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BARYON RESONANCE COUPLINGS IN THE REACTIONS $\pi N \to \pi\Delta$ AND $\pi N \to \rho N$: COMPARISON WITH THEORY AND RELATED REACTIONS*

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ABSTRACT

We find good agreement between the results of our measurements of $\pi N \to \pi\Delta$ and the predictions of broken $SU(6)_W$ and Melosh transformations. The D13($\sim$ 1700) is observed to be in a $[70, 1^-]$ while the P33 ($\sim$ 1700) is assigned to a $[56, 0^+]$. The signs of resonant amplitudes in $KN \to \pi\Sigma(1385)$, where reliably determined, are in agreement with out results. There is surprisingly good agreement between our ρN amplitudes and the corresponding photoproduction amplitudes.

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1. Introduction

In this paper we summarize the results we have obtained on the signs and couplings of the resonance amplitudes in the reactions

$$\pi N \rightarrow N^* \rightarrow \pi\Delta \tag{1}$$

$$\pi N \rightarrow N^* \rightarrow N\rho \tag{2}$$

These results follow from a partial wave analysis of the reaction $\pi N \rightarrow \pi\pi N$ for energies up to 2000 MeV, which provided a unique description of the πN scattering amplitudes in this energy range[1]. We compare these new results with the predictions of the current theories on the classification of resonant states[2, 3, 4].

Application of SU(3) symmetry allows us to predict in certain cases the signs of resonance amplitudes in the corresponding negative strangeness 1 reaction

$$K^- p \rightarrow Y^* \rightarrow \pi\Sigma(1385) \tag{3}$$

and a comparison is made with the experimental results where they exist. Finally, the photoproduction of N^* resonances is related by vector dominance to reaction (2) and we can study and compare the production of the major N^* resonances in these two situations.

The difficulties of extracting meaningful resonance parameters have been discussed in ref. [5] and attempts to compare the parameters from several different methods of fitting were presented in ref. [6]. Where applicable we use these numerical estimates of coupling strengths and transition amplitudes to develop the quantitative aspects of the comparison with theory and to point out possible problems.

2. N^* Resonances in the Reaction $\pi N \rightarrow \pi\Delta$ and Higher Symmetry Schemes

In fig. 1 we show our signs for the transition amplitudes for the well known N^* resonances below a mass of 2000 MeV. We also include the results for the 'new' resonances we observe, the D13(1700), the P33(1700) and the possible P11(1700) (ref. [1,4]). We use the universal "Baryon first" convention; further discussion of the signs is in ref. [7].

The importance of these measurements lies in the fact that we can use them to test higher symmetry schemes and the classifications they imply for the non-strange baryon states. Currently the symmetric quark model[8] is very successful in classifying the resonances in supermultiplets which are representations of $SU(6) \times O(3)$. Indeed, the $[56, 0^+]$, $[56, 2^+]$, $[70, 1^-]$ are almost complete and it is then valuable to test the application of symmetries to the decay mechanisms. Application of the collinear symmetry group $SU(6)_W$ immediately gives problems, the most notable being that it predicts zero coupling for the dominant helicity amplitudes for photoproduction of the D13(1520) and F15(1690) resonances[9]. Specific models for the breaking of this symmetry have been proposed by various authors[2], in which the relationships between the different orbital angular momentum states (in the decays $\pi\Delta$, πN) implied by $SU(6)_W$ are relaxed; this is ℓ-broken $SU(6)_W$. Recently these schemes have derived major theoretical support by Gilman et al. using Melosh transformations[3].

In Table 1 we compare the results of these calculations with our experimental results for the $[70, 1^-]$, $[56, 2^+]$, $[56, 0^+]_{n=2}$ multiplets. A number of comments are in order.

a) For the $[70, 1^-]$ multiplet we have agreement on all of the signs we measure reliably. The D13(1700) fits into this scheme. The dominant term in the transition matrix element is the symmetry breaking term, $(3, \bar{3})_1 - (\bar{3}, 3)_{-1}$, in the notation of Gilman et al. [3], and this corresponds to a sign relation between the S- and D-waves opposite to that predicted by $SU(6)_W$, but given by the anti-$SU(6)_W$ term of Rosner et al. [2].

