RHIC Spin Group 4-Year Research Plan

Introduction

The RHIC Spin Group was initiated in 2000, with the goal to provide leadership and support for the RHIC spin program at BNL, for each of the spin experiments, and for common requirements of the spin program, particularly for polarimetry. It was decided that the three areas, STAR spin, PHENIX spin, and polarimetry would be within one group, funded by DOE Medium Energy.

The goal of the RHIC spin program is to understand the spin structure of the proton, using the strongly interacting probes, quarks and gluons, of one colliding proton to probe the structure of the other colliding proton. The RHIC spin program directly addresses the **Physics Goals** of the DOE Medium Energy Program, as described in the **NSAC subcommittee report on Performance Measures**: "…understanding the structure of protons and neutrons that make up nuclei in terms of quarks and gluons…" and includes "High energy proton-proton collisions provide a complementary window into how the quarks and gluons build up the nucleons." Two **DOE Milestones** directly concern our program:

- **2008: Make measurements of spin carried by the glue in the proton with polarized proton collisions at center of mass energy root(s)=200 GeV.**
- **2013: Measure flavor-identified q and qbar contributions to the spin of the proton via the longitudinal-spin asymmetry of W production.**

We will describe below the initial measurements toward completing the 2008 milestone. A crucial first step has been accomplished, to experimentally confirm the theoretical understanding of the particle production at RHIC through cross section measurements. Perturbative QCD predictions describe the RHIC cross sections for pion and direct photon production. This is required to confidently extract information on the gluon and quark polarizations from the measured asymmetries from polarized collisions. First results on asymmetries, sensitive to the gluon polarization, have been reported. Very large gluon polarization, suggested as a way to mask valence quark contributions to the proton spin, has been ruled out. These first results measured pion and jet production asymmetries. Ongoing running, with higher luminosity and polarization, will improve the precision of these measurements, and add direct photon production and correlations between jets and between photon and jet to the probes for gluon polarization. We are well on our way to satisfy the 2008 milestone.

Major progress has also been made toward the 2013 milestone with successful acceleration of polarized protons to 205 GeV, crossing two large spin resonances and maintaining most polarization. We will describe the additional experimental preparations needed to meet this milestone.

Included in the proton spin sum rule is the unknown orbital angular momentum contribution, L, to the proton spin. Generalized parton distributions were introduced to lead to information on L. Another approach to learning about L is from single spin asymmetries in proton-proton collisions. Our group has led and published a measurement showing large single spin asymmetry for forward pion production, and we will describe a major initiative to explore this effect, toward learning about the transverse spin structure of the proton, and about the orbital angular momentum contribution to the proton spin.

The document **Research Plan for Spin Physics at RHIC** was presented to DOE in February, 2005 [1]. This document is a primary source for the four year research plan discussed here. Table 6, reproduced below, gives the planned measurements for the RHIC spin program through 2012. The first DOE Milestone, on gluon polarization in 2008, will be completed with the jet and pion asymmetry measurements, proceeding now, and with direct photon measurements which are just starting. Indeed, running at 500 GeV energy will also provide valuable data toward the gluon polarization, with running through 2012. Detector improvements, such as the vertex detectors, will open additional probes to the gluon polarization, improving this measurement still further. The DOE Milestone on quark and anti-quark polarization, identified by flavor, will be met with the 500 GeV running 2009-2012.

Table 1 RHIC spin example schedule from the RHIC Spin Plan assuming 10 physics weeks of operation per year, technically driven. Luminosities are 0.7 times maximum.

Fiscal Year	Spin Weeks	CME (GeV)	P	L(pb^{-1})	Remarks
2002	5	200	0.15	0.5	First pol. pp collisions! Transverse spin
2003	4	200	0.3	1.6	Spin rotators commissioned, First helicity measurements
2004	3	200	0.4	3	New betatron tune developed First jet absolute meas. P
2005	10	200	0.5	14	A_{LL} (π^0, jet) Also 500 GeV studies
2006	10	200	0.7	32	AGS Cold Snake commissioned, NEG vacuum coating complete
2007	10	200	0.7	88	
2008	10	200	0.7	106	Direct γ
2009	5	200	0.7	266	Target complete for 200 GeV;
	5	500			PHENIX μ trig, W starts
2010	10	500	0.7	266	W physics
2011	10	500	0.7	266	
2012	10	500	0.7	266	Completes 500 GeV target

In addition to the spin measurements, our group also probes gluon saturation in a gold nucleus, a **DOE Heavy Ion Milestone for 2012.** A paper on initial work has been submitted, and the STAR Forward Meson Spectrometer, to be built and installed for 2007, will test predictions of gluon saturation for deuteron-gold collisions. Timely completion of these measurements is required to assure primacy in experimental tests of possible gluon saturation before the onset of operations of the Large Hadron Collider at CERN.

The RHIC Spin Group and the other spin groups have made many other important contributions to RHIC heavy ion physics as well. The beam-beam counters (BBC), introduced to STAR by our group, have been used to trigger to obtain minimum bias proton reference data, and to provide centrality and vertex information for very central heavy ion collisions. Our group led the analysis and discovery of π^0 suppression at PHENIX, and the E_T measurements there. We also note that physicists on site train students in analog and bit-level preparation and detailed understanding of the detector.

Plans for 2007-2010 period

STAR

- **2007** – complete FMS; measure gluon density in gold nucleus via d+Au collisions.
- **2008** – measure transverse spin asymmetries for π^0–π^0 correlations.
- **2009** – complete A_{LL} measurements for prompt photon production, γ–jet and γ–hadron correlations at $\sqrt{s}$ = 200 GeV to probe $\Delta g(x)$; transverse spin asymmetries for inclusive production at $\sqrt{s}$ = 500 GeV.
- **2010** – A_{LL} measurements for prompt photon production at $\sqrt{s}$ = 500 GeV

PHENIX

- **2007** – measurement of A_{LL} for π^0 and charged pions, first data toward direct photon asymmetry. Construction of muon trigger chambers and vertex detector.
- **2008** – measurement of A_{LL} for π^0, charged pion, direct photons. Construction of muon trigger chambers and vertex detector.
- **2009** – installation of muon trigger chambers and barrel vertex detector (2 layers). Measurement of A_{LL} for π^0, charged pion, direct γ at $\sqrt{s}$=200 GeV. Begin data taking for $\sqrt{s}$=500 GeV, A_L for W boson production and A_{LL} for π^0 and direct γ (access lower momentum fraction than for $\sqrt{s}$=200 GeV.
- **2010** – installation of complete barrel vertex detector (4 layers). Continue measurements of A_L for W bosons and A_{LL} for π^0 and direct γ, at $\sqrt{s}$=500 GeV

Polarimetry

- **2007** – Continue measurements with pC and polarized jet polarimeters. Consider developing an unpolarized jet polarimeter with higher target density. The decision would depend on whether the stability of the pC calibration is sufficient in 2006 to achieve 5% polarization precision. The robustness of the carbon targets is also an issue. The required analysis team includes members of STAR and PHENIX who will work on the polarimetry monitoring and analysis on a rotating basis.
- **2008-2010** – Same. Continue to provide monitoring and precision polarization results for the experiments.

Physics Discussion

1. NLO pQCD calculations and measured cross sections

With the use of helical-dipole Siberian Snake magnets to preserve beam polarization produced in an optically pumped ion source through the acceleration sequence, RHIC allows measurements of spin observables for particles produced in polarized proton collisions over the energy range $60 \leq \sqrt{s} \leq 500$ GeV. These spin observables can provide insight into the spin structure of the proton by use of fixed-order perturbative QCD calculations that rely on factorization theorems to convolute proton spin structure distributions with the partonic scattering cross sections (Table 1). The best calculations are next-to-leading order (NLO) pQCD. The ingredients of these calculations include parton distribution functions, mostly determined from unpolarized deep inelastic scattering, and fragmentation functions, mostly determined from e^+e^- collision data. In polarized proton collisions, the hard partonic scattering serves as a probe of the spin structure of the proton. In comparison to polarized deep inelastic scattering experiments, polarized proton collisions provide direct access to the gluon spin structure of the proton since the partonic probes have a color charge, unlike the leptonic probes used in deep inelastic scattering that have only an electric charge. To establish the applicability of this framework, comparison of measured particle production cross sections to NLO pQCD calculations are essential.

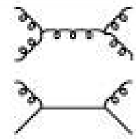
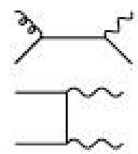
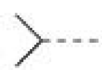
Reaction	Dom. partonic process	probes	LO Feynman diagram
$\vec{p}\vec{p} \to \pi + X$	$\vec{g}\vec{g} \to gg$ $\vec{q}\vec{g} \to qg$	Δg	
$\vec{p}\vec{p} \to \text{jet(s)} + X$	$\vec{g}\vec{g} \to gg$ $\vec{q}\vec{g} \to qg$	Δg	(as above)
$\vec{p}\vec{p} \to \gamma + X$ $\vec{p}\vec{p} \to \gamma + \text{jet} + X$ $\vec{p}\vec{p} \to \gamma\gamma + X$	$\vec{q}\vec{g} \to \gamma q$ $\vec{q}\vec{g} \to \gamma q$ $\vec{q}\vec{\bar{q}} \to \gamma\gamma$	Δg Δg $\Delta q, \Delta\bar{q}$	
$\vec{p}\vec{p} \to DX$, BX	$\vec{g}\vec{g} \to c\bar{c}, b\bar{b}$	Δg	
$\vec{p}\vec{p} \to \mu^+\mu^- X$ (Drell-Yan)	$\vec{q}\vec{\bar{q}} \to \gamma^* \to \mu^+\mu^-$	$\Delta q, \Delta\bar{q}$	
$\vec{p}\vec{p} \to (Z^0, W^{\pm})X$ $\vec{p}p \to (Z^0, W^{\pm})X$	$\vec{q}\vec{\bar{q}} \to Z^0$, $\vec{q}'\vec{\bar{q}} \to W^{\pm}$ $\vec{q}'\bar{q} \to W^{\pm}$, $q'\vec{\bar{q}} \to W^{\pm}$	$\Delta q, \Delta\bar{q}$	

Table 2 Key processes at RHIC for the determination of the parton distributions of the longitudinally polarized proton, along with the dominant contributing subprocesses, the parton distribution predominantly probed, and representative leading-order Feynman diagrams.

