BNL-34592
CONF-8308166--1

BNL--34592
DE84 010896

STATUS OF THE GLUEBALLS†

S.J. LINDENBAUM

Brookhaven National Laboratory, Upton, New York 11973

and

City College of New York, New York, New York 10031

Invited Lecture presented at the
21st Course of the International School of Subnuclear Physics on
"How Far we are From the Electronuclear Interactions and the Other Gauge Forces", Erice, Trapani-Sicily, 3-14 August, 1983.

† This research was supported by the U.S. Department of Energy under Contract Nos. DE-AC02-76CH00016 (BNL) and DE-AC02-79ER10550A (CCNY).

STATUS OF THE GLUEBALLS†

S.J. Lindenbaum

Brookhaven National Laboratory, Upton, New York 11973

and City College of New York, New York, New York 10031

INTRODUCTION

QCD[1] was invented to explain hadronic states and interactions. The most crucial and elegant part of QCD is $SU(3)_{color}$ with local gauge invariance.

The most characteristic feature of this non-abelian local gauge theory is the self interaction of the gauge bosons (gluons) which becomes stronger as their relative energy decreases (i.e. asymptotic freedom - infrared slavery).

Thus in a hadronic theory based on $SU(3)_c$ (i.e. a pure Yang Mills theory[2]) and confinement, all the hadrons in the world would be glueballs[3] (i.e. multi-gluon resonant states). The quarks at present are in the category addressed by Rabi's question "who ordered that? However when they are added to the theory we face the anamoly that the hadrons were found to consist of quark-built states, and until recently there was no good evidence for glueballs. Therefore the discovery of glueballs - the missing link in QCD - is (in my opinion) a very necessary condition for

† This research was supported by the U.S. Department of Energy under Contract Nos. DE-AC02-76CH00016 (BNL) and DE-AC02-79ER10550A (CCNY).

establishing QCD and locally gauge invariant $SU(3)_c$. It is also very important if one wishes to maintain the viability of unification or partial unification theories including $SU(3)_c$.[39]

Due to the recent successes of the Electro-Weak Group,[4] $SU(2)_L \times U(1)$, if $SU_3(c)$ controls hadronic interactions, we would have the situation where local gauge invariant groups explain the dynamics of strong as well as electromagnetic and weak physical phenomena at least at energies - those presently attainable.

In this lecture I will show that the BNL/CCNY $g_T(2120)$, $g_T'(2220)$ and $g_T''(2360)$ all with $I^G J^{PC} = 0^+2^{++}$ observed[5] in $\pi^- p \to \phi\phi n$ are produced by glueball(s):

1. If QCD is correct;
2. If the OZI rule is universal for weakly coupled glue in Zweig disconnected diagrams where the disconnection is due to the creation or annihilation of new quark flavors.

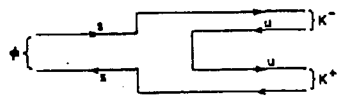
Since the above axioms merely represent modern QCD practice and agree with experiments, I consider this the discovery of glueball(s).[5-6,20-21]

It is obvious that every conclusion of a "discovery" depends on input axioms - implied or explicitly stated (which I prefer). The simpler, more fundamental and the better their justification by experiment the axioms are, the more justified is the conclusion of a discovery. I will also briefly discuss the status of some other glueball candidates, two in particular, those arising from the J/ψ radiative decay.

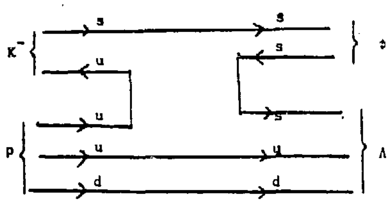
In my Erice Lecture last summer[6] I presented the results of the BNL/CCNY glueball search in the reaction $\pi^- p \to \phi\phi n$.[15,19-20] At that time we had ≈ 1203 events. These events clearly demonstrated a complete breakdown of the Zweig (or OZI) suppression[7-9] in the Zweig disconnected diagram $\pi^- p \to \phi\phi n$ (see Fig. 1) which we also had observed in the first experiment[10] to ever observe double φ production.

CONNECTED

ALLOWED PROCESS



$\phi \to K^+K^-$



$K^-p \to \phi\Lambda$

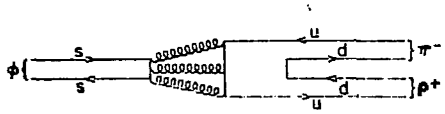
Figure 1a: Zweig connected (allowed reaction) diagrams for the u,d,s quark system.

Except for these experiments the Zweig rule appears to be universally followed in disconnected diagrams in hadronic interactions where the disconnection is due to creation or annihilation of new flavor(s) of quark(s). This is shown clearly in Fig. 1 for the u,d,s quark system where the matrix element for the Zweig connected diagram is two orders of magnitude larger than for the corresponding Zweig disconnected diagram.[8,11-12]

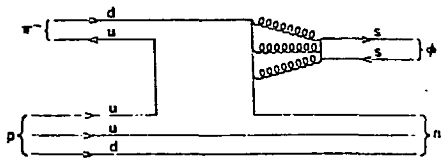
Figures 1a and 1b show that this occurs both in the decay and production processes. Figures 2a and 2b show that the J/ψ system exhibits even much greater Zweig suppression factors for Zweig disconnected diagrams. It should be noted in Fig. 2b that in addition to the well-known and striking Zweig suppression which

DISCONNECTED

FORBIDDEN (SUPPRESSED)



$\phi \to \pi^- \rho^+$



$\pi^- p \to \phi n$

Figure 1b: Zweig disconnected diagrams (suppressed reaction) for the u,d,s, quark system. The helixes represent gluons bridging the disconnection.

occurs when the $c\bar{c}$ quarks annihilate there is a huge suppression in the Zweig disconnected diagram where $\psi(3685) \to J/\psi\ (3100 + 2\pi)$ which results in a width of the $\psi(3685) = 250 \pm 40$ kev even though the $\pi^+\pi^-$ case occurs in $(33 \pm 2)\%$ of the cases and the $\pi^0\pi^0$ case occurs in $(17 \pm 2)\%$ of the cases.

Figure 3 shows a similar and even more striking situation existing in the upsilon system since the $\Upsilon'(10{,}020) \to \Upsilon(9460)\pi\pi$ $(30 \pm 6)\%$ of the time with the $\Gamma_{\Upsilon(10,020)} = (30 \pm 10)$ kev whereas the $\Gamma_{\Upsilon(9460)} = 42 \pm 15$ kev. Thus the suppression in the first Zweig disconnection is strong enough to maintain the width of the Υ' consistent within errors with the width of the Υ. The

CONNECTED

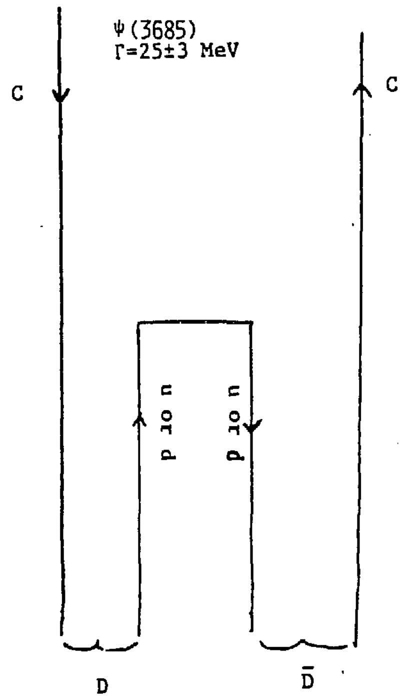


Figure 2a: A Zweig connected diagram for the ψ(3685) decay.

same striking phenomena occurs in the process Υ"(10,020) → Υ(9460) + 2π which although it occurs ~ 10% of the time results in a width of the Υ" which is consistent with the width of the Υ. Thus it is experimentally clear from the ψ and Υ systems that what I will call a double hairpin type of disconnection in a Zweig diagram is strongly suppressed.

Lipkin has argued[13] that what I call a double hairpin type of disconnected Zweig diagrams such as Fig. 6, $\pi^- p \rightarrow \phi\phi n$ (which is the process we are observing) should not be Zweig suppressed (or only suppressed by a very small factor) since it is related by crossing to $\phi + n \rightarrow \phi + \pi^- + p$. He refers to this as a crossed pomeron diagram which is just elastic ϕ-nucleon scattering with additional pion production states and there is no reason to

DISCONNECTED

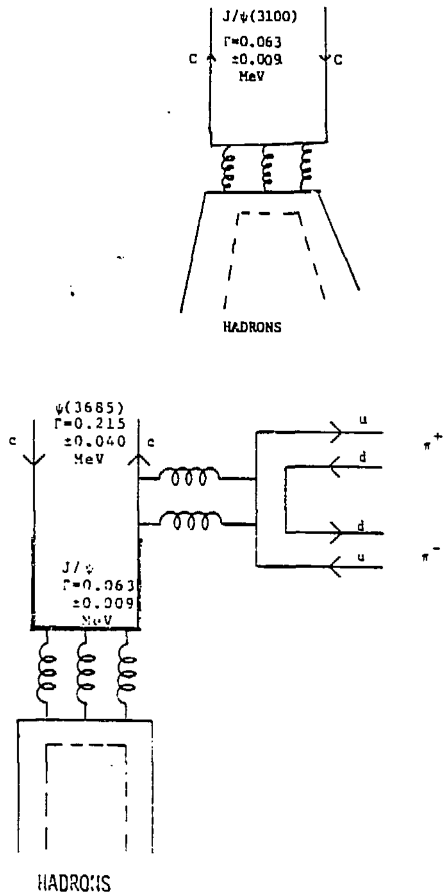


Figure 2b: Zweig disconnected diagrams in the J/ψ and excited ψ states.[40]

believe this process is forbidden. Reference (13) has overlooked the fact that when you cross in that manner you get into different kinematic and physical regions and that you cannot simply relate the two reactions.[14] For example considering the kinematics only the crossed reaction (e.g. $\phi + n \rightarrow \phi\pi^- + p$) corresponds to very high momentum transfers and a very high mass for the $\pi^- + p$ system. Diffraction dissociation at very high momentum transfers and very high masses would be expected to be negligibly small and

DISCONNECTED ZWEIG DIAGRAMS IN Υ SYSTEM

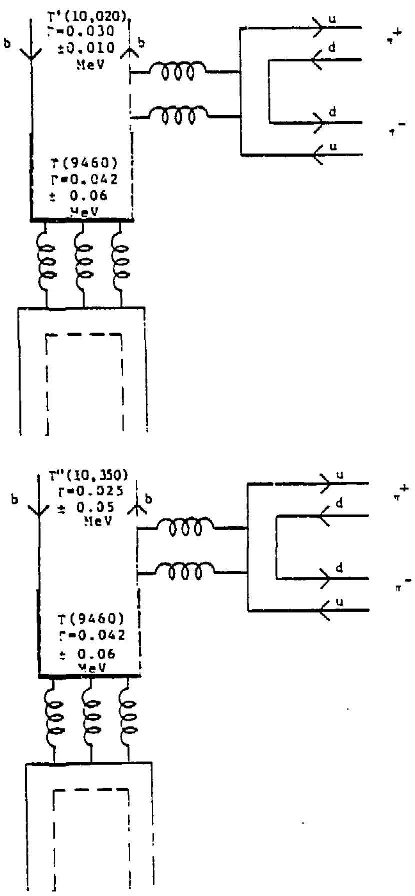


Figure 3: Zweig disconnected diagrams in the Υ system.[40-41]

thus these processes would be expected to be suppressed much more than the Zweig suppression factors we are dealing with. The fact that $\sigma(\pi^- p) \rightarrow \phi\phi n \approx 20$ nanobarns whereas diffraction dissociation which Ref. 13 says is large (~ 10 mb) differ by a factor of 10^6 emphasizes that it is not justified to relate the two processes in the naive way Ref. 13 has.

