NARROW STRUCTURES IN HIGH STATISTICS DIFFRACTIVE PHOTOPRODUCTION *

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Abstract

The narrow dip structure, observed by the Fermilab experiment E687 in diffractive photoproduction of $3\pi^+3\pi^-$, is studied by means of a new fit function. This new fit describes this narrow structure as strongly interfering with a broad resonance, which is compatible with the well known meson $\rho(1700)$. A simple mixing mechanism is proposed to explain why this resonance appears as a dip, and a possible interpretation, in terms of hybrid states, is discussed.
A new analysis of sub-structures in the $2\pi^+2\pi^-$ final state of the E687 diffractive photoproduction is performed by means of a procedure, successfully used to observe the $\rho - \omega$ interference, in the two pions final state.
A new measurement of these multi-pions final states with a statistics, at least, one order of magnitude bigger, such as the one foreseen for DAΦNE2, would confirm the existence of the dip, as a genuine resonance in the six-pions final state, and it would permit a clear identification of the sub-structures in the four-pions final state.

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 the $3\pi^+3\pi^-$ diffractive photoproduction. The quantum numbers of this structure, interpreted as a resonance, and then of the six charged pions final state, are $J^{PC} = 1^{--}$, $G = +1$, since it decays in an even number of pions, and consequently $I = 1$.
A similar structure has been observed by the DM2 collaboration [2], with a lower statistics, in the channels $e^+e^- \to 3\pi^+3\pi^-$ and $e^+e^- \to 2\pi^+2\pi^-2\pi^0$. BaBar is investigating these channels, in an annihilation process with initial state radiation.

FITTING STRATEGY

To obtain the quantum numbers of the six pions final state a connection between diffractive photoproduction and e^+e^- annihilation is established. In order to define this relation we assume that, if the energy of the photon is high and the momentum transfer to the target is small, the diffractive process follows the naive diffractive photoproduction expectations, that is:

- the produced hadronic mass M has exactly the quantum numbers of the photon;
- Vector Meson Dominance holds [3], then the production of the final state is mediated by the coupling of the photon to a vector meson V and the relation between the diffractive photoproduction cross section of this vector meson V, and its e^+e^- annihilation cross section is:

$$\sigma^{\rm diff}_{\gamma N \to VN} \propto \Gamma^{ee}_V \cdot \sigma_{VN \to VN}, \quad (1)$$

where

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

Since, consistent with our assumptions, the elastic cross section $\sigma_{VN\to VN}$ should vary slowly with M, by differentiating eq. 1 we have:

$$\frac{1}{M^2} \cdot \left.\frac{d\sigma_{\rm diff}}{dM}\right|_{\gamma N \to 6\pi N}(M) \propto \sigma_{e^+e^- \to 6\pi}(M). \quad (3)$$

The diffractive photoproduction cross section, as a function of M and weighted by a factor $1/M^2$ is proportional to the e^+e^- annihilation cross section at the center of mass energy M.

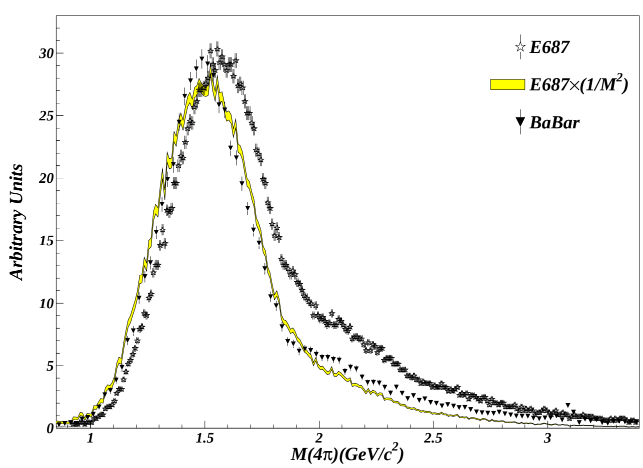

Figure 1: BaBar and E687 $2\pi^+2\pi^-$ invariant mass distribution. The band represents the E687 data normalized to the BaBar cross section via eq. 3.

