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THE PRODUCTION MECHANISM FOR THE REACTION $K^+p \rightarrow K^*p$ AT 3 GeV/c

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The 81 cm Saclay hydrogen bubble chamber was exposed at the CERN proton synchrotron to a separated K^+ beam[1] with a momentum of $2.965 \pm .015$ GeV/c ($E_{cm} = 2.60$ GeV). In the study of the three-body final state:

$$K^+p \rightarrow K^o\pi^+p \quad (1)$$

for which the cross section is 2.1 ± 0.2 mb, we find that the two dominant reactions are

$$K^+p \rightarrow K^{*+}p,\ K^{*+} \rightarrow K^o\pi^+ \quad (2)$$

and

$$K^+p \rightarrow N^{*++}K^o,\ N^{*++} \rightarrow p\pi^+ . \quad (3)$$

The cross sections for reactions (2) and (3) are each 0.8 ± 0.1 mb. We report here the main results of the analysis of reaction (2). This analysis shows that the angular distributions are consistent with the assumption that the predominant production mechanism is the exchange of a vector meson. The detailed analysis of reaction (1) together with the study of reaction (3) will be reported elsewhere[2].

A total of 1901 events that were inside a fiducial volume and that had two positive outgoing tracks as well as an associated decay of a neutral particle were analysed using the computer programs THRESH, GRIND, BAKE, SLICE, and SUMX. All events were examined to see if the ionisation of the tracks was consistent with the kinematic fits. About 99 o/o of the events were assigned an unambiguous interpretation by means of the above procedure combined, when necessary, with remeasurements or use of the MILLSTONE program.

In this sample there are 747 events which fit the hypothesis $K^o p\pi^+$. Figure 1 is a Dalitz plot for these events. One can see that both the $N^*(1238)$ and the $K^*(890)$ are produced copiously. By means of a likelihood analysis of the Dalitz plot population we find that 38 ± 3 o/o of the events are K^*p, 38 ± 3 o/o are N^*K^o and 24 ± 3 o/o are non-resonant events. We find the mass and width of the K^{*+} to be $M_{K^*} = 891 \pm 3$ MeV and $\Gamma_{K^*} = 47 \pm 4$ MeV.

For the analysis of the K^* events the 183 events which are in the K^* band (0.86 GeV $< M_{K^o\pi^+} < 0.96$ GeV) but not in the N^* band (1.15 GeV $< M_{p\pi^+} < 1.33$ GeV) were chosen. This sample contains 60 o/o of the K^* events and has an estimated contamination of 15 non-K^* events.

It seems appropriate to interpret these reactions under the assumption that the production mechanism is one-meson exchange. This approach is suggested by the fact that the K^* is produced predominantly in the forward direction relative to the incident K^+ in the cm system, as can be seen in Figure 2. The exchange process diagram is illustrated in Figure 3.

It is convenient to analyse reaction (2) in the rest frame of the K^*, choosing for the z-axis the direction of the incident K^+ in this frame, and for the y-axis the normal to the plane of production. If there is pion exchange, then, since the particles incident to the K^* vertex are spinless, the orbital angular momentum (ℓ) at this vertex is one, the spin of the K^*. Since the component of the orbital angular momentum in the direction of the incident K^+ (the z-axis) must be zero, the angular momentum of the K^* is described by the spherical harmonic Y_1^o, and the angular distribution of the K^o relative to the K^+ is proportional to $\cos^2\theta$. If there is vector meson exchange (ρ, ω or φ), conservation of angular momentum and parity again allow only $\ell = 1$. This orbital angular momentum can couple with the vector meson spin functions S_1^1 and S_1^{-1} but cannot couple with S_1^0 to produce a state of spin one. This gives rise to two terms in the K^* matrix element, one proportional to Y_1^1 and the other proportional to Y_1^{-1}. These terms produce an angular distribution proportional to $\sin^2\theta$.

