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# ON THE NARROW DIP STRUCTURE AT 1.9 GeV/c$^2$ IN DIFFRACTIVE PHOTOPRODUCTION

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## Abstract

The narrow dip observed at 1.9 GeV/c$^2$ by the Fermilab experiment E687 in diffractive photoproduction of $3\pi^+3\pi^-$ is examined. The E687 data are refitted, a mechanism is proposed to explain why this resonance appears as a dip, and possible interpretations are discussed.

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## 1 Introduction.

The E687 experiment at Fermilab has observed [1] a narrow dip at M = $1.911 \pm 0.004 \pm 0.001$ GeV/c $^2$ and with a width $\Gamma$ = 29 $\pm$ 11 $\pm$ 4 MeV/c$^2$ in $3\pi^+3\pi^-$ diffractive photoproduction. If interpreted as a resonance, it has J$^{PC} = 1^{--}$ quantum numbers, G=+1 because of the six-pion final state and consequently I=1. The structure found by E687 recalls what was observed with lower statistical significance by the DM2 collaboration [2] [3], in the channels $e^+e^- \rightarrow 3\pi^+3\pi^-$ and $e^+e^- \rightarrow 2\pi^+2\pi^-2\pi^0$. BABAR is investigating the same channels by means of initial state radiation with better statistical significance than DM2, thanks to the very high integrated luminosity provided by PEP-II.

In this paper we refit the E687 data and discuss the extent to which this new resonance interferes with known vector resonances. We propose a mechanism, pointed out for somewhat similar circumstances [4], to explain why this resonance appears as a dip and examine some possible interpretations.

## 2 Fitting procedure and resonance parameters

It is difficult to obtain spin and parity of a six-pion final state. Supported by the E687 diffraction photoproduction data, we assume that in the selected experimental conditions the incident photon energy is high enough and the momentum transfer to the target small enough to fulfill naive diffractive photoproduction expectations, namely:

1. photon quantum numbers are transferred to the produced hadronic mass M;

2. Vector Meson Dominance [5] holds, i.e., diffractive photoproduction cross section and e$^+$e$^-$ annihilation at a c.m. energy M are related, for a given final state of mass M, as follows:

$$\sigma^{diff}_{\gamma N \rightarrow VN} \propto \Gamma^{ee}_V \cdot \sigma_{VN \rightarrow VN} \tag{1}$$

   where

$$\Gamma^{ee}_V \sim \frac{1}{3\pi^2} \cdot \int dM \cdot M^2 \sigma_{e^+e^- \rightarrow V}(M) \tag{2}$$

Consistent with this assumption, we expect the vector meson elastic cross section $\sigma_{VN \rightarrow VN}$ to vary very slowly as a function of M, depending on the V valence quark flavors. At the E687 photon-beam energies, corrections due to the variation with M of the target form factor (diffractive $t$-slope) are expected to be very small, since $t_{min} \sim \frac{M^4}{(2E_\gamma)^2} \sim 2 \cdot 10^{-4}\ GeV^2$, to be compared to the diffractive slopes $\sim 2 \cdot 10^{-2}\ GeV^2$. Provided the aforementioned assumptions are valid for a superposition of vector mesons with the same valence quarks as in the case of an isovector final state, by differentiating Eq. 1 and dropping V we expect the following:

$$\frac{1}{M^2} \cdot \frac{d\sigma_{diff}}{dM}_{\gamma N \rightarrow 6\pi N}(M) \propto \sigma_{e^+e^- \rightarrow 6\pi}(M). \tag{3}$$

Therefore, the diffractive photoproduction mass spectrum as a function of M, once weighted by a factor $1/M^2$, can be directly compared to e$^+$e$^-$ annihilation at the c.m. energy M. The fair agreement between

$e^+e^- \to 2\pi^+2\pi^-$ [6] and the weighted diffractive photoproduction of $2\pi^+2\pi^-$ [7] supports this relationship. A better agreement would be obtained at high invariant masses assuming a mild dependence on M of the aforementioned factors. In the following diffractive photoproduction data is considered weighted by the $1/M^2$ factor to facilitate comparison with $e^+e^-$ annihilation data.

