Double Helicity Asymmetry and Cross Section for η Production in Polarized pp Collisions at PHENIX

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Abstract. Measurements of double helicity asymmetries for inclusive hadron production in polarized proton-proton collisions are sensitive to spin–dependent parton distribution functions, in particular to the gluon distribution, Δg. This study presents the double helicity asymmetry and the cross section for η production ($\vec{p}+\vec{p} \to \eta + X$). The cross section measurement yields valuable data for the extraction of the fragmentation functions, which are unknown at present but are a prerequisite for the extraction of the spin–dependent parton distribution functions.

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INTRODUCTION

Present knowledge about spin–dependent parton distribution functions (PDFs) in the nucleon mainly comes from next-to-leading order (NLO) QCD fits (see, e.g., [1, 2]) to the spin–dependent structure function g_1 as measured in polarized inclusive deep–inelastic scattering (DIS) experiments (see, e.g., [3, 4]). The resulting spin–dependent gluon PDFs have rather large uncertainties due to the fact that the exchanged virtual photon does not couple directly, i.e., at leading order, to the gluon. Thus, additional data from polarized pp scattering in which longitudinally polarized gluons are directly probed via scattering off longitudinally polarized gluons or quarks should greatly reduce the uncertainties in the NLO fits, especially for the gluon distribution.

First results from the PHENIX and the STAR collaborations at the Relativistic Heavy Ion Collider (RHIC) are available, measuring double helicity asymmetries in inclusive π^0 [5] and jet production [6], respectively. The double helicity asymmetry is defined as

$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} = \frac{\Delta\sigma}{\sigma}, \quad with \quad \Delta\sigma \propto \sum_{abc} \Delta f_a \otimes \Delta f_b \otimes \Delta\hat{\sigma}^{ab\to cX'} \otimes D_c^h \qquad (1)$$

where the cross section σ^{++} (σ^{+-}) describes the reaction where both protons have the same (opposite) helicity. The spin–dependent term is given on the right hand side, where Δf_a, Δf_b represent the spin–dependent PDFs for quarks (u,d,s) and gluons, and $\Delta\hat{\sigma}$ are the spin–dependent hard scattering cross sections calculable in perturbative QCD.

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The fragmentation functions (FFs) D_c^h represent the probability for a certain parton c to fragment into a certain hadron h, and thus they are not needed in the case of jet production. It is apparent that the extraction of the spin–dependent PDFs from, e.g., the PHENIX π^0 data, critically depends on the knowledge of the FFs. It therefore is desirable to extract the spin–dependent PDFs using different channels, not only because of possibly different systematic uncertainties involved in the A_{LL} measurement, but also because of the different FFs involved. The latter can be extracted based on cross section measurements from independent data, mainly from e^+e^- colliders.

This study focuses on A_{LL} in η production ($\vec{p}+\vec{p} \to \eta + X$). In contrast to the π^0 the η FFs are unknown, but at least the quark FFs can be reasonably well constrained based on the existing η cross section measurements from e^+e^- collider data. The extraction of gluon FFs requires either e^+e^- data taken in a wide range of $\sqrt{s}$ values, or cross section measurements from, e.g., pp scattering. The η cross section has been recently extracted by the PHENIX collaboration based on the data taken in 2003 [7]. An extraction based on the data from 2005, with improved statistics and a wider range in transverse momentum is in progress. It will serve as an important input for the η FF extraction which is in preparation [8].

Apart from serving as input in a global fit in order to constrain the spin–dependent gluon PDF, the A_{LL} in η production might have a second interesting application. Due to the s-quark content in the η wave function which is absent in the π^0, it is expected that the fragmentation from s-quarks into η mesons is larger than the one into π^0 mesons. If the s-quark contribution turns out to be significant, the A_{LL} in η production might help to constrain the spin–dependent s-quark PDF, either in a global fit or by a dedicated analysis focusing on possible differences between the A_{LL} in π^0 and η production.

