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# THE DECAY CHANNEL $A_2^- \to \eta\pi^-$ IN THE REACTION $\pi^- p \to p\pi^-\pi^+\pi^-\pi^\circ$ AT 40 GeV/$c$

Yu. M. ANTIPOV*, G. ASCOLI**, R. BUSNELLO***, M.N. KIENZLE-FOCACCI***, W. KIENZLE+, R. KLANNER++, L.G. LANDSBERG*, A.A. LEBEDEV*, C. LECHANOINE+++, P. LECOMTE***, M. MARTIN***, V. ROINISHVILI‡, A. WEITSCH‡‡ and F.A. YOTCH*

*CERN-IHEP Boson Spectrometer Group*

*(Joint Experiment of the Institute of High-Energy Physics, Serpukhov, USSR, and the European Organization for Nuclear Research, Geneva, Switzerland)*

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Abstract: We have measured the branching ratio $A_2^- \to \eta\pi^-/A_2^- \to \rho\pi = 0.22 \pm 0.03$ (statistical error; systematic error $\pm$ 0.02) at 40 GeV/$c$. From an analysis of the decay angular distribution we obtain a $J^P = 2^+$ wave in a pure $|M| = 1$ state, produced by natural parity exchange.

## 1. Introduction

The CERN-IHEP boson spectrometer has been operating at the Serpukhov proton accelerator to investigate $\pi^- p$ interactions at 25 and 40 GeV/$c$. The measurement of the inelastic reactions $\pi^- p \to X^- p$ [1] suggested a strong production of the $A_2$ meson ($M$ = 1310 MeV, $\Gamma$ = 100 MeV, spin and parity $J^P = 2^+$). This was confirmed by the analysis of the reaction $\pi^- p \to \pi^-\pi^+\pi^- p$ [2,3], where a partial-wave method was used to extract the $A_2$ signal from the data. In this paper we investigate production and decay of the $A_2$ in the reaction†

$$\pi^- p \to \eta^\circ \pi^- p$$
$$\hookrightarrow \pi^+\pi^-\pi^\circ \text{ (or } \gamma)$$

* IHEP, Serpukhov, USSR.
** University of Illinois, Urbana, Ill., USA.
*** University of Geneva, Geneva, Switzerland.
+ CERN, Geneva, Switzerland.
++ University of Munich, Munich, Germany, now at University of Illinois, Urbana, Ill., U.S.A.
+++ CERN, now at University of Geneva.
‡ Institute of Physics, Tbilisi, USSR.
‡‡ University of Munich, now at Stanford Linear Accelerator Center, Calif., USA.

† As we cannot kinematically separate the two decay modes $\eta \to \pi^+\pi^-\pi^\circ$ and $\eta \to \pi^+\pi^-\gamma$, in our analysis we treat the neutral particle as a $\pi^\circ$.

at 40 GeV/$c$ in the momentum transfer interval $0.17 < |t| < 0.33$ (GeV/$c$)$^2$. In this reaction the $A_2$ appears with very little background, which simplifies the analysis as compared to the $3\pi$ decay mode.

## 2. Selection and identification of $\pi^-\pi^+\pi^-\pi^0$ events

The trigger (see ref. [1]) requires that an incident beam particle interacts inside the liquid hydrogen target and produces a slow recoil proton which is detected in the proton telescope. The events of the reaction $\pi^- p \to p\pi^-\pi^+\pi^-\pi^0$ are selected in the off-line analysis by the following criteria:

(i) an incident particle measured by the beam hodoscopes;

(ii) a proton, momentum analysed by time of flight and the direction measured by the two wire spark chambers of the proton telescope; the proton track has to intersect with the beam track inside the target (proton vertex);

