Study of $X(1600)$ $J^{PC} = 1^{-+}$ hybrid

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Abstract

Preliminary results of a study of an exotic $J^{PC} = 1^{-+}$ state with the VES experiment are presented. The 1^{-+} partial wave exhibits a structure at $\sim 1.6\,GeV/c^2$ in the $\eta'\pi^-$, $\omega\pi^0\pi^-$ and $\pi^+\pi^-\pi^-$ systems. The wave suppression in the $\eta\pi^-$ system w.r.t. the $\eta'\pi^-$ favours the hybrid interpretation of the signal. A mass dependent fit favours its resonant behaviour with Breit-Wigner parameters $M \approx 1.6\,GeV/c^2$ and $\Gamma \approx 0.3\,GeV/c^2$.

1. The 1^{-+} wave in the $\eta'\pi^-$ system

The wave notation used in the case of two spinless particles system is $J^P M^\eta$, where M is a projectional number of spin J w.r.t. the z-axis, in our case in the Gottfried-Jackson frame, and η designates "reflectivity" which for $M = 0$ corresponds to an exchange "naturality".

The spin-parity is determined by an orbital momentum L between two mesons. The P - state of two pseudoscalar particles has exotic $q\bar{q}$ inaccessible $J^{PC} = 1^{-+}$ numbers. The Partial Wave Analyses (PWA) of the $\eta'\pi^-$ system by the VES Coll. [1] has revealed a dominance of the $J^P M^\eta = 1^-1^+$ wave at masses higher than the $a_2(1320)$ mass, with maximum at $\sim 1.6\,GeV/c^2$ (fig.3, central plot). An important observation was its remarkable excess in this system compared to that one in the $\eta\pi^-$ system (fig.1).

Such an hierarchy looks very natural for a hybrid $q\bar{q}g$ 1^{-+} meson decay [2]. It can be qualitatively explained within a nonrelativistic quark model by virtue of two concurrent diagrams for the transition to two pseudoscalars.

The conclusion was drawn that a system with gluon plays a large rôle in the formation of $\eta'\pi^-$ at $1.6\,GeV/c^2$.

2. The 1^{-+} wave in the $\pi^+\pi^-\pi^-$ system

The PWA of the three pions system was performed with the use of modified Illinois programme [3] based on an isobar model. The wave notation $J^P M^\eta L(isobar)$ includes an orbital momentum L between a pion and an intermediate dimeson system, or *isobar*.

An essential feature of our analyses is the parameterization of the waves production by a full density matrix ρ, contrary to the rank 1 matrix of the analyses [4]. An incoherence is enabled not only between different $J^P M^\eta$ waves as in [5], but also for the same $J^P M^\eta$ waves with different $L(isobar)$. So, the present results are obtained with the largest waves of each J^P being decoupled in the ρ matrix from the smaller ones.

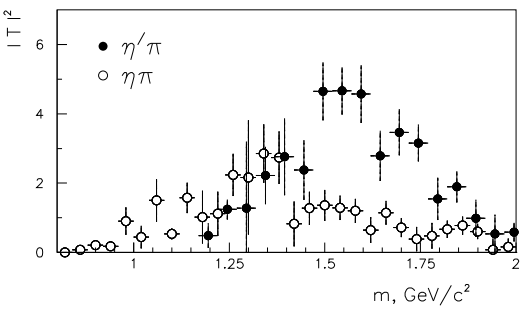

Figure 1. The matrix elements squared of the 1^-1^+ wave in the $\eta'\pi^-$ and $\eta\pi^-$ systems

The flexibility of the parameterization accounts effectively for an incoherence of physical waves which can originate from different sources, such as a coexistence of different production mechanisms, an averaging over a t' range for waves with different t'-dependencies, restraint of the isobar model, measurement errors of the detector, and others. Otherwise, in the "tight" parameterization model, the unaccounted incoherence leads to a distortion (mostly decrease) of phase motion of physical signals and to the appearance of unphysical ones.