RECONSTRUCTION OF η MESONS

The η meson is reconstructed via its main decay channel $\eta \to \gamma\gamma$ with a branching ratio of about 40%. The three-body decay $\eta \to \pi^+\pi^-\pi^0$ not only has a smaller branching ratio of about 23%, but in addition also has a smaller acceptance in the PHENIX spectrometer and therefore has not been considered yet. The data were taken at the PHENIX [9] experiment in 2005. The primary detector used in this analysis is the electromagnetic calorimeter (EmCal), located at a radial distance of about 5 m from the beam pipe. It covers the pseudo–rapidity range $|\eta| < 0.35$ and has an azimuthal acceptance of $\Delta\phi = \pi$. The EmCal consists of eight sectors, six of which are composed of a total of 15552 lead–scintillator (PbSc) sandwich modules (5.5 cm x 5.5 cm x 37.5 cm), and two sectors of lead-glass (PbGl) cherenkov calorimeters, consisting of a total of 9216 modules (4 cm x 4 cm x 40 cm).

A cluster in the EmCal is assumed to originate from a photon if the following criteria are met. First, the cluster may not be associated with a signal from a charged particle in the Pad Chamber just in front of the EmCal (PC3); an exception is made if the signal position in the EmCal and in the PC3 are aligned in such a way that the particle likely came from the vertex on a straight line, i.e., it was not bent in the central magnetic field. In this case the cluster is accepted as a photon candidate since it is assumed that the original photon converted into an e^+e^- pair just before the PC3. Furthermore, since electromagnetic showers in the EmCal are not confined within a single module, a shower profile analysis can be used in order to reject hadrons which usually produce broader showers than photons. Since hadrons are slower than photons, an additional time of flight cut is used for the photon identification.

Using all possible pairs of photon candidates, the two–photon invariant mass can be calculated. In order to exclude clusters with potentially wrongly reconstructed energies from the calculation, the module with the largest energy deposition in a cluster may not be in the outermost two columns or rows of an EmCal sector, and there may not be a noisy or dead module in the eight surrounding modules. An upper limit of 0.7 is placed on the energy asymmetry $(E_1 - E_2)/(E_1 + E_2)$ of the two cluster energies E_1 and E_2 in order to reduce the combinatorial background. Finally, the transverse momentum p_T of the di–photon is required to be larger than 2 GeV/c. The invariant mass distribution for two different p_T bins is shown in Fig.1. In the vicinity of the η peak the distribution is well described by a fit to a Gaussian plus a second–order polynomial. For the asymmetry calculation the events within a 2σ window around the mean of the η peak are used, whereby the number of background events N^{BG} is given by the integral under the polynomial within this window.

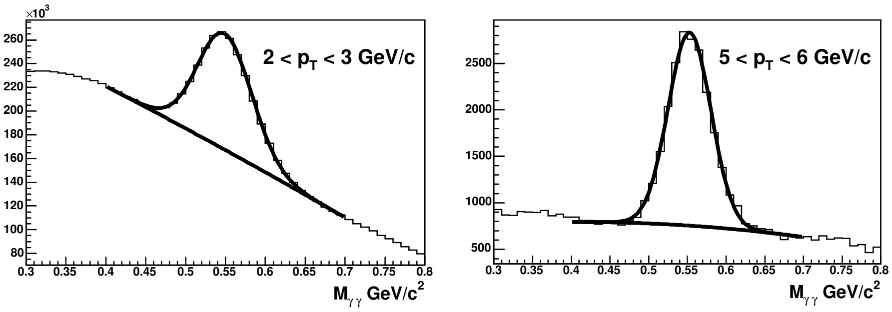

FIGURE 1. Two photon invariant mass distribution for two different p_T bins.

