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Recent Mid-Rapidity $A_{LL}^{\pi^0}$ Measurements in Longitudinally Polarized Proton-Proton Collision at $\sqrt{s} = 510$ GeV with PHENIX Experiment

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It is one of the important purposes of relativistic heavy ion collider (RHIC) longitudinally polarized proton program to constrain the gluon helicity distribution (Δg) to the proton by measuring the double helicity asymmetries (A_{LL}) via various probes such as π^0 ($A_{LL}^{\pi^0}$). The measurement at center of mass energy, $\sqrt{s} = 200$ GeV has been successfully finished and published. To explore lower x region, where dominant uncertainty remains, new measurements were carried out at an increased $\sqrt{s} = 510$ GeV. At this increased energy central $A_{LL}^{\pi^0}$ measurements can reach a lower x range of $0.01 < x$, while the previous can reach x range, $0.05 < x$. Also the statistical precision at the same transverse momentum (P_T) is substantially improved due to accumulating about 10 times as much luminosity. Preliminary results of $A_{LL}^{\pi^0}$ are presented. Larger asymmetry is observed at $\sqrt{s} = 510$ GeV than at $\sqrt{s} = 200$ GeV at the same $x_T = 2P_T/\sqrt{s}$ which is expected due to evolution.

Keywords: PHENIX; $A_{LL}^{\pi^0}$; $\sqrt{s} = 510$ GeV.

1. Motivation

The Proton spin can be decomposed into several terms as

$$S_{proton} = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g \tag{1}$$

where $\Delta\Sigma$ is the helicity contribution of quarks and anti-quarks, ΔG is the gluon helicity contribution, and L_q and L_g are helicity contribution of angular momentum of quark and gluon, respectively. From deep inelastic scattering experiments (DIS), it is known that $\Delta\Sigma$ alone is not sufficient fulfill this sum rule.[1] Thus measuring spin contribution from other terms in Eq. (1) is important. High energy polarized proton-proton collisions at RHIC are a powerful tool to constrain Δg through quark-gluon and gluon-gluon scatterings by measuring A_{LL} of various probes such as π^0. The measurement at $\sqrt{s} = 200$ GeV has been performed and published.[2] To access lower Bjorken x region where large uncertainty remains,[3] $A_{LL}^{\pi^0}$ measurement at higher $\sqrt{s} = 510$ GeV is being performed. The measurements at $\sqrt{s} = 510$ GeV can cover Bjorken x region, $0.01 < x$, while the previous measurement at $\sqrt{s} = 200$ GeV can cover the x region from $0.05 < x$.

2. A_{LL} and Its Interpretation

A_{LL} of final state hadron C in longitudinally polarized proton-proton collision, $p + p \rightarrow C + X$, can be defined in terms of differences in cross-section as

$$A_{LL} = \frac{d\Delta\sigma}{d\sigma} = \frac{d\sigma_{++} - d\sigma_{+-}}{d\sigma_{++} + d\sigma_{+-}}, \tag{2}$$

where $\sigma_{++(+-)}$ stands for hadron production cross-section in same(opposite) proton helicity collision.

The polarized cross-section, $\Delta\sigma$ can be factorized into:

$$\begin{aligned} d\Delta\sigma = \sum_{a,b,c} & \Delta f_a(x_a, \mu) \otimes \Delta f_b(x_b, \mu) \\ & \otimes d\Delta\hat{\sigma}^c_{ab}(x_a P_a, x_b P_b, P_C/z_c, \mu, \mu') \otimes D_c^C(z_c, \mu') \end{aligned} \tag{3}$$

, where $\Delta f = f_+(x, \mu) - f_-(x, \mu)$ is helicity parton distribution function (PDF) describing the difference in density of partons being aligned (+) and anti-aligned (-) with proton's helicity at a certain Bjorken x. $\hat{\sigma}^c_{ab}$ is the partonic level cross-section for the process $a+b \rightarrow c$. $D_c^C(z_c, \mu')$ is fragmentation function (FF) of a parton c into a final state hadron C at a fractional energy z_c. The unpolarized cross-section can be factorized in a similar way. While the $\hat{\sigma}$ can be calculated in perturbative QCD (pQCD) the PDFs and FFs need to be obtained from experiment. The unpolarized PDFs and the π^0 FFs are reasonably well constrained by unpolarized DIS data and e^+e^- annihilation, respectively.

As π^0 at mid-rapidity are predominantly created in gluon-gluon and quark-gluon scattering, it is a good probe to access Δg.

As a first test, we confirm the validity of the factorized next-to-leading order (NLO) pQCD calculations. It can be tested by comparing the measured π^0 cross-sections to theory calculations. As can be seen in Fig. 1, the agreement is quite reasonable.

