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ON DIFFRACTIVE PHOTOPRODUCTION AND ELECTROPRODUCTION
OF THE ψ 's

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A B S T R A C T

The diffractive photoproduction cross-sections for the various ψ resonances are estimated in the charm scheme and compared with those expected in the colour one. We argue that photoproduction will be able to discriminate the two schemes.

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One of the most common attitudes one takes towards the newly discovered ψ resonances ¹⁾⁻⁴⁾ is that they are vector mesons with a $c\bar{c}$ quark structure and $G = -1$, $T = 0$ (c = charmed quark) ⁵⁾⁻⁷⁾. The attractiveness of this scheme is based on the importance of the c quark for the weak interactions and their unification with the strong and electromagnetic ones ⁸⁾. Accepting this quark structure and in the spirit of generalized vector dominance (GVD), we assume that there exists actually a series of such mesons, called here φ_{cn} , with masses ^{6),7)}

$$m_{\varphi_{cn}}^2 = m_{\varphi_c}^2 (1 + \alpha_c n); \quad n = 0, 1, 2, \dots \quad (1)$$

The observed states at 3.1, 3.7 and 4.1 GeV are presumably the first three in the series. Of course, the widths of the higher φ_{cn} 's may be so large that it will be impossible to identify them. Nevertheless the lower resonances (say, up to $n=3$ or 4), will probably be amenable to experimental study. From the masses of the first two φ_c 's we find

$$\alpha_c = 0.42. \quad (2)$$

Since the photons give the only available beam of particles containing charmed quarks (provided charmed particles exist), it is evident that photoproduction and electroproduction experiments will play a very important rôle in the study of the properties of the above mesons. In the present note we use GVD to estimate the corresponding cross-sections for the various φ_c 's, in the charm scheme. Our results differ considerably from those expected in the colour octet interpretation. Therefore photoproduction experiments will be useful to discriminate the two schemes. They can also provide tests for the various GVD assumptions ^{9),6),7)}. Below we first state our input conditions and then give our results.

INPUT CONDITIONS

The existence of four quarks, apart from colour, implies $U(4)$ symmetry for the current propagator at asymptotic energies ¹⁰⁾. The reason is that at these energies the differences in the quark masses are not important ⁸⁾. Combining this asymptotic $U(4)$ symmetry with local duality ¹¹⁾, we obtain

$$\frac{m_{\varphi_{cn}}^2}{f_{\varphi_{cn}}^2} = \frac{m_{\varphi_c}^2}{f_{\varphi_c}^2} ; \quad n = 0, 1, 2, \dots \quad (3)$$

where

$$\langle 0 | j_\mu^{em} | \varphi_{cn} \rangle = \frac{m_{\varphi_{cn}}^2}{f_{\varphi_{cn}}} \epsilon_\mu , \quad (4)$$

and

$$\begin{aligned} \frac{1}{f_p^2} : \frac{1}{f_\omega^2} : \frac{1}{f_\varphi^2} : \frac{1}{f_{\varphi_c}^2} &= 9 : 1 \frac{\alpha_\omega}{\alpha_p} : 2 \frac{\alpha_\varphi}{\alpha_p} : 8 \frac{\alpha_c}{\alpha_p} = \\ &= 9 : 1 : 1.68 : 1.6 . \end{aligned} \quad (5)$$

instead of the usual $SU(4)$ result $9:1:2:8$. The constants $\alpha_p, \alpha_\omega, \alpha_\varphi$ define the spacings of the p -, ω - and φ -like states ^{9),10),7)} in a fashion analogous to ^{*}) (1). It is worth emphasizing that GVD has induced a large (i.e., by a factor of five) $SU(4)$ breaking for the squares of the vector photon couplings in (5). This is solely due to the masses of the low vector mesons. Asymptotic $U(4)$ symmetry remains always exact. From Eqs. (3)-(5), we obtain ^{6),**)}

^{*}) It was obtained in Ref. 6) $\alpha_p = \alpha_\omega = 2, \alpha_\varphi = 1.6$.

^{**)} Actually there is an ambiguity in the application of local duality for φ_c . Depending on the interpretation we may obtain

$$\Gamma(\varphi_c \rightarrow h) \Gamma(\varphi_c \rightarrow e^+ e^-) / \Gamma_{\varphi_c} = 4.0 \pm 0.4 \text{ keV}$$

or the result quoted in the text [see Ref. 6].

$$\Gamma(\phi_c \rightarrow e^+e^-) \simeq 4.0 \pm 0.4 \text{ keV}; \quad \Gamma(\phi_{c1} \rightarrow e^+e^-) = 3.3 \pm 0.4 \text{ keV}.$$

These results may be in agreement ¹²⁾ with the colliding beam experiments ^{2),3)}, thereby providing some support for (3).

