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K-MESON INTERACTIONS (EXPERIMENTAL)

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ALVAREZ: We have never seen any but I do not know what the limits are.

FILTHUTH: I want to come back to the discussion we had a few days ago concerning the  $K$  meson yield from  $\pi^-$ -proton collisions at 16 BeV/c as observed in our hydrogen bubble chamber, and the  $K$  meson production rate from an internal target of the CERN proton synchrotron.

We find 0.1  $K^0$  meson per  $\pi^- + p$  reaction. This corresponds to a  $K^0$  to (all)  $\pi$  fraction of 2%. For the ratio of  $K^0$  to  $\Lambda^0$  we get 3. This suggests that a large fraction of our  $K^0$  mesons come from  $K, \bar{K}$  pair production processes. Von Dardel and his group measured the  $K^+$  and  $K^-$  meson rate, for various momenta, from an internal target (aluminium and iron). They obtain (relative to  $\pi$  mesons of corresponding momentum) a  $K^+$  fraction of 8% and a  $K^-$  fraction of 2%. The large excess of  $K^+$  can be explained by assuming that most of the  $K^+$  mesons are produced in normal associated production reactions yielding  $Y + K^+$ . The  $K^-$  mesons are probably produced by secondary  $\pi$  mesons coming from proton-nucleon or pion-nucleon collisions inside the same nucleus. We know from our 16 BeV/c  $\pi^- p$  interactions that most of the secondary  $\pi$  mesons have momenta of the order of 2 to 3 BeV/c. At such

low energies the  $Y + K^+$  production is the governing reaction. The  $K^-$  mesons observed by von Dardel, which can come only from  $K\bar{K}$  reactions, have the same rate as our  $K^0$  mesons produced in hydrogen.

LEITNER: I would like to ask if you have considered the possible effects of the 900 MeV  $\pi^-$ -proton resonance on these angular distributions you showed?

SCHWARTZ: The point is the following. The cusp is a well-defined one. It is a very sharp "left turn" so you have to be very careful that you are seeing this behavior in a very small energy region compared to the energy region involved in this resonance. Secondly, the resonance seems to be in a rather high angular momentum state, and I don't see how you could understand the resonances having any effect on the  $S$  and  $P$  waves in this analysis.

LEITNER: If it were not a pure resonance there might be some  $S$  or  $P$  wave and it might take only slight amounts to affect things.

SCHWARTZ: A resonance exists in a particular state presumably. You can also take the possibility that the resonance exists in several states simultaneously. That would be a rather remote thing; at least we have never seen anything like that in the history of high energy physics.

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## K-MESON INTERACTIONS (EXPERIMENTAL)

Rapporteur: D. Miller,

Lawrence Radiation Laboratory, University of California, Berkeley, California

I would first like to summarize our knowledge of the detailed nature of the  $K$  interactions by starting at the lowest energies and proceeding up. At the end we may obtain an overall view of the  $K$  interactions by examination of the total cross sections over the energy range 0 to 10 BeV.

### I. K ABSORPTION PROCESS AT REST

Detailed studies of the absorption process have been carried out or are in progress for  $K^-$ -mesons stopped in  $H_2$ ,  $D_2$ , He, and emulsion nuclei. Rather than discuss all the charge states which may be pro-

duced, the major features may be summarized in Table I.

Table I. The percentages of direct  $\Sigma$ , direct  $\Lambda^0$ , indirect  $\Lambda^0$ , and non-mesonic absorption of stopped  $K^-$  mesons in  $H_2$ ,  $D_2$ , He, and emulsion nuclei

	$H_2$	$D_2$	He	Emulsion
Direct $\Sigma$ . . . . .	82%	67%	38%	
Direct $\Lambda^0$ . . . . .	18%	15%	27%	
Indirect $\Lambda^0$ . . . . . ( $\Sigma$ - $\Lambda^0$ conversion)		18%	35%	
Non-Mesonic Absorption . . . . .		$\sim 1\%$	$15 \pm 4\%$	$30 \pm 7\%$

Block has reported the interesting result that in  $61 \pm 6\%$  of the  $K^-$  absorptions in He in which a hyperon and a pion are produced directly (this excludes the  $\Sigma$ - $\Lambda^0$  conversion process), the three residual nucleons emerge as a bound  $H^3$  or  $He^3$ . From this observation he proposes a model of the  $K^-$ -He absorption process in which the elementary absorption always results in the production of an  $He^3$  or  $H^3$ . For the details of a subsequent isotopic spin analysis of reaction rates using this model see Session S 3.

