COMPARISON OF SOME SU(6)$_W$ PREDICTIONS ON COLLINEAR PROCESSES WITH EXPERIMENT*

J. D. Jackson

University of Illinois, Urbana, Illinois

(Received 15 October 1965)

Recently Carter et al.[1] have made a large number of predictions for collinear processes on the basis of a relativistic generalization of SU(6) that is common (as a subgroup) to several higher symmetry schemes. In this Letter we compare some of these predictions with existing experimental data and find gross disagreement. Some arguments are given to show that the failures of the predictions are to be expected, and that the symmetry schemes are probably valid (if at all) only for vertices and perhaps for nonperipheral contributions to reaction amplitudes.

Predictions.—The predictions of SU(6)$_W$ are for the squares of matrix elements in the forward (or backward) directions for two-body or quasi-two-body reactions. They are of three basic types:

(a) Relations between processes involving different members of the SU(6) meson and baryon multiplets. For example,

$$\sigma(K^+ + p \to K^* + p) = \tfrac{2}{3}\sigma(K^+ + p \to K^{*0} + N^{*++}), \quad (1)$$

$$\sigma(K^- + p \to \bar{K}^0 + n) = \tfrac{3}{16}\sigma(K^- + p \to K^{*-} + p), \quad (2)$$

where σ represents the square of the matrix element at 0° (or 180°). Equations (1) and (2) are parts of the predictions given in Eqs. (6) and (14) of reference 1. Many others are given in Table II of reference 1.

(b) Relations between reactions involving different charge states for the same initial and final isospin multiplets. For example,

$$\sigma(K^- + p \to \pi^+ + Y_1^{*-}) = 4\sigma(K^- + p \to \pi^- + Y_1^{*+}). \quad (3)$$

(c) Predictions as to the polarization and/or alignment of particles produced in the forward direction. For example, in the reactions $K^+ + p \to K^* + p$ and $K^+ + p \to K^* + N^*$ it is predicted that the resonances are all unpolarized.

Comparison with experiment.—Many data exist with which to test these predictions. Tables I, II, III, and IV contain some data[2-22] which will be compared with the theory here. For predictions of type (a) above, the sometimes sizable mass differences make ambiguous a comparison between experiment and relations obtained from unbroken symmetry. We will use the recipe of Meshkov, Snow, and Yodh (MSY),[23] namely a comparison of squares of invariant amplitudes as a function of the Q value in the final state.[24] For relations of type (b) and (c) no corrections for mass differences are necessary. These tests are thus relatively clean cut. But even for the comparisons of type (a), where different recipes can be used to compare theory and experiment, the disagreements are generally so complete that the differences in method are unimportant.

In Fig. 1 a comparison is made between the two sides of Eq. (1) for the forward direction. The data are given in Table I, and also the inverse strength factor x that normalizes the data to the SU(6)$_W$ prediction. The quoted cross

Table I. Experimental data on forward production in $K^+ + p \to K^* + p$ and $K^+ + p \to K^* + N^*$.

Process	Number from reference 1	P (GeV/c)	Q (GeV)	$\frac{d\sigma}{d\Omega}(0°)$ (μb/sr)	$\Delta(\cos\theta)$	x	Reference
$K^+ + p \to K^* + p$ ($K^0 + \pi^+ + p$)	Eq. (6)	1.96	0.39	630 ± 90	0.1	1.5	2
		2.26	0.51	220 ± 50	0.1	1.5	3
		2.30	0.52	520 ± 130	0.1	1.5	4
		3.0	0.79	460 ± 60	0.05	1.5	5
		3.5	0.95	480 ± 80	0.05	1.5	6
		5.0	1.42	300 ± 100	0.04	1.5	6
$K^+ + p \to K^{*0} + N^{*++}$ ($K^+ + \pi^- + \pi^+ + p$)	Eq. (6)	1.96	0.09	290 ± 40	0.2	1	7
		2.26	0.21	450 ± 60	0.05	1	3
		3.0	0.49	1360 ± 140	0.05	1	8
		3.5	0.67	1200 ± 150	0.05	1	9
		5.0	1.12	1720 ± 200	0.05	1	6

Table II. Experimental data on forward production in $K^- + p \to \bar{K}^0 + n$ and $K^- + p \to K^{*-} + p$.

