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S-Wave Structure in the Kπ System*

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We have analysed the Kπ spectrum (4827 events) of the reaction $K^+n \rightarrow K^+\pi^-p$ at 9 GeV/c and find independent of any particular assumption of the production mechanism the existence of a broad S-wave enhancement. Since its phase with respect to the $K^*(890)$ P-wave is correctly given by a relativistic Breit-Wigner amplitude, we interpret this enhancement as a resonance of mass $1.305 \pm .030$ GeV/c^2 and width $0.330 \pm .060$ GeV.

The determination of S-wave resonances in the Kπ spectrum and the existence of 0^+ nonets is of considerable interest.[1] Whereas there are several prospective isospin 0 and 1 members,[2] the existence of the isospin ½ components have not yet been conclusively shown. The Kπ phase shift analyses[3-6] give two ambiguous solutions for the S-wave phase shift, one exhibiting a sharp resonance at the $K^*(890)$ and the other rising monotonically to between 50 and 70 degrees at 1.1 GeV/c^2. Evidence that the Kπ S-wave system is

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resonant in the mass region between 1.1 and 1.4 GeV/c^2 has been presented by three groups but the resonance parameters are not well determined. Chien et al.[7] found a mass "near 1.1 GeV/c^2" and a width consistent with 0.4 GeV. Yuta et al.[4] found a mass "about 1.2 GeV/c^2" for one of their solutions and Firestone et al.[8] found a mass "$\approx$ 1.37 GeV/c^2" and a width "less than 0.15 GeV". In addition, Antich et al.[9] report that the low mass side of the K_N(1420) is dominated by P-wave. Our analysis was carried out with a sample of 4827 events of the reaction $K^+n \rightarrow K^+\pi^-p$ (10 events/μb per nucleon) obtained from an exposure of the Brookhaven 80 inch deuterium-filled bubble chamber to a 9 GeV/c rf separated beam and finds unambiguous evidence for a broad S-wave enhancement at 1.3 GeV/c^2.

We present the $K\pi$ mass spectrum for 1638 events with $-t < 0.1$ GeV^2/c^2 (Fig. 1a) and for 2111 events with $0.1 < -t < 0.4$ GeV^2/c^2 (Fig. 1b) where t is the four-momentum transfer squared between the incident K^+ and the outgoing $K^+\pi^-$. The upper histogram for each momentum transfer region shows the polar events, $|\cos\theta_J| > 0.7$, and the lower histogram shows the equatorial events, $|\cos\theta_J| < 0.7$, where θ_J is the Jackson angle. The prominent structures are the K^*(890) and the K_N(1420). In the low momentum transfer region there is an excess of events between these two resonances in the equatorial region. This is a clear indication of S-wave structure.

In order to isolate the S-wave contribution we parameterize the $K\pi$ system up to 1.6 GeV/c^2 by its spin density matrix elements and fit to the relative fractions of S, P-and D-waves. While these density matrix elements can be determined in a completely model independent way the errors are substantial. Since all the density matrix elements $\rho_{mm'}$ with m or m' equal to 2 are found to be consistent with zero, we constrain them to be zero. In the region of interest ($m(K\pi) > 1.1$ GeV/c^2) all of the natural parity exchange contributions to $\rho_{mm'}$ with m or m' equal to 1 are also consistent with zero.

We have therefore assumed that only unnatural parity exchange contributes. We employ a maximum likelihood fit which constrains the density matrix to be positive definite.[10] The results of our fit are shown by the relative amounts of the partial waves in Fig. 2a and 2b for the two intervals in t used previously. For the D- and P-waves we find the $K_N(1420)$ and the $K^*(890)$ at the expected positions. In the high t interval a P-wave amplitude persists through most of the mass region and so reproduces the result of Antich et al.[9] The S-wave amplitude is rather ill-defined for $0.1 < -t < 0.4$ GeV/c^2. For $-t < 0.1$ it is, however, clearly resolved into a narrow spike under the $K^*(890)$ and a broad enhancement centered near 1.3 GeV/c^2. Assuming that the broad enhancement is a resonance we find a mass of 1.305 ± .030 GeV/c^2 and a width of 0.330 ± .060 GeV.

