Double Longitudinal Spin Asymmetry in Neutral Pion Production in Polarized p+p Collisions at $\sqrt{s} = 200$ GeV at PHENIX

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Abstract. A major goal of the RHIC spin program is to measure $\Delta g$, the gluon contribution to the proton’s spin. Measurements by PHENIX of the double longitudinal spin asymmetry, $A_{LL}$, of the neutral pion production at mid-rapidity in polarized proton collisions have been shown to constrain $\Delta g$. Results from the 2005 RHIC run, as well as high $p_T$ data from the 2006 RHIC run, are presented. The results disfavor maximal positive and negative values of $\Delta g$. A measurement of azimuthally independent double transverse spin asymmetry, $A_{TT}$, is also presented.

Keywords: Proton structure, Proton spin
PACS: 14.20.Dh, 13.85.Ni, 13.88.+e

INTRODUCTION

In 1988, using polarized DIS, the European Muon Collaboration found $\Delta \Sigma$, the quark contribution to the proton’s spin, to be consistent with zero. Since then, many experiments have shown that while nonzero, $\Delta \Sigma$ ($\sim 25$-35%) is smaller than expected by a naive quark model. The remaining component must be carried by the gluon spin and the quark and gluon orbital angular momentum.

The gluon contribution is not well constrained by these fixed target experiments. By colliding longitudinally polarized protons at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL), we can probe the gluon contribution to the proton spin directly. For any specified interaction, $p + p \rightarrow C + X$, by measuring the asymmetry in the production of $C$ between like and unlike helicity collisions, we can probe the gluon contribution to the proton spin, $\Delta g$. This double longitudinal spin asymmetry is defined as

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

where $\sigma_{++}$ ($\sigma_{+-}$) is the cross section with same (opposite) helicity. Experimentally, what is actually measured is

$$A_{LL} = \frac{1}{|P_1||P_2|} \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}}, \quad R = \frac{L_{++}}{L_{+-}}.$$
FIGURE 1. Azimuthally independent double transverse spin asymmetry, $A_{TT}$, in $\pi^0$ production during 2005 RHIC running period with transversely polarized protons. Due to small remaining transverse beam polarizations in longitudinally polarized beams, $A_{TT}$ is a contamination in our measured asymmetry. A systematic uncertainty of $0.075 \times \delta A_{LL}$ is applied to the measured $A_{\pi^0 LL}$.

MEASUREMENT

A proton-carbon Coulomb Nuclear Interference (CNI) polarimeter [2] was used on a fill-by-fill basis for measuring the relative polarization. For 2005 (2006), the average polarization was 47% (62%). In 2004, the absolute polarization in RHIC was measured with a polarized hydrogen gas jet target [1], reducing the relative uncertainty in the CNI value to 20% per beam. This leads to a 40% scaling uncertainty for our final $A_{LL}$. Finalized results from the jet target for 2005 and 2006 were not ready as of this work.

In RHIC, the stable polarization direction is vertical, and so the beam polarization must be rotated parallel to the beam momentum axis when entering the PHENIX interaction area. By measuring the amplitude of a single transverse spin asymmetry in forward neutrons [2], the remaining transverse polarization component can be determined.

The actual measured asymmetry is

$$A_{meas} = (1 - \varepsilon)A_{LL} + \varepsilon A_{TT}, \quad A_{TT} = \frac{\sigma_{\uparrow\uparrow} - \sigma_{\uparrow\downarrow}}{\sigma_{\uparrow\uparrow} + \sigma_{\uparrow\downarrow}}$$  \hspace{1cm} (3)

where $A_{TT}$ is the azimuthally independent double transverse spin asymmetry. (Note that $A_{LT}$ is parity violating.) $\varepsilon$ is the product of the remaining transverse spin components of the two beams, which in 2005 was found to be 0.014. In the 2005 run, a small data sample was taken with both beams transverse and was used in the measurement of $A_{TT}$ is shown in Fig. 1. It was found to be consistent with zero. Therefore, we assume a systematic uncertainty in our $A_{LL}^{\pi^0}$ of $0.075 \times \delta A_{LL}|_{stat}$.

To measure relative luminosity (Eq. 2), we use beam-beam counters [3]. In PHENIX for the 2005 (2006) run, uncertainty in relative luminosity was $\delta R = 1.0 \times 10^{-4}$ ($\delta R = 1.1 \times 10^{-4}$) corresponding to a $\delta A_{LL}|_R = 2.3 \times 10^{-4}$ ($\delta A_{LL}|_R = 1.5 \times 10^{-4}$).
The PHENIX Electromagnetic Calorimeter [4] is specifically designed for very good energy and spacial resolution, at the cost of limited acceptance ($|\eta| < 0.35$, $\Delta \phi = 2 \times 90^\circ$) and, in combination with a high $p_T$ photon trigger, is used to measure $\pi^0$ yield. The $\pi^0$ cross-section has been measured at PHENIX for a wide $p_T$ range covering the $p_T$ range used in the $A_{LL}$ measurement. Comparing NLO pQCD (using KKP fragmentation functions) to the data shows good agreement for the entire $p_T$ range [5]. Therefore, we can use NLO pQCD to interpret our measured $\pi^0 A_{LL}$ in terms of $\Delta g$.

