STUDY OF THE K^+K^- SYSTEM PRODUCED IN $\pi^+ d \to K^+K^- + X$ at 10 GeV/c

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I. Introduction

We propose to use the SLAC LASS facility to study the reaction $\pi^+ d \to K^+K^- + X$. As will be described below, we expect to obtain important information on several tests of the Okubo-Zweig-Iizuka (OZI) selection rule. These tests involve studies of the reactions $\pi^+ n \to K^+\phi^o\Lambda^o$, $\pi^+ n \to K^+K^- p$ and $\pi^+ p \to K^+K^-\Delta^{++}$. In the latter two reactions the attempt is to measure coupling constants such as $g_{\phi N\bar{N}}$ and compare with $g_{\phi K\bar{K}}$ and $g_{\phi\pi\rho}$. We will also study the reaction $\pi^+ N \to MN$, $M \to K^+\bar{K}^*$, $\bar{K}^* \to K^-\pi^+$ which is of particular interest to Reggeized Deck Models (here M is a heavy meson state - not necessarily resonant). In addition the reactions $\pi^+ n \to K^+K^- p$ and $\pi^+ p \to K^+K^-\Delta^{++}$ will allow the study (through the usual extrapolations to the pion pole) of the meson-meson scattering reaction $\pi^+\pi^- \to K^+K^-$.

II. General discussion and Physics Questions

A. Overview

According to the quark model with ideal mixing, the ϕ meson is a pure state, $s\bar{s}$, of strange quarks. It is therefore of immediate interest to investigate the mechanism of ϕ production in interactions of non-strange mesons. This is particularly important in view of the fact that there may be a close analogy with the production of ψ mesons (or of charmed states) from non-charmed hadrons.(1,2) An important idea in understanding such processes is the OZI selection rule,(3) which states that the quark-antiquark pair in the meson do not annihilate, but that production and decay take place through planar connected quark diagrams. The K^+K^- decay mode of the ϕ^o has the experimental advantage that in low multiplicity final states it produces a clean and efficient trigger for use with the LASS system. An experimental set up in which the LASS System is used to preferentially trigger on K^+K^- events would therefore produce a large amount of data of the reactions involving ϕ mesons. This data can be studied to better understand the $s\bar{s}$ quark systems, to help refine the theoretical models for such states, and to illuminate theoretical models for other unusual quark combinations such as $c\bar{c}$.

Production of ϕ mesons is not the only mechanism which feeds the $K^+K^- + X$ reaction. The other mechanisms are also worthy of detailed study. For example, the process $\pi^+N \to \overline{K^{*o}}\, K^+N$, $\overline{K^{*o}} \to K^-\pi^+$ will create events which produce a trigger. Such events can be studied in terms of a Reggeized Deck Model and can produce data with which such models can be refined and tested. In addition, $\pi^+\pi^-$ scattering into K^+K^-, for example in the reaction $\pi^+n \to K^+K^-p$, will also feed the K^+K^- final states. In addition to studying $(K^+K^-) + p$ final states it is possible to study $K^+ + Y^o$, with $Y^o \to K^-p$ in the same data.

B. Trigger Considerations

With an incident pion beam of about 10 GeV/c it is proposed to run the LASS System with a fairly loose multiplicity trigger and with the requirement that no charged particle produce light in C1 (the segmented Cerenkov Counter at the exit end of the solenoid system). The multiplicity will be defined using hodoscopes in the region between C1 and the dipole magnet. The requirement here will be that 2, 3, or 4 charged particles be detected. The threshold in C1 (using Methyl Chloride as the gas) would be set at $\beta \sim .998$ ($p_p \sim 16$ GeV/c, $p_K \sim 8.5$ GeV/c, $p_\pi \sim 2.4$ GeV/c). In this configuration ϕ mesons produced at the pion vertex will trigger the system with high probability independent of the baryon vertex configuration, because any charged pions emitted at the baryon vertex will be low momentum pions in the laboratory. Reactions such as $\pi^+ + n \to \phi^o + p$ where all final state particles are heavy will not produce a veto signal in C1. On the other hand, the reaction $\pi^+ + p \overset{Y}{\to} \Delta^{++} + \phi^o$ will, in the case of a baryon exchange graph, have trigger efficiency less than 50% since if the π^+ emitted in the Δ^{++} decay has $p_\pi > 2.4$ GeV/c it will veto the event. Other reactions o interest such as $\pi^+ + n \to K^+\phi^o\Lambda^o$ will have trigger efficiencies of nearly 100%. Monte Carlo studies of trigger rates for final states with no strange particles vary from <1% (typical for any reaction with a fast "leading" π^+) to ∿ 25% for a six-prong with the fastest pion being a π^o. We estimate the cross section for $\pi^+ + d \to K^+K^- + X$ to be ∿ 1 mb at 10 GeV/c,[4] and using the known cross-sections for other π^+d reactions, the ratio of K^+K^- events satisfying the trigger to π events satisfying the trigger is

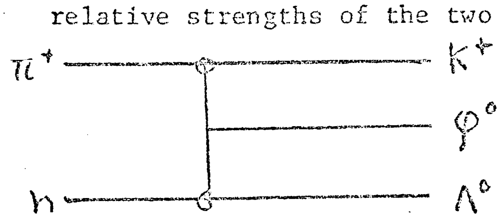
$$\frac{K^+K^-}{\pi} \sim \frac{1}{1}$$

(for a more detailed discussion of trigger considerations see Section III). Information on the estimated trigger efficiency for every reaction considered in the discussion of the physics of this proposal is contained in Table I.

C. Physics Considerations

(i.) $\pi^+ + n \to K^+\phi^o\Lambda^o$

If this process is observed with reasonable statistics it would allow an excellent study of the OZI rule within one final state. By studying the four-momentum transfers from the incident π^+ to either the K^+ or to the ϕ, the relative strengths of the two diagrams:



and

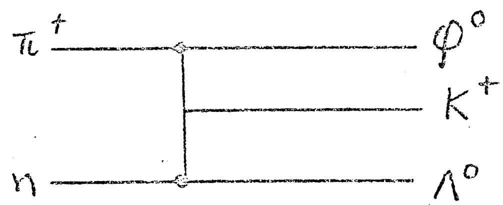


Diagram 1 Diagram 2

may be compared directly. We emphasize the fact that the first diagram is a connected quark graph, while the second is an OZI violating disconnected graph. Unfortunately no measurement of this cross-section exists at any energy to our knowledge. Simple considerations yield lower bound estimates of ∿ 50 nb. and upper bound estimates of ∿ 1 μb (See Section IV). Fairly detailed multi-Regge calculations (K.E. Lassila) yield estimates of ∿250 nb.[5], however these calculations have not included all of the possible diagrams so a more appropriate estimate of the cross-section from these calculations might be in the range of 200 to 700 nb. How many events in this final state are needed to make a definite conclusion about the rate of OZI violation is unfortunately a function of this rate itself. There are too many unknown factors to be able to conclude that we can successfully study the OZI rule in this final state. However, it is so interesting that we have used this final state to calculate running times. Our conclusions from this study (See Section IV for more details) are as follows:

(1) If $\sigma(\pi^+ n \to K^+\phi^o\Lambda^o)$ is ≥ 500 nb and the intensity of the "OZI violating" diagram is ≥ 10% of the other diagram, we can do a good job with ∿ 500 hrs. of experimental running time. With about 500 hrs. we have a chance to be able to do a good job for a 10% violation even if the cross-section is ∿ 200 nb. This would require using events (Λ^o or Σ^o) where the Λ^o is not seen (neutral decay or failure to reconstruct) but is inferred from the missing mass alone. (To insist on Λ reconstruction imposes a factor of 3 reduction in event rate.) In the absence of real data for the missing mass distribution in this reaction, using LASS, it is not possible to conclude whether such events can be used for this analysis or not.

(2) The two major questions, the rate for this process and the usefulness of the missing mass events can be settled with 100 hrs. of running time.

(3) Most other channels of interest will have sufficient statistics with 100 hrs. of running.

Therefore we request 100 hrs. of running followed by at least 4 months off of the machine. During this time we will try to isolate the $K^+\phi^o\Lambda^o$ sample.

If we can isolate 50 to 100 events in this final state from this preliminary data we request an additional 400 hrs. to complete this study.

If we have $\sim$ 400 events in the $K^+\phi^o\Lambda^o$ final state, the separation of the two Feynman graphs that have been considered seems to be straightforward. The most basic variables to use seem to be t_K and t_ϕ where t_i is the square of the four-momentum transfer from the incident pion to particle i. We generated 350 events of the OZI obeying diagram with the dependence on $t_K \sim e^{3.5t_K}$ and 70 events of the OZI violating diagram with the dependence on $t_\phi \sim e^{3.5t_\phi}$. This Monte Carlo data is shown in Figure 1 as circles and dots. A rather simple analysis then resulted in attributing 347 events to the OZI obeying process. In addition to the statistical uncertainties, the separation of the overlap region was estimated to contribute an uncertainty of $\pm$ 6 events in the 347 events.

