PROCEEDINGS OF SCIENCE

Direct photon cross section and double helicity asymmetry at mid-rapidity in $\vec{p}$+$\vec{p}$ collisions at $\sqrt{s}$ = 510 GeV

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Double helicity asymmetries A_{LL} in hadron, jet and direct photon production in $\vec{p}$+$\vec{p}$ collisions at the Relativistic Heavy Ion Collider (RHIC) are sensitive to the gluon helicity contribution to the proton's spin. Unlike hadrons and jet, direct photon production provides clean access to the polarized gluon distribution since there is no hadronization. However, the small direct photon production cross section compared to that of π^0 and jet production has so far limited its utility in extracting the polarized gluon distribution. With recent increases in RHIC luminosity, we expect this limitation to be partially overcome and try to revisit this "golden" measurement of polarized gluons based on RHIC data from 2013. This analysis will measure the direct photon cross section and A_{LL} from the data collected employing the PHENIX detector at mid-rapidity ($|\eta| < 0.35$). This will be the first direct photon cross section and A_{LL} measurement in $\vec{p}$+$\vec{p}$ at $\sqrt{s}$ = 510 GeV with this detector. We report the current status of analysis and the procedures to measure the direct cross section and A_{LL}.

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1. Introduction

Proton plays a key role in the composition of visible matter in the universe. Based on the framework of perturbative QCD (pQCD), the structure of proton is described by parton distribution functions (PDFs). Experimental measurements of (polarized) PDFs are not only important to give pQCD prediction power as well as testing it, but also interesting to its own right. Among those PDFs, the polarized PDF for gluons $\Delta g(x)$ draws much attention because it corresponds to the long standing spin puzzle, which states that the quark spin contributes only about 30% to the proton spin [1]. Polarized deep inelastic scattering (pDIS) probes the gluon spin through gluon fusion or parton evolution, of which both are not leading order effect. Jet, hadron and direct photon production in polarized $\vec{p}$+$\vec{p}$ collisions probe gluon polarization at leading order. However, hadron and jet production include fragmentation process, which will introduce uncertainties when extracting the gluon polarization. Since there is no hadronizaion for direct photon production, this is the most "clean" channel. In addition, the dominant process in direct photon production is quark-gluon scattering $q+g \to \gamma+q$, so this can also probe the sign of the gluon polarization. However, due to the small cross section of the direct photon, the luminosity of the previous RHIC run is not high enough to give meaningful result to constrain the gluon spin from direct photon production [2, 3, 4]. With the increase of the luminosity, we will revisit this "golden" channel and hope to constrain the gluon spin further. We will first measure the direct photon cross section and confirm it is consistent with pQCD. Then we can use pQCD to extract gluon contribution. This work is still in progress, we will give the analysis procedures in this proceeding.

RHIC is the only polarized proton-proton collider in the world. In the 2013 of RHIC run, it collided the polarized proton breams at a collision energy of $\sqrt{s}$ = 510 GeV. The PHENIX detector is located at the eight o'clock position of the RHIC ring (fig. 1). The primary detector used in this analysis is the electromagnetic calorimeter (EMCal), which consists of six sectors of lead scintillator (PbSc) and two sectors of lead glass (PbGl). The EMCal can measure the energy and position of the photon shower. the Drift Chamber (DC) is used for vetoing charged tracks. The Beam Beam Counter (BBC) is used to measure the luminosity.

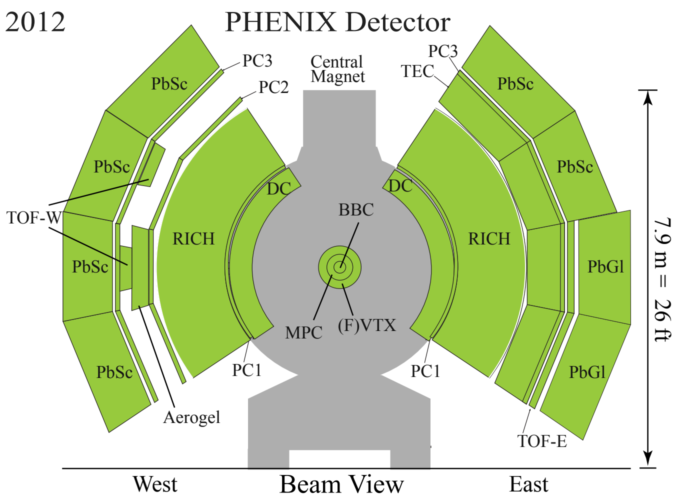

Figure 1: Beam view of PHENIX detector.

