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A Proposal to Measure the Differential Cross Section
for Several Baryon Exchange Reactions

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Title: A Measurement of the Differential Cross Sections
for Several Baryon Exchange Reactions

Manpower: 6 Ph.D. Scientists (5 listed on title page plus
one Research Associate)
4 Graduate Students
2 Engineers: D. Olive, M. Shrimplin

Description: The Purdue/ANL recoil spectrometer, on-line to an
EMR 6050 computer, will be used to detect mesons
from u-channel processes produced at laboratory
angles between 70° and 140° . Two changes to the
existing apparatus will be made: (1) reversal of
the polarity of the SCM-105 spectrometer magnet,
(2) addition of a time-of-flight system to the
spectrometer. Differential cross sections for
these u-channel processes will be measured.

Beam Requirements: The experiment will be performed in the unseparated,
 17° Meson Beam and utilize the available intensities
of $2.5 \times 10^8 \pi^-/\text{ZGS pulse}$ and $2.0 \times 10^8 K^-/\text{ZGS pulse}$
at 5.0 GeV/c.

Time Request: 60 shifts of data taking and 20 shifts of tuning.

I. SUMMARY

We propose to measure the differential cross sections for several backward (u-channel) reactions of the type $\pi^- p \rightarrow X^- \pi^+$ ($X^- = \Delta^-(1236), \dots$) and $K^- p \rightarrow Y^- \pi^+$ ($Y^- = \Sigma^-, Y^{*-}(1385), \dots$) in the u-range $0 \geq u \geq -0.7$ (GeV)² at 5.0 GeV/c. Data for these reactions are scarce or nonexistent. We propose to gather high statistics data which will make possible meaningful tests of SU(3) and Regge model predictions for the reactions:

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

$$K^- p \rightarrow Y^{*-}(1385) \pi^+ \quad (2)$$

$$\pi^- p \rightarrow \Delta^-(1236) \pi^+ \quad (3)$$

The experiment we propose is a continuation of our studies of backward reactions begun in E-348, in which the differential cross sections for reactions of the type $\pi^- p \rightarrow X^+ \pi^-$ ($X^+ = p, \Delta^+(1236), \dots$) and $K^- p \rightarrow Y^+ \pi^-$ ($Y^+ = \Sigma^+, Y^{*+}(1385), \dots$) are being measured. We intend to use the present E-348 apparatus with only two changes: (a) reversal of the polarity of the SCM-105 magnet used in the spectrometer in order to maximize the acceptance for positive recoil particles and (b) addition of a time-of-flight system to the spectrometer to aid in the separation of recoil π^+ 's from background protons. We will use the 17^O Beam, where intensities of $2.5 \times 10^8 \pi^-$ and 20,000 K^- per pulse are presently available.

In Section III we discuss the theoretical interest in the backward reactions $K^- p \rightarrow \Sigma^- \pi^+$, $K^- p \rightarrow Y^{*-}(1385) \pi^+$, and $\pi^- p \rightarrow \Delta^-(1236) \pi^+$ and summarize the present experimental situation regarding these reactions. In Section IV we present the expected counting rates for the proposed experiment.

A total of eighty shifts is requested for this experiment.

II. INTRODUCTION

The experimental study of two body reactions in which only a few trajectories are exchanged continues to be a prime source of our understanding of high energy dynamics. Great strides have been made in the past five years in understanding the systematics of t-channel processes. We feel that this is due to the availability of high statistics data in which various members of the baryon octet and decuplet are produced. With these data it is now possible to test SU(3) for the t-channel as well as to make various consistency checks with only a minimum of theoretical assumptions. It is even possible in some instances to determine the scattering amplitudes directly.¹

No similar situation exists for u-channel processes. The reasons for this situation are clear. The backward cross sections are down by two or three orders of magnitude ($\frac{d\sigma}{du} \sim 10 \mu\text{b}/(\text{GeV})^2$) from forward cross sections, making it difficult for bubble chambers to gather statistics. Except for a single experiment² which studied the reaction $\pi^- p \rightarrow \Delta^-(1236) \pi^+$ by measuring recoil π^+ 's scattered backward near 180° ($u \gtrsim -0.1 (\text{GeV})^2$), spark chamber/counter experiments have concentrated on detecting and momentum analyzing a fast forward proton and therefore have been inherently limited to the study of only backward elastic scattering. Thus, except for backward πp elastic and charge exchange scattering, the data for backward reactions are scarce or nonexistent.

