High Energy Physics and Nuclear Physics

Volume 19, Number 2

On the Testing of Models of the Pomeron Structure (Parton Distribution Functions)

He Zhenmin, Lin Zhongjin,[1] Qin Kecheng,[2] and Peng Hongan[2]

(Department of Physics, Hebei Normal University, Shijiazhuang Hebei, China)
[1](Department of Physics, Xiamen University, Xiamen, China)
[2](Department of Physics, Peking University, Beijing, China)

The contributions of the double pomeron exchange (DPE) to the production of high-energy p+p($\bar{p}$) collisions are calculated using both the Ingelman-Schlein model and the Donnachie-Landshoff model of the parton distribution functions for the pomeron ($\mathbb{P}$). For the I-S model, in which gluons dominate the pomeron, the cross sections at high energy increase with energy $\sqrt{S}$ as $\ln^2 S$ or $\ln S$. Its total cross section, $\sigma(S)$, is about 10^2–10^3 nb in the TeV energies region. For the D-L model, in which $\mathbb{P}$ is considered a nonperturbative gluons system and its coupling with quarks is something like isoscaler photons with $C = +1$, its cross-section behavior with energy is a bit complicated. In the same energy range as in the I-S model, cross sections in the D-L model are only 1–3 nb, which is smaller than that of the former by 2–3 orders of magnitude. So if we assume that the parameterizations of both models are reliable, their J/ψ production processes should themselves become a good means of testing these models.

Key words: structure of pomeron, double pomeron exchange, Ingelman-Schlein model, Donnachie-Landshoff model.

Received on February 8, 1994. Supported by the National Natural Science Foundation of China Doctoral Foundation of National Education Committee of China and the Natural Science Foundation of Hebei Province.

1. INTRODUCTION

It is well known that in Regge theory the trajectory with the vacuum quantum number called pomeron, $\mathbb{P}$, plays a particular and very important role for soft processes in high-energy strong interactions. Although many physicists have tried to study the nature of pomeron in the framework of QCD, no one has yet gotten a clear understanding of its dynamical properties and its reality structure [1]. But groups at CERN and DESY have reported the clear observation of typical hard processes such as large p_T jets, B-meson production, and large gap events in rapidity distributions in high-energy p+p($\bar{\text{p}}$) and e+p diffraction collisions [2]. The analysis of these hard diffractive processes must involve the problem of the structure of $\mathbb{P}$. So far there exist two approaches for elucidating the structure of pomeron. One is the model proposed by Ingelman-Schlein, which followed and developed early conjectures about pomeron from QCD and suggested that the pomeron is mainly composed of gluons [3]. The other model was proposed by Donnachie-Landshoff [4], in which the $\mathbb{P}$ are rather like an isoscaler ($C = +1$) photon phenomenologically and are dominated by q($\bar{\text{q}}$). It is very interesting to see if one of these models could reflect the reality of nature. Since gluons are flavorless, one cannot differentiate these two models effectively from the deep inelastic scattering process. Some physicists [4] thought they may be differentiated by h-h collision processed with a moderate p_T jet in its final states. In this paper we point out that the J/ψ production process with double pomeron exchange (DPE) in high-energy p+p($\bar{\text{p}}$) collisions may be an effective approach to differentiating these two models, because in TeV energy ranges, the difference of the cross sections obtained from both models can be very large, sometimes by a factor of hundreds! We have computed cross sections $\sigma(S)$ of the mentioned process with energies from SppS to LHC range and have plotted them out. Owing to the lacking of deep understanding of the nature of $\mathbb{P}$, there are inevitable ambiguities in both models. At the end of this paper we have made some comments about them.

2. FORMULATION OF DPE AND PARTON DISTRIBUTION FUNCTIONS OF THE INGELMAN-SCHLEIN MODEL

Since the details of kinematics and the mechanism of the hard diffractive scattering process of J/ψ production as well as its formulations have been given in our previous papers [5], we only make some recapitulations here. As indicated in Fig. 1, the DPE process demands the longitudinal momentum fraction of $\mathbb{P}$, z_i is limited in $0 < z_i < 0.1$ ($x_{F,i} \equiv (2p'_{i\parallel}/\sqrt{S}) \geq 0.9$), and the square of momentum transfer, $|t| \leq 1$ GeV^2, is less than S, S_i, and M_X^2, at least by a factor of hundreds. So we have

$$\begin{cases} M_X^2 \approx (1-|x_{F,1}|)(1-|x_{F,2}|)S \approx z_1 z_2 S \\ S_1 = (1-|x_{F,2}|)S \approx \dfrac{M_X^2}{(1-|x_{F,1}|)}, \quad S_2 = (1-|x_{F,1}|)S \approx \dfrac{M_X^2}{(1-|x_{F,2}|)} \end{cases} \tag{1}$$