In general the angular distribution of the K^0 from the decay of the K^* can be expressed in the form[3]:

$$W_{K^*}(\theta, \varphi)\, d\cos\theta\, d\varphi = \frac{3}{4\pi}\left[\begin{array}{l}\rho_{0,0}\cos^2\theta + \frac{1}{2}(1-\rho_{0,0})\sin^2\theta \\ -\rho_{1,-1}\sin^2\theta\cos 2\varphi - \sqrt{2}\,\mathrm{Re}\rho_{1,0}\sin 2\theta\cos\varphi\end{array}\right] d\cos\theta\, d\varphi \qquad (4)$$

from which one obtains:

$$W_{K^*}(\theta)\, d\cos\theta = \frac{3}{4}\left[(1-\rho_{0,0}) + (3\rho_{0,0}-1)\cos^2\theta\right] d\cos\theta \qquad (4a)$$

$$W_{K^*}(\varphi)\, d\varphi = \frac{1}{2\pi}\left[1 - 2\rho_{1,-1} + 4\rho_{1,-1}\sin^2\varphi\right] d\varphi \qquad (4b)$$

where θ and φ are the polar and azimuthal angles and the ρ values are elements in the spin space density matrix of the K^*.

In the one-meson exchange model the parameter $\rho_{0,0}$ can be interpreted as the fraction of the events which proceed by way of pion exchange. In the case of pion exchange the distribution in the angle φ is isotropic, whereas it is generally nonisotropic in the case of vector meson exchange. Indeed, φ is exactly the angle used in the well-known Treiman-Yang test[4] for the exchange of a spinless meson. A non-zero value of $\rho_{1,-1}$ places an upper limit upon $\rho_{0,0}$:

$$\rho_{0,0} \leqslant 1 - 2\,|\rho_{1,-1}| \qquad (5)$$

a relation which can be derived by imposing the condition that the distribution function in equation (4) must not be negative. The quantity $\mathrm{Re}\rho_{1,0}$ must be zero in the one-meson exchange model, described above.

In Fig. 4 the θ and φ angular distributions are presented. The parameters $\rho_{0,0}$ and $\rho_{1,-1}$ were evaluated by a maximum likelihood analysis of the data based on equations (4a) and (4b). The parameter $\mathrm{Re}\rho_{1,0}$ was calculated by means of the equation:

$$\mathrm{Re}\rho_{1,0} = -\frac{5}{4\sqrt{2}}\,\langle\sin 2\theta\cos\varphi\rangle \qquad (6)$$

The values of $\rho_{0,0}$, $\rho_{1,-1}$ and $\mathrm{Re}\rho_{1,0}$, as well as the final corrected values[5] are presented in Table I.

The striking feature of the K^* events is that $\rho_{0,0}$ (the fraction of events which proceed by way of pion exchange) is very small: only 7 ± 6 o/o of the events can be attributed to one pion exchange. The data are consistent with the hypothesis that all of the K^* events proceed via the exchange of a vector meson. To our knowledge this is the most clear-cut example of a reaction which appears to be peripheral in nature, but for which the lightest possible known particle is not the particle exchanged. This behaviour of the K^*p events is in sharp contrast with that of the $K^+p \rightarrow K^*N^*$ events observed in the $K^+p\pi^+\pi^-$ final state and which seem to be dominated by pion exchange(8)(9). Vector meson exchange has also been observed at lower energies although not so strongly. At 1.96 GeV/c some vector meson exchange can be detected and for 1.45 GeV/c K^+ it was reported(7) that the ratio of vector to pseudoscalar meson exchange is 1.51 ± 0.26. Thus the evidence is that vector meson exchange becomes more dominant as the energy increases.

In connection with the identification of the exchanged particle (or system), two qualifying points need to be considered. In the first place, Gottfried and Jackson(3) have pointed out that these data do not necessarily indicate that a 1^- meson is exchanged. They only indicate that the parity of the exchanged system is $(-1)^J$, ($J \neq 0$ is the spin of the exchanged system). In the second place, although we have evidence for the determination of the quantum numbers of the exchanged system, the determination of its mass is much more of an open question. The distribution in the momentum transfer is peaked at much smaller values than would be expected from an unmodified one-meson exchange model calculation, unless a mass of about 250 MeV is used for the exchanged meson. Even then the fit to the forward peak is poor. Alternatively, if the mass of the ρ meson is used, one can obtain a good fit to the data (see Fig. 2) by using a form factor of the type $e^{-\Delta^2/t^2}$ with t equal to about 0.6 GeV/c. The need for a form factor to obtain agreement with the data is by no means a peculiarity of this reaction or of vector meson exchange. For example, such a form factor is also needed in the $K^+p \rightarrow K^*N^*$ reaction(8)(9).

