Sensitivity to Gluon Polarization at RHIC

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In the RHIC spin project, we will measure the gluon polarization. There are two major experiments, PHENIX and STAR, at RHIC and both will measure the gluon polarization. Asymmetry measurements of the inclusive π^0 and the prompt photon by finely segmented EM calorimeter at PHENIX will be mainly discussed and the sensitivity to the gluon polarization measurement will be shown.

1. INTRODUCTION

The gluon polarization measurement is one of the most important goals of the RHIC spin project. The motivation of the gluon polarization measurement comes from the results of the polarized DIS experiments, which show the fraction of the quark polarization in the proton, $\Delta\Sigma$, is only about 30%. We have to investigate other sources to explain remaining fraction of the proton spin. The first candidate is the gluon polarization in the proton, ΔG.

In the DIS experiments, there is no direct coupling between the photon and the gluon. One method to measure the gluon polarization is to use Q^2 evolution. This is proposed at the polarized HERA by covering wide range of x and Q^2. Another method is to use semi-inclusive DIS. This will be done at HERMES, COMPASS and polarized HERA.

On the other hand, at RHIC with polarized proton collisions, we can perform direct measurement of ΔG by using direct reactions, $g + g$ or $g+q$. There are two major experiments, PHENIX and STAR, at RHIC. Table 1 shows the gluon polarization measurements at RHIC, their detectors, acceptances, and processes.

2. PHENIX AND STAR

There are finely segmented EM calorimeter [1] (EMCal) and muon detectors for the gluon polarization measurement at PHENIX. By using the EMCal, ΔG can be measured by prompt photon production and π^0 production. By using muon detectors, ΔG can be measured by heavy flavor production. This includes quarkonia production and open charm production.

The advantage of the STAR detector is the large acceptance EM calorimeter and TPC. By using both detectors, ΔG can be measured by prompt photon + jet and di-jet productions. Because the STAR detector can detect both the photon and the jet in the prompt photon production, the parton kinematics can be reconstructed and the gluon's x value can be obtained.

On the other hand, in the PHENIX detector, correlation between photon's p_T and gluon's x are used to evaluate the gluon's x in the prompt photon production.

In this manuscript, we will mainly discuss the ΔG measurements by photon detection at PHENIX. For those at STAR, refer to Ref.[2] in detail.

3. ΔG MEASUREMENT WITH PHOTON DETECTION

The PHENIX EMCal consists of both lead–scintillator sampling calorimeter and lead glass calorimeter. Both have fine granularity about 0.01 in both the η direction and the ϕ direction. They have an advantage to identify π^0 by the invariant mass reconstruction of $\pi^0 \to 2\gamma$ decay.

By using the EMCal, we will detect the prompt photon at PHENIX. The dominant process of the prompt photon production is the gluon Compton process, $gq \to \gamma q$. We can investigate the gluon

Table 1
Gluon polarization measurements at RHIC.

experiment	detector	acceptance	process	
PHENIX	EM calorimeter	$\|\eta\| \leq 0.35$	prompt photon	$gq \to \gamma q$
		$\Delta\phi = \pi/2 \times 2$	inclusive π^0	$g+g,\ g+q$
	muon detector	$1.2 \leq \|\eta\| \leq 2.4$	heavy flavor	$gg \to c\bar{c}, b\bar{b}$
		$\Delta\phi = 2\pi$		
STAR	EM calorimeter	$-1 \leq \eta \leq 2$		
		$\Delta\phi = 2\pi$	prompt photon + jet	$gq \to \gamma q$
	TPC	$-2 \leq \eta \leq 2$	di-jet	$g+g,\ g+q$
		$\Delta\phi = 2\pi$		

distribution with clear interpretation. For the collision of longitudinally polarized protons, the asymmetry $A_{LL} = 1/P_B^2 \cdot (N_{++} - N_{+-})/(N_{++} + N_{+-})$ is measured, where N_{++} (N_{+-}) is the number of observed prompt photon normalized by luminosity with parallel (anti-parallel) beam helicity. P_B is the polarization magnitude of each beam. For the gluon Compton process, the asymmetry is factorized;

$$A_{LL} = \Delta G/G \cdot A_1^p \cdot \hat{a}_{LL}(gq \to \gamma q) \quad (1)$$

where A_1^p is the quark polarization given by the DIS experiments, and the asymmetry for elementary process $gq \to \gamma q$, $\hat{a}_{LL}(gq \to \gamma q)$ is calculable. As a result, we can obtain a ratio of polarized to unpolarized distributions of the gluon, $\Delta G/G$.