The first RHIC runs resulted in the measurement of neutral pion production cross sections at mid-rapidity (π^0 production angle of ~90°) and at large rapidity (π^0 production at small angles relative to the colliding beams). Normalization of the cross sections requires a precise measurement of the luminosity of the colliding beams. Controlled scans of one beam relative to the other, greatly facilitated by the fact that each beam is in a separate ring at RHIC, permits accurate measurement of the collision luminosity. The resulting π^0 production measurements in comparison to NLO pQCD calculations are shown in Fig. 1. The agreement between theory and experiment is very good, unlike for particle production at lower $\sqrt{s}$. As also found for particle production at the Tevatron, the agreement between theory and experiment works well for particles produced with transverse momentum as low as $p_T \approx 2$ GeV/c.

Later RHIC runs have resulted in measurements of the p_T dependence of the cross section for inclusive jet production at STAR and inclusive photon production at PHENIX. As for π^0 production, NLO pQCD gives a good description of measured yields and so provides a reliable basis for interpretation of gluon polarization from measurement of A_{LL} for these final states.

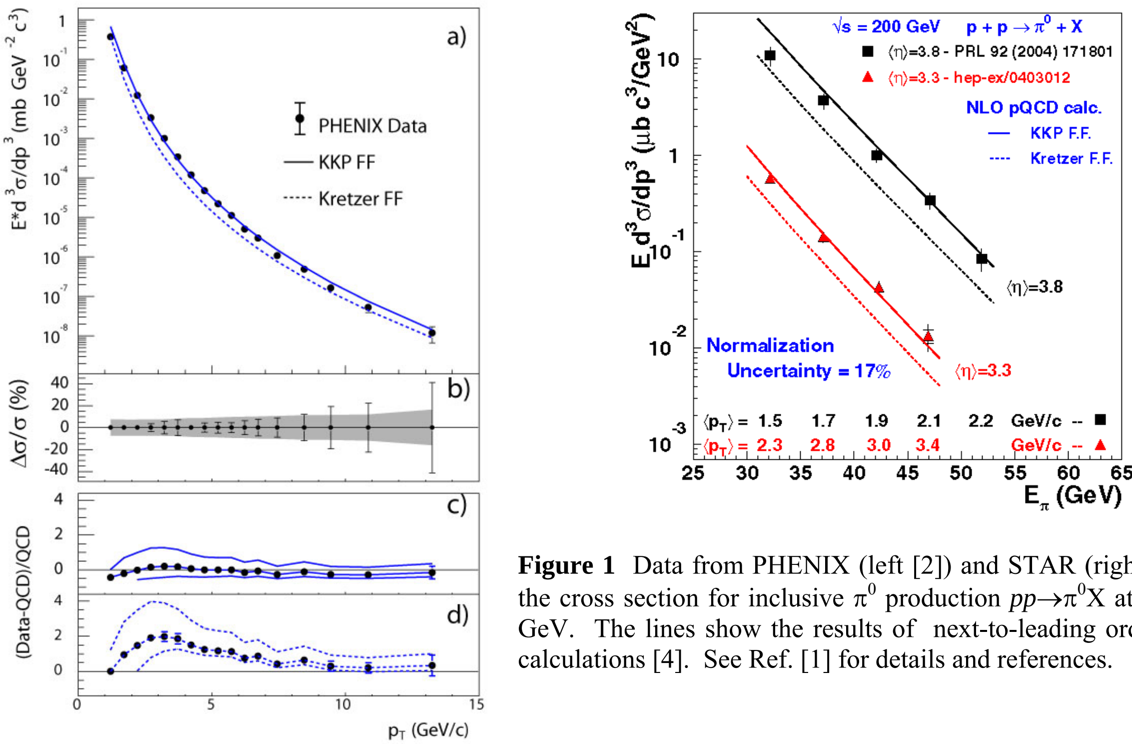


Figure 1 Data from PHENIX (left [2]) and STAR (right [3]) for the cross section for inclusive π^0 production $pp \rightarrow \pi^0 X$ at $\sqrt{s}$ = 200 GeV. The lines show the results of next-to-leading order pQCD calculations [4]. See Ref. [1] for details and references.

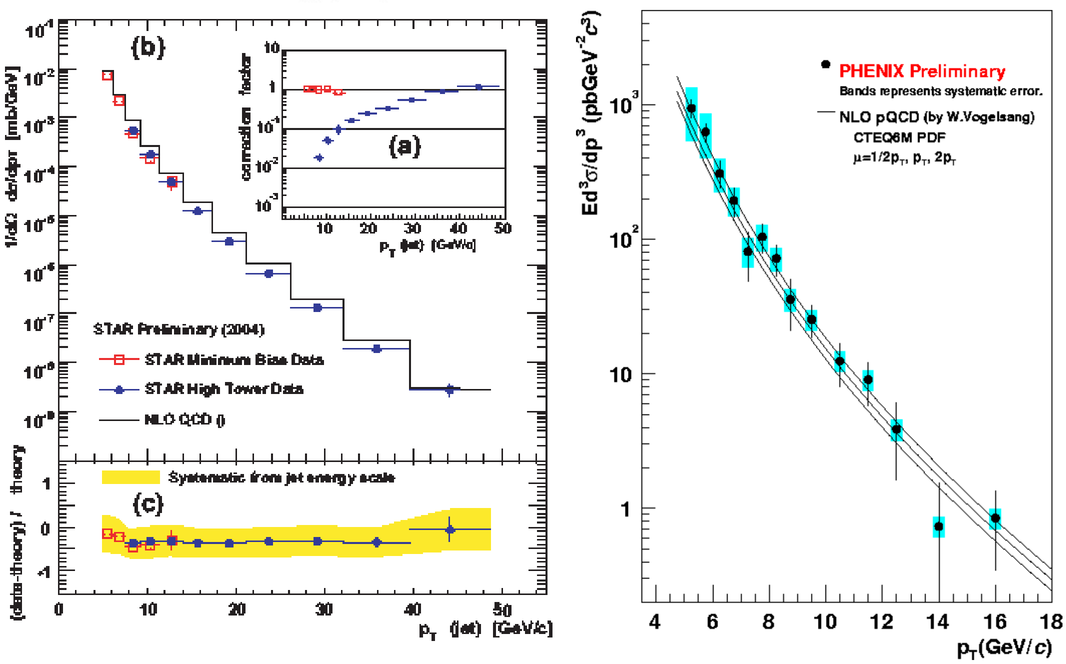


Figure 2 Cross section data from STAR (left [5]) for inclusive jet production at midrapidity and PHENIX (right [6]) for inclusive photon production at midrapidity in *pp* at $\sqrt{s}$ = 200 GeV. The lines show the results of the next-to-leading order pQCD calculations for these produced particles.

2. Helicity structure of proton—gluon.

Measurements of the two-spin helicity asymmetry, A_{LL}, for particles produced in longitudinally polarized proton collisions at energies where pQCD is applicable provides sensitivity to possible polarization of gluons. Of greatest interest is the integral of the gluon helicity contribution over all Bjorken *x* since this determines the contribution gluons make to the spin of the proton. Determination of the *x* dependence remains an important goal. Direct photon production and photon-hadron or photon-jet correlations are the golden probes of gluon polarization because of the dominance of the QCD Compton process (row 3 of Table 2). But, production rates of photons require the highest possible luminosities and polarizations from the collider and optimal performance of the detectors. As RHIC has developed its capabilities for polarized proton running, PHENIX and STAR have focused on measurements of A_{LL} for inclusive π^0 and jet production. Good sensitivity to gluon polarization remains for high-p_T π^0 and jet production, although the information is less direct than for photon production because of the larger number of contributing hard-scattering processes. Measurements of A_{LL} that have been completed to date are shown in Fig. 3. The quality of these measurements eliminates the scenario of maximal gluon polarization that could be consistent with the limited Q^2 dependence available from polarized inclusive deep inelastic scattering.

As shown in the RHIC Spin Plan, Fig. 4 illustrates the sensitivity we expect for measurements of gluon polarization in the proton. RHIC will measure this with a number of probes, which will test our understanding of the underlying physics, and produce a robust result for this key measurement. The expected sensitivity of the ongoing DIS experiment at CERN, COMPASS, is also shown. Measuring the gluon polarization is a worldwide quest, and RHIC will provide the most sensitive and definitive results. The figure shows expected results for both high cross

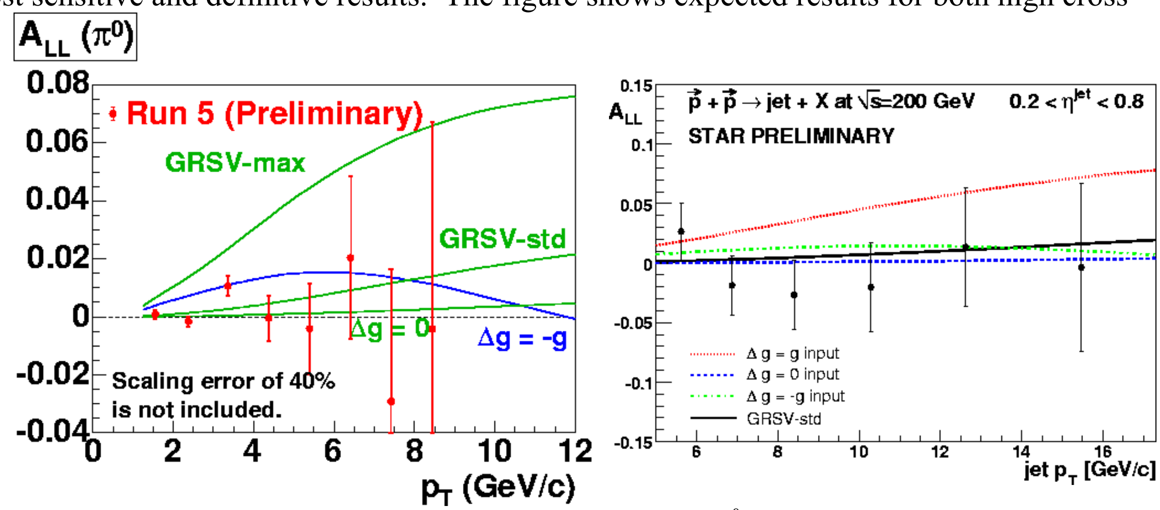


Figure 3 Measurements of A_{LL} from PHENIX (left [7]) for inclusive π^0 production at midrapidity and STAR (right [8]) for inclusive jet production in collisions of longitudinally polarized protons at $\sqrt{s}$ = 200 GeV. The lines show next-to-leading order calculations pQCD using as input different assumptions about gluon polarization.

section processes (left panel, jets) and for the more theoretically precise but lower cross section process of direct photon production.

