Ref.TH.1986-CERN

THE SU(3) PROPERTIES OF THE PHOTON AND THE NEW RESONANCES

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ABSTRACT

We propose some model-independent tests for the presence of an SU(3) singlet piece in the electromagnetic current. Tests are also proposed to determine whether or not the new resonances $\psi(3.105)$ and $\psi'(3.965)$ are admixtures of an SU(3) singlet and the eighth component of an octet. It is pointed out that the study of e^+e^- annihilation into certain exclusive channels can help to resolve the SU(3) structure of the photon, ψ and ψ' .

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A common feature of many theoretical models (gauge theories, quark models, schemes with charm or colour) is that in addition to the usual octet part, they require a piece in the electromagnetic current which transforms like an $SU(3)$ singlet. Clearly, it is very important to put experimental limits on the presence of this singlet piece, independently of any particular model. The presence of an $SU(3)$ singlet part in the photon is also relevant for the newly discovered resonances $\psi(3.105)$ ¹⁾ and $\psi'(3.695)$ ²⁾, since their decays into a lepton-antilepton pair seem to proceed through a photon. This coupled with the decay modes $\psi \rightarrow 5\pi$ or 7π (no even number of pions) and $\psi' \rightarrow \psi + 2\pi$ suggest their G conjugation parity G and charge conjugation parity C to be odd, so the simplest choice for their isospin is $I=0$. However, they could be pure $SU(3)$ singlets or the eighth component of an octet or a mixture depending on whether the photon has an $SU(3)$ singlet part or not. In this note we consider some tests for the presence of an $SU(3)$ singlet piece in the electromagnetic current as well as the $SU(3)$ properties of the ψ and ψ' , which we take to be 1^- vector particles for our discussion.

To obtain reasonably clear tests for an $SU(3)$ singlet piece, it is clear that one-photon processes offer the best possibility. We consider the various processes one by one.

1. VECTOR MESON NONET (ρ, ω, ϕ) DECAYS INTO e^+e^-

The decays have already been considered some years ago by Mathur and Okubo ³⁾ and we refer the reader to their work.

2. DEEP INELASTIC LEPTON-PROTON PROCESSES

Lipkin and Paschos ⁴⁾ have suggested that testing of inequalities on the structure functions may help in deciding the $SU(3)$ structure of the photon.

3. MAGNETIC MOMENTS OF THE BARYONS

The presence of an $SU(3)$ single will affect the Coleman and Glashow ⁵⁾ sum rules. The new sum rules are

$$\begin{aligned} \mu_p &= \mu_{\Sigma^+} & \mu_{\Sigma^-} &= \mu_{\Xi^-} & \mu_{\Xi^0} &= \mu_n \\ 2\mu_{\Sigma^0} &= \mu_{\Sigma^+} + \mu_{\Sigma^-} \end{aligned} \quad (1)$$

$$\mu_{\Sigma^-} = -\mu_p - 4\mu_n + 6\mu_\Lambda \quad (2)$$

$$\mu_{\Sigma^0} = 3\mu_\Lambda - 2\mu_n \quad \mu_{\Lambda\Sigma^0} = \sqrt{3}(\mu_\Lambda - \mu_n) \quad (3)$$

where we have expressed the magnetic moments in terms of μ_p , μ_n and μ_Λ which are the best determined experimentally. The relations (1) are the same as before, however, (2) and (3) are different. In the absence of a singlet part $2\mu_\Lambda = \mu_n$, and one would recover the old relations. We feel a more accurate determination of μ_Λ , μ_{Σ^+} etc., is needed to make a firm estimate of the singlet contribution. Let us only mention that for relation (2) the experimental values for the right-hand side is 0.73 ± 0.3 , whereas the left-hand side (μ_{Σ^-}) is only quoted to lie between -1.6 and $+0.8$.

4. e^+e^- ANNIHILATION INTO EXCLUSIVE CHANNELS

In annihilation, through one photon, into the quasi-two-body channels $P+V$ and $T+V$ one can hope to see the presence of an $SU(3)$ singlet piece in the electromagnetic current. The P , V and T stand for the pseudo-scalar $0^- (\pi, K, \eta; \eta')$, the vector $1^- (\rho, K^*(892), \phi; \omega)$ and the tensor $2^+ (A_2, K_T^*(1420), f; f')$ nonets. We use C^6 which can be defined for a self-conjugate octet as being equal to the charge conjugation number C of the eighth component. Thus $C = +1$ for P and T and -1 for V and the photon γ . The C selection rule (or equivalently one can use U spin arguments) requires that only the symmetrical combination of PV or TV couples to the photon. Denote by $\gamma(8)$ and $\gamma(1)$ the octet and $SU(3)$ singlet part of the photon, and define the amplitudes $A_8 \equiv \gamma(8) \rightarrow (PV)_{SD}$ and $A_1 \equiv \gamma(1) \rightarrow (PV)_1$. Then a straightforward $SU(3)$ analysis gives ($a \equiv A_1/A_8$)

