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The Gluon Emission Model for Vector Meson Decay*

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1. Introduction

Quantum Chromodynamics (QCD), the heart of the so-called Standard Model, was developed along the lines of the most successful theoretical structure in all of physics, namely, Quantum Electrodynamics (QED), which represents the interactions between the electron and the electromagnetic field, photons serving as the mediator between the two entities. QCD, therefore, contains many objects which are analogous to those within QED. There are the quarks, for example, which come in six “flavors” (up, down, strange, charm, bottom, top), serving as the analogous construct to the electron and its cousins, the muon and the tauon. Plexification, of course, always accompanies the proceeding by analogy to any theory, and so we find that quarks must come not only in flavors, but also in “colors” (three total), and they must be fractionally charged (one or two thirds of the electron charge in absolute value). What mediates the quark and the strong field, analogous to the photon in QED, is the gluon. In QED all quantum events are described by a coupling between the electron and the photon, called the fine structure constant of magnitude approximately 0.007. Regarding the coupling between quarks and the strong field responsible for hadronization ... the production of hadron pairs in a colliding beams experiment, for example ... the situation in QCD is quite different. Work continues at present in the field of high-energy physics to determine the precise nature of the quark-gluon coupling, but one overarching behavior pattern of such coupling, called the strong coupling, is that it is *not* a constant. Rather, it varies generally as the reciprocal of the natural logarithm of the energy wrapped up in the colliding beams.

In the work which follows we will have occasion to investigate the phenomenon of vector meson formation and decay in accord with a QCD model, called the Gluon Emission Model (GEM), first developed by F. E. Close in the 1970s. The GEM follows rigorously the precepts of QED proper, the *only* QCD quantity entering into the calculations being the strong coupling parameter, which replaces the fine structure constant in the relevant places. The GEM thus provides for a self-contained formalism that follows the constructs of QED essentially as closely as is possible at the present time. As we will see, even the precise form for the strong coupling parameter may be determined within the GEM, the valid range

* Much work presented in this Chapter is taken from D. White, “GEM and the Y(1S)”, *The Journal of Informatics and Mathematical Sciences*, Vol. 2, Nos. 2 & 3 (2010), pp. 71 - 93.

being the range of energy encompassed by the known vector mesons themselves. Let us begin by reviewing a central feature of QED:

In all quantum systems in which natural decay occurs between an excited level and the ground state, the absorption cross-section goes as¹

$$\sigma(\omega) = K\alpha|V|^2 (1/m)^2(1/\omega)L(\omega) \quad (1)$$

where K is a constant, ω represents photon frequency, $|V|^2$ represents the square of the matrix element descriptive of the photon emission process, the system has mass m , $L(\omega)$ is a Lorentz Amplitude with a peak at $\omega = \omega_0$ and with a width Γ , and $\alpha = (1/137.036)$ represents the fine structure constant. Assuming "asymptotic freedom", i.e., that we may ignore the masses of the decay products (light hadron pairs) in relation to the total energy involved in the system under investigation, we may employ Eq. 1 to predict the width of vector mesons by making the following substitutions to take us from a general quantum electrodynamics (QED) to a specific quantum chromodynamics (QCD) process:

We substitute for the photon frequency ω the gluon energy Q_0 . We evaluate the right hand side of Eq. 1 at a specific vector meson mass, m_v , i.e., $Q_0 = m = m_v$. (Hence, the associated Lorentz Amplitude equals unity.) We require $|V|^2$ to be proportional to $\Sigma_i(q_i)^4$, where q_i = quark charge (in units of electron charge magnitude) associated with the quarks comprising the relevant vector meson. The above criterion is consistent with a spin-spin interaction² proportional to q_i^2 , where i denotes quark flavor, giving rise to spin-flip transitions, and the sum is required only in the case of the ρ , as it comprises both the up quark (u) of charge $q_u = 2/3$ and the down quark (d) of charge $q_d = -1/3$. We postulate $|V|^2$ to be proportional to only $\Sigma_i(q_i)^4$, i.e., the precise form of the interaction is universal to all vector mesons in their ground states, except for quark charge differences.

We replace α by α_s , the strong coupling parameter, which has the well-known form from QCD gauge invariance theories of³:

$$\alpha_s = B[\ln(Q_0/\Lambda)]^{-1} \quad (2)$$

where B is a constant and Λ is a parameter, called the QCD scale factor, to be determined. Again, we emphasize that commensurate with the above replacements is that we must assume that the initial energy involved in the formation of a given vector meson is extremely high, i.e., in the "asymptotically free" region of energy space, where the masses of emerging hadron pairs as decay products can be neglected. Accordingly, then, we find in terms of the above ansatz (normalizing to the ρ)

$$\Gamma_v = A(m_\rho/m_v)^3(\Sigma_i(q_i)^4)[\ln(m_v/\Lambda)]^{-1} \quad (3)$$

where Γ_v represents the width of a given vector meson, v , A is a constant to be determined, and Λ , the QCD scale factor, is to be determined, as well.

The constants, A and Λ , may be determined (see Section 2 below for the determination of the values of A and Λ) by simultaneously fitting the width of the ρ and the width of the kaon branch of the ϕ to the form of Eq. 3 above, and B may be determined by evaluating α_s at the $Y(1S)$ energy through the utilization of the experimentally determined partial width associated with the $Y(1S) \rightarrow e^+e^-$ decay in conjunction with the GEM-theoretical hadronic width of the $Y(1S)$ (see Section 2 below). In conventional terms we will find that the hadronic width of any vector meson may be expressed as the following:

$$\Gamma_v \approx (\alpha_s / 2\pi)(10,042)(2m_e)(m_\rho / m_v)^3(\sum_i q_i^4) \quad (4)$$

where m_e represents the electron mass of 0.511 Mev, so that $2m_e = 1.022$ Mev., α_s represents the strong coupling parameter, given by $\alpha_s = 1.2[\ln(m_v/50 \text{ Mev})]^{-1}$, m_ρ represents the mass of the ρ -meson, m_v represents the mass of the vector meson with designate "v", and q_i represents the charge of the relevant quark type(s) "i" to undergo the spin-flip to form the vector meson under consideration. As mentioned above, the q_i involved in ρ formation, are $q_u = 2/3$ and $q_d = -1/3$, where "u" designates an "up quark" and "d" designates a "down quark". Only $q_s = -1/3$, where "s" designates a "strange quark", is involved in the formation of the kaon branch of the ϕ , whereas q_u , q_d , and q_s are all involved in the formation of the $K^*(892)$. In addition, as we will see below, the q_i mainly associated with the $J(3097)$ is actually q_s , and that associated with the $Y(1S)$ is actually $q_c = 2/3$, where "c" is the designate for the "charm quark".

2. The constants, A and Λ , and the specific form of α_s

Focusing now upon Eq. 3 above, A and Λ can be determined simultaneously by utilizing the appropriate q_i and m_v associated with the ρ and ϕ mesons in conjunction with their published widths (see, for example, pdg.lbl.gov; "Meson Table" (2004)). The result⁴ is that $A \approx 1960$ Mev and $\Lambda \approx 50$ Mev. What is most interesting about the above result is the extremely small value for Λ as per the GEM applied to the ρ and the ϕ , as the accepted value⁵ for Λ as of 1996 is around 290 Mev. Nevertheless, in QCD, Λ is considered to be an arbitrary parameter, so no "rules" laid forth within QCD itself are violated by such result. Hence, the GEM formulation of Γ_v becomes:

$$\Gamma_v \approx (1960 \text{ Mev}) (m_\rho / m_v)^3(\sum_i q_i^4) [\ln(m_v/50 \text{ Mev})]^{-1} \quad (5)$$

Now, in the asymptotically free regions of energy space we expect the ratio of a vector meson's electron/positron partial width (Γ_{ee}) to its hadronic width to be approximately (α/α_s) , where α is the fine structure constant = $(1/137.036)$, due to electromagnetic, rather than strong coupling at the pair vertex. At the $Y(1S)$ energy ($m_Y = 9460$ Mev according to the 2004 "Meson Table") from the 2004 "Meson Table" on p. 86, $\Gamma_{ee} = 1.31$ Kev, while the *theoretical* hadronic width, as per the GEM, of the $Y(1S)$ is, as we will see below, assuming single gluon emission, 41 Kev. (As we will in addition see below, the GEM requires that the resonant state at the $Y(1S)$ energy be characterized by an essentially instantaneous transition from its root bb^* state (b represents the bottom quark, while b^* represents the bottom anti-quark) to an excited cc^* state (c represents the charm quark, while c^* represents the charm anti-quark) before its decay.)

