THE 1^+ NONETS IN LIGHT QUARK MESON SPECTROSCOPY

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The status of the 1^+ nonets is shortly reviewed.
Results from recent high statistics experiments, performing a partial wave analysis of 3π and $K\pi\pi$ systems, have given conclusive evidence for the existence of A_1, H, Q_A and Q_B mesons. Some questions remain concerning the assignment of the E-meson.

Introduction.

The naive non-relativistic quark model has been the guiding principle in meson spectroscopy for many years. Until recently, however, the experimental evidence for the existence of the various nonets of the $q\bar{q}$ system, nicely grouped according to the radial excitation number n and the angular momentum L, was meagre. Only for n=L=0 all particles were known (the $J^{PC}=0^{-+}$ and 1^{--} nonets). For values of n or L different from 0, however, few particles were identified. This was already true at the first level of excitation, i.e. for n or L equal to 1. Apart from the ρ' no candidates were known to fill the position of the first radial excitation of the 0^{-+} and 1^{--} nonets. Even more unsatisfactory was the situation for the four L=1 nonets ($J^{PC}=2^{++}$, 1^{++}, 1^{+-}, 0^{++}) of which only the 2^{++} members were fully identified. In particular a lot of confusion existed concerning the isovector member of the 1^{++} nonet and the strange 1^{+} candidates, the famous A_1 and Q enhancements. Similar problems existed for the 0^{+} nonet.

In the last few years there has been much progress in the indentification of the members of the 1^{+} nonets. Evidence has been found for the A_1, for two strange 1^{+} particles Q_a, Q_b and for the H meson ($I\ J^{PC}=01^{+-}$). The spin parity of the I=0, C=+ D meson has been convincingly demonstrated to be 1^{+}, while 1^{+} is also the most probable spin-parity assignment for the E meson. The two 1^{+} nonets are therefore almost complete. Also indications exist for several radial excitations of the L=0 and L=1 $q\bar{q}$ system.

In this talk the experimental evidence is reviewed for the 1^{+} nonets. The status of the 0^{+} nonet and the first radial excitation of the 1^{-} nonet will be discussed by others at this meeting. The progress in this sector of meson spectroscopy comes mainly from a few high statistics experiments which do a partial wave analysis (PWA) of 3π and $K\pi\pi$ systems. The ACCMOR collaboration[1,2] has studied the reactions

$$\pi^- p \to \pi^-\pi^+\pi^- p \text{ at 63 and 94 GeV, and}$$

$$K^- p \to K^-\pi^+\pi^- p$$

$$\to K^-\pi^+\pi^-\pi^0 p \text{ at 63 GeV}$$

$$\quad\quad\quad\quad \llcorner\!\!\to \gamma\gamma$$

A BNL experiment[3] studied

$$\pi^- p \to \pi^- \pi^+ \pi^0 p \text{ at } 8.45 \text{ GeV}, \quad \pi^0 \to \gamma\gamma$$

The statistics in these experiments is typically one order of magnitude larger than of previous experiments, having of the order of 1000 events/10 MeV mass bin.

The PWA of the three particle system is done according to the standard isobar model. Partial waves are classified according to $J^P L M^\eta$ (a,b) where the notation is explained by fig. 1. For the analysis of the 3π data of the ACCMOR collaboration the Illinois approach[4] is used; for the other data the LBL-SLAC approach[5] has been chosen.

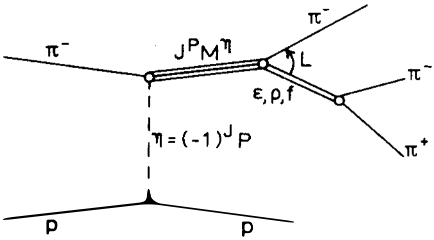

Fig. 1 The 3π system in the isobar model.

The 1^+ mesons.

A complication in the study of the broad enhancements associated with A_1, Q and H particles is the presence of an interfering background due to the Deck process (fig. 2). Bowler[6] formulated a model which corrects the bare Deck amplitude of fig. 2a with a term that accounts for the rescattering through the resonance (fig. 2b). The presence of the coherent amplitude leads to significant shifts in the position of the resonance peak in the invariant mass spectrum. In all experiments discussed here the data have been fitted to this model or a comparable multi Regge model.

