Vector meson electroproduction in QCD*

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Abstract: Based on the generalized QCD vector meson dominance model, we study the electroproduction of a vector meson off a proton in the QCD inspired eikonalized model. Numerical calculations for the total cross section $\sigma_{\rm tot}$ and differential cross section $d\sigma/dt$ are performed for ρ, ω and ϕ meson electroproduction in this paper. Since gluons interact among themselves (self-interaction), two gluons can form a glueball with quantum numbers $I^G, J^{PC} = 0^+, 2^{++}$, decay width $\Gamma_{\rm t} \approx 100$ MeV, and mass of $m_{\rm G}$=2.23 GeV. The three gluons can form a three-gluon colorless bound state with charge conjugation quantum number $C=-1$, called the Odderon. The mediators of interactions between projectiles (the quark and antiquark pair fluctuated from the virtual photon) and the proton target (a three-quark system) are the tensor glueball and the Odderon. Our calculated results in the tensor glueball and Odderon exchange model fit to the existing data successfully, which evidently shows that our present QCD mechanism is a good description of meson electroproduction off a proton. It should be emphasized that our mechanism is different from the theoretical framework of Block et al. We also believe that the present study and its success are important for the investigation of other vector meson electro- and photoproduction at high energies, as well as for searching for new particles such as tensor glueballs and Odderons, which have been predicted by QCD and the color glass condensate model (CGC). Therefore, in return, it can test the validity of QCD and the CGC model.

Key words: vector meson electroproduction, tensor glueball and Odderon exchange, QCD inspired eikonalized model

PACS: 25.30.Rw, 24.85.+p, 12.40.-y **DOI:** 10.1088/1674-1137/36/8/003

1 Introduction

Vector meson electroproduction provides an interesting laboratory for studying the interplay between perturbative and nonperturbative quantum chromodynamics (QCD). A microscopic understanding of vector meson electroproduction remains an elusive goal of hadronic physics. Vector meson production has been measured in electroproduction by Zeus [1, 2]. H1 [3] has also measured the differential cross section for ρ, ω and ϕ mesons at high $|t|$ in electroproduction. In recent years many more data have been obtained in HERA experiments, with high accuracy and statistics, and their comparison with theoretical calculations provides an opportunity to study diffractive production of vector mesons $\gamma^*+p \rightarrow V+p$ (V=J/ψ, ϕ, ρ, ω, Υ). We are now able investigate the quark-gluon structure of hadrons. And it definitely offers an opportunity to search for new physics and new particles such as the quest for H-particles, Higgs bosons, tensor glueballs, and Odderons, which have been predicted by QCD and the color glass condensate (CGC) model. Therefore, in return, it can test the validity of QCD and the CGC model.

In QCD, hadrons are described in terms of quarks, anti-quarks, and gluons. Correctly speaking, a vector meson is made up of a quark and an antiquark. The quantum numbers of a vector meson J^{PC} are the same as those for the photon $J^{PC}=1^{--}$. Moreover, our generalized QCD vector meson dominance model also tells us that the photon emitted by the incident electron in the initial state can split into a vector meson before its interaction with the proton target. All these facts lead us to believe that the vector meson

Received 25 October 2011

* Supported by Guangxi Science Foundation for Young Researchers (0991009), Department of Guangxi Education (200807MS112), Department of Guangxi Education for the Excellent scholars of Higher Education (2011-54) and Doctoral Science Foundation of Guangxi University of Technology (11Z16)

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electro-production off the proton in QCD proceeds through a strong interaction between a quark-antiquark pair fluctuated by a virtual photon radiated from the incoming electron and the quark-gluon system of the target proton.

In previous papers [4], we calculated the differential cross section for vector meson J/ψ electroproductions off the proton at high energies. Now we use the same QCD inspired eikonalized approximation to study ρ, ω and ϕ meson production. Although our model is similar to the model proposed initially by Block et al. [5–7] in many ways, there are many significant differences between the two models. For example, the force mediators between the bound quark-antiquark pair (vector meson) and the proton in our model are tensor glueballs and Odderons, which are colorless objects, but the mediators in the Block model are two single colorful gluons, which are forbidden to exchange in an colorless meson-proton interaction process. Second, we consider the contributions from virtual gluons both in meson and proton targets to our predicting cross sections, which the Block calculation did not. We also use a different value of $P_{\rm had}$ to fit the data for the total cross section $\sigma_{\rm tot}$ and differential cross section $d\sigma/dt$ of ZEUS and H1 experiments. In Section 2, we introduce the QCD-inspired eikonalized model and present the related formulism of cross sections in the model. Section 3 shows our theoretical predictions and comparison with the Block et al result. Finally, our summary and concluding remarks are reserved for Section 4.

