SPIN-PARITY ANALYSIS OF 3π DECAYS IN THE A_2 MESON REGION

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A Dalitz plot with 600 events in the A_2 mass region has been obtained at 7 GeV/c in the reaction $\pi^-p \rightarrow pA_2^-$, where $A_2^- \rightarrow \pi^+\pi^-\pi^-$, using a system of wire spark chambers in connection with the CERN-Missing-Mass Spectrometer. A spin parity analysis shows that for the overall A_2 region ($1260 < M < 1360$ MeV) $J^P = 2^+$ is favoured $P(\chi^2) = 40\%$ over $1^-, 1^+, 2^-$p (all with $P(\chi^2) < 0.5\%$). When the A_2 region is divided into A_2^{high} and A_2^{low} as suggested by the missing mass spectrum, the distributions still favour 2^+ over 1^-, particularly for A_2^{low}.

Since 1967, when the first Missing-Mass Spectrometer data on the A_2 region [1] presented evidence that in the mass region between 1260 and 1360 MeV there exist in fact two peaks separated by a narrow hole, supporting evidence in different reactions and centre of mass energies have been presented [2-4].

A possible explanation of the effect is the presence of two resonances very close in mass with the same spin parity or a double pole [1]. An alternative would be to have two resonances with different quantum numbers [5] as perhaps suggested by the $K\bar{K}$ spectrum of ref. 3. In order to obtain direct experimental evidence on the spin parity, we have analysed the Dalitz plot of A_2^{low} and A_2^{high} obtained in the reaction $\pi^-p \rightarrow p\pi^+\pi^-\pi^-$ at incident momentum of 7 GeV/c and four-momentum transfers to the proton in the range 0.18 - 0.32 (GeV/c)^2.

675 events have been obtained in the A_2 region. A comparison between the two peaks shows no clear difference of the density distribution of the Dalitz plot, and we find 2^+ favoured for both the A_2^{high} and A_2^{low} regions, but other hypotheses cannot be definitely ruled out. The spin-parity analysis on the total A_2 fits well $J^P = 2^+$ whereas other assignments are rejected ($P(\chi^2) < 0.5\%$).

The laboratory angles of the three charged decay pions of the A_2 were measured with a system of two-wide-gap wire spark chambers with magneto-strictive read-out [6]. They were placed as seen in fig. 1 in the forward direction of the CERN missing-mass spectrometer [7], which determined the laboratory angle and momentum of the recoil proton and therefore the missing mass. A missing-mass spectrum of the A_2 meson with high statistics, obtained in the same run, has been published [1]. The mass-bite accepted with full efficiency was $850 < M < 1650$ MeV.

In 65% of the cases, all three pions of an A_2 decay went into the fiducial area (150×150 cm^2) of the wire chambers corresponding to an angular acceptance $\pm 21^o$. Data acquisition, sampling, and control of the entire system was done by an online computer.

Identification of 3π *events.* We have selected the events in the wire chambers which have three tracks coming from the target and giving a good geometrical reconstruction to the proton vertex. Applying three-momentum conservation to these events, with the hypothesis that in the reaction

$$\underset{(1)}{\pi^-} + \underset{(2)}{p} \rightarrow \underset{(3)}{p} + \underset{(4)}{X^-} \qquad (1)$$

only the decay $X^- \rightarrow \pi^+\pi^-\pi^-$ is present, gives the momenta p_i ($i = 1, 2, 3$) of the decay pions

$$\sum_{i=1}^{3} p_i = p_1 - p_3 \qquad (2)$$

where p_1 and p_3 are known from the missing-mass spectrometer. Therefore the invariant mass of X^-