From the Regge pole theory and the factorization theorem the differential cross section for Fig. 1 is

$$S_1 S_2 \frac{d^4\sigma}{dS_1 dS_2 dt_1 dt_2} = \frac{1}{4}\sigma^T_{\mathbb{P}\mathbb{P}}(t_1, t_2, M_X^2) g_N^2(t_1) g_N^2(t_2) \left(\frac{S}{S_1}\right)^{2(\alpha_{\mathbb{P}}(t_1)-1)} \left(\frac{S}{S_2}\right)^{2(\alpha_{\mathbb{P}}(t_2)-1)} \tag{2}$$

where $g_N^2(t) = g_N^2(0)e^{R_N^2 t}$ is the $\mathbb{PPP}$ coupling "constant," $\sigma^T_{\mathbb{PP}}$ is the total cross section of $\mathbb{P}$-$\mathbb{P}$ collisions, which experimentally are approximately t-independent and become a function of M_X^2 only when $M_X^2 \gg m_N^2$. $\alpha_{\mathbb{P}}(t) \approx 1 - 0.25$ GeV^{-2}t is the Regge trajectory of $\mathbb{P}$ at small $|t|$.

For the hard semi-inclusive process p+p($\bar{\text{p}}$)$\to$p+p($\bar{\text{p}}$)+J/ψ+X, as shown in Fig. 1(b), the cross section is easily obtained in place of $\sigma^T_{\mathbb{PP}}(M_X^2)$ by $\sigma_{\mathbb{P}+\mathbb{P}\to J/\psi+X'}$ in Eq. (2). After integrating Eq. (2) with $t_i (i = 1, 2)$ and using Eq. (1), we get

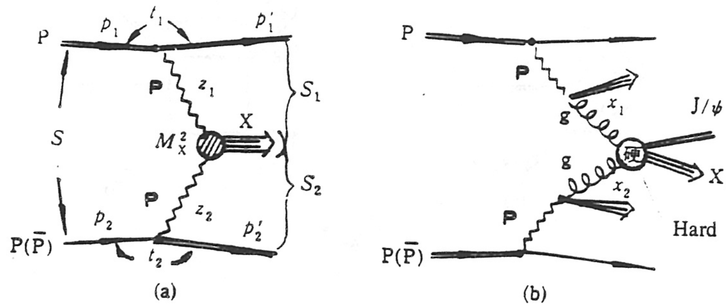


Fig. 1

$$\frac{\mathrm{d}\sigma}{\mathrm{d}M_X^2} = \frac{\sigma_{\mathbb{P}\mathbb{P}\to J/\psi X_h}(M_X^2)g_N^4(0)}{8M_X^2\alpha_{\mathbb{P}}'\left(2\alpha_{\mathbb{P}}'\ln\left(\frac{S}{M_X^2}\right)+R_N^2\right)}\ln\left(\frac{2\alpha_{\mathbb{P}}'\ln\frac{(1-c)S}{M_X^2}+R_N^2}{2\alpha_{\mathbb{P}}'\ln\frac{1}{(1-c)}+R_N^2}\right) \tag{3}$$

where $C = 0.9$ is the lower limit of $x_{F,i}$. Given the parton distribution functions of $\mathbb{P}$, convoluted with cross sections of the hard subprocess, we get the cross section $\sigma_{\mathbb{P}\mathbb{P}\to J/\psi+X'}(M_X^2)$.

The I-S model assumes that gluons dominate the pomeron. By analogy with that of the nucleon, the gluon distribution functions of pomeron are parameterized as follows:

$$\begin{cases} G_{0s}^{\mathbb{P}}(x) = 42(1-x)^5, \quad G_{0h}^{\mathbb{P}}(x) = 6(1-x) \\ G_{\frac{1}{2}}^{\mathbb{P}}(x) = \frac{15}{4}\frac{1}{\sqrt{x}}(1-x) \\ G_{1s}^{\mathbb{P}}(x) = \frac{6}{x}(1-x)^5, \quad G_{1h}^{\mathbb{P}}(x) = \frac{2}{x}(1-x). \end{cases} \tag{4}$$

It should be noted that as emphasized in [3], these distributions obey the momentum sum rule $\int_0^1 xG^{\mathbb{P}}(x)\mathrm{d}x = 1$, as that of a nucleon.

