THE A_1 MESON PRODUCED AT 63 AND 94 GeV/c IN THE REACTION $\pi^-p \to \pi^-\pi^-\pi^+p$

ACCMOR COLLABORATION

(Amsterdam-CERN-Cracow-Munich-Oxford-Rutherford)

G. Thompson (Contact Person)

Department of Nuclear Physics, Oxford University, UK.

1. ABSTRACT

The results are presented of partial wave analyses of almost 600,000 events from the reaction $\pi^-p \to \pi^-\pi^-\pi^+p$ at 63 and 94 GeV/c and with a higher momentum transfer trigger. The shape of the 1^+S ($\rho\pi$) mass spectrum changes substantially as a function of t, and is not compatible with predictions of the Deck model. In addition, the phase of this partial wave rises by ∿90° over a mass range of 400 GeV/c^2 relative to 0^-P, 2^-P and the 2^+D production phases. These features provide compelling evidence for a resonant A_1 of mass ∿1280 MeV/c^2 and width ∿300 MeV/c^2 and indeed a rescattering model with such a state fits the data well.

2. INTRODUCTION

In the naive quark model, a p-wave $q\bar{q}$ should give rise to two, I = 1, spin-parity $J^P = 1^+$ mesons. The positive G-parity candidate, the B(1235) has been long established in the $\omega\pi$ decay mode. The negative G-parity A_1, presumed to decay $\rho\pi$, has defied certain identification principally because of the confusion of pion diffractive dissociation (Deck Model) into the same final state at low ($\rho\pi$) masses. Attempts to use charge exchange reactions[1] to eliminate this background have met the problem of low statistics and increased complication from the I = 0 channel. Small cross-sections also affect similar attempts to use baryon exchange reactions[2] though here there are specific claims for a comparatively narrow resonance of mass ∿1.04 GeV/c^2. This experiment uses very high statistics (some order of magnitude greater than the previous highest forward production experiment[3]) and a more detailed model for coherent background to detect the need for such a resonant state.

The data of this publication come from 598,128 events of the reaction

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

with incident momenta of 63 and 94 GeV/c on the ACCMOR WA3 forward spectrometer[4]. The momenta are high enough to ensure that in the mass region investigated, the three pion vertex is well separated from the baryon and there is no possibility of N* contamination within the reaction. There is uniform geometric acceptance in momentum transfer (t') and for the purposes of analysis the events are selected in bins $0.0 < |t'| < 0.05$ (GeV/c)^2 (low t') and $0.05 < |t'| < 0.7$ (GeV/c)^2 (high t'). Additionally a 94 GeV/c sample was taken with a selective high t' trigger and here the data is subdivided in bins of $0.16 < |t'| < 0.3$ (GeV/c)^2, and $0.3 < |t'| < 0.7$ (GeV/c)^2 (collectively, very high t').

Within these |t'| bins the data has been subject to two energy independent partial wave analyses based on the isobar model of sequential decay*. In this paper intensities of a given partial wave refer to the acceptance corrected number of events in a given bin

---

* For a detailed comparison of the SLAC amplitude analysis and the University of Illinois density matrix formalism, as used here, see Ref. 4.

multiplied by an appropriate diagonal density matrix element and relative phases are those of an off-diagonal element, though, in this area, the rank of the density matrix is close enough to unity to identify this with the phases between true proton spin amplitudes.

Throughout, the data has been fitted in the Gottfried-Jackson (t channel), frame in mass bins of 20 MeV/c^2 compatible with the (3π) mass resolution of σ = 10-12 MeV/c^2. Within each bin a rough $|t'|$ dependence has been imposed on each wave found from separate fits with 100 MeV/c^2 mass cuts and small t' divisions.

The spectroscopic nomenclature will assume the result of negligible contribution from unnatural parity exchange and, unless stated otherwise, that production is in the predominant M = 0 mode.

