Signature of the gluon orbital angular momentum[†]

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The Relativistic Heavy Ion Collider (RHIC) spin program at Brookhaven National Laboratory has revealed that the gluon helicity contribution ΔG to the proton spin sum rule

$$\frac{1}{2}=\frac{1}{2}\Delta\Sigma+\Delta G+L_q+L_g, \tag{1}$$

is nonvanishing and likely sizable. Together with the known quark helicity contribution $\Delta\Sigma\sim 0.3$, the result indicates that parton helicities account for a significant fraction of the proton spin. Yet, there still remain huge uncertainties about the small-x contribution to $\Delta G=\int_0^1 dx\Delta G(x)$. Resolving this issue is one of the major goals of the future Electron-Ion Collider (EIC).

Another obvious goal of the EIC is to measure the orbital angular momentum (OAM) of quarks and gluons $L_{q,g}$. However, progress in this direction is relatively slow, although there have been a few suggestions[1] for experimental observables in recent years. In this report we propose a new and promising observable for the gluon OAM in Deep Inelastic Scattering and make a quantitative prediction for the EIC.

Specifically, we calculate longitudinal double spin asymmetry (DSA) in exclusive dijet production in electron-proton collisions $ep\to\gamma^*p\to jjp'$ where both the incoming electron and proton are longitudinally polarized. The part of the cross section which depends on the proton and electron polarizations takes the form

$$d\sigma^{h_ph_l}\sim h_ph_l\cos(\phi_{l_\perp}-\phi_{\Delta_\perp})\mathfrak{Re}(A_2A_3^*), \tag{2}$$

where $h_l,h_p=\pm1$ are the electron and proton helicities. $\phi_{l_\perp}$ and $\phi_{\Delta_\perp}$ are the azimuthal angles of the outgoing lepton and the proton, respectively. A_2 is the known[2] twist-2 amplitude for dijet production. A_3 is a twist-3 amplitude which contains the OAM and which is calculated for the first time in this work. The details can be found in the published letter. Here we show the final result after certain approximations

$$\begin{aligned}&\mathfrak{Re}(A_2A_3^*) \qquad (3)\\ &\propto\mathfrak{Re}\left[\left\{\mathcal{H}_g^{(1)*}+\frac{4q_\perp^2}{q_\perp^2+\mu^2}\mathcal{H}_g^{(2)*}\right\}\mathcal{L}_g-\mathcal{H}_g^{(1)*}\tilde{\mathcal{H}}_g\right],\end{aligned}$$

where $q_\perp$ is the transverse momentum of the two jets which are assumed to be symmetric and $4\mu^2=Q^2$ is the photon virtuality. $\mathcal{H}_g^{(1,2)}$, $\mathcal{L}_g$ and $\tilde{\mathcal{H}}_g$ are the Compton form factors of the unpolarized gluon generalized parton distribution (GPD), the gluon OAM and the gluon helciity GPD, respectively. We observe an interesting interplay between the gluon OAM and the gluon helicity. The latter contribution was missed in the previous calculation of a related observable.[1]

In Fig. 1, we show our numerical result for the cross section for the EIC kinematics at $\delta\phi=\phi_{l_\perp}-\phi_{\Delta_\perp}=0$ for $Q^2=2.7$ GeV^2 plotted as a function of skewness ξ (longitudinal momentum fraction the proton loses in scattering). We see that the OAM and helicity contributions are comparable in magnitude, but with opposite signs. This is consistent with the theoretical prediction[3] that the gluon OAM and gluon helicity parton distributions cancel in the small-x region. For larger values of Q^2, our result (3) predicts that the two contributions add up. This can be tested in experiment by varying Q^2.

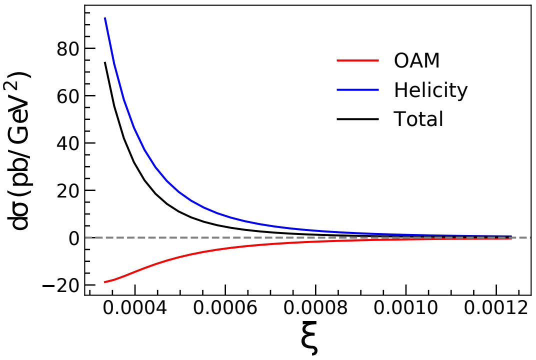

Fig. 1. Spin-dependent part of the cross section at $Q^2=2.7$ GeV^2 as a function of the skewness variable ξ. The 'OAM' and 'Helicity' contributions come from the $\mathcal{L}_g$ and $\tilde{\mathcal{H}}_g$ terms in (3), respectively.

In conclusion, we have made the first quantitative prediction for an observable sensitive to the parton OAM at the EIC. Our result adequately demonstrates the feasibility of accessing the gluon OAM from DSA. It also emphasizes that, due to the admixture of the gluon helicity contribution, in order to extract the OAM reliably, one needs an accurate determination of $\Delta G(x)$ down to $x\sim 10^{-3}$.

References

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