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A Proposal to Measure the Differential Cross Sections for
Several Δ^{++} Exchange Reactions

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Title: A Measurement of the Differential Cross Sections for Several Δ^{++} Exchange Reactions.

Manpower: 7 Ph.D. Scientists (6 listed on title page plus one Res. Assoc.)
2 Graduate Students
2 Engineers, D. Olive, M. Shrimplin

Description: A wire spark chamber spectrometer using an SCM105 magnet will be on-line to an EMR 6050 computer. Mesons (produced at laboratory angles between 140° and 70°) from u-channel processes will be detected and the differential cross sections for these processes will be measured.

Time Scale: The equipment will be ready for installation by June 1973.

Equipment:

- A. Supplied by Purdue
 - 1. All scintillation counters, wire chambers and all associated pulsing electronics and readout system.
 - 2. Time of flight system including specially built 12 bit ADC.
 - 3. Cherenkov counters for beam and forward arm of spectrometer (a counter on loan from Michigan is suitable for this purpose).
 - 4. At least 75% of fast electronics
- B. Supplied by ANL
 - 1. An unseparated π^- beam of intensity 2.5×10^6 with 2×10^4 K^- per pulse at or near 6.0 GeV/c.
 - 2. A 2 foot long, 2 inch diameter liquid hydrogen target.
 - 3. One SCM 105 magnet.
 - 4. Surveying and rigging, including shielding for time-of-flight counters.
 - 5. Fast electronics from SHELF.
 - 6. EMR 6050 computer interfaced to SAC system.

Time Request: 140 shifts of data taking, 40 shifts of tuning, and such time in a test beam whose energy is at least 1 GeV/c as required to test the time of flight system.

Data Analysis: We expect to modify the existing software for the EMR 6050 so that it will handle our geometry. Some of the data will be analyzed on-line while the data is accumulated; however, the majority of the data analysis would be performed on the Purdue-IBM 360/44 computer. Publication of the first results of this experiment would come about 6 months following the completion of the run.

I. Summary

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. Even so, little other than elastic and charge exchange data have been taken systematically for backward (u-channel exchange) reactions.

We propose here to further study u-channel reactions in the incident momentum range from 3 to 6 GeV/c and for u values $.1 < |u-u_0| < (\sim 1.0)$ (GeV/c)², where $u_0 = u(180^\circ)$. We will build a spectrometer utilizing spark chambers and counters to detect and momentum analyze the backward going meson. With this information the mass of the forward going baryon may be calculated. In some cases the proton from the decay of this baryon will be detected in spark chambers near the forward direction; hence, polarization for a reaction such as

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

will be measured.

II. Discussion

In a 1971 review article Berger and Fox⁽¹⁾ have lucidly presented the theoretical and experimental picture, with respect to u-channel reactions. Figures 1 and 2 show typical data for elastic scattering in the backward direction for the energy range in which we are interested. Backward charge exchange and π^+p elastic scattering both show the well known dip around $u' = |u-u_0| \approx 0.2$ (GeV/c)², whereas π^-p elastic falls off rather uniformly with slope parameter of ~ 3 (GeV/c)⁻².

This qualitative behavior is accounted for by a rather wide range of models which start with very different assumptions. We wish not to dwell on the details of these models but rather to repeat a point made by Berger and Fox: all models are accommodated due to the paucity of data.

A survey indicates that data are scarce to non-existent for all but backward elastic scattering and pion charge exchange. Great strides have been made in the past two years in understanding the systematics of t-channel processes. This, we think, is due primarily to the large variety of high statistics data now available in which various members of the baryon octet and decouplet are produced. With this data it is now possible to test SU(3) for the t-channel as well as to make various other consistency checks with only a minimum of theoretical assumptions.⁽²⁾ It is even possible in some instances to determine the scattering amplitudes directly.⁽³⁾

No similar situation exists for u-channel processes. The reasons for this situation are clear. The cross sections for backward reactions are down by two or three orders of magnitude making it difficult for the bubble chamber to gather statistics. Spark chamber experiments have concentrated on detecting and momentum analyzing the fast forward proton and have therefore been inherently limited to the study of only backward elastic scattering.

