Longitudinal Spin Transfer of Λ and $\bar{\Lambda}$ Hyperons in Polarized Proton-Proton Collisions at $\sqrt{s} = 200\,\text{GeV}$

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Abstract. The longitudinal spin transfer D_{LL} of Λ and $\bar{\Lambda}$ hyperons produced with large transverse momenta p_T in polarized proton-proton collisions is sensitive to the helicity distribution functions of strange quarks and anti-quarks, and to polarized fragmentation functions. This contribution reports a measurement of the longitudinal spin transfer D_{LL} in the inclusive production of Λ and $\bar{\Lambda}$ hyperons at central rapidities in polarized proton-proton collisions at a center of mass energy of $\sqrt{s} = 200\,\text{GeV}$. The data were collected with the STAR experiment at RHIC and correspond to $\sim 3\,\text{pb}^{-1}$ and $\sim 50\%$ beam polarization.

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INTRODUCTION

The combination of data on the spin dependent structure function g_1 in polarized deep-inelastic lepton-nucleon scattering and the couplings in weak hyperon decay lead to the puzzling notion that the sum of strange quark and anti-quark spins preferentially point opposite to the proton spin [1]. Semi-inclusive deep-inelastic scattering measurements form a complementary path to the (strange) polarization of the nucleon sea, but currently provide no evidence for such polarization [2, 3]. The semi-inclusive data, however, cover a smaller kinematic range than the inclusive data.

In the hard scattering of protons, the longitudinal spin transfer D_{LL} of Λ and $\bar{\Lambda}$ hyperons produced with large transverse momenta p_T is expected to be sensitive to the helicity distribution functions of strange quarks and strange anti-quarks, and to polarized fragmentation functions [4]. D_{LL} quantifies the transfer of longitudinal polarization from the polarized beam proton to the Λ in singly polarized proton-proton collisions,

$$D_{LL} \equiv \frac{\sigma(pp_+ \to \Lambda_+ X) - \sigma(pp_+ \to \Lambda_- X)}{\sigma(pp_+ \to \Lambda_+ X) + \sigma(pp_+ \to \Lambda_- X)}, \tag{1}$$

and similarly for $\bar{\Lambda}$. Here, σ denotes the inclusive production cross section and the subscripts $+$ and $-$ denote particle helicity. In a proton-proton collision experiment with one fully polarized beam, D_{LL} is the Λ ($\bar{\Lambda}$) polarization along its moving direction. Its precise measurement may thus shed light on the above puzzle. This contribution reports on measurements of D_{LL} in the inclusive production of Λ and $\bar{\Lambda}$ hyperons in polarized proton-proton collisions at a center of mass energy of $\sqrt{s} = 200\,\text{GeV}$. These data cover p_T up to 4 GeV with 10% precision, thus far limited by statistics. Prior STAR measurements have determined that the inclusive $\Lambda+\bar{\Lambda}$ spin averaged cross section at $\sqrt{s}=200\,\text{GeV}$ is in reasonable agreement with perturbative QCD expectations [5].

MEASUREMENT

The present data were collected with the STAR experiment [6] at RHIC in the year 2005 and correspond to $\sim 3\,\text{pb}^{-1}$ and $\sim 50\%$ average longitudinal beam polarization. RHIC beam bunches with net positive and negative proton helicities were collided at the STAR interaction region in four different combinations, $++$, $+-$, $-+$, and $--$ and STAR events were sorted accordingly.

The events used in this analysis were recorded if they satisfied a minimum bias (MB) trigger condition, defined by coincident signals from Beam-Beam Counters around the beam pipe at either side of the STAR interaction region. About $3\cdot 10^6$ of such beam collision events were analyzed. In addition, about $3\,\text{pb}^{-1}$ was sampled with a jet patch (JP) trigger condition, imposing the minimum bias condition and a threshold of about 6.5 GeV on the transverse energy deposited in at least one patch of towers in the Barrel Electromagnetic Calorimeter. This trigger is the same as in the 2005 STAR jet spin-asymmetry measurement [8].

