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E-132 Extension

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Progress Report For E-132

A Study of $K^{-}p$ Interactions Using LASS

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Introduction

Experiment E-132 is a study of meson spectroscopy and meson production dynamics in K^-p interactions at 11 GeV/c. The two principle areas of interest are:

(i) the study of the hypercharge exchange reactions, $K^-p \to X^o \Lambda^o$ and $K^-p \to X^- \Sigma^+$, where X^o and X^- are non-strange mesons decaying into $K\bar{K}$, $\pi\pi$, $\pi\pi\pi$, $K\bar{K}\pi$, $K\bar{K}\pi\pi$ final states. These data will permit a search for many missing quark model $s\bar{s}$ states with good experimental sensitivity (e.g. the three missing 1^+ I=0 states in the 1.4 GeV region and the 3^- and radially excited $1^-\phi$ states expected in region above the f').

(ii) the study of the high mass natural spin parity K*'s and the unnatural spin parity Q and L spectroscopy using the $K\pi$, $K\pi\pi$, and $K\pi\pi\pi$ final states. The data from E-132 will enable us to extend the $K\pi$ and $K\pi\pi$ partial wave analyses of our previous 13 GeV $K^{\pm}p$ data (E75) to the high mass region above 1.6 GeV. Such partial wave analyses have proven to be both necessary and very successful at extracting resonance information from such data given sufficient statistics.

The large acceptance, good resolution and particle identification properties of LASS permits a higher statistics study of these meson states with higher mass and with higher decay multiplicity than has been possible with forward spectrometers. In proposal E-132, we demonstrated that a 500 hour run at 180 pps (equivalent) with a $\geq$ 2 charged particle forward trigger would yield an experimental sensitivity of 800-1000 events/μb for all these final states. Furthermore, this scale of experiment is necessary to provide sufficient data to perform successful $K\pi$ and $K\pi\pi$ partial wave analyses in the high mass region and to search with good sensitivity for the missing $s\bar{s}$ states.

Progress Report

We next report on our progress since the approval for 100 hours of data in January 1977. Following the completion of E-127 "The study of direct lepton production in $\pi^- p$ interactions at 16 GeV", in April 1977, substantial modifications to the LASS detector arrangement in the region between the solenoid and dipole magnets were undertaken. All of the equipment in this region was removed in order to install the light pipes and phototubes for the bottom 90^o of the Cerenkov counter C1 located at the exit of the solenoid. In addition a 28 element scintillation counter hodoscope was installed on the downstream end of C1 to provide (i) the multiplicity trigger for E-132, and (ii) particle identification of low momentum particles by time of flight. All E-127 shower counters were removed, and a 4th spark chamber and a 2nd 25 cm. square "plug" proportional chamber were added to improve track finding redundancy in this region. Finally,a new proportional chamber hodoscope with both X and Y readout was added. The LASS system was re-established by early June in time for initial test data runs by E-128, E-129, and E-132.

In June 1977, E-132 received 17 shifts for checkout and setup followed by 20 shifts (including 4 brownouts) for data collection. The performance and reliability of the entire LASS spectrometer was excellent during this period. Less than 3 data taking hours were lost during the whole data taking week due to problems with the LASS spectrometer. The efficiency of the spectrometer components was also excellent. For example, the gap efficiency of the 28 MS spark chamber readout planes ranged from 95 to 99%; the 27 planes of PWC readout were typically between 98 and 99% efficient; and the 35 readout planes of the CD spark chamber generally ranged between 85 and 95% efficiency. The K^- beam was very stable and easy to operate. The data acquisition and online analysis system performed smoothly as well.

Since the end of the data taking cycle, the prime focus of the analysis effort has been to make systematic studies of the LASS software and its improvement as well as developing an optimized set of constants for the production analysis. At present, we are dealing only with relatively small data runs for these studies and have not yet begun large scale production. In the small data samples now processed, we have reconstructed a clean sample of elastic events as well as $K_o \to \pi\pi$ and $K \to \pi\pi\pi$ decays. This effort is continuing.

During the data taking period, we recorded a total of 7×10^6 events on tape corresponding to 61×10^6 K^- particles incident on the .9 m hydrogen target. The trigger for this data consisted of a valid beam particle in coincidence with at least 2 hits in the scintillation counter hodoscope following C_1. The probability per incident beam particle that the trigger was satisfied was 0.115. This unexpectedly high trigger rate and the resulting significant losses from event dead time caused us to run the experiment at 2-2.5 K^- per pulse. This is a factor of 2 less than anticipated in the proposal and results entirely from the factor of 2 higher trigger rate; data taken at a higher incident flux indicates that all detectors operate at 5 incident particles per pulse with no difficulty.

During the June run and subsequently through off line analysis, we have studied and understand in detail the origins of the observed trigger rate. The essence of the problem is just that the target empty rate was 0.06, over 50% of the target full rate. Most of the non hydrogen rate comes from 2 sources of similar size: (i) hadronic interactions, primarily in the material between the target and the scintillation counter hodoscope but also a smaller amount from some entrance flanges in the target. (ii) K decay and one particle interaction final states that produce a δ ray of sufficient energy to spiral through the solenoid and reach the hodoscope. Through study of the data tapes, we have developed a hardward trigger that will remove these sources and yield a software measured trigger rate equal to 0.055 per incident K^-. This will be accomplished by i) building a new beam defining x-y scintillation quadrant hodoscope of smaller size (1/8" thick, 1.25" diameter) and ii) using the hardware PWC cluster logic developed for LASS to require 2 hits outside a 3.2 cm square deadened beam region in proportional chamber 1.5 which is 0.5 m. downstream of the hydrogen target. The requirement of 2 hits in the "twixt" region scintillation hodoscope will be maintained as well.

These modifications to the trigger system for E-132 lower the June trigger rate by a factor of 2 and enable us to increase the beam flux by the same factor to 5 K^-/pulse. This means that we will be able to operate LASS in the manner described in proposal E-132 and thus we will be able to attain our desired event/μb sensitivities in a 500 hour run. Because of the trigger rate limitation in June,we have approximately 10% of this data on hand. Therefore we request 450 hours at 180 pps to complete E-132. In addition we will require 1 week of setup and check out time specifically for E-132 purposes associated with each block of high rate time for data collection.

SLAC PROPOSAL E-132
Received December 29, 1976

SUMMARY

1. Title of Experiment: A Study of K^-p Interactions Using LASS.

2. Spokesman: R. K. Carnegie, B. N. Ratcliff

Experimenters:

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3. Summary:

We plan to study K^-p interactions at 10 GeV/c using the LASS spectrometer. The large acceptance, high resolution, and excellent particle identification properties of LASS allow the high statistics study of meson states of higher mass, spin and multiplicity than has been possible with the previous generation of forward spectrometers. In a 500 hour run at 180 pps(equivalent) using a multiplicity trigger, we expect to obtain a sensitivity of 800-1000 events/ub with nearly uniform acceptance in all kinematic variables. Of particular interest are the spectroscopy of high-mass, high-spin K^* states produced in final states such as $K\pi$, $K\pi\pi$, and $K\pi\pi\pi$; the extension of the partial wave analysis of the $K\pi$ and $K\pi\pi$ systems into the high mass region; and the study of hypercharge-exchange reactions, where a study of mesons decaying into $K\bar{K}$, $K^*\bar{K}$, $K\bar{K}\pi$, and $K\bar{K}\pi\pi$ will permit a systematic search for those $\lambda\bar{\lambda}$ states which are predicted by the quark model but have not been observed. The level of the experiment is sufficient to perform a detailed partial wave analysis of the L region of the $K\pi\pi$ final state as well as to search for and study the properties of new states with small production cross sections.

4. Equipment Required for the Experiment

- LASS spectrometer, including detection system and the on-line data acquisition system.
- 36" Liquid Hydrogen target
- Existing RF separated beam line 20-21 providing 5 K^-/pulse at 10 GeV/c.
- Time-of-flight hodoscope (furnished by Carleton University)

5. Extimate of Time Requirements

- Data (including empty target) 500 hours (180 pps equivalent)

In addition, we will require ~2-3 weeks of low repetition rate running for apparatus checks and alignment, plus the testing of the new Carleton University time-of-flight hodoscope.

6. Data Analysis

a) On-line: We will require the LASS on-line data acquisition system including the data link to the 370/168 triplex system for data logging, equipment checkout and monitoring.

b) Off-line: Reconstruction of the data is estimated to require $\sim$2000 hours of 370/168 time over a time interval of approximately 18 months. An additional $\sim$500 hours will be needed for Monte Carlo studies and analysis of the large number of physics topics in this experiment. One half of the physics analysis and Monte Carlo studies will be performed on the computers of Carleton University and the National Research Council of Canada.

A STUDY OF K^-P INTERACTIONS USING LASS

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I. INTRODUCTION

An important continuing problem in hadron physics is the measurement and understanding of the spectrum of hadron states including, in parallel, the study of the exchange mechanisms involved in the production of these states. Historically, progress in meson spectroscopy has tended to lag behind that in baryon spectroscopy, due in part to the fact that mesons must be studied in production experiments. Yet, in terms of classification schemes such as SU(3), the experimental verification of the meson multiplet structure remains of fundamental importance.

