Recent Results of Double Helicity Asymmetries from PHENIX

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The search for the gluon contribution to the proton spin, ΔG, is critical to understanding the proton spin puzzle. The PHENIX experiment at the Relativistic Heavy Ion Collider (RHIC) is able to directly probe gluon polarization using collisions between two polarized proton beams. ΔG is determined from the double longitudinal asymmetry, A_{LL}, for a final state to be observed between same and opposite sign helicity proton interactions. In this talk we will summarize the recent A_{LL} measurements. At mid-rapidity, $|\eta| < 0.35$, we can probe ΔG in the Bjorken-x range $0.05 < x < 0.2$. At forward rapidity we can probe ΔG down to $x \sim (1-3) \times 10^{-3}$.

1 Introduction

For more than two decades, it has been clear that the longitudinal spin structure of the proton cannot be described by quark spin contributions alone, as they account for only about 30% of its $\frac{1}{2}\hbar$ spin. The search for the remaining spin is deemed the "proton spin puzzle". The accounting is summarized by the spin-sum rule:

$$\frac{1}{2} = \frac{1}{2}\sum_q (\Delta q + \Delta \bar{q}) + \Delta G + L_{g,q}$$

The $\Delta q(\Delta \bar{q})$ represent the individual quark(antiquark) spin contributions which are measured from deep inelastic scattering (DIS) processes. The ΔG and $L_{g,q}$ terms represent the gluon spin and orbital angular momenta contributions from gluons and quarks, respectively. For a theoretical treatment of the spin decomposition, the reader is referred to Ref. [1] and [2].

The goal of the ΔG program in PHENIX is to determine how much of the missing spin comes from gluon polarization, and several measurements have been carried out using different final states. The observable that can be related to ΔG is the double longitudinal asymmetry, A_{LL}, measured from longitudinally polarized protons. It is defined as:

$$A_{LL} = \frac{\Delta\sigma}{\sigma} = \frac{1}{P_B P_Y}\frac{N^{++} - RN^{+-}}{N^{++} + RN^{+-}}$$

where σ is the total cross section for $pp \to \pi^0 + X$ and $\Delta\sigma = \sigma^{\overrightarrow{p}\overrightarrow{p}\to\pi^0+X} - \sigma^{\overrightarrow{p}\overleftarrow{p}\to\pi^0+X}$. P_B and P_Y are the beam polarizations. $N^{++(+-)}$ refers to the scaled yield from same(opposite) sign helicity interactions. $R = L^{++}/L^{+-}$ is the relative luminosity where $L^{++(+-)}$ is the luminosity for the same(opposite) helicity bunch crossings. The $\overrightarrow{p}\overrightarrow{p}$ indicates that the initial states of the protons are either both positive helicity or both negative helicity. The notation $\overrightarrow{p}\overleftarrow{p}$ indicates that one proton has negative helicity while the other has positive helicity. We use the π^0 as the included particle in the final state, but it could be any measured state.

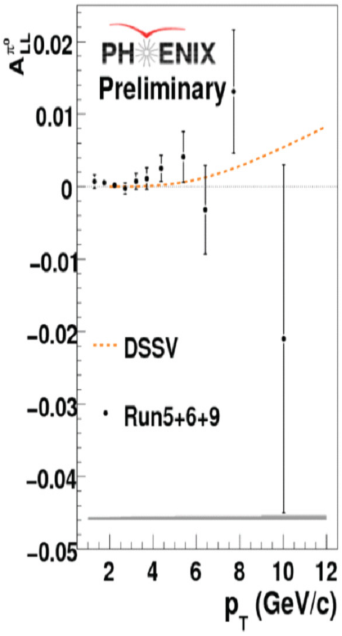

Figure 1: The measurement of the asymmetry for π^0 production at mid-rapidity is shown for the combined datasets from 2005,2006 and 2009. The red dashed line shows the prediction based on the DSSV model.

