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In a study of associated production by 1.12-Bev/c negative pions incident on a liquid hydrogen bubble chamber, we find a discrepancy between the K^0 and K^+ production and decay dynamics, if we use currently accepted values for the masses involved. The discrepancy is most easily resolved if the mass of the K^0 exceeds that of the K^+ by about 5 Mev.

The experiment is sensitive to the mass values, in spite of the high energies involved, because one is working close to associated production threshold. The method follows.

The average beam momentum $\overline{P}_{inc}$ and its rms half width $\delta\overline{P}_{inc}$ are determined from 16 selected events of the type

$$\pi^- + p \rightarrow \Sigma^- + K^+ , \qquad (1)$$

in which the K^+ stops in the chamber, and thus has its momentum accurately determined by range. Using currently accepted mass values (Table I), we obtain the result

$$\overline{P}_{inc} = 1123.5 \pm 2.4 \text{ Mev/c}, \qquad (2)$$

$$\delta\overline{P}_{inc} = 8.2 \pm 2 \text{ Mev/c},$$

where the error in beam momentum includes propagation of the (relatively small) contributions from the uncertainties in the π^-, Σ^-, and K^+ masses, as given in Table I.

For each event of the type

$$\pi^- + p \rightarrow \Lambda + K^0 , \qquad (3)$$

with one or both of the Λ and K^0 decaying in the chamber, the momentum of the incident pion is calculated from the production and decay dynamics. This is done as a routine part of the data analysis. When 494 Mev is used as the K^0 mass, the beam momenta thus obtained are systematically about 1% too low, as compared with the $\Sigma^- K^+$ result in Eq. (2). This is the discrepancy referred to at the beginning.

The data were accordingly rerun through an improved IBM program which includes the added feature that it propagates errors in the beam momentum. In this program a K^0 mass of 498.0 Mev was used; this was close to the value suggested by the discrepancy. The discrepancy was thereby of course very much reduced.

From the events in which both the Λ and K^0 decay in the chamber we then select those with small errors, $\delta P_{inc} < 20$ Mev/c, on the incident pion momentum. It is a simple matter to transform the residual discrepancy between the resulting P_{inc} and the value obtained from Eq. (2) into a deviation of M_{K^0} from 498, and propagate the errors thereon.

There were 34 ΛK^0 events that passed the selection criterion. From these events, and using the value $M_{K^0} = 498$ in the IBM program, we obtain $P_{inc} = 1121.1 \pm 2.3$. In order to agree with the $\Sigma^- K^+$ result (2) the K^0 mass must be increased by an additional 0.8 Mev. We finally obtain the result

$$M_{K^0} - M_{K^+} = 4.8 \pm 1.1 \text{ Mev}, \qquad (4)$$

where the error includes the uncertainties in P_{inc} as determined from the 34 ΛK^0 events, and from the 16 ΣK^+ events, and also includes the errors in the

π^-, Σ^-, K^+, and Λ masses. We emphasize that it is the mass difference which is determined--the result in Eq. (4) would be unchanged to first order even if the currently accepted K^+ mass were found to be too low.

We next turn to the question of possible systematic errors. The determination of beam momentum for a ΛK^0 event depends on measurements of the momentum and laboratory-system production angle of the K^0. (The Λ production and decay are used to check the event for consistency, but are not used in the actual determination of P_{inc}.) The K^0 momentum in turn is determined almost completely by angle measurements on the decay pions, and is quite insensitive to the measurement of their curvature in the 11-kilogauss magnetic field. (In other words the magnitude and error of the K^0 - K^+ mass difference obtained above would have been essentially unchanged if the magnetic field had been turned off.) The question then becomes one of systematic errors in angle measurements.

The best confirmation that angle measurements are not significantly wrong comes from the work of Baggett and McCormick.[1] In order to determine the incident pion momentum, they analyzed elastic π^-p scatters in which the proton stops in the chamber. Their events are taken from the same series of bubble chamber pictures that contain the associated production events. The beam momentum is essentially given by proton range and pion angle. Their result, P_{inc} = 1135 ± 10 Mev/c, agrees (within the errors) with our $\Sigma^- K^+$ result. This agreement means that angles are measured very well indeed; one standard deviation on their result represents a systematic shift of 0.1 degree in pion angle.

The angle errors needed to reconcile our data with $M_{K^0} - M_{K^+} = 0$ are, however, about 1 degree.

If we weigh in the possibility of small systematic angle errors of the order of 0.1 degree, the rms error in Eq. (4) is increased from 1.1 to 1.14 Mev.

The masses used in this determination, and the partial derivatives of M_{K^0} with respect to them, are given in Table I.

For a compilation and weighted average of our K^0 mass and K^0 and $\bar{K}^0$ mass values obtained by other workers we refer to the accompanying Letter by Rosenfeld, Tripp, and Solmitz.[2]

Finally we remark that our $K^0 - K^+$ mass excess has the opposite sign, and roughly three times the magnitude expected[3] if (a) the K^0 and K^+ are members of the same multiplet, (b) the mass difference is purely electromagnetic, and (c) the strong interactions are assumed to have a negligible effect. The suggestion of Pais, that the K^0 and K^+ may have opposite intrinsic parity,[4] would naturally invalidate assumption (a).

We would like to thank Roger L. Douglas and George R. Kalbfleisch for their assistance in analysing data, John Dardis and Paul Kenny for interesting discussions, and Luis W. Alvarez for his advice and encouragement.

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References and Footnotes

1. Private communications from Lee Baggett, Jr. and Bruce H. McCormick, and University of California Radiation Laboratory Report No. 8302.
2. A.H. Rosenfeld, R.D. Tripp, and F. Solmitz, Phys. Rev. Lett. * .
3. S. Gasiorowicz and A. Petermann, Phys. Rev. Lett. 1, 457 (1958).
4. A. Pais, Phys. Rev. 112, 624 (1958).

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*This is the accompanying letter.

Table I

Mass values and their derivatives used in computing $K^0 - K^+$ mass difference

	π^-	Σ^-	K^+	Λ
Mass, M	139.63	1196.50	494.00	1115.20
δM_{rms}	0.06	0.50	0.20	0.14
$\partial M_{K^0}/\partial M$	- 0.03	0.73	1.06	- 0.54

Note: The first two lines in Table I contain mass values and their rms errors, in Mev, used in our determination of the K^0-K^+ mass excess. They correspond to Table I of M. Gell-Mann and A.H. Rosenfeld, Annual Review of Nuclear Science 7, (1957). The last line gives partial derivatives of our K^0 mass value with respect to the other assumed masses, in Mev per Mev. The smallness of the dependence, -0.03, on the π^- mass reflects the fact that the π^- mass "cancels" to first order in the $K^0 - K^+$ mass difference. The nearly 1:1 (1.06) dependence on the K^+ mass reflects the fact that to first order our $K^0 - K^+$ mass excess is independent of the value assigned to the K^+ mass. The contribution to the error in $M_{K^0} - M_{K^+}$ that arises from errors in the masses listed in this table is obtained by multiplying the 2nd and 3rd rows of the table together, with the usual squaring and adding of terms.