Midrapidity Spin Asymmetries at STAR

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Abstract. Single- and double-spin asymmetries have been measured for the leading charged particle at mid-rapidity in collisions of polarized protons at $\sqrt{s}$ of 200 GeV. Raw asymmetries consistent with zero were measured at the sensitivity level of 10^{-3} over the p_T range from 0.2 to several GeV/c. Instrumental asymmetries are also zero with similar precision.

INTRODUCTION

This year, the STAR detector joined with other experiments at RHIC recording the first collisions of polarized protons at $\sqrt{s}$ = 200 GeV. These measurements represent a leap by an order of magnitude in the energy of studies with polarized proton beams. Both beams were polarized vertically with alternating spin directions, allowing for extraction of possible single- and double-spin transverse asymmetries for a number of processes. The analysis reported here focused on the determination of asymmetries for the detected charged particle of highest transverse momentum (p_T) within the pseudorapidity range $|\eta| \leq 1.4$ in each event recorded with a minimum-bias trigger. For p_T well in excess of 1 GeV/c, it is expected that this leading charged particle arises from jet production, where leading-twist perturbative QCD (pQCD) predicts vanishingly small single-spin effects at mid-rapidity [1].

We have developed an analysis procedure taking advantage of the full azimuthal symmetry of the STAR detector to permit simultaneous and independent extraction of single- and double-spin physics asymmetries and a number of possible instrumental asymmetries [2]. The multiple null tests incorporated in this procedure provide a stringent assessment of the robustness of transverse spin asymmetry measurements.

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[1] For the full author list and acknowledgments, see the appendix to the proceedings.

EXPERIMENTAL SETUP AND EVENT SELECTION

The Time Projection Chamber (TPC) positioned in the uniform magnetic field of the STAR detector (see Fig. 1) enabled reconstruction of the event vertex and of the momentum for charged particles emerging from that vertex, with p_T up to several GeV/c and $\eta \equiv -\ln(\tan\frac{\theta}{2})$ up to 1.4. Beam-Beam Counters (BBC) situated at $3.4 < |\eta| < 5.0$ on either end of STAR served to provide both the minimum bias trigger and a relative luminosity ($\mathscr{L}_\tau$) monitor for the different beam spin combinations [3].

The leading charged particle (LCP) was chosen as the charged track with the largest p_T among reconstructed primary tracks with at least 20 TPC hits, out of a possible 45 hits. The azimuthal direction (ϕ) of the LCP – measured from the detector-fixed positive x-axis, directed into the plane of Fig. 1 – defined the quantization axes x', y' for each event. ϕ distributions of LCP's were accumulated for several bins in η and p_T, for both charge signs, and for the four spin combinations (τ) of the colliding beams. Typical characteristics of the measured LCP's are shown in Fig. 2.

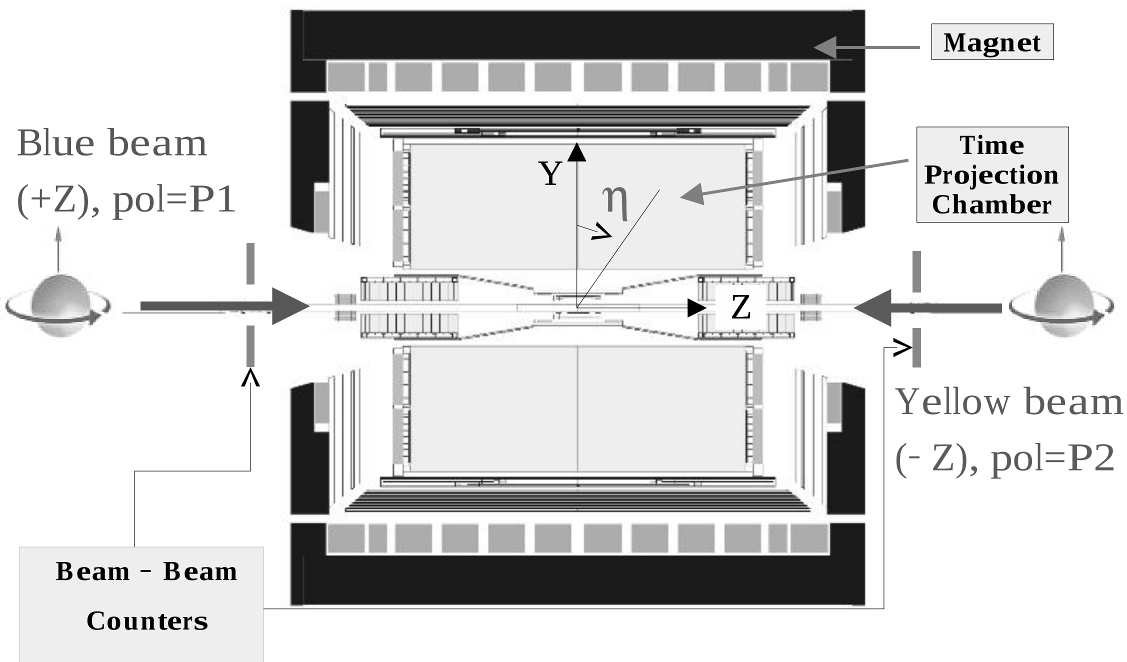

FIGURE 1. View of the STAR detector and of the detector-fixed reference frame used in this analysis.