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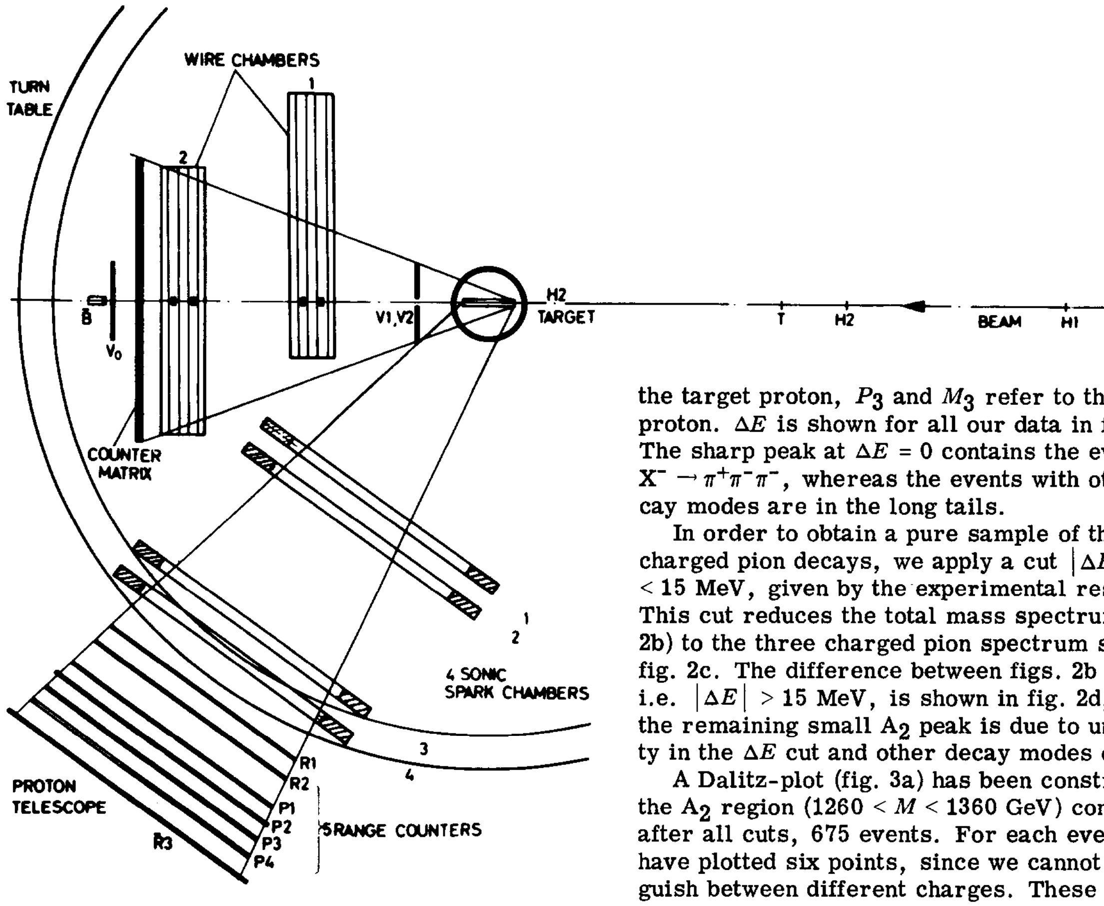

Fig. 1. CERN Missing-Mass Spectrometer (schematic layout) with wire chambers in the forward direction for decay analysis.

$$M_X^2 = \left\{\sum_{i=1}^{3} (p_i^2 + m_i^2)^{\frac{1}{2}}\right\}^2 - \left\{\sum_{i=1}^{3} p_i\right\}^2 \qquad (3)$$

can be obtained without using a magnet. This method fails for events which are coplanar in the laboratory system (see below under biases).

A constraint to eliminate the events where $X^- \to \pi^+\pi^-\pi^- + n\pi^0$'s is obtained by requiring energy conservation. We define the difference ΔE between the out-going and the incident energy in reaction (1):

$$\Delta E = \sum_{i=1}^{3} (p_i^2 + m_i^2)^{\frac{1}{2}} + (P_3^2 + M_3^2)^{\frac{1}{2}} - (P_1^2 + M_1^2)^{\frac{1}{2}} - M_2 \qquad (4)$$

where P_1, M_1 refer to the incident pion, M_2 to the target proton, P_3 and M_3 refer to the recoil proton. ΔE is shown for all our data in fig. 2a. The sharp peak at $\Delta E = 0$ contains the events with $X^- \to \pi^+\pi^-\pi^-$, whereas the events with other decay modes are in the long tails.

