Study of $\bar{p}N$ annihilations into five pions

U. Thoma (for the Crystal Barrel Collaboration) [a]

[a]Institut für Strahlen- und Kernphysik, Nussallee 14-16, D-53115 Bonn, Germany

The preliminary analysis of four high statistic 5π data sets taken with the Crystal Barrel detector shows that at least two scalar states are needed to describe the data, the $f_0(1370)$ with $m = 1395 \pm 40\,\mathrm{MeV}/c^2$, $\Gamma = 275 \pm 55\,MeV/c^2$ and the $f_0(1500)$ with mass and width compatible with previous findings. The first one decays dominantely into $\sigma\sigma$ and $\rho\rho$, the second one into $\sigma\sigma$ and $\pi^*(1300)\pi$. In addition to the dominant scalar intensity the $\pi^*(1300)$ plays an important role in the 5π-dynamics. We found a mass of $m = 1375 \pm 40\,\mathrm{Me}V/c^2$ and a width of $\Gamma = 268 \pm 50\,MeV/c^2$ with a dominat decay into $\rho\pi$. The $(\pi\pi)_s\pi$ decay of the $\pi^*(1300)$ is less than 15% of its $\rho\pi$ decay as expected for a radial excitation of the π.

1. Introduction

The $f_0(1370)$ and $f_0(1500)$ have been studied in detail in $\bar{p}p$ annihilations at rest by the Crystal Barrel Collaboration[1]–[3]. The peculiar decay pattern of the $f_0(1500)$ into two pseudo-scalar mesons led to the speculation it may be the scalar glueball mixed with normal scalar mesons[4][5]. Of particular importance for any interpretation are the decays of the $f_0(1500)$ into four pions[6] to disentangle the glueball content of the observed states.

2. Data and partial wave analysis

In order to address these questions, we have examined both $\bar{p}d$ and $\bar{p}p$ annihilation at rest into five–pion final states.

$$\bar{p}p \to 5\pi^0 \quad \bar{p}d \to \pi^-4\pi^0 p_{spectator} \quad \bar{p}p \to \pi^+\pi^-3\pi^0 \quad \bar{p}d \to \pi^+2\pi^-2\pi^0 p_{spectator}$$

The different data sets were recorded by stopping antiprotons from LEAR in a liquid hydrogen or in a liquid deuterium target. The Crystal Barrel detector is equipped for charged particle tracking in a magnetic field of 1.5 T and is able to measure photons with high precision in a CsI calorimeter covering 98% of 4π[7]. The data was taken with a trigger on the corresponding number of charged particle; more than 30 000 events were retained for the final analysis for all four reactions. In annihilations in deuterium we asked for a proton momentum lower than 100 MeV/c in order to select reactions on quasi-free neutrons. In addition an anticut on $\eta, \omega \to 3\pi$ was applied. The analysis of the four different data sets allows to profit from their different sensitivities with respect to different resonances and decay modes and provides important constraints for the fit.

The neutral 4π invariant mass distributions for the four data sets are shown in Fig.1. In all data a clear enhancement compared to phase space is visible in the region of 1500 MeV/c^2. This is a first hint for the existence of the $f_0(1500)$. Fig.2 shows some additional

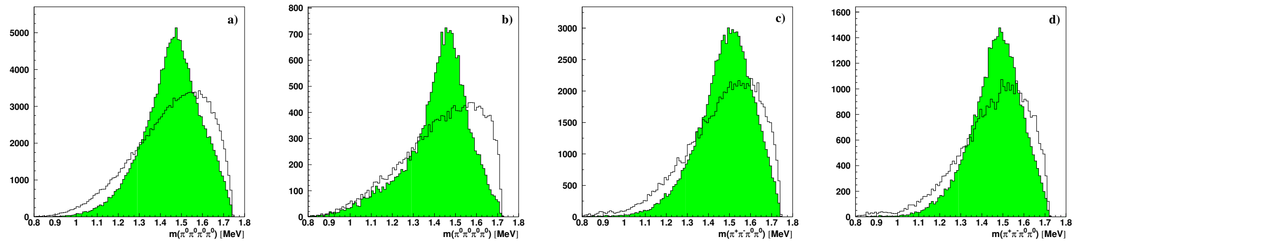

Figure 1. Neutral 4π invariant mass for all four data sets: (a) $5\pi^0$, (b) $\pi^-4\pi^0$, (c) $\pi^+\pi^-3\pi^0$ and (d) $\pi^+2\pi^-2\pi^0$. Shaded distribution shows: data, curve: phasespace.

