The Scalar Glueball and the $^3P_0$ mesons

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Abstract. A review about the results on the spectroscopy of light scalar mesons is given. Special emphasis is given to the results in Antiproton-Proton annihilation, where the observation of the $f_0(1500)$ as a possible candidate for the scalar glueball has stimulated the discussion about the lowest lying scalar mesons. Possible assignments of nonets will be discussed with the focus to the open question in experiment and theory.

INTRODUCTION

The discovery of the glueball candidate $f_0(1500)$ by the Crystal Barrel Collaboration has brought new impetus in the field of light meson spectroscopy. The existence of glueballs is one of the most striking predictions of QCD in the low energy region [1]. Lattice gauge calculations predict how the spectrum of glueballs would look like in a world without quarks; the mass spectrum should start with a scalar glueball ground state and the mass is expected to be of the order 1.5 to 1.8 GeV/c^2. However, the pattern gets much more complicated when quarks are introduced. Not only since $\bar{q}q$-states show up in addition to glueballs, $\bar{q}q$-states will also mix with them. Therefore the precise determination of masses, widths and decay fractions of the scalar mesons is important in order to disentangle the gluonic nature of one or more states.
The present report will review the experimental status in the field of scalar mesons and afterwards discuss the present situation in our understanding of the different experimental states. Special emphasize is given to the isoscalar scalar mesons, by far the most difficult part in scalar meson spectroscopy.

THE EXPERIMENTAL SITUATION

A The Isospin $\frac{1}{2}$ scalar mesons

The scalar mesons with Isospin $\frac{1}{2}$ are the least controversial among all known scalar states and will give us the fixpoint for the isoscalar and isovector partners

of the $J^{PC} = 0^{++}$ nonet.
The LASS collaboration at Stanford [2] has extensively investigated the $I = \frac{1}{2}$-sector by studying the reaction $K^- p \rightarrow K^- \pi^+ n$ at 11 GeV/c. The extracted $K\pi$-S-wave is a superposition of $I = \frac{1}{2}$ and $I = \frac{3}{2}$ states. This ambiguity was disentangled by imposing purely elastic amplitudes from treshold to 1.29 GeV/c^2 for the $K\pi$-S-wave plus the results for the $I = \frac{3}{2}$-behaviour from an earlier experiment [3]. For low $K\pi$-masses the intensity is remarkable and had to be taken into account. A reasonable description of the data was obtained by a Breit-Wigner amplitude with a mass dependent width and a background amplitude, parametrized by an effective range approximation. Unitarity was imposed by fixing the relative phase between the Breit-Wigner and the background amplitude. The Breit-Wigner amplitude determines the mass and width of the lowest lying $(K\pi)$-S-wave resonance to m = 1430 $\pm 4 \pm 5$ MeV/$c^2$and $\Gamma = 287$ $\pm 10 \pm$ 21 MeV/c^2. The next resonant contribution of the $I = \frac{1}{2}$ $(K\pi)$-S-wave was found around 1.9 GeV/c^2. Two different solutions were found in this mass region, but both of resonant character. The K*(1430) and the K*(1950) therefore set the scale for the scalar nonet, because the resonant contributions of the $(K\pi)$-S-wave were determined unambiguosly by the LASS-data. A recent reanalysis of the $K\pi$-S-wave using the background amplitude plus a K-Matrixformalism has confirmed the LASS-results and has found no evidence for resonant contributions below 1.4 GeV/c^2 [4].

