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Berkeley, California

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June 15, 1965

OBSERVATION OF CORRELATIONS BETWEEN VECTOR-MESON AND BARYON-RESONANCE DECAYS*

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In our studies of double-resonance formation in the channel

$$M^+ + p \longrightarrow \begin{array}{l} V^0 \\ \hookrightarrow M^+ + \pi^- \end{array} + \begin{array}{l} \Delta^{++} \\ \hookrightarrow p + \pi^+ , \end{array} \qquad (1)$$

we have observed marked angular correlations between the decay angular distribution of the vector meson and that of the 3/2, 3/2 baryon resonance $\Delta^{++}(1238)$. Here M^+ represents the π^+ or K^+ meson and V^0 the ρ^0 or K^{*0} vector-meson resonance respectively. As is well known[1-5], for small values of four-momentum transfer squared, t, the decay angular distributions at the two vertices for these reactions follow the general features of a pseudoscalar meson exchange model (PSME). However, the actual differential production cross sections disagree strongly with simple exchange models. Two remedies for this difficulty with the PSME model have been suggested. One has been the introduction of form factors at the respective vertices[6]. The alternative has been to consider absorption effects due to initial- and final-state interactions[7,8]. The angular-correlation effects we have observed indicate that final-state interactions play an important role and therefore imply the need to consider absorption effects.

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

In this note we present experimental data showing the existence of decay correlations between the K^{*0} and the Δ^{++} resonances, very similar to those observed between the ρ^0 and Δ^{++} resonances[1,2]. These data come from three distinct experiments, all carried out in the Brookhaven National Laboratory's 20-inch bubble chamber exposed in the Brookhaven-Yale separated beam[9] at the A. G. S. The experiments involve the following reactions:

$$\pi^+ p \rightarrow \pi^+\pi^-\pi^+ p \qquad \text{at 3.65 BeV/c} \ [10] \qquad (2)$$

$$K^+ p \rightarrow K^+\pi^-\pi^+ p \qquad \text{at 1.96 BeV/c} \ [11] \qquad (3)$$

$$K^+ d \rightarrow K^+\pi^-\pi^+ p(n) \qquad \text{at 2.3 BeV/c.} \qquad (4)$$

In reaction (4) the K^+p channel was separated from the K^+n channel by demanding that the laboratory momentum of the neutron be less than that of the proton, and further, less than 300 MeV/c. With these criteria, the momentum distribution for the neutron agrees well with that given by the Hulthén wave function for the deuteron, and its laboratory angular distribution is approximately isotropic, showing that it is reasonable to treat it as a spectator to a reaction on the proton as target.

It has been shown earlier that appreciable fractions of reactions (2) and (3) proceed via double-resonance formation[10,11]. We note here that reaction (4) is also dominated by K^{*0} and Δ^{++} production and that a significant proportion of the reaction goes via their simultaneous production in a quasi-two-body process. This may be seen from fig. 1, which shows the phase-space triangle plot of $M_{p\pi^+}$ versus $M_{K^+\pi^-}$ for the data at 2.3 BeV/c.

The number of events involved in the three experiments are 1784, 410, and 904, respectively. Of these, the numbers assigned to $V^0\Delta^{++}$ "double resonance" formation are 555, 262, and 426, and finally, the numbers of events which fulfill our small-four-momentum-transfer cutoff criterion,

$t < 0.5$ BeV^2, are 429, 124, and 248 respectively.* These last three numbers correspond to the sample with which we are concerned here.

We have compared the data in reactions (3) and (4) on $K^{*0}\Delta^{++}$ production and find them sufficiently similar to permit their combination for greater statistical accuracy. In what follows we use the combined data for these reactions.