It should be emphasized that one difficulty in this study was that the two diagrams were treated in an incoherent fashion. If both diagrams contribute appreciable amounts of data, the effects of coherence in the overlap region of the t_K, t_ϕ variables can be evaluated.

(ii.) $\pi^+ n \to \phi^o + p$

A 100 hr. run would have $\sim$350 events/μb with $\phi^o \to K^+K^-$ (ignoring inefficiencies for event reconstruction). At 15 GeV/c the reaction $\pi^+ p \to \phi^o \Delta^{++}$ has been observed by Baltay et al[6] and the cross-section is estimated to be $\sim$ 13 μb. (Other estimates for $\sigma(\pi^+ n \to \phi^o p)$ are $\sim$.35 μb.[7]) Therefore we should have $\sim$ 120 events in the $\phi^o p$ final state. (For 500 hrs. this would be > 600 events). A study of the t distribution should therefore be possible. Events in which the proton is produced forward and the ϕ^o backwards in the center-of-mass should serve as a measure of the coupling constant $g_{\phi N\bar{N}}$. This coupling constant is at present thought to be small but would be expected to be of the order of $g_{\phi\rho\pi}$ which also violates the OZI rule.

(iii.) $\pi^+ p \to \phi^0 \Delta^{++}$

Here one would expect ~4500 events for 100 hrs. In this case, however, the nucleon exchange case is suppressed by the trigger. The estimated trigger efficiency for this reaction varies from 1.0 for $|t_\phi| \leq 1\ (GeV/c)^2$ to ~ 0.6 for $|t_\phi| \sim 2\ (GeV/c)^2$.

(iv.) $\pi^+ + N \to K^+ + \overline{K}^{*0}(890) + N$,
$\quad\quad\quad\quad\quad\quad\quad\quad \mapsto K^- \pi^+$

The trigger efficiency for this final state varies with the momentum of the charged pion which results from the $\overline{K^*}$ decay. We point out that the kinematics using deuterium are such that a $\overline{K^*}$ which yields a missing neutral particle in the decay is not useful, i.e. missing mass in this configuration is not sufficient to identify the $\overline{K^*}$. Thus other charge states, e.g. $\pi^+ n \to K^{*+} K^- p$, $K^* \to K^+ \pi^0$, will not be useful. Even including all of these losses we should have 5000 to 6000 events from the channels completely determined, i.e. $\pi^+ N \to K^+ K^- \pi^+ N$. (For estimates on these cross-sections see Appendix B.)

The reaction $\pi^+ N \to K^+ \overline{K^{*0}} N$ is of particular interest to the study of Reggeized Deck models, as only two diagrams contribute:

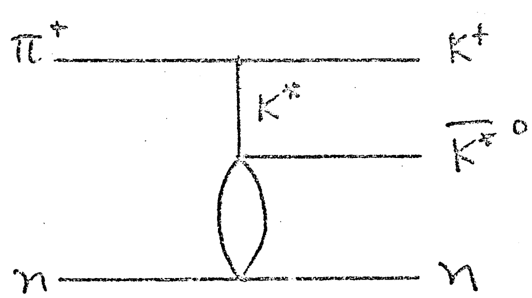


Diagram 3

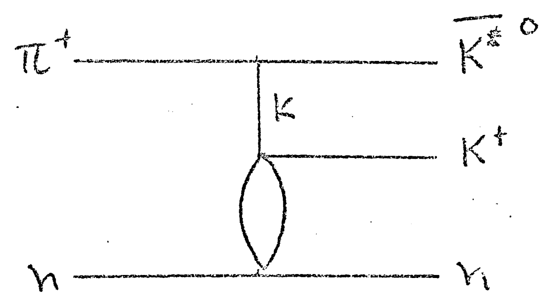


Diagram 4

which involve either K* or K exchange.[8] Since the final states are identical, these two diagrams interfere, and a prediction of the intensity involves the absolute square of the sum of the amplitudes. Thus the analysis would yield valuable information on the relative phases of the two amplitudes, and past experience indicates such phase information to be of importance in evaluating the claimed successes of Reggeized Deck Models.

(v.) Mass of Higher K^*'s

The cross-section for production of $(3K)^+$ by pions is unknown. It is possible however to study this system with statistics of about 700 events/μb. The $K\phi$ and Kf' systems are sub-systems of this $(3K)^+$ system. If a K^*-type resonance with width ∿ 100 MeV exists and has a product of production cross-section times branching ratio to 3K mesons ≳100 nb it should be possible to observe it in this experiment. Since π production of this system would be supressed relative to K production, and E-75 at SLAC has reported no such effects in K induced reactions, it is not likely that this experiment will yield a positive signal however the search of the data should be made and results published.

(vi.) Higher Mass Non-Strange Mesons $(2K)^0$

The Regge recurrence of the ϕ, the so-called ϕ', is expected at a mass of about 1.8 - 1.9 GeV/c^2. We have good acceptance for $M(K\bar{K})$ to nearly 3 GeV/c^2, and so should be able to observe such a resonance with good statistics if the product of its production cross-section and branching ratio to K^+K^- is ≳ 100 nb. Other decay modes, such as $(K\bar{K}^*)$ and $(\bar{K}K^*)$ will have about half the acceptance of the $(K\bar{K})$ mode due to the veto by a fast forward pion from the K* decay.

(vii.) $\pi\pi \rightarrow K^+K^-$ Scattering and Phase Shift Analysis

In (ii) and (iii) the result of the experiments reported in references 6 and 7 were used /to estimate that in a 100 hr. run there would be $\sim$ 8500 events of the reaction $\pi^+ n \to \phi^o p$ and $\sim$4500 events of the reaction $\pi^+ p \to \phi^o \Delta^{++}$. At 15 GeV/c the more general reaction $\pi^+ p \to K^+ K^- \Delta^{++}$ has $\sigma \sim 50$ μb,(6) and at 8 GeV/c it is 31 ± 5 μb.(9) The reaction $\pi^+ n \to K^+ K^- p$ at 5.4 GeV/c has $\sigma = 137 \pm 27$ μb.(10) If at 10 GeV/c we take the sum of these two channels to equal 120 μb (a very conservative estimate), then in a 500 hr. run there would be $\sim$ 200,000 events which could be used to study the $\pi\pi \to K^+ K^-$ scattering by the standard techniques of extrapolations to the pion pole. The presence of both the $K^+ K^- p$ and $K^+ K^- \Delta^{++}$ reactions in the same experiment provides an important test of extrapolation techniques, which differ for the two reactions.(11) The latest results on $\pi^+ \pi^-$ elastic scattering show sizeable effects at $K\bar{K}$ threshold due to the effects of unitarity and of the S* pole.(12) It would be interesting to study $\pi^+ \pi^- \to K^+ K^-$ scattering directly. This reaction has not been well explored; most of the data on the δ(970) coming from indirect channels such as $\eta\pi$.(13) High statistics in $\pi\pi \to K\bar{K}$ will eliminate the need for model dependent analyses, and opens a new avenue of exploration of the meson-meson interaction. The Argonne EMS group has a significant data sample of $\pi^- p \to K^+ K^- n$ and $\pi^+ n \to K^+ K^- p$ at lower energy.(14) However their analysis is restricted to the region $M(K\bar{K}) < 1.8$ GeV and backward $K\bar{K}$'s did not trigger their spectrometer. The higher incident energy of our experiment will allow good acceptance for $M(K\bar{K})$ to nearly 3 GeV, and furthermore will reduce the Chew-Low boundary and allow the physical region to get closer to the pion pole at all masses, thus reducing extrapolation errors. A 5100 event study of $\pi^- p \to K^o_s K^o_s n$ at 6 GeV/c published by the Notre Dame- Argonne group(15) has recently given evidence of a new I = 1 resonance in the S-wave $K\bar{K}$ system at 1255 MeV (Γ = 80 MeV). An Argonne preprint,(16) confirms the existence of the resonance but claims an Isospin of I = 0. Our 40,000 events (for the 100 hr. run) in the two reactions $\pi^+ p \to K^+ K^- \Delta^{++}$ and $\pi^+ n \to K^+ K^- p$ should resolve this question.

III. Detailed Trigger Considerations

The cross-section for $\pi^+ d \to K^+ K^-$ + anything has not been measured at 10 GeV/c. Three different methods have been used to estimate this cross-section as shown in Appendix A. If we take 1.0 mb as a reasonable estimate, then for original data reduction the worst case occurs if we have a 100% trigger efficiency for such events. For a 100 hr. run this would yield $\sim$ 700,000 events. More realistic estimates would be $\sim$ 600,000 events with $\sim$ 400,000 of these capable of being reconstructed allowing for known and/or estimated reconstruction efficiencies using the LASS system. Either of these is an amount of data which can be handled, particularly since a large fraction is really useful for physics analysis, as has been emphasized in Section II C.

