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Proposal for

MASTER

HIGH MOMENTUM TRANSFER STUDIES OF $\pi^- p \rightarrow \pi^0 n$

TO BE PERFORMED AT THE ZERO GRADIENT SYNCHROTRON

ARGONNE NATIONAL LABORATORY

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I INTRODUCTION

Recent successes in the interpretation of some high energy scattering phenomena (1, 2) have encouraged a new round of experimental studies of elastic scattering and related processes. These studies are turning up a wealth of detailed structure in the s-, t-, and u-dependence of the cross sections and polarizations (3, 4, 5). It can be seen from Figure 1, where the CERN data for $\pi^- p \rightarrow \pi^0 n$ is compared with recent Cornell-Brookhaven data for $\pi^- p \rightarrow \pi^- p$, that there is a striking dip in the elastic scattering cross section at $t \sim -3.0 (\text{BeV}/c)^2$, just beyond the scope of the charge exchange experiment. The curve fitting the charge exchange results is a Regge-ized rho-exchange fit (6). It is clear that charge exchange measurements must be extended to higher t, not only to check the model, but also to compare with the structure seen in elastic scattering.

The reactions $\pi^- p \rightarrow \eta n$ and $K^- p \rightarrow \bar{K}^0 n$ are also of interest, particularly when interpreted within the framework of the Regge Model. Figure 2 (from ref. (2)) shows our present knowledge of $d\sigma/dt$ for these two reactions.

We propose to study the reactions:

$$\pi^- p \rightarrow \pi^0 n$$

$$\pi^- p \rightarrow \eta^0 n$$

at 5.9 BeV/c from $t = -1.5$ to $t = -7.0 (\text{BeV}/c)^2$. * We will improve on the

* In the region of very large angles, Ruddick has just completed a measurement from 120° ($t = -7$ at 6 BeV/c) to 180° for $\pi^- p \rightarrow \pi^0 n$ in E-140 at Argonne National Laboratory, A.G.S.

FIGURE 1

FIGURE 2

background suppression of the CERN experiments by detecting the neutron as well as the two gamma vertices.] Our experiment will need the 17° beam for a total of 90 shifts, about half of which time should be at 5.9 BeV/c, 1×10^5 per pulse, 500 msec spill.

We have designed our experiment to measure cross sections of $.02 \mu\text{b}/(\text{BeV}/c)^2$ to $\pm 20\%$.

We are also studying the compatibility of studying the reactions:

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

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

$$\pi^- p \rightarrow \Sigma^0 K^0$$

to see if any useful information can be obtained during the same run, without jeopardizing the main measurement.

II EXPERIMENTAL ARRANGEMENT

The apparatus for this measurement is basically simple -- two thin plate chambers in the π^- beam, a liquid hydrogen target, a γ -detecting chamber covering small angles on one side and a neutron-detecting chamber on the other. Since both γ 's and neutrons can be detected in chambers with brass plates, we can double the solid angle in an arrangement like that shown in Figure 3. The basic simplicity of the chamber configuration is due to the facts: (1) the opening angle in the lab system between the π^0 and the neutron is essentially independent of t (viz $\sim 60^\circ$), and (2) even the lowest energy π^0 's (1.8 BeV/c) emit their two gammas with an opening angle less than 12° , 75% of the time. The division (if any) into γ -chamber and n-chamber will be made during the analysis of the data.

The liquid hydrogen target will be 8" long and the γ -n chambers (in modules) will have a sensitive volume 36" x 36" x ~ 20 " on either side of the beam. The plate thickness will vary from 1/8" brass in the "gamma-detecting" modules to 1/4" in the "neutron detecting" modules. The total thickness will be between 1.5 and 2.0 collision lengths (7" to 9") or 13 to 17 radiation lengths. Thin plate chambers TP1 and 2 define the path of the incoming pions and TP3 will remove the ambiguity if more than one track shows in the other two. The distance between TP1 and 2 should be about 100 inches.