We propose to use the Purdue/ANL Recoil Spectrometer system to detect and momentum analyze backward going π^+ 's, from which we can then calculate the missing mass of the forward going baryon. Thus, we will not be restricted to only elastic scattering and will be able to study quasi-two-body reactions in which forward baryons are produced.

III. THEORETICAL INTEREST AND EXPERIMENTAL SITUATION

In this section we present some of the theoretical interest in the reactions we wish to measure and indicate the present experimental situation regarding the various theoretical predictions.

A. Test of Exchange Degeneracy (EXD) Using $K^- p \rightarrow \Sigma^- \pi^+$

Berger and Fox³ have suggested a study of $K^- p \rightarrow \Sigma^- \pi^+$ as a definitive test of exchange degeneracy. This reaction has an exotic t-channel which, within the framework of Regge theory or Regge theory plus weak cuts, implies degeneracy of the trajectories exchanged in the u-channel, viz., Δ_0 with $D_{15}(N_\beta)$ and N_α with N_Y . Experimentally one should find no dip or break in $\frac{d\sigma}{du}$. Any break or dip would be direct evidence for broken exchange degeneracy. Fits to πN data by Berger and Fox are in disagreement with (N_α, N_β) and (Δ_0, D_{15}) EXD but are not conclusive. These fits lead them to expect a break in $\frac{d\sigma}{du}$ for $K^- p \rightarrow \Sigma^- \pi^+$ at $u \approx -0.2$ (GeV/c)². High statistics data for this reaction exhibiting such a break would provide the first instance in which a process with an explicit exotic channel showed EXD breaking.

The published data on this reaction at 3.5,⁴ 3.95,⁵ 4.07,⁶ 4.25,⁷ and 5.47⁶ GeV/c are shown in Fig. 1. Two of the experiments have too few events to be able to say anything about structure in $\frac{d\sigma}{du}$, while the two higher statistics experiments^{5,7} show only a hint of a dip in $\frac{d\sigma}{du}$ at $u \approx -0.2$ (GeV)² (a ~ 1 standard deviation effect). Using published cross sections^{5,7} and assuming an $s^{-3.5}$ energy dependence for $\frac{d\sigma}{du}$, we expect about 1800 events for this reaction in the u-range $0 > u > -0.7$ (GeV)². This is more than 20 times the number of events reported by the highest statistics experiment.⁷ Thus, whether a break or dip exists in $\frac{d\sigma}{du}$ at $u \approx -0.2$ (GeV)² will be answered conclusively by the proposed experiment.

We will also measure the cross section for $K^- p \rightarrow Y^{*-}(1385) \pi^+$, which will provide another test of exchange degeneracy.⁸ As in $K^- p \rightarrow \Sigma^- \pi^+$, the t-channel is exotic, and the same trajectories are exchanged in the u-channel. Thus, any dip or break in $\frac{d\sigma}{du}$ will be direct evidence for broken exchange degeneracy.

B. Tests of SU(3) Symmetry

1. As first noted by Meshkov et al.,⁹ simple SU(3) predicts

$$\begin{aligned} \frac{1}{3} \frac{d\sigma}{du} (\pi^- p \rightarrow \Delta^-(1236) \pi^+) &= \frac{d\sigma}{du} (K^- p \rightarrow Y^{*-}(1385) \pi^+) \\ &= \frac{d\sigma}{du} (\pi^- p \rightarrow Y^{*-} K^+) \\ &= \frac{d\sigma}{du} (K^- p \rightarrow \Xi^{*-} K^+) \end{aligned}$$

The first cross section prediction is of most interest to us since we can measure both of these cross sections simultaneously in the same apparatus. This should provide an especially reliable and meaningful test of this prediction, which has not yet been tested. Some data for the backward reaction $\pi^- p \rightarrow \Delta^-(1236) \pi^+$ are available,^{10,11} but only slight, if any, indications for the process $K^- p \rightarrow Y^{*-}(1385) \pi^+$ have been found at 2.24,¹² 3,¹³ 3.5,⁴ 4.1,¹⁴ 5.5,¹⁴ and 6¹⁵ GeV/c.