To study the angular correlation effect we show scatter plots of $\cos\alpha_\Delta$ versus $\cos\alpha_V$ where these represent the angles between the "incident" proton and scattered proton in the Δ^{++} center-of-mass system and the incident and

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*The criteria used to define the double-resonance regions are: reaction (2): 1120 MeV $\leq M_{p\pi^+} \leq$ 1320 MeV, 650 MeV $\leq M_{\pi^+\pi^-} \leq$ 850 MeV; reactions (3) and (4): 1130 MeV $\leq M_{p\pi^+} \leq$ 1300 MeV, 840 MeV $\leq M_{K^+\pi^-} \leq$ 940 MeV. The different $M_{p\pi^+}$ regions chosen in K^+ and π^+ interactions reflect a slight systematic difference in the observed Δ mass. No background corrections were made because triangle plots showed that at $t \leq 0.5$ BeV^2, background to double-resonance production is small. In reaction (2) each of the two a priori indistinguishable π^+'s was in turn combined with the proton to see if $M_{p\pi_a^+}$ lay in the Δ region. If so the other π^+ was combined with the π^- to see if $M_{\pi_b^+\pi^-}$ lay in the ρ region. Of 555 events, 489 had $M_{p\pi_a^+}$ in the Δ region and $M_{\pi_b^+\pi^-}$ in the ρ region with $M_{p\pi_b^+}$ and $M_{\pi_a^+\pi^-}$ outside these respective regions, and the former combinations have been used. An additional 56 had both $M_{p\pi_a^+}$ and $M_{p\pi_b^+}$ in the Δ region but only one $\pi^+\pi^-$ combination in the ρ region. This together with the appropriate $M_{p\pi^+}$ have been used. For 10 events both $M_{p\pi_a^+}$ and $M_{p\pi_b^+}$ lay in the Δ region, and both $\pi_a^+\pi^-$ and $\pi_b^+\pi^-$ in the ρ region. Here both combinations have been used with half weight. Incidentally, these ten events all have $\cos\alpha_\rho < -0.4$.

outgoing M^+ in the V^0 center-of-mass system respectively (See figs. 2a and 3a). To obtain a quantitative measure of the observed correlations, we have plotted the decay angular distribution of the V^0 meson for three intervals in $\cos\alpha_\Delta$. These are the two polar intervals $\cos\alpha_\Delta$ = -1.0 to -0.4 and +0.4 to +1.0 and the equatorial interval -0.4 to +0.4. Conversely $\cos\alpha_\Delta$ has also been plotted for the same three intervals of $\cos\alpha_V$. These distributions are shown in figs. 2 b-g and 3 b-g. The curves shown in these figures represent the best fit to the expansion $I(\cos\alpha) = A + B\cos\alpha + C\cos^2\alpha$. The coefficients normalized to A = 1.0 are listed in tables I and II. The fits are good, and higher-order terms are not required.

For a pure PSME no angular information can be transmitted between vertices, and hence one expects no correlation to occur. Thus each of the three distributions in $\cos\alpha_V$ and $\cos\alpha_\Delta$ would have to be identical. As may be readily noted by examining figs. 2 and 3, two distinct differences in the three distributions for $\cos\alpha_\Delta$ are:

(a) The distributions in $\cos\alpha_\Delta$ corresponding to the two polar regions of $\cos\alpha_V$ show a marked difference. The distribution in $\cos\alpha_\Delta$ which goes with $\cos\alpha_V$ in the interval 0.4 to 1.0, i.e., corresponding to forward decay of the vector meson (or forward scattering of the incident meson) shows a distribution consistent with that expected for pure PSME, i.e., $I(\cos\alpha_\Delta) = 1 + 3\cos^2\alpha_\Delta$. Thus, aside from a small asymmetry effect presumably related to the well-known minor phase shifts in the π^+p scattering, the Δ^{++} resonance appears completely aligned in accordance with PSME model. On the other hand, for $\cos\alpha_V$ in the interval -1.0 to -0.4, i.e., backward decay of the vector meson relative to the direction of the incident meson, the distributions in $\cos\alpha_\Delta$ show $I(\cos\alpha_\Delta)$ much closer to isotropy. The effects on the $\cos\alpha_V$ distribution of choosing different ranges of $\cos\alpha_\Delta$ is less marked.