In recent years, several high statistics spectrometer experiments[1] have had substantial success in disentangling the meson resonance content of certain specific channels ($\pi\pi$, $K\bar{K}$, $\pi\pi\pi$, $K\pi$, $K\pi\pi$), particularly in regions of low invariant mass. For example, a 13 GeV $K^{\pm}p$ experiment (E-75) performed by this group, using a forward dipole spectrometer, observed the two axial vector mesons (Q mesons) required by the quark model through a partial wave analysis of the $K\pi\pi$ final state [3]. (See Fig. 1) However, many of the expected quark model states have still not been observed even in the low lying nonets. Three of the four $I = 0$, $J^P = 1^+$ states are still missing, while very few states in the $L = 2$ $q\bar{q}$ super multiplet are well established. Furthermore, the status and interpretation of the 0^+ nonet (δ, κ, ϵ, S^*) has become highly uncertain. Recent analyses of new experimental $K\bar{K}$ and $K\pi$ data [4] suggest possible narrower S wave structures at higher masses in addition to the broad lower mass enhancements in the S wave cross section. It has also been argued that threshold effects may be confusing the interpretation of the δ and S^* states.[5]

The recent emergence of the "new spectroscopy" of the Ψ family and its associated SU(4) interpretation has emphasized the importance of strengthening our understanding of the simpler SU(3) descriptions of mesons. The Ψ, χ spectrum already includes both radially excited states and most of the $c\bar{c}$ ground states with L = 0 and L = 1.(6) This is in striking contrast with our much more limited knowledge of the corresponding $\lambda\bar{\lambda}$ states for example, and radially excited states in general. Furthermore, experimental information on the decay transistions and production mechanisms involved in the production of $\lambda\bar{\lambda}$ and K* states, which is relevant to tests of Zweig's rule, is also needed.

We propose an experiment to study meson production in K^-p interactions at 10 GeV/c using the LASS detector at SLAC. This experiment represents a natural extension of the 13 GeV $K^{\pm}p$ experiment done by this same group using the dipole spectrometer portion of LASS. The improved acceptance of LASS permits high statistics studies of the known mesons and the search for new mesons with larger mass, higher spin, or higher decay multiplicity than was possible with the dipole system. By using a nonrestrictive trigger, many different final states can be recorded simultaneously yielding data relevant to many of the questions listed above. We will not attempt to discuss all of the observable final states here; rather a few of the reactions of particular interest will be dicussed in the next sections as representative examples of the broad range of physics topics available in this experiment.

I-2 Hypercharge Exchange Reactions

A unique aspect of K^-p interactions involves the study of the hypercharge exchange reactions, $K^-p \rightarrow X^0\Lambda$ and $K^-p \rightarrow X^-\Sigma^+$, where X^0 and X^- are non-strange mesons with $K\bar{K}$, $\pi\pi$, $K^*\bar{K}$, and $\pi\pi\pi$ decay modes. The I = 0, $\lambda\bar{\lambda}$ members of each SU(3) nonet are expected to couple to $K\bar{K}$ and $K^*\bar{K}$ systems most strongly and therefore are best studied using incident K^- beams. In fact, very few data are available on any of the $\lambda\bar{\lambda}$ mesons other than the ϕ and the f'. One expects both the $3^-\phi$ and the radially excited ϕ' to exist in the region above the f' meson. The detection of the $K^*\bar{K}$ final state will permit a search for the missing I = 0 members of the two $J^P = 1^+$ nonets. The only firmly established state among the four expected is the D meson. It is also of interest to search for and measure the $\pi\pi$ or $\pi\pi\pi$ non-strange decay modes of these $\lambda\bar{\lambda}$ states, which are expected to be strongly inhibited according to the Zweig rule.

Some of the hypercharge exchange reactions to be studied are:

$K^- p \rightarrow K^+ K^- \Lambda$	(ϕ, f', spin-3 ϕ,....)
$\rightarrow \pi^+ \pi^- \Lambda$	(ρ, S*, f, g,....)
$\rightarrow K^0 K^{\pm} \pi^{\mp} \Lambda$	(D,E,....)
$\rightarrow \pi^+ \pi^- \pi^{\pm} \Sigma^{\mp}$	(A_1, A_2, A_3...)
$\rightarrow \pi^+ \pi^- \pi^0 \Lambda$	(A_1, A_2, A_3...)

In our previous experiment (E75), we were only able to study ϕ, f', and ρ production using the first two reactions [7]; i.e., the low multiplicity, low mass regime. These K^+K^- and $\pi^+\pi^-$ data are shown in Fig. 2. In the $\pi^+\pi^-$ channel, Fig. 2b, we observed a very striking ρ-ω interference pattern, and the S* meson appears just below the $K\bar{K}$ threshold, The proposed LASS experiment will have an order of magnitude more f' events, and be able to study the high mass region and higher multiplicity reactions for the first time. As noted in the reaction list, the experiment will also be able to search for the elusive A_1 in both charged and neutral 3π states.

For these reactions with meson production opposite a Λ recoil system, the spin polarization will be measured at both vertices; this permits a detailed investigation of the exchange mechanisms involved.

I-3 K* Production

The proposed experiment will yield very large data samples for the study of K* spectroscopy and production mechanisms using reactions such as:

$$K^- p \rightarrow K^- \pi^+ n$$
$$\rightarrow \bar{K}^0 \pi^- p$$
$$\rightarrow K^- \pi^+ \pi^- p$$
$$\rightarrow K^- K^+ K^- p$$
$$\rightarrow \bar{K}^0 \pi^+ \pi^- n$$
$$\rightarrow K^- \pi^+ \pi^+ \pi^- n.$$

(i) $K^- p \rightarrow K^- \pi^+ \pi^- p$

Both experimental information and our understanding of the 1^+ and 2^- unnatural spin parity meson states has been very meagre. In fact no 2^- states are established, while from the quark model, we expect two 1^+ and 2^- nonets to exist. As indicated above, a three body partial wave analysis of the $K\pi\pi$ system in the high statistics 13 GeV $K^\pm p \rightarrow K^\pm \pi^+ \pi^- p$ experiment (75,000 K^+ events; 55,000 K^- events) found the two 1^+ Q mesons required by the quark model, (3) and, in addition, found evidence for a radially excited pseudoscalar meson, the K' (1400).(8)

Many experiments have observed a second broad enhancement in the $K\pi\pi$ mass spectrum between 1.6 and 1.9 GeV in the diffractive reaction $Kp \rightarrow K\pi\pi p$ in addition to the much larger Q enhancement observed between 1.1 and 1.5 GeV.(9) Preliminary results from our present partial wave analysis are shown in Fig. 3 and indicate that several different J^P states in addition to 2^- are contributing with similar strength in this high mass region. It would be particularly desirable to analyze the 2^- $K\pi\pi$ system with similar sensitivity to that available in the Q study. If the two expected L states were found, one would then be able to compare and contrast the L and Q results on mass splitting, SU(3) mixing, decay modes, production properties, and so on.

In this LASS experiment, the increment in data available will be a factor of 3 in the Q region (1.0-1.5 GeV) and a factor of 10 in the L region

(1.5-2.0 GeV). The 120,000 events expected in the L region will permit a $K\pi\pi$ partial wave analysis to be applied to the L region with comparable sensitivity to the previous Q analysis.

(ii) $K^-p \rightarrow K^-\pi^+n$, $\bar{K}^0\pi^-p$

In the $K\pi$ channel of the 13 GeV experiment, in addition to observing and studying the $1^-K^*(890)$, $2^+K^*(1420)$, and $3^-K^*(1780)$,[10] evidence was also found for a 4^+K^* near 2.1 GeV,[11] and a tantalizing indication for a 5^- K^* near 2.35 GeV. In Fig. 4a, a scatter plot for the observed $K\pi$ events showing $\cos\theta_J$ for the $K\pi$ system vs. the $K\pi$ mass is presented for the reaction $K^-p \rightarrow K^-\pi^+n$. The cluster of events in particular $\cos\theta_J - m_{K\pi}$ regions at high mass, which corresponds to peaks in the observed $K\pi$ moments Y_6^0, Y_8^0 as shown in Figs. 4b-c., is the signature of these high mass K^*. The vastly improved high mass acceptance of LASS and the subsequent increase in statistics should allow a definitive measurement of the 3^-, 4^+, and 5^- K^* states. Several experiments have now observed the $K^*(1780)$, but there are inconsistencies in the widths obtained [2,12]. An accurate observation of this sequence of natural spin parity states is important both for particle classification schemes and for the concept of Regge trajectories.

(iii) $K^-p \rightarrow \bar{K}^0\pi^+\pi^-n$, $K^-\pi^+\pi^+\pi^-n$

The higher multiplicity $\bar{K}^0\pi^+\pi^-n$ and $K^-\pi^+\pi^+\pi^-n$ final states will provide an important new dimension for (a) the study of these high mass natural spin parity states, and (b) the study of the unnatural parity 1^+ and 2^- states in non-diffractive channels. The preliminary $K\pi$ scattering phase shift analysis of our 13 GeV $K\pi$ data indicates that the $K^*(1780)$ elasticity is only ~ 15%. Recently, a clear narrow peak at 1.7 GeV with unknown J^P has been observed in the $K^0\pi^+\pi^-$ mass spectrum for this reaction at 6 GeV.[13]

I-4 Statistical Senstivity

Due to the high acceptance of LASS, the beam time required by the proposed experiment is modest. The event/μb sensitivity in LASS, as determined by Monte Carlo studies described in Section II, depends slightly on the event topology, particle identification, and resolution requirements of specific reactions, but is typically 800 events/μb for 500 hours of data taking at 180 pps. The actual number of events that will be observed are contained in Table IV for many of the reactions listed above. This experiment will obtain approximately 6000 events per 25 MeV for the reaction $K^-p \rightarrow K^-\pi^+\pi^-p$ in the L region, $1.5 < m(K\pi\pi) < 2.0$ GeV. This corresponds to the number of events per 25 MeV that were available in the Q peak region, $1.2 < m(K\pi\pi) < 1.4$ GeV in E-75 and which may be taken as both the necessary and sufficient statistical level for a useful partial wave analysis of the $K\pi\pi$ system.