Charged particle tracks were reconstructed with the Time-Projection Chamber (TPC) in the 0.5 T STAR magnetic field for pseudo-rapidities $|\eta|\leq\sim 1.3$ and all azimuthal angles ϕ. Particles were identified using the agreement of the measured and expected ionization loss dE/dx in the TPC where possible. The Λ and $\bar{\Lambda}$ candidates were reconstructed by searching the events for the parity-violating hadronic decays $\Lambda\rightarrow p\pi^-$ and $\bar{\Lambda}\rightarrow\bar{p}\pi^-$, which have a branching ratio of 63.9(5)% [7]. Topological selections similar to those in Ref. [5] were applied to reduce backgrounds. Candidate events were retained only if at least one $p\pi^-$ or $\bar{p}\pi^+$ track pair was found and its reconstructed invariant mass $1.105 < M < 1.125\,\text{GeV}$ was in agreement with the $\Lambda(\bar{\Lambda})$ mass $m_{\Lambda,\bar{\Lambda}} = 1.115683(6)\,\text{GeV}$ [7].

The parity-violating hadronic decays $\Lambda\rightarrow p\pi^-$ and $\bar{\Lambda}\rightarrow\bar{p}\pi^-$ are self spin-analyzing. The Λ ($\bar{\Lambda}$) polarization can thus be determined from the angular distribution of the decay (anti-)proton in the Λ ($\bar{\Lambda}$) rest frame, which is usually described in terms of the rest-frame angle θ between the (anti-)proton momentum and the Λ ($\bar{\Lambda}$) polarization vector. Figure 1 shows a) the distribution of M versus $\cos\theta$ for Λ candidates from MB data after topological selections and b) the projection onto M after $\cos\theta$ was restricted to $\cos\theta < -0.2$ to eliminate a $K^0_\text{s}\rightarrow\pi^+\pi^-$ background originating from misidentified pions. In total about $30\cdot 10^3$ Λ and $24\cdot 10^3$ $\bar{\Lambda}$ candidates were retained from MB data. Their average p_T is about $1.3\,\text{GeV}$ and $|x_F|\sim 8\cdot 10^{-3}$. The candidate sample obtained from JP triggered data was about 80% larger.

The spin asymmetry D_{LL} was extracted in small intervals in $\cos\theta$ as follows,

$$D_{LL} = \frac{1}{\alpha P_\text{b}\,\langle\cos\theta\rangle}\frac{N^+ - N^-}{N^+ + N^-}, \tag{2}$$

where $\alpha = +(-)0.642(13)$ is the $\Lambda(\bar{\Lambda})$ decay parameter [7], P_b is the measured proton beam polarization at the STAR interaction region [9, 10, 11], and the yields N^+

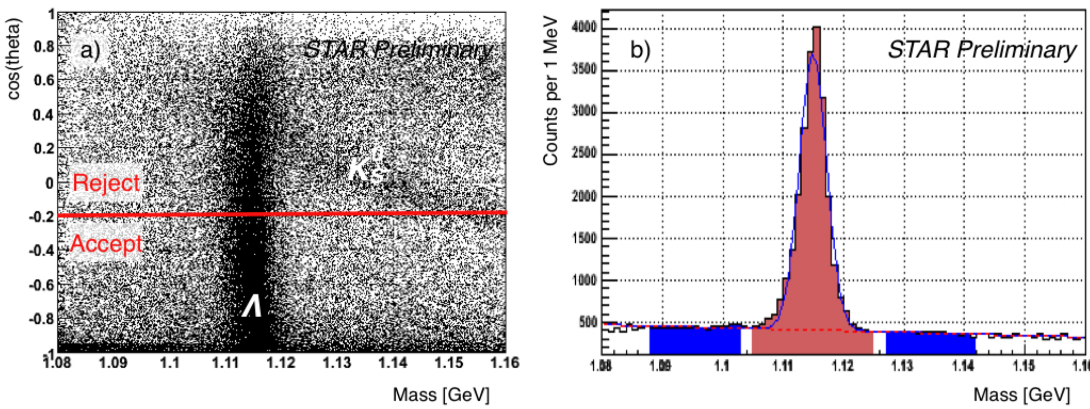

FIGURE 1. a) The invariant mass distribution of $p\pi^-$ track pairs from MB data versus $\cos\theta$ after topological selections and b) the invariant mass distribution of the Λ candidates with the additional constraint $\cos\theta < -0.2$ used to eliminate K_s^0 background. The shaded area with $1.105 < M < 1.125\,\text{GeV}$ below the peak was used to select signal candidates and the shaded intervals away from the peak were used in assessing residual background.

and N^- are obtained from the spin-sorted $\Lambda(\bar{\Lambda})$ candidate yields n^{++}, n^{+-}, n^{-+}, and n^{--} weighted by measured ratios of luminosities L [12]. Specifically, $N^+ = n^{++} \cdot L^{--}/L^{++} + n^{+-} \cdot L^{--}/L^{+-}$ and $N^- = n^{-+} \cdot L^{--}/L^{-+} + n^{--}$. Spin-sorted yields from intervals in M above and below $m_{\Lambda,\bar{\Lambda}}$, as indicated in Figure 1b), were used to correct for residual background contributions. The analysis method makes use of QCD symmetries in the $\Lambda(\bar{\Lambda})$ production process to form a ratio in which the detector acceptance (largely) cancels [13].

