Spin physics with STAR at RHIC

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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, we finalized the STAR results for the longitudinal double-spin asymmetry, A_{LL}, for inclusive jet production in 200 GeV *pp* collisions based on data that were recorded in 2009, completed a preliminary analysis of A_{LL} for inclusive jets in 510 GeV *pp* collisions based on data that STAR recorded in 2012, made the first observations of the Collins effect in *pp* collisions based on data from 500 GeV collisions in 2011 and 200 GeV collisions in 2012, and found further support, in the form of forward-mid-rapidity di-jet correlations, for last year's observation that the large transverse single-spin asymmetries that have been seen for inclusive hadron production at forward rapidities at RHIC are unlikely to arise from conventional 2 → 2 parton scattering.

A major goal of the RHIC spin program is to determine the gluon polarization in the proton over a wide range of x. The longitudinal double-spin asymmetry, A_{LL}, for inclusive jet production is an ideal tool in this effort because the cross section is large and dominated by quark-gluon and gluon-gluon scattering processes, both of which have large partonic

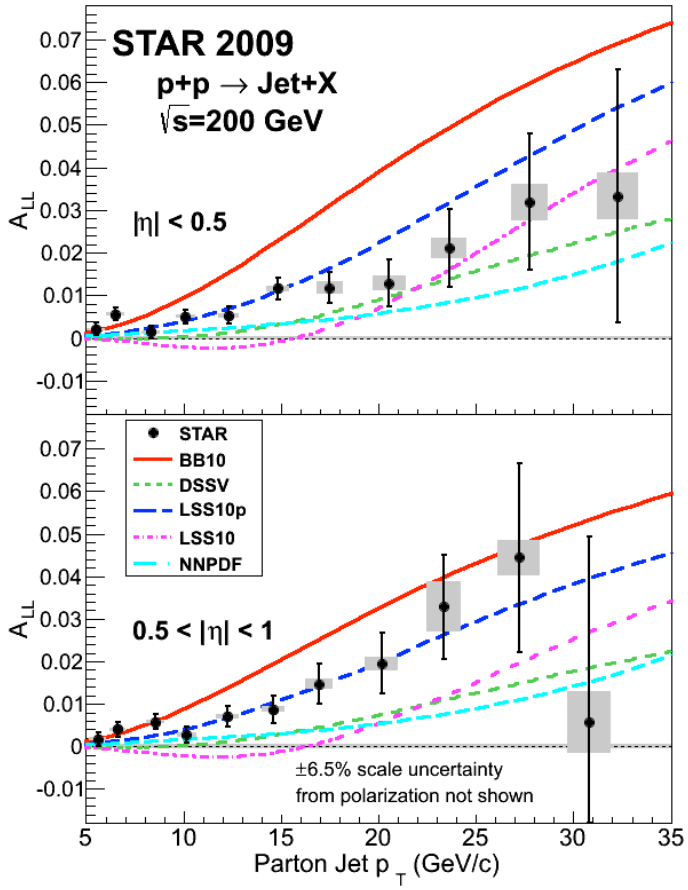

FIG. 1. A_{LL} for inclusive jet production in 200 GeV *pp* collisions, based on data that STAR recorded in 2009, together with predictions based on several recent polarized parton distribution fits. See [1] for details.

asymmetries. Fig. 1 shows the final STAR results for A_{LL} for inclusive jets in 200 GeV collisions, based on data that were recorded in 2009. The paper describing these results was submitted to Physical Review Letters this past year [1]. These results have now been included in new global analyses of the polarized parton distribution functions by the DSSV [2] and NNPDF groups [3]. Both groups find that the 200 GeV STAR inclusive jet A_{LL} results provide ~3-sigma evidence of positive gluon polarization in the proton within the sampled region, $x > 0.05$.

Since then, we have focused on completing a similar analysis of the inclusive jet data that STAR recorded in 2012 at the higher collision energy of 510 GeV. The higher center-of-mass energy provides access to gluon polarization down to $x \sim 0.02$. The first STAR preliminary results for A_{LL} for inclusive jets in 510 GeV collisions [4], shown in Fig. 2, were presented at the SPIN 2014 conference in Beijing in October, 2014. We find that A_{LL} at 510 GeV is consistent with those global analyses that successfully describe our previous 200 GeV results. It is also consistent with our previous measurements at 200 GeV in the overlapping x_T range. We are now working on the remaining steps necessary to turn these preliminary results into final results.