There are other erroneous statements in Ref. 13 that were addressed in Ref. 14. In particular one should note that Ref. 13 concludes the reaction $\psi(3685) \rightarrow J/\psi(3100) + 2\pi$ is Zweig allowed since it is also a crossed Pomeron diagram. Ref. 13 ignores the fact that the full width of $\psi(3685)$ is only ≈ 215 kev and thus this Zweig disconnected diagram (our Fig. 2b) is strikingly suppressed.

$\Upsilon(\Upsilon'') \to \Upsilon + 2\pi$ decays also impressively show that so-called crossed Pomeron diagrams (in the notation of Ref. 13) also exhibit very strong suppressions and thus this line of reasoning is obviously fallacious for the reasons I have already mentioned.

The reason why the $\psi' \to J/\psi + 2\pi$, and $\Upsilon'(\Upsilon'') \to \Upsilon + 2\pi$ have large branching ratios is probably at least partly due to the fact that these transitions can proceed by two relatively softer gluons compared to the direct three-gluon decays of the ψ', Υ' and Υ'', and also the kinematics of the decay favor the 2π channel, whereas there are many channels which compete for the three gluon partial decay width. Thus if we assume the OZI rule is universal for weakly coupled glue in Zweig disconnected diagrams where the disconnection is due to the creation or annihilation of new flavors of quarks, then the breakdown of the OZI suppression that we observe in $\pi^-p \to \phi\phi n$ must be due to strongly coupled glue. A glueball being a multi-gluon resonance would like in all hadronic resonance phenomena correspond to effectively strong coupling and thus the OZI suppression which in QCD is viewed as due to weakly coupled multi-glue intermediate states would be broken down by a glueball. Thus in the reaction $\pi^-p \to \phi\phi n$ the multi-gluon system in the intermediate state which forms the $\phi\phi$ system would in the absence of glueballs lead to only Zweig suppressed $\phi\phi$ production. However the $\phi\phi$ system has a variable mass and all the possible glueball quantum numbers for $C = +$. Thus at those masses where the multigluon intermediate state forms a glueball with $C = +$ the Zweig suppression will be broken down and the $\phi\phi$ system will contain the glueball resonance parameters and quantum numbers. Thus the $\phi\phi$ system in the reaction $\pi^-p \to \phi\phi n$ will act as a filter passing glueball states and rejecting the other $q\bar{q}$ states.

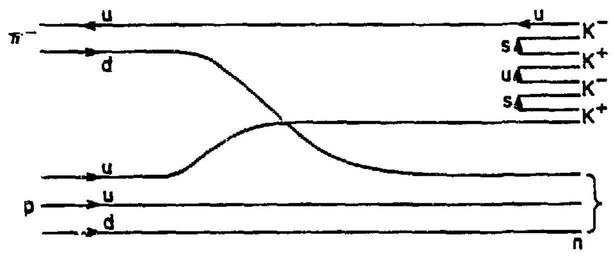


Figure 4: The Zweig quark line diagram for the reaction $\pi^- p \rightarrow K^+K^-K^+K^- n$, which is connected and OZI allowed.

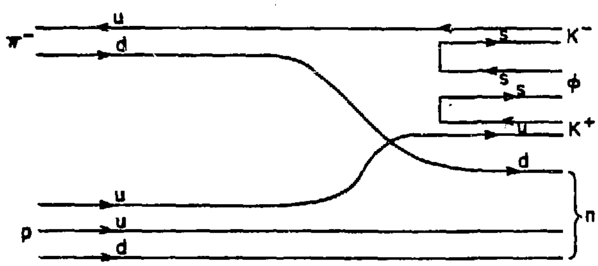


Figure 5: The Zweig quark line diagram for the reaction $\pi^- p \rightarrow \phi K^+K^- n$, which is connected and Zweig allowed.

Other alternatives such as the possibility of more complicated hadronic states will be discussed later. Figures 4-6 show the three reactions we have observed.

During last years ERICE lecture[6] I discussed the 1203 $\pi^- p \rightarrow \phi\phi n$ events we had then. This spring we finished a run which raised the statistics to ≈ 4,000 $\pi^- p \rightarrow \phi\phi n$ events[5] and in this lecture I will discuss these results and their analysis and interpretation.

Figure 7 demonstrates the dramatic breakdown of the OZI (or Zweig) suppression we saw in the earlier data[10,15,16,19] also occurs in the new sample. We see the general ≈ uniform background

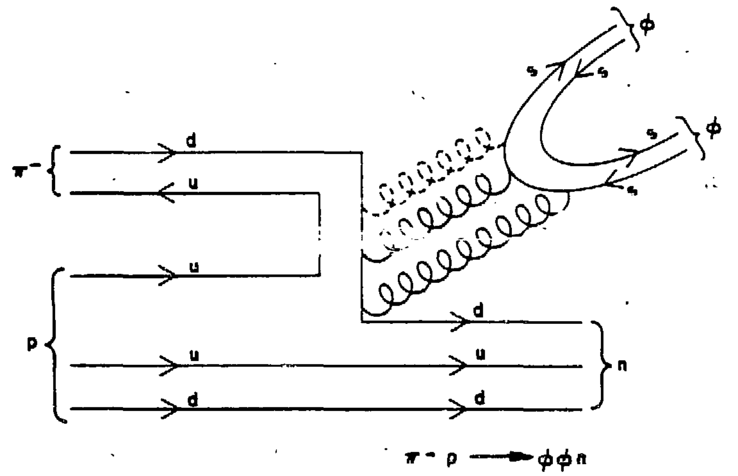


Figure 6: The Zweig quark line diagram for the reaction $\pi^- p \rightarrow \phi\phi n$ which is disconnected (i.e. a double hairpin diagram) and is OZI forbidden. Two or three gluons are shown connecting the disconnected parts of the diagram depending upon the quantum numbers of the $\phi\phi$ system.

from the reactions a) $\pi^- p \rightarrow K^+K^-K^+K^- n$ which is OZI (or Zweig) allowed and the two ϕ bands representing b) $\pi^- p \rightarrow \phi K^+K^- n$ which is also Zweig allowed. Where the two ϕ bands cross we have the Zweig forbidden reaction $\pi^- p \rightarrow \phi\phi n$. The black spot shows an obvious more-or-less complete breakdown of the Zweig suppression. This has been quantitatively shown[16] to be so in these reactions, and also by comparing K^- induced ϕ and $\phi\phi$ production.[17-18] The black spot when corrected for double counting and resolution ≈ 1,000 times the density of reaction (a) and ≈ 50 times the density of reaction (b). If one projects out the ϕ bands as shown in Fig. 8, there is a huge $\phi\phi$ signal which is ≈ 10 times greater than the background from reaction (b) even with rather wide cuts. The recoil neutron signal is shown in Fig. 9 and is also very clean ≈ 97% neutron.

The acceptance corrected $\phi\phi$ mass spectrum in the ten mass bins which were used for the partial wave analysis is shown in Fig. 10. All waves with J = 0 - 4, L = 0 - 3, P ± and η (exchange

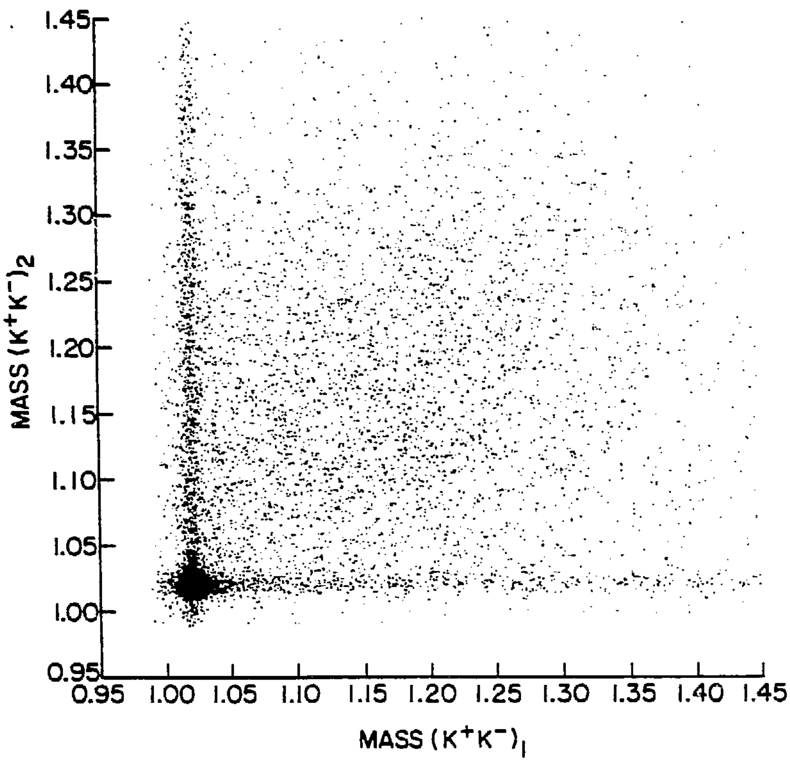


Figure 7: Scatter plot of $\overline{K^+K^-}$ effective mass for each pair of $\overline{K^+K^-}$ masses. Clear bands of $\phi(1020)$ are seen with an enormous enhancement (black spot) where they overlap (i.e. $\phi\phi$) showing essentially complete breakdown of OZI suppression.

naturality) = ± were allowed in the partial wave analysis. Thus 52 waves were considered. The incident π^- lab momentum vector and the lab momentum vectors of the four kaons completely specified an event. The Gottfried-Jackson frame angles β(polar) and γ(azimuthal) are shown in Fig. 11. These and the polar angles (θ_1, θ_2) of the K^+ decay in the ϕ rest systems relative to the ϕ direction and the azimuthal angles α_1 and α_2 of the K^+ decay direction in the ϕ_1, ϕ_2 rest systems (see Fig. 12) were also used to specify an event.

