

Improved measurement of double helicity asymmetry in inclusive midrapidity π^0 production for polarized $p + p$ collisions at $\sqrt{s} = 200$ GeV

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We present an improved measurement of the double helicity asymmetry for π^0 production in polarized proton-proton scattering at $\sqrt{s} = 200$ GeV employing the PHENIX detector at the Relativistic Heavy Ion Collider (RHIC). The improvements to our previous measurement come from two main factors: Inclusion of a new data set from the 2004 RHIC run with higher beam polarizations than the earlier run and a recalibration of the beam polarization measurements for the earlier run, which resulted in reduced uncertainties and increased beam polarizations. The results are compared to a Next to Leading Order (NLO) perturbative Quantum Chromodynamics (pQCD) calculation with a range of polarized gluon distributions.

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From polarized lepton-nucleon deep inelastic scattering (DIS) experiments it is known that only $\sim 25\%$ of the proton spin can be attributed to the spins of the quarks and antiquarks [1]. The rest of the proton spin is assumed to be carried by the gluons and orbital angular momentum.

The double helicity asymmetry of inclusive π^0 production in polarized $p + p$ collisions, $A_{LL}^{\pi^0}$, is directly sensitive to the polarized gluon distribution function in the proton through gluon-gluon and gluon-quark subprocesses [2]. Results on $A_{LL}^{\pi^0}$ from polarized $p + p$ collisions at $\sqrt{s} = 200$ GeV using the PHENIX detector at the Relativistic Heavy Ion Collider (RHIC) were published earlier [3]. The unpolarized cross section for π^0 production is described well by next-to-leading-order perturbative QCD (NLO pQCD) calculations within the theoretical scale uncertainty [4]. The double spin asymmetry can hence be reliably interpreted in terms of the polarized gluon and polarized quark distributions in the nucleon.

$A_{LL}^{\pi^0}$ is the difference between π^0 production cross sections for like helicity and unlike helicity proton collisions, divided by the sum. Experimentally, $A_{LL}^{\pi^0}$ is obtained from the difference in production rates for polarized collisions of like and unlike helicities, divided by the sum, and normalized by the product of the polarizations of each beam.

The published $A_{LL}^{\pi^0}$ data [3] were collected in the 2003 RHIC run (Run-3) when the average polarization of the beams in RHIC was 0.35 and 0.30 for the “blue” and “yellow” ring, respectively. Recalibration of the proton-carbon CNI polarimeter [5], based on a polarized atomic hydrogen gas jet at RHIC [6], changed the absolute scale of beam polarizations by 22%. In addition, this recalibration reduced the uncertainty in the polarization measurement for each beam from $\sim 34\%$ to $\sim 18\%$ (and for a product of two beam polarizations from 65% to 28%). An important, but less significant, change in Run-3 data as published occurred when we found a polarization pattern error in 10% of the data files of Run-3, and this was corrected.

In 2004, one week of RHIC operation was dedicated to the study and improvement of the beam polarization in RHIC. The PHENIX detector took data during this time. The results of this run (Run-4) are presented here combined with the data from the previous year.

The statistical uncertainty of a double spin asymmetry is inversely proportional to the square root of the figure of merit defined by $\mathcal{L}P_B^2P_Y^2$, where the P_B and P_Y are the beam polarization values of the blue and yellow RHIC beams, respectively, and \mathcal{L} is the integrated luminosity collected by the experiment. Table I shows the average beam polarization values, the integrated luminosities and the figures of merit of the two runs. The Run-3 figure of merit in [3] was 1.2 nb^{-1} .

The stable spin direction in RHIC is vertical, and spin rotators are used to provide longitudinal polarization at PHENIX [7]. For the Run-3 and Run-4 data sets, the longitudinal fraction of the beam polarization was >0.98 and >0.99 , respectively. Details of the Run-4 analysis method including the handling of detector efficiency, relative luminosity, determination of the longitudinal fraction of the beam polarization in the PHENIX interaction region, and the background subtraction are described in our Run-3 publication [3].

Table II and Fig. 1 show the results of the Run-3 reanalysis and the Run-4 analysis. Bunch-to-bunch and fill-to-fill systematic uncertainties for the asymmetry measurements are negligible. Also indicated for each data set are the total scale uncertainties due to the uncertainty in beam polarization, which consists of two terms: an 18% scale

TABLE I. Comparison of the data sets from 2003 (Run-3) and 2004 (Run-4) RHIC runs.

Run	$\langle P_B \rangle$	$\langle P_Y \rangle$	$\mathcal{L} \text{ (nb}^{-1}\text{)}$	$\mathcal{L}\langle P_B P_Y \rangle^2 \text{ (nb}^{-1}\text{)}$
Run-3	0.35	0.30	220	2.6
Run-4	0.45	0.44	75	2.9

TABLE II. $A_{LL}^{\pi^0}$ for four p_T bins. The total point-to-point uncertainties are shown. Scale uncertainties of 28%, 24% and 18% for Run-3, Run-4 and combined runs are not included. For the combined results, uncorrelated systematic uncertainties for Run-3 and Run-4 have been included as point-to-point uncertainties, and are shown in parenthesis.