The Isovector S-wave states

The lowest lying isovector state is the $a_0(980)$. This resonance is well established by different experiments. The mass is fairly well determined [5], but the precise knowledge of the width is still controversial. The presence of $a_0(980)$ is far beyond any doubt, but the interpretation of the particle is still controversial. In 1994, the Crystal Barrel Collaboration presented evidence for the next isovector scalar meson. The $a_0(1450)$ was found in the $\pi\pi\eta$-dalitzplot analysis, decaying the $\pi\eta$ [6]. Figure 1 a) shows the dalitzplot. The $a_0(1450)$ is hardly to detect and only the phase motion along the $a_0(980)$ edge gives an indication of the existence of a second a_0 in this final state. Mass and width were determined by Crystal Barrel to be m = 1470 $\pm$ 25 MeV/c^2, Γ = 265 $\pm$ 30 MeV/c^2 [6]. The $a_0(1450)$ was found to be rather inelastic. A recent analysis of the Obelix Collaboration, using $\bar{\text{p}}$p-annihilation into $\text{K}^0_s K^\pm \pi^\mp$ at three different target densities (i.e. different initial S- to P-wave ratio) found incompatible results. Instead of the rather broad state from the Crystal barrel analysis, a narrow a_0 with m = 1290 $\pm$ 10 MeV/c^2 and Γ = 80 $\pm$ 5 MeV/c^2 was found. This result is in contradiction to a partial wave analysis of the $\text{K}^0_l \pi^\pm K^\mp$-channel by Crystal Barrel [8]. This analysis is compatible with the previous Crystal Barrel results on $\pi^0\pi^0\eta$ concerning mass and width of the $a_0(1450)$. The ratio of partial widths $\Gamma_{\bar{\text{K}}\text{K}}/\Gamma_{\pi\eta} \simeq 0.7$ is consistent with the expectations for an isovector $\bar{\text{q}}$q-state at this mass, assuming SU(3) couplings [9]. A very weak evidence for the $\pi^0\eta'$-decay channel was found by Crystal Barrel in the

$\pi^0\pi^0\eta'$-final state, but limited statistics in connection with a sizable background prevents stronger conclusions [10]. Hence, a coupled channel analysis of $\pi^0\pi^0\eta$ and $\bar{K}K\pi$ final states in $\bar{p}p$-annihilation is strongly required, in order to get reliable parameters for the second isovector state. Desirable would be a confirmation of this resonance in other production mechanism like central production or two-photon-physics, because neither in the Crystal Barrel data on the different final states nor in the data of the Obelix collaboration, the signal of the $a_0(1450)$ can be identified as a clear peak in the Dalitz-plot. One has to rely on the results of the partial wave analysis. Unfortunately, the available high-statistics data from Pion-scattering to the $\pi\eta$-final state seems to be not sensitive to the isovector S-wave [11]. The cross section in the $\pi\eta$-final state is dominated by ρ-exchange and since scalar mesons do not couple to $\rho\pi$ because of parity conservation, the isovector scalar mesons are strongly suppressed in pion-proton-scattering.

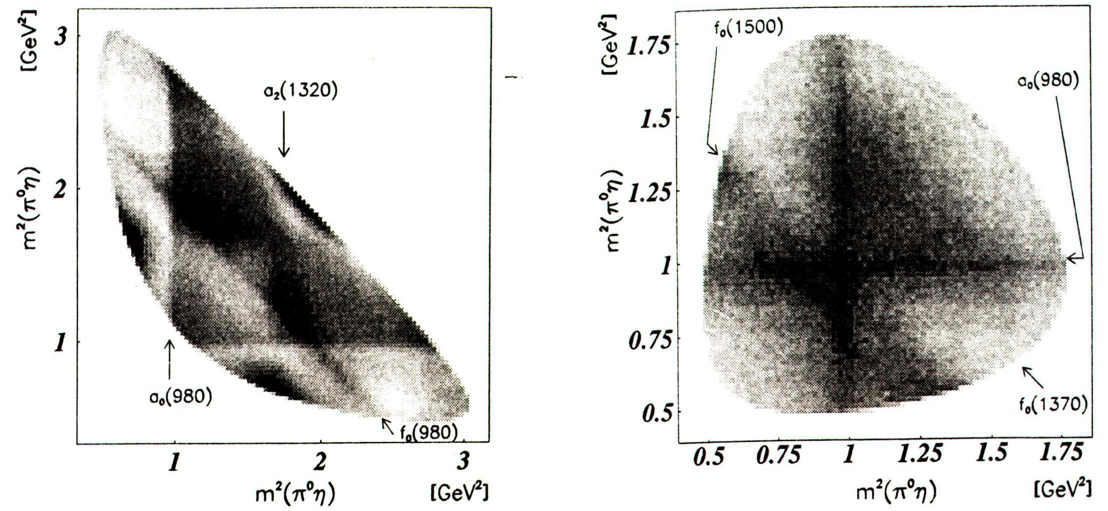


FIGURE 1. The $\pi^0\pi^0\eta$ (left,a) and the $\pi^0\eta\eta$ (right,b) Dalitz-plots measured by Crystal Barrel

