SS-138
2124

PROPOSAL FOR A NEUTRON SPECTROMETER FACILITY AT NAL

Peter E. Schlein
University of California, Los Angeles

ABSTRACT

A neutron spectrometer facility is proposed which would permit the measurement of $\pi\pi$ and $K\pi$ total cross sections. Time of flight (to ±5%) and angular measurements (to ±20-40 mrad) on the neutron will permit the differential cross section $d^2\sigma/dtdm$ (t is momentum transfer and m is the missing mass above the neutron) to be extrapolated to the pion exchange pole for reactions of the class $Xp \to n$ + (everything). This neutron spectrometer may later be coupled with an appropriate downstream multi-particle detector to study specific $\pi\pi$ and $K\pi$ inelastic channels.

I. INTRODUCTION

The present proposal is for a neutron spectrometer facility and associated beam transport system to permit the high statistics detection and measurement of slow recoil neutrons from processes of the type:

$$X + p \to n + \text{(anything)}, \qquad (1)$$

where $X = \pi^{\pm}, K^{\pm}, \bar{p}$ or p. A program of experiments is envisioned for each of these beam particles in which measurements would be made over a wide range of beam momentum of the doubly differential cross sections $d^2\sigma/dtdm$ (t is the momentum transfer from proton to neutron and m is the missing mass above the neutron). Time of flight (to ±5%) and angle measurements (to ±20-40 mrad) on the neutron are necessary.

Aside from the general interest in the t dependence of all reactions at high energy, the specific motivation behind these proposed experiments is to study $d^2\sigma/dtdm$ at low values of t (from 0.3 GeV^2 down to 0.01 GeV^2 or lower) and to extrapolate the observed distributions to the pion exchange pole (at $t = -m_\pi^2$ in our metric) at fixed m to obtain (initially) the $X\pi^+$ total cross section. A suggested <u>later</u> addition to the facility of an appropriate multi-particle detector (including π^0's) and associated magnet downstream from the target will permit the study of individual $X\pi^+$ inelastic (as well as elastic) channels.

II. PHYSICS AND ANALYSIS BACKGROUND

There exists now considerable evidence [1-3] that pion exchange dominates the low momentum transfer components of the reactions $Xp \to X\pi^+ n$ and $Xp \to X\pi^- \Delta^{++}$ up to the highest momenta examined thus far. These processes thus result dominantly from $X\pi^+$ and $X\pi^-$ elastic scattering respectively. It has, in addition, recently been demonstrated[4] at 6.6 GeV/c that for the reactions:

$$pp \to (\pi^- p)\Delta^{++}, \quad (\pi^- \pi^o p)\Delta^{++}, \quad (\pi^+ \pi^- n)\Delta^{++} \qquad (2a, b, c)$$

the relative cross sections when $t_{p,\Delta} < 0.2$ GeV^2 bear the same relationship as the relative cross sections for the processes:

$$\pi^- p \to \pi^- p, \quad \pi^- \pi^o p, \quad \pi^- \pi^+ n. \qquad (3a, b, c)$$

This strongly suggests that the final states (2a, b, c) result from an initial proton scattering on a virtual π^- when the other proton is in the virtual state $p \to \pi^- \Delta^{++}$.

Similarly, the processes:

$$pp \to (\pi^+ p)n, \quad (\pi^+ p \pi^+ \pi^-)n \qquad (4a, b)$$

are found[5] to occur with approximately the same relative cross sections as the $\pi^+ p$ reactions:

$$\pi^+ p \to \pi^+ p, \quad \pi^+ p \pi^+ \pi^- \qquad (5a, b)$$

suggesting that one proton scatters on a virtual π^+ when the other proton is in the state $p \to \pi^+ n$.

There is now a great need to study processes of these types with incident π's, K's, and p's up to the highest beam momenta and lowest momentum transfers accessible. The 6.6 GeV/c pp bubble-chamber results coupled with other studies described in Refs. 1, 2, and 3, demonstrate that extrapolation to the pion exchange pole of $d^2\sigma/dtdm$ should yield $X\pi^+$ elastic and inelastic cross sections. In particular, these results also suggest that the extrapolation functions are rather simple functions of t and that they are similar functions for elastic and inelastic processes (otherwise the different pp final states in the physical region of the Chew-Low plot would not occur with approximately the same relative rates as the on-shell $\pi^+ p$ cross sections).

