Spin Physics at RHIC

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Abstract. The physics goals that will be addressed by colliding polarized protons at the Relativistic Heavy Ion Collider (RHIC) are described. The RHIC spin program provides a new generation of experiments that will unfold the quark, anti-quark and gluon contributions to the proton’s spin. In addition to these longer term goals, this paper describes what was learned from the first polarized proton collisions at $\sqrt{s}=200$ GeV. These collisions took place in a five-week run during the second year of RHIC operation.

I. INTRODUCTION

The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory was built to study the collisions of heavy ions having energies up to 100 GeV/nucleon. The physics goal of these studies is to find a new state of matter where quarks and gluons are not confined in hadrons. PHENIX and STAR are two large experiments and PHOBOS and BRAHMS are two small experiments designed to study relativistic heavy ion collisions at RHIC. Details about these detectors can be found in Ref. [1].

In addition to having the capability to produce heavy ion collisions at energies up to $\sqrt{s_{NN}} = 200$ GeV, RHIC is the first high-energy accelerator designed to allow the acceleration, storage and collisions of polarized proton beams with center of mass energies up to $\sqrt{s} = 500$ GeV. Helical dipole magnets in each ring serve as ‘Siberian Snakes’ that help preserve the beam’s polarization during acceleration and storage [2]. A pair of Siberian Snake magnets in each ring make the vertical direction the stable spin axis. These magnets were commissioned during RHIC run 2 to provide collisions of transversely polarized protons at $\sqrt{s}=200$ GeV. Spin rotator magnets positioned on either side of the STAR and PHENIX interaction regions will permit future studies with longitudinally polarized proton beams. Final preparations of the PHENIX and STAR detectors for the study of high-energy polarized proton collisions will soon be completed. In addition, the PP2PP experiment is being built to study the elastic scattering of polarized proton beams at RHIC.

This paper briefly describes the long-term physics goals of the RHIC spin program. These goals have been described in a recent review [3]. What is new in this area is the first collisions of polarized protons at RHIC. This paper provides a description of what was learned from the first RHIC run producing collisions of polarized protons. Many details about the run were described in parallel session talks at SPIN 2002. This overview serves as a roadmap to these more detailed descriptions.
II. PHYSICS GOALS OF THE RHIC SPIN PROGRAM

The RHIC spin program aims to unravel the spin structure of the proton. Understanding how the valence quarks, gluons and sea quark-antiquark pairs conspire to produce the spin of the proton is equally as important as understanding how these constituents produce the proton’s mass. The quark contribution ($\frac{1}{2} \Delta \Sigma$), the gluon contribution ($\Delta G$) and possible orbital angular momentum of the proton’s constituents must sum to the proton spin of $\frac{1}{2}$. To date, spin structure studies have relied on deep inelastic scattering (DIS) of charged leptons as was reviewed at this Symposium [4, 5]. The contribution quarks make to the overall spin of the proton has been found to be substantially smaller than expected ($\Delta \Sigma = 0.23 \pm 0.04 \pm 0.06$). Polarization of the gluons that bind the quarks and/or orbital angular momentum of the proton’s constituents must carry the rest. Since gluons carry no electric charge, real or virtual photons only probe the gluon through its splitting into $q\bar{q}$ pairs. Use of this photon-gluon fusion process provides a means of establishing the gluon contribution to the proton’s spin that is being actively pursued by the COMPASS experiment at CERN [6] and is a planned pursuit at SLAC [7]. COMPASS aims to probe gluon polarization by detecting $D$ mesons from $\gamma g \to c\bar{c}$ interactions employing a polarized $\mu$ beam and a polarized target. One of the goals of the RHIC spin program is to utilize the color charge of the quarks to couple directly to the gluon field within the proton. Existing measurements of quark polarization from DIS experiments enable the use of quarks as an ‘analyzer’ of gluon polarization in $pp$ collisions, particularly for final states where a large transverse momentum ($p_T$) photon is produced. Gluon polarization will be probed at RHIC by measurements of longitudinal double spin asymmetries ($A_{LL}$).

