Reaction $\gamma p \to F^+F^-p$ as a possible test for 0^{++} glueball state

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The reaction $\gamma p \to F^+F^-p$, which seems most appropriate to throw some light on the existence of a scalar glueball, and which also could be used to decide about the mass scale of this object, is examined. The total-invariant-mass and squared-momentum-transfer distributions are obtained, and the coupling of the glueball candidate to F^+F^- is estimated.

Quantum chromodynamics leads in hadronic spectroscopy to the possibility of a new type of hadrons, called glueballs.[1] The present status of these objects is summarized in many reviews.[2] For the $J^{PC}=0^{++}$ glueball state, phenomenological predictions based on some different models lead to a large mass-scale range. Indeed we find the following predictions: from potential theory[3] $m(0^+)=1.15$ GeV; from the effective-Lagrangian approach[4] $1.0 \lesssim m(0^+) \lesssim 2.0$ GeV; the string model[5] predicts a $J^P=0^{(?)}$ unstable state with mass equal to 1.7 GeV; lattice theory[6] gives $m(0^+) \lesssim 1.0$ GeV; and the MIT bag model[7] gives $m(0^+) \sim 1.0$ GeV. The ITEP group[8] predicts a mass $m(0^+) \sim 1.4$ GeV.

In this Brief Report we wish to propose a reaction which can be used to throw some light on the question, and even on the existence of the glueballs, if $m(0^+) \sim 4.0$ GeV. This choice is based on the assumption that a good place to search for glueballs is in reactions in which it is possible to observe a violation of the suppression due to the Okubo-Zweig-Iizuka (OZI) rule,[9] as has been stressed in an earlier paper.[10] There, a model was proposed which explains the main features of the experimental data of the reaction $\pi^- p \to \phi\phi n$ (Ref. 11) starting from the introduction of a 2^{++}-glueball-exchange mechanism to generate the violation of the OZI rule.[10,12] The fact that in the 2–3-GeV range of the $\phi\phi$ mass no S wave of $\phi\phi$ was observed as would be produced by a spin-zero glueball is in agreement with Refs. 3–8, i.e., $m(0^+) \approx 1$ GeV.

In the framework of that model we study here the glueball contribution to the final state F^+F^-. In order to observe such a state and simultaneously test the ITEP-group mass prediction, we consider a reaction of the type $\gamma p \to Xp$ with X in a S-wave state, where we assume the following.

(i) The vector-dominance model for the photon-induced reaction is good. Thus, the photon amplitude can be related to the vector-meson-induced amplitudes as

$$A_{\text{photon}} = \sum_i \left(\frac{e}{2\gamma_i}\right) A^{(i)}_{V\,\text{meson}} \;, \tag{1}$$

where $1/2\gamma_i$ is the photon-(i)-meson coupling strength and the summation is over all vector mesons $(V^{(i)})$, $\rho, \omega, \phi, \ldots$. The fact that we observe a proton both in the final and in the initial states and that X is in an S wave determines the exchanged particle as V^i.

(ii) The OZI rule can be applied and for this X cannot have quarks u and d as we will discuss below. This limits our analysis to the possibility $m(0^+) \sim 4.0$ GeV.

(iii) The invariant mass of X must be near 4.0 GeV, which suggests observing charmed mesons as X. Indeed the only charmed and (or) strange meson[13] satisfying these conditions is the $F(1971)$ with $J^P=0^-$, which is a $(c\bar{s})$ state.

The $A^{(i)}$ amplitude representing the reaction $\gamma p \to F^+F^-p$ via $V^{(i)}$ can be easily constructed using the same model used in Ref. 10 (see Fig. 1):

$$A^{(i)}_{V\,\text{meson}} = R(V^{(i)}p \to Gp)\Phi(s_1)T(G \to F^+F^-) \;, \tag{2}$$

where R represents the production amplitude, via $V^{(i)}$,

$$\Phi(s_1) = [s_1 - M^2 + iM\Gamma(s_1)]^{-1} \tag{3}$$

is the glueball resonance propagator with mass M, and T represents the decay amplitude. The production mechanism can be treated as a high-energy $2 \to 2$ reaction well described by a standard $V^{(i)}$-exchange Reggeized amplitude:[14]

$$\frac{R(V^{(i)}p \to Gp)}{g_{\rho pp}g_{\rho\rho G}} = \tilde{g}_{ipp}\tilde{g}_{iiG}\{1 - \exp[-i\pi\alpha_i(t_2)]\} \times \left(\frac{s}{s_0}\right)^{\alpha_i(t_2)} \frac{1}{\sin\pi\alpha_i(t_2)} \;, \tag{4}$$

