Longitudinal and Transverse Spin Transfer of Λ and $\overline{\Lambda}$ Hyperons in Polarized p+p Collisions at $\sqrt{s} = 200$ GeV at RHIC-STAR

Yike Xu[1 *]
for STAR Collaboration

1 Institute of Frontier and Interdisciplinary Science & Key Laboratory of Particle Physics and Particle Irradiation (MOE), Shandong University, Qingdao, Shandong, 266237, China
* yxu@rcf.rhic.bnl.gov

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Abstract

Measurements of the longitudinal spin transfer, D_{LL}, and the transverse spin transfer, D_{TT}, of the $\Lambda(\bar{\Lambda})$ hyperon in polarized p+p collisions are expected to be sensitive to the helicity distribution and transversity distribution of the $s(\bar{s})$ quark in proton and the corresponding polarized fragmentation functions. This contribution presents the new preliminary results of the $\Lambda(\bar{\Lambda})$ D_{LL} and D_{TT} using data collected at RHIC-STAR experiment in 2015, with twice larger statistics than previously published results.

1 Introduction

Since the surprising results on the spin structure of the proton by the EMC experiment in the late 1980s [1], much progress has been made in understanding the origin of the proton spin. However, the sea quark contribution to the proton spin, for example, the polarized distributions of the strange quark(anti-quark), $s(\bar{s})$, is still not well constrained by experimental data. The Λ hyperon contains a strange constitute quark, which is expected to carry most of Λ spin. The Λ polarization, $P_{\Lambda(\bar{\Lambda})}$, can be determined from the angular distribution of the weakly decayed daughters. The spin transfer of the Λ hyperon in proton-proton collisions provides a way to study the $s(\bar{s})$ quark contribution to the proton spin [2–4]. Recently, strange quark polarization has been extracted from a model calculation incorporating the STAR measurements of the hyperon spin transfer [5].

The longitudinal and transverse spin transfer asymmetries, D_{LL} and D_{TT}, of Λ hyperons in p+p collisions are defined in Eq 1. They are naturally connected to the polarized parton distribution functions in the proton and polarized fragmentation functions. D_{LL} provides access to the helicity distribution of strange quark, while D_{TT} is coupled to the transversity distribution.

$$
\begin{aligned}
D^{\Lambda}_{LL} &\equiv \frac{d\sigma^{(p^+p\to\Lambda^+X)} - d\sigma^{(p^+p\to\Lambda^-X)}}{d\sigma^{(p^+p\to\Lambda^+X)} + d\sigma^{(p^+p\to\Lambda^-X)}} = \frac{d\Delta\sigma^{\Lambda}}{d\sigma^{\Lambda}};\\
D^{\Lambda}_{TT} &\equiv \frac{d\sigma^{(p^\uparrow p\to\Lambda^\uparrow X)} - d\sigma^{(p^\uparrow p\to\Lambda^\downarrow X)}}{d\sigma^{(p^\uparrow p\to\Lambda^\uparrow X)} + d\sigma^{(p^\uparrow p\to\Lambda^\downarrow X)}} = \frac{d\delta\sigma^{\Lambda}}{d\sigma^{\Lambda}},
\end{aligned}
\tag{1}
$$

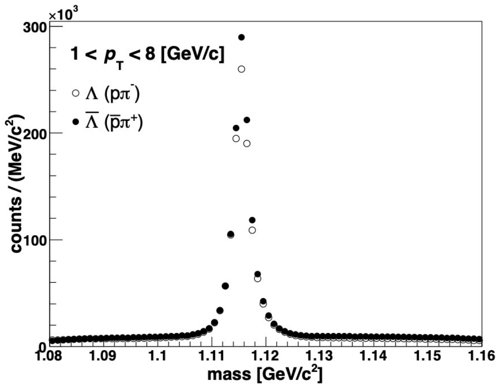

Figure 1: The invariant mass distribution for Λ and $\bar{\Lambda}$ candidates with $1 < p_T < 8$ GeV/c after applying selection cuts as in [7].

where p^+/p^- and Λ^+/Λ^- denote the helicity of the colliding proton and the Λ hyperon, and $\uparrow/\downarrow$ denotes the positive or negative transverse polarization of them. $d\delta\sigma^\Lambda$ ($d\Delta\sigma^\Lambda$) is the transversely (longitudinally) polarized cross section and $d\sigma^\Lambda$ is the unpolarized cross section. The polarized cross section can be factorized into the convolution of parton distribution functions, polarized partonic cross-section and the polarized fragmentation function.

This contribution presents the new preliminary results of D_{LL} and D_{TT} for $\Lambda(\bar{\Lambda})$ in proton-proton collisions at $\sqrt{s} = 200$ GeV, with hyperon pseudo-rapidity $|\eta| < 1.2$ and transverse momenta up to 8.0 GeV/c. This dataset is about twice as large as the previously published D_{LL} and D_{TT} results [6, 7].