High energy collisions of protons produce hadronic jets, photons, vector bosons ($W, Z, \gamma$) and other particles having large $p_T$ or large mass. From studies at unpolarized hadron colliders, it is known that perturbative QCD can provide quantitative predictions of the cross sections for such processes, particularly when next-to-leading order (NLO) contributions are included. Extending these phenomenological analyses to include spin degrees of freedom leads to the expectation that pQCD will provide a quantitative framework to interpret spin observables for jets, photons, and other particles produced in polarized proton collisions.

As previously described [8], the ‘golden probe’ of gluon polarization at RHIC will be photon production in longitudinally polarized proton collisions. It is expected that the QCD Compton process ($qg \to q\gamma$) will be the dominant source of photons, with physics backgrounds arising from fragmentation photons and the $q\bar{q} \to \gamma g$ process, the latter process corresponding to time-reversed photon-gluon fusion. Experimentally, photon production is challenging because the total cross section is small relative to prolific sources of photons from neutral meson decays. Simulations for both PHENIX and STAR have demonstrated that these backgrounds can be minimized. Coincident detection of the away-side jet with the prompt photon can provide information about the Bjorken $x$ values of the initial-state interacting partons. Recent results from the Tevatron [9] suggest that NLO pQCD can provide a quantitative description of photon production cross sections.

The production of $W$ bosons in the collision of longitudinally polarized protons is expected to result in spectacularly large parity violation. As in charged current weak interactions that gives rise to the flavor sensitivity to neutrino deep inelastic scatter-
ing, parity violating spin asymmetries for $W$ production in $pp$ collisions will isolate valence quark ($\Delta u = u; \Delta d = d$) and sea anti-quark ($\Delta \bar{u} = \bar{u}; \Delta \bar{d} = \bar{d}$) polarizations [10]. Utilization of the electroweak interaction is expected to be a more precise measure of these polarizations than semi-inclusive DIS experiments that are presently underway. Imprecise knowledge of fragmentation functions is a dominant systematic error for semi-inclusive DIS studies.

The collision of transversely polarized proton beams can be used to study the transversity structure function. Although this is a twist-2 function of equal importance as the longitudinal spin distribution functions ($\Delta q(x)$, $\Delta \bar{q}(x)$ and $\Delta G(x)$) for understanding the proton’s spin structure, transversity cannot be probed in inclusive DIS because of helicity conservation. Transverse spin asymmetry measurements at RHIC are expected to shed light on the transversity structure functions and should provide a timely complement to new measurements of transverse spin effects in semi-inclusive DIS [5] and in jet studies from $e^+e^-$ collisions [11].

The development of the RHIC accelerator complex to produce polarized proton collisions with a luminosity of $0.8(2) \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$ at $\sqrt{s}=200(500) \text{ GeV}$ and with beam polarizations of 70% will be required to attain these long term physics goals. Completion and full development of the PHENIX and STAR experiments is also required. Intermediate physics goals can be attained in the first RHIC spin runs, providing an understanding of how to reach the requisite precision to measure small spin effects in the collider environment while providing the first glimpses of the proton’s spin structure probed in high-energy polarized proton collisions.

III. SPIN ASYMMETRY MEASUREMENTS IN A COLLIDER

A collider has significant differences, both advantageous and potentially problematic, from traditional fixed target experiments that severely impact the measurement of spin observables. One positive aspect is that in a collider polarization reversals occur at the bunch crossing frequency. For RHIC run 2, the inverse of this frequency was 214 nsec. This is expected to be reduced to 107 nsec in subsequent runs. These time scales are very short compared to most sources of time dependent variations in a detector’s response, such as gain drifts, thereby reducing sensitivity to this class of systematic errors. Rapid polarization reversals place stringent demands on timing of detector signals to preserve the correct association of events with the polarization state of the beams. The detector response must also be minimal to backgrounds which are not associated with the passing beams. Out-of-time background events effectively obtain random polarization assignments.

