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PRODUCTION AND DECAY OF BOSON RESONANT STATES
IN $\pi^- + p$ INTERACTIONS AT 3.2 GeV/c

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Lyndon M. Hardy, Janos Kirz, and Donald H. Miller

July 3, 1964
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(Presented by Donald H. Miller)

July 3, 1964

ABSTRACT

Production and decay correlations for the \( \pi \omega \) resonance at 1220 MeV
(B meson), the \( \pi \rho \) state at 1097 MeV (\( \Lambda_1 \) meson), and the \( \pi \rho \) state at
1310 MeV (\( \Lambda_2 \) meson) have been studied in detail. Interpretations are pre-
sented in terms of possible quantum number assignments. In addition,
evidence for the existence of other decay modes for the \( \Lambda_2 \) meson state,
i.e., \( \Lambda_2 \to K\bar{\eta} \) and \( \Lambda_2 \to \pi\eta \) are discussed.

In a continuing study of the interactions of $\pi^-$ mesons at 1.5 to 4.2 GeV/c, we have investigated production and decay of strangeness $S = 0$ boson resonant systems. We discuss the significant results obtained to date.

I. $\pi^- p \to \pi^+ \pi^0 \pi^- p$

The effective-mass distributions were plotted for all pion combinations at 3.2 and 4.2 GeV/c. Marked structure was observed only in the $M(\pi^+ \pi^- \pi^0)$ distributions shown in Fig 1, a and b. The $\omega$ meson is produced copiously, although the intermediate-state $\omega N^*(1238)$ does not contribute strongly as in the analogous $\pi^+ p \to \omega \pi^+ p$ reaction. As reported earlier, the possibility for a resonant $\pi\omega$ interaction was investigated by plotting separately the $M(\pi^+ \pi^- \pi^0)$ distributions for events with either of the two $M(\pi^+ \pi^- \pi^0)$ combinations in the $\omega$ interval (750 to 810 MeV). The results are given in Fig. 1, c and d. At 3.2 GeV/c, a large peak is observed at 1220 MeV with full-width $\Gamma = 180\pm 30$ MeV; at 4.2 GeV/c, the effect has essentially disappeared. To illustrate that this peak, called the $B$ meson, is associated with $\omega$ events, a detailed plot of the data is shown in Fig. 2, c, d, and e for several intervals in $M(\pi^+ \pi^- \pi^0)$.

General studies of the production and decay correlations for the $\pi\omega$ peak have revealed no convincing evidence for a unique $J^P$ assignment. Several groups have looked for $\pi^\pm \pi^0$ enhancements at 1220 MeV in the reactions $\pi^\pm p \to \pi^\pm \pi^0 p$, but observed none. The decay $B \to K\bar{K}$ is more difficult to detect than $B \to \pi\omega$ (see discussion below); no evidence for the decay $B \to K\bar{K}$ has been obtained. Neither decay is forbidden by $G$ or $A$ parity alone, so that if the $B$ enhancement represents a pure state, such decays are likely forbidden by conservation of $J^{PG}$. Since the neutral $\pi\omega$ system has $C = -1$, decay into $\pi\pi$ and $K\bar{K}$ would be allowed for $J^P = 1^-, 3^-$, etc; in addition, decay of a 0+...
state into \( \pi \omega \) is forbidden. Consequently, comparison of the observed internal correlations with the predictions for \( J^P = 0^-, 1^+, 2^-, \) and \( 2^+ \) are particularly interesting. The predicted correlations for the simplest forms for decay matrix elements are summarized in Table I, where \( \theta \) is the angle between the normal to the \( \omega \) decay plane and the momentum of the recoil pion evaluated in the \( \omega \) rest frame.

Table I. Internal correlations for several \( J^P \) assignments for the \( B \) meson.

<table>
<thead>
<tr>
<th>State</th>
<th>Angular Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 0^- )</td>
<td>( \cos^2 \theta )</td>
</tr>
<tr>
<td>( 1^+ )</td>
<td>( 1 )</td>
</tr>
<tr>
<td>( 1^- )</td>
<td>( \sin^2 \theta )</td>
</tr>
<tr>
<td>( 2^+ )</td>
<td>( \sin^2 \theta )</td>
</tr>
<tr>
<td>( 2^- )</td>
<td>( a + b \cos^2 \theta )</td>
</tr>
</tbody>
</table>

The data are shown in Fig. 3 for several intervals of \( \pi \omega \) mass. In each case the \( M(\pi^+ \pi^- \pi^0) \) combination closest to 784 MeV was arbitrarily considered as the \( \omega \); however, the result is insensitive to this choice. As a crude correction for background, the average of the distributions for the two adjacent intervals was subtracted. The remaining events give poor fits to either the \( \sin^2 \theta \) or \( \cos^2 \theta \) distributions.