b) The sign tests in the $[56, 2^+]$ are fewer in number but indicate the dominance of the $(8,1)_0 - (1,8)_0$ term which gives the same relative sign of the P- and F-wave amplitudes predicted by pure $SU(6)_W$. The presence of only the F-wave decay of the F35(1830) resonance[10] is surprising (when a P-wave would have been expected on kinematic angular momentum barrier grounds), and could indicate mixing with another F35 from some other supermultiplet (e.g., $[70, 2^+]$).[11] A more quantitative treatment[12] of the decays of the $[56, 2^+]$ has shown that this result is compatible with the experimental data.

c) We measure a negative sign for the coupling in the $\pi\Delta$ decay of the PP33 in the vicinity of 1700 MeV. Table 1 shows that if it were in the $[56, 2^+]$ it would have to have a positive sign (for both the "normal" and "anti"-SU(6) couplings); hence, it must belong in $[56, 0^+]_{n=2}$, as a partner of the PP11(1470). Similarly, this negative sign also rules out the possibility that the PP33(1700) can belong to a $[70, 2^+]$.

d) Our sign for the $\Delta\pi$, PP11 decay of the P11(1700), together with the theoretical work on modified SU(6) (refs. [2,3]), indicates that this state may belong to yet another $[56, 0^+]$ supermultiplet. If this is the case, it would correspond to the third even parity radial excitation of the nucleon. This raises the interesting question: where are the other members of the $[56, 0^+]_{n=2}$ and $[56, 0^+]_{n=4}$?

Many of these results can also be derived from the quark model[13] and where quantitative estimates have been made these are included in Table 1. The major discrepancy is in the sign of the FP15 amplitude. This can, however, be corrected by a modest change in the quark model parameters.[14]

3. The SU(3) Related Reaction $K^- p \rightarrow \pi\Sigma(1385)$

Our measurements of the relative signs of the transition amplitudes in reaction (1) allow us in certain circumstances to predict the signs of the transition amplitudes in reaction (3). The relevant group symmetric decompositions are

incident state: $8 \otimes 8 = 1 \oplus 8_f \oplus 8_d \oplus 10 \oplus 10^* \oplus 27$, coupling constant g (4)

final state: $10 \otimes 8 = 8 \oplus 10 \oplus 27 \oplus 35$, coupling constant g'_{10} (5)

Thus whenever the intermediate resonant state is a member of a decuplet, the structure of the transition amplitude is

$$T_{(res)} \sim c\, g\, c'_{10}\, g'_{10} \tag{6}$$

whereas if the intermediate state belongs to an octet we have

$$T_{(res)} \sim (c_f g_f + c_d g_d)\, c'_8\, g'_8 \tag{7}$$

where the c's are the appropriate SU(3) Clebsch-Gordan coefficients and the g's the coupling constants.

When we measure the decay of an intermediate Δ (i.e., belonging to a decuplet) in reaction (1) we determine the product, $g\, g'_{10}$ in (6). This means that the corresponding decays of all other members in the intermediate decuplet can be immediately predicted using the appropriate SU(3) Clebsch-Gordan coefficients. Unfortunately no data exist at present on decuplet Y_1^* decays into $\pi\Sigma(1385)$. However, when the intermediate state belongs to an octet, in order to make predictions using (7) we need to know the f and d type coupling to the incident channels. Thus we can only make predictions where these have been reliably measured, i.e., for the $3/2^-$, $5/2^-$ and $5/2^+$ octets[15].

Equation (5) also demonstrates that the decay of a pure singlet Y_0^* into $\pi\Sigma(1385)$ is forbidden. However, if the state is not pure, then this decay can occur through an octet component; thus the D03(1520), although a predominantly singlet state, is observed[16] to decay into $\pi\Sigma(1385)$.

