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Production of 0^{++}glueball from double diffractive process in high energy $p + p(\bar{p})$ collision

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Abstract. Motivated by the recent experiments about candidates for glueball from different processes, we discuss in this paper the production of 0^{++} glueball from double diffractive scattering at momentum transfer $|t| \lesssim 1 GeV^2$ in high energy $p + p(\bar{p})$ collision. We employ the phenomenology of Pomeron ($I\!P$) of Donnachie-Landshoff, the field theory model of $I\!P$ of Landshoff-Nachtmann and the relevant calculating approach. We assume while $I\!P$ coupling with glueball, the 0^{++} glueball can be considered as a bound state of two non-perturbative massive gluons. We evaluate the dependence of cross section for 0^{++} glueball production on system energy $\sqrt{s}$ and show that it could be tested experimentally.

1 Introduction

Since the color $SU(3)$ gauge theory is possessed of self-coupling character between gluon fields, it had been predicted long before the quantum chromodynamics (QCD) became the basic framework of strong interaction, that there would exist in hadronic spectroscope states which are formed from pure gluon field–glueball [1]. Though now there are still few strict theoretical proof and conclusive experimental evidence to confirm its existence, recently there are a lot of reports analysing relevant experimental data showing that several candidates of glueball and/or states in which glueball mixing with quark pair have been observed experimentally [2]. It is widely believed that glueballs should easily be produced in processes which abound of gluon constituent, thus experimentalists concentrate their attention to seek glueballs on $p\bar{p}$ annihilation [3], J/ψ radiative decay [4], and high energy central $h-h$ collisions [5]. Glueball production from J/ψ radiative decay has been analyzed in a model independent manner by Close *et.al.* [6], yet there has not been any analysis in central $h-h$ collision and in $p\bar{p}$ annihilation.

In high energy central $h-h$ collisions the increase of the cross section with increasing center of mass energy [7] is consistent with the double pomeron exchange (DPE) machanism, which was predicted to be a rich source of gluonic states [8]. A large glueball production cross section in the central region is predicted by Gershtein and Logunov [9], they related the rise of total cross section with increasing energy to the exchange of glueballs in the $t-$channel or to the collising of the soft gluon seas of the interacting particles. These observations show that glueball production in high energy $h-h$ central collisions would be intimately connected with the non-perturbative mechanism.

In this paper, we discuss the glueball production from double diffractive scattering in high energy $p + p(\bar{p})$ collisions,

$$p + p(\bar{p}) \to p + p(\bar{p}) + G. \tag{1}$$

As a first attempt, we consider $J^{PC} = 0^{++}$ glueball only.

Our approach is on the basis of the phenomenology of $I\!P$ from Donnachie-Landshoff [10], the field theory model of $I\!P$ from Landshoff-Nachtmann [11]. Based on the approach above, a more refined and sophisticated model of diffractive scattering had been proposed by Cudell and Hernandez [12], concentrating on Higgs diffractive production in pp collision $p + p \to p + p + H$, they obtained a result close to that of Bialas and Landshoff [13] using the L-N model of DPE.

Since the glueballs are produced through DPE, it is believed that they are to be found mainly in the central region of final state rapidity distribution and with large symmertry rapidity gaps from each of the final diffractive protons (or antiprotons) which are characteristic of DPE processes. In principle, it could be easily detected and distinguished from all other strong backgrounds. We will come back to this point in last section.

As for how to link L-N field theory of $I\!P$ with the phenomenology of Regge behaviour, we follow the approach of Bialas and Landshoff [13]. Since the information of coulping of 0^{++} glueball with nonperturbative gluon coupling is very scarce, we adopt the color singlet approximation [14], which is always used in heavy qurak physics. Under this approximation the coupling structure is $Bg^{\alpha\beta}\delta_{eh}$, where α, β and e, h are the Lorentz and color indexes of the two non-perturbative gluons respectively, the parameter B can be estimated from the branching ratio of J/ψ radiative decay to 0^{++} glueball.