TRIGGER REQUIREMENT

$$B_1 B_2 \overline{B_3} \overline{\gamma} \overline{C}$$

The trigger requirement is simply that of a charged particle in ($B_1 B_2 \bar{B}_3$), and neutrals out ($\bar{C}$), together with the requirement that no gammas are emitted ($\bar{\gamma}$) which miss the gamma chamber aperture. The counters $\bar{\gamma}$ are 7 layer Pb-scintillator sandwiches, comprising 7 radiation lengths of lead. The counters B and $\bar{C}$ are scintillation counters. The purpose of the $\bar{\gamma}$ counter occupying the forward $\pm 10^\circ$ cone is to veto the forward peak of $\pi^- p \rightarrow \pi^0 n$ as well as any inelastics giving forward gamma rays. The baffle of $\bar{\gamma}$ counters in the "backward" direction (6 modules defining the vertical aperture are not shown) will suppress triggers due to events producing either charged or neutral particles outside the spark chamber aperture.

The spark chambers will be photographed by two cameras. The experience of recent experiments using less complete neutral triggers than that proposed here indicates that we will not be camera rate (10 per second) limited with 10^5 pions in a 500 millisecond spill.

III. EXPECTED EVENT RATE

The event rate has been calculated as >20 per shift for the $\pi^0 n$ final state and >16 per shift for the $\eta^0 n$ final state. Details of this calculation are as follows:

LH Target Length: 20 cm (1.4 g/cm^2)

π^- intensity: $10^5/\text{pulse}$

	<u>$\pi^0 n$</u>	<u>$\eta^0 n$</u>
Cross section*	0.02	$0.02 \text{ } \mu\text{b}/(\text{BeV}/c)^2$
Detection efficiency (See discussion below)	0.35	0.28
Events/ $(\text{BeV}/c)^2$ per shift	4.7	3.8

The detection efficiencies quoted in the calculations above were obtained by a Monte Carlo calculation with the geometry indicated in Figure 3.

For the $|t|$ range from 1.5 to 7 the rates would be 20 per shift and 16 per shift, respectively. The goal of the experiment is a statistical uncertainty of $\pm 20\%$ or better if the cross section is $\geq 0.02 \mu\text{b}/(\text{BeV}/c)^2$. The number of shifts required to do this will, of course, depend upon the background encountered. We expect the most troublesome background to be that produced by the reaction:

* The cross section is of course much greater than this for the first few bins in t .

$$\pi^- p \rightarrow \pi^0 \pi^0 n$$

for which we estimate the cross section to be of the order of a millibarn at this beam momentum. We estimate that the number of these events which can escape the anticoincidence system and simulate the kinematics of the $\pi^0 n$ final state to within the resolution of the apparatus to be about half of the number of $\pi^- p \rightarrow \pi^0 n$ events. To subtract background and achieve 20% statistics on a cross section of $.02 \mu\text{b}/(\text{BeV}/c)^2$ in a Δt bin of $1 (\text{BeV}/c)^2$ will require a running time of about 20 shifts. To allow for tuning and apparatus malfunction, we are requesting a total of 90 shifts to perform the experiment.

IV. Data Analysis

The film will be scanned for events in which two gammas are observed to convert in the upstream portion of one of the chamber arrays and a neutron converts in the other array. All other topologies will be rejected. The information from the film will consist of the conversion points of the two gammas and the neutron as well as the line on which the vertex lies (extrapolated from the beam chambers TP1 & 2).

Since we will not know where along the π^- track the main scattering vertex lies, and since we do not wish to rely on a gamma ray energy measurement, the event reconstruction will have only one constraint on it. The degree to which background can be separated depends upon the precision of the reconstruction. In estimating the contamination due to background we have pessimistically assumed that the reconstruction must be performed by using the bisector of the angle between the two gammas as the most probable pion direction, and the opening angle to estimate the π^0 energy.

The net result of the reconstruction procedure will be a histogram of the π^0 decay opening angle distribution in the C.M. system, similar to that obtained in reference (8) (See Figure 4 below). In this one should see the characteristic opening angle distribution of the π^0 and η^0 superimposed on a more-or-less continuous background. From such a histogram for each bin in t , the number of true events can be extracted from the background.

FIG. 4. Histogram showing the experimental opening-angle distribution at $T_{\pi^-} = 704$ MeV. The inset shows the region of the η peak with an expanded vertical scale. Events were chosen from the region between the vertical lines to form the angular distribution of the bisectors.

FIGURE 4

In all probability, the trigger rate will be many times the event rate. We intend to scan film on our flying spot scanner which we have had in operation for some months. Experience with this machine to date indicates that we could probably analyse 50,000 frames per month on this machine. We do not anticipate, therefore, that a high trigger rate will be a significant problem.