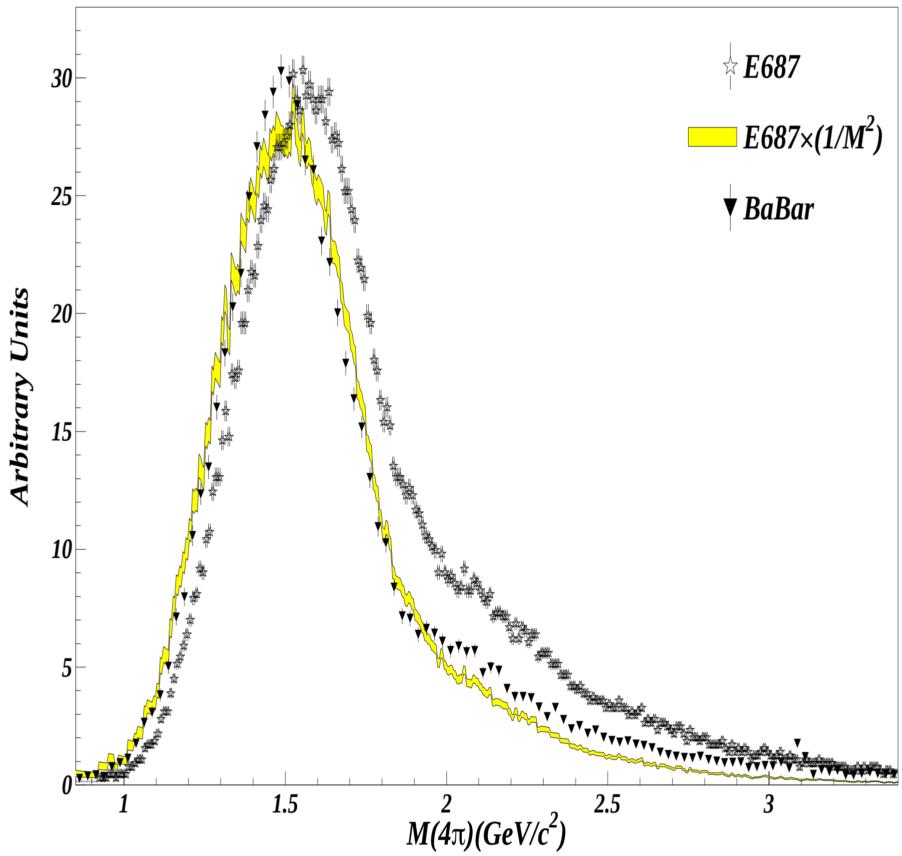


Figure 1: BaBar and E687 $2\pi^+2\pi^-$ invariant mass distributions. The E687 acceptance corrected yields (band) have been normalized to the BaBar cross-sections via Eq. 3.

Data in [1] have been fitted by considering a narrow resonance $V_0$ and a Jacob-Slansky continuum [8]. In the Jacob-Slansky (J-S) model the diffractive continuum is represented by an amalgamation of broad resonances, which may interfere with the narrow resonance $V_0$:

$$F_{JS}(M) = f_{JS}^2(M) = c_0 + c_1 \frac{e^{\frac{-\beta}{M-M_0}}}{(M-M_0)^{2-\alpha}}.$$

In this paper we extract from the continuum another resonance in addition to the $V_0$ narrow resonance. We then perform a fit of the $1/M^2$ weighted data with two BW-resonances plus a function $f_{JS}(M)$, representing the background. This fit function, made of two resonances $V_{0,1}$ and a background contribution

$f_{JS}(M)$, describes the invariant mass distribution in the whole accepted mass range $1.5 \div 3.2\ GeV$ with $\chi^2/dof = 1.06$, in the selected mass range $1.65 \div 2.4\ GeV$ with $\chi^2/dof = 0.80$ as shown in Fig. 2, and the resulting shape is similar to the one in [1]. The fit parameters are reported in Tab. 1. The masses and widths of $V_{0,1}$ are consistent with the narrow resonance in [1], i.e., $M_0 = 1.910 \pm 0.010\ GeV$ and width $\Gamma_0 = 37 \pm 13\ GeV$, and with the known vector recurrence $\rho(1700)$, quoted in the PDB [9]. Phases and partial widths are also reported in Tab. 1. Partial widths are given in arbitrary units and only their relative ratio is meaningful. This is due to the fact that the E687 data are presented as (efficiency corrected) yield, and not as a cross section.

The function $F_{JS}(M)$ not only models the slowly rising continuum, which includes all the vector mesons resonances, but also any non-interfering incoherent background that might remain after statistically subtracting from the $3\pi^+3\pi^-$ invariant mass distribution. The level of the incoherent background is relatively high, about 30%. However, it is difficult to estimate the magnitude of what remains after subtraction. According to the relative phases there is a large interference of $F_{JS}$ with $V_1$, which confirms that the residual incoherent background contribution is not important.

