Accessing Gluon Polarization in Large-P_T SIDIS

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Abstract

This work undertakes an analysis of polarized semi-inclusive deep inelastic scattering (SIDIS) at leading order (LO) to understand better the potential of future experiments at Jefferson Lab (JLab) and the Electron-Ion Collider (EIC) to further constrain the helicity-dependent gluon parton distribution function (PDF) Δg. In our work, we reproduce calculations for the unpolarized cross-section and extend to the case of longitudinal polarization in the initial state lepton and hadron in order to compute double spin asymmetry values, specialized to high transverse momentum of the produced hadron. We find that this process is sensitive to the gluon channel and is theoretically and statistically capable of distinguishing the two gluon solutions obtained from previous JAM fits.

Introduction

In this work, we consider the SIDIS process

$$lP \to l'HX, \tag{1}$$

which is shown as a Feynman diagram in the one photon exchange in Fig. 1. In particular, we consider longitudinal polarization in the initial state and specialize to large transverse momentum of the produced hadron, which will allow us to consider hard gluon emissions at the born level and thus to directly access the gluon polarization.

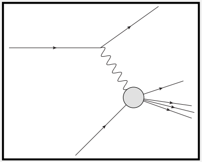

Figure 1: Semi-inclusive deep inelastic scattering process in the one-photon exchange approximation.

Approach

In the one photon exchange approximation, the hadronic cross section is given as

$$\frac{d\sigma}{dx\,dQ^2\,dz\,dP^2_{H,T}} = \frac{\pi\alpha^2_{em}}{2zQ^4} L_{\mu\nu} W^{\mu\nu}, \tag{2}$$

where the leptonic tensor $L_{\mu\nu}$ is exactly calculable in QED and the hadronic tensor is calculated using a collinear factorization theorem [1]

$$W^{\mu\nu} = \sum_{i,j} \int_x^1 \frac{d\xi}{\xi} \int_z^1 \frac{d\zeta}{\zeta^2} \hat{W}^{\mu\nu} f_{i/P}(\xi) D_{H/j}(\zeta). \tag{3}$$

The PDFs $f_{i/P}$ and fragmentation functions (FFs) $D_{H/j}$ are determined from current parameters fit by previous Jefferson Lab Angular Momentum Collaboration (JAM) studies. Now, the partonic structure tensor $\hat{W}^{\mu\nu}$ can be calculated at the born level in the same was as the lepton tensor.

Hard Scattering Amplitudes

At the born level, the contributing diagrams are simple $2 \to 2$ diagrams.

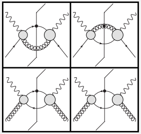

Figure 2: Tree level diagrams for large transverse momentum SIDIS at the parton level. Note that the grey blobs represent all the possible allowed connections between partons and the black dot indicates the fragmenting parton.

To allow polarization at the parton level, we use the following spinor and polarization vector products for the quark and gluon polarizations, respectively [2].

$$u(p,s)\overline{u}(p,s) = \frac{1}{2}(1 + \lambda\gamma_5)\not{p} \tag{4}$$

$$\epsilon^{\mu}(p)\epsilon^{*\nu}(p) = \frac{1}{2}\left(-g^{\mu\nu} + \frac{i\lambda}{p\cdot X}\epsilon^{\mu\nu\alpha\beta}p_{\alpha\beta}\right). \tag{5}$$

Results

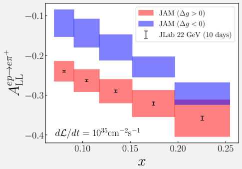

Figure 3: Double spin asymmetry ($A_{LL} = d\Delta\sigma/d\sigma$) values with positive and negative gluon replicas at $\sqrt{s} = 6.5$ GeV for selected JLab 22 GeV kinematics.

Discussion

As seen in Fig. 3, the SIDIS process is quite sensitive to the gluon channel. The bands representing the asymmetries for the positive and negative helicity-dependent gluon PDFs are distinct in a kinematically accessible range for JLab with a 22 GeV electron beam at a practical luminosity.

Acknowledgements

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References

[1] B. Wang, J. O. Gonzalez-Hernandex, T. C. Rogers, and N. Sato, Phys. Rev. **D99**, 9(2019).
[2] D. de Florian and W. Vogelsang, Phys. Rev. **D57**, 7(1998).

