

# Role of $J/\psi$ production in electron-ion collisions

Zexuan Chu,<sup>1</sup> Jinhui Chen<sup>1,2,\*</sup>, Xiang-Peng Wang<sup>3,†</sup> and Hongxi Xing<sup>4,5,6,‡</sup>

<sup>1</sup>Key Laboratory of Nuclear Physics and Ion-beam Application (MOE) and Institute of Modern Physics, Fudan University, Shanghai 200433, China

<sup>2</sup>Shanghai Research Center for Theoretical Nuclear Physics, NSFC and Fudan University, Shanghai 200438, China

<sup>3</sup>Technical University of Munich, TUM School of Natural Sciences, Physics Department, James-Frank-Strasse 1, 85748 Garching, Germany

<sup>4</sup>Key Laboratory of Atomic and Subatomic Structure and Quantum Control (MOE), Guangdong Basic Research Center of Excellence for Structure and Fundamental Interactions of Matter, Institute of Quantum Matter, South China Normal University, Guangzhou 510006, China

<sup>5</sup>Guangdong-Hong Kong Joint Laboratory of Quantum Matter, Guangdong Provincial Key Laboratory of Nuclear Science, Southern Nuclear Science Computing Center, South China Normal University, Guangzhou 510006, China

<sup>6</sup>Southern Center for Nuclear-Science Theory (SCNT), Institute of Modern Physics, Chinese Academy of Sciences, Huizhou 516000, China



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Within the framework of nonrelativistic QCD (NRQCD) effective field theory, we study the leptonproduction of  $J/\psi$  at next-to-leading order in perturbative QCD for both unpolarized and polarized electron-ion collisions. We demonstrate that the  $J/\psi$ -tagged deep inelastic scattering in the future Electron-Ion Collider can be served as a golden channel for reasons including constraining NRQCD long-distance matrix elements, probing the nuclear gluon distribution functions, as well as investigating the gluon helicity distribution inside a longitudinal polarized proton.

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**Introduction.**  $J/\psi$  production has been the focus of much theoretical and experimental interest in the past decades. Understanding its production mechanism and using it as a probe to QCD matter are among the most active and challenging subjects in particle and nuclear physics [1–3]. Among several extensively used models and effective field theories for the description of heavy quarkonium production, the most sophisticated one in high energy collisions is provided by nonrelativistic QCD (NRQCD) effective field theory [4], in which the  $J/\psi$  hadronization mechanism is encoded in the nonperturbative long-distance matrix elements (LDMEs). In the past decades, through explicit perturbative calculation of  $J/\psi$  production at next-to-leading order (NLO) in electron-positron, proton-proton, and electron-proton collisions within the NRQCD factorization

framework, significant progress has been made to extract the LDMEs from world data, see, e.g., [5–11]. However, no consensus has been reached yet to identify the universalities of these LDMEs and to understand the polarization of the produced  $J/\psi$  [12,13].

On the other hand, taking advantage of the fundamental properties of heavy quarkonium and its production mechanism, it has been proposed that heavy quarkonium can be served as a sensitive probe of the fundamental properties of nuclear matter. Remarkable examples include the identification of quark gluon plasma [14–16], probing the gluon jet quenching effect in heavy ion collisions [17,18], and searching for signatures of gluon saturation in ultraperipheral collisions [19], as well as the study of short-range correlation in nuclei [20]. Moreover, with the advent of electron-ion colliders [21,22], new proposals of using  $J/\psi$  production in lepton-proton collisions to probe the nucleon structure have been put forward recently, see, e.g., [23–30]. All these proposals are driven by the prominent feature that  $J/\psi$  in deep inelastic scattering (DIS) is dominated by virtual photon-gluon fusion process, which can be inferred from the leading order diagram as shown in Fig. 1(a). Such a unique feature drives the expectation that  $J/\psi$  production is more sensitive to the gluon content of nucleon and nuclei,

\* Contact author: [chenjinhui@fudan.edu.cn](mailto:chenjinhui@fudan.edu.cn)

† Contact author: [xiangpeng.wang@tum.de](mailto:xiangpeng.wang@tum.de)

‡ Contact author: [hxing@m.scnu.edu.cn](mailto:hxing@m.scnu.edu.cn)

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compared to the generally recognized observables like dijet production [31,32], which suffers contamination from a virtual photon-quark interaction channel.

