COMMENTS ON A_2 PRODUCTION

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We discuss the analysis of high energy A_2 production data, inclusing comparisons with ω and f_o production and possible f_o - A_2 interference effects.

The A_2 resonance region mass spectrum and its decay characteristics have been studied in many experiments. However, the production mechanisms have received much less attention. Now that the A_2 is seen [1] at higher energies as a single state with a width of about 100 MeV, we feel that it is meaningful to discuss the production process. The A_2 state produced at higher energies we shall treat as the normal A_2, to be identified with the SU(3) partner of the f_o, f'_o and $K^*(1420)$ and as the exchange degenerate partner of the ρ and g. Any narrow destructively interfering dip or splitting seen at lower energy [2] may then be treated † as a small perturbation on the dominant normal A_2 production. We shall summarize some theoretical approaches to high energy production of A_2 in $\pi N \to A_2 N$. Some specific predictions from absorbed Regge cut models and from comparisons with $\pi N \to A_2 \Delta$; $\pi N \to f_o N$; $\pi N \to \omega N$, etc., will be presented. We discuss finally the possibility of observing f_o - A_2 interferences in the reactions $\pi N \to K\bar{K}N$ and $\pi N \to K\bar{K}\Delta$ at high energy.

Parity exchanged. General arguments [3] give the following decomposition, valid to O(1/*s*), into unnatural (U) and natural (N) parity exchange in terms of the A_2 density matrix elements

$$\rho_1^N = \rho_{11} + \rho_{1-1}, \quad \rho_2^N = \rho_{22} - \rho_{2-2}, \quad \rho_o^U = \rho_{oo},$$

$$\rho_1^U = \rho_{11} - \rho_{1-1}, \quad \rho_2^U = \rho_{22} + \rho_{2-2}$$

where ρ_{ij} is measured in any frame with y axis normal to the production plane [such as the s channel helicity frame (SHF) or the Gottfried-Jackson frame (THF)]. Experimentally, for the 3π mode of A_2 decay, the density matrix elements can only be measured when a complete spin-parity analysis is performed to select $J^P = 2^+$ states from the background. For the $K\bar{K}$ mode, the background to the A_2 signal is much smaller. Data suggest [4] $\rho_{11} \sim \rho_{1-1} \sim 0.5$ with all other elements small to a first approximation in the THF. This indicates a dominance of natural parity exchanges.

Quark model. In the quark model the A_2 is an $l = 1$ $q\bar{q}$ state so that excitation from a π meson necessitates adding angular momentum to the $q\bar{q}$ system. Arguments [5] have been given that this angular momentum to be added will be perpendicular to the production plane in the THF. Then the resulting qq state has only helicity 0 or 1 coming from a quark spin flip in the THF and so $\rho_{2i} = 0$ for all i. Data [4] for $\pi^- p \to A_2^- p$ confirm this suggestion.

Isospin. We shall use f_o and ρ to denote isospin 0 and 1 exchanges for convenience. Then for the amplitudes,

$$\pi^- p \to A_2^- p = f_o + \rho$$

$$\pi^+ p \to A_2^+ p = f_o - \rho$$

$$\pi^- p \to A_2^o n = \sqrt{2}\,\rho .$$

Experimental cross-section data show [6] $\sigma^- \sim \sigma^+ \sim 2\,\sigma^o$ so that $I_t = 0$ exchanges must be dominant.

ρ, f_o Regge poles. To proceed further we shall

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† The nearly maximum destructive interference claimed [2] in 3 and 7 GeV/*c* A_2^- production and 3 GeV/*c* A_2^o production requires A_2 (normal state) and $\tilde{A}_2$ (anomaly) amplitudes to be comparable in strength, coherent in spin structure and precisely related in phase. If the $\tilde{A}_2$ is produced by lower lying Regge trajectories, the splitting will go away with increasing energy but it would require additional strong phase or coherence changes to produce a large splitting at 3 *and* 7 GeV/*c* and none at 17 and 20 GeV/*c*. However, it would be relatively easy to arrange a phase or coherence difference between A_2^+ and A_2^- production at 7 GeV/*c* to explain the lack of splitting for A_2^+.

discuss the natural parity exchanges ρ and f_o since they seem to dominate in the data. For the THF amplitudes, only $\lambda_{A_2} = 1$ contributes if the quark model argument is valid. Thus $\rho_{11} = \rho_{1-1} = 0.5$ and all other elements are zero. To discuss the structure of the helicity amplitudes and eventual absorption corrections we shall, however, discuss the SHF amplitudes.

