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 $e^+e^- \to \omega\pi$ [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 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 $e^+e^- \to \eta\pi^+\pi^-$ 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. A clear picture of the two $\pi^+\pi^-$ resonances interfering with the $\rho(770)$ 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 $e^+e^- \to 4\pi$ in the energy range 1.05–1.38 GeV, and by [17] in $\tau \to 4\pi$ decays. CLEO [24] and Belle [25] observe the $\rho(1450) \to \omega\pi$ decay mode in B-meson decays, however, do not find $\rho(1700) \to \omega\pi^0$. A similar conclusion is made by [26], 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 [27,28], 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 [29] (referred to as $C(1480)$) and recently confirmed by [30]. While [31] shows that it may be a threshold effect, [5] and [32] suggest two independent vector states with this decay mode. The $C(1480)$ has not been seen in the $\overline{p}p$ [33] and e^+e^- [34,35] experiments. However, the sensitivity of the two latter is an order of magnitude lower than that of [30]. Note that [30] 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 [36–42] may be interpreted in terms of either $J^P = 1^-$ $\rho(770) \to \omega\pi$ production [43], or $J^P = 1^+$ $b_1(1235)$ production [41,42]. We argue that no special entry for a $\rho(1250)$ is needed. The LASS amplitude analysis [44] showing evidence for $\rho(1270)$ is preliminary and needs confirmation. For completeness, the relevant observations are listed under the $\rho(1450)$.

Recently [45] 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. [46–48] suggest its exotic structure (molecular or multiquark), while [49] and [50] explain it by the interference between the $\rho(1450)$ and $\rho(1700)$. We quote [45] as $X(1575)$ in the section "Further States."

Evidence for ρ-like mesons decaying into 6π states was first noted by [51] in the analysis of 6π mass spectra from e^+e^- annihilation [52,53] and diffractive photoproduction [54]. Clegg [51] 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 $f_1(1285)\pi^+\pi^-$ [55]. The relativistic quark model [56] 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 [57,58]) , by the FENICE experiment (a narrow structure in the R value [59]) , by BaBar in ISR (a narrow structure in $e^+e^- \to \phi\pi$ final state [60], but much broader in $e^+e^- \to 3\pi^+3\pi^-$ and $e^+e^- \to 2(\pi^+\pi^-\pi^0)$ [61]) , by CMD-3 (also a rather broad dip in $e^+e^- \to 3\pi^+3\pi^-$ [62]) . Most probably, these structures emerge as a threshold effect due to the opening of the $N\bar{N}$ channel [63,64].

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