Measurement of Double Helicity Asymmetries (A_{LL}) in $\pi^{\pm}$ production at mid-rapidity in longitudinally polarized p + p collisions with PHENIX experiment

Taebong Moon for the PHENIX Collaboration[1]

[1] *Department of Physics, Yonsei University*

One of the main goals of the RHIC spin program is the determination of the gluon helicity contribution to the proton spin. This can be accessed by measuring double spin asymmetries (A_{LL}) of pion production at mid-rapidity in longitudinally polarized proton collisions with the PHENIX experiment. The ordering of the asymmetries with the charge of the final state pions can directly infer the sign of the gluon spin contribution.

Charged pions are reconstructed in the central PHENIX tracking system. The asymmetries are evaluated between collisions of bunches with the same and opposite helicity after correcting for differences in luminosity and for beam polarizations. The A_{LL} measurements of pion production at $\sqrt{s}$ = 200 GeV have been published previously. To extend our understanding of the gluon polarization to a lower gluon momentum fraction (x), high statistics data was collected at a higher $\sqrt{s}$ = 510 GeV in 2012-2013. We present the physics motivation, the analysis procedure and current status of the $\pi^{\pm} A_{LL}$ measurements at mid-rapidity.

I. INTRODUCTION

The spin of the proton is $\frac{1}{2}\hbar$ which is explained by the angular momentum sum rule in terms of quark and gluon components [1]. The result of EMC experiment [2] and others suggested that the spin contribution of quarks and anti-quarks ($\Delta\Sigma$) to the proton spin is about 30 percents. The rest of the proton spin might be carried by the gluons (ΔG) and the orbital angular momenta of quarks (L_q) and gluons (L_g).

One of the main goals of the RHIC spin program is the determination of the gluon helicity contribution to the proton spin. To explore this polarized proton collisions have been provided at the Relativistic Heavy Ion Collider (RHIC) uniquely in the world.

In perturbative Quantum Chromodynamics (pQCD), pion and high p_T jet productions are sensitive to the gluon helicity distributions (Δg) in the proton where their production is dominated by gluon-related interactions, for example, q-g and g-g scatterings.

RHIC A_{LL} results in inclusive π^0 production at $\sqrt{s}$ = 62.4 GeV and 200 GeV from PHENIX [3–6] and inclusive jet production at $\sqrt{s}$ = 200 GeV from STAR [7, 8] suggested a positive contribution of gluon polarization to the proton spin for the gluon momentum fraction x > 0.05. Also π^0 A_{LL} at $\sqrt{s}$ = 510 GeV from the RHIC 2012 and 2013 data sets extends the x coverage down to x $\sim$ 0.01 and confirms the evidence for non-zero ΔG [9]. For complementary information, the ordering of the asymmetries with the charge of the final state pions can directly infer the sign of the gluon spin contribution.

The gluon helicity distribution (Δg) can be accessed by measuring the double helicity asymmetries (A_{LL}) in $\pi^{\pm}$ production in longitudinally polarized p+p collisions. The asymmetry is defined as

$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} \tag{1}$$

where, $\sigma_{++}(\sigma_{+-})$ denotes the $\pi^{\pm}$ cross section from a collision with the same (opposite) proton beam helicity.

At $\sqrt{s}$ = 510 GeV in 2013, PHENIX recorded a total integrated luminosity of 108 pb^{-1} within a 30 cm vertex region and average polarization of $\bar{P}_B(\bar{P}_Y) = 0.55 \pm 0.02$ (0.56 ± 0.02), where $\bar{P}_B(\bar{P}_Y)$ is the polarization of RHIC's Blue (Yellow) beam.

We present the analysis procedure and current status of the $\pi^{\pm} A_{LL}$ measurement at mid-rapidity.