A similar feature also exists in  $J/\psi$  photoproduction that has been measured by HERA [33–35], with complete NLO calculations performed in Refs. [36–38], leading to constraints on LDMEs particularly sensitive to the prediction of  $J/\psi$  polarization at the LHC [6]. Likewise, the leptonproduction of  $J/\psi$  has also been measured at HERA [34,39–41], which was compared with the NRQCD prediction at leading order (LO) [42,43] and at NLO considering color-singlet contribution in Ref. [44]. In this Letter, we emphasize the exceptional role of  $J/\psi$ -tagged DIS in the future Electron-Ion Collider (EIC) [21,45]. In particular, through explicit calculation at NLO for  $J/\psi$  production in unpolarized electron-proton ( $ep$ ) collisions, we explore the novel opportunities to constrain the LDMEs  $\langle\mathcal{O}^{J/\psi}(^1S_0^{[8]})\rangle$  and  $\langle\mathcal{O}^{J/\psi}(^3P_0^{[8]})\rangle$  considering the high luminosity of EIC, which could provide new insights into the  $J/\psi$  production mechanism. In addition, we present numerical results for the nuclear modification factor at NLO for electron-nucleus ( $eA$ ) collisions. We find out that the  $J/\psi$ -tagged DIS could be an excellent probe to gluon collinear distribution of nuclei. Furthermore, we extend such a calculation to polarized  $ep$  collision at NLO for the first time. Numerical results on double longitudinal spin asymmetry are presented to test the sensitivity to nucleon helicity distributions. The results presented in this Letter strongly motivate the measurement of  $J/\psi$ -tagged DIS at the future EIC.

*NLO calculation for  $J/\psi$  production at EIC.* We start with prompt  $J/\psi$  production in  $ep$  collision,

$$e(\ell) + P(p) \rightarrow e(\ell') + J/\psi + X, \quad (1)$$

where  $\ell$ ,  $p$ , and  $\ell'$  are, respectively, the momentum of the incoming electron and proton and the outgoing electron. In particular, we focus on the  $J/\psi$ -tagged DIS event, where the phase space for the prompt  $J/\psi$  is integrated out. In practice,  $J/\psi$  tagging is subject to limitations from the detector's kinematic coverage. Extrapolating from the experimentally covered phase space to the full phase space typically relies on fully differential theoretical calculations of  $J/\psi$  production in DIS, similar to the methodology used in experimental measurements of the reduced charm cross section in DIS [46].

Within the framework of NRQCD and leading twist collinear factorization, the differential cross section for the  $J/\psi$ -tagged DIS can be written as [47]

$$\frac{d\sigma}{dQ^2 dy} = \sum_{i,n} \int dx f_{i/p}(x, \mu_F^2) C_i(n) \langle\mathcal{O}^{J/\psi}(n)\rangle, \quad (2)$$

where  $Q^2 = -q^2$  with  $q = \ell - \ell'$  standing for the momentum of the virtual photon,  $y = p \cdot q / p \cdot \ell$ ,  $f_{i/p}$  is the

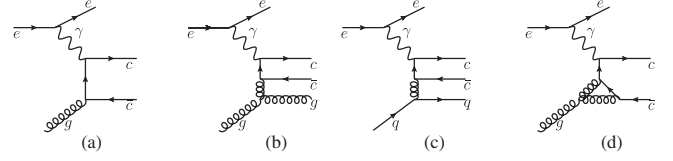


FIG. 1. Representative Feynman diagrams for LO (a), real correction from gluon (b) and quark (c) channels at NLO, and virtual correction (d) at NLO for  $J/\psi$  production in DIS.