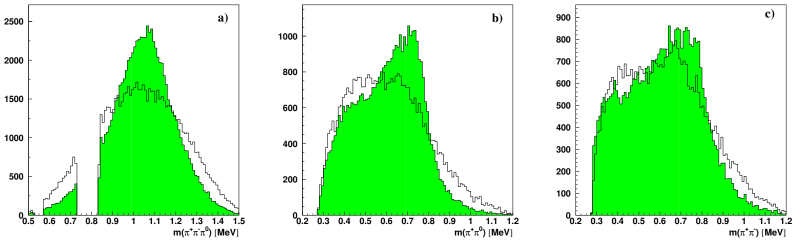

Figure 2. (a) $\pi^+\pi^-\pi^0$, (b) $\pi^+\pi^0$, and (c) $\pi^+\pi^-$ invariant mass of the $\pi^+2\pi^-2\pi^0$ data set. The shaded distribution shows the data, the curve the phasespace.

invariant mass distributions, now only for the $\pi^+2\pi^-2\pi^0$ data set. Fig.1 and 2 suggest contributions from particles like $f_0(1500)$, $\rho'(1450)$ and the charged and neutral $\rho(770)$. In addition, particles like the σ (σ is always used as shorthand for the full $\pi\pi$-S-wave) and the $\pi^*(1300)$ may contribute. The amplitudes listed in Tab.1 are used in the fits. In the following the results are summarized obtained for the π^* and the scalar mesons. For the ρ'-states see [8].

2.1. The $\pi^*(1300)$

The $\pi^*(1300)$ plays a role in the $\pi^*\pi$-decays of f_0- and ρ'-states and in the direct production with a σ or a ρ. It was found that the π^* decays dominantly into $\rho\pi$. Fig.3a,b shows a scan of the π^* mass and width for the $\pi^-4\pi^0$-data set. While the scan for the $\pi^* \to \rho\pi$-decay shows a clear maximum in $\log(\mathcal{L})$, which indicates that we observe this decay mode, the scan for $\pi^* \to \sigma\pi$ does not show evidence for the $\sigma\pi$ decay mode. If both partial widths are left free we get an upper limit of 15% for the $\sigma\pi$-decay mode. The mass and width for the $\pi^*(1300)$ was found to be m=(1375 ± 40)MeV and Γ=(268 ± 50)MeV.

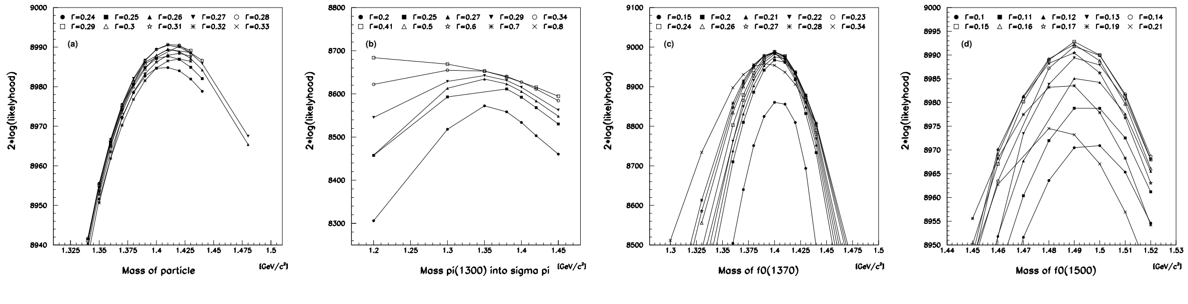

Figure 3. Scan of the π^* mass and width; a) only the decay $\pi^* \to \rho\pi$ allowed, b) only $\sigma\pi$-decay mode. Scan of c) $f_0(1370)$ and d) $f_0(1500)$ mass and width. The different curves indicate different widths of the scanned particle, the best description of the data is reached at a maximum in $\ln(\mathcal{L})$. All amplitudes given in Tab.1 have been introduced.