In the $K^*(890)$ region the Treiman-Yang angle (Fig. 3e) is quite anisotropic even for $-t < 0.1$ GeV^2/c^2. This plus the observation that ρ_{1-1}, which is a measure of the difference between natural and unnatural parity, is zero[11] shows that a model ignoring natural parity exchange cannot be correct in this region. Without further assumptions regarding the production mechanism we cannot distinguish true S-wave from depolarized P-wave.[12] Since the S-wave enhancement at about 0.89 GeV/c^2 closely follows the P-wave $K^*(890)$ structure, we draw no conclusion as to its interpretation.[13]

We turn now to the enhancement at 1.3 GeV/c^2. The S-wave is sizeable in the 1.1 - 1.3 GeV/c^2 mass region (where there is essentially no P- or D-wave present) and thus cannot be depolarized P- or D-wave. Note also that the Jackson angle distribution is rather flat. One can justify the assumption of unnatural parity dominance in the high mass region as follows. For the region between 1.1 and 1.3 GeV/c^2 the S-wave dominates and it can only be produced by unnatural parity exchange. In the region of 1.3 to 1.6 GeV/c^2 we observe that the moments of the decay distribution can be expressed:

$$\langle Y_0^{2}\rangle = \frac{1}{7}\sqrt{\frac{5}{\pi}}\,(3\,\rho_{00}^{D} + \rho_{11}^{D} - \rho_{22}^{D}) + \frac{1}{2\sqrt{\pi}}\,\rho_{00}^{SD} + \frac{1}{\sqrt{5\pi}}\,(\rho_{00}^{P} - \rho_{11}^{P}) \qquad (1)$$

and

$$\langle Y_0^{4}\rangle = \frac{1}{7\sqrt{\pi}}\,(3\rho_{00}^{D} - 4\rho_{11}^{D} + \rho_{22}^{D}. \qquad (2)$$

Assuming that $\rho_{22}^{D} = 0$ one obtains

$$\langle Y_0^{2}\rangle - 5\langle Y_0^{4}\rangle = \frac{5}{7}\sqrt{\frac{5}{\pi}}\,\rho_{11}^{D} + \frac{1}{2\sqrt{\pi}}\,\rho_{00}^{SD} + \frac{1}{\sqrt{5\pi}}\,(\rho_{00}^{P} - \rho_{11}^{P}). \qquad (3)$$

Experimentally for $-t < 0.1$ GeV^2/c^2 and $1.3 < M(K\pi) < 1.6$ GeV/c^2 we find that[14]

$$\langle Y_0^{2}\rangle - 5\langle Y_0^{4}\rangle = -0.05 \pm 0.04. \qquad (4)$$

Since the three terms on the right hand side of equation (3) are all positive,[15] they must be very small. Therefore, the only remaining contributions to the isotropic term are ρ_{00}^{D} and ρ_{00}^{S} which can only be produced by unnatural parity exchange (ρ_{00}^{SP} is small due to the smallness of the P-wave at low t). Thus our assumption of unnatural parity dominance is valid in the region of interest, and hence we have definite evidence for a broad S-wave enhancement. Moreover, if we drop the constraint of unnatural parity exchange dominance in our fit we find similar results for the region of interest but with larger errors.

We now consider whether the enhancement at 1.3 GeV/c^2 is resonant by examining the S-P-wave interference. In Fig.3a we present the forward - backward ratio of the outgoing K^+ in the Gottfried-Jackson frame for $-t <$ 0.1 GeV^2/c^2. We observe a strong forward asymmetry below 0.9 GeV/c^2, a well defined cross-over to negative values at 0.96 GeV/c^2 and a return to positive values between 1.1 and 1.2 GeV/c^2.

In order to calculate the S-P-wave interference, we assume pure π exchange and neglect all D-wave. It has been shown[3,5] that a relativistic Breit-Wigner representation of the P-wave amplitude reproduces the $K^*(890)$ phase shifts very well. We therefore adopt for our S- and P-waves such a

Breit-Wigner parameterization with a conventional choice of mass dependent widths.[16] The P-wave is elastic. It is reasonable to assume that the S-wave below 1.4 GeV/c^2 is completely elastic as well, since a $J^P = 0^+$ object cannot decay into 3 pseudoscalar mesons and four mesons are only produced in our 6-prong data with effective masses above 1.48 GeV. We neglected the small[17] and slowly varying isospin 3/2 contribution.