A comparison of the event/μb sensitivity of the proposed experiment with the data obtained in E-75 varies for each reaction. As indicated previously, there is an order of magnitude increase in the number of events for $K^-p \rightarrow f'\Lambda$ and $K^-p \rightarrow Lp$; this factor increases (decreases) for higher (lower) $K\bar{K}$ and $K\pi\pi$ masses. In addition, this experiment provides a major data sample for meson decays to highly inelastic final states such as $K^oK^{\pm}\pi^+$, $K^o\pi^+\pi^-$, and $K^-\pi^+\pi^-\pi^+$.

We have initially selected a momentum of 10 GeV for this experiment in order to obtain the largest data samples for the hypercharge exchange reactions while being well matched to the best K, π particle identification capabilities of LASS. As E-75 has demonstrated, the availability of high energy RF separated K beams at SLAC makes the study of K^-p interactions particularly well suited to LASS and SLAC.

I-5 Summary

The proposed experiment in LASS will (1) extend the partial wave analysis of the $K\pi$ and $K\pi\pi$ systems into the very interesting high mass region; (2) allow a search for and study of high mass, high spin K^* states in several final states; (3) greatly extend available data on the hypercharge exchange reactions; and (4) include a search for many missing $\lambda\bar{\lambda}$ states with good experimental sensitivity. In particular, many of the missing iso-scalers are expected to be strongly produced by incident K^- beams and to decay preferentially to $K\bar{K}\pi$ and $K\bar{K}\pi\pi$. Moreover, LASS opens up quantitatively new areas of pursuit (such as observing the Λ^0 recoil with high statistics and studying 1-c final states with a missing π^0) which allow a new range of phenomena to be studied.

II. DESCRIPTION OF EXPERIMENT

II-1 Apparatus

This experiment uses the LASS spectrometer facility and the existing RF-separated beam line. LASS contains two large magnets and associated detectors as shown in Fig. 5. The first magnet is a superconducting solenoid of 23 KG field with the field direction parallel to the beam direction. This is followed by a 27 KG-m dipole magnet with a vertical field. The solenoid is effective in measuring the interaction products which have large production angles and relatively low momenta. High energy secondaries, tending to stay close to the beam line, are not measured well in the solenoid, but will pass through the dipole for measurement there. Particle identification is provided by Cerenkov counters C1 and C2 and a time of flight (TOF) hodoscope. Several proportional wire chambers (PWC) and scintillation counter hodoscopes provide a variety of trigger capabilities.

Brief descriptions of particular portions of the apparatus that are of importance to this experiment follow. A complete description of LASS is given in the appendix of SLAC proposal E-109. The performance of this system for several different sample reactions is discussed in detail along with acceptance and resolutions in section II-2.

II-1.1 Beam. LASS is situated in the existing 20-21 beam line at SLAC[14]. This is a 4 stage beam with 2 RF separators and will provide a cleanly separated K^- beam of useable flux at energies up to about 13 GeV. Two threshold Cerenkov counters provide K/π identification just before the target. A set of scintillation counter hodoscopes and proportional wire chambers measure the incident momentum ($\Delta p/p \sim .25\%$, rms) and trajectory ($\Delta\theta \sim .5$ mr, $\Delta x \sim .5$ mm) of each beam particle.

II-1.2 Solenoid. The solenoid has a useful diameter of 1.75 m, is 3.5 m long, and has a field of 23 kg with a uniformity of ~1% on axis and better than 3% within a radium of 75 cms. It consists of four coil segments plus iron end caps. The first coil segment is 1 meter long and contains a 36" long, 2" diameter liquid hydrogen target. Surrounding the target, there are 10 gaps of cylindrical wire spark chambers (WSC) with 15 planes of capacitive diode readout. These chambers have a 2mm wire spacing (the largest radius chamber has 4 mm spacing) with the wires crossing at a ($2 \tan^{-1} 0.1$) angle to give a z resolution of ± 1 cm. The cylindrical system also includes a 2 mm spacing axial wire proportional chamber of a 5 cm radius.

Following each of the 4 coil segments of the solenoid, there is a 6.4" slot in which a wire spark chamber plus proportional wire chamber module is inserted. Both have 1 mm wire spacing. Each spark chamber has two gaps with four co-ordinates and uses capacitive diode readout. The PWC has three readout co-ordinates, an active area of 25 cm x 25 cm, and covers the beam area overlapping the deadened region of the WSC. In addition to these modules there is a full size 2 mm wire spacing, 4 co-ordinate readout proportional wire chamber inside coil segment 2 to provide time resolution constraints for track reconstruction.

II-1.3 Dipole Spectrometer. Located downstream of the solenoid is a conventional spark chamber-dipole magnet-spark chamber spectrometer. The dipole magnet aperture is 1.75 m wide x 1.00 m high and 2 m along the beam. In front of the magnet there are 3 WSC modules with a total lever arm of 1.0 m. There are also two 4 mm wire spacing proportional wire chamber hodoscopes to provide timing information for track identification and for potential trigger applications. Immediately downstream of the magnet there is a PWC hodoscope and the downstream spark chamber package consisting of 4 2-gap magnetostrictive readout chambers. The present geometry of the region between the solenoid and dipole magnets has been modified from the geometry shown in figure 5 in order to accomodate a shower counter array for use in a lepton pair experiment (E-127). We are studying whether this arrangement is appropriate for the proposed experiment.

II-1.4 Particle Identification. Particle identification is provided by C1, a 38-element atomospheric pressure threshold Cerenkov hodoscope at the end of the solenoid; by C2, an 8-element pressurized threshold Cerenkov counter following the dipole spectrometer; and by a 24-element time of flight (TOF) hodoscope located just downstream of C1. The particle separation that can be expected from these hodoscopes is as follows: C1 filled with neopentane at atomospheric pressur provides π/K separation between 1.6 and 5.7 GeV/c; the gas and pressure in C2 can be selected to give π/K identification in a momentum band partially overlapping and extending that of C1; and the TOF hodoscope gives good K/π separation up to 1.3 GeV/c, K/p separation up to 2.1 GeV/c, and π/p separation up to 2.5 GeV/c.

II-1.5 Trigger. The primary emphasis in this experiment is the detection and study of forward produced mesons which decay into 2,3, or 4 prong final states together with the observation of the recoil baryon. (P,Δ ,,Λ, etc.). We are continuing to study and develop continued hardware triggers and software filters that best exploit the capabilities of LASS for this experiment. Present Monte Carlo and initial test data studies with LASS indicate that the most suitable trigger is to require 2 or more charged particles to exit from the solenoid. The 24 element TOF scintillation counter hodoscope at the downstream end of C1 provides this capability in a simple and straightforward way. To reduce the number of triggers from $K^- \rightarrow \pi^+\pi^-\pi^-$ beam decays, we also intend to restrict the interaction and decay region to coincide with the hydrogen target by using the standard x-y counter beam logic and by requiring that at least one charged particle be recorded outside the beam region in PWC 1.5 located just downstream of the target.

The probability that a given beam particle will give rise to an interaction (or decay) that satisfies this trigger can not be directly measured yet in LASS, but initial tests suggest a 0.04 - 0.05 probability. At 5 K^- per pulse and

180 pps, this leads to some dead time losses which can be alleviated by operating LASS at a somewhat reduced pulse repetition rate. Alternatively, the LASS trigger system can combine several different triggers each of which can be prescaled. Thus, for example, one could trigger on all 3 and 4 prongs and a fraction of the 2 prongs.

LASS has a software filter facility which uses a 168/E processor to perform calculations during the event dead time and which can then remove unwanted events or flag events for future first pass analysis. These more specific triggers can make use of (1) scintillation counter and proportional chambers (2) particle identification information, and (3) the three induced readout proportional chamber wheels located inside the solenoid which provide a direct measurement of P_L and P_T for the outgoing secondary particles. An example of a trigger of interest would be to require the production of a high mass $K^-\pi^+$ system in a 2 prong final state. Such a trigger is of interest in a search for K^*'s with spin ≥ 4.

This software filter feature will also be used in an off-line mode to select the data for final processing and analysis.

II-2 Expected LASS Performance

Monte Carlo studies of some representative K^-p reactions have been made to determine how LASS can be expected to perform in terms of acceptance, resolution, particle identification, and event rates. Events were generated at the center of the liquid hydrogen target and the outgoing particles were followed through the spectrometer. The apertures of the system were taken into account in determining geometric acceptance. Estimates of spatial resolution for the various track chambers, plus multiple scattering, were used to calculate the momentum and angular resolutions of outgoing tracks. The expected characteristics of Cerenkov counter C1 and the TOF system, plus the known characteristics of Cerenkov counter C2 were used to predict whether π-K-p separation could be made on each track.

II-2.1 Reactions Studied. Three topologically different K^-p reactions were simulated b Monte-Carlo at an incident beam momentum of 10 GeV/c. They were chosen as being representative of the production of meson states decaying into two, three, and four charged particles. The reactions considered were:

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

where the $K\pi\pi$ system comes from the decay of a hypothetical L-meson (M=1770 MeV, Γ = 140 MeV) according to $L \rightarrow K^{*0}(890)\ \pi^-$, $K^*(890) \rightarrow K^-\pi^+$. The t-dependence was of the form e^{7t} and the L and K* were allowed to decay isotropically.

(2) $K^-p \rightarrow \Lambda\ K^+K^-$,

where the $K\bar{K}$ system comes from $f' \rightarrow K^+K^-$,

with $M_{f'}$ = 1530, $\Gamma_{f'}$ = 60 MeV, and $d\sigma/dt \sim e^{3t}$.

