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Measuring The Sea Quark Polarization

Yousef Makdisi
(for the RHIC Spin Collaboration *)
RHIC Project,Brookhaven National Laboratory, Upton NY 11973

ABSTRACT

Spin is a fundamental degree of freedom and measuring the spin structure functions of the nucleon should be a basic endeavor for hadron physics. Polarization experiments have been the domain of fixed target experiments. Over the years large transverse asymmetries have been observed where the prevailing QCD theories predicted little or no asymmetries, and conversely the latest deep inelastic scattering experiments of polarized leptons from polarized targets point to the possibility that little of the nucleon spin is carried by the valence quarks.

The possibility of colliding high luminosity polarized proton beams in the Brookhaven Relativistic Heavy Ion Collider (RHIC) provides a great opportunity to extend these studies and systematically probe the spin dependent parton distributions specially to those reactions that are inaccessible to current experiments. This presentation focuses on the measurement of sea quark and possibly the strange quark polarization utilizing the approved RHIC detectors.

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Spin is a fundamental degree of freedom and measuring the spin structure functions of the nucleon should be a basic endeavor for hadron physics. Polarization experiments have been the domain of fixed target experiments. Over the years large transverse asymmetries have been observed where the prevailing QCD theories predicted little or no asymmetries, and conversely the latest deep inelastic scattering experiments of polarized leptons from polarized targets point to the possibility that little of the nucleon spin is carried by the valence quarks.

The possibility of colliding high luminosity polarized proton beams in the Brookhaven Relativistic Heavy Ion Collider (RHIC) provides a great opportunity to extend these studies and systematically probe the spin dependent parton distributions specially to those reactions that are inaccessible to current experiments. This presentation focuses on the measurement of sea quark and possibly the strange quark polarization utilizing the approved RHIC detectors.

1. Introduction

Deep inelastic scattering experiments of longitudinally polarized leptons from longitudinally polarized targets have been the main vehicle, in the past decade, for measuring the nucleon spin structure functions. The Yale/SLAC [1] experiment and later the NMC [2] experiment at CERN provided the first detailed measurement of the first moment of the proton spin structure function

$$\Gamma_1^p = \int g_1^p(x)\,dx = 0.126 \text{ +/- } .010 \text{ (stat) +/- } 0.015 \text{ (syst)}$$

First results from the SMC [3] experiment on a similar measurement of the deuteron spin structure function give

$$\Gamma_1^d = 0.023 \text{ +/- } 0.020 \text{ (stat) +/- } 0.015 \text{ (syst)}$$

and determine the value for the neutron to be

$$\Gamma_1^n = -0.08 \text{ +/- } 0.04 \text{ (stat) +/- } 0.04 \text{ (syst)}$$

These results suggest that, contrary to intuition, the contribution of the valence quarks to the overall spin of the nucleon is exceedingly small. What follows then is either the gluons or the sea quarks are highly polarized or both. Note that if the gluons are not polarized then the strange quarks will carry significant polarization, thus the need to measure the contributions of those partons inside the nucleon.

Deep inelastic experiments are not adept at differentiating between quark flavors and provide little sensitivity to the gluon contribution due to the lack of coupling between leptons and gluons. A proposal from

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the RHIC Spin Collaboration [4] details the physics potential and goals of a polarized RHIC collider utilizing two RHIC detectors STAR [5] and PHENIX [6]. Polarized gluon distribution functions will be studied through direct photon production as well as inclusive single and dijet production (see H. Spinka these proceedings). The Drell Yan process is our best candidate to probe the sea quark distributions and a recent work by Bourrely and Soffer [7] suggest W+/- production as another potential mechanism.

2. Physics and Rates

The RSC proposal will use two longitudinally polarized colliding proton beams to measure the double spin asymmetry A_{LL} defined as the difference between the measured cross sections with parallel and anti parallel beam helicities divided by the sum. This is related to the sum of the respective parton asymmetries of all the sub processes that contribute to the cross section.

$$A_{LL}\, d\sigma = \Sigma_{ij}\, 1/(1+\delta_{ij}) \int dx_a\, dx_b\, [\, \Delta f_i^{a}(x) \,.\, \Delta f_j^{b}(x) \,.\, \hat{a}_{LL}^{ij}\, d\sigma_{ij} + (\, i \Leftrightarrow j\,)\,]$$

