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OBSERVATION OF AN ANOMALY IN THE $\pi^+\pi^-$ SYSTEM AT 980 MeV*

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An anomaly at 980 MeV is seen in both the mass distribution and angular distribution of the $\pi^+\pi^-$ system produced in the reaction $\pi^+p \to \Delta^{++}\pi^+\pi^-$ at 7 GeV/c. Experimental results for the related final states $\Delta^{++}K^+K^-$, $\Delta^{++}\pi^+\pi^-\pi^+\pi^-$, and $\Delta^{++}\pi^+\pi^-$ (neutrals) are presented.

Investigations of the $\pi^+\pi^-$ system long ago established the existence of the ρ and f^0 mesons. Further studies have established the existence of a large s-wave contribution to the amplitude near 750 MeV, but ambiguities have prevented a unique determination of the s-wave amplitude [1,2]. Other effects in the $\pi^+\pi^-$ system below 1500 MeV have been suggested but not established [2].

There have been two previous indications of narrow structure near 1000 MeV. At the Berkeley Conference in 1967, Veillet presented a compilation of the forward-backward asymmetry in the $\pi^+\pi^-$ decay from the reaction $\pi^-p \to \pi^+\pi^-n$, which showed a substantial drop within a region of less than 50 MeV [3]. Selove, interpreting this reaction in terms of $\pi\pi$ scattering, noted that the drop was most probably associated with $K\bar{K}$ threshold [4]. Bizzarri et al. observed a dip in the $\pi^+\pi^-$ mass distribution at 940 MeV in the reaction $\bar{p}p \to \omega\pi^+\pi^-$ at rest [5]. Their interpretation of the effect was hampered by overlapping B-meson bands, and they did not associate the effect with $K\bar{K}$ threshold.

*Work done under the auspices of the U. S. Atomic Energy Commission.

We have observed a definite, narrow anomaly in the $\pi^+\pi^-$ system near 980 MeV, both in the mass distribution and in the angular distributions in the reaction $\pi^+p \to \Delta^{++}\pi^+\pi^-$ at 7.1 GeV/c. The anomaly is most easily understood as a rapid variation in the s-wave $\pi\pi$ amplitude associated with $K\bar{K}$ threshold.

Our experiment is a 700 000-picture exposure (~45 events/μb) of the SLAC 82-inch bubble chamber to an rf-separated π^+ beam at 7.1 GeV/c. We have selected events of the reactions

(1)	$\pi^+p \to \Delta^{++}\pi^+\pi^-$	27 000 events
(2)	$\Delta^{++}K^+K^-$	700
(3)	$\Delta^{++}\pi^+\pi^-\pi^+\pi^-$	2300
(4)	$\Delta^{++}\pi^+\pi^-$ (neutrals $\geq 2\pi^0$)	12 000

where Δ^{++} means $M_{p\pi^+} < 1.4$ GeV. We have restricted $t'_{p\Delta} = |t-t_{min}| < 0.1$ GeV^2 to reduce ambiguities between the two (or three) π^+ in the final state and also to enhance the ratio of pion-exchange events to background. In case of ambiguity, the $p\pi^+$ combination with the smallest t was selected.

The selection criteria for reaction (1) have been presented in a previous publication [6]. The criteria for reaction (2) were identical, and no significant contamination of reaction (2) by reaction (1) has been found. Since reaction (3) and (4) provide only upper limits on certain effects, contamination in these reactions has been only cursorily investigated.

The mass resolution of the $\pi^+\pi^-$ system near 980 MeV is ± 6.5 MeV (HWHM) and does not depend strongly on the decay angles of the $\pi^+\pi^-$ system. References [6] and [7] describe our determination of the mass resolution of the $\pi^+\pi^-$ system.