Thus,

$$\alpha_s |_{Y \text{ energy}} \approx \alpha (41/1.31) = 0.2284 \quad (6)$$

Setting (from the general form for α_s described above) $0.2284 = B[\ln(9460/50)]^{-1}$, we obtain $B \approx 1.2$; hence, the GEM determines that

$$\alpha_s \approx 1.2[\ln(Q/50 \text{ Mev})]^{-1} \quad (7)$$

With the strong coupling parameter defined as above, it presumably valid over the entire range of energy from the ρ energy to that of the $Y(1S)$, the GEM width formula for vector mesons takes the form, then, of

$$\Gamma_v \approx (1633 \text{ Mev}) (m_p/m_v)^3 (\sum_i(q_i)^4) \alpha_s \quad (8)$$

Expressing Eq. 8 in more conventional form, we have:

$$\Gamma_v \approx (\alpha_s / 2\pi)(10,263 \text{ Mev})(m_p/m_v)^3 (\sum_i(q_i)^4) \quad (9)$$

Yet more formally, we finally obtain:

$$\Gamma_v \approx (\alpha_s / 2\pi)(10,042)(2m_e)(m_p/m_v)^3 (\sum_i(q_i)^4) \quad (10)$$

3. The Feynman Diagrams of the GEM

As per F. Close, the GEM treats the virtual photon and the gluon as, essentially, two aspects of the same entity, which we will call "the four-momentum propagator" designated as " ζ ". Thus, as stated in Section 2 above, the ratio of the partial width associated with a given decaying pair of quarks comprising a given vector meson associated with electron-positron decay to the hadronic width of same is simply (α/α_s) , where, again, " α " represents the fine structure constant = $(1/137.036)$. Hence, the general form for the partial width of a vector meson undergoing e^+e^- decay would be given by

$$\Gamma_{v-ee} \approx (\alpha/2\pi)(10,042)(2m_e)(m_p/m_v)^3 (\sum_i(q_i)^4) \quad (11)$$

A relevant Feynman Diagram will make the various aspects of the GEM easier to picture, so let us look now to Fig. 1 below, which represents the Feynman Diagram (FD) associated the formation and decay of vector meson " X " in its simplest possible form.

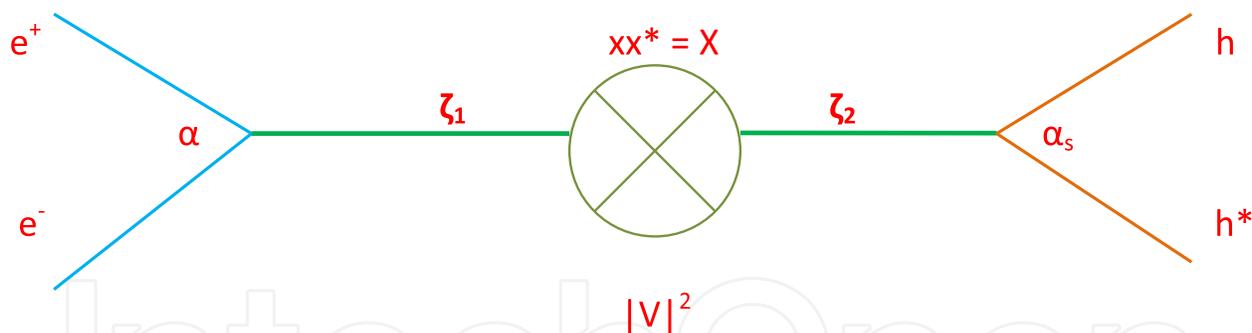


Fig. 1. Basic Feynman Diagram for Conventional Vector Meson Formation/Decay via the GEM

In Figure 1 ζ_1 represents, in part, a virtual photon created at the e^+e^- annihilation vertex, coupling at said vertex represented as α ; then, in Close's terms, the virtual photon couples to a gluon with coupling strength "1", which then couples to the xx^* ... a given quark - anti-quark pair, also with coupling strength "1". In our notation ζ_1 simply represents a four-momentum propagator, created at the e^+e^- vertex and absorbed (as a gluon) at the xx^* node. The details of the absorption of ζ_1 are contained in the integrated absorption cross-section as exhibited in the Introduction, and $|V|^2$, proportional to q_x^4 , describes the formation of the spin one resonance. From there ζ_2 (a gluon) is emitted, resulting in coupling to hadrons (h ; h^*), the coupling at the latter vertex of magnitude α_s . The calculation of the width of the xx^* state then, given the stated mechanism of a spin-flip of one of the "x quarks" due to a spin -

spin interaction proportional to q_x^2 , proceeds straight along the dictates of standard QED, except for the replacement of α by α_s at the hh^* vertex.

For comparison, immediately below we present the FD associated with the same X meson, assumed to exist in the realm of asymptotic freedom, decaying into an electron-positron pair.

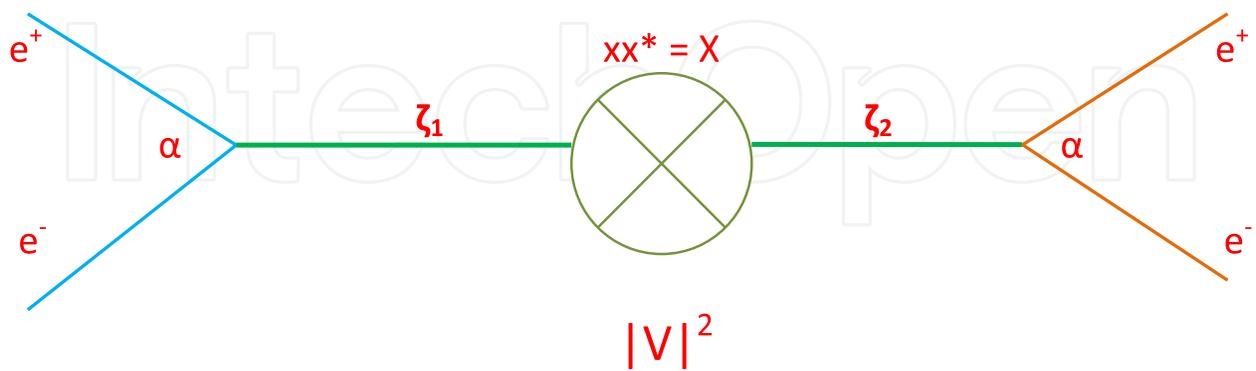


Fig. 2. Basic Feynman Diagram for Conventional Vector Meson Formation & Decay into an Electron/Positron Pair via the GEM

The only fundamental difference between Figure 1 and Figure 2 is that in Figure 2 ζ_2 starts out as a gluon and ends up as a virtual photon at the right hand vertex, at which point the coupling, of course, is now α . Hence, all in the width calculation associated with Figure 1 is the same in Figure 2, except that α_s in Eq. 10 is replaced by α . Of note, too, and we shall return to the point made here, Figure 2 represents rigorously a straight-forward calculation in QED, again, given the stated mechanism for the formation of the resonance state. However, it is also important to note that Figure 2 applies only to vector mesons existing in the realm of “asymptotic freedom”, i.e., to the $J(3097)$, the $Y(1S)$, and “Toponium”, or the “T” meson.

Immediately below we will view the detailed FDs required by the GEM to describe the widths of the ρ , the ϕ , the $K^*(892)$... a very interesting case, as the $K^*(892)$ is not conventionally thought of as a vector meson per se, though it is of the spin one variety ... the $J(3097)$, the $Y(1S)$, and the “T”.

The ρ -meson

Although the width of the ρ (and the ϕ) as determined by the GEM is guaranteed to be a match to experiment by construction, the ρ is a good place to start with the elucidation of the application of the GEM to the various spin one mesons because of the simplicity involved. Let us begin by viewing Figure 3 below ... the FD associated with the formation and decay of the ρ meson.

In Figure 3 ζ_1 represents a virtual photon created at the e^+e^- vertex which transmutes to a gluon, which, in turn, is absorbed by the $[q_uq_u^* + q_dq_d^*]$ combination; ζ_2 represents the emitted gluon, which converts to pion pairs. The application of Eq. 10 results in the following for the hadronic width of the ρ :

$$\Gamma_\rho \approx (\alpha_s / 2\pi)(10,042)(2m_e)(\Sigma_i(q_i^4)) \approx (\alpha_s / 2\pi)(10,042)(2m_e)(17/81) \tag{12a}$$

where

$$\alpha_s = 1.2[\ln(776/50)]^{-1} = 0.4376 \tag{12b}$$

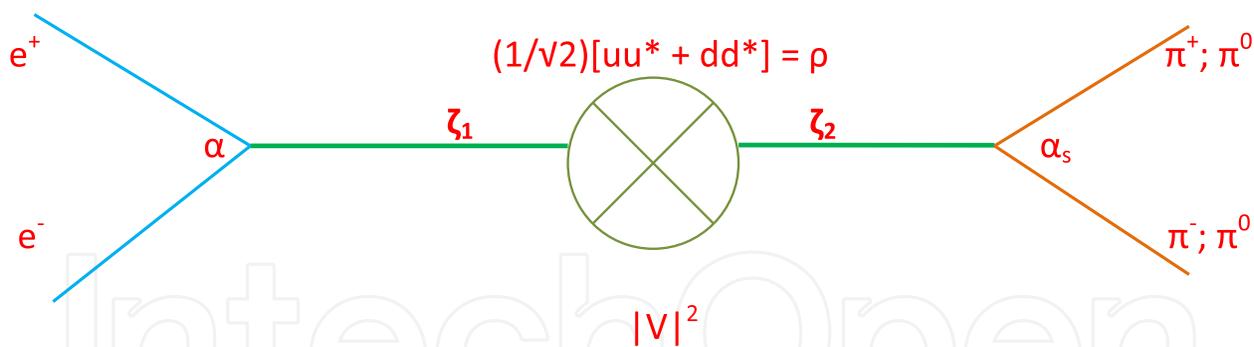


Fig. 3. Basic Feynman Diagram for Formation and Decay of the ρ meson via the GEM

Hence,

$$\Gamma_\rho \approx 150 \text{ Mev} \tag{12c}$$

Though adaptation of Figure 2 and Eq. 11 do not formally apply, as asymptotic freedom does not apply to the ρ , we note that in the event that it were to apply, we would obtain for the electron/positron partial width, $\Gamma_{\rho-ee}$, the following:

$$\Gamma_{\rho-ee} \approx (\alpha / 2\pi)(10,042)(2m_e)(17/81) \approx 2.50 \text{ Mev}$$

a figure⁷ about 355 times too high, indicating that the transmutation coupling of the ζ_2 gluon to its virtual photon identity is only 0.0028, as opposed to 1 in the asymptotically free energy regime.

