CM-P00058296

Archives

Ref.TH.1476-CERN

SU(3) AND THE $\Sigma(1385)\pi$ DECAY MODE OF THE D_{03} RESONANCES

D. Faiman
CERN - Geneva

and

D. E. Plane
Max-Planck Institut für Physik und Astrophysik, Munich

A B S T R A C T

By assuming the existence of a second octet with $J^P = \frac{3}{2}^-$ whose couplings are related via $SU(6)_w \times O(3)$ to those of the established $\frac{3}{2}^-$ "nonet", we reconcile recent measurements on the $\Sigma(1385)\pi$ decay modes of the $D_{03} \bar{K}N$ resonances with their other partial widths. The predicted properties of the third as yet unobserved D_{03} state raise important questions regarding the measurement of resonant parameters.

Ref.TH.1476-CERN

16 March 1972

Recent experimental investigation ^{1),2)} of the $\Sigma(1385)\pi$ decay modes of the $\Lambda(1520)$ and $\Lambda(1690)$ resonances poses a serious problem for the hitherto successful mixed singlet-octet description of these resonances. Specifically the observed partial widths of 1.66 ± 0.24 MeV ¹⁾ and 1.0 ± 0.9 MeV ²⁾ for their respective s wave decays into $\Sigma(1385)\pi$ lead to a singlet-octet mixing angle of $75^\circ \pm 10^\circ$ in contrast to the value of $25^\circ \pm 6^\circ$ derived ³⁾ from a study of their BP (baryon octet, pseudoscalar meson octet) decay rates. Indeed as explained in Ref. 1), in order to obtain agreement with the latter mixing angle the partial width for $\Lambda(1690) \rightarrow \Sigma(1385)\pi$ would have to be 73 MeV. The purpose of this note is to point out that not only are the new observations not in conflict with the usual ideas of mixing, but that they are in fact in quantitative agreement with the 25° mixing picture, if this angle is given a slightly different interpretation.

The idea is as follows : we assume the existence of three basic D_{03} resonances as required by the $\underline{70}, 1^-$ classification ⁴⁾ of the baryons in $SU(6) \times O(3)$. That is, for $J^P = \frac{3}{2}^-$, we have two $SU(3)$ octets and a singlet, along with a decuplet that of course contains no Λ member. The advantage of such an $SU(6)$ classification is that not only are the F/D ratios of these octets fixed and their respective couplings inter-related but also the decay products, be they stable baryons or decuplet resonances, can be treated on an equal footing, these latter states belonging as they do to a $\underline{56}, 0^+$ representation. In particular, five parameters will suffice to describe the decays of $\Lambda(1520)$, $\Lambda(1690)$ and a third as yet unobserved D_{03} state : three mixing angles and two coupling constants (s and d wave). These may be compared with the five parameters required in the now unsuccessful nonet $SU(3)$ description.

We parametrize the decay widths in terms of the familiar potential theory expression :

$$\Gamma = c^2 G^2 B_\ell \frac{k}{M_R} M_N$$

but take the couplings to be related by $SU(6)_w$ symmetry ⁵⁾. In this expression the c's are now $SU(6)_w \times O(3)$ Clebsch-Gordan coefficients with mixing included where appropriate, G is a coupling constant which takes the values f for s wave decays and g for d wave decays, B_ℓ is a barrier penetration factor, k is the centre-of-mass momentum

of the decay products and M_R is the resonance mass. M_N is the proton mass inserted for dimensional purposes. We have chosen the same form for B_ℓ that was found to be successful in Ref. 3), i.e., with zero radius of interaction ^{*}), giving $B_\ell = k^{2\ell}$.

We suppose $\Lambda(1520)$, $\Lambda(1690)$ and some third D_{03} resonance to be linear orthogonal superpositions of the three basis states which may be represented in quark model notation as $\{8\}^{\frac{1}{2}}$, $\{8\}^{\frac{3}{2}}$ and $\{1\}^{\frac{1}{2}}$. The superscript indicates the doublet or quartet nature of the total quark spin. Hence in the notation of Ref. 6), we write :

$$\begin{pmatrix} \Lambda[\quad] \\ \Lambda(1690) \\ \Lambda(1520) \end{pmatrix} = \begin{pmatrix} \Lambda_{11}^d & \Lambda_{12}^d & \Lambda_{13}^d \\ \Lambda_{21}^d & \Lambda_{22}^d & \Lambda_{23}^d \\ \Lambda_{31}^d & \Lambda_{32}^d & \Lambda_{33}^d \end{pmatrix} \begin{pmatrix} \{8\}^{\frac{1}{2}} \\ \{8\}^{\frac{3}{2}} \\ \{1\}^{\frac{1}{2}} \end{pmatrix}$$

where the Λ_{ij}^d form a real orthogonal matrix. Taking the relevant Clebsch-Gordan coefficients from Ref. 6), one could in principle obtain the mixing parameters as follows.