3. PHENIX Longitudinal Spin Runs

Since 2003, PHENIX had taken several longitudinal spin runs. A summary of PHENIX longitudinal spin data taking is shown in Table. 1. The analysis of the 2013 $\sqrt{s} = 510$ GeV data is being reported here while the previous analysis of data

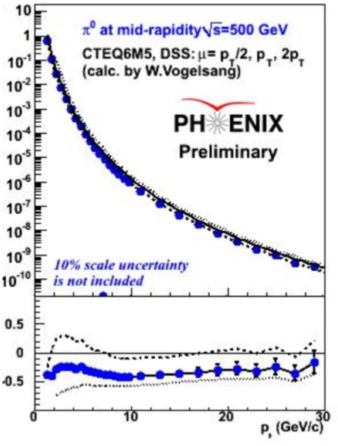

Fig. 1. Top: Comparison of π^0 cross-sections at $\sqrt{s} = 500$ GeV as a function of the P_T with the NLO pQCD calculations. The dashed and dotten lines represent the variation of the sale by a factor of two.
Bottom: Relative differences of the cross-section to the NLO calculations.

Table 1. Summary of PHENIX Longitudinal Spin Runs.

Year	$\sqrt{s}$ (GeV)	L (pb^{-1})	P (%)	FoM (P^4L)
2003	200	0.35	27	0.0019
2004	200	0.12	40	0.0031
2005	200	3.4	49	0.19
2006	200	7.5	57	0.79
2006	62.4	0.080	48	0.0042
2009	500	10.	40	0.26
2009	200	14.	57	1.4
2011	500	1.7	48	0.88
2012	510	30.	52	2.2
2013	510	150.	55	14.

at $\sqrt{s} = 200$ GeV has been published for the 2005, 2006 and 2009 running periods. One can see that the luminosity (L) and figure of merit (FoM≡P^4L) of 2013 data taking period is ten times larger compared to the data being analyzed in the previous analysis.

4. Introduction to PHENIX Detector

The PHENIX experiment consists of two mid-rapidity and two forward-rapidity spectrometers as shown in Fig. 2. The mid-rapidity spectrometers specialize in hadron, electron and photon identification and cover $|\eta| < 0.35$ in pseudorapidity and $2 \times \frac{\pi}{2}$ in azimuth. The forward-rapidity spectrometers specialize in muon identification and cover $1.2 < |\eta| < 0.24$ in pseudorapidity and 2π in azimuth.

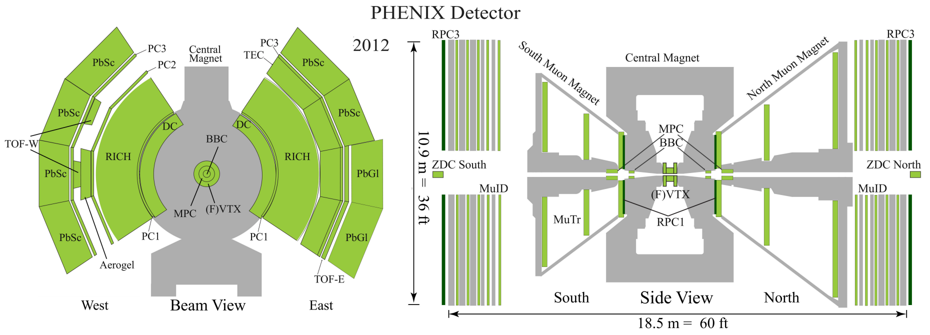

Fig. 2. PHENIX Detector Configuration

For π^0 reconstruction, two high-granularity electromagnetic calorimeters (EMCal) in mid-rapidity are used. The EMCals are made up of 6 sectors of Pb-Scintillator sampling calorimeters and 2 sectors of Pb-Glass Cherenkov radiator. The calorimeters are well-suited to measure photons from π^0 decay. Photons are being triggered when certain energy thresholds in adjacent 4x4 blocks of EMCal towers are reached. Charged particles are rejected via position sensitive pad chambers (PC) in front of EMCals with the same acceptance.

For luminosity measurements, beam-beam counters (BBC), two arrays of 64 quartz Cherenkov radiator with PMTs, are used which are located at $3.1 < |\eta| < 3.9$. To estimate systematic uncertainty from relative luminosity, a second sets of luminosity detectors is needed. The zero-degree calorimeters (ZDC) which consist of W-Cu absorber and polymethyl methacrylate optical fiber Cherenkov radiator with PMTs at position of $|\eta| > 6$ are used for this. Both detectors have full azimuthal coverage. While BBCs are sensitive mostly to charged particles, ZDCs predominantly measure neutral particles in particular neutrons.

