THE \( \rho(1450) \) AND THE \( \rho(1700) \)

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In our 1988 edition, we replaced the \( \rho(1600) \) entry with two new ones, the \( \rho(1450) \) and the \( \rho(1700) \), because there was emerging evidence that the 1600-MeV region actually contains two \( \rho \)-like resonances. Erkal [1] had pointed out this possibility with a theoretical analysis on the consistency of 2\( \pi \) and 4\( \pi \) electromagnetic form factors and the \( \pi \pi \) scattering length. Donnachie [2], with a full analysis of data on the 2\( \pi \) and 4\( \pi \) final states in \( e^+e^- \) annihilation and photoproduction reactions, had also argued that in order to obtain a consistent picture, two resonances were necessary. The existence of \( \rho(1450) \) was supported by the analysis of \( \eta \rho^0 \) mass spectra obtained in photoproduction and \( e^+e^- \) annihilation [3], as well as that of \( e^+e^- \to \omega \pi \) [4].

The analysis of [2] was further extended by [5,6] to include new data on 4\( \pi \)-systems produced in \( e^+e^- \) annihilation, and in \( \tau \)-decays (\( \tau \) decays to 4\( \pi \), and \( e^+e^- \) annihilation to 4\( \pi \) can be related by the Conserved Vector Current assumption). These systems were successfully analyzed using interfering contributions from two \( \rho \)-like states, and from the tail of the \( \rho(770) \) decaying into two-body states. While specific conclusions on \( \rho(1450) \to 4\pi \) were obtained, little could be said about the \( \rho(1700) \).

Independent evidence for two 1\( ^- \) states is provided by [7] in 4\( \pi \) electroproduction at \( \langle Q^2 \rangle = 1 \) (GeV/c\(^2 \)), and by [8] in a high-statistics sample of the \( \eta \pi \pi \) system in \( \pi^-p \) charge exchange.

This scenario with two overlapping resonances is supported by other data. Bisello [9] measured the pion form factor in the interval 1.35–2.4 GeV, and observed a deep minimum around 1.6 GeV. The best fit was obtained with the hypothesis of \( \rho \)-like resonances at 1420 and 1770 MeV, with widths of about 250 MeV. Antonelli [10] found that the \( e^+e^- \to \eta \pi^+\pi^- \) cross section is better fitted with two fully interfering Breit-Wigners, with parameters in fair agreement with those of [2] and [9]. These results can be considered as a confirmation of the \( \rho(1450) \).
Decisive evidence for the \( \pi\pi \) decay mode of both \( \rho(1450) \) and \( \rho(1700) \) comes from \( \bar{p}p \) annihilation at rest [11]. It has been shown that these resonances also possess a \( K\bar{K} \) decay mode [12–14]. High-statistics studies of the decays \( \tau \to \pi\pi\nu_\tau \) [15,16], and \( \tau \to 4\pi\nu_\tau \) [17] also require the \( \rho(1450) \), but are not sensitive to the \( \rho(1700) \), because it is too close to the \( \tau \) mass. A recent very-high-statistics study of the \( \tau \to \pi\pi\nu_\tau \) decay performed at Belle [18] reports the first observation of both \( \rho(1450) \) and \( \rho(1700) \) in \( \tau \) decays.

The structure of these \( \rho \) states is not yet completely clear. Barnes [19] and Close [20] claim that \( \rho(1450) \) has a mass consistent with radial \( 2S \), but its decays show characteristics of hybrids, and suggest that this state may be a \( 2S \)-hybrid mixture. Donnachie [21] argues that hybrid states could have a \( 4\pi \) decay mode dominated by the \( a_1\pi \). Such behavior has been observed by [22] in \( e^+e^- \to 4\pi \) in the energy range 1.05–1.38 GeV, and by [17] in \( \tau \to 4\pi \) decays. Alexander [23] observes the \( \rho(1450) \to \omega\pi \) decay mode in \( B \)-meson decays, however, does not find \( \rho(1700) \to \omega\pi^0 \). A similar conclusion is made by [24], who studied the process \( e^+e^- \to \omega\pi^0 \). Various decay modes of the \( \rho(1450) \) and \( \rho(1700) \) are observed in \( \bar{p}n \) and \( \bar{p}p \) annihilation [25,26], but no definite conclusions can be drawn. More data should be collected to clarify the nature of the \( \rho \) states, particularly in the energy range above 1.6 GeV.