As stated in the RHIC Spin Plan, polarized proton operations at $\sqrt{s}$ = 200 GeV will continue until the middle of the fiscal year 2009 run. At that point, it is expected that 275 pb^{-1} of integrated luminosity will have been delivered, most of which is planned to have 70% beam polarization. One of the motivations driving this plan is to measure A_{LL} for prompt photon production, including inclusive measurements of γ-hadron and γ-jet correlations. Particularly the latter can be used to probe the *x* dependence of gluon polarization, as shown in Fig. 5, through rapidity correlations. The large rapidity coverage of the STAR detector enables this measurement. As described below, the addition of a Forward Meson Spectrometer to STAR will increases its rapidity coverage thereby enhancing sensitivity to the *x* dependence of gluon polarization.

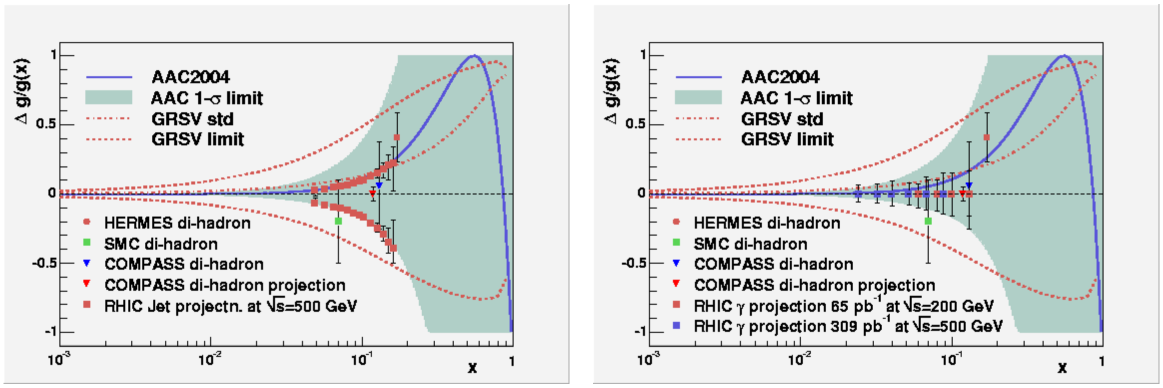


Figure 4 Plot of models of the gluon polarization, $\Delta g(x)$ / $g(x)$ versus log x, where x is the fraction of the proton momentum carried by the gluon. The curves in both panels show $\Delta g(x)$ / $g(x)$ from two analyses of polarized deep-inelastic (DIS) scattering data. The left panel shows STAR sensitivities from jet production at √s = 500 GeV, and the right panel shows projections for PHENIX for direct-photon production at 200 and 500 GeV. Results and projections from existing fixed-target leptoproduction of dihadrons are also shown. Experiments measure the beam helicity asymmetry A_{LL}. Its conversion to $\Delta g(x)$ / $g(x)$ requires a global analysis. This plot represents an example of sensitivity to $\Delta g(x)$ / $g(x)$ from the different experiments. See Ref. [1] for more details and references.

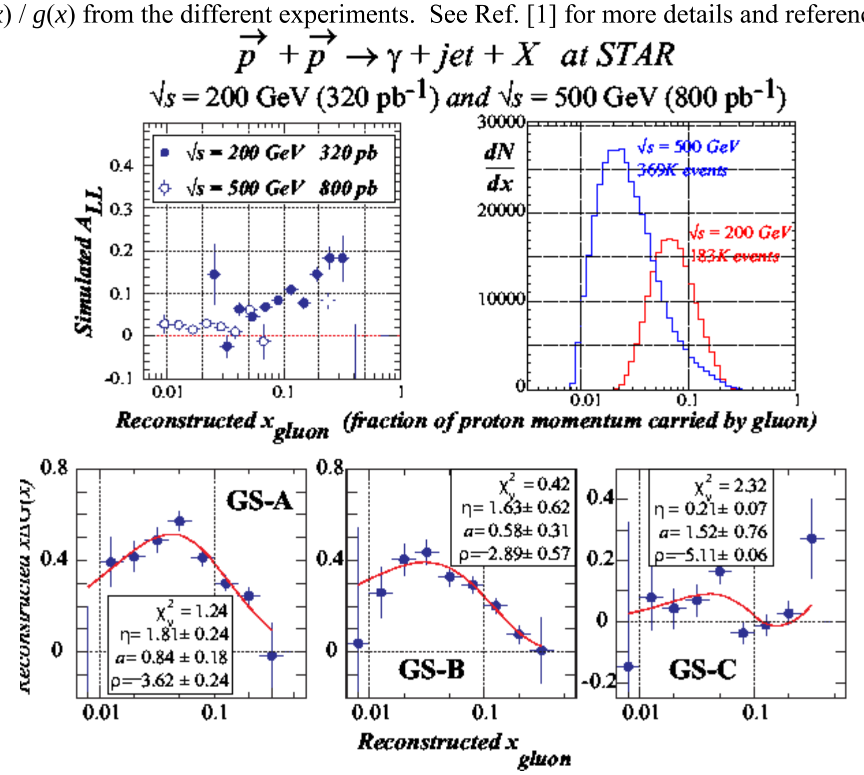
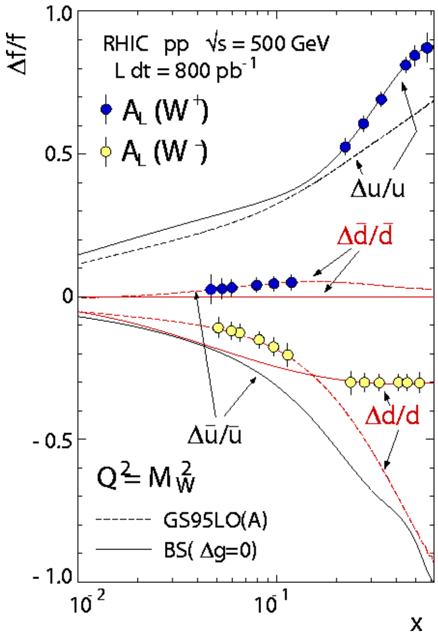


Figure 5 Simulated gluon polarization sensitivities for a measurement and an analysis of A_{LL} for γ-jet coincidences with the STAR detector at √s = 200 and 500 GeV, illustrating the importance of rapidity correlations to determine the Bjorken-x dependence of $\Delta g(x)$. Through rapidity correlations, x can be reconstructed event-by-event assuming collinear qg collisions. (Upper) Simulated A_{LL} and event distribution [15] for set-A gluon polarization. (Lower) $\Delta g(x)$ reconstructed using a leading-order analysis of simulations based on three different input distributions consistent with polarized deep inelastic scattering. The net gluon contribution to the proton spin is given by the area under the $x\Delta g(x)$ curve, integrated from $0<x<1$. The sampled integrated luminosities planned for the RHIC spin program will result in measurement uncertainties ~2× larger than those shown. See Ref. [1] for further details.



3. Helicity structure of proton—q and qbar.

In Fig. 6, we show the expected sensitivity to anti-quark polarization, sorted by flavor. This is a direct measurement by observing the parity violating production of W bosons, with RHIC running at √s=500 GeV. RHIC will provide definitive measurements, where only model-dependent results presently exist from DIS. The result addresses how it is that the combination of quark and anti-quarks in the proton carry little of the proton spin. The focus on the dependence of the spin structure on anti-quark flavor will provide a profound test of the mechanisms for producing the sea of quark-anti-quark pairs that strongly influences nucleon structure.

Figure 6 Quark and antiquark polarization in the proton, $\Delta f(x)$ / $f(x)$, versus log x with models for up and down quarks and antiquarks, with expected uncertainties for RHIC. The x variable is the fraction of the proton momentum carried by the quark or antiquark. See Ref. [1] for details and references.

The W measurements are based on the very different probabilities for finding quarks versus finding anti-quarks in the colliding protons at large momentum fraction x. We will measure single beam helicity asymmetries, averaging over the spin directions of the other beam. Ws produced forward from the polarized beam will be formed predominantly from quarks from the polarized beam, and from anti-quarks from the unpolarized beam. And Ws produced backward select anti-quarks from the polarized beam. The charge sign of the W then identifies the flavors of the quark and anti-quark. For forward/backward production, the measured parity violating asymmetry A_L then directly measures the quark/anti-quark polarization in the polarized proton.

To accomplish the W measurements, both PHENIX and STAR must upgrade their detectors. PHENIX requires additional triggering selection, as discussed below in the PHENIX section. The detectors for this are being funded by NSF, and we expect them to be in place for √s=500 GeV running in 2009. A proposal for STAR forward tracking is being developed. The tracking is necessary to identify the charge sign of the very stiff forward electrons from W decay which will be observed by the endcap calorimeter.