2 QCD inspired eikonalized model

According to the eikonalized approximation, we can write down the scattering amplitude [6] of the process in the center of mass system as:

$$F_{\rm c.m}(s,t)=\frac{k}{\pi}\int {\rm e}^{{\rm i}\vec{q}\cdot\vec{b}}a(b,s){\rm d}^2\vec{b}, \qquad (1)$$

which ensures unitarity in the two-dimensional transverse impact parameter space $\vec{b}$, where $a(b,s)$ is the scattering amplitude in the impact parameter frame with $a(b,s)=\langle\psi_i|\prod_{i=1}^{A}[1-\Gamma_i(b-s_i)]|\psi_i\rangle$, and Γ_i is the profile function describing two-body interaction. Here ${\rm d}^2\vec{b}=2\pi b db$ and $\vec{q}$ is a two-dimensional vector in space $\vec{b}$ and $q^2=-t$ with $t=-2k^2(1-\cos\theta)$ being the invariant four-momentum transfer. θ is the scattering angle in the center of mass system.

It has been pointed out that the scattering amplitude of hadron-hadron scattering in a QCD inspired model is given by $F(s,t)=F_+(s,t)+F_-(s,t)$, where $F_+(s,t)$ is the crossing even amplitude and $F_-(s,t)$ is the crossing odd amplitude of the interaction process. The quark-quark, gluon-gluon interactions and quark-gluon interference term contribute to the crossing even amplitude $F_+(s,t)$, and the QCD Odderon exchange term contributions are responsible for the crossing odd amplitude $F_-(s,t)$. According to the assumption of the generalized QCD vector meson dominance model for electroproduction off the target proton, the virtual photon emitted from the incident electron behaves like a system of a quark and antiquark bound state and it strongly interacts with the target proton consisting of three valence quarks and gluons. Specifically, the virtual photon-proton interaction could, in fact, be replaced by the interaction of a quark-antiquark pair with a system of three valence quarks and gluons of the target proton. For these two strongly interacting systems (quark-antiquark pair and three valence quarks gluons system), the quark gluon degrees of freedom are naturally involved. In this case, the mediators of the interacting force could be the tensor glueball, which consists of two Reggeized gluons with a mass of 2.23 GeV, the decay width $\Gamma\approx 100$ MeV, the quantum numbers I^G, $J^{PC}=0^+,2^{++}$ and the charge conjugation number $C=+1$, and the Odderon consisted of three gluons with conjugation number $C=-1$. The mechanism of the scattering process, $\gamma^*+{\rm p}\rightarrow {\rm V}+{\rm p}$ with ${\rm V}=\rho$, ω and ϕ, is similar to the one for $\gamma^*+{\rm p}\rightarrow {\rm J}/\psi+{\rm p}$. The diagrammatic representation of the interacting mechanism can be found from Ref. [4].

Assuming that $F_{\gamma^*{\rm p}}(s,t)$ is a general scattering amplitude, then the total cross section $\sigma_{\rm tot}^{\gamma^*{\rm p}}(s)$ and differential cross section $[{\rm d}\sigma(s,t)/{\rm d}t]_{\gamma^*{\rm p}}$ can be normalized in such a way that [6]

$$\sigma_{\rm tot}^{\gamma^*{\rm p}}(s) = \frac{P_{\rm had}^{\gamma^*{\rm p}}}{s}{\rm Im}F_{\gamma^*{\rm p}}(s,t=0), \qquad (2)$$

$$\left[\frac{{\rm d}\sigma(s,t)}{{\rm d}t}\right]_{\gamma^*{\rm p}} = \frac{P_{\rm had}^{\gamma^*{\rm p}}}{16\pi s^2}\,|\,F_{\gamma^*{\rm p}}(s,t)\,|^2, \qquad (3)$$