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TABLE I

Parameter	Range	Uncorrected value	Corrected[5] value
$\rho_{0,0}$	0,1	0.11 ± 0.05	0.07 ± 0.06
$\rho_{1,-1}$	-1/2, 1/2	0.34 ± 0.04	0.32 ± 0.06
Re $\rho_{1,0}$	$\frac{-1}{2\sqrt{2}}, \frac{1}{2\sqrt{2}}$	0.05 ± 0.04	0.10 ± 0.05

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3. K. Gottfried and J.D. Jackson, Physics Letters 8, 144 (1964) and to be published in Nuovo Cimento.

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5. The K^* sample that has been used may be biased because about 12 o/o of the K^* events (which are in the region of the Dalitz plot where the K^* and the N^* bands cross) have been taken away from the total K^* sample. The corrected values of the parameters are based on an analysis of a reduced sample that is free of this bias. This reduced sample includes only those K^* events which are in the right half of the Dalitz plot. More specifically it includes those events for which the K^o from the K^* decay goes backwards in the K^* rest frame relative to the direction of the K^* in the overall cm. The events in this reduced sample should also obey equation (4) when the data are folded in such a way that one plots against $|\cos\theta|$ rather than $\cos\theta$ and against φ modπ rather than φ. The values obtained for the ρ parameters from this reduced sample are in agreement with those obtained from the larger sample. A further correction made to the ρ parameters allows for background effects. The values of the parameters that were calculated from a non-resonant sample of events were used to correct the parameters from the K^* sample under the assumption that the population of the non-resonant events, as well as the θ and φ angular distributions for them are independent of the position in the Dalitz plot. This correction was largest for $\rho_{0,0}$ though even in this case the correction was less than the statistical error. Many checks were made to see if there are any biases in the data which might affect the values of the parameters, especially in view of the fact that $\rho_{0,0}$ has changed somewhat from the preliminary value reported[8]. We find no reason to believe that this

change is due to a systematic effect. In particular, we find that when the K^* peak is divided into a number of mass intervals and the events in each interval are analysed separately, the data show no mass dependent effect.

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FIGURE CAPTIONS

Fig. 1 - A Dalitz plot for the $K^+p \rightarrow K^o p \pi^+$ events

Fig. 2 - A Feynman diagram illustrating the exchange mechanism which may characterise the $K^+p \rightarrow K^* p$ reaction

Fig. 3 - Histogram of the cm angular distributions for the K^* from the reaction $K^+p \rightarrow K^* p$, $K^* \rightarrow K^o \pi^+$. In addition to the statistical errors there is a systematic uncertainty of about 10 o/o when the values are interpreted as differential cross section measurements. The curve is given by the vector meson exchange formula[10]:

$$\frac{d\sigma}{d\Omega} = \frac{(\hbar c)^2}{3s} \frac{q'}{q} \left(\frac{f^2}{4\pi}\right) \frac{1}{M^2_{K^*}} \frac{1}{(M^2_\rho + \Delta^2)^2} \left| F_V(\Delta^2) \right|^2 x$$

$$\left\{ \frac{(G_V + G_T)^2}{4\pi} \frac{\Delta^2}{4} \left[(M_K - M_{K^*})^2 + \Delta^2\right] \cdot \left[(M_K + M_{K^*})^2 + \Delta^2\right] + 2s q^2 q'^2 \sin^2\theta \left[\frac{G_V^2}{4\pi} + \frac{G_T^2}{4\pi} \frac{\Delta^2}{4M_p^2}\right] \right\}.$$

where q and q' are cm momenta of the incident K^+ and the outgoing K^*, and s is the square of the total cm energy.
The form factor was chosen to have the form $F_V(\Delta^2) = e^{-\Delta^2/t^2}$.
The curve plotted represents $G_T = 0$ (appropriate for ω exchange),

$$\frac{G_V^2}{4\pi} \frac{f^2}{4\pi} = 12, \text{ and } t = 0.70 \text{ GeV/c}$$