Following now Greco we also assume ⁹⁾

$$G_D(\phi_{cn} P) = \frac{m_{\phi_c}^2}{m_{\phi_{cn}}^2} G_D(\phi_c P). \quad (6)$$

This relation implies a scaling behaviour for the diffractive vector meson cross-sections. Such a result has been shown by Rittenberg and Rubinstein, in the framework of dual resonance models ¹³⁾. It is also of great relevance for scaling in deep inelastic electroproduction. The photoproduction of ϕ_c , ϕ_{c1} and hopefully ϕ_{c2} , offers a unique opportunity for an almost direct test of (6). Finally we use the diagonal approximation (DA) in process ⁹⁾ $V_1 N \rightarrow V_2 N$. This approximation simply neglects such processes when $m_{V_1}^2 \neq m_{V_2}^2$.

PHOTOPRODUCTION OF ϕ_c 's

From Eqs. (1), (3), (6), DA and the $c\bar{c}$ assumption for the new resonances we have ⁷⁾

$$\begin{aligned} \left. \frac{dG(\gamma P \rightarrow \phi_c P)}{dt} \right|_{t=0} &= \frac{\alpha}{16\pi} \cdot \frac{4\pi}{f_{\phi_{cn}}^2} G_D^2(\phi_{cn} P) = \\ &= \frac{1}{(1 + \alpha_{cn})^3} \cdot \left. \frac{dG(\gamma P \rightarrow \phi_c P)}{dt} \right|_{t=0}. \end{aligned} \quad (7)$$

Using (2), we get

$$\frac{\sigma(\gamma P \rightarrow \varphi_c(3.1) P)}{\sigma(\gamma P \rightarrow \varphi_{c1}(3.7) P)} = \left(\frac{B_{\varphi_{c1}}}{B_{\varphi_c}} \right) (1 + \alpha_c)^3 \simeq 3, \quad (8)$$

$$\frac{\sigma(\gamma P \rightarrow \varphi_c(3.1) P)}{\sigma(\gamma P \rightarrow \varphi_{c2}(4.1) P)} = \left(\frac{B_{\varphi_{c2}}}{B_{\varphi_c}} \right) (1 + 2\alpha_c)^3 \simeq 6.2, \quad (9)$$

when the slope parameters satisfy

$$B_{\varphi_c} \simeq B_{\varphi_{c1}} \simeq B_{\varphi_{c2}} \quad (10)$$

We remark that the ratios in (8) and (9) depend only on the spacing parameters α_c and n .

From (5) and DA we also have

$$\left. \frac{d\sigma(\gamma P \rightarrow \varphi_c P)}{dt} \right|_{t=0} = \frac{\alpha}{18\pi} \left(\frac{4\pi}{f_\rho^2} \right) \left(\frac{\alpha_c}{\alpha_\rho} \right) G_D^2(\varphi_c P), \quad (11)$$

To estimate $\sigma_D(\varphi_c P)$ we recall that the application ⁷⁾ of (1)-(6) and DA to deep inelastic electroproduction and photoproduction shows that

$$G_D(\varphi_c P) \ll \frac{m_\rho^2}{m_{\varphi_c}^2} G_D(\rho P) \simeq 1.4 \text{ mb}, \quad (12a)$$

for $\sqrt{s} \lesssim 7 \text{ GeV}$. Substituting $B_{\varphi_c} \simeq (3-8) \text{ GeV}^{-2}$ and (12a) in (11) we obtain

$$\sigma(\gamma P \rightarrow \varphi_c P) \ll (5-25) \text{ mb}. \quad (12b)$$

This is in agreement with experiment ¹⁴⁾. On the other hand at very high energies (i.e., $\sqrt{s} \gg 7$ GeV) there are not yet deep inelastic data to guide us. Relying on the tensor dominated Pomeron dynamics and SU(4) symmetry for the tensor-vector-vector (TVV) couplings, we expect that ^{15),16)}

$$\sigma_D(\varphi_c P) \sim \frac{\alpha'_P}{\alpha'_{\varphi_c}} \left(\frac{m_P^2}{m_{\varphi_c}^2} \right) \sigma_D(P P) \simeq 4.5 \text{ mb}, \quad (13a)$$

and

$$\sigma(\chi P \rightarrow \varphi_c P) \sim (16-20) \text{ mb}, \quad (13b)$$

where $\alpha'_P = 0.8$, $\alpha'_{\varphi_c} = 0.25$. These results are very rough, since SU(4) breaking for the (TVV) couplings may easily induce a large violation ^{*}) in (13). They can be made intuitive though, as follows. We know that the Pomeron couples stronger to the non-strange than to the strange quarks, since

$$\frac{\sigma_D(P P)}{\sigma_D(\varphi P)} \sim 2.$$

It seems therefore natural to expect that the Pomeron coupling to the charmed quarks will be even smaller, thereby giving a small value for $\sigma_D(\varphi_c P)$.