This relationship is supported by the agreement between the annihilation cross section data of [4] and the diffractive photoproduction data of [5], weighted by the factor $1/M^2$, in the case of the $2\pi^+2\pi^-$ final state (fig. 1). The agreement, at high invariant mass of these two sets of data, can

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be improved by considering a mild dependence on M of the elastic cross section $\sigma_{VN\to VN}$, and then a weighting factor more complicated than $1/M^2$.
In the following we will use diffractive photoproduction data weighted by $1/M^2$, to have a direct connection with the e^+e^- annihilation data.
The data of the diffractive photoproduction of $3\pi^+3\pi^-$ have been already analysed in [1] by considering a narrow resonance V_0 and a Jacob-Slansky continuum [6]. The Jacob-Slansky (J-S) function

$$F_{JS}(M) = c_0 + c_1 \frac{e^{-\frac{\beta}{M-M_0}}}{(M-M_0)^{2-\alpha}} \quad (4)$$

is real and it describes the diffractive continuum as summation of broad resonances, which may interfere with the narrow V_0.
Since the mass of the dip is near by the mass of the meson $\rho(1700)$, to account the possible inteference between V_0 and this particle, we extract from the continuum another resonance. Then we perform a fit with a function which has three contributions: two Breit-Wigner (BW) resonances, the narrow V_0 and the broad V_1, and a real J-S function to describe the background (fig.2).

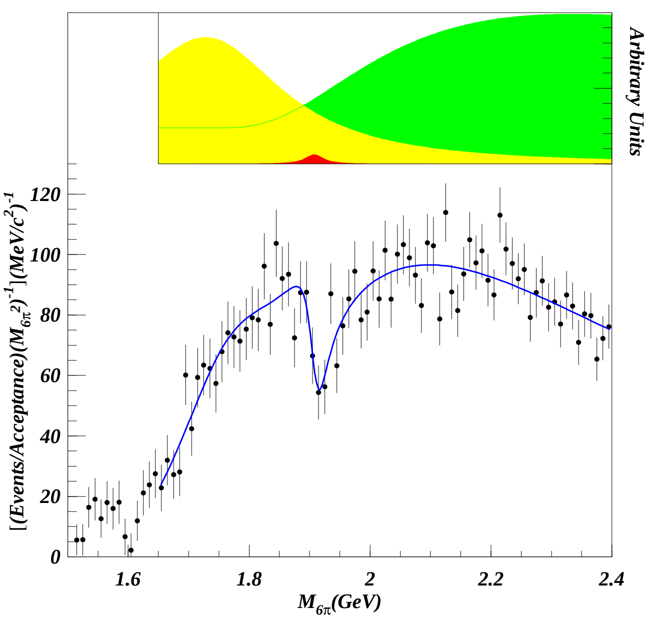

Figure 2: E687 $3\pi^+3\pi^-$ invariant mass distribution. Continuous line: fit with two resonances and a J-S continuum. Inset: relative contribution of each amplitude without interference.

This new fit function describes the invariant mass distribution in the whole data mass range $1.4 \div 3.2\ GeV$ with $\chi^2/dof = 1.06$ and, with $\chi^2/dof = 0.80$, in the selected mass range $1.65 \div 2.4\ GeV$. The fit parameters are reported in tab. 1 and tab. 2. The mass and the witdh of V_0 are consistent with the values found in [1]. The mass and width, obtained for the BW added to the fit function to describe a resonance V_1, are well compatible with those of the known vector recurrence $\rho(1700)$ [7].

Res.	Mass (MeV/c^2)	Width (MeV/c^2)	$\frac{B_{ee}B_{6\pi}}{M^2}$ $(\frac{\text{Yield}}{10MeV})$	Phase (deg.)
V_0	1910 ± 10	37 ± 13	5 ± 1	10 ± 30
V_1	1710 ± 34	315 ± 100	17 ± 3	140 ± 10

Table 1: Fit results of the two BW

c_0 (GeV^{-1})	c_1 $(GeV^{1-\alpha})$	M_0 (MeV)	α	β (GeV)
84 ± 55	900 ± 400	1650 ± 50	0	1.4 ± 0.2

Table 2: Fit results of the J-S function.

