RHIC Spin Physics - Status of the Polarized Collider and Spin-Flavor Structure of the Nucleon

N. Saito [a][b]*

[a]The Institute of Physical and Chemical Research (RIKEN),
Radiation Laboratory,
Saitama 351-0198, Japan
and

[b]RIKEN BNL Research Center,
Brookhaven National Laboratory,
Upton, NY 11973-5000, USA

The Relativistic Heavy Ion Collider, which is under construction at Brookhaven National Laboratory will become the first polarized proton collider. The status of the accelerator and experiments is briefly overviewed. Among various measurements with polarized pp collisions, a study of spin-flavor structure of the nucleon with W production is discussed.

1. INTRODUCTIN

Hadron collisions have been an essential part of the structure study of the nucleon in addition to deep inelastic scattering of leptons from the nucleon (DIS). The data of Drell-Yan production of lepton pairs have been used to constrain anti-quark distribution in the nucleon. Charge asymmetry in W production has been used to determine the ratio of the u quark distribution to the d quark distribution. Productions of high p_T prompt photons and high E_T jets have been major sources of gluon information in the proton.

In the case of the spin structure studies, DIS is only source of information due to a lack of data from polarized hadron collisions. Although the previous effort to create a polarized proton/anti-proton beam from $\Lambda/\bar{\Lambda}$ decay was successful [1], the intensity and/or energy was not high enough to constrain the spin structure of the nucleon. Consequently the polarized gluon, anti-quark distributions and separation of flavors remain unconstrained.

The Relativistic Heavy Ion Collider (RHIC) will be turned on soon at Brookhaven National Laboratory (BNL). A primary purpose of the RHIC is to search for a new state of a matter, quark-gluon plasma in heavy ion collisions. Now it has extended its capability, with planned collisions of polarized proton beams up to 500 GeV in the center-of-mass system.

Goals of the spin physics at RHIC include the spin structure of the nucleon, symmetry tests, especially parity violating effects, single transverse-spin asymmetry which presumably originates in higher twist effects, and double transverse-spin effects in QCD [2].

A Letter of Intent to *polarize* RHIC was submitted in April 1991 to the BNL Physics Advisory Committee by the RHIC Spin Collaboration, which evolved from a polarized collider workshop held in 1990 [3]. It was followed by a proposal for spin physics with the PHENIX and STAR detector systems. Finally funding for accelerator and spin physics upgrade for PHENIX has been realized by RIKEN-BNL collaboration for RHIC spin physics, which was signed in September 1995.

With the completion of the RHIC as a polarized collider, it will become a machine to study QCD in its two extreme conditions, high temperature and high Q^2 with the spin degree of freedom.

In the next section, the status of the polarized collider is described. After brief description of

*e-mail: saito@bnl.gov

four experiments at RHIC, which are to start this year, a study of spin-flavor structure of the proton is described.

2. RHIC AS A POLARIZAD COLLIDER

In this section, two areas of efforts to realize the acceleration of polarized proton beam at RHIC are described: one is to maintain polarization through the acceleration and storage process at RHIC, and the other is to measure the polarization of the accelerated beam.

2.1. Polarized Collider

As a polarized collider, the RHIC will provide high polarization of 70%, high energy up to 500 GeV, and high luminosity of 2×10^{32} cm^{-2}sec^{-1} or more.

To maintain polarization through the acceleration process, two sets of superconducting helical dipole magnets (HDM) per ring are to be installed. Each set comprises four right-handed HDM's which rotate the proton spin by 180° while leaving the orbit unchanged. Each HDM is 2.4 m long and is operated at ~4 T at maximum. A combination of right-handed and left-handed HDM's will be used to rotate proton spin to the longitudinal direction for two major experiments, PHENIX and STAR.

Currently three HDM's have been produced and tested at operation current successfully. Two sets of HDM's are to be installed by November, and one ring will be commissioned for polarization to 100 GeV in the first year, to be ready for spin physics in the second year of RHIC running.

2.2. Polarimeter

A reliable measurement of beam polarization is required to commission and use the polarized proton beams. We are planning three different types of polarimeters stage by stage: (i) a pC CNI polarimeter to utilize analyzing power residing in Coulomb-Nuclear-Interference region of pC elastic scattering, (ii) a large-x_F pion polarimeter to use the large $\mathcal{A}_N$ observed over the RHIC energy range, and (iii) a polarized gas jet target to calibrate the beam polarization with target polarization which can be measured to 5% precision.