As of this work, the full data production for the 2006 run was not completed. However, events with a sufficiently high energy photon were filtered during data taking for fast analysis. Due to the photon energy requirement, only data above $p_T = 5$ GeV are shown. Results from 2006 for $p_T < 5$ GeV will be available when the whole data set is produced.

**ASYMMETRY CALCULATION**

$A_{LL}$ is calculated using Eq. 2 for the diphoton invariant-mass range of $\pm 25$ MeV/$c^2$ around the $\pi^0$ peak ($A_{LL}^{\pi^0+BG}$) and in two 50 MeV/$c^2$ wide mass regions on either side ($A_{LL}^{BG}$). Fitting the mass peak, we obtain $w_{BG}$, the fraction of background in the peak region. To obtain $A_{LL}^{\pi^0}$, we use

$$A_{LL}^{\pi^0} = \frac{A_{LL}^{\pi^0+BG} - w_{BG}A_{LL}^{BG}}{1 - w_{BG}}.$$  \hfill \(4\)

Bunch shuffling [3] was performed to evaluate systematic uncertainty from bunch to bunch or fill to fill. For both the 2005 and 2006 runs, bunch-to-bunch and fill-to-fill systematic uncertainty is negligible compared with our current statistical uncertainty.

**$A_{LL}^{\pi^0}$ RESULTS**

Preliminary results from the 2005 RHIC run [7] are plotted in Fig. 2 (blue circles). These data correspond to an integrated luminosity ($L$) of 1.8 pb$^{-1}$ (70% of total 2005 luminosity) and average polarization ($\langle P \rangle$) of 47%, giving a figure of merit ($\langle P \rangle^4 L$) of 0.088 pb$^{-1}$. During the longitudinal polarization running period in 2006, PHENIX recorded $L = 7.5$ pb$^{-1}$ with $\langle P \rangle = 62\%$, corresponding to a figure of merit 12.6 times larger than that of the 2005 result. Results from a fast track analysis on a sub-sample of the 2006 data with a high $p_T$ photon are plotted in Fig. 2 (red triangles).

The data in Fig. 2 are plotted with four theory curves based on [6] assuming different input values of $\Delta g$ at $Q^2=0.4$ GeV$^2$. Three curves cover the full range of possibilities: the maximal positive value $\Delta g = g$ (GRSV-max), maximal negative value $\Delta g = -g$, and $\Delta g = 0$, where $g$ is the unpolarized gluon parton distribution function. The fourth curve, labeled GRSV-std, assumes a value of $\Delta g$ from the best fit to the world DIS data as of [6].

By calculating $\chi^2/NDF$ for the four theory curves using data from 2005 and 2006, both positive and negative maximal scenarios are found to have less than 0.1% likelihood of fitting our data. Both GRSV-std and $\Delta g = 0$ are found to be consistent with our data, with likelihood of 2-9% and 11-12%, respectively. The range comes from including the
scaling uncertainty in beam polarization. Theoretical uncertainties have not been taken into account. To remove possible soft physics influence, this test has been repeated neglecting the data with \( p_T < 2 \) GeV. Again, positive and negative maximal gluon polarizations are strongly disfavored, while GRSV-std (1-6%) and \( \Delta g = 0 \) (8-9%) are not inconsistent with our data.

**SUMMARY**

During the 2005 RHIC run, \( A_{\pi^0}^{LL} \) was measured at mid-rapidity and \( \sqrt{s} = 200 \) GeV with the PHENIX detector. 2005 was the first significant run with polarized protons. In 2006, the figure of merit increased by a factor of 7.5. Using a small subset of the full 2006 data set with a high \( p_T \) photon for a fast analysis, \( A_{\pi^0}^{LL} \) was presented for \( 5 \) GeV < \( p_T \) < 9 GeV. The 2005 and 2006 results strongly disfavor a large positive \( \Delta g \), and also disfavor a maximal negative \( \Delta g \). Both GRSV standard and \( \Delta g = 0 \) are consistent with our data.

**REFERENCES**

1. H. Okada et al., *hep-ex/0601001* (2006).
2. A. Bazilevsky et al., *hep-ex/0610030* (2006).
3. S. S. Adler et al., *Phys. Rev. Lett.* 93, 202002 (2004).
4. K. Adcox et al., *Nucl. Inst. Meth. A* 499, 469 (2003).
5. S. S. Adler et al., *Phys. Rev. Lett.* 91, 241803 (2003).
6. M. Glück et al., *Phys. Rev. D* 63, 094005 (2001).
7. K. Boyle et al., Proceedings of the 17th Particles and Nuclei International Conference (PANIC 2005), Sante Fe, U.S.A., 2005.