The Isoscalar states

The precise spectroscopy of the isoscalar states is the most challenging task in meson spectroscopy. Not only $\bar{q}q$-states couple to the isoscalar S-wave, but also multiquark-states and the scalar glueball should have a sizeable coupling. In addition, broad, overlapping states can mix and many thresholds like $\bar{K}K$, 4π, $\eta\eta$, $\eta\eta'$, $\omega\omega$ etc. will open in the range from $\pi\pi$-threshold up to 1.8 GeV/c^2.
The lowest lying and experimentally well established isoscalar resonance is the $f_0(980)$. Mass and couplings differ in the various analysis [5], but the resonant character of the structure is obvious. The latest edition of the Particle data group refers a second resonance in this region and because of the still unknown parameters they call it $f_0(400-1200)$. The present picture of the isoscalar S-wave states

below 1.2 GeV/c^2 is strongly influenced by the analysis of the Au, Morgan, Pennington collaboration (AMP) [12]. This comprehensive analysis has used the complete database available at this time. The data on $\pi\pi \rightarrow \pi\pi$ came from the CERN-Munich collaboration [13], which extracted the $\pi\pi$-S-wave from the $\pi^- p$-scattering data to $\pi^+\pi^- n$ at 17 GeV/c. The results from this data are supported by previous experiments, in particular by the LBL experiment of Protopopescu et al. [14]. Because of the strong ρ-contribution in the $\pi^+\pi^-$-P-wave, which can lead to correlations with the S-wave, AMP have used the additional information from the reaction $\pi^+ p \rightarrow \pi^0\pi^0\Delta^{++}$ at 8 GeV/c [15]. Unfortunately, this data disagree below 1 GeV/c^2 with the CERN-Munich and LBL data and were used only for masses above 1 GeV/c^2.

The most promising data on $\pi\pi$-scattering will come from the E852 experiment at Brookhaven [11]. High statistics data will be available soon from the reaction $\pi^- p \rightarrow \pi^0\pi^0 n$ at 18 GeV/c. The $\pi^0\pi^0$ final state is free from any ρ-contribution and will provide strong constraints to all analysis concerning the isoscalar states. At this conference [16] several analysis reported evidence for a narrow $\pi\pi$-S-wave resonance around 700 MeV/c^2. The visible evidence presented here is a small enhancement of the extracted $\pi\pi$-S-wave phase motion in this mass region and the improvement in χ^2 comes mainly from this region. Hence, data without any ρ-contribution will be able to give the precise behaviour of the isoscalar $\pi\pi$-phase shift in the region below 1.2 GeV/c^2. The possible existence of a narrow, low mass $\pi\pi$-S-wave resonance was also tested by Crystal Barrel in $\bar{\mathrm{p}}\mathrm{p}$-annihilations to 5 π^0 [29]. No evidence for such a state was found.

In addition, AMP has used information for $\pi\pi \rightarrow \bar{\mathrm{K}}\mathrm{K}$ [17,18] and from central production [19].

The amplitude analysis of AMP has used a 2×2-K-matrix with couplings to $\pi\pi$ and $\bar{\mathrm{K}}\mathrm{K}$ plus a polynomial background. The requires at least one pole below 1.2 GeV/c^2, the narrow $f_0(980)$. In addition to the $f_0(980)$, the 3 pole solution has two further broad poles. The $\epsilon(900)$ with a width of about 750 MeV/c^2(which can be identified with the $f_0(400-1200)$) and a 400 MeV/c^2broad state at 1430 MeV/c^2.

The region around 1 GeV/c^2 was found to be very delicate in this first analysis. A closer look to the sheet structure of the solution around 1 GeV/c^2 showed, that the narrow state at the $\bar{\mathrm{K}}\mathrm{K}$-threshold splits into two nearby states, a Breit-Wigner like resonance plus a $\bar{\mathrm{K}}\mathrm{K}$ bound state, which appears as a single pole in sheet II.

After data from DM2 and Mark III on J/Ψ-decays into $\phi(\pi\pi, \bar{\mathrm{K}}\mathrm{K})$ were available, Morgan and Pennington made a reanalysis of the exciting region around 1 GeV/c^2 [20]. The broad component, the $f_0(400-1200)$ was still present. The situation concerning the $f_0(980)$ was clarified. With the additional contraints, the $f_0(980)$ appears as one pole on sheet II and one pole on sheet III of the complex energy plane. The implications of this result will be discussed later. However, this comprehensive analysis has demonstrated the sensitivity of the fits to the amount and quality of data. In particular, precise knowledge of the $\bar{\mathrm{K}}\mathrm{K}$-threshold is mandatory and we can look forward to high statistics datasets which will come from E852 [11].