proton parton distribution functions (PDFs),  $x$  is the momentum fraction of the proton carried by parton  $i$ , and  $\mu_F$  is the factorization scale.  $C_i(n)$  is the short-distance coefficient with initial parton  $i$  and final Fock state  $c\bar{c}[n]$ ,  $\langle\mathcal{O}^{J/\psi}(n)\rangle$  is the LDME representing the hadronization of  $c\bar{c}[n]$  Fock state to the final observed  $J/\psi$ , which has definite power counting of  $v$ , the relative velocity of the heavy quark and antiquark in the quarkonium rest frame. Up to  $\mathcal{O}(v^4)$  in  $v$  expansion, without considering the  $v^2$  suppressed relativistic corrections for the color-singlet channel, the  $^3S_1^{[1]}$ ,  $^1S_0^{[8]}$ ,  $^3S_1^{[8]}$ ,  $^3P_J^{[8]}$  channels will contribute to the factorization formula in Eq. (2). For the  $^3P_J^{[8]}$  channel, we use the relation  $\langle\mathcal{O}^{J/\psi}(^3P_J^{[8]})\rangle = (2J+1)\langle\mathcal{O}^{J/\psi}(^3P_0^{[8]})\rangle$  to convert all the P-wave LDMEs to  $\langle\mathcal{O}^{J/\psi}(^3P_0^{[8]})\rangle$ , so that  $C_i(^3P_J^{[8]})$  represents the P-wave short-distance coefficients summed over  $J = 0, 1, 2$ . For the process considered in this Letter, it has been argued that nonperturbative corrections arising from diffractive leptonproduction, higher twist effects, and higher order terms in the NRQCD velocity expansion should be suppressed as  $Q^2$  is increased in Ref. [47].

As shown in Fig. 1(a), the  $J/\psi$ -tagged DIS at LO is solely determined by the gluon channel. Therefore, only the color octet intermediate states  $c\bar{c}(^1S_0^{[8]})$  and  $c\bar{c}(^3P_J^{[8]})$  contribute and the corresponding short-distance coefficients can be expressed as [47]

$$C_g^{(0)}(^1S_0^{[8]}) = \frac{1 + (1-y)^2}{y} C_0, \quad (3)$$

$$C_g^{(0)}(^3P_J^{[8]}) = \left[ \frac{1 + (1-y)^2}{y} \frac{3Q^2/m^2 + 28}{Q^2 + 4m^2} - \frac{32yQ^2}{(Q^2 + 4m^2)^2} \right] C_0, \quad (4)$$

where  $C_0 = \frac{2\pi^2\alpha_s\alpha_e^2}{Q^2(Q^2+4m^2)m} \delta(xyS - Q^2 - 4m^2)$  with  $m$  the charm quark mass and  $S = (\ell + p)^2$ ,  $e_c$  is the charm quark electrical fractional charge, and  $\alpha_s$  and  $\alpha$  are, respectively, the QCD and QED coupling constant.

According to the LO result, one would expect that the  $J/\psi$ -tagged DIS can be uniquely used to determine the gluon distribution in proton. However, such a unique feature could be contaminated by the quark channel, which appears at higher orders. In order to test such an effect and

check the convergence of higher order corrections, we perform the first complete NLO calculation for  $J/\psi$ -tagged DIS, that is, at  $\mathcal{O}(\alpha^2\alpha_s^2)$ . At NLO, in addition to the real and virtual corrections for  $^1S_0^{[8]}$  and  $^3P_J^{[8]}$  channels from quark and gluon channels, as shown in the representative diagrams in Figs. 1(b) and 1(d), one also needs to include contributions from both  $^3S_1^{[1]}$  and  $^3S_1^{[8]}$  channels, where the former only exists in the gluon channel. In our calculation, the Feynman amplitudes are generated using FEYNARTS [48], the color and Dirac algebra are performed with the help of FEYNALC [49], which results in four diagrams for the quark channel and eight diagrams for the gluon channel in real correction, and 17 diagrams for virtual correction including six counterterm diagrams.