An almost identical fit is obtained with $G_T = 3.7\, G_V$, (appropriate for ρ exchange)

$$\frac{G_V^2}{4\pi} \frac{f^2}{4\pi} = 10, \text{ and } t = 0.56 \text{ GeV/c}$$

Fig. 4 - Histograms of the distribution in $\cos\theta$ and φ for the decay of the K^+p events. The curves represent the best fit to the data, namely $1 - 0.76 \cos^2\theta$ and $1 + 4.3 \sin^2\varphi$.

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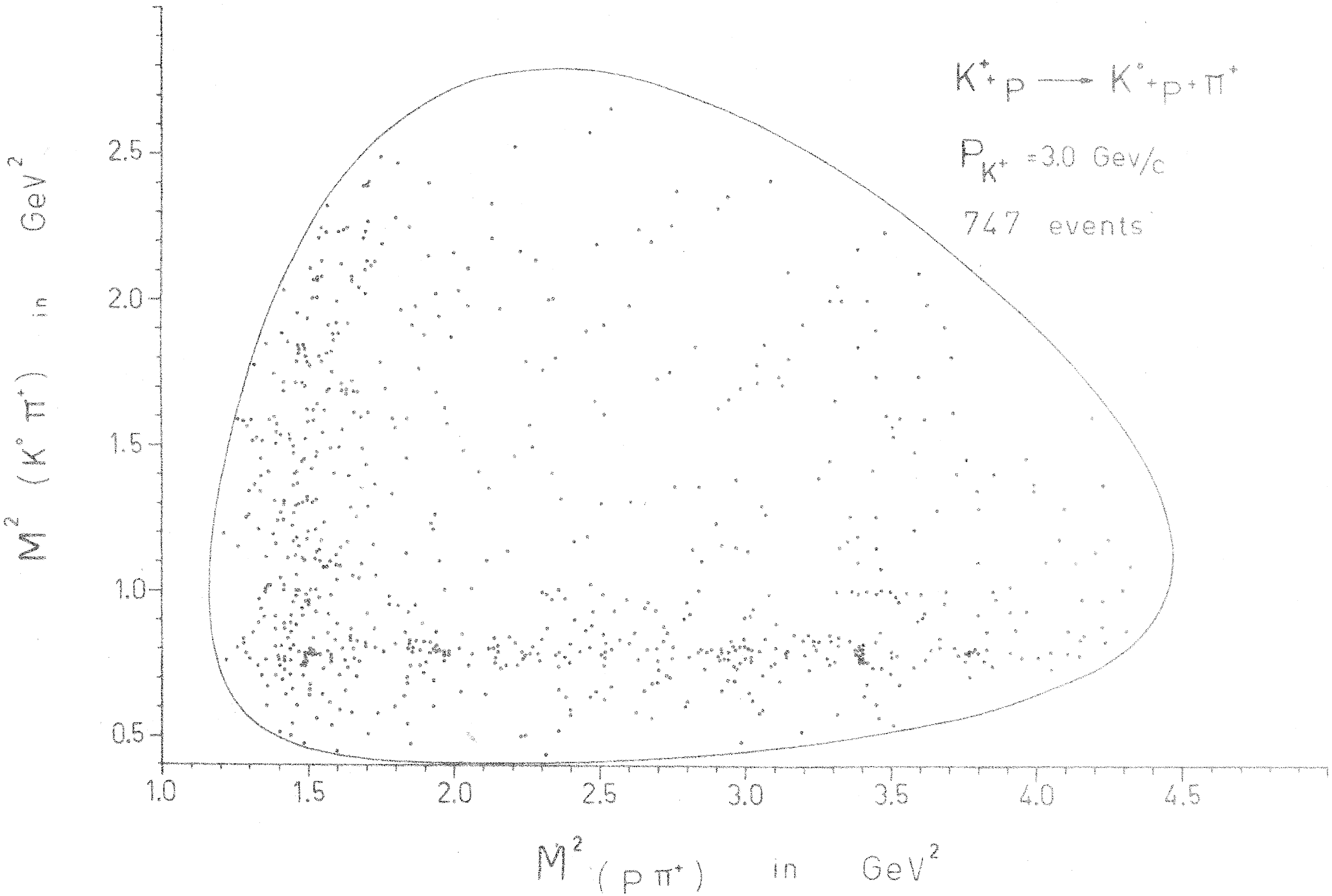