Process	Number from reference 1	P (GeV/c)	Q (GeV)	$\frac{d\sigma}{d\Omega}(0°)$ (μb/sr)	$\Delta(\cos\theta)$	x	Reference
$K^- + p \to \bar{K}^0 + n$	Eq. (14)	1.025	0.365	1250	0.2	1	10
		1.125	0.405	1380	0.2	1	10
		1.22	0.460	300 ± 60	0.05	1	11
		1.455	0.565	480 ± 100	0.1	1	12
		1.70	0.665	550	0.1	1	10
		1.80	0.715	440 ± 60	0.05	1	13
		1.95	0.780	540 ± 80	0.05	1	13
		2.45	0.970	142 ± 20	0.05	1	14
		2.70	1.065	115 ± 15	0.05	1	14
		3.0	1.18	258 ± 40	0.1	1	15
$K^- + p \to K^{*-} + p$	Eq. (14)	1.80					
$(\bar{K}^0 + \pi^- + p)$		1.95	0.355	310 ± 50	0.1	9/32	13
		3.0	0.785	376 ± 40	0.1	9/32	15
		3.5	0.95	396 ± 60	0.08	9/32	16

Table III. Experimental data on forward and backward differential cross sections for some reactions listed in Table II of reference 1.

Process	Number from reference 1	P (GeV/c)	Q (GeV)	$\frac{d\sigma}{d\Omega}(0°)$ (μb/sr)	$\frac{d\sigma}{d\Omega}(180°)$ (μb/sr)	$\Delta(\cos\theta)$	x	Reference
$K^- + p \to \pi^+ + \Sigma^-$	1	2.24	0.99	8	20	0.2	1	17
		3.0	1.28	$\leq 2.5 \pm 1.0$	19 ± 4	0.1	1	15
$K^- + p \to K^0 + \Xi^0$	2	3.0	0.80	2.5 ± 0.6	2.5 ± 0.6	See reference 18	1	18
$K^- + p \to K^+ + \Xi^-$	3	2.24	0.52	$\cdots$	22	0.2	1/4	17
		3.0	0.81	0.6 ± 0.2	7.0 ± 1.4	0.4, 0.2	1/4	15
$K^- + p \to K^{*+} + \Xi^-$	5	2.24	0.12	$\cdots$	5.2	0.2	1/16	17
		3.0	0.41	$\leq 0.5 \pm 0.3$	5.3 ± 1.3	0.2	1/16	15
$K^- + p \to \pi^- + Y^{*+}$	9	2.24	0.81	80 ± 10	$\leq 9.0 \pm 4.0$	0.1	1/8	17
		3.0	1.10	37 ± 10	$< 1.5 \pm 1.0$	0.2	1/8	15
$K^- + p \to \pi^+ + Y^{*-}$	10	2.24	0.81	$\leq 9 \pm 4$	14 ± 6	0.4	1/32	17
		3.0	1.10	3.5 ± 1.8	3.5 ± 1.8	0.2	1/32	15
$\pi^+ + p \to \pi^0 + N^{*++}$	28	1.59	0.58	420 ± 40	180 ± 30	0.1	1/12	19
		2.75	1.07	250 ± 30	8.0 ± 4.0	0.1	1/12	20
		3.54	1.43	170 ± 50	$\cdots$	0.02	1/12	21
		4.0	1.57	680 ± 150	$\cdots$	0.013	1/12	22

Table IV. Experimental spin-density matrix elements in the forward direction for $K^+ + p \to K^* + p$ and $K^+ + p \to K^{*0} + N^{*++}$ at 3 GeV/c. [SU(6)$_W$ predictions are given in parentheses.]