(b) The distribution in $\cos\alpha_\Delta$ corresponding to the equatorial region in $\cos\alpha_V$ differs from the theoretical value for pure PSME. However, in the equatorial region the contribution of the vector-meson decay is expected to be minimal. Therefore non - p-wave terms in the meson-meson scattering amplitude and incoherent background are relatively more important. The departures seen in this region may thus not be too surprising.

We have also looked for correlations between ϕ_V and ϕ_Δ the Treiman-Yang angles at the two decay vertices as well as between ϕ_V and $\cos\alpha_\Delta$, and ϕ_Δ and $\cos\alpha_V$. No significant correlation effects were observed for these quantities.

In addition to the above effects we note some dependence of the four-momentum transfer on $\cos\alpha_V$. In both ρ^0 and K^{*0} production, forward decay of the meson resonance is associated with a somewhat sharper four-momentum-transfer distribution than is backward decay.

When we first observed the correlation effect in $\rho^0\,\Delta^{++}$ production[1], we could not rule out the possibility that it was related to Bose symmetrization for the two π^+ mesons occurring in the final state. The present observation of the same effect in $K^{*0}\,\Delta^{++}$ production makes it unlikely that Bose symmetrization is the dominant factor.

Thus the angular correlation effect is probably related to final-state interactions.* It is important to note that the introduction of form factors to explain production angular distributions does not help in the interpretation of correlation effects. On the other hand, final-state interactions form an integral part of the absorption model, and a sufficiently detailed model might hopefully explain both effects.

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*An alternative approach has been consider by A. S. Goldhaber[12]. This involves exchange of two pseudoscalar mesons. In such a case, correlation effects are no longer excluded, even without invoking final-state interactions.

In an attempt to identify the dynamic origin of the final-state interactions we have looked at mass distributions of all relevant two- and three-particle systems as functions of $\cos\alpha_V$. Although the mass distributions in all these systems are strongly correlated to $\cos\alpha_V$, it is not possible, from our experimental data, to single out one specific process that identifies the final-state interaction involved. Thus complete understanding of the correlation effect must await further study, both from the theoretical and experimental points of view.

Although we have stressed here certain significant similarities in K^{*0} and ρ^0 production, one major difference is evident from the coefficients given in tables I and II, namely, the large forward-backward asymmetry in ρ^0 decay[13] is to be contrasted with a small asymmetry in K^{*0} decay. We have examined the latter asymmetry as the $K^+\pi^-$ mass traverses the resonance region. Figure 4 shows the dependence of the ratio $(F - B)/(F + B)$ on the $K^+\pi^-$ mass, where F and B are the numbers of events in which the K^+ is emitted forward and backward in the $K^+\pi^-$ center of mass. The slight asymmetry can be interpreted as due to the presence of a small, slowly varying, s-wave phase shift in the $K^+\pi^-$ system. This is to be contrasted with ρ^0 decay, where the asymmetry remains constant through the entire resonance region and consequently can not be interpreted in the same way.

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References

1) G. Goldhaber, Lecture at the Conference on Particle and High Energy Physics at Boulder, Colorado, 1964, unpublished.

2) Aachen-Berlin-Birmingham-Bonn-Hamburg-London (I. C.)-München Collaboration, Phys. Rev. 138 (1965) B 897.

3) G. Goldhaber, W. Chinowsky, S. Goldhaber, W. Lee and T. O'Halloran, Phys. Letters 6 (1963) 62.

4) R. Kraemer, L. Madansky, I. Miller, A. Pevsner, C. Richardson, R. Singh, and R. Zdanis, Proceedings of the Athens Topical Conference on Recently Discovered Resonant Particles, Editors, B. A. Munir and L. J. Gallaher (University of Ohio, Athens, Ohio, 1963), p. 130.

