Polarized Proton Measurements with the STAR Detector.

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When polarized proton running begins at the Relativistic Heavy Ion Collider (RHIC), STAR will play a major role in measurement of the spin dependent quark and gluon structure functions [1]. As the only RHIC detector with large rapidity coverage $-1 < \eta < 2$ for detection of electromagnetic and hadronic energy, it is only the STAR detector which has the required acceptance for jet-jet and jet-direct photon reconstrution at RHIC. STAR will also measure high p_t positrons and electrons for W analysis.

A quarter-section view of the STAR Detector is shown in Figure 1. The baseline detector utilizes a time projection chamber (TPC) in a solenoidal magnetic field of 0.5T covering approximately 4 units of the central rapidity. Additionally, a silicon vertex tracker (SVT) will be used to locate the position of the primary and secondary vertices to high accuracy. The combined information from the TPC and SVT will be used to enable tracking, momentum analysis, and particle identification via $\frac{dE}{dx}$ in the $\frac{1}{\beta^2}$ region.

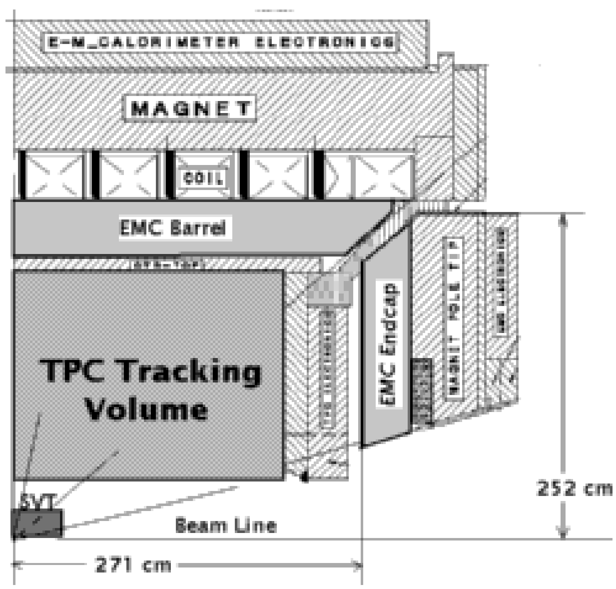

Figure 1: Main components of STAR detector. The figure shows a quarter section of the apparatus which includes the SVT,TPC, Barrel EMC and Endcap EMC. The interaction vertex is the lower left corner.

Electromagnetic calorimetry in STAR consists of two subsystems, the EMC barrel $-1 < \eta < 1$ and the EMC endcap $1 < \eta < 2$. Both are lead-scintillator sampling calorimeters with highly segmented shower max detectors for position resolution. The energy resolution of the EMC is $16\%/\sqrt{E}$. At a depth of approximately 5X, near the location of the maximum number of shower electrons for photons of 3-5 GeV/c, a wire chamber with fine spatial resolution will be used to locate electrons and positrons from W decays and to help distinguish direct photons from π^0 decays.

In this paper, measurement errors anticipated in a STAR spin run for the quark, antiquark and gluon polarizations are presented. These errors correspond to a luminosity given by "standard data sets" which corresponds to a 100 day run at high energy $\sqrt{s} = 500$ GeV and integrated luminosity of 800 $pbarns^{-1}$ (320 $pbarns^{-1}$ at $\sqrt{s} = 200$ GeV). In this error analysis, jet events are included if their jet axis is at least .7 units of rapidity from the detector rapidity limit. Photons and electrons are considered over the full EMC rapidity coverage $-1 < \eta < 2$.

The cutoff in data at small x results in the limits imposed by beam energy, minimum p_t and the ratio $\frac{x_1}{x_2}$ (rapidity range). For direct photons-jet events, $p_t > 10.$ GeV/c is the required condituion. For dijets, the cut $p_t > 15$ GeV/c is used.

The best small x measurement comes from the highest energy pp running, $\sqrt{s} = 500$. It is clear, that if lower p_t data could be interpreted, the region $x < .02$ would produce a very large number of events.