- 1) First g^2 from the measured decay partial width

$$\Gamma[\Delta(1670, \frac{3}{2}^-) \rightarrow N\pi] = \frac{2}{27} g^2 \frac{k^5 M_N}{M_{\Delta(1670)}}.$$

- 2) Three independent measurements are then required to determine the Λ_{ij}^d 's, for example ;

$$\Gamma[\Lambda(1520, \frac{1}{2}^-) \rightarrow N\bar{K}] = \frac{2}{3} (\Lambda_{31}^d + \Lambda_{33}^d)^2 g^2 \frac{k^5 M_N}{M_{\Lambda(1520)}}$$

$$\Gamma[\Lambda(1520, \frac{1}{2}^-) \rightarrow \Sigma\pi] = \frac{1}{45} (\sqrt{5}\Lambda_{31}^d + \sqrt{2}\Lambda_{32}^d - 3\sqrt{5}\Lambda_{33}^d)^2 g^2 \frac{k^5 M_N}{M_{\Lambda(1520)}}$$

^{*}) Our g^2 thus has the dimensions $(\text{GeV})^{-4}$. It may be compared with $G^2 r^4/9$ in the limit of $r \rightarrow 0$, where G is the more familiar dimensionless form of coupling : $G^2(kr)^4/[9 + 3(kr)^2 + (kr)^4]$.

$$\Gamma[\Lambda(1690, \frac{3}{2}^-) \rightarrow N\bar{K}] = \frac{2}{3} (\Lambda_{21}^d + \Lambda_{23}^d)^2 g^2 \frac{k^5 M_N}{M_{\Lambda(1690)}} .$$

With the mixing matrix Λ_{ij}^d thus determined, it is a simple matter to predict the ratio of the s wave decays of these two D_{03} states into $\Sigma(1385)\pi$ and compare the result with experiment. These decays are given by the expressions

$$\Gamma[\Lambda(1520, \frac{3}{2}^-) \rightarrow \Sigma(1385)\pi]_{s\text{-wave}} = \frac{2}{9} (\sqrt{2}\Lambda_{31}^d + \sqrt{5}\Lambda_{32}^d)^2 f^2 \frac{k M_N}{M_{\Lambda(1520)}}$$

$$\Gamma[\Lambda(1690, \frac{3}{2}^-) \rightarrow \Sigma(1385)\pi]_{s\text{-wave}} = \frac{2}{9} (\sqrt{2}\Lambda_{21}^d + \sqrt{5}\Lambda_{22}^d)^2 f^2 \frac{k M_N}{M_{\Lambda(1690)}}$$

where for the $\Lambda(1520)$ rate, a mean decay momentum of 25 MeV/c should be used ⁷⁾.

In fact we have performed a least-squares fit to some forty s and d wave decay processes for which experimental data are available, taking advantage of the observed signs of resonant amplitudes in order to eliminate ambiguities inherent in the quadratic nature of the above equations. The over-all fit is rather successful but a full elaboration of the fitting procedure and discussion of results will be presented elsewhere. The result relevant to our present discussion is that we find the unique solution :

$$\Lambda_{ij}^d = \begin{bmatrix} -.397 & -.898 & .188 \\ .805 & -.439 & -.399 \\ .441 & -.006 & .898 \end{bmatrix}$$

with $g^2 = 12.24 \text{ GeV}^{-4}$ and $f^2 = 1.297$. These values of the parameters yield the following decay rates which compare quite favourably with the experimental data.

	Γ_{Theory}	$\Gamma_{\text{Experiment}}^{8)}$
$\Delta(1670) \rightarrow N\pi$	29.8 MeV	$36.4 \pm 10.3 \text{ MeV}$
$\Lambda(1520) \rightarrow N\bar{K}$	7.1 MeV	$7.0 \pm 0.65 \text{ MeV}$
$\Lambda(1520) \rightarrow \Sigma\pi$	5.2 MeV	$6.5 \pm 0.61 \text{ MeV}$
$\Lambda(1690) \rightarrow N\bar{K}$	11.3 MeV	$6.3 - 12.1 \text{ MeV}$
$\Lambda(1690) \rightarrow \Sigma\pi$	24.8 MeV	$15.0 - 52.0 \text{ MeV}$
$\Lambda(1690) \rightarrow \Lambda\gamma$	$\sim 0 \text{ MeV}$	not seen
$\Lambda(1520) \xrightarrow{L=0} \Sigma(1385)\pi$	1.7 MeV	$1.66 \pm 0.24 \text{ MeV}^{1)}$
$\Lambda(1690) \xrightarrow{L=0} \Sigma(1385)\pi$	1.0 MeV	$1.0 \pm 2.4 \text{ MeV}^{2)}$ $- 0.9$

Notice that Λ_{33}^d is the direction cosine of $\Lambda(1520)$ with respect to the $\{1\}$ axis, the corresponding angle being $26^\circ \pm 3^\circ$. Similarly $\Lambda(1690)$ tilts at an angle of $\sim 67^\circ$ from this axis, i.e., $\sim 23^\circ$ from the "octet plane" but it does not lie in the plane formed by $\Lambda(1520)$ and the $\{1\}$ axis, in contrast to the old nonet picture.