We propose to build a spectrometer to detect and momentum analyze the backward going meson. By so doing we remove the restriction to elastic scattering. With the present technique the mass of the forward going baryon and the momentum transfer, u , are determined with good resolution without requiring the detection of the decay products of the baryon. However, we propose to detect one or more of these particles to measure polarizations (in Σ^+ production) and improve signal to background by vertex reconstruction.

We wish to do this experiment in a high intensity beam ($\sim 2.5 \times 10^8$ pions per pulse and 2×10^4 kaons per pulse) in the energy range from 3.0 to 6.0 GeV/c. Thus we will have access to cross sections not measured previously with good statistics. In a following section we will present expected rates for some of these reactions. Here we wish to further investigate the interest in their study.

The only known trajectory of "elementary" particles with two units of charge is the Δ^{++} trajectory. Except for those that exchange Δ^{++} , reactions with two units of charge in the exchange channel are exotic. This gives Δ^{++} exchange reactions a rather special interest since it is possible to isolate unambiguously a single trajectory by measuring one differential cross section. It is the prime purpose of the experiment proposed here to investigate in some detail properties of such reactions. Some examples are $\pi^- p$ backward elastic scattering, $K^- p \rightarrow \Sigma^+ \pi^-$, and $\bar{p} p \rightarrow \pi^+ \pi^-$.

$\pi^- p$ Backward Elastic Scattering

With this apparatus it will be possible to accumulate precise data at several energies on $\pi^- p$ backward elastic scattering. This data will not only be very useful for diagnostic purposes to provide better understanding of the apparatus; it will also be interesting in its own right. There is not good data available in the 3.0 to 6.0 GeV/c energy range for $\pi^- p$ backward elastic scattering. The $\pi^+ p$ data suggest that backward elastic scattering reaches asymptotic behavior by 5 GeV/c, but it is not yet possible to tell in the case of $\pi^- p$ elastic scattering. The various Regge models predict very different s dependence at large u for this reaction. An accurate measurement of the differential cross-section at several energies out to $u \sim -1$ (GeV/c)² will help to clarify this situation by establishing the energy dependence as a function of u (effective Δ_0 trajectory).

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

At present the Δ_0 trajectory has been isolated only in elastic scattering; hence a measurement of $K^- p \rightarrow \Sigma^+ \pi^-$ will be very valuable in that any deviations from the predictions of Δ_0 exchange would provide a clear challenge to theory. Furthermore, since the weak decay parameters of the Σ^+ are known, it is a straightforward matter to measure the polarization.

$SU(3)$ in the u -channel predicts⁽⁴⁾

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

$$\text{and} \quad P(K^-p \rightarrow \Sigma^+\pi^-) = P(\pi^-p \rightarrow p\pi^-). \quad (2)$$

We will test these simple predictions. The only breaking should be due to the mass difference of the external lines. Measuring both reactions in the same apparatus provides the possibility of a meaningful and trustworthy comparison.

Figure 3 shows a comparison of presently available data for $K^-p \rightarrow \Sigma^+\pi^-$ and $\pi^-p \rightarrow p\pi^-$ at 4 GeV/c. Within the accuracy of the data the differential cross sections are consistent with being equal; however, the data is of such quality as to not exclude breaking of $SU(3)$ by a rather large amount. Clearly, improved data as well as the polarization measurement in $K^-p \rightarrow \Sigma^+\pi^-$ would allow a more sensitive and meaningful test.

At the same time we will also accumulate data on the processes

$$\pi^-p \rightarrow \Delta^+\pi^-$$

$$\text{and} \quad K^-p \rightarrow Y^*(1385)\pi^-.$$

These reactions also proceed only through Δ^{++} exchange but are of further interest because now the octet member is replaced by a decouplet member, thus allowing an octet-decouplet production comparison. This data will, however, be subject to the usual uncertainties in the subtraction of physical background.

