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Energy Spectrum of π^+ in $K^+ \to \pi^+\pi^0\pi^0$ Decay*

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There is some experimental evidence for a $\pi^+\pi^-$ resonance, σ, of mass about 400 MeV.[1,2] A model for K and $\eta \to 3\pi$ decay, in which these decays go via an intermediate $\sigma + \pi$ state, has been proposed by Brown and Singer[3] (see Fig. 1a). This model allows a calculation of the pion spectra in K, η decay as a function of the resonance parameters m_σ, Γ_σ. A recent study of 97 $\eta \to \pi^+\pi^-\pi^0$ decays showed that the π^0 spectrum in these events was consistent with the model for $m_\sigma = 381 \pm 5$ MeV and $\Gamma_\sigma = 48 \pm 8$ MeV,[4] and this observation has been considered additional evidence for the existence of the σ resonance.[2,5]

We have studied the kinetic-energy spectrum of the π^+ meson in τ' decay from 10 MeV to the maximum value of 53 MeV. The energy of the charged secondary was measured in 3400 examples of τ' decay at rest. The π^+ energy distribution in a bias-free sample of 1792 of these decays is shown in Fig. 2.

The best agreement between this spectrum and the predictions of the Brown and Singer model is achieved for $m_\sigma = 337 \pm 4$ MeV and $\Gamma_\sigma = 87 \pm 9$ MeV; the corresponding χ^2 value is 5.9 compared to the expected value of 6. The probability that our data could be fitted by $m_\sigma = 381$ and $\Gamma_\sigma = 48$ MeV is less than 0.1%. It is evident that the Brown and Singer model is not simultaneously compatible with the experimental observations on τ' and η decay, and that this model cannot be used to determine resonance parameters. The probability that our spectrum could be fitted to the model, using the resonance parameters given in references 1 and 2 is less than 0.5%.

Comparison with τ, K_2^0, and η Decay

In the $M \rightarrow 3\pi$ decay (M is K or η), the final state is described by two independent variables. One possible combination is the Dalitz-Fabri variables $x = \sqrt{3}\,(T_1 - T_2)/Q$ and $y = (3T_3 - Q)/Q$, where T is the pion kinetic energy, and particle 3 is either the unlike pion in τ, τ' decay or the neutral pion in $K_2^0, \eta \rightarrow \pi^+\pi^-\pi^0$ decay. Alternatively, one may use the Mandlestam variables s_3 and $(s_1 - s_2)$, with $s_i = (k_M - q_i)^2$, where k_M, q_i is the 4-momenta of the decaying particle and pions, respectively, and i = 1, 2, or 3.

For decays such as $K, \eta \rightarrow 3\pi$, where Q is smaller than the particle masses, the decay amplitude A can be approximated by the first few terms of a power series in s_i.[6,7] An expansion about the symmetry point $s_0 = (s_1 + s_2 + s_3)/3$ gives

$$A = C\left[1 + \alpha(s_3 - s_0) + \mathcal{O}(s_i^2) + \cdots\right].$$

When the expansion is made in the variables x and y, the terms up to first order are $C(1 + \beta y)$, and $(s_3 - s_0) = 2/3\, m_M Q_M y$ when the $\pi^\pm - \pi^0$ mass difference is neglected.

Weinberg has shown that if the three pions in τ and τ' decay are in a pure isospin state I = 1, then the coefficients of the linear terms in the expansion of A are in the ratio -2/1 for τ' and τ.[6] Deviations from the ratio -2 are expected because of the inexactness of isotopic spin invariance in the two decays. In fact, the experimental value of the ratio depends upon the choice of variables. Thus, $\alpha_{\tau'}/\alpha_\tau = \beta_{\tau'}/\beta_\tau \times Q_{\tau'}/Q_\tau$.

The π^+ spectrum in Fig. 2 is consistent with a linear matrix element with $a_{\tau'} = 0.24 \pm 0.02$ for s_i in units of $(m_\pi)^2$. The corresponding χ^2 is 6.7, compared to an expected value of 6. Studies of $\tau^{\pm}$ decay show that it is also well described by a linear matrix element.[8,9] We find

$$a_{\tau'}/a_{\tau} = -2.3 \pm 0.4 .$$

The π^0 spectrum in 83 $K_2^0 \rightarrow \pi^+\pi^-\pi^0$ decays is consistent with a linear matrix element.[10] One consequence of the $\Delta I = 1/2$ rule is that the π^0 spectrum in $K_2^0 \rightarrow \pi^+\pi^-\pi^0$ decay should be identical with the π^+ spectrum in τ' decay,[11] and this implies that $a_{\tau'}/a_{K_2^0} = 1$. We find

$$a_{\tau'}/a_{K_2^0} = 1.4 \pm 0.3.$$

These observations on τ, τ', and K_2^0 decay are thus consistent with the $\Delta I = 1/2$ rule, but do not exclude violation of the rule.

