ρ'-decays in $\bar{p}d$ annihilation

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ρ'-states have been studied in several decay modes observed in data on $\bar{p}d$ annihilation at rest with the Crystal Barrel detector at LEAR. A comparison between the experimental results and theoretical calculations gives hints about the nature of the ρ' states.

1. INTRODUCTION

As a result of the analysis of e^+e^--annihilation into 2π and 4π [1], evidence emerged in 1987 that the 1600 MeV region actually contains two ρ-like resonances. This fact and the following analysis were summarized by Clegg and Donnachie [2]. They confirm the definite evidence for at least two ρ'-states and suggest that the ρ's are mixed states of conventional quarkonia and hybrid states.

These results were further interpreted by Close and Page [3,4]: The $\rho(1450)$ decays favor a hybrid interpretation while its mass would suggest a 2^3S_1 $q\bar{q}$ state. Table 2 contains results on theoretical calculations concerning ρ'-decays. The calculations were based on the $^3P_0$-model; the result shows a very characteristic difference between the 2S and the 1D states. These are evident in their couplings to the 4π final states. 2S couples very weakly to these whereas 1D couples very strongly to both πa_1 and πh_1. Moreover, both $q\bar{q}$-states have moderately large couplings to $\pi\pi$ and $\pi\omega$. Hybrid decays can be calculated within the flux-tube model [3]. The decay into πh_1 is suppressed relative to πa_1 and decays into 2π are weak.

In order to disentangle the nature of the ρ'-states we analysed Crystal Barrel data. In particular, we investigated their decays into 2π, 4π and $\pi\omega$.

2. $\rho(1450)$ AND $\rho(1700)$ DECAYS OBSERVED BY CRYSTAL BARREL

The ρ'-states have been studied in various final states of $\bar{p}d$ annihilation at rest which will be discussed in the following. 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.

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

Figure 1 (left) shows the symmetrized Dalitz-plot for $\bar{p}d$-annihilation into $\pi^-\pi^0\pi^0$ plus spectator proton [5]. Here the invariant masses squared for the π^- combined with one π^0 are plotted versus the combination with the other π^0. The description of the enhancement at the right upper side of the phase space needs two ρ'-states decaying into $\pi^-\pi^0$. The prominent structures are vertical and horizontal bands due to the $\rho^-(770)$ decaying into