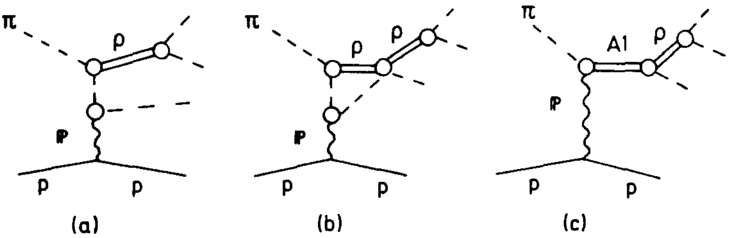

Fig. 2 Three diagrams contributing to the amplitude for diffractive production

a) One-pion exchange Deck mechanism;

b) Deck mechanism with tescattering through $\rho\pi$ final state interactions;

c) Direct diffractive A_1 meson production.

(a) The A_1 meson.

The evidence for the A_1 from the ACCMOR data is shown in fig. 3. The intensity of the 1^+S0^+ ($\rho\pi$) partial wave is shown for samples with increasing t'. In addition the phase with respect to the A_2 ($2^+D^+1^+$) $\rho\pi$ wave is shown, after subtracting the phase variation of the 2^+D1^+ wave expected for a BW with resonance parameters of the A_2.

The data clearly demonstrate the forward motion expected for a resonant 1^+S0^+ ($\rho\pi$) wave. The best values for the mass and width from a fit with the Bowler model are

$$M_{A_1} = 1280 \pm 30 \text{ MeV}$$
$$\Gamma_{A_1} = 300 \pm 20 \text{ MeV}$$

The $\pi^+\pi^-\pi^o$ data from reference [3] confirm the resonant bahaviour of the 1^+S ($\rho\pi$) wave. The phase of the nucleon helicity flip, natural parity exchange 1^+S wave with respect to an I=2 1^+S ($\rho\pi$) reference wave, shown in fig. 4, has a large forward motion of $\sim 150^o$.

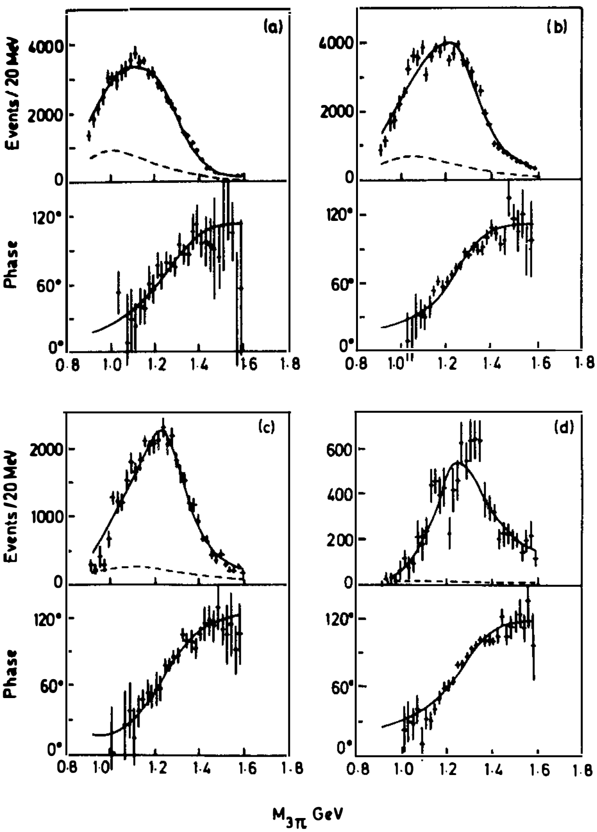

Fig. 3 Results from the ACCMOR collaboration[1)] of fitting the 1^+S0^+ intensity and phase measured with respect to the A_2 production amplitude. The solid curves represent the results of a fit with the Bowler model.