This is particularly relevant to the 1^{-+} waves in the case concerned. The "tight" parameterization gives a prominent signal in the $1^-1^+P\rho$ wave at $M \sim 1.6 GeV/c^2$ (fig.2(a)), meantime the "loose" model results in merely a shoulder of much lower

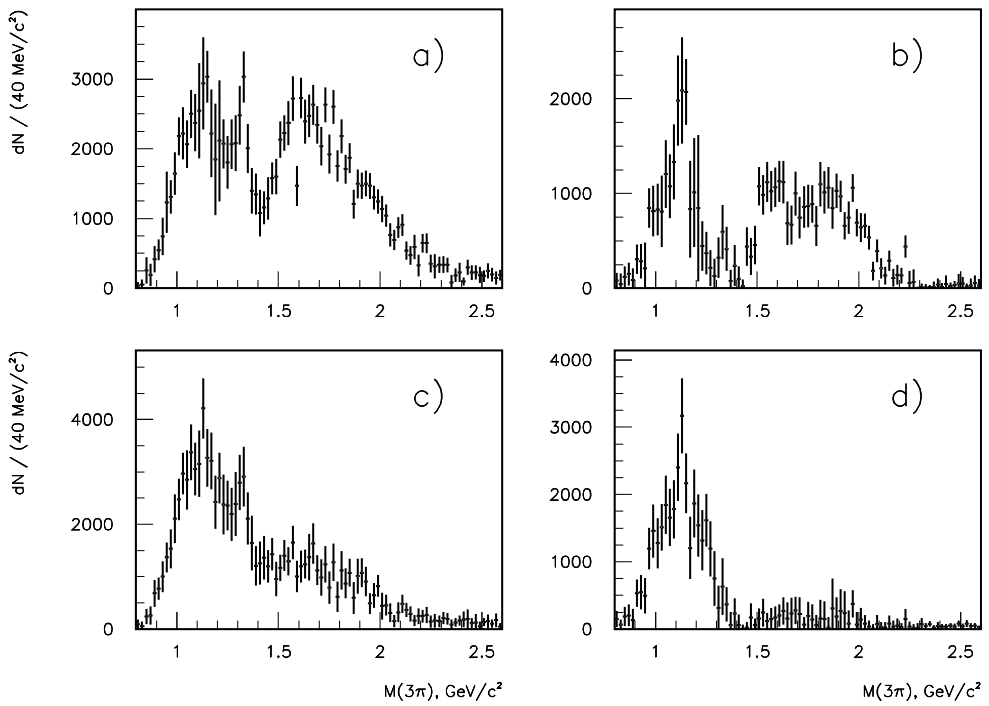

Figure 2. The intensities of the $J^P M^\eta = 1^-1^+$ (a) and 1^-1^- (b) waves in the $\rho\pi$ system with the $0.03 < -t' < 0.7\,GeV^2$ cut for the "tight" density matrix parameterization (see text). The two intensities for the "loose" parameterization are shown respectively on (c) and (d).

intensity at this place (fig.2(c)). The physical meaningfulness of the latter result is supported by a strong suppression of the $1^-1^-P\rho$ wave (fig.2(d)) in the negative "naturality" sector governed by non-Pomeron exchange, contrariwise to the former parameterization, where the $\eta = -1$ wave (fig.2(c)) contributes with comparable intensity (see also [4]).

Within the "loose", or "incoherent", model one can isolate the major vector-state V describing the waves production coherently by means of an expansion of the ρ matrix to two terms accordingly to eigenvalues of the matrix : $\rho = \rho_L + \rho_S$. The rank 1 matrix $\rho_L^{\alpha\beta} = V_\alpha \cdot V_\beta^*$ corresponds to the leading eigenvalue of the ρ, and the ρ_S absorbs all the rest.

The rationality of such breakdown is justified by the observation, that the known resonances (a_1, a_2, $\pi_2(1670)$, $\pi(1800)$) are well described by the ρ_L, which gathers in most cases about 60 to 80 % of a wave intensity.

With such expansion a small signal is visible in the amplitude squared of the leading part of the $1^-1^+P\rho$ wave [6] (the rightmost histogram of the fig.3) at $M \approx 1.6\,GeV/c^2$ with the $0.06 < -t' < 0.7\,GeV^2$ cut, which suppresses a large peak at $\approx 1.1\,GeV/c^2$. We consider the latter which lies just in the region of the huge $1^+0^+S\rho$ wave, as an artifact of the analyses.

3. The 1^{-+} wave in the $\omega\pi^0\pi^-$ system

The waves notation in this case is $J^P M^\eta L[S](isobar)$, where S is a total spin of the (isobar + meson) system.