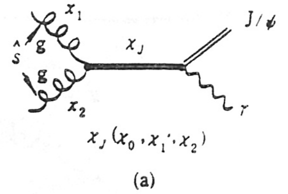
Processes of J/ψ production by gluon-gluon fusion include two hard subprocesses as shown in Figs. 2(a) and (b). Their cross sections were given in [5]. Those are

$$\mathrm{d}\hat{\sigma}_{J/\psi}^{(a)}(\hat{s}) = \sum_{J=0}^{2}\frac{(2J+1)}{8m_\chi^3}\Gamma(\chi_J\to gg)B(\chi_J\to J/\psi\gamma)\delta\left(\frac{\hat{S}}{m_\chi^2}-1\right) \tag{5a}$$

$$\mathrm{d}\hat{\sigma}_{J/\psi}^{(b)}(\hat{s}) = \frac{5\alpha_s^3(m_J^2)|R_J(0)|^2}{9m_J^5}\left\{\frac{2(r+1)}{r^2(r-1)}-\frac{4\ln r}{r(r-1)^2}+\frac{2(r-1)}{r(r+1)^2}+\frac{4\ln r}{(r+1)^3}\right\} \quad (r\equiv\hat{s}/m_J^2) \tag{5b}$$

After convoluting Eq. (4) with Eqs. (5a) and (5b), we get DPE cross sections

$$\sigma_{\mathbb{P}\mathbb{P}\to J/\psi X_h}(M_X^2) = \int_0^1 \mathrm{d}x_1 G^{\mathbb{P}}(x_1)\int_0^1 \mathrm{d}x_2 G^{\mathbb{P}}(x_2)\mathrm{d}\hat{\sigma}_{J/\psi}(\hat{s}) \tag{6}$$



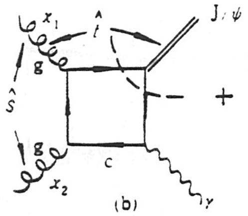


Fig. 2

Putting Eq. (6) into Eq. (3) and integrating it over M_X^2, we obtain the cross sections of the p+p($\bar{p}$) → p+p($\bar{p}$) + J/ψ+X process in the I-S model.

$$\sigma(S) = \int_{M_{XT}^2}^{0.01S} dM_X^2 \frac{d\sigma}{dM_X^2} = \int_1^{0.01S/M_{XT}^2} du \frac{d\sigma}{du} \left(u \equiv \frac{M_X^2}{M_{XT}^2}\right) \tag{7}$$

where the lower limit is the threshold of M_{XT}^2 (i.e., m_χ^2 and m_J^2 for Figs. 2(a) and (b), respectively).

3. THE POMERON MODEL OF DONNACHIE-LANDSHOFF AND ITS INDUCED CROSS-SECTION EXPRESSIONS

Based on analysis of the additive quark rule in h-h collisions, the increasing total cross section $\sigma(S)$ with energy, the behavior of $d\sigma/dt$ at small $|t|$, and the single- and double-diffractive dissociation were studied from the field theory model [6]. Donnachie-Landshoff asserted that the ℙ, as a nonperturbative multigluon system, was rather like an isoscaler ($C = +1$) photon when coupling with a quark (antiquark). They have emphasized that, like a photon, the pomeron structure function consists of two pieces; one resembles that of a hadron (hadronlike part), the other (a point-like part) is peculiar to the pomeron, which is the same as that of a photon. Here we have two different modes for the DPE J/ψ production; one is the exclusive mode as shown in Figs. 3 and 4, and the other is the semi-inclusive mode as shown in Fig. 5.

