NAL PROPOSAL No. 59

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A PROPOSAL TO STUDY THE REACTION $\pi^- p \to \pi^- \pi^+ n$ AT THE NATIONAL ACCELERATOR LABORATORY

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Abstract :

A proposal is made to study the reaction $\pi^- p \rightarrow \pi^- \pi^+ n$ at incident π^- momenta of 20, 40, 60, and 80 GeV/c. Of particular interest in this final state are the s and t dependences of ρ, f°, and N* production, and the dynamics of the so-called multiperipheral region of the Dalitz plot. The directions of the incident π^- and outgoing π^- and π^+ are determined by multiwire proportional counters and wire spark chambers. The direction and time-of-flight of the neutron is measured by means of a scintillation counter hodoscope.

Names of Experimenters :

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II. PHYSICS JUSTIFICATION

Our proposal to study the process $\pi^- + p \rightarrow \pi^- + \pi^+ + n$ is taken as a convenient example of the more general reaction of a particle A scattering on a proton to give the final state $A + \pi^+ + n$. From such a reaction at high energies, one would hope to gain information on:

1) the production and decay of $(A\pi^+)$ resonant states.
2) the production and decay of $n\pi^+$ resonances.
3) A-π^+ elastic scattering.
4) diffraction disassociation of the proton.
5) multiperipheralism.

We do not wish to imply that this list is exhaustive, nor that the items listed are exclusive. Items 3, 4, and 5 would appear to be different names for similar processes, for instance, and in the current language of Veneziano and duality models, items 1 and 2 are also indistinguishable from 3, 4, or 5.

Our general purpose then is to study in a single experiment the dynamics of the production of the three-particle final state, covering completely the range from quasi-two particle final states to the multiperipheral domain. The choice of the particular reaction $\pi^- + p \rightarrow \pi^- + \pi^+ + n$ is motivated by the availability of the beam, the ease of detection of low energy (momentum transfer) neutrons, and the minimum complexity of the final state, both in sense of the number of particles and their spins (as opposed to a ρ-π- nucleon final state, e.g., where the ambiguities in identifying the ρ, the various spin substates of the ρ, and admixture of other isospins and spins of the π-π system all tend to complicate the analysis).

In particular we wish to study the reactions:

$$\pi^- + p \rightarrow \rho^\circ + n \qquad (1)$$

$$\pi^- + p \rightarrow f^\circ + n \qquad (2)$$

$$\pi^- + p \rightarrow \pi^+ + \pi^- + n \qquad (3)$$

and possibly

$$\pi^- + p \rightarrow \pi^- + N^{*+} \qquad (4)$$

Reaction (4) includes all the N*'s in principle, but they may not be distinguishable from each other or from a background due to Reaction (3). Reaction (3) is taken to mean the case when no pair of final state particles is in a resonant state. The isolation of this Reaction (3) with good statistics is the major concern of the experiment, and this is in turn the major motivation for beam energies of 20 GeV and higher. Only with such energies does a sufficient fraction of the Dalitz plot for the three final state particles contain no resonance bands.

Rather than invoke any particular model for the dynamical behaviour of Reactions (1-3), we simply express the conviction that significant information at the proposed energies on these reactions will be extremely useful as a guide to a better understanding of particle interactions. Specifically, a knowledge of the (presumably slowly varying or simple) dynamical behaviour of Reaction (3) in the region where it is isolated from Reactions (1), (2), and (4) should:

(a) be a guide to multiperipheral models

(b) yield a measurement of the π-π elastic cross section at high π-π masses

(c) provide data on π-π scattering from hopefully asymptotic energies down to the resonance region, when combined information from Reactions (1) and (2).

Reactions (1) and (2) should provide new and important data on the s and t dependence of ρ° and f° production.

Currently available data[1/] relevant to this experiment are limited by incident energy and statistics and seem useful only as a qualitative guide.

III. EXPERIMENTAL ARRANGEMENT

The experimental arrangement is shown in Fig. 1. The direction of the incident π^- is measured to ± 0.2 mr by means of multi-wire proportional counters. Interactions take place in a 30 cm. long liquid hydrogen target. The directions of the outgoing charged particles are measured by either a multi-wire proportional counter, if the outgoing angle is small ($\sim$ 4 mr), or a magnetostrictive readout wire spark chamber, if the outgoing angle is greater than $\sim$ 4 mr. The neutron direction and time-of-flight are measured by a 52 element scintillation counter hodoscope. Each hodoscope element is 10 cm x 25 cm x 30 cm.

