STRONG DECAYS OF ρ RADIAL EXCITATIONS *

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(Received July 13, 2000)

We have searched for ρ' decays in $\bar{p}N$ annihilation at rest. They may provide information on the nature of the ρ' states; are they hybrids or $q\bar{q}$ states? A comparison between data and theoretical calculations gives ambiguous results. Furthermore, we have found hints for a radial excitation of the $b_1(1235)$ at 1610 MeV.

PACS numbers: 13.25.Jx

1. Introduction

In 1987, evidence emerged that the 1600 MeV region actually contains two ρ-like resonances. This was the result of the analysis of e^+e^- annihilation into 2π and 4π [1]. In the following years, these analyses have been extended and new data have been included. In a review, Clegg and Donnachie confirmed the evidence for at least two ρ' states and claimed that the ρ's cannot be part of nonets of pure $q\overline{q}$ states [2]. Mixing with additional states seems to be required.

These results were interpreted by Close and Page [4]: the $\rho(1450)$ decays favour a hybrid interpretation while the $\rho(1450)$ mass would suggest a 2^3S_1 $q\overline{q}$ state.

2. Theoretical calculations

Table I shows results of theoretical calculations on the ρ' decays. Using the $^3P_0$ model, the 2^3S_1 and the 1^3D_1 $q\bar{q}$ states show very characteristic differences in their couplings to the 4π final states. The 2^3S_1 state couples

* Presented at the Meson 2000, Sixth International Workshop on Production, Properties and Interaction of Mesons, Cracow, Poland, May 19–23, 2000.

very weakly to all of them whereas the 1^3D_1 state couples strongly to both πa_1 and πh_1. Both states have moderately large couplings to $\pi\pi$ and $\pi\omega$.

Within the flux-tube model the suppression of πh_1 relative to πa_1 is a crucial test of a hybrid ρ' state. The decay into 2π is predicted to vanish.

TABLE I

Partial decay widths for ρ' states. A "-" denotes a decay not yet calculated.

Decay mode	$\pi\pi$	$\pi\omega$	πa_2	πa_1	πh_1	$\rho\rho$	$\pi^*\pi$	$\rho\sigma$	$K\overline{K}$
Calculated partial widths in the $^3P_0$ model [3]:									
2^3S_1 $\rho(1465)$	74	122	0	3	1	0	-	-	35
1^3D_1 $\rho(1700)$	48	35	2	134	124	0	14	-	36
3^3S_1 $\rho(1900)$	1	5	46	26	32	70	16	-	1
Calculated partial widths in the flux-tube model [4]:									
Hybrid $\rho(\sim 1500)$	0	5–10	~ 0	140	0	0	0	-	-

3. $\rho(1450)$ and $\rho(1700)$ decays observed by Crystal Barrel

In the following subsections different channels of $\bar{p}d$-annihilation at rest into ρ' and a recoiling pion will be presented. For all these channels, a cut on the proton spectator momentum of 100 MeV ensures that the annihilation takes place on a quasi-free neutron.

3.1. $\bar{p}d \to \pi^-\pi^0\pi^0 p_{\text{spectator}}$

Figure 1(a) shows the symmetrized Dalitz-plot for $\bar{p}d$-annihilation into $\pi^-\pi^0\pi^0$ plus spectator proton [5]. The most prominent structures are vertical and horizontal bands due to the $\rho^-(770)$ decay into $\pi^-\pi^0$. In the diagonal, a band arises from the f_2 decaying into $\pi^0\pi^0$. Furthermore, a band-structure due to the $f_0(1500)$ also decaying into $\pi^0\pi^0$ is visible.

The description of the enhancement on the right upper side of the phase space requires a ρ' state at 1410 MeV. The high-mass region requires a 1780 MeV ρ' state.

3.2. $\bar{p}d \to K_SK^-\pi^0 p_{\text{spectator}}$ $(K_S \to \pi^+\pi^-)$

The main structure in the Dalitz-plot (Fig. 1(b)) for $\bar{p}d \to K_SK^-\pi^0 p_{\text{spec}}$ are the crossing $K^*(892)$ bands. A good description of the data requires two ρ' states — the $\rho(1450)$ and the $\rho(1700)$.

