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$K_2^0 p$ INTERACTIONS AT LOW MOMENTUM

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ABSTRACT

An analysis is given of about 1200 K_2^0 p interactions of the types $\Lambda^0\pi^+$, $\Sigma^0\pi^+$, and K_1^0 p at a mean K_2^0 momentum of 300 MeV/c. The relation between these reactions and the scattering lengths from K^+ and K^- experiments is discussed, and a substantial P wave is reported in the $\Lambda^0\pi^+$ reaction.

INTRODUCTION

We have studied the K_2^0 p interactions around 300 MeV/c.[1] As pointed out by Biswas,[2] a measurement of the ratio R of K_1^0 to hyperon production in the K_2^0 p reaction can resolve the ambiguity between the solutions for the complex zero-range scattering lengths obtained in low-energy K^-p experiments.[3-5] The latest status of these solutions is that Kim obtained a unique answer[4] in accord with the $(1/2)^-$ interpretation for the $Y^*(1405)$, while Sakitt et al. obtained two ambiguous solutions.[5] Our determination of R shows that the only acceptable solution is the one consistent with the Dalitz-Tuan interpretation of the $Y_0^*(1405)$ as a $\bar{K}$-N virtual bound-state resonance.[6] Thus, while the negative-strangeness amplitudes in the K_2^0 p interactions are purely in the isotopic-spin T = 1 state, our results coupled with those from K^+p, K^-d,[7] and K^-p experiments determine the spin and parity of the T = 0 resonance Y_0^* (1405) to be $(1/2)^-$. Furthermore, we find a considerable amount of P-wave amplitude to be present in the $K_2^0\ p \rightarrow \Lambda^0\pi^+$ reaction, in which a strong forward-backward asymmetry is observed in the production distributions. We have ascertained that this amount of P-wave can be attributed to the presence of the Y_1^* (1385) resonance below the $\bar{K}N$ threshold.

EXPERIMENTAL TECHNIQUE

The experimental layout at the Bevatron is illustrated in Fig. 1. A K^+ beam (~ 800 MeV/c) was produced from a target placed in the external proton beam of the Bevatron. The K^+ beam was focused to a small spot on a charge-exchange target near the 25-in. hydrogen bubble chamber,[8] creating the K_2^0 beam. Pions and protons accompanying

the K^+ beam were deflected vertically by an electrostatic separator so as to miss the charge-exchange target, orbit through the bubble-chamber fringe field, and be stopped far enough away to cause no appreciable background. With 1000 K^+ incident on the target, about one K_2^0 entered the chamber each pulse, and a K_2^0 decay or interaction occured on the average every 17 pictures. To date about 1200 interactions that lead to a visible Λ^0 or K_1^0 decay have been analyzed. This represents approximately half of our available sample.

RESULTS

The interactions considered here are:[9]

$$K_2^0\, p \rightarrow K_1^0\, p,\quad K_1^0 \rightarrow \pi^+\pi^-, \qquad \text{403 events} \qquad (1)$$

$$\rightarrow \Lambda^0\pi^+,\quad \Lambda^0 \rightarrow \pi^- p, \qquad \text{481 events} \qquad (2)$$

$$\rightarrow \Sigma^0\pi^+,\quad \Sigma^0 \rightarrow \gamma\Lambda^0,\ \Lambda^0 \rightarrow \pi^- p. \qquad \text{332 events} \qquad (3)$$

Of the various potential sources of scanning bias in the analysis of these reactions, nearly all are of the order of a few percent at most, and have been corrected for. The ambiguities between reactions are quite small. Because of the low energies involved, the K_1^0 and Λ^0 decays can be recognized at the scan table in nearly every instance, and in combination with kinematic fitting, we obtain a unique identification of the decay particle. For Λ^0 and Σ^0 production, these events look the same at the scan table, but there is only a 3% overlap after the kinematic fitting. Figure 2 shows the K_2^0 momentum distribution for the three interactions studied. This corresponds to the true K_2^0 spectrum folded into the interaction cross sections. From our data we have evaluated the ratio R given by

$$R = \frac{\sigma(K_1^0\ p)}{\sigma(Y)} = \frac{\sigma(K_1^0\ p)}{\sigma(\Lambda^0\pi^+) + 2\sigma(\Sigma^0\pi^+)} . \tag{4}$$