Direct Photon Measurements

The clearest window into the gluon distribution is the measured cross section for direct high p_t γ's. The dominant process is

$$u + G \rightarrow jet_u + \gamma$$

and the longitudinal double spin asymmetry A_{LL} is approximately proportional to the product

$$\left(\frac{\Delta u(x_1)}{u(x_1)}\right)\left(\frac{\Delta G(x_2)}{G(x_2)}\right) + (x_1 \leftrightarrow x_2).$$

For a u quark in the range $.1 \leq x_1 \leq .4$ the polarization is known experimentally to be large, $\frac{\Delta u(x_1)}{u(x_1)} > x_1$.

We define a kinematic region for the measurement with $p_t \geq 10$ GeV/c and include jets in the rapidity range $-.3 \leq \eta_1 \leq 1.3$ and γ's in the range $-1. \leq \eta_2 \leq 2.$ For this region the scale of asymmetry is given by $A_{LL} \simeq (constant)\frac{\Delta G(x)}{G(x)}$. The constant comes from a weighted integration of u quark polarization multiplied by parton level analyzing power and is typically .1 to .3 depending on kinematic cuts.

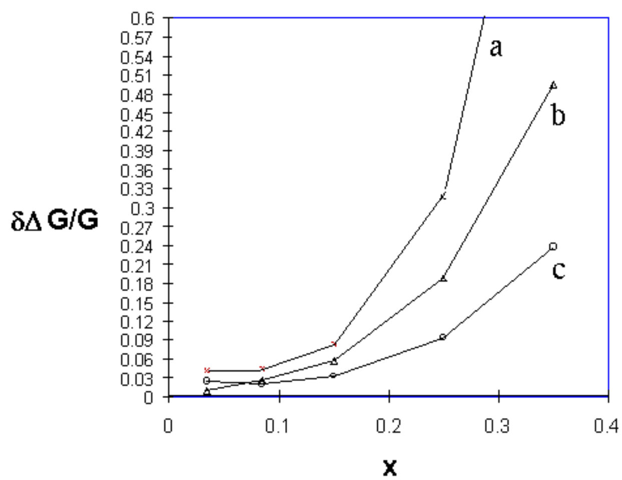

Figure 2: Measurement Error in $\frac{\Delta G}{G}$ vs x for Direct Photon + Jet Events. Curve (a) represents the errors for $\sqrt{s} = 500$ GeV with a EMC barrel only, curve (b) represents $\sqrt{s} = 500$ GeV with a EMC barrel+endcap. Curve (c) represents $\sqrt{s} = 200$ GeV with a EMC barrel+endcap.

Since the gluon structure function is strongly peaked at $x \leq .1$ and the u quark polarization grows with x for $x \geq .1$, it is clear that asymmetric jet-direct photon detection requires the full rapidity coverage available in STAR. The expected errors in $\frac{\Delta G(x)}{G(x)}$ from direct photon + jet events are shown in Figure 2 and in Table 1.

Jet-Jet Measurements

The jet energy resolution in STAR will be similar to that obtained in collider detectors which utilize combined hadronic+electromagnetic calorimeters. Jets will be reconstructed by adding "electromagnetic" + "tracking" energy deposited within a characteristic radius ($\sqrt{\eta^2 + \phi^2} \leq R$). Jet definitions are subjective, with reasonable jet radii ranging from .5 to 1. units of rapidity. The energy of the jet is determined by summing the charged track energy and the EMC energy (eight to twenty towers of size .1 x .1 in $\eta \times \phi$). About 8% of the energy of the jet is undetected due mostly to neutrons. Depending on the definition of the jet, 15-25% of the jet energy may fall outside the defining radius R. While the resolution of the EMC part of the detector will be about $\frac{16\%}{\sqrt{E}}$, the jet energy resolution, as in other collider detectors, will be dominated by the fluctuations associated with the defining algorithm for the jet.

For pp interactions at $\sqrt{s} = 500$ GeV, in the kinematic region where $x_1 < .1$ **or** $x_2 < .1$, the dominant subprocess contributing to the jet cross section measurable with STAR is $G+G \rightarrow jet+jet$. The asymmetry A_{LL} is proportional to the product $\left(\frac{\Delta G(x_1)}{G(x_1)}\right) \times \left(\frac{\Delta G(x_2)}{G(x_2)}\right)$.