The f' was given the decay angular distribution observed in E-75.

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

$\quad\quad\quad\quad\quad\quad\quad\quad \hookrightarrow \pi^+\pi^-$

where the $K^-\pi^+K^0$ system comes from the decay of the E meson (M_E = 1416 MeV; Γ_E = 60 MeV) according to $E \rightarrow K^{*0}(890)\ K^0_s$, $K^{*0} \rightarrow K^-\pi^+$, $K^0_s \rightarrow \pi^+\pi^-$. The t-dependence was e^{3t} and all states were allowed to decay isotropically. The K^0_s decayed at the primary interaction point.

For each of the above reactions the outgoing mesons were followed through the spectrometer. Charged meson decay, nuclear absorption, and possible triggering inefficiencies have been neglected, except in calculating event rates.

II-2.2 Geometric Acceptance. Unlike the situation for forward dipole spectrometers, we find in general that nearly all of the particles which escape the target are detected and measured. The geometric acceptance of LASS is therefore close to 100% for the reactions considered, and the effective acceptance is instead determined by kinematic and particle identification criteria, which we now discuss.

II-2.3 Missing-mass Resolution and Kinematic Acceptance. Table I gives the FWHM of the distribution in missing mass (MM) against the outgoing mesons in reactions (1) - (3). In each case, the contribution from the expected error on the beam momentum ($\Delta p/p = 0.25\%$, rms) has been folded in.

We take as a basic kinematic acceptance criterion that the MM be within one pion mass of the recoil baryon (proton or Λ^o) mass. A cut of this size is expected to give a fairly clean separation between the reaction of interest and background reactions with a recoil Δ^+ (1238) instead of a proton, or a recoil Σ (1385) or Λ (1405) instead of a Λ^o. Using this MM criterion, the overall kinematic acceptance for reactions (1) - (3) is found to be 70-80% (see Table 1).

II-2.4 Momentum Resolution. Figure 6 shows the fractional momentum error, $\Delta p/p$, vs momentum for the outgoing K^- in reaction (3). This plot is typical of the momentum resolution to be expected from LASS. Two separate groupings of tracks are observed: one group, with $< \Delta p/p > \sim 1\%$ per GeV/c, which dœs not pass through the dipole and are therefore measured only in the solenoid region, and a second group, with $< \Delta p/p > \sim 0.1\%$ per GeV/c, which is measured both upstream and downstream of the dipole magnet. (The spread in $\Delta p/p$ at fixed p for the "solenoid-only" tracks is due primarily the spread in P_T, the momentum component perpendicular to the solenoid B-field).

II-2.5 Invariant Mass Resolution. Table I gives average invariant mass resolutions for various combinations of outgoing particles for events satisfying the kinematic acceptance criterion. The 15-MeV $K\pi\pi$ mass resolution for reaction (1) is well matched to a partial wave analysis of the L region in 25-MeV bins.

II-2.6 Acceptance vs M,t, and Cos θ. We have studied the dependence of kinematic acceptance on such variables as momentum transfer, decay angles, and mass of produced $K\pi\pi$, $K\bar{K}$, and $K^*\bar{K}$ systems in reactions (1) - (3). In general we find that the kinematic acceptance is quite uniform in all of these variables. To illustrate this, Fig. 7 shows, for reactions (2) and (3), (a) acceptance vs $M(K\bar{K})$ and $M(K^*\bar{K})$; (b) acceptance vs t; and (c) acceptance vs Cos $\theta_{Helicity}$ for $f' \rightarrow K^+K^-$ decay.

II-2.7 <u>Particle Identification.</u> For each of the out-going mesons in the reactions considered, Table 2 shows the fraction identified by time-of-flight, by C1, and by C2 separately, and by all together. We see that $\geq 70\%$ of the mesons are identified.

As an aid in understanding the numbers in Table II, we show in Fig. 8 the corresponding momentum distributions of the outgoing mesons. We see that the $K^{\pm}$ in all three reactions peak higher in momentum than the $\pi^{\pm}$. There are relatively few $K^{\pm}$ below 1.3 GeV/c - where TOF gives π/K separation - so that most of the $K^{\pm}$ which are identified are done so by C1. On the other hand, a large fraction of the π's do have $p < 1.3$ GeV/c, so that TOF alone identifies a substantial fraction of the $\pi^{\pm}$.

Table II also gives (a) the fraction of events for which all outgoing charged mesons are identified and (b) an effective event identification efficiency, based on strangeness conservation, which will be used below in calculating event rates. For reaction (1) this efficiency is the probability that the K^- or π^- is identified. For reaction (2) it is the probability that (i) the Λ is seen and the K^+ or K^- is identified or (ii) the Λ is not seen and the K^+ is identified. For reaction (3) it is the probability that (i) the Λ is seen and the π^+(from K*) or K^- is identified or (ii) the Λ is not seen and the K^- is identified. In reaction (2) and (3) the probability that the Λ is seen is taken to be 0.41[= 0.64 (the Λ reconstruction efficiency) x 0.642 (the Λ branching ratio into $p\pi^-$)].

II-2.8 <u>1-C Physics.</u> Since LASS is a large acceptance device with excellent momentum resolution for nearly all measured tracks, we expect to study reactions with a missing π^0 using 1-C fits to the observed charged particles. A sample reaction of interest is

$$K^-p \rightarrow \pi^+\pi^-\pi^0\Lambda,$$

where a three-body partial-wave analysis of the $\pi^+\pi^-\pi^0$ system would allow a search for hypercharge exchange production of the A_1.

In the absence of detailed knowledge of the real physics backgrounds, it is difficult to predict the cleanliness of the final data samples from such reactions. However, one can always improve the resolutions on a data sample by decreasing acceptance. A Monte Carlo study shows that for a typical large acceptance data sample, the separation between $\pi^+\pi^-\pi^0$ and states with ≥ 2 π^0 s (or with no π^0 s) is $> 4\sigma$, which implies an ambiguity at the one percent level if the 1-C reaction and background reactions are produced with the same cross section. By comparison of the LASS measurement errors with those of other large acceptance devices (such as bubble chambers and the Omega spectrometer) we are confident that the 1-C reactions can be sufficiently well reconstructed kinematically to permit a complete study of the state containing the missing π^0. Furthermore, we are currently acquiring experience (in E-127) in detecting electrons and photons in a large area shower counter wall at the exit of the solenoid. It is hoped that such information could be used to further constrain the missing π^0 events.

II-3 Event Rates. Expected event rates per μb of production cross section for reactions (1) - (3) have been estimated from the kinematic acceptance given in Table I and the effective event identification efficiencies given in the last column of Table II. We have assumed a beam flux of 5 K^- per pulse at 180 pps, track reconstruction efficiency of 85% on beam tracks and 90% on secondary tracks (based on E-75 experience), particle absorption of 8% per track, and an overall data taking efficiency of 50% including empty target and other calibration runs. We have also assumed a triggering efficiency of 90%. In addition, we have required that none of the outgoing charged K's or π's in an event decays before reaching the time-of-flight hodoscope. We find that a 500-hour run corresponds to between 800 and 900 events/μb for all 3 of our sample reactions.

In Table III we give expected topological cross sections for K^-p interactions at 10 GeV/c, and in Table IV we summarize the cross section and total number of events expected for several specific K^-p reactions. Useful samples exist even for reactions with rather low cross sections. For example, the sample should contain ~ 2200 $K^-p \rightarrow f'\Lambda$ events. Note particularly that a 500 hour run gives an average of ~ 6000 events/ 25 MeV · bin in the L region for the reaction $K^-p \rightarrow K^-\pi^+\pi^-p$ As noted previously, this corresponds to the number of events /25 MeV which are estimated to be required for a partial wave analysis of the $K\pi\pi$ system on the basis of E-75 experience in the Q region.

II-4 Data Reduction

II-4.1 Data Acquisition. The LASS data acquisition system is fully capable of handling the rather high data rates expected in this experiment and provides very flexible and complete monitoring of the experimental apparatus. The system utilizes a PDP-11/20 to pass data from the individual LASS detectors to the SLAC Triplex system via a high speed data link. The data is recorded on the high density 6250 BPI tape drives of the triplex system while some fraction undergoes a complete analysis including equipment monitoring, track finding, event reconstruction and histograming. During unavoidable "down" periods of the triplex system, an IBM 1800 provides a back-up capability for equipment monitoring and allows data to be written to tape using two 800 BPI drives.

II-4.2 Event Reconstruction and Analysis. The LASS 370/168 off-line reconstruction programs are identical to those utilized on-line. An extensive effort is being made to develop an efficient code to keep the required 370/168 analysis time as small as possible. In addition, we are presently studying means to greatly reduce the number of events which must be processed by the complete analysis program.

More specifically, we expect to be able to develop software filters for events of interest using (1) the proportional line chambers in the solenoid to provide a more selective multiplicity check than is allowed by the general trigger; (2) the three-induced readout proportional chamber wheels located inside the solenoid to provide a direct measure of the P_L, P_T of the outgoing secondary particles; and (3) particle identification information. The filters can, of course, be invoked at the off-line analysis stage using the 370/168 alone. However, as presently envisaged, the filtering will be performed by the 168/E processor facility being developed for LASS. This processor can be used either as a filtering processor in an off-line mode or as a software triggering facility in an on-line mode. In either case, the processor will indicate which events should be flagged for complete reconstruction.

The 168/E processor also has the more general capability of performing portions of the track finding code. By using it to perform the repetitive, time-consuming portions of the track finding algorithms, it should be possible to reduce the 370 time requirement substantially.