where $P_{\rm had}^{\gamma^*{\rm p}}$ is an appropriate probability of the virtual photon fluctuation into a vector meson V. Eqs (2, 3) are the fundamental formulae of our present study of vector meson electroproduction off the proton at high energies. Now, the required task to reach our goal is to work out the amplitude $F_{\gamma^*{\rm p}}(s,t)$ in the QCD inspired eikonalized model. According to the Glauber multiple scattering theory [8], the scattering amplitude is given by

$$F(q)=\frac{{\rm i}k}{2\pi}\int {\rm e}^{{\rm i}q\cdot\vec{b}}[1-{\rm e}^{{\rm i}\chi(s,b)}]{\rm d}^2\vec{b}, \qquad (4)$$

and the eikonal phase transition function $\chi(s,\vec{b})$ is defined by

$$\chi(s,\vec{b})=-\frac{2m}{k}\int_0^\infty V\left(\sqrt{b^2+z^2}\right)\mathrm{d}z, \tag{5}$$

where $V\left(\sqrt{b^2+z^2}\right)$ is the interaction, and $\vec{b}$ is the impact vector in the colliding plane. The amplitude $F(s,t)$ can be simply expressed by $\chi(s,\vec{b})$. Therefore, calculation of the amplitude $F(s,t)$ now becomes a task to calculate χ.

Due to $F(s,t)=F_+(s,t)+F_-(s,t)$, the profile function χ in the QCD inspired eikonalized model of high energy baryon-baryon scattering [5] can be expressed as

$$\chi(s,\vec{b})=\chi_{\rm even}(s,b)+\chi_{\rm odd}(s,\vec{b}). \tag{6}$$

The even eikonal profile functions $\chi_{\rm even}$ for pp and $\bar{\rm p}$p elastic scattering in QCD can be expressed by summing three contributions from the quark-quark, the gluon-gluon interactions and the quark-gluon interference terms. They are individually factorized into a product of a cross section $\sigma(s)$ times an impact parameter space distribution function $W(b,\mu)$, that is

$$\begin{aligned}\chi_{\rm even} &= \chi_{\rm qq}(b,s)+\chi_{\rm gg}(b,s)+\chi_{\rm qg}(b,s)\\ &= {\rm i}[\sigma_{\rm qq}(s)W(b;\mu_{\rm qq})+\sigma_{\rm gg}(s)W(b;\mu_{\rm gg})\\ &\quad +\sigma_{\rm qg}(s)W(b;\sqrt{\mu_{\rm qq}\mu_{\rm gg}})].\end{aligned} \tag{7}$$

The factor i has been inserted in the second line of Eq. (7) since the high energy eikonal profile function is largely imaginary. The impact parameter space distribution functions $W(b,\mu)$ used in Eq. (7) are taken to be the convolutions of two dipole form factors, i.e., we parameterize $W(b;\mu)$ as the Fourier transform of two dipole form factors of the nucleon [6]:

$$W(b;\mu)=\frac{\mu^2}{96\pi}(b\mu)^3K_3(b\mu), \tag{8}$$

where $K_3(x)$ is a modified Bessel function of the second kind. $\chi_{\rm even}$ is responsible for the crossing even amplitude $F_+(s,t)$, and $\chi_{\rm odd}$ corresponds to the contributions from the crossing odd amplitude $F_-(s,t)$ and is given by [6]

$$\chi_{\rm odd}(b,s) = -{\rm i}\sigma_{\rm odd}(s)W(b,\mu_{\rm odd}). \tag{9}$$

Let us now derive our theoretical expression for the total cross section and differential cross section of the γ^*p elastic scattering. Since the eikonal phase $\chi_{\gamma^*{\rm p}}$ for γ^*p elastic scattering clearly reads

$$\chi^{\gamma^*{\rm p}}=\chi^{\gamma^*{\rm p}}_{\rm even}+\chi^{\gamma^*{\rm p}}_{\rm odd}. \tag{10}$$

