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$\gamma p \to F^+ F^- p$ REACTION AS A POSSIBLE TEST FOR $0^{++}$ GLUEBALL STATE[†]

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# $\gamma p \to F^+F^-p$ REACTION AS A POSSIBLE TEST FOR $0^{++}$ GLUEBALL STATE[†]

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## ABSTRACT

The reaction $\gamma p \to F^+F^-p$ which seems most appropriate to throw some light on the existence of a scalar glueball, and that 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.

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Quantum chromodynamics leads in the hadronic spectroscopy to the possibility of a new type of hadrons, called glueballs.[1] The present status of these objects is summarised 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 effective lagrangean approach[4] $1.0 \lesssim m(0^+) \lesssim 2.0$ GeV; string model[5] predicts a $J^P = 0^{(?)}$ unstable state with mass equal 1.7 GeV; lattice theory[6] gives $m(0^+) \lesssim 1.0$ GeV and MIT bag model[7] gives $m(0^+) \sim 1.0$ GeV. Only the ITEP group[8] predicts a larger mass $m(0^+) \sim 4.5$ GeV.

In this letter we wish to propose a reaction which can be used to throw some light on that question, and even on the glueballs existence, 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 $\pi^- p \to \phi\phi n$[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 produced by spin zero glueball is in agreement with refs. 3-8, i.e., either $m(0^+) \approx 1$ GeV or $m(0^+) \approx 4.0$ 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:

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

$$A_{photon} = \sum_i \left(\frac{e}{2\gamma_i}\right) A^{(i)}_{v-meson} \tag{1}$$

where $1/2\gamma_i$ is the photon-(i) meson coupling strenght 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 a S-wave determine 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 limitates 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 to observe charmed mesons as X. Indeed the only charmed and (or) strange meson[13] satisfying these conditions is the F(2021) 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.

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

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]

$$R(V^{(i)}p \to Gp)/(g_{\rho pp} g_{\rho \rho G}) = \tilde{g}_{ipp} \tilde{g}_{iiG} \{1 - \exp[-i\pi\alpha_i(t_2)]\} \times$$

$$\times \left(\frac{s}{s_0}\right)^{\alpha_i(t_2)} \frac{1}{\sin \pi \alpha_i(t_2)} \tag{4}$$

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

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

where we have introduced the branching ratio $\eta_{GFF} = \Gamma_{GFF}/\Gamma$, and $|\vec{p}_F| = \lambda^{1/2}(s_1, m_F^2, m_F^2)/2\sqrt{s_1}$, is the F meson momentum in the rest frame of $F^+F^-$. The coupling constant is calculated 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 $\Gamma$ 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

$$\frac{d\sigma}{dM_{FF}dt_2} = 2M_{FF}\left[2^{10}\pi^4\lambda(s, 0, m_p^2)\right]^{-1} x$$

$$x \; s_1^{-1}\lambda^{1/2}(s_1, m_F^2, m_F^2) |A|^2 \tag{7}$$

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 dis tributions are normalized up to a factor $\eta_{GFF}/g_{\rho pp}^2 g_{\rho\rho G}^2$.

In order to obtain these distributions we use some approxima tions justified as follows: the w and $\phi$ contributions can be neglected because of their small couplings to the photon[17] which is in fair agreement with the quark model prediction.[18]

$$\frac{1}{\gamma_\rho^2}:\frac{1}{\gamma_w^2}:\frac{1}{\gamma_\phi^2}:\frac{1}{\gamma_\psi^2} = 9:1:2:8 \quad ; \quad \gamma_\rho^2|4\pi = 0.64 \pm 0.1 \tag{8}$$