For reactions which do not involve any kaons in the final state and which leak through the trigger extensive Monte Carlo calculations have been done. Table II shows the effects of the $\pi^+ p$ interactions at 10 GeV/c. These yield a trigger cross-section of $\sim$ 0.5 mb. If we double this to take into account the $\pi^+ n$ interactions we then have about 1.0 mb trigger from "no K" events or again $\sim$ 700,000 events on tape for a 100 hour run. While this is not ideal it certainly yields a manageable amount of data, that is $\sim 1.4 \times 10^6$ events on tape. The effect of reactions $\pi^+ d \to K^+ + X$ is difficult to evaluate. However, as a "worst case" estimate one might assume that these also contribute an additional 0.7×10^6 events on tape. (Some of this, for example $\pi^+ n \to K^+ \Lambda^o$, may also be interesting physics). Our conclusion from this is that the data from a 100 hr. run are manageable considering our available computational facilities. The data from the additional 400 hrs. would also be manageable if the $K^+\phi^o\Lambda^o$ reaction occurs with a frequency which makes that run advisable. We would however use the real data from the first 100 hrs. in an attempt to tighten the trigger for this additional running.

IV. Detailed Considerations for $\pi^+n \to K^+\phi^o\Lambda^o$

The diagram

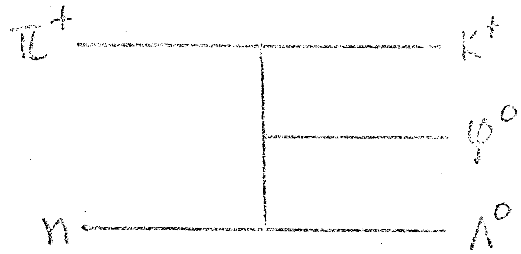


Diagram 1

for this reaction obeys the OZI rule and the diagram

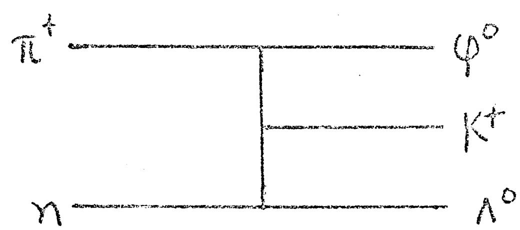


Diagram 2

does not obey the OZI rule. Since the cross-section for the process is not known it is necessary to try and develop estimates or at least "bounds".

A. <u>Lower Limit</u> (G. Kane's suggestion)

In this method one tries to generalize from two body reactions such as $\pi^+n \to K^*\Lambda$ and $\pi^+n \to \phi + N^*$ where K* (or N*) means any massive system which can decay to $K\phi$ (or $K\Lambda$). A conservative estimate is that typical cross-sections for each two body channel are 1/3 to 1/2 μb. Then one sums over-all such channels and gets $\sigma \gtrsim 1$ μb for such two body reactions. But now average values of the branching ratios for $K^* \to K\phi$ and $N^* \to \Lambda K$ must be put in. For the N^*, one can use averages of known real N^* systems and 5% is reasonable. For branching ratios of $K^* \to K\phi$ one uses SU(3) models. The range is ∿ 2% to ∿ 10% and so one would take ∿ 5% as an average. The result then is 1 μb × 0.05 ∿ <u>50 nb as a lower limit</u>.

B. <u>Upper Limit</u> (G. Kane's suggestion)

The general approach of this method is to treat ϕ and Λ^o production as having independent probabilities and therefore the probability for $\pi^+ n \to \phi^o \Lambda^o + X^+$ to be the product of these two probabilities. We estimate that at 15 GeV/c $\pi^+ p \to \phi^o + X^{++}$ has $\sigma \sim .25$ mb. Since this is a rough estimate anyway we will take the same σ for $\pi^+ n \to \phi + X^+$ at 10 GeV/c. For $\sigma(\pi^+ n \to \Lambda^o + X^+)$ at 10 GeV/c we estimate ∿ .5 mb to 1.0 mb. Then one would estimate that $\sigma(\pi^+ n \to \phi^o \Lambda^o + X^+)$ at 10 GeV/c to be given approximately by:

$$\left(\frac{.5\text{mb}}{25\text{mb}}\right) \times \left(\frac{.25\text{mb}}{25\text{mb}}\right) \times 25 \text{ mb} \approx 5 \times 10^{-3}\text{mb} = 5 \ \mu\text{b}.$$

The X^+ must have $S = +1$ but in some instances of course this will be $K^o + \pi^+ + (N\pi^o)$. If we assume no polarization in isotopic spin space the number of K^+ and K^o will be equal or ≈ 2.5 μb for $\pi^+ n \to \phi^o \Lambda^o K^+ + (n\pi)$. Now for this rough estimate one must ask what percentage have $n = 0$, i.e. no extra pions? So 2.5 μb is the upper limit in this view and if one uses phase space or known multiplicities at these energies one would take ∿ 40% for $n = 0$ (since there are already 4 particles in the final state $K^+ K^- K^+ \Lambda^o$) and a more realistic upper limit might be ∿ 1 μb.

Even as an upper limit these are very questionable estimates. For example in most channels in πn interactions, ϕ production is suppressed by the OZI rule. That suppression factor is automatically built into this estimate which is however for a channel in which the suppression is not valid. But we have no idea how much one should raise these upper limit numbers because of this argument, so in fact we will leave them alone.

C. Multi-Regge Calculations (K.E. Lassila)

Using standard Multi-Regge Deck model calculations Dr. K. E. Lassila has estimated a number of graphs contributing to $\pi^+ n \to K^+ \phi^0 \Lambda^0$ (all at 10 GeV/c).(5) The OZI rule violating graph

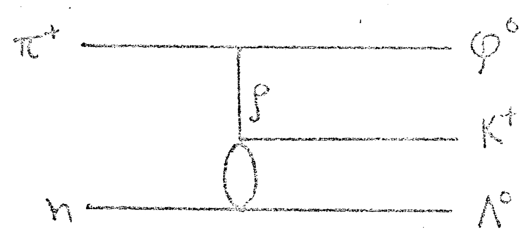


Diagram 5

has been estimated at $\sim$ 40 nb. In this, the amplitude for $\rho^+ + n \to K^+\Lambda^0$ has been taken to be equal to the amplitude for $\pi^+ + n \to K^+ + \Lambda^0$, with estimates for spin flip and kinematic corrections included.

In order to estimate

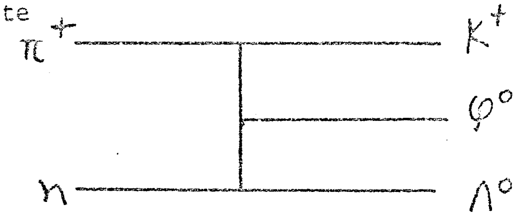


Diagram 1

he started with the diagram

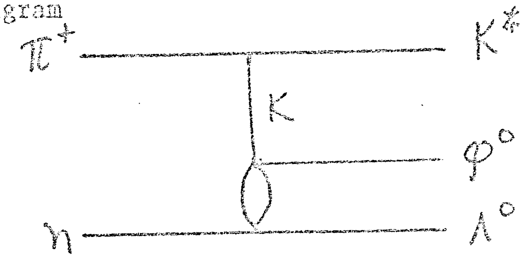


Diagram 6

and used known amplitudes for $K + n \to \phi + \Lambda$. This graph gives $\sim$ 50 nb. The graph

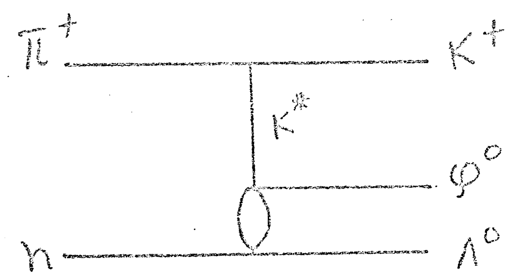


Diagram 7

would then be enhanced by two factors: (1) the increase in phase space with the lighter mass K^+ at the top vertex, or equivalently, the decrease in t_{min} necessary for $\pi^+ \to K^+$ instead of $\pi^+ \to K^*$ and (2) the fact that both spin flip and non-flip amplitudes contribute to graph 6 and only the flip amplitude contributes to graph 7. Since these are at best rough estimates the effect of the change in t_{min} has been calculated but the $K^*n \to \phi\Lambda$ amplitude is taken to be equal to the $KN \to \phi\Lambda$ amplitude. Among other approximations made, this does not count the spin non-flip amplitude. The result is then $\sim$ 220 nb for this graph. So the two graphs total $\sim$ 250 nb. In addition for graph 6 the equivalent graph where Q is exchanged has not been included. Summing all of these, the best range for an estimate from these calculations would seem to be $\sim$ 200 nb to $\sim$ 700 nb. A summary of relevant cross sections may be found in Table III.

