Measurements of ΔG at RHIC PHENIX

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Abstract. The PHENIX spin program utilizes polarized protons in the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory to study the spin structure of the proton. We measure double-longitudinal spin asymmetries in various channels (e.g. π^0, $\pi^{\pm}$, γ, e, and μ). which are sensitive to the gluon contribution to the proton's spin, ΔG. Substantial improvements in the polarization and luminosity of polarized protons allow us to put substantial constraints on ΔG in the measured kinematic region (0.02<x<0.3).

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LONGITUDINAL PROTON SPIN STRUCTURE AT PHENIX

PHENIX is sensitive to Δg(x) through multiple channels covering a wide range of x_g leading to a robust measurement. Δg(x) is extracted from measurements of the double spin longitudinal asymmetry (A_{LL}) for these various channels:

$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P_b P_y} \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}}$$

where ++ denotes same sign helicity, + – denotes opposite sign helicity, and A_{LL} is comprised of measurements of the Polarization (P), helicity dependent particle yields (N), and the relative luminosity ($R=L_{++}/L_{+-}$). The relative luminosity is measured and evaluated by two global detectors, the BBC and ZDC which cover different pseudo-rapidity regions.

The RHIC accelerator has steadily progressed to the high luminosity and polarizations required for a detailed understanding of the proton spin structure (see Table 1). The results presented in this paper are primarily from Run 6.

TABLE 1. PHENIX Longitudinally Polarized Runs

Year	√s	Recorded L	Polarization	Figure of Merit (P^4L)
2003 (Run 3)	200 GeV	0.35 pb^{-1}	27%	1.9 nb^{-1}
2004 (Run 4)	200 GeV	0.12 pb^{-1}	40%	3.1 nb^{-1}
2005 (Run 5)	200 GeV	3.40 pb^{-1}	49%	200 nb^{-1}
2006 (Run 6)	200 GeV	7.50 pb^{-1}	57%	790 nb^{-1}
2006 (Run 6)	62.4 GeV	0.08 pb^{-1}	48%	4.2 nb^{-1}
2009 (Run 9)	500 GeV	~10 pb^{-1}	~35%	~150 nb^{-1}
2009 (Run 9)	200 GeV	in progress		

The PHENIX detector has a high rate capability utilizing a fast DAQ and specialized triggers, high granularity detectors, and good mass resolution and particle

ID at the sacrifice of acceptance. Detection of π^0, γ, and η utilizes the finely grained electromagnetic calorimeter, $\pi^{\pm}$ detection uses the drift chamber and ring imaging Cherenkov detector, and μ are detected through our forward spectrometer consisting of Muon ID and Muon Tracker.

A_{LL} is connected to $\Delta g(x)$ in the context of pQCD, and the success of NLO cross-section calculations at RHIC indicate that the spin program has a solid theoretical foundation [1]. For these proceedings, $\Delta G^{[a,b]} \equiv \int_a^b \Delta g(x)\,dx$ and $\Delta G^{[0,1]} \equiv \Delta G$.

Neutral Pion A_{LL}

Figure 1(a) shows PHENIX run 5 and 6 π^0 A_{LL} results at $\sqrt{s}$=200GeV [2]. The run 5 data was not consistent with GRSV-max in this x-range, while the Run-6 statistics is sufficient to differentiate GRSV-std from GRSV-ΔG =0 [3].

