Hybrid Mesons

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Abstract

The theoretical expectations and experimental results on hybrid mesons with exotic quantum numbers $I^G J^{PC} = 1^- 1^{-+}$ are reviewed.

The theoretical estimations of hybrid meson mass tend to converge at $M(\hat{\rho}) = 1.6 \div 2.0$ GeV. The predictions for decay widths are very contradictory.

The experimental results obtained at the VES (IHEP, Protvino) facility point to the existence of hybrid resonance with exotic quantum numbers of $I^G J^{PC} = 1^- 1^{-+}$ with $M \approx 1.6$ GeV.

1. Why it is worth studying hybrid mesons

In spite of impressive success of Yang-Mills approach in the construction of theories of electroweak and strong interactions, the key parts of these theories remain not well understood. In the electroweak sector the hottest question is the mechanism of breaking of $SU(2) * U(1)$ gauge symmetry. This mechanism works at energies near the unitarity limit for electroweak interactions, at approximately 1 TeV. So, there is clear understanding how to address this problem from experiment al side and hopefully experiments at LHC will be able to clarify it in not very distant future.

The situation is quite different in quantum chromodynamics, where clear strategy is not elaborated yet. The main problem in this case is that the nonlinearity of fundamental interactions leads to nonperturbative effects and, in particular, to nonperturbative QCD vacuum [1, 2]. Characteristics of this vacuum are crucial for the light quark hadron spectroscopy, where hadrons are of the size $r \approx 1/\lambda_{QCD} \approx 1$ Fermi. Therefore, from the first glance, one may hope that detailed study of hadron spectra in the region of $1 \div 2$ GeV could give essential information for understanding the QCD vacuum and other nonperturbative QCD effects. However the knowledge of nonperturbative QCD physics is far from being satisfactory and based mainly on models rather than on the fundamental theory. In first approximation the main characteristics of light hadrons are defined by their quark content and by simplest parameters of QCD vacuum - average density of "gluon condensate" $< G^a_{\mu\nu} G^a_{\mu\nu} >$ and "quark condensate" $< q\bar{q} >$ [2]. The important exceptions are $J^{PC} = 0^{-+}, 0^{++}$ states, which are driven by short range physics [3]. Both theoretical expectations [3, 2] and experimental data [5] point to very strong quark-gluon mixing in these states.

It looks natural to try to get new information on nonperturbative QCD by studying glueballs (symbolically called gg) [4] and hybrids ($q\bar{q}g$) – those objects whose existence is possible due to the nonlinearity of QCD and which are of nonperturbative origin. The lightest glueballs have quantum numbers of $J^{PC} = 0^{++}$, which are very common for ordinary $q\bar{q}$ mesons. By this reason the specific physics of glueballs is very much shadowed by great number of $q\bar{q}$ states [6]. The situation is more promising in the hybrid sector, where, among the lightest states, those with exotic quantum numbers $J^{PC} = 1^{-+}$ could exist [7]. This set of quantum numbers is not possible for ordinary $q\bar{q}$ mesons.

2. Models of hybrid mesons

2.1 Predictions for masses

The spectrum of hybrid mesons was calculated in different models — bag model, flux tube model, constituent gluons model, QCD spectral sum rules, lattice QCD and others. The important feature of all these calculations is that the mesons with exotic quantum numbers $J^{PC} = 1^{-+}$ are relatively light. The hybrid resonance with quantum numbers of $I^G J^{PC} = 1^- 1^{-+}$ is often named $\hat{\rho}$, as in the theoretical models the $q\bar{q}$ pair in this resonance is in the same spin-orbital state $^3S_1$ as in the ρ meson. In our evaluation of theoretical predictions for masses of hybrid mesons we will rely on the QCD spectral sum rules and lattice QCD, as these models are based on fundamental QCD interaction and potentially give predictions which are not very much model dependent. The first calculation [8] of the mass of the $J^{PC} = 1^{-+}$ hybrid meson in the model of QCD spectral sum rules gave unexpectedly low mass $M(1^{-+}) \approx 1.2$ GeV. Other groups give very different predictions on the basis of the same approach, ranging to $M = 2.1$ GeV [9]. The most recent results [10] give the mass of the lightest 1^{-+} hybrid $M(1^{-+}) \approx 1.6$ GeV and predicts unusually small mass of its first radial excitation: $M(\hat{\rho}') = M(\hat{\rho}) + 0.2$ GeV.

