Invited Talk -

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HADRONIC PRODUCTION OF GLUEBALLS†

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HADRONIC PRODUCTION OF GLUEBALLS*

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INTRODUCTION

Local Gauge Invariance of $SU(3)_c$ and color confinement would require that the only hadrons in the world be glueballs. However when we add the quarks and obtain QCD it is experimentally clear that quark built states mask the expected glueballs. Thus discovery of glueballs is essential for the viability of QCD.

In this talk I will review the conference papers on the hadronic production of glueballs, and searches for glueballs.

PART A - GLUEBALL PRODUCTION. GLUEBALLS PRODUCED IN THE REACTION $\pi^- p \to \phi\phi n$.

The BNL/CCNY collaboration (Etkin et al.[1]) increased their statistics from 1200 to ≈ 4000 events[2] in the Zweig disconnected diagram reaction $\pi^- p \to \phi\phi n$, which is OZI forbidden. In Fig. 1a we see the general ≈ uniform background from the reaction a) $\pi^- p \to K^+K^-K^+K^- n$ which is OZI allowed and the two ϕ bands representing b) $\pi^- p \to \phi K^+K^- n$ which is OZI allowed. Where the two ϕ bands cross we have the OZI forbidden reaction c) $\pi^- p \to \phi\phi n$ and the black spot shows an obvious more or less complete breakdown of the OZI suppression. This has been quantitatively shown to be so in these reactions and also comparing with K induced ϕ and $\phi\phi$ production.[3] The black spot when corrected for double counting and resolution is ≈ 1,000 times the density of reaction a) and ≈ 50 times the density of reaction b). The huge $\phi\phi$ signal is ≈ 10 times greater than the background from reaction b) even with rather wide cuts. The recoil neutron signal is also very clean, ≈ 97% neutrons.

It should be noted that Lipkin, Phys. Lett. 124B, 509 (1983) erroneously concluded $\psi'(3685 \to J/\psi(3100) + 2\pi$ ≈ OZI allowed and $\pi^- p \to \phi\phi n$ ≈ OZI allowed since both are related to diffraction excitation by crossing. He ignored fact that crossing brings you into different physical and kinematic regions and you cannot naively relate reactions by crossing. For example $\phi + n \to \phi + \pi^- + p$ involves high momentum transfer and a high mass $\pi^- p$ system whereas diffractive dissociation which he says is large, becomes very small at high momentum transfers and high masses. He also says OZI is only applicable to single hairpin disconnections, ignoring the fact that the $\psi'(3685) \to J/\psi(3100) + 2\pi$ and $\Upsilon' \to \Upsilon + 2\pi$ reactions are double hairpin disconnections, yet they keep typical narrow Zweig suppressed widths. By Lipkins crossing argument they should be ≈ OZI allowed, and the widths should be ~ 10^3 wider. Thus his conclusions are obviously erroneous.

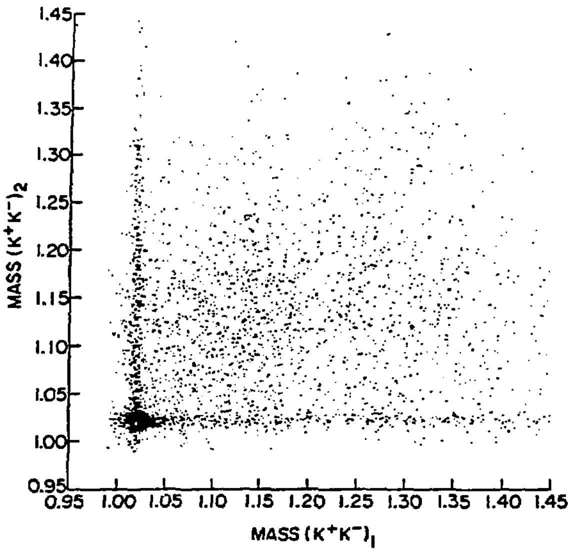

Fig 1a

Scatter plot of K^+K^- effective mass for each pair of 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.