The MPS II at BNL (see Fig. 13) was used in the same experimental arrangement as described earlier.[10,13] The results of

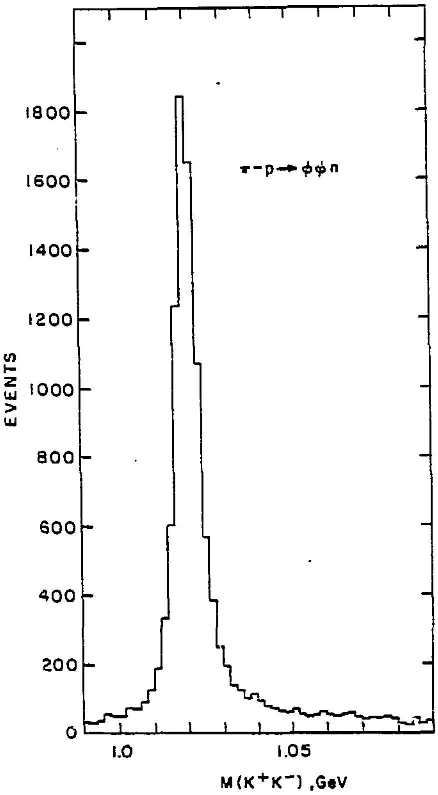


Fig. 8

The effective mass of each K^+K^- pair for which the other pair was in the ϕ mass band.

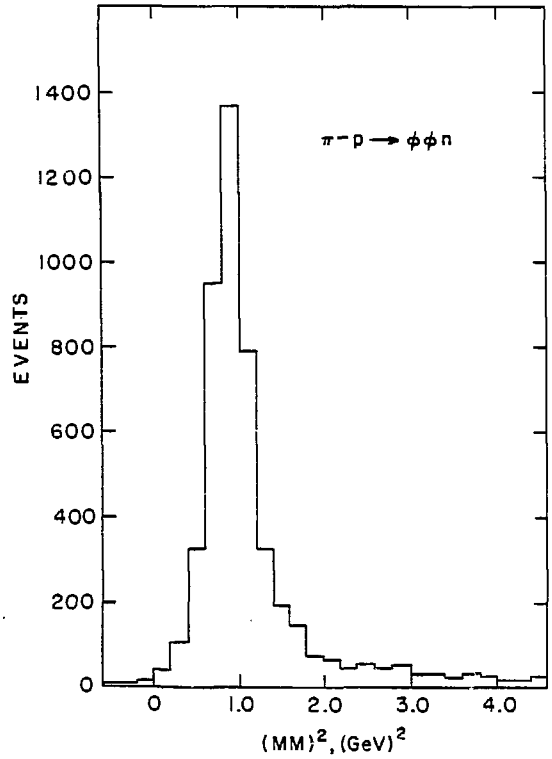


Fig. 9

The missing mass squared for the neutral recoiling system for the $\phi\phi$.

the mass independent partial wave analysis are shown in Figs. 14 and 15. In the analysis of 1200 events performed last year we had determined that our data contained two $J^{PC} = 2^{++}$ waves.[6,19] The predominant one being an S-wave with spin 2 peaked in the lower mass region and the other being a D-wave with spin 2 peaked at higher masses.

In this analysis of ≈ 4,000 events,[5] these two waves were again selected with a very high statistical precision >> 10σ. However the fit was totally unacceptable and required a third D-wave with spin 0 as shown in Fig. 14. The relative phase motion

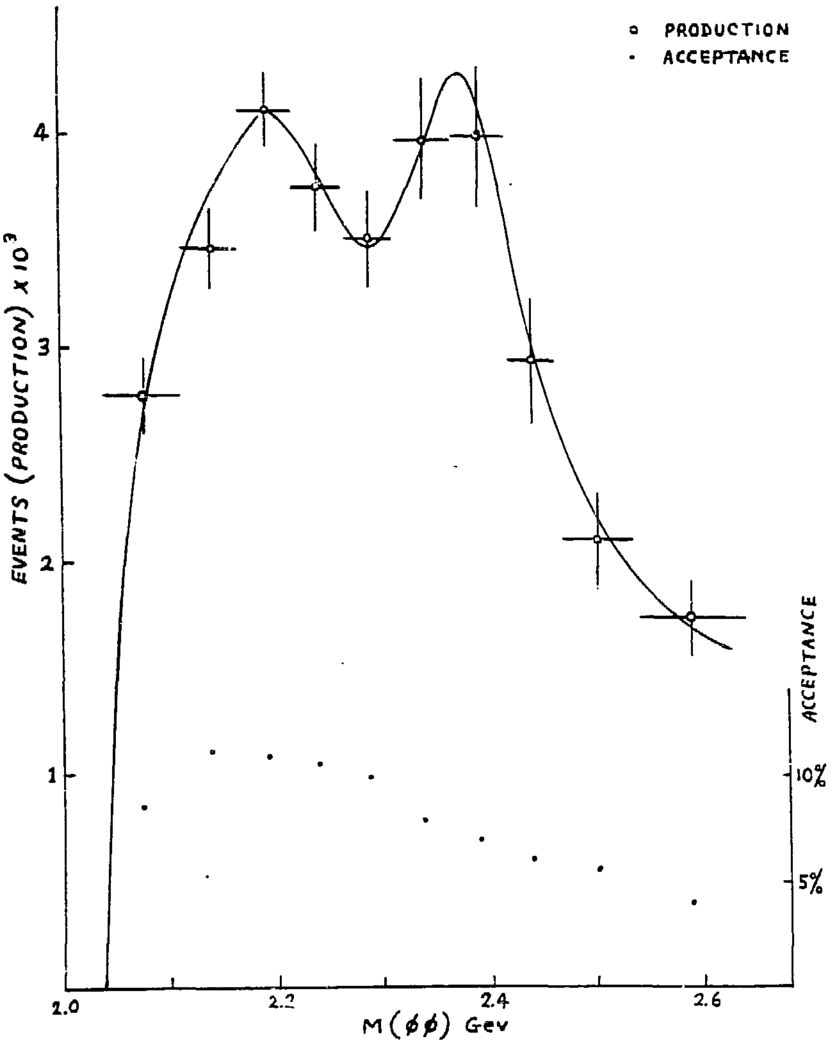


Figure 10: The ϕϕ mass spectrum corrected for acceptance. The solid line is the fit to the data with the three resonant states to be described later. The points at the bottom of the diagram are the acceptance for each mass bin to be read with the scale at the right.

of the D waves using the S wave as a reference is shown in Fig. 15. The statistical significance of this third wave was ≈ 25σ. Although there was an indication for this third wave in the earlier 1200 event sample, it could not be considered statistically

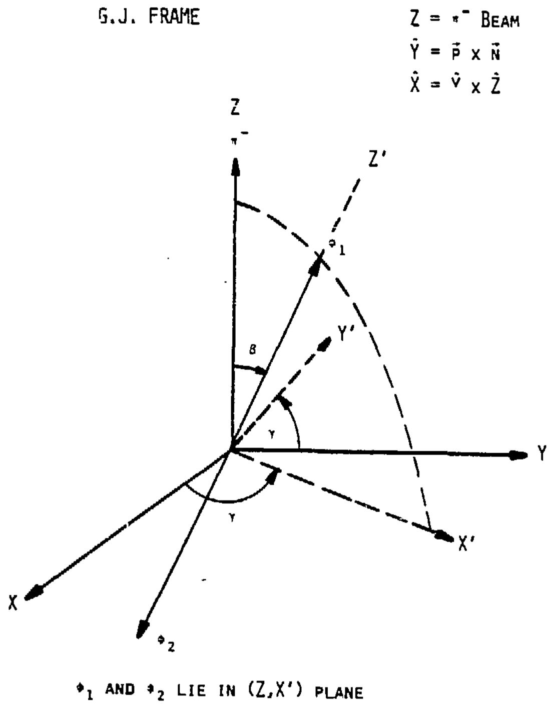


Figure 11: The Gottfried-Jackson frame with polar angle β and azimuthal angle γ.

significant at that time. It should be noted that the 1200 event data sample and the new ≈ 4,000 event data sample agree very well with each other within statistical errors. One should note that the results of the partial wave analysis are quite insensitive to the acceptance and the detailed shape of the mass spectrum. We also found that for $|t'| < 0.3\ \mathrm{GeV}^2$, the t' distribution is consistent with $e^{(9.4 \pm 0.7)t'}$. If one looks at the quark structure of Fig. 6, one essentially has a pion exchange radiating several gluons (thought to represent a glueball) and thus one would expect a peripheral production mechanism, which is what we observe.

One might ask at this point why are we so incredibly selective - picking 3 waves out of 52 with the statistical significance of the third wave ≈ 25σ. The answer is that the background is small enough and incoherent and thus does not have a significant

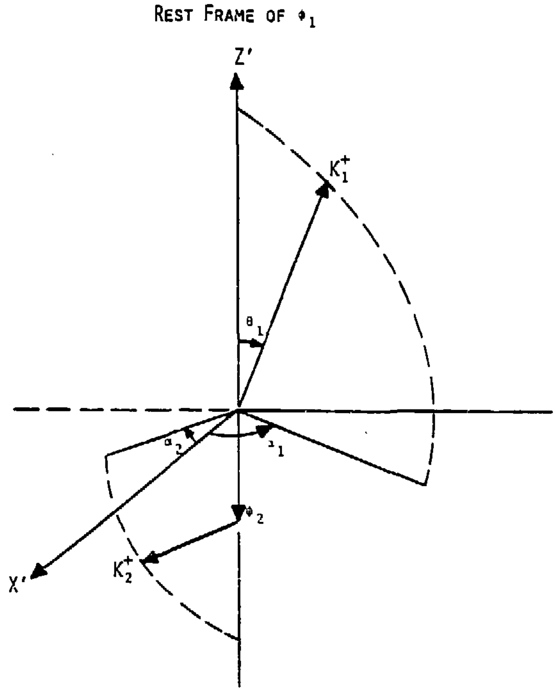


Figure 12: The ϕ_1 rest frame with the polar angle θ_1 of the decay K_1^+ (relative to ϕ direction) and the azimuthal angle α_1 of the decay K_1^+.

effect on the $\phi\phi$ system individual wave signals. The $\phi\phi$ system wave signals are shown (roughly to scale) in Fig. 16 for M = 0 waves. The PWA clearly demonstrated that only M = 0 waves were significant in the fit, thus these are the most relevant. It is clear from Figs. 16a and 16b, that every wave has its own characteristic signature and thus the $\phi\phi$ system is an unusually selective wave content analyzer. This is in large measure due to the fact that each ϕ has spin 1 and thus the six angular variables and their correlations have large characteristic signatures which are very sensitive to the exact quantum numbers of each wave. Furthermore our very low incoherent background allows us to see the characteristics of the $\phi\phi$ system clearly.