4. Transverse spin structure of proton—L and transversity

In a broader view of the RHIC spin program, the goal is determine how the proton acquires its ½$\hbar$ intrinsic angular momentum from its quark and gluon constituents. Recent experimental and theoretical developments suggest the presence of orbital motion of the quarks and/or gluons within a polarized proton. Measurements of transverse spin asymmetries for particles produced in p+p collisions at RHIC energies may provide direct insight into orbital motion of the partons and if this motion contributes to the net spin of the proton. Experiments at RHIC serve as an important complement to ongoing experiments at e^+e^- colliders and fixed-target experiments that study semi-inclusive deep inelastic scattering from transversely polarized targets. Theoretical understanding of transverse spin asymmetries is developing rapidly as evidenced by five international workshops on the subject within the past year, focus on transverse spin at major conferences and plans for additional workshops in the near future.

Transverse single spin asymmetries (SSA) have been observed in particles produced in hadronic interactions over a broad range of collision energies. Generally, these spin effects were observed in kinematics where fixed-order pQCD could not explain measured cross sections [9]. Large spin effects are not expected in simple applications of QCD since hard scattering of partons cannot produce sizeable transverse SSA for interactions involving the light up and down quarks. The experimental observations prompted development of QCD-inspired models that attribute these striking spin effects to intrinsic transverse momentum (k_T) of the quarks and/or gluons either in distribution functions (Sivers effect [10]) or in their fragmentation back to hadrons (an essential component of the Collins effect [11]).

The Sivers effect attributes transverse SSA to a correlation between the k_T of a quark or gluon bound in the proton with its transverse spin. In other words, non-zero Sivers distribution functions imply orbital motion of quarks and/or gluons in transversely polarized protons. A final- or initial-state interaction is an essential component in the Sivers effect. Qualitatively, this apparent complication is critical to allow sampling of only parts of the orbital motion rather than averaging over the full orbit. Given that the transverse SSA arises from the distribution function, transverse SSA are expected either in inclusive hadron production, in inclusive jet production, or in particles produced directly in the hard partonic scattering (for example, direct photon production). Recent evidence for a non-zero Sivers effect has been reported by the HERMES collaboration in their study of semi-inclusive deep inelastic scattering from a transversely polarized hydrogen target.

The Collins effect attributes transverse SSA as being due to the presence of a non-zero transversity distribution function. This makes the quarks transversely polarized before they undergo a hard scattering. The transverse spin of the scattered quark in the final state is revealed by spin- and k_T-dependent fragmentation resulting in azimuthal asymmetries of the produced hadrons about the thrust axis. Evidence of a non-zero Collins function has recently been submitted for publication by the Belle collaboration in their study of the azimuthal asymmetry of dihadrons produced in e^+e^- collisions. A non-zero Collins function can provide access to the transversity distribution. At leading order and in a basis of transverse polarization states, transversity has a probabilistic interpretation analogous to that for $\Delta q(x)$ in a helicity basis. Transversity cannot be measured in inclusive deep inelastic scattering experiments because it is a chiral odd distribution. Accessing transversity is important to determine the nucleon tensor charge and as a test of our understanding of the non-perturbative spin structure of the nucleon.

The results above were preceded by measurements of transverse SSA for neutral pions produced at large rapidity completed by STAR during the first polarized proton run and led by members of our group. Those first results, obtained with a prototype Forward Pion Detector (FPD) are shown in Fig. 7 in comparison to theoretical calculations available prior to the measurements. Also shown are more precise data obtained in RHIC runs 3,5 with the completed STAR FPD. In contrast to the situation at lower collision energies, non-zero transverse SSA are observed for neutral pion production in the same kinematics where NLO pQCD gives a good description of the measured cross section.

Transverse SSA have also been reported by the BRAHMS collaboration for π^+ production at η=3.9 and π^- production at η = 3.4 and 3.9 in collisions of transversely polarized protons at $\sqrt{s}$ = 200 GeV. Positive asymmetries are observed for π^+ and negative asymmetries are observed for

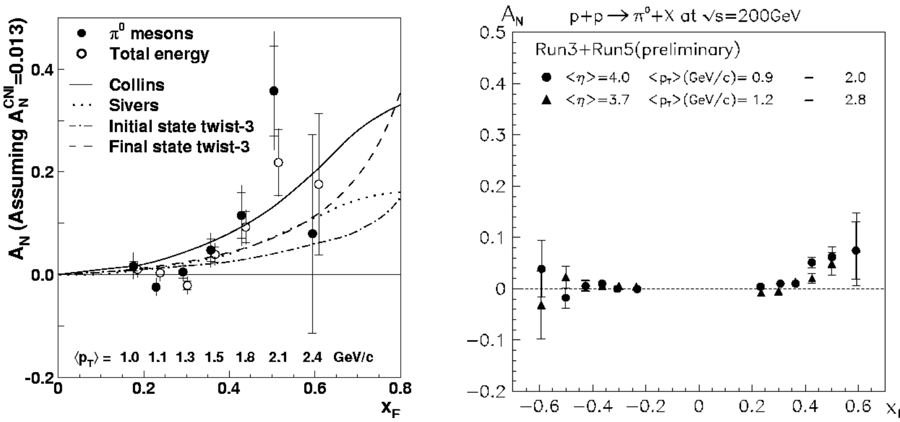


Figure 7 (*Left*) Transverse single-spin asymmetries for π^0 production at <η>=3.8 in polarized *pp* collisions at √s = 200 GeV reported by the STAR collaboration [4]; (*Right*) More precise measurements completed in runs 3,5 [12].

π^- produced at large x_F. Near zero asymmetries were reported for π^+ production at large negative x_F [13]. An important next step is to disentangle contributions to transverse SSA observed for pion production at RHIC energies following a method described below.

5. Probing for gluon saturation via studies of forward particle production

The experimental methods used to determine cross sections for forward π^0 production in p+p collisions at √s = 200 GeV were readily extended to measurements of cross sections in the deuteron beam direction for d+Au collisions at $\sqrt{s_{NN}}$=200 GeV. The importance of the comparison of forward particle production cross sections in d+Au and p+p collisions was already recognized at a BNL workshop on p+A physics in 2001 that was part of the last NSAC Long Range Planning exercise. The opportunity to conduct exploratory measurements was seized by members of our group in measurements conducted at STAR at the end of the first RHIC d+Au run. The essential features of this measurement, in comparison to the results reported by the BRAHMS collaboration, was to measure inclusive π^0 production cross sections at the smallest

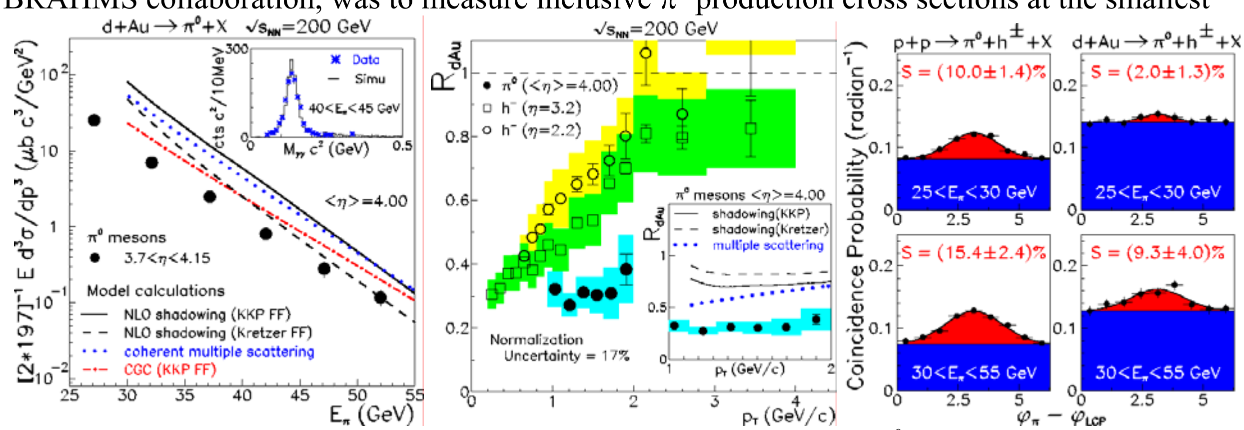


Figure 8 (Left) The x_F dependence of the scaled cross section for forward π^0 production in d+Au collisions compared to conventional and gluon saturation model calculations; (Middle) ratio of d+Au to p+p cross sections scaled so that no nuclear effects give unity. The observed suppression of the π^0 cross section at <η>=4.00 cannot be explained by conventional calculations; (Right) Coincidence probability versus azimuthal angle difference between a forward π^0 and the leading charged hadron with p_T>0.5 GeV/c observed at midrapidity. The peak observed for p+p collisions supports the partonic scattering picture. The peak is significantly smaller in d+Au collisions [14].

possible scattering angle and to look at azimuthal correlations between a π^0 produced at large η and midrapidity charged particles. In pQCD, rapidity correlations between pairs of jets, pairs of hadrons serving as jet surrogates or γ-jet events enables determination of the Bjorken-x dependence of the distribution functions. Of particular interest is the gluon density because of its rapid rise as $x\rightarrow 0$. Basic considerations of the unitarity of the scattering matrix require that the gluon density cannot increase to arbitrarily large values as x continues to decrease. One cure to this divergence is the notion of gluon saturation as described within the Color Glass Condensate effective theory. Within that picture, the basic mechanism for particle production differs from leading-twist pQCD at fixed-order. Consequently, the Bjorken-x of the gluons probed decreases rapidly with increasing η to $\approx 10^{-4}$ for pions produced at $\eta=4$. In a saturation picture, the large x quark from the deuteron beam undergoes multiple interactions through the dense gluon field, resulting in multiple recoil partons instead of one, thereby modifying the $\Delta\phi$ distribution for di-hadron correlations and possibly leading to the appearance of monojets. Fig. 8 shows the results from the exploratory measurements conducted at the end of the first RHIC d+Au run [14]. Although the data are suggestive of the onset of gluon saturation in a heavy nucleus at RHIC collision energies, they are not conclusive. Increased acceptance for forward particle detection is required. The STAR Forward Meson Spectrometer will provide this. A second RHIC d+Au run, preceding the start of operation of the Large Hadron Collider, can provide conclusive results related to the gluon saturation question.