The analysis of the angular distribution of 480  $\Lambda^0$ 's produced by  $K^-$  absorption in He has been reported by Leitner. The value of  $\alpha\bar{P} = 0.04 \pm 0.08$ , found for the asymmetry parameter, is consistent with the absence of longitudinal polarization in the sample. A measurement by the Munich and Turin groups of the asymmetry parameter of 345  $\Lambda^0$ 's produced by  $K^-$  mesons absorbed in emulsion nuclei has been reported by Gottstein (Session S 3). The result is consistent with the absence of any longitudinal polarization in the sample.

## II. BOUND HYPERON - NUCLEON SYSTEMS

### 1. Two-body systems

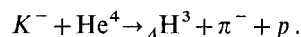
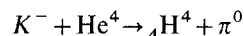
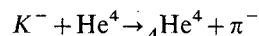
Gottstein (Session S 3) has reported a further search by the Bologna, Parma, and Munich groups for two-body hyperon-nucleon systems. In a group of 90 mesonic hyperfragments, no evidence was found for

$\Lambda p \rightarrow nn\pi^+$ . In 527  $\Sigma^+ \rightarrow p + \pi^0$  no evidence was found for  $\Sigma^+ p \rightarrow p + p$  or  $\Sigma^+ p \rightarrow p + n + \pi^+$ . Mass measurements on 43  $\Sigma^-$  tracks greater than 3 mm (an additional 15 were measured by Eisenberg at the Weizman Institute and by the Chicago group) showed no evidence for deuteronic mass.

The  $\Sigma^- n$  production reaction in deuterium was re-examined and the conclusion strengthened that the rate is substantially less than 1% of the free  $\Sigma^- n$  production. It would appear that the hyperon-nucleon interaction is not sufficiently strong to produce binding in a two-body system.

### 2. Hyperfragments with more than one nucleon

When  $K^-$  mesons are absorbed in He, hyperfragments can be produced with a baryon number greater than 2. In the work of the He collaboration group as reported by Puppi (Session S 3), the following reactions were identified by careful kinematic analysis



In addition it was possible to measure the ratio

$$r = \frac{\text{yield of } ({}_A He^4 + \pi^-)}{\text{yield of } (\Lambda^0 + He^3 + \pi^-) + \text{yield of } ({}_A He^4 + \pi^-)} = 20 \pm 7\%.$$

The importance of this quantity will be discussed further in the talk by Matthews. The systematics of the decays are reported in the proceedings of the conference.

## III. $K^-$ INTERACTIONS IN FLIGHT

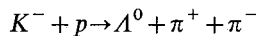
### 1. $K^-$ Interactions at 300 MeV/c and 400 MeV/c

At 300 MeV/c momentum, data in hydrogen and deuterium are available. Both results are from the Alvarez bubble chamber group at the Lawrence Radiation Laboratory. The hydrogen results were reported last year at Kiev and the deuterium work at this conference (Session S 3). The preliminary deuterium data were not in particularly good agreement with the requirements of charge independence,

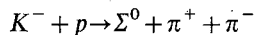
possibly because of the neglect of multiple pion production as well as the presence of small systematic errors in identification. Further investigation is under way. However, assuming charge independence, a fit may be made to the data. It was found that at 300 MeV/c the deuterium results are in substantial agreement (within 10 to 15% statistical errors) with the predictions of an impulse type of model, using the hydrogen branching ratios. In particular, the  $\Sigma$ - $\Lambda$  conversion process now accounts for only about 10% of the total  $\Lambda^0$  production. Since rescattering in the  $\pi n$  system should be about as important for  $K^-$  absorption at 300 MeV/c as at rest, the good agreement with an impulse model supports the assumption that the difference in the  $H_2$  and  $D_2$  results arises from the behavior of the energy dependence of the absorption amplitudes as well as rescattering in the hyperon-nucleon system.

In addition, since the branching ratios are similar, the absolute absorption rates on the neutron and proton should correspond to those of free particles. Using this assumption we found that the charge exchange cross section is about equal to that for free protons. At 400 MeV/c the relative absorption rates in hydrogen are qualitatively similar to those shown at 300 MeV/c, although the steady rise in  $\Lambda^0\pi^0$  production continues.