Both the pC CNI polarimeter and large-x_F pion polarimeter have been tested at the BNL-AGS successfully. Figure 1 shows asymmetries for inclusive $\pi^{\pm}$ and p productions in pC collisions at 21.6 GeV/c as functions of x_F. Observed asymmetries are similar to measurements at Fermilab using a 200 GeV polarized proton beam [4]: asymmetries for pions grow with x_F, and π^+ and π^- show *mirror* asymmetries. With these polarimeters, the precision of the polarization measurement in early stages of the RHIC spin program will be ~10%.

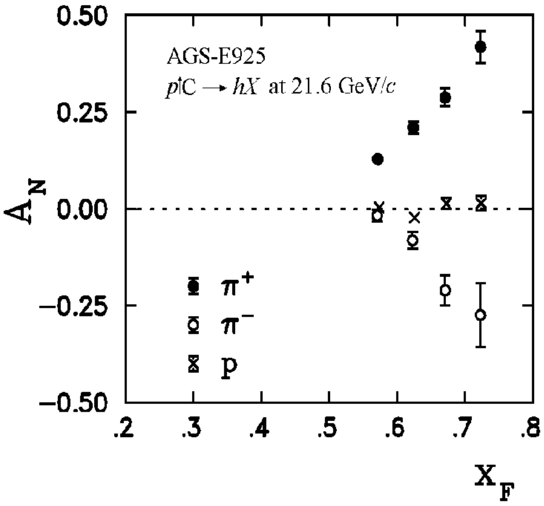

Figure 1. Asymmetries $\mathcal{A}_N$ for inclusive hadron production measured with 21.6 GeV/c polarized proton beam extracted from AGS.

3. RHIC EXPERIMENTS

There are four experiments which will start this year; PHENIX, STAR, BRAHMS, and PHOBOS. BRAHMS aims to measure hadrons with lower p_T in a wide range of rapidity. PHOBOS covers wide acceptance to measure charged particle multiplicities. event-by-event basis. The

STAR detector has a large acceptance TPC in its heart to detect charged hadrons with excellent momentum resolution. Recently, an Endcap EM calorimeter was proposed to enhance rapidity coverage in forward direction. This extends the spin physics capability of STAR detector significantly. The PHENIX measurements focus on detection of photons and leptons as well as hadrons with high momentum resolution and superb particle identification in selective acceptance. As shown in Figure 2, it comprises Inner detectors (Beam-Beam Counter and Multiplicity Vertex Detector) and four arms, two at central rapidity and the other two at large rapidity. The Central Arms, each cover $|\eta| \leq 0.35$ and $33.75^\circ \leq |\phi| \leq 123.75^\circ$, consist of a finely granulated EM calorimeter, Ring-Image-Cherenkov detector for electron identification, and three types of tracking chambers, Drift Chamber, Pad Chamber, and Time-Expansion Chambers. Forward and backward directions ($1.2 \leq |\eta| \leq 2.4$) are covered by full azimuth muon arms.

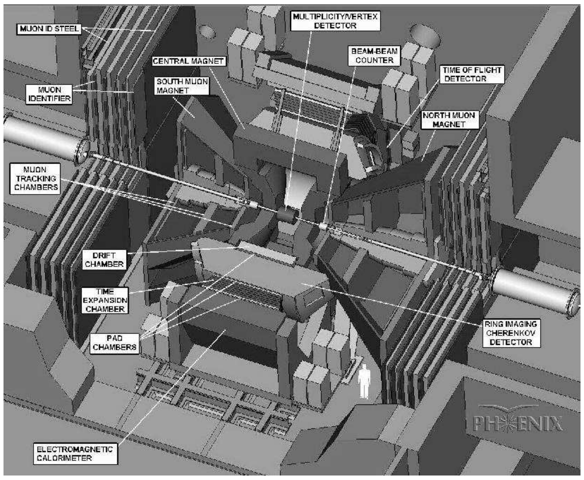

Figure 2. PHENIX detector system.

Since the stable spin direction of the beam is vertical, transverse spin asymmetries such as $\mathcal{A}_{TT}$ and $\mathcal{A}_N$ can be measured at all collision points. PHENIX and STAR can also use spin rotators for longitudinal polarization. These experiments can measure the parity violating asymmetry,

$$\mathcal{A}_L \equiv \frac{\sigma(-) - \sigma(+)}{\sigma(-) + \sigma(+)}, \tag{1}$$

where "+" and "−" represents helicity states of beams.

4. RHIC SPIN PHYSICS

Primary goal of RHIC spin physics is to elucidate the spin structure of the nucleon. The study includes measurement of gluon polarization $\Delta G(x)/G(x)$, anti-quark polarization $\Delta\bar{q}_i(x)/\bar{q}_i(x)$ and the transversity distribution $\Delta_T q(x)$ in the proton. Gluon measurements are described by Goto [5]. In this paper, we will describe how weak boson production in polarized pp collision will uncover the spin-flavor structure of the proton.