6. STAR

The Solenoidal Tracker at RHIC (STAR) is shown in its configuration for RHIC run 6 in Fig. 9. At its heart is a time projection chamber (TPC) embedded in a 0.5T solenoidal magnetic field that provides charged particle tracking in the range $|\eta| \leq 1.2$. The TPC is surrounded by the barrel electromagnetic calorimeter (EMC) that provides essential triggering and energy measurements for high-p_T electrons, positrons and photons. The run-6 configuration also includes shielding on the interaction-region side of the quadrupole triplet just beyond the DX

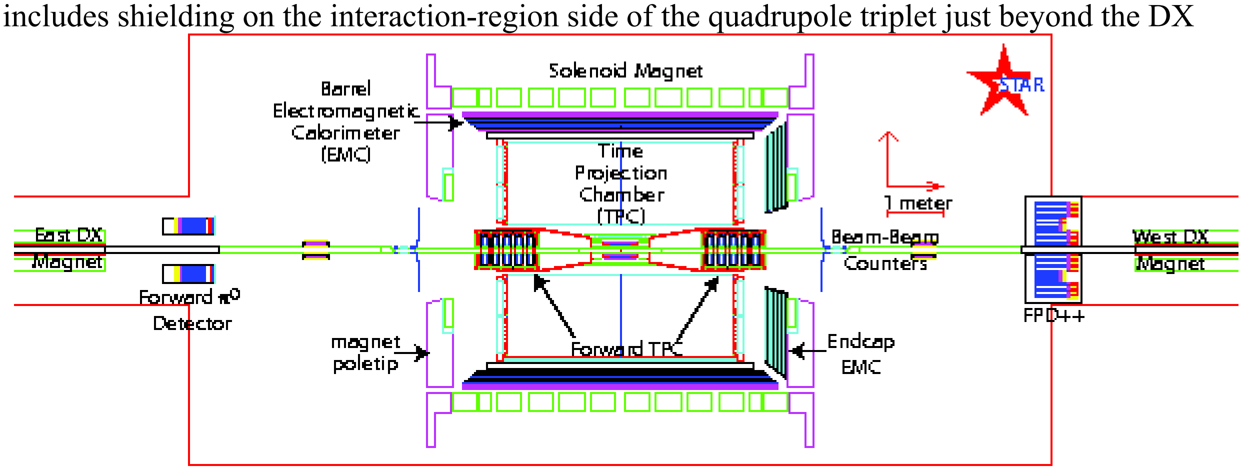


Figure 9 Schematic layout of STAR in its configuration for RHIC run 6. The FPD++ is an engineering test of a Forward Meson Spectrometer planned to replace it for RHIC run 7. The FMS will provide 2π azimuthal coverage in the forward direction, thereby providing STAR with nearly hermetic calorimetric coverage in the interval $-1 < \eta < 4$.

magnets shown in Fig. 9. The shielding addition is important to reduce backgrounds observed in the barrel EMC in previous runs. The forward time projection chambers (FTPC) track charged particles produced in the range $2.8 \leq |\eta| \leq 3.8$. This range overlaps the coverage of the Forward Pion Detector (FPD) that utilizes modular lead-glass electromagnetic calorimetry for triggering and reconstruction of single photons and neutral pions produced in the forward direction. For RHIC run-6, the FPD++ was installed west of STAR as an engineering test of the planned Forward Meson Spectrometer (FMS) intended for completion prior to the start of operations in fiscal year 2007. The endcap EMC spans $1.07 \leq \eta \leq 2.0$. The beam-beam counters (BBC) are scintillator annuli that span $2.5 \leq |\eta| \leq 5.0$ to provide a minimum bias trigger for STAR, spin-dependent and spin-independent luminosity measurements and a local polarimeter to measure the polarization direction of the colliding beams.

An upgrade to tracking in the forward direction is required for the W physics program to enable a measurement that will discriminate daughter electrons from daughter positrons. Observation of W production at 90° in the center of mass mixes contributions from antiquarks from the two colliding protons. Forward W production isolates antiquark contributions from one or the other proton. Planning for this tracking upgrade is underway. The earliest a forward tracking upgrade to STAR would be available is 2010.

a. Gluon polarization measurements with barrel EMC, endcap EMC and FMS

STAR is measuring the p_T dependence of the cross section and the two-spin helicity asymmetry (A_{LL}) for jets produced at midrapidity in the collisions of longitudinally polarized protons at $\sqrt{s} = 200$ GeV. The neutral energy, primarily from photon daughters of neutral pions from the jets, is measured by the barrel and endcap EMC and serves as the event trigger. The charged hadron contribution to the jets is determined from tracks reconstructed from the TPC. Normalization of the cross section and the spin-dependent luminosity, required for the A_{LL} measurement, is provided by measurements made with the BBC.

As the luminosity for polarized proton collisions at RHIC improves, STAR will focus on particles produced with smaller cross sections. In particular, the p_T dependence of photon production is a golden probe of gluon polarization, since the QCD Compton subprocess dominates γ production. As outlined in Ref. [15], the broad rapidity coverage of STAR will allow for measurement of γ-jet and γ-hadron correlations. Measuring A_{LL} for these correlations can determine the Bjorken-*x* dependence of gluon polarization. Inclusive measurements are sensitive to a weighted average of gluon polarization over a range of Bjorken-*x* through the convolution integrals inherent to pQCD calculations.

Results from RHIC (Fig. 2) have established the applicability of NLO pQCD over a broad range of rapidity at $\sqrt{s} = 200$ GeV. The implication of this result is to use the rapidity variable as a means of controlling relative contributions of different partonic subprocesses and the Bjorken-*x* range of the partons selected from the colliding protons. In NLO pQCD, forward particle production is dominated by valence quarks from one beam interacting with primarily quarks and gluons with small Bjorken-*x* from the other beam. Although we know that quarks (and antiquarks) cannot account for the spin of the proton from polarized deep inelastic scattering measurements, it is also known from these measurements that quark polarization is large for valence quarks, at large Bjorken-*x*. Furthermore, the QCD Compton process has its largest possible helicity dependence when the photon is produced in the direction of the incident quark. The angular dependence of the spin dependence of the QCD Compton process is completely analogous to the spin dependence of Compton scattering in quantum electrodynamics. Forward photon production at RHIC is then analogous to the backscattering of laser light from high-energy electron beams employed to make beams of high energy photons. Hence, measurement of A_{LL} for photons produced at large rapidity at RHIC will provide exceptional sensitivity to gluon polarization at low-*x*. Expansion of the STAR FPD to a Forward Meson Spectrometer [16] will enable measurements of cross sections and A_{LL} for large-rapidity photon production.

b. Transverse spin with FMS, endcap EMC and barrel EMC

Measurements beyond forward inclusive π production are required to disentangle Collins and Sivers contributions to transverse single-spin asymmetries (SSA). Improved forward detector

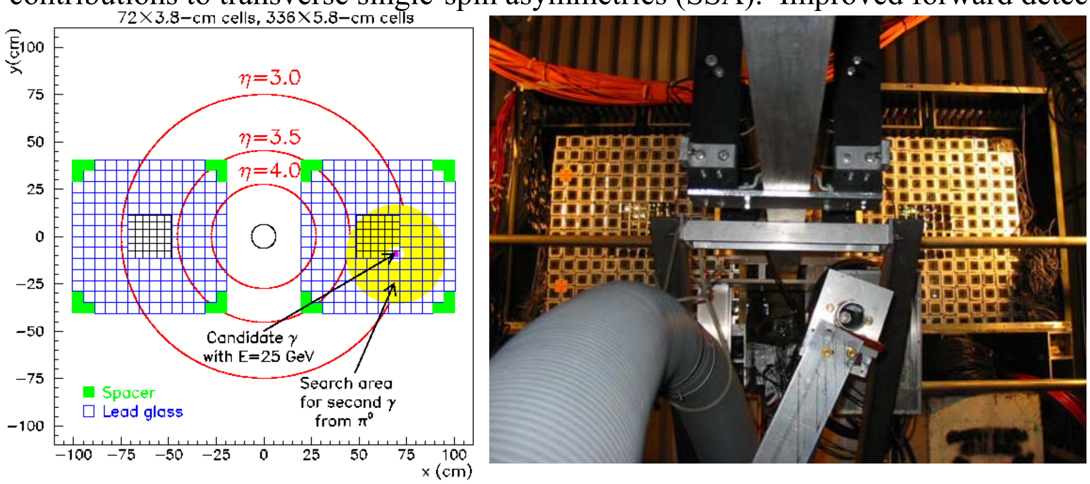


Figure 10 (Left) Schematic view of the STAR FPD++ as seen from the interaction point looking to the west. The calorimeter size is matched to the requirements for discriminating prompt photons from photon daughters of neutral mesons. The yellow shaded region corresponds to 95% of the decay phase space for π^0 produced at large rapidity. (Right) The STAR FPD++ in its configuration for RHIC run 6.

instrumentation at STAR and PHENIX are needed for these measurements since prompt photon production must exclude photon daughters from π^0 and η decays and jets have typical cone radii of 0.7 in η−ϕ space. Improved forward instrumentation is also critical to future measurements of the gluon density in the gold nucleus, discussed below. Plans for improvement of forward instrumentation include the FPD++ mounted to the west of the STAR magnet (Fig. 10). The FPD++ is an engineering test of the FMS.