The γ^*p scattering amplitude $F_{\gamma^*{\rm p}}$ in Eq. (4) can evidently be expressed as

$$\begin{aligned}F_{\gamma^*{\rm p}}(s,t) &= \frac{k}{2\pi}\int{\rm d}^2\vec{b}{\rm e}^{{\rm i}\vec{q}\cdot\vec{b}}(\chi^{\gamma^*{\rm p}}_{+}+\chi^{\gamma^*{\rm p}}_{-})\\ &\cong \frac{k}{2\pi}\int{\rm d}^2\vec{b}{\rm e}^{{\rm i}\vec{q}\cdot\vec{b}}(\chi^{\gamma^*{\rm p}}_{\rm even}+\chi^{\gamma^*{\rm p}}_{\rm odd}).\end{aligned} \tag{11}$$

Using the vector meson dominance and the QCD inspired model, the virtual photon-proton total cross section can then be written as

$$\sigma^{\gamma^*{\rm p}}_{\rm tot}(s)=2P^{\gamma^*{\rm p}}_{\rm had}\int[1-{\rm e}^{-\chi^{\gamma^*{\rm p}}_I(b,s)}\cos(\chi^{\gamma^*{\rm p}}_R(b,s))]{\rm d}^2\vec{b}, \tag{12}$$

where $P^{\gamma^*{\rm p}}_{\rm had}$ is the probability that a virtual photon splits into a quark-antiquark pair. The differential scattering cross section can be written as

$$\frac{{\rm d}\sigma^{\gamma^*{\rm p}}}{{\rm d}t}(s,t)=\frac{P^{\gamma^*{\rm p}}_{\rm had}}{4\pi}\left|\int J_0(qb)(1-{\rm e}^{{\rm i}(\chi^{\gamma^*{\rm p}}_{\rm even}+\chi^{\gamma^*{\rm p}}_{\rm odd})(b,s)}){\rm d}^2\vec{b}\right|^2. \tag{13}$$

In the generalized QCD vector meson dominance model, the virtual photon is a quark-antiquark bound state, in contrast to the proton, which is a three-quark bound state with gluons in it. The γ^*p total cross section is obtained from the even eikonal profile functions for pp or $\bar{\rm p}$p by the substitutions $\sigma_{ij}\to\frac{2}{3}\sigma_{ij}$ and $\mu_{ij}\to\sqrt{\frac{2}{3}}\mu_{ij}$. Therefore Eq. (7) becomes

$$\begin{aligned}\chi^{\gamma^*{\rm p}}_{\rm even} &= \chi^{\gamma^*{\rm p}}_{\rm qq}(b,s)+\chi^{\gamma^*{\rm p}}_{\rm gg}(b,s)+\chi^{\gamma^*{\rm p}}_{\rm qg}(b,s)\\ &= {\rm i}\left[\frac{2}{3}\sigma_{\rm qq}(s)W\left(b;\sqrt{\frac{2}{3}}\mu_{\rm qq}\right)\right.\\ &\quad +\frac{2}{3}\sigma_{\rm gg}(s)W\left(b;\sqrt{\frac{2}{3}}\mu_{\rm gg}\right)\\ &\quad \left.+\frac{2}{3}\sigma_{\rm qg}(s)W\left(b;\sqrt{\frac{2}{3}}\sqrt{\mu_{\rm qq}\mu_{\rm gg}}\right)\right].\end{aligned} \tag{14}$$

By the same way we can obtain the profile functions $\chi_{\rm odd}$ for the Odderon exchange contribution to the γ^*p scattering amplitudes, that is, substitutions of $\sigma_{ij}\to\frac{2}{3}\sigma_{ij}$ and $\mu_{ij}\to\sqrt{\frac{2}{3}}\mu_{ij}$ in Eq. (9). Then Eq. (9) becomes

$$\begin{aligned}\chi^{\gamma^*{\rm p}}_{\rm odd}(b,s) &= -{\rm i}\frac{2}{3}\sigma_{\rm odd}(s)W\left(b,\sqrt{\frac{2}{3}}\mu_{\rm odd}\right)\\ &= -{\rm i}\frac{2}{3}C_{\rm odd}\Sigma_{\rm gg}\frac{m_{\rm o}}{\sqrt{s}}W\left(b,\sqrt{\frac{2}{3}}\mu_{\rm odd}\right).\end{aligned} \tag{15}$$

In the next section, the numerical calculations for ρ, ω and ϕ meson electroproduction off the proton in the QCD inspired eikonalized model will be performed by using Eqs. (12), (13) with the profile functions χ in Eqs. (14), (15).

