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$J/\psi + \gamma$ Production of Double Diffractive Dissociation Process in $p + p(\bar{p})$ Collision and the Pomeron Model of Donnachie-Landshoff

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Abstract

Using double pomeron exchange mechanism, we have studied diffractive dissociation process $p+p(\bar{p}) \to X_p + X_{p(\bar{p})} + J/\psi + \gamma$ at high energy and have shown that these processes can be effectively used to test the pomeron structure model proposed by Donnachie and Landshoff.

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1 Introduction

Early in 1960's physicists already well realized that in high energy strong interactions the Regge trajectory with vacuum quantum number, pomeron (IP), plays a particular and very important role for soft processes, such as energy dependence of $\sigma_{tot}(s)$ in h-h and h-l collisions, the behavior of elastic differential cross section $\frac{d\sigma}{dt}$ at small $|t|$, the single and double diffractive dissociation processes, etc.[1]. However no one at that time understood what pomeron is. Since 1970's physicists have tried to study the nature of pomeron in the framework of QCD. The popular conjecture is to consider the pomeron as a non-perturbative multi-gluon system [2], however no any real understanding has been obtained yet. In recent years, on the other hand, the groups at CERN have reported about the clear observations of the hard diffractive scattering phenomena in high energy $p + p$ collisions: UA8 Collab. has discovered high P_T-jets in diffractively produced high mass systems [3], while UA1 Collab. has observed the diffractive production of bottom mesons [4]. These typical hard diffractive events manifest in themselves that a pomeron was radiated from the quasi-elastically forward scattered proton (anti-proton) and a hard parton level scattering occurred in IP-p (IP-$\bar{p}$) collisions. These observations compelled physicists to try to explain the reaction mechanism, and the issue of the parton structure of pomeron arose.

So far there exist two approaches for elucidating parton structure of pomeron .One is the model proposed by Ingelman and Schlein (I-S), which followed directly from early traditional conjectures and suggested that the pomeron is mainly composed of gluons [5]. In hard diffractive scattering events, it is assumed in I-S model that the pomeron behaves essentially as a hadron and the concept of pomeron structure function is introduced. In addition it is assumed that the gluon distribution in the pomeron satisfies a momentum sum rule. Fritzsch and Streng followed this line and even assumed that in small x region the behavior of this gluon distribution may be the same as that in the nucleon [6]. The other model was proposed by Donnachie and Landshoff (D-L) based on analyzing a lot of high energy soft processes, especially considering the additive quark rule for total cross section and the construction of field theory model about the pomeron [7]. They argued that phenomenologically the pomeron, as a non-perturbative multi-gluon system, was rather like an isoscalar (C=+1) photon when coupling to a quark or anti-quark. They have emphasized that, like a photon, the pomeron structure function consists of two pieces: one resembles that of a hadron (hadron-like part) and may be dominated by mesons with vacuum quantum number (e.g. f meson etc.) ; the other part (point-like part) is peculiar to the pomeron, which is the same as that of a photon. In the lowest order QCD the form of the point-like part can be calculated from a box diagram. In addition, since the pomeron is not an on-shell particle, no momentum sum rule for its parton distribution is asserted in D-L model.

The feasibility of experimentally testing these models has been discussed by using deep inelastic scattering processes. Since gluon has no coupling with photon, the difference between two models is rather small and one could hardly draw any clear-cut conclusion to show which model is based on correct mechanism [7].

In this paper we want to point out that an important difference between these two models is in the hard subprocess coming from double pomeron exchange (DPE). It seems that one could expect to test the D-L model quantitatively by using above mentioned " sub-exclusive" processes, especially by using the following clean reactions at high energies:

$$p + p(\bar{p}) \to X_p + X_{p(\bar{p})} + J/\psi + \gamma \tag{1}$$

which produces $J/\psi + \gamma$ in the final states through DPE mechanism, and $X_p, X_{p(\bar{p})}$ are the diffractive dissociation products of p, $p(\bar{p})$ respectively. In Sec.II we give the formalism of D-L model and the cross sections of the double diffractive dissociation reactions. In Sec.III we present the results of the total cross sections in the reaction of Eq.(1) for the total c.m. energy $\sqrt{s}$ from 50 GeV to 20 TeV and some discussions about the comparison with the inclusive results for I-S model are given.