The calculations of the masses of the light 1^{-+} hybrids in the lattice QCD model were performed by different groups in very different approximations [11]. All these results are consistent within 10% and predict the mass of the lightest 1^{-+} hybrid at $M \approx 2.0$ GeV. The precision of these calculations is not very well defined, because in all the models the chiral dynamics is not well reproduced and the effects of $q\bar{q}$ sea are only partially accounted for.

2.2 Predictions for decay widths

The most intensive decay modes of $\hat{\rho}(1600)$ are $\rho\pi$, $b_1\pi$, $f_1\pi$, $\eta'\pi$ and $\eta\pi$. The widths of these decays were calculated in different models with very different results.

2.2.1 $\hat{\rho} \to \rho\pi$

In the potential quark model with constituent gluon [12, 13], as well as in the flux tube model [14, 15], the decays of a hybrid meson to the pair of mesons having identical spatial wave functions are forbidden by the special symmetry of the Hamiltonian in these models. This selection rule leads to the suppression of the decay $\hat{\rho}(1600) \to \rho\pi$ due to the assumed similarity of the wave functions for ρ and π mesons. The predicted width is $2 \div 8$ MeV.

The calculations in the QCD spectral sum rules leads to completely different result. In this model the decay $\hat{\rho} \to \rho\pi$ is the dominant one and its widths is $10 \div 100$ MeV [16] or even 0.6 GeV [9].

2.2.2 $\hat{\rho}(1600) \to \eta\pi$ and $\hat{\rho}(1600) \to \eta'\pi$

The decays $\hat{\rho}(1600) \to \eta\pi$ and $\hat{\rho}(1600) \to \eta'\pi$ via "gluon splitting" (Fig.1 a)) are forbidden by isotopic symmetry [17] and the decays with η/η' formation by gluons (Fig. 1b)) are allowed.

This diagram(1 b)) enhances decays to SU(3) singlets and gives very unusual relative intensities of these two decays $|M_{\hat{\rho}(1600)\to\eta'\pi}|^2/|M_{\hat{\rho}(1600)\to\eta\pi}|^2 = 1/tg\theta_{PS}$. The SU(3) breaking could lead to additional enhancement of the decay to $\eta'\pi$ [18]. The width of this decay is relatively small $\Gamma_{\eta'\pi} \approx 3$ MeV in the model of QCD spectral sum rules [10] and could be as high as $\Gamma_{\eta'\pi} \approx 1$ GeV in the same model if the coupling of η' to two gluons through the anomaly is included into the model [18].

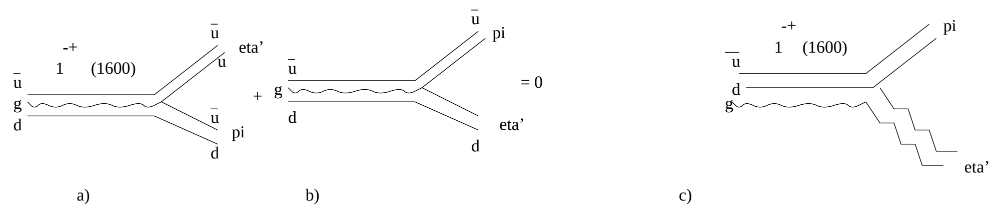

Figure 1: The decay $\hat{\rho}(1600) \to \eta'\pi$. The decays a) + b) are forbidden by isotopic symmetry, c) allowed decay.

2.2.3 $\hat{\rho}(1600) \to b_1\pi$ and $\hat{\rho}(1600) \to \mathrm{f}_1\pi$

These decays are not suppressed and have normal hadronic widths. The estimations of their widths in different models [13, 15] give reasonably consistent results: $\Gamma_{\hat{\rho}\to b_1\pi} = 50 \div 200$ MeV, $\Gamma_{\hat{\rho}\to f_1\pi} = 10 \div 50$ MeV.

3. Exotic wave $J^{PC} = 1^{-+}$

3.1 Signals at $M \approx 1.3 \div 1.4$ GeV

The exotic wave $J^{PC} = 1^{-+}$ in $\eta\pi$ channel was studied in different processes:
– in charge exchange reaction $\pi^- p \to \eta\pi^0 n$ [19, 20, 21, 22]
– in diffractive-like reaction $\pi^- p \to \eta\pi^- p$ [24, 25, 26]
– in Primakoff reaction $\pi^+ Z \to \pi^+ \eta Z$ [28]
– in $p\bar{p}$ and $p\bar{n}$ annihilation [29].