To the extent that reliable data are available for $\pi^- p \rightarrow Y^{*-} K^+$ and $K^- p \rightarrow \Xi^{*-} K^+$, we will test the other two predictions.

2. SU(3) also predicts^{16,17} that

$$\frac{d\sigma}{du} (K^- p \rightarrow \Sigma^- \pi^+) = \frac{d\sigma}{du} (K^- p \rightarrow \Xi^0 K^0).$$

Existing data¹⁸ indicate these processes do not have equal cross sections.^{19,20} Various theoretical considerations have been proposed to account for the discrepancy; among them, angular momentum barrier effects¹⁹

and a Regge picture in which the $\Xi^0 K^0$ reaction involving strangeness exchange is suppressed relative to the $\Sigma^- \pi^+$ reaction which does not involve strangeness exchange.²⁰ At present, only poor experimental data exist for these reactions. However, high statistics measurement of the angular distribution for the $\Sigma^- \pi^+$ reaction, combined with existing $\Xi^0 K^0$ data¹⁸ could provide a more detailed picture of the nature of the inequality and shed some light on the dynamical mechanisms involved.

C. Test of an Additive Quark Model

Using an additive quark model and experimental cross sections for πN backward elastic and charge exchange data at 6 GeV/c, Bailes et al.²¹ predict that the backward cross section for $\pi^- p \rightarrow \Delta^-(1236) \pi^+$ is 50 ± 8 times the backward cross section for $\pi^- p \rightarrow \Delta^+(1236) \pi^-$ and about the same as for $\pi^+ p$ backward elastic scattering.

Derado²² has extended the calculations of Bailes et al. for comparison with his own data at 4 GeV/c. He predicts that the cross section for $\pi^- p \rightarrow \Delta^-(1236) \pi^+$ is greater than the cross section for $\pi^- p \rightarrow \Delta^+(1236) \pi^-$ by a factor of 55 ± 20 at $u = 0.154$ (GeV)² (exactly backward scattering) and by a factor of 20 ± 7 at $u = 0$. His own data, shown in Fig. 2, qualitatively bear out this prediction. His cross section for $\pi^- p \rightarrow \Delta^+(1236) \pi^-$ is consistent with being zero, while his cross section for $\pi^- p \rightarrow \Delta^-(1236) \pi^+$ is about the same as for $\pi^+ p$ backward elastic scattering.

We note that SU(6)_w predicts²³ that

$$\frac{d\sigma}{du} (\pi^- p \rightarrow \Delta^-(1236) \pi^+) = 12 \frac{d\sigma}{du} (\pi^- p \rightarrow \Delta^+(1236) \pi^-)$$

in the exactly backward direction in qualitative agreement with the additive quark model. Although the SU(6)_w prediction holds rigorously

only in the exact backward direction, we can test it to the extent that an extrapolation of the data to the exactly backward direction is valid.

As shown in Fig. 5, a clear signal for $\pi^- p \rightarrow \Delta^+(1236) \pi^-$ is seen in our E-348 data in the u-region $0 \geq u \geq -0.7$ (GeV)² (the signal is even more pronounced at 3 GeV/c). In E-348 the apparatus also accepted events from reactions with recoil π^+ 's in the u-range $-0.5 \geq u \geq -1.4$ (GeV)²; a preliminary analysis of this data shows clear evidence for $\pi^- p \rightarrow \Delta^-(1236) \pi^+$ at 3 and 5 GeV/c. Due to the usual peaking of $\frac{d\sigma}{du}$ in the backward direction, we expect the counting rate for $\pi^- p \rightarrow \Delta^-(1236) \pi^+$ to be substantially larger in the proposed experiment ($0 \geq u \geq -0.7$ (GeV)²) than in E-348 ($-0.5 \geq u \geq -1.4$ (GeV)²). Thus, we expect no trouble in gathering high statistics data for $\pi^- p \rightarrow \Delta^-(1236) \pi^+$, and we will be able to make a significant test of the additive quark model.

