Planned Research

of

RHIC Spin Group

at

Brookhaven National Laboratory

(2007 – 2010)

April, 2006

U.S. Department of Energy

Office of Science

BROOKHAVEN NATIONAL LABORATORY

Document Contents

Attachment A:

A package should be prepared for transmittal to the reviewers via email (e.g. Word or PDF files) containing at a minimum the following material:

- a list of current personnel supported by the DOE Medium Energy program, highlighting personnel who have significant leadership roles on scientific and technical committees, and a management organization chart (1 page);
  see page 3
- a statement of the scientific accomplishments made in the last four year period, and the way in which they contributed to the Nuclear Physics program's long term and short term performance measures (≤2 pages). Refer to Attachment B;
  see pages 4-5
- a 4-year research plan (FY 2006-2009), including a front page that summarizes the research goals and milestones that will contribute to the overall progress towards a Nuclear Physics program long-term performance measure (≤20 pages). Refer to Attachment B;
  see pages 6-26
- an analysis of the adequacy of the existing budget and justification of the proposed out-year budgets (≤ 2 pages);
  see pages 27-28
- impact, if any, of proposed research on other fields of science and education (1 page);
  see page 29
- a statement of outreach activities (1 page);
  see page 29
- a short CV for each member of the group including their top three publications (1 page for each member);
  see pages 30-35
- a list of scientific publications and significant awards received in the preceding four years;
  see pages 36-45
- a copy of the relevant sections of the Field Work Proposals supporting research in Medium Energy Nuclear Physics (see Attachment B); and
  see attachment #1 following page 46
- any other information deemed relevant to this review by the Laboratory (1 page).
  none

Personel RHIC Spin Group
March, 2006

Gerry Bunce—Group Leader, RHIC Spin Group; Deputy Group Leader, RBRC Experiment Group (resident Group Leader); Spokesman, RHIC Spin Collaboration (RSC wrote spin proposals for STAR and PHENIX, umbrella group to promote and coordinate program); Chair, Research Plan for Spin Physics at RHIC (2005); polarimetry; PHENIX.

Les Bland—Leader for STAR spin in RHIC Spin Group; PI for Forward Pion Detector, FPD++ (2006), Forward Meson Spectrometer (2007); co-chair, STAR Spin Physics Group 1999-2004; developed case for Endcap Calorimeter at IU.

Sandro Bravar—Leader of RHIC polarimetry including design and development of pC and pp polarimeters; built AGS pC polarimeter; advisor for COMPASS at CERN.

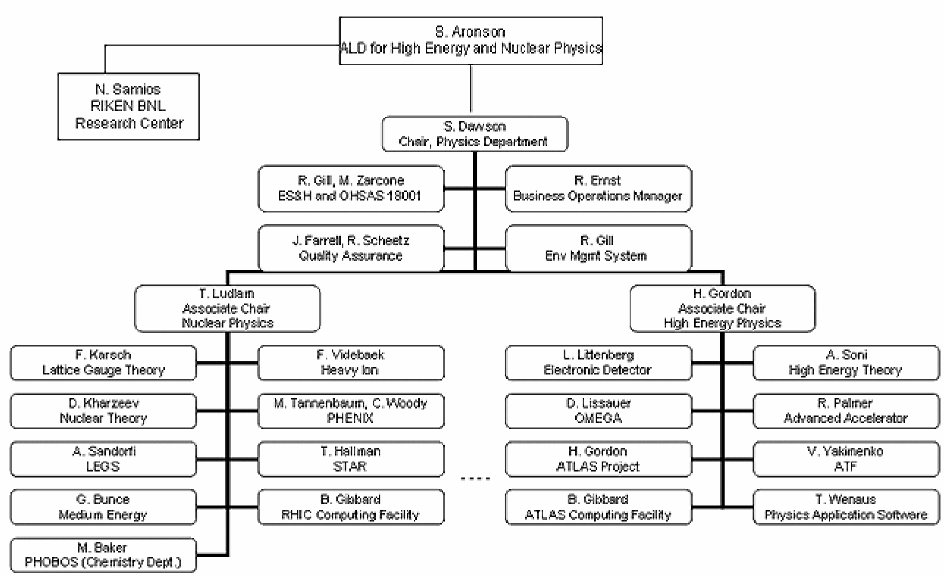
Akio Ogawa—STAR, co-chair STAR Spin Physics Group 2004-present; FPD, FPD++, FMS; organizer of RSC 2003-2005; Belle polarized quark fragmentation analysis (RBRC collab.)

Sasha Bazilevsky—PHENIX, calorimeter calibration, software, analysis; leads A_{LL} analysis group; $\sigma(\pi^0)$, E_T analysis; organizer of RSC 2005-present.

Ron Gill—Polarimetry; Physics Safety Officer

Group Leader: G. Bunce
Deputy Group Leader: L. Bland
Secretary: M. Echmalian (0.5 FTE)
STAR: L. Bland (Leader), A. Ogawa, A. Bravar (0.2 FTE)
PHENIX: G. Bunce (Leader), A. Bazilevsky
Polarimetry: A. Bravar (Leader), R. Gill (0.5 FTE), G. Bunce
Total FTEs: scientists 5.5, secretary 0.5

Management Organization Chart



Scientific Accomplishments

1. Organized, provided information, coordinated development of RHIC spin program through meetings with experimenters, machine physicists, theorists. Includes review in Ann Rev. Nucl. Part. Physics “Prospects of RHIC Spin”, accelerator design report for spin program published in NIM, Research Plan for Spin Physics at RHIC, submitted to DOE in 2005.
2. Developed RHIC polarimetry (pC and pp jet). Includes waveform digitizer readout (supported development by Satish Dhawan at Yale, ITEP development of FPGA coding) from 2001, built AGS pC polarimeter in 2002/3.
3. Proposed and introduced beam-beam counters (BBC) to STAR as minimum bias trigger; discovery of analyzing power and use as local polarimeter for longitudinal polarization.
4. Proposed and introduced Forward Pion Detector (FPD) to STAR; discovered large forward π^0 transverse spin asymmetry, leading to modern era of transverse spin physics (with also results of Hermes and Belle); gluon saturation physics with FPD.
5. Proposed and introduced very forward neutron local polarimeter at PHENIX after group discovered neutron asymmetry in IP12 (with RBRC and others), provides measurement of vertical and radial polarization in collision, degree of longitudinal polarization.
6. Cross sections demonstrating applicability of pQCD for production of π^0 at mid-rapidity (PHENIX), forward (STAR), and production of direct photons at mid-rapidity (PHENIX).
7. Led A_{LL} measurements for π^0, PHENIX.
8. Participated in A_{LL} measurements for jets, STAR.
9. Accepted proposals for muon trigger upgrade (PHENIX, NSF) and Forward Meson Spectrometer (STAR, DOE).

(Numbers after milestone refer to accomplishments listed above)

2008 DOE Milestone on gluon polarization: 1,2,3,5,6,7,8,9

This milestone is addressed by development of the RHIC program plan (1); invention and application of new polarimetry for high energy protons (2); a first level collision trigger and local polarimeter to set up and monitor longitudinal polarization for STAR (3); discovery of analyzing power for very forward neutrons, new local polarimeter to set up and monitor longitudinal polarization for PHENIX (5); cross section measurements that demonstrate applicability of the theory used to extract the gluon polarization from measurements (6); initial published measurements sensitive to the gluon polarization from PHENIX (7); initial measurements being prepared for publication, sensitive to the gluon polarization from STAR (8); extended coverage for photon, π^0, and jet to measure gluon polarization at lower momentum fraction for STAR (9).

2013 DOE Milestone on q, qbar polarization: 1,2,3,5,9

This milestone is addressed by the program, polarimeter, and local polarimeter developments described for the gluon polarization milestone (1,2,3,5). The muon trigger upgrade for PHENIX is required to use full luminosity for W boson production for the q/qbar polarization measurements (9).

Developing World Focus on Transverse Spin: 1,2,3,4,5,6

Although this is not a DOE Milestone, measurements at RHIC have shown large asymmetries for transverse spin. This and other new measurements of large asymmetries have led to a new world focus on transverse spin. The RHIC program development and polarimeters are required (1,2,3,5), and the theoretical understanding of the interactions via quark and gluon subprocesses (6). The FPD was used to measure the large forward asymmetries for π^0 at STAR (4). Also, the BRAHMS experiment has measured large asymmetries for π^+ and π^- with opposite sign. These measurements were supported by our group's purchase of special scaler modules built by UC Berkeley for their use in these measurements.

2012 DOE Milestone to determine gluon densities at low x in cold nuclei: 3,4,6

This milestone is addressed by (1) installation of forward calorimetry in STAR. Specifically, the Forward Pion Detector (2003), the FPD++ (2006) and plans for a Forward Meson Spectrometer (FMS); (2) results for forward π^0 cross sections in p+p collisions and their comparison to NLO pQCD calculations suggesting the predominance of valence quarks scattering from gluons as the mechanism for forward p0 production; (3) results for forward π^0 production in d+Au collisions suggesting the scaled cross section is strongly suppressed; and (4) results from exploratory studies of azimuthal correlations for pairs of hadrons separated by large rapidity intervals. In p+p collisions, the data support the partonic scattering picture. In d+Au collisions, there is evidence of suppression of the correlation peak, but the data are not conclusive evidence of gluon saturation. More comprehensive measurements will be pursued when the FMS is in place at STAR, providing nearly hermetic calorimetric coverage for $-1 < \eta < 4$. The broad coverage will enable measurement of the *x* dependence of the gluon density in the gold nucleus via a study of π^0–π^0 and γ–π^0 rapidity correlations from d+Au collisions.

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 $60 \le \sqrt{s} \le 500$ 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.

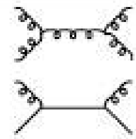
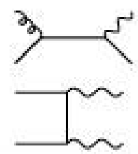
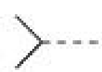
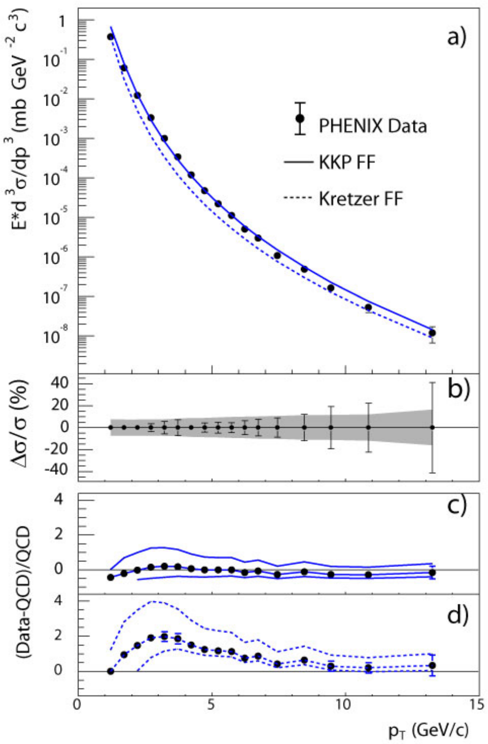
Reaction	Dom. partonic process	probes	LO Feynman diagram
$\vec{p}\vec{p} \to \pi + X$	$\vec{g}\vec{g} \to gg$ $\vec{q}\vec{g} \to qg$	Δg	
$\vec{p}\vec{p} \to \text{jet(s)} + X$	$\vec{g}\vec{g} \to gg$ $\vec{q}\vec{g} \to qg$	Δg	(as above)
$\vec{p}\vec{p} \to \gamma + X$ $\vec{p}\vec{p} \to \gamma + \text{jet}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

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.