The $\psi$ contribution (and also the $\phi$ one) can be also disregarded because the OZI suppression factor for the coupling $\psi$pp is much larger than the $\phi$pp one, and we know $\tilde{g}_{\phi pp} << \tilde{g}_{wpp}$ and $\tilde{g}_{wpp} \sim 1$. Then the $\rho$ contribution in dominant and the Reggeized amplitude is dominated by a $\rho$-exchange where[19] $\alpha_\rho(t_2) = 0.55 + 0.9t_2$. Now as $\rho$ 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 fulfiled. Thus keeping only the $\rho$ 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 1, where we also show the coupling constants $g_{G_sFF}$ obtained. The values found are comparable, if $\eta_{G_sFF} \sim 1$, to other hadronic coupling constants, and in particular comparable to $g_{G_T\phi\phi}$ [10] if $\eta_{G_T\phi\phi} \sim 1$. We have used $p_{lab} = 24$ GeV. The total-invariant-mass distribution, $d\sigma/dM_{F^+F^-}$, is obtained from expression (7) integrated in $t_2$ in the range $-1 \leq t_2 \leq 0$. Fig. 2 shows this distribution for some values in Table 1. The squared-momentum-transfer distribution, $d\sigma/dt_2$, can be parametrized by $\exp(bt_2)$, and the slope obtained is $b = 6.6$ GeV$^{-2}$, calculated for $0.65 \leq |t_2| \leq 0.75$ GeV$^2$ and $4.04 \leq M_{FF} \leq 5.04$ GeV. The value of the slope shows the peripherical 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" is observed in the mass spectrum indicating a glueball in the region $\sim 4.0$ GeV, we would understand why such 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" is 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 bellow 2 GeV will have no influence in this reaction.

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FIGURE CAPTION

FIG. 1. Diagram representing the $\gamma p \rightarrow F^{+}F^{-}p$ reaction using vec-
tor dominance model and a scalar glueball in the $s_1$-chan-
nel. $s = (p_a + p_b)^2$, $s_1 = (p_1 + p_2)^2$ and $t_2 = (p_b - p_3)^2$.