Figures 17a-17c show the comparison of Monte Carlo generated events to the observed angular variables and their characteristic

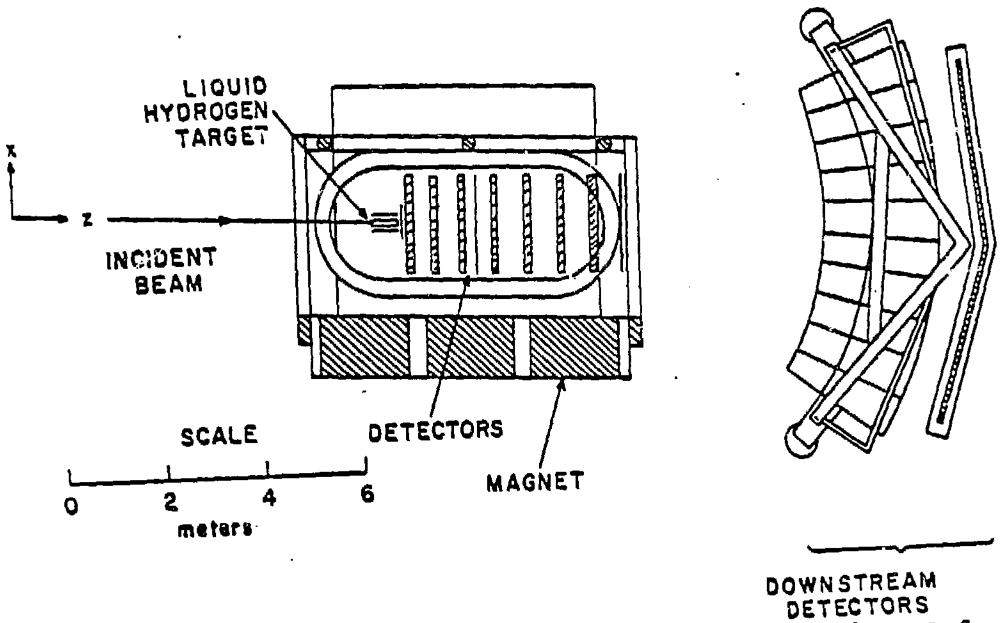


Figure 13: The MPS II and the experimental arrangement (see Refs. 10 and 19 for further details).

combination. It is clear the agreement is very good, and this is true for all ten mass bins. The amplitudes and phase motion (see Figs. 14 and 15) of the waves relative to the S-wave clearly reveals resonance or Breit-Wigner behavior. The S-wave had to be used as a reference due to the fact that the background is both small and incoherent. It is important to note that the appropriate phase motion is the most sensitive test of resonant behavior, and we have clearly demonstrated that it occurs in just the required manner. In the analysis we actually employed the K-matrix method[22] which is approximately equivalent to but a somewhat more realistic approach to fitting the relativistic Breit-Wigner's. Nevertheless in this case either method would give results consistent with each other since the effects of other channels (taken into account in the K-matrix) are small.

Three resonant states (or K-matrix poles) were required to obtain an acceptable fit. Attempts to fit the results with two resonant states (or K-matrix poles) in which the three required

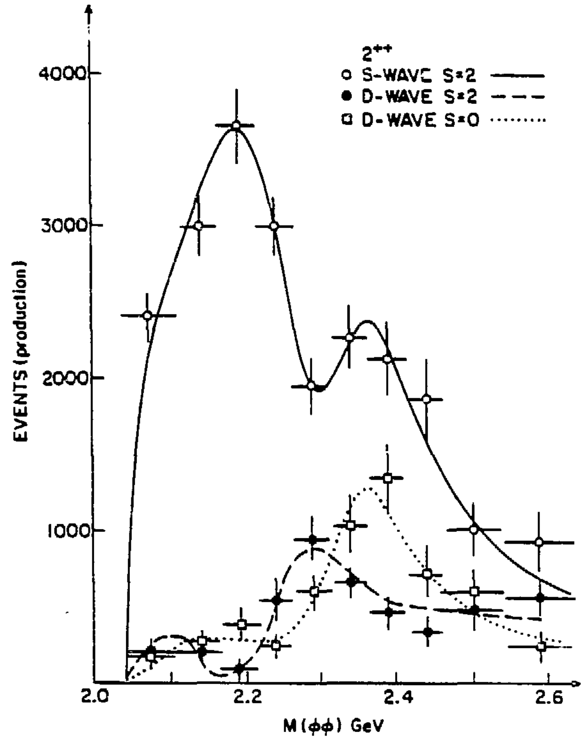


Figure 14: The three 2^{++} partial waves at production in 50 MeV bins (except ends). The smooth curves are derived from a K-matrix fit.

waves were used were rejected by 13σ, whereas the three resonance fit was quite good. The deduced Breit-Wigner parameters, quantum numbers and estimated content of the individual waves for the three states and the estimated errors are shown in Table I. The Argand plot deduced from the K-matrix fit is shown in Fig. 18, and it clearly shows the characteristics expected of resonance behavior. By increasing the statistics from ≈ 1200 events to ≈ 4,000 events the upper of the two resonant $I^G J^{PC} = 0^+ 2^{++}$ states was resolved into two states with the same quantum numbers.

It should be noted that the mixing of waves is substantial in these three $J^{PC} = 2^{++}$ states and the exact wave content of each resonance or K-matrix pole is therefore sensitive to details and somewhat uncertain. However from the glueball physics point of

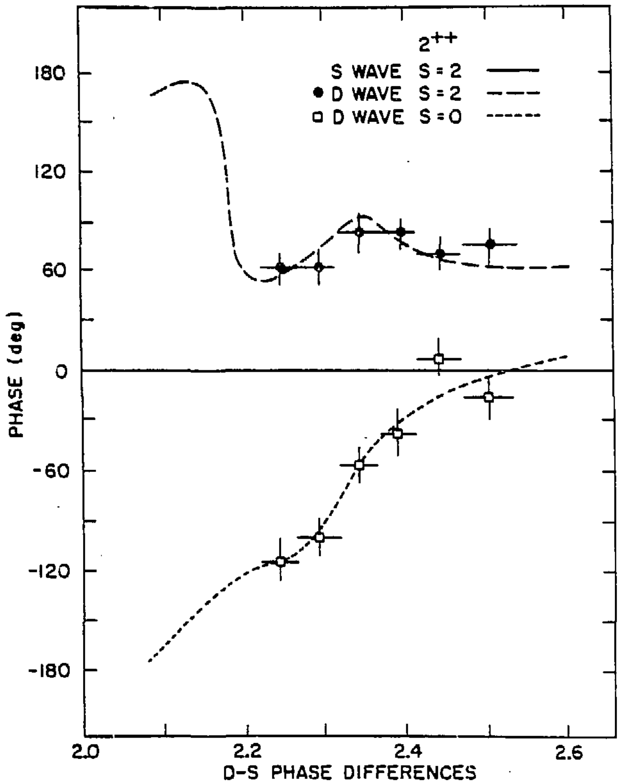


Figure 15: D-S phase difference from the partial wave analysis. The smooth curves are derived from a K-matrix fit.

view we are at present mostly interested in the quantum numbers and parameters of the resonant states and not very concerned about their exact wave contents.

<u>If one assumes as input axioms</u>:

1. QCD is correct;

2. The OZI rule is universal for weakly coupled glue in Zweig disconnected diagrams where the disconnection is due to the introduction of new flavors of quarks, <u>then the states we observe must represent the discovery of 1-3 glueballs.</u>[20,21,5]

Note that axiom (2) allows only resonating glue (i.e. glueballs) to break the Zweig suppression. One primary glueball could break down the Zweig suppression and possibly mix with two quark or other possible states.

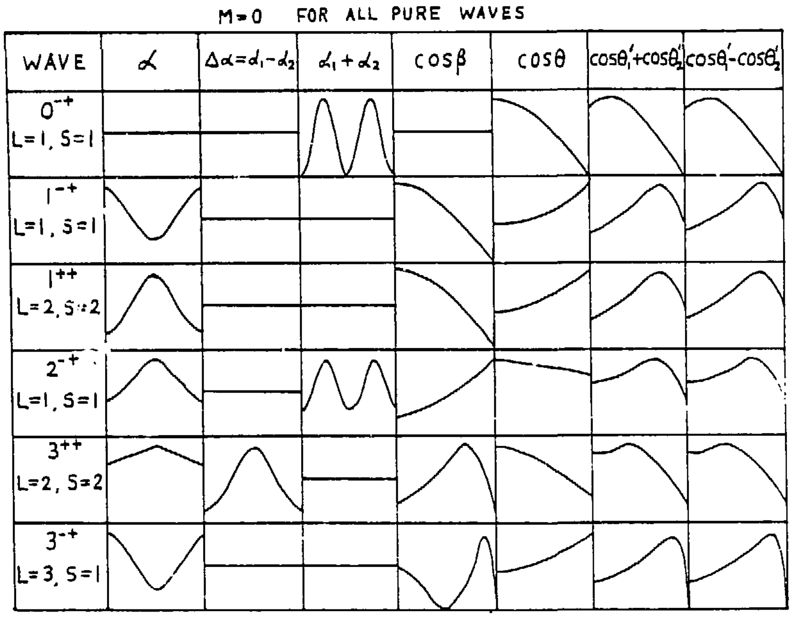


Figure 16a: Various pure waves from $J^{PC} = 0^{++}$ to $J^{PC} = 4^{++}$ with M = 0.