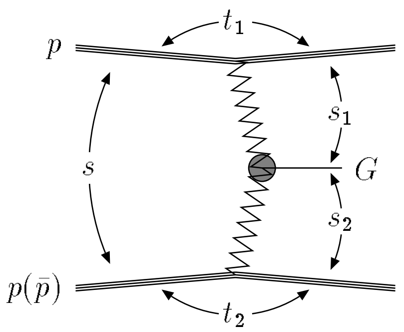

Fig. 1. Sketch diagram for (1) via DPE

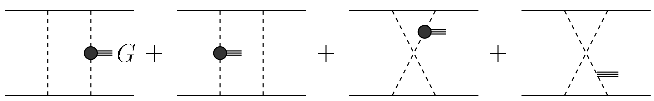

Fig. 2. G production in $q-q(\bar{q})$ scattering via DPE, dotted lines are non-perturbative gluon of IP

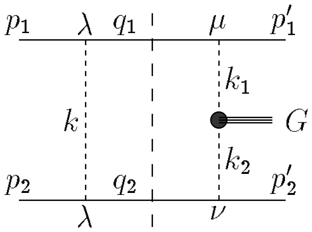

Fig. 3. $s-$channel discontinuity of the first diagram in Fig. 2. q_1, q_2 lines are limited on their mass shell

The outline of the paper is as follows. We describe in detail our calculating scheme in Sect. 2. In Sect. 3, we give the formalism and derive the coupling constant B of the two nonperturbative gluons with 0^{++} glueball. Results and some related discussions are given in last Sect. 4.

2 Calculating scheme

In phenomenology of IP given by Donnachie-Landshoff [10], the nucleon is to be treated as a bound state composed of three clusters, they are formed from non-perturbative QCD effects and their size are much smaller than nucleon radius. The core of each cluster is a valence quark, surrounded by sea quarks and gluons. Furthermore D-L have demonstrated that in coupling with nucleon, the IP behaves,to a good approximation, like a isoscalar (C= + 1) photon. So it means that the coupling of IP with a nucleon is actually that of IP with the three clusters (constituent quark) in an incoherent manner. In this IP model one does not need to consider the interaction of IP with any other parton (sea quark or gluons) in the nucleon. With this model Donnachie and Landshoff have successfully explained a lot of experimental effects in high energy soft strong interaction processes [15].

In discussing glueball production from DPE, we adopt the same point of view: we should not start such a problem from parton model and perturbative QCD at all, but instead from non-perturbative QCD and assume the glueball to be a bound state of two small flavorless clusters (or "constituent" gluons) which are formed from gluons by non-perturbative QCD effects, and are massive. As in the case of the nucleon, we assume the coupling of IP with glueball is actually that of IP with these "constituent" gluons, and we do not need to consider the interaction of IP with any other massless gluons in the glueball.

In view of the available data for elastic diffractive scattering and the feasiblity of D-L IP model in high energy h-h collisions, we restricted the momentum transfer of scattered proton (antiproton) to to be small,$e.g$ $|t_i|\lesssim 1.0GeV^2$. The whole process is sketched in Fig. 1.

From Regge pole theory [16] and IP model of D-L, when $m_N^2 \ll s_1$, $s_2 \ll s$, and $|t_i|\lesssim 1GeV^2$, the asymptotic form of the amplitude for Fig. 1 is

$$(\frac{s}{s_2})^{\alpha_{IP}(t_1)-1}(\frac{s}{s_1})^{\alpha_{IP}(t_2)-1}F^{(G)}$$

$$\times(\alpha_{IP}(t_1),\alpha_{IP}(t_2),z)F_1(t_1)F_1(t_2)\gamma_\lambda\otimes\gamma^\lambda \quad (2)$$

where $t_i=(p_i-p_i')^2$, $z=\frac{s_1s_2}{sm^2}$, and m is the 0^{++} glueball mass, $\alpha_{IP}(t)$ is Regge pole trajectory of IP. From data analysis [10] when $|t|$ is small, $\alpha_{IP}(t)\approx\alpha_{IP}(0)+\alpha_{IP}'t = 1.086+0.25GeV^{-2}t.F_1(t)$ is the Dirac form factor of proton. The direct product of gamma matrix shows that the external proton lines will be traced when we calculate the cross section.

Since the diffractive scattering condition requires

$$\frac{s_1}{s},\ \frac{s_2}{s}<\delta \quad (3)$$

it is usually assumed $\delta=0.1$, hence in the asymptotic form (2) one could neglect lower powers of $(\frac{s}{s_1})$ and $(\frac{s}{s_2})$. $F^{(G)}(\alpha_{IP}(t_1),\alpha_{IP}(t_2),z)$ is the $IP-IP-G$ vertex function, its general structure is known [17], but its concrete form needs further consideration.

Since IP-nucleon coupling should be considered as pomeron incoherently coupled with three constituent quarks, and according to field theory model, the IP exchange is just the exchange of two non-perturbative gluons [11,18], thus Fig. 1 can be shown in detail as Fig. 2.

In the field theory model of pomeron, the $IP-IP-G$ vertex function $F^{(G)}(\alpha_{IP}(t_1),\alpha_{IP}(t_2),$ $z)$ for $|t_i|\lesssim 1.0GeV^2$ can be calculated by the sum of Feynman amplitudes of Fig. 2 which demonstrated in [13] is equal to the $s-$channel discontinuity of the first diagram, which is shown in Fig. 3. This simplify our calculation greatly. The black blob in Fig. 3 is the vertex function of 0^{++} glueball with gluons of IP which will be discussed in next section.

