

FIRST PHENIX RESULTS ON DOUBLE LONGITUDINAL ASYMMETRY MEASUREMENT IN π^0 PRODUCTION IN POLARIZED p-p COLLISIONS AT $\sqrt{s} = 200\text{GeV}$

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Abstract

The measurement of double spin asymmetry in mid-rapidity π^0 production in polarized proton-proton collisions at $\sqrt{s} = 200$ GeV from Run III of the Relativistic Heavy Ion Collider (RHIC) is presented. This is the first measurement of double spin asymmetry made at RHIC. The measured asymmetry as a function of transverse momentum p_T is plotted and compared with the pQCD fits from the polarized DIS experiments.

1. Introduction

Measurement of the gluon polarization in a polarized proton is a major goal of the RHIC-Spin program. It can be probed through the longitudinal double spin asymmetry (A_{LL}) in high p_T hadron production [1].

PHENIX recent results on invariant cross section measurements for inclusive π^0 production in proton-proton (pp) collisions [2] showed excellent agreement with pQCD calculations employing the gluon-to-pion fragmentation functions (Fig. 1). It established a solid theoretical foundation for polarized gluon density measurements at RHIC.

During the year 2003 run, RHIC was successfully operated for the first time as a collider of longitudinally polarized protons at a center of mass energy of 200 GeV. We present the first PHENIX results on A_{LL} for mid-rapidity π^0 production in four p_T bins in the range of 1-5 GeV/c obtained from the data corresponding to the integral luminosity of 0.215 pb^{-1} , the average beam polarization being 26%.

To calculate A_{LL} , we measured the number of π^0 's (N) and integral luminosity (L) from the colliding protons with the same ($++$) and the opposite ($+ -$) helicity:

$$A_{LL} = \frac{1}{|P_B||P_Y|} \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}}, \quad R = \frac{L_{++}}{L_{+-}}, \quad (1)$$

where P_B and P_Y are beam polarizations.

Below we briefly discuss the polarization measurements at RHIC resulting in the values of $P_{Y/B}$, the proton spin orientation in beams, the measurements of the relative luminosity R over the run, special trigger used to collect high p_T π^0 's and π^0 reconstruction in PHENIX detector's Electromagnetic Calorimeter (EMCal) [3]. This will be followed by the asymmetry results and systematic uncertainty discussion.

2. Beam polarization and spin orientation

At RHIC the beam polarization was measured using transverse single spin proton-Carbon scattering in the Coulomb Nuclear Interference (CNI) kinematics [4]. An absolute uncertainty of 30% was assigned to the value of polarization. This systematic error doesn't affect the significance of A_{LL} measurements, because it scales A_{LL} value and its error in the same way.

The stable direction of the proton spin in the a storage ring (such as RHIC) is vertical. For the longitudinal double spin asymmetry measurement, this has to be rotated by 90° . This was done by the spin rotator magnets located on either sides of the experimental areas just before the two beams enter the experimental area, and another set of spin rotators restore the beam transverse after the experimental area. The experimental confirmation of the spin direction in PHENIX experimental area and monitoring the longitudinalness of the beams were achieved with the a local polarimeter device, consisted of Zero-Degree Calorimeter (ZDC) [5] and Shower Max Detector (7 vertical and 8 horizontal 1.5 mm scintillator strips). The device utilized a transverse single spin asymmetry discovered in 2001-2 in forward neutron production in pp scattering at $\sqrt{s} = 200$ GeV [6]. Observation of no asymmetry in this device meant that the spin rotator magnets were converting the proton beam from transverse to longitudinal. The average asymmetry observed for all data runs selected for the analysis indicated that the longitudinal components of the proton spin in two beams were $0.974^{+0.013+0.001}_{-0.032-0.009}$ and $0.993^{+0.005+0.000}_{-0.014-0.009}$, respectively.

