Double helicity asymmetry measurements with PHENIX detector at RHIC

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Abstract. Relativistic heavy ion collider (RHIC) at Brookhaven National Laboratory (BNL) is capable of colliding high energy polarized proton beams. These collisions provide a new technique to explore and understand the origin of nucleon spin. PHENIX detector at RHIC has started making measurements of double spin asymmetries that would eventually lead to the polarized gluon distribution. We present the results from these measurements made in 2003 and 2004 and present an outlook based on the data collected in 2005.

Keywords: spin, RHIC, PHENIX, nucleon spin, polarized gluon distribution, spin puzzle.
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MEASUREMENTS WITH A POLARIZED COLLIDER

Most of what we know so far about the nucleon spin structure comes from deep inelastic scattering (DIS) experiments performed with polarized leptons scattering off polarized fixed targets [1]. This is about to change. The Relativistic Heavy Ion Collider (RHIC), shown schematically in Figure 1 with components crucial for the spin program, was commissioned in 2002 at the Brookhaven National Laboratory (BNL) [2]. It is the first collider capable of colliding *polarized* proton beams. The center of mass (CoM) energies from ~60 GeV up to 500 GeV are possible, with varying luminosities, however major operations for physics are planned at 200 GeV and 500 GeV in CoM. Each ring of the collider (at RHIC they are called the “blue” and the “yellow”) is filled with bunches of polarized protons (~10^{11}/bunch) from a chain of injectors consisting of the polarized source, the LINAC (200 MeV/c), the booster (~2 GeV/c), the alternating gradient synchrotron (AGS) (~24 GeV/c). In RHIC polarized protons have been accelerated to 100 GeV/c and collided routinely for physics measurements at Sqrt(s)=200 GeV in 2003, 2004 and 2005 (Runs 3,4,5 respectively). In future there are plans to accelerate them to 250 GeV/c. Techniques based on proton-Carbon and proton-proton elastic scattering in the coulomb nuclear interference (CNI) kinematic region are used to make measurements of beam polarization [3] in RHIC.

A polarized collider allows exquisite control over the experimental systematic uncertainties normally associated, and typically a cause of significant concern, with any spin related experiment. The principal concern always comes from “false asymmetries” of may kinds, principally, the time variation of detector performance w.r.t. the different orientations of spin directions of the probe and the target involved in scattering [4]. At RHIC, each bunch is prepared with a specific (up or down) polarization. The typical time interval between the bunch-crossings is of the order of 100s of ns. As such, all false asymmetries associated with time dependence of detector operation and efficiencies become irrelevant or negligibly small for spin asymmetry calculations. A second order effect due to uneven filling of the differently polarized bunches with polarized protons remains, but has been (Runs 3 and 4) shown to be smaller than 2×10^{-4} [5].