III. BRIEF DESCRIPTION OF PROPOSED FACILITY

In simplest terms, the proposed neutron spectrometer consists of a liquid hydrogen target of a few cm length (see Fig. 1) around which are positioned at some radial distance, r, a series of closely packed scintillators for neutron detection.

As much of the azimuthal distribution (above the median plane) as possible should be covered to maximize counting rate. Current technology seems capable of localizing the traversal point of the neutron through the scintillator to within 2 cm.

The target length ℓ and radial distance r are determined as described below from consideration of the required θ_{lab} resolution and counting rate.

A counter C_1 signals the entrance of a beam particle. A veto counter array C_2 insures that no charged particles emerge transversely from the target. A special-purpose veto counter C_3 serves to insure that there is no longitudinal emission of charged particles and is used as discussed below in a particular series of experiments to measure $\pi^-\pi^+$, $K^-\pi^+$, and $\bar{p}\pi^+$ total-neutrals cross sections.

Depending on background circumstances, a borax neutron shield house may have to be erected around the neutron spectrometer array.

It is suggested that eventually one may want to couple this neutron spectrometer with a downstream multi-particle detector to study specific $\pi\pi$ and $K\pi$ inelastic channels.

IV. IMPORTANCE OF SLOW NEUTRON DETECTION

The relationship between neutron laboratory energy and momentum transfer is

$$T_{neutron} = \frac{t}{2 \cdot m_n} .$$

Thus we have:

$t(GeV^2)$	T_n (MeV)	Flight time per 1 meter path (nanosecond)
0.3	150	5.9
0.2	100	7.2
0.1	50	10.2
0.02	10	20.3
0.01	5	32.3
0.005	2.5	46.0

In view of the expected drop-off in $d\sigma/dt$ for $t \lesssim 0.02\ GeV^2$ in reactions (1) due to the π-nucleon-nucleon coupling in the matrix element, it is important to measure neutrons with as small an energy below 10 MeV as possible. 5 MeV is a minimum; 2.5 MeV would be superb.

The pp experiment of Ma et al.,[6] has demonstrated the existence of a drop-off for $t < 0.02\ GeV^2$ in $d\sigma/dt$ for $pp \rightarrow \Delta^{++}n$ at 6.6 GeV. More data is necessary to verify the precise shape of this fall-off as well as to carry the investigation to lower values of momentum transfer and to other related reactions involving incident pions and kaons as well. A resolution of ±5% in t and 10-50 MeV or so in mass (depending on mass) would be adequate.

V. SOME SUGGESTED INITIAL EXPERIMENTS

1. Measurements of $d^2\sigma/dtdm$ for reaction (1) with no selections made on the missing system when extrapolated to the pion exchange pole will yield the total $X\pi^+$ cross section as a function of mass m of the system. In this way $\bar{p}\pi$ and $p\pi$ (for calibration and checking purposes) and $\pi\pi$, $K\pi$ total cross sections can be obtained.

The measurements of $\pi\pi$ and $K\pi$ are, of course, unique and can be obtained in no other way. These results should be independent of the beam momentum used and thus can be stringently checked. The later addition of the downstream multi-particle detector mentioned in the introduction would then permit the detailed study of specific inelastic $\pi\pi$ and $K\pi$ interactions.

2. The use of a veto counter C_3 just downstream of the target to insure that no charged particles emerged from the target will permit measurements of the total-neutrals cross sections for $\pi^-\pi^+$, $K^-\pi^+$, $\bar{p}\pi^+$.

