TENSOR DOMINANCE AND IDENTIFICATION OF θ ($f_2(1720)$) AS A TENSOR GLUEBALL

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Abstract

The energy-momentum tensor matrix element for the tensor glueball is obtained from the tensor dominance model. Branching ration of $\theta(f_2(1720))$ in J/ψ radiative decay is calculated which agrees with the observed experimental branching ratio. By incorporating a soft form factor, we show that $\theta(f_2(1720))$ has flavor independent decays to $K\bar{K}$, $\eta\eta$, and $\pi\pi$. The very form factor is needed to understand the supression of θ in $K^-p \to \Lambda K_S K_S$ as well as as well as its emergence in the central productions of $\pi p \to \pi(K^+K^-)p$ and $pp \to p(K^+K^-)p$. This flavor symmetric feature of θ is further enhanced by comparing $f_2(1525)$ and θ in J/ψ decays to $\gamma K\bar{K}$, $\omega K\bar{K}$ and $\phi K\bar{K}$. The absence of θ in $\gamma\gamma \to K_S K_S$ and $K^-p \to \Lambda K_S^\circ K_S^\circ$ led us to conclude that the quark content in θ is very low. With θ shown to be flavor singlet and void of quarks, we believe that θ could indeed be a tensor glueball, subject to the verification of the soft form factor.

The experimental information concerning glueball candidates in J/ψ radiative decays and other channels like hadronic collisions and $\gamma\gamma$ reactions has been mounting significantly in the last few years[1]. A prominent candidate of the pseudoscalar glueball, $\iota(1440)$ (new name is $\eta(1440)$) was first observed nearly eight years ago[1] and experimental support for it have been increasing since then[2]. Its large production rate in the J/ψ radiative decay and its small two photon decay rate suggest strongly that it is composed of mainly glue, since gluons are dominant component in the J/ψ decay final state and they have no electric charge.

Another prominent candidate for glueball was also discovered in the J/ψ radiative decay; it is a tensor meson $\theta(1720)$ (new name in the particle data table is $f_2(1720)$). Its conspicuously "near" flavor-independent decays to $\eta\eta$[2], $K\bar{K}$[3], amd $\pi\pi$[3] and its decoupling from $\gamma\gamma$ in the $\gamma\gamma \to K^+K^-$ and $K_S^\circ K_S^\circ$

reactions[4] suggest that it is a strong contender for a bona fide glueball.

There are new experimental information concering $\theta(1720)$. These are J/ψ decays to $\gamma K\bar{K}$, $\omega K\bar{K}$, and $\phi K\bar{K}$[5] and hadronic reactions $K^-p \to \Lambda K_S^\circ K_S^\circ$[6], $\pi^+p \to \pi^+(K^+K^-)p$[7] and $pp \to p(K^+K^-)p$[7]. The advent of these new data from the hadronic reactions has presented a grave dilemma in reconciling with data from the J/ψ decays[8,9]. Turning it around to consider it a clue, we are able to show that these new data actually lend support to the identification of $\theta(1720)$ as a glueball.

Before we analyze the experimental data, I would like to mention a recent work on the prediction of J/ψ radiative decay width of θ based on a tensor dominance model[10]. Recently, the energy-momentum tensor matrix element between the vacuum and the glueball is obtained from the tensor dominance model[10]. This allows us to calculate the tensor glueball production rate in J/ψ radiative decay[11] and compare with experiments[10].

Let us first define energy momentum tensor-pseudoscalar-pseudoscalar amplitude, energy momentum tensor-tensor coupling, and form factors as the following:

$$\begin{aligned} \langle p|\theta_{\mu\nu}(0)|p'\rangle &= F_1(\Delta^2)\Sigma_\mu\Sigma_\nu + F_2(\Delta^2)(\Delta_\mu\Delta_\nu - g_{\mu\nu}\Delta^2) \quad , \\ \langle T|\theta_{\mu\nu}(0)|0\rangle &= g_T\, m_T^3\, \varepsilon_{\mu\nu} \quad , \\ \langle p,p'|T\rangle &= \varepsilon_{\mu\nu}\, \Sigma^\mu\, \Sigma^\nu\, G_{TPP'}/m_T \quad , \end{aligned} \tag{1}$$

where

$$\Sigma_\mu = (p+p')_\mu, \quad \Delta_\mu = (p-p')_\mu \quad ,$$

and $\varepsilon_{\mu\nu}$ stands for the polarization tensor. The tensor meson dominance leads to

$$F_1(\Delta^2) = \sum_T \frac{g_T\, G_{TP\bar{P}}\, m_T^2}{(m_T^2 - \Delta^2)} \quad . \tag{2}$$

Since $F_1(0) = 1/2$ from the energy momentum relation, we obtain the following sum rule:

$$F_1(0) = \sum_T g_T G_{TP\bar{P}} = \frac{1}{2} \tag{3}$$

From the decay rates of 148 MeV, 70 MeV, 100f MeV, and 20f MeV for $\Gamma(f \to \pi\pi)$, $\Gamma(f' \to K\bar{K})$, $\Gamma(\theta \to K\bar{K})$ and $\Gamma(\theta \to \pi\pi)$, we obtain

$$g_\theta = \frac{0.5}{G_{f\pi\pi}} \sqrt{\frac{1}{f}} \times 0.18 \quad , \tag{4}$$

where f is the fraction of the decay modes. The J/ψ radiative decay to glueball is calculated with only the matrix element $\langle 0|T(A_\mu^a(x_1)A_\nu^b(x_2))|G\rangle$ unknown[11]. Now that this is approximated via the tensor dominance[10], the calculated J/ψ radiative decay rate to $\theta(1720)$ multiplied by the branching ratio of the decay modes is predicted to be

$$\Gamma = (\alpha_s)^2 \times 2.5 \text{ KeV} \ , \tag{5}$$

which is 0.1 KeV [0.13 KeV] when 0.2 [0.23] is used for α_s. This value is compared very favorably with the experimental value of 0.1 ± 0.018 KeV. Note that the unknown fraction f is not needed in eq.(5).