K⁺ + p ⟶ K° + p + π⁺
P_K+ = 3.0 Gev/c
747 events
M² (K° π⁺) in GeV²
M² (p π⁺) in GeV²
0.5
1.0
1.5
2.0
2.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5

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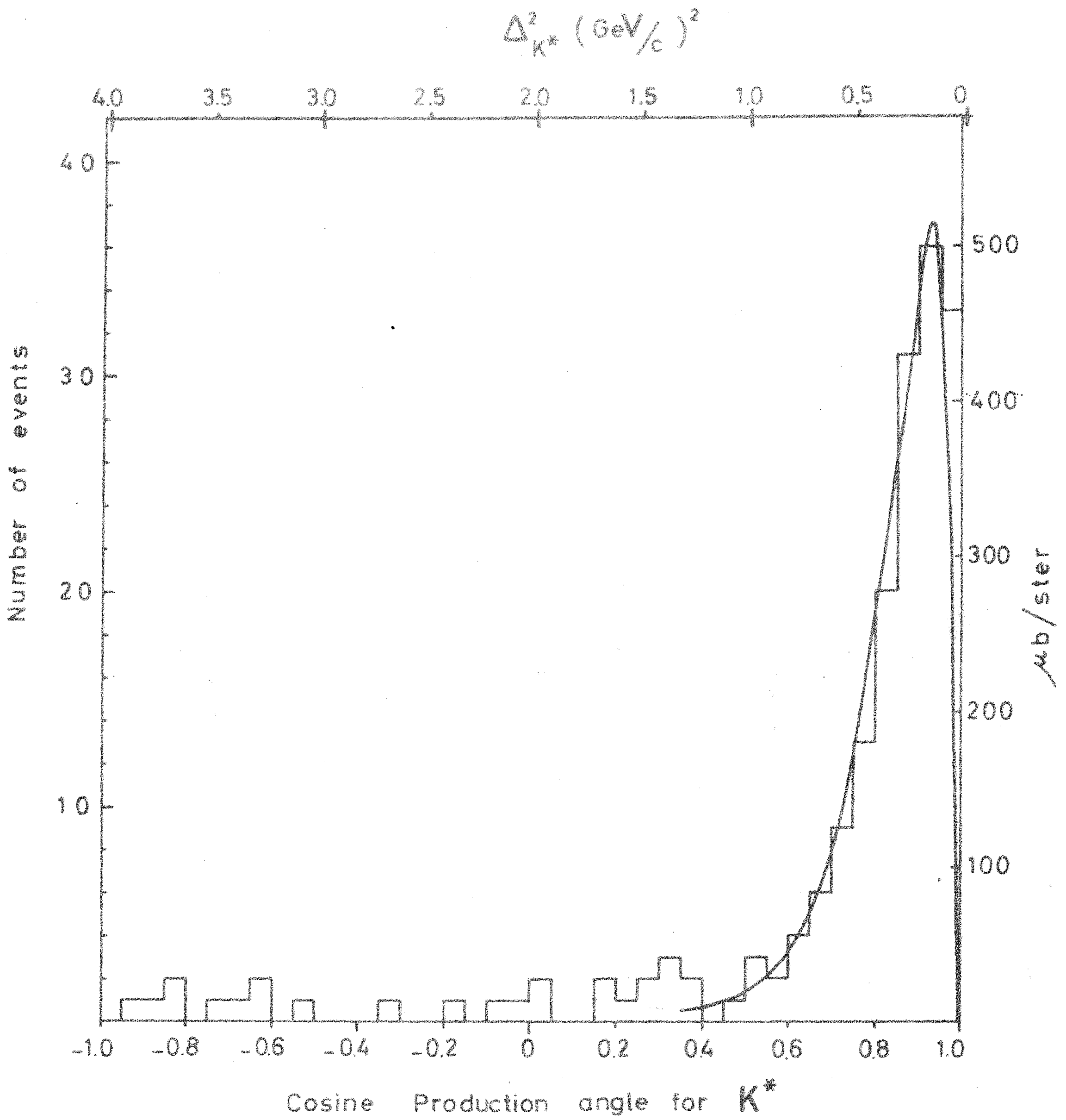