EXTRACTION OF SPIN OBSERVABLES

For a given reaction process of choice – here the production of LCP's at some η ,p_T, and charge, the yields ($N_{\pm\pm}$) may depend on the polarizations of the beams ($\pm P_1, \pm P_2$, each assumed here to have equal magnitudes for the two spin orientations):

$$N_\tau(\phi,\eta) = \mathscr{L}_\tau \cdot \sigma(\eta) \cdot eff(\phi,\eta) \cdot [\ 1 \pm A_{y'}(\eta) P_1 \cos(\phi) \ \mp A_{y'}(-\eta) P_2 \cos(\phi) \pm \frac{A_{y'y'} + A_{x'x'}}{2}(|\eta|) P_1 P_2 \ \pm \frac{A_{y'y'} - A_{x'x'}}{2}(|\eta|) P_1 P_2 \cos(2\phi)\ ] \quad (1)$$

where $\tau = \{++,+-,-+,--\}$ denotes the polarization state (with the first coefficient indicating the spin orientation of beam 1), σ the unpolarized cross section, eff the detection efficiency, $A_{y'}$ the analyzing power, and A_{jj} the relevant double-spin correlation coefficients. Beam 1 (2) is heading in the $+z$ $(-z)$ direction in Fig. 1. The dependences of the factors in Eq. 1 on other variables such as p_T or charge sign have been suppressed for simplicity.

Equation 1 includes all the polarization observables allowed by symmetry principles for a detector with full azimuthal coverage when the two beam polarizations are purely transverse. The indistinguishability of the two proton beams is reflected in the antisymmetry of $A_{y'}$, and the symmetry of $A_{x'x'}$ and $A_{y'y'}$, about $\eta = 0$, assumed in Eq. 1. In pQCD treatments of polarized proton-proton scattering [1], the analyzing power $A_{y'}$ is commonly referred to as A_T, while the two-spin correlation combination $(A_{y'y'} - A_{x'x'})/2$ is called A_{TT}. The other allowed combination $(A_{x'x'} + A_{y'y'})/2$, which we refer to below as A_Σ, is normally neglected in pQCD treatments, but can be quite large in low energy pp interactions [4].

Raw experimental yields were normalized to the relative luminosities $\mathscr{L}_\tau$ measured by the BBC, and these normalized yields ($H_\tau = N_\tau / \mathscr{L}_\tau$) were then combined to form 3 independent ratios:

$$R_1(\phi,\eta) = \frac{H_{++}(\phi,\eta) + H_{+-}(\phi,\eta) - H_{-+}(\phi,\eta) - H_{--}(\phi,\eta)}{\sum_\tau H_\tau(\phi,\eta)} ,$$
$$R_2(\phi,\eta) = \frac{H_{++}(\phi,\eta) - H_{+-}(\phi,\eta) + H_{-+}(\phi,\eta) - H_{--}(\phi,\eta)}{\sum_\tau H_\tau(\phi,\eta)} ,$$
$$R_3(\phi,\eta) = \frac{H_{++}(\phi,\eta) - H_{+-}(\phi,\eta) - H_{-+}(\phi,\eta) + H_{--}(\phi,\eta)}{\sum_\tau H_\tau(\phi,\eta)} . \quad (2)$$

In the absence of instrumental asymmetries, these ratios extract the physics asymmetries as follows:

$$R_1(\phi,\eta) = A_T(\eta) P_1 \cdot \cos(\phi) , \quad (3)$$
$$R_2(\phi,\eta) = -A_T(-\eta) P_2 \cdot \cos(\phi) , \quad (4)$$
$$R_3(\phi,\eta) = A_\Sigma(|\eta|) P_1 P_2 + A_{TT}(|\eta|) P_1 P_2 \cdot \cos(2\phi) . \quad (5)$$