where $\alpha_i(t_2)$ is the $V^{(i)}$ trajectory, $s_0 = 1$ GeV^2, $\tilde{g}_{ipp} = g_{ipp}/g_{\rho pp}$, and $\tilde{g}_{iiG} = g_{iiG}/g_{\rho\rho G}$. As in Ref. 10 we avoid nonessential complications taking into account the spin structure only in the decay amplitude, which is very simple in the case of a coupling $0^+ \to 0^-0^-$, when it is given by

$$T(G \to F^+F^-) = \frac{1}{\sqrt{4\pi}} g_{GFF} \;, \tag{5}$$

where g_{GFF} is the coupling constant between glueball and

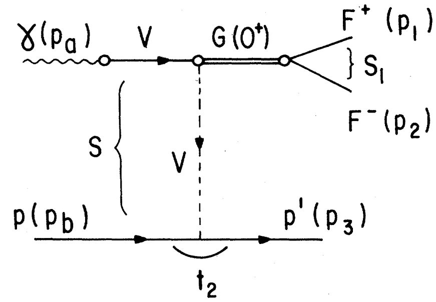

FIG. 1. Diagram representing the $\gamma p \to F^+F^-p$ reaction using the vector-dominance model and a scalar glueball in the s_1 channel. $s=(p_a+p_b)^2$, $s_1=(p_1+p_2)^2$, and $t_2=(p_b-p_3)^2$.

F^+F^- mesons. The glueball width in the FF (S-wave) channel can be obtained by the well-known[15] formula:

$$\Gamma_{GFF}=\frac{1}{2M}\frac{|\mathbf{p}_F|}{\sqrt{s_1}}\frac{(g_{GFF})^2}{4\pi}=\eta_{GFF}\Gamma(s_1)\ , \quad (6)$$

where we have introduced the branching ratio $\eta_{GFF}=\Gamma_{GFF}/\Gamma$, and

$$|\mathbf{p}_F|=\lambda^{1/2}(s_1,m_F{}^2,m_F{}^2)/2\sqrt{s_1}$$

is the F-meson momentum in the rest frame of F^+F^-. The coupling constant is calculated by replacing s_1 by M^2 in expression (6). Although the width of the glueball is a crucial parameter for its observability, not much is known about it. It is reasonable to expect Γ to be in the range 50–350 MeV for a glueball state.[16,12(a)] Thus, we can estimate the value of g_{GFF} to within a factor 2.

The differential cross section is defined by

$$\frac{d\sigma}{dM_{FF}dt_2}=2M_{FF}[2^{10}\pi^4\lambda(s,0,m_p{}^2)]^{-1}\times s_1{}^{-1}\lambda^{1/2}(s_1,m_F{}^2,m_F{}^2)|A|^2\ , \quad (7)$$

where A is given by (1) and the terms in front of it come from phase-space and flux factors. We stress that the obtained distributions are normalized up to a factor $\eta_{GFF}/(g_{\rho pp}g_{\rho\rho G})^2$.

In order to obtain these distributions we use some approximations justified as follows: The ω and ϕ contributions can be neglected because of their small couplings to the photon,[17] which is in fair agreement with the quark-model prediction:[18]

$$\frac{1}{\gamma_\rho{}^2}:\frac{1}{\gamma_\omega{}^2}:\frac{1}{\gamma_\phi{}^2}:\frac{1}{\gamma_\psi{}^2}=9:1:2:8,\quad \gamma_\rho{}^2|4\pi=0.64\pm0.1\ . \quad (8)$$

TABLE I. Values of the coupling constant g_{GFF} (upper limit) obtained from Eq. (6), for several width values.

Γ (GeV)	$g_{GFF}/(\eta_{GFF})^{1/2}$
0.05	5.1
0.10	7.2
0.15	8.8
0.20	10.1
0.25	11.3
0.30	12.4
0.35	13.4

The ψ contribution (and also the ϕ one) can also be disregarded because the OZI suppression factor for the coupling ψpp is much larger than the ϕpp one, and we know $\tilde{g}_{\phi pp} \ll \tilde{g}_{\omega pp}$ and $\tilde{g}_{\omega pp}\approx 1$. Then the ρ contribution is dominant and the Reggeized amplitude is dominated by a ρ exchange where[19] $\alpha_\rho(t_2)=0.55+0.9t_2$ (t_2 in GeV^2). Now as ρ contains only u and d quarks, it is clear why we have requested X not to have quarks u and d as we wish item (ii) to be fulfilled. Thus, keeping only the ρ contribution in Eq. (1), we have integrated (7) in the limits given below. We have used different values for the full width. They are listed in Table I, where we also show the coupling constants g_{G_sFF} obtained. The values found are comparable, if $\eta_{G_sFF}\approx 1$, to other hadronic coupling constants, and, in particular, comparable to $g_{G_T\phi\phi}$ (Ref. 10) if $\eta_{G_T\phi\phi}\approx 1$. We have used $p_{\rm lab}=24$ GeV. The total-invariant-mass distribution $d\sigma/dM_{F^+F^-}$ is obtained from expression (7) integrated in t_2 in the range—1 GeV^2 $\leq t_2 \leq 0$. Figure 2 shows this