We discuss first the exclusive mode as shown in Fig. 4(a). Since now the coupling of ℙ to a quark (antiquark) is like that of a photon, and the expression of a hard subprocess in Fig. 4 completely corresponds with gluon-gluon fusion process g+g → J/ψ+γ, the formulations have been accounted for in detail in [7]. Thus we could write out directly the matrix element of Fig. 4(b):

$$M = 2NAe_c(M_a + M_b + M_c)_{\alpha\beta\rho}\varepsilon_\alpha(P_1)\varepsilon_\beta(P_2)\varepsilon_\rho(\Upsilon) \tag{8}$$

where factor N is the suppression factor due to the finite size of $\mathbb{P}(R_{\mathbb{P}} \sim 0.05$ fm), factor A is the "coupling constant" of c($\bar{c}$) with J/ψ in color-singlet model, and $e_c = 2/3e$ is the charge of c quark. From the symbols labeled in Fig. 4(b),

$$M_{a,\alpha\beta\rho} = \frac{8}{(\hat{s} - m_J^2)(\hat{t} - m_J^2)} \mathrm{Tr}\{\hat{\varepsilon}^J(i\hat{p} - m_c)\gamma_\rho(i(\hat{p} + \hat{k}) + m_c)\gamma_\beta(i(\hat{p} - \hat{q}_1) - m_c)\gamma_\alpha\}$$

Interchanging ($q_1 \rightleftarrows q_2$, $\alpha \rightleftarrows \beta$) and ($q_2 \rightleftarrows -k$, $\beta \rightleftarrows \rho$), we can obtain expressions $M_{b,\alpha\beta\rho}$ and $M_{c,\alpha\beta\rho}$, respectively, from that of $M_{a,\alpha\beta\rho}$.

It should be emphasized that since ℙ does not couple to a conserved current (the same as in the case of a virtual photon), the sum of the polarization vectors of the ℙ is determined by the scattering tensor form of incident particles P($\bar{P}$):

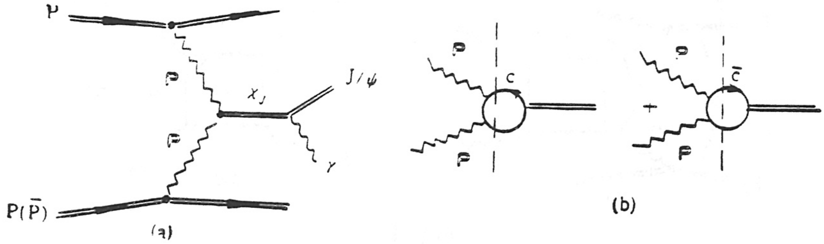


Fig. 3

$$\sum \varepsilon_\mu(P_i)\varepsilon_\nu^*(P_i) \equiv L_{i,\mu\nu} = \frac{1}{4m_N^2}\mathrm{Tr}(\not{p}_i' + m_N)\gamma_\mu(\not{p}_i + m_N)\gamma_\nu)$$
$$= -(p_i \cdot p_i' - m_N^2)\delta_{\mu\nu} + (p_{i\mu}p_{i\nu}' + p_{i\mu}'p_{i\nu}) \quad i = 1,2. \tag{9}$$

From Eq. (8) and the Feynman rule of $\mathbb{P}$ given in [8], the square of the matrix element for Fig. 4(a) is

$$|\mathcal{M}|^2 = |D_\mathrm{P}(t_1)D_\mathrm{P}(t_2)|^2 L_{1,\alpha\alpha'}L_{2,\beta\beta'}M_{\alpha\beta\rho}M^*_{\alpha'\beta'\rho'}\sum\varepsilon_\rho\varepsilon^*_{\rho'} \tag{10}$$

where $D_\mathbb{P}(t) = 3\beta_0^2(\omega/E)^{1-2\alpha_\mathbb{P}(t)}$, $F_N(t)$ is the effective propagator of $\mathbb{P}$, while is the electric form factor of nucleon, and

$$F_N(t) = \frac{4m_N^2 - 2.8t}{4m_N^2 - t}\left(1 - \frac{t}{0.7\mathrm{GeV}^2}\right)^{-2}$$

For Fig. 4(a), the differential cross section of P+p($\bar{\mathrm{p}}$) → P+p($\bar{\mathrm{p}}$)+J/ψ+X, is

$$d\sigma = \frac{1}{4[(p_1 \cdot p_2)^2 - m_N^4]}(2\pi)^4\sum|\mathcal{M}|^2\delta^4(p_f - p_i)$$
$$\times\frac{d^3p_1'}{(2\pi)^3 2E_1'}\frac{d^3p_2'}{(2\pi)^3 2E_2'}\frac{d^3k}{(2\pi)^3 2k_0}\frac{d^3p_J}{(2\pi)^3 2E_J} \tag{11}$$

