ΔG MEASUREMENTS AT PHENIX

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One of the goals of the spin physics program in the PHENIX experiment at Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory is to explore the spin structure of the proton. Especially the direct measurement of the gluon polarization in the proton is necessary to understand the constituents of the proton spin. The latest results by the PHENIX experiment are reported.

1. Introduction

From 1980s, polarized deep inelastic scattering (DIS) experiments have been performed to explore the spin structure of the nucleon and revealed that the contribution from the quarks and anti-quarks is only about 30%.[1] The rest of the nucleon spin is supposed to be carried by gluon and orbital angular momentum of partons. Currently we only have poor knowledge about the gluon contribution to the nucleon spin since it is difficult to study the behavior of the gluon by DIS, in which the electromagnetic force is the dominant interaction and it can't directly probe gluons. One of the major motivations of the RHIC-spin program is to determine the gluon polarization in the proton (Δg) via polarized proton-proton collisions, where gluons in the proton can participate in the reaction at the leading order.

The measurement of double helicity asymmetry (A_{LL}) in the proton-proton collision is the promising method to study Δg in the experiment. A_{LL} is defined as the asymmetry of the helicity-dependent cross section and can be roughly translated into a quadratic function of Δg over g, the unpolarized gluon distribution, as follows.

$$A_{LL} \equiv \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} \sim \alpha \left(\frac{\Delta g}{g}\right)^2 + \beta \left(\frac{\Delta g}{g}\right) + \gamma, \qquad (1)$$

where σ is the cross section and its subscripts denote the helicity state of the beams. Each term of the right side of Eq.1 corresponds to the process with gluon-gluon, gluon-quark and quark-quark scattering in QCD (quantum chromodynamics) subprocess and the coefficients are related to the polarized quark distributions and A_{LL} in each subprocess.

The polarized proton-proton run was operated in 2001 at RHIC for the first time. Through many developments of the accelerator, the first long spin run at $\sqrt{s} = 200$ GeV was successfully completed in 2005 and PHENIX accumulated integrated luminosity (L) of 3.8 pb^{-1} with average beam polarization (P) of 47%, which is 40 times larger in figure of merit for A_{LL} (P^4L) than the past years.

2. The PHENIX detector

The PHENIX detector consists of global detectors and four spectrometers.[2] The global detectors include a pair of beam-beam counters (BBC) and zero degree calorimeters (ZDC). BBC determines collision points of beams and provides a minimum bias trigger. BBC is also important for the spin run as a detector to measure relative luminosity. ZDC is used to evaluate the uncertainty of relative luminosity by comparing its trigger rate with that of BBC. In addition, ZDC has another role as a local polarimeter to monitor the direction of the beam polarization.

Two spectrometers out of four are constructed at the central region (central arm) and one arm covers pseudo rapidity (η) from -0.35 to 0.35 and azimuthal angle (ϕ) of 90°. The central arm is composed of tracking chambers, particle identification detectors and electromagnetic calorimeters (EMCal) at the end. Photons and charged particles are detected by these arms. One of the features of the central arm is a high-energy photon trigger by means of EMCal to efficiently collect photons, π^0s and jets with high transverse momentum (p_T). The other two spectrometers cover the forward region, $1.2 < |\eta| < 2.4$ with full azimuth. These arms are composed of three stations of tracking chambers and a 5-layer sandwich of chambers and steel to identify muons (muon arm).

3. Recent results

In this report, we concentrate on the results related to the Δg measurements. Many other interesting issues by PHENIX are also reported in these proceedings.[3−4]

Neutral and charged pions. Fig.1(left) shows A_{LL} in pion production (A_{LL}^{π}) measured in 2005 run with four theoretical curves based on next-to-leading-order (NLO) perturbative QCD (pQCD) for $A_{LL}^{\pi^0}$.[5] Owing to huge statistics of pions and the high-energy photon trigger, $A_{LL}^{\pi^0}$ can be measured with good accuracy. Moreover, the progress in the accelerator performance made the precision of $A_{LL}^{\pi^0}$ improved significantly from previous years [6−7] and the data rejected the case of $\Delta g = g$. Δg obtained by translating $A_{LL}^{\pi^0}$ using a simple model based on Eq.1 indicates that our data has the capability to constrain Δg with more than twice the accuracy than ever before. Therewith, new issues come up. One is that the measured kinematical region corresponds to only limited range of Bjorken x. Another is that a probe by π^0 is insensitive to the sign of Δg since A_{LL}^{π} is described as a quadratic function of $\frac{\Delta g}{g}$. Recently the global QCD fits to the polarized DIS data with our π^0 results were done by other groups. [8-9]

