RUSSIAN ACADEMY OF SCIENCES
PETERSBURG NUCLEAR PHYSICS INSTITUTE

Preprint 2001

V. V. Anisovich, D. V. Bugg*, T. H. Burnett**,
A. V. Sarantsev, I. Scott*, S. Sutlie**, B. S. Zou*

Resonances in $J/\Psi \to \gamma\ (\pi^+\pi^-\pi^+\pi^-)$.

* Queen Mary and Westfield College, London E1 4NS
United Kingdom.
** University of Washington, Seattle, Washington 98195,
USA

Gatchina · 1994

УДК 539.12.01

Резонансы в $J/\Psi \to \gamma(\pi^+\pi^-\pi^+\pi^-)$ распаде

Аннотация

В.В.Анисович, Д.В.Багг, Т.Г.Бюрнет, Б.С.Зу, А.В.Саранцев, Я.Скотт, С.Сутли

Экспериментальные данные реакции $J/\Psi \to \gamma(\pi^+\pi^-\pi^+\pi^-)$, полученные коллаборацией MARK-III, были переанализированы нами с учетом рождения $\sigma\sigma$ и $\rho\rho$ в конечном состоянии. Здесь под σ подразумевается S волновая $\pi\pi$-амплитуда. Мы нашли резонансы с $I^G = O^+ : J^{PC} = O^{++}$ с массой 1505 и 2100 МэВ и $J^{PC} = 2^{++}$ с массой 1770 МэВ. Резонансы с $J^{PC} = O^{++}$ распадаются главным образом на $\sigma\sigma$. 2^{++}-резонанс также имеет сильную моду распада на это состояние. Обсуждается спектр семи низших глюбольных состояний, проявляющихся в распаде на η, η', $q\bar{q}$ P-волну, σ и $f_2(1270)$ мезоны.

Abstract

Mark III data on $J/\Psi \to \gamma(\pi^+\pi^-\pi^+\pi^-)$ have been re-analyzed including $\sigma\sigma$ final states as well as $\rho\rho$. Here σ stands for the $\pi\pi$ S-wave amplitude. We find resonances with $I = 0$ $J^{PC} = 0^{++}$ at 1505 MeV, 2^{++} at 1770 ± 20 MeV and 0^{++} at 2100 MeV. The 0^{++} resonances decay dominantly to $\sigma\sigma$, and the 2^{++} resonance has a strong decay mode to $\sigma\sigma$ with $L = 2$. We discuss a spectrum for the seven lowest glueball states, consistent with dominant decays through η, η' and $q\bar{q}$ P-states σ and $f_2(1270)$.

© ПИЯФ, 1994

Fig.1 (a) reproduces the $\eta\eta$ spectrum observed [1] in the Fermilab E760 experiment on $\bar{p}p \to \pi^0\eta\eta$ at center of mass energies $\simeq 3.0$ GeV. It bears a striking resemblance to that observed in $J/\Psi \to \gamma(2\pi^+2\pi^-)$ in Mark III data [2], shown in Fig.1(b), and in DM2 data [3]. Previously, the J/Ψ data have been interpreted in term of $J^{PC} = 0^{-+}$ resonances decaying to $\rho\rho$ with $L = 1$. However, these quantum numbers are forbidden to $\eta\eta$.

The coincidence in Fig. 1 prompts us to re-analyze the Mark III data, adding the possibility of $\gamma\sigma\sigma$ final states, where σ stands for the $\pi\pi$ S-wave; this amplitude squared has a broad maximum close to the ρ. We find a considerably superior fit with 0^{++} resonances at 1505 and 2100 MeV and a 2^{++} resonance at 1770 MeV. All show strong decays to $\sigma\sigma$. It is widely recognised that radiative J/Ψ decays are a likely source of mesons with large admixtures of glueball states. This leads us to speculations about a possible glueball spectrum and favoured decay modes.

