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Measurements of double helicity asymmetries (A_{LL}) at mid- and forward rapidities in longitudinally polarized $p+p$ collisions at $\sqrt{s}$ = 510 GeV with the PHENIX experiment

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One of the main goals of the RHIC spin program as well as the PHENIX experiment is to determine the gluon spin contribution to the total spin of the nucleon. Recent longitudinally polarized proton-proton collision results at RHIC at a center-of-mass energy of 200 GeV have indicated a nonzero gluon spin contribution at x above 0.05. In recent years RHIC has been operating at a higher center-of-mass energy which allows to extend the covered range. PHENIX has published neutral pion asymmetries at central rapidities which clearly confirm the nonzero gluon contributions and extend the measured range to 0.01. Another measurement of J/ψ asymmetries at forward rapidities extends the sensitivity until 0.001.

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1. Introduction

The spin composition of the nucleon is still not well understood. While at intermediate x the quark spin contribution is reasonably well measured the gluon spin contribution was until recently only poorly constrained. The main reason is that in DIS experiments the sensitivity to gluons only enters at the sub-leading order in α_S or via the DGLAP evolution of the $g_1(x,Q^2)$ structure function. Given that so far only fixed target polarized DIS experiments were available the lever arm in Q^2 is not enough to sufficiently extract the gluon spin contribution. In contrast, hadron or jet production in polarized proton-proton collisions as performed at RHIC at low to intermediate transverse momenta, P_T, are dominated by gluon-gluon and quark-gluon hard scattering processes. Therefore, one has sensitivity to the gluon spin contribution in double spin asymmetries, although, as long as one measures inclusive final states only, only through convolutions over the participating parton distribution functions. The double spin asymmetries for hadron production are defined as:

$$A_{LL}^{h}(P_T) = \frac{\sum_{a,b} \Delta f_a(x_1,Q) \otimes \Delta f_b(x_2,Q) \Delta\hat{a}_{a+b\to c+d} \otimes D_1^{c,h}(z,Q)}{\sum_{a,b} f_a(x_1,Q) \otimes f_b(x_2,Q) \hat{a}_{a+b\to c+d} \otimes D_1^{c,h}(z,Q)} \quad , \tag{1.1}$$

where $(\Delta)f_a(x,Q)$ are the (un-)polarized parton distribution functions for the two colliding protons and $D_1^{c,h}(z,Q)$ is the fragmentation function of finding a hadron h off an outgoing parton c. These asymmetries are experimentally extracted by calculating the count rate differences for a certain hadron type normalized by their sum and the average beam polarizations $< P_i >$:

$$A_{LL}(P_T) = \frac{1}{< P_1 >< P_2 >} \cdot \frac{N^{\to\to}(P_T) - RN^{\to\leftarrow}(P_T)}{N^{\to\to}(P_T) + RN^{\to\leftarrow}(P_T)} \quad , \tag{1.2}$$

where $R = \mathscr{L}^{\to\to}/\mathscr{L}^{\to\leftarrow}$ is the relative luminosity accumulated in both spin orientation states.

At central rapidities gluon x above 0.02 and 0.01 can be accessed for pion production at 200 GeV and 510 GeV, respectively, with pion transverse momenta large enough that a perturbative treatment is applicable. For the three different pion charges at the same transverse momenta the only terms different in the asymmetries are the quark-gluon contribution and the fragmentation function. Therefore, in principle the ordering of the three asymmetries directly shows the sign of the gluon helicity probed. PHENIX has measured all charges at 200 GeV [1, 2] but due to trigger limitations the precision is not sufficient so far. At 510 GeV the charged pion analysis is ongoing while the neutral pion analysis will be discussed below. At forward rapidities the collisions become more asymmetric and thus the lower of the fractional energies probed can reach 0.001. Very forward pion asymmetries are currently being analyzed as well. In addition, forward J/ψ production is also sensitive to these asymmetric collisions. Even taking into account feed-down, J/ψs are predominantly produced at RHIC energies by gluon-gluon fusion and therefore it is in principle a very clean channel to access the gluon spin. However, the production mechanism is not well understood which makes the direct interpretation at present difficult. The J/ψ results will also be discussed below as they are at present the measurements constraining the gluon helicity to the lowest x available.