3. With incident proton beam, C_3 not used, and with a pair of wire planes downstream from the target (no magnet necessary), the reaction $pp \rightarrow p\pi^+ n$ may be studied. With the emergence of two tracks whose angles (but not momenta) are measured with the wire planes, the reaction is a 2-constraint fit if the neutron time of flight is used, or a 1-constraint fit if the neutron time-of-flight is not used. Thus this reaction may be used to calibrate the neutron counters. Aside from the calibration usefulness of this reaction, a detailed study of $d^2\sigma/dtdm$, with an order of magnitude higher statistics than the work of Ma et al.,[6] and at higher beam momentum than 6.6 GeV/c, and thus with lower momentum transfer, will shed additional light on the one pion-exchange character of the reaction.

4. With incident π^+ mesons and the same wire-planes used in (3), the reaction

$$\pi^+ p \rightarrow \pi^+ \pi^+ n$$

may be studied. The same constraint situation as in (3) also exists here. The $T = 2$ $\pi\pi$ elastic cross section may be measured with this reaction. Measurements in the $\pi\pi$ threshold region will yield the s-wave $T = 2$ scattering length.

5. Similarly, with incident K^+ mesons, the reaction

$$K^+ p \rightarrow K^+ \pi^+ n$$

may be studied to yield the $T = 3/2$ $K\pi$ elastic cross section.

VI. KINEMATICS

Since the goal of the proposed series of experiments is to measure the distribution in the Chew-Low plane ($d^2\sigma/dtdm$), it is convenient to consider the relationship between the missing mass m and the observable quantities $p_{neutron}$ (t) and θ_{lab}:

$$-m^2 = \left| p_{beam} + p_{target} - p_{neutron} \right|^2$$

$$= -m^2_{beam} - 2p_{beam}\, p_{neutron} \cos\theta_{lab} + 2T_{neutron}\, (E_{beam} + m_p)$$

or: $$m^2 = m^2_{beam} + 2p_{beam}\, t^{1/2} \cos\theta_{lab} - t\, (E_{beam} + m_p)/m_p.$$

For $\cos\theta_{lab} = +1$, this is the equation of the Chew-Low boundary. Figures 2 and 3 show contours of constant $\cos \theta_{lab}$ for incident proton beams of 7 and 60 GeV/c respectively. It is straight-forward to select the range of $\cos \theta_{lab}$ necessary to cover a particular range of missing mass.

The resolution in θ_{lab} for fixed p_{beam}, t, and m is given by:

$$d\,\theta_{lab} = \frac{m}{p_{beam}\, t^{1/2} \sin \theta_{lab}}\, dm\,.$$

The following examples demonstrate that a θ_{lab} resolution of perhaps 15 mrad is necessary:

reaction	m	p_{lab}	t	Δm	assumed $\langle \sin \theta_{lab} \rangle$	$\Delta\theta_{lab}$ (mrad)
pp	1.24	7	0.02	0.01	0.7	18
pp	2.0	7	0.02	0.02	0.7	58
pp	4.0	60	0.02	0.03	0.7	20
πp	4.0	60	0.02	0.03	0.7	20
πp	2.0	7	0.02	0.03	0.7	87

VII. DETERMINATION OF RADIAL DISTANCE TO NEUTRON DETECTOR

Given that the interaction point in the neutron counter can be localized to 2 cm (by measuring the time difference in light signals received at opposite ends of the scintillator), and with $\Delta\,\theta_{lab}$ determined as above by the kinematic conditions, a given target length then implies a specific radial distance to the neutron detector.

For example, a 13 mrad $\Delta\,\theta_{lab}$ and a 13 cm target length imply r = 10 meters.

$$\frac{\ell}{L} = 0.013 \text{ rad.} \qquad L = \frac{13 \text{ cm}}{0.013} = 10^3 \text{ cm.}$$

Since the counter area (and hence cost and background) go as r^2, it is desirable to keep r as small as possible. To do this and not exceed the requisite $\Delta\,\theta_{lab}$ means making the target length smaller (at a loss in counting rate). To optimize these parameters, it is thus necessary to know:

1. Experimental cross section expected for the reaction and p_{lab}, m, t under consideration.

2. Expected background rate in neutron counters per cubic meter used; perhaps this can be minimized, at least for slow neutrons, by using a borax shield around the entire neutron detector array. We thus make no attempt to arrive at a detailed design of the apparatus here, but rather assume no background is present and try to show what counting rate may be expected in a typical experiment (at 7 and 60 GeV/c, respectively).