The phase space factor may be rewritten as

$$\frac{d^3p_1'}{2E_1'}\frac{d^3p_2'}{2E_2'} = \frac{\pi^2 S}{4(p_1 \cdot p_2)^2}dt_1dt_2d\omega_1d\omega_2 \simeq \frac{\pi^2}{S}dt_1dt_2d\omega_1d\omega_2$$

Integrating over the phase space of the final state we get the total cross section of the process shown in Fig. 4(a):

$$\sigma(S) = \frac{1}{8S^2}\int_{-1}^0 dt_1\int_{-1}^0 dt_2\int_{m_{J/2}}^{\frac{\sqrt{S}}{20}}d\omega_1\int_{m_{J/2}}^{\frac{\sqrt{S}}{20}}d\omega_2\int\frac{d^3k}{(2\pi)^3 2k_0}\int\frac{d^3p_J}{(2\pi)^3 2E_J}$$
$$|D_\mathrm{P}(t_1)D_\mathrm{P}(t_2)|^2\sum|m|^2\delta^4(q_1 + q_2 - p_J - k) \tag{12}$$

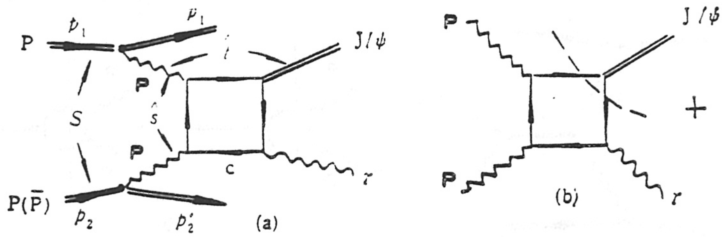


Fig. 4

where

$$|m|^2 = L_{1,\alpha\alpha'}L_{2,\beta\beta'}M_{\alpha\beta\rho}M^*_{\alpha'\beta'\rho'}. \quad \left(\begin{matrix}\text{Sum over the polarization} \\ \text{of photons.}\end{matrix}\right)$$

Since pomeron does not couple with a conserved current, the calculations for $|m|^2$ are rather complicated. After tedious algebraic manipulations, $|m|^2$ can be represented as sum of scalar functions of $\hat{s}$, $\hat{t}$, and $\hat{u}$. Taking all terms proportional to m_N^2 as zero approximately, $|m|^2$ can be further simplified. Putting the evaluated $|m|^2$ and Eq. (10) into Eq. (12), we get finally the cross section with Fig. 4:

$$\sigma(S) = 47.5N^2 \int_{-1}^{0} dt_1 \int_{m_{J/2}}^{\frac{\sqrt{S}}{20}} d\omega_1 \frac{(1.257 - t_1)^2}{(3.52 - t_1)^2(0.7 - t_1)^4}\,\omega_1 \left(\frac{2\omega_1}{\sqrt{S}}\right)^{\frac{-t_1}{2}}$$

$$\cdot \int_{-1}^{0} dt_2 \int_{m_{J/2}}^{\frac{\sqrt{S}}{20}} d\omega_2 \frac{(1.257 - t_2)^2}{(3.52 - t_2)^2(0.7 - t_2)^4}\,\omega_2 \left(\frac{2\omega_2}{\sqrt{S}}\right)^{\frac{-t_2}{2}} f\left(\frac{4\omega\,\omega_2}{m_J^2}\right) \tag{14}$$

where as [8] we take $N^2 = 0.001$, and $f(r)$ ($r \equiv 4\omega_1\omega_2/m_J^2$) is the sum of rational fraction terms with $\ln r$ emerged in the numerator. Comparing $f(r)$ with the corresponding expression of conserved current in the parentheses of Eq. (5b), it can be seen that the denominators of all terms in both expressions are the same as one by one. Furthermore, after integrating over r, both of their results have only a small difference.

The approach of evaluating the exclusive process shown in Fig. 3(a) is nearly the same as that for Fig. (4), only easier. The matrix element and differential cross section $d\sigma/dp_J$, which corresponds to Fig. 3(a), had been calculated in [8] in discussing the odderon (the Regge trajectory with vacuum quantum number but $C = -1$). Results are obtained by integrating it over p_J.