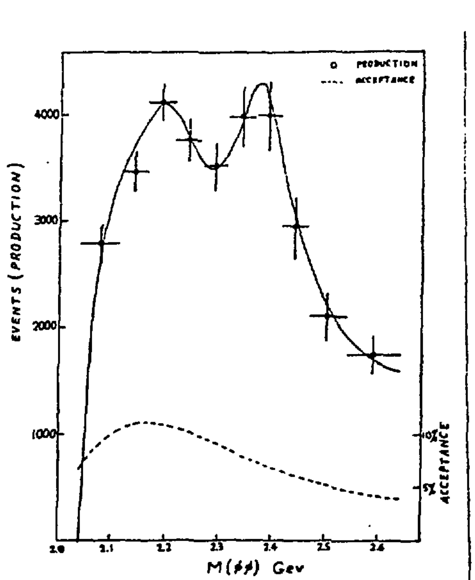

Fig. 1b

The $\phi\phi$ mass spectrum corrected for acceptance. The solid line is the fit to the data with the three resonant states. The dashed line is the acceptance.

The acceptance corrected $\phi\phi$ mass spectrum in the ten mass bins which were used for the partial wave analysis (PWA) is shown in Fig. 1b.

All waves with $J = 0\text{–}4$, $L_{max} = 3$ and $P = \pm$, η(exchange naturally) $= \pm$ were allowed in the PWA. The Gottfried Jackson frame angles β (polar), γ (azimuthal) 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 were used. The results of the mass independent PWA are shown in Figs. 2 and 3. The curves shown are the results of a 3 pole K-matrix fit which was required to obtain a good fit $\approx 1\sigma$.

Previously[1,3b] we had found two resonant $J^{PC} = 2^{++}$ states. When we increased the statistics from 1200 to $\approx$ 4000 the new data was very consistent with the previous data within statistics but now required a third $J^{PC} = 2^{++}$ state (two states qualitatively fit the data but were $> 10\sigma$ away from a good fit). The third state represents a resolution of the previous higher energy state into two as a result of increased statistics. The phase motion in Fig. 3 is a clear indication of resonance behavior. The Argand plot for the three waves is shown in Fig. 4. The angular distributions which are most important in selecting the three $J^{PC} = 2^{++}$ states are $\alpha_1 - \alpha_2$ and α and $\alpha_1 + \alpha_2$. They are shown in Fig. 5 compared to the acceptance corrected (for the fit) Monte Carlo calculation. All observed angular distributions in all mass bins agree with the acceptance corrected Monte Carlo very well.

The K-matrix method is approximately equivalent to, but a somewhat more realistic approach to fitting than relativistic Breit Wigner's. The deduced Breit Wigner parameters and quantum numbers for the three states are shown in Table I.

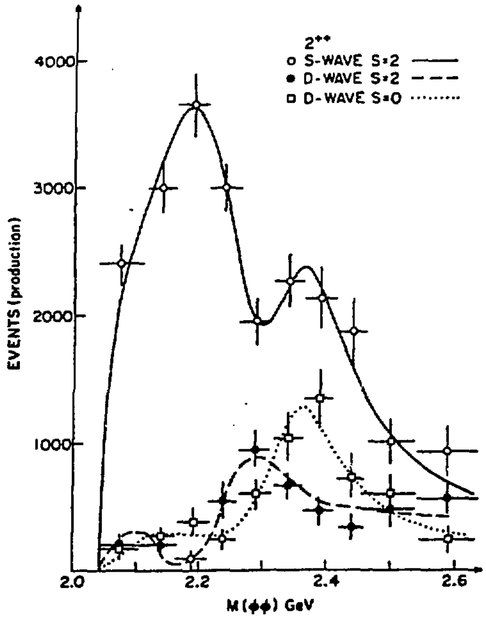

Fig. 2
The three waves with significant amplitudes. Three K-matrix poles were required for a good fit shown by curves.