2 Formalism of D-L pomeron model and cross sections of double diffraction in exclusive reactions

In the lowest order of QCD, the two diagrams drawn in Fig.1 and Fig.2 are important for the reactions of Eq.(1). The hard subprocess associated with Fig.1 is shown in Fig.3, where two pomerons scatter into J/ψ and a photon through a charm-quark loop . The hard subprocess associated with Fig.2 is shown in Fig.4, where firstly the two pomerons annihilate into a charmonium χ_J with quantum number ^3P_J ($J = 0, 1, 2$) and then the χ_J decays into J/ψ and a photon. In calculating the vertex of J/ψ, γ and χ_J we have used colour singlet model approximation [8] as people usually do. Since the quark-pomeron coupling in D-L model belongs to the vectorial type, the algebraic formalism of the subprocess $I\!P + I\!P \to J/\psi + \gamma$ is the same as that of $g + g \to J/\psi + \gamma$[9]. It should be noticed that the pomeron does not couple to a conserved current so some care must be taken for summing over the pomeron polarization and this makes the algebraic manipulation complicated. Let us first discuss the process corresponding to Fig. 1. Since in the dissociative subsystems X_p and $X_{p(\bar{p})}$ all internal variables, except for the global momenta p_1' and p_2', are irrelevant to $J/\psi + \gamma$ production one could factorize and integrate over these variables. Then the differential cross section for Fig.1 is obtained as

$$d\sigma = \frac{1}{4[(p_1 \cdot p_2)^2 - m_N^4]^{\frac{1}{2}}}(2\pi)^4 \Sigma \mid M \mid^2 \delta^4(q_1 + q_2 - P - k) \cdot \frac{d^3p_1'}{2E_1'(2\pi)^3} \cdot \frac{d^3p_2'}{2E_2'(2\pi)^3} \cdot \frac{d^3P}{2E_P(2\pi)^3} \cdot \frac{d^3k}{2k_0(2\pi)^3} , \quad (2)$$

where the 4-momenta are marked in the figures. According to the rule of D-L model, the matrix element M should be

$$M = D_p(t_1)D_p(t_2)M_{\alpha\beta\rho}\epsilon^{p_1,\alpha}\epsilon^{p_2,\beta}\epsilon^{\gamma,\rho} \equiv D_p(t_1)D_p(t_2)\mathcal{M} , \quad (3)$$

where ϵ^p, ϵ^γ are the polarization vectors of IP and the photon respectively. $D_p(t)$ is the effective propagator of the pomeron radiated by the proton and can be expressed as [7]

$$D_p(t) = -3\beta_0^2(\frac{\omega}{E})^{1-2\alpha_p(t)}(\frac{1 + e^{-i\pi\alpha_p(t)}}{Sin\pi\alpha_p(t)}) . \quad (4)$$

The factor 3 in Eq.(4) indicates that IP couples with three quarks in the proton separately. β_0 is the coupling constant of pomeron with quark, which, according to Ref.[10], is related to the strength of the gluon condensation in the non-perturbative QCD vacuum (β_0=1.8 GeV^{-1}). $\alpha_p(t) \approx \alpha_p(0) + \alpha_p' t$ is the linear expansion of Regge trajectory for pomeron at small $|t|$ and from data analysis $\alpha_p(0) \approx$1.085, $\alpha_p' \approx$0.25 GeV^{-2}. Other symbols as $E_i = p_{i0}$, $\omega_i \equiv q_{i0} = p_{i0} - p_{i0}'$ are also marked in the figures. After some operation, the phase space elements of final state variables p_1', p_2' can be rewritten as

$$\frac{d^3p_1'}{2E_1'}\frac{d^3p_2'}{2E_2'} = \frac{\pi^2 s}{4(p_1 \cdot p_2)^2} dt_1 dt_2 d\omega_1 d\omega_2 \approx \frac{\pi^2}{s} dt_1 dt_2 d\omega_1 d\omega_2$$

