OVERVIEW OF LONGITUDINAL SPIN PHYSICS AT PHENIX

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We present a brief overview of the longitudinal spin physics program in the PHENIX experiment at the Relativistic Heavy Ion Collider at BNL. The main goal is to study the longitudinal spin structure of the proton with strongly interacting probes at high energy to resolve the long standing "spin crisis". The latest results from PHENIX are presented.

1. Introduction

It is well known from early polarized DIS experiments that only about 30% of the proton spin can be attributed to the spin sum of the quarks and antiquarks.[1] The rest of the proton spin must come from gluons and orbital angular momentum, however, their actual contributions are poorly known at present. One prominent candiate for solving this missing spin puzzle is the gluon polarization. For a high energy proton, it is known that about half of the proton's linear momentum is carried by gluons, so it is not unreasonable to expect that gluons' spin may play a similar role for the proton spin. Currently, our knowledge of the polarized gluon distribution, $\Delta g(x)$, suffers from large theoretical and experimental uncertainties in extraction from the limited polarized DIS results since gluons are charge neutral and do not directly couple to virtual photons at leading order.

The RHIC-SPIN program provides a new tool for the study of the proton spin structure. Unlike DIS, the Relativistic Heavy Ion Collider at BNL collides polarized proton beams at high energy where (polarized) quarks and gluons interact directly at the partonic level at leading order, thus allowing us to directly access both the polarized quark and gluon distributions inside the proton.

The double longitudinal spin asymmetry A_{LL} in high energy particle X production in polarized p+p collisions is directly sensitive to the polarized quark and/or gluon distribution functions in the proton through quark-gluon interaction. In perturbative QCD, A_{LL}^X is given by,

$$A_{LL}^X = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} \approx \frac{\Delta f(x_1)}{f(x_1)} \times \frac{\Delta f'(x_2)}{f'(x_2)} \times \hat{a}_{LL}^X \tag{1}$$

where σ_{++} (σ_{+-}) is the cross section of the reaction producing particle X when two colliding particles have the same (opposite) helicity, $f(x)$ ($\Delta f(x)$) is the unpolarized (polarized) parton distribution function that we would like to extract and $\hat{a}_{LL}^X$ is the double spin asymmetry for the partonic subprocess $f + f' \to X$ and can be calculated in pQCD.

One important channel for measuring gluon polarization at RHIC is the heavy quark production. It is expected that heavy quark production in polarized p+p collisions at $\sqrt(s) = 200GeV$ is dominated by gluon-gluon interaction and the double spin asymmetry is proportional to the polarized gluon distribution function:

$$A_{LL}^{Q\bar{Q}} \approx \frac{\Delta g(x_1)}{g(x_1)} \times \frac{\Delta g(x_2)}{g(x_2)} \times \hat{a}_{LL}^{Q\bar{Q}} \tag{2}$$

where $g(x)$ ($\Delta g(x)$) is the unpolarized (polarized) gluon distribution function and $\hat{a}_{LL}^{Q\bar{Q}}$ is the double spin asymmetry for the partonic subprocess $g + g \to Q\bar{Q}$, with $Q = c$ or b.

Other high energy particles, such as π^0, can also be used to study gluon polarization through subprocesses like $g + g \to \pi^0$ and $g + q \to \pi^0$. The unpolarized π^0 cross section measured by PHENIX is well described by NLO pQCD calculations within theoretical uncertainty so the $A_{LL}^{\pi^0}$ can be reliably used to extract the gluon polarization.[2]

Another important channel for gluon polarization measurement is the direct photon production in polarized p+p collisions. Direct photons are predominantly produced via $g + q \to q + \gamma$ process and the double spin asymmetry is given by,

$$A_{LL}^{\gamma} \approx \frac{\Delta g(x_1)}{g(x_1)} \times \frac{\Delta q(x_2)}{q(x_2)} \times \hat{a}_{LL}^{g+q\to q+\gamma} \tag{3}$$

It is important to note that with direct photons, we can also unambiguously determine the sign of the gluon polarization, which is difficult to extract in other channels such as in the heavy flavor production, since the asymmetry is directly proportional to $\Delta g(x)$.

