Experimental Review on Scalars, Glueballs and $\pi\pi$ S-wave

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In the last years more scalar states have been found than fit into the $\bar{q}q$ nonet. This is particularly interesting for the search for exotic non-$\bar{q}q$ states. The present picture of the scalar mesons suggests that the $J^{PC} = 0^{++}$ glueball ground state has been discovered.

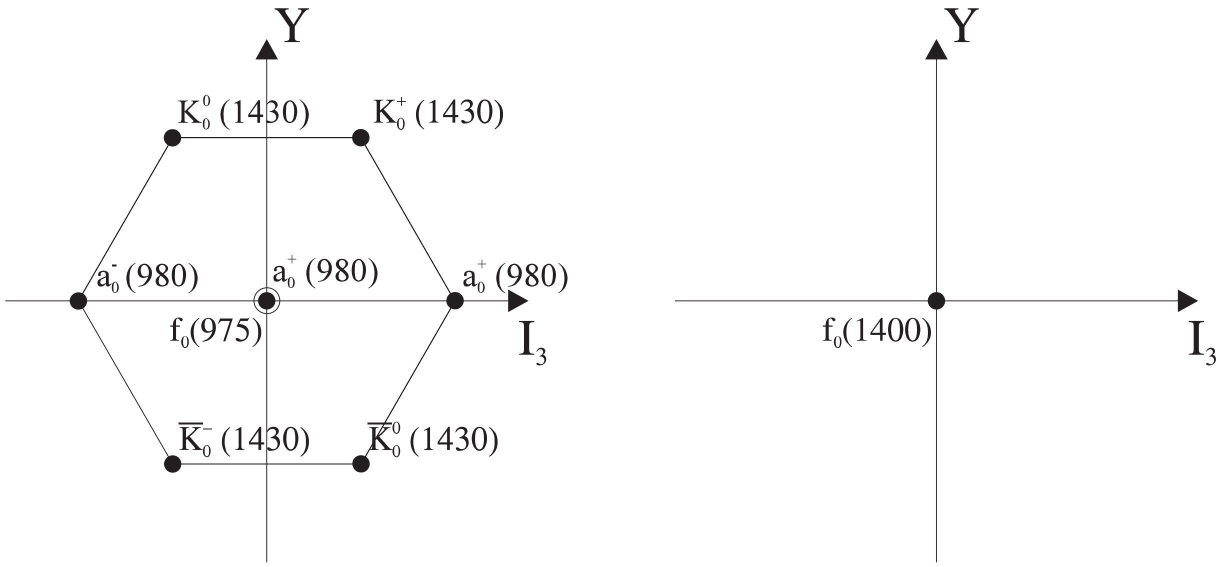

Figure 1: *The common representation of the scalar nonet and its members as seen for many years.*

1 Introduction

For a long time the states considered as members of the scalar $\bar{q}q$ nonet were the $a_0(980)$, $f_0(975)$, $f_0(1300)$ and the $K_0^*(1430)$ [1](see fig. 1).

Whereas the $K_0^*(1430)$ perfectly fits into what one would expect from comparison to the masses of the tensor and axial mesons, it has always been problematic to accept the $a_0(980)$ and the $f_0(975)$ as ordinary 0^+ mesons. As they are too light, too narrow and couple much too strongly to $\bar{K}K$ they are generally believed to be $\bar{K}K$ molecules [2, 3]. Evidence for an isoscalar and an isovector 0^+ state with almost exactly the masses and widths as their tensor partners have been reported [4, 5] but was never confirmed. An overview about recent results in this sector and their implications to the 0^+ nonet will be given.

2 0^{++} candidates

2.1 Results from $\pi\pi$ S-wave scattering

Two recently published analyses of $\pi\pi$ scattering data [6, 7] fit the steep slope of the scattering phase near the $\bar{K}K$ threshold at $1\,\mathrm{GeV}/c^2$ (see fig. 2) with a narrow resonance coupling 50% to $\bar{K}K$, which the authors identify with the $f_0(975)$.