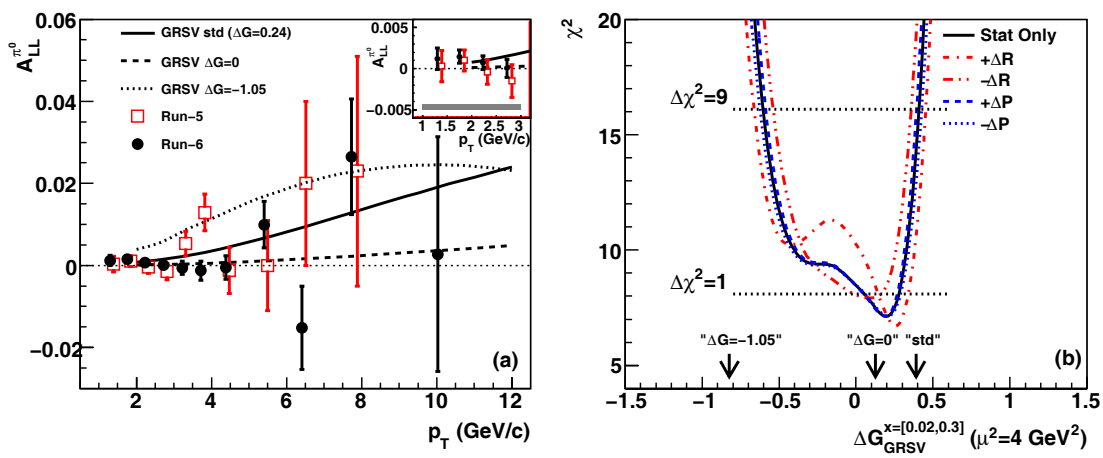

FIGURE 1. (a) Run 5 and 6 A_{LL} for π^0 production as a function of p_T. NLO pQCD expectations based on different inputs for ΔG in the GRSV parameterization [3] are plotted. (b) The χ^2 profile as a function of ΔG in the GRSV parameterization with x in the range [0.02,0.3] using the combined Run5 and Run6 data considering only statistical uncertainty, or also varying by $\pm 1\sigma$ the two primary experimental systematic uncertainties, from beam polarizations ($\pm\Delta$P) and relative luminosity ($\pm\Delta$R).

Within the GRSV parameterization, the data are sensitive to x_g from 0.02 to 0.3 and $\Delta G_{GRSV}^{x=[0.02,0.3]} \sim 0.6 \times \Delta G_{GRSV}^{x=[0,1]}$. Each p_T bin corresponds to a wide range in x_g overlapping with other p_T bins, and the data is not very sensitive to the variation of $\Delta g(x)$ within the measured range. In order to evaluate uncertainties and understand how these measurements relate to ΔG, we produced χ^2 vs ΔG plots. This was done by generating $\Delta g(x)$ curves for different values of the first moment of ΔG, calculating A_{LL} for each ΔG, and then comparing the A_{LL} data to curves. Figure 1b shows the results of such an analysis within the GRSV parameterization. From this analysis, we find that $\Delta G_{GRSV}^{x=[0.02,0.3]}\left(\mu^2 = 4\,GeV^2\right) = 0.2 \pm 0.1\ (1\sigma)$ and $0.2^{+0.2}_{-0.8}\ (3\sigma)$, where the errors are statistical. The primary systematic uncertainties come from the polarization (P) and relative luminosity (R) measurements. In order to evaluate these uncertainties,

we vary them by $\pm 1\sigma$. The systematic uncertainty due to the relative luminosity is found to give an additional uncertainty of 0.1, while the uncertainty due the polarization is negligible. We have used a similar analysis technique to get a handle on theoretical uncertainties. In particular, we have explored uncertainties due to the scale dependence and shape of the $\Delta g(x)$ parameterization. When we varied the theoretical scale μ from $2p_T$ to $p_T/2$ we saw a 0.1 shift for the positive constraint and a larger shift for the negative constraint. We also varied the $\Delta g(x)$ parameterizations for the parameterizations on the market. While the parameterizations provided different constraints at the 1σ level, they all converged to a consistent constraint of $-0.7 < \Delta G^{x=[0.02,0.3]} < 0.5$ at the 3σ level. Ref. [2] provides further details.

In order to put the most accurate constraints on $\Delta g(x)$ the data have been included in a global analysis with polarized DIS, SIDIS, and pp results [4]. As expected, the new global fits favor small ΔG in the measured RHIC region, but low-x is unconstrained.

In order to extend the x range to higher x, PHENIX measured A_{LL} at 62.4GeV (Figure 2a) [5]. Although the results come from a run with limited P^4L, they provide better statistical precision at higher x than previous measurements at 200GeV. Future measurements at higher $\sqrt{s}$=500GeV and upgrades in the forward direction will extend our sensitivity to lower x.