Donnachie and Landshoff have also given the quark distribution functions in their model for pomeron, and we can use them to compute the contribution of the semi-inclusive process. Production of J/ψ through DPE at the lowest order α_S in QCD is shown in Fig. 5(a).[1]

The photonlike distribution function of the c(c̄) quark in $\mathbb{P}$ is [4,9]:

$$F^{I}_{c/\mathbb{P}}(x) = \frac{1}{3}\, C_c \pi x(1 - x) \frac{\mu_0^2}{\mu_0^2(1 - x) + m_c^2} \tag{15}$$

[1] In describing J/ψ particle with nonrelativistic color-singlet model, the absolute value of momentum of the c(c̄) quark coupled with J/ψ must be equal to each other and half of that of J/ψ, (i.e., $p_J/2$). Therefore, a pair of c and c̄ emitted independently from two pomerons could satisfied this kinematic limit only if they have exchanged a gluon between themselves.

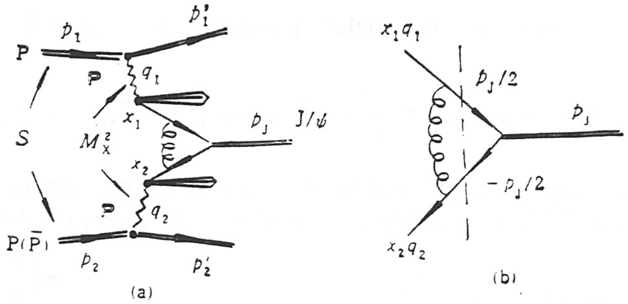


Fig. 5

where, as [4,9] show, $C_c = 0.045$, $\mu_0 = 1.1$ GeV, and $m_c = 1.5$ GeV. The hadronlike distribution functions of pomeron are

$$F^{II}_{c/P}(x,t) = 0.02\left(\frac{-t}{-t+0.36}\right)[\alpha^0_P(-t+0.36)]^{-\varepsilon}x^{-\varepsilon}(1-x)^5\frac{\mu_0^2}{\mu_0^2(1-x)+m_c^2}$$

where $\varepsilon = 0.085$. On account of diffractive kinematic limit ($|t| \le 1$ Gev^2) and because $F^{II}_{c/P}(x,t)$ varies smoothly with t, it can be written approximately as

$$F^{II}_{c/P}(x) = 0.85\times10^{-2}x^{-\varepsilon}(1-x)^5\frac{\mu_0^2}{\mu_0^2(1-x)+m_c^2} \tag{16}$$

which is an expression for $F^{II}_{c/P}$ at $t = -0.2$ GeV^2.

Using the nonrelativistic color-singlet model once more for J/ψ, the matrix element of Fig. 5(b) is

$$M_{fi} = g^2 A\bar{v}(x_2q_2)\gamma_\nu\frac{\lambda_\beta}{2}\frac{\hat{\varepsilon}^J(\not{p}_J+m_J)}{2\sqrt{2}}\frac{\lambda_\alpha}{2}\gamma_\mu u(x_1q_1)\frac{\delta_{\alpha\beta}\delta_{\mu\nu}}{\left(x_1q_1-\frac{p_J}{2}\right)^2-i\varepsilon} \tag{17}$$

After some manipulations we get

$$\Sigma|M_{fi}|^2 = \frac{64A^2\pi^2\alpha_s^2}{81\left(x_1q_1-\frac{p_J}{2}\right)^2}\left[\frac{5}{2}m_J^4+6x_1x_2(q_1\cdot q_2)m_J^2-4x_1x_2(q_1\cdot p_J)(q_2\cdot p_J)\right]. \tag{18}$$

Substituting it into following expression for subprocess $c+\bar{c}\to J/\psi$ yields

$$d\hat{\sigma}_{c\bar{c}\to J}(\hat{s}) = \frac{1}{\sqrt{(x_1q_1\cdot x_2q_2)^2-m_c^4}}\Sigma|M_{fi}|^2(2\pi)^4\delta^4(x_1q_1+x_2q_2-p_J)\frac{d^3p_J}{(2\pi)^3 2E_J}$$

and after integrating over p_J, we get

$$\hat{\sigma}_{c\bar{c}\to J}(\hat{s}) = \frac{2\cdot4^5\pi^2\alpha_s^2|R_J(0)|^2}{9\sqrt{3}\,m_J^3}\delta(\hat{s}-m_J^2) \tag{19}$$

where $A^2 = \dfrac{|R_J(0)|^2}{2\pi m_j}$, $\hat{s} = (x_1q_1 + x_2q_2)^2 = x_1x_2M_X^2$. After convoluting Eq. (19) with Eqs. (15) or (16), we get the cross section for semi-inclusive process P+P → J/ψ+X′:

$$\sigma_{PP\to J/\psi X}(M_X^2) = \int_0^1 dx_1 F_{c/P}(x_1) \int_0^1 dx_2 F_{c/P}(x_2) \hat{\sigma}_{c\bar{c}\to J}(\hat{s}) \tag{20}$$