In addition both analyses need a slowly increasing background phase arising from a very broad resonance (500 - $800\,\mathrm{MeV}/c^2$ width) above $1\,\mathrm{GeV}/c^2$ in mass. This resonance is purely elastic in $\pi\pi$ and can be identified with the $f_0(1300)$. The large uncertainty of mass and width is reflected in the entry in the PDG table [8], where only ranges for their values are given. Note that these results disfavour a $\bar{K}K$ interpretation of the $f_0(975)$ [7].

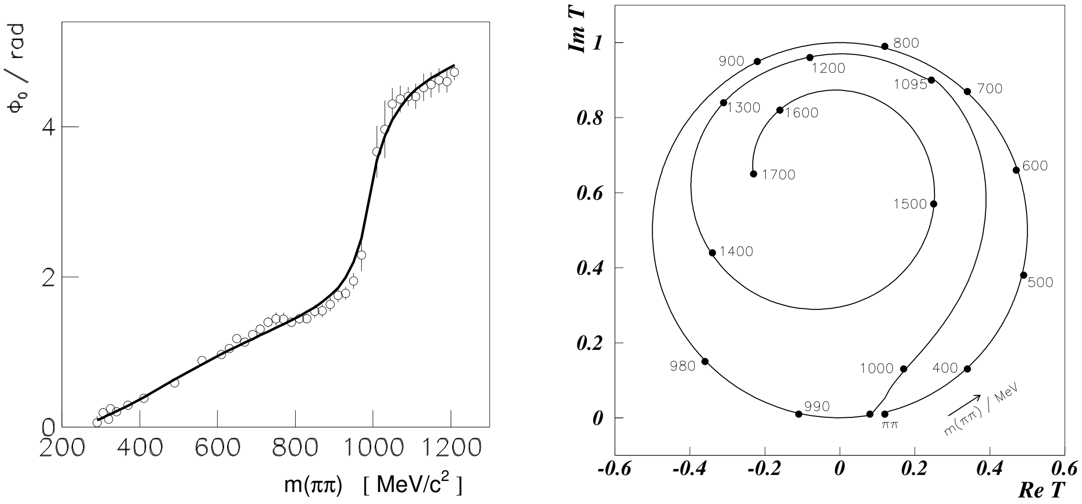

Figure 2: *The $\pi\pi$ scattering phase as measured in [15]. The picture is taken from [14]. The right plot shows the Argand diagram.*

2.2 A resonance at 1370 MeV/c^2 decaying to $\rho\rho$

Analyses of Rome-Syracuse [9], Obelix [10] and Crystal Barrel (CBAR) [11] data of the 5π final states yield an unambiguous signal for a scalar resonance decaying to 4π. The full spin-parity analysis performed by the CBAR collaboration determined the mass to 1374 ± 38 MeV/c^2 and the width to 375 ± 61 MeV/c^2(see fig. 3). This analysis also found that the 4π decay mode proceeds dominantly via $\rho\rho$ with a small contribution from $\sigma\sigma$.

2.3 A glueball candidate at 1500 MeV/c^2

The CBAR collaboration [12] observed a new 0^{++} state ($f_0(1500)$) decaying to $\pi\pi$ and $\eta\eta$ [13]. From a simultanuous fit to the reactions $\bar{p}p \to 3\pi^0$, $2\pi^0\eta$ and $\pi^0\eta\eta$ at rest, and additionally $\pi\pi$ scattering data [15], the mass and width were determined to be 1490 ± 13 MeV/c^2 and 120 ± 15 MeV/c^2, respectively. These values depend slightly on model assumptions. This variation dominates the error on mass and width.

