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$\gamma\gamma$ Interaction in the Generalized QCD Vector Meson Dominance Model and the QCD Inspired Eikonalized Approximation

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Abstract: Based on the generalized QCD vector meson dominance model and the QCD Inspired Eikonalized approximation, $\gamma\gamma$ interaction has been studied in this paper. Unlike the usual calculations of the $\gamma\gamma$ interaction by the Feynman box diagram technique, we explore the process by QCD theory in which $\gamma\gamma$ elastic scattering proceeds through a strong interaction between two pairs of quark-antiquark fluctuated by two scattering photons. Due to the fact that the mediator of strong interaction is colorful gluon, and gluon has a property of self-interaction which can bind exchanging gluons together to form glueballs. The colorless tensor glueball (two Reggeized gluon bound state) and Odderon (three Reggeized gluon bound state) could be the mediators of the interaction between the two quark-antiquark pairs. This mechanism is very different from the other theoretical descriptions of the process. In particular, the contributions from virtual gluon, bound quark-antiquark to form a fluctuated meson, are taken into account. We calculate the total cross section $\sigma_{\rm tot}$, the differential cross section $d\sigma/dt$, the ratio of the real part to the imaginary part of the forward scattering amplitude ρ, and the nuclear slope parameter function β of $\gamma\gamma$ elastic scattering. Our theoretical predictions for $\sigma_{\rm tot}$ are consistent with the experimental data within error bars of the data. The data for $d\sigma/dt$, ρ and β are urgently needed to test our theoretical model.

Key words: $\gamma\gamma$ interaction; generalized QCD vector meson dominance model; QCD inspired eikonalized approximation

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1 Introduction

The linearity of Maxwell's vacuum equations does not allow electromagnetic waves propagating in vacuum to interact, and therefore photon-photon scattering is forbidden in classical physics. However, in the theory of quantum electrodynamics (QED), the quantum vacuum possesses nonlinear properties so that the photon-photon scattering may occur, owing to the interaction with virtual

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electron-positron pairs. As we know that QED non-linear vacuum effects is of importance in the neighborhood of strongly magnetized astrophysical system[1-2]. Effects such as electron-positron pair creation and elastic photon-photon scattering may even play an important role in future laser-plasma experiment[3-5]. Moreover, since the photon-photon elastic scattering is a purely diffractive process of particle physics, namely there is no any quantum number exchanged between initial and final state of the $\gamma\gamma$ interacting system, it can offer a variety of insights into the diffractive mechanism of particle physics. At the same time, this $\gamma\gamma$ process can also provide many opportunities to learn about quark gluon contents of photon nature, to search for new physics and new particles such as the tensor glueball and Odderon, which have been predicted by QCD, QCD variants and Color Glass Condensate model (CGC) [6-8]. Therefore, it can, in return, test the validity of various theories and models, in particular QCD and CGC model.

Many studies of $\gamma\gamma$ interaction have been done both experimentally and theoretically. Theoretically, Refs. [9-11] describe photon-photon scattering in terms of the Lagrangian density of Heisenberg and Euler[12]. In addition, its cross section has been confirmed by the QED calculation of Karplus and Neumann[13]. However, Karplus and Neuman's calculation is not reliable because they have put some additional but unphysical conditions on the QED calculation[14] so as to reproduce the result obtained by Heisenberg and Euler. In particular, the effective Lagrangian proposed by Heisenberg and Euler for the vacuum polarization effects is physically incorrect since it disagrees with the observation that photon is always massless. In this respect, it is quite important that a new calculation of the photon-photon scattering must be done in a modern theory at the present.

