First transversely polarized proton + proton collision in the sPHENIX experiment at RHIC

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Following the successful commissioning[1,2] of the sPHENIX detector[3,4] using Au + Au collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV in the relativistic heavy ion collider (RHIC), further commissioning and a physics data collection run was executed using transversely polarized $p+p$ collisions at $\sqrt{s} = 200$ GeV in 2024 (Run24). This addresses the origin of the proton spin, which has been the long lasting question of quantum chronodynamics (QCD). Colliding polarized protons against each other at high energies can help investigate how the spin of a proton is carried by its constituent quarks and gluons. Prior to the RHIC, it was known that only 1/3 of the proton spin was carried by quark spin. Previous works at RHIC revealed that the gluon spin also contributes to the proton spin. However, the quark and gluon spins cannot entirely explain 100% of the proton spin. If there is any remainder, it is the orbital angular momentum of the partons within the proton which is poorly known.

The sketch in the Fig. 1 depicts the sensitivity to the orbital motion of the gluon inside the transversely polarized proton in the $p + p$ collision.[5] This orbital motion is predicted to induce the left-right asymmetry in the collision products (probe). Jet(s), heavy flavors, and a direct photon are considered as golden probes for the orbital motion, which is what sPHENIX is designed to determine.

The polarizations of proton beams were measured by the proton-carbon and hydrogen jet (H-Jet) polarimeters[6] implemented at the 12 o'clock region of the RHIC ring. Figure 2 shows the observed polarizations of the blue and yellow beams by the H-Jet detector throughout the $p+p$ collisions in Run24. As shown in the plot, the RHIC successfully provided polarizations as high as 53 and 57% on average for the blue and yellow beams, respectively.

The spin orientation of the proton beam was monitored locally at sPHENIX throughout the $p+p$ run using local polarimetry[7] to control the systematic effect from a possible non-vertical component.[8] Conventionally, the polarization vector has been altered between the up and down bunch by bunch basis to minimize the systematic error induced by the detector acceptance difference between the left- and right-hand sides of the beam.[9] The analyzing power A_{N} given in equation 1 forms the counts of the observed product for the polarized beam up ($N^{\uparrow}$) and down ($N^{\downarrow}$):

$$A_{\mathrm{N}} = \frac{1}{P}\frac{N^{\uparrow} - RN^{\downarrow}}{N^{\uparrow} + RN^{\downarrow}}, \qquad (1)$$

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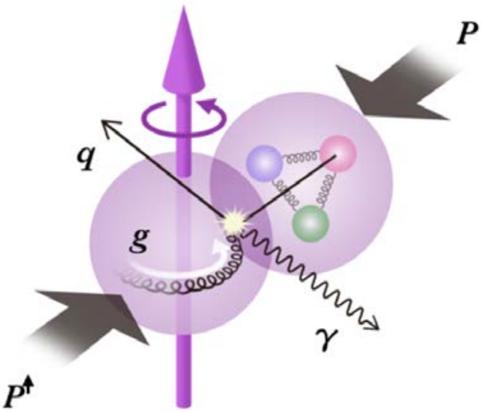

Fig. 1. Sketch of the sensitivity to the orbital motion of gluon in the high-energy transversely polarized $p + p$ collision.

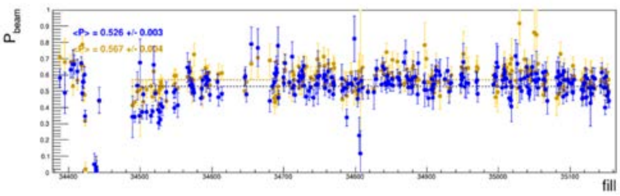

Fig. 2. Polarizations for the blue and yellow beams observed by the H-Jet detector throughout the $p+p$ collisions in Run24.

where P represents the beam polarization and R represents the "relative luminosity," which is given by the ratio of luminosity measurements for up ($L^{\uparrow}$) and down ($L^{\downarrow}$) spin by the minimum bias detector. Newly implemented scalers counted luminosity for up and down spins bunch by bunch and integrated it for all counts for up and down bunches, respectively. In this manner, the relative luminosity can be measured with high statistical precision without prescaling.

References

1) I. Nakagawa *et al.*, RIKEN Accel. Prog. Rep. **57**, 56 (2023).
2) Y. Akiba *et al.*, RIKEN Accel. Prog. Rep. **57**, S1 (2023).
3) An Upgrade Concept from the PHENIX Collaboration, arXiv:1207.6378v2 (2012).
4) Technical Design Report of sPHENIX (2019), `https://indico.bnl.gov/event/7081/`.
5) N. J. Abdulameer *et al.*, Phys. Rev. Lett. **130**, 251901 (2024).
6) A. Zelenski *et al.*, Nucl. Instrum. Methods Phys. Res. A **536**, 248 (2005).
7) J. Hwang *et. al.*, in this report.
8) PHENIX Collab., Phys. Rev. D **88**, 032006 (2013).
9) I. Nakagawa, Ukr. J. Phys. **69**, 799 (2024).

DOI:10.34448/RIKEN.APR.58-116