Probing Gluon Sivers Function in Inelastic Photoproduction of $J/\psi$ at the EIC

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We present a recent calculation of the single spin asymmetry in inclusive photoproduction of $J/\psi$ at the future EIC, that can be used to probe the gluon Sivers function.

1. Introduction

$J/\psi$ production in $ep$ and $pp$ collisions is known to be an effective tool to probe the gluon TMDs, as the contribution comes at leading order (LO) through $\gamma g$ and $gg$ initiated processes. One of the most interesting gluon TMDs is the gluon Sivers function (GSF) which probes the coupling of the intrinsic transverse momenta of the gluons with the transverse spin of the nucleon. The Sivers function\cite{1,2} is a time reversal odd (T-odd) object and initial and final state interactions play an important role in the Sivers asymmetry. The gluon Sivers function for any process can be written as a linear combination of two gluon Sivers functions, one containing a C-even operator (f-type) and the other C-odd (d-type)\cite{3}. Compared to the quark Sivers function, much less is known about the gluon Sivers function, apart from a positivity bound\cite{4}. In this talk, we present a recent calculation\cite{5} of single spin asymmetry in inelastic photoproduction of $J/\psi$ at the future EIC.

2. Calculation of the asymmetry

The process considered is

$$e(l) + p^\uparrow(P) \rightarrow J/\psi(P_h) + X$$

(1)

where the quantities within brackets are the momenta. We use the kinematics where the interaction takes place through the exchange of an (almost) real photon $\gamma (q) + g(k) \rightarrow J/\psi(P_h) + g(p_g)$. We consider only the direct photon contribution and contribution from the resolved photon is eliminated by imposing a cut on the variable $z = \frac{P_H \cdot P}{E_q}$, which is the energy fraction transferred from the photon to the $J/\psi$ in the rest frame of the proton. The inelasticity variable $z$ for inclusive photoproduction can be measured in experiments by Jacquet-Blondel method. The
leading order (LO) process \( \gamma + g \rightarrow J/\psi \) contributes at \( z = 1 \) (see\(^6\)) for the calculation of Sivers asymmetry in electroproduction) and we use a cutoff \( z < 0.9 \) to remove this contribution. Also contribution to \( J/\psi \) production from gluon and heavy quark fragmentation was removed by imposing a cut on \( P_T \), which is the transverse momentum of the \( J/\psi \). We assume TMD factorization for the process considered and generalized parton model (GPM) with the inclusion of the intrinsic transverse momenta. We use NRQCD\(^7\) to calculate the production of \( J/\psi \). The \( c\bar{c} \) pair can be produced in color singlet (CS) or color octet (CO) state. In \( eP \) collision, non-zero asymmetry can be observed only if the \( c\bar{c} \) pair is produced in the CO state\(^8\). The SSA is defined as

\[
A_N = \frac{d\sigma^\uparrow - d\sigma^\downarrow}{d\sigma^\uparrow + d\sigma^\downarrow}.
\]  

where \( d\sigma^\uparrow \) and \( d\sigma^\downarrow \) are the differential cross-sections measured when one of the particle is transversely polarized up (\( \uparrow \)) and down (\( \downarrow \)), respectively, with respect to the scattering plane.

We consider the inclusive process \( e(l) + p^i(P) \rightarrow J/\psi(P_h) + X \). The virtual photon radiated by the initial electron is almost real, \( q^2 = -Q^2 \approx 0 \). The numerator and the denominator of the asymmetry are given by

\[
d\sigma^\uparrow - d\sigma^\downarrow = \frac{d\sigma^{ep^i \rightarrow J/\psi X}}{dzd^2P_T} - \frac{d\sigma^{ep^i \rightarrow J/\psi X}}{dzd^2P_T} = \frac{1}{2z(2\pi)^2} \int \int dx_\gamma dx_g d^2k_{\perp g} f_{\gamma / e}(x_\gamma) f_{g / p}(x_g, k_{\perp g}) \Delta_N g_{\gamma + g} \left( \hat{s} + \hat{t} + \hat{u} - M^2 \right) \frac{1}{2\hat{s}} \left| M_{\gamma + g \rightarrow J/\psi + g} \right|^2,
\]