We use dimensional regularization ( $D = 4 - 2\epsilon$ ) to regularize infrared and collinear divergences in real correction and infrared, collinear, and ultraviolet (UV) ones in virtual correction. In particular, although various schemes are developed to handle  $\gamma_5$  in dimensional regularization, such as naive dimensional regularization [50], we use the 't Hooft-Veltman scheme [51,52] as implemented in FEYNALC [49]. In real correction, we integrate over the whole phase space of the outgoing particles except for the outgoing electron, which results in soft ( $\sim 1/\epsilon$ ), collinear ( $\sim 1/\epsilon$ ), and soft-collinear ( $\sim 1/\epsilon^2$ ) divergences. Regarding virtual corrections, we use the packages APART [53] and FIRE [54] for the reduction of loop integrals. The derived UV divergences are removed through the renormalization procedure. Notice that we adopt a mixed renormalization scheme [55], in which the renormalization constants of the heavy quark mass ( $Z_m$ ), heavy quark field ( $Z_2$ ), and gluon field ( $Z_3$ ) are defined in the on-shell scheme, while the renormalization constant of the strong coupling ( $Z_g$ ) is defined in the  $\overline{\text{MS}}$  scheme. The soft, collinear, and soft-collinear divergences are canceled in the sum of real and virtual corrections or absorbed into the redefinition of the nucleon/nucleus PDF  $f_{g/p}(x, \mu_F^2)$  in the  $\overline{\text{MS}}$  scheme. There is no IR divergence in our calculation at NLO resulting from the mixing between the  $^3P_J^{[8]}$  channels and the  $^3S_1^{[8]}$  channel because the  $^3S_1^{[1]}$  channel is not involved at LO. Since we focus on the DIS event with  $Q^2 > 0$  in our study, there will be no divergence resulting from the QED splitting  $e \rightarrow e\gamma$  [25].

Likewise, one can also calculate the cross section for  $J/\psi$ -tagged DIS at NLO in longitudinal polarized collisions. As we expected, one encounters the same singularities as in the unpolarized case, except for the redefinition of longitudinal polarized PDFs  $\Delta f_{g/p}(x, \mu_F^2)$ . After the regularization of all singularities, we are left with the finite part, which results in the following differential cross section at NLO:

$$\frac{d\Delta\sigma}{dQ^2 dy} = \sum_{i,n} \int dx \Delta f_{i/p}(x, \mu_F^2) \Delta C_i(n) \langle \mathcal{O}^{J/\psi}(n) \rangle. \quad (5)$$

In this calculation, we obtain for the first time the fully analytical expressions for the short-distance coefficients  $C_i(n)$  for unpolarized and  $\Delta C_i(n)$  for longitudinal polarized cases at NLO.<sup>1</sup> Such analytical results will be very efficient in the global analysis of LDMEs and PDFs for nucleon/nucleus when experimental data are available.

*J/ψ as a probe to nonperturbative functions.* In this section, we show phenomenological results by employing the obtained NLO analytical expressions under future EIC designs. We choose a center-of-mass energy of  $\sqrt{s} = 100$  GeV to illustrate the power of  $J/\psi$  as a probe to nonperturbative functions. To be consistent with the adopted LDMEs, we implement the following setup in our numerical calculation. We use an on-shell heavy quark mass  $m = 1.5$  GeV. The uncertainty from the mass range  $1.4 \leq m_c \leq 1.6$  GeV causes around 10% variation. We neglect the initial charm quark contribution from proton PDFs and consider  $n_f = 3$  for the active light quark flavors in the PDF convolutions. The collinear factorization scale  $\mu_F$  and the renormalization scale  $\mu_R$  are set to  $\mu_F = \mu_R = \sqrt{Q^2 + 4m^2}$ . We observe around 15% and 10% variations at LO and NLO, respectively, due to the scale variation of  $\sqrt{Q^2 + 4m^2}/2 \leq \mu_F = \mu_R \leq 2\sqrt{Q^2 + 4m^2}$ . For the evaluation of  $\alpha_s$ , we choose  $n_f = 5$  to determine  $\Lambda_{\text{QCD}}^{\overline{\text{MS}}}$ .

