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DIFFRACTIVE PHOTOPRODUCTION OF STRANGENESS AND CHARM--
OVERLAP OF QCD AND REGGE MODELS

by

D. P. Roy

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DIFFRACTIVE PHOTOPRODUCTION OF STRANGENESS AND CHARM--
OVERLAP OF QCD AND REGGE MODELS*

D. P. Roy[†]
High Energy Physics Division
Argonne National Laboratory
Argonne, Illinois 60439

ABSTRACT

We suggest an overlap between the perturbative QCD and Regge models for the diffractive photoproduction of strangeness and possibly charm, and support it by explicit comparison between the model predictions. This enables us to estimate some of the QCD model parameters--most notably the gluon x distribution over the region $0 \leq x \leq 1$.

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[†]On leave from Tata Institute of Fundamental Research, Bombay-400005, India.

The photon-gluon fusion model (Fig.1a) has been suggested by several authors as the dominant perturbative QCD mechanism for charm production in deep inelastic electron or muon scattering.¹ Moreover, it has been suggested by some of these authors that the model extends to much lower values of Q^2 and/or quark mass, hopefully going down to photoproduction of strangeness ($Q^2 = 0$, $m_q = m_s$); where the quark mass is assumed to fix the scale of the QCD coupling α_s as $Q^2 \rightarrow 0$. Of course, photon-gluon fusion is not the only QCD mechanism for $c\bar{c}$ ($s\bar{s}$) production, and it is not even clear if it is the dominant one for the net production cross-section.² It seems to be clear, however, that the alternative mechanisms for $c\bar{c}$ ($s\bar{s}$) production are suppressed in the diffractive region,³ where the γG fusion contribution peaks. Besides, the recent data on muoproduction and photoproduction of both γ and open charm, seem to support the fusion model prediction for the diffractive $c\bar{c}$ production, over a wide region of $Q^2 (= 0 - 10)$.³⁻⁵ On the whole, it seems reasonable to assume γG fusion as the dominant QCD mechanism for diffractive production, at least for charm.

Fig.1a illustrates the γG fusion model for charm or strangeness ($q\bar{q} = c\bar{c}, s\bar{s}$) production. Let us restrict to large s and real $\gamma (Q^2 = 0)$. The production cross-section is given by^{1,5}

[†]This refers to a final state consisting of two clusters of low invariant mass each ($\ll s$), separated by a large rapidity gap ($\sim \ln s$), the faster of which contains a pair of charm (strange) particles.

$$\left. \frac{d\sigma}{dM^2} \right|_{\gamma p \rightarrow q\bar{q}(M^2)X} = \frac{\bar{\sigma}(M^2)}{s} G(M^2/s) \quad (1)$$

$$\begin{aligned} \bar{\sigma}(M^2) = & \left(\frac{1}{2}\right) e_q^2 \alpha_s \frac{4\pi}{M^2} \left[\left(1 + \frac{4m_q^2}{M^2} - \frac{8m_q^4}{M^4}\right) \ln \left\{ \frac{M^2}{2m_q^2} \right. \right. \\ & \times \left. \left. \left(1 + \left(1 - \frac{4m_q^2}{M^2}\right)^{\frac{1}{2}} - \frac{2m_q^2}{M^2}\right) \right\} - \left(1 - \frac{4m_q^2}{M^2}\right)^{\frac{1}{2}} \left(1 + \frac{4m_q^2}{M^2}\right) \right] \end{aligned} \quad (2)$$

where $G(x)$ is the familiar probability distribution of the gluon, carrying momentum fraction x of the target proton; and $\bar{\sigma}(M^2)$ is the total cross-section for the subprocess $\gamma G \rightarrow q\bar{q}$.[†] It is evident from Eqs.(1,2) that for any reasonable gluon distribution (e.g. solutions I-III below) the $q\bar{q}$ system is strongly peaked at low M^2 , and it has a large lab rapidity, as it carries all the incident photon energy. The model further assumes that the color compensation between the two color octet states, $q\bar{q}$ on the left and the recoil system X on the right, takes place via soft gluon exchanges (collectively denoted by the dashed line in Fig.1a) involving negligible energy transfer back from $q\bar{q}$ to X . This means that the final state hadrons $H_{q\bar{q}}$ resulting from the $q\bar{q}$ system has practically the same invariant mass (M^2) and lab rapidity as the latter. This also means that the recoil system X is dominated by the lowest energy color singlet state available, i.e. the proton, as pointed out in Ref.5. Thus