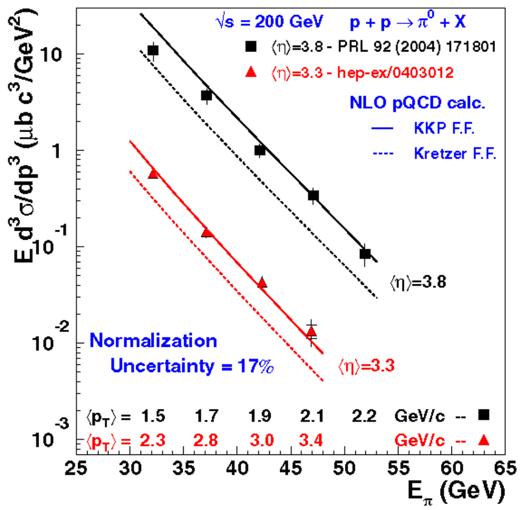


Figure 1 Data from PHENIX (left [2]) and STAR (right [3]) for the cross section for inclusive π^0 production $pp \rightarrow \pi^0 X$ at $\sqrt{s}$ = 200 GeV. The lines show the results of next-to-leading order pQCD calculations [4]. See Ref. [1] for details and references.

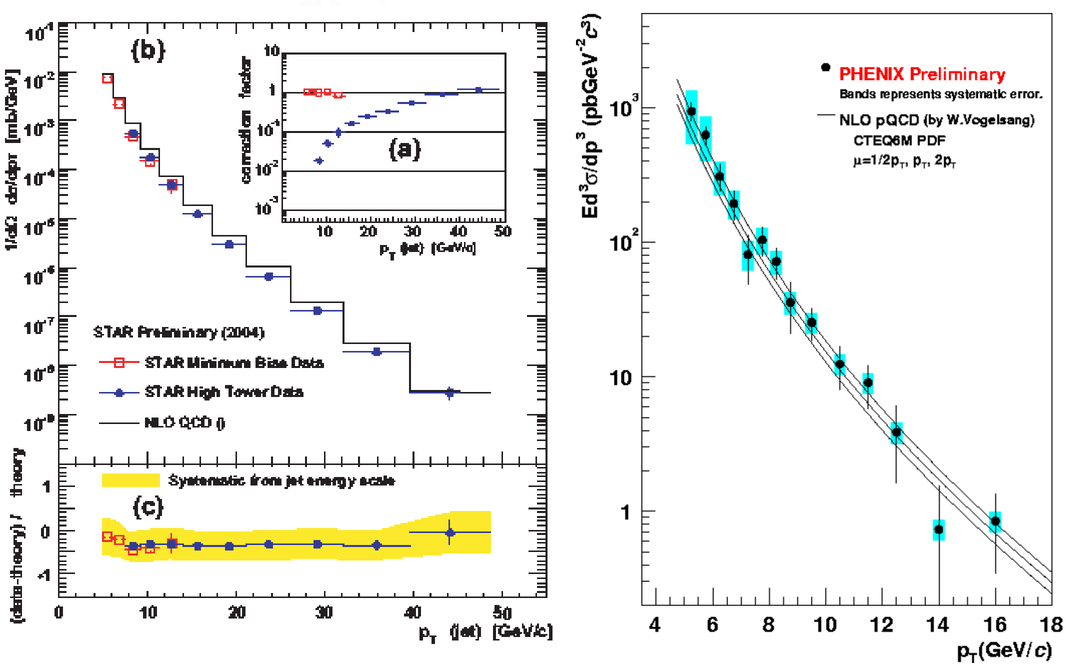


Figure 2 Cross section data from STAR (left [5]) for inclusive jet production at midrapidity and PHENIX (right [6]) for inclusive photon production at midrapidity in *pp* at $\sqrt{s}$ = 200 GeV. The lines show the results of the next-to-leading order pQCD calculations for these produced particles.

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

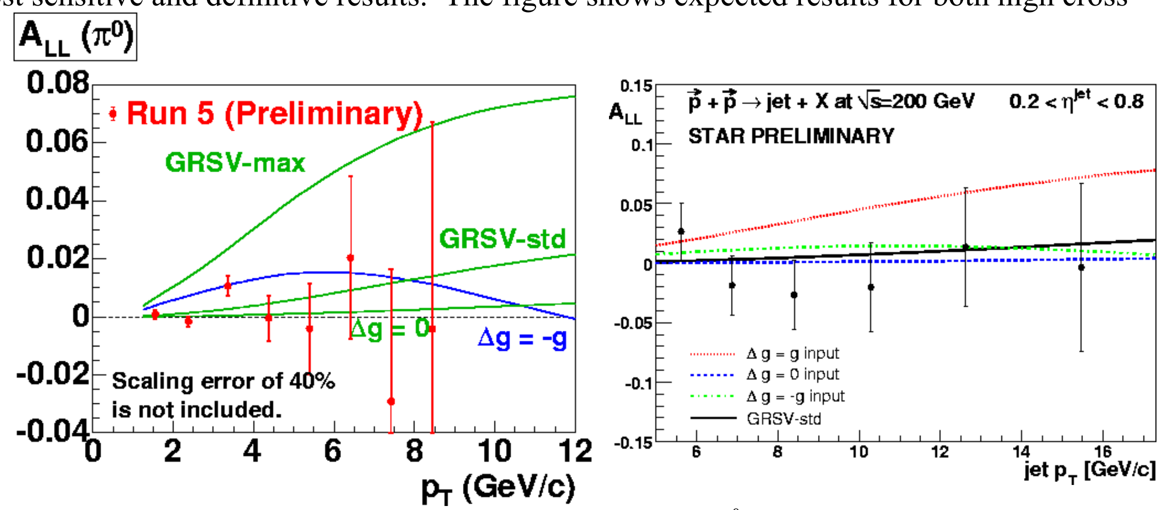


Figure 3 Measurements of A_{LL} from PHENIX (left [7]) for inclusive π^0 production at midrapidity and STAR (right [8]) for inclusive jet production in collisions of longitudinally polarized protons at $\sqrt{s}$ = 200 GeV. The lines show next-to-leading order calculations pQCD using as input different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

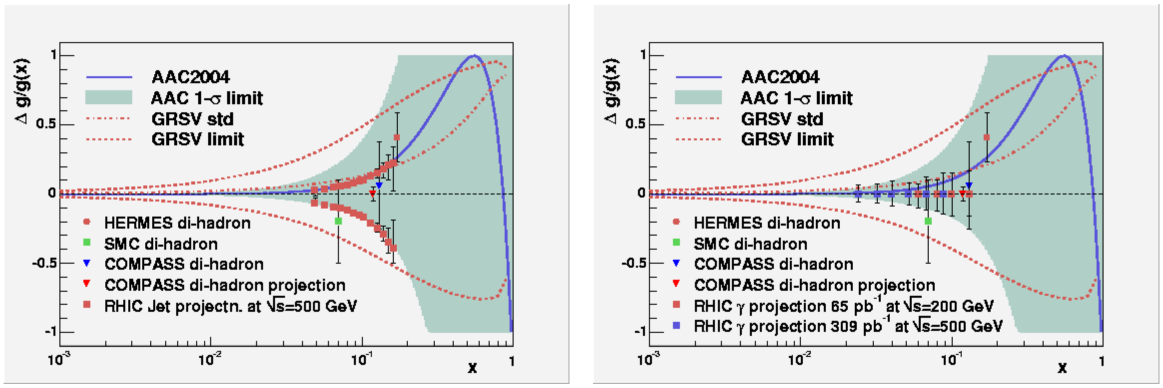


Figure 4 Plot of models of the gluon polarization, $\Delta g(x) / g(x)$ versus log x, where x is the fraction of the proton momentum carried by the gluon. The curves in both panels show $\Delta g(x) / g(x)$ from two analyses of polarized deep-inelastic (DIS) scattering data. The left panel shows STAR sensitivities from jet production at $\sqrt{s}$ = 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.

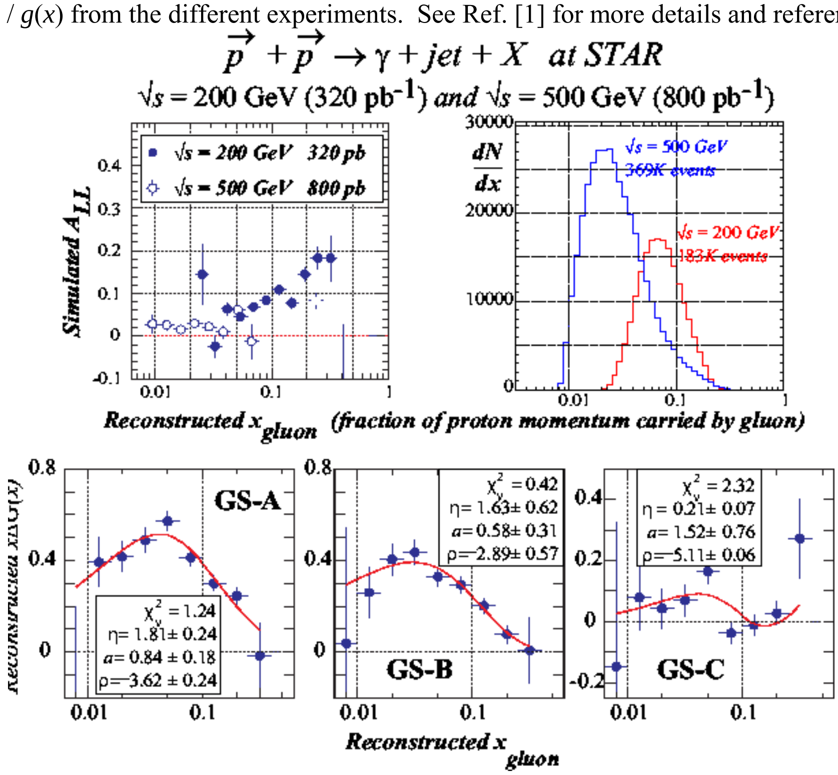


Figure 5 Simulated gluon polarization sensitivities for a measurement and an analysis of A_{LL} for γ-jet coincidences with the STAR detector at $\sqrt{s}$ = 200 and 500 GeV, illustrating the importance of rapidity correlations to determine the Bjorken-x dependence of $\Delta g(x)$. Through rapidity 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.