Putting Eq. (20) into Eq. (3) and integrating over M_X^2 analogy with that of Eq. (7), the cross section for the D-L model on DPE semi-inclusive J/ψ production in p+p(p̄) collision can be obtained:

$$\sigma^{I}(S) = 9.73 \times 10^2 \int_1^{\frac{S}{960}} du \frac{1}{u^3\left(\ln\left(\frac{S}{u}\right) + 4.74\right)} \ln\left(\frac{\ln\left(\frac{S}{u}\right) + 2.435}{9.303}\right) \cdot \int_{\frac{1}{u}}^1 dx \frac{(1-x)(1-ux)}{x(1-0.35x)(0.35-ux)} \tag{21}$$

$$\sigma^{II}(S) = 3.007 \cdot \int_1^{\frac{S}{961}} du \frac{1}{u^{5.915}\left(\ln\left(\frac{S}{u}\right) + 4.74\right)} \ln\left(\frac{\ln\left(\frac{S}{u}\right) + 2.435}{9.303}\right) \cdot \int_{\frac{1}{u}}^1 dx \frac{(1-x)^5(1-ux)^5}{x^5(1-0.35x)(0.35-ux)} \tag{22}$$

The unit of all preceding cross sections is the nano-barm (nb).

4. RESULTS AND DISCUSSIONS

The total cross sections $\sigma(S)$ computed from the I-S and D-L models are shown in Figs. 6 and 7. In Fig. 6, curves labeled with numbers from 1 to 5 denote results obtained from gluon distributions G^P_{0h}, G^P_{0s}, $G^P_{1/2}$, G^P_{1h}, and G^P_{1s}, respectively, of the I-S model in Eq. (4). It is shown in [5] that for G^P_1 mode, which behaves like $1/x$ in the small x region, the cross section increases as $\ln^2 S$ at $\sqrt{S} \geq 1$ GeV. Likewise, for $G^P_{1/2}$ mode, which has a $1/\sqrt{x}$ singularity as $x \to 0$, the cross section increases nearly in the same way when $\sqrt{S}$ is larger than several TeVs. Only for G^P_0 mode, which is regular as $x \to 0$, the cross section increases with energy as $\ln S$ at the TeV region. From Fig. 6 we can also see that in the TeV region, although the cross sections for various gluon distributions are different from each other, they all lie in the range of 10^2–10^3 nb.

In contrast, all the cross sections of D-L model as shown in Fig. 7 are very small in the contributions of both exclusive processes. Curves labeled $J = 0$, 1, and 2 are obtained from Fig. 3(a) with three intermediate states χ_J ($J = 0$, 1, and 2); their sum is shown by the curve Σ. The result of the other exclusive process shown in Fig. 4(a) is represented by the curve F. The semi-inclusive cross sections obtained from Eqs. (21) and (22) are represented by curves I and II, respectively. We see from Fig. 7 that the behavior of these curves is quite different, but all of them are no larger than several nb in the whole TeV region and smaller than those of the I-S model by a factor of 10^2 to 10^3! Therefore, if the parameters used in both models are reliable, it may be possible to test and differentiate these two models with the DPE J/ψ production process from high-energy P+p(p̄) collisions as suggested here.

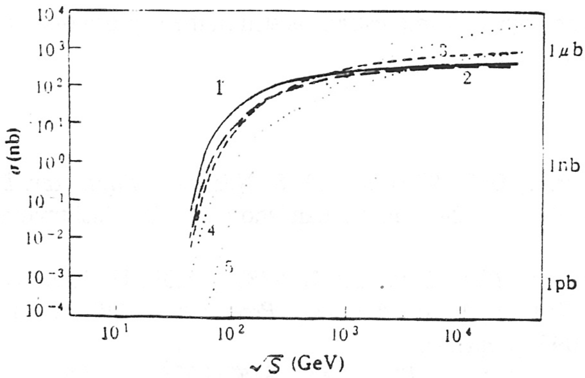


Fig. 6

We have yet no clear understanding of the partonic structure and the QCD dynamics of pomerons, so any model in existence is inevitably fraught with ambiguities. About the two models discussed previously we would like to make the following comments.