We now list under a separate entry the \( \rho(1570) \), the \( \phi\pi \) state with \( J^{PC} = 1^{--} \) earlier observed by [27] (referred to as \( C(1480) \)) and recently confirmed by [28]. While [29] shows that it may be a threshold effect, [5] and [30] suggest two independent vector states with this decay mode. The \( C(1480) \) has not been seen in the \( \bar{p}p \) [31] and \( e^+e^- \) [32,33] experiments. However, the sensitivity of the two latter is an order of magnitude lower than that of [28]. Note that [28] can not exclude that their observation is due to an OZI-suppressed decay mode of the \( \rho(1700) \).

Several observations on the \( \omega\pi \) system in the 1200-MeV region [34–40] may be interpreted in terms of either \( J^P = 1^- \rho(770) \to \omega\pi \) production [41], or \( J^P = 1^+ b_1(1235) \) production [39,40]. We argue that no special entry for a \( \rho(1250) \) is needed.
The LASS amplitude analysis [42] showing evidence for $\rho(1270)$ is preliminary and needs confirmation. For completeness, the relevant observations are listed under the $\rho(1450)$.

Recently [43] reported a very broad $1^{--}$ resonance-like $K^+K^-$ state in $J/\psi \rightarrow K^+K^-\pi^0$ decays. Its pole position corresponds to mass of 1576 MeV and width of 818 MeV. [44–46] suggest its exotic structure (molecular or multiquark), while [47] and [48] explain it by the interference between the $\rho(1450)$ and $\rho(1700)$. We quote [43] as $X(1575)$ in the section “Further States.”

Evidence for $\rho$-like mesons decaying into 6π states was first noted by [49] in the analysis of 6π mass spectra from $e^+e^-$ annihilation [50,51] and diffractive photoproduction [52]. Clegg [49] argued that two states at about 2.1 and 1.8 GeV exist: while the former is a candidate for the $\rho(2150)$, the latter could be a manifestation of the $\rho(1700)$ distorted by threshold effects. BaBar reported observations of the new decay modes of the $\rho(2150)$ in the channels $\eta'(958)\pi^+\pi^-$ and $f_1(1285)\pi^+\pi^-$ [53]. The relativistic quark model [54] predicts the $2^3D_1$ state with $J^{PC} = 1^{--}$ at 2.15 GeV which can be identified with the $\rho(2150)$.

The E687 Collaboration at Fermilab reported an observation of a narrow-dip structure at 1.9 GeV in the $3\pi^+3\pi^-$ diffractive photoproduction [55]. A similar effect of the dip in the cross section of $e^+e^- \rightarrow 6\pi$ around 1.9 GeV has been earlier reported by DM2 [51], where 6π included both $3\pi^+3\pi^-$ and $2\pi^+2\pi^-2\pi^0$. Later the dip in the $R$ value (the total cross section of $e^+e^- \rightarrow$ hadrons divided by the cross section of $e^+e^- \rightarrow \mu^+\mu^-$) was observed by [56], again around 1.9 GeV. This energy is close to the $NN$ threshold, which hints at the possible relation between the dip and $NN$, e.g., the frequently discussed narrow $NN$ resonance or just a threshold effect. Such behaviour is also characteristic of exotic objects like vector $q\overline{q}$ hybrids. Note that [57] failed to find this state in the reaction $\overline{p}p \rightarrow 3\pi^+2\pi^-\pi^0$. A reanalysis of the E687 data by [58] shows that a dip may arise due to interference of a narrow object with a broad $\rho(1700)$ independently of the nature of the former. BaBar studied the processes $e^+e^- \rightarrow 3\pi^+3\pi^-$ and $e^+e^- \rightarrow 2\pi^+2\pi^-2\pi^0$ using the
radiative return, and observed a structure around 1.9 GeV in both final states [59]. The data are not well described by a single Breit-Wigner state, and a good fit is achieved while taking into account the interference of such a structure with a Jacob-Slansky amplitude for continuum. The mass of this state obtained by BaBar is consistent with [56] and [55], but the width is substantially larger. Recently [28] observed a structure at 1.9 GeV in the radiative return to the $\phi \pi$ final state, with a much smaller width of $48 \pm 17$ MeV consistent with that of [56,58]. We list these observations under a separate particle $\rho(1900)$, which needs confirmation.

References