Exclusive vector meson photoproduction at next-to-leading order

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Outline

- Motivation
- Model description
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- Summary and outlook

Motivation

◆The vector meson through photoproduction processes provide a unique way to test QCD.

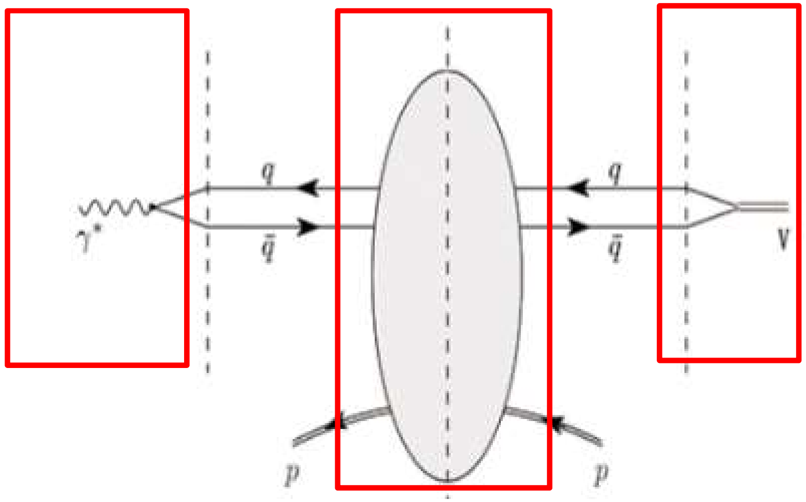
- probing the generalized gluon density at small *x*

◆The vector meson production mechanism has been studied by various approaches:

- the nonrelativistic QCD (NRQCD) factorization Phys. Rev. D 51 (1995) 1125
- perturbative-QCD (pQCD) fragmentation function factorization Phys. Lett. B 613 (2005) 45
- *k*t factorization Phys. Rev. D 77 (2008) 054016
- Color dipole model Phys. Rev. D 88 (2013) 074016
- …

All these models can well describe the experimental data under some uncertainties. So, we would like to enhance the precision of the Color dipole model through extending the leading order CGC model to the next-to-leading order level.

The vector meson production in the dipole frame can be divided into three separate subprocesses.



1.The formation of a dipole derived from the photon fluctuation.
2.The interaction between the dipole and the proton.
3.The recombination of the outgoing quark-antiquark pair to produce the final vector meson

The imaginary part of the scattering amplitude can be written as

$$\mathcal{A}_{T,L}^{\gamma^* p \rightarrow Vp}(x, Q, \mathbf{q}) = \mathrm{i} \int_0^1 \frac{dz}{4\pi} \int d^2\mathbf{r} \int d^2\mathbf{b} (\Psi_V^* \Psi)_{T,L} \times \mathrm{e}^{-\mathrm{i}[\mathbf{b}-(1-z)\mathbf{r}]\cdot\mathbf{q}} T(x, \mathbf{r}, \mathbf{b}),$$

$$\mathcal{A}_{T,L}^{\gamma^* p \to Vp}(x, Q, \mathbf{q}) = \mathrm{i} \int_0^1 \frac{dz}{4\pi} \int d^2\mathbf{r} \int d^2\mathbf{b} (\Psi_V^* \Psi)_{T,L} \times \mathrm{e}^{-\mathrm{i}[\mathbf{b}-(1-z)\mathbf{r}]\cdot\mathbf{q}} T(x, \mathbf{r}, \mathbf{b}),$$

By taking into account the real part of the scattering amplitude and the skewness effect, the differential cross section can be written in terms of the imaginary part

$$\frac{d\sigma_{T,L}^{\gamma^* p \to Vp}}{dt} = \frac{(1+\beta^2) R_g^2}{16\pi} \mid \mathcal{A}_{T,L}^{\gamma^* p \to Vp}(x, Q, \mathbf{q}) \mid^2,$$

$$\beta = \tan(\frac{\pi\delta}{2}),$$

$$\delta \equiv \frac{\partial \log(\mathcal{A}_{T,L}^{\gamma^* p \to Vp})}{\partial \ln(1/x)}.$$

$$R_g(\delta) = \frac{2^{2\delta+3}}{\sqrt{\pi}} \frac{\Gamma(\delta + 5/2)}{\Gamma(\delta + 4)},$$

$$\mathcal{A}_{T,L}^{\gamma^* p\to Vp}(x,Q,\mathbf{q}) = \mathrm{i}\int_0^1 \frac{dz}{4\pi}\int d^2\mathbf{r}\int d^2\mathbf{b}(\Psi_V^*\Psi)_{T,L}\times \mathrm{e}^{-\mathrm{i}[\mathbf{b}-(1-z)\mathbf{r}]\cdot\mathbf{q}}T(x,\mathbf{r},\mathbf{b}),$$