One significant challenge that is presented by collider experiments is the possibility of accidental correlation between polarization directions and luminosity of the colliding beams. This correlation can arise because each ring is injected with individual bunches of protons with particular polarization orientations. An injection pattern is chosen so that in one ring (Yellow) alternating bunches have opposite polarization direction and the other ring (Blue) has bunch pairs with alternating polarization (Fig. [1]). Due to the potential correlation between luminosity and polarization, accurate measurement
FIGURE 1. STAR data from a bunch crossing scaler system with input from a beam-beam counter coincidence [12] providing a measure of luminosity. There are two groups of five bunch crossings with few counts, corresponding to the ‘abort gaps’ (RF cycles with no beam) in the Blue and Yellow rings. Counts in the abort gaps arise from single beam backgrounds. The pattern of polarization directions for the Blue and Yellow beams at STAR is also shown. The non-uniformity of the yield versus bunch number produces differences in the relative luminosity for different polarization directions.

of the relative luminosity of bunch crossings with different polarization directions is required. This is accomplished by counting experiments using fast detectors capable of discriminating collisions from beam-related backgrounds. An example from RHIC run 2 is shown in Fig. 1, with more details described in Ref. [12]. Methods are being developed to average out any relationship between intensity and polarization by reversing the spins of the stored beams and by recogging the beams so that different bunches collide.

When measuring transverse single spin asymmetries, an azimuthally symmetric detector configuration can be used to measure spin-dependent cross ratios (spin up/down yields with left/right detectors), thereby making detector acceptance and luminosity asymmetries higher order corrections [13]. For observables involving longitudinal polarization there is no spin-dependent modulation of scattering rates that varies harmonically with the azimuthal angle. Hence, accurate measurements must be made to prevent the relative luminosity determination from being a limiting systematic error of future $A_{LL}$ measurements. The large cross section reactions needed for high rate relative luminosity monitors must themselves have minimal longitudinal double spin asymmetries. Identifying suitable monitoring reactions is one of the primary goals for RHIC run 3 when longitudinally polarized proton collisions are planned for the PHENIX and STAR experiments.

It is planned to develop an AC dipole that will efficiently reverse the polarization of the stored beam [14]. This tool, used in conjunction with changes in which beam
bunches overlap (recogging), will be fully developed in subsequent RHIC runs. These developments are expected to further reduce spin dependent relative luminosity as a major source of systematic error for spin asymmetry measurements.

Backgrounds in a collider also differ in important ways from those for fixed target experiments. One difference between the two environments is that there are two beams in a collider, traveling in opposite directions, that can lead to twice the background. As with the spin information, timing plays a critical role in discriminating signals from collisions versus those from backgrounds. Time differences between counters mounted fore and aft of the interaction region can be used to identify collisions relative to beam-related backgrounds.

IV. FIRST POLARIZED PROTON COLLISIONS

The first collisions of transversely polarized protons occurred during RHIC run 2 in the period from early December, 2001 to late January, 2002. The first three weeks of this run were dedicated to accelerator commissioning, with a particular focus on commissioning the ‘Siberian Snake’ magnet pairs in each ring. Officially, data taking for $\sqrt{s}=200$ GeV \(pp\) collisions began on December 20\(^{th}\), initially at low luminosity. Two weeks into the run, the average luminosity increased to \(0.5 \times 10^{30}\) cm\(^{-2}\) s\(^{-1}\), and stayed at that value until the end of the run. Knowledge of the beam polarization is subject to the caveats discussed below.

The RHIC polarimeters detect low-energy recoil carbon ions produced by $p+^{12}$C elastic scattering reactions at small $\vec{q}$, where the Coulomb scattering amplitude is comparable in magnitude to the strong-interaction amplitude. Details about the design [15] and performance [16] of these Coulomb-Nuclear Interference (CNI) polarimeters were described at this conference. At present, the effective analyzing power of the CNI polarimeters is measured only near the injection energy [17]. Ultimately, these polarimeters will be calibrated by determining the beam polarization from proton elastic scattering from a polarized hydrogen gas jet target, effectively transferring knowledge of the target polarization to provide knowledge of the beam polarization. The first opportunity to make these measurements will occur during RHIC run 4. Prior to that, the effective analyzing power of the CNI polarimeter can only be determined by special stores in RHIC involving an acceleration ramp followed by a deceleration ramp. Measurements with the CNI polarimeter at the injection energy, flattop energy and then again at the injection energy can transfer the calibration of the polarimeter effective analyzing power to high energy, if there is found to be minimal polarization loss in both ramps. Deceleration ramps were attempted during RHIC run 2, but were unsuccessful because of beam loss during deceleration. Continuation of this development is planned for run 3.