In the following we first derive the forward diffractive scattering amplitude for (1) in L-N field theory model of IP, then identify it with the corresponding Regge behaviour formula (2) at $t_i=0$ to obtain the normalized value of $IP-IP-$ glueball vertex function $F^{(G)}(\alpha_{IP}(t_1),$ $\alpha_{IP}(t_2),z)|_{t_1=t_2=0}$ [1]. After this we extend $F^{(G)}(\alpha_{IP}(t_1),$

[1] Since in D-L model, $\alpha_{IP}(t)|_{t=0}\equiv 1+\varepsilon\approx 1.086$, so it seems having some inconsistent with this identification, which has

$\alpha_{IP}(t_2), z)|_{t_1=t_2=0}$ to $|t_i| \neq 0$ case, discuss DPE production of glueball using (2).

3 Formalism and coupling constant B

It is very convenient to use the Sudakov variables to calculate the loop integral of Fig. 3:

$$\begin{aligned} k &= \frac{\bar{x}p_1}{s} + \frac{\bar{y}p_2}{s} + v \\ p_1' &= x_1 p_1 + \frac{\bar{y}_1 p_2}{s} + v_1 \\ p_2' &= \frac{\bar{x}_2 p_1}{s} + y_2 p_2 + v_2 \end{aligned} \quad (4)$$

Where we have put the light quark mass equal zero. the vectors v, v_1, and v_2 are transverse to p_1 and p_2, so they effectually are two dimensional, $v^2 = -\mathbf{v^2}, v_i^2 = -\mathbf{v}_i^2$. Then

$$\begin{aligned} t_1 &= (p_1 - p_1')^2 = -\mathbf{v}_1^2/x_1 \\ t_2 &= (p_2 - p_2')^2 = -\mathbf{v}_2^2/y_2 \\ s_1 &\sim s(1-y_2) \\ s_2 &\sim s(1-x_1) \end{aligned} \quad (5)$$

As mentioned above, we first need the $s-$ channel discontinuity of Fig. 3 at $t_1 \approx t_2 \approx 0$, so we set $v_1 \approx v_2 \approx 0$, then

$$\begin{aligned} \int d^4k\delta(q_1^2)\delta(q_2^2) &\sim \frac{1}{2s}\int d\bar{x}d\bar{y}d^2\mathbf{v}\delta(\bar{y}-\mathbf{v}^2)\delta(-\bar{x}-\mathbf{v}^2), \\ \int d^4p_1'\delta({p_1'}^2) &\sim \frac{1}{2}\int dx_1 d\bar{y}_1\delta(x_1\bar{y}_1)d^2\mathbf{v}_1, \\ \int d^4p_2'\delta({p_2'}^2) &\sim \frac{1}{2}\int d\bar{x}_2 dy_2\delta(\bar{x}_2 y_2)d^2\mathbf{v}_2. \end{aligned} \quad (6)$$

We explain how we can get the direct product gamma matrices form $\gamma_\lambda \otimes \gamma^\lambda$ as (2) from Fig. 3. The upper quark line in Fig. 3 has matrices $\gamma^\mu\gamma\cdot q_1\gamma_\lambda$, for large s its asymptotic form equivalent to

$$2q_1^\mu\gamma^\lambda, \quad (7)$$

because in calculating the differential cross section, we also need to multiply $\gamma\cdot p_1$ on the left and $\gamma\cdot p_1'$ on the right of this expression. When these are included, the difference between (7) and the original expression gives contribution to cross section that is of order δ. Similarly, from the lower quark line we obtain $2q_2^\nu\gamma_\lambda$.

Now from Fig. 3, the amplitude of $q-q(\bar{q})$ diffractive scattering through DPE at $t_1=t_2=0$ is

$$M^{(G)}\gamma^\lambda\otimes\gamma^\lambda,$$
$$M^{(G)} = \frac{ig^6}{2\pi^2 s}\int d^2vW^{(G)}D(-\mathbf{v}^2)D(-x_1\mathbf{v}^2)D(-y_2\mathbf{v}^2), \quad (8)$$

explained in [13]. Furthermore, this problem has studied by Ross [19] who using a hybrid model in which one uses PQCD to treat interactions between gluons, but takes a L-N type non-perturbative propagator for the gluon. In the leading logarithm approximation, by summing a dominant subset of diagrams, the phenomenology required Regge behaviour is obtained