For completeness, the \( \pi \eta \) mass distribution is shown in Fig. 2, a and b together with a control region. Although a slight enhancement appears near 1300 MeV, the data suggest that the observed \( \pi \eta \) events do not result primarily from decay of an unstable boson.
The effective-mass distributions for $\pi^+ p$ and $\pi^+\pi^- p$ combinations indicate that most $\pi^+\pi^- p$ events in the 3- to 4.2-GeV/c region are produced through the intermediate states $\pi^- p N^{*++}(1238)$ and $\rho^0\pi^- p$. In a study of $\pi^+ p \rightarrow \pi^+\pi^+\pi^- p$ final states at 3.65 GeV/c, Goldhaber et al. demonstrated the existence of a strong $\pi\rho$ interaction (the $A$ enhancement) in the interval 1.0 to 1.4 GeV, and suggested that it might represent two unresolved peaks. The $\pi^-\rho^0$ mass distribution for the 3.2-GeV/c events is plotted in Fig. 4, where two clearly resolved peaks are apparent. The lower peak ($A_1$) occurs at $1080 \pm 10$ MeV with $\Gamma \approx 100$ MeV, and the upper ($A_2$) at $1310$ MeV with $\Gamma \approx 80$ MeV. Since the peaks are decreased little when events with $\Delta^2(p) \leq 0.86(\text{GeV/c})^2$ are plotted separately, we assume they are produced in peripheral collisions involving $\rho$ exchange.

The Dalitz plots associated with these events have been discussed elsewhere. Since the $J^P$ assignment for the 1310-MeV state may be determined independently (see below), we comment only on the 1080-MeV enhancement. Based on selection criteria which eliminated (a) the $N^{*++}\pi^-\pi^-$ final states and (b) events with $\Delta^2(p) > 0.8 (\text{GeV/c})^2$, the Dalitz plot appeared consistent with $J^P = 0^-$, under the assumption that the 1080-MeV peak represented a pure state. However, subsequent study indicates that the distribution in $p_{\rho} \cdot q$ (where $q$ is the normal to the $\pi\rho$ decay plane, and $p_{\rho}$ the momentum of the incident pion in the $\pi\rho$ c.m. system) contains a significant admixture of $\sin^2 \theta$, in contradiction with a $0^-$ assignment. In addition, contamination from events associated with the high-energy tail of the $N^{*++}$ tends to populate the edges of the Dalitz plot so that its significance is obscure. We conclude that the present data provide no convincing support for any particular $J^P$ assignment.
A study of those features of the Dalitz plot common to both $\pi^+ p$ and $\pi^- p$ production of the 1080-MeV peak would be useful.

III. $\pi^- p \rightarrow KKN$

Because of the strong selection rules governing decay of unstable bosons into $K\bar{K}$, the $K^+ K^- n$ and $K^- K^+_n$ events are especially important. The $K\bar{N}$ and $K\bar{K}$ mass distributions at 3.2 GeV/c are given in Fig. 5, a, b, c, and d. In addition to $K\bar{N}$ peaks corresponding to decay of the intermediate state $K^0 Y^0 (1520)$, strong peaks are observed in the $K^+ K^- n$ and $K^- K^+_n$ systems at 1340 MeV. Since (a) these peaks correspond closely in position and width to the 1310-MeV $\pi^- p$ peak and (b) the distribution in nucleon momentum-transfer (not shown) are also similar, it appears reasonable to assume that they represent alternative decay modes of the same unstable boson. The only assignments consistent with both $K^- K^+_n$ and $K^+ K^- n$ decays are $J^P = 0^+, 2^+, 4^+$, etc; since $3\pi$ decay of a $J^P = 0^+$ state is forbidden, the lowest allowed assignment is $J^{PC} = 2^{+-}$. The Dalitz plot for the 1310-MeV peak is consistent with this assignment. A rough estimate of the relative path lengths measured for the $\pi^- p$ and $K^- K^0_n$ events leads to $(A_2^- \rightarrow K\bar{K})/ (A_2^- \rightarrow \pi p) = 30 \pm 7\%$. About half of the $\pi^- p$ path length has been studied at 4.2 GeV/c; consequently, the $K\bar{K}$ peak at 1310-MeV in Fig. 5f indicates that the production cross section for this state has decreased by a factor of about three.

