Pom-CQM of J/Ψ Photoproduction on nucleon

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2nd APCTP Workshop on the Physics of Electron Ion Collider: ePIC Physics and Detectors
December 01, 2023

Presentation Overview

Introductions

- The J/Ψ photo-production reactions on the nucleon can provide information on
  - The roles of gluons in J/Ψ -Nucleon interaction
  - The structure of the nucleon.
- The calculation J/Ψ-N from QCD is not available, we need to extract J/Ψ-N interaction from photoproduction data.
- The J/Ψ-N interaction are needed to exam J/Ψ to investigate the production of Pentaquarks reported by LHC, the production of nuclei with hidden charms, and the J/Ψ production in relativistic heavy-ion collisions.
- The extraction of J/Ψ-N interaction can be used to test the results from PQCD models or LQCD calculations

Introductions

J/Ψ Photoproduction progress

- The traditional method, the J/Ψ -nucleon (N) can be extracted from the photo-production data by using the vector meson dominance (VMD) assumption.
- In previous study, we reviewed six models which applied to investigate JLab data. [Eur. Phys. J. A (2022) 58:252]

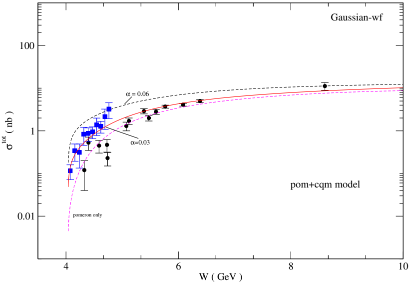


Figure: Total cross section of Pomeron Exchange Model and Constituent Quark Model of J/Ψ Photoproduction

Introductions

- We found that the Pomeron-Exchange gives a good agreement of all high energy hadronic process but can not describe the JLab data at $W \leq 7$GeV
- We improved the Pomeron-Exchange model by including charm quark-N potential to be interpreted as multi-gluon exchange.
- to evaluate $c\bar{c}$-loop mechanism in this Figure, We need J/Ψ wave-function from CQM model

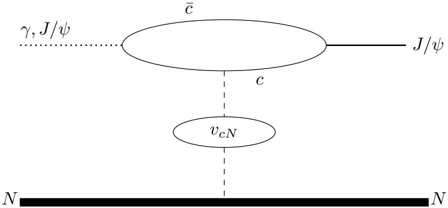


Figure: Model with the $c\bar{c}$-loop mechanisms calculated from quark-nucleon potential

Pomeron Exchange

The Pomeron-exchange amplitude define to describe the photo-production of vector mesons by assuming that the incoming photon is converted into a vector meson V by using the Vector Meson Dominance (VMD) defined by

$$L_{\rm VMD} = \frac{em_V^2}{f_V}\phi_V^{\mu}(x)A_{\mu}(x), \tag{1}$$

where $\phi_V(x)$ and $A_\mu(x)$ are the field operators for the vector meson V and the photon, respectively. The coupling constant f_V is traditionally determined by using Eq. (1) to calculate the $V \to \gamma \to e^+e^-$ decay width:

$$\Gamma_{V\to e^+e^-} = \frac{1}{3}\alpha_{em}^2 m_V \frac{4\pi}{f_V^2}. \tag{2}$$

Pomeron Exchange

The Pomeron-exchange amplitude $\mathcal{M}_{\mathbb{P}}^{\mu\nu}(k, p_f, q, p_i)$ can be written as

$$\mathcal{M}_{\mathbb{P}}^{\mu\nu}(k, p_f, q, p_i) = G_{\mathbb{P}}(s, t)\mathcal{T}_{\mathbb{P}}^{\mu\nu}(k, p_f, q, p_i) \tag{3}$$

with

$$\begin{aligned} \mathcal{T}_{\mathbb{P}}^{\mu\nu}(q, p, q', p') &= i\,2\frac{e\,m_V^2}{f_V}[2\beta_{q_V}F_V(t)][3\beta_{u/d}F_1(t)] \\ &\quad \times \{\not{q}g^{\mu\nu} - q^{\mu}\gamma^{\nu}\}\,, \end{aligned} \tag{4}$$

where M_V is the mass for the vector meson. a form factor for the Pomeron-vector meson vertex is also introduced with

$$F_V(t) = \frac{1}{m_V^2 - t}\left(\frac{2\mu_0^2}{2\mu_0^2 + m_V^2 - t}\right), \tag{5}$$

where $t = (q - k)^2 = (p_f - p_i)^2$.