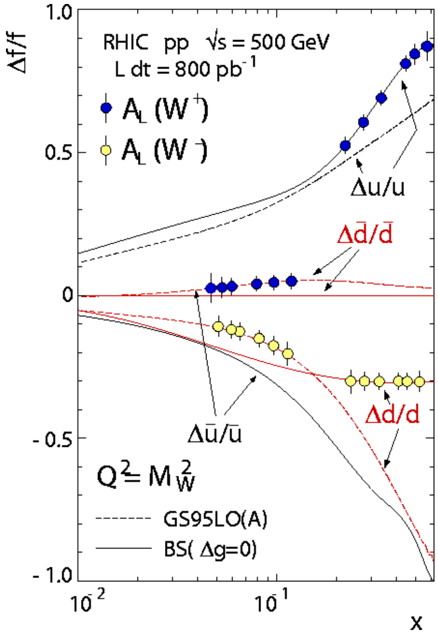


Figure 6 Quark and antiquark polarization in the proton, $\Delta f(x)$ / $f(x)$, versus log x with models for up and down quarks and antiquarks, with expected uncertainties for RHIC. The x variable is the fraction of the proton momentum carried by the quark or antiquark. See Ref. [1] for details and 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 ½ℏ 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

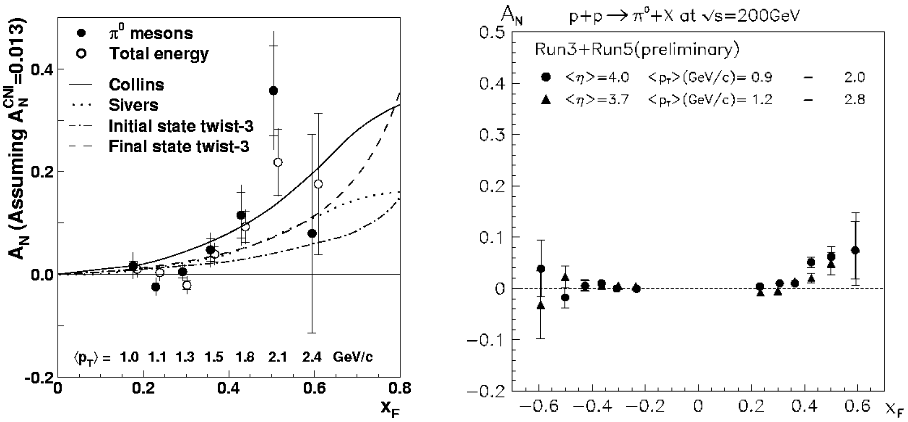


Figure 7 (*Left*) Transverse single-spin asymmetries for π^0 production at <η>=3.8 in polarized *pp* collisions at $\sqrt{s}$ = 200 GeV reported by the STAR collaboration [4]; (*Right*) More precise measurements completed in runs 3,5 [12].

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 $\sqrt{s}$ = 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

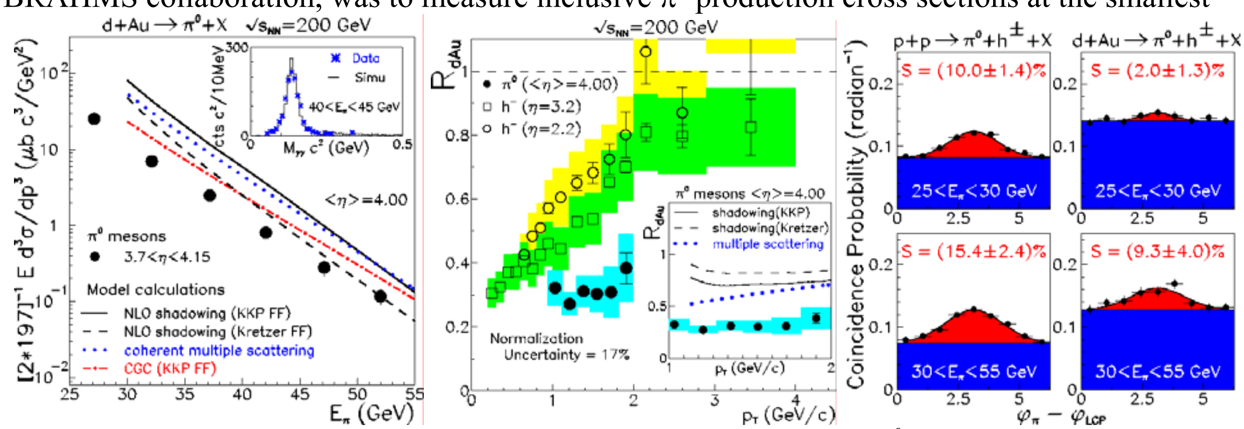


Figure 8 (Left) The x_F dependence of the scaled cross section for forward π^0 production in d+Au collisions compared to conventional and gluon saturation model calculations; (Middle) ratio of d+Au to p+p cross sections scaled so that no nuclear effects give unity. The observed suppression of the π^0 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 η=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

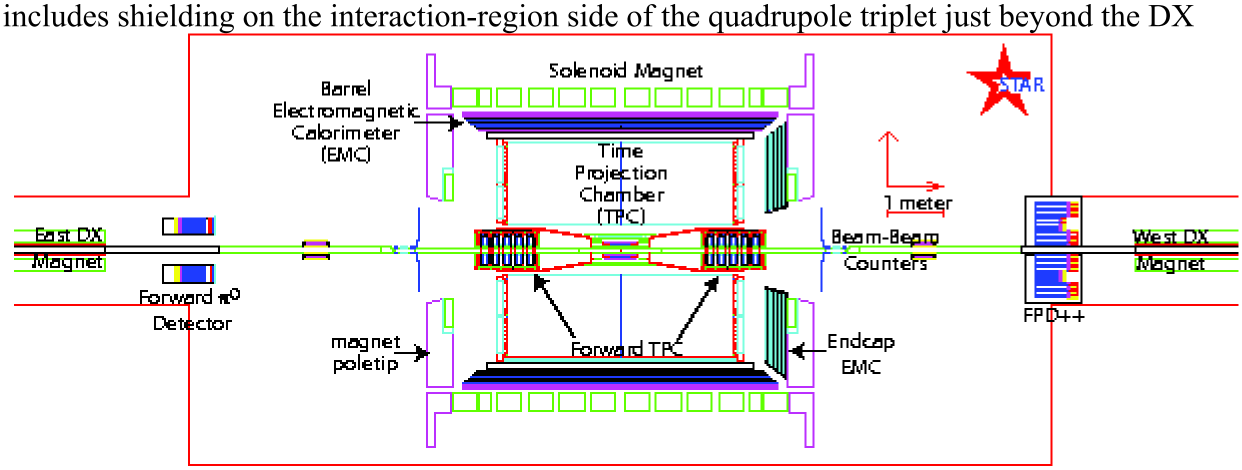


Figure 9 Schematic layout of STAR in its configuration for RHIC run 6. The FPD++ is an engineering test of a Forward Meson Spectrometer planned to replace it for RHIC run 7. The FMS will provide 2π azimuthal coverage in the forward direction, thereby providing STAR with nearly hermetic calorimetric coverage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

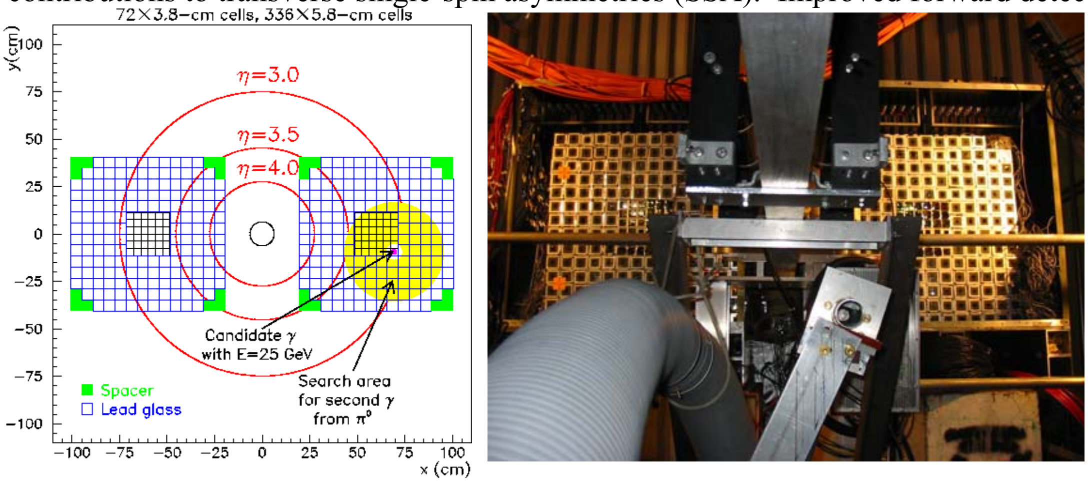


Figure 10 (Left) Schematic view of the STAR FPD++ as seen from the interaction point looking to the west. The calorimeter size is matched to the requirements for discriminating prompt photons from photon daughters of neutral mesons. The yellow shaded region corresponds to 95% of the decay phase space 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

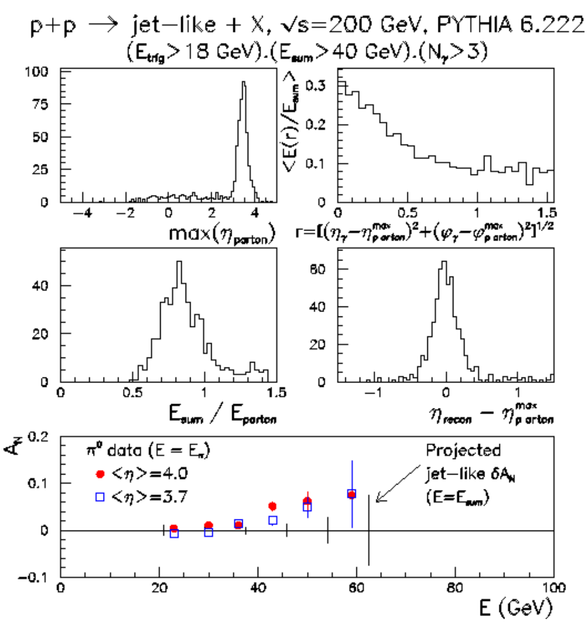


Figure 11 PYTHIA simulations of FPD++ response for p+p collisions at $\sqrt{s}$=200 GeV. E_{trig} (E_{sum}) is the energy sum in the central section (entire) of the calorimeter; (upper left) most forward hard-scattered parton η distribution; (upper right) distribution of photon energy relative to the 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%.