3. RESULTS OF THE PARTIAL WAVE ANALYSIS

The intensity of the s-wave $\rho\pi$ $J^P = 1^+$ state (1^+S) is shown for 93 GeV/c data in Fig. 1,2 (a), (b), the 63 GeV/c data appearing similar to Fig. 1. There is little s dependence

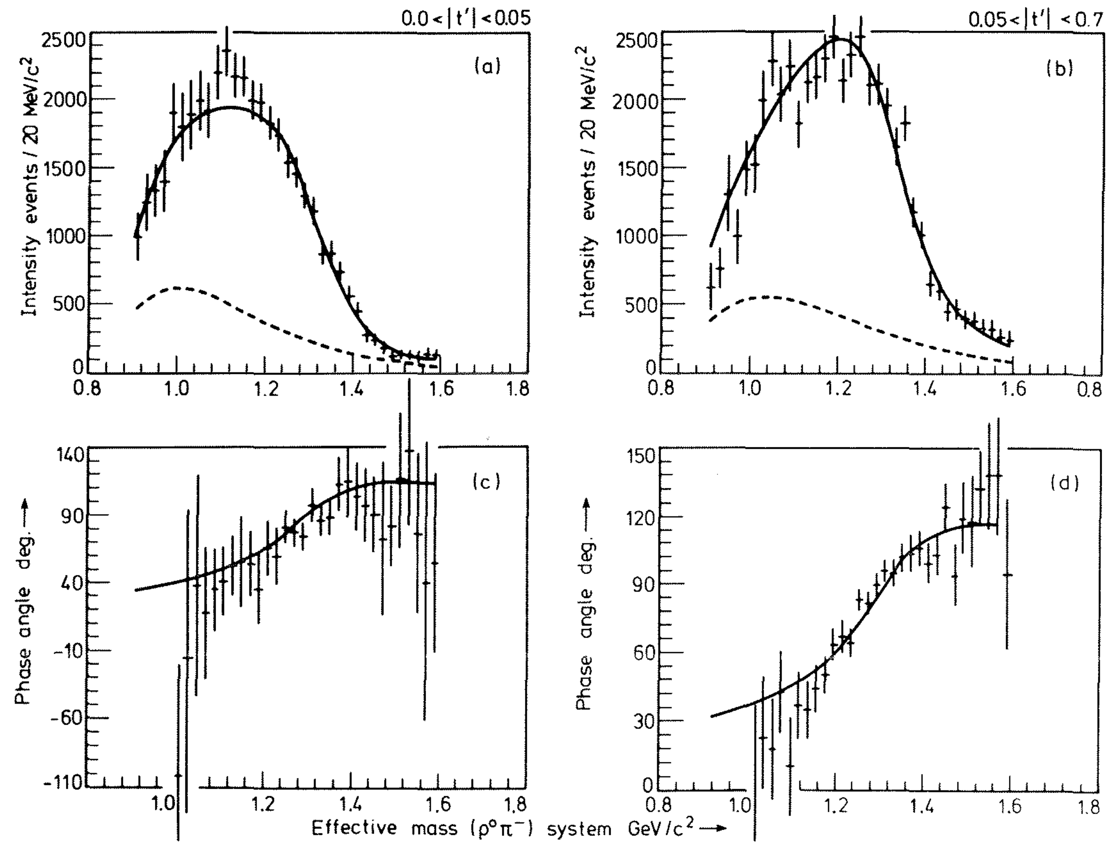

Fig. 1: 94 GeV/c data, 1^+S intensity (a,b) and phases (c,d) relative to 2^+ $D_{M=1}$

of the spectrum shape for a given $|t'|$ cuts, but comparison between 1(a) and 1(b) and with 2(a) and 2(b) shows that at a given s there are some large changes in shape as a function of t'. From low to high t' the qualitative change is from a broad peak in the 1.1 GeV/c^2 region, to a flat top from 1.1 to 1.3 with rapid fall off, to, finally, a narrower peak in the 1.3 GeV/c^2 region. It is certainly clear that a resonance alone could never describe these phenomena, and it will become equally clear that no simple diffractive model can

