

72. $\rho(1450)$ and $\rho(1700)$

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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 $e^+e^- \rightarrow \omega\pi$ [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 $\rho(1450) \rightarrow 4\pi$ were obtained, little could be said about the $\rho(1700)$.

Independent evidence for two 1^- states is provided by [7] in 4π electroproduction at $\langle Q^2 \rangle = 1$ (GeV/c)², and by [8] in a high-statistics sample of the $\eta\pi\pi$ system in π^-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 $e^+e^- \rightarrow \eta\pi^+\pi^-$ 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 $\tau \rightarrow \pi\pi\nu_\tau$ [15,16], and $\tau \rightarrow 4\pi\nu_\tau$ [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 $\tau \rightarrow \pi\pi\nu_\tau$ decay performed at Belle [18] reports the first observation of both $\rho(1450)$ and $\rho(1700)$ in τ decays. A clear picture of the two $\pi^+\pi^-$ resonances interfering with the $\rho(770)$ in e^+e^- annihilation was also reported by BaBar using the ISR method [19].

The structure of these ρ states is not yet completely clear. Barnes [20] and Close [21] 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 [22] argues that hybrid states could have a 4π decay mode dominated by the $a_1\pi$. Such behavior has been observed by [23] in $e^+e^- \rightarrow 4\pi$ in the energy range 1.05–1.38 GeV, and by [17] in $\tau \rightarrow 4\pi$ decays. CLEO [24] and Belle [25] observe the $\rho(1450) \rightarrow \omega\pi$ decay mode in B -meson decays, however, do not find $\rho(1700) \rightarrow \omega\pi^0$. A similar conclusion is made by [26,27], who studied the process $e^+e^- \rightarrow \omega\pi^0$ and do not observe a statistically

significant signal of the $\rho(1700)$. Various decay modes of the $\rho(1450)$ and $\rho(1700)$ are observed in $\bar{p}n$ and $\bar{p}p$ annihilation [28,29], 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 [30] (referred to as $C(1480)$) and recently confirmed by [31]. While [32] shows that it may be a threshold effect, [5] and [33] suggest two independent vector states with this decay mode. The $C(1480)$ has not been seen in the $\bar{p}p$ [34] and e^+e^- [35,36] experiments. However, the sensitivity of the two latter is an order of magnitude lower than that of [31]. Note that [31] 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 [37–43] may be interpreted in terms of either $J^P = 1^-$ $\rho(770) \rightarrow \omega\pi$ production [44], or $J^P = 1^+$ $b_1(1235)$ production [42,43]. We argue that no special entry for a $\rho(1250)$ is needed. The LASS amplitude analysis [45] showing evidence for $\rho(1270)$ is preliminary and needs confirmation. For completeness, the relevant observations are listed under the $\rho(1450)$.

Recently [46] 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. [47–49] suggest its exotic structure (molecular or multiquark), while [50] and [51] explain it by the interference between the $\rho(1450)$ and $\rho(1700)$. The latter statement is qualitatively supported by BaBar [52] and SND [53]. We quote [46] as $X(1575)$ in the section “Further States.”

Evidence for ρ -like mesons decaying into 6π states was first noted by [54] in the analysis of 6π mass spectra from e^+e^- annihilation [55,56] and diffractive photoproduction [57]. Clegg [54] 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 $f_1(1285)\pi^+\pi^-$ [58]. The relativistic quark model [59] predicts the 2^3D_1 state with $J^{PC} = 1^{--}$ at 2.15 GeV which can be identified with the $\rho(2150)$.

We no longer list under a separate particle $\rho(1900)$ various observations of irregular behavior of the cross sections near the $N\bar{N}$ threshold. Dips of various width around 1.9 GeV were reported by the E687 Collaboration (a narrow one in the $3\pi^+3\pi^-$ diffractive photoproduction [60,61]), by the FENICE experiment (a narrow structure in the R value [62]), by BaBar in ISR (a narrow structure in $e^+e^- \rightarrow \phi\pi$ final state [63], but much broader in $e^+e^- \rightarrow 3\pi^+3\pi^-$ and $e^+e^- \rightarrow 2(\pi^+\pi^-\pi^0)$ [64]), by CMD-3 (also a rather broad dip in $e^+e^- \rightarrow 3\pi^+3\pi^-$ [65]). A dedicated scan of the $N\bar{N}$ -threshold region by CMD-3 confirms this effect in the $e^+e^- \rightarrow 3\pi^+3\pi^-$ and $e^+e^- \rightarrow K^+K^-\pi^+\pi^-$ final states, but does not see it in the cross section of $e^+e^- \rightarrow 2\pi^+2\pi^-$ [66]. Most probably, these structures emerge as a threshold effect due to the opening of the $N\bar{N}$ channel [67,68,69].

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