The main difficulties in the detailed study of the 1^{-+} wave in the $\eta\pi$ channel at $M \approx 1.3 \div 1.4$ GeV are the presence of very strong signal of ordinary $a_2(1320)$-meson and continuous ambiguities in the mass independent partial wave analysis of final state with two spinless particles. In all these experiments the exotic wave $J^{PC} = 1^{-+}$ was reliably observed. Its parameters and interpretation strongly depend on particular experiment.

In the charge exchange reaction at $P_\pi = 18$ GeV [22] the signal in the 1^{-+} wave is peaking at $M = 1.24$ GeV. The statistics of this experiment does not allow to extract relative phase of the 1^{-+} wave and dominant 2^{++} wave. In the experiments of the GAMS collaboration [20, 21] at higher momentum the signal in the 1^{-+} wave is broad and depends on the beam momentum. The analysis of this reaction in the framework of mass-dependent PWA model [21] shows that the data could be described without exotic 1^{-+} resonance.

In the diffractive-like reaction $\pi^- p \to \eta\pi^- p$ at the momentum of $P_\pi = 6.3$ GeV/c the signal in the wave 1^{-+} was observed at KEK[25]. The shape of this signal is the same as that of the $a_2(1320)$-meson. The relative phase motion of 1^{-+} wave and 2^{++} wave is not seen. These two facts were interpreted in [25] as the strong indication on the existence of 1^{-+} resonance with parameters: $M = 1323 \pm 5, \quad \Gamma = 143 \pm 13$ MeV.

In the experiment of the VES collaboration at $P_\pi = 36.6$ GeV/c [24] a clear broad signal in the 1^{-+} wave with maximum at $M \approx 1.4$ GeV was observed (fig 2).

The relative phase motion between the 1^{-+} wave and 2^{++} wave in the region of the $a_2(1320)$ meson of $\approx 100^0$ was found. The deficit of phase motion (100^0 instead of 180^0) could be explained by different physical effects:
– partial incoherency of the 1^{-+} and 2^{++} waves;
– nonresonant background in the 2^{++} wave;
– slowly growing phase of 1^{-+} wave.

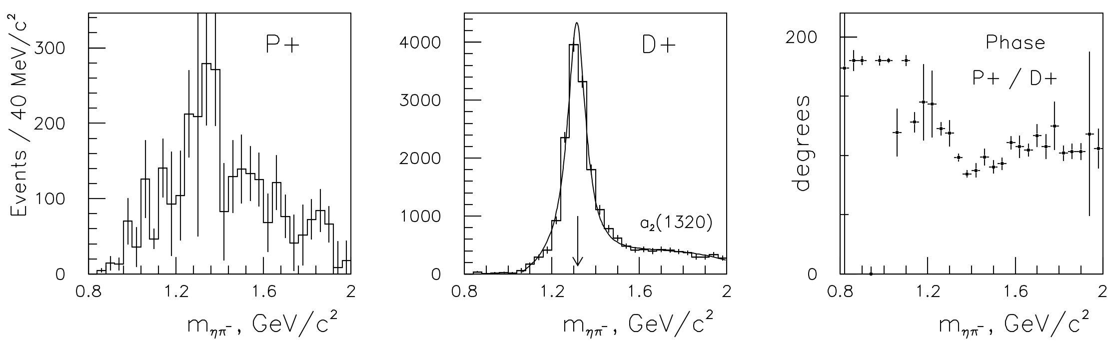

Figure 2: The $J^P M^\eta = 2^+1^+,\ 1^-1^+\eta\pi$ wave intensities (a, b) and their phase difference (c).

The inevitable imperfections of the PWA model, like neglecting of waves with higher angular momentum and any imperfections in acceptance or resolution, also tend to decrease visible phase motion between 1^{-+} and 2^{++} wave. By all these reasons, the signal at $M = 1.4$ GeV was not interpreted as resonance by the VES collaboration. The very similar behaviour of the 1^{-+} wave was observed by the E852 collaboration [26]. The results of this experiment were explained by this collaboration as an observation of a new exotic resonance with parameters $M = 1370 \pm 16^{+50}_{30}, \quad \Gamma = 385 \pm 40^{+65}_{-105}$ MeV [26, 38]. In the paper [30] the alternative explanation of observed features of the 1^{-+} signal was proposed where the intensity of this wave and its phase motion are driven by the nonresonant production of Deck type modified via K-matrix by broad resonance at $M \approx 1.6$ GeV.

