π^0 Double Longitudinal Helicity Asymmetry Measurements at PHENIX

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Abstract. Measurement of the gluon’s contribution to the proton spin, \( \Delta G \), is an important component of the RHIC spin program. One particular avenue for constraining \( \Delta G \) is through the \( \pi^0 \) double longitudinal helicity asymmetry, \( A_{LL} \). The large \( p+p \rightarrow \pi^0 \) cross section coupled with the high resolution of the PHENIX EM-Calorimeter make this an attractive measurement. After some discussion of the measurement, existing PHENIX \( \pi^0 A_{LL} \) results at center of mass energies \( \sqrt{s} = 62.4 \) and 200 GeV are presented, including new 200 GeV results from the RHIC run ending in 2009. Projections for future 500 GeV results are also shown.

1. Introduction
High energy polarized proton-proton collisions at RHIC are a powerful way to probe the spin of the proton, which can be written in terms of its composite parts (quark spin, gluon spin, and their respective orbital angular momenta) as

\[
S_p = \frac{1}{2} = \frac{1}{2} \Delta S + \Delta G + L_q + L_g. \tag{1}
\]

Measurements of longitudinal helicity asymmetries at RHIC have significantly constrained the gluon spin component \( \Delta G \), more so than previous unpolarized and fixed-target polarized deep inelastic scattering (DIS) experiments.

2. Factorization
Interpretation of RHIC results relies on factorization, a formalism in which cross-sections are factorized into parton distribution functions (PDFs), parton-level cross sections, and, in some processes, fragmentation functions. For example, the difference of like and unlike helicity cross-sections for the process \( \vec{p} + \vec{p} \rightarrow C + X \) is, factorized,

\[
d\Delta \sigma = \sum_{a,b,c} \int_0^1 dx_a \int_0^1 dx_b \int_0^1 dz_c \Delta f_a(x_a, \mu) \Delta f_b(x_b, \mu) D_c^C(z_c, \mu') d\Delta \hat{\sigma}_{ab}(x_a P_a, x_b P_b, P_C / z_c, \mu, \mu'). \tag{2}
\]

Here \( D_c^C(z_c, \mu') \) is the fragmentation function, the probability for parton \( c \) to fragment into hadron \( C \). The functions \( \Delta f(x, \mu) = f_+(x, \mu) - f_-(x, \mu) \) are polarized parton distribution functions giving the difference in number density of partons at momentum fraction \( x \) aligned (+) and anti-aligned (−) with the proton’s helicity. Finally, \( \hat{\sigma}_{ab} \) is the partonic level cross section for the process \( a + b \rightarrow c \).
In order to confirm the validity of factorization, it is tested in the unpolarized case. We use data on unpolarized PDFs from DIS and measurements of fragmentation functions mostly from $e^+ e^-$ scattering. Together with perturbative quantum chromodynamics (pQCD) calculated partonic cross-sections, they give us predictions for the $p+p$ cross section which we then compare to our measurement.

Results of this comparison for various center of mass energies are shown in Figure 1. Note the agreement with factorization, indicating that we may use it to interpret our $A_{LL}$ results.

Figure 1. (a) $\pi^0$ cross section at 62.4 GeV, showing agreement with a NLL pQCD calculation [1]. (b) $\pi^0$ cross section at 200 GeV [2]. The dashed line in the inset shows the contribution from soft physics. (c) $\pi^0$ cross section at 500 GeV.

3. $\pi^0$ Double Longitudinal Helicity Asymmetry

We can define a “double longitudinal helicity asymmetry” in terms of differences in cross sections as

$$A_{LL} = \frac{d\Delta\sigma}{d\sigma} = \frac{d\sigma^{++} - d\sigma^{+-}}{d\sigma^{++} + d\sigma^{+-}},$$

(3)

where ++ and +- stand for like and unlike helicity collisions. This can be written in terms of experimental observables as

$$A_{LL} = \frac{1}{P_B P_Y} \frac{N^{++} - RN^{+-}}{N^{++} + RN^{+-}}, R = \frac{L^{++}}{L^{+-}},$$

(4)

where $P_B$ and $P_Y$ are the polarizations of RHIC’s “blue” and “yellow” beams, $N$s are the yields of the final state particle of interest (in this case di-photons from $\pi^0$ decays), and $R$ is the relative luminosity of like and unlike helicity collisions. In this equation all efficiencies (acceptance, reconstruction, trigger bias) are assumed to cancel between numerator and denominator, which requires the properties of ++ and +- collisions to be similar. This is achieved at RHIC by having a short time between beam crossings (106 ns) and cycling through all necessary helicity combinations within eight beam crossings.