In the S-wave zero-effective-range approximation the relevant cross sections are related to the strangeness = +1, T = 0 and 1 scattering lengths a_0 and a_1 which are real,[7] and the strangeness = -1, T = 1, complex scattering length $\bar{A}_1 = \bar{a}_1 + i\bar{b}_1$ by[2]

$$\sigma(K_1^0\ p) = \pi \left| \frac{1}{2}\left(\frac{a_0}{1-ika_0} + \frac{a_1}{1-ika_1}\right) - \frac{\bar{A}_1}{1-ik\bar{A}_1} \right|^2 \tag{5}$$

and

$$\sigma(Y) = \frac{2\pi}{k} \frac{\bar{b}_1}{|1-ik\bar{A}|^2} , \tag{6}$$

where k is the momentum of the K_2^0 in the overall center of mass. This ratio is a function of K_2^0 energy, and because of interference in the K_1^0 p reaction between the strangeness +1 and -1 scattering amplitude turns out to be quite sensitive to the differences between the two K^-p solutions. An earlier determination of R was made by Luers et al., at 230 MeV/c.[10] On the basis of 113 events, they obtained R = 0.4 to 0.9, which lies about midway between the two solutions and could thus not resolve the ambiguity.

We have evaluated the ratio R in 5 momentum intervals. The result is given in Fig. 3 and Table 1, along with the predictions based on the scattering-length determination from the experiments of Sakitt et al.,[5] and of Kim[4] at low energy, and from Tripp at somewhat higher energies.[11] From Fig. 3 we conclude that the correct set of solutions is the one giving the smaller values for R.[12] This is the set that predicts a $\bar{K}N$ bound state near 1405 MeV. We further conclude that our data agree well with the prediction for R based upon the T = 1 scattering

lengths from Kim's experiment, but differ considerably from that based upon the preferred solution of Sakitt et al.[5] These predictions also depend upon the strangeness = +1 scattering lengths, which are assumed from previous K^+ experiments. It should be pointed out that above 250 to 300 MeV/c one may expect a breakdown of the zero-effective-range approximation and that the theoretical predictions in this region may not be quite correct.

In the K^-p experiments below 300 MeV/c, there has been no need to assume amplitude other than S-wave in order to explain the observed distributions.[3-5, 11] In Fig. 4 we show the variation of the $\Lambda^0\pi^+$ angular distribution with momentum (see also Table I). At the lowest momentum there is only a small amount of P wave compared with S wave (about 15% in the amplitude). As the momentum increases, a strong backward peak appears in the distributions, indicating the presence of a larger amount of P-wave amplitude. Table I gives the results of fitting these curves to Legendre polynomials. Expansions to orders higher than second do not improve the fits significantly except perhaps in the 250 to 300-MeV/c region. The presence of such a substantial amount of P wave in the T = 1 state can be explained in terms of the Y_1^* (1385) resonance, which lies 50 MeV below the $\bar{K}N$ threshold. The high-energy tail of that resonance extends into the energy region being studied in this experiment. We have calculated the expected amount of P wave from the Y_1^* (1385), using the Breit-Wigner formula with energy-dependent widths, and find substantial agreement with the observed asymmetry, except in the lowest momentum interval. Here the predicted P-wave amplitude is somewhat in excess of that observed.

We observe no significant Λ^0 polarization, which implies that the S- and P-wave amplitude vectors must be relatively real.

The angular distributions for K_1^0 p production are much more isotropic, and can be fitted to a linear function of $\cos\theta$, except for the highest momentum region (See Table I). One would expect less asymmetry to appear in this reaction than for $\Lambda^0\pi^+$ for two reasons: (1) The P-wave amplitude is still smaller, since the phase-space and barrier-penetration factors are more inhibiting than for the Λ^0 channel. (2) The P-wave amplitude vector resulting from the tail of the $Y_1^*(1385)$ is expected to be approximately real and negative, while the S-wave is largely imaginary due to the strong absorption. As a consequence, the two vectors are nearly out of phase.

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FOOTNOTES AND REFERENCES

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

†Deceased.