Calculation of the cross section from the data will involve a knowledge of the intrinsic detection efficiency of the system for γ 's and neutrons. The γ detection efficiency can be fairly well calculated by the normalization of Monte Carlo calculations to the observed data, since the chamber will be about 15 radiation lengths long. We believe that the neutron detection efficiency can be determined from existing data to an accuracy of $\pm 20\%$. If counting statistics in the main run warrant it, we would propose calibrating our chambers in a separate experiment.

References

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ADDENDUM TO PROPOSAL P-207

HIGH MOMENTUM TRANSFER STUDIES OF CHARGE EXCHANGE PION SCATTERING

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It has been pointed out⁽¹⁾ that our high t charge exchange experiment should be run at more than one energy, in order to determine the s -dependence as well as the t -dependence of the cross section. This would be particularly interesting if the t -dependence shows any dominant features, like the dip observed in π^+p elastic scattering at several incident momenta^(2,3). Since our experiment is expected to be cleaner at lower incident momenta⁽⁴⁾, the low momentum runs should clearly be run first, serving in addition as a feasibility evaluation for the rest of the experiment.

We therefore propose to tune up and run the experiment at 3.0 BeV/c, stop for data analysis, run at say 4.5 BeV/c, stop for data analysis, and finally run at 6.0 BeV/c. If the first test gives a clear indication of feasibility, the second stop might actually be omitted, in view of the short time duration of the actual data taking runs. It is also clear that if the analysis of the 6.0 BeV/c data shows the results to be clean and interesting, the experiment should then be run at 7 or 8 BeV/c in the small angle beam proposed for the second proton area. We will be able to cover the $|t|$ range 1.5 to 3.6 (BeV/c)² at the lowest momentum and 1.5 to 6.0 (BeV/c)² at the intermediate momentum. This will involve a slight repositioning of the spark chamber arrays described in the original proposal.

We can estimate the s- and t-dependence of the charge exchange cross section by noticing that the existing data⁽⁵⁾ at high t show the same dependence on p_{lab} and t as the corresponding elastic pion scattering data⁽³⁾ (see figure A-1 taken from reference (3) where these data are compared), except that the absolute value of the charge exchange cross section is a factor of 6 lower than that for elastic scattering at any s and t⁽⁶⁾. A dip at $t = -3 \text{ (BeV/c)}^2$ is seen in the π^-p elastic differential cross section at $p_{lab} = 3.0 \text{ BeV/c}$ ⁽³⁾ where the value observed in the minimum is 2 ± 1 microbarns/ster, or 5.2 ± 2.6 microbarns/ $(\text{BeV/c})^2$. A dip is also reported⁽²⁾ at

FIG. 3. Comparison of π^+p elastic-scattering data of this Letter with π^-p elastic-scattering data from Ref. 1 at laboratory momenta where both are available. The abscissas, $-t$, are in $(\text{GeV/c})^2$. The smooth curves are free-hand fits to charge-exchange data taken from Ref. 5 (2.46 GeV/c) and Ref. 6 (3.07 and 3.67 GeV/c).

the same t value for $p_{\text{lab}} = 6$ BeV/c, where the value in the minimum is $0.15 \pm .06$ microbarns/(BeV/c)². In the above assumption, we then expect 0.9 microbarn/(BeV/c)² at $p_{\text{lab}} = 3$ BeV/c, and $.025$ microbarn/(BeV/c)² at $p_{\text{lab}} = 6$ BeV/c at the bottom of such a dip in the charge exchange cross section.

At the present time it looks advisable to use a 10 cm target instead of the 20 cm target proposed in P-207, since the actual data runs are quite brief. This, together with the herein proposed additional runs (at a higher rate) at 3.0 and 4.5 BeV/c, will increase the required time from the 90 shifts proposed in P-207 to a total of 130 shifts. This does not include any estimate for running at 7 or 8 BeV/c in the second proton area, should this prove advisable.

Background arising from $\pi^- p \rightarrow \pi^0 \pi^0 n$

We consider this reaction to be the most serious source of background in the experiment. If two of the $\pi^0 \gamma$'s fail to produce an anticoincidence signal or convert in a chamber the event can produce the same topology as the elastic charge exchange scattering. Of these cases, some might reconstruct with a small chi squared on the hypothesis of its being an elastic event.