In $\bar{p}p$ and $\bar{p}n$ annihilation into $\eta\pi\pi$ the wave 1^{-+} was observed and interpreted as a resonance with parameters: $M = 1400 \pm 20 \pm 20, \Gamma = 310 \pm 50^{+50}_{-30}$ MeV [29].

To summarize the status of the 1^{-+} wave at $M \approx 1.3 \div 1.4$ GeV we can say that this wave is seen in different reactions. The parameters of this wave vary from one experiment to another and are not well understood. The resonance interpretation of this wave does not lead to reasonable description of all experimental data. The behaviour of this wave could be explained without dominant resonance contribution. Of course, all these arguments do not exclude the existence of 1^{-+} resonance at $M = 1.3 \div 1.4$ GeV.

3.2 Signal at $M \approx 1.6$ GeV

3.2.1 The wave $J^{PC} = 1^{-+}$ in the $\eta'\pi$ channel

The reaction $\pi^- A \to \eta'\pi A$ was firstly studied by the VES collaboration [23, 24]. It was found that the wave $J^{PC}M^\eta = 1^{-+}1^+$ is the dominant one [24] in diffractive-like production of $\eta'\pi-$ system at $P_\pi = 36.6$ GeV/c It has maximum at $M \approx 1.6$ GeV (Fig. 6 b)). Recently this result was confirmed by the E852 collaboration [27]. Due to the smallness of other waves and poor knowledge of their parameters the phase motion of $1^{-+}1^+$ wave is not known and the resonance nature of the signal could not be established from the data on this channel. Assuming that this signal is a Breit-Wigner resonance, the parameters were found [39]: $M = 1.57 \pm 0.02 \pm 0.02$ GeV, $\Gamma = 0.55 \pm 0.06 \pm 0.04$ GeV. The most striking feature of this wave is that its intensity in the $\eta'\pi$ channel is higher than that in the $\eta\pi$ channel.

3.2.2 The wave $J^{PC} = 1^{-+}$ in the $b_1\pi$ channel of $\omega\pi^-\pi^0$ system

The partial wave analysis of the reaction $\pi^- A \to \omega\pi^-\pi^0 A$ was carried out by the VES collaboration [40]. In this reaction the exotic wave $J^{PC} = 1^{-+}$ is clearly seen in the $b_1\pi$ channel. This wave has a peak at $M = 1.6 \div 1.7$ GeV. The outcome of the mass independent PWA at high t' was used for the mass-dependent fit of the ρ-matrix elements corresponding to the waves $J^{PC}M^\eta = 1^-1^+$ $b_1\pi$ and $J^{PC}M^\eta = 2^+1^+$ $\omega\rho$. The $b_1\pi$ amplitude was saturated by a Breit-Wigner resonance and a coherent background. The $\omega\rho^-$ amplitude was described by the $a_2(1320)$-meson. In this model, the broad signal in this wave at higher masses is nothing else but a tail of the a_2 meson due to the opening of the $\omega\rho$ channel. The results of the fit point out to the resonance nature of the $b_1\pi$ signal (Fig. 3). The most clear indication on the resonance nature of observed signal is the raising of the phase difference $\phi(1^-1^+\mathtt{S}b_1\pi) - \phi(2^+1^+\mathtt{S}\omega\rho)$ at $M \approx 1.6$ GeV (Fig. 3 c)). The range of the parameters variation is large due to the freedom in the 2^+1^+ wave model.