An event trigger is formed by:

1) Appropriate beam defining counters, including threshold Čerenkov counters to distinguish π's from K's and anti-protons in the beam.
2) A neutron count in delayed coincidence.
3) Two and only two charged particles in the final state. This part of the trigger will be formed by signals from plastic scintillation counter hodoscopes and also from the multi-wire proportional counters.
4) The absence of signals in veto counters which cover the directions not included in the π hodoscope.
5) The absence of signals in lead-lucite sandwich counters which are sensitive to γ-ray induced showers.

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[1] J. Ballam et al., unpublished SLAC-PUB-716 (16 GeV/c)
Honecker et al., Nucl. Phys. **B13**, 571 (1969), (16 GeV/c)

When the event trigger is satisfied the spark chambers are fired and read out on-line to an SDS Σ-2 computer. The status of each hodoscope element, multiwire proportional counter, and encoded neutron time-of-flight and pulse height are also recorded.

Data acquisition time.

The calculation of the event rate is based on the following assumptions:

1) Incident flux of 10^6 pions/pulse.
2) 30 cm. liquid hydrogen target.
3) 2 meter flight path for neutrons
4) Neutron counter efficiency of 25% for $T_{\text{neutron}} > 20$ MeV.

With these assumptions we obtain:

1 event/microbarn/100 machine pulses. This gives e.g. at 20 GeV/c about 2.5 events per pulse in the $\pi^-\pi^+n$ channel. Our goal is 1000 events per microbarn at each energy so we require 100,000 machine pulses at each energy. Then 100,000 pulses at 20 GeV/c would give 250,000 $\pi^-\pi^+n$ total including 35,000 each ρ's and f°'s.

Background.

Background comes from two main sources.

1. Accidental triggers. These events come from a genuine two charged particle event in accidental coincidence with a background count in one of the neutron counters. We estimate the two charged particle rate to be of the order of 1000 per pulse. The neutron counter

background rate is an unknown factor and cannot be determined until the machine is turned on and some shielding studies made. However, from our experience at the ZGS at Argonne we guess something like 10^4 counts per pulse in the entire neutron bank. At the ZGS we found this number to be strongly dependent on the shielding and on the threshold settings of the discriminators.

We obtain then, with a 50 nanosecond gate, 1/2 trigger per pulse. A one second spill has been assumed. These accidentally triggered events will not, in general, satisfy the momentum and energy balance equations and will be rejected.

2. Missing neutral pions. Events of the type $\pi^- p \rightarrow \pi^- \pi^+ n$ + (missing neutral pions) will be rejected first of all by the trigger requirement that there be no gamma ray induced showers in lead-lucite sandwich counters surrounding the apparatus. Those events that fail to register in the shower counters (5%) will have to be rejected by kinematical analysis, i.e. the momentum and energy balance equations.

Kinematic Reconstruction

The equations of conservaton of momentum and energy must be used to:

1) determine the momenta of the charged pions
2) reject events which are false triggers
3) reject events in which there are missing neutrals.

The first test of a valid event is to construct a quantity called the momentum imbalance defined by $p_{imbal} = (\overline{p}_{beam} - \overline{p}_{neut}) \cdot \hat{k}$ where $\overline{p}_{beam}$ and $\overline{p}_{neut}$ are the vector momenta of the incident beam and recoil neutron respectively and $\hat{k}$ is a unit vector perpendicular to the plane of the outgoing charged pions. If there are no missing neutral pions p_{imbal} is zero, up to experimental measurement errors. A calculation of p_{imbal} for some Monte-Carlo generated events with experimental resolution folded in shows a Gaussian-like distribution with a half width at half maximum of about 20 Mev/c. This indicates that any event with a missing neutral pion that has a component of momentum perpendicular to the di-pion decay plane of $\sim$50 MeV/c will be rejected.

The measurement errors include:

1) ±1 ns time of flight resolution.

2) uncertainty in the neutron direction due to finite counter size and uncertainty in knowing the target vertex.

3) 2 mm wire spacing in the multiwire proportional counters.

4) ±1 mm resolution in the wire spark chambers.

5) ±1% $\delta p/p$ in the incident beam momentum.