Direct observation of elastic photon-photon scattering among real photons would, because of its fundamental importance to QED, be of great scientific importance. Although, during the last decades several suggestions on how to detect elastic photon-photon scattering have been made[15], no suggestions have, so far, led to actual detection of photon-photon scattering among real photons. The measurements with sufficient accuracy must be very difficult since photon cannot be at rest but always at the speed of light. To detect photon-photon scattering, the related process is photon splitting mechanism[16]. In fact, it is well known that a photon interacts with another photon via the box diagrams[14], where fermions and antifermions are created from the vacuum state. Namely, the photon-photon scattering is the reaction process arising from the particle nature of photon, in contrast to its wave nature such as conventional diffraction or interference phenomena in optics. In QCD, a photon can split into a quark-antiquark pair. The photon self-energy is born of this splitting quark-antiquark loop. The quark-antiquark loop in incident photon certainly interacts with another loop in target photon through strong interaction since they all have a long life time to interact each other during the scattering process. This picture naturally forms a new basic mechanism of photon-photon interaction. We name this mechanism as generalized QCD vector meson dominance model. It has been successfully applied in our previous publications on Υ meson photo-production and ρ meson electroproduction off the proton at high energies[17]. Now, we try to extend the model to the study of high energy $\gamma\gamma$ elastic scattering.

In this paper we study the $\gamma\gamma$ interaction in the generalized QCD vector meson dominance model and using the QCD inspired eikonalized approximation. We take all the contributions from quarks and virtual gluons in two fluctuated mesons to measured physical quantities into account. The mediators of the interaction between two colliding vector mesons are the tensor glueball and Odderon, instead of the usual Pomeron exchange in the conventional study of particle diffraction.

This paper consists of five parts. In Sect. 2, we briefly introduce the generalized QCD vector meson dominance model. In Sect. 3, we present our QCD inspired eikonalized approximation and its formulism. In Sect. 4, our present theoretical predictions and its comparisons with experimental data are given. Finally, we reserve our summary and conclusions for Sect. 5.

2 Generalized QCD vector meson dominance model

The first people to point out that a photon (even virtual photon) can fluctuate into a vector meson was Gribov[18]. In order to introduce this Gribov's vector meson dominance model, we begin with studying the process of vector meson electroproduction $\gamma N \rightarrow VN$ at high energies. According to Gribov's model, before γN interaction takes place the incident photon exclusively fluctuates into a vector meson V. The life time (coherence length) of the fluctuated vector meson can be expressed as

$$\tau = l_c = \frac{1}{m x_B}, \quad x_B = \frac{Q^2}{s}, \tag{1}$$

where Q^2 is the photon virtuality (momentum squared), and m is the mass of the target nucleon. This coherence length of the fluctuated vector meson is much larger at high energies than the size of the meson. In this case the photon-nucleon interaction can be replaced by meson-nucleon interaction. The model assumes that the hadronic components of the vacuum polarization of the photon consist exclusively of the known vector mesons (ρ, ω, ϕ, J/ψ, Υ). Since Gribov's work, the interaction between the photon and hadronic matter has been remarkably well described by this vector meson dominance model.

According to the quark model of hadron structure in QCD, a meson consists of a quark and an antiquark. Nucleon is made up of three valence quarks. They all are bound together tightly by exchanging gluons. For instance, vector mesons are believed to be a bound state of quark-antiquark pair with quantum number $J^{PC} = 1^{--}$ which is just the quantum number of photon.

$$\rho^+ = u\bar{d},\ \rho^- = d\bar{u},\ \rho^0 = \frac{1}{\sqrt{2}}(d\bar{d} - u\bar{u}),$$

$$\omega = \frac{1}{\sqrt{2}}(d\bar{d} + u\bar{u}),\ \phi = s\bar{s},\ J/\psi = c\bar{c},\ \Upsilon = b\bar{b}.$$

Therefore, it is reasonable and safe to believe that the photon-nucleon interaction may proceed through strong interaction between quark-antiquark pair fluctuated by the incident photon and the three quark system inside the target nucleon. From the standard model of particle physics, quarks, being charged, couple to the photon and so the strong sector contribution to the photon propagator arises, in a manner analogous to the electron-positron loops in QED.

In QCD, the mediator of interaction is colorful gluon and gluon has a self-interaction property. Due to this self-interaction, the multigluon exchanged between two different quark groups in incident meson and target nucleon can form glueballs-the colorless bound states of pure gluons. Therefore, in QCD the mediators of the interaction between meson and nucleon would be glueballs: the tensor glueball (two Reggeized gluon bound state) and/or Odderon (three Reggeized gluon bound state), and so on. In other words, in QCD the leading interaction mediators between projectile photon and target nucleon could be the colorless tensor glueball and/or colorless Odderon[19]. However, a single gluon exchange is forbidden because color quantum number is of conservation.