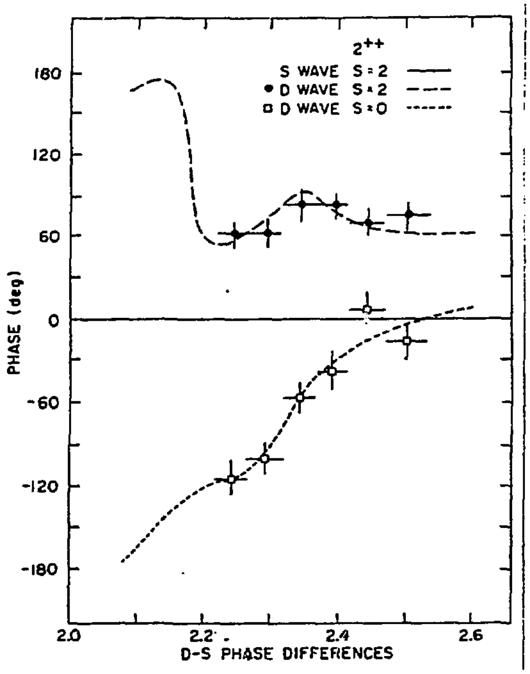

Fig. 3
D–S phase differences from PWA. The fit is shown.

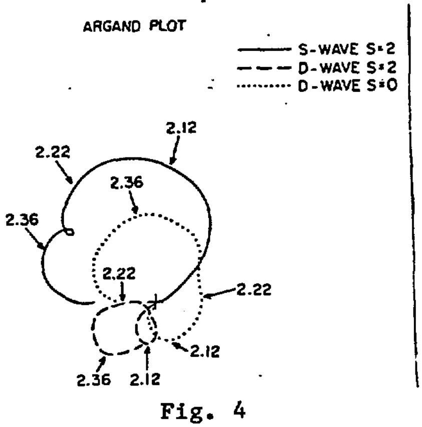

Fig. 4
Argand plot from K-matrix

<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 introduction of new types (i.e. flavors) of quarks;

<u>then the states we observe must represent the discovery of 1-3 glueballs.</u> Note that axiom (2) allows only resonating glue (i.e. glueballs) to break the OZI suppression. One primary glueball could break down the OZI suppression and possibly mix with two quark states.

Since these axioms merely represent modern QCD practice and strikingly agree with the data in the ϕ, J/ψ and T systems[3b] it is reasonable to consider this the discovery of glueballs.

T.D. Lee has calculated J = 2 glueballs in the strong coupling limit and obtains three sets of degenerate states.[4] The constituent (i.e. gluon has effective mass) gluon models[5] would predict three low-lying $J^{PC} = 2^{++}$ glueballs. The mass estimates from the MIT bag and lattice gauge groups are