Putting Eqs.(3) (4) into Eq.(2) we get

$$\begin{aligned}\sigma(s) &= \frac{1}{8s^2}\int_{-1}^{0} dt_1 \int_{-1}^{0} dt_2 \int_{\frac{1}{2}m_J}^{\frac{\sqrt{s}}{20}} d\omega_1 \int_{\frac{1}{2}m_J}^{\frac{\sqrt{s}}{20}} d\omega_2 \int \frac{d^3P}{2E_P(2\pi)^3}\int \frac{d^3k}{2k_0(2\pi)^3} \\ &\cdot \mid D_p(t_1)D_p(t_2)\mid^2 \bar{\Sigma} \mid \mathcal{M} \mid^2 \delta^4(q_1+q_2-P-k) \quad . \qquad (5)\end{aligned}$$

The lower limits of the integrals over $t_i(i=1,2)$ and the upper limits of the integrals over ω_j in Eq.(5) are determined by the kinematic regions for diffractively produced pomerons. By the definition of the diffractive production, it should be satisfied that $\mid t_j \mid \ll \hat{s} < s$, in common practice it is usually assumed that $\mid t \mid < 1$ GeV^2, $\omega_j < 0.1$, $E_j \simeq 0.05\sqrt{s}$. $\mathcal{M}$ in Eq.(5) is the sum of the matrix elements of the hard subprocesses in which the term $\mathcal{M}^{(a)}$ is shown in Fig.3, $\mathcal{M}^{(b)}$ and $\mathcal{M}^{(c)}$ correspond to its possible crossings. In addition their anticlock-wise quark loops give a factor 2. Therefore we have

$$\mathcal{M} = 2NAF_c e_q (\mathcal{M}^{(a)} + \mathcal{M}^{(b)} + \mathcal{M}^{(c)})_{\alpha\beta\rho}\epsilon^{p_1\alpha}\epsilon^{p_2\beta}\epsilon^{\gamma\rho} \quad , \qquad (6)$$

where according to ref.[11] the factor N is meant as a reminder that we have neglected the finite size [12] of pomeron and it has the same suppressive effect on the amplitude as in ref.[7] where Donnachie- Landshoff have given a well-defined Ansatz, the coupling between pomeron and heavy or off-shell quarks has a form factor which goes like $\mu_0^2/(\mu_0^2+m^2-k^2)$. (k is the momentum of the quark and the parameter $\mu_0 \simeq 1.2$ GeV is the inverse of pomeron's radius.) Factor A is the "coupling constant" between J/ψ and the charm-quark, $e_q = \frac{2}{3}e$ is the charge of the charm-quark and F_c is the colour space factor. It is shown in Eq.(4) that $D_p(t)$ contains a factor β_0^2, which means β_0 should not appear in $\mathcal{M}$. In the colour singlet model [8], the J/ψ is treated as a nonrelativistic $c\bar{c}$ bound state and the binding energy between the charm quarks is neglected, so we have $2m_c = m_{J/\psi}$. Now we have from Fig.3

$$\mathcal{M}^{(a)}_{\alpha\beta\rho} = \frac{8}{(\hat{s}-m_J^2)(\hat{t}-m_J^2)} Tr\left\{\hat{\epsilon}^J(i\hat{p}-m_c)\gamma_\rho[i(\hat{p}+\hat{k})+m_c]\gamma_\beta(i(\hat{p}-\hat{q}_1)-m_c)\gamma_\alpha\right\} \quad , \quad (7)$$