RESULTS AND SUMMARY

Figure 2a) shows preliminary results for the Λ and $\bar{\Lambda}$ D_{LL} from MB data for positive and negative η. Positive η is taken along the momentum direction of the polarized beam. The data are statistics limited. Systematic uncertainty at the level of 0.01 is estimated from uncertainties in the measured ratios of luminosities, residual transverse beam polarization components at the STAR interaction region, and uncertainties in α and the beam polarization. At the present level of precision, the Λ and $\bar{\Lambda}$ D_{LL} are found consistent with each other and consistent for both η values with no spin transfer effects.

TheΛ and $\bar{\Lambda}$ results from MB data are compared in Figure 2b) with $\bar{\Lambda}$ results obtained from JP data for positive η. As expected the JP data extend to considerably larger values of p_T up to $4\,\text{GeV}$. In this region the inclusive $\Lambda + \bar{\Lambda}$ spin averaged yield is in reasonable agreement with perturbative QCD expectations [5] for suitable choices of the spin averaged fragmentation function. The systematic uncertainties in the JP D_{LL} measurement are estimated to be somewhat larger than those in the MB measurement, mostly because of possible biases introduced by the JP trigger requirement. These effects were studied through Monte Carlo simulation. The data on D_{LL} remain statistics

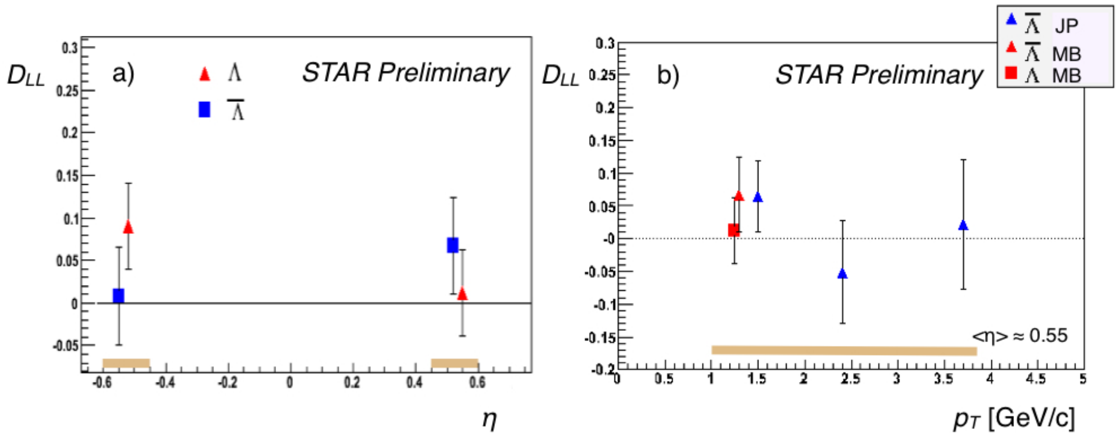

FIGURE 2. Left: preliminary results for the longitudinal spin transfer D_{LL} of inclusive Λ and $\bar{\Lambda}$ hyperons in proton-proton collisions at $\sqrt{s} = 200\,\text{GeV}$ versus pseudo-rapidity η from data obtained with a beam-collision trigger. Positive η is taken along the direction of the polarized beam. Right: preliminary results for D_{LL} for Λ and $\bar{\Lambda}$ at positive η compared to preliminary results obtained for the $\bar{\Lambda}$ with a jet trigger. The uncertainties on the data points are statistical and the shaded bands indicate the estimated size of the total systematic uncertainty, not including the scale uncertainty introduced by the beam polarization measurement.

limited and to within the present uncertainties of about 10% no evidence is found for p_T dependence.

In summary, the present measurements of D_{LL} form a proof-of-principle that pave the way for future measurements with better precision, which may provide new constraints on the polarized (anti-)strange sea quark polarization in the polarized nucleon and polarized fragmentation functions.

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