We also checked the effect of replacing the $f_{JS}(M)$ amplitude with a broad $V_2$ Breit-Wigner amplitude, fit results with three Breit-Wigner, shown in Tab. 2, are consistent with the previous values of $V_0$ and $V_1$, in particular $M_0 = 1.910 \pm 0.010\ GeV$ and $\Gamma_0 = 33 \pm 13\ GeV$.

| Resonances | Mass (GeV/c$^2$) | Width (MeV/c$^2$) | $B_{ee}B_{3\pi^+3\pi^-}/M^2$ (Yield/10 MeV) | Phase (deg.) |
|---|---|---|---|---|
| $V_0$ | $1.910 \pm 0.010$ | $37 \pm 13$ | $5 \pm 1$ | $10 \pm 30$ |
| $V_1$ | $1.730 \pm 0.034$ | $315 \pm 100$ | $17 \pm 3$ | $140 \pm 10$ |

| Background | $c_0$ $(GeV^{-1})$ | $c_1$ $(GeV^{1-\alpha})$ | $M_0$ $(GeV)$ | $\alpha$ | $\beta$ $(GeV)$ | Phase (deg.) |
|---|---|---|---|---|---|---|
| $F_{JS}$ | $84 \pm 55$ | $900 \pm 400$ | $1.65 \pm 0.05$ | 0 | $1.4 \pm 0.2$ | 0 (fixed) |

Table 1: Fit results with two Breit-Wigner and one Jacob-Slansky amplitudes.

| Resonances | Mass (GeV/c$^2$) | Width (MeV/c$^2$) | $B_{ee}B_{3\pi^+3\pi^-}/M^2$ (Yield/10 MeV) | Phase (deg.) |
|---|---|---|---|---|
| $V_0$ | $1.910 \pm 0.010$ | $33 \pm 13$ | $5 \pm 2$ | $84 \pm 30$ |
| $V_1$ | $1.650 \pm 0.050$ | $240 \pm 80$ | $21 \pm 4$ | $150 \pm 30$ |
| Background | Mass (GeV/c$^2$) | Width (MeV/c$^2$) | $B_{ee}B_{3\pi^+3\pi^-}/M^2$ (Yield/10 MeV) | Phase (deg.) |
| BW | $2.250 \pm 0.030$ | $830 \pm 150$ | $24 \pm 1$ | 0 (fixed) |

Table 2: Fit results with three Breit-Wigner amplitudes.