Table 1
Amplitudes examined for the four 5π data sets. The π^*, a_1, h_1 and the a_2 decay into $\rho\pi$. Amplitudes including the $\pi^* \to \sigma\pi$ decay have also been tried but were found to be negligible.

	$5\pi^0$	$\pi^-4\pi^0$	$\pi^+\pi^-3\pi^0$	$\pi^+2\pi^-2\pi^0$	
$\bar{p}N \to f_0\pi;\quad f_0 \to \sigma\sigma$	x	x	x	x	$f_0(1370)$,
$\bar{p}N \to f_0\pi;\quad f_0 \to \rho\rho$			x	x	$f_0(1500)$
$\bar{p}N \to f_0\pi;\quad f_0 \to \pi^*\pi$	x	x	x	x	
$\bar{p}N \to f_0\pi;\quad f_0 \to \pi^*\pi$			x	x	
$\bar{p}N \to f_0\pi;\quad f_0 \to a_1\pi$			x	x	
$\bar{p}N \to \rho'\pi;\quad \rho' \to \rho\sigma$		x	x	x	$\rho'(1450)$,
$\bar{p}N \to \rho'\pi;\quad \rho' \to a_1\pi$		x	x	x	$\rho'(1700)$
$\bar{p}N \to \rho'\pi;\quad \rho' \to h_1\pi$			x	x	
$\bar{p}N \to \rho'\pi;\quad \rho' \to \pi^*\pi$		x	x	x	
$\bar{p}N \to \rho'\pi;\quad \rho' \to \rho\rho$			x	x	$\rho'(1450)$,
$\bar{p}N \to \pi^*\sigma;$		x	x	x	$\pi^*(1300)$
$\bar{p}N \to \pi^*\rho;$			x	x	$\pi^*(1300)$
$\bar{p}N \to f_2\pi;\quad f_2 \to \sigma\sigma$	x	x	x	x	$f_2(1270)$,
$\bar{p}N \to f_2\pi;\quad f_2 \to \rho\rho$			x	x	$f_2(1565)$
$\bar{p}N \to f_2\pi;\quad f_2 \to a_2\pi$			x	x	
$\bar{p}N \to a_1\sigma;$		x	x	x	$a_1(1260)$
$\bar{p}N \to a_1\rho;$			x	x	$a_1(1260)$
$\bar{p}N \to h_1\rho;$				x	$h_1(1170)$
$\bar{p}N \to a_2\rho;$			x	x	$a_2(1320)$

2.2. The f_0 states

The $\pi^-4\pi^0$-data set is the most sensitive to scalar contributions since there is only one combination to form a f_0 and since the number of allowed intermediate states is smaller than in the data sets involving more charged pions (see Tab.1). The data definitely demands two scalar states. The fit to the mass and width of these two states optimize at $m = 1395 \pm 40\,\mathrm{MeV}/c^2$ and $\Gamma = 275 \pm 55\,\mathrm{MeV}/c^2$ for the lighter state and to $m = 1490 \pm 30\,\mathrm{MeV}/c^2$ and $\Gamma = 140 \pm 40\,\mathrm{MeV}/c^2$ for the heavier state. The maxima in ln(L) of the two states are shown in Fig. 3c,d. As visible in Fig.3d the width of the more massive state is consistent with 130 MeV. This value leads to a better consistency with the $\bar{p}p \to 5\pi^0$ data and is in a close agreement with earlier publications. Therefore we impose this value in all further fits.

Summarizing the results obtained from the fits to all data sets, the following relative decay fractions of the scalar states were found:

$$f_0(1370): \quad \frac{\rho\rho}{\sigma\sigma} = 0.6 \pm 0.2 \quad \frac{a_1\pi}{\sigma\sigma} = 0.2 \pm 0.1 \quad \frac{\pi^*(1300)\pi}{\sigma\sigma} < 0.18$$
$$f_0(1500): \quad \frac{\rho\rho}{\sigma\sigma} < 0.3 \quad \frac{a_1\pi}{\sigma\sigma} = 0.3 \pm 0.2 \quad \frac{\pi^*(1300)\pi}{\sigma\sigma} = 0.7 \pm 0.5$$