The ϕ -meson

Application of the GEM to the kaon branch of the ϕ meson (ϕ_K) follows similar lines as to the ρ . The FD associated with the formation and decay of the kaon branch of the ϕ follows:

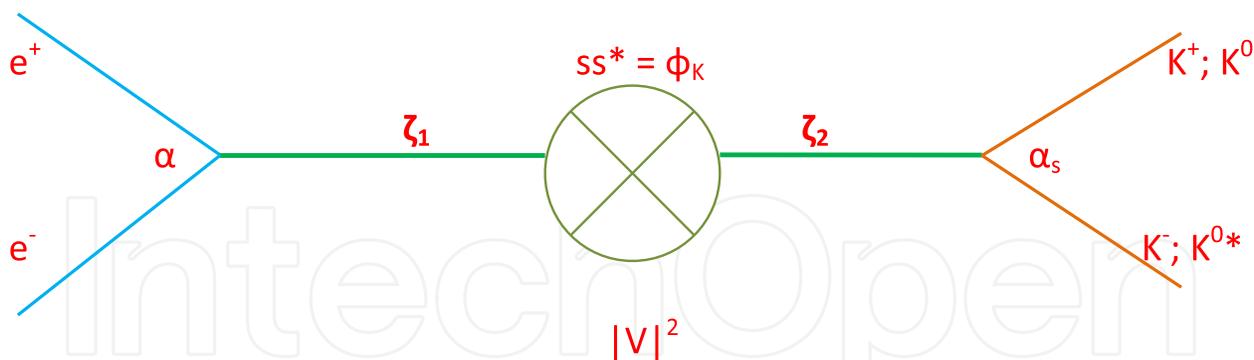


Fig. 4. Basic Feynman Diagram for Formation and Decay of the Kaon Branch of the ϕ Meson via the GEM

For the hadronic width of the kaon branch of the ϕ we obtain:

$$\Gamma_{\phi-K} \approx (\alpha_s / 2\pi)(10,042)(2m_e)(m_\rho / m_v)^3(\sum_i(q_i)^4) \approx (\alpha_s / 2\pi)(10,042)(2m_e)(776/1019)^3(1/81) \tag{13a}$$

where

$$\alpha_s = 1.2[\ln(1019/50)]^{-1} = 0.3981 \tag{13b}$$

Hence,

$$\Gamma_{\phi-K} \approx 3.55 \text{ Mev} \quad (13c)$$

Again applying Eq. 11 to the kaon branch of the ϕ , we obtain for its e^+e^- partial width the following:

$$\Gamma_{\phi-K-ee} \approx (\alpha / 2\pi)(10,042)(2m_e)(776/1019)^3(1/81) \approx 0.0650 \text{ Mev}$$

a figure⁷ still way too high as compared to experiment, but here about 52 times so, indicating that the ζ_2 gluon to virtual photon transmutation coupling has risen to 0.0194.

The $K^*(892)$

The situation regarding the $K^*(892)$ is highly interesting. Close had developed the GEM in the 1970s to describe two distinct processes: (1) the production of pion pairs associated with the ρ resonance and (2) the production of kaon pairs associated with the ϕ resonance. In a sense, then, the GEM was first envisioned to be "route specific", i.e., the spin-flip process involving up and down quarks, which resonates at the ρ mass, was thought of as "the pion route" in thinking of the decay of quark - anti-quark structures, while the spin-flip process involving the strange quark, which resonates at the ϕ mass, was thought of as the corresponding "kaon route". At that time no one had thought of applying the GEM to the $K^*(892)$, because, although energetically possible, the $K^*(892)$ did not exhibit "a pion route" in its decay; rather, the $K^*(892)$ decays almost exclusively into various $\{\pi, K\}$ combinations, with equal probability of occurrence among the various allowed decay products. Such circumstance led to the invention of the "isospin" quantum number, a half integer value for which signifying a forbidden decay route that is energetically possible. However, since the spin associated with the $K^*(892)$ is one, it is quite feasible that the GEM, appropriately mitigated to fit the situation pertaining to the $K^*(892)$'s isospin, may be applied to the $K^*(892)$ resonance. In fact, the GEM has been applied to the $K^*(892)$ quite successfully^{4, 8}. The reasoning leading to the proper mitigation is as follows:

Since pions and kaons are the decay products of the $K^*(892)$, with the various types of pions combining with correspondingly allowed various types of kaons and all types showing up with equal probability, it is reasonable to assume that the $K^*(892)$... for purposes of discussion here considered as a composite entity of mass, 894 Mev, i.e., no distinction as to charged mode versus neutral mode being made ... comprises a linear combination of $\{uu^*, dd^*, \text{ and } ss^*\}$ in equal measure. Symbolically, we may represent the $K^*(892)$, therefore, as

$$K^*(892) = (1/\sqrt{3})[uu^* + dd^* + ss^*] \quad (14)$$

Now, the associated value of $(\sum_i(q_i)^4)$ would be $(18/81)$, but the "pion route" does not occur, though it is energetically possible. So, segmenting the decay in terms of "routes", the $\{\pi, K\}$ route, whose $(\sum_i(q_i)^4) = (18/81)$ does occur, whereas the "pion route", whose $(\sum_i(q_i)^4) = (17/81)$ does not occur. The allowed route is thus favored over the forbidden route by the factor $(18/17)$, therefore. Hence, we postulate that the isospin quantum number = $(1/2)$ assigned to the $K^*(892)$ signifies that of the energetically possible routes available to the $K^*(892)$ resonance, $(18/35)$ of them manifests in the decay process (the $\{\pi, K\}$ route), whereas $(17/35)$ of them fails to materialize (the pion route). We thus multiply the right hand side of Eq. 10 by $(18/35)$ to obtain the width of the $K^*(892)$. First, let us view the associated FD:

The GEM yields for the width of the $K^*(892)$ the following:

$$\Gamma_{K^*} \approx (18/35)(\alpha_s / 2\pi)(10,042)(2m_e)(m_p/m_v)^3(\sum_i(q_i)^4)$$

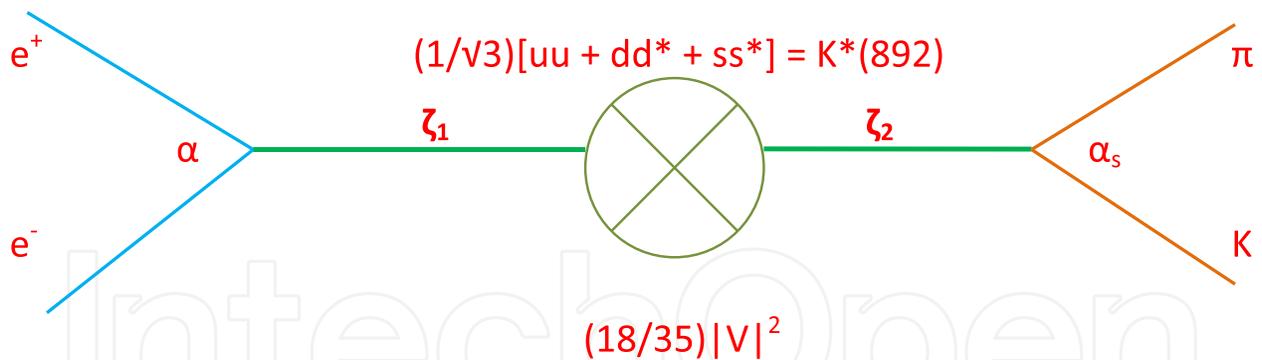


Fig. 5. Basic Feynman Diagram for Formation and Decay of the $K^*(892)$ via the GEM

$$\approx (18/35)(\alpha_s / 2\pi)(10,042)(2m_e)(776/894)^3(18/81) \quad (15a)$$

where

$$\alpha_s = 1.2[\ln(894/50)]^{-1} = 0.4161 \quad (15b)$$

Hence,

$$\Gamma_{K^*} \approx 50.80 \text{ Mev} \quad (15c)$$

The average of the widths associated with the charged and neutral modes of the $K^*(892)$ is stated⁹ as $\Gamma_{K^*}(\text{PDG}) = 50.75 \text{ Mev}$. Hence, the GEM as applied to the $K^*(892)$ provides for fabulous agreement with experiment. Moreover, the GEM demonstrates quite clearly that the $K^*(892)$ is not a “strange meson” in the usual sense, i.e., it is seen not as a us^* , su^* , ds^* , or sd^* structure at all; rather it is seen, similar to the theoretical structures of the ρ and the ϕ , as comprising a linear combination of more than one type of quark - anti-quark pair, its specific nature expressed via Eq. 14.