As shown in Fig. 11, multi-photon final states can be observed with the FPD++ to serve as a surrogate for a forward jet. The azimuthal symmetry of the FPD++ around the thrust axis of the jet, selected by triggering on energy deposited in the macula of the compound eye of the calorimeter, enables sensitivity to the Sivers effect via transverse SSA for measurements that integrate over all multi-photon final states. Sensitivity to the Collins effect is enabled via measurement of the spin dependence of the azimuthal distribution of photons about the thrust axis. Simulations showing that multi-photon final states reconstruct the forward jet and the projected sensitivities for measurement of A_N

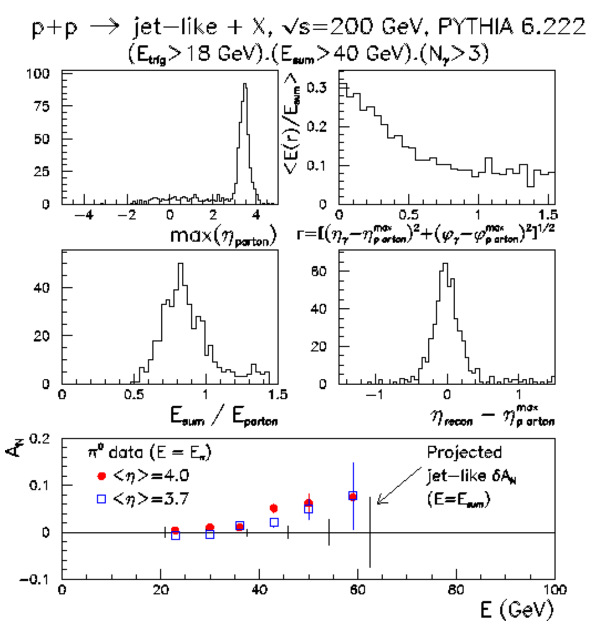


Figure 11 PYTHIA simulations of FPD++ response for p+p collisions at $\sqrt{s}$=200 GeV. E_{trig} (E_{sum}) is the energy sum in the central section (entire) of the calorimeter; (upper left) most forward hard-scattered parton η distribution; (upper right) distribution of photon energy relative to the thrust axis showing a standard jet shape atop an underlying event contribution; (middle left) photon energy sum scaled by the most forward hard-scattered parton energy; (middle right) difference distribution of the η reconstructed from the vector sum of the detected photon momenta and the parton η; (bottom) projected statistical precision for jet-like events for 5 pb^{-1} of polarized proton integrated luminosity with beam polarization of 50%.

assuming 5 pb^{-1} of integrated luminosity with 50% beam polarization are shown in Fig. 11. The STAR FMS will provide much greater forward acceptance and sophisticated topological triggering possibilities. The latter are critical for the measurement spin-dependent π^0–π^0 correlations and for transverse SSA for prompt photon production.

Transverse SSA were measured for inclusive π^0 and $h^{\pm}$ production at midrapidity during RHIC run 2 with statistical precision comparable to what was achieved in the forward direction for hadrons produced with the same p_T [17]. The midrapidity transverse SSA are consistent with zero. These results, in conjunction with the forward particle production results, support the notion that only those particles produced in the proximity of beam rapidity provide sensitivity to the quantum numbers of the colliding protons. Further studies of the spin dependence of di-hadron and di-jet azimuthal correlations for mid-rapidity particle production are planned. These studies have been suggested to provide sensitivity to the gluon Sivers function via a direct measurement of the spin dependence of the momentum imbalance between jet or hadron pairs. Studies of the spin dependence of the azimuthal correlations of pairs of hadrons within a single jet can provide sensitivity to the transversity structure function through the Collins effect.

c. Gluon saturation with FMS

Substantial improvement in the sensitivity to the low-*x* gluon density in a heavy nucleus beyond what was available in the first RHIC d+Au run is provided by the addition of a Forward Meson Spectrometer (FMS) to STAR. The nearly contiguous electromagnetic calorimetry spanning $-1 < \eta < 4$ will permit inclusive measurements of photon production cross sections. In addition, hadronic surrogates from jets can be used to look at di-hadron correlations spanning a broad rapidity interval. The broad rapidity coverage that STAR would have with the FMS

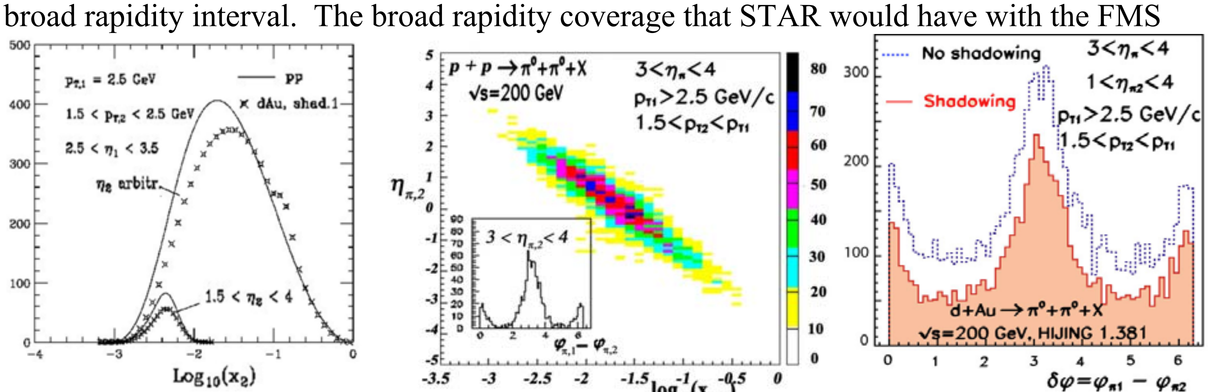


Figure 12 (Left) pQCD calculation of the cross sections for coincident π^0-π^0 production at large rapidity in p+p and d+Au collisions at $\sqrt{s_{NN}}$=200 GeV. The smallest *x* values are probed when both neutral pions are detected at large rapidity. (Middle) PYTHIA simulation of π^0-π^0 production at large rapidity in p+p collisions at $\sqrt{s}$=200 GeV. The rapidity of the associated π^0 is strongly correlated with the *x* value of the soft parton involved in the partonic scattering. (Right) HIJING simulation for π^0–π^0 production at large rapidity in d+Au collisions at $\sqrt{s}$=200 GeV. Compared to the p+p simulations, the peaks in $\Delta\phi$ corresponding to elastic parton scattering, sit ato a background from other mechanisms for particle production. See Ref. [16] for details and references.

addition will enable hadroproduction measurements sensitive to a broad range of Bjorken-*x* for the gluons in the gold nucleus. For *x*>0.02, measurements at RHIC overlap the Bjorken-x interval where scaling violations in fixed-target deep-inelastic scattering have determined the gluon density in a heavy nucleus. The FMS addition to STAR will extend the sensitivity to the gluon density to *x*~0.001, within the context of pQCD. If the Color Glass Condensate description of gluon saturation [18] is correct, then the FMS extension of calorimetric coverage out to η~4 will be probing the gluon density in the gold nucleus down to x~10^{-4}. Direct determination of the gluon density in the gold nucleus is important to understand how a quark-gluon plasma is created in the collision of two ultrarelativistic heavy ions. Definitive evidence of gluon saturation is important to this quest and also has many implications for particle production in ion collisions at the Large Hadron Collider at CERN.

Staff: L. Bland, A. Ogawa, 1 additional staff (2006/7); 2 additional post docs (2006/7; 2007/8)

4-year plan:

- **2007 – complete FMS; measure gluon density in gold nucleus via d+Au collisions.**
- **2008 – measure transverse spin asymmetries for π^0–π^0 correlations.**
- **2009 – complete A_{LL} measurements for prompt photon production, γ-jet and γ-hadron correlations at $\sqrt{s}$ = 200 GeV to probe $\Delta g(x)$; transverse spin asymmetries for inclusive production at $\sqrt{s}$ = 500 GeV.**
- **2010 – A_{LL} measurements for prompt photon production at $\sqrt{s}$ = 500 GeV.**

7. PHENIX

The focus of PHENIX spin, and our group, for 2003-2009 is the measurement of the gluon polarization using inclusive π^0 and direct photon production. A strength of PHENIX is in its very high granularity electromagnetic calorimeters ($\delta\phi \times \delta\phi$=0.01 $\times$ 0.01 radians) and in its very high data taking capability of 5 kHz. A schematic of the PHENIX detector is shown in Fig. 13. π^0 can be identified up to p_T=25 GeV/c, and direct photons for p_T>5 GeV/c, as already presented in Figs. 1 and 2. The expected sensitivity of PHENIX for the gluon polarization measurement using π^0 is shown in Fig. 14. The sensitivity using direct photons was presented in Fig. 4. Our group (Bazilevsky) has led all of the software work, with Kyoto and Stony Brook students and RBRC members, to identify the photon clusters, calibration, the cross section measurement for π^0 ([2], Fig. 1), and the A_{LL} measurements for π^0 for 2003 [19], 2004 (to appear as a Brief Report in PR), and 2005 (Fig. 3) [6].