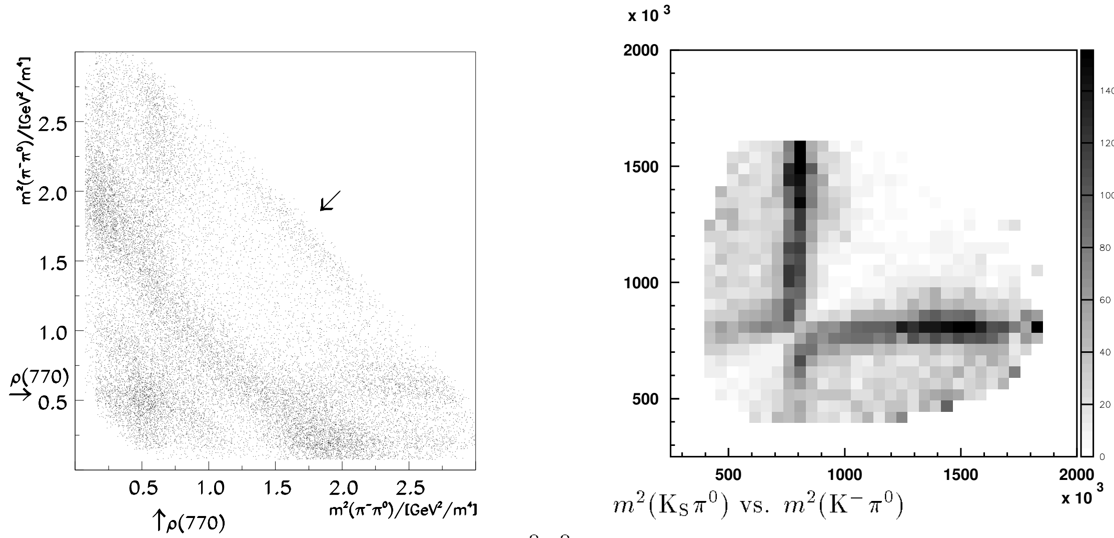


Figure 1. left: $\bar{\mathrm{p}}\mathrm{d} \rightarrow \pi^-\pi^0\pi^0\mathrm{p}_{\mathrm{spec}}$: symmetrized Dalitz-plot. right: $\bar{\mathrm{p}}\mathrm{d} \rightarrow \mathrm{K_S K^-}\pi^0\mathrm{p}_{\mathrm{spec}}\,(\mathrm{K_S} \rightarrow \pi^+\pi^-)$: Dalitz-plot. A cut for slow K^- momenta has been applied due to problems in the Monte Carlo simulation for this kinematical region.

$\pi^-\pi^0$. In the diagonal two bands arise from the $\mathrm{f}_2(1270)$ and the $\mathrm{f}_0(1500)$ decaying into $\pi^0\pi^0$.

2.2. $\bar{\mathrm{p}}\mathrm{d} \rightarrow \mathbf{K_S K}^-\pi^0\mathrm{p}_{\mathrm{spectator}}\,(\mathbf{K_S} \rightarrow \pi^+\pi^-)$

Figure 1 (right) shows the Dalitz-plot for $\bar{\mathrm{p}}\mathrm{d} \rightarrow \mathrm{K_S K^-}\pi^0\mathrm{p}_{\mathrm{spec}}$. The main structure are the crossing K*(892) bands. The description of the data needs two ρ'-states, the $\rho(1450)$ and the $\rho(1700)$.

2.3. $\bar{\mathrm{p}}\mathrm{d} \rightarrow \pi^+\pi^-\pi^-\pi^0\pi^0\mathrm{p}_{\mathrm{spectator}}$ and $\bar{\mathrm{p}}\mathrm{d} \rightarrow \pi^-\pi^0\pi^0\pi^0\pi^0\mathrm{p}_{\mathrm{spectator}}$

A simultaneous analysis of two different 5π final states from $\bar{\mathrm{p}}\mathrm{d}$-annihilation at rest has been used to study the decays of both the $\rho(1450)$ and the $\rho(1700)$ into 4π [6]. From the partial wave analysis we obtain that about 5% of $\bar{\mathrm{p}}\mathrm{n}$-annihilations into $\pi^+\pi^-\pi^-\pi^0\pi^0$ decay into $\rho(1450)\pi$. The upper left pie chart in Table 1 illustrates the decay fractions of the $\rho(1450)$ into $\pi\mathrm{a}_1$, $\rho\sigma$, $\rho\rho$, $\pi^*\pi$ and $\pi\mathrm{h}_1$. They are of similar stengths.

For the decay of the $\rho(1700)$ the fraction for $\pi\mathrm{h}_1$ dominates. The pie charts in the right column illustrate the $\rho(1450)$ and $\rho(1700)$ decay fraction observed in the $\pi^-\pi^0\pi^0\pi^0\pi^0$ channel.

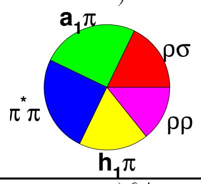
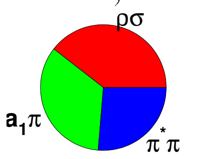
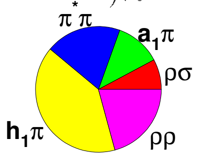
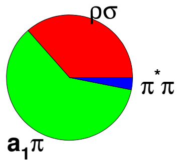
2.4. $\bar{\mathrm{p}}\mathrm{d} \rightarrow \omega\pi^-\pi^0\mathrm{p}_{\mathrm{spectator}} \quad (\omega \rightarrow \pi^+\pi^-\pi^0)$