For detecting the V_0 resonance, it is crucial its interference with both the background and the broad resonance V_1. In fact if there were no interference, the amplitude of V_0 would be negligible with respect to the background (inset fig. 2).

THE MIXING MECHANISM

To understand the reason why the resonance V_0 appears as a dip in the diffractive photoproduction cross section, we consider a simple mixing mechanism, which describes the production of the six pions final state, as a process mediated by the two resonances V_0 and V_1. Because V_0 has a small e^+e^- partial width with respect to the broad resonance V_1, in the extreme limit of full mixing it cannot couple directly to the six pions.

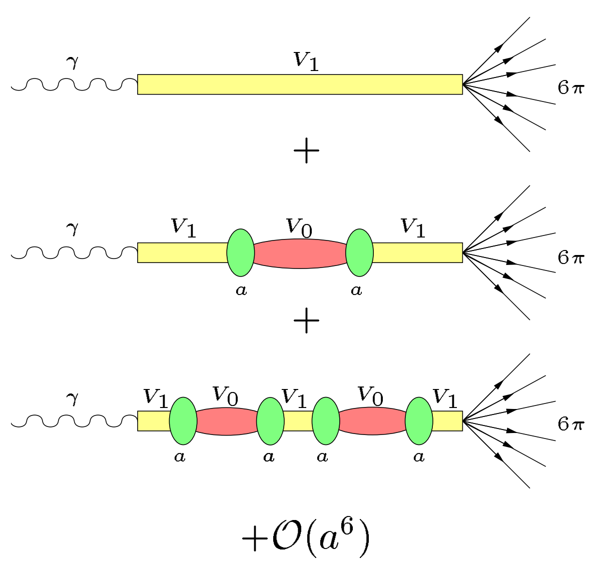

Figure 3: Diagram describing the coupling between the photon and the six pions final state via a V_0, V_2 interference terms contribution.

Then, as shown in fig. 3, the amplitude of the process

$\gamma \to [V_0, V_1] \to 3\pi^+3\pi^-$ can be written as:

$$A \propto \frac{1}{M^2 - M_1^2}\left(1 + a\frac{1}{M^2 - M_0^2}a\frac{1}{M^2 - M_1^2} + \right.$$
$$+ \ a\frac{1}{M^2 - M_0^2}a\frac{1}{M^2 - M_1^2}a\frac{1}{M^2 - M_0^2}a\frac{1}{M^2 - M_1^2} +$$
$$\left. + \ \mathcal{O}(a^6)\right) = \frac{M^2 - M_0^2}{(M^2 - M_1^2)(M^2 - M_0^2) - a^2} \qquad (5)$$

and it contains the propagators of the two vector mesons V_0 and V_1, and their coupling constant a. M_0 and M_1 represent the complex masses of the resonances. The amplitude in eq. 5 gives a cross section with a dip at $M \sim M_0$, independent on the nature of the vector meson V_0 and in agreement with the structure observed in the E687 data.