*Sensitivity to NRQCD LDMEs:* We first present the dependence of the  $J/\psi$ -tagged DIS cross section on the LDMEs, which are determined through global analysis of world data at NLO accuracy within the framework of NRQCD. With different fitting strategies, various sets of  $J/\psi$  LDMEs are obtained, which challenges the universality of these nonperturbative functions. In this work, we adopt the LDMEs from five groups: Bodwin *et al.* [5], Butenschoen and Kniehl [6], Chao *et al.* [7], Gong *et al.* [8] and Brambilla *et al.* [10,11], in which the charm quark mass  $m$  and the NRQCD factorization scale are chosen as  $\mu_\Lambda = m = 1.5$  GeV. The corresponding values are summarized in Table I.

The LDMEs from Bodwin *et al.*, Chao *et al.*, and Gong *et al.* give a  $^1S_0^{[8]}$  dominance scenario and thus naturally conform the almost unpolarized  $J/\psi$  hadron production data at large  $p_T$ . However, the  $^1S_0^{[8]}$  dominance scenario contradicts the  $\eta_c$  hadron production data under the assumption of heavy quark spin symmetry [4,57–59]. The LDMEs from Butenschoen *et al.* lead to the  $J/\psi$  polarization puzzle problem [60]. Although, the LDMEs from Brambilla *et al.* do not have the above issues,  $\langle \mathcal{O}^{J/\psi}(^1S_0^{[8]}) \rangle$  from Brambilla *et al.* is poorly constrained

<sup>1</sup>Refer to the mathematical file included in Supplemental Material [56] for the complete expressions of  $C_i(n)$  and  $\Delta C_i(n)$ , or contact us via email.

TABLE I.  $J/\psi$  NRQCD LDMEs from five different groups.

|                           | $\langle \mathcal{O}(^3S_1^{[1]}) \rangle \text{ GeV}^3$ | $\langle \mathcal{O}(^1S_0^{[8]}) \rangle 10^{-2} \text{ GeV}^3$ | $\langle \mathcal{O}(^3S_1^{[8]}) \rangle 10^{-2} \text{ GeV}^3$ | $\langle \mathcal{O}(^3P_0^{[8]}) \rangle 10^{-2} \text{ GeV}^5$ |
|---------------------------|----------------------------------------------------------|------------------------------------------------------------------|------------------------------------------------------------------|------------------------------------------------------------------|
| Bodwin <i>et al.</i>      | 0                                                        | $9.9 \pm 2.2$                                                    | $1.1 \pm 1.0$                                                    | $1.1 \pm 1.0$                                                    |
| Butenschoen <i>et al.</i> | 1.32                                                     | $3.04 \pm 0.35$                                                  | $0.17 \pm 0.05$                                                  | $-0.91 \pm 0.16$                                                 |
| Chao <i>et al.</i>        | 1.16                                                     | $8.9 \pm 0.98$                                                   | $0.30 \pm 0.12$                                                  | $1.26 \pm 0.47$                                                  |
| Gong <i>et al.</i>        | 1.16                                                     | $9.7 \pm 0.9$                                                    | $-0.46 \pm 0.13$                                                 | $-2.14 \pm 0.56$                                                 |
| Brambilla <i>et al.</i>   | 1.18                                                     | $-0.63 \pm 3.22$                                                 | $1.4 \pm 0.42$                                                   | $5.83 \pm 1.86$                                                  |