where $\hat{s}=(q_1+q_2)^2$, $\hat{t}=(q_1-P)^2$, $\hat{s}+\hat{t}+\hat{u}=m_J^2+q_1^2+q_2^2$. After making the following interchanges in the Eq.(7): $q_1 \rightleftharpoons q_2$, $\alpha \rightleftharpoons \beta$ and $q_1 \rightleftharpoons -k$, $\beta \rightleftharpoons \rho$, one obtains the expressions of $\mathcal{M}^{(b)}_{\alpha\beta\rho}$ and $\mathcal{M}^{(c)}_{\alpha\beta\rho}$ from that of $\mathcal{M}^{(a)}_{\alpha\beta\rho}$ [1] respectively.

In deriving the $\bar{\Sigma}\ |\mathcal{M}|^2$ in Eq.(5), one should sum over the polarization vectors of the photon, J/ψ and the pomeron respectively. For the photon and J/ψ , as usually, we have

$$\begin{aligned} \Sigma\ \epsilon^\gamma_\rho(k)\ \epsilon^{*\gamma}_{\rho'}(k) &= -g_{\rho\rho'} \\ \Sigma\ \epsilon^J_\mu(P)\ \epsilon^{*J}_{\mu'}(P) &= -g_{\mu\mu'} + \frac{P_\mu P_{\mu'}}{m_J^2} \end{aligned} \quad . \quad (8)$$

However, the pomeron does not couple to a conserved current, so in the expression about the sum over the polarization vectors of the pomeron, as in the case of a virtual photon, we adopted the tensor form arising from a fermion current coupling with the pomeron

$$\Sigma\ \epsilon^{q_i}_\alpha(q_i)\epsilon^{*q_i}_{\alpha'}(q_i) = g_{\alpha\alpha'}\frac{q_i^2}{2m_N^2} + \frac{p_{i\alpha}p'_{i\alpha'} + +p'_{i\alpha}p_{i\alpha'}}{m_N^2} \qquad (i=1,2)\ . \quad (9)$$

After tedious algebraic manipulations we get

[1] Making an inspection of the effective phase space of high energy diffractive processes, one could always put the q_i $(i=1,2)$ as zero in deriving the $\Sigma\ |\mathcal{M}|^2$ whenever they appear in an invariant in the combination with other variables.

$$\bar{\Sigma} \mid \mathcal{M} \mid^2 = 256 N^2 A^2 F_c^2 e_q^2 m_J^2 s^2 (1 - \sqrt{\frac{\hat{s}}{s}})^2 \{ 2m_J^4 \hat{s}^4 - 5m_J^6 \hat{s}^3 - m_J^8 \hat{s}^2 + 11 m_J^4 \hat{s}^3 \hat{t}$$

$$-10 m_J^6 \hat{s}^2 \hat{t} - m_J^2 \hat{s}^4 \hat{t} + \hat{s}^4 \hat{t}^2 - 8 m_J^2 \hat{s}^3 \hat{t}^2 + 24 m_J^4 \hat{s}^2 \hat{t}^2 - 7 m_J^6 \hat{s}^2 \hat{t} + m_J^8 \hat{t}^2$$

$$+2\hat{s}^3 \hat{t}^3 - 14 m_J^2 \hat{s}^2 \hat{t}^3 + 14 m_J^4 \hat{s} \hat{t}^3 - 2m_J^6 \hat{t}^3 + \hat{s}^2 \hat{t}^4 - 7 M_J^2 \hat{s} \hat{t}^4 + m_J^4 \hat{t}^4 \}$$

$$\cdot [m_N^4 \hat{s}^2 (\hat{s} + \hat{t})^2 (\hat{s} - m_J^2)^2 (\hat{t} - m_J^2)^2]^{-1} \quad , \tag{10}$$