VIII. COUNTING RATES

10^6 particles/pulse passing through a 13-cm target have a total track length of 0.43×10^6 feet or a yield of 500 events/mb/pulse. Assuming a neutron counter efficiency of ~20% and that the counters cover an azimuthal range $\Delta\phi = \pi$ and a $\Delta \cos \theta_{lab} \sim 0.5$, we have an effective yield of $500 \times 1/5 \times 1/2 \times 1/2 = 25$ events/mb/pulse.

At 7 GeV/c, the interesting cross section in $pp \to p\pi^+ n$ (namely for $t < 0.3$ GeV^2 and $1.14 < m_{\pi^+p} < 1.42$ GeV) is 1.5 mb, giving a counting rate of 37 events/pulse for events with $t < 0.3$ GeV^2 $\Delta m \sim 0.3$ GeV.

To obtain estimates at higher beam momenta, we just assume that the p_{lab}^{-2} behavior which is observed to be valid to 28 GeV/c remains valid. Thus at 70 GeV/c the counting rate is ~4 events/pulse.

Since strong interaction total cross sections are approximately independent of p_{lab}, one can expect these order of magnitude rates to describe the situation at higher missing mass values (~4 events/pulse per 0.3 GeV Δm range with $t < 0.3$ GeV^2 at $p_{lab} = 70$ GeV/c).

If the linear dimensions of the system are cut down by a factor of ~5 so that the neutron counters are at a radial distance of 2 meters and the target length is ~2.6 cm, the counting rates for $pp \to \Delta^{++} n$ are ~7 and ~1 event/pulse at 7 and 70 GeV/c respectively. Of course, when one takes into account the entire missing mass range, the total counting rate is correspondingly higher.

IX. DESIRED STATISTICS FOR POLE EXTRAPOLATION

In the recent pole extrapolation analysis[6] of $pp \to p\pi^+ n$ at 6.6 GeV/c with m_{π^+p} in the Δ^{++} region (1.14 - 1.42 GeV), there were 1750 events with $t < 0.3$ GeV^2. This mass region was divided into 9 Δm bins with roughly equal numbers of events (~200 events) for each region in which the extrapolation is done. It was concluded in that work that at least an order of magnitude increase in statistics is desirable (~2000 events).

Thus we suggest that one should obtain at least 2000 useful events per Δm region for which the extrapolation is to be done independent of the magnitude of Δm. At higher m where one may not require as fine a mass resolution as at low m, a $\langle\sigma\rangle$ for the Δm region under consideration is thus obtained.

REFERENCES

[1]See review talk by Peter E. Schlein at The Informal Meeting on Experimental Meson Spectroscopy, University of Pennsylvania, April 26-27, 1968. Published in Meson Spectroscopy, ed. C. Baltay and A. H. Rosenfeld (W. A. Benjamin, Inc., 1968) p. 161.

[2]Gunther Wolf, Single and Double Pion Production by OPE and a Comparison with Experimental Data Between 1.6 and 20 GeV/c, Phys. Rev. (in press - 1969).

[3]Eugene Colton and Peter E. Schlein, Experimental Validity of One-Pion Exchange and Prospects for Studying $\pi\pi$ and $K\pi$ Scatterings, invited talk at the Conference on $\pi\pi$ and $K\pi$ Interactions, Argonne National Laboratory, May 14, 1969 (to be published in proceedings - 1969).

[4]Eugene Colton, Peter E. Schlein, Eugene Gellert, and Gerald A. Smith, Phys. Rev. Letters 21, 1548 (1968).

[5]Eugene Colton and Peter E. Schlein, Experimental Comparison Between On- and Off-Mass-Shell Inelasticities in $\pi^+ p$ Scattering, submitted to Phys. Rev., Comments and Addenda (July 1969).

[6]Z. Ming Ma, Gerald A. Smith, R. J. Sprafka, Eugene Colton, and Peter E. Schlein, Pole Extrapolation Results from $pp \to \Delta^{++} n$ at 6.6 GeV/c, Phys. Rev. Letters 23, 342 (1969).