The mass distribution and spherical harmonic moments of the $\pi^+\pi^-$ system in reaction (1) are shown in fig. 1. Three sharp effects near 980 MeV are observed: 1) The effect in $\langle Y_1 \rangle$ is a strong discontinuity at 980 MeV. (fig. 1a). Since $\langle Y_1 \rangle$ below 1100 MeV is primarily due to the interference between s and p waves, the effect must be due to a rapid change in either the s-wave or the p-wave amplitude. 2) There is a sharp rise in $\langle Y_2 \rangle$ near 980 MeV. (fig. 1b). Since the dominant contribution to $\langle Y_2 \rangle$ is approximately proportional to $|p|^2/(|s|^2 + |p|^2)$, either the p-wave could be increasing or the s-wave could be decreasing. 3) The anomaly in the mass distribution (fig. 1c) exhibits the following characteristics: a shoulder between 910 and 950 MeV, a sharp drop between 950 and 980 MeV, and a flat region above 980 MeV. The sharp drop in the mass distribution, when combined with the $\langle Y_1 \rangle$ and $\langle Y_2 \rangle$ information, implies that the effect we are observing is in the s-wave amplitude.

The other moments in fig. 1, $\langle Y_3 \rangle$ through $\langle Y_6 \rangle$, show no narrow effect near 980 MeV.** The $m \neq 0$ moments of the $\pi^+\pi^-$ system (not shown) are all small, indicating the strong dominance of the spin-projection-zero components in the $\pi\pi$ system. However, they are definitely inconsistent with zero in some cases.

We have investigated the dependence of these distributions of the $\pi^+\pi^-$ system as a function of t' and $p\pi^+$ mass. We have also studied the effect of final state interactions where one of the decay products from the Δ^{++} combine with the $\pi^+\pi^-$ system to give either a $p\pi^+\pi^-$ or $\pi^+\pi^+\pi^-$ effect. No qualitative changes or biases have been found, although quantitative changes do occur.

**It is worthwhile to point out that the strong variation in $\langle Y_3 \rangle$ near 1260 MeV, combined with the knowledge that the d-wave is resonant near 1260 MeV, shows that a significant odd-wave amplitude must be present under the f^0-meson. The absence of $\langle Y_5 \rangle$ structure near 1260 MeV indicates the odd wave in this region is probably the p-wave.

Results from other channels*** are shown in fig. 2, with $\langle Y_1 \rangle$ from the $\pi^+\pi^-$ system duplicated for reference. The rise in the K^+K^- cross section at threshold (fig. 2b) is within 10 MeV of the sharp effect in $\langle Y_1 \rangle_{\pi\pi}$. The moments $\langle Y_1 \rangle$ through $\langle Y_4 \rangle$ for the K^+K^- system (fig. 2e-h) show that the s-wave is by far the dominant amplitude near threshold, although p- and d- waves are clearly present at the 10% level. The cross section for $\pi^+\pi^-\pi^+\pi^-$ (fig. 2c) is negligible compared with the $\pi^+\pi^-$ channel for masses below 1020 MeV. The cross section for $\pi^+\pi^-\pi^0\pi^0$ (fig. 2d) is negligible below 900 MeV, and between 900 and 1020 MeV is less than 8% of the $\pi^+\pi^-$ cross section. (It should be mentioned that the $\omega\pi^0$ channel contributes to $\pi^+\pi^-\pi^0\pi^0$, not to $\pi^+\pi^-\pi^+\pi^-$, and has a threshold of 920 MeV.)

We have presented the experimental observations free of any assumptions about the production mechanism of the $\pi^+\pi^-$ system. Previous studies of reaction (1) have shown that pion exchange dominates the amplitude for small momentum transfer [2]. Thus, the systems we are studying can be analyzed as final states in the $\pi^+\pi^-$ scattering process; the coincidence in mass of the anomaly we are observing and the strong rise in $K\bar{K}$ cross section at threshold then has a natural interpretation. We are seeing the effect of unitarity (the conservation of probability) in a two-channel system [8]. Since the $K\bar{K}$ system at threshold is an s-wave, this interpretation requires that the $\pi^+\pi^-$ anomaly at 980 MeV is an s-wave effect, in agreement with our conclusion from the data.