p_T ($\langle p_T \rangle$) (GeV/c)	Run-3 (10^{-2})	Run-4 (10^{-2})	Run-3+Run-4 (10^{-2})
1–2 (1.59)	-0.97 ± 0.85	-0.35 ± 0.72	$-0.60 \pm 0.56(0.10)$
2–3 (2.39)	-0.92 ± 0.90	0.56 ± 0.82	$-0.10 \pm 0.61(0.10)$
3–4 (3.37)	-0.90 ± 1.88	0.03 ± 1.79	$-0.41 \pm 1.30(0.09)$
4–5 (4.38)	-1.37 ± 4.19	7.90 ± 4.04	$3.23 \pm 2.98 (0.65)$

uncertainty (9% for each beam), due to the proton-carbon CNI polarimeter calibration, common for each data set; and an uncorrelated uncertainty (21% in Run-3 and 16% in Run-4). The additional p_T -independent systematic uncertainty related to the relative luminosity measurement between colliding bunches with the same and opposite helicities was estimated to be below 1.5×10^{-3} .

Table II and Fig. 2 show the combined asymmetries for Run-3 and Run-4 data. The point-to-point uncertainties include the uncorrelated polarization uncertainties described above. Figure 2 also presents two NLO pQCD calculations using different assumptions for the polarized gluon distribution. One uses the best global fit to the inclusive DIS data (GRSV-std) and the other uses a polarized gluon distribution equal to the unpolarized distribution at the input scale of $Q^2 = 0.4 \text{ GeV}^2$ (GRSV-max) [2,8].

Following the discussion in [3], we compared our results with theoretical curves, calculating confidence levels (C.L.) for all p_T points ($> 1 \text{ GeV}/c$) and for the three

highest p_T points ($> 2 \text{ GeV}/c$). The data are consistent with GRSV-std with a C.L. = 61–63% (73–74%) for the range in polarization uncertainty of the measurement, considering all four points (the three highest p_T points). The results are less consistent with the large gluon polarization, with C.L. = 0.04–2% (0.3–5%) for GRSV-max [2,8]. These confidence levels do not include the theoretical uncertainty from the choice of scales or of the parton distribution functions or fragmentation function.

In summary, we present results for $A_{LL}^{\pi^0}$ that are improved over our previous publication [3]. Both the statistical and systematic uncertainties are reduced by more than a factor of 2. The new results probe the polarized gluon distribution in the proton with improved resolving power. We conclude that the observed asymmetry is small and not consistent with a maximal gluon polarization.

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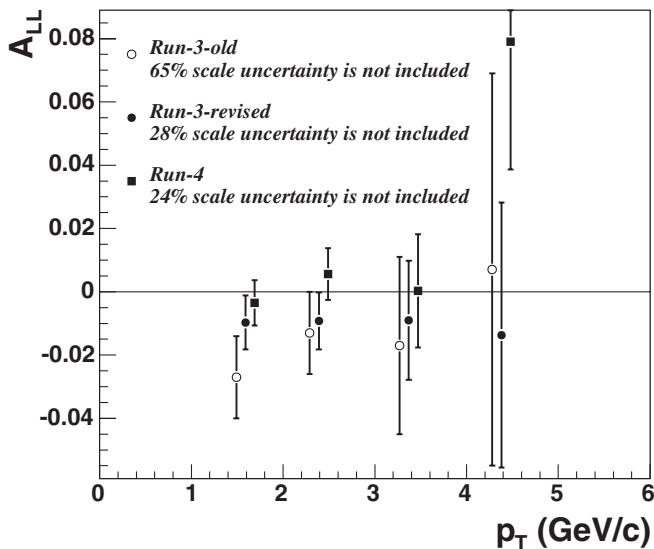


FIG. 1. Run-3 and Run-4 results on $A_{LL}^{\pi^0}$ versus mean p_T in each bin. Run-3-old results from [3] are also shown for comparison. For clarity, Run-3-old and Run-4 points are shifted by $-0.1 \text{ GeV}/c$ and $+0.1 \text{ GeV}/c$, respectively.

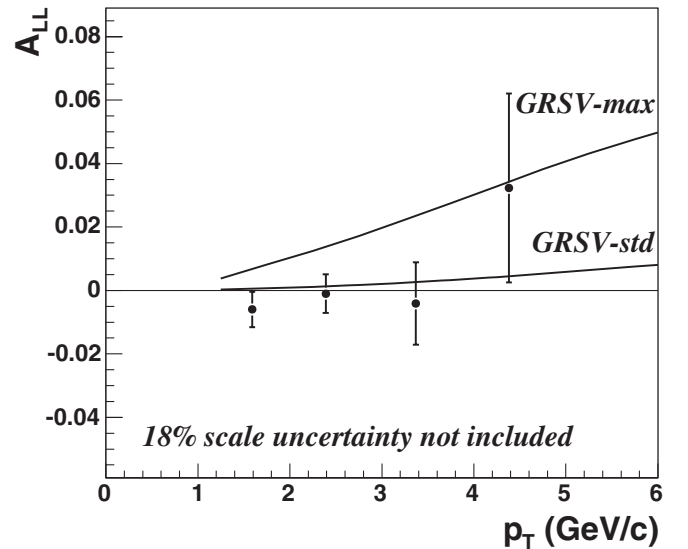


FIG. 2. Run-3+Run-4 combined results on $A_{LL}^{\pi^0}$ versus mean p_T in each bin. Two theoretical calculations based on NLO pQCD are also shown for comparison with the data (see text and [2,8] for details).

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