101: Crystal Barrel Results on Two-Body Decays of the Scalar Glueball

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Abstract. The Crystal Barrel Collaboration observes scalar meson resonances in $\bar{p}p$ annihilation. Based on the measurements and partial wave analyses these are candidates for the $^3\mathrm{P}_0$ groundstate nonet. The supernummerary $f_0(1500)$ resonance is identified as a scalar groundstate glueball. Important information for its characterization comes from the decay pattern into pseudoscalar and scalar mesons. Data on kaonic decays in the mass region up to 1700 MeV are now avaible at Crystal Barrel. New analysis results are presented.

1 The Crystal Barrel Detector

The Crystal Barrel detector [1] was located at the Low Energy Antiproton Ring (LEAR) at CERN. Antiprotons with a momentum of 200 MeV/c were stopped in a liquid hydrogen target placed in the center of the apparatus. Here the proton-antiproton annihilation occured. Measurement of charged tracks was performed with two cylindrical proportional wire chambers, which could be replaced by a silicon micro strip detector, and a jet drift chamber with 23 sensitive wire layers. A barrel-shaped calorimeter consisting of 1380 CsI(Tl) crystals with photodiode readout and coverig 94% of the solid angle 4π detected photons from the decay of neutral mesons like π^0 and η with a precision in the energy of $2.5\%/\sqrt[4]{E}$. The assembly was embedded in a solenoid providing a homogeneous magnetic field of 1.5 T parallel to the incident antiproton beam.

2 Three pseudoscalar final states

Suitable channels to explore the scalar mesons are the three neutral pseudoscalar meson final states. The reaction proceeds in two steps: the scalar resonance is produced together with a recoil particle and in the second step decays into two pseudoscalar mesons. Scalar mesons decaying into two pseudoscalar mesons are dominantely produced from $^1\mathrm{S}_0$ initial state of the $\bar{p}p$ -system in liquid hydrogen. Centrifugal barriers hindering the reaction are absent. A large sample of events triggered to include only neutral particles which decay into photons was accumulated. An amount of 712,000 $\pi^0\pi^0\pi^0$, 198,000 $\pi^0\eta\eta$ and 977 $\pi^0\eta\eta'$ events could be reconstructed. To extract the resonance content in these annihilation channels a partial wave analysis was performed using the K-matrix formalism and describing the final states simultaneously [2]. In this analysis model the decay from a proton-antiproton initial state into the three final state particles proceeds successively via intermediate two-body states with a certain spin parity J^{PC}. If the intermediate states are resonant they are parametrized by a mass pole and couplings to the two-body channels. A common feature of the all neutral final states mentioned is the isoscalar scalar resonance $f_0(1500)$. It could be described with a common mass and couplings to $\pi\pi$, $\eta\eta$ and $\eta\eta'$.

The Crystal Barrel collaboration observes the $f_0(1500)$ also in the $5\pi^0$ final state in $\bar{p}p$ annihilation at rest [3]. The selection of this 10 photon final state made use of the all-neutral data sample. The $4\pi^0$ invariant mass shows after subtraction of the $\eta \to 3\pi^0$ events a peak at a mass of 1450 MeV. This structure strongly deviates from phase space distribution. The partial wave analysis explains it as $f_0(1500)$ decaying to $\sigma\sigma$ (σ is a name for the low energy part of the $\pi\pi$ S-wave) with $\sigma \to \pi^0\pi^0$ and either produced together with the $3\pi^0$ resonance $\pi(1300)$ or produced together with $f_0(1370)$ and the low mass tail of a resonance above 1700 MeV in the same S-wave. The σ is interpreted as a glue-rich object.

The $f_0(1500)$ is observed in the decay into $K_L K_L$ by studying the final state $K_L K_L \pi^0$ of annihilation at rest [4]. The π^0 is fully reconstructed, one K_L is missing and one K_L undergoes a hadronic interaction in the CsI(TL) crystals with an average probability of 54%. This is sufficient information to reconstruct the kinematics of an event and to perform a partial wave analysis on the Dalitz plot. The plot is shown in fig. 1 a). The resonance features in the $K\pi$ system are the $K^*(892)$ and the $K^*(1430)$. In the $\bar{K}K$ subsystem isospin I=0 and I=1 is possible. Therefore $f_2(1270)$ and $a_2(1320)$ are seen together. The $f_2'(1525)$ adds to the $I = 0$ $\bar{K}K$ D-wave. A strong contribution of the $\bar{K}K$ S-wave is found. At least two poles in a 1×1 K-matrix are needed in the S-wave to arrive at a satisfactory description of the data. These belong to the I=0 resonances $f_0(1370)$ and $f_0(1500)$. The result stays ambiguous since one also expects the presence of the $a_0(1450)$ resonance which was observed in its $\pi^0\eta$ decay [5]. Any contribution of the $a_0(1450)$ between 0% and 15% does only affect the $\bar{K}K$ S-wave but not the quality of the fit.