We first discuss the fit to Mark III data. We find a satisfactory fit with resonances decaying to $\sigma\sigma$ and $\rho\rho$; $\sigma f_2(1270)$ has been tried, but is not needed. The ρ is described by a Breit-Wigner amplitude with a centrifugal barrier of radius 0.68 fm. The parametrization of the σ amplitude is given in equns. (23)-(28) of Anisovich et al. [5]; it fits $\pi\pi \to \pi\pi$ and $\pi\pi \to K\bar{K}$ data accurately up to 1.3 GeV with a broad enhancement near 0.8 GeV and a two-pole structure at the $K\bar{K}$ threshold.

The Mark III data are fitted to $J/\Psi \to \gamma X$ with X having $J^P = 0^+$, 0^- or 2^+. We have tried in addition 4^+, 2^- and 1^+ but find negligible contributions, as in the earlier analyses [2,3]. Amplitudes are written in terms of relativistic tensor expressions. These are lengthy but straightforward, and will be given in full in a more detailed paper. Couplings of resonances to J/Ψ and photon are given in Table 1, and also the decay channels. For a single resonance $X \to \sigma\sigma$, all 2^+ amplitudes take the same phase; likewise all $X \to \rho\rho$ amplitudes have a separate common phase. The amplitudes are symmetrised in terms of identical particles and include centrifugal barriers where necessary, with radius 0.68 fm.

We now discuss separately the mass ranges (a) 1300–1650 MeV, (b) 1650–1900 MeV, and (c) 1900–2350 MeV, though they are all fitted with a single set of amplitudes. The fit is made by optimizing $S = \log$ likelihood. The resonances fitted to the data are summarized in Table 2. In the first mass range, the extreme low energy region down to threshold requires an

$f_0(1335) \to \sigma\sigma$ contribution. Next, a strong $0^- \to \rho\rho$ component is required from 1400 to 1750 MeV. It accounts for 40% of the cross section integrated up to 2350 MeV. It is suppressed close to the $\rho\rho$ threshold by the $L = 1$ centrifugal barrier. The resonance mass optimises strongly in the region of 1440 MeV, as shown in Fig. 2(d). The width of the resonance we fit is 105 MeV, rather larger than that of $\iota(1440)$, possibly because of the opening of the decay channel to $\rho\rho$.

However the $\iota(1440)$ and $f_0(1335)$ amplitudes alone do not describe the region 1300 1650 MeV. Adding a further 0^+ resonance at 1505 MeV improves S by 60. It is our experience elsewhere that a change of 20 in S needs to be taken seriously and 40 is definitive. The fitted resonance gives an optimum at 1490 MeV, as shown in Fig. 2(c). This is close to where the Crystal Barrel group finds a 0^+ resonance [4,5], so we confirm the 0^+ assignment. Its presence in J/Ψ radiative decays, the traditional hunting ground for glueballs, strengthens the case for a glueball interpretation. We have tried 2^+ for the 1505 MeV peak, but this gives a poorer fit despite the large number of possible amplitudes in Table 1. Some 2^+ amplitude is required in this region, but is well described by the tail of $f_2(1770)$.

In region (b), 2^+ gives a distinct optimum at 1770 ± 20 MeV, Fig.2(b), but 0^- and 0^+ do not. Also 0^- gives S worse by 58 and 0^+ worse by 42. Some 0^- and 0^+ contributions are needed in this mass range, but are adequately fitted by the tails of $\iota(1440)$, $f_0(1335)$, $f_0(1505)$ and $f_0(2100)$. We have tried adding $\theta(1710)$ with $J^P = 0^+$, but this does not significantly improve the fit. We find a width for $f_2(1770)$ of 150 ± 40 MeV, rather narrower than the 264 ± 25 MeV quoted by E760 [1]. However, their peak rides on a large background, to which the width determination may be sensitive.

In region (c), the 0^+ identification is definite. It gives a strong optimum in Fig.2(a); 0^- gives no such optimum and S is worse by 58, while 2^+ gives a weak optimum near 2200 MeV, but a value of S worse by 42 despite the large number of possible amplitudes. GAMS have observed a 2^+ resonance in $\eta\eta$ at 2175 MeV [6]. When we add this to $f_0(2100)$, S improves by 25. It is suggestive of the presence of this resonance, but not quite definitive.