Then for exchange of a natural parity Regge pole X in SHF amplitude $F_{if}^{\lambda A_2}(n)$, where i and f are initial and final nuclear helicities and n is the over-all helicity flip, we will have $F^o = 0$ and

$$F^1_{++}(1) = F^1_{--}(1) = \sqrt{\frac{t_o - t}{4m^2}}\, \gamma^{++}_{XNN}\, \gamma^1_{X\pi A_2}\, R(X)$$

$$F^2_{++}(2) = F^2_{--}(2) = \left(\frac{t_o - t}{4m^2}\right) \gamma^{++}_{XNN}\, \gamma^2_{X\pi A_2}\, R(X)$$

$$F^1_{+-}(2) = F^1_{-+}(0) = \left(\frac{t_o - t}{4m^2}\right) \gamma^{+-}_{XNN}\, \gamma^1_{X\pi A_2}\, R(X)$$

$$F^2_{+-}(3) = F^2_{-+}(1) = \left(\frac{t_o - t}{4m^2}\right)^{3/2} \gamma^{+-}_{XNN}\, \gamma^2_{X\pi A_2}\, R(X).$$

The ρ and f_o couplings to πA_2 can be obtained from duality considerations in the three reactions $\pi^+\pi^+ \to \pi^+\pi^+$, $\pi^+\pi^+ \to \pi^+A_2^+$ and $\pi^+\pi^+ \to A_2^+A_2^+$. The natural parity exchanges in each case are ρ and f_o and these must cancel in the imaginary part since doubly charged mesons are not observed. Then the $\pi^+A_2^+$ Regge couplings of ρ and f_o must be equal, both for $\lambda(A_2) = 1$ and 2 separately: $\gamma^{\lambda}_{\rho\pi A_2} = \gamma^{\lambda}_{f_o\pi A_2}$. The $\lambda = 1$ and 2 vertices may be related from the quark model argument that they correspond to pure $\lambda = 1$ after transformation to the THF.

The ρ and f_o SHF couplings to NN are well known [7] and ρ dominates the spin flip while f_o dominates the non-flip:

$$\gamma^{++}_{f_oNN} \sim 5\, \gamma^{++}_{NN}, \qquad \gamma^{+-}_{f_oNN} \sim -0.1\, \gamma^{+-}_{\rho NN},$$

$$\gamma^{+-}_{\rho NN} \sim -5\, \gamma^{++}_{\rho NN}.$$

A further difference arises from the signature factors $R(f_o) = (1 + \exp(-i\pi\alpha)R$ and $R(\rho) = (-1 + \exp(-i\pi\alpha)R$.

Then the dominant contribution will be the f_o contribution to $F(1)$ since it has a large residue and a small power of $(t - t_o)$. The next most important contributions come from the ρ in $F(1)$, $F(2)$ and $F(0)$. The ρ contribution to the cross-section should then be much smaller than the f_o contribution although possible contributions from cuts in $F^1_{-+}(0)$ make this somewhat model dependent. With ρ and f_o out of phase by 90^o, the cross-section data quoted previously give $|f|^2 \sim 3|\rho|^2$ for the averaged contributions. This is quite consistent with our discussion. Also all pole amplitudes vanish in the forward direction in agreement with $d\sigma/dt$ data [4, 8] that show a forward turn-over.

Regge cut modifications. Since the Pomeron is assumed to conserve s channel helicity, the characteristics of absorption corrections are simpler to discuss in the SHF. Thus for ρ and f_o, no contributions will arise to ρ_{oo} even after absorption. The major change will be to the amplitude $F^1_{-+}(0)$, which has a factor $(t - t_o)$ for a factorizing Regge pole, whereas the cut correction is non-zero at $t = 0$. This cut contribution will have $I_t = 1$. We then predict that at the forward direction the cross-section for A_2^o production is twice as large as for $A_2^{\pm}$ production. Thus the forward dip in A_2^o production should be less sharp than in $A_2^{\pm}$ production.