2. Direct photon cross section measurement

The sources of direct photon can be compton scattering ($g+q \rightarrow \gamma+q$), quark-antiquark annihilation ($q+\bar{q} \rightarrow \gamma+g$), parton fragmentation to photon and quark bremsstrahlung. Backgrounds are mainly decay photons from π^0, η, η' and ω. The direct photon yield can be calculated using either a subtraction method, or an isolation method. In the subtraction method, we calculate the direct photon yield as

$$N_{dir} = N_{incl} - (1+A)(1+R)N_{\pi^0}, \tag{2.1}$$

where R is π^0 one photon missing ratio and A is other hadrons' to π^0's photon ratio. The π^0 yield is obtained by subtracting the background from the yield integral around the π^0 invariant mass peak. The background is obtained by using the regions adjacent to the peak and interpolating in the signal region. (fig. 2). Due to the energy cut and detector effects such as masked area, finite detector size and resolution, there is some chance we get only one photon from π^0, the ratio between number of missed photons and that of reconstructed photons is called missing ratio R. It can be calculated by single-π^0 and detector geometry simulation. Two photons will start merging at high p_T, which is cut by photon shower shape. Produced ratio for η/π^0, ω/π^0 and η'/π^0 can be estimated by 200 GeV data [5] or PYTHIA simulation. To get the ratio of photons from other hadrons to the pi0 decay photons A, we multiply the branching ratios and take photon merging into account.

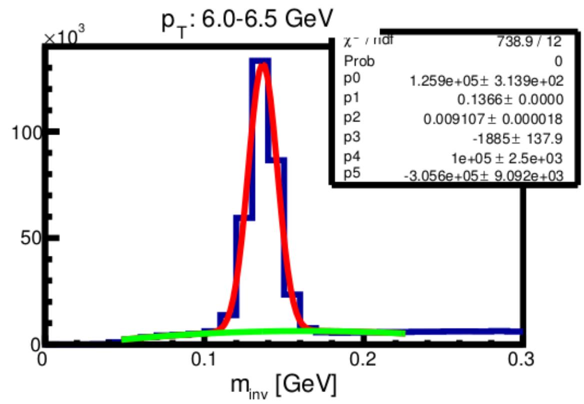

Figure 2: Yield of π^0background in p_T = 6-6.5 GeV.

Isolation cut is a method to measure the isolated direct photon cross section. It is done by requiring the energy in a cone around the primary photon to be less than some fraction of the energy of the primary photon (fig. 3). The cone size is chosen to 0.5 and the energy fraction is chosen to 0.1. Since fragmented photon and decay photon come with jets, this will select photons from quark-gluon Compton scattering and quark-antiquark annihilation, and therefore increase the signal-to-background ratio. The isolated direct photon yield is calculated as

$$N^{iso}_{dir} = N^{iso}_{incl} - (n^{iso}_{\pi^0} + RN^{iso}_{\pi^0}) - A^{iso}(1+R)N^{iso}_{\pi^0}, \tag{2.2}$$

where $n^{iso}_{\pi^0}$ ($N^{iso}_{\pi^0}$) is the number of π^0 decay photons pass isolation cut with (without) partner photon. A^{iso} is the photon ratio from other hadron decays to π^0decay photons, including the effect of isolation cut. R is the same missing ratio as in the subtraction method.

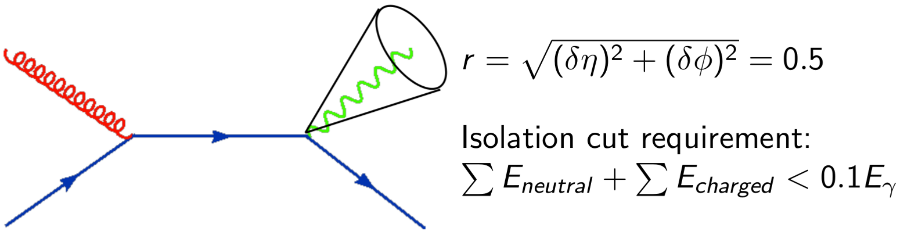

Figure 3: Isolation cut.