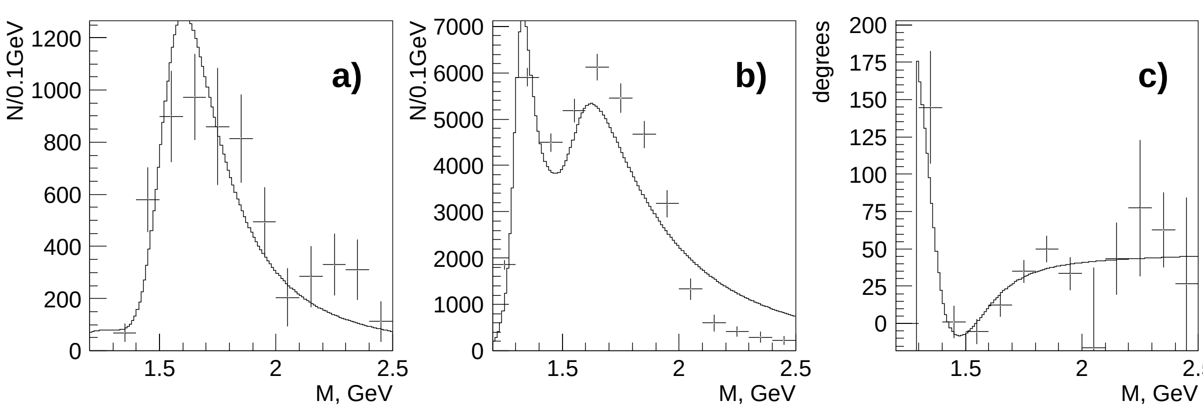

Figure 3: The system $\omega\pi^-\pi^0$: a) the $J^PM^\eta = 1^-1^+\mathtt{S}b_1\pi$ wave intensity, b) the $J^PM^\eta = 2^+1^+\mathtt{S}\omega\rho$ wave intensity, c) $\phi(1^-1^+\mathtt{S}b_1\pi) - \phi(2^+1^+\mathtt{S}\omega\rho)$.

3.2.3 The wave $J^{PC} = 1^{-+}$ in the $\rho\pi$ channel

Here the results of the VES collaboration [31] on the wave 1^{-+} in the $\rho\pi$ channel are presented. The results on the reaction $\pi^- Be \to \pi^+\pi^-\pi^- Be$ are based upon the statistics of about $6.0 \cdot 10^6$ events for low t' region ($-t' < 0.03\ GeV^2$) and $3.0 \cdot 10^6$ for high t' ($0.03 < -t' < 1.0\ GeV^2$). Our previous results were published in [32]. The PWA of the $\pi^+\pi^-\pi^-$ system was performed in the 0.8–2.6 GeV mass region in 20 MeV bins. The modified version of the Illinois PWA program [33] was used for the analysis. This version of the PWA program uses isobar model and relativistic covariant helicity formalism [34] to construct amplitudes and density matrix of sufficiently high rank ρ_{ij} to describe the 3π state. The set of partial waves is given below:

FLAT							
$\mathbf{0^-}$	$0^-\mathtt{S0}^+\,\epsilon$	$0^-\mathtt{S0}^+\,f_0$	$0^-\mathtt{P0}^+\,\rho$	$0^-\mathtt{D0}^+\,f_2$			
$\mathbf{1^+}$	$1^+\mathtt{S0}^+\,\rho$	$1^+\mathtt{P0}^+\,\epsilon$	$1^+\mathtt{D0}^+\,\rho$	$1^+\mathtt{P0}^+\,f_2$	$1^+\mathtt{P0}^+\,f_0$		
	$1^+\mathtt{S1}^+\,\rho$	$1^+\mathtt{P1}^+\,\epsilon$	$1^+\mathtt{D1}^+\,\rho$	$1^+\mathtt{P1}^+\,f_2$	$1^+\mathtt{S1}^-\,\rho$		
$\mathbf{1^-}$	$1^-\mathtt{P1}^+\,\rho$	$1^-\mathtt{P0}^-\,\rho$	$1^-\mathtt{P1}^-\,\rho$				
$\mathbf{2^-}$	$2^-\mathtt{S0}^+\,f_2$	$2^-\mathtt{D0}^+\,\epsilon$	$2^-\mathtt{D0}^+\,f_2$	$2^-\mathtt{P0}^+\,\rho$	$2^-\mathtt{F0}^+\,\rho$	$2^-\mathtt{D0}^+\,f_0$	
	$2^-\mathtt{S1}^+\,f_2$	$2^-\mathtt{D1}^+\,\epsilon$	$2^-\mathtt{D1}^+\,f_2$	$2^-\mathtt{P1}^+\,\rho$	$2^-\mathtt{F1}^+\,\rho$	$2^-\mathtt{S1}^-\,f_2$	$2^-\mathtt{P1}^-\,\rho$
$\mathbf{2^+}$	$2^+\mathtt{D1}^+\,\rho$	$2^+\mathtt{D0}^-\,\rho$	$2^+\mathtt{D1}^-\,\rho$	$2^+\mathtt{P1}^+\,f_2$			
$\mathbf{3^+}$	$3^+\mathtt{S0}^+\,\rho_3$	$3^+\mathtt{P0}^+\,f_2$	$3^+\mathtt{D0}^+\,\rho$	$3^+\mathtt{S1}^+\,\rho_3$			
$\mathbf{4^-}$	$4^-\mathtt{P0}^+\,\rho_3$	$4^-\mathtt{D0}^+\,f_2$	$4^-\mathtt{F0}^+\,\rho$				
$\mathbf{4^+}$	$4^+\mathtt{F1}^+\,f_2$	$4^+\mathtt{G1}^+\,\rho$					