Process	Particle	ρ_{11}	ρ_{00}	$\rho_{\frac{3}{2}\frac{3}{2}}$	$\rho_{\frac{1}{2}\frac{1}{2}}$	$\Delta(\cos\theta)$	Reference
$K^+ + p \to K^* + p$	K^*	0.42 ± 0.06 (0.33)	0.15 ± 0.12 (0.33)			0.07	5
$K^+ + p \to K^* + N^*$	K^*	0.07 ± 0.04 (0.33)	0.86 ± 0.08 (0.33)			0.03	8
	N^*			-0.01 ± 0.04 (0.25)	0.51 ± 0.04 (0.25)	0.03	8

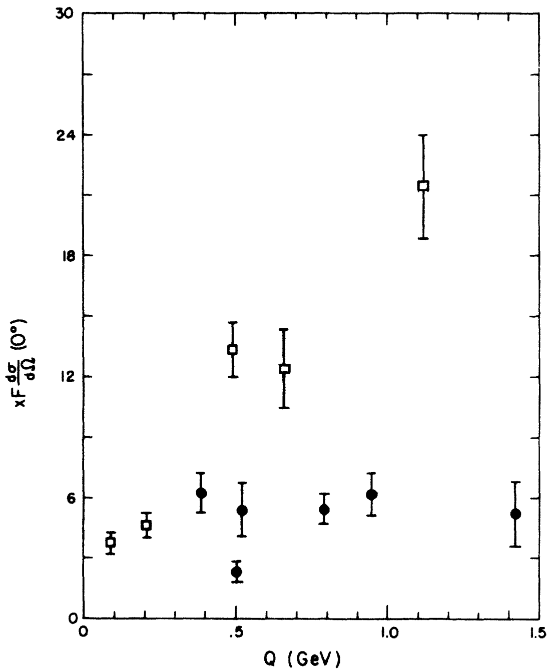

FIG. 1. MSY plot of the square of the matrix element in the forward direction for $K^+ + p \rightarrow K^* + p$ (solid circles) and two-thirds of the corresponding quantity for $K^+ + p \rightarrow K^{*0} + N^{*++}$ (open squares) versus the Q value in the final state. The units are $(\mathrm{GeV})^2$ mb/sr for the ordinate and GeV for the abscissa. According to $SU(6)_W$ the two sets of points should lie on the same curve.

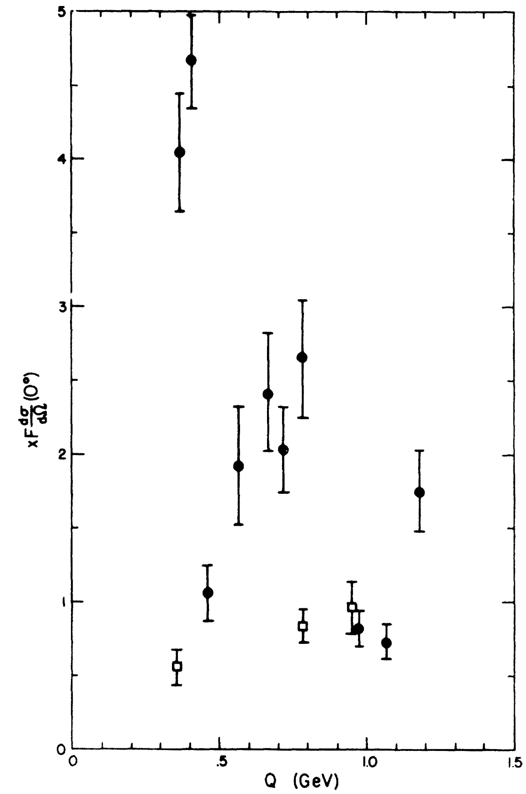

FIG. 2. MSY plot of the square of the matrix element in the forward direction for $K^- + p \rightarrow \bar{K}^0 + n$ (solid circles) and 9/32 of the corresponding quantity for $K^- + p \rightarrow K^{*-} + p$ (into $\bar{K}^0 + \pi^- + p$) (open squares) versus the Q value in the final state. The units are the same as in Fig. 1. According to $SU(6)_W$ the two sets of points should lie on the same curve.

sections on both reactions are for a particular charge configuration (one decay mode of K^*); the tabulated values of x include a correction factor for this. According to $SU(6)_W$ the two sets of points in Fig. 1 should lie on the same smooth curve. While at low Q values this seems to be true, the energy dependences of the two processes are so different that at higher momenta the squares of the matrix elements disagree by a factor of four or more.

