# Prospects of the Gluon Polarization Measurement at PHENIX

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**Abstract.** The Relativistic Heavy Ion Collider (RHIC) started operation as a polarized proton collider in December, 2001 with transverse-spin beams. From the data collected by the PHENIX experiment, we will report measurements of single transverse-spin asymmetries. From 2003, we will start the gluon polarization measurement with longitudinal-spin collisions. In this article, we report on the systematic studies performed in the previous run and then discuss the processes by which PHENIX intends to measure the gluon polarization during the next several years.

## INTRODUCTION

Since deep inelastic scattering (DIS) experiments of polarized leptons from polarized nucleons showed that only 10–30% of the proton spin is carried by the quarks and anti-quarks, we have been pursuing origin of the missing spin. In the PHENIX experiment [1] at the Relativistic Heavy Ion Collider (RHIC), the gluon polarization can be measured over a large range of gluon momentum fraction ($x_{gluon}$) by using many processes.

The RHIC started operation as a polarized proton collider in December, 2001 with

**TABLE 1.** Summary of the physics processes to be measured at PHENIX as probes of the gluon polarization. The full luminosity corresponds to 320 pb$^{-1}$ at $\sqrt{s}$ = 200 GeV and 800 pb$^{-1}$ at $\sqrt{s}$ = 500 GeV for 10-week operation.

| | luminosity | channels | $x_{gluon}$ coverage |
|---|---|---|---|
| run-3<br>(2003) | 3 pb$^{-1}$ @ $\sqrt{s}$ = 200 GeV | $\pi^0$ / $\pi^\pm$<br>single-electron | 0.05–0.2<br>0.005–0.1 |
| baseline plan<br>(2004–) | 10% – full luminosity<br>@ $\sqrt{s}$ = 200 GeV and 500 GeV | prompt-$\gamma$<br>$J/\psi$<br>e-$\mu$ coincidence | 0.04–0.3<br>0.005–0.2 |
| upgrade plan<br>(2005–) | full luminosity<br>@ $\sqrt{s}$ = 200 GeV and 500 GeV | $\gamma$–jet<br>heavy flavor<br>with displaced vertex | wider |

[1] For the full PHENIX Collaboration author list and acknowledgements, see Appendix “Collaborations” of this volume.

transverse-spin collisions. In this run (run-2), we measured single transverse-spin asymmetries ($A_N$) of neutral pions, charged hadrons, $J/\psi$'s, single-muons, *etc.* In addition, we performed many systematic studies for the future measurement of the gluon polarization. One of the important systematic studies was the measurement of the relative luminosity, and another was the development of a device to monitor polarization of beams at the PHENIX collision point, called the local polarimeter.

Beginning in run-3, we will start to probe the gluon polarization with measurements in many channels. Table 1 summarizes the physics processes which will be measured and are discussed in this article.

## SYNOPSIS OF THE RUN-2 (2001–2002)

In run-2, PHENIX was operated with both Central Arms and the South Muon Arm. First level trigger systems were developed and operational for the polarized proton run. One of them was an EM calorimeter trigger which selected high-$p_T$ particles in the Central Arms [2], and another one was a muon-identification trigger in the Muon Arm [3]. The DAQ system was upgraded to deal with high event rate in the proton run and was able to handle 1 kHz of triggers with a 70 MB/sec bandwidth.

The maximum value of the luminosity reached up to $1.5\times10^{30}$ cm$^{-2}$ sec$^{-1}$ and the integrated luminosity recorded at PHENIX was 0.15 pb$^{-1}$. The beam polarization was 14% on average in the Blue ring, 17% on average in the Yellow ring, and the maximum value achieved was 25%. This low polarization was a result of the slow ramp rate of the backup motor generator in the AGS, the use of which was necessitated by the breakdown of the primary system during run-2. Despite this, we have many $A_N$ measurements. In the Central Arms which cover mid-rapidity region ($x_F \sim 0$), we measured neutral pions [4], charged hadrons [2], $J/\psi$'s [3], *etc.* In the South Muon Arm which covers forward-rapidity region ($1.2 < \eta < 2.2$), we also measured $J/\psi$'s [3] and single-muons [5]. We have already reported cross sections of $\pi^0$ and $J/\psi$, which are vital for the systematic study to understand the detector performance for asymmetry measurements.

In addition, we performed many systematic studies for the future double longitudinal-spin asymmetry ($A_{LL}$):

$$A_{LL} = \frac{1}{P_B \cdot P_Y} \cdot \frac{N_{++} - R \cdot N_{+-}}{N_{++} + R \cdot N_{+-}}$$

where $P_B$ and $P_Y$ are the polarization of colliding beams in the RHIC rings, $N_{++}$ ($N_{+-}$) are the number of events or yields from collisions with parallel (antiparallel) beam helicity, and $R$ is ratio of the luminosities for collisions with parallel ($L_{++}$) and antiparallel ($L_{+-}$) beam helicity ($L_{++}/L_{+-}$).