The notations of the waves are given here in the form of $\mathrm{J^PLM}^\eta$ isobar [33]. The FLAT wave is constant over all variables and non-interfering with other waves. The isobars $\rho(770)$, $f_2(1270)$, $\rho_3(1690)$ have been described by relativistic Breit-Wigner functions with standard parameters. The S-wave in the channel $\pi^+\pi^-$ has been parametrized by two different states, namely a "narrow" resonance with the $f_0(980)$ parameters and ϵ[*], a "broad" wave which is the AMP M-solution [36] with $f_0(980)$ pole removed. The parameterization by two states allows us to describe the experimental behaviour of the S-wave. The PWA with parameterization of $\pi\pi$ S-wave by three or four resonances ($f_0(800), f_0(980), f_0(1300), f_0(1500)$) gives essentially the same results. In addition to the waves listed in the table, other waves with higher spin or with negative exchange naturality were included in the PWA and then excluded as insignificant.

To make the resonant picture more clear the following method has been used. Hermitian density matrix of an arbitrary rank d can be represented in terms of its eigenvectors and eigenvalues:

$$\rho^{ij} = \sum_{k=1}^{d} V_k^i * V_k^{*j} * e_k = \rho_L^{ij} + \rho_S^{ij},$$

$$\rho_L^{ij} = V_1^i * V_1^{*j} * e_1, \quad \rho_S^{ij} = \sum_{k=2}^{d} V_k^i * V_k^{*j} * e_k.$$

Here we singled out a term corresponding to the largest eigenvalue into ρ_L, and collected all other terms into ρ_S. This decomposition has the following advantages:

– the matrix ρ_L has rank one, therefore arguments of its nondiagonal elements are indeed phase differences for the corresponding pairs of waves;

[*] We call it ϵ instead of f_0 because it includes the broad part of $\pi\pi$ amplitude and does not coincide with any specific f_0 resonance.

– in this approach ρ_S does not only describe a small incoherence which is expected in the physical process (e.g. due to the different production mechanisms), but can also work as "garbage collector", which absorbs incoherent parts of the initially almost coherent density matrix, arising because of various imperfections of the PWA model. With this PWA we clearly see well established resonances in different decay modes: $\pi(1300) \to \rho\pi,\ \pi(1300) \to \epsilon\pi,\ a_1(1260) \to \rho\pi,\ a_1(1260) \to \epsilon\pi,\ a_2(1320) \to \rho\pi,\ \pi_2(1670) \to f_2\pi,\ \pi_2(1670) \to \rho\pi,\ \pi_2(1670) \to \epsilon\pi,\ 42050 \to \rho\pi$
and decays of not well established resonances: $a_1(1750) \to \rho\pi,\ \pi_2(2100) \to \epsilon\pi,\ a_3(1850) \to \rho\pi$.

The most intensive 1^{-+} wave has nonzero angular momentum projection on Gottfried-Jackson z-axis and therefore is better visible at high t' (Fig. 4 c). The intensity of this wave is very small and does not exceed 2% of total intensity at any $M_{3\pi}$. At $M \approx 1.2$ GeV the bump is seen in all three waves $1^{-+}1^{+}, 1^{-+}1^{-}$ and $1^{-+}0^{-}$. These structures are produced mainly by the leakage from the very intensive 1^{++} channel due to imperfections of PWA model. Three facts point to this interpretation: strong dependence of these signals on the parameters of PWA model, incoherence of the $1^{-+}1^{+}$ signal with others, anomalously narrow t'-dependence.