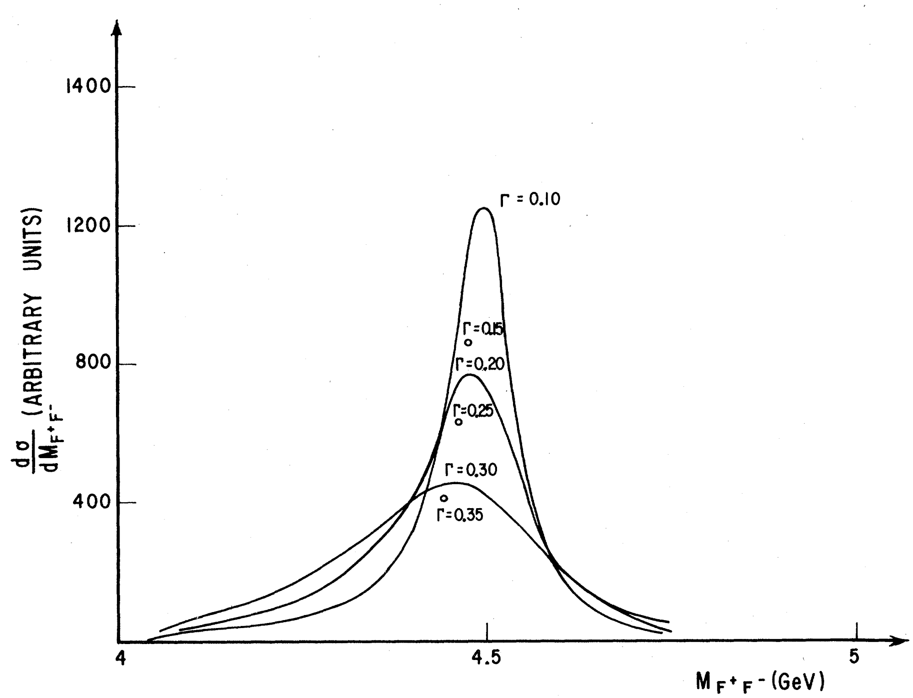

FIG. 2. $M_{F^+F^-}$ distributions for S wave using different values for the width as shown in Table I. We present only three curves and the circles represent the maxima of the other ones.

distribution for some values in Table I. The squared-momentum-transfer distribution $d\sigma/dt_2$ can be parametrized by $\exp(bt_2)$, and the slope obtained is $b = 6.6\ \text{GeV}^{-2}$, calculated for $0.65 \leq |t_2| \leq 0.75\ \text{GeV}^2$ and $4.04 \leq M_{FF} \leq 5.04$ GeV. The value of the slope shows the peripheral character of the studied reaction.

To conclude, we wish to point out that the experimental study of the proposed reaction would lead to a clean-cut observation of the scalar glueball and thus it may be considered a crucial experiment. If some "resonance" were observed in the mass spectrum indicating a glueball in the region ~ 4.0 GeV, we would understand why such a scalar glueball did not contribute to the S wave of the system $\phi\phi$ in the reaction $\pi^- p \to \phi\phi n$,[11] which did not reach the 4-GeV region. However, if no "resonance" were observed, there would be two possibilities. First, the suppression due to the OZI rule is not violated by glueball production. Thus, the total cross section $\sigma(\gamma p \to F^+ F^- p)$ would be comparable with that of a reaction where the OZI rule can be applied. A second case could be that scalar-glueball mass lies below the threshold of the F^+F^- production, between 3 and 4 GeV. Notice that a possible glueball below 2 GeV will have no influence in this reaction.

Concerning the feasibility of the measurement proposed the main problems are related to the detection of the pair $F\bar{F}$. The first evidence of $F\bar{F}$ has been found by the DASP group[20] in an e^+e^- experiment with one F having the decay $F^\pm \to \eta\pi^\pm$. Subsequent photoproduction experiments done at CERN,[21] using the Omega spectrometer with a 20–70-GeV photon beam, observed F signals in $\eta\pi$ and $\eta 3\pi$ among other channels. However, these results were not confirmed in e^+e^- collisions with the Crystal Ball experiment.[22]

New evidence for F production[23] in e^+e^- collisions, looking for the decay mode $F^\pm \to \phi\pi^\pm$, indicates a peak at 1970 ± 5 MeV in the invariant mass. Although the experimental status of the F meson is not yet well established, the existence of a photoproduction experiment, in the same region of energy, as referred above, seems to be an indication of the feasibility of the measurements proposed in this paper.

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