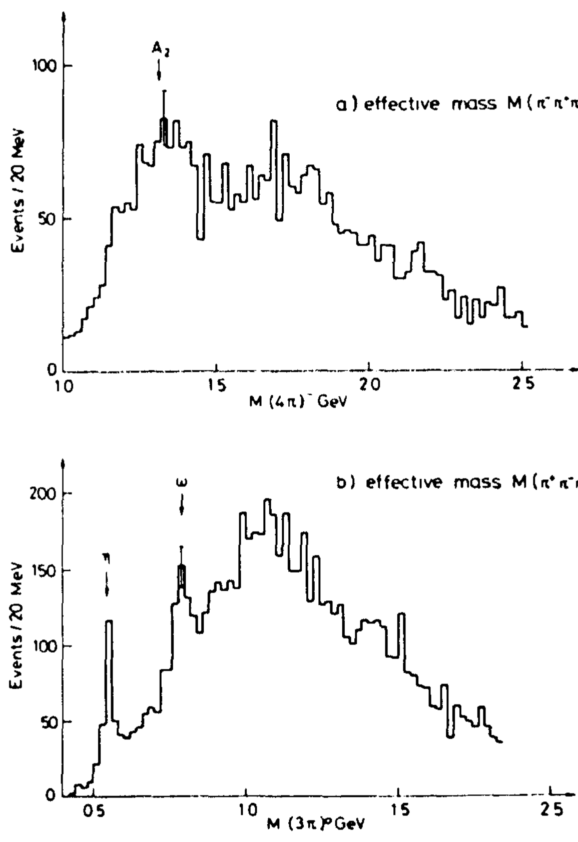


Fig. 1. (a) Effective mass $M(\pi^-\pi^+\pi^-\pi^0)$ at 40 GeV/$c$ [$0.04 < |t| < 0.33$ (GeV/$c$)$^2$]. (b) Effective mass $M(\pi^+\pi^-\pi^0)$ at 40 GeV/$c$. There are two entries per event.

Table 1
Statistics of the events used for the analysis

| Momentum transfer [$(GeV/c)^2$] | 0.17 – 0.33 | 0.10 – 0.33 | 0.04 – 0.33 |
|---|---|---|---|
| Number of $\pi^- p \to \pi^-\pi^+\pi^-\pi^0 p$ | 2900 | 1400 | 3900 |
| Number of $\eta$ in the intervals $0.17 \leq |t| \leq 0.33\ (GeV/c)^2$ | 60 | 25 | 35 |

(iii) three charged tracks originating from the proton vertex, measured and momentum analysed in the magnetic spectrometer;

(iv) the $\chi^2$ probability obtained by fitting the hypothesis $\pi^- p \to p\pi^-\pi^+\pi^-\pi^0$ to the data exceeds 0.03 (four-momentum conservation, one-constraint fit).

The number of the selected events is listed in table 1. In figs. 1a and 1b we plot the effective mass $M(\pi^-\pi^+\pi^-\pi^0)$ and the two combinations $M(\pi^+\pi^-\pi^0)$.

In the $\eta$ region the background from events $\pi^- p \to \pi^- K^- K^+ p$ and $\pi^- p \to \pi^- \bar{p}pp$ does not exceed 1%; the background from the reaction $\pi^- p \to p\pi^-\pi^+\pi^-$ and $\pi^- p \to p\pi^-\pi^+\pi^-\ (n\pi^0)$, $n \geq 2$, is less than 3%.

The $\pi^-\pi^+\pi^-\pi^0$ mass resolution is of the order of $\Gamma = 40$ MeV.

## 3. Mass, width, and branching ratio

In order to estimate the $A_2 \to \eta\pi$ signal we select the $\pi^+\pi^-\pi^0$ combination whose mass is nearest to the $\eta$ mass.

Fig. 2. shows the scatter plot of $M(\pi^+\pi^-\pi^0)$ in the interval 0.47 – 0.65 GeV *versus* $M(\pi^-\pi^+\pi^-\pi^0)$ in the interval 0.9 - 1.75 GeV.

