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Gluon polarization and jet production at STAR

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Summary. — At RHIC kinematics, polarized jet hadroproduction is dominated by gg and qg scattering, making the jet longitudinal double-spin asymmetry, A_{LL}, sensitive to gluon polarization in the nucleon. I will present STAR results of A_{LL} from inclusive jet and dijet measurements for the RHIC 2006 run totaling $5.5\,\mathrm{pb}^{-1}$ of integrated luminosity with 55% beam polarization at center-of-mass energy 200 GeV. I will also present preliminary results from the analyses of data from the 2009 run, which collected a much larger sample ($25\,\mathrm{pb}^{-1}$ with 57% polarization) at 200 GeV. The results are compared with theoretical calculations of A_{LL} based on various models of the polarized gluon distribution function in the nucleon. The STAR data place significant constraints on allowed theoretical models.

PACS `13.87.-a` – Jets in large-Q^2 scattering.
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1. – Introduction

The study of the internal spin structure of the proton is an integral part of the Relativistic Heavy Ion Collider (RHIC) spin physics program. The polarized proton collider is especially well suited to measure the polarized gluon contribution to the proton spin. The Solenoidal Tracker at RHIC (STAR) experiment, with its large acceptance, retains an advantage in accessing $\Delta g(x)$ via jet production.

The longitudinal spin sum rule dictates how the proton spin is constructed from the spin and orbital momenta of its partonic constituents:

$$(1) \qquad \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_z,$$

where the quark polarization, $\Delta\Sigma \approx 0.3$, has been measured in deep-inelastic scattering experiments. However, ΔG, the gluon polarization, and L_z, the parton orbital angular momentum, are still poorly constrained [1]. RHIC stands to bring significant advances in the mapping of $\Delta g(x)$.

RHIC collected data at $200\,\mathrm{GeV}$ center-of-mass energy in polarized proton-proton collisions with integrated luminosity of $5.4\,\mathrm{pb}^{-1}$ in 2006 and $25\,\mathrm{pb}^{-1}$ in 2009. The beam polarization was measured with Coulomb-nuclear interference (CNI) proton-carbon polarimeters [2] calibrated with a polarized atomic hydrogen-gas target [3]. The average beam polarization was 55% in 2006 and 57% in 2009.

The STAR detector subsystems [4] relevant to jet analysis are the Time Projection Chamber (TPC) immersed in a $0.5\,\mathrm{T}$ longitudinal magnetic field and used to reconstruct charged particle tracks with pseudorapidity $|\eta| < 1.3$. The Barrel Electromagnetic Calorimeter (BEMC) with towers at $|\eta| < 1$ and the Endcap Electromagnetic Calorimeter (EEMC) with towers at $1 < \eta < 2$ were used to measure neutral particles and for triggering with jet patches of fixed size $\Delta\eta \times \Delta\phi = 1.0 \times 1.0$. The Beam-Beam Counters (BBC) with $3.3 < |\eta| < 5.0$ and Zero-Degree Calorimeters (ZDC) located $\sim 18\,\mathrm{m}$ downstream of the interaction point were used for monitoring relative luminosities. A timing window imposed on the BBCs was used as part of the minimum bias trigger requirement in 2006. All of these detectors cover full azimuth ($\Delta\phi = 2\pi$).

2. – Analysis and results

Jets were reconstructed using a midpoint-cone algorithm [5] with seed transverse energy $0.5\,\mathrm{GeV}$, split-merge fraction 0.5 and cone radius 0.7. Tracks and towers were required to have a minimum transverse momentum of $0.2\,\mathrm{GeV}/c$. A_{LL} is formally defined as the ratio of the difference over the sum of cross sections with opposite helicity states. It can be measured at RHIC with [6]:

$$(2) \qquad\qquad A_{LL} = \frac{1}{P_1 P_2} \frac{N^{++} - R N^{+-}}{N^{++} + R N^{+-}} \,,$$

where P_1 and P_2 are the beam polarizations, $R = \mathcal{L}^{++}/\mathcal{L}^{+-}$ is the ratio of luminosities, and N^{++} and N^{+-} are the jet yields for equal and opposite helicity beams.

Several important improvements over the 2006 run were realized, both before and after the taking of the 2009 data. Overlapping jet patches were added to the trigger and lower E_T thresholds were adopted for both the BEMC and EEMC. These upgrades helped increase trigger efficiency and reduce trigger bias. They resulted in a 37% increase in jet acceptance over the 2006 run. Upgrades in the data acquisition system, DAQ1000, allowed STAR to record events at several hundred Hz during the 2009 run, with only 5% dead time for the jet data, compared with $40\,\mathrm{Hz}$ with 40% dead time during the 2006 run. The enhanced DAQ capability also allowed STAR to remove the BBC coincidence requirement, which helped trigger more efficiently at high jet p_T. Improvements in jet reconstruction were also implemented. The electromagnetic calorimeters are ~ 1 hadronic interation length thick. Many charged hadrons deposit a MIP (minimum ionizing particle), while others shower and deposit a sizeable fraction of their energy when passing through. The strategy adopted in analyses through 2006 was to subtract a MIP from an EMC tower with a charged track passing through. In the 2009 run, the total momentum of the charged track is subtracted from the struck EMC tower. This significantly reduces the response to fluctuations from charged hadron showering and reduces the average difference between jet energies at the detector and particle level. The net benefit comes in the form of an improved overall jet energy resolution of 18%, compared to 23% in the 2006 analysis.
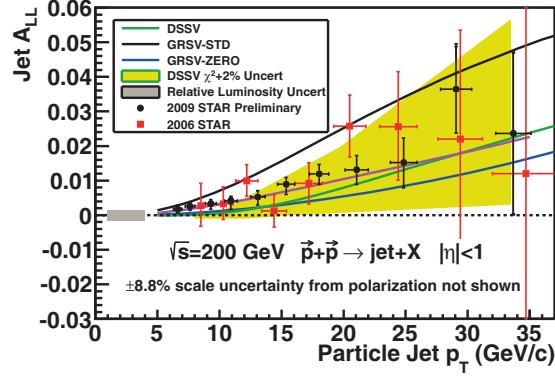
Fig. 1. – STAR 2006 (red squares) [7] and 2009 (black circles) inclusive jet A_{LL} vs. jet p_T for $|\eta| < 1$ [8]. The GRSV [9] model is a previous global analysis for polarized parton densities that included DIS data. The GRSV-ZERO curve (blue) represents the special case of no gluon polarization. The DSSV [10] model (green), in addition to DIS and SIDIS data, is the first to incorporate RHIC polarized proton-proton data. The DSSV $\chi^2 + 2\%$ curve [11] (magenta) is described in the text.