The next momentum interval at which new data exists is 1.15 BeV/c. The detailed analysis is in an early phase. In the work reported by Good (Session S3), the reactions



and



were examined. A first analysis of the fits obtained for these two hypotheses showed

$$\Lambda^0\pi^+\pi^- \text{ (50 events)}$$

$$(\Lambda^0 \text{ or } \Sigma^0)\pi^+\pi^- \text{ (92 events)}$$

$$\Sigma^0\pi^+\pi^- \text{ (27 events).}$$

A study of the ambiguous events allowed the tentative assignment 77 probable  $\Lambda^0\pi^+\pi^-$  and 15 probable  $\Sigma^0\pi^+\pi^-$ , so that

$$\frac{\Lambda^0\pi^+\pi^-}{\Sigma^0\pi^+\pi^-} \cong 3 \pm 1.$$

The momentum spectra for the pions are shown in Fig. 1. Good has pointed out that the events in the  $\pi^+$  peak must produce a corresponding kinematic peak in the  $\pi^-$  spectrum. The  $\pi^+$  peak corresponds to a total energy of  $1370 \pm 25$  MeV in the  $\Lambda^0\pi^-$  system. If one assumes the reaction is



a corresponding peak might be expected for the reaction  $K^- + p \rightarrow Y^{*+} + \pi^-$  where the hyperon isobar is produced with the opposite charge. Indeed, such a peak is evident in the  $\pi^-$  spectrum. In fact, the data are consistent with hyperon isobar formation in approximately 75% of the events. The full width of the peak is about  $\pm 50$  MeV. Since the relative momentum of the  $\Lambda^0\pi^-$  system at the peak is 200 MeV/c (compared to 230 MeV/c relative momentum

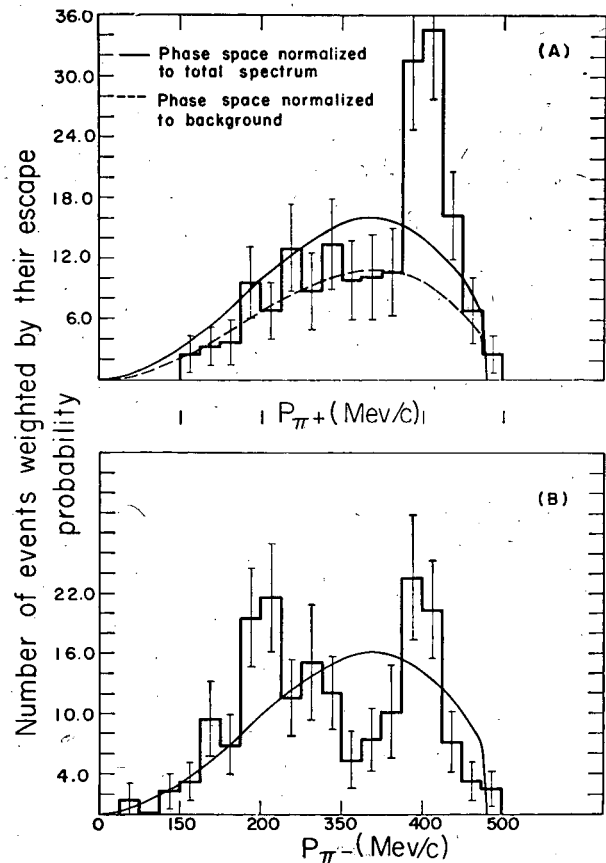


Fig. 1 Momentum spectrum in the  $K^-p$  center-of-mass of the  $\pi^+$  and  $\pi^-$  mesons emitted in the reaction  $K^- + p \rightarrow \Lambda^0 + \pi^+ + \pi^-$ . The solid line shows the phase space spectrum normalized to the total number of events. The dashed line shows the phase space spectrum normalized to the (background) events not in the high energy peak.

for the  $3,3 \pi N$  resonance) it is tempting to identify this resonance with that predicted by the use of global symmetry models.

It is apparent that much effort will be spent in the coming year confirming the existence of this resonance and measuring its properties, as well as searching for new resonances in other strange particle systems accessible to experiment.