The number of $\eta$ events from the $A_2$ decay is evaluated by applying an $A_2$ cut (1.215 – 1.415 GeV) and fitting the $\pi^+\pi^-\pi^0$ mass distribution with a Gaussian plus a polynomial background. We obtain

$$M(\eta) = 0.551 \pm 0.002 \text{ GeV}, \quad \Gamma(\text{exp}) = 0.023 \pm 0.003 \text{ GeV}.$$

The $A_2$ signal is estimated by applying an $\eta$ cut (0.515 – 0.585 GeV) and fitting the $\pi^-\pi^+\pi^-\pi^0$ mass distribution with a Breit-Wigner plus a linear background. We find

$$M(A_2) = 1.31 \pm 0.01 \text{ GeV}, \quad \Gamma(A_2) = 0.12 \pm 0.02 \text{ GeV}.$$

For the evaluation of the $A_2$ branching ratio we use that part of the data [about the first half*] for which we have done a simultaneous analysis of the $\rho^0\pi^-$ events coming from the $\pi^- p \to \pi^-\pi^+\pi^- p$ reaction [2, 3] in the same $t$-interval**. The

* These data have been chosen because there the systematic corrections are smallest.

** $0.17 < |t| < 0.33\ (GeV/c)^2$.

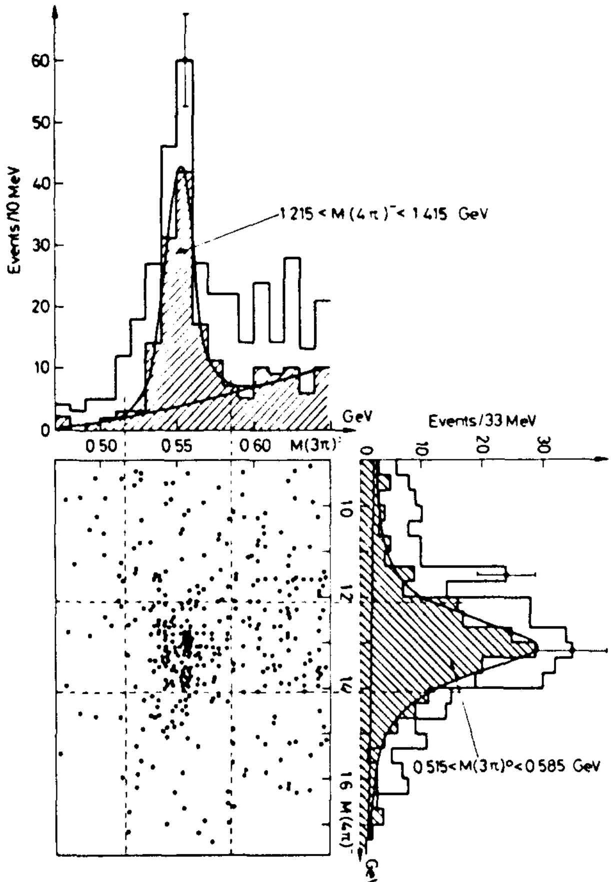


Fig. 2. Scatter plot the effective mass $M(\pi^-\pi^+\pi^0)$ *versus* $M(\pi^-\pi^+\pi^-\pi^0)$ $[0.17 < |t| < 0.33\ (\mathrm{GeV}/c)^2]$. Events are selected with the $\pi^+\pi^-\pi^0$ mass in the interval 0.45 – 0.65 GeV. Shaded are events for the interval $[1.215 < M(\pi^-\pi^+\pi^-\pi^0) < 1.415$ GeV] and $[0.515 < M(\pi^+\pi^-\pi^0) < 0.585$ GeV]. Solid lines are: (i) a Gaussian shape plus a polynomial background for the $\pi^+\pi^-\pi^0$ mass distribution; (ii) a Breit-Wigner shape plus a linear background for the $\pi^-\pi^+\pi^-\pi^0$ mass distribution.

$A_2 \to \eta\pi$ events in the $\pi^- p \to \pi^-\pi^+\pi^-\pi^0 p$ sample are estimated from the $A_2$ and the $\eta$ signal as in fig. 2. The number of events thus obtained is corrected for the acceptance and inefficiencies of the spectrometer [3], see table 2. For the branching ratio $B$ we obtain

$$B = \frac{N_{A_2 \to \eta\pi}}{N_{A_2 \to \rho\pi}} = 0.22 \pm 0.03$$

(statistical error, the systematic error is ± 0.02).