The J(3097)

Application of the GEM in accord with Figure 1, with $x = c$, seems reasonably straightforward, but it turns out to be problematic. However, when one sees that the hadronic width of the J(3097), designated as simply the “J” henceforth, given by the application of Eq. 10 in accord with Figure 1 with $x = c$, is roughly sixteen times too large, as compared to experimental results, coupled with the fact that the hadronic width of the $Y(1S)$ given by the application of Eq. 10 in accord with Figure 1 with $x = b$ is roughly sixteen times too small, as compared with experimental results, it becomes obvious as to what physically must transpire as regards both the J and the $Y(1S)$. Restricting the discussion to the J for the time being, in what we call “the zeroth order approximation”, the basic cc^* structure of the J must make a point-like transition to an ss^* structure of equal mass, whereupon one of the s quarks undergoes a spin flip to form the associated resonance¹⁰, the point-like transition from cc^* to ss^* instantaneous, thus having no influence on the J’s width. Indeed, the resonance does not even form until an s (or s^*) quark undergoes a spin-flip. That the cc^* to ss^* transition is necessary is quite understandable: The J is not massive enough for it to be able to decay into hadrons via emission of two c quarks; hence, it must transition to a quark pair of lesser bare mass each. The simplest possible assumption is that the cc^* transitions to the quark pair type characterized by the next smallest mass, viz., the s type. Nothing prevents the cc^* structure from decaying into leptons (e^+e^- and $\mu^+\mu^-$), however. It is found¹⁰ in fact, that in order for both the hadronic width of the J and the leptonic width of the J as determined via the GEM to match the results of experiment, $(8/9)^{\text{ths}}$ of the cc^* structure must undergo a slightly “un-

point-like" transition to ss^* , described by a form factor, $f < 1$, which, in turn, decays into both hadrons and leptons as per Eq. 10 and Eq. 11, respectively, while $(1/9)^{\text{th}}$ of the original cc^* structure remains to decay into leptons exclusively. We may picture the complete details of the J formation and decay via the following two arrays of FDs, the first such array descriptive of what we may now call "the first order approximation" to the width of the J, the second such array descriptive of what we call "the second order approximation".

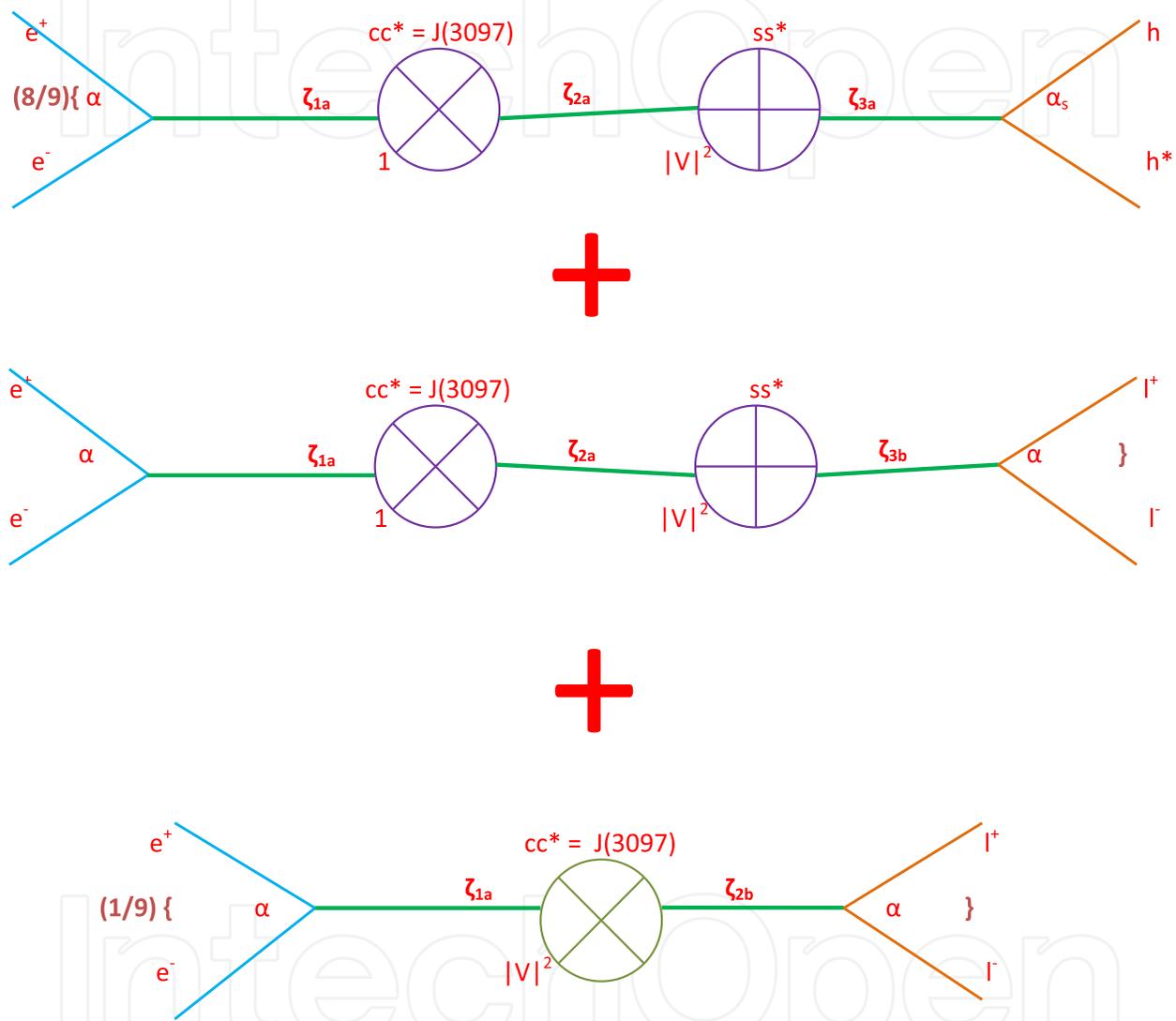


Fig. 6a. Feynman Diagram Array Characterizing the Formation and Decay of the J(3097) in First Order Approximation via the GEM

In Figure 6a above "1" represents a leptonic decay product, ζ_{2a} represents the gluon involved in a point-like transition from cc^* to ss^* , and all other " ζ " designates should be understood from previous discussion. Transforming the schematic representation of Figure 6a into the calculation of the full (hadronic plus leptonic) width of the J in first order approximation, denoted as $\Gamma_{J\text{-full-1}}$, proceeds as follows (the factors of "2" in Eq. 16a, immediately in front of the factors " $(\alpha / 2\pi)$ " take into account muon pair production in accord with "e- μ universality"):

$$\Gamma_{J\text{-full-1}} \approx (8/9)\{(\alpha_s / 2\pi)(10,042)(2m_e)(m_\rho / m_J)^3(q_s)^4 + 2(\alpha / 2\pi)(10,042)(2m_e)(m_\rho / m_J)^3(q_s)^4\}$$

$$+ (1/9)\{2(\alpha / 2\pi)(10,042)(2m_e)(m_p/m_J)^3(q_c)^4\} \quad (16a)$$

Thus,

$$\Gamma_{J\text{-full-1}} \approx (8/9)\{(\alpha_s / 2\pi)(10,042)(2m_e)(776/3097)^3(1/81) + 2(\alpha / 2\pi)(10,042)(2m_e)(776/3097)^3(1/81)\} + (1/9)\{2(\alpha / 2\pi)(10,042)(2m_e)(776/3097)^3(16/81)\}$$

The value of the strong coupling parameter at the J mass is given by

$$\alpha_s = 1.2[\ln(3097/50)]^{-1} = 0.2908 \quad (16b)$$

Therefore,

$$\Gamma_{J\text{-full-1}} \approx (8/9)\{92.2491 \text{ Kev} + 4.6298 \text{ Kev}\} + (1/9)\{74.0769 \text{ Kev}\} \approx 94.35 \text{ Kev} \quad (16c)$$

The value for $\Gamma_{J\text{-full-1}}$ obtained via the first approximation of the GEM is a match to experiment, as according to PDG (2009), the full width of the J via experiment is (93.2 ± 2.1) Kev . As well, the hadronic width alone via the first approximation of the GEM is a match to experiment (82.00 Kev via the GEM vs. (81.7 ± 0.5) Kev via experiment (PDG (2009)); the leptonic width via the first approximation of the GEM is 12.35 Kev, which is about 11% more than that reported by the PDG currently (11.10 ± 0.16) Kev (PDG (2009)).