In fig. 2 we summarize our predictions; we now discuss the experimental situation. Analysis of the reaction (3), observed as

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

has allowed measurements of the $\pi\Sigma(1385)$ decay rate of the D03(1520) (ref. [16]), and the relative signs and magnitudes[17] of the decays of the D03(1690), D05(1830), F05(1815), D13(1660), D15(1765). The comparison between our predictions and these measurements is made in Table 2.† We see that the only

†We have made an exhaustive study, in conjunction with the authors of ref. [17], of the sign conventions used in the two analyses in order to be certain that the comparisons are reliable. Specifically, we both conform to the convention of S. M. Deem, RHEL preprint RPP/H/68. One test was to consider the angular distribution in $\pi N \to \pi\Delta$ ($\bar{K}N \to \pi\Sigma(1385)$) associated with the interference of D5 and F5 waves and ensure that in both cases the same predictions were obtained.

major discrepancy is for the D05(1830) and that this corresponds to a disagreement with SU(3) internal to the analysis of the K^-p reaction. The same conclusions have been reached by the authors of ref. [17]. No comparison with the sign of the D03(1520) transition amplitude can be made, as there is no overlap between the two analyses of refs. [16] and [17].

Having checked the signs, we proceed to compare the coupling constants. We use the results of refs. [16, 17] to calculate the coupling constants and mixing angle for the $3/2^-$, $5/2^-$ and $5/2^+$ states.†† The N* partial widths have been

††In order to calculate the coupling constants we make the following assumptions:

$$T_{res} = \sqrt{x_{el} x_{inel}}$$

$$\Gamma_{inel} = \Gamma_{tot} x_{inel} = \Gamma_{tot} \frac{T^2_{res}}{x_{el}}$$

where T_{res} is the reaction amplitude at resonant energy, and x_{el} is the measured elasticity.

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estimated from a K-matrix fit to the elastic and inelastic resonance amplitudes[6]. In the case of the N* D13(1520) we assume that this is a pure $^2[8]$ state of the [70]. To calculate the coupling constants we use the standard relationship in which the partial widths for the decay are given by

$$\Gamma = (c' \; g')^2 \, B_L(pr) \, \frac{P}{E} \, M_P \tag{9}$$

where c' is the appropriate SU(3) Clebsch-Gordan coefficient, g' the coupling constants and $B_L(pr)$ the angular momentum barrier factor of Blatt and Weisskopf[18], where the radius r is taken to be 1 fm.† The results are shown in Table 3.

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†Since these transitions involve an unstable particle in the final state the product $B_L(pr)p$ has been averaged over the resonance shape. In the case of the Δ the line shape of ref. [1] has been used. For the Σ(1385) the Breit-Wigner parameters of PDG were used.

We can make the following comments:

a) The measurements of g' for the $5/2^-$ and $5/2^+$ octets are in good agreement.

b) In the case of the $3/2^-$ states $\Gamma_{\pi\Delta}$ of the D13(1520) appears to be too small (indeed, using this value and the Λ(1520) width would give an unphysical mixing angle). This indicates that the usual approach to mixing is too simple and one must consider more sophisticated mixing schemes involving mixing of all three Λ states, all three Σ states and the two N* states[2]. A relatively successful reanalysis[12] of the $[70, 1^-]$ multiplet has recently been performed which incorporates both these new measurements and more sophisticated mixing.

c) The inelastic width of the D13(1700) is large, supporting the predictions of Faiman and Plane[2].

d) The D-wave decay of the D13(1520) (ref. [1]) is surprisingly important.

e) The values of g' are sensitive to our estimates of x_{el} and Γ_{tot} and are thus not as reliable as an overall fit to all the transition amplitudes[2, 12].

4. Nρ Couplings and Photoproduction

The unique partial wave amplitude description of $\pi N \rightarrow \pi\pi N$ up to 2000 MeV allows us to study the ρN decays of the N* and Δ resonances. The signs of these resonance decay amplitudes are summarized in fig. 3 and we have indicated there the reliability of the interpretation. Ambiguous signs result from either the resonance contribution being too small (for reliable measurement) or because the resonance loop is rotated through $\sim\pm 90^{\circ}$ by the presence of backgrounds. We feel that only the DS13(1520), FP15(1690), PP13(1700), FP35(1890) waves are reliable measurements and that the FF37, although large, suffers from the background problem discussed above.