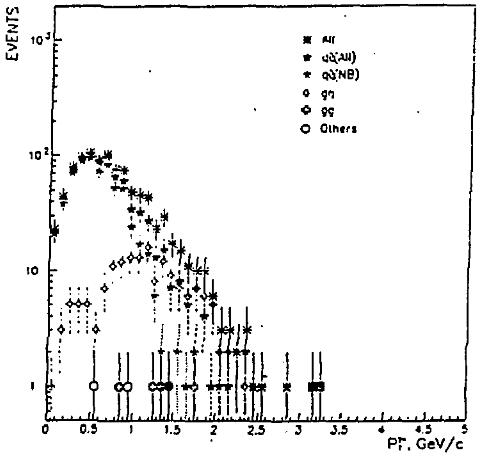
These measurements result in sums of products of two partonic distributions. For example, in Drell Yan the product is that of $[\Delta q(x)/q(x)]\ .\ [\Delta\bar{q}(x)/\bar{q}(x)]$. The sea quark distribution is then extracted if the associated valence quark distribution is known.

The proposal assumes 100 days of running at an overall efficiency of 50%, a luminosity of 2×10^{32} cm^{-2} sec^{-1} at center of mass energy of 500 GeV, and beam polarization of 70%.

1. The Drell Yan Process

Lepton pairs from Drell Yan production are detected in both STAR and PHENIX through the process $pp \Rightarrow \gamma^* + X \Rightarrow l+ l- + X$. Monte Carlo simulations [8] of the production rates were carried out for both detectors using PYTHIA with the EHLQ1 set of parton structure functions. STAR will detect electron positron pairs using the proposed electromagnetic barrel and endcap calorimeters with acceptance in $|\eta| \leq 2.0$ and $\phi = 2\pi$; PHENIX will use its barrel calorimeter with coverage of $|\eta| \leq 0.35$ and $\phi = \pi$ along with the dimuon endcap that covers $1.1 \leq \eta \leq 2.5$ and $\phi = 2\pi$. Lepton pair production can proceed through several partonic processes, qq annihilation, qq Bremsstrahlung, and qg production, figure 1.

Figure 1. Contributions to the dilepton rates from various partonic processes PHENIX ($\mu\mu$), $\sqrt{S}$=200 GeV, and $M_{\mu\mu}$=2-3 GeV/c^2.



A cut on the sum of the q and $\bar{q}$ momenta to equal that of the virtual photon eliminates the Bremsstrahlung events and a cut on transverse momentum p_t< 1 GeV/c of the produced pairs assures a sample where the $q\bar{q}$ annihilation process dominates. Table I shows the event rates available from each detector for different center of mass collision energies.

M_{ee} , GeV/c² (√S=200)	5-9	9-12	12-15	15-20	20-25
Without Endcaps	33,000	21,000	8,500	5,500	1,900
With Endcaps	71,000	50,000	21,000	13,500	4,300

$M_{\mu\mu}$, GeV/c²	2-5	5-9	9-12
Events (√S= 200)	96,000	23,000	4,000
Events (√S= 500)	240,000	79,000	19,000

Table I. Dilepton rates for both STAR and PHENIX

Good e/π rejection of the order of 100:1 for each lepton is required . In addition, STAR will run with a threshold of $E_T > 4$ GeV/c^2 in order to achieve manageable trigger rates. These simulations do not include contributions from open charm production that has a substantial cross section and the combinatorics from which present a potential background to the Drell Yan measurement.

A rate of 10,000 events per bin allows a 2% statistical error in the asymmetry measurement A_{LL} when the beam polarization is taken into account. The above table shows that both STAR and PHENIX can achieve such sensitivities for dilepton masses up to 25 and 15 GeV/c^2 respectively. Larger values of A_{LL} are expected if the kinematic variables are chosen to ensure that the interacting quark from one proton carries an appreciable polarization ($x_1 > 0.1$). Similarly, the momentum fraction carried by the struck antiquark should be away from zero where one expects no polarization. Representative kinematic coverages for both detectors are shown in figure 2. The STAR detector has the better coverage due to its large geometrical acceptance.The kinematic acceptance in PHENIX can be improved by running at lower center of mass energies. However, this is likely to result lower sensitivity.