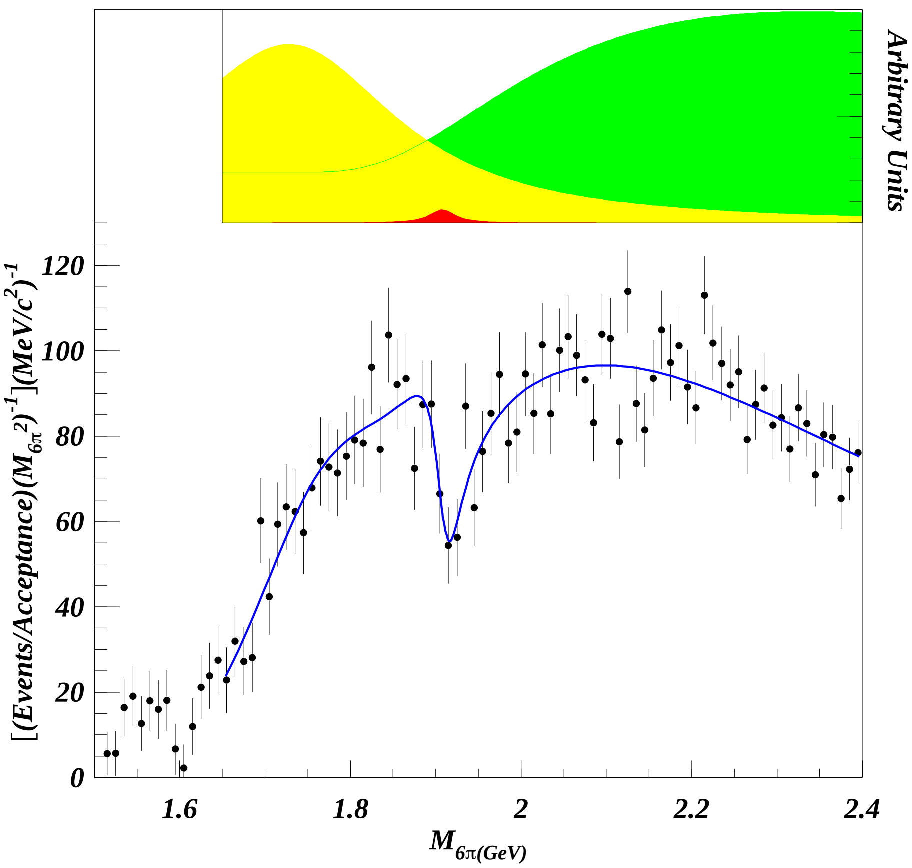


Figure 2: E687 $3\pi^+3\pi^-$ invariant mass distribution. Continuous line: fit with two resonances and Jacob-Slansky continuum (parameters in Tab. 1). Inset: relative fraction of each amplitude without interference.

## 3 Discussion and possible interpretations

The narrow resonance $V_0$ pointed out by E687 has a small width and a small production cross section, i.e., a small $e^+e^-$ partial width with respect to the broad prominent $\rho(1700)$ resonance. In this situation a simple mixing mechanism can explain the dip structure independently of the nature of $V_0$. In the extreme limit of full mixing, with the assumption that $V_0$ cannot couple directly to the six-pion final state, the corresponding amplitude, as shown in (Fig. 3), must include the propagator of a broad vector meson, say $V_1$, added to the $V_0$ propagator times the coupling constant $a$ between $V_1$ and $V_0$, possibly repeated:

$$\begin{aligned} A &\propto \frac{1}{M^2-M_1^2}(1+a\frac{1}{M^2-M_0^2}a\frac{1}{M^2-M_1^2}+ \\ &\quad +a\frac{1}{M^2-M_0^2}a\frac{1}{M^2-M_1^2}a\frac{1}{M^2-M_0^2}a\frac{1}{M^2-M_1^2}+\mathcal{O}(a^6)) \\ &\propto \frac{M^2-M_0^2}{(M^2-M_1^2)(M^2-M_0^2)-a^2}. \end{aligned} \tag{4}$$

Here the six-pion invariant mass squared is $M^2$, the complex number $M$ stands for mass and width of any $\rho$ recurrence $V_1$ nearby, $M_0$ is the complex mass for the narrow resonance $V_0$. This amplitude, with a zero at the unmixed $V_0$ mass pole $M_0$ in the limit of negligible unmixed width, will produce a narrow dip at $\sqrt{(s)} \sim M_0$ in the cross section, which is consistent with what has been observed in the E687 analysis. This phenomenon was originally introduced at the time the toponium was expected on top of the $Z^0$ [4].

It should be noted that the observation of $V_0$ strongly depends on the interference mechanism. Fig. 2 reports in the inset what could be expected if $V_0$ did not interfere with another broad resonance. If this were the case, there would be no hope of detecting this resonance. Therefore also in other channels the evidence strongly depends on the interference pattern, unless dynamical reasons make the coupling of $V_0$ to that specific channel very strong.

We now discuss a physical interpretation of $V_0$. This resonance cannot be interpreted as a glueball, a bound state of valence gluons, because a glueball is expected to be an isoscalar. Incidentally all the present lattice calculations, in the quenched approximation, agree in predicting the lightest isoscalar vector glueball at $\sim 4\,GeV$.

This structure could be interpreted as multiquark or molecular state(s). These states should be narrow and clustered near the constituent total mass, even if calculations have shown that they should not exist as resonances [10], with some possible remarkable exception [11]. A particular case of multiquark states is represented by $N\overline{N}$ bound states and resonances, which should cluster at the $N\overline{N}$ threshold and $V_0$ is nearby. Therefore a $N\overline{N}$ resonance has to be considered and there is evidence of bumps in the $V_0$ mass region [12]. Recently new results from BES seem to indicate the presence of a structure in this energy region [13]. However, OBELIX has looked for such a resonance in $\overline{n}p \to 3\pi^+2\pi^-\pi^0$ with a negative result [14], so this interpretation is unlikely, taking into account that the $N\overline{N}$ channel should be strongly coupled according to this interpretation. The possibility of having the narrow resonance out of the OBELIX narrow kinematical region of invariant masses, because of small mass shifts between experiments, should also be