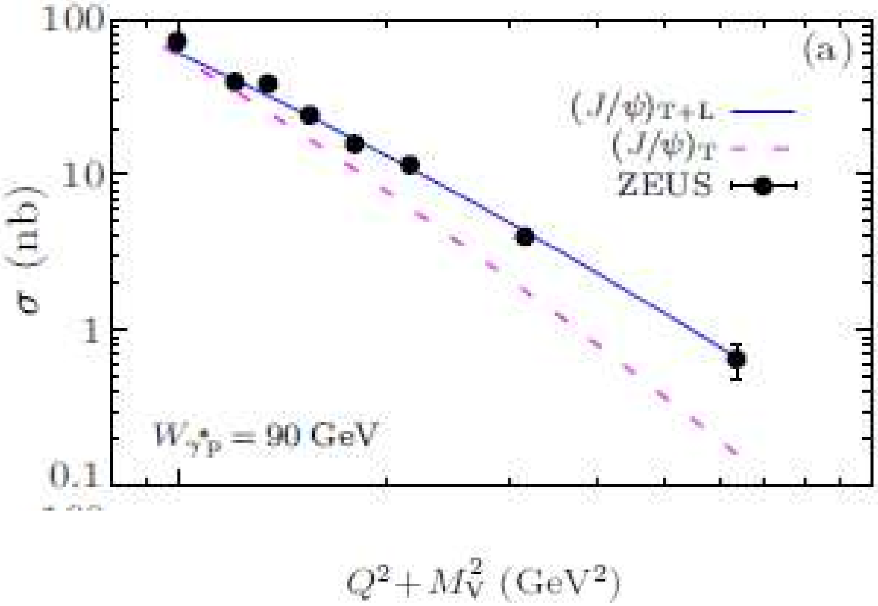
The overlap function is well known in the literature

$$(\Psi_{\mathrm{V}}^*\Psi)_{\mathrm{T}} = \hat{e}_{\mathrm{f}} e \frac{N_{\mathrm{c}}}{\pi z(1-z)}\{m_{\mathrm{f}}^2 K_0(\epsilon r)\phi_{\mathrm{T}}(r,z) - [z^2+(1-z)^2]\epsilon K_1(\epsilon r)\partial_r\phi_{\mathrm{T}}(r,z)\}$$

Phys. Rev. D 74 (2006) 074016

$$(\Psi_{\mathrm{V}}^*\Psi)_{\mathrm{L}} = \hat{e}_{\mathrm{f}} e \frac{N_{\mathrm{c}}}{\pi} 2Qz(1-z)K_0(\epsilon r)\left[M_{\mathrm{V}}\phi_{\mathrm{L}}(r,z)+\delta\frac{m_{\mathrm{f}}^2-\nabla_r^2}{M_V z(1-z)}\phi_{\mathrm{L}}(r,z)\right],$$

In our study, we shall use the boosted Gaussian expression for scalar functions.



The longitudinal overlap function has a significant effect on vector meson production, especially in the region of larger Q^2.

Dipole-proton scattering amplitude

$$\mathcal{A}_{T,L}^{\gamma^* p \to V p}(x, Q, \mathbf{q}) = \mathrm{i} \int_0^1 \frac{dz}{4\pi} \int d^2\mathbf{r} \int d^2\mathbf{b} (\Psi_V^* \Psi)_{T,L} \times \mathrm{e}^{-\mathrm{i}[\mathbf{b}-(1-z)\mathbf{r}]\cdot\mathbf{q}} T(x, \mathbf{r}, \mathbf{b}),$$

The key ingredient to accurately calculate the differential cross section is the dipole-proton scattering amplitude. It depends on the Bjorken variable, the dipole transverse size and the impact parameter.

In order to extend the leading order CGC model to the next-to-leading order, we should rewrite the dipole-proton scattering amplitude in terms of the momentum transfer q instead of impact parameter b.

By using the Fourier transform $\widetilde{T}(x, \mathbf{r}, \mathbf{q}) = \int d^2\mathbf{b} \mathrm{e}^{-\mathrm{i}\mathbf{b}\cdot\mathbf{q}} T(x, \mathbf{r}, \mathbf{b}).$

the scattering amplitude can be written as

$$\mathcal{A}_{T,L}^{\gamma^* p \to V p}(x, Q, \mathbf{q}) = \mathrm{i} \int_0^1 \frac{dz}{4\pi} \int d^2\mathbf{r} (\Psi_V^* \Psi)_{T,L} \times \mathrm{e}^{\mathrm{i}z\mathbf{r}\cdot\mathbf{q}} \widetilde{T}(x, \mathbf{r}, \mathbf{q}),$$

Dipole-proton scattering amplitude

The Fourier-transformed dipole scattering amplitude

$$\widetilde{T}(x, \mathbf{r}, \mathbf{q}) = 2\pi R_p^2 e^{-B\mathbf{q}^2} \mathcal{N}(x, r).$$

Phys. Rev. D 76 (2007) 034011

R is the proton radius.