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

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

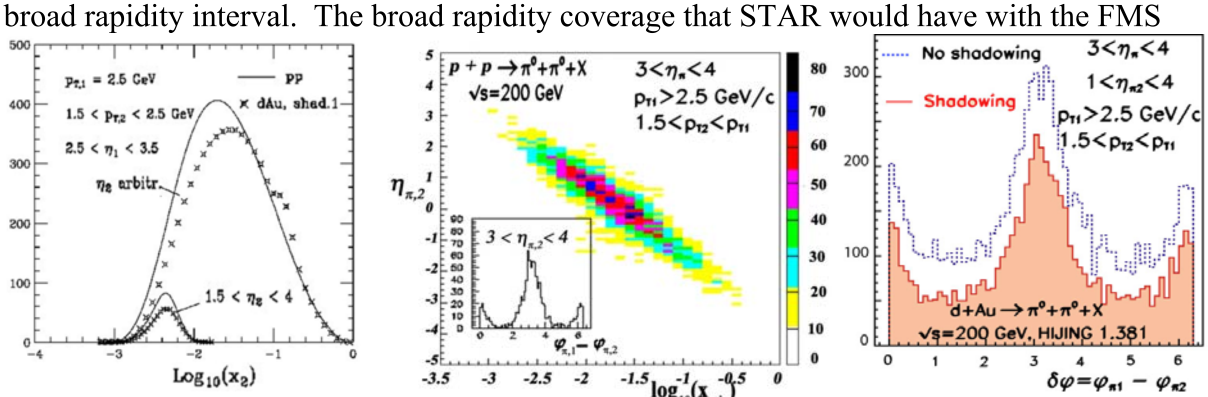


Figure 12 (Left) pQCD calculation of the cross sections for coincident π^0-π^0 production at large rapidity in p+p and d+Au collisions at $\sqrt{s_{NN}}$=200 GeV. The smallest *x* values are probed when both neutral pions are detected at large rapidity. (Middle) PYTHIA simulation of π^0-π^0 production 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 × 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].

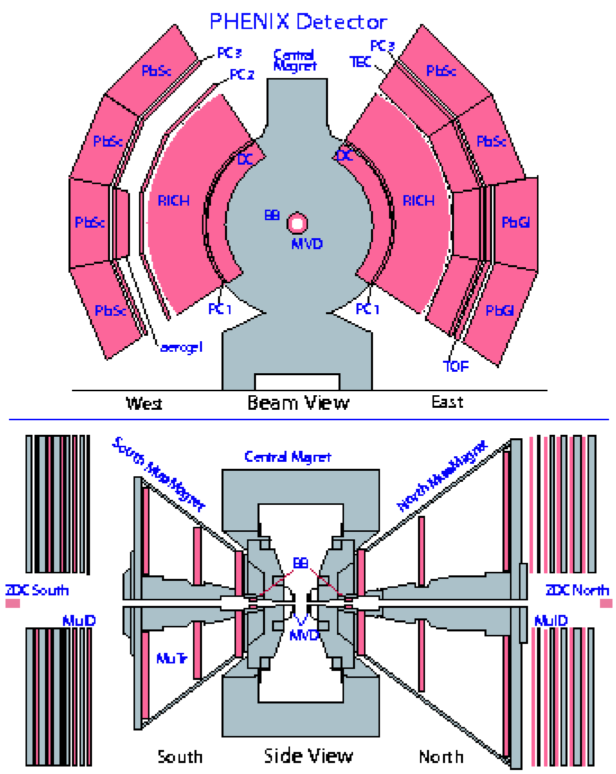
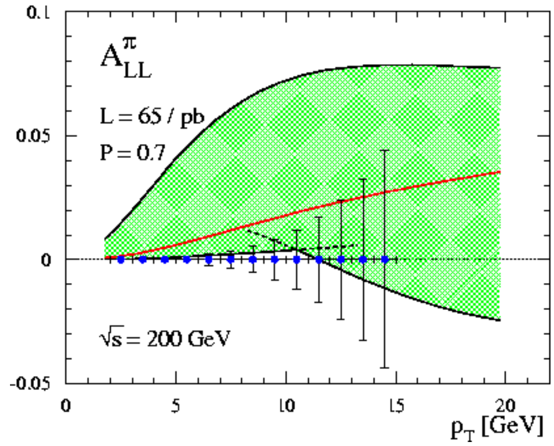


Figure 13 Plan and side views of the PHENIX

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.

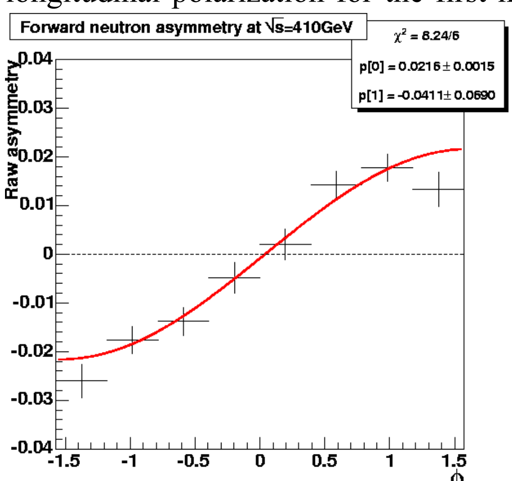


Figure 15 Transverse single spin asymmetry for far forward neutrons detected in the Zero Degree Calorimeters at PHENIX for $\sqrt{s}$ = 410 GeV polarized p+p collisions. This spin effect is used to measure the polarization direction of colliding polarized protons at PHENIX.

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.

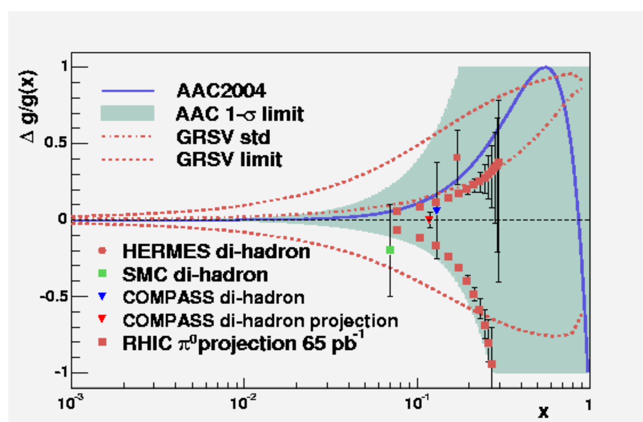


Figure 16 Plot of the gluon polarization, $\Delta g / g$, versus x, the fraction of the proton momentum carried by the gluon. Projections are for RHIC-PHENIX future measurements for π^0 at $\sqrt{s}$=200 GeV. See Ref. [1] for details.

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).

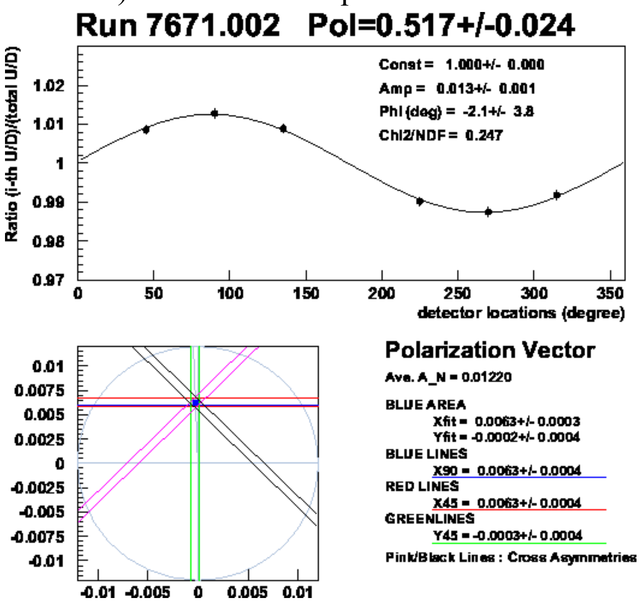


Figure 17 Raw asymmetries versus detector location (azimuthal angle) measured by pC polarimeter. Fits to the amplitude and phase of the harmonic modulation determine the vertical and radial polarization components of the beam.

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.

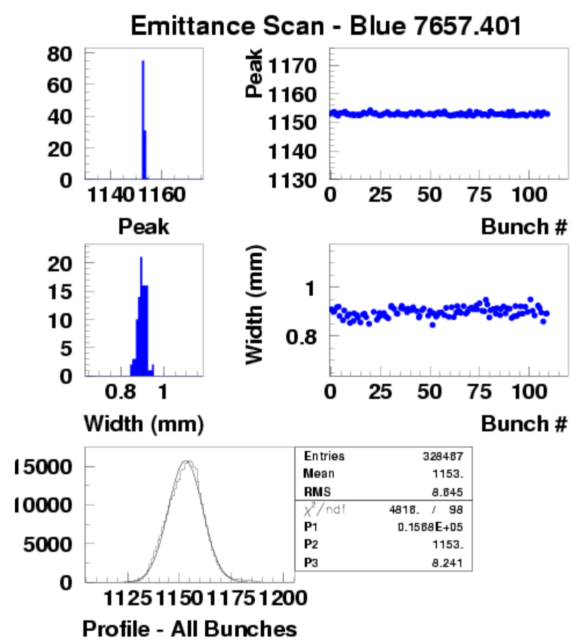


Figure 18 Measurements with the pC polarimeter that determine the emittance of the RHIC beams via a scan of the carbon ribbon target across the beam. Systematic bunch-to-bunch variations in the emittance are observed..

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.

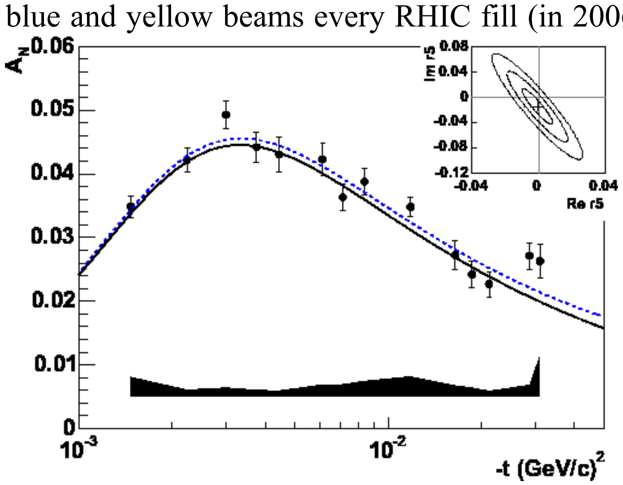


Figure 19 The |t| dependence of the analyzing power for p+p elastic scattering for 100 GeV protons scattering from the polarized jet target.

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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Budget Adequacy, Issues, Justification

The present (FY 2006) level of support for the RHIC Spin Group is inadequate. The goal of the group is to develop and support the RHIC spin program through developing strong spin groups based at BNL for STAR and PHENIX, and through developing common required tools such as polarimetry. The original group outline, given to the Symons panel on Medium Energy in 1998, recommended 2 staff members in each area, 6 total. The panel and DOE instead recommended that strong groups be formed, rather than providing a skeleton representation for spin physics at BNL. The agreed upon group size was targeted at 4-5 in STAR and in PHENIX, with 2 in polarimetry, about 11 total.

On this basis, G. Bunce transferred from the AGS Department to Physics to lead and develop the new group. Also on this basis, L. Bland resigned his position as a tenured professor at Indiana to join the new group, to develop the new STAR spin group at BNL. (It was decided to have a single Medium Energy spin group, rather than separate groups for STAR and PHENIX.) The present group sizes are STAR—2, PHENIX—2, polarimetry—1.5. Note that we have had very adequate support for equipment, through the DOE Office of Nuclear Physics (pC and jet polarimeters, including waveform digitizers built by Yale) (STAR—BB, FPD, FPD++, FMS) (PHENIX—neutron local polarimeter, EMCal/RICH trigger, Global Level 1 Trigger for spin, and through NSF (PHENIX forward muon trigger).