In the high mass range, there is a minor technicality. We are fitting with resonances up to 2100 MeV. At yet higher masses > 2350 MeV, there is a broad peak in the mass spectrum. We accommodate it by an incoherent phase space contribution to the cross section, weighted by a Breit-Wigner

shape with $M = 2700$ MeV, $\Gamma = 400$ MeV. Without the tail of this contribution, fits to the mass spectrum from 2100 to 2350 MeV are distorted in shape, but the assignment of J^P is not affected.

Our final fit to the mass spectrum is shown by the histogram on Fig.1(b). Masses and widths of $f_0(1505)$ and $f_0(2100)$ are fixed to the more accurate values from refs. [5] and [1] respectively. Other distributions, integrated from 1300 to 2350 MeV are compared with the fit in Fig.3; Fig. 3(b) is sensitive to $\rho - \sigma$ interference in $\pi^+\pi^-$. Fits to individual mass ranges (a), (b) and (c) are just as good as in Fig. 3.

We now compare with earlier data. Around 1770 MeV, there are two previous candidates for 2^+ resonant states. In particular, GAMS [7] claim a 2^+ resonance at 1810 MeV in 4π final states. Their peak sits on a strongly sloping background and emerges only after cuts to the production angle, so the 40 MeV mass difference from $f_2(1770)$ may not be significant. Secondly, GAMS observe a narrow $\eta\eta$ resonance at 1744 ± 15 MeV [8], but do not determine J^P. It seems likely this can be identified with the peak in E760 data and $f_2(1770)$. Interference with background amplitudes can easily shift mass peaks by 25 MeV.

We now come to a possible interpretation of the results. The strong $J^{PC} = 0^{++}$ resonance at 2100 MeV is very striking; it seems far too strong to be a second radial excitation of $f_0(1335)$. Some new spectroscopy is required. Likewise, $f_0(1505)$ does not fit naturally into the $q\bar{q}$ $^3P_0$ nonet. It is too heavy compared with $^3P_1$, $^3P_2$ and $^1P_1$ nonets; and the $^3P_0$ nonet is already completed by $f_0(1335)$ [4,5], $a_0(1450)$ [9] and $G(1590)$, now identified by the Crystal Barrel group in $K\bar{K}$ final states[10].

Gerstein et al. [11] have argued that glueballs decay to $\eta\eta$ and $\eta\eta'$. We collect into Fig. 4 other known resonances with these decays. The 2^{++} resonance at 2175 MeV is observed in $\eta\eta$ [6] and could be the same state as seen at 2220 MeV in $\eta\eta'$[12]. GAMS [13] also report a resonance at 1910 MeV decaying to $\eta\eta'$ but not $\eta\eta$; they suggest $J^{PC} = 1^{-+}$, though this needs confirmation. There is a new 2^{-+} candidate. Cooper [14], analyzing Crystal Barrel data on $\bar{p}p \to \eta\pi^0\pi^0\pi^0$, has recently reported two $I = 0$ $J^{PC} = 2^{-+}$ states at 1650 MeV in $A_2(1320)\pi$ and a second at 1850 MeV decaying purely to $f_2(1270)\eta$. We select the latter as a glueball candidate because of its decay mode. Mark III data on $J\psi \to \gamma(\eta\pi\pi)$ [15] also show a peak at 1850 MeV, though no J^P analysis has yet been done.

There is a close similarity between Fig. 4 and the spectrum proposed for glueballs in a simple cavity model by Jaffe and Johnston [16], but the energy is shifted up by $\simeq 550$ MeV. They do not consider spin splitting. In their scheme the $(TE1)(TM1)$ states lie at the centre of gravity of $(TE1)^2$ and $(TM1)^2$. For states in Fig. 4 this predicts 1890 MeV, remarkably close to the 2^{-+} and possible 1^{-+} states. However $\iota(1440)$ lies much lower in mass, possibly because of strong mixing with η and η'.