At first inspection, the Nρ amplitudes appear to be very large. We will demonstrate that these couplings are comparable in size to those of photoproduction (after application of the vector dominance model) and possess many similar properties. In order to make comparisons we use the results of Knies, Moorhouse, Oberlack, Rosenfeld and Rittenberg[19], and of Metcalf and Walker[23], and consider the five resonances D13(1520), F15(1690), P13(1700), F35(1890) and F37(1930). We can compare both the signs and magnitudes of the couplings using the definitions of Walker[20].

In order to extract a magnitude for the ρN amplitudes we first project out the transverse ρ component from the partial wave amplitude and calculate a barrier penetration factor using simple Blatt and Weisskopf[18] barrier factors and averaging over the ρ shape used in ref. [1]. In order to calculate the equivalent γN reaction we simply assume a 'ρ' meson of mass zero and scale this barrier factor. Clearly, this is a very crude method of extrapolation as it certainly does not ensure that the longitudinal ρN coupling goes to zero as the ρ mass approaches zero. We should therefore not expect good quantitative agreement.

To compare the signs of the transition amplitudes with photoproduction we adopt the following procedure:

(i) Take the $N\pi \rightarrow N\rho$ signs from refs. [1,6] which are shown in fig. 3.

(ii) Construct helicity matrix elements for transverse ρ's using eq. (21) of ref. [7]. For the results see ref. [22].

(iii) Convert to the ordering $\pi N \rightarrow \rho N$. †

(iv) Construct the A and B amplitudes of Walker[20] from these helicity matrix elements.

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†The important result required for this change is

$$\langle \lambda_c \lambda_d | S^J | \lambda_a \lambda_b \rangle = (-1)^{J-S_c-S_d} \langle \lambda_d \lambda_c | S^J | \lambda_a \lambda_b \rangle$$

The comparison of the signs of the amplitudes is made in Table 4, while Table 5 gives a quantitative comparison of the strength of the couplings. We have included the F37 in these tables despite the background problems which lead to difficulties in the identification of the sign of the resonant amplitude. A more sophisticated test using the quark model and our preliminary results was performed by Moorhouse and Parsons[21]. Comparisons with $SU(6)_W$ predictions have also been made by Faiman[24]. However, due to problems in the phase definitions of the different authors conclusions based on these comparisons are dubious. We therefore prefer to restrict ourselves to comparison of our final results with photoproduction where these conventions are well known[20].

The following points can be noted:

a) The major amplitudes, D13 (A and B) and F15 (B) have the same relative signs as in photoproduction.

b) In general the photoproduction helicity structure is qualitatively preserved and the numerical agreement surprising, considering the simplicity of the method.

5. Conclusions

We may draw the following conclusions from these comparisons.

a) The relative signs of ten large resonant amplitudes in our $\pi\Delta$ partial wave analysis agree with the predictions for the $[70, 1^-]$ and $[56, 2^+]$, based on ℓ-broken $SU(6)_W$ or Melosh transformations. Of the quark model predictions currently available only that for the FP15 wave is in disagreement.

b) The D13($\sim$1700) has both a large width ($\sim$300 MeV) and the correct sign to lie in the $[70, 1^-]$ whereas the P33($\sim$1700) appears to be the partner of P11(1470) in a radial excitation of the $[56, 0^+]$.

c) The possible P11($\sim$1700) observed in our analysis[1] has a P-wave decay which may imply its classification in a further $[56, 0^+]$ — a possible third radial excitation of the nucleon.

These points emphasize the importance of measuring coupling signs in classifying resonance states.

d) From our N* and Δ couplings, we can predict Y_0^* and Y_1^* couplings which are in good agreement with the limited number of reliable experimental observations.

e) The magnitudes of the $\Lambda(1520)$, $\Lambda(1690)$, $N^*(1520)$ decays into $\pi\Sigma(1385)$ and $\pi\Delta(1238)$ imply that a simple mixing prescription for the $3/2^-$ baryons is not satisfactory. A new analysis[12] incorporating these results and utilizing a more sophisticated approach to mixing has shown the consistency of the data with the present classifications.

f) The crude comparison of photoproduction and ρN amplitudes is surprisingly good, the major helicity amplitudes for the D13(1520) and F15(1690) having the correct sign. The amplitudes tend to preserve the helicity structure of photoproduction and have the correct order of magnitude.

g) In our studies of the $\pi\pi N$ final state, we have obtained coupling signs and strengths for the amplitudes describing $\pi N \to \pi\Delta$, ρN, ϵN. If these were stable particle reactions there would be no way to relate the relative signs of the amplitudes for these three final states. However, due to the overlap of the resonant final states and the sensitivity of the isobar model analysis to these interferences the signs of the couplings for all three final states are fixed. Of course, an overall uncertainty of ± 1 remains for the whole set of amplitudes, and also for the comparison between the $\pi N \to \rho N$ and $\gamma N \to \pi N$ amplitudes.