II. EXPERIMENTAL SETUP

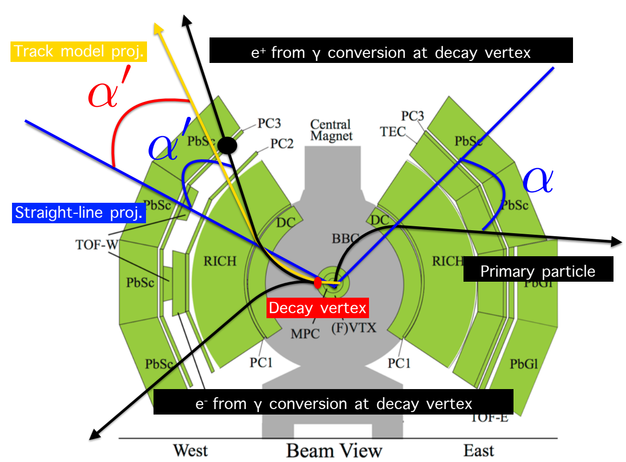

FIG. 1: A beam view of the central arm detectors.

For the measurement of $\pi^{\pm} A_{LL}$, we used the PHENIX central arm spectrometers (CA) which cover $|\eta| < 0.35$ in pseudo-rapidity and $\Delta\phi = 2 \times \frac{\pi}{2}$ in azimuth.

The CA is composed of the drift chamber (DC), pad chamber (PC), Ring-Imaging Cherenkov Detector (RICH) and Lead-scintillator (PbSc) and Lead-glass

(PbGl) Electro-Magnetic Calorimeter (EMCal).

The drift chamber (DC) and pad chamber (PC) are the main tracker for charged particle reconstruction and momentum measurement. The RICH and EMCal are used to separate high p_T $\pi^{\pm}$ from charged particle background. In addition, the EMCal can trigger on rare events with high p_T photons, electrons and hadrons. Yet, unlike the π^0 which can be triggered via photons in the EMCal, no dedicated charged hadron trigger exists and thus $\pi^{\pm}$ has limited statistics compared to π^0.

Beam-Beam Counters (BBC), located at ± 1.44 m from the nominal interaction point along the beamline and covering $3.1 < |\eta| < 3.9$, are used to calculate collision vertex and the relative luminosity, and trigger the minimum bias (MB) event. Zero Degree Calorimeters (ZDC), positioned at ± 18 m and covering $|\eta| > 6$, can also be used as another relative luminosity monitor for the estimation of systematic uncertainty from the relative luminosity.

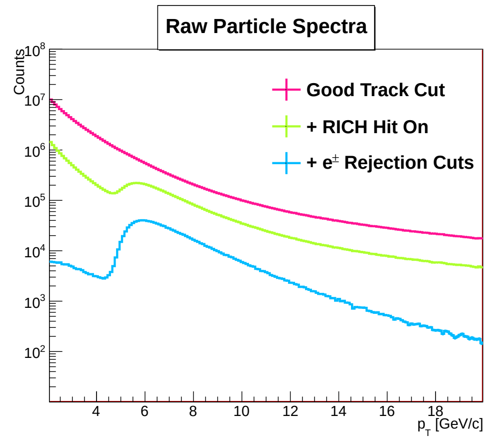

FIG. 2: Raw particle spectra as a function of p_T for the 2013 data set. This shows the charged pion turn on at ~ 4.7 GeV/c after requiring RICH PMT hit of the track.

III. ANALYSIS

For high p_T $\pi^{\pm}$ analysis, pion events firing the EMCal trigger coincidence with the MB trigger were analyzed. Figure 2 shows raw particle spectra as track cuts are applied. When a charged particle passes through a di-electric medium, CO_2 gas in the RICH, it emits Cherenkov light with a different threshold of momentum depending on particle species as shown in table 1, and then fires the array of photomultiplier tubes (PMT). Tracks can be divided according to RICH response at 5 to 16 GeV/c. Only electrons and pions can leave hits on the RICH PMT plane at 5 to 16 GeV/c but not for kaons and protons. Pions below 5 GeV do not create Cheronkov light and are therefore suppressed in the spectra. Above only electrons remain as background.

TABLE I: The energy threshold for the emission of Cherenkov radiation for each particle in the PHENIX RICH.

Particle	Electron	Pion	Proton	Kaon
Threshold [GeV/c]	0.03	4.7	16	30

The remaining background is electron. Electron deposits most of their energy in the EM shower and the EMCal can be used to determine the probability that the shape of cluster associated with the track is electro-magnetic. So primary electron can easily be distinguished with the deposited energy/momentum and shower shape cuts from $\pi^{\pm}$. The other background is secondary electron from photon conversion and/or decay-in-flight. The transverse momentum is derived from alpha angle (α) between track model projection and straight line projection to the collision vertex, shown in Fig. 1. Also the PHENIX tracking algorithm assumes that tracks originate from the collision vertex. Therefore, off-vertex tracks may be mis-reconstructed with an arbitrarily large momentum. We reject conversion electrons by applying cuts on the deviation of the hit position from the track model projection. Therefore, the raw yield is more suppressed and is steeply falling with p_T.