III. Experimental Method and Apparatus

The apparatus we propose is pictured schematically in Figure 4. The beam which goes from left to right in the figure strikes a two (2) foot long liquid hydrogen target. The beam particle type will be tagged with two differential Cherenkov counters and two threshold counters. One differential counter will be set to count kaons and one will count pions. One threshold counter will be set to count only pions and the other counter, pions and kaons. An antiproton, $\bar{p}$, will, of course, be defined as no Cherenkov count.odoscopes

in the beam will determine the incident beam direction to ± 1 mr and the momentum resolution to $\pm 3/4\%$.

A magnetic spectrometer designed around one of the ZGS SCM-105 magnets with a 14" gap will detect the backward (in the center of mass) meson. The detectable production angles which vary from $\sim 70^\circ$ to $\sim 140^\circ$ in the laboratory for this apparatus are measured in a set of four (4) wire spark chambers with magnetostrictive readout placed between the target and the SCM-105. The spacing between these chambers is $\sim 6"$. The bend angle through the magnet is determined by measuring the particle direction behind the magnet in a second set of four (4) wire spark chambers.

A coincidence between the scintillators S1 and S2 will indicate the passage of a charged particle through the spectrometer. S1 is placed between the target and the first set of chambers so that multiple scattering in it affects only the angular resolution and not the momentum resolution. S2 is a hodoscope composed of 13 counters each of whose dimensions are 12" x 36" x 3/8". This hodoscope is the last detector element of the spectrometer.

Because of the two foot length of the hydrogen target we have written a Monte Carlo program in order to understand the acceptance of the system. The p bite is very close to a constant 10° ; hence; the program considers only the horizontal plane. Figure 5 shows the boundaries of the $p - \theta$ plot generated by randomly choosing target z position, momentum and angle of the particle for a 13 KG field in the SCM-105. The geometry is as indicated in Figure 4.

The spectrometer is designed in such a way as to take advantage of kinematic focussing for two body and quasi-two body reactions by bending toward the beam direction. The design optimizes the acceptance for such reactions with emphasis on the u' range from $\sim .1$ (GeV/c)² to ~ 1 (GeV/c)². In order to investigate in detail the u' acceptance for the reactions in

which we are interested we have generated events distributed uniformly in u' for a variety of reactions. Figure 6 indicates the u' acceptance of the spectrometer for π^-p backward elastic scattering and $K^-p \rightarrow \Sigma^+\pi^-$ at 3.0 GeV/c and 6.0 GeV/c. For the reaction $K^-p \rightarrow \Sigma^+\pi^-$, in which we find particular interest, the acceptance ranges from ~ 0.1 (GeV/c) 2 to ~ 1.1 (GeV/c) 2 before it falls below the $25\% \times \frac{\Delta\phi}{2\pi}$ point at 6 GeV/c. At 3.0 GeV/c the range is ~ 0.1 to $.85$ (GeV/c) 2 . It should be noted that the acceptance has a smooth shape so that the geometrical efficiency corrections will not introduce artificial structure in the cross sections. In addition, the geometry is simple so that these corrections should not be unduly difficult.

Another set of four spark chambers will be placed in the forward direction so as to measure the direction of the forward going proton for backward elastic scattering as well as the decay proton from baryon decays such as:

and

The proton from these decays is constrained kinematically to lie within a relatively small cone about the original direction of the baryon. For example, at 6 GeV/c the proton from the decay of the forward produced Σ^+ will lie within $\sim 2^\circ$ of the Σ^+ direction. In the case of the Σ^+ decay a knowledge of the weak decay parameters allows us to measure the polarization of the Σ^+ by measuring

the decay asymmetry of the proton relative to the reaction plane.

As will be discussed in greater detail in a later section, the singles rates in the spectrometer are such that a trigger such as BEAM·S1·S2 would not be restrictive enough. The acceptance for protons in the spectrometer is large enough that protons from t-channel processes (forward elastic scattering, etc.) would dominate the trigger without further restriction.