The first approximation assumes that $(8/9)^{\text{ths}}$ of the original cc^* state undergo a point-like transition to an excited ss^* state, leaving $(1/9)^{\text{th}}$ of the original cc^* state to decay into leptons. A point-like transition is instantaneous, so it has no effect on the width of the original construction (i.e., the J). In terms of a *form factor*, f , a point-like transition is consistent with $f = 1$. As it is difficult to see how *any fraction* of the original cc^* state could “know” to make an instantaneous transition, leaving a remnant to do other things, we believe a second order approximation is in order. Our reasoning is simply that, logically, we feel that there simply *must* be some type of communication between the cc^* and ss^* states *before* the cc^* to ss^* transition takes place in order for the proper remnant to consistently remain to decay into leptons. Hence, we reason that $f < 1$ describes the cc^* to ss^* transition. Statistically, $f = (1 - q_s^2) = (8/9)$ is necessary to describe the hadronic width of the J. Since f is not appreciably different than 1, the leptonic width of the J, relative to the first order approximation, will be mitigated slightly. The second order FD for the J follows:

In Figure 6b $f = (8/9)$ multiplies the entire array. Denoting the full width of the J in second order approximation by $\Gamma_{J\text{-full-2}}$, we find in accord with Figure 6b:

$$\Gamma_{J\text{-full-2}} \approx (8/9)[(\alpha_s / 2\pi)(10,042)(2m_e)(m_p/m_J)^3(q_s)^4 + 2(\alpha / 2\pi)(10,042)(2m_e)(m_p/m_J)^3(q_s)^4 + (1/9)\{2(\alpha / 2\pi)(10,042)(2m_e)(m_p/m_J)^3(q_c)^4\}] \quad (16d)$$

Thus,

$$\Gamma_{J\text{-full-2}} \approx (8/9)[(\alpha_s / 2\pi)(10,042)(2m_e)(776/3097)^3(1/81) + 2(\alpha / 2\pi)(10,042)(2m_e)(776/3097)^3(1/81) + (1/9)\{2(\alpha / 2\pi)(10,042)(2m_e)(776/3097)^3(16/81)\}]$$

Again, the value of the strong coupling parameter at the J mass is given by Eq. 16b, viz.,

$$\alpha_s = 1.2[\ln(3097/50)]^{-1} = 0.2908$$

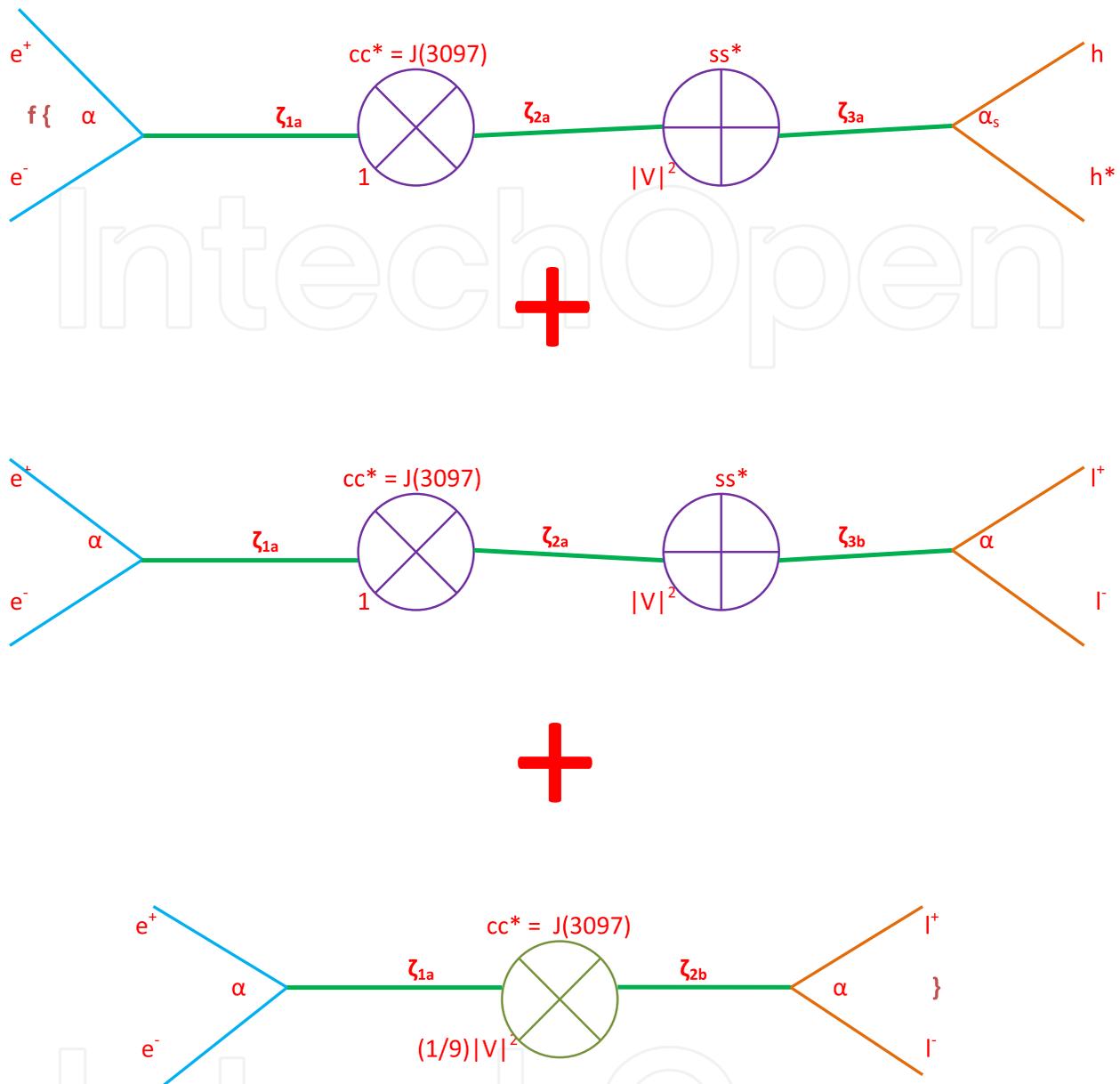


Fig. 6b. Feynman Diagram Array Characterizing the Formation and Decay of the J(3097) in Second Order Approximation via the GEM

Therefore,

$$\Gamma_{J\text{-full-2}} \approx (8/9)[92.2491 \text{ Kev} + 4.6298 \text{ Kev} + (1/9)\{74.0769 \text{ Kev}\}] \approx 93.43 \text{ Kev} \quad (16e)$$

The full width of the J under second order approximation is thus nearly an exact match to experiment (93.4 Kev via the GEM vs. 93.2 Kev from PDG (2009)). The hadronic width of the J is unchanged from first to second approximation; so, it remains a match with experiment (82.0 Kev via the GEM vs. 81.7 Kev from PDG (2009)). As well, the leptonic width of the J via the GEM (11.4 Kev) is now only 2.7% higher than that reported by the PDG ((11.1 ± 0.2) Kev).

The $Y(1S)$

Analogous to the J , the $Y(1S)$, originally a bb^* construction, must transition to a cc^* excited state of the same mass as that of the bb^* state in order to decay into hadrons. Unlike the J , however, there is no reason to suspect that leptons emerge from the bb^* state. Hence, we assume that all types of $Y(1S)$ decays ensue from the cc^* excited state. Corroborative evidence abounds in support of such assumption, as we shall see, so let us proceed with the viewing of the two FDs which depict the hadronic decay of the $Y(1S)$ and the leptonic decay of the $Y(1S)$, respectively:

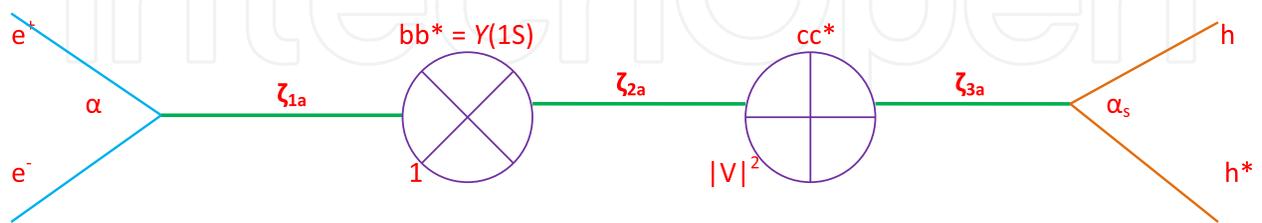


Fig. 7a. Basic Feynman Diagram for $Y(1S)$ Formation and Decay into Hadrons via the GEM