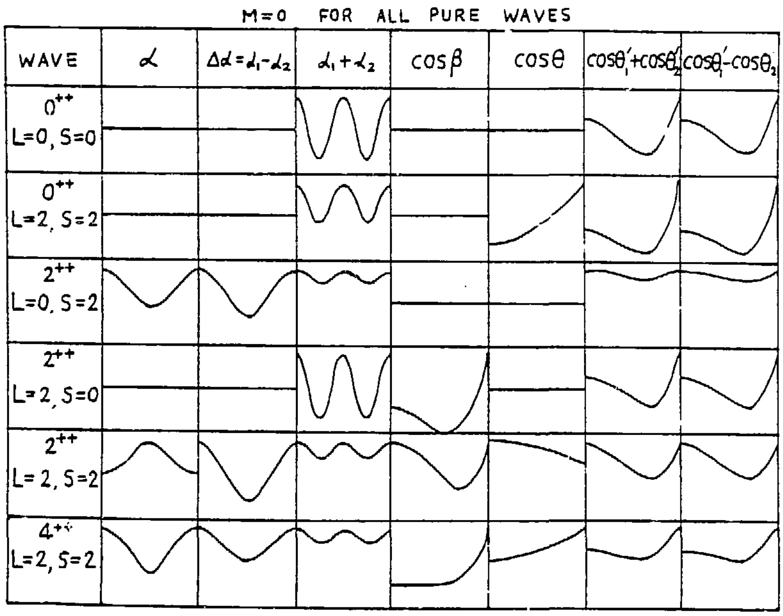


Figure 16b: Various pure waves from $J^{PC} = 0^{-+}$ to $J^{PC} = 3^{-+}$ with M = 0.

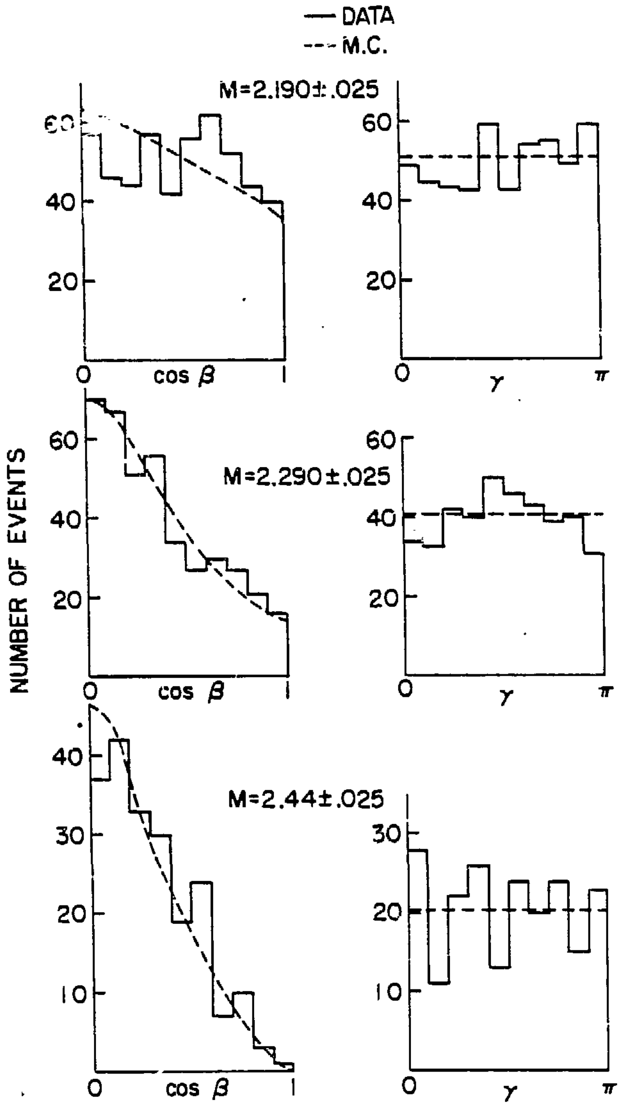


Figure 17a: Cos β and γ for three representative mass bins, where β is the polar angle and γ is the azimuthal angle of a given φ in the G.J. frame.

Since these axioms strikingly agree with the data in the φ, J/ψ and T systems, and merely represent modern QCD practice, it is reasonable to consider this the discovery of glueballs.

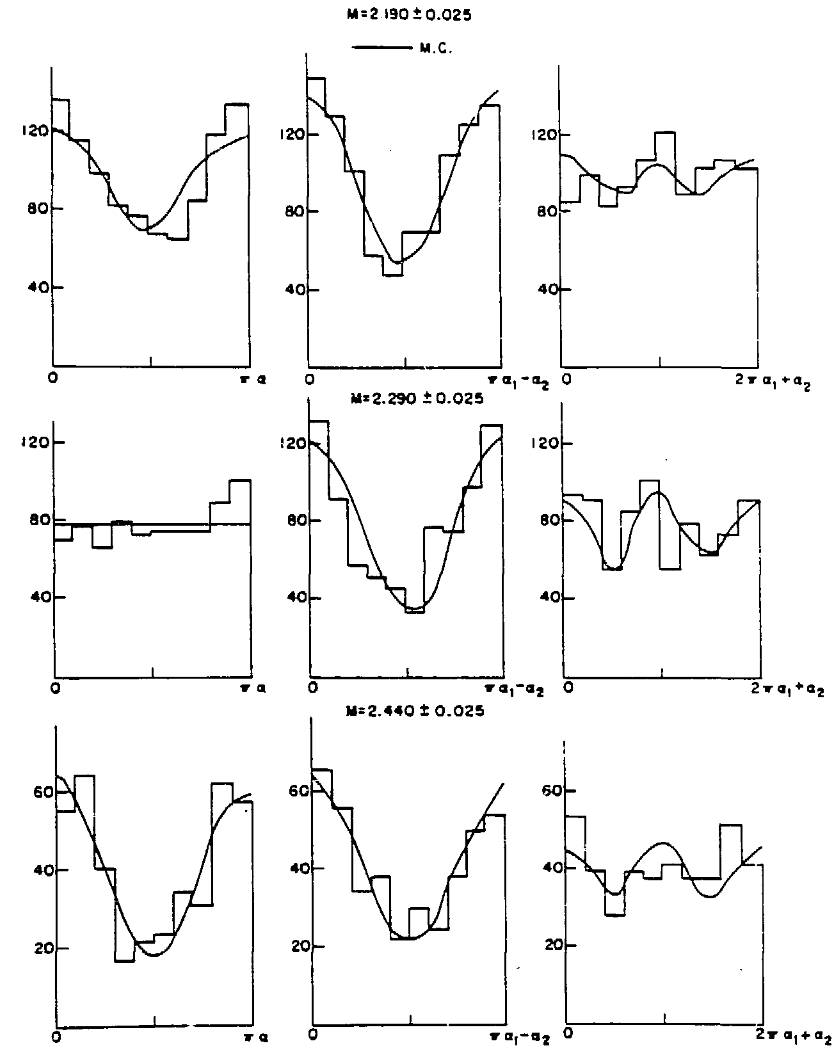


Figure 17b: α, $\alpha_1 - \alpha_2$, and $\alpha_1 + \alpha_2$ for three representative mass bins, where α is the azimuthal angle of the K^+ in the ϕ rest frame measured from the x-axis of the G.J. frame.

The constituent (i.e. gluon has effective mass) gluon models[23-24] would predict three low lying $J^{PC} = 2^{++}$ glueballs. The mass estimates from the MIT bag calculations and the lattice gauge groups[25-28] cover the range $\approx 1.7 - 2.5$ GeV for $J^{PC} = 2^{++}$ glueballs. Thus we are clearly in the right ballpark for agreement with present phenomenological mass calculations.

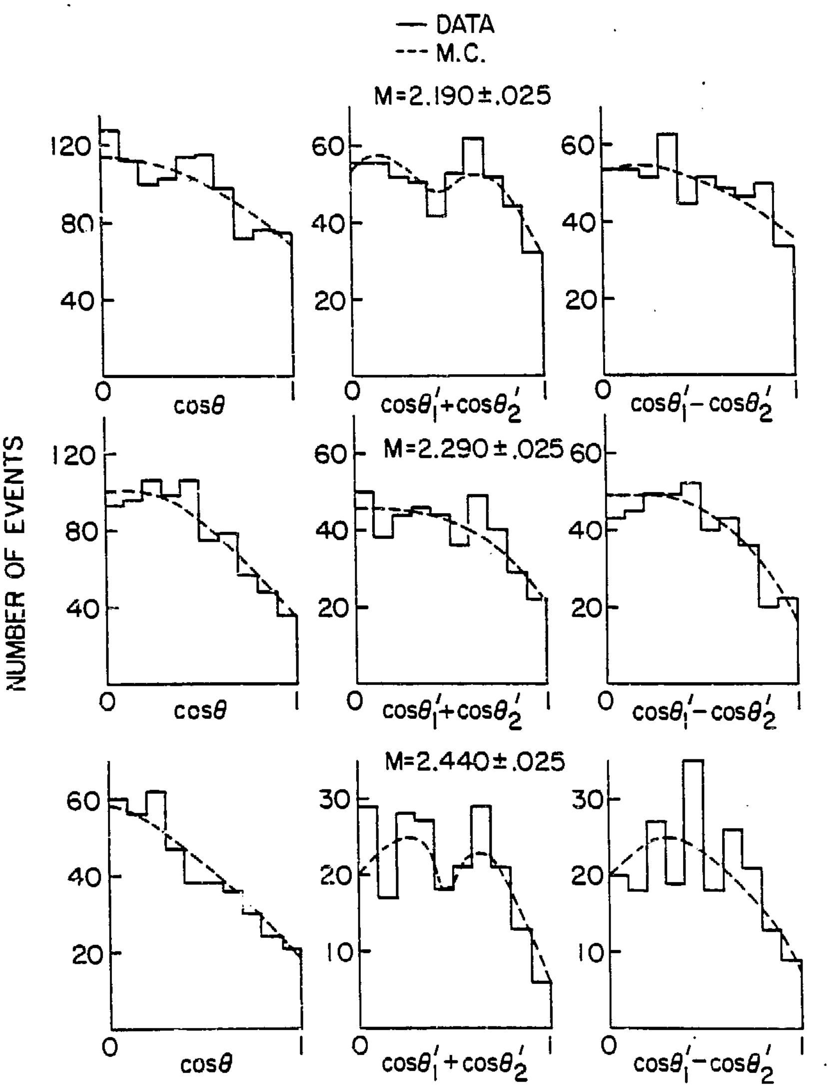


Figure 17c: Cosθ, $\cos\theta_1' + \cos\theta_2'$, and $\cos\theta_1' - \cos\theta_2'$ for three representative mass bins, where θ is the polar angle of the K^+ in the φ rest frame measured from the other φ as the z-axis.

T.D. Lee has analytically calculated J = 2 glueballs in the strong coupling limit[29] and obtains three glueball states which correspond to our three states. His strong coupling calculation gives the mass differences between these three states in terms of two parameters, one being essentially the effective strength of the coupling and then a mass scale parameter. In order to try to adjust his strong coupling calculation to the real world of intermediate coupling we took the mass of the 0^{++} glueball as ≈ 1 GeV from the Lattice Gauge calculations, and fit our three masses with the other parameter and found a reasonable fit.