#### IV. $K^+$ -NUCLEON INTERACTION

Because of the conservation of strangeness the  $K^+$  nucleon interaction does not result in the production of a hyperon with the disappearance of the nucleon. Therefore, the emphasis is placed on a measurement of the phase shifts required to describe the elastic and charge exchange scattering. Ticho has reported (Session S3) on the measurement of single pion production in  $K^+ - p$  collisions at 812 MeV/c. The cross section for this process is 1.4 mb. Very little detailed analysis of this process is available at present. With the exception of the counter experiments of Kycia, Kerth, and Baender<sup>1)</sup>, a large amount of the  $K^+$  scattering work has been carried out in nuclear emulsions. The  $K^+ - p$  scattering results indicated that  $s$  wave scattering dominates the  $T = 1$  state and that the total cross section is essentially constant at 15 mb up to momenta of 500 MeV/c.

Ticho has reported on a comprehensive  $K^+$  experiment carried out at the Lawrence Radiation Laboratory and at UCLA. An electrostatically separated  $K^+$  beam was used with suitable degraders to obtain scatterings in the momentum interval 0 to 800 MeV/c in both  $H_2$  and  $D_2$ . Some preliminary analysis of this work is now available. Their first efforts were directed at a determination of the  $K^+$  charge exchange cross section on deuterium. The total charge exchange cross section is shown in Fig. 2. The strong momentum dependence is apparent. No correction has been applied here for the operation of the Pauli principle, which is particularly important for scattering at small forward angles. Because of the relatively weak  $K^+$ -nucleon interaction it might be expected that the impulse model, without rescattering corrections, would provide a reasonable description of the  $K^+ - D$  interaction at high energy. Fig. 3 shows the distribution in momentum and angle compared to

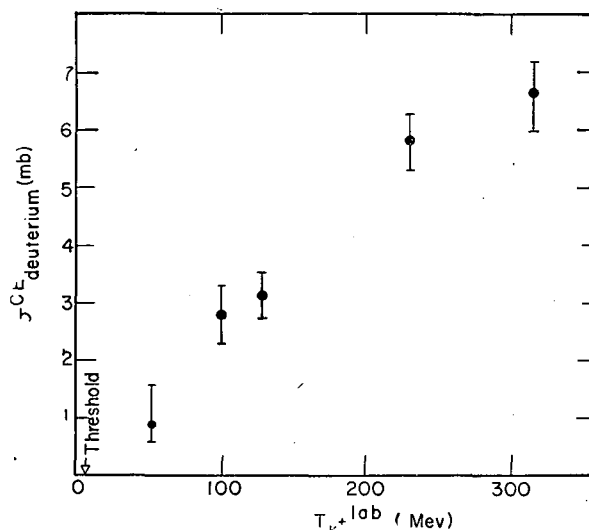


Fig. 2  $K^+ - d$  charge exchange cross section vs.  $K^+$  meson kinetic energy.

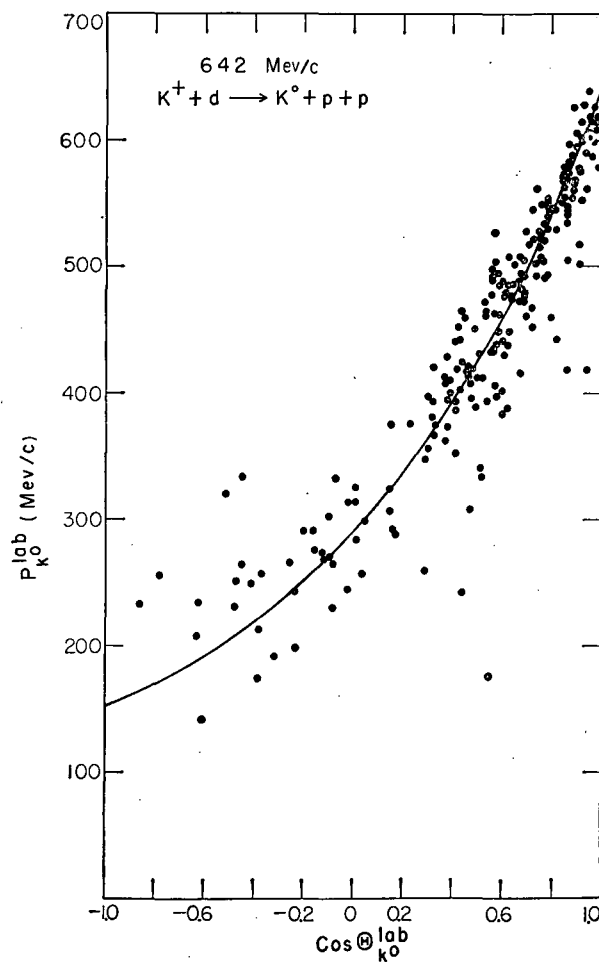


Fig. 3 Kinematics of  $K^+ - d$  scattering. The solid curve is calculated for free  $K^+$ -neutron collisions.