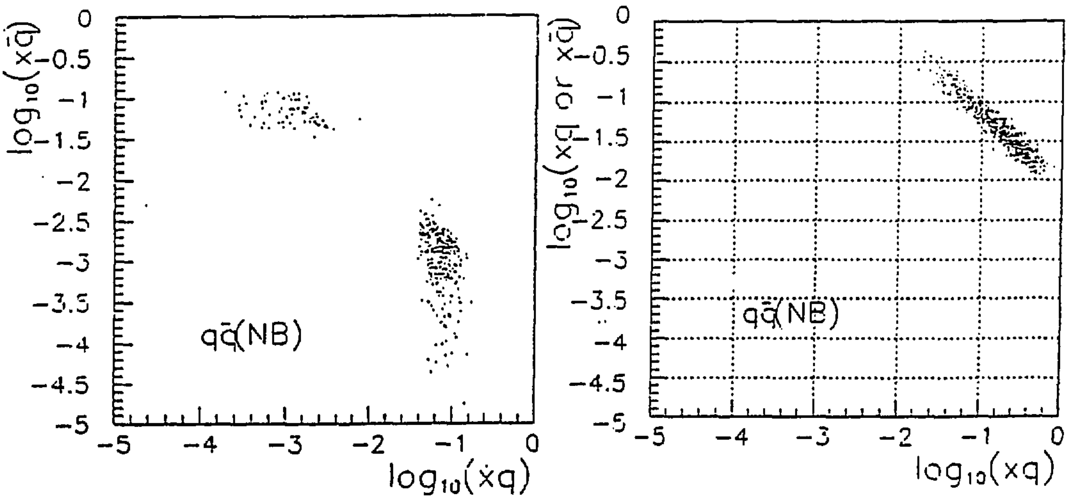


Figure 2. Diplots of the kinematic regions covered by the PHENIX and STAR detectors respectively. The axes refer to the momentum fractions carried by the interacting partons.

2. Measuring the sea polarization via W^+ / W^- production

Bourrely and Soffer [7] suggest using the parity violating asymmetries A_L^{PV} and A_{LL}^{PV} in W^+ and W^- production to get another handle on the sea quark polarization. They predict a large sensitivity to sea quark polarization in W^-production as well as a strong dependence on rapidity. The effect is most pronounced at y = -1. Their same calculation for A_{LL} in W^- production also reveals a strong dependence on sea quark polarization with a sensitivity that is relatively flat between -1< y < 1 which is quite desirable for the STAR and PHENIX geometries. The W^+ measurement is used for normalization purposes, Figure 3.

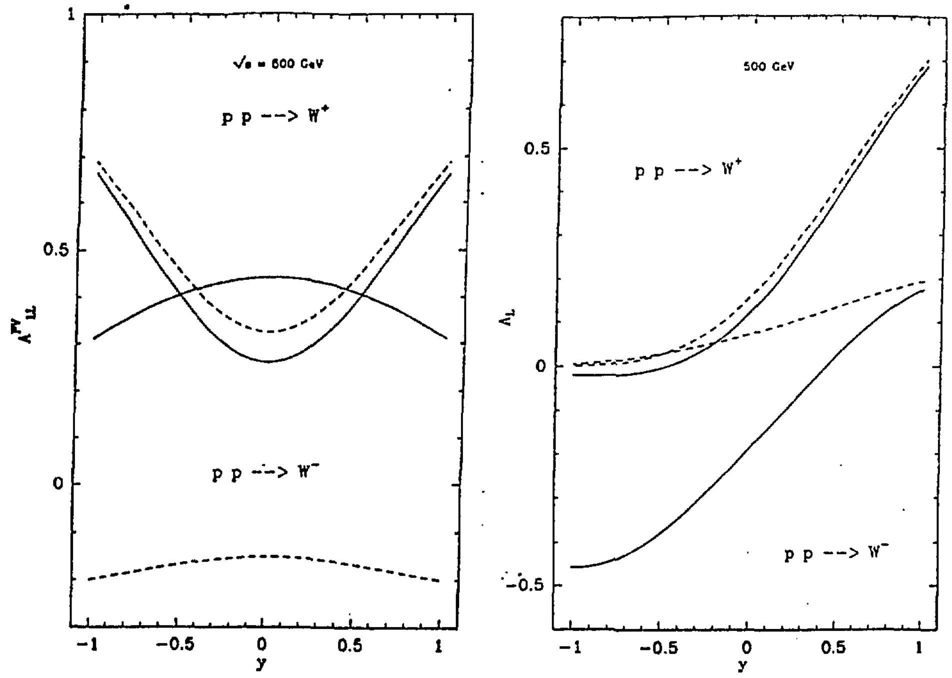


Figure 3. Predictions for Parity violating asymmetries in W production. The solid lines with sea quark polarization, and the dashed lines with zero polarization.

There is appreciable acceptance for W production in STAR and PHENIX. The rates were calculated using the same PHYTHIA simulation package described earlier. Table II shows the expected number of events for running at center of mass energy of 500 GEV. These rates provide for sensitivities at the level of a few percent.