The complete problem has one more equation of constraint, that of energy balance. One can best show the full problem by constructing a parallelepiped from the unit vectors in the directions of the two charged pions ($\hat{n}_1$ and $\hat{n}_2$) and the neutron ($\hat{n}_3$). The equation $\vec{p}_{beam} = \vec{p}_1 + \vec{p}_2 + \vec{p}_3$ determines the size of the parallelepiped. The magnitudes of the momenta p_1, p_2, and p_3 can then be found by $p_1 = \vec{p}_{beam} \cdot \vec{k}_1$ etc. where $\vec{k}_1 = (\hat{n}_2 \times \hat{n}_3)/(\hat{n}_1 \cdot \hat{n}_2 \times \hat{n}_3)$. In this notation the first equation of constraint is $p_3 = p_{neutron}$ (as determined by the time of flight). This equation is essentially the same as that for $p_{imbal}=0$. The second equation of constraint is $E_{beam} + m_p = E_1 + E_2 + E_3$ where E_1 and E_2 are the energies of the two pions and E_3 is the energy of the neutron. This last equation will enable us to resolve existence of slow missing neutral pions which might otherwise not be detected by the gamma ray veto counters or the momentum imbalance. The full problem, of course, must be solved by a chi-square minimization using both equations of constraint simultaneously.

IV APPARATUS

The following equipment is requested to be supplied by NAL:

1) Liquid hydrogen target

2) Threshold Čerenkov counters to distinguish pions from kaons and protons in the beam.

The rest of the apparatus is to be supplied by the University of Illinois high energy group. Most of the equipment is standard and it, or similar apparatus, has been used by us in previous experiments. It can easily be made ready by July 1972.

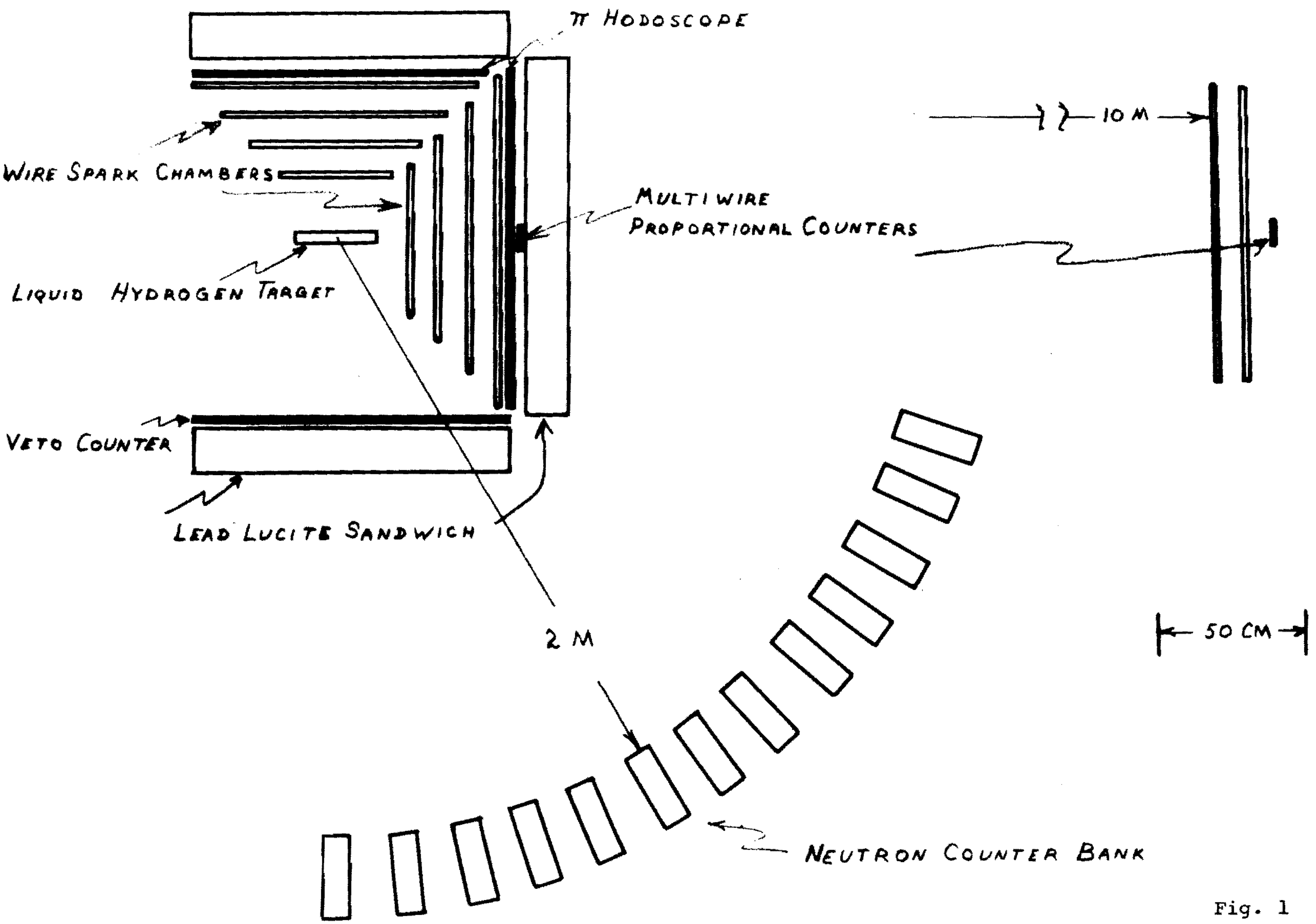
π HODOSCOPE
WIRE SPARK CHAMBERS
MULTIWIRE PROPORTIONAL COUNTERS
LIQUID HYDROGEN TARGET
10 M
VETO COUNTER
LEAD LUCITE SANDWICH
2 M
50 CM
NEUTRON COUNTER BANK