At $M \approx 1.6$ GeV a broad shoulder is seen. Its intensity at $M \approx 1.6$ GeV is only 3% of the intensity of the $a_2(1320)$ signal at its maximum. The observation of a signal in the $1^{-}1^{+}P(\rho)$ wave with $M = 1.62 \pm 0.02$ GeV, $\Gamma = 0.24 \pm 0.05$ GeV was previously reported as preliminary by the VES collaboration [37]. Later, the observation of the relatively narrow resonance at $M \approx 1.6$ GeV was reported by the E852 [38]. It was shown in [39] that the intensity and the shape of this wave are very much dependent on the details of the PWA model. With our PWA model we do not see the narrow signal at $M \approx 1.6$ GeV in the wave $1^{-+}1^{+}$. Moreover, the intensity of the signal at $M \approx 1.6$ GeV in the unnatural parity exchange sector is compatible with zero (Fig.4 d)) as one could expect, contrary to the results reported in [38]. The result of [38] can be reproduced partially by the use of oversimplified PWA model with fully coherent waves in $2^{-+}, 1^{++}$ and 0^{-+} sectors (Fig.4 a,b). It indicates that the appearance of a relatively strong signal with comparable intensity in both positive and negative naturalities [38] is an artefact of too tight PWA model. Instead, the signal in the wave $1^{-+}1^{+}$ is very broad and less intensive than the signal reported in [38].

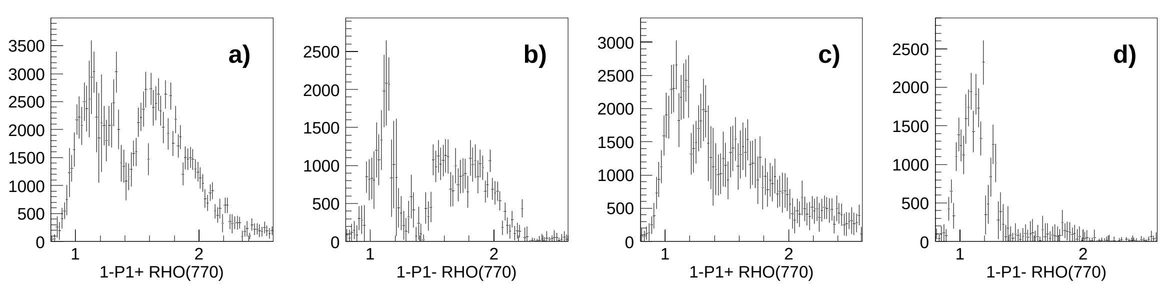

Figure 4: tensities of the $J^P M^\eta = 1^{-}1^{+}$ (a) and the $1^{-}1^{-}$ (b) waves in the $\rho\pi$ system at high t' for the "tight" density matrix parameterization (see text). Two intensities for the "loose" parameterization are shown respectively on (c) and (d).

It can be seen in Fig. 5, where the fraction of $1^{-+}1^{+}$ wave corresponding to the highest eigenvalue of density matrix is shown. In Fig. 5 b) the absolute phase of this wave is shown as well. To get the reference phase we used the results of the mass-dependent fit of the most intensive $0^{-+}, 2^{++}, 2^{-+}$ and 4^{++} waves by known Breit-Wigner resonances and phase space-like backgrounds. The shape of the 1^{-+} signal and its phase rising at $M \approx 1.6$ GeV do not exclude the presence of the resonance in this region. Due to its smallness and broadness, this signal taken alone can not be unambiguously interpreted as a resonance. At the same time, clear bumps are seen at $M \approx 1.6$ GeV in two other channels, $\eta'\pi$ [24] and $b_1(1235)\pi$ [40] (Fig. 6). These observations taken alltogether point to the possible existence of exotic resonance at $M \approx 1.6$ GeV.

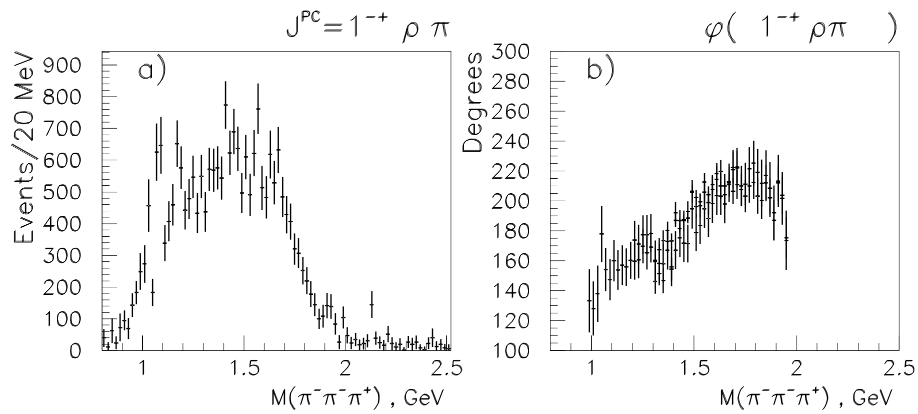

Figure 5: The $J^P M^\eta = 1^-1^+ \mathtt{S}\rho$ wave intensity (a) and its absolute phase estimation (b).