On the other hand, all investigations evidently show that the Pomeron exchange mechanism is an only successful description of high energy particle diffraction. Regge Pomeron assumption has remarkably well explained all high energy diffractive data. However, as the advent of QCD, people believes that the Pomeron could be the tensor glueball[20]. With quantum number $I^G J^{PC} = 0^+ 2^{++}$, Mass $M_G = 2.23$ GeV and decay width about $\Gamma_G \approx$

100 MeV. The reason is that although the tensor glueball has not been identified in experiment, its existence has been predicted surely by QCD, CGC and other QCD variants. Moreover the tensor glueball lies on the Pomeron trajectory $\alpha_P(t)=1.08+0.20\,t$ and has the Pomeron vacuum quantum numbers $I^G J^{PC}=0^+ J^{++}$. Needless to say, it mediates the strong interaction that the Pomeron does. Particularly, the investigations of pp and $p\bar{p}$ elastic scattering clearly show that the Odderon must exist in order to fit the experimental data[21].

Now let us to apply the above ideas to $\gamma\gamma$ elastic scattering. According to the above discussions, the Feynman diagrams shown in Figs. 1～2 would be the most possible mechanism of $\gamma\gamma$ interaction, where the fully dressed quark, gluon propagators, the tensor Glueball and Odderon propagators, the vertices of glueball coupling to quark and antiquark, and the photon-quark coupling vertex are appeared.

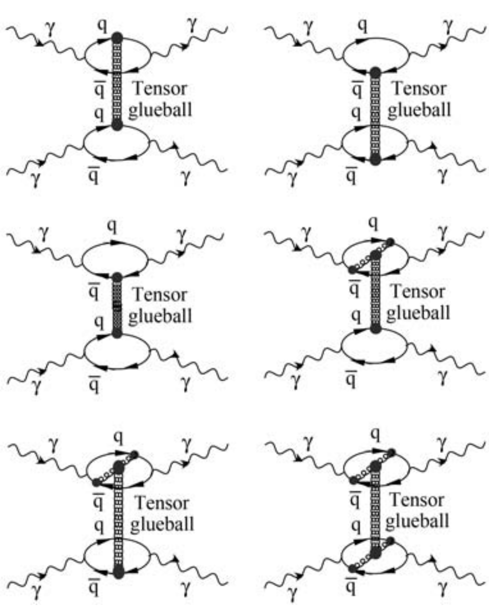

Fig. 1 Mechanism of the exclusive $\gamma\gamma$ process proceeding through the tensor glueball exchange.

In summary of this section, we claim that in QCD the $\gamma\gamma$ scattering process proceeds through strong interaction between two quark-antiquark pairs fluctuated respectively by two colliding photons before their interaction to take place. The leading mediators of their interaction could be the colorless tensor glueball and Odderon. The quarks and virtual gluons inside the two fluctuated mesons make their contributions to the physical quantities of the process. We named this mechanism of photon-photon interaction generalized QCD vector meson dominance model which has been successfully applied to vector meson Υ photo-production and ρ electro-production off the proton in the framework of QCD inspired eikonalized approximation[17]. Of course, this is certainly an approximation, but in the region around the vector meson masses, it appears to be a good approximation.

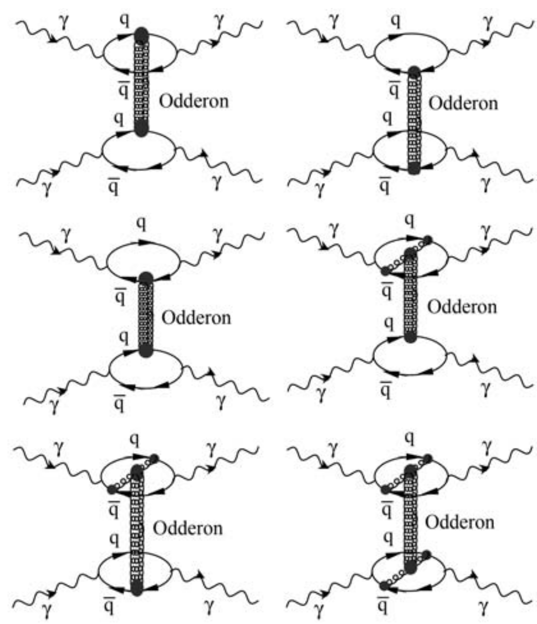

Fig. 2 Mechanism of the exclusive $\gamma\gamma$ process proceeding through the Odderon exchange.