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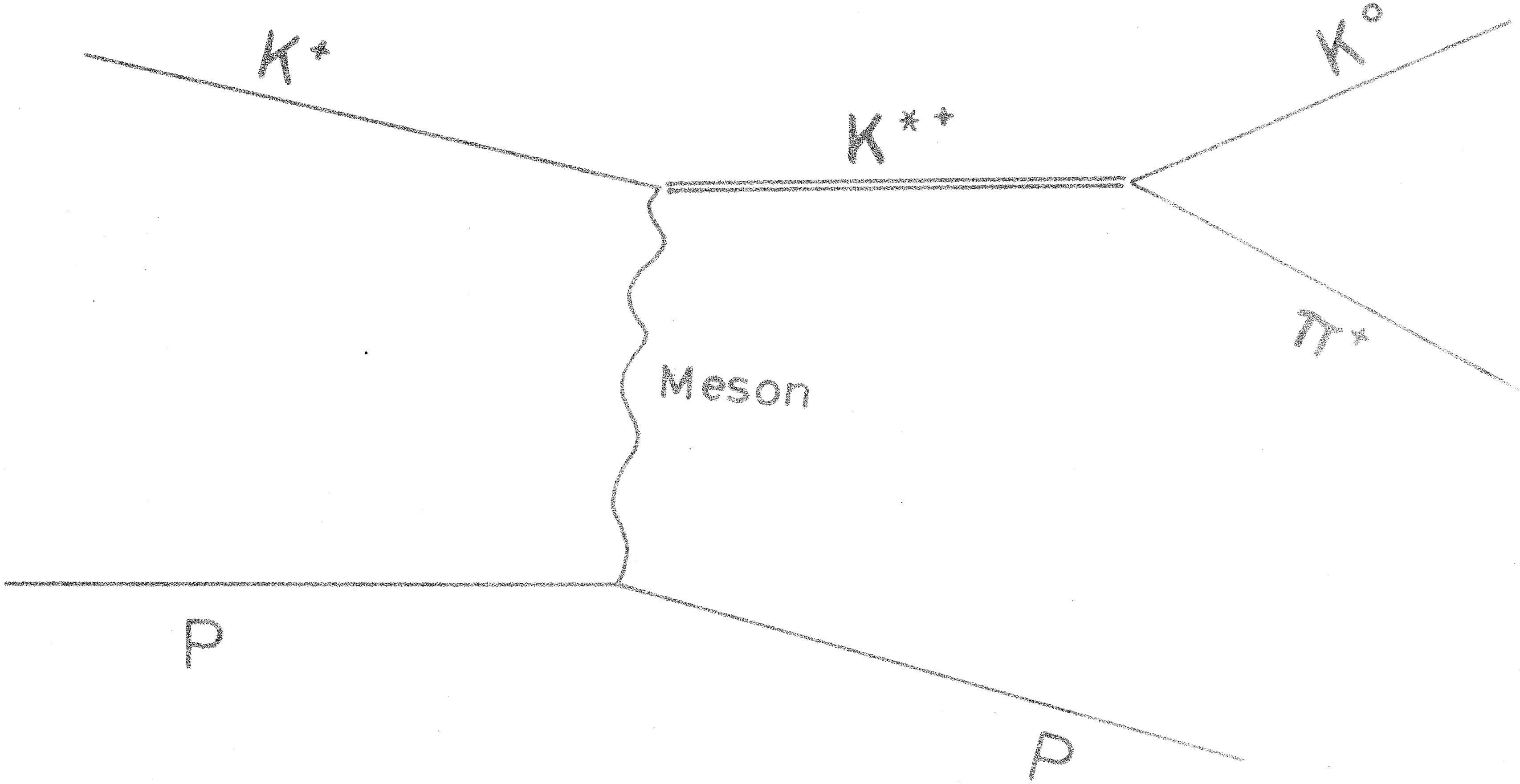