The physics plan with the present group size is not sustainable, for the STAR forward physics initiative for helicity structure, for transverse spin, and for saturation physics; and for polarimetry. For PHENIX, RBRC and RIKEN have a large group of young scientists based at BNL on spin; however, we recommend one additional staff scientist to provide experienced leadership.

The FPD++ for STAR was built for the 2006 RHIC run using a large number of physics undergraduate and graduate students (4 from Stony Brook, 1 from Texas A&M, 4 from Penn State and 1 from Berkeley) with only local leadership from Bland and Ogawa. A planned additional staff member for this group, to replace Bernd Surrow (now MIT), was dropped due to the FY 2005 budget shortfall.

The RHIC polarimeters are now widely used for polarization and luminosity development, in addition to measurements every 1-2 hours during each store for the experiments. The experiments are now beginning to make precision measurements of physics asymmetries. In 2005, 1000 polarization measurements were made, with a full time staff on the polarimetry of 2. This has been inadequate and unsustainable. (We note that the SLAC SLD polarimetry was staffed with 10 Ph.D. scientist FTEs each year, for a polarimetry system no more exotic than RHIC's.)

We propose to add 2 physicists to STAR in 2006-7 (1 staff, 1 post-doc), 1 physicist to polarimetry in 2006-7 (post-doc), 1 physicist to PHENIX in 2008 (staff), 1 physicist to STAR in 2008 (post-doc). The proposed group structure is then:

- STAR—3 staff, 2 post-docs (4.6 FTEs)
- PHENIX—3 staff (3 FTEs)
- Polarimetry—1.5 staff, 1 post-doc (2.3 FTEs)

Total scientist FTEs: 10 (in 2008) (now 5.5)

We believe that the proposed, and planned, group size for STAR, with additional groups within STAR that have joined the spin effort, will support the ambitious and exciting program discussed in the RHIC Spin Plan. We believe that the proposed number of experienced physicists for PHENIX, with the RBRC and RIKEN young scientists, will sustain and drive the spin program.

We have initiated an effort in polarimetry to move operations to CAD, and to focus on developing and leading a sustainable analysis team from our group, STAR, and PHENIX. It is crucial that this group be led by a strong and experienced spin physicist (as it is by A. Bravar), and that it be based in the BNL Physics Department. With the additional post-doc for our group, and 2 rotating members of the polarimeter analysis group each from PHENIX and STAR, the total analysis FTEs will be about 6 to 7 during runs. Our goal, already in progress, is to perform the polarimeter offline analysis in real time, and then to normalize with the jet soon after the run is completed.

Proposed Budget:

These estimates represent our present planning and are slightly different from the Field Work Proposal.

Budget Table

Resource Category	FY 2007	FY 2008	FY2009	FY 2010
Salaries w/fringe and indirects	1,588.3	1,868.5	1,943.3	2,020.0
Material, Services & Travel w/indirects	209.3	215.3	221.6	228.0
Other: Space, Power, Dept burdens, etc. w/indirects	291.1	330.0	342.5	355.4
Total	2,088.8	2,413.9	2,507.3	2,604.4
MST Direct Purchasing $ Power	140.3	144.3	148.5	152.8

Staffing Table

Staff		FY 2007	FY 2008	FY2009	FY 2010
	Scientific	9.0	10.0	10.0	10.0
	Administrative	0.5	0.5	0.5	0.5
Total		9.5	10.5	10.5	10.5

The research plan is based on equipment support for STAR and PHENIX as described in the **Mid-Term Strategic Plan: 2006-2011 For the Relativistic Heavy Ion Collider** available at http://www.bnl.gov/henp/docs/RHICplanning/RHIC_Mid-termplan_print.pdf.

Impact on other fields and education

The RHIC Spin program has been a magnet to attract students from many different areas. There are 10 graduate students associated with the RIKEN/BNL Research Center working at Brookhaven National Laboratory (BNL). In total, there are 10 students who have received their PhD on work related to the RHIC spin program. Presently, there are 5 graduate students who spend significant time at BNL beyond their normal shift duties to work on the spin program.

Undergraduate students have also had a significant involvement in the RHIC spin program. In total, 7 students associated with the Summer Undergraduate Laboratory Intern program have been in residence at BNL over the past four years to work with members of the RHIC Spin Group. In addition, four undergraduate physics majors from Stony Brook University have spent time at BNL in the past year as part of their laboratory training curriculum. They have assisted with the construction of the FPD++ calorimeters which serve as the engineering test of the Forward Meson Spectrometer at STAR. This project has also attracted students during the summer. In the summer of 2005, four undergraduate students from Penn State University and one student from University of California at Berkeley were in residence at BNL preparing and testing detectors for the FPD++. The work involved inspection of the lead-glass detectors to select those with good optical coupling of the photomultiplier tubes to the lead glass, cleaning and wrapping the detectors with reflectors and then testing individual detectors with a light emitting diode (LED), whose light output was monitored by a reference detector. In the tests, gain curves were measured for each detector from data acquired for LED pulses at four different high-voltage settings, resolution of the optics and photomultiplier were determined from data acquired for LED pulses, the rate dependence of each photomultiplier was measured and six measurements of the transverse dimensions of each lead glass block were made. The students recorded all of this information into a spreadsheet.

Including graduate students who have visited BNL to work on the FPD++/FMS project, in total 13 students have been involved in the project working at BNL, to date.

The goal remains to have the undergraduate students from Stony Brook University be involved in virtually all aspects of a high-visibility experiment at RHIC. This has been ongoing, from their efforts to prepare and test detector assemblies, to their assistance in stacking the FPD++ calorimeters (Fig. 10), their assistance in testing electronics for the FPD++ and their participation in commissioning of the detector during RHIC operations. Commissioning work continues at the writing of this proposal. Following that, they will be involved in online monitoring of the detector performance during collisions and analysis of the resulting data.

Outreach Activities

The BNL RHIC Spin Group participates in multiple outreach activities. Activities include providing tours of PHENIX and STAR, associated with the BNL Summer Sunday program and at other times. In addition, there has been participation in the Women in Science Education (WISE) program, including lecture/demonstrations to 10th grade high school women. We have also helped judge local science fairs.

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Education and degrees:
1967: B.S. in Physics, MIT, Cambridge, MA
1971: Ph.D., University of Michigan, Ann Arbor, MI (Advisor: O.E. Overseth)
2003: Fellow, APS

Career:
2000-present: Group Leader, RHIC Spin Group
2000: Senior Physicist, Physics Department
1998-present: Deputy Group Leader, RIKEN BNL Research Center
1991-present: Co-Spokesman, RHIC Spin Collaboration
1989-2002: Program Manager, Muon g-2 Experiment, BNL
1985-1986: Visiting Physicist, L.A.P.P., Annecy-le-Vieux, France (UA1)
and Professor Invite, Universite de Provence, Aix-Marseille, France
1981-1985: Deputy Division Head, Experimental Planning Division, BNL
1979-2000: Physicist (tenured 1982), AGS Department, BNL
1977-1979: Associate Physicist, Accelerator Department, BNL
1973-1977: Research Associate, U. Wisconsin, Madison (with L.G. Pondrom)
1971-1973: Visiting Physicist, D.Ph.P.E., CEN/Saclay, France (with R. Turlay)

Main achievements:
---Established experiment groups for RHIC Spin and RBRC.
---Developed proton-carbon and proton-proton (jet) polarimetry for RHIC
---Measurements of cross section for pi^0 and direct photon establish applicability of NLO pQCD to RHIC spin measurements
---Developed approach for RHIC spin measurements, first A_LL result
---Developed RHIC spin program [1] and RHIC Spin Collaboration
---Precision measurement of muon g-2 [2]
---Hard scattering measurements with exclusive reactions, color transparency
---Discovery of lambda [3] and cascade polarization in high energy production, including measurement of magnetic moments
---Early rare K decay searches including discovery of $K^+ \rightarrow \pi^+ e^+ e^-$
---Confirmation of Glauber model with deuteron-proton double scattering

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Education and degrees:
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1979-1983: Ph.D. Department of Physics, University of Pennsylvania

Career:
2003-present: tenured Physicist, Brookhaven National Laboratory
2001-2003 : Physicist, Brookhaven National Laboratory
1999-2001 : Professor of Physics, Indiana University
1987-1999 : Associate Professor of Physics, Indiana University
1984-1987 : Assistant Professor of Physics, Indiana University
1983-1984 : Research Associate, University of Texas

Awards and National Service:
1985: Alfred P. Sloan Foundation Fellowship
1985: Presidential Young Investigator Award
1988-1990: Division of Nuclear Physics Program Committee
1998-2002: Member Nuclear Science Advisory Committee
2003: Outstanding Mentor, DOE OS Undergraduate Research Programs

Main achievements:
---Designed, implemented and operate STAR beam-beam counters used as the minimum bias trigger for p+p collisions; absolute luminosity monitor for p+p collisions; spin-dependent relative luminosity monitor and local polarimeter to establish the polarization direction in polarized p+p collisions at the STAR interaction point.
---Designed, implemented and continued the development of forward electromagnetic calorimetry (EMC) at STAR. The first prototype established the functionality of STAR endcap EMC in RHIC collision environment and resulted in the only spin dependent effect observed to date in kinematics where NLO pQCD calculations agree with measured cross sections. The STAR forward pion detector was then used for increased precision in the measurement of these spin effects and the measurement of neutral pion cross sections in d+Au and p+p collisions. Strong suppression of the forward neutral pion cross section is observed in d+Au collisions.

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(3) "Future of Low-x Forward Physics at RHIC" L.C. Bland, et al. Eur. Phys. J. C43 (2005) 427.

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Education and degrees:
1990: Laurea in Fisica, University of Trieste, Italy
1994: Ph.D., University of Iowa, Iowa City, IA

Career:
2005-present: Physicist, Physics Department, BNL
2003-2005: Associate Physicist, Physics Department, BNL
2001-2003: Assistant Physicist, Physics Department, BNL
1995-2001: Scientific Collaborator, University of Mainz, Germany
1991-1994: INFN Fellow, University of Trieste, Italy

Main achievements:
---Leading proton polarimetry at RHIC
---Developed proton-Carbon and proton-proton polarimetry for RHIC
---First precision measurement of A_N in elastic proton-proton scattering and confirmation of the CNI shape [1]
---Built the COMPASS trigger for muon scattering
---Developed the COMPASS spin physics case [2]
---Precision measurements of proton and neutron polarized structure functions (Spin Muon Collaboration)
---Measurement of pion production asymmetries (A_N) with polarized proton and antiproton [3] beams (E704 Collaboration)
---Discovery of large spin effects (A_N and D_{NN}) in lambda production in high energy collisions (E704 Collaboration)

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Education and degrees:
1985-1992: M.S., Department of Physics, Moscow State University, Moscow
February 1999: Ph.D., Institute for High Energy Physics (IHEP), Protvino, Russia

Career:
2005-present: Associate Physicist, BNL
2003-2005: Assistant Physicist, BNL
2002-2003: RIKEN Fellow, RIKEN BNL Research Center
1999-2002: Research Associate, RIKEN BNL Research Center
1992-1999: Scientific Researcher (staff position), IHEP, Protvino, Russia.