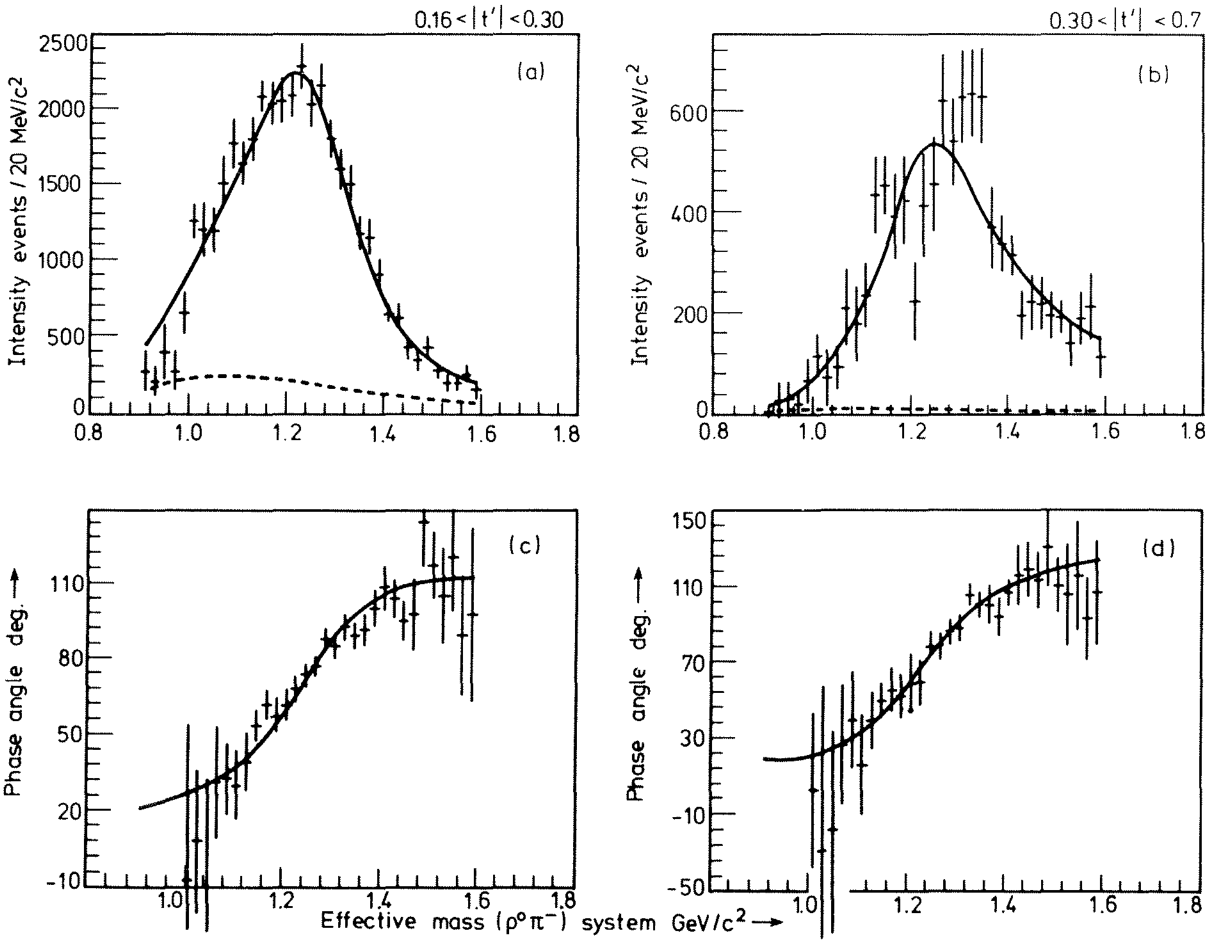

Fig. 2: 94 GeV/c data high t', 1^+S intensity (a,b) and phases (c,d) relative to $2^+D_{M=1}$

duplicate this behaviour either.

This data would not support narrow resonances at masses around 1.1 GeV/c^2, unless highly unlikely conspiracies damp resulting phase variation.

If there is any resonant content in the mass spectrum it should be evident from a sizeable change in the production phase of the 1^+S partial wave. The relative phases with respect to the other major waves in the low mass region are displayed for 93 GeV/c data, high t', in Fig. 3. Those with respect to 1^+P ($\varepsilon\pi$) and 0^-S ($\varepsilon\pi$) show, at most, excursions of only 20-30° and are compatible with previous experiments. Those with respect to $0^-P(\rho\pi)$ and $2^-P(\rho\pi)$ show positive evidence for large phase changes in the vicinity of 1.3 GeV/c^2. Below 1.1 GeV/c^2 there are problems with ambiguous solutions but it is clear that at higher masses there is a discrepancy which may only be resolved by supposing the forward motion of some reference phases (1^+P, 0^-S) or the reverse motions of others (0^-P, 2^-P).