TABLE I

Three Resonance Fit

$M_1 = 2.120^{+.020}_{-.120}$ $\Gamma_1 = .300^{+.150}_{-.050}$ - 40% data:

S-wave, S = 2 $-30\%^{+70\%}_{-10\%}$ coupling sign (+) defined

D-wave, S = 2 $-50\%^{+10\%}_{-50\%}$ coupling sign (−)

D-wave, S = 0 $-20\%^{+30\%}_{-20\%}$ coupling sign (−)

$M_2 = 2.220^{+.090}_{-.020}$ $\Gamma_2 = .200 \pm .050$ - 40% data

S-wave, S = 2 $-40\%^{+10\%}_{-20\%}$ coupling sign (+)

D-wave, S = 2 $-50\%^{+20\%}_{-10\%}$ coupling sign (+)

D-wave, S = 0 $-10\%^{+10\%}_{-10\%}$ coupling sign (+)

$M_3 = 2.360 \pm .020$ $\Gamma_3 = .150^{+.150}_{-.050}$ - 15% data

S-wave, S = 2 $-25\%^{+25\%}_{-10\%}$ coupling sign (+)

D-wave, S = 2 - 0% + 25% coupling sign (−)

D-wave, S = 0 $-75\%^{+15\%}_{-25\%}$ coupling sign (+)

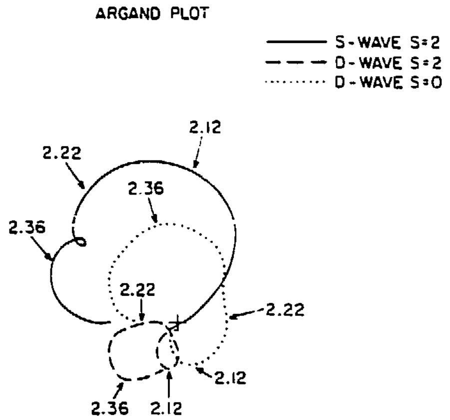


Figure 18: Argand plot from K-matrix.

I have many years ago used a similar procedure in the case of the Pauli-Dancoff strong coupling calculations of the nucleon isobars. In that case when we put in the known f^2 and a reasonable value for the cut-off, the strong coupling calculation results gave reasonable agreement with the experimental observations on nucleon isobars.

<u>What About the Width of Glueballs?</u>

In all hadrons, the hadronization process consists of creation of one or more $q\bar{q}$ paris. This must occur near the outer region of confinement involving strongly interacting soft glue, probably including collective interactions, if we are to have resonances decay with typical hadronic widths ($\Gamma_{hadronic}$ ~ 100 to several hundred MeV).

For example the $\rho(770) \rightarrow \pi\pi$ requires production of one quark pair. The width of the $\rho(770)$ is $\Gamma_\rho = 154 \pm 5$ MeV. The $\rho'(600) \rightarrow 4\pi$ requires the production of three quark pairs. Yet $\Gamma_{\rho'} \approx 300 \pm 100$ MeV. Thus even though production of two additional quark pairs is required the $\Gamma_{hadronic}$ actually increases. This example clearly shows that hadronization easily occurs via collective soft glue effects and this is the basis of typical hadronic widths.

A glueball is nothing more than a resonating multi-gluon system. The glue-glue coupling is stronger than the quark-glue coupling and thus it would be expected, via gluon splittings before the final hadronization, to have a similar hadronization process to a $q\bar{q}$ hadron. In other words a glueball would be expected to have typical hadronic widths. This is certainly to be expected for ordinary (non-exotic) J^{PC} states. In the case of exotic J^{PC} states, this arguement may not be relevant since no one yet knows what suppresses the unobserved exotic sector. In other words, Meshkov's oddballs[23] may be narrow.

I have previously discussed[6,16b] some well-known peculiarities of the OZI rule. In particular if one introduces successive steps both of which are OZI allowed, one can on paper defeat the OZI rule.

For example, $\phi \to \rho\pi$ is OZI forbidden, but $\phi \to K^+K^+ \to \rho\pi$ represents two successive OZI allowed processes which appears to defeat the OZI rule. Similarly, $\pi^-p \to \phi n$ is OZI forbidden, but $\pi^-p \to K^+K^-n \to \phi n$ representing two successive OZI allowed processes which appears to defeat the rule. One can also introduce other complicated intermediate states or processes other than hard multi-gluons to jump the disconnected part of the diagram and also appear to defeat the rule.

Thus the OZI rule is peculiar in that you can defeat it by two-step processes or in QCD language changing the nature of the multi-gluon exchange needed in the one-step diagram to a series of the ordinary OZI allowed gluon exchanges.* Thus based on the experimental validity of the rule, Zweig's diagrams are to be taken literally as one step processes and the multi gluon exchanges needed to connect disconnected parts of the diagram are not to be tampered with.

* This may at least partly be explained by the fact that when you draw quark line diagrams for typical two-step allowed processes in a Zweig forbidden diagram, you are annihilating quark pairs after hadronization has occurred. Since annihilations occur at short distances, and hadronization as I have discussed occurs at large distances, these two-step processes are probably dynamically discriminated against. However it appears that why the OZI rule works so well in Zweig disconnected diagrams will only be understood when one has calculated the dynamics involved using QCD with intermediate and strong couplings.

If one does not accept axiom 2 and demotes the universal OZI rule to the improbable OZI accident could what we see be due to very non-ideally mixed radial excitations or 4-quark states containing $s\bar{s}$ pairs, etc.

Even in this event (for which there is no evidence) it would take a second striking accident for three $I^G J^{PC} = 0^+ 2^{++}$ resonant states and essentially nothing else to occur within the narrow high mass interval of ≈ 2120 to 2360 MeV. Since inventing enough unlikely accidents can destroy any theory I do not consider these possible explanations plausible.

OTHER GLUEBALL CANDIDATES

The radiative decay of the J/ψ is thought to occur as shown in Fig. 19 where one of the usual three gluons emitted in the annihilation of the $c\bar{c}$ pair is replaced by a photon. Thus it has been argued[30-31] that the two-gluon system could recoil from the photon and preferentially form

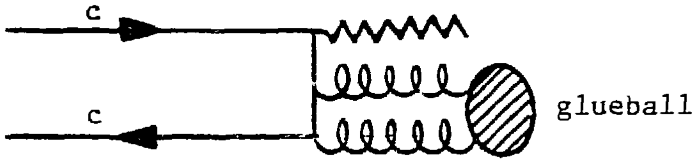


Figure 19: The dominant diagram in radiative J/ψ decay.

a glueball. The first and most discussed glueball candidate of this type is the iota (1440).[32] The status of the iota (1440) with $J^{PC} = 0^{-+}$, $M \approx 1440^{+20}_{-15}$ and $\Gamma \approx 55^{+20}_{-30}$ was recently thoroughly reviewed in the Paris Conference.[33] Some concern was expressed that the ITHEP calculations on instanton effects would move a 0^{-+} glueball up to 2.0-2.5 GeV mass region. The possibility that the iota (1440) is a radial excitation rather than a glueball has also been discussed.

Another glueball candidate of this type is the θ(1640) with $J^{PC} = 2^{++}$ favored, 95% C.L., $M \approx 1700 \pm 50$, $\Gamma \approx 160 \pm 50$. See Ref. 33 for a review of the status of these glueball candidates.

Recently at the Experimental Meson Spectroscopy Conference there were papers discussing them.[23b,34] Opinions differ strongly. The most recent and thorough review was made by Sid Meshkov.[23b] He concluded the iota (1440) and θ(1640) are not glueballs but also cited alternate explanations[34,35] in which they could be.

One can directly search for a nonet + glueball + decuplet with characteristic mixing splittings. The $g_S(1240)$ with $J^{PC} = 0^{++}$, $M = 1240 \pm 10$ MeV, and $\Gamma = 140 \pm 10$ MeV is one such a glueball candidate.[36] Of course other explanations such as the mixture of singlets from two nonets (one of which could be a radial excitation) are alternatives. The direct pattern recognition search for glueballs is a difficult and so far inconclusive program.

At the Brighton Conference just preceeding this lecture, the Mark III collaboration reported in radiative J/ψ decay,[37] new data observing the iota and the θ. For the iota, the $K^0_S K^0_S \pi^0$ mode was observed in addition to the previously seen $K^+K^-\pi^0$ and $K^0_S K^{\pm}\pi^{\mp}$ modes. The Breit-Wigner fit parameters determined were $M = 1.46 \pm 0.01$ GeV and $\Gamma = 0.097 \pm 0.0025$ GeV. In the case of the θ the Breit-Wigner parameters were determined as $M = 1.719 \pm 0.006$ GeV, $\Gamma = .117 \pm .023$ GeV. The iota and θ situation did not appear to change substantially from the prior review[33] and the only essentially new development was the evidence for a new narrow structure ($\xi(2200)$).

It should be noted the question has often been raised as to whether $\phi\phi$ states are seen in radiative decay of the ψ. The new MK III results observe $\psi \rightarrow \gamma\phi\phi$.[37] Their detection efficiency for $\phi\phi$ is very low in the mass region of the $g_T(2120)$, $g_T'(2220)$ and $g_T''(2360)$. Thus they find only ~10 events in this mass region. However if one corrects their $\phi\phi$ mass spectrum for the detection efficiency it is not inconsistent with the shape of the mass spectrum seen by BNL/CCNY. However one should note we are comparing ≈ 4,000 observed events to ~ 10. It appears that the MK III can only observe strong signal, narrow, high mass states such as the η_c and thus is not likely to be able to observe the BNL/CCNY states.

Conclusions

If you assume as input axioms:

1. QCD is correct;

2. The OZI rule is universal for weakly coupled glue in disconnected Zweig diagrams where the disconnection is due to the creation or annihilation of new flavor(s) of quark(s), then the BNL/CCNY $g_T(2120)$, $g_T'(2220)$ and $g_T(2360)$ are produced by 1-3 primary glueballs. One or two broad primary glueballs could in principle break down the OZI suppression and mix with one or two quark states which accidentally have the same quantum numbers and nearly the same mass. However the simplest explanation of the rather unusual characteristics of our data is that we have found a triplet of $J^{PC} = 2^{++}$ glueball states.

Since our input axioms are in good agreement with experiments and merely represent modern QCD practice, we have very probably discovered 1-3 $J^{PC} = 2^{++}$ glueballs.

The iota(1440) and the θ(1700) observed in J/ψ radiative decay are glueball candidates. The pros and cons of which have been discussed briefly here and more extensively in the references cited. Other recent glueball searches[38] have not yet led to candidates.

