Recent PHENIX Results on $\pi^{\pm}$ and η Production in polarized pp Collisions at RHIC at $\sqrt{s} = 200$ GeV

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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 focuses on double helicity asymmetries in η ($\vec{p}+\vec{p} \rightarrow \eta + X$) and charged pion production ($\vec{p}+\vec{p} \rightarrow \pi^{\pm} + X$) at mid-rapidity, as well as on the η cross section and fragmentation functions.

1 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., [2, 3]) to the spin–dependent structure function g_1 as measured in polarized inclusive deep–inelastic scattering (DIS) experiments (see, e.g., [4, 5]). The resulting spin–dependent PDFs for the gluon 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 gluon distribution. This has recently been demonstrated in a global NLO fit [6] using, for the first time, the available inclusive and semi-inclusive DIS data together with first results from polarized pp scattering at the Relativistic Heavy Ion Collider (RHIC). The results used were double helicity asymmetries in inclusive π^0 [7] and jet [8] production from the PHENIX and STAR experiments, respectively. The double helicity asymmetry is defined as

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

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 rhs of Eqn. 1, 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. 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.

This study focuses on A_{LL} in η ($\vec{p}+\vec{p} \rightarrow \eta + X$) and charged pion production ($\vec{p}+\vec{p} \rightarrow \pi^{\pm} + X$), as well as on the η cross section and fragmentation functions.

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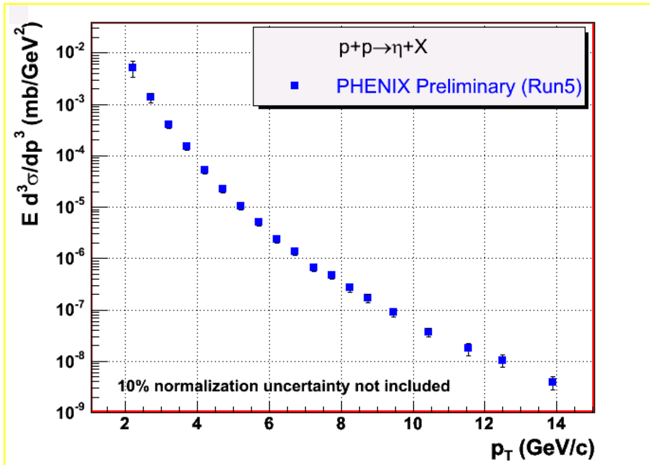

Figure 1: Cross section for mid-rapidity inclusive η production at $\sqrt{s} = 200$ GeV as a function of p_T.

2 Eta cross section and fragmentation functions

The η meson is reconstructed via its main decay channel $\eta \rightarrow \gamma\gamma$ with a branching ratio of about 40%. The three-body decay $\eta \rightarrow \pi^+\pi^-\pi^0$ not only has a smaller branching ratio of about 23%, but in addition also has a smaller acceptance in the PHENIX spectrometer [9] and therefore has not been considered. The primary detector used in this analysis is the electromagnetic calorimeter, 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 preliminary η cross section as a function of p_T from data taken in 2005 is shown in Fig. 1. It is consistent with an earlier PHENIX cross section measurement [10] covering a smaller range in p_T. Using the code of Ref. [11] this result from pp scattering together with various η cross section measurements from e^+e^- scattering have been used to extract preliminary fragmentation functions for η production. The resulting contributions of the various scattering subprocesses gluon–gluon (gg), quark–gluon(qg), and quark–quark (qq) to the η production as a function of p_T are shown in Fig. 2. They are compared to the fractional contribution of the subprocesses to the π^0 production [11]. The η production has a larger contribution from gg scattering and thus enhanced sensitivity to the gluon PDF when compared to the π^0. This is expected due to the additional strange quark contribution in the wave function of η mesons which is absent for the π^0.

The s-quark contribution in the η wave function also opens up the possibility of studying the polarized strange quark PDF (Δs). Special interest arises from the fact that Δs has been assumed to be negative based on inclusive DIS data, however, semi-inclusive DIS measurements [12, 13] find Δs to be compatible with zero or slightly positive. The η A_{LL} measurement is in principle sensitive to Δs as shown in Fig. 2, where the contribution of subprocesses involving s quarks rises to 10% at $p_T = 10$ GeV. However, potentially large uncertainties are possible due to the absence of semi-inclusive data on η production in this preliminary FF determination.