For RHIC run 2, knowledge of the magnitude of the beam polarization at the collision energy results from the assumption that the effective analyzing power of the CNI polarimeter does not depend on energy. Model calculations suggest only a small increase in the effective analyzing power with increasing energy [18]. Based on the assumption that the effective analyzing power is independent of beam energy, the beam polarization at the collision energy averaged 17% in the Yellow ring and 13% in the Blue ring.
over the last two weeks of the run, with the difference reflecting subtle effects in the acceleration ramps of the two rings. The ratio of the measured CNI polarimeter spin asymmetries at the collision energy to those at the injection energy for a given RHIC fill was on average smaller than unity. Hence, the measured asymmetries at 100 GeV set an upper limit on the beam polarization at the collision energy, since acceleration is highly unlikely to increase the beam polarization. The polarization magnitude was limited by the AGS, the last accelerator in the chain used to inject the RHIC rings. Failure of the AGS power source necessitated use of a less powerful backup, resulting in a slower acceleration cycle, thereby reducing the polarization.

The physics goals of the first polarized proton collisions at $\sqrt{s} = 200$ GeV included:

- the measurement of unpolarized observables to provide the requisite $pp$ reference data for the RHIC heavy-ion program,
- commissioning of the accelerator complex for polarized proton collisions,
- making the first measurements of spin asymmetries in a polarized proton collider,
- identifying reactions that will provide the basis for local polarimeters in subsequent runs which utilize the spin rotator magnets, and
FIGURE 3. STAR results for azimuthal angle correlations between high $p_T$ charged hadrons produced in $p+p$ collisions at $\sqrt{s}=200$ GeV [23]. The correlations are between a trigger particle with $4 < p_T^{\text{trig}} < 6$ GeV/c and associated particles with $2$ GeV/c $< p_T < p_T^{\text{trig}}$. Both the near side ($\Delta \phi = 0$) and away side ($\Delta \phi \neq 0$) correlations are consistent with expectations from jet and dijet events.

- commissioning of the PP2PP Roman pots for the study of proton elastic scattering at small $\Delta \phi$

These goals represent important benchmarks of progress to both the RHIC spin program and the RHIC heavy-ion program. As is evident in the following description, these goals were met in the first polarized proton collision run.

**IV.a Unpolarized proton observables**

Many of the results for unpolarized $pp$ collision observables were reported at the recent Quark Matter 2002 conference [19]. Minimum bias data samples were recorded at all RHIC experiments. High $p_T$ triggers based on the central arm electromagnetic calorimeters (EMC) enabled PHENIX to obtain the $p_T$ variation of mid-rapidity $\pi^0$ production out to 12 GeV/c (Fig. 2). These data are compared with next-to-leading order pQCD calculations, and agree with the calculations over an impressive eight orders of magnitude [20]. This good agreement between data and theory bodes well for using pQCD to interpret spin observables at RHIC energies. PHENIX was also able to measure $J=0$ production cross sections in their central detector arms by detecting $e^+e^-$ coincidences and in their south muon arm by detecting $\mu^+\mu^-$ coincidences [21]. Polarization observables for open charm production in $pp$ collisions is anticipated to be another important channel for studying gluon polarization. PHENIX plans to commission their north muon arm during RHIC run 3, thereby completing the baseline detector.