Because all areas of the analysis system are in a state of flux, it is difficult to estimate very precisely the analysis time needed for the experiment. Based on our present knowledge, we would conservatively estimate that ~ 2000 hours of 370/168 time would be required to fully reconstruct all events. Because of the scale of the experiment, this time would be expected to be spread over ~ $1\frac{1}{2}$ years. Development of the techniques outlined above could reduce this time requirement substantially.

A full set of programs are in existence to complete the physics analyses of the two and three-body meson decay states. These programs were developed for use in our previous $K^{\pm}p$ experiment (SLAC E-75) and are immediately applicable to the experiment proposed here. It is estimated that the completion of this large number of physics topics would require an additional 400-500 hours of 370/168 time. One half of this physics analysis would be performed on the computers of Carleton University and the National Research Council of Canada.

II-5 Running Time.

This proposal requires the equivalent of 500 hours of data taking time at 180 pps. Because the major portions of LASS will be set-up prior to this experiment, little additional set-up time will be required. Three weeks at 10-20 pps should be sufficient to study the new time of flight hodoscope, as well as check the set-up and operation of the other LASS detectors and the K^- beam.

III Summary.

We plan to study K^-p interactions at 10 GeV/c using the LASS spectrometer. The large acceptance, high resolution, and excellent particle identification properties of LASS allow the high statistics study of meson states of higher mass, spin and multiplicity than has been possible with the previous generation of forward spectrometers. In a 500 hour run at 180 pps. (equivalent) using a multiplicity trigger, we expect to obtain a sensitivity of 800-1000 events/μb with nearly uniform acceptance in all kinematic variables. Of particular interest are the spectroscopy of high-mass, high-spin K*states produced in final states such as $K\pi$, $K\pi\pi$, and $K\pi\pi\pi$; the extension of the partial wave analysis of the $K\pi$ and $K\pi\pi$ systems into the high mass region; and the study of hypercharge exchange reactions, where a study of mesons decaying into $K\bar{K}$, $K^*\bar{K}$, $K\bar{K}\pi$, and $K\bar{K}\pi\pi$ will permit a systematic search for those $\Lambda\bar{\Lambda}$ states which are predicted by the quark model but have not been observed. The statistical level of the experiment is sufficient to perform a detailed partial wave analysis of the region of the $K\pi\pi$ final states as well as to search for and study the properties of new states with small production cross sections.

References

1. For example:

   Argonne-EMS, $\pi^- p \to \pi^+\pi^- n$, $K\bar{K}n$ at 6 GeV/c

   SLAC E-75, $K^\pm p \to K\pi n$, $K\pi\Delta$, $K^\pm\pi\pi p$ at 13 GeV/c

   CERN - Munich, $\pi^- p \to \pi^+\pi^- n$, $K^+K^- n$ at 17 GeV/c

   Serpukhov-CERN, $\pi^- p \to \pi^-\pi^-\pi^+ p$ at 25/40 GeV/c

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Table I

MISSING - MASS RESOLUTION, KINEMATIC ACCEPTANCE, AND INVARIANT MASS RESOLUTION

	Reaction	Missing-mass Resolution (FWHM in MeV)[a]	Kinematic Acceptance[b]	Invariant mass resolution (rms)	
(1)	$K^- p \rightarrow pL$	140 MeV	69%	$K^-\pi^+\pi^-$	15 MeV
	$L \rightarrow K^-\pi^+\pi^-$			$K^-\pi^+$	8
(2)	$K^- p \rightarrow \Lambda f_r'$	120	69%	K^+K^-	11 MeV
	$f' \rightarrow K^+K^-$				
(3)	$K^- p \rightarrow \Lambda E$,	140	80%	$K^-\pi^+K_s^o$	12 MeV
	$E \rightarrow K^-\pi^+K_s^o$,			$K^-\pi^+$	5
	$K_s^o \rightarrow \pi^+\pi^-$			$\pi^+\pi^-(K_s^o)$	7

[a] Missing-mass against forward mesons.

[b] Missing-mass within M_π of recoil baryon mass.

Table II

PARTICLE IDENTIFICATION PROBABILITIES

Reaction	Particle	TOF	C1	C2	TOF +C1 +C2	all mesons identified	effective event i.d. efficiency
(1) $K^-p \rightarrow pK^-\pi^+\pi^-$	K^-	.07	.73	.08	.78	.34	.97
	$\pi^\pm$	.23	.50	.04	.71		
(2) $K^-p \rightarrow \Lambda K^+K^-$	$K^\pm$	.05	.65	.02	.70	.62	.79
	K^-	.04	.83	.11	.85		
(3) $K^-p \rightarrow \Lambda K^-\pi^+K^o_s$	$\pi^+(K^*)$	.29	.37	.04	.65	.23	.92
$(K^o_s \rightarrow \pi^+\pi^-)$	$\pi^\pm(K^o)$	.31	.25	.03	.57		

Table III

K^-p TOPOLOGICAL CROSS SECTIONS AT 10 GeV/c

Reaction	Cross Section (mb)
0-prongs	0.76 ± 0.1
2-prongs	10.38 ± 0.25
4-prongs	8.47 ± 0.1
6-prongs	2.69 ± 0.05
8-prongs	0.29 ± 0.03
$\geq$ 10-prongs	~ 0.0
Total	22.5 ± 0.2
Elastic	3.15

Table IV

CROSS SECTIONS AND EXPECTED NUMBER OF EVENTS

FOR SOME SPECIFIC K^-p REACTIONS

Reaction	Cross Section^{+} (μb)	Expected Number of Events
$K^-p \to K^+K^-\Lambda$	12	10800
$\to \phi\Lambda$, $\hookrightarrow K^+K^-$	7	6300
$\to f'\Lambda$, $\hookrightarrow K^+K^-$	2.5	2250
$K^-p \to \pi^+\pi^-\Lambda$	40	36000
$\to \rho\Lambda$	10	9000
$\to f\Lambda$	4	3600
$K^-p \to K^o_s K^{\pm}\pi^{\mp}\Lambda$, $\hookrightarrow \pi^+\pi^-$	~ 4	3300
$K^-p \to K^+K^-\pi^+\pi^-\Lambda$	~ 10	8200
$K^-p \to \pi^+\pi^-\pi^o\Lambda$	98	42000
$\to \omega\Lambda$	10	4200
$K^-p \to \pi^+\pi^-\pi^-\Sigma^+$	~ 25	23000

Reaction	Cross Section (μb)	Expected Number of Events
$K^-p \to K^-\pi^+n$	350	320,000
$\to$ forward $(K^-\pi^+) + n$	~150	135,000
$\to K^*(890)\, n$, $\hookrightarrow K^-\pi^+$	64	59,000
$\to K^*(1420)\, n$, $\hookrightarrow K^-\pi^+$	36	33,000
$K^-p \to \bar{K}^o_s\pi^-p$	~75	75,000
$\to$ forward $(\bar{K}^o_s\pi^-) + p$	~60	60,000
$\to K^*(890)p$, $\hookrightarrow \bar{K}^o\pi^-$	~21	20,000
$\to K^*(1420)\, p$, $\hookrightarrow \bar{K}^o\pi^-$	~6	6,000
$K^-p \to K^-\pi^+\pi^-\, p$	850	760,000
$\to$ "Q" p [$1.0 < M(K\pi\pi) < 1.5$ GeV]	260	230,000
$\to$ "L" p [$1.5 < M(K\pi\pi) < 2.0$ GeV]	140	125,000
$K^-p \to K^-K^+K^-\, p$	30	17,000
$K^-p \to \bar{K}^o_s\pi^+\pi^-n$, $\pi^+\pi^-$	100	78,000
$K^-p \to K^-\pi^+\pi^+\pi^-n$	430	270,000

All K^o reaction cross sections include requiring $K^o_s \to \pi^+\pi^-$ decay.

Figure Captions

1. Data and results of a phase shift analysis showing the two axial vector mesons required by the quark model (from experiment E-75).

2. Invariant mass distributions for the forward mesons produced in $K\bar{K}\Lambda$ and $\pi\bar{\pi}\Lambda$ final states (from E-75).

