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NLO QCD Corrections to Exclusive Quarkonium Electroproduction

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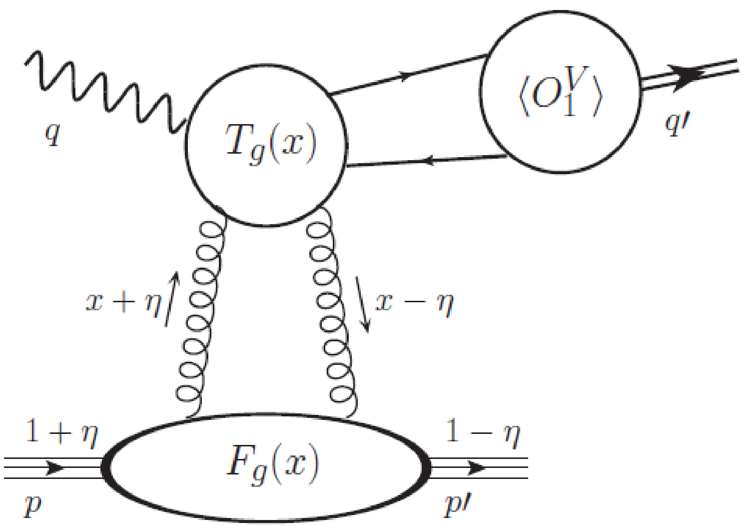
Motivations

- The processes of exclusive electro- and photo-production of quarkonium $\gamma p \to V\, p$ with $V = J/\psi$ or Υ, are particular interesting and important but yet not well explored, especially the former



Motivations

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- Here, the photon can be highly virtual for electroproduction or real for photoproduction.
- These processes provide unique opportunities in studying the quarkonium production mechanism, and perturbative QCD calculation reliability.
- They are experimentally adjustable in physical parameters, say for example the virtuality of the photon.

H1 and ZEUS collaborations, Nucl. Phys.B 222, 131 (2012)

Motivations

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- Furthermore, they are gluon rich, hence extremely sensitive to the gluon distribution in the nucleon, particular to the off-diagonal effects.

- Stable theoretical calculations are necessary therefore to reduce the uncertainty of gluon density distribution in the still vague domain of small Bjorken variable x_B.

- In experiment, J/ψ production processes have been extensively studied at HERA, whereas for ϒ production the data are limited to the photoproduction case.

Motivations

- For future, some projects on deep inelastic experiment are in progress or proposed, like ENC at FAIR, eRHIC at BNL, LHeC at CERN and EIC in China, where the EEQ process will be further explored attentively.

- Theoretically, two main frameworks are employed in the evaluation, that is the QCD collinear factorization and BFKL k_T factorization.

Motivations

- Although the BFKL approach has a solid perturbative QCD foundation, can sum up large logarithms of energy ln(1/x) and implies the k_T information of gluon in the nucleon in the description of hard diffractive processes, it is impaired by the absence of full NLO calculation

- Higher order calculation in collinear factorization hopefully can explain the existing Υ exclusive photoproduction data, but is fraught with difficulties for the J/ψ case.

D. Yu. Ivanov, A. Schafer, L. Szymanowski, G. Krasnikov, (2015); S. P. Jones, A. D. Martin, M. G. Ryskin, T. Teubner, (2016); S. P. Jones, A. D. Martin, M. G. Ryskin, T. Teubner, (2016).

Motivations

- The exclusive quarkonium electroproduction processes, which in some sense are even more important in physics due to the adjustable virtuality of the intermediate photon, have not been explored properly

- We calculate the NLO QCD corrections to exclusive quarkonium electroproduction processes, and investigate their implications to the parton distribution in the nucleon.