FIG. 2. $M_{F^{+}F^{-}}$ distributions for S-wave using different values
for the width as shown in Table 1. We present only three
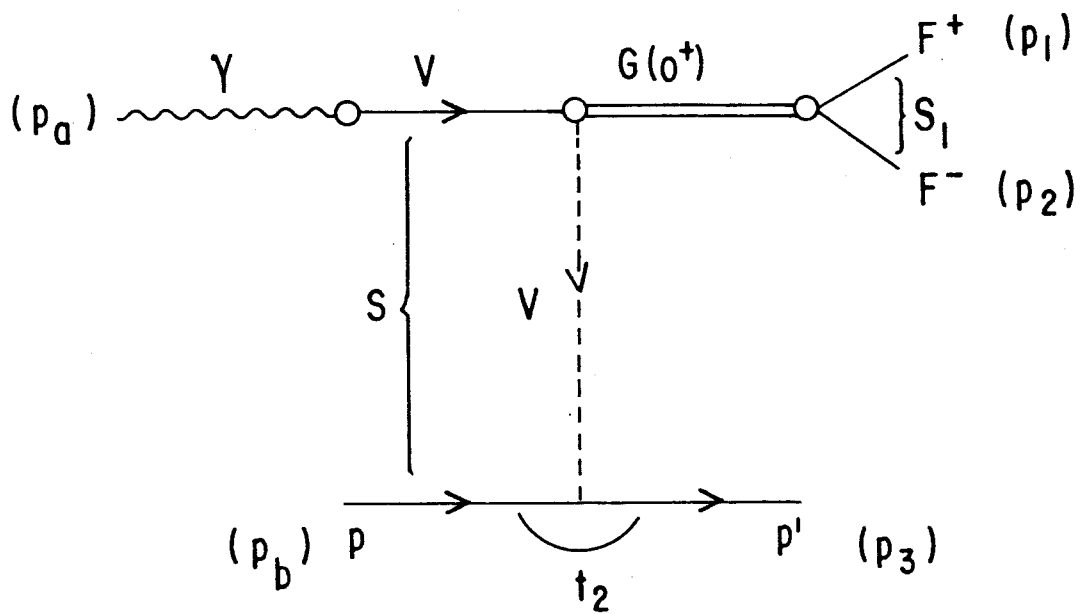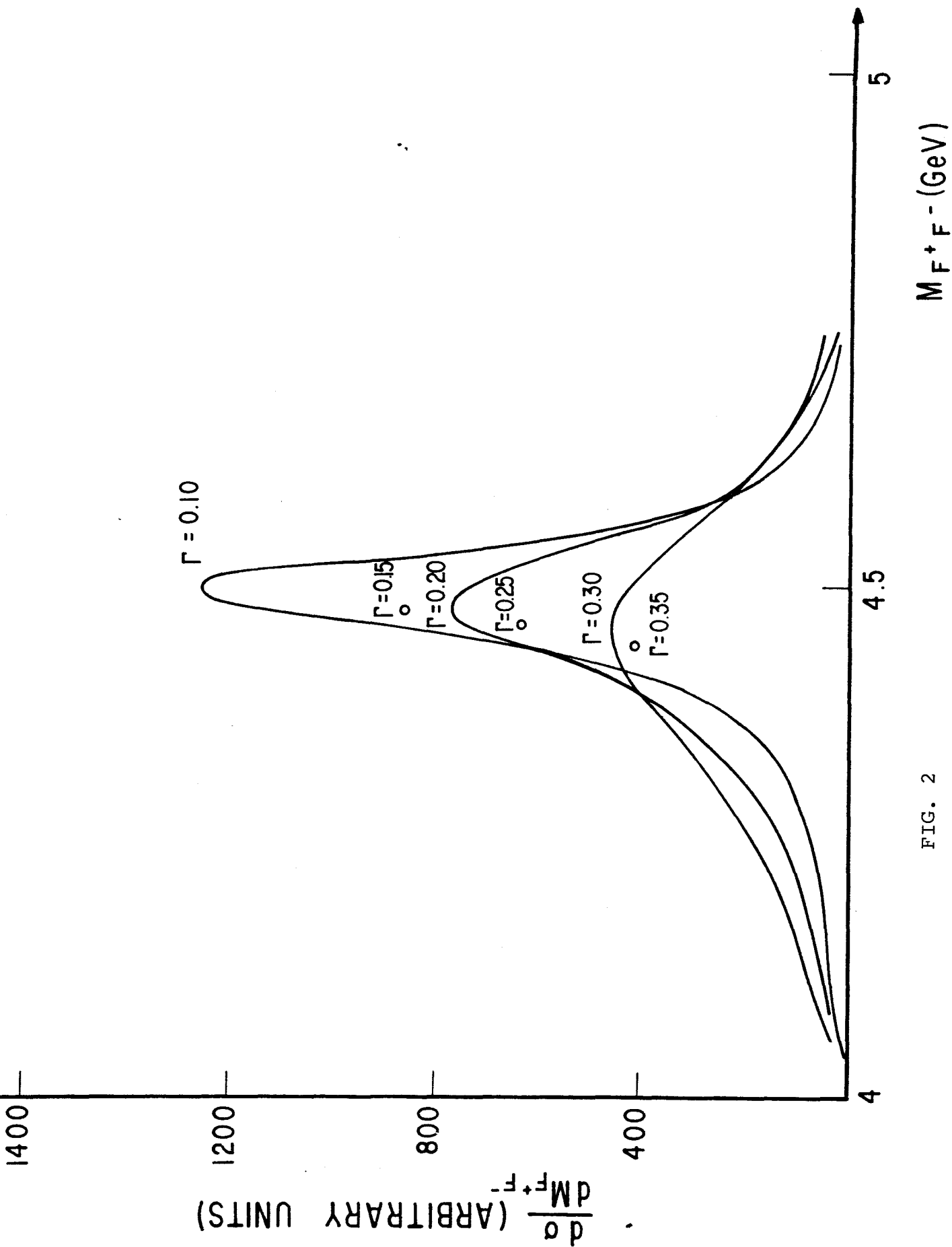curves and the dots represent the maxima of the other
ones.

FIG. 1

FIG. 2

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

| $\Gamma$(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 |

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