3. Relative luminosity

For the relative luminosity measurements, we used the number of coincidence of the two beam-beam counters [7] (BBC), which were located along the beam line at ± 1.44 m from the nominal interaction point and subtended the pseudorapidity range $\pm(3.0-3.9)$ with full azimuthal coverage. Due to low background ($\sim 10^{-4}$) and high statistics (detects $\sim 50\%$ of proton-proton collisions [2]), BBC is an ideal relative luminosity monitor. Another background free detector, ZDC, was used to estimate the accuracy of relative luminosity measurements and to confirm the zero- A_{LL} of BBC coincidence counts, meaning no false asymmetry in-

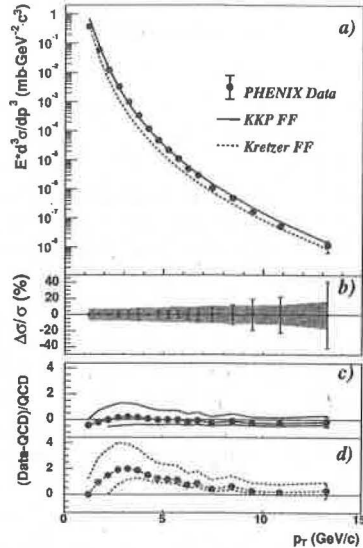


Figure 1: a) The invariant differential cross section for inclusive π^0 production (points) and the results from NLO pQCD calculations with equal renormalization and factorization scales of p_T using the “Kniehl-Kramer-Pötter” (solid line) and “Kretzer” (dashed line) sets of fragmentation functions. b) The relative statistical (points) and point-to-point systematic (band) errors. c,d) The relative difference between the data and the theory using KKP (c) and Kretzer (d) fragmentation functions with scales of $p_T/2$ (lower curve), p_T , and $2p_T$ (upper curve). In all figures, the normalization error of 9.6% is not shown.

roduced by BBC as a relative luminosity device.

The ratio R averaged over the whole data sample used in the analysis was close to unity. The accuracy of relative luminosity measurements δR was estimated to be 2.5×10^{-4} , which, for the average beam polarization of 26%, translated to $\delta A_{LL} = 1.8 \times 10^{-3}$. It is negligible compared to pure N^{π^0} statistical error contribution to A_{LL} experimental uncertainty.

4. π^0 measurements

Neutral pions were reconstructed with fine granulated ($\Delta\varphi \times \Delta\eta \sim 0.01 \times 0.01$) PbSc ECal [3], which covered the pseudorapidity range of $|\eta| < 0.35$ and an azimuthal angle interval of $\Delta\varphi \approx 135^\circ$.

High p_T π^0 's were collected using an electromagnetic-calorimeter-based high p_T photon trigger in which threshold discrimination was applied independently to sums of the analog signals from overlapping 4×4 groupings of adjacent ECal towers [2]. The trigger efficiency reached plateau at photon energy of ~ 3 GeV. The photon trigger efficiency for π^0 's varied from 6% in the 1-2 GeV/c p_T bin to 95% in the 4-5 GeV/c p_T bin.

The number of π^0 's was obtained by integrating the counts under π^0 peak in ± 25 MeV/c² mass window in two photon invariant mass distributions. Shower profile analysis was used for photon identification [8]. Only photon pairs with the energy asymmetry, $|E_1 - E_2|/(E_1 + E_2)$, less than 0.8 were used in the analysis. The collected statistics was 1.8 million, 1.1 million, 201 thousand and 38 thousand in four p_T bins from 1 GeV/c to 5 GeV/c. The background contribution (combinatorial+hadronic) varied from 45% in the 1-2 GeV/c bin to 5% in the 4-5 GeV/c bin.

To estimate the contribution of background to π^0 A_{LL} measurements, we used counts adjacent to the π^0 peak in two photon invariant mass distributions.

5. A_{LL} results

The spin asymmetry for each beam fill¹ A_{LL}^{fill} was calculated using Eq. 1. For the A_{LL}^{fill} error evaluation, we considered only the statistical error on N :

$$\sigma_{A_{LL}^{fill}} = \frac{1}{|P_B||P_Y|} \cdot \frac{\sigma_{N_{++}+N_{+-}}}{N_{++} + N_{+-}}. \quad (2)$$

The statistical error is given by $\sigma_N = \sqrt{k^2 N^{ev}}$, where N^{ev} is the number of recorded events and k is count multiplicity per event ($N = \bar{k}N^{ev}$). In a "Poisson limit" (k is always 0 or 1), $\sigma_N = \sqrt{N}$.