The strong decays into σ and $f_2(1270)$ are striking. They are both $q\bar{q}$ states with $L = 1$. Isgur and Paton [17] suggest that hybrids decay to one $q\bar{q}$ state with $L = 0$ and a second with $L = 1$, because one unit of orbital angular momentum parallel to the $q\bar{q}$ axis is carried by the gluonic string. It is tempting to extrapolate this idea to glueballs, though it does not follow directly from the algebra of the present flux-tube model. It would explain the strong decays to σ and $f_2(1270)$ for states in Fig. 4.

There is a second important consequence. A naive expectation for glueballs is flavour-blindness, hence strong $K\bar{K}$ modes. However, if decays to $q\bar{q}$ P-states are preferred, the heavy $K_0^*(1430)$ would inhibit $s\bar{s}$ decays, which would then proceed through the $s\bar{s}$ components of η and η' rather than through $K\bar{K}$ or $K\bar{K}^*$.

The strong decays into $\sigma\sigma$ could also be associated with the $^3P_0$ model for $\bar{q}q$ production in the QCD strong coupling limit [17].

We thank the Mark III group for generously making their data available. VVA and AVS thank the Royal Society for financial support in two visits to QMWC.

$J^P(X)$	Production Amplitudes	Decay Channels
0^+	${}^1S_0$	$[\sigma\sigma]_{L=0}, [\rho\rho]_{L=0}$
0^-	${}^3P_0$	$[\rho\rho]_{L=1}$
2^+	${}^5S_2$, ${}^5D_2$, ${}^3D_2$, ${}^1D_2$, ${}^5F_2$	$[\sigma\sigma]_{L=2}, [\rho\rho]_{L=0}$

Table 1: Amplitudes included in the fit. The notation is ${}^{2S+1}L_J$, where S is the combined spin of J/Ψ and γ, L is the orbital angular momentum of the photon and J is the spin of X.

J^P	Mass (MeV)	Γ (MeV)	Decays
0^-	1440	105	$\rho\rho$
0^+	1335	280	$\sigma\sigma$
0^+	1505	148	$\sigma\sigma(92\%)$, $\rho\rho(8\%)$
2^+	1770	150	$\sigma\sigma(30\%)$, $\rho\rho(70\%)$
0^+	2104	200	$\sigma\sigma(88\%)$, $\rho\rho(12\%)$

Table 2: Resonances fitted to the Mark III data.

References

[1] T.A.Armstrong et al., Phys. Lett. B **307**, 399 (1993).

[2] R.M.Baltrasaitis et al., Phys. Rev. D **33**, 1222 (1986).

[3] D.Bisello et al., Phys. Rev. D **39**, 701 (1989).

[4] V.V.Anisovich, D.V.Bugg, A.V.Sarantsev and B.S.Zou, Phys. Rev. D **50** (1994).

[5] V.V.Anisovich et al., Phys. Lett. B **323**, 233 (1994).

[6] Yu.D.Prokoshkin, Hadron 89, ed. F. Binon, J.-M. Frère and J.-P. Peigneux. (Editions Frontières, 1989), p27.

[7] D.Alde et al., Phys. Lett. B **201**, 160 (1988).

[8] D.Alde et al., Phys. Lett. B **284**, 457 (1992).

[9] C.Amsler et al., Phys. Lett B 333,277,(1994).

[10] C.Amsler, Proc. of the Glasgow Conference, 1994.

[11] S.S. Gerstein, A.K. Likhoded and Yu.D. Prokoshkin, Zeit. Phys. C **24**, 305 (1984).

[12] D. Alde et al., Phys. Lett. B **177**, 120 (1986).

[13] D.Alde et al., Yad. fiz. **54**, 751 (1991).

[14] A.R.Cooper, Ph.D thesis, University of London (1994).

[15] T.H.Burnett, BNL Workshop on Glueballs and Exotic Mesons, 1988.

[16] R.L.Jaffe and K.Johnson, Phys. Lett. **60B**, 201 (1976).

[17] N.Isgur and J.Paton, Phys. Rev. D **31**, 2910 (1985).

Figure Captions

Fig. 1. (a) The $\eta\eta$ mass spectrum from $\bar{p}p \rightarrow \eta\eta\pi^0$ at 3.0 GeV CM energy, ref. 1: (b) the 4π mass spectrum from Mark III data on $J/\Psi \rightarrow \gamma(4\pi)$, ref. 2; crosses are data points and the histogram our fit.