An important channel for the study of the ρ'-decays is $\bar{\mathrm{p}}\mathrm{d}$-annihilation into $\omega\pi^-\pi^0\mathrm{p}_{\mathrm{spec}}$. Since the ω decays into $\pi^+\pi^-\pi^0$, this data is part of $\bar{\mathrm{p}}\mathrm{d} \rightarrow \pi^+\pi^-\pi^-\pi^0\pi^0\mathrm{p}_{\mathrm{spec}}$ discussed above. Figure 2 (left) shows the invariant $\pi^+\pi^-\pi^0$ mass distribution for all four combinations.

The 5π background below the ω-signal is well known from the partial wave analysis mentioned above. This allows a subtraction and a cut for the ω-signal to produce the Dalitz-Plot shown in Figure 2 (right). The main structure in the diagonal is due to the $\rho^-(770)$ decaying into $\pi^-\pi^0$.

A scan for one ρ' within the framework of a partial wave analysis with fixed mass and

Table 1
Decay fraction for ρ'-decay observed in $\bar{\mathrm{p}}\mathrm{d} \to 5\pi \mathrm{p}_{\mathrm{spec}}$.

$\bar{\mathrm{p}}\mathrm{n} \to$	$\pi^+\pi^-\pi^-\pi^0\pi^0$	$\pi^-\pi^0\pi^0\pi^0\pi^0$
$\rho(1450)\pi$ $m = 1435\,\mathrm{MeV}$ $\Gamma = 325\,\mathrm{MeV}$	$(4.8 \pm 0.9)\%$ 	$(3.8 \pm 0.2)\%$ 
$\rho(1700)\pi$ $m = 1700\,\mathrm{MeV}$ $\Gamma = 235\,\mathrm{MeV}$	$(5.3 \pm 1.0)\%$ 	$(9.6 \pm 1.0)\%$ 

width for every scanpoint yields a variation of $2\ln(\mathcal{L})$. There is some evidence for two ρ'-like structures in the regions around 1435 MeV and 1760 MeV.

3. COMPARISON BETWEEN THEORY AND EXPERIMENTAL RESULTS

The results will now be compared to the theoretical branching fractions (in MeV) as shown in Table 2. Therefore, the experimental branching fractions of the ρ' have been normalised to one characteristic channel of the theoretical calculations.

For the $\rho(1450)$ we find a strong decay into πa_1 but also decays into πh_1 and $\pi\pi$. Hybrids should not decay into the latter two modes. Yet there is also no agreement between the πa_1 and πh_1 decay rates and thoses expected for the 2S radial excitations. The decay