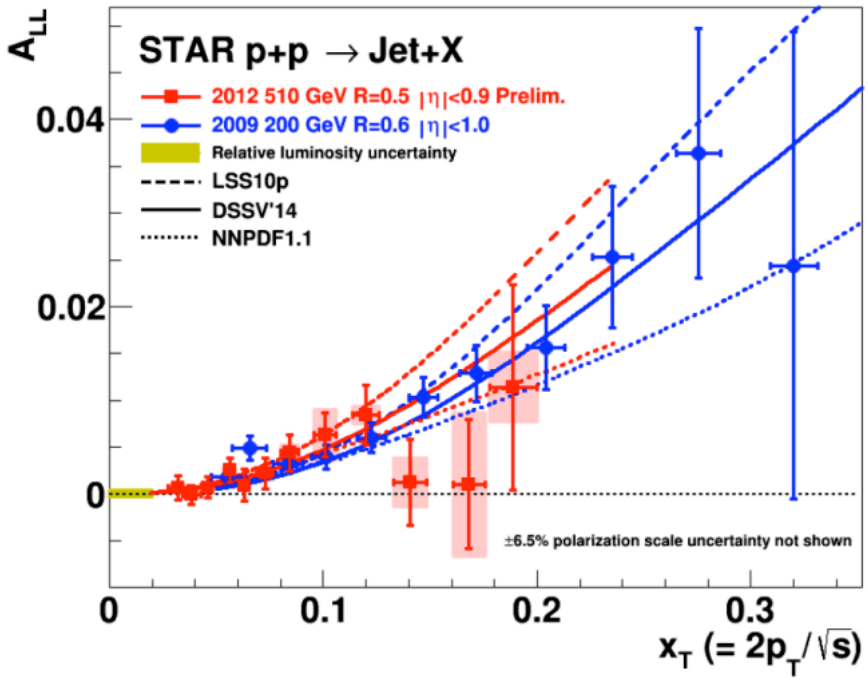

FIG. 2. A_{LL} for inclusive jet production in 510 GeV *pp* collisions, compared to that for 200 GeV collisions [4]. The curves show three recent polarized parton distribution function fits that describe the 200 GeV results.

Inclusive jets also provide access to a wealth of transverse spin observables. During this past year, STAR reported the first observation of the Collins effect in *pp* collisions [5], based on the azimuthal distributions of charged pions in mid-rapidity jets. We have now released preliminary results of measurements in both 200 and 500 GeV *pp* collisions, as shown in Fig. 3 [6]. The results at the two energies agree with each other, and are qualitatively similar to the Collins asymmetries that have been measured at comparable x values in semi-inclusive deep-

inelastic lepton scattering (SIDIS). These data will provide important insights into quark transversity in the range $0.1 < x < 0.3$ where it is only weakly constrained by existing SIDIS measurements, as well as evolution effects in transverse-momentum-dependent fragmentation functions and factorization breaking effects for fragmentation functions in *pp* collisions.

