CERN-EP/79-109
28 September 1979

A₂ MESON PRODUCTION AT 63 AND 94 GeV IN THE REACTION $\pi^-p \rightarrow \pi^- \pi^- \pi^+ p$

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ABSTRACT

The A₂ meson is studied in the decay mode $\rho^0 \pi^-$ using partial wave analyses of 600 000 events from the reaction $\pi^-p \rightarrow \pi^- \pi^- \pi^+ p$ at 63 and 94 GeV. Common production mechanisms are indicated for this resonance and diffractive 1⁺ and 2⁻ components.

(Submitted to Physics Letters B)

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1. INTRODUCTION

The only significant natural spin parity series contribution in partial wave analyses of diffractive 3π systems has been the $J^P = 2^+ A_2$ meson. It is important to determine whether or not the A_2 is produced diffractively in violation of the Gribov-Morrison rule. It is also of interest to measure the resonance as far as possible from the peak, in order that this partial wave may serve as a reliable reference amplitude in the low 3π mass region.

This letter describes an experiment performed at incident energies up to 100 GeV, in which A_2 production is studied in detail.

2. THE APPARATUS AND DATA

The experiment WA3 was carried out in the West Area of the CERN SPS, using a tagged hadron beam focused on the 50 cm liquid-hydrogen target of a two-magnet forward spectrometer shown in Fig. 1.

This apparatus comprised 80 magnetostrictive wire spark chamber planes (S) and was equipped with two large multi-cellular Čerenkov detectors (C1, C2). Proportional chamber (H1) and scintillator (H2) hodoscopes were used to select forward charged multiplicity, and scintillator-lead sandwich counters (V1, V2) around the target and before the first magnet vetoed high-multiplicity events.

Following vertex cuts, Čerenkov identification and cuts in the missing mass of the unmeasured recoil system, 598 128 events of the reaction

$$\pi^- p \rightarrow \pi^- \pi^- \pi^+ p$$

were obtained in three approximately equal samples. Two of these, at 63 GeV and 94 GeV incident momenta, have data down to zero momentum transfer squared to the proton (standard trigger), whilst the third sample at 94 GeV only, was biased to select $|t'| > 0.16 \text{ GeV}^2$ (high t' trigger). Throughout, a background from other reactions of $\approx 4 \pm 2\%$ remains.

The three-pion effective mass spectra from these events are shown in Fig. 2 for the region of interest $0.7 \leq M(3\pi) \leq 1.7 \text{ GeV}$. The data are subdivided into the momentum transfer intervals in which the analysis was performed. For the

standard trigger these were $0.0 \leq |t'| \leq 0.05 \text{ GeV}^2$ (Fig. 2a) and $0.05 \leq |t'| \leq 0.7 \text{ GeV}^2$ (Fig. 2b), and for the high t' trigger $0.16 \leq |t'| \leq 0.3 \text{ GeV}^2$ (Fig. 2c) and $0.3 \leq |t'| \leq 0.7 \text{ GeV}^2$ (Fig. 2d). Although all display a broad bump between 1.1 and 1.4 GeV, great variations of structure may be seen.

The solid points on Fig. 2 show the effect of the acceptance corrections used in the analysis. A large part of these originate from δ -electron vetoes, which do not bias the 3π system. Geometric losses average around 18%.

3. PARTIAL-WAVE ANALYSES

Energy-independent partial-wave analyses of the three-pion final state have been carried out in the momentum transfer regions given, and in mass bins of 20 MeV compatible with the resolution of $\sigma = 10\text{-}12 \text{ MeV}$. Both the amplitude parametrization [1] and the density matrix formulation [2] have been used and detailed comparisons of the two techniques are presented elsewhere [3]. There is a common approach of a two-step decay with no rescattering. Mass and width values for the ρ^0 , f^0 , and g^0 isobars have been taken from particle data tables, whilst the S-wave $\pi^-\pi^+$ interaction has been parametrized from two-body phase-shift analyses [4].

The results in this paper are based on the density matrix method. The intensity of a partial wave is given by the acceptance-corrected number of events in a bin multiplied by a diagonal density matrix element. The relative phase is that of an appropriate off-diagonal element. The rank of the density matrix is close enough to unity to identify this with the phase between true proton-spin amplitudes. Where combined data are used, intensities have been summed and phases averaged, with uncorrelated errors assumed.

The partial wave nomenclature ($J^P_{LM}^\eta$) used gives the total spin (J) and parity (P) of the 3π system followed by the angular momentum between the isobar and odd pion in spectroscopic notation. The fits are in the t-channel frame, and states are chosen to be eigenstates of reflection parity η . It is found that unnatural parity series with $J_z = M = 0$ and $\eta = +1$ production dominates. $M^\eta = 0^+$ may be assumed unless stated otherwise.