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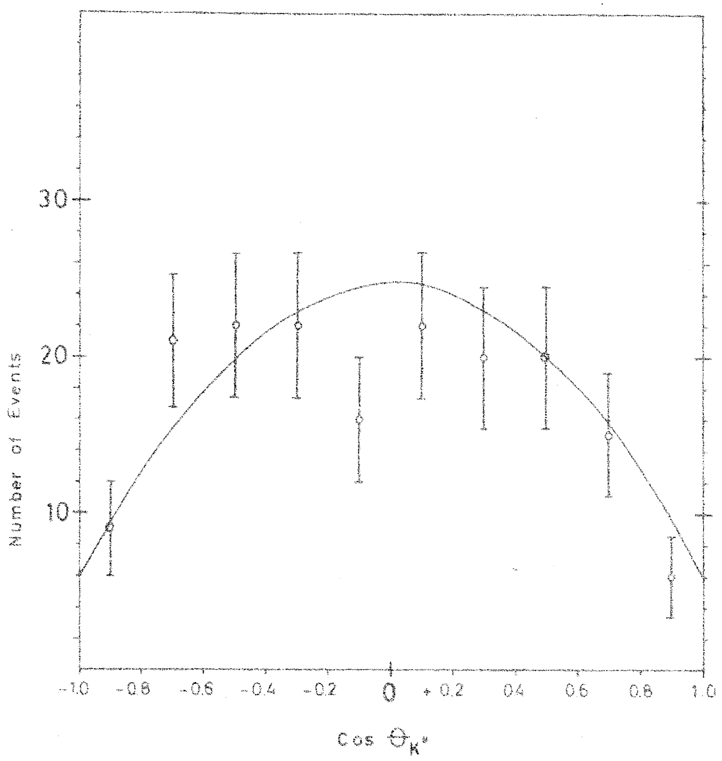

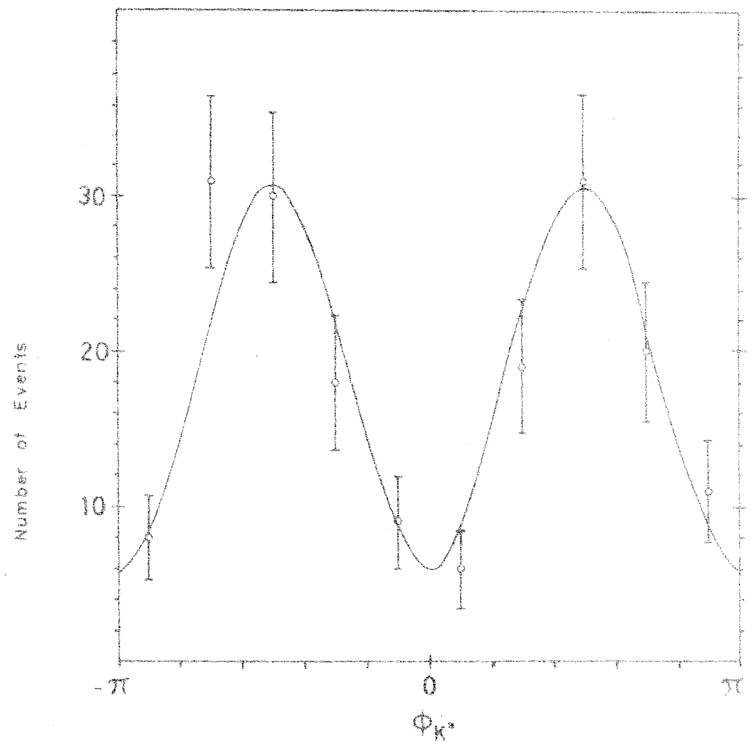

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