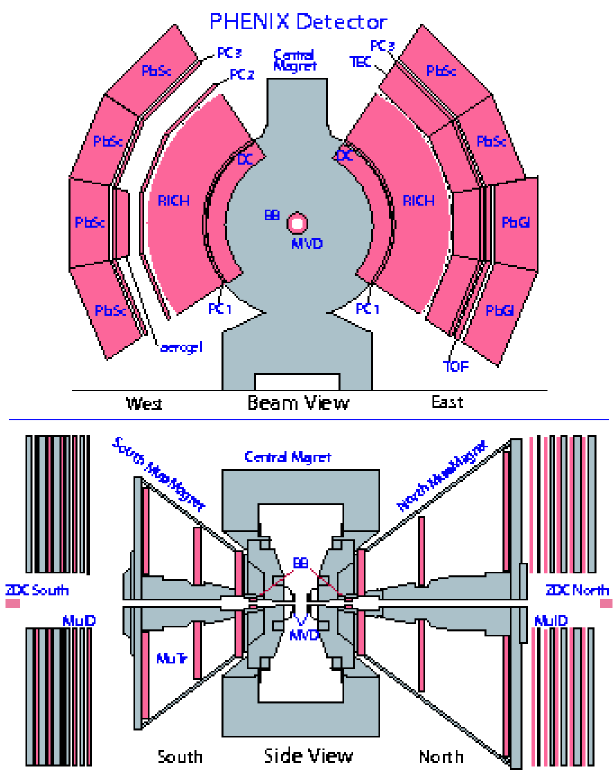


Figure 13 Plan and side views of the PHENIX

An important ingredient to both the gluon and quark/anti-quark polarization measurements is the measurement of the spin direction at collision using the local polarimeter. This is used to establish longitudinal polarization via the settings of the spin rotators on either side of PHENIX. Very forward neutron production was discovered to be sensitive to the beam transverse polarization direction, in an experiment done by our group, including Les Bland, RBRC, Kyoto, and RIKEN, in 2001 [20]. Local polarimeters were set up using the existing Zero Degree Calorimeters and shower maximum detectors, to observe the spin direction at collision for each

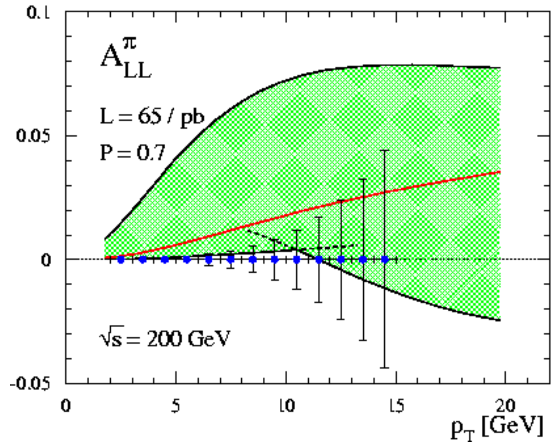


Figure 14 The current uncertainty in A_{LL} for π^0 due to Δg and projected sensitivities for measurements by PHENIX at midrapidity and $\sqrt{s}$=200 GeV for integrated luminosity of 65/pb and polarization of 70%. Note the "cusp" in the theory band near p_T=10 GeV/c resulting from use of a gluon distribution with strong negative polarization. The cusp occurs when the process $qg \rightarrow qg$ (which contributes negatively to the spin asymmetry for Δg<0) starts to dominate over $gg \rightarrow gg$ (which is always positive). This is emphasized by the dashed lines.

beam from 2002. Indeed, the first current settings for the spin rotators provided sideways (radial) polarization and this was corrected to obtain longitudinal polarization for the first measurement of A_{LL} [19]. In 2005, data were also taken with the local polarimeters for collisions at $\sqrt{s}$=410 GeV, during the machine studies to accelerate to higher energy. Fig. 15 shows the observed left-right asymmetry. The local polarimeters, therefore, will work for the W physics running at $\sqrt{s}$=500 GeV.

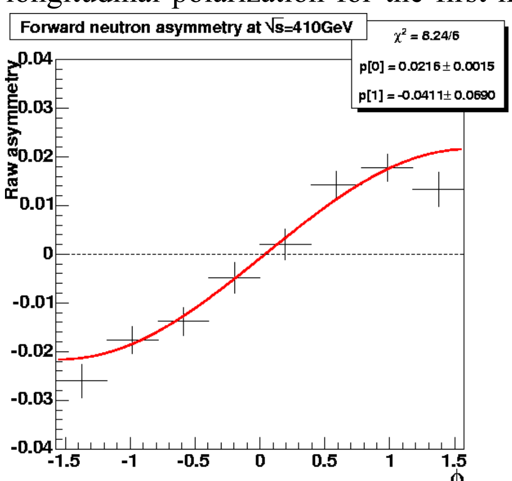


Figure 15 Transverse single spin asymmetry for far forward neutrons detected in the Zero Degree Calorimeters at PHENIX for $\sqrt{s}$ = 410 GeV polarized p+p collisions. This spin effect is used to measure the polarization direction of colliding polarized protons at PHENIX.

The sensitivity of the PHENIX π^0 measurements toward gluon polarization are shown in Fig. 16, for the expected integrated luminosity and polarization in Table 1, in 2009. A systematic uncertainty on the raw asymmetry measurements of 10^{-3}, already achieved, has been assumed. The curves indicate different levels of gluon polarization. The GRSV limit curve, where the gluons are fully polarized at an input scale of Q^2=0.4 GeV^2/c^2, has already been ruled out by the data presented to PANIC (from the 2005 run), Fig. 3a. Also shown are the reported measurements of Hermes, SMC, and COMPASS and projections of COMPASS (a single point). The red rectangles show the PHENIX expected sensitivity, plotted on the GRSV standard curve. The sensitivities split into two curves, for positive and negative gluon polarization, due to the quadratic dependence of the measured A_{LL} on the gluon polarization for the gluon-gluon scattering graph. However, the sensitivities are excellent. The correct approach to using the A_{LL} and other data to obtain the gluon polarization is to perform a global analysis, which will be undertaken soon.

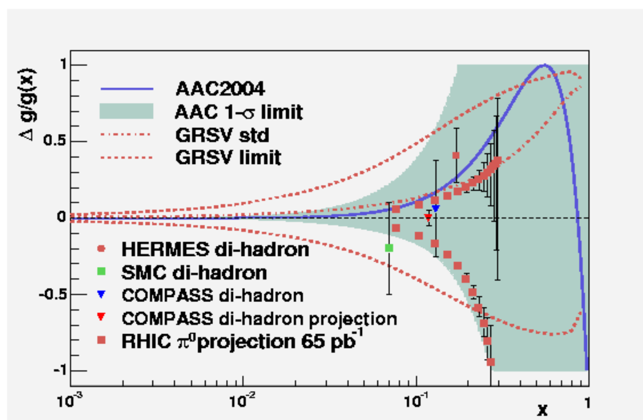


Figure 16 Plot of the gluon polarization, $\Delta g / g$, versus x, the fraction of the proton momentum carried by the gluon. Projections are for RHIC-PHENIX future measurements for π^0 at $\sqrt{s}$=200 GeV. See Ref. [1] for details.

The planned Silicon Vertex Tracker will provide identified heavy flavor to probe the gluon polarization, through the gluon fusion graph of Table 2, row 4. The heavy flavor channel isolates the gluon graph and applicability of pQCD. The lower p_T of the gluons gives a reach to lower momentum fraction for gluon polarization. The signal is quadratic in gluon polarization, however, so the sensitivity is reduced for lower gluon polarization. The vertex detector is discussed in the RHIC Spin Plan and the proposal [20].

The focus of our group for the $\sqrt{s}$=500 GeV running, in 2009-2012, is to obtain a large sample of W bosons. A single helicity asymmetry, parity violating, directly measures the quark or anti-quark polarization in the proton by flavor. Here we discuss only the muon arms where the separation between quark and anti-quark is clear. Fig. 6 shows the sensitivity for quark and anti-quark polarization by flavor. This has also been studied using the RHICBOS W simulation which takes into account multi-gluon emission, presented in the RHIC Spin Plan.

An improved trigger is required for PHENIX to be able to take all the W physics data at high luminosity. The luminosity expected results in a 10 MHz collision rate, one collision per bunch crossing. The existing muon trigger based on penetration of the muon ID detectors, and iron/chamber sandwich, cuts muons with p<2.7 GeV/c. From measurements, we will need to improve the rejection factor from the present 250 to >5000. A resistive plate chamber system has been proposed to NSF to provide this trigger. This upgrade has been approved in 2005, and design and prototyping are underway. This is discussed in more detail in the RHIC Spin Plan and the proposal [20].

Another device, the nose cone calorimeter, would be expected to provide considerable improvement for signal/background for W bosons. The calorimeters would replace the present brass muon filters upstream and downstream of the collision point. The device would be used to require isolation for W candidate muons. We do not yet have a simulation to estimate the background improvement, but a factor of 5 appears reasonable based on isolation studies of photon and π^0 data. However, contributions from the underlying event may be important for the forward muon arm regions. This device is discussed in the RHIC Spin Plan and information is available at Ref. [20].

Staff: G. Bunce, A. Bazilevsky, 1 additional staff (2007/8); post docs likely from RBRC

<u>4 Year Plan</u>

- **2007: measurement of A_{LL} for π^0 and charged pions, first data toward direct photon asymmetry. Construction of muon trigger chambers and vertex detector.**
- **2008: measurement of A_{LL} for π^0, charged pion, direct photons. Construction of muon trigger chambers and vertex detector.**
- **2009: installation of muon trigger chambers and barrel vertex detector (2 layers). Measurement of A_{LL} for π^0, charged pion, direct γ at $\sqrt{s}$=200 GeV. Begin data taking for $\sqrt{s}$=500 GeV, A_L for W boson production and A_{LL} for π^0 and direct γ (access lower momentum fraction than for $\sqrt{s}$=200 GeV.**
- **2010: installation of complete barrel vertex detector (4 layers). Continue measurements of A_L for W bosons and A_{LL} for π^0 and direct γ, at $\sqrt{s}$=500 GeV.**

8. Polarimetry

Polarimetry for RHIC is supported from DOE and RIKEN funds. There are three types of polarimeters:

1) fast polarimeters in RHIC giving relative polarization measurements;
2) an absolute polarimeter in RHIC using a polarized hydrogen jet;
3) a fast AGS polarimeter.

We may also propose for FY 2007-8 a fourth:

4) a fast absolute polarimeter in RHIC that uses the results of 2).

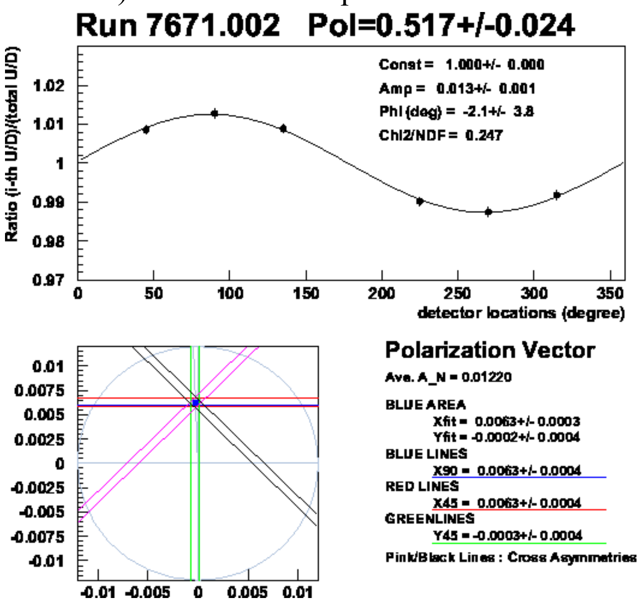


Figure 17 Raw asymmetries versus detector location (azimuthal angle) measured by pC polarimeter. Fits to the amplitude and phase of the harmonic modulation determine the vertical and radial polarization components of the beam.