Now let's turn to the experimental side. In order to pin down a glueball among candidates in the spectrum of exotic mesons, it is imperitive to be able to show that it is not $q\bar{q}$, $q^2\bar{q}^2$ or $q\bar{q}g$ type of mesons. It would be ideal, if we could find a pure glueball which, by definition, would be flavor singlet and free of quarks. However, for glueballs with ordinary quantum numbers†, we do expect them to mix with $q\bar{q}$ states in general. When and if they mix substantially, it tends to cloud the issue and mires the identification. One suspects that lack of evidence for flavor independent

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†By ordinary quantum numbers, we mean those which are accessible to $q\bar{q}$ states.

decay pattern has rendered the identification of $\iota(\eta(1440))$ as a 0^{-+} glueball somewhat difficult a task.

On the other hand, with the help of the above mentioned new experiments, one could establish the flavor independent decay pattern in $\theta(f_2(1720))$ and that it is void of quark content. We shall attempt to dwell on this and put forward our analysis and arguments in two parts. The first part is on the flavor independence and the second part on the null quark content.

I) <u>Flavor independence</u>: Several experiments related to the production and decay of $\theta(f_2(1720)$ are analyzed in the following:

1) Decays of θ to $\eta\eta$, KK and $\pi\pi$.

θ was discovered in J/ψ radiative decay and was observed to decay to $\eta\eta$[2], $K\bar{K}$[3] and $\pi\pi$[3]. Their branching rations are :

$$B(J/\psi\rightarrow\gamma\theta)B(\theta\rightarrow\eta\eta) = (2.6\pm0.8\pm0.7)\times10^{-4} ;$$
$$B(J/\psi\rightarrow\gamma\theta)B(\theta\rightarrow K^+K^-) = (4.8\pm0.6\pm0.9)\times10^{-4} ; \qquad (6)$$
$$B(J/\psi\rightarrow\gamma\theta)B(\theta\rightarrow\pi^+\pi^-) = (1.6\pm0.4\pm0.3)\times10^{-4} .$$

With a mass and width determined from the K^+K^- data,

$$m_\theta = 1.72\pm0.007 \text{ GeV}/c^2 ; \qquad (7)$$
$$\Gamma_\theta = 0.132\pm0.015 \text{ GeV}/c^2 .$$

One conspicuous feature that one could not help noticing in (6) is that the decay pattern of θ is more flavor symmetric than the other known mesons. For comparison, we note that the ratios

$$\frac{B(\theta\rightarrow\eta\eta)}{B(\theta\rightarrow K\bar{K})} \sim 0.27 , \frac{B(\theta\rightarrow\pi\pi)}{B(\theta\rightarrow K\bar{K})} \sim 0.25 \qquad (8)$$

are much larger than the corresponding ratios in other 2^{++} mesons[12,3], e.g.

$$\frac{B(f_2(1270)\rightarrow K\bar{K})}{B(f_2(1270)\rightarrow\pi\pi)} \sim 0.03 , \qquad \frac{B(A_2(1320)\rightarrow K\bar{K})}{B(A_2(1320)\rightarrow\rho\pi)} \sim 0.07 ,$$

$$\frac{B(f_2'(1525) \to \pi\pi)}{B(f_2'(1525) \to K\bar{K})} \sim 0.05 \quad . \tag{9}$$

This has been an impetus to considering $\theta(1720)$ as a glueball candidate[13,14]. However, it is pointed out that the decay is still not perfectly flavor symmetric[2,3,5]. If $\theta(f_2(1720))$ is a pure SU(3) singlet, we expect the following rates (with phase space correction):

$$K\bar{K} : \eta\eta : \pi\pi = 1 : 0.18 : 1.9 \quad . \tag{10}$$

Yet, the observed rates are

$$K\bar{K} : \eta\eta : \pi\pi = 1 : 0.27 : 0.25 \quad , \tag{11}$$

where $\pi\pi$ is suppressed while $\eta\eta$ enhanced ralative to $K\bar{K}$. Suggestions to consider that the decay pattern results from the mixture with $f_2(1270)$ and $f_2'(1525)$ were made[13,14]. But, it is found that the mixing picture can not accomodate the two photon widths $\Gamma(f_2' \to \gamma\gamma)$ and $\Gamma(\theta \to \gamma\gamma)$[13,5]. So, how can one understand the decay pattern? It has been suggested by the author that since the momentum transfer involved in the $\pi\pi$ decay is large ($q^2 = 2.88(\mathrm{GeV}/c)^2$), a soft form factor e^{-q^2/Λ^2} (Λ~1 GeV) could explain the decay ratios[15]. A similar kinematic effect which suppresses the hadronization of $\bar{u}u + \bar{d}d$ to $\pi\pi$ compared to that of $\bar{s}s$ to $K\bar{K}$ is given by M. Chanowitz[16].

How does one justify a soft form factor for the glueball-meson coupling? We note first that $q\bar{q}$ mesons are very small objects. The electric form factor of the pion gives a charge radius of $\langle r_\pi^2 \rangle_c^{1/2} = 0.663 \pm 0.006$ fm[17]. However, we learned from VDM that this includes the contribution from the induced vector meson propagators. When the vector meson propagator is taken out, the intrinsic core (or the $q\bar{q}$ separation) of the meson is small. We can estimate the size of the $q\bar{q}$ separation in the pion from the general relation of VDM: $\langle r^2 \rangle_c = 6/m_\rho^2 + \langle r^2 \rangle_s$. From the experimental charge radius of the pion and the rho meson mass, we obtain the strong size of the pion $\langle r^2\rangle_s^{1/2}$ to be ~0.2 fm, which is much smaller than its charge radius of 0.663 fm. There are models built on this idea of an intrinsic core to explain the electromagnetic structures and the hadronic transitions of the pion, the kaon[18] and the nucleon[19]. The vector dominance idea has been backed up recently by the QCD via lattice simulations. The electric form factor of the pion has been measured in SU(2)[20] and SU(3)[21]. The measured $\langle r^2\rangle_c$ varies with the hopping parameter κ (or quark mass), hence the measured ρ meson mass, in such a way that the above mentioned VDM relation for $\langle r^2\rangle_c$ holds quite well.