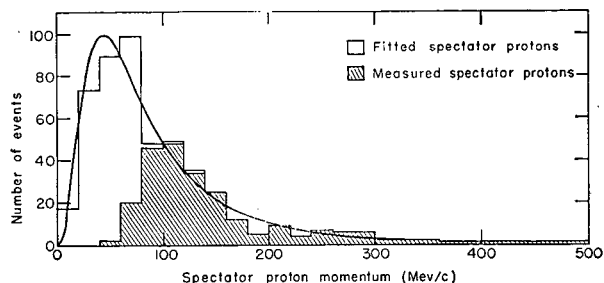


Fig. 4 Momentum spectrum of the recoil proton in  $K^+-d$  collisions. The solid line is the Fourier transform of the Hulthén wave function.

that expected for free  $K^+-N$  scattering. In Fig. 4, the momentum spectrum of the recoil proton is compared with the Fourier transform of the Hulthén wave function. The agreement is excellent. The results for the angular distributions are shown in Fig. 5. The measured angular distributions are shown for momenta 350 MeV/c, 530 MeV/c, and 642 MeV/c. The laboratory distributions have been converted to center-of-mass distributions in two ways.

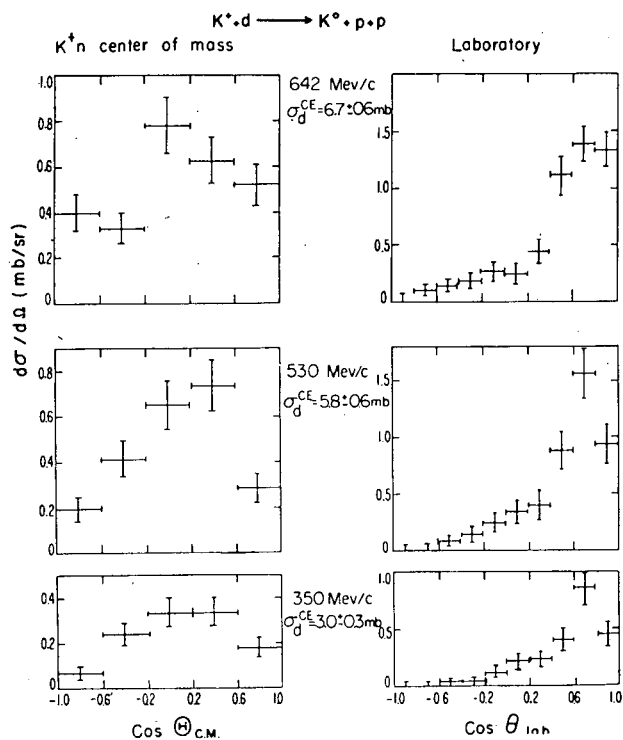


Fig. 5 Laboratory and center-of-mass distributions for  $K^+ + d \rightarrow K^0 + p + p$  at 30 MeV/c, 530 MeV/c, and 642 MeV/c incident  $K^+$  momentum.

First, the neutron was assumed at rest—secondly, in the spirit of the impulse model, the target neutron was assumed to have a momentum equal and opposite to that of the recoil proton observed. The results were substantially the same. The effects of the Pauli principle in the forward direction are apparent. Some preliminary phase shift analyses of these results have been attempted under simplifying assumptions, the details of which are given in Ticho's report (Session S3).

### V. K INTERACTIONS FROM 1 TO 8 BeV

Kerth has reported the results of an experiment at the Lawrence Radiation Laboratory in which the total  $K^-p$  and  $K^-n$  cross sections were measured in the energy range 0.6 to 3.8 BeV. The purity of the electronically selected  $K^-$  beam was better than 99%.

The total cross sections on hydrogen were measured by the "good geometry" transmission technique. An effort was made to determine the  $K^-n$  total cross section by using deuterium as a target. After the usual  $D_2-H_2$  subtraction, the Glauber correction was applied. This was usually about 10%. Von Dardel (Session S3) has reported on the measurements made by his group at CERN utilizing an electronically separated  $K^-$  beam up to 8 BeV/c. Total cross sections of  $K^-$  and  $K^+$  on hydrogen were measured. Fig. 6 shows the  $K^-p$  and  $K^-n$  cross sections as a function of  $K^-$  momentum.