Despite the large peak at 1310 MeV, we have looked for the decays $A_0 (1250 \text{ MeV}) \rightarrow K^+_n K^- n$ and $B (1220 \text{ MeV}) \rightarrow K^- K^+_n$. No shoulder is apparent on the low-mass side of the 1310-MeV peak either in the distributions for all events in Fig. 5, b and d or when the low momentum-transfer events are plotted separately. From this we estimate that $(B \rightarrow K^- K^0)/(B \rightarrow \pi \omega)$ is less
than 10%. Since we have not measured two prongs at 3.2 GeV/c, a similar estimate for the $f_0$ is not possible.

IV. $\pi^- p \rightarrow K\pi N$

The effective-mass distributions for all pairs in this final state demonstrate that many events represent decay of the intermediate states $K\pi Y_0^*(1520)$ and $N\bar{N}K^*$ or $N\bar{N}K^*$. No evidence for production of the 1310-MeV boson ($A_2$) was observed in the $K\pi$ distributions.

To search for bosons whose decay into $K\pi$ might be forbidden, we divided the events into $(K\pi\pi)^0$ and $(K\pi\pi)^-$ and plotted these groups separately in Figs. 6a, b. The mass distribution for the neutral combinations tends to peak strongly at 1430 MeV, producing a marked deviation from the phase-space prediction. The same effect persists in the low-momentum-transfer events, $\Delta^2(n) < 1.2$ (GeV/c)$^2$. This enhancement cannot be a kinematic reflection of the $K^*Y_0^*(1520)$, since the $Y_0^*(1520)$ is observed primarily in the $pK^+(K\pi)^0$ events. If it were associated with the $K^*$ production mechanism, it is likely that a similar peak would appear in the $(K\pi\pi)^-$ system. We conclude that the peak at 1430 MeV with $\Gamma \approx 80$ MeV probably represents a valid $K\pi\pi$ effect. In a study of $p\bar{p}$ annihilations at rest, Armenteros et al. observed a $(K\pi\pi)^0$ peak at 1430 MeV with $\Gamma \approx 60$ MeV. It is likely that both peaks represent the same effect. If they result from decay of an unstable boson, the absence of any enhancement in $(K\pi\pi)^-$ suggests the assignment $I = 0$. 
REFERENCES


2. The effect was observed concurrently by M. Abolins, R. L. Lander, W. A. W. Mehlhop, N. Xuong, and P. M. Yager, Phys. Rev. Letters 11, 384 (1963) and G. Goldhaber et al., private communication.


FIGURE LEGENDS

Fig. 1. Effective-mass distributions for \( \pi^+\pi^-\pi^0 \) combinations at (a) 3.2 GeV/c and (b) 4.2 GeV/c. The \( \pi\omega \) effective masses are also plotted assuming that all \( \pi^+\pi^-\pi^0 \) masses in the 750 to 810-MeV interval are possible \( \omega \) mesons.

Fig. 2. Effective-mass distributions for (a, b) \( \pi\eta \) combinations and (c, d, e) \( \pi\omega \) combinations at 3.2 GeV/c.

Fig. 3. Distribution in \( \cos\theta \) for 3.2 GeV/c events with several intervals in \( \pi\omega \) mass, and \( 770 < M_\omega < 800 \) MeV.

Fig. 4. Effective-mass distributions for \( \pi^+\rho^-\) events at 3.2 GeV/c with \( 600 < M_\rho < 850 \) MeV. Events with \( M(\pi^+p) \) in \( N^{++} \) interval have been eliminated.

Fig. 5. Effective-mass distributions for \( N\bar{K} \) and \( K\bar{K} \) combinations in \( K\bar{K}N \) final states at 3.2 and 4.2 GeV/c.

Fig. 6. Effective-mass distributions for \( K\bar{K}\pi \) combinations in \( K\bar{K}\pi N \) final states at 3.2 GeV/c.
Fig. 1
Fig. 2
Fig. 3
No $N^{*++}; 0.600$

$\leq M(\pi^+\pi^-) < 0.850$ GeV

$M(\pi^-\rho^0)$

$\Delta^2(p) < 0.86$ (GeV/c)$^2$

Fig. 4
**Fig. 5**
$K^0 K^\pi^-, K^0 K^\pi^-$

$\Delta^2(n) \leq 1.2 \text{ (GeV/c)}^2$

$1430 \pm 40 \text{ MeV}$

$K^+ K^- K^0, K^0 K^- K^0$

$\Delta^2(p) \leq 1.2 \text{ (GeV/c)}^2$
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