D. Effective Data Rates

Here we are dealing with two major uncertainties. The uncertain cross-section has already been discussed. Whether the events with the Λ^o not observed or reconstructed can be used is an additional factor of ~ 3 uncertainty. (Neutral Λ^o decay $\sim 1/3$, and because reconstruction in LASS requires p_T for each track > 75 MeV/c about 1/2 of the $\Lambda^o \to p\pi^-$ will not reconstruct). We have used the Hulthen wave function in a Monte Carlo generation of events for deuterium and then have examined the missing mass distribution for the Λ^o. In this case the FWHM was $\sim$ 150 MeV. This suggests that such events can be used. That may be putting too much weight on the computer simulation of LASS and a final decision is not possible without real data. (It is also a function of how fast the $\Lambda\pi$, $\Sigma\pi$, etc background rises from threshold). We will therefore try to calculate how many events can be observed per 100 nb per 100 hrs. for each of two cases, reconstructed Λ^o and all Λ^o. (Note, if the MM technique works then $\pi^+ p \to K^+ \phi^o \Sigma^+$ events may also be useful yielding an additional rate factor in the range of 1.5 to 2.0).

The $\phi^o \to K^+K^-$ rate is ~ 0.47. We will assume a total "event reconstruction efficiency" of 2/3. (Note: this efficiency does not include the 1/3 Λ^o reconstruction efficiency referred to earlier). So for 100 nb and 100 hrs. we would have:

I: $K^+\phi^o\Lambda^o$ (Λ^o reconstructed)	:	$70 \times .47 \times 2/3 \times 1/3 = 7$ events
II: $K^+\phi^o\Lambda^o$ (all Λ^o)	:	$70 \times .47 \times 2/3 = 21$ events
III $K^+\phi^o Y$ (i.e. Λ^o, Σ^o, Σ^+)	:	$70 \times .47 \times 2/3 \times 2 = 42$ events

The next question is how many events in this final state are needed to do a decent test of the OZI rule? If the answer is arbitarily set at 400 events, then Case I for 500 hrs. of running requires $\sigma(\pi^+ n \rightarrow K^+\phi^o\Lambda^o) \geq$ 1 μb.

Case II for 500 hrs. requires $\sigma(\pi^+ n \rightarrow K^+\phi^o\Lambda^o) \sim$ 400 nb.

Case III for 500 hrs. requires $\sigma(\pi^+ N \rightarrow K^+\phi^o Y) \sim$ 200 nb.

For this last case this would mean $\sigma(\pi^+ n \rightarrow K^+\phi^o\Lambda^o)$ of ~ 100 nb.

For this analysis the states $K^+\phi^o\Lambda^o$, $K^+\phi^o\Sigma^o$ and $K^+\phi^o\Sigma^+$ are equivalent. The only important criterion is that there should not be an extra pion of any charge. If such a pion is present between the ϕ^o and the hyperon in the Feynman graph, the graph becomes an OZI violating graph.

The huge uncertainties which float around in this particular reaction lead us to suggest that a part of the data, ~ 100 hrs. , be taken first and the results of that run be used to evaluate the possibilities for continuing the study of this particular channel for an additional 400 hrs.

TABLE I. Monte Carlo Estimates of Trigger Efficiencies

Reaction	Diagram	Section and Page	Estimated Trigger Efficiencies
$\pi^+ n \rightarrow K^+ \phi^o \Lambda^o$	1	II.C.i, page 3 III, page 10 III.C, page 13	~ 0.93
$\pi^+ n \rightarrow \phi^o K^+ \Lambda^o$	2	II.C.i, page 3 III, page 10	> 0.99
$\pi^+ n \rightarrow \phi^o p$ [a]	–	II.C.ii, page 5	~ 0.95
$\pi^+ p \rightarrow \phi^o \Delta^{++}$	–	II.C.iii, page 6	1.00 for $\|t\|<1$ ~ 0.60 for $\|t\| \sim 2$
$\pi^+ N \rightarrow K^+ \bar{K}^{*o} N$ [b]	3	II.C.iv, pages 6 and 7	~ 0.66
$\pi^+ N \rightarrow \bar{K}^{*o} K^+ N$	4	II.C.iv, pages 6 and 7	~ 0.40
$\pi^+ n \rightarrow \phi' p$ [c] with $\phi' \rightarrow K^+ \bar{K}^{*-} + K^{*+} K^-$ with $\phi' \rightarrow K^+ K^-$	–	II.C.vi. page 7	 ~ 0.13 ~ 0.33

a) We assumed a distribution $\sim e^{4t_\phi}$

b) With the decay $\bar{K}^{*o} \rightarrow K^- \pi^+$ assumed.

c) We assumed a distribution $\sim e^{4t_{\phi'}}$.

Table II. Non-strange Contributions to trigger from $\pi^+ p$ at 10 GeV/c

Multiplicity	Channel	σ (mb)	Trigger Eff.	σ_{Trig} (mb)
2 prongs	all	~ 10.5		
	elastic	~ 4.8	0.00	0.0
	inelastic	~ 5.7	0.01	0.06
4 prongs	all	~ 9.5		
	$p\pi^+\pi^+\pi^-$	~ 1.5	0.01	0.02
	missing neutrals	~ 8.0		
	a.) fast $\pi^\pm$	~ 6.0	0.01	0.06
	b.) fast π^0	~ 2.0	0.10	0.20
6 prongs	all	~ 3.0		
	$p3\pi^+2\pi^-$	~ .4	0.01	0.00
	missing neutrals	~ 2.6		
	a.) fast $\pi^\pm$	~ 2.1	0.01	0.02
	b.) fast π^0	~ 0.5	0.25	0.13
$\geq$ 8 prongs	all	2.0	0.00	0.00