5) M. Ferro-Luzzi, R. George, Y. Goldschmidt-Clermont, V. P. Henri, B. Jongejans, D. W. G. Leith, G. R. Lynch, F. Muller and J. M. Perreau, Nuovo Cimento, to be published.

6) See, for example, E. Ferrari and F. Selleri, Suppl. del Nuovo Cimento 24 (1962) 453.

7) K. Gottfried and J. D. Jackson, Nuovo Cimento 34 (1964) 735; J. D. Jackson, Rev. Mod. Phys., to be published.

8) L. Durand and Y. T. Chiu, Phys. Rev. Letters 12 (1964) 399; 13 (1964) 45E.

9) C. Baltay, J. Sandweiss, J. Sanford, H. Brown, M. Webster, and S. Yamamoto, Nucl. Instr. Methods 20 (1963) 37.

10) G. Goldhaber, J. L. Brown, S. Goldhaber, J. A. Kadyk, B. C. Shen, and G. H. Trilling, Phys. Rev. Letters 12 (1964) 336.

11) W. Chinowsky, G. Goldhaber, S. Goldhaber, W. Lee, and T. O'Halloran, Phys. Rev. Letters 9 (1962) 330.

12) A. S. Goldhaber, Phys. Rev. 135 (1964) B508.

13) G. Goldhaber, in Second Coral Gables Conference on Symmetry Principles at High Energy, Eds. B. Kursunoglu, A. Perlmutter, and I. Sakmar (W. H. Freeman and Company, San Francisco, 1965), p. 34.

Table I

Expansion coefficients of $I(\cos\alpha_\Delta)$ and $I(\cos\alpha_\rho)$ as functions of the polar and equatorial intervals in $\cos\alpha_\rho$ and $\cos\alpha_\Delta$, respectively. Also shown is the $(F-B)/(F+B)$ ratio. The variation of the expansion coefficient for $I(\cos\alpha_\Delta)$ with $\cos\alpha_\rho$ indicates the correlation effect discussed in the text. The 429 events analyzed here correspond to channel (2) for $t \leq 0.5$ BeV^2. They are illustrated in fig. 2.

Coefficients for Δ^{++} decay

Curve in fig. 2	$\cos\alpha_\rho$	A	B	C	$(F-B)/(F+B)$	Number of events
e.	-1.0 to -0.4	1.0	0.1 ± 0.3	1.2 ± 0.7	0.05 ± 0.09	118
f.	-0.4 to 0.4	1.0	0.3 ± 0.2	-0.3 ± 0.4	0.13 ± 0.10	76
g.	0.4 to 1.0	1.0	0.7 ± 0.3	3.7 ± 1.0	0.15 ± 0.06	235

Coefficients for ρ^0 decay

Curve in fig. 2	$\cos\alpha_\Delta$	A	B	C	$(F-B)/(F+B)$	Number of events
b.	-1.0 to -0.4	1.0	6.8 ± 3.3	19.2 ± 11.2	0.43 ± 0.08	133
c.	-0.4 to 0.4	1.0	0.4 ± 0.3	1.5 ± 0.7	0.10 ± 0.09	124
d.	0.4 to 1.0	1.0	4.5 ± 1.2	10.3 ± 3.9	0.39 ± 0.07	172

Table II

Expansion coefficients of $I(\cos\alpha_\Delta)$ and $I(\cos\alpha_{K^*})$ as functions of the polar and equatorial intervals in $\cos\alpha_{K^*}$ and $\cos\alpha_\Delta$ respectively. Also shown is the $(F - B)/(F + B)$ ratio. The variation of the expansion coefficient for $I(\cos\alpha_\Delta)$ with $\cos\alpha_{K^*}$ indicates the correlation effect discussed in the text. The 372 events analyzed here correspond to channels (3) and (4) for $t \leq 0.5$ BeV^2. They are illustrated in fig. 3.

