

$\rho(1450)$ 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

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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].

References:

1. C. Erkal, Z. Phys. **C31**, 615 (1986).
2. A. Donnachie and H. Mirzaie, Z. Phys. **C33**, 407 (1987).
3. A. Donnachie and A.B. Clegg, Z. Phys. **C34**, 257 (1987).
4. A. Donnachie and A.B. Clegg, Z. Phys. **C51**, 689 (1991).
5. A.B. Clegg and A. Donnachie, Z. Phys. **C40**, 313 (1988).
6. A.B. Clegg and A. Donnachie, Z. Phys. **C62**, 455 (1994).
7. T.J. Killian *et al.*, Phys. Rev. **D21**, 3005 (1980).
8. S. Fukui *et al.*, Phys. Lett. **B202**, 441 (1988).
9. D. Bisello *et al.*, Phys. Lett. **B220**, 321 (1989).
10. A. Antonelli *et al.*, Phys. Lett. **B212**, 133 (1988).
11. A. Abele *et al.*, Phys. Lett. **B391**, 191 (1997).
12. A. Abele *et al.*, Phys. Rev. **D57**, 3860 (1998).
13. A. Bertin *et al.*, Phys. Lett. **B434**, 180 (1998).
14. A. Abele *et al.*, Phys. Lett. **B468**, 178 (1999).
15. R. Barate *et al.*, Z. Phys. **C76**, 15 (1997).
16. S. Anderson, Phys. Rev. **D61**, 112002 (2000).
17. K.W. Edwards *et al.*, Phys. Rev. **D61**, 072003 (2000).
18. M. Fujikawa *et al.*, Phys. Rev. **D78**, 072006 (2008).
19. J.P. Lees *et al.*, Phys. Rev. **D86**, 032013 (2012).
20. T. Barnes *et al.*, Phys. Rev. **D55**, 4157 (1997).
21. F.E. Close *et al.*, Phys. Rev. **D56**, 1584 (1997).
22. A. Donnachie and Yu.S. Kalashnikova, Phys. Rev. **D60**, 114011 (1999).
23. R.R. Akhmetshin *et al.*, Phys. Lett. **B466**, 392 (1999).
24. J.P. Alexander *et al.*, Phys. Rev. **D64**, 092001 (2001).
25. D. Matvienko *et al.*, Phys. Rev. **D92**, 012013 (2015).
26. R.R. Akhmetshin *et al.*, Phys. Lett. **B562**, 173 (2003).
27. M.N. Achasov *et al.*, Phys. Rev. **D94**, 112001 (2016).
28. A. Abele *et al.*, Eur. Phys. J. **C21**, 261 (2001).
29. M. Bargiotti *et al.*, Phys. Lett. **B561**, 233 (2003).
30. S.I. Bityukov *et al.*, Phys. Lett. **B188**, 383 (1987).
31. B. Aubert *et al.*, Phys. Rev. **D77**, 092002 (2008).
32. N.N. Achasov and G.N. Shestakov, Phys. Atom. Nucl. **59**, 1262 (1996).
33. L.G. Landsberg, Sov. J. Nucl. Phys. **55**, 1051 (1992).
34. A. Abele *et al.*, Phys. Lett. **B415**, 280 (1997).
35. V.M. Aulchenko *et al.*, Sov. Phys. JETP Lett. **45**, 145 (1987).
36. D. Bisello *et al.*, Z. Phys. **C52**, 227 (1991).
37. P. Frenkiel *et al.*, Nucl. Phys. **B47**, 61 (1972).
38. G. Cosme *et al.*, Phys. Lett. **B63**, 352 (1976).
39. D.P. Barber *et al.*, Z. Phys. **C4**, 169 (1980).
40. D. Aston, Phys. Lett. **B92**, 211 (1980).
41. M. Atkinson *et al.*, Nucl. Phys. **B243**, 1 (1984).
42. J.E. Brau *et al.*, Phys. Rev. **D37**, 2379 (1988).
43. C. Amsler *et al.*, Phys. Lett. **B311**, 362 (1993).

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44. J. Layssac and F.M. Renard, Nuovo Cimento **6A**, 134 (1971).
45. D. Aston *et al.*, Nucl. Phys. (Proc. Supp.) **B21**, 105 (1991).
46. M. Ablikim *et al.*, Phys. Rev. Lett. **97**, 142002 (2006).
47. G.-J. Ding and M.-L. Yan, Phys. Lett. **B643**, 33 (2006).
48. F.K. Guo *et al.*, Nucl. Phys. **A773**, 78 (2006).
49. A. Zhang *et al.*, Phys. Rev. **D76**, 036004 (2007).
50. B.A. Li, Phys. Rev. **D76**, 094016 (2007).
51. X. Liu *et al.*, Phys. Rev. **D75**, 074017 (2007).
52. J.P. Lees *et al.*, Phys. Rev. **D88**, 032013 (2013).
53. M.N. Achasov *et al.*, Phys. Rev. **D94**, 112006 (2016).
54. A.B. Clegg and A. Donnachie, Z. Phys. **C45**, 677 (1990).
55. D. Bisello *et al.*, Phys. Lett. **107B**, 145 (1981).
56. A. Castro *et al.*, LAL-88-58(1988).
57. M. Atkinson *et al.*, Z. Phys. **C29**, 333 (1985).
58. B. Aubert *et al.*, Phys. Rev. **D76**, 092005 (2007).
59. S. Godfrey and N. Isgur, Phys. Rev. **D32**, 189 (1985).
60. P.L. Frabetti *et al.*, Phys. Lett. **B514**, 240 (2001).
61. P.L. Frabetti *et al.*, Phys. Lett. **B578**, 290 (2004).
62. A. Antonelli *et al.*, Phys. Lett. **B365**, 427 (1996).
63. B. Aubert *et al.*, Phys. Rev. **D77**, 092002 (2008).
64. B. Aubert *et al.*, Phys. Rev. **D73**, 052003 (2006).
65. R.R. Akhmetshin *et al.*, Phys. Lett. **B723**, 83 (2013).
66. R.R. Akhmetshin *et al.*, Phys. Lett. **B794**, 64 (2019).
67. A. Obrazovsky and S. Serednyakov, Sov. Phys. JETP Lett. **99**, 315 (2014).
68. J. Heidenauer *et al.*, Phys. Rev. **D92**, 054032 (2015).
69. A.I. Milstein and S.G. Salnikov, Nucl. Phys. **A977**, 60 (2018).