In general these results from the analysis of

$$\pi N \to \pi\pi N$$

add a large new quantity of data which support our present classification of the baryons, improve our understanding of decay mechanisms and indicate the next supermultiplets of states that we should expect.

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Table 1

Comparison of Experimental and Theoretical Coupling Signs for $\pi N \to \pi\Delta$

$SU(6)_W \times O(3)$ Multiplet	Resonant Amplitude	Experiment Sign[a]	$SU(6)_W$[b] $(8,1)_0-(1,8)_0$	'anti' $SU(6)_W$[b] $(3,\bar{3})_1-(\bar{3},3)_{-1}$	Quark Models[b,c]
	DS13(1520)	+	+	- √	* - √
	DD13(1520)	+	-	- √	- √
	SD11(1550)	0	-	+ ?	
	SD31(1640)	+	+	- √	
	DS33(1670)	-	-	+ √	
$[70,1^-]$	DD33(1670)	(-?)	+	+ (√)	
	DD15(1670)	-	+	+ √	* + √
	DS13(1700)	+	+	- √	
	DD13(1700)	(-?)	+	+ (√)	
	SD11(1715)	-	-	+ √	
	FP15(1688)	+	- √	+	+ x
	FF15(1688)	(-?)	+ (√)	+	
	PP13(1860)	0	- ?	-	
	PF13(1860)	0	+ ?	-	
	FF37(1930)	-	+ √	+	* + √
$[56,2^+]$	FP35(1880)	0	+ ?	-	
	FF35(1880)	-	+ √	+	* + √
	PP33( )	0	- ?	-	
	PF33( )	0	- ?	+	
	PP31(1910)	0	- ?	-	
	PP11(1470)	-	+ √	+	
$[56,0^+]_{n=2}$	PP33(1700)	-	+ √	+	

a) (?) implies measurement not as reliable as others; 0 implies decay not observed (i.e., $|T_{ij}| < 0.1$).

b) The theoretical predictions for the coupling signs are only defined up to an overall -1 sign.

c) We follow the notation of Moorhouse and Parsons[22] where a * indicates a theoretically reliable sign because no subtraction of amplitudes is involved.

Table 2

Comparison of Transition Amplitudes Observed

in $K^-p \rightarrow \pi\Sigma(1385)$ Reactions and Predictions from $\pi N \rightarrow \pi\Delta$

Resonant Amplitude	K^-p	Prediction[a)]	Comment
DS03(1690)	-	- ✓	
DS13(1660)	-	- ✓	
DD05(1830)	-	+ x	Disagreement with SU(3) internal to K^-p analysis, but DD15 amplitude is 1.5 times larger than DD05 so we believe the former
DD15(1765)	-	- ✓	
FP05(1815)	-	- ✓	
FP15(1915)	+ ?	+	Amplitude is in the correct half of Argand diagram, but no resonance is seen.

a) Prediction only up to an overall minus sign.

Table 3

Coupling Constants for the $3/2^-$, $5/2^-$ and $5/2^+$ Octets

Multiplet	Resonance	$\Gamma_{\pi\Delta}$ or $\Gamma_{\pi\Sigma}$ a)	g'	Comments
$3/2^-$	N*DS13(1520)	16	.38	No mixing with D13(1700)
	ΛDS03(1520)	1.66	.78	Mixing only between these states with $\theta = 40^o$
	ΛDS03(1690)	20.5		
	ΣDS13(1660)	7.5	.68	No mixing with other Σ states
$5/2^-$	N*DD15(1670)	72	1.08	
	ΣDD15(1765)	10.8	1.33	
$5/2^+$	N*FP15(1690)	14	.33	
	Λ FP05(1815)	8.4	.32	

a) $\Gamma_{\pi\Delta}$ values from Longacre et al.[6]