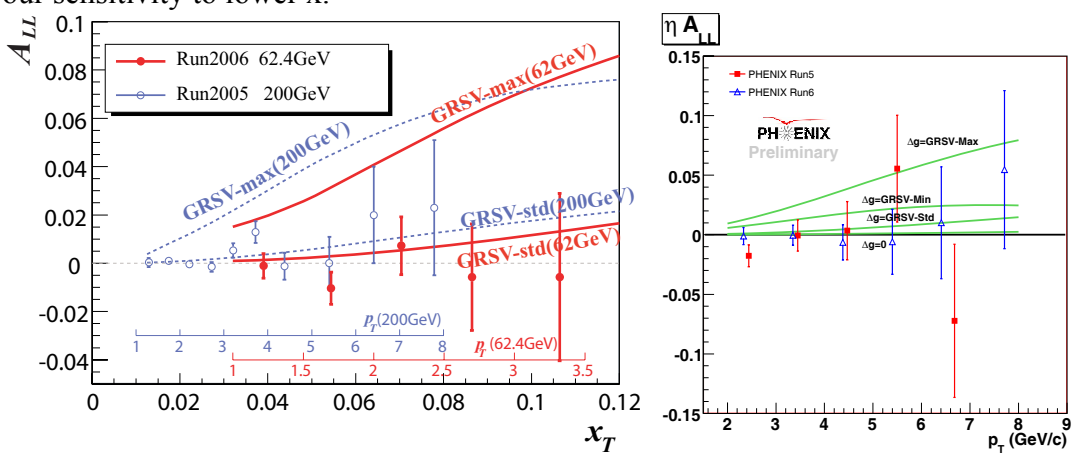

FIGURE 2. (a) Run 5 and 6 A_{LL} for inclusive π^0 production at $\sqrt{s}$ = 62 and 200 GeV vs x_T ($x_T=2p_T/\sqrt{s}$) as a function of p_T.; (b) A_{LL} for inclusive η production. The results are compared to NLO pQCD calculations.

OTHER MEASUREMENTS

PHENIX measurements of A_{LL} for η (Figure 2b) and $\pi^{\pm}$ (Figure 3) will place additional constraints when they are included in the global analysis. The η has a different flavor structure than the π^0 and is an independent probe of ΔG. The $\pi^{\pm}$ measurements provide additional constraints particularly for negative values of ΔG. The quark-gluon sub-process starts to dominate for p_T>5GeV, and $D_u^{\pi^+} > D_u^{\pi^0} > D_u^{\pi^-}$, so we expect the measurement to be sensitive to the sign of Δg when comparing with our neutral pion result (e.g if ΔG>0, then $A_{LL}^{\pi^+} > A_{LL}^{\pi^0} > A_{LL}^{\pi^-}$).

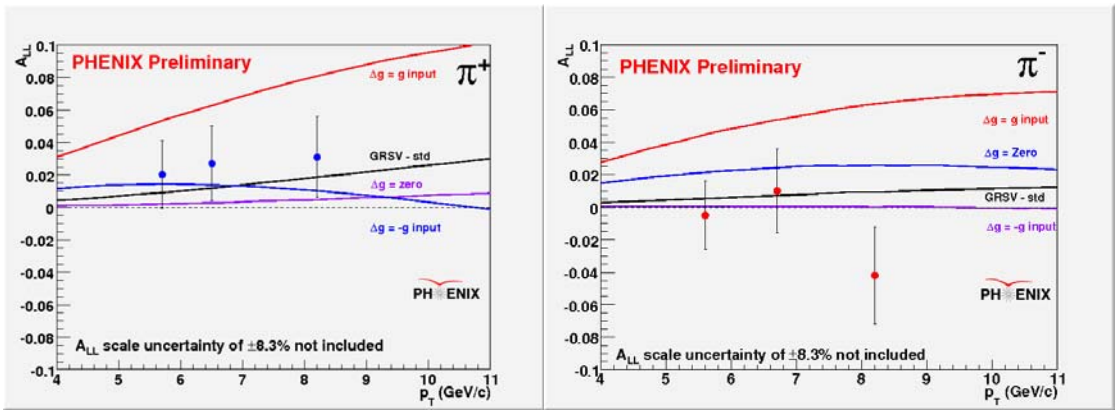

FIGURE 3. A_{LL} for charged pions from Runs 6.

PHENIX also has A_{LL} measurements of prompt photons and heavy flavor (electrons and muons). However, the measurements require great P^4L to provide significant additional constraints to $\Delta g(x)$.

CONCLUSIONS

RHIC is a novel accelerator which provides collisions of high energy polarized protons. This allows us to study the spin structure of the proton with strongly interacting probes at high enough $\sqrt{s}$ where NLO pQCD is applicable. PHENIX inclusive π^0 A_{LL} data provide a significant constraint on ΔG in the x range ~[0.02,0.3]. The effect of statistical as well as experimental and theoretical uncertainties give $\Delta G_{GRSV}^{x=[0.02,0.3]}\left(\mu^2 = 4\,GeV^2\right) = 0.2 \pm 0.1(stat) \pm 0.1\,(sys)\ {}^{+0.0}_{-0.4}\,(shape) \pm 0.1\,(scale)$.

At the 3σ level a constraint of $-0.7 < \Delta G^{x=[0.02,0.3]} < 0.5$ is nearly shape independent. Other PHENIX A_{LL} data are available. The $\pi^{\pm}$ and η measurements will be included in the ΔG constraint. The γ, e, and μ measurements need more P^4L. Extending x coverage is crucial. This will be accomplished in the future through additional channels from higher luminosity and polarization, different $\sqrt{s}$, and upgrades particularly in the forward direction.

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