There is a clear, isolated peak in the $\pi^0\pi^0$ invariant mass spectrum and a band in the Dalitz plot (see fig. 4). The CBAR collaboration gives relative branching ratios for the $f_0(1500)$to $\pi\pi$:$\eta\eta$:$\eta\eta'$:$\bar{K}K = 3 : (0.72 \pm 0.37) : (1.05 \pm 0.44) :< 1.4$. These numbers take into account the data available on the $\pi^0\eta\eta'$ final state [16] and result from a coupled-channel analysis allowing also for a not yet measured $\bar{K}K$ decay mode. It can be shown that this decay pattern does not fit into the $\bar{q}q$ picture regardless what value is assumed for the scalar octet-singlet mixing angle [17]. On the other hand, these numbers can be explained by a large pure glue component of the $f_0(1500)$. This gluonic admixture is due to the lowest lying glueball which is expected to have a mass around 1550 MeV [18]. A signal at around 1500 MeV/c^2 in $\pi^0\pi^0$ and $\eta\eta$ has also been seen in $\bar{p}p$ annihilation in flight at CBAR [19] and E-760 [20].

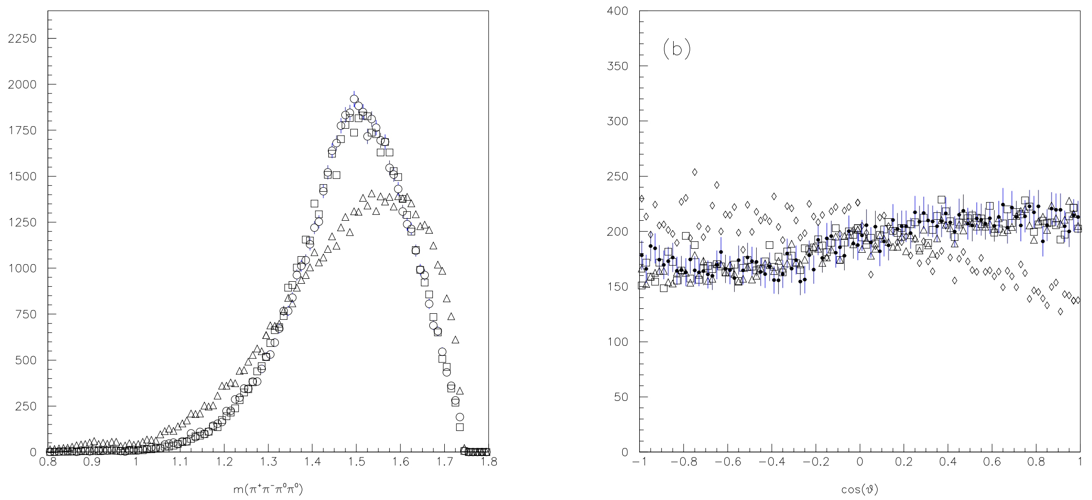

Figure 3: *The $\pi^+\pi^-\pi^0\pi^0$ effective mass and angular distribution for $A^0 \to B^+C^-$ in the reaction $\bar{p}p$ at rest going to 5π [11]. The circles in the mass spectrum and the dots in the angular distribution represent the data, the squares the result of the best fit. Triangles in the left plot and diamonds in the right plot indicate five π phase space.*