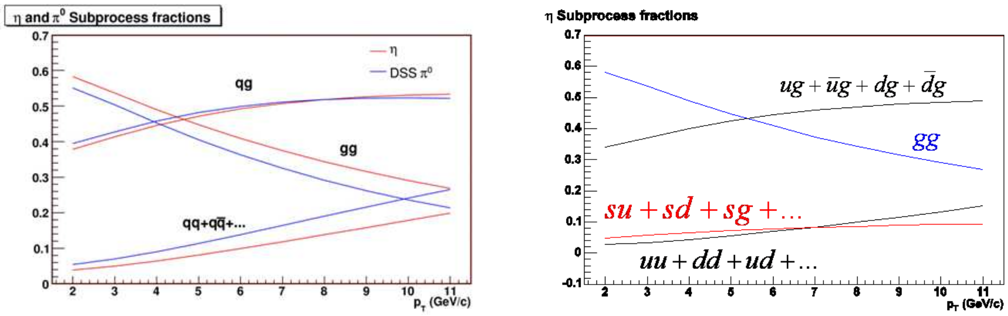

Figure 2: Left panel: Fractional contribution of gluon–gluon (gg), quark–gluon(qg), and quark–quark (qq) scattering to η (preliminary) and π^0 [11] production as a function of p_T. Right panel: The fractional contributions to η production (preliminary) are shown for scattering involving (red line) or not involving (black lines and blue line) strange quarks.

3 Double Helicity Asymmetry for $\pi^\pm$ and η

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

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

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 [14], using an unpolarized ultra–thin carbon ribbon target, and from $\vec{p}\vec{p}$ scattering, using a polarized atomic hydrogen gas-jet target [15]. The average polarization value for the data from 2005 (2006) is 49% (57%).

The double helicity asymmetry for η production as a function of p_T from the 2005 [16] and 2006 data is shown in the left panel of Fig. 3. It is consistent with zero over the measured range. The results are compared to NLO pQCD calculations [17], using the above mentioned preliminary FFs and the GRSV set of polarized PDFs [18]. The standard GRSV set ($\Delta g =$ GRSV-Std) has been modified by assuming the polarized gluon PDF to be zero ($\Delta g = 0$), equal ($\Delta g =$ GRSV-Max), or opposite ($\Delta g =$ GRSV-Min) to the unpolarized gluon PDF at the input scale. It is apparent that the maximum and minimum scenarios are ruled out by this data alone, and that future data can further constrain the polarized gluon PDF.

The double helicity asymmetry for charged pion production as a function of p_T is shown in the right panel of Fig. 3. Similar to the case of η production the data has been compared to NLO pQCD calculations [1]. So far only the maximum gluon scenario can be excluded, however, the advantage of the charged pion data is in its increased sensitivity to the sign of ΔG. In fact, the sign can be studied in a model independent way. Due to the fact that qg scattering dominates in the measured p_T region and that the polarized u (d) quark PDFs are well known from DIS, a positive or vanishing gluon polarization would lead to

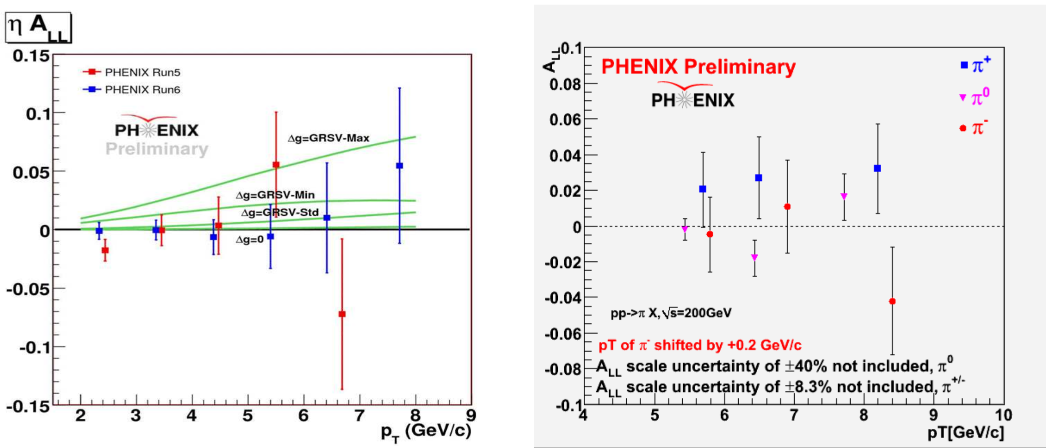

Figure 3: Double helicity asymmetry for mid-rapidity inclusive η (left panel) production from the 2005 [16] and 2006 data and pion (right panel) production from the 2006 data at $\sqrt{s} = 200$ GeV as a function of p_T. The results for the η asymmetry are compared to NLO pQCD calculations [17, 18]. See text for details.

$A_{LL}^{\pi^+} > A_{LL}^{\pi^0} > A_{LL}^{\pi^-}$ due to the increasing (decreasing) contribution of negatively (positively) polarized d (u) quarks. As can be seen in the right panel of Fig. 3, in which the PHENIX A_{LL} result for π^0 production in the p_T region of interest is shown as well, additional data will be needed to provide the desired constraint on the sign of the polarized gluon PDF.

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