Fig 4. shows the final fit for the $\pi^-4\pi^0$ data set. Masses and widths of the scalar states as well as their relative production strength determined from the $\pi^-4\pi^0$ data set can now be introduced in the $5\pi^0$ data set. The result for this fit with only one free parameter – the relative phase between the two f_0's – is shown in Fig. 5. The fit nicely agrees with the data. From this data we derived branching ratios given in Tab. 2 using the determined

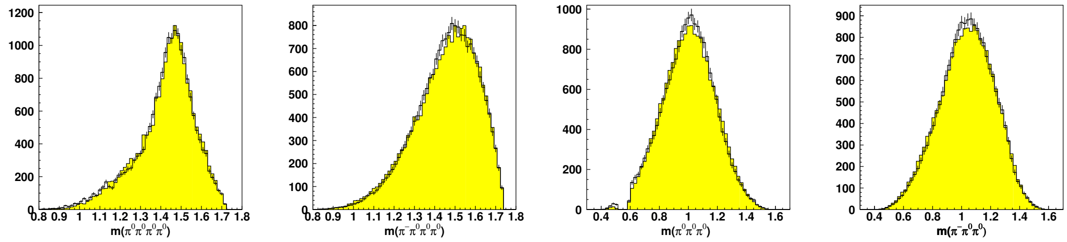

Figure 4. A comparison between the data, (points with error bars), and the fit, (shaded region), to the $\pi^-4\pi^0$ data set. The effect of the η–anti-cut in the $3\pi^0$–invariant mass is clearly visible.

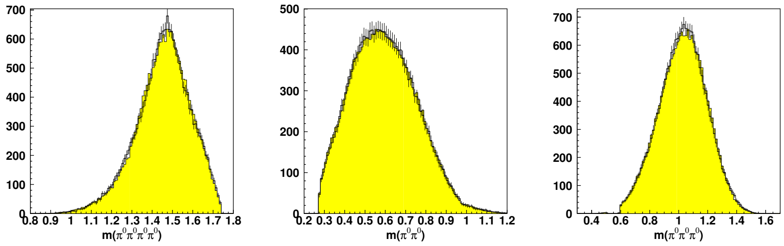

Figure 5. Quality of the fit to the $5\pi^0$ data. Masses, widths and the relative production strength of the particles have been fixed to the results found in fitting the $\pi^-4\pi^0$ data set. Data: line with error bars, fit: shaded area.

relative ratios for the different 4π-decay modes. The 4π-decay modes of the $f_0(1370)$ clearly dominate all other observed decay modes while for the $f_0(1500)$ they are in the same order of magnitude as the sum of all decays into two pseudoscalar states.

Table 2
4π-branching ratios for $f_0(1370)$ and $f_0(1500)$ in comparison with the branching ratios into two pseudoscalar states (in units of 10^{-4}). The later branching ratios are taken from [9].

	$\sigma\sigma$	$\rho\rho$	$\pi^*\pi$	$a_1\pi$	4π
$f_0(1370)$	127.6±39.6	78.0±34.3	<20.0	28.0 ±16.8	234.
$f_0(1500)$	19.0±11.9	<6.0	13.2±13.0	6.0±5.4	38.
	$\pi\pi$	$\eta\eta$	$\eta\eta'$	KK	$\sum$
$f_0(1370)$	19.2 ± 7.2	0.4± 0.2		$7.0 \pm 1.6 - 18.8 \pm 4.0$	32.5
$f_0(1500)$	24.6 ± 2.7	1.91±0.24	1.61 ± 0.06	4.52±0.36	32.6

REFERENCES

1. V. V. Anisovich *et al.*, Phys. Lett. **B323**, 233 (1994).
2. C. Amsler *et al.*, Phys. Lett. **B340**, 259 (1994), **B342**, 433 (1995), **B353**, 571 (1995), **B355**, 425 (1995).
3. A. Abele *et al.*, Phys. Lett. **B385**, 425 (1996).
4. C. Amsler and F. Close, Phys. Rev. **D53** 295 (1996).
5. J. Sexton *et al.*, Phys. Rev. Lett. **75** 4563 (1995).
6. M. Strohmeier-Presicek *et al.*, Phys. Lett. **B438** 21 (1998).
7. E. Aker *et al.*, Nucl. Inst. Meth. **A 321** 69 (1992).
8. B. Pick, this conference.
9. E. Klempt, AIP conference proceedings 432, Hadron'97.