D. Test of Duality

F. Halzen²⁴ has presented the results of calculations based on a u-channel SU(3) amplitude analysis combined with duality constraints and F/D coupling ratio information. A result of interest is:

$$\begin{aligned} \frac{d\sigma}{du} (K^- p \rightarrow \Sigma^- \pi^+) &= 2 \frac{d\sigma}{du} (\pi^- p \rightarrow \Sigma^0 K^0) \\ &= \frac{2}{3} \frac{d\sigma}{du} (\pi^- p \rightarrow \Lambda K^0) \end{aligned}$$

Although there is good backward data for the ΛK^0 final state^{25,26} as shown in Fig. 3, at present there is only low statistics data for the other two reactions.^{5,6,7,27} For this reason, no definitive test of these relations has been possible. High statistics data on the $\Sigma^- \pi^+$ backward angular distribution will provide a strong test of this prediction. If these relations hold, specific tests of SU(3) symmetry predictions, duality constraints, and presently accepted F/D ratios for these reactions are possible.

E. Test of SU(6)_w Predictions

SU(6)_w predicts relationships between cross sections in the exactly backward or forward direction. Among these predictions are several for reactions we will either measure in the proposed experiment or are in the process of measuring in E-348:

$$\begin{aligned}\frac{d\sigma}{du} (K^- p \rightarrow \Sigma^- \pi^+) &= \frac{1}{32} \frac{d\sigma}{du} (K^- p \rightarrow Y^{*-}(1385) \pi^+) \\ &= \frac{1}{96} \frac{d\sigma}{du} (\pi^- p \rightarrow \Delta^-(1236) \pi^+) \\ &= \frac{1}{8} \frac{d\sigma}{du} (K^- p \rightarrow Y^{*+}(1385) \pi^-) \\ &= \frac{1}{8} \frac{d\sigma}{du} (\pi^- p \rightarrow \Delta^+(1236) \pi^-)\end{aligned}$$

To the extent that the extrapolation of our cross sections to the exactly backward direction is valid, we will test these predictions. In addition, these data may aid in resolving the validity of various dynamical models.

Of course, we will examine other SU(6)_w predictions which involve our measured cross sections and existing data. For example, Carter et al.²³ predict that

$$\begin{aligned}\frac{d\sigma}{du} (K^- p \rightarrow \Sigma^- \pi^+) &= \frac{1}{4} \frac{d\sigma}{du} (K^- p \rightarrow \Xi^- K^+) \\ &= \frac{d\sigma}{du} (\pi^- p \rightarrow \Sigma^- K^+).\end{aligned}$$

Thus, we can compare our measurements for $K^- p \rightarrow \Sigma^- \pi^+$ with existing data for $K^- p \rightarrow \Xi^- K^+$ ^{28,29} and $\pi^- p \rightarrow \Sigma^- K^+$,²⁷ both of which involve the exchange of strange trajectories. We can make further tests of several schemes mentioned in connection with SU(3) which attempt to account for the breaking of predicted symmetry. For example, using the prescription of Kayser et al.,²⁰ it is expected that

$$\begin{aligned}\left[\frac{d\sigma}{du} (K^- p \rightarrow \Sigma^- \pi^+) - \frac{1}{32} \frac{d\sigma}{du} (K^- p \rightarrow Y^{*-} \pi^+) \right] &> \\ \left[\frac{d\sigma}{du} (\pi^- p \rightarrow \Sigma^- K^+) - \frac{1}{4} \frac{d\sigma}{du} (K^- p \rightarrow \Xi^- K^+) \right] &.\end{aligned}$$

IV. APPARATUS

A plan view of the Purdue/ANL Recoil Spectrometer is shown in Fig. 4. It is the same as that used for E-348 and consists of Cerenkov and scintillation counters to define and count the beam, a magnetic side-arm spectrometer to provide momentum and position information for the slow recoil π^+ 's, and a set of forward spark chambers to provide position information on the fast forward baryon decay products. Also included are other Cerenkov and scintillation counters which may be used to define a variety of triggers. The counter denoted S1 in Fig. 4 provides both trigger and dE/dX information on the recoil particle. Only two changes will be made to the existing apparatus to conduct this experiment, viz. install a time-of-flight system to aid in the separation of π^+ 's and protons in the spectrometer, and reverse the polarity of the SCM-105 spectrometer magnet to maximize acceptance for positively charged recoil pions.

