Measurement of direct-photon cross section and double-helicity asymmetry at $\sqrt{s} = 510$ GeV in $\vec{p} + \vec{p}$ collisions†

Y. Goto,[*1] Y. Akiba,[*1] H. En'yo,[*1] I. Nakagawa,[*1] R. Seidl,[*1] Y. Watanabe,[*1] and S. Yokkaichi[*1]
for the PHENIX Collaboration

In polarized-proton collisions, spin-asymmetry measurements are sensitive to the polarized partonic structure of the proton and allow investigating its spin decomposition. Determining how fundamental properties of a particle, such as spin, comprise its constituents is crucial for understanding quantum chromodynamics (QCD). Perturbative QCD (pQCD) can describe unpolarized cross sections, whereas spin-dependent observables have historically offered additional insights. Polarized deep-inelastic scattering has shown that only a part of the proton spin is carried by quarks. A large fraction of the proton spin has been suggested to be carried by gluons. At the Relativistic Heavy Ion Collider (RHIC), gluons are accessible at leading order in hard scattering. Measurements of double-helicity asymmetry (A_{LL}) are directly sensitive to the polarized gluon distribution via longitudinally polarized $\vec{p} + \vec{p}$ collisions.

A_{LL} of direct-photon production in longitudinally polarized $\vec{p} + \vec{p}$ collisions is sensitive to both sign and magnitude of the gluon-spin contribution to the proton spin. Direct photons are photons that do not originate from the decay of final-state hadrons. The quark-gluon Compton process $qg \to q\gamma$ in proton-proton collisions at the RHIC is the dominant contributor to the production of direct photons with transverse momentum (p_T) higher than 5 GeV/c. Direct photons do not involve color interactions in the final state. Therefore, they provide a direct probe to the initial state of the colliding protons. For this reason, in the 1992 RHIC-spin proposal, A_{LL} was considered to be a *golden* channel to access the gluon spin.

The data were collected in 2013 with the PHENIX detector in the RHIC at $\sqrt{s} = 510$ GeV within pseudorapidity $|\eta| < 0.25$. Figure 1 shows A_{LL} of isolated direct-photon production in longitudinally polarized proton-proton collisions at $\sqrt{s} = 510$ GeV for $6 < p_T < 20$ GeV/c. The next-to-leading-order pQCD calculation was obtained using the DSSV14 polarized parton distribution function (PDF), NNPDF3.0 unpolarized PDF, and GRV fragmentation function for renormalization and factorization scales $\mu = p_T$ with a 1σ uncertainty band.[1)] The calculation is in good agreement with the results, within experimental uncertainties. The two dashed curves in Fig. 1 are obtained from a global analysis conducted in the JAM Collaboration.[2)] These curves show two distinct sets of solutions that differ in sign for the polarized gluon PDF, Δg. Even though the solutions with $\Delta g < 0$ violate the positivity assumption, $|\Delta g| < g$, previous data used in the global analysis study could not exclude them owing to the mixed contributions from quark-gluon and gluon-gluon interactions. However, the direct-photon A_{LL} originates mainly from the quark-gluon interactions and has $\chi^2 = 4.7$ and 12.6 for 7 data points for the $\Delta g > 0$ and $\Delta g < 0$ solutions, respectively. The χ^2 values differ by 7.9, suggesting that the negative solution is disfavored at more than 2.8σ level.

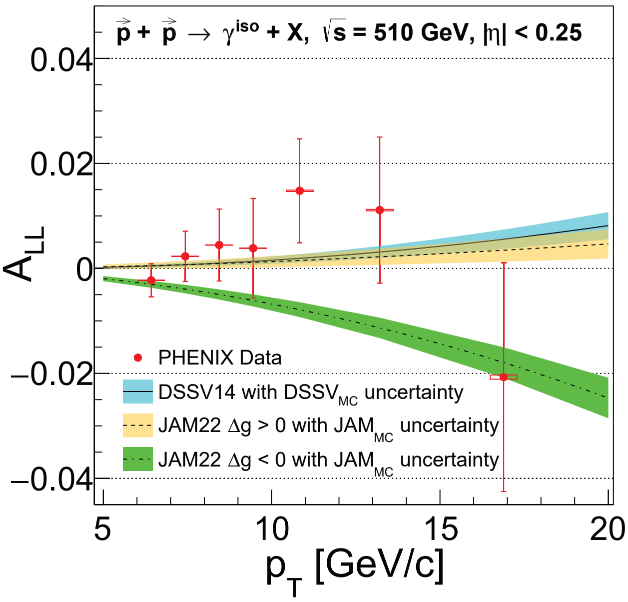

Fig. 1. Double-helicity asymmetry A_{LL} vs p_T for isolated direct-photon production in polarized $p + p$ collisions at $\sqrt{s} = 510$ GeV at midrapidity. Vertical error bars (boxes) represent the statistical (systematic) uncertainties. The systematic uncertainties for $p_T < 10$ GeV/c are smaller than the marker size. Not shown are a 3.9×10^{-4} shift uncertainty from relative luminosity and a 6.6% scale uncertainty from polarization.

References

1) D. de Florian *et al.*, Phys. Rev. Lett. **113**, 012001 (2014).
2) Y. Zhou, N. Sato, and W. Melnitchouk (Jefferson Lab Angular Momentum Collaboration), Phys. Rev. D **105**, 074022 (2022).

† Condensed from the article in Phys. Rev. Lett. **130**, 251901 (2023)

*1 RIKEN Nishina Center

DOI:10.34448/RIKEN.APR.57-025