The I-S model is a phenomenological model that attacks the problem of the structure of pomerons from QCD. With the assumption of the compact form of gluon distribution functions of P and the analogy with nucleons, this model is rather appealing for physicists. Yet there are some doubts. The most doubtful point of this model is not the assumption of gluon dominance in pomerons, but why the gluon distributions in pomerons would also satisfy the momentum sum rule like nucleons, since the pomeron could never be an on-shell particle and or even an ordinary hadron!

The D-L model is based on analysis of h-h soft processes at high energies. It depends heavily on the "additive quark rule" in the total cross sections of h-h scattering. Just upon this point, the D-L model suggests that the $\mathbb{P}$ analogy with a ($C = +1$) photon is present and asserts that in $\mathbb{P}$, as in the case of a virtual photon, no momentum sum rule for parton distribution is allowed. The D-L model also has assumed that the "blackness" of the pomeron is the same as that of a proton, and that from this the radius of a pomeron and the suppression factor N^2 in Eq. (8) could be determined. But if N varies to a large degree, the results of this model would be altered dramatically. In addition, some recent papers have questioned the additive quark rule; no doubt this would have serious consequences for this model.

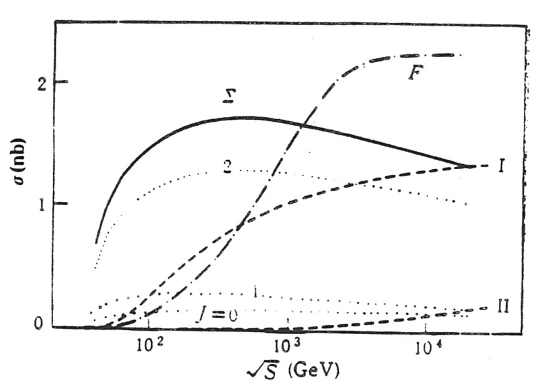


Fig. 7

Of course, all the preceding comments would also have brought the same queries on other processes for testing the partonic structure of pomerons. On the whole, it seems that the study of the mysterious pomeron, although very interesting, is still in the exploratory stage, both in experimental and in theoretical aspects.

REFERENCES

[1] F. E. Low, *Phys. Rev.*, **D12**(1975): p. 163; S. Nassinov, *Phys. Rev. Lett.*, **34**(1975): p. 1286; *Phys. Rev.*, **D14**(1976): p. 246; P. V. Landshoff and O. Nachtmann, *Z. Phys.*, **C35**(1987): p. 405.

[2] UA8, R. Bonino *et al.*, *Phys. Lett.*, **B211**(1988): p. 239; UA1, K. Wacker *et al.*, *Phys. Lett.* **B311**(1993): p. 317; UA8, A. Brandty *et al.*, *Phys. Lett.*, **B297**(1992): p. 417; ZEUS, D. Allen *et al.*, DESY 93–093 (preprint).

[3] G. Ingelman and P. E. Schlein, *Phys. Lett.*, **B152**(1985): p. 256.

[4] A. Donnachie and P. V. Landshoff, *Nucl. Phys.*, **B303**(1988): p. 634.

[5] Peng Hongan, He Zhenmin, and Qin Kecheng, *High-Energy Phys. and Nucl. Phys.* (Chinese Edition), **18**(1994): p. 1078; Peng Hongan, Qin Kecheng, and He Zhenmin, *High-energy Phys. and Nucl. Phys.* (Chinese Edition), **19**(1995): p. 34.

[6] P. V. Landshoff and O. Nachtmann, *Z. Phys.*, **C35**(1987): p. 405; O. Nachtmann, HD-THEP-89-9.

[7] E. L. Berger and D. Jones, *Phys. Rev.*, **D23**(1981): p. 1521; R. Baier and R. Ruckl, *Z. Phys.*, **C19**(1983): p. 251.

[8] A. Schafer, L. Mankiewicz, and O. Nachtmann, 1991, *Phys. Lett.*, **272B**: p. 419; E. Stein and A. Schafer, 1993, *Phys. Lett.*, **B300**: p. 403.

[9] A. Donnachie and P. V. Landshoff, CERN-TH5020/88 (preprint).