$\Gamma(\Lambda(1520)) \rightarrow \pi\Sigma(1385)$ from Mast et al.[16]

Remaining $\Gamma_{\pi\Sigma(1385)}$ from Prevost et al.[17]

Table 4

The signs of the helicity amplitudes at resonance extracted from $N\pi \to N\rho$ compared with the signs for isovector excitation $\gamma p \to \pi^+ n$. For isospin $\frac{1}{2}$ resonances this means we have to extract the isovector contribution, $A^{VI} = A^p - A^n$. The $N\rho$ signs are defined only up to an overall ±1 sign. The ρ partial wave amplitudes T^{IJLS} are converted to photoproduction amplitudes A and B following the definition of ref. [20], where

$$A^{IJL}_{1/2} = \Sigma\, \alpha^{IJLS} \cdot T^{IJLS}$$

$$B^{IJL}_{3/2} = \Sigma\, \beta^{IJLS} \cdot T^{IJLS}$$

— the α, β are products of Clebsch-Gordan coefficients.

	Resonance Mass	D13 (1520)	F15 (1690)	P13 (1700)	F35 (1890)	F37 (1930)
From fig. 3 and ref. [6]	$N\pi \to N\rho$	+	+	-	-	(-?)
Amplitudes for $\gamma p \to \pi^+ n$ estimated from $\pi N \to \rho N$	A	-	-	-	-	(+?)
	B	+	+	0	+	(-?)
Amplitude for $\gamma p \to \pi^+ n$ from photoproduction[19]	A	-	0	0	(- ?)	-
	B	+	+	0	(- ?)	+

Table 5

Cross sections at resonance and helicity structure for isovector contribution to excitation. In this table γ represents the isovector component of the photon only.

Resonance		$\sigma(\gamma p \to \pi^+ n)$ μb	$x_{\gamma N}\, x_{\pi N}$ $(\times 10^3)$	$x_{\pi N}$	$x_{\gamma N}$ $(\times 10^3)$	Γ_{tot} MeV	$\Gamma^{1/2}_{\gamma N}$	$\Gamma^{1/2}_{\left(\frac{1}{2}\right)}$ a)	$\Gamma^{1/2}_{\left(\frac{3}{2}\right)}$ a)
D13	'ρN'	23.5	4.48	0.50	8.96	130	1.08	.54	.94
	γN	28.8	5.49		10.98		1.20	.26	1.17
F15	'ρN'	5.58	1.19	0.60	1.98	140	.53	.30	.43
	γN	14.3	3.04		5.06		.84	.12	.83
P13	'ρN'	1.07	.47	0.25	1.86	255	.68	.68	0
	γN	.13	.057		0.23		.24	.22	.10
F35	'ρN'	.86	0.266	0.17	1.56	240	.61	.35	.50
	γN	.50	0.157		0.93		.47	0	.47
F37	'ρN'	2.4	0.62	0.45	1.37	190	.51	.13	.49
	γN	0.84	0.218		0.48		.30	.13	.27

a) $\Gamma_{\left(\frac{1}{2}\right)}$ and $\Gamma_{\left(\frac{3}{2}\right)}$ correspond to the radiative widths (in MeV) of the N* or Δ in helicity 1/2 and 3/2 states.

Figure Captions

1. The signs of resonance transition amplitudes in the reaction $N\pi \rightarrow \Delta\pi$. Dashed arrows indicate that the determination is not as reliable as for the other amplitudes.

2. Predictions of the signs for the transition amplitudes for Y_0^* and Y_1^*. The $\Delta\pi$ signs are measured in a partial wave analysis of $\pi N \rightarrow \pi\pi N$ — see refs. [1,6], are repeated here from fig. 1. The signs for the Y_1^* and Y_0^* are predicted using eq. (6) or (7) — see text.

3. The signs of resonance transition amplitudes in the reaction $N\pi \rightarrow N\rho$. Dashed arrows indicate that the determination is not as reliable as for the other amplitudes. ρ_1 and ρ_3 mean that $S = S_N + S_\rho = 1/2$ and $3/2$ respectively.