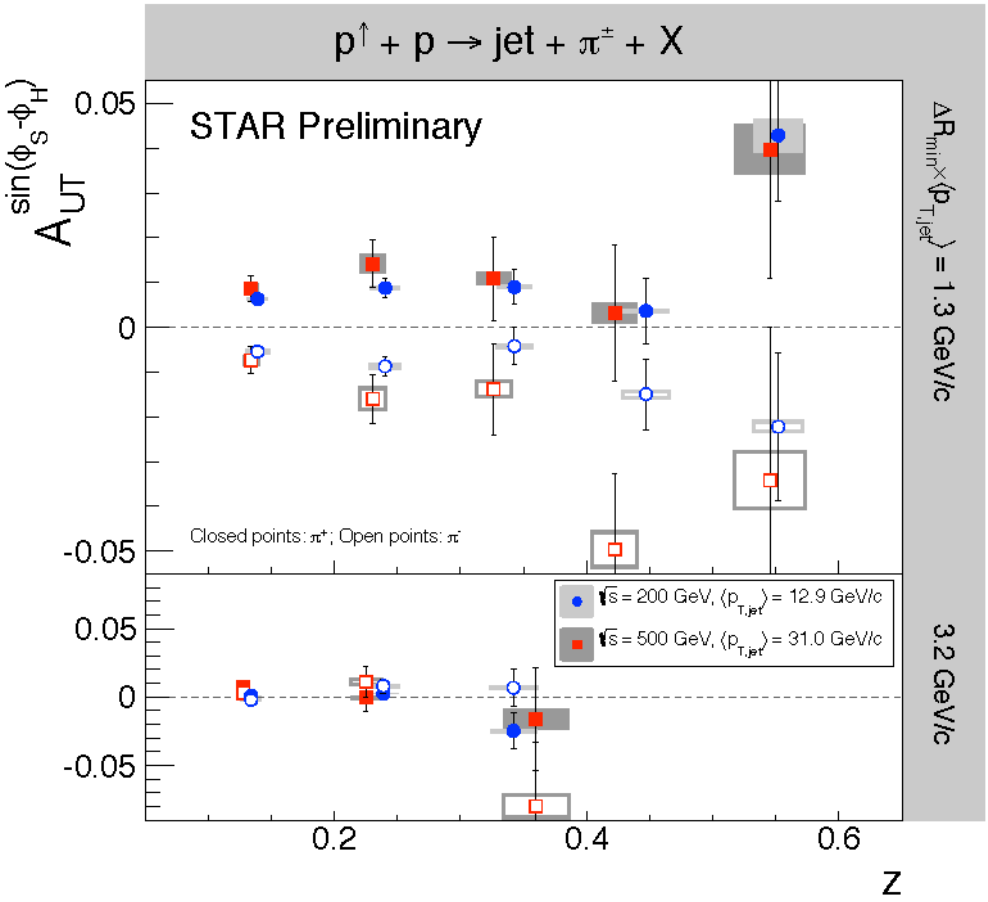

FIG. 3. Collins effect measurements in 200 and 500 GeV *pp* collisions [6]. The p_T ranges at the two energies have been chosen to sample the same x_T regions. We find that the asymmetries are quite sensitive to j_T, the transverse momentum of the pion relative to its parent jet thrust axis, as demonstrated by the different signal magnitudes in the upper and lower

The 500 GeV results in Fig. 3 focus on the high-p_T region where quark-initiated scattering makes a significant contribution to the cross section. Lower-p_T jets in 500 GeV collisions are more likely to arise from gluon-gluon scattering. Therefore, the 500 GeV Collins effect measurements have been complemented with studies of the total inclusive jet asymmetry, A_N, and the gluon analog of the Collins effect. The former provides information regarding the gluon Sivers function. The latter, sometimes referred to as the "Collins-like effect", involves a convolution of the gluon linear polarization in a transversely polarized proton with the gluon analog of the Collins fragmentation function. The STAR 500 GeV data provide the first ever experimental sensitivity to these novel gluon distributions. A paper describing the measurements of the inclusive jet A_N, the Collins effect, and the Collins-like effect with the 500 GeV data is

currently being written up for publication. It will be followed by a paper describing the 200 GeV results as soon as they are finalized.

The STAR Forward Meson Spectrometer (FMS) provides electromagnetic calorimetry in the pseudo-rapidity region $2.5 < \eta < 4$. But unlike mid-rapidity, the FMS has no charged hadron tracking to complement it. Therefore, in the forward direction STAR can only reconstruct "EM-jets" from the neutral fragments, mostly photons from π^0 decays. We are investigating the transverse single-spin asymmetry, A_N, for forward EM-jet production in 500 GeV *pp* collisions that were recorded by STAR in 2011. In last year's *Progress in Research*, we showed that A_N for EM-jets is a strong function of the number of photons in the jet. Most of the 2-photon EM-jets, and a significant fraction of the 1-photon events, arise from an isolated π^0. They have large asymmetries, consistent with previous STAR measurements. As the number of photons in the jet increases, A_N is seen to decrease, eventually being consistent with zero for EM-jets that contain 5 or more photons. During this past year, we examined the spin asymmetries when the EM-jets are separated according to whether or not a coincident away-side EM-jet is observed by the mid-rapidity STAR calorimeters. As shown in Fig. 4, the asymmetries for isolated π^0 production are found to be substantially smaller when an away-side mid-rapidity jet is seen [7]. Taken together, these observations raise serious question whether the large transverse spin asymmetries that have