A similar comparison of the two sides of Eq. (2) is made in Fig. 2 from the data listed in Table II. Again x for the $K^{*-}p$ reaction includes a correction for the other, unobserved decay mode of the K^{*-}. The charge exchange data for $Q < 0.9$ GeV reflect the various resonant states in the s channel [$Y^*(1815)$ at $Q \simeq 0.4$ and the $Y^*(2065)$ at $Q \simeq 0.7$]. This means that a comparison with the $K^{*-}p$ process as a function of Q value is misleading. Threshold occurs at a center-of-mass energy $W = 1.43$ GeV for charge exchange and at $W = 1.83$ GeV for the $\bar{K}^*N$ process. Only the $Y^*(2065)$ resonance will appear in the latter reaction. An alternative recipe is to use the center-of-mass energy W as the abscissa. This will move the open-squared points in Fig. 2 to the right by 0.4 GeV and will put the first point at the position of the $Y^*(2065)$. The agreement between the two sets of points is not enhanced by this shift, but the resonant structure in the charge exchange makes debatable the significance of the disagreement.

In any comparison of experimental data with theoretical predictions at zero degrees, the question of extrapolation of the data arises. For production processes the statistical accuracy is usually sufficiently limited that bins of the order of 0.1 in $\cos\theta$ are employed. One possibility is then to fit a smooth curve to the histogram and use its intercept at zero degrees. This is a subjective process, however, and we have taken instead the value of the cross section in the final bin as our value at 0° (or 180°). The bin sizes are given in the tables. There is no doubt that an error is introduced by this procedure, but it is not likely to alter any of our conclusions.[25]

Table II of reference 1 contains 36 different collinear processes all related to each other. Our Table III and Figs. 3 and 4 compare some of these reactions. In every case the proportionality factor of $SU(6)_W$ has been divided out before plotting so that the prediction is that all the points should lie on one curve. Figures 3 and 4 are semilog plots for the forward and backward directions, respectively. It should be noted that (i) the over-all disagreement is a factor of 100 or more so that differences in recipes for plotting, reasonable changes in normalization of the data, background subtractions, etc., are of no consequence; (ii) reactions with a change in baryonic charge $\Delta Q = 2$