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8. The charge-exchange target subtends ±2 deg horizontally, and ±0.4 deg vertically at the center of the chamber. The direction of the K_2^0 line of flight is computed from the known target and interaction positions, and this information is used in the fitting procedure.
9. In addition, reactions $\Sigma^+\pi^0 (\Sigma^+ \rightarrow \pi^+ n)$ and $K^+ n$ have been scanned for, but these events have not been fully analyzed.
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11. M. B. Watson, M. Ferro-Luzzi, and R. D. Tripp, Phys. Rev. 131, 2248 (1963). Above 300 MeV/c, there is evidence for an aymmetry in the angular distribution in the $\Lambda^0\pi^0$ channel, in qualitative agreement with the asymmetry reported in this letter.

12. There is additional evidence to help resolve the ambiguity in favor of the Dalitz-Tuan interpretation. Specifically, in the K^-p experiment of Ref. 11 in the momentum range 300 to 500 MeV/c, interference was observed between the Y_0^* (1520) resonance and the S-wave background. The continuity argument of T. Akiba and R. H. Capps, Phys. Rev. Letters 8, 457 (1963), then implied that the relative phase of the isotopic-spin-0 and -1 channels was such that only one set of scattering lengths was possible. In addition, recent K^-p charge-exchange experiments [G. S. Abrams and B. Sechi-Zorn, Phys. Rev. 139, B454 (1965) and W. Kittel, G. Otter, and I. Wacok, Phys. Letters 21, 349 (1966)] are consistent with only this set of solutions, as is the experiment by E. F. Beall, G. Sayer, T. V. Devlin, P. Shephard, and J. Solomon, Bull. Am. Phys. Soc. 11, 326 (1966).

Table I.[a] R, ϵ,[b] and coefficients in Legendre-polynomials expansion to fit production angular distributions.

K_2^0 momentum range (MeV/c)	0 to 200	200 to 250	250 to 300	300 to 400	Above 400
Av. K_2^0 momentum (MeV/c)	160	225	275	340	460
Observed number of events	261	304	224	277	150
R	0.19±.03	0.25±.04	0.35±.05	0.40±.05	0.55±.10
ϵ	0.35±.03	0.36±.03	0.32±.04	0.34±.04	0.41±.06
Fit to $\Lambda^0\pi^+$ distributions (Fig. 4)					
A_1	-0.52±.15	-0.99±.14	-1.07±.17	-0.94±.18	-1.18±.23
A_2		0.49±.21	-0.19±.25	0.61±.25	1.02±.27
A_3			0.40±.32		
A_4			-1.06±.63		
Confidence level of fit (%)	76	34	5	13	25
Fit to K_1^0 p distributions					
A_1	0.36±.33	-0.41±.32	-0.13±.31	-0.53±.20	-1.12±.22
A_2					0.68±.33
A_3					-1.15±.41
Confidence level of fit (%)	31	81	24	94	77

a. In this table R, ϵ, and the coefficient A_1, A_2. A_3, and A_4 are based upon the corrected number of events. The coefficients have been normalized to a constant term $A_0 = 1$. The Σ^0 production distributions are all consistent with isotropy.

b. $\epsilon = \sigma(\Lambda^0)/[\sigma(\Lambda^0) + 2\sigma(\Sigma^0)]$.

FIGURE LEGENDS

Fig. 1. Experimental arrangement at the Bevatron, with detail of 25-in. hydrogen bubble chamber and charge-exchange target.

Fig. 2. Distribution of K_2^0 momentum for the observed reactions.

Fig. 3. R vs K_2^0 momentum. The uncertainties in the predicted values of R are indicated by the shaded bands based on the quoted errors in the K^- and K^+ experiments. The data points are the result of the present experiment.

Fig. 4. Angular distributions for $\Lambda^0\pi^+$ production. The production angle is here defined to be the direction of the Λ^0 relative to the K_2^0 in the overall center of mass. The dashed curves represent the best fit to the data, as given in Table I.