[†] It is simply obtained by multiplying the pair production cross-section $\sigma(\gamma, +e^+e^-)$ ⁶ by $(\frac{1}{2})e_q^2\alpha_s/\alpha$, where e_q is the quark charge and the factor $\frac{1}{2}$ comes from color averaging.

$$\begin{aligned} \frac{d\sigma}{dM^2} \Big|_{\gamma p \rightarrow q\bar{q}(M^2)X} &\approx \frac{d\sigma}{dM^2} \Big|_{\gamma p \rightarrow H_{q\bar{q}}(M^2)X} \\ &\approx (1 + \epsilon) \frac{d\sigma}{dM^2} \Big|_{\gamma p \rightarrow H_{q\bar{q}}(M^2)p} \end{aligned} \quad (3)$$

i.e. the final state is characterized by a cluster of hadrons containing a charm (or strange) particle pair, peaked at (1) low M^2 and (2) large rapidity gap from the recoil cluster; and (3) dominance of the recoil cluster by the single proton state.

One immediately notes that all the three features above are also characteristics of the Regge model of diffractive production, i.e. Pomeron (P) exchange. The first two follow, from the Pomeron trajectory being ≈ 1 , and the third one from its elastic coupling being very much larger than the inelastic ones--more precisely

$$\sigma_{Ap \rightarrow AX}^P \approx \left(1 \frac{1}{3} - 1 \frac{1}{2}\right) \sigma_{Ap \rightarrow Ap}^P. \quad (4)$$

Of course, going from hadron diffraction to diffractive photoproduction of specific flavors involves using vector meson dominance (Fig.1b). From one's experience with VMD phenomenology, however, one expects it to be fairly reliable for ϕ (strangeness production). It is expected to get worse as one moves further from the vector meson pole, either by increasing Q^2 or m_q , i.e. as the QCD model is expected to get better. Nonetheless, it is tempting to speculate that

there is an overlap region between the two models, which hopefully includes the photoproduction of strangeness ($Q^2 = 0$, $m_q = m_s$); and check the phenomenological consequences.

One must check first, the quantitative consistency between the two sets of model predictions as regards the magnitude and the M^2 and s dependences of the cross-section, within the rather large uncertainty of the gluon distribution function, of course. In particular, the QCD model prediction for M^2 (or s) dependence at fixed x ($= M^2/s$), is independent of $G(x)$; and should match the Regge model prediction. In case it succeeds, then the assumed overlap between the two models would be able to determine the gluon distribution function $G(x)$ in terms of the Regge model.[†] At least, it should be able to discriminate between the widely different solutions for $G(x)$, suggested in the literature. In comparing the two models, one should bear in mind, of course, their regions of validity. The Regge model for diffraction seems to hold over the range $M^2/s \leq 1$; which means it can determine $G(x)$ over the range $x = 0 - .1$. As for the γG fusion model, one may assume a range $M^2 = (1 - 10) \cdot M_{th}^2$, over which the predicted cross-section falls by decade or more, for any reasonable gluon distribution.

In the Regge model, the diffractive photoproduction cross-section for strangeness (Fig.1b) is expected to lie in the range

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[†]Note that the Bjorken x for the gluon G is simply related to the Feynman x for the recoil proton, via $x = (1 - x_F)$.