2. PHENIX Experiment

The PHENIX detector consists of global detectors at very large pseudo-rapidity and four spectrometers. A pair of beam-beam counters(BBC) that cover the pseudo-rapidity range $3 < |\eta| < 4$ have been used for the minimum bias trigger as well as for the relative luminosity measurement. Two central arm spectrometers cover $-0.35 < \eta < 0.35$ in pseudo-rapidity, azimuthal angle of 180 degrees, and have been used to measure charged particles and photons. The two muon spectrometers in the forward and backward directions measure high energy muons in pseudo-rapidity $1.2 < |\eta| < 2.4$ and cover full azimuthal angle. This allows PHENIX to do a wide range of measurements using different probes including pions, electrons, muons, prompt photons and jets.

The stable direction of the proton spin in RHIC is vertical. In order to provide collisions with longitudinal polarization at PHENIX, the region around the PHENIX experiment includes sets of magnets (spin rotators) to rotate the spin to the longitudinal directions at the collision point, and then put it back to vertical after the interaction point to maintain the required vertical polarization around RHIC. The transverse beam polarizations are measured in RHIC independently in each beam using proton-carbon elastic scattering in the Coulomb-nuclear interference region for a fast on-line measurement as well as with a polarized atomic hydrogen gas jet for an absolute beam polarization calibration.[3] In the PHENIX interaction region, the local polarimeters (Zero-Degree-Calorimeters at very forward region), which are sensitive to the transverse polarization at collision, are used to set up the spin rotators for the longitudinal spin configuration at interaction point.

3. Experimental Results

During the RHIC polarized p+p run in 2005, PHENIX accumulated $3.8pb^{-1}$ of integrated luminosity with an average beam polarization of 47%. This is the first high luminosity polarized p+p run at RHIC with the figure of merit (FOM) more than 40 times of the sum of all previous runs. Many results have been produced from this set of data, including double longitudinal spin asymmetries with π^0 and J/ψ at $\sqrt{s} = 200GeV$ from early fast-track data production. Figure 1 shows the preliminary results on double spin asymmetries in π^0 and $J\psi$ production from PHENIX.

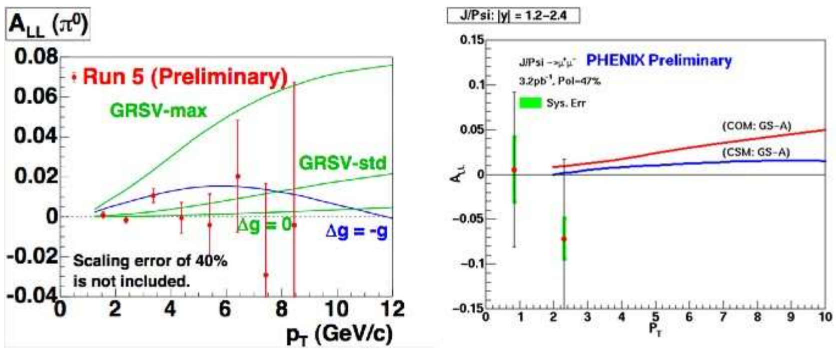

Figure 1. PHENIX preliminary results on double spin asymmetry vs p_T in π^0 and J/ψ production. Theoretical calculations are also shown for comparison with the data

Many other channels are also being explored for gluon polarization measurements including open charm, direct photon, charged pion and η production. Analyses are underway and preliminary results are expected soon.

4. Summary and Outlook

In the future with significantly improved luminosity and polarization of 70% (about a factor of 100 improvement in FOM), we will precisely determine the contribution of the gluon polarization to the proton spin. In addition to $\Delta g(x)$, with the future $500GeV/c$ runs, we will also measure the flavor identified quark and antiquark polarization $\Delta u(x), \Delta\bar{u}(x), \Delta d(x), \Delta\bar{d}(x)$ via $W^{\pm} \to \mu^{\pm} + \nu$ channel. It is expected that RHIC-SPIN will provide key inputs toward the resolution of the “spin crisis”.

References

1. J. Ashman *et al.*, Phys. Lett. **B 206**, 364 (1988); Nucl. Phys. **B328**, 1 (1989).
2. S. S. Adler *et al.* (PHENIX Collaboration), Phys. Rev. Lett. 93 (2004) 202002.
3. O. Jinnouchi *et al.*, RHIC/CAD Accelerator Physics Note (2004), Vol. 171; T. Wise *et al.*, Proceedings of the Spin 2004 Symposium, P.757, 507 (unpublished).