Spin physics with STAR at RHIC

Z. Chang, P. Djawotho, J.L. Drachenberg, C.A. Gagliardi, L. Huo, M.M. Mondal,
R.E. Tribble, and the STAR Collaboration

Our group continues to play major roles in STAR investigations of both longitudinal and transverse spin phenomena in polarized *pp* collisions at RHIC. During the past year, our analysis efforts have focused on the 200 GeV longitudinal spin data that were recorded by STAR during 2009 and 200 GeV transverse spin data that were recorded during 2008.

One of the primary goals of the RHIC spin program is to determine the gluon contribution to the proton spin. At RHIC energies, jet production at mid-rapidity is dominated by *gg* and *qg* scattering. This makes the double longitudinal-spin asymmetry A_{LL} for inclusive jet production a sensitive probe of gluon polarization. For several years, our group has carried a leading role in the STAR inclusive jet A_{LL} analyses. Just as this year began, STAR released preliminary measurements of A_{LL} for inclusive jets in 200 GeV *pp* collisions recorded during 2009, based on an analysis that we performed at Texas A&M [1]. Fig. 1 shows a comparison of the 2009 preliminary results with previous measurements from 2006 [2], together with theory predictions from GRSV [3] and DSSV [4]. The yellow triangular region in Fig. 1 shows the χ^2+2% uncertainty region identified in the DSSV global analysis. The 2009 data are more

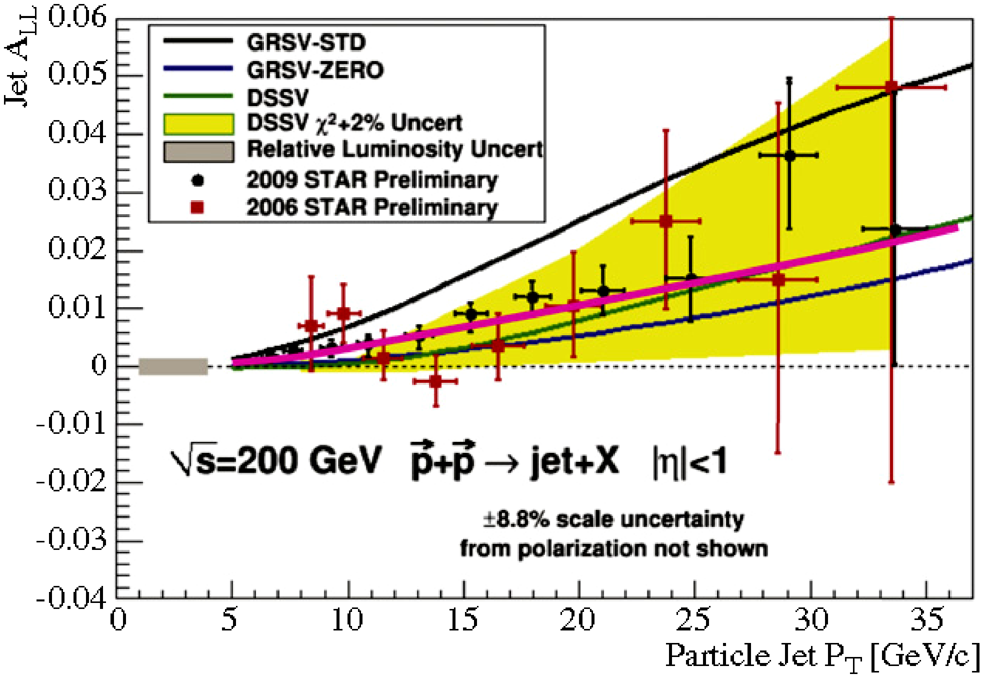

FIG. 1. 2009 (black circles) [1] and 2006 (red squares) [2] STAR measurements of the inclusive jet A_{LL} vs. p_T. The curves show predictions based upon the GRSV [3] and DSSV [4] polarized parton distributions. The yellow band shows the DSSV χ^2+2% uncertainty region [4]. The magenta curve shows a new global fit by the DSSV group [5] that includes these preliminary 2009 results among the input

precise than the 2006 data by a factor of four in the low-p_T bins and a factor of three in the high-p_T bins. The STAR 2009 inclusive jet results fall between the predictions from DSSV and GRSV-STD.