We have therefore devised a method to eliminate almost all of the acceptance for such protons while leaving the acceptance for negative particles changed. A veto counter, V1, is placed before the SCM 105 so as to cover only a portion of the angular acceptance of the spectrometer (see Fig. 4). Positive particles passing through V1 will hit the upstream end of S2 while negative particles hit the downstream end. Specifically, if the 13 counters of S2 are labelled S2a, S2b,S2m starting at the upstream end, we define V2 to be the logical OR of S2a through S2f. The region of the acceptance covered by V1·V2 is almost all the acceptance for positive particles.

Thus, one possible trigger is

$$\text{BEAM} \cdot \text{S1} \cdot \text{S2} \cdot (\text{V1} \cdot \text{V2}).$$

However, we wish to be as conservative as possible in designing the trigger so we will consider restricting the veto signal even further. Most of the counts in V1·V2 will come from forward elastic scattering. Thus, we will require a fast pion in the forward arm by demanding a count in C, as well as in S3 before vetoing the event. (C is a gas Cherenkov counter set to count pions.) Thus our trigger will be

$$\text{BEAM} \cdot \text{S1} \cdot \text{S2} \cdot (\text{V1} \cdot \text{V2} \cdot \text{S3} \cdot \text{C}).$$

Such a trigger eliminates most peripheral processes and does not bias the acceptance for $\pi^- p \rightarrow p \pi^-$ and $K^- p \rightarrow \Sigma^+ \pi^-$.

In addition, we will find it convenient to choose which beam particles are allowed to trigger the system under computer control (one of the laboratory EMR 6050's will be used on-line). Pion induced reactions will certainly dominate kaon and $\bar{p}$ reactions. We will therefore scale down triggers according to beam particle type.

In addition, a time of flight (TOF) system will be started by a small counter placed immediately before the target and stopped by a signal derived from S2. In this way we expect to separate mesons from protons and in some instances, to be discussed later, to separate pions and kaons.

Simply stated, the experiment we propose detects a meson produced from 70° to 140° in the laboratory, measures its angle and momentum, and hence the mass of the baryon system. By detecting decay products of the baryon system we can improve our signals by vertex considerations with later analysis as well as measure polarization of Σ^+ .

IV. Resolutions

In this section we will present results of calculations we have made in order to estimate the missing mass resolution, u' resolution, and TOF resolution. In so doing we will examine questions such as multiple scattering, energy loss, and particle decay in the meson spectrometer.

A. Mass Resolution

We express the mass squared of the forward going baryon system as

$$M_4^2 = (p_1 + p_2 - p_3)^2 \quad (3)$$

where (1) implies beam, (2) implies target, and (3) the scattered meson. Then

$$M_4^2 = (E_1 + M_2 - E_3)^2 - \vec{p}_1^2 - \vec{p}_3^2 + 2 |\vec{p}_1| |\vec{p}_3| \cos \theta_3. \quad (4)$$

Each of the variables in this expression are measured. We assume that they are determined independently so that the experimental r.m.s. width of M_4 is given by

$$\Delta M_4 = \left[\left(\frac{\partial M}{\partial p_1} \delta p_1 \right)^2 + \left(\frac{\partial M}{\partial p_3} \delta p_3 \right)^2 + \left(\frac{\partial M}{\partial \theta_3} \delta \theta_3 \right)^2 \right]^{1/2}. \quad (5)$$

For the beam we have taken the momentum resolution to be $\pm 3/4\%$. In order to arrive at values for δp_3 and $\delta \theta_3$ it was necessary to consider in detail the effects of multiple scattering in the target, target vacuum jacket and super insulation, S1, V1, air and the spark chambers. In addition, a chamber resolution of 1 mm was assumed. Table I indicates the materials, thicknesses and radiation lengths considered. The results of the calculation depends on momentum (and therefore kinematics) due to the importance of the multiple scattering. Into $\delta \theta_3$ we have folded ± 1 mr for the beam direction determination and we have assumed a knowledge of the SCM 105 field integral to $\pm 1/2\%$. (5)

Figure 7 indicates how the missing mass resolution depends on u' , incident energy and type of interaction. In these graphs we present ΔM_4 vs u' at 3.0 and 6.0 GeV/c for a variety of reactions.