[†]This is analogous to the assumption of overlap between the quark parton and Regge models for σ_T^p , which enables one to determine the $x \rightarrow 0$ limit of the valence and sea quark distribution functions in terms of the Regge model.

$$\begin{aligned}
\frac{d\sigma}{dM^2} \Big|_{\gamma(\psi) p \rightarrow H(M^2) p} &= \frac{d\sigma^{\text{PPP}}}{dM^2} + \frac{d\sigma^{\text{PPR}}}{dM^2} \\
&= \frac{1\mu b}{5M^2}
\end{aligned} \tag{5a}$$

and

$$= \frac{1\mu b}{5M^2} + \frac{1\mu b \text{ GeV}^2}{2M^4} \tag{5b}$$

The normalization of the triple Pomeron term (PPP) is estimated through Pomeron factorization and VMD⁷

$$\begin{aligned}
\frac{d\sigma}{dM^2} \Big|_{\gamma(\psi) p \rightarrow H(M^2) p} &= \left(\frac{\sigma^T_{\gamma(\psi) p}}{\sigma^T_{pp}} \right) \frac{d\sigma}{dM^2} \Big|_{pp \rightarrow H(M^2) p} \\
&\approx \left(\frac{8\mu b}{40\text{mb}} \right) \frac{1\text{mb}}{M^2}
\end{aligned} \tag{6}$$

with an expected uncertainty of $\pm 50\%$. The magnitude of the PPR term has been simply assumed to be in the range $0 \leq \sigma^{\text{PPR}} \leq \sigma^{\text{PPP}}$, which is about twice the latitude of model predictions and phenomenological estimates in hadron diffraction.⁸ The resulting cross-sections (Eqs. 5a,b) represent the range of M^2 distributions expected in the Regge model. The model predicts the cross-section to be s independent, where we have neglected the slow logarithmic fall arising from finite Pomeron slope. Whereas the normalization prediction is explicitly based on VMD, the predicted M^2 dependence and s independence are expected to be valid more generally--e.g. in most generalized VMD models.⁷

In estimating the $\gamma p \rightarrow H_{SS}(M^2) p$ cross-section in the

γG fusion model, via Eqs.(1-4), we set

$$\alpha_S^S(1+t) = .27 \quad (7)$$

i.e.

$$\alpha_S^S \approx .4 \quad (8)$$

For the strange quark mass we use

$$m_S = .5 \quad (9)$$

But we have checked that changing this to .4 or .6 changes the normalization by $\pm 25\%$ without affecting the M^2 and s dependences appreciably. From this and a conservative estimate of the latitude in α_S^S , we guess the overall normalization uncertainty to be $\pm 60\%$. For the gluon distribution we take three solutions

$$G(x) = \frac{1}{x} (1-x)^5 (1.03 + 13.5x) \quad (I)$$

$$\frac{3}{x} (1-x)^5 \quad (II)$$

$$\frac{5.5}{x} (1-x)^{10} \quad (III)$$

as shown in Fig.2. The Solution II follows from the power counting rule of Brodsky and Farrar;⁹ whereas the broad Solution I and the steep Solution III are obtained in two different QCD fits to the ep , μp data by Fox¹⁰ and by Buras and Gaemer¹¹ respectively. It illustrates the degree of uncertainty involved in estimating $G(x)$ from the scale

breaking data.

We first compare the M^2 (or s) dependence of the two models at fixed x ($= .02$), which does not depend on the $G(x)$ function. Fig.3a shows the extrema of the Regge prediction (Eq.5a,b) against the γG fusion model prediction, where the normalization corresponds to the $G(x)$ Solution I, and the prediction for $m_s = .4$ and $.6$ are also shown alongside $m_s = .5$ for comparison. One sees that the γG fusion model prediction is remarkably close to the Regge curve B (Eq.5b) (They differ by only 30% in falling through a decade). We feel uncomfortable, of course, for the fact that the curve B is only the steepest extreme of the Regge prediction. However, the latitude in the M^2 shape prediction of this model is not unreasonably large; and besides it seems quite plausible that the soft gluon exchange mechanism for color compensation, discussed earlier, would make the M^2 distribution of the γG fusion model somewhat flatter. In any case, for consistency one must use the Regge curve B for subsequent comparisons.