3 QCD inspired eikonalized model

As it has been pointed out in the preceding section, the scattering amplitude of photon-photon scattering in our generalized QCD vector meson dominance model arises from the contributions of quark-quark, gluon-gluon interaction and quark-gluon interference. In the high energy eikonal description of particle-particle scattering, the diffractive amplitude consists of two parts: $F(s,t)=F_+(s,t)+F_-(s,t)$, where $F_+(s,t)$ is the crossing even amplitude with charge conjugation quantum number $C=+1$ and $F_-(s, t)$ is the crossing odd amplitude with $C=-1$. The quark-quark, gluon-gluon interactions and quark-gluon interference term contribute to the crossing even amplitude $F_+(s, t)$ through the tensor glueball exchange and the contributions of the QCD Odderon exchange is responsible for the crossing odd amplitude $F_-(s, t)$. The total cross section $\sigma_{tot}(s)$, ratio of the real part to the imaginary part of the forward scattering amplitude $F(s, t=0)$, $\rho(s)$, and the nuclear slope parameter function $\beta(s)$, are normalized in such a way that[17]

$$\sigma_{tot.}=\frac{1}{s}\mathrm{Im}\,F(s,\ t=0)\ , \tag{2}$$

$$\rho(s)=\frac{\mathrm{Re}\,F(s,\ t=0)}{\mathrm{Im}\,F(s,\ t=0)} \tag{3}$$

$$\beta(s)=\frac{\mathrm{d}}{\mathrm{d}t}\left[\ln\frac{\mathrm{d}\sigma(s,\ t)}{\mathrm{d}t}\right]_{t=0}. \tag{4}$$

Where $\frac{\mathrm{d}\sigma(s,\ t)}{\mathrm{d}t}$ in Eq. (4) is the differential cross sections of the process under study, which is determined by $F(s, t)$ through normalization such that

$$\frac{\mathrm{d}\sigma(s,\ t)}{\mathrm{d}t}=\frac{1}{16\pi s^2}|F(s,\ t)|^2. \tag{5}$$

Eqs. (2)～(5) are the fundamental formulae of our present study. Clearly, Our task now is to figure out the amplitude $F(s, t)$. In the Glauber multiple scattering theory[22], the scattering amplitude for two body interaction is given by

$$F(q)=\frac{\mathrm{i}k}{2\pi}\int \mathrm{e}^{\mathrm{i}q\boldsymbol{b}}\left[1-\mathrm{e}^{\mathrm{i}\chi(s,\ \boldsymbol{b})}\right]\mathrm{d}^2\boldsymbol{b}$$

and $\chi(s, \boldsymbol{b})$ is eikonal profile function which is defined by

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

with $V(\sqrt{b^2+z^2})$ being interaction used, and $\boldsymbol{b}$ is the impact vector in colliding plane. Therefore, the amplitude $F(s, t)$ can be simply expressed by $\chi(s, \boldsymbol{b})$ via the series expansion of $\mathrm{e}^{\mathrm{i}\chi}$ in $\mathrm{i}\chi$. Then, calculating the amplitude $F(s, t)$ becomes a task to calculate the $\chi(s, \boldsymbol{b})$. In the QCD inspired eikonalized approximation the total profile function χ is a sum of the different contributions from quarkquark (χ_{qq}), gluon-gluon (χ_{gg}), and quark-gluon interference term (χ_{qg}) and the Odderon exchange term (χ_{odd}),

$$\begin{aligned}\chi(s,\ \boldsymbol{b})&=\chi_{even}(s,\ \boldsymbol{b})+\chi_{odd}(s,\ \boldsymbol{b})\\&=\chi_{qq}(s,\ \boldsymbol{b})+\chi_{gg}(s,\ \boldsymbol{b})+\\&\quad\chi_{qg}(s,\ \boldsymbol{b})+\chi_{odd}(s,\ \boldsymbol{b})\ ,\end{aligned} \tag{6}$$

where χ_{even} is responsible for the crossing even amplitude $F_+(s, t)$ and χ_{odd} corresponds to the crossing odd amplitude $F_-(s, t)$.