The effect of such a ρ cut in $F^1_{-+}(0)$ on the density matrix elements should be larger for A_2^o production than for $A_2^{\pm}$ production since the $I_t = 1$ relative contributions are different. When transformed to the THF, the cut will also enter the amplitudes with $\lambda_{A_2} = 0$ and 2. A measure of the cut contribution is then ρ_{oo} in the THF and this is ≤ 0.1 for present $A_2^{\pm}$ production data. The contribution to ρ_{20} and ρ_{22} should be smaller than that to ρ_{oo} while ρ_{10} and ρ_{21} receive contributions from cut-pole interference and could be more significantly modified.

At $t = -0.6$ GeV^2 the ρ Regge pole amplitudes vanish while those for f_o do not. Thus no dip is expected in $\pi^{\pm}p \to A_2^{\pm}p$ at this value of momentum transfer while for $\pi^-p \to A_2^on$ the pole amplitudes are zero so that a dip is expected in a weak cut model. For the strong cut or Michigan model, however, zeros are anticipated [9] in single flip amplitudes at $t = -0.6$ GeV^2 irrespective of the pole signature. Since we have argued that $\pi^{\pm}_p \to A_2^{\pm}p$ is dominated by single flip, this would lead to such a dip at -0.6 GeV^2 although present data [8] give no indication of any such structure. For $\pi^-p \to A_2^on$, a mixture of amplitudes is expected and the Michigan model would suggest the absence of a dip. For this reaction $\rho_2^N\, d\sigma/dt$ could be useful for dip hunting since the over-all non-flip amplitude does not contribute.

Unnatural parity exchanges. The exchange contributions of η and B mesons seem to be small experimentally for $\pi^{\pm}p \to A_2^{\pm}p$. The ηNN coupling is known to be small [7]. Furthermore, η has a low lying trajectory, and so it should be negligible at higher energies. The B contribution relative to ρ can be argued to be similar for ω

production and for A_2^0 production from a duality discussion of $\pi^+\pi^+ \rightarrow \rho^+\rho^+$ and $\pi^+\pi^+ \rightarrow B^+B^+$. Then unnatural parity contributions ρ_0^U and ρ_1^U should be of the same size for ω and A_2^0 production while ~ 25% smaller for $A_2^\pm$ production which is dominated by $I_t = 0$ exchange. This would also explain the claimed [6] difference in the energy dependence between the neutral and charged A_2 production cross-sections, the latter [6] being in good agreement with ρ and f_0 exchanges.

Another source of unnatural parity exchange contributions arises from cut modifications to ρ and f_0 as discussed above. We have argued that these will not contribute to ρ_{00} in the SHF. The energy dependence of such effects should be different from those due to lower lying η and B contributions.

Comparison with other reactions. For natural parity exchanges one expects $\pi N \rightarrow A_2\Delta$ to show similar features to $\pi^-p \rightarrow A_2^0 n$ since the $N\Delta\rho$ vertex is flip dominated like the $N\bar{N}\rho$ vertex. Another reaction with similar exchanges is $\pi N \rightarrow \omega N$ (and $\pi N \rightarrow \omega\Delta$) where ρ and B are allowed. As discussed previously, a comparison of unnatural parity exchange contributions in A_2^0 production with the contributions ($\rho_{00} \sim 0.3$ at high energies) found in ω production is of interest. Features of $\rho_1^N\, d\sigma/dt$ should be the same for ω production as for A_2^0 production, however. This quantity for production seems [10] to show a dip at $t \sim -0.6$. Similarly $d\sigma/dt$ for $\pi N \rightarrow A_2\Delta$ at 3.7 GeV/c [11] shows such structure. We would thus expect such a dip for $\pi^-p \rightarrow A_2^0 n$.