a) $0.0 \leq |t'| \leq 0.05$ GeV^2

b) $0.05 \leq |t'| \leq 0.7$ GeV^2

c) $0.16 \leq |t'| \leq 0.3$ GeV^2

d) $0.16 \leq |t'| \leq 0.7$ GeV^2

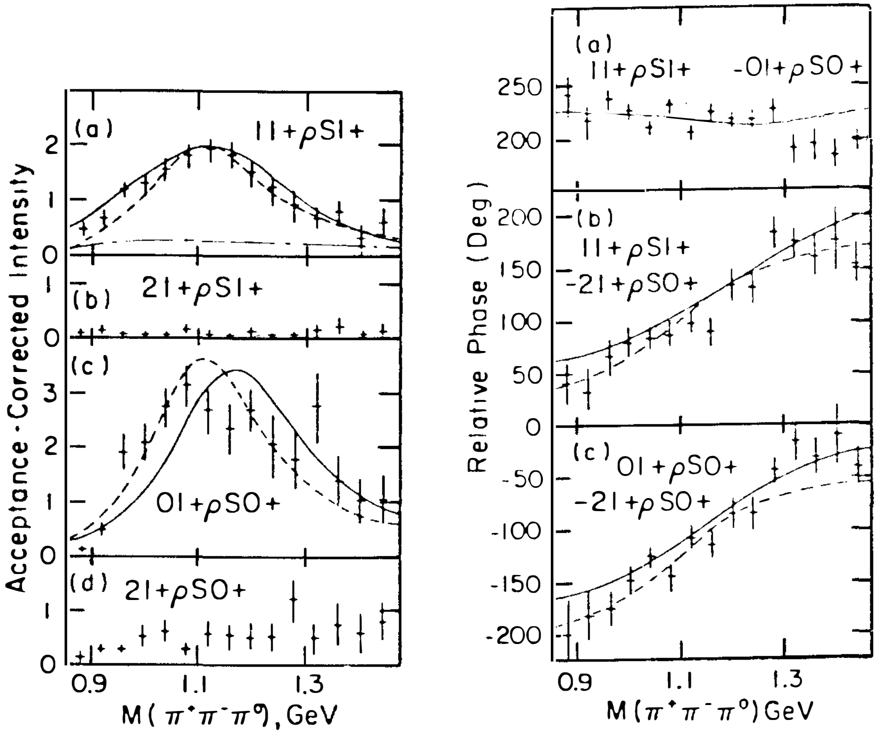

Fig. 4 Results from Dankowych et al.[3] for the $\pi^+\pi^-\pi^0$ system showing the intensity of the nucleon helicity flip, natural parity exchange 1^+S waves and their phases with respect to an I=2 1^+S ($\rho\pi$) reference wave.

If the data are fitted with the model of Bowler the A_1 resonance parameters are found to be

$$M_{A_1} = 1240 \pm 80 \text{ MeV}$$

$$\Gamma_{A_1} = 380 \pm 100 \text{ MeV}$$

in good agreement with the ACCMOR results.

These two experiments not only present convincing evidence for the existence of the A_1 but also indicate that its mass is in the range 1200 - 1300 MeV rather than at 1040 MeV as was determined from an analysis of the 3π system produced backward in the reaction $K^-p \to \Sigma^- 3\pi$ [7]

This would also better agree with the masses of the other I=1 and I=0 members of the L=1 nonets which are all in the same 1200 - 1300 MeV mass range, indicating that hyperfine splitting effects are small.

(b) The H meson.

Convincing evidence for the H-meson is found in the data of reference [3]. Both the natural parity exchange (NPE), nucleon helicity non-flip I=0 1^+S0^+ ($\rho\pi$) wave and the NPE, flip I=0 1^+S1^+ ($\rho\pi$) wave show resonant behaviour (fig. 4,5). A fit using the Bowler prescriptions gives

$$M_H = 1190 \pm 60 \text{ MeV}$$

$$\Gamma_H = 320 \pm 50 \text{ MeV}$$

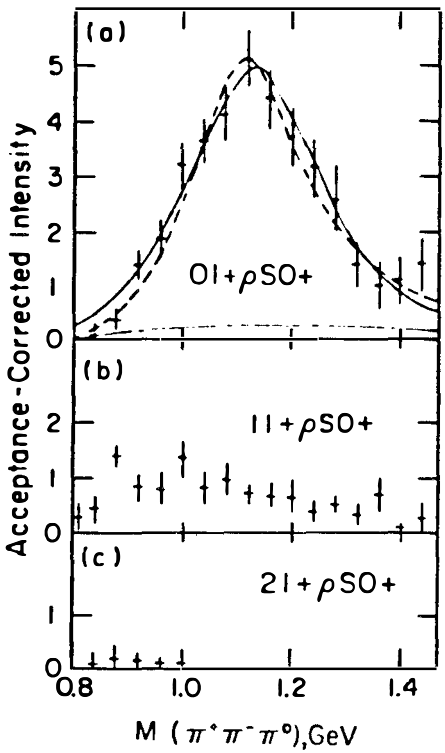

Fig. 5 Results from Dankowych et al.[3)] showing the intensities of the nucleon helicity nonflip, natural parity exchange 1^+S waves.

(c) The Q-meson.