For the form factor , we introduce a virtuality and vector meson mass dependent slope

$$B(Q^2) = B' + \frac{B''}{Q^2 + M_V^2}.$$

IIM

$$\mathcal{N}(x,r) = \begin{cases} \mathcal{N}_0 \left(\frac{rQ_s}{2}\right)^{2\left(\gamma_s + \frac{1}{\kappa\lambda Y}\log\frac{2}{rQ_s}\right)} & : \quad rQ_s \le 2 \\ 1 - \mathrm{e}^{-A\log^2(BrQ_s)} & : \quad rQ_s > 2 \end{cases},$$

This is obtained by solving the leading order BK equation.

Phys. Lett. B, 590 (2004) 199

rcBK

$$\frac{\partial S(r,Y)}{\partial Y} = -\int d^2r_1 \tilde{K}(\mathbf{r},\mathbf{r}_1,\mathbf{r}_2) S(r,Y)$$

$$\tilde{K}(\mathbf{r},\mathbf{r}_1,\mathbf{r}_2) = \frac{\bar{\alpha}_s(r^2)}{2\pi}\left[\frac{1}{r_1^2}\frac{\alpha_s(r_1^2)}{\alpha_s(r^2)} + \frac{1}{r^2}\left(\frac{\alpha_s(r^2)}{\alpha_s(r_1^2)} - 1\right)\right]$$

This is obtained by solving the the next-to-leading order BK equation with running coupling corrections.

Phys. Rev. D 95 (2017) 116009

Data selection

J/ψ	σ	60	Eur.Phys.J. C46 (2006) 585
	$\frac{d\sigma}{dt}$	28	Nucl.Phys. B695 (2004) 3
ρ	σ	135	Eur. Phys. J. C (2000) 13 371
	$\frac{d\sigma}{dt}$	20	JHEP 05 (2010) 032
ϕ	σ	61	
	$\frac{d\sigma}{dt}$	28	Nucl.Phys. B718 (2005) 3
Total		332	PMC Phys. A1 (2007) 6

Fit results

IIM

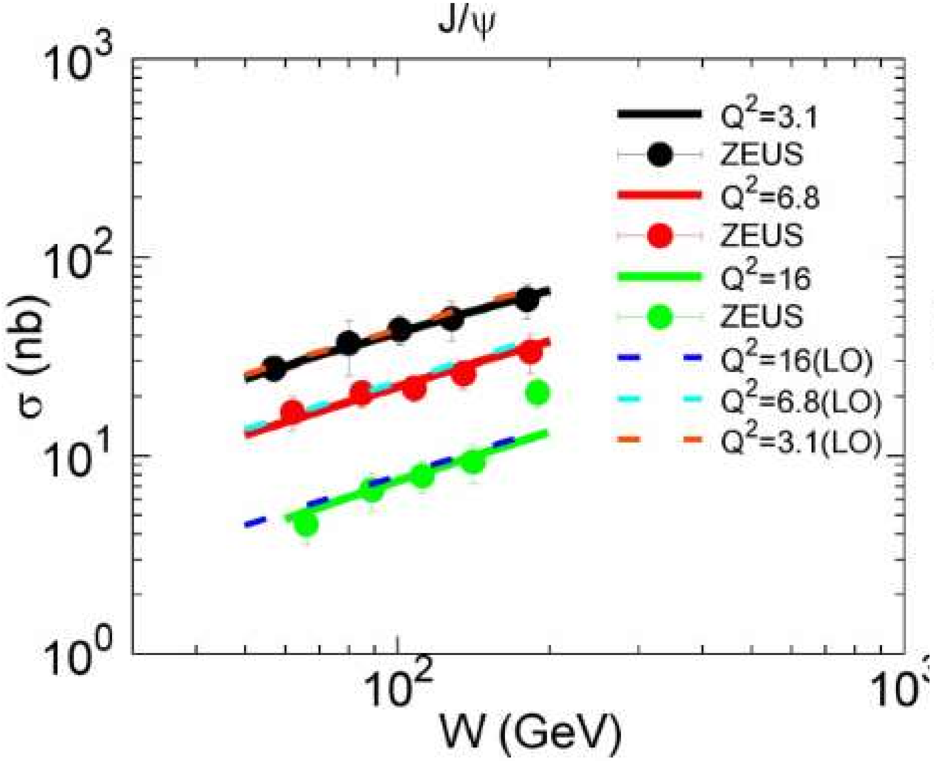
Meson	Observable	Data	B'	B''	$\chi^2/d.o.f$
J/ψ	σ	60	1.86	-1.74	0.47
	$\frac{d\sigma}{dt}$	28	2.32	-3.24	1.12
ρ	σ	135	1.84	-1.81	0.86
	$\frac{d\sigma}{dt}$	20	2.86	-1.4	2.08
ϕ	σ	61	2.29	-1.26	1.17
	$\frac{d\sigma}{dt}$	28	2.25	0.91	0.31
Total		332	2.06	-1.56	0.9