## 4. Decay angular distribution

We use the angular distribution of the $\eta\pi$ decay in the $A_2$ rest frame to determine the density matrix elements of the $A_2$ meson. Fig. 3 shows the scatter plot of the $A_2$ decay angles $\cos\theta$ and $\phi$; $\theta$ and $\phi$ are the angles of the $\eta$ meson in the rest frame of $A_2$; the $z$-axis is in the direction of the incident $\pi^-$ and the $y$-axis is along the normal to the production plane (see fig. 3).

The angular distribution for a spin parity $2^+$ resonance for a parity conserving process is as follows:

$$W(\theta,\phi) = \frac{15}{16\pi}\,[3\rho_{00}(\cos^2\theta - \tfrac{1}{3})^2 + 4\rho_{11}\sin^2\theta\cos^2\theta + \rho_{22}\sin^4\theta$$
$$- 2\cos\phi\sin 2\theta\ \{\mathrm{Re}\,\rho_{21}\sin^2\theta + \sqrt{6}\,\mathrm{Re}\,\rho_{10}(\cos^2\theta - \tfrac{1}{3})\}$$
$$- 2\cos 2\phi\sin^2\theta\ \{2\rho_{1-1}\cos^2\theta - \sqrt{6}\,\mathrm{Re}\,\rho_{20}(\cos^2\theta - \tfrac{1}{3})\}$$
$$+ 2\,\mathrm{Re}\,\rho_{2-1}\cos 3\phi\sin^2\theta\sin 2\theta + \rho_{2-2}\cos 4\phi\sin^4\theta].$$

The density matrix elements are determined by fitting the observed angular dis-

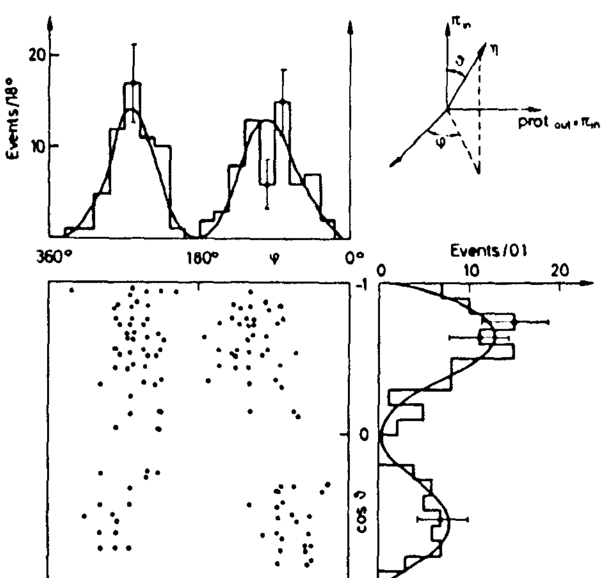


Fig. 3. Scatter plot of the $A_2$ decay angles in the Gottfried-Jackson system ($\cos\theta$ and $\phi$). Histograms are the data measured at 40 GeV/$c$. Solid lines are the results of the maximum likelihood fit multiplied by the acceptance of the spectrometer.

Table 2
Number of $A_2$ events in region 1.215 – 1.415 GeV, $0.17 \leq |t| \leq 0.33$ $(GeV/c)^2$

| | Decay mode | |
|---|---|---|
| | $\rho\pi$ [b)] | $\eta\pi$ |
| From fit | 743 ± 32 | 52 ± 8 |
| After corrections for | | |
| Geometrical acceptance | 816 ± 35 | 78 ± 11 |
| Spark chamber efficiency | 906 ± 40 | 116 ± 16 |
| Unseen decay modes[a)] | 1812 ± 80 | 403 ± 58 |
| Branching ratios to $\rho\pi$ | 1.00 | 0.22 ± 0.03 |

a) $\rho$ : for unseen decay modes we use $\rho \to \pi^+\pi^-/\rho \to$ total = 0.50
$\eta$ : for unseen decay modes we use $\eta \to (\pi^+\pi^-\pi^0 + \pi^+\pi^-\gamma)/\eta \to$ total = 0.289 ± 0.006 from ref. [4].
b) From ref. [3].