where we used the approximation in footnote (1), so $\bar{\Sigma} \mid \mathcal{M} \mid^2$ is now independent of t_i and ω_i . After completing the integrals over variables k and P, Eq.(5) becomes

$$\sigma(s) = \frac{1}{8s^2} \int_{-1}^{0} dt_1 \int_{-1}^{0} dt_2 \int_{m_J/2}^{\sqrt{s}/20} d\omega_1 \int_{m_J/2}^{\sqrt{s}/20} d\omega_2 \mid D_p(t_1) D_p(t_2) \mid^2 \int_{-(\hat{s}-m_J^2)}^{0} d\hat{t} \frac{\pi}{2\hat{s}} \bar{\Sigma} \mid \mathcal{M} \mid^2 . \tag{11}$$

From Eq.(10) we have

$$\int_{-(\hat{s}-m_J^2)}^{0} d\hat{t} \frac{\pi}{2\hat{s}} \bar{\Sigma} \mid \mathcal{M} \mid^2 = 256 N^2 A^2 F_c^2 e_q^2 \frac{s^2}{m_N^4} (1 - \sqrt{\frac{\hat{s}}{s}})^2 \cdot \{ (r^5 - 13r^3 - 17r^2 - 4r + 1)$$

$$+2r(4r^2 + 3r + 1) \ell n r \} / \{ r^2 (r-1)(r+1)^3 \} \quad , \tag{12}$$

where $r \equiv \frac{\hat{s}}{m_J^2} = \frac{4\omega_1\omega_2}{m_J^2}$. Putting Eqs.(4), (12) into Eq.(11), we finally get the expression for the double diffractive dissociation cross section corresponding to the Fig.1.

Now turning to the hard subprocesses IP + IP $\to \chi_j \to J/\psi + \gamma$, ($j = 0, 1, 2$), a simple and reasonable way is to divide the whole process into two steps. Firstly, $p + p(\bar{p})$ change to $p + p(\bar{p}) + \chi_j$ through DPE, and then χ_j decays into J/ψ and γ. We shall directly use the measured branch ratios of the decays in the second step.

Paralleling to the calculation of Eq.(5), the cross section for $p + p(\bar{p}) \to p + p(\bar{p}) + \chi_j$ through DPE is obtained as

$$\sigma^{(j)}(s) = \frac{1}{8s^2}\int_{-1}^{0} dt_1 \int_{-1}^{0} dt_2 \int_{m_{\chi_j}/2}^{\sqrt{s}/20} d\omega_1 \int_{m_{\chi_j}/2}^{\sqrt{s}/20} d\omega_2 \mid D_P(t_1) D_P(t_2) \mid^2 \int \frac{d^3 p_j}{2E_j (2\pi)^3}$$
$$\cdot \bar{\Sigma} \mid \mathcal{M}^{(j)} \mid^2 \delta^4(q_1 + q_2 - p_j) \qquad (13)$$

In the center of mass system $\mathbf{p}_1 + \mathbf{p}_2 = 0$, $E_1 = E_2 = \sqrt{s}/2$, we have $p_1 \cdot q_2 = \omega_2\sqrt{s} - t_2/2$ and $p_2 \cdot q_1 = \omega_1 \sqrt{s} - t_1/2$. Under the approximation of the footnote (1), the components of 4–vectors q_1 and q_2 are $(\omega_1, \omega_1, 0, 0)$ and $(\omega_2, -\omega_2, 0, 0)$ respectively and we have $\omega_1 + \omega_2 = E_j$, $\omega_1 - \omega_2 = p_j$, with $p_j^2 = \sqrt{E_j^2 - m_{\chi_j}^2}$. Now Eq.(13) becomes

$$\sigma^{(j)}(s) = \frac{1}{16s^2}\int_{-1}^{0} dt_1 \int_{-1}^{0} dt_2 \int_{0}^{\sqrt{s}/10} \frac{d^3 p_j}{2E_j (2\pi)^3} \mid D_P(t_1) D_P(t_2) \mid^2 \bar{\Sigma} \mid \mathcal{M}^{(j)} \mid^2 \qquad (14)$$