It is interesting to note (see Figure 7c for example) that for $\pi p \rightarrow X\pi$ at 6.0 GeV/c ΔM_4 is everywhere less than 60 MeV and rises to this value only for elastic scattering at the largest momentum transfer, u' . The resolution improves for higher missing masses and lower u' . This is due primarily to the fact that mass resolution is dominated by momentum resolution. At $u' = 0.1$ (GeV/c)² the missing mass resolution is typically less than 15 MeV. A more characteristic number over the entire u range would be ~ 30 MeV which is certainly adequate for the separation of p , Λ^+ or Σ , $Y^*(1385)$ for example. It is clear that the resolution attainable is better than similar experiments done in the forward direction even with the added difficulties introduced by multiple scattering of the lower energy meson in the present experiment. This is due, among other things, to the rapid variation of p and θ with u for a given M_4 as compared to very slow variation near $t \approx 0$.

We consider this to be a major advantage of the present technique and anticipate little difficulty in separating the lower lying baryon states.

B. u Resolution

Since

$$u = (p_2^2 - p_3^2) = m^2 + m^2 - 2m E \quad (6)$$

the u resolution of the apparatus depends only on how well we measure the momentum of the meson in the spectrometer.

In this context we point out that backward elastic scattering will provide a powerful tool for understanding the system in detail. Opening angle and coplanarity constraints allow selection of a relatively pure sample of elastic events. The momentum of the meson track can then be forced to satisfy the two body kinematics and then be used to calibrate the SQM-105 $\int B.d\ell$.

Assuming an error of $\pm 1\%$ in the field integral and introducing bend angle uncertainties due to multiple scattering and chamber resolution we have evaluated

$$\delta u = \frac{\partial u}{\partial p_3} \cdot \delta p_3 = \frac{-2m_0 p_3}{E_3} \cdot \delta p_3 \quad (7)$$

and find that nowhere is δu larger than $\sim .015 \text{ (GeV/c)}^2$, and only at the largest u values does it obtain this value. Near $u' = -.1 \text{ (GeV/c)}$ the resolution is $\delta u \sim .002 \text{ (GeV/c)}^2$; these are r.m.s. values.

C. TOF Resolution

Given the momentum and velocity of a particle as measured by the spectrometer, how well can we assign a mass to it?

$$m^2 = p^2 (\beta^{-2} - 1) \quad (8)$$

$$\text{and} \quad \delta m^2 = \left[\left(\frac{\partial m^2}{\partial p} \delta p \right)^2 + \left(\frac{\partial m^2}{\partial \beta} \delta \beta \right)^2 \right]^{1/2} \quad (9)$$

If $\delta \tau$ is the r.m.s. error in the TOF and L is the path length, then

$$\frac{\delta \beta}{\beta} = \frac{\beta c}{L} \delta \tau \quad (10)$$

It is then easy to show that

$$\delta m^2 = 2m \left\{ \left(m \frac{\delta p}{p} \right)^2 + \left(\frac{YPC}{L} \delta \tau \right)^2 \right\}^{\frac{1}{2}}. \quad (11)$$

We have estimated $\frac{\delta p}{p}$ as described in the previous two sections. L is ≈ 15 ft. for this apparatus. What is $\delta \tau$?

We expect to start a TAC with a small beam counter immediately before the target and stop it with a signal derived from one of the 13 hodoscope counters (S2). These counters will have the dimensions 12" x 36" x 3/8". Using the spark chamber trajectories we will correct the time of flight for impact point on the scintillator and for path length from the target. We expect to test one of these counters and the TOF electronics in a test beam to determine the resolution thus obtainable. Discussions with groups⁽⁶⁾ who have performed high resolution TOF measurements recently lead us to believe that a FWHM resolution of 1.2 ns is readily obtained. Hence, in what follows an rms resolution $\delta \tau \pm .6$ ns is assumed.