The jet-jet sensitivities reported in Table 1 were based on measurements of such an asymmetric region in x_1 vs x_2. Because the asymmetry is not linearly related to $\frac{\Delta G(x)}{G(x)}$, assumptions about the scale of polarization must be made to extract the errors in measurement. With assumptions ranging from $\frac{\Delta G(x)}{G(x)} = .05$ to $\frac{\Delta G(x)}{G(x)} = x$, a range of errors in $\frac{\Delta G(x)}{G(x)}$ for $x > .05$ is determined.

At higher p_t (30-50 GeV/c), the most asymmetric jets come from quark-gluon interactions. At the highest p_t, the measurement of A_{LL} reflects the bilinear product of valence quark polarizations. Depending on triggering and prescaling, the number of dijet events collected in a standard $\sqrt{s} = 500$ GeV nominal run will be between 10^7 and 10^8. In principle, di-jets are the most sensitive measure of $\left(\frac{\Delta G(x)}{G(x)}\right)$ at all but highest x. However, the analysis is more complicated for jet-jet events than that for direct photons.

$W^{\pm}$ and Z^0 Measurements

The $W^{\pm}$ and Z^0 production will be studied via decays to electrons and positrons. The $W^{\pm}$ single spin asymmetries provide a unique and sensitive probe of parton spin dependent distributions. Indeed the unpolarized $\bar{u}$ and $\bar{d}$ distributions will be well measured at RHIC also. Production of W^+ from polarized protons can determine the polarization of $\bar{d}$ quarks in the proton while corresponding W^- measurements determine the polarization of the $\bar{u}$ quarks. In some models of the proton, the $\bar{d}$ quarks are unpolarized and the $\bar{u}$ quarks are highly polarized [2].

In STAR, the only limitation is statistics. At $\sqrt{s} = 500$ GeV, from 50,000 to 100,000 W^+ will be produced in a standard run period and about 25% as many W^-. The production of W's is peaked near central rapidity, with about half of the events produced at rapidity less than 0.5. The observed electron distribution is broader however due to the decay distribution of the W.

As an illustration, consider the case of electrons measured in the production of W^-. One can define the incident direction for one of the beams to be positive so that small angle scattering from that beam hits the end-cap. For a d quark in that positive incident beam, W^- production and the parity violating decay will produce an electron at relatively small forward angles. The kinematics and structure functions for d and $\bar{u}$ quarks will tend toward the selection of a d quark with larger x than that of the $\bar{u}$ antiquark and thus positive rapidity for the W^-. The electron rapidity will tend to be even more positive because of the forward decay angle.

The point here is that in the central rapidity region, we make W^-'s with d quarks from either incident beam but at larger (positive) rapidity we make W^-'s mostly with d quarks from the proton which was moving in the positive direction.

Thus the electrons observed in the end-cap are most interesting because the incident direction of the d quark is known. For end-cap W^- events, we can define a single spin asymmetry A_L by flipping the spin of either beam. With one choice we measure $A_L = \frac{\Delta d}{d}$ with the other choice we measure $A_L = \frac{\Delta \bar{u}}{\bar{u}}$.

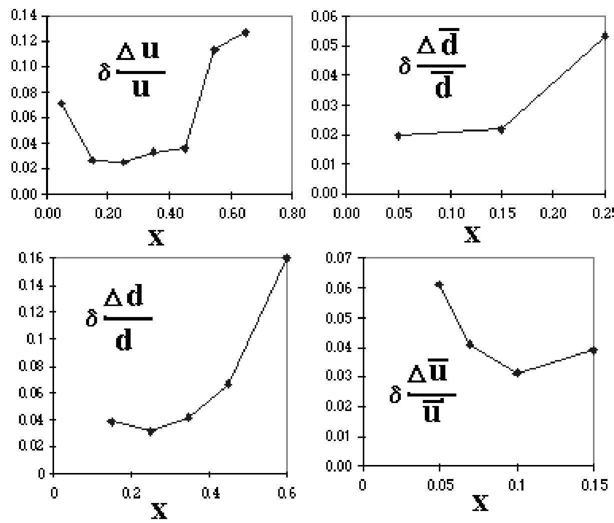

Figure 3: Measurement Error for quark and antiquark polarizations vs x from W decays.