The following argument leads to an estimate of the size of the effect in terms of $\pi\pi$ scattering. The drop in the $\pi^+\pi^-$ cross section from 950 MeV to 980 MeV will be taken as a measure of the elastic s-wave unitary limit. (This estimate is roughly consistent with the limit

***Previous results on the $K\bar{K}$ and 4π channels can be found in references [9] and [10]. In particular, reference [9], which observed the strong rise at threshold of the $K\bar{K}$ cross section, pointed out that effects should be visible in the $\pi\pi$ system at this mass.

obtained by multiplying the p-wave limit from the ρ-meson peak by 4/27.) Then the maximum K^+K^- cross section from our data is $12 \pm 2\%$ times the elastic unitary limit. Accounting for isotopic spin we find that at 1020 MeV the elasticity η of ππ s-wave elastic scattering is given by $\eta^2 = 0.36 \pm 0.1$, where we have used our result that the other s-wave inelastic channels have negligible cross section at this energy.

A subsequent paper will discuss more detailed conclusions which can be drawn from our data about the s-wave ππ scattering amplitude, and the implications of our data for the S^* resonance. We have shown here that a strong, narrow, s-wave anomaly exists in the $\pi^+\pi^-$ system near 980 MeV, and that the effect appears to be associated with the $K\bar{K}$ threshold.

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Figure Captions

Fig. 1. Number of events and spherical-harmonic moments as a function of $\pi^+\pi^-$ mass in the reaction $\pi^+p \to \Delta^{++}\pi^+\pi^-$ at 7.1 GeV/c. The Δ^{++} selection criterion is $M_{p\pi^+} < 1.4$ GeV. A selection of $t' < 0.1$ GeV^2 has been made. The argument of the $\langle Y_\ell \rangle$ is $\pi^+_{in} \cdot \pi^+_{out}$ in the $\pi^+\pi^-$ rest frame.

Fig. 2. (a) $\langle Y_1 \rangle$ for the $\pi^+\pi^-$ system (same as fig. 1a)

(b) Mass distribution from the reaction $\pi^+p \to \Delta^{++}K^+K^-$.

(c) Mass distribution from the reaction $\pi^+p \to \Delta^{++}\pi^+\pi^-\pi^+\pi^-$.

(d) Mass distribution from the reaction $\pi^+p \to \Delta^{++}\pi^+\pi^-$ (neutrals $\geq 2\pi^0$). Selections on $M_{p\pi^+}$ and t' are the same as those used in fig. 1.

(e)-(h) Spherical-harmonic moments as a function of K^+K^- mass in the reaction $\pi^+p \to \Delta^{++}K^+K^-$.