2. Detector setup and measurement setup

The PHENIX experiment consists of two central detectors covering a rapidity range of $|\eta| <$

0.35 and 90 degrees in azimuth each instrumented with drift and pad chambers, electromagnetic calorimetry as well as Ring image cherenkov detectors and time-of-flight systems. The central detectors are particularly well suited for electromagnetic particles such as π^0 decay photons, direct photons as well as electrons from heavy flavor decays. The forward rapidities of $1.2 < |\eta| < 2.4$ are instrumented with a hadron absorber, a radial magnet, tracking chambers and muon identifying chambers sandwiched between steel plates as well as resistive plate counters for triggering and timing. These detector systems are dedicated to muon measurements from heavy flavor, J/ψ and W boson decays. At very forward rapidities two beam-beam collision counters (BBCs) are sitting at rapidities $3.1 < |\eta| < 3.9$ for predominantly charged particles and $|\eta| > 6.8$ for neutrons (ZDCs) which are used to measure the bunch-by-bunch luminosities delivered to PHENIX.

For the central neutral pion asymmetries, photon pairs with an invariant mass between within 25 MeV of the nominal π^0 mass are selected. The fraction of combinatorial background under the π^0 peak has been evaluated using the sidebands and a Gaussian progression technique. The asymmetries in the sidebands are also used to evaluate and correct the asymmetry contribution from the combinatorial background under the peak. The relative luminosity is evaluated using the BBC detectors after pile-up correction; systematic uncertainties are assigned by comparing them to relative luminosities obtained with the ZDCs. The systematic uncertainties are $3.6 \cdot 10^{-4}$ for the relative luminosity, 6.5% due to the beam polarization uncertainties and smaller uncertainties due to the background fraction evaluation.

The $J\psi$ decay muons are identified by traversing at least three layers of the muon identifier and are reconstructed with opposite charge and an invariant mass within 2σ of the J/ψ mass peak as defined by the mass resolution of the detector. Again combinatorial backgrounds are subtracted by evaluating the background asymmetry in the sideband and performing a Gaussian progression technique to find the background fraction under the peak. The systematic uncertainties are again dominated by the beam polarization uncertainties, background fraction evaluation and relative luminosity calculation.

3. Results

The central π^0 asymmetries at 200 [1] and 510 GeV [3] are displayed in Fig. 1 as a function of $x_T = p_T/\sqrt{s}$. One clearly sees the increasingly nonzero asymmetries with increasing x_T. The theoretical curves based on several, more or less, global fits [4, 5, 6], which partially included the 200 GeV data, are also shown. The curves at both collision energies agree perfectly with the data. As a consequence the central values in the previously accessed x range will not change but the uncertainty band will be reduced. The magnitude of the asymmetries is slightly larger at 510 GeV due to the fact that the transverse momenta are larger and DGLAP evolution increases the gluon spin contribution at higher scales. At low x_T one sees, that the higher collision energy data extends to lower values as x_T is a proxy for x. Using a Pythia simulation, the actual x coverage of this measurements has been found to reach down to 0.01.

The forward J/ψ double spin asymmetries are displayed in Fig. 2 as a function of transverse momentum P_T and rapidity. The asymmetries are all positive but each point is consistent with zero within the statistical uncertainties. Given the uncertainty in the production mechanism the two extreme cases for the partonic analyzing powers ± 1 can be taken in a reweighing procedure