Total Non-strange trigger cross section ∿ 0.51

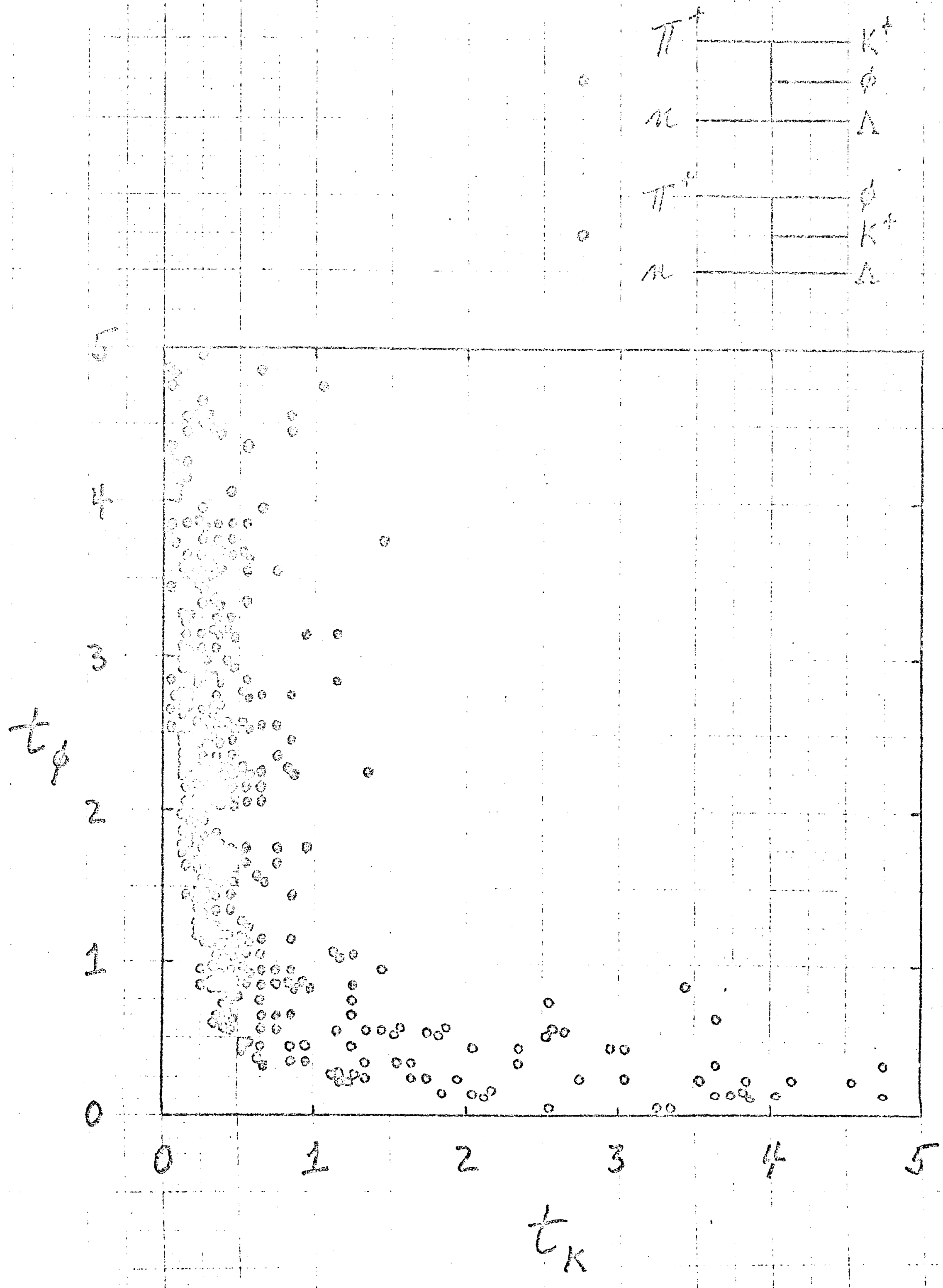


Figure 1

Table III. Summary of cross sections at 10 GeV/c

$\pi^+ d \to K^+K^- + \text{Anything}$	∿ 1 mb.	(See Appendix A)
$\pi^+ p \to K^+K^-\pi^+ p$	∿ 80 μb.	(73 ± 7 μb. at 8 GeV/c and 90 ± 10 μb. at 16 GeV/c)
$\pi^+ p \to K^+K^-\Delta^{++}$	∿ 50 μb.	(31 ± 5 μb. at 8 GeV/c)
$\pi^+ n \to K^+K^- p$	∿ 150 μb.	(137 ± 27 μb. at 5.4 GeV/c)
$\pi^+ p \to \phi\Delta^{++}$	∿ 13 μb.	(13 μb. at 15 GeV/c)
$\pi^+ n \to \phi p$	∿ .35 μb.	(.35 μb. at 11 GeV/c)
$\pi^+ n \to K^+\phi\Lambda$	200 nb. → 700 nb.	(See Appendix B)

Footnotes

(1.) J. J. Aubert, et al., Phys. Rev. Lett. 33,1404 (1974); Nucl. Phys. B89 (1975)1.

(2.) B. Knapp, et al., Phys. Rev. Lett. 34,1044 (1975).

(3.) G. Zweig, CERN-TH 412 (1964), unpublished; S. Okubo, Phys. Lett. 5 165 (1963).

(4.) See Appendix A.

(5.) K. Lassila, ISU. See Appendix B.

(6.) See e. g. C. Baltay, et al., in Argonne Conference Proceedings p. 289.

(7.) See e. g. R. Diebold, et al., Phys. Rev. Lett. 32,1463 (1974); or B. Hyams,
The number 13 μb is via private communication.
et al., Argonne Preprint ANL-HEP-CP-75-58; or T. Ludlam, thesis, Yale University (1969); or B. Hyams et al, Nucl. Phys. B22, 189 (1970).

(8.) K. Lassila and E. Pietilainen, ISU preprint 1976.

(9.) Aderholz, et. al., Nucl. Phys. B14, 255 (1969).

(10.) M. Farber, et al., Nucl. Phys. B29, 237 (1971).

(11.) For a discussion of the differences in extrapolation techniques needed for the Δ and neutron reactions see e.g. A. Firestone et al., Phys. Rev. D5, 2188 (1972); E. Colton and E. Malamud, Phys. Rev. D3, 2033 (1971); and Z. Ming Ma, et al., Phys. Rev. Lett. 23, 342 (1969).

(12.) S. Protopopescu, et al., Phys. Rev. D7, 1280 (1973).

(13.) See, for example, the sections on the ε, S*, $\delta(970)$ and κ in the Review of Particle Properties, 1974, pages 74 through 77, 83-84, and 102-103 and references contained therein.

(14.) See A. J. Pawlicki, et al., Phys. Rev. D12, 631 (1975), and A. J. Pawlicki, et al., Argonne Preprint ANL-HEP-PR-76-26.

(15.) N. M. Cason, et al., Phys. Rev. Lett. 36, 1485 (1976).

(16.) A. J. Pawlicki, et al., "Isospin of the New Scalar $K\bar{K}$ State," Comments to Phys. Rev. Lett. (in press).

APPENDIX A Estimate of $\sigma(\pi^+ d \to K^+K^- + \text{Anything})$

We have used three independent methods of estimating $\sigma(\pi^+ d \to K^+K^- + \text{Anything}$ at 10 GeV/c.

Method (1):

At 16 GeV/c,(A1), the sum of $\sigma(\pi^+ p \to \pi^+ pK^+K^-)$

$\sigma(\pi^+ p \to \pi^+ pK^+K^-\pi^o)$

and $\sigma(\pi^+ p \to \pi^+\pi^- K^+K^- n)$ is $\sim$ 210 μb.

At 13 GeV/c(A2), this sum is $\sim$ 160 μb.

At 8.5 GeV/c(A3), this sum is $\sim$ 180 μb.

At 8 GeV/c(A4), this sum is $\sim$ 200 μb.

At 5 GeV/c(A5), this sum is $\sim$ 270 μb.

We therefore guess that at 10 GeV/c $\sigma(\pi^+ p \to K^+K^-$ in four-prongs) $\sim$ 200 μb. Since $\pi^+ n \to \pi^+ nK^+K^-$, $\pi^+ nK^+K^-\pi^o$ and $\pi^o pK^+K^-$ are similar to the above three reactions, we double this cross section to $\sim$ 400 μb for deuterium. This is the estimate for four-prongs. We therefore scale this cross-section

$$\text{by} \quad \frac{\sigma(\geq 4\text{-prongs})}{\sigma(4\text{-prongs})} \approx \frac{16 \text{ mb}}{8.84 \text{ mb}} = 1.8$$

to get 1.8 x 400 = 720 μb.

Method (2):

Figure A1 shows $\sigma(\pi^+ p \to K\overline{K} + \text{Anything})$. The highest energy on this graph is 8 GeV/c. If we continue the trend to 10 GeV/c we get $\sim$ 2 mb. Of course, at some point this cross section will reach a maximum, turn over and begin to fall. We shall assume that this happens at or above 10 GeV/c. If the $I = 1$ $K\overline{K}$ system is unpolarized in isotopic spin space, and we make the extreme assumption of neglecting the $I = 0$ $K\overline{K}$ system we have to divide by

6 for K^+K^-, then multiply by 2 for deuterium and we would have 2/3 mb as the lower-limit estimate. If, on the other hand, we assume the I = 0 $K\bar{K}$ system is equal to the $I = 1, I_Z = 0$ $K\bar{K}$ system we only divide by 4 instead of 6 and we have an estimate of 1 mb. If, at the other extreme, the $K\bar{K}$ system is assumed to be pure I = 0, we would divide by only 2 (to account for $K^0\bar{K}^0$) and have an upper-limit estimate of 2 mb. These are the extreme limits, and the most likely case estimate is 1 mb.

Method (3):

$\sigma(\pi^+ p \to K^0\bar{K}^0$ + Anything) has been measured at 8.5 GeV/c[A3] to be 250 ± 75 μb. If we assume that the energy dependence here is the same as that for $\sigma(\pi^+ p \to K\bar{K}$ + Anything) , we would scale this up for 10 GeV/c as in method (2) above to get σ(10GeV/c) ∿ 335 μb. Then doubling this for deuterium would give an estimate of 670 μb.

Conclusion:

The three methods of estimating $\sigma(\pi^+ d \to K^+K^-$ + Anything)

yield: (1) ∿ 890 μb.

(2) from 667 μb. to 2 mb., with a best guess at ∿ 1 mb.

(3) ∿ 670 μb.

For this proposal we round the numbers off and use 1 mb. as the estimate. One-third to one-half of the estimated trigger rate for our experiment will scale linearly with the estimate for this cross-section.

References for Appendix A

(A1) ABBCCW Collaboration, TBP-71.

(A2) Gaidos, et al., Nucl. Phys. B32, 10 (1971).

(A3) Krebs, 1970 (Thesis).

(A4) Aderholz, et al., Nucl. Phys. B11, 259 (1969).

(A5) BDNPT Collaboration, Nucl. Phys. B16, 221 (1970).