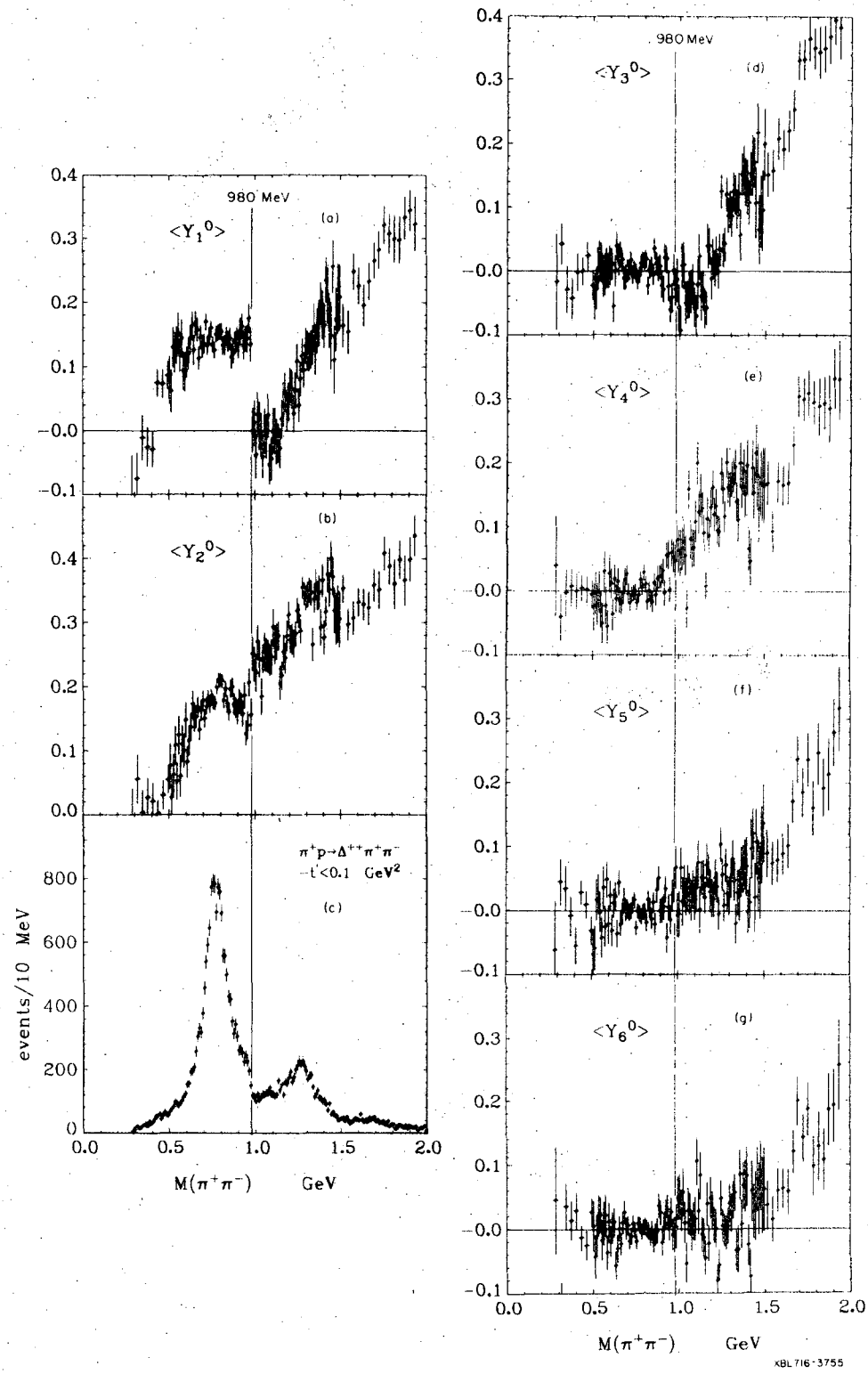
980 MeV
<Y1⁰>
(a)
<Y2⁰>
(b)
π⁺p→Δ⁺⁺π⁺π⁻
-t'<0.1 GeV²
(c)
events/10 MeV
M(π⁺π⁻) GeV
<Y3⁰>
(d)
<Y4⁰>
(e)
<Y5⁰>
(f)
<Y6⁰>
(g)
XBL 716-3755