REFERENCES

1. H. Fritzch and M. Gell-Mann, XVI Int. Conf. on High Energy Physics, Chicago-Batavia, 1972, Vol. 2, pp. 135; H. Fritzch, M. Gell-Mann and H. Leutwyler, Phys. Lett. 47B, 365 (1973); S. Weinberg, Phys. Rev. Lett. 31, 49 (1973); S. Weinberg, Phys. Rev. D 8, 4482 (1973); D.J. Gross and F. Wilczek, ibid. 3633 (1973).
2. C.N. Yang and R.L. Mills, Phys. Rev. 96, 191 (1954).
3. a) Fritzch and Minkowski, Nuovo Cimento 30A, 393 (1975). b) R.P. Freund and Y. Nambu, Phys. Rev. Lett. 34, 1645 (1975). c) R. Jaffee and K. Johnson, Phys. Lett. 60B, 201 (1976). d) Kogut, Sinclair and Susskind, Nucl. Phys. B114, 199 (1975). e) D. Robson, Nucl. Phys. B130, 328 (1977). f) J. Bjorken, SLAC Pub. 2372.
4. S. Glashow, J. Ioliopulos, L. Maianai, Phys. Rev. D 2, 1285 (1970); A. Salam, Elementary Particle Theory, Nobel Symposium, Ed. N. Svartholm (Wiley Interscience 1968); S. Weinberg, Phys. Rev. Lett. 19, 1264 (1967).
5. S.J. Lindenbaum. Hadronic Production of Glueballs. Proc. 1983 Intern. Europhysics Conf. on High Energy Physics, Brighton, U.K., July 20-27, 1983, J. Guy and C. Costain, Editors (Rutherford Appleton Laboratory), p. 351-360.
6. S.J. Lindenbaum. Evidence for Explicit Glueballs from the Reaction $\pi^- p \to \phi\phi n$. Proc. of the 20th Course: Gauge Interactions; Theory and Experiment, International School of Subnuclear Physics, Erice, Trapani, Italy, August 3-14, 1982, (to be published). BNL # 32096. (Continued)

6. Continued:

b) S.J. Lindenbaum, Evidence for Glueballs. Proc. 1982 APS Meeting of the Division of Particles and Fields, University of Maryland, College Park, Maryland, October 28-30, 1982. Eds. William E. Caswell and George A. Snow, AIP Conf. Proc. #98, Particles and Fields Subseries #29, pp.218-246.

7. G. Zweig, CERN REPORTS TH401 and 412 (1964).

8. S. Okubo, Phys. Letts. 5, 165 (1963); Phys. Rev. D 16, 2336 (1977).

9. J. Iizuba, Prog. Theor. Physics. Suppl. 37-38, 21 (1966); J. Iizuba, K. Okuda and O. Shito, Prog. Theor. Phys. 35, 1061 (1966).

10. A. Etkin, K.J. Foley, J.H. Goldman, W.A. Love, T.W. Morris, S. Ozaki, E.D. Platner, A.C. Saulys, C.D. Wheeler, E.H. Willen, S.J. Lindenbaum, M.A. Kramer, U. Mallik, Phys. Rev. Lett. 40, 422-425 (1978); Phys. Rev. Lett. 41, 784-787 (1978).

11. D. Cohen et al., Phys. Rev. Lett. 38, 269 (1977).

12. D.S. Ayres et al., Phys. Rev. Lett. 32, 1463 (1974).

13. H.J. Lipkin, Phys. Lett. 124B, 509 (1983).

14. S.J. Lindenbaum, Phys. Lett. 131B, 221-223 (1983).

15. S.J. Lindenbaum, C. Chan, A. Etkin, K.J. Foley, M.A. Kramer, R.S. Longacre, W.A. Love, T.W. Morris, E.D. Platner, V.A. Polychronakos, A.C. Saulys, Y. Teramoto, C.D. Wheeler. A New Higher Statistics Study of $\pi^- p \rightarrow \phi\phi n$ and Evidence for Glueballs. Proc. 21st Intern. Conf. on High Energy Physics, Paris, France, 26-31 July 1982, Journal de Physique 43, P. Petiau and M. Porneuf, Editors (Les Editions de Physique, Les Ulis, France), pp. C3-87 - C3-88.

16. a) S.J. Lindenbaum, Hadronic Physics of $q\bar{q}$ Light Quark Mesons, Quark Molecules and Glueballs. Proc. of the XVIII Course of the International School of Subnuclear Physics, July 31-August 11, 1980, Erice, Trapani, Italy, Subnuclear Series, Vol. 18, "High Energy Limit", Ed. A. Zichichi, pp. 509-562; b) S.J. Lindenbaum, Il Nuovo Cimento, 65A, 222-238 (1981).

17. T. Armstrong et al., CERN EP/82-103 (1982).

18. M. Baubillier et al., Phys. Lett. 118B, 450 (1982).

19. A. Etkin, K.J. Foley, R.S. Longacre, W.A. Lovė, T.W. Morris, E.D. Platner, V.A. Polychronakos, A.C. Saulys, C.D. Wheeler, C.S. Chan, M.A. Kramer, Y. Teramoto, S.J. Lindenbaum. The Reaction $\pi^-p \rightarrow \phi\phi n$ and Evidence for Glueballs. Phys. Rev. Lett. 49, 1620-1623 (1982).

20. S.J. Lindenbaum. The Discovery of Glueballs. Surveys in High Energy Physics, Vol. 4, pp. 69-126, John M. Charap, Editor (Harvard Academic Publishers, London, 1983).

21. S.J. Lindenbaum. Glueballs in the Reaction $\pi^-p \rightarrow \phi\phi n$. Invited Lecture. Proc. Hadronic Session of the Eighteenth Rencontre De Moriond, La Plagne-Savoie-France, January 23-29, 1983, Vol. I, Gluons and Heavy Flavours, J. Tran Thanh Van, Editor (Editions Frontieres, Gif sur Yvette, France), pp. 441-468.

22. R.S. Longacre. Glueballs in the Reaction $\pi^-p \rightarrow \phi\phi n$ at 22 GeV/c. Proc. of the Seventh Intern. Conf. on Experimental Meson Spectroscopy, April 14-16, 1983, Brookhaven National Laboratory, S.J. Lindenbaum, Editor (AIP Conf. Proc., Particles and Fields Subseries, to be published).

23. a) S. Meshkov. Proc. Hadronic Session of the Eighteenth Rencontre De Moriond, La Plagne-Savoie-France, January 23-29, 1983, Vol. I, Gluons and Heavy Flavours, J. Tran Thanh Van, Editor (Editions Frontieres, Gif sur Yvette, France), pp. 427-440. (Continued)

23. Continued:

b) S. Meshkov. Glueballs. Proc. Seventh Intern. Conf. on Experimental Meson Spectroscopy, April 14-16, 1983, Brookhaven National Laboratory, S.J. Lindenbaum, Editor (AIP Conf. Proc., Particles and Fields Subseries, to be published).

24. a) C. Carlson, J. Coyne, P. Fishbane, F. Gross, S. Meshkov, Phys. Rev. D 23, 2765 (1981). b) J. Coyne, P. Fishbane and S. Meshkov, Phys. Lett. 91B, 259 (1980); C. Carlson, J. Coyne, P. Fishbane, F. Gross and S. Meshkov, Phys. Lett. 99B, 353 (1981).

25. C.E. Carlson, T.H. Hansson and C. Peterson, Phys. Rev. D 27, 1556 (1983).

26. C. Rebbi. Proc. 21st Intern. Conf. on High Energy Physics, Paris, France, 26-31 July 1982, Journal de Physique 43, P. Petiau and M. Porneuf, Editors (Les Editions de Physique, Les Ulis, France), pp. C3-723; B. Berg, Calculations in 4d Lattice Gauge Theories (unpublished).

27. B. Berg and A. Billoire, Phys. Lett. 113B, 65 (1982); 114B, 324 (1982).

28. K. Ishikawa et al., Phys. Lett. 116B, 429 (1982); 120B, 387 (1983).

29. T.D. Lee. Time as a dynamical variable CU-TP-266; Talk at Shelter Island II Conf., June 2, 1983; also, ERICE Lectures, August 3-14, 1983 (these proceedings).

30. M. Chanowitz, Phys. Rev. Lett. 46, 981 (1981).

31. J.F. Donoghue, Experimental Meson Spectroscopy - 1980, Sixth Int. Conf., Brookhaven National Laboratory, April 25-26, 1980, Eds. S.U. Chung and S.J. Lindenbaum, AIP Conf. Prof. #67, Particles and Fields Subseries #21, pg. 104-119.

32. Edwards et al., Phys. Rev. Lett. 48, 458 (1982); 49, 259 (1982).

33. E. Bloom. Proc. 21st Intern. Conf. on High Energy Physics, Paris, France, 26-31 July 1982, Journal de Physique 43, P. Petiau and M. Porneuf, Editors (Les Editions de Physique, Les Ulis, France), pp. C3-407.

34. J. Donoghue. The η', The Iota and the Pseudoscalar Mesons. Proc. of the Seventh Intern. Conf. on Experimental Meson Spectroscopy, April 14-16, 1983, Brookhaven National Laboratory, S.J. Lindenbaum, Editor (AIP Conf. Proc., Particles and Fields Subseries, to be published).

35. W.F. Palmer and S.S. Pinski, Production, Decay and Mixing Models of the Iota Meson.

36. A. Etkin, K.J. Foley, R.S. Longacre, W.A. Love, T.J. Morris, S. Ozaki, E.D. Platner, V.A. Polychronakos, A.C. Saulys, Y. Teramoto, C.D. Wheeler, E.H. Willen, K.W. Lai, S.J. Lindenbaum, M.A. Kramer, U. Mallik, W.A. Mann, R. Merenyi, J. Marraffino, C.E. Roos, M.S. Webster, Phys. Rev. D 25, 2446 (1982).

37. K. Einsweiler. Proc. 1983 Intern. Europhysics Conf. on High Energy Physics, Brighton, U.K., July 20-27, 1983, J. Guy and C. Costain, Editors (Rutherford Appleton Laboratory), p. 348-350.

38. See Reference 5 for a brief review and references to the individual papers.

39. J.C. Pati and A. Salam, Phys. Rev. D 8, 1240 (1973); Phys. Rev. D 10, 275 (1974); H. Georgi and S.L. Glashow, Phys. Rev. Lett. 32, 438 (1974); see papers by Beg and Sugawara, XX Int. Conf. on High Energy Physics, Madison, Wisconsin, July 1980; R.N. Mohapatra and R.E. Marshak, Phys. Rev. Letts. 44, 1316 (1980).