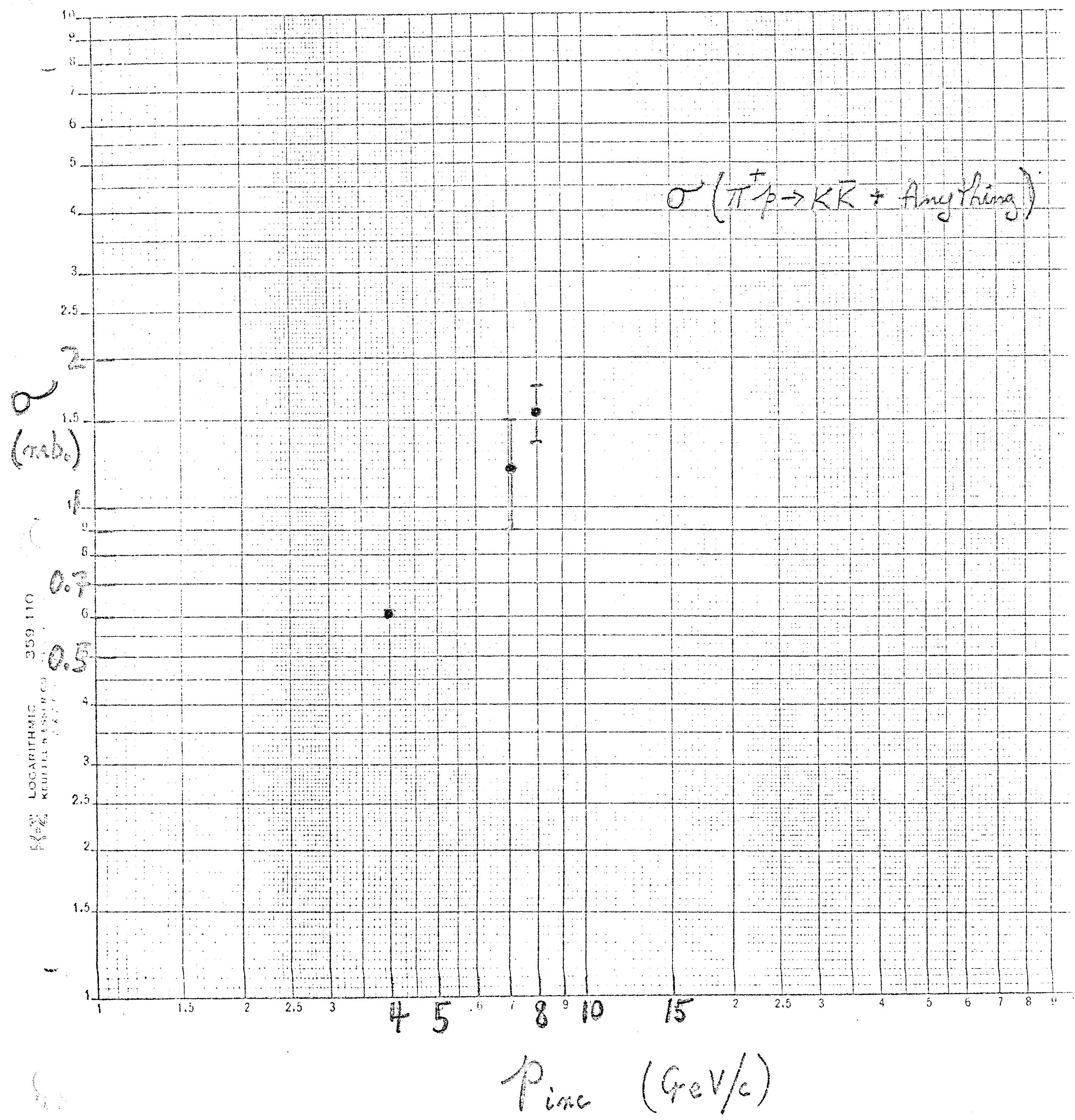

σ (π⁺p → KK̄ + Anything)
σ (mb.)
Pinc (GeV/c)
359-110 LOGARITHMIC KEUFFEL & ESSER CO.

Figure A1

APPENDIX B Discussion of Double-Regge Diagrams

by: K. E. Lassila and E. P. Pietiläinen

The double Regge exchange diagrams drawn in the text are expected to contribute strongly to and possibly dominate certain regions of phase space. Other contributions are usually there, but are harder to predict, and do not have the distinctive "signature" which labels the double Regge (particularly diffractive) contributions. The two theoretical calculations which will be elaborated on here are (I) $\pi N \to K^* \phi \Lambda$ and (II) $\pi N \to \bar{K}^* K N$.

(I) $\pi N \to K^* \phi \Lambda$: The process of interest, $\pi N \to K \phi \Lambda$, when written as a Regge-Deck amplitude involves subprocesses which have not been studied experimentally. Therefore, the $K^* \phi \Lambda$ final state was studied using the diagram

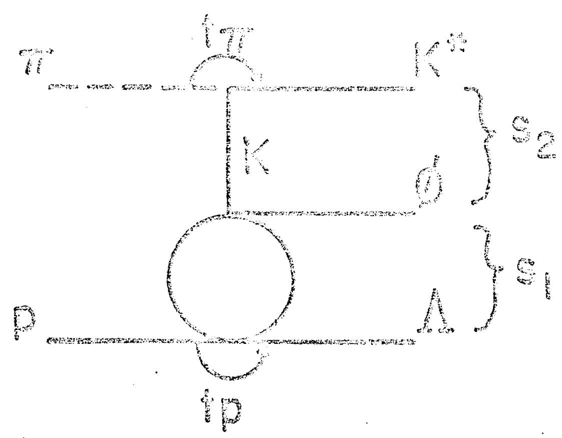


Diagram B.I.1

which also defines the kinematical variables. Additionally u_2 is the momentum transfer squared from the incident π to the outgoing ϕ. The amplitude can then be written as

$$A(s, s_2, s_1, t_\pi, t_p) = g(t_\pi) R(s_2, \alpha_K) \, A_{Kp \to \phi\Lambda}(s_1, t_p), \qquad \text{(B.I.1)}$$

where $g(t_\pi)$ describes the $K^* K \pi$ vertex, $R(s_2, \alpha_K)$ describes the Reggeized K exchange, and $A_{Kp \to \phi\Lambda}(s_1, t_p)$ is the amplitude for the subreaction $Kp \to \phi\Lambda$. For ease in programming we actually wrote the amplitude in terms of u_2 instead of the more standard t_π. The absolute value of $A(s, s_2, s_1, t_\pi, t_p)$ integrated over all of phase space with appropriate incident flux factors inserted gives the total cross section

$$\sigma_{\pi N \to K^* \phi \Lambda} = N \int d\Phi |A(s, s_2, s_1, t_\pi, t_p)|^2, \qquad \text{(B.I.2)}$$

where $d\Phi$ is the relevant phase space element and where the absolute value squared of the subprocess amplitude $|A_{Kp \to \phi\Lambda}|^2$ times the two body flux and appropriate 2π factors is obtainable from the measured total cross section for $K^- p \to \phi\Lambda$ as given in CERN-HERA72-2. Since $K^- p \to \phi\Lambda$ is a reaction which proceeds by spin flip, we parametrized the t_p dependence by an exponential times $\sqrt{-t_p}$ in the amplitude. The exponential was assumed to have a slope of 5 and the normalization was fixed by the $Kp \to \phi\Lambda$ cross-section. Both of the standard forms for the s_2 dependence of the Regge propagator squared were tried

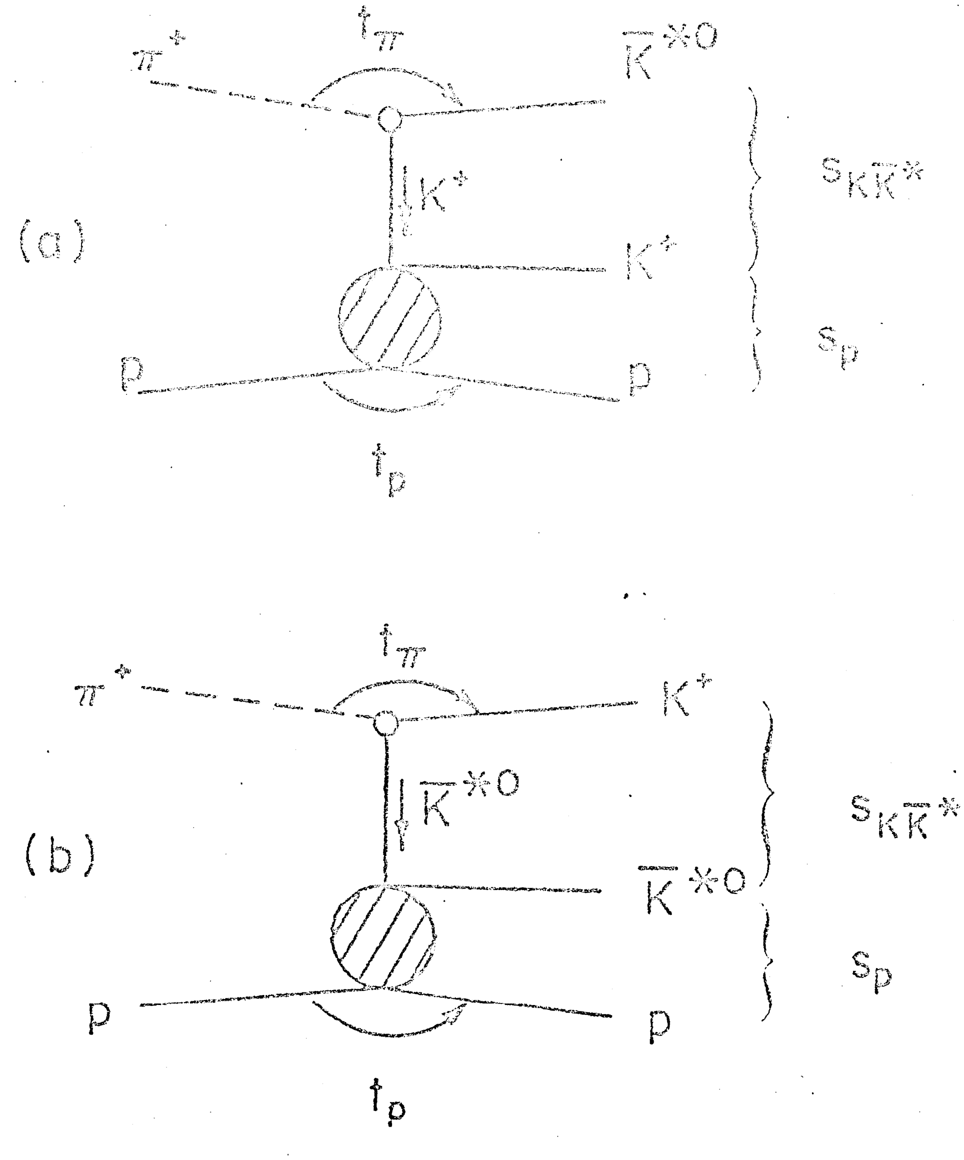
$$[\tfrac{1}{2}(s_2 - u_2)]^{2\alpha_K}/(m_K^2 - u_2)^2 \quad \text{and} \quad s_2^{2\alpha_K}/(m_K^2 - u_2)^2. \qquad \text{(B.I.3)}$$