3. Preliminary results from $K\pi\pi$ phase shift analysis between 1.0 and 2.0 GeV/c^2 (from E-75).

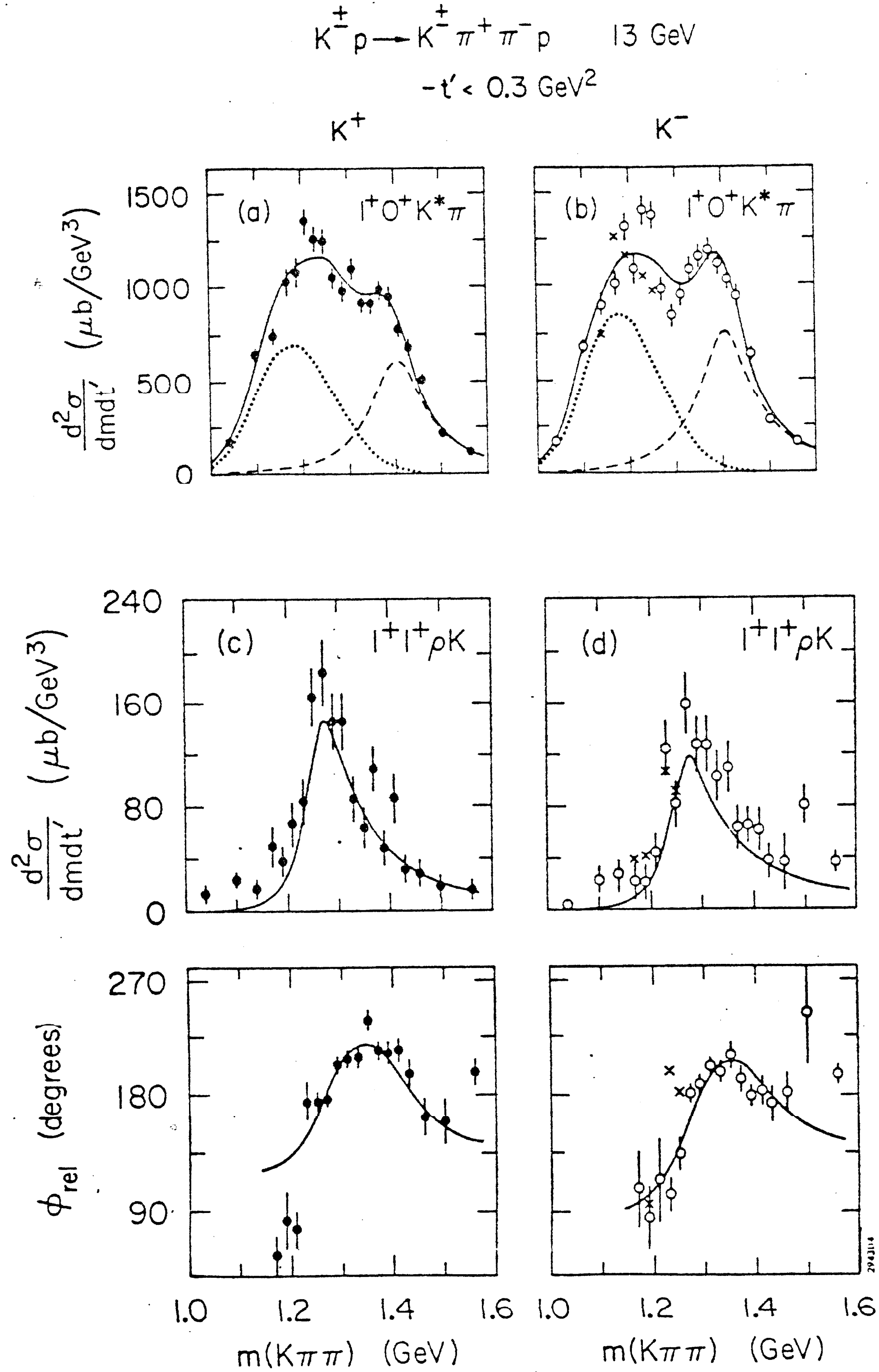
4. Invariant mass of $K\pi$ system vs. cos θ_J (a) and observed $K\pi$ moments (b-c). (From E-75).

5. Plan view of the experimental set-up. Solid lines represent spark chambers, dashed lines represent proportional wire chambers, dotted lines proportional wire hodoscopes, and dot-dashed lines indicate scintillation counters.

6. Fractional momentum error vs. momentum of outgoing K^- in the reaction $K^-p \rightarrow \Lambda K^-\pi^+K_s^o$.

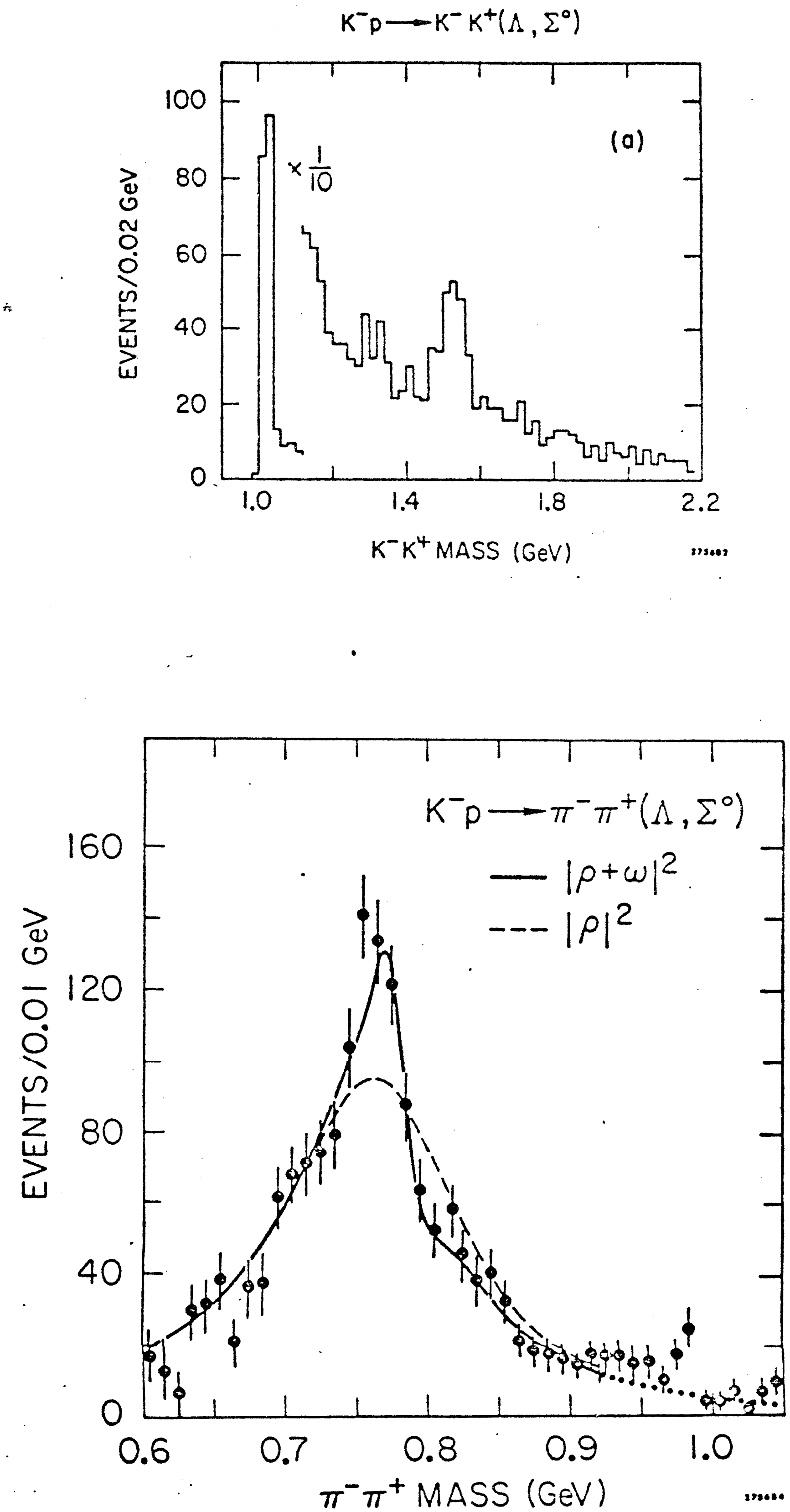
7. Monte Carlo acceptance curves for several different final states vs. (a)Invariant mass, (b) momentum transfer, and (c) cos θ_H.

8. Momentum distributions of the outgoing mesons for reactions (1) - (3) described in text.



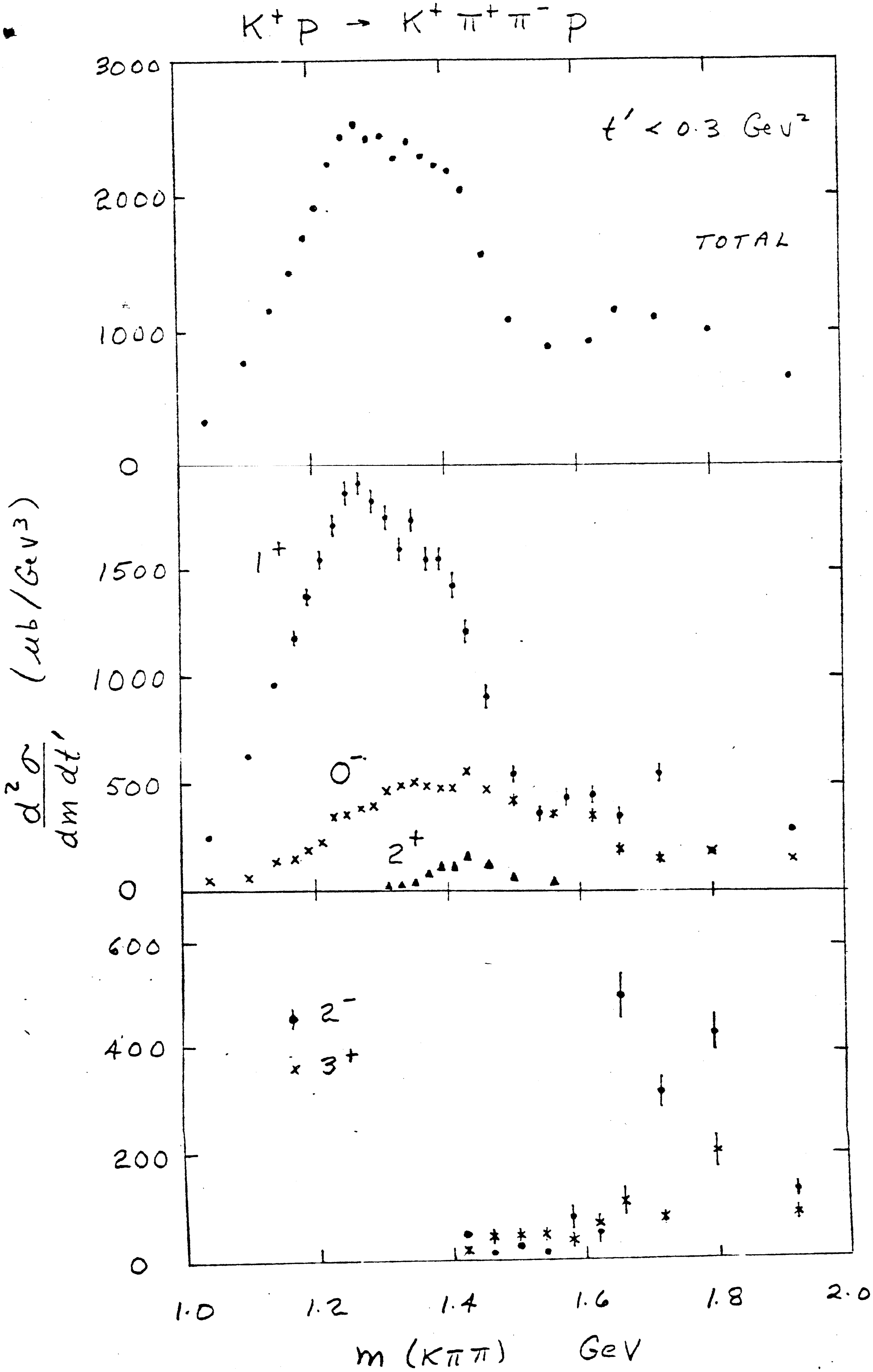
K± p → K± π+ π− p 13 GeV
−t′ < 0.3 GeV²
K+
K−
(a) 1+0+K*π
(b) 1+0+K*π
(c) 1+1+ρK
(d) 1+1+ρK
d²σ/dmdt′ (μb/GeV³)
φrel (degrees)
1500
1000
500
0
240
160
80
0
270
180
90
1.0
1.2
1.4
1.6
m(Kππ) (GeV)

