Strong decays of $\boldsymbol{\rho}$ radial excitations*

Burkhard Pick

representing the Crystal Barrel Collaboration

Institut für Strahlen-und Kernphysik der Universität Bonn
Nußalle 14-16, 53115 Bonn, Germany

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.

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

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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	–	–

Table 1. Partial decay widths for ρ'-states. A "–" denotes a decay not yet calculated.

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

Figure 1a) 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.

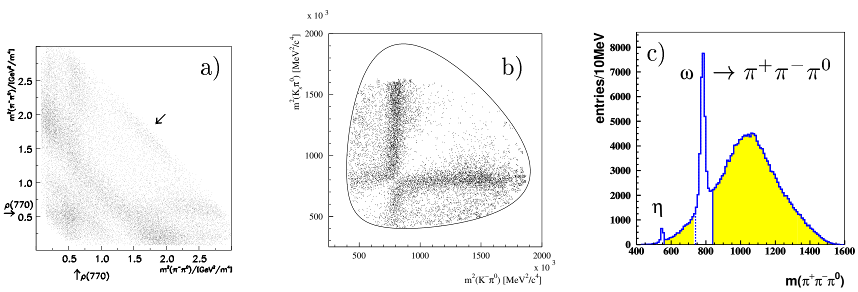


Fig. 1. a) $\bar{p}d \to \pi^-\pi^0\pi^0 p_{spec}$: symmetrized Dalitz-plot. b) $\bar{p}d \to K_S K^-\pi^0 p_{spec}$ ($K_S \to \pi^+\pi^-$): Dalitz-plot. A cut for slow K^- momenta has been applied due to problems in the Monte Carlo simulation for this kinematical region [6]. c) $\bar{p}d \to \omega\pi^-\pi^0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

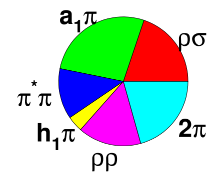
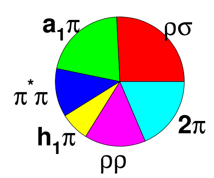
$\bar{\mathrm{p}}\mathrm{n} \to \rho(1450)\pi$	$\bar{\mathrm{p}}\mathrm{n} \to \rho(1700)\pi$
$m = 1435\,\mathrm{MeV} \quad \Gamma = 325\,\mathrm{MeV}$	$m = 1700\,\mathrm{MeV} \quad \Gamma = 235\,\mathrm{MeV}$
	

Table 2. ρ' decay rates normalized to all 4π decays without $\pi\omega$.

3.2. $\bar{\mathrm{p}}\mathrm{d} \to K_{\mathrm{S}} K^- \pi^0 \mathrm{p}_{\mathrm{spectator}}$ $(K_{\mathrm{S}} \to \pi^+\pi^-)$

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

3.3. $\bar{\mathrm{p}}\mathrm{d} \to \pi^+\pi^-\pi^-\pi^0\pi^0\mathrm{p}_{\mathrm{spectator}}$ *and* $\bar{\mathrm{p}}\mathrm{d} \to \pi^-\pi^0\pi^0\pi^0\pi^0\mathrm{p}_{\mathrm{spectator}}$

A simultaneous analysis of two different 5π final states from $\bar{\mathrm{p}}$d-annihilation at rest has been used to study the decays of both the $\rho(1450)$ and the $\rho(1700)$ into 4π [7]. Table 3.3 illustrates the decay rates of the ρ'-states. The normalization does not include the $\pi\omega$ channel.

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

An important channel for the study of the ρ'-decays is $\bar{\mathrm{p}}$d-annihilation into $\omega\pi^-\pi^0\mathrm{p_{spec}}$. Since the ω decays into $\pi^+\pi^-\pi^0$, this data is part of $\bar{\mathrm{p}}\mathrm{d} \to \pi^+\pi^-\pi^-\pi^0\pi^0\mathrm{p_{spec}}$ as shown in Figure 1c). 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 1. The ratios of $2\pi : 4\pi : \pi\omega$ are listed in Table 3.

The interpretation of the $\rho(1450)$ as a $2^3\mathrm{S}_1$ state is in conflict with data. The theoretical prediction demands a large coupling to $\pi\pi$ and $\pi\omega$ and small

		2π		4π		$\pi\omega$
	hybrid	0	:	28	:	1–2
	$2^3\mathrm{S}_1\,\rho(1465)$	1	:	0.05	:	1.7
	$1^3\mathrm{D}_1, \rho(1700)$	1	:	5.7	:	0.7
	$3^3\mathrm{S}_1\,\rho(1900)$	1	:	190	:	0.2
$\rho(1450)$	Crystal Barrel	1	:	3.8 ± 0.3	:	weak(?)
$\rho(1700)$	Crystal Barrel	1	:	4.3 ± 0.2	:	seen

Table 3. Comparison between theory and and experimental results.

coupling to 4π. The hybrid interpretation needs a large decay width to $\pi\mathrm{a}_1$ supported by data; but the $\pi\pi$ coupling is not small.

The $\rho(1700)$ decays strongly to $\pi\mathrm{a}_1$ like the hybrid or the $1^3\mathrm{D}_1$ state. The $\pi\pi$ decay and its mass prefer the $1^3\mathrm{D}_1$ interpretation.

Within the model predictions, the date are in conflict with a pure $\mathrm{q}\overline{\mathrm{q}}$ 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 $\mathbf{b_1(1235)}$ – the 2P $\mathbf{b_1(1600)}$

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 $\mathrm{b}_1(1235)$ ground state. Recent observations of a $a_1'(1700)$ at CLEO, VES and E852 (BNL) [8] and a $\mathrm{h}_1(1600)$ at E852 [9] support the conjecture that the radial excitations have lower masses than expected.

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