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Some technical details & results

According to QCD factorization, the EEQ processes may be allocated into three domains, namely

a. The hard partonic process γ^* g(q) → Q Q g(q)

b. The transition from the Q Q pair to the physical quarkonium state

c. The parton distribution within the nucleon. The parton distribution in the nucleon refers to the so-called generalized parton distribution (GPD)

Some technical details & results

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- **Working in light-cone coordinate is convenient, we choose a frame where q and p are collinear**

- **By introducing two light like vectors $n_+=(1,0,0,1)/\sqrt{2}$ and $n_-=(1,0,0,-1)/\sqrt{2}$, their momenta can be expanded as**

$$\bar{p}^\mu = n_+^\mu + \frac{m_N^2 - t/4}{2} n_-^\mu \,, \quad \bar{q}^\mu = -\xi n_+^\mu + \frac{Q^2 - M^2}{4\xi} n_-^\mu$$

$$\xi = -\frac{\bar{q}\cdot n_-}{\bar{p}\cdot n_-} \approx \frac{Q^2 - M^2}{2s + Q^2 - M^2} \,, \quad \eta = \frac{1}{2}\frac{\Delta\cdot n_-}{\bar{p}\cdot n_-} \approx \frac{Q^2 + M^2}{2s + Q^2 - M^2}$$

Some technical details & results

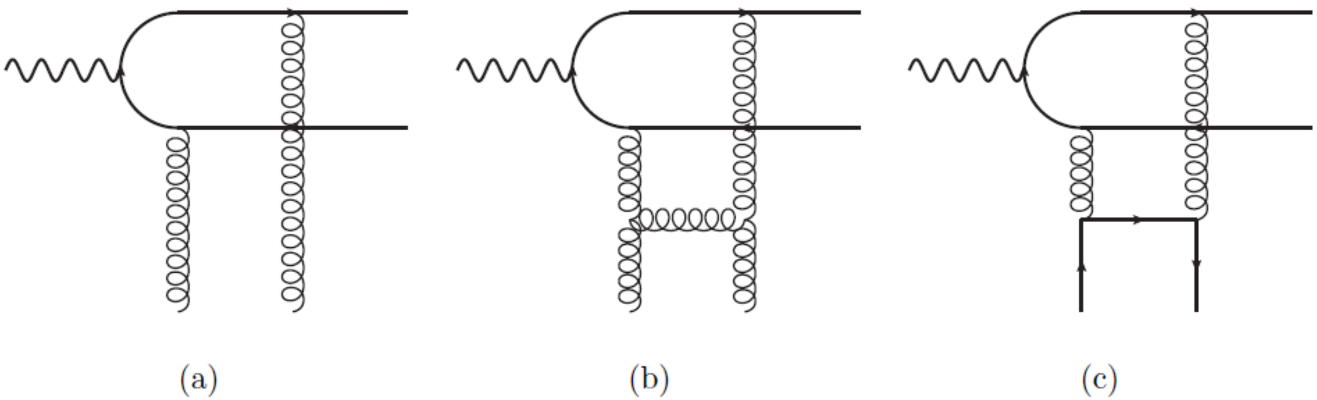
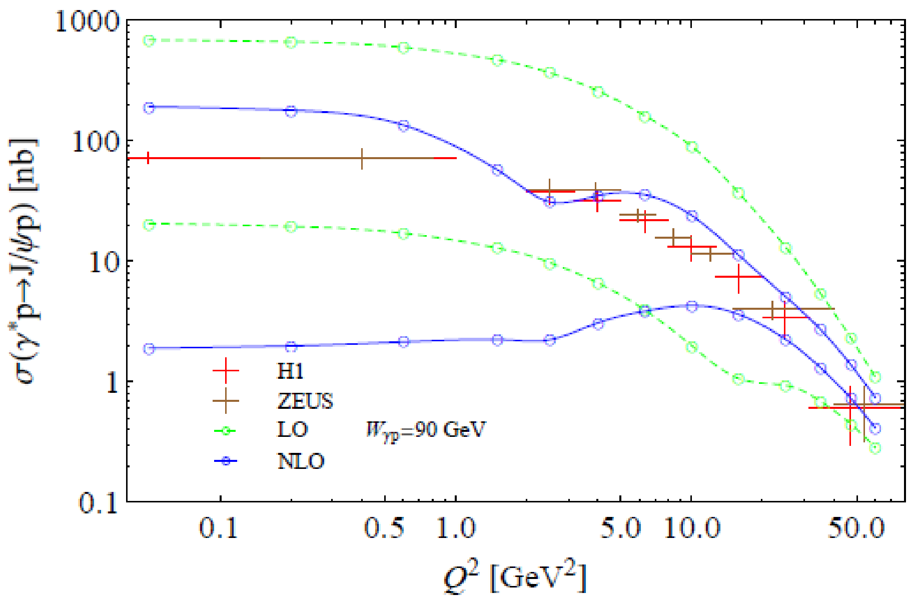