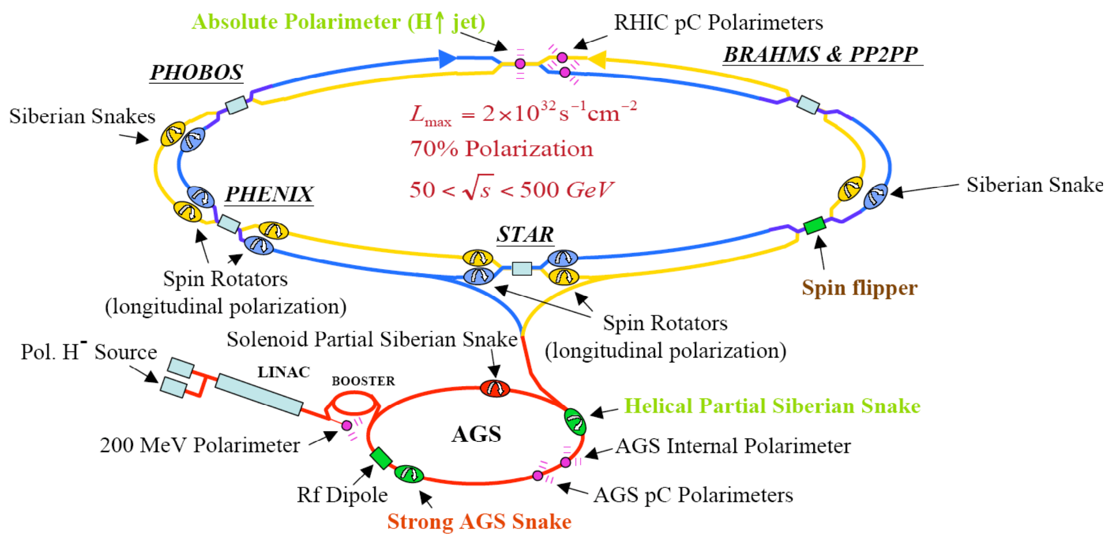

FIGURE 1: Layout of the RHIC as a polarized proton collider. Of significant importance to spin program are the components: the polarized proton source, the partial and strong AGS Siberian snakes, the AGS polarimeters, the RHIC Siberian snakes, the RHIC polarimeters (pC and hydrogen jet), and the spin rotator magnets around the PEHNIX and STAR detectors in both rings.

The spin rotator magnets (SRM) located on both sides of the experiment rotate (turn) the vertically oriented proton spins to longitudinal before the beam enters the experimental area, and turn them back to vertical orientation before the proton beams leave the experimental area. As such depending on whether these magnets are on or off, the experiments pursue programs of single or double longitudinal (helicity) asymmetry measurement or single and double transverse spin asymmetries.

The first stage of the RHIC Spin program witl CoM collisions at 200 GeV has started producing results. The first measurements of double spin asymmetry in RHIC will be discussed in this paper. Measurement of polarized gluon distribution is one of the major goals of the RHIC spin program [6]; the others being a) polarized quark and anti-quark distributions, separated by their flavor, using parity violating W boson production in polarized pp scattering and b) exploration of transverse spin effects in the nucleon [6,7].

In the present paper we present the results on the double spin asymmetry A_{LL} for inclusive π^0 production in longitudinally polarized protons-proton collisions corresponding to 0.22 nb^{-1} in Run-3 (2003) [5] and 0.75 nb^{-1} in Run-4 (2004) integrated with the PHENIX detector. The PHENIX experiment has reported the unpolarized cross section for π^0 production at mid-rapidity [8] for p_T = 1-14 GeV/c, which is described extremely well by the next-to-leading-order perturbative QCD (NLO pQCD) calculations over eight orders of magnitude. This becomes the basis on which we believe that the measured asymmetries will be interpretable in terms of polarized gluon distribution in the pQCD formalism.

THE PHENIX DETECTOR

The PHENIX detector [9] at RHIC is one of the two large collider detectors at RHIC used for the study of both, the heavy ion and polarized proton-proton collision studies. The design philosophy of PHENIX, dictated initially & mainly by the study of heavy ion collisions, was to emphasize high resolution measurements of electromagnetic final states and remnants of heavy ion collisions at the cost of not having full acceptance. With minimal additions to the original plan, the detector was made suitable for spin physics measurements. The design focuses on measurements of rare events in high rate environment, and as such, has highly efficient trigger. The experimental acceptance of PHENIX broadly divided in to two: 1) the central spectrometer coupled with fine grained electromagnetic calorimetry, tracking chambers and excellent particle identification devices, and 2) forward and backward muon spectrometers. The central spectrometer covers a pseudo rapidity region of –0.35 to 0.35 and an approximate azimuthal coverage of -45^o to $+45^o$ w.r.t. the horizontal plane on both sides (east and west) of the beams. It consists of a central spectrometer magnet, Time of Flight (TOF) detectors, Pad Chambers (PC), Drift Chamber (DC), Ring Imaging Cerenkov Counter (RICH), Lead Glass(PbGl) and Lead Scintillator (PbSc). The forward and backward muon spectrometers consist of a radial field north and south muon tracking magnets backed by muon identification systems. The muon spectrometer and mu-ID system cover 2π in azimuthal acceptance and an η range of 1.2 to 2.4. In addition to these specialized detector systems, there exist two global detector systems: the Beam-Beam Counters (BBC) covers 2π acceptance in azimuth and 2.8 to 3.2 in η, and a Zero Degree Calorimeter (ZDC) at the end of the interaction region, between the two beam pipes when they separate and accepts neutrons scattered in the region +/- 2 mrad. The global detectors were designed for multiplicity measurements. The BBCs are used as collision counters and the ZDCs are used to catch the neutrons produced or released in the collisions. In heavy ion collisions the combination of BBC and ZDC hit multiplicity comparison is used to judge the centrality of nuclear collisions, while in polarized proton-proton collisions, the ratio of hits in the two as a function of bunch number indicates the relative luminosity uncertainties we may have in our double asymmetry calculation. The ZDC along with a Shower Max Detector (SMD) is also used as a local polarimeter to monitor the direction of the spin vector of the colliding proton bunches in the experimental area [10].