2 Experiments and Hyperon Reconstruction

The Relativistic Heavy Ion Collider (RHIC) is the world's first and only polarized hadron-hadron collider. RHIC runs proton-proton collisions at $\sqrt{s} = 200$ GeV and $\sqrt{s} = 510$ GeV with proton beams longitudinally or transversely polarized. In 2015, RHIC delivered 200 GeV p+p collisions with an average beam polarization of 56% and an integrated luminosity of 52 pb^{-1} . The STAR (Solenoidal Tracker At RHIC) experiment [8] is located at the 6 o'clock position of the RHIC ring. For D_{TT} and D_{LL} analyses, several sub-detectors were used, including the Time Projection Chamber (TPC), ElectroMagnetic Calorimeter (EMC), and Time Of Flight (TOF) detector. Hard scattering events were selected with a Jet Patch trigger which was based on energy depositions in the EMC. Additionally, BBC (Beam-Beam Counter) and VPD (Vertex Position Detector) were used to monitor the relative luminosity.

The $\Lambda(\bar{\Lambda})$ candidates are identified from the topology of their weak decay channels, $\Lambda \to p\pi^-$ ($\bar{\Lambda} \to \bar{p}\pi^+$). Pairs of proton and pion tracks measured in the TPC are used to reconstruct the $\Lambda(\bar{\Lambda})$ candidates. TOF information is also used to improve particle identification. Then, a series of topological cuts are tuned to further reduce the background. The side-band method is used as in [6, 7] to estimate the residual background fraction, which is less than 10%. The spin transfer of the Λ hyperon is obtained by subtracting the contribution from residual background, for example, $D_{LL} = (D_{LL}^{raw} - rD_{LL}^{bkg})/(1-r)$, where D_{LL}^{raw} and D_{LL}^{bkg} are the spin transfers for signal and side-band regions, and r is the background fraction. A similar definition is used for D_{TT}. Figure 1 shows an example of Λ candidates invariant mass distribution.

The spin transfer analyses are performed for the $\Lambda(\bar{\Lambda})$ candidates associated with a jet. The reconstructed jet axis is used as a proxy of the momentum direction of the fragmenting quark, which is needed in determining the polarization direction for D_{TT} measurements [7]. The anti-

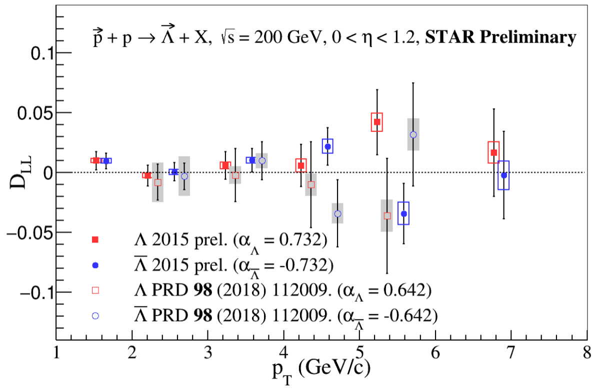

Figure 2: Preliminary results of D_{LL} for Λ and $\bar{\Lambda}$ from STAR 2015 data versus hyperon p_T, together with previously published results. The results for the $\bar{\Lambda}$ and the previously published results have been shifted slightly to larger p_T for clarity.

k_T algorithm is used to reconstruct jets, similar as in Ref. [9,10], with resolution parameter of $R = 0.6$. Then, we require jet transverse momentum $p_T > 5$ GeV/c and $-0.7 < \eta_{detector} < 0.9$. The detector pseudorapidity, $\eta_{detector}$, is defined by extrapolating the jet thrust axis into the BEMC detector, and calculating the pseudorapidity of that intersection point relative to the center of the STAR detector. The correlation between $\Lambda(\bar{\Lambda})$ candidates and the reconstructed jets is made by constraining the distance $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$ between momentum directions of $\Lambda(\bar{\Lambda})$ candidates and the reconstructed jets in $\eta - \phi$ space. The $\Lambda(\bar{\Lambda})$ hyperons in the near-side of jets ($\Delta R < 0.6$) are kept for the D_{TT} and D_{LL} analyses.