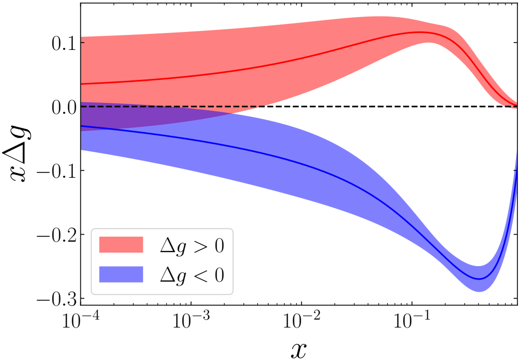
Abstract

Proton Spin Puzzle

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

$$\frac{1}{2}\Delta\Sigma \lesssim 30\%$$

$$\Delta G = \int_{x_{\min}}^{1} \Delta g(x)\, \mathrm{d}x$$



Jefferson Lab

Introduction

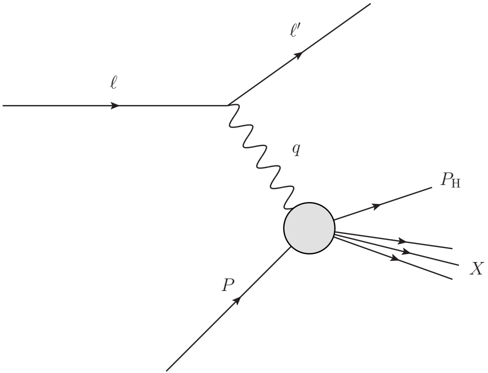
Semi-inclusive DIS (SIDIS)

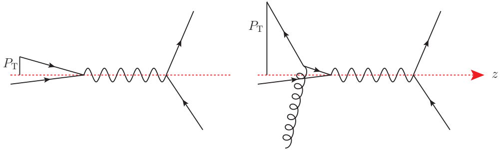
$$l + N \to l' + H + X$$

Large transverse momentum:

$$P_{H,T}/z = q_T \gtrsim Q$$

Why large $P_{H,T}$?





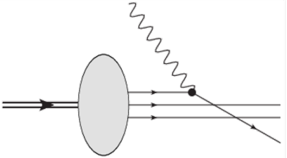
Approach

$$\frac{\mathrm{d}\sigma_{\mathrm{H}}}{\mathrm{d}x\,\mathrm{d}y\,\mathrm{d}z\,\mathrm{d}P_{\mathrm{T}}^2} = \frac{\pi^2\alpha_{\mathrm{em}}^2}{2zQ^4} L_{\mu\nu} W^{\mu\nu}$$

$$\rightarrow L_{\mu\nu} = 2(\ell_\mu \ell'_\nu + \ell'_\mu \ell_\mu - g_{\mu\nu} \ell \cdot \ell' - i\lambda_\ell \epsilon_{\mu\nu\alpha\beta} \ell^\alpha \ell'^\beta)$$

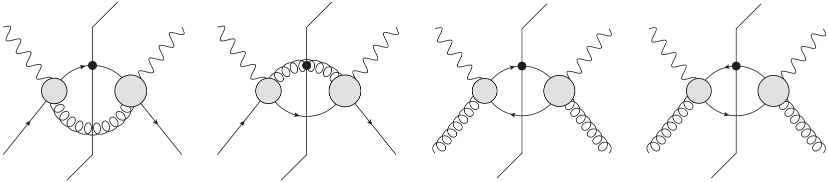
But $W^{\mu\nu}$ not so simple $\rightarrow$ Collinear factorization (large Q^2, P_T)

$$W^{\mu\nu} = \sum_{i,j} \int_x^1 \frac{\mathrm{d}\xi}{\xi} \int_z^1 \frac{\mathrm{d}\zeta}{\zeta^2} \widehat{W}_{i,j}^{\mu\nu} \underbrace{f_{i/P}(\xi) D_{H/j}(\zeta)}_{\text{JAM}}$$



Hard Scattering Amplitudes

$$\widehat{W}^{\mu\nu} = \sum_{\text{graphs}} \mathcal{M}^{\mu}\mathcal{M}^{\dagger\nu}$$



$$u(p,s)\overline{u}(p,s) = \frac{1}{2}(1+\lambda\gamma_5)\not{p}$$

$$\epsilon^{\mu}(p)\epsilon^{*\nu}(p) = \frac{1}{2}\left(-g^{\mu\nu} + \frac{i\lambda}{p\cdot X}\epsilon^{\mu\nu\alpha\beta}p_{\alpha}X_{\beta}\right)$$

Results

$$A_{\mathrm{LL}} = \frac{\mathrm{d}\Delta\sigma}{\mathrm{d}\sigma}$$

$$\delta A_{\mathrm{LL}} = \frac{1}{\sqrt{\mathcal{L}\sigma}}$$