Fig.3b compares the M^2 distribution of the Regge model (Eq.5a,b) with those of the γG fusion model, for the three gluon distributions mentioned above, at fixed $s = 100$ and 1000 . One sees that the Regge curve B is remarkably close to the γG fusion model prediction for the broad gluon distribution (Solution I), in both the M^2 and the s dependence.[†] In

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[†] The two are, of course, related in view of the agreement between the two models at fixed x , noted above.

contrast, it is in serious disagreement with the predictions for the steeper gluon distributions (particularly Solution III), in both M^2 and s dependence. Even the normalization is in serious disagreement with that of Solution III. It may be noted in this connection that since the Regge model for diffraction predicts a s -independent cross-section over its range of validity ($x < .1$), it is evident from Eq.(1) that it favors a flat $xG(x)$ over the range $x = 0 - .1$, i.e. the broad gluon distribution of Solution I.⁺

It is worthwhile to check if the results obtained above for diffractive photoproduction of strangeness, are consistent with the diffractive photoproduction of charm, although the prediction of Regge model and VMD (Fig.1b) for the latter case is admittedly less reliable. As discussed earlier, one does not expect a quantitative prediction of normalization in this model; however, the predicted M^2 dependence and s independence may still be reasonable. It is then evident from the discussion of the previous paragraph that the predicted s independence would again suggest a flat $xG(x)$ over the range $x = 0 - .1$, in agreement with Solution I. In order to check the consistency of the two models for the M^2 distribution at fixed x , however, one has to have some idea about the M^2 dependence, expected in the Regge model. Now, it is not clear whether the energy scale is governed by M^2 , or by $q_{\perp}^2(M^2)$

⁺It may even be tempting to identify the mild drop of $xG(x)$ as $x \rightarrow 0$ in this solution (Fig.2) with the slow logarithmic fall of the diffractive cross-section expected in the Regge model.

as in the case of the Veneziano model. In fact, there are suggestive evidences from charm phenomenology in favor of the latter choice.[†] We may therefore guess the M^2 dependence to be in the range

$$\left. \frac{d\sigma}{dM^2} \right|_{\gamma(\Psi) p \rightarrow H(M^2) p} \propto \frac{1}{M^2} \quad (10a)$$

$$\text{and} \quad \propto \frac{1}{(M^2 - 8)} \quad (10b)$$

assuming a Ψ slope $\approx \frac{1}{2}$. The PPR contribution is presumably suppressed by the large $M_{th}^2 (\approx 16)$ and the low charmonium intercept. For the γG fusion model we simply change the quark charge and replace the Eqs.(8,9) by

$$\alpha_S^C = .3 \quad (11)$$

$$m_C = 1.5 \text{ (1.65)} \quad (12)$$

where the two sets are related through $\alpha_S(m_q) = 6\pi/(33-2n_f) \ln(m_q/\Lambda)$. The resulting M^2 distribution at fixed $x(=.02)$ are shown in Fig.4a. One sees reasonable agreement between the γG fusion model and the Regge model prediction B (Eq.(10b)). The M^2 distributions at fixed $s(=1000)$ are compared in Fig.4b. The Regge model prediction (curve B) is clearly seen to favor the broad gluon distribution of Solution I. in agreement with the earlier case.

[†]The two choices would make little difference, of course, for the phenomenology of light particles, including ϕ .

It is instructive to compare the above result with the gluon distribution, estimated in a recent phenomenological analysis by Barger, Keung and Phillips.⁵ Assuming that Ψ accounts for a constant fraction of the $\gamma p \rightarrow c\bar{c}(M^2)X$ cross-section, over $4m_c^2 < M^2 < M_{th}^2$ (see Eqs.1,2), they estimate $xG(x)$ from the s dependence of the $\gamma p \rightarrow \Psi X$ cross-section data over $s \approx 20-300$ ($x \approx .04-.60$). Parametrizing $xG(x)$ by $\frac{1}{2} (n+1)(1-x)^n$, they obtain $n=4.5$, close to the Solution II above. It is clear from their data compilation, however, that over the region $x \leq 0.1$ ($s \geq 100$), the data is equally consistent with a flat cross-section, i.e. a flat $xG(x)$. Even more importantly, the assumption of Ψ accounting for a constant fraction of the net charmonium photoproduction cross-section, seems to conflict with the Regge model of diffraction, which predicts the even c charmonium production to go down with energy and hence the fraction for Ψ to increase. It is easy to see that this effect will lead to a broadening of the gluon distribution.