A solution to this difficulty may be found by reference to the 1^+S - $2^+D_{M=1}$ phase difference (Fig. 4). It may be noted that in both |t'| regions there is a large backward movement corresponding to the A_2 meson[5] but this is by no means the full $\sim$180° as expected from a pure Breit-Wigner and indeed the edges of the distributions may indicate

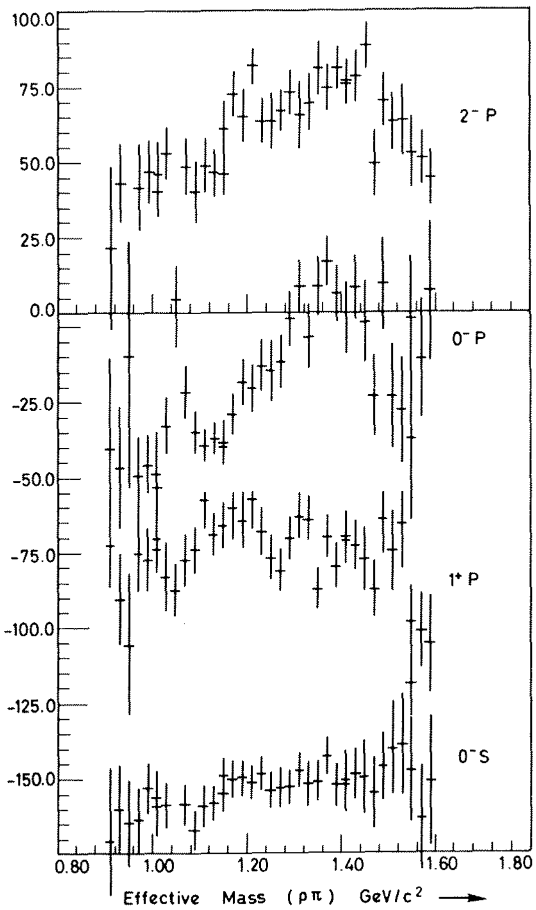

Fig. 3: 94 GeV/c data, phase relative to 0^-S, 0^-P, 1^+P, 2^-P at high t'

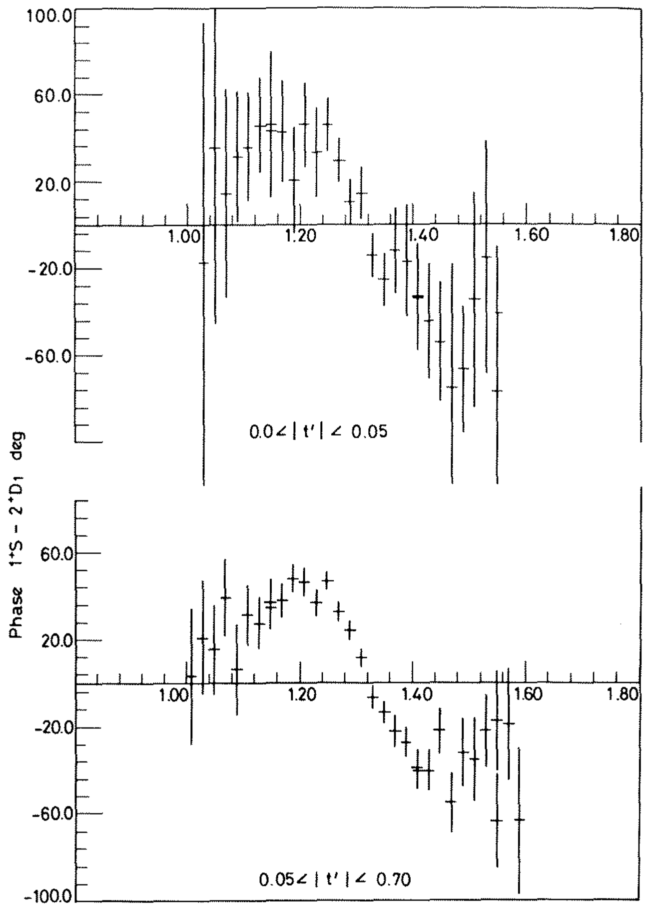

Fig. 4: 94 GeV/c data, phase relative to $2^+D_{M=1}$ at low t' and high t'

