection Chamber (TPC) and the Barrel Electromagnetic Calorimeter (BEMC). The TPC provides the momentum of charged particles in the pseudorapidity range $-1.3 \lesssim \eta \lesssim 1.3$ for all azimuthal angles $\phi$. The BEMC is a lead-scintillator sampling calorimeter which measures electromagnetic energy deposits. During the data taking period in 2005, the BEMC covered $0 < \eta < 1$ and $0 < \phi < 2\pi$. The remaining half, covering $-1 < \eta < 0$, was commissioned before the data taking in 2006. Beam-Beam Counters (BBC), located on each side of the STAR interaction region, provided the beam collision trigger and were used to measure the relative luminosities for different helicity configurations and as well as transverse beam polarization components at STAR.

The majority of the jet data were collected using a new dedicated jet-patch (JP) trigger that required a transverse energy sum in at least one of six BEMC patches, each covering $\Delta \eta \times \Delta \phi = 1 \times 1$. The JP trigger efficiency is higher than the efficiency of the high tower trigger (HT), which selects on an energy deposit in a BEMC tower of size $\Delta \eta \times \Delta \phi = 0.05 \times 0.05$ and was used also in previous data taking periods. In addition, the JP trigger selects a less biased distribution of jets than the HT trigger does. The HT and JP triggers were used with two different energy thresholds.

Jets were reconstructed with a midpoint cone algorithm with a cone radius of 0.4 and using charged TPC tracks and BEMC energy deposits. The details for other parameters can be found in Ref. Only jets with reconstructed transverse momenta $p_T > 5$ GeV/c that fulfilled the trigger conditions were considered in the analysis. Jets with their axis between a nominal $\eta$ of 0.2 and 0.8 were selected so that the effects from the BEMC acceptance edges were small. BBC timing information was used to accept events with vertex positions along the beam direction in the inner region of STAR for which tracking efficiencies are uniform. The same timing information was used in the beam luminosity measurement. Beam background caused an occasional signal in the BEMC. Its contribution to the jet yield was suppressed by requiring the ratio of jet energy in the BEMC to the total jet energy to be between 0.1 and 0.8.

3 Results

The jet yields were sorted by equal ($N^{++}$) and opposite ($N^{+-}$) helicity combinations of the colliding proton beams and $A_{LL}$ was evaluated according to:

$$A_{LL} = \frac{\sum (P_1 P_2) N^{++} - RN^{+-}}{\sum (P_1 P_2)^2 (N^{++} + RN^{+-})},$$

where $P_1 P_2$ is the product of the measured beam polarizations and $R$ is the measured ratio of luminosities for equal and opposite proton beam helicities. The average online beam polarization was $\sim 50\%$. The ratio $R$ was between 0.8 and 1.2, and was measured to $\mathcal{O}(10^{-3})$ accuracy. The yields $N^{++}$ and $N^{+-}$ were recorded concurrently since the proton beam helicities alternated for successive beam bunches in one beam and for successive pairs of beam bunches in the other beam. To further minimize systematic effects in the measurement of $A_{LL}$, the beam helicity pattern was alternated between RHIC beam fills.
Figure 1: The longitudinal double-spin asymmetry $A_{LL}$ versus jet transverse momentum $p_T$ for inclusive jet production in polarized proton-proton collisions at $\sqrt{s} = 200$ GeV. The filled symbols show the present data and the open symbols the published results. The error bars indicate the size of the statistical uncertainties. The band shows the size of the total systematic uncertainty in the present data. The uncertainty from the beam polarization is not included. The curves show different theoretical predictions for gluon polarization in the polarized proton and are discussed in the text.

The asymmetry was calculated for the combined sample of about 1.97 M jets of JP and HT triggered data. Figure 1 shows $A_{LL}$ as a function of jet $p_T$ with statistical error bars for the present and published data and the systematic uncertainty band for the present data, not including the 25% scale uncertainty from the online beam polarization measurement. The leading contributions to the systematic uncertainty band arise from the bias introduced by the BEMC trigger requirements and from a conservative upper limit on possible false asymmetries in the measurement. Other systematic uncertainties include effects from non-longitudinal beam polarization components at the STAR interaction region, from uncertainty in the measurement of $R$, and from beam background. Systematic checks with randomized beam-spin patterns showed no evidence for bunch-to-bunch or fill-to-fill systematics in $A_{LL}$.