Fig. 1

Addendum to Proposal #59

(A Proposal to Study the Reaction $\pi^- p \rightarrow \pi^-\pi^+ n$)

at the National Accelerator Laboratory

L. Holloway and D. Mortara
7/14/71

We offer this addendum to our initial proposal in support of the desirability of both the study of the reaction $\pi^- p \rightarrow \pi^-\pi^+ n$ and our technique. The desirability is founded on the representative set of physical processes which can be studied; the advantage of our technique lies in the large solid angle acceptance and the over-constrained kinematics.

Two-body final states which can be studied include $\rho^\circ n$, $f^\circ n$, and $g^\circ n$. These reactions will yield information on the energy dependence of π or π-trajectory exchange. Perhaps more interesting will be any deviation from simple π exchange predictions. For example, it is presumed that the energy dependence of π exchange relative to the higher lying A_2 trajectory must eventually manifest itself in the form of different spin alignment and s-dependence of the $\rho^\circ n$ and $f^\circ n$ production and decay amplitudes. The observation of such effects would be an important validation of the Regge trajectory formalism.

No $\pi\pi$ resonances above the g have been established. At present the linear rising trajectory of natural parity states (ρ, f, and g in the $\pi\pi$ channel) is very striking. Clearly the sensitive search available in the proposed experiment for higher mass $\pi\pi$ resonances will be rewarding in this context.

At very large (above any resonances) $\pi\pi$ masses, the experiment will provide data on the $\pi\pi$ scattering cross section, and its s and t dependence. Since there is no asymmetry with respect to charge in the detection apparatus, nor any significant limitation on momentum acceptance, we will be able to study $\pi\pi$ scattering at forward, intermediate, and backward angles.

When both the $\pi^+ n$ and $\pi^+\pi^-$ masses are large (and the momentum transfers to the π^- and n are small) the data can be used to test various multiperipheral formalisms. Since all the kinematic variables are measured, no "a priori" averaging over unmeasured variables occurs. As a consequence, we expect to be able to maintain a flexibility in our data with respect to new models, requiring distributions in different variables, and to provide impetus for new models by using this flexibility.

Finally, we would like to emphasize several features of our apparatus which are unique and desirable in the study of the $\pi\pi$ system.

1. The acceptance of our apparatus is nearly uniform over the entire $\pi\pi$ effective mass range. This means we will be able to see any large mass $\pi\pi$ bumps and also observe large effective $\pi\pi$ masses which are crucial for testing multiperipheral models.
2. The acceptance of our apparatus is nearly uniform over the entire range of $\pi\pi$ decay angles. This point is particularly crucial in observing high spin $\pi\pi$ resonances. The reason is a high spin particle decay tends to send one pion very nearly forward in the lab with high momentum whereas the other pion comes off at a rather large angle in the lab and with a small momentum. Magnet spectrometer systems are not efficient for these types of events due to finite aperature and momentum band pass limitations.
3. The kinematics are over-constrained. Sufficient variables are measured to over-constrain the four-momentum balance equations twofold. This is very desirable in eliminating background in which there are missing neutrals.

<u>Charge determination</u>

In order to uniquely specify each event as to its charge configuration we have decided to place a small bending magnet downstream to deflect the forward going pion. This will not be a momentum determination but strictly a charge determination.