The experimental verification of (8), (9) for the $\varphi_c, \varphi_{c1}, \varphi_{c2}$ mesons, as well as the validity of (13), will provide strong support to the charm, as opposed to the colour octet interpretation. Indeed, if we assume that φ_c, φ_{c1} are the colour-octet analogues of ω, φ respectively, we find for their couplings to the photon ¹⁷⁾

$$\frac{1}{f_{\varphi_c}^2} : \frac{1}{f_{\varphi_{c1}}^2} = 2. \quad (14)$$

^{*}) See discussion following Eqs. (5).

Now it is crucial to observe that, in the colour scheme, φ_c and φ_{c1} would be made out of the same quarks as the ordinary ω and φ . The only difference would be that the quarks would now combine to make colour octets instead of singlets. For example, we have

$$\varphi = \frac{1}{\sqrt{3}} (\lambda_R \bar{\lambda}_R + \lambda_W \bar{\lambda}_W + \lambda_B \bar{\lambda}_B) , \quad (15a)$$

while 17)

$$\varphi_{c1} = \frac{1}{\sqrt{6}} (\lambda_R \bar{\lambda}_R + \lambda_W \bar{\lambda}_W - 2 \lambda_B \bar{\lambda}_B) \quad (15b)$$

and correspondingly

$$W = \frac{1}{\sqrt{6}} (P_R \bar{P}_R + \eta_R \bar{\eta}_R + P_W \bar{P}_W + \eta_W \bar{\eta}_W + P_B \bar{P}_B + \eta_B \bar{\eta}_B) , \quad (15c)$$

$$\varphi_c = \frac{1}{\sqrt{12}} (P_R \bar{P}_R + \eta_R \bar{\eta}_R + P_W \bar{P}_W + \eta_W \bar{\eta}_W - 2 P_B \bar{P}_B - 2 \eta_B \bar{\eta}_B) . \quad (15d)$$

Using again tensor-dominated Pomeron dynamics ^{15),16)} (or the quark counting rules) and $SU(3)_{\text{colour}}$ symmetry, we expect at very high energies that

$$\sigma_D(\varphi_c P) \simeq \sigma_D(\omega P) \simeq 23 \text{ mb} , \quad (16a)$$

$$\sigma_D(\varphi_{c1} P) \simeq \sigma_D(\varphi P) \simeq 11.6 \text{ mb} . \quad (16b)$$

The assumptions entering the derivation of (16) are similar to those of (13a). Notice that (16) does not have any mass-dependent depressing factors ¹⁵⁾ as does (13a). Using (14), (16), we obtain

$$\frac{\sigma(\gamma P \rightarrow \varphi_c(3.1)P)}{\sigma(\gamma P \rightarrow \varphi_{c1}(3.7)P)} \simeq \frac{f_{\varphi_{c1}}^2}{f_{\varphi_c}^2} \cdot \frac{\sigma_D^2(\varphi_c P)}{\sigma_D^2(\varphi_{c1} P)} \simeq 8 , \quad (17)$$

in the colour scheme.

Equations (16), (13) imply that photoproduction of φ_c , being proportional to $\sigma_D^2(\varphi_c p)$, will be at high energies, at least an order of magnitude bigger in the colour than in the charm case. Moreover, from (17), (8), we see that the ratio of the φ_c to φ_{c1} production, is at least twice as large for colour than for charm. We conclude therefore that photoproduction experiments will probably provide a clear distinction between the charm and colour interpretations of the new resonances.

DIFFRACTIVE ELECTROPRODUCTION OF THE φ_c 's

The availability of high energy lepton beams makes now possible the electroproduction φ_c 's. We hope that missing mass electroproduction experiments will be able to study the first two or three of them. Using DA we predict ⁷⁾

$$\frac{\sigma_L(\gamma^* P \rightarrow \varphi_{cn} P)}{\sigma_T(\gamma^* P \rightarrow \varphi_{cn} P)} \sim \frac{q^2}{v^2}, \quad (18)$$

$$\sigma_T(\gamma^* P \rightarrow \varphi_{cn} P) = \left(\frac{m_{\varphi_{cn}}^2}{q^2 + m_{\varphi_{cn}}^2} \right)^2 \sigma(\gamma P \rightarrow \varphi_{cn} P), \quad (19)$$

where $(n=0,1,\dots)$ and q^2, v are the four-momentum squared and the lab energy of the virtual photon, respectively. Notice that the cross-sections are mainly transverse and that the form factor in (19) depends on $m_{\varphi_{cn}}^2$. The experimental validity of (19) for φ_c, φ_{c1} and hopefully φ_{c2} , will provide a crucial test of DA in GVD.

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