$$\frac{\sigma(e^+e^- \rightarrow \pi^+\rho^-)}{\sigma(e^+e^- \rightarrow K^+\bar{K}^{*0})} = \left| \frac{1-a}{2+a} \right|^2 \quad (4)$$

In addition, one has $\sigma(e^+e^- \rightarrow K^0\bar{K}^{*0}) = \sigma(e^+e^- \rightarrow \bar{K}^0 K^{*0})$ and $\sigma(e^+e^- \rightarrow \pi^+\rho^-) = \sigma(e^+e^- \rightarrow K^+\bar{K}^{*0}) = \sigma(e^+e^- \rightarrow K^-\bar{K}^{*+}) = \sigma(e^+e^- \rightarrow \pi^-\rho^+) = \sigma(e^+e^- \rightarrow \pi^0\rho^0)$, which hold irrespective of whether the $SU(3)$ singlet part is present or not. We have not listed the other not so useful $SU(3)$ relations. Since the $K^* \rightarrow K\pi$, $\rho \rightarrow 2\pi$ decay by strong interactions, the complete identification of the quasi-two-body $P+V$ channel would require the measurement of all the three

resulting pseudoscalars and would be difficult experimentally. However, one may obtain an estimate of a , through the ratio

$$r_1(s) = \frac{\sigma(e^+e^- \rightarrow \pi^0 \rho^0 \rightarrow \pi^0 \pi^+ \pi^-)}{\sigma(e^+e^- \rightarrow K^0 \bar{K}^{*0} \rightarrow K^0 \pi^+ K^-)} = \frac{3}{2} \left| \frac{1-a}{2+a} \right|^2 \rho_T(s) \quad (5)$$

where $\sqrt{s}$ = total c.m. energy of the e^+e^- system.

The momenta of π^+ and π^- in one case, and π^+ and K^- in the other can be measured and one can check that they resonate and then make a 1C constraint for the undetected π^0 and K^0 to determine the ratio. The phase space correction factor ρ_P , using the coupling

$$\frac{1}{\sqrt{s}} g_{\pi V \rho} \varepsilon^{\mu\nu\sigma\lambda} F_{\mu\nu} V_\sigma \partial_\lambda P$$

comes out to be $(k_1/k_2)^3$, where k_1 and k_2 are the c.m. momenta for $\pi^0 \rho^0$ and $K^0 \bar{K}^{*0}$, for a given $\sqrt{s}$.

With a 1C fit it may possibly be cleaner to study the ratio

$$r_2(s) = \frac{\sigma(e^+e^- \rightarrow K^+ K^{*-} \rightarrow K^+ \bar{K}^0 \pi^-)}{\sigma(e^+e^- \rightarrow \bar{K}^0 K^{*0} \rightarrow \bar{K}^0 K^+ \pi^-)} = \left| \frac{1-a}{2+a} \right|^2 \quad (6)$$

to estimate 'a'. Note in this case no phase space correction is necessary.

$e^+e^- \rightarrow T+V$

The SU(3) analysis for this is exactly the same as that for $e^+e^- \rightarrow P+V$, and all one has to do is to replace P by T . However, the phase space and other factors for specific states of kaons and pions are different. Further the $K^{*+} K_T^{-*}$ or $K_T^{-*} K^{*+}$ will be hard to identify as they go to $K \bar{K} \pi \pi$ combinations involving two neutrals. In this case one can hope to study the ratio

$$r_3(s) = \frac{\sigma(e^+e^- \rightarrow \rho^+ A_2^- \rightarrow 2\pi^+ 2\pi^- \pi^0)}{\sigma(e^+e^- \rightarrow K^{*+} \bar{K}_T^{*-} \rightarrow \pi^- K^+ \pi^+ K^-)} = 1.45 \left| \frac{1-b}{2+b} \right| \rho_T(s) \quad (7)$$