3 Theoretical predictions and comparison with experimental data

3.1 The total cross section

From Ref. [5] we can conclude a simple analytic function together with their asymptotic behavior. A forward amplitude varying as E^{α} contributes to the total cross section as $E^{\alpha-1}$ ($s=2(m^2+mE)$, E is laboratory energy, m is the proton mass). If the amplitude is even, the amplitude phase is $\mathrm{e}^{-\mathrm{i}\pi\alpha/2}$. For odd amplitude, the phase is $\mathrm{ie}^{-\mathrm{i}\pi\alpha/2}$. As is known, the total even contribution is not yet analytic. For large s, the even profile function in Eq. (7) can be made analytic via substituting the s in Eq. (7) by $s\mathrm{e}^{-\mathrm{i}\pi/2}$(see the table on P. 580 of Ref. [5], along with Ref. [9], with $\alpha=0.5$). Therefore, the contribution to the total cross section from quark-quark, gluon-gluon, and quark-gluon interference terms now can be rewritten as

$$\sigma_{\mathrm{gg}}(s) = 2\pi\left(\frac{\epsilon}{\mu_{\mathrm{gg}}}\right)^2\left(\lg^2\frac{s}{s_0}-\frac{\pi^2}{4}\right) -\mathrm{i}\pi^2\left(\frac{\epsilon}{\mu_{\mathrm{gg}}}\right)^2\lg^2\frac{s}{s_0}, \tag{16}$$

$$\sigma_{\mathrm{qq}}(s) = \Sigma_{\mathrm{gg}}\left(C+C^{\mathrm{even}}_{\mathrm{Regge}}\frac{m_0}{\sqrt{s}}\cos\frac{\pi}{4}\right) = +\mathrm{i}\Sigma_{\mathrm{gg}}C^{\mathrm{even}}_{\mathrm{Regge}}\frac{m_0}{\sqrt{s}}\sin\frac{\pi}{4}, \tag{17}$$

$$\sigma_{\mathrm{qg}}(s) = \Sigma_{\mathrm{gg}}C^{\log}_{\mathrm{qg}}\lg\frac{s}{s_0}-\mathrm{i}\Sigma_{\mathrm{gg}}C^{\log}_{\mathrm{qg}}\frac{\pi}{2}. \tag{18}$$

The odd eikonal profile function $\chi_{\mathrm{odd}}=-\mathrm{i}\sigma_{\mathrm{odd}}W(b,\mu)$ accounts for the difference between pp and $\mathrm{p\bar{p}}$ elastic scattering, $\chi_{\mathrm{pp}}=\chi_{\mathrm{even}}+\chi_{\mathrm{odd}}$ and $\chi_{\mathrm{p\bar{p}}}=\chi_{\mathrm{even}}-\chi_{\mathrm{odd}}$, and must vanish at high energies. A Regge behaved analytic odd eikonal profile function $\chi_{\mathrm{odd}}(b,s)$ can be well parameterized as Eq. (9). So, the odderon exchange contribution to the total cross section can be rewritten as

$$\sigma_{\mathrm{odd}}(s)=C_{\mathrm{odd}}\Sigma_{\mathrm{gg}}\frac{m_0}{\sqrt{s}}\cos\frac{\pi}{4}+\mathrm{i}C_{\mathrm{odd}}\Sigma_{\mathrm{gg}}\frac{m_0}{\sqrt{s}}\sin\frac{\pi}{4}. \tag{19}$$

The parameters in Eqs. (16–19) and their physical meanings are given in our previous publications [10, 11]. Although all the above formulae are similar to those given by the Block et al eikonalized model, there are some significant differences between the two models. For examples, see below.

1) The mediators of the interaction between the incident vector meson and the target proton are a colorless tensor glueball and an Odderon, rather than two single colorful gluons.

2) From fitting experimental data, the values P_{had} of the appropriate probability for a virtual photon splitting into a ρ, ω, ϕ are taken to be $P^{\rho\mathrm{p}}_{\mathrm{had}}=1/11.1$, $P^{\omega\mathrm{p}}_{\mathrm{had}}=1/10$, $P^{\phi\mathrm{p}}_{\mathrm{had}}=1/10$ in our present calculations. However, Block used the value of $\frac{1}{240}$ for all of the production processes (some parameters come from Ref. [12]), which is one order smaller in magnitude than ours.