In 15 feet a 1 GeV/c proton and a 1 GeV/c pion are separated by 5.5 ns. There is no question that pions and kaons will be separated from protons.

At 1 GeV/c, pions and kaons are separated by 1.6 ns. Hence, roughly speaking, pions and kaons are separated by about two and a half standard deviations. To be more quantitative, we have evaluated Eq. 11 above for a number of reactions in the range of kinematics covered by this apparatus. The results of these calculations are shown in Figure 8. In Fig. 9 we show directly the error in m^2 as a function of momentum. From this information we try to imagine how a histogram of mass squared, m^2 , of the particle in the spectrometer would look ($m_{\pi}^2 \sim .02$, $m_K^2 \sim .244$).

We see from the graphs that pions and kaons behave qualitatively alike and that δm^2 has the range .015 to .08 (GeV²) as u' rises from 0.1 (GeV/c)²

to 1.0 (GeV/c)^2 . Hence, if we histogram all particles up to 1 GeV/c , the tails of the mass peaks would of course be dominated by the high momentum transfer events as expected. In reality we would proceed as follows: make plots of m^2 for several different ranges of momenta. We then determine experimentally the highest momentum for which a clear separation is possible.

The details of this separation must await the experiment. An important question which has been ignored above is that of the relative abundance of pions and kaons in the backward direction. Most two body u-channel cross sections for π and K are expected to be comparable in magnitude. It is not unlikely that after a cut on missing mass, say $M_M < 2.0 \text{ GeV}$, that pions and kaons would have comparable abundances except for kaon decay.

The number of decay lengths for kaons in the apparatus ranges from ~ 2 at $u' \sim 0.1$ to ~ 0.6 at $u' \sim 1 \text{ (GeV/c)}^2$. The loss due to kaon decay therefore varies from $\sim 85\%$ to 45% .

Should the relative abundance be such that kaons are not obscured by the tail of the pion peak then we will have the TOF resolution to separate π 's and K's in the range of u' accepted by the system. If kaon production is small compared to pions in the backward direction, then kaons should pose no difficulty in measuring processes with the signature (beam π or K) goes to (π in the spectrometer).

D. Energy Loss and Nuclear Interactions

The lowest momentum pion that we are interested in measuring in the spectrometer is $\sim 250 \text{ MeV/c}$. The total momentum lost in the spectrometer before S2 for such a pion is $\sim 5 \text{ MeV/c}$ and the error made in determining momentum due to ionization loss before the magnet is $\sim 4 \text{ MeV/c}$. Of course, this may be corrected for in the analysis.

The interaction probability for a ~ 250 MeV/c pion traversing the spectrometer is $\sim 4\%$.

V. Counting Rates

In order to estimate the number of events expected at each energy for the reactions of interest we have performed a Monte Carlo integration of the differential cross section over the apparatus. For π^-p backward elastic scattering we used the existing data⁽⁷⁾ in our energy range.

In the case of $K^-p \rightarrow \Sigma^+\pi^-$ we have assumed (as SU(3) suggests) that the differential cross section is equal to that of π^-p backward elastic scattering.

In addition to geometrical efficiency we have assumed a tracking efficiency of 90%. Particle decay has also been considered.

The results of these calculations are presented in Table II. Here we give the total number of events expected per shift integrated over the spectrometer acceptance.

Based on these estimates we anticipate running at 3.0, 4.0 and 6.0 GeV/c incident beam momenta with the time divided so as to accumulate approximately equal statistics at each energy.

We request 140 shifts for data taking divided among the three energies as indicated in Table II. The event yields expected for each reaction type are also indicated. In addition, we request 40 shifts for tuning the system. Hence, the ZGS time requested is 180 shifts.

VI. Trigger Rates

We discuss here the analysis performed to determine our total trigger rate. Since the trigger requires that a charged particle pass through the spectrometer, we have found it convenient to consider the inclusive reaction

$$\pi^-p \rightarrow \pi^- + \text{anything}$$

to estimate the rate for events where the charge of this particle is negative.