Main achievements:
---Participated in the design of the Lead Scintillating Electromagnetic Calorimeter (EMCal) for PHENIX (15552 towers), including the detailed GEANT simulation of EMCal response used to optimize the EMCal characteristics for PHENIX
---Designed and developed the offline package for data analysis from EMCal (both PbSc and PbGl - 24768 towers). Based on test beam data, developed algorithms for cluster reconstruction and particle identification in EMCal in wide energy (0.3-80 GeV) and impact angle (0-20 degrees) ranges. A number of ideas were developed and implemented to effectively use the PHENIX EMCal in high multiplicity environment and at high transverse momentum.
---Led the group for the transverse energy (ET) measurements in heavy ion collisions. The N2 PHENIX physics paper on this topic was published, discovering that the energy density created at RHIC in central gold-gold collisions is well above the energy needed for phase transition.
---Participated in the group to analyze pi0 yields in heavy ion collisions, led to discovery of high pT hadron suppression in central collisions [1].
---Led the group to measure pi0 production in proton-proton collisions. The unpolarized pi0 cross section was found to be in good agreement with NLO pQCD calculations [2]. This allows the interpretation of the RHIC spin results in the framework of NLO pQCD.
---Led the group to produce result on pi0 double helicity asymmetry - first RHIC result sensitive to gluon polarization in the proton [3].

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[3] S.S. Adler, et al., "DOUBLE HELICITY ASYMMETRY IN INCLUSIVE MIDRAPIDITY PI0 PRODUCTION FOR POLARIZED P+P COLLISIONS AT S(NN)**(1/2) = 200-GEV", Phys.Rev.Lett. 91:241803,2003.

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Education and Degrees:
1971: B.S., Pennsylvania State University, State College, PA
1974: M.S., Iowa State University, Ames, IA
1977: Ph.D., Iowa State University, Ames, IA

Career:
1980 – present: Physicist, Brookhaven National Laboratory
1977 – 1980: Post Doctoral Fellow, Iowa State University, at Brookhaven National Laboratory

Main Achievements:
---Worked with RHIC spin program to develop polarimeters and analysis techniques.
---Member of pp2pp collaboration, developed detectors and techniques for measuring elastic proton scattering at RHIC.
---Developed DAQ for hypernuclear physics fixed target program at the AGS.
---Constructed and maintained the isotope separator user facility at the HFBR, including ion source and target development, DAQ and analysis software, and detector support infrastructure.

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[3] R. L. Gill, R. F. Casten, D. D. Warner, D. S. Brenner, and W. B. Walters. IBA calculations near the Z = 64 subshell. Phys. Lett. 118B, 251–7 (1982).

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Education and degrees:
1992: B.S. in Physics, Nagoya University, Japan
1994: M.S. in Physics, Nagoya University, Japan
1997: Ph.D. in Physics, Nagoya University, Japan

Career:
2005-present: Associate Physicist, BNL
2003-2005: Assistant Physicist, BNL
2002-2003: Research Associate, BNL,
1997-2002: Postdoctoral Researcher. Penn State University

Main achievements:
--- Participating in the STAR Beam-Beam Counter (BBC) and Forward Pi0 Detector (FPD) project. I took roles in design, construction, testing, commissioning, building readout electronics,
online and offline analysis software, calibrations and physics analysis.
--- Participating in the inclusive forward pi0 measurements in polarized proton-proton collisions. The unpolarized pi0 cross section was found to be in good agreement with NLO pQCD calculations, and large analyzing power was observed [1].
--- Participating in the forward pi0 measurements in deuteron-gold collisions, Inclusive forward pi0 cross section, as well as azimuthal correlation between leading charged particles, were found to be suppressed compared to normalized proton-proton collisions, suggesting possible gluon saturation at low-x.
--- As a visiting scientist of RBRC, participating on RBRC effort on Belle (at KEK, Japan) collaboration to measure Collins fragmentation function [2]
--- Serving as Spin Physics Working Group co-convenor in the STAR collaboration since 2004.
--- Hard scattering measurements with exclusive reactions, color transparency
--- Participated in Spin Muon Collaboration (SMC) at CERN and led the analysis of 2004 deuteron data [3].

[1] J. Adams *et al.* (STAR Collaboration), CROSS-SECTIONS AND TRANSVERSE SINGLE SPIN ASYMMETRIES IN FORWARD NEUTRAL PION PRODUCTION FROM PROTON COLLISIONS AT S**(1/2) = 200- GEV. Phys.Rev.Lett.92:171801,2004
[2] A. Ogawa, D. Gabbert, M. Grosse Perdekamp, R. Seidl, K. Hasuko,
SPIN DEPENDENT FRAGMENTATION FUNCTIONS AT BELLE
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Publications 2001 – 2006, RHIC Spin Group

Primary Publications – Members of Group Played Major Role

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Attachment #1

Field Work Proposal Sections

U. S. DEPARTMENT OF ENERGY
FIELD WORK PROPOSAL

1. B&R No.	2. Contractor No.:	3. Date Prepared:	4. Task Term:
KB0101022	PO-001	03/01/2006	Begin: Continuing End: Open

5. Work Proposal No.:

6. Work Authorization No.: KBCH136

7. Title: Spin and Nuclear Structure Investigations with Hadronic Probes

8. Principal Investigator(s) : Bunce, Gerry (631- 344-4771

9. Headquarters/Operations Office Program Manager:
Tippens, William, B.

10. Operations Office Work Proposal Reviewer:

11. Contractor Work Proposal Manager:
Dawson, Sara L. (631- 344-3854
Ludlam, Thomas W. (631- 344-7753

12. Headquarters Organization:
Office of Science

13. Operations Office: CHICAGO

14. Contractor Name:
BROOKHAVEN SCIENCE ASSOCIATES
BROOKHAVEN NATIONAL LABORATORY

15. HQ Organizational Code:
SC

16. DOE Organizational Code:
CH

17. Contractor Code:
BN

18. Work Proposal Description (Approach, anticipated benefit in 200 words or less, suitable for public release) :

The goal of "Spin and Nuclear Structure Investigations with Hadronic Probes" is to study the spin structure of the proton using polarized proton collisions in the Relativistic Heavy Ion Collider (RHIC).

The RHIC accelerator collides beams of polarized protons, reaching very high energy. Experiments at RHIC study the polarization of the constituents of the protons—the gluons that hold the proton together, the quarks and the anti-quarks. RHIC is the most sensitive machine for this study, complementing results from the Stanford Linear Accelerator Center (SLAC), the Centre Europeén de Recherche Nucléaires (CERN) and Deutsches Elektronen-Synchrotron (DESY) which show that the quarks themselves carry only about 20% of the proton spin.

This work is performed in support of the DOE Mission on Science and Technology as defined in the Office of Science Strategic Plan. It addresses the Objective of Exploring Matter and Energy and specifically the Challenge of Components of Matter. It is a component of the Brookhaven National Laboratory Critical Outcome on Excellence in Science and Technology and particularly supports the Objectives of Research Quality and Relevance to DOE Mission.

19. Principal Investigator (s) :

Signature(s) ______ Date 03/01/2006

20. Contractor Work Proposal Manager:

_Signature ______ Date 03/01/2006

21. Operations Office Review Official:

Signature ______ Date

22. Detail Attachments:
- (☒) a. Purpose
- (☒) b. Approach
- (☒) c. Technical progress
- (☐) d. Future accomplishments
- (☒) e. Relationships to other projects
- (☐) f. Explanation of milestones
- (☐) g. Other (Specify Topic)

WORK PROPOSAL REQUIREMENTS FOR OPERATING/EQUIPMENT OBLIGATIONS AND COSTS

Contractor Name: **Brookhaven Science Associates/ Brookhaven National Laboratory**	Contractor Number: **PO-001**	Work Authorization No: **KBCH136**	Date Prepared: **03/01/2006**
Title: Spin and Nuclear Structure Investigations with Hadronic Probes			**B&R Code: KB0101022**

			FY 2007		FY 2008				
23. Staffing (In staff years)	**Prior Years**	**FY 2006**	**President s**	**Revised**	**Request**	**Authorized**	**FY 2009**	**FY 2010**	**Total to Complete**
a. Scientific.............		5.7	8.7	8.7	9.6				
b. Other Direct..........		0.5	0.5	0.5	0.5				
c. Total Direct...........		**6.2**	**9.2**	**9.2**	**10.1**				
24. Operating Expense (in thousands)									
a. Total Obligations.....		**1,813**	**2,100**	**2,100**	**2,241**				
b. Total Costs............		**1,732**	**2,088**	**2,088**	**2,241**				
25. Equipment (in thousands)									
a. Equip Obligations....		**0**	**0**	**0**	**0**				
b. Equip Costs...........		**0**	**0**	**0**	**0**				

26. Milestone Schedule (Tasks)	**Proposed Schedule**

Footnotes:

22. Detail Attachments

a. Purpose

- To understand the proton: how is the spin of the proton formed from its constituents?

This work effort may support at a minimum level or concurrently, as appropriate, the Technology Transfer and Science Education missions of the Department of Energy.

b. Approach

1. RHIC Spin

RHIC Spin Group scientific members are A. Bazilevsky (PHENIX); L. Bland (STAR); A. Bravar, (Polarimetry and STAR); G. Bunce (PHENIX); W. Guryn (pp2pp Spokesperson through 12/31/05; detailee DOE from 1/1/06); R. Gill (Polarimetry); A. Ogawa (STAR); G. Rakness, Post Doc (shared position with Penn. State U., STAR to 9/1/05).

The proposed development of the RHIC Spin Group is to build staff to reach 5 members for each of the PHENIX and STAR spin efforts in the group by FY 2008. This includes members with emphasis on polarimetry. (Note that this level has not been accomplished.)

The goal of the Medium Energy RHIC Spin Group is to develop and support the physics program at RHIC for collisions of polarized protons. The group defines physics goals and develops the capabilities of the RHIC experiments to probe the spin content of the proton. Members of the Medium Energy RHIC Spin Group provide focus and leadership at Brookhaven for spin research for their experiment. At the same time, the members of the RHIC Spin Group work on common spin tools and a coordinated spin program. The collaborations at RHIC that have approved spin experiments are PHENIX, STAR, and BRAHMS. The pp2pp experiment data taking was completed in 2003.

c. Technical Progress

Technical Progress in FY 2005 and Expected Progress in FY 2006

Number of publications 38.

1. RHIC Spin

The FY 2005 run of RHIC included the first long run for the spin program, after the success of the machine development for spin in FY 2004. Polarization of 45% to 50% was regularly provided, along with higher luminosity, for the 14 weeks of spin running. The experiments PHENIX and STAR emphasized running with longitudinal polarization toward obtaining a strong constraint on the gluon contribution to the proton spin. BRAHMS took data with transverse polarization. The polarized jet target ran continuously during the run toward providing precision polarization measurements. The run included a very successful test to accelerate the beams to 205 GeV, with collisions at $\sqrt{s}$ = 410 GeV, the highest energy yet for polarized collisions. The experiments were able to take some data to test local polarimetry.