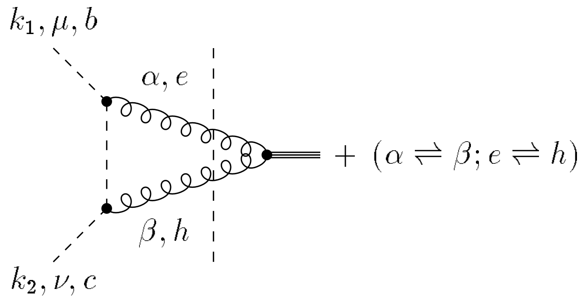

Fig. 4. Vertex of glueball and gluons of IP. Vertical dashed line limit cutting lines on mass shell

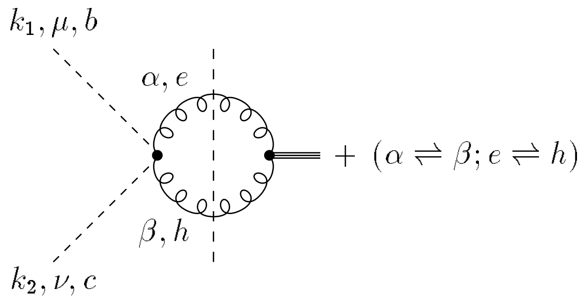

Fig. 5. The same as Fig. 4, but for four gluons vertex

where $D(q^2)$ is non-perturbative gluon propagator of IP, g is the coupling constant between non-perturbative gluon with quark,

$$g^2D(q^2) = -A\ exp(\frac{q^2}{\mu^2}), \quad (9)$$

where $\mu = 1.1GeV$, $A^2\mu^2 = 72\pi\beta^2$,$\beta^2 = 3.93GeV^{-2}$ is $IP-$nucleon coupling constant in the pomeron D-L model [20].

Using the approximation matrix form (7), we get from Fig. 3, the $W^{(G)}$ in (8),

$$W^{(G)} = q_1^\mu A_{\mu\nu}^{(G)} q_2^\nu, \quad (10)$$

where vertex function $A_{\mu\nu}^{(G)}$ connecting the gluons of IP with 0^{++} glueball. The simplest diagrams for this vertex function shown in Fig. 4 and Fig. 5.

In deriving these vertex functions, for calculating simplicity but not necessary we have used color singlet model approximation [14] for the vertex, which requires gluon lines cut by vertical dashed line in these figures are limited on mass shell. Thus from Fig. 4 we get

$$\begin{aligned} A_{\mu\nu,bc}^{G_3} &= 2BF_{\mu\alpha\lambda}(k_1, -\frac{1}{2}P, q)D(q^2)g^{\alpha\beta}F_{\beta\nu\rho} \\ &\times(-\frac{1}{2}P, k_2, -q)g^{\rho\lambda}\cdot f_{beg}f_{hcg}\cdot\delta_{eh}, \end{aligned} \quad (11)$$

where

$$\begin{aligned} F_{\mu_1\mu_2\mu_3}(r_1, r_2, r_3) &= (r_1-r_2)_{\mu_3}g_{\mu_1\mu_2} + (r_2-r_3)_{\mu_1}g_{\mu_2\mu_3} \\ &+(r_3-r_1)_{\mu_2}g_{\mu_3\mu_1} \\ r_1+r_2+r_3 &= 0. \end{aligned} \quad (12)$$

From Fig. 5 we get

$$A^{G_4}_{\mu\nu,bc} = -12Bg_{\mu\nu}f_{beg}f_{hcg}\delta_{eh}. \tag{13}$$

From (10) to (13) we get

$$\begin{aligned}
W^{G_3} &= \frac{-B\ D(q^2)}{4s^2}\cdot(5m^2s^3+10m^2s^2\mathbf{v}^2+16m^2s\mathbf{v}^4\\
&\quad +15s^3\mathbf{v}^2x_1+15s^3\mathbf{v}^2y_2-10s^3\mathbf{v}^2+6s^2\mathbf{v}^4x_1\\
&\quad +6s^2\mathbf{v}^4y_2+4s^2\mathbf{v}^4+12s\mathbf{v}^6x_1+12s\mathbf{v}^6y_2+24\mathbf{v}^8)\\
q^2 &= \frac{-1}{4s}(m^2s+2s\mathbf{v}^2x_1+2s\mathbf{v}^2y_2+4\mathbf{v}^4)\\
W^{G_4} &= -12B(\frac{1}{2}s+\frac{\mathbf{v}^4}{s})\\
W^{(G)} &= W^{G_3}+W^{G_4}
\end{aligned} \tag{14}$$

From (8), (9), (14), we get $M^{(G)}$, for Fig. 3, which is $F^{(G)}(\alpha_{IP}(t_1),\alpha_{IP}(t_2),z)|_{t_1=t_2=0}$ as we explained in Sect. 2.