3.2.4 Parameters of the exotic resonance

The fit to the $\eta'\pi$, $b_1\pi$ and $\rho\pi$ intensities with incoherent sum of a single Breit-Wigner resonance and backgrounds in each channel was performed (Fig. 6). The fit results in the following parameters:
$M = 1.56 \pm 0.06$ GeV, $\Gamma = 0.34 \pm 0.05$ GeV
and the branching ratio:
$Br(b_1\pi) : Br(\eta'\pi) : Br(\rho\pi) = 1 : 1.0 \pm 0.3 : 1.5 \pm 0.5.$

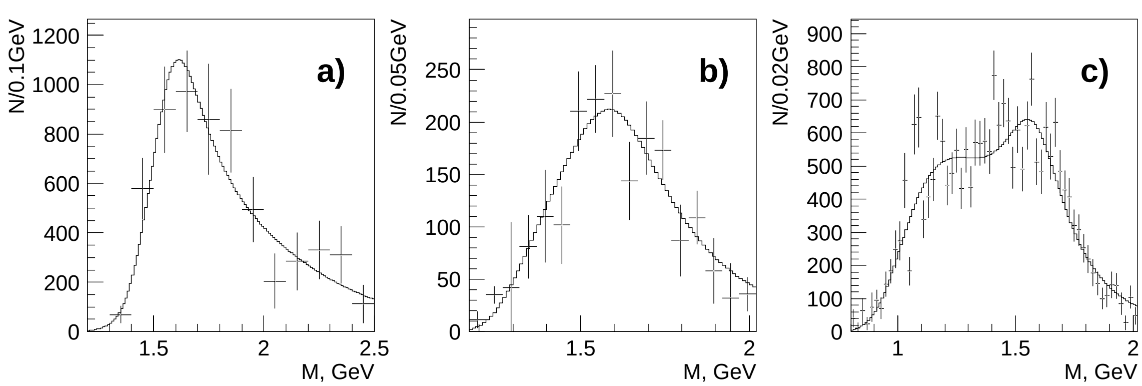

Figure 6: Intensities of the $J^P M^\eta = 1^-1^+$ waves in the channels: $b_1(1235)\pi$, $\eta'\pi$ and $\rho\pi$.

A resonance with these quantum numbers can not be constructed from $q\bar{q}$ pair and could be either some kind of a multiquark state or a hybrid meson. Despite large uncertainty in the estimations of branching fractions for the 1^{-+} state, the enhanced decay to $\eta'\pi$ looks very peculiar for hybrid mesons [18]. On the basis of this feature we consider the hybrid interpretation of the observed state as preferable.

Conclusion

After ten years, the experimental study of hybrid mesons have done very significant step – from the first observations of exotic waves to the detailed study of these waves in different reactions. At low mass $M = 1.3 \div 1.4$ GeV the experimental situation is still contradictory, and attempts of separation of possible resonance from nonresonant background do not lead to any selfconsistent results.

At higher mass, $M \approx 1.6$ GeV, the resonance-like signal is seen in three channels ($\eta'\pi$, $b_1\pi$ and $\rho\pi$). Probably the same signal is seen in the $f_1\pi$ channel [41]. The mass of hybrid resonance at $M \approx 1.6$ GeV agrees reasonably well with theoretical estimations. The relative branchings fractions of decays into these three channels are hardly possible to confront with the theory, as theoretical predictions on decay widths are very contradictory. In view of absence of solid predictions on decay branchings, the hybrid interpretation is based on only one observed feature of $\hat{\rho}(1600)$ - enhanced intensity of the decay $\hat{\rho}(1600) \rightarrow \eta'\pi$.

The observation of $\hat{\rho}(1600)$ opens a new area in hadron physics - spectroscopy of hybrid mesons. Now we can try to observe $\hat{\rho}(1600)$ in different channels, in different reactions, in different isospin states. We may try also to find and study its radial excitations, SU(3) partners, hybrids with other quantum numbers, both exotic and nonexotic etc. Of course, these measurements will provide very nontrivial information on strong interactions in nonperturbative region.

Most of these experiments are very natural for U-70 IHEP accelerator. Development of this direction should be of prime importance for the Institute for High Energy Physics, Protvino.

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