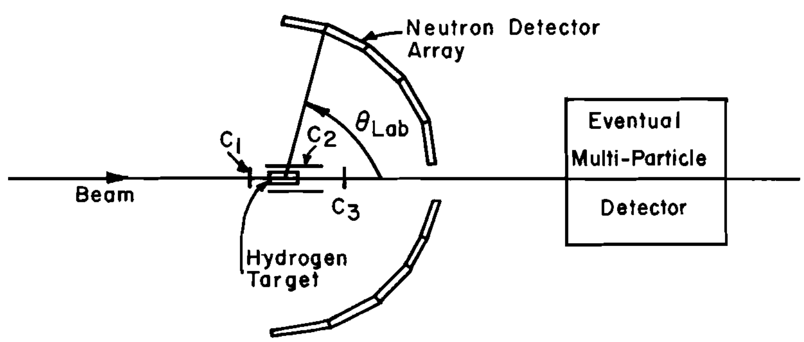

Fig. 1. Proposed layout of neutron spectrometer.

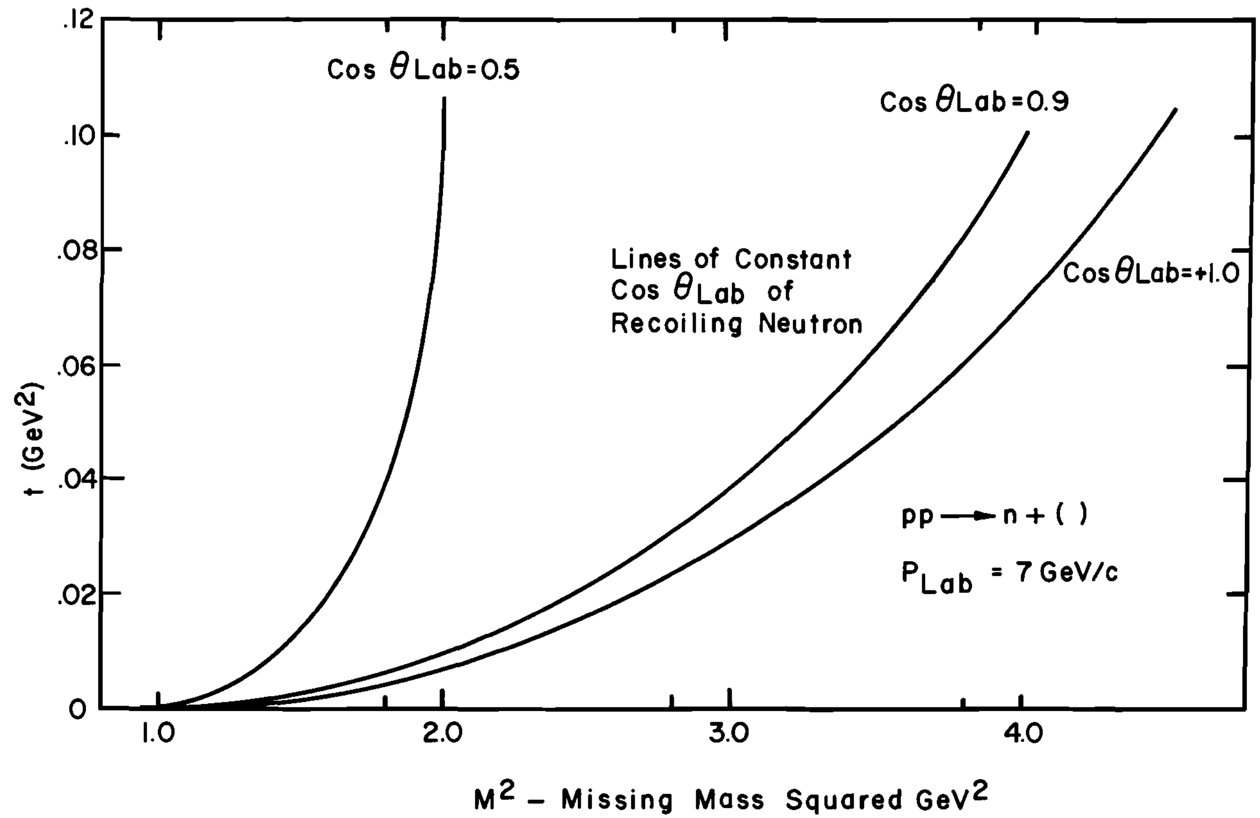

Fig. 2. Contours of constant cos θ_{lab} for inelastic pp reactions at 7 GeV/c.