Another source of comparison is the reaction $\pi N \rightarrow f_0 N$. Here π exchange dominates but ρ_1^N and ρ_2^N select out A_2 exchange. Since the $\rho\pi A_2$ and $f_0\pi A_2$ couplings are equal from EXD arguments we predict that, for Regge pole exchange,

$$\tan^2(\tfrac{1}{2}\pi\alpha)\, \rho_1^N \frac{d\sigma}{dt}(\pi^-p \rightarrow f_0 n) = \rho_1^N \frac{d\sigma}{dt}(\pi^-p \rightarrow A_2^0).$$

The modification of $F(0)$ by cuts will perturb this relation somewhat. A final amusing consequence is that, in the $\bar{K}K$ decay mode, it is possible to observe interference between f_0 and A_2. The Regge pole exchanges give a 90^o phase difference in production due to the A_2 and ρ signature factors. Then at a mass between the f_0 and A_2 resonance peaks where the Breit-Wigner phases are about 135^o for f_0 and 45^o for A_2, one may have substantial interference. From duality diagram arguments the interference will be destructive for $\pi^+n \rightarrow (\bar{K}K)^0 p$ and for $\pi^+p \rightarrow (\bar{K}K)^0\Delta^{++}$ and constructive for $\pi^-p \rightarrow (\bar{K}K)^0 n$. Using $\rho_1^N\, d\sigma/dm^2$ to select natural parity exchange, since EXD gives equal f_0 and A_2 couplings to $K\bar{K}$ and also equal A_2 and ρ production amplitudes (apart from signature factors), one will have equal strength amplitudes and full coherence in the $A_2 - f_0$ interference. Note that $\rho_{00}\, d\sigma/dm^2$ should, however, separate out almost pure f_0 production proceeding by π exchange.

Conclusion. Present data on the production of the normal A_2 can be understood naturally with ρ and f_0 exchange where f_0 exchange is dominant. We have discussed the helicity amplitude structure of the exchange contributions and presented expectations for density matrix elements and differential cross-section structure. Comparisons with other reactions were presented and $f_0 - A_2$ interference was discussed.

The most useful data to further such analyses would be measurements of $d\sigma/dt$ and density matrix elements as functions of t inclusing the important regions $t \sim t_{min}$ and $t \sim -0.6$ GeV^2. Measurements at widely separated energies (say 10 and 20 GeV/c) for $A_2^\pm$ and A_2^0 production with accurate relative normalization will be most valuable.

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References

[1] M. Alston-Garnjost et al., Phys. Letters 33B (1970) 607;
G. Grayer et al., CERN Preprint (1970);
K. J. Foley et al., Phys. Rev. Letters 26 (1971) 413.
[2] G. E. Chikovani et al., Phys. Letters 25B (1967) 44;
H. Benz et al., Phys. Letters 28B (1968) 233.
R. Baud et al., Phys. Letters 31B (1970) 397;
H. Basile et al., Nuovo Cimento Letters 4 (1970) 838.
[3] J. P. Ader, M. Capdeville, G. Cohen-Tannoudji and Ph. Salin, Nuovo Cimento 56A (1968) 952.
[4] G. Ascoli et al., Phys. Rev. Letters 25 (1970) 962;
T. F. Johnston et al., Nuclear Phys. B24 (1970) 253;
G. Grayer et al., CERN Preprint (1970).
[5] A. Białas, A. Kotanski and K. Zalewski, Krakow Preprint TPJU 70-30 (1970).
[6] J. T. Carroll et al., Phys. Rev. Letters 25 (1970) 1393;
M. Deutschman et al., CERN D. Ph. II Phys. 70-43 (1970).
[7] C. Michael, Springer Tracts in Modern Phys., Vol. 55, ed. G. Höhler (Springer Verlag, Berlin, 1970);
see also: C. Michael and R. Odorico, CERN Preprint TH. 1282 (1971).
[8] M. Alston-Garnjost et al., Phys. Letters 34B (1971) 156.
[9] G. Kane, F. Henyey and M. Ross, Nuclear Phys. B23 (1970) 269.
[10] J. Tran Thanh Van, Orsay Preprint (1970);
G. S. Abrams et al., Phys. Rev. Letters 23 (1970) 673 and 25 (1970) 619;
Bari-Bologna-Firenze-Orsay collaboration, Nuovo Cimento 65A (1970) 637.
[11] K. W. J. Barnham et al., UCRL 20050 (1970).