where b is the ratio of the amplitudes $\gamma(1) \rightarrow T+V$ and $\gamma(8) \rightarrow T+V$. The factor 1.45 comes from the Clebsch-Gordan coefficients and the experimental branching ratio ⁷⁾ for $A_2^- \rightarrow \rho^0 \pi^-$ and $\bar{K}_T^{*0} \rightarrow \pi^+ K^-$. To obtain an estimate of the phase space factor ρ_T we have used the simple coupling $1/\sqrt{s} g_{TV} F^{\mu\nu} T_{\mu\alpha} (\partial_\nu V^\alpha)$. This gives

$$P_T(s) = \frac{p_1^5 [P(m_v, m_T) \cdot Q(s, m_v, m_T)]_{\rho A_2}}{p_2^5 [P(m_v, m_T) \cdot Q(s, m_v, m_T)]_{K^* K_T^*}} \quad (8)$$

with

$$P(m_v, m_T) = \frac{1}{m_v^2 m_T^2}$$

and

$$Q(s, m_v, m_T) = 2s + 4m_v^2 + 3m_T^2$$

Further p_1 and p_2 are the c.m. momenta for $\rho^+ A_2^-$ and $K^{0*} \bar{K}_T^{0*}$, respectively, for a given total c.m. energy $\sqrt{s}$. As an example for $\sqrt{s} = 2.5$ GeV, $p_T = 10.88$. (Note that the $K^{0*} \bar{K}_T^{0*}$ threshold is at 2.3 GeV!)

5. PHOTOPRODUCTION OF VECTOR MESONS

The processes $\gamma N \rightarrow V^0 N$, where $V^0 = \rho^0, \omega, \phi$, at high energies may tell us something about the SU(3) singlet part of the photon. At high energies we assume that this process results from $\gamma \rightarrow V^0$ and the V^0 scatters through a Pomeron [an SU(3) singlet] exchange on the nucleon N. If the photon has an SU(3) singlet piece, then one would expect

$$\frac{\sigma(\gamma N \rightarrow \omega N)}{\sigma(\gamma N \rightarrow \phi N)} = \left(\frac{\sin \theta_v - \beta \cos \theta_v}{\cos \theta_v + \beta \sin \theta_v} \right)^2 \cdot \frac{\sigma(\omega N \rightarrow \omega N)}{\sigma(\phi N \rightarrow \phi N)} \quad (9a)$$

and

$$\frac{\sigma(\gamma N \rightarrow \rho^0 N)}{\sigma(\gamma N \rightarrow \phi N)} = \frac{3}{(\cos \theta_v + \beta \sin \theta_v)^2} \cdot \frac{\sigma(\rho^0 N \rightarrow \rho^0 N)}{\sigma(\phi N \rightarrow \phi N)} \quad (9b)$$

where β is the ratio of the coupling of the singlet part $\gamma(1)$ to $V_1 = \sin \theta_v \phi + \cos \theta_v \omega$ to the usual coupling of the octet part $\gamma(8)$ to $V_8 = \cos \theta_v \phi - \sin \theta_v \omega$, and θ_v is the ω - ϕ mixing angle. The data available at present energies require other exchanges in addition to the Pomeron, to understand $\gamma N \rightarrow \omega N$. So to obtain an estimate of β from (9a) one has to wait for data at much higher energies. However, present energies do permit an estimate of β from (9b), as both the processes involved there proceed predominantly through Pomeron exchange. Unfortunately, the errors are too large to obtain a meaningful estimate of β 8).

It is interesting to note that, both in the Han-Nambu colour ⁹⁾ or "charm" SU(4) ¹⁰⁾ schemes, $\beta = 0$. It should be noted that if γ is purely octet and ψ (or ψ') a pure SU(3) singlet, then it cannot be diffractively produced like the other vector mesons. Experimentally, the photoproduction of ψ ¹¹⁾ has been seen, though the cross-section for $\gamma N \rightarrow \psi N$ seems smaller than that for ρ^0, ω, ϕ . This diffractive photoproduction of ψ would suggest that either the photon has a singlet part or ψ has an octet part, or both are mixtures of an SU(3) singlet and octet. More accurate experiments of the photoproduction of ψ and ψ' would be very useful in unravelling the SU(3) classification of these resonances.