The pomeron in D-L model is phenomenologically like an isoscalar photon, therefore we could take over almost all the tensor analysis formalism used in the processes $g_1 + g_2 \to \chi_j$ by [illegible] et al.[13] to our amplitude of $I\!P + I\!P \to \chi_j$. As before, in the colour singlet approximation for χ_j $(j = 0, 1, 2)$ states let

$$\mathcal{M}^{(j)} = \varepsilon^{g_1 \mu} \varepsilon^{g_2 \nu} A^{(j)}_{\mu\nu} \qquad (15)$$

We have from Ref.[13]

$$A^{(0)}_{\mu\nu} = \frac{2NF_c a}{\sqrt{6} m_0} \{[(q_1 \cdot q_2) g_{\mu\nu} - q_{2\mu} q_{1\nu}](m_0^2 + q_1 \cdot q_2) - g_{\mu\nu} q_1^2 q_2^2\}$$
$$A^{(1)}_{\mu\nu} = i NF_c a \{ q_1^2 \varepsilon_{\alpha\mu\nu\beta} \epsilon^\alpha q_2^\beta - q_2^2 \varepsilon_{\alpha\mu\nu\beta} \epsilon^\alpha q_1^\beta \}$$
$$A^{(2)}_{\mu\nu} = \sqrt{2} NF_c a M \{ [(q_1 \cdot q_2) g_{\mu\sigma} g_{\nu\tau} + g_{\mu\nu} q_{1\sigma} q_{2\tau} - g_{\mu\sigma} q_{1\nu} q_{2\tau} - g_{\nu\sigma} q_{2\mu} q_{1\tau}] \epsilon^{\sigma\tau} \} \qquad (16)$$

where ϵ_μ, $\epsilon_{\mu\nu}$ are the polarization vector and tensor of χ_1 and χ_2 states respectively. They satisfy

$$\epsilon_\mu p_1^\mu = 0, \quad \Sigma \epsilon_\mu \epsilon_\nu = -g_{\mu\nu} + \frac{p_{1\mu} p_{1\nu}}{m_1^2}$$

and

$$\epsilon_{\mu\nu} = \epsilon_{\nu\mu}, \quad \epsilon^{\mu}_{\mu} = 0, \quad \epsilon_{\mu\nu} p_2^{\mu} = 0 \ ,$$

$$\Sigma\ \epsilon_{\mu\nu}\epsilon_{\alpha\beta} = \frac{1}{2}[Q_{\mu\alpha}Q_{\nu\beta} + Q_{\mu\beta}Q_{\nu\alpha}] - \frac{1}{3}Q_{\mu\nu}Q_{\alpha\beta} \quad ,$$

where

$$Q_{\mu\nu} \equiv -g_{\mu\nu} + \frac{p_{2\mu}p_{2\nu}}{m_2^2} \quad . \tag{17}$$

In the Eq.(16) the coefficient $a \equiv \frac{4}{(q_1 \cdot q_2)^7}\sqrt{\frac{3}{8\pi m_c}}\varphi'(0)$ and $\varphi'(0)$ denotes the derivative of the wave function of χ_j at the origin in the coordinate space, which can be determined from $\Gamma^{\chi_2}_{2\gamma}$ by the expression

$$| \varphi'(0) |^2 = 45\frac{m_\chi^4}{2^{10}\alpha^2}\Gamma^{\chi_2}_{2\gamma}$$