The actual comparison between the calculated forward-backward ratio and the data points is presented in Fig. 3a. The solid curve represents the superposition of the P-wave and the S-wave at 1.3 GeV/c^2, calculated with the known mass and width[18] of the $K^*(890)$ and the mass and width obtained for the broad S-wave enhancement in Fig. 2a. We see that this curve roughly follows the trend of the data points. A superposition of the P-wave and the low mass narrow S-wave enhancement of Fig. 2 alone would not even come close to a description of the negative values of the forward-backward ratio. The dashed curve includes, in addition, a narrow S-wave resonance ($M = 0.86$ GeV/c^2, $\Gamma = 0.045$ GeV) but it would be beyond the sophistication of our model to claim more than compatibility with the existence of a narrow S-wave resonance. The model used to calculate the solid curve in Fig. 3a is certainly more simple than reality, since the assumption of pion-exchange dominance even for $-t < 0.1$ GeV^2/c^2 is not totally correct for masses below 1.1 GeV/c^2. Nevertheless, it has been shown that the forward-backward asymmetry is a better measure of S-P-wave interference than the Jackson angle distribution in such situations.[19]

In summary we have established the existence of an S-wave enhancement of mass 1.305 ± 0.03 GeV/c^2 and width 0.33 ± 0.06 GeV. From the observation that the phase relations between Breit-Wigner amplitudes correctly reproduce the observed S-P-wave interference terms, we conclude that this enhancement may be interpreted as a resonance. Its isospin assignment is ½, since no such structure has been observed in reported $K^-\pi^-$ spectra.[17]

We find no compelling evidence for a narrow S-wave resonance underneath the $K^*(890)$, since our fits in this region depend crucially on the assumption of no natural parity exchange for small momentum transfers and since the forward-backward asymmetry is roughly accounted for by the $K^*(890)$ and the broad S-wave resonance at 1.3 GeV/c^2 alone. On the other hand, we cannot exclude the existence of such a narrow S-wave resonance.

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is rising from 0°, it follows that $\rho_{oo}^{SD} \propto \sin\delta_S \sin\delta_D \cos(\delta_S-\delta_D)$ is positive. This statement holds module 180° in either phase shift. The Treiman-Yang angle is found to be flat over the mass range 1.1-1.6 GeV/c^2 and this implies that the third term $\rho_{oo}^{P} - \rho_{11}^{P}$ is either positive or insignificant.

16. Our choice of width is $\Gamma(m) = \Gamma_o \left(\frac{q}{q_o}\right)^{2\ell+1} \frac{m_o}{m}$ where ℓ and m are relative orbital angular momentum and mass of the $K\pi$ system and q the momentum of either particle in the $K\pi$ frame. The subscript o denotes the values of these variables at the resonance position. See J. D. Jackson, Nuovo Cimento 34, 1644 (1964) and J. Pisut and M. Roos, Nucl. Phys. B6, 325 (1968).

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FIGURE CAPTIONS

Fig. 1. $M(K\pi)$ effective mass spectrum (a) for $-t < 0.1$ $(GeV/c)^2$ (b) for $0.1 < -t < 0.4$ $(GeV/c)^2$. The upper histogram in each case is for polar events $|\cos \theta_J| > 0.7$ and the lower for equatorial events $|\cos \theta_J| < 0.7$ where θ_J is the Jackson angle and t is the four-momentum transfer squared.

Fig. 2. Fitted amounts of S-, P- and D-waves for (a) $-t < 0.1$ and (b) $0.1 < -t < 0.4$ GeV^2/c^2 where t is the four-momentum transfer squared.

Fig. 3. (a) Forward-backward ratio for the K^+ in the Gottfried-Jackson frame for $-t < 0.1$ GeV^2/c^2 (b-d) Jackson angle distributions for the $K\pi$ mass intervals 0.83-0.95, 1.1-1.3 and 1.3-1.6 GeV/c^2. (e-f) Treiman-Yang angle distributions for the same $K\pi$ mass intervals.