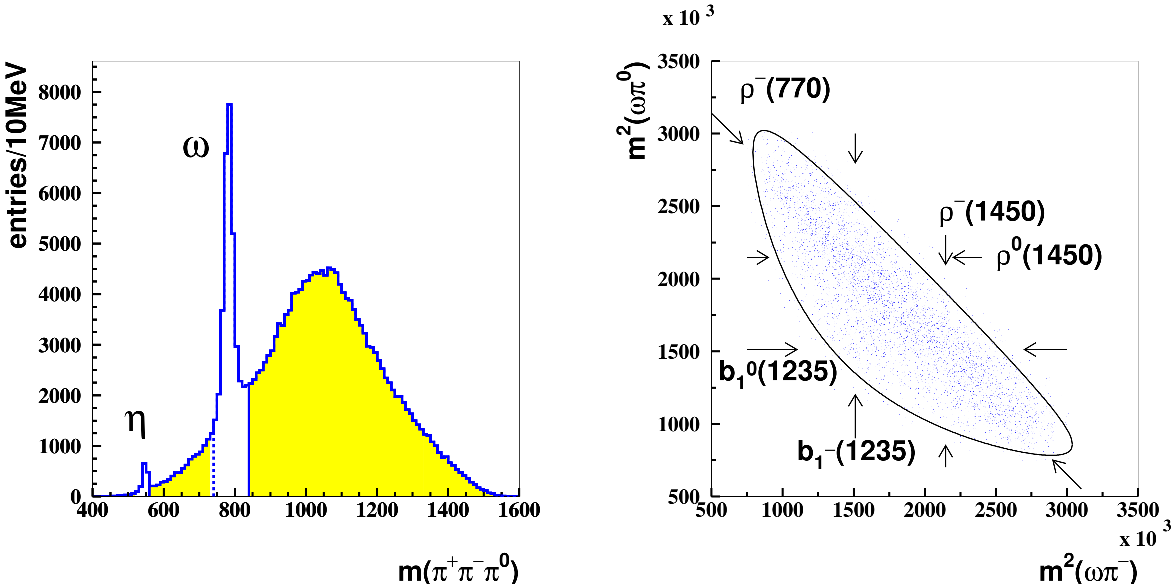


Figure 2. $\bar{\mathrm{p}}\mathrm{d} \to \omega\pi^-\pi^0\mathrm{p}_{\mathrm{spec}}$ (12 748 events): invariant $\pi^+\pi^-\pi^0$ mass and Dalitz-plot. The arrows mark the positions of the $\mathrm{b}_1(1235)$ and the $\rho(1450)$.

Table 2
Partial widths of ρ'-states calculated within the $^3P_0$-model [7] and the flux-tube-model [7]. *: Channel for normalisation.

decay mode	$\pi\pi$	$\pi\omega$	πa_2	πa_1	πh_1	$\rho\rho$	$\pi^*\pi$	$\rho\sigma$	$K\overline{K}$
$2^3S_1\,\rho(1465)$ [7]	74	122	0	3	1	0	–	–	35
$\rho(1450)$ Crystal Barrel	74*	seen		185 $\pm$111	82 $\pm$74	67 $\pm$30	185 $\pm$185	163 $\pm$126	seen
$1^3D_1\,\rho(1700)$ [7]	48	35	2	134	124	0	14	–	36
$\rho(1450)$ Crystal Barrel	48*	seen		120 $\pm$72	53 $\pm$48	43 $\pm$19	120 $\pm$120	106 $\pm$82	seen
Hybrid-$\rho(\sim 1500)$ [8]	0	5–10	~ 0	140	0	0	0	–	–
$\rho(1450)$ Crystal Barrel	56	seen		140* $\pm$84	62 $\pm$56	50 $\pm$22	140 $\pm$140	123 $\pm$95	seen
$1^3D_1\,\rho(1700)$ [7]	48	35	2	134	124	0	14	–	36
$\rho(1700)$ Crystal Barrel	48*	seen		139 $\pm$67	182 $\pm$173	96 $\pm$58	130 $\pm$120	96 $\pm$53	seen
$3^3S_1\,\rho(1900)$ [7]	1	5	46	26	32	70	16	–	1
$\rho(1700)$ Crystal Barrel	1*	seen		2.9 $\pm$1.4	3.8 $\pm$3.6	2.0 $\pm$1.2	2.7 $\pm$2.5	2.0 $\pm$1.1	seen

pattern of the $\rho(1450)$ is not inconsistent with the pattern expected for the 1^3D_1 state but experimental and calculated masses disfavor this interpretation.

The comparison of the 2π and 4π decay fractions shows that the $\rho(1450)$ suggests that the $\rho(1450)$ is not a pure 2^3S_1 state but could be mixed with a hybrid.

hybrid	2π	:	4π	=	0	:	140
2^3S_1					1	:	0.05
Crystal Barrel					1	:	9.2 ± 3.5

For the $\rho(1700)$, our results favor the 1D state:

1^3D_1	2π	:	4π	=	1	:	5.7
3^3S_1					1	:	190
Crystal Barrel					1	:	13.4 ± 4.9

while the assignment $\rho(1700) = 2^3S_1$ is less plausible.

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