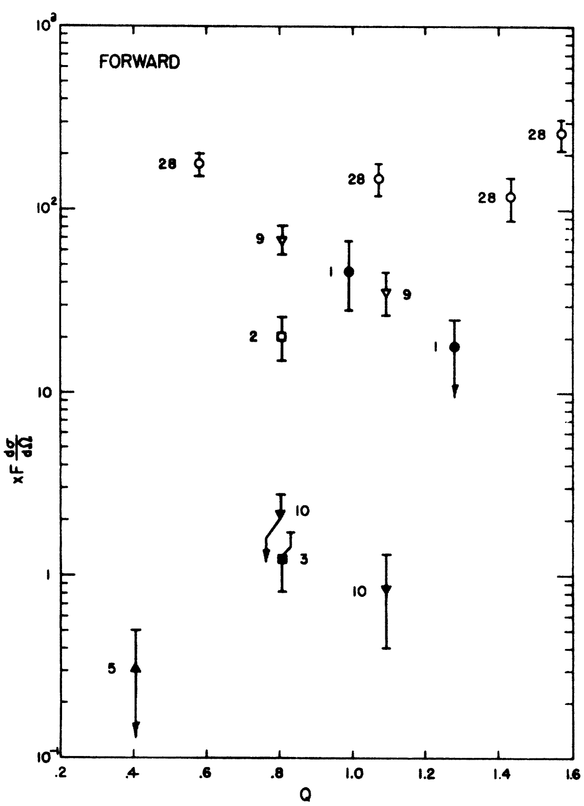

FIG. 3. Semilog MSY plot of the squares of matrix elements in the forward direction versus final-state Q value for some reactions listed in Table II of reference 1. The units are $(\mathrm{GeV})^2\mu\mathrm{b/sr}$ for the ordinate and GeV for the abscissa. The numbers beside the points are the entry numbers in that table, and are also listed in our Table III. The observed cross sections have been multiplied by $x = 3/$(strength given in Table II of reference 1). The prediction of $SU(6)_W$ is that all the points should lie on a single curve as a function of Q. Points with arrows on the bottom are upper bounds.

(the solid points in Figs. 3 and 4) lie generally lower than other processes, at least in the forward direction, and (iii) for processes of type (b) above (e.g., reactions 2 and 3, or 9 and 10), where no recipe is needed, the discrepancies are factors of 10 to 40 in the forward direction, but consistent with theory in the backward direction. These disagreements for type (b) processes are in contrast with the close agreement found by Olsson[26] between the $SU(6)_W$ predictions and experiment for various charge states in the reaction $\pi + N \to \pi + N^*$ near threshold. A reason for the possibility of disagreement here and agreement for Olsson is discussed below.

Comparison of $SU(6)_W$ predictions with experiment for spin alignments [type (c) above] is in some ways the most sensitive test of the theory since spin is what the theory is all about. There are data[5] at 3 GeV/c for K^* density matrix elements as a function of production angle for $K^+ + p \to K^* + p$, and also for both the K^* and N^* in $K^+ + p \to K^{*0} + N^{*++}$ at the same momentum.[8] The experimental results are compared with the predictions in Table IV.

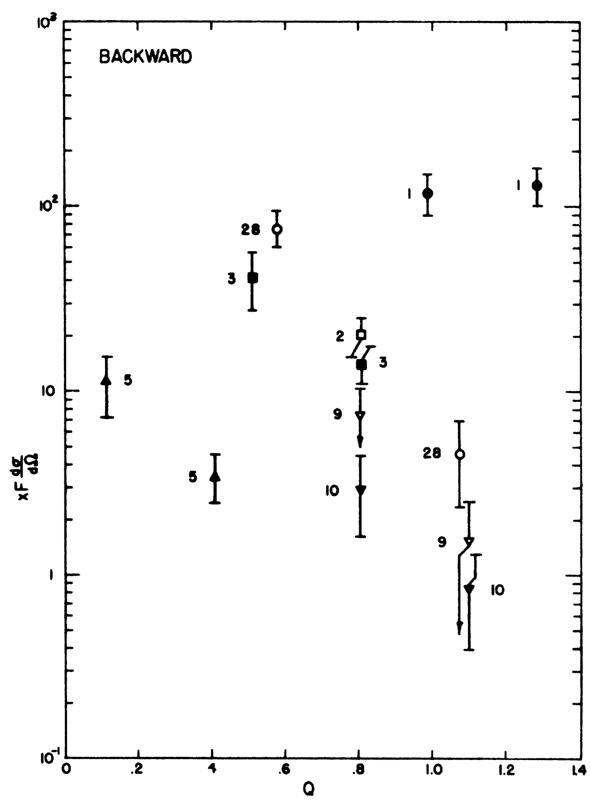

FIG. 4. Same as Fig. 2, but for the backwards direction.