Experimentally, Eq. 1 can be accessed as

$$A_{LL} = \frac{1}{P_B P_Y} \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}} \tag{2}$$

where, $N_{++}(N_{+-})$ stands for the yield of $\pi^{\pm}$ candidates from the collisions in the same (opposite) helicity. R is the relative luminosity between colliding bunches with different spin configurations as

$$R = \frac{L_{++}}{L+-} \tag{3}$$

IV. CURRENT STATUS AND RESULT

The result of mid-rapidity $\pi^{\pm}$ analysis at $\sqrt{s} = 200$ GeV with the 2009 data set using a Hadron Blinder Detector (HBD) has already been published [10].

Figure 3 shows invariant cross sections for π^+ and π^- with pQCD predictions and comparison of averaged $\pi^{\pm}$ cross section and π^0 cross section by PHENIX. Also the ratio of the π^- to π^+ cross sections at PHENIX [11] together with STAR result [14] are shown in Fig. 4. At low p_T, where charged pion production is dominated by g-g scattering, π^- to π^+ ratio is close to 1. At higher p_T, where q-g scattering dominates charged pion production, this symmetry is broken due to the valence structure of the proton. Anything that has u quark component is enhanced against the ones with d quark component. That's

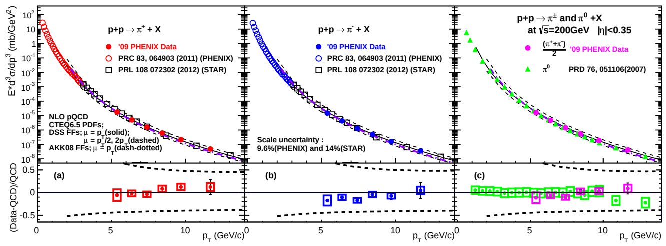

FIG. 3: Invariant cross sections for (a) π^+ and (b) π^- as a function of p_T and (c) comparison of averaged $\pi^\pm$ cross section and π^0 cross section measured by PHENIX [11] with pQCD predictions [12, 13] and STAR results [14].

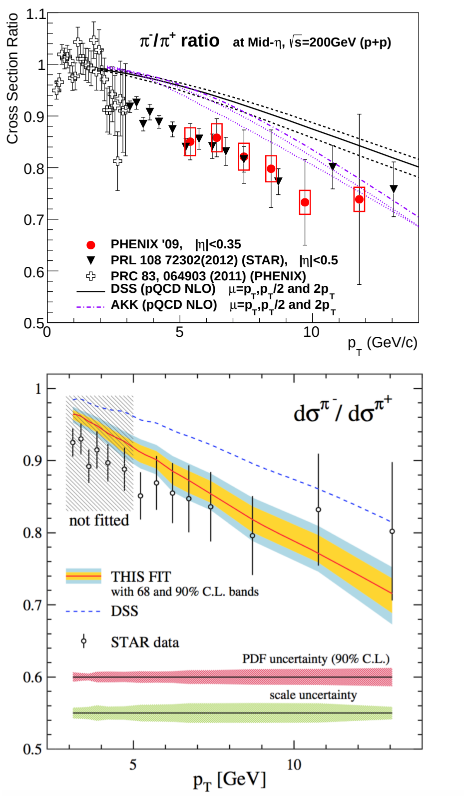

FIG. 4: The top panel shows the ratio of the π^- to π^+ cross sections as a function of p_T from PHENIX and STAR. Note that recent DSS curve is not included here. The bottom panel shows the π^-/π^+ cross section ratio from STAR and the recent DSS curve [15].

why π^- to π^+ ratio becomes smaller with p_T. Figure 4 shows the PHENIX charged pion result at 200 GeV is in good agreement with STAR and the DSS14 recent global fit. The agreement of data and pQCD assures the validity of parton distribution functions (PDFs) and fragmentation functions (FFs) adopted for the global analysis on ΔG.