Fig. 2. Plots of S=log likelihood scanning the fitted masses of (a) $f_0(2100)$, (b) $f_2(1770)$, (c) $f_0(1505)$ and (d) $\eta(1440)$.

Fig. 3. Comparison with data summed from 1300 to 2350 MeV for (a) $\pi^+\pi^-$ mass, (b) $\pi^+\pi^+$ and $\pi^-\pi^-$ mass, (c) $\cos\theta$, where θ is the angle of π^+ with respect to the $\pi^+\pi^-$ pair in their rest frame (adding both combinations), (d) as (c) for $\pi^+\pi^+$ and $\pi^-\pi^-$ pairs, (e) the azimuthal angle ϕ between the planes of $\pi^+\pi^-$ pairs in the rest frame of X, (f) as (e) for $\pi^+\pi^+$ and $\pi^-\pi^-$ pairs. Crosses are data and histograms the fit. The vertical scale shows the number of events.

Fig. 4. A suggested spectrum for the lowest seven glueball states.

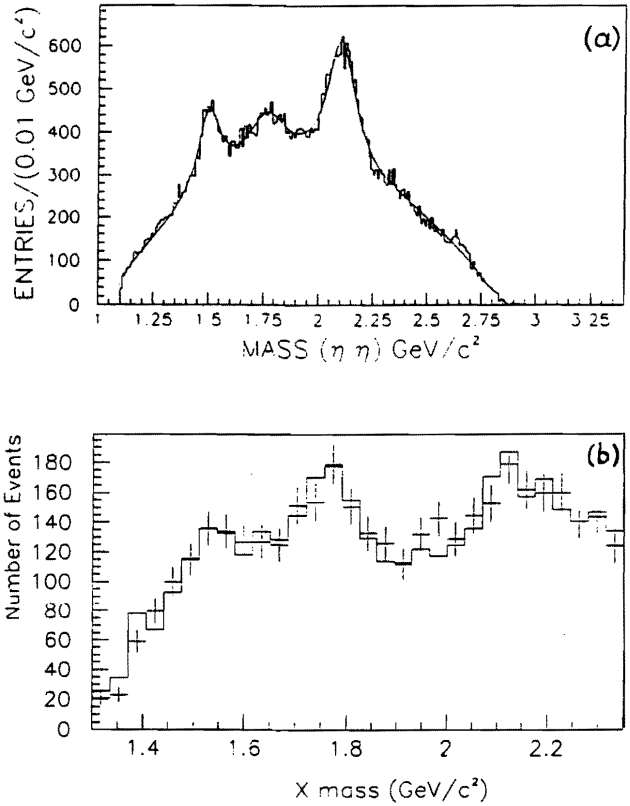
(a)
ENTRIES/(0.01 GeV/c²)
600
500
400
300
200
100
0
1
1.25
1.5
1.75
2
2.25
2.5
2.75
3
3.25
MASS (η η) GeV/c²
(b)
Number of Events
180
160
140
120
100
80
60
40
20
0
1.4
1.6
1.8
2
2.2
X mass (GeV/c²)

Fig. 1.

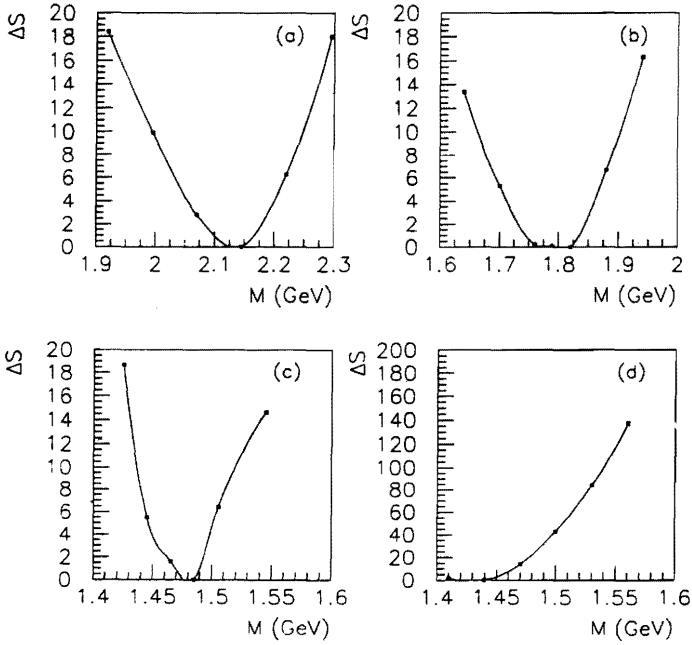

Fig. 2.