While for the K^*p reaction, one might argue that the disagreement is only one and a half standard deviations, for K^*N^* the disagreement is total.[27]

Discussion. – The comparisons just presented show that the predictions of Carter et al.[1], based on $SU(6)_W$, disagree with experiment at almost every turn. While it is true that some of the relationships stem merely from SU(3) (e.g., equality of Reactions 1 and 2), most of the predictions are unique to $SU(6)_W$, or to the hybrid $U(3) \otimes U(3)$ that utilizes the generators $A(\lambda_i)$ and $A(\lambda_i \sigma_z)$.[28] If one wishes to take cognizance of the well-known fact that SU(3) is badly broken (e.g., $NN\pi$ couplings are much larger than NYK couplings) without prejudging $SU(6)_W$, then the $\pi+N \to \pi+N^*$ points in Figs. 3 and 4 (labelled 28) can be ignored. But their omission makes a negligible improvement in the over-all picture. A clue to understanding why the disagreements are so complete can be found in Eq. (3). The Y^* production reaction involving a change of two units in the baryonic charge is predicted to have a cross section four times as large as that involving no change in the baryonic charge. Clearly this flies in the face of fact and simple phenomenological theory. The process with $\Delta Q = 0$ is known to be peripheral in nature, while the $\Delta Q = 2$ reaction is less probable and involves large momentum transfers. In terms of simple exchanges, the $\Delta Q = 0$ process can and does go by K^* exchange, while that with $\Delta Q = 2$ must proceed via baryon exchange, or something more complicated. These differences are not reflected in the relations of Table II, reference 1, because the only allowable exchanges in the t channel come from the representation $\underline{405}$ (that is why there are unique relations between 36 different reactions).

The absence of the $\underline{35}$ representation of the mesons in the t channel is obvious for those reactions involving $\Delta Q = 2$ and/or $\Delta Y = 2$ for the baryons. But its absence for allowed processes like the right-hand side of Eq. (3) must be traced to the specific form of $M1$ coupling for the $B(V)D$ vertex.[29] For the degenerate case of a common mass m for the initial and final mesons, and a common mass M for the baryons, it can be shown that the $M1$ coupling vanishes in both the forward and backward directions. In fact, in the same limit, it is easy to show that the $P(V)V$, $P(P)V$, $B(P)B$, and $B(P)D$ vertices all vanish in the forward direction. As a consequence, all $SU(6)_W$ predictions for reactions like those in Eq. (1) and the right-hand sides of Eqs. (2) and (3) are really predictions concerning the nonperipheral part of the cross sections. This explains the gross disagreements shown in Fig. 1 and Table IV, since both reactions are known to be peripheral and largely understood on the basis of a simple model.[30] Similarly, it is not surprising that reactions known to be peripheral, such as 9 and 28 in Fig. 3, are sometimes an order of magnitude or more larger than processes involving $\Delta Q = 2$ and/or $\Delta Y = 2$. Furthermore, the more favorable comparison of Reactions 9 and 10 in the backward direction becomes understandable. Evidence that the $SU(6)_W$ predictions may indeed be valid for nonperipheral contributions is found in Olsson's comparison[26] of $SU(6)_W$ with data on $\pi+N \to \pi+N^*$ near threshold. The N^* production there is predominantly s wave; peripheral contirbutions are unimportant.

Breaking the symmetry by using the physical masses in the one-meson-exchange diagrams will, of course, give nonvanishing results. But typically, these changes are not great. For a process like $K^+ + p \xrightarrow{(\pi)} K^* + p$ for example, the cross section is still proportional to Δ^2 [from the $p(\pi)p$ vertex] and the minimum value of Δ^2 is sufficiently small at incident momenta of a few GeV/c that the cross section falls almost to zero in the forward direction. Much more important than symmetry breaking by the masses is the influence of inelastic processes on the low partial waves. The modifications produced by these effects are well known.[30] The particular point of relevance here is that the detailed cancellations that occur in the simple exchange diagrams in order to give vanishing (or nearly vanishing) amplitudes are destroyed by the absorptive effects in the low partial waves.[31] Attempts at a quantitative understanding of these modifications have so far involved an admittedly crude model, but the presence of such effects is beyond question.

Conclusions. – The comparison with experiment and the discussion establish that straightforward application of $SU(6)_W$ and similar symmetries to S-matrix elements is an enterprise unlikely to meet with success, apart from some special situations such as the Johnson-Treiman relations. The most important feature omitted in such attempts is the modifications introduced by the existence of competing channels and the resultant inelasticities of the low partial waves.[32] Perhaps all that can be hoped is that the higher symmetry schemes describe vertices and that dynamical calculations based on such couplings will have some meaning.