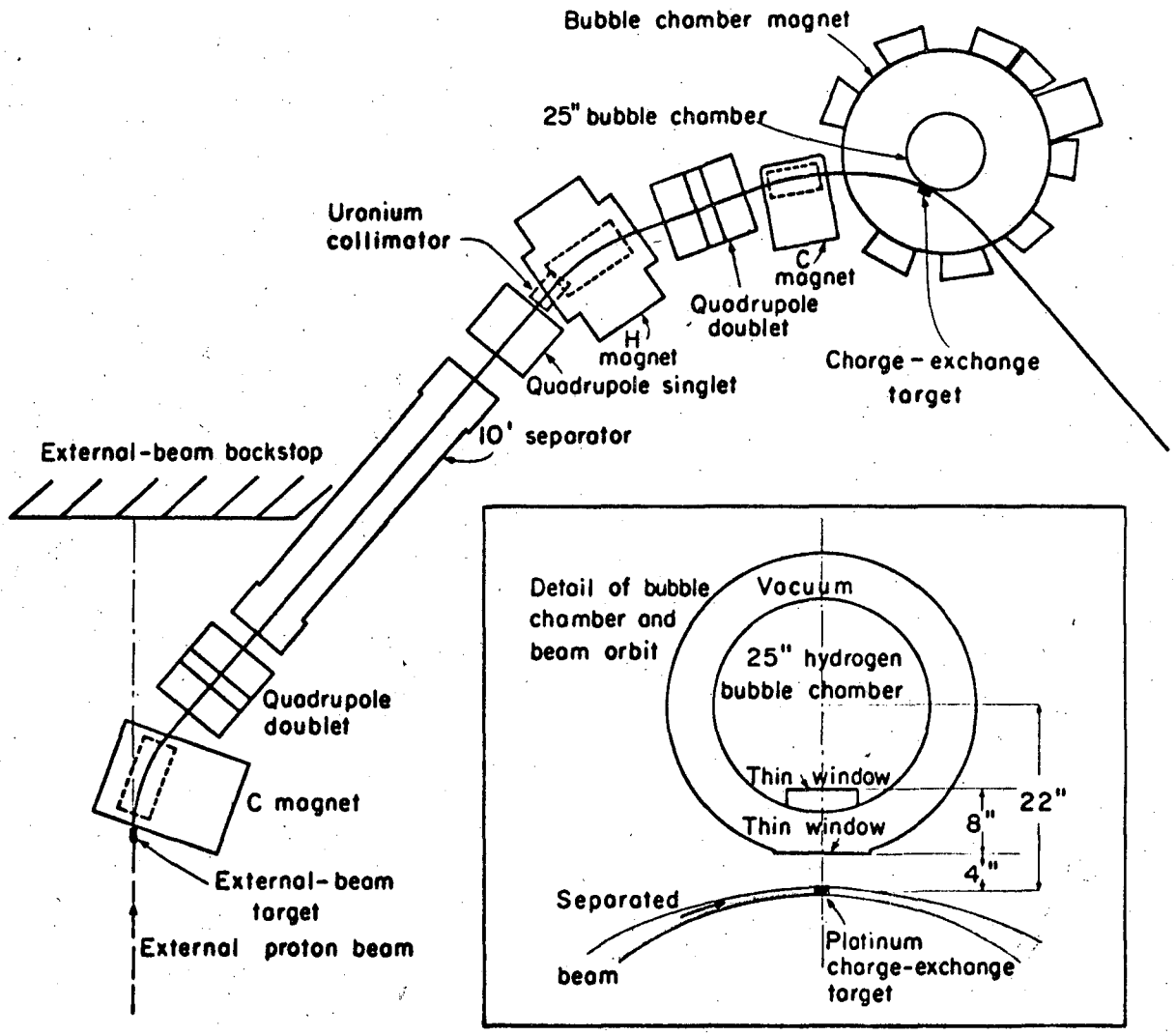
Bubble chamber magnet
25" bubble chamber
Uranium collimator
C magnet
Quadrupole doublet
H magnet
Quadrupole singlet
Charge-exchange target
10° separator
External-beam backstop
Quadrupole doublet
C magnet
External-beam target
External proton beam
Detail of bubble chamber and beam orbit
Vacuum
25" hydrogen bubble chamber
Thin window
Thin window
22"
8"
4"
Separated beam
Platinum charge-exchange target