In addition, there is a lattice calculation of the SU(2) Coulomb gauge quark-antiquark wave function at $\beta = 2.431$[22]. The interesting point one notices is that, unlike the form factor calculation in Refs. 20 and 21, the measured π and ρ wavefunctions are nearly independent of the lagrangian quark mass, hence the ρ meson mass. We interpret this as a measure of the intrinsic quark-antiquark density despite its possible gauge dependence. Using the lattice spacing of 0.126 fm at $\beta = 2.431$[23], we deduce the intrinsic radius $\langle r^2\rangle_s^{1/2}$ for the pion measured this way to be ~0.35 fm. This is significantly smaller than the experimental charge radius or that of the lattice form factor measurement extrapolated to the chiral limit. The smallness of the meson size is also consistent with the fact that point coupling is sufficient to describe the OZI allowed $q\bar{q}$ meson decays in the SU(3) multiplet[24], e.g. $\rho \to \pi\pi$, $\phi \to K\bar{K}$, $f_2 \to \pi\pi$ and $f_2' \to K\bar{K}$. When the form factors are included to improve the calculations of meson decays, it is found[25,26] that a hard form factor e^{-q^2/Λ^2} with $\Lambda \geq 2$ GeV/c[25,26] is needed which reflects the small meson sizes as expected.

On the other hand, the tensor glueball is likely to be a larger object compared to the $q\bar{q}$ mesons. Recent advances in the glueball calculations[27] involking fuzzy operators extending over the whole volume of the lattice appears to show much better signal to noise ratio than the previous calculation with simple plaquettes.

Furthermore, it appears that the tensor glueball mass starts to be stablized after the lattice size reaches $z = M_{0+}L$ at 10 and larger[28]. All these results from the lattice are suggestive that the glueball size may be larger than the ordinary mesons. More direct evidence comes from our recent analysis of glueball wavefunctions[29]. Preliminary results show that the tensor glueball is about 2.5-3 times larger than the scalar glueball and the pion[29]. Therefore, we introduce a soft form factor e^{-q^2/Λ^2} to the θ-meson coupling to reflect the large θ size. We shall work out its consequences and will look for verification both experimentally and theoretically. With the inclusion of this form factor, the θ decay rates has the following ratios,

$$K\bar{K} : \eta\eta : \pi\pi = 4q_K^5\, e^{-2q_K^2/\Lambda^2} : q_\eta^5\, e^{-2q_\eta^2/\Lambda^2} : 3q_\pi^5\, e^{-2q_\pi^2/\Lambda^2} \quad . \tag{12}$$

With $q_K^2 = 1.98\ \mathrm{GeV}^2/c^2$, $q_\eta^2 = 1.75\ \mathrm{GeV}^2/c^2$, $q_\pi^2 = 2.88\ \mathrm{GeV}^2/c^2$, and $\Lambda^2 = 1\ \mathrm{GeV}^2/c^2$, we obtain the ratios

$$K\bar{K} : \eta\eta : \pi\pi = 1 : 0.29 : 0.32 \quad , \tag{13}$$

which is in very good agreement with the observed ratios in (11). Notice that since $q_\eta < q_K$ and $q_\pi > q_K$, the introduced form factor enhances $\eta\eta$ while suppress $\pi\pi$ relative to $K\bar{K}$, in the right direction toward the experimental ratios.

Given that the postulated form factor effect can restore the flavor symmetry in θ decay, the next question is whether there is any other experimental manifestation of this form factor. It turns out the answer is positive. This brings us to the next experiment.

2) $K^-P \rightarrow \Lambda\, K_S^\circ K_S^\circ$.

This LASS experiment[6] was done at a beam momentum of 11 GeV/c. Looking at the $K_S^\circ K_S^\circ$ spectrum, one is disturbed to learn that while $f_2'(1525)$ is quite prominent, there is no trace of $\theta(f_2(1720)$ (see fig. 1). This has granted a puzzle. As analyzed by Longacre et al.[8], this peripheral reaction can be conveniently considered as K^+K^- scattering in the one particle exchange picture (see Fig. 2). In this picture one expects the ratio of cross sections for the f_2' and θ production to be approximately

$$\frac{\sigma(\theta)}{\sigma(f_2')} \sim \frac{B^2(\theta \rightarrow K\bar{K})}{B^2(f_2' \rightarrow \bar{K}K)} \quad , \tag{14}$$

based on unitary and when slightly different kinematic factors are neglected. Since no other decay modes are observed[30], the ratio should be ~ 30%. Yet the observed ratio is < 3%. So, it appears that we have a genuine puzzle.

It turns out the jigsaw puzzle will fit once the form factor in glueball-meson coupling is incorporated. In the one-particle -exchange picture, the S-matrix is written as

$$\langle \Lambda K_S^\circ K_S^\circ | S | K^- p\rangle \approx \frac{\langle K_S^\circ K_S^\circ | T | K^+K^-\rangle \; \langle K^+\Lambda | T | p\rangle}{t - m_K^2} \tag{15}$$

Looking at the resonance productions of f_2' and θ, the differential cross section can be written as

$$\frac{d\sigma}{dt} \sim g(t)\; F^2_{f_2',\theta}(q^2) \quad , \tag{16}$$

where $g(t)$ involves the K^+ propagator and the K-N-Λ form factor, besides the phase space. $F_{f_2'}(q^2)/F_\theta(q^2)$ is the f_2'/θ $K\bar{K}$ form factor and q is the 4-momentum transfer between the incoming and the exchanged K mesons.