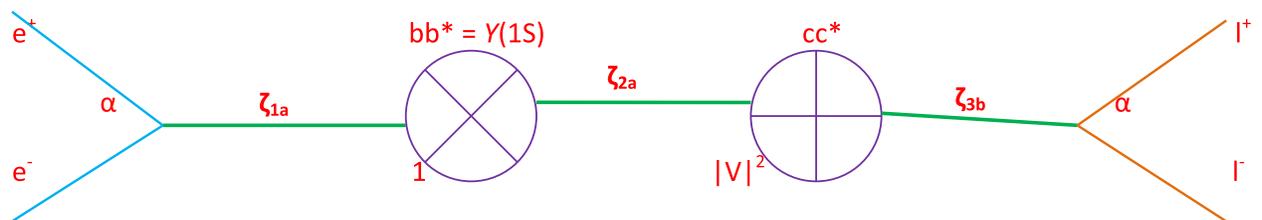


Fig. 7b. Basic Feynman Diagram for $Y(1S)$ Formation and Decay into Leptons via the GEM

From Eq. 10 the hadronic width of the $Y(1S)$, denoted by Γ_{Y-H} , via the GEM theoretical structure is given by:

$$\Gamma_{Y-H} \approx (\alpha_s / 2\pi)(10,042)(2m_e)(m_p / m_Y)^3(q_c)^4 \approx (\alpha_s / 2\pi)(10,042)(2m_e)(776/9460)^3(16/81) \quad (17a)$$

where

$$\alpha_s = 1.2[\ln(9460/50)]^{-1} = 0.2289 \quad (17b)$$

Hence,

$$\Gamma_{Y-H} \approx 40.76 \text{ Kev} \quad (17c)$$

The PDG in the 2008 Meson Table (PDG (2008), p.119) reports the corresponding figure as

$$\Gamma_{Y-H}(\text{PDG}) = 49.99 \text{ Kev} \quad (17d)$$

a figure 23% higher than the GEM-theoretical result.

However, if we look at the leptonic width of the $Y(1S)$, denoted by Γ_{Y-L} , as derived via the GEM, we find from Eq. 11 (the right hand side of same multiplied by "3" to take into account muon and tauon pairs in accord with "e- μ - τ universality") that

$$\Gamma_{Y-L} \approx 3(\alpha / 2\pi)(10,042)(2m_e)(m_p / m_Y)^3(q_c)^4 \approx 3(\alpha / 2\pi)(10,042)(2m_e)(776/9460)^3(16/81) \quad (18a)$$

Hence,

$$\Gamma_{Y-L} \approx 3.90 \text{ Kev} \quad (18b)$$

which represents a match to the PDG's report from the same 2008 Meson Table of

$$\Gamma_{Y-L}(\text{PDG}) = (4.03 \pm 0.14) \text{ Kev} \quad (18c)$$

Specific to the e^+e^- partial width (Γ_{Y-ee}), the GEM obviously determines $\Gamma_{Y-ee} \approx 1.30 \text{ Kev}$, while the PDG in the above-mentioned source (p. 119) states $\Gamma_{Y-ee}(\text{PDG}_1) \approx 1.34 \text{ Kev}$ directly, but indirectly, in terms of its stated fractional branching ratio on p.119, a different value is inferred, viz., $\Gamma_{Y-ee}(\text{PDG}_2) \approx 1.29 \text{ Kev}$. From the latter we infer that according to the PDG (2008), the experimentally determined value for the e^+e^- partial width of the $Y(1S)$ is given by

$$\Gamma_{Y-ee}(\text{PDG}) = (1.31 \pm 0.03) \text{ Kev} \quad (18d)$$

a match to that of the GEM, i.e.,

$$\Gamma_{Y-ee} \approx 1.30 \text{ Kev} \quad (18e)$$

Herein (i.e., the match between Eq. 18d and Eq. 18e) lies the source of a paradox that the hadronic width as given by the GEM (i.e., $\sim 41 \text{ Kev}$) should be correct, though it is so seriously discrepant with that reported by the PDG (i.e., 50 Kev). The paradox unfolds as follows: In order to obtain the constant "B" in the general expression for α_s , once Λ was determined, the assumption was made that, since the $Y(1S)$ exists well into the realm of asymptotic freedom,

$$\alpha/\alpha_s = (\text{e}^+\text{e}^- \text{ partial width})/(\text{hadronic partial width})$$

as associated with the $Y(1S)$.

In Section 2 we inserted $\Gamma_{Y-ee}(\text{PDG}) = 1.31 \text{ Kev}$ for the e^+e^- partial width, and for the hadronic partial width, we inserted the *GEM-theoretical width*, i.e., $\Gamma_{Y-H} \approx 41 \text{ Kev}$. We then obtained the general relation,

$$\alpha_s = B[\ln(9460/50)]^{-1} = \alpha(41/1.31)$$

from which we solved for "B" to obtain, $B = 1.2$

In turn, as "B" is a multiplier on the right hand sides of all width calculations via the GEM theory, and as all width calculations, as seen above, represent nearly exact matches with experiment in all cases except as to the hadronic width of the $Y(1S)$, it is difficult to fathom the source of the disparity between $\Gamma_{Y-H} = 41 \text{ Kev}$ and $\Gamma_{Y-H}(\text{PDG}) = 50 \text{ Kev}$.

After a good number of years of pondering, it turns out that there is, actually, a very simple, and at the same time a very plausible solution to the paradox mentioned above, viz., we postulate an additional route for $Y(1S)$ decay into hadrons, a route assumed not to have a high probability of occurrence for the J or the other vector mesons of mass less than that of the J. As the basis for the existence of the additional route available to the $Y(1S)$, we point to the fact that there is roughly three times the energy spectrum available to the $Y(1S)$ in its decay (9460 Mev worth) as compared to the next lightest vector meson, i.e., the J (3097 Mev worth). With three times the energy spectrum (as compared to the J) available to the $Y(1S)$, we think it plausible that decays resulting in hadrons as products may be allowed to take place through the *bifurcation* of the gluon emitted from the resonance state (or more simply stated: via emission of two gluons), rather than what has heretofore been assumed in accord

with Figure 7 a, in which a single gluon, ζ_{3a} , converts to hadrons to mark the final stage of the decay process. Specifically, we propose that, in addition to the route as described immediately above, a route exists in which ζ_{3a} bifurcates into two gluons, each of which then converts to hadrons. The FD associated with the proposed additional route is seen immediately below.

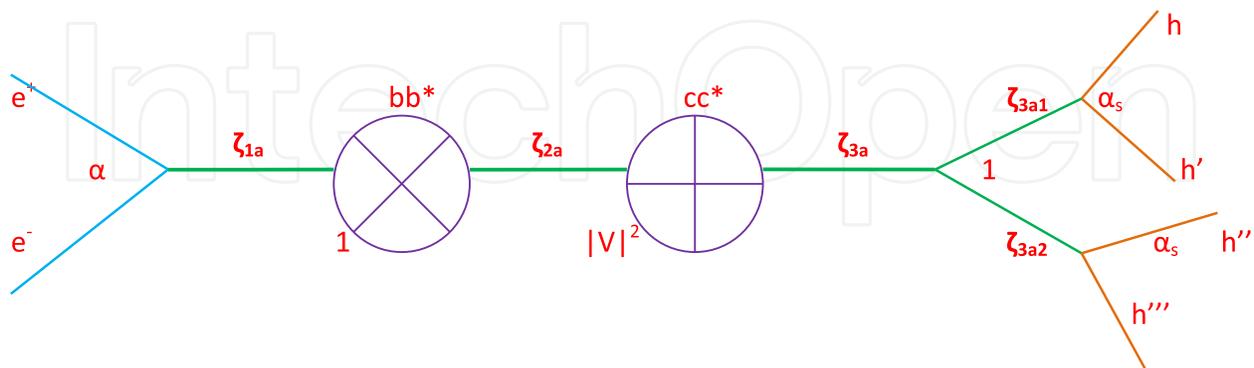


Fig. 8. Basic Feynman Diagram for Postulated Additional Route for $Y(1S)$ Formation and Decay into Hadrons (h , h' , h'' , and h''') via the GEM

The additional route, which we denote as the “bifurcated gluon route for hadron decay” (BGRHD), effectively adds α_s times Γ_{Y-H} , or $(0.2289)(40.76 \text{ Kev}) = 9.33 \text{ Kev}$ to the GEM-theoretical width of the $Y(1S)$. The reformulated situation regarding the $Y(1S)$ may be summarized, therefore, as follows:

Denoting the partial width due to the BGRHD as Γ_{Y-BGH} , we have

$$\Gamma_{Y-BGH} = 9.33 \text{ Kev} \quad (19)$$

From above we have

$$\Gamma_{Y-H} = 40.76 \text{ Kev}$$

Also from above we have

$$\Gamma_{Y-L} = 3.90 \text{ Kev}$$

The net hadronic width of the $Y(1S)$ as per the GEM would now be given by

$$\Gamma_{Y-(H+BGH)}(\text{GEM 2010}) = 50.09 \text{ Kev} \quad (20)$$

which now represents a nearly perfect match to

$$\Gamma_{Y-H}(\text{PDG}) = 49.99 \text{ Kev}$$

In addition the full width of the $Y(1S)$ as per the GEM would now be given by

$$\Gamma_{Y-\text{full}}(\text{GEM 2010}) = 53.99 \text{ Kev} \quad (21)$$

which also represents a nearly perfect match to $\Gamma_{Y-\text{full}}(\text{PDG}) = (54.02 \pm 1.25) \text{ Kev}$