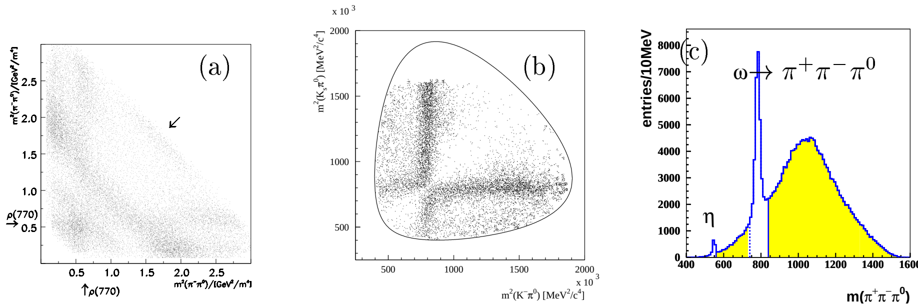


Fig. 1. (a) $\bar{p}d \to \pi^-\pi^0\pi^0 p_{\rm spec}$: symmetrized Dalitz-plot; (b) $\bar{p}d \to K_S K^- \pi^0 p_{\rm spec}$ ($K_S \to \pi^+\pi^-$): Dalitz-plot — a cut for slow K^- momenta has been applied due to problems in the Monte Carlo simulation for this kinematical region [6]; (c) $\bar{p}d \to \omega\pi^-\pi^0 p_{\rm spec}$: invariant $\pi^+\pi^-\pi^0$ mass.

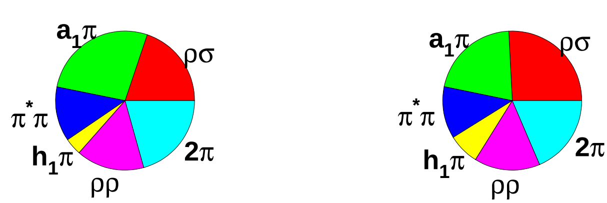
3.3. $\bar{p}d \to \pi^+\pi^-\pi^-\pi^0\pi^0 p_{\rm spectator}$ and $\bar{p}d \to \pi^-\pi^0\pi^0\pi^0\pi^0 p_{\rm spectator}$

A simultaneous analysis of two different 5π final states from $\bar{p}d$-annihilation at rest has been used to study the decays of both the $\rho(1450)$ and the $\rho(1700)$ into 4π [7]. Table II illustrates the decay rates of the ρ' states. The normalization does not include the $\pi\omega$ channel.

TABLE II

ρ' decay rates normalized to all 4π decays without $\pi\omega$.

$\bar{p}n \to \rho(1450)\pi$	$\bar{p}n \to \rho(1700)\pi$
$m = 1435$ MeV $\quad \Gamma = 325$ MeV	$m = 1700$ MeV $\quad \Gamma = 235$ MeV



3.4. $\bar{p}d \to \omega\pi^-\pi^0 p_{\rm spectator}$ $\quad(\omega \to \pi^+\pi^-\pi^0)$

An important channel for the study of the ρ' decays is $\bar{p}d$-annihilation into $\omega\pi^-\pi^0 p_{\rm spec}$. Since the ω decays into $\pi^+\pi^-\pi^0$, this data is part of $\bar{p}d \to \pi^+\pi^-\pi^-\pi^0\pi^0 p_{\rm spec}$ as shown in Fig. 1(c). Since the 5π background below the ω-signal is well known, a partial wave analysis for this channel can be performed.

A scan for one ρ' with fixed mass and width for every scan-point yields a clear optimum at 1760 MeV. A scan with two ρ' states, one with the fixed mass of 1700 MeV and the other one varied, shows no evidence of a coupling of $\rho(1450)$ to $\pi\omega$.

4. Comparison between theory and experimental results

The results will now be compared to the theoretical partial decay widths (in MeV) shown in Table I. The ratios of $2\pi : 4\pi : \pi\omega$ are listed in Table III.

The interpretation of the $\rho(1450)$ as a 2^3S_1 state is in conflict with data. The theoretical prediction demands a large coupling to $\pi\pi$ and $\pi\omega$ and small coupling to 4π. The hybrid interpretation needs a large decay width to πa_1 supported by data; but the $\pi\pi$ coupling is not small.

TABLE III

Comparison between theory and experimental results (preliminary).

		2π	4π	$\pi\omega$
	hybrid	0	28	1–2
	$2^3S_1\,\rho(1465)$	1	0.05	1.7
	$1^3D_1, \rho(1700)$	1	5.7	0.7
	$3^3S_1\,\rho(1900)$	1	190	0.2
$\rho(1450)$	Crystal Barrel	1	3.8 ± 0.3	weak(?)
$\rho(1700)$	Crystal Barrel	1	4.3 ± 0.2	seen

The $\rho(1700)$ decays strongly to πa_1 like the hybrid or the 1^3D_1 state. The $\pi\pi$ decay and its mass prefer the 1^3D_1 interpretation.

Within the model predictions, the date are in conflict with a pure $q\overline{q}$ or hybrid interpretation. Mixing can occur and my possibly explain the observed decay rates. But then a third state in this mass region should be present.

5. Radial excitation of $b_1(1235)$ — the 2P $\mathrm{b_1}(1600)$

A scan for a additional b_1 state yields a strong signal in $2\ln(\mathcal{L})$ at a mass of 1610 MeV. Likely, this evidences a radial excitation of the $b_1(1235)$ ground state. Recent observations of $a_1'(1700)$ at CLEO, VES and E852 (BNL) [8] and $h_1(1600)$ at E852 [9] support the conjecture that the radial excitations have lower masses than expected.

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