and suffers from large uncertainties. In Fig. 2, we plot the  $J/\psi$ -tagged DIS differential cross section as a function of  $Q^2$  using CT18NLO [61] for proton PDFs and the five sets of LDMEs shown in Table I. Notice that the low  $Q^2$  region might cover a small kinematic window that exceeds the fitting regime of some sets of LDMEs, so the corresponding extrapolation uncertainty is not obvious as can be revealed in the  $Q^2$ -dependent LDME uncertainty represented by the bands. We find that the LDMEs from five groups lead to visible differences within the LDME uncertainties. We have checked that the differential cross sections are dominated by  $^1S_0^{[8]}$  and  $^3P_J^{[8]}$  channels. The values of the LDMEs  $\langle \mathcal{O}^{J/\psi}(^1S_0^{[8]}) \rangle, \langle \mathcal{O}^{J/\psi}(^3P_0^{[8]}) \rangle$  from the groups of Bodwin and Chao are very close, and thus lead to almost identical predictions, which are an order of magnitude larger compared with the predictions obtained using the LDMEs from Butenschoen *et al.* and significantly larger than those derived using the LDMEs from Gong *et al.* The LDMEs from Brambilla *et al.* give similar predictions to Bodwin *et al.* and Chao *et al.* at low  $Q^2$  but gradually converge toward those using the LDMEs from Gong *et al.*

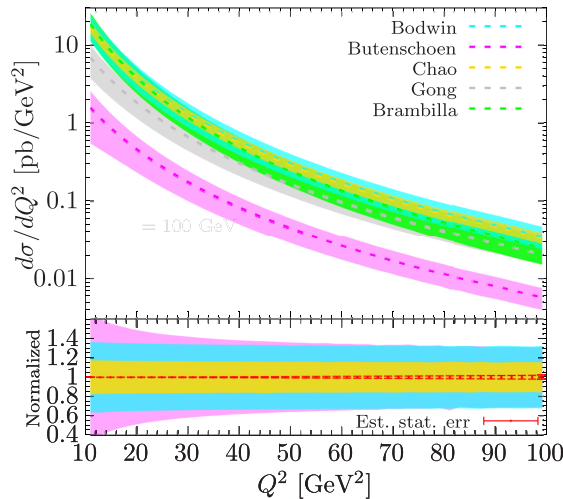


FIG. 2. NLO differential cross section as a function of  $Q^2$  for  $J/\psi$ -tagged DIS process. The error bands come from the uncertainties of the LDMEs. Lower: the bands show the ratio normalized to the best-fit results, while the vertical bar depicts estimated statistical error in the future EIC with integrated luminosity  $100 \text{ fb}^{-1}$ .

at large  $Q^2$ , which leads to a distinct shape of  $Q^2$  dependence. The difference of  $J/\psi$ -tagged DIS differential cross section evaluated with the LDMEs from five different groups clearly demonstrates that this observable is a very sensitive probe of NRQCD LDMEs, especially for  $\langle \mathcal{O}^{J/\psi}(^1S_0^{[8]}) \rangle$  and  $\langle \mathcal{O}^{J/\psi}(^3P_0^{[8]}) \rangle$ . Note that the produced  $J/\psi$  through the  $^1S_0^{[8]}$  channel is unpolarized, while the produced  $J/\psi$  at large  $p_T$  through the  $^3P_J^{[8]}$  channels is transversely polarized from hadroproduction [7,62]. Therefore, it would be also interesting to study the polarization of  $J/\psi$  at the EIC in future.

