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Double Longitudinal Spin Asymmetry Measurements of Inclusive π^0 and η Production at PHENIX in 200 GeV Polarized p+p Collisions

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A major emphasis of the RHIC spin program at BNL is to understand the gluon spin contribution, ΔG, to the spin of the proton. The PHENIX experiment at RHIC probes ΔG, utilizing its highly segmented calorimeter, by measuring the double longitudinal spin asymmetry , A_{LL}, in the production of inclusive channels like π^0 and η. π^0 data from runs 2005 and 2006 were included in a recent NLO global analysis, DSSV, and set substantial new constraints on the polarized gluon distribution in the proton over the kinematic range $0.05 < x < 0.2$. With improved luminosity and polarization, the figure of merit for the 2009 data set was a factor of 1.5 better that the previous runs combined. We present the 2009 results for π^0 and η A_{LL}, along with a discussion of the results from inclusion of these data in a recent update of the DSSV global analysis.

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1. Introduction

The quark and anti-quark contributions to the spin of the proton measured with polarized deep-inelastic scattering (DIS) fixed target experiments amount to only 30% [1]. Consequently, the rest of the spin of the proton must come from the gluons and the orbital angular momentum of both quarks and gluons. The gluon polarization, ΔG, is poorly constrained from scaling violations in the DIS data [2], and more precise and direct measurements are needed. Polarized p+p collisions at the Relativistic Heavy Ion Collider (RHIC) provide a very suitable environment, rich with strongly interacting probes, to measure ΔG directly and precisely. There are many processes where the gluon participates directly. In addition, the high c.m. energy and high transverse momentum, p_T, make next-to-leading order (NLO) perturbative Quantum Chromodynamics (pQCD) analysis more reliable. As a test of NLO pQCD applicability, RHIC measured the cross sections vs p_T for several probes, π^0 [3], η [4], jets [5], and direct photons [6] at $\sqrt{s} = 200$ GeV. These cross sections were well described by the NLO pQCD calculations within the uncertainties of these calculations. The spin program of the PHENIX experiment [7] utilizes these advantages to measure ΔG.

At RHIC, ΔG is accessed through measurements of the double longitudinal spin asymmetries, A_{LL}, in the production of particular final state. The asymmetries are defined as:

$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} \tag{1.1}$$

where $\sigma^{++}(\sigma^{+-})$ is the cross section when the colliding proton beams have equal (opposite) helicities. In leading order this can be factorized as the sum of all partonic subprocesses, $ab \to cX$, where parton c fragments into the detected hadron. As an example, in this framework A_{LL} for π^0 can be understood as the convolution:

$$A_{LL}^{\pi^0} = \frac{\sum_{abc} \Delta f_a \otimes \Delta f_b \otimes \Delta\hat{\sigma} \otimes D_c^{\pi^0}}{\sum_{abc} f_a \otimes f_b \otimes \hat{\sigma} \otimes D_c^{\pi^0}}, \tag{1.2}$$

where $f_a(\Delta f_a)$ are the unpolarized (polarized) parton distribution functions, and $D_c^{\pi^0}$ is the fragmentation function of c into π^0. The (polarized) partonic scattering cross-section for $ab \to cX$ is denoted by (Δ) $\hat{\sigma}$; both of which are calculable at NLO pQCD [8]. The inclusive measurements from RHIC provide significant constraints on ΔG in the accessible kinematic range. Over the past decade, the RHIC accelerator has steadily improved its performance toward the high luminosity and polarization required for studying the proton spin structure.

2. Experiment and Analysis

The PHENIX detector [7] 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 (EMCal), $\pi^{\pm}$, e, and J/ψ ($\to e^+e^-$) detection uses the drift chamber and ring imaging Cherenkov detector, and $\mu^{\pm}$ are detected through the forward spectrometers consisting of Muon ID and Muon Tracker. The very forward detectors, beam-beam counter (BBC) and zero-degree calorimeter (ZDC), are used to determine the collision vertex position and time, the proton beam luminosity and polarization (ZDC plus some scintillators are used for this), and form a minimum bias trigger.