In order to obtain a pure sample of three charged pion decays, we apply a cut $|\Delta E| <$ < 15 MeV, given by the experimental resolution. This cut reduces the total mass spectrum (fig. 2b) to the three charged pion spectrum shown in fig. 2c. The difference between figs. 2b and 2c, i.e. $|\Delta E| > 15$ MeV, is shown in fig. 2d, where the remaining small A_2 peak is due to uncertainty in the ΔE cut and other decay modes of the A_2.

A Dalitz-plot (fig. 3a) has been constructed for the A_2 region ($1260 < M < 1360$ GeV) containing, after all cuts, 675 events. For each event we have plotted six points, since we cannot distinguish between different charges. These data have been obtained in 58 hours of running.

Biases. Two kinds of biases have been examined in detail by a Monte-Carlo calculation in which possible polarization effects of the A_2 were not taken into account.

i) Geometrical biases due to limits in the finite solid angle of the wire chambers (including the "beam killers", see fig. 1). The loss of events due to solid angle cuts amounts to 35%. The lost events are uniformly distributed over the whole Dalitz plot.

ii) Coplanarity bias. Since our method fails for coplanar events, they fall into the tails of the ΔE distribution (fig. 2a) and they are removed by the $|\Delta E| < 15$ MeV cut. This is not a uniform loss, but it deviates from uniformity at maximum 25% at the border of the Dalitz plot (whereas the most interesting hypotheses 1^- and 2^+ differ mainly in the center; their distinction being therefore not affected).

Spin-parity analysis . The density distribution of the Dalitz plot depends on the spin-parity of the resonance. In the analysis, an incoherent