With the addition of the BGRHD the calculation of “B” in the expression for α_s is uncompromised, while at the same time the major discrepancy between the hadronic width of the $Y(1S)$ as determined via the GEM versus via the methods engaged by the PDG is completely removed. For that reason we believe the postulate as to the addition of the

BGRHD is a viable one. In fact, if we postulate that in addition to the BGRHD there is a companion route for leptons, i.e., a bifurcated gluon route for lepton decay (BGRLD), whose FD is identical to that of Figure 9, except that on the far right hand side of the diagram, each “ α_s ” is replaced by “ α ” and “ $h, h', h'',$ and h''' ” are replaced by “ $l_i^+, l_i^-, l_j^+,$ and l_j^- ”, respectively, where “ i ” and “ j ” denote lepton types and $i = j$ is allowed, $(3.90 \text{ Kev} / 137.036) = 0.03 \text{ Kev}$ would be added to

above, thus bringing

$$\frac{\Gamma_{Y\text{-full}}(\text{GEM 2010})}{\Gamma_{Y\text{-full}}(\text{GEM 2010})} \rightarrow 54.02 \text{ Kev} \tag{22}$$

i.e., the realization of an exact match to experiment.

4. Speculations based upon the GEM

The T-Meson

To address the T-meson, thought to be a tt^* (where “ t ” represents the top quark) state of mass approximately 340000 Mev, but never “discovered” to date, is quite speculative on our part, but we think it important to do so because the GEM provides a perfectly logical reason as to why the T has yet to be “found”, i.e., unequivocally shown to exist by experiment. Said reason is just the opposite of the prevailing view as to the “invisibility” of the T, which is: “the T doesn’t last long enough for it to be found.” In a sense such is true; after all, the bb^* of the $Y(1S)$ transitions instantaneously to a cc^* state according to the GEM, but the mass of the original bb^* state is preserved in the resulting cc^* state, thus allowing for the “finding” of a resonance at the $Y(1S)$ mass. Assuming the T to act in like manner to the $Y(1S)$, the following FD would apply as regards hadron production:

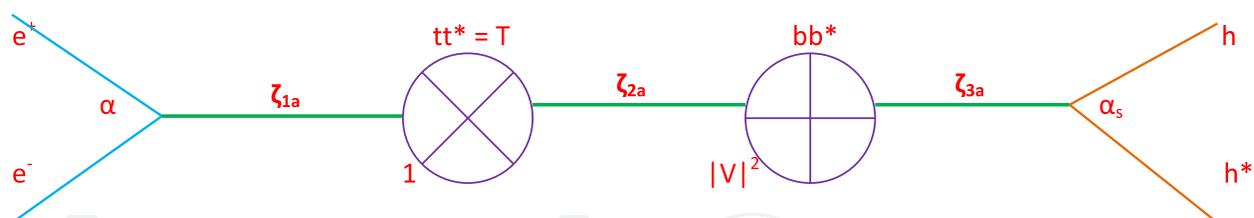


Fig. 9. Basic Feynman Diagram for T Formation and Decay into Hadrons via the GEM

The hadronic width of the T, from Eq. 4 would be:

$$\begin{aligned} \Gamma_T &\approx (\alpha_s / 2\pi)(10,042)(2m_e)(m_p / m_T)^3(q_b)^4 \\ &\approx (\alpha_s / 2\pi)(10,042)(2m_e)(776 / 340000)^3(1/81) \end{aligned} \tag{23a}$$

where

$$\alpha_s = 0.90[\ln(340000/50)]^{-1} = 0.1020 \tag{23b}$$

(In Eq. 23b the constant “1.2” in the expression for α_s becomes¹¹ “0.90” beyond 100000 Mev, and in Eq. 23a $q_b = -1/3$.)

Hence,

$$\Gamma_T \approx 0.024 \text{ ev} \tag{23c}$$

Thus, we see that, contrary to the “convenient explanation” as to why the T has not so far been observed, the T lives for a *very long time* (about 6 ps)! It’s just that its width to mass ratio makes it impossible right now for the experimental apparatus to pick up such a narrow signal amongst the “noise” inherent in the energy background needed to produce the T.

Color-by-Color Disengagement from Lepton Production

We must go a bit beyond the scope of the material thus far presented in order to discuss the phenomenon of color-by-color disengagement from lepton production, as we must now make reference to the excited states of the Ψ -series and Y -series mesons, designated respectively as $\Psi(NS)$ and $Y(NS)$, where $N > 1$ designates an excited state. It turns out that as regards lepton decay, partial widths of the above objects, when $N = 2$, the associated form factors (f_i) which provide for excellent agreement with experiment are as follows¹²:

For the $\Psi(2S)$ $f_1 = 1 - q_s^2 = 8/9$ (as was found above for the $J = \Psi(1S)$), and for the $Y(2S)$ $f_2 = 1 - q_c^2 = 5/9$ (analogous to the $\Psi(2S)$). We will designate the form factor for the $Y(1S)$ (as per above) as $f_3 = 1$. What is highly interesting, as it turns out, is that in terms of the above form factors, the leptonic partial widths of many of the $\Psi(NS)$ and $Y(NS)$ states are excellently described by the GEM if the latitude exists to multiply the resulting GEM-width formulas involving the appropriate form factors by “(n/6)”, where “n” is an integer, the interpretation being that as N increases, the number of quark colors participating in lepton decay decreases ... effectively by “half colors” at a time. We illustrate the quark color disengagement phenomenon by reproducing the results from the reference¹² associated with footnote # 12 below:

Meson	Mass (Mev)	$\Gamma_{ee}(\text{GEM})$	$\Gamma_{ee}(\text{PDG})$	# of Colors Operative
$\Psi(1S)$	3097	5.72	5.55 ± 0.16	3
$\Psi(2S)$	3686	2.26	2.36 ± 0.04	2
$\Psi(3S)$	4039	0.86	0.86 ± 0.07	1
$\Psi(4S)$	4153	0.79	0.83 ± 0.07	1
$\Psi(5S)$	4421	0.65	0.58 ± 0.07	1

Chart 1. Color Participation in Lepton Production in the Ψ -Series

In Chart 1 all electron/positron partial widths are expressed in Kev. Note that a near-match with experiment occurs for the $J(3097)$, as per Section C above, assuming three colors are operative in electron/positron decay ($n = 6$). A near-match with experiment results for the $\Psi(2S)$ assuming two colors are operative in said decay ($n = 4$), and statistical matches with experiment are evident if we assume only one color participates in electron/positron decay ($n = 2$) as associated with the $\Psi(3S)$, $\Psi(4S)$, and $\Psi(5S)$. As to the $\Psi(NS)$ objects, then, the GEM provides an excellent match to experiment (from the PDG’s 2009 “Meson Table”) if we assume that sequentially progressive disengagement ... color-by-color ... of quark colors manifests in lepton decay.

The situation is similar to, but slightly different than the above, as regards the $Y(NS)$ series, as seen in Chart 2 below.

Again, all partial widths are expressed in Kev, and, again, we see excellent agreement with experiment if we assume $n = 6$ associated with the $Y(2S)$ (three colors operative), $n = 5$ associated with the $Y(3S)$ (either “2½ colors” operative or an even mix of three colors and two colors taking part in the decay), $n = 3$ associated with the $Y(4S)$ (either “1½ colors”

Meson	Mass (Mev)	$\Gamma_{ee}(\text{GEM})$	$\Gamma_{ee}(\text{PDG})$	# of Colors Operative
Y(2S)	10023	0.624	0.612 ± 0.11	3
Y(3S)	10355	0.471	0.443 ± 0.008	2½
Y(4S)	10579	0.266	0.272 ± 0.029	1½
Y(5S)	10860	0.33	0.31 ± 0.07	2
Y(6S)	11019	0.157	0.13 ± 0.03	1

Chart 2. Color Participation in Lepton Production in the Y-Series

operative or an even mix of two colors and one color taking part in the decay), $n = 4$ associated with the Y(5S) (two colors operative), and $n = 2$ associated with the Y(6S) (one color operative). At the present juncture, perhaps the best guess as how to handle the results associated with the Y(3S) and Y(4S) would be to speculate that the GEM description should be due to a nearly even mix of two and three contributing colors in one case, and a nearly even mix of one and two contributing colors in the other case, rather than making the claim that the GEM has shown that the quark colors become fragmented beyond 10 000 Mev, especially when one notes that all results associated with integer color contributions in Chart 2 represent statistical matches with experiment. Note, as well, that the progressive color disengagement behavior with increasing mass is preserved if only integer color contributions are considered.