Sensitivity to nuclear PDFs: The high luminosity of the electron-nucleus program at the EIC, combined with the gluon-dominated  $J/\psi$ -tagged DIS process, promises profound insights into nuclear gluon distribution. To delve deeper into the role of the  $J/\psi$ -tagged DIS process at the EIC in elucidating nuclear partonic structure, we investigate the nuclear modification factor defined as follows:

$$R_{eA} = \frac{d\sigma^{eA}}{dx_B} \bigg/ \frac{d\sigma^{ep}}{dx_B}, \quad (6)$$

in which we have adopted EPPS21 parametrization [63] for nuclear PDFs and CT18ANLO for proton PDFs. In the top panel of Fig. 3, we present the nuclear modification factor plotted against the Bjorken variable  $x_B = (Q^2 + 4m^2)/(2p \cdot q)$ . We observe that the five sets of LDMEs yield nearly identical results for  $R_{eA}$ , indicating the insensitivity of LDME choices and substantially reducing theoretical uncertainty arising from LDME variations. In the middle panel of Fig. 3, we use the LDMEs from Bodwin *et al.* as an example to show the normalized (by central values) uncertainty of the predicted  $R_{eA}$ . The blue band represents normalized uncertainty resulting from the nuclear PDFs uncertainty using EPPS21 parametrization, from which we can see that the relative uncertainty increases as  $x_B$  gets larger and becomes significant when  $x_B$  approaches 0.6. The normalized uncertainty coming from the statistical error, which is based on the best fit of EPPS21 and the expected EIC integrated luminosity  $10 \text{ fb}^{-1}/A$  for  $eA$  collisions [45] and the detector response simulation [64], is shown in the vertical red bars. It is obvious that the uncertainties from the estimated statistical error and LDME from the Bodwin set represented by the cyan band are negligible comparing to those resulting from the EPPS21 uncertainty. It is important

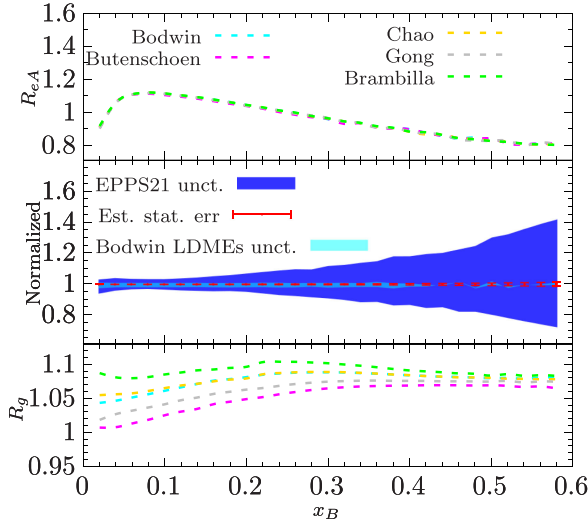


FIG. 3. The nuclear modification factor as a function of  $x_B$  for leptonproduction of  $J/\psi$  in  $ePb$  collision at  $\sqrt{s} = 100$  GeV with  $20 < Q^2 < 100$  GeV<sup>2</sup>. The middle panel shows the comparison of uncertainties in nuclear PDFs, LDMEs from Bodwin's set, and estimated statistical error in the future EIC. In the lower panel,  $R_g$  is defined as the ratio of  $J/\psi$ -tagged differential cross sections in  $eA$  collision without and with contributions from quark channels.

to note that the  $eA$  differential cross section is dominated by the gluon channel in all regions of  $x_B$  considered as it was shown in the bottom panel of Fig. 3, where  $R_g$  is defined as the ratio of  $J/\psi$ -tagged differential cross sections in  $eA$  collision without and with contributions from quark channels. The fact that the gluon channel gives 100%–110% of the differential cross section calculated at  $\mathcal{O}(\alpha^2\alpha_s^2)$ , which means the quark channels only give small negative contribution at  $\mathcal{O}(\alpha^2\alpha_s^2)$ , strongly indicates that the  $J/\psi$ -tagged DIS process can be served as a clean probe to access the nuclear gluon distribution at the future EIC.