In the L=1 $q\bar{q}$ system two strange 1^+ mesons are expected. One belonging to the 1^{++} nonet (Q_A), the other to the 1^{+-} nonet (Q_B). Since strange mesons are not eigenstates of C mixing can occur, especially since the mass difference is expected to be small. Instead of the pure octet states Q_A and Q_B physical states Q_a, Q_b are observed

$$|Q_a\rangle = |Q_A\rangle \cos\Theta_Q + |Q_B\rangle \sin\Theta_Q$$

$$|Q_b\rangle = -|Q_A\rangle \sin\Theta_Q + |Q_B\rangle \cos\Theta_Q$$

The analysis of a 13 GeV $K^-p \rightarrow K^-\pi^+\pi^-p$ experiment at SLAC[8)] first demonstrated the existence of two Q particles. In the ACCMOR experiment the SLAC results are confirmed with larger statistics. Even the raw mass spectrum shows clearly the two peak structure of the Q bump (fig. 6). In the $K^-\pi^+\pi^-\pi^o$ data the ωK decay channel of the Q_b is demonstrated. A coupled channel analysis was done using two resonances with 6 decay channels [$K^*\pi$ (S-wave), $K^*\pi$ (D-wave), ρK, $\kappa\pi$, εK and ωK (for which the couplings are fixed to $\sqrt{1/3}\,\rho K$)]. A rescattered Deck amplitude was included, while the mixing of Q_a and Q_b was taken into account to reduce the number of parameters in the fit.

The results are shown in fig. 7. New in these results is the evidence for a d-wave $K^*\pi$ decay.

The best values for mass and width are

$M_{Q_a} = 1410 \pm 25$ MeV $\qquad \Gamma_{Q_a} = 195 \pm 25$ MeV

$M_{Q_b} = 1270 \pm 10$ MeV $\qquad \Gamma_{Q_b} = 90 \pm 8$ MeV

The mixing angle Q_a from the fit is 56 ± 3^o which corresponds to mass values for the pure octet states.

$M_{Q_A} = 1310 \pm 15$ MeV

$M_{Q_B} = 1370 \pm 20$ MeV

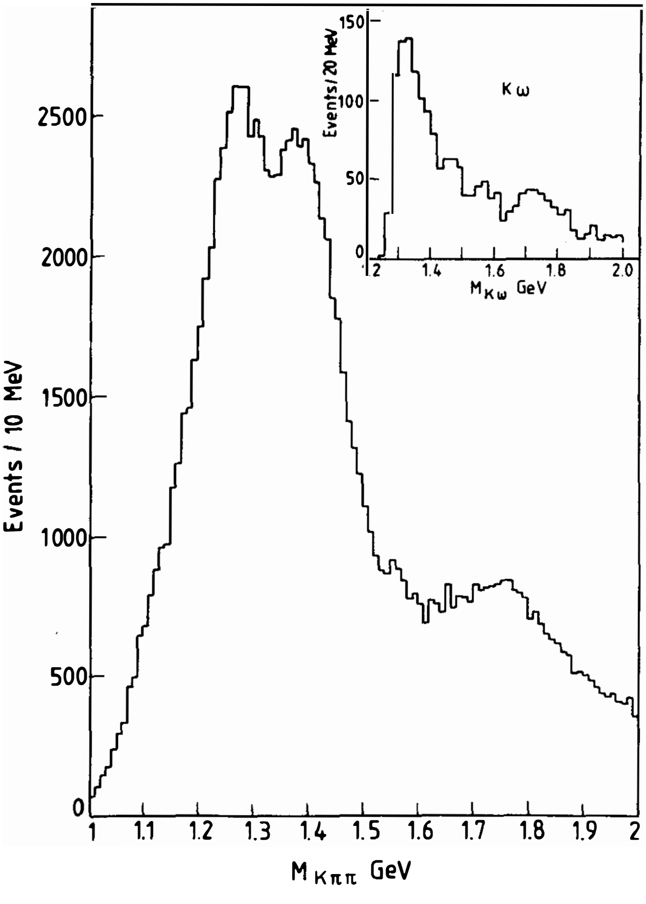

Fig. 6 The $K^-\pi^-\pi^+$ mass spectrum as measured by the ACCMOR collaboration[2]. The raw Kω mass spectrum is shown as an insert.