3 D_{LL} & D_{TT} Measurements and Results

3.1 D_{LL} Measurements and Results

D_{LL} is measured from asymmetry of Λ counts with opposite beam polarizations in small $\cos\theta^*$ bins, where the θ^* is the angle between the $\Lambda(\bar{\Lambda})$ polarization direction and the (anti-) proton momentum in the $\Lambda(\bar{\Lambda})$ rest frame [11]:

$$D_{LL} = \frac{1}{\alpha P_{beam} \langle\cos\theta*\rangle} \frac{N^+ - RN^-}{N^+ + RN^-} \tag{2}$$

where the $\langle\cos\theta^*\rangle$ is the average value of each $\cos\theta^*$ bin, $N^{+/-}$ is the Λ count in a $\cos\theta^*$ bin when the helicity of the polarized beam is positive or negative, $R = \mathscr{L}^+/\mathscr{L}^-$ is the relative luminosity ratio, $\alpha = 0.732 \pm 0.014$ is the decay parameter and P_{beam} is the beam polarization.

Figure 2 shows new D_{LL} preliminary results based on the 2015 data at 200 GeV, together with the published results from the 2009 data [6]. The new results have about two times larger statistics than the previously published results, and are consistent with them. The new results cover transverse momenta up to 8.0 GeV/c, and are consistent with zero within uncertainties. These results are also comparable with model calculations in [2].

3.2 D_{TT} Measurements and Results

For the transverse spin transfer D_{TT}, the hyperon polarization direction is defined as the transverse polarization direction of the outgoing parton, which is obtained by rotating the polarization vector of the incoming parton along the normal direction of the partonic scattering plane.

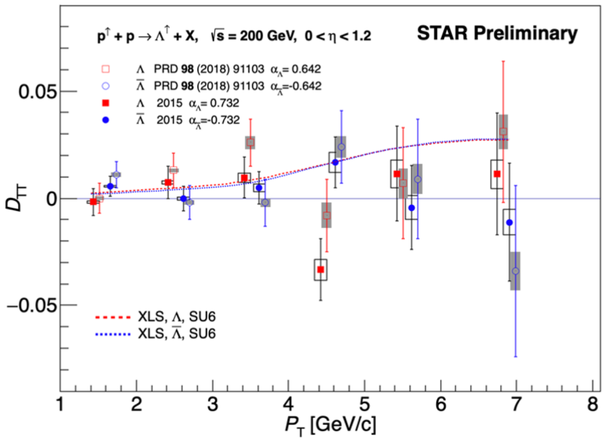

Figure 3: Preliminary results of D_{TT} for Λ and $\bar{\Lambda}$ from STAR 2015 data versus hyperon p_T, together with previously published results. The $\bar{\Lambda}$ results and the previously published results have been shifted slightly to larger p_T values for clarity.

The scattering plane is spanned by the momentum directions of incoming and outgoing partons [7]. Here the reconstructed jet axis is used as the momentum direction of the outgoing parton.

D_{TT} is measured from a cross-ratio asymmetry using Λ counts with opposite beam polarizations within small $\cos\theta^*$ bins [7]:

$$D_{TT} = \frac{1}{\alpha P_{beam}\langle\cos\theta^*\rangle} \frac{\sqrt{N^{\uparrow}(\cos\theta^*)N^{\downarrow}(-\cos\theta^*)} - \sqrt{N^{\uparrow}(-\cos\theta^*)N^{\downarrow}(\cos\theta^*)}}{\sqrt{N^{\uparrow}(\cos\theta^*)N^{\downarrow}(-\cos\theta^*)} + \sqrt{N^{\uparrow}(-\cos\theta^*)N^{\downarrow}(\cos\theta^*)}}. \quad (3)$$

With the cross-ratio method, the relative luminosity and the acceptance are both cancelled, which helps to reduce systematic uncertainties.

Figure 3 shows the new preliminary D_{TT} results from 2015 data, together with previously published results from 2012 dataset [7] versus $\Lambda(\bar{\Lambda})$ p_T in positive pseudo-rapidity region relative to the polarized beam. The statistical uncertainties of the new results exhibit a $\sqrt{2}$ improvement compared to previously published results as expected. The new results are consistent with zero within uncertainties, and are also consistent with model predictions [4].

4 Summary and Outlook

Longitudinal (D_{LL}) and transverse (D_{TT}) spin transfer measurements in p+p collisions can provide access to the strange quark helicity and transversity distributions in the proton and the polarized fragmentation functions. New preliminary results of D_{LL} and D_{TT} in p+p collisions at 200 GeV from STAR 2015 dataset were reported, with twice the statistics of the previous results. The new results are consistent with previous measurements, and are consistent with zero within uncertainties, which indicate that the strange quark polarized distribution and/or the polarized fragmentation function of $\Lambda(\bar{\Lambda})$ is small.

STAR has expanded its acceptance by installing a series of detector upgrades, in particular in the forward rapidity region. More proton-proton collision data will be collected at STAR in 2022 at 510 GeV and in 2024 at 200 GeV. That will significantly increase the statistics of Λ hyperon samples. Those forward detector upgrades allow for a rich Λ physics program in the forward rapidity region, including not only spin transfer measurements but also the transverse hyperon polarization in unpolarized proton collisions.

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