Let us now to apply Glauber formulism to the $\gamma\gamma$ elastic scattering at high energies. Assuming $\chi^{\gamma\gamma}$ is total profile function of photon-photon elastic scattering and each term $\chi_{ij}(s, \boldsymbol{b})$ in Eq. (6) can be expressed by a product of the corresponding total cross section $\sigma_{ij}(s)$ and the probability distribution function of partons (quarks and gluons) inside hadron $W(b, \mu_{ij})$, namely $\chi_{ij}=\sigma_{ij}(s)W(b, \mu_{ij})$. We then arrive at

$$\begin{aligned}\chi^{\gamma\gamma}_{even}&=\chi^{\gamma\gamma}_{qq}(s,\ b)+\chi^{\gamma\gamma}_{gg}(s,\ b)+\chi^{\gamma\gamma}_{qg}(s,\ b)\\&=\mathrm{i}\left[\frac{4}{9}\sigma_{qq}(s)W\left(b;\frac{3}{2}\mu_{qq}\right)+\frac{4}{9}\sigma_{gg}(s)\times\right.\\&\left.W\left(b;\frac{3}{2}\mu_{gg}\right)+\frac{4}{9}\sigma_{qg}(s)W\left(b;\frac{3}{2}\sqrt{\mu_{qq}\mu_{gg}}\right)\right]\ ,\end{aligned} \tag{7}$$

where σ_{ij}(s) is the related total cross section arose by exchanging the tensor glueball and

$$\begin{aligned}\chi^{\gamma\gamma}_{odd}&=\frac{4}{9}\sigma_{odd}(s)W\left(b;\frac{3}{2}\mu_{odd}\right)\\&=\frac{4}{9}C_{odd}\Sigma_{gg}\frac{m_0}{\sqrt{s}}W\left(b;\frac{3}{2}\mu_{odd}\right)\ ,\end{aligned} \tag{8}$$

here $\sigma_{odd}(s)$ is the total cross section arose by exchanging the Odderon. χ is a complex function $\chi(\boldsymbol{b},\ \mathrm{s})=\chi_R(\boldsymbol{b}, s)+\chi_I(\boldsymbol{b}, s)$ which depends on the energy s and impact parameter $\boldsymbol{b}$. According to the above discussions, the formulae $\sigma_{tot.}$(s), $\mathrm{d}\sigma/\mathrm{d}t$, ρ, β for $\gamma\gamma$ elastic scattering can be written down as

$$\begin{aligned}\sigma^{\gamma\gamma}_{tot.}(s)=4P^{\gamma\gamma}_{had}\int&\left[1-\mathrm{e}^{-\chi_I^{\gamma\gamma}(b,\ s)}\times\right.\\&\left.\cos\left(\chi_R^{\gamma\gamma}(b,\ s)\right)\right]\mathrm{d}^2\boldsymbol{b}\ ,\end{aligned} \tag{9}$$

$$\frac{\mathrm{d}\sigma^{\gamma\gamma}}{\mathrm{d}t}(s, t)=\frac{P_{\text{had}}^{\gamma\gamma}}{4\pi}\times \left|\int J_0(qb)\left[1-\mathrm{e}^{-\chi_{\mathrm{I}}(b, s)+\mathrm{i}\chi_{\mathrm{R}}(b, s)}\right]\mathrm{d}^2\boldsymbol{b}\right|^2, \quad (10)$$

$$\rho^{\gamma\gamma}(s)=\frac{\mathrm{Re}\left\{\mathrm{i}\int\left(1-\mathrm{e}^{-\chi_{\mathrm{I}}(b, s)+\mathrm{i}\chi_{\mathrm{R}}(b, s)}\right)\mathrm{d}^2\boldsymbol{b}\right\}}{\mathrm{Im}\left\{\mathrm{i}\int\left(1-\mathrm{e}^{-\chi_{\mathrm{I}}(b, s)+\mathrm{i}\chi_{\mathrm{R}}(b, s)}\right)\mathrm{d}^2\boldsymbol{b}\right\}}, \quad (11)$$