Fig. 1

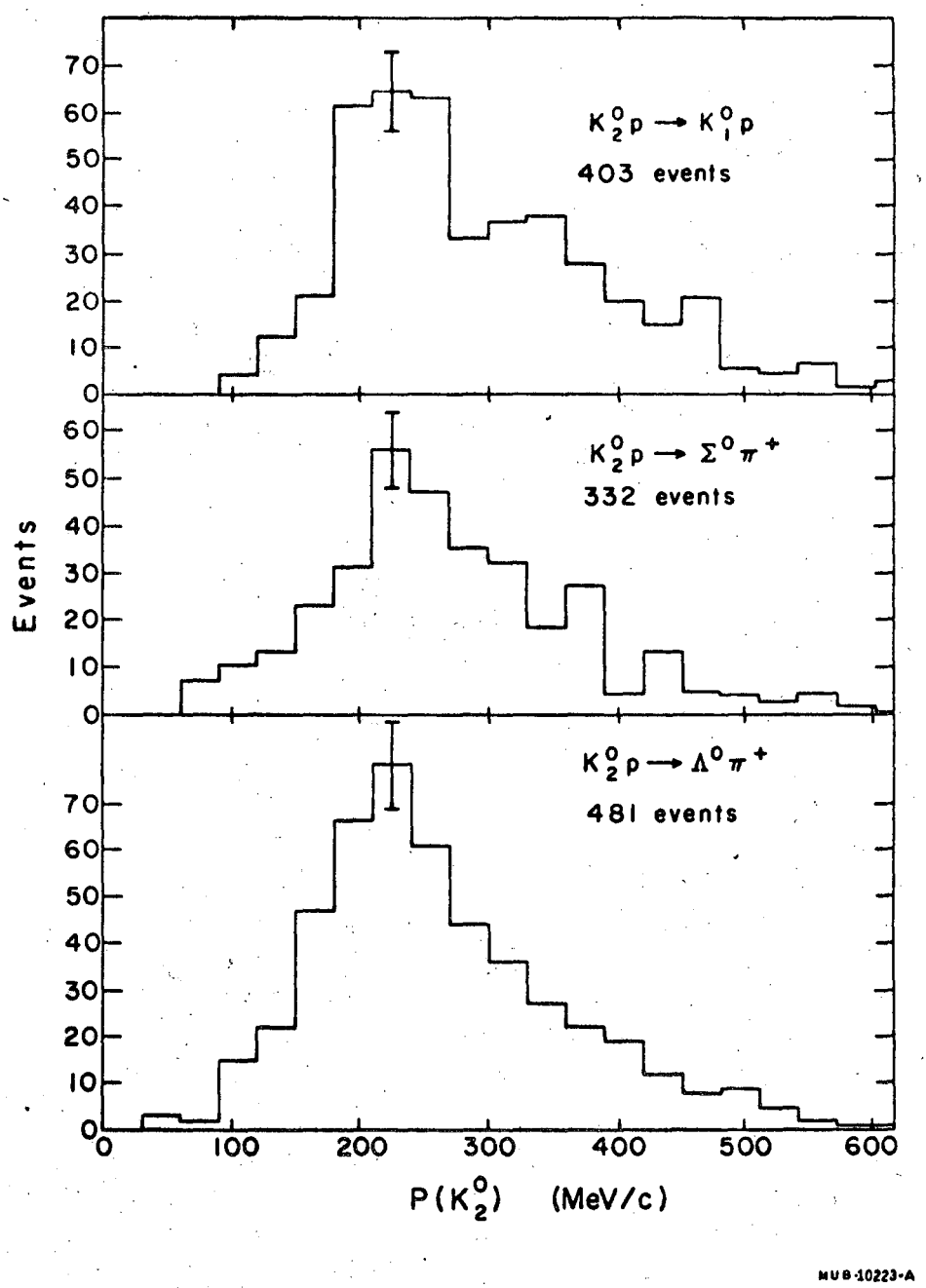
$K_2^0 p \rightarrow K_1^0 p$
403 events
$K_2^0 p \rightarrow \Sigma^0 \pi^+$
332 events
$K_2^0 p \rightarrow \Lambda^0 \pi^+$
481 events
Events
0
10
20
30
40
50
60
70
0
100
200
300
400
500
600
$P(K_2^0)$ (MeV/c)
MUB-10223-A