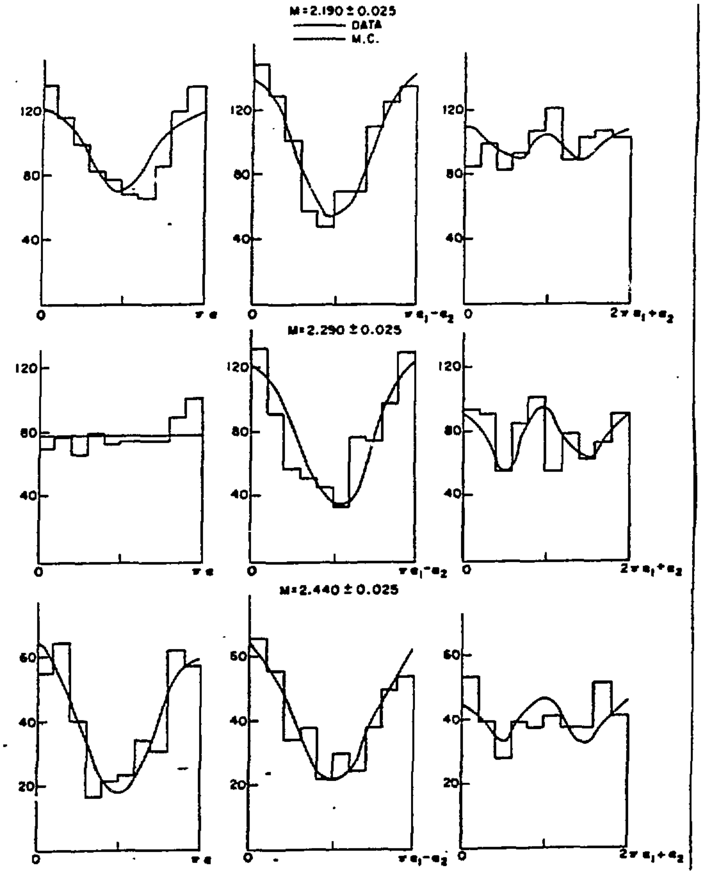

Fig. 5
α, $\alpha_1 - \alpha_2$ and $\alpha_1 + \alpha_2$ for three representative mass bins, where α is effectively the azimuthal angle for the K^+ in ϕ decay relative to the ϕ direction in its rest frame.

TABLE I

Resonant States in $\pi^- p \to \phi\phi n$
(±) refers to sign of the coupling

State	I^G	J^{PC}	Mass (MeV)	Γ (MeV)	S-wave S=2	D-wave S=2	D-wave S=0
$g_T(2120)$	0^+	2^{++}	2120^{+20}_{-120}	300^{+150}_{-50}	~50% +	~50% −	
$g_{T'}(2220)$	0^+	2^{++}	2220 ± 20	200 ± 50	~50% +	~50% −	
$g_{T''}(2360)$	0^+	2^{++}	2360 ± 20	200 ± 50			~100% +

≈ 2 GeV for $J^{PC} = 2^{++}$ glueballs. Thus we are in the right ballpark for agreement with present phenomenological mass calculations.

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

Even in this event 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. See Reference 6 for more details.

PART B – SEARCH FOR NARROW ENHANCEMENTS IN $\phi\phi$ SYSTEM

$\pi^- + Be \rightarrow \phi\phi$ + anything, 85 GeV/c CERN Ω' Experiment.[7]

This experiment was probably motivated by narrow enhancements previously found at 2.1 GeV/c^2 by Daum et al, Phys. Lett. 104B, 24 (1981). They find no narrow enhancements and obtain upper limits for them (see Fig. 6).

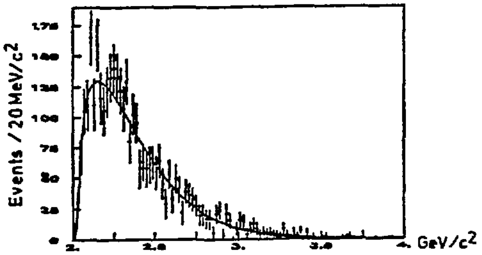

Fig. 6a

The $\phi\phi$ mass distributions after background subtraction.

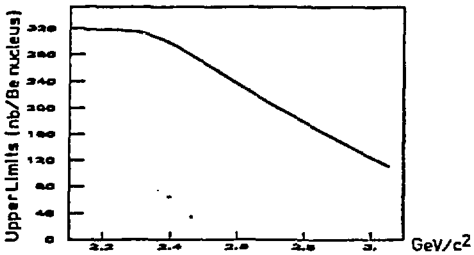

Fig. 6b

Upper limits on narrow resonance production cross section from Be target at the 99.7% confidence level. The FWHM resolution varies from ≈ 12 MeV/c^2 at the low mass end to ≈ 26 MeV/c^2 at the high mass end.

ACCMOR[8] (same group as Daum et al.) also find their previous narrow enhancement washed out with higher statistics. See Fig. 7 for their new results.

PART C – DOUBLE POMERON EXCHANGE AND OTHER CENTRAL REGION GLUEBALL SEARCHES

The Pomeron may be just a representation of diffraction scattering. Nevertheless several theorists assume it is a two or more gluon particle. If so double Pomeron exchange which is expected to be a central region process and relatively energy independent could be a place to search for glueballs.