Fig. 1

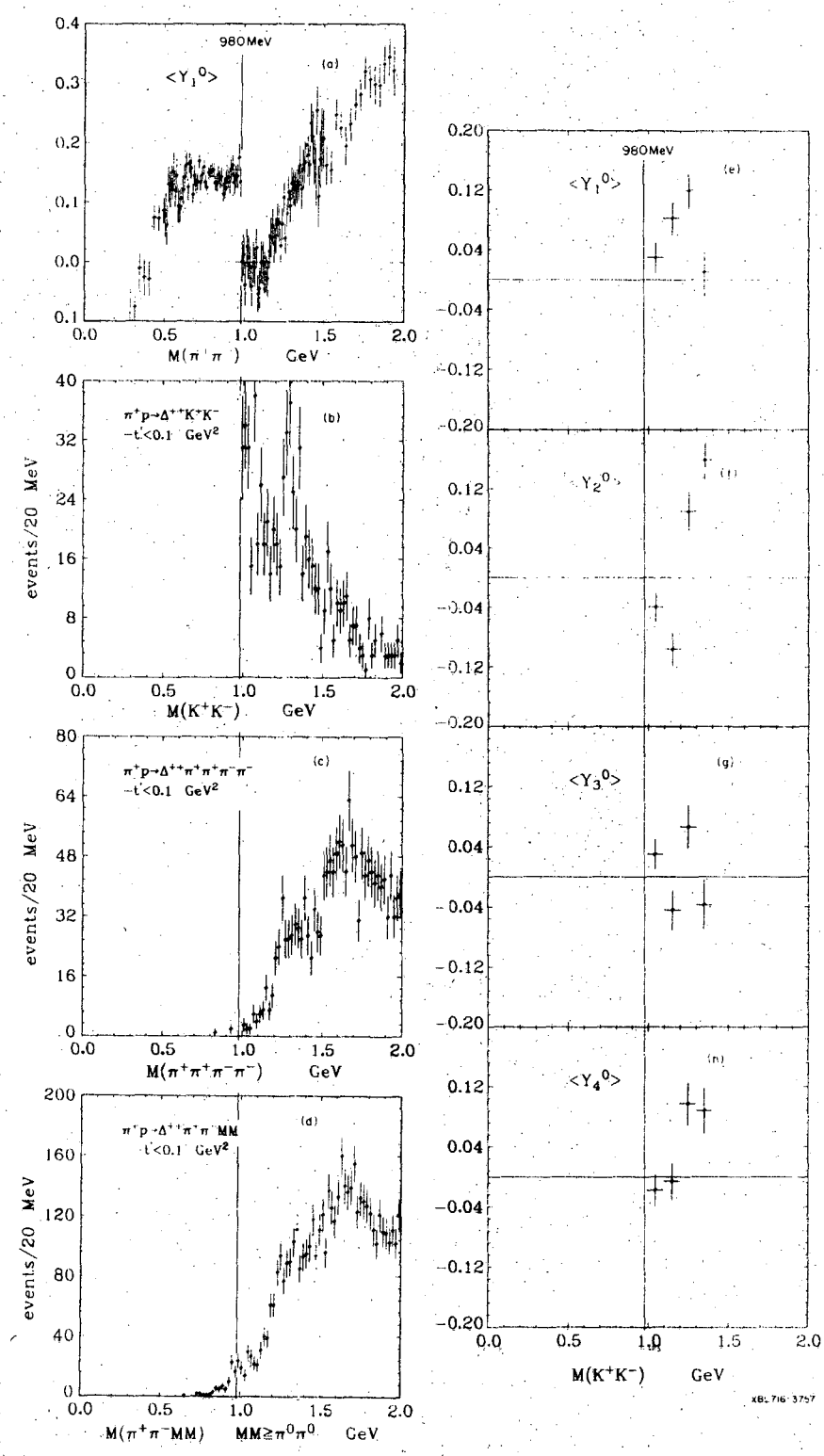
980MeV
<Y1⁰>
(a)
M(π⁺π⁻) GeV
π⁺p→Δ⁺⁺K⁺K⁻
−t'<0.1 GeV²
(b)
events/20 MeV
M(K⁺K⁻) GeV
π⁺p→Δ⁺⁺π⁺π⁺π⁻π⁻
−t'<0.1 GeV²
(c)
M(π⁺π⁺π⁻π⁻) GeV
π⁺p→Δ⁺⁺π⁺π⁻MM
−t'<0.1 GeV²
(d)
M(π⁺π⁻MM) MM≥π⁰π⁰ GeV
(e)
Y2⁰>
(f)
<Y3⁰>
(g)
<Y4⁰>
(h)
M(K⁺K⁻) GeV
XBL 716-3757

Fig. 2

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