A_{LL}s in $\pi^\pm$ and π^0 production in longitudinally polarized p+p collisions at $\sqrt{s} = 200$ GeV with the 2009 data set are shown in Fig. 5. The limited statistical precision of the charged pion data does not allow us direct inference of the sign of ΔG as the complementary information.

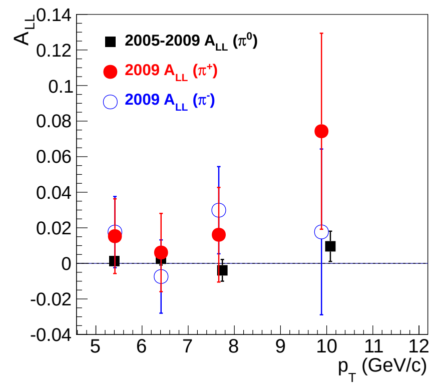

FIG. 5: Comparisons of A_{LL} in π^0 and $\pi^\pm$ productions in polarized p+p collisions at $\sqrt{s} = 200$ GeV from PHENIX.

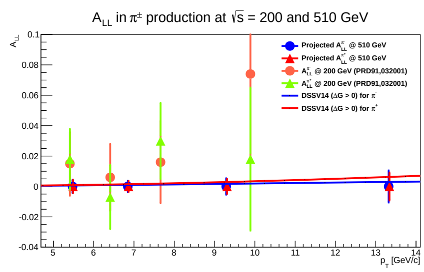

FIG. 6: Comparisons of projected A_{LL} in $\pi^\pm$ production at $\sqrt{s} = 510$ GeV and published A_{LL} at $\sqrt{s} = 200$ GeV from PHENIX.

The comparison plot of projected A_{LL} in $\pi^\pm$ production at $\sqrt{s} = 510$ GeV and published A_{LL} at $\sqrt{s} = 200$ GeV along with DSSV14 curve with positive gluon polarization is shown in Fig. 6. The uncertainty of charged pion at 510 GeV was significantly improved compared to 200 GeV. As the complementary probe, charged pion might help double-check the sign of the gluon polarization.

V. SUMMARY AND OUTLOOK

In summary, the π^0 A_{LL} result observed non-zero asymmetry in inclusive hadron production. As a complementary probe, charged pion analysis is on going with highly improved statistics and might help to directly infer the sign of the gluon polorization.

[1] R. L. Jaffe and A. Manohar, Nucl. Phys. **B337**, 509 (1990).

[2] J. Ashman et al. (European Muon), Nucl. Phys. **B328**, 1 (1989).

[3] S. S. Adler et al. (PHENIX), Phys. Rev. **D73**, 091102 (2006), hep-ex/0602004.

[4] A. Adare et al. (PHENIX), Phys. Rev. **D76**, 051106 (2007), 0704.3599.

[5] A. Adare et al. (PHENIX), Phys. Rev. **D79**, 012003 (2009), 0810.0701.

[6] A. Adare et al. (PHENIX), Phys. Rev. Lett. **103**, 012003 (2009), 0810.0694.

[7] B. I. Abelev et al. (STAR), Phys. Rev. Lett. **97**, 252001 (2006), hep-ex/0608030.

[8] B. I. Abelev et al. (STAR), Phys. Rev. Lett. **100**, 232003 (2008), 0710.2048.

[9] A. Adare et al. (PHENIX), Phys. Rev. **D93**, 011501 (2016), 1510.02317.

[10] A. Adare et al. (PHENIX), Phys. Rev. **D91**, 032001 (2015), 1409.1907.

[11] A. Adare et al. (PHENIX), Phys. Rev. **C83**, 064903 (2011), 1102.0753.

[12] D. de Florian, R. Sassot, and M. Stratmann, Phys. Rev. **D75**, 114010 (2007), hep-ph/0703242.

[13] S. Albino, B. A. Kniehl, and G. Kramer, Nucl. Phys. **B803**, 42 (2008), 0803.2768.

[14] G. Agakishiev et al. (STAR), Phys. Rev. Lett. **108**, 072302 (2012), 1110.0579.

[15] D. de Florian, R. Sassot, M. Epele, R. J. Hernndez-Pinto, and M. Stratmann, Phys. Rev. **D91**, 014035 (2015), 1410.6027.