The pion pole model of $\eta \rightarrow 3\pi$ and $K \rightarrow 3\pi$ decay (Fig. 1b) postulates that these decays proceed via an intermediate one-pion state.[12] Barton and Rosen have shown that, for this decay mechanism, the coefficient a is the same in τ' and η decay.[13] This deduction depends upon the assumption that as m_M varies from the K to the η mass, the change in structure of the three-pion amplitude can be neglected. A comparison of the π^0 spectrum in η decay[4] with our τ' spectrum gives

$$a_{\tau'}/a_{\eta} = 0.78 \pm 0.12,$$

in agreement with reference 13. However, it has been shown that these spectra would also be identical in the event that both decays lead to a totally symmetric $I = 1$ state with subsequent π-π interaction.[14,15]

Experimental Details

The K^+ mesons were brought to rest in the Berkeley 30-inch heavy-liquid bubble chamber filled with freon C_3F_8. The τ' decay mode was identified by the decay $\pi^+ \to \mu^+ + \nu$ of the charged-pion secondary after it had come to rest; the range of the μ meson from π decay at rest is 1.44 mm in freon. The π^+ energy was determined by a range measurement in all events.

It was essential that the scanning efficiency for τ' decay be independent of the range of the π^+ meson. For this reason the final spectrum was restricted to the 1792 decays in which the angle between the π^+ meson and the film plane was $\leqslant 45$ deg. This insured that the projected range in the film plane of all events in the spectrum exceeded 5 mm. A rescan of 55% of the data confirmed that scanning efficiency was constant across the spectrum.

The spectrum shown in Fig. 2 has been corrected for the following effects:

a. Contamination by τ' decays in flight in the K^+ meson momentum interval 0 to 200 MeV/c. Above 200 MeV/c, K^+ decays in freon can be identified by ionization of the primary track.

b. Contamination by $K\mu_3$ decays in which the μ meson scattered a few millimeters before stopping, thus simulating a $\pi \to \mu + \nu$ decay.

c. Loss of events due to the π^+ interacting, decaying in flight, or going out through the chamber walls.

The corrections are listed in Table 1. They are very small and leave the experimental values almost unchanged. Full details concerning the estimation of these corrections will be provided in a later report.

In conclusion, our results are consistent with the $\Delta I = 1/2$ rule, the linear-matrix-element approximation, and the pion pole model for $K, \eta \rightarrow 3\pi$ decays. However, they raise doubts concerning the validity of the Brown and Singer model of τ, τ', and η decay.

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REFERENCES

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1. N. P. Samios, A. H. Bachman, R. M. Lea, T. E. Kalogeropoulos, and W. D. Shephard, Phys. Rev. Letters 9, 139 (1962).
2. R. Del Fabbro, M. DePretis, R. Jones, G. Marini, A. Odian, G. Stoppini, and L. Tau, "Two-Body Effective-Mass Spectra in the Products of the Reaction $\gamma + p \rightarrow p + \pi^+ + \pi^-$" (submitted to Phys. Rev. Letters).
3. L. M. Brown and P. Singer, Phys. Rev. 133, B812 (1964).
4. F. S. Crawford Jr., R. A. Grossman, L. J. Lloyd, Leroy R. Price, and E. C. Fowler, Phys. Rev. Letters 11, 564 (1963).
5. C. Woo, Phys. Rev. Letters 12, 308 (1964).
6. S. Weinberg, Phys. Rev. Letters 4, 87 (1960).
7. C. Zemach, Phys. Rev. 133, B1201 (1964).
8. S. McKenna, S. Natali, M. O'Connell, J. Tietger, and N. C. Varshneya, Nuovo Cimento 10, 763 (1958).
9. M. Ferro-Luzzi, D. H. Miller, J. J. Murray, A. H. Rosenfeld, and R. D. Tripp, Nuovo Cimento 22, 1087 (1961).
10. D. Luers, I. S. Mittra, W. J. Willis, and S. S. Yamamoto, Phys. Rev. 133, B1276 (1964).
11. R. F. Sawyer and K. C. Wali, Nuovo Cimento 17, 938 (1960).
12. M. A. Baqi Bég and P. C. DeCelles, Phys. Rev. Letters 8, 46 (1962).
13. G. Barton and S. P. Rosen, Phys. Rev. Letters 8, 414 (1962).
14. M. A. Baqi Bég, Phys. Rev. Letters 9, 67 (1962).
15. K. C. Wali, Phys. Rev. Letters 9, 120 (1962).