Vector Mesons as Vacuum Excitations

One basic reality demonstrated by the GEM is the prime role that the electromagnetic interaction plays in vector meson formation and decay. The spin-flip responsible for all spin one mesons takes place via the electromagnetic interaction. The transitioning of the four-momentum from cc^* states to ss^* in the $\psi(\text{NS})$ decays, as evidenced via the mathematical form of the form factor, f_1 , is seen to take place via the electromagnetic interaction, as is the case regarding the analogous transition from bb^* to cc^* in the Y(NS) decays. A second reality demonstrated by the GEM represents a radical departure from current assumptions about the structures of vector mesons in general ... but especially about the structure of the K^* ... viz., that all vector mesons are represented by

$$\chi_v = (1/\sqrt{n})[\sum_{i=1}^n (Q_i Q_i^*)] \quad (24)$$

where Q_i represents a quark of flavor, "i", Q_i^* represents the associated anti-quark, and "n" represents the number of flavors operative at the energy scale of the relevant meson's rest energy. Thus, for example, the neutral K^* does *not* comprise a ds^* or an sd^* , and the charged K^* does *not* comprise a us^* or an su^* . Rather, there is a general "K* construction" given by Eq. 14, the decay of which features a "favored energy" of 892 Mev resulting in a net charge of ± 1 amongst its decay products ... *and* another "favored energy" at 896 Mev resulting in no net charge amongst its decay products. In the literature similar considerations apply to the various D^* and B^* states¹³. In other words the GEM illustrates that vector mesons are not actually "unstable particles" which form at collision sites, but rather are manifestations of a "quark sea" as part of the construction of what we call "the vacuum" ... much analogous to Dirac's idea of the "electron sea" of old. Just as the electrons in the Dirac Sea were thought to be excited via the electromagnetic interaction, we see from the above that one may surely think of the formation of vector mesons as an electromagnetic excitation of relevant quarks in a "quark sea" ... where a given quark is promoted to a positive energy state by a virtual gluon, which, unlike in electron/positron production, where the electron flies away from its

“vacuum hole”, produces the circumstance that a tightly bound quark/anti-quark pair becomes virtually extant, in which vicinity the spin-flip of one of the quarks occurs, thus producing what we call “a vector meson”. Whether one thinks of the vacuum in accord with Brian Greene as “the fabric of the cosmos”, or, more conventionally, in accord with the pioneers of Quantum Electrodynamics (QED), as “a sea of leptons” (i.e., electrons, muons, taus, and six flavors of quarks), the vacuum is certainly a “something” as opposed to “nothing at all”. If one treats vector mesons as vacuum excitations, i.e., “an excitation of the sea of leptons” and follows the rules laid down by the pioneers of QED (i.e., the calculation of the relevant Feynman Diagrams) with the one exception of replacing α by α_s (it derived solely via the GEM) in the hadronic partial width calculations, one acquires fine agreement with experiment. Hence, we believe, vector mesons thought of as vacuum excitations makes perfect sense.

5. Summary

The Gluon Emission Model has been shown to serve very nicely as a basis for calculations of not only the widths of the ρ meson, the ϕ meson, the $K^*(892)$, the J meson, and the Y meson, but also for the determination of the strong coupling parameter, α_s , over the entire range of energy over which the above objects exist. We have seen that the GEM has built into its framework two precepts of prime importance for the carrying out of the above types of calculations: (1) the specification of a quark spin-flip matrix element as the central determinant of a vector meson resonance and (2) the virtual photon and the gluon as two aspects of the same entity, viz., the four-momentum propagator. The prime significance of (1) is that the square of the quark spin-flip matrix elements in vector meson width calculations are proportional to q_i^4 , where q_i represents the magnitude of the charge of quark type “ i ”. The significance of (2) is that the virtual photon and the gluon essentially obtain their identities from what the vertices of origin and termination are in the relevant Feynman Diagram. The ramifications of (1) are that, as $(2/3)^4$ is 16 times $(1/3)^4$, it is quite easy to determine that the cc^* (charm - anti-charm) structure of the $J(3097)$ must transmute to an ss^* (strange - anti-strange) in nearly a point-like manner, such that it is the ss^* structure that undergoes the spin-flip at the $J(3097)$ resonance. Similarly, the $Y(1S)$ must transmute in point-like manner from its original bb^* (bottom - anti-bottom) structure to a cc^* structure before decaying. The ramification of (2) is that the leptonic width to hadronic width ratio associated with the same basic decaying structure must be in the ratio of α to α_s . We saw that the GEM predicts the hadronic width of the $Y(1S)$ to be ~ 41 Kev, assuming that the $Y(1S)$, as lower energy mesons do, decays solely via the emission of a single gluon, whereas the figure for same as stated in the 2008 Meson Table from the Particle Data Group (PDG) is ~ 50 Kev. The discrepancy noted above (23%) is seen to be extremely important, because, if we were to assume that the GEM was in error by such amount, it turns out that all other GEM calculations, currently essentially exactly on the mark as to the ρ , the ϕ , the $K^*(892)$, the J , and α_s , would have to be rendered as 23% too large by bringing the GEM’s determination of the $Y(1S)$ in line with the PDG’s determination of same through adjustment of the GEM’s determination of α_s . Hence, in order to make the GEM as currently constructed fit the PDG as to the hadronic width of the $Y(1S)$, all other GEM calculations would be discrepant by the same amount, i.e., 23%, at each diverse point of the energy spectrum where the GEM has been successfully applied. Clearly, then, what needed to be addressed are the details in the GEM’s determination of the width of the $Y(1S)$, with an eye

towards any reasonable modifications that might remove the above-mentioned disparity, with the satisfactory result being the assumption of an additional decay route for the $Y(1S)$, i.e., the bifurcated gluon route.

Unlike the theoretical structures prevalent in the literature that one encounters as to determining the width of the vector mesons, the GEM theory is about as simple as it gets: One fundamental process is posited for the formation and decay of any spin one meson, i.e., a quark spin-flip; the gluon absorption cross-section for said process is then integrated over energy, and from there, the Feynman Diagram resulting in hadron or lepton pairs is then calculated.

Form factors associated with the $\psi(1S)$ and $Y(2S)$, calculated directly from relevant experimental data, are given by $f_1 = (1-q_s^2) = (8/9)$ in the case of the ψ -series mesons and $f_2 = (1-q_c^2) = (5/9)$ in the case of the Y -series mesons, where $q_s = -1/3$ represents the charge of the strange quark and $q_c = 2/3$ represents the charge of the charm quark. The form factors represent the fraction of the originally produced quark/anti-quark (QQ^*) state which makes a transition to a QQ^* state of the next lowest mass ... ss^* in the case of the ψ -series mesons and cc^* in the case of the Y -series mesons ... and thus figure prominently into the calculation of the hadronic and leptonic widths of a given meson via the constructs of the Gluon Emission Model. We have seen that $f_1 = (8/9)$ is representative of all ψ -states, if, and only if, it is assumed that one quark color (in the case of the $\psi(2S)$) or two quark colors (in all other cases) become disengaged from lepton production. A similar set of circumstances is observed as to the Y -series mesons, such illustrating that all three quark colors are functional in lepton production in $Y(2S)$ decay, fewer than three functional in $Y(3S)$ and $Y(4S)$ decay, with likely only one color functioning in $Y(5S)$ and $Y(6S)$ decay. For each meson series, then, lepton decay is characterized by the phenomenon of sequential disengagement of quark color from lepton production as a function of increasing mass.

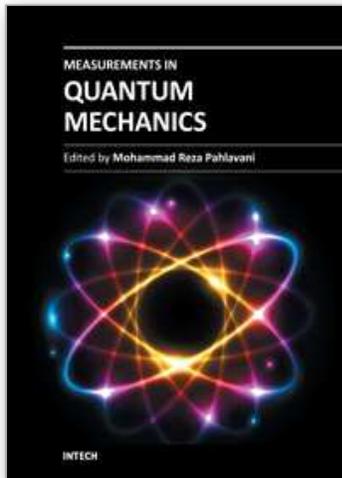
Finally, we have seen that the GEM suggests, contrary to a rigid interpretation of the Standard Model, in which vector mesons are treated as unstable particles, that vector mesons are quite realizable as electromagnetic vacuum excitations of a constituent "quark sea", analogous to the "Dirac Sea" of electrons of old. Specifically, the GEM construct yields agreement with experiment only if it is assumed that vector mesons are represented as linear combinations of quark spin-flip excitation possibilities. The $K^*(892)$ is a case in point, but, further, there appears to be no hope for reliable width calculations of any ψ -series mesons if such elements of said series are represented solely as cc^* objects. A like statement, of course, holds for the elements of the Y -series as immutably bb^* "particles".

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Perhaps quantum mechanics is viewed as the most remarkable development in 20th century physics. Each successful theory is exclusively concerned about "results of measurement". Quantum mechanics point of view is completely different from classical physics in measurement, because in microscopic world of quantum mechanics, a direct measurement as classical form is impossible. Therefore, over the years of developments of quantum mechanics, always challenging part of quantum mechanics lies in measurements. This book has been written by an international invited group of authors and it is created to clarify different interpretation about measurement in quantum mechanics.

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