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 ρ-like resonances. Erkal [1] had pointed out this possibility with a theoretical analysis on the consistency of 2π and 4π electromagnetic form factors and the $\pi\pi$ scattering length. Donnachie [2], with a full analysis of data on the 2π and 4π 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 4π-systems produced in e^+e^- annihilation, and in τ-decays (τ decays to 4π, and e^+e^- annihilation to 4π can be related by the Conserved Vector Current assumption). These systems were successfully analyzed using interfering contributions from two ρ-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 4π electroproduction at $\langle Q^2 \rangle = 1$ $(\mathrm{GeV}/c)^2$, 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 ρ-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 $\overline{p}p$ annihilation at rest [11]. It has been shown that these resonances also possess a $K\overline{K}$ 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 τ 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 τ decays.

The structure of these ρ 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 4π 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 $\overline{p}n$ and $\overline{p}p$ annihilation [25,26], but no definite conclusions can be drawn. More data should be collected to clarify the nature of the ρ 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 $\overline{p}p$ [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 $J/\psi \to K^+K^-\pi^0$ 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 ρ-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 $e^+e^- \to 6\pi$ 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 $e^+e^- \to$ hadrons divided by the cross section of $e^+e^- \to \mu^+\mu^-$) was observed by [56], again around 1.9 GeV. This energy is close to the $N\overline{N}$ threshold, which hints at the possible relation between the dip and $N\overline{N}$, *e.g.*, the frequently discussed narrow $N\overline{N}$ 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 $\overline{n}p \to 3\pi^+2\pi^-\pi^0$. 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 $e^+e^- \to 3\pi^+3\pi^-$ and $e^+e^- \to 2\pi^+2\pi^-2\pi^0$ 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 ± 17 MeV consistent with that of [56,58]. We list these observations under a separate particle $\rho(1900)$, which needs confirmation.

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