Palano et al.[9] studied $pp \rightarrow pp + Xo$ (central) and $\pi^+ p \rightarrow \pi^+ p + Xo$ (central). Their data suggests the S*(980) when $Xo = \pi^+\pi^-$. When $Xo = K_S^0 K^\pm \pi^\mp$ they see clear D and E meson signals with higher signal to background ratio (i.e. same order as for E/iota) than seen in peripheral reactions (see Fig. 8). But they see no signal for the decay $E \rightarrow \eta_0 \pi^+\pi^-$ (or $\delta^\pm \pi^\mp$ as is often assumed in spin-parity analyses) in contrast to the $\eta_0 \pi^+\pi^-$ signals for the D^0 and η' which are clearly seen.

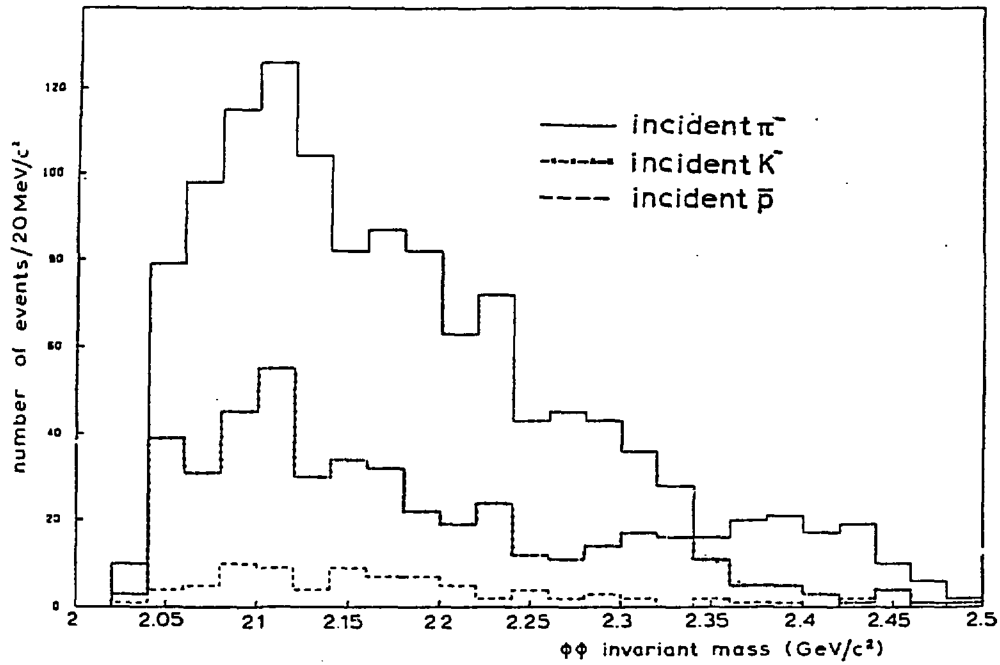

Fig. 7 The φφ invariant mass distributions for incident π^-, K^- and $\bar{p}$.

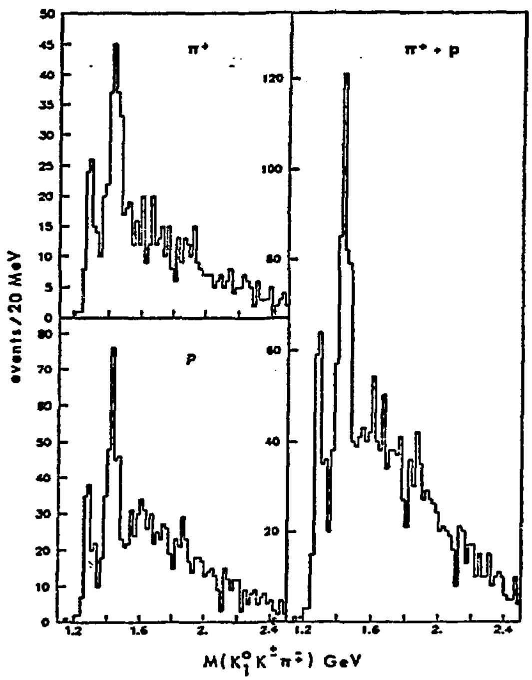

Fig. 8
Effective mass distributions:
Labels: π^+ means incident π^+, p means incident protons, $\pi^+ + p$ means sum of preceeding two.