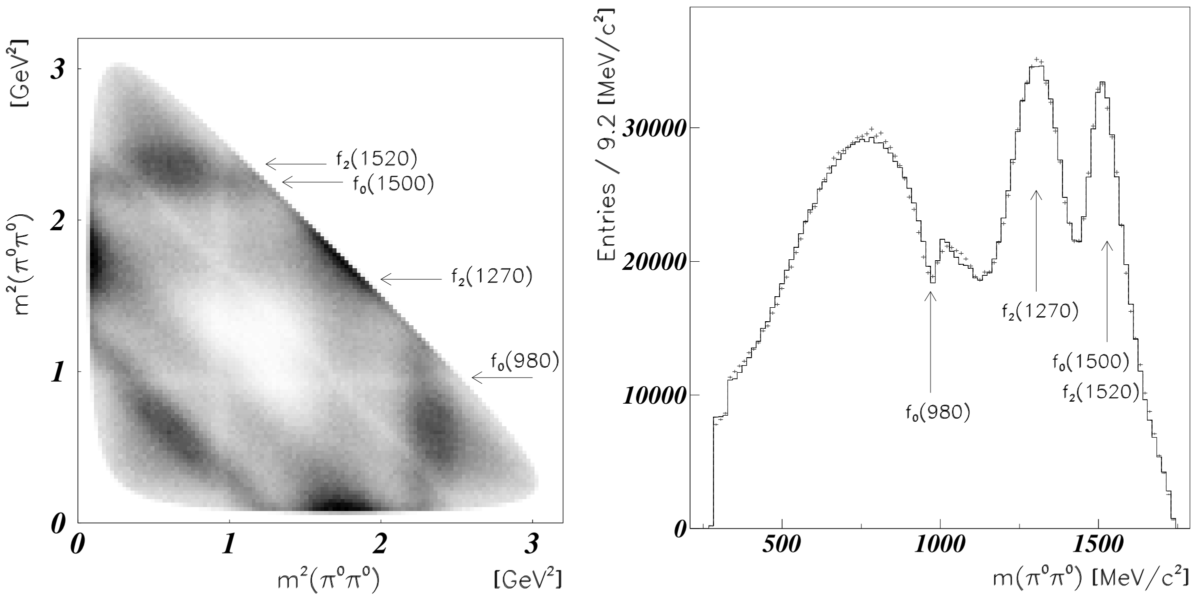

Figure 4: *Dalitz plot and $\pi^0\pi^0$ effective mass for the reaction $\bar{p}p$ at rest goes to $3\pi^0$ as seen by the CBAR experiment. The data can only be described by introducing a significant amount of an isoscalar 0^{++}resonance at 1500 MeV/c^2.*

2.4 A scalar at 1710 MeV/c^2

From several experiments there has been evidence for a resonance at 1710 MeV/c^2 ($f_J(1710)$) decaying to $\bar{K}K$. The spin is still to be determined as one group claims spin zero, another spin