DSSV was the first polarized parton distribution fit that included deep-inelastic scattering, semi-inclusive deep-inelastic scattering, and RHIC data on an equal footing [4]. The STAR 2005 and 2006 inclusive jet A_{LL} measurements played a significant role in constraining $\Delta g(x)$ in DSSV. Last summer we obtained a copy of the DSSV source code from the authors. The original DSSV analysis treated all STAR (and PHENIX) systematic uncertainties as point-to-point effects, added in quadrature with the respective statistical uncertainties. We revised the DSSV inclusive jet A_{LL} subroutines to treat properly our dominant correlated systematics: relative luminosity and the overall jet energy scale. We also included the new results from the 2009 STAR data. We then explored how the 2009 STAR data impact the best fit for the gluon polarization. We find that the new STAR data lead to an increase in the integral of $\Delta g(x)$ over the region $0.05 < x < 0.2$ and significantly reduce the uncertainty. We also find that the 2009 STAR results have a significant impact on the integral of $\Delta g(x)$ over the region $0.2 < x < 1$, in contrast to previous RHIC measurements. The DSSV group has now substituted our modified inclusive jet A_{LL} routines into their analyses. They have also substituted similar modified inclusive π^0 A_{LL} routines from PHENIX, and added new results from COMPASS. The magenta curve in Fig. 1 shows a new preliminary best fit from the DSSV group [5] that incorporates these modifications. The integral of $\Delta g(x)$ over the region $0.05 < x < 0.2$ is approximately 0.13, consistent with the fits that we performed. This represents the first experimental evidence for non-zero gluon polarization in the proton.

The dominant systematic uncertainties in the 2009 measurement originate from differences between the true and reconstructed jet p_T, the non-uniform trigger sampling of the underlying partonic processes (gg, qg, and qq), and relative luminosities. During the past year, we have been working to reduce and finalize the trigger and reconstruction bias uncertainties. Previous STAR inclusive jet analyses have estimated trigger and reconstruction bias using samples of PYTHIA events processed through a GEANT model of the STAR detector. Such "pure simulation" events lack the pile-up backgrounds that are present in real data. Charged hadron tracks or electromagnetic calorimeter towers from pile-up can inadvertently be included in a jet. The pile-up can also reduce the tracking efficiency of the TPC by several percent [6]. In the early years of RHIC, the luminosities were low enough that pile-up backgrounds were not a significant problem in pp collisions. This is no longer true at current RHIC pp collision rates. For the 2006 and preliminary 2009 A_{LL} measurements, corrections were applied for the pile-up effects on the reconstructed jet energies. The corrections did a good job accounting for the average shift in the reconstructed jet energies. The uncertainties associated with the event-by-event fluctuations due to pile-up effects were larger.

During the past year, we have developed techniques to embed full PYTHIA+GEANT simulations into recorded STAR zerobias events, thereby folding both the average and event-by-event effects of pile-up into our simulations without the need for external corrections. The cpu time required to produce microDST's from the embedded events is at least an order of magnitude longer than is required for pure simulation samples. In order to keep the total cpu requirements tolerable, we modified the standard STAR embedding and event reconstruction procedure to occur in two passes, first simulating the electromagnetic calorimeters and trigger, then simulating the TPC only for those events that satisfy the trigger requirements. The PYTHIA information is saved for all simulated events, including those that fail the trigger.

For the preliminary 2009 result, the systematic uncertainties from trigger and reconstruction bias were 50-100% of the statistical uncertainties for several low- to intermediate-p_T bins. For these jet p_T's, the dominant effect arises from underlying event contributions that cause low-p_T parton jets to be reconstructed as higher-p_T particle and detector jets. Previous STAR jet analyses have used a STAR implementation of the mid-point cone algorithm that was developed for the Tevatron Run 2. The main external parameter, the cone radius R, has been chosen based on the physical coverage of the TPC and electromagnetic calorimeters combined with examinations of the recorded data. We adopted $R = 0.4$ for 2003-05 and $R = 0.7$ for 2006 and the preliminary 2009 analyses. The simulations required to estimate trigger and reconstruction bias were then done using those parameters. For the final 2009 analysis, we are turning this procedure around. We are performing a detailed comparison of the jets in our embedded PYTHIA+GEANT events at the parton, particle, and detector levels, using four different cone radii (R = 0.4, 0.5, 0.6, and 0.7) and four different jet reconstruction algorithms (the STAR mid-point cone algorithm, plus the k_T, Anti-k_T, and CDF mid-point cone algorithms from the FastJet package). We have found that we can reduce the systematic bias substantially at the expense of a modest loss of jet statistics. We are now working to optimize of the total uncertainties.

Another major goal of the RHIC spin program is to unravel the origin of the large transverse single-spin asymmetries that have been seen at forward rapidities at RHIC [7]. The asymmetries have been attributed to the Sivers effect, a correlation between the spin of the incident proton and the transverse momentum of the quark or gluon that experiences the hard scattering, the Collins effect, which arises from the spin-dependent fragmentation of polarized scattered quarks, or a combination of the two. The Sivers effect provides a window into parton orbital motion because it requires interference between amplitudes involving partons with different orbital angular momenta. The Collins effect provides a means to explore quark transversity, the third collinear, leading-twist parton distribution function. (The other two are the unpolarized distribution and the helicity distribution, which is explored in longitudinally polarized collisions.)