Recent results from the SMC collaboration [3] illustrate the difficulty in assigning the x dependence of the quark contribution to the proton spin to specific quark and antiquark flavors. In the region of x covered by STAR (see Table 1 and Figure 3) the results from the W measurements should reduce the uncertainty in $\frac{\Delta u(x)}{u(x)}, \frac{\Delta \bar{u}(x)}{\bar{u}(x)}, \frac{\Delta d(x)}{d(x)}$ and $\frac{\Delta \bar{d}(x)}{\bar{d}(x)}$ by nearly an order of magnitude compared to errors reported by SMC.

Conclusion

There has been increased interest in the spin structure in the nucleon over recent years. A so-called "crisis" emerged a few years ago when results from deep inelastic scattering spin measurements of the quark structure functions showed that the valence quarks have a small share of the total spin of the nucleon. This raised the question as to whether a significant spin orientation of gluons and non-valence quarks could account for the observed deficit. There are three possible components to the total spin of the proton,

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + \Delta L.$$

The terms $\Delta\Sigma$ and ΔG account for the first moments of the quark and gluon distributions. The ΔL term refers to orbital angular momentum. Analysis of recent data [4] indicates $\Delta u = 0.83 \pm 0.03$, $\Delta d = -0.43 \pm 0.03$, $\Delta s = -0.10 \pm 0.03$, $\Delta\Sigma \equiv \Delta u + \Delta d + \Delta s = 0.31 \pm 0.07$. The recent quark data have inspired predictions for a rather highly polarized gluon distribution [5].

The error in the integral,

$$\delta\left[\Delta G(x_{min})\right] = \delta\left[\int_{x_{min}}^{1} dx G(x) \frac{\Delta G(x)}{G(x)}\right],$$

from direct photon measurements (Figure 2, curve b) is $\delta\,[\Delta G(x_{min} = .04)] = 0.15$. Only by systematically determining ΔG can we infer the orbital angular momentum and complete the picture of how the spin degrees of freedom are organized in the nucleon. STAR will make a major contribution to this complete picture.

Table 1

Process	Measured Function	Number Events	Measurement Error $\delta\left[\frac{\Delta f_a(x)}{f_a(x)}\right]$				
			x range				
	$\frac{\Delta f_a(x)}{f_a(x)}$		$0. - .05$	$.05 - .1$	$.1 - .2$	$.2 - .3$	$> .3$
γ+Jet	$\frac{\Delta G(x)}{G(x)}$	1×10^6	.01	.02	.05	.15	.3
Jet + Jet	$\frac{\Delta G(x)}{G(x)}$	4×10^7	.006-.03	.01-.03	.02	.03	.08
W^+	$\frac{\Delta \bar{d}}{d}$	9×10^4	.03	.03	.02	.05	
	$\frac{\Delta u}{u}$			.05	.02	.02	.03
W^-	$\frac{\Delta \bar{u}}{\bar{u}}$	2×10^4	.06	.04	.03	.03	
	$\frac{\Delta d}{d}$				.04	.03	.04
Z^0 A_{NN}	$\frac{\Delta u}{u}_T \times \frac{\Delta \bar{u}}{\bar{u}}_T$	7×10^3		.05	.03	.05	

Table 1: This is a brief outline of the sensitivity to fundamental quark and gluon polarizations obtained with STAR in a 100 day pp run at $\sqrt{s} = 500$ GeV. Sensitivity is defined as the minimal parton polarization which would be observable and is the statistical error associated with the parton polarization measurement. The range of errors quoted for some of the jet-jet entries reflects the sensitivity of errors in gluon polarization to the magnitude of that polarization. The assumptions range from $\left(\frac{\Delta G(x)}{G(x)} = x\right)$ to $\left(\frac{\Delta G(x)}{G(x)} = .05\right)$. For the Z^0, it is the sensitivity to the product of two transverse parton polarizations which is reported. Dijets and direct photons were selected to have $p_t > 15$ GeV/c and $p_t > 10$ GeV/c respectively.

[1] Details of the STAR detector are in the STAR Conceptual Design Report, LBL PUB-5347, June 1992.

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