STAR obtained a significant $pp$ minimum bias data sample that will provide critical reference data for its heavy-ion program. The relatively low luminosity for the first polarized proton collisions minimizes the influence of ‘pile-up’ background in the STAR time projection chamber (TPC). In future years, higher luminosity $pp$ collisions will require sophisticated offline analysis algorithms to discriminate charged particle tracks associated with the triggered event from pileup tracks that are produced in the
FIGURE 4. Results from PP2PP obtained during a single RHIC fill with reduced emittance and special focusing to permit positioning their Roman pots close to the beam. The left (right) figure shows the horizontal (vertical) position correlation for events detected in silicon detectors mounted in the Blue and Yellow rings either side of the interaction point. Elastic scattering events from $pp$ collisions can be cleanly identified.

bunch crossings before or after the triggered event. Even with only a minimum bias trigger, STAR embarked on its program of jet physics, exploiting the complete azimuthal coverage of the TPC for $\eta < 1$. As shown in Fig. 3, evidence for jet and di-jet events was obtained from di-hadron correlation studies [22]. Cone and $k_T$ jet reconstruction algorithms are presently being applied to the reconstructed TPC tracks for charged particles. The results from these analyses are qualitatively consistent with expectations. Quantitative results for jet yields and correlations require detailed understanding of the TPC efficiency. With the commissioning of the half barrel EMC ($2\pi$ azimuthal coverage for $0 < \eta < 1$) in RHIC run 3, STAR will be able to trigger on and fully reconstruct jets. Complete coverage from the barrel EMC ($1 < \eta < 1 + 1$), and the coverage from the endcap EMC ($1 + 1 < \eta < 2$), will be added for subsequent runs. Jet physics is an important component of the STAR spin physics program.

RHIC run 2 also saw the commissioning of the PP2PP experiment. Their goal is to measure proton elastic scattering cross sections and spin observables for polarized proton collisions at $s=200$ and 500 GeV. The experiment utilizes ‘Roman pots’ to place silicon detectors close to the beams, observing the elastically scattered protons in coincidence. The emphasis is on measuring the $j_T$ dependence for elastic scattering in the vicinity of the maximal interference between the Coulomb and strong interaction amplitudes. Elastic scattering events were observed [23] during the commissioning run in a dedicated store where the beams were scraped to reduce their emittance (Fig. 4). Further runs are planned in RHIC run 3, and beyond, to attain the goals of the physics program.
FIGURE 5. Results from the PHENIX spin group for the analyzing power for forward neutron production. Shown in the figure are the measured spin-dependent asymmetries scaled by the Blue ring beam polarization, assuming the effective analyzing power of the CNI polarimeter does not depend on energy.

IV.b First spin asymmetry measurements and local polarimetry

A suitable context for understanding the first polarized proton collisions at RHIC, which used transverse polarization, is the E-704 experiment at Fermi National Laboratory. Prior to RHIC, E-704 studied polarized proton interactions at the highest $\sqrt{s}$. E-704 was a fixed target experiment using a high-energy polarized proton beam produced by hyperon decay, resulting in polarized proton interactions at $\sqrt{s}=20$ GeV, an order of magnitude lower than the first RHIC spin run. Large analyzing powers, increasing in magnitude as Feynman $x$ increases beyond $x_F = 0.3$, were found by E-704 for both charged [24] and neutral pion [25] production at moderate $p_T$. At mid-rapidity, analyzing powers were found to be consistent with zero. Theoretical models that aimed to understand the E-704 analyzing powers generally predicted similar trends at RHIC energies, even though they attributed the large Feynman $x$ analyzing powers to different dynamics.

The E-704 results motivated two separate large $x_F$ measurements during RHIC run 2. The goal of both of these measurements was to observe reactions with large analyzing powers that could provide the basis for local polarimeters at the PHENIX and STAR experiments. Spin rotator magnets will be used during RHIC run 3 to produce nominally longitudinal beam polarization at PHENIX and STAR. Local polarimeters sensitive to either remnant vertical or radial polarization components are required to properly tune the spin rotator magnets. Space constraints at PHENIX and STAR differ, implying that different techniques for local polarimetry are likely to be needed.