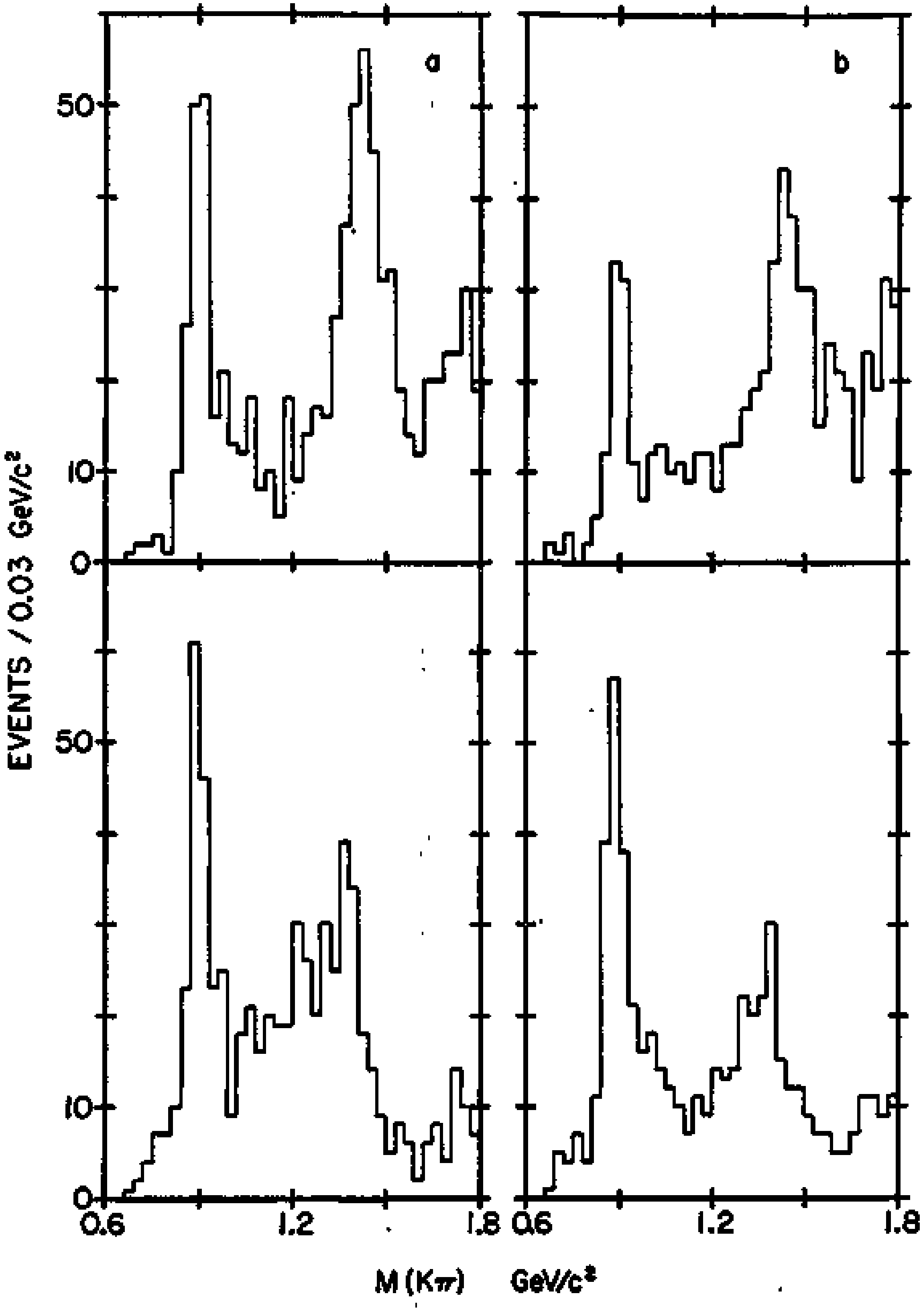


FIG. 1

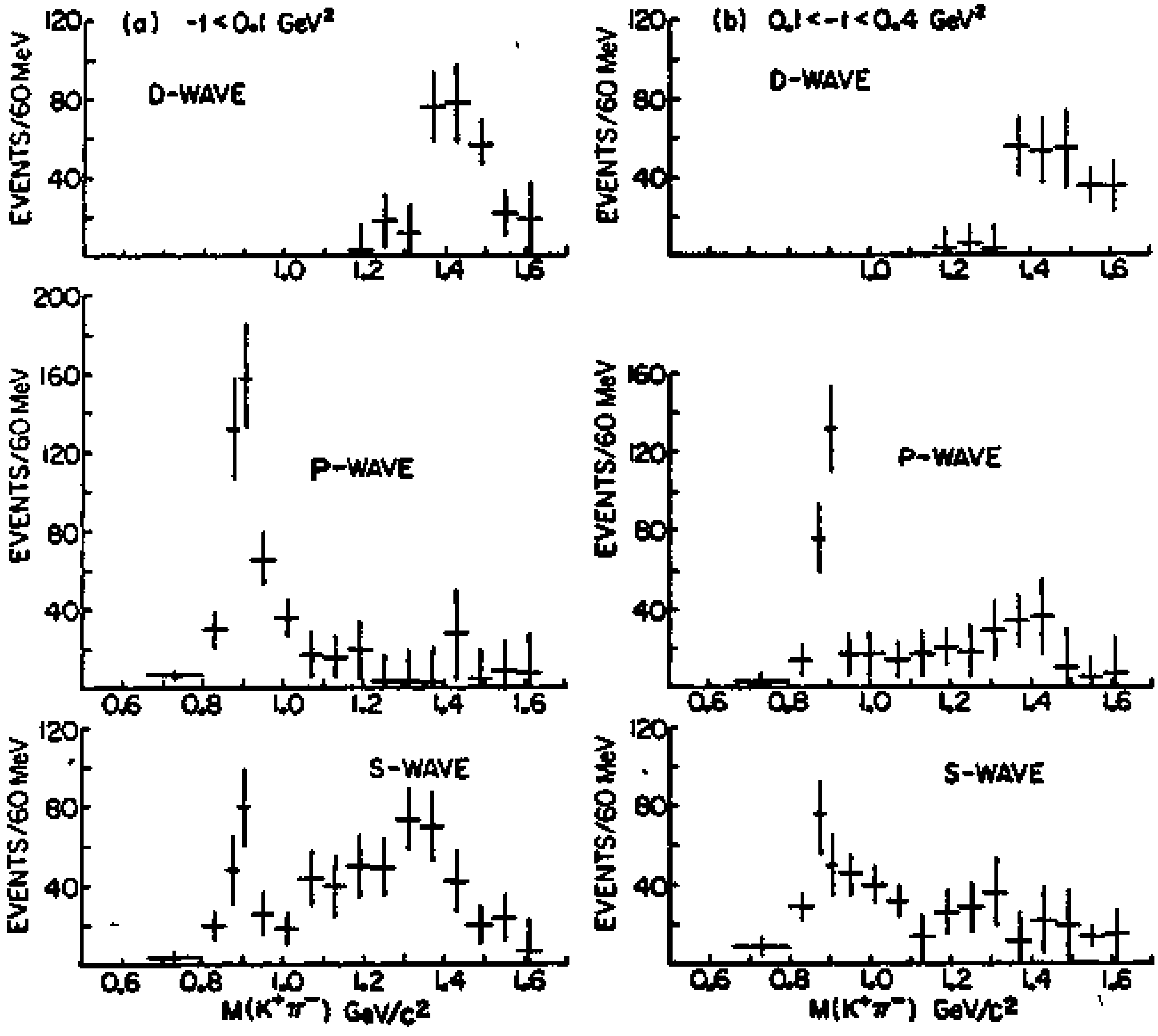
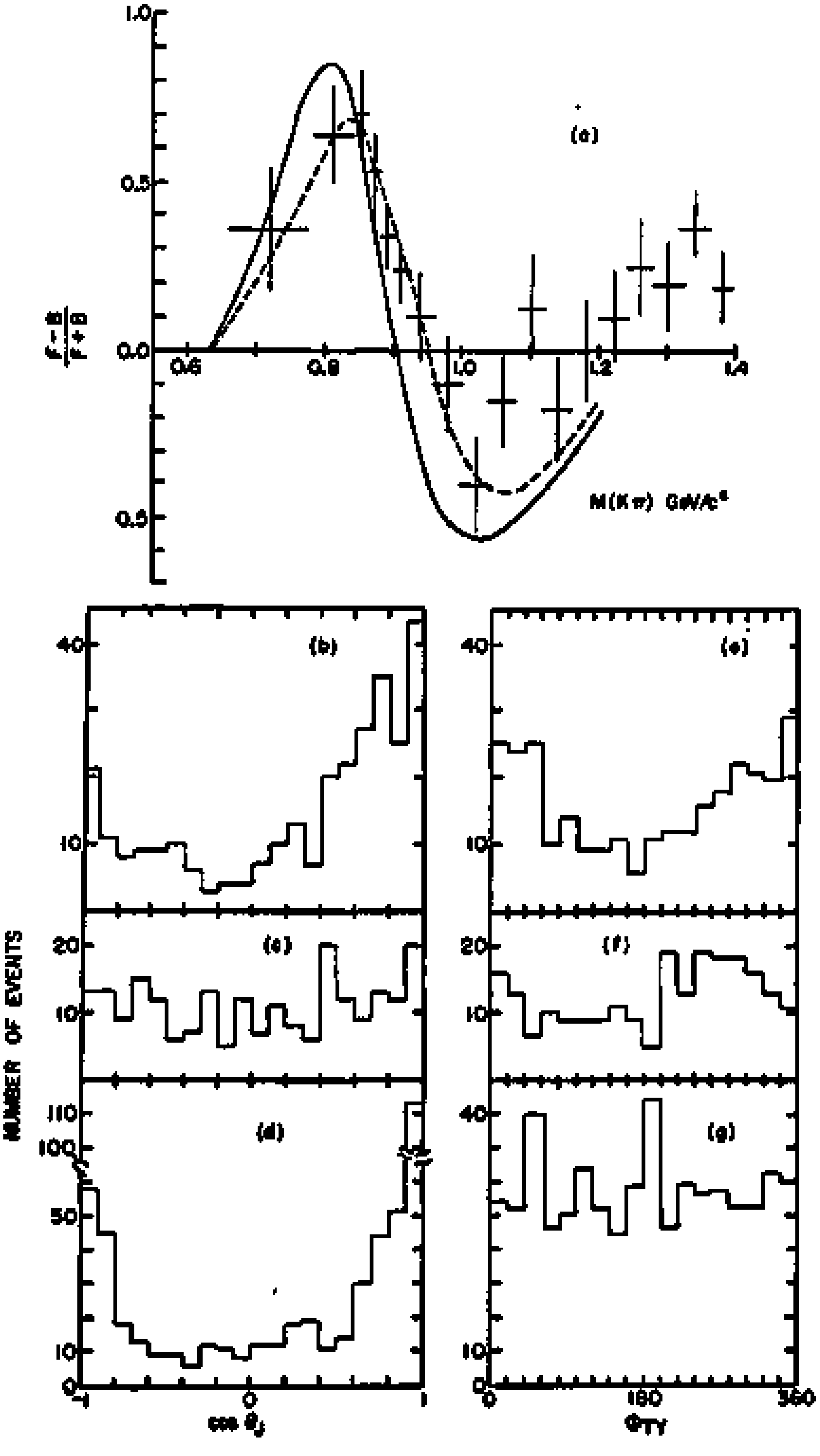

(a) -t < 0.1 GeV²
(b) 0.1 < -t < 0.4 GeV²
D-WAVE
P-WAVE
S-WAVE
EVENTS/60 MeV
120
80
40
200
160
0.6
0.8
1.0
1.2
1.4
1.6
M(K⁺π⁻) GeV/c²

FIG. 2



(a)
1.0
0.5
0.0
0.5
0.6
0.8
1.0
1.2
1.4
F−B / F+B
M(Kπ) GeV/c²
(b)
(c)
(d)
(e)
(f)
(g)
40
10
20
10
110
100
50
10
0
NUMBER OF EVENTS
-1
0
1
cos θ_J
0
180
360
Φ_TY

Fig. 3