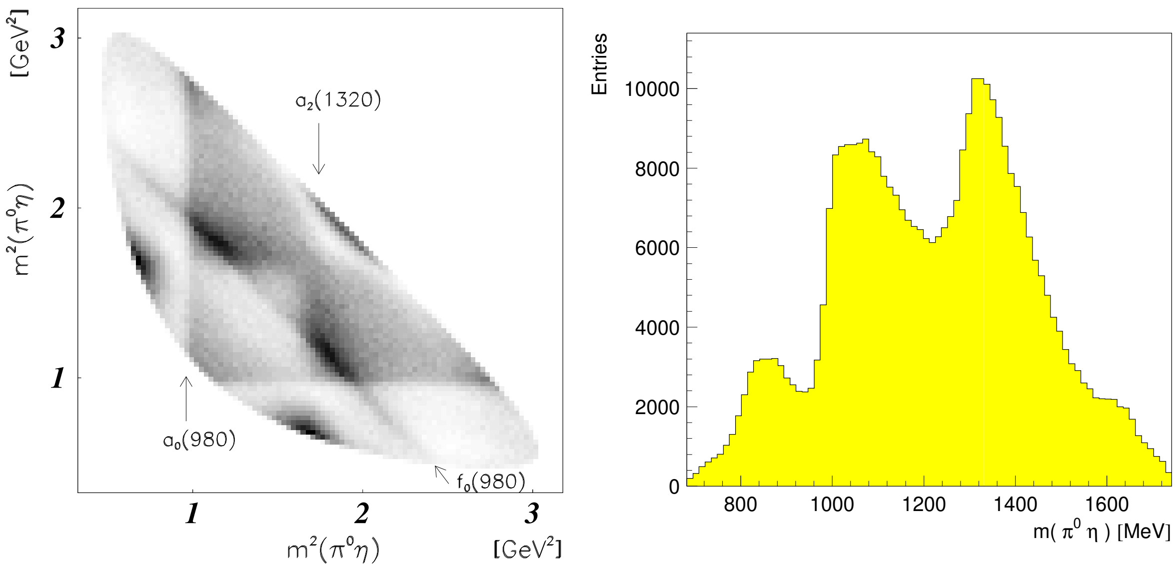

Figure 5: *Dalitz plot and effective mass distributions in the final state $2\pi^0\eta$ from $\bar{\mathrm{p}}\mathrm{p}$ annihilation at rest as measured by the Crystal Barrel collaboration.*

two (see also discussion in [8]). A solution might be the existence of two overlapping states, hiding each other. Here we assume the existence of a 0^{++} in this mass region with a large $\mathrm{s\bar{s}}$ component because of its strong coupling to Kaons.

2.5 A new isovector from Crystal Barrel

In the $\pi^0\pi^0\eta$ final state in $\bar{\mathrm{p}}\mathrm{p}$ annihilation at rest the CBAR collaboration observes a new isovector 0^+ object with mass and width of 1450 ± 40 MeV/c^2 and 270 ± 40 MeV/c^2 [21]. This results from a sophisticated coupled-channel analysis, which preserves full analyticity and unitarity of the lorentz invariant transition amplitude applied, to the high statistics data samples already mentioned. The method used is based on a K-matrix formalism [22] taking also into account the production process [23]. Neither in the Dalitz plot nor in the $\pi^0\eta$ effective mass spectrum this object can be seen by eye, the new meson, however, is unambiguously needed to describe the data.

3 Building an extended multiplet

Assuming the $\mathrm{a_0}(1450)$ to be the isovector member of the scalar meson nonet replacing the $\mathrm{a_0}(980)$ and taking the $\mathrm{f_J}(1710)$ as its $\mathrm{s\bar{s}}$ partner we are left with three new candidates for the isoscalar meson in the 0^{++} octet, which was occupied by the $\mathrm{f_0}(975)$. The three states are observed with decay properties which are untypical for this interpretation. The $\mathrm{f_0}(1300)$ is almost entirely elastic in $\pi\pi$ and may therefore be due to attractive forces between pions behaving as Goldstone bosons in the picture of perturbative chiral theory. The $\mathrm{f_0}(1370)$ decaying dominantly to $\rho\rho$ might be a $\rho\rho$ molecule. And the $\mathrm{f_0}(1500)$ shows properties of a glueball. So what does the 0^+ nonet look like? One solution could be to enlarge the $SU(3) \times \overline{SU(3)}$ nonet to a $SU(3) \times \overline{SU(3)} \times U(1)$ decuplet [24], containing also the 0^{++} glueball ground state. The observed isoscalar states will be mixtures of the $\bar{q}q$ state of the octect, the $\bar{q}q$ state of the singlet and the glueball. In a decuplet containing the standard meson nonet extended by a pure glue state, we cannot restrict ourselves to one particle only when searching for a glueball. An efficient mixing model is required for glueball phenomenology.

4 Outlook

Light meson spectroscopy is important for the exploration of QCD in its highly non perturbative regime. In the mass region 1-2 GeV/c^2 many states appear and therefore sophisticated experiments are needed to yield insight into this complicated field of physics. Experiments will have to investigate the nature of the $a_0(980)$ and the $f_0(975)$, e.g. by studying radiative Φ decays at DAΦNE. Also an experiment [25] is planned to measure the $\pi\pi$ scattering length at threshold with high precision. This is urgently needed to prove fundamental principles of QCD. Among the future prospects of CBAR is the measurement of kaonic final states to detect the $\bar{K}K$ decay modes of the resonances, the confirmation of the $a_0(1450)$ and the spin-determination of the $f_J(1710)$.

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