In the $A_{LL}$ measurement, the relative luminosity ($R$) measurement is very important to normalize the parallel-helicity yield and the antiparallel-helicity yield. In the measurement of neutral pions and charged hadrons which will be discussed later, our goal is to measure a 0.3% level asymmetry, so we require a sub-0.1% level measurement of the relative luminosity. To meet this challenge, we made crossing-by-crossing scalers to measure the counts in four trigger detectors for each of the 120 bunch crossing at PHENIX. For this luminosity-scaler counters, we used the Beam-Beam Counter (BBC) which covers $3.0 < |\eta| < 3.9$, the Normalization Trigger Counter (NTC) which extends the rapidity coverage of the BBC, and the Zero-Degree Calorimeter (ZDC) [6] which detects neutrons at the most forward region. For the other scaler, we used the minimum-bias trigger made by the BBC and the NTC. By using these crossing-by-crossing scalers, we found the relative luminosity measurement had a 0.3% systematic error in good RHIC fills. By investigating the vertex distribution and other data for each crossing, we found that bunch-by-bunch characteristics of the RHIC beam gave rise to this systematic uncertainty. We are still investigating the relationship between this uncertainty and the accelerator parameters. To improve on this uncertainty in run-3, we plan to install an additional luminosity telescope as a fourth luminosity-scaler counter. We will also have recogging and spin-flip of the beam [7]. With this procedure, we average the bunch-by-bunch characteristics of the RHIC beam and thus anticipate a 10-times better relative luminosity measurement.

In run-2, we also developed a local polarimeter to be used at PHENIX. For the operation with the spin rotators in run-3, we need to confirm that we have longitudinal polarized protons at the PHENIX collision point. Since spin dynamics between the spin rotators is completely transparent to the rest of the accelerator, we need a local polarimeter.

To develop this polarimeter, we installed two calorimeters (one hadron calorimeter and one EM calorimeter) at a previously uninstrumented collision point (IP12) and measured $A_N$ for neutrons, photons and neutral pions at the most forward region [8]. The kinematic region, $p_T < 0.3$ GeV/$c$ and $x_F > 0.2$, was covered. Both the hadron calorimeter and the EM calorimeter showed $\sim 10\%$ asymmetry for neutrons over a wide $x_F$ region. We presently don't understand the physics process that results in this unexpectedly large asymmetry. In any case, this asymmetry gives a basis for the local polarimeter at PHENIX. We are implementing position-sensitive counters in the ZDC [6] to measure the neutron asymmetry at PHENIX. The position-sensitive counters will be comprised by 7-channel hodoscopes for both X- and Y-directions at the shower maximum position of the ZDC.

## BASELINE PLAN (2003–)

In run-3 which will start in 2003, we anticipate an integrated luminosity of about 3 pb$^{-1}$ at $\sqrt{s}$ = 200 GeV with 50% beam polarization. In this run, our main goal is to measure the double longitudinal-spin asymmetries ($A_{LL}$) for neutral pions and for charged hadrons. For the gluon polarization measurement, these channels serve as an alternative to the jet measurement in the limited acceptance. Expectation of the non-zero $A_{LL}$ measurement of neutral pions and charged hadrons is shown in Fig.1, which is compared with the GS95 NLO polarized PDF model-A [9]. When extracting the gluon polarization, all channels will be utilized.

In run-4 and beyond, we expect 10% to 100% of the design luminosity (320 pb$^{-1}$ at $\sqrt{s}$ = 200 GeV; 800 pb$^{-1}$ at $\sqrt{s}$ = 500 GeV). With the much improved statistics, we will be able to distinguish the differences between the asymmetries for neutral pions and charged hadrons. This difference of the asymmetries is caused by different species