The definite structure in the  $K^-$ -proton cross section occurring between 1 BeV/c and 2 BeV/c is better

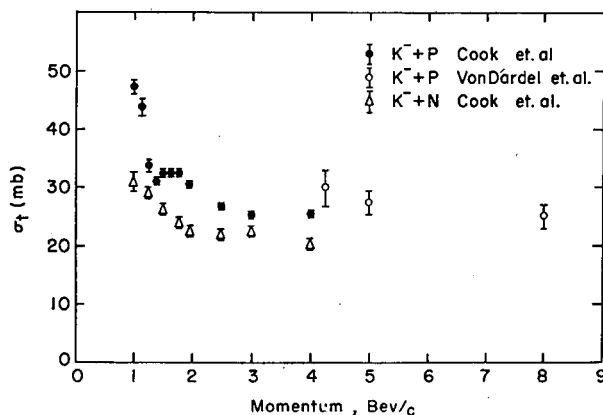


Fig. 6 Total  $K^-p$  and  $K^-n$  cross sections as functions of the laboratory momentum of the  $K^-$  meson.



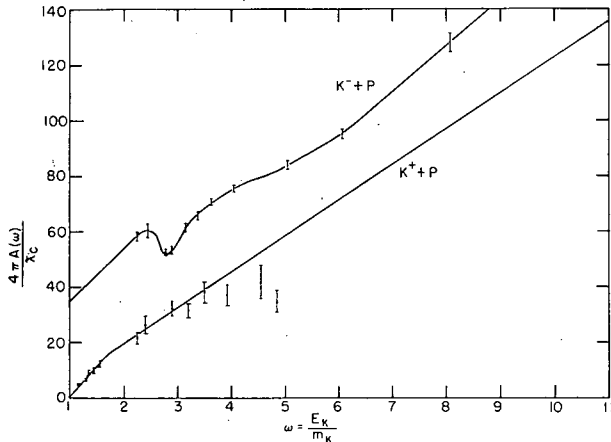


Fig. 7 The imaginary part of the forward scattering amplitude for  $K^-$  and  $K^+$ -proton collisions as a function of the total laboratory energy in units of the  $K$  meson mass.

demonstrated in the behavior of the imaginary part of the  $K^-p$  forward scattering amplitude as is shown in Fig. 7.

The charge exchange cross section was determined by counting the events in which a  $K^-$  entered the target and no charged particle or  $\pi^0$  emerged. The  $\pi^0$ 's were detected by surrounding the target with a  $1/4$ " wrap of lead and an array of counters. Presumably, only  $K_2^0$  mesons could then escape undetected. In the interval 1.0 to 3.5 BeV/c the charge exchange cross section was found to be between 2 and 4 mb.

The available  $K^+p$  data is presented in Fig. 8. The data of Lykhachev et al measured at Dubna and reported at this conference by Chuvilo (Session

S 3) are included. Whether or not the remarkable structure in the  $K^+p$  cross section suggested by the data is valid must be determined by further experiment.

Kerth also reported the measurement of the elastic scattering angular distribution at 1.95 BeV/c in the angular interval  $4^\circ$  to  $25^\circ$  in the laboratory. The data may be fitted using an optical model and yields an r.m.s. radius for the  $K^-p$  interaction of about 1 fermi. An interesting feature of the data is that the measured forward scattering cross section is significantly larger than  $\left| \frac{\sigma_T}{4\pi\lambda} \right|^2$  so that there is evidence for a real part of the forward scattering amplitude.

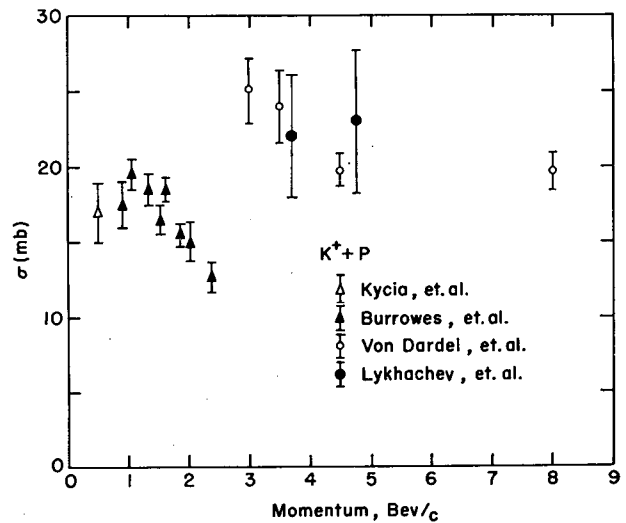


Fig. 8 Total  $K^+p$  cross section as a function of the laboratory momentum of the  $K^+$  meson.