Table 1. Corrections to the τ' spectrum.

Energy interval (MeV)	Observed τ' Decays	Corrections			Corrected τ' Decays
		a	b	c	
10-15	277	-4.7	-0.3	0.0	272
15-20	270	-5.1	-1.4	1.9	265.4
20-25	287	-5.1	-1.4	4.0	284.5
25-30	262	-4.8	-1.4	6.3	262.1
30-35	241	-4.4	-1.4	8.0	243.2
35-40	200	-3.9	-1.5	9.0	203.6
40-45	129	-3.4	-1.5	7.6	131.7
45-50	96	-2.9	-1.7	7.7	99.1
50-53	30	-1.5	-1.2	2.6	29.9

FIGURE LEGENDS

Fig. 1. Feynman diagrams (a) for the decays $K^+ \rightarrow \pi^+\pi^0\pi^0$, $\eta \rightarrow \pi^+\pi^-\pi^0$, assuming dominance of a dipion intermediate state, and (b) for η and τ' decay, assuming a one-pion intermediate state.

Fig. 2. Histogram of π^+ kinetic energy T_3 between 10 and 53 MeV in $K^+ \rightarrow \pi^+\pi^0\pi^0$ decay. The smooth curves are the distributions expected for a constant decay amplitude, and a decay amplitude having a linear dependence on T_3. The curves are normalized to the 10 to 53 MeV interval.

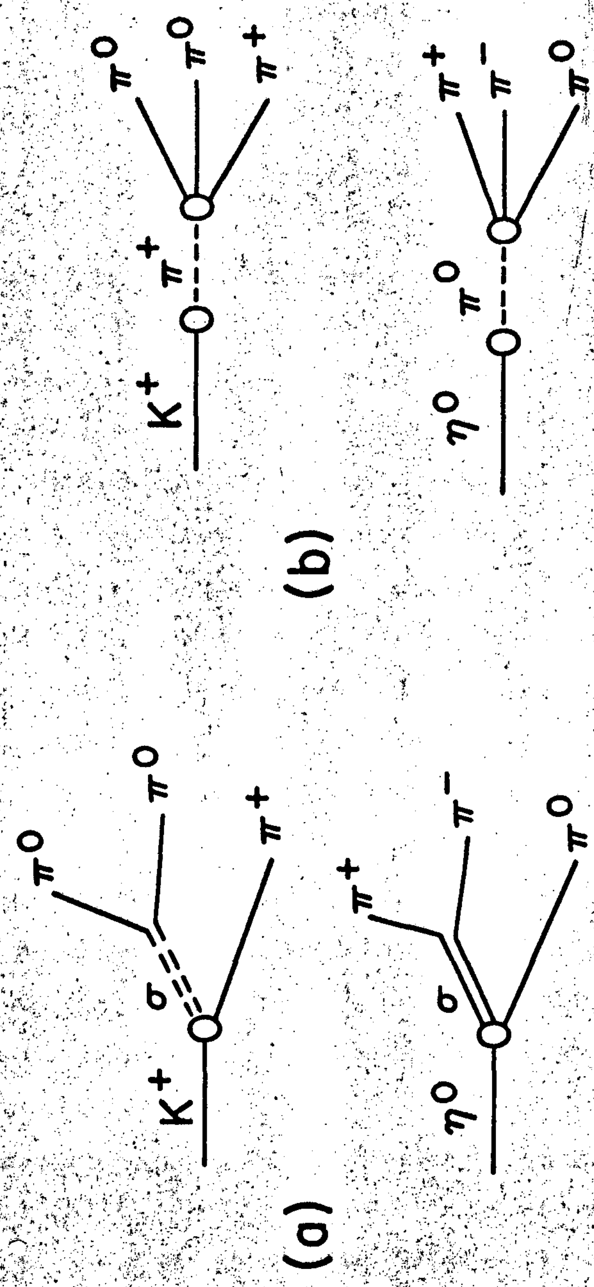

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Fig. 1.