Resonance	Coupling Sign	
	L	(L+2)
P_{11}(1470)	↓	
D_{13}(1520)	↑	↑
S_{31}(1630)	↑	
D_{15}(1670)	↓	
F_{15}(1690)	↑	↓
D_{33}(1670)	↓	↓
S_{11}(1700)	↓	
P_{33}(1700)	↓	
P_{11}(1700)	↓	
D_{13}(1700)	↑	↓
F_{35}(1890)		↓
F_{37}(1930)	↓	

2583A1

Fig. 1

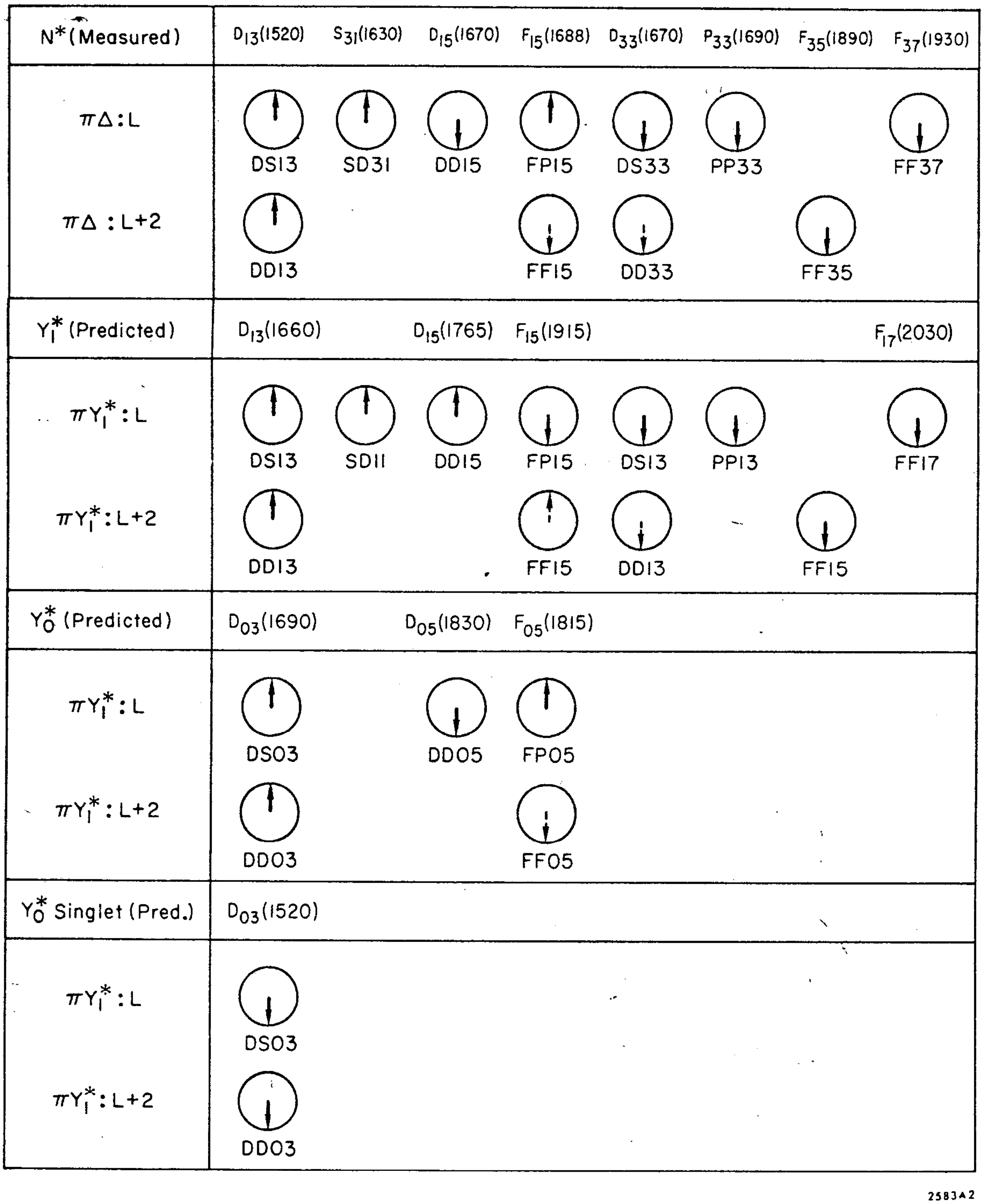
N* (Measured)
D_{13}(1520) S_{31}(1630) D_{15}(1670) F_{15}(1688) D_{33}(1670) P_{33}(1690) F_{35}(1890) F_{37}(1930)
$\pi\Delta$: L
DS13 SD31 DD15 FP15 DS33 PP33 FF37
$\pi\Delta$: L+2
DD13 FF15 DD33 FF35
Y_1^* (Predicted)
D_{13}(1660) D_{15}(1765) F_{15}(1915) F_{17}(2030)
πY_1^* : L
DS13 SD11 DD15 FP15 DS13 PP13 FF17
πY_1^* : L+2
DD13 FF15 DD13 FF15
Y_0^* (Predicted)
D_{03}(1690) D_{05}(1830) F_{05}(1815)
πY_1^* : L
DS03 DD05 FP05
πY_1^* : L+2
DD03 FF05
Y_0^* Singlet (Pred.)
D_{03}(1520)
πY_1^* : L
DS03
πY_1^* : L+2
DD03
2583A2