$$\beta^{\gamma\gamma}(s)=\frac{1}{2}\frac{\int\left[1-\mathrm{e}^{-\chi_{\mathrm{I}}(b, s)+\mathrm{i}\chi_{\mathrm{R}}(b, s)}\right]b^2\mathrm{d}^2\boldsymbol{b}}{\int\left[1-\mathrm{e}^{-\chi_{\mathrm{I}}(b, s)+\mathrm{i}\chi_{\mathrm{R}}(b, s)}\right]\mathrm{d}^2\boldsymbol{b}}, \quad (12)$$

where $P_{\text{had}}^{\gamma\gamma}=P_{\text{had}}^2$, and $P_{\text{had}}^{\gamma\gamma}$ in Eqs. (9), (10) is the probability that a real photon fluctuates into a quark-antiquark pair before it interacts with another photon-the partner in colliding.

The crossing even amplitude is not yet analytic. For large s the even amplitude $F_+(s, t)$ can be made analytic by the substitution $s\to s\mathrm{e}^{-\mathrm{i}\pi/2}$. Therefore, the contributions to total cross section from quark-quark, gluon-gluon, quark-gluon interference can be rewritten as

$$\sigma_{\mathrm{gg}}(s)=2\pi\left(\frac{\varepsilon}{\mu_{\mathrm{gg}}}\right)^2\left[\log^2\frac{s}{s_0}-\frac{\pi^2}{4}\right]- \mathrm{i}\pi^2\left(\frac{\varepsilon}{\mu_{\mathrm{gg}}}\right)^2\log^2\frac{s}{s_0}, \quad (13)$$

$$\sigma_{\mathrm{qq}}(s)=\Sigma_{\mathrm{gg}}\left[C+C_{\text{Regge}}^{\text{even}}\frac{m_0}{\sqrt{s}}\cos\left(\frac{\pi}{4}\right)\right]+ \mathrm{i}\Sigma_{\mathrm{gg}}C_{\text{Regge}}^{\text{even}}\frac{m_0}{\sqrt{s}}\sin\left(\frac{\pi}{4}\right), \quad (14)$$

$$\sigma_{\mathrm{qg}}(s)=\Sigma_{\mathrm{gg}}C_{\mathrm{qg}}^{\log}\log\left(\frac{s}{s_0}\right)-\mathrm{i}\Sigma_{\mathrm{gg}}C_{\mathrm{qg}}^{\log}\frac{\pi}{2}. \quad (15)$$

The crossing odd amplitude $F_-(s, t)$ is not yet analytic too. It can be made analytic in the same way as that for $F_+(s, t)$. Therefore,

$$\sigma_{\text{odd}}(s)=C_{\text{odd}}\Sigma_{\mathrm{gg}}\frac{m_0}{\sqrt{s}}\cos\left(\frac{\pi}{4}\right)+ \mathrm{i}C_{\text{odd}}\Sigma_{\mathrm{gg}}\frac{m_0}{\sqrt{s}}\sin\left(\frac{\pi}{4}\right). \quad (16)$$

The parameters in Eqs. (13)～(16) and their physical explanations are given in our previous publication[17] and listing in the following Table 1.

Table 1　The parameters used in our calculations to fit experimental data

Fixed	Fitted
$m_0=0.6$ GeV	$C=5.65\pm0.14$
$\varepsilon=0.3$	$C_{\mathrm{qg}}^{\log}=0.0167\pm0.0037$
$\mu_{\mathrm{qq}}=0.89$ GeV	$\Sigma_{\mathrm{gg}}=\frac{9\pi\alpha_s^2}{m_0^2}$
$\mu_{\mathrm{gg}}=0.73$ GeV	$C_{\text{Regge}}^{\text{even}}=25.3\pm2.0$
$\mu_{\text{odd}}=0.53$ GeV	$C_{\text{odd}}=-(7.62\pm0.28)$
$\alpha_s=0.5$	$s_0=1.0\ \mathrm{GeV}^2$