Next, the ϕ-dependence of the ratios R_1 and R_2 were fitted by the trigonometric series

$$F(\phi) = a_0 + a_1 \cdot \cos(\phi) + a_2 \cdot \cos(2\phi) . \quad (6)$$

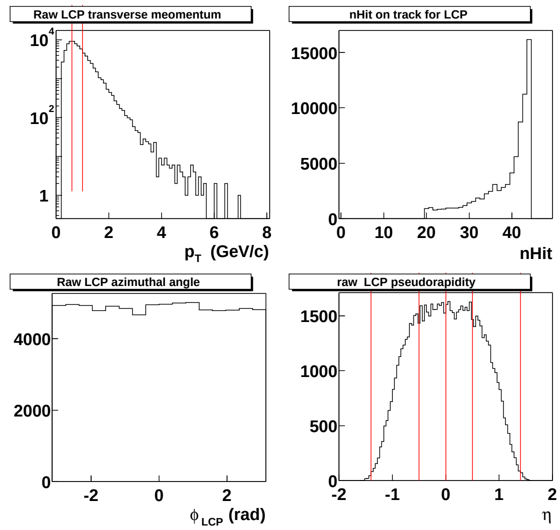

FIGURE 2. Characteristics of selected LCPs: p_T, number of points on track, ϕ and η distributions. Dashed vertical lines mark bins in p_T and η . Spectra are not corrected for the detection efficiency. The 'beam-gas' backgrounds and the false reconstructed vertex contributions are also not subtracted.

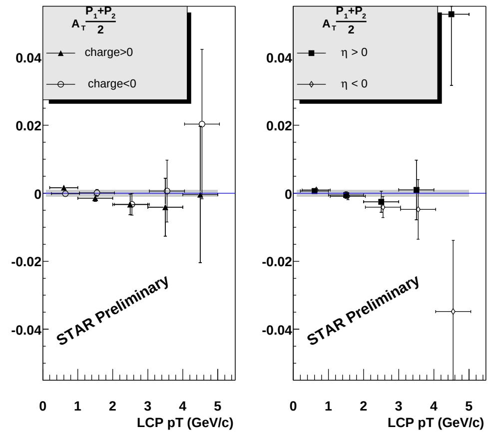

FIGURE 3. Product of transverse spin analyzing power A_T and beam polarization for the choices of opposite charges (left) and pseudo-rapidities (right). Total of 6.1 million events with three or more reconstructed primary tracks were used. The spin-dependent luminosity corrections contribute to a_1 in the second order and were not applied here. The average $(P_1 + P_2)/2 \simeq 0.11$ for the runs included.

The same formula (6) was fitted to the ratio R_3, but we named the coefficients b_0, b_1, b_2 in this case. The orthogonality of the three terms in $F(\phi)$ ensures that the three coefficients can be determined without correlations among them.

We thus extract a total of 9 coefficients, each a function of p_T, η and charge sign, four of which give the physics asymmetries in Eqs. (3,4,5), and five of which should vanish in the absence of instrumental asymmetries. In particular, the coefficients a_0 and b_0 are sensitive to errors in relative luminosity monitoring. In this sense, extraction of A_Σ (from b_0) is subject to the same problems we will face in subsequent years in measuring A_{LL} with longitudinally polarized beams in an attempt to extract information on the gluon polarization in a polarized proton [5]. It is difficult to distinguish among a real ϕ-independent two-spin asymmetry in a reaction of interest, a similar asymmetry in the luminosity-monitoring reaction, and a luminosity monitoring error that happens to be different when the beam spins are parallel *vs.* antiparallel.

RESULTS

A total of 6.1 million minimum bias events were analyzed to extract the coefficients a_1 and the analyzing power A_T. Since the luminosity monitor scalers were not fully commissioned for all of these runs, a smaller sample of 2.8M events was subjected to the full analysis to extract all nine coefficients. The beam polarizations were monitored in RHIC with Coulomb-nuclear interference polarimeters [6], whose effective analyzing power at 100 GeV is not yet known. Under the assumption that the polarimeters have the same analyzing power as their measured values at the RHIC injection energy of 24.3 GeV, the time-averaged beam polarizations were $P_1 = 0.12$, $P_2 = 0.17$ for the 2.8M events, and $(P_1+P_2)/2 = 0.11$ for the 6.1M events. The statistical error of these average polarizations is below 0.01, but they are subjected to large normalization uncertainties.

By averaging the a_1 values obtained from the fits to R_1 and R_2, we obtain the single-spin asymmetry $A_T(P_1+P_2)/2$. The results are shown as a function of p_T in Fig. 3, for the two charge signs (integrated over all η) in the left frame and separately for positive and negative η (summed over both charge signs) on the right. The values of A_T are consistent with zero within statistical limits of 0.01 for p_T of 1.5 GeV/c and of 0.16 at p_T of 4.5 GeV/c. The gray band in Fig. 3 depicts the estimated systematic error for a_1 of 10^{-3}. This estimated systematic error is based on the observed values of the instrumental asymmetries, the consistency of a_1 values extracted for different choices of cuts (e.g. on the minimal number of the primary tracks in the event or on the minimum number of TPC hits required for the LCP track) and for different event samples with large or small 'beam-gas' backgrounds.