Notice also that the $\{8\}^{\frac{3}{2}}$ state plays no significant role in the make-up of $\Lambda(1520)$ but that it is crucial in suppressing the s wave $\Sigma(1385)\pi$ decay of $\Lambda(1690)$.

Notice lastly that these values of the parameters predict a small but measurable d wave decay mode for $\Lambda(1690)$ into $\Sigma(1385)\pi$, namely

$$\frac{4}{45} (\sqrt{5} \Lambda_{21}^d - 2\sqrt{2} \Lambda_{22}^d)^2 g^2 \frac{k^5 M_N}{M_{\Lambda(1690)}} = 4.8 \text{ MeV.}$$

What of the unobserved state ? Taking 1830 MeV as a not unreasonable guess at its mass, we may then predict the following decay properties :

$$\begin{aligned}
 \Lambda [1830] &\rightarrow N\bar{K} & : & 9.3 \text{ MeV} \\
 \Lambda [1830] &\rightarrow \Sigma\pi & : & 57.8 \text{ MeV} \\
 \Lambda [1830] &\rightarrow \Lambda\gamma & : & 0.2 \text{ MeV} \\
 \Lambda [1830] &\rightarrow \Sigma(1385)\pi & : & 359.0 \text{ MeV} \quad (\text{s wave}) \\
 & & : & 10.3 \text{ MeV} \quad (\text{d wave})
 \end{aligned}$$

i.e., a total width in excess of 400 MeV and an elasticity no greater than 0.02, the precise figures being of course dependent on the unknown mass of this state. With such properties it is hardly surprising that no evidence has been reported for the resonance. Nevertheless it does raise an important question. Namely, to what extent should a possible resonant (or even non-resonant !) background be catered for in the assessment of the hyperon resonance parameters. For example, on account of its large width, our hypothetical $\Lambda [1830]$ would have appreciable $\Sigma\pi$ and s wave $\Sigma(1385)\pi$ amplitudes in the 1690 MeV mass region. Most investigations of $\Lambda(1690)$ have assumed no D_{03} amplitude at all except the purely resonant $\Lambda(1690)$ amplitude, and this over a mass range extending to 1900 MeV. In view of the goodness of the present fit to the known data [notwithstanding wide disagreements on the properties of $\Lambda(1690)$ ⁹⁾] we would urge future phase shift analyses to take into consideration the effects of a possible third D_{03} resonance.

ACKNOWLEDGEMENTS

The authors wish to thank Dr. D. Olive and Professor N. Schmitz for some helpful suggestions.

REFERENCES

- 1) T.S. Mast, M. Alston-Garnjost, R.O. Bangerter, A. Barbaro-Galtieri, F.T. Solmitz and R.D. Tripp - "A Study of the Decay $\Lambda(1520) \rightarrow \Sigma(1385)\pi$ ", Phys.Rev.Letters, to be published, and "An Analysis of $K^-p \rightarrow \Lambda\pi^+\pi^-$ in the Region of the $\Lambda(1520)$ ", to be published.
- 2) J. Prevost et al. - "Partial Wave Analysis of $\bar{K}N \rightarrow \Sigma(1385)\pi$ Between 0.6 and 1.2 GeV/c", paper presented by R. Barloutaud to the Amsterdam International Conference on Elementary Particles, June 30 - July 6, 1971, as quoted in Ref. 1).
- 3) D.E. Plane, P. Baillon, C. Bricman, M. Ferro-Luzzi, J. Meyer, E. Pagiola, N. Schmitz, E. Burkhardt, H. Filthuth, E. Kluge, H. Oberlack, R. Barloutaud, P. Granet, J.P. Porte and J. Prevost - Nuclear Phys. B22, 93 (1970).
- 4) R.H. Dalitz - Les Houches Lectures (1965), Gordon and Breach, New York (1965).
- 5) H.J. Lipkin - Phys.Rev. 159, 1303 (1967).
- 6) D. Faiman - Nuclear Phys. B32, 573 (1971). Note that the required $SU(6)_w$ Clebsch-Gordan coefficients may be obtained from the tables in reference by simply dropping the kinematic factor peculiar to the specific model employed therein. A justification of this statement will be found in Ref. 5) above.
- 7) The authors are indebted to Professor R.D. Tripp for discussions on this point.
- 8) Particle Data Group - Revs.Modern Phys. 43, part II (1971), unless otherwise indicated.
- 9) See footnote h to the baryon table in Ref. 8)