Putting Eqs.(4),(9),(15) and (16) into Eq.(14), tedious algebraic manipulations give the cross sections of the processes $p + p(\bar{p}) \to X_p + X_{p(\bar{p})} + \chi_j$

$$\sigma^{(j)}(s) = \frac{729N^2\beta_0^8 \,| \varphi'(0) |^2}{16(2\pi)^4 s m_j} \int_{-1}^{0} dt_1 \int_{-1}^{0} dt_2 \int_0^{\sqrt{s}/10} d^3 p_j \frac{1}{E_j} \cdot \left\{ \frac{\sqrt{p_j^2 + m_j^2} + p_j}{\sqrt{s}} \right\}^{1-2\alpha_p(t_1)} \left\{ \frac{\sqrt{p_j^2 + m_j^2} - p_j}{\sqrt{s}} \right\}^{1-2\alpha_p(t_2)} \cdot | N_j(t_1, t_2) |^2, \tag{18}$$

where

$$| N_0(t_1,t_2) |^2 = \frac{1}{3(m_0^2 - t_1 - t_2)^4}[(t_2 - t_1)^4 - 6m_0^2(t_2 - t_1)(t_2^2 - t_1^2) + 9m_0^4(t_1 + t_2)^2] + O(\frac{1}{\sqrt{s}})$$

$$| N_1(t_1,t_2) |^2 = \frac{-1}{(m_1^2 - t_1 - t_2)^4}[(t_2^2 - t_1^2)^2 + 8m_1^2 t_1 t_2 (t_1 + t_2)] + O(\frac{1}{\sqrt{s}})$$

$$| N_2(t_1,t_2) |^2 = \frac{2}{3(m_2^2 - t_1 - t_2)^4}[(t_2 - t_1)^4 + 12m_2^4 t_1 t_2] + O(\frac{1}{\sqrt{s}}) \quad . \tag{19}$$

The total cross section of all the processes corresponding to the Fig.2 is

$$\sigma(s) = \frac{\Gamma^{\chi_0}_{J/\psi+\gamma}}{\Gamma^{\chi_0}_{tot}}\sigma^{(0)}(s) + \frac{\Gamma^{\chi_1}_{J/\psi+\gamma}}{\Gamma^{\chi_1}_{tot}}\sigma^{(1)}(s) + \frac{\Gamma^{\chi_2}_{J/\psi+\gamma}}{\Gamma^{\chi_2}_{tot}}\sigma^{(2)}(s) \quad , \tag{20}$$

where the branch ratios are [13]

$$\frac{\Gamma^{\chi_0}_{J/\psi+\gamma}}{\Gamma^{\chi_0}_{tot}} = 0.0066, \quad \frac{\Gamma^{\chi_1}_{J/\psi+\gamma}}{\Gamma^{\chi_1}_{tot}} = 0.273, \quad \frac{\Gamma^{\chi_2}_{J/\psi+\gamma}}{\Gamma^{\chi_2}_{tot}} = 0.135 \tag{21}$$

In Eqs.(10) and (18), we have taken the suppression factor $N = 0.03$ [21] and let $m_J = 3.1$ GeV, $m_j \equiv m_{\chi_j} = 3.5$ GeV, ($j = 0, 1, 2$).