A. Resolution

The beam and recoil particle information will be used to calculate the mass of the forward going baryon system. This mass will provide the primary constraint for separating reaction types (e.g., $K^- p \rightarrow (\Sigma^-, Y^{*-}, \dots) \pi^+$; $\pi^- p \rightarrow (\Delta^-, \Delta^{*-}, \dots) \pi^+$). Figs. 5 and 6 show the results of such an analysis from E-348 for $\pi^- p \rightarrow X^+ \pi^-$ and $K^- p \rightarrow X^+ \pi^-$, respectively, where X^+ denotes the mass of the forward baryon system. The RMS width of the proton peak from backward elastic scattering was approximately 25 MeV/c² at 3.0 GeV/c and 40 MeV/c² at 5.1 GeV/c. This resolution is clearly adequate to detect the Δ^- and separate it from higher mass resonances. From the reaction $K^- p \rightarrow \Sigma^+ \pi^-$ at 3.0 GeV/c, the RMS width of the Σ^+ peak was found to be approximately 19 MeV/c². This increased to approximately

32 MeV/c² at 5.1 GeV/c. Again, this resolution is sufficient to separate the Σ^- 's from the more massive Υ^{*-} 's. For both the E-348 reactions cited the u-resolution was found to be better than 0.05 (GeV/c)².

B. Time-of-Flight (TOF)

The TOF system will be employed with dE/dX information in order to separate pions from protons in the spectrometer. To determine the contribution to the RMS width of the recoil mass, the TOF resolution was examined for a "worst case." This case corresponded to an ~ 800 MeV/c particle traversing ~ 3.3 meters through the spectrometer magnet. A typical RMS TOF resolution of 1.5 nsec was assumed. The separation between pion and proton was found to be ~ 5.8 nsec with predicted RMS widths of ± 318 MeV/c² for a recoil π^+ and ± 72 MeV/c² for a recoil proton. Thus, we find adequate resolution for separating pions and protons in the spectrometer.

C. Counting Rates

In order to estimate the counting rates for the proposed experiment, we have performed Monte Carlo integrations of differential cross sections over the acceptance of the apparatus. Whenever possible, experimental values of the differential cross sections have been used. Counting rates have been scaled to 5 GeV/c using an $s^{-3.5}$ energy dependence of $\frac{d\sigma}{du}$. The presently available fluxes of $2.5 \times 10^8 \pi^-$ and 20,000 K^- per ZGS pulse in the 17⁰ Beam have been assumed.

1. $K^- p \rightarrow \Sigma^- \pi^+$

Using the 3.95 GeV/c data of Moscoso et al.,⁵ we estimate the counting rate for $K^- p \rightarrow \Sigma^- \pi^+$ at 5 GeV/c to be 32 ± 22 events/shift. Using the 4.25 GeV/c data of Blokzijl et al.,⁷ we estimate this counting rate

to be 31 ± 16 events per shift. Thus, we expect about 30 events/shift or a total of 1800 events for this reaction from presently existing data.

We have also estimated the counting rates using previously mentioned SU(3) and SU(6)w cross section relationships. The SU(3) prediction by Halzen²⁴ that

$$\frac{d\sigma}{du} (K^- p \rightarrow \Sigma^- \pi^+) = \frac{2}{3} \frac{d\sigma}{du} (\pi^- p \rightarrow \Lambda K^0)$$

and published data²⁵ on $\pi^- p \rightarrow \Lambda K^0$ at 4 and 6.2 GeV/c results in a counting rate of 8 ± 1 events/shift. The SU(6)w prediction by Carter et al.²³ that

$$\frac{d\sigma}{du} (K^- p \rightarrow \Sigma^- \pi^+) = \frac{1}{4} \frac{d\sigma}{du} (K^- p \rightarrow \Xi^- K^+)$$

combined with data²⁸ on $K^- p \rightarrow \Xi^- K^+$ at 5 GeV/c results in a counting rate of 12 ± 3 events/shifts. Although these counting rates based on theoretical predictions are somewhat lower than those we calculate directly from existing $K^- p \rightarrow \Sigma^- \pi^+$ data, they still result in ~ 500 events for this reaction, about an order of magnitude greater than existing data.

2. $\pi^- p \rightarrow \Delta^-(1236) \pi^+$

We have used the experimental differential cross section for this reaction given by Derado¹¹ at 4 GeV/c. The Monte Carlo integration of this cross section over the acceptance of the apparatus results in a counting rate of 8500 ± 2500 events/shift at 5 GeV/c. Thus, we expect no trouble in gathering high statistics data for this reaction.