and

\[
d\sigma^\uparrow + d\sigma^\downarrow = \frac{d\sigma^{ep^i \rightarrow J/\psi X}}{dzd^2P_T} + \frac{d\sigma^{ep^i \rightarrow J/\psi X}}{dzd^2P_T} = \frac{2}{2z(2\pi)^2} \int \int dx_\gamma dx_g d^2k_{\perp g} f_{\gamma / e}(x_\gamma) f_{g / p}(x_g, k_{\perp g}) \Delta_N g_{\gamma + g} \left( \hat{s} + \hat{t} + \hat{u} - M^2 \right) \frac{1}{2\hat{s}} \left| M_{\gamma + g \rightarrow J/\psi + g} \right|^2.
\]

\( x_\gamma \) and \( x_g \) are the light-cone momentum fractions of the photon and gluon respectively. The Weizsäcker-Williams distribution function, \( f_{\gamma / e}(x_\gamma) \), describes the density of photons inside the electron. The \( J/\psi \) production rate is calculated in NRQCD based color octet model. We follow the approach given in\(^9\) and the details of the calculation can be found in\(^6\). Here, we report on some of our numerical results in the kinematics of the future planned EIC.
3. Results

For the numerical estimates of the SSA we assume Gaussian parametrization of unpolarized TMDs and best fit parameters from\textsuperscript{10} for the gluon Sivers function. These are denoted by SIDIS1 and SIDIS2, respectively. Also, following\textsuperscript{11} we parametrize the GSF in terms of $u$ and $d$ quark Sivers functions\textsuperscript{12}. Two different choices in this line are labeled as BV-a and BV-b. For the dominating channel of photon-gluon fusion, contribution to the numerator of the SSA comes mainly from GSF. As the heavy quark pair is produced unpolarized, there is no contribution from the Collins function. Figs 1 and 2 show plots of the SSA for $\sqrt{s} = 100$ GeV and 45 GeV respectively which will be possible at the future EIC. The asymmetry depends strongly on the parametrization for the GSF, it is positive for SIDIS1 and SIDIS2 and negative for BV-a and BV-b parametrizations. The magnitude of the asymmetry is largest for BV-b. We have incorporated contributions from the $3S_1^{(8)}$, $1S_0^{(8)}$ and $3P_J^{(0,1,2)}(8)$ in the asymmetry. Numerical estimates of the unpolarized cross section shows that the data from HERA can be explained if both CS and CO contributions are incorporated.

4. Conclusion

We have presented a recent calculation of the SSA in inclusive photoproduction of $J/\psi$ production in the kinematics of the future EIC. A sizable asymmetry in NRQCD based color octet model is reported, for the range $0 < P_T < 1$ GeV and $0.3 < z < 0.9$. This asymmetry can give direct access to the GSF.
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References

1. D. W. Sivers, Phys. Rev. D41, 83 (1990).
2. D. W. Sivers, Phys. Rev. D43, 261 (1991).
3. M. G. A. Buffing, A. Mukherjee, and P. J. Mulders, Phys. Rev. D88, 054027 (2013), 1306.5897.
4. P. J. Mulders and J. Rodrigues, Phys. Rev. D63, 094021 (2001), hep-ph/0009343.
5. S. Rajesh, R. Kishore, and A. Mukherjee, Phys. Rev. D98, 014007 (2018), 1802.10359.
6. A. Mukherjee and S. Rajesh, Eur. Phys. J. C77, 854 (2017), 1609.05596.
7. G. T. Bodwin, E. Braaten, and G. P. Lepage, Phys. Rev. D51, 1125 (1995), [Erratum: Phys. Rev.D55,5853(1997)], hep-ph/9407339.
8. F. Yuan, Phys. Rev. D78, 014024 (2008), 0801.4357.
9. D. Boer and C. Pisano, Phys. Rev. D86, 094007 (2012), 1208.3642.
10. U. D’Alesio, F. Murgia, and C. Pisano, JHEP 09, 119 (2015), 1506.03078.
11. D. Boer and W. Vogelsang, Phys. Rev. D69, 094025 (2004), hep-ph/0312320.
12. M. Anselmino, M. Boglione, U. D’Alesio, F. Murgia, and A. Prokudin, JHEP 04, 046 (2017), 1612.06413.