4　Theoretical prediction and comparison to experimental data

Using above related formulae with $P_{\text{had}}^{\gamma\gamma}$ given by Ref. [17] leads to our present numerical predictions of the physical observable quantities of $\gamma\gamma$ elastic scattering at high energies. Our theoretical results are shown in Figs. (3)～(6). Fig. 3 shows $s^{1/2}$-dependence of total cross section and the corresponding experimental data given by Ref. [23]

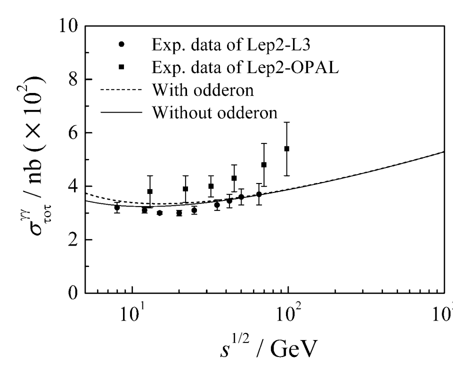

Fig. 3　$s^{1/2}$-dependence of total cross section section $\sigma_{\text{tot.}}$ of $\gamma\gamma$ elastic scattering at high energies. are given by Ref. [23].

with $s^{1/2}$ being c. m. energy of $\gamma\gamma$ system. As is seen, our theory reproduces the experimental data remarkably well for total cross section. The present predictions of differential cross section $\mathrm{d}\sigma(s, t)/\mathrm{d}t$, the ratio of the real part to imaginary part of forward scattering amplitude ρ and the nuclear slop parameter function β are respectively shown in Figs. 4～6. However, there are no any data (as our knowledge) at the present to test these theoretical predictions. We urgently need data to examine our theoretical predictions.

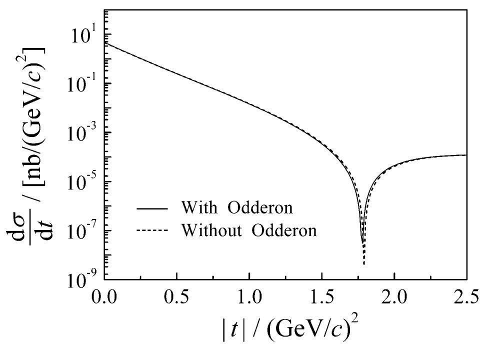

Fig. 4　$|t|$-dependence of differential cross of $\gamma\gamma$ elastic scattering at the energy . The data of $\sqrt{s}=80$ GeV.

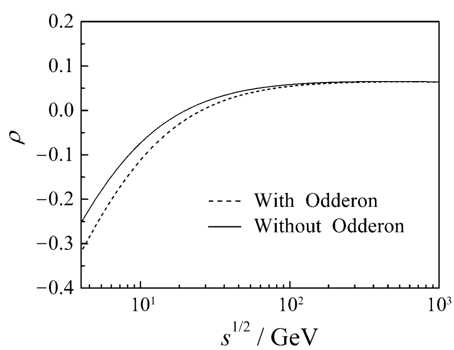

Fig. 5 $s^{1/2}$-dependence of the ratio of the real part to the imaginary part of forward scattering amplitude ρ for $\gamma\gamma$ elastic scattering at high energies.

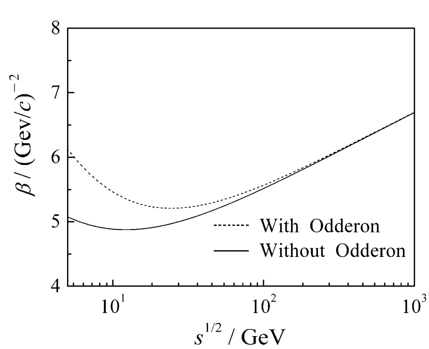

Fig. 6 $s^{1/2}$- dependence of slop parameter function β of $\gamma\gamma$ elastic scattering at high energies.