4. THE A_2 MESON

In the J^P natural parity series $M^\pi = 0^+$ is forbidden. In Fig. 3 the intensity of the 2^+D1^+ ($\rho\pi$) partial wave is displayed for the data in $0.05 \leq |t'| \leq 0.7 \text{ GeV}^2$ (Fig. 2b). The dashed curve is a fit with a relativistic Breit-Wigner expression, using a mass-dependent width including a D-wave Blatt and Weisskopf barrier factor. The results of fits to the different data samples are given in Table 1. It may be seen that all mass and width parameters are compatible and that each fit demands a small but significant amount of background (reducing the χ^2 considerably), represented here by the incoherent addition of an exponential e^{-AM} ($A \approx 10 \text{ GeV}^{-2}$) multiplied by ($\rho\pi$) phase space.

The calculated Breit-Wigner phase is shown in Fig. 4, superimposed on the observed mass-dependence of the phase between 2^+D1^+ and all the other principal partial waves.

The 2^+D1^+ differential cross-section in the mass interval $1.26 \leq M(3\pi) \leq 1.36 \text{ GeV}$ is shown in Fig. 5 using all data. The distribution is fitted with the functional form $t'e^{Bt'}$, the dip in the forward direction from helicity flip being clearly evident. The values of slope parameters, B , obtained from the differently triggered data samples, are given in Table 1 and agree.

The total A_2 cross-sections are also given in Table 1, integrated over mass and t' . In the limited mass region 1.2 to 1.4 GeV the cross-sections of the integrated 2^+D1^+ intensity may be used, with those of previous analyses [5], to give a good measurement of the production dependence on momentum. The parametrization $\sigma \propto p^{-n}$ may be seen in Fig. 6 with a value for the exponent of $n = 0.40 \pm 0.03$, in agreement with the corresponding quantity for the unnatural parity states 1^+S ($\rho\pi$) [6], in the mass region 1.0-1.2 GeV where $n = 0.42 \pm 0.04$, and 2^-S ($f\pi$) [7], in the mass region 1.5-1.8 GeV where $n = 0.43 \pm 0.06$. This suggests the same production mechanism for 1^+S , 2^+D , and 2^-S .

Similar production mechanisms might also be expected to give the constant ($2^+D1^+ - 1^+S0^+$) interference phase observed over the s and t ranges studied (Table 2).

To complete the information on A_2 production, the 2^+D sub density matrix in the interval $1.26 \leq M(3\pi) \leq 1.36$ GeV is given in Table 3. Only production in the $M^\eta = 1^+$ state is significant and no variation is seen except for the rise in $\text{Re } \rho_{21}$ at very high t' , probably due to a net helicity flip of 2 for the (small) $M = 2$ contribution.

5. CONCLUSIONS

A_2 meson production and decay into $\rho^0\pi^-$ has been measured in the final state $\pi^-\pi^-\pi^+$ at high energies over a wide momentum transfer interval. Both intensity and phase from a relativistic Breit-Wigner amplitude give good agreement with the data, though a small background is required. Studies of interference phases, as a function of momentum transfer, and total cross-section dependence on beam momentum show compatibility with the same natural parity exchange production mechanism that dominates the rest of the 3π spectrum.

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Table 1

Resonance parameters for fits to A_2

Data	63 GeV $0.05 < t' < 0.7 \text{ GeV}^2$	94 GeV $0.05 < t' < 0.7 \text{ GeV}^2$	94 GeV $0.16 < t' < 0.7 \text{ GeV}^2$	All data combined
Mass (MeV)	1317 $\pm$ 3	1318 $\pm$ 3	1317 $\pm$ 3	1317 $\pm$ 2
Γ_0 (MeV) (resolution corrected, $\sigma = 10\text{--}12 \text{ MeV}$)	103 $\pm$ 12	105 $\pm$ 10	90 $\pm$ 10	96 $\pm$ 9
Background (1.2–1.4 GeV region) (%)	4.0 $\pm$ 0.6	6.3 $\pm$ 0.6	3.8 $\pm$ 0.4	4.6 $\pm$ 0.5
Exponential slope B (GeV^{-2}) in $t'_{eBt'}$ fit	7.6 $\pm$ 0.2	7.5 $\pm$ 0.2	7.1 $\pm$ 0.1	7.3 $\pm$ 0.1
Background subtracted total A_2 ($2^{+}D1^{+}$) cross-section (μb)	22.0 $\pm$ 3.4	18.8 $\pm$ 2.6	22.9 $\pm$ 2.5	—