One experiment was conducted at interaction point 12 (IP12) in the RHIC ring by members of the PHENIX spin group [26]. They designed and constructed a calorimeter consisting of a 5 (horizontal) $\times$ 12 (vertical) matrix of PbWO$_4$ detectors that was positioned 18 meters distant from the interaction point immediately following the DX magnet east of IP12, and hence sensitive to spin effects from collisions associated with
the polarization direction of the proton beam in the Blue ring. The objective was to be sensitive to possible analyzing powers associated with large $x_F$ $\gamma$ or $\pi^0$ production. The geometry of their calorimeter implied that 50 GeV energy deposition corresponded to a maximum $p_T$ of 150 MeV/c. The experiment could discriminate incident $\gamma$ and neutrons by use of counters that were located in front of and behind the calorimeter. Through the course of the run, a portion of a Zero Degree neutron Calorimeter (ZDC) module was installed west of IP12, again 18 meters distant from the interaction point, to confirm results that were obtained from analysis of the data during the run.

The conclusion from this experiment (Fig. 5) is that there are sizable analyzing powers for low $p_T$ neutron production in polarized proton collisions at $\sqrt{s} = 200$ GeV. These results will serve as the basis of local polarimetry at the PHENIX experiment in RHIC run 3 by equipping the ZDC’s fore and aft of PHENIX with position sensitive shower maximum detectors.

At STAR, electromagnetic calorimeters were mounted upstream of the DX magnet in close proximity to the beam pipe and 7.5 meters distant from the STAR interaction point [27]. A Pb-scintillator sampling calorimeter, equipped with a two orthogonal planes of scintillator strips serving as a position-sensitive shower maximum detector was mounted north of the beam. Simple 4 $\times$ 4 matrices of lead glass detectors were mounted in three locations, directly south of and above and below the beam pipe. Since the calorimeters were mounted east of STAR, they were sensitive to spin effects from collisions associated with the polarization direction of the proton beam in the Yellow ring. The calorimeter mounted north of the beam was able to identify neutral pions with good invariant mass resolution, and was sensitive to transverse momenta in the range, $1 < p_T < 4$ GeV/c.

The conclusion from the STAR measurement is that forward neutral pion production at RHIC energies has large analyzing powers that increase with increasing Feynman $x$. The results at $\sqrt{s} = 200$ GeV (Fig. 3) bear a strong similarity to the E-704 results [25] and to theoretical predictions based on the lower energy data. Given that the effective analyzing power of the CNI polarimeter is measured only at the RHIC injection energy, these results are lower limits on the $\pi^0$ analyzing power at $\sqrt{s} = 200$ GeV. Attempts are underway to equip STAR with electromagnetic calorimetry mounted at large pseudorapidity as a more permanent Forward $\pi^0$ Detector (FPD). The new FPD will enable further study of the Feynman $x$ and $p_T$ dependence of analyzing powers for forward $\pi^0$ production, and can also serve as a local polarimeter for the tuning of the spin rotator magnets.

In addition to these two experiments aimed at identifying local polarimeters for the future, analyzing powers for particle production at mid-rapidity will result from RHIC run 2. STAR reported the analyzing power for leading charged particles at mid-rapidity out to $p_T = 5$ GeV/c [31]. As expected by naive pQCD, $A_N$ is found to be zero at mid-rapidity. PHENIX will ultimately be able to make quantitative statements to much higher $p_T$ from their mid-rapidity neutral pion and charged hadron data.

In summary, the polarized proton run at $\sqrt{s} = 200$ GeV during RHIC run 2 accomplished important goals, including:

- measurement of mid-rapidity particle production cross sections over a broad range of $p_T$. These measurements are well described by NLO pQCD, which bodes well
FIGURE 6. STAR results for the analyzing power for events dominated by $\pi^0$ production at large pseudorapidity ($3 < \eta < 4$). The data are compared to calculations available prior to the measurement. Ref. [28] is based on the Collins effect, corresponding to a spin dependent fragmentation. Ref. [29] is based on a twist-3 quark-gluon correlation responsible for the spin effect evaluated at $p_T = 1.5$ GeV/c. Ref. [30] is based on the Sivers effect, where the spin effects arise from a correlation between the quark spin and its transverse momentum in the distribution function.