Fig. 1



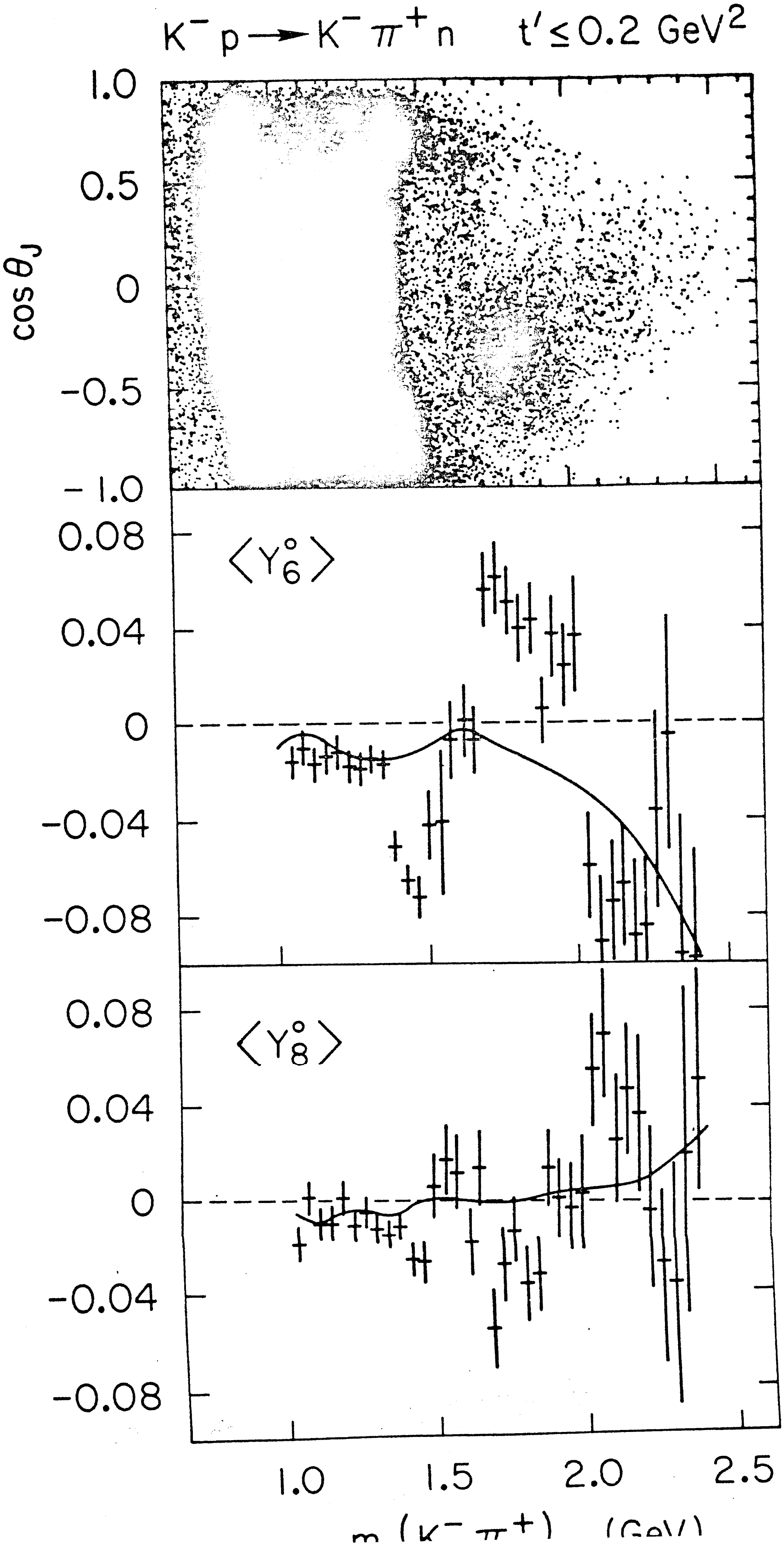
K⁻p → K⁻K⁺(Λ, Σ°)
(a)
× 1/10
EVENTS/0.02 GeV
K⁻K⁺ MASS (GeV)
K⁻p → π⁻π⁺(Λ, Σ°)
|ρ+ω|²
|ρ|²
EVENTS/0.01 GeV
π⁻π⁺ MASS (GeV)

Fig. 2



K⁺p → K⁺π⁺π⁻p
t′ < 0.3 GeV²
TOTAL
1⁺
0⁻
2⁺
2⁻
3⁺
3000
2000
1000
0
1500
1000
500
0
600
400
200
0
d²σ/dm dt′ (μb/GeV³)
1.0
1.2
1.4
1.6
1.8
2.0
m (Kππ) GeV

Fig. 3



$K^- p \rightarrow K^- \pi^+ n$ $t' \leq 0.2$ GeV^2
$\cos\theta_J$
1.0
0.5
0
-0.5
-1.0
$\langle Y_6^0 \rangle$
0.08
0.04
0
-0.04
-0.08
$\langle Y_8^0 \rangle$
0.08
0.04
0
-0.04
-0.08
1.0
1.5
2.0
2.5