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In 2009, the PHENIX collaboration collected 14 pb^{-1} of data with average polarization of 55%. To select events with hight p_T π^0 or η, a high energy photon trigger was used, where the summed energy of 4x4 EMCal towers is above a certain threshold, along with MB trigger provided by the BBC. Both π^0 and η are identified through their photon decay channel, the branching ratio is 99% for the π^0 and 39% for the η [9]. The photons are reconstructed in the finely segmented EMCal with high efficiency. The invariant mass spectrum is formed from all pairs of photons, and the asymmetry is calculated in a window of 112-162 MeV (480 - 620 MeV) around the π^0 (η) mass peak. The asymmetry in the background is calculated from sidebands around the mass peak and the background fraction is determined from fitting the peak region with a Gaussian and polynomial functions.

3. Results and Summary

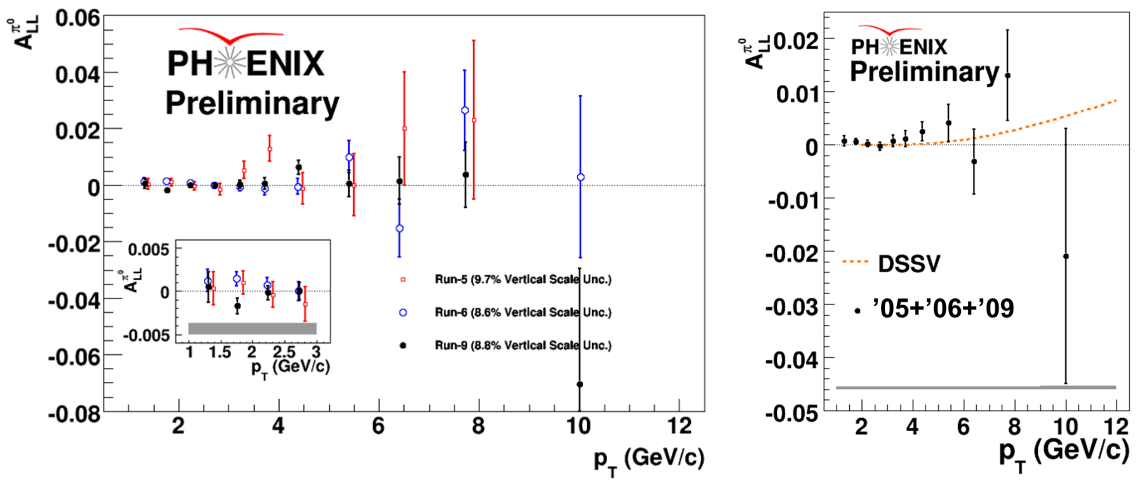

Figure 1: A_{LL} for π^0 at $\sqrt{s} = 200$ GeV from data collected in 2005, 2006 and 2009 as a function of p_T (left panel) and combined along with DSSV (right panel).

The left panel in Figure 1 shows A_{LL} of π^0 from the 2005 and 2006 data [10] compared with that of 2009 data, all collected at $\sqrt{s} = 200$ GeV. The figure shows that 2009 A_{LL} measurement is consistent with previous PHENIX measurements. The right panel in Figure 1 shows the combined PHENIX measurements along with the DSSV best fit (that only included 2005 and 2006 measurements) [11] which clearly indicates that the combined data favor a larger A_{LL} value. Figure 2 shows A_{LL} of the combined η results from 2005, 2006, and 2009. Despite being statistically limited, η results provide an important systematic cross check due to its large opening angle and being immune to cluster merging at higher p_T. Additionally, it is expected that η has a different sensitivity to ΔG from π^0 since the flavor content of η is different, and thus it is hoped that η will play an important role with higher statistics.

The impact of the preliminary 2009 PHENIX and STAR data, shown in the right panel of Figure 3, was gauged by including them in a new global QCD fits based on the DSSV framework. The fit, labeled DSSV++ and shown in the right panel of Figure 3, while fully consistent with