The coupling constant was taken basically from K^* decay, requiring that at the pole position this match the Regge residue. We used the largest value for $g(t_\pi)^2/4\pi$, namely 1.66, which appears in the literature. This double Regge contribution to the $\pi N \to K^* \phi\Lambda$ reaction was calculated as a function of the incident lab momentum with the result [for these numbers $[\tfrac{1}{2}(s_2 - u_2)]^{2\alpha_K}$ is used] that a peak value of 44 nb was found at 12 GeV/c pion momentum; and, 35 nb and 41 nb were calculated for 10 and 15 GeV/c momentum. As described in the text, extrapolations from this one particular contribution in Diagram B.I.1 were then attempted, some with our experimental colleagues. We would be surprised if actual measurement gave an answer for the process depicted in Diagram B.I.1 greater than $\sim$55 nb or less than $\sim$25 nb.

In this calculation, the standard spinless particle assumption was made. This assumption generally gives a good order of magnitude cross-section estimate even for quite complicated processes. However, this calculation is an estimate of the cross-section for $\pi N \rightarrow K^* \phi\Lambda$ with an exchanged K while the process of interest is $\pi N \rightarrow K\phi\Lambda$ with any reasonable exchange K^*, K^{**} et cetera. For the reaction of interest the "two-to-two" sub-processes for which amplitudes must be used in the calculation are reactions such as $K^* N \rightarrow \phi\Lambda$ or $K^{**} N \rightarrow \phi\Lambda$. These processes are virtual and no data exists. Various guesses were tried and the results were always consistent with the estimates discussed in the text. The extrapolation from $K^*\phi\Lambda$ to $K\phi\Lambda$ in the text used only mass scaling. Our general conclusion then is that these estimates are reasonable and should not be off by an order of magnitude.

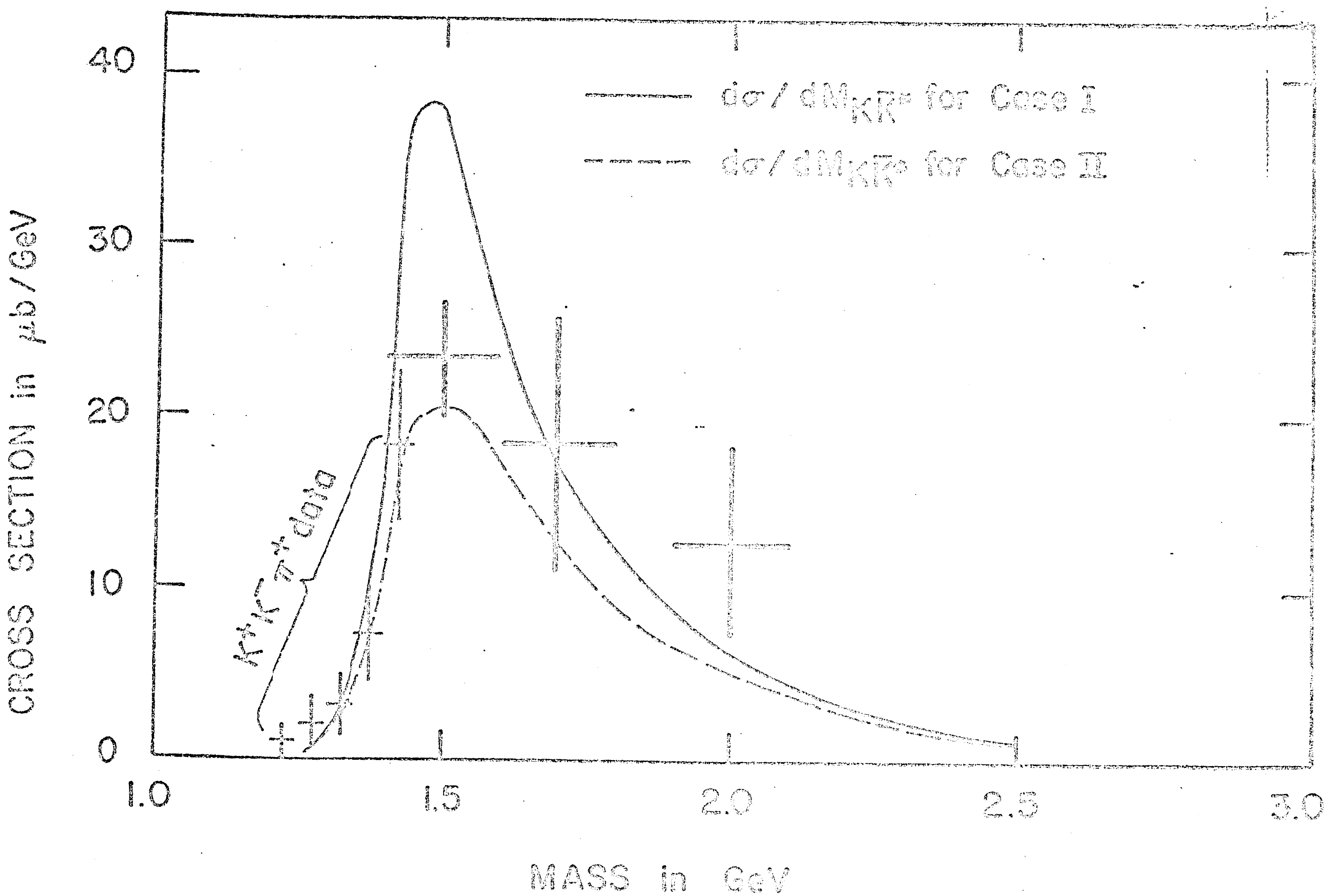
(II) $\pi N \rightarrow K\bar{K}^* N$: Since an important contribution to the Q enhancement is believed to be the diffraction dissociation of the incident K meson into a pion and a K^* (with subsequent rescattering by the pion from the target nucleon), the pion from crossing considerations must dissociate into $K\bar{K}^*$. Thus for $\pi^+ N \rightarrow (K^+ \bar{K}^{*o})N$ we can draw the two Reggeized-Deck diagrams shown in Fig. B.II.1 at the end of this appendix. The amplitudes for each of these are written in precisely the form indicated in Eq. (B.I.1), where the variable $s_2 = s_{K\bar{K}^*}$ and the 2-2 amplitude $A_{Kp \rightarrow \phi\Lambda}(s_1, t_p)$ is replaced by $A_{Kp \rightarrow Kp}$ or $A_{\bar{K}^* p \rightarrow \bar{K}^* p}$. At the start we assume spinless particles and also that the $\bar{K}^{*o} p \rightarrow \bar{K}^{*o} p$ scattering amplitude is well approximated by the amplitude for $K^- p \rightarrow K^- p$ to lowest order in the quark model. The result of integrating Eq. (B.I.2) over all variables except s_2 gives the curves shown in Fig. B.II.2. In this figure the calculation is compared with somewhat poor data at 16 GeV/c pion momentum for $\pi^+ p \rightarrow (K^+ K^- \pi^+)p$. An incoherent sum of the two amplitudes for each of the two Regge propagators is shown in this figure, with the solid curve given by the first form in Eq. (B.1.3) and the dashed curve given by the second form. In Figure B.II.3 we show the separate contributions due to K exchange and K^* exchange to the distribution in the effective mass squared of the $(\bar{K}^* p)$ system in the final state. Remarkably, a clean separation for a segment of the $\bar{K}^*$ exchange amplitude results if a cut is made, $s_{\bar{K}^* p} < 13 GeV^2$. It should therefore be possible to extract information on the $\bar{K}^* p$ scattering cross-section from the data in the proposed experiment. Given that a kinematical region can be found where $\bar{K}^* p$ scattering is evident, it should be also possible to extract information on the helicity amplitudes involved. These can be compared with the theoretical calculations of the type we are doing now which will allow one to say whether or not $\bar{K}^* p$ scattering conserves helicity and in which frame. Because $\pi N \to (K\bar{K}^*)N$ is cleaner (e.g., less possible contributing diagrams) than any of the standardly analyzed diffractive Regge-Deck processes, it could possibly provide the information that has been lacking to really tie down the ρK diffractive component of the Q meson.