The author wishes to acknowledge helpful discussions with H. W. Wyld, H. J. Lipkin, S. Meshkov, and D. Horn, and to thank the various experimenters for making available their as yet unpublished data.

---

*Work supported in part by the National Science Foundation and the U. S. Office of Naval Research Contract No. ONR 1834(05).

[1]J. D. Carter, J. J. Coyne, S. Meshkov, D. Horn, M. Kugler, and H. J. Lipkin, Phys. Rev. Letters 15, 373 (1965). Predictions concerning polarization of particles were kindly provided to the author by D. Horn.

[2]S. Goldhaber, W. Chinowsky, G. Goldhaber, and T. O'Halloran, Phys. Rev. (to be published).

[3]F. Bomse, J. Cole, R. Zdanis, A. Pevsner, I. Miller, R. Singh, G. Kane, and R. Kraemer, in Proceedings of the Second Topical Conference on Resonant Particles (Ohio University, Athens, Ohio, 1965), p. 405; and private communication.

[4]S. Goldhaber, I. Butterworth, G. Goldhaber, A. A. Hirata, J. A. Kadyk, T. A. O'Halloran, B. C. Shen, and G. H. Trilling, in Proceedings of the International Conference on High-Energy Physics, Dubna, 5-15 August 1964 (to be published) (UCRL-11465); and private communication.

[5]M. Ferro-Luzzi, R. George, Y. Goldschmidt-Clermont, V. P. Henri, B. Jongejans, D. W. G. Leith, G. R. Lynch, F. Muller, and J. M. Perreau, Nuovo Cimento 36, 1101 (1965).

[6]Private communication of preliminary results from the CERN group of reference 5 and from F. Grard, J. Debaisieux, J. Heughebart, L. Pape, and R. Windmolders.

[7]W. Chinowsky, G. Goldhaber, S. Goldhaber, W. Lee, and T. O'Halloran, Phys. Rev. Letters 9, 330 (1962); G. Goldhaber, W. Chinowsky, S. Goldhaber, W. Lee, and T. O'Halloran, Phys. Letters 6, 62 (1963).

[8]M. Ferro-Luzzi, R. George, Y. Goldschmidt-Clermont, V. P. Henri, B. Jongejans, D. G. W. Leith, G. R. Lynch, F. Muller, and J. M. Perreau, Nuovo Cimento 39, 417 (1965); and private communication.

[9]F. Grard, J. Debaisieux, J. Heughebaert, L. Pape, and R. Windmolders, in Proceedings of the International Conference on High-Energy Physics, Dubna, 5-15 August 1964 (to be published); and private communication.

[10]M. L. Stevenson, in Lectures in Theoretical Physics (University of Colorado Press, Boulder, Colorado, 1965), Vol. 7B, p. 285.

[11]M. Ferro-Luzzi, F. T. Solmitz, and M. L. Stevenson, in Proceedings of the International Conference on High-Energy Nuclear Physics, Geneva, 1962, edited by J. Prentki (CERN Scientific Information Service, Geneva, Switzerland, 1962), p. 376.

[12]B. Buschbeck-Czapp, I. Wacek, W. A. Cooper, A. Fridman, E. Malamud, G. Otter, E. Gelsema, and A. Tenner, Proceedings of the Sienna International Conference on Elementary Particles (Societȁ Italiana di Fisica, Bologna, Italy, 1963), Vol. I, p. 166.

[13]P. M. Dauber, W. M. Dunwoodie, P. Schlein, W. E. Slater, L. T. Smith, D. H. Stork, and H. K. Ticho, in Proceedings of the Second Topical Conference on Resonant Particles (Ohio University, Athens, Ohio, 1965), p. 380.

[14]A. Barbaro-Galtieri and R. Tripp, in Proceedings of the International Conference on High-Energy Nuclear Physics, Dubna, 1965 (to be published); University of California Radiation Laboratory Report No. UCRL-11429 (unpublished).