As shown by the AMP-analysis, the $\pi\pi$-phaseshift requires a second broad resonance around 1 GeV/c^2. The parameters of this resonance are not well determined; obviously the Particle data group has assigned a wide mass range to this structure [5].
During the last years, the Crystal Barrel experiment at LEAR (CERN) has provided many high statistics datasets on different 3 pseudoscalar final states. Antiprotons with a momentum of 200 MeV/c were stopped in a liquid hydrogen target. The target is surrounded by two proportional wire chambers, a jet drift chamber for the measurement of charged particles and a barrel shaped calorimeter consisting of 1380 CsI(Tl) crystals with photodiode readout. The barrel covers a solid angle of 97% of 4π and has 2.5% energy resolution for 1 GeV photons. The typical angular resolution is about 25 mrad in azimuthal and polar angle. A trigger on zero-prong final states in connection with a special trigger on two-photon inv. masses has allowed to get high statistics datasets for final states with more than one η. A detailed description of the apparatus can be found elsewhere [21].
The Crystal Barrel group has made a coupled channel analysis of three high statistics 3 pseudoscalar final states : $3\pi^0$ with 712.000 events, $\pi^0\pi^0\eta$with 280.000 events and $\pi^0\eta\eta$ with 198.000 events [7]. The $\pi^0\eta\eta$data set was mainly taken with the special trigger setup mentioned above. For the isoscalar S-wave resonances a $3 \times 3 - K$-matrix parametrisation was used to guarantee unitarity in the case of nearby, overlapping resonances [22]. In these final states, only S- and D-wave occur in the dipion- or di-eta-system, which keeps the number of partial waves small. However, in the edges of the $3\pi^0$Dalitz plot the interference of low and high mass $\pi\pi$-S-waves with the $\pi\pi$-D-wave prevents a unique solution. By a simultaneous fit to the CERN-Munich data [23] the ambiguity was solved. For the isoscalar S-wave the data required four T-matrix poles. The narrow $f_0(980)$, a broad component which should be identified with the $f_0(400-1200)$, the $f_0(1370)$ and the $f_0(1500)$. The analysis of only the $3\pi^0$ final state had found equivalent solutions with and without the $f_0(1370)$ [24], however the coupled channel analysis and a combined with $3\pi^0$ from annihilation in gazeous hydrogen [25] definetely requires the presence of the $f_0(1370)$. The parameters of the $f_0(1370)$ are not precisely known, nevertheless a resonant structure is present in the data and can be seen in the $\pi^0\eta\eta$ Dalitz plot, indicated with the arrows in figure 1 b). The problem of overlapping, nearby resonances manifests itself in the problem of precise parameters for the $f_0(1370)$, although precise and high statistics data are available. The most exciting result from the Crystal Barrel data is the $f_0(1500)$. First very weak indications of this resonance were seen in $\bar{\rm p}$n-annihilations [26] and K$^-$-scattering data [27], but only the Crystal Barrel data had allowed the manifestation of this resonance. Crystal Barrel has found 6 decay modes of the $f_0(1500)$: $\pi\pi$, $\eta\eta$, $\eta\eta'$, $\bar{\rm K}$K, $\sigma\sigma$ and $\pi^*\pi$. The $\eta\eta'$-decay mode was found in the analysis of the $\pi^0\eta\eta$ final state, where the special trigger was used to increase the number of η's and η''s [28]. The $\bar{\rm K}$K-branching fraction was determined with the analysis of the K$_l^0$K$_l^0\pi^0$Dalitz plot. The high statistics on data without any charged contribution has allowed to select this final state with one interacting and one non-interacting K$_l^0$. The final