Coefficients for Δ^{++} decay

Curve in fig. 3	$\cos\alpha_{K^*}$	A	B	C	(F-B)/(F+B)	Number of events
e.	-1.0 to -0.4	1.0	-0.03 ± 0.2	0.5 ± 0.4	0.01 ± 0.09	135
f.	-0.4 to 0.4	1.0	-0.06 ± 0.4	1.2 ± 1.0	0.01 ± 0.12	71
g.	0.4 to 1.0	1.0	0.75 ± 0.3	2.5 ± 0.9	0.22 ± 0.08	166

Coefficients for K^{*0} decay

Curve in fig. 3	$\cos\alpha_\Delta$*	A	B	C	(F-B)/(F+B)	Number of events
b.	-1.0 to -0.4	1.0	0.6 ± 0.5	4.7 ± 1.9	0.07 ± 0.10	114
c.	-0.4 to 0.4	1.0	0.3 ± 0.5	4.5 ± 1.9	0.07 ± 0.10	114
d.	0.4 to 1.0	1.0	1.3 ± 0.6	6.7 ± 2.5	0.19 ± 0.08	144

Figure Legends

Fig. 1. (a) Triangle plot of $M_{p\pi^+}$ vs $M_{K^+\pi^-}$ for reaction (4); (b) same as (a) but with $t \leq 0.5$ BeV^2.

Fig. 2. Study of the $\rho^0 \Delta^{++}$ system. (a) Scatter plot of $\cos\alpha_\Delta$ vs $\cos\alpha_\rho$, (b) - (d) angular distribution in $\cos\alpha_\rho$ for various intervals in $\cos\alpha_\Delta$ as indicated, and (e) - (g) angular distribution in $\cos\alpha_\Delta$ for various intervals in $\cos\alpha_\rho$ as indicated.

Fig. 3. Same as fig. 2 but for the $K^{*0}\Delta^{++}$ system.

Fig. 4. Distribution of the $(F - B)/(F + B)$ ratio for K^{*0} decay vs. the $K^+\pi^-$ mass distribution. Data are from reactions (3) and (4).

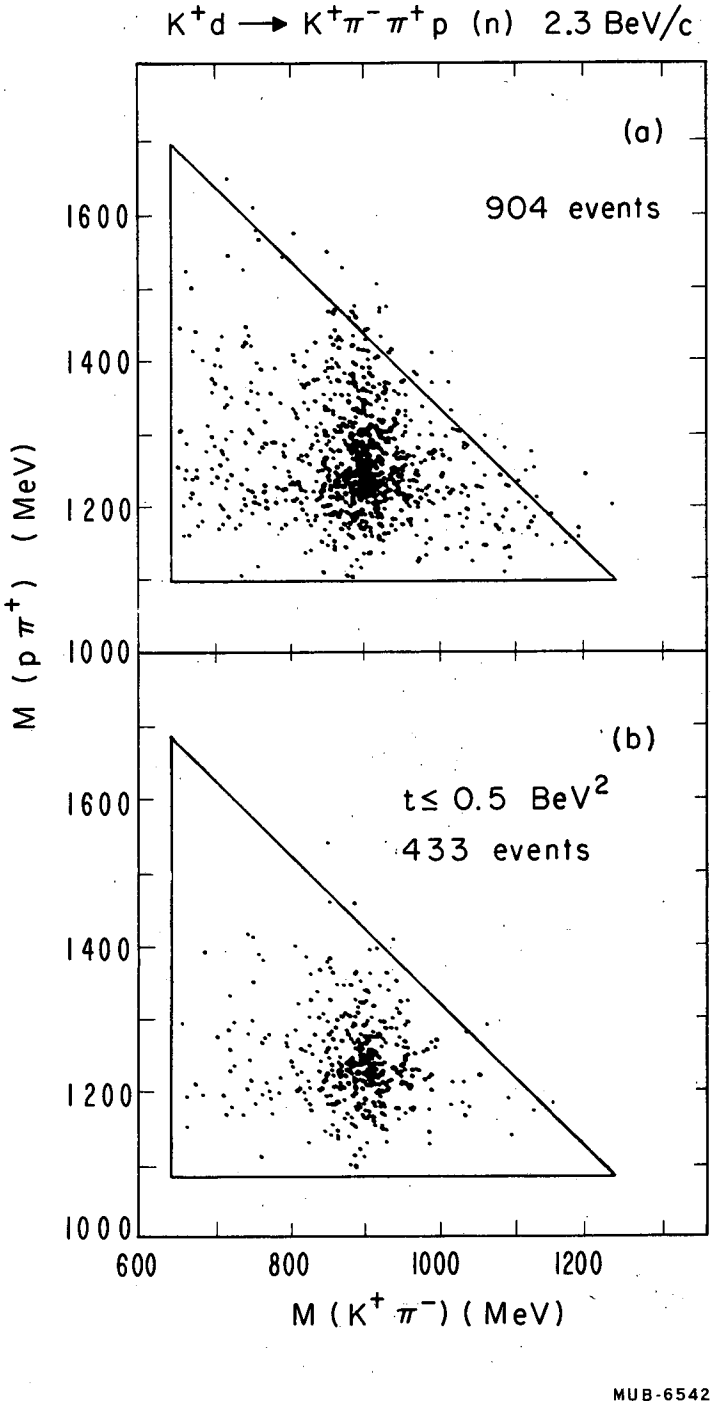
$K^+d \rightarrow K^+\pi^-\pi^+p$ (n) 2.3 BeV/c
(a)
904 events
(b)
$t \leq 0.5$ BeV^2
433 events
M ($p\pi^+$) (MeV)
M ($K^+\pi^-$) (MeV)
1600
1400
1200
1000
600
800
1000
1200
MUB-6542