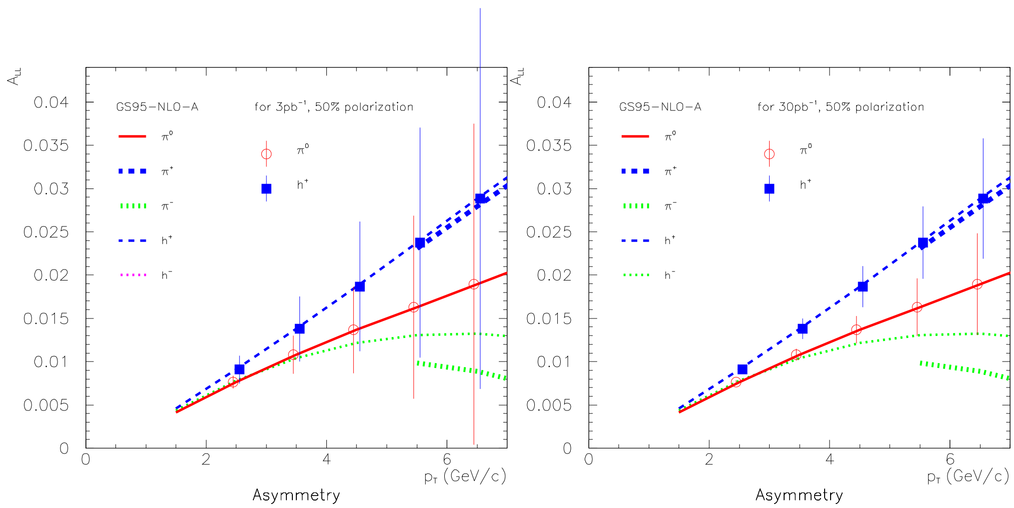


**FIGURE 1.** Expectation for the neutral pions and charged hadron $A_{LL}$ measurement in run-3 (left) and run-4 (right).

of initial quarks because the origin of $\pi^+$ is mainly u-quark, and those of $\pi^0$ and $\pi^-$ are both u-quark and d-quark. In these runs, we will start the measurement of $A_{LL}$ with prompt photons and heavy flavor (channels like single-electrons, $J/\psi$'s and the electron–muon coincidence channel [10]).

The prompt photon process is a clean channel dominated by the gluon Compton process ($gq \to \gamma q$). By measuring $A_{LL}$, we can directly factor out the gluon polarization in the leading-order. With the high performance EM calorimeters at PHENIX, we can remove backgrounds from $\pi^0$ decays effectively. Before the background reduction, we have about 10 times larger background photons in the low momentum region. After the reduction by reconstructing $\pi^0$ and applying the isolation cut, background level can be well lower than 1 [11]. This measurement will cover the $x_{gluon}$ region of 0.04 to 0.3.

By measuring heavy flavor production, the $x_{gluon}$ coverage will be extended down to 0.005. The heavy flavor is produced by the gluon fusion process ($gg \to Q\bar{Q}$). Wide region is covered by many channels complementarily. In these measurements, one of the most clean channel is the electron–muon coincidence channel. In the invariant mass plots of unlike-sign pairs and like-sign pairs, bottom pairs can be identified as high invariant mass pairs. Background is evaluated by the like-sign pairs. By this measurement, $x_{gluon}$ region 0.02 to 0.2 will be covered [10].

## UPGRADE PLAN (2005–)

We also plan to pursue the gluon polarization with upgraded detectors at full luminosity. In the full luminosity runs, we will measure $A_{LL}$ of prompt photon and heavy flavor production with higher statistics and cleaner channels. The major upgrade plan for the gluon polarization is a silicon detector upgrade. We also plan to have the Time Projection Chamber (TPC) surrounding the silicon detector. In the current strawman design, the silicon detector system consists of four layers of barrel detectors which cover $|\eta| < 1$ and almost full azimuthal angle, and four layers of endcap detectors to match with the Muon Arms.

With this detector, by identifying displaced vertices, we expect much better heavy flavor production measurement. One channel we will see is a B-meson identification with a $J/\psi$ decay which will be detected as a displaced muon-pair vertex in the endcap part and an electron-pair vertex in the barrel part. In the barrel part, we will have good displaced vertex resolution evaluated with distance of the closest approach (DCA) value smaller than 50 $\mu$m at $p_T > 1$ GeV/$c$. Another channel is a bottom pair measurement. This is an extension of the electron–muon coincidence measurement. By detecting a muon and a displaced vertex of bottom decay, we expect about thirty times larger statistics than the electron–muon coincidence measurement with the baseline detector.

The silicon detector will also serve as a tracker, which will show much better performance in combination with the TPC upgrade. By using this and the EM calorimeter, we will measure the prompt photon + jet production. This will enable us to reconstruct the kinematics of the event, pin down the $x_{gluon}$, and make the gluon polarization measurement much more sensitive and clean.

## SUMMARY

The polarized proton collision run in 2001-2002 at PHENIX was very successful. Highly selective trigger systems were developed and operational for the proton run. From these data, we have reported cross sections of $\pi^0$ and $J/\psi$, and will report the $A_N$ measurements in the near future. Studies of the relative luminosity measurement and the local polarimeter were performed as needed for the gluon polarization measurement in the next runs. We plan to measure $A_{LL}$ to probe the gluon polarization using many channels (neutral pions, charged hadrons, and single-electrons in run-3; prompt photons and heavy flavor production channels in run-4 and beyond) with both the baseline detector and the upgraded detectors.

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