data set contains 37,500 events and the partial wave analysis demonstrates, that the $\bar{K}K$-S-waves contributes to about 70% to this final state [4]. The isoscalar and the isovector S-wave can be found in the $K_l^0K_l^0$-S-wave. With the known branching ratio of $a_0(1450)$ in $\bar{p}p$-annihilations from the $\pi^0\pi^0\eta$-analysis [7], a contribution of (7.7 ± 2.1)% to the $K_l^0K_l^0\pi^0$final state was calculated with SU(3)-couplings for an isovector state. Therefore the $\bar{K}K$ must be dominantly $I=0$. The fit requires at least two (isoscalar) scalar resonances, which can be identified because of mass and width with the $f_0(1370)$ and the $f_0(1500)$. At this conference [31], a systematic analysis of the 4π decays of $f_0(1370)$ and $f_0(1500)$ was presented. Previous analysis on 5 π final states in $\bar{p}n$-annihilations had found only one scalar resonance, the $f_0(1370)$, but had disagreed completely in the relative branching fractions to $\sigma\sigma$ and $\rho\rho$ [32,33]. The analysis of the $5\pi^0$ final state from Crystal Barrel has definitely shown, that the $f_0(1500)$ decays to 4π [29], mainly to $\sigma\sigma$ and with less extend to $\pi^*\pi$. A parallel analysis of $\pi^+\pi^-3\pi^0$, 5 π^0, $\pi^-4\pi^0$ and $\pi^+2\pi^-2\pi^0$ [31] confirms the results of the 5 π^0 analysis and determines, that the $\rho\rho$-decay of the $f_0(1500)$ is not required by the present analysis. The 5 π^0final state was not sensitive to the parameters of the second required scalar resonance [29]. The parallel analysis is much more sensitive to this question and shows, that a second scalar is present and decays to $\sigma\sigma$ and $\rho\rho$. The present status of the analysis can not definitely rule out a very broad state, but the most likely solution allows the identification with the $f_0(1370)$ [31].
The Crystal Barrel results had stimulated several reanalyses, for example [30,34]. Allowing the $\sigma\sigma$-decay channel for the 0^{++}-partial wave, Bugg and collaborators [30] have shown, that the MARK III data on $J/\Psi\to2\pi^+2\pi^-\gamma$ are compatible with a scalar assignment to the structure at 1500 MeV/c^2, former identified as of pseudoscalar nature. Today, there is no controversy about the fact, that the $f_0(1500)$ is present in annihilation-data, scattering data and central production.
Dunwoodie [40] has shown at this conference, that a reanalysis of the MARK III data on radiative J/Ψ-decays to $K_s^0K_s^0$, K^+K^- and $\pi\pi$ require a scalar resonance around 1700 MeV/c^2. Mass and width were determined to be

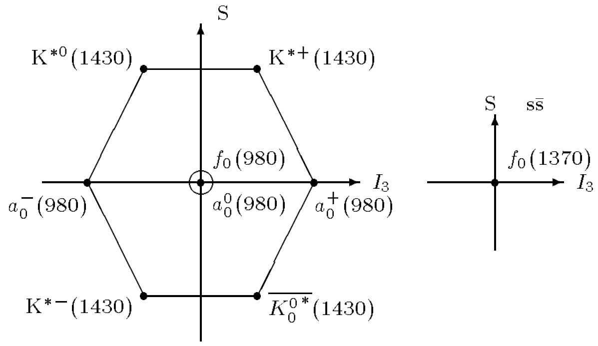
$$m = 1704^{+16}_{-23}\,\mathrm{MeV}/c^2 \;\; \Gamma \;=\; 124^{+52}_{-44}\,\mathrm{MeV}/c^2.$$

This confirms the observation of Bugg et al. [30], that scalar intensity around 1700 MeV/c^2 is also present in the radiative J/Ψ-decays to 4π. Present Crystal Barrel data on the $K^+K^-\pi^0$ final state taken with an antiproton momentum of 1.94 GeV/c shows a structure at 1700 MeV/c^2. Unfortunately, the spin parity analysis is still ambiguous and only even spin can be assigned to the visible band [41].

Classification of scalar mesons

The canonical nonet

The most simple classification is to start with the lowest lying scalar mesons. With this "canonical" assignment, one gets the following nonet.