[15]Amsterdam-Paris (E.P.)-Saclay Collaboration, in Proceedings of the Oxford International Conference on Elementary Particles, 20-25 September 1965 (to be published).

[16]N. Hague, D. Scotter, and B. Musgrave et al., Phys. Letters 14, 338 (1965).

[17]J. Leitner, private communication.

[18]A private communication from the group of reference 15 states that the angular distribution is more or less isotropic. The total cross section is given as 32 ± 8 μb by Badier et al., Phys. Letters 16, 171 (1965).

[19]A. Daudin, M.-A. Jabiol, C. Kochowski, C. Lewin, F. Selleri, S. Mongelli, A. Romano, and P. Waloschek, Phys. Letters 7, 125 (1963); P. Daronian, A. Daudin, M.-A. Jabiol, C. Lewin, C. Kochowski, B. Ghidini, S. Mongelli, and V. Picciarelli, to be published.

[20]Saclay-Orsay-Bologna-Bari Collaboration, Phys. Letters 13, 341 (1964).

[21]M. Abolins, D. D. Carmony, D.-N. Hoa, R. L. Lander, C. Rindfleisch, and N.-H. Xuong, Phys. Rev. 136, B195 (1964).

[22]Aachen-Berlin-Birmingham-Bonn-Hamburg-London (I.C.)-München Collaboration, Phys. Rev. 138, B897 (1965).

[23]S. Meshkov, G. A. Snow, and G. B. Yodh, Phys. Rev. Letters 12, 87 (1964).

[24]The square of the invariant amplitude is obtained by multiplying the differential cross section in the center-of-mass frame by $F=qW^2/q'$, where q, q' are the magnitudes of the momenta in the initial and final states, respectively, and W is the total energy in the center of mass.

[25]For some of the reactions the bin size is $\Delta(\cos\theta)=0.05$ or less and there is little error involved. As an illustration of the alternative of fitting a smooth curve, we note that for the data shown in Fig. 1 the K^*N^* points would all be increased by a factor of 1.2 to 1.4, while the K^*p points would be lowered by 10 to 20%. Thus the disagreement would be worsened, but the qualitative conclusion would be unchanged.

[26]M. G. Olsson, Phys. Rev. Letters 15, 710 (1965).

[27]To avoid misunderstanding we observe that $SU(6)_W$

does not always predict zero alignment for reaction products, even when only a single amplitude governs the process. The observation of R. Blankenbecler, M. L. Goldberger, K. A. Johnson and S. Treiman [Phys. Rev. Letters 14, 518 (1965)] on the absence of transverse polarization in pseudoscalar meson-baryon reactions in such cases is still true for polarizations of higher spin reaction products, but is not relevant for alignments.

[28] $SU(6)_W$ is based on the generators $A(\lambda_i)$, $A(\lambda_i\sigma_z)$, $A(\lambda_i\beta\sigma_x)$, $A(\lambda_i\beta\sigma_y)$. See R. F. Dashen and M. Gell-Mann, Phys. Letters 17, 142, 145 (1965) for discussion of hybrid symmetries. The collinear hybrid $U(3) \otimes U(3)$ predicts the same results as $SU(6)_W$ for reactions 1, 2, 3, and 16 of Table II, reference 1. (Private communication from H. Ruegg and D. V. Volkov.)

[29] P, V, B, and D stand for pseudoscalar mesons, vector mesons, the octet of spin $\frac{1}{2}$ baryons, and decimet of $\frac{3}{2}^+$ baryons, respectively. The particle in parentheses is the virtual exchanged particle.

[30] J. D. Jackson, J. T. Donohue, K. Gottfried, R. Keyser, and B. E. Y. Svensson, Phys. Rev. 139, B428 (1965).

[31] For a particularly dramatic example of this, see reference 30, above Fig. 22.

[32] In the language of $SU(6)_W$ this means that noncollinear intermediate states are apparently important. See footnote 7 of reference 1.