Table 3
Density matrix elements

| | Element | Value | Angular distribution [a)] |
|---|---|---|---|
| Natural parity exchange | $\rho_{11} + \rho_{1-1}$ | 0.97 ± 0.06 | $c4 \sin^2 \phi \sin^2 \theta \cos^2 \theta$ |
| | $\rho_{22} - \rho_{2-2}$ | 0.03 ± 0.05 | $c \sin^2 2\phi \sin^4 \theta$ |
| | $\mathrm{Re}(\rho_{21} + \rho_{2-1})$ | 0.02 ± 0.07 | $-c2 \sin 2\phi \sin \phi \sin^2 \theta \sin 2\theta$ |
| Unnatural parity exchange | $\rho_{00}$ | 0.00 ± 0.06 | $c3[\cos^2 \theta - \frac{1}{3}]^2$ |
| | $\mathrm{Re}(\rho_{10})$ | 0.00 ± 0.03 | $-c2\sqrt{6} \cos \phi \sin 2\theta [\cos^2 \theta - \frac{1}{3}]$ |
| | $\mathrm{Re}(\rho_{20})$ | 0.00 ± 0.03 | $c2\sqrt{6} \cos 2\phi \sin^2 \theta [\cos^2 \theta - \frac{1}{3}]$ |
| | $\rho_{11} - \rho_{1-1}$ | 0.00 ± 0.05 | $c4 \cos^2 \phi \sin^2 \theta \cos^2 \theta$ |
| | $\rho_{22} + \rho_{2-2}$ | 0.00 ± 0.05 | $c \cos^2 2\phi \sin^4 \theta$ |
| | $\mathrm{Re}(\rho_{21} - \rho_{2-1})$ | 0.00 ± 0.05 | $-c2 \cos 2\phi \cos \phi \sin^2 \theta\ 2\theta$ |

tribution to $W(\theta, \phi)A(\theta, \phi, t)$, where $A(\theta, \phi, t)$ is the acceptance of the forward spectrometer for $(4\pi)^-$ events. It includes both the geometrical acceptance of the system, and the experimentally determined efficiency of the spark chambers and of the track-finding program. As may be seen from fig. 3 the variation of the acceptance function with angles accounts quite well for the asymmetries in the observed angular distributions.

The data used for the analysis are those of the overlap region of fig. 2. No background subtraction has been made, since* it amounts to only ~ 10%.

The density matrix elements are determined by a maximum likelihood fit to the data (fig. 3) and are shown in table 3.

Our results are compatible with those found in the $\rho\pi$ decay mode (see refs. [2, 3]). The $A_2$ is produced by natural parity exchange in a pure $|M| = 1$ state in the Gottfried-Jackson system.

## Conclusion

The branching ratio for the $\eta\pi$ decay mode relative to $\rho\pi$ decay of the $A_2$ is $0.22 \pm 0.03$ (statistical error only; systematic error is $\pm 0.02$), well in accord with the world average of $0.211 \pm 0.023$ of ref. [4]; this confirms that the $2^+D\,(\rho\pi)$ wave observed in the $\pi^-\pi^+\pi^-$ system by a partial-wave analysis (ref. [2]) is indeed the $A_2$ resonance.

At 40 GeV/$c$ the $A_2^-$ is produced by natural parity exchange in a pure $|M| = 1$ state in the Gottfried-Jackson system.

## References

[1] Y.M. Antipov et al., Phys. Letters 40B (1972) 147.
[2] Y.M. Antipov et al., Nucl. Phys. B63 (1973) 153.
[3] R. Klanner, Ph. D. thesis, University of Munich (1973), and CERN-NP internal report 73–9 (1973).
[4] Review of Particle Properties, Particle Data Group, Rev. Mod. Phys. 45 (1973) 1.

* By varying the cut on the $\eta$ signal we have verified that this background does not alter our conclusions.