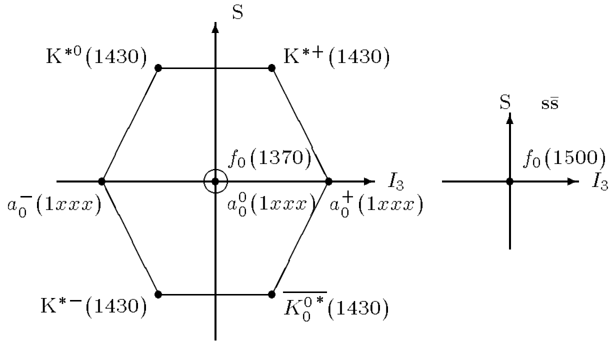


$f_0(980)$ and $a_0(980)$ are degenerated in mass and therefore one would expect as in the case of vectormesons a nearly ideal mixing. The mass formulae does not work with the masses given above, the $\tan^2\Theta$ gets negative as a fact of the high K*(1430) mass. The partial widths of the $f_0(1370)$ are not well determined, nevertheless one can rule out $\bar{\rm K}$K as the dominant decay mode [4]. I have put in the $f_0(1370)$ instead of a possible $f_0(400-1200)$, because the parameters of the latter are badly determined and the resonant character is still questionable. But what is the nature of $f_0(980)$ and $a_0(980)$?
Because of the strong couplings to $\bar{\rm K}$K (with masses close to the $\bar{\rm K}$K-threshold) and their small $\gamma\gamma$-width, $f_0(980)$ and $a_0(980)$ have been assumed to be $\bar{\rm K}$K-molecules [42]. For the $f_0(980)$ the 2γ partial width is $\Gamma_{\gamma\gamma} = (0.56{\pm}0.11)keV$ [5]. For $a_0(980)$, the Particle Data Group refers only the product branching ratio $\Gamma_{\gamma\gamma}B(a_0(980) \rightarrow \eta\pi) = 0.24 \pm 0.08keV$. With the relative ratio for $a_0(980)$ to $\bar{\rm K}$K and $\eta\pi$ [35], one gets a partial width of $\Gamma_{\gamma\gamma} = (0.30 \pm 0.10)keV$ for the $a_0(980)$. Therefore the two-photon partial width are nearly similar and according to Barnes [36] close to the predictions for $\bar{\rm K}$K molecules and much smaller than for q̄q-states. Nevertheless, in [37] a compilation of theoretical predictions is given. The large range of possible results makes a definite statement from two-photon couplings rather difficult. At this conference [38] first data from the SMD detector at Novosibirsk on radiative ϕ-decays to $f_0(980)/a_0(980)\gamma$ were presented. The decays to $\pi\pi$ and $\pi\eta$ were shown and the rates are consistent with a model of Achasov [39], assuming a q̄qq̄q nature of these mesons.
The group of Speth at Jülich [43] has analysed based on the Jülich exchange model for $\pi\pi$-interaction [44] $\pi\pi$-scattering data [13] and the J/Ψ-decays to ϕ $\pi^+\pi^-$ and ϕ K$^+$K$^-$ from MARK III and DM2. They have included all possible s-,t- and u-channel diagramms and found a sufficient description of the datasets. The investigation of the pole structure yields a single pole on the second sheet with a mass of 1015 MeV/$c^2$and a width of 30 MeV/c^2. This pole was identified with the $f_0(980)$ and the high mass was explained with the strong $\pi\pi/\bar{\rm K}$K-coupling. A further s-channel resonance was found around 1400 MeV/c^2. The single pole on the second Riemann sheet for the $f_0(980)$, which moves back to 985 - i0 in the limit of zero $\pi\pi/\bar{\rm K}$K-coupling is in favour of a molecule interpretation. The same model was applied to $\pi\eta$-scattering, where the ρ-exchange is now repulsive for I = 1,

destroying the $\bar{K}K$-bound state. In this model, the $a_0(980)$ is only a dynamically generated effect. Tests of this model on the available database of $\pi\eta$-final states are mandatory.
The comprehensive analysis of Morgan and Pennington has shown, that the $f_0(980)$ appears as genuine pole in sheet II and III, which is expected for an ordinary $\bar{q}q$-state. This picture is confirmed by recent results from LEP. Lafferty [45] has presented results from two-photon-physics at LEP. The properties of the $f_0(980)$ from this analysis are consistent with the assumption of an standard $\bar{q}q$-meson. The unitarized quark model of Törnquist [46] explains the degeneracy of $f_0(980)$ and $a_0(980)$ with large distortions from the opening of the $\bar{K}K$-threshold. In his model, $f_0(980)$ and $a_0(980)$ are $\bar{q}q$-states, but with large admixtures from the 2 meson-continuum.
To summarize the discussion on the nature of $f_0(980)$ and $a_0(980)$, there are still many arguments in favour of a standard $\bar{q}q$-interpretation. The nonet described above must not necessarily the true one. The assignment of the $f_0(1370)$ as the singlet in this nonet is controversial and as well the quadratic mass formulae can not be valid in this case. The near $\bar{K}K$ threshold is a crucial point and we have to have the best database available on $\bar{K}K$ final states. Taking these data and performing coupled channel analyses with the $\pi\pi$ and $\pi\eta$-data, respectively should be the most promising step further.