All the calculations referred to below were performed assuming an incident π^- momentum of 5.9 Bev/c. The background problem should be considerably diminished at the lower momenta for the reasons cited above.

Three kinds of events were generated by Monte Carlo methods:

- a) $\pi^- p \rightarrow \pi^0 n$
- b) $\pi^- p \rightarrow \pi^0 N^*(1238) \rightarrow \pi^0 \pi^0 n$
- c) $\pi^- p \rightarrow \pi^0 \pi^0 n$ (phase space distribution)

The data provided to the reconstruction program consisted of the spatial position (x,y,z) of the conversion points of the two gamma rays and neutron as well as two points on the incoming particle track (beam chambers). All of these coordinates were given ± 0.5 cm random errors with a gaussian distribution. No information about vertex location within the target was used in the reconstruction. The gamma and neutron conversion points were distributed with respect to depth in the chamber in an exponential distribution with appropriate conversion lengths for these particles.

The reconstruction program was patterned after the procedure described by Berge et. al.⁽⁷⁾ as that used in the GUTS bubble chamber program. The method is essentially to adjust the measured quantities to force them to agree with the hypothesis that the event is an elastic one. This adjustment is done in a manner such as to minimize the chi squared between the measured

and adjusted quantities. An event which is not elastic will either not reconstruct (the procedure is an iterative one and certain pathological cases may diverge), reconstruct with a large chi squared (the most common situation), reconstruct with absurd physical parameters (such as the vertex being outside the target) or reconstruct perfectly well and thereby simulate an elastic event.

We put cuts on the reconstructed data with regard to two quantities: χ^2 and $\theta/\theta_{\min}$ (the calculated π^0 decay opening angle divided by the minimum possible opening angle at that energy), and further demanded that the reconstructed vertex lie within the target (taken to be 10 centimeters long). We found that 80% of the elastic charge exchange events passed these requirements while 96% of the N^* events and 95% of the phase space events were rejected. If one assumes that the gamma anticoincidence efficiency is 90% then 0.4% of the N^* events and 0.5% of the phase space events will appear as elastic charge exchange.

Background from N^* events. Since the N^* production kinematics are very similar to that of the charge exchange process for these incident momenta, it is fair to compare cross sections at the same t value. We conclude that, in order for the N^* events to present a serious contamination, the cross section for these events would have to be 200 times that of the elastic charge exchange process at the t values of interest. Since the total cross section for $\pi^- p \rightarrow \pi^0 N^* \rightarrow \pi^0 \pi^0 n$ at this momentum is about $38 \mu\text{b}^{(8)}$ compared to $100 \mu\text{b}$ for $\pi^0 n$ this does not seem to be a serious source of background.

Background from phase space events. If we take the $\pi^- p \rightarrow \pi^0 \pi^0 n$ non-resonant background cross section to be $0.4 \text{mb}^{(9)}$ at this momentum and combine this with the phase space Monte Carlo runs, we find that the background introduced will be equivalent to a cross section of $0.3 \mu\text{b}/(\text{Bev}/c)^2$.

In this calculation, we believe we have been pessimistic at every point where an unknown quantity had to be estimated (such as vertex location precision, gamma anticoincidence efficiency, etc.). We consider $0.3 \mu\text{b}/(\text{Bev}/c)^2$ to be an upper limit on the background and believe that a factor of 10 lower would be a more realistic guess.

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- (4) The cross section at high t should be about 6 times larger at $p_{lab}=3$ BeV/c than at 6 BeV/c, and the inelastic events which cause background should be less copiously produced and more easily separated.
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- (6) Note the factor 6 refers specifically to values at $t = -1.2$, but that we note from figure A-1 that the charge exchange data is consistent with the same t -dependence.
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- (8) This is calculated from data presented in a bubble chamber study of $\pi^-p \rightarrow \pi^0\pi^-p$ at 6 BeV/c by R.B. Bell et al, P.R.L. 20, 164 (1968)
- (9) This is a guess based on the fact that the total cross section for $\pi^-p \rightarrow \pi^+\pi^-n$ and $\pi^-p \rightarrow \pi^0\pi^-p$ are 1.1 and 0.7 mb respectively at 6 BeV/c (R.B. Bell et al, Ibid).