#### LIST OF REFERENCES AND NOTES

1. Kerth, Kycia, and Baender. Phys. Rev. **118**, 553 (1960).

#### DISCUSSION

ALVAREZ: Miller spent some time talking about a search for the  $(\Sigma^-n)$  hyperfragment in deuterium. This was motivated partly by the fact that at Kiev there was a report of two  $(\Sigma^-n)$  hyperfragments. One of these has since been retracted in a very nice letter by Occhialini who pointed out that one of the

things that caught him was a mistake in a table of constants that he used for scattering. I wonder what happened to the other one. I once heard a rumor that this one was in bad repute. Is there anyone here who can say whether or not the remaining  $(\Sigma^-n)$  hyperfragment still looks good?

BLOCK: I have good second-hand information. I spoke to Occhialini this spring about this problem and the second event was in bad repute from the very beginning even before they discovered these errors in the good ones. As you mentioned the first published event was retracted. I might add one comment that in this same search, we also searched for  $\Sigma^-n$  and  $\Sigma^-nn$  events in  $K^-$ -helium interactions with essentially negative results. In order to clarify the remarks on hyperfragments, I might mention that the hyperfragments were formed in three reactions. One reaction is  $K^- + \text{He}^4 \rightarrow \pi^- + {}_A\text{He}^4$  and we found in a sample of 1100  $K$  stoppings some 25 of that type of reaction. Of these, in a selected sample of 15, 10 went into  $\pi^0$  decays, 3 into  $\pi^-$  decays and 2 into non-mesonic decays. The other reactions in which hyperfragments were formed are:  $K^- + \text{He}^4 \rightarrow \pi^0 + {}_A\text{H}^4$  (6 events) and  $K^- + \text{He}^4 \rightarrow {}_A\text{H}^3 + \pi^- + p$  (2 events).

Lastly, I would like to emphasize the difference between the helium data and the deuterium data by calling attention to the fact that approximately 25 MeV is lost to the final state since it is used to break up the alpha particle. This is the major difference in my mind between the helium data and the deuterium data. Therefore, this very rapid change of direct  $\Lambda^0$  production as Miller emphasized, indicates a rather rapidly varying matrix element for this process with the energy that is available. If you accept the " $\Lambda\pi$  resonance" as a possible explanation for this effect, the  $K^-n$  interaction in helium is much closer to the peak of the resonance which is at  $-62$  MeV in terms of  $K^-$ -nucleon kinetic energy. The deuterium data explores this matrix element very near zero MeV; we are exploring it in the  $-20$  to  $-30$  MeV range so that this might explain the somewhat pathological behavior of the direct  $\Lambda^0$  production.

SUDARSHAN: No mention was made of the binding energy of the hyperfragments. I just wanted to point out that the binding energies of the low mass number hyperfragments are very important for the analysis of the hyperfragments as well as for the phenomenology of the  $\Lambda^0$  nucleon interaction; in particular the binding energy of the doublet  ${}_A\text{H}^4$ ,  ${}_A\text{He}^4$ . There is a small difference between the two best values quoted for them (one would normally expect them to be equal) and the low energy  $\Lambda$ -nucleon

parameters are very sensitively dependent on this binding energy.

LEVI-SETTI: The two quoted values agree within experimental error; but there are no new values for these binding energies.

EISENBERG: I should like to comment about the non-mesic or multinucleon capture of a  $K^-$  in emulsion. The total rate turns out to be roughly 30% but the final state  $\Sigma^-n$  is missing. That is to say the matrix element for the  $K^-$  capture on two nucleons in the isotopic spin  $3/2$  state is presumably very close to zero in emulsion.

MILLER: There was another thing I meant to mention and that is the asymmetries looked for in  $\Lambda^0$  decay. There were two experiments performed—one was in the helium chamber with a sample of about 480  $\Lambda^0$ . Another, reported by Gottstein, was in nuclear emulsion with a few hundred events. In each case  $\alpha\bar{P}$  was consistent with zero. There was no evidence for longitudinal polarization of the  $\Lambda^0$  which were produced.