A $\bar{q}q$ nonet

Neglecting $f_0(980)$ and $a_0(980)$, the next possible nonet could be the following one.

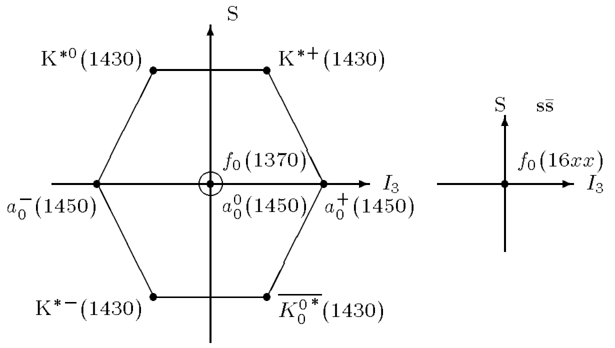


The mass and width of the a_0 are controversial and one gets mixing angles of 27^0 (m=1300 MeV/c^2)and 49^0 (m=1470 MeV/c^2). Both mixing angles are not far away from ideal mixing, but the couplings determined by Crystal Barrel (see following table] [4,41] definitely rule out the possibility, that the $f_0(1500)$ is mostly $\bar{K}K$. Therefore we can skip this assignment.

	$\pi^0\pi^0$	$\eta\eta$	K_LK_L	$\eta\eta'$	$4\pi^0$
$f_0(1370)$	1330 ± 50	1360 ± 35	1380 ± 40	$--$	1300
	300 ± 80	$300-600$	360 ± 50	$--$	230
$f_0(1500)$	1500 ± 15	1505 ± 15	1515 ± 25	1545 ± 25	1500
	120 ± 25	120 ± 30	105 ± 15	100 ± 40	150
rel.coupl.	1	0.27 ± 0.11	0.24 ± 0.10	0.19 ± 0.08	1.13 ± 0.3

Another $\bar{q}q$ nonet

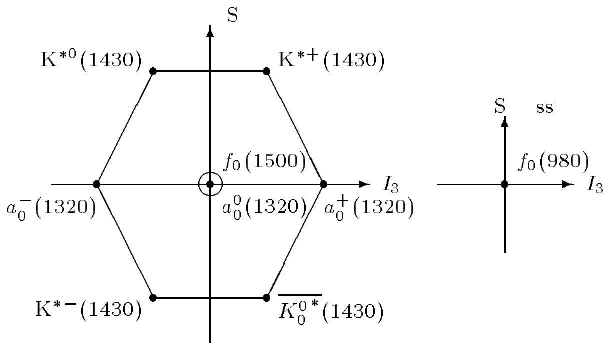
Amsler and Close [9] have suggested the following nonet for the ground state scalar mesons.



The couplings are based on SU(3) and the $f_0(1500)$ comes out as a mixture of q̄q and glue. Still controversial is the missing ss̄-state in this nonet. The Crystal Barrel data on $K^+K^-\pi^0$ taken at 1.94 GeV/cshow structures at 1700 MeV/c^2 and 1900 MeV/c^2, however the data did not allow a definite spin-parity assignment [41]. Recent experimental result from central production [47] supports the gluonic nature of the $f_0(1500)$ by a special kinematic selection, wich separates states with strong glue contribution from ordinary q̄q-mesons.

An alternative nonet

Metsch has presented [48] an alternative explanation of the experimental results.



In this full relativistic model instanton induced interactions are responsible for the mixing and the parameters were adjusted on the well known pseudoscalars. Applying this to the scalar mesons, the $f_0(980)$ is mainly singlet with a strong coupling to K̄K and the $f_0(1500)$ is mainly octet. $f_0(980)$ and $a_0(980)$ must be of different nature and the $f_0(1370$ finds no place in this nonet.