The unpolarized parton distribution functions (PDF) are denoted by $f(x)(\bar{f}(x))$ for each (anti-)quark flavor and $g(x)$ for the gluons, where x is the Bjorken-x. The polarized PDFs are denoted by $\Delta f(x), \Delta\bar{f}(x)$ and $\Delta g(x)$. The total gluon spin contribution is then $\Delta G = \int_0^1 \Delta g(x)dx$. By factorizing the cross sections as a product of PDFs, partonic cross sections, $\hat{\sigma}$, and fragmentation functions D_f^h, for parton f to fragment into hadron h, the cross sections can be written as convolutions:

$$\Delta\sigma^{pp\to h+X} = \sum_{a,b} \Delta f_a \otimes \Delta f_b \otimes \Delta\hat{\sigma}^{f_a f_b \to fX} \otimes D_f^h$$

$$\sigma^{pp\to h+X} = \sum_{a,b} f_a \otimes f_b \otimes \hat{\sigma}^{f_a f_b \to fX} \otimes D_f^h$$

2 Constraining ΔG by Measuring A_{LL}

In Figure 1 we show the combined result for the π^0 A_{LL} at central rapidity, $|\eta| < 0.35$. The de Florian, Sassot, Stratmann and Vogelsang (DSSV) prediction (Ref. [3] and [4]) is also shown. At low p_T this measurement is sensitive roughly equally to gluon-gluon and quark-gluon interactions, but when $p_T > 5$ GeV/c it is dominated by quark-gluon processes and $A_{LL} \propto \Delta g \Delta f$. The DSSV global analysis did not include these data sets. By running a modified analysis which includes this result the constraints on ΔG can be improved for the region of gluon sensitivity, $0.05 < x_g < 0.2$. The results are shown in Figure 2. Within the accessed x range, the uncertainty band has decreased and a once favored node in $\Delta g(x)$ at $x_g \sim 0.1$ is now disfavored. With no change in the sign of Δg, this result favors a more positive value for $\Delta G^{[0.05-0.2]} = \int_{0.05}^{0.2} \Delta g(x)dx$.

In addition to the π^0 measurement, A_{LL} has been measured in several other channels. The results are summarized in Figure 3. In Fig. 3a A_{LL} was measured for the inclusive $\pi^0 - \pi^0$ channel. Despite lower statistics, this final state constrains the inital parton x values better than a single inclusive measurement. In Fig. 3b we show the charged hadron A_{LL} incorporating the 2009 dataset. Due to the preferred fragmentation for $u \to \pi^+$ and $d \to \pi^-$, the sign of ΔG can be obtained. In Figure 3c we show the combined A_{LL} result for the η meson. The strangeness of the η allows the strange quark fragmentation functions to enter the ΔG extraction providing an independent cross check of the π^0 measurement. In Fig. 3d, the result from single electron detection from heavy quark mesons is shown. This channel is dominated by gluon-gluon fusion. Therefore, $A_{LL}^{pp\to e+X} \propto \Delta G^2$. The main advantage of this channel is the decreased uncertainty from the heavy quark fragmentation functions. This leads to less uncertainty when extracting ΔG from this channel.

In order to constrain $\Delta g(x)$ for $x < 0.05$, it is necessary to measure hadrons at forward rapidity using the Muon Piston Calorimeter (MPC). The MPC has 2π azimuthal coverage with $3.1 < |\eta| < 3.9$. Due to its segmentation, the two photons from π^0 decays are reconstructed as a single cluster due to merging if $p_{T,\pi^0} > 2$ GeV/c. Therefore, we measure $A_{LL}^{cluster}$ and from PYTHIA simulations we estimate that approximately 80% of this sample is from merged π^0's.

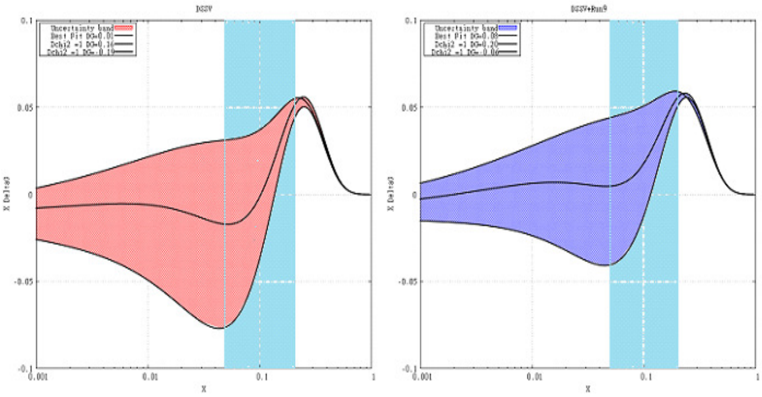

Figure 2: (Left) The DSSV curve before the results from the 2005,2006 and 2009 datasets are accounted for. The value of $\int_{0.05}^{0.2} \Delta g(x)dx$ is small but with large uncertainty. (Right) The best fit for ΔG using the DSSV framework shows the improved constraints on ΔG within the range of sensitivity.