Since the spectrometer will only accept particles with small laboratory momenta, we associate the negative background particles with target fragmentation.⁽⁸⁾ We have summarized target fragmentation data ($p_L < 0.5$ GeV/c) in the following form:

$$\frac{d^2\sigma}{dp_L dp_T^2} = A \exp(-b_1(p_L - a) - b_2 p_T^2)$$

where p_L and p_T are the longitudinal and transverse momenta measured in the laboratory. R. W. Anthony et al.⁽⁹⁾ have plotted $d^2\sigma/dp_L dp_T^2$ against beam momentum for various p_L and $p_T^2 = 0$ and found it to be independent of beam momentum above 3 GeV/c in the target fragmentation region. We have fitted the inclusive spectra of Chen et al.⁽¹⁰⁾ to determine A , b_1 , a , b_2 . Having determined these constants, we calculated the counting rate by doing a Monte-Carlo integration of the differential cross section over the acceptance of the spectrometer. The resulting rate was 7 triggers per 10^8 incident pions.

To check this calculation we have examined Purdue bubble chamber⁽¹¹⁾ data at 13 GeV for the reaction

$$\pi^+ p \rightarrow \pi^- + \text{anything}$$

in 4 and 6 pronged events. For 4 prong events we find that 10^{-4} of the events will trigger the spectrometer. A total 4 prong cross section of 8.6 mb implies that the cross section for accepted 4 prong events is approximately $1\mu\text{b}$. For 6 prong events we find that 3×10^{-4} of the events will trigger the spectrometer. A total 6 prong cross section of 4.5 mb implies that the cross section for accepted 6 prong events is also approximately $1\mu\text{b}$. These results support the conclusion of our model and hence we feel that negative tracks will not give an excessive counting rate.

As discussed briefly in Section III, protons would give an unacceptable trigger rate for the simple BEAM.S1.S2 trigger because of the large forward elastic scattering cross section. If we make the trigger BEAM.S1.S2.(V1.V2.S3.C) the acceptance for elastic scatters is substantially reduced. The trigger rate due to elastics is then reduced at 4.0 GeV from 32 to 7 triggers per 10^6 pions. At 3 and 6 GeV/c the trigger rates become 9 and 3 triggers per 10^6 pions respectively. It should be noted that since we plan to selectively trigger on the beam species, the forward elastic events will only contribute dead time for other pion induced reactions, and not for reactions induced by K^- or $\bar{p}$.

VII. Other Physics

In addition to studying the low lying baryons it may also be possible to measure $\frac{d\sigma}{du}$ for some of the higher lying Δ 's, N^* 's and Y^* 's. Because the kinematics vary only slowly with missing mass our acceptance in the baryon mass extends to masses greater than 2.0 GeV before the u-range accessible becomes so small as to be uninteresting.

In addition to the study of Δ^{++} exchange reactions proposed above, the apparatus also has access to other interesting reactions. For example, by changing the polarity of the SCM 105 so that the spectrometer acceptance is maximized for positive particles we could measure the differential cross section for

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

This reaction has an exotic t-channel, hence the cross section must be entirely baryon exchange. Berger and Fox⁽¹⁾ suggest a study of this reaction for the reason that the exotic t-channel implies exchange degeneracy of the Δ_8 and N_8 as well as of N_8 and N_Y . Their fits to the elastic and backward charge exchange data suggest exchange degeneracy is violated. We might therefore expect for the first time to observe such breaking for a re-

action with an exotic channel by measuring $K^-p \rightarrow \Sigma^- \pi^+$. Using the data of the BGLOR collaboration⁽¹²⁾ we estimate a counting rate of ~ 50 events per shift for this channel.