For t_1, $t_2 \neq 0$, the general structure of $F(\alpha_{IP}(t_1),\alpha_{IP}(t_2),z)$ can be analyzed from Regge theory and this has been done by Drummond *et. al.* [17]. They have shown that when $|t_1|$, $|t_2|$ are small, $F(\alpha_{IP}(t_1),\alpha_{IP}(t_2),z)$ is an analytic function, it is finite for any z and varies slowly with t_1, t_2. Since in our process, $s \gg s_1, s_2 \gg m_N^2$, we can see from (2) the most important and sensitive factors varing on t_1, t_2 are $\frac{s}{s_1}^{\alpha_{IP}(t_2)-1}$ and $\frac{s}{s_2}^{\alpha_{IP}(t_1)-1}$, in a good approximation, $F(\alpha_{IP}(t_1),\alpha_{IP}(t_2), z)$ can be replaced safely by its value at $t_1=t_2=0$, then we have:

$$\begin{aligned}
&F(\alpha_{IP}(t_1),\alpha_{IP}(t_2),z)|_{|t_1|,|t_2|\leq 1GeV^2}\\
&\quad \simeq F(\alpha_{IP}(t_1),\alpha_{IP}(t_2),z)|_{t_1=t_2=0} = M^{(G)}
\end{aligned} \tag{15}$$

Thus the amplitude $T^{(G)}$ for glueball production in $p-p(\bar{p})$ high energy double diffractive scattering from D-L and L-N *IP* model and formalism, in a good approximation, can be expressed as

$$\begin{aligned}
&T^{(G)}\\
&= 9M^{(G)}(\frac{s}{s_2})^{\alpha_{IP}(t_1)-1}(\frac{s}{s_1})^{\alpha_{IP}(t_2)-1}F_1(t_1)F_1(t_2)\gamma_\lambda\otimes\gamma^\lambda.
\end{aligned} \tag{16}$$

where factor 9 comes from 3 quarks in nucleon, $F_1(t)$ is the Dirac form factor of proton, we use the exponential approximation for $F_1(t)$ at small $|t|$ that is $F_1(t)\simeq e^{\lambda t}$, $\lambda \simeq 2GeV^2$, thus the cross section is

$$\begin{aligned}
\sigma^{(G)} &= \frac{F_c^G}{2(2\pi)^5}(\frac{s}{m^2})^{2\varepsilon}\int\frac{dx_1}{x_1}\frac{dy_2}{y_2}|\ M^{(G)}\ |^2\delta\big((1-x_1)\\
&\quad \times(1-y_2)-\frac{m^2}{s}\big)\cdot\int d^2v_1d^2v_2(1-x_1)^{2\alpha'\mathbf{v}_1^2/x_1}\\
&\quad (1-y_2)^{2\alpha'\mathbf{v}_2^2/y_2}\cdot e^{-2\lambda(\mathbf{v}_1^2/x_1+\mathbf{v}_2^2/y_2)}
\end{aligned} \tag{17}$$

where $F_c^G = \frac{4}{9}$ is the color factor.

Let us now consider the coupling constant B of constituent gluons with 0^{++} glueball, which could be fixed by radiative decay mode $J/\psi \to \gamma + f_0(1500)$ as shown in Fig. 6[2], where