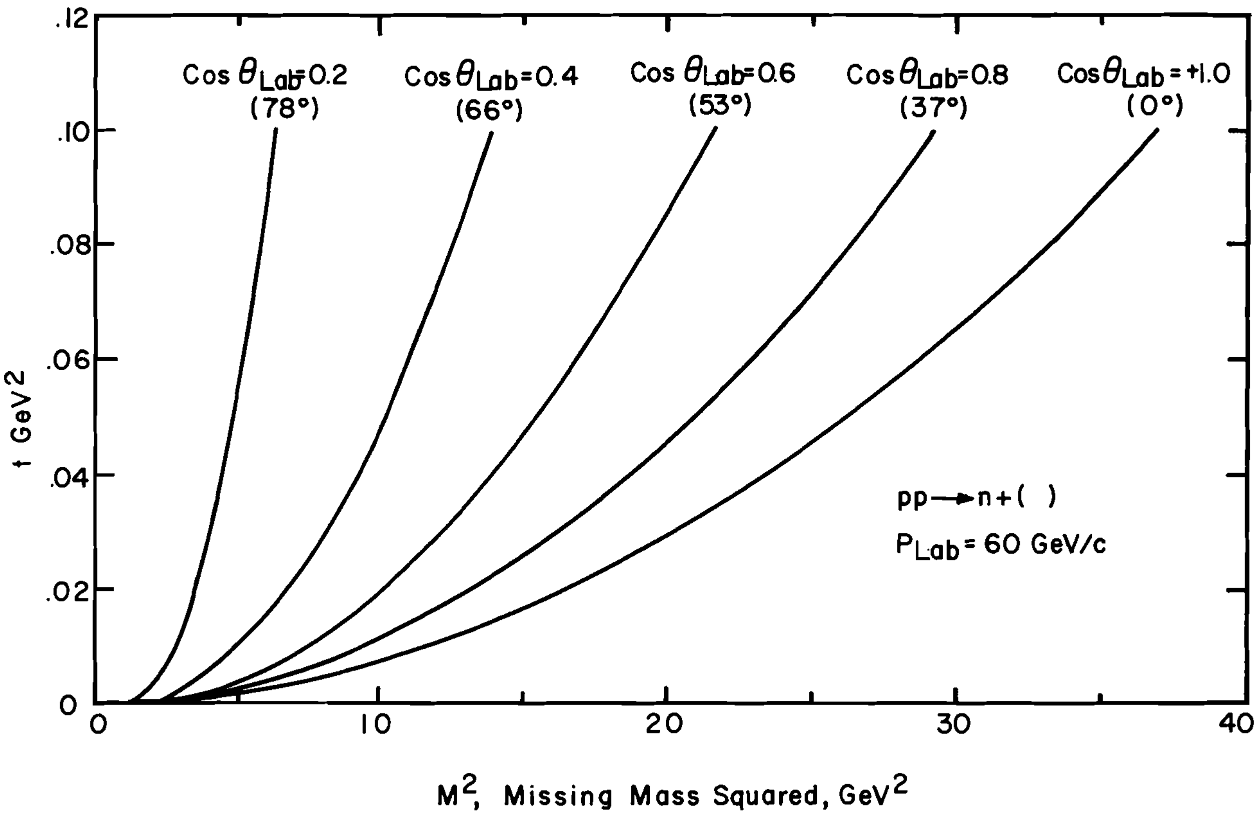

Fig. 3. Contours of constant cos θ_{lab} for inelastic pp reactions at 60 GeV/c.