DOUBLE HELICITY ASYMMETRY

Experimentally, the double helicity asymmetry (Eqn. 1) translates into

$$A_{LL} = \frac{1}{|P_B||P_Y|}\frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}}, \quad with \quad R \equiv \frac{L_{++}}{L_{+-}}, \tag{2}$$

where N_{++} (N_{+-}) is the experimental yield for the case where the beams have the same (opposite) helicity. The relative luminosity R is measured by a coincident signal in two beam–beam counters, which have a full azimuthal coverage at a distance of about ± 1.4 m from the target. The achieved uncertainty on R is on the order of 10^{-4}. The polarizations of the two colliding beams at RHIC are denoted by P_B and P_Y. The degree of polarization is determined from the combined information of a $\vec{p}C$ polarimeter [10], using an unpolarized ultra–thin carbon target, and from $\vec{p}\vec{p}$ scattering, using a polarized atomic hydrogen gas-jet target [11]. The preliminary average polarization value for the data from 2005 is 47% with an uncertainty of 20% per beam, leading to a 40% scale uncertainty in the preliminary A_{LL} result.

The double helicity asymmetry for η production is calculated as

$$A_{LL}^{\eta} = \frac{A_{LL}^{\eta+BG} - rA_{LL}^{BG}}{1-r}, \quad with \quad r \equiv \frac{N^{BG}}{N^{\eta}+N^{BG}}, \tag{3}$$

where $A_{LL}^{\eta+BG}$ is the asymmetry from the events in the 2σ window around the mean of the η peak, and A_{LL}^{BG} is the background asymmetry calculated in an invariant mass region below (300–400 MeV/c^2) and above (700–800 MeV/c^2) the η peak (see Fig. 1). The asymmetries in the two regions are consistent with each other and therefore have been combined to form A_{LL}^{BG}. The ratio r gives the number of background events divided by all events in the 2σ window around the mean of the η peak. The background corrected asymmetry A_{LL}^{η} as a function of p_T is shown in Fig. 2. As discussed above, the asymmetry can only be related to the spin–dependent gluon distribution after the η fragmentation functions have been extracted. Similar to the PHENIX results on the π^0 asymmetry, the η asymmetry is consistent with zero over the measured range. It should be noted that the data taken in 2006 will improve the statistical error for A_{LL}^{η} by about a factor of three.

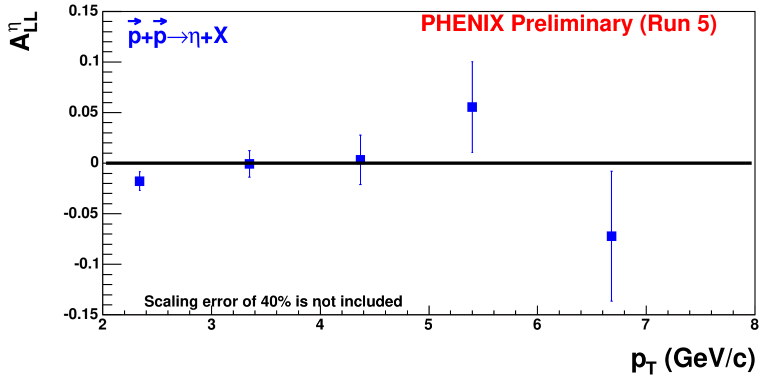

FIGURE 2. Double helicity asymmetry for the inclusive η production as a function of p_T.

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REFERENCES

1. J. Blümlein, H. Böttcher, Nucl. Phys. B 636 (2002) 225.
2. D. de Florian, G.A. Navarro, and R. Sassot, Phys. Rev. D 71 (2005) 094018.
3. [HERMES Collaboration], A. Airapetian et al., Phys. Rev. D (in press), hep-ex/0609039.
4. [COMPASS Collaboration], V.Yu. Alexakhin et al., hep-ex/0609038.
5. [PHENIX Collaboration], S.S. Adler et al., Phys. Rev. Lett. 93 (2004) 202002. S.S. Adler et al., Phys. Rev. D 73 (2006) 091102.
6. [STAR Collaboration], B.I. Abelev et al., submitted to Phys. Rev. Lett., hep-ex/0608030.
7. [PHENIX Collaboration], S.S. Adler et al., submitted to Phys. Rev. C, nucl-ex/0611006.
8. M. Stratmann, private communication.
9. [PHENIX Collaboration], K. Adcox et al., Nucl. Instrum. Meth. A 499 (2003) 469.
10. O. Jinnouchi et al., RHIC/CAD Note 171 (2004).
11. H. Okada et al., Phys. Lett. B (in press), hep-ex/0601001.