The report Research Plan for Spin Physics at RHIC was developed, covering the program until 2012, and submitted to DOE February 11, 2005.

For FY 2006, a long spin run is planned, using higher luminosity and higher polarization, expected from the first use of the new “Cold Snake” in the AGS. The Cold Snake, a device to avoid spin resonances, is expected to allow the AGS to accelerate higher intensity beam, with higher polarization, compared to the previous method of avoiding spin resonances (using an AC dipole). The principle was tested in FY 2005. The plan for this run includes transverse and longitudinal polarization for PHENIX and STAR. BRAHMS will run only during a planned short lower energy run (sqrt(s)=62 GeV).

The planned evolution of the RHIC spin program is shown in Table 1 at the end of section 22d.

There are 3 distinct areas related to RHIC Spin activities.

1.1 Polarimetry

Polarimetry for RHIC is supported from DOE and RIKEN funds. There are four types of polarimeters:
1) fast polarimeters in RHIC giving relative polarization measurements;
2) an absolute polarimeter in RHIC using a polarized hydrogen jet;
3) local polarimeters at the experiments to measure the effect of the spin rotators at the experiments;
4) a fast AGS polarimeter.
We may also propose for FY 2007-8 a fifth:
5) a fast absolute polarimeter in RHIC that uses the results of 2).

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. A faster readout was used successfully for FY 2005, with separate readout for the separate polarimeters in the two RHIC rings to allow simultaneous measurement of the beam polarization on the acceleration ramp. New mounting of the silicon detectors, based on the successful method used for the AGS polarimeter in FY 2004, was used for RHIC. Beam induced current was eliminated.

The pC polarimeters continue to 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. 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 will be used. The polarimeters will 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 will also allow RHIC to directly monitor the beam emittance, important to maximize luminosity.

2) The polarized jet target was used to measure the polarization continuously in FY 2005, alternating between blue and yellow beams every few days. The jet target polarization, measured using a Breit-Rabi polarimeter, was 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 ran simultaneously with the RHIC fast proton-carbon polarimeters to provide an absolute calibration for the pC polarimeters. 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 with far superior precision to previous measurements by Fermilab E704. 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. The reason for this difference is not known at this time.

In FY 2006, the readout of the jet polarimeter will be separated from the carbon polarimeter, mainly to simplify the operation of the polarimeters by the operating crews. Yale, through a contract with BNL and with support from RBRC, provided 96 additional WFD channels to do this.

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 will be 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.

There are two separate requests for funds: from CA-D for the jet itself, replacement silicon detectors, and installation with preparations for operation; and this request from the Physics Department (RHIC Spin Group) for R&D for electronics. Funds are included in this request for the support of ITEP work. The waveform digitizers are funded by contract with Yale, through the RHIC Spin Group. The contract started in FY 2004, through FY 2005, and provided WFD channels and ongoing R&D on a faster digizer with larger bandwidth. Six new large area silicon detectors and new preamplifiers were prepared for the FY 2005 run, and were used to measure the polarization of both RHIC beams. 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 experiments use local polarimeters to monitor the spin rotator settings for longitudinal polarization. An issue for both experiments, as the luminosity increases, will be saturation from multiple collisions in one crossing, and this will continue to be studied. PHENIX presently requires a collision trigger from beam-beam counters in coincidence with a neutron in one ZDC to measure residual transverse polarization at collision. STAR uses asymmetries in beam-beam counters, and has the hardware needed for a ZDC local polarimeter. The beam-beam counters will saturate at full RHIC spin luminosity.

4) The AGS polarimeter used 4 silicon detectors in FY 2005. Implementation of faster readout was delayed to FY 2006. For FY 2006, responsibility for the AGS polarimeter was assumed by CAD, with advice from the RHIC Spin Group expert (Bravar).

5) 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, 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.

1.2 Heavy Ion Experiments Spin Program

The measurement of the gluon polarization is a world-wide goal, due to the unexpectedly small contribution to the proton spin from quarks, as measured by electron and muon probes in a series of beautiful experiments at SLAC, CERN, and DESY over the last 20 years. RHIC, with strongly interacting quark and gluon probes, has the best machine to measure the gluon polarization. These measurements are sensitive to gluon polarization through a combination of angular momentum selection rules for the particular probes, and through the very large cross sections for jet production. Future measurements will also use direct photon production as a probe, as luminosity and polarization increase. These measurements are expected to provide the greatest precision on the gluon polarization.

The jet and π^0 probes were the basis of data taken in FY 2005 (and previous years) by STAR and PHENIX, probing the gluon polarization in the proton, and results were published for the helicity asymmetry for π^0 from the 2003 run by PHENIX. The p-p run in FY 2004 was short and focused on development; with much higher polarization achieved with the addition in the AGS of a new helical Siberian Snake. For measurements of the two-spin longitudinal asymmetry, the statistical errors are proportional to the inverse polarization-squared. Data from FY 2004 significantly improved the sensitivity for gluon polarization, and the long run in FY 2005 improved the expected sensitivity by a factor of about 4 (in uncertainty). BRAHMS took data with transverse polarization in FY 2005 and observed large asymmetries.

The FY 2006 spin run will provide data on jet (and pion) production at high p_T with longitudinally polarized proton beams. These events are expected to be sensitive to the gluon polarization via gluon-gluon and quark-gluon scattering at a level to determine whether the gluon carries most or little of the proton spin. With high luminosity, the experiments will also collect first asymmetry data on the golden probe of gluon polarization, direct photon production. This run will feature the first data with the complete STAR endcap calorimeter to obtain fully reconstructed photon + jet events. These data allow reconstruction of the gluon momentum fraction, to better determine the gluon’s contribution to the proton’s spin. Gluon polarization will be measured at PHENIX with leading pions from jets. Heavy quark production in PHENIX (with combined electron-muon coincidence triggers) will be used to independently measure gluon polarization.

Results from the first polarized proton run at RHIC revealed that large transverse spin effects observed at an order of magnitude lower collision energy in the E704 experiment persist to collisions of transversely polarized protons at RHIC. The underlying physics involves either or both the transversity structure function through the Collins effect or possible sensitivity to parton orbital angular momentum within the proton through the Sivers effect. Understanding transverse spin structure is a goal of the world spin community and is actively being pursued by the HERMES and COMPASS experiments. There are also significant recent developments in theory fueled in part by results from RHIC. Indeed, in FY 2005, special workshops were held on transverse spin at Jefferson Lab, Brookhaven, and Como, Italy.

In the FY 2006 run, STAR will use about 1/3 of the run to study transverse spin with a new large forward detector. PHENIX plans to also study transverse spin using a measurement of spin-correlated momentum imbalance between di-hadrons detected at midrapidity, predicted to be sensitive to the gluon Sivers function.

STAR Spin Progress and Plans:

- Measurement of A_{LL} for midrapidity jet production with the completed barrel and endcap EMC and for forward pion production. The measurements will be made with substantially higher polarization and integrated luminosity than were available in the FY 2003 run, thereby enabling determination of A_{LL} to higher p_T where quark-gluon scattering becomes the dominant subprocess. With sufficient integrated luminosity, there will also be a sample of direct photon events.

- Embark on measurement of spin-correlated momentum imbalance between di-jets produced at midrapidity to gain sensitivity to the gluon Sivers function. Measure analyzing power of forward π^0 production to disentangle the x_F and p_T dependences.

- Expansion of the forward π^0 detector to an engineering test configuration of the forward meson spectrometer. Addition of more lead glass detectors from detectors recycled from a FermiLab experiment has been completed to provide identification of heavier mesons through their all photon decays and forward near-side (forward inclusive jet) and away-side (forward di-jet) π^0–π^0 coincidences. Larger area coverage is required to increase the photon acceptance and hence the efficiency for the reconstruction of heavier mesons, forward π^0–π^0 coincidences and ultimately forward direct photon events. From π^0–π^0 coincidences, transverse asymmetries can be studied with respect to the Collins angle of the jet and discrimination between the Collins and Sivers mechanisms is possible. Further refurbishing of detectors, support stands, and readout electronics will be required To complete the STAR forward meson spectomreter. The engineering test modules will be operated during the FY 2006 run. Completion of the forward meson spectrometer is planned prior to the start of the FY 2007 run.

- Development of design for forward tracking to improve momentum resolution for forward W production. Forward W production allows the most direct connection between expected large parity violation and quark/anti-quark polarization. Improvements in forward tracking at rapidities spanned by the endcap EMC are needed to discriminate W^+ from W^- especially as the pseudorapidity approaches 2.

PHENIX Spin Progress and Plans:

- A new result on the helicity asymmetry for π^0 production from the FY 2004 run, including an improved calibration of the polarimeters based on the jet, has been prepared submitted as a Brief Report to the Physical Review. The result is inconsistent with maximal gluon polarization. The BNL RHIC Spin Group led this analysis.

- The π^0 events during the FY 2005 run were shipped via the grid to RIKEN, Japan, and analyzed there in the summer 2005 by the PHENIX spin group, including BNL. Preliminary results for A_{LL} were presented to the PANIC symposium in New Mexico, October 2005. The measured asymmetries for FY 2003 and 2004, between p_T = 2-5 GeV/c, were consistent with small or moderate gluon polarization, and rule out maximal gluon polarization models.

- A direct photon cross section paper, for p_T=3-17 GeV/c, is being prepared for submission to Physical Review Letters. The result is described well by the prediction of perturbative QCD, for p_T=5 GeV/c and higher. This process will provide a particularly clean measurement of the gluon polarization as we reach high luminosity and beam polarization.

- There are several issues that need to be addressed as we reach higher luminosity. The beam-beam counting rate will saturate at the highest RHIC proton luminosities. To monitor the relative luminosity, a correction scheme has been developed for high luminosity using the recorded bunch shapes in RHIC (the wall current monitors). Another issue is to replace the beam-beam coincidence as a collision requirement in the trigger, which will be studied in 2006.

- Measurement of A_{LL} for pion and heavy quark production, with high polarization and high integrated luminosity is the focus of the FY 2006 run. These measurements are very sensitive to the gluon polarization in the polarized protons. With high luminosity, asymmetry results will reach to higher p_T, where quark-gluon scattering dominates. This provides greatest sensitivity to the gluon polarization.

- First asymmetry measurements of A_{LL} for direct photon production. The quark-gluon subprocess dominates direct photon production for proton-proton scattering. Therefore, this probe provides the cleanest direct measurement of gluon polarization.

- Construction of micro vertex detector. This detector will be important for both heavy ion and spin. For spin, heavy quark processes can be identified through secondary vertices. Heavy quark production is dominated by gluon-gluon scattering and is sensitive to the gluon polarization at smaller momentum fraction. Also, the detector will provide a jet "axis" to use to reconstruct the parton kinematics for direct photon + jet and pion + jet reactions. This gives better precision on the momentum fraction of the quarks and gluons in these processes.