Fig. 2

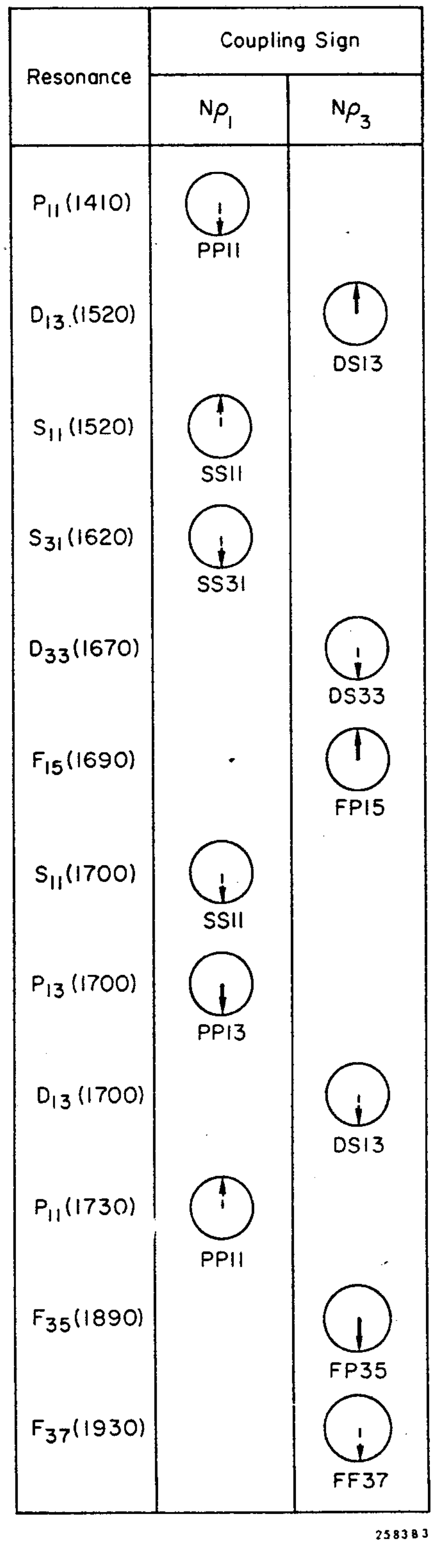
Resonance
Coupling Sign
$N\rho_1$
$N\rho_3$
$P_{11}(1410)$
PP11
$D_{13}(1520)$
DS13
$S_{11}(1520)$
SS11
$S_{31}(1620)$
SS31
$D_{33}(1670)$
DS33
$F_{15}(1690)$
FP15
$S_{11}(1700)$
SS11
$P_{13}(1700)$
PP13
$D_{13}(1700)$
DS13
$P_{11}(1730)$
PP11
$F_{35}(1890)$
FP35
$F_{37}(1930)$
FF37
258383

Fig. 3