6. SU(3) PROPERTIES OF $\psi(3.105)$ AND $\psi'(3.695)$

We take these to be 1^- vector mesons with $I=0$ and $G=C=-1$, for reasons mentioned earlier. Consequently, they have $C=-1$ like the photon. The only way they differ from a photon is in not having a $I=1$ part. For simplicity we assume that ψ be a mixture of SU(3) singlet part denoted by $\psi(1)$ and the eighth component of an octet, $\psi(8)$. We make the discussion in terms of ψ and mention later the modifications necessary for the case of ψ' . Denote by c the ratio of the amplitudes $\psi(1) \rightarrow P+V$ and $\psi(8) \rightarrow P+V$. The C selection rule permits only symmetrical couplings of ψ to PV (or TV). The simple SU(3) analysis, at $\sqrt{s} = 3.105$ gives

$$\frac{\sigma(e^+e^- \rightarrow \pi^+\rho^-)}{\sigma(e^+e^- \rightarrow K^0\bar{K}^{0*})} = \left| \frac{2-c}{1+c} \right|^2 \quad (10)$$

In addition, one has the relations $\sigma(e^+e^- \rightarrow K^0\bar{K}^{0*}) = \sigma(e^+e^- \rightarrow \bar{K}^0 K^{0*}) = \sigma(e^+e^- \rightarrow K^+\bar{K}^{*-}) = \sigma(e^+e^- \rightarrow K^-\bar{K}^{+*})$ and $\sigma(e^+e^- \rightarrow \pi^+\rho^-) = \sigma(e^+e^- \rightarrow \pi^-\rho^+) = \sigma(e^+e^- \rightarrow \pi^0\rho^0)$, which are true even if ψ is an arbitrary mixture of $\psi(1)$ and $\psi(8)$. It is interesting to compare (10) with (4). In particular, we note that for a pure octet γ ($a=0$), singlet ψ ($c=\infty$) and pure octet ψ ($c=0$), the indicated ratio is $1/4$, 1 and 4 , respectively. Thus, the study of the ratio $r_1(s)$ at the resonance and away from it would tell us about the SU(3) properties of the photon and ψ . Note that at $\sqrt{s} = 3.105$, $\rho_P = 1.17$.

In particular, in both a charm model and a Han-Nambu colour model for the new particles, ψ would be a pure SU(3) singlet and one would expect that $c=\infty$. Furthermore, a direct coupling of ψ to ordinary hadrons is suppressed in both cases (either by Zweig's rule or by colour conservation), so that both interpretations would prefer a ψ coupled through a photon

to the final hadrons. In our language this would imply that $r_1(s)$ is given by (5) and does not change across the resonance. This, in turn, would mean that the photon has an $SU(3)$ singlet part. On the other hand, from experiments [namely from the difference of $\sigma(\text{hadrons})/\sigma(\mu\mu)$ at the resonance and outside], one can argue that ψ couples to the hadrons directly about 80% of the time. However, the situation is far from clear, therefore a study of the variation of $r_1(s)$ across the resonance would help in the understanding of this problem.

For $e^+e^- \rightarrow T+V$ channel, one obtains

$$r_3(\sqrt{s} = 3.105) = 1.45 \left| \frac{2-d}{1+d} \right|^2 \rho_T(3.105) \quad (11)$$

where d is the ratio of the amplitudes $\psi(1) \rightarrow T+V$ and $\psi(8) \rightarrow T+V$. Using (8), $\rho_T(3.105) = 2.94$.

The study of the ratio r_3 across the mass of the ψ would be very interesting. The remarks about $r_1(s)$ above apply to $r_3(s)$ also. In this context, it should be remarked that experimentally $\psi \rightarrow 2\pi^+ 2\pi^- \pi^0$ ($\sim 30\%$), and $\psi \rightarrow K^+ K^- \pi^+ \pi^-$ ($\sim 1\%$) decay channels have been seen ¹²⁾.

The $SU(3)$ transformation property of the ψ' can be studied by examining $r_1(s)$ and $r_3(s)$ across $\sqrt{s} = 3.695$. We only note that $\rho_P = 1.11$ and $\rho_T = 2.33$ at the ψ' mass.

It seems that experimentally the $K\bar{K}$ decay mode of ψ and ψ' is not seen or is suppressed ¹²⁾. This can be understood if they are $SU(3)$ singlets, because then their decay into $P+P$ is forbidden by the C selection rule. If they are $SU(3)$ singlets, then the question of an $SU(3)$ singlet piece in the electromagnetic current may become easier to answer experimentally in the context of the remarks above. We realize that the tests proposed above would be extremely hard to study experimentally. However, we feel that the detection of an $SU(3)$ singlet piece in the electromagnetic current would be of fundamental importance and deserves vigorous experimental study.

Acknowledgements

We would like to thank F.E. Close, G.V. Dass and C.A. Heusch for discussions regarding photoproduction. We are grateful to Prof. J.S. Bell for a critical reading of the manuscript and suggestions.

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