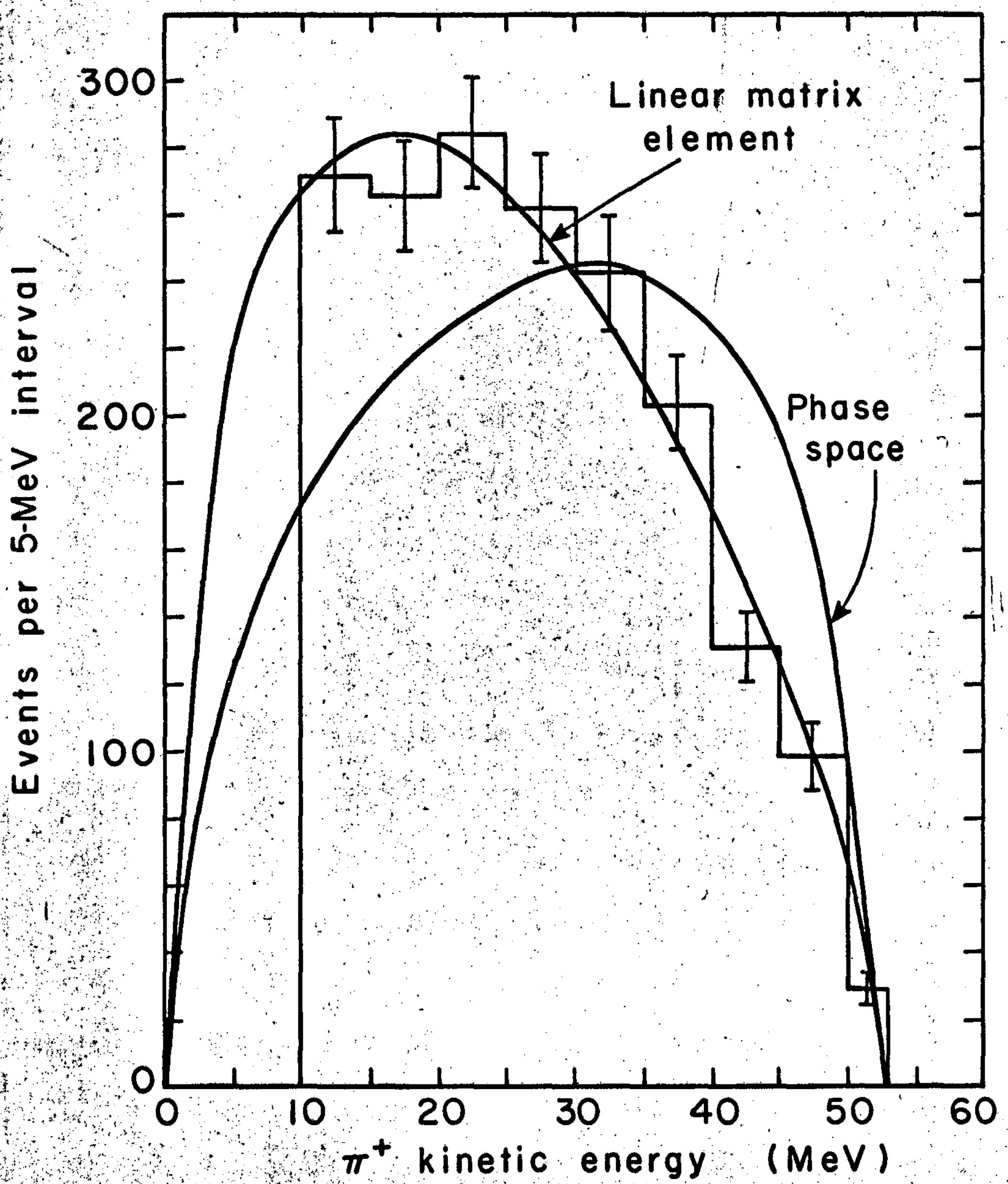
Linear matrix element
Phase space
Events per 5-MeV interval
300
200
100
0
0
10
20
30
40
50
60
π^+ kinetic energy (MeV)
MUB-3188

Fig. 2.