To resolve the isospin ambiguity the final state $K_L K^\pm \pi^\mp$ of $\bar{p}p$ annihilation at rest was selected [6]. In the reaction $\bar{p}p \to K_L K^\pm \pi^\mp$ only the $I = 1$ $\bar{K}K$ resonances are produced. By applying isospin symmetry one can calculate their contributions to the $K_L K_L \pi^0$ channel. The $K_L K^\pm \pi^\mp$ final state was reconstructed by requiring a missing K_L and two charged particles, which are identified by dE/dx [6]. An amount of 11,373 events went into the Dalitz plot displayed in fig. 1 b). The branching ratio for the proton antiproton annihilation at rest into this final state is found compatible with earlier bubble chamber determinations on less statistics. The average is: $BR(\bar{p}p \to K_L K^\pm \pi^\mp) = 2.74 \pm 0.10) \cdot 10^{-3}$ [6]. The total fraction of background from other annihilation channels is below 2%. The partial wave analysis revealed necessity for the introduction of the $I = 1$ resonance $a_0(1450)$. Mass and width were determined as $m = (1480 \pm 30)$ MeV and $\Gamma = (265 \pm 15)$ MeV, respectively. The comparison with the annihilation channel $\pi^0\pi^0\eta$ yields the relative ratio $B(a_0 \to \bar{K}K)/B(a_0 \to \pi\eta) = 0.88 \pm 0.23$ which agrees well with the prediction from SU(3) flavour symmetry assuming that this object is member of the scalar nonet. Having determined its contribution the $f_0(1500)$ decay to $\bar{K}K$ can be fixed. The relation is shown in fig. 2. The branching ratio for $f_0(1500)$ from this combined analysis is: $B(\bar{p}p \to \pi f_0; f_0 \to \bar{K}K) = (4.52 \pm 0.36) \cdot 10^{-4}$.

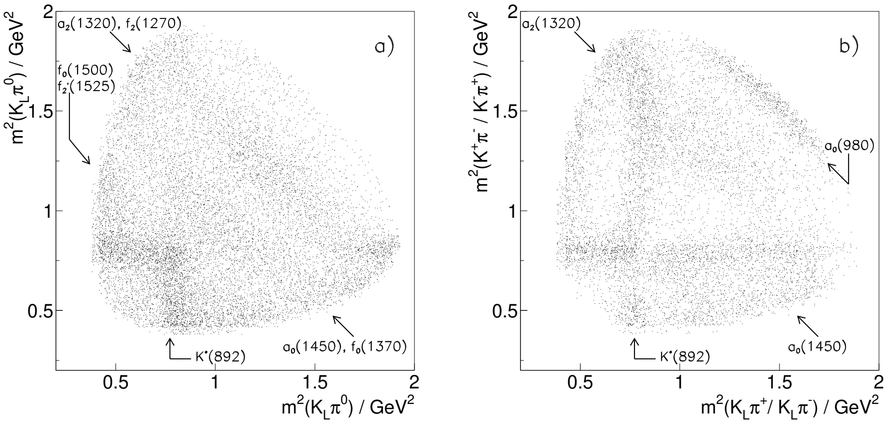

Fig. 1. The Dalitz plots for the annihilation reactions a) $\bar{p}p \to K_L K_L \pi^0$ and b) $\bar{p}p \to K_L K^\pm \pi^m p$ in liquid hydrogen.

3 Summary

The phase space corrected couplings of $f_0(1500)$ are:
$\pi\pi : \eta\eta : \eta\eta' : \bar{K}K = 1 : 0.25 \pm 0.11 : 0.35 \pm 0.15 : 0.24 \pm 0.09$. Due to these couplings and the strong $\sigma\sigma$ decay the $f_0(1500)$ appears as ω-like member of the scalar meson nonet. Other candidates for a nonet in this mass range are the $I = 0$ $f_0(1370)$, $I = \frac{1}{2}$ $K^*(1430)$ and $I = 1$ $a_0(1450)$. The mass of $m = 1505 \pm 9$ MeV would fit but the $I = 0$ nonet position is also occupied by the $f_0(1370)$. The width $\Gamma = 111 \pm 12$ MeV of $f_0(1500)$ is relatively small in comparison to the other scalar mesons having Γ greater than 250 MeV. Hence, it appears supernummerary. The $f_0(1500)$ matches the mass range of lattice gauge calculations for the scalar groundstate glueball [7]. The strong

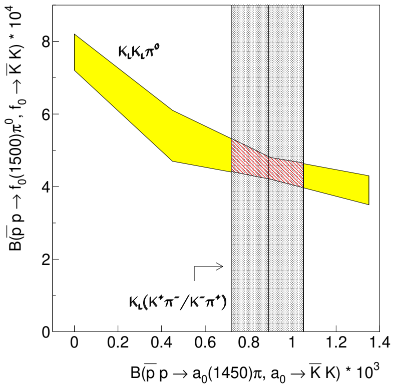

Fig. 2. Determination of the branching ratio of $f_0(1500)$ in the reaction $\bar{p}p \to K_LK_L\pi^0$ [4] (light hatched area), where it is correlated with the $a_0(1450)$ production. The $a_0(1450)$ contribution is fixed in the analysis of the reaction $\bar{p}p \to K_LK^{\pm}\pi^{m}p$ [6].

coupling to $\eta\eta$, $\eta\eta'$ and $\sigma\sigma$ can be understood in terms of the decolorization mechanism: The constituent gluons couple to the glue-content of the decay mesons and are color-neutralized afterwards by the exchange of gluons [8]. The naive expectation of the flavour democratic decay of a glueball can be explained by the mixing with nearby $\bar{q}q$ meson states [9][10]. The strength of the mixing depends on the mass of the ϕ-like state which therefore is predicted at higher mass. To explore the mass region above 1700 MeV the Crystal Barrel Collaboration is analyzing annihilation channels at higher momenta of the incoming antiprotons.

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