SAKURAI: I have two questions concerning the "Good" resonance. What is the width? Second, is it possible to perform an Adair type test to establish the angular momentum of the state in question?

GOOD: All the events in the peak are contained in an interval 100 MeV wide so that the full width at half maximum must be appreciably less than 100 MeV. It really has not been measured. We do not know what the experimental errors are so that any such number would be an upper limit to the width. As for an Adair analysis we hope so, and we will certainly try. There is also the possibility of determining the spin in other ways. For instance, if one defines the plane of production by the incoming  $K$  and the first  $\pi$ , the one which is emitted with the  $Y^*$ , the  $Y^*$  then might be polarized and the asymmetry of the  $\Lambda^0$  into which it decays might be quite different for  $s_{1/2}$ ,  $p_{1/2}$ , and  $p_{3/2}$  possibilities.

ALVAREZ: I would like to mention that since this resonance has been referred to many times as the "Good" resonance, I think Good would be the first one to say that he would like to hear the names of those who actually did find it while he was at Wisconsin. Namely Graziano, Wojcizicki and

Margaret Alston. They have been analyzing the data from the old  $K^-$  run.

LEITNER: I would like to point out that in the  $K^-$ -helium experiment designed to look for parity non-conservation in  $K^-$  helium interactions the average  $\Lambda^0$  momentum was of the order of 300 MeV/c and so is quite different from the Soloviev search which was at much higher energy (400 to 1000 MeV/c).

CHEW: I wonder if Good would like to explain why the  $\pi^+$  and  $\pi^-$  spectra associated with the  $\Lambda^0$  look different, one with two peaks and the other with one peak.

GOOD: Each event is plotted twice, since they each have a  $\pi^+$  and  $\pi^-$ . If you find a group of  $\pi^+$

in a peak then just from energy and momentum conservation there will be a low energy group of  $\pi^-$ . There also is a high energy peak in the  $\pi^-$  spectrum corresponding to a  $\pi^-$  made with a  $Y^{*+}$  and it in turn makes some low energy  $\pi^+$  so it is sort of complicated. Our results are consistent with producing the  $Y^*$  in both of its charge states in unequal numbers.

ALVAREZ: I think that does not quite answer the question of Chew, as to why the spectra look different. Good pointed out a few days ago, that in the same way as one has different production rates of  $\Sigma^-$  and  $\Sigma^+$  in  $K^-p$  reactions, one may have different rates of production of the  $Y^{*+}$  and  $Y^{*-}$  because of interference between the isotopic spin 1 and isotopic spin 0 production amplitudes.

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## STRONG INTERACTION OF STRANGE PARTICLES (THEORETICAL)

**Rapporteur: P. T. Matthews**

Imperial College of Science and Technology, London, England

It is my job to summarize the theoretical work on strong interactions of strange particles which was presented in Session S 3 last week. I shall attempt to do more or less this, but instead of trying to report everything, I have taken the liberty of concentrating on the three main topics which I think will be of the most interest to this large group. This means that I will omit, somewhat arbitrarily, some papers which lie outside these fields, and I apologize here and now to those concerned.

### I. DAY-SNOW SUCHER THEOREM

I should like to start with the present status of the Day-Snow-Sucher theorem<sup>1)</sup> which was one of the most exciting things presented at Kiev last year. As you know, this theorem concerns the  $l$ -values of the states from which nuclear absorption takes place in  $\pi^-$  or  $K$ -mesic atoms. Although it concerns

low energy atomic phenomena, it has, of course, very important implications in high energy physics, particularly in the determination of the spins and parities of elementary particles. The interpretation of the Panofsky experiment on  $\pi^-$  absorption by protons used to be based on what I shall call the Wightman picture, in which it was assumed that the  $\pi$  meson, after getting into an outer Bohr orbital, cascades all the way down to the ground state before absorption takes place. When this picture was applied to the  $K$ -meson it led to strongly competitive absorption from the  $2p$  state, owing to the larger mass and consequent tighter binding of the  $K$ -meson. It was suggested some eighteen months ago by Madansky that a possibly important effect was being neglected. On the atomic scale the mesic atoms are small objects and, from the point of view of the hydrogen atoms, they may be regarded as neutral particles. These neutral particles penetrate deeply into the hydrogen atoms, where they undergo Stark