Fig. 2

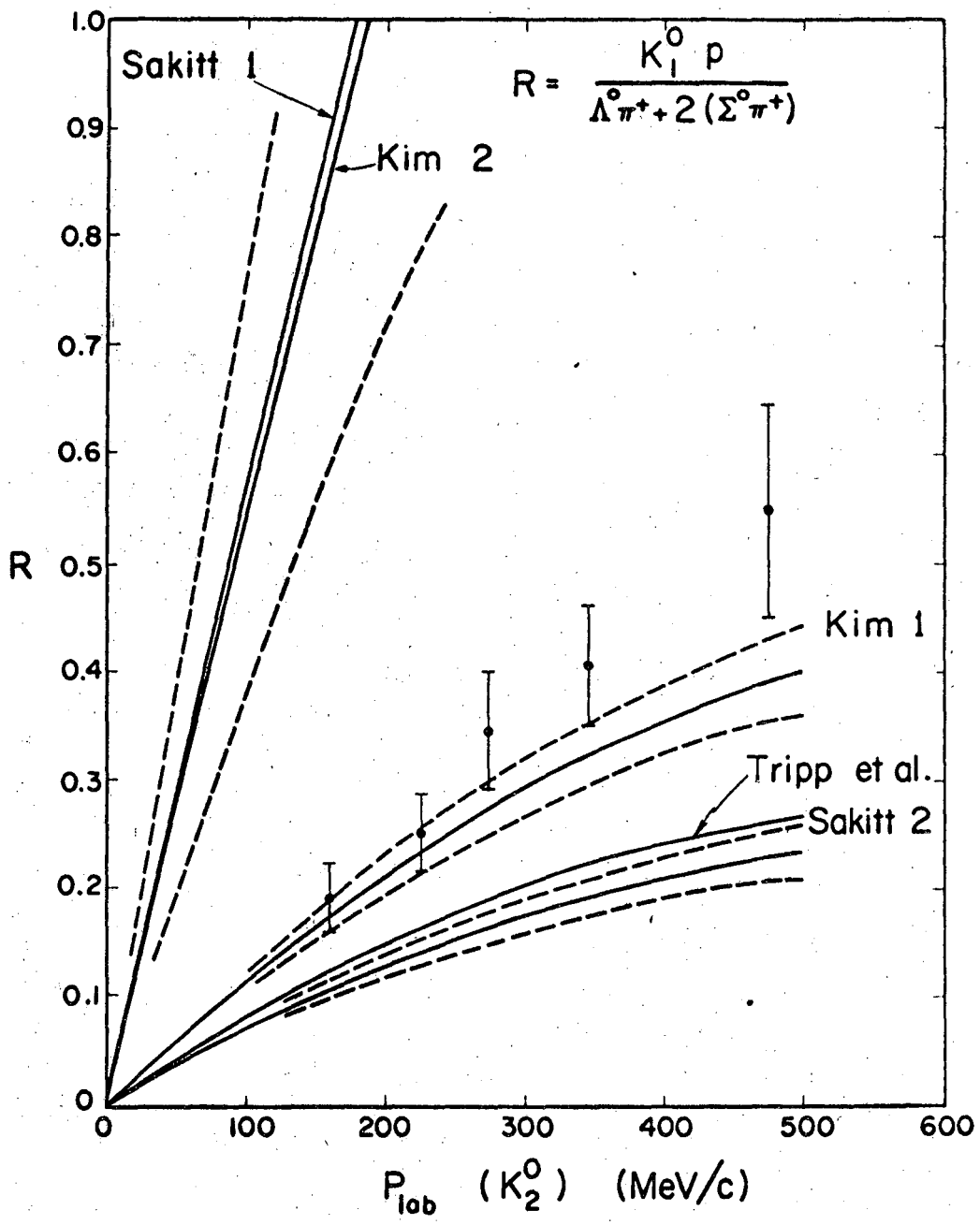
Sakitt 1
Kim 2
R = $\frac{K_1^0 p}{\Lambda^0\pi^+ + 2(\Sigma^0\pi^+)}$
Kim 1
Tripp et al.
Sakitt 2
R
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
100
200
300
400
500
600
P_{lab} (K_2^0) (MeV/c)