40. Particle Data Group Tables, Phys. Letts. 111B, 12 (1982).

41. J. Lee-Franzini. Υ Spectroscopy from CUSB. Proc. of the Seventh Intern. Conf. on Experimental Meson Spectroscopy, April 14-16, 1983, Brookhaven National Laboratory, S.J. Lindenbaum, Editor (AIP Conf. Proc., Particles and Fields Subseries, to be published).

STATUS OF THE GLUEBALLS

DISCUSSION

Chairman: S.J. Lindenbaum

Scientific Secretaries: S. Capstick, N. Ohta

-BERNSTEIN:

This is a question from one experimentalist to another: why can't an OZI forbidden process like $\pi^- p \to \phi\phi n$ be mediated by multiple soft gluon exchange? There your argument about weak coupling does not apply, and I might think that a ϕ resonance could be made from multiple gluons.

-LINDENBAUM:

In the Zweig disconnected diagram $\pi^- p \to \phi\phi n$ you get creation of two $s\bar{s}$ pairs, and if you look at the diagram the other way around you get annihilation of two $s\bar{s}$ pairs. Those annihilations only occur at very small distances and so they emit hard gluons. The soft gluons come in the outer areas of the confinement region, and that is where you are not, in these very simple processes, creating and annihilating the quarks which make the diagram disconnected. I might add, multiple gluon creation of $q\bar{q}$ pairs would be expected to occur in allowed processes which correspond to connected diagrams. In this case the moving quark lines, as they separate (at large distances), serve as a source of soft multi-gluons, which leads to the hadronization process.

-BERNSTEIN

Is that a quantitative argument or a hope?

-LINDENBAUM:

There is no quantitative argument possible at present other than in the weak coupling region of QCD. However, the OZI forbidden processes are expected to occur at small distances and thus the quark glue coupling should be weak for these processes.

-BERNSTEIN:

Does Lipkin now agree with your assessment of his argument?

-LINDENBAUM:

I don't think so. I presented my statements on the subject at the Brighton Conference and nobody disagreed with them and a number of theorists agreed. My reply has also been accepted for publication by Physics Letters.[14]

-HOU:

If the acceptance for $\phi\phi$ is improved in the $\psi \to \chi\gamma$ experiments and your glueballs are not seen, you are still safe if they are three gluon glueballs.

Could you explain why $\psi' \to \psi\pi\pi$ and $T' \to T\pi\pi$ are OZI forbidden? I find both your argument and Lipkin's equally convincing. I wouldn't call it OZI suppressed because the two pions are emitted through soft gluons, with only 600 MeV available. Why is this "OZI forbidden" process dominating the decay?

-LINDENBAUM:

The hardness or softness of the gluons depends on the ratio Q^2/Λ, and Λ is not well known. If you don't attribute the narrowness of the ψ', T' and especially the T'' to the Zweig suppression, then what do you attribute it to? Lipkin argued that the $\psi'(3685)$ goes via the 2π mode 50% of the time. He then said that we can get $\pi + \psi' \to \psi + \pi$ from $\psi' \to \psi + 2\pi$ by crossing one π, which is diffractive excitation of the ψ and has a large cross section, so

-LINDENBAUM (continued):

the process is OZI allowed. He also used this so-called crossed Pomeron diagram arguement to conclude $\pi^- p \rightarrow \phi\phi n$ is $\approx$ OZI allowed, since it is related by crossing to $\phi + n \rightarrow \phi + \pi^- + p$ which is merely elastic scattering with additional production of a pion and is not expected to be suppressed. I pointed out that when you cross in that manner you get into different physical and kinematic regions, and you cannot simply relate the two processes. For example considering the kinematics alone, the crossed process corresponds to high momentum transfer and high mass diffractive dissociation and thus is expected to be negligibly small.

-HOU:

I have made a naive pole model analysis of $\psi' \rightarrow \psi\pi\pi$ and $\Upsilon' \rightarrow \Upsilon\pi\pi$ going through a 0^{++} Σ-model object. The small size of $\psi' \rightarrow \psi\pi\pi$ can be understood as partly due to phase space and partly due to the pole particle being off shell. So the narrowness cannot be used as a proof of the OZI rule.

LINDENBAUM:

This is equivalent to having two step allowed processes which replace a Zweig forbidden process, and there is no evidence for this occurring in the ϕ, J/ψ and Υ systems. However, let me reiterate, that my rigorous conclusions are based on my second axiom which states that the OZI rule cannot be broken by such processes.

-OHTA:

Is there any reason why glueballs exist only in spin-2 and possibly in spin-0 states? Also why are these spin-2 states nearly degenerate?

-LINDENBAUM:

They need not exist only in spin-0 and spin-2 states, however all theoretical calculations find the lowest lying states are 0^{++} and then 2^{++}. In our experiment we cannot probe the C = - sector because $\phi\phi$ has C = +, but our experiment has no bias to any particular J^P. It has just turned out that we have found a cluster of 2^{++} states in the mass region we are probing. Prof. Lee said that based on his strong coupling calculations he expected three J = 2 states. As described in my proceeding's paper, adjusting his strong coupling constant calculations to the real world, we find his mass formula gives agreement with the mass splittings of the states we observe. In the constituent gluon model as proposed by Meshkov, the two gluon sector contains three low-lying 2^{++} states.

-EREDITATO:

In which channel do you experimentally look for $\phi\phi$?

-LINDENBAUM:

The channel is (22 GeV/c) $\pi^- p \rightarrow \phi\phi n$. Each $\phi \rightarrow K^+K^-$ and we identify the four K's.

-CATTO:

Earlier you talked about other glueball candidates, like the $J^{PC} = 0^{-+}$ iota(1440), and you mentioned that the instanton effects would move this up to ~ 2-2.5 GeV. Do you feel this is a plausible calculation?

-LINDENBAUM:

That statement was made by the I.T.H.E.P. group and reported by E. Bloom in his rapporteur talk at the Paris Conference a year ago. He said that he was worried about the iota for that reason. The 0^- states are particularly sensitive to instanton effects.

-KLEVANSKY:

I am having a logic problem. As I understand it you wish to add to the data that exists confirming QCD by establishing the existence of glueballs Yet your identification of glueballs relies on the assumption of the correctness of QCD. So if you identify anything under this assumption I don't see that this says anything <u>for</u> QCD. You can only disprove it.

-LINDENBAUM:

As far as I am concerned there is no theory that you can ever experimentally prove without assuming the theory. No theory can be mathematically proven without input axioms.

-KLEVANSKY:

The input axioms should not be the conclusion.

-LINDENBAUM:

But to experimentally show a theory is correct, we must take the theory and calculate or predict various things and find experimental agreement. Thus you must assume a theory to experimentally prove it.

-BATTISTON:

In your paper submitted to <u>Surveys In High Energy Physics</u> you showed the $\phi\phi$ mass distribution for $K^-p \to \phi\phi\Lambda/\Sigma$. This distribution has a mass peak at ~ 2.3 GeV. This peak is broader than your peak, but statistically significant. The reaction $K^-p \to \phi\phi\Lambda/\Sigma$ is Zweig allowed. How do you explain this peak?

-LINDENBAUM:

Our distribution peaks earlier and falls faster than that one. Because $K^-p \to \phi\phi\Lambda/\Sigma$ is OZI allowed, there is no reason to

-LINDENBAUM (continued):

expect the two distributions to be the same. That reaction will transmit things other than glueballs.

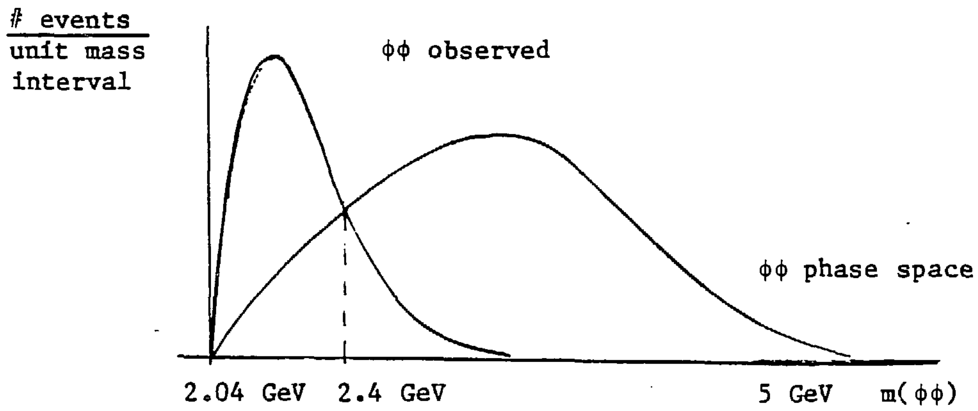
To explain the structure of the distribution we must do a partial wave analysis, but because of the poor statistics no analysis has been done.

-BATTISTON:

Can you show me the distribution of the phase space for the ϕ system with the hypothesis that no resonance is present?

-LINDENBAUM:

It would peak at higher masses and look roughly like this:



-BATTISTON:

Can you explain why your axiom of the correctness of QCD rules out the possibility of $\phi\phi$ resonance states?

-LINDENBAUM:

The second axiom rules out any breakdown of the OZI Rule except through glueballs.

-BATTISTON:

Couldn't a $\phi\phi$ resonance state increase the cross-section without introducing 2 resonant intermediate state of glue?

-LINDENBAUM:

You are ignoring the Zweig disconnected diagram argument, which I take as an axiom, and which is experimentally verified.

-KASPER:

He is not ignoring the axiom, he is assuming that it is not occurring in resonance, and that having produced the four strange quarks they resonate, and this accounts for the increased cross-section.

-LINDENBAUM:

Again you will find that you are making a two-step allowed process which changes the nature of the mulit-gluon exchange in a Zweig disconnected diagram to that corresponding to two successive allowed steps. Doing this could destroy all Zweig disconnected diagrams, which will remove the explanation for OZI suppression and change the OZI rule to the unlikely OZI accident. I made a qualitative argument for the validity of the one step diagrams, based on the fact that annihilation occurs at small distances and hadronization occurs at large distances.

-CATTO:

I noticed that some of the lattice gauge theory results are either higher or lower than the results of your experiments. For which J^{PC} states have these calculations been done?

-LINDENBAUM:

The ones I showed were all for $J^{PC} = 2^{++}$. Lattice calculations have only been done for 0^{++} and 2^{++}. The results of these

-LINDENBAUM (continued):
calculations lie been 1.7 - 3 GeV and they average to ~ 2 GeV.

-OGILVIE:

The lattice calculations have better figures for the 0^{++} state. Is there any hope of cleaning up the experimental status of the 0^{++} glueball?

-LINDENBAUM:

The prospects are not too good. There are too many possible explanations for the 0^{++} glueball candidates.