For the sample of 2.8M events, we have extracted each of the nine coefficients in each of 12 kinematic bins (2 charge signs, 2 η bins, 3 p_T bins). All the measurements are consistent with zero within 3σ. The total χ^2 value for the deviation of these 108 measurements from zero is 107. We show a sample of the results in Fig. 4.

The unphysical coefficients a_0 and a_2 extracted from eqs. (3,4) contain important cross-check information about possible systematic errors. For example, a non-zero a_0 might arise from a non-zero analyzing power of a process measured by the luminosity monitor (BBC) folded with a possible azimuthal non-uniformity of that detector. Fig. 4a shows the p_T-dependence of a_0, also consistent with zero within statistical limits of 10^{-3}.

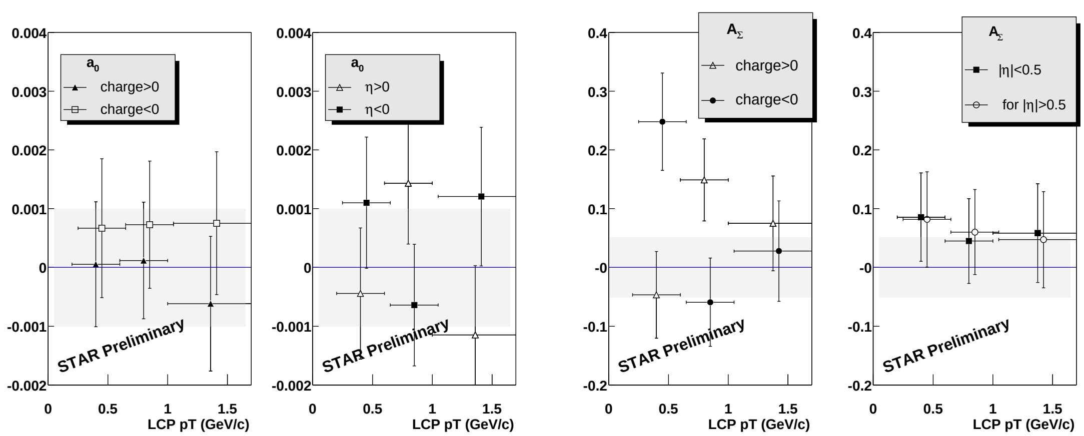

FIGURE 4. a) Instrumental asymmetry a_0 is consistent with zero. b) Physically allowed ϕ independent double-spin correlation coefficient $A_\Sigma = b_0/P_1P_2$. The last p_T bin in both figures contains any p_T above 1 GeV/c. The η range was chosen as $|\eta| > 0.5$ or $|\eta| < 0.5$ to accommodate the symmetry of eq. (5). A sample of 2.8M events with one or more reconstructed primary tracks was used. The spin-dependent luminosity corrections were applied to the measured yields. The gray band depicts the estimated systematic error of 10^{-3}.

The values of the physically allowed double-spin correlation coefficient $A_\Sigma = b_0/P_1P_2$ are shown in fig. 4b. Its average is marginally consistent with zero, deviating by 2.3σ. This deviation most likely represents a purely statistical fluctuation but could be a hint of a spin-dependent A_Σ contribution in LCP production, or in a process measured by the luminosity monitor. Note that the sensitivity level to the spin correlations is only of order 0.1 even at low p_T, because the product of beam polarizations was only of order 0.02.

SUMMARY

The first measurements of the single- and double-spin asymmetries for the leading charged particle at mid-rapidity in pp collisions at $\sqrt{s} = 200$ GeV yield values statistically indistinguishable from zero. The results are consistent with theoretical predictions for charged pions [7], [8] extrapolated to mid-rapidity.

All together, there were three coefficients extracted from each equation in formula (2), leading to simultaneous measurement of 4 physics raw asymmetries (eq. 3 - 5), plus 5 terms sensitive to instrumental asymmetries. The instrumental asymmetries consistent with zero confirm that STAR is a valuable detector for measurements of colliding polarized protons.

In the same runs, STAR has observed a significant non-zero transverse spin asymmetry for π^0 measured at forward rapidity, presented at this conference by G.Rakness [9]. The simultaneous measurement of zero and non-zero asymmetries with the same apparatus builds our confidence that STAR is ready to pursue the more challenging measurement of A_{LL} in the near future.

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