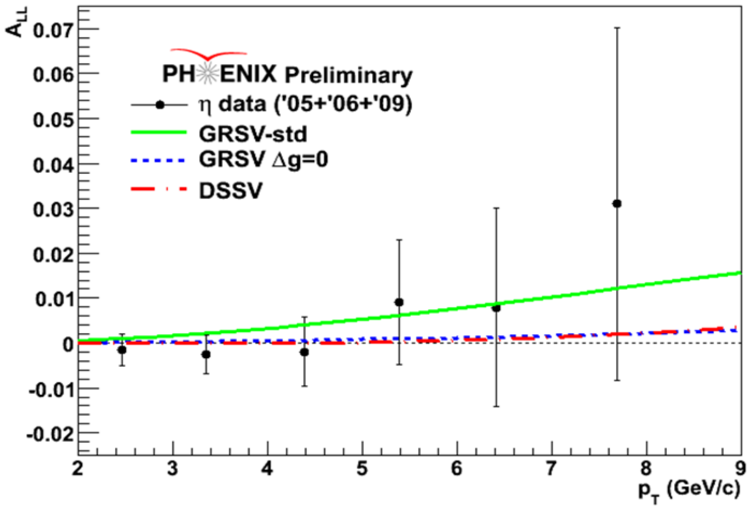

Figure 2: A_{LL} for η at $\sqrt{s} = 200$ GeV from data collected in 2005, 2006 and 2009 combined as a function of p_T. Statistical uncertainties and GRSV and DSSV models are also shown.

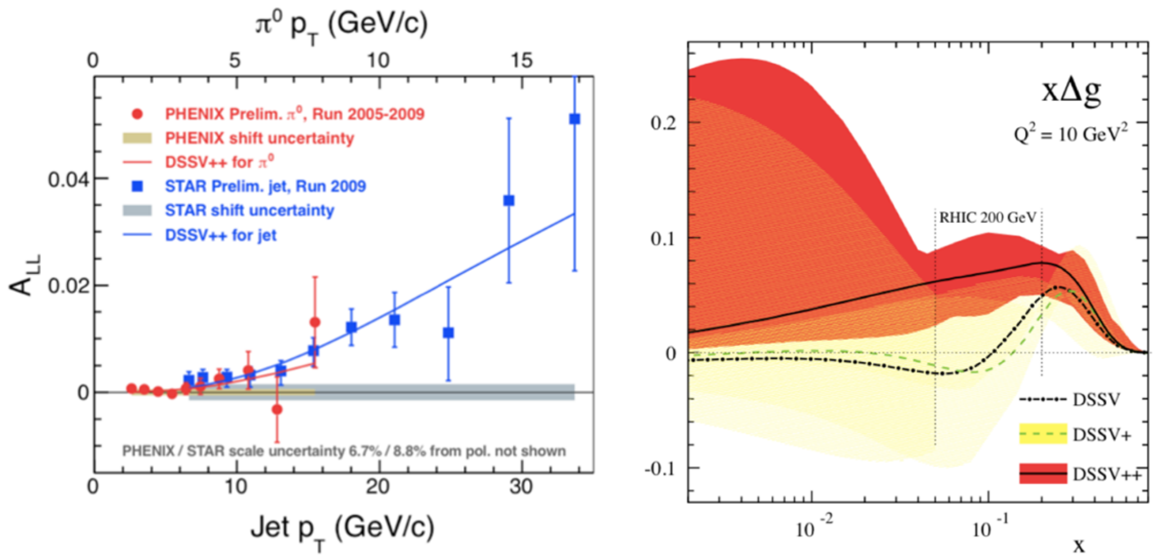

Figure 3: Left panel: Preliminary 2009 RHIC data compared to the DSSV++ fit. Right panel: Uncertainties in $\Delta g(x)$ with (red band) and without (yellow band) RHIC 2009 data.

the previous DSSV fit within the uncertainties, shows a preference for a sizable (relative to the total proton spin of $1/2\hbar$) gluon contribution, $\int_{00.05}^{0.2} \Delta g(x)dx = 0.1^{+0.06}_{-0.07}$ with significantly reduced uncertainties [12]. The right panel of Figure 3 also shows the DSSV+, which supplements the RHIC data used in the original DSSV analysis with recent results from polarized deep-inelastic scattering (DIS) obtained by COMPASS [13].

In summary, We reported on A_{LL} measurements from the inclusive probes, π^0 and η. The results from $A_{LL}^{\pi^0}$ probe provide significant constraints on the gluon spin contribution to the proton spin in the accessed kinematic range, $0.05 < x < 0.2$, when compared to NLO pQCD calculations. The addition of PHENIX and STAR data to the DSSV fit leads to a preference for a sizable gluon contribution in the accessed kinematic range, $0.1^{+0.06}_{-0.07}$. However, despite this very important achievement, uncertainties remains significant in the unmeasured low-x region and prevent reliable determination of the full ΔG integral.

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