Hence,

$$q^2 = m^2_{f_2',\theta} - 2t - 2m^2_K \quad .$$

To compare the production cross sections of f_2' and θ, we note that $F_{f_2'}(q^2) \sim 1$, yet $F_\theta(q^2) = e^{-q^2/\Lambda^2}$. Therefore, with the inclusion of the form factor, eq. (9) should be modified to

$$\frac{\sigma(\theta)}{\sigma(f_2')} \sim \frac{B^2(\theta\to K\bar{K})}{B^2(f_2'\to K\bar{K})} \frac{\int_{t_{min}}^{t_{max}} dt\; g(t) e^{-2q^2/\Lambda^2}}{e^{-2q_K{}^2/\Lambda^2}\int_{t_{min}}^{t_{max}} g(t) dt} \quad . \tag{17}$$

Since for θ production,

$$q^2_{min} = m^2_\theta - 2\ (m_\Lambda - m_N)^2 - 2m^2_K = 2.41\ \text{GeV}^2 > q^2_K = 1.98\ \text{GeV}^2 \quad , \tag{18}$$

we immediately anticipate a suppression. With $t_{min} = -2\ \text{GeV}^2$, $t_{max} = (m_\Lambda - m_N)^2 = 0.031\ \text{GeV}^2$, and $g(t)$ approximated by $e^{-b|t|}$ where $b = 2.5\ \text{GeV}^{-2}$, we obtain a ratio of $\sigma(\theta)/\sigma(f_2')$ to be $< 5\%$ which is quite compatible with the experimental observation of $\lesssim 3\%$.

Hence, the puzzle may well be kinematic in nature due to the kinematic constraint in the peripheral production.

By the same token, the $\pi\pi \to \theta \to K\bar{K}$ strength $|D_o|$ from the $\pi^- p \to K^\circ_S K^\circ_S n$ reaction will be reduced by ~30% with the inclusion of the form factor. Together with the form factor reduction of $K\bar{K} \to \theta \to K\bar{K}$ from the above analysis, this should bring the hadronic production data and the J/ψ radiative decay data much closer in agreement with each other in the coupled channel analysis of Longacre et al.[8].

For universality reasons, we might expect that a similar soft form factor may be involved in the peripheral production of ι (1460), the leading pseudoscalar glueball candidate. In a recent experiment, $f_1(1285)$ and ι ($\eta(1460)$) are observed in the $K^\circ_S K^\circ_S \pi^\circ$ system in the exclusive reaction $\pi^- p \to K^\circ_S K^\circ_S \pi^\circ n$ at

21.4 GeV/c[31]. It is observed that when the momentum-transfer distribution for various $K_S^\circ K_S^\circ \pi^\circ$ mass intervals are fitted with a function of the form $e^{-b|t|}$. The parameter b has a value of about 2.5 GeV^{-2} for $f_1(1285)$ production which is about the same as for f_2' production in the LASS experiment[6]. It remains at that value until up to the ι ($\eta(1460)$) region where it rises sharply to 4-5 GeV^{-2}. In addition to the sharp peripheral production of the nonresonant background, the rise in b in the ι ($\eta(1460)$) region may also be due to the soft form factor of the $\pi\delta\iota$ coupling. It would be nice if one could factor out the background and verify this with the available data. For central productions, presumably there is no more kinematic constraint like eq. (18). Therefore, one expects $\theta(1720)$ to be produced there along with $f_2'(1525)$. Indeed θ is seen in the central production mechanism as we shall see next.

3) Central production of θ.

The reaction $\pi^+ p \to \pi^+(K^+K^-)p$[7], $pp \to p(K^+K^-)p$[7], and $pp \to p\ (K_S^\circ K_S^\circ)p$[32] where the K^+K^- and $K_S^\circ K_S^\circ$ are centrally produced have been studied using the Omega facility at CERN with the π^+/p beams at 85 GeV/c and 300 GeV/c. In both the spectra of K^+K^- and $K_S^\circ K_S^\circ$ (see Fig. 3), θ is seen in addition to f_2'.

As we remarked earlier, since there is no kinematic constraint on q^2 (i.e. eq. (18)) in central productions, the fact that θ does show up in these reactions is again consistent with the soft form factor we introduced in the glueball-meson coupling. It would be very helpful to compare the q^2 dependence in the productions of f_2' and θ in this experiment which may provide a direct evidence for the soft form factor.

4) $J/\psi \to \gamma K\bar{K}$, $\omega K\bar{K}$ and $\phi K\bar{K}$.

Flavor dependence of θ and f_2' are also examined in J/ψ decays to $\gamma\bar{K}K$, $\omega K\bar{K}$ and $\phi K\bar{K}$.[5,9] The $K\bar{K}$ spectra in these decays are plotted in Fig. 4. It is found that while θ is seen in all three channels, f_2', an $s\bar{s}$ meson, is obviously suppresed in the $\omega K\bar{K}$ channel. These findings seem to suggest that the associated production of flavors (e.g. Fig. 5(a)) dominate the hadronic the doubly OZI suppressed higher orders.

Even though it is harder to quantify than the previous experiments in 1) and 2), these decays clearly demonstate that θ is much more flavor symmetric than the $s\bar{s}$ meson f_2'.

II) Null quark content: There are two experiments which are taken as good evidence to show that there is very little quark content in θ.

1) $\gamma\gamma \to K_S^{\circ} K_S^{\circ}$.

It has been known for sometime that tensor mesons $f_2(1270)$ and $f_2'(1525)$ are clearly detected in photon-photon productions, whereas θ is not observed.[4] The best upper limit is $\Gamma_{\gamma\gamma}(\theta) B(\theta \to K\bar{K}) < 0.09$ KeV at 95% C.L. set by the PLUTO experiment.[4] For comparison, the same experiment measures $\Gamma_{\gamma\gamma}(f_2') B(f_2' \to K\bar{K}) = 0.10 \begin{smallmatrix} +0.04 + 0.03 \\ -0.03 - 0.02 \end{smallmatrix}$ KeV.[4] This can be seen in Fig.6.

This decoupling from photons is an expected attribate of glueballs. Since glue does not couple to photons directly, the production of glueballs in $\gamma\gamma$ reactions will proceed with the quark loops which should be suppressed by $O(\alpha_S^2)$. The fact that θ is not seen in $\gamma\gamma$ also suggests that the quark content in θ is rather low.

2) $K^- p \to \Lambda K_S^{\circ} K_S^{\circ}$

Earlier we demonstated that this LASS experiment[6] can be explained by the existence of a soft form factor which in turn could prove the flavor singlet nature of θ. Now it also serves the purpose of revealing the fact that there is very little ($\lesssim 3\%$) quarks ($u\bar{u}$, $d\bar{d}$, or $s\bar{s}$) in θ. Otherwise, it should have been observed at certain appropriate level (>3%) compared to the production of f_2'.