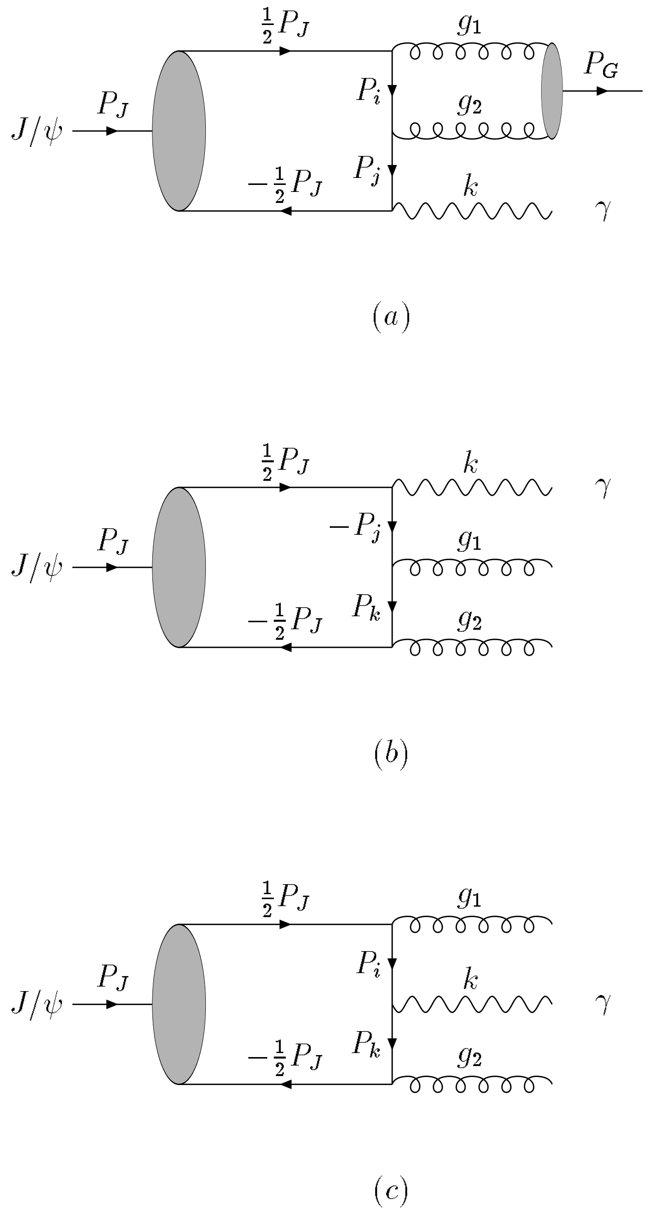

Fig. 6. Glueball production in radiative decay of J/ψ

$$\begin{aligned}
p_i &= \frac{1}{2}(p_J - p_G)\\
p_j &= k - \frac{1}{2}p_J\\
p_k &= \frac{1}{2}(p_G - p_J)\\
g_1 &= g_2 = \frac{1}{2}p_G
\end{aligned} \tag{18}$$

[2] Close argue in [21] that the scalar $f_0(1500)$ may be a glueball$-q\bar{q}$ mixture, here for simplicity we assume it is a pure glueball

It is well know that the J/ψ is dominatly an S- wave state and the non – relativistic quark potential model is very successful in describing the static properties of the J/ψ. The inclusice processes of heavy quarkonium decay to light hadrons are accessible to PQCD [22]. For heavy-quarkonium, the annihilation time $\sim \frac{1}{m_Q}$ is much smaller than the time that scales the $Q\bar{Q}$ binding effect. Hence the short – distance annihilation of the $Q\bar{Q}$ pair can be separated from the long- distance effect of $Q\bar{Q}$ binding. In the case of $J/\psi \to \gamma + G$, the long- distance effects of $Q\bar{Q}$ and gg binding can be separated from the hard subprocess. The gg binding effect is included in the non-perturbative coupling constant B of constituent gluons with the 0^{++} glueball.

Using the color singlet model approximation [14] for J/ψ vertex as usual, we get the amplitude of $J/\psi \to \gamma + f_0$

$$M^J = 2A_0 e_q g_G^2 B(M^{(a)}_{\mu\nu\rho} + M^{(b)}_{\mu\nu\rho} + M^{(c)}_{\mu\nu\rho}) g^{\rho\nu} \varepsilon_\mu(\gamma) \quad (19)$$

where $\epsilon^\mu(k)$ is the polarization vector of photon, $e_q = \frac{2}{3}e$ is the charge of charm quark, coefficient A_0 fixed from $\Gamma_{J\to e^+e^-}$:

$$A_0^2 e_q^2 = \frac{\Gamma_{J\to e^+e^-} m_J}{2\alpha} \quad (20)$$

and

$$M^{(a)}_{\mu\nu\rho} = \frac{1}{\sqrt{2}} Tr[\gamma\cdot\epsilon_J(\frac{1}{2}\gamma\cdot p_J + m_c) \times\gamma_\mu \frac{\gamma\cdot p_j + m_c}{p_j^2 - m_c^2}\gamma_\nu \frac{\gamma\cdot p_i + m_c}{p_i^2 - m_c^2}\gamma_\rho]$$

$$M^{(b)}_{\mu\nu\rho} = \frac{1}{\sqrt{2}} Tr[\gamma\cdot\epsilon_J(\frac{1}{2}\gamma\cdot p_J + m_c) \times\gamma_\nu \frac{\gamma\cdot p_k + m_c}{p_k^2 - m_c^2}\gamma_\rho \frac{-\gamma\cdot p_j + m_c}{p_j^2 - m_c^2}\gamma_\mu]$$

$$M^{(c)}_{\mu\nu\rho} = \frac{1}{\sqrt{2}} Tr[\gamma\cdot\epsilon_J(\frac{1}{2}\gamma\cdot p_J + m_c) \times\gamma_\nu \frac{\gamma\cdot p_k + m_c}{p_k^2 - m_c^2}\gamma_\mu \frac{\gamma\cdot p_i + m_c}{p_i^2 - m_c^2}\gamma_\rho] \quad (21)$$