3) We expand the factor of $(1-\mathrm{e}^{\mathrm{i}\chi})$ in Eq. (4)

$$1-\mathrm{e}^{\mathrm{i}\chi}=-\mathrm{i}\chi+\frac{1}{2!}\chi^2+\frac{1}{3!}\mathrm{i}\chi^3+\cdots. \tag{20}$$

Unlike Block et al's theoretical calculations, we only consider the first approximation $1-\mathrm{e}^{\mathrm{i}\chi}\simeq-\mathrm{i}\chi$ and do not consider the secondary correction $+\frac{1}{2!}\chi^2$ and higher order approximation. We will investigate this problem in our upcoming work.

Then we obtain our numerical predictions of ρ, ω and ϕ meson electroproduction off the proton at high energies from Eqs. (2–19). Our results are shown in Figs. 1–6. Fig. 1 shows the s-dependence of the total cross section and the comparison with experimental data given by Ref. [1].

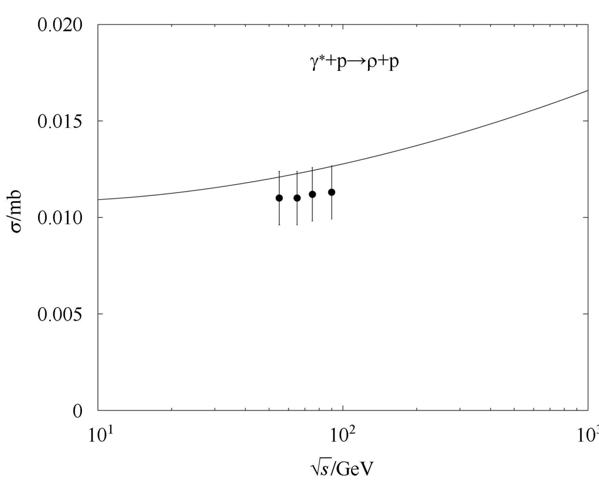

Fig. 1. The s-dependence of the total cross section of ρ electroproduction. The solid curve is our theoretical prediction. The circle black points are from the Zeus collaboration [1].

3.2 The differential cross section

The differential cross section $[\mathrm{d}\sigma/\mathrm{d}t]^{\gamma^*\mathrm{p}}$ for the reaction $\gamma^*+\mathrm{p}\to\mathrm{V}+\mathrm{p}$ with V= ρ, ω and ϕ is plotted in Figs. 2–6.

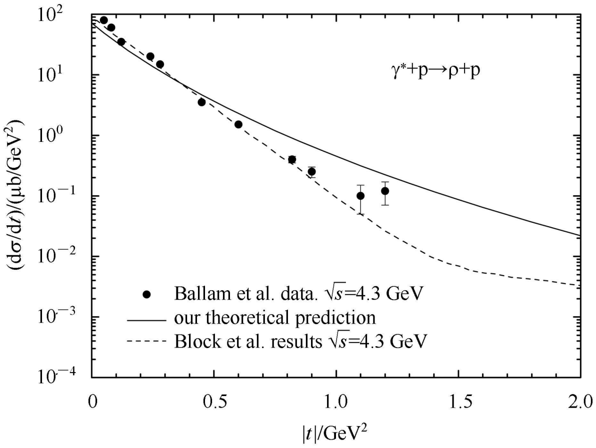

Fig. 2. The t-dependence of differential cross section for ρ electroproduction at $\sqrt{s}$ = 4.3 GeV. The solid curve is our theoretical prediction. The dashed line is Block et al's theoretical result[6]. The black circles are the Zeus data at $\sqrt{s}$ = 4.3 GeV, extracted from Fig. 13 of Ref. [6].