In summary, we suggest an overlap between the perturbative QCD and Regge models for the diffractive photoproduction of strangeness and charm (i.e. the γG fusion and the Pomeron exchange mechanisms), which seems to be supported by comparison of their M^2 distribution at fixed x . This enables one to determine the gluon x distribution in terms of the Regge model parameters over its range of validity ($x=0-.1$). It seems to suggest a broad gluon distribution, very much like the Solution I above.¹⁰ It also provides other predictions

e.g. the extent of proton dominance of the recoil cluster X , and the dominance of the diffractively excited cluster H by odd c states as $x \rightarrow 0$ (Fig.1a). All these features are outside the scope of perturbative QCD calculation, as they involve soft gluon interactions. Finally, we expect such an overlap will prove helpful to the efforts of building a theoretical model for the Pomeron as a multigluon state.

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REFERENCES

1. L. M. Jones and H. W. Wyld, Phys. Rev. D17 (1978) 759; 2332;
J. Babcock, D. Sivers and S. Wolfram, Phys. Rev. D18 (1978) 162;
H. Fritzsch and K. Streng, Phys. Lett. 72B (1978) 385;
M. Gluck and E. Reya, Phys. Lett. 79B (1978) 453; 83B (1979) 98;
J. Leveille and T. Weiler, Nucl. Phys. B147 (1979) 147;
V. Barger, W. Y. Keung and R. J. N. Phillips, Phys. Rev. D20
(1979) 630.
2. See e.g. F. Halzen and D. M. Scott, Phys. Lett. 72B (1978) 404.
3. LBL-FNAL-Princeton Coll.: A. R. Clark et al. Phys. Rev.
Lett. 43 (1979) 187; LBL Preprint 10747 and 10879 (1980).
4. European Muon Coll.: H. Stier, Proc. of Intl. Symp. on
Lepton and Photon Interactions, FNAL (1979).
5. V. Barger, W. Y. Keung and R. J. N. Phillips, Phys. Lett.
91B (1980) 253.
6. See e.g. J. M. Jauch and F. Rohrlich, The Theory of Photons
and Electrons, Chapter 13.
7. J. J. Sakurai and D. Schildknecht, Phys. Lett. 40B (1972) 121;
D. Sivers, Nucl. Phys. B106 (1976) 95;
D. P. Roy, Phys. Lett. 68B (1977) 76.
8. S. N. Ganguli and D. P. Roy, Regge Phenomenology of Inclusive
Reactions, Physics Reports (to be published).
9. S. Brodsky and G. Farrar, Phys. Rev. Lett. 31 (1973) 1153.
10. G. Fox, Nucl. Phys. B131 (1977) 107.
11. A. J. Buras and K. J. F. Gaemers, Nucl. Phys. B132 (1978) 249.

FIGURE CAPTIONS

1. Diffractive photoproduction of $c\bar{c}(s\bar{s})$. (a) Photon gluon fusion model--the dashed line represents the soft gluon exchanges responsible for color compensation between the two clusters; (b) VMD and Regge model.
2. The broad¹⁰(I), power counting⁹(II) and steep¹¹(III) gluon distributions. The present analysis is restricted to the region $x = 0 - .1$.
3. $d\sigma/dM^2(\gamma p \rightarrow H_{s\bar{s}}(M^2)p)$. (a) Fixed $x = .02$. The dotted lines A,B are the Regge model predictions of Eqs.(5a,b). The solid, dashed and chain-dashed lines are γG fusion model predictions for $m_s = .5, .6$ and $.4$, with the normalization of the $G(x)$ Solution I. (b) Fixed s . The solid lines ($s = 100$) and dashed lines ($s = 1000$) are the γG fusion model predictions for the three gluon distributions, with $m_s = .5$.
4. $d\sigma/dM^2(\gamma p \rightarrow H_{c\bar{c}}(M^2)p)$ at (a) fixed $x = .02$ and (b) fixed $s = 1000$. The dotted lines A,B are the Regge model predictions of Eqs.(10a,b) with free normalization. The solid and dashed lines are the γG fusion model predictions for $m_c = 1.5$ and 1.65 .

(a)

(b)

Fig. 1

Fig. 2

Fig. 3

Fig. 4