5. Analysis Procedure

Eq. (2) can be re-written in terms of experimental observables as

$$A_{LL} = \frac{1}{P_B P_Y} \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}}, R = \frac{L_{++}}{L_{+-}} \tag{4}$$

where P_B and P_Y are the polarization of RHIC's "Blue" and "Yellow" beams, $N_{++(+-)}$ is yield of π^0 candidate from same(opposite) helicity collisions, and R is relative luminosity of same and opposite helicity collisions. The trigger efficiency and detector acceptance are assumed to be the same for same and opposite collisions and cancels between numerator and denominator as the colliding bunches in RHIC have alternating spin patterns.

As the collision rate increased during the 2013 running period, multiple collisions per bunch crossing need to be taken into account. The relative luminosity has been fully corrected for this effect.

The relative luminosity has been corrected also for luminosity miscount by finite resolution of vertex width of luminosity detectors.

To correct for the asymmetry and dilution of the combinatorial background, the asymmetries are also evaluated for background events in the sideband regions below and above the π^0 peak (47-97 MeV/c^2 and 177-227 MeV/c^2). The actual $A_{LL}^{\pi^0}$ is then calculated from the the π^0 peak asymmetry (A_{LL}^{Peak}) and the background asymmetry (A_{LL}^{Side}) as:

$$A_{LL}^{\pi^0} = \frac{A_{LL}^{Peak} - rA_{LL}^{Side}}{1 - r} \tag{5}$$

where r is the background fraction under π^0 peak. It is obtained by fitting the invariant mass spectrum with a Gaussian for the π^0 signal and a third order polynomial for the background.

6. $A_{LL}^{\pi^0}$ Result

Preliminary result have been obtained from the 2013 data taking period at $\sqrt{s} = 510$ GeV in the P_T range 2 GeV/c $< P_T <$ 20 GeV/c which corresponds to $0.008 < x_T < 0.08$, where $x_T = \frac{2P_T}{\sqrt{s}}$. Figure 3 shows the results as a function of the P_T while Fig. 4 shows the results as a functions of x_T in comparison to the previous 200 GeV/c results and DSSV14[3] theory curves for the two energies. Within the uncertainties the new results are consistent with the theory predictions. This is expected behavior as the P_T and scale is larger and thus more polarization is expected in the gluons due to DGLAP evolution.

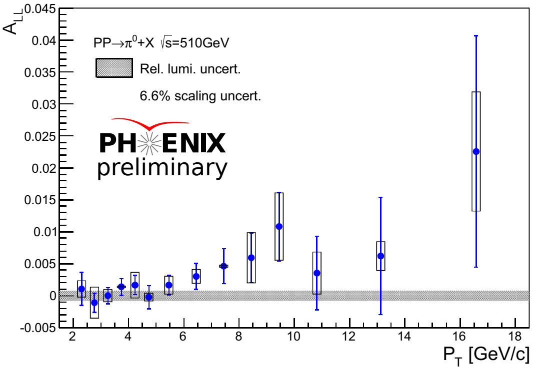

Fig. 3. Preliminary PHENIX measurements of $A_{LL}^{\pi^0}$ as function of P_T. The grey band corresponds to the systematic uncertainty due the relative luminosity. The open boxes correspond to point-to-point systematic uncertainties. A 6.6% overall scaling uncertainty due to the polarization is not shown.

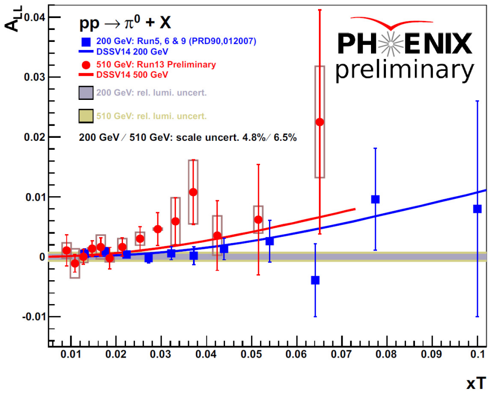

Fig. 4. Comparison of $A_{LL}^{\pi^0}$ at $\sqrt{s} = 200$ GeV and at $\sqrt{s} = 510$ GeV as a function of x_T. The corresponding DSSV14 curves[3] are also shown.

7. Expected Impact and Outlook of the Analysis

The central π^0 analysis is currently prepared for publication and it is expected that the uncertainties fill further reduce.

Due to the lower x it can reach, it will help reduce the uncertainties of Δg which are still large below the range of the previous published experiments (< 0.05).

Additionally, the analysis of electromagnetic clusters at forward rapidities of the muon pistol calorimeters (MPC) is ongoing. The MPCs are electromagnetic Pb-W calorimeters at forward rapidities $3.1 < |\eta| < 3.9$. At such forward rapidities more asymmetric, predominantly quark-gluon collisions are common which reach x of 0.002 and will further extend the range to be covered for global helicity fits.

References

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