THE DOUBLE SPIN ASYMMETRY A_{LL} IN π^0 PRODUCTION

In perturbative QCD A_{LL} in π^0 production is directly sensitive to the polarized gluon distribution function in the proton through gluon-gluon and gluon-quark scattering sub-processes [11]. The double spin asymmetry in π^0 production is given by

$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}}$$

where σ_{++} and σ_{+-} are the cross sections of this reaction when the two colliding particles have the same and opposite helicity, respectively (neglecting parity violating difference in the cross sections between (++) and (--) and (+-) and (-+) beam helicity configurations). This can also be written as,

$$A_{LL} = \frac{1}{P_{blue} \cdot P_{yellow}} \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}}; \qquad R = \frac{L_{++}}{L_{+-}}$$

where $P_{yellow/blue}$ are the beam polarizations and R is the ratio of luminosities of the protons colliding with like (++) to unlike(+-) helicities.

The analysis presented in the paper of the double spin asymmetry inπ^0 production will use the multiplicity in BBC, the ZDC for relative luminosity issues, and the central arm calorimeters for identification of π^0 event selection. The run 3 results of double spin asymmetry in π^0 production have already been published [5]. We calculate the A_{LL} in the two-photon invariant mass range of +/- 25 MeV around the π^0 mass peak. We define this region as signal. Then correct for the A_{LL} of the background to extract the $A_{LL}(\pi^0)$:

$$A_{LL}(\pi^0) = \frac{A_{LL}^{raw} - rA_{LL}^{BG}}{1-r}; \quad \Delta A_{LL}(\pi^0) = \frac{\sqrt{(\Delta A_{LL}^{raw})^2 + r^2(\Delta A - LL^{BG})^2}}{1-r}$$

where r is the fraction of the background in the signal region of $M_{\gamma\gamma}$. The measurements were performed in p_T range 1-5 GeV/c separated in 4 bins (1-2, 2-3,3-4 and 4-5 GeV/c). The background constituted 31%, 13%, 7% and 5% fraction of the total number of events seen in each of the p_T bins.

The uncorrelated bunch-to-bunch or fill-to-fill systematic uncertainty in A_{LL} was evaluated using the "bunch-shuffling" method. In this we assign random polarization orientation to the beam bunches and evaluate the double spin asymmetries. We repeat this exercise multiple number of times and see the results of the center and the width of distributions of asymmetries. Bunch spin shuffling should result in a zero asymmetry, and the width of the distribution should be smaller or equal to the statistical uncertainty estimated in the asymmetry. Either of these conditions not being satisfied indicates problems with the asymmetry measurement, systematic in nature, that would need more attention. In our case no such effort was needed. All systematic sources of uncertainty estimated were significantly smaller than the statistical ones.

RESULTS

Figure 2 shows the combined Run-3 and Run-4 results for π^0 asymmetry result and their statistical uncertainties. The curves shown along with the data points are calculations of A_{LL} vs. p_T for next to leading order perturbative QCD fits performed on the polarized deep inelastic scattering data [12]. The GRSV-best corresponds to the best-fit gluon distribution from such an exercise and corresponds to $\int_0^1 \Delta g(x)dx = 0.7$ at Q^2=1 GeV^2. The GRSV-max corresponds to a hypothesis by the authors that the maximum value the polarized gluon density ΔG can take is that of the unpolarized gluon G itself. The NLO pQCD fits to the DIS data are unable to distinguish between the best fit and maximal gluon distribution scenarios [13].

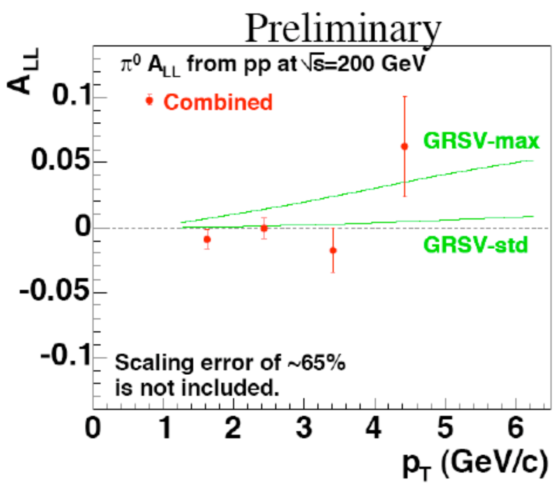

FIGURE 2 The PHENIX measurement of double spin asymmetry in π^0 production in polarized pp collisions from Run-3 and Run-4. The data are combined data sets weighted by the statistical errors of the two measurements. The theoretical curves of GRSV-std and GRSV-max are evaluated from the best fit at NLO to the world sample of DIS data from polarized fixed target experiments.

DISCUSSION OF RESULT & OUTLOOK

The data are consistent with ΔG=0 and also with GRSV-std curve with about 20-25% confidence level. Compared with this, the GRSV-max curve is inconsistent with the data with a χ^2 confidence level of ~0.2-1%. While one is inclined to infer that the larger value of ΔG is ruled out, presently we do not do that. The main reason being the uncertainties of theoretical nature (uncertainty due to scale variation in the GRSV NLO pQCD analysis, those due to the variation of α_S, the assumptions of the low x behavior of the spin structure functions) have not been included in this analysis. We feel the statistical uncertainty so far is too large to be concerned with these issues for the moment. We also note that the uncertainties due to experimental systematic such as the beam polarization measurement are also large, 65% at the time of release of these data. They consist mainly of the unknown absolute calibration of the p-Carbon CNI polarimeter. As this paper goes to print, this has been reduced to 20% [3]. These uncertainties are scale uncertainties which do not affect the *statistical significance* of any of the data points shown.

RHIC Run-5 recently ended. Compared to the data presented in this paper, an improvement of the order of ~30-50 in the figure of merit has been achieved, due to significantly enhanced beam polarization (average 26% and 39% in run Runs 3 and 4 increased to average 50% in Run-5) and a larger statistical sample (~350 nb^{-1} in Runs 3&4 compared to 3.6 pb^{-1} in Run-5). PHENIX expects to make the first definitive measurement of the $\Delta G/G$ in the accessible kinematic region using this method.

In Run-6, a cold super conducting Siberian Snake, recently installed in AGS is expected to be operational for physics. This is the last hardware related to the RHIC Spin program to go in, and is expected to boost the beam polarization in AGS (and hence in to RHIC) to above 60%. It is also expected to improve the beam aperture in to the RHIC and hence the beam intensity in to RHIC, allowing higher luminosity collisions in RHIC. The two together, with reasonably long polarized proton runs will allow measurements of polarized gluon distribution using rarer probes of polarized gluon distribution in pp collisions in the next few years.

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