Abstract. The scalar meson G(1590) is considered as a possible glueball. The decay mechanism, characteristic of a glueball, is proposed (the discolouring of gluons by gluons) which allows one to understand the increase of $G \to \eta \eta$ decay rate, as compared to the decays $G \to \pi \pi$ and $G \to K \bar{K}$ observed in the experiment. It is proposed to measure the ratio of branching ratios $R = BR(G \to \eta \eta') / BR(G \to \eta \eta)$, which is sensitive to the gluon content of G(1590). In the one-pion exchange model the predicted $R$ values are within the range: $2 < R < 3.7$.

1. Introduction

The recent paper [1] reported on the observation of a new scalar meson G(1590) decaying into a pair of $\eta$-masons, produced in the $\pi^- p$ exclusive charge-exchange channel:

$$\pi^- p \to G \eta \to \eta \eta.$$ (1)

Its mass and full width are $M = (1592 \pm 25)$ MeV and $\Gamma = (210 \pm 40)$ MeV. Its quantum numbers are $I^G(J^G C) = 0^+(0^+)$ . G(1590)-meson production cross-section in channel (1) at 38 GeV/c incoming pion momentum is equal to

$$\sigma(\pi^- p \to Gn) \cdot BR(G \to \eta \eta) = (33 \pm 8) \text{nb.}$$ (2)

A remarkable feature of G(1590)-meson is the suppression of $G \to \pi \pi$ decay channel as compared to $G \to \eta \eta$: $BR(G \to \pi^0 \pi^0) / BR(G \to \eta \eta) < 1/3$ (3) as well as the absence of $G \to K \bar{K}$ decays at the level of $BR(G \to K \bar{K}) / BR(G \to \eta \eta) < 0.6$. (4)

The last conclusion in [1] has been made using $S$-wave data on the $\pi^- p \to K \bar{K} n$ reaction [2]. It excludes the possibility to interpret G(1590) as a state with hidden strangeness or a four-quark state $(u\bar{u} + d\bar{d})s\bar{s}/\sqrt{2}$.

Since it is difficult to relate the observed properties of G(1590)-meson to the state composed of normal quarks, it is proposed to interpret it as a glueball (gluonium) [1]. This letter presents the arguments in favour of this viewpoint. The additional possibility to check it up experimentally is pointed out.

2. Gluon Discolouring

First of all let us show that in the framework of the above hypothesis one may qualitatively explain the increase of $G \to \eta \eta$ decay rate, as compared to $G \to \pi \pi$, $K \bar{K}$. Usually, when considering scalar gluonium decays into mesons composed of quarks, the diagrams are taken into account which correspond to the transition of two gluons into a quark–antiquark pair $q\bar{q}$, with its further transformation into a meson pair $\pi \pi$, $K \bar{K}$, $\eta \eta$ etc. (see, e.g. Fig. 1a) or into multimeson states (Fig. 1b).

The treatment of these transitions in the framework of the QCD perturbation theory shows their smallness (of $\alpha_s^2$ order). However, in the case of scalar gluonium the account for nonperturbative corrections eliminates the suppression and results in a large (200 $\div$ 300 MeV) width of this state [3].

At the same time one should note that the conclusion on the large full width of scalar gluonium may be linked to multi-meson decay channels, not contradicting the smallness of two-meson channels. On the other hand, if to restrict oneself to the graphs of Fig. 1 only it would be impossible to explain the increase of decays via $\eta \eta$ channel, as compared with $\pi \pi$ and $K \bar{K}$.

Such a possibility appears if side by side with the diagrams of Fig. 1 the diagram shown in Fig. 2 is taken into account which is a gluon analogue of the ordinary planar diagrams in a quark sector. The use of this diagram seems quite natural due to the “gluonium” nature of $\eta$ and $\eta'$ mesons [4]. The existence of a strong coupling of $\eta$ and $\eta'$ with two-gluon...
channel follows directly from the data on the radiative decays $J/\psi \rightarrow \gamma gg \rightarrow J/\psi \rightarrow \gamma + \text{hadrons}$, where clear transitions $J/\psi \rightarrow \gamma \eta$ and $J/\psi \rightarrow \gamma \eta'$ are seen. From the theoretical point of view two-gluon channel is linked not only to SU(3)$_c$-singlet but also to SU(3)$_c$-octet because of symmetry breaking. This former takes place e.g. due to the large mass of a strange quark [4].