The mass-independent PWA results [7] in statistically significant contribution of the $1^-1^+S(b_1)$ wave for sizeable momentum transferred squared ($0.08 < |t'| < 0.7\ GeV^2$). Its intensity has a broad bump at $1.5 \div 1.9\,GeV/c^2$ (fig.3, the histogram on the left).

One of the dominant waves in this region is the $2^+1^+S2(\rho)$, with a clear signal of the $a_2(1320)$ meson. It is taken as a reference one when describing the wave under study.

We fit to the mass dependence of the corresponding elements of a density matrix. Models with a coherent background and Breit - Wigner resonance(s) in one or two of these waves were tried. The fit strongly favours the resonance behaviour of the $1^-1^+S(b_1)$ amplitude demanded by a non-trivial behaviour of the imaginary part of the non-diagonal element. However the parameters of the

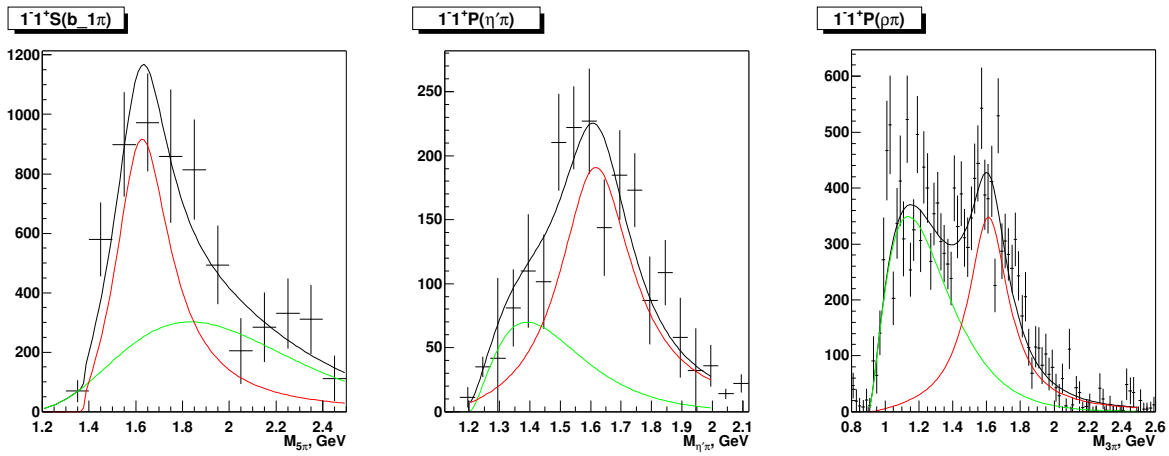

Figure 3. The 1^-1^+ wave intensities in the (from left to right) $b_1\pi$, $\eta'\pi$ and $\rho\pi$ systems. A fit result (see text) is shown by curves.

resonance ranges rather widely with variations of the model of the reference wave. In particular, the latter can be influenced by an interplay of a coupling of the $a_2(1320)$ to the $\omega\pi\pi$ channel and the phase space available with an account of the ρ line shape.

4. A COMBINED FIT TO THE 1^{-+} INTENSITIES. CONCLUSION

A combined fit to the 1^{-+} wave intensities in all three channels was performed (fig.3, solid line). The model included a single Breit-Wigner resonance shown by dotted line, with the barrier factor corresponding to the particular channel, and a smooth background separately for each of the channels (dashed line).

The signal parameters obtained in the fit are:

$$M = 1.61 \pm 0.02\ GeV/c^2\ ,\ \ \Gamma = 0.29 \pm 0.03\ GeV/c^2 \quad (1)$$

The withdrawal of the least prominent $\rho\pi$ signal from the fit leads to parameters which are well compatible within the errors with these of (1).

The branching ratios of the decays to three channels are

$$Br(b_1\pi) : Br(\eta'\pi) : Br(\rho\pi) = 1 : 1.0\pm0.3 : 1.6\pm0.4 \quad (2)$$

In conclusion, the structure, observed in the $q\bar{q}$-exotic $J^{PC} = 1^{-+}$ wave in the $\eta'\pi^-$, $\rho^0\pi^-$ and $(b_1\pi)^-$ channels, is described by a single resonance with the Breit-Wigner parameters given by eq.(1).

We regard this signal as a strong candidate to a hybrid $q\bar{q}g$ resonance.

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