The curves in Figure 1 show NLO pQCD evaluations for $A_{LL}$ based on commonly used polarized parton distribution functions. The curve labeled GRSV-std is based on a best fit to inclusive DIS data. The other curves correspond to maximally positive ($\Delta g = g$), negative ($\Delta g = -g$), or vanishing ($\Delta g = 0$), gluon polarizations at a 0.4 GeV$^2$/c$^2$ initial scale of the parton parametrizations.

The present data are in good agreement with the our published results in the region of kinematic overlap $5 < p_T < 17$ GeV/c, where they improve significantly the precision, and extend jet $p_T$ up to 30 GeV/c. The corresponding range of gluon momentum fractions sampled by data is $0.03 \lesssim x \lesssim 0.3$. The fraction of the first moment of the GRSV-std polarized gluon distribution is about half over this $x$ range. The data are not consistent with the GRSV scenario of maximal positive gluon spin contribution to the proton spin ($\Delta g = g$).

An additional 8.5 pb$^{-1}$ was sampled in 2006 with beam polarizations of $\sim 60\%$. This will improve the precision of inclusive $A_{LL}$ measurements and offers good prospects for dijet analyses.
4 Summary

We reported preliminary measurements of the longitudinal double-spin asymmetry $A_{LL}$ for the inclusive production of jets in polarized proton-proton collisions at $\sqrt{s} = 200 \text{ GeV}$ with jet $p_T$ up to 30 GeV/c. The $A_{LL}$ data, compared to the commonly used GRSV set of polarized parton distributions, exclude the scenario with a large positive gluon spin contribution to the nucleon spin. Future inclusion of our data as well as data in Refs. 11, 12 in global analyses should improve our knowledge of the polarized gluon distribution for $0.03 \lesssim x \lesssim 0.3$. First promising works in this direction have already been published\[13\].

Acknowledgments

It is a pleasure to thank organizers for a stimulating conference and the European Union ”Marie Curie” Programme for partial support.

References

1. G. Bunce, N. Saito, J. Soffer and W. Vogelsang, Ann. Rev. Nucl. Part. Sci. \textbf{50} (2000) 525.
2. Special Issue: RHIC and Its Detectors, Nucl. Instrum. Meth. \textbf{A499}, (2003).
3. B. Jäger, M. Stratmann and W. Vogelsang, Phys. Rev. D \textbf{70}, 034010 (2004).
4. B. I. Abelev \textit{et al.} [STAR Collaboration], Phys. Rev. Lett. \textbf{97}, 252001 (2006).
5. J. Kiryluk [STAR Collaboration], arXiv:hep-ex/0501072
6. G. C. Blazey \textit{et al.}, arXiv:hep-ex/0005012.
7. O. Jinnouchi \textit{et al.}, arXiv:nucl-ex/0412053.
8. H. Okada \textit{et al.}, arXiv:hep-ex/0601001
9. J. Kiryluk for STAR Collaboration, AIP Conf. Proc. \textbf{675}, 424 (2003).
10. M. Glück, E. Reya, M. Stratmann and W. Vogelsang, Phys. Rev. D \textbf{63}, 094005 (2001).
11. HERMES, A. Airapetian \textit{et al.}, Phys. Rev. Lett. \textbf{84}, 2584 (2000); SMC, B. Adeva \textit{et al.}, Phys. Rev. D \textbf{70}, 012002 (2004); COMPASS, E. S. Ageev \textit{et al.}, Phys. Lett. B \textbf{633}, 25 (2006).
12. PHENIX, S. S. Adler \textit{et al.}, Phys. Rev. D \textbf{73}, 091102 (2006); arXiv:0704.3599 [hep-ex].
13. M. Hirai, S. Kumano and N. Saito, Phys. Rev. D \textbf{74}, 014015 (2006); G. A. Navarro and R. Sassot, Phys. Rev. D \textbf{74}, 011502 (2006).