Our acceptance for the inclusive processes

$$\pi^- p \rightarrow X_{\pi}^{\pm}$$

$$K^- p \rightarrow X_{\pi}^{\pm}$$

is shown in Fig. 10. In the process of gathering data for the u channel processes we will inevitably obtain high statistics data on these inclusive processes. In addition it may also be possible to examine some two body correlations to some extent using the forward chambers. Such data in the ZGS energy range is useful in order to establish how limiting behavior is approached.

VIII. Conclusion

The experiment we propose will provide valuable new data on baryon exchange differential cross sections and polarization. Such data is badly needed in order to test high energy models for baryon exchange and lead the way to their refinement.

TABLE I
Materials, Thicknesses and Radiation Lengths
in Spectrometer

	MATERIAL	THICKNESS (inches)	RADIATION LENGTHS
TARGET	Liquid Hydrogen	$\sqrt{2}$	.0040
	Mylar Jacket	.005	.0004
	Super Insulation	.010	.0009
	Vacuum Jacket	.010	.0009
SCINTILLATOR	Polystyrene	.250	.0152
ONE SPARK CHAMBER	Mylar Backing and Windows	.009	.0008
	Aluminum Foil	.002	.0006
	Aluminum Wire	.001	.0003
	He-Ne Gas in Chamber	.375	2.3×10^{-5}
SPACE BETWEEN CHAMBERS	Air	8.0	.0007
HELIUM BAG IN MAGNET	Helium	40.0	.0002
	Mylar	.010	.0009

TABLE II

Estimated Rates For Some Baryon Exchange Processes

P_{lab}	$\pi^- p \rightarrow p \pi^-$		$K^- p \rightarrow \Sigma^+ \pi^-$		$\bar{p} p \rightarrow \pi^+ \pi^-$	
	EVENTS/ SHIFT	SHIFTS, TOT. EVENTS	EVENTS/ SHIFT	SHIFTS TOT. EVENTS	EVENTS/ SHIFT	SHIFTS TOT. EVENTS
3.0 GeV/c	5700	20	120	20	3	20
		114K		2400		60
4.0 GeV/c	2900	30	65	30	2	30
		87K		1950		60
6.0 GeV/c	1050	90	25	90	1	90
		95K		2250		90

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5. Discussions with B. Wicklund and C. Akerlof lead us to believe such accuracy is readily obtainable.
6. A system similar to the one we propose was used by Iowa State, ANL, Purdue in E-238 - under circumstances more adverse than those we propose. In that experiment the TOF resolution integrated over all 26 neutron counters was FWHM 1.2 ns. (A. F. Garfinkel, F. Peterson, private communication.) FWHM resolution of 1.2 ns. has been obtained under typical running conditions in E-396 at BNL using counters whose dimensions are 25" x 24" x $\frac{3}{4}$ ". (G. Larson, private communication.)
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Figure Captions

- Fig. 1. Compilation of data presently available for $\pi^- p \rightarrow p \pi^-$ in the 3.0 to 6.0 GeV/c momentum range.
- Fig. 2. Typical data for $\pi^+ p \rightarrow p \pi^+$ in the 3.0 to 6.0 GeV/c range.
- Fig. 3. Comparison of $K^- p \rightarrow \Sigma^+ \pi^-$ and $\pi^- p \rightarrow p \pi^-$ at 4 GeV/c.
- Fig. 4. Plan View of Proposed Apparatus.
- Fig. 5. $p - \theta$ plot for apparatus.
- Fig. 6. Acceptance in the variable $u' = u - u_0$.
- Fig. 7. Missing mass resolution (ΔM_s vs. u').
- Fig. 8. TOF resolution: The rms error in the determination of the mass squared of the particle is plotted against u' for some reactions of interest.
- Fig. 9. TOF resolution: δm^2 is plotted against laboratory momentum.
- Fig. 10. Acceptance of the spectrometer for the variables P_L and P_T^2 .

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6A

Figure 6B

ARBITRARY UNITS

Figure 6C

ARBITRARY UNITS

Figure 6D

Figure 7A

Figure 7B

Figure 7C

Figure 8A

Figure 8B

Figure 8C

Figure 8D

Figure 9

Figure 10