Boson	STAR barrel & Endcaps	PHENIX Barrel
W^+	80,000	16,000
W^-	30,000	6,000

Table II. W production for STAR and PHENIX

3. *Transverse quark polarization*

The proposed polarized RHIC facility allows for the beam polarization to be rotated so that transverse double spin asymmetries could be measured. These measurements are sensitive to the transverse spin structure functions of the partons within the nucleon that have never been measured. Theoretical calculations [9] are underway to assess the differences between longitudinal and transverse spins. Only the quarks are expected to participate as the glouns cannot carry transverse spin.

Large transverse single spin asymmetries have been observed in inclusive pion production experiments at transverse momenta up to 4 GeV/c , Figure 4. Perturbative QCD calculations expected these effects to be quite small and to vanish at high momentum transfer. However, perturbative calculations to orders next to leading twist do show some promise in explaining these single spin asymmetries.

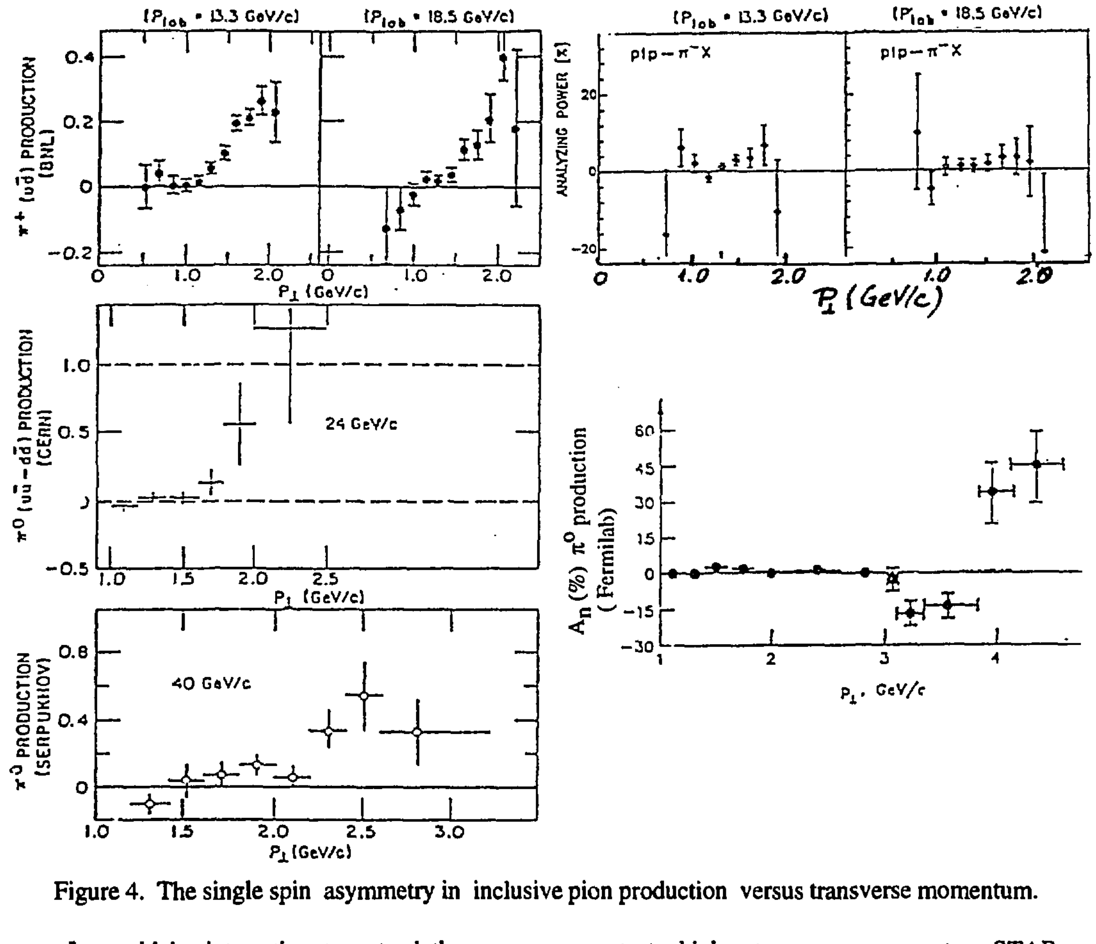


Figure 4. The single spin asymmetry in inclusive pion production versus transverse momentum.

It would be interesting to extend these measurements to higher transverse momenta. STAR and PHENIX will measure neutral pion production up to p_t of 20 GeV/c but lack any particle identification for high momentum charged hadrons. A third RHIC detector, The Forward Angle and Mid rapidity Spectrometer [10] can achieve pion, kaon, and proton separation for momenta up to 25 GeV/c albeit with small acceptance. The case for kaons is particularly interesting as these hadrons carry strange valence quarks. These could provide an interesting indication of the polarization of the strange quarks from the parent protons.

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