- Construction will begin on prototype chambers to provide a fast trigger for muons from W decay. Background from pion decay can be greatly reduced by introducing a minimum momentum requirement of around 5 GeV/c. This necessary upgrade is being supported with NSF funds. Resistive plate chambers are planned to provide the fast tracking, with existing electronics for amplification and a local trigger decision.

BRAHMS Spin Progress:

The BRAHMS experiment has observed large asymmetries for pion production from collisions of transversely polarized protons. Large asymmetries were observed, positive for π^+ and negative for π^-, the same mirror asymmetry that had been seen at much lower energy by E704 at Fermilab. The STAR experiment has previously published the observation of a positive asymmetry for the π^0, also similar to E704. BRAHMS took data for transverse pion asymmetries in FY 2005 at $\sqrt{s}$ = 200 GeV, and reported preliminary results at the DIS 2005 meeting. BRAHMS plans to run in FY 2006 during $\sqrt{s}$ = 62 GeV running.

1.3 The pp2pp Experiment

Final results on the analyzing power have been published in Physics Letters. A paper is being prepared on two-spin asymmetries.

The experiment is not approved for more running. The collaboration has submitted a proposal to STAR for a series of measurements that include covering a larger momentum transfer range and measurements in combination with the STAR detector.

d. Future Accomplishments

Expected Progress in FY 2007

1. <u>RHIC Spin</u>

A 10-week spin run is being considered for FY 2007, following the spin Research Plan. 70% polarization and high luminosity is expected for this run. This run will emphasize data collection with longitudinal polarization to measure the gluon polarization in the proton, using direct photon production, and transverse spin collisions to study the physics of forward pion asymmetries. A new forward detector with greatly expanded coverage is expected to be in place for the STAR experiment.

1.1 Polarimetry

We plan to continue to use both proton-carbon and the polarized hydrogen jet polarimeters in RHIC. The carbon polarimeter gives fast feed-back if loss of polarization occurs for any reason, and is important for machine development, such as polarization measurements on the acceleration ramp to 250 GeV. The polarized jet gives absolute polarization for 1-2 day periods.

A new polarimeter is being considered, using a high density unpolarized hydrogen target, in the form of either micro-pellets or a gas. The high density would allow measurements within 5 minute periods or so, and the polarized jet provides the absolute analyzing power for proton-proton scattering. The recoil protons from pp scattering in the CNI region are higher energy than the carbon recoils from pC scattering for the carbon polarimeter. With the higher energy, the proton recoil energy can be measured well (the carbon recoils lose energy in the silicon entrance layer that results in a lack of precision for the carbon energy, and for the carbon analyzing power calibration). Also, the pp reaction can be measured at its peak in analyzing power due to the higher recoil energy, giving a three times larger analyzing power than for carbon. The larger analyzing power implies less scattering to obtain the same precision, reducing detector radiation damage.

1.2 Heavy Ion Experiments Spin Program

STAR Spin Plans:

- Measurements of photon + jet with barrel and endcap calorimeters and forward meson spectrometer, with longitudinal polarization, at $\sqrt{s}$ = 200 GeV. The coincidence measurements allow reconstruction of the momentum fractions of the scattering quarks and gluons, giving more precise information to determine the gluon polarization in the proton in detail.

- Measure A_{LL} for large rapidity photon production. Direct photons observed at $\eta \sim 3$ are predominantly produced by quarks with large Bjorken *x* that are highly spin polarized when longitudinally polarized protons collide with $\sqrt{s} \geq$ 200 GeV. The leading-order diagram is QCD-Compton backscattering, corresponding to the QCD analog of laser backscattering from energetic electron beams producing high-energy photons. Consequently the quark-gluon subprocess has a very large a_{LL}. Therefore, measurement of A_{LL} for large rapidity direct photon production has exceptional sensitivity to gluon polarization down to x_{gluon} = 0.001.

- Measurements of forward heavy meson and forward $\pi^0-\pi^0$ production with transverse polarization at $\sqrt{s}$ = 200 GeV to test the universality of the Sivers distribution function and to distinguish Collins and Sivers mechanisms possibly responsible for the large spin asymmetries.

- Continue measurements of the spin dependence of the momentum imbalance between mid-rapidity jet pairs to probe for a possible gluon Sivers function.

- Complete and submit proposal for forward tracking for $W^{\pm}$ charge sign determination.

- Studies of luminosity monitoring at the highest luminosities at RHIC.

PHENIX Spin Plans:

- Measurements of A_{LL} for direct photon production. The quark-gluon subprocess dominates direct photon production for proton-proton scattering. Therefore, this probe provides the cleanest direct measurement of gluon polarization.

- Construction will continue on chambers to provide a fast trigger for muons from W decay. Background from pion decay can be greatly reduced by introducing a minimum momentum requirement of around 5 GeV/c. The detector is expected to be installed for the FY 2009 run.

- Continue construction of micro vertex detector. The detector is expected to be installed for the FY 2009 run. This detector will be important for both heavy ion and spin.

- Development of a nose cone calorimeter, to replace the brass filters used for the muon arms, is being planned, for both heavy ion and spin. For the spin program, the calorimeter provides jet energy for forward processes, and isolation for W boson identification.

Expected Progress in FY 2008

1. RHIC Spin

A ten week spin run is planned in the spin Research Plan for FY 2008. This run, plus 5 weeks of running in FY 2009, is expected to complete the running needed to probe the gluon polarization at $\sqrt{s}$ = 200 GeV. Analysis will focus on pion, jet, direct photon, heavy quark, and transverse spin asymmetries.

1.1 Polarimetry

The RHIC carbon polarimeters will be used to study acceleration to 250 GeV. Development will continue for an unpolarized hydrogen target polarimeter in RHIC, including first measurements with the new polarimeter, if it is decided to proceed with this polarimeter.

1.2 Heavy Ion Experiments Spin Program

STAR Spin Plans:

- Continue measurements of photon + jet with barrel and endcap calorimeters and forward meson spectrometer, with longitudinal polarization, at $\sqrt{s}$ = 200 GeV. The coincidence measurements allow reconstruction of the momentum fractions of the scattering quarks and gluons, giving more precise information to determine the gluon polarization in the proton in detail. The range of gluon momentum fraction probed will be x_{gluon} = 0.001 to 0.2.

- Measurements of forward heavy meson production and forward π^0–π^0 production with transverse polarization at $\sqrt{s}$ = 200 GeV to map out the x dependence of the Collins and Sivers functions.

- Complete measurements of the spin dependence of the momentum imbalance between mid-rapidity jet pairs to quantify the gluon Sivers function.

- Construction and installation of forward tracking for $W^{\pm}$ charge sign determination.

- Studies of luminosity monitoring at the highest luminosities at RHIC.

PHENIX Spin Plans:

- Measurement of gluon polarization using direct photon production.

- Construction of detectors to improve the μ trigger for W measurements. This work is expected to be completed for the FY 2009 run.

- Development of silicon vertex detector. This detector is also expected to be completed for the FY 2008 run. Measurements of photon + jet with barrel and endcap calorimeters and forward pion/jet detectors, with longitudinal polarization, at √s = 200 GeV.

- Studies of luminosity monitoring at the highest luminosities at RHIC.

- Development of nose cone calorimeter.

Table 1. The RHIC Spin Plan (Note that the plan below is an example. This plan was presented in the February 2005 Research Plan for Spin Physics at RHIC, submitted to DOE, and has been updated for FY 2006 based on the expected 14 week proton run. The actual run plan depends on experiment beam requests and Program Advisory Committee approval.

RHIC SPIN EXAMPLE RUN PLAN* — **January, 2006**

Year	Acceleration/ Polarimetry	P	Weeks (Commiss./ Physics)	√s	LT	Physics
2002	RHIC Snakes, CNI Polarimeters	15%	8 (3/5)	200 GeV	0.5 pb^{-1}	Transverse spin, systematic studies, start learning curve
2003	Spin Rotators, AGS CNI Polarimetry	35%	8 (4/4)	200 GeV	1.6 pb^{-1}	A(LL), A(N), A(NN) STAR, PHENIX Gluon polarization (jets,π^0) A(N),A(NN): pp2pp
2004	Polarized Jet-- Absolute Polarization	46%	5 (4/1)	200 GeV	3 pb^{-1}	Development of spin program: study luminosity issues; improve pol. with low-field helical Snake in AGS; new pol. jet, abs. P to 10%
2005	AGS Strong Snake commissioning	47%	15 (5/10)	200 GeV	13 pb^{-1}	Develop luminosity in long spin run; new high-field helical Snake in AGS for polarization; gluon pol. with jets, π^0, abs. P to 5% (jet)
2006	AGS Strong Snake	60%	14 (1/2/11)	200 GeV 62,500 GeV	40 pb^{-1}	Gluon pol.--direct gamma Transverse spin
2007		65%	10 (0/10)	200 GeV	88 pb^{-1}	Direct photon gluon pol. Transverse spin
2008		70%	10 (0/10)	200 GeV	106 pb^{-1}	Statistics for direct photons

RHIC Spin Design Goals: 70% polarization, L = 2 x 10^32 cm^{-2} s^{-1} (root(s) = 500 GeV)

LT = 320 pb^{-1} for root(s) = 200 GeV **LT = 800 pb^{-1} for √s = 500 GeV**

3. Capital Funding Requests

See Capital Request under FWP PO-004 (KB0202012) for RHIC Spin, and for PHENIX and STAR spin related requests.

e. Relationship to Other Projects

RHIC SPIN

The program of the Medium Energy RHIC Spin Group is closely tied to the heavy ion experimental groups, PHENIX and STAR, and includes BRAHMS. The members of the PHENIX and STAR experiments are full collaborators in the spin physics, as well as vice versa: the RHIC Spin Group members are full collaborators in the heavy ion physics program. The spin runs at 200 GeV serve as p-p comparison runs for the heavy ion program.

One of the primary motivations to build a Forward Meson Spectrometer at STAR is to measure the x dependence of the gluon density in the gold nucleus down to values of $x \sim 10^{-3}$. Such a measurement is of significant importance to the heavy ion program to understand the initial state that could evolve to form a quark-gluon plasma. The impetus to pursue measurement of the gluon density in the gold nucleus is from the Medium Energy RHIC Spin Group.

The RHIC Spin Group collaborates closely with the Collider-Accelerator Department (C-AD) staff at BNL in preparation of polarimetry, collection and interpretation of polarimeter data, and participation in spin commissioning and running. The collaboration includes tests and calibrations in the AGS, fast polarimeters in RHIC and AGS, the absolute polarimetry using a polarized jet in RHIC (CA-D coordinates this effort, and is responsible for the jet, with collaborators as discussed in the text).

The RHIC Spin Group collaborates with the RIKEN BNL Research Center and RIKEN in all of the above areas. Major collaborative groups in this work include University of Wisconsin (jet), Indiana University (jet, STAR spin, polarimetry, general spin program), ITEP (Moscow) (polarimetry and pp2pp), Argonne National Laboratory (polarimetry, STAR spin), Yale (polarimetry, wave form digitizers for polarimetry), and many other groups mentioned in the text above, participating in STAR, PHENIX, pp2pp, and polarimetry efforts.