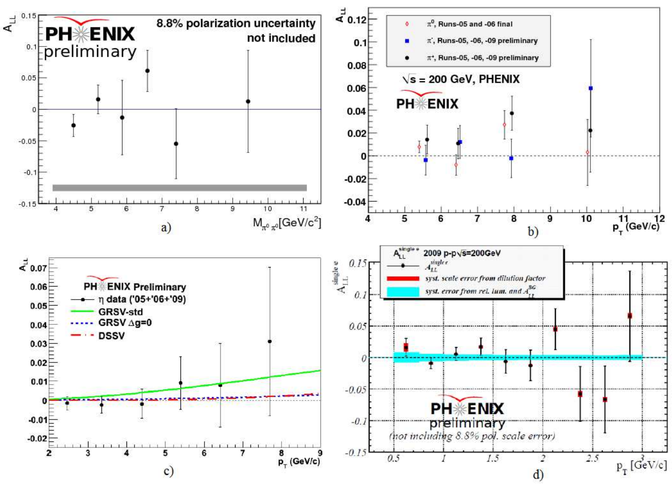

Figure 3: The A_{LL} results are shown for several final states measured at mid-rapidity. The measurements include (a) di-π^0 production, (b) identified charged pions, (c) η mesons, and (d) single electrons. Each measurement makes a specific contribution, as described in the text, toward constaining ΔG.

Unlike at mid-rapidity, where only at $p_T > 5$ GeV/c is the process fraction dominated by quark-gluon interactions, for the MPC this is already true at $p_T > 2$ GeV/c. The result for the measurement of the single cluster A_{LL} is shown in Figure 4. While the MPC single cluster measurement is most sensitive at $x_g \sim O(10^{-2})$ it also has very broad sensitivity. In order to be sensitive to more precise x_g ranges at low-x it is necessary to trigger on di-hadron events where, like in the mid-rapidity case, the event kinematics are better constrained. High-p_T di-hadron events are heavily dominated by an underlying highly asymmetric partonic interaction (with a heavily boosted center of mass) between a valence quark and gluon. This means that to good approximation, for the forward di-hadron measurement, $A_{LL} \propto \Delta f \Delta g$, and the measurement can distinguish between positive and negative values of $\Delta g(x)$ for the better constrained region of x that is involved.

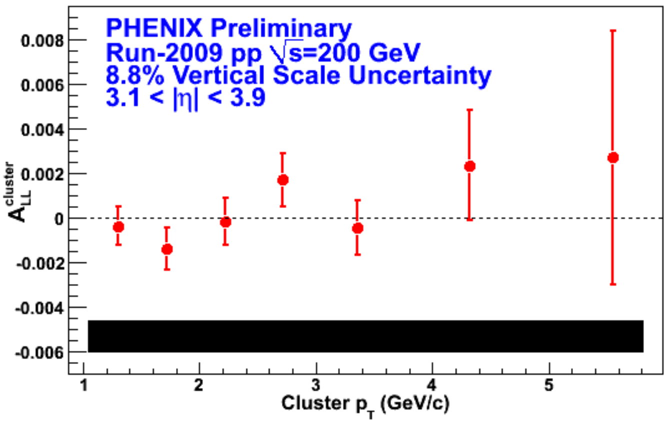

Figure 4: At forward rapidity, the MPC has the capability to be sensitive to gluons with significantly lower x than in the central arm. Here the A_{LL} result for forward single clusters is shown. The black systematic uncertainty band arises from the relative luminosity determination.

To measure this, however, it was necessary to commission a trigger upgrade. Since the previous trigger was only capable of triggering on a single high p_T cluster, the rejection power was too small. This was fixed in the new trigger by requiring two azimuthally separated hadrons each with a somewhat lower threshold than the single hadron case. The new trigger was commissioned successfully for the 2012 dataset, which has very recently concluded. PHENIX projections anticipate that this trigger has the potential to distinguish between some models of ΔG.

It is anticipated that the 2013 dataset for pp collisions at $\sqrt{s}$ = 500 GeV will have up to 20 times more integrated luminosity that then the 2009 dataset. The most important issue for future high statistics measurements of A_{LL}, as demonstrated in Figure 4, is therefore to understand and minimize the systematic effects from relative luminosity that will start to dominate the overall uncertainty.

3 Acknowledgements

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