Fig. 1

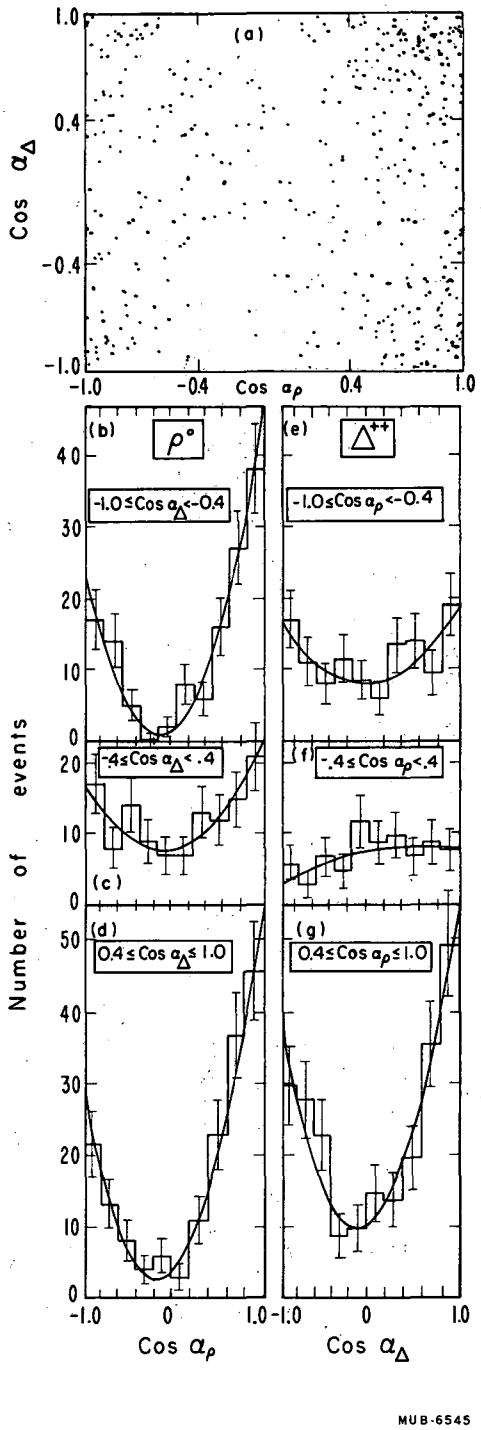
(a)
Cos α_Δ
Cos α_ρ
(b) ρ°
$-1.0 \le \text{Cos}\,\alpha_\Delta < -0.4$
$-.4 \le \text{Cos}\,\alpha_\Delta < .4$
(c)
(d)
$0.4 \le \text{Cos}\,\alpha_\Delta \le 1.0$
(e) Δ^{++}
$-1.0 \le \text{Cos}\,\alpha_\rho < -0.4$
(f)
$-.4 \le \text{Cos}\,\alpha_\rho < .4$
(g)
$0.4 \le \text{Cos}\,\alpha_\rho \le 1.0$
Number of events
Cos α_ρ
Cos α_Δ
MUB-6545