Substitute (21) into (19), after sum and average over initial states and final states respectively, we get

$$\bar{\bar{\sum}} |M^J|^2 = \frac{2}{3} A_0^2 B^2 e_q^2 g_G^4 \frac{1024(m^6 - m_j^2 m^4 + 11m^2 m_j^4 + m_J^6)}{m_J^4 (m_J^2 - m^2)^2}, \quad (22)$$

then decay width of $J/\psi \to \gamma + f_0$ is

$$\Gamma_{J\to\gamma+f_0} = \frac{m_J^2 - m^2}{16\pi m_J^3} F_c^J \bar{\bar{\sum}} |M^J|^2, \quad (23)$$

where color factor $F_c^J = \frac{2}{3}$.

Combining (20), (22), and (23) together, we obtain

$$B^2 = \frac{\Gamma_{J\to\gamma+f_0}}{\Gamma_{J\to e^+e^-}} \frac{9\pi\alpha m_J^6 (m_J^2 - m^2)}{128 g_G^4 (m_J^6 + 11 m_J^4 m^2 - m_J^2 m^4 + m^6)}. \quad (24)$$

The decay widths $\Gamma_{J\to e^+e^-}$ and $\Gamma_{J\to\gamma+f_0}$ can be found in [23],$\frac{\Gamma_{J\to\gamma+f_0}}{\Gamma_{J\to e^+e^-}} = \frac{8.2\times10^{-4}}{6.02\times10^{-2}}$, so when g_G and m are fixed, one gets coupling constant B. For $\frac{g_G^2}{4\pi} = \frac{12\pi}{50ln[m_J/\Lambda]}, \Lambda = 0.20GeV, m = 1.5GeV$, we have $B^2 = 3.8\times10^{-6}GeV^2$.

4 Results and discussions

We first give some brief comments on the parameters used in our paper.

1. 0^{++} glueball mass m.
   From several models (*e.g.* lattice QCD, bag model, potential model, and QCD sum rule) analysis, the lowest state mass of 0^{++} all are fixed at $1.5 \sim 1.7GeV$ [21]. Experimentally, relevant data also manifest a clear signal of 0^{++} resonance state at about $1.5GeV$ in the central region of high energy $p-p$ collision, thus we let $m = 1.5GeV$.
2. Nonperturbative coupling constant g.
   In the Abelian gluon theory of Landshoff and Nachtmann, the nonperturbative gluon only couples to quark, thus $g^2 D(q^2)$ always appear together and can be normalised by the constant A in (9), the nonperturbative constant g does not enter the calculation of LN model[3]. But in non-Abelian case, especially including gluon self-interactions, as showed in Fig. 4 and Fig. 5, g connot be all absorbed by normalized condition (9), so g enters indeed into our the calculation. Unfortunately our knowledge for the non-perturbative coupling constant g is very poor now, in order to get a sensible answer for the gluon structure function at small x [24] $\alpha_n = \frac{g^2}{4\pi}$ of order one is needed, here we take the value $\alpha_n = \frac{g^2}{4\pi} \sim 0.7$.

Putting these parameters into (17), the double diffractive production cross section of (1) for $\sqrt{s}$ from 20GeV to 2×10^4 GeV, where $|t_1|$, $|t_2| \lesssim 1GeV^2, \delta = 0.1$ are evaluated, as shown in Fig. 7. We see for $\sqrt{s} = 23.7GeV, 29Gev$, $630GeV(SppS)$ and 1.8 TeV (Tevatron) energies, the double diffractive production cross sections are $1.6\times10^2 nb$, $2.5\times10^2 nb, 2.8\mu b$ and $4.6\mu b$ respectively. In the Joint CERN-IHEP experiment in $300GeV$ central $\pi^- N$ collisions ($\sqrt{s} = 23.7GeV$),the production cross section in the range $0 < x_F < 0.3$ (the experiment setup lead to the acceptance is zero for $x_F < 0$,) is $0.2\pm0.1\mu b$. Taking account of the addtive quark rule, this corresponds to 0.4–1.4μb in $P - P(\bar{P})$ central collisions at the same center-of-mass energy in the range $-0.3 < x_F < 0.3$. Since $f(1500)$ is produced dominately at small $|t|$ [7,25], our results are reasonble.