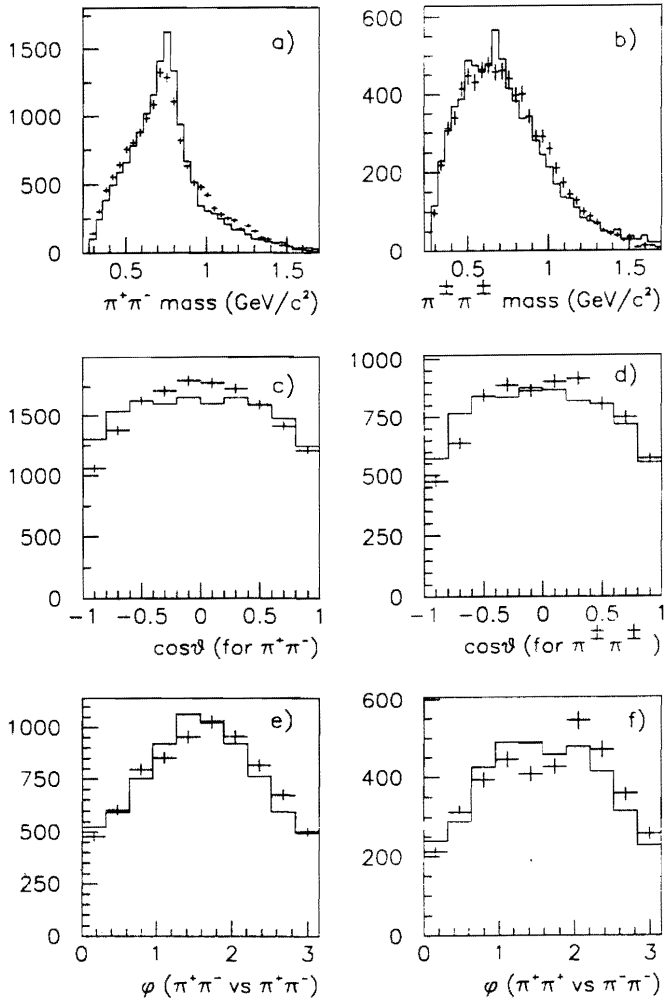
a)
b)
c)
d)
e)
f)
$\pi^+\pi^-$ mass (GeV/c²)
$\pi^\pm\pi^\pm$ mass (GeV/c²)
cosϑ (for $\pi^+\pi^-$)
cosϑ (for $\pi^\pm\pi^\pm$)
φ ($\pi^+\pi^-$ vs $\pi^+\pi^-$)
φ ($\pi^+\pi^+$ vs $\pi^-\pi^-$)

Fig. 3.

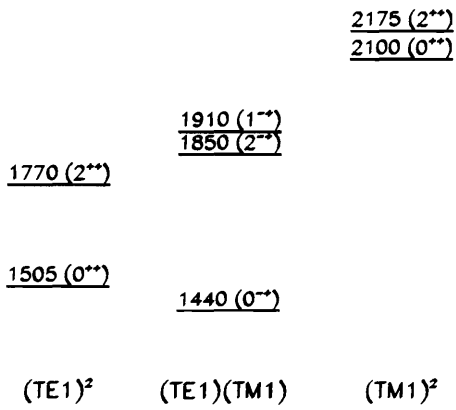

Fig. 4.

РТП ПИЯФ,зак.375,тир.120,уч.-изд.л.0,7; 26/УШ-1994 г.
Ответственный А.В.Саранцев
Бесплатно