Fig. 2

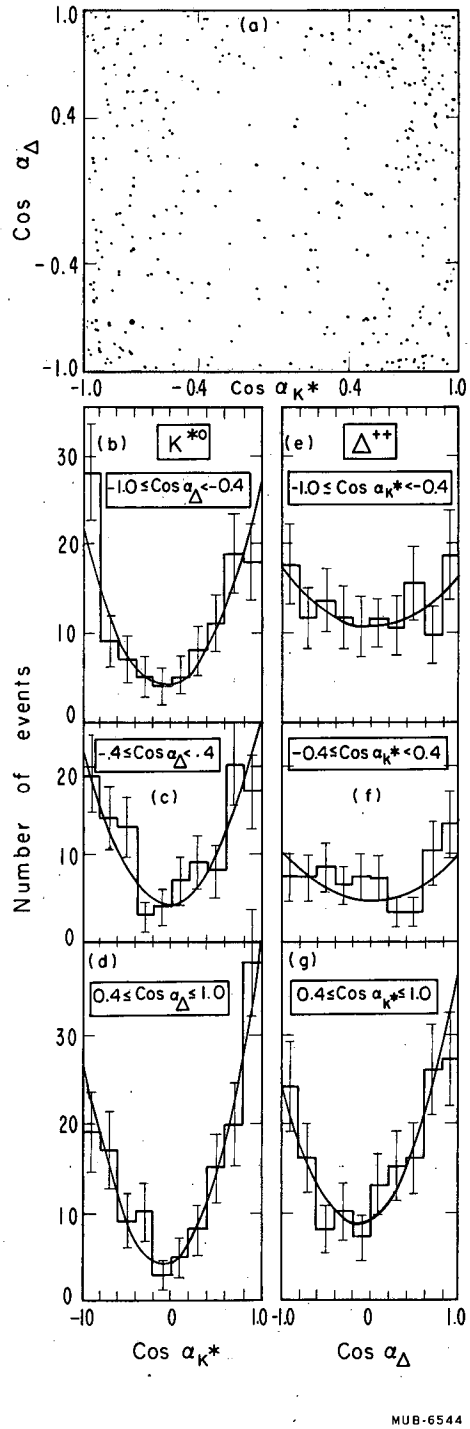
(a)
Cos α_Δ
Cos α_{K^*}
(b) K^{*0}
$-1.0 \le \cos\alpha_\Delta \le -0.4$
(c)
$-.4 \le \cos\alpha_\Delta \le .4$
(d)
$0.4 \le \cos\alpha_\Delta \le 1.0$
(e) Δ^{++}
$-1.0 \le \cos\alpha_{K^*} \le -0.4$
(f)
$-0.4 \le \cos\alpha_{K^*} \le 0.4$
(g)
$0.4 \le \cos\alpha_{K^*} \le 1.0$
Number of events
Cos α_{K^*}
Cos α_Δ
MUB-6544