To summerize, various decay and production experiments involing θ are analyzed. In order to understand the decay pattern of θ into $K\bar{K}$, $\eta\eta$ and $\pi\pi$, we postulated a soft form factor for the glueball-meson coupling. This form factor renders the decays of θ flavor independent. The suppression of θ (relative to f_2') in $K^-p \to \Lambda K_S^\circ K_S^\circ$ can be explained by the effect of this form factor. The non-suppression of θ in central productions[7,32] is also understandable because they don't have the same kinematic constraint as does the peripheral production of θ in $K^-p \to \Lambda K_S^\circ K_S^\circ$. The evidence of flavor symmetry in θ is further enhanced by comparing θ against f_2' in J/ψ decays to γ $K\bar{K}$, ω $K\bar{K}$, and ϕ $K\bar{K}$. The fact that θ is not observed in $\gamma\gamma \to K_S^\circ K_S^\circ$ and $K^-p \to \Lambda K_S^\circ K_S^\circ$ at the same level as f_2' is an indication that the quark content in θ is very low. From $K^-p \to \Lambda K_S^\circ K_S^\circ$, we estimate the quark content to be less than 3%. It is interesting to note that a recent lattice calculation[33] shows no evidence for the glueball-meson mixing in the 0^{++} glueball. It would be nice to check the tensor glueball case as well.

Combining these various experiments, we are convinced that once the soft form factor is confirmed, θ can be shown to be quite flavor symmetric and essentially void of quarks. <u>In this case, in the context of QCD, it must be a fairly pure glueball</u>. We showed earlier that the matrix element for the energy-momentum tensor $\langle G|\theta_{\mu\nu}|o\rangle$ has been obtained recently from the tensor dominance model.[10] The branching ratio of $\theta(1720)$ in J/ψ radiative decay calculated with this matrix element agrees very well with the observed branching ratio.[10] Thus, when the predicted decay rates of $K\bar{K}$, $\eta\eta$, and $\pi\pi$ in in eq. (11) and the predicted suppression of θ relative to f_2' in $K^-p \to \Lambda K_S^\circ K_S^\circ$ are included, we conclude that the status of θ as a glueball is good even at the quantitatively level. While we can not say the same about other glueball candidates, e.g. ι (1440), the relative ease in identifying θ(1720) as a tensor glueball is centainly blessed with the fact that there is hardly any mixing with the ordinary $q\bar{q}$ mesons. For the future, it would be nice if this soft form factor can be checked and verified in the central production and other experiments. It would also constitute a theoretical challenge to understand the glueball-meson form factor and why the mixting with $q\bar{q}$ meson is so small. Work is being undertaken to measure the glueball size on the lattice[29]. It should provide at least a semi-quantitative clue to the asserted soft form factor. This talk is based on the manuscript[34] which has been submitted for publication.

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Figure Captions

Fig. 1. $K_S^\circ K_S^\circ$ mass spectrum from the LASS experiment $K^- P \to K_S^\circ K_S^\circ \Lambda$ is compared to the Mark III results from radiative J/ψ decay. The LASS data have been scaled to match with the Mark III data at the $f_2'(1525)$ peak. This is taken from Ref. 6.

Fig. 2. The one particle exchange picture for the peripheral production of f_2' and θ in $K^-P \to K_S^\circ K_S^\circ \Lambda$.

Fig. 3. a) K^+K^- mass spectrum centrally produced in the reactions $pp \to p(K^+K^-)p$ at 300 GeV/c. The spectrum is fitted by using two non-interfering Breit-Wingers. The data is from Ref. 32.
b) The $K_S^\circ K_S^\circ$ spectrum produced at 85 GeV/c and 300 GeV/c.

Fig. 4. Study of K^+K^- final states in various J/ψ decays. The data is taken from Ref. 5.

Fig. 5. Strong J/ψ decay diagrams:
a) singly OZI suppressed process which leads to associated production of flavors.
b) doubly OZI suppressed process which is more "falvor independent" than a).

Fig. 6. Invariant $K_S^\circ K_S^\circ$ mass spectrum in $\gamma\gamma \to K_S^\circ K_S^\circ$ reaction. The shaded histogram represents the Monte Carlo expectation for exclusive f_2' production with $\Gamma_{\gamma\gamma}(f_2') \cdot B(f_2' \to K\bar{K}) = 0.10$ keV via helicity 2. The same spectrum is obtained for helicity 0 and $\Gamma_{\gamma\gamma}(f_2') \cdot B(f_2' \to K\bar{K}) = 0.17$ keV. This is taken from the PLUTO data in Ref. 4.