1) Fast polarimetry in RHIC is based on very small angle polarized proton-Carbon (pC) elastic scattering in the Coulomb-Nuclear Interference (CNI) region. Typically 20 million events are collected in 30 seconds, giving a 3% relative measurement of the beam polarization. Deadtime-less readout is based on waveform digitizers (WFD) developed at Yale University. This approach was invented for RHIC, based on the expected sensitivity to the proton polarization in the CNI region from the electromagnetic helicity-flip amplitude that is responsible for the proton anomalous magnetic moment.

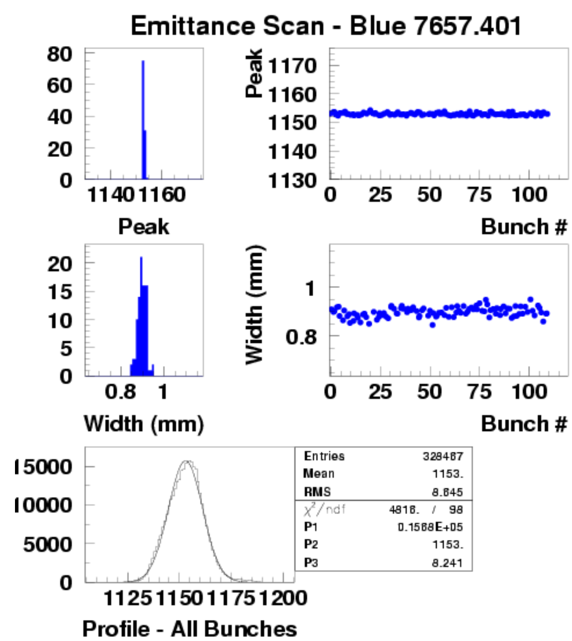


Figure 18 Measurements with the pC polarimeter that determine the emittance of the RHIC beams via a scan of the carbon ribbon target across the beam. Systematic bunch-to-bunch variations in the emittance are observed..

Two technologies were crucial: fabrication of macroscopic length (2 cm), 10 or less micrometer wide, 200 angstrom or so thick carbon targets by Indiana U.; and the WFDs. A significant hadronic helicity flip amplitude has also been found [22], making it necessary to calibrate the analyzing power, done with the polarized jet (2).

The pC polarimeters provide the polarization normalization for the experiments. Measurements on the acceleration ramp were used to look for any polarization loss, particularly for studies of acceleration to 205 GeV (Bai et al., accepted for publication at PRL). Measurements of the spin tune, used to set up the Siberian Snakes and for spin flipping, will use frequency-dependent radial polarization measurements from these polarimeters. Development of this feature will take place in FY 2006.

Also in FY 2006, a new method of moving the target through the beam is being used. The polarimeters regularly measure the polarization profile through the beam, and the average polarization over the beam size (the targets are 5-10 microns wide, much narrower than the beam of order 1 mm). This new technique also allows RHIC to directly monitor the beam emittance, important to maximize luminosity.

The pC polarimeters consist of a carbon target that is rotated through the beam for the measurement, and six silicon strip detectors at a scattering angle of nearly 90° to the beam, at a radius of 15 cm from the target. The detectors are placed at 90° and 45° in azimuth, with 0° the vertical direction. A left-right asymmetry is measured for a vertical component of beam using the 90° and the 45° detectors. An up-down asymmetry from a sideways (radial) beam polarization is measured using the 45° detectors. Each of the total of 72 silicon strips can be used as an individual polarimeter, providing a direct measurement of systematic measurement uncertainties. The beam is bunched, with alternating polarization direction for each bunch. Using the azimuthal dependence of the event yield for each bunch, this alternating spin sign can be monitored, and beam systematics can be monitored.

For each event, the WFD for the hit strip reports the pulse height, and time at 1/4 pulse height, relative to the RHIC bunch timing of the beam crossing the target. The recoil carbon locus is clearly seen from the time of flight versus recoil energy correlation. By selecting these events, and then combining the azimuthal information and the spin sign information, a raw asymmetry is measured, and the direction of the transverse component of the polarization vector. This is shown in Fig. 17. By normalizing using the jet (2), the absolute polarization is measured. A beam emittance measurement is shown in Fig. 18. This measurement is done for each bunch in RHIC, taking 2 s.

2) The polarized jet target is used to measure the polarization continuously, alternating between blue and yellow beams every RHIC fill (in 2006). The jet target polarization, measured using a Breit-Rabi polarimeter, is very stable with an atomic hydrogen polarization of 96%. The target polarization is used to calibrate the polarization dependence of elastic pp scattering in the Coulomb Nuclear Interference (CNI) region. This is then applied to determine the beam polarization. Silicon detectors, with waveform digitizer readout, measure the CNI scattering. This runs simultaneously with the RHIC fast proton-carbon polarimeters to provide an absolute calibration for the pC polarimeters.

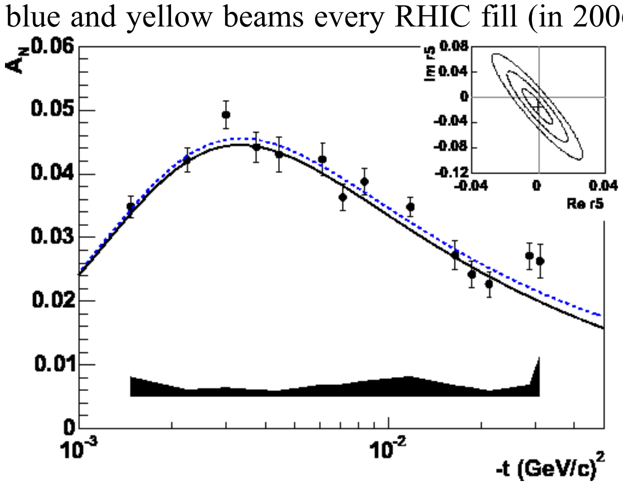


Figure 19 The |t| dependence of the analyzing power for p+p elastic scattering for 100 GeV protons scattering from the polarized jet target.

Engineering running and calibration to about 10% was successfully completed in FY 2004 and a paper has been submitted to Physical Review Letters on the precision measurement of polarized proton-proton elastic scattering [23]. Fig. 19 shows the measured analyzing power versus the 4-momentum transfer squared variable *t*. This is the first observation of the predicted CNI behavior with precision, as first suggested by Schwinger. We find the analyzing power (the right-left asymmetry) to be fully described by the calculated purely electromagnetic spin flip amplitude with no hadronic spin flip necessary. This situation is unlike the proton-carbon result, where a large hadronic spin flip amplitude is required to describe the data [22]. The reason for this difference is not known at this time.

The RHIC Spin Group has been responsible for the silicon detectors and CNI elastic scattering data analysis, with major collaborators including the RIKEN BNL Research Center, ITEP (Moscow), and Yale. FY 2006 is a transition year to move more operational responsibilities to CAD (silicon detectors and electronics) and to develop a larger analysis team using PHENIX and STAR. We intend to fully analyze the data during the run with regular adjustments of the polarimeter parameters as necessary to produce preliminary polarization results at the end of running. Both carbon and jet data will be analyzed in this way.

A 7% measurement of the beam polarization was accomplished in FY 2004 (blue beam only). Data analysis for FY 2005 is ongoing for both the jet and carbon polarimeters. The goal is to achieve a 5% measurement. Based on the carbon studies for FY 2005, this will require continual use of the jet polarimeter with the carbon polarimeters providing corrections for different bunch polarizations and for periods when the jet polarimeter is used for the other beam.

3) The AGS pC polarimeter was built by our group, with participation from CAD, ITEP, UCLA, and RBRC. The AGS polarimeter is used to tune the AGS to improve and monitor the polarization, including measurements along the acceleration ramp. These measurements are used to identify energies where polarization is lost. For FY 2006, responsibility for the AGS polarimeter was assumed by CAD, with advice from the RHIC Spin Group expert (Bravar).

4) We are considering developing a new unpolarized hydrogen target polarimeter for RHIC. The new polarimeter will use the analyzing power measurement of the polarized jet target polarimeter (2) above, with an expected 1000 times denser unpolarized hydrogen target in RHIC to provide the absolute beam polarization to experiments. With this new polarimeter it is expected to reach a precision of better than 5% absolute, which is the goal for polarimetry for the spin program. The measurements with the polarized jet in FY 2004 showed a very large analyzing power for proton-proton scattering, largely due to access to lower *t*, three times larger than for proton-carbon scattering (used for 1). With the high density and high analyzing power, precision measurements will be made in minutes. Further, a factor of 10 less scattering is required (due to the high analyzing power, compared to proton-carbon), so this will greatly reduce radiation damage of the silicon detectors used for polarimetry, and greatly reduce emittance blowup from the measurements, compared to proton-carbon.

Staff: A. Bravar, R. Gill, post doc (2006/7)

4 Year Plan:

- **2007—Continue measurements with pC and polarized jet polarimeters. Consider developing an unpolarized jet polarimeter with higher target density. The decision would depend on whether the stability of the pC calibration is sufficiently stable in 2006 to achieve 5% polarization precision. The robustness of the carbon targets is also an issue. The required analysis team includes members of STAR and PHENIX who will work on the polarimetry monitoring and analysis on a rotating basis.**
- **2008-2010—Same. Continue to provide monitoring and precision polarization results for the experiments.**

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