A_{LL} of charged pions are also measured at 0.5 – 2.0 GeV/c in p_T and drawn on Fig.1(left). As well as these results themselves are the additional information toward Δg, they are useful to estimate the contamination from the soft QCD process, which is one of the concerns in $A_{LL}^{\pi^0}$ measurement. Because the size of measured $A_{LL}^{\pi^{\pm}}$ is smaller than 1% at $p_T < 1$ GeV/c, where pions are generated through the soft reaction, we estimate the contamination from the soft QCD process is less than 0.1% at $p_T > 2$ GeV/c supposing that its contribution is less than 10%.

Jet. Another promising probe is A_{LL} in jet production (A_{LL}^{jet}). In addition to high statistics comparable with pions, the advantage is that jet is free from the uncertainty from the hadron fragmentation. In the experiment, jet is reconstructed by collecting energy and momentum of photon and charged particles within the cone with R ($= \sqrt{\eta^2 + \phi^2}$) of 0.3 due to the limited detector acceptance. The ratio of the observed p_T (p_T cone) to the real p_T of initial scattered parton is estimated by use of PYTHIA simulation to be about 80%. Fig.1(right) displays A_{LL}^{jet} as a function of p_T cone obtained from 2003 data, with theoretical curves [10] which are normalized based on the simulation. The variation of several curves represents the systematic uncertainty of the p_T scale and indicates that the measurement will have a sensitivity to determine Δg in the near future with enough statistics.

Direct photon. One of the attractive channels to study Δg is direct photon. Since direct photons are directly generated in parton scattering, there is no uncertainty from the fragmentation like the case of jet. Moreover, they have an advantage over jet in terms of the detector acceptance. In addition to these features, the measurement of direct photon A_{LL} have an ability to solve the duality of the sign of Δg because of no contribution from gluon-gluon scatterings in the direct photon production. On the other hand, the difficulty is its poor statistics compared with other channels. At this moment, PHENIX presented only the cross section[11] and more statistics is needed for A_{LL} to obtain enough accuracy.

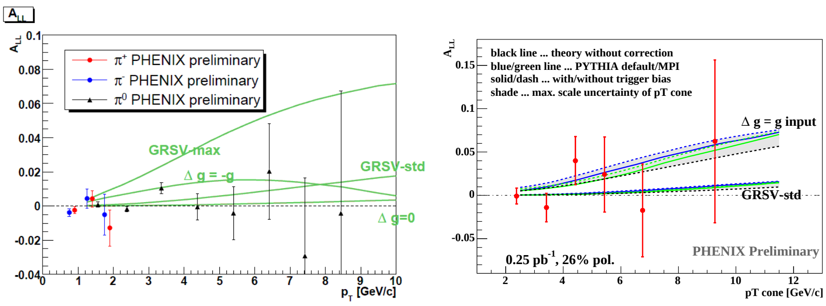

Figure 1. Left figure shows A_{LL} in π^+ (red), π^- (blue) and π^0 (black) production measured using 2005 data as a function of p_T, with four NLO pQCD calculations for π^0. GRSV-std represents the case of the best fits to the DIS data and other curves are calculated with the input of $\Delta g = g$ (GRSV-max), $\Delta g = 0$ and $\Delta g = -g$ at the input scale of $Q^2 = 0.4$ GeV^2. Right figure shows A_{LL} in jet production as a function of p_T observed by the detector (p_T cone) with two theoretical calculations (same description as left figure). Horizontal scale of the theoretical curves are normalized based on the PYTHIA simulation. Black; without scaling (original), blue; scaled using default PYTHIA, green; scaled using PYTHIA with the correction of multi-parton interaction which reproduces data better than default PYTHIA. The bias of high-energy photon trigger is (not) considered in the solid (dashed) line.

4. Summary and future prospects

RHIC succeeded the first long spin run in 2005 and has recently finished another spin run in 2006 where PHENIX accumulated ~7 times larger statistics in figure of merit for A_{LL}. The latest results of PHENIX are reported here and it is shown that our data have begun to constrain Δg. Meanwhile, new problems are also appearing, such as the determination of the sign of Δg and the limited range of Bjorken x. It is suggested to utilize direct photon to solve the former difficulty. The latter is also expected to be improved by measurements at $\sqrt{s} = 500$ GeV which will start from 2009.

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