Figure 1 shows the measured inclusive jet A_{LL} vs. jet p_T for the 2006 ($-0.7 < \eta < 0.9$) [7] and 2009 ($|\eta| < 1$) [8] data alongside theory predictions of GRSV [9] and DSSV [10]. The STAR data fall between the predictions of DSSV and GRSV-STD. The dominant systematic uncertainties originate from differences between the reconstructed and true jet p_T and the trigger sampling the underlying partonic processes (qq, qg and gg) differently. The 2009 data are more precise than the 2006 data by a factor of four in low-p_T bins and a factor of three in high-p_T bins. The magenta curve [11] shows a fit to the previous datasets for which the truncated integral of Δg over the region $0.001 < x < 1$ was varied allowing the χ^2 of the fit to change by 2%. It provides a very good description of the new 2009 results. The truncated integral of $\Delta g(x)$ over the range $0.05 < x < 0.2$ is 0.13 [11]. Figure 2 presents the 2009 result in two rapidity ranges, permitting comparisons with models for collisions with different average partonic scattering angles, x ranges and subprocess mixtures.
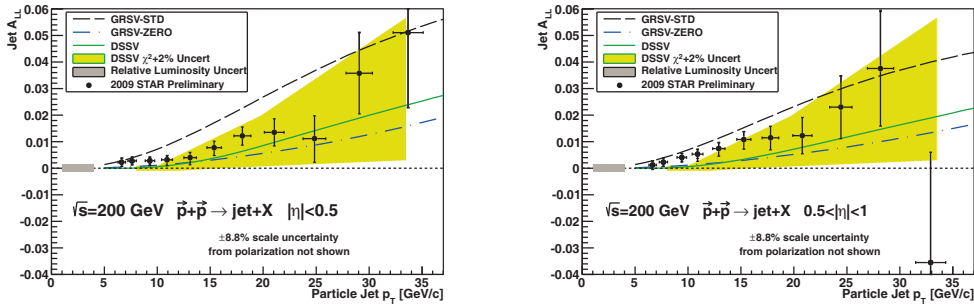

Fig. 2. – STAR 2009 inclusive jet A_{LL} vs. jet p_T for the pseudorapidity ranges $|\eta| < 0.5$ (left panel) and $0.5 < |\eta| < 1$ (right panel).
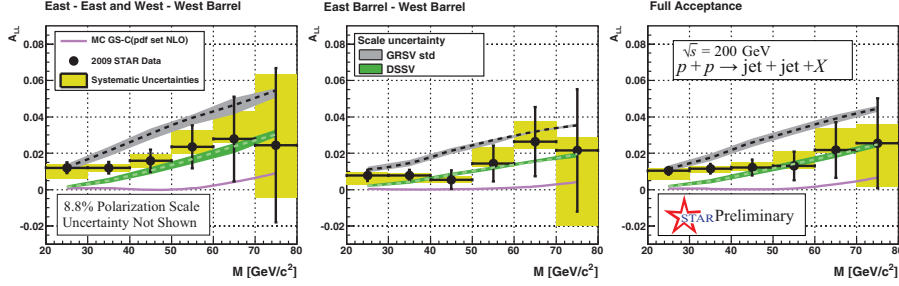
Fig. 3. – STAR 2009 dijet A_{LL} [12] measured in three pseudorapidity acceptances to better constrain the kinematics of the hard-scattering partons.

Figure 3 shows the measured dijet A_{LL} [12] compared with the predictions of GRSV [9], DSSV [10] and GS-C [13]. The dijet results, which also fall between the DSSV and GRSV predictions, will help constrain the shape of $\Delta g(x)$.

3. – Conclusion

The STAR experiment measured the inclusive jet double-helicity asymmetry A_{LL} in polarized proton-proton collisions at $\sqrt{s} = 200$ GeV. The STAR 2005 and 2006 measured inclusive jet A_{LL} were included in the first global analysis [10] to use polarized jets and played a significant role in constraining $\Delta g(x)$ at RHIC kinematics. The markedly increased precision of the 2009 result is expected to vastly reduce the present large uncertainty of the gluon polarization of the proton once included in a global analysis of polarized parton densities. The complementary STAR measurement of A_{LL} for dijets from 2009 will reduce the uncertainty in $\Delta g(x)$ associated with extrapolating beyond the x range explored by the inclusive jet measurement.

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