3 Results and discussions

In this paper we have formulated the hard diffractive dissociation processes $p + p(\bar{p}) \to X_p + X_{p(\bar{p})} + J/\psi + \gamma$ within the pomeron model of Donnachie-Landshoff and have evaluated the cross sections for the total c.m. energy $\sqrt{s}$ from 50 GeV to 20 TeV. The results are shown in the Fig. 5. The curve labeled F is the contribution from the subprocess as shown in the Fig.3, the curves labeled $j = 0, 1, 2$ are contributions from subprocesses with the intermediate states χ_0, χ_1, and χ_2, respectively, as shown in Fig.4. The sum of these χ_j states is the curve Σ. The total contribution, $\sigma^{(\Sigma+F)}(s)$, in the whole energy range is always less than 70 nb. Comparing it with that of typical strong processes , the above cross sections are rather small. However, we should not be surprised at it since they just come from the contributions of DPE mechanism and D-L pomeron model. It is interesting to compare $\sigma^{(\Sigma+F)}(s)$ with those cross sections evaluated from the diffractive inclusive processes $p + p(\bar{p}) \to X_p + X_{p(\bar{p})} + J/\psi + \gamma + X$ within I-S model. Its Feynman diagram is shown in Fig.6. We have evaluated [15] the total cross section for the latter processes in I-S model at the same energy range. It increases with energy very fast at outset, then varies as $(\ell n s)^2$ after $\sqrt{s}$ beyond 500 GeV and approaches to $O(10^3)$nb at $\sqrt{s} = 20$ TeV, almost two orders of the magnitude larger than $\sigma^{(\Sigma+F)}(s)$. So it seems that in DPE mechanism of $J/\psi + \gamma$ production, the cross sections from D-L model would be overwhelmed by that of I-S model and it looks experimentally very hard to test D-L model in such reactions. However, it is in fact not the case. If we inspect the products in the IP-IP collision (where the pomerons come from DPE mechanism),instead of the inclusive one $IP + IP \to J/\psi + \gamma + X$ in I-S model where it is assumed that the structure of IP in high energy collisions is the same as that of the nucleon, one could get just an exclusive reaction $IP + IP \to J/\psi + \gamma$ in D-L model. Therefore if one investigates the rapidity distribution of the final state particles, Eq. (1) may be a useful reaction to test the D-L model experimentally. Although the cross sections are rather small as mentioned, there may still be some advantages for the test:

1) The major point of inspecting the distribution of final state particles should be concentrated on the central part of the rapidity. From the sub-processes in D-L model as shown in the Fig.3 and the Fig.4, and from the kinematics, we know that there must be a large gap in the rapidity region between J/ψ and the photon, i.e. between their decaying products [2]. However, for I-S model in the inclusive processes as shown in the Fig.6, except for J/ψ and the photon, the remnants in the final states of $IP + IP$ sub-system would share the energy and momentum continuously and therefore no distinct gap would emerge.

2) It is a crucial problem of D-L model to ignore the coupling between pomeron and charm-quark for both inclusive and exclusive processes. In former case it is reflected in the undetermined charm-quark distribution of IP and in the latter case it is reflected in the

[2] Of course, for either exclusive or inclusive $p + p(\bar{p})$ DPE diffractive processes at high energies, there are always large gaps in the rapidity distributions between the diffractively scattered protons (or the diffractive dissociated products) and other final state particles.

unknown suppression factor N^2 as in Eqs.(10) and (18), where we have taken a rather small value N^2=0.01. However, if this factor could be increased or even removed (the coupling between IP and charm-quark seems to be point like), then our results would increase two orders of the magnitude. In conclusion, it is expected that under the luminosities reached by $Sp\bar{p}S$ and will be designed in LHC, after several months of data accumulation, one could implement such experiments. Therefore, the above hard diffractive dissociation process could be a hopeful means to test D-L pomeron model.

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Figure Caption

Fig.1 Feynman diagram of $p + p(\bar{p}) \to X_p + X_{p(\bar{p})} + J/\psi + \gamma$ processes (through charm quark loop)

Fig.2 Feynman diagram of $p + p(\bar{p}) \to X_p + X_{p(\bar{p})} + J/\psi + \gamma$ processes (through χ_J intermediate states)

Fig.3 Hard subprocess diagram of Fig.1. (the dashed line means non-relativistic colour singlet approximation have been used on J/ψ state)

Fig.4 Hard subprocess diagrams of Fig.2. (the dashed line means non-relativistic colour singlet approximation have been used on χ_J states)

Fig.5 Total cross sections contributed from various hard subprocesses(see the text)

Fig.6 Feynman diagram of the processes $p + p(\bar{p}) \to X_p + X_{p(\bar{p})} + J/\psi + \gamma + X$ in the model, the bulb labeled h means hard subprocess shown in Fig.3 and Fig.4