POSSIBLE INTERPRETATIONS

This resonance cannot be interpreted as a glueball, because such a state is expected to be an isoscalar. The most natural interpretation would be a multiquark or molecular state, which is clustered near the constituent total mass, and precisely the $N\overline{N}$ bound state, because it has a mass very similar to that found for V_0, $M_0 \sim 1.9\ GeV$. However, this possibility has been excluded by the result of the Obelix experiment [8], which has looked for this resonance in the process $\overline{n}p \to 3\pi^+2\pi^-\pi^0$, with a negative result.
Narrow resonances consistent with a $N\overline{N}$ bound state have been observed at $\sim 1.87\ GeV$, just below the $N\overline{N}$ threshold [9], but this baryonium candidate is hardly in agreement with the dip V_0, because of the $\sim 40\ MeV$ mass difference.
The narrow resonance V_0 could be interpreted as an hybrid $q\bar{q}g$ bound state. The existence of such a bound states is predicted in many theoretical approaches [10]. In the color flux tube model (FTM) [11], these new species of hadrons, called hybrids, have both quark and gluonic degrees of freedom in evidence. The FTM predicts nonstrange hybrids at $\sim 1.9\ GeV$ and strange hybrids at $\sim 2.1\ GeV$. Similar predictions have been obtained in lattice calculations [12].
Since the gluons do not couple directly to the photons, the hybrids are characterized by small, but not vanishing, electromagnetic widths. Moreover, the breaking mechanism of the color strings, connecting the valence quarks, forbids decay into two identical mesons and imposes spin and parity of the products [13].
These selection rules, concerning the two-body final states, should favor high multiplicity channels and relative small widths for the hybrid decays.

ANALYSIS OF SUB-STRUCTURES IN FOUR PIONS FINAL STATE

The high sensibility of the E687 experiment permits to detect clearly the $\rho-\omega$ interference in the $\pi^+\pi^-$ final state [5, 14].
The interference pattern is evident in the residual, fig. 4b, that is the difference between the E687 $\pi^+\pi^-$ final state data and the fit, performed with only one resonance, as shown in fig. 4a.
By adding in the fit function another interfering Breit-Wigner, to account the ω resonance, the interference pattern is correctly described. The fig. 4c shows the new residual once the $\rho-\omega$ interference has been considered.
The same procedure can be used in the case of the $2\pi^+2\pi^-$ final state.

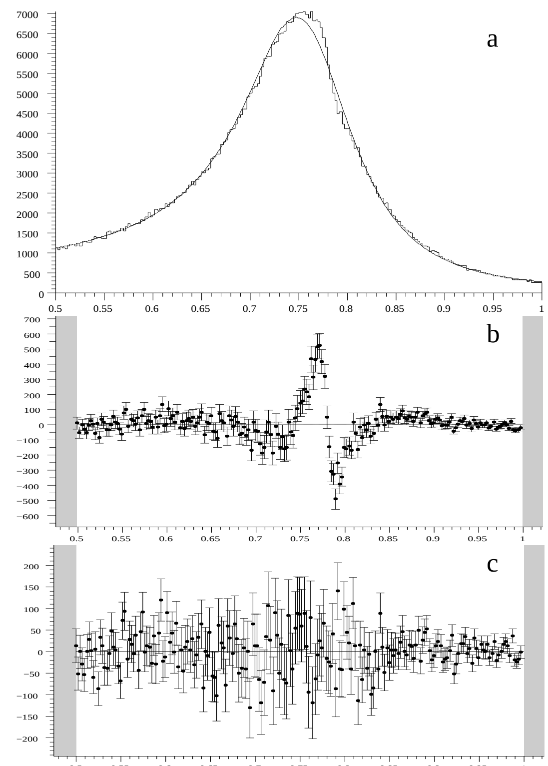

Figure 4: a) E687 $\pi^+\pi^-$ invariant mass distribution. Continuous line: fit with one resonance (ρ). b) Residual (fit-data). c) Residual once added the ω resonance.

In fact, even in this case, the fit (fig. 5a) performed by using a sum of three interfering broad resonances, does not describe the fluctuating behavior of the data, as shown in the residual (fig. 5b).

This oscillating behavior can be interpreted as a pattern of interference among the broad leading resonances and some other sub-structures, which, since the effect is of $\sim 5\%$, must have small e.m. widths.
To determine the parameters of these possible sub-structures we perform a fit of the residual (fig. 6).

We find at least five interfering structures (tab. 3), but to have a clear identification of this resonances, we need much more precise data.
However, is under study a new fit based on the formalism of the K-matrix, which is the most suitable tool to handle a set of near and interfering resonances.