The resulting A_{LL} was obtained after the fitting of all A_{LL}^{fill} 's to a constant. The fitting χ^2 as well as "bunch shuffling" technique were used to confirm the errors assigned to A_{LL} 's. In each "bunch shuffling" we randomly assigned the helicity sign to every bunch crossing and did the whole procedure to calculate A_{LL} and χ^2 described above. Mean values of χ^2/NDF (NDF is the number of degrees of freedom) were very close to unity in all p_T bins. The widths of the distributions of A_{LL} values for N obtained in all bunch shuffles were consistent with errors assigned to A_{LL} 's. It denoted that errors were properly

¹Each fill is characterized by a constant polarization of the beams.

Table 1: A_{LL} in %.

pt, GeV/c	N^{π^0}	Background	N^{π^0} after bckg. corr.
1-2	-2.8 ± 1.2	-0.6 ± 1.4 (45%)	-4.6 ± 2.5
2-3	-2.2 ± 1.5	-3.5 ± 2.7 (17%)	-1.9 ± 1.9
3-4	-0.2 ± 3.3	9.4 ± 9.2 (7%)	-0.9 ± 3.6
4-5	-2.3 ± 7.4	38 ± 24 (5%)	-4.5 ± 7.9

assigned to A_{LL} values. In other words, all other noncorrelated bunch-to-bunch and fill-to-fill systematic errors are much smaller than N^{π^0} statistical errors. (Certainly, it does not exclude correlated systematic errors for all bunches and fills, such as the error on polarization).

A number of systematic checks (variation of photon identification criteria, mass window range to count π^0 s) were performed to look for possible systematic effects on the measured A_{LL} values. None were found. We also calculated the single spin asymmetries for both beams ($A_L = -\frac{\sigma_{++} - \sigma_{--}}{\sigma_{++} + \sigma_{--}}$) as well as double spin asymmetries between $(++)$ and $(--)$ and between $(+-)$ and $(-+)$ helicity configurations. As expected, these parity violating asymmetries were consistent with zero (within statistical 1.5σ).

Table 1 summarizes A_{LL} results obtained for N^{π^0} and background counts in four p_T bins. Finally, the A_{LL} of N^{π^0} was corrected for A_{LL} of background:

$$A_{LL}^{\pi^0} = \frac{A_{LL} - r A_{LL}^{bckg}}{1 - r}, \quad \sigma_{A_{LL}^{\pi^0}} = \frac{\sqrt{\sigma_{A_{LL}}^2 + r^2 \sigma_{A_{LL}^{bckg}}^2}}{1 - r}, \quad (3)$$

r is background contribution to π^0 yield (shown in brackets in third column of Table 1).

Fig. 2 shows our A_{LL} results (points) as well as theory curves [9]. The obtained sensitivity is not yet sufficient to discriminate between different gluon polarization models. The expected statistics and beam polarization in the next runs (in 2004-2005) will decrease the error bars 3-7 times.

References

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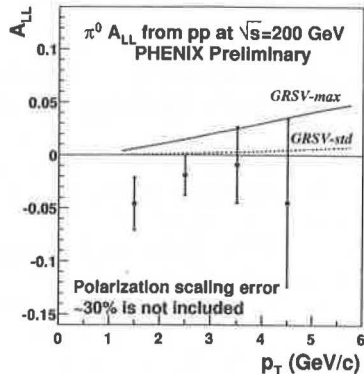


Figure 2: PHENIX A_{LL} data points vs. theory calculations (lines).

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Discussion

Q. (J. Nassalski, SINS, Warsaw): What is the source of the large background seen in $m_{\gamma\gamma}$ distribution at small p_T ?

A: There are two major sources of background in mass spectrum: hadronic and combinatorial (both hadronic and photonic). We didn't apply any photon identification cuts except shower profile cut in the EMCal, which is effective only for > 1 GeV EMCal clusters.

We expect the EMCal Time-of-Flight cut and charge veto will help to decrease the hadronic background twice. One of the way to decrease the combinatorial background is two photon energy asymmetry cut. But it'll also cut the π^0 statistics, which is crucial in our current work.

Q. (V. Mochalov, IHEP, Protvino): What is the average number of π^0 's in event? If there is a big multiplicity the asymmetry can be compensated (or you select π^0 's with largest p_T ?).

A: We have a special trigger on p_T . And the average π^0 multiplicity is 0.1 or single π^0 in event.