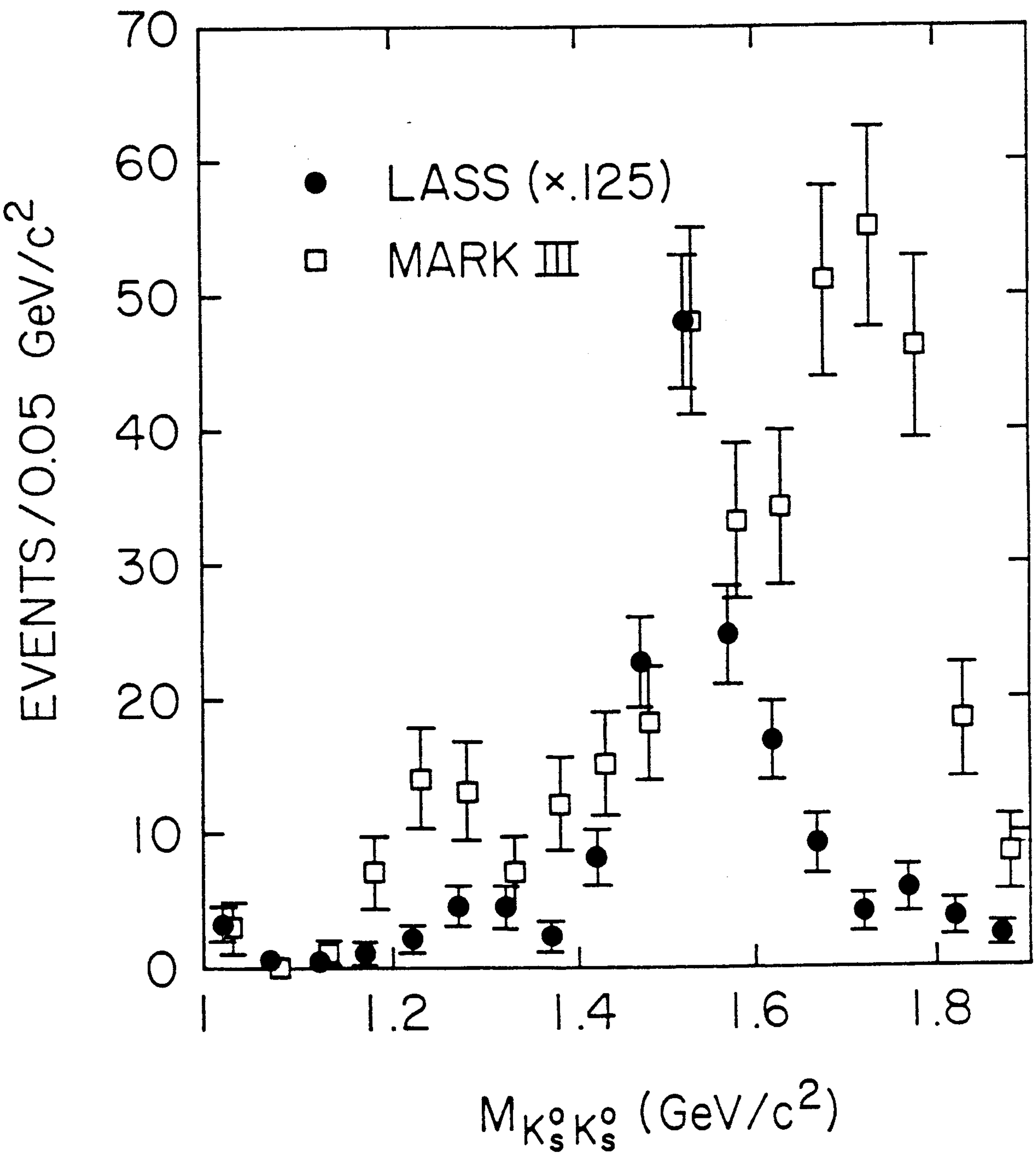

70
60
50
40
30
20
10
0
LASS (×.125)
MARK III
EVENTS/0.05 GeV/c²
1
1.2
1.4
1.6
1.8
$M_{K_s^0 K_s^0}$ (GeV/c²)

Fig. 1

$K^- P \rightarrow \Lambda K_S^0 K_S^0$

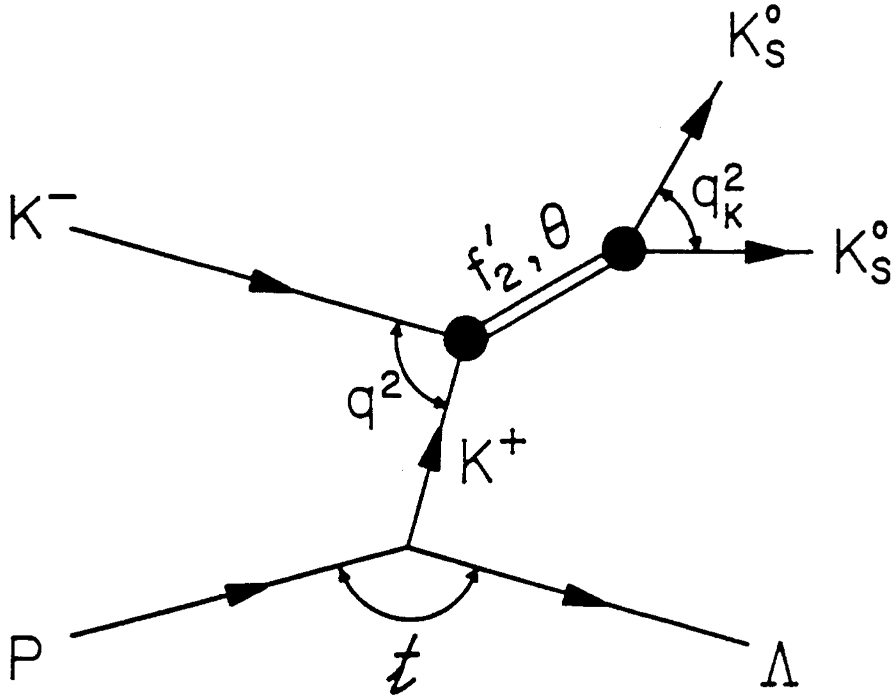


Fig. 2

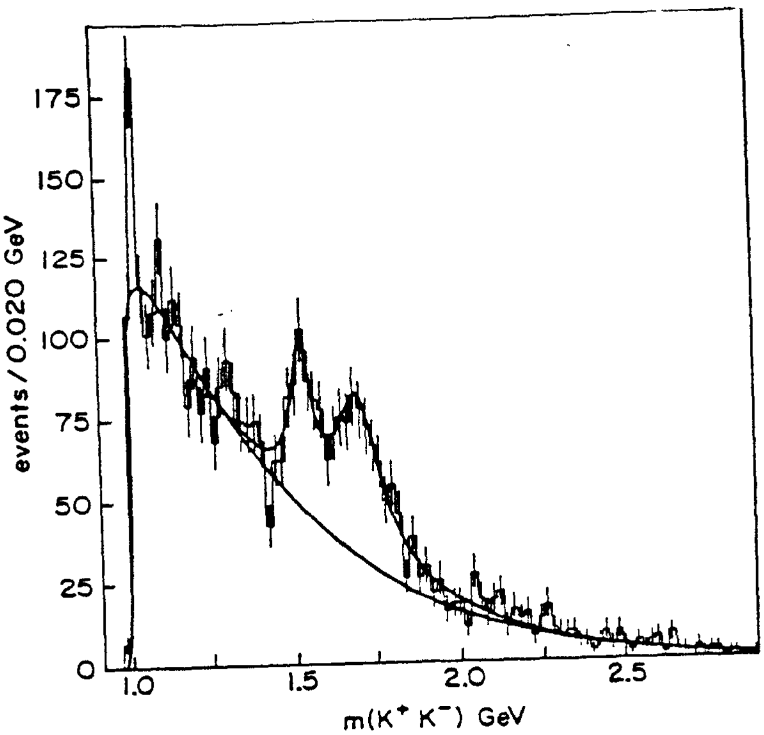

175
150
125
100
75
50
25
0
events / 0.020 GeV
1.0
1.5
2.0
2.5
m(K⁺ K⁻) GeV

Fig. 3(a)