**Sensitivity to nucleon helicity distribution:** We extend our NLO calculation of leptonproduction of  $J/\psi$  from unpolarized to polarized  $ep$  collisions, aiming at probing the proton-gluon helicity distribution, which is of significant importance in understanding the configuration of proton spin [65]. We focus on the double longitudinal spin asymmetry for leptonproduction of  $J/\psi$  defined as

$$A_{LL} = \frac{d\sigma(+,+) - d\sigma(+,-)}{d\sigma(+,+) + d\sigma(+,-)} = \frac{d\Delta\sigma}{d\sigma}, \quad (7)$$

where the first and the second signs  $(+, -)$  in the parentheses right after  $d\sigma$  represent the helicity of the incoming lepton and proton, respectively. We apply NNPDFpol parametrization [66] for the longitudinal polarized proton PDFs and NNPDF2.3 for unpolarized one.

As we can see from the top panel of Fig. 4, the predicted central values of  $A_{LL}$  with the optimized LDMEs sets from five groups are considerably different, except for those

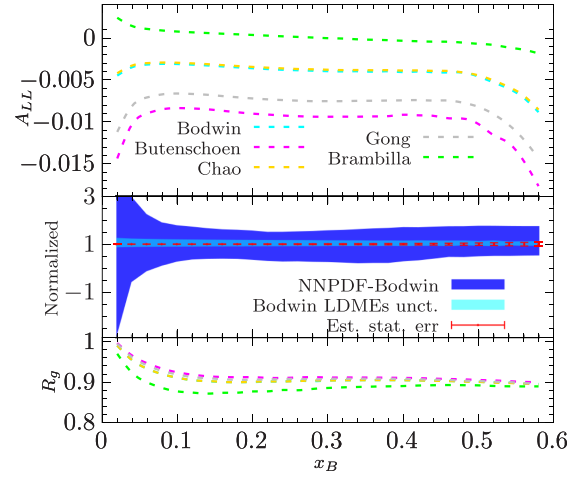


FIG. 4. The double longitudinal spin asymmetry as a function of  $x_B$  for leptonproduction of  $J/\psi$  in  $ep$  collisions at  $\sqrt{s} = 100$  GeV with  $20 < Q^2 < 100$  GeV<sup>2</sup>. The middle panel shows the comparison of uncertainties in polarized PDFs, LDMEs from Bodwin's set, and estimated statistical error in the future EIC. In the lower panel,  $R_g$  is defined as the ratio of  $J/\psi$ -tagged differential cross sections in polarized  $ep$  collision without and with contributions from quark channels.

from Bodwin *et al.* and Chao *et al.* due to their close values of  $\langle \mathcal{O}^{J/\psi}(1S_0^{[8]}) \rangle$ ,  $\langle \mathcal{O}^{J/\psi}(3P_0^{[8]}) \rangle$ . Once the values of  $J/\psi$  LDMEs are fixed in unpolarized collision, one can use the theory predictions of  $A_{LL}$  to constrain the gluon helicity distribution since  $A_{LL}$  is dominated by the gluon channel, as was shown in the bottom panel of Fig. 4, where  $R_g$  is defined as the ratio of  $d\Delta\sigma$  evaluated without and with the contributions from quark channels, respectively. The middle panel of Fig. 4 shows the relative large uncertainty coming from the lack of precise knowledge of the gluon helicity distribution. Similar to those for nuclear PDF, the uncertainty from polarized PDFs is more significant than those from LDMEs. We expect the future EIC with integrated luminosity  $100 \text{ fb}^{-1}$  for  $ep$  collisions [45] will provide a crucial constraint on the gluon contribution to proton spin.

**Summary.** We calculate the leptonproduction of  $J/\psi$  with five sets of LDMEs at NLO, under both unpolarized and polarized situations. The difference arises from various LDMEs, indicating that the  $J/\psi$ -tagged DIS is a very sensitive probe to solve the problem of the universality of NRQCD LDMEs by comparing with the future EIC data. Additionally, considering both the high collision luminosity and highly polarized beams in the future EIC, as well as the dominance of the gluon channel in the  $J/\psi$ -tagged DIS process, this process can also serve as a unique opportunity to probe the nuclear gluon distribution and polarized gluon distribution. All these aspects strongly motivate the measurement of  $J/\psi$ -tagged DIS at the future EIC.

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