Pomeron Exchange

Electromagnetic form factor of the nucleon as

$$F_1(t) = \frac{4m_N^2 - 2.8t}{(4m_N^2 - t)(1 - t/0.71)^2}. \quad (6)$$

The crucial ingredient of Regge phenomenology is the propagator $G_{\mathbb{P}}$ of the Pomeron, it is of the following form:

$$G_{\mathbb{P}} = \left(\frac{s}{s_0}\right)^{\alpha_P(t)-1} \exp\left\{-\frac{i\pi}{2}\left[\alpha_P(t) - 1\right]\right\}, \quad (7)$$

where $s = (q + p_i)^2 = W^2$, $\alpha_P(t) = \alpha_0 + \alpha'_P t$, and $s_0 = 1/\alpha'_P$.
for $\alpha_P(t) \sim 1$ in the small $|t|$ region

CQM Model

The Hamiltonian of a Constituent Quark Model(CQM) in the center of mass frame is written as

$$H = 2m_c + \frac{\vec{p}}{m_c} + V(\vec{r}, \vec{s}_c, \vec{s}_{\bar{c}}) \tag{8}$$

The interaction potential is

$$V(\vec{r}, \vec{s}_c, \vec{s}_{\bar{c}}) = \alpha_0 r + v_{c\bar{c}}(\vec{r}, \vec{s}_c, \vec{s}_{\bar{c}}) \tag{9}$$

where the term $\alpha_0 r$ is representing the quark confinement mechanism which is well established by LQCD model, $v_{c\bar{c}}$ is a quark-quark interaction.

CQM Model

The $\gamma + p \to J/\psi + p$ can be calculated by dynamical formulation as

$$\begin{aligned} \langle \mathbf{p}' m_V m_{s'} \mid B_{VN,\gamma N} \mid \mathbf{q}\lambda m_s \rangle &= \sum_{m_c, m_{\bar{c}}} \frac{1}{(2\pi)^3} \frac{e_c}{\sqrt{2|\mathbf{q}|}} \int d\mathbf{k} \, \langle J_V m_V | \tfrac{1}{2} \tfrac{1}{2} m_c, m_{\bar{c}} \rangle \\ &\quad \times \phi(\mathbf{k} - \frac{1}{2}\mathbf{p}') \delta_{m_s, m_{s'}} v_{cN}(\mathbf{p}' - \mathbf{q}) \\ &\quad \times \frac{1}{W - E_N(\mathbf{q}) - E_c(\mathbf{q} - \mathbf{k}) - E_c(\mathbf{k}) + i\epsilon} \\ &\quad \times \bar{u}_{m_q}(\mathbf{k}) [\epsilon_\lambda \cdot \gamma] v_{m_{\bar{q}}}(\mathbf{q} - \mathbf{k}). \end{aligned} \tag{10}$$

CQM Model

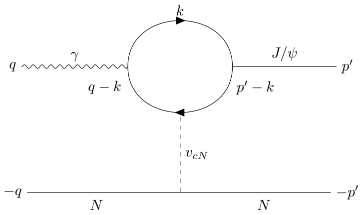


Figure: Momentum variables of the J/Ψ photoproduction process

assuming that the quark-nucleon potential is Yukawa form $v_{cN}^{(1)}(r) = \alpha \frac{e^{-\mu r}}{r}$ with $\mu = 0.3$ adopted from LQCD model.

$$v_{cN}(\mathbf{t}) = \frac{2\alpha}{(2\pi)^2} \frac{1}{\mathbf{t}^2 + \mu^2} \tag{11}$$

where $\mathbf{t} = \mathbf{p}' - \mathbf{q}$

Final State Interaction

The total CQM amplitude including final state interaction is

$$T^{\mathrm{CQM}}_{VN,\gamma N}(W) = B_{VN,\gamma N} + T^{(\mathrm{fsi})}_{VN,\gamma N}(W), \tag{12}$$

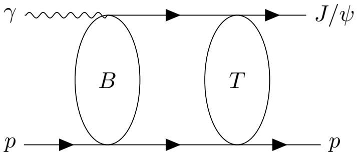


Figure: J/Ψ photoproduction process including FSI

Where the FSI amplitude could be written as

$$T^{(\mathrm{fsi})}_{VN,\gamma N}(W) = T_{VN,VN}(W)\frac{1}{W - H_0 + i\epsilon}B_{VN,\gamma N}. \tag{13}$$

Final State Interaction

the matrix element of $V_{VN,VN}$ can be written as

$$\begin{aligned} \langle \mathbf{k}_V m_V, \mathbf{p} m_s | V_{VN,VN} | \mathbf{k}'_V m'_V, \mathbf{p}' m'_s \rangle &= \delta_{m_V, m'_V} \delta_{m_s, m'_s} \\ &\times \delta(\mathbf{k}_V + \mathbf{p} - \mathbf{k}'_V - \mathbf{p}') \langle \mathbf{p} | V_{VN} | \mathbf{p}' \rangle , \end{aligned} \tag{14}$$

where

$$\langle \mathbf{p} | V_{VN} | \mathbf{p}' \rangle = 2 \int d\mathbf{k} \, \phi^* \left(\mathbf{k} - \tfrac{\mathbf{p}}{2} \right) v_{cN}(\mathbf{p}' - \mathbf{p}) \phi(\mathbf{k} - \tfrac{\mathbf{p}'}{2}). \tag{15}$$

Here the factor 2 is from summing the contributions from two quarks in J/Ψ.