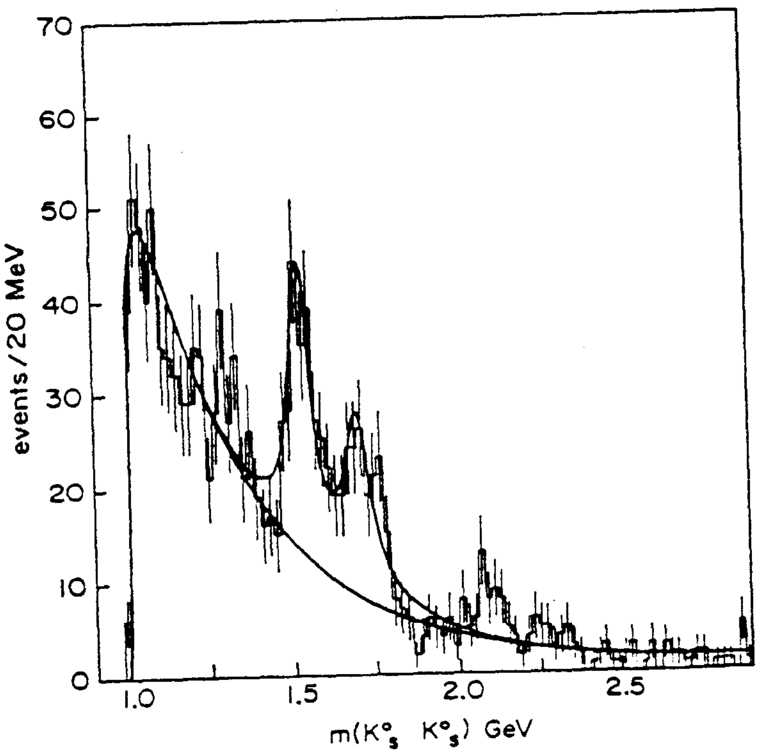
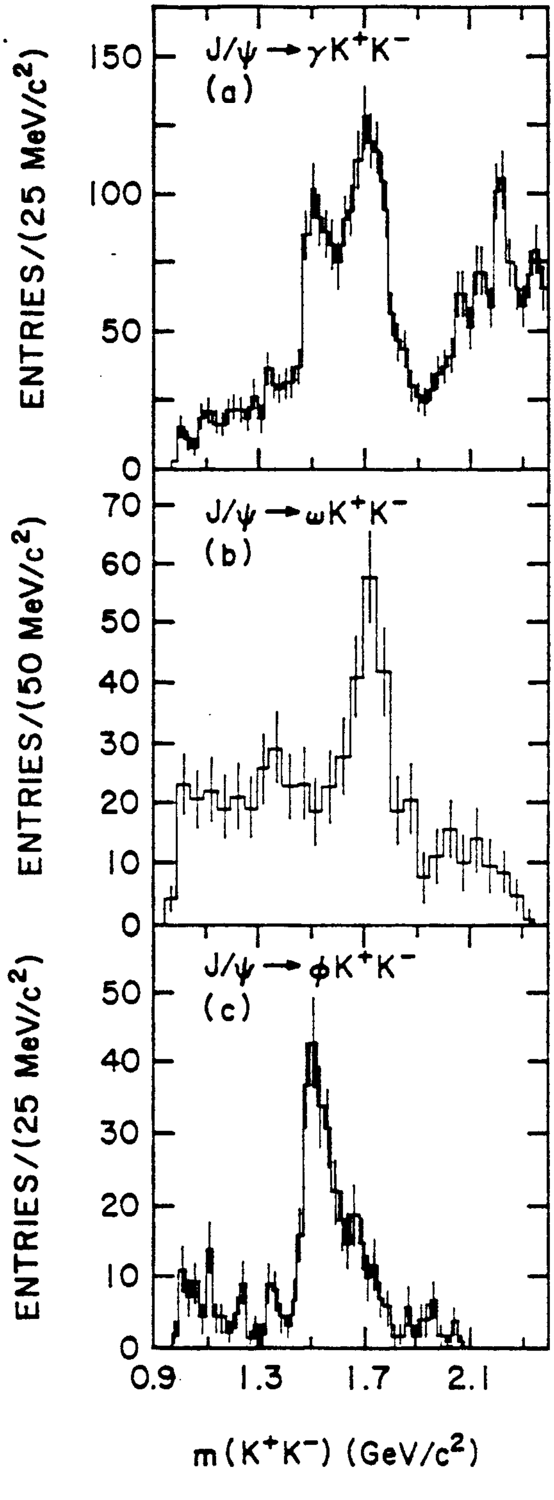

70
60
50
40
30
20
10
0
events / 20 MeV
1.0
1.5
2.0
2.5
m(K^0_s K^0_s) GeV

Fig. 3(b)



J/ψ → γK⁺K⁻
(a)
J/ψ → ωK⁺K⁻
(b)
J/ψ → φK⁺K⁻
(c)
ENTRIES/(25 MeV/c²)
ENTRIES/(50 MeV/c²)
ENTRIES/(25 MeV/c²)
0
50
100
150
0
10
20
30
40
50
60
70
0
10
20
30
40
50
0.9
1.3
1.7
2.1
m(K⁺K⁻) (GeV/c²)