Table 2

Relative phase 2^+D1^+ (A_2) with respect to 1^+S0^+
(Mass interval $1.26 \leq M(3\pi) \leq 1.36$ GeV)

$ t' $ limits (GeV ²)	Relative phase (degrees)		$ t' $ limits (GeV ²)	Relative phase (degrees)	
	Standard trigger			High t' trigger	
	63 GeV	94 GeV		94 GeV	
0.00-0.02	-7 ± 31	-6 ± 18	0.16-0.18	-3 ± 6	
0.02-0.05	-1 ± 14	-1 ± 14	0.18-0.21	-8 ± 4	
0.05-0.08	1 ± 11	-6 ± 8	0.21-0.25	-5 ± 4	
0.08-0.14	-3 ± 7	-5 ± 7	0.25-0.30	-6 ± 4	
0.14-0.30	-8 ± 6	-8 ± 5	0.30-0.38	-11 ± 4	
0.30-1.00	-10 ± 10	2 ± 10	0.38-0.47	-12 ± 5	
			0.47-1.00	-1 ± 7	

Table 3

 A_2 polarization, $1.26 \leq M(3\pi) \leq 1.36$ GeV

P _{lab} (GeV)	Standard trigger		High t' trigger 94 GeV								
	63 GeV	94 GeV									
t' limits (GeV ²)	0.0-0.7	0.0-0.7			0.16-0.18	0.18-0.21	0.21-0.25	0.25-0.30	0.30-0.38	0.38-0.47	0.47-1.00
Intensity of 2 ³ D (Events)	3402	5256			1351	1904	2292	2299	2606	2301	3841
"Natural parity exchange"											
ρ ₁₁ + ρ ₁₋₁	0.90 ± 0.03	0.91 ± 0.03			0.91 ± 0.06	0.89 ± 0.04	0.92 ± 0.04	0.92 ± 0.04	0.88 ± 0.04	0.92 ± 0.03	0.90 ± 0.03
ρ ₂₂ - ρ ₂₋₂	0.05 ± 0.03	0.03 ± 0.02			0.03 ± 0.06	0.03 ± 0.05	0.03 ± 0.04	0.03 ± 0.04	0.04 ± 0.03	0.04 ± 0.03	0.06 ± 0.02
Re (ρ ₂₁)	0.12 ± 0.02	0.10 ± 0.02			0.11 ± 0.03	0.09 ± 0.02	0.11 ± 0.02	0.11 ± 0.02	0.09 ± 0.02	0.12 ± 0.02	0.19 ± 0.02
Im (ρ ₂₁)	-0.08 ± 0.08	-0.04 ± 0.07			-0.07 ± 0.19	-0.01 ± 0.14	0.00 ± 0.12	-0.05 ± 0.10	-0.02 ± 0.11	-0.05 ± 0.10	-0.03 ± 0.06
"Unnatural parity exchange"											
Trace of ρ	0.05 ± 0.04	0.06 ± 0.03			0.06 ± 0.08	0.08 ± 0.06	0.05 ± 0.05	0.05 ± 0.05	0.07 ± 0.05	0.03 ± 0.04	0.04 ± 0.03

Figure captions

- Fig. 1 : WA3 (ACCMOR) spectrometer showing target (T), magnets (M), spark chamber packs (S), Čerenkov detectors (C), multiplicity triggers (H), and veto counters (V).
- Fig. 2 : Effective mass $3\pi^-$ histograms: for summed 63 and 94 GeV data with standard trigger (a) $0.0 \leq |t'| \leq 0.05 \text{ GeV}^2$, (b) $0.05 \leq |t'| \leq 0.7 \text{ GeV}^2$; and for 94 GeV data with high t' trigger (c) $0.16 \leq |t'| \leq 0.30 \text{ GeV}^2$, (d) $0.30 \leq |t'| \leq 0.7 \text{ GeV}^2$. Crosses indicate data before and solid points after acceptance corrections.
- Fig. 3 : Intensity of 2^+D1^+ ($\rho\pi$) partial wave for $0.05 \leq |t'| \leq 0.7 \text{ GeV}^2$ (standard trigger) with a fit of a relativistic Breit-Wigner amplitude.
- Fig. 4 : Comparison of relative phase of the 2^+D1^+ ($\rho\pi$) partial wave with respect to other major contributing waves for the same data as in Fig. 3.
- Fig. 5 : Differential cross-section, dN/dt' , of the 2^+D1^+ intensity with a fit of the function $t'e^{Bt'}$. Standard trigger data is normalized to the total cross-section of the high t' trigger data.
- Fig. 6 : Cross-section for the integrated 2^+D1^+ intensity for $1.2 \leq M(3\pi) \leq 1.4 \text{ GeV}$ as a function of incident momentum.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6