Result and Discussion

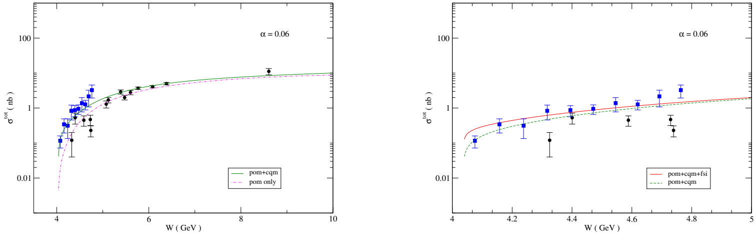


Figure: Total Cross section of J/Ψ photoproduction using $v_{cN}^{(1)}(r)$ at $\alpha = 0.06$ compare with JLab experimental data

Differential Cross Section

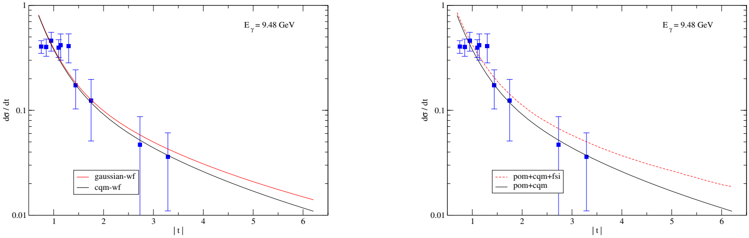


Figure: Differential Cross section of comperision of gaussian wf with $\alpha = 0.03$ and CQM wavefunction with $\alpha = 0.06$

Differential Cross Section

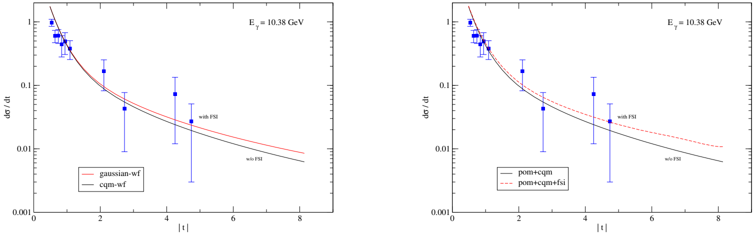
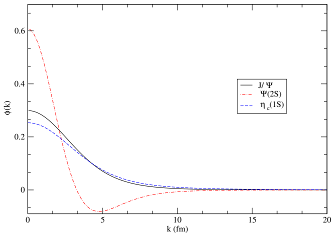


Figure: Differential Cross section of comparision of gaussian wf with $\alpha = 0.03$ and CQM wave-function with $\alpha = 0.06$

$\eta_c(1S)$ and $\Psi(2S)$ prediction

prelimenary result

by using the same the c-N potential with J/Ψ production, we predict the cross section of $\eta_c(1S)$ and $\Psi(2S)$



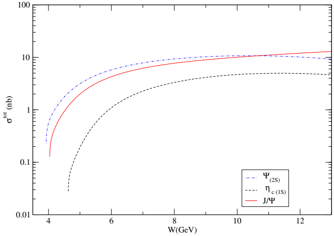


Figure: Total cross section of $\eta_c(1S)$ and $\Psi(2S)$ including CQM wave-function of each particles at $\alpha = 0.06$

On-going work

The short-range part from LQCD is less well determined, we plan to fit data with a new yukawa form $v^{(2)}_{cN}(r) = \alpha[\frac{e^{-\mu r}}{r} - \frac{e^{-\mu_1 r}}{r}]$

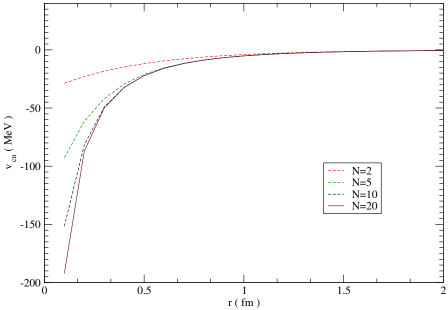


Figure: plot of $v^{(2)}_{cN}(r)$ with $\mu_1 = N$ x μ

Summary and conclusion

- Including CQM wave-function in J/Ψ Photo-production process, has a good improvement compare with gaussian wave-function
- The short-range part from LQCD is less well determined, we need to extend $v_{cN}^{(1)}(r)$ to $v_{cN}^{(2)}(r)$
- FSI has a large contribution at near threshold

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Thank You