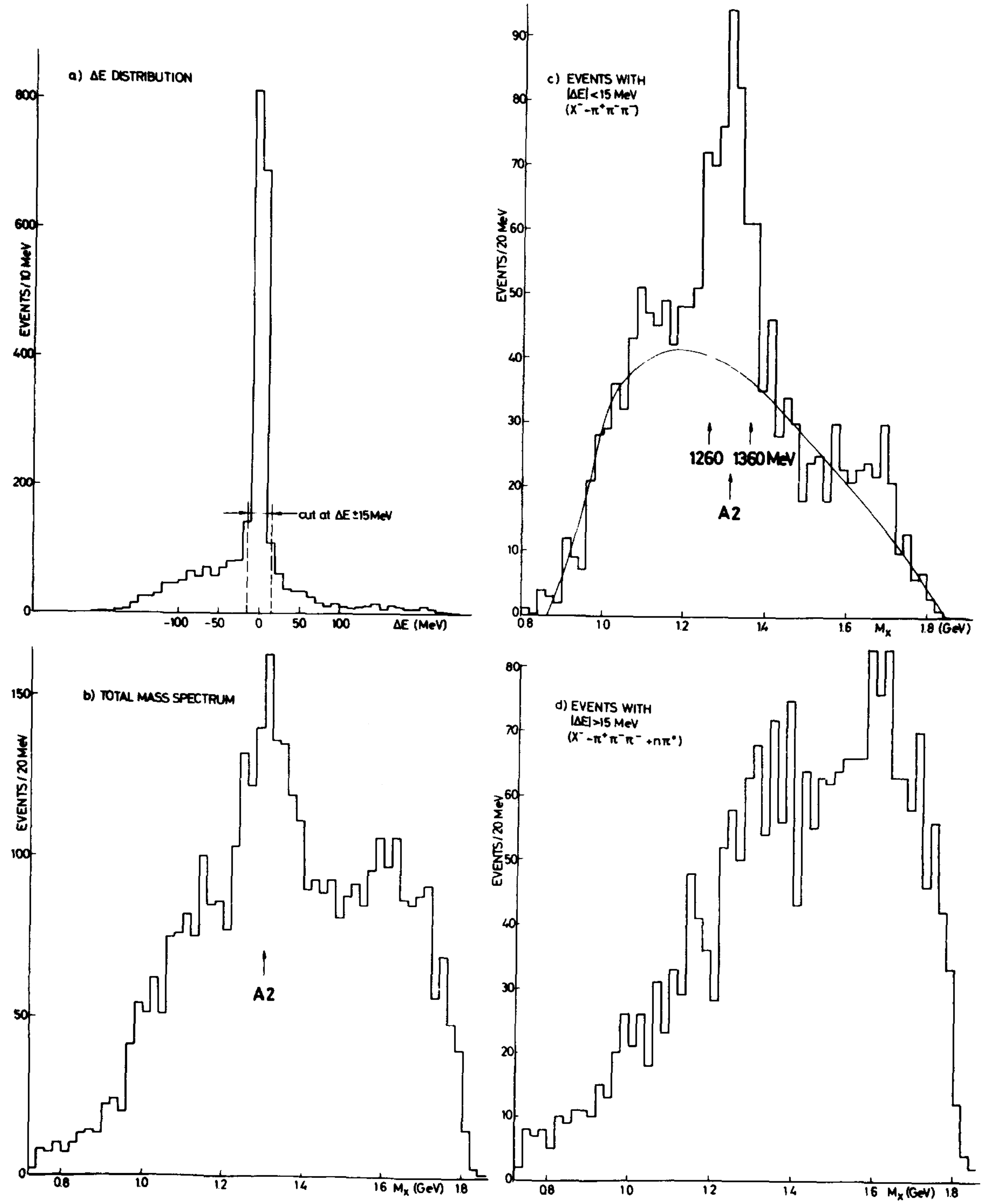

Fig. 2. Selection of events with $X^- \to 3$ charged pions. a) Difference ΔE between the outgoing and the incident energy; b) Total missing mass spectrum; c) Events for $|\Delta E| < 15$ MeV (A_2 enhanced); d) Events for $|\Delta E| > 15$ MeV.

Table 1.
Confidence levels for different spin-parities in the A_2 region.

Mass interval	Hypothesis	% resonance	% $\pi\rho$ background	% 3π background	$P(\chi^2)$
A_2^{low}	2^+	40	10	50	38%
$1254 < M_X < 1307$ MeV	1^-	30	40	30	0.3%
A_2^{high}	2^+	40	0	60	54%
$1307 < M_X < 1360$ MeV	1^-	30	40	30	10%
	2^+	40	20	40	38%
Total A_2	1^-	30	40	30	0.1%
$1260 < M_X < 1360$ MeV	2^-(p)	30	40	30	0.1%
	1^+(s)	40	30	30	0.1%
	1^+(d)	30	40	30	0.1%

mixture of resonance and two background terms have been assumed. For the resonant term we have used the theoretical distributions of Zemach [7] for the $\rho\pi$ decay of a 3π resonance. For the background we have assumed two terms, a $\rho\pi$ background with a distribution uniform in the ρ bands and a 3π background uniform over the whole Dalitz plot.

Since our events must enter six times in the Dalitz plot, we have studied only the density distribution of one sextant where each event is counted only once. For this purpose we have used as variables the three-pion mass M and the polar coordinates r and θ within the sextant of the Dalitz plot. From r we define a new variable $S = (r/R)^2$ where R is the distance from the centre to the edge of the Dalitz plot for the particular M value.

If one integrates over M (taking into account the Breit-Wigner shape of the resonance) and θ, the distribution of the events as a function of S has a characteristic shape for each particular spin-parity value of the resonance. A uniform 3π background adds a contributions which is constant as a function of S. The $\rho\pi$ background has a very similar shape to a 2^- or 1^+s state.

Results. The main aim of the analysis is to obtain further information on the possible spin parities of the two regions A_2^{low} and A_2^{high}. The existence of the $\eta\pi$ decay mode apparently over the full width [3] of the A_2 suggests that the assignments 1^-, 2^+ are the most interesting. In particular 1^- has been suggested for A_2^{low} [2] to account for the absence of $K\bar{K}$ in the A_2^{low} region in the BNL experiment [3].