From a more fundamental theoretical viewpoint the study of this reaction may also prove very revealing. Diffractive Regge-Deck processes appear certain to exist, but what should be done when two diagrams as in Fig. B.II., contribute in the same range of kinematic variables? Our expectation from the duality principle is that both diagrams in Fig. B.II.1 should be replaced by a single dual amplitude since the variable $s_{K\bar{K}^*}$ is the same for each diagram. In the appropriate kinematical limits this amplitude would be equivalent to the diffractive diagrams of Fig. B.II.1. Since this process does not have a contribution from the nucleon exchange amplitude as is the case in conventionally studied Reggeized-Deck reactions the data may give a good hint to theorists on how to proceed with deducing the true amplitude. A good way to proceed initially, then, is by fitting the data with the two contributions discussed on p. 6 of the text.



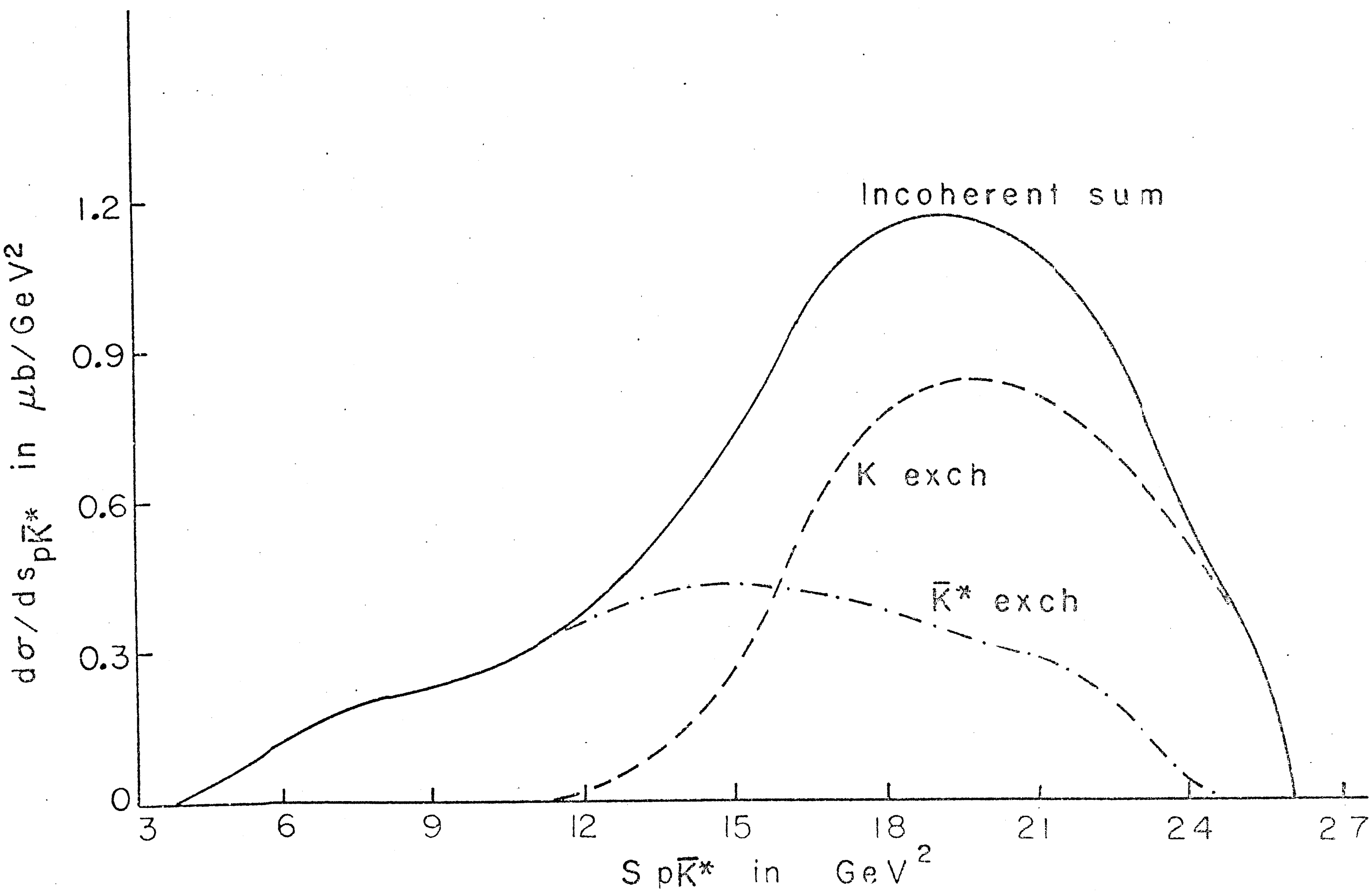
t_π
π^+
$\overline{K}^{*0}$
K^+
(a)
K^+
$s_{K\overline{K}^*}$
p
p
s_p
t_p
t_π
π^+
K^+
$\overline{K}^{*0}$
(b)
$\overline{K}^{*0}$
$s_{K\overline{K}^*}$
p
p
s_p
t_p

Figure B.II.1



40
30
20
10
0
CROSS SECTION in μb / GeV
1.0
1.5
2.0
2.5
3.0
MASS in GeV
dσ / dM$_{K\bar{K}^*}$ for Case I
dσ / dM$_{K\bar{K}^*}$ for Case II
$K^+K^-\pi^+$ data

Figure B.II.2



Incoherent sum
K exch
$\bar{K}^*$ exch
1.2
0.9
0.6
0.3
0
3
6
9
12
15
18
21
24
27
$d\sigma/ds_{p\bar{K}^*}$ in $\mu b/GeV^2$
$S_{p\bar{K}^*}$ in GeV^2

Fig. B.II.3

SLAC PROPOSAL NO. E-128
Received September, 1976

SUMMARY

1.) Title of Experiment: Study of the K^+K^- System produced in

$\pi^+d \to K^+K^- + X$ at 10 GeV/c.

2.) Spokesmen: W. J. Kernan and/or A. Seidl

Experimenters: Name	Institution
E. W. Anderson	Iowa State University and Ames Laboratory, ERDA
H. B. Crawley	"
A. Firestone	"
W. J. Kernan	"
D. L. Parker	"
J. Chapman	University of Michigan
B. P. Roe	"
J. Vander Velde	"
A. Seidl	"

Plus at least two postdoctoral physicists.

3.) Summary:

We propose to measure the cross-section for $\pi^+n \to K^+\phi^o\Lambda^o$. If this cross-section is large enough to yield $\geqslant 400$ events we will use this data to study the percentage violation of the OZI rule in this one final state. The events $\pi^+N \to \phi^o p$ will be used to try to evaluate $g_{\phi N\bar{N}}$. Searches for high mass mesons which decay into two or more kaons will be made. Phase shift studies of the reaction $\pi\pi \to K^+K^-$ will be made and the mass range will be extended beyond that available in the Argonne EMS experiment*.

4.) Equipment Required for the Experiment

LASS spectrometer including detection system and the on-line data acquisition

*See for example References 14 and 16.

32P

system.

· Liquid deuterium target.

Existing beam line 20/21.

5.) Estimate of time requirements:

π^+d at 10 GeV/c Run #1 100 hours at 100 pps.

If this yields sufficient events in the $K^+\phi^o\Lambda^o$ final state so that the OZI tests are possible then a subsequent run to be made.

π^+d at 10 GeV/c Run #2 400 hours at 100 pps.

In addition we will require ∿ 150 to 200 hours of low repetition rate for apparatus checks, trigger checks, alignment, etc. (Some of this time may b in conjunction with other tests, running, etc. This would have to be negotiated between the experiments, SLAC operations, etc.)

6.) Data Analysis:

a.) On-line: We will require the LASS Computer System, including the link to the 370/168 computer complex for data logging, experiment control and monitoring.

b.) Off-line: The reconstruction of the data from Run #1 will require the equivalent of ∿140 hours on the 370/168. We request from SLAC (1) the "minimal services" described in step 1, Appendix A, of "Interim Charging Policy for Triplex..." dated March 23, 1976, and (2) that ∿ 10% of our reconstruction be processed at SLAC for data checks (∿ 15 hours). The remaining reconstruction and data analysis for Run #1 will be done at our home institutions.

Available Computers:

University of Michigan	Amdahl 470
	PDP10 (HEP group)
Iowa State University	IBM 370/158 and 360/65
	PDP 11/45 (HEP group)

If run #2 is carried out we hope to refine the trigger so that the computing requirements for this are significantly less than a factor of 4 higher than those for Run #1 with the sharing algorithm to be essentially the same as that described for Run #1.