Fig. 3

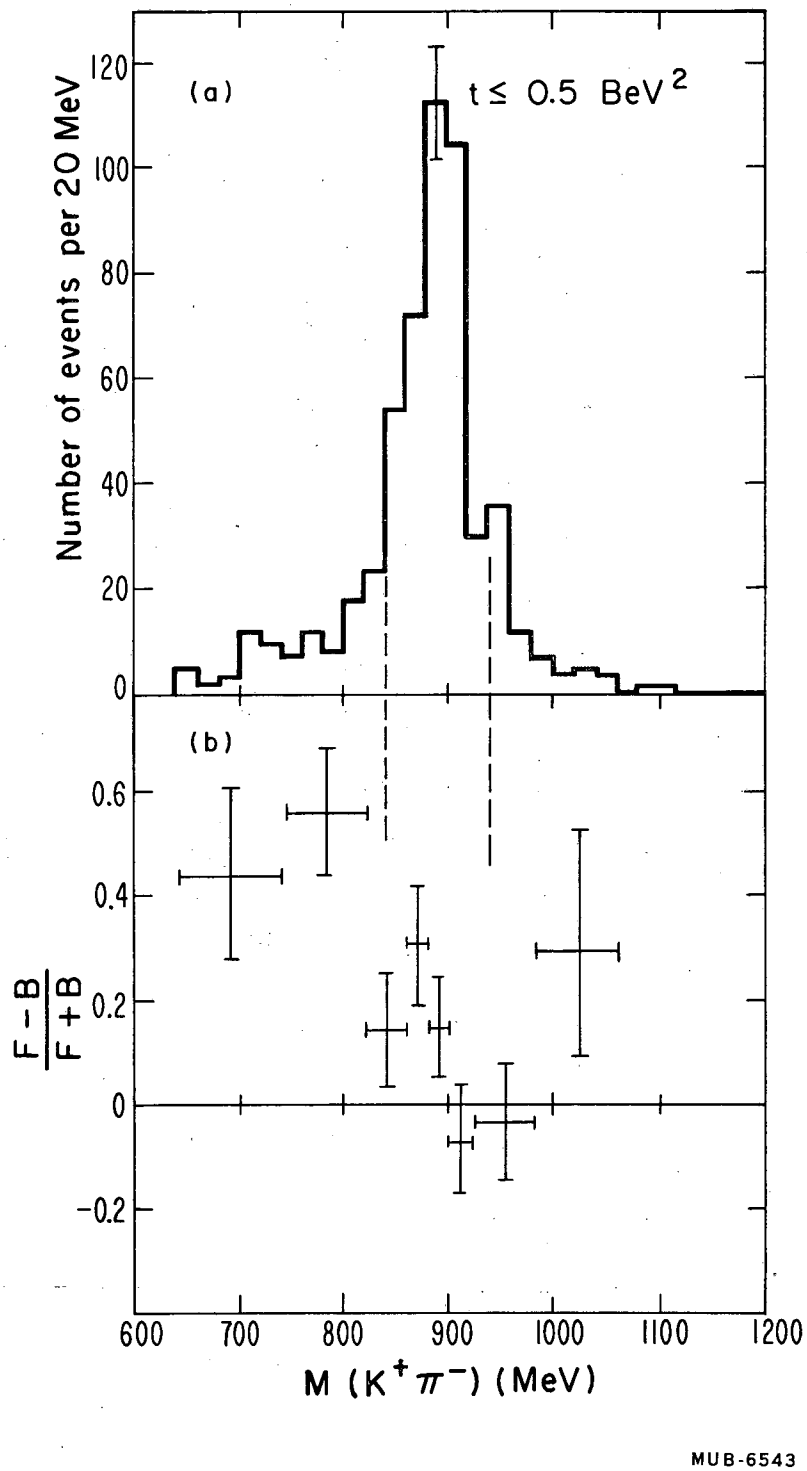
(a)
t ≤ 0.5 BeV²
Number of events per 20 MeV
120
100
80
60
40
20
0
(b)
0.6
0.4
0.2
0
-0.2
F-B / F+B
600
700
800
900
1000
1100
1200
M (K⁺π⁻) (MeV)
MUB-6543

Fig. 4

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