Fig. 3

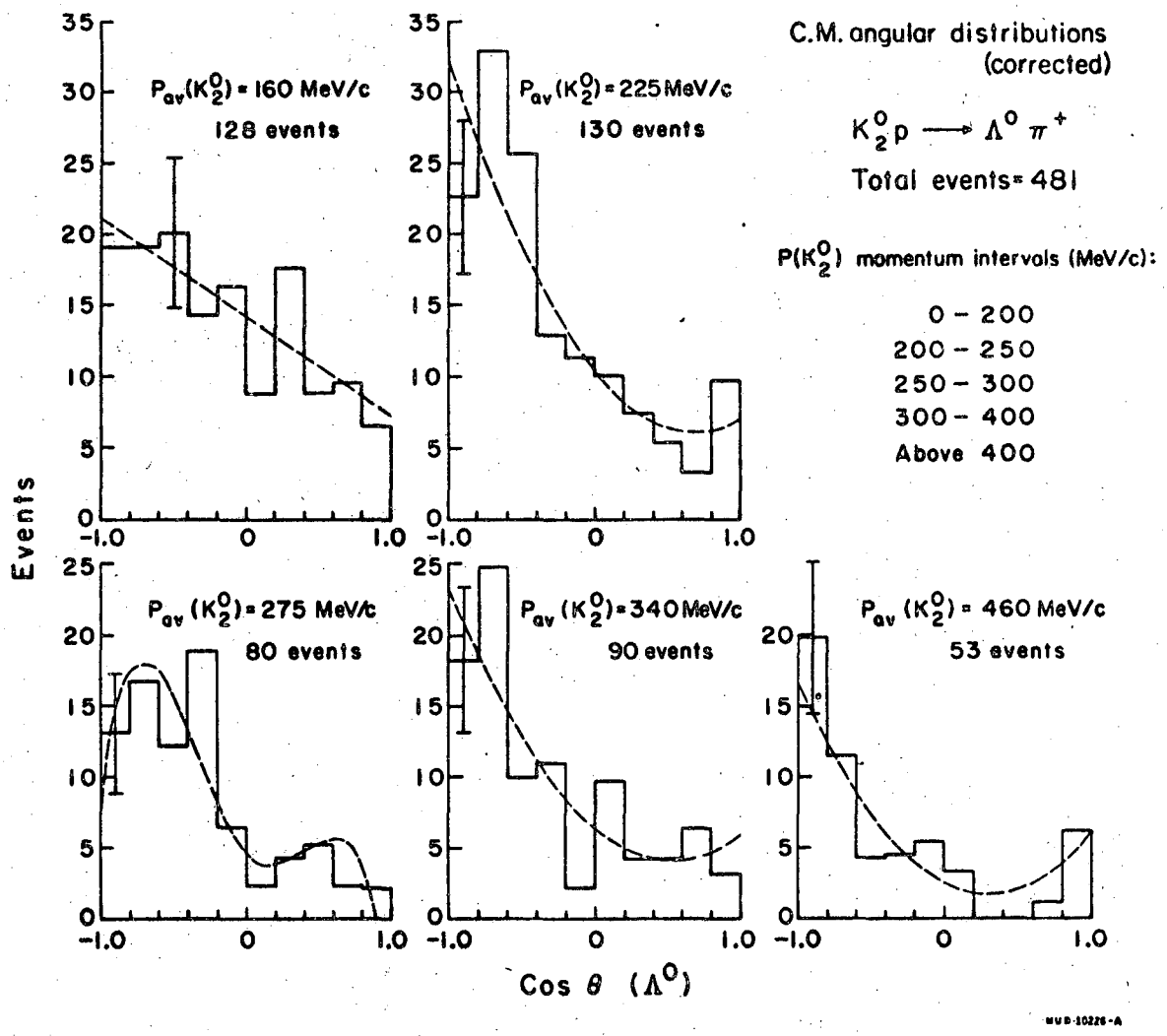
C.M. angular distributions (corrected)
$K_2^0 p \longrightarrow \Lambda^0 \pi^+$
Total events = 481
$P(K_2^0)$ momentum intervals (MeV/c):
0 – 200
200 – 250
250 – 300
300 – 400
Above 400
$P_{av}(K_2^0)$ = 160 MeV/c
128 events
$P_{av}(K_2^0)$ = 225 MeV/c
130 events
$P_{av}(K_2^0)$ = 275 MeV/c
80 events
$P_{av}(K_2^0)$ = 340 MeV/c
90 events
$P_{av}(K_2^0)$ = 460 MeV/c
53 events
Events
Cos θ (Λ^0)
MUB-10226-A

Fig. 4

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