3. $K^- p \rightarrow Y^{*-}(1385) \pi^+$

Only slight, if any, indications of this reaction have been seen at 2.24,¹² 3,¹³ 3.5,⁴ 4.1,¹⁴ 5.5,¹⁴ and 6¹⁵ GeV/c. Thus, we were not

able to use experimental values for the differential cross section for this reaction.

Using the SU(3) prediction of Meshkov et al.⁹ that

$$\frac{d\sigma}{du} (K^- p \rightarrow Y^{*-}(1385) \pi^+) = \frac{1}{3} \frac{d\sigma}{du} (\pi^- p \rightarrow \Delta^-(1236) \pi^+)$$

and the experimental cross section $\pi^- p \rightarrow \Delta^-(1236) \pi^+$ at 4 GeV/c given by Derado,¹¹ we estimate the counting rate for $K^- p \rightarrow Y^{*-}(1385) \pi^+$ to be 23 ± 7 events/shift or a total of 1380 ± 420 events.

If we use the SU(6)_w prediction of Carter et al.²³ that

$$\frac{d\sigma}{du} (K^- p \rightarrow Y^{*-}(1385) \pi^+) = 32 \frac{d\sigma}{du} (K^- p \rightarrow \Sigma^- \pi^+)$$

and existing data^{5,7} for $K^- p \rightarrow \Sigma^- \pi^+$, we obtain a counting rate of 950 ± 650 events/shift at 5 GeV/c. Since SU(6)_w holds rigorously only in either the exact forward or backward direction, this counting rate may be too optimistic. However, it does hint that the counting rate for this reaction may be somewhat higher than that for $K^- p \rightarrow \Sigma^- \pi^+$.

V. TIME REQUEST

We request a total of 80 shifts for the proposed experiment. Twenty shifts will be used for tuning the time-of-flight system, and the remaining 60 shifts will be used for data taking.

VI. CONCLUSION

The proposed experiment will provide high statistics data on several baryon exchange reactions, for which little or no data presently exists. Such data are badly needed in order to refine our understanding of hadron dynamics in backward reactions.

There are many interconnections among the backward reactions we will study in the proposed experiment and in E-348. Measurements of these reactions in the same apparatus, many of them simultaneously, will provide especially reliable data for testing these relationships.

Because of the rapid fall-off of the differential cross sections with energy ($\frac{d\sigma}{du} \sim s^{-3.5}$), it is extremely difficult to perform these measurements above the ZGS energy region. Thus, the ZGS and the high flux capabilities of the 17⁰ Beam provide a unique opportunity for making these measurements.

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Figure 1a $K^-p \rightarrow \Sigma^+\pi^-$ at 3.5 GeV/c⁴

Reaction	Event	4.07 GeV/c s.m. prod. cosine ($\bar{K}^+\pi^-$)	Event	5.47 GeV/c s.m. prod. cosine ($\bar{K}^+\pi^-$)
$K^-p \rightarrow \Sigma^+\pi^-$ (backward-hemi- sphere events)	1	-0.095	1	-0.676
	2	-0.139	2	-0.926
	3	-0.137	3	-0.974
	4	-0.951		
	5	-0.973		
$K^-p \rightarrow \Sigma^+\pi^+$ (all events)	1	0.963	1	0.776
	2	0.538	2	0.246
	3	0.160	3	-0.718
	4	-0.577	4	-0.950
	5	-0.598	5	-0.951
	6	-0.974	6	-0.973

Figure 1b $K^-p \rightarrow \Sigma^+\pi^+$ at 4.07 and 5.47 GeV/c⁶

Figure 1c $K^-p \rightarrow \Sigma^- \pi^+$ at $3.95 \text{ GeV}/c^5$

Figure 1d $K^-p \rightarrow \Sigma^- \pi^+$ at $4.25 \text{ GeV}/c^7$

Figure 2 $\pi^- p \rightarrow \Delta^-(1236) \pi^+$ at 4.0 GeV/c¹¹

Figure 3 Angular Distributions for $K^-p \rightarrow \Lambda K^0$

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Figure 4

Figure 5

Figure 6