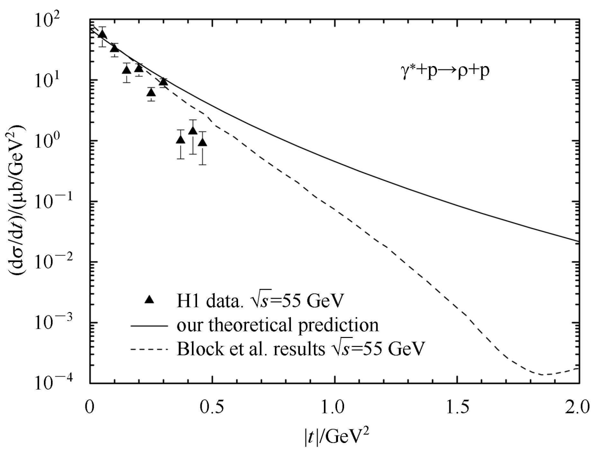

Fig. 3. The t-dependence of differential cross section for ρ electroproduction at $\sqrt{s}$ = 55 GeV. The solid curve is our theoretical prediction. The dashed line is Block et al's theoretical result [6]. The black triangle is the data from the H1 [3], extracted from Fig. 13 of Ref. [6], for $\sqrt{s}$ = 55 GeV.

From Figs. 2–6 our theoretical result gives a perfect fit to the experimental data at $|t|$ <0.5 GeV^2, but at the region of $|t|$ >0.5 GeV^2 we have no data to compare. We compare our result with Block et al's results. The solid curve is our theoretical prediction. The dashed line is Block et al's theoretical result [6]. From Figs. 1–6 we can conclude that, based on the generalized QCD vector meson dominance, our calculated results of the total cross section and differential cross section for the vector meson electroproduction in the QCD inspired eikonalized model fit to their corresponding experimental measurements reasonably well. Therefore, we may claim that the QCD inspired eikonalized model could be a good description of the vector meson electroproduction off the proton. In the model, the total cross section and differential cross section are formalized by a sum of four contributions, namely from quark-quark, gluon-gluon interactions, quark-gluon interference terms and Odderon exchange term contributions. According to our numerical calculations, the quark-quark interactions make a dominant contribution to the total cross section $\sigma_{\text{tot}}^{\gamma^* \text{p}}$ and differential cross section $\text{d}\sigma^{\gamma^* \text{p}}/\text{d}t$. The

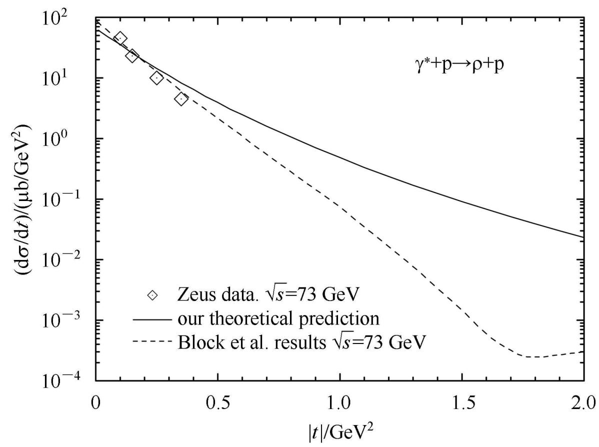

Fig. 4. The t-dependence of differential cross section for ρ electroproduction at $\sqrt{s}$ = 73 GeV. The solid curve is our theoretical prediction. The dashed line is Block et al's theoretical result [6]. The diamonds are Zeus data at $\sqrt{s}$ = 73 GeV, extracted from Fig. 13 of Ref. [6].

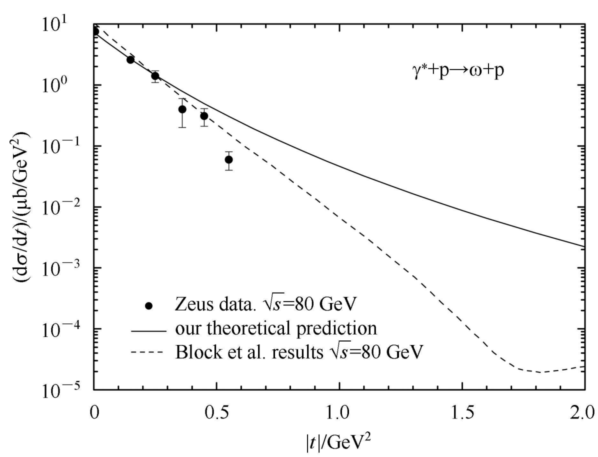

Fig. 5. The t-dependence of the differential cross section for ω electroproduction at $\sqrt{s}$ = 80 GeV. The solid curve is our theoretical prediction. The dashed line is Block et al's theoretical result [6]. The black circles are the Zeus data at $\sqrt{s}$ = 80 GeV, extracted from Fig. 14 of Ref. [6].