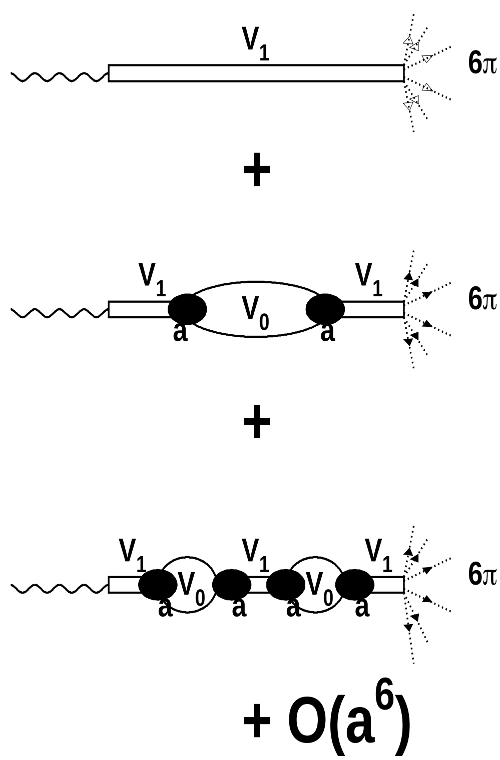


Figure 3: Diagram describing the $e^+e^-$ annihilation via a $V_0, V_1$ interference term contribution.

kept in mind.

On the other hand, similar dips and narrow structures in other $e^+e^-$ annihilation channels have been observed in this energy region and the old argument supporting the existence of $N\overline{N}$ bound states and resonances near threshold is still very compelling [15][16][17][18][19]. In the case of vector $N\overline{N}$ states, annihilation into $e^+e^-$ may cross the threshold. Such bound states and resonances would appear as a steep variation in the nucleon time-like form factors near threshold [20] and a dip in the multihadronic cross section [21]. Indeed, a steep variation in the nucleon time-like form factors and also a dip in the total $e^+e^-$ multihadronic cross section have been observed, in agreement with a narrow resonance at $\sim 1.87\ GeV$, just below the $N\overline{N}$ threshold [22]. However this baryonium candidate is hardly consistent with the E687 dip because of the $\sim 30\ MeV$ mass difference. A cusp effect connected with the crossing of an unidentified threshold [23] could give rise to a steep downward step, followed however by a slow rise, if any at all.

The $V_0$ could plausibly be interpreted as a hybrid, i.e. a $q\bar{q}g$ bound state. Many theoretical approaches predict the existence of hybrid states [24]. In the framework of the flux tube model [25][26], the hybrid new degree of freedom is identified in the excitation of the color flux tube connecting the valence quarks. The flux tube model predicts nonstrange hybrids at $\sim 1.9\ GeV/c^2$ and strange hybrids at $M \sim 2.1\ GeV/c^2$. A similar prediction has been obtained by lattice calculations [27][28][29]. Small, but not vanishing, e.m. widths characterize hybrids, since the gluon does not couple to the photon. The way the string breaks forbids decay into two identical mesons and imposes spin and parity of the decay products [30]. Because of these selection rules in two-body decay, high multiplicity channels should be preferred and a relatively small width foreseen. Narrow hybrids are predicted, in particular a vector isoscalar hybrid, a few MeV wide, still at $\sim 1.9\ GeV$ [30].

On the other hand, it is not unanimously agreed that valence gluons exist at all. In the $1/N_{color}$ expansion there is no suppression of gluon creation and it has been claimed there is no reason to expect valence gluons [31]. It has also been argued that in classical field theory, pure gauge bound states are not likely to exist: in fact, in analogy with electric charges, internal directions somewhere become antiparallel, whereas continuity requires close fields pointing in the same direction [32]. On the contrary, valence gluons are naturally foreseen if confinement is properly described by the bag model [31].

Diffractive photoproduction was recently pointed out as a powerful tool to search for hybrids [33]. Future searches both at high and low energy should particularly address both the confirmation of the E687 effect as well as the search for the $1^{--}$ isoscalar partner of the E687 state, i.e. any effect in the invariant mass distribution of an odd-number of pions.

## 4 Conclusions

We have investigated the nature of the dip structure observed by E687 in diffractive photoproduction. A coherent fit of two BW resonances plus an $F_{JS}(M)$ amplitude of the E687 data is consistent with a narrow resonance strongly interfering with known vector mesons, such as $\rho(1700)$. We have pointed out that in this scenario such a resonance has to appear as a dip in the mass spectrum. An interpretation of the $V_0$ as a $1^{--}$, isovector hybrid is in agreement with expected mass, width, and decay mode. A $N\overline{N}$ resonance is unlikely according to OBELIX, which has looked for such a resonance in $\overline{n}p \rightarrow 3\pi^+2\pi^-\pi^0$ with a negative result.

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