Summary

The experimental evidence of the lowest lying scalar mesons was discussed. Obviously, the is a supernumeracy of states for the possible nonet places. Different classifications were presented, but every model has his own shortcommings. Nevertheless, there is evidence for mixing of scalars and glue. The isoscalar scalar states $f_0(400-1200)$ and $f_0(1370)$ play a keyrole for the mixing scheme. Here more coupled channel analysis are required to pin down the exact numbers. At present, the $f_0(1500)$ seems to be a state with a large gluonic admixture, but only the precise knowledge of couplings and the observation in different production modes can establish the the nature of the states. Still desirable would be additional information to the present database : high statistics on radiative J/Ψ-decays (τ-charm-fectory), more statistics on D_s-decays, improved database on kaon-scattering, the glueball filter of central production and high statistics data on two-photon couplings.

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REFERENCES

1. H. Fritzsch and M. Gell-Mann, XVI Int. Conf. on High Energy Physics, Vol 2 (1972) 135
2. D. Aston et al., Nucl. Phys. **B 296** (1988) 493
3. S. Weinberg et al., Phys. Rev. **B 672** (1965) 137
4. C. Amsler et al., Phys. Lett. **B 385** (1996) 425
5. R.M. Barnett, Phys. Rev. **D 54** (1996) 1-720
6. C. Amsler et al., Phys. Lett. **B 333** (1994) 277
7. C. Amsler et al., Phys. Lett. **B 355** (1995) 425
8. M. Heinzelmann, this conference
9. C. Amsler and F. Close, Phys. Rev. **D53** (1996) 295
10. A. Abele et al., Phys. Lett. **B 404** (1997) 179
11. A. Ostrovidov, this conference
12. K.L. Au, D. Morgan and M. Pennington, Phys. Rev. **D35** (1987) 1633
13. G. Grayer et al., Nucl. Phys. **B 75** (1974) 189
14. S. Protopopescu et al., Phys. Rev. **D7** (1973) 1280
15. N.M. Cason et al., Phys. Rev. **D28** (1983) 1586
16. Ishida, this conference
17. D. Cohen et al., Phys. Rev. **D22 (1980)** 2595
18. A. Etkin et al., Phys. Rev. **D28 (1982)** 1786
19. T. Akesson et al.,Nucl. Phys. **B 264** (1986) 154
20. D. Morgan and M. Pennington, Phys. Rev. **D48 (1993)** 1185
21. E. Aker et al., Nucl. Instr. **A 322** (1992) 69
22. S.U. Chung et al., Ann. Phys. 4 (1995) 404
23. W. Ochs, University of Munich thesis, 1974

24. C. Amsler et al., Phys. Lett. **B 342** (1995) 433
25. M. Herz, Nucl. Phys. **B 56A** (Proc. Suppl.) (1997) 210
26. L. Gray et al., et al., Phys. Rev. **D27 (1983)** 304
27. D. Aston et al., Nucl. Phys. **B 301** (1988) 525
28. C. Amslet et al., Phys. Lett. **B 340** (1995) 259
29. C. Amsler et al., Phys. Lett. **B 380** (1996) 453
30. D.V. Bugg et al., Phys. Lett. **B 353** (1995) 378
31. U. Thoma, Antiproton nucleon annihilations at rest into five pions, this conference
32. C. Amsler et al., Phys. Lett **B 322** (1994) 431
33. M. Gaspero, Nucl. Phys. **A562** (1993) 407
34. F. Antinori et al., Phys. Lett. **B 353** (1995) 589
35. C. Amsler, Proton-Antiproton Annihilation and Meson Spectroscopy with the Crystal Barrel, hep-ex/9708025
36. T. Barnes, Phys. Lett. **B 165** (1985) 434
37. T. Oest et al., Z. Phys. **C 47** (1990) 343
38. S. Seredinyakov, this conference
39. Sov. J. Nucl. Phys. **48** (1980) 566
40. W. Dunwoodie, J/ΨRadiative decay into two pseudoscalar mesons (MARK III), this conference
41. M. Doser, Recent results from the Crystal Barrel experiment, this conference
42. J. Weinstein and N. Isgur, Phys. Rev. **D41** (1990) 2236
43. Janssen et al., Phys. Rev. **D52** (1995) 2690
44. Lohse et al., Nucl. Phys. **A516** (1990) 513
45. G. Lafferty, proceedings of this conference
46. N. Törnquist, Phys. Rev. Lett. **42** (1982) 624
47. A. Kirk, Search for new particles in central production, this conference
48. B. Metsch, Quark structure of light mesons, this conference
49. E. Klempt, B. Metsch, H. Petry and B. Münz, Phys. Lett. **B 361** (1995) 120