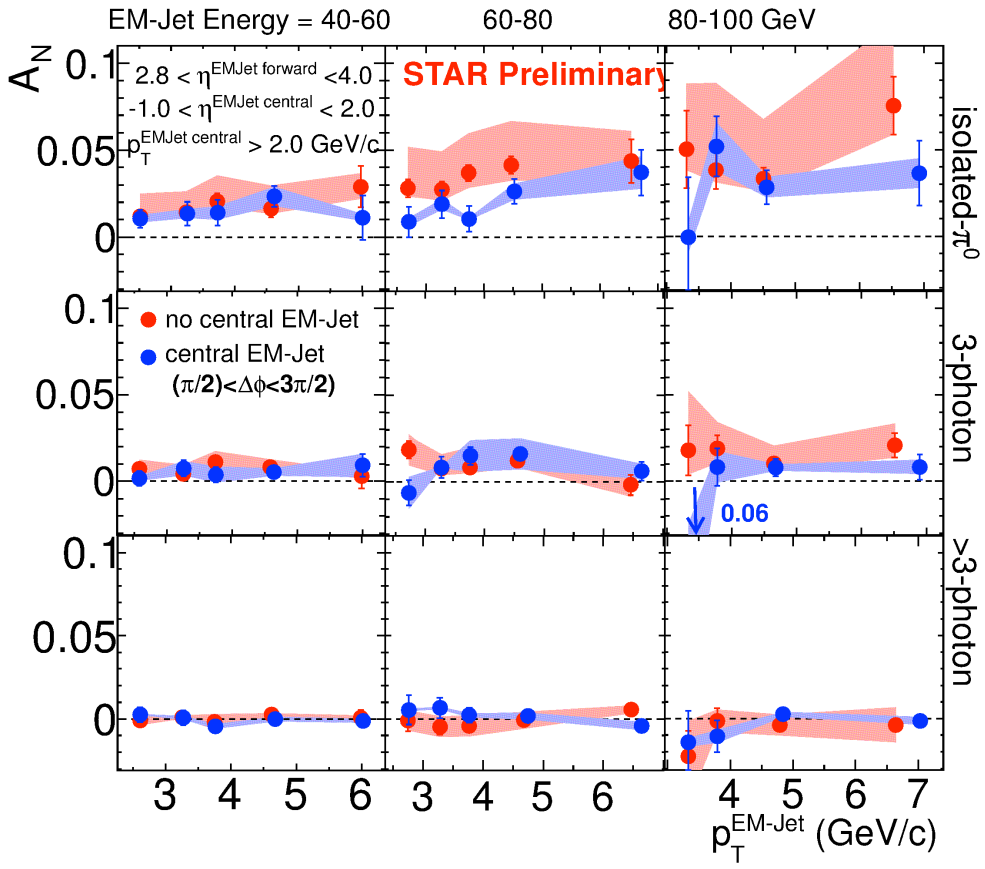

FIG. 4. A_N for forward EM-jet production as a function of energy, p_T, and whether or not a coincident away-side EM-jet is seen at mid-rapidity [7].

been seen for forward inclusive hadron production arise from conventional $2 \rightarrow 2$ parton scattering. At present, we are working on Monte Carlo simulations to finalize the systematic uncertainties for these measurements.

[1] L. Adamczyk *et al*. (STAR Collaboration), arXiv:1405.5134.
[2] D. DeFlorian *et al*., Phys. Rev. Lett. **113**, 012001 (2014).
[3] E.R. Nocera *et al*. (NNPDF Collaboration), Nucl. Phys. B **887**, 276 (2014).
[4] Z. Chang, for the STAR Collaboration, invited talk at SPIN 2014.
[5] J.K. Adkins, for the STAR Collaboration, talk at SPIN 2014.
[6] E.C. Aschenauer *et al*. (RHIC Spin Collaboration), arXiv:1501.01220.
[7] M.M. Mondal, for the STAR Collaboration, arXiv:1407.3715.