Akesson et al.[10] studied $pp \to pp + \pi^+\pi^-$ ($X_F > .95$ central) at $\sqrt{s} = 63$ ($\approx$ 90% data) and $\sqrt{s} = 45$ ($\approx$ 10%). The mass distributions are similar at both energies.

Their data is consistent with DPE and is shown in Fig. 9. They see S* (980) in low mass region. Novikov et al. suggested the S*(980) may harbor a large admixture of 0^{++} glueballs.

High mass region exhibits an approximately flat plateau $\approx$ 1600-2300 MeV/c^2 followed by a relatively rapid decrease. Most conventional hypothesis is that heavy state (e.g. ε(2300)) plays a similar role to S*(980) in causing rapid drop in σ. They have no explanation for rapid drop in region of 1400 MeV/c^2.

Breakstone et al.[11] also studied $pp \to \pi^+\pi^-$ with $|y| < 1$. Their rapidity plot (Fig. 10) shows separation of central system and fast protons when trigger system selecting central region is used. The solid curve shows what happens with a minmimum bias trigger. This effect would be more or less the same for the previous experiments discussed.

For J/ψ radiative decay see References 12-13. K. Gottfried[14] gave the Plenary Talk.

Conclusions:

1. $g_T(2120)$, $g_{T'}(2220)$ and $g_{T''}(2360)$ are produced by glueballs if a) QCD is correct, and b) the OZI rule is "universal" (as described in text).
2. There is no evidence for narrow enhancement, i.e. in $\phi\phi$ inclusive experiments.
3. DPE searches for glueballs are proceeding and have isolated central region (see text).

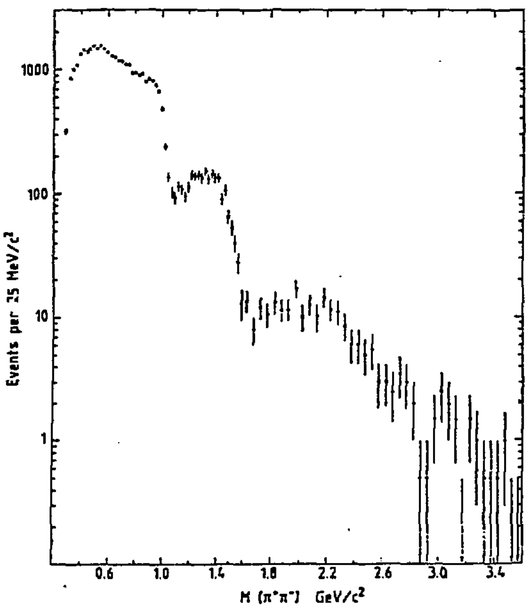

Fig. 9
Mass spectrum of central $\pi^+\pi^-$ events, not corrected for acceptance.

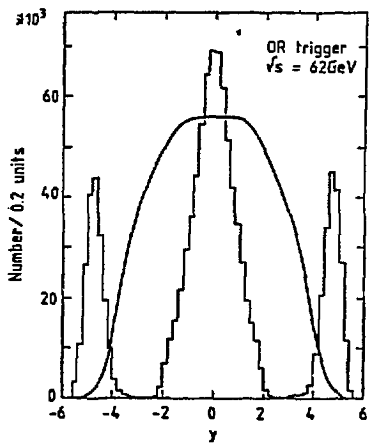

Fig. 10
Rapidity distribution

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