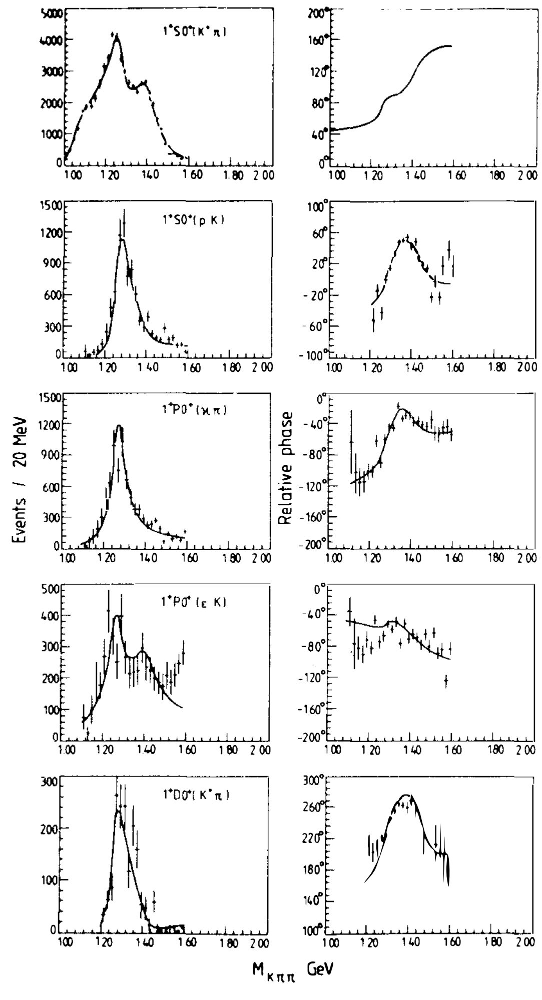

Fig. 7 Results from the ACCMOR collaboration[2] of a partial-wave analysis in the Q region, $1.0 \leq M_{K\pi\pi} \leq 1.6$ GeV, for 1^+0^+ waves, $0 \leq |t'| \leq 0.05$ GeV^2. The phases are measured with respect to 1^+S0^+ $(K^*\pi)$. The curves represent the fits obtained with two Q resonances and coherent background.

(d) The D and E mesons.

If we accept the D and E as its isoscalar members, the 1^{++} nonet is complete. The J^P of the D-meson is well defined as 1^+, in particular by a partial wave analysis of the $\eta\pi\pi$ system by Stanton et al.[9]. The situation for the E-meson is less clear. Dionisi et al.[10] have analyzed the $K^o_s K^{\pm}\pi^{\mp}$ system in 3.95 GeV $\pi^- p \rightarrow K^o_s K^{\pm}\pi^{\mp} n$ interactions and indicate a strong preference for $J^P=1^+$. This, however, is in disagreement with previous $\bar{p}$ p results which favour $J^P=0^-$ [11].

Another problem with the E-meson is its production characteristics. It is generally assumed that the E is the $s\bar{s}$ member of the 1^+ nonet. The near mass degeneracy of A_1 and D is in agreement with that assumption. However, the Dionisi data indicate a rather large cross section of about 10 μb in $\pi^- p$ interactions. On the other hand a comparable cross section is measured for D-production in $K^- p \rightarrow Dn$ at 4.2 GeV, while in the same experiment the evidence for the E-meson is hard to find[13]. These results would suggest that the D and E if both belonging to the 1^{++} nonet are far from ideally mixed.

Another possible indication for such an assumption comes from a comparison of the decay widths of the various nonet members assuming SU(3) symmetric couplings. In reference [2] the couplings are determined from a fit to the Q-meson data and are used to predict the width of $A_1 \rightarrow \rho\pi$ and $B \rightarrow \omega\pi$ decays. These values appear to be in prefect agreement with the observed widths. The predictions for the $K^* K$ partial width of the E-meson depends on the E, D mixing angle. With the couplings from the Q-analysis a mixing angle of 55^o is required - significantly larger than the 35^o corresponding to perfect mixing - to reproduce the observed width of about 40 MeV. Some care, however, is here required. The E-meson has a mass just above the $K^* K$ threshold. The calculated width therefore becomes very sensitive to the assumptions which are put into the determination of the phase space factor.

In conclusion the situation concerning the E-meson is still rather confused. An isoscalar $s\bar{s}$ member of the 1^{++} nonet is certainly expected at a mass of about 1420 MeV. However, the particle that has been observed at this mass cannot unequivocally be assigned to this state. Possibly the situation is complicated by the presence of other particles in this mass region, like glueballs and radial excitations of η, and η', which make a clear identification difficult.

Conclusions.

Conclusive evidence now exists for most of the members of the two $J^P=1^+$ nonets expected for a $q\bar{q}$ system with L=1. The A_1 has a mass in the range 1200 - 1300 MeV. This is larger than previous low statistics data seemed to indicate but clearly is in better agreement with the masses of the other L=1 $q\bar{q}$ mesons. Also the I=0, $J^{PC}=1^{+-}$ H-meson has now been firmly established leaving the $s\bar{s}$ member of the 1^{+-} nonet as the only undiscovered particle of the two 1^+ nonets. Using the Gell-Man-Okubo formula its mass is predicted to be ~1.48 GeV.

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