This past year, we completed an exploratory study of spin-dependent two-particle correlations in transversely polarized proton collisions from the 2008 RHIC run [8]. By correlating trigger π^0s from the STAR FMS with charged tracks at similar pseudorapidity measured with the STAR FTPC, we explored interference fragmentation functions (IFF) and Sivers asymmetries in a kinematic region where we have already measured large A_N for inclusive pions [7]. IFFs are sensitive to quark transversity and closely related to the Collins effect.

The Sivers asymmetry depends on the azimuthal distribution of di-hadron pairs about the beam axis. The IFF asymmetry depends on both the azimuthal location of the di-hadron pair about the beam axis and the azimuthal orientation of the pair. These two effects decouple when the di-hadrons are measured with an azimuthally symmetric detector. Unfortunately, the 2008 data have large, poorly understood acceptance distortions in both the FMS and the FTPC. These distortions coupled the Sivers and IFF asymmetries. We developed data-driven procedures to obtain the Sivers and IFF asymmetries in the presence of these distortions. The procedures that we developed have now been adopted by other STAR collaborators to measure the Collins asymmetry in mid-rapidity jet production.

Fig. 2 shows the final results for the IFF and Sivers asymmetries. The asymmetries were measured as a function of the maximum separation distance ΔR_{max} between the π^0 and the charged hadron. Large ΔR_{max} maximizes the di-hadron yield. However, it also leads to a large underlying event background that dilutes the spin asymmetries of interest. Small ΔR_{max} maximizes the signal-to-background ratio, but with a much smaller di-hadron yield. The measured IFF asymmetries are close to expectations. However, the limited statistics available in the 2008 data set prevent any strong conclusions.

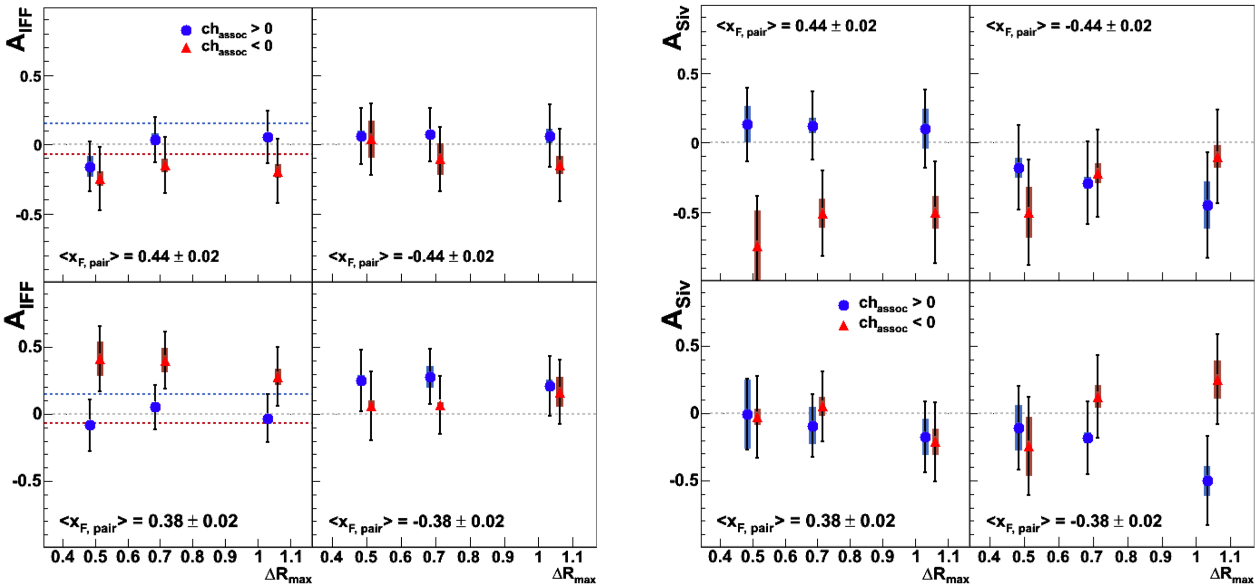

FIG. 2. The left four panels show forward π^0-charged hadron IFF asymmetries, as a function of the maximum separation distance ΔR_{max} between the hadrons. The right four panels show forward π^0-charged hadron Sivers asymmetries. Blue circles (red triangles) show results for positively (negatively) charged hadrons. Each individual panel shows results for the specified di-hadron Feynman-*x*. The dashed lines in the leftmost panels show the expected scale of the IFF asymmetries

More details regarding the spin-dependent di-hadron asymmetries can be found in [8].

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