* Equal spin-parity for A_2^{high} and A_2^{low} would most easily explain the interference between the two peaks in the total MMS + CBS A_2 mass-spectrum [2].

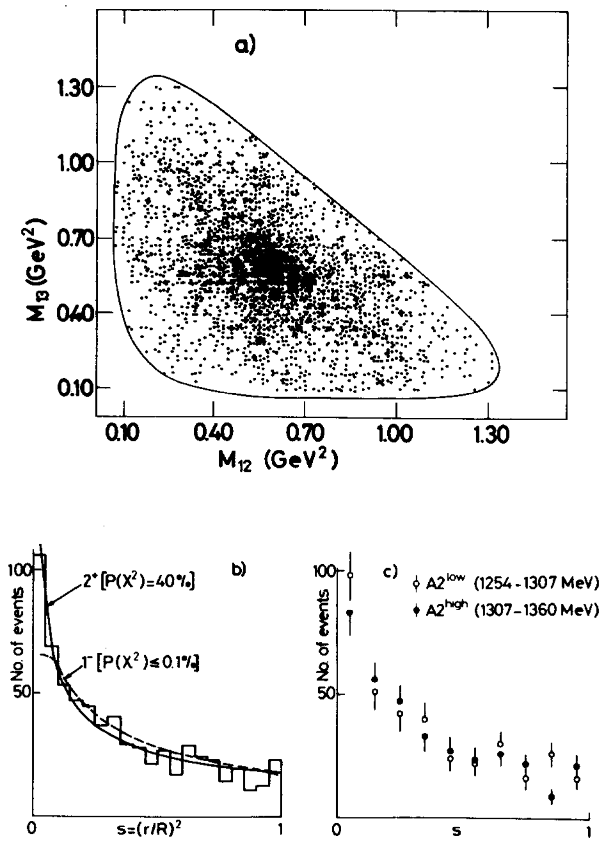

Fig. 3. Spin parity analysis of the A_2 Dalitz plot.
a) Dalitz plot for $1260 < M < 1360$ MeV;
b) Radial density distribution of one sextant of the Dalitz plot, fitted with the hypotheses $J^P = 2^+$ (solid line) and $J^P = 1^-$ (dashed line);
c) Radial density distributions for A_2^{low} (1254 - 1307 MeV) and A_2^{high} (1307 - 1360 MeV).

Since the statistics and mass resolution for our decay analyzed 3 pion events selected above were insufficient to detect the hole in the centre of the A_2 we used the information from the overall split A_2 [2] to devide the A_2 region into two halves and examine these independently. We assume that in the A_2 there exist two independent resonances with masses of 1284 and 1330 MeV and widths of 30 MeV. Fig. 3c shows the radial Dalitz plot distribution for the two mass regions $1254 < M_{3\pi} < 1307$ and $1307 < M_{3\pi} < 1360$. No significant difference can be seen in the two distributions. When we fit the two regions A_2^{low} and A_2^{high} with 2^+ and 1^- hypotheses we find that 2^+ is favored in both regions, although the 1^- cannot be ruled out for A_2^{high}.
The results are shown in table 1.

We have also examined the spin parity for the overall A_2 mass region $1260 < M_{3\pi} < 1360$. For the overall sample the 2^+ is strongly preferred over the assignments 1^-, 1^+, 2^-, as shown for example for 1^- in fig. 3b. In table 1 we have listed the best χ^2 obtained for each hypothesis. We have made the condition that the resonance be at least 30%, which is deduced from the amplitude of the A_2 peak in the missing-mass spectrum. The percentage of uniform background is also at least 30%, from the comparison of the $\pi\rho$ mass spectrum relative to the total 3π spectrum.

We conclude that the 3π Dalitz plots for the mass regions of A_2^{low} and A_2^{high} taken separately favor spin parity 2^+. Assuming a single spin parity for the overall region we obtain a clear preference for 2^+ over other simple spin parity hypotheses [8].

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