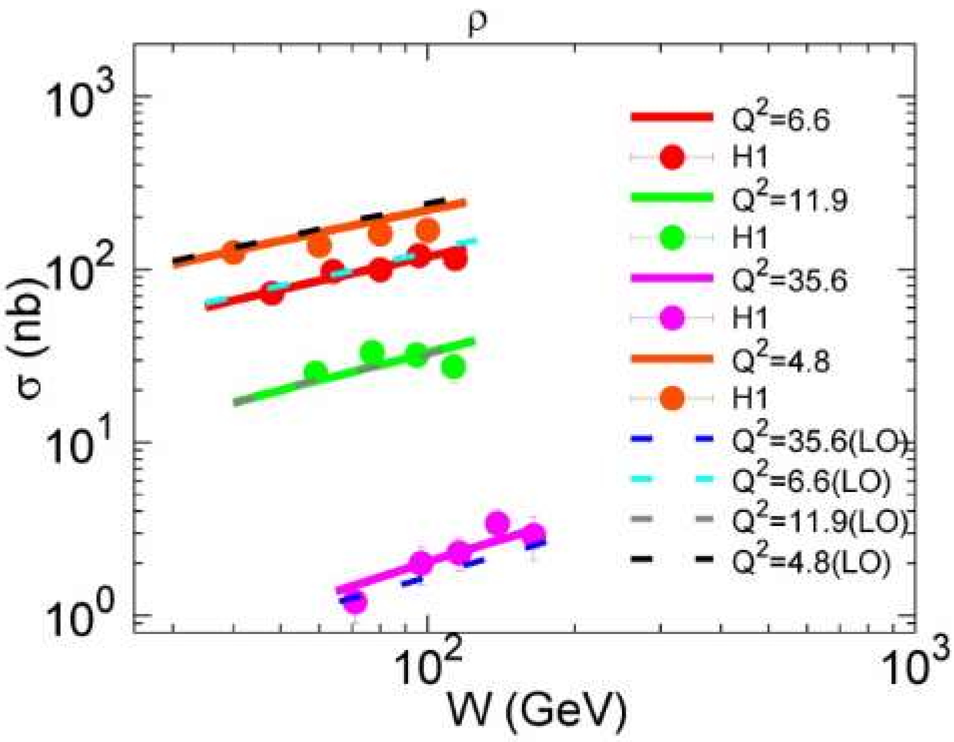
rcBK

Meson	Observable	Data	B'	B''	$\chi^2/d.o.f$
J/ψ	σ	60	1.98	-0.55	0.77
	$\frac{d\sigma}{dt}$	28	1.82	2.29	1.17
ρ	σ	135	2.04	0.04	2.51
	$\frac{d\sigma}{dt}$	20	2.58	0.18	2.58
ϕ	σ	61	1.89	1.14	1.72
	$\frac{d\sigma}{dt}$	28	1.65	3.96	1.08
Total		332	1.98	0.67	1.82

we can see that the χ^2/d.o.f results from next-to-leading order are smaller than leading order , which indicate that the next-to-leading order effect cannot be neglected in the calculation of vector meson production.

Fit results





we can see that the χ^2/d.o.f results from next-to-leading order are smaller than leading order, which indicate that the next-to-leading order effect cannot be neglected in the calculation of vector meson production.

Summary and outlook

The exclusive vector meson photoprpoduction is investigated by taking into account the running coupling corrections in the framework of color glass condensate. It show that the χ^2/d.o.f results from the next-to-leading order are smaller than the leading order.

rcBK equation only include the quark loops. In addition to the running coupling corrections, the gluon loops also has a large contribution to the dipole amplitude. The exclusive vector meson production with a full next-to-leading order BK equation are worth to explore.

Thank you for your attention