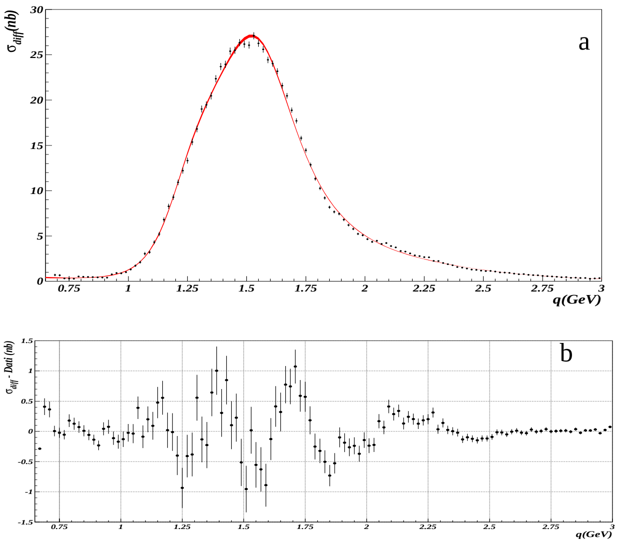

Figure 5: a) E687 $2\pi^+2\pi^-$ invariant mass distribution. Continuous line: fit with three broad resonances. b) Residual (fit-data).

Res.	$\Gamma_{ee}B_{4\pi}$ (eV/c^2)	Mass (MeV/c^2)	Width (MeV/c^2)	Phase (deg.)
V_1	40 ± 20	1209 ± 6	218 ± 16	147 ± 2
V_2	50 ± 20	1465 ± 8	265 ± 23	244 ± 5
V_3	1.1 ± 0.6	1820 ± 25	100 ± 30	40 ± 35
V_4	3 ± 2	2030 ± 20	170 ± 80	150 ± 20
V_5	1.3 ± 0.7	2460 ± 24	190 ± 60	140 ± 20

Table 3: Fit results of the residual in fig. 5b.

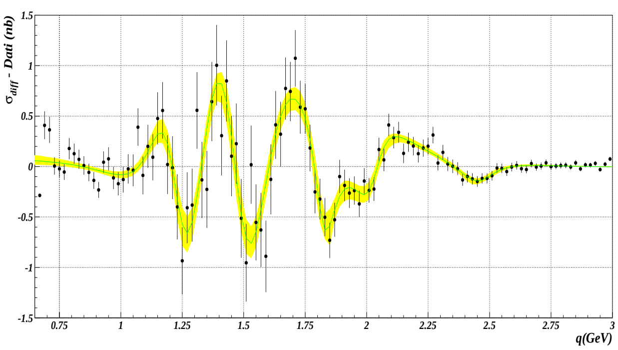

Figure 6: Fit of the residual of the $2\pi^+2\pi^-$ E687 data.

CONCLUSION

We have investigated the nature of the dip, found by the E687 experiment in diffractive photoproduction, by performing a fit with a new function. The nature of the dip appears consistent with a narrow resonance, strongly interfering with the vector meson $\rho(1700)$.
The interpretation as $N\overline{N}$ bound state is unlikely according to the negative result of the Obelix experiment. An interpretation of V_0 as an $J^{PC} = 1^{--}$, isovector hybrid, is consistent with the expected mass, width and decay mode.

An analysis of the E687 $2\pi^+2\pi^-$ final state data has been performed. The difference between the data and a first fit with three broad Breit-Wigner's, shows a complex interfering pattern. By fitting directly this pattern we found five sub-structures, weakly coupled to the photon. But the interpretation of these structures in terms of resonances needs much more precise data.
As already said, a new measurement of the cross-section of the process $e^+e^- \rightarrow 2\pi^+2\pi^-$, in the energy region $1 \div 2\ GeV$, feasible in the "high-energy" DAΦNE2, would give a value of $\sigma(e^+e^- \rightarrow 2\pi^+2\pi^-)$ one order of magnitude more precise than this, and then the secrets of this rich energy region could be revealed.

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