contributions from the gluon-gluon interaction and the quark-gluon interference term reduce rapidly as $|t|$ increases. The odderon contribution decreases slowly as $|t|$ increases. It should be emphasized here that in the QCD inspired eikonalized model, the mediators of the interaction are the tensor glueball and the Odderon. This is a very different characteristic of our calculations compared with other theoretical calculations.

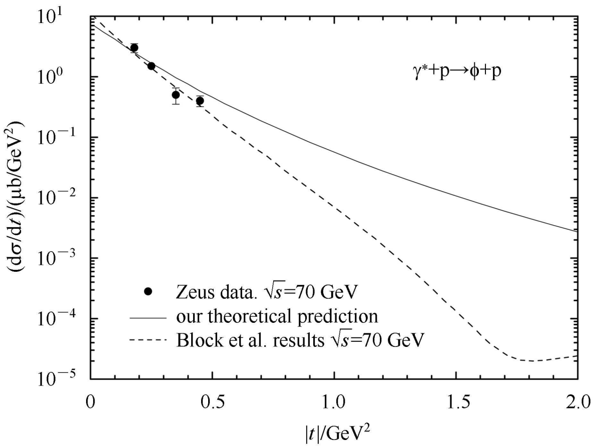

Fig. 6. The t-dependence of differential cross section for ϕ electroproduction at $\sqrt{s}$ = 70 GeV. The solid curve is our theoretical prediction. The dashed line is Block et al's theoretical result [6]. The black circles are the Zeus data at $\sqrt{s}$ = 70 GeV, extracted from Fig. 15 of Ref. [6].

4 Summary and calculational remarks

Based on the generalized QCD vector meson dominance model and a proton consisting of quarks and gluons, we investigate the vector meson ρ, ω and ϕ electroproduction off the proton in the QCD inspired eikonalized approximation. The QCD inspired eikonalized model takes the quark-quark, gluon-gluon interactions and quark-gluon interference terms into account for the crossing even amplitude $F_+(s,t)$, and the contributions from the Odderon exchange terms are responsible for the crossing odd amplitude $F_-(s,t)$. The interaction between the virtual photon and target proton is treated as a strong interaction of a quark-quark pair with the quark gluon constituents in target proton. The mediators of the interaction are a tensor glueball with charge conjugation quantum number $C=+1$ and a QCD Odderon with $C=-1$.

The present model provides a good description of the experimental data. Though our QCD inspired eikonalized model is based on Block's theoretical framework, we adjust $P_{\rm had}$ from Eq. (13) and only consider the first approximation in Eq. (20). When linking the factor 2/3 exclusively to the quark composition of our eikonal profile functions in Eqs. (7, 9), we find that the total cross section and differential cross section of the ρ, ω and ϕ electroproduction off the proton, $\gamma^*+{\rm p}\rightarrow{\rm V}+{\rm p}$, can be well expressed by a sum of four contributions from quark-quark, gluon-gluon interactions, quark-gluon interference terms and Odderon exchange terms. From the present analysis of our numerical calculations we find that the quark-quark interaction makes a dominant contribution to the fitting to experimental data of $\gamma^*+{\rm p}\rightarrow{\rm V}+{\rm p}$ with V= ρ, ω and ϕ. The Odderon exchange contribution plays an important role in explaining the data and its contribution to ${\rm d}\sigma/{\rm d}t$ slow decreasing as $|t|$ increases.

We emphasize once again that the Odderon exchange term makes a significant contribution to the observable total cross section and differential cross section of the ρ, ω and ϕ electroproduction off the proton, $\gamma^*+{\rm p}\rightarrow{\rm V}+{\rm p}$. Therefore, we may claim that the γ^*p scattering could provide a good opportunity to search for new particle, the Odderon, which has been predicted by QCD and the CGC model and to study glueball physics.

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