The account for the two-gluon component in the $\eta$ and $\eta'$ structure [3] allows one to estimate the ratio of the probabilities of radiative decays $J/\psi \rightarrow \gamma \eta$ and $J/\psi \rightarrow \gamma \eta'$ which is expressed through the matrix elements

$$A_\eta = \left\langle 0 \left| \frac{3}{4} \frac{\sigma^2}{\pi} G^a_{\mu \nu} \bar{G}^a_{\mu \nu} \right| \eta \right\rangle \approx \frac{3}{2} f_\eta m_\eta^2;$$

$$A_{\eta'} = \left\langle 0 \left| \frac{3}{4} \frac{\sigma^2}{\pi} G^a_{\mu \nu} \bar{G}^a_{\mu \nu} \right| \eta' \right\rangle \approx \frac{3}{4} f_{\eta'}^2 m_{\eta'}^2.$$  

The calculated ratio $BR(J/\psi \rightarrow \gamma \eta')/BR(J/\psi \rightarrow \gamma \eta) = 3.7$ [3] agrees well, within the theoretical calculation uncertainty, with the experimentally obtained value [5].

$$BR(J/\psi \rightarrow \gamma \eta') = 4.7 \pm 0.6.$$  

The above-made assumption on the gluon nature of $G(1590)$-meson and the dominance of the contribution of Fig. 2 diagram in its two-particle decay modes allows not only to explain qualitatively the increase of $G \rightarrow \eta \eta$ decay rate but also to predict, when using (5) and (5'), the ratio of $G \rightarrow \eta \eta'$ and $G \rightarrow \eta \eta$ decay probabilities:

$$R = \frac{BR(G \rightarrow \eta \eta')}{BR(G \rightarrow \eta \eta)} = \frac{A_{\eta'}}{A_\eta} \left\langle \frac{P_{\eta'}}{P_\eta} \right\rangle \approx \left( \frac{m_\eta}{m_{\eta'}} \right)^4 \frac{P_{\eta'}}{P_\eta} \approx 4.$$  

(7)

(here $P_{\eta'}/P_\eta = 0.427$ is the ratio of phase spaces in $G \rightarrow \eta \eta'$ and $G \rightarrow \eta \eta$ channels).

The increase of $\eta \eta$ two-meson decay channel relative to $\pi \pi$ and $KK$ decays is a unique glueball's property which arises due to the discoloring of gluons by gluons. Therefore, it may be considered as one of the most important signatures of a glueball.

Another essential sign is that relation (7) holds for glueballs. Since, however, relation (7) was obtained under the assumption on the dominant contribution of Fig. 2 diagram, it is necessary to estimate how ratio (7) varies when other decay mechanisms are taken into account.

3. Account for Quark Diagrams and OPE Model

As it was pointed out in paper [1], the cross-section of reaction (1) is well described in one-pion exchange model (OPE), analogously to charge-exchange reactions of pions into $\rho, \phi, g, h, r$ mesons on protons. This means that there exists a coupling $G \rightarrow \pi \pi$ due to the contribution of the Fig. 1a diagram. The same diagram generates the coupling of $G$ with other two-particle channels: $KK, \eta \eta$ and $\eta \eta'$. Though, according to our assumption the contribution of Fig. 2 diagram dominates as compared to Fig. 1a nevertheless the interference of these two contributions in $G \rightarrow \eta \eta$ and $G \rightarrow \eta \eta'$ decays may change the numerical value of relation (7). Below we give the estimation of this effect using OPE model.

If one assumes that the appearance of strange quarks in annihilation diagrams is suppressed by a factor $f^2$ (usually it is assumed that $f^2 = 1/3 + 1/2$) then to the Fig. 1a diagram there corresponds the amplitude of the transition $M_1$ into the state

$$|2\pi^+\pi^- + \pi^0 n^0\rangle + 2f(K^+ K^- + K^0\bar{K}^0) + \eta\eta'(|\sin^2\delta + f^2 \cos^2\delta + \eta\eta'(|\cos^2\delta + f^2 \sin^2\delta)$$

$$- 2\eta\eta'(1 - f^2)) \sin\delta \cos\delta \rangle,$$

where $\delta = \theta - 35.3^\circ$, and $\theta$ is the octet-singlet mixing angle for pseudoscalar mesons.

To the diagram of Fig. 2 there corresponds the amplitude of the transition $M_2$ into the state

$$|\eta\eta + 2r\eta\eta' + r^2\eta\eta'\rangle$$

where $r$ is the ratio of the effective coupling constants of $\eta'$ and $\eta$ with two gluons in $0^-$ state (we note that amplitude (8) at $f^2 < 1$ like amplitude (9) doesn't contain the suppression, pointed out by H. Lipkin, of glueball decay via $\eta \eta'$ channel). Taking into account the direct coupling with gluons only (as it was made in [3]) one has $r = A_{\eta'}/A_{\eta}$ (5). It is more preferable, however, to use directly for $r$ the experimentally obtained ratio (6) taking into account the uncertainty in the theoretical calculations. In this case one has:

$$r^2 = \frac{BR(J/\psi \rightarrow \gamma \eta')}{BR(J/\psi \rightarrow \gamma \eta)} \frac{K_{\eta'}^3}{K_{\eta}^3} = (4.7 \pm 0.6)1.23 = 5.8 \pm 0.7$$

(10)