4.1. Spin-flavor Structure of the Nucleon

The charged weak boson is produced through pure V-A coupling and the chirality of the quark and anti-quark in the reaction is fixed. Since W couples to weak charge, which is almost identical to flavor if we focus on one generation, the production is also sensitive to the flavor structure of the proton.

A parity violating asymmetry for W^+ production in pp collision can be expressed as [6]

$$\mathcal{A}_L(W^+) = \frac{\Delta u(x_1)\bar{d}(x_2) - \Delta\bar{d}(x_1)u(x_2)}{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)}. \tag{2}$$

For W^- production, u and d should be exchanged in this expression. The asymmetry is simply a linear combination of the quark and anti-quark helicity distributions and it converges to $\Delta u(x)/u(x)$ at the limit of $x_1 \gg x_2$ and to $\Delta\bar{d}(x)/\bar{d}(x)$ at the limit of $x_2 \gg x_1$ [6]. Production of $W^\pm$ can be identified by the detection of muons with high transverse momentum ($p_T \geq 20$ GeV/c). With the assumed integrated luminosity of 800 pb^{-1} at $\sqrt{s} = 500$ GeV, which correspond to 10 weeks with 70% efficiency and full luminosity, we can expect about 5,000 events for each W^+ and W^-. Together with beam polarization of 70%, we should reach a statistical error of 2%.

Furthermore, the x-range can be selected using the muon momentum which is correlated with x by

$$p_\mu = \frac{\sqrt{s}}{4}[(1+\cos\theta)x_u + (1-\cos\theta)x_{\bar{d}}], \tag{3}$$

where θ represents decay angle in the rest frame of W. Using the muon sample which is divided into several momentum bins (and thus x-bins), we have estimated the sensitivities of our measurements with statistical errors only. The results are plotted on two models for polarized parton distributions in Figure 3. Our measurement will clearly separate the models.

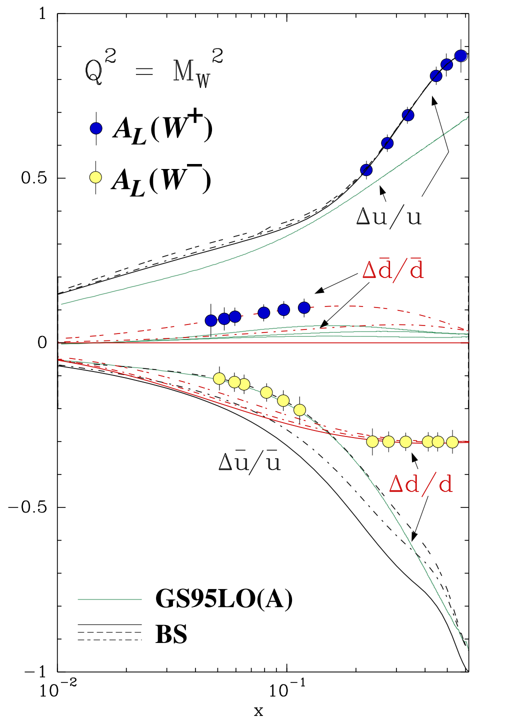

Figure 3. Models on polarized parton distributions. Overplotted are projected statistical errors with PHENIX muon arm and 800 pb^{-1}.

5. SUMMARY

Completion of RHIC as a polarized collider will open a new era of high-energy spin physics. The development and fabrication of helical dipole magnets have been successful and test measurements of polarimeters are also successful . At the highest energy of RHIC *pp* operation, we should be able to provide severe constraints on the spin-flavor structure of the proton with W production.

We will start heavy ion physics running this November and spin physics in the next year.

Acknowledgment. The author is grateful for the PHENIX Collaboration. He would like to thank Dr. Thomas Roser for the materials for RHIC machine aspects. He is also grateful to Drs. Gerry Bunce and Mike Tannenbaum for the discussions to improve this paper.

This work has been done within the frame work of RIKEN BNL Collaboration for RHIC Spin Physics.

REFERENCES

1. Fermilab E581/E704 experiments. D.P. Grosnick *et al.*, Nucl.Instrum.Meth. **A290** (1990) 269.
2. R.L. Jaffe and N. Saito, Phys. Lett. **B382** (1996) 165.
3. *Proceedings of the Polarized Collider Workshop*, University Park, PA (1990), eds J. Collins, S. Heppelmann and R.W. Robinett, AIP conf. proc. No. 223, (AIP, New York, 1991)
4. D.L. Adams *et al.* Phys.Lett. **B264** (1991) 462.
5. Y. Goto, these proceedings.
6. C. Bourrely and J. Soffer, Nucl. Phys. **B445** (1995) 341.