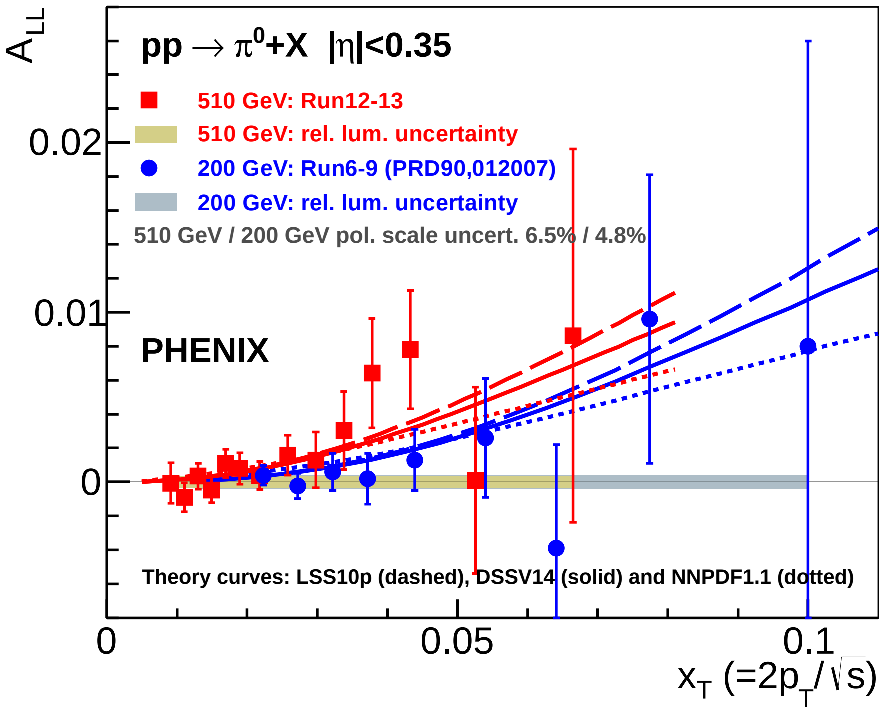

Figure 1: Neutral pion double spin asymmetries at collision energies of 200 GeV (blue) and 510 GeV (red) as a function of $x_T = P_T/\sqrt{s}$. The corresponding parameterizations using the DSSV14, NNPDFpol1.1 and LSS10 global fits are also shown (red and blue lines, respectively).

to evaluate the impact of the data. Using the NNPDFpol1.1 replicas [5], one can see moderate improvements in terms of the gluon polarization uncertainties at the lowest x but the central value does move either up or down depending on the sign of the partonic analyzing power. When the production mechanism question is decided, these results will therefore clearly improve our knowledge on the gluon spin contribution at small x.

4. Summary

In summary, PHENIX has contributed several very important results to pin down the gluon spin contribution to the nucleon while more are still being analyzed. The central pion asymmetries confirm the previous global fit results and extend the knowledge towards smaller x. The forward J/ψ asymmetries extend the covered range even further but with limited precision and the still lingering uncertainty in the J/ψ production mechanism. Together, the PHENIX results will help reduce the uncertainties on the gluon helicity in the $x > 0.001$ range substantially before an electron-ion collider will improve the precision towards lower x.

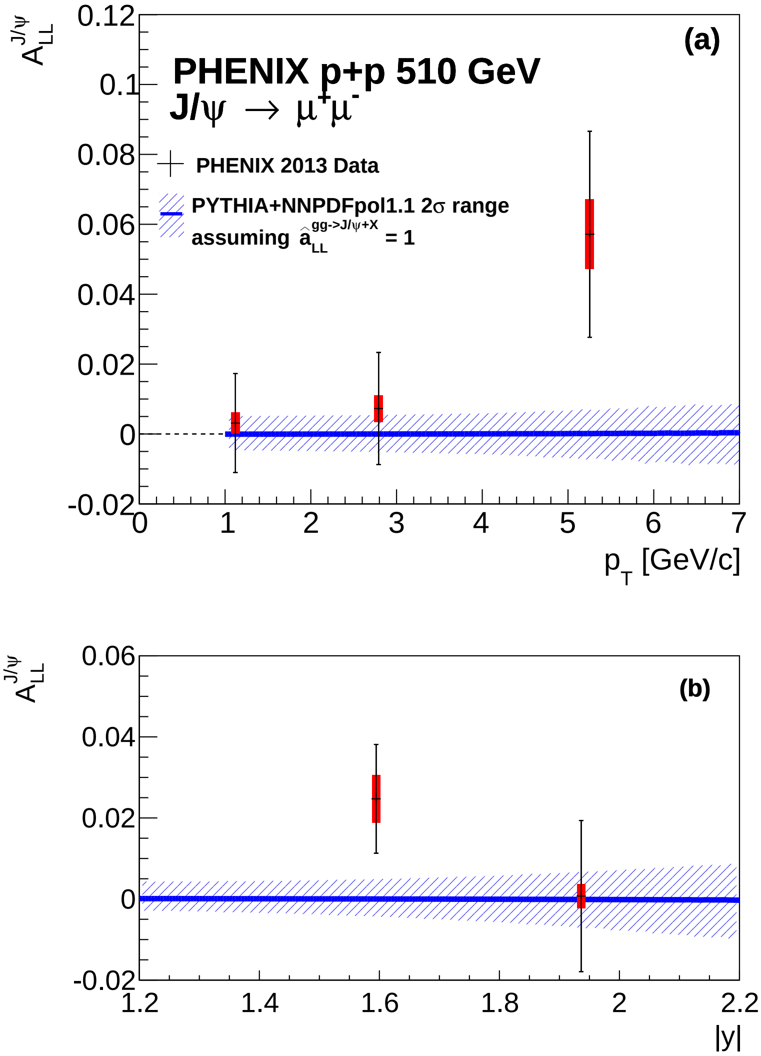

Figure 2: J/ψ double spin asymmetries as a function of P_T and y. The corresponding parameterizations using the NNPDFpol1.1 global fits and assuming a partonic analyzing power of $+1$ are also shown (blue lines and band).

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