5 Summary and conclusions

Based on the generalized QCD vector meson dominance model proposed by us, the photon-photon elastic scattering at high energies has been investigated in the QCD inspired eikonalized approximation. Unlike the usual calculations of the $\gamma\gamma$ interaction in the Feynman box diagram technique, we explore the process in terms of QCD theory by which we claim the $\gamma\gamma$ elastic scattering proceeds exclusively through a strong interaction between two pairs of quark-antiquark fluctuated from the two scattering photons. Because the mediator of strong interaction is colorful gluon which has a property of self-interaction, the exchanging gluons can form colorless glueballs. The tensor glueball and Odderon could be the mediators of the interaction between the two colliding quark-antiquark pairs. This mechanism is of a complete QCD characteristics and is different from the other conventional theoretical descriptions. In particular, the contributions from virtual gluon, bound quark-antiquark to form a fluctuated meson, are taken into account.

We calculate the total cross section $\sigma_{tot.}(s)$, differential cross section $d\sigma(s, t)/dt$, ratio of the real part to imaginary part of the forward scattering amplitude $\rho(s)$ and nuclear slop parameter function $\beta(s)$ of $\gamma\gamma$ elastic scattering at high energies in the generalized QCD vector meson dominance model under the QCD inspired eikonalized approximation. Our numerical prediction for total cross section is consistent with the existing experimental data. Although we urgently need experimental data to examine our other theoretical predictions (ρ, β, $d\sigma/dt$), the good agreement of total cross section $\sigma_{tot.}(s)$ prediction with the experimental data within error bars of the data leads us to conclude that the generalized QCD vector meson dominance model in the QCD inspired eikonalized approximation has a strongly predictive power to photon-photon elastic scattering at high energies. We will apply the generalized QCD vector meson dominance model to other diffraction processes in our coming research work.

It should be emphasized that as is seen from the Figs. 3～4, the contribution from Odderon exchange to total cross section and differential cross section is negligible. The reason is that the Odderon exchange term is higher order term comparing to the tensor glueball exchange, and the Odderon also has charge conjugation $C=-1$ but tensor glueball has $C=+1$. Therefore, the Odderon contribution has been suppressed heavily since there is no quantum number C exchange in photon-photon elastic scattering.

Direct observation of elastic photon-photon scattering among real photons would be of great scientific importance. During the last decades, several suggestions on how to detect elastic photon-photon scattering have been proposed, but no suggestions, so far, have led to actual detection of photon-photon scattering among real photons. The measurement with sufficient accuracy must be very difficult since photon cannot be at rest but always at the speed of light. To detect photon-photon scattering, the related process would be some photon splitting processes.

Figs. 5～6 clearly show that in the energy region of $s^{1/2}$ smaller than 100 GeV, the Odderon exchange contribution play an important role in β and ρ. Therefore, measuring the β and ρ and comparing with the theoretical predictions may provide an opportunity to discover the new particle of Odderon and new physics.

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在具有 QCD 特征的程函近似和推广的 QCD 向量介子为主模型中光子-光子的相互作用

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摘要：基于推广的 QCD 向量介子为主的模型(QCD-VMD)和具有 QCD 特征的程函近似，研究了光子-光子的相互作用。与通常用费曼盒子图计算光子-光子的相互作用不同，采用 QCD 理论揭示了光子-光子的相互作用过程，认为光子-光子的弹性散射是通过两个散射的光子所涨落成的两个夸克-反夸克对之间的强相互作用而进行的。由于强相互作用的传播子是带色的胶子和胶子的自相互作用的性质，交换的胶子可以形成无色的胶子球，无色的张量胶子球(两个雷其化的胶子束缚态)和 Odderon(三个雷其化的胶子束缚态)，可以是两个夸克-反夸克对之间的作用的媒介子，这个机制非常不同于其他理论描述，特别是考虑了由虚胶子(束缚夸克和反夸克形成的涨落介子)的贡献。计算了总截面 $\sigma_{\rm tot}$，微分截面 $d\sigma/dt$，向前散射振幅实部与虚部的比率 ρ 和 $\gamma\gamma$ 弹性散射的核斜率参数函数 β。在实验误差的范围内，对总截面 $\sigma_{\rm tot}$ 的理论预言和实验数据是一致的，但急需 $d\sigma/dt$，ρ 和 β 的实验数据来检验本理论模型。

关键词：光子-光子相互作用；推广的 QCD 向量介子为主模型；具有 QCD 特征的程函近似

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