Fig. 4

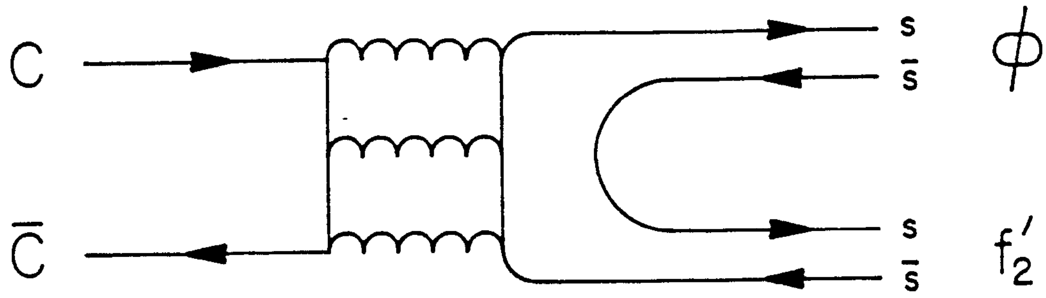


Fig. 5(a)

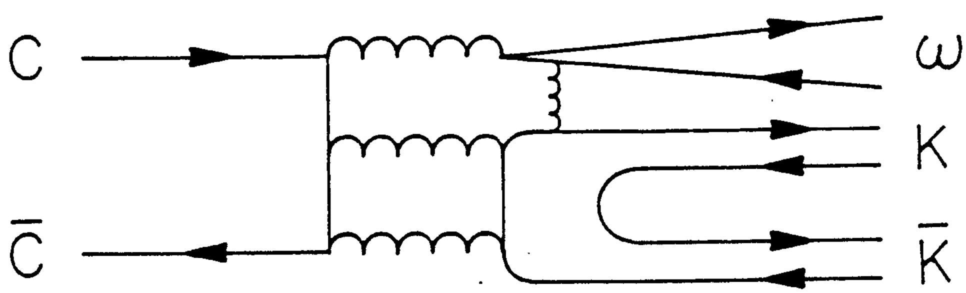


Fig. 5(b)

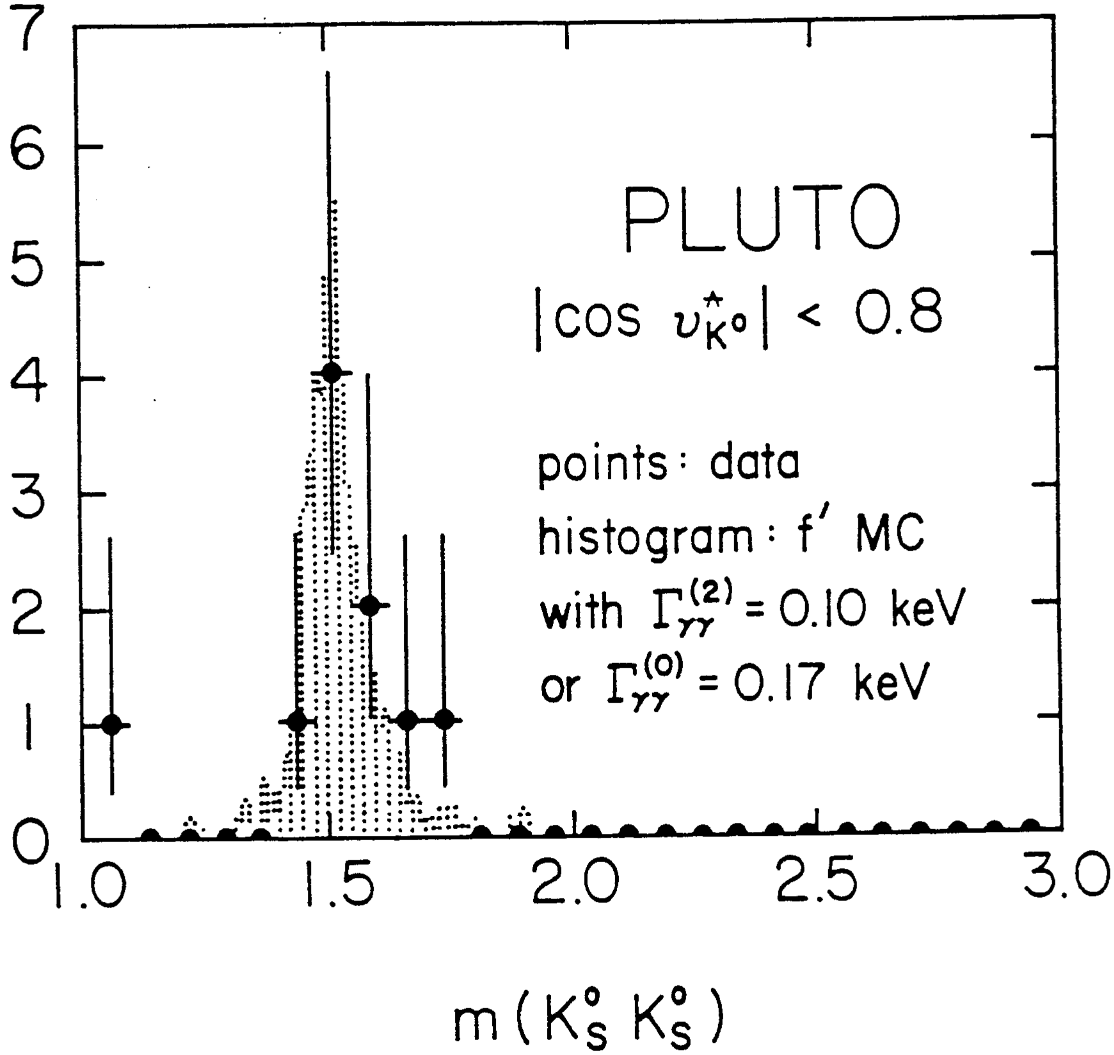

PLUTO
$|\cos \vartheta^{*}_{K^0}| < 0.8$
points: data
histogram: f′ MC
with $\Gamma^{(2)}_{\gamma\gamma} = 0.10$ keV
or $\Gamma^{(0)}_{\gamma\gamma} = 0.17$ keV
0
1
2
3
4
5
6
7
1.0
1.5
2.0
2.5
3.0
$m(K^0_S K^0_S)$

Fig. 6