To account for background contributions, di-photon yields are counted in two separate invariant mass windows, one encompassing the $\pi^0$ mass peak and another the combination...
of two sidebands on either side of the peak where the $\pi^0$ contribution is negligible. $A_{LL}$ is then calculated separately for each of these invariant mass windows, and the true physics asymmetry, $A_{LL}^{\pi^0}$, is extracted using the equation

$$A_{LL}^{\pi^0} = \frac{A_{LL}^{\text{peak}} - rA_{LL}^{\text{sidebands}}}{1 - r} \quad (5)$$

where $r$ is the fraction of background under the $\pi^0$ mass peak.

4. The PHENIX Detector

The PHENIX detector's central arm contains high-granularity electromagnetic calorimeters (6 sectors of Pb-Scintillator sampling calorimeter and 2 of Pb-Glass Cherenkov radiator) in a pseudorapidity range of $|\eta| < 0.375$ and with 2 times $\frac{\pi}{2}$ coverage in azimuth [3]. These calorimeters are well-suited to measure $\pi^0$ decay photons.

EMCal triggering is done on summed energy deposits in blocks of towers, overlapping 4x4 blocks in the case of the $\pi^0A_{LL}$ analyses.

For relative luminosity measurements, PHENIX uses a pair of beam-beam counters, each an array of 64 quartz Cherenkov radiators with PMTs. These sit at $\Delta\eta = \pm(3.1 \text{ to } 3.9)$, and have full azimuthal coverage. At the rates seen thus far in 62.4 and 200 GeV collisions, the rate of their coincidence can be taken as proportional to the $p+p$ collision rate, although analyzing higher rate 500 GeV data will require multiple collisions in one beam crossing to be taken into account.

5. $\pi^0A_{LL}$ Results and Projections

PHENIX has existing $\pi^0A_{LL}$ results for $\sqrt{s} = 62.4$ and 200 GeV, including a new 200 GeV preliminary result for the RHIC run ending in 2009, shown in Figures 2 and 3.

![Figure 2. PHENIX measurement of $\pi^0A_{LL}$ at $\sqrt{s} = 62.4$ GeV [1].](image)

Some 500 GeV data was also collected in 2009, on which data analysis is still underway. Future 500 GeV running will increase this data set, and projections for $\pi^0A_{LL}$ are shown in Figure 4. This data will be important for constraining $\Delta G$ at lower parton momentum fraction $x$, since higher $\sqrt{s}$ corresponds to lower $x$.

6. Use in Global Analysis

PHENIX $\pi^0A_{LL}$ and other RHIC results have been used in a global analysis by de Florian, Sassot, Stratmann and Vogelsang (DSSV) [4]. The RHIC results are of particular importance
Figure 3. PHENIX measurements of $\pi^0A_{LL}$ at 200 GeV. The grey systematic uncertainty band is shown for 2009 and is almost entirely due to systematic uncertainty on the relative luminosity, $R$.

Figure 4. Projection for future PHENIX $\pi^0A_{LL}$ results at $\sqrt{s} = 500$ GeV.

for constraining $\Delta G$. The central result for $\pi^0A_{LL}$ in the DSSV global analysis is shown with some PHENIX $\pi^0A_{LL}$ data in Figure 5.

Some work has already been done to study the impact of the most recent Run 9 results on DSSV. For further details, see [5].

References
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[2] Adare A et al (PHENIX Collaboration) 2007 Phys. Rev D 76 051106
[3] Aphecetche L et al 2003 Nuclear Instruments and Methods in Physics Research Section A 499 521-536
[4] de Florian D, Sassot R, Stratmann M and Vogelsang W 2009 Phys. Rev. D 80 034030
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Figure 5. PHENIX 200 GeV $\pi^0 A_{LL}$ combined results from Runs 5+6+9 compared to the DSSV global analysis done prior to Run 9 [4]. The grey band shows the systematic uncertainty from the relative luminosity, $R$. 

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