The direct photon cross section is calculated by

$$E\frac{d^3\sigma}{dp^3} = \frac{1}{\mathscr{L}} \cdot \frac{1}{2\pi p_T} \cdot \frac{1}{\Delta p_T \Delta y} \cdot \frac{N_{dir} \cdot r_{pileup}}{\varepsilon_{BBC}\varepsilon_{ERT}\varepsilon_{ToF}\varepsilon_{prob}\varepsilon_{acc}\varepsilon_{conv}}. \tag{2.3}$$

The absolute luminosity $\mathscr{L}$ can be determined from BBC counts by $\mathscr{L} = \frac{N_{BBC}}{\sigma_{BBC}}$, where σ_{BBC} is the cross section for p+p collisions triggered by BBC. This can be measured by Vernier scan [6]. ε_{BBC} can be obtained from the dataset without BBC trigger. Acceptance ε_{acc}, including geometrical acceptance due to finite detector size and masked areas, reconstruction efficiency due to cluster minimum energy cut, and p_T smearing due to detector resolution, can be determined from single photon and detector geometry simulation. ε_{conv} is photon conversion rate. This mainly comes from VTX detector and can be calculated by radiation length or detector simulation.

3. Measurement of direct photon longitudinal double-spin asymmetry

Each beam in RHIC has 120 bunches, of which 111 bunches are filled. The polarization patterns for bunches are called spin patterns. 16 spin patterns are used in Run 13 and we group them to 4 patterns for even and odd crossing separately. The longitudinal double-spin asymmetry A_{LL} is defined as

$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P_B P_Y} \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}}, \tag{3.1}$$

where $P_{B(Y)}$ is polarization of the blue (yellow) beam. The polarization magnitude is measured by p-Carbon, H-Jet polarimeters. $R = \frac{L_{++}}{L_{+-}}$ is the relative luminosity between different helicity states.

Bunch shuffling is a useful technique to test for additional RHIC fill-to-fill uncorrelated systematic uncertainties that may have been overlooked. We assign each bunch a random polarization for ten-thousand iterations, calculate A_{LL}, δA_{LL} and χ^2 for each iteration. The resulting χ^2/DOF (here DOF = number of fills) can indicate whether the uncorrelated uncertainty is calculated correctly or not.

Existing RHIC data with $\sqrt{s}$ = 200GeV mainly probe the region for Bjorken x within 0.05 and 0.2 in the mid-rapidity. From those data, STAR jet data clearly imply a polarization of gluons in this range[7]. There is also $\pi^0 A_{LL}$ measurement at PHENIX[8]. Since the luminosity of Run 13 is twenty times larger than that of Run 6, the projected statistical uncertainty is much smaller in Run 13 (fig. 4). We hope our results will add additional independent constraints on the ΔG.

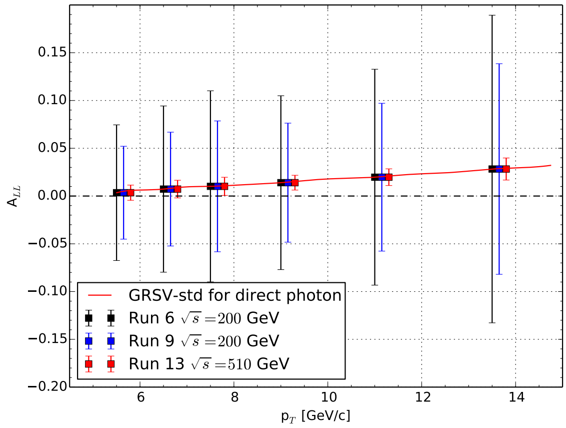

Figure 4: Projected uncertainty for direct photon A_{LL} measurement.

4. Summary

The recent RHIC data shows that the gluon spin is vital to understanding of the proton spin structure. The advantage of the direct photon measurement in p+p collisions is that it probes the gluon spin at leading order without the need for fragmentation functions. Data from 2013 provided the highest integrated luminosity at 510 GeV and is expected to provide further constraint on the contribution of the gluon to the proton spin.

References

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