Fig. 4

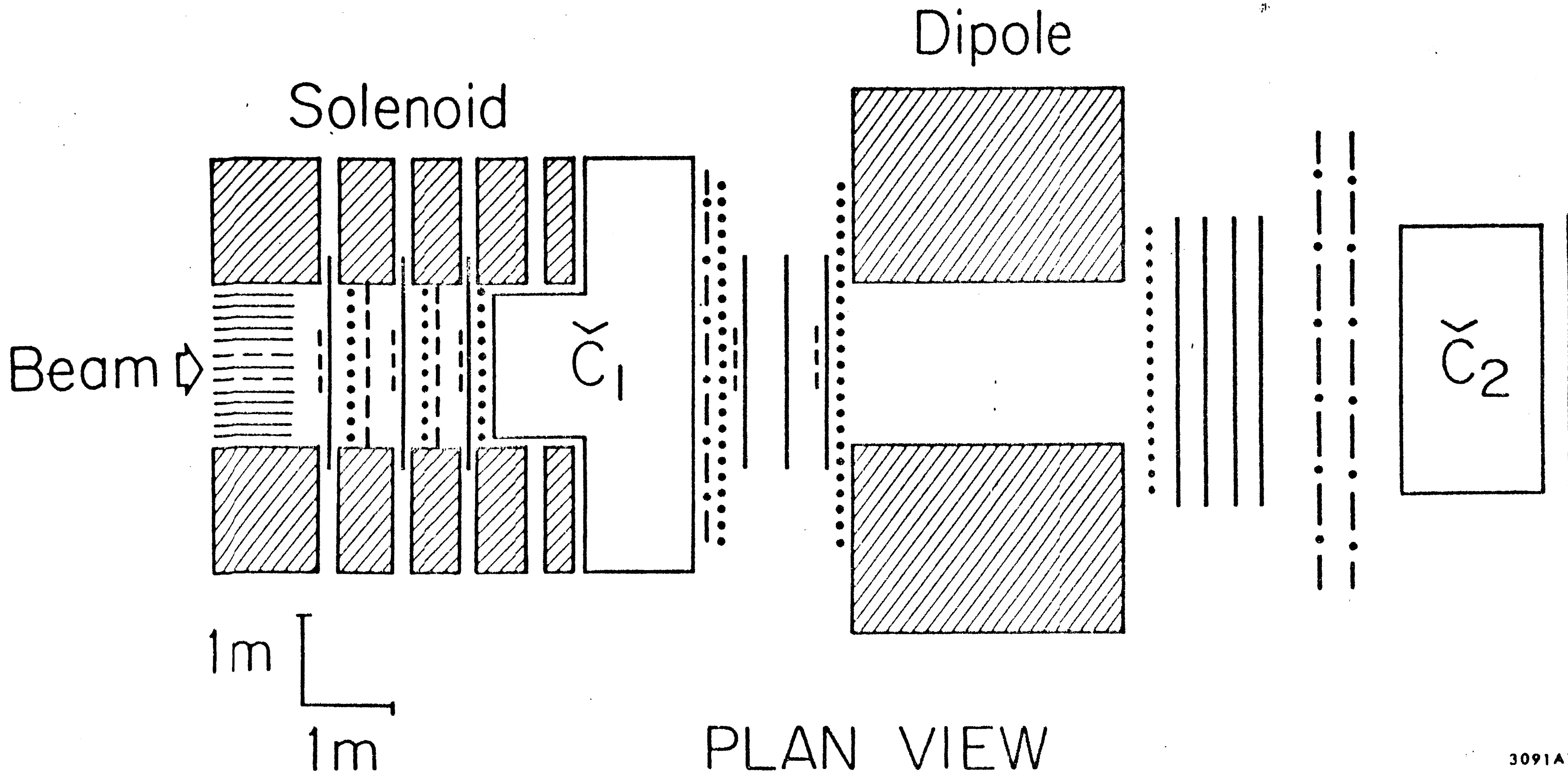


Fig. 5

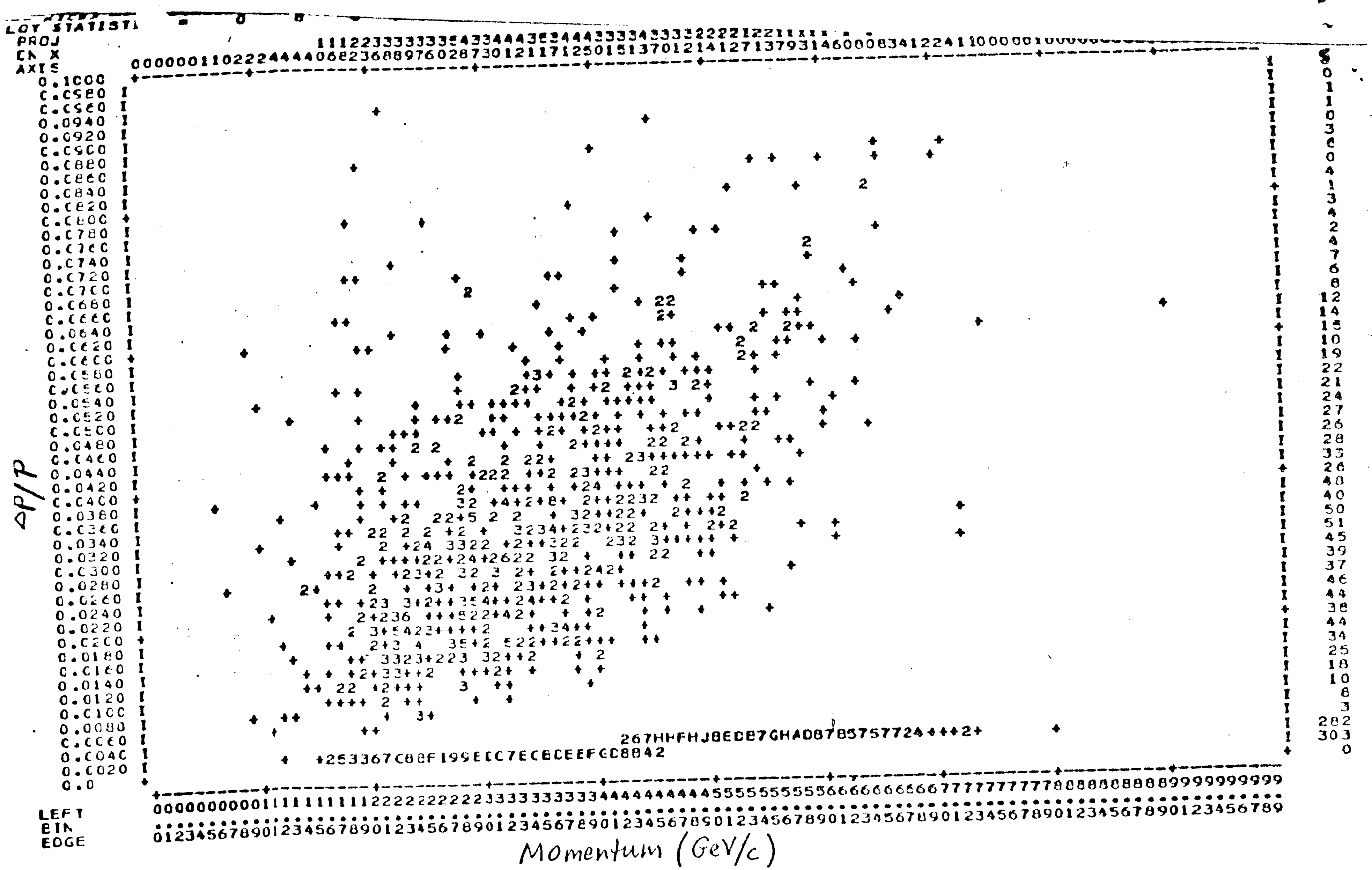


Fig. 6

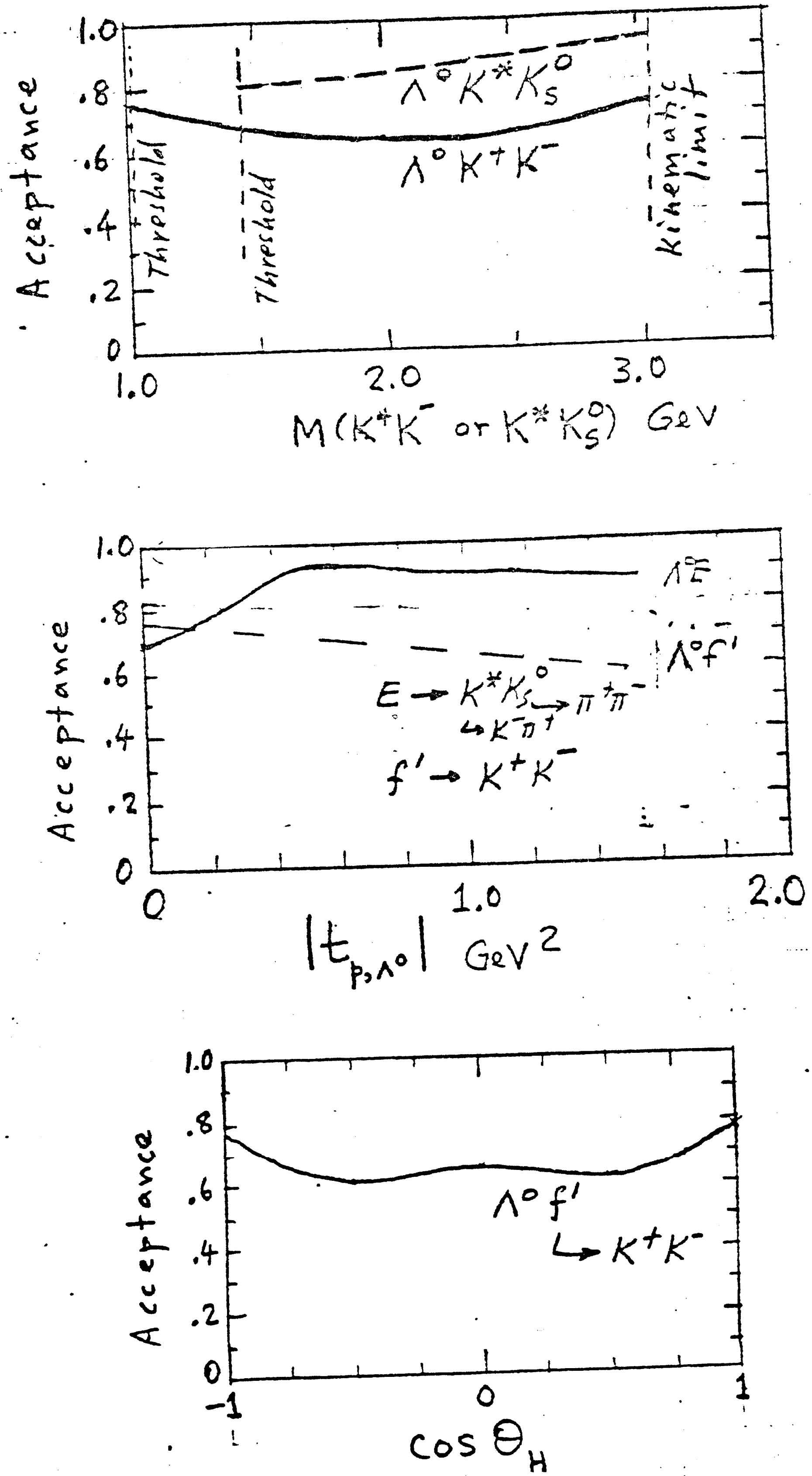

Acceptance
1.0
.8
.6
.4
.2
0
Threshold
Threshold
$\Lambda^0 K^* K_S^0$
$\Lambda^0 K^+ K^-$
Kinematic limit
1.0
2.0
3.0
M(K^+K^- or $K^*K_S^0$) GeV
Acceptance
1.0
.8
.6
.4
.2
0
ΛE
$\Lambda^0 f'$
$E \to K^* K_S^0$
$K_S^0 \to \pi^+\pi^-$
$K^* \to K^-\pi^+$
$f' \to K^+K^-$
0
1.0
2.0
$|t_{p,\Lambda^0}|$ GeV^2
Acceptance
1.0
.8
.6
.4
.2
0
$\Lambda^0 f'$
$\to K^+K^-$
-1
0
1
cos Θ_H

Fig.-7