We have restricted ourseleves to calculate elastic diffractive production process. It is easily extend to

[3] Even in processes which are absent for gluon selfinteractions, may meet the same troubles. For example, in discussiong the diffractive Higgs production process $p+p \to p+p+H$, only after supposing implicitely that coupling constant between top quark with IP equals to that of u, d quark with IP, then constant $g$can be all absorbed in (9)

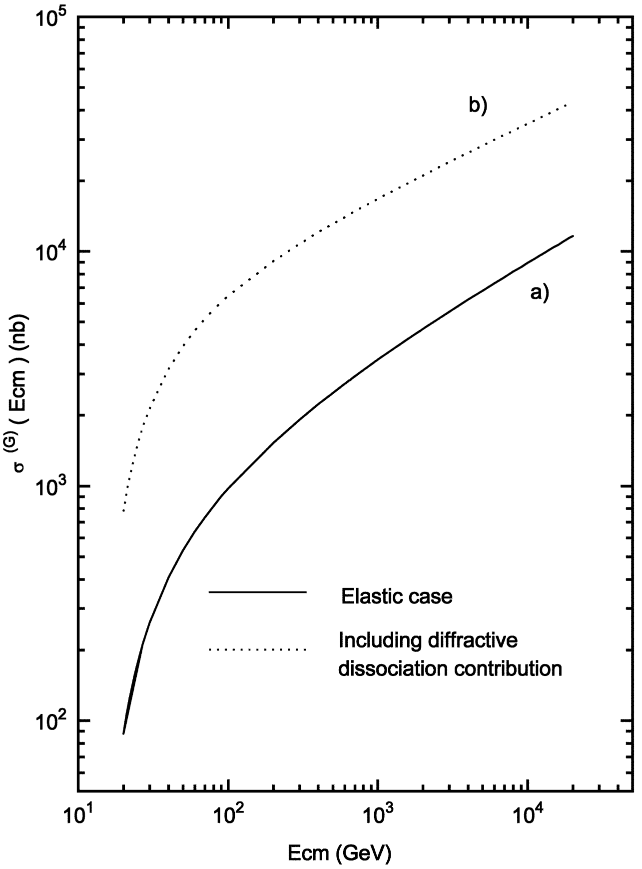

Fig. 7. Production cross section of 0^{++} glueball in double diffractive $P - P(\bar{P})$ collision. **a** Elastic case, **b** Including the diffractive dissociation contribution

diffractive dissociation processes by removing the form factor $F_1(t_i)(i = 1, 2)$ in (2) and thereafter, the resulting cross sections are also show in Fig. 7. We can see that as center of mass energies increased the ratio of the cross section of diffractive dissociation to that of elastic one is reduced from 6 at $\sqrt{s} = 23$GeV to 3 at $\sqrt{s} = 20$Tev.

Throughout the calculation we work in Feynman gauge. If one were to work in another gauge, the function $D(q^2)$ must be substantially modified to ensure that physical observables are gauge independent.

In connection with the problem of experimentally detecting the process (1), we make following discussions:

1. Since glueballs in process (1) are produced through DPE in high energy $p - p(\bar{p})$ collision, they should be found mainly in the central region of rapidity distribution of final particles, there will be a large symmetry rapidity gaps from each of the final proton (antiproton) direction. However the final state interactions *i.e.* soft color interactions between pre-glueball and outgoing pro-nucleons, may decrease the gap rate. The estimated gap survival rate is 10^{-2} at Fermilab Tevatron [26]. Furthermore, the produced glueball is a light object ($m_G \sim 1.5GeV$), they will be produced in a broad rapidity range, for example, at Tevatron those glueballs are in the rapidity region of $-5.9 < \eta < 5.9$.
2. We take the D-L IP model and DPE process to discuss glueball production process at small $|t|$, like all other high energy diffractive processes discussed using the same model, the common remarkable character and parameter-independent property are the energy dependence of total cross sections which are proportional to $s^{2(\alpha_{IP}(0)-1)}$. So the cross section in this model always increases slowly with the increase of the center of mass energy. We can use this point together with the large rapidity gap signal to distinguish this production mechanism of glueball from others, especially from gluon - gluon fusion mechanism in parton model, since the production cross section might decrease rapidly as energy increases in the later case.

In conclusion, using the field theroy model of pomeron exchange and the color singlet approximation of glueball, we obtain a parameter-free prediction of the cross section of 0^{++} glueball production in diffractive process, when combine it with the experiment measurable quanties such as $\sigma(hh \to hhG) \cdot BR(G \to h1 + h2 + \cdots)$ we can get the important quantities $BR(G \to h1 + h2 + \cdots)$, saying $BR(G \to K\bar{K})$, on the other hand, if we know $BR(G \to h1 + h2 + \cdots)$ then glueball production *via* DPE process can be a test on the approach we used.

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