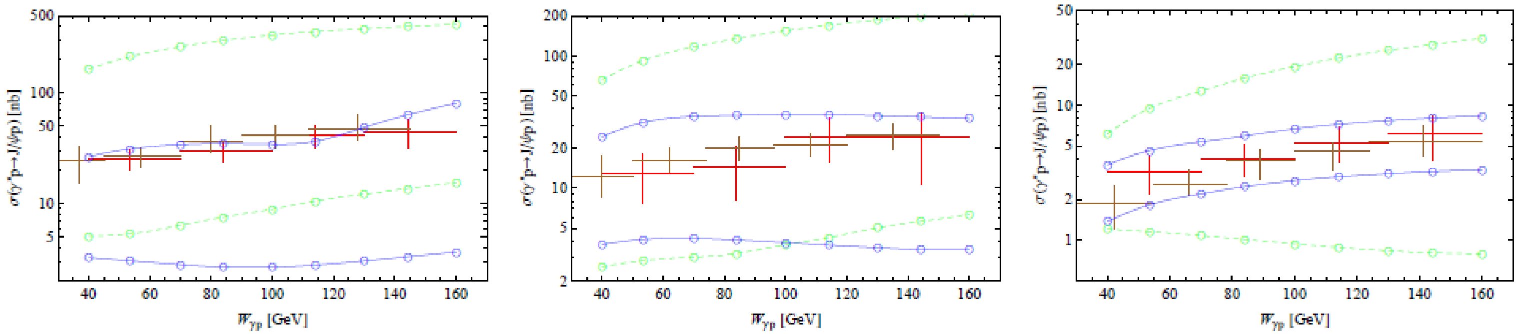
FIG. 2: Typical Feynman diagrams for LO (a) and NLO (b, c) partonic processes.

Some technical details & results



- The total cross section of exclusive J/ψ electroproduction as function of Q^2 at $W_{\gamma p}$=90 GeV. The LO and up-to-NLO theoretical predictions are represented by double-dashed-green and double-solid-blue lines, referring to the upper and lower bounds of uncertainties

Some technical details & results



(a) (b) (c)

- **The total cross section of exclusive J/ψ electroproduction as function of W with different Q^2. (a) $Q^2 = 3.2$ GeV^2, (b) $Q^2 = 7.0$ GeV^2, (c) $Q^2 = 22.4$ GeV^2**

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Summary and Comments

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① We calculated analytically the exclusive electroproduction of quarkonium in the NRQCD framework and collinear factorization scheme up to the NLO QCD accuracy

Zi-Qiang Chen & CFQ, arXiv:1903.00171

② Numerical evaluation about the cross section of exclusive J/ψ electroproduction at different Q^2 and W are performed

③ At large Q^2, say Q^2 >10 GeV^2, the NLO corrections may greatly reduce the theoretical uncertainty, and hence enable the predictions more reliable

Summary and Comments

④ **We find a good agreement with the H1 and ZEUS data**

⑤ **At small Q^2, say $Q^2 < 5$ GeV^2, the pQCD analysis on exclusive J/ψ production tends to be dubious**

⑥ **We schematically calculate the exclusive Υ electroproduction in HERA condition**

Summary and Comments

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⑦ **In the calculation we made use of the Forward Model together with the NLO GPD evolution equation to evaluate GPDs at DGLAP region**

⑧ **The input PDFs and the initial scale were set to be MSTW08 and μ_0=1 GeV. As a trial, another set of input PDF, the CT14 was also used**

⑨ **We found at reasonably large η and μ_F regions, say μ_F >2.4 GeV and η > 0.001, the two different choices give similar results**

Summary and Comments

⑩ We conclude that the Forward Model is simpler, parameter-free and adequate to explain the data

⑪ In the future, with more reliable theoretical calculation, we are expected to get more information on the GPD while confronting to the experimental data

Last…

THANKS