residual forward motion of the 1^+S contribution. When the fitted A_2 parameters are used to predict the absolute phase motion of that wave and this is subtracted from the data of Fig. 4, the result, seen in Figs. 1 and 2, is that the forward motion of the 1^+S phase by ∿90° is indeed confirmed in the 1.2-1.4 GeV/c^2 region.

There is thus a strong indication from both intensity and phase that a resonant object with mass ∿1.3 GeV/c^2 is being produced with a rather flatter $|t'|$ differential cross-section than a background with which it is produced coherently. To further elucidate the spectrum, it is, therefore, necessary to adopt a model in which the standard Deck-type diagram is modified by a resonant state, which will be produced both directly and in interference with this mechanism.[6]

3. MODEL DEPENDENT FITS

The solid lines of Figs. 1 and 2 display the results of a rescattering model at 94 GeV/c. With the standard trigger at 63 and 94 GeV/c there is an acceptable χ^2 in intensity and phase for a seven parameter fit simultaneous in low and high t' data. In Fig. 2, for the very high t' data at 94 GeV/c, separate normalisation has been allowed for (a) and (b) because of doubts about the ability with which the intensity of Deck mechanisms may be calculated at high average t' . Throughout, the diffractive component is a projection of a OPE Deck type model. Separate tests have shown that the inclusion of ρ exchange diagrams and possible reggeisation make qualitatively minor changes. With the exception of the very low level found above $|t'| = 0.3$ GeV/c^2 each fit agrees to within $\sim$20% with the absolute predictions of such models to the intensity that would be present if there were no resonant component (dashed lines). The kinematic component alone can only contribute a maximum of $\sim$30° phase change (zero without reggeisation) and even if normalised upwards invariably peaks too soon and too shallowly to be at all compatible with these high statistics data.

In each of the different $m(3\pi)$ and t' regions fitted, the values of the fit parameters are consistent and indicate the need for an A_1 resonance of mass 1280 ± 40 MeV/c^2, width 300 ± 30 MeV/c^2. Production appears to be with a momentum transfer slope $\sim$7 $(\text{GeV}/c)^{-2}$ to be compared to the overall intensity in this region of 10.1 ± 0.9 $(\text{GeV}/c)^{-2}$. The production phase prefers to be about -50° with respect to pure Deck, though tests have shown that this parameter is not crucial to the good agreement of intensity and phase shapes. Indeed fits to another rescattering model[7] in which this phase is held constant at zero cannot be ruled out and also call for resonance parameters at roughly the same values.

4. CONCLUSIONS

The absolute magnitude of the 1^+S $(\rho\pi)$ partial wave and its substantial change of shape as a function of momentum transfer has proved to be incompatible with diffractive Deck mechanisms. A broad peak at around 1.3 GeV/c , seen better at higher $|t'|$, and an accompanying large phase change in the data provides compelling evidence for a resonant A_1. Fits to a model in which such a state provides rescattering corrections to a simple Deck model produce satisfactory χ^2 and indicate a mass 1280 ± 40 MeV/c^2 and width 300 ± 30 MeV/c^2.

5. REFERENCES

1. Baltay et al, Phys. Rev. Lett. 39, 591, (1977).
2. Gavillet et al, Phys. Lett. 69B, 119, (1977).
3. Antipov et al, Nuc. Phys. B63, 141 and 153 (1973).
4. Spalding, Thesis, Oxford University, 1979.
5. The A_2 meson produced at 63 and 94 GeV/c in the reaction $\pi^-p \rightarrow \pi^-\pi^-\pi^+p$. This Conference.
6. Aitchison and Bowler, Journal of Phys. G. 3, 1503 (1977).
7. Basdevant and Berger, Phys. Rev. D16, 657 (1977).