The measurement is challenging experimentally. This is because of many backgrounds. Major background comes from 2γ decay of π^0. We need background reduction techniques, e.g. invariant mass reconstruction and isolation cut [3]. At PHENIX, we can achieve good background reduction with the high performance EMCal.

Although π^0 is a background against the prompt photon measurement, it also serves for a gluon polarization measurement as an alternative to jet in the small acceptance of PHENIX. Because most π^0's originate from QCD jets, the inclusive π^0 measurement reflects the initial parton state of the QCD jet production process, i.e. $g+g$, $g+q(\bar{q})$, $q(\bar{q})+q(\bar{q})$. The A_{LL} measurement of π^0 is interpreted by combining the polarized parton distribution function, the asymmetry of elementary processes, $\hat{a}_{LL}$, and the fragmentation function of π^0 . An advantage of this measurement is abundance of π^0. We can perform this in year–2, the first year of the polarized proton collision (2000–2001). We can constrain the gluon polarization, although it has uncertainties in the contributing reaction and fragmentation processes.

4. SENSITIVITY TO THE ΔG MEASUREMENT

For these two measurements, we performed simulation studies by using PYTHIA with GRV94LO parton distribution function.

Figure 1 shows the estimated error bars of our A_{LL} measurement of the prompt photon in year–3 (2001–2002) with $\sqrt{s} = 200$GeV and 320pb^{-1}. As a result of the background reduction, we can identify the prompt photon in the region of 10GeV/c < p_T <30GeV/c. This naively corresponds to the gluon's x region of $0.1 < x < 0.3$. To evaluate the A_{LL} measurement, four sets of the polarized parton distribution functions with different gluon polarization were compared and shown in Fig.1. Soffer and Virey's model [4] has ΔG value 2.00, and Gehrmann and Stirling's three models [5] have ΔG value of 1.71, 1.63 and 1.02. In the year–3 run, we will get enough statistics to distinguish these models and we will obtain $\Delta G/G$ in $0.1 < x < 0.3$.

Figure 2 shows the estimated error bars of our A_{LL} measurement of the inclusive π^0 in year–

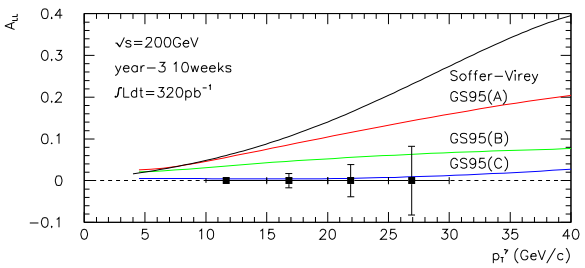

Figure 1. Statistical errors of the asymmetry measurement of the prompt photon at PHENIX. The asymmetry calculations using Soffer–Virey model and three Gehrmann–Stirling models are also shown.

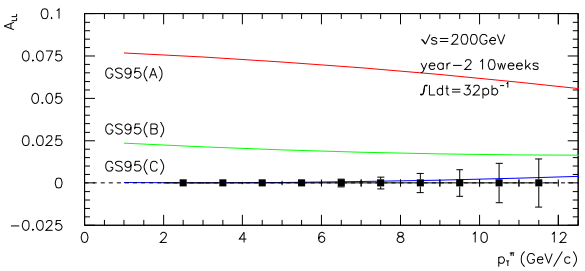

Figure 2. Statistical errors of the asymmetry measurement of the inclusive π^0 at PHENIX. The asymmetry calculations using three Gehrmann–Stirling models are also shown.

2 (2000–2001) with $\sqrt{s}$ = 200GeV and 32pb^{-1}. Gehrmann and Stirling's three models were compared. The statistical errors for the year–2 measurement are enough small to distinguish these models. We need further study of the systematic uncertainties.

5. SUMMARY

For the polarized proton collisions at RHIC, the commissioning run will start in the year–1 period starting from November 1999. From year–2, we will start $\sqrt{s}$ = 200GeV run, and after taking $\sqrt{s}$ = 200GeV run data, we will run with $\sqrt{s}$ = 500GeV. We have discussed the gluon polarization measurement. At PHENIX, we can measure the asymmetry of the inclusive π^0 in year–2, and that of the prompt photon in year–3. In the measurement of the prompt photon, we will obtain $\Delta G/G$ in the gluon's x region 0.1 $< x <$ 0.3 from $\sqrt{s}$=200GeV run and the region 0.04 $< x <$ 0.16 from $\sqrt{s}$=500GeV run. We will also measure the asymmetry of the heavy flavor production to know the gluon polarization. At STAR, the asymmetry measurements of prompt photon + jet and di-jet production will be performed. After these gluon polarization measurements, we expect to be able to analyze all these data globally to get the best knowledge about the gluon polarization.

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