For future RHIC studies of the spin structure of the proton,

- the clear observation of jet events in $pp$ collisions. Jet production and $\gamma + \text{jet}$ coincidences for longitudinally polarized proton collisions will be a primary means of establishing gluon polarization,

- the observation of $pp$ elastic scattering collisions. Only small backgrounds are observed in silicon detectors placed close to the beams, thereby demonstrating that RHIC is a well controlled accelerator providing a clean environment for studying $pp$ elastic scattering for colliding beams in the CNI regime (small $j_t$), and

- the observation of large spin asymmetries in the collision of transversely polarized protons. These measurements demonstrate proper handling of the spin labeling of bunches and matching with the RHIC polarimeter results. The reactions that give rise to these large analyzing powers will be used as local polarimeters at PHENIX and STAR in future runs, and themselves represent important transverse spin physics results.

Low polarization from the AGS is an important issue that must be addressed in future RHIC spin runs. New polarimeter and accelerator hardware are expected to increase the polarization of beams stored in RHIC.
Spin rotator magnets have now been installed at the PHENIX and STAR experiments and will be commissioned during RHIC run 3. These magnets will precess the proton beam’s polarization from the vertical stable spin direction set by the two helical dipole Siberian Snakes in each ring, to longitudinal at the interaction points of these two experiments, and then back again. Tuning the spin rotator magnets requires robust local polarimetry to establish that vertical and radial polarization components are small. The analyzing power results from RHIC run 2 should provide the requisite feedback for this important development work. In addition to this development, the luminosity for polarized proton collisions in RHIC run 3 is projected to be $10^{31} \text{cm}^{-2}\text{s}^{-1}$ by using a tighter focus ($\beta = 1$ m) and by increasing the number of bunches in the Blue and Yellow ring from 55 to 110. The high-power generator is expected to be repaired and used for the AGS. The projected beam polarization for RHIC run 3 is 40%, with a goal of further improvements on that value. Polarized proton collisions will be at $p_{T} = 200 \text{GeV}$ for run 3.

With longitudinal polarization for both proton beams, and the projected improvement in the polarized beam operation of the AGS injector to RHIC, it should be possible to embark on the first measurements of $A_{LL}$ for mid-rapidity $\pi^0$ production at PHENIX and for mid-rapidity $(0 \quad \eta \quad 1)$ jet production at STAR (Fig. 7). Projections for the integrated luminosity and the beam polarization for polarized beam operations in RHIC run 3 suggest sufficient statistical sensitivity to discriminate extreme scenarios for the degree to which gluons are polarized within the proton. Systematic errors need to be sufficiently controlled to provide robust measurements of $A_{LL}$. Careful relative luminosity measurements for bunch crossings with equal and opposite longitudinal polarizations are required as is an absolute calibration of the analyzing power of the RHIC polarimeter for proton beam energy of 100 GeV.
Looking beyond RHIC run 3, there are several accelerator and detector developments on the horizon:

- Polarized beams will be accelerated to 250 GeV to allow collisions at $p^+p^-=500$ GeV. The highest collision energies are important for determining gluon polarization at small $x$ and necessary for studying spin asymmetries for $W$ production.
- The polarized hydrogen gas jet target is expected to be first available for RHIC run 4. This will ultimately provide a robust means of determining the beam polarization with a projected accuracy of 5% expected to be attained during RHIC run 5.
- Improvements in the AGS polarization are expected for runs 4 and 5, leading to the goal of 70% polarization for the beams stored in RHIC. A new fast polarimeter, based on the RHIC CNI polarimeter, has been built for the AGS for run 3, and several new hardware improvements are being considered for the AGS for runs 4 and 5. These include a strong partial Siberian Snake, expected to be available for run 5.
- The STAR barrel and endcap electromagnetic calorimeters will be completed and commissioned for RHIC run 5. These calorimeters provide $2\pi$ azimuthal coverage for the pseudorapidity interval $1 < \eta < 2$, playing a crucial role in spin physics measurements involving jets, photons and high-energy electrons and positrons.
- Upgrades to PHENIX are planned to improve triggering capabilities for the muon arms required to fully exploit their $W$ physics program. There are also plans to improve their mid